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Extensive Air Shower Simulation with CORSIKA: A User's Guide (Version 6.6 from April 20, 2007)

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Abstract

Extensive Air Shower Simulation with CORSIKA:
A User's Guide

CORSIKA is a detailed simulation program for extensive air showers initiated by high energy cosmic particles. The user's guide explains the installation of the code, all the necessary input data sets, the selection of simulation parameters, and the structure of the program outputs.

Zusammenfassung

Simulation ausgedehnter Luftschauer mit CORSIKA:
Eine Benutzeranleitung

CORSIKA ist ein Programm zur detaillierten Simulation von ausgedehnten Luftschauern, die durch hochenergetische kosmische Strahlung ausgelöst werden. Die vorliegende Anleitung erläutert die Installation des Programms, alle nötigen Eingabedateien, die Wahl der Simulationsparameter und die Struktur der Ausgaben des Programms.

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1 Introduction

CORSIKA (**CO**smic **R**ay **SI**mulations for **KA**scade) is a detailed Monte Carlo program to study the evolution and properties of extensive air showers in the atmosphere. It was developed to perform simulations for the KASCADE experiment [1] at Karlsruhe in Germany. This experiment measures the elemental composition of the primary cosmic radiation in the energy range 3×10^{14} to 1×10^{17} eV and after its upgrade to KASCADE-Grande [2] it is reaching 10^{18} eV.

The CORSIKA program [3] allows to simulate interactions and decays of nuclei, hadrons, muons, electrons, and photons in the atmosphere up to energies of some 10^{20} eV. It gives type, energy, location, direction and arrival times of all secondary particles that are created in an air shower and pass a selected observation level.

CORSIKA is a complete set of standard FORTRAN routines. It uses no additional program libraries for the simulation of air showers. Therefore, it runs on (almost) every computer where FORTRAN is available.

The CORSIKA program consists basically of 4 parts. The first part is a general program frame handling the in- and output, performing decay of unstable particles, and tracking of the particles taking into account ionization energy loss and deflection by multiple scattering and the Earth's magnetic field. The second part treats the hadronic interactions of nuclei and hadrons with the air nuclei at higher energies. The third part simulates the hadronic interactions at lower energies and the fourth part describes transport and interaction of electrons, positrons, and photons. CORSIKA contains several models for the latter three program parts that may be activated optionally with varying precision of the simulation and consumption of CPU time.

High-energy hadronic interactions may be treated by one of the models: The Dual Parton Model DPMJET [4], the simple Monte Carlo generator HDPM [5] which is inspired by the Dual Parton Model and tries to reproduce relevant kinematical distributions being measured, the quark-gluon-string model QGSJET [6, 7], the mini-jet model SIBYLL [8, 9], or VENUS [10]. As a sixth alternative there is added a link to the NEXUS model [11], which combines algorithms of VENUS and QGSJET with new ideas, based on H1 and Zeuss data. The last model included is EPOS [12]. It is based on the NEXUS framework but with important improvement concerning hard interactions and nuclear and high density effect. It is the only model available here reproducing most recent RHIC data. The hadronic interaction cross-sections at higher energies are adopted according to the used model.

The low-energy hadronic interactions are simulated alternatively with one of the codes: FLUKA [13], a very refined model with many details of nuclear effects, GHEISHA [14], that is a well approved detector Monte Carlo program in the energy region up to some hundred GeV, or UrQMD [15], which describes microscopically the low energetic hadron-nucleus collisions.

The interactions of electrons and photons can be treated either with the EGS4 code [16] following each particle and its reactions explicitly, or using the analytic NKG formulae [17] to obtain electron densities at selected locations and the total number of electrons at up to 10 observation levels.

Further on it is optionally possible to explicitly generate Cherenkov light in the atmosphere, to handle electronic and muonic neutrinos and anti-neutrinos, and to simulate showers with flat incidence. Recently the HERWIG [18] interaction routines have been linked [19] with COR-

SIKA to handle primary neutrinos. To shorten the computing times for ultra-high energy showers above 10^{16} eV the thin sampling option exists, by which only a fraction of the secondary particles is followed in the shower development. There exists as well a program version that is not suited for air shower simulation but for testing the hadronic interaction models.

A detailed description of the CORSIKA program frame, the used cross-sections, the hadronic interaction model HDPM, the electromagnetic interaction models, and the particle decays has been published in Ref. [3]. For details of the DPMJET, EPOS, NEXUS, QGSJET, SIBYLL, VENUS, FLUKA, GHEISHA, UrQMD, and EGS4 programs see Refs. [4, 12, 11, 6, 7, 8, 10, 13, 14, 15, 16]. However, minor modifications were made to these codes to adapt them for simulation of extensive air showers. A comparison of the various hadronic interaction models is given in Ref. [20].

Besides the explanation [3] of the physics implemented in CORSIKA, this CORSIKA GUIDE is a supplementary description of the technical handling and running of CORSIKA6600. It contains information about the installation of the program, the required input data, file formats, parameter settings, outputs, and other technical details. This CORSIKA GUIDE is an updated version of Ref. [21].

For **citation of CORSIKA in your publications** you might use Ref. [3] which is available from the CORSIKA www-page `http://www-ik.fzk.de/corsika/` .

Please do not forget also to make a **reference to the hadronic interaction models** which you used in your simulations. The correct references you find in the bibliography (page 119) of this CORSIKA GUIDE and (in LaTeX format) in the file '*references*.tex' (see directory `doc/`).

If you have problems in installing or running the program, suggestions to improve the code concerning physics, computing, or handling, please contact:

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Tel.: +49-(0)7247-82-8134	Tel.: +49-(0)7247-82-3777

All users of CORSIKA are kindly asked **not to hand over the program to interested new users**, but rather to send their name and address to the above addresses. By these means new users can be provided with news about the latest program version, error corrections, and updates. Thus problems with outdated versions should be avoided.

2 Installation

The CORSIKA 6.6 set is distributed as gzipped .tar file consisting of several files and directories:

- a file *README* giving these short instructions how to proceed,

- an executable shell script file *corsika-install* to be used to install CORSIKA,

- a file *AUTHORS* giving the names of authors,

- a file *COPYING* giving copyright instructions,

- a file *ChangeLog* giving the CORSIKA history,

- a file *INSTALL* giving detailed instructions how to use *./corsika-install* to install CORSIKA,

- a file *NEWS* giving latest news about CORSIKA,

- a file *cDO_NOT_RUN_CONFIGURE* to remind users not to use *./configure* but *./corsika-install* instead,

- files $Makefile$.am, $Makefile$.in, $aclocal$.m4, $configure$.in, $configure$. These files and the subdirectory config/ are needed for the installation and should not be changed unless you know exactly what you are doing. All subdirectories have a $Makefile$.am and a $Makefile$.in which are needed by $configure$ to create the proper $Makefile$s.

- a subdirectory bernlohr/ containing 'bernlohr' package[2]. It is a set of **C**-routines for Imaging Atmospheric Cherenkov Telescopes (IACT) and for use of external atmospheric profiles in the ATMEXT option; several atmospheric profiles *atmprof*i.dat are included together with various auxiliary files. This package is provided by K. Bernlöhr.

- a subdirectory coast/ containing a package[3] of **C**$^{++}$-routines which might be used in combination with the ROOTOUT option,

- a subdirectory doc/ containing:
  - a postscript file *CORSIKA_PHYSICS*.ps containing the physics description of CORSIKA (Report FZKA 6019) (The file *CORSIKA_PHYSICS*.pdf contains it in Acrobat format.),
  - a postscript file *CORSIKA_GUIDE6600*.ps giving this User's Guide (The file *CORSIKA_GUIDE6600*.pdf contains it in Acrobat format.),
  - a file $references$.tex giving the actual references to CORSIKA and the hadronic interaction models in LaTeX format (to be used in your publications),

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[2]*bernlohr-1.34*.tar.gz is automatically extracted if needed.
[3]$COAST\_cors$.tar.gz is automatically extracted if needed.

- a subdirectory `dpmjet/` containing source files of the DPMJET-II.55 model ($dpmjet253c$.f, $dpmjet254$.f, $dpmjet255$.f, $dpmjet256$.f),

- a subdirectory `epos/` containing the source package for the EPOS model[4].

- a subdirectory `herwig/` where to install HERWIG and containing a *README* file inside,

- a subdirectory `include/` containing the $config.h$.in file which is needed by *configure* to do $config$.h. The file $config$.h contains all the preprocessor commands needed by CORSIKA.

- a subdirectory `lib/` together with a script file *libtool* are created when compiling CORSIKA. The subdirectory contains all object files and libraries.

- a subdirectory `nexus/` containing the source package for the NEXUS model[5].

- a subdirectory `run/` to be used to run CORSIKA containing:
  - 14 data sets containing the energy dependent cross sections for nucleon-nucleus processes (*NUCNUCCS*), for electromagnetic interactions (6 sets *EGSDAT5_x.x*), for QGSJET01 (*QGSDAT01* and *SECTNU*), for QGSJET-II (*sectnu-II-03*) (because of its size the *qgsdat-II-03* file has to be downloaded separatly and copied here)[6], numerical data to be used by the VENUS routines (*VENUSDAT*), cross section table for UrQMD (*UrQMD-⟨VER⟩-xs*.dat) and for the DPMJET routines the Glauber tables (*GLAUBTAR*.DAT) and nuclear data (*NUCLEAR*.BIN[7]),
  - 3 data sets *atmabs*.dat, *mirreff*.dat, and *quanteff*.dat to take into account the atmospheric absorption, mirror reflectivity, and quantum efficiency of Cherenkov radiation,
  - 3 input examples (*all-inputs*, *nexus-inputs* and *epos-inputs*) to steer the simulation with any model, with NEXUS or with EPOS,
  - the binary files of CORSIKA after compilation.

- a subdirectory `src/` containing:
  - the major part of the source code ($corsika$.F and $corsika$.h) which is a FORTRAN code file with some **C**-preprocessor commands, that contains the code of CORSIKA including the EGS4 and HDPM model routines. It contains also the interfaces to FLUKA, GHEISHA, UrQMD, DPMJET, EPOS, NEXUS, QGSJET, SIBYLL, and VENUS, but without those hadronic interaction codes,

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[4]$epos160\_cors$.tar.gz is automatically extracted if needed.

[5]$nexus3.97\_cors$.tar.gz is automatically extracted if needed.

[6]This file is in a binary format and is only available for LINUX machines on the CORSIKA ftp server. Users of other systems should let the computer recalculate this file at the first run. It takes about one day of computing time.

[7]The *NUCLEAR*.BIN file may be used only with those computers (DEC-UNIX, LINUX) applying the IEEE standard for direct access read and write. For other computers (DEC-VAX, HP) a different *NUCLEAR*.BIN file is necessary which is available from CERN or from the author of DPMJET <johannes.ranft@cern.ch>.

- 5 separate files with pure FORTRAN code of the GHEISHA, QGSJET01c, QGSJET-II-03, SIBYLL2.1, and VENUS routines (*gheisha_2002d*.f, *qgsjet01c*.f, *qgsjet-II-03*.f, *sibyll2.1*.f, and *venus*.f),

- 2 separate files with the pure **C**-code of the PRESHOWER and STACEE (*preshw*.c and *stacee*.c),

- 2 FORTRAN routines to read the CORSIKA particle output files (*corsikaread*.f and *corsikaread_thin*.f compiled the first time CORSIKA is compiled and installed in `run/`),

- 2 special **C**-routines needed for compilation (*timerc*.c and *trapfpe*.c),

- a routine (*plottracks3c*.f) and its include file (*work*.inc) to visualize shower plots established with the option PLOTSH.

- a **C**-routine *map2png*.c to visualize the shower plots established with the option PLOTSH2.

- a subdirectory `urqmd/` containing the source package of the UrQMD model[8].

The CORSIKA code and the files belonging to it can be obtained from Forschungszentrum Karlsruhe by anonymous ftp. Before access the host name of your computer is checked for authorization. If you want to transfer CORSIKA files to your computer system you might proceed as follows (commands that you have to type are underlined):

```
ftp ftp-ik.fzk.de
Trying 141.52.67.78...
Connected to ikserv.fzk.de.
220 ftp-ik FTP server (Version [number & date]) ready.
Name (ftp-ik.fzk.de:username):  anonymous [or ftp]
331 Guest login ok, send your complete e-mail address as password.
Password:  (your_mail_address)
230-    PROBLEMS
230-    If your FTP client crashes or hangs shortly after login please try
230-    using a dash (-) as the first character of your password.  This will
230-    turn off the informational messages that may be confusing your FTP
230-    client. Administrative contact: bekk@ik.fzk.de
230-
230-
230-                      Welcome to ftp-ik.fzk.de, the
230-              ******  I N F O and S O F T  Server  ******
230-          Forschungszentrum Karlsruhe, Institut fuer Kernphysik
230-                  KASCADE Collaboration Karlsruhe
230-
230-
230- current directory: /     local time:  [date & time]
```

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[8]*urqmd1.3_cors*.tar.gz is automatically extracted if needed.

```
230- You are user number # out of a possible total of 10 in your domain class
230- All transfers to and from ftp-ik.fzk.de are logged. If you don't like this
230- then disconnect now!
230-
230- Guest login ok, access restrictions apply.
Remote system type is UNIX.
Using binary mode to transfer files.
ftp > cd pub/corsika/v660
250 CWD command successful.
ftp > mget *
mget corsika-6600.tar.gz?  y
.
.
.
ftp > quit
221-You have transferred # bytes in # files.
221-Total traffic for this session was # bytes in # transfers.
221-Thank you for using the FTP service on ftp-ik.
221 Goodbye.
```

For faster transmission we have compressed the *corsika-6600.tar* file. Before using this file first you have to decompress it by applying the 'gunzip' procedure.

If you are not successful to fetch files from the subdirectory `pub/corsika/v660` (because of 'permission denied'), then please try to copy the *README* file located in the subdirectory `pub/` . This file has no limited access and should be readable by you. If you have copied this *README* file successfully please send an e-mail to <dieter.heck@ik.fzk.de> or <tanguy.pierog@ik.fzk.de>. The automatic registration of each access to this file from outside gives a hint what to change to enable your access to the CORSIKA files.

The files belonging to FLUKA are collected in an object file library. This library and the necessary data files are distributed by the FLUKA organization for different computers and compiler versions. You find further details on the web page:
`http://www.fluka.org/` .

The files belonging to the HERWIG code may be downloaded from the web page:
`http://hepwww.rl.ac.uk/theory/seymour/herwig/` .

2.1 Program File Preparation

By unpacking the *corsika-6600.tar* file with the command
`tar xvf` *corsika-6600.tar*
the file structure of CORSIKA will be established. To install CORSIKA you type

```
./corsika-install
```

(no argument) and answer the questions ... it's done !

The main part of the CORSIKA source is no longer kept as a CMZ-file[9]. The main source file is now *corsika*.F with all common blocks in *corsika*.h. It's a FORTRAN source file with some **C**-preprocessor commands which allows optional compilation of some part of the code. It uses standard $Makefile$ and compiler options, and therefore doesn't require any special software to be installed on your machine[10]. Using the shell script *corsika-install*, the user can interactively select the specific CORSIKA version for his application and compile it to get directly ready-to-run executable binary files in the `run/` subdirectory. Computer dependent options and $Makefile$s are prepared automatically by the shell script $configure$ called by *corsika-install*. The $configure$ is a standard portable shell script used together with $make$ by GNU-packages to be installed, but $configure$ should **<u>NOT</u>** be used directly to get a proper installation of CORSIKA. The *corsika-install* shell script has been designed to get a "user friendly" machine dependent installation, so that binary files can be compiled in parallel from the same source directory but on different systems[11] (in a large computer farm for instance). All object files and libraries are "hidden" in a `lib/` subdirectory. If you already used a former version of CORSIKA, and you want to use a $corsika\_compilefile$.f as before, you can optionally save this file during the installation process to compile it yourself.

The *corsika-install* script checks for all options if they can be used on your computer, so comments appearing during the installation should be read carefully.

2.1.1 Options

At present CORSIKA versions may be generated with the following hadronic interaction models with their cross-section (for determining the mean free path between the interactions) using the options:

DPMJET selects DPMJET 2.55 routines for the simulation of high energy hadron-nucleus and nucleus-nucleus collisions. Also the DPMJET cross-sections are selected.

EPOS selects the EPOS routines for the simulation of high energy hadron-nucleus and nucleus-nucleus collisions. Also the EPOS cross-sections are selected.

NEXUS selects the NEXUS 3.97 routines for the simulation of high energy hadron-nucleus and nucleus-nucleus collisions. Also the NEXUS 3.97 cross-sections are selected.

QGSJET selects QGSJET01c routines for the simulation of high energy hadron-nucleus and nucleus-nucleus collisions. Also the QGSJET01c cross-sections are selected.

QGSII selects QGSJET-II-03 routines for the simulation of high-energy hadron-nucleus and nucleus-nucleus collisions. Also the QGSJET-II-03 cross-sections are selected.

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[9]CMZ [22] (**C**ode **M**anagment System using **Z**EBRA)

[10]A shell terminal, a **C**-compiler and a FORTRAN compiler are included in any UNIX based system.

[11]In principle, any system could be used, but only LINUX, Mac OSX, Dec OSF, SunOS, AIX have been tested.

SIBYLL selects SIBYLL 2.1 routines for the simulation of high-energy hadron-nucleus and nucleus-nucleus collisions. Also the SIBYLL cross-sections are selected.

VENUS selects VENUS routines for the simulation of high-energy hadron-nucleus and nucleus-nucleus collisions. Also the VENUS cross-sections are selected.

FLUKA selects the FLUKA 2006 model[12] for the simulation of low-energy hadron-nucleus collisions. Always the appropriate FLUKA cross-sections are used. This option may be combined with all high energy interaction models excluding DPMJET 2.55.

GHEISHA selects the GHEISHA 2002d routines for the simulation of low-energy hadron-nucleus collisions. Always the appropriate GHEISHA cross-sections are used. This option may be combined with all high energy interaction models.

URQMD selects the UrQMD 1.3_cors routines for the simulation of low-energy hadron-nucleus collisions. Always the appropriate UrQMD cross-sections are used. This option may be combined with all high energy interaction models.

The **default** setting obtained without specifying any option is QGSJET. For low-energy hadronic interactions the GHEISHA model is taken.
In addition to these options you may select the following preprocessing options:

ANAHIST selects code to generate a histogram file *datnnnnnn*.lhbook for a short analysis of essential properties of the particles arriving at ground (as it is usually performed for the showers simulated at Lyon for the Auger experiment). This option needs linking with the CERN library to get the routines of the HBOOK and ZEBRA packages [23].

ATMEXT selects code for treatment of the atmosphere according to MODTRAN model for various atmospheres by tabulated values. ATMEXT is recommended with the CERENKOV option for careful treatment of refractive index. This option links with (compiled) *atmo*.c, *fileopen*.c, and *straux*.c routines of the 'bernlohr' package.

AUGCERLONG selects code to fill the Cherenkov column in the table giving the longitudinal particle distribution.

AUGERHIST selects code to generate a histogram file *datnnnnnn*.lhbook, containing various histograms of different particle types at up to 20 vertical atmospheric depths to follow the development of shower properties, which are of interest for the Auger experiment (Cherenkov and fluorescence photon production). This option needs the THIN option and linking with the CERN library to get the routines of the HBOOK and ZEBRA packages [23].

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[12]As there exist several FLUKA libraries suited for different computers, the preprocessor-option **LINUX** will be automatically selected if you have a LINUX system for a correct extraction of the code to be coupled with the LINUX variants of the FLUKA libraries.

AUGERINFO selects code which writes a file named $DATnnnnnn$.info instead of DAT-$nnnnnn$.dbase file.

CEFFIC selects code to respect the atmospheric absorption, mirror reflectivity, and photomultiplier quantum efficiency of Cherenkov light. This option is only available in connection with the CERENKOV option.

CERENKOV selects code for additional generation of Cherenkov light. It needs the simulation with EGS4.

CERWLEN selects Cherenkov code including the wavelength dependent generation of Cherenkov photons and respects their wavelength dependent refraction of the atmosphere. This option is only available in connection with the CERENKOV option.

COMPACT selects a compacted output format for the particle file (unit MPATAP) which is different from the standard output, but better suited for simulations of very large numbers of low energy showers, which produce mostly no or only very few particles.

CURVED selects special code to treat showers with large zenith angles $70° < \theta < 90°$.

IACT selects code for simulation of **I**maging **A**tmospheric **C**herenkov **T**elescope arrays. This option is only available in connection with the CERENKOV option and links with (compiled) *iact*.c routines of the 'bernlohr' package.

IACTEXT selects code for extended interfacing with the *iact*.c routines of the 'bernlohr' package. This option is only available in connection with the IACT + CERENKOV option.

INTCLONG selects the longitudinal distribution of Cherenkov photons in longitudinally integrated form. (The default gives the generation of photons/step, so called differential longitudinal distribution.) INTCLONG excludes the NOCLONG option. This option is only available in connection with the CERENKOV or AUGCERLONG option.

INTTEST selects special features for the test of the interaction models (needs routines of the HBOOK and ZEBRA packages [23]). This option is not suited for extensive air shower simulation.

LPM selects those EGS4 routines which include the LPM-effect, but without using the THIN option.

NEUTRINO selects code by which neutrinos emerging from pion, kaon, and muon decays are tracked explicitly but without interaction.

NOCLONG deselects the longitudinal Cherenkov photon distribution. NOCLONG excludes the INTCLONG option. This option is only available in connection with the CERENKOV or AUGCERLONG option.

NUPRIM selects the HERWIG code to treat the first interaction of a primary neutrino.

PLOTSH selects code which enables plotting the tracks of the electromagnetic, muonic, and hadronic particles to demonstrate the development of a shower optically.

PLOTSH2 selects code which enables plotting the tracks of the electromagnetic, muonic, and hadronic particles to demonstrate the development of a shower optically, avoiding the large output files of PLOTSH.

PRESHOWER selects routines for coupling with a **C**-program package to describe the interaction of primary gammas with the Earth's magnetic field at EeV energies and to treat the resulting swarm of em-particles falling onto the top of atmosphere as one shower.

ROOTOUT selects routines for writing the particle output in a *root* file e.g. for off-line analysis of the particle output by *root* routines.

SLANT selects a slant depth scale for the longitudinal distributions instead of the vertical depth scale used otherwise.

STACEE selects **C**-routines to write the Cherenkov output in the format which is in use with the STACEE experiment [24].

STACKIN selects code to read in the parameters (type, energy, momenta) of secondary particles resulting from the interaction of an exotic primary (WIMP) which has been treated off-line by a separate program.

THIN selects the thinning mechanism to reduce the computing time for full simulations, especially for EGS4, and activates the LPM-effect.

UPWARD selects code to treat upward going particles. This option treats particles in the upward direction (zenith angle $\geq 90°$).

VIEWCONE selects the primary direction to come from a cone around a fixed zenith and azimuth angle.

VOLUMECORR selects the angular dependence of the zenith angle distribution as it is needed for a vertical long string detector e.g. AMANDA (see page 48). (The default takes the zenith angle distribution as observed by a horizontal flat detector.)

VOLUMEDET selects the angular dependence of the zenith angle distribution as it will be observed by a volume detector e.g Cherenkov telescope (see page 47). (The default takes the zenith angle distribution as observed by a horizontal flat detector.)

The major part of the program is machine independent due to the restriction to FORTRAN standards. Nevertheless, there are a few points where computer specific adaptations were necessary. There are prepared options for PCs and work stations running under UNIX (also LINUX) and for Apple Macintosh computers. The versions are automatically[13] activated for the following options:

UNIX selects code for calculation on UNIX systems including derivatives like LINUX (e.g. DEC-station under ULTRIX, ALPHA-station under DEC-UNIX [Tru64])[14].

MAC selects code for calculation on a former 68k-APPLE Macintosh.

Within the *corsika*.F file the optional code for the various versions (to be unpacked by the preprocessor) is marked by

```
#if __flag__
      ...
#else
      ...
#endif
```

blocks. If you are using a sequential computer other than the ones listed here you should try to adapt the UNIX (or perhaps MAC) version to your machine as this is most straight forward to understand.

In the `src/` subdirectory, the *corsika*.F file contains some explanations, the main program with more than 110 subroutines and functions, the EGS4 routines, the NKG routines, the HDPM model routines, the interface routines to FLUKA, GHEISHA, UrQMD, DPMJET, EPOS NEXUS, QGSJET, SIBYLL, and VENUS, the special routines for Cherenkov light generation,

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[13]Thanks to *configure*, *corsika-install* checks your machine configuration and sets the proper options.

[14]Some UNIX machines (HP, IBM RS6000, and installations with GNU g77 compiler [e.g. LINUX]) need the record length parameter RECL (used in the OPEN statement for the external stack MEXST) in bytes instead of 4-byte words. This holds also for DEC-UNIX running the f77 compiler with the option '-assume bytrecl'. For easy adaptation the additional preprocessor-option **BYTERECL** is available to enlarge the RECL-parameter by a factor 4.

Most UNIX systems offer a system routine *date_and_time* which overcomes the millenary border. In systems without this internal routine the preprocessor-option **OLDDATE** selects an older routine for date and time. The similar option **OLDDATE2** selects an alternative needed for PGF77 environment on LINUX platforms (IN2P3 Computing Center at Lyon) or HP-UX machines (with the +E1 option of the fort77 compiler).

The preprocessor-option **IBMRISC** selects the routines *date* and *clock* available on IBM RS6000 machines.

If necessary you might select the option **TIMERC** or you should adapt subroutine *prtime* to call the routines of your system for date and time.

The options **BYTERECL**, **OLDDATE**, **OLDDATE2**, **IBMRISC**, and **TIMERC** are only available in connection with the UNIX option and can not be selected if it's not adapted to your system.

the routines for generation of Auger-oriented histograms, and the interaction test routines. It is about 64200 lines long. The $corsika$.h file (length about 4300 lines) file contains the general common blocks with their explanations. These common blocks are included into the source file during preprocessing.

The **C**-file $timerc$.c contains a 'date and time' routine *timerc* for those UNIX or LINUX systems where the more modern *date_and_time* system routine is not available. The files $preshw$.c and $stacee$.c contain the PRESHOWER **C**-routines and the STACEE **C**-routines.

The $gheisha\_2002d$.f, $qgsjet$-II-03.f, $qgsjet01c$.f, $sibyll2.1$.f, and $venus$.f routines are about 18200, 12200, 7500, 8100, and 18000 lines, respectively.

Because of its size the DPMJET code has been divided into 4 portions $dpmjet253c$.f, $dpmjet$-254.f, $dpmjet255$.f, and $dpmjet256$.f with 42400, 2300, 40500, and 25700 lines each in the `dpmjet/` subdirectory.

The 30 UrQMD 1.3_cors program files with the 12 include files are collected within the urqmd-1.3_cors.tar.gz[15] file in `urqmd/` subdirectory.

The 21 EPOS program files with the 5 include files and the 5 data files are collected within the epos160_cors.tar.gz[15] file in the `epos/` subdirectory.

The 21 NEXUS 3.97 program files with the 5 include files and the 4 data files are collected within the nexus3.97_cors.tar.gz[15] file in the `nexus/` subdirectory.

The load modules of the FLUKA 2006 library routines and the FLUKA data files may be downloaded (after being authorized) from the official FLUKA web page: `http://www.fluka.org/` and properly installed on your machine by setting the environment variable FLUPRO[16]. For further information on the FLUKA package you may consult the FLUKA web page or contact A. Ferrari[17].

The HERWIG routines needed for the NUPRIM version may be downloaded from `http://hepwww.rl.ac.uk/theory/seymour/herwig/` and adapted according to the README file in the `herwig/` subdirectory (see subsection A.1).

2.1.2 Example

As an example, if you have the file *corsika-6600*.tar.gz in the current directory, the installation on a LINUX system will look like (commands you are giving are underlined):

```
> tar -zxf corsika-6600.tar.gz
> cd corsika-6600/
> ./corsika-install

Compile CORSIKA in lib/Linux and copy executable in run/

checking whether to enable maintainer-specific portions of Makefiles...  no
checking build system type...  i686-suse-linux
checking host system type...  i686-suse-linux
```

---

[15]Automatically unpacked if selected.

[16]Assuming *csh* shell one uses: `setenv FLUPRO flukadirectory`.

[17]<alfredo.ferrari@cern.ch> or <alfredo.ferrari@mi.infn.it>.

```
checking for a BSD-compatible install...  /usr/bin/install -c
checking whether build environment is sane...  yes
checking for gawk...  gawk
checking whether make sets $(MAKE)...  yes
checking for pgf77...  no
checking for g77...  g77
Following environment variables will be used ...
LIBS     = -L./lib/Linux/lib
LDFLAGS  =
CC       =
CFLAGS   = -g
CXX      =
CXXFLAGS = -g
CPP      =
CPPFLAGS =
F77      = g77
FFLAGS   = -fbounds-check -g
Fortran optimization :  -O0
checking for cc...  cc
checking for C compiler default output file name...  a.out
checking whether the C compiler works...  yes
checking whether we are cross compiling...  no
checking for suffix of executables...
checking for suffix of object files...  o
checking whether we are using the GNU C compiler...  yes
checking whether cc accepts -g...  yes
checking for cc option to accept ANSI C...  none needed
checking dependency style of cc...  gcc3
...
```
It may take a while ...
```
checking if libtool supports shared libraries...  yes
checking whether to build shared libraries...  yes
checking whether to build static libraries...  yes
checking whether -lc should be explicitly linked in...  no
creating libtool
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


          Welcome to the CORSIKA extraction macro
==============================================================================

          create an executable of a specific CORSIKA version
```

```
      Please read the documentation for a detailed description
                of the options and how to use it.


Note:  press Enter (blank line) to select an option followed by "(default)"


- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
checking for include/config.h...  no
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


Which high energy hadronic interaction model do you want to use ?
1 - DPMJET 2.55
2 - NEXUS 3
3 - QGSJET 01C (default)
4 - QGSJET II
5 - SIBYLL 2.1
6 - VENUS 4.12
7 - EPOS

r - restart make
x - exit make
(only one choice possible)
3


select QGSJET QGSJETOLD
It will use program qgsjet01c.f (with enlarged commons) for linking
checking for ./src/qgsjet01c.f...  yes


- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


                 presently selected options are

         UNIX BYTERECL QGSJET QGSJETOLD


- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
...
```

Answer the questions to select the options you want to use in CORSIKA (see section 2.1.1 page 7 and section 3 page 24 for details). Press "Enter" to select the options marked by "(default)". After each question, you can choose to restart the installation at the first question ("r") or to stop now ("x").

If an option needs some other files, the installation program will test if they exist[18]. If a problem

---

[18]The bernlohr, epos, nexus and urqmd packages will be automatically unpacked in their subdirectories.

occurs [19], the installation program will suggest the solution. Just follow what is written. Using the default options on a LINUX system, you will get:

```
...
=========================================================================

                        finally selected options are

            UNIX BYTERECL QGSJET QGSJETOLD GHEISHA

=========================================================================

Make corsika6600 executable file ?

yes - make source and compile (default)
no - do not compile now but make source to compile later ...

r - restart make
x - exit make
```

At this point, you should press "Enter" (yes). Select "no" only if you want to modify the source code before compiling or if you want to use your former installation tools, you prepared for an older version of CORSIKA using a "compilefile.f". This option will preprocess the source code, save it in subdirectory `src/` *as "corsika" followed by the version number "6600", an underscore with the selected high energy hadronic interaction model [20] and an underscore with the selected low energy hadronic interaction model [21] (and an optional "_int" if you select the "INTTEST" option), and create the $Makefiles$. But it will not run* `make`*. See section 11 page 101 for more details.*

```
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
checking for fpp...  no
checking for cpp...  cpp -traditional-cpp
checking for /etc/issue...  yes
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


=========================================================================

Do you want to save the "src/corsika6600_QGSJET_gheisha_compilefile.f" ?
y - yes, save it for special uses
```

---

[19]Trying to use the CERN library when not installed for instance.

[20]HDPM, DPMJET, EPOS, NEXUS, QGSJET, QGSII, SIBYLL, or VENUS.

[21]fluka, gheisha, or urqmd.

15

```
n - no, I don't need it (default)
y
```

If you want to see the code used to compile your CORSIKA program, you can answer "y", but this is not needed by the automatic compilation. Finally the installation program creates proper Makefiles and then runs make install *to compile your CORSIKA program.*

```
compilefile.f not saved

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

configure:  creating ./config.status
config.status:  creating Makefile
config.status:  creating bernlohr/Makefile
config.status:  creating coast/Makefile
config.status:  creating coast/CorsikaIntern/Makefile
config.status:  creating coast/CorsikaFileIO/Makefile
config.status:  creating coast/CorsikaROOT/Makefile
config.status:  creating coast/CorsikaToROOT/Makefile
config.status:  creating coast/rootout/Makefile
config.status:  creating dpmjet/Makefile
config.status:  creating epos/Makefile
config.status:  creating herwig/Makefile
config.status:  creating nexus/Makefile
config.status:  creating urqmd/Makefile
config.status:  creating src/Makefile
config.status:  creating run/Makefile
config.status:  creating include/config.h
config.status:  executing depfiles commands

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

run "make install" in lib/Linux/

Making install in src
make[1]:  Entering directory './lib/Linux/src'
cpp -traditional-cpp -DHAVE_CONFIG_H -I. -I../../../src -I../include
        ../../../src/corsika.F > compilefile.f
g77 -O0 -g -c -o corsika-compilefile.o 'test -f
        'compilefile.f' || echo '../../../src/''compilefile.f
if cc -DHAVE_CONFIG_H -I. -I../../../src -I../include -g -MT
        trapfpe.o -MD -MP -MF ".deps/trapfpe.Tpo" -c -o trapfpe.o
```

```
        ../../../src/trapfpe.c;
then mv -f ".deps/trapfpe.Tpo" ".deps/trapfpe.Po"; else rm -f
        ".deps/trapfpe.Tpo"; exit 1; fi
g77 -O0 -g -c -o qgsjet01c.o ../../../src/qgsjet01c.f
g77 -O0 -g -c -o gheisha_2002d.o ../../../src/gheisha_2002d.f
/bin/sh ../libtool --mode=link g77 -O0
        -o corsika corsika-compilefile.o qgsjet01c.o gheisha_2002d.o
        trapfpe.o -L../lib
mkdir .libs
g77 -O0 -g -o corsika corsika-compilefile.o qgsjet01c.o
        gheisha_2002d.o trapfpe.o -L../lib
g77 -c -o corsikaread.o ‘test -f ’../../../src/corsikaread.f‘ || echo
        ’../../../src/’‘../../../src/corsikaread.f
/bin/sh ../libtool --mode=link g77 -O0 -o corsikaread corsikaread.o
        -L../lib
g77 -fbounds-check -O0 -g -o corsikaread corsikaread.o
        -L../lib
g77 -c -o corsikaread_thin.o ‘test -f ’../../../src/corsikaread_thin.f‘
        || echo ’../../../src/’‘../../../src/corsikaread_thin.f
/bin/sh ../libtool --mode=link g77 -O0
        -o corsikaread_thin corsikaread_thin.o -L../lib
g77 -O0 -g -o corsikaread_thin corsikaread_thin.o -L../lib
make[2]:  Entering directory ‘./lib/Linux/src’
/bin/sh ../../../config/mkinstalldirs ./run
/bin/sh ../libtool --mode=install /usr/bin/install -c corsika
        ./run/corsika
/usr/bin/install -c corsika ./run/corsika
/bin/sh ../libtool --mode=install /usr/bin/install -c corsikaread
        ./run/corsikaread
/usr/bin/install -c corsikaread ./run/corsikaread
/bin/sh ../libtool --mode=install /usr/bin/install -c corsikaread_thin
        /run/corsikaread_thin
/usr/bin/install -c corsikaread_thin ./run/corsikaread_thin
make[2]:  Nothing to be done for ‘install-data-am’.
make[2]:  Leaving directory ‘./lib/Linux/src’
make[1]:  Leaving directory ‘./lib/Linux/src’
Making install in .
make[1]:  Entering directory ‘./lib/Linux’
make install-exec-hook
make[2]:  Entering directory ‘./lib/Linux’


--> "corsika6600Linux_QGSJET_gheisha" successfully installed in :
```

```
    run/

--> You can run CORSIKA in run/ using for instance :
    ./corsika6600Linux_QGSJET_gheisha < all-inputs > output.txt



make[3]:  Leaving directory './lib/Linux'
make[2]:  Nothing to be done for 'install-data-am'.
make[2]:  Leaving directory './lib/Linux'
make[1]:  Leaving directory './lib/Linux'
```

Now the installation is finished. As written, an executable binary file is copied into the `run/` subdirectory where all data files are placed. The name of this file is composed by "corsika" followed by the version number "6600", the system name as given by the `uname` UNIX command, an underscore with the selected high energy hadronic interaction model[22] and an underscore with the selected low energy hadronic interaction model[23] (and an optional "_int" if you select the "INTTEST" option). As a consequence, you can select different model combinations on different systems without any conflict[24].

2.2 Data Files

2.2.1 Input Files

To run a simulation one needs to read several input files. These are:

- The Glauber tables to derive nucleon-nucleus and nucleus-nucleus cross-sections from hadron-nucleon cross-sections are listed in file *NUCNUCCS* which is 2873 lines long. They are read via logical unit NUCNUC (NUCleus-NUCleus interactions, by default 11).

- The cross-sections and branching ratios for the EGS4 routines are contained in the data files *EGSDAT5_x.x* with a length of 3021 lines each. These files differ in the lowest kinetic energy to be followed within a range between 3 MeV (x.x = 3.) and 50 keV (x.x = .05). Only one of the sets is selected by the program and connected to the logical unit KMPI (by default 12) in a manner appropriate to the lowest energy of em-particles specified by the user. As the muon nuclear interactions use the routines to treat photonuclear interactions, always an *EGSDAT5_x.x* must be read in.

- The DPMJET routines need the Glauber tables named *GLAUBTAR*.DAT. Additionally some parametrized data contained within the data file *pomtab*.dat are read in. The latter

---

[22]HDPM, DPMJET, EPOS, NEXUS, QGSJET, QGSII, SIBYLL, or VENUS.

[23]fluka, gheisha, or urqmd.

[24]In case of conflict, using different options but with the same models for instance, the program will ask you if you want to rename the binary file.

will be generated at the first call within that directory from where you are calling COR-SIKA. This calculation needs c. 20 min on DEC 3000/600 AXP with 175 MHz. Later calls will read in this data file *pomtab*.dat. This file is written and read via logical unit 37, and *GLAUBTAR*.DAT is read via unit 47. The binary file *NUCLEAR*.BIN is read from unit 14 and fits only for computers which read data in the direct access mode according with the IEEE conventions (DEC-UNIX, LINUX). For other machines (DEC-VAX, HP) a different binary file is needed, which you may get from CERN or from the author of DPMJET <johannes.ranft@cern.ch>.

- The EPOS routines get user-specified parameters from a scratch file via logical unit EPOPRM (by default 97) and need some parametrized data contained within the data files *epos*.inics, *epos*.iniev, *epos*.ini1b, *epos*.inirj and *epos*.initl. If the latter files are not existent or do not fit with the user-specified parameters, they are established in a time consuming procedure (some 100 h on a DEC 3000/600 AXP with 175 MHz).

- The NEXUS routines get user-specified parameters from a scratch file via logical unit NEXPRM (by default 97) and need some parametrized data contained within the data files *nexus*.inics, *nexus*.iniev, *nexus*.inirj, and *nexus*.initl. If the latter files are not existent or do not fit with the user-specified parameters, they are established in a time consuming procedure (some 100 h on a DEC 3000/600 AXP with 175 MHz).

- The more recent QGSJET-II-03 routines need some parametrized data contained within the data files *qgsdat-II-03* and *sectnu-II-03*. (The QGSJET01c routines need some parametrized data contained within the data files *QGSDAT01* and *SECTNU*). They will be generated at the first call within that directory from where you are calling CORSIKA. This generation is time consuming (c. **4 days** on a 1GHz Pentium LINUX or DEC-ALPHA 1000 XP for QGSJET-II-03 rsp. 30 h on DEC 3000/600 AXP with 175 MHz for QGSJET01c). Later calls will read in these data files *qgsdat-II-03* and *sectnu-II-03* (resp. *QGSDAT01* and *SECTNU*). These data files are written and read via logical units 1 and 2. **Attention: The *qgsdat-II-03* file will have a size of $\approx$ 131 MB.**

- The STACKIN option needs the parameters (typ, energy, momenta) of the secondary particles coming from the interaction of an exotic primary in a separate file. Its file name is specified by the keyword INFILE (page 54). The first line of the file contains (format free after a leading blank) the number of secondaries and the primary energy (GeV). The following lines contain the current particle number, the particle type, the energy (GeV), the longitudinal momentum, and the two transverse momenta (GeV/c) in the format (2I5,4(1X,E15.7)). The momenta are relative to the direction of the (exotic) primary defined by THETAP (page 51) and PHIP (page 52).

- The VENUS option reads the file *VENUSDAT* which contains parametrized structure function integrals and is 2051 lines long. The file is read via logical unit 14.

- The FLUKA option needs various data files from the FLUKA library, so you should set an environment variable pointing to the FLUKA library[25].

- The URQMD option looks for the existence of the *tables*.dat decay width file. If this file exists, it is read in, otherwise the decay width tables are calculated and this file is created.

- The ATMEXT option needs tabulated atmosphere input data of the MODTRAN model contained in the *atmprofi*.dat files which are read in by the *atmo*.c routines of the 'bernlohr' package. Details are given in the comments at the beginning of *atmo*.c and in the documentation supplied with the 'bernlohr' package.

- The CEFFIC option reads the atmospheric absorption table *atmabs*.dat, photomultiplier quantum efficiency table *quanteff*.dat and/or mirror reflectivity table *mirreff*.dat via logical units MCERABS (by default 20), MCERQEF (by default 21), and MCERMIR (by default 22) respectively.

- Besides these data files CORSIKA needs the input of steering keywords to select the subject and the parameters of the simulation. They have to be supplied by the user. They are read via logical unit MONIIN (MONItor INput, by default 5). The format of the steering keywords and their effect is described in detail in Sect. 4 (page 49 ff.). Examples are given on page 80 and in the file 'inputs'.

All this files are placed in the `run/` subdirectory, where the program can be run.

2.2.2 Output Files

There are several streams of CORSIKA output:

- One is control information about the simulation run itself. This (standard) output[26] comes via the logical unit MONIOU (MONItor OUtput, by default 6). In case of a debugging run very much information is written to the logical unit MDEBUG (Monitor for DEBUGging, by default 6). Further details on this file are given in Sec. 10.1 (page 87).

- The second output stream contains the information about all the particles that reach the observation level. It gets the file name '$DATnnnnnn$' and is written onto the output directory DSN (keyword DIRECT page 70) via output unit MPATAP (PArticle TAPe, by default 90) as a 'sequential' 'unformatted' FORTRAN file[27]. $nnnnnn$ is the run number specified in the keyword RUNNR (page 49). This output may be suppressed (see keyword DIRECT and keyword PAROUT, page 70). Further details on this file are given in Sect. 10.2 (page 88).

---

[25]Assuming csh shell one uses: `setenv FLUPRO` *flukadirectory*.

[26]Renaming this output to '$DATnnnnnn$.txt' and redirecting it to the directory specified by the keyword DIRECT is convenient as by the shell commands 'dir' or 'ls -l' all files belonging to one run are displayed consecutively which facilitates book-keeping.

[27]To read this data set the FORTRAN programs *corsikaread.f* resp. *corsikaread_thin.f* placed in the `src/` directory may be used.

- Optionally a table of the number of the binned γ's, $e^{\pm}$ and $\mu^{\pm}$ particles might be written out to the file '$DATnnnnnn$.tab' onto the output directory DSN (keyword DIRECT page 70) via output unit MTABOUT (TABle OUTput, by default 46). $nnnnnn$ is the run number specified in the keyword RUNNR (page 49). To be activated by the keyword PAROUT (page 70). Further details on this file are given in Sect. 10.6 (page 98).

- The longitudinal distribution of particle numbers and energy deposits can be written out to the file '$DATnnnnnn$.long' onto the output directory DSN (keyword DIRECT page 70) via the unit MLONGOUT (LONGitudinal OUTput, by default 48). $nnnnnn$ is the run number specified in the keyword RUNNR (page 49). This output is activated by the FLONGOUT flag (see keyword LONGI page 67). Further details on this file are given in Sect. 10.5 (page 98).

- Another (optional) output file contains the compressed information of the Cherenkov photons. It gets the file name '$CERnnnnnn$' and is written onto the output directory DSN (keyword DIRECT page 70) via output unit MCETAP (CErenkov TAPe, by default 91). $nnnnnn$ is the run number specified in the keyword RUNNR (page 49).

- To establish a summary file on the contents of an air shower library an optional output file containing a run summary is written to '$DATnnnnnn$.dbase' on the directory DSN (keyword DIRECT page 70) via output unit MDBASE (Data BASE, by default 45), activated by keyword DATBAS (page 74). $nnnnnn$ is the run number specified in the keyword RUNNR (page 49). Using the AUGERINFO option the name of this file will be '$DATnnnnnn$.info' and the formats are adapted to the requirements of the Auger experiment. Further details on this file are given in Sect. 10.7 (page 98).

- The PLOTSH files contain all tracking steps for each particle with start and end point to produce demonstration plots of the development of showers. They are written onto the directory DSN via the units 55 (file '$DATnnnnnn$.track_em' for em-particles), 56 (file '$DATnnnnnn$.track_mu' for muons), and 57 (file '$DATnnnnnn$.track_hd' for hadrons) (see Sect. 3.5.12 page 41). $nnnnnn$ is the run number specified in the keyword RUNNR (page 49).

- The PLOTSH2 map files are, basically, two-dimensional histograms containing the number of tracks in each xy-/xz-/yz-bin. Details are given in Sect. 3.5.13, page 42. The map files are named '*DATnnnnnn*.<spec>_<proj>.map', where <spec> stands for 'em', 'mu', or 'hd', and <proj> stands for 'xy', 'xz', or 'yz'. They are written onto the directory DSN via the unit 55. $nnnnnn$ is the run number specified in the keyword RUNNR (page 49).

- The interaction test option INTTEST generates histograms; their data are written to the file with the name defined by keyword HISTDS (page 78) via the output unit LUNPLT (Logical UNit for PLoT, by default 52).

- The ANAHIST and the AUGERHIST options generate histograms; their data are written to the file named '*datnnnnnn*.lhbook' via the output logical unit 53. $nnnnnn$ is the run

number specified in the keyword RUNNR (page 49). Further details on this file are given in Sect. 10.4 (page 97).

During the calculation the program uses a temporary data set (scratch file) as an external particle stack if the internal one is over-full. This data set is connected to unit MEXST (EXternal STack, by default 96).

The names of EPOS data files *epos*.inics, *epos*.iniev, *epos*.ini1b, *epos*.inirj, and *epos*.initl may be changed using the keyword EPOPAR (page 59). The parameters given in the keyword EPOPAR are written to a scratch file connected to unit NEXPRM (by default 97). This file is read by the EPOS routines when initializing EPOS.

Similarly, the names of NEXUS data files *nexus*.inics, *nexus*.iniev, *nexus*.inirj, and *nexus*.initl may be changed using the keyword NEXPAR (page 60). The parameters given in the keyword NEXPAR are written to a scratch file connected to unit NEXPRM (**neX**US **P**a**R**a**M**eters, by default 97). This file is read by the NEXUS routines when initializing NEXUS.

Some values of the in- and output units may be redefined by changing their values in the corresponding BLOCK DATA subprograms. Table 1 lists all units together with their default values and the corresponding file names.

Unit name	default	I/O	File name and file
MONIIN	5	I	*input*, steering keywords
MONIOU	6	O	simulation control output on line printer
MDEBUG	6	O	debug output if DEBUG it selected
NUCNUC	11	I	*NUCNUCCS*, nucleus-nucleus cross-sections
MPATAP	90	O	*DATnnnnnn*, particle output and simulation results
MEXST	96	I/O	external particle stack, scratch file
	1	I/O	*epos*.inics, various tables for EPOS
	1	I/O	*epos*.iniev, various tables for EPOS
	1	I/O	*epos*.ini1b, various tables for EPOS
	1	I/O	*epos*.inirj, various tables for EPOS
	1	I/O	*epos*.initl, various tables for EPOS
	1	I/O	*nexus*.inics, various tables for NEXUS
	1	I/O	*nexus*.iniev, various tables for NEXUS
	1	I/O	*nexus*.inirj, various tables for NEXUS
	1	I/O	*nexus*.initl, various tables for NEXUS
	1	I/O	*qgsdat-II-03* (rsp. *QGSDAT01*), various tables for qgsjet-II-03 (rsp. QGSJET01c)
	2	I/O	*sectnu-II-03* (rsp. *SECTNU*), nucleus-nucleus cross-sections for qgsjet-II-03 (rsp. QGSJET01c)
LUNOUT	11	O	control output of FLUKA
KMPI	12	I	*EGSDAT5_x.x*, EGS4 cross-sections
	14	I	*VENUSDAT*, structure function integrals for VENUS
NBERTP	14	I	*NUCLEAR*.BIN, nuclear data for DPMJET and FLUKA
LUNERR	15	O	error output of FLUKA
MCERABS	20	I	*atmabs*.dat for atmospheric absorption of Cherenkov light (CEFFIC option)
MCERQEF	21	I	*quanteff*.dat for photomultiplier quantum efficiency of Cherenkov light (CEFFIC option)
MCERMIR	22	I	*mirreff*.dat for mirror reflectivity of Cherenkov light (CEFFIC option)
LSTCK	23	I	STACKIN input data file
ifcx & ifch	31	O	EPOS or NEXUS check file (not opened)
ifhi	35	O	EPOS or NEXUS histo file (not opened)
IUNIT	37	I/O	*pomtab*.dat, various data for DPMJET
MDBASE	45	O	*DATnnnnnn*.dbase (resp. *DATnnnnnn*.info), run summary file for use in an air shower library
MTABOUT	46	O	*DATnnnnnn*.tab, table output of γ, $e^\pm$, and $\mu^\pm$
	47	I	*GLAUBTAR*.DAT, Glauber tables for DPMJET
MLONGOUT	48	O	*DATnnnnnn*.long, output of longitudinal particle numbers and energy deposit
ifdt	51	O	EPOS or NEXUS data file (not opened)
ifcp	52	O	EPOS or NEXUS copy file (not opened)
LUNHST	53	O	histogram output file for ANAHIST/AUGERHIST vers.
LUNPLT	54	O	histogram output file for INTTEST version
	55	O	*DATnnnnnn*.<spec>_<proj>.map, output of PLOTSH2
	55	O	*DATnnnnnn*.track_em, output of PLOTSH (em comp.)
	56	O	*DATnnnnnn*.track_mu, output of PLOTSH (muon comp.)
	57	O	*DATnnnnnn*.track_hd, output of PLOTSH (hadron comp.)
	75	I/O	(*tables*.dat) decay widths tables for UrQMD
	76	I/O	(*UrQMD-⟨VER⟩-xs*.dat) total cross section table for UrQMD
MCETAP	91	O	*CERnnnnnn*, Cherenkov photon output
NEXPRM	97	I/O	EPOS or NEXUS parameters, scratch file

Table 1: Logical units for in- and output with their default values and file names.

3 Program Options

3.1 High-Energy Hadronic Interaction Models

3.1.1 DPMJET Option

DPMJET [4] (**D**ual **P**arton **M**odel with **JET**s) is a program developed to describe high-energy hadronic interactions of hadron-nucleus and nucleus-nucleus collisions using the two-component Dual Parton Model with soft chains and multiple mini-jets at each elementary interaction. For CORSIKA the version DPMJET 2.55 is available.

For using DPMJET you first have to select the DPMJET option when extracting the FORTRAN code from the source file. The $Makefile$ will automatically compile[28] $dpmjet253c$.f, $dpmjet254$.f, $dpmjet255$.f, $dpmjet256$.f, together in a library $libdpm$.a and then link it with the compiled $gheisha\_2002d$.f code (resp. UrQMD library) and with your CORSIKA program. In your input file you may supply the keyword (page 58):

```
DPMJET    T    0
```

Setting DPMJET to .false. (F) the simple HDPM routines are used (see also Sect. 3.1.3 page 26).

If in your calling directory the data set '$pomtab$.dat' is not yet existent it will be calculated at the first call of subroutine $prblm2$ (of $dpmjet256$.f) (which takes c. 20 min on a DEC 3000/600 AXP with 175 MHz). The DPMJET option[29] needs about the same CPU-time as the VENUS option (NKG enabled, EGS4 disabled) at primary energies of 10^{15} eV. Technically it is possible to use DPMJET up to the highest energies.

DPMJET activates also the inelastic hadron-nucleus cross-sections at higher energies which are calculated by the subroutine $dpjsig$. Nucleus-nucleus cross-sections are derived from the DPMJET nucleon-nucleon cross-sections using the Glauber tables of CORSIKA [3]. The DPMJET cross-sections are selected automatically when the DPMJET option has been used for extracting the FORTRAN code from the source file. In your input file you may supply the keyword (page 58):

```
DPJSIG    T
```

Setting DPJSIG to .false. (F) you will use the default cross-sections of CORSIKA as described in Ref. [3].

It should be emphasized, that the DPMJET option cannot be combined with the FLUKA option because of several identical subroutine names used within DPMJET and FLUKA.

---

[28]The FORTRAN compiler options described in Sect. A.1 (page 106) are used.

[29]Experience shows that because of the complexity and the sparse internal documentation of DPMJET not all possibilities for error stops or crashes are detected and eliminated. These errors are diffi cult to trace back, and we are not able to support users in those cases.

3.1.2 EPOS Option

EPOS [12] like NEXUS combines features of the former VENUS [10] and QGSJET [6] with extensions enabling a safe extrapolation up to higher energies, using the universality hypothesis to treat the high energy interactions [11]. Compared to NEXUS, many technical problems have been solved and the screening effects have been simplified using a more phenomenological approach mainly based on the recent RHIC data. In addition, high density effects have been included. The most actual version is EPOS 1.60.

For using EPOS you first have to select the EPOS option when extracting the FORTRAN code from the source file. The $Makefile$ will compile[30] $epos*.f$ in the $libepos$.a library and then link it with the compiled $gheisha\_2002d$.f code (resp. FLUKA library or UrQMD library) and with your CORSIKA program. In your input file you may supply the keyword (page 58):

```
EPOS    T    0
```

Setting EPOS to .false. (F) the simple HDPM routines are used (see also Sect. 3.1.3 below).

The standard parameters for EPOS are set in subroutine $aaset$ of the $epos$-bas-xxx.f file. If in your calling directory the data sets $epos$.inics, $epos$.iniev, $epos$.ini1b, $epos$.inirj, and $epos$.initl are not existent or not compatible with the selected parameters, they will be calculated at the first call of subroutine $psaini$ of $epos$-sem-xxx.f (which takes some 100 h on a DEC 3000/600 AXP with 175 MHz).

Normally all parameters of EPOS are set by subroutine $aaset$ (of the $epos$-bas-xxx.f file) called from subroutine $nexini$. In special cases it may be necessary to overwrite one or more of these parameters or to rename the data files to identify $epos$.inixx files established for different parameter sets. This is performed using the keyword

```
EPOPAR        aaaaaaaaaa
```

in the input file (see footnote to keyword EPOPAR, Sect. 4.27 page 59). *aaaaaaaaaa* is a command line as described in the EPOS documentation. These *aaaaaaaaaa* commands are written onto the file connected with the logical unit NEXPRM (by default 97) and read by subroutine *aread* of the *epos*-bas-xxx.f file.

The EPOS option needs roughly 7.5 times more CPU-time than the VENUS option ($E_0 = 10^{15}$ eV, NKG enabled, EGS4 disabled).

EPOS activates also the inelastic hadron-nucleus interaction cross-sections at higher energies. They are calculated by the subroutine *nexsig*. The EPOS cross-sections are selected automatically when the EPOS option has been used for extracting the FORTRAN code from the source file. In your input file you may supply the keyword (page 59):

```
EPOSIG    T
```

Setting EPOSIG to .false. (F) you will use the default cross-sections of CORSIKA as described in Ref. [3].

The *epos-inputs* in run/ subdirectory is an example input file to run CORSIKA with EPOS.

---

[30]The FORTRAN compiler options described in Sect. A.1 (page 106) are used.

3.1.3 HDPM Routines

HDPM is a set of routines to simulate high-energy hadronic interactions. These routines are fast and adjusted to experimental data where available. Proton-proton interactions simulated with HDPM and other models agree fairly well with each other (see Ref. [20]). Experimental data are however rare for high energy nucleon-nucleus or nucleus-nucleus collisions and here the results start to disagree due to the simpler modeling in HDPM. If one is interested in differences of air showers induced by different nuclei one probably gets more realistic results by the detailed simulation with other models (DPMJET, EPOS, NEXUS, QGSJET, SIBYLL, VENUS) than with the HDPM routines.

As the HDPM routines are default you have nothing to specify when extracting the FORTRAN code from the source file. But the compiled $gheisha\_2002d$.f code (resp. FLUKA library or UrQMD library) will be linked with your CORSIKA program.

3.1.4 NEXUS Option

neXus [11] (**NEX**t generation of **U**nified **S**cattering approach) combines features of the former VENUS [10] and QGSJET [6] with extensions enabling a safe extrapolation up to higher energies, using the universality hypothesis to treat the high energy interactions [11]. It handles nucleus-nucleus collisions with an up to date theoretical approach. The most actual version is NEXUS 3.97.

For using NEXUS you first have to select the NEXUS option when extracting the FORTRAN code from the source file. The $Makefile$ will compile[31] $nexus$-xxx.f in the $libnexus$.a library and then link it with the compiled $gheisha\_2002d$.f code (resp. FLUKA library or UrQMD library) and with your CORSIKA program. In your input file you may supply the keyword (page 59):

```
NEXUS     T     0
```

Setting NEXUS to .false. (F) the simple HDPM routines are used (see also Sect. 3.1.3 above). The standard parameters for NEXUS are set in subroutine $aaset$ of the $nexus$-bas.f file. If in your calling directory the data sets $nexus$.inics, $nexus$.inicsei, $nexus$.inidi, $nexus$.iniev, $nexus$.inigrv, $nexus$.inirj, $nexus$.inirjei, and $nexus$.initl are not existent or not compatible with the selected parameters, they will be calculated at the first call of subroutine $psaini$ of $nexus$-sem.f (which takes some 10 h on a DEC 3000/600 AXP with 175 MHz).

Normally all parameters of NEXUS are set by subroutine $aaset$ (of the $nexus$-bas.f file) called from subroutine $nexini$. In special cases it may be necessary to overwrite one or more of these parameters or to rename the data files to identify $nexus$.inixx files established for different parameter sets. This is performed using the keyword

```
NEXPAR          aaaaaaaaaa
```

in the input file (see footnote to keyword NEXPAR, Sect. 4.30 page 60). *aaaaaaaaaa* is a command line as described in the NEXUS documentation. These *aaaaaaaaaa* commands are written

---

[31]The FORTRAN compiler options described in Sect. A.1 (page 107) are used.

onto the file connected with the logical unit NEXPRM (by default 97) and read by subroutine *aread* of the *nexus*-`bas.f` file.

The NEXUS option needs roughly 7.5 times more CPU-time than the VENUS option ($E_0 = 10^{15}$ eV, NKG enabled, EGS4 disabled).

NEXUS activates also the inelastic hadron-nucleus interaction cross-sections at higher energies. They are calculated by the subroutine *nexsig*. The NEXUS cross-sections are selected automatically when the NEXUS option has been used for extracting the FORTRAN code from the source file. In your input file you may supply the keyword (page 60):

```
NEXSIG    T
```

Setting NEXSIG to .false. (`F`) you will use the default cross-sections of CORSIKA as described in Ref. [3].

The *nexus-inputs* in `run/` subdirectory is an example input file to run CORSIKA with NEXUS.

3.1.5 QGSJET Option

QGSJET [6, 7] (**Q**uark **G**luon **S**tring model with **JET**s) is a program developed to describe high-energy hadronic interactions using the quasi-eikonal Pomeron parametrization for the elastic hadron-nucleon scattering amplitude. The hadronization process is treated in the quark gluon string model. The most actual version is QGSJET-II-03.

For using QGSJET you first have to select the QGSJET and QGSII options when extracting the FORTRAN code from the source file. Without QGSII you will extract the link routines for the older QGSJET01c program.

The $Makefile$ will link the compiled $qgsjet$-II-03.f (resp. $qgsjet01c$.f) and $gheisha$-$\_2002d$.f codes (resp. FLUKA library or UrQMD library) with your CORSIKA program. The $qgsjet$-II-03.f package will behave differently compared with the older $qgsjet01c$.f of former CORSIKA versions.

In your input file you may supply the keyword (page 60):

```
QGSJET    T    0
```

Setting QGSJET to .false. (`F`) the simple HDPM routines are used (see also Sect. 3.1.3 page 26).

If in your calling directory the data sets *qgsdat-II-03*[32] and *sectnu-II-03* (rsp. $QGSDAT01$ and $SECTNU$) are not yet existent they will be calculated at the first call of subroutine `gqaini` (resp. `psaini`) (which takes c. **4 days** on a 1 GHz Pentium LINUX resp. 30 h for *QGSDAT01* on a DEC 3000/600 AXP with 175 MHz). The resulting *qgsdat-II-03* file will have a **size of** $\approx$ **131 MB**. The QGSJET option needs about 3 times more (qgsjet-II-03) resp. the same (qgsjet01c) CPU-time than/as the HDPM option (NKG enabled, EGS4 disabled).

QGSJET activates also the inelastic hadron-nucleus interaction cross-sections at higher energies which are supplied in the *qgsdat-II-03* file read in by the qgsjet-II-03 [7] (rsp. the *QGSDAT01 file* read in by the qgsjet01c [6]) program package. The nucleus-nucleus cross-sections are contained in the file *sectnu-II-03* (rsp. *SECTNU*). The qgsjet-II-03 cross-sections (rsp. QGSJET01c

---

[32]Binary type file available for LINUX system on the CORSIKA ftp server for downloading

cross-sections[33]) are selected automatically when the QGSJET option has been used for extracting the FORTRAN code from the source file. In your input file you may supply the keyword (page 61):

```
QGSSIG    T
```

Setting QGSSIG to .false. you will use the default cross-sections of CORSIKA as described in Ref. [3].

3.1.6 SIBYLL Option

SIBYLL [8] is a program developed to simulate hadronic interactions at extreme high energies based on the QCD mini-jet model. The actual [9] version is SIBYLL 2.1.
For using SIBYLL you first have to select the SIBYLL option when extracting the FORTRAN code from the source file. The $Makefile$ will link the (compiled) $sibyll$2.1.f and $gheisha\_2002d$.f codes (resp. FLUKA library or UrQMD library) with your CORSIKA program. In your input file you may supply the keyword (page 61):

```
SIBYLL    T    0
```

Setting SIBYLL to .false. (F) the simple HDPM routines are used (see also Sect. 3.1.3 page 26). The SIBYLL option needs about the same CPU-time as the HDPM option (NKG enabled, EGS4 disabled).
SIBYLL activates also the inelastic hadronic interaction cross-sections at higher energies which are supplied with the SIBYLL [8] program package. They are based on QCD calculations, details are given in [8]. SIBYLL also delivers nucleus-nucleus cross-sections. The SIBYLL cross-sections are selected automatically when the SIBYLL option has been used for extracting the FORTRAN code from the source file. In your input file you may supply the keyword (page 61):

```
SIBSIG    T
```

Setting SIBSIG to .false. (F) you will use the default cross-sections of CORSIKA as described in Ref. [3].

3.1.7 VENUS Option

VENUS [10] (**V**ery **E**nergetic **NU**clear **S**cattering) is a program developed to simulate ultra-relativistic heavy ion collisions. The actual version is VENUS 4.12.
For using VENUS you first have to select the VENUS option when extracting the FORTRAN code from the source file. The $Makefile$ will link the compiled $venus$.f and $gheisha\_2002d$.f codes (resp. FLUKA library or UrQMD library) with your CORSIKA program. In your input file you may supply the keyword (page 62):

---

[33]Omitting the QGSJETOLD selection uses hadron-air cross-sections increased by 3 % to take into account the individual nuclear radii of ^{14}N and ^{16}O as stated in Ref. [25].

```
VENUS    T    0
```

Setting VENUS to .false. (F) the simple HDPM routines are used (see also Sect. 3.1.3 page 26). Normally all parameters for VENUS are supplied by the routine `venini`. In special cases it may be necessary to overwrite one or more of these parameters specified by its name PARCHA and its new value PARVAL. This is performed using the keyword (page 62)

```
VENPAR    PARCHA    PARVAL
```

in the input file (page 62).

The VENUS option needs roughly 15 times more CPU-time than the HDPM option (NKG enabled, EGS4 disabled).

VENUS activates also the inelastic hadron-nucleus interaction cross-sections at higher energies which are calculated by the subroutine `vensig`. Nucleus-nucleus cross-sections are derived from the VENUS nucleon-nucleon cross-sections using the Glauber tables of CORSIKA [3]. The VENUS cross-sections are selected automatically when the VENUS option has been used for extracting the FORTRAN code from the source file. In your input file you may supply the keyword (page 62):

```
VENSIG    T
```

Setting VENSIG to .false. you will use the default cross-sections of CORSIKA as described in Ref. [3].

3.2 Low-Energy Hadronic Interaction Models

3.2.1 FLUKA Option

FLUKA (**FLU**ctuating **KA**scade) [13] is a package of routines to follow energetic particles through matter by the Monte Carlo method. In combination with CORSIKA only that part is used which describes the low-energy hadronic interactions. A detailed description of the processes simulated by FLUKA 2006 may be found on the FLUKA web page :
` http://www.fluka.org/ `.
FLUKA is used within CORSIKA to calculate the inelastic hadron cross-sections with the components of air and to perform their interaction and secondary particle production, including many details of the de-excitation of the target nucleus.
If you have selected the FLUKA option[34], the $Makefile$ will link the FLUKA library with your CORSIKA program (pages 107 and 109).
To run the FLUKA version, an environment variable[35] tells the system where to find the binary data files (page 19) needed by the FLUKA routines.
It should be emphasized, that the FLUKA option cannot be combined with the DPMJET option because of several identical subroutine names used within FLUKA and DPMJET.

---

[34]See footnote page 8 for the usage of the preprocessor-option **LINUX**.
[35]Assuming csh shell one uses: `setenv FLUPRO` *flukadirectory*.

3.2.2 GHEISHA Option

GHEISHA (**G**amma **H**adron **E**lectron **I**nteraction **SH**ower code) is an interaction package widely used in the detector Monte Carlo program GEANT [26] that has proven its qualities in describing hadronic collisions up to some 100 GeV in many experiments. A detailed description of the physics processes covered by GHEISHA may be found in Ref. [14]. The GHEISHA version is taken as distributed in October 17, 1994 with the GEANT package [26] version 3.21/03 by CERN. Recently some errors were eliminated using fixes obtained from SLAC [27] and now all variables are used in double precision. To discriminate against the uncorrected single-precision GHEISHA version it is renamed to $gheisha\_2002d$.f. GHEISHA is used in CORSIKA to calculate the elastic and inelastic cross-sections of hadrons below 80 GeV in air and their interaction and particle production.
The $Makefile$ will link the compiled $gheisha\_2002d$.f code with your CORSIKA program, if you have selected the GHEISHA option.

3.2.3 URQMD Option

UrQMD (**U**ltra-**r**elativistic **Q**uantum **M**olecular **D**ynamics) is an interaction package designed to treat low energy hadron-nucleus interactions. A detailed description of this model may be found in Ref. [15]. UrQMD 1.3_cors is used in CORSIKA to perform the elastic and inelastic interactions of hadrons below 80 GeV in air. The actual linking routines operate with the special UrQMD 1.3_cors version adapted to CORSIKA.
For using UrQMD you first have to select the URQMD option when extracting the FORTRAN code from the source file. For compilation of the *compilefile*.f the UrQMD 1.3_cors include files $boxinc$.f, $colltab$.f, $comres$.f, $coms$.f, $inputs$.f, $newpart$.f, and $options$.f must be available. So the *corsika-install* script will install this files if needed before doing a $Makefile$ to make a UrQMD library $liburqmd$.a from the UrQMD 1.3_cors FORTRAN files and then link it with your CORSIKA program (pages 107 and 109). In your input file you may supply the keyword (page 76):

```
URQMD     T     0
```

Setting the first parameter FURQMD to .false. (F) the program will stop.

3.3 Electromagnetic Interactions (NKG/EGS4 Option)

The NKG and EGS4 options are selected by flags of the input file keyword ELMFLG only. A detailed description of the EGS4 program can be found in Ref. [16], and the modifications applied to it are published in Ref. [3].
For using NKG and/or EGS4 you have to activate the flags of the keyword (page 64)

```
ELMFLG     T     T
```

in the input file.

It must be emphasized that at the highest electron and γ-energies above 10^{17} eV the NKG option does not contain the Landau-Pomeranchuk-Migdal effect (which is added to EGS4) which may alter the shower development by the decrease of the pair formation and bremsstrahlung cross-sections with increasing energy. Therefore the analytical NKG treatment deviates more and more from results gained by the EGS4 option. For example in a γ-induced shower (10^{19} eV energy, inclined with $\theta = 60°$, without PRESHOWER option) the maximum of the electron longitudinal development simulated by EGS4 is reached deeper in the atmosphere by ≈ 100 g/cm^2 slant depth than predicted by NKG.

3.3.1 NKG Treatment

The first flag activates the analytic NKG treatment of the electromagnetic component. The longitudinal electron numbers and pseudo-age parameters[36] are calculated every 100 g/cm^2 above the lowest observation level and the lateral electron densities are calculated for a radial grid of 80 points at the two lowest observation levels. The inner grid radius is fixed at 100 cm, while the outer radius RADNKG (in cm) is selected by the keyword (page 64):

```
RADNKG      200.E2
```

Also lateral pseudo-age parameters[36] are calculated.
As the NKG formulas do not take into account the curvature of the Earth's surface, for the CURVED option the NKG option is suppressed. As with the COMPACT option the NKG parameters cannot be written out onto the particle file, the NKG flag must be disabled in this case.

3.3.2 EGS4 Treatment

The second flag of the keyword ELMFLG activates the full Monte Carlo treatment of the electromagnetic component by the EGS4 package. Both flags may be activated or deactivated independently. No special option for extracting the FORTRAN code from the source file is required. By selecting the CERENKOV option the EGS4 routines are activated automatically.
In most applications (especially Cherenkov radiation from showers induced by primaries with energies in the GeV range) an abbreviated treatment of the multiple scattering of electrons within the EGS4 code is not recommended. If you can afford a lower quality of your simulations but no long computing times, you may specify an enlarged step length factor STEPFC by the keyword (page 64):

```
STEPFC      1.0
```

(See also the comments in Sect. 4.42 page 64.) A detailed discussion on the use of this step length is given in [28].
In the standard version treating pair production and bremsstrahlung, the EGS4 routines do not regard the Landau-Pomeranchuk-Migdal (LPM) effect which should be applied at energies

---

[36]These pseudo-age parameters should only be used qualitatively. For scientific applications you extract better age parameters from a fit to the lateral distribution of the electrons as simulated by the EGS4 option.

above $E_{lab} > 10^{16}$ eV. The LPM-effect is switched on automatically using the THIN option (see Sect. 4.44 page 65) or the LPM option (see Sect. 3.5.9 page 40).

The files named *EGSDAT5_x.x* replace the files *EGSDAT4_x.x*, *EGSDAT3_x.x*, *EGSDAT2_x.x*, or *EGSDATA* used in older CORSIKA versions. For the extrapolation to the highest energies the photo-nuclear cross section is extrapolated according to Cudell et al. [29] published by the Particle Data Group. The low energy threshold of these files ranges from 0.05 MeV to 3 MeV. They differ from the older data sets by the arrangements of the tables containing the $e^{\pm}$-branching ratios and γ-branching ratios, thus giving a more smooth branching ratio for the rare processes of electro-nuclear and photo-nuclear interactions rsp. of $\mu^+\mu^-$ pair formation. A data set with an energy threshold far below ELCUT(4) implies the explicit, but unnecessary production of many bremsstrahlung photons above threshold but below ELCUT(4), resulting in a considerable prolongation of wasted CPU-time. Therefore CORSIKA automatically selects the *EGSDAT5_x.x* set best suited for the user's specification of the ELCUT(3) and ELCUT(4), thus saving CPU-time.

3.4 Cherenkov Options

3.4.1 Cherenkov Standard Option

The routines treating the Cherenkov radiation have been supplied by the HEGRA Collaboration [30] and considerably improved by K. Bernlöhr [31]. The Cherenkov light production by electrons, positrons, muons, and charged hadrons is considered in the subroutine `cerenk`. The Cherenkov photons are considered within a wavelength band which may be specified by the lower and upper limits WAVLGL and WAVLGU. Atmospheric absorption of the Cherenkov photons is not taken into account by default, but might be added by the CEFFIC option (see Sect. 3.4.5 page 35). Only Cherenkov photons arriving at the lowest observation level are recorded.

Charged particles create Cherenkov photons at each tracking step when the condition $\beta > 1/n$ ($\beta = v/c$ and n = refractive index) is fulfilled. The step is subdivided into smaller sub-steps such that the number of Cherenkov photons per sub-step is less than the fixed number CERSIZ, predefined by an input keyword. In such a sub-step all the photons are sent in a compact bunch along a straight line, defined by the emission angle θ_C relative to the electron or hadron direction and a random value for the angle ϕ around this direction.

As the major part of the Cherenkov light is produced by electrons it makes no sense to simulate showers with Cherenkov light production unless using the EGS4 option. Therefore the CERENKOV option automatically activates the EGS4 option, too. The CERENKOV option reduces the step length factor STEPFC to 1 by default (page 64).

For higher primary energies it is impossible to write all the photon bunches of one shower to the output file. Therefore, only those bunches are recorded which hit an array at the lowest observation level consisting of NCERX × NCERY photon detectors with ACERX × ACERY cm^2 area each arranged with a grid spacing of DCERX and DCERY cm in x and y direction, respectively. Each bunch is represented by 7 words which are the number of Cherenkov photons, the x and y position coordinates at the observation level, direction cosines u and v, arrival time,

and height of production above sea level.

To obtain this program version the CERENKOV option has to be selected when extracting the FORTRAN code from the source file. Via the keyword (page 71)

```
CERARY    27   27    1500.    1500.    100. 100.
```

the geometry of your Cherenkov array may be defined. A rotation of the Cherenkov array x-axis relative to North may be respected by the keyword (page 69):

```
ARRANG    0.
```

The bunch size may be selected by the keyword (page 72):

```
CERSIZ    0.
```

The optimal choice of the bunch size depends on the employment of the atmospheric absorption, mirror reflectivity, and photomultiplier quantum efficiency (CEFFIC option, see Sect. 3.4.5 below). Without the CEFFIC option a CERSIZ = 5 is reasonable, as about one photon of such a bunch survives in an off-line treatment of these effects.

By the keyword (page 72)

```
CERFIL    T
```

the Cherenkov output is directed to the separate Cherenkov output file MCETAP or to the particle output file MPATAP. In case of a separate output file the Cherenkov output is structured as the particle output file. It contains the event header and the event end block and in between the data blocks. The data structure of the Cherenkov output data set is given in Table 10 (page 93). In the case the Cherenkov bunches are stored together with the other shower particles on the same particle output file, a Cherenkov bunch is treated like a particle.

The definition of an array of Cherenkov detectors serves to reduce the required disk space for Cherenkov shower. On the other hand one loses the possibility of using an air shower several times during the analysis with different core locations with respect to the detector. Keeping in mind the excessive computation time for Cherenkov showers a possibility is introduced to use Cherenkov showers multiple times with only a tolerable increase of storage space. Therefore, already during the simulation it is defined how often a single shower should be used and where in the array the core locations should be. The core locations for each event are chosen with the Sobol quasi-random number generator [32] and are stored in the event header. Correspondingly, the array of Cherenkov detectors is placed several times in the observation plane and store all Cherenkov bunches that hit one of the detectors. This possibility is selected by the keyword (page 73):

```
CSCAT    ICERML    XSCATT    YSCATT
```

An event is used ICERML times and the core is scattered in the range -XSCATT $\leq x_{core} \leq$ XSCATT and -YSCATT $\leq y_{core} \leq$ YSCATT. For the analysis of such CORSIKA events the user has to use the same core locations in the analysis that have been determined during the simulation. The output will basically scale with the number of times each event is used, but it is still considerably smaller than the output of the complete Cherenkov component would be.

To obtain this program version the CERENKOV option has to be selected when extracting the FORTRAN code from the source file.

3.4.2 Cherenkov Wavelength Option

In the CERWLEN option the index of refraction is made wavelength dependent. As a consequence, photon bunches will carry a specific wavelength. Photons of shorter wavelengths (with larger index of refraction) will result in larger Cherenkov cone opening angles and larger bunch sizes. For very fast particles this will generally have a small effect (less than $0.03°$ in the opening angle, for example) but near the Cherenkov threshold the effect can be larger.

This option may also require to use a smaller maximum bunch size (see keyword CERSIZ page 72) since all photons in a bunch are of the same wavelength and, therefore, the peak quantum efficiency rather than the average quantum efficiency determines the maximum acceptable bunch size. (In combination with the CEFFIC option (see Sect. 3.4.5 page 35) you should use a maximum bunch size of 1, as usual.)

To obtain this program version the CERWLEN option has to be selected in combination with the CERENKOV option when extracting the FORTRAN code from the source file.

3.4.3 Imaging Atmospheric Cherenkov Telescope Option

The routines treating the Cherenkov radiation for **I**maging **A**tmospheric **C**herenkov **T**elescopes (`IACT` option) have been supplied by K. Bernlöhr [31]. The Cherenkov light production by electrons, positrons, muons, and charged hadrons is considered in the subroutine *cerenk*. The positions of the telescopes are defined by the keyword (page 73)

```
TELESCOPE    0.  0.   0.   0.
```

giving the coordinates relative to the center of the lowest observation level (see Sect. 4.67 page 73). The data set name for the telescope-specific data output is defined by the keyword (page 73):

```
TELFIL    filename
```

For further details of the IACT option see Ref. [31], the comments at the beginning of the *iact*.c routines and the documentation supplied with the 'bernlohr' package.

To obtain this program version the IACT option has to be selected together with the CERENKOV option when extracting the FORTRAN code from the source file. The $Makefile$ will compile the needed **C** files of the 'bernlohr' package in the $libbern$.a library and then link it with your CORSIKA program.

3.4.4 Imaging Atmospheric Cherenkov Telescope Extension Option

With the IACTEXT option the interface to the *telout* function (*iact*.c routines) is extended by parameters describing the emitting particle. This extended information is stored as an additional photon bunch (after the normal one) with mass, charge, energy, and emission time replacing the `cx`, `cy`, `photons`, and `zem` fields, respectively, and are identified by a wavelength of 9999. The compact output format is disabled for making that possible. In addition, all particles arriving at the observation level are included in the `eventio` format output file, in a photon-bunch like block identified by array and detector numbers 999.

The `x`, `y`, `cx`, `cy`, and `ctime` fields keep the normal sense, with coordinates, directions and time counted in the detection level reference frame. The particle momentum is filled into the `zem` field (negative for upward-moving particles) and the particle ID is filled into the `lambda` field. If thinning is used, the particle weight is in the `photons` field.

When compiling *iact*.c manually (instead of taking advantage of the *corsika-install* script or the GNU-makefile supplied with the 'bernlohr' package), an additional option `-DIACTEXT` is required to have a consistent interface on both sides.

To obtain this program version the IACTEXT option has to be selected together with the CERENKOV and IACT options when extracting the FORTRAN code from the source file.

3.4.5 Cherenkov Light Reduction Option

The standard simulation of Cherenkov photons does not regard light absorption within the atmosphere, telescope mirror reflectivity, or quantum efficiency of the detecting photomultiplier tubes. In the CEFFIC option these effects are taken into account at an early stage of the Cherenkov photon simulation, thus the computing time is shortened considerably and the requirements for storage of Cherenkov output are reduced additionally.

Data tables containing information on these three effects as function of photon wavelength are needed in this option depending on the status of the flags specified by the keyword (page 72):

```
CERQEF      F     F     F
```

Standard tables for atmospheric absorption (*atmabs*.dat), mirror reflectivity (*mirreff*.dat) (measured for the recoated mirrors of the Whipple telescope, Sept. 1993), and quantum efficiency (*quanteff*.dat) (measured for Hamatsu R1398HA photomultipliers with UV-window and 1.125" tube) are supplied with CORSIKA. For other installations the user should establish corresponding tables[37].

By early eliminating those Cherenkov photons which are absorbed within the atmosphere, not reflected by the mirror, or not producing photo electrons within the photomultiplier, those suppressed photons are also not counted in the various forms of the longitudinal distributions (see Sect. 3.4.6 below).

As in the CEFFIC option the atmospheric absorption is treated only in a manner suited for planar atmospheres, you should not combine the CEFFIC option with CURVED.

To obtain this program version the CEFFIC option has to be selected together with the CERENKOV option when extracting the FORTRAN code from the source file.

---

[37]The *atmabs*.dat table is composed of 105 wavelength values between 180 and 700 nm in steps of 5 nm; one line for each wavelength, beginning with the wavelength value [nm] as integer, followed by 51 extinction values, starting at sea level up to 50 km height in steps of 1 km. The data format is (105(I4,5(10F10.3),F10.3)).

For the same 105 wavelengths the *mirreff*.dat and *quanteff*.dat tables contain reflectivity resp. quantum efficiency values written in the format (8F6.3). Further details may be taken from the comments in the employed subroutine `tpdini`.

3.4.6 INTCLONG and NOCLONG Options

In the Cherenkov version the longitudinal distribution of photons is given in differential mode (i.e. the number of photons generated within each step) by default. By the preprocessor option INTCLONG the integral mode is selected (i.e. accumulated number of generated Cherenkov photons for each step) which needs additional computing time. If both kinds of longitudinal distribution are of no interest, you may deselect the Cherenkov photon distribution completely by the preprocessor option NOCLONG thus saving computing time.

The option INTCLONG is effective also with the AUGCERLONG option (see Sect. 3.5.3 page 37).

To obtain these program versions the INTCLONG rsp. NOCLONG option has to be selected together with the CERENKOV rsp. AUGCERLONG option when extracting the FORTRAN code from the source file.

3.4.7 STACEE Option

In the STACEE option the output of the Cherenkov file is generated in a format as used for the STACEE experiment [24]. Details on the output data structure may be obtained from the members of the STACEE Collaboration. The appropriate **C**-routines are available in the `src/` subdirectory, linked after compilation by the $Makefile$.

To obtain this program version the STACEE option has to be selected when extracting the FORTRAN code from the source file.

3.5 Other Non-standard Options

3.5.1 ANAHIST Option

The ANAHIST option produces a series of histograms generated with HBOOK routines [23]. The histograms are written into the file named '$datnnnnnn$.lhbook' (page 97) onto the output directory DSN specified by the keyword DIRECT (page 70). To suppress the ordinary particle output file the keyword PAROUT (page 70) might be used. This analysis gives a short overview on various shower properties of the particles arriving at the observation level. The histograms are only established for the lowest observation level. Radial thinning is not applied to the particles sorted into the histograms.

Because of its permanent modifications a comprehensive description of the ANAHIST option is not available.

To obtain this program version the ANAHIST option has to be selected when extracting the FORTRAN code from the source file. The HBOOK routines require linking of the CERN libraries with the program; they are not supplied with the CORSIKA package.

3.5.2 ATMEXT Option with External Atmospheres

The ATMEXT option allows to use external tabulated atmospheres of the MODTRAN model documented in Ref. [33]. They are provided together with the 'bernlohr' package as files *atm-*

profi.dat and read in with special routines written in **C**. Further details may be found in Ref. [31], at the beginning of the *atmo*.c routines and in the documentation supplied with the 'bernlohr' package.

The CURVED option needs the atmospheres in the 5-layer model rather than interpolated from ATMEXT tables. Therefore in the CURVED option AATM, BATM, CATM values are fitted to the tabulated atmospheres and the table interpolation is disabled.

To obtain this program version the ATMEXT option has to be selected when extracting the FORTRAN code from the source file. A linking with the (compiled) *atmo*.c routines of the 'bernlohr' package is done by the $Makefile$.

3.5.3 AUGCERLONG Option

With the AUGCERLONG option it is possible to fill the Cherenkov column in the table of the longitudinal particle distribution without full simulation of the Cherenkov radiation. Because of an elongation of the CPU time the AUGCERLONG option should only be used if the longitudinal Cherenkov distribution is really needed. By the INTCLONG option (page 36) the integrated instead of the differential longitudinal Cherenkov intensity may be selected. The keywords CERSIZ (page 72) and CWAVLG (page 71) are activated with the AUGCERLONG option.

To obtain this program version the AUGCERLONG option has to be selected when extracting the FORTRAN code from the source file.

3.5.4 AUGERHIST Option

The AUGERHIST option produces a series of histograms generated with HBOOK routines [23]. The histograms are written into the file named '*datnnnnnn*.lhbook' (page 97) onto the output directory DSN specified by the keyword DIRECT (page 70). AS the HBOOK routines use only lower case characters, the DSN directory name should not contain capitals. These histograms show properties of different particle types at up to 20 horizontal levels (to be defined by keyword OBSLEV, page 68). They enable to study the longitudinal development of various shower parameters. At each defined level a series of histograms is generated e.g. for radial distances of different particle species, for the energy deposit by different particle species as function of distance from the shower axis, for energy spectra (as function of distance) and much more. Examples are given in Ref. [34]. For histograms relating to the emission of Cherenkov radiation the bunch size and wavelength band has to be specified using the keywords CERSIZ (page 72) and CWAVLG (page 71).

Only particles arriving at the lowest observation level are directed to the particle output file (page 88) and/or the table output file (keyword PAROUT page 70) and/or binned into the ANAHIST histograms.

Because of its permanent modifications a comprehensive description of the AUGERHIST option is not available.

The AUGERHIST option works only in combination with the THIN option. To obtain this program version the AUGERHIST option has to be selected when extracting the FORTRAN

code from the source file. The HBOOK routines require linking of the CERN libraries with the program; they are not supplied with the CORSIKA package.

3.5.5 AUGERINFO Option

The AUGERINFO option produces an output file named '$DATnnnnnn$.info' replacing the '$DATnnnnnn$.dbase' file, when activated by the DATBAS keyword (page 74). The output format of the .info file differs from that of the .dbase file to enable the automatic production of a data base for the Auger experiment showing the content of the CORSIKA shower library at the IN2P3 computing center Lyon.
To obtain this program version the AUGERINFO option has to be selected when extracting th FORTRAN code from the source file.

3.5.6 COMPACT Output Option

The standard output of CORSIKA is not adequate when simulating a large number of showers initiated by primaries of so low energies, that only a small percentage of them produces particles arriving at the detector level. As most data blocks of the MPATAP file would be filled up with zeros, a large amount of useless information for the data blocks and the unnecessary overhead of the event header and event end blocks would be written in this case. This is avoided in the COMPACT option, which writes out only the run header and the full event header for the first event. For subsequent events only shortened event headers (the first 12 parameters) are written. Event end blocks are omitted completely, the run end block is written as usual. The data blocks have a maximal length of 39 particles, trailing zeros are suppressed. Further details are given in Sect. 10.3 (page 96).
As the NKG parameters are not written out in the COMPACT version, the NKG flag (keyword ELMFLG page 64) should be disabled. The COMPACT option should not be combined with the ROOTOUT option.
To obtain this program version the COMPACT option has to be selected when extracting the FORTRAN code from the source file.

3.5.7 CURVED Atmosphere Option

The standard CORSIKA program models the Earth's atmosphere as a flat disc where the density of the air decreases with the height. The shower calculations and tracking are using Cartesian coordinates. In a flat atmosphere the thickness increases with $1/\cos\theta$. This is a good approximation for inclined showers if their zenith angles are below $\approx 70°$. Above this value the differences between a flat and a curved atmosphere become more and more important. At $90°$ eventually the thickness of the flat atmosphere becomes infinite whereas the correct thickness is ≈ 37000 g/cm^2.
Within the CURVED atmosphere option for large zenith angles above $\approx 70°$ the Earth's atmosphere is no longer assumed to be completely flat (as in the standard version for smaller zenith angles). Rather the atmosphere is replaced by a 'sliding plane atmosphere'. Each times the horizontal displacement of a particle exceeds a limit of 6 to 20 km (dependent on altitude), a

transition to a new, locally plane atmosphere is performed. By these means the advantages of the simpler transport formulas within a planar atmosphere are combined with the faster simulation speed by avoiding the lengthy and more complicated treatment by using a true spherical system. Because of technical reasons only one observation level may be specified in the CURVED option.

In the CURVED option the ionization energy loss, deflection within the Earth's magnetic field, and the generation of Cherenkov photons is enabled for charged hadronic primaries on their path between entering the atmosphere and the first interaction (which is disabled in the standard version without using keyword TSTART, page 53). The arrival time refers to the start at the margin of the atmosphere, which is indicated by a negative value of element 7 of the event header block (page 91).

The NKG formulas do not take into account the curvature of the Earth's surface. Therefore the NKG output is suppressed in the CURVED option.

The combination of the CURVED option with the UPWARD option is described in the section UPWARD (page 46).

As in the CEFFIC option the atmospheric absorption is treated only in a manner suited for planar atmospheres, you should not combine the CURVED option with CEFFIC.

The CURVED option needs the atmospheres in the 5-layer model rather than interpolated from ATMEXT tables. Therefore in the CURVED option AATM, BATM, CATM values are fitted to the tabulated atmospheres and the table interpolation is disabled.

To obtain this program version the CURVED option has to be selected when extracting the FORTRAN code from the source file.

3.5.8   INTTEST Interaction Test Option

With this option the interaction model routines can be tested which are used to describe the hadronic collisions. Only the first interactions are simulated and no air showers are developed. Various projectiles (keyword PRMPAR) and targets (keyword INTTST) may be selected. The result of the test is a series of histograms generated with the HBOOK routines [23] and written to the unit HISTDS. The histograms show properties of the secondary particles produced in the first interaction e.g. distributions of transverse momenta, of squared transverse momenta, of longitudinal momenta, of Feynman x-distributions, of rapidity and pseudo-rapidity distributions, and various particle multiplicity distributions.

To obtain this program version the INTTEST option has to be selected when extracting the FORTRAN code from the source file. The HBOOK routines require linking of the CERN libraries with the program; they are not supplied with the CORSIKA package. Via the keywords with their parameters (page 76 - 78)

```
INTTST    ITTAR    MCM

INTDEC    LPI0    LETA    LHYP    LK0S

INTSPC    LSPEC
```

```
    DIFOFF      NDIF

    TRIGGER     NTRIG

    HISTDS      HISTDS
```
the conditions of the interaction test run have to be specified.

Because of its permanent modification a comprehensive description of the INTTEST option is not available. It should be noted that the combinations of allowed parameters for the INTTEST option differ from the standard version without explicitly noting this or checking this during the program run.

To obtain this program version the INTTEST option has to be selected when extracting the FORTRAN code from the source file.

3.5.9 LPM Option

The LPM option switches on the Landau-Pomeranchuk-Migdal effect (which is added to EGS4) causing an effective reduction of the pair production and bremsstrahlung cross-sections [35] at the highest energies. With this option it is possible to include the LPM-effect without selecting the THIN option.

3.5.10 NEUTRINO Option

Muonic and electronic neutrinos and anti-neutrinos originate from the decays of $\pi^{\pm}$, the leptonic decays of $K^{\pm}$ and K_L°, and the decays of $\mu^{\pm}$. The neutrino formation is simulated with exact kinematics of all two and three body decays taking into account the polarization of the muons. The neutrino trajectories are followed down through the atmosphere disregarding any interaction with the target nuclei of the air. The neutrinos are written to the particle output file using the particle type numbers 66 to 69, if their energy exceeds the cutoff energy ELCUT(1).

To obtain this program version the NEUTRINO option has to be selected when extracting the FORTRAN code from the source file.

3.5.11 NUPRIM Option for Primary Neutrinos

With this program version showers induced by primary neutrinos can be simulated. Possible primary particles are (up to now) ν_e, $\overline{\nu_e}$, ν_μ, and $\overline{\nu_\mu}$. Because of the low cross-sections of neutrino-induced interactions it is recommended to fix the height of the primary interaction using the keyword FIXHEI (page 53). As the first (neutrino-induced) interaction is handled by the HERWIG code [18], a link [19] with the HERWIG routines is necessary. HERWIG produces - besides others - secondary particles (with charm) which cannot yet be treated by CORSIKA (see page 81). Those particles decay immediately employing the decay routines of HERWIG. The interactions of secondary particles coming from the primary neutrino reaction are treated by the selected high-energy rsp. low-energy hadronic interaction model or by NKG/EGS4. Secondary neutrinos are explicitly generated only, if the NEUTRINO option (page 40) is selected,

but they are not treated by HERWIG. Initiating a shower with non-neutrino primary particles will not call the HERWIG routines.

Sequence 5 of the CORSIKA random generator is foreseen for HERWIG, therefore you should initialize it (see Sect. 4.3 page 50).

For using the NUPRIM version you first have to select the NUPRIM option when extracting the FORTRAN code from the source file. The *Makefile* will compile the HERWIG FORTRAN routines and link them with your CORSIKA program.

A combination of the NUPRIM option with the INTTEST option is not possible.

3.5.12 PLOTSH Shower Plot Production Option

In the PLOTSH option the start and end points of each particle track are written to extra files (see Table 1 page 23); separate files are used for the electromagnetic, muonic, and hadronic component. Each track is written unformatted as one block consisting of 10 real*4 numbers: Particle identification, Energy (in GeV), Xstart, Ystart, Zstart (all in cm), Tstart (in sec), Xend, Yend, Zend (all in cm), and Tend (in sec). In case of THINning the particle Weight is added at the end of each block.

Plots may be constructed from the content of these files by using the *plottracks* program. The program *plottracks3c.f* (available in `src/`) converts the particle track maps generated by the PLOTSH option into PPM image files (readable by *xv*). *plottracks* is automatically compiled[38] when the PLOTSH option is selected.

The program *plottracks* reads in the '*DATnnnnnn*.track_em', '*DATnnnnnn*.track_mu', and '*DATnnnnnn*.track_hd' files specified on the command line by the parameter run=*nnnnnn* (integer between 0 and 999999). Then it converts and combines them into 4 PPM images '*tracknnnnnn*.em.ppm', '*tracknnnnnn*.mu.ppm', '*tracknnnnnn*.had.ppm', and '*tracknnnnnn*.all-.ppm' of the same resolution as the maps. By default, the electromagnetic, muonic, and hadronic maps are taken as the red, green, and blue channels of the RGB image, respectively.

As with increasing shower energy and decreasing threshold the number of tracks increases drastically you should simulate not more than 1 shower at a time to keep the output on the units 55, 56, and 57 at a tolerable size.

Via the keyword (page 78)

```
PLOTSH    T
```

the PLOTSH option is enabled or disabled.

This option is not recommended for ordinary shower production because of the large output files to be produced.

To obtain this program version the PLOTSH option has to be selected when extracting the FORTRAN code from the source file.

---

[38]g77 plottracks3c.f -o plottracks

3.5.13 PLOTSH2 Shower Plot Production Option

In the PLOTSH2 option air showers are visualized in a simple way, without having to deal with a (very large) track file. With the PLOTSH2 option map files are generated separately for the electromagnetic particles, muons, and hadrons. For each particle species maps are generated in all three projections (x-y, x-z, and y-z). The map files are written onto the directory DSN via the unit 55 and are named '*DATnnnnnn*.<spec>_<proj>.map', where <spec> stands for 'em', 'mu', or 'hd', and <proj> stands for 'xy', 'xz', or 'yz'. *nnnnnn* is the run number specified in the keyword RUNNR (see page 49). These map files are, basically, two-dimensional histograms containing the number of tracks in each xy-/xz-/yz-bin. The resolution of the maps is set via the three integer parameters IXRES, IYRES, and IZRES in the COMMON /CRPLOTSH2/. The unformatted map files consist of a two-word header containing the horizontal and vertical resolution of the respective map file, followed by the rows of map values[39]. These files are then easily processed further, for example by *map2png* (see below).
To control the plotting, the keyword PLAXES followed by 6 parameters (see page 79) might be used in the input file:

```
PLAXES   -5.E5  5.E5  -5.E5  5.E5  0.  3.E6
```

The keyword

```
PLCUTS   0.3  0.3  0.003  0.003 1.E5 T
```

(see page 79) serves to define energy cuts in the same order as those for the keyword ECUTS (hadrons, muons, electrons, photons) (see page 66). An additional parameter defines an upper bound on the time (in ns) passed since the first interaction, while the final logical determines whether only track segments inside the three-dimensional box given by the axis ranges should be plotted.
Via the keyword

```
PLOTSH    T
```

the PLOTSH2 option is enabled or disabled (see page 78).
This option is not recommended for ordinary shower production.
To obtain this program version the PLOTSH2 option has to be selected when extracting the FORTRAN code from the source file.

The **C**-program *map2png* (available in `src/`) converts the particle track maps generated by the PLOTSH2 option into PNG image files. The only prerequisite needed by the program is *libpng*, which is included in virtually all recent LINUX distributions. If this library is not available for your system, please use PLOTSH option instead. *map2png* is automatically compiled[40] when the PLOTSH2 option is selected.

---

[39]Note that on LINUX systems, the header and each row are preceded and followed by an additional word.
[40]`gcc [-Lpath_to_libpng] -lpng -lm map2png.c -o map2png`
The bracketed option is only needed if the path to 'libpng.so' is not included in the LD_LIBRARY_PATH variable.

The program *map2png* reads in the map files specified on the command line (via the path to *DATnnnnnn*) and combines them into a single PNG image of the same resolution as the maps. By default, the electromagnetic, muonic, and hadronic maps are taken as the red, green, and blue channels of the RGB image, respectively. However, it is possible to specify other colors to be used for the different particle types. The projection to be used as well as whether to use a linear or logarithmic color scale can be specified on the command line. To see a list of options, simply run *map2png* without arguments.

3.5.14 PRESHOWER Option

The PRESHOWER option selects code and **C**-routines [36] to describe the pair production of ultra-high energetic ($E_0 > 10^{19}$ eV) primary photons and bremsstrahlung interactions of the secondary em-particles within the Earth's magnetic field before reaching the top of atmosphere. Within the atmosphere the resulting swarm of em-particles is treated as one shower. To model correctly the field components of the Earth's magnetic dipole field in the outer space additional input is required to specify the location and the time of the experiment. The keyword (page 57)

```
GCOORD    -69.585   -35.463   2003.   1   0
```

gives the longitudinal and lateral position of the experiment on the Earth's globe, the year (the Earth's magnetic field is time dependent), a print indicator, and a stop indicator (for the case no preshowering occurred). Details of this input are given in Sect. 4.23. With the stop indicator it is possible to skip those events where no preshowering occurred. Nevertheless the event header and event end sub-blocks are written to MPATAP.

The appropriate **C**-routines belonging to the PRESHOWER option are available in the `src/` subdirectory, compiled and linked by the $Makefile$.

To obtain this program version the PRESHOWER option has to be selected when extracting the FORTRAN code from the source file.

3.5.15 ROOTOUT Option

The ROOTOUT option selects code which directly transmits the particle output (normally directed to MPATAP) to **C**$^{++}$-routines [41] to write an output '$DATnnnnnn$.root' file in *root* format, e.g. for *root* off-line analysis of the particle output data without storing the huge particle output data file MPATAP. The Cherenkov output file MCETAP is not affected by the ROOTOUT selection.

The ROOTOUT option should not be combined with the COMPACT option[42].

The appropriate **C**$^{++}$-routines belonging to the ROOTOUT option are available in the `coast/` subdirectory, compiled and linked by the $Makefile$.

The default COAST ROOTOUT data format is thought for fast and easy off-line analysis of CORSIKA data and is NOT a general replacement for CORSIKA binary data files. Due to the chosen data structure one shower including all particles and all Cherenkov photons is stored in

---

[41]Through COAST package automatically installed in `coast/` .
[42]This option compiles only on LINUX and MacOSX machines.

the computer's memory entirely before it is written to disk. This needs a lot of memory for high energy and/or high quality showers.

To obtain this program version the ROOTOUT option has to be selected when extracting the FORTRAN code from the source file and *root* should be installed on your system.

3.5.16 SLANT Option

With the SLANT option the longitudinal distributions (page 67 and Sect. 10.5 page 98) are given in slant depth bins along the shower axis instead of vertical depth bins used in the standard case. This slant depth scale is more appropriate to investigations of very inclined showers.

In the SLANT option [37, 38] the ionization energy loss, deflection within the Earth's magnetic field, and the generation of Cherenkov photons is enabled for charged hadronic primaries on their path between entering the atmosphere and the first interaction (which is disabled in the standard version without using keyword TSTART, page 53). The arrival time refers to the margin of the atmosphere, which is indicated by a negative value of element 7 of the event header block (page 91).

To obtain this program version the SLANT option has to be selected when extracting the FORTRAN code from the source file.

3.5.17 STACKIN Option

With the STACKIN option the parameters of secondary particles will be read into the CORSIKA stack. Thus interactions of very exotic primaries may be treated off-line in a suitable interaction program avoiding a direct coupling of such programs with CORSIKA. The air shower generated by these resulting secondary particles is simulated in CORSIKA, and all options may be combined with STACKIN. To characterize the altitude of the first interaction the keyword FIXHEI must be used, the shower axis is defined by the angles THETAP and PHIP (pages 51 and 52). This externally treated first interaction starts the clock by default (the keyword TSTART is disabled).

The file containing the parameters of the particles has to be specified by the keyword INFILE (page 54) and is read in via the logical unit LSTCK (by default 23, page 19). The first line is read with free format (with a leading blank character) and contains the number of secondaries and the primary energy. The following lines are read with the format (2I5,4(1X,E15.7)) containing current particle number, particle type (see Table 4 page 82), total energy (GeV), longitudinal momentum (GeV/c), and transverse momenta (GeV/c). The momenta are taken relative to the direction of the shower axis (direction of the exotic particle).

To obtain this program version the STACKIN option has to be selected when extracting the FORTRAN code from the source file.

3.5.18 Option for Thinning

For primary energies $E_0 > 10^{16}$ eV the computing times become excessively long (they scale roughly with the primary energy). To reduce the times to tolerable durations the so called

'thin sampling' mechanism (also named 'variance reduction' [16]) is introduced [35]. When thinning is active all particles below the adjustable fraction of the primary energy (thinning level $\varepsilon_{th} = E/E_0$) which emerge from an interaction are exposed to the thinning algorithm. Only one of these particles is followed and an appropriate weight is given to it, while the other particles below the thinning level are dropped. Details on this formalism may be found in Refs. [16, 35, 39].

A further improvement [40] to reduce undesired statistical fluctuations of particle densities far from the shower core uses a limitation of the weights. Particles emerging from an interaction

ε_{th}	none	10^{-6}	10^{-5}	10^{-4}	10^{-3}
Time (min)	98	51	7.2	1.2	0.16
particles	413078	58313	11466	2211	419

Table 2: Computing times and number of particles for various thinning levels, without application of weight limits and radial thinning.

which would exceed a specified weight limit are excluded from the thinning algorithm. Using different weight limits for em-particles and hadronic (including muonic) particles enables a drastic reduction of computing time, if the user's interest is focused onto a precise lateral distribution of muons on the expenses of larger fluctuations of the em-part.

A third algorithm to save space on disks reduces the number of particles close to the shower core where anyway the detectors will saturate. Particles arriving at the detector level within a selected core distance $rmax$ are selected at random with a probability $prob \propto (r/rmax)^4$ and, when surviving[43], their weight factor is multiplied with the inverse of this probability, irrespective of exceeding the weight limit. This radial thinning is not effective for the table output '$DATnnnnnn$.tab' (see keyword PAROUT page 70 and Sect. 10.6 page 98), nor for the '$datnnnnnn$.lhbook file generated in the ANAHIST and/or AUGERHIST versions.

Via the keyword (page 65)

```
    THIN     EFRCTHN     WMAX     RMAX
```

you may specify the energy fraction EFRCTHN of the primary energy, below which the thinning process becomes active. Above this energy no thinning will take place. WMAX gives the maximum weight factor[44], which should not be exceeded. The core distance up to which the radial thinning at detector level takes place is specified by RMAX.

Via the keyword (page 65)

```
    THINH     THINRAT     WEITRAT
```

or the keyword (page 66)

---

[43]To ensure the surviving of enough particles close to the shower axis RMAX should be chosen not too large.

[44]In case of a primary energy spectrum (ULIMIT > LLIMIT) the value of WMAX is used for the low energy end of the energy interval and slides to higher values according with the sliding primary energy.

```
THINEM    THINRAT    WEITRAT
```

differing thin levels and weight limits can be specified for hadronic or electromagnetic particles overwriting the ratios

$$\text{THINRAT} = \varepsilon_{th_{em}}/\varepsilon_{th_{hadr}} \quad \text{and} \quad \text{WEITRAT} = \text{WMAX}_{em}/\text{WMAX}_{hadr}$$

which are set to 1 by default.

The effect of various thinning levels $\varepsilon_{th} = E/E_0$ on the computing time and the number of particles on MPATAP may be seen from Table 2 which is established with default CORSIKA parameters (QGSJET option, EGS4 activated) for vertical proton induced showers of 10^{15} eV primary energy (DEC 3000/600 AXP with 175 MHz), with $\varepsilon_{th_{em}}/\varepsilon_{th_{hadr}} = 1$, with infinite weight limit, and without radial thinning. As to each particle an appropriate weight must be attributed, the output format described in Sect. 10.2 (page 88 ff.) has to be changed to incorporate this additional parameter of each particle. Consequently MPATAP and MCETAP **output data generated with the THIN option differ** from those generated in simulations without this option (see also Sect. 10.2.2 page 96).

An optimum choice of the various thinning parameters depends on the information which should be drawn from the simulations. To minimize the additional fluctuations (caused by the thin sampling algorithm) for muonic particle densities at large distances > 300 m from the shower core - which is one of the problems of the Auger experiment - a suitable setting [40] of WEITRAT would be

$$\text{WEITRAT} \approx 100$$

while the choice of WMAX is optimized for the primary energy E_0 (given in GeV) and the selected thinning level EFRCTHN for em-particles to

$$\text{WMAX} = \text{EFRCTHN} \cdot E_0 \,.$$

To obtain this program version the THIN option has to be selected when extracting the FORTRAN code from the source file.

3.5.19 UPWARD Option

The UPWARD option selects code which treats the upward travelling particles. For primary particles the zenith angle is restricted to $0° < \theta < 70°$ and $110° < \theta < 180°$.
No additional keyword has to be specified.
The UPWARD option might be combined with the CURVED option (page 38). This enables to start showers with arbitrary zenith angles $0° < \theta < 180°$ and secondary particles with arbitrary zenith angles are followed. [38].
For showers with skimming incidence (zenith angle $= 90°$) the minimum altitude of the shower axis above sea level is specified by HIMPACT(i) (keyword IMPACT, page 54) and defines the geometry completely. The zenith angle at the entrance into the atmosphere is calculated with it. The angles THETPR(i) (see keyword THETAP page 51) have no meaning and are overridden. The keyword IMPACT may be combined with the keywords FIXHEI (page 53) or FIXCHI (page 53) to start the shower before reaching the minimum altitude of the shower axis.

For showers with zenith angles > 90° (e.g. initiated by neutrinos, page 40) the starting point of the shower resp. the first interaction must be defined by the keywords FIXHEI (page 53) or FIXCHI (page 53); in this case the observation level (page 68) must be chosen preferentially at the top of the atmosphere, but at minimum above the starting point of the shower. (The shower axis must cross the observation level.)

To obtain the UPWARD program version the UPWARD option has to be selected when extracting the FORTRAN code from the source file.

3.5.20 Viewing Cone Option

The VIEWCONE option enables the generation of showers within the viewing cone of e.g. a Cherenkov telescope. Around the fixed incidence angle defined by THETPR(1) and PHIPR(1) (page 51) a (hollow) cone is defined with its tip pointing towards the detector. The inner and outer limiting angles of this cone are defined by the keyword VIEWCONE (page 52). The zenith angular dependence of the chosen detector geometry (see Sect. 3.5.21 below) is maintained for flat horizontal resp. spherical detectors, while the VOLUMECORR option is not supported. Showers originating from those portions of the cone which exceed the allowed range of COR-SIKA are not simulated, rather they are skipped and a new angle is selected at random out of the range of the cone.

To obtain this program version the VIEWCONE option has to be selected when extracting the FORTRAN code from the source file.

3.5.21 Volume Detector and Vertical String Geometry Options

With this options it is possible to select at random the zenith angle in a manner which respects the geometrical acceptance of the detector.

The **default** primary intensity distribution I goes with the zenith angle θ like

$$I \propto sin\theta \cdot cos\theta$$

The sin term respects the solid angle element of the sky, while the cos term takes the geometrical efficiency of a flat horizontal detector into account[45]. This allows to use each shower several times with the shower axis intersecting the detector array with equal distribution in x and y at random. The area to be covered by randomly scattering the shower axis is independent from the zenith angle and extends horizontally.

Using the VOLUMEDET option, the primary intensity distribution I goes with the zenith angle like

$$I \propto sin\theta$$

respecting only the solid angle elements of the sky. This is appropriate for detectors of approximated spherical geometry, e.g. atmospheric Cherenkov telescopes. To use a shower several

---

[45]Selecting in the CURVED version the zenith angle θ at random one should keep in mind that for the default version the probability vanishes at $\theta = 90°$. If the zenith angle range is specified as $\theta_1 < \theta < \theta_2$ with $\theta_1 < 90°$ and $90° < \theta_2$ the zenith angle is selected at random from $\mathrm{MIN}(\theta_1, 180° - \theta_2) < \theta < \mathrm{MAX}(\theta_1, 180° - \theta_2)$.

times you might scatter it on an area, which has fixed extensions in a plane perpendicular to the shower axis.

Using the VOLUMECORR option, the primary intensity distribution is a more complicated function of the zenith angle, which respects the geometry of a long vertical string detector (e.g. AMANDA experiment [41] and other neutrino telescopes) with a ratio of $l/d = length/diameter$ of the sensitive volume. The functional form of the zenith angle distribution becomes

$$ I \propto (d/2)^2 \cdot \pi \cdot sin\theta \cdot (cos\theta + 4/\pi \cdot l/d \cdot sin\theta) \quad . $$

The l/d ratio (defining the DETector ConFiGuration) has to be read in using the keyword DETCFG (page 69).

The VOLUMECORR option cannot be combined with the VIEWCONE option.

To obtain these program versions the VOLUMEDET rsp. VOLUMECORR option has to be selected when extracting the FORTRAN code from the source file.

3.6 Combination of Options

In principle most options may be combined. Do not combine FLUKA with the present version DPMJET 2.55 because of severe clashes caused by duplicate names.

DPMJET, EPOS, NEXUS, QGSJET, and SIBYLL are tested only with UNIX work stations. You can not select more than one high-energy hadronic interaction model at a time. In principle a combination of NUPRIM with all hadronic interaction models is possible (page 108).

The combination of PRESHOWER with NUPRIM makes no sense as your primary may be either a high-energy gamma ray or a neutrino. Neither PRESHOWER nor NUPRIM may be combined with STACKIN.

The ROOTOUT option should not be combined with the COMPACT option.

The combination of INTTEST with PLOTSH or PLOTSH2 is not reasonable as in the INTTEST option the development of showers is suppressed. Also a combination of INTTEST with ANAHIST, AUGERHIST, CURVED, PRESHOWER, STACKIN, or THIN gives no sense, as you are simulating just the first interaction without development of a complete shower. A combination with UPWARD makes no sense as in INTTEST anyway all upward going particles are respected. The combination of NUPRIM with INTTEST is not supported. The combination of FLUKA with INTTEST is not foreseen.

IACT is only possible with CERENKOV; IACT and ATMEXT have been tested only with UNIX computers.

VOLUMEDET and VOLUMECORR exclude each other, as you may use only one detector geometry at a time. Similarly INTCLONG and NOCLONG are excluding each other.

As in the CEFFIC option the atmospheric absorption is treated only in a manner suited for planar atmospheres, you should not combine the CURVED option with CEFFIC.

The combination of VOLUMECORR with VIEWCONE is not supported.

The AUGERHIST option cannot be combined with the IACT, CURVED, INTTEST, PLOTSH, or PLOTSH2 options.

Using the *corsika-install* script file (see Sect. 2.1.2 page 12) conflicting options are indicated and will be avoided automatically.

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4 Steering of the Simulation

The simulation of air showers is steered by commands (keywords) that have to be given on unit MONIIN (MONItor INput) in the card image format. A command consists of a keyword usually up to 6 characters long (left shifted, upper or lower case characters) and one or more arguments in the form:

```
KEYWRD    arg1  arg2  arg3  ...  arg$n$      comments
```

The keyword and the arguments must be separated at minimum by one blank. The last argument may be followed by comments up to column 80. Additional comments may be given on separate cards with the first 6 characters (the keyword) kept blank, with the first character a c or a C followed by a blank, or with the first character a *. In the IACT option (page 34) the cards starting with 'IACT ' are treated additionally as comment cards. Internally all characters including the keywords are converted to upper case characters, except the characters following the keywords EPOPAR, DIRECT, HISTDS, HOST, IACT, INFILE, NEXPAR, TELFIL, and USER. If you want to specify one of these character arguments by a blank, you should include the blank within apostrophes or quotation marks. The sequence of steering keywords is arbitrary. The valid keywords, the internal argument names, their nature (A = character, F = floating, I = integer, or L = logical), their default settings, their descriptions, and their limitations are listed in the following.

As CORSIKA is primarily designed to simulate EAS in the energy range 10^{11} eV to some 10^{20} eV the code contains parametrizations and approximations which are valid only for a limited range of some arguments. Leaving the recommended range might cause incorrect results or even end the execution of the program with an error message.

4.1 Run Number

```
RUNNR     NRRUN
```

Format = (A5, I), Default = 1
NRRUN : Run number of this simulation. This number is used to form part of the name of the various output files.
Limit is: $0 \leq \mathrm{NRRUN} \leq 999999$

4.2 First Event Number

```
EVTNR     SHOWNO
```

Format = (A5, I), Default = 1
SHOWNO : Event number of first shower. The second shower will get number SHOWNO+1 and so on.
Limit is: $1 \leq \mathrm{SHOWNO} \leq 999999$

4.3 Random Number Generator Initialization

```
SEED      ISEED(i,k),i=1... 3
```

Format = (A4, 3I), Defaults = k, 0, 0
ISEED$(1, k)$: Contains the seed of the random number sequence k.
ISEED$(2..3, k)$: Contain the number of calls N_{in} to the generator that are performed for initialization such that $N_{in} =$ISEED$(2, k) + 10^9 \cdot$ISEED$(3, k)$.
At present at most $k = 5$ sequences are used: Sequence 1 for the hadron shower, 2 for the EGS4 part, 3 for the simulation of Cherenkov photons (only for CERENKOV option), 4 for the random offset of Cherenkov telescope systems with respect of their nominal positions (only for IACT option), and 5 for the HERWIG routines in the NUPRIM version. Their activation follows the sequence of occurrence of the keyword lines.
At minimum 2 seeds must be activated.
The use of ISEED$(2, k) > 0$ and especially of ISEED$(3, k) > 0$ should be avoided as presetting the random number generator by billions of calls needs considerable computing time. To get different random sequences it is sufficient to modify ISEED$(1, k)$.
When the `eventio` and other separate functions are enabled in the IACT option, an external random generator may be used [46].
Limit (to get independent sequences of random numbers) is: $1 \leq$ ISEED$(1, k) \leq 900\,000\,000$

4.4 Number of Showers

```
NSHOW     NSHOW
```

Format = (A5, I), Default = 10
NSHOW : Number of showers to be generated in a run.
Limit is: NSHOW ≥ 1

4.5 Primary Particle Definition

```
PRMPAR     PRMPAR(1)
```

Format = (A6, I), Default = 14
PRMPAR(1) : Particle type of the primary particle. See Table 4 (page 82) for the particle codes. Limits are: $1 \leq$ PRMPAR(1) ≤ 5699 . Resonances are excluded. Primary neutrinos can only be used in the NUPRIM option (page 40). Instable nuclei with mass number 5 or 8 may be used only with SIBYLL or QGSJET cross-sections. Presently charmed particles are not yet supported by CORSIKA.
This keyword is not available in the STACKIN option.

---

[46]The FLUKA model uses its own random number generator. As a consequence, an event cannot be reproduced using the same CORSIKA seed.

4.6 Energy Range

```
ERANGE    LLIMIT    ULIMIT
```

Format = (A6, 2F), Defaults = 1.E4, 1.E4
LLIMIT : Lower limit and
ULIMIT : Upper limit of the primary particle energy range (in GeV). The primary energy is selected at random out of this interval. If LLIMIT = ULIMIT, the primary energy is fixed at this value.
The energies are total energies and include the particle rest mass.
Limits are: LLIMIT > HILOW (by default 80 GeV/nucleon fo rnuclei, see page 63); below this limit a simple superposition model is used. ULIMIT ≤ 1.E11 GeV for primary photons and electrons (but keep in mind that no LPM-effect is included in NKG!); for primary hadrons and nuclei no upper limit is recommended, but **the user should take care not to overstretch the selected hadronic interaction model**. See also Ref. [20]. It is recommended for HDPM: ULIMIT ≤ $1 \cdot 10^{17}$ eV and for VENUS: ULIMIT ≤ $2 \cdot 10^{16}$ eV.
This keyword is not available in the STACKIN option.

4.7 Slope of Spectrum

```
ESLOPE    PSLOPE
```

Format = (A6, F), Default = 0.
PSLOPE : Exponent γ of differential primary energy spectrum. The primary energy is taken at random from an exponential energy spectrum of the form $dN/dE_0 \propto E_0^{\gamma}$. PSLOPE has no meaning in case of fixed primary energy. The energies are total energies and include the particle rest mass.
This keyword is not available in the STACKIN option.

4.8 Zenith Angle Definition

```
THETAP    THETPR(1)    THETPR(2)
```

Format = (A6, 2F), Defaults = 0., 0.
THETPR(1) : Low edge of zenith angle range of primary particle (in °).
THETPR(2) : High edge of zenith angle range of primary particle (in °).
The zenith angle is selected at random out of this interval in a manner which respects equal particle fluxes from all solid angle elements of the sky and a registration by a horizontal flat detector arrangement[47]. THETPR is the angle of incidence at a horizontal detector. THETPR(i)

---

[47]In the case you use a volume detector (sphere) or a vertical long string detector instead of a flat horizontal detector, you should respect this by selecting the preprocessor option VOLUMEDET (for sphere) or VOLUMECORR (for vertical long string) to get the angular dependence of the shower intensity as observed with such detectors (see Sect. 3.5.21 page 48).

= 0. is vertical. If THETPR(1) = THETPR(2), the zenith angle is fixed at this value. Limits[48] are: 0.$\leq$ THETPR(i) $\leq$ 70.

4.9 Azimuth Angle Definition

```
PHIP      PHIPR(1)    PHIPR(2)
```

Format = (A4, 2F), Defaults = 0., 0.
PHIPR(1) : Low edge of azimuth angle range of primary particle (in °).
PHIPR(2) : High edge of azimuth angle range of primary particle (in °).
The azimuth angle is selected at random out of this interval.
If PHIPR(1) = PHIPR(2), the azimuth angle is fixed at this value. For $\phi = 0°$ the shower axis points to magnetic North, for $\phi = 90°$ it points to West, see Fig. 1 (page 84).
Limits are: -360. $\leq$ PHIPR(i) $\leq$ 360 [49].

4.10 Viewing Cone Specifications

```
VIEWCONE      VUECON(1)    VUECON(2)
```

Format = (A8, 2F), Defaults = 0., 0.
VUECON(1) : Inner limiting angle of viewing cone (in °).
VUECON(2) : Outer limiting angle of viewing cone (in °).
The VIEWCONE option (see Sect. 3.5.20 page 47) selects the direction of primaries in a circular cone around the fixed primary direction THETPR(1) and PHIPR(1) (page 51) with the inner opening VUECON(1) and the outer opening VUECON(2). The zenith angular dependence of the selected detector geometry is maintained for flat horizontal resp. spherical detectors (see Sect. 3.5.21 page 47).
Limits: 0. $\leq$ VUECON(1) $\leq$ VUECON(2) < 90. The generation of showers with angles beyond the range of the program validity is skipped.
This keyword is only available in the VIEWCONE option.

---

[48]The zenith angle limitation is recommended for the standard CORSIKA version because of some approximations made in subroutine *NKG*. At $\theta > 70°$ also the curvature of the Earth's surface must be taken into account. For large zenith angles you should use the CURVED option (page 38).
For the CURVED option the limit is 0.$\leq$ THETPR(i) < 90.; for the CURVED option combined with the CERENKOV option the limit is 0.$\leq$ THETPR(i)$\leq$ 88.
For the UPWARD option with upward going primary the limits are 110. $\leq$ THETPR(i) $\leq$ 180.
For the CURVED option combined with the UPWARD option THETPR(i) has to be chosen in a manner excluding the range 90. < THETPR(i) < 90. + δ. The angle δ <90° is spanned between the upward going shower axis and the horizontal detector plane above the shower starting point. Further details are given in [38, 42]. The keyword IMPACT (page 54) for skimming horizontal showers overrides THETPR(i).
[49]In the output file the corresponding ϕ of each shower is given in the range $[-\pi, \pi]$ radian.

4.11 Starting Altitude

```
FIXCHI     THICK0
```

Format = (A6, F), Default = 0.

THICK0 : The starting altitude (in g/cm^2 mass overburden) of the primary particle is set for all showers. This choice is not effective if the height of the first interaction is set by FIXHEI > 0. (see Sect. 4.13 below). With this keyword the development of subshowers starting at the chosen altitude within the atmosphere may be followed. The starting altitude must be above the lowest observation level.

In the UPWARD version with an upward primary particle the starting altitude must be below the observation level (page 46).

Limit is: $0. \leq$ THICK0.

4.12 Starting Point of Arrival Timing

```
TSTART     TMARGIN
```

Format = (A6, L), Default = F

TMARGIN : Flag indicating the starting point of the arrival time scale. If TMARGIN = .false., the first interaction starts the clock. If TMARGIN = .true., the entrance into the atmosphere (resp. THICK0, see above) is taken for starting the internal clock. Additionally, the ionization energy loss, deflection within the Earth's magnetic field, and the generation of Cherenkov photons is enabled for charged hadronic or muonic primaries on their path between entering the atmosphere and the first interaction, which otherwise is disabled in the standard version (for the CURVED and SLANT options see page 38 rsp. 44). For TMARGIN = .true. the height of the first interaction is written negative to element 7 of the event header block.

This keyword is not available in the CURVED, SLANT, or STACKIN options, and TMARGIN is set .true. by default in the CURVED and SLANT options.

4.13 First Interaction Definition

```
FIXHEI     FIXHEI     N1STTR
```

Format = (A6, F, I), Defaults = 0., 0

FIXHEI : Fixes the height (in cm) of the first interaction of hadronic primaries (rsp. the starting altitude for em-particles) for all showers in a run. If FIXHEI = 0., the height of the first interaction is varied at random according to the appropriate mean free path. In case of unstable hadronic primaries and fixed height the first interaction will not be a decay. The fixed height must be above the lowest observation level. If FIXHEI > 0. is set, the starting altitude of the primary is not effective (see Sect. 4.11 above).

In the CURVED version the keyword FIXHEI cannot be used for em-primary particles.

In the UPWARD version with an upward primary particle the starting altitude must be below the observation level (page 46).

In the STACKIN version FIXHEI is needed to specify the altitude of the first, externally treated interaction.

N1STTR : Fixes the target of the first interaction: 1 = Nitrogen, 2 = Oxygen, 3 = Argon, $else =$ random selection according to the atmospheric abundances. This option is only applicable for high-energy hadronic primaries, i.e. primaries with an energy per nucleon of $E_{lab} \geq$ HILOW (see page 63). Also in the NUPRIM version it may be used. In case of unstable hadronic primaries and predetermined target the first interaction will not be a decay.

Limits are: $0. \leq$ FIXHEI $<$ border of atmosphere at 112.8E5 cm for atmospheric models $1 <$ MODATM < 9 or MODATM > 17 .

4.14   Skimming Incidence

```
IMPACT     HIMPACT(1)    HIMPACT(2)
```

Format = (A6, 2F), Default = 0., 0.

HIMPACT(1) : Lower value (in cm) for minimum altitude of horizontal shower axis.

HIMPACT(2) : Upper value (in cm) for minimum altitude of horizontal shower axis. The actual minimum altitude is selected at random out of this interval with uniform distribution. Zenith angles given by the keyword THETAP (page 51) are overridden by a calculation from the actual minimum altitude. See UPWARD option page 46.

Limits are: OBSLEV(1) $\leq$ HIMPACT(i) $\leq$ min(FIXHEI, FIXCHI, border of atmosphere [at 112.8E5 cm for atmospheric models $1 <$ MODATM < 9 or MODATM > 17]).

This keyword is only available in the combination of the CURVED option with the UPWARD option.

4.15   Stack Input File Name

```
INFILE     FILINP
```

Format = (A6, A64), Defaults = ' '

FILINP : File name to define the name and directory of the input file containing the parameters of secondary particles. Lower case characters of FILINP are not converted to capitals. Please keep in mind that in FORTRAN an automatic expansion of UNIX names like '*home*' is not possible, rather you should give the full expanded name of the directory ending with a '/' character.

Limit is: FILINP must not begin with a ~ (tilde) character.

This keyword is only available in the STACKIN option.

4.16   Atmospheric Model Selection

```
ATMOD     MODATM
```

Format = (A5, I), Default = 1
MODATM : Gives the number of the atmospheric parametrization.

MODATM = 0: Atmosphere as read in by keywords ATMA, ATMB, ATMC, and ATMLAY (uppermost layer unchanged).
MODATM = 1: U.S. standard atmosphere as parametrized by Linsley.
MODATM = 2: AT115 Central European atmosphere for Jan. 15, 1993.
MODATM = 3: AT223 Central European atmosphere for Feb. 23, 1993.
MODATM = 4: AT511 Central European atmosphere for May 11, 1993.
MODATM = 5: AT616 Central European atmosphere for June 16, 1993.
MODATM = 6: AT822 Central European atmosphere for Aug. 22, 1993.
MODATM = 7: AT1014 Central European atmosphere for Oct. 14, 1993.
MODATM = 8: AT1224 Central European atmosphere for Dec. 24, 1993.
MODATM = 9: Atmosphere as read in by keywords ATMA, ATMB, ATMC. Layers as in MODATM = 1 . . . 8.
MODATM = 10: Atmosphere as read in by keywords ATMA, ATMB, ATMC, and ATMLAY (uppermost layer also read in).
MODATM = 11: South pole atmosphere for March 31, 1997 (MSIS-90-E).
MODATM = 12: South pole atmosphere for July 01, 1997 (MSIS-90-E).
MODATM = 13: South pole atmosphere for Oct. 01, 1997 (MSIS-90-E).
MODATM = 14: South pole atmosphere for Dec. 31, 1997 (MSIS-90-E).
MODATM = 15: South pole atmosphere for January after Lipari.
MODATM = 16: South pole atmosphere for August after Lipari.
MODATM = 17: Malargüe winter atmosphere I after Keilhauer.
MODATM = 18: Malargüe winter atmosphere II after Keilhauer.
MODATM = 19: Malargüe spring atmosphere after Keilhauer.
MODATM = 20: Malargüe summer atmosphere after Keilhauer.
MODATM = 21: Malargüe autumn atmosphere after Keilhauer.
MODATM = 22: U.S. standard atmosphere as parametrized by Keilhauer.
The various atmospheric models are described in Appendix D (page 112 ff.).
Limits are: $0 \leq \text{MODATM} \leq 22$.

4.17   Atmospheric Parameters A(i)

```
ATMA     AATM1    AATM2    AATM3    AATM4    (AATM5)
```

Format = (A4, 4F), Defaults = 0., 0., 0., 0. (for ATMOD 0)
Format = (A4, 5F), Defaults = 0., 0., 0., 0., 0. (for ATMOD 10)
AATMi : A-parameters for 4 layers of atmospheric model # 0 (or for 5 layers of atmospheric model # 10). For the 5th layer a linear decrease is assumed, which in case of ATMOD = 0 uses the same parameters as the U.S. standard atmosphere. To be used with ATMOD = 0 or 10 .
Limit is: $0. < \text{AATM5}$

4.18 Atmospheric Parameters B(i)

```
ATMB      BATM1      BATM2      BATM3      BATM4
```

Format = (A4, 4F), Defaults = 0., 0., 0., 0.
BATMi : B-parameters for 4 layers of atmospheric model # 0. For the 5th layer a linear decrease is assumed with the same parameters as for the U.S. standard atmosphere. To be used with ATMOD = 0 or 10.
Limits are: BATM$i \neq 0$.

4.19 Atmospheric Parameters C(i)

```
ATMC      CATM1      CATM2      CATM3      CATM4      (CATM5)
```

Format = (A4, 4F), Defaults = 0., 0., 0., 0. (for ATMOD 0)
Format = (A4, 5F), Defaults = 0., 0., 0., 0., 0. (for ATMOD 10)
CATMi : C-parameters for 4 layers of atmospheric model # 0 (or for 5 layers of atmospheric model # 10). For the 5th layer a linear decrease is assumed, which in case of ATMOD = 0 uses the same parameters as the U.S. standard atmosphere. To be used with ATMOD = 0 or 10.
Limits are: CATM$i > 0$.

4.20 Atmospheric Layer Boundaries

```
ATMLAY      HLAY2      HLAY3      HLAY4      HLAY5
```

Format = (A6, 4F), Defaults = 4.D5, 10.D5, 40.D5, 100.D5
HLAYi : Layer lower boundaries (in cm) for the layers of atmospheric model # 0 and # 10. A value of 0. is adopted for the HLAY1. If not specified, the default values of MODATM = 1 are used for MODATM = 0 and 10. For other models (MODATM $\neq 0$ and $\neq 10$), the default values correspond with the selected model MODATM. Should only be used with ATMOD = 0 or 10.
Limits are: $0. <$ HLAYi.

4.21 External Tabulated Atmosphere

```
ATMOSPHERE      IATMOX      FREFRX
```

Format = (A10, I, L), Defaults = 0, F
IATMOX : Use MODTRAN [33] atmospheric model `IATMOX = i` (in terms of density and refractive index) instead of CORSIKA built-in model. This requires a file named *atmprofi*.dat. MODTRAN model atmospheres supplied with the 'bernlohr' package include tropical ($i = 1$), mid-latitude summer (2), mid-latitude winter (3), sub-arctic summer (4), sub-arctic winter (5),

and U.S. standard atmosphere 1976 (6). User supplied models are possible (i$\geq$ 7).

FREFRX : If .true., the atmospheric refraction for Cherenkov photons is taken into account (for plane-parallel atmosphere); if .false., refraction is ignored. The value of this second argument is ignored if the CERENKOV option is not selected.

This keyword is only available in the ATMEXT option and needs linking with the (compiled) *atmo*.c routines of the 'bernlohr' package.

4.22   Earth's Magnetic Field

    MAGNET   BX   BZ

Format = (A6, 2F), Defaults = 20.40, 43.23

BX : Is the horizontal component of the Earth's magnetic field (in μT) to the x-direction of the detector (North) and

BZ : Is the vertical component of the Earth's magnetic field (in μT) downwards.

The default values represent the magnetic field for the Karlsruhe location. The values of other locations may be obtained from the program *Geomag* which is available on-line in the world wide web [45]. The value H of *Geomag* corresponds with our BX, the value Z with our BZ. For orientation see also Fig. 1 (page 84).

Limits are: BX, BZ $\neq$ 0. .

4.23   Experiment Coordinates for Preshowering

    GCOORD   GLONG   GLAT   GRFYEAR   IPREPR   IPRSTP

Format = (A6, 3F, 2I), Defaults = -69.585, -35.463, 2003., 1, 0

GLONG : Gives the geographical longitude (in °, West length is negative) of the experiment.

GLATI : Gives the geographical latitude (in °, South latitude is negative) of the experiment.

GRFYEAR : Gives the year of the experiment (the magnetic field is varying with time). These coordinates are used to calculate the magnetic dipole field of the Earth's globe above the atmosphere of the experiment's position in the case of a preshower induced by ultra-high energetic primary photons. The default values give the position coordinates of the southern Pierre Auger Observatory at Malargüe (Argentina) for the year 2003.

IPREPR : Print indicator[50]: IPREPR $\leq$ 0 disables preshower printing; IPREPR = 1 prints details of preshower in case of MAXPRT (page 69) or DEBUG (page 75); IPREPR $\geq$ 2 always prints details of preshower.

IPRSTP : If IPRSTP $\neq$ 0 events without preshowering are skipped.

Limits are: -180. $\leq$ GLONG $\leq$ 180.; -90. $\leq$ GLATI $\leq$ 90.; 1965. $\leq$ GRFYEAR $\leq$ 2005.

---

[50]The print statements within the PRESHOWER C-routines write only to the standard output. A redirecting of the standard output to a logical unit differing from 6 (see keyword OUTPUT page 71) usually will not affect the output of the PRESHOWER C-routines.

This keyword is only available in the PRESHOWER option.

4.24   DPMJET Selection Flag

DPMJET   FDPMJT   LEVLDB

Format = (A6, L, I), Defaults = T, 0
FDPMJT : If .true., the DPMJET routines are used to treat the high-energy hadronic interactions. If .false., the HDPM routines are used to treat the high-energy hadronic interactions.
LEVLDB : Gives amount of debug output for the DPMJET code in case of DEBUG. With increasing value up to 8 the debug output becomes more and more detailed. This output cannot be redirected and always appears on unit 6.
Limits are: $0 \leq$ LEVLDB ≤ 8 .
This keyword is only available in the DPMJET option.

4.25   DPJSIG Selection Flag

DPJSIG   FDPJSG

Format = (A6, L), Default = T
FDPJSG : If .true, the DPMJET high-energy hadronic cross-sections are used. If .false., the default cross-sections as described in Ref. [3] are used.
This keyword is only available in the DPMJET option.

4.26   EPOS Selection Flag

EPOS   FNEXUS   ISH0N

Format = (A5, L, I), Defaults = T, 0
FNEXUS : If .true., the EPOS routines are used to treat the high-energy hadronic interactions. If .false., the HDPM routines are used to treat the high-energy hadronic interactions.
ISH0N : Determines amount of debug output for the EPOS routines. With increasing number ISH0N > 0 the output becomes more and more detailed. This output appears on the unit MDEBUG.
For more information look into the EPOS documentation. Additional debugging is effective by setting print parameters using EPOPAR *print . . . .* This debug output is written to the `ifch` file (see Table 1 page 23).
Limits are: $0 \leq$ ISH0N ≤ 9 .
This keyword is only available in the EPOS option.

4.27   EPOS Parameters

> EPOPAR   *parcha*

Format = (A6, A74), Defaults = ' '
parcha : Command line to be read by subroutine *aread* of program block *epos*-`bas-xxx.f`. The possible command lines are described in the EPOS documentation. Use lower case characters. Lower case characters of *parcha* are not converted to capitals. Do not use the commands *application ...*, *set nevent ...*, *run*, or *stop* within your input parameters, these will cause unpredictable results or crashes. Only $epos$.inixx names might be changed by standard users[51].
This keyword is only available in the EPOS option.

4.28   EPOSIG Selection Flag

> EPOSIG   FNEXSG

Format = (A6, L), Default = T
FNEXSG : If .true., the EPOS high-energy hadronic cross-sections are used. If .false., the default cross-sections as described in Ref. [3] are used.
This keyword is only available in the EPOS option.

4.29   NEXUS Selection Flag

> NEXUS   FNEXUS   ISH0N

Format = (A5, L, I), Defaults = T, 0
FNEXUS : If .true., the NEXUS routines are used to treat the high-energy hadronic interactions. If .false., the HDPM routines are used to treat the high-energy hadronic interactions.
ISH0N : Determines amount of debug output for the NEXUS routines. With increasing number ISH0N > 0 the output becomes more and more detailed. This output appears on the unit MDEBUG.

---

[51]A typical EPOPAR input looks like:
EPOPAR fname inics ˜corsika-6600/epos/epos.inics
EPOPAR fname iniev ˜corsika-6600/epos/epos.iniev
EPOPAR fname inihy ˜corsika-6600/epos/epos.ini1b
EPOPAR fname inirj ˜corsika-6600/epos/epos.inirj
EPOPAR fname initl ˜corsika-6600/epos/epos.initl
EPOPAR fname check ˜corsika-6600/epos/epos.check
EPOPAR fname histo ˜corsika-6600/epos/epos.histo ! for interaction test only
EPOPAR fname data ˜corsika-6600/epos/epos.data ! for debugging only
EPOPAR fname copy ˜corsika-6600/epos/epos.copy ! for debugging only
EPOPAR fname log ˜corsika-6600/epos/epos.log ! for debugging only
EPOPAR printcheck screen ! for debugging only.

For more information look into the NEXUS documentation. Additional debugging is effective by setting print parameters using NEXPAR *print ....* This debug output is written to the `ifch` file (see Table 1 page 23).

Limits are: $0 \leq$ ISH0N ≤ 9.

This keyword is only available in the NEXUS option.

4.30 NEXUS Parameters

NEXPAR	*parcha*

Format = (A6, A74), Defaults = ' '

parcha : Command line to be read by subroutine *aread* of program block *nexus*-`bas.f`. The possible command lines are described in the NEXUS documentation. Use lower case characters. Lower case characters of *parcha* are not converted to capitals. Do not use the commands *application ...*, *set nevent ...*, *run*, or *stop* within your input parameters, these will cause unpredictable results or crashes. Only $nexus$.inixx names might be changed by standard users[52].

This keyword is only available in the NEXUS option.

4.31 NEXSIG Selection Flag

NEXSIG	FNEXSG

Format = (A6, L), Default = T

FNEXSG : If .true., the NEXUS high-energy hadronic cross-sections are used. If .false., the default cross-sections as described in Ref. [3] are used.

This keyword is only available in the NEXUS option.

4.32 QGSJET Selection Flag

QGSJET	FQGS	LEVLDQ

---

[52] A typical NEXPAR input looks like:

NEXPAR fname inics ˜corsika-6600/nexus/nexus.inics
NEXPAR fname iniev ˜corsika-6600/nexus/nexus.iniev
NEXPAR fname inirj ˜corsika-6600/nexus/nexus.inirj
NEXPAR fname initl ˜corsika-6600/nexus/nexus.initl
NEXPAR fname check ˜corsika-6600/nexus/nexus.check
NEXPAR fname histo ˜corsika-6600/nexus/nexus.histo ! for interaction test only
NEXPAR fname data ˜corsika-6600/nexus/nexus.data ! for debugging only
NEXPAR fname copy ˜corsika-6600/nexus/nexus.copy ! for debugging only
NEXPAR fname log ˜corsika-6600/nexus/nexus.log ! for debugging only
NEXPAR printcheck screen ! for debugging only.

Format = (A6, L, I), Defaults = T, 0

FQGS : If .true., the qgsjet-II-03 (rsp. QGSJET01c) routines are used to treat the high-energy hadronic interactions. If .false., the HDPM routines are used to treat the high-energy hadronic interactions.

LEVLDQ : Gives amount of debug output for the qgsjet-II-03 (rsp. QGSJET01c) code in case of DEBUG. With increasing value up to 4 the debug output becomes more and more detailed. This output cannot be redirected and always appears on unit 6.

Limits are: $0 \leq \text{LEVLDQ} \leq 4$.

This keyword is only available in the QGSJET option.

4.33   QGSSIG Selection Flag

```
QGSSIG      FQGSSG
```

Format = (A6, L), Default = T

FQGSSG : If .true., the qgsjet-II-03 (rsp. QGSJET01c) high-energy hadronic cross-sections are used. If .false., the default cross-sections as described in Ref. [3] are used.

This keyword is only available in the QGSJET option.

4.34   SIBYLL Selection Flag

```
SIBYLL      FSIBYL      ISDEBUG
```

Format = (A6, L), Default = T, 0

FSIBYL : If .true., the SIBYLL routines are used to treat the high-energy hadronic interactions. If .false., the HDPM routines are used to treat the high-energy hadronic interactions.

ISDEBUG : Debug level; with increasing level the SIBYLL 2.1 debug output becomes more and more detailed. This output cannot be redirected and always appears on unit 6.

This keyword is only available in the SIBYLL option.

4.35   SIBSIG Selection Flag

```
SIBSIG      FSIBSG
```

Format = (A6, L), Default = T

FSIBSG : If .true., the SIBYLL high-energy hadronic cross-sections are used. If .false., the default cross-sections as described in Ref. [3] are used.

This keyword is only available in the SIBYLL option.

4.36 VENUS Selection Flag

```
VENUS     FVENUS     ISH00
```

Format = (A5, L, I), Defaults = T, 0
FVENUS : If .true., the VENUS routines are used to treat the high-energy hadronic interactions.
If .false., the HDPM routines are used to treat the high-energy hadronic interactions.
ISH00 : Determines the amount of debug output for VENUS routines. With increasing number ISH00 $\geq$ 90 the output becomes more and more detailed. This output appears on the unit MDEBUG. For more information look into the listing of subroutine *venini*.
Limits are: $0 \leq$ ISH00 ≤ 98 .
This keyword is only available in the VENUS option.

4.37 VENUS Parameters

```
VENPAR     PARCHA(i)     PARVAL(i)
```

Format = (A6, A6, F), Defaults = '   ', 0.
PARCHA(i) : Name of VENUS parameter to be changed.
PARVAL(i) : New value of VENUS parameter to be changed.
A maximum of $i = 100$ VENUS parameters may be set by the user in arbitrary sequence. The available names and their meaning may be taken from the listing of subroutine $venini$.
The VENUS parameters should not be changed by standard users.
This keyword is only available in the VENUS option.

4.38 VENSIG Selection Flag

```
VENSIG     FVENSG
```

Format = (A6, L), Default = T
FVENSG : If .true., the VENUS high-energy hadronic cross-sections are used. If .false., the default cross-sections as described in Ref. [3] are used.
This keyword is only available in the VENUS option.

4.39 HDPM Interaction Parameters & Fragmentation

```
HADFLG     NFLAIN   NFLDIF   NFLPI0   NFLPIF   NFLCHE   NFRAGM
```

Format = (A6, 6I), Defaults = 0, 0, 0, 0, 0, 2
Steering flags of the high-energy hadronic interaction model HDPM and of the projectile nucleus fragmentation of all hadronic interaction models.

NFLAIN : The number of interactions of a projectile in a target nucleus may fluctuate (NFLAIN = 0) or is calculated as an average value (NFLAIN $\neq$ 0).
NFLDIF : No diffractive interactions are allowed in case of more than 1 interaction in the target (NFLDIF = 0) or diffractive interactions are possible (NFLDIF $\neq$ 0).
NFLPI0 : The rapidity distribution of π° is taken different from that of charged pions as indicated by collider data (NFLPI0 = 0) or is taken as for charged pions (NFLPI0 $\neq$ 0).
NFLPIF : The number of π° fluctuates in the same way as the number of charged pions (NFLPIF = 0) or fluctuates independently as parametrized from collider data (NFLPIF $\neq$ 0).
NFLCHE : Charge exchange reactions for the proj. and target particles are allowed (NFLCHE = 0) or inhibited (NFLCHE $\neq$ 0).

NFRAGM : A primary nucleus fragments at the first interaction completely into free nucleons (NFRAGM = 0) or successively by assuming that the non-interacting nucleons proceed as one new nucleus (NFRAGM = 1). This new nucleus may evaporate nucleons or alpha-particles with a transverse momentum distribution according to experimental data [43] (NFRAGM = 2, default) or with a transverse momentum distribution according to Goldhaber's theory [44] using 0.090 GeV/nucleon as the average transverse momentum (NFRAGM = 3). NFRAGM = 4 gives identical fragments as NFRAGM = 2 or 3, but without transverse momenta.

The NFRAGM flag is used also to steer the fragmentation in the various interaction models as described for the HDPM routines. EPOS, NEXUS and VENUS use the same evaporation model as HDPM with the same meaning of NFRAGM, while SIBYLL and QGSJET deliver themselves realistic nuclear fragments with according transverse momenta; they are selected by NFRAGM $\geq$ 2. In principle DPMJET offers a very detailed nuclear fragmentation model with evaporation. But there is no allowance to distribute it. Therefore the nuclear evaporation as used for HDPM, EPOS, NEXUS, and VENUS is coupled with DPMJET and the meaning of NFRAGM follows HDPM. Additionally NFRAGM = 5 is used to activate the DPMJET evaporation module if it exists.
Limits are: $0 \leq all\ flags < 100$

4.40   Transition Energy between Models

```
HILOW      HILOELB
```

Format = (A5, F), Default = 80.
HILOELB : Allows to define the transition energy[53] (E_{lab} in GeV) between high and low-energy hadronic interaction model.
Limits depend on the used interaction model, for most high-energy hadronic interaction models the low-energy limit is in the range of ≈ 80 GeV, for SIBYLL ≈ 60 GeV, while most low energy models enable a limit as high as several 100 GeV.

---

[53]With the INTTEST option the default value of this border is at 49 GeV rsp. 101 GeV, depending whether a high- or low-energy hadronic interaction model should be tested. For testing of DPMJET, EPOS, NEXUS, QGSJET, and VENUS the default value is set to 49 GeV, for SIBYLL to 60 GeV. If none of those models is selected, the default value is set to 101 GeV to test the models FLUKA, GHEISHA, or UrQMD.

4.41   Electromagnetic Interaction Steering Flags

```
ELMFLG    FNKG    FEGS
```

Format = (A6, 2L), Defaults = T, F
FNKG : If .true., the NKG option is switched on for calculating the electromagnetic sub-cascades analytically. For the electron kinetic energy threshold the value of ELCUT(3) is taken (keyword ECUTS page 66). If .false., the NKG option is disabled[54].
FEGS : If .true., the EGS4 option is selected to calculate all interactions of e^+, e^-, and photons in the atmosphere explicitly. (The second random number sequence should be initialized for use in the EGS4 part. Otherwise the default initialization is taken.) If .false., the EGS4 option is disabled.
In the CERENKOV option this flag is obsolete as EGS4 is selected automatically.
The two options may be selected or disabled independently at the same time.

4.42   Electron Multiple Scattering Length Factor

```
STEPFC    STEPFC
```

Format = (A6, F), Default = 1.
STEPFC : Factor by which the multiple scattering length for electrons and positrons in EGS4 simulations is elongated relative to the value given in [16]. A detailed discussion on the use of the step length is given in [28]. An enlargement of this factor may be tolerated to reduce computing time, but simultaneously the electron lateral distribution on ground becomes slightly narrower. With STEPFC = 10. the CPU-time is reduced by a factor of ≈ 1.7 (relative to the default value). A reduction of STEPFC will increase the computing time considerably, e.g with STEPFC = 0.1 by a factor of ≈ 5.
Limits are: $0. <$ STEPFC ≤ 10.0

4.43   Radius of NKG Lateral Range

```
RADNKG    RADNKG
```

Format = (A6, F), Default = 200.E2
RADNKG : Gives the outer range radius (in cm) within which the lateral NKG distribution is calculated for 10 radii equidistant in logarithmic scale. The inner radius is always kept at 100 cm.
Limit is: RADNKG > 100.

---

[54]In the CURVED version the NKG formulas are no longer valid, therefore the NKG flag is disabled automatically in this version. The NKG flag should be disabled in the COMPACT version, as the resulting NKG parameters cannot be written out onto the particle output file.

4.44 Thinning Definition

```
THIN     EFRCTHN    WMAX     RMAX
```

Format = (A4, 3F), Defaults = 1.E-4, 1.E30, 0.E0

EFRCTHN : Factor ε_{th} which defines the energy fraction of the primary energy below which the thinning algorithm becomes active. If the fraction is selected in a manner that this energy is below the lowest energy threshold of ELCUT(i), $i = 1...4$ (keyword ECUTS page 66), thinning will not become active but the particle output data structure will contain the weight (= 1.) for each particle.

WMAX : Weight limit for thinning. If the weight of a particle exceeds WMAX, no further thinning is performed[55].

RMAX : Maximum radius (in cm) at observation level within which all particles are subject to inner radius thinning. Particles are selected with probability $(r/rmax)^4$. The weight of surviving particles is multiplied by the appropriate factor (inverse of probability). This thinning neither affects the shower development nor the table output nor the histogram output of the ANAHIST or AUGERHIST versions, rather only the particle output file written onto MPATAP (and the Cherenkov output file written onto MCETAB). For RMAX ≤ 0. no radial thinning is applied.

Limits are: ULIMIT·EFRCTHN $\leq 1 \cdot 10^{16}$ eV (for ULIMIT see keyword ERANGE page 51); $0.1 \leq$ WMAX $\leq 1 \cdot 10^{20}$.

This keyword is only available in the THIN option.

4.45 Hadronic Thinning Definition

```
THINH    THINRAT    WEITRAT
```

Format = (A5, 2F), Defaults = 1., 1.

THINRAT : Defines hadronic thinning limit differing from em-thinning limit EFRCTHN by the ratio of $\varepsilon_{th_{em}}/\varepsilon_{th_{hadr}}$ which gives the ratio between the energy of the em-particles (specified by keyword THIN, see above) and the energy of the hadronic particles below which the thinning algorithm becomes active for these particle species (see also Sect. 4.44 above).

WEITRAT : Defines hadronic weight limit differing from em-weight limit WMAX by the ratio[56] of weight limit of em-particles to weight limit of hadronic particles in case of thinning (see also Sect. 4.44 above).

A simultaneous use of the keyword THINH together with THINEM is not tolerated and will lead to an error stop.

Limits are: ULIMIT·EFRCTHN/THINRAT $\leq 1 \cdot 10^{16}$ eV (for ULIMIT see keyword ERANGE page 51); $1 \cdot 10^{-4} \leq$ WEITRAT $\leq 1 \cdot 10^6$.

This keyword is only available in the THIN option.

---

[55]See footnote page 45.

[56]In the Slowenian thinning [40] an ϵ is defined which gives the inverse of WEITRAT. There the weight limit w_{max} is defined for em-particles and from this the weight limit for hadrons and muons is derived by $\epsilon \cdot w_{max}$.

4.46 Electromagnetic Thinning Definition

```
THINEM    THINRAT    WEITRAT
```

Format = (A6, 2F), Defaults = 1., 1.
THINRAT : Defines em-thinning limit differing from hadronic thinning limit EFRCTHN by the ratio of $\varepsilon_{th_{em}}/\varepsilon_{th_{hadr}}$ which gives the ratio between the energy of the em-particles and the energy of the hadronic particles (specified by keyword THIN, see above) below which the thinning algorithm becomes active for these particle species (see also Sect. 4.44 above).
WEITRAT : Defines em-weight limit differing from hadronic weight limit WMAX by the ratio[56] of weight limit of em-particles to weight limit of hadronic particles in case of thinning (see also Sect. 4.44 above).
A simultaneous use of the keyword THINEM together with THINH is not tolerated and will lead to an error stop.
Limits are: ULIMIT·EFRCTHN·THINRAT $\leq 1 \cdot 10^{16}$ eV (for ULIMIT see keyword ERANGE page 51); $1 \cdot 10^{-4} \leq$ WEITRAT $\leq 1 \cdot 10^{6}$.
This keyword is only available in the THIN option.

4.47 Energy Cut-Offs

```
ECUTS    ELCUT(i), i=1... 4
```

Format = (A5, 4F), Defaults[57] = 0.3, 0.3, 0.003, 0.003
ELCUT(i) : The low energy cut-off (in GeV) of the particle kinetic energy may be chosen differently for hadrons (without π^0's) ($i = 1$), muons ($i = 2$), electrons ($i = 3$), and photons (including π^0's) ($i = 4$). For nuclei ELCUT(1) is applied to the energy per nucleon.
It is in the responsibility of the user to choose the cut-off values in a reasonable way not to eliminate those parent particles which might decay to secondaries which you are looking for in the investigated problem (e.g. decay of muons to electrons).
Limits are: ELCUT(1)[58] ≥ 0.05 ; ELCUT(2) ≥ 0.05; ELCUT(3), ELCUT(4) ≥ 0.00005
The value of ELCUT(3) is also taken as threshold value for the NKG calculation. In this case an upper limit of ELCUT(3) < 0.08 is recommended.

4.48 Time Cut-Off

```
TIMLIM    DSTLIM
```

Format = (A6, F), Default = 1.D8
DSTLIM : Gives the distance (in cm) a particle would travel with velocity of light downstream

---

[57]For the INTTEST option: Defaults = 0., 0., 0., 0. and all limits are ELCUT(i) ≥ 0.
[58]ELCUT(1) is used also for neutrinos in the NEUTRINO option. In the URQMD option ELCUT(1) should be ≥ 0.3 GeV.

the detector before cut away by the time limit. An additional security time of 20 μsec (corresponding with ≈ 6 km) is taken into account.

Limit is: DSTLIM > 0.

This keyword is only available in the CURVED option.

4.49 Longitudinal Shower Development

    LONGI   LLONGI   THSTEP   FLGFIT   FLONGOUT

Format = (A5, L, F, 2L), Defaults = F, 20.0, F, F

LLONGI : If .true., the longitudinal development of particle numbers for gammas (EGS4), positrons (EGS4), electrons (EGS4), positive and negative muons, hadrons, all charged, nuclei, and Cherenkov photons (CERENKOV) is sampled. Moreover the longitudinal development of the energy content in the various particle species (same order as before, but without Cherenkov photons) is sampled. Additionally the longitudinal development of energy deposit by ionization energy loss and by angular or energy cuts is sampled. See also Sect. 10.1 page 87. To get the sampling in slant depth instead of the (default) vertical depth you should use the SLANT option (page 44). If .false., the longitudinal development is not sampled.

THSTEP : Vertical step width (resp. slant step width in the SLANT version) for sampling of the longitudinal development (in g/cm^2). The sampling is done in vertical (resp. slant) depth. The altitudes are not depending on the zenith angle of the primary particle (except the preprocessor option SLANT has been selected). In the curved version the minimum step size has to be selected in a manner that no more than 1875 steps are needed to pass through the complete atmosphere.

FLGFIT : If .true. and LLONGI also .true., the longitudinal development of all charged particles number is fitted. If .false., the fit is suppressed.

FLONGOUT : If .true. and LLONGI also .true., the longitudinal distributions of particle numbers and energy deposit for the various particle groups are written to the '$DATnnnnnn$.long' file (see Sect. 10.5 page 98).

If .false. and LLONGI .true., the longitudinal distributions only of the particle numbers for the various particle species are written out to the particle output file '$DATnnnnnn$' in extra 'LONG' sub-blocks (see Sect. 10.2, Table 6 page 89 and Table 11 page 94).

Limits are: 1. $\leq$ THSTEP $\leq$ 1875.

20. $\leq$ THSTEP $\leq$ 1875 for the SLANT version and horizontal incidence.

Normally only to the number distribution of all charged particles a function of the Gaisser-Hillas type [46]

$$N(t) = N_{max} \cdot \left(\frac{t - t_0}{t_{max} - t_0} \right)^{\frac{t_{max} - t_0}{a + bt + ct^2}} \cdot exp\left(\frac{t_{max} - t}{a + bt + ct^2} \right)$$

is fitted to describe the dependence on the atmospheric depth t and the resulting 6 parameters $N_{max}, t_0, t_{max}, a, b,$ and c and the χ^2/dof are stored in the event end block. The longitudinal

development of the electromagnetic particles is only sampled if EGS4 is selected (see ELM-FLG). If only NKG is activated the fit is applied to the NKG longitudinal distribution which consists of particle numbers from only ≤ 10 levels. If neither EGS4 nor NKG is selected the charged particle distribution contains only muons and charged hadrons. In the AUGERHIST version also a Gaisser-Hillas type function is fitted to the longitudinal energy deposit, if EGS4 is selected.

In the Cherenkov versions the longitudinal distribution of photons is given in differential mode (i.e. the number of photons generated within each step) as default. By the preprocessor option INTCLONG the integral mode is selected (i.e. accumulated number of generated Cherenkov photons for each step) which needs additional computing time. If both kinds of the distribution are of no interest, you may deselect the Cherenkov photon distribution completely by the preprocessor option NOCLONG thus saving computing time.

4.50 Muon Multiple Scattering Treatment

```
MUMULT     FMOLI
```

Format = (A6, L), Default = T
FMOLI : If .false., the muon multiple scattering angle is selected by Gauss approximation. If .true., the muon multiple scattering angle is selected for large steps by Molière's theory and for small steps by adding many single Coulomb scattering events.

4.51 Additional Muon Information

```
MUADDI     FMUADD
```

Format = (A6, L), Default = F
FMUADD : If .false., no additional muon information is written to particle output file. If .true., additional information on muons at their origin is written to the particle output file. This additional muon information consists of 7 data words according to Table 9 (page 93) and precedes the corresponding muon particle on particle output file. The first data word contains the particle identification 75 (μ^+) or 76 (μ^-) combined with generation, which in this case may differentiate between muons originating from K-decay (normal generation counter) and $\pi^\pm$-decay (generation counter incremented by 50). The 7th data word contains the altitude (in cm) of the muon birth instead of time (see also Table 9 page 93).
This keyword is not available in the INTTEST option.

4.52 Observation Level Definition

```
OBSLEV     OBSLEV(i)
```

Format = (A6, F), Default = 110.E2

OBSLEV(i) : Observation level i above sea level (in cm). This keyword has to appear once for each level to be defined. At maximum up to 10 observation levels are possible[59]. Their sequence is arbitrary.

In the UPWARD version (page 46) for upward going primaries the observation level should be chosen preferentially at the top of atmosphere, but at minimum above the starting point of the shower. Th e value of OBSLEV has to be selected in a manner that the shower axis crosses the observation level.

Limits are[60]: $0 \leq$ OBSLEV(i) < *top of atmosphere*

4.53   Array Rotation

    ARRANG   ARRANG

Format = (A6, F), Default = 0.

ARRANG : Defines a rotation angle (in °) between the array x-direction and magnetic north direction; positive if array x-direction points to the West.

Limits are: -180. $\leq$ ARRANG $\leq$ 180.

4.54   String Detector Configuration

    DETCFG   DETCFG

Format = (A6, F), Default = 0.

DETCFG : Gives the geometry configuration of a long vertical string detector as the ratio *height/diameter*.

Limit is: DETCFG > 0.

This keyword is only available in the VOLUMECORR option.

4.55   Event Printout

    MAXPRT   MAXPRT

Format = (A6, I), Default = 10

MAXPRT : Is the maximum number of events that produce a detailed printout during the simulation run.

Limit is: MAXPRT $\geq$ 0

---

[59]Only one observation level is possible in the CURVED option. Up to 20 levels might be speci fi ed for the production of histograms in the AUGERHIST version.

[60]For atmospheric models 1 < MODATM < 9 limits are: $-1.\text{E}5 <$ OBSLEV(i) < 112.8E5

4.56 Particle Printout

```
ECTMAP    ECTMAP
```

Format = (A6, F), Default = 1.E4
ECTMAP : Defines a cut in the particle γ factor (or energy in GeV for em-particles and neutrinos) above which they are printed out on the logical unit MONIOU when passing an observation level.

4.57 Output Directory

```
DIRECT    DSN
```

Format = (A6, A64), Defaults = 'anynameupto64characters'
DSN : May be used to define a name of an output directory. Lower case characters of DSN are not converted to capitals. Do not use capitals with the ANAHIST or AUGERHIST options as the HBOOK routines use only lower case characters. To suppress the output you might give `/dev/null` [61] or use the keyword PAROUT.
If you want to write into the directory from where you are starting your CORSIKA run, you should give: `DIRECT ' '` or `DIRECT " "` (a blank enclosed in apostrophes or quotation marks). Please keep in mind that in FORTRAN an automatic expansion of UNIX names like '*home*' is not possible, rather you should give the full expanded name of the directory ending with a '/' character.
Limit is: DSN must not begin with a ~ (tilde) character.

4.58 Table Output

```
PAROUT    FPAROUT    FTABOUT
```

Format = (A6, 2L) Defaults = T, F
FPAROUT : If .false., the particle output onto MPATAP is suppressed. This might be of advantage with the CERENKOV option to suppress the particle output file but keeping the Cherenkov output file (see Sect. 4.64).
FTABOUT : If .true., the tabular output of the charged particle development is written out to the file '$DATnnnnnn$.tab' onto the output directory DSN (see Sect. 4.57 above).

4.59 Compact Output

```
COMOUT    COMOUT
```

---

[61]A dummy directory named `/dev/null` must be mounted in the system.

Format = (A6, F), Default = T
COMOUT : If .true., the particle output is written in COMPACT form (see page 38). If .false., the standard CORSIKA particle output is written.
This keyword is only available in the COMPACT option.

4.60 Printer Output Unit

    OUTPUT   MONNEW

Format = (A6, I), Default = 6
MONNEW : Logical unit of simulation control output on line printer. Make sure that your selection of MONNEW is not conflicting with existing definitions (see Table 1 page 23).

4.61 Cherenkov Detector Array Definition

    CERARY   NCERX   NCERY   DCERX   DCERY   ACERX   ACERY

Format = (A6, 2I, 4F), Defaults = 27, 27, 1500., 1500., 100., 100.
NCERX : Number of Cherenkov detectors in X-direction.
NCERY : Number of Cherenkov detectors in Y-direction.
DCERX : Grid spacing (in cm) of Cherenkov detectors in X-direction. The DCERX value has no relevance in case of NCERX = 1.
DCERY : Grid spacing (in cm) of Cherenkov detectors in Y-direction. The DCERY value has no relevance in case of NCERY = 1.
ACERX : Length (in cm) of each Cherenkov detector in X-direction.
ACERY : Length (in cm) of each Cherenkov detector in Y-direction.
The altitude of this array is at the lowest observation level. For the definition of the X and Y-directions see Fig. 1 (page 84) and keyword ARRANG (page 69).
Limits are: NCERX, NCERY $\geq$ 1 ; DCERX, DCERY, ACERX, ACERY $\geq$ 1.
This keyword is only available in the CERENKOV option, but not in the IACT option for Cherenkov telescopes.

4.62 Cherenkov Wavelength Band

    CWAVLG   WAVLGL   WAVLGU

Format = (A6, 2F), Defaults = 300., 450.
WAVLGL : Lower limit (in nm) of the wavelength band for Cherenkov radiation production.
WAVLGU : Upper limit (in nm) of the wavelength band for Cherenkov radiation production.
Limits are: 100. $\leq$ WAVLGL $<$ WAVLGU $\leq$ 900.
This keyword is only available in the CERENKOV, AUGCERLONG, and AUGERHIST option.

4.63 Cherenkov Bunch Size Definition

```
CERSIZ    CERSIZ
```

Format = (A6, F), Default = 0.
CERSIZ : Defines the maximal bunch size of Cherenkov photons that are treated together. If set to 0., by the subroutine *getbus* the program calculates a bunch size which is found to be appropriate for the HEGRA-array.
Limit is: CERSIZ $\geq$ 0.
This keyword is only available in the CERENKOV, AUGCERLONG, and AUGERHIST option.

4.64 Cherenkov Output Steering

```
CERFIL    LCERFI
```

Format = (A6, L), Default = T
LCERFI : If .true., Cherenkov output is written to the Cherenkov output file MCETAP. If .false., Cherenkov output is written to the particle output file MPATAP.
In the IACT option (Cherenkov telescopes) with LCERFI .true., the output file name DSN (specifyed by keyword DIRECT) should be set to /dev/null [62] to suppress the normal Cherenkov output file, as the Cherenkov telescope output will be written to the eventio output file[63].
LCERFI automatically will be set .true. in the COMPACT version to prevent a writing of Cherenkov photons to the COMPACT output.
This keyword is only available in the CERENKOV option.

4.65 Cherenkov Quantum Efficiency

```
CERQEF    CERQEF    CERATA    CERMIR
```

Format = (A6, 3L), Defaults = F, F, F
CERQEF : If .true., quantum efficiency of detector photomultiplier is taken into account. It needs reading in the *quanteff*.dat file.
CERATA : If .true., the atmospheric absorption of Cherenkov photons is taken into account. It needs reading in the *atmabs*.dat file.
CERMIR : If .true., the mirror reflectivity of Cherenkov telescopes is taken into account. It needs reading in the *mirreff*.dat file.
Respecting these effects at an early stage of the Cherenkov photon simulation drastically reduces computing time and storage requirements for Cherenkov photon output. For the influence onto the longitudinal distribution of Cherenkov photons see Sect. 3.4.5 page 35 and keyword LONGI page 68.

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[62] The existence of /dev/null is assumed, see footnote of Sect. 4.57.
[63] Details on the eventio format may be found in the documentation supplied with the 'bernlohr' package.

This keyword is only available in the CEFFIC option together with the CERENKOV option.

4.66 Multiple Use of Cherenkov Events

```
CSCAT     ICERML    XSCATT    YSCATT
```

Format = (A5, I, 2F), Defaults = 1, 0., 0.
ICERML : Number of uses of each event.
XSCATT : Maximum scattering of core location in $\pm X$ direction (in cm). See Sect. 3.4.1 page 32 ff.
YSCATT : Maximum scattering of core location in $\pm Y$ direction (in cm). See Sect. 3.4.1 page 32 ff.
Limits are: $0 \leq$ ICERML ≤ 20 ; XSCATT, YSCATT ≥ 0.
In case of IACT option (Cherenkov telescopes) ICERML telescope arrays are simulated randomly (see keyword SEED page 50) in the specified area which is a circle of radius XSCATT, if YSCATT $= 0.$, or within a rectangle of area 2 XSCATT $\cdot$ 2 YSCATT.
This keyword is only available in the CERENKOV option.

4.67 Cherenkov Telescope Dimensions

```
TELESCOPE    X    Y    Z    R
```

Format = (A9, 4F)
X, Y, Z : Coordinates of Cherenkov telescope (in cm) relative to the center of the observation level. This keyword adds a new telescope at position X, Y, Z with radius R, within which the telescope is fully contained. At least one telescope has to be specified. For the definition of the X and Y-directions see Fig. 1 (page 84) and keyword ARRANG (page 69).
Limits are: $0 < R$; $1 \leq$ number of telescopes < 1000.
This keyword is only available in the CERENKOV option together with the IACT option for Cherenkov telescopes.

4.68 Cherenkov Telescope Data File Name

```
TELFIL    TELFNM
```

Format = (A6, A100)
TELFNM : The telescope-specific data are to be written to a file named TELFNM in `eventio` format[64]. Lower case characters of TELFNM are not converted to capitals. If this file exists and is write-enabled, new data are appended. After ending the run the file will be set read-only to

---

[64]Details on the `eventio` format may be found in the documentation supplied with the 'bernlohr' package.

avoid accidental overwriting. The file name `/dev/null` [65] suppresses the output file.

If you want to write into the directory from where you are starting your CORSIKA run, you should give: `TELFIL ' '` or `TELFIL " "` (a blank enclosed in apostrophes or quotation marks). Please keep in mind that in FORTRAN an automatic expansion of UNIX names like '*home*' is not possible, rather you should give the full expanded name of the directory ending with a '/' character.

This keyword is only available in the CERENKOV option together with the IACT option for Cherenkov telescopes.

4.69   Write Data Base File

    DATBAS   FDBASE

Format = (A6, L), Default = F

FDBASE : If .true., all essential run parameters are written to the file '*DATnnnnnn*.dbase' (resp. '*DATnnnnnn*.info' in the AUGERINFO version) onto the output directory DSN (keyword DIRECT page 70). This file may be used to build a data base for examining the content of an air shower library (page 98).

This keyword is only available in the UNIX options.

4.70   User Name

    USER   USER

Format = (A4, A20), Defaults = ' '

USER : A user name is read in to be written to the '$DATnnnnnn$.dbase' file. Lower case characters of USER are not converted to capitals.

4.71   Host Name

    HOST   HOST

Format = (A4, A20), Defaults = ' '

HOST : A host name is read in to be written to the '$DATnnnnnn$.dbase' file. Lower case characters of HOST are not converted to capitals.

---

[65]The existence of `/dev/null` is assumed, see footnote of Sect. 4.57.

4.72 Debugging

```
DEBUG    DEBUG    MDEBUG    DEBDEL    NDEBDL
```

Format = (A5, L, I, L, I), Defaults = F, MONIOU, F, 100000

DEBUG : If .false., debugging is disabled. If .true., additional output for debugging purposes is given on logical unit MDEBUG.

MDEBUG : Logical unit where to write debugging information. Make sure that your selection of MDEBUG is not conflicting with existing definitions (see Table 1 page 23).

DEBDEL : If .true., the debugging printouts are activated after NDEBDL particles above the ECTMAP energy have been printed. If .false., delayed debugging is disabled. This feature helps to trace run time errors that have occurred in long simulation runs.

NDEBDL : See DEBDEL

4.73 Debugging EGS

```
EGSDEB    JCLOCK
```

Format = (A6, I), Default = 2147483647

JCLOCK : Counter for delayed start of EGS4 debugging. After activation of debug by DEBUG or by NDEBDL (see Sect. 4.72 above) each pass of subroutine *electr* is counted. If the counter exceeds JCLOCK, the debug statements within the EGS4 portion are activated. This output appears on the unit MDEBUG.

4.74 FLUKA Printing

```
FLUDBG    FFLUDB
```

Format = (A6, L), Default = F

FFLUDB : If .true. the two files '$DATnnnnnn$.flout' for additional information on the parameters used by FLUKA and '$DATnnnnnn$.flerr' on possible FLUKA error messages are written onto the output directory DSN (keyword DIRECT page 70). If by the keyword DIRECT the directory /dev/null has been specified, the two files are opened within the directory from where the job has been started.

If .false. in the LINUX option the two files are written to fort.11 rsp. fort.15 and may be redirected at runtime to /dev/null using shell commands like setenv FORT.11 /dev/null resp. setenv FORT.15 /dev/null. Without the LINUX option the files are opened directly to the directory /dev/null [66].

This keyword is only available in the FLUKA option.

---

[66]The existence of /dev/null is assumed, see footnote of Sect. 4.57.

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4.75 GHEISHA Debugging

```
GHEIDB      GHEISDB
```

Format = (A6, L), Default = F
GHEISDB : If .true., in the DEBUG case also the GHEISHA routines produce debug output. This output appears on the unit MDEBUG.
This keyword is only available in the GHEISHA option.

4.76 URQMD Debugging

```
URQMD      FURQMD      IUDEBUG
```

Format = (A5, L, I), Default = T, 0
FURQMD : If .true., the UrQMD routines are used for the low-energy hadronic interactions. If .false., the program will stop.
IUDEBUG : If > 0, in the DEBUG case also the routines of UrQMD produce some output. With increasing value of IUDEBUG this printout becomes more and more detailed. This output appears on the unit MDEBUG.
Limit is: $0 \leq$ IUDEBUG ≤ 3 .
This keyword is only available in the URQMD option.

4.77 Cherenkov Debugging

```
CDEBUG      LCERDB
```

Format = (L), Default = F
LCERDB : If .false., Cherenkov debug output is disabled. If .true., the Cherenkov routines produce debug output. This output appears on the unit MDEBUG.
This keyword is only available in the CERENKOV option.

4.78 Interaction Test Target Definition

```
INTTST      ITTAR      MCM
```

Format = (A6, 2I), Defaults = 0, 0
ITTAR : Defines the target for the interaction test option: 1 = proton; 2 = neutron; 9 = Beryllium; 12 = Carbon; 14 = Nitrogen; 16 = Oxygen; 40 = Argon; 99 = air.
MCM : Defines the reference system for which the interaction products are plotted. 1 = rest system of 1 target nucleon and 1 projectile nucleon[67]; 2 = laboratory system; 3 = rest system of

---

[67]In photo-nuclear interactions the cm-system of the photon with one nucleon.

all secondary particles (but not the spectators).
This keyword is only available in the INTTEST option.

4.79   Interaction Test Decay

```
INTDEC    LPI0    LETA    LHYP    LK0S
```

Format = (A6, 4L), Defaults = T, T, T, T
LPI0 : If .true. the π° particles decay before gathering them in the interaction test.
LETA : If .true. the η particles decay before gathering them in the interaction test.
LHYP : If .true. all hyperons decay before gathering them in the interaction test.
LK0S : If .true. the K°_s particles decay before gathering them in the interaction test.
This keyword is only available in the INTTEST option.

4.80   Interaction Test Spectator Definition

```
INTSPC    LSPEC
```

Format = (A6, L), Default = T
LSPEC : If .true. spectators are plotted, if .false. spectators are not plotted in the interaction test.
This keyword is only available in the INTTEST option.

4.81   Interaction Test Diffraction Flag

```
DIFOFF    NDIF
```

Format = (A6, I), Default = 0
NDIF : Allows to select diffractive or non-diffractive interactions only[68]. 0 = diffractive and non-diffractive interactions mixed; 1 = non-diffractive interactions only; 2 = diffractive interactions only. With the QGSJET01c interaction model NDIF = 2 cannot be selected. With the EPOS, NEXUS and QGSJET-II models only NDIF = 0 is possible.
This keyword is only available in the INTTEST option.

---

[68]For photo-nuclear interactions the meaning is: 0 = multi-hadron production and vector meson production mixed; 1 = no vector meson production, only multi-hadron production; 2 = only vector meson production, no multi-hadron production.

4.82   Interaction Test Trigger Condition

```
TRIGGER    NTRIG
```

Format = (A7, I), Default = 0
NTRIG : Allows to select various trigger conditions for comparison with experimental data:
0 = accepts all events;
1 = accepts only events according to the UA5-experiment [47] trigger;
2 = accepts only events according to the CDF-experiment [48] trigger.
3 = accepts only events according to the P238-experiment [49] trigger.
NTRIG $\neq$ 0 may be combined only with NDIF = 0 .
This keyword is only available in the INTTEST option.

4.83   Interaction Test Histogram Output

```
HISTDS    HISTDS
```

Format = (A6, A120), Defaults = 'HISTO.CORSIKA.INTTEST'
HISTDS : May be used to specify a name of the histogram output directory and data file. Lower case characters of HISTDS are not converted to capitals. Do not use capitals as the HBOOK routines use only lower case characters. The data file name is extended by a string containing information about projectile, target, energy, and the type of interaction which has been selected. At the end of the data file name .hbook is appended such that the total data file name would look like

HISTO.CORSIKA.INTTEST.P0014T14E100E3.diffractive.hbook   for a proton projectile on nitrogen target with a lab energy of 100E3 GeV including diffractive events.
If you want to write into the directory from where you are starting your CORSIKA run, you should give: `HISTDS ' '` or `HISTDS " "` (a blank enclosed in apostrophes or quotation marks). Please keep in mind that in FORTRAN an automatic expansion of UNIX names like '*home*' is not possible, rather you should give the full expanded name of the directory ending with a '/' character.
Limit is: HISTDS must not begin with a ~ (tilde) character.
This keyword is only available in the INTTEST option.

4.84   Plot Output

```
PLOTSH    PLOTSH
```

Format = (A6, L), Default = F
PLOTSH : If .true., the track start- and endpoints of the electromagnetic, muonic, and hadronic component of the shower are given out separately and may be used to plot the shower development.

This keyword is only available in the PLOTSH and PLOTSH2 option.

4.85   Plot Axes Definition

```
PLAXES    X1   X2   Y1   Y2   Z1   Z2
```

Format=(A6,6F), Defaults = -500000., 500000., -500000., 500000., 0., 3000000.
X1, X2 : They denote the X axis range (in cm) to be plotted in the map.
Y1, Y2 : They denote the Y axis range (in cm) to be plotted in the map.
Z1, Z2 : They denote the Z axis range (in cm) to be plotted in the map.
The point of first interaction determines the zero point of the X and Y axes (see Fig. 1 page 84).
Depending on the choice of these parameters, the whole shower may be visualized, or one can
'zoom in' on interesting regions of the shower.
Limits are: X1 < X2, Y1 < Y2, Z1 < Z2 .
This keyword is only available in the PLOTSH2 option.

4.86   Plot Energy Cut Definition

```
PLCUTS    ELCUTS(1...4)   TCUT   FBOXCUT
```

Format=(A6,5F,L), Defaults 0.3, 0.3, 0.003, 0.003, 100000., F
ELCUTS(1...4) : ELCUTS denote the energy cuts in the same order as those for the keyword
ECUTS (hadrons, muons, electrons, photons) (see page 66).
TCUT : This is an upper bound on the time (in ns) passed since the first interaction. If, at the
end point of a track, the time is above TCUT, the track is **not** plotted. This cut allows a visual-
ization of the shower development.
FBOXCUT : This flag determines whether only track segments inside the three-dimensional
box given by the axis ranges should be plotted. If .true., all track segments whose endpoints
both fall outside this box are not plotted.
This keyword is only available in the PLOTSH2 option.

4.87   End of Steering

```
EXIT
```

Format = (A4)
This keyword ends the keyword input.

5 Input Example

The keyword input file for a CORSIKA run including QGSJET and CERENKOV options may look like the following list.

```
RUNNR  1                          number of run
EVTNR  100400                     no of first shower event
SEED   100401  0  0               seed for hadronic part
SEED   100402  0  0               seed for EGS4 part
SEED   100403  0  0               seed for Cherenkov part
NSHOW  10                         no of showers to simulate
PRMPAR 5626                       primary particle code (iron)
ERANGE 2.00E4  4.00E4             energy range of primary (GeV)
ESLOPE -2.7                       slope of energy spectrum
THETAP 0.  10.                    range zenith angle (deg)
PHIP   -180.  180.                range azimuth angle (deg)
QGSJET T  0                       QGSJET for high energy & debug level
QGSSIG T                          QGSJET cross-sections enabled
HADFLG 0  0  0  0  0  2           HDPM interact.flags & fragmentation flag
ELMFLG T  T                       elmag. interaction flags NKG, EGS4
STEPFC 1.                         multiple scattering step length factor
RADNKG 200.E2                     outer radius (cm) of NKG elect. distrib.
MAGNET 20.4  43.23                magnetic field central Europe (/uT)
ECUTS  .3 .3  .015  .015          energy cuts: hadr. muon elec. phot. (GeV)
LONGI  T  20.  T    T             longitud, stepsize(g/cm^2), fit, out
MUMULT T                          muon multiple scattering by Moliere
MUADDI T                          additional muon information
OBSLEV 110.E2                     observation level (cm)
ARRANG 18.25                      angle between north to array-grid (deg)
MAXPRT 10                         max. no of printed events
ECTMAP 1.E2                       printout gamma factor cut
DIRECT /home/user/corsika/run/    directory of particle output
CERARY 10 8 1200. 1500. 80. 50.   Cherenkov detector grid (cm)
CWAVLG 300.  450.                 Cherenkov wavelength band (nm)
CERSIZ 5.                         bunch size Cherenkov photons
CERFIL F                          Cherenkov output file
CSCAT  5  1000.  1000.            scatter Cherenkov events (cm)
DATBAS T                          write data base file
USER   you                        user name for data base file
HOST   your_host                  host name for data base file
DEBUG  F  6  F  999999999         debug flag, log. unit, delayed debug
EXIT
```

6 Units in CORSIKA

Within CORSIKA uniform units for the various dimensions are used as far as possible. But there are deviations at that program parts which are coupled to CORSIKA. Table 3 gives an overview on the used units.

Quantity	CORSIKA	EGS4	FLUKA GHEISHA UrQMD	SIBYLL	DPMJET EPOS NEXUS QGSJET VENUS
length	cm	cm			
energy	GeV	MeV	GeV	GeV $^3)$	GeV
mass	GeV	MeV	GeV	GeV	GeV
time	sec $^1)$	sec			
magn. field	μT				
density	g/cm^3	g/cm^3			
mass overburden	g/cm^2				
angle	rad $^2)$	rad			
wavelength	nm				

$^1)$ For output files also nsec is used.

$^2)$ For in- and output files also $^\circ$ is used.

$^3)$ In some subroutines also TeV is used.

Table 3: Units used in CORSIKA and the coupled programs.

7 Coordinate System

The coordinates in CORSIKA are defined with respect to a Cartesian coordinate system with the positive x-axis pointing to the magnetic North, the positive y-axis to the West, and the z-axis upwards. The origin is located at sea level. This definition is necessary, because the Earth's magnetic field is taken into account. By default the magnetic field is implemented for the location of Karlsruhe (49° N, 8° E) as described at the keyword MAGNET (page 57). The zenith angle θ of a particle trajectory is measured between the particle momentum vector and the negative z-axis, and the azimuthal angle ϕ between the positive x-axis and the horizontal component of the particle momentum vector (i.e. with respect to North) proceeding counterclockwise. This is shown in Fig. 1.
Attention: This definition disagrees from definitions of other air-shower simulation programs and from the conventions of the Auger experiment!

8 Particles in CORSIKA

CORSIKA is able to treat the particles (without charm[69]) that are listed in Table 4. The particle codes have in general been chosen according to the convention in the GEANT detector simulation code [26]. Exceptions are the resonances (ρ, K^*, and Δ), the η particles which are split in

---

[69]Particles with identifications 116<ID<173 are not yet available in the program.

Particle identifications			
Identification	Particle	Identification	Particle
1	γ	51	ρ°
2	e^+	52	ρ^+
3	e^-	53	ρ^-
		54	Δ^{++}
5	μ^+	55	Δ^+
6	μ^-	56	Δ°
7	π°	57	Δ^-
8	π^+	58	$\overline{\Delta}^{--}$
9	π^-	59	$\overline{\Delta}^-$
10	K°_L	60	$\overline{\Delta}^\circ$
11	K^+	61	$\overline{\Delta}^+$
12	K^-	62	$K^{*\circ}$
13	n	63	K^{*+}
14	p	64	K^{*-}
15	$\overline{p}$	65	$\overline{K^*}^\circ$
16	K°_S	66	ν_e
17	η	67	$\overline{\nu}_e$
18	Λ	68	ν_μ
19	Σ^+	69	$\overline{\nu}_\mu$
20	Σ°		
21	Σ^-	71	$\eta \to \gamma\gamma$
22	Ξ°	72	$\eta \to 3\pi^\circ$
23	Ξ^-	73	$\eta \to \pi^+\pi^-\pi^\circ$
24	Ω^-	74	$\eta \to \pi^+\pi^-\gamma$
25	$\overline{n}$	75	μ^+ add. info.
26	$\overline{\Lambda}$	76	μ^- add. info.
27	$\overline{\Sigma}^-$		
28	$\overline{\Sigma}^\circ$		
29	$\overline{\Sigma}^+$		
30	$\overline{\Xi}^\circ$		
31	$\overline{\Xi}^+$		
32	$\overline{\Omega}^+$		
50	ω		

Table 4: Particle identifications as used in CORSIKA (to be continued).

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Particle identifications[69](continued)			
Identification	Particle	Identification	Particle
116	D°	149	$\overline{\Lambda_c}^-$
117	D^+	150	$\overline{\Xi_c}^-$
118	$\overline{D}^-$	151	$\overline{\Xi_c}^\circ$
119	$\overline{D}^\circ$	152	$\overline{\Sigma_c}^{--}$
120	D_s^+	153	$\overline{\Sigma_c}^-$
121	$\overline{D_s}^-$	154	$\overline{\Sigma_c}^\circ$
122	η_c	155	$\overline{\Xi'_c}^-$
123	$D^{*\circ}$	156	$\overline{\Xi'_c}^\circ$
124	D^{*+}	157	$\overline{\Omega_c}^\circ$
125	$\overline{D^*}^-$		
126	$\overline{D^*}^\circ$	161	Σ_c^{*++}
127	D_s^{*+}	162	Σ_c^{*+}
128	$\overline{D_s^*}^-$	163	$\Sigma_c^{*\circ}$
130	J/ψ	171	$\overline{\Sigma_c^*}^{--}$
131	τ^+	172	$\overline{\Sigma_c^*}^-$
132	τ^-	173	$\overline{\Sigma_c^*}^\circ$
133	ν_τ		
134	$\overline{\nu}_\tau$		
137	Λ_c^+		
138	Ξ_c^+		
139	Ξ_c°		
140	Σ_c^{++}		
141	Σ_c^+		
142	Σ_c°		
143	$\Xi_c'^+$		
144	$\Xi_c'^\circ$		
145	Ω_c°		
$A \times 100 + Z$	nucleus of Z protons and $A - Z$ neutrons $(2 \leq A \leq 59)$		
9900	Cherenkov photons on particle output file		

Table 4: (continued) Particle identifications as used in CORSIKA.

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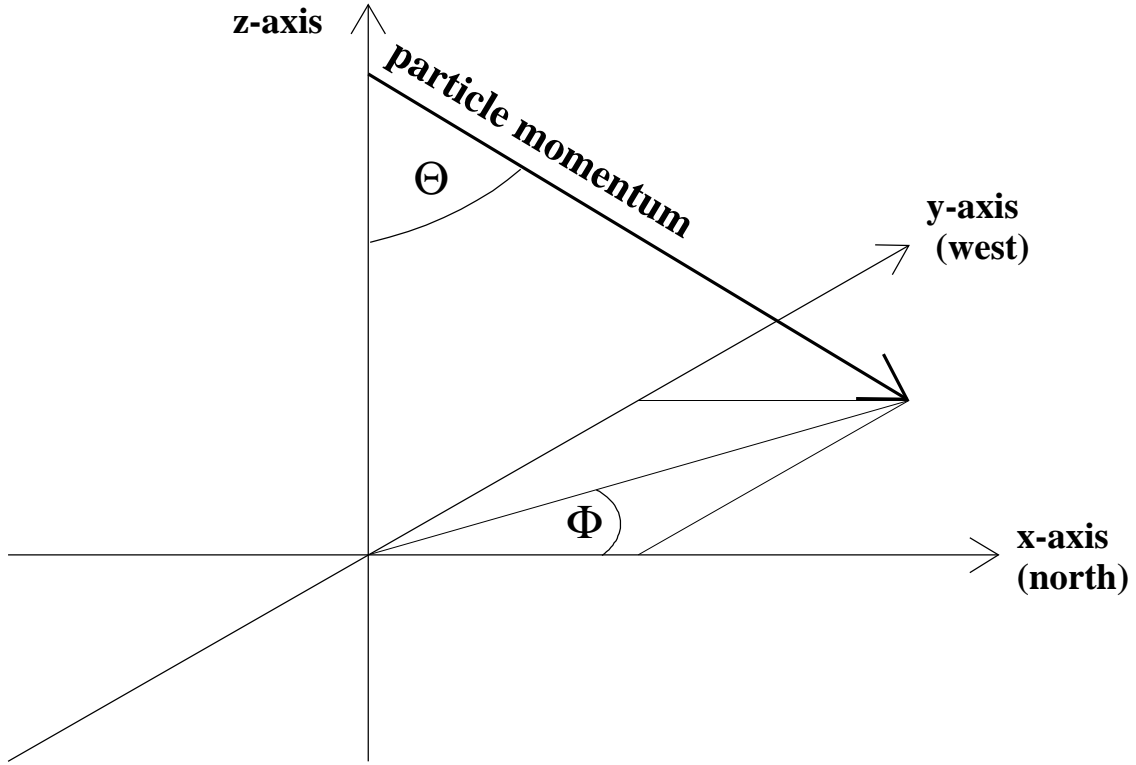
Figure 1: Coordinate system in CORSIKA.

4 types according to their decays in the HDPM routines, the ω, the different types of neutrinos (to be generated in the NEUTRINO option), the nuclei, and the Cherenkov photons. The codes of the charmed particles correspond with those of DPMJET. The charmed particles are already defined for future extensions of CORSIKA. Cherenkov photons can not be a primary particle for an air shower simulation.

9 Running the CORSIKA Program

Depending on the program version CORSIKA needs at minimu 7 MB memory. Especially DPMJET, EPOS, and NEXUS need a huge amount of internal memory. Empirical values of required memory for DEC AXP computers are given in Table 5. Using UrQMD instead of GHEISHA needs 8.6 Mbyte additionally. Using FLUKA instead of GHEISHA needs about

Option	HDPM	SIBYLL 2.1	QGSJET01c	VENUS	DPMJET2.55	NEXUS3.97	EPOS
Memory Mbyte	7.6	12	10	21	52	>100	>300

Table 5: Required memory for various CORSIKA/GHEISHA options (DEC-ALPHA).

100 Mbyte additionally. To be able to simulate central collisions of primary ^{56}Fe nuclei with atmospheric ^{40}Ar at higher energies some program parts need large arrays (e.g. the intermediate stack STACKINT needs 2 MB, in EPOS, NEXUS and VENUS the arrays dimensioned by MXPTL need about 10 MB). If the energy range is limited to < 100 TeV, some of those large arrays may be dimensioned smaller thus saving memory. On machines with little memory the permanent swapping might significantly contribute to the overall computing time.
A simplified flow diagram of CORSIKA is given in Appendix B (page 110).
The sequence of the initializing procedures is given in Appendix C (page 111).
CORSIKA runs fastest (full simulation adopted without THINning) when using no EGS4, no DPMJET, no EPOS, no NEXUS, no VENUS, no NEUTRINO, no Cherenkov light generation. For this program version the computing time on a DEC 3000/600 AXP station (175 MHz) is ≈ 2 min per shower for primary protons of energy 10^{15} eV, vertical incidence, NKG enabled, with one observation level at 110 m a.s.l. and with the hadron and muon energy cut at 0.3 GeV. Under the same conditions an iron induced shower consumes ≈ 2.6 min. The computing time scales roughly with the primary energy. The full EGS4 option without longitudinal profile is roughly $50\times$ slower than the fastest version mentioned above (with ELCUT(3,4) at 3 MeV). If longitudinal profiling is selected which requires an extended EGS4 simulation without several accelerating tricks the slowing down amounts to a factor of ≈ 150. There is not much experience what the time consumption is for the CERENKOV option, but the time consumption will be even higher. The use of SIBYLL or QGSJET results in similar computing times as HDPM. The use of VENUS needs 8 times more CPU-time than the fastest version (HDPM) and a combined EGS4-VENUS option is about 50+8 = 58 times slower since the times do not multiply but add. The use of DPMJET gives times of the same order of magnitude as the VENUS option. EPOS or NEXUS (NKG, no EGS) needs 7.5 times the computing time of VENUS, i.e. about 60 times the computing time of HDPM (NKG, no EGS). FLUKA needs ≈ 7 times computing time of GHEISHA, UrQMD ≈ 40 times that of GHEISHA.
In case of THINning (Sect. 3.5.18 page 44) the computing time strongly depends on the energy fraction below which thinning becomes active. On a DEC 3000/600 AXP (175 MHz) a 10^{19} eV proton induced shower, simulated with QGSJET01c & EGS4, one observation level at 110 m a.s.l., and default settings (NKG and LONGI enabled), needs with EFRCTHN = $1 \cdot 10^{-3}$ about

1 min, with EFRCTHN $= 1 \cdot 10^{-4}$ about 7.5 min, with EFRCTHN $= 2 \cdot 10^{-5}$ about 54 min, and with EFRCTHN $= 5 \cdot 10^{-6}$ about 530 min [35].

The particle output format is described in Sect. 10.2 (page 88 ff.). For each particle that penetrates an observation level 7 words with 4 bytes each are stored on the particle output file. Proton showers at 10^{15} eV deliver at sea level roughly 0.8 MB particle output when calculated with the NKG option ($E_h, E_\mu > 0.3$ GeV). With EGS4 about 30 MB output are written due to the huge amount of photons and electrons that are explicitly stored ($E_e, E_\gamma > 0.003$ GeV)[70]. The particle output in the CERENKOV option is additionally increased as the Cherenkov photons are stored, either separately on the Cherenkov output file, or together with the particles on the particle output file.

While running, the interactions produce plenty of secondary particles which are stored in an intermediate stack which is foreseen for 20000 particles. After completing an interaction all particles (in case of THINning only a fraction of them) are moved to the internal stack. The size of this internal stack is large enough to keep 680 (in case of thinning 624) particles. If the size of the internal stack is full, 680 (624) particles are temporarily added to the external stack. If the internal stack is empty 340 (312) particles are re-read from the external stack. Only half of the internal stack is read back to avoid a permanent shifting of data from and to the internal stack if it is just full and the number of secondaries oscillates with a small amplitude around 680 (624).

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[70]These energy cuts correspond with the sensitivities of the KASCADE array detectors.

10 Outputs

There are two major output files produced by a simulation run. The control printout (txt file) allows to survey the simulation run. The particle output file is written to the data file '$DATnnnnnn$' with $nnnnnn$ being the run number specified in the keyword RUNNR (page 49). This file becomes very large when simulating showers in great detail (EGS4, low thresholds, ...). In the CERENKOV version an additional file '$CERnnnnnn$' might be written. Optionally a tabular output (γ, $e^\pm$, and $\mu^\pm$ particles at ground and longitudinal development of charged particles) is written out to the file '$DATnnnnnn$.tab'. Further on the longitudinal distributions of particle numbers and energy deposits may be written to file '$DATnnnnnn$.long'. The output file '$DATnnnnnn$.dbase' (resp. '$DATnnnnnn$.info') is destinated to be used in a data base for examining the content of an air shower library.

10.1 Control Printout (.txt File)

The simulation run produces a printout (txt file, unit MONIOU, by default standard output)[71] that allows to control the simulation and informs about the general run, the program version with interaction model, steering keywords, physical constants, the atmospheric model, and the primary particle (about 200 lines). For each shower it prints roughly 400 lines containing the random number generator status, time at beginning of a shower, the primary particle at the place of the first interaction, the number of secondaries reaching the observation levels with energies above ECTMAP (page 70), the stack statistics, internal and external stack usage, energy-multiplicity and energy-elasticity relations, interaction statistics for nucleons, pions, kaons, and strange baryons per kinetic energy interval, an interaction length statistics for the above particles and a decay statistics for muons, summaries of secondaries for each observation level, NKG electromagnetic shower information, and the longitudinal shower development.

The NKG output (keyword ELMFLG, page 64) comprises a table on the longitudinal development of the electromagnetic shower component giving every 100 g/cm^2 the number of electrons and the longitudinal pseudo-age parameter[72]. For the lateral electron distribution the densities (in $electrons$/cm^2) are calculated on a grid of 80 points (8 directions separated by $45°$ with 10 distances between 1 m and RADNKG (page 64) for each direction) and the lateral pseudo-ages for those various distances are determined. The lateral distribution is calculated only for the lowest two observation levels.

For the longitudinal development (keyword LONGI page 67) three tables are generated:

- The first one gives the particle numbers of $\gamma, e^+, e^-, \mu^+, \mu^-$, hadrons, all charged, nuclei, and Cherenkov photons as function of atmospheric depth.

- The second one reflects the energy content within the various particle species $\gamma, e^+, e^-, \mu^+, \mu^-$, hadrons, charged particles, and the energy sum as function of atmospheric depth.

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[71]Renaming the standard (log) output to '$DATnnnnnn$.txt' and redirecting it to the directory specified by the keyword DIRECT (page 70) is convenient (page 88) as by the shell commands 'dir' or 'ls -l' all files belonging to one run are displayed consecutively which facilitates book-keeping.

[72]See footnote page 31.

For all particle species the particle rest mass is included within the energy.

- The third table gives the energy dissipated within the atmosphere specified for various processes: Energy contained within γ's absorbed in the atmosphere or falling below (energy or angular) cut, ionization energy loss of $e^\pm$, energy contained within $e^\pm$ falling below cuts, ionization energy loss of $\mu^\pm$, energy contained within $\mu^\pm$ falling below cuts, ionization energy loss of hadrons, energy contained within hadrons falling below cuts, energy taken away by ν's, and the energy sum for each depth bin. For $\pi^\pm$ and $K^\pm$ falling below the energy or angular cuts 1/4 of the energy is attributed to the hadronic energy, while 3/4 is attributed to neutrinos. For the neutral $K^\circ_{L,S}$ this ratios are 1/2.

  The last bin of the cut energies reflects the energy content of particles arriving at detector level. In this table the rest mass of nucleons and electrons is **not** counted, while the rest mass of the corresponding anti-particles (which might undergo annihilation) is counted **twice**. Energies of unstable hadrons and muons are added up including their rest mass. This counting is necessary to respect the target nucleons or electrons involved into the shower development, thus enabling a correct energy balancing.

For writing out the longitudinal tables to the '$DATnnnnnn$.long' file or as 'LONG' blocks to the particle output file '$DATnnnnnn$' see the FLONGOUT flag (page 67).

The control printout contains as well all kinds of warnings and error messages. System errors may be redirected in UNIX systems[73] to the standard output[74] (txt file) by the & character following immediately the $>$ character as given in the example:

```
corsika <inputs >& /home/user/corsika/run/DATnnnnnn.txt
```

assuming that all output should go to the directory /home/user/corsika/run/ as given in the example on page 80. Users are advised to check this printout carefully for any indications of problems during the run time and keeping it together with the particle output for later consultation.

When errors occur the DEBUG option may help in localizing the bug. This option entails a very detailed printout of the simulation process that easily fills large disks when enabled for many showers.

All these informations are printed per event. For low energy primaries and high statistics this printout per event may not be necessary and can be suppressed by selecting a maximum number of showers to be printed (keyword MAXPRT page 69). At the end of each run a short run summary is printed with similar tables as for single showers but averaged over all showers of the actual run.

10.2 Normal Particle Output

The particle and Cherenkov photon output files contain the information about the simulation run and about all particles reaching observation levels. This is what has to be analyzed for detailed

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[73]The usage of the korne-shell is assumed.

[74]For the naming of standard output see the footnotes page 20 and 87.

energy spectra and distributions. These files are written to the directory DSN (as defined by keyword DIRECT, page 70) as 'sequential' 'unformatted' FORTRAN files. They may be read by the programs *corsikaread*.f rsp. *corsikaread_thin*.f . The particle output file and the Cherenkov photon output file are structured as shown in Table 6, with the sub-blocks as given in Tables 7 to 13. All quantities are written as single precision real numbers.

Block structure
RUN HEADER nrun
EVENT HEADER 1
DATABLOCK
DATABLOCK
...
...
(LONG 1:1)
...
(LONG 1:n)
EVENT END 1
EVENT HEADER 2
DATABLOCK
DATABLOCK
...
...
(LONG 2:1)
...
(LONG 2:n)
EVENT END 2
...
...
EVENT HEADER nevt
DATABLOCK
DATABLOCK
...
...
(LONG nevt:1)
...
(LONG nevt:n)
EVENT END nevt
RUN END nrun

Table 6: Block structure of the particle and Cherenkov photon output files. (The LONG blocks eventually occur only in the particle output file.)

Run header sub-block: (once per run)	
No. of word	Contents of word (as real numbers R*4)
1	'RUNH'
2	run number
3	date of begin run (yymmdd)
4	version of program
5	number of observation levels (maximum 10)
$5+i$	height of level i in cm
16	slope of energy spectrum
17	lower limit of energy range
18	upper limit of energy range
19	flag for EGS4 treatment of em. component
20	flag for NKG treatment of em. component
21	kin. energy cutoff for hadrons in GeV
22	kin. energy cutoff for muons in GeV
23	kin. energy cutoff for electrons in GeV
24	energy cutoff for photons in GeV
	physical constants and interaction flags:
$24+i$	C(i), $i = 1, 50$
$74+i$	0, $i = 1, 20$ (no longer used)
$94+i$	CKA(i), $i = 1, 40$
$134+i$	CETA(i), $i = 1, 5$
$139+i$	CSTRBA(i), $i = 1, 11$
$150+i$	0, $i = 1, 104$ (no longer used by CORSIKA, but reserved for KASCADE-CRES applications)
$254+i$	AATM(i), $i = 1, 5$
$259+i$	BATM(i), $i = 1, 5$
$264+i$	CATM(i), $i = 1, 5$
270	NFLAIN
271	NFLDIF
272	NFLPI0+100×NFLPIF
273	NFLCHE+100×NFRAGM

Table 7: Structure of the run header sub-block.

---

[75]EVTH(77) has the following contents if converted to an integer with suitable rounding applied:
bit 1 CERENKOV option compiled in
    2 IACT option compiled in
    3 CEFFIC option compiled in
    4 ATMEXT option compiled in
    5 ATMEXT option used with refraction enabled
    6 VOLUMEDET option compiled in
    7 CURVED option compiled in (see also EVTH(79))
    9 SLATN opton compiled in
11-21 table number for external atmosphere table (but limited to 1023 if the number is larger).

No. of word	Contents of word (as real numbers R*4)
Event header sub-block: (once per event)	
1	'EVTH'
2	event number
3	particle id (particle code or $A \times 100 + Z$ for nuclei)
4	total energy in GeV
5	starting altitude in g/cm^2
6	number of first target if fixed
7	z coordinate (height) of first interaction in cm
	(negative, if tracking starts at margin of atmosphere, see TSTART)
8	px momentum in x direction in GeV/c
9	py momentum in y direction in GeV/c
10	pz momentum in -z direction in GeV/c
	(pz is positive for downward going particles)
11	zenith angle θ in radian
12	azimuth angle ϕ in radian
13	number of different random number sequences (max. 10)
$11 + 3 \times i$	integer seed of sequence i
$12 + 3 \times i$	number of offset random calls (mod 10^6) of sequence i
$13 + 3 \times i$	number of offset random calls (/ 10^6) of sequence i
44	run number
45	date of begin run (yymmdd)
46	version of program
47	number of observation levels
$47 + i$	height of level i in cm
58	slope of energy spectrum
59	lower limit of energy range in GeV
60	upper limit of energy range in GeV
61	cutoff for hadrons kinetic energy in GeV
62	cutoff for muons kinetic energy in GeV
63	cutoff for electrons kinetic energy in GeV
64	cutoff for photons energy in GeV
65	NFLAIN
66	NFLDIF
67	NFLPI0
68	NFLPIF
69	NFLCHE
70	NFRAGM
71	x component of Earth's magnetic field in μT
72	z component of Earth's magnetic field in μT
73	flag for activating EGS4
74	flag for activating NKG
75	low-energy hadr. model flag (1.=GHEISHA, 2.=UrQMD, 3.=FLUKA)
76	high-energy hadr. model flag (0.=HDPM,1.=VENUS, 2.=SIBYLL, 3.=QGSJET, 4.=DPMJET, 5.=neXus, 6.=EPOS)
77	CERENKOV flag [75]

Table 8: Structure of event header sub-block (to be continued).

Event header sub-block: (continued)	
No. of word	Contents of word (as real numbers R*4)
78	NEUTRINO flag
79	CURVED flag (0=standard, 2=CURVED)
80	computer flag (3=UNIX, 4=Macintosh)
81	lower edge of θ interval (in $°$)
82	upper edge of θ interval (in $°$)
83	lower edge of ϕ interval (in $°$)
84	upper edge of ϕ interval (in $°$)
85	Cherenkov bunch size in the case of Cherenkov calculations
86	number of Cherenkov detectors in x-direction
87	number of Cherenkov detectors in y-direction
88	grid spacing of Cherenkov detectors in x-direction in cm
89	grid spacing of Cherenkov detectors in y-direction in cm
90	length of each Cherenkov detector in x-direction in cm
91	length of each Cherenkov detector in y-direction in cm
92	Cherenkov output directed to particle output file ($= 0.$)
	or Cherenkov output file ($= 1.$)
93	angle (in rad) between array x-direction and magnetic north
94	flag for additional muon information on particle output file
95	step length factor for multiple scattering step length in EGS4
96	Cherenkov bandwidth lower end in nm
97	Cherenkov bandwidth upper end in nm
98	number i of uses of each Cherenkov event
$98 + i$	x coordinate of ith core location for scattered events in cm
$118 + i$	y coordinate of ith core location for scattered events in cm
139	SIBYLL interaction flag (0.= no SIBYLL, 1.=vers.1.6; 2.=vers.2.1)
140	SIBYLL cross-section flag (0.= no SIBYLL, 1.=vers.1.6; 2.=vers.2.1)
141	QGSJET interact. flag (0.=no QGSJET, 1.=QGSJETOLD,
	2.=QGSJET01c, 3.=QGSJET-II)
142	QGSJET X-sect. flag (0.=no QGSJET, 1.=QGSJETOLD,
	2.=QGSJET01c, 3.=QGSJET-II)
143	DPMJET interaction flag (0.=no DPMJET, 1.=DPMJET)
144	DPMJET cross-section flag (0.=no DPMJET, 1.=DPMJET)
145	VENUS/NEXUS/EPOS cross-section flag (0=neither, 1.=VENUSSIG,
	2./3.=NEXUSSIG, 4.=EPOSSIG)
146	muon multiple scattering flag (1.=Molière, 0.=Gauss)
147	NKG radial distribution range in cm
148	EFRCTHN energy fraction of thinning level hadronic
149	EFRCTHN·THINRAT energy fraction of thinning level em-particles
150	actual weight limit WMAX for thinning hadronic
151	actual weight limit WMAX·WEITRAT for thinning em-particles
152	max. radius (in cm) for radial thinning
153	inner angle of viewing cone VIEWCONE (in $°$)
154	outer angle of viewing cone VIEWCONE (in $°$)
155	transition energy high-energy/low-energy model (in GeV)
156	skimming incidence flag (0.=standard, 1.=skimming)
157	altitude (cm) of horizontal shower axis (skimming incidence)
158...273	not used

Table 8: (continued) Structure of event header sub-block.

Particle data sub-block : (up to 39 particles, 7 words each)	
No. of word	Contents of word (as real numbers R*4)
$7 \times (n-1) + 1$	particle description encoded as:
	part. id$\times 1000$ + hadr. generation[76] $\times 10$ + no. of obs. level
$7 \times (n-1) + 2$	px, momentum in x direction in GeV/c
$7 \times (n-1) + 3$	py, momentum in y direction in GeV/c
$7 \times (n-1) + 4$	pz, momentum in -z direction in GeV/c
$7 \times (n-1) + 5$	x position coordinate in cm
$7 \times (n-1) + 6$	y position coordinate in cm
$7 \times (n-1) + 7$	t time since first interaction (or since entrance into atmosphere)[77] in nsec
	[for additional muon information: z coordinate in cm]
	for $n = 1 \ldots 39$
	if last block is not completely filled, trailing zeros are added

Table 9: Structure of particle data sub-block.

Cherenkov photon data sub-block : (up to 39 bunches, 7 words each)	
No. of words	Contents of word (as real numbers R*4)
$7 \times (n-1) + 1$	number of Cherenkov photons in bunch
	[in case of output on the particle output file:
	$99.E5 + 10 \times$NINT(number of Cherenkov photons in bunch) + 1]
$7 \times (n-1) + 2$	x position coordinate in cm
$7 \times (n-1) + 3$	y position coordinate in cm
$7 \times (n-1) + 4$	u direction cosine to x axis
$7 \times (n-1) + 5$	v direction cosine to y axis
$7 \times (n-1) + 6$	t time since first interaction (or since entrance into atmosphere)[77] in nsec
$7 \times (n-1) + 7$	height of production of bunch in cm
	for $n = 1 \ldots 39$
	if last block is not completely filled, trailing zeros are added

Table 10: Structure of Cherenkov photon data sub-block.

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[76]The generation counter is set to 0 before the first interaction and augmented by each hadronic interaction or decay. The decay of π-mesons increases this counter by 51, thus the muons coming from π-decays are discriminated from those originating in K-decays.

[77]See keyword TSTART page 53.

'Longitudinal' sub-block: (up to 26 depth steps/block)	
No. of word	**Contents of word (as real numbers R*4)**
1	'LONG'
2	event number
3	particle id (particle code or $A \times 100 + Z$ for nuclei)
4	total energy in GeV
5	(total number of longitudinal steps)$\times 100 +$ number of longitudinal blocks/shower
6	current number m of longitudinal block
7	altitude of first interaction in g/cm^2
8	zenith angle θ in radian
9	azimuth angle ϕ in radian
10	cutoff for hadron kinetic energy in GeV
11	cutoff for muon kinetic energy in GeV
12	cutoff for electron kinetic energy in GeV
13	cutoff for photon energy in GeV
$10 \times n + 4$	vertical (resp. slant) depth of step j in g/cm^2
$10 \times n + 5$	number of γ-rays at step j
$10 \times n + 6$	number of e$^+$ particles at step j
$10 \times n + 7$	number of e$^-$ particles at step j
$10 \times n + 8$	number of μ^+ particles at step j
$10 \times n + 9$	number of μ^- particles at step j
$10 \times n + 10$	number of hadronic particles at step j
$10 \times n + 11$	number of all charged particles at step j
$10 \times n + 12$	number of nuclei[78] at step j
$10 \times n + 13$	number of Cherenkov photons at step j
	for $n = 1, 26$ and for j longitudinal steps for 1st 'LONG' block: 1 ... j ... 26 for 2nd 'LONG' block: 27 ... j ... 52 ...... for m^{th} 'LONG' block: $(m-1) \cdot 26 + 1$ ... j ... $m \cdot 26$ if last block is not completely filled, trailing zeros are added

Table 11: Structure of 'longitudinal' sub-block. (These type of blocks are written only if 'LONGI' is enabled and 'FLONGOUT' is disabled, page 67.)

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[78]Nuclei (A > 1) are not counted with the 'hadron' species. They are assumed to be completely stripped and therefore counted with their charge Z in the 'all charged' species.

Event end sub-block : (once per event)	
No. of word	Contents of word (as real numbers R*4)
1	'EVTE'
2	event number
	statistics for one shower :
3	weighted number of photons arriving at observation level(s)
4	weighted number of electrons arriving at observation level(s)
5	weighted number of hadrons arriving at observation level(s)
6	weighted number of muons arriving at observation level(s)
7	number of weighted particles written to particle output file MPATAP. (This number includes also Cherenkov bunches, if Cherenkov output is directed to MPATAP, but excludes additional muon information.)
	NKG output (if selected) :
$7 + i$	$i = 1, 21$ lateral distribution in x direction for 1. level in cm^{-2}
$28 + i$	$i = 1, 21$ lateral distribution in y direction for 1. level in cm^{-2}
$49 + i$	$i = 1, 21$ lateral distribution in xy direction for 1. level in cm^{-2}
$70 + i$	$i = 1, 21$ lateral distribution in yx direction for 1. level in cm^{-2}
$91 + i$	$i = 1, 21$ lateral distribution in x direction for 2. level in cm^{-2}
$112 + i$	$i = 1, 21$ lateral distribution in y direction for 2. level in cm^{-2}
$133 + i$	$i = 1, 21$ lateral distribution in xy direction for 2. level in cm^{-2}
$154 + i$	$i = 1, 21$ lateral distribution in yx direction for 2. level in cm^{-2}
$175 + i$	$i = 1, 10$ electron number in steps of 100 g/cm^2
$185 + i$	$i = 1, 10$ pseudo-age in steps of 100 g/cm^2
$195 + i$	$i = 1, 10$ distances for electron distribution in cm
$205 + i$	$i = 1, 10$ local pseudo-age 1. level
$215 + i$	$i = 1, 10$ height of levels for electron numbers in g/cm^2
$225 + i$	$i = 1, 10$ height of levels for electron numbers in cm
$235 + i$	$i = 1, 10$ distance bins for local pseudo-age in cm
$245 + i$	$i = 1, 10$ local pseudo-age 2. level
$255 + i$	$i = 1, 6$ parameters of longitudinal distribution of charged particles
262	χ^2 per degree of freedom of fit to longitudinal distribution
263	weighted number of photons written to particle output file
264	weighted number of electrons written to particle output file
265	weighted number of hadrons written to particle output file
266	weighted number of muons written to particle output file
267	number of em-particles emerging from preshower
268..273	not used

Table 12: Structure of event end sub-block.

Run end sub-block : (once per run)	
No. of word	Contents of word (as real numbers R*4)
1	'RUNE'
2	run number
3	number of events processed
4...273	not used yet

Table 13: Structure of run end sub-block.

10.2.1 Version without Thinning

The information is stored unformatted in a fixed block structure with a block length of 22932 bytes. A block consists of 5733 words each 4 bytes long[79]. Each block consists of 21 sub-blocks of 273 words. These sub-blocks can be a RUN HEADER, EVENT HEADER, DATA BLOCK, LONGitudinal, EVENT END, or a RUN END sub-block (see Table 6). The contents of the sub-blocks are listed in Tables 7 to 13.

10.2.2 Thinning Option

To take the weight parameter for each particle the data structure of the version without thinning has to be extended for the THIN option. The structure of the output (see Table 6 page 89) remains unchanged, but the blocksize is enlarged to a length of 26208 bytes. Now a block has 6552 words each 4 bytes long[79], consisting of 21 sub-blocks of 312 words. The ends of the sub-blocks RUN HEADER (see Table 7 page 90), EVENT HEADER (see Table 8 page 91), LONGitudinal (see Table 11 page 94), EVENT END (see Table 12 page 95), and RUN END (see Table 13) are filled up with zeros, while the data blocks (Tables 9 and 10 page 93) contain 8 words for each particle resp. Cherenkov bunch, the last one being the weight. Again 39 particles are collected within one data sub-block.

10.3 Compact Output

The compact particle output available in the COMPACT option (Sect. 3.5.6 page 38) is organized similar to the normal particle output (see Sect. 10.2 page 88 ff.) with the following modifications:

- The block size of the records has variable length.

- In the block structure (Table 6 page 89) the 'event end' blocks are omitted completely.

- Only the first event header block has its full length (273 resp. 312 4-byte words) and starts with the characters 'EVTH'. The headers of subsequent events are shortened and contain only the first 12 parameters of Table 8 (page 91) and start with the characters 'EVHW'.

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[79]On UNIX installations using the GNU g77 compiler, on HP UNIX stations, and some other machines the blocks comprise two additional words giving the record length.

- The data blocks have variable length, trailing zeros are omitted. They are headed by a 4-byte integer which defines the length (in 4 byte words) of the appended data block. The maximal length amounts to 1+273 4-byte words (resp. 1+312 4-byte words in case of thinning).

Therefore a special reading routine for this output is necessary. The Cherenkov output is not affected by the COMPACT option, but it must be directed to the Cherenkov output file MCETAP (page 72, LCERFI = .true.).

10.4 .lhbook File Output

The optional file '*datnnnnnn*.lhbook' written to the directory DSN (see keyword DIRECT, page 70) contains histograms produced by the ANAHIST (page 36) and/or the AUGERHIST (page 37) options. Do not use capitals in the DSN directory name as the HBOOK routines tolerate only lower case characters. only lower case characters only Table 14 gives the numbering of the hbook histograms. The histograms with numbers <1000 are produced by ANAHIST, while those with numbers above come from the AUGERHIST option. If both options are selected, both series of numbers appear in parallel without interferences. Both series of histograms are added up for many showers and normalized correctly before writing them to output. The AUGERHIST histograms are produced for up to 20 levels (to be specified by the keyword OBSLEV, page 68) which are denoted by ii with $01 \leq ii \leq 20$, and for various particle types denoted by jj with $00 \leq jj \leq 04$ with the meaning: $00 = gamma$, $01 = electron$, $02 = positron$, $03 = muon$, $04 = hadron$.

histo number	dimension	content of histograms
1 - 28	1-dim	longitudinal distributions
99	2-dim	particle codes vs log10(r)
101 - 331	1-dim	ground particle distributions
341 - 451	2-dim	ground particle distributions
999	1-dim	density normalization
10iijj	1-dim	lateral particle distributions
20ii10	1-dim	Cherenkov photons vs. emission angle
30iijj	1-dim	energy spectra
40iijj	1-dim	deposited energy vs. distance
41iijj	1-dim	releasable energy vs. distance

Table 14: Histogram numbering of the '*datnnnnnn*.lhbook' file.

10.5 .long File Output

The optional file '$DATnnnnnn$.long' written to the directory DSN (keyword DIRECT page 70) contains a table of the longitudinal distribution of various particle numbers, arranged in the columns:
$depth$, γ, e^+, e^-, μ^+, μ^-, $hadrons$, $charged\ particles$, $nuclei$, $Cherenkov\ photons$[80].
In a second table the longitudinal distributions of energy deposit (in GeV) by various particle species are given in columns: $depth$, $\gamma\ energy\ cut$, $e^\pm\ ionization$, $e^\pm\ energy\ cut$, $\mu^\pm\ ionization$, $\mu^\pm\ energy\ cut$, **hadron ionization**, $hadron\ energy\ cut$, $neutrino$, $sum\ of\ all$. For both tables the binning is in vertical depth (in g/cm^2) as specified by the keyword LONGI, rsp. slant depth (in g/cm^2) if the SLANT option (page 44) has been selected. This table output is activated by the keyword LONGI (page 67).

10.6 .tab File Output

The optional file '$DATnnnnnn$.tab' written to the directory DSN (keyword DIRECT page 70) contains information on the particles arriving at the lowest detector level. Activation is done by the keyword PAROUT (page 70). There are 3 tables containing separately the number of γ, $e^\pm$, and $\mu^\pm$ particles binned into energy (40 bins ranging from 100 keV to 10 TeV in logarithmic steps), time delay relative to a spherical shower front (30 bins ranging from 10 nsec to 10 μsec in logarithmic steps), and core distance (20 bins ranging from 50 m to 5 km in logarithmic steps).
Additionally a fourth table is written containing the longitudinal development of γ, e^+, e^-, μ^+, μ^-, $hadrons$, and $all\ charged$ particles (see Sect. 10.1 page 87) in steps as defined by keyword LONGI (page 67). This fourth table output is activated by the parameter LLONGI of keyword LONGI.

10.7 .dbase File and .info File Output

To build up a data base as a directory of a shower library which enables a computer aided search for specific shower events, the '$DATnnnnnn$.dbase' file (page 74) may be used. The content of the '$DATnnnnnn$.dbase' file consists of parameter words enclosed within # marks, followed by the information on the corresponding parameter. The list of parameter words and their contents is given in Table 15 (page 99). In the AUGERINFO version this file is named '$DATnnnnnn$.info' and for each parameter a new line is started omitting the # mark separators. It should be noted, that some of the parameters listed in Table 15 are present only with the selected options e.g. for thinning (page 44), for external atmospheres (page 36), for viewing cone (page 47), or for Cherenkov telescopes (page 34).

---

[80]The Cherenkov photon longitudinal distributions are influenced by selecting the preprocessor options INTC-LONG and NOCLONG (page 36, see also page 68) and AUGCERLONG (page 37).

Content of $DATnnnnnn$.dbase (resp. $DATnnnnnn$.info) file	
Keyword	Content (Format)
#version#	version number (F6.3)
#versiondate#	date of version YYYYMMDD (I9)
#modelversion#	version number of high-energy hadronic interaction program (F8.3)
#rundate#	date of run YYYYMMDD (I9)
#computer#	computer option (I2) (3=UNIX/LINUX, 4=Macintosh)
#curved#	number indicating CURVED option (I2)(2=curved, 0=else)
#neutrino#	number indicating NEUTRINO option (I2)
#cerenkov#	number indicating CERENKOV option (I2)
#runnumber#	run number (I7)
#primary#	particle code of primary particle (I5)
#e_range_l#	lower end of primary energy range (E14.7)
#e_range_u#	upper end of primary energy range (E14.7)
#slope#	slope of primary energy spectrum (E15.7)
#nkg#	number indicating use of NKG option (I2)
#egs#	number indicating use of EGS4 option (I2)
#model#	high-energy hadr. int. model (0=HDPM, 1=VENUS, 2=SIBYLL, 3=QGSJET, 4=DPMJET, 5=NeXus/EPOS) (I2)
#gheisha#	low-energy hadr. model(1=GHEISHA, 2=UrQMD, 3=FLUKA) (I2)
#isobar#	low-energy hadr. model(1=GHEISHA, 2=UrQMD, 3=FLUKA) (I2)
#model+crossect#	high-energy hadr. model and cross-sections (0=HDPM, 1=VENUS, 2=SIBYLL, 3=QGSJET, 4=DPMJET, 5=NeXus, 6=EPOS (I2); cross-section numbers to be added: 0=HDPMSIG, 10=VENUSSIG, 20=SIBYLLSIG, 30=QGSSIG, 40=DPMJETSIG, 50=NEXUSSIG/EPOSIG)
#hadflag1#	number indicating NFLAIN (I2)
#hadflag2#	number indicating NFLDIF (I2)
#hadflag3#	number indicating NFLPI0 (I2)
#hadflag4#	number indicating NFLPIF (I2)
#hadflag5#	number indicating NFLCHE (I2)
#hadflag6#	number indicating NFRAGM (I2)
#longi#	number indicating use of longitudinal sampling (I2)
#longistep#	step width for longitudinal sampling (E14.7)
#magnetx#	horizontal component of Earth's magnetic field (E15.7)
#magnetz#	vertical component of Earth's magnetic field (E15.7)
#nobslev#	number of observation levels (I3)
#obslev1#	height of highest observation level (E15.7)
#obslev2#	height of 2nd observation level (E15.7)
#obslev3#	height of 3rd observation level (E15.7)
#obslev4#	height of 4th observation level (E15.7)
#obslev5#	height of 5th observation level (E15.7)
#obslev6#	height of 6th observation level (E15.7)
#obslev7#	height of 7th observation level (E15.7)
#obslev8#	height of 8th observation level (E15.7)
#obslev9#	height of 9th observation level (E15.7)
#obslev10#	height of 10th observation level (E15.7)
#hcut#	energy for hadron cut (E14.7)
#mcut#	energy for muon cut (E14.7)
#ecut#	energy for electron cut (E14.7)

Table 15: Content of $DATnnnnnn$.dbase (resp. $DATnnnnnn$.info) file (to be continued).

Content of $DATnnnnnn$.dbase (resp. $DATnnnnnn$.info) file (continued)	
Keyword	Content (Format)
#gcut#	energy for gamma cut (E14.7)
#theta_l#	lower end of θ range (E14.7)
#theta_u#	upper end of θ range (E14.7)
#phi_l#	lower end of ϕ range (E15.7)
#phi_u#	upper end of ϕ range (E15.7)
#fixhei#	fixed height of first interaction (E14.7)
#n1sttr#	first target (I3) (0=random air, 1=Nitrogen, 2=Oxygen, 3=Argon)
#fixchi#	starting altitude of primary particle (E14.7)
#stepfc#	multiple scattering step length factor (E14.7)
#arrang#	array rotation angle (E15.7)
#himpact1#	lower limit of horizont. shower axis (skimming incid.) (E14.7)
#himpact2#	upper limit of horizont. shower axis (skimming incid.) (E14.7)
#muaddi#	number indicating use of additional muon information (I2)
#nseq#	number of used sequences for random generator (I2)
#seq1seed1#	seed of sequence 1 (I9)
#seq1seed2#	number of calls of sequence 1 (I9)
#seq1seed3#	billions of calls of sequence 1 (I9)
#seq2seed1#	seed of sequence 2 (I9)
#seq2seed2#	number of calls of sequence 2 (I9)
#seq2seed3#	billions of calls of sequence 2 (I9)
#seq3seed1#	seed of sequence 3 (I9)
#seq3seed2#	number of calls of sequence 3 (I9)
#seq3seed3#	billions of calls of sequence 3 (I9)
#size#	size of particle tape output (I10)
#dsn_events#	data set name of particle tape output (A59)
#dsn_prtout#	data set name of txt file output (A9)
#tape_name#	name of data tape (A10)
#backup#	name of backup tape (A10)
#howmanyshowers#	number of showers to generate (I10)
#host#	host computer name (A20)
#user#	user name (A20)
#atmosphere#	Modtran atmosphere model number (I3)
#refract#	number indicating use of refractive index (I2)
#viewcon_l#	inner limiting angle of viewing cone (E14.7)
#viewcon_u#	outer limiting angle of viewing cone (E14.7)
#telescope i #	coordinates x, y, z, r of telescope i (4F11.1)
#cscat #	number and range of scattering in x, y (2F10.1)
#thinning#	number indicating use of thinning (I2)
#thinnlev_had#	thinning level hadronic (E14.7)
#thinnlev_em#	thinning level em (E14.7)
#maxweight_had#	weight limit hadronic (E14.7)
#maxweight_em#	weight limit em (E14.7)
#rad_max#	maximum radius for radial thinning [m] (E14.7)
#energy_prim#	primary energy of first shower (E14.7)
#theta_prim#	primary's θ of first shower (E14.7)
#phi_prim#	primary's ϕ of first shower (E14.7)

Table 15: (continued) Content of $DATnnnnnn$.dbase (resp. $DATnnnnnn$.info) file.

11   Hints for Programmers

If you need any option, addition, or other extension which is not (yet) covered by CORSIKA, feel free to program it. (Please contact D. Heck or T. Pierog before doing so.) If your addition is of general interest, it might be worth to take it over into the next official CORSIKA release. At the beginning of the *corsika*.h file you find a rather complete list of all global variables used in /COMMONS/. This enables to check the names which you give your variables for conflicts with names already used within CORSIKA. The names of the CORSIKA commons start with CR.... to prevent conflicts with common or subroutine names of linked interaction program packages.

As the largest fraction of the CORSIKA routines is written in CAPITAL letters, you are advised to use lower case characters for your private program extensions. This facilitates to distinguish your programming from the official code.

We advise you to use:
`./corsika-install [help] [dev] [options] [configure options]`
to handle your compilation/installation processes.
Various options are available in *./corsika_install*:

- **help**: Display a help file and stop.

- **dev**: Machine dependent CORSIKA installation: *Makefile*s, object files and libraries are installed together with their source codes. This option should only be used if you want an easy access to *Makefile*s. By default (no dev), *Makefile*s, object files and libraries are installed in `lib/'uname'` (The same source can be used for different systems.). All options can be used with or without dev.

- **make**: Execute `make all` (if CORSIKA is already installed once). Compile and link, but do not copy binaries to `run/`, and *./configure* is not called at all (no option selection ... except if it was never done before. If *Makefile*s are not yet installed, *./configure* will be called once).

- **install**: Execute `make install` (if CORSIKA is already installed once). Compile, link and copy binaries into `run/`, but *./configure* is not called at all (except if it was never done before. If *Makefile*s are not yet installed, *./configure* will be called once).

- **clean**: Execute `make clean` (if CORSIKA is already installed once). Remove all object files and stop.

- **distclean**: Execute `make distclean` (if CORSIKA is already installed once). Remove all files produced by the installation (but not the binaries in `run/`) and stop.

- **Configure options**: Any option can be transfered to *configure*, for more information use **-h** or **–help**[81], but `--prefix`, `--bindir` and `--libdir` are already defined in

---

[81]Call *config ure* help.

corsika-install. You should not change this options. Values defined in `$CC`, `$CCLAGS`, `$CXX`, `$CXXFLAGS`, `$CPP`, `$CPPFLAGS` and `$LDFLAGS` environment variable are always used if defined. To use the values defined in `$F77` and `$FFLAGS` environment variable in *./corsika-install*, the following environment variable has to be defined:

```
setenv CORSIKA_USER_COMP yes
```

If `$CORSIKA_USER_COMP` is not empty, then *./corsika-install* does not set any FORTRAN compiler name or flags. If they are not defined by you (see A.1 to know the recommended flags), *./configure* will give some default value (compilation not guaranteed). So don't use this option if you don't know exactly what you are doing (no support for this).

Run it a first time to select the options you want to use (saved in `$libdir/include-/config.h`) and then work directly on the `src/corsika`.F file (FORTRAN+preprocessor commands). To compile this modified source without calling *configure* again, use *./corsika-install* `[dev] make` for debugging. It's equivalent just to go into the proper subdirectory (depending on `dev`) and to type

```
rm -f compilefile.f
make
```

This will update the $compilefile$.f with your modifications and then compile it. When the compilation is successful, you can link objects and libraries into $run/corsika\langle VER\rangle\langle OS\rangle$-$\langle HIGH\rangle\_\langle low\rangle$[82] by typing

```
./corsika-install install
```

in your `corsika-6600/` directory[83].
When the development phase is over, you can use the standard procedure

```
./corsika-install [dev]
```

to have binary files with different options (If `dev` is not used any more, you will have to type *corsika-install* `distclean` or `make distclean` in `corsika-6600/` first.).
We strongly recommend to use this scheme (instead of the traditional $compilefile$.f) because it is the easiest way for you and for us, if later this modification has to be implemented in the official release of CORSIKA (with proper preprocessor commands) or if you want to use your modifications with different CORSIKA options.

---

[82]Where $\langle VER\rangle$ is the version number, $\langle OS\rangle$ is the operating system used for compilation, $\langle HIGH\rangle$ is the chosen high energy hadronic interaction model and $\langle low\rangle$ is the chosen low energy hadronic interaction model.

[83]The *./corsika-install* compiles and installs all the libraries needed by CORSIKA to be linked with and then creates a binary file in `run/`. Then, if you change *corsika*.F, doing simply *./corsika-install* `make` will produce a *corsika* executable file in `src/`. You can then copy this file into `run/` to use it with all the data files.

If you prefer to work on *compilefile*.f anyway, you can use the produced $Makefile$s to compile it. To produce the $Makefile$s, use *./corsika-install* `dev` (note the `dev` option[84]), select your options and, at the end, save the source code and do not compile. Then, you only have to rename your source file $corsika\langle VER\rangle\langle OS\rangle\_\langle HIGH\rangle\_\langle low\rangle\_compilefile$.f to *compilefile*.f and then you have to type *make* in `src/` to compile or *make* `install` in your `corsika-6600/` directory to (compile and) link to get a binary file. In this case, you should not use *./corsika-install* any more, because this will not take into account your modifications (and even overwrite the *compilefile*.f). Of course, if you already used some "home-made" $Makefile$s with a former version of CORSIKA, you can use it with this *compilefile*.f.

12   In Case of Problems . . .

In spite of our care to avoid faults in the physics model and errors in the programming of CORSIKA and in writing this CORSIKA GUIDE, you may have problems of technical or physical nature with the code or the results you obtain from it. Please report all problems to the address mentioned on page 2. When applying for help in cases of crash, **it is recommended to transmit the control printout file (txt file)**, as it contains the selected preprocessor options as well as it echos the employed input keywords with their parameters.

Special interest exists in comparisons of CORSIKA simulations with experimental cosmic ray data.

Suggestions to improve CORSIKA in any respect are welcome.

---

[84]If you don't use the `dev` option when running *./corsika-install*, you can follow the same following scheme but using $Makefile$s located in `corsika-6600/lib/'uname'/` and `corsika-6600/lib/'uname'/src/` (for instance `corsika-6600/lib/Linux/src/` if you work on a LINUX system) instead of just `corsika-6600/`.

13 Acknowledgments

A Compilation and Linking

Using the *corsika-install* script, it will call $make$ automatically and nothing has to be done. But for expert people who want to do their own $Makefile$, a description of what has to be done is given in this appendix.

A.1 Compilation

After running `./corsika-install` asking not to compile at the end of the selection process, you get a source file $corsika\langle VER\rangle\langle OS\rangle\_\langle HIGH\rangle\_\langle low\rangle\_compilefile$.f in the `src/` subdirectory. This subdirectory is the working directory for the following commands. This *corsika_compilefile*.f FORTRAN file and the $dpmjet25i$.f, *epos*`*.f`, *nexus*-`xxx.f`, $qgsjet$-II-03.f (rsp. $qgsjet01c$.f), $sibyll2.1$.f, $venus$.f, and $gheisha\_2002d$.f sources and/or the *urqmd* FORTRAN files have to be compiled before linking them together to obtain an executable module. To prevent overwriting of local variables by optimization of some compilers SAVE statements (which replace the '- static' option to be used for the previous release) have been implemented throughout in the FORTRAN files of *corsika_compilefile*.f, $gheisha\_2002d$.f, dpm-$jet25i$.f, $qgsjet$-II-03.f (rsp. $qgsjet01c$.f), $sibyll2.1$.f, and $venus$.f. It is recommended to use the 'bounds check' [85] option for first trials to inhibit uncontrolled array operations outside the allowed index range.

- For DEC-UNIX machines the procedure looks like
  `f77 -c -check_bounds $1.f 2>$1.err`
  (This means: Suppress the loading phase; generate code to perform runtime checks on subscript.)

- Procedures for LINUX computers with GNU g77 compilers should be used without optimization[86] and are
  `g77 -c -O0 $1.f 2>$1.err`
  to ensure correct simulations.

- Procedures for LINUX hosts (with 64bit AMD CPU's) with GNU g77 compilers should be used without optimization[86] and are
  `g77 -c -O0 -m32 $1.f 2>$1.err`
  to ensure correct simulations with the correct data format of the binary output files.

- Hosts with Portland pgf77 compiler available might use
  `pgf77 -c -O2 $1.f 2>$1.err`
  which gives a fast and reliable executable on LINUX hosts.

---

[85] But not using GFORTRAN compiler, it will result in unexpected stop.

[86] Do not use the optimization without carefully checking the results. There is bad experience with GNU g77 (v0.5.24 and egcs-2.91.66) which frequently brings NaN in the particle output file for the x and y coordinates of particles or results in unidentified hang-ups within the QGSJET routines. Also the g77 optimization causes the DADMUL integration routine to end with an error stop (message: DBRSGM: IFAIL= 1 ....) despite the correct programming respecting all FORTRAN standards.

- Compile procedures for IBM RS6000 are

  ```
  xlf -c -C -O -qextname -qsave -qmaxmem=-1 $1.f 2>$1.err
  ```

- For HP-UX processors the compilation procedures look like

  ```
  fort77 -c -K +E1 +ppu +Dportable -O2 +Onolimit $1.f 2>$1.err
  ```
  and the `+E1` option should also be used in the link step.

These compiler procedures should be used for all needed FORTRAN programs. Our experience with machines other than DEC or LINUX are sparse.

DPMJET option: To compile the $dpmjet25$i.f files (i=3c,4,5,6) in `../dpmjet/`, a procedure equivalent to the one for f77 compilers on DEC-UNIX machines[87] is recommended:

```
f77 -c -C -fpe4 -check underflow -check overflow -g3 -O1
```

(This means: Suppress the loading phase; generate code to perform runtime checks on subscript; continue program after overflow, zero divide, invalid data, or underflow; check underflow and overflow at run time; produce trace back and debugging information in object file; enable local optimizations.)
As the file $dpmjet253$c.f (PYTHIA package) is extremely large you presumably have to give in advance[88]

```
limit datasize unlimited
limit stacksize unlimited
```

to overcome the small default values of many compilers which lead to an error stop during compilation. For machines other than DEC-UNIX and LINUX there is no experience with the compilation of DPMJET routines.

EPOS option: The compiler procedures of the standard case (see begin of this subsection A.1) should be used.
To compile the $epos*$`.f` source files in `../epos/` you should use the $Makefile$.ka available with EPOS (omitting the link step).
For compiling and linking EPOS you presumably have to give[89]

```
limit datasize unlimited
limit stacksize unlimited
```

to overcome the small default values of many compilers which lead to an error stop during linking. Linking is performed e.g. by

---

[87]For GNU g77 compilers the options
```
-c -C -fno-automatic -finit-local-zero -Wunused -Wuninitialized
-malign-double -O
```
might be used.

[88]Usage of csh shell is assumed. In other shells (sh or ksh) you should use `ulimit -d unlimited` and `ulimit -s unlimited` .

[89]See footnote at DPMJET compilation page 106.

```
f77 corsika_compilefile.o gheisha_2002d.o ../epos/*.o -o corsika6600
```

where the compiled EPOS program parts are expected to be available within the subdirectory `../epos/` .

NEXUS option: The compiler procedures of the standard case (see begin of this subsection A.1) should be used.

To compile the *nexus*-`xxx.f` source files in `../nexus/` you should use the $Makefile$.ka available with NEXUS (omitting the link step).

For compiling and linking NEXUS you presumably have to give[90]

```
limit datasize unlimited
limit stacksize unlimited
```

to overcome the small default values of many compilers which lead to an error stop during linking. Linking is performed e.g. by

```
f77 corsika_compilefile.o gheisha_2002d.o ../nexus/*.o -o corsika6600
```

where the compiled NEXUS program parts are expected to be available within the subdirectory `../nexus/` .

FLUKA option: For compiling the CORSIKA-FLUKA version of the *corsika_compilefile*.f, the FLUKA include files should be available in the subdirectory from which you are calling the compiler to include them into the CORSIKA-FLUKA linking routines at the appropriate places. Preferentially you use the f77 rsp. g77 compiler with the option

`-I`*flukadirectory*`/flukapro`

to indicate the compiler where to find the include files. For all steps using the FLUKA package you presumably have to give[90]

```
limit datasize unlimited
limit stacksize unlimited
```

to overcome the small default values of many compilers which lead to an error stop during linking.

URQMD option: For compiling the CORSIKA-URQMD version of the *corsika_compilefile*.f, the UrQMD include files *boxinc*.f, *colltab*.f, *comres*.f, *coms*.f, *inputs*.f, *newpart*.f, and *options*.f should be available in the directory from which you are calling the compiler to include them into the CORSIKA-URQMD linking routines at the appropriate places. Alternatively you may use the f77 rsp. g77 compiler with the option

`-I../urqmd`

to indicate the compiler where to find the include files. The compiler procedures of the standard case (see begin of this subsection A.1) should be used to compile the *corsika_compilefile*.f .

The *urqmd1.3_cors*.tar.gz file contains the UrQMD1.3_cors source routines with slight modifications to adapt them for the use with CORSIKA. To compile these UrQMD source files one

---

[90]See footnote at DPMJET compilation.

uses the (g)make command with the option -f GNUmakefile_corsika (omitting the link step) in the ../urqmd/ subdirectory.

NUPRIM option: When compiling the CORSIKA-NUPRIM version of the *corsika_compile-file*.f, the HERWIG_C.INC include file should be available in the subdirectory from which you are calling the compiler to include it into the CORSIKA-HERWIG linking routines at the appropriate places. Alternatively you may use the f77 rsp. g77 compiler with the option

```
-I../herwig
```

to indicate the compiler where to find the include file.
This include file is a simple copy of the HERWIGnn.INC file provided with the source code of the HERWIG model. In the herwig/ subdirectory you give the command:

```
cp HERWIGnn.INC HERWIG_C.INC
```

Before compiling the HERWIG routines you should

- remove (erase or comment off) the function *HWRGEN* with entries *HWRSET* and *HWRGET* thus using the CORSIKA random generator (sequence 5) within the HERWIG routines;

- when using the NUPRIM option together with NEXUS or EPOS: Rename the COMMON /JET/ within Herwig.

The compiler procedures of the standard case (see begin of this subsection A.1) should be used for the CORSIKA-NUPRIM version as well as for HERWIG.

C-file: If you have specified the TIMERC, the PRESHOWER, or the STACEE option you need the compilation of the **C**-file *timerc*.c, *preshw*.c or *stacee*.c using a command like

```
cc -c timerc.c     (resp. cc -c preshw.c  or  cc -c stacee.c ).
```

For the compilation of the **C**-routines of the bernloehr package see the instructions delivered with the bernloehr package.

A.2   Linking

For linking of most CORSIKA versions typically a procedure is used (assuming QGSJET is employed) like:

```
f77 corsika_compilefile.o gheisha_2002d.o qgsjet-II-03.o -o corsika
```

For linking the large packages of FLUKA, UrQMD, DPMJET, EPOS, HERWIG, NEXUS, and VENUS you presumably have to give[91]

```
limit datasize unlimited
limit stacksize unlimited
```

---

[91]See footnote at DPMJET compilation page 106.

to overcome the small default values of many compilers which lead to an error stop during linking.

If the `pgf77` compiler has been used for compilation, you should also use pgf77 for linking:

```
pgf77 corsika_compilefile.o gheisha_2002d.o qgsjet-II-03.o -o corsika
```

For linking **FLUKA** versions the FLUKA library has to be included in the link step:

```
f77 corsika_compilefile.o qgsjet-II-03.o -Lflukadirectory -lflukahp -o corsika
```

For linking FLUKA with `pgf77` you should use the option `-g77libs` in the link step to ensure that the runtime library[92] of `g77` is available as it is needed for running the FLUKA routines.

In the run step of FLUKA versions the environment variable FLUPRO has to be set

```
setenv FLUPRO flukadirectory
```

which is necessary to link the data files which will be read in by the FLUKA package. Additionally the stacksize and datasize limits have to be overcome also in the run step.

Linking of **URQMD** versions is performed easiest (e.g. for DEC-UNIX) by

```
f77 corsika_compilefile.o qgsjet-II-03.o ../urqmd/obj_urqcors/*.o \
  -o corsika6600_QGS-II_urq13
```

to include the `.o` files of UrQMD which are stored into the subdirectory `../urqmd/obj_urqcors` by the GNU-make compilation procedure.

No other libraries are normally required.

If you have specified the TIMERC, the PRESHOWER, or the STACEE option, you need the linking of the compiled **C**-file $timerc$.o (resp. $preshw$.o or $stacee$.o).

For linking the compiled **C**-routines of the bernloehr package see the instructions delivered with the bernloehr package.

---

[92]Be aware that the FLUKA LINUX version and the runtime library are fitting together.

B   Flow Diagram

START

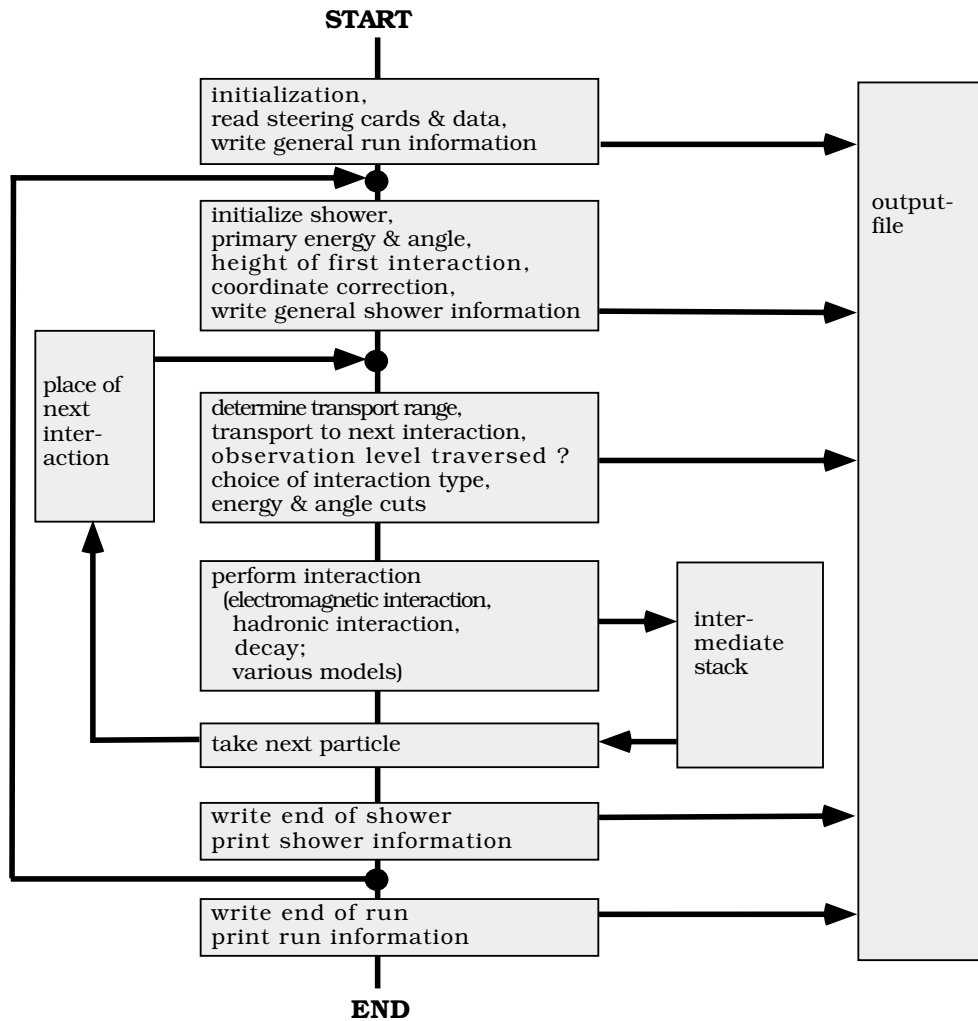| initialization, read steering cards & data, write general run information |
| initialize shower, primary energy & angle, height of first interaction, coordinate correction, write general shower information |
| determine transport range, transport to next interaction, observation level traversed ? choice of interaction type, energy & angle cuts |
| perform interaction (electromagnetic interaction, hadronic interaction, decay; various models) |
| place of next inter-action |
| inter-mediate stack |
| take next particle |
| write end of shower print shower information |
| write end of run print run information |
| output-file |

END

Figure 2: Simplified flow diagram of CORSIKA.

C   Sequence of Initializations

The sequence of initializations is shown for the QGSJET option (INTTEST option in brackets) as example, other interaction model options may differ slightly. The indentation gives the hierarchy of subroutines. Subroutine names are written in CAPITALS.

```
AAMAIN (CORSIKA main program)
    START
        write CORSIKA version and options
        PAMAF
            set particle masses and decay times
        DATAC
            read keywords from input
        set OBSLEV, atmospheres and layers
        initialize random generator
        read NUCNUCCS cross-section tables
        FILOPN
            open output files and external stack
        QGSINI
            initialize QGSJET-II
            QGSET (QGSJET-II)
            QGAINI (QGSJET-II)
                read qgsdat-II-03 and sectnu-II-03
            QGSSIGINI
        CGHINI
            initialize GHEISHA
        EGSIN1
            initialize EGS4
        EGSIN2
            read EGSDAT5_x.x
        calculate physical constants
        (set projectile and target for HSINI)
        (HSINI)
            (histogram initialization for INTTEST)
    INPRM
        check input parameters
        set various parameters:  magn. field, Cherenkov...
        MUPINI
            set μ-parameters and μ-cross-section tables
        write RUNHEADER
        write .dbase (resp.  .info) file
    ININKG
        initialize NKG parameters
    clear statistics arrays:  multiplicity, elasticity, weight...
    shower loop
    .
    .
```

D Atmospheres

The atmosphere adopted consists of N_2, O_2, and Ar with the volume fractions of 78.1%, 21.0%, and 0.9% [50]. The density variation of the atmosphere with altitude is modeled by 5 layers. In the lower four of them the density follows an exponential dependence on the altitude leading to a relation between the mass overburden $T(h)$ of the atmosphere and the height h of the form

$$T(h) = a_i + b_i \cdot e^{-h/c_i} \quad i = 1, \ldots, 4 \quad . \tag{1}$$

In the fifth layer the mass overburden decreases linearly with height

$$T(h) = a_5 - b_5 \cdot h/c_5 \quad .$$

The boundary of the atmosphere in this model is defined at the height where the mass overburden $T(h)$ vanishes (which is at $h = 112.8$ km for the U.S. standard atmosphere).

Various atmospheres are foreseen: U.S. standard atmosphere parametrized according to J. Linsley [51], 7 typical atmospheres as measured above Stuttgart (about 60 km away from Karlsruhe) at various days of 1993 and transmitted by Deutscher Wetterdienst Offenbach (parametrized according to Ref. [52]), 4 South pole atmospheres (parametrized by D. Chirkin according to the MSIS-90-E model [53]), two South pole atmospheres by P. Lipari [54], and 5 seasonal dependent atmospheres for the Pierre Auger Observatory experiment at Malargüe (Argentina) (parametrized by B. Keilhauer [55], who provided also a new parametrization of the U.S. standard atmosphere). The parameters a_i, b_i, and c_i are selected in a manner that the function $T(h)$ is continuous at the layer boundaries and can be differentiated continuously. In Tables 16 - 35 the parameters for the various models are listed. Additional atmospheres [33] are available by the keyword ATMOSPHERE (page 56) in the ATMEXT option (page 36). User specific atmosphere parameters may be read in using the keywords ATMOD, ATMA, ATMB, ATMC, and ATMLAY.

U.S. Standard Atmosphere

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0 ... 4	-186.5562	1222.6562	994186.38
2	4 ... 10	-94.919	1144.9069	878153.55
3	10 ... 40	0.61289	1305.5948	636143.04
4	40 ... 100	0.0	540.1778	772170.16
5	> 100	0.01128292	1	10^9

Table 16: Parameters of the U.S. standard atmosphere (after Linsley).

Middle Europe

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0 . . . 4	-118.1277	1173.9861	919546.
2	4 . . . 10	-154.258	1205.7625	963267.92
3	10 . . . 40	0.4191499	1386.7807	614315.
4	40 . . . 100	$5.4094056 \cdot 10^{-4}$	555.8935	739059.6
5	> 100	0.01128292	1	10^9

Table 17: Parameters of the AT115 atmosphere (January 15, 1993).

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0 . . . 4	-195.837264	1240.48	933697.
2	4 . . . 10	-50.4128778	1117.85	765229.
3	10 . . . 40	0.345594007	1210.9	636790.
4	40 . . . 100	$5.46207 \cdot 10^{-4}$	608.2128	733793.8
5	> 100	0.01128292	1	10^9

Table 18: Parameters of the AT223 atmosphere (February 23, 1993).

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0 . . . 4	-253.95047	1285.2782	1088310.
2	4 . . . 10	-128.97714	1173.1616	935485.
3	10 . . . 40	0.353207	1320.4561	635137.
4	40 . . . 100	$5.526876 \cdot 10^{-4}$	680.6803	727312.6
5	> 100	0.01128292	1	10^9

Table 19: Parameters of the AT511 atmosphere (May 11, 1993).

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0 ... 4	-208.12899	1251.474	1032310.
2	4 ... 10	-120.26179	1173.321	925528.
3	10 ... 40	0.31167036	1307.826	645330.
4	40 ... 100	$5.591489 \cdot 10^{-4}$	763.1139	720851.4
5	> 100	0.01128292	1	10^9

Table 20: Parameters of the AT616 atmosphere (June 16, 1993).

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0 ... 4	-77.875723	1103.3362	932077.
2	4 ... 10	-214.96818	1226.5761	1109960.
3	10 ... 40	0.3721868	1382.6933	630217.
4	40 ... 100	$5.5309816 \cdot 10^{-4}$	685.6073	726901.3
5	> 100	0.01128292	1	10^9

Table 21: Parameters of the AT822 atmosphere (August 22, 1993).

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0 ... 4	-242.56651	1262.7013	1059360.
2	4 ... 10	-103.21398	1139.0249	888814.
3	10 ... 40	0.3349752	1270.2886	639902.
4	40 ... 100	$5.527485 \cdot 10^{-4}$	681.4061	727251.8
5	> 100	0.01128292	1	10^9

Table 22: Parameters of the AT1014 atmosphere (October 14, 1993).

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0 ... 4	-195.34842	1210.4	970276.
2	4 ... 10	-71.997323	1103.8629	820946.
3	10 ... 40	0.3378142	1215.3545	639074.
4	40 ... 100	$5.48224 \cdot 10^{-4}$	629.7611	731776.5
5	> 100	0.01128292	1	10^9

Table 23: Parameters of the AT1224 atmosphere (December 24, 1993).

South pole

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0 ... 4	-137.656	1130.74	867358.
2	4 ... 10	-37.9610	1052.05	741208.
3	10 ... 40	0.222659	1137.21	633846.
4	40 ... 100	-0.000616201	442.512	759850.
5	> 100	0.00207722	1	$5.4303203 \cdot 10^9$

Table 24: Parameters of South pole atmosphere for March 31, 1997 (MSIS-90-E).

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0 ... 4	-163.331	1183.70	875221.
2	4 ... 10	-65.3713	1108.06	753213.
3	10 ... 40	0.402903	1424.02	545846.
4	40 ... 100	-0.000479198	207.595	793043.
5	> 100	0.00188667	1	$5.9787908 \cdot 10^9$

Table 25: Parameters of South pole atmosphere for Jul. 01, 1997 (MSIS-90-E).

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0 ... 4	-142.801	1177.19	861745.
2	4 ... 10	-70.1538	1125.11	765925.
3	10 ... 40	1.14855	1304.77	581351.
4	40 ... 100	-0.000910269	433.823	775155.
5	> 100	0.00152236	1	$7.4095699 \cdot 10^9$

Table 26: Parameters of South pole atmosphere for Oct. 01, 1997 (MSIS-90-E).

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0 ... 4	-128.601	1139.99	861913.
2	4 ... 10	-39.5548	1073.82	744955.
3	10 ... 40	1.13088	1052.96	675928.
4	40 ... 100	-0.00264960	492.503	829627.
5	> 100	0.00192534	1	$5.8587010 \cdot 10^9$

Table 27: Parameters of South pole atmosphere for Dec. 31, 1997 (MSIS-90-E).

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0. ... 2.67	-113.139	1133.10	861730.
2	2.67 ... 5.33	-79.0635	1101.20	826340.
3	5.33 ... 8.0	-54.3888	1085.00	790950.
4	8.0 ... 100.0	0.0000	1098.00	682800.
5	> 100.0	0.00421033	1	$2.6798156 \cdot 10^9$

Table 28: Parameters of South pole atmosphere for January (Lipari).

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0. ... 6.67	-59.0293	1079.00	764170.
2	6.67 ... 13.33	-21.5794	1071.90	699910.
3	13.33 ... 20.0	-7.14839	1182.00	635650.
4	20.0 ... 100.0	0.0000	1647.10	551010.
5	> 100.0	0.000190175	1	$59.329575 \cdot 10^9$

Table 29: Parameters of South pole atmosphere for August (Lipari).

Malargüe (Argentina)

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0. ... 8.0	-150.247839	1198.5972	945766.30
2	8.0 ... 18.1	-6.66194377	1198.8796	681780.12
3	18.1 ... 34.5	0.94880452	1419.4152	620224.52
4	34.5 ... 100.0	$4.8966557223 \cdot 10^{-4}$	730.6380	728157.92
5	> 100.0	0.01128292	1	10^9

Table 30: Parameters of the average Malargüe (Argentina) winter atmosphere I.

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0. ... 8.3	-126.110950	1179.5010	939228.66
2	8.3 ... 12.9	-47.6124452	1172.4883	787969.34
3	12.9 ... 34.0	1.00758296	1437.4911	620008.53
4	34.0 ... 100.0	$5.1046180899 \cdot 10^{-4}$	761.3281	724585.33
5	> 100.0	0.01128292	1	10^9

Table 31: Parameters of the average Malargüe (Argentina) winter atmosphere II.

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0. ... 5.9	-159.683519	1202.8804	977139.52
2	5.9 ... 12.0	-79.5570480	1148.6275	858087.01
3	12.0 ... 34.5	0.98914795	1432.0312	614451.60
4	34.5 ... 100.0	$4.87191289 \cdot 10^{-4}$	696.42788	730875.73
5	> 100.0	0.01128292	1	10^9

Table 32: Parameters of the average Malargüe (Argentina) spring atmosphere.

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0. … 9.0	-136.562242	1175.3347	986169.72
2	9.0 … 14.6	-44.2165390	1180.3694	793171.45
3	14.6 … 33.0	1.37778789	1614.5404	600120.97
4	33.0 … 100.0	$5.06583365 \cdot 10^{-4}$	755.56438	725247.87
5	> 100.0	0.01128292	1	10^9

Table 33: Parameters of the average Malargüe (Argentina) summer atmosphere.

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0. … 8.0	-149.305029	1196.9290	985241.10
2	8.0 … 13.0	-59.771936	1173.2537	819245.00
3	13.0 … 33.5	1.17357181	1502.1837	611220.86
4	33.5 … 100.0	$5.03287179 \cdot 10^{-4}$	750.89705	725797.06
5	> 100.0	0.01128292	1	10^9

Table 34: Parameters of the average Malargüe (Argentina) autumn atmosphere.

Keilhauer's U.S. standard atmosphere

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (cm)
1	0. … 7.0	-149.801663	1183.6071	954248.34
2	7.0 … 11.4	-57.932486	1143.0425	800005.34
3	11.4 … 37.0	0.63631894	1322.9748	629568.93
4	37.0 … 100.0	$4.35453690 \cdot 10^{-4}$	655.67307	737521.77
5	> 100.0	0.01128292	1	10^9

Table 35: Parameters of the U.S. standard atmosphere (after Keilhauer).

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