High Energy and Prompt Neutrino Production in the Atmosphere

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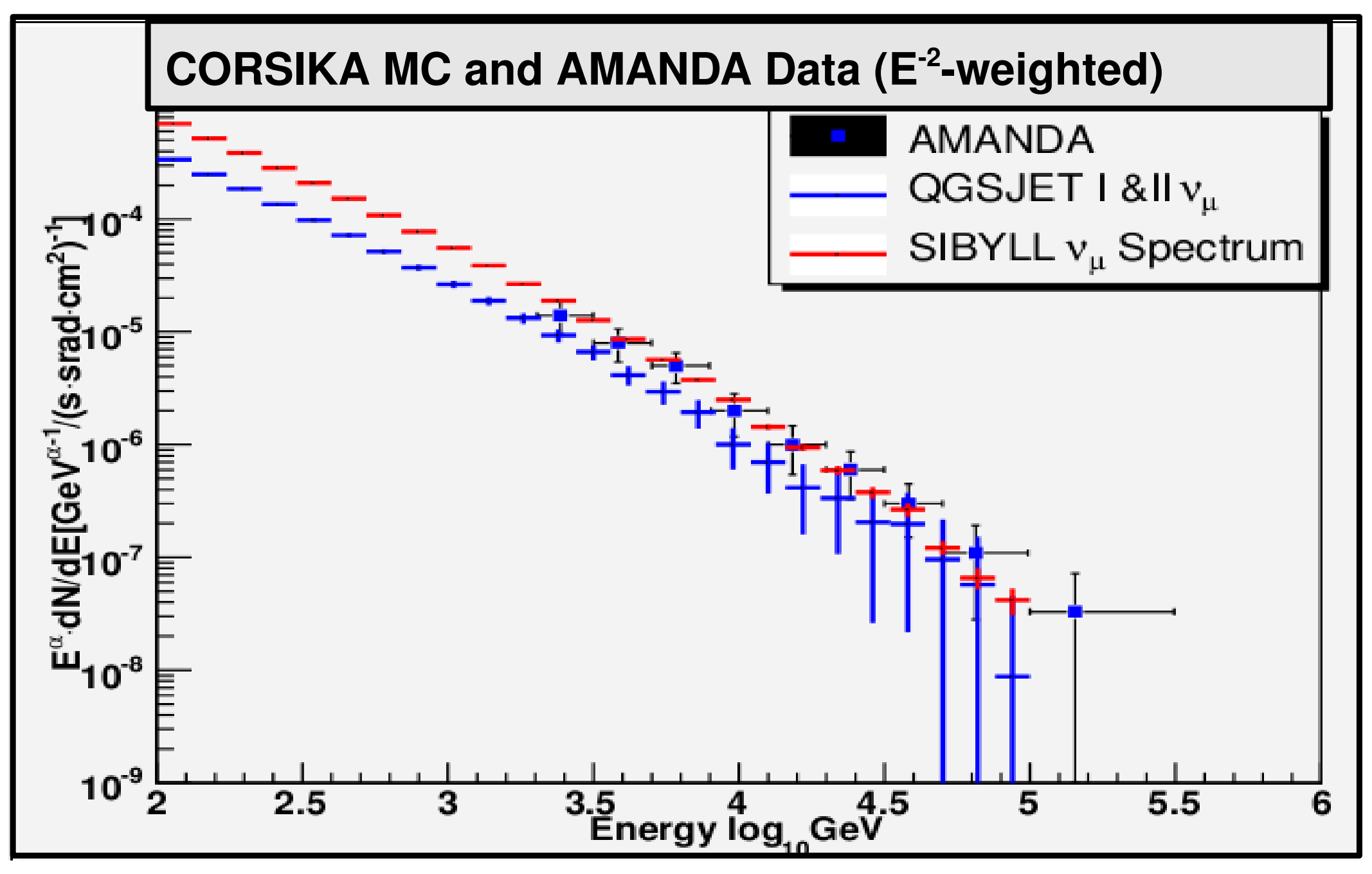
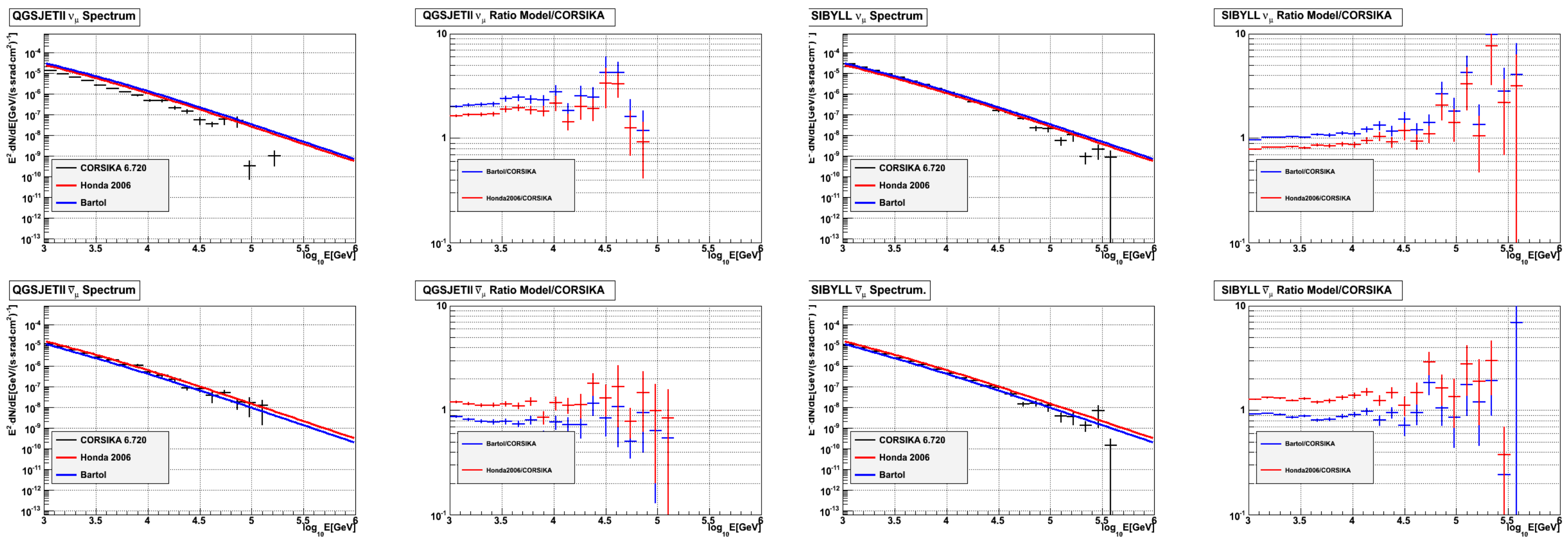
Abstract: Atmospheric neutrinos and muons have been extensively measured by underground experiments in the region below 10GeV. The AMANDA neutrino telescope has measured the spectrum of atmospheric neutrinos up to 100 TeV and IceCube, which has about 100 times higher acceptance, is expected to collect unprecedented statistics at even higher energies in the near future. Since high energy atmospheric neutrinos are the foreground for extraterrestrial events, their study is of fundamental importance. With IceCube it will be possible to investigate the high energy tail above 1TeV, where kaon and charm physics become relevant. We are working on understanding high energy hadronic models and compare Monte-Carlo data generated with the CORSIKA air shower simulation package to results from particle physics experiments. We also show the effect of improving the simulation of charm production within CORSIKA after calibrating the hadronic model DPMJET against experimental data.

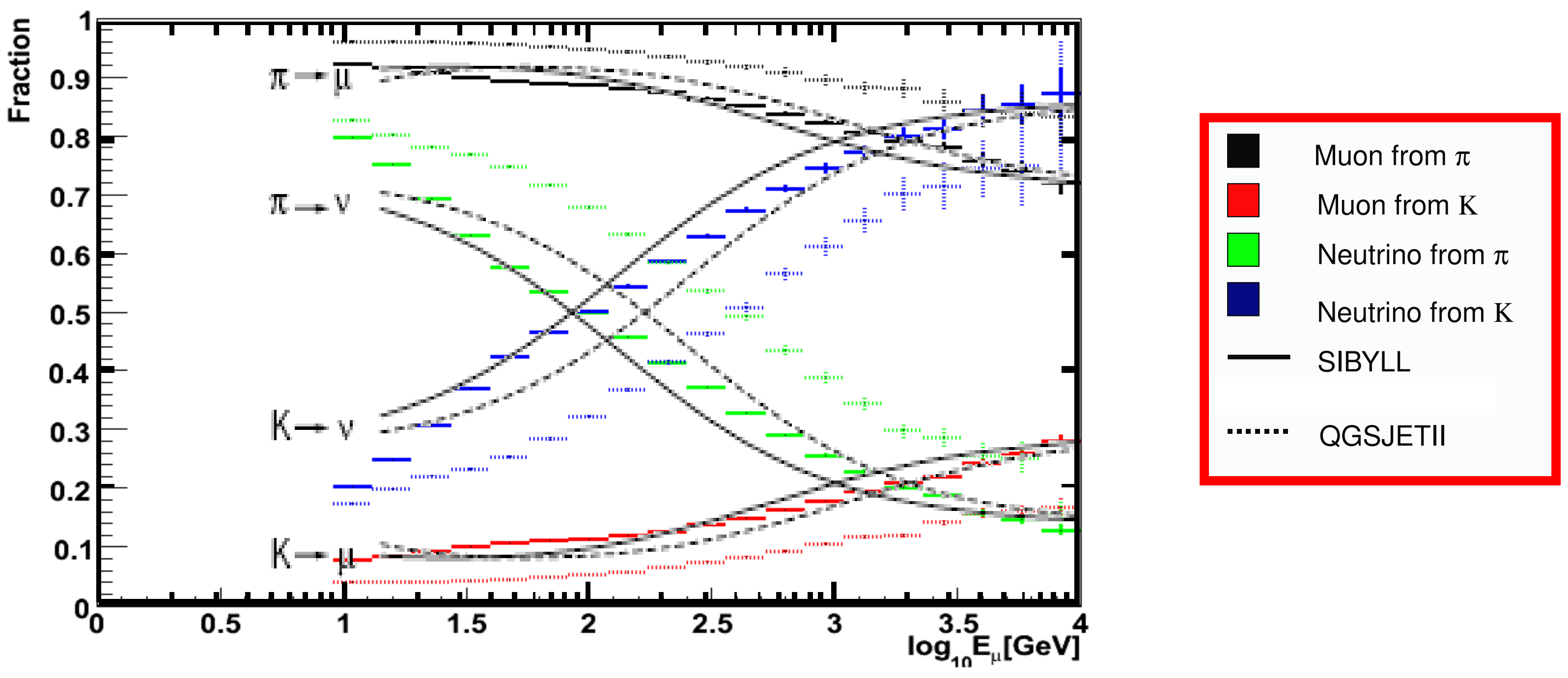
The main goal of **Neutrino Telescopes** is the detection of high energy neutrinos from extraterrestrial sources such as Supernova Remnants, Active Galactic Nuclei (AGN), and Gamma Ray Bursts (GRB) [1]. However, extraterrestrial neutrinos are concealed by the intense flux of atmospheric neutrinos produced through interactions of cosmic rays in the Earth's atmosphere via decays of π and K mesons. This foreground has to be understood In order to allow its separation from a potential extraterrestrial neutrino signal.

One way to model the atmospheric neutrino flux is to use the air shower simulation package **CORSIKA**, which is a standard tool in cosmic ray experiments [2]. The plot below shows the atmospheric neutrino spectrum as measured by AMANDA [3] compared to Monte-Carlo simulations using CORSIKA with different high-energy hadronic interaction models. Most commonly, CORSIKA is used to simulate muons in air showers. Here, we investigate the applicability of CORSIKA to atmospheric neutrino simulations.



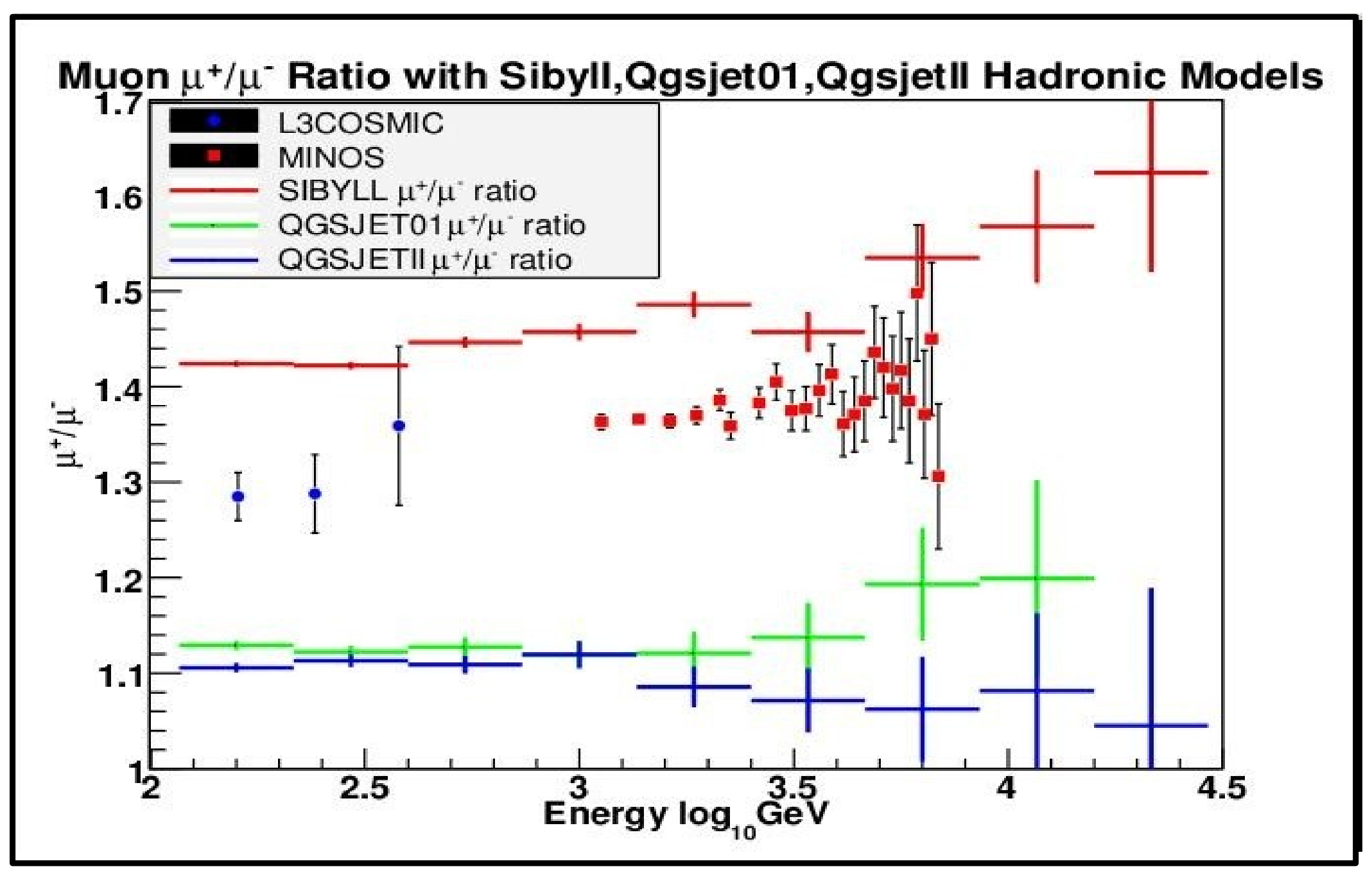


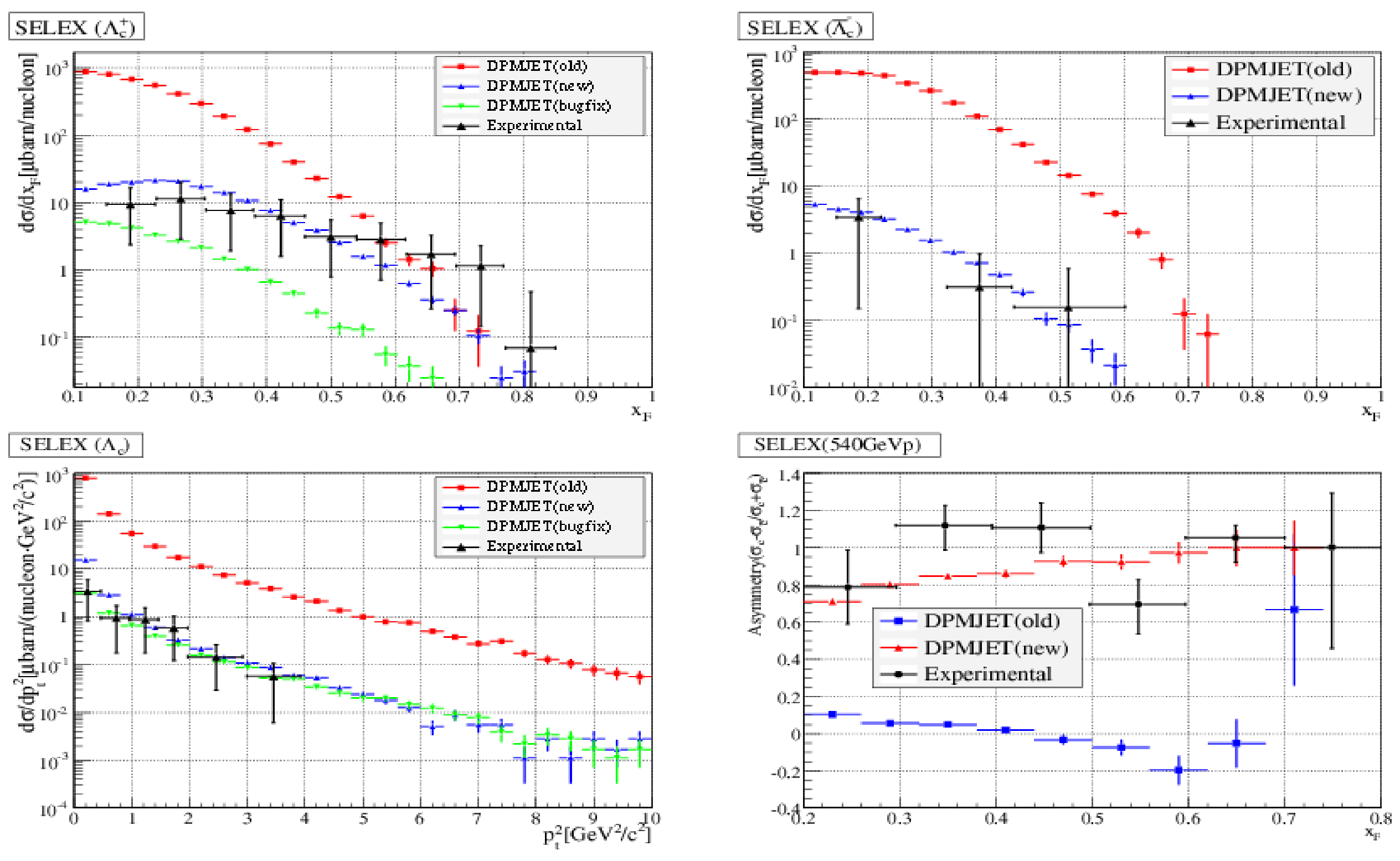
The hadronic interaction package **SIBYLL** [4] predicts a more significant fraction of μ and ν_μ from K decays than other interaction models. This results from the fact that in SIBYLL K mesons are produced with higher multiplicities than in e.g. **QGSJET** [5]. Since π meson production varies little between interaction models, this is the main source of discrepancies in the final lepton spectra. Above, we show comparisons of neutrino spectra generated with the two packages as implemented in CORSIKA are compared to phenomenological flux models [6,7]. Of the currently available models, SIBYLL most accurately reproduces the predicted spectra, both for neutrinos and antineutrinos.



Benchmarking high energy interaction models with muons is very effective, but the kinematics of **$\pi^\pm$ and $K^\pm$ decays** are different for muons and neutrinos. The figure on top shows the fractional contribution of π and K *decays* to μ and ν_μ fluxes (from [8]), superimposed on Monte-Carlo data. Above 100GeV, neutrinos are mostly produced by K decays, whereas for muons π decays remain dominant up to the highest energies. Neutrinos are therefore more affected by the higher uncertainties on K production cross sections than muons.

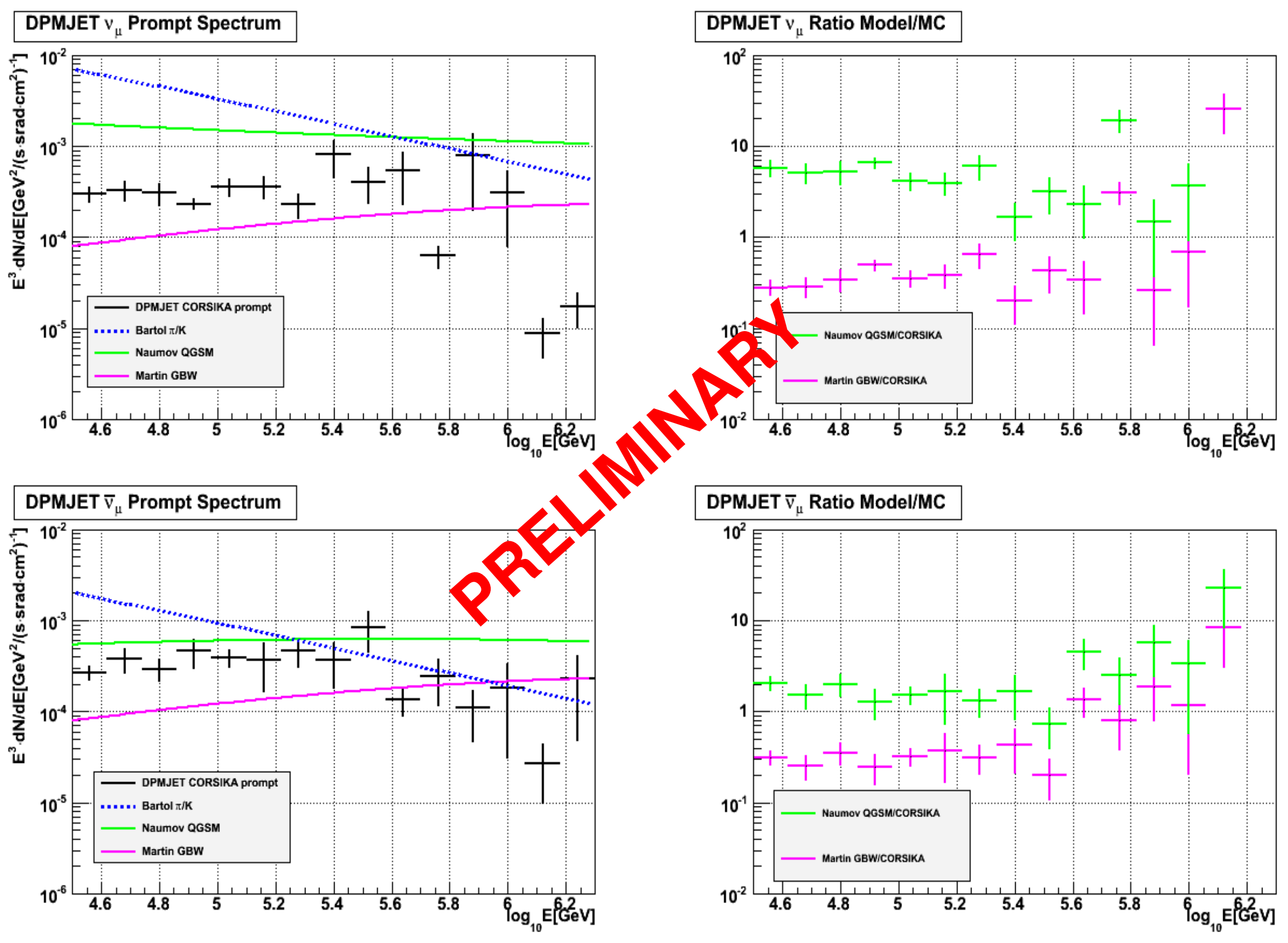
K physics is consequently the major factor in understanding the neutrino spectrum up to about 100 TeV, after which charm production starts to play an important role. Of the CORSIKA hadronic interaction models, SIBYLL produces the most pronounced K^+/K^- asymmetry. This excess in K^+ multiplicity produces a slightly higher μ^+/μ^- than experimentally measured by **MINOS** and **L3+Cosmic**, as shown below [9,10]. This asymmetry should express itself in a corresponding excess of ν_μ over anti ν_μ.





An important component to the atmospheric neutrino flux comes from prompt decay of **Charm** hadrons. Located at the high end of the energy spectrum, it forms a persistent background in searches for diffuse extraterrestrial neutrino fluxes. Recently, charm production was updated in the **DPMJET** hadronic simulation package for CORSIKA [11]. The top plot shows the differential production cross sections for Λ_c production in proton-nucleus interaction as generated with the new version, in comparison with the old version and experimental data from SELEX [12]]. It can be seen that the new simulation accurately reproduces the “leading quark” effect, resulting in an asymmetry of production cross sections between particle and antiparticle.

The plot below shows the first result for the prompt atmospheric neutrino spectrum simulated with the new DPMJET version. In general, spectrum and flux agree reasonably well with current phenomenological models [13,14], the drop at the high end is most likely due to low statistics of the Monte-Carlo sample. Influences of cosmic ray composition on the final result, especially at the high end of the spectrum are currently under investigation.



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