Cosmic Ray Composition with AMANDA and IceCube

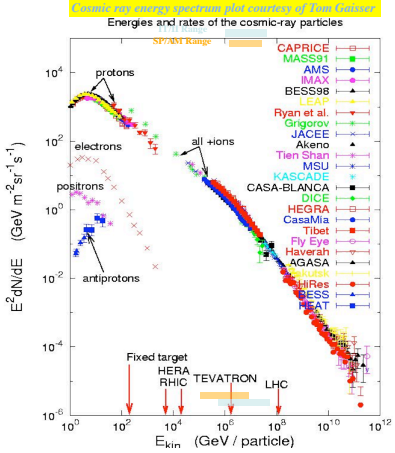
Karen Andeen and Jonathan Eisch for the IceCube Collaboration, UW-Madison

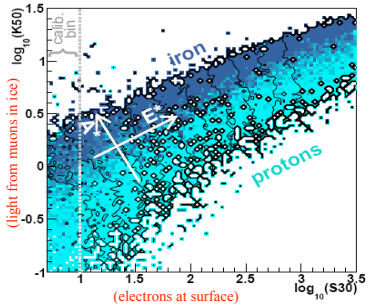
Overview: The mass composition of high-energy cosmic rays around and above the knee (3 PeV) is dependent upon cosmic ray production, acceleration and propagation. The study of cosmic ray composition therefore provides hints to the origin of these particles. At the South Pole, neutrino and cosmic ray detectors (IceCube/IceTop and their predecessors AMANDA-II/SPASE-2) provide joint measurements of the muonic and electronic components of air showers. The location of the neutrino telescopes—deep in the Antarctic ice—allows them to view TeV muons while the surface arrays assess shower size at a high altitude (~3000m). This unique detector arrangement provides an opportunity for precision measurements of the cosmic ray spectrum and composition which are complementary to those made around sea level. We will report the status of two separate analyses: the first utilizes coincident events between the SPASE-2 surface array and the AMANDA-II neutrino telescope, which operated between 2000 and 2006 as a standalone detector, while the second uses data taken with IceCube's larger IceTop surface array and deep IceCube neutrino telescope, which are both currently under construction and have reached about half their final size.

INTRODUCTION

While the flux of cosmic rays at earth has been carefully measured (Fig. 1), the sources of high-energy particles above the "knee" in the energy spectrum (~3 PeV) are not known. The acceleration of cosmic rays at their sources, and their propagation from the sources to earth, are also not well-understood. However, the cosmic ray flux and mass composition can provide clues to the acceleration and propagation of charged particles at different energies; both quantities are necessary for a complete picture of the origin of cosmic rays. In Antarctica, the combination of neutrino telescopes (AMANDA, IceCube) and cosmic ray detectors (SPASE, IceTop) allows for sensitive measurements of the particle flux and composition.

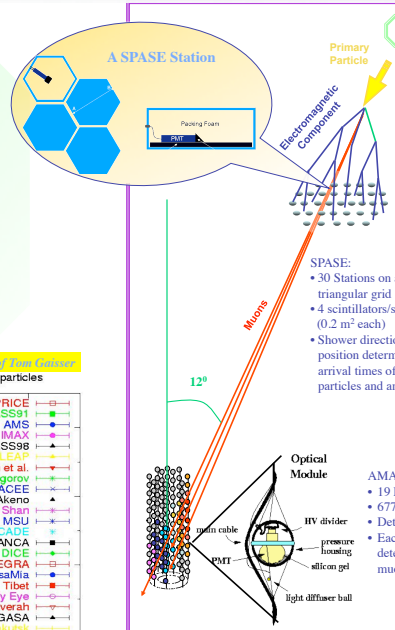
Cosmic ray energy spectrum plot courtesy of Tom Gaisser





As seen on the **left**, the measurable parameters for SPASE and AMANDA give a clear separation between two particle types, as well as distinct energy bands in a simple Monte Carlo simulation. This is partly due to the fact that the South Pole atmospheric depth is particularly close to shower maximum. This allows for an excellent energy resolution, as seen in the proton and iron showers at a fixed energy of 10^{16} eV shown on the **right**.

DETECTOR LAYOUTS AND DETAILS

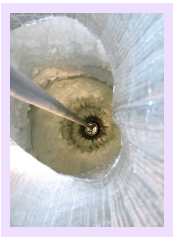


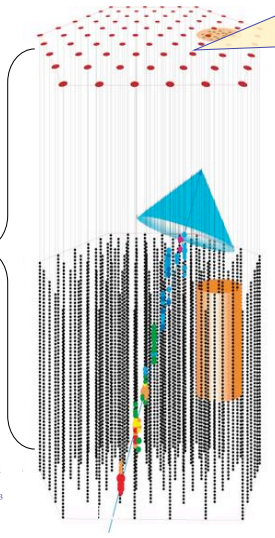
SPASE:
- 30 Stations on a 30 m triangular grid
- 4 scintillators/station (0.2 m^2 each)
- Shower direction and core position determined from arrival times of charged particles and amplitude.

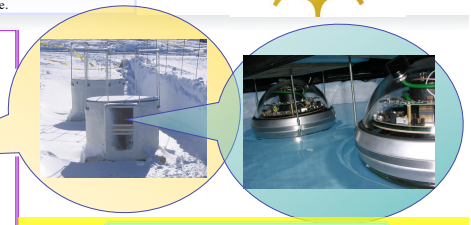
AMANDA:
- 19 Detector Strings
- 677 total Optical Modules (OM)
- Detector volume: 0.02 km^3
- Each OM has a PMT which detects Cherenkov light from muons passing through the ice

IceTop:
- Currently 40 stations, 125m triangular grid.
- 2 Ice Cherenkov 2.7m^2 detectors/station
- 80 stations when complete, covering about 1km^2

IceCube:
- Currently 40 strings, 80 when complete.
- Each string has 60 digital optical modules
- Detector volume: 0.9 km^3







MEASURABLE PARAMETERS

S30: The lateral distribution at the surface is fit to NKG function and is evaluated at 30m from shower core.

K50: The lateral distribution of photons from the muon bundle (cluster of high-energy muons near the shower core) in AMANDA-II is fit to OM hits and evaluated at 50m from the shower axis.

measure of the electromagnetic component of the air shower

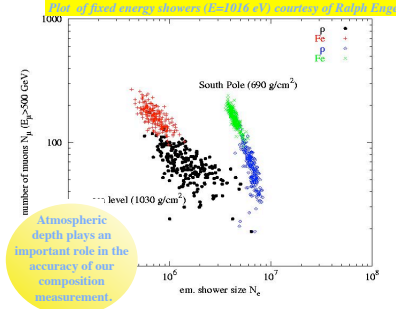
measure of the muon component of the air shower

S100: Lateral distribution at the surface is fit to a Double Logarithmic Parabola function and is evaluated at 100m from shower core.

dE/dx: Muon bundle energy loss is fit using a log likelihood reconstruction after the muon bundle geometry has been fit.

Hit Time Residual: Time difference between actual and expected arrival times of hits from direct photons. Related to the mass-dependent muon bundle size.

Plot of fixed energy showers (E=1016 eV) courtesy of Ralph Engel

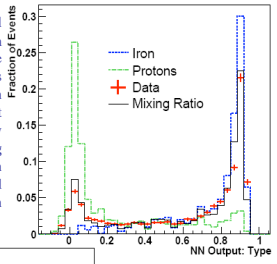


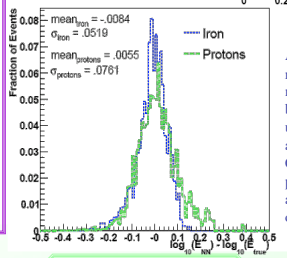
Atmospheric depth plays an important role in the accuracy of our composition measurement.

NEURAL NETWORK TECHNIQUE

We use a simple SPASE-2/AMANDA-II Monte Carlo simulation composed of proton and iron showers to illustrate the neural network technique. The input parameters are $\log_{10}$(S30) and $\log_{10}$(K50). The output parameters are particle type (0 for proton showers and 1 for iron showers) and energy. The network is trained on half of the Monte Carlo and tested on the other half before being applied to three years of SPASE-2/AMANDA-II coincident data.

At the **right**, the neural network type output from one energy bin (here 1PeV<E_{NN}<1.6PeV) is shown. The simulation assumes a two-component (proton and iron) primary spectrum, so a **mixing ratio** of proton to iron simulation has been found which best fits the data in each energy bin.





At the **left**, the energy resolution of the neural network output energies between 1 and 10 PeV using the simple SPASE and AMANDA Monte Carlo simulation for proton and iron showers are shown as examples of the two extremes.

FUTURE PROSPECTS

SPASE/AMANDA

We are currently generating new Monte Carlo including a full detector simulation using Corsika's SIBYLL with the FLUKA and GEISHA hadronic interaction Models and including helium and oxygen along with iron and proton showers. We intend to apply the above neural network technique to three years of coincident data for a total livetime of about 360 days.

IceCube/IceTop

We intend to use the fully digital data acquisition system of IceCube/IceTop to investigate shower front fluctuations and muon bundles for primary mass dependant parameters. Simulation is currently underway to study the ability of IceTop/IceCube to differentiate between light, medium, and heavy elements.