



Measuring Cosmic Ray Composition at the Knee with SPASE-2 and AMANDA-II

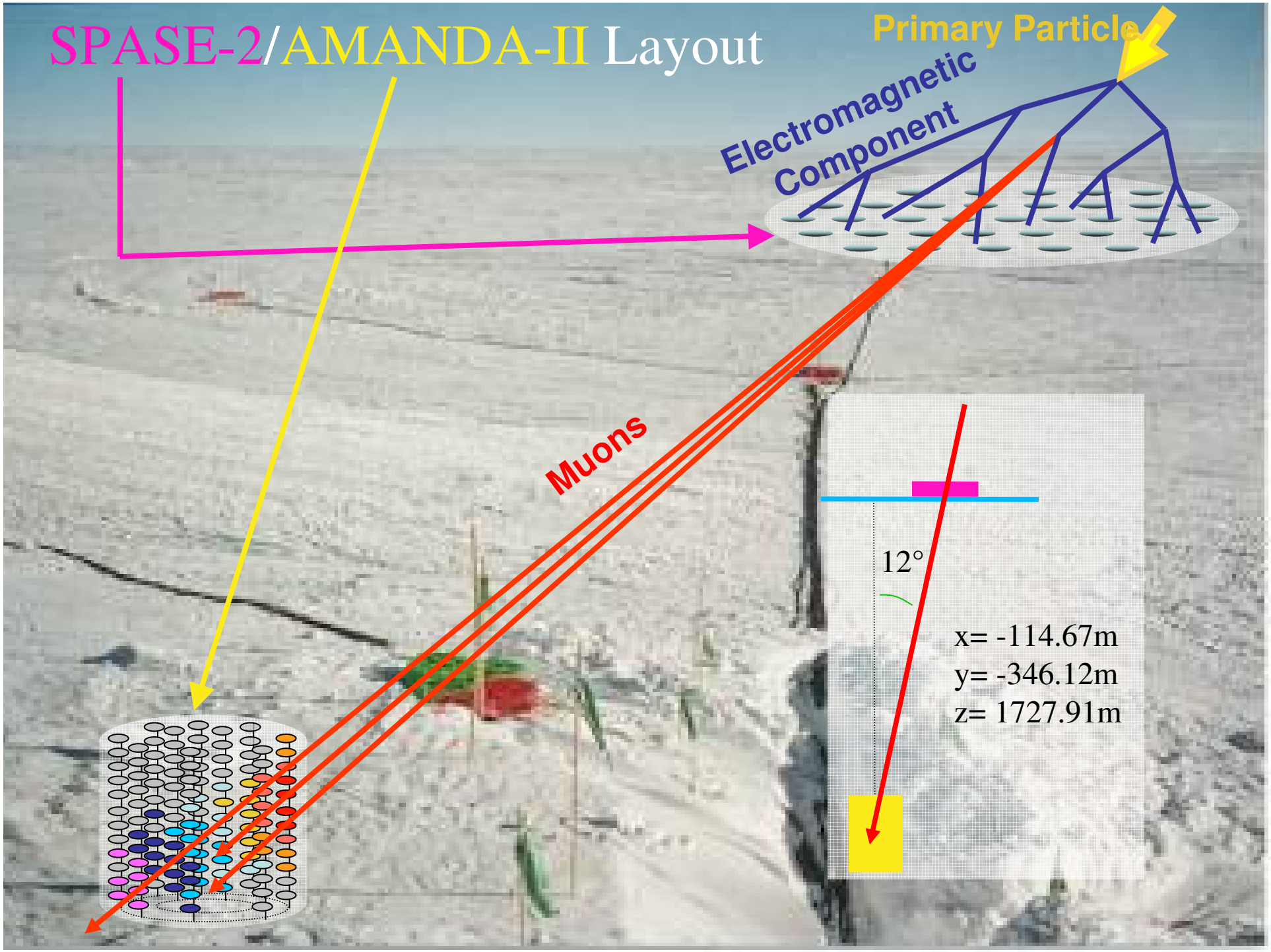
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for the IceCube Collaboration

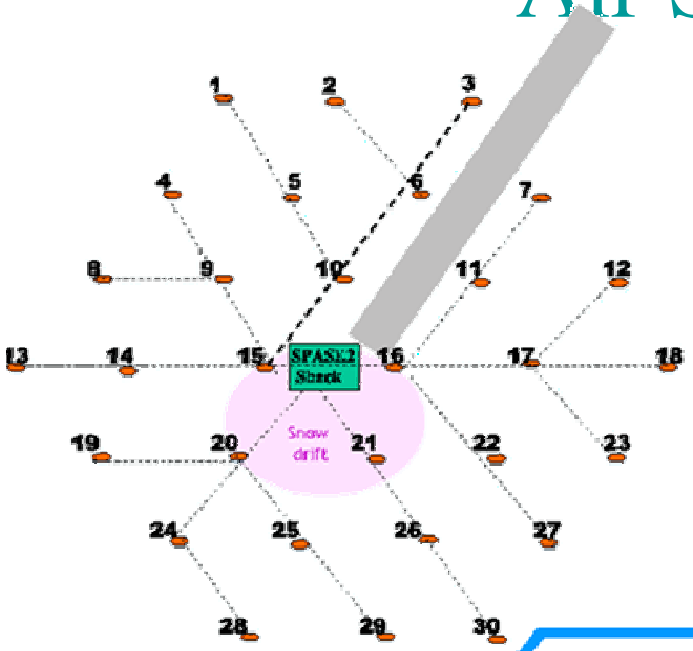
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* Presenter



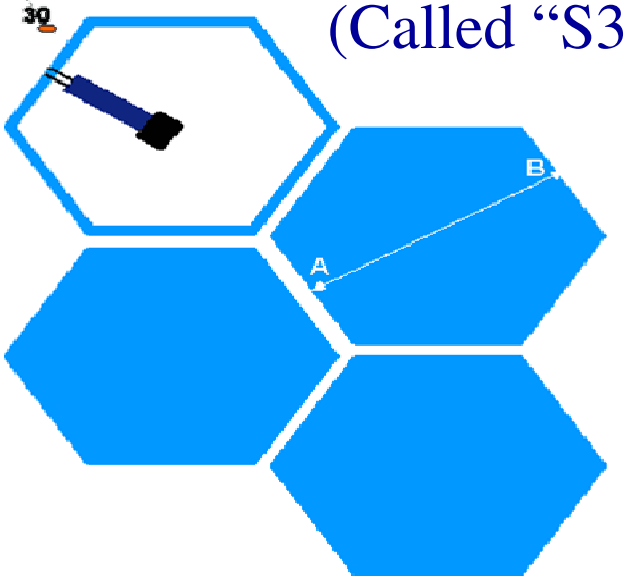
July 4, 2007


SPASE-2/AMANDA-II Layout
Primary Particle
Electromagnetic Component
Muons
12°
x= -114.67m
y= -346.12m
z= 1727.91m

SPASE-2: South Pole Air Shower Experiment



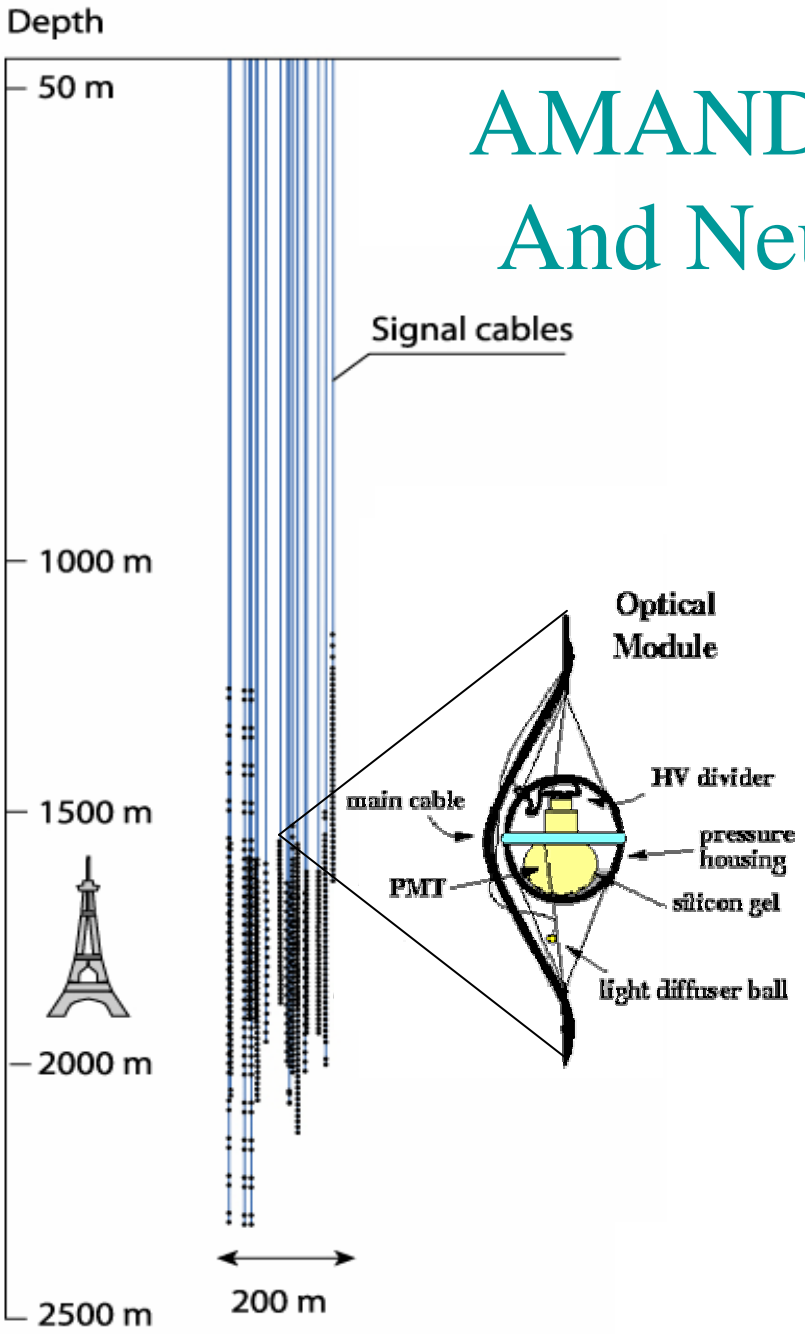
- 30 Stations, 30 m triangular grid
- 4 scintillators/station (0.2 m^2 each)
- Shower direction and core position determined from arrival times of charged particles and amplitude.
- Lateral distribution fit to NKG function and is evaluated at 30m from shower core. (Called "S30")





ICRC'07
Mérida, México

AMANDA-II: Antarctic Muon And Neutrino Detector Array

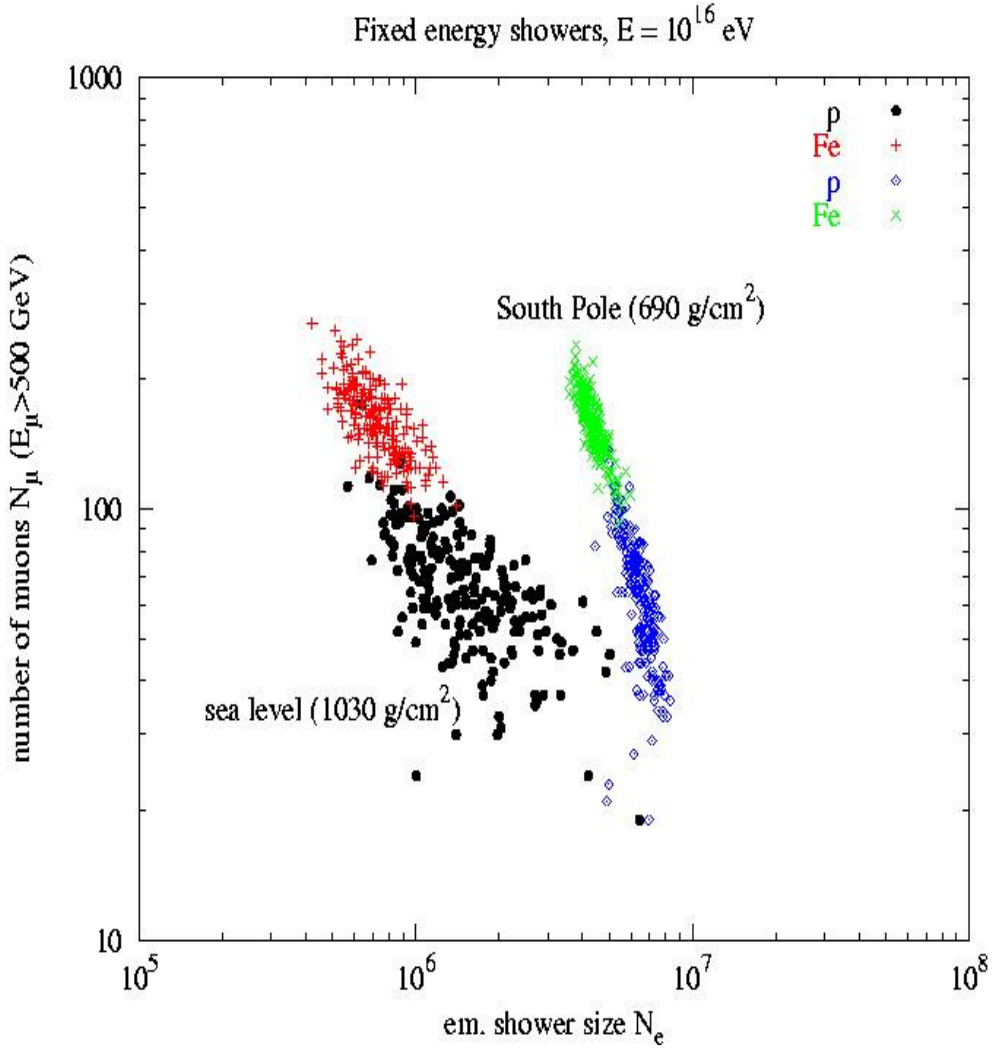


- 19 Detector Strings
- 677 total Optical Modules (OM)
- Each OM has a PMT which detects Cherenkov light from muons passing through the ice
- Lateral distribution of photons from muon bundle in AMANDA-II is fit to OM hits and evaluated at 50m from the shower axis. (Called "K50")

What do K50 and S30 tell us?

- S30 is measure of electromagnetic component of air shower
- K50 is measure of the muon component of air shower
  - Separation of primary mass and energy
- SPASE-2/AMANDA-II are at a good atmospheric depth for energy resolution.

Plot courtesy of Ralph Engel



Coincident Events for Composition at the South Pole





Simulation

- MOCCA [SIBYLL 1.7]
- Proton and Iron showers from 100 TeV to 100 PeV
- E^{-1} Spectrum, weighted to $E^{-2.7}$ below the knee (at 3 PeV) and $E^{-3.0}$ above

Data

- Coincident events from years 2003-2005
- Total livetime of 369 days

Quality Cuts

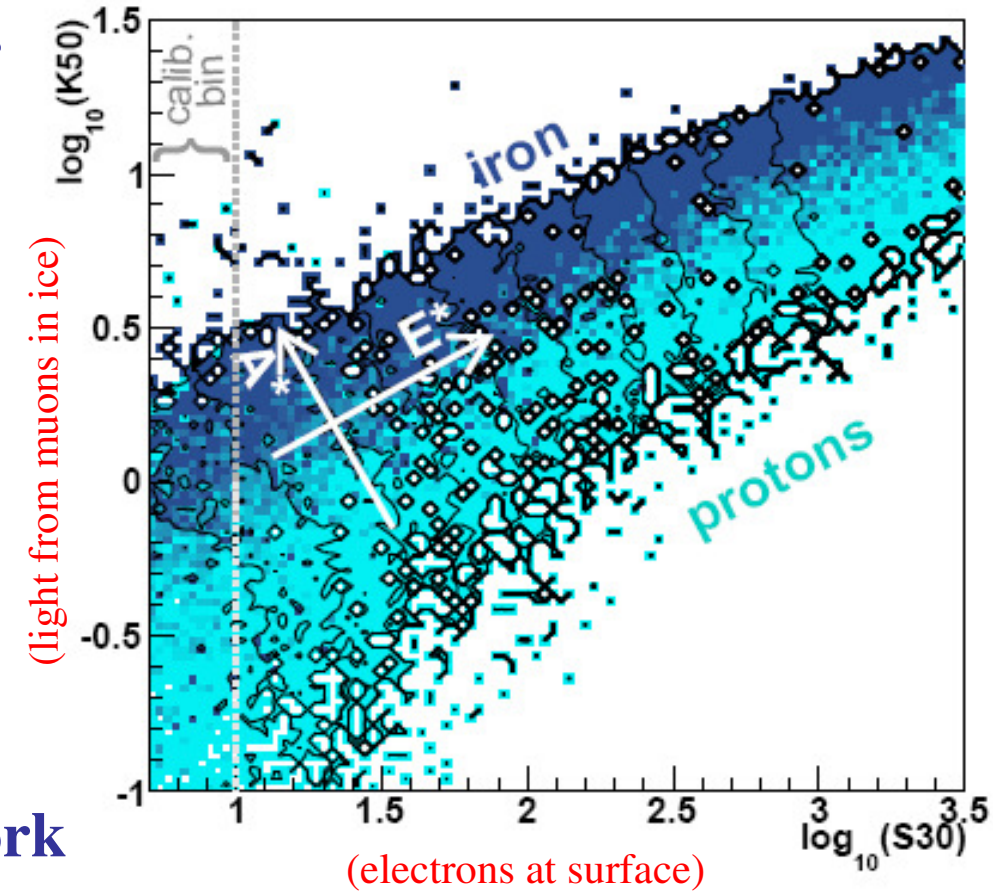
- Shower core falls within the SPASE-2 array
- Muons pass within the volume of the AMANDA-II detector
- Energy is large enough to be well-reconstructed

105,216 events after cuts (SPASE-2/AMANDA-B10 had 5,655)



Resolving Mass and Energy

- Two methods for finding mass and energy:
  - Rotation
  - Neural Network
- Rotation worked well for energies relevant to previous analysis
- Loss of linearity at higher energies pertinent to new analysis; therefore, need new method ➡ **Neural Network**

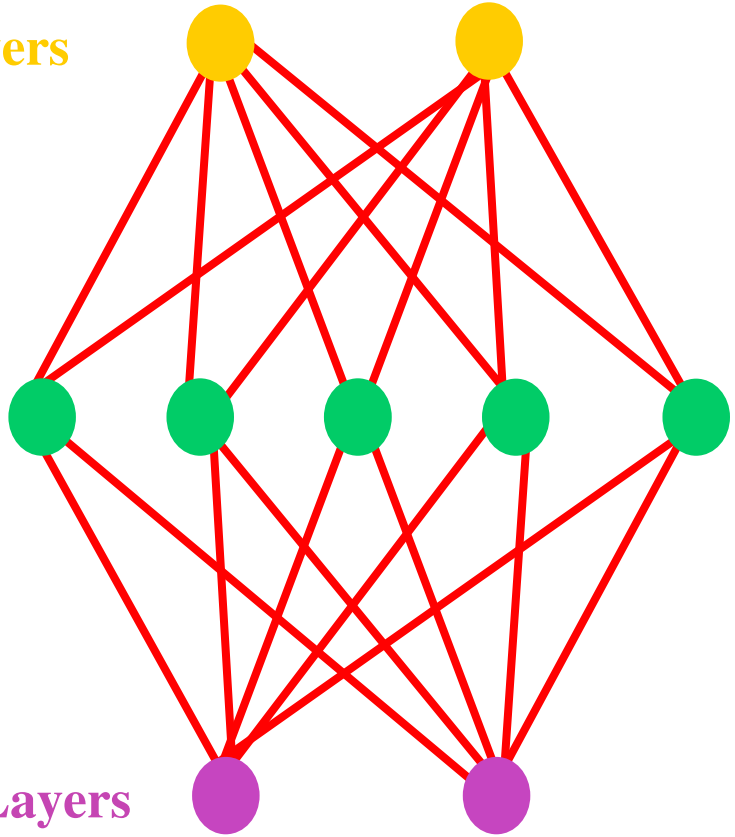


A Neural Network (using ROOT)

(# muons) (# electrons)

$\log_{10}$(K50) $\log_{10}$(S30)

2 Input Layers



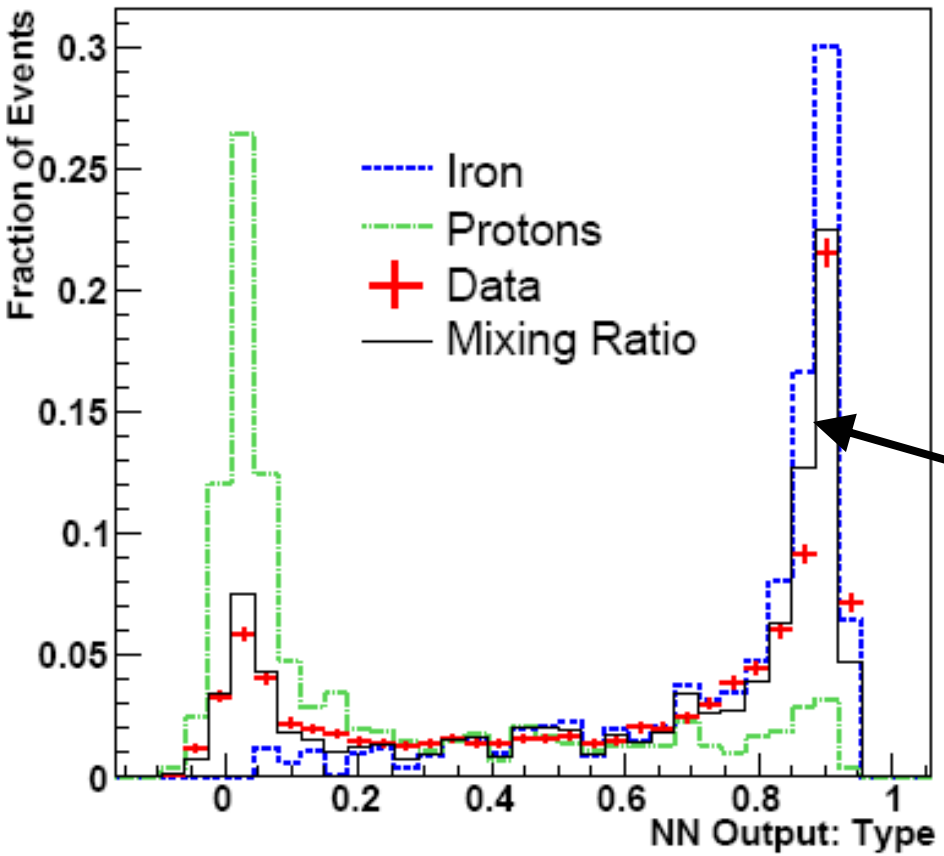
5 Hidden Nodes (Gave best energy resolution)

2 Output Layers

Type(0 or 1) $\log_{10}$(Energy)

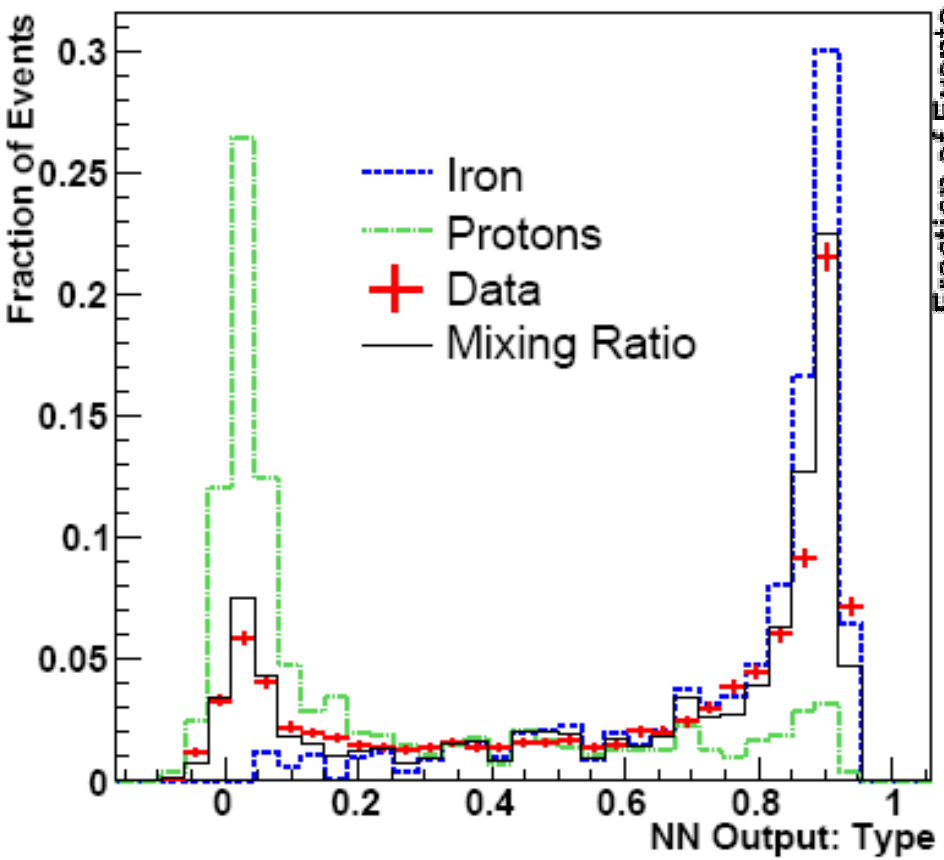
NN is trained on ½ of MC, tested on the other ½, then applied to the data.

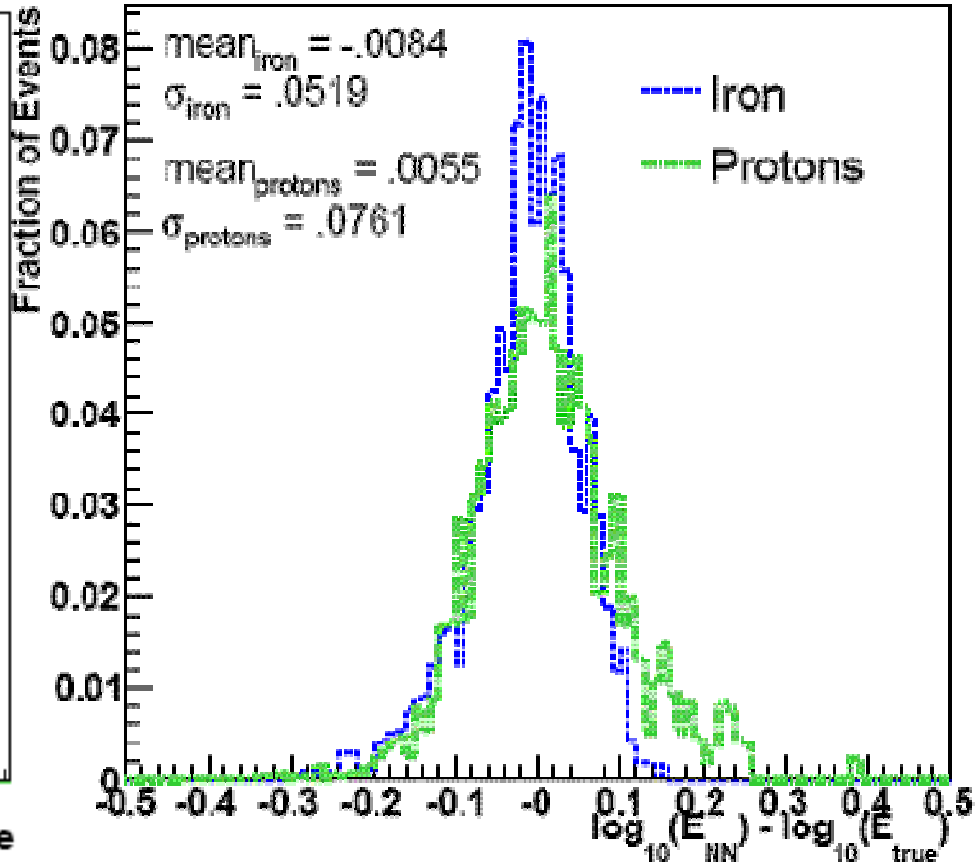
Interpreting NN Results



- NN Particle Type output for one energy bin (here, $\log_{10}(E_{NN}/\text{GeV})$ between 6.0 and 6.2).
- A **mixing ratio** is found which is the best fit of the data in each energy bin.

Interpreting NN Results

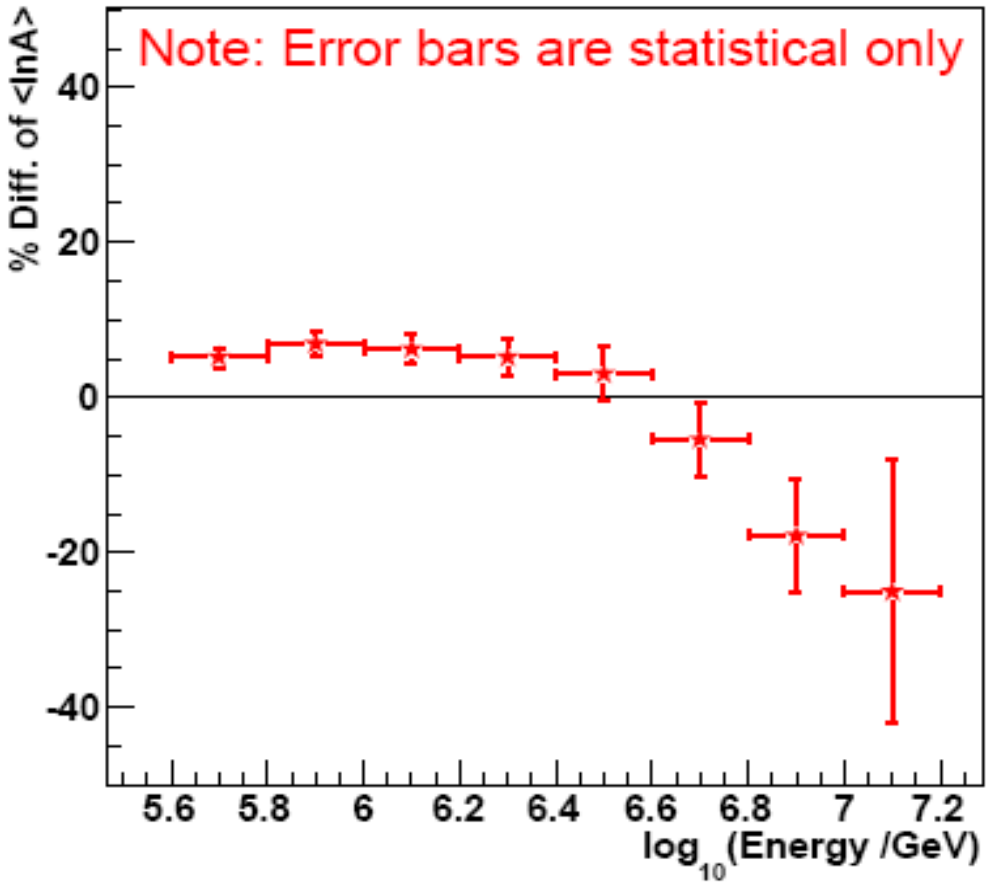




Energy Resolution for Simulated Protons and Iron

NN Results Compared to Rotation Method

- Methods agree reasonably well
- Deviations at high energy as expected due to non-linearity above these energies





Conclusions and Outlook



- NN is a valid and useful analysis technique for composition
- Will apply to the SPASE-2/AMANDA-II analysis shortly using a new CORSIKA-generated Monte Carlo simulation, including more intermediate particle types
- Will also be applied to IceCube/IceTop analysis in the future

