Cosmic Rays in IceCube: Composition-Sensitive Observables

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Threshold energy: 300 TeV

80 pairs of frozen water tanks separated by ~10 m

- 60 optical modules per string
- String spacing: ~125 m

See Tom Gaisser's talk (HE.1.5, 9:30-10:00, July 5)
IceTop Tank

Measures energy deposition by shower particles
IceTop-IceCube coincident events

**Simulation**
- CORSIKA [GHEISHA-SIBYLL]
- Energy: [50,5000] in TeV
- Sampling area: $\pi \times 1200^2$

**Quality cuts**
- Edge cut
- Zenith < 20°
- $N_{\text{string}} > 1$
- Beta < 6

16 pairs of IceTop tanks & 9 IceCube strings in 2006
Shower Size

Lateral distribution fit

\[ f(r) = S_{100} \left( \frac{r}{100 \text{ m}} \right)^{-\beta - \kappa \cdot \log (r/100 \text{ m})} \]

\( S_{100} \) depends on primary mass

See Stefan Klepser's talk
(HE.1.1.A, 10:54-11:06, July 9)

Energy determination by Neural Network
(SPASE-AMANDA analysis)
Muon Multiplicity

Minimum muon energy:

300 GeV @ top of IceCube
500 GeV @ bottom of IceCube

@ IceTop level (~700 g/cm²)
by Ralph Engel

by Tom Gaisser
Charge

sensitive to primary mass

$0.5 < S_{100} < 1.3$

from a shower axis to hit DOM
Optical Properties of Ice

Average optical parameters:

\[ \lambda_{\text{abs}} \sim 110 \text{ m @ 400 nm} \]
\[ \lambda_{\text{sca}} \sim 20 \text{ m @ 400 nm} \]
Muons in an iron shower spread more widely than those in a proton shower, so iron showers have more late hits than proton showers.
Summary

- Energy estimator, $S_{100}$, depends on primary mass. Neural Network resolves the problem with additional mass-sensitive observables as demonstrated by the SPASE-AMANDA analysis (K. Andeen, et al, OG.1.2).

- In addition to charge, timing information can be used to study cosmic ray composition.

- Appropriate correction needs to be made for depth-dependent optical properties of ice.

- Hit DOMs close to the shower axis may be best suited for this analysis.

- Coincident data taken in 2007 are being analysed (52 tanks).
Vertical string map: AMANDA and IceCube-9
- **04/05**
  - 1 IceCube string
  - 8 IceTop tanks

- **05/06**
  - 10 IceCube strings
  - 24 IceTop tanks

- **06/07**
  - 12 IceCube strings
  - 24 IceTop tanks