Cosmic Ray Flux Measurement with AMANDA-II

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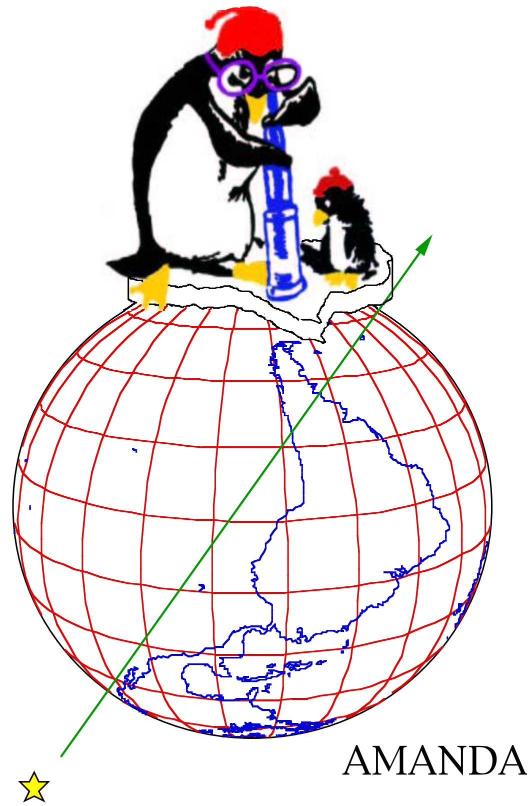

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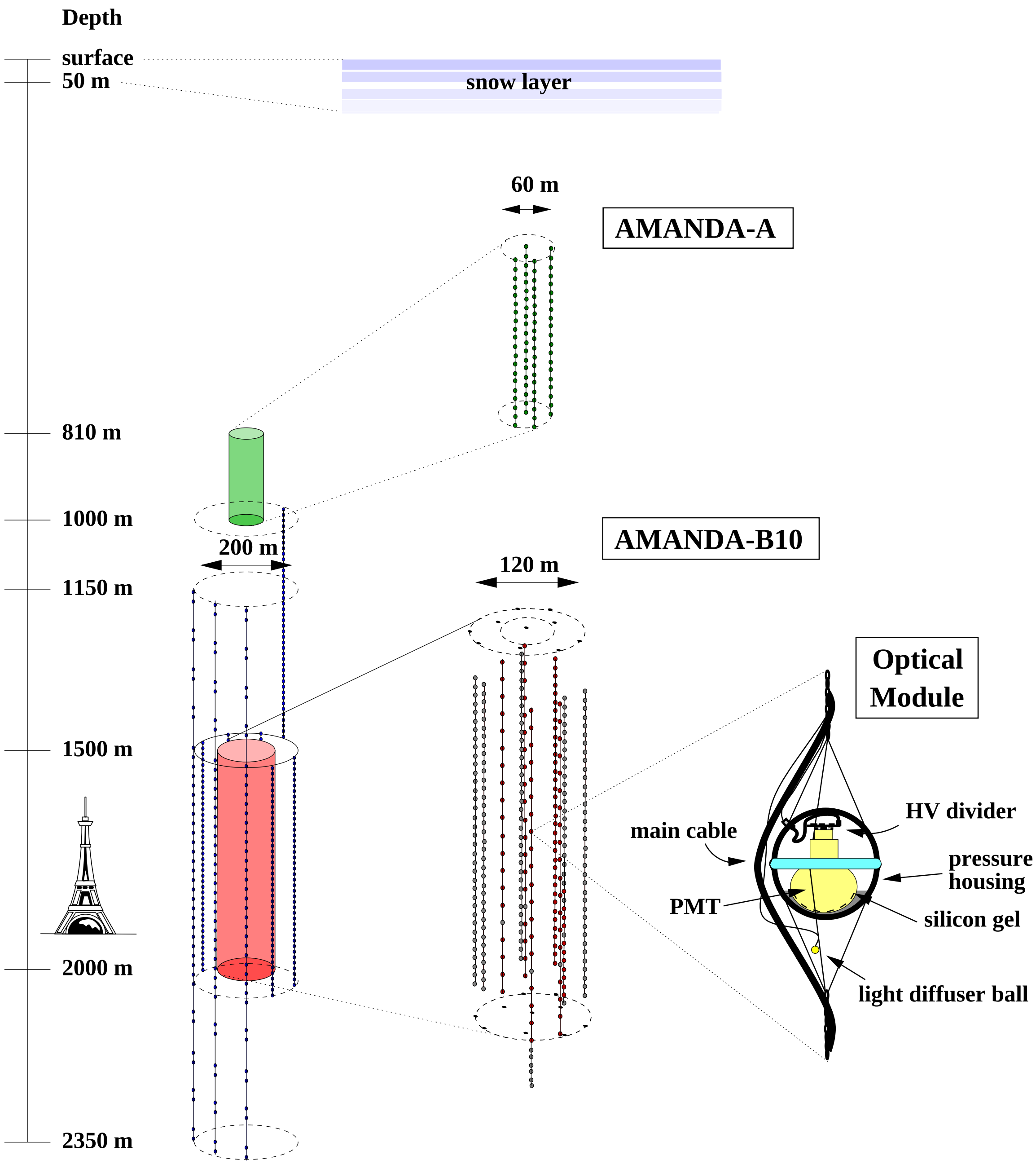
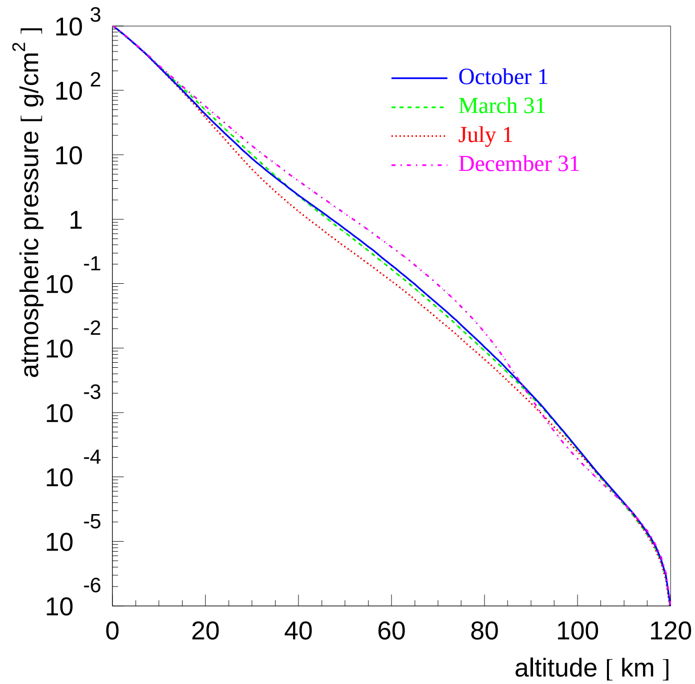


AMANDA as of 2000
Eiffel Tower as comparison
(true scaling)

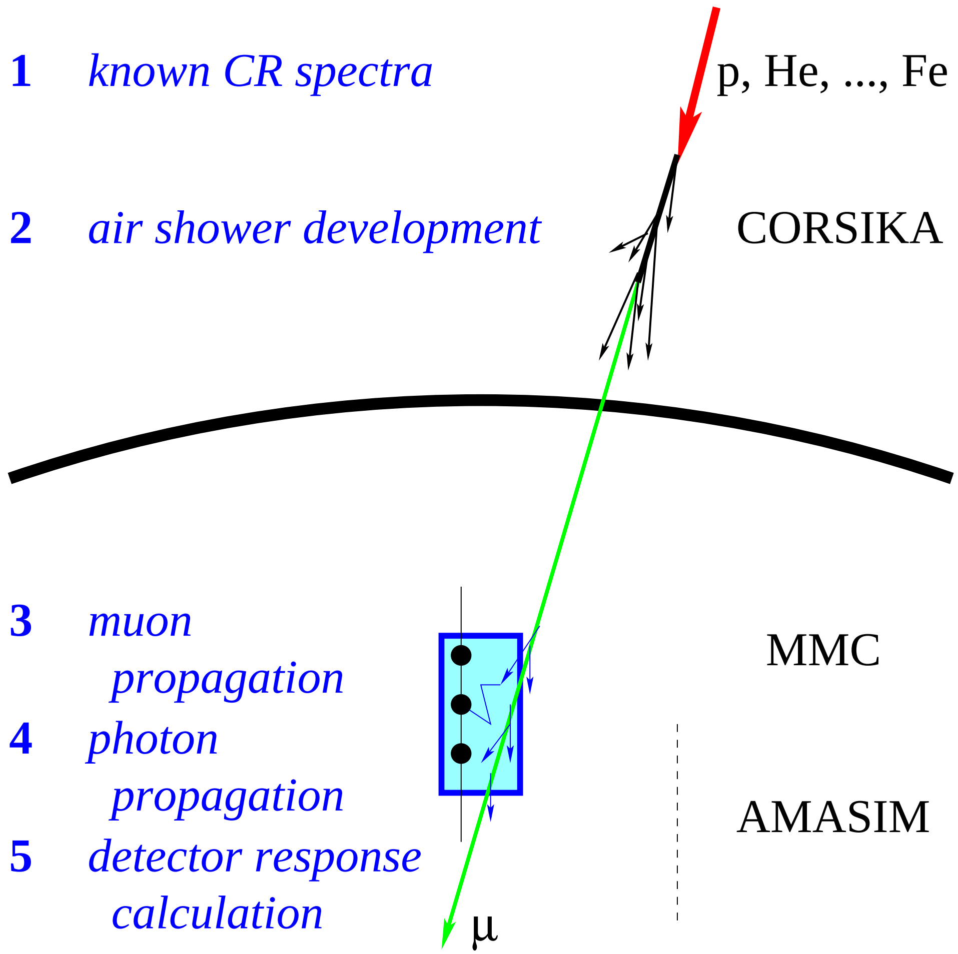
zoomed in on
AMANDA-A (top)
AMANDA-B10 (bottom)

zoomed in on one
optical module (OM)

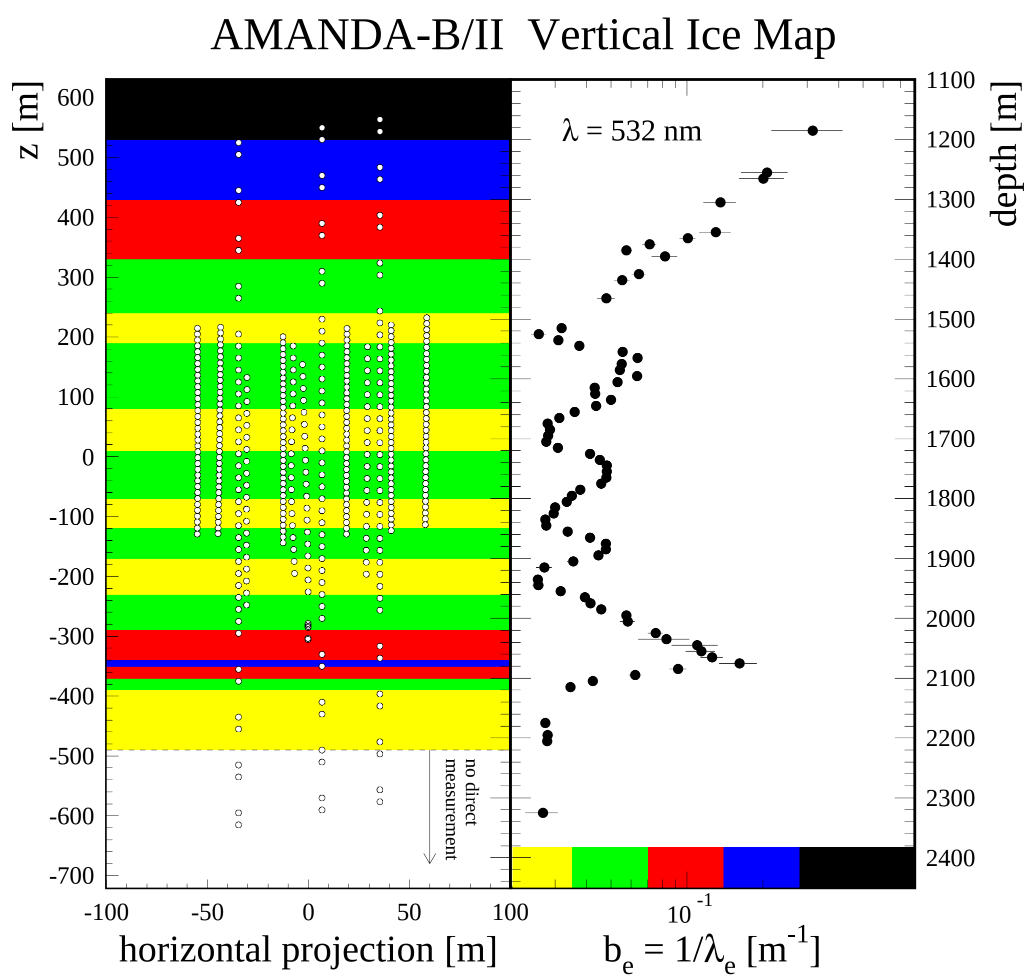
AMANDA-II is a neutrino telescope composed of 677 optical sensors organized along 19 strings buried deep in the Antarctic ice cap.



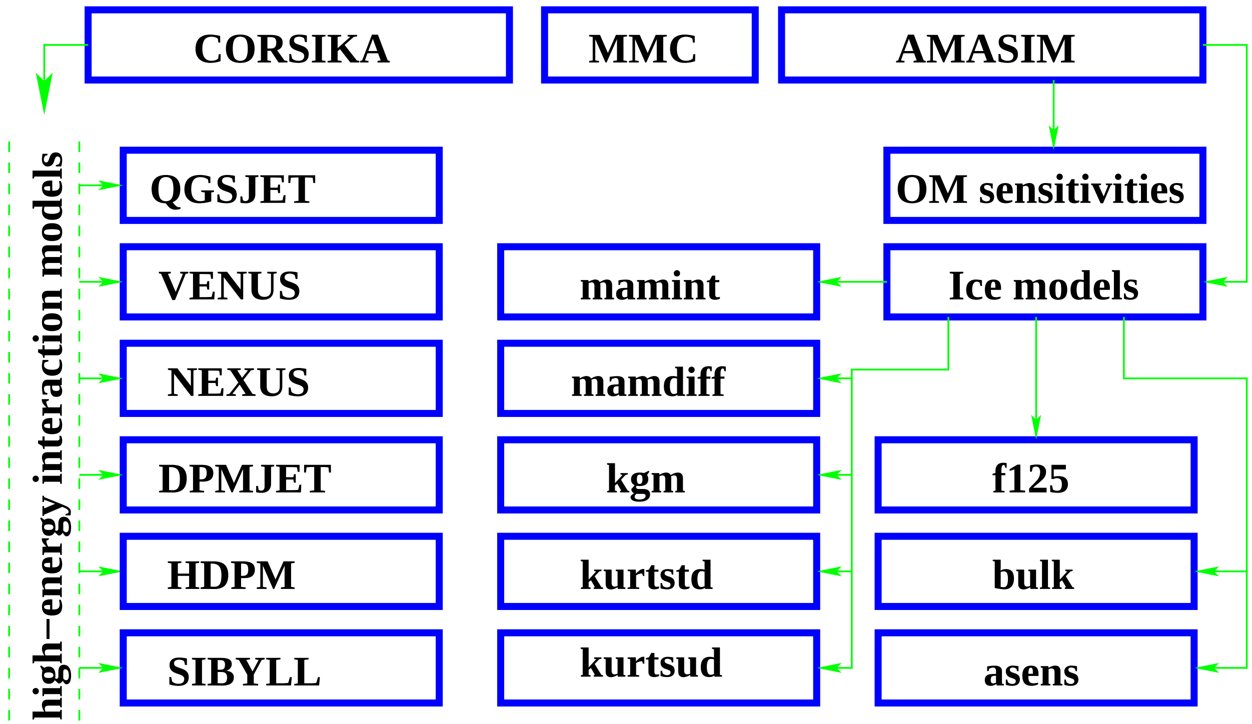
Several samples (different seasons) of AMANDA-II data from year 2000 were analyzed.



To simulate background an air shower generator (CORSIKA) is run, then muons are propagated (with MMC), and then the photons are propagated and detector response is evaluated (with AMASIM).



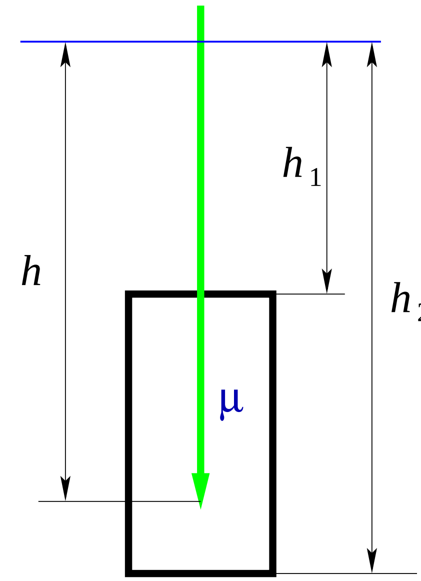
Properties of ice have been measured quite precisely. However, due to computational constraints exact measured ice properties are difficult to implement. Several ice models therefore exist. Also, parameters of ice models as well as sensitivities of the optical sensors have been varied somewhat.



Additionally, all 6 high-energy interaction models available with CORSIKA were tested.

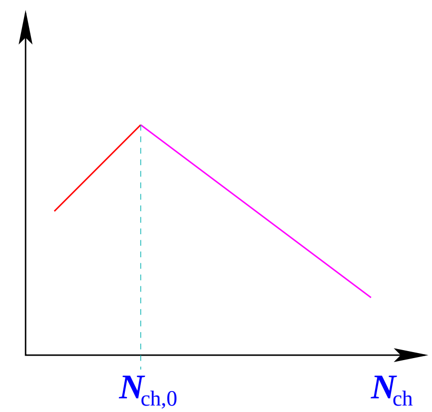
	QGSJET	VENUS	NEXUS	DPMJET	HDPM	SIBYLL
Gribov-Regge	+	+	+	+		
Minijets	+		+	+		+
Sec. Interactions		+	+			
N-N Interactions	+	+	+	+		
Superposition					+	+
Max. Energy (GeV)	$> 10^{11}$	$2 \cdot 10^{7}$	$2 \cdot 10^{8}$	$> 10^{11}$	10^{8}	$> 10^{11}$
CPU time/shower (ms)	0.8	30	365	73	1.6	1.1

Suppose a flux of vertical muons with spectrum $\Phi = \Phi_0 \cdot E^{-\gamma}$ is propagated through ice, losing energy continuously according to $dE/dx = a + b \cdot E$.

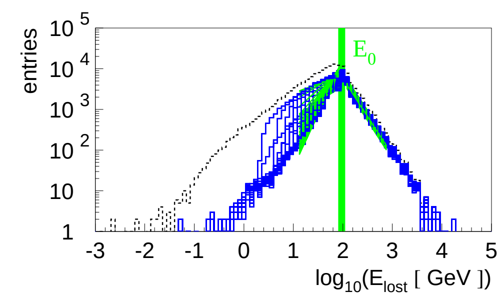


$$N_{\text{ch}} \approx \int_{h_1}^{h_2} \frac{dE}{dx}(h)\rho dh = (a + bE)\int_{h_1}^{h_2} e^{-bh}\rho dh$$

where ρ is proportional to the vertical density of optical sensors and depends on the their sensitivities and optical properties of the ice. Solving for $E(N_{\text{ch}})$ and inserting it into $\Phi = \Phi_0 \cdot E^{-\gamma}$ one gets

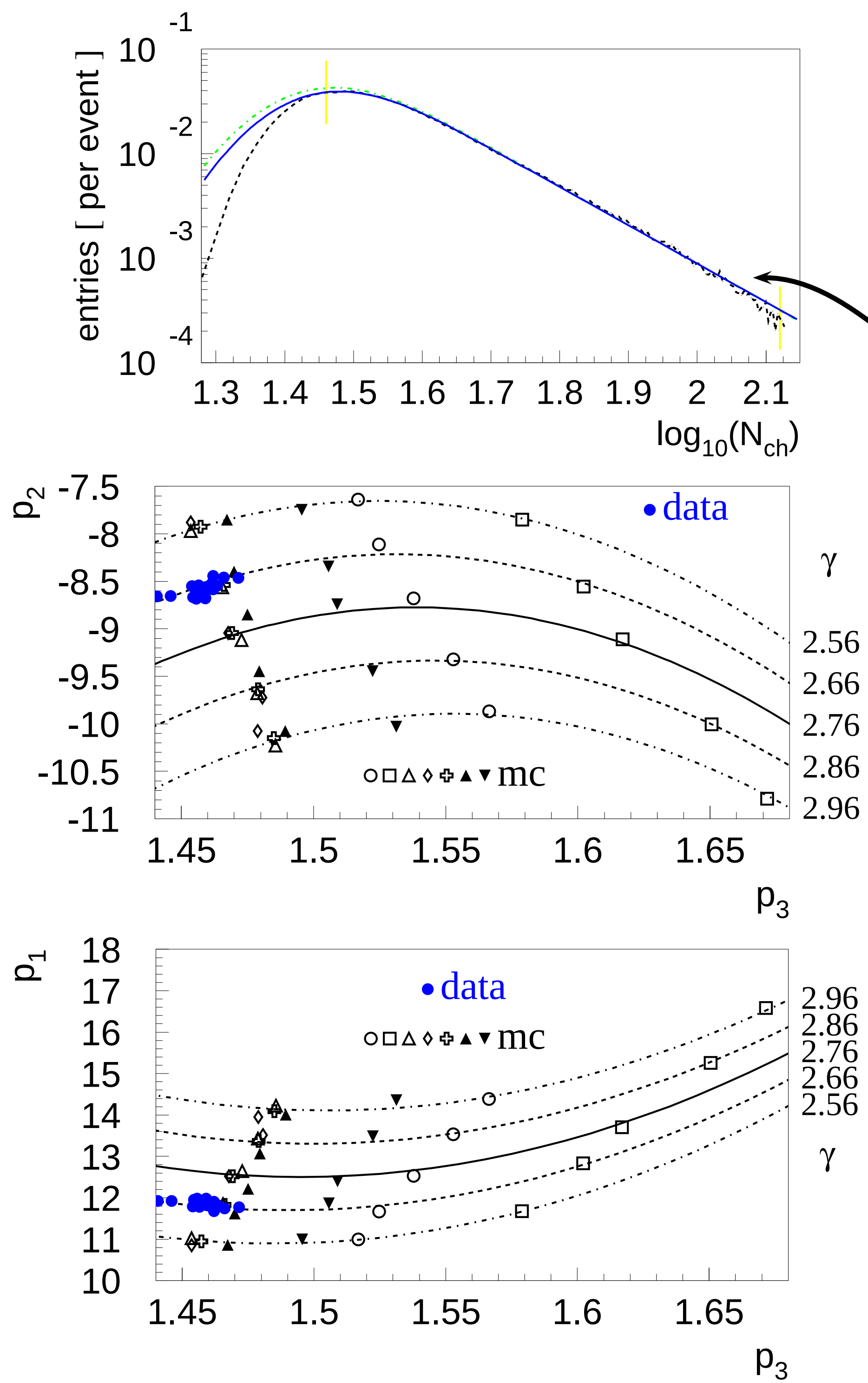


$$\Phi = \Phi_0 \cdot \begin{cases} (\frac{N_{\text{ch}} - a\rho A}{b\rho A})^{-\gamma} \\ (\frac{N_{\text{ch}} + \rho C - a\rho B}{b\rho B})^{-\gamma} \end{cases} \quad \Rightarrow$$



$$N_{\text{ch}} \cdot \frac{d(\log \Phi)}{dN_{\text{ch}}} = \begin{cases} \frac{-\gamma N_{\text{ch}}}{N_{\text{ch}} - a\rho A} \\ \frac{-\gamma N_{\text{ch}}}{N_{\text{ch}} + \rho C - a\rho B} \end{cases}$$

One therefore gets the break in the N_{ch} distribution at $N_{\text{ch},0}$ corresponding to $E_0 = (e^{bh_2} - 1) \cdot a/b$.

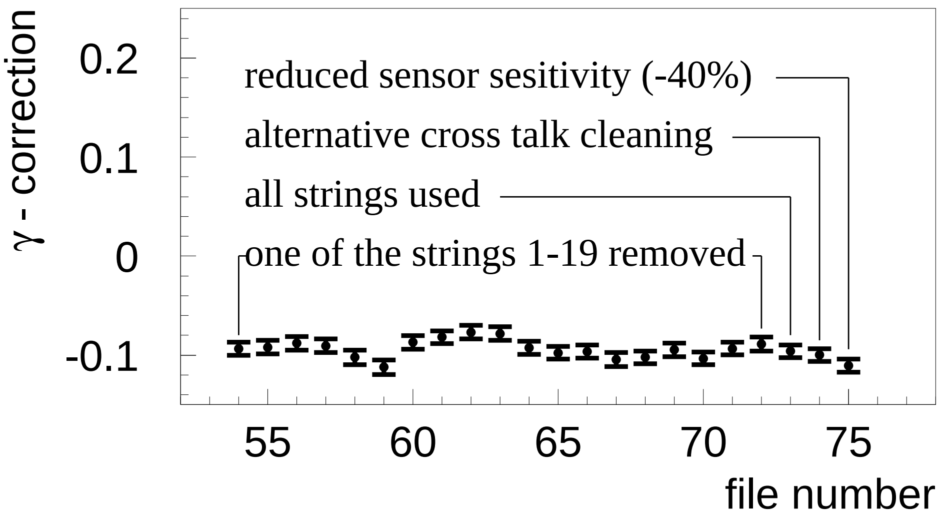


log(N_{ch}) distribution is fit with

$$f(x) = (e^{p_1 + p_2 \cdot x}) \cdot \frac{1 - \mathrm{erf}(\frac{p_3 - x}{p_4})}{2}$$

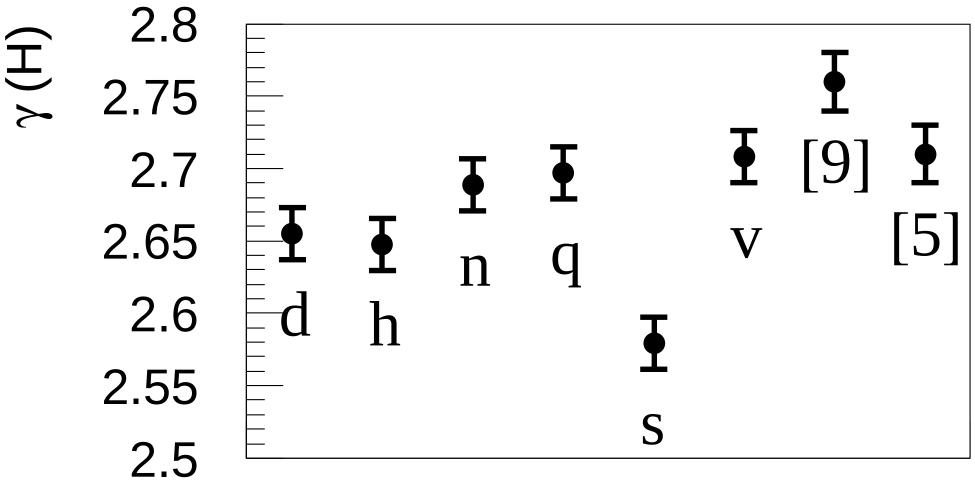
The fit parameters corresponding to same spectral index correction (0, ±0.1, ±0.2) appear to lie along empirical parabola fits independent of the used ice model.

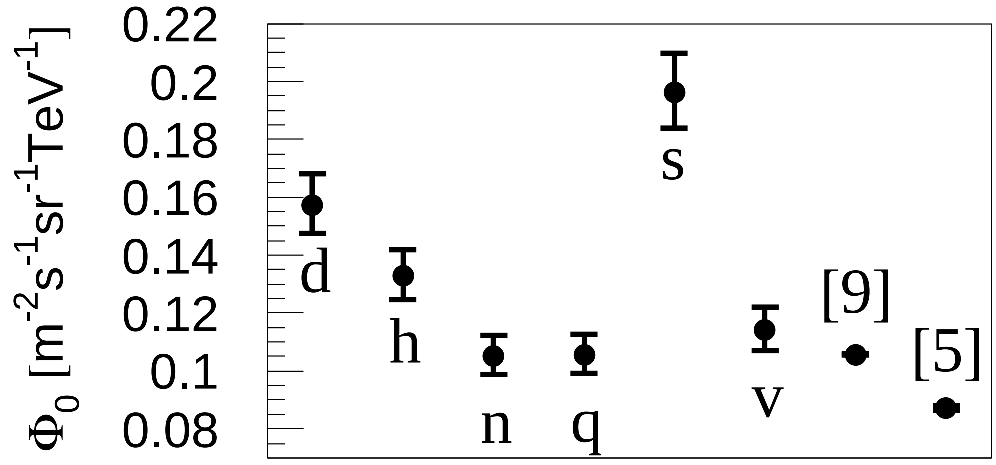
Results



results demonstrated remarkable stability with respect to detector configuration changes and choice of the ice model

$$\gamma = 2.76(\mathrm{H}) - 0.063 \pm 0.007(\mathrm{ice}) \pm 0.014(\mathrm{atm}) \pm 0.009(\mathrm{conf}) = 2.70 \pm 0.02$$
$$\Phi_0 = 0.1057(\mathrm{H}) + 0.000 \pm 0.002(\mathrm{ice}) \pm 0.004(\mathrm{atm}) \pm 0.006(\mathrm{conf}) = 0.106 \pm 0.007$$





Results for DPMJET, HDPM, NEXUS, QGSJET, SIBYLL, VENUS (for H)

Conclusions

1. Results depend on the strong features of the muon flux, not small variations in the detector simulation settings.

2. Muon flux is most consistent with predictions of the QGSJET, VENUS, and NEXUS high-energy interaction models.

3. Detailed discussion of the method and results are to appear in my dissertation (look for it here: http://amanda.berkeley.edu/~dima/work/)