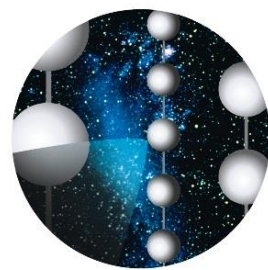




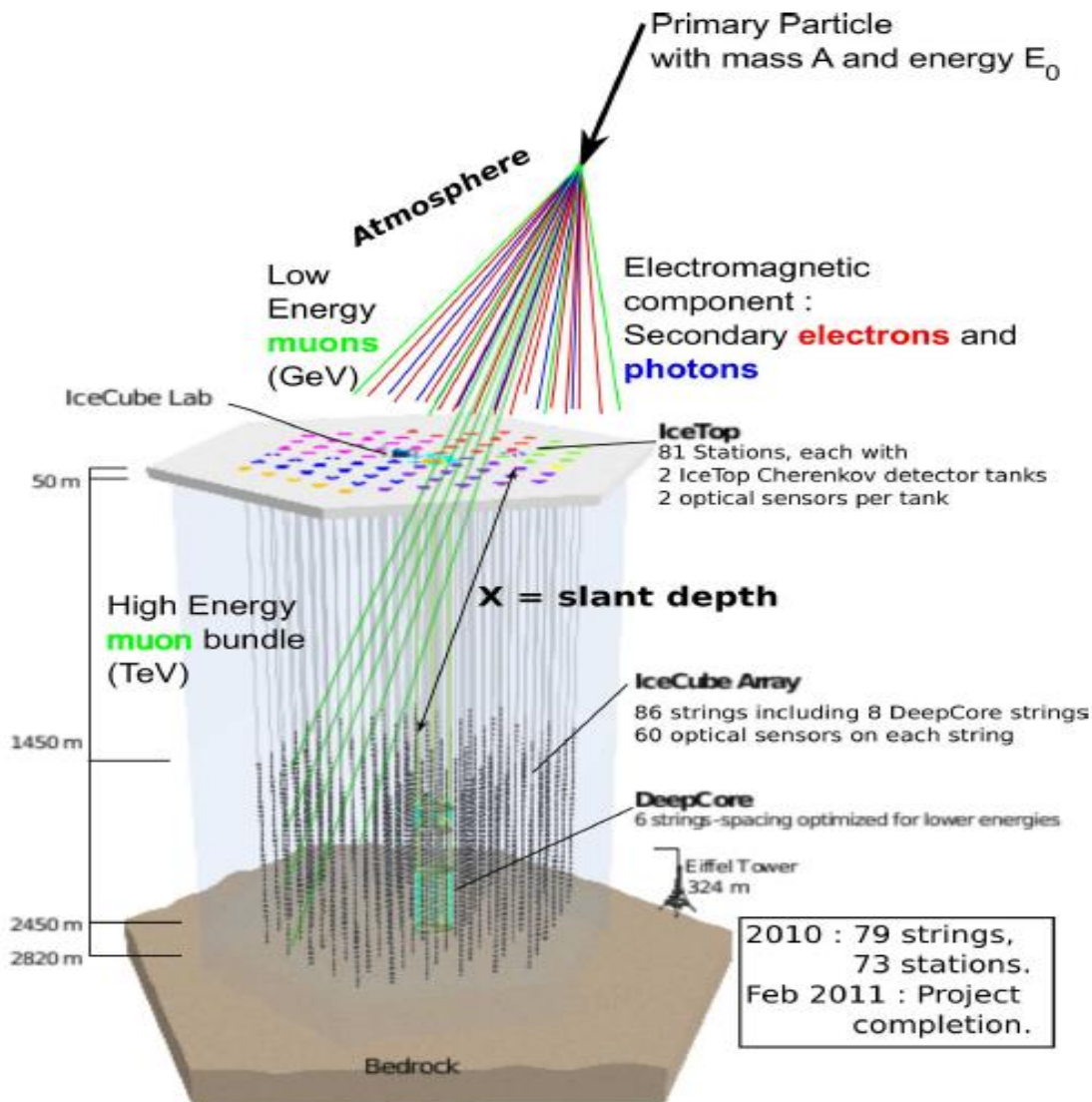
Measuring cosmic ray energy spectrum with IceCube



Bakhtiyar Ruzybayev



IceCube



Surface Only: IT73

- 327 days of live time.
- 12M events after quality cuts,
 $\log_{10}(E/\text{GeV}) > 6.2$
- Measures energy using linear relationship between $\log_{10}(S_{125})$ and $\log_{10}(E_{\text{true}})$.
- Assumes composition to derive energy (Default model: H4a from *T.K. Gaisser, Astropart. Phys. 35 (2012) 801-806*).
- Tests composition by looking at energy spectrum in different zenith ranges.

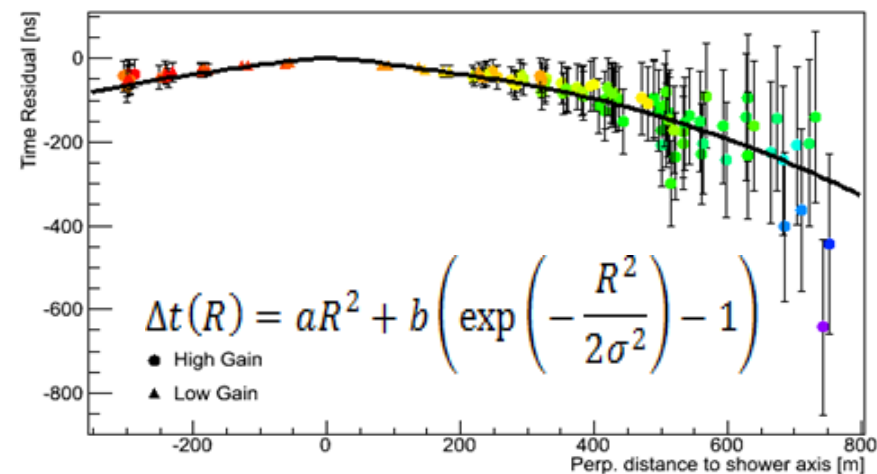
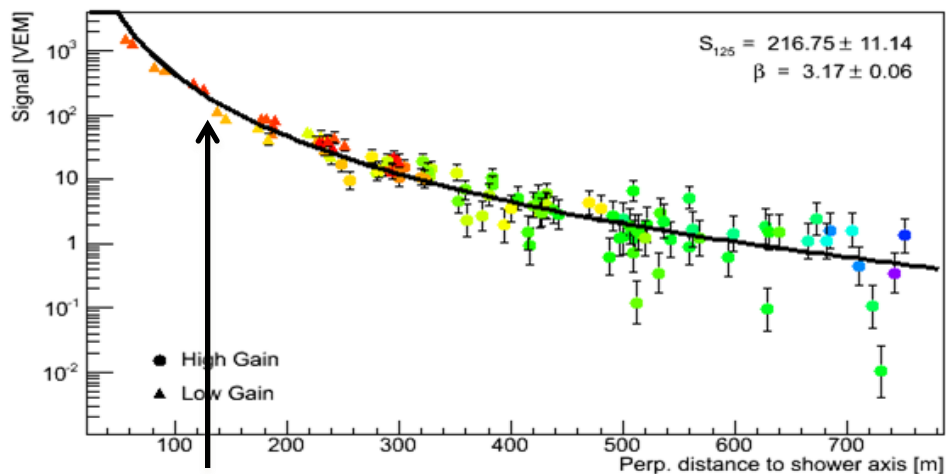
Surface and In Ice: IC79/IT73

- 310 days of live time.
- 1.56M events after quality cuts,
 $\log_{10}(E/\text{GeV}) > 6.4$
- Multivariate Neural Network Analysis .
- Measures Composition.
- Measures composition independent energy spectrum.

Published:

Phys. Rev. D 88, 042004 (2013)

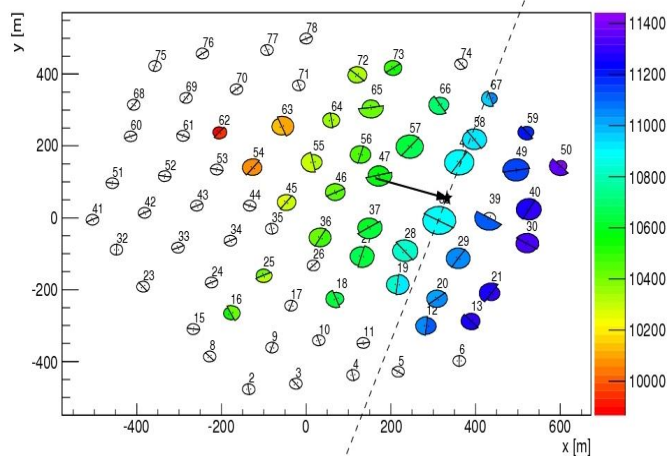
URL: <http://link.aps.org/doi/10.1103/PhysRevD.88.042004>



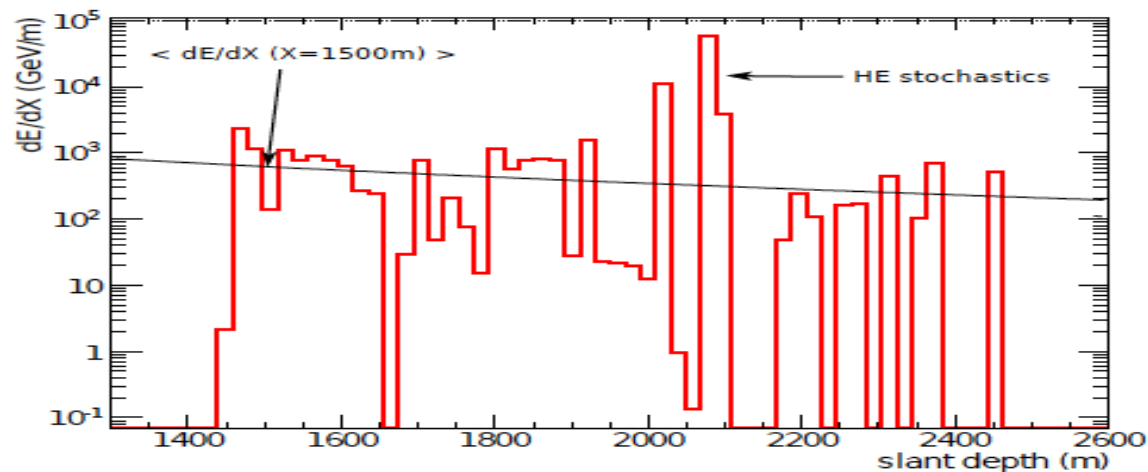
$$S(r) = S_{125} e^{-\frac{d \sec \theta}{\lambda} \left(\frac{r}{125 \text{ m}} \right)^{-\beta - k \log \left(\frac{r}{125 \text{ m}} \right)}}$$

Attenuation due to snow

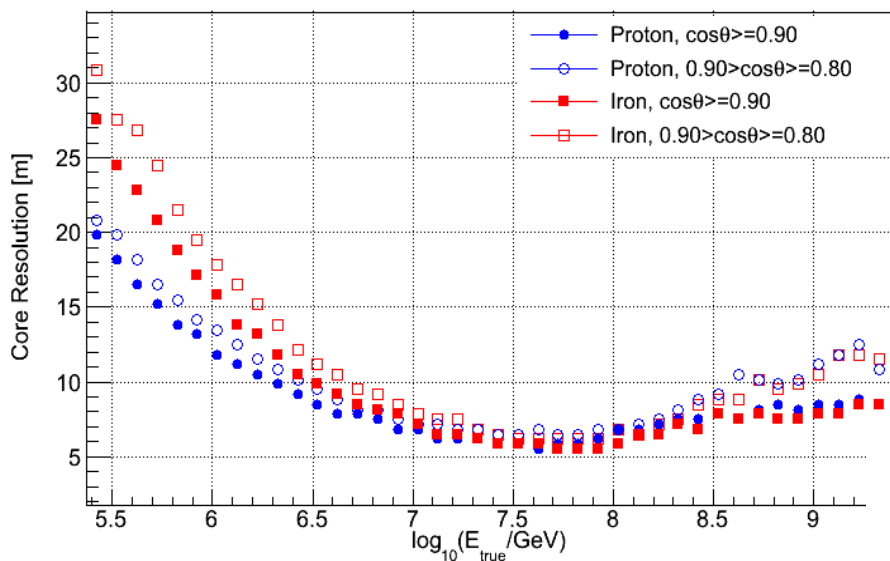
Run 116113 Event 62337765



Run 116545 event 58761981

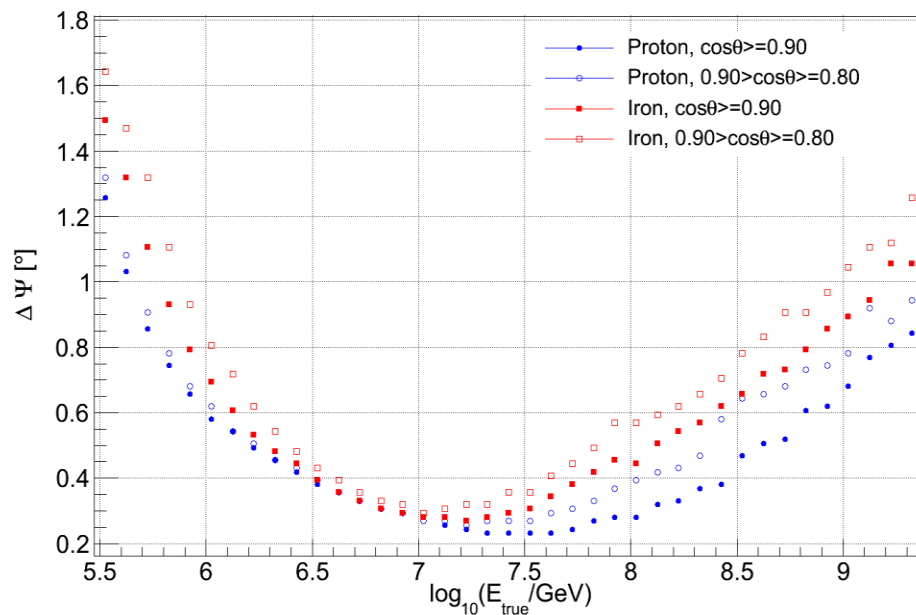


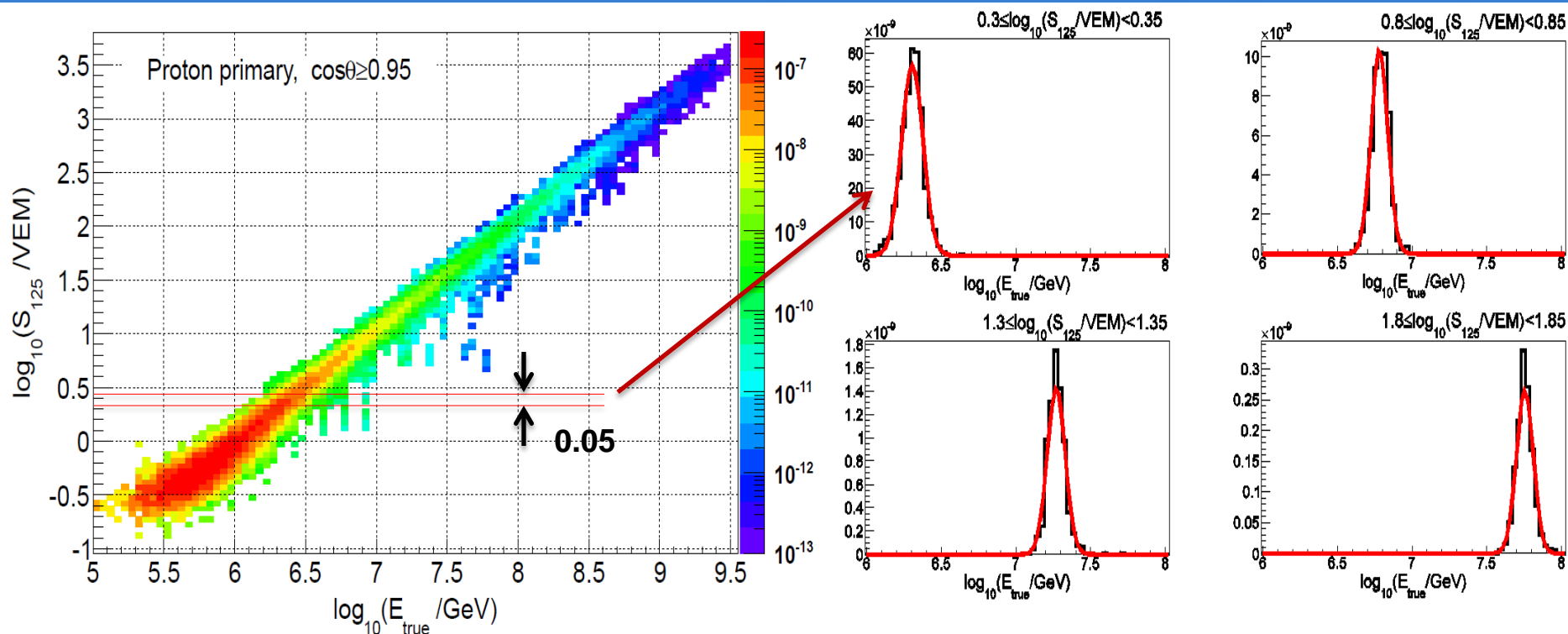
Muon bundle energy loss dE/dX (GeV/m) and stochastic behavior in deep ice.



Core resolution : 6-13 m

Angular resolution: $0.2^\circ - 0.8^\circ$





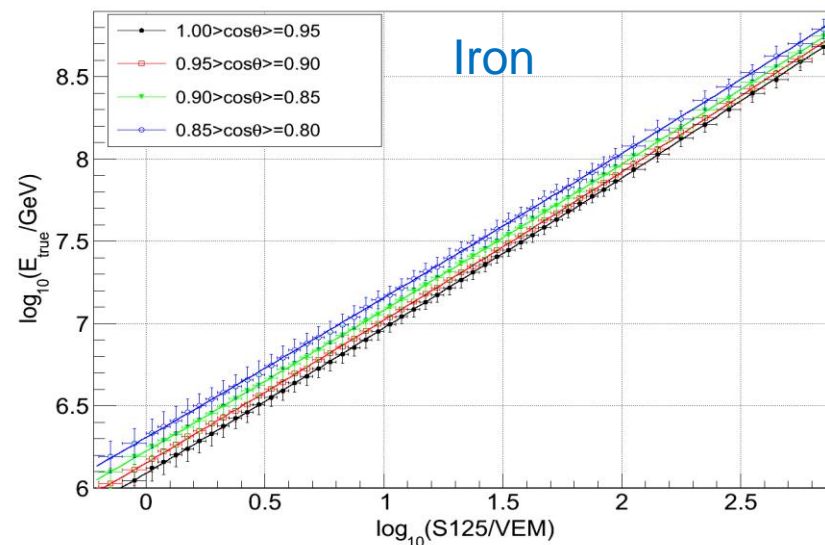
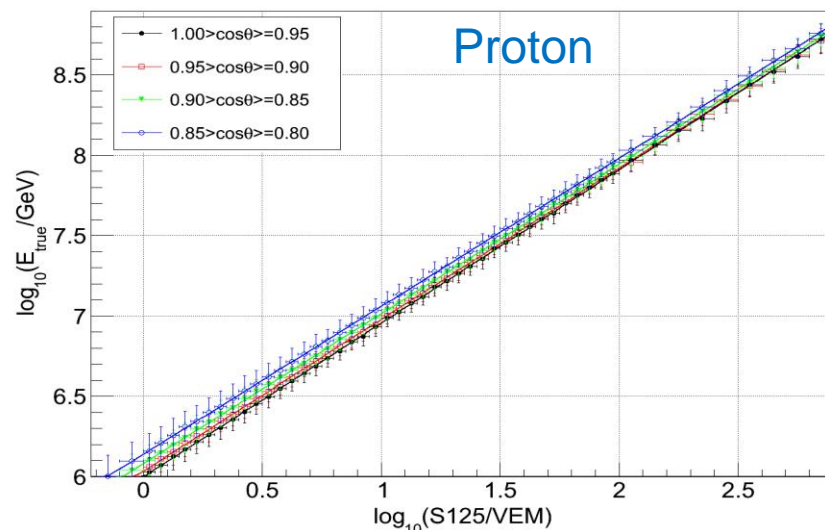
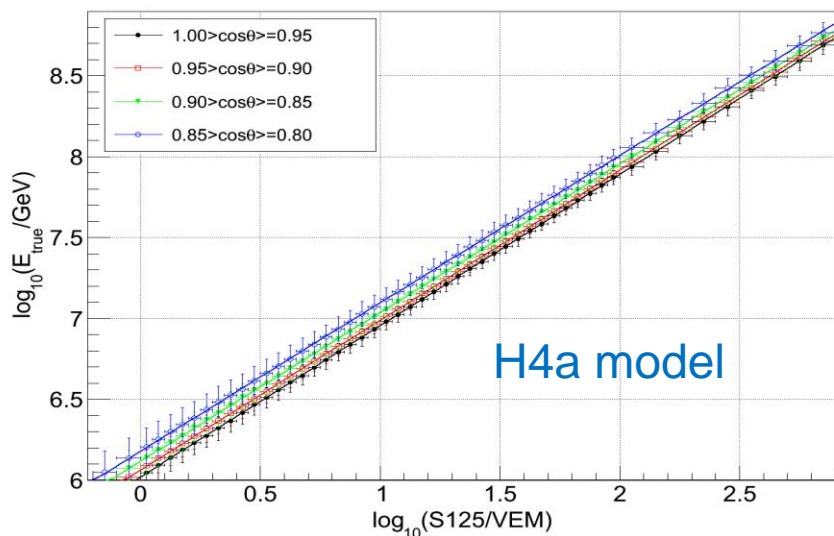
Simulation:

- CORSIKA v6990
- Sibyll 2.1 – FLUKA
- Primaries: H, He, O, Fe
- South Pole July atmosphere.
- E^{-1} spectrum: 100 TeV - 3 EeV.
- Zenith: 0-40°.
- 42000 showers per primary.
- Detailed detector response.

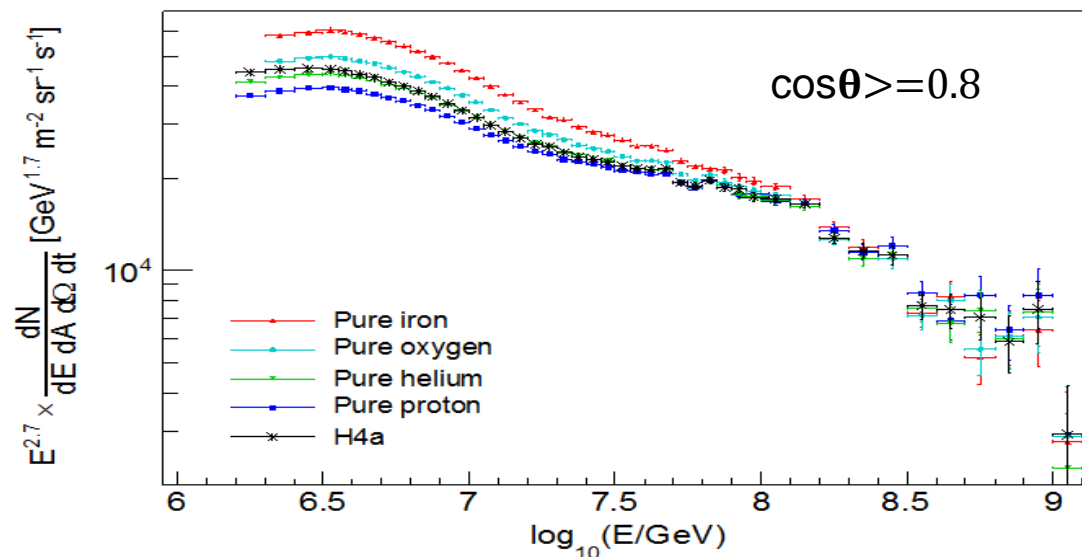
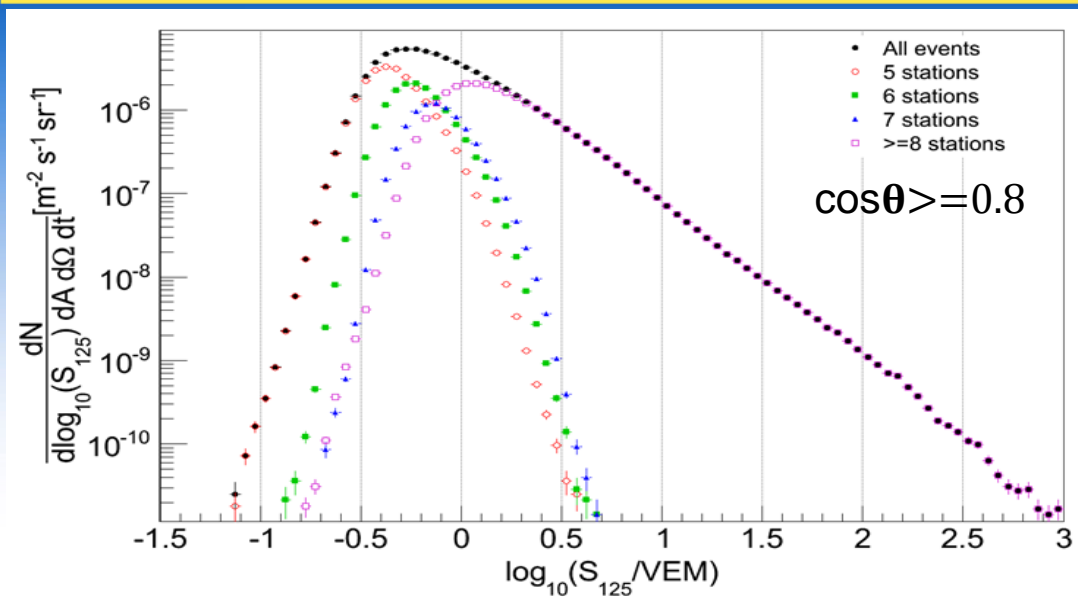
Relationship between S125 and Primary Energy is mass and zenith dependent.

Final result assumes composition model from:
T.K. Gaisser, Astropart.Phys. 35 (2012) 801-806
 (referred to as H4a)

$$\log_{10}(E) = p_1 \log_{10}(S125) + p_0$$



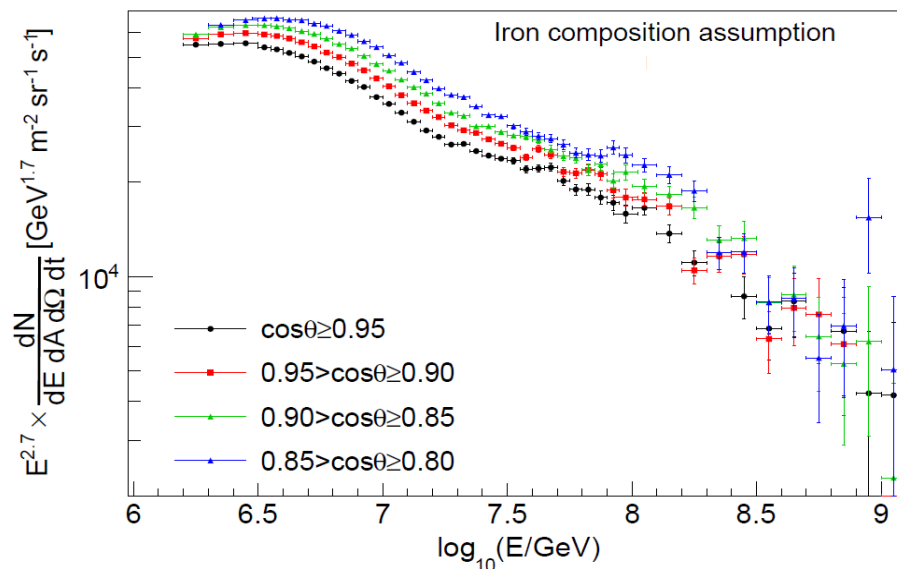
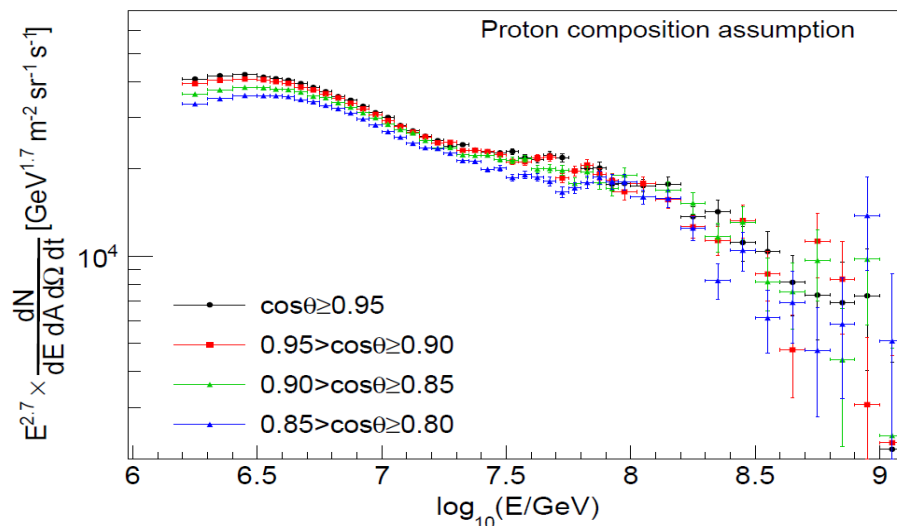
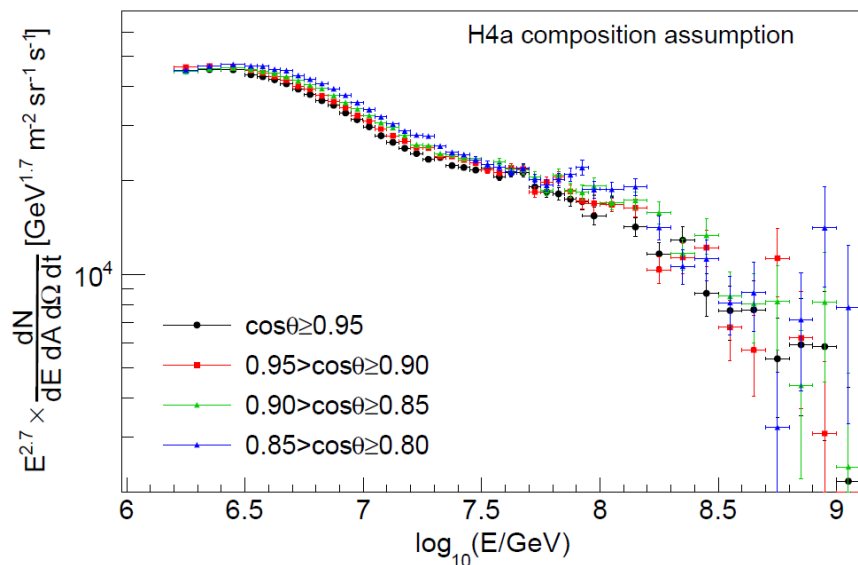
Composition with IceTop only

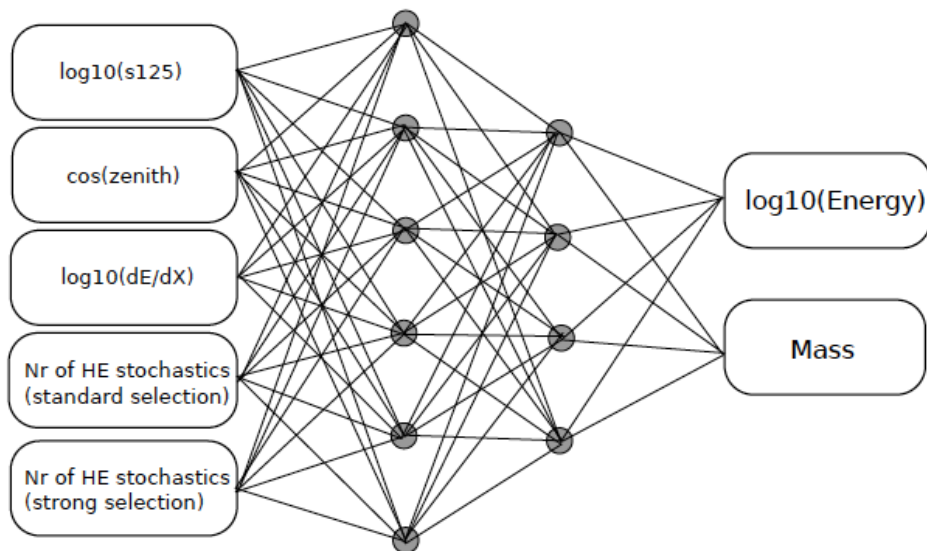
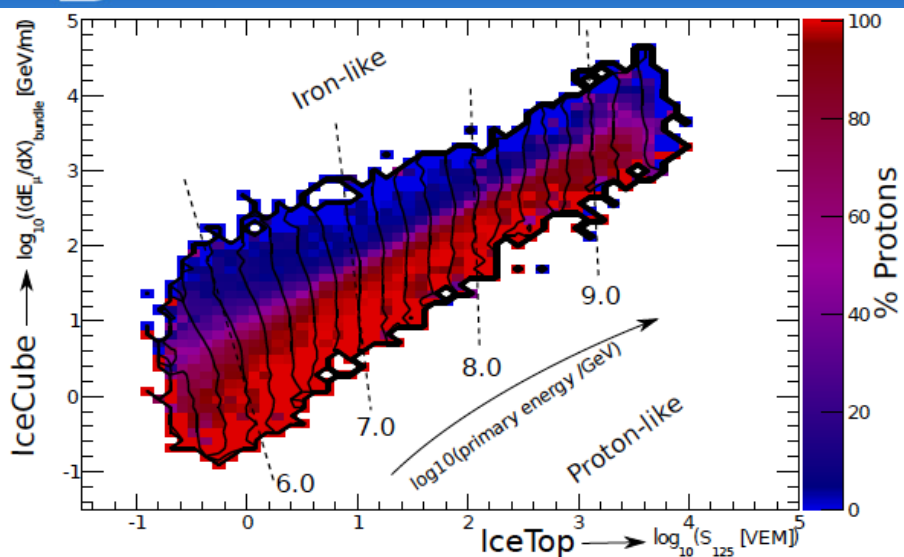


- Assuming Cosmic ray flux is isotropic
- Same composition in all directions

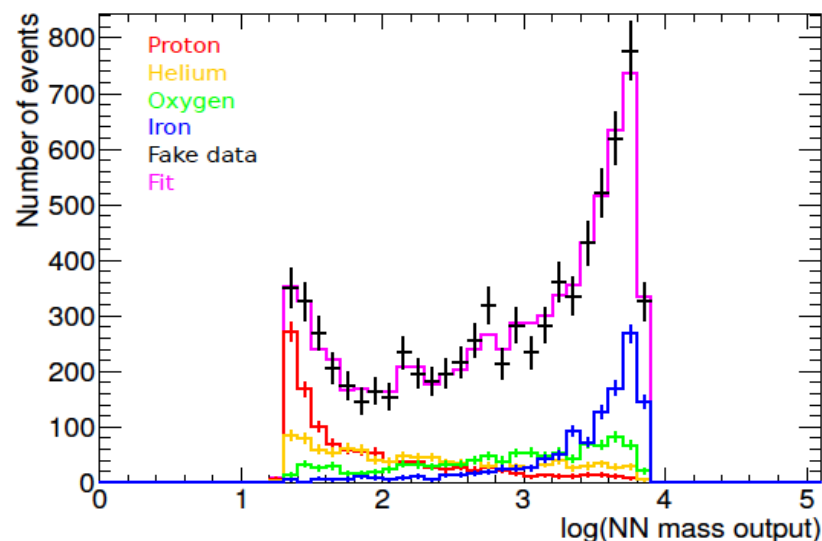


Correct composition should give same spectrum in 4 zenith bins.



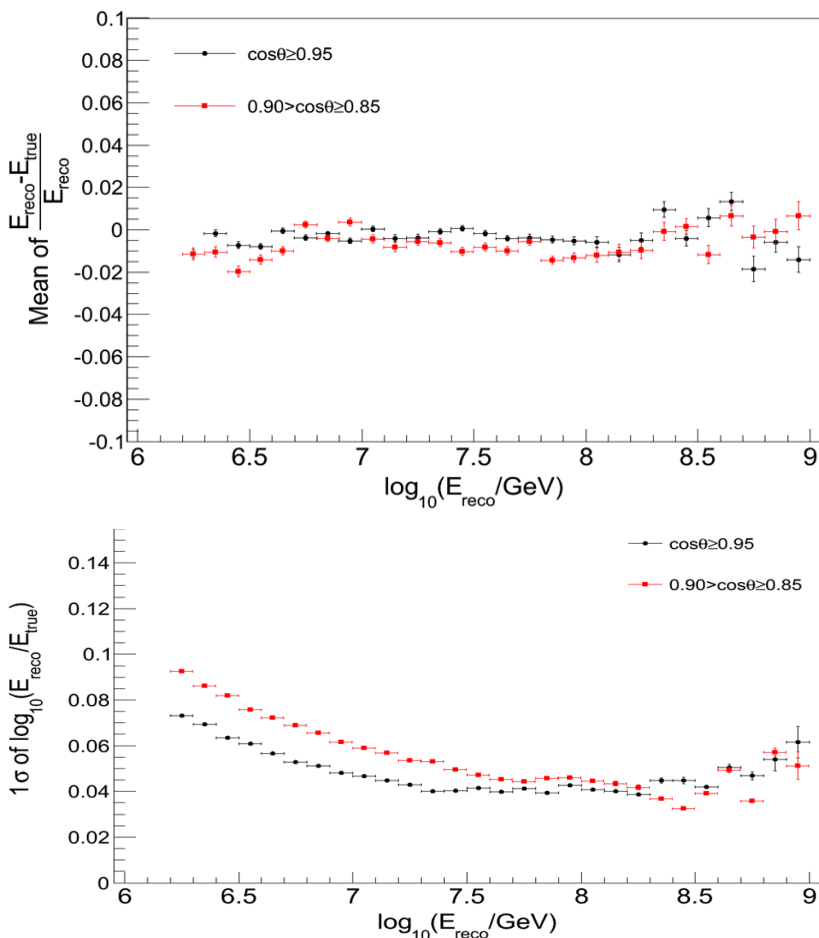


- 5-6-4-2 Neural Network to map 5 observables to Primary Energy and Mass
- Energy spectrum directly from NN output
- Composition from fitting data in E_{reco} bins to template histograms (H,He,O,Fe) from NN mass output

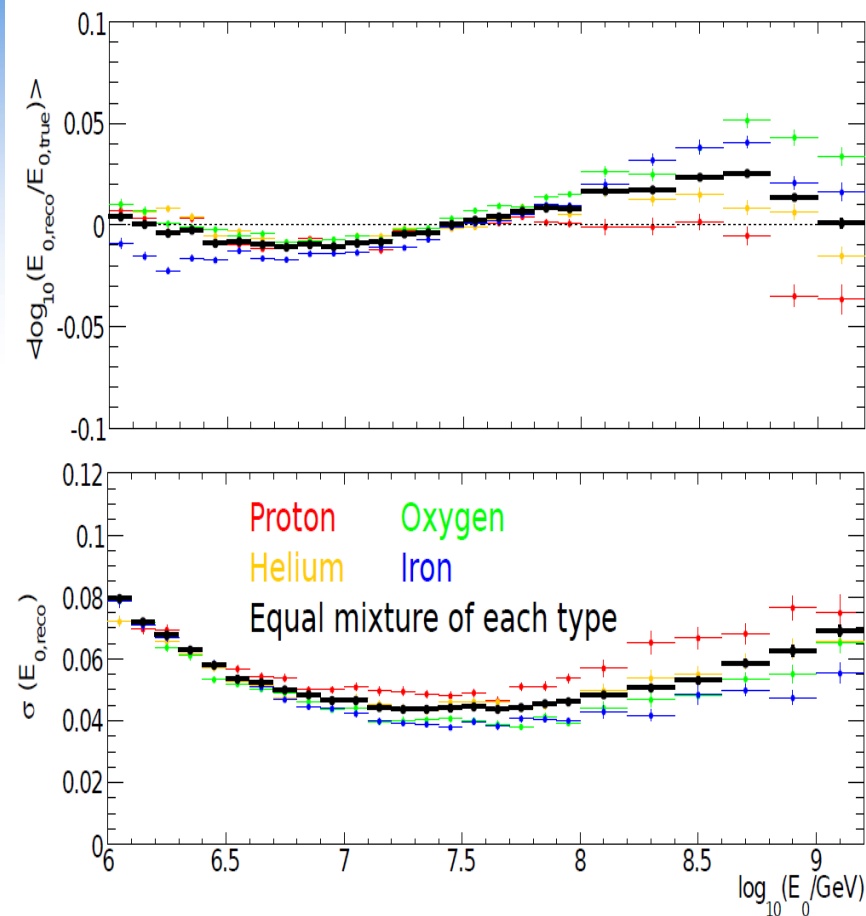


e.g. Template histograms for 4 mass groups in one energy bin for a fake dataset scrambled from MC

Surface Only: IT73

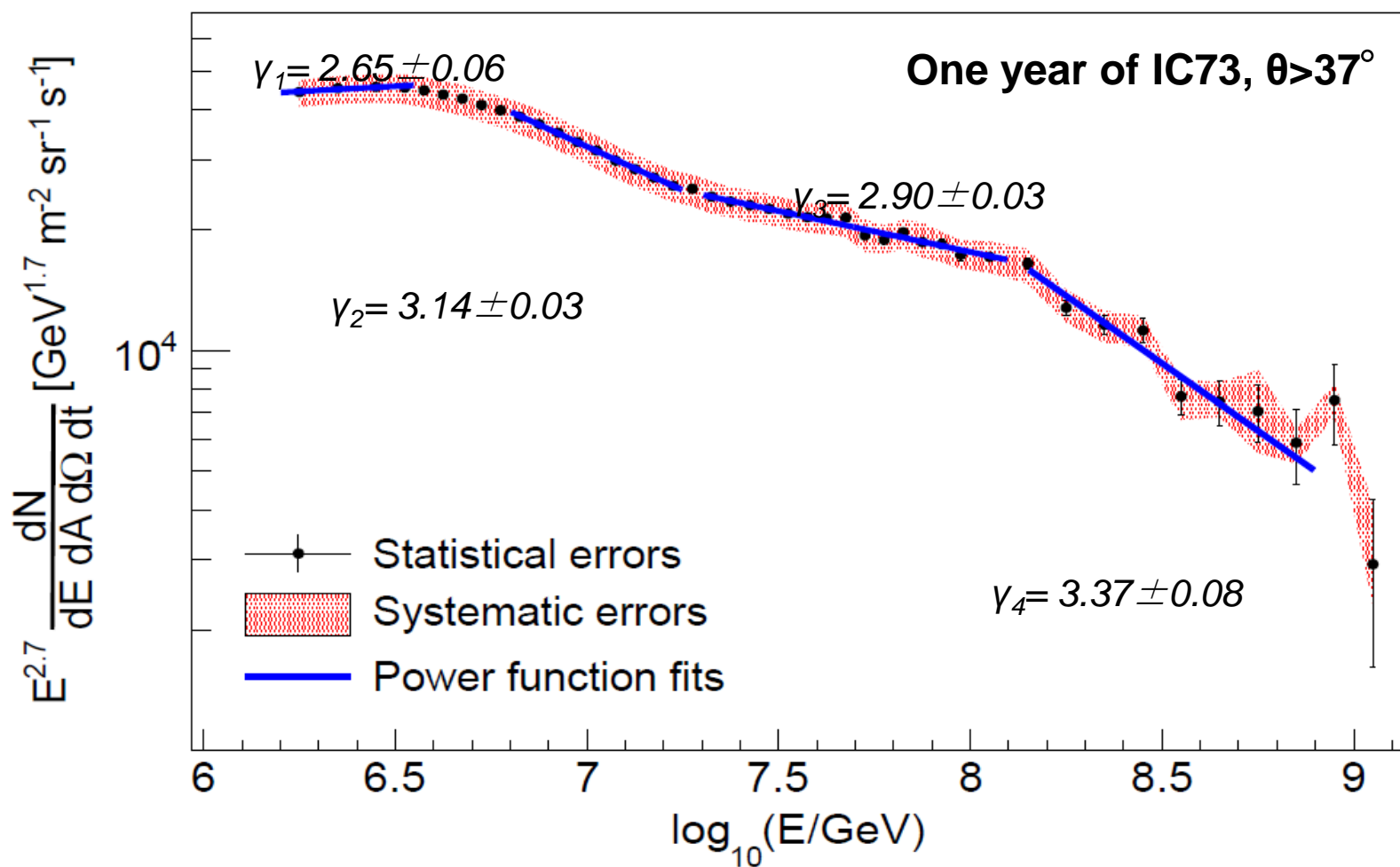


Surface and In Ice: IC79/IT73



Use variable bin sizes: $\Delta \log_{10}(E) = 0.05$ for $6.5 < \log_{10}(E/\text{GeV}) < 8$

$\Delta \log_{10}(E) = 0.1$ for $6.2 < \log_{10}(E/\text{GeV}) < 6.5$ and $8 < \log_{10}(E/\text{GeV}) < 9$



Phys. Rev. D 88, 042004 (2013),

URL: <http://link.aps.org/doi/10.1103/PhysRevD.88.042004>

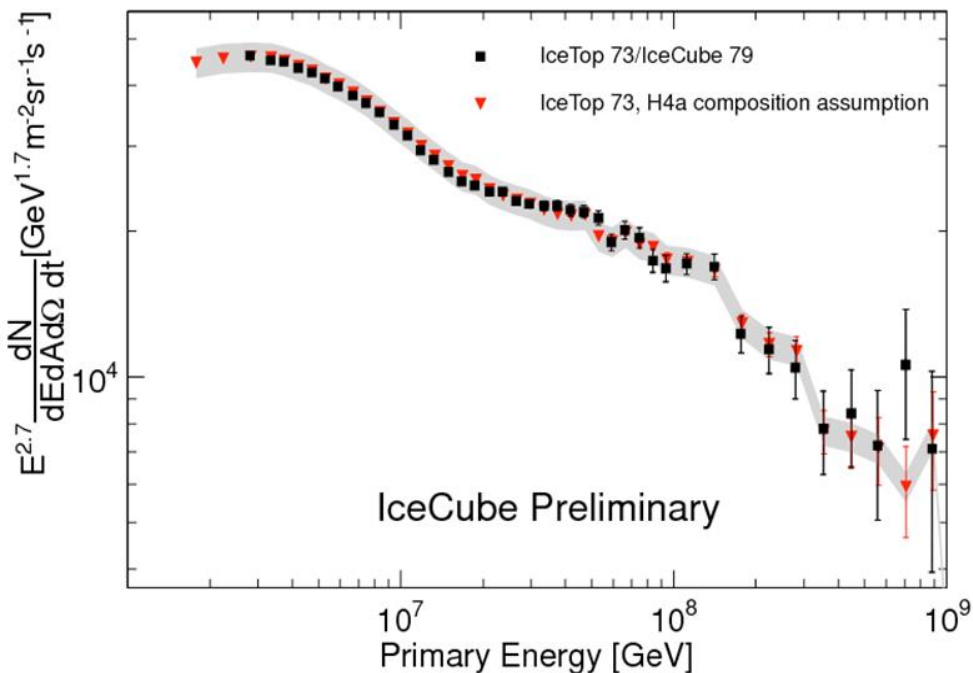
	3 PeV	30 PeV
Energy scale (VEM calibration)	$\pm 4\%$	$\pm 5\%$
Snow Correction	$\pm 5\%$	$\pm 6\%$
Interaction models [†]	-2%	-4%
Composition [*]	$\pm 7\%$	$\pm 7\%$
Ground pressure [§]	$\pm 2\%$	$\pm 0.5\%$

[†] From the difference between QGSJet-II-03 and SYBILL 2.1.

^{*} Fixed for all energies, description follows.

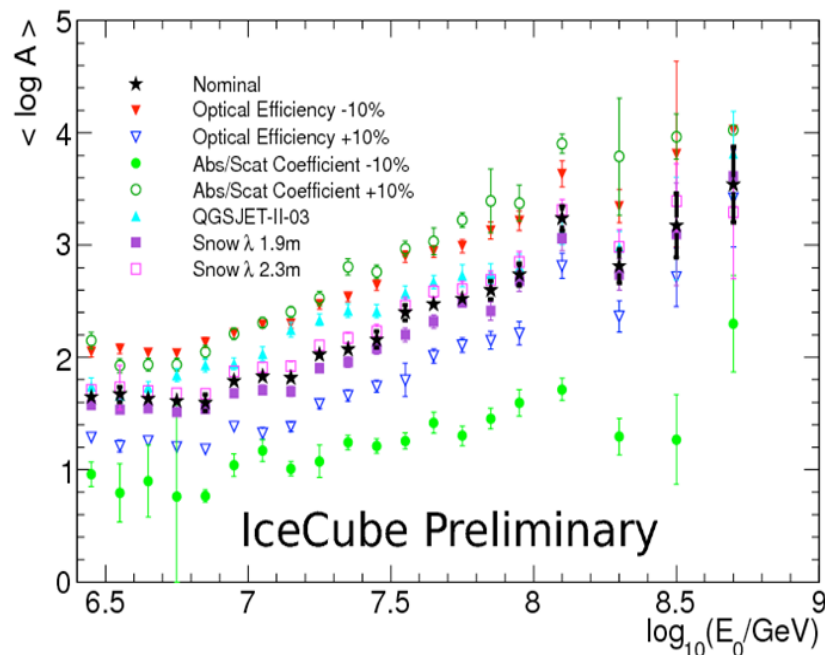
[§] From difference between high/low pressure sub-samples (690 hPa/670 hPa).

Systematics are under study and will finalize soon

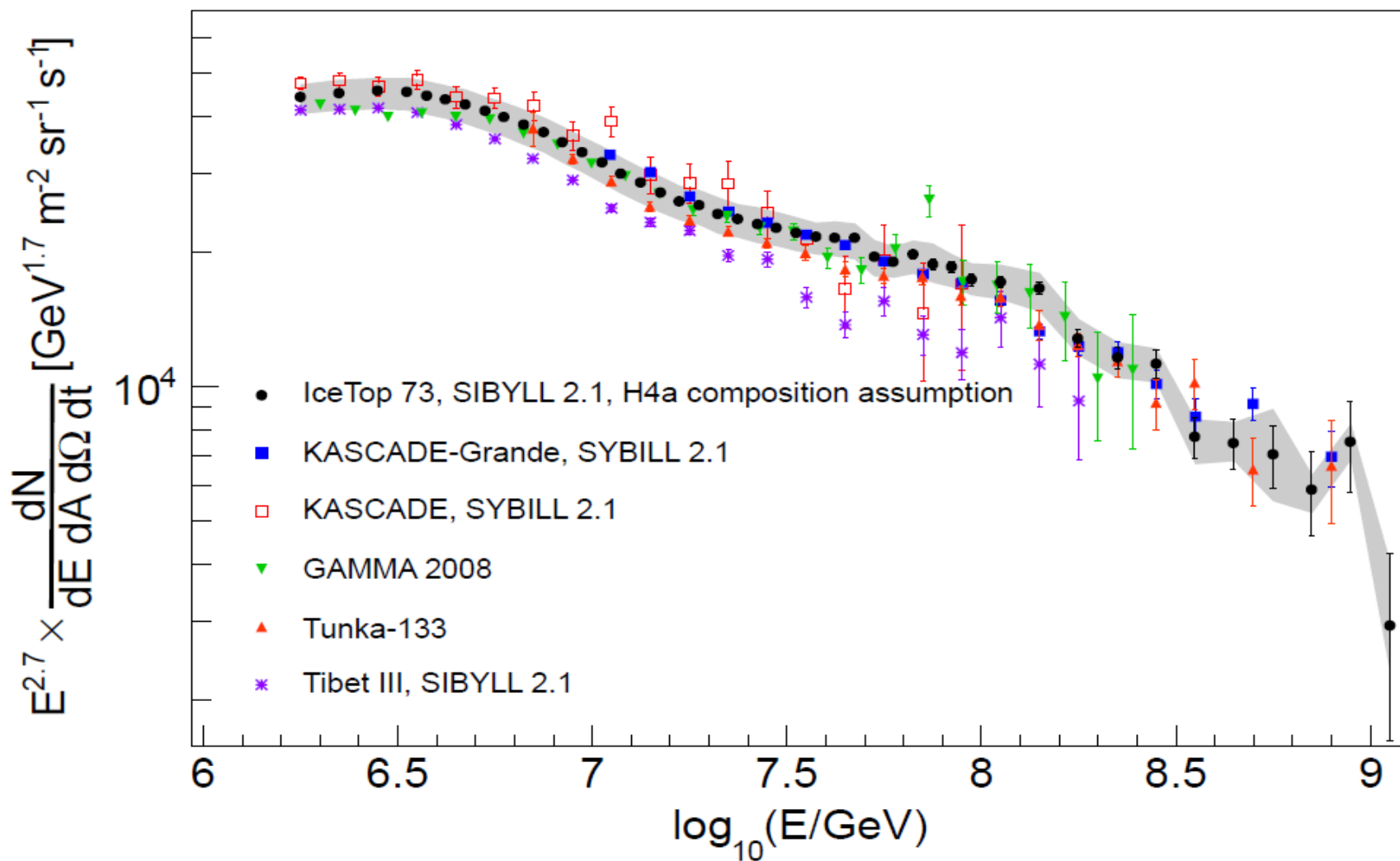


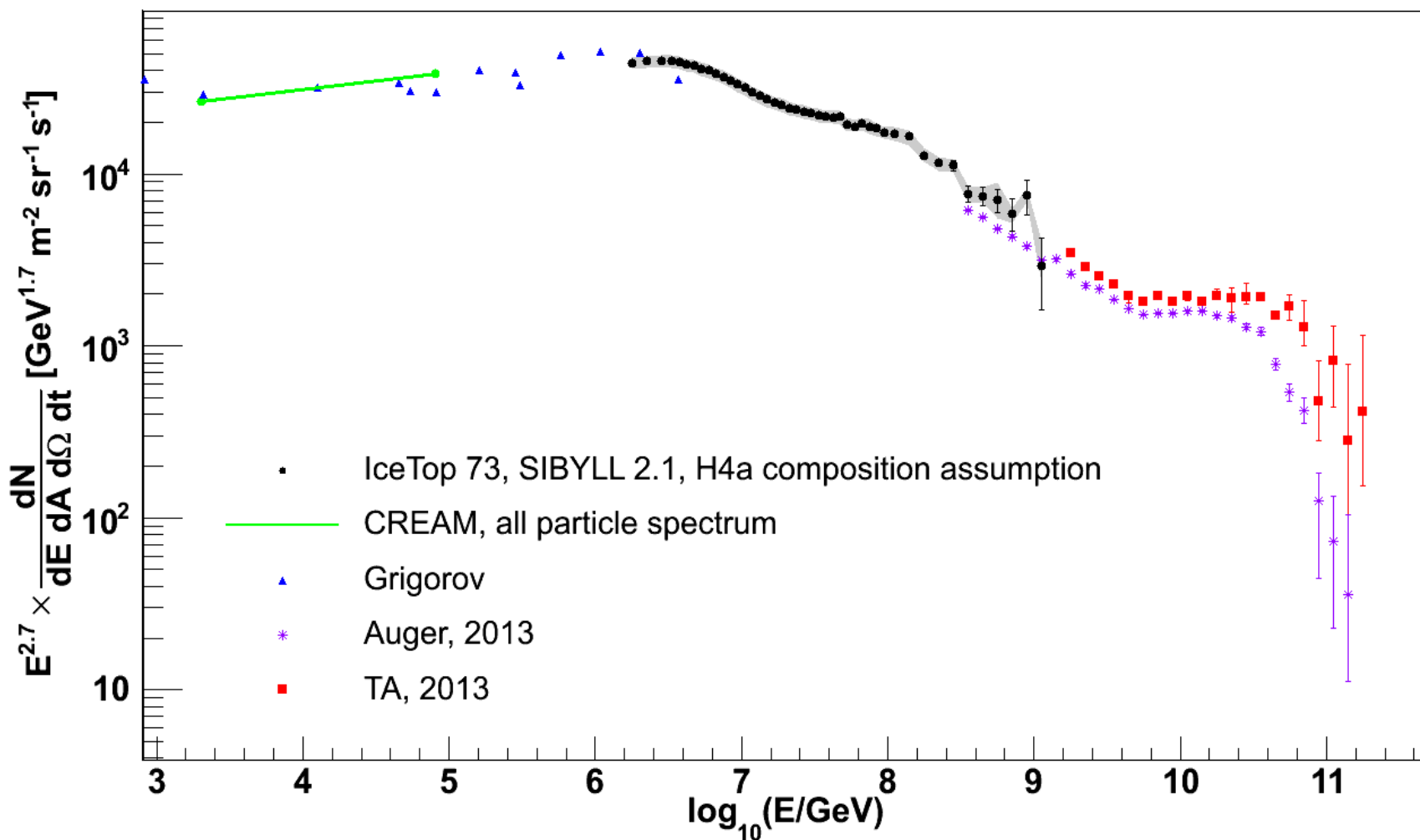
gray band is ± 7 composition systematics of IceTop-73 analysis

Excellent agreement between
two independent analyses



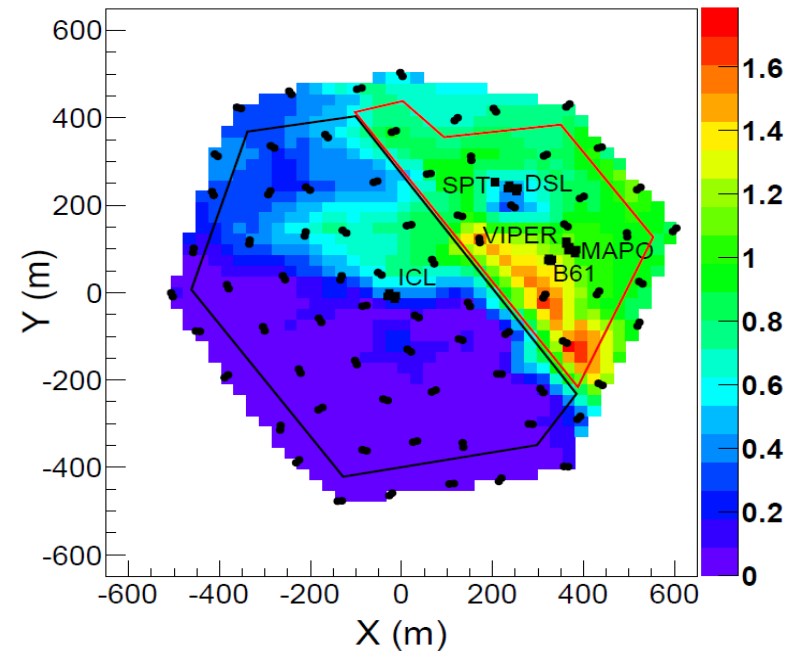
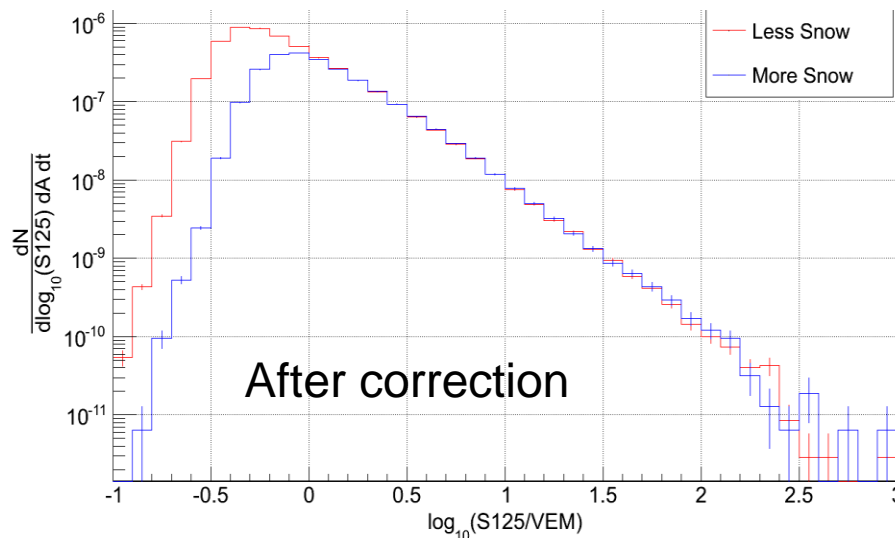
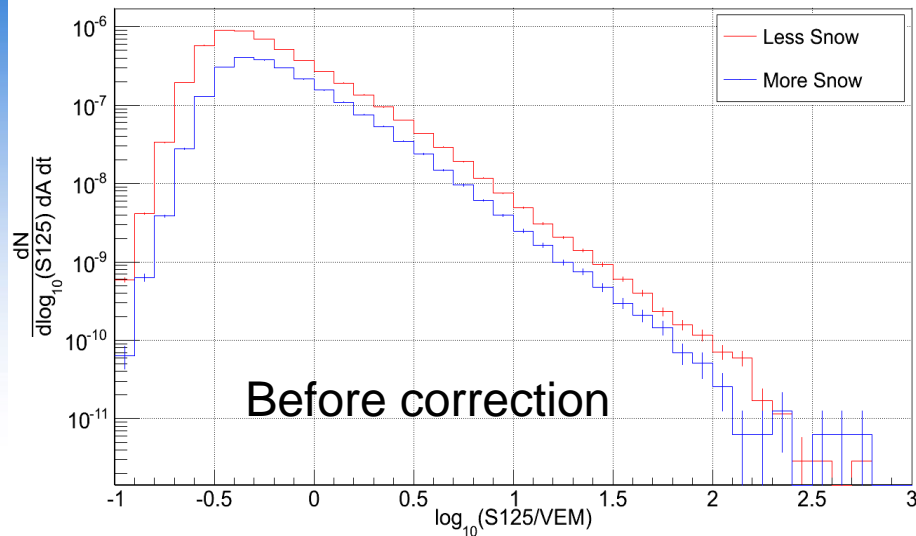
Clear trend towards heavier
composition with in measured
energy range





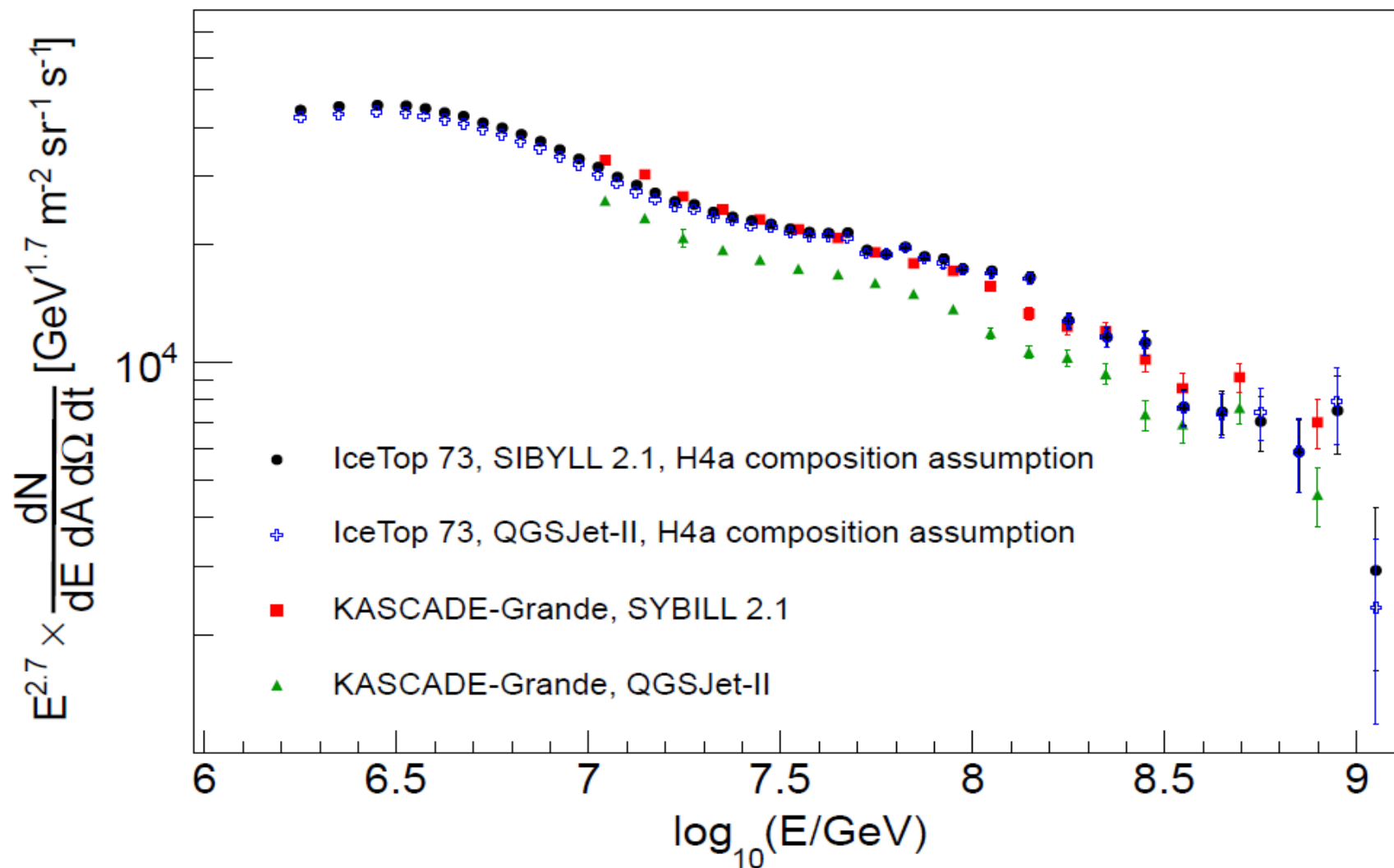
- High resolution measurement of cosmic ray all particle spectrum in 1.58 PeV – 1.26 EeV region with one year of data from 2010-2011.
- The spectrum does not follow a simple power law above the knee up to 1 EeV.
- We observe a spectral hardening at 18 ± 2 PeV (124800 events expected, 139880 observed).
- The spectrum steepens at 130 ± 30 PeV (4213 events expected, 3673 observed).
- Good agreement between recent measurements of other experiments.
- Overlap with UHE measurements around EeV.
- Spectrum shows large structures hinting to a different mechanism above the knee.
- Composition gets heavier up to at least 100 PeV

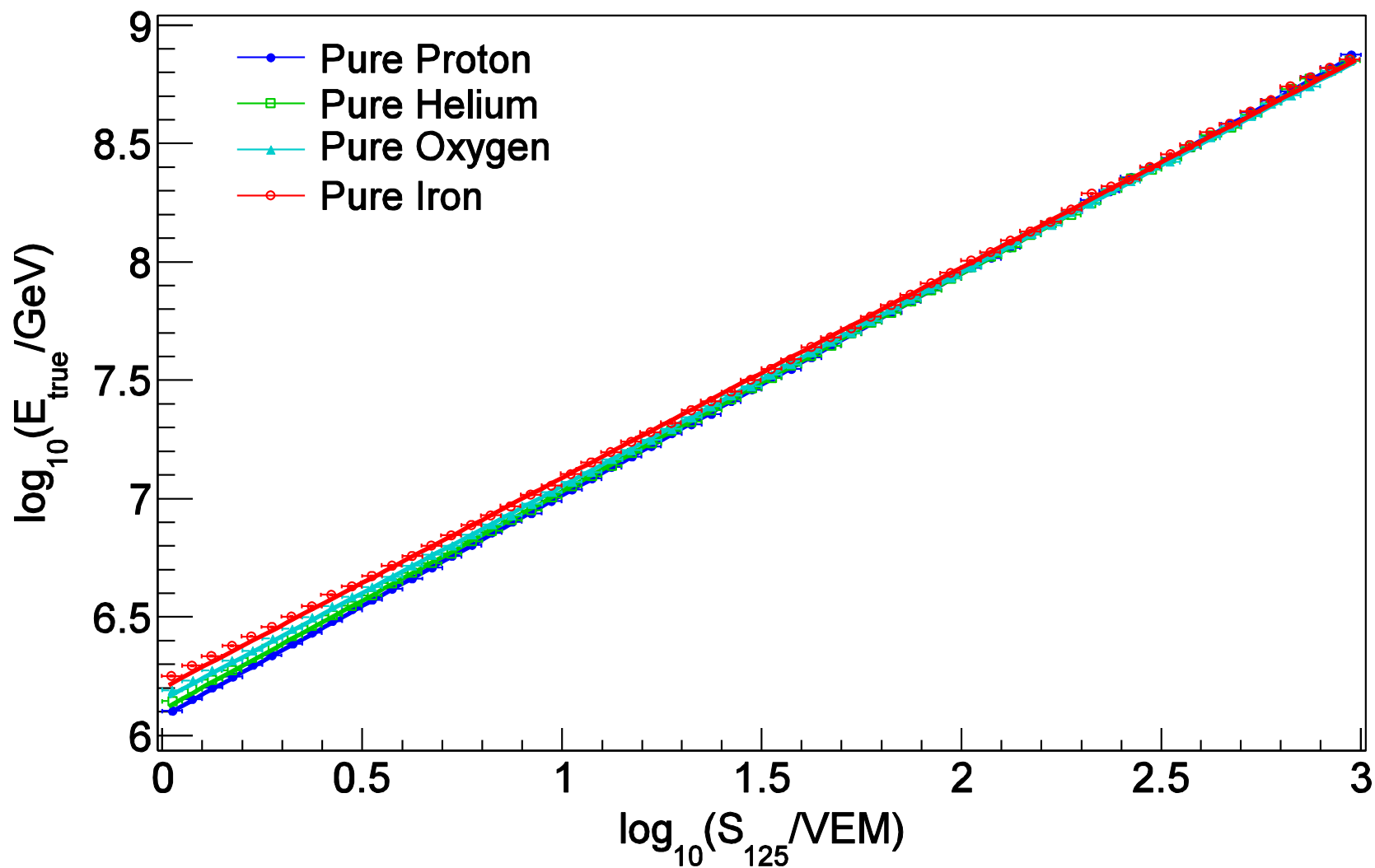
Back up slides

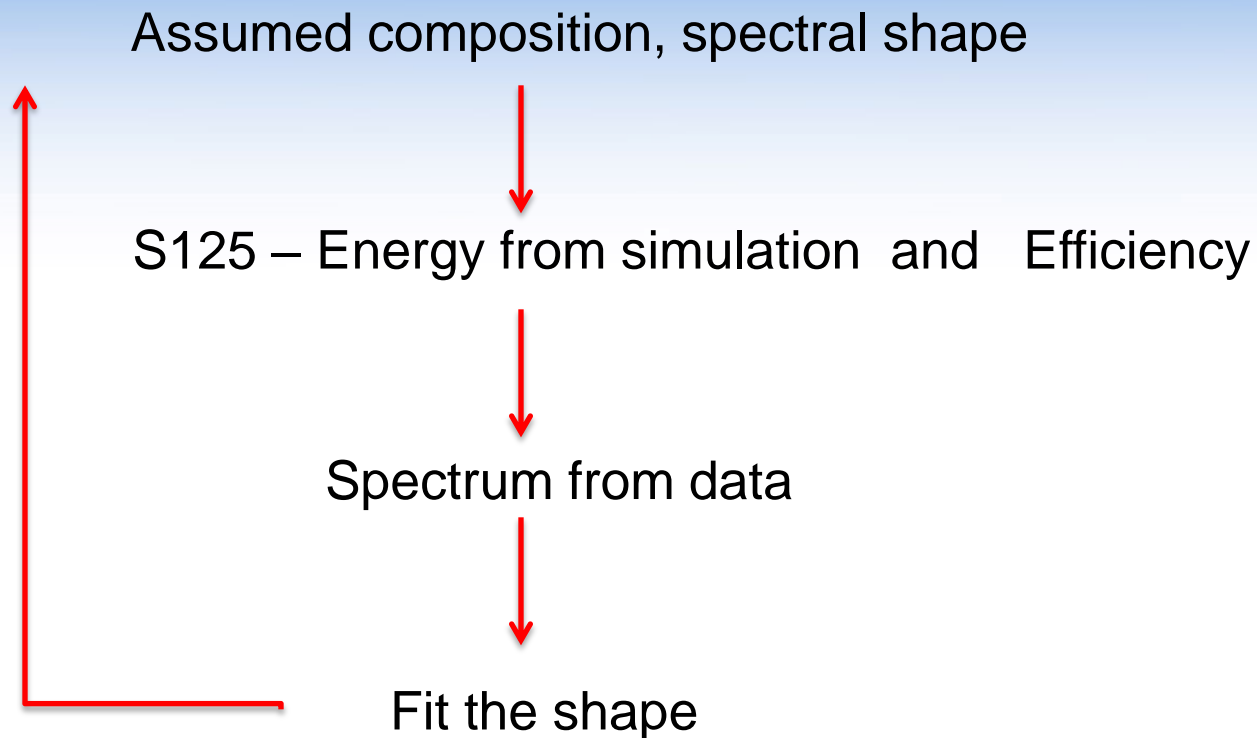


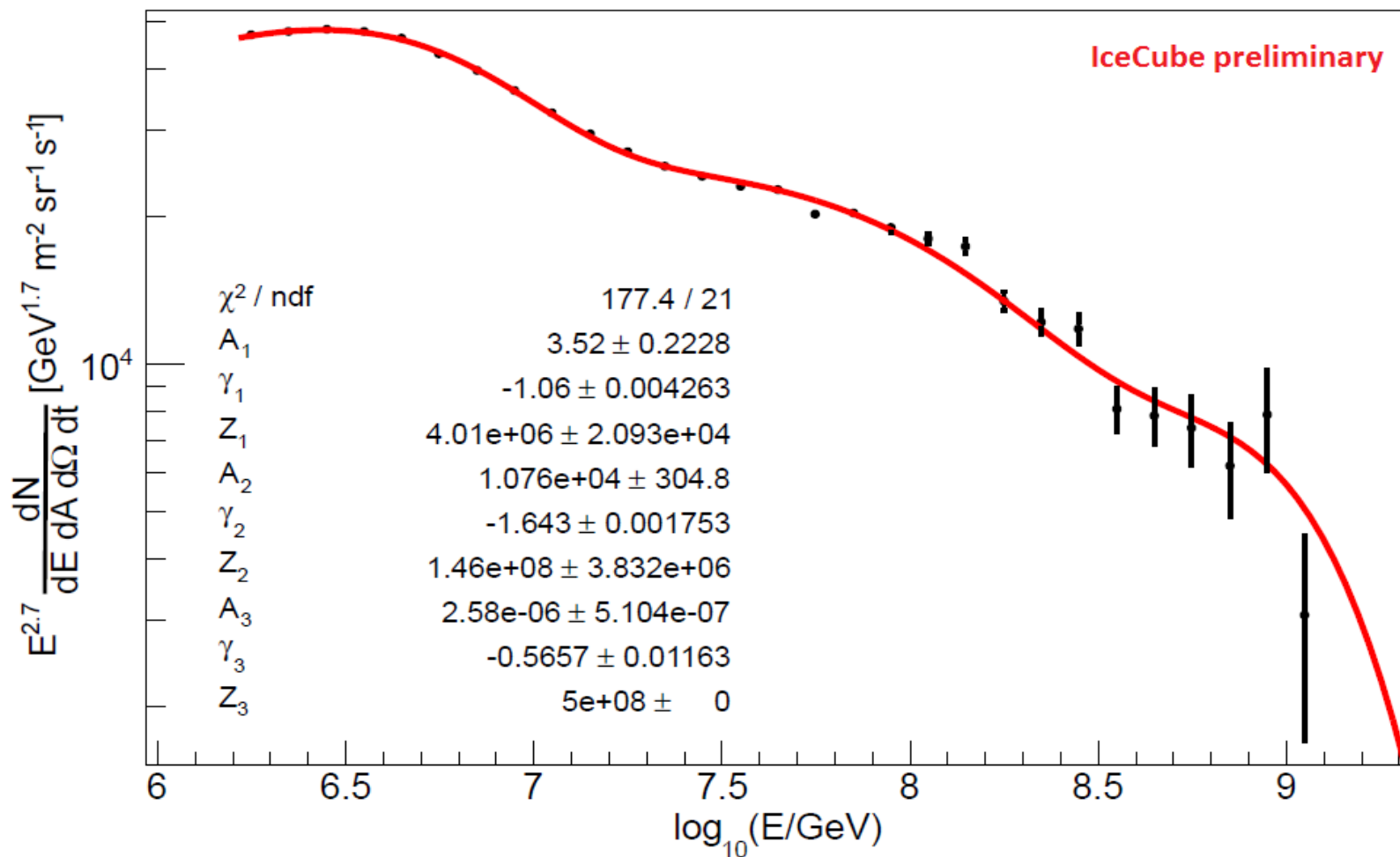
To correct for snow, expected signal for each tank is reduced according to the formula below.

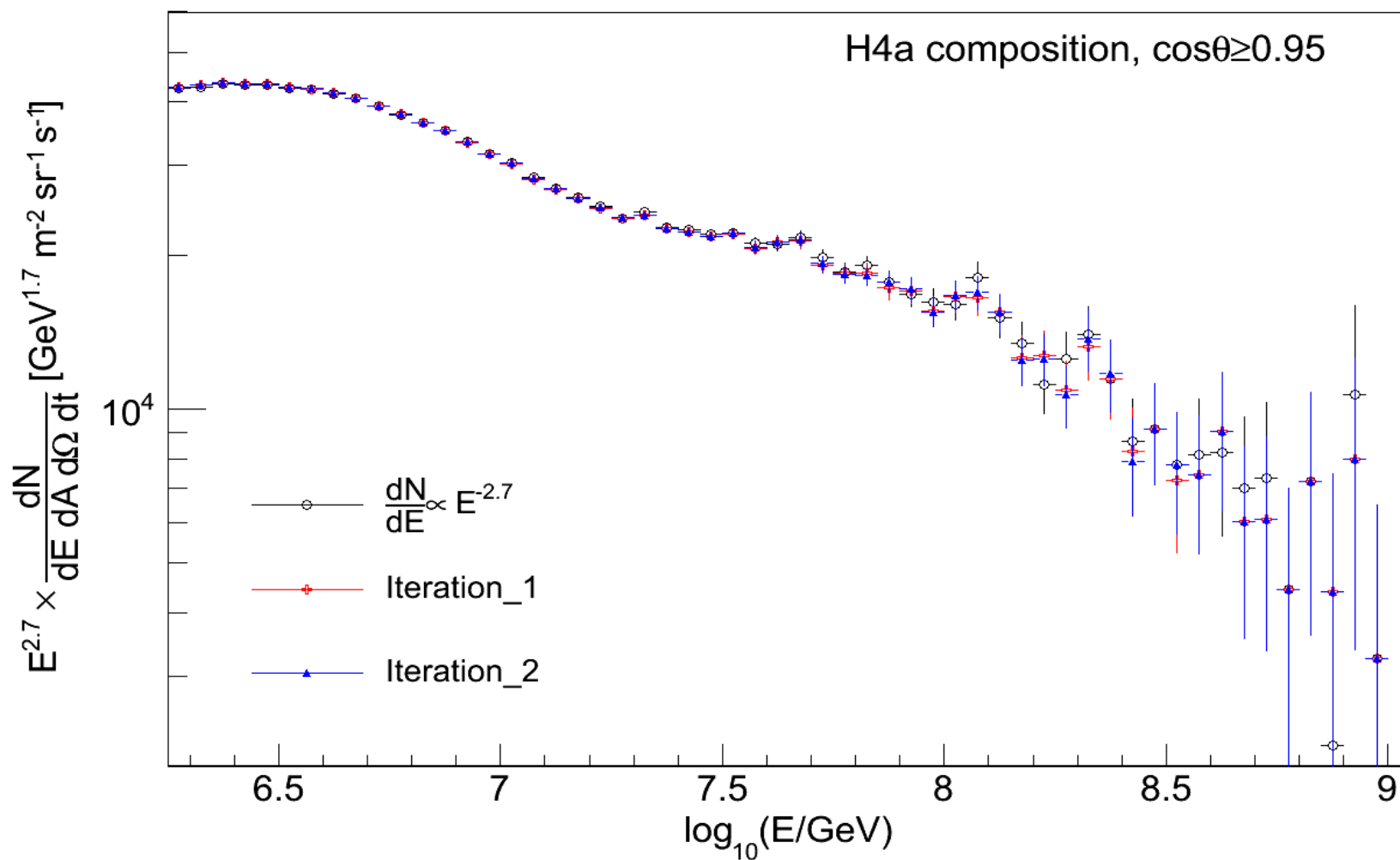
$$S_{corrected} = S_{expected} * \exp\left(-\frac{d \sec\theta}{\lambda}\right)$$

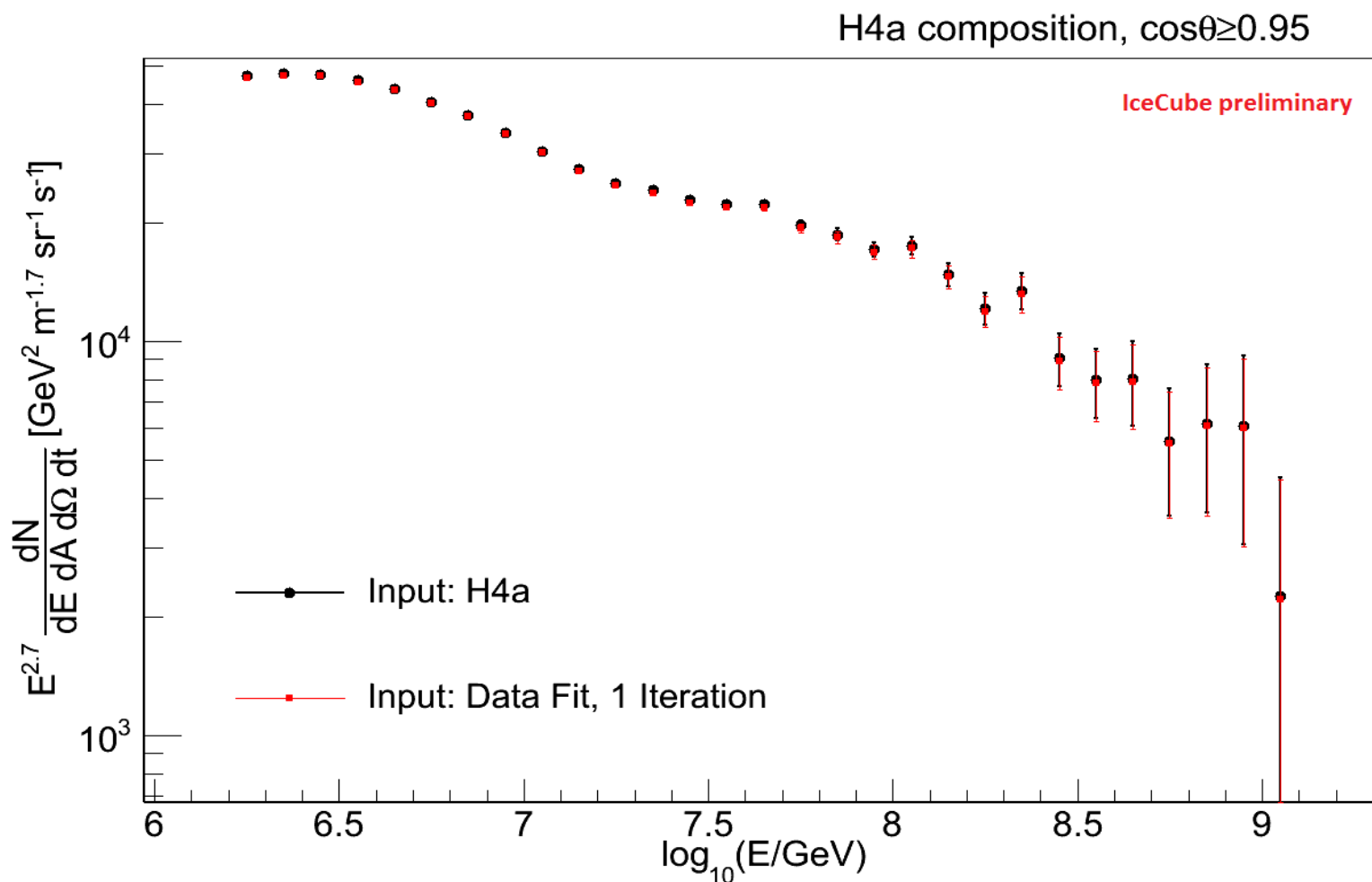






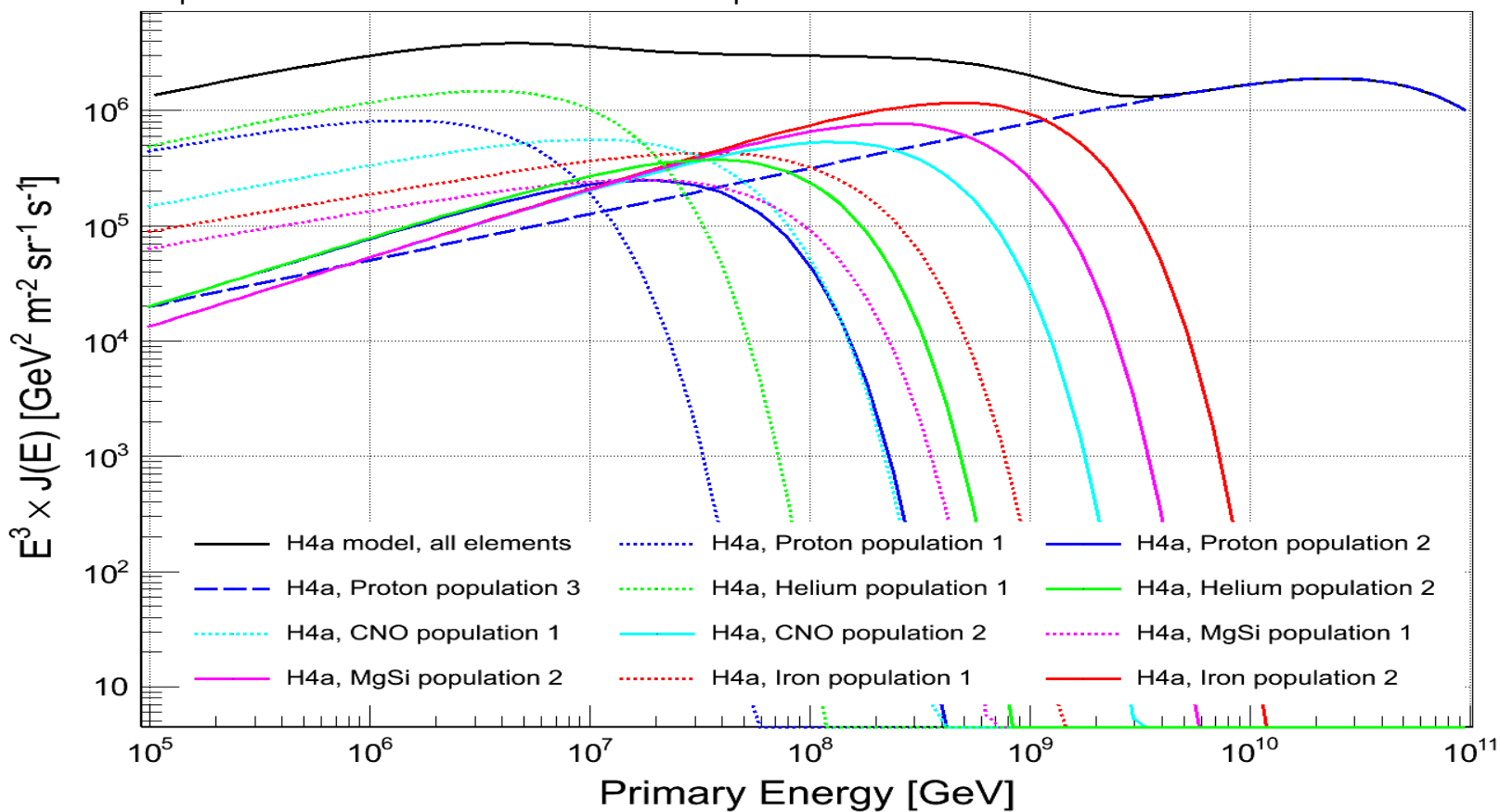






result the result converge after one iteration

<http://www.sciencedirect.com/science/article/pii/S0927650512000497>



$$\frac{dN_i}{d\ln E} = \sum_{j=1}^3 a_{i,j} E^{-\gamma_{i,j}} \times \exp \left[-\frac{E}{Z_i R_{c,j}} \right]$$

