Latest Cosmic Ray Composition Results from IceTop and IceCube

PoS(ICRC2019)172

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on behalf of the IceCube Collaboration

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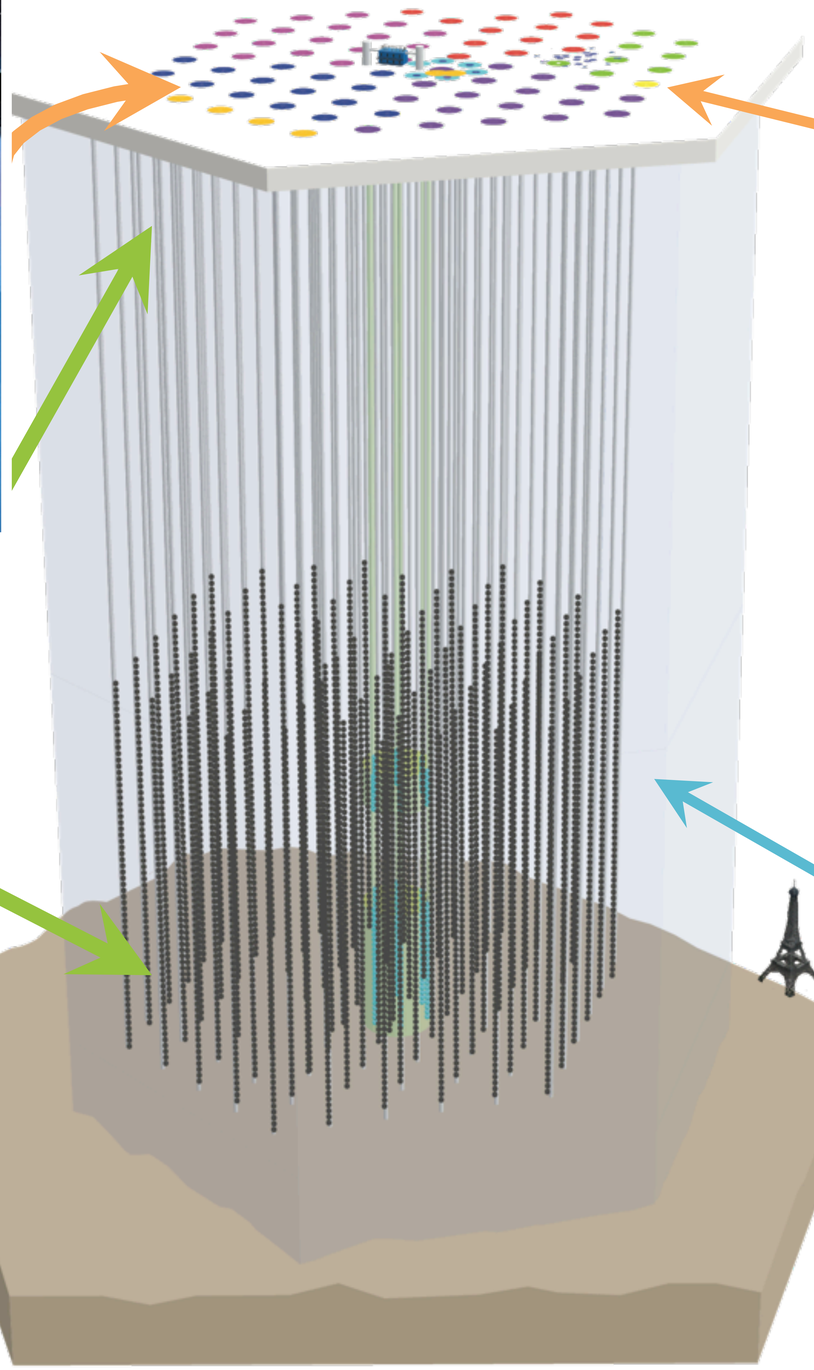
* speaker

Outline:

- Introduction to IceTop/IceCube
- Energy spectrum
- Composition
- Future
- Summary

IceCube Neutrino Observatory



Deployed over 6 seasons: Completed in 2011

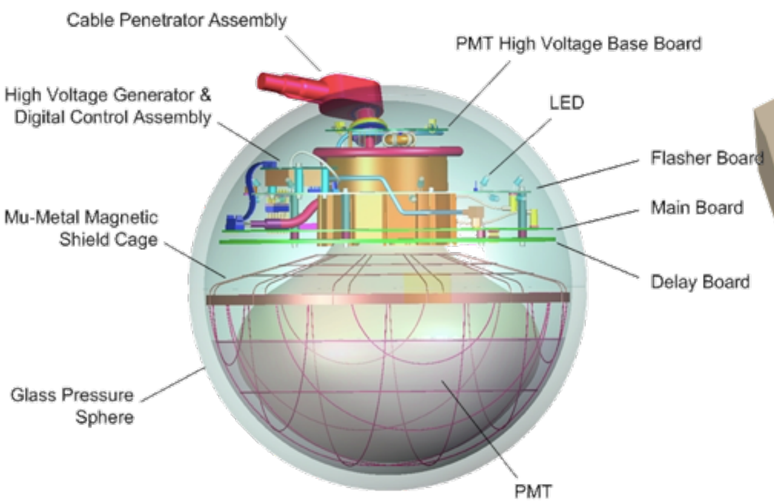
IceTop (Surface Air Shower Array):

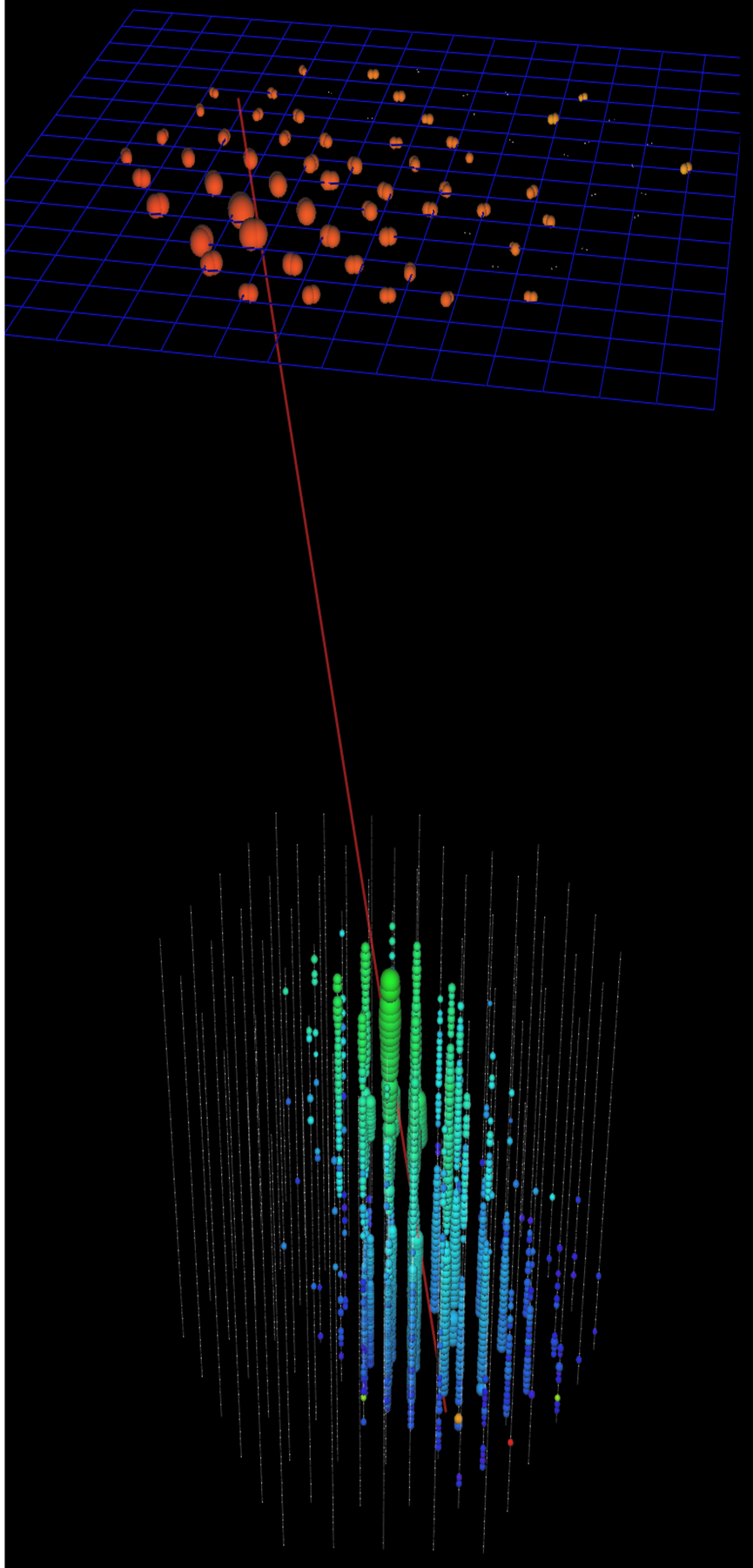
- ~1 km^2 instrumented area
- 81 stations with 2 tanks each
- 125m spacing between stations
- 2 DOMs per tank→ 324 total DOMs
- Measure electromagnetic and low energy muon components of air shower

IceCube (In-Ice Array):

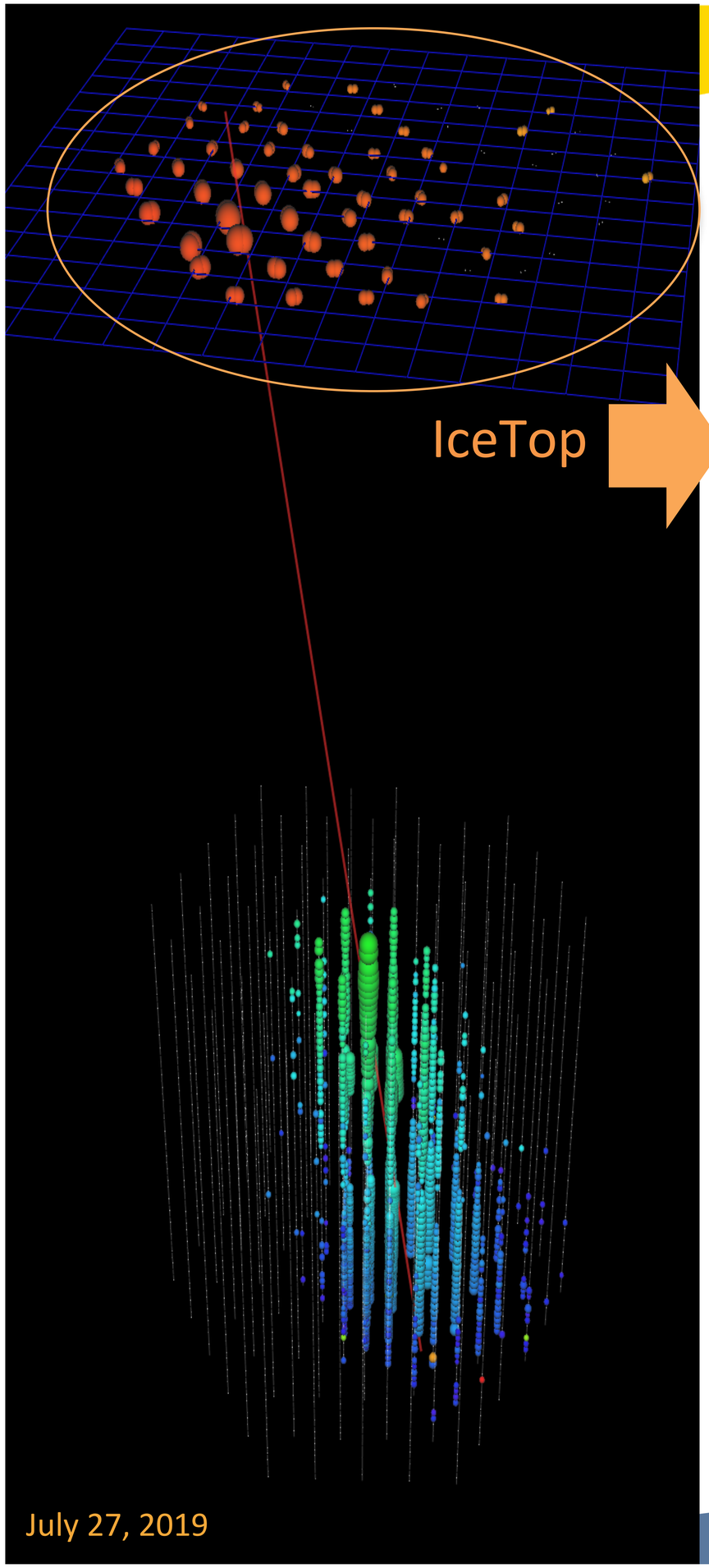
- ~1 km^3 instrumented volume
- 86 strings with 60 DOMs each with 17m spacing→5160 total DOMs,
- Depth: 1.45-2.45 km
- Measure high energy muon component of air shower

Same DOMs used for IceCube and IceTop

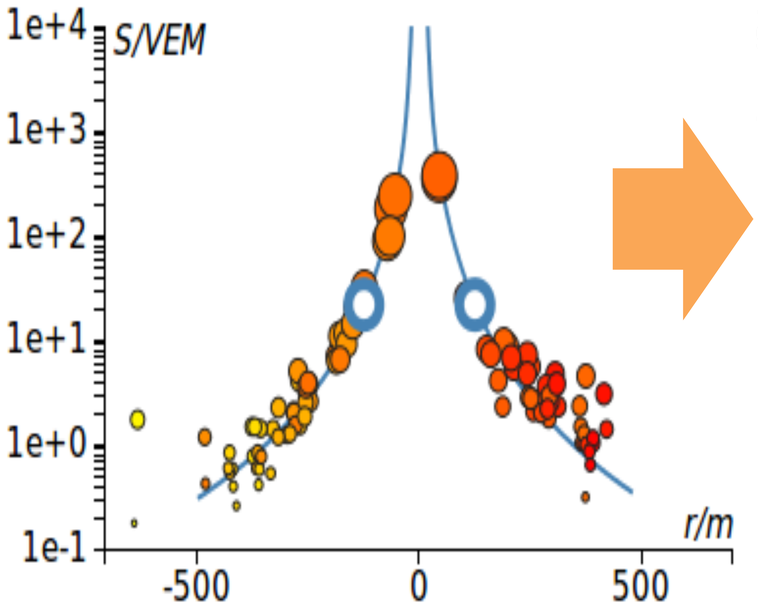




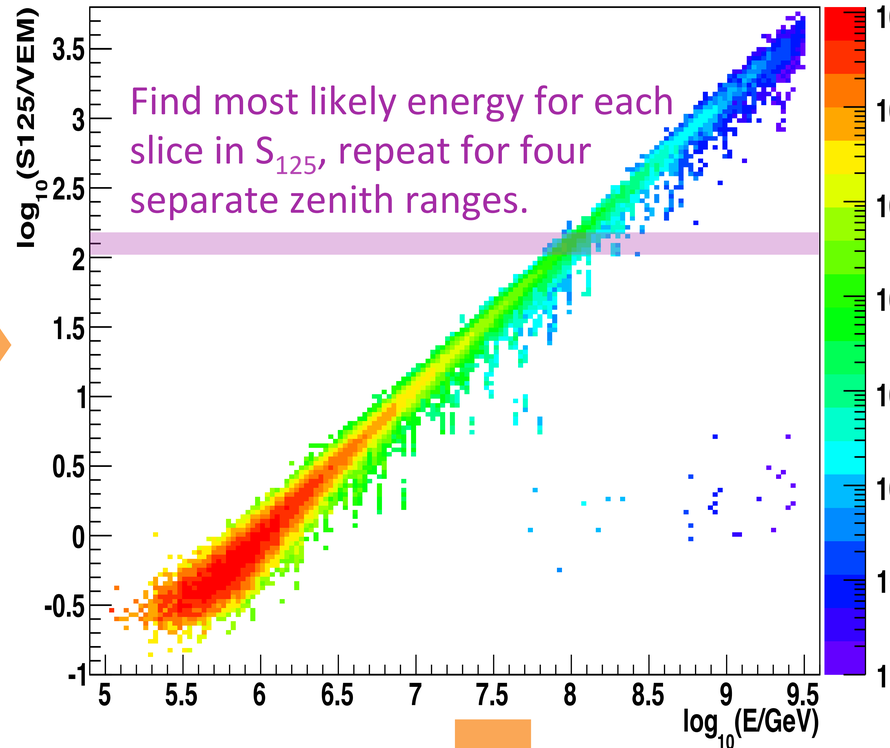
IceTop Energy Spectrum



Electromagnetic Part of Shower:
(S_{125}) = IceTop Energy Proxy
Nearly composition independent

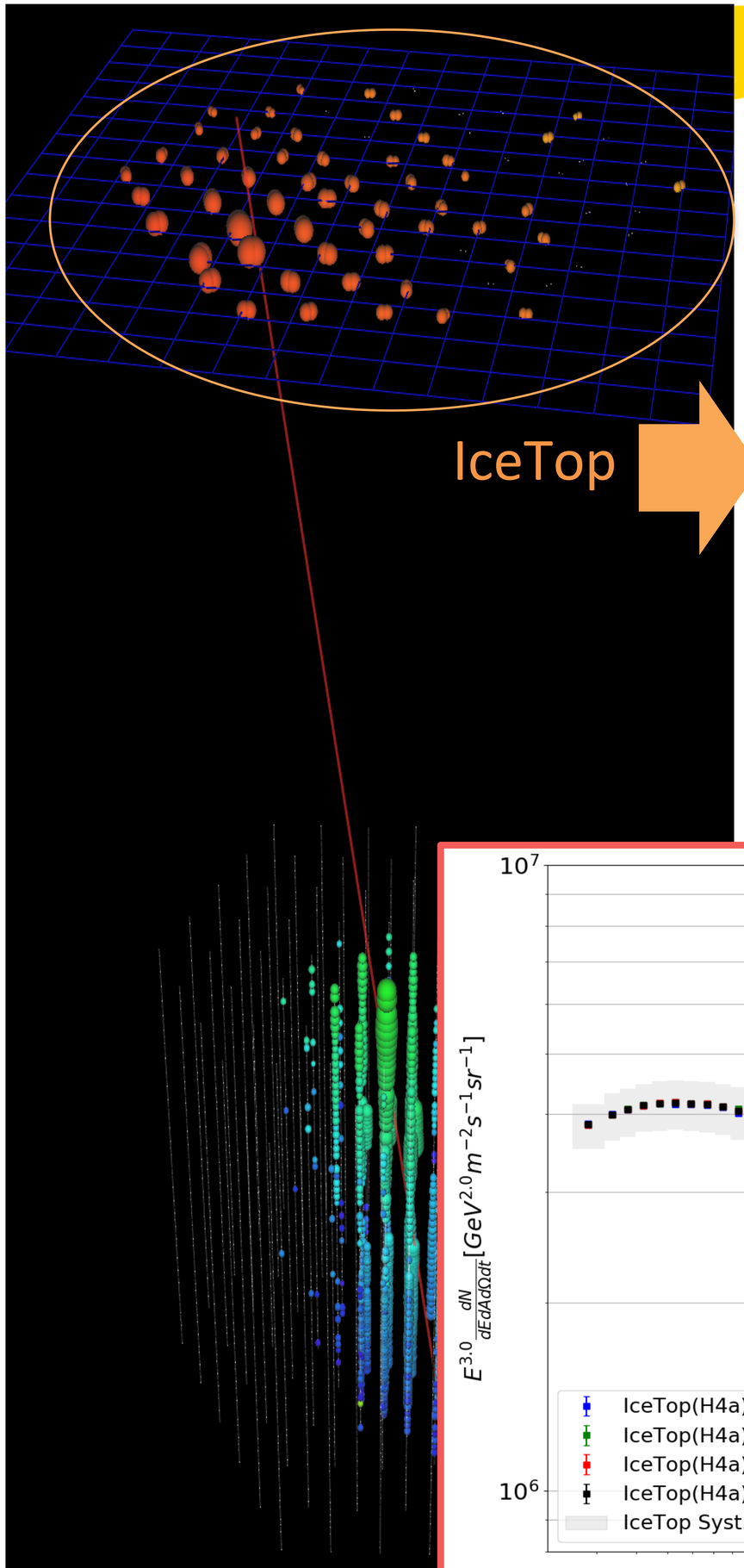


$$S = S_{125} \cdot \left(\frac{r}{125\,m}\right)^{-\beta-\kappa\log_{10}\left(\frac{r}{125\,m}\right)}$$



- IceTop Energy Spectrum unfolded using maximum likelihood method.
  (Composition assumed from H4a model: *Front. Phys.(Beijing) 8 (2013) 748-758*)
- 3 yrs of data (May '10 – Jun '13)
- Standard cuts *(PRD 88 (2013) 042004)*
- Data set divided into individual years shows consistency

IceTop Energy Spectrum



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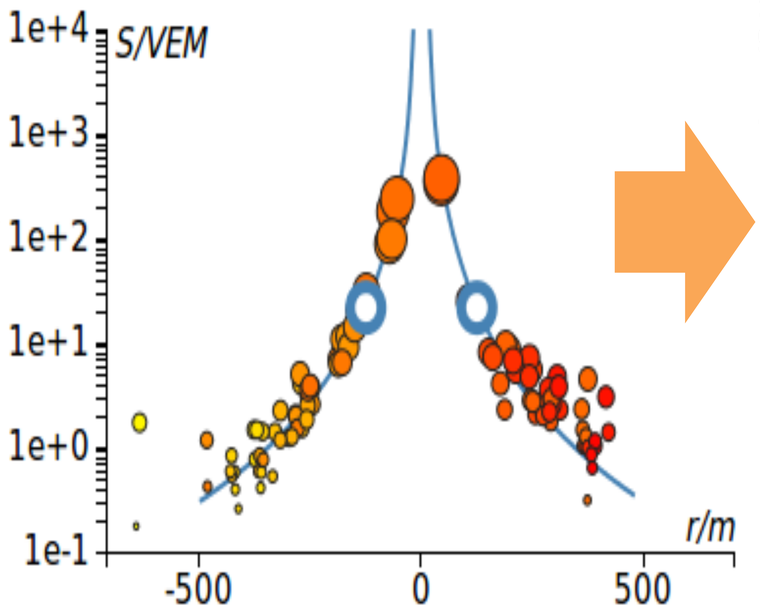

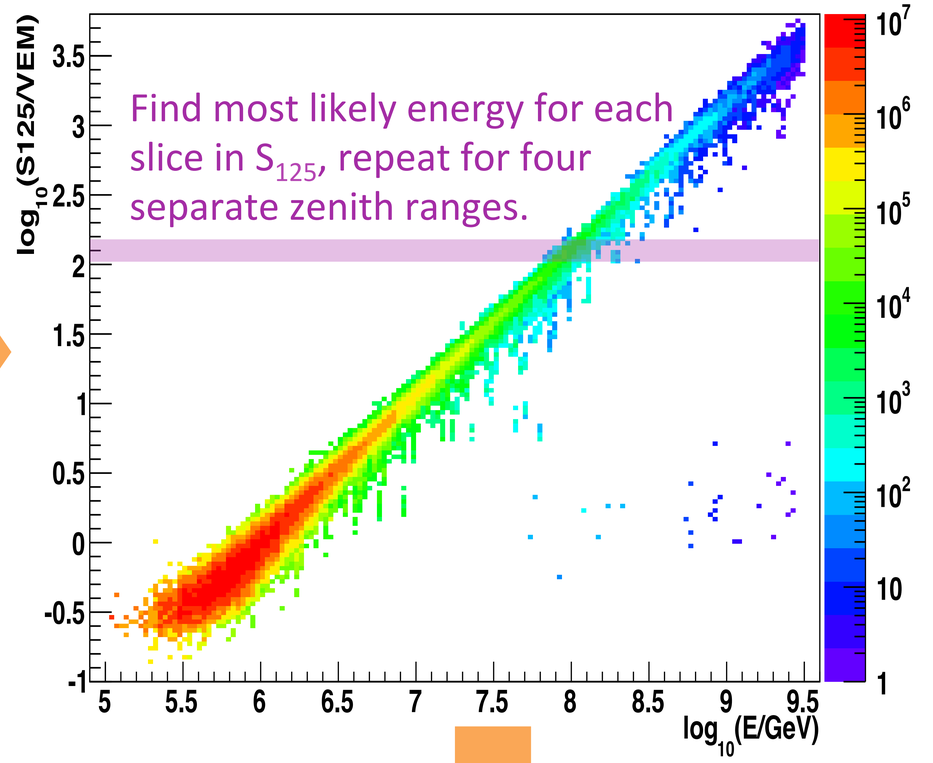

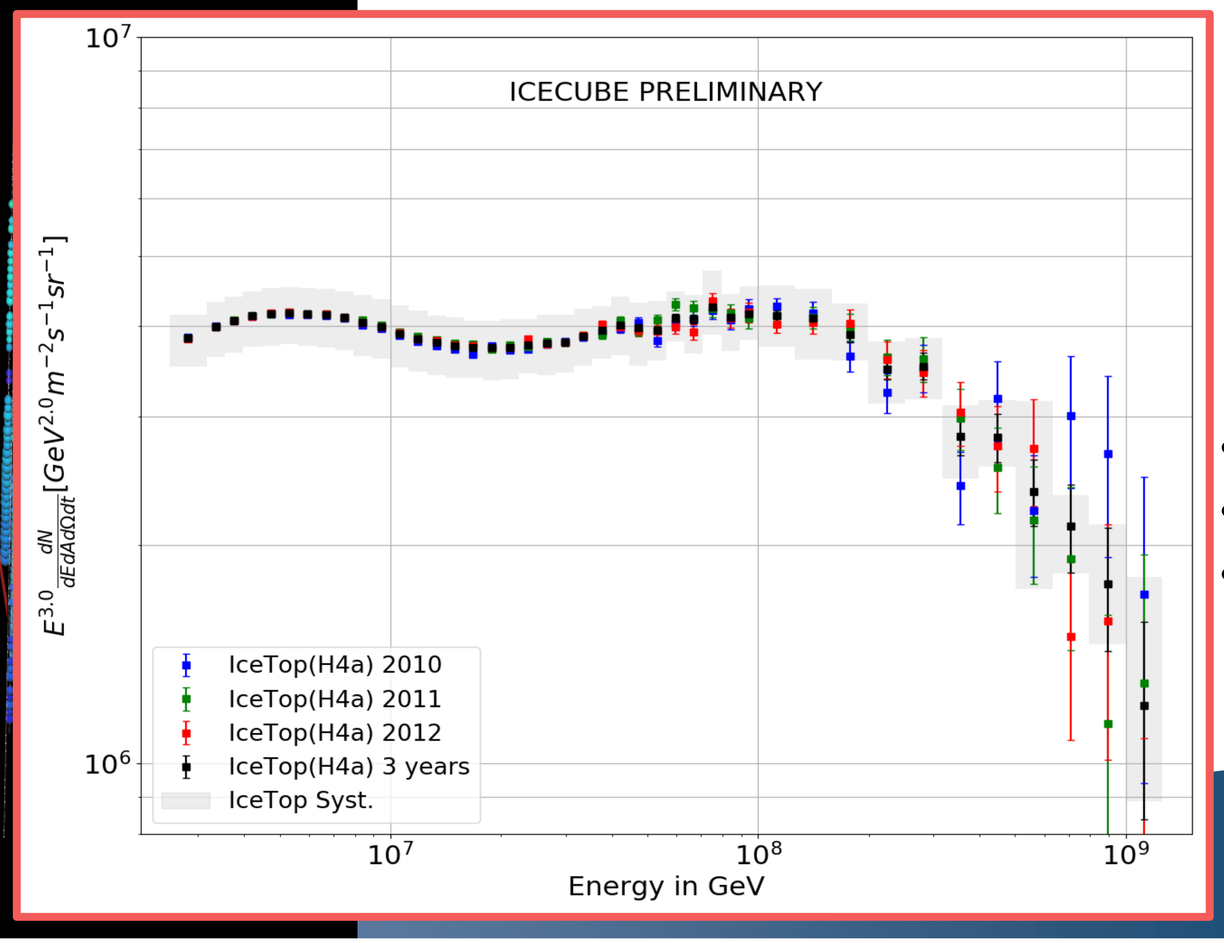

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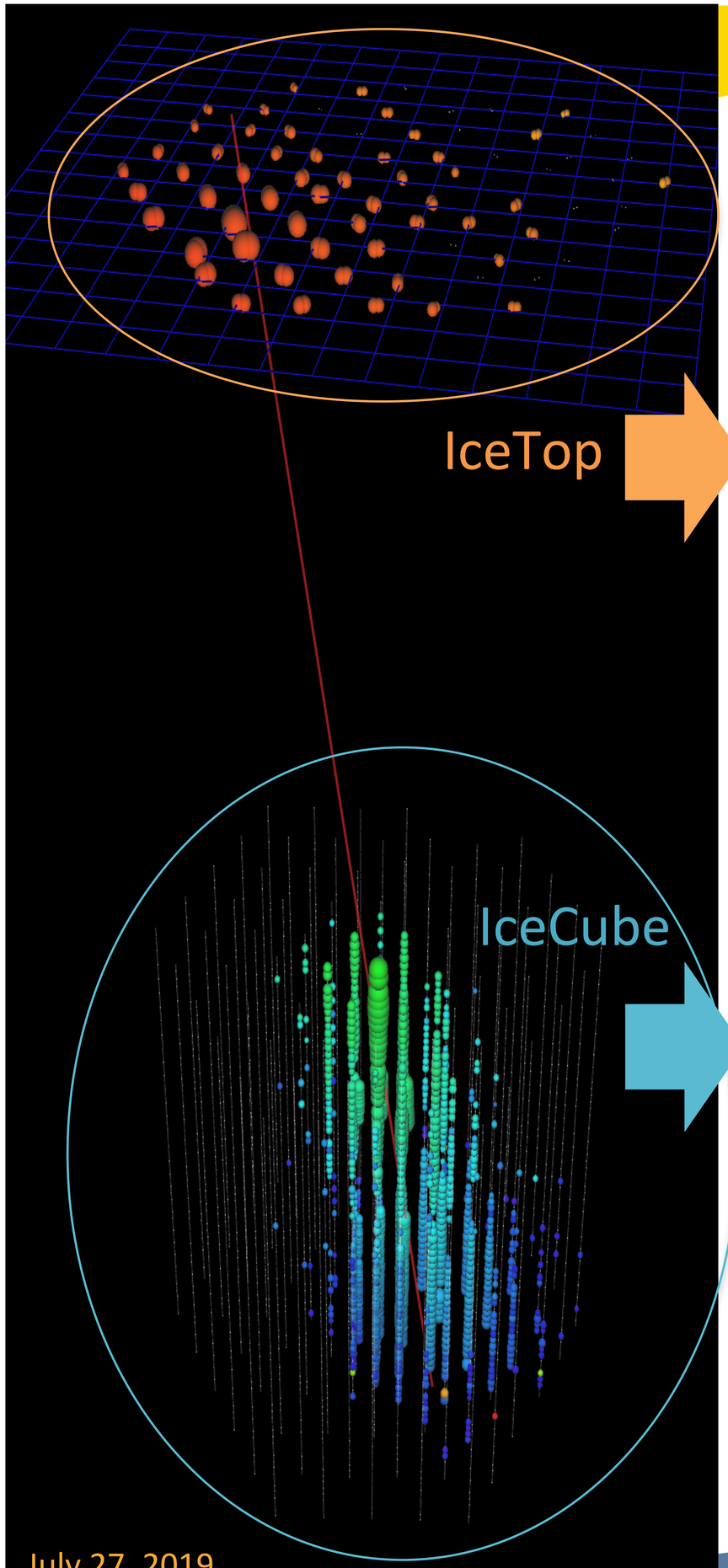
Coincident Measurements



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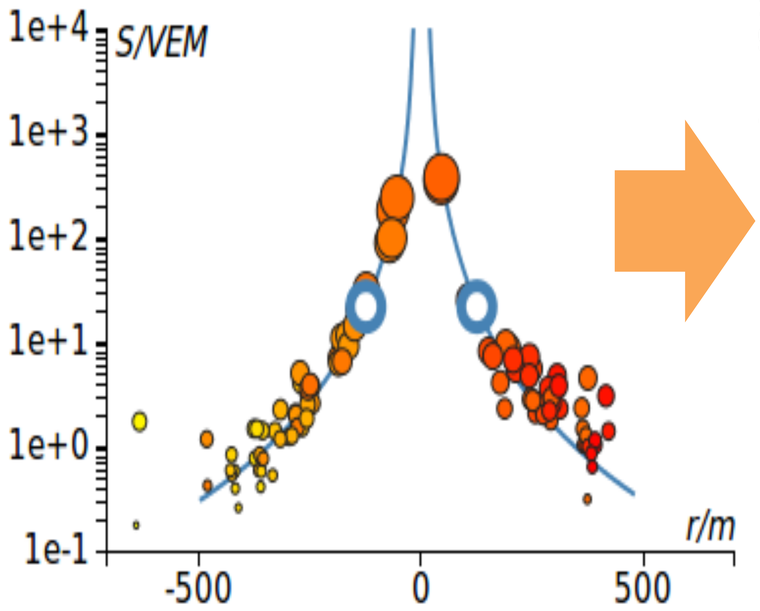
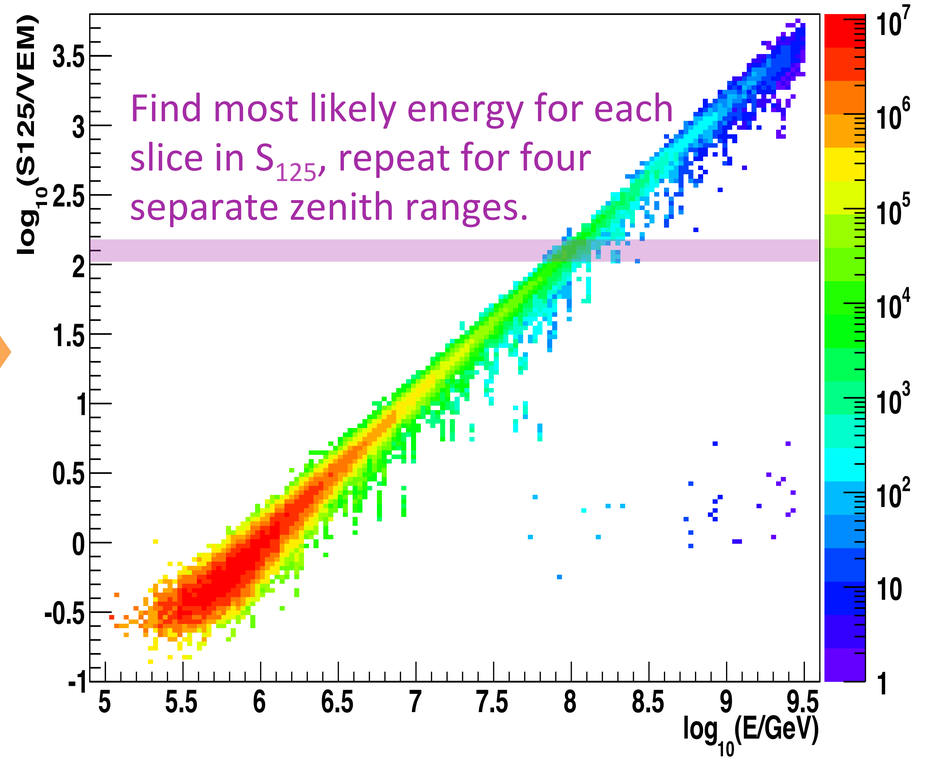
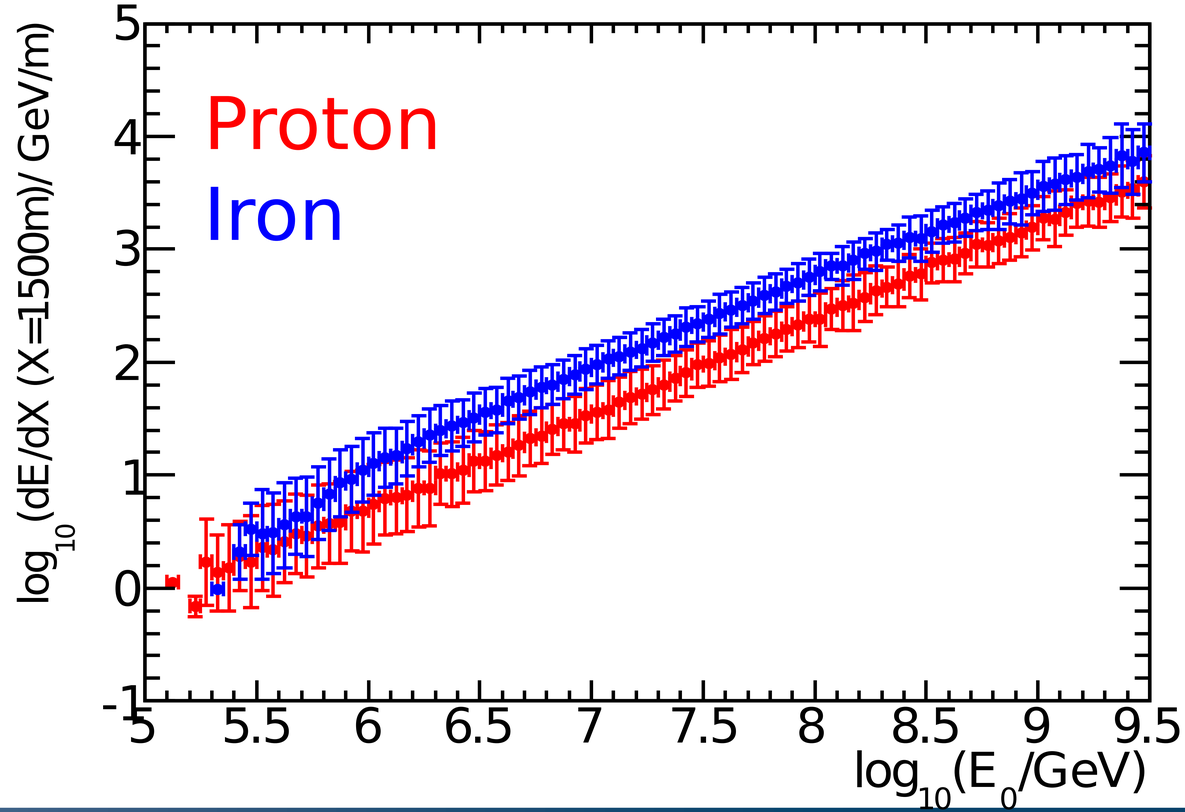


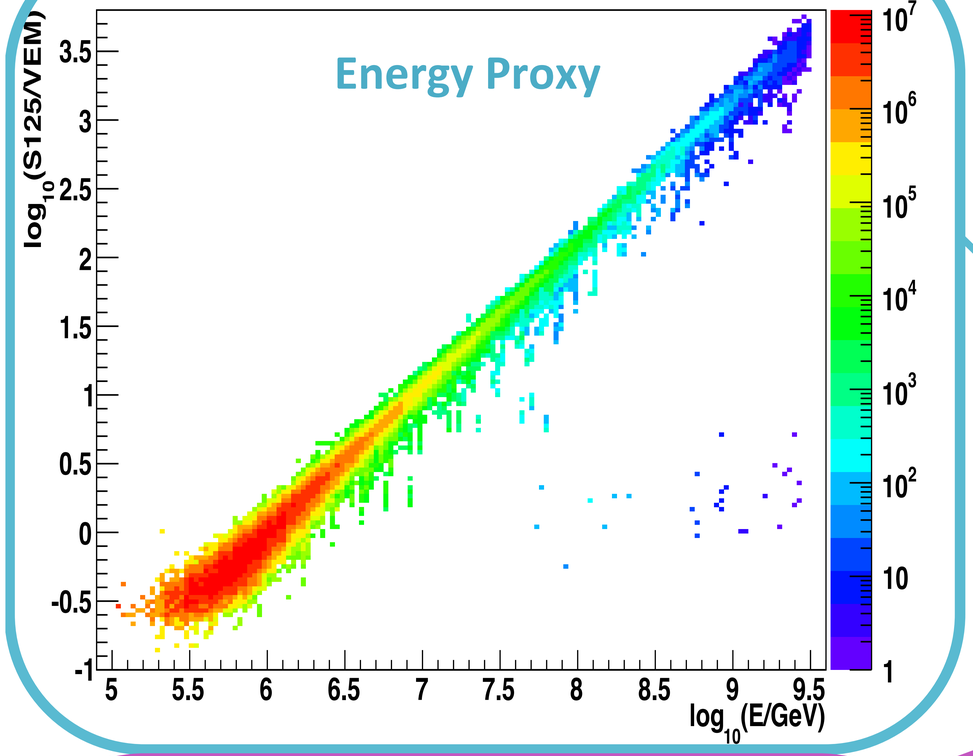


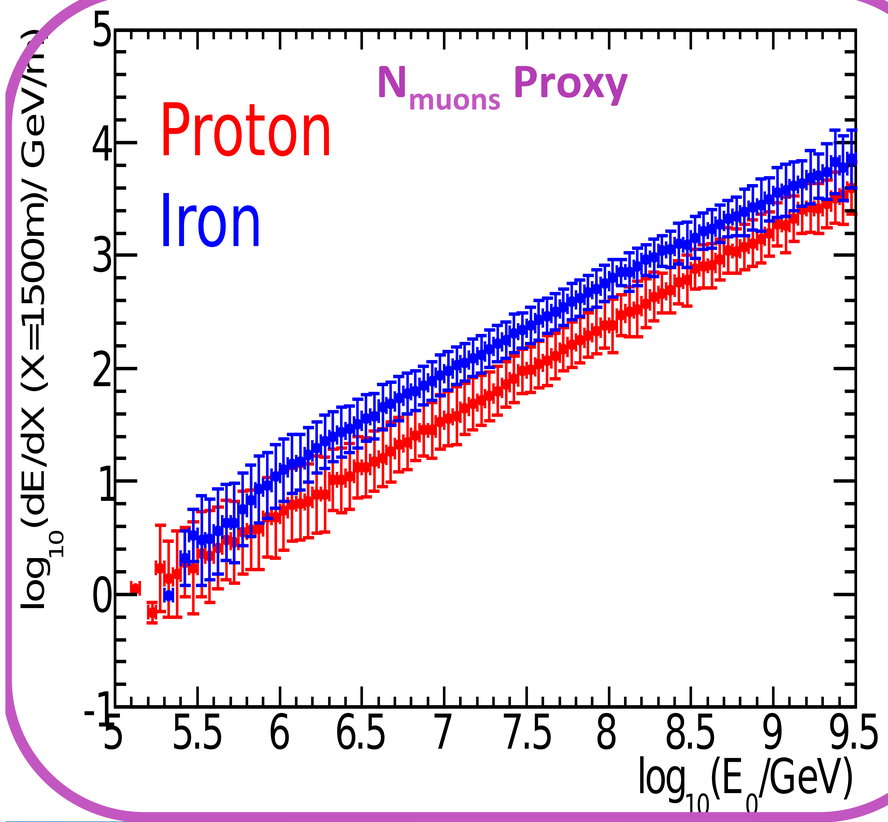
High Energy Muons (>500 GeV)
Energy loss (dE/dX) at fixed slant depth (X=1500m) in the glacial ice

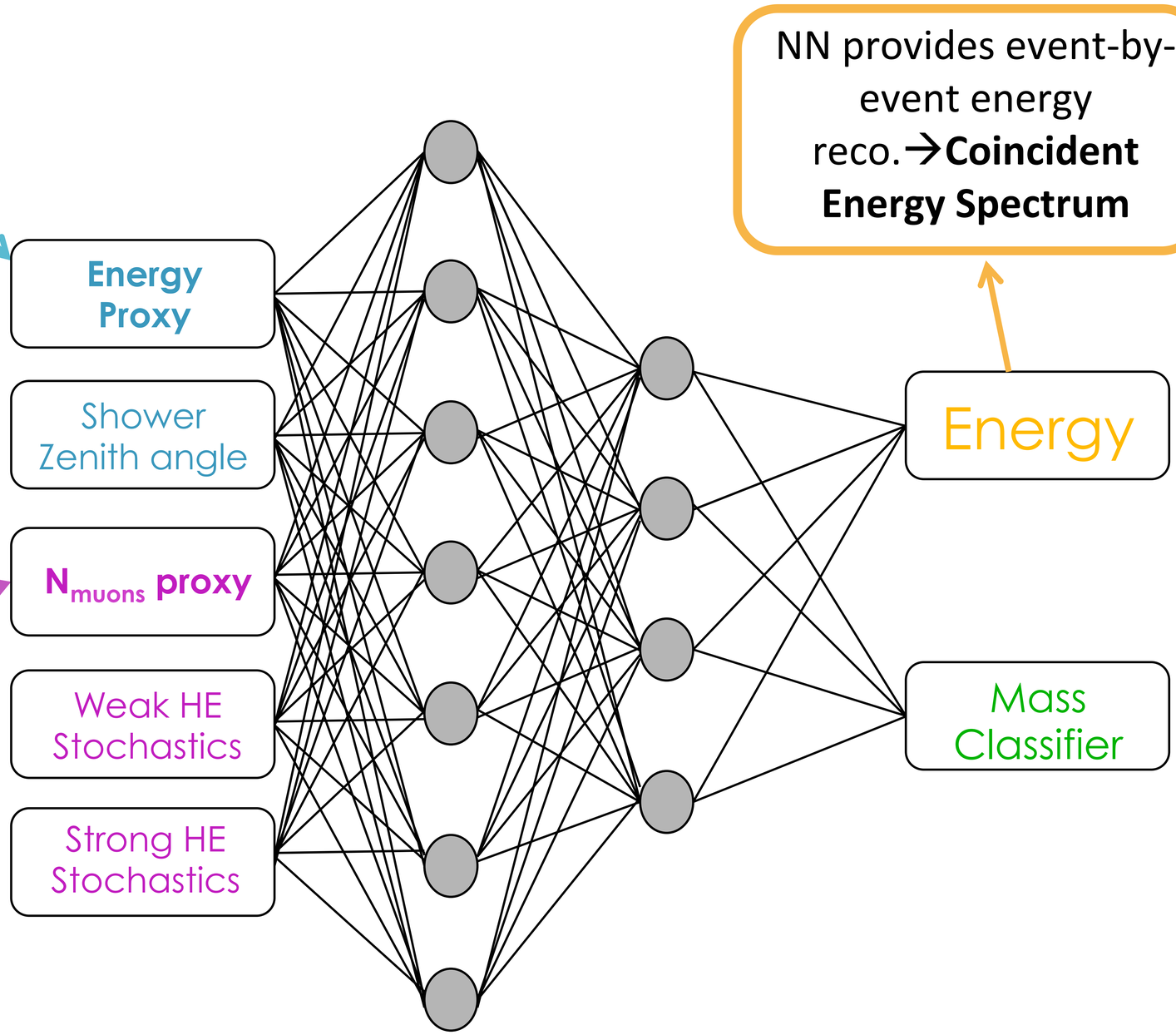
→ strong composition sensitivity



Coincident Analysis: Spectrum and Composition



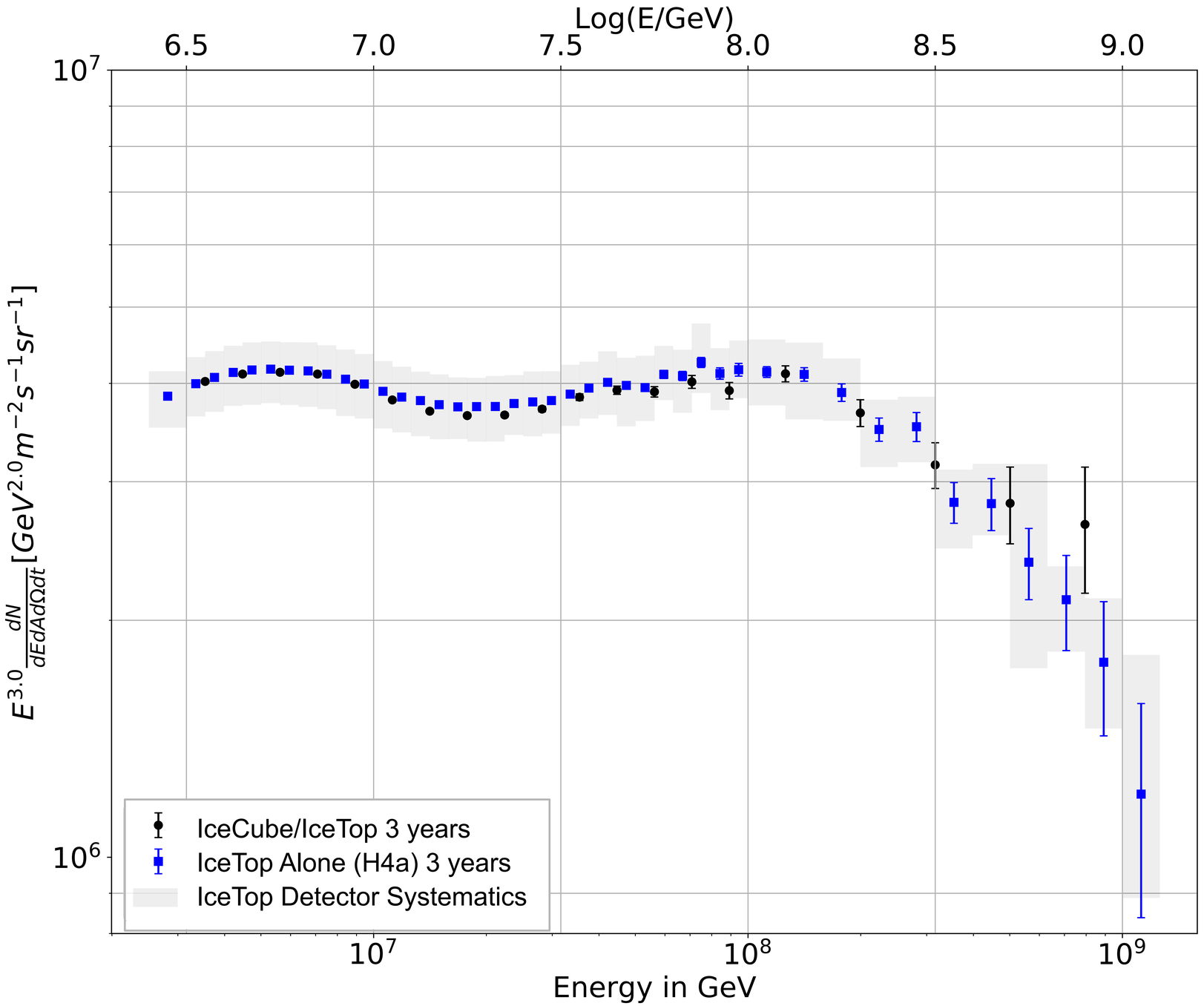




NN provides event-by-event energy reco.→**Coincident Energy Spectrum**

J. Phys.: Conf. Ser. 718 052033
Proceedings of ICRC2013(0861)
Astropart.Phys. 42: 15, 2013

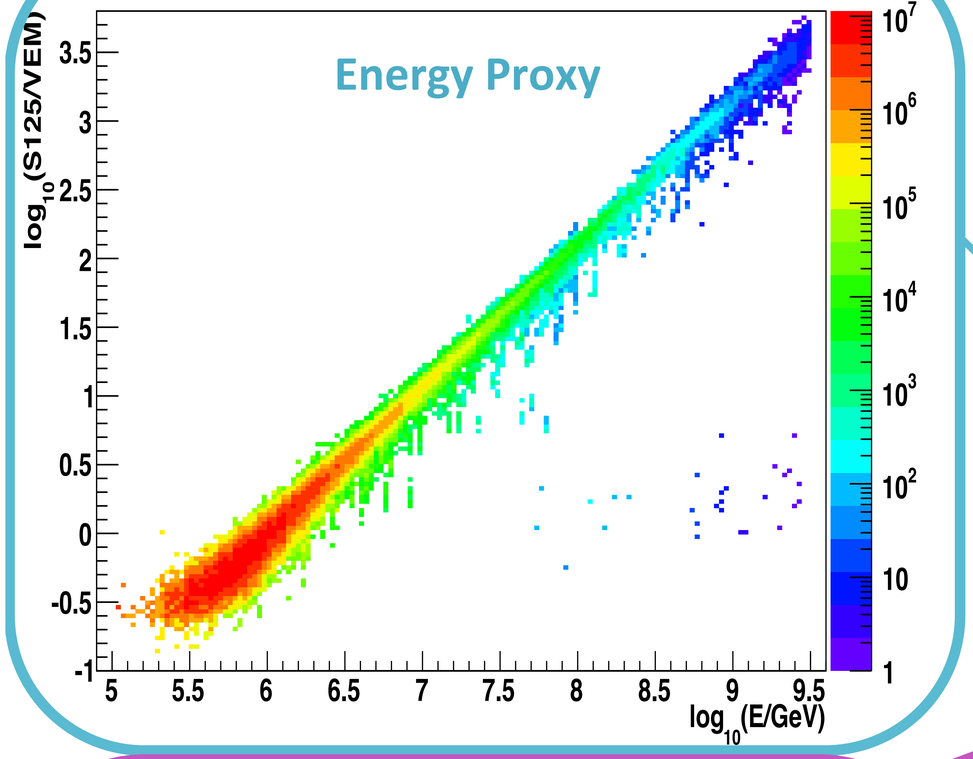
Coincident Energy Spectrum

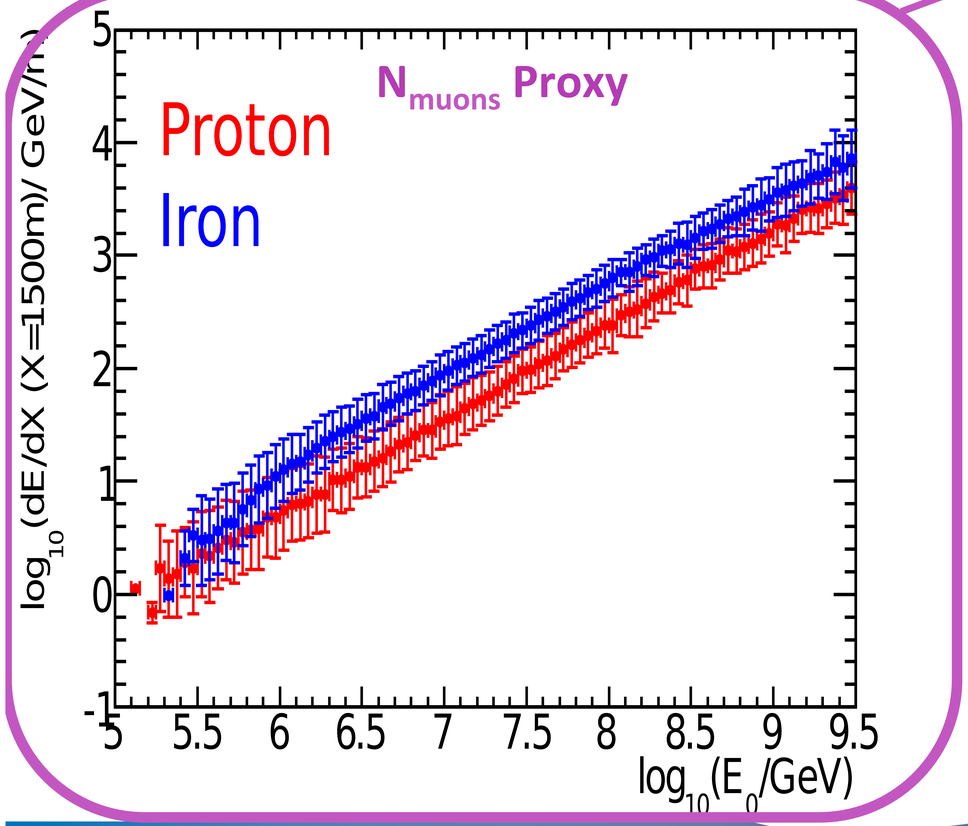


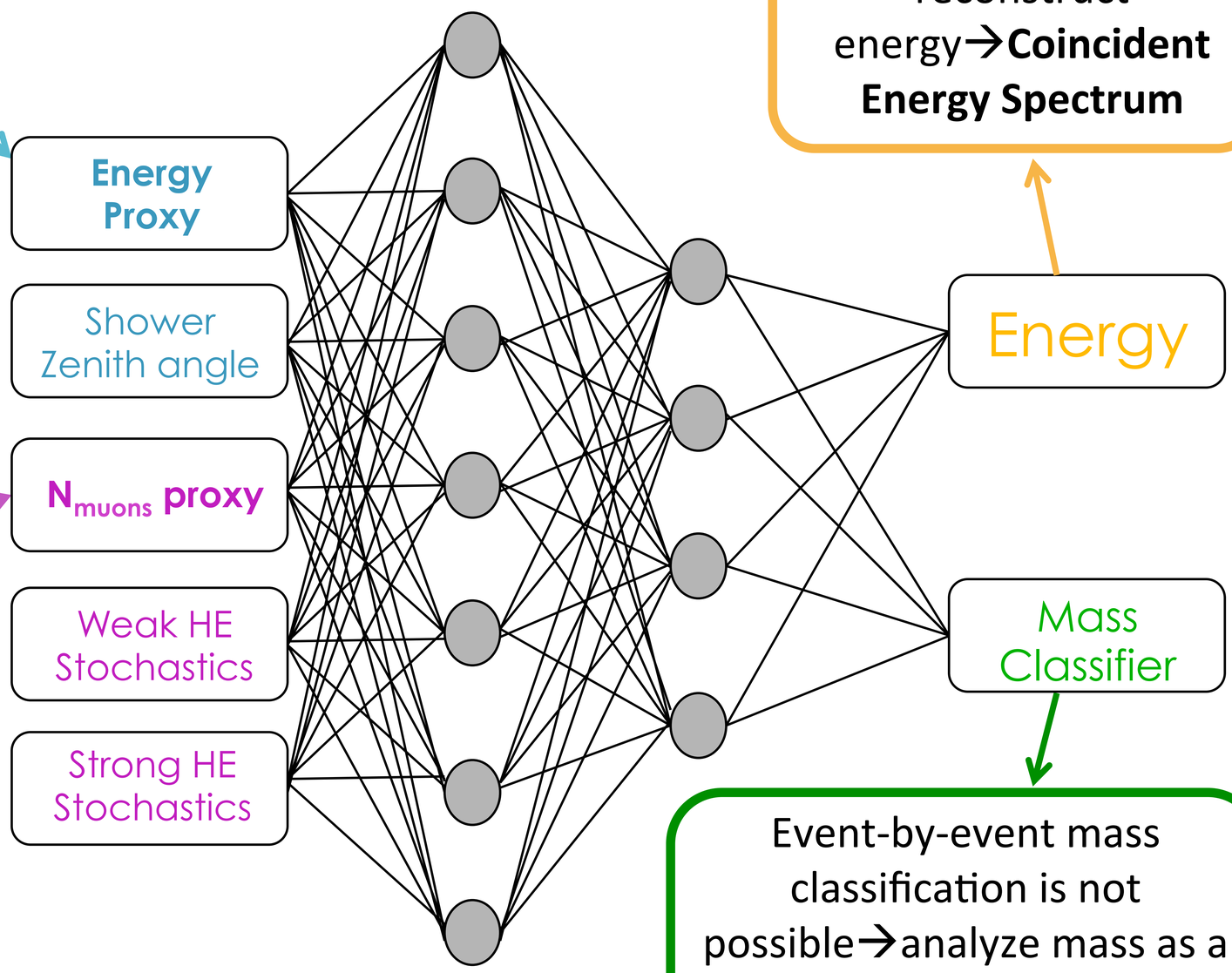
Same data set as IceTop alone analysis, shown together for comparison

Coincidence requirement → fewer events and smaller energy range than IceTop alone analysis.

Coincident Analysis: Spectrum and Composition





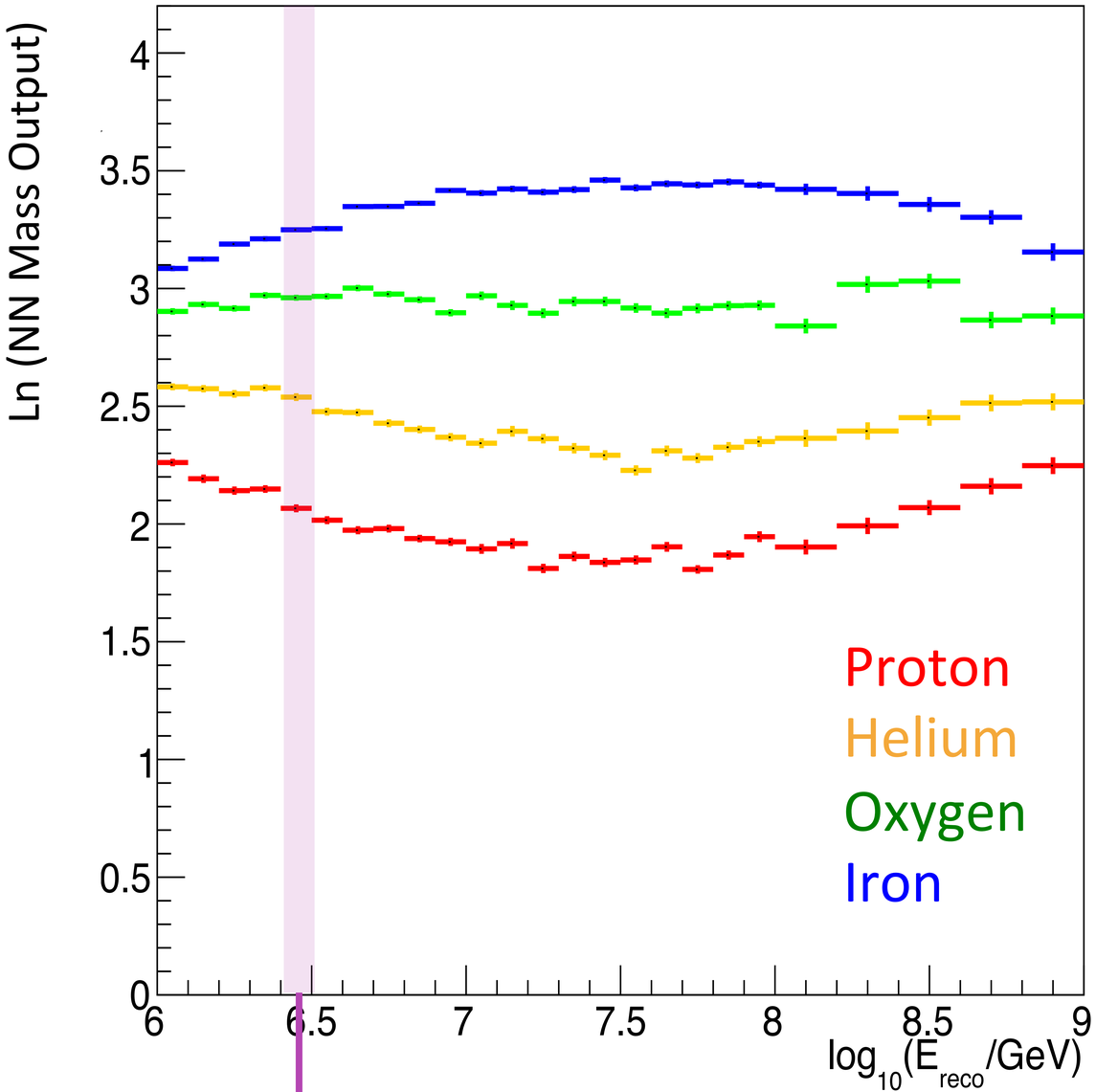


Use NN to directly reconstruct energy→**Coincident Energy Spectrum**

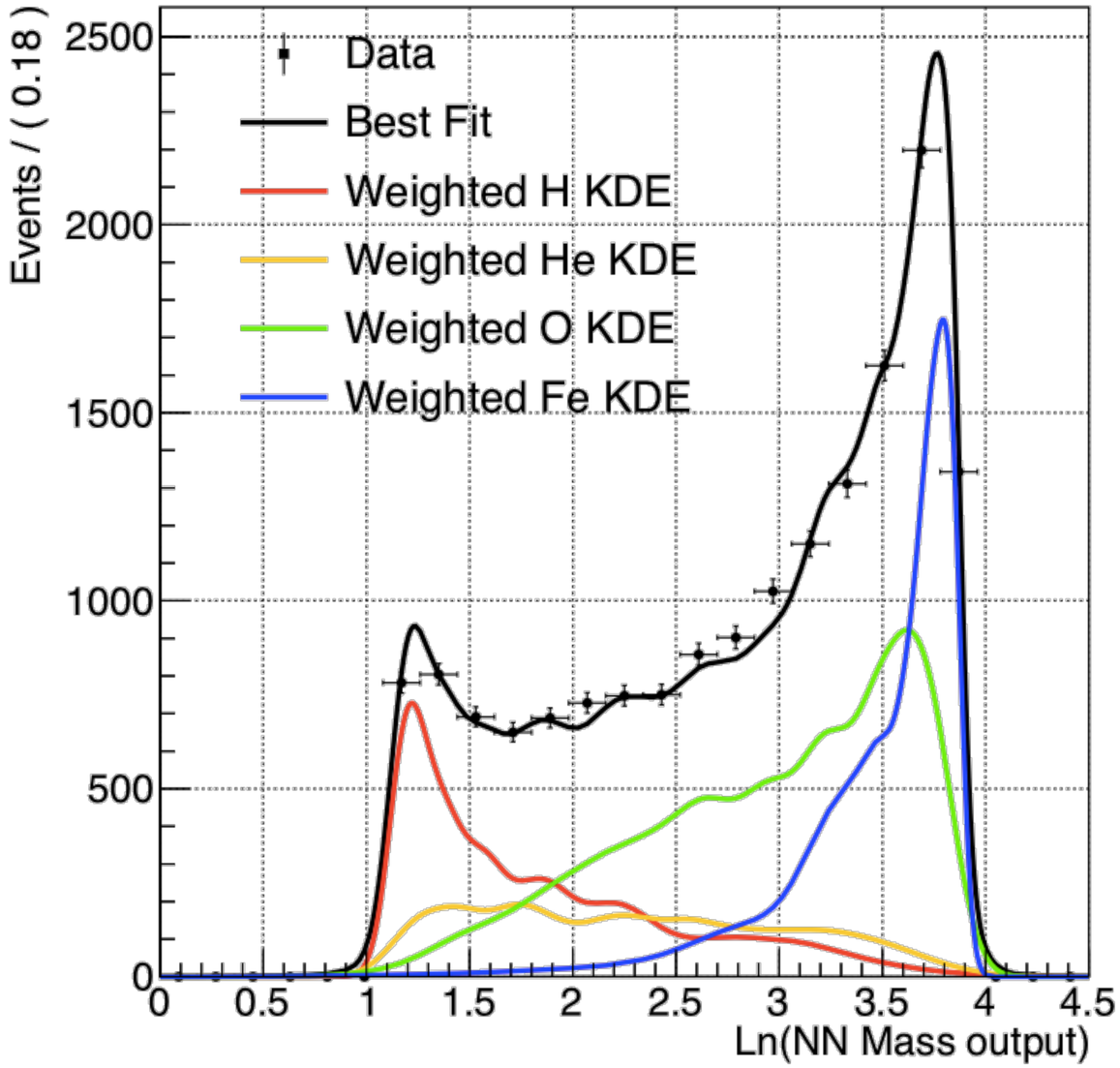
Event-by-event mass classification is not possible→analyze mass as a function of energy on a statistical basis.

J. Phys.: Conf. Ser. 718 052033
Proceedings of ICRC2013(0861)
Astropart.Phys. 42: 15, 2013

Coincident Analysis: Mass Output

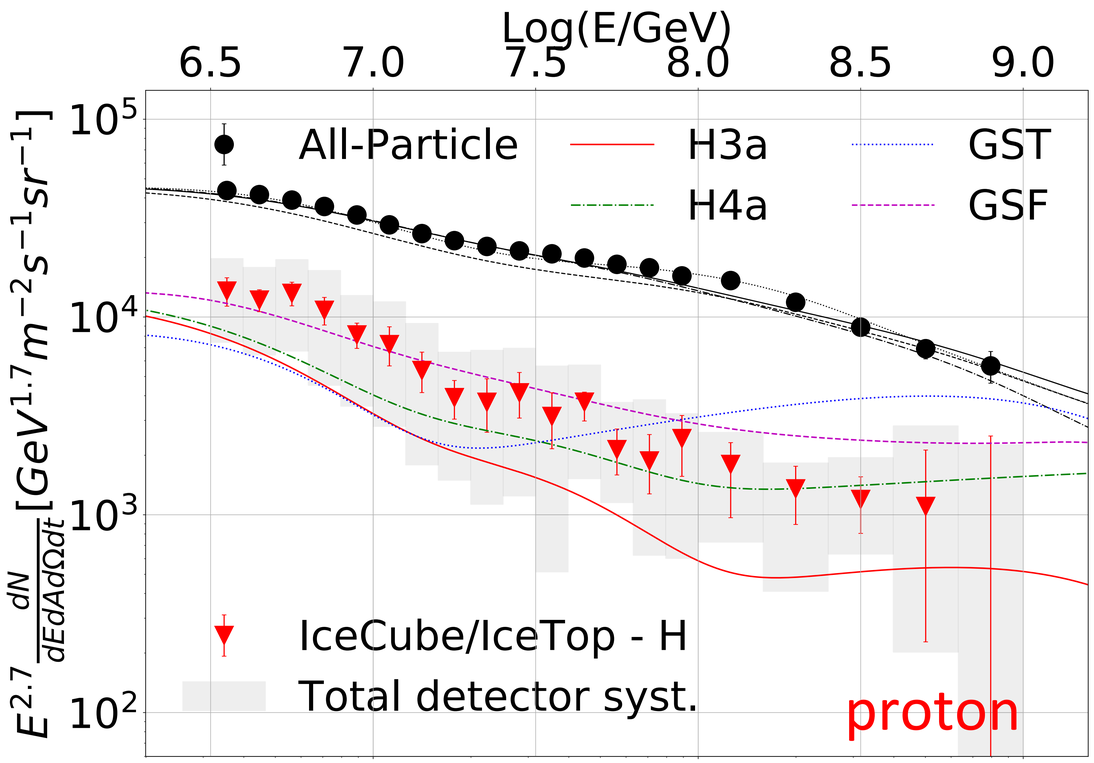


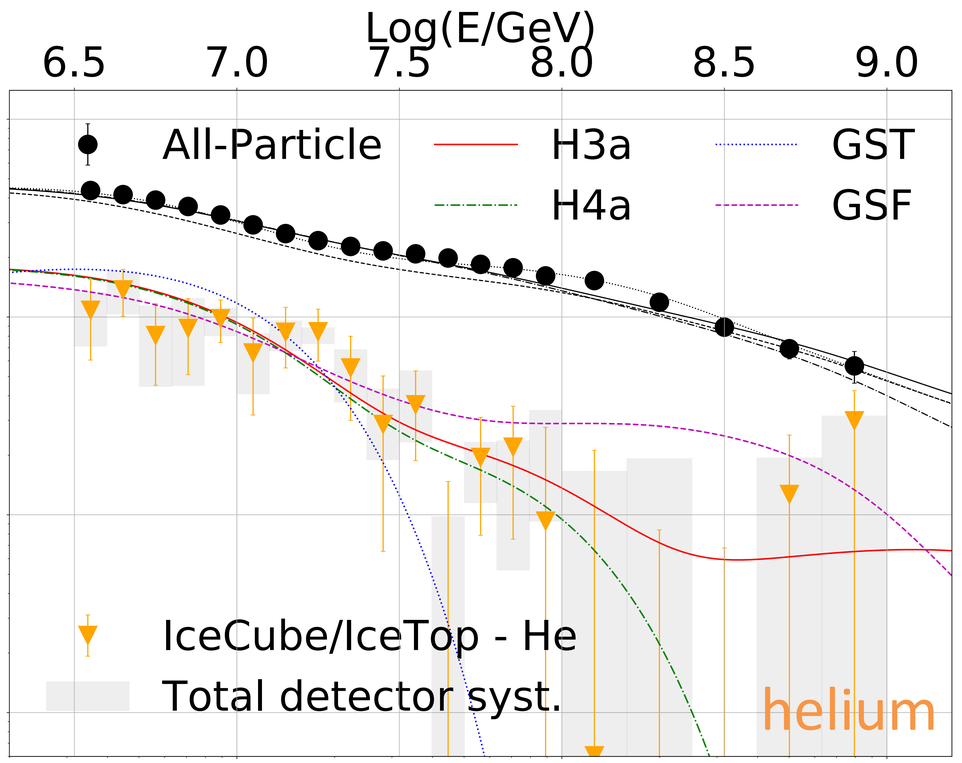
Log(E/GeV): 7.4 - 7.5

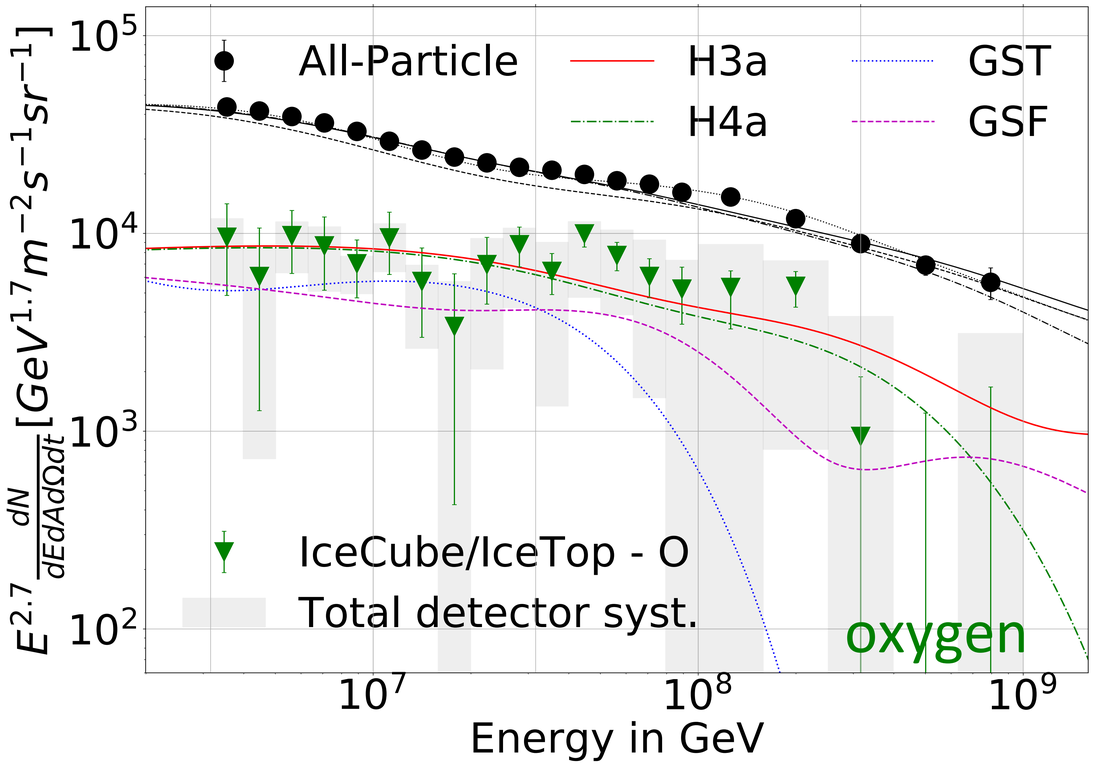


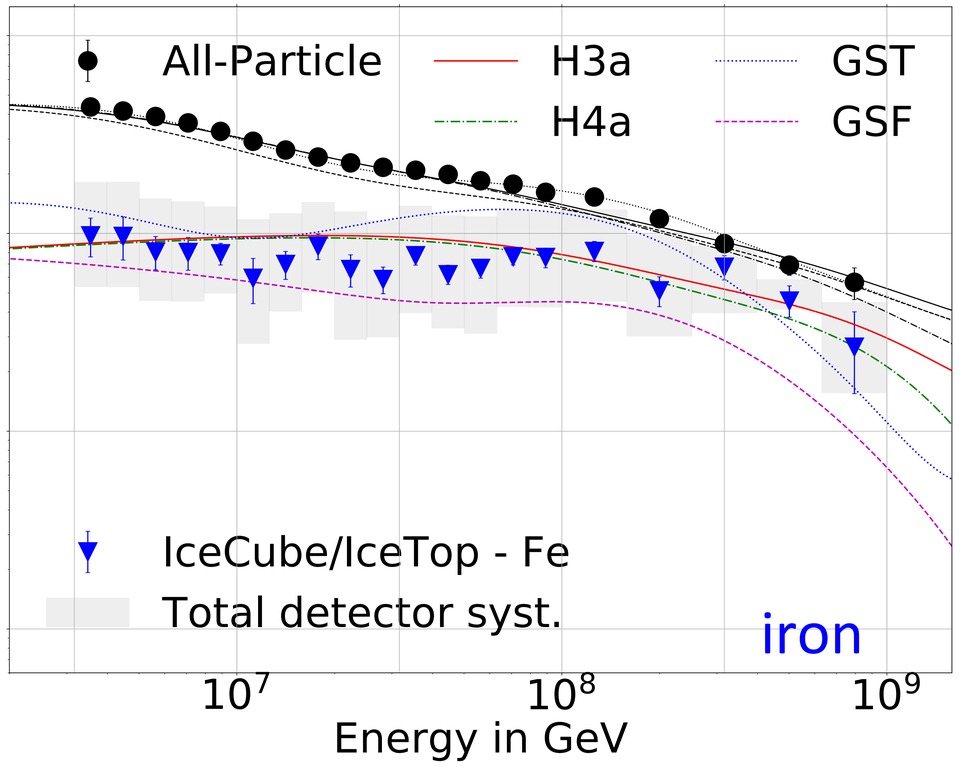
For each slice in energy make templates using KDE method
Use unbinned likelihood method to find best fit to data

Composition Measurement





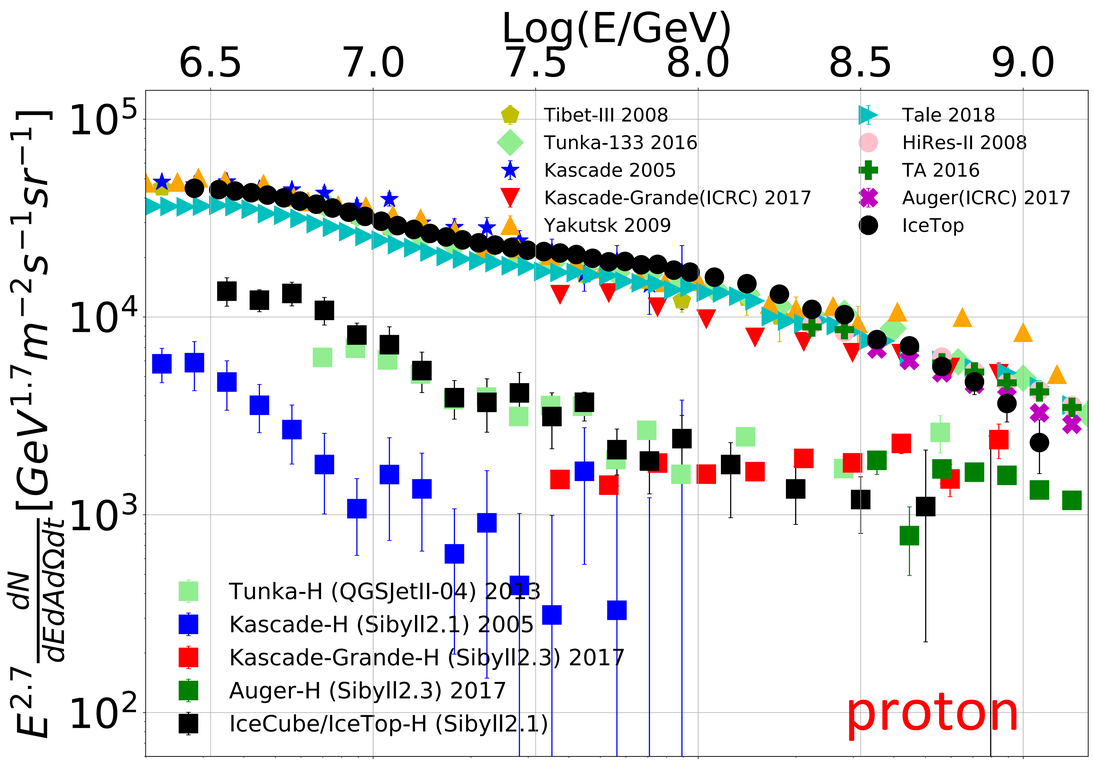


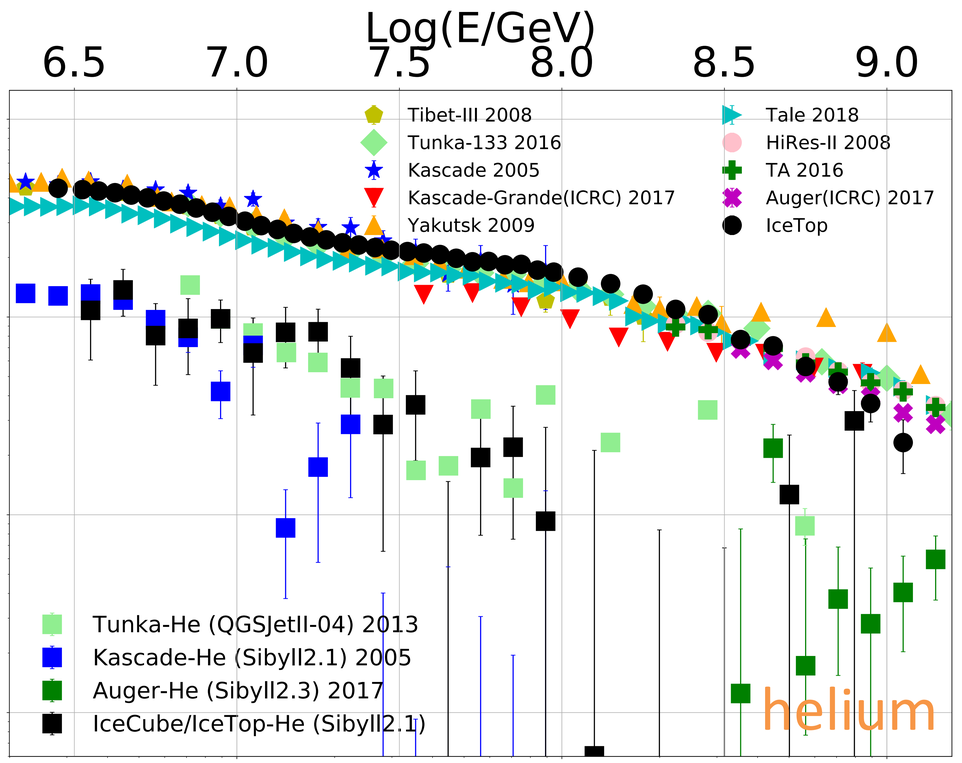


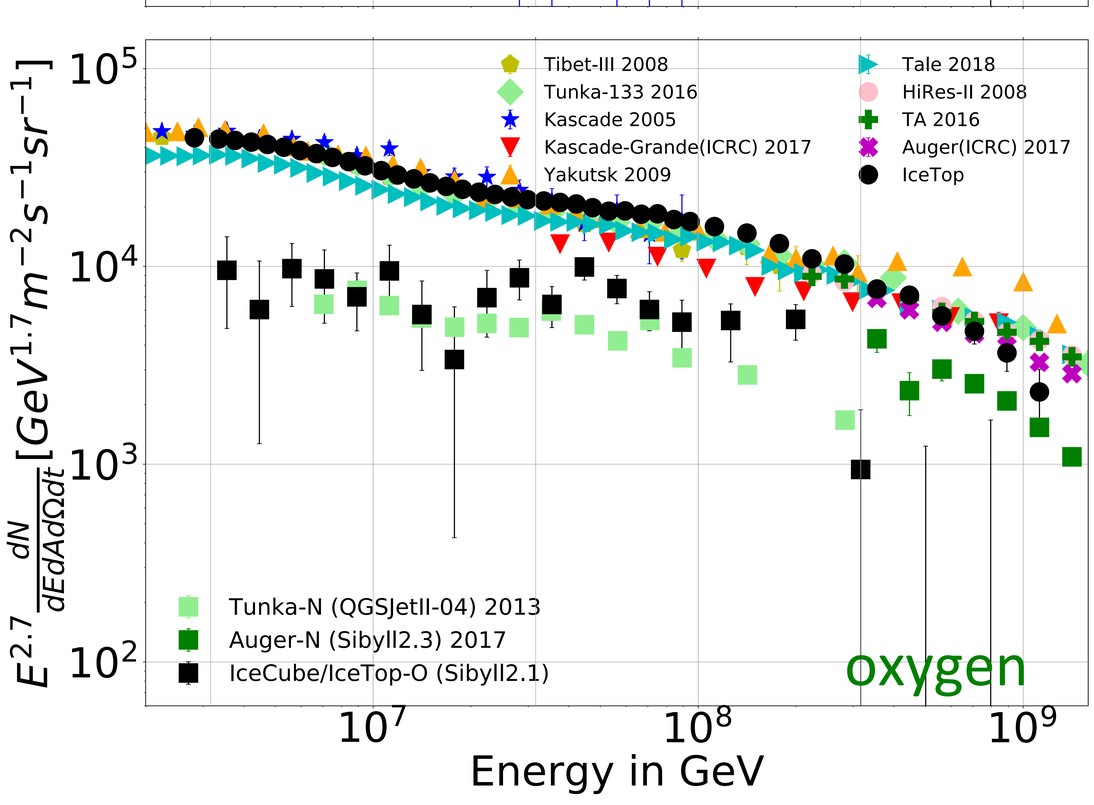
Composition becomes heavier with increasing energy up to 10^8 GeV

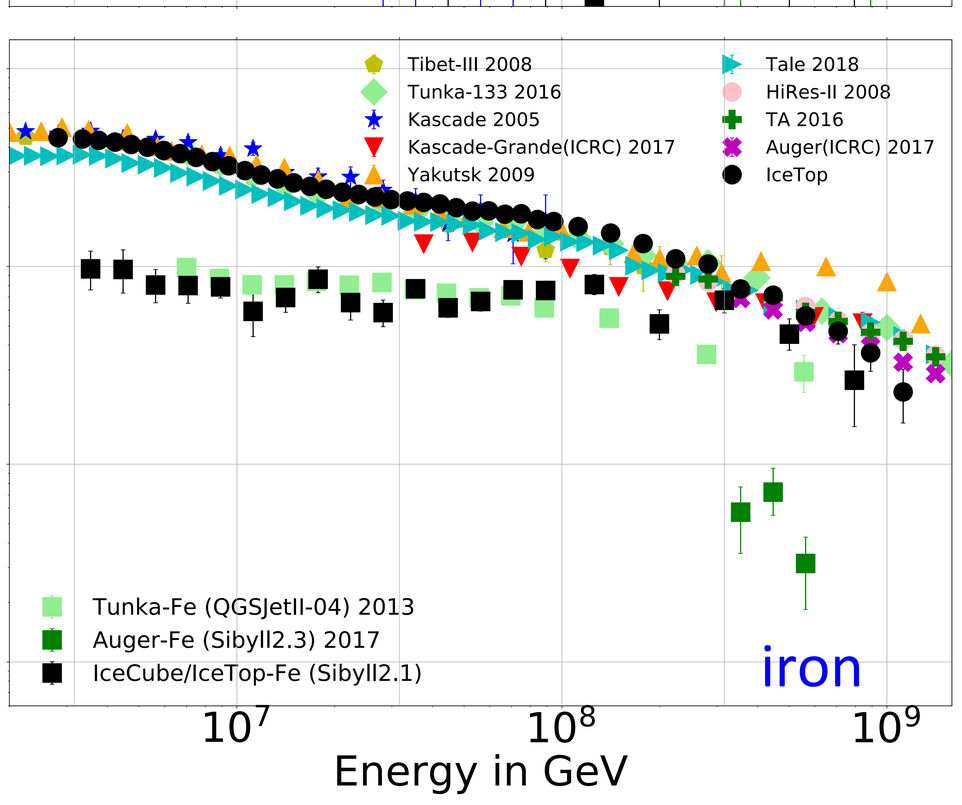
Agreement with models within statistical and systematic uncertainties

Composition Measurement



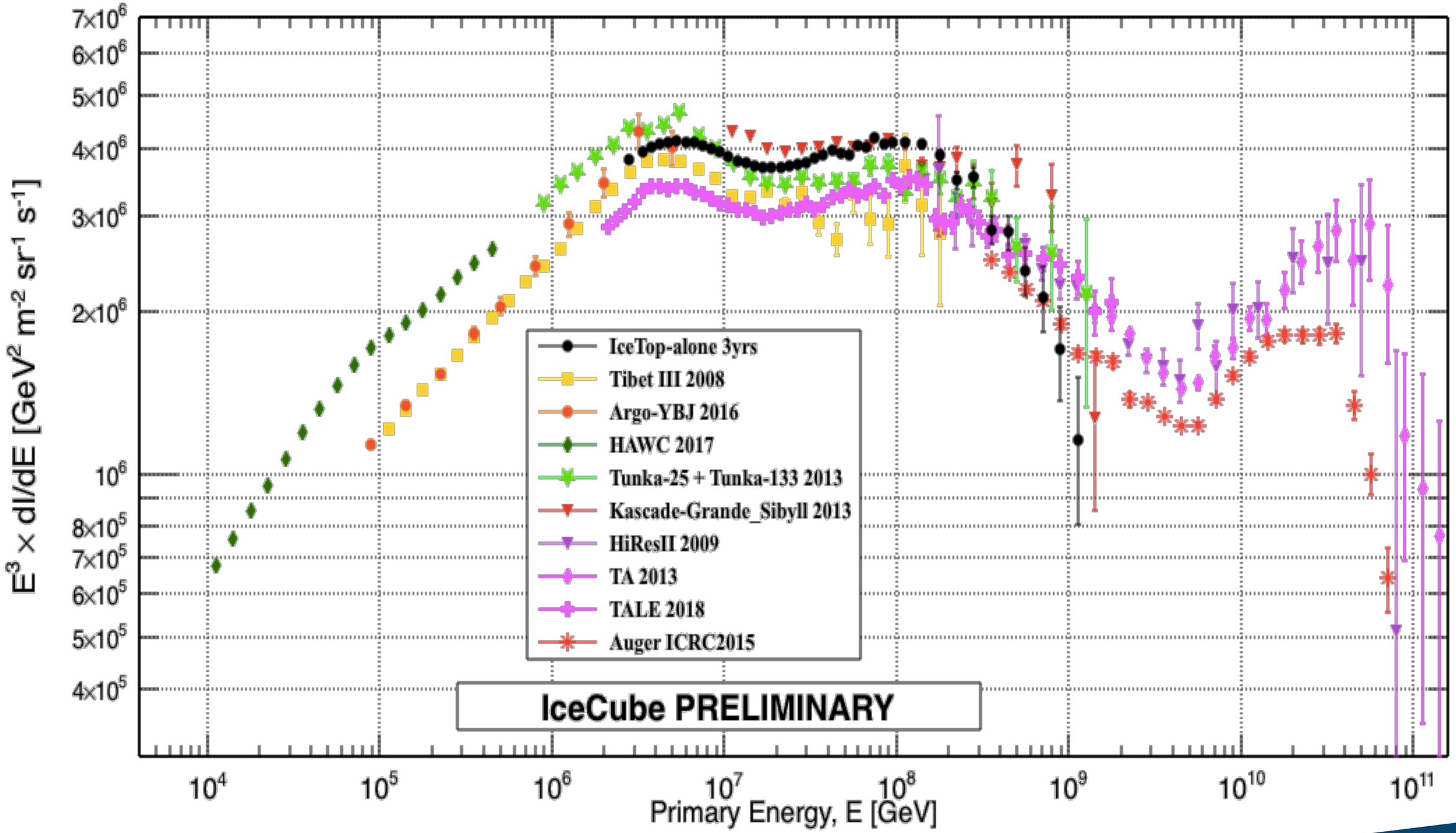




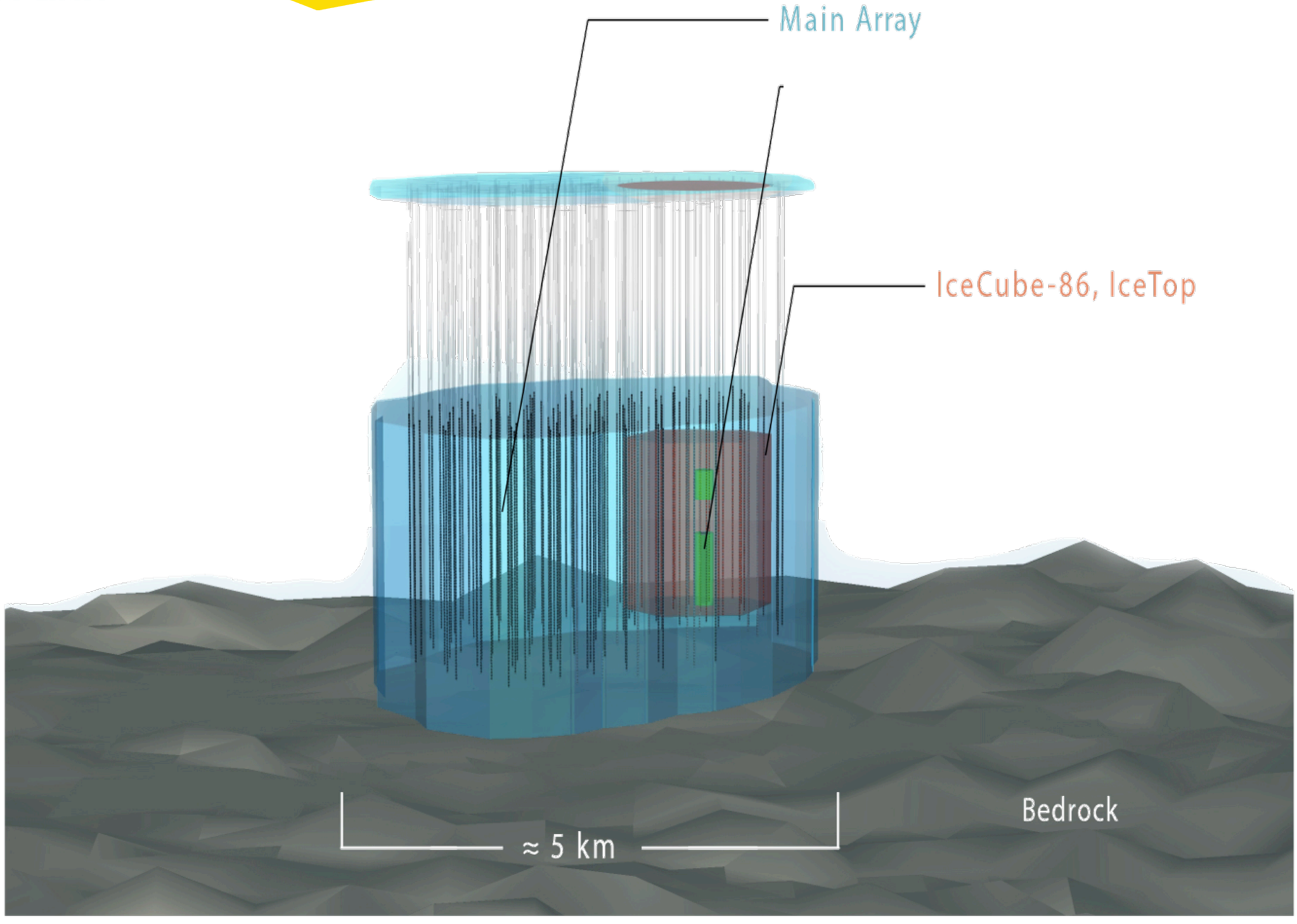


General agreement with composition results from other experiments (within statistical and systematic uncertainties.)

IceTop Energy Spectrum



Future Dreams…



With an increase of just x10 in volume,
the coincident aperture increases by x40

Summary

- IceTop is used independently to reconstruct the primary cosmic ray energy spectrum from PeV to EeV
- IceTop is used in coincidence with IceCube to reconstruct both the primary cosmic ray energy spectrum and the composition.
- Both analysis techniques agree with each other, and agree independently across all years.
- Paper submitted to PRD (arXiv:1906.04317 [astro-ph.HE]). We expect publication shortly:

Can't get enough of IceCube/IceTop? For…

IceTop/IceCube cosmic ray overview: see Dennis Soldin's talk (earlier today)

Latest Reconstruction Techniques: see Emily Dvorak's poster [PS1-157]

Surface Array Upgrades: see the Scintillator upgrade poster [PS1-190], the Radio upgrade poster [PS1-210:], and the IceAct upgrade poster [PS1-179]

Future Composition Plans: see Matthias Plum's poster [PS3-204]

And many more…

THE ICECUBE COLLABORATION

AUSTRALIA
University of Adelaide

BELGIUM
Université libre de Bruxelles
Universiteit Gent
Vrije Universiteit Brussel

CANADA
SNOLAB
University of Alberta–Edmonton

DENMARK
University of Copenhagen

GERMANY
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University of Delaware
University of Kansas
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FUNDING AGENCIES

Fonds de la Recherche Scientifique (FRS-FNRS)
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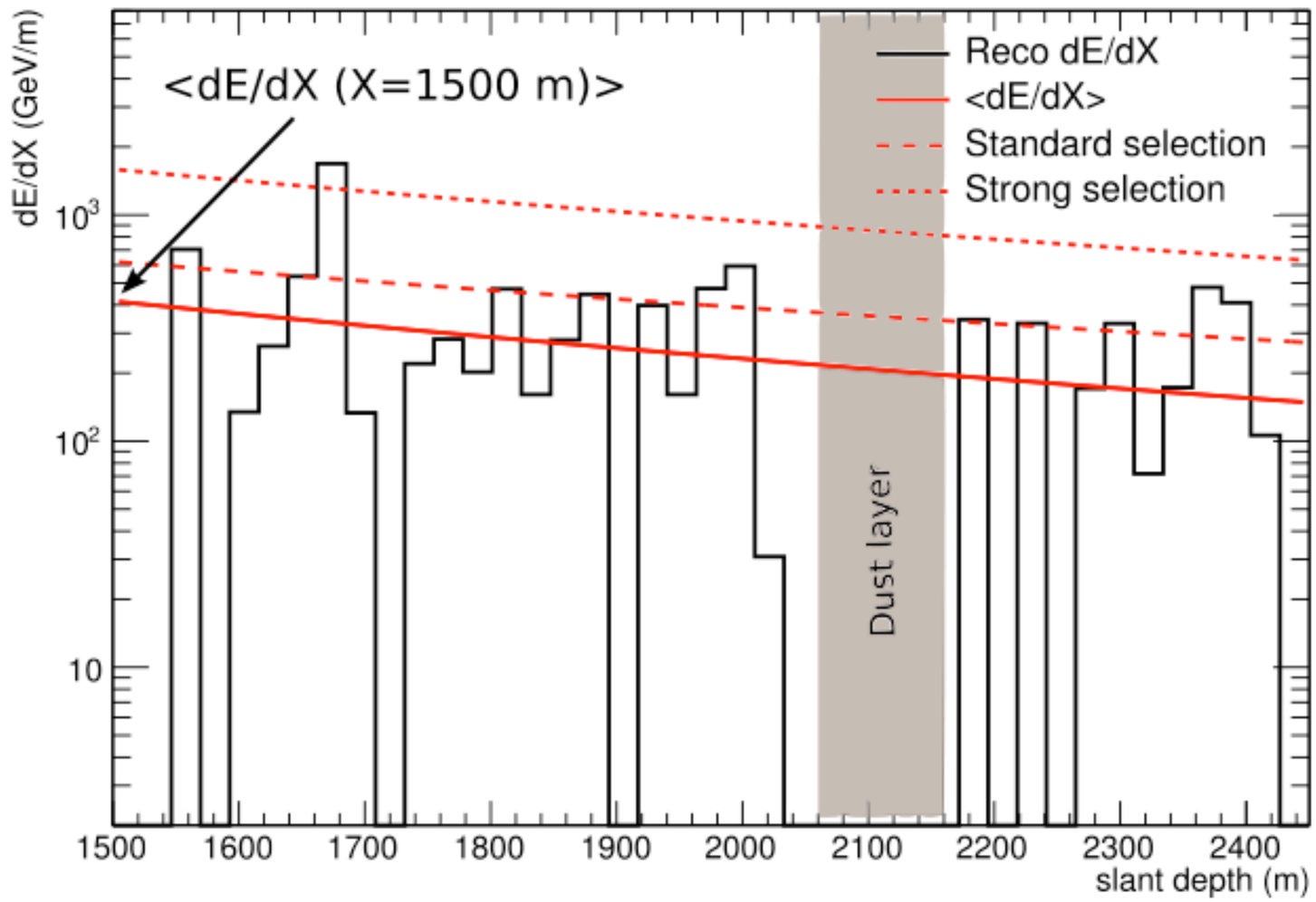
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)
Japan Society for the Promotion of Science (JSPS)
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat
The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

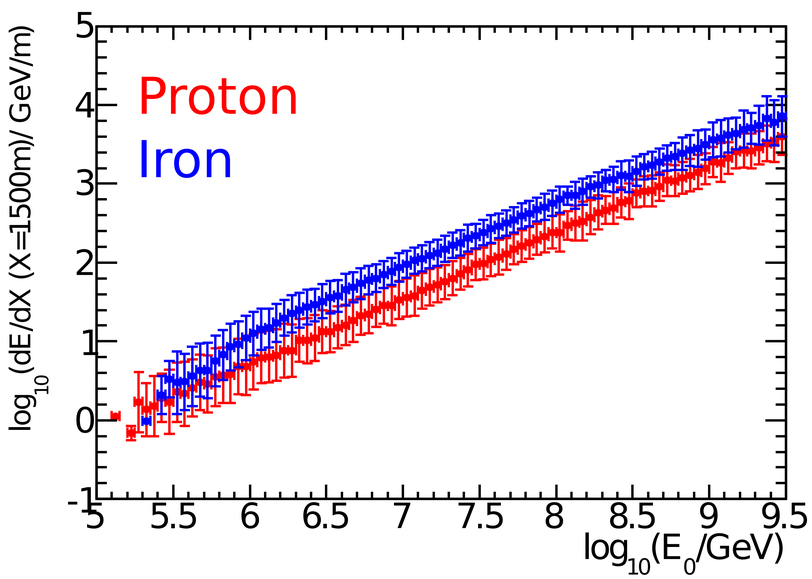
IceCube South Pole Neutrino Observatory
icecube.wisc.edu

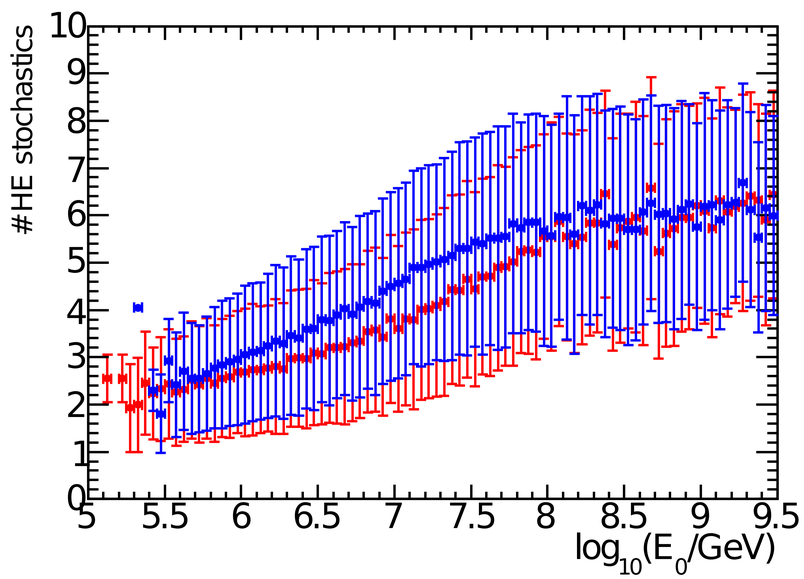
Thank You
UNITED STATES ANTARCTIC PROGRAM

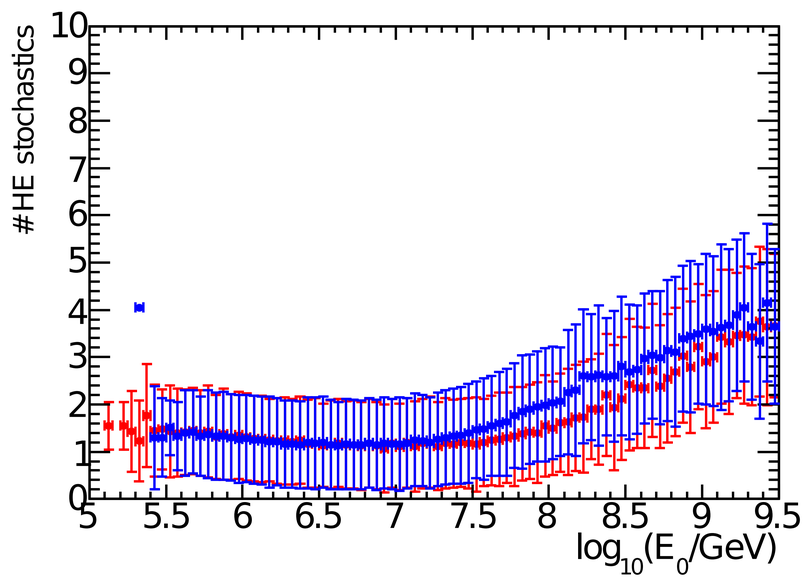
Backup

Composition Sensitive Parameters

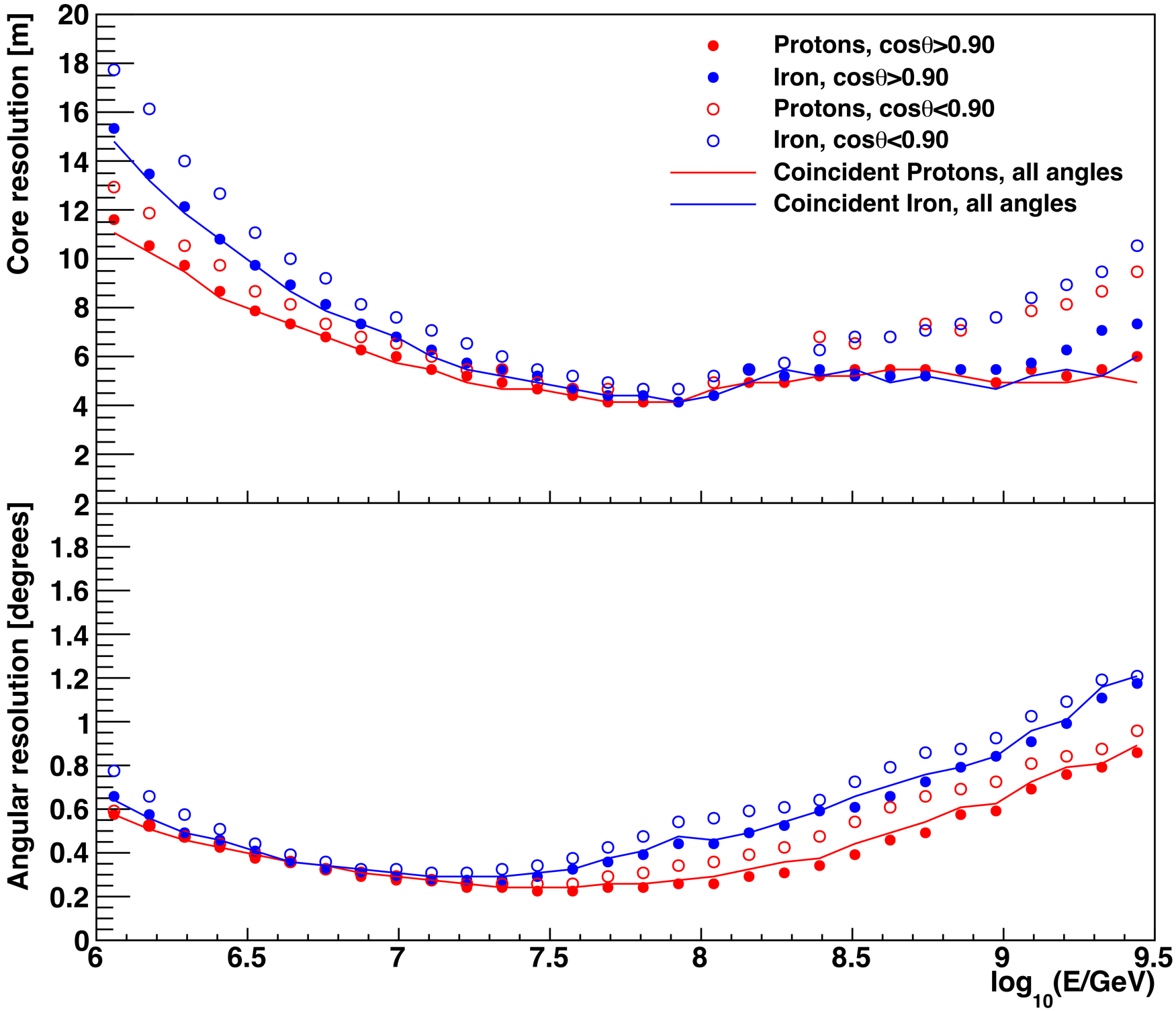








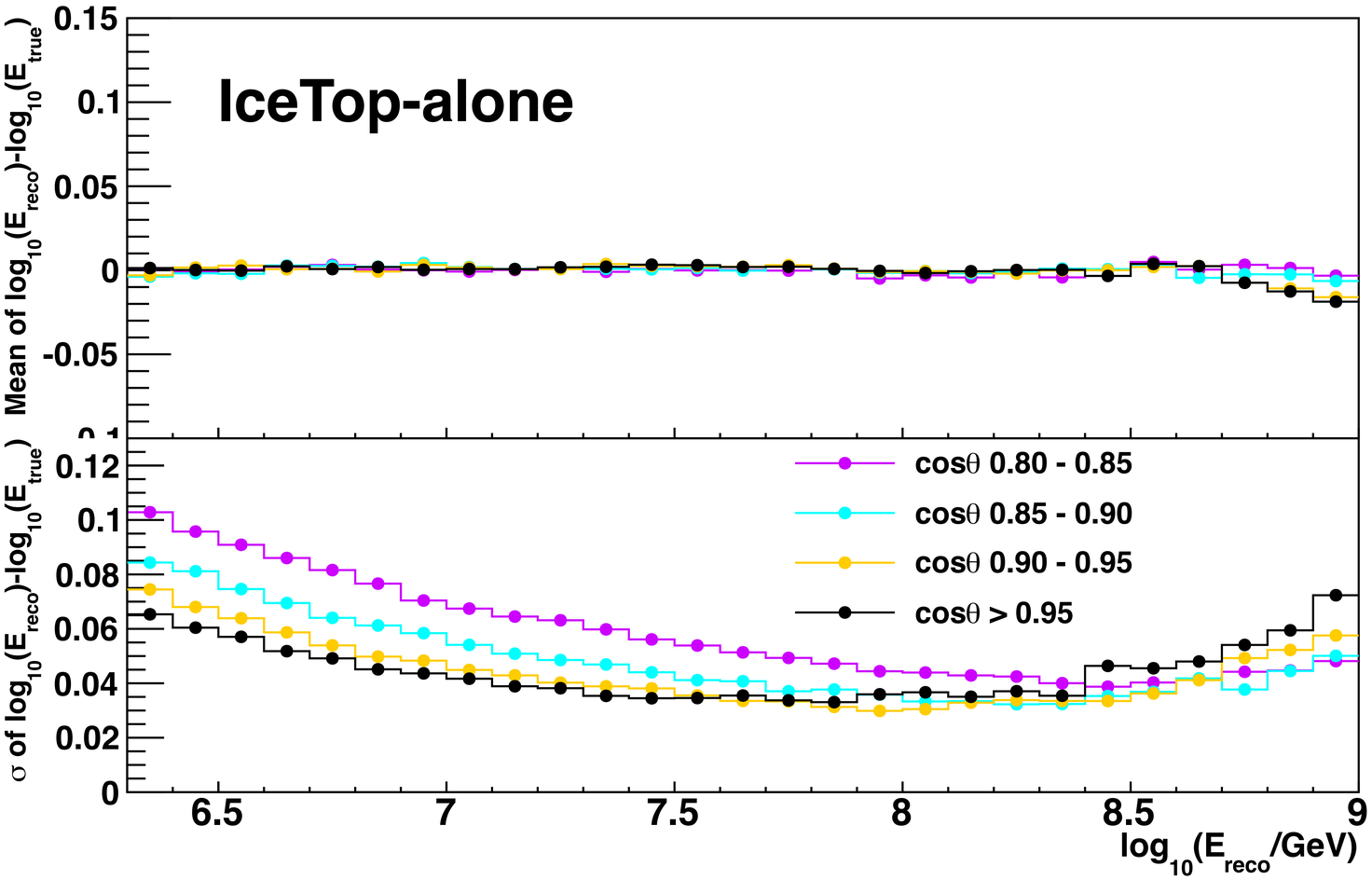
Core and Angular Resolution



Core Position:
within 5-10 m

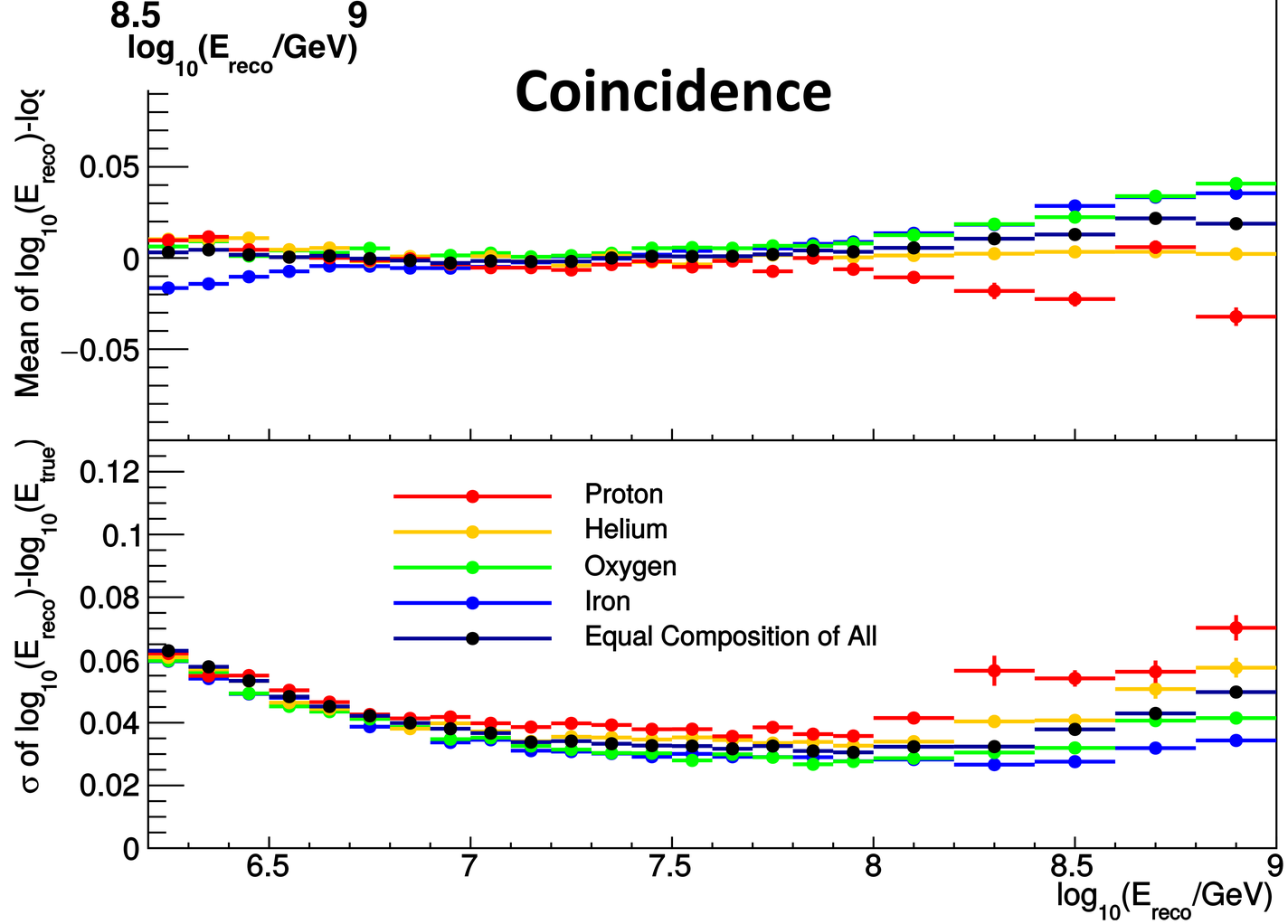
Direction:
within 1°

Energy Resolution and Bias

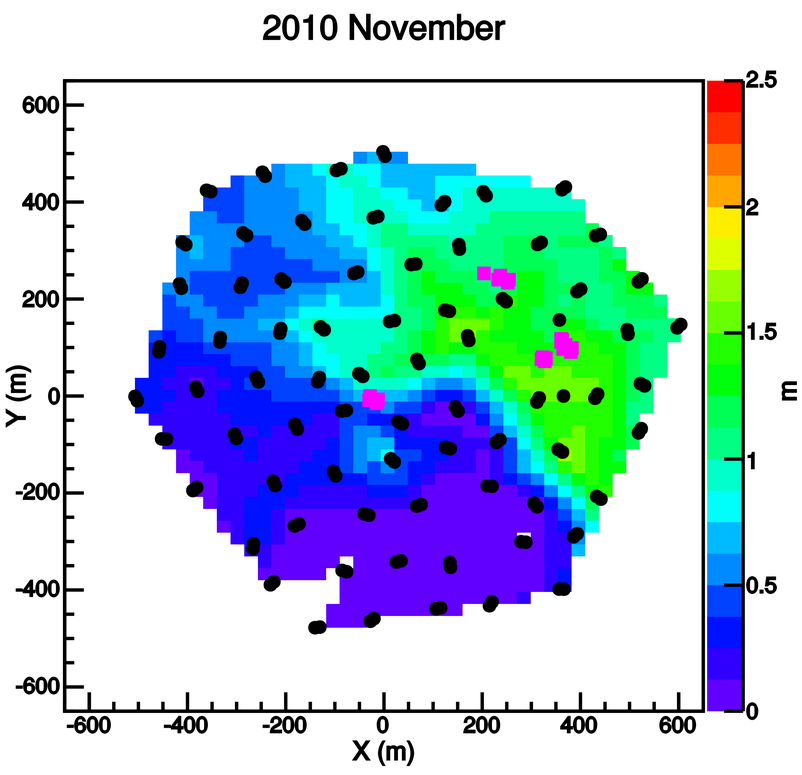


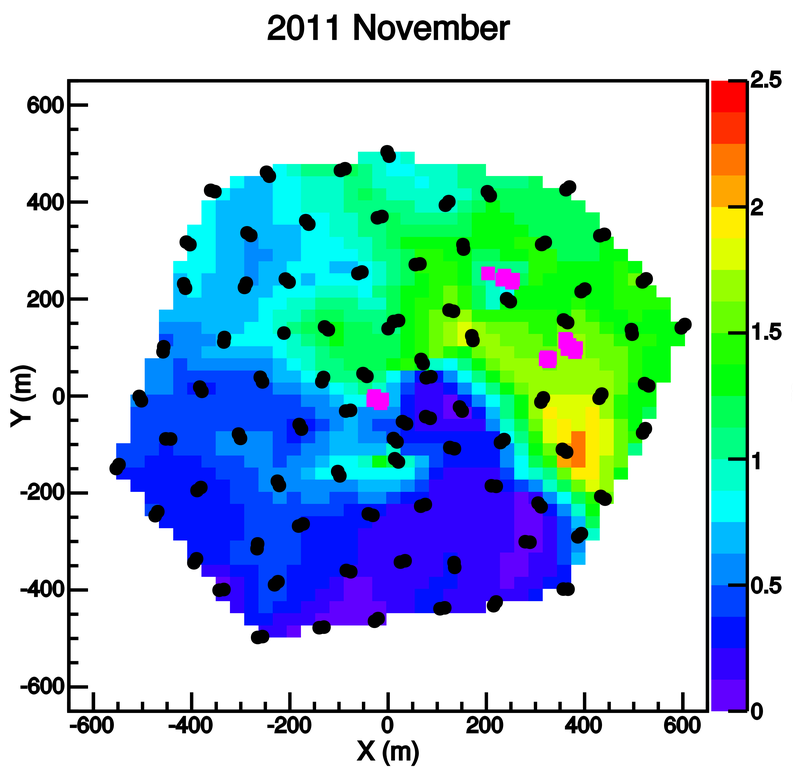
Bias: Near zero

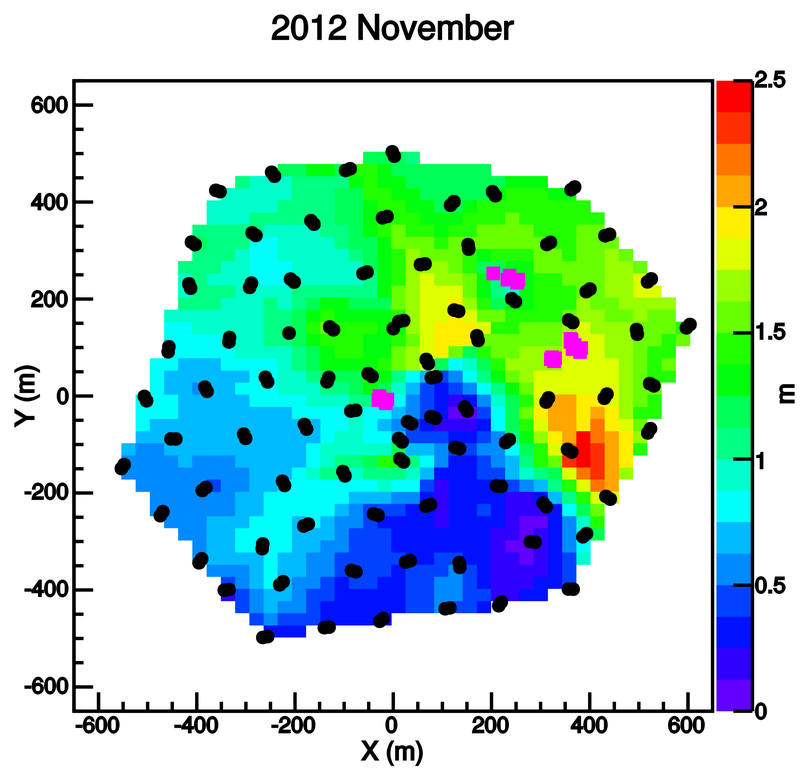
Resolution: Best between 10-300 PeV (Worsens where position/ anguar resoution suffer due to misreconstructions



Oh Snow!







Snow accumulates at ~20 cm per year on average.

Coincident Detector Systematics

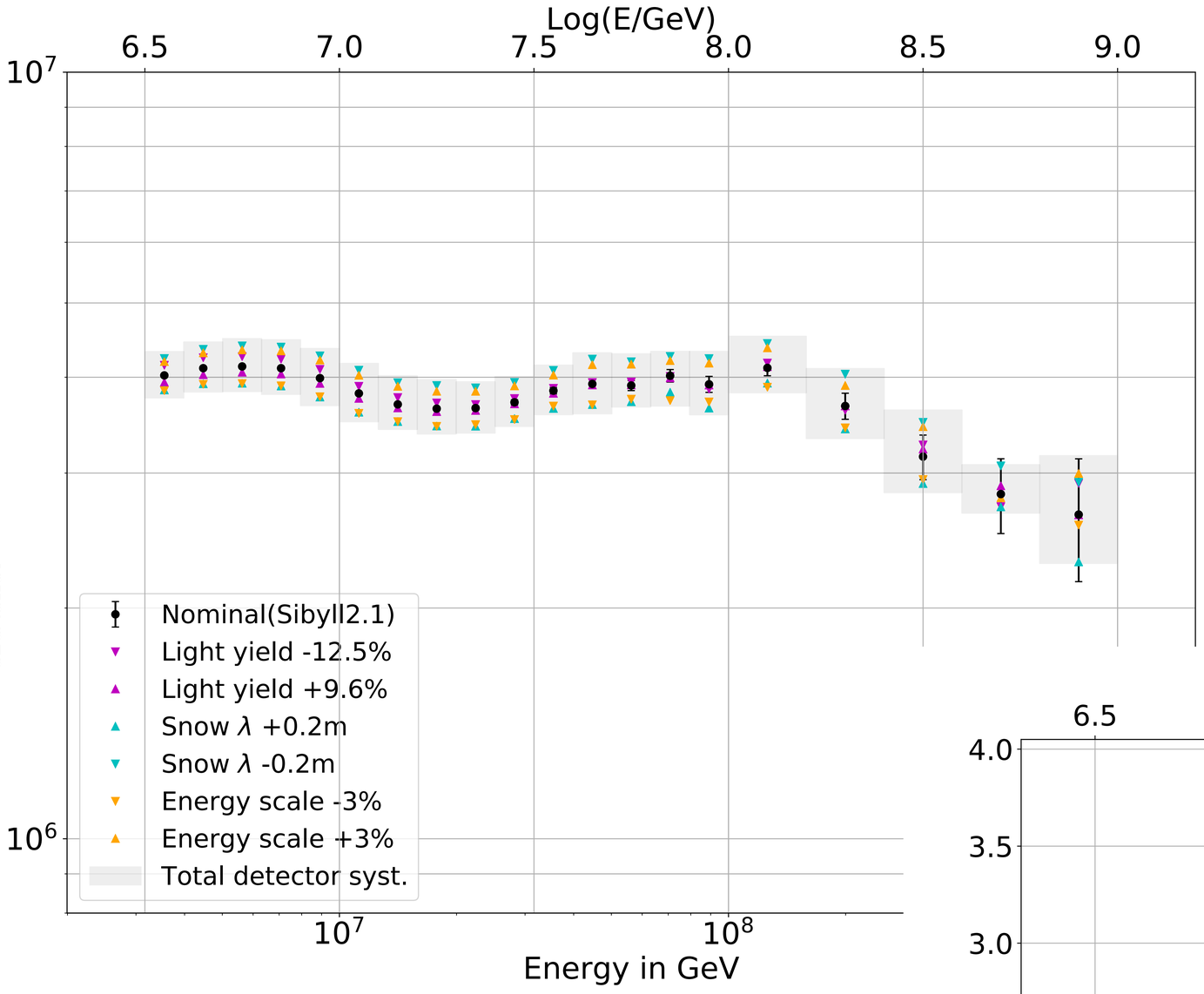
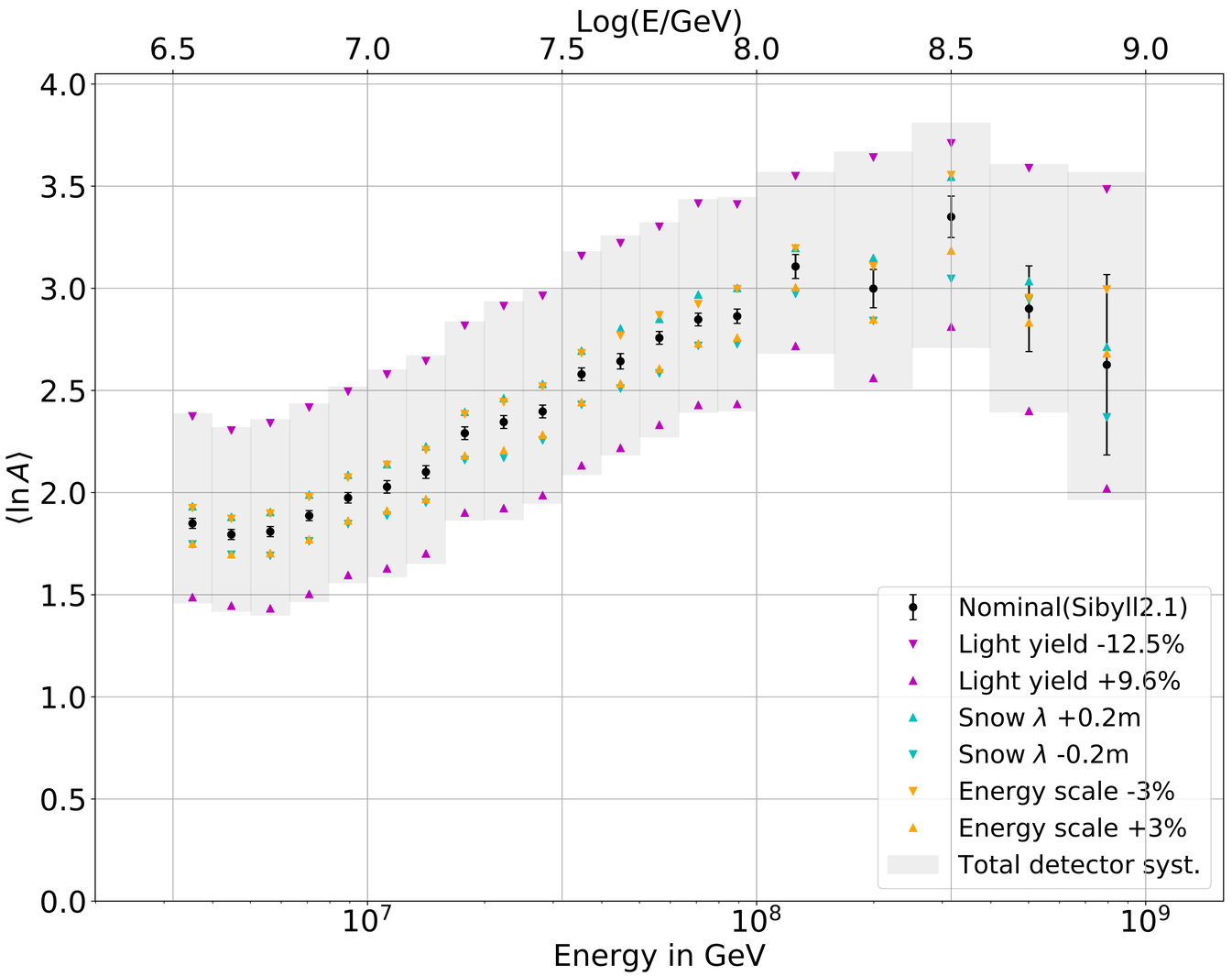
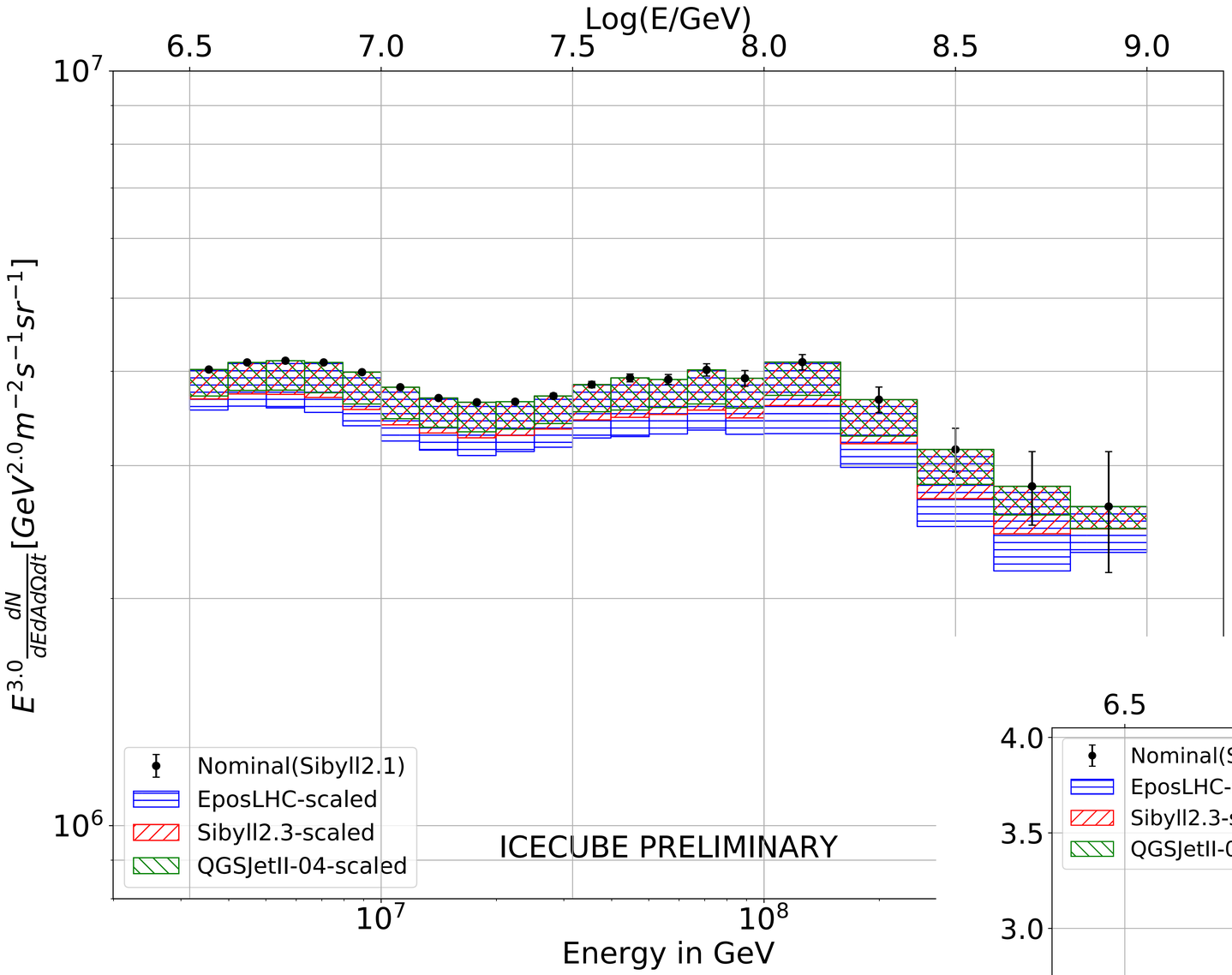


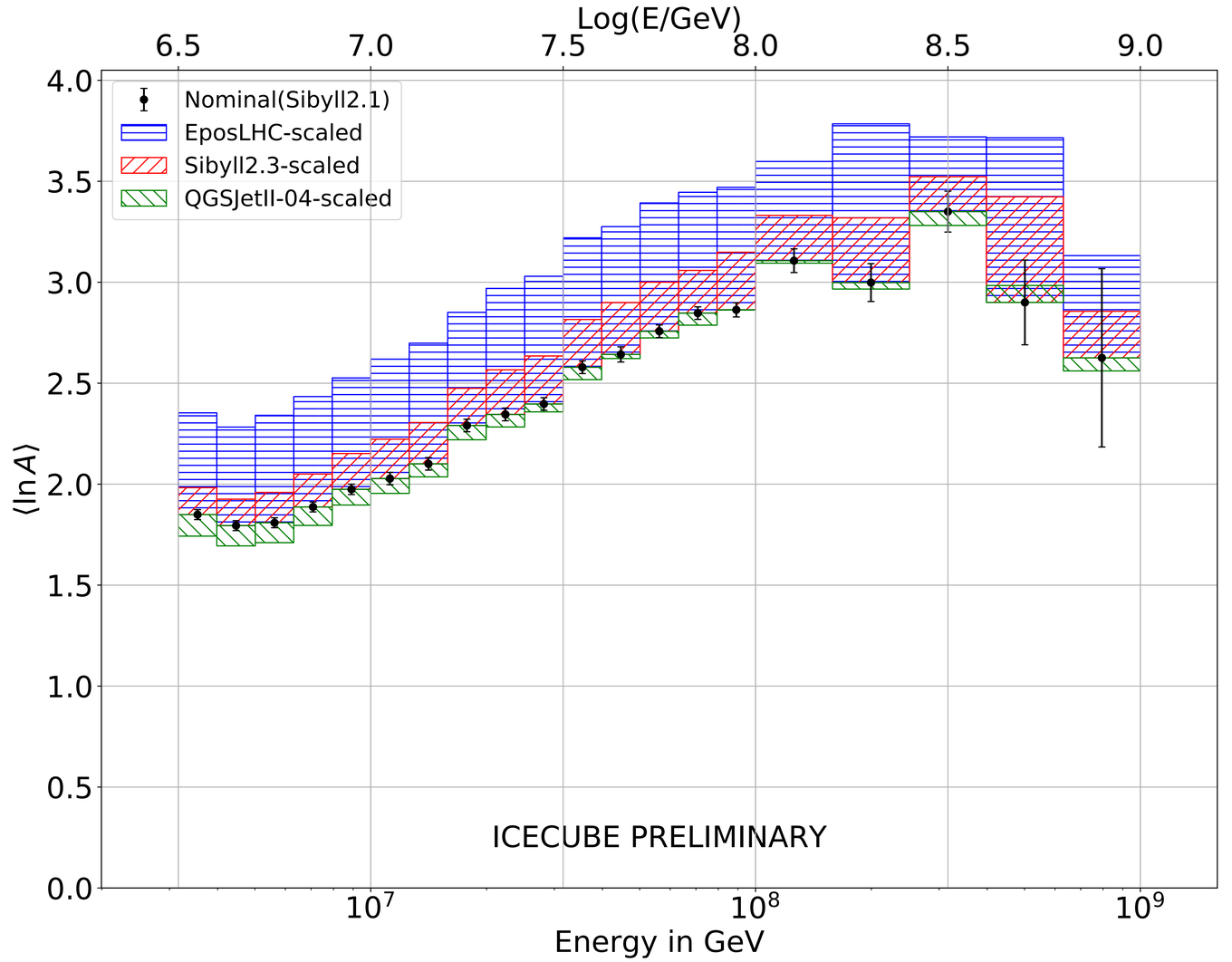
TABLE II. Sytematic light yield shift

Effect	Light yield shift
+10% scattering	+3.6%
+10% absorption	−11.8%
−7.1% scattering and absorption	+7%
30 cm hole ice scattering	+4.5%
100 cm hole ice scattering	−2.9%
DOM efficiency	±3%
Total Light Yield Effect	+9.6%,−12.5%



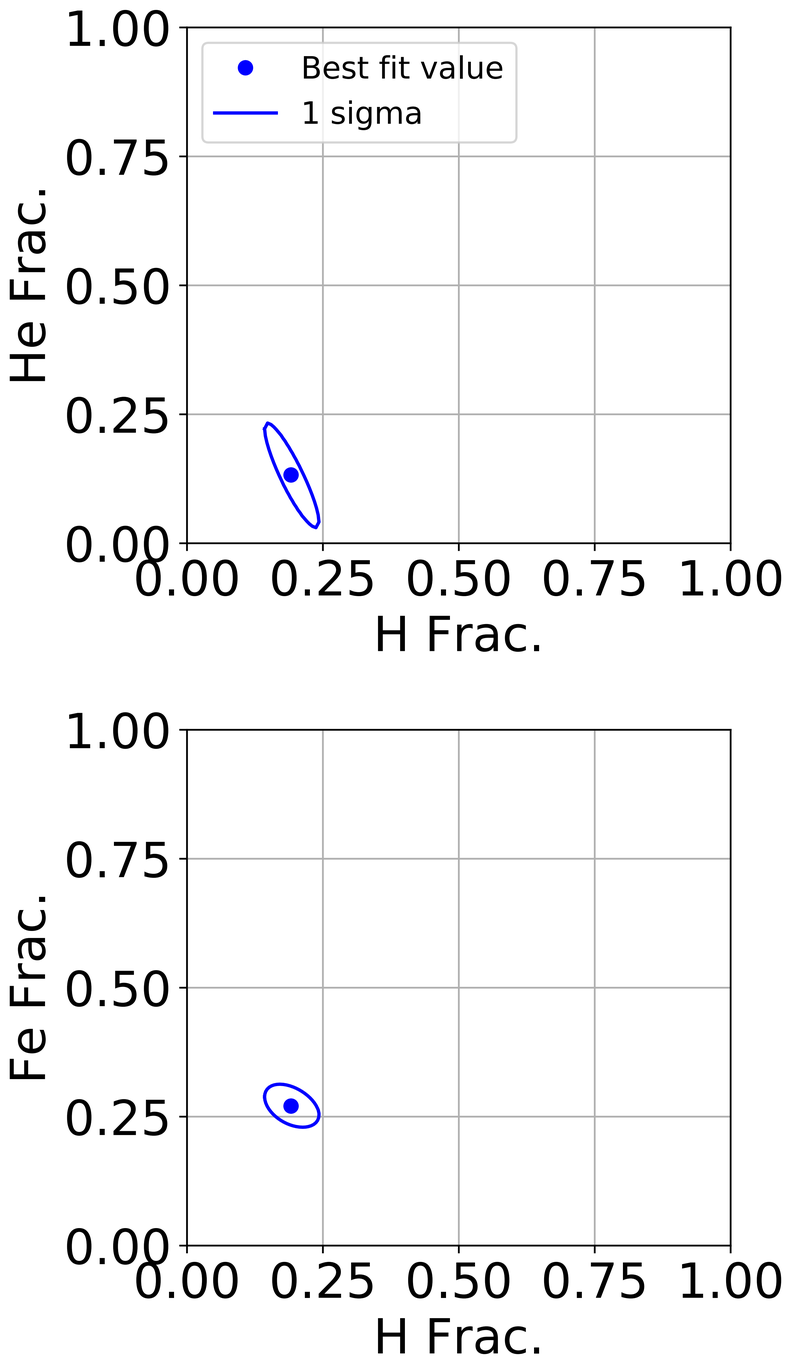
Model Systematics

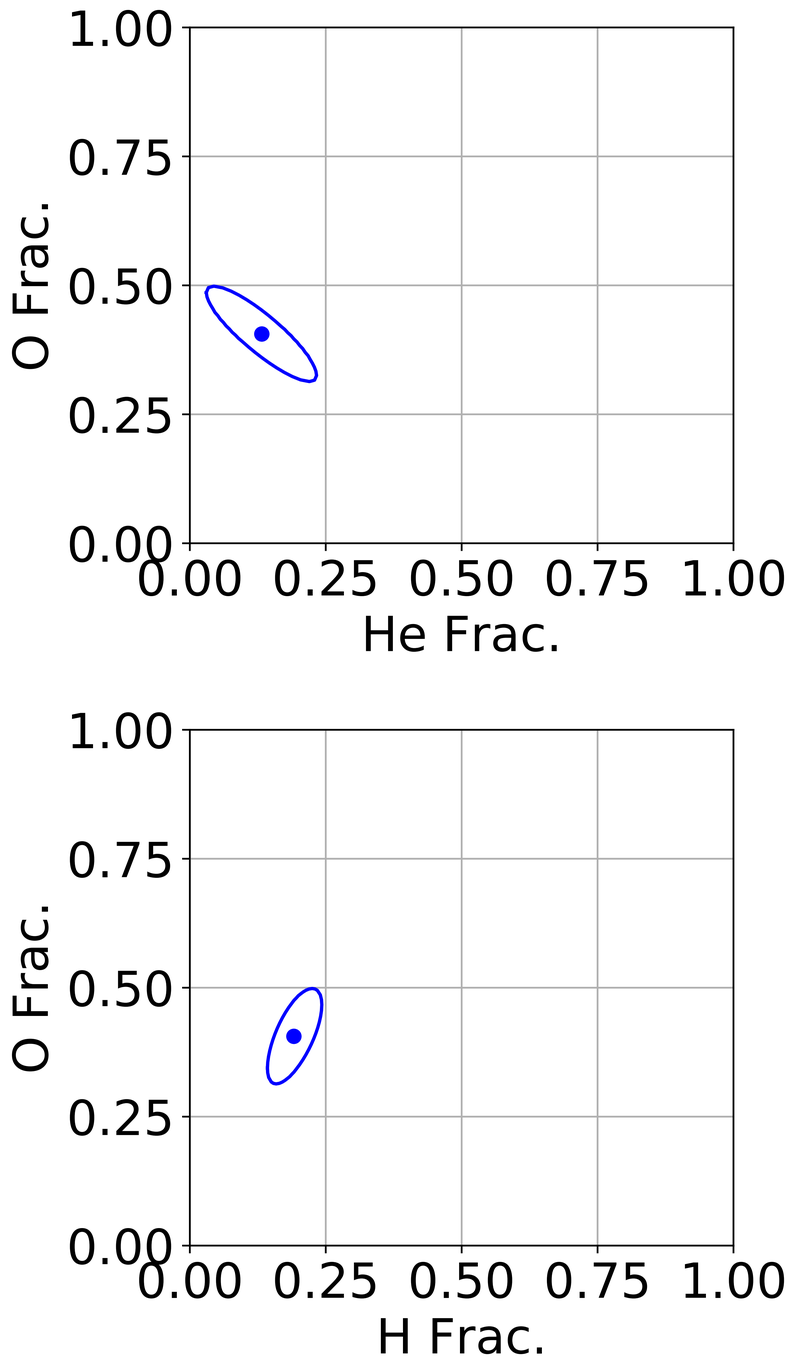


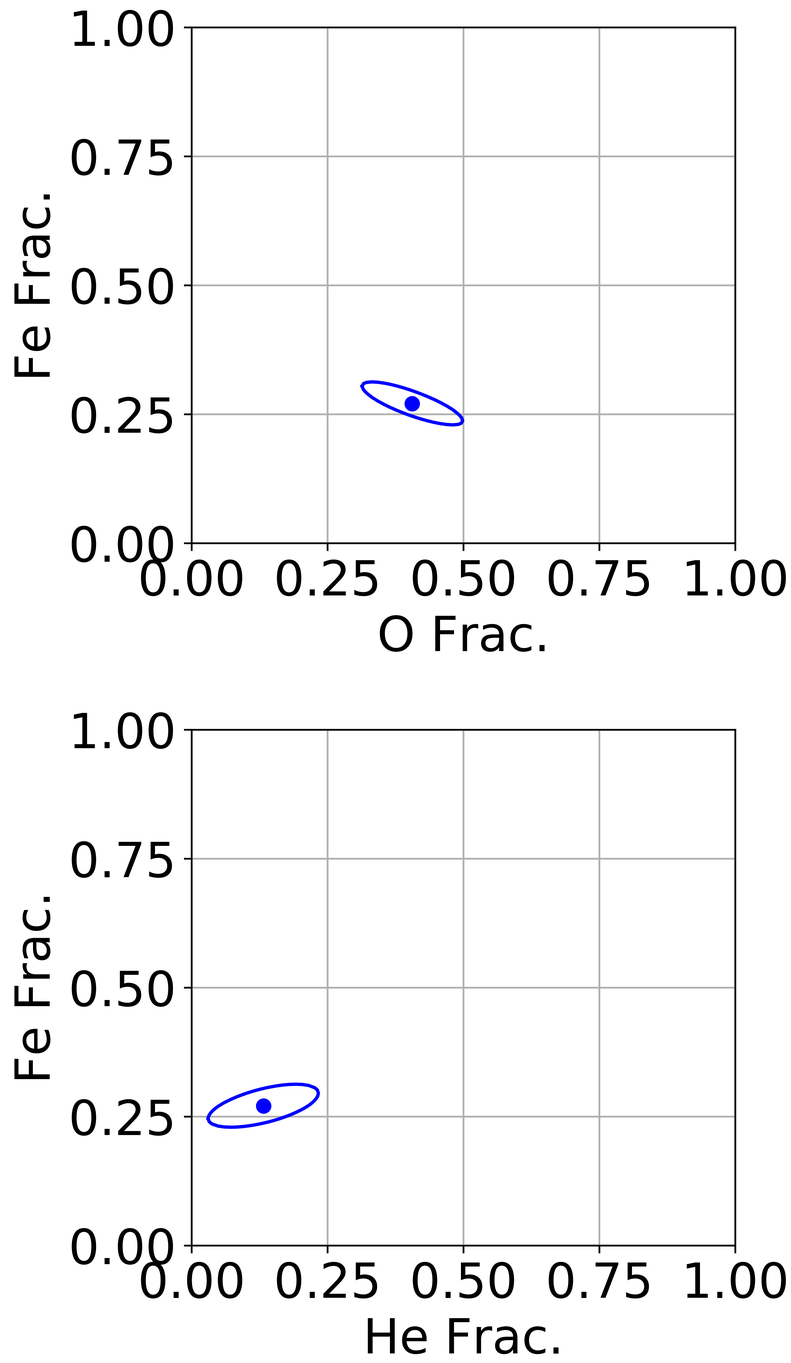
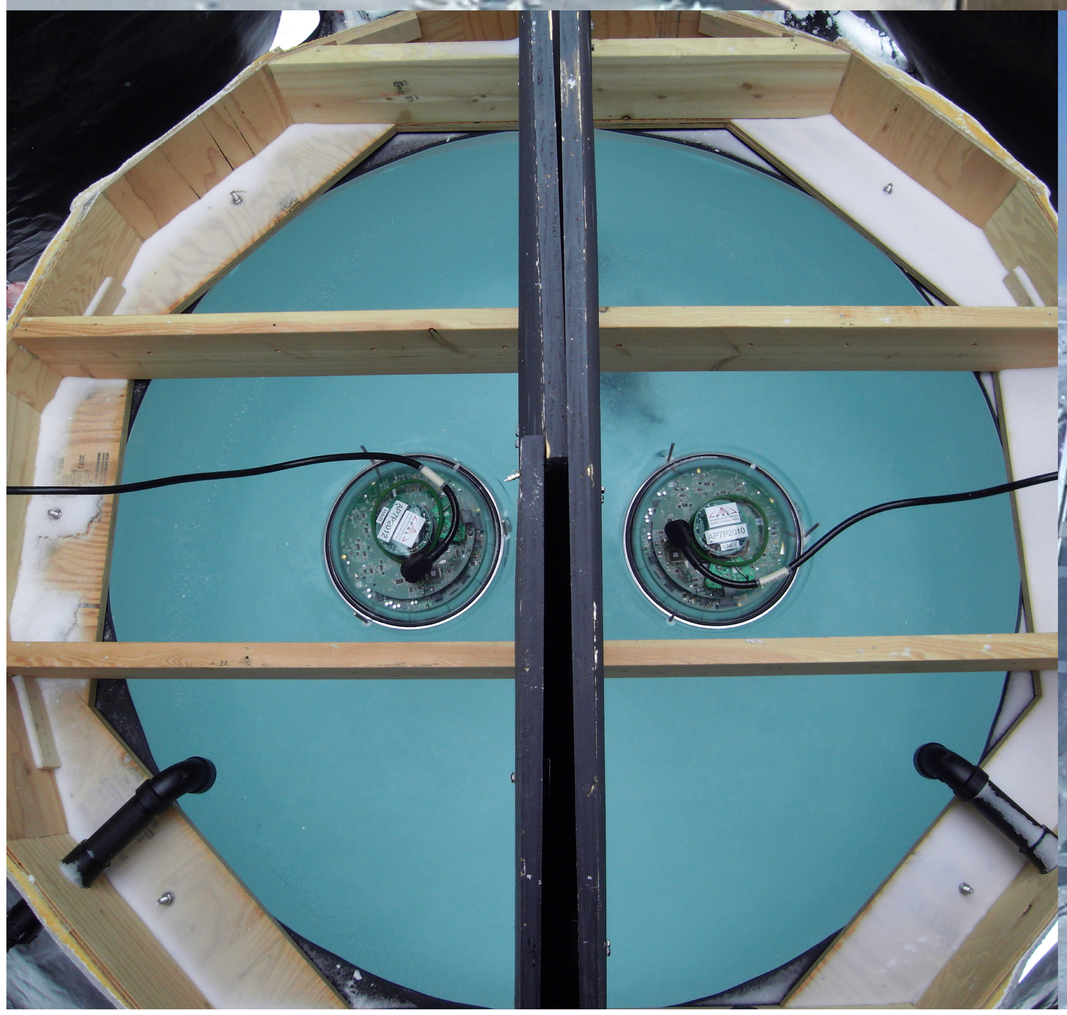
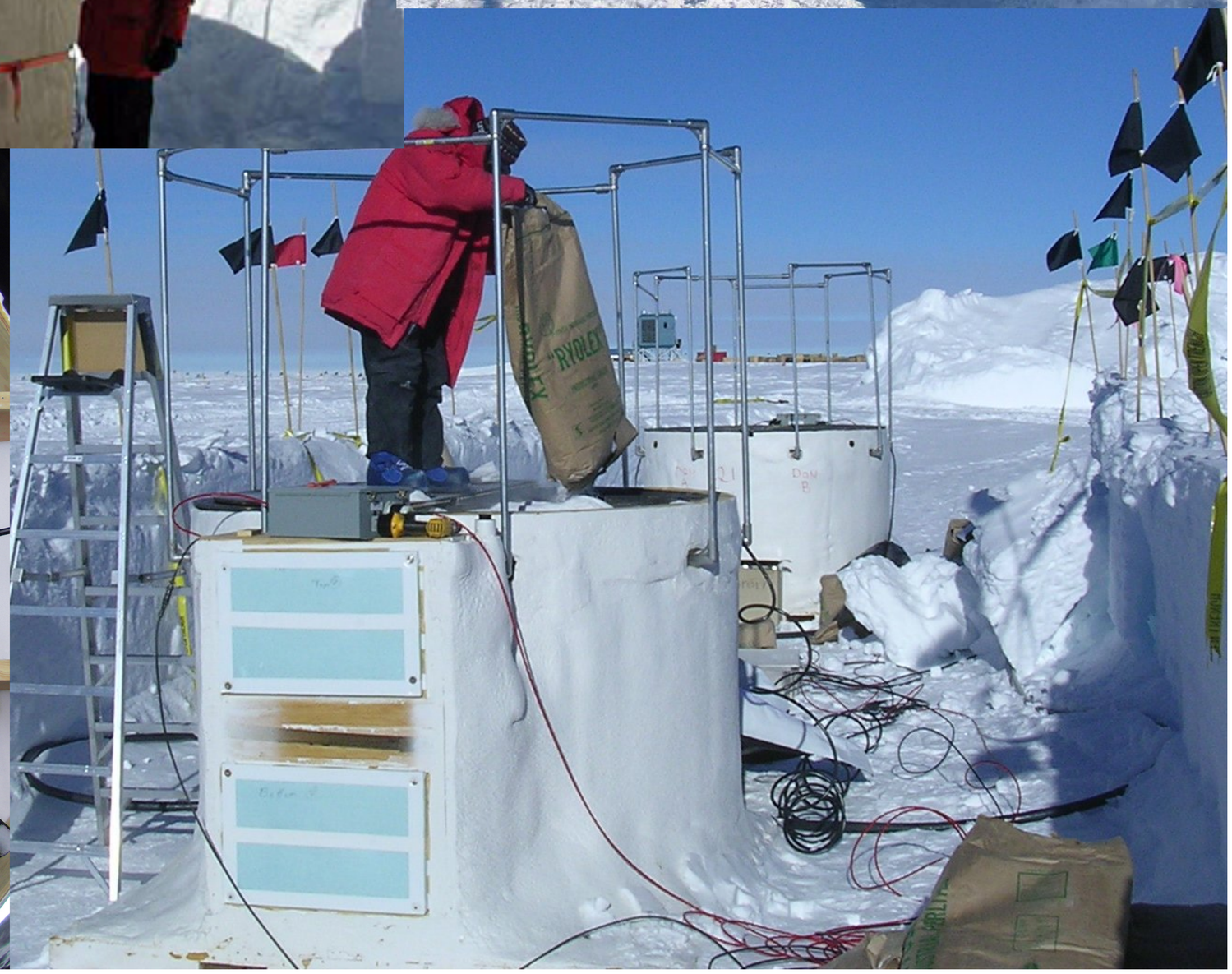


Correlations between Elements

Log(E/GeV): 7.4 - 7.5







IceTop In the Wild