Status of the IceTop air shower array at the South Pole

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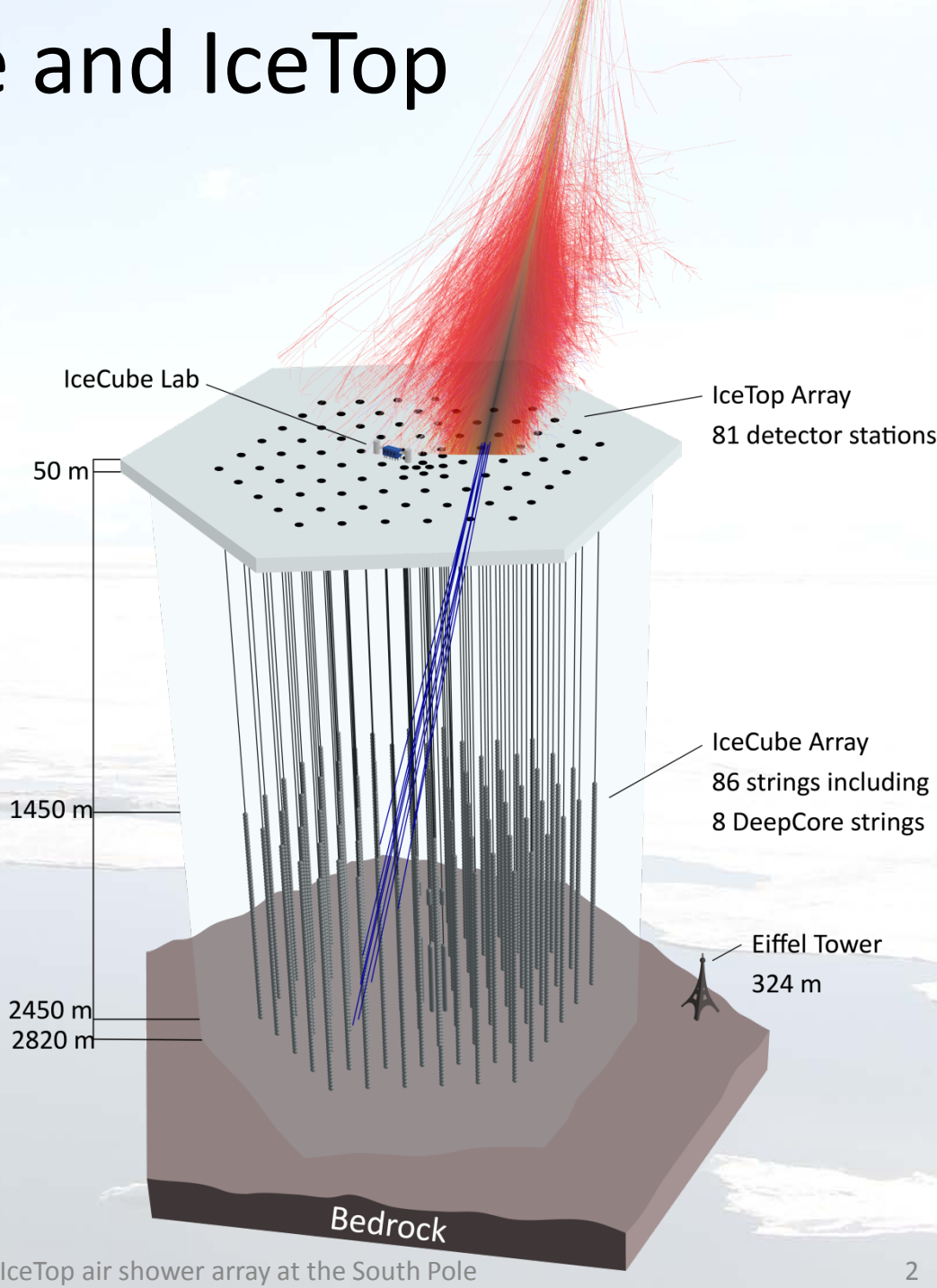
IceCube and IceTop

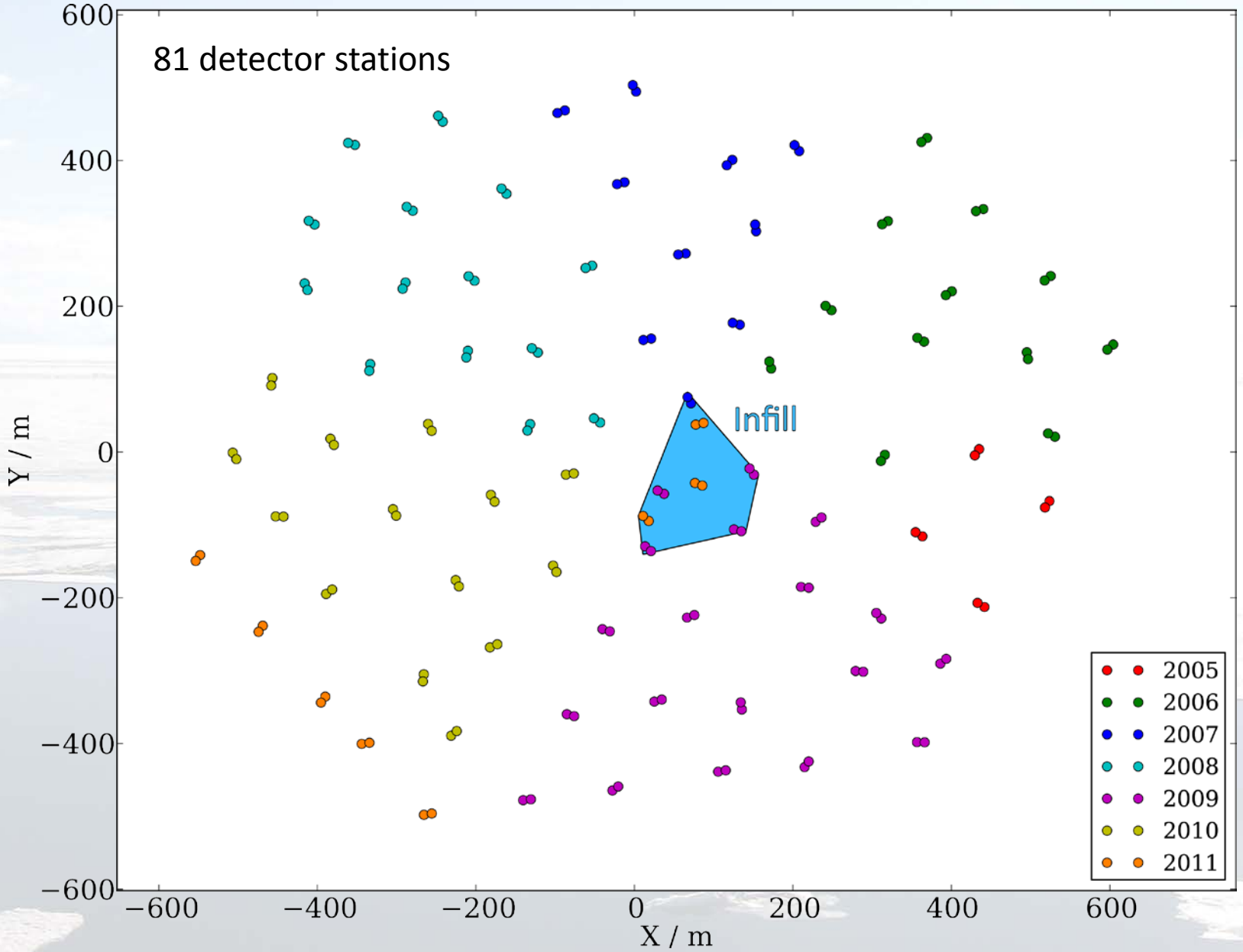
- 1km² air shower array
- 1km³ neutrino telescope
- **3D air shower detector**

- 2835 m.a.s.l. – 690g/cm²
- 125m detector spacing
- **Energy range 300TeV – 1EeV**

- **Electromagnetic** component in IceTop
- TeV **muon bundle** in IceCube

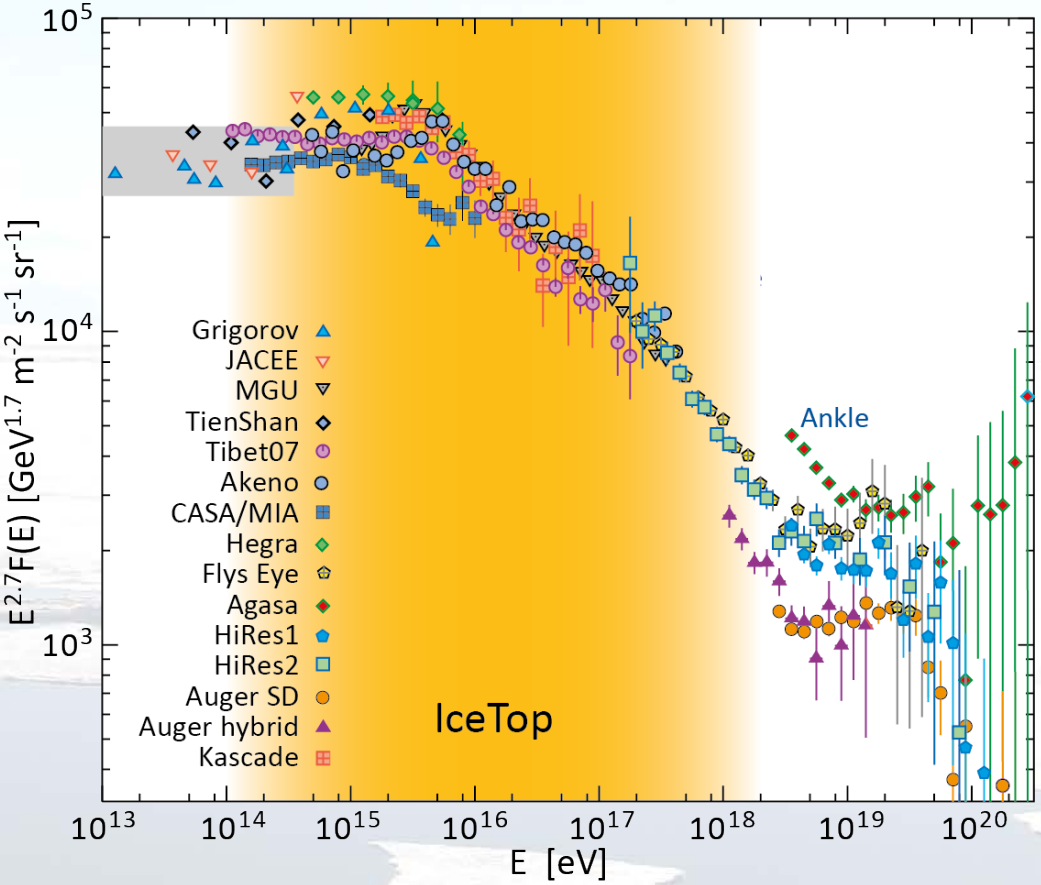


IceTop Array

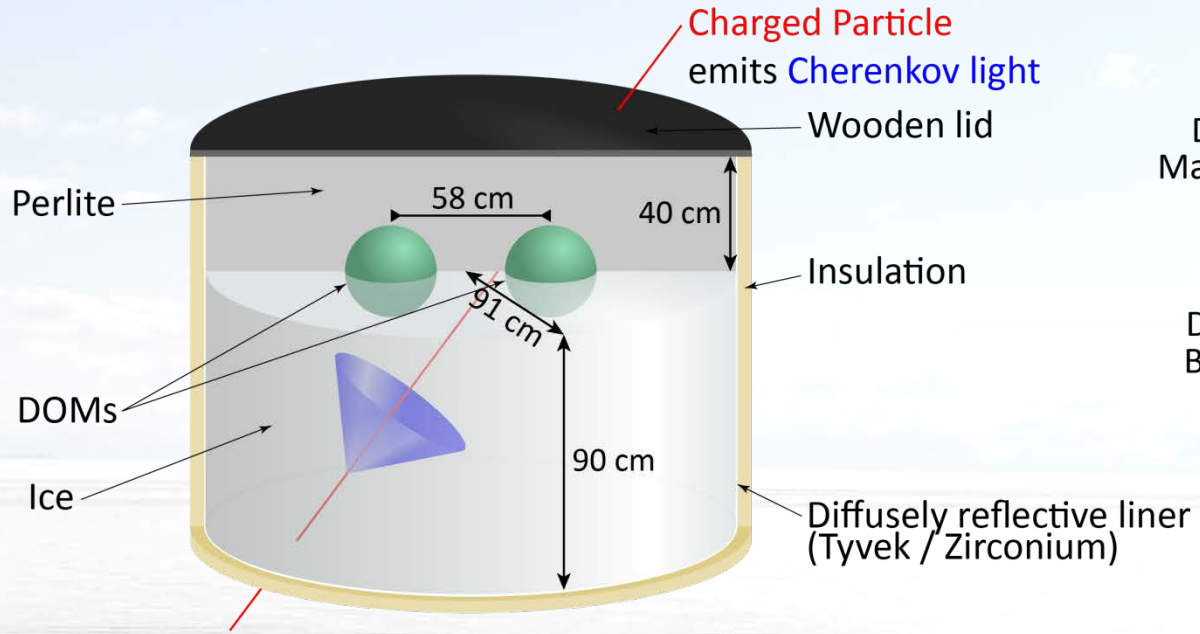


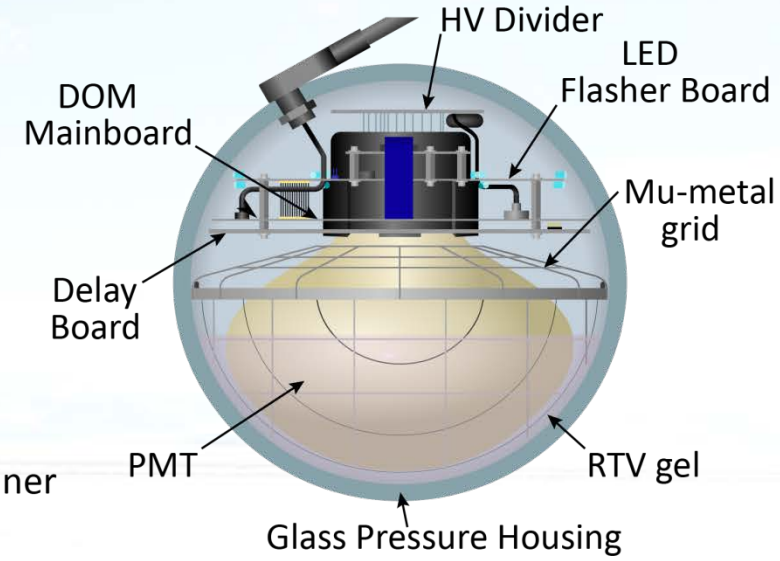
IceTop Energy Range

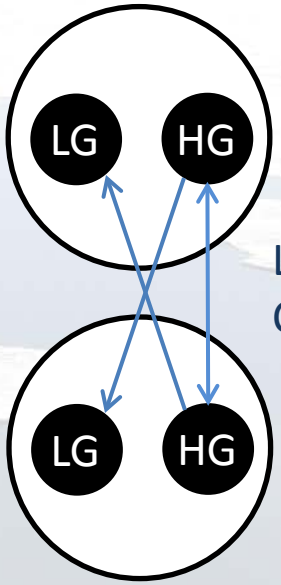
- **Threshold**: 300TeV
  Infill: ~100TeV
  - Overlap with **direct measurements**
- **Max. energy**: O(1EeV)
  Limited by statistics
  - Connection to **Auger**
- Knee and 2nd knee
- End of galactic cosmic rays?
- Spectrum and composition: Important information on **acceleration mechanisms**



IceTop Tanks

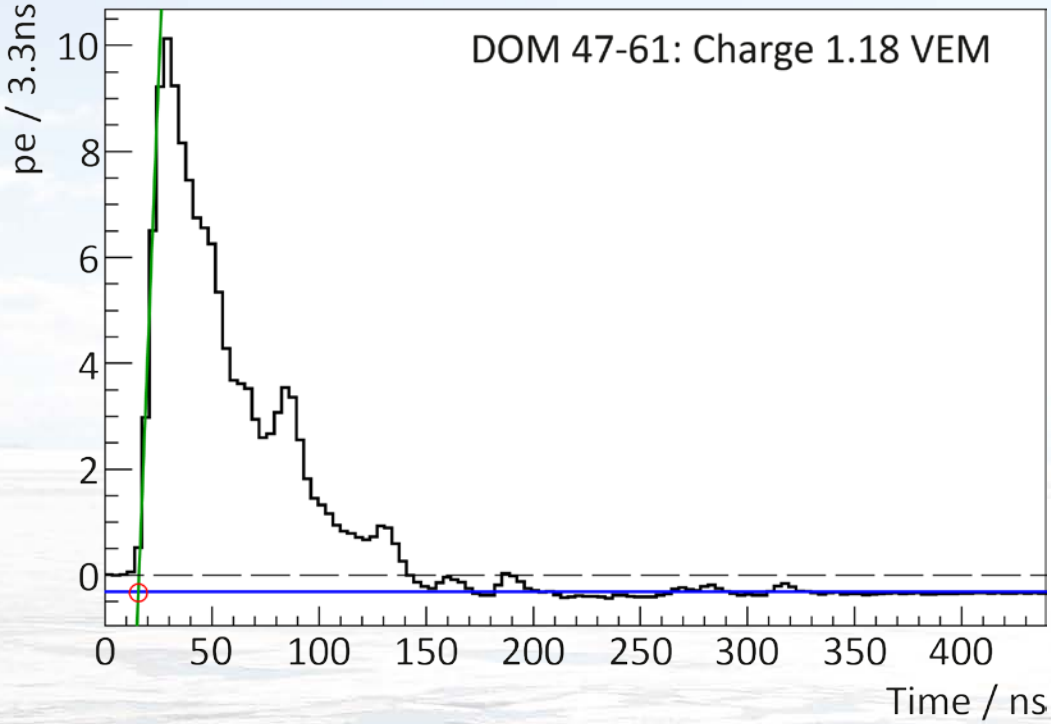


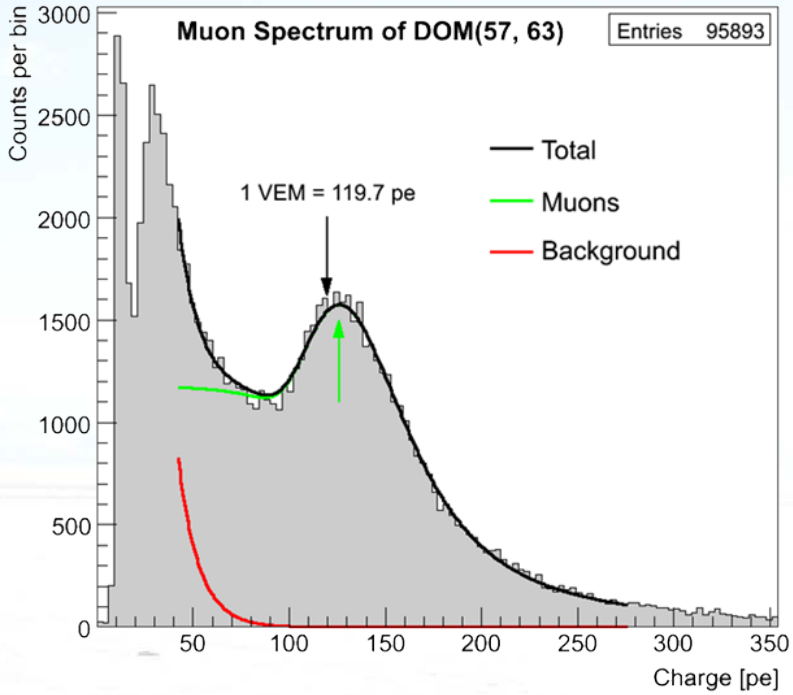




Local
Coincidence

Signals and Calibration

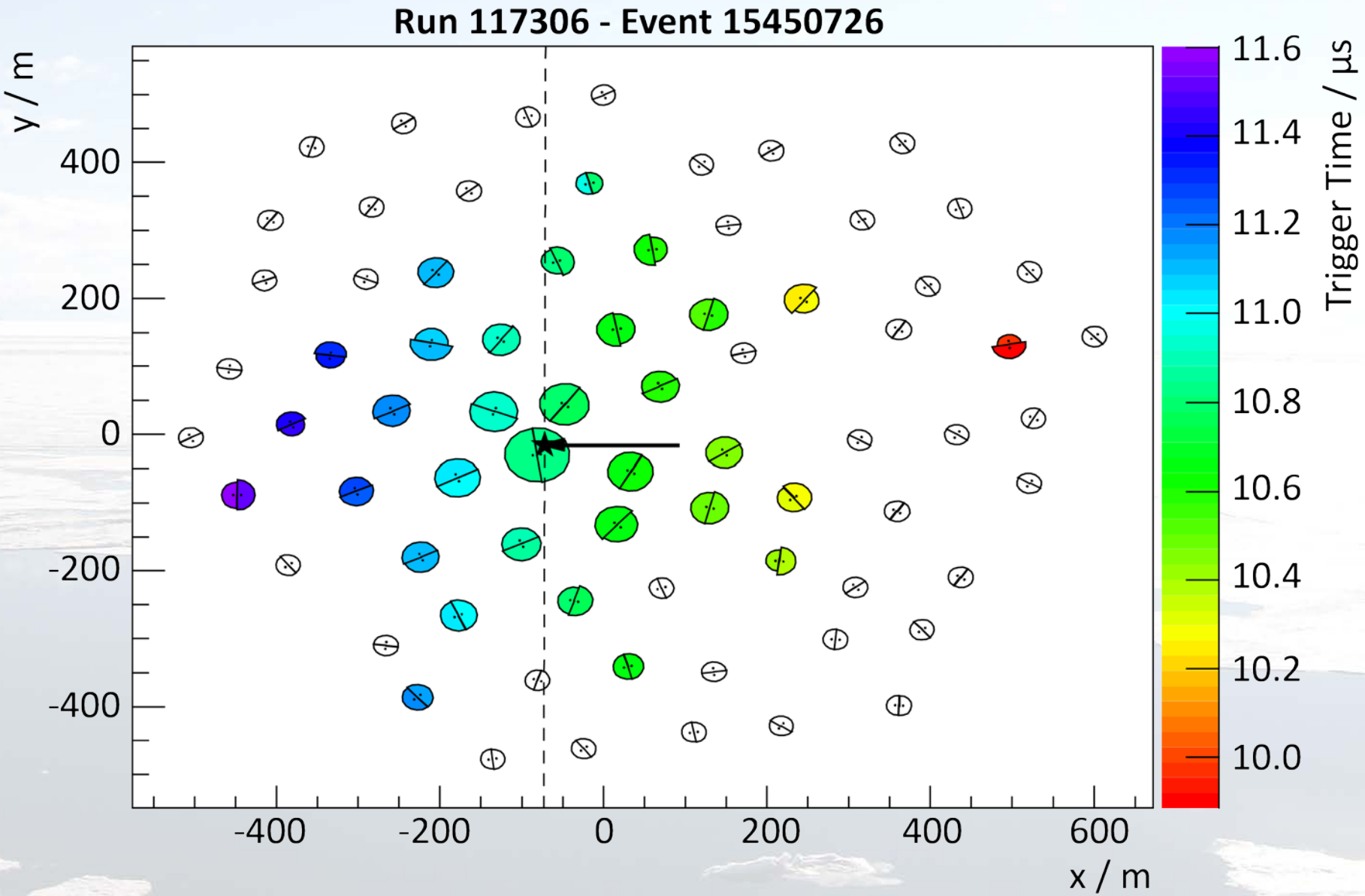




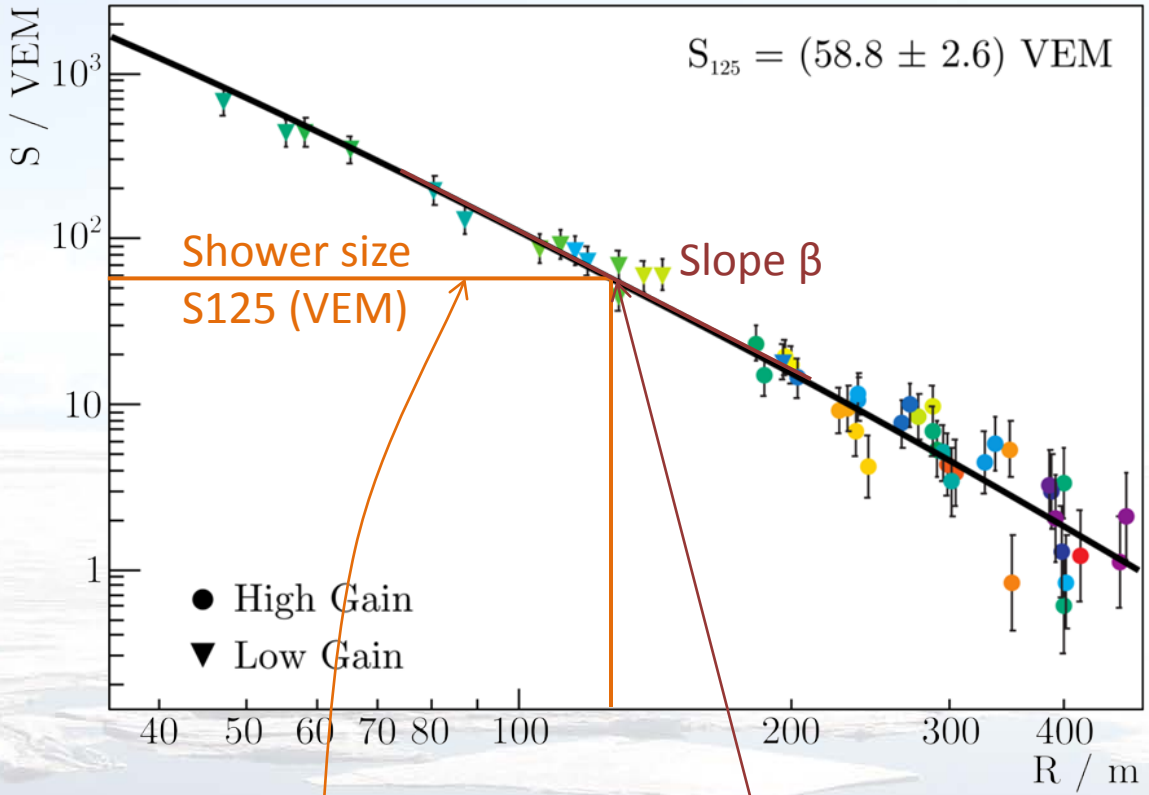
- DOMs record 422ns **waveforms**
- Signals dominated by **photons**
- Calibration using **single muons**
  - Large number of muons from low energy primaries
  - Distinctive light yield from muons
  - Position of “muon peak” = 1 Vertical Equivalent Muon


AIR SHOWER RECONSTRUCTION

Air Shower Footprint



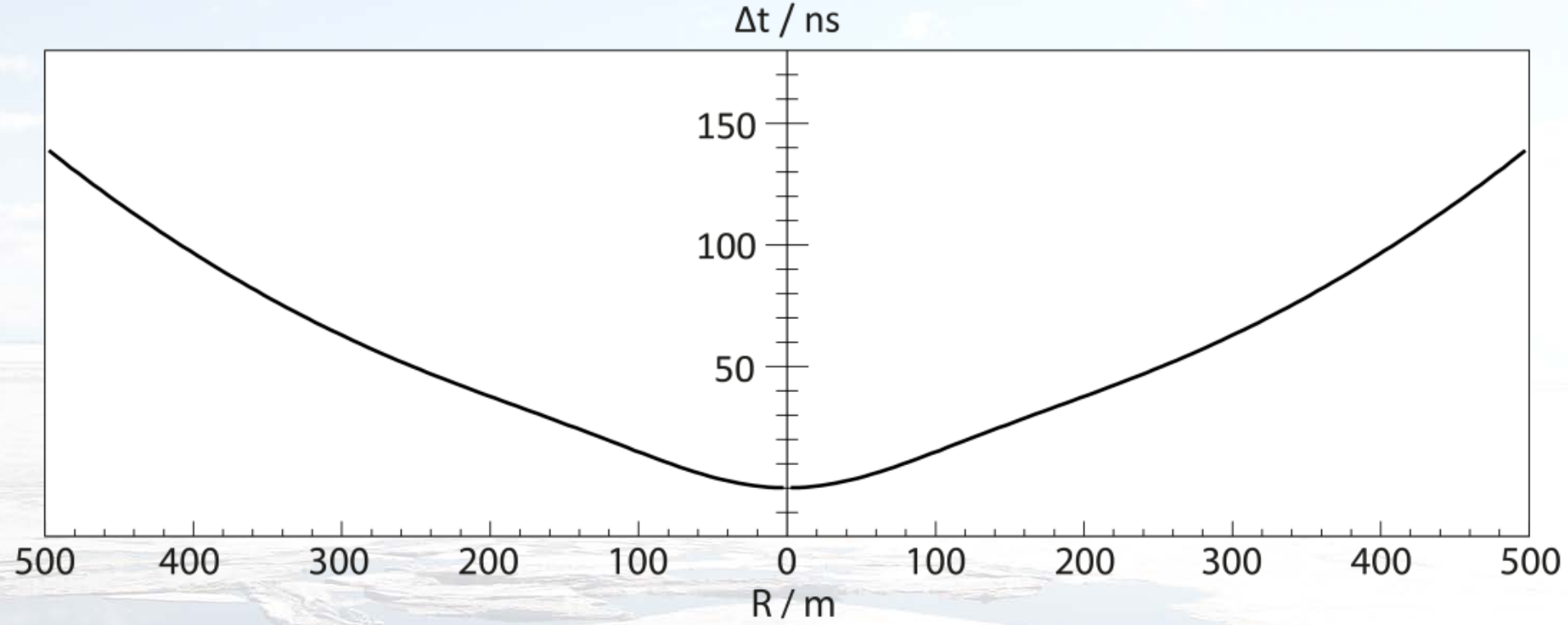
Lateral Distribution Function



$$S(R) = S_{125} \cdot \left(\frac{R}{125\ \mathrm{m}}\right)^{-\beta-\kappa \log(R/125\ \mathrm{m})}$$

$$\kappa = 0.303 = \mathrm{const}$$

Shower Front



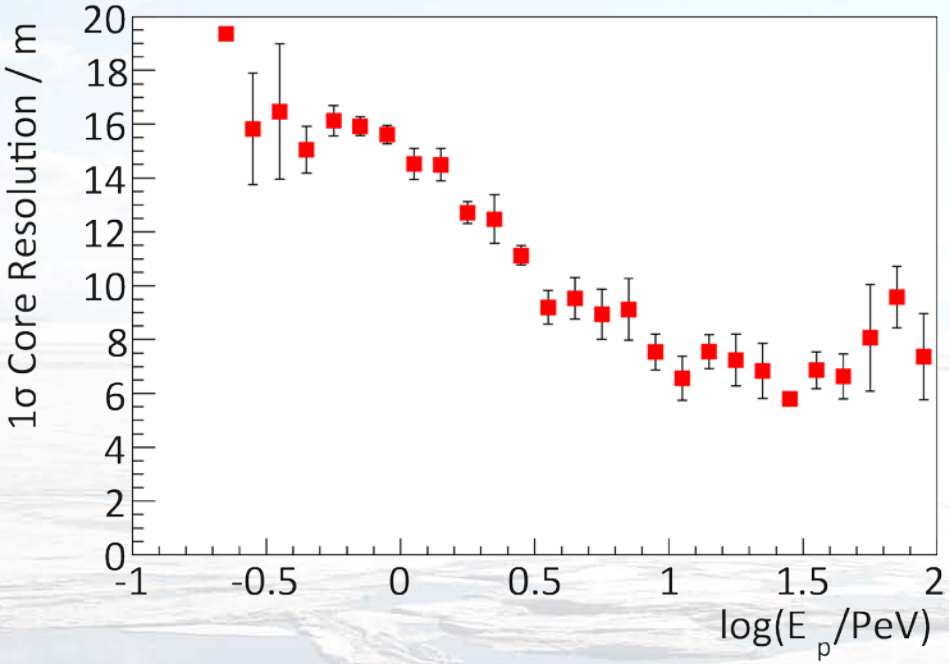
- Fixed shape:

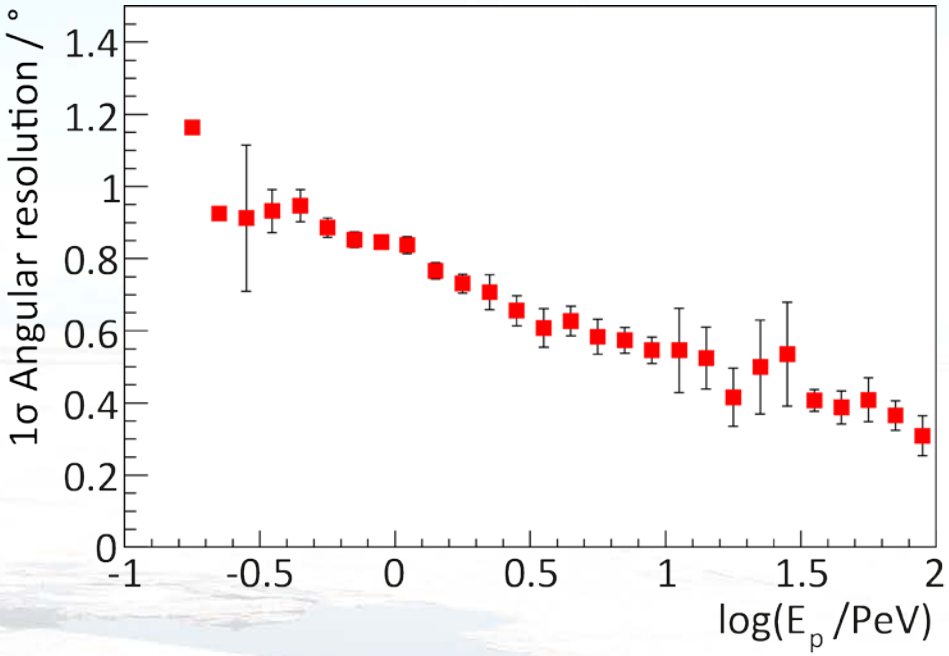
$$\Delta t(R) = a\,R^2 + b\left(\exp\left(-\frac{R}{2\sigma^2}\right) - 1\right)$$

- a, b, and σ are constants

Reconstruction Performance

26-station configuration





- After **containment** cuts:
  - Core position resolution < 10m
  - Angular resolution < 1°


SPECTRUM & COMPOSITION

Composition Measurement with IceTop

Electromagnetic component

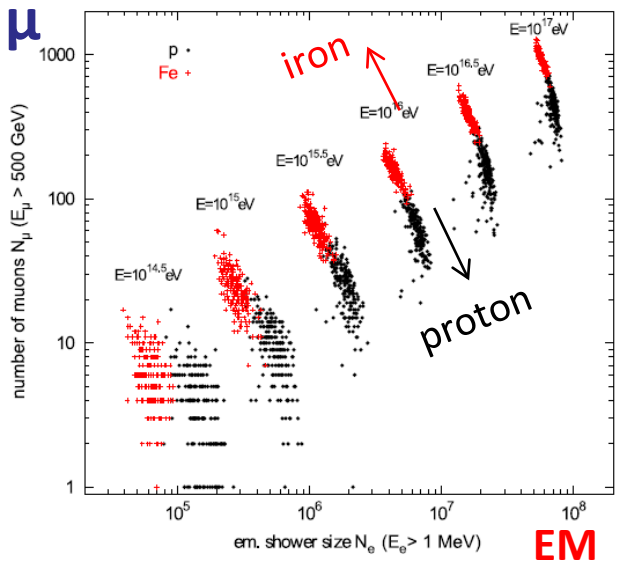
GeV muons

Inclined Showers

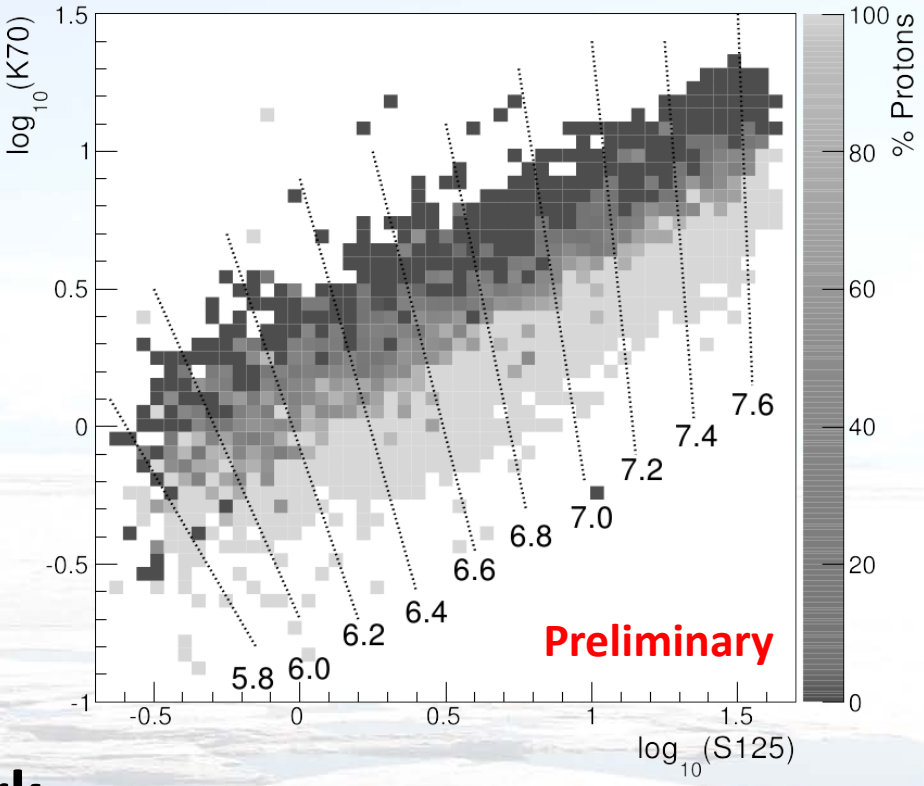
IceTop

IceCube

TeV muons

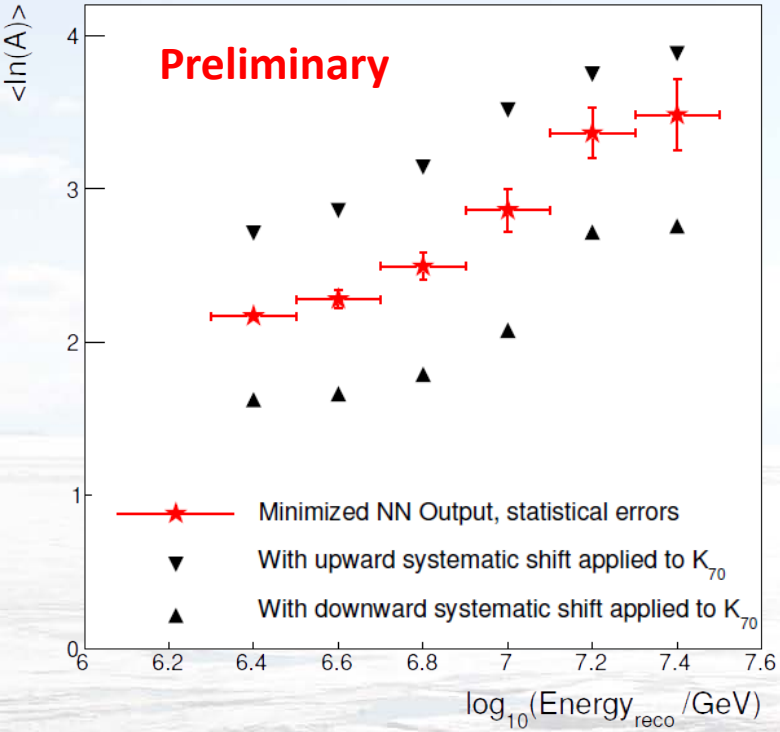


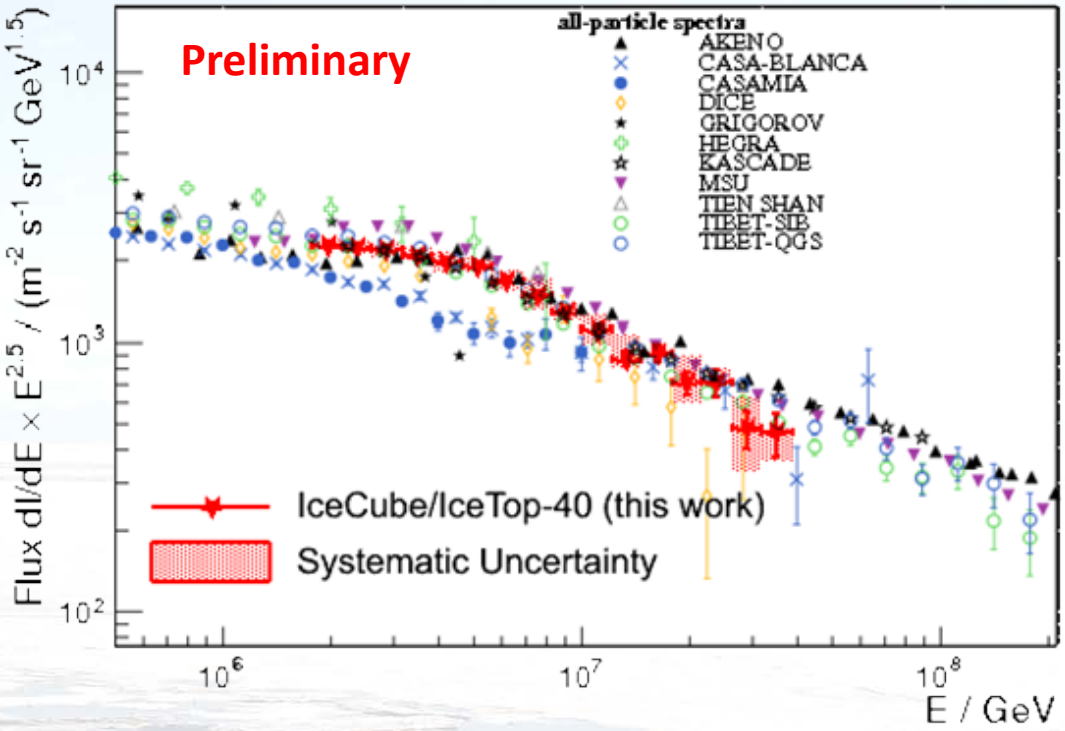
IceTop-IceCube Coincidences



- **Neural network**
- Inputs:
  - Shower size S_{125}
  - Muon bundle size K70
- Outputs:
  - Primary energy
  - Primary mass

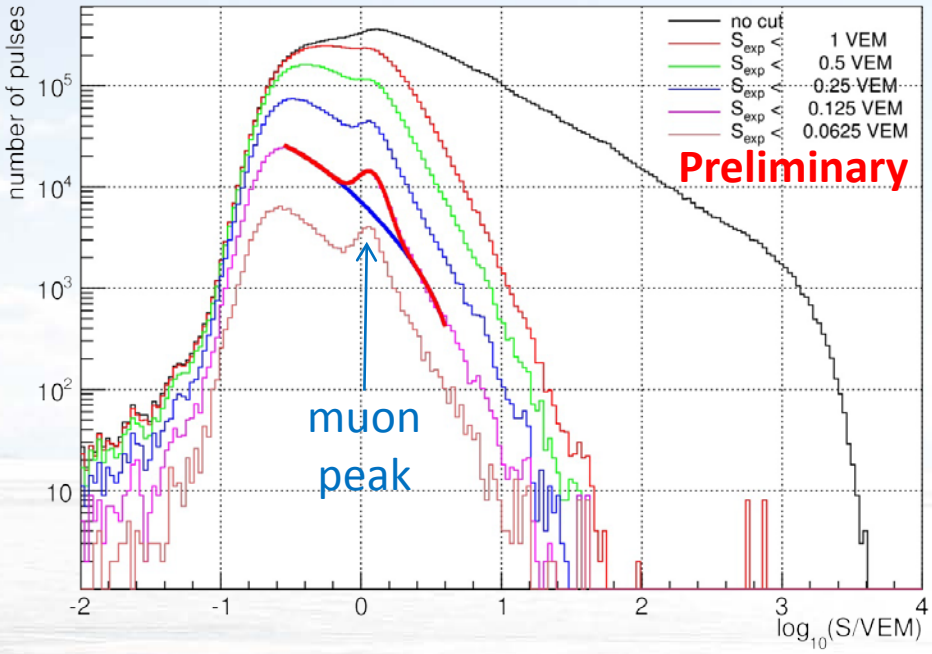
IceTop-IceCube Coincidences

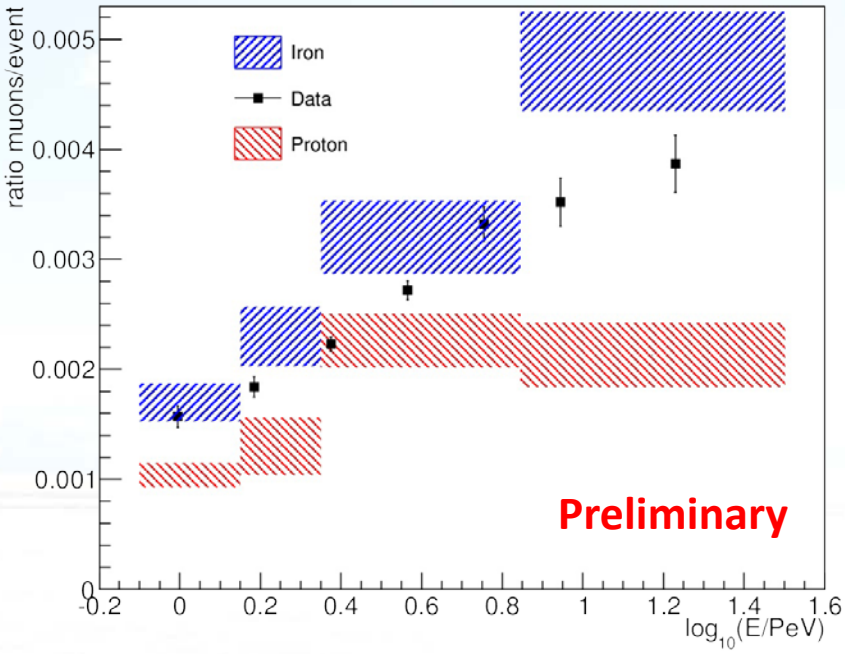




- **40-Station** configuration
- Sub-Array with only small amount of snow on tanks
- 1 month of data
- **Systematics** dominated

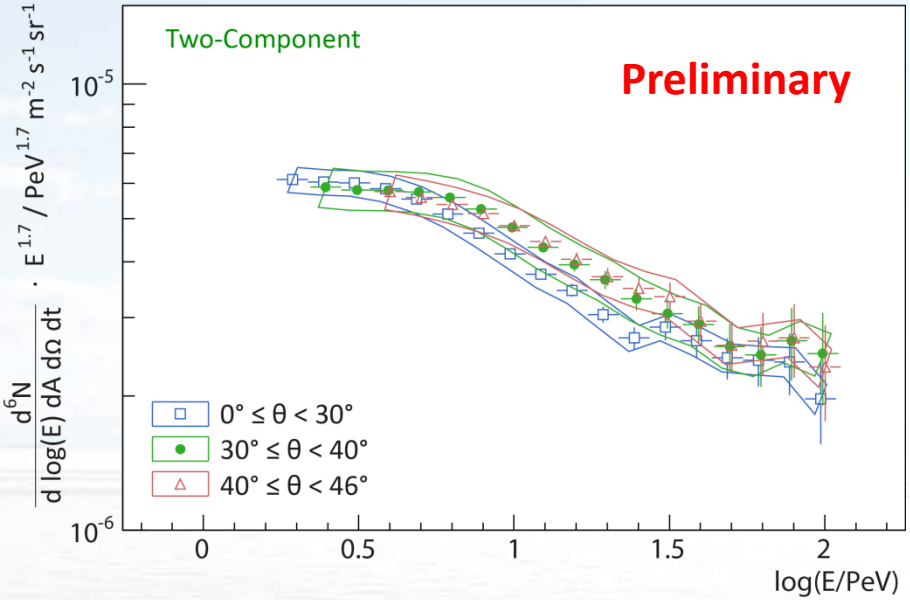
Muon Counting in IceTop

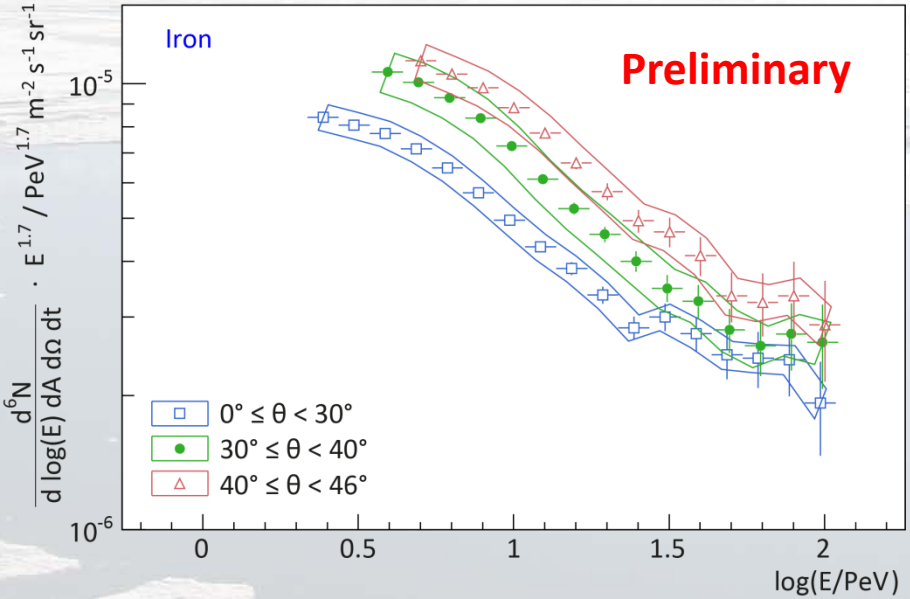




- **GeV muons** in IceTop tanks
- Muons ⇔ Large signals at shower **periphery**
- 1 VEM charge enhanced if $\langle \text{Signal} \rangle_{\text{em}} \ll \langle \text{Signal} \rangle_{\mu}$
- Statistical muon **counting**
- Will profit from **SLC**: Charge stamps if no Local Coincidence

Inclined Showers



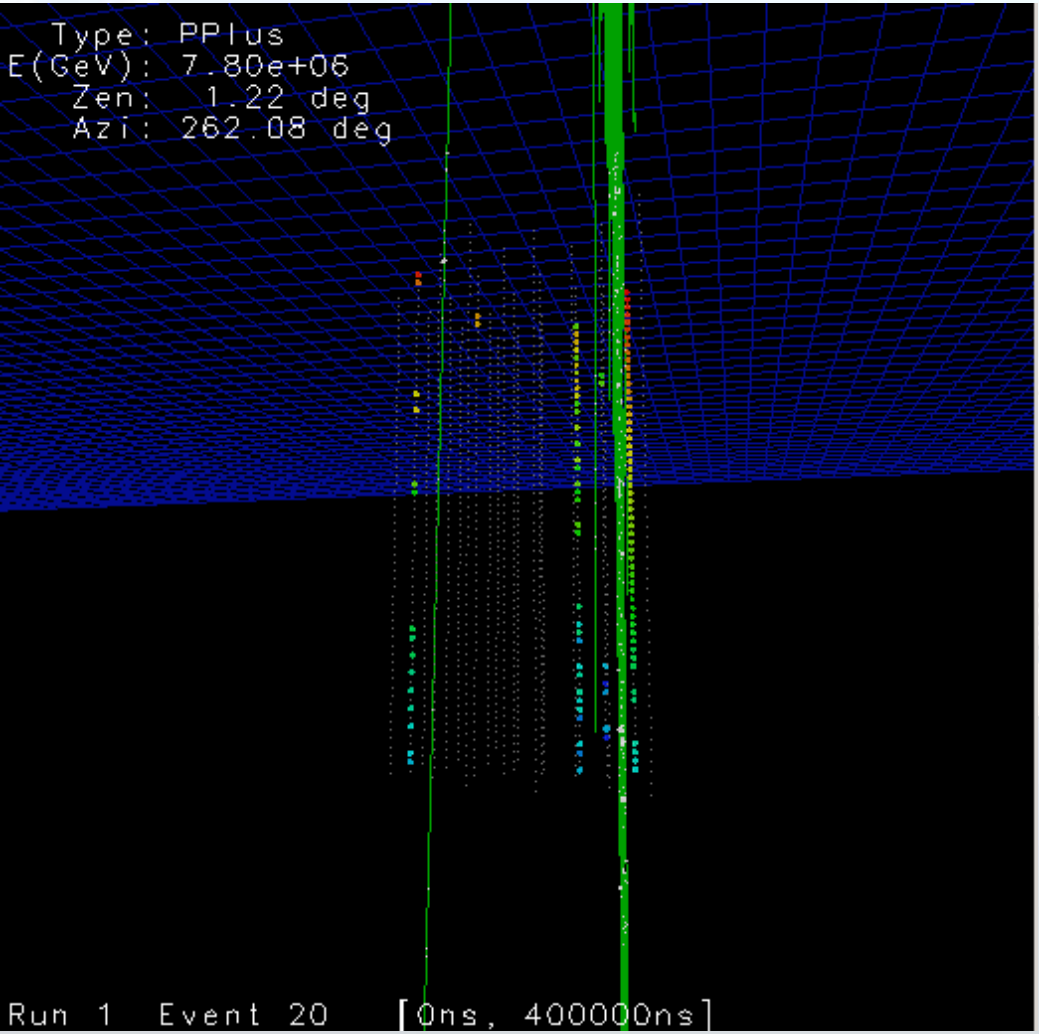


- Energy spectra in **different zenith angle** ranges
- **Heavier** primaries
  ⇒ **stronger** shower attenuation
- **Isotropy**
  ⇒ spectra must agree
- Composition sensitivity from **shower development**

- **IceTop-26** analysis 1-100PeV

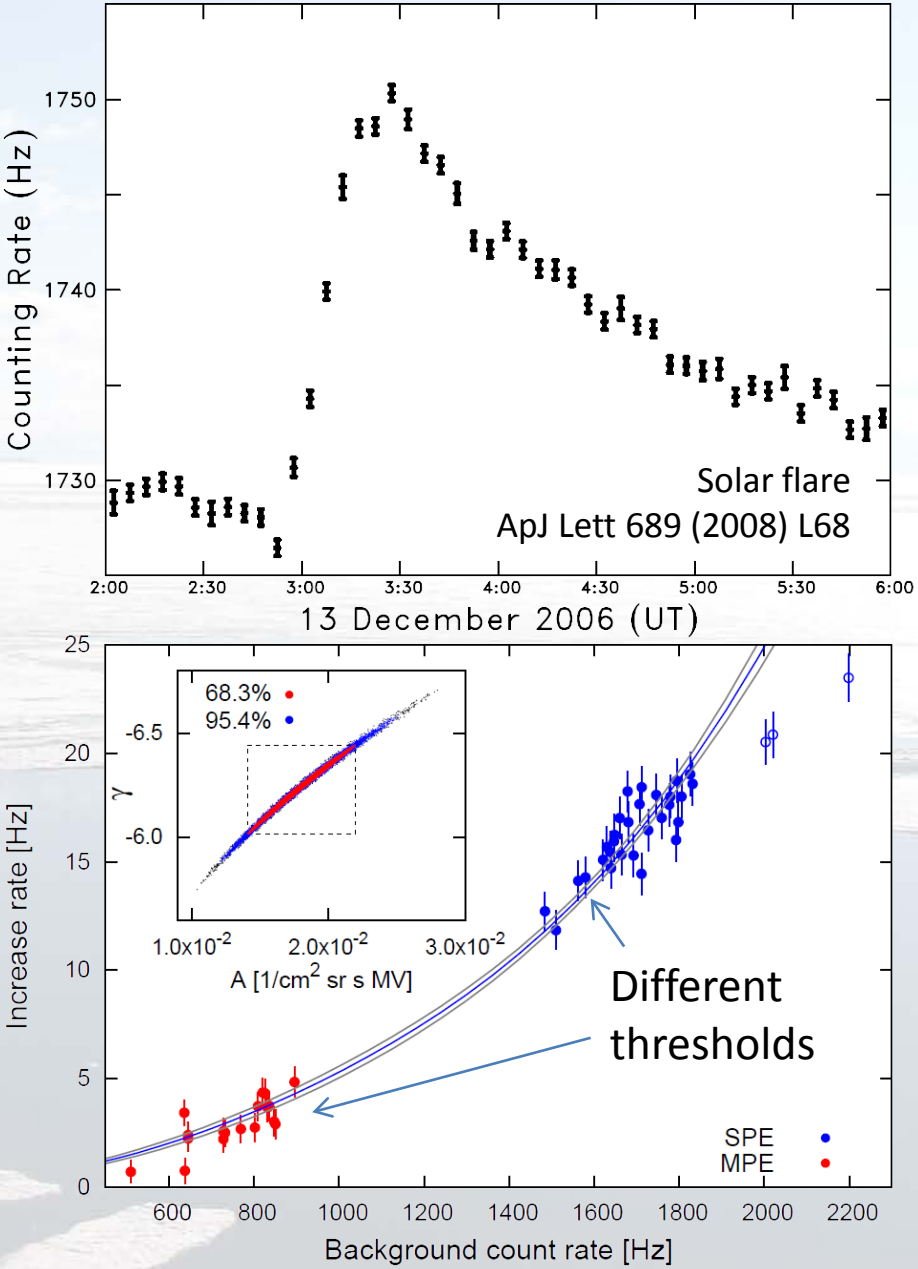

OTHER ANALYSES

High-p_T muons



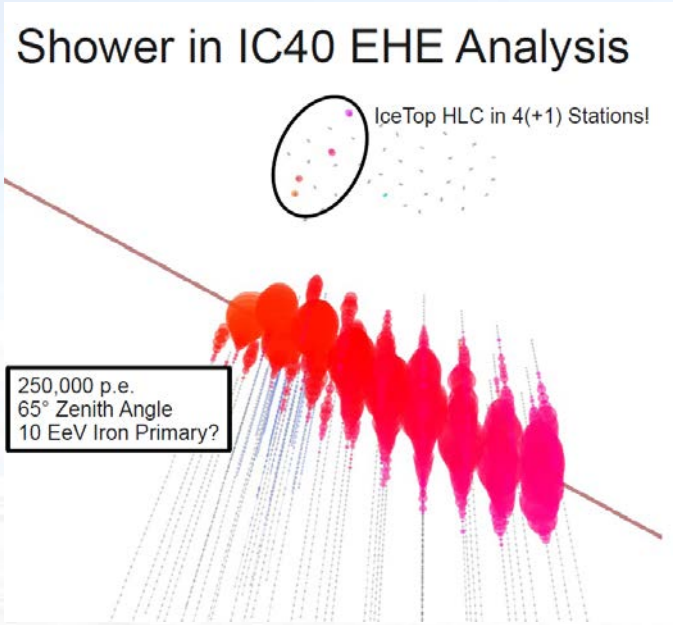
- Muon **separation spectrum** > 150m
- Test of models
- High-p_T muons from **charm decays**
- IceTop delivered **direction reconstruction**

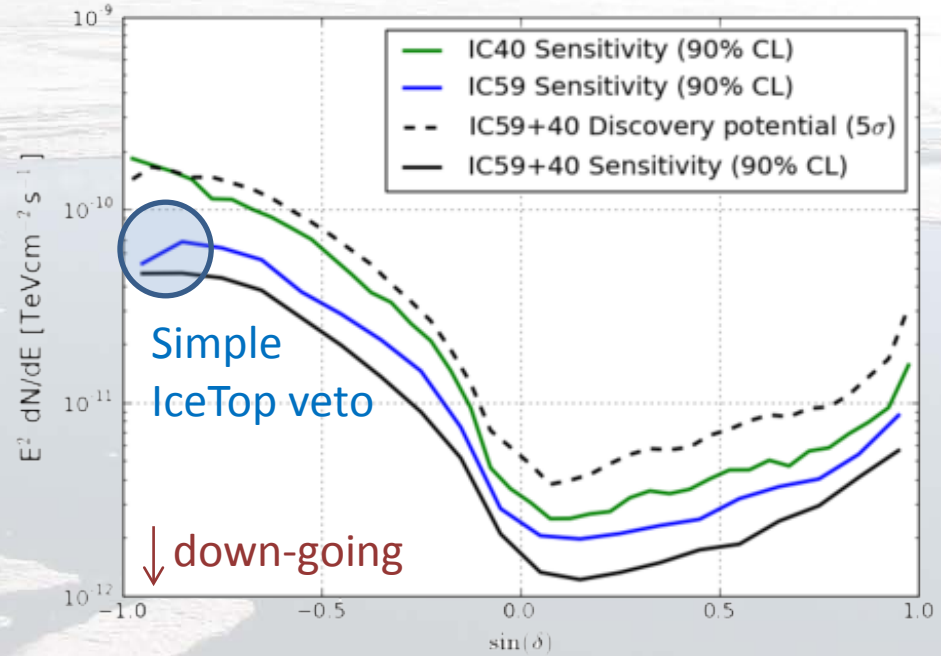
Low-energy transient events



- Discriminator rates sensitive to **GeV primary** flux
- Additional discriminators:
  - Various thresholds
  - **Spectroscopy**
- Solar flares
- Supernovae
- GRBs

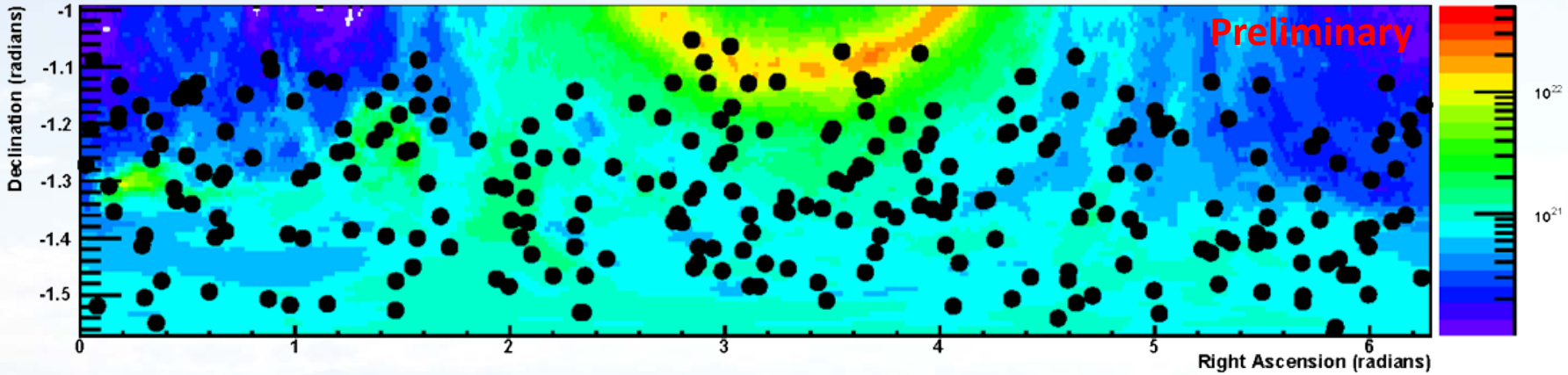
Veto for neutrino search

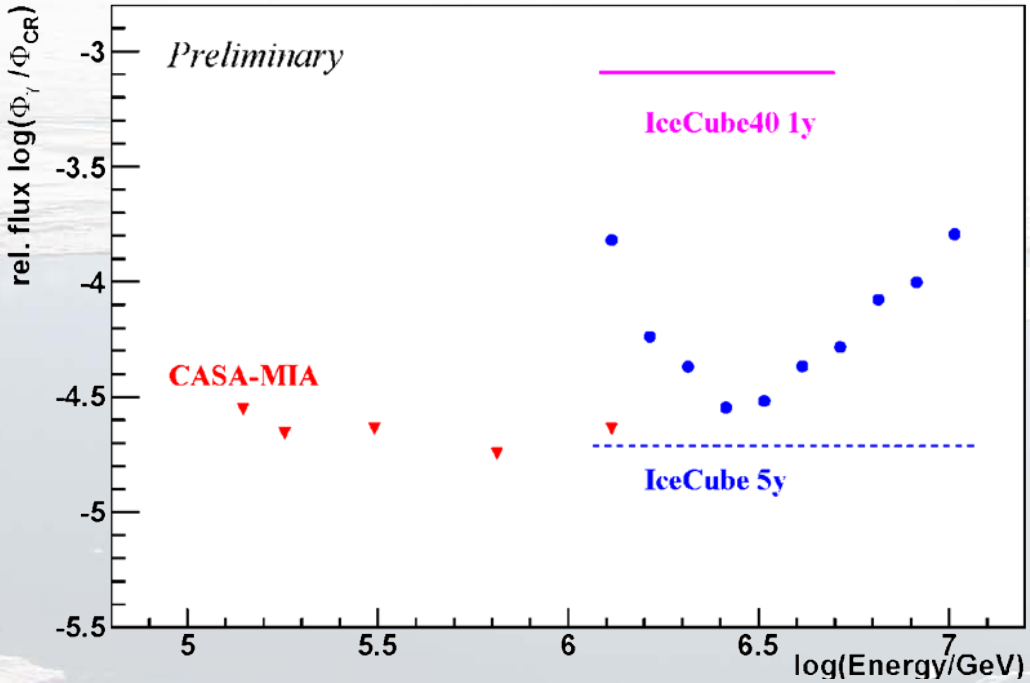




- Earth not transparent for **PeV neutrinos**
- Look **above horizon**
- Large atmospheric **muon background**
- Use IceTop as **veto**
- At sufficiently high energy:
  - ~ 100% background rejection
  - > 90% signal efficiency
- SLC: Improve capabilities
  - Larger zenith angles

PeV Photon search with IceCube veto





- Photon showers are **muon poor**
- Use IceCube as a veto
- Upper limit on E^{-2} flux at 1.2PeV (99% c.l.):

$$\Phi < 7.0 \cdot 10^{-19} \mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{TeV}^{-1}$$

Summary

- IceCube/IceTop construction complete
- **First results:**
  - Cosmic-ray energy spectrum and composition
  - Physics of air showers
  - Heliospheric physics, transient events
  - EAS veto for high-energy neutrino searches
  - …
- **Ongoing efforts:**
  - Composition measurement with muons in IceCube
  - Cosmic-ray anisotropy measurement
- **Future plans:**
  - Horizontal air showers
  - Radio extension (RASTA)