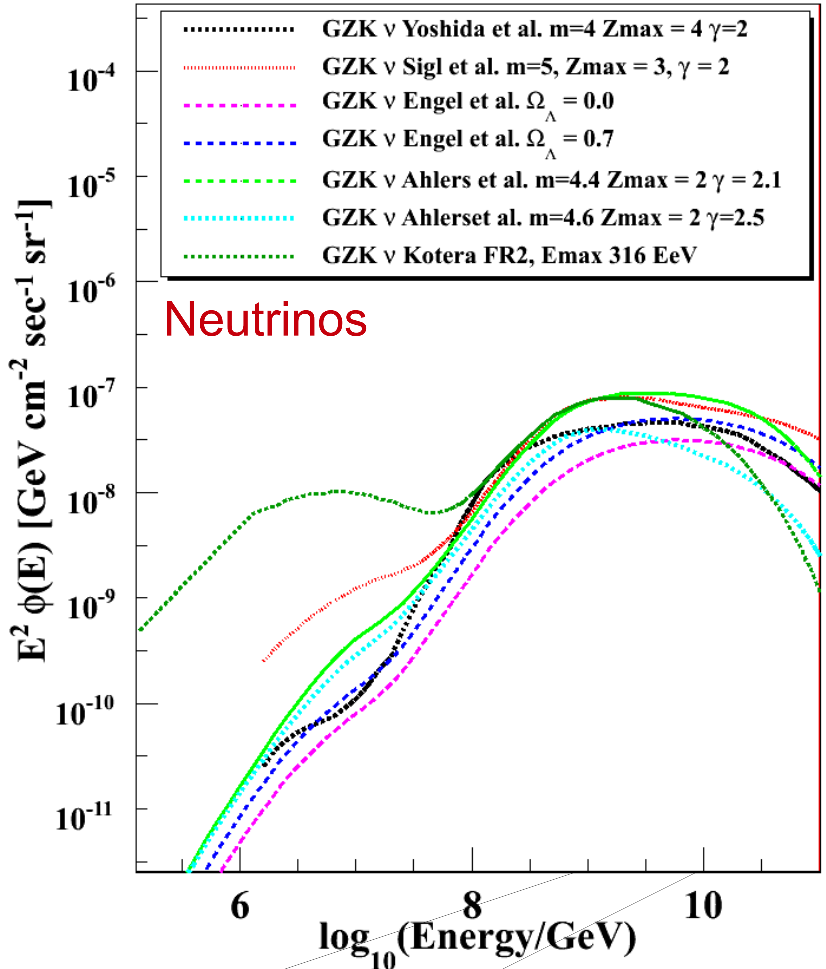
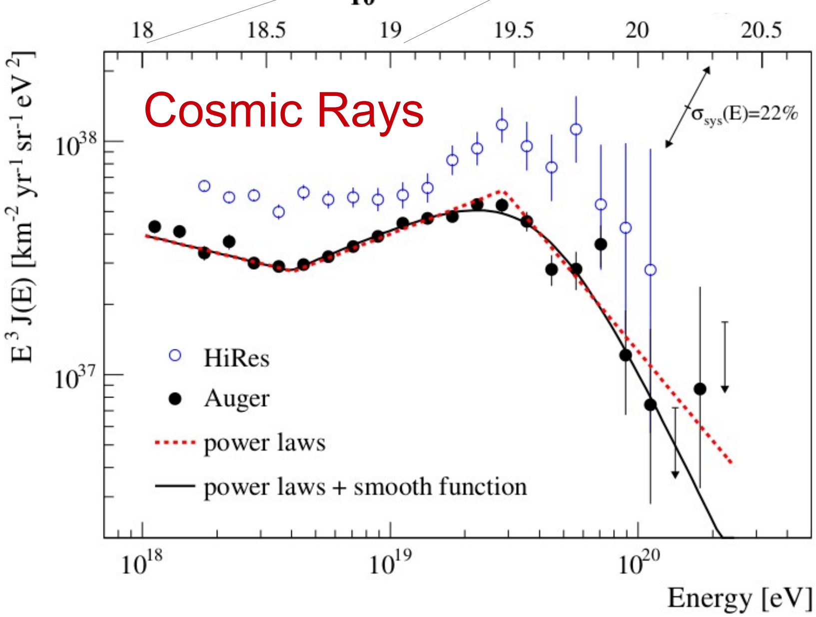
Recent results of a search for cosmogenic PeV to EeV neutrinos with IceCube

Eike Middell for the IceCube Collaboration
DESY

ISVHECRI - 2012-08-14





arXiv:1002.1975v1

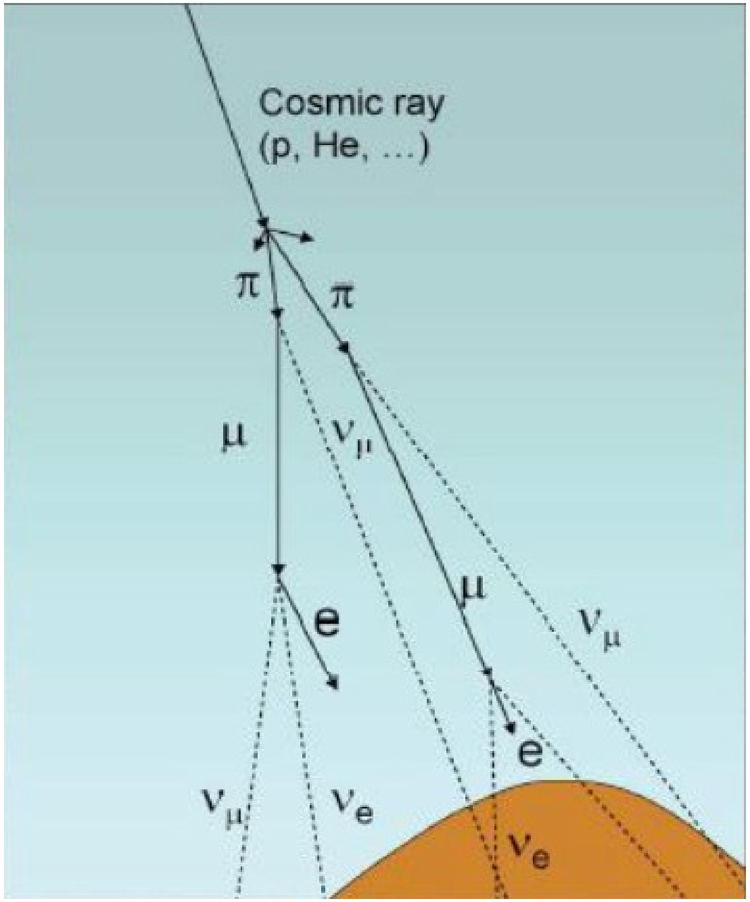
Cosmogenic Neutrinos

- extragalactic cosmic rays loose energy due to interactions with the cosmic radiation background
- $\geq 10^{19}$ eV: Greisen-Zatsepin-Kuzmin cut-off photohadronic interactions with CMB:

$$p\gamma_{2.7K} \rightarrow \pi^+ + X \rightarrow \mu^+ + \nu \rightarrow e^+ + \nu' s$$

- guaranteed flux of ≥PeV neutrinos
- carrying information on CR sources:
  - location
  - cosmological evolution
  - spectra

Atmospheric Neutrinos

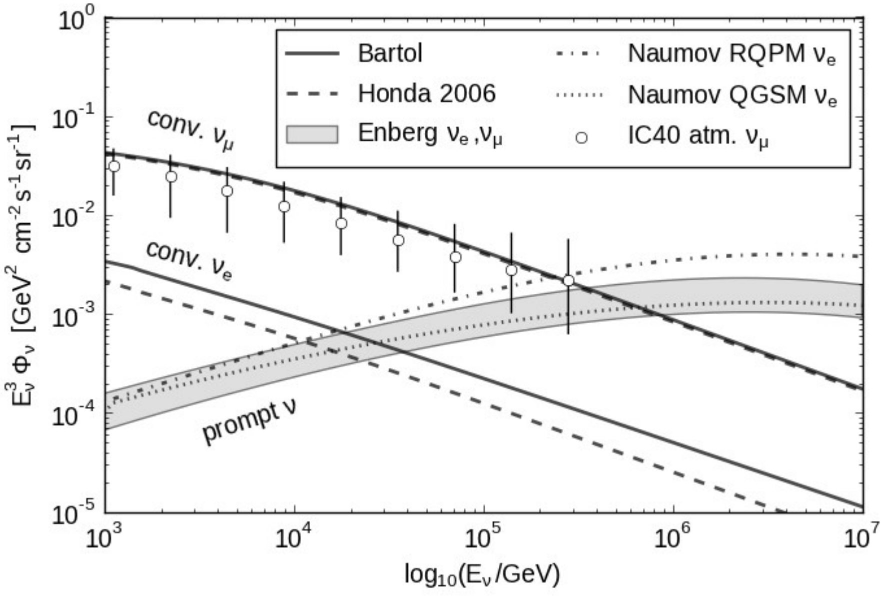


conventional atm. neutrinos:

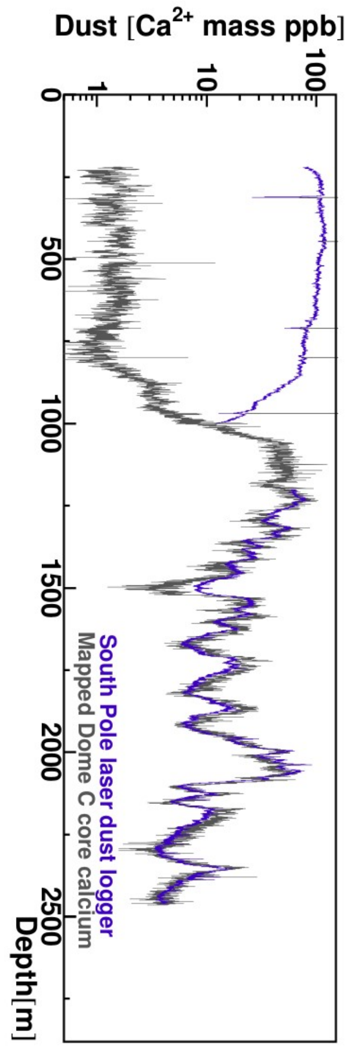
- originating from decays of π, K
- spectrum determined by interplay of meson decay and interaction ($\Phi \sim E^{-3.7}$)

prompt atm. neutrinos:

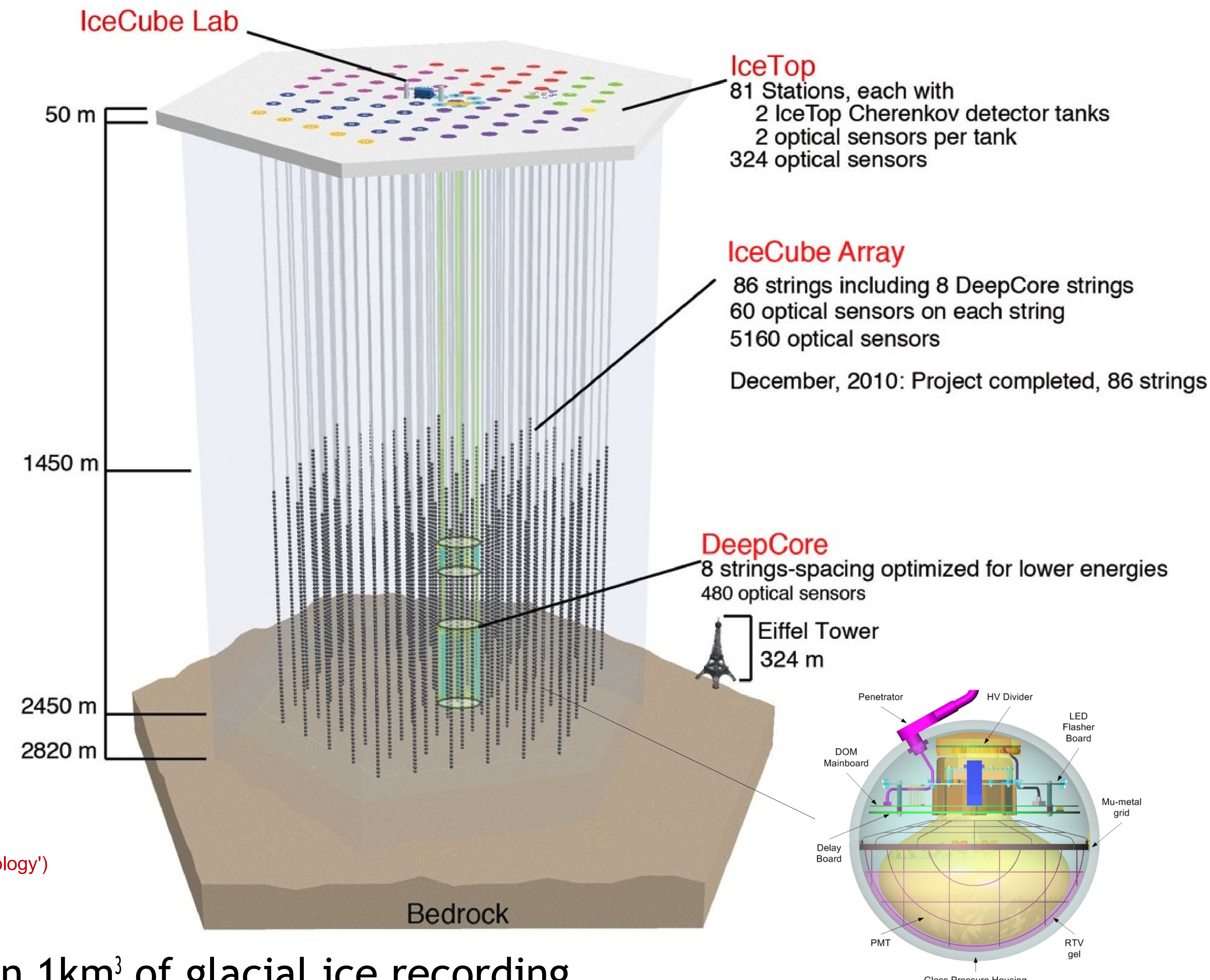
- originating from decays of charmed mesons
- spectrum follows cosmic rays ($\Phi \sim E^{-2.7}$)
- particle physics of p-Air collisions, heavy-flavour production, probing parton distributions at very small x



- no measurement of prompt neutrinos, yet
- prompt → considered signal
  conventional → considered background



Dust Logger measurements
(to appear in 'Journal of Glaciology')



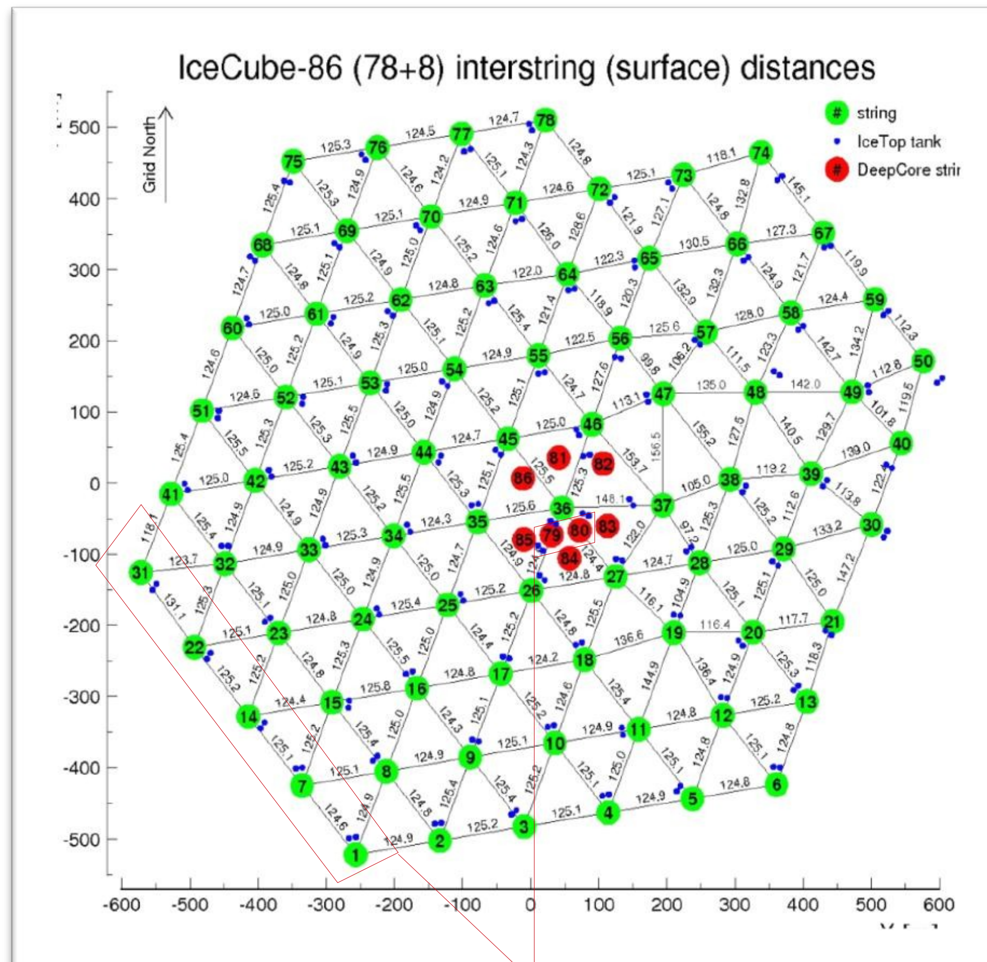
5160 DOMs in 1km^3 of glacial ice recording Cherenkov light emitted by charged secondaries generated in the neutrino interaction

Digital Optical Module

Searches & Data Samples

7 years of construction and
concurrent data taking:
9 strings (2006)
22 strings (2007)
40 strings (2008)
59 strings (2009)
→ 79 strings (2010)
→ 86 strings (2011)

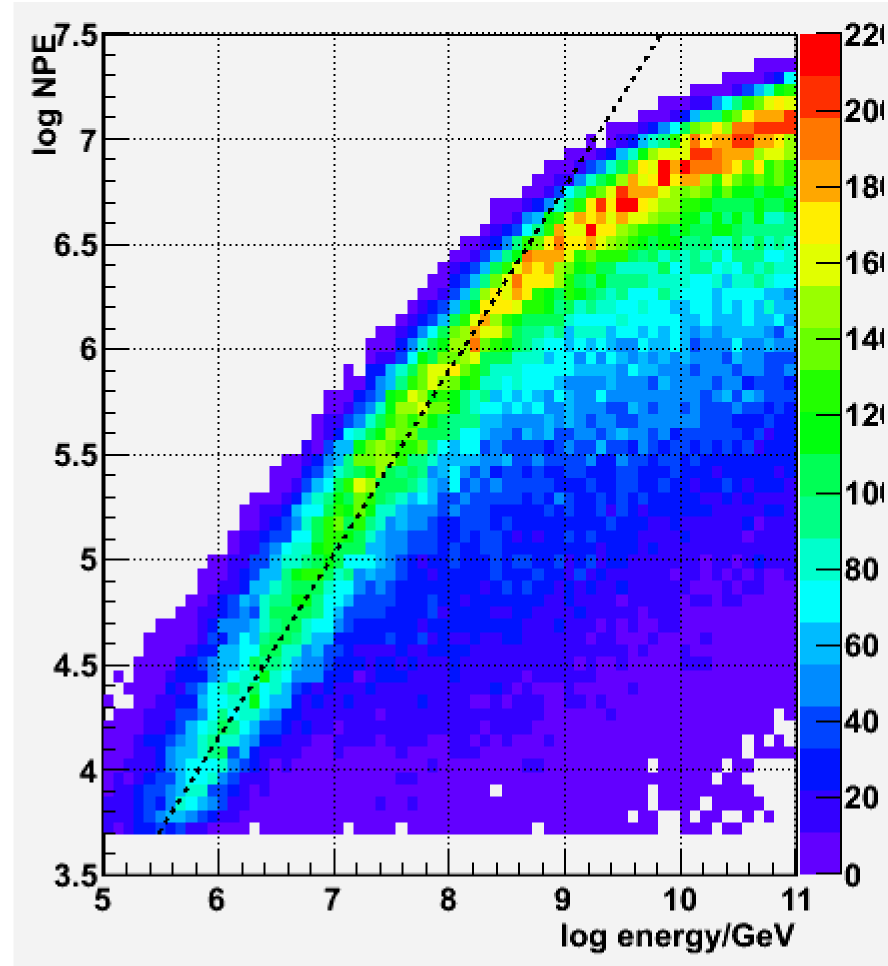
- analysis developed by Aya Ishihara & Keiichi Mase (Chiba)
- combine the data from IceCube-79 and IceCube-86 (very similar detector configurations)
- IC-79: 5/2010 – 5/2011 (319.07d)
  IC-86: 5/2011 – 5/2012 (353.67d)
  → 672.7 days of effective lifetime
- 10% of experimental data set aside to develop the analysis

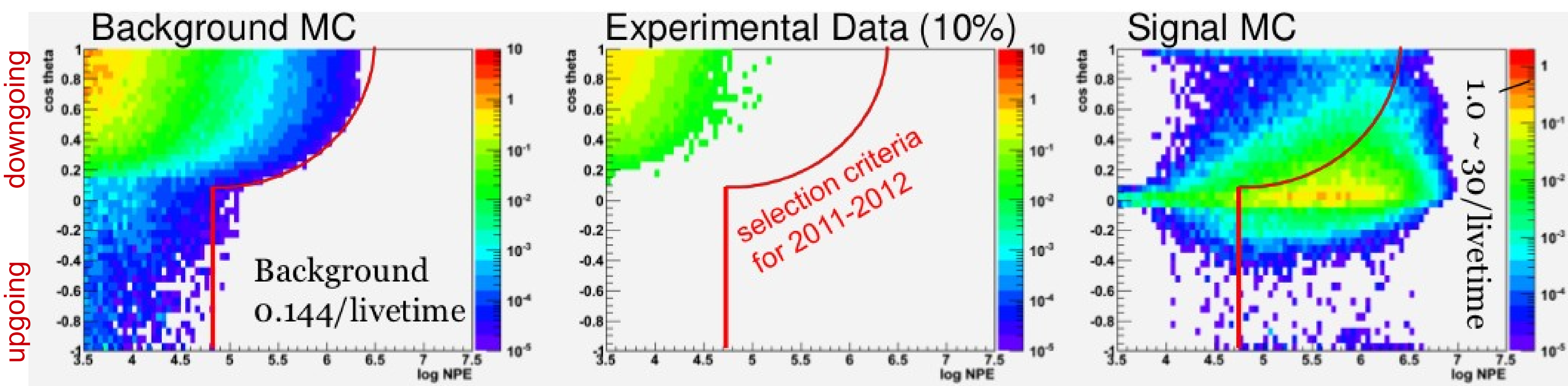


differences IC-79 → IC-86

Event Selection

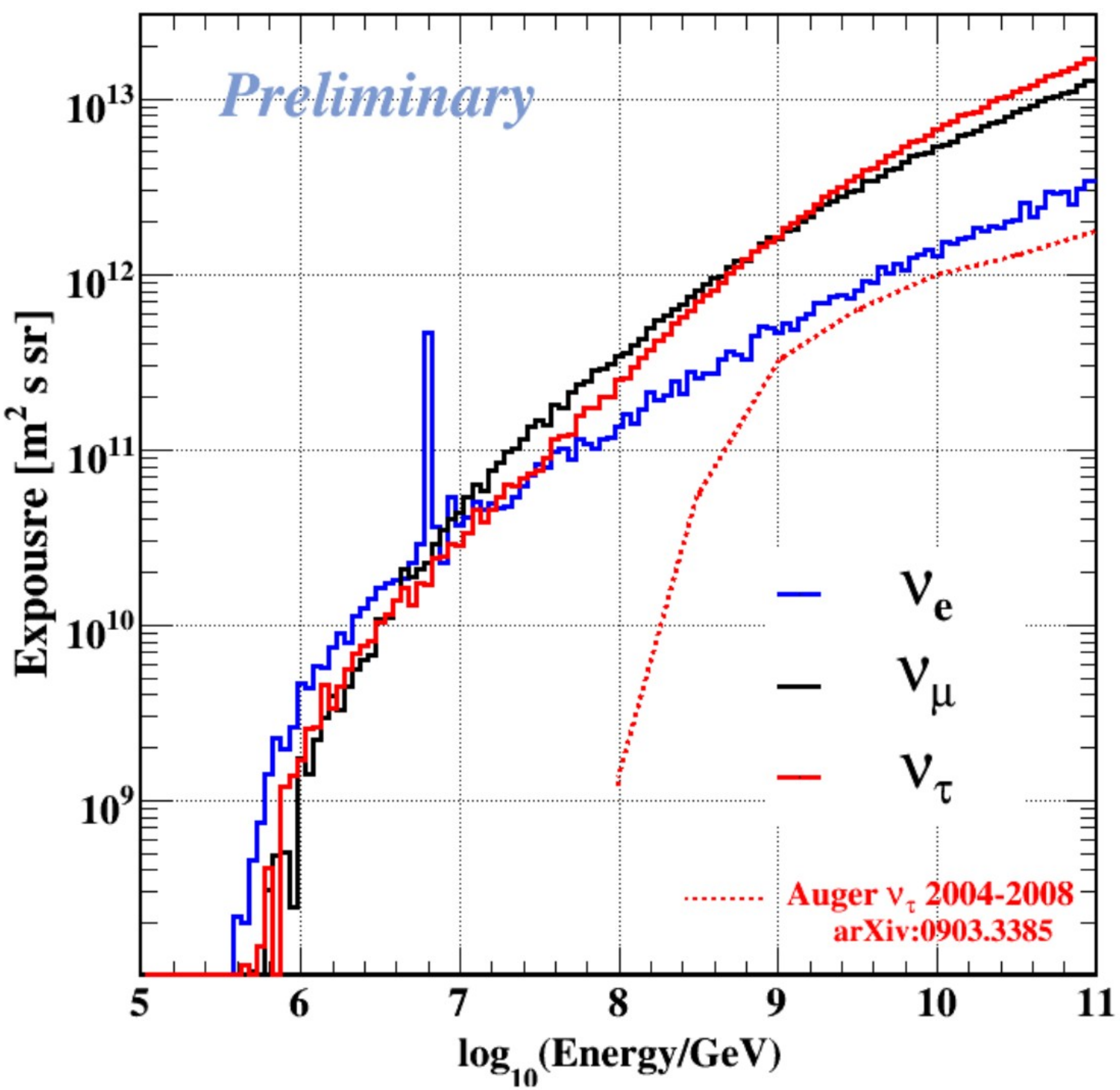
- select events based on estimators for the direction and deposited energy
- deposited energy → Cherenkov photons → 1) number of recorded photoelectrons 2) number of triggered DOMs (> 300)
- straight line fit through hit pattern → zenith angle
- use a higher energy threshold for downgoing events



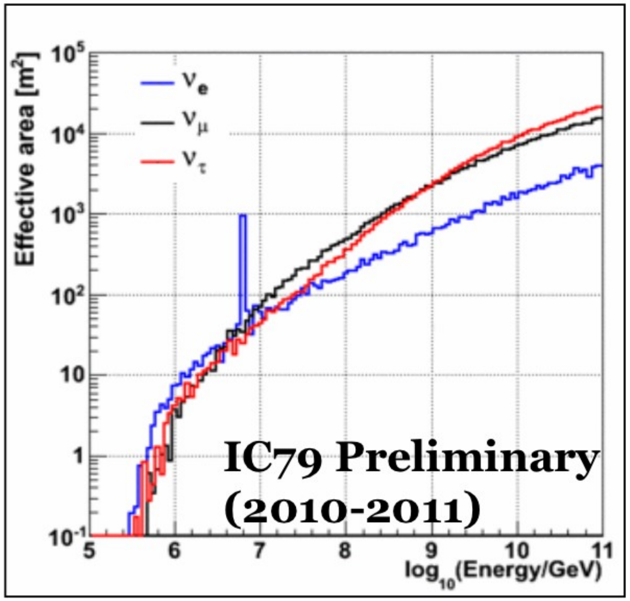


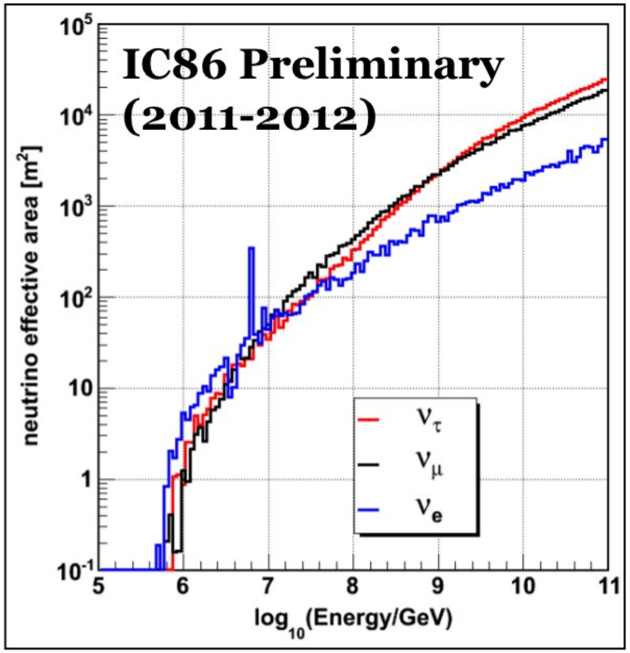
selection criteria for 2010-2011 very similar: slightly different cut region, track reconstruction

IceCube UHE 2 Years Exposure (2010-2012)



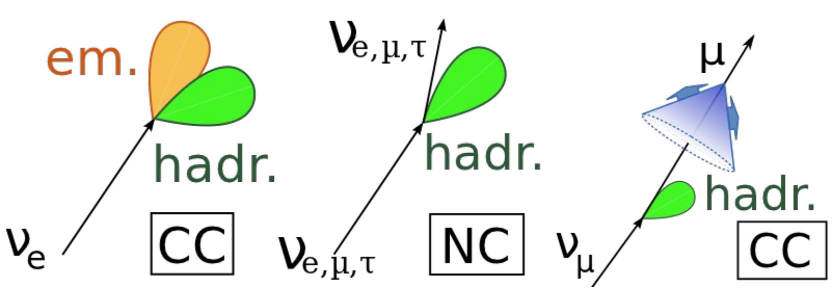
Effective Areas

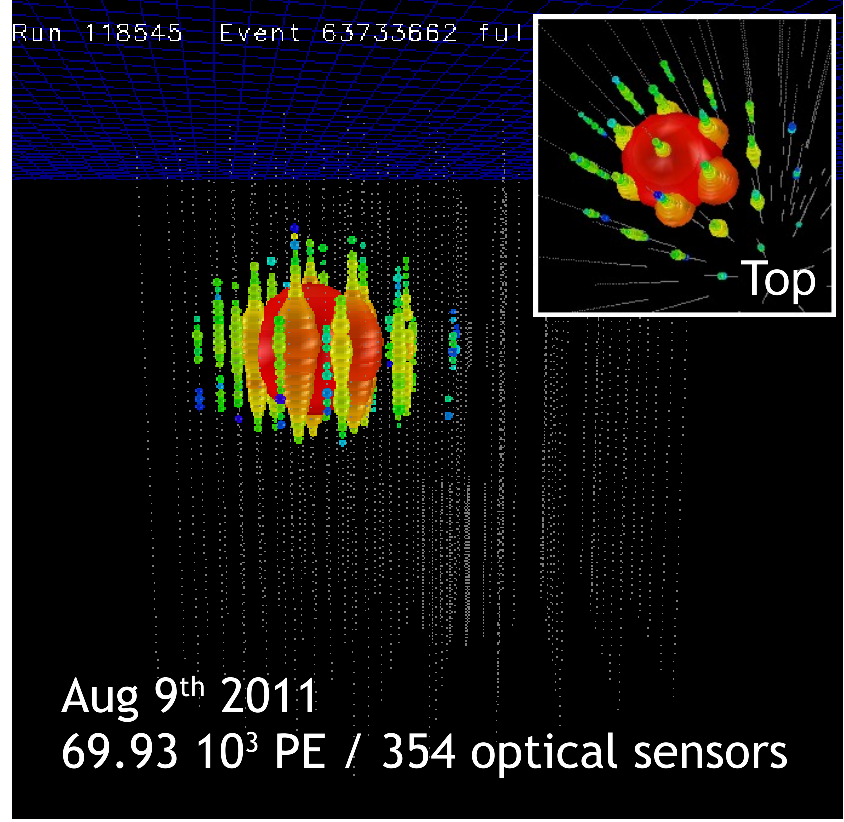


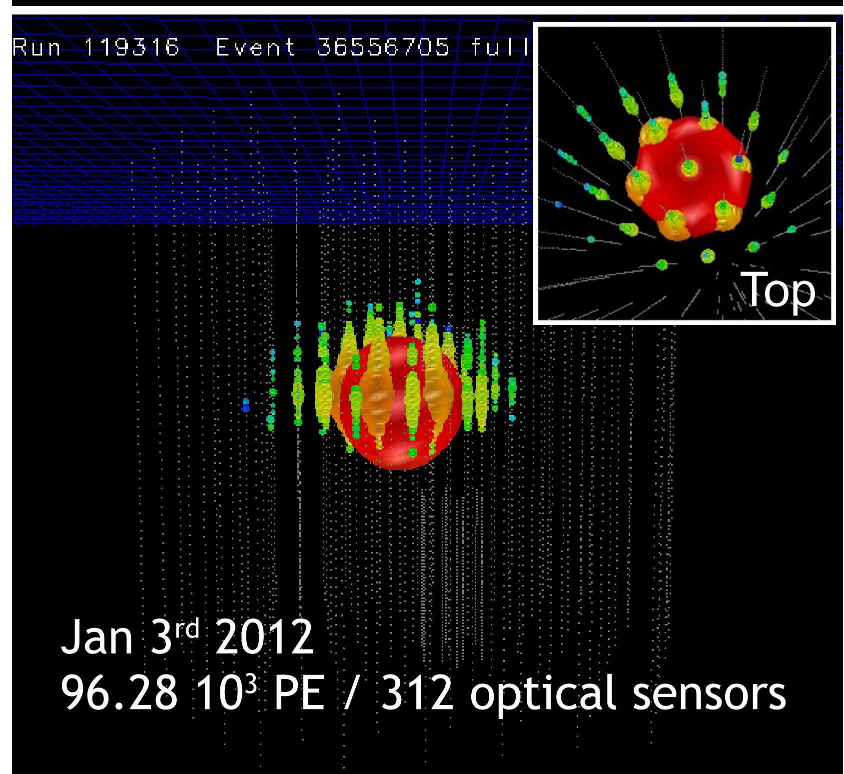


Passing Events

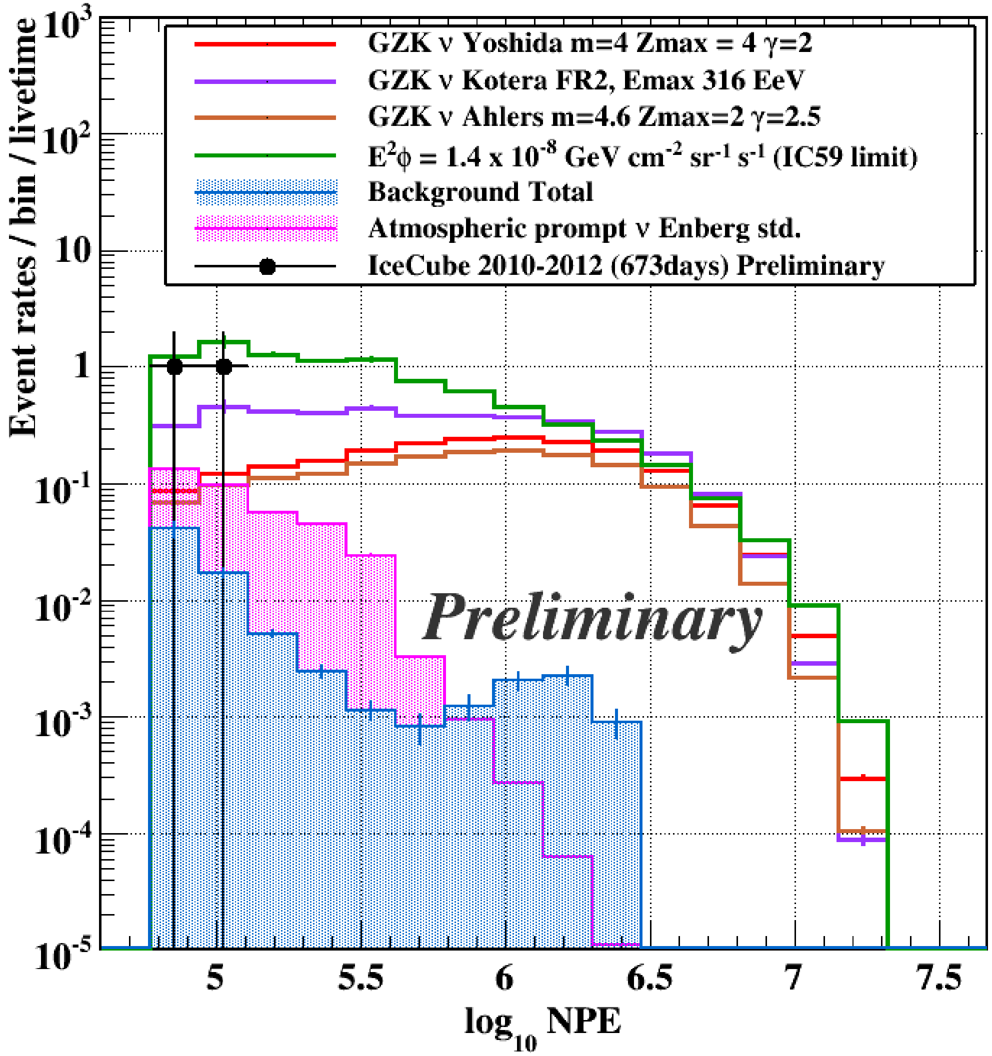
- 2 events / 672.7 days
  pass all selection criteria
- expected from atm. muon and conv. neutrino background: 0.14 events
- preliminary p-value: 0.0094 (2.36σ)
- cascade-like events:
  expected from CC & NC events with particle showers in the final state

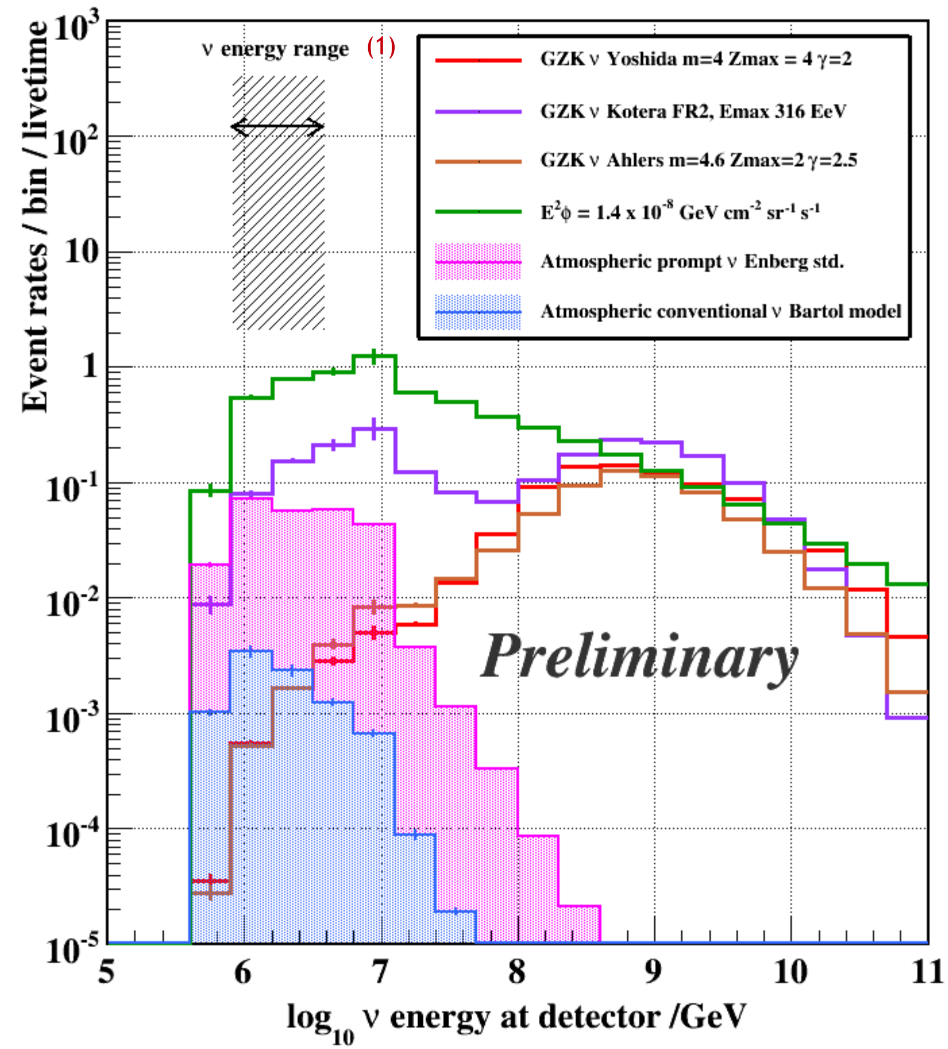






NPE and energy distributions





(1) shaded energy range includes contribution from neutral current interactions of an E^{-2} all flavor neutrino flux. NC events cause larger error bar.

(Preliminary)

Expected Event Counts

Models	IceCube-40 2008-2009 (333 days) Phys. Rev. D83 092003 (2011)	IceCube 79+86 2010-2012 (672.7 days)
Prompt atm. nu (Enberg) [4]		0.4
IC59 diffuse limit $E^2\Phi = 1.4\mathrm{x}10^{-8}$ GeV cm^{-2} sr^{-1} s^{-1}		9.1
Background (conv. atm. nu + atm. μ)	0.11	0.14 (conservative)
Experimental data	**0**	**2**
GZK (Yoshida m=4) [1]	0.57	2.1
GZK (Ahlers max.) [2]	0.89	3.2
GZK (Ahlers best fit)[2]	0.43	1.6
GZK (Kotera, dip FRII)[3]		4.1
GZK (Kotera, dip SFRII) [3]		1.0

(1) Yoshida et al The ApJ 479 547-559 (1997), (2) Ahlers et al, Astropart. Phys. 34 106-115 (2010), (3) Kotera et al, (4) R. Enberg, M.H. Reno, and I. Sarcevic, Phys. Rev. D 78, 043005 (2008)

Ongoing cross-checks to derive a better energy estimate (Preliminary)

- to better constrain the energy estimate:
  - reconstruct the event with a particle shower hypothesis
  - incorporate our knowledge on optical imhomogenity of the South Pole ice (either tabulated or in form of a photon propagator code)
  - consider DOM saturation effects
- simulate events similar to the observed:
  - to estimate reconstruction performance
  - to actually reconstruct the events (Markov Chain Monte Carlo)

current estimates on the deposited energy:

Aug 9th 2011 event

1.1 – 1.6 PeV

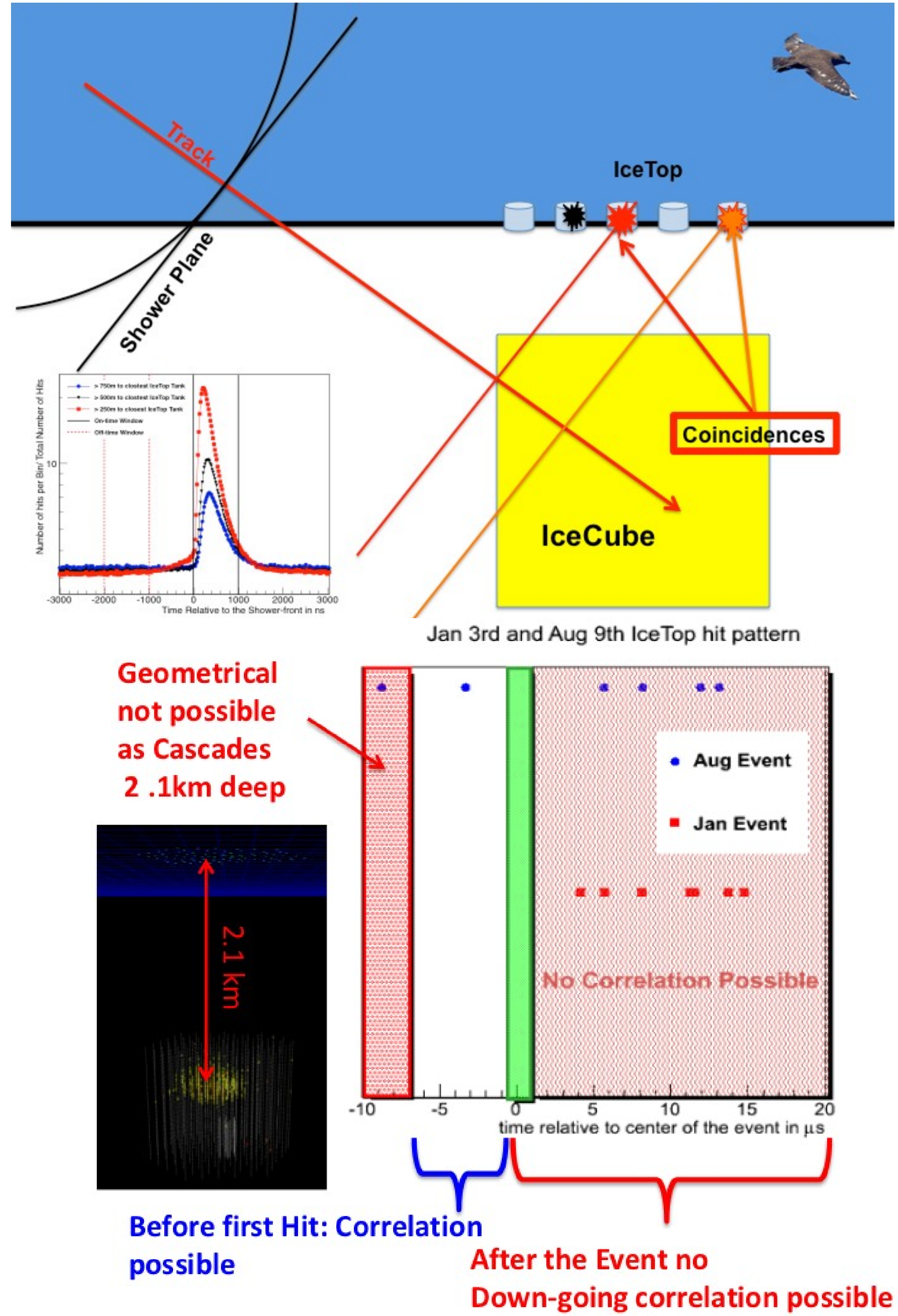
Jan 3rd 2012 event
1.3 – 2.0 PeV

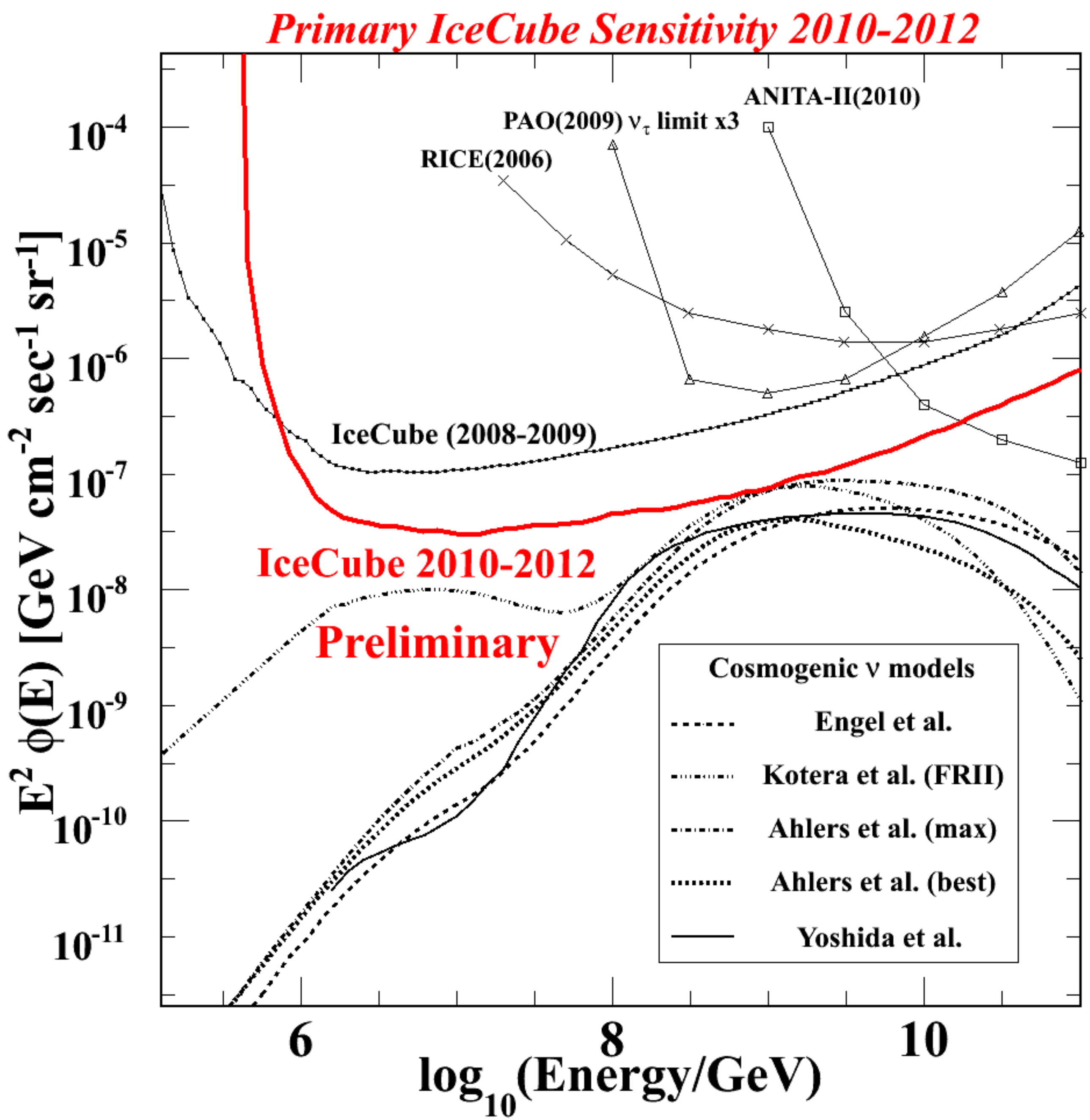
- below Glashow Resonance
- given energy range reflects spread of different methods and ice models

Additional Tests on the Origin of these Events (Preliminary)

- look for coincident signals in IceTop surface detectors
  → veto downgoing and horizontal atmospheric muons created in air showers
- time window of 8μs
- for the two events we see 0 and 1 hits, respectively
- lower than the expected 2.08 hits/8μs background rate

  → no evidence for an air shower
- high confidence in the veto efficiency for highly energetic air showers
- uncertain veto efficiency for prompt neutrino events




Primary IceCube Sensitivity 2010-2012
ANITA-II(2010)
PAO(2009) ντ limit x3
RICE(2006)
IceCube (2008-2009)
IceCube 2010-2012
Preliminary
Cosmogenic ν models
Engel et al.
Kotera et al. (FRII)
Ahlers et al. (max)
Ahlers et al. (best)
Yoshida et al.
E² φ(E) [GeV cm⁻² sec⁻¹ sr⁻¹]
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
6
8
10
log₁₀(Energy/GeV)

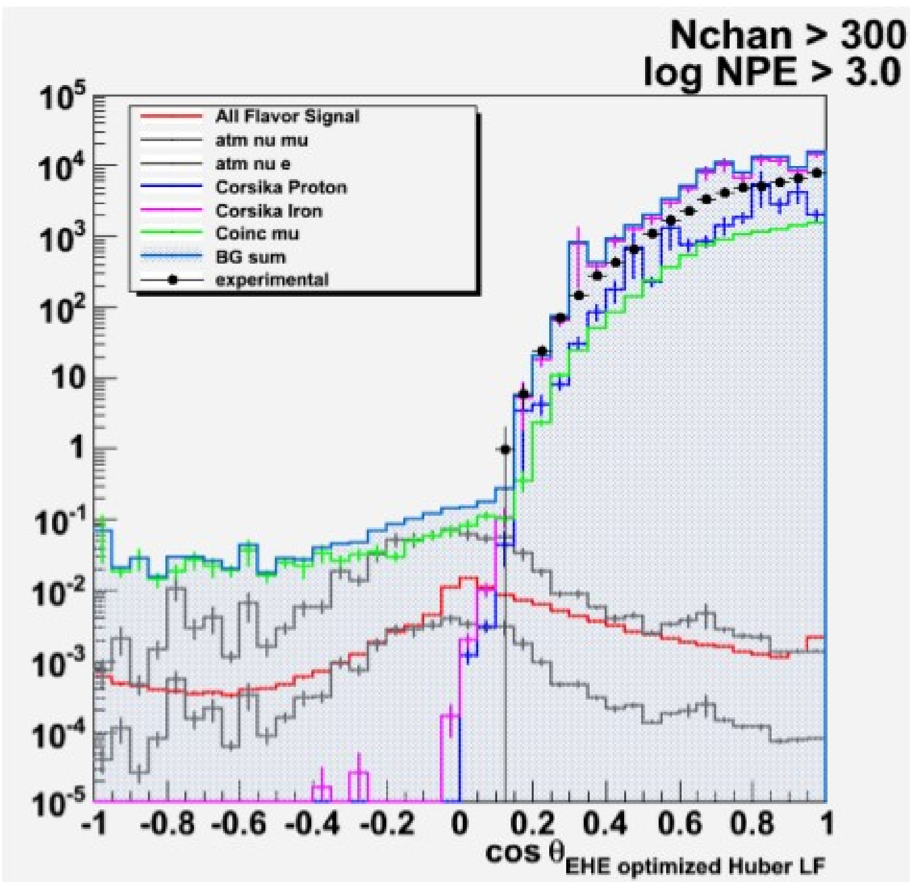
Summary

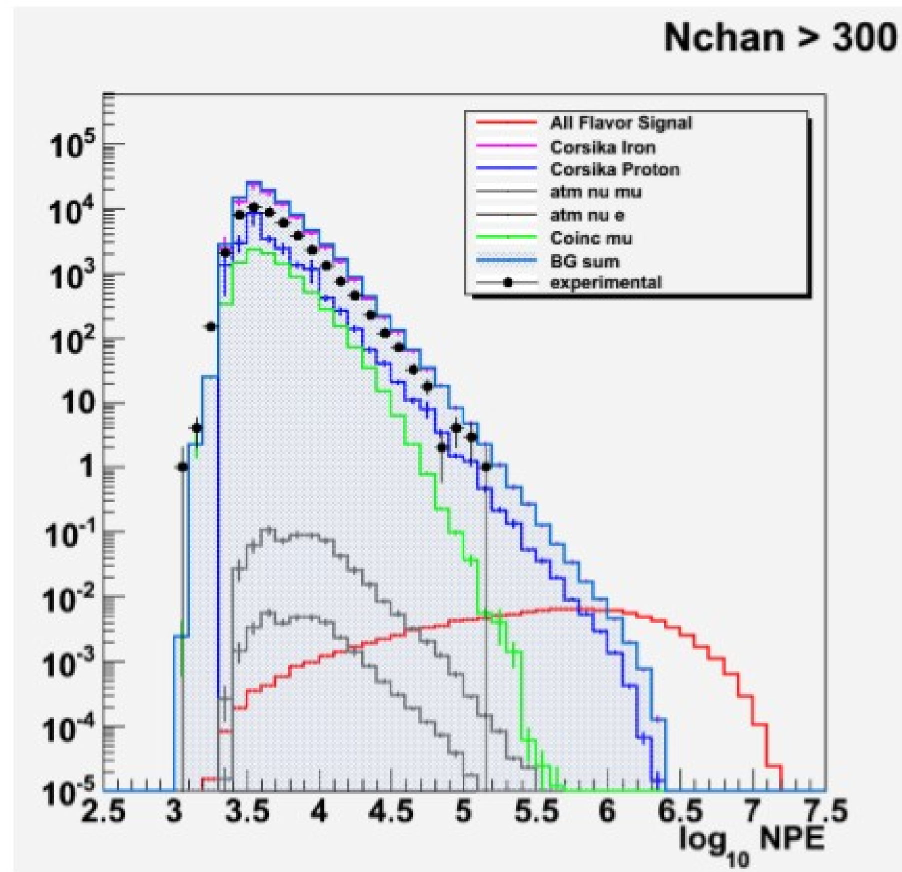
- searched for neutrinos with PeV and greater energies in nearly two years of IceCube data
- 2 events observed over an expected background of 0.14 (2.36σ)
  - cascade-like events (any flavour, CC/NN interaction inside the detector)
  - energy estimated to be 1-2 PeV (after intensive cross-checks)
- at these energies it becomes unlikely that the events originate from the conventional atmospheric neutrino flux
- looking forward to confirmation of the result by dedicated analyses searching for cascade-like events
- **Very interesting times for neutrino astrophysics!**

Backup

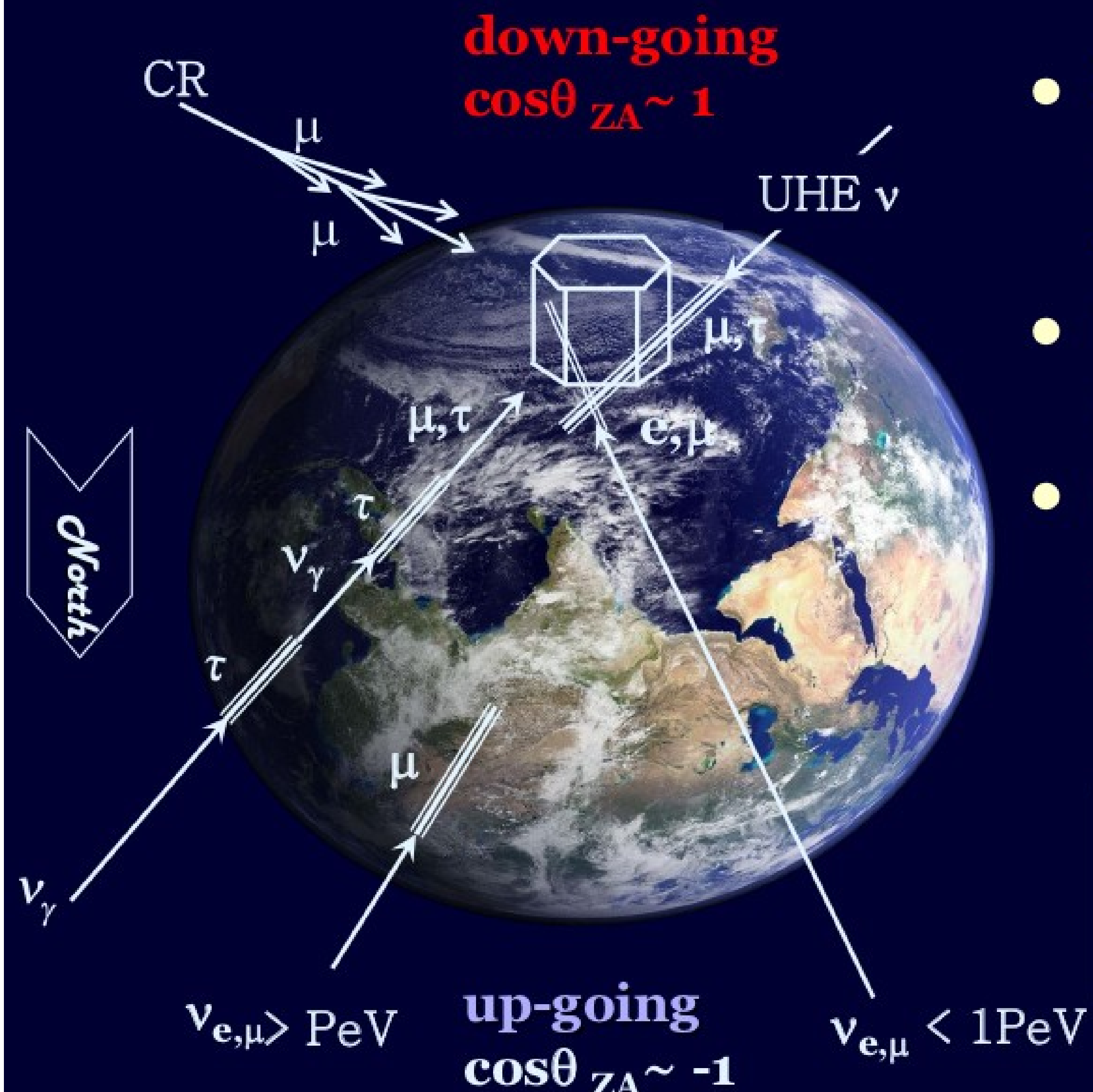
Initial level NPE and cos theta distributions

NPE and cos zenigh angle distributions comparisons with burn sample





UHE Neutrinos In the Earth…



- Generally neutrinos identified as “through the Earth” up-going events
- Earth is opaque for UHE neutrinos
- UHE neutrino-induced events are coming from above and near horizontal direction

UHE neutrino mean free path
$\lambda_n \sim 100$ km << R_{Earth}
$\sigma^{cc}_{nN} \sim 10^{-6\sim-4}$ mb

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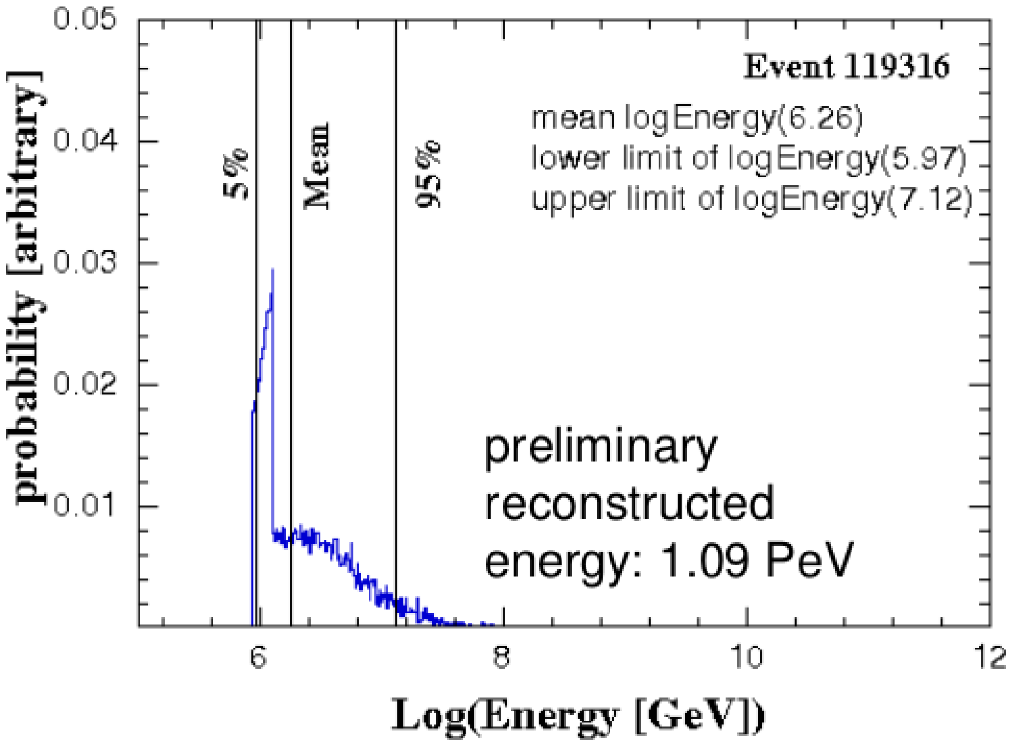
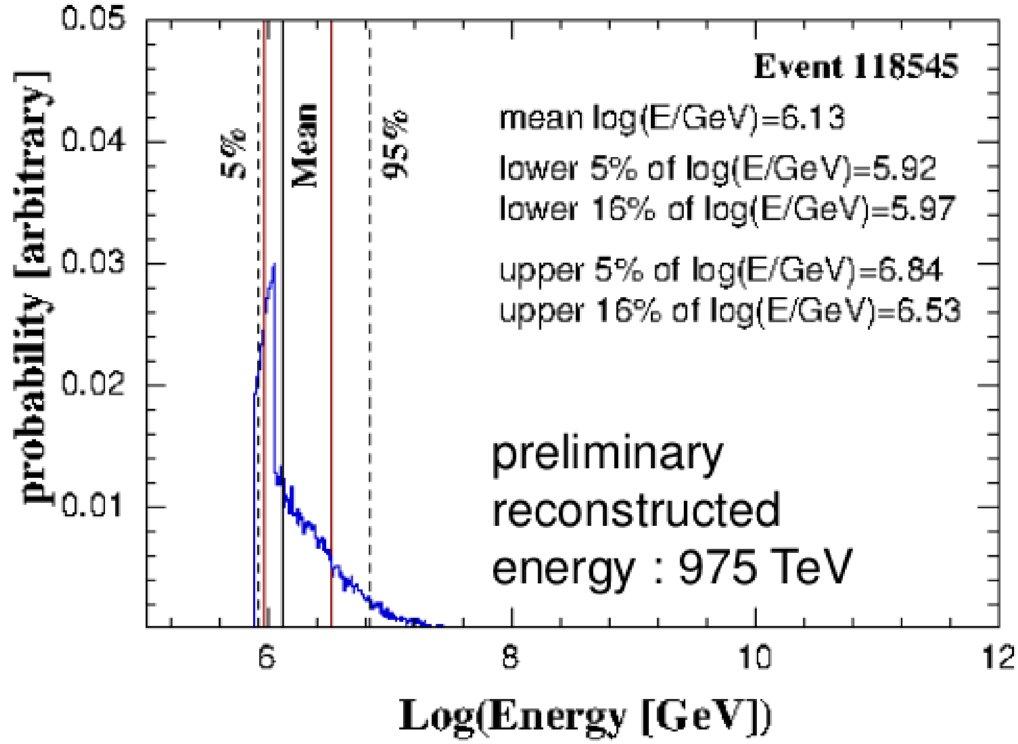
Passing rates (stat. errors only)

Passing rates (per burn sample live time of 498.350 hours) table

	Experimental	Atm mu SIBYLL Fe	Coincident muon	atmospheric neutrinos	Atm mu SIBYLL H	Signal
Filter Online	3539908 (1.973Hz)					
Filter Offline (NPE > 1000, Nch > 50)	1.615 $\times 10^6$	2.34+/-0.08 $\times 10^6$	2.881+/-0.005 $\times 10^5$	163.2+/-3.0	9.85+/-1.3 $\times 10^5$	0.1528+/- 0.0006
(NPE > 1000, Nch > 300)	44458	8.37+/-0.49 $\times 10^4$	9.48+/-0.03 $\times 10^3$	0.648 +/- 0.032	2.16+/-0.34 $\times 10^4$	0.1136+/- 0.0004
(NPE > 10^3.5, Nch > 300)	34411	6.85+/-0.40 $\times 10^4$	7655.0+/-23.0	0.625+/-0.031	1.75+/-0.32 $\times 10^4$	0.1133+/- 0.0004
(NPE > 10^4.0, Nch > 300)	3019	5.65 +/- 0.271 $\times 10^3$	558.7+/-3.4	0.185+/-0.011	631.72+/-59.61	0.1102+/- 0.0004
(NPE > 10^4.5, Nch > 300)	134	253.4 +/- 13.9	9.53 +/- 0.20	0.0232 +/- 0.0013	27.7 +/- 2.2	0.1019+/- 0.0004
Final criteria	0.0	0.00059 +/- 0.00024	6.37e-07 +/- 4.50e-07	0.0028 +/- 0.0002	8.2e-05 +/- 5.7e-05	0.0645 +/- 0.0003

Neutrino energy estimation





A method of the cascade energy reconstruction
- Poisson likelihood for all pulses
- Analytic likelihood maximization for energy
- Numerical minimization (Gulliver) in x, y, z, time, zenith, azimuth

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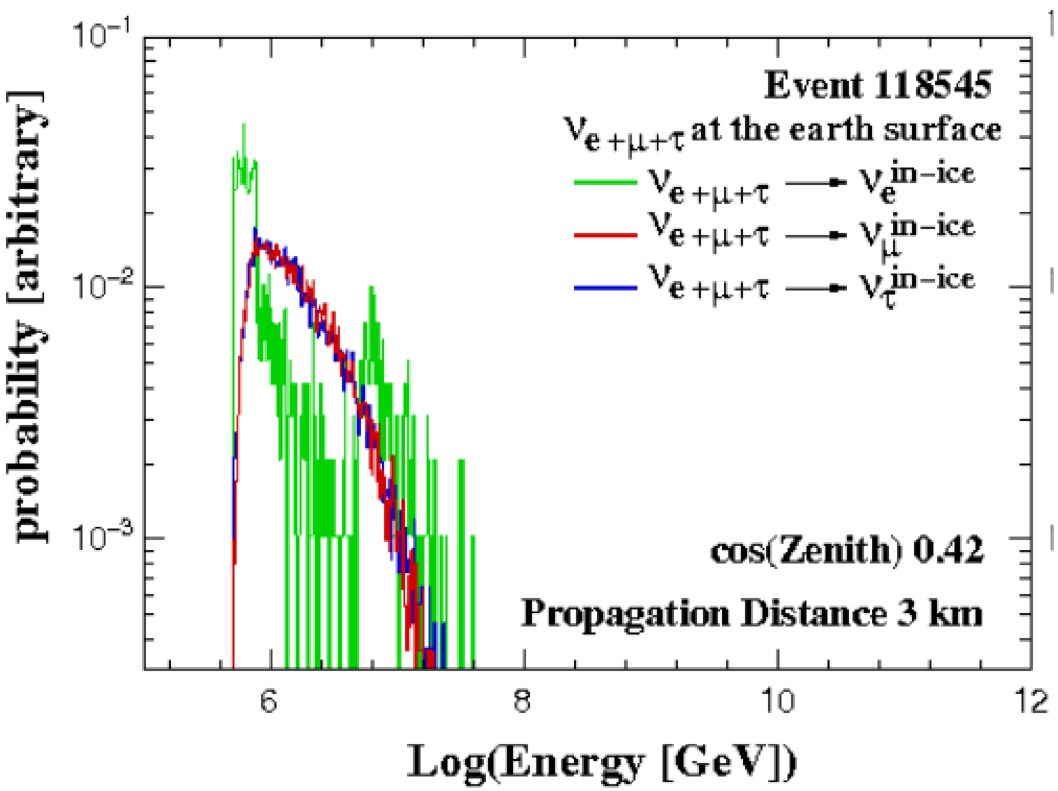
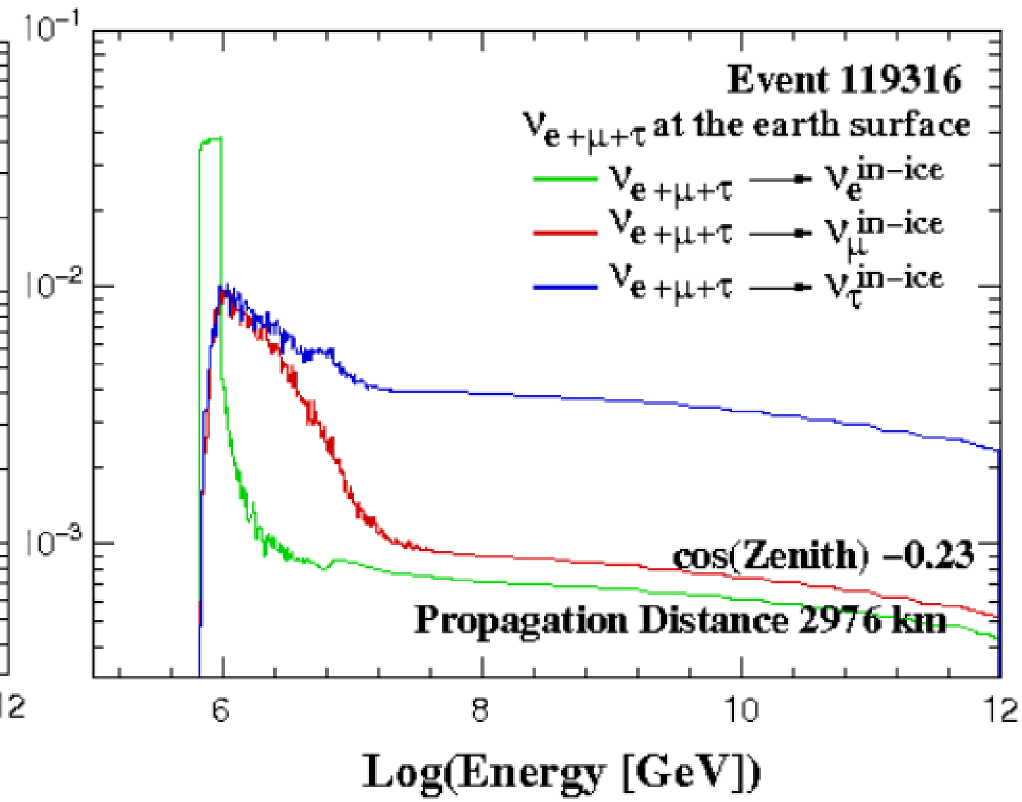
Surface Energy Distribution of Flavor Dependence

For the downward-going geometry difference due to different parent neutrino flavors on surface is small. For the upward-going geometry it is more relevant, still uncertainty extend not more than 1 energy decades.





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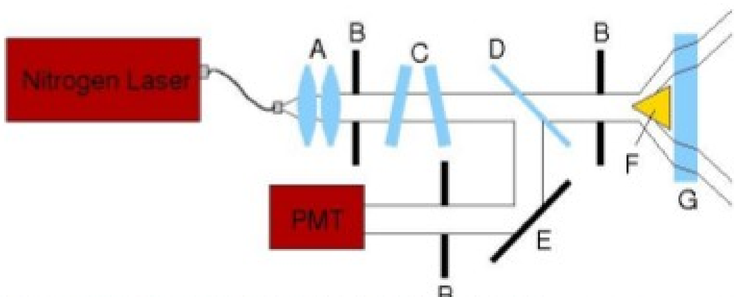
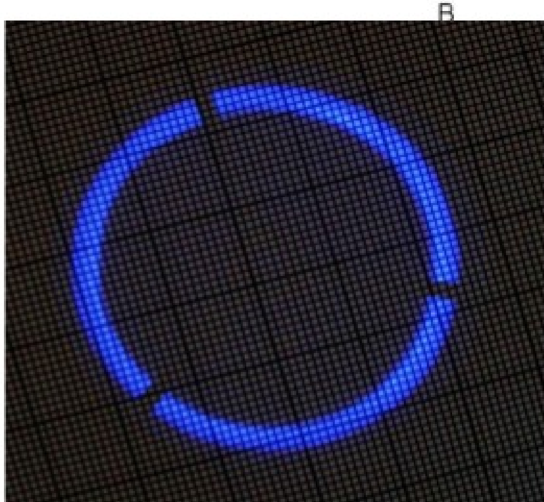
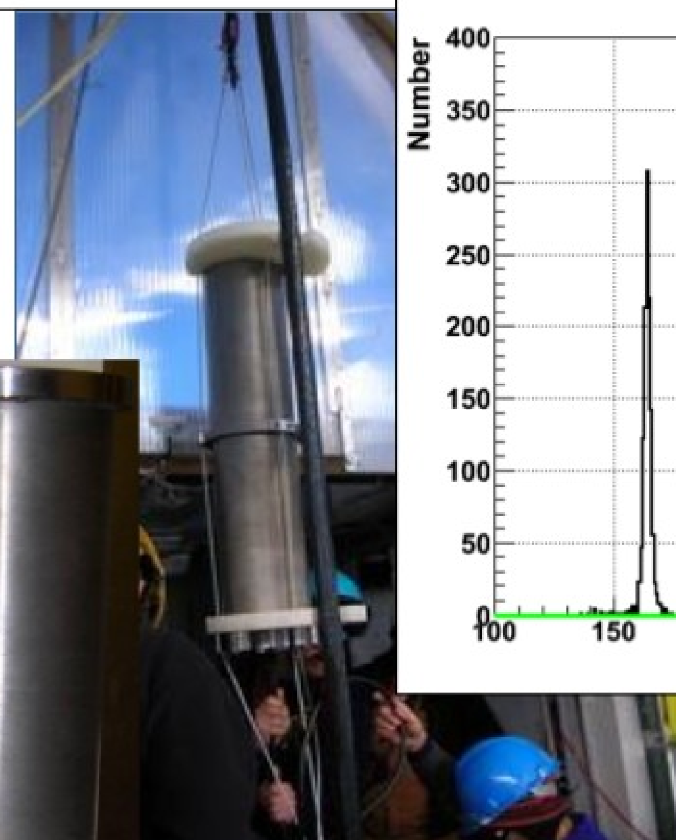
In-*situ* energy scale calibration

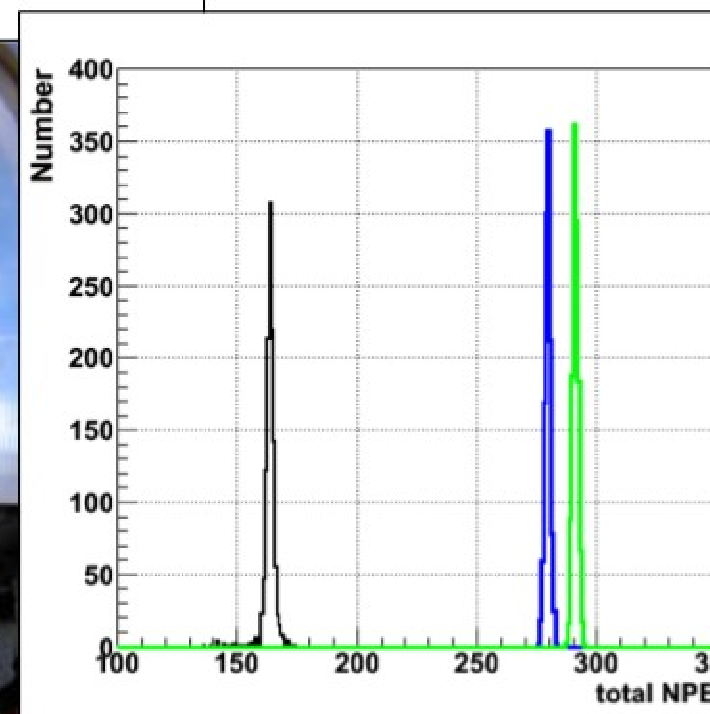
Calibrated light source: Standard Candle

- in-situ calibrated N_2 pulsed laser
- light wavelength 337 nm
- at 100% intensity generates 4×10^{12} photons per pulse emitted at 41°
- output adjustable between 0.5% ~ 100%









Zenith Reconstruction Performance