IceCube: Ultra-high Energy Neutrinos

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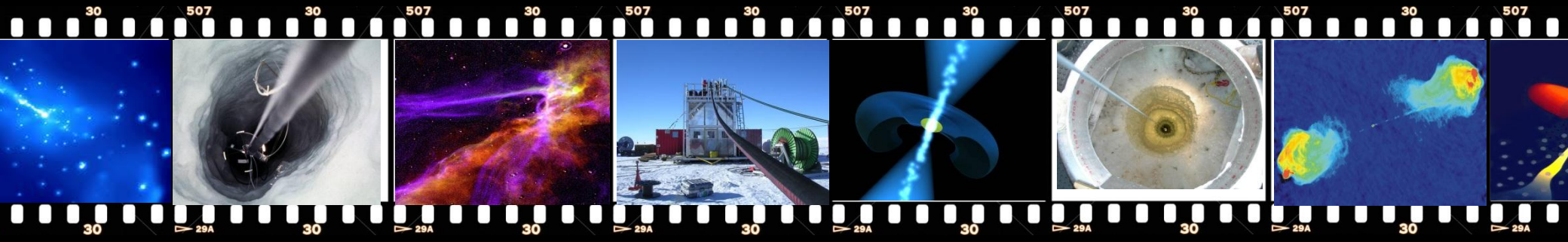
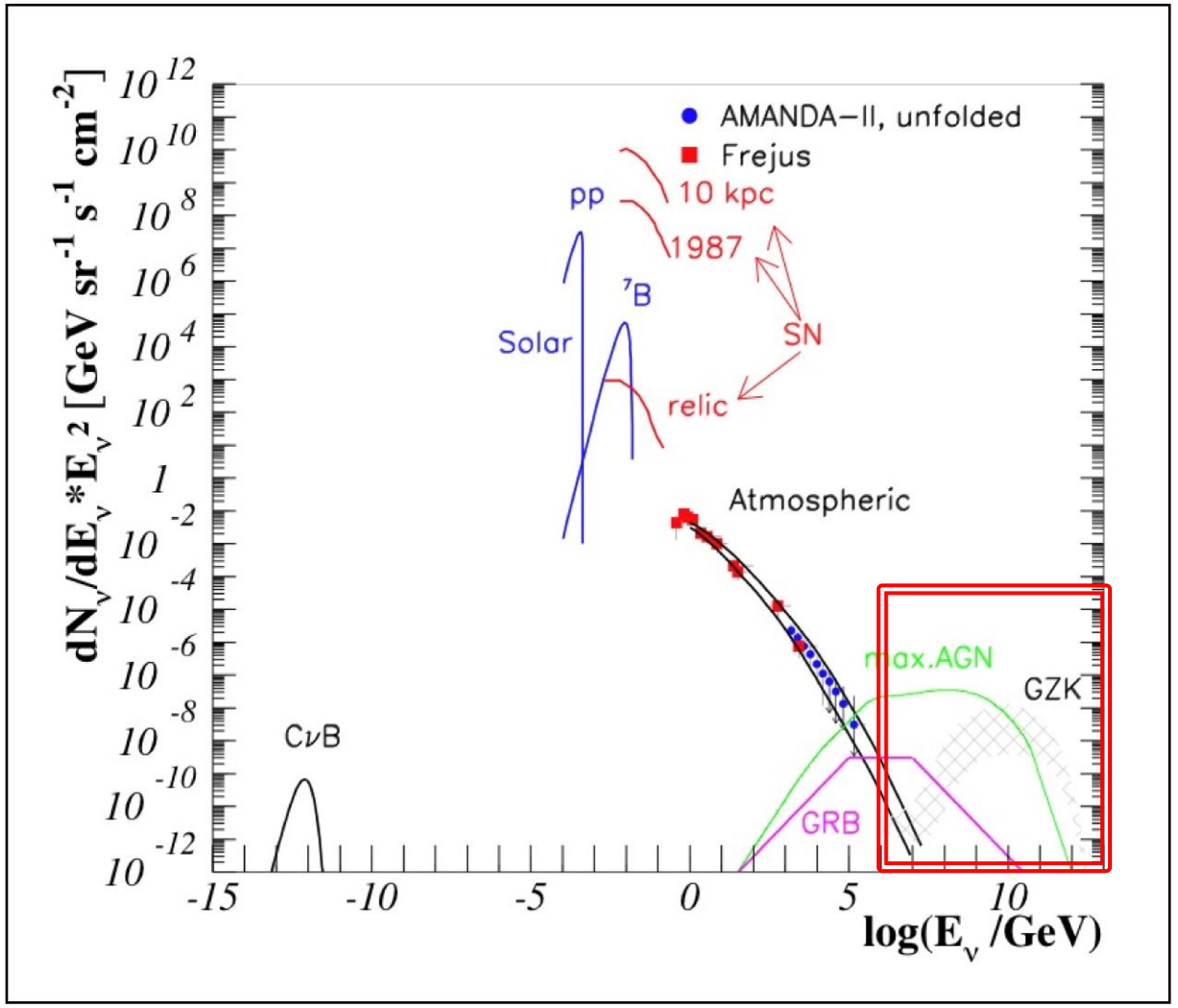
for the **IceCube** collaboration



Neutrino2012 at Kyoto June 8th 2012

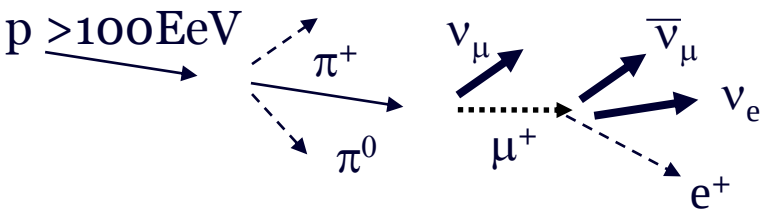
Ultra-high Energy Neutrinos: PeV and above



- Energies above dominant atmospheric neutrinos
- Cosmic frontier - PeV gamma-ray horizon limited to a few tens of kpc (our galaxy radius)
- Cosmogneic neutrino production is a ‘guaranteed’ ν source

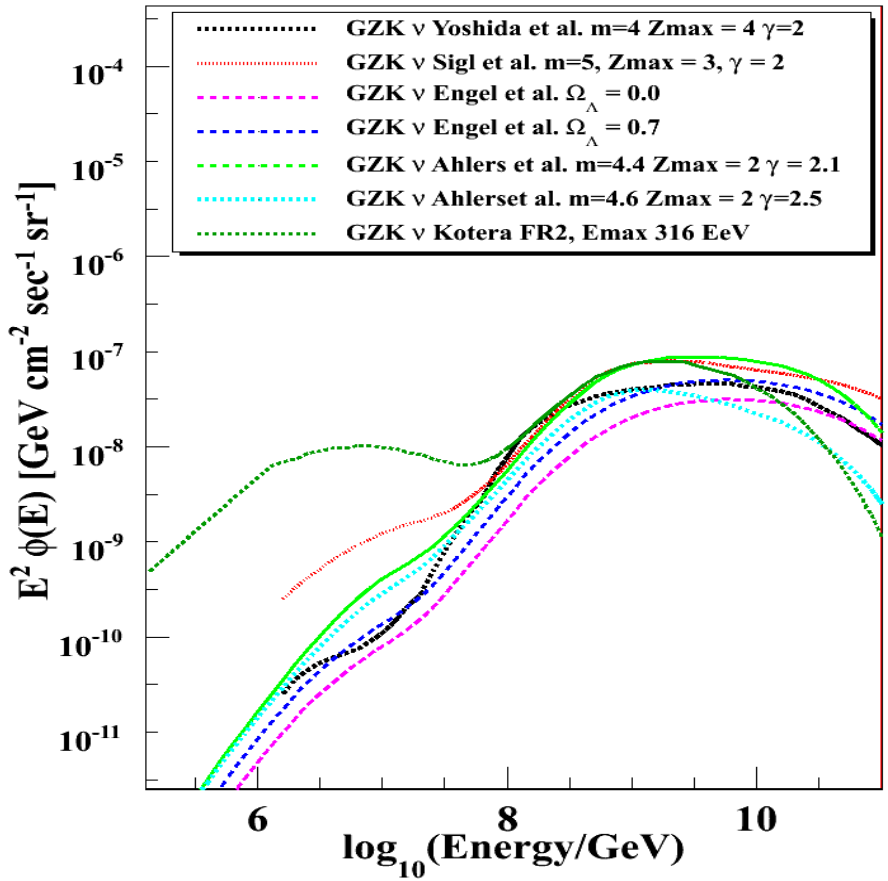
The highest energy neutrinos

cosmogenic neutrinos: EHE cosmic-ray and CMB induced neutrinos
Off-Source (<50Mpc) astrophysical neutrino production



The main energy range: $\mathbf{E_\nu \sim 10^{8\text{-}10}\ GeV}$

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



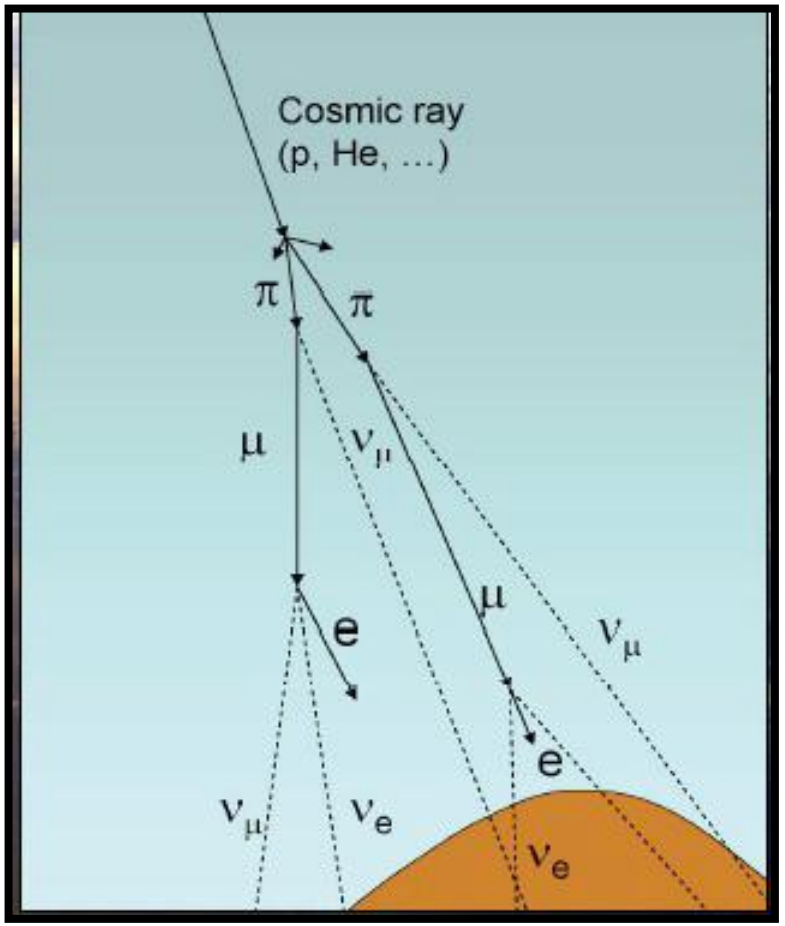
Various GZK models

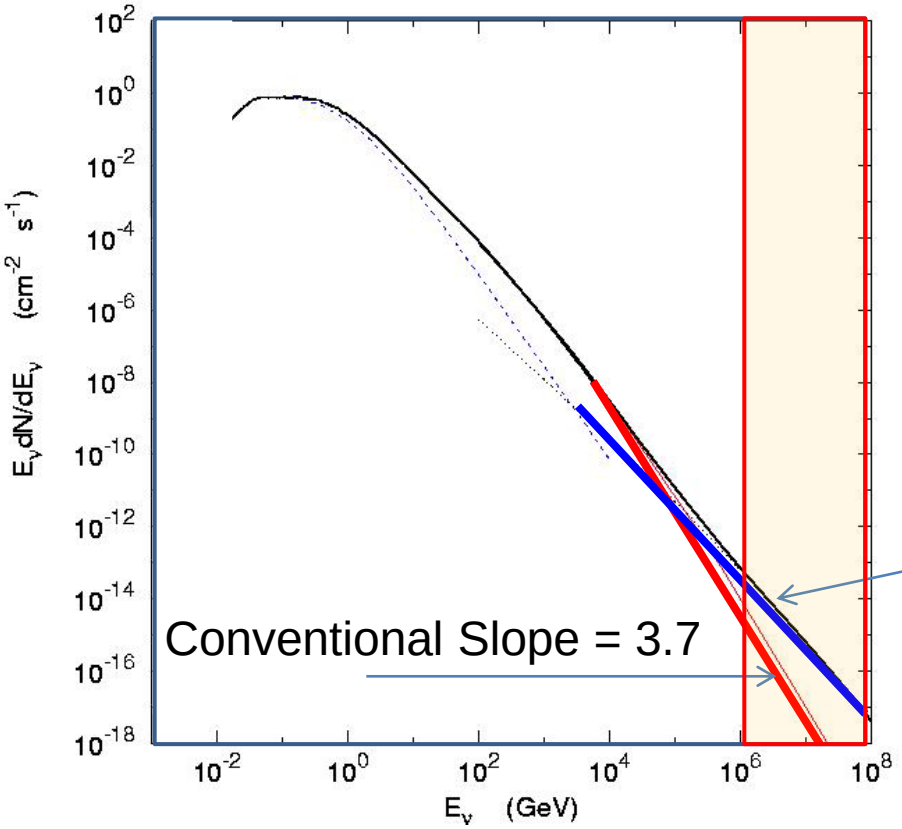
Carries important physics

- Location of the cosmic-ray sources
- Cosmological evolution of the cosmic-ray sources
- Cosmic-ray spectra at sources
- The highest energy of the cosmc-rays
- Composition of the cosmic-rays
- Particle physics beyond the energies accelerators can reach

Atmospheric neutrinos in PeV

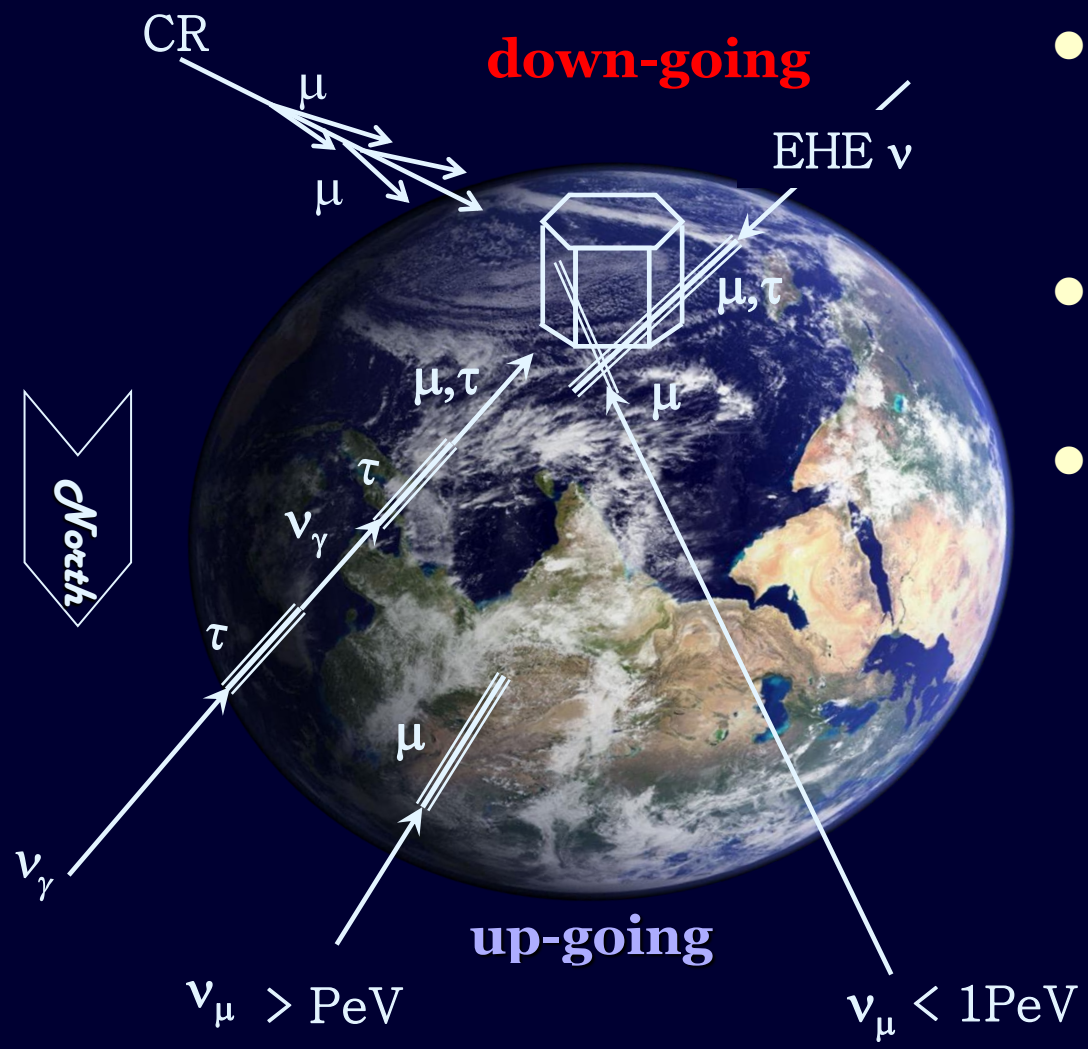
- Conventional atmospheric neutrinos from decays of pion and kaons
- Prompt atmospheric neutrinos form decays of heavy flavor short lived mesons (charm, bottom)
- Prompt harder than conventional still steeper than astronomical spectra
- Transition around 3 x 10^5 GeV depending on the models





Physics of heavy flavor particle production

UHE Neutrinos In the Earth…



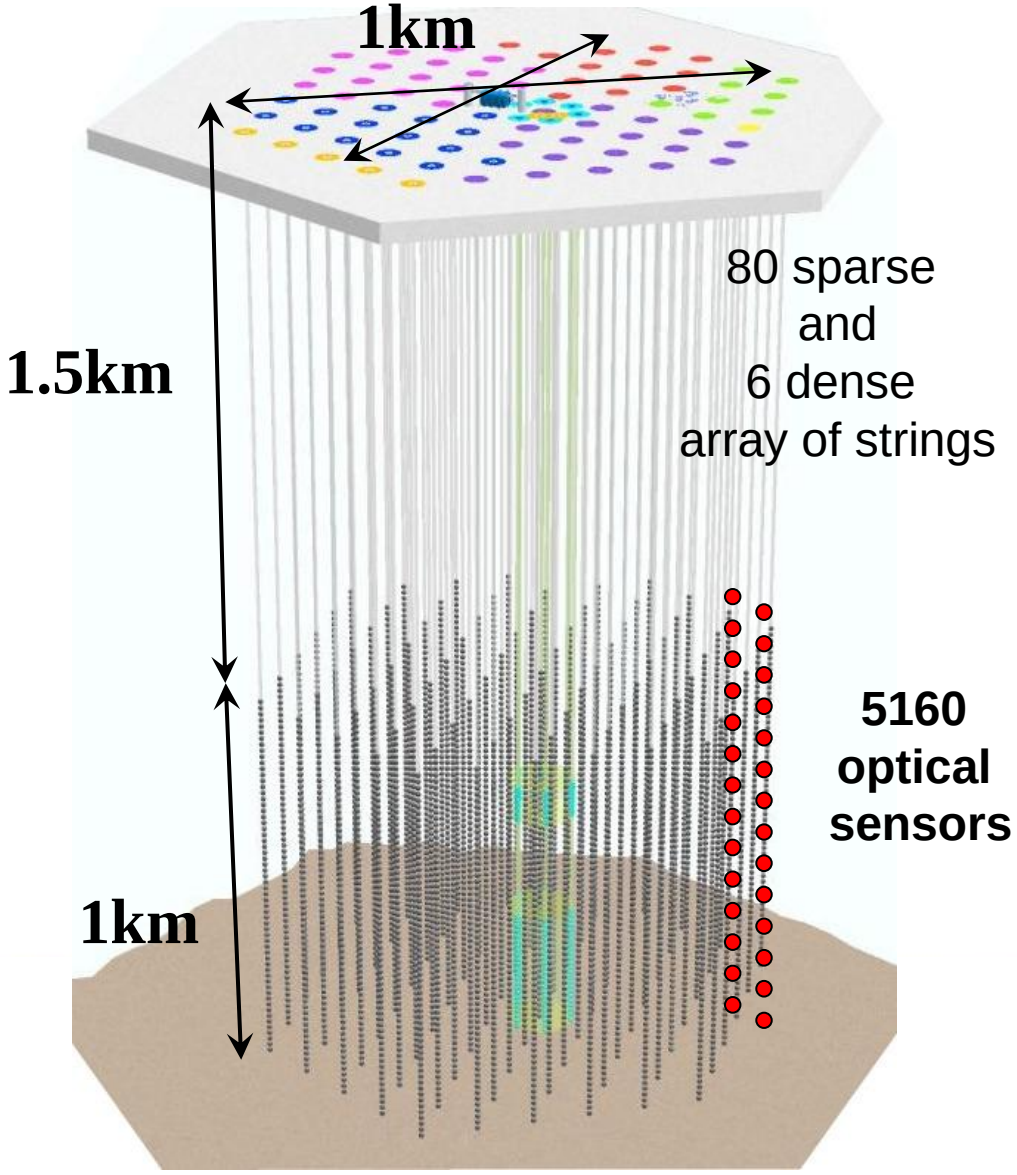
- Generally neutrinos identified as "through the Earth" up-going events
- Earth is opaque for EHE neutrinos
- EHE neutrino-induced events are coming from above and near horizontal direction

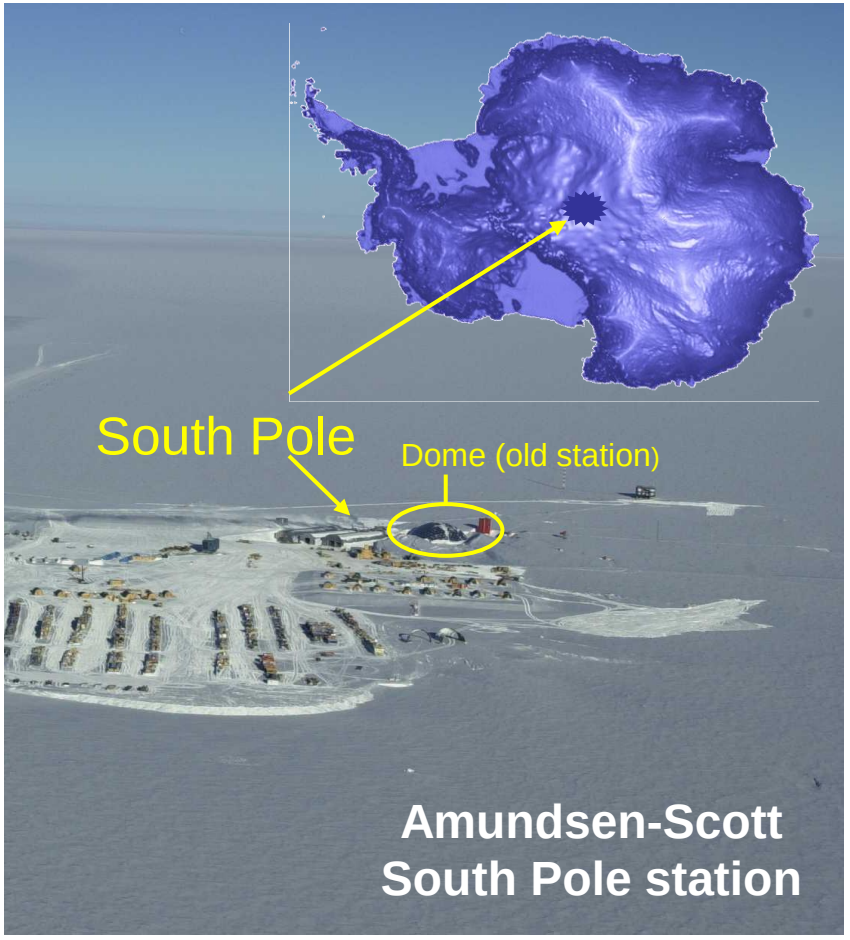
EHE neutrino mean free path

$l_n \sim 100$ km << R_{Earth}

$\sigma^{cc}_{nN} \sim 10^{-6\sim-4}$ mb

The IceCube Detector



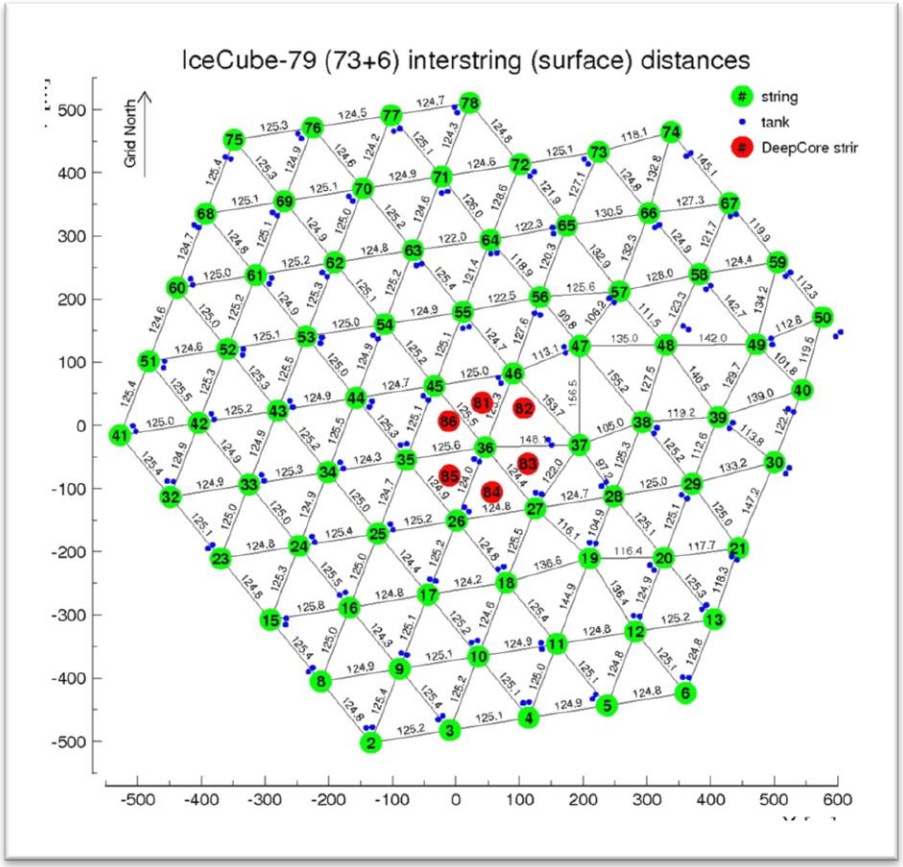


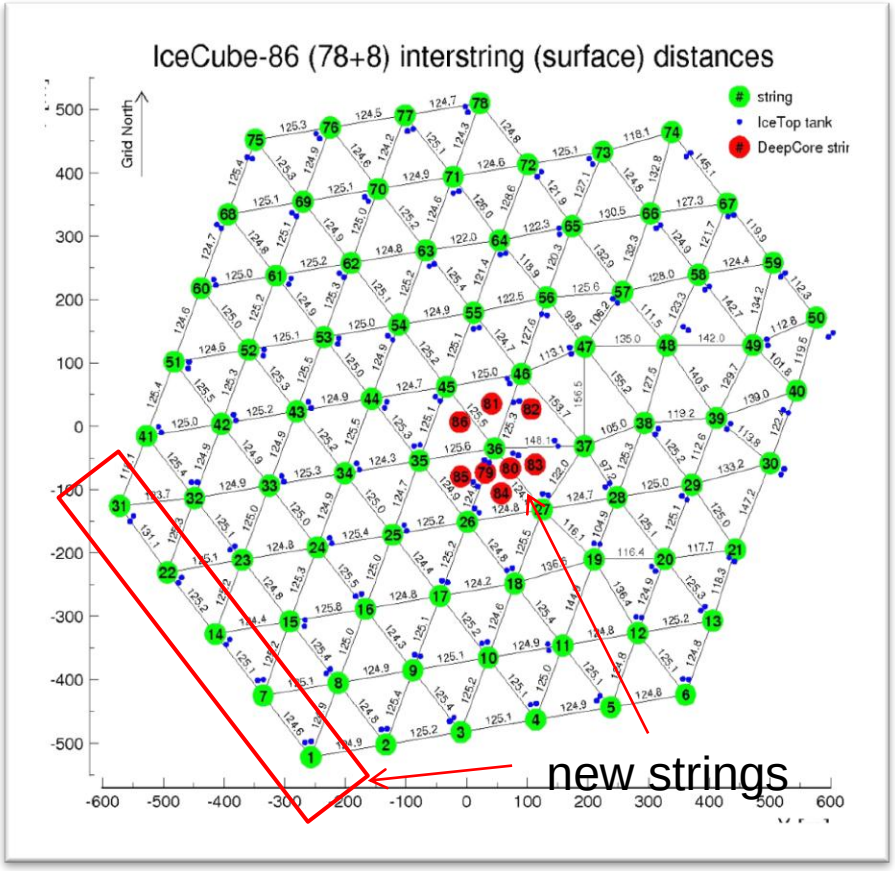
Data samples

9 strings (2006)
22 strings (2007)
40 strings (2008)
59 strings (2009)
79 strings (2010)
86 strings (2011)

2010-2011 - 79 strings config.
May/31/2010-May/12/2011
Effective livetime 319.07days

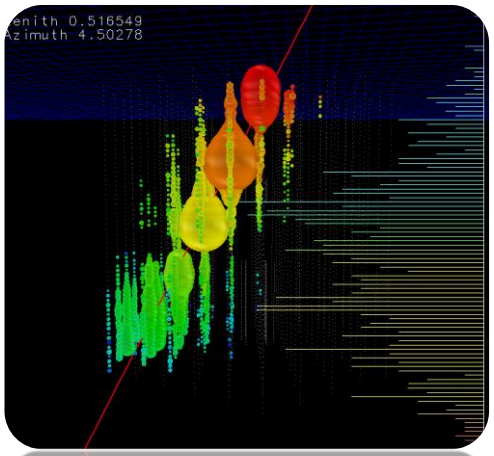
2011-2012 – 86 strings config
May/13/2011-May14/2012
Effective livetime 353.67 days

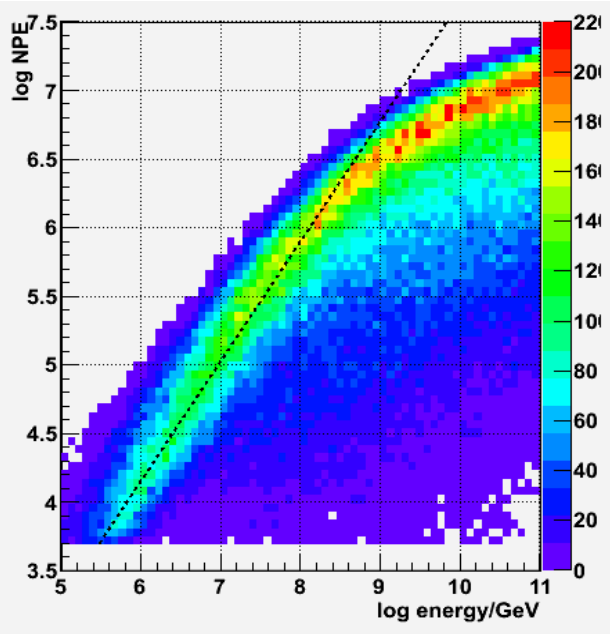




IceCube has been in a stable operation for more than 5 years

The Event Selection

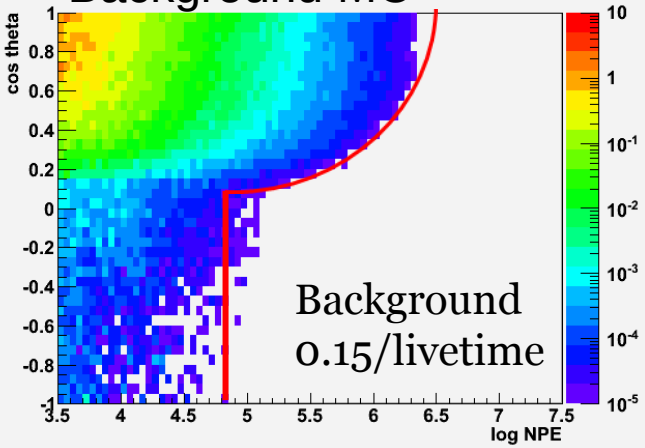




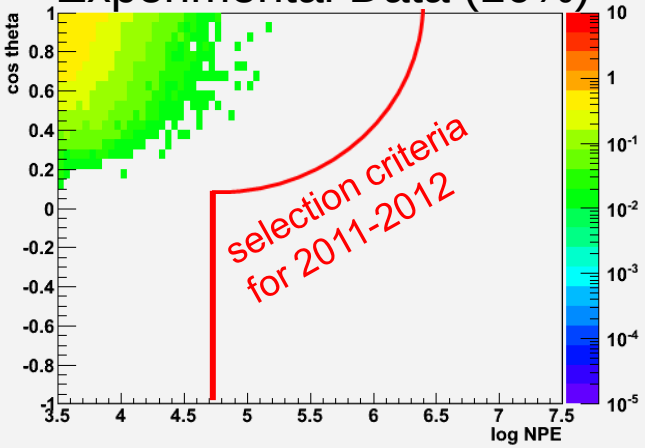
Energy of incoming particle ∝ Energy-losses in detector ∝ number of photo electrons (NPE)

- Optimization based MC / MC verification based on 10% 'burned' experimental sample

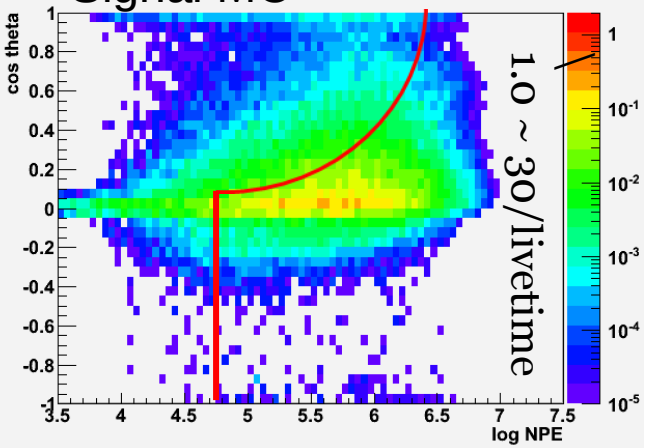
Background MC



Experimental Data (10%)



Signal MC

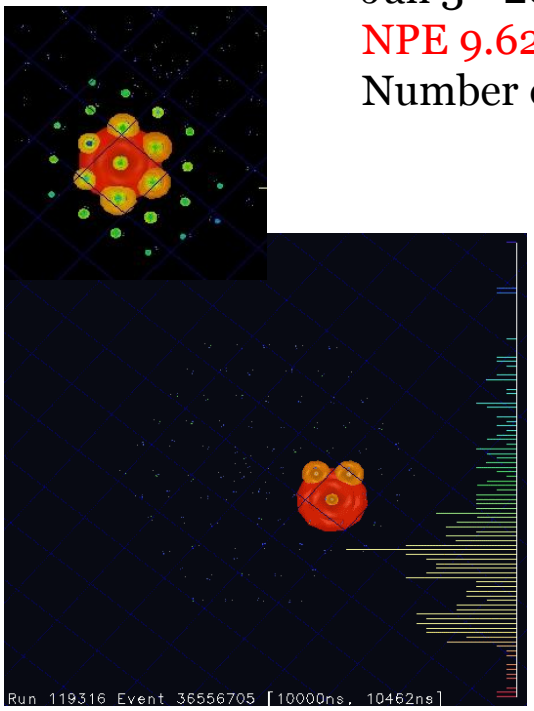


See the details of 2010-2011 data analysis at Poster #xxxx (Keiichi Mase)

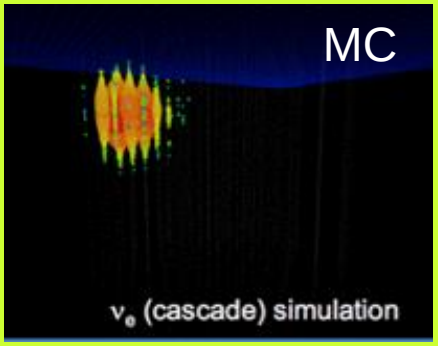
Two events passed the selection criteria

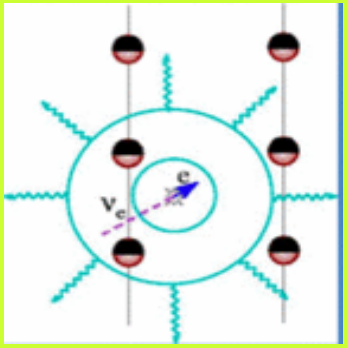
Run119316-Event36556705
Jan 3rd 2012
NPE 9.628×10^4
Number of Optical Sensors 312

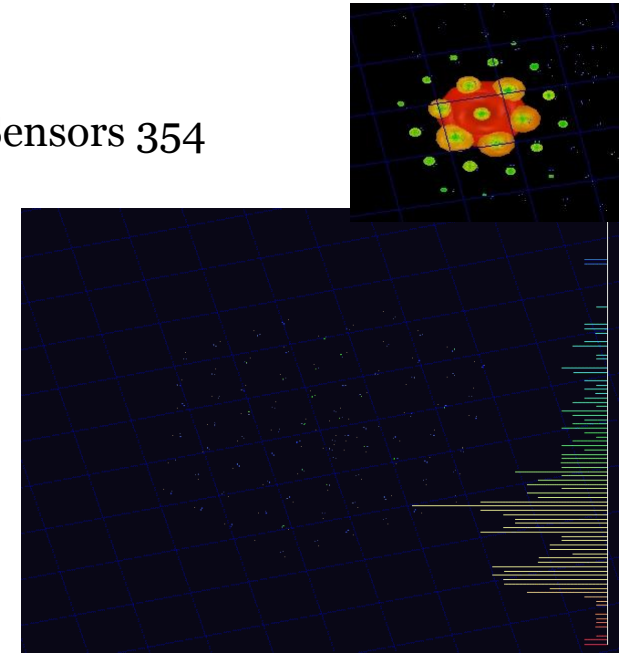
Run118545-Event63733662
August 9th 2012
NPE 6.9928×10^4
Number of Optical Sensors 354

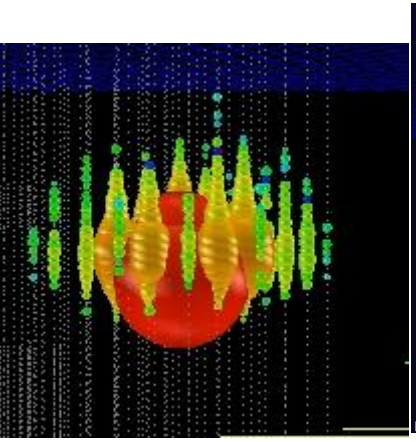


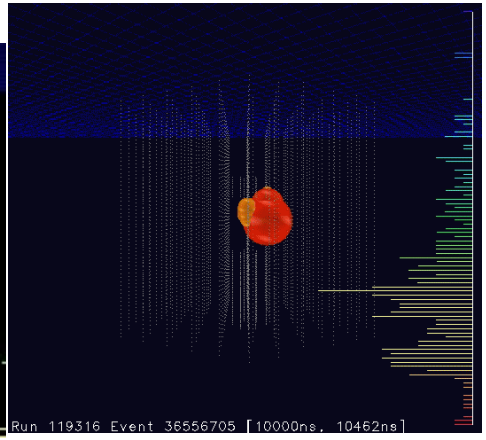
CC/NC interactions in the detector

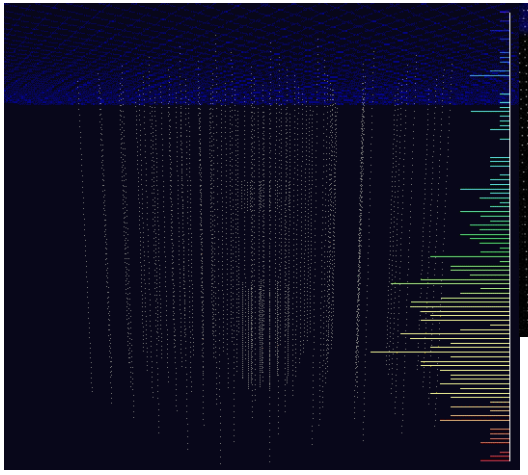


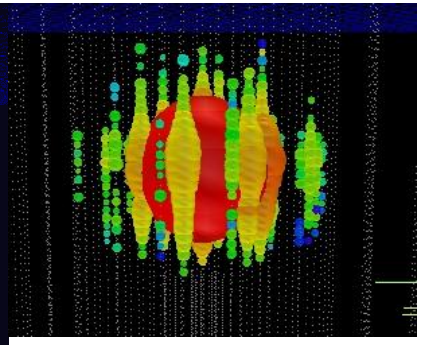




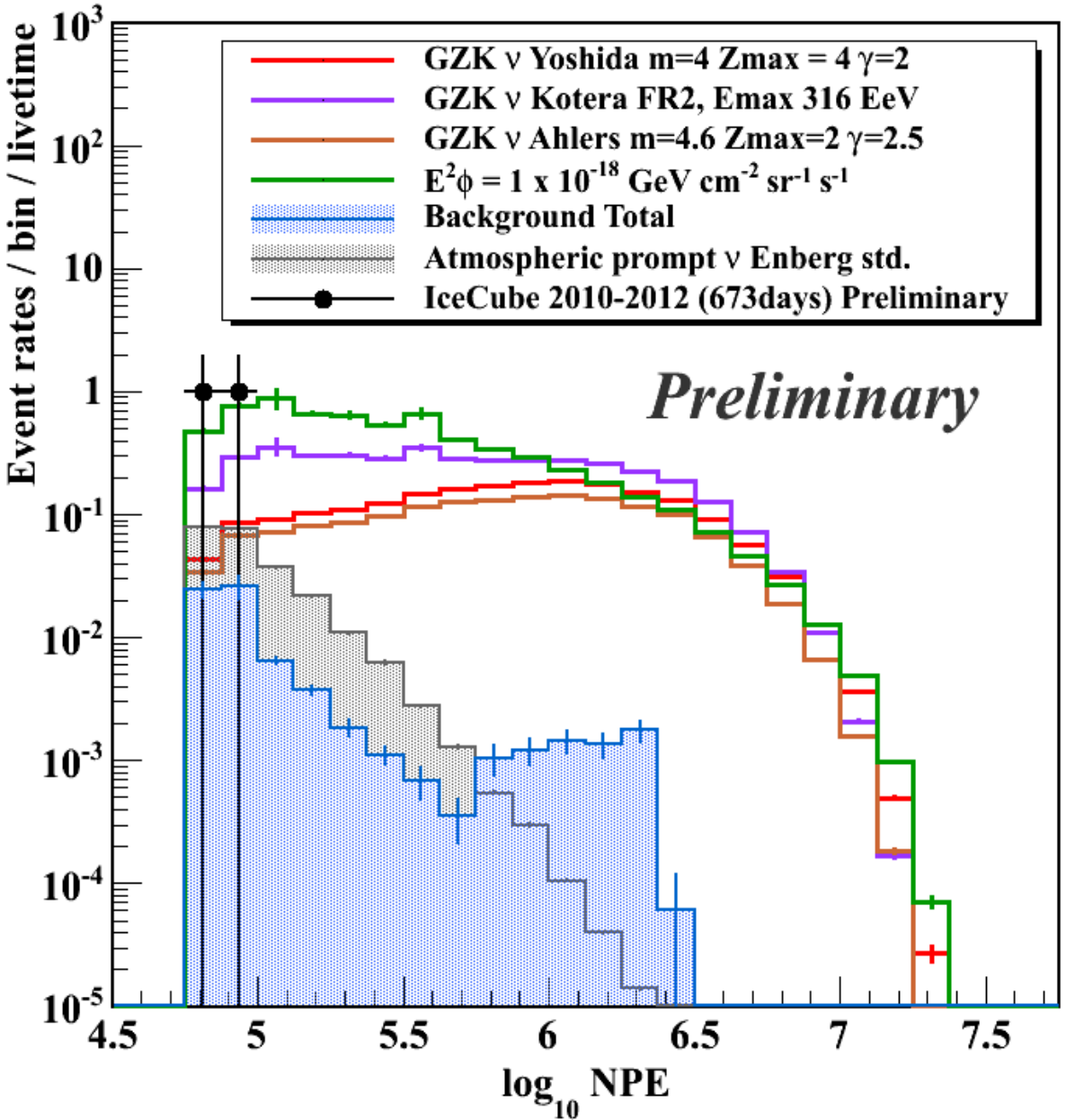








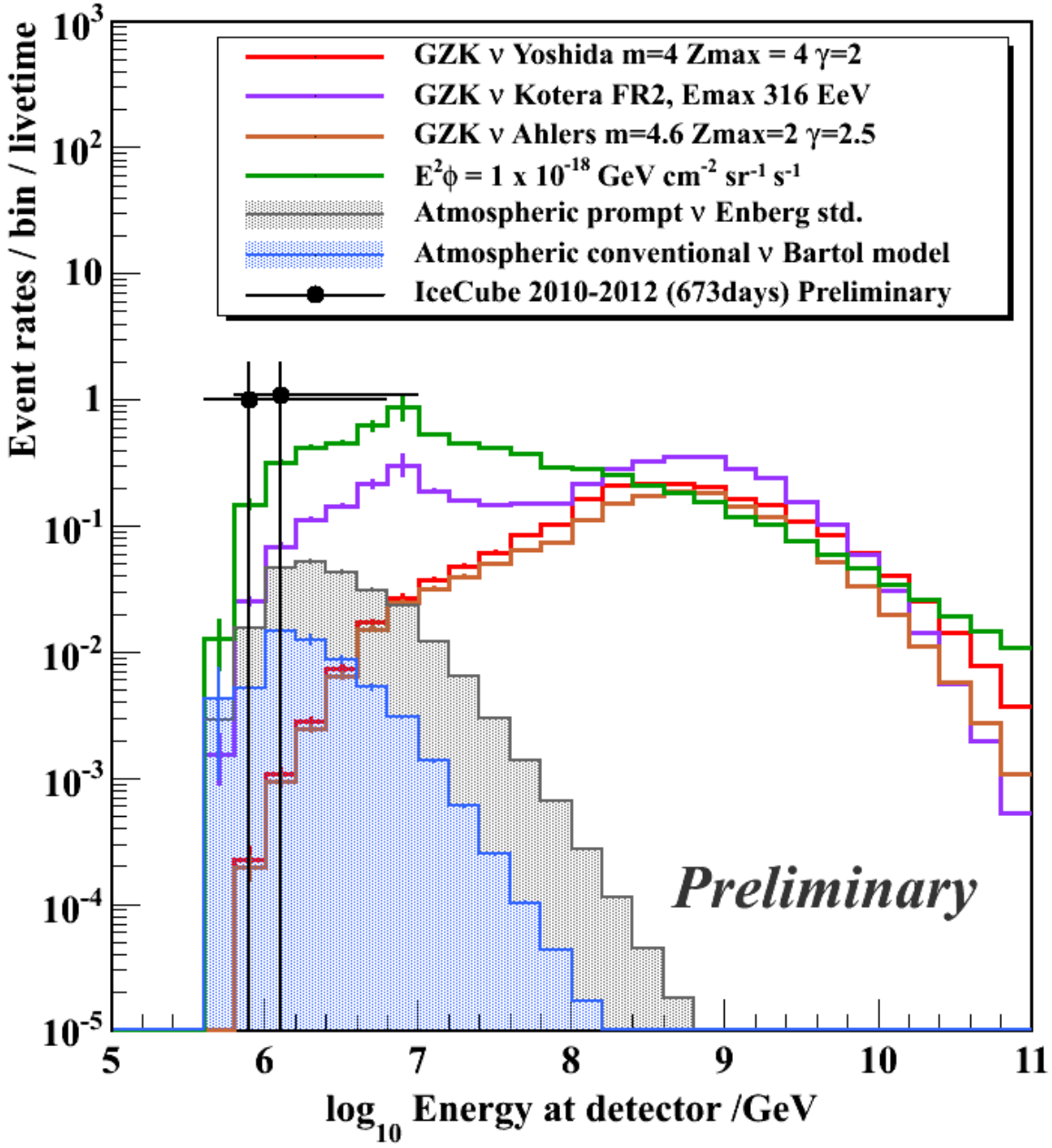
Event Brightness (NPE) Distributions 2010-2012



- Observed 2 high NPE events
- Near the NPE threshold

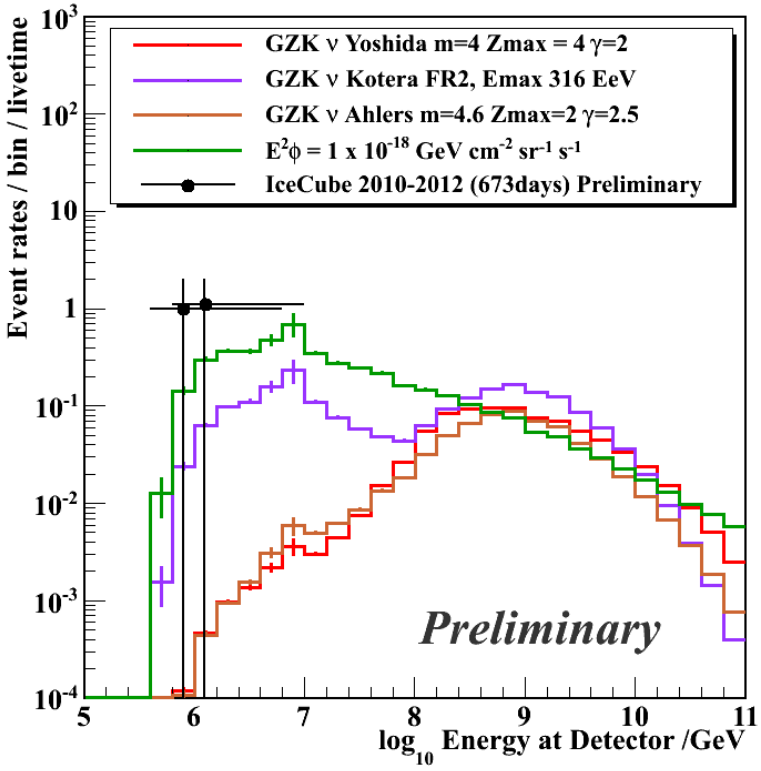
- Possibility of the origin includes
  - cosmogenic ν
  - on-site ν production from the cosmic-ray accrelators
  - atmospheric prompt ν
  - atmospheric conventional ν

Energy Distributions 2010-2012



- Most likely to be PeV to 10 PeV neutrinos

Cascade channel only



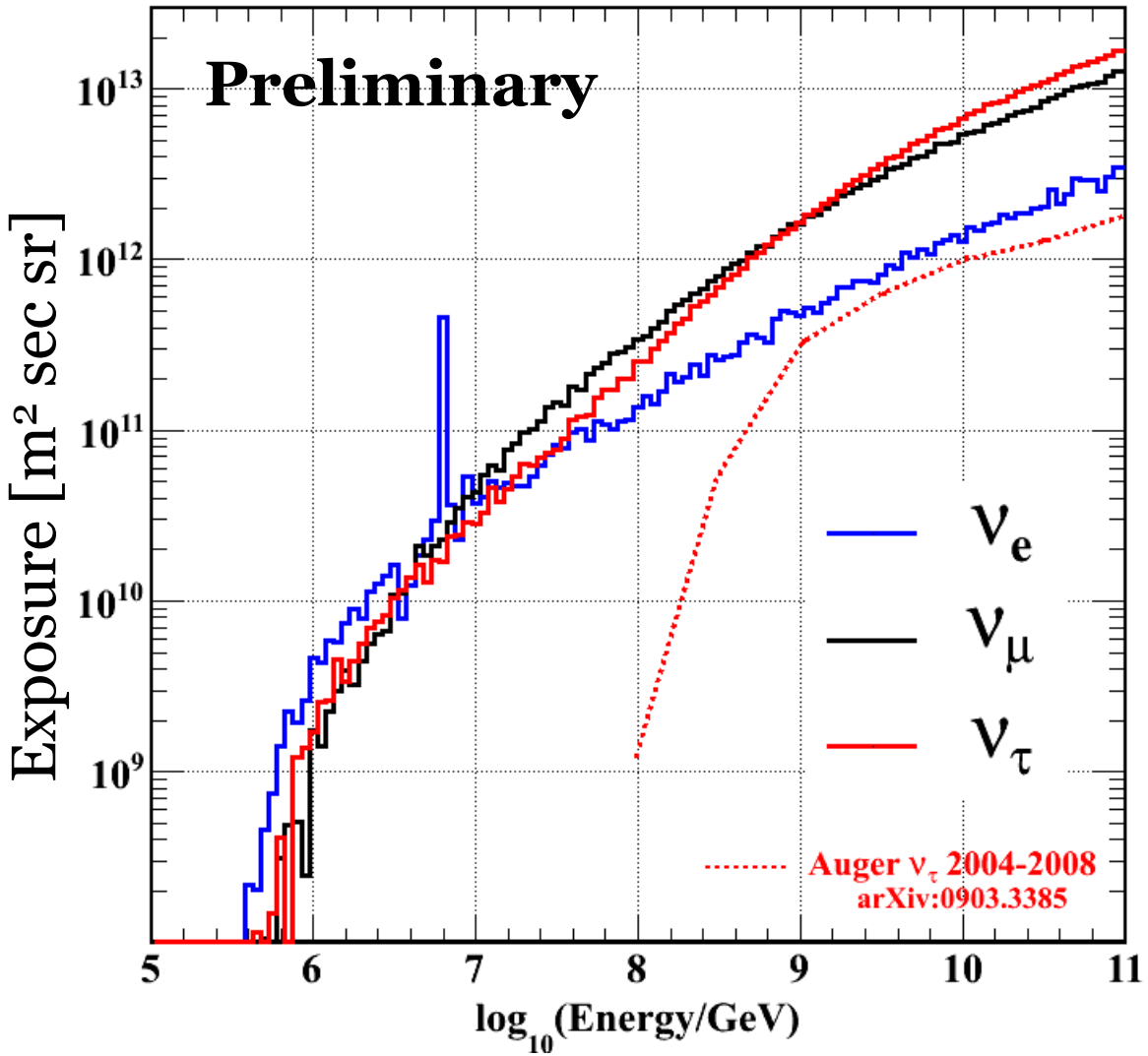
Expected Numbers of UHE Events

Models Preliminary	IceCube 2008-2009 Phys. Rev D83 092003 (2011) 333days	IceCube 2010-2012 672.7days	
		$E^{detector} < 10^8$ GeV	All contributions
Atmos. prompt ν (Enberg std.)^		0.2	0.2
$E^2\phi = 1 \times 10^{-8}$ GeV cm^{-2} sr^{-1} sec^{-1}		4.9	6.5
GZK (Yoshida m=4)*	0.57	0.4	2.1
GZK (Ahlers max) **	0.89	0.5	3.2
GZK (Ahlers best fit) **	0.43	0.3	1.6
GZK (Kotera, dip FRII) ***		1.7	4.1
GZK (Kotera, dip SFR1)***		0.6	1.0
Background (atm. ν + atm. μ)	0.11	0.14	0.14
Experimental data	0	2	2

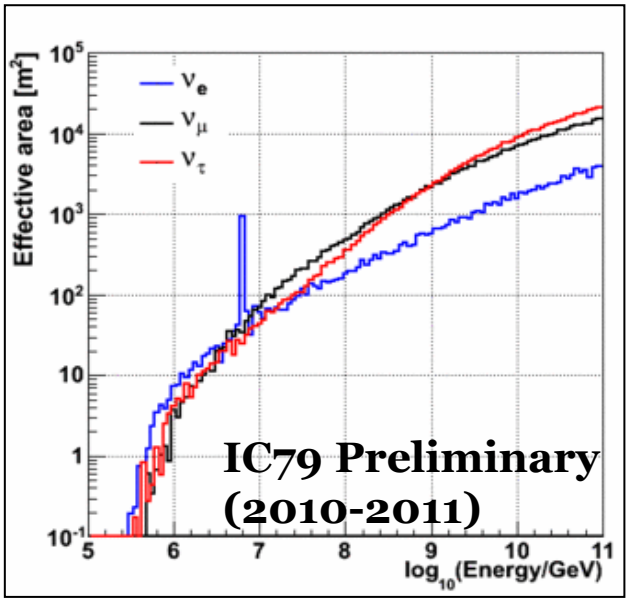
*Yoshida et al The ApJ 479 547-559 (1997), **Ahlers et al, Astropart. Phys. 34 106-115 (2010, ***Kotera et al, ^R. Enberg, M.H. Reno, and I. Sarcevic, Phys. Rev. D 78, 043005 (2008)

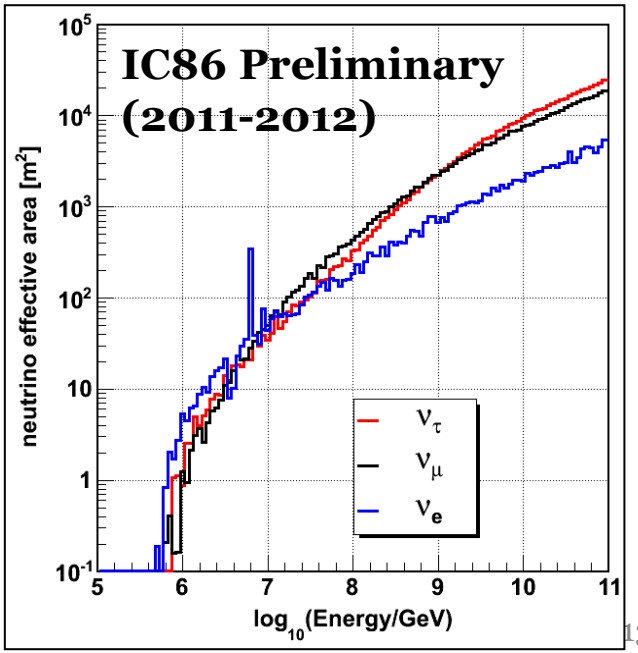
The Exposure and Effective Area

IceCube UHE 2 Years Exposure (2010-2012)

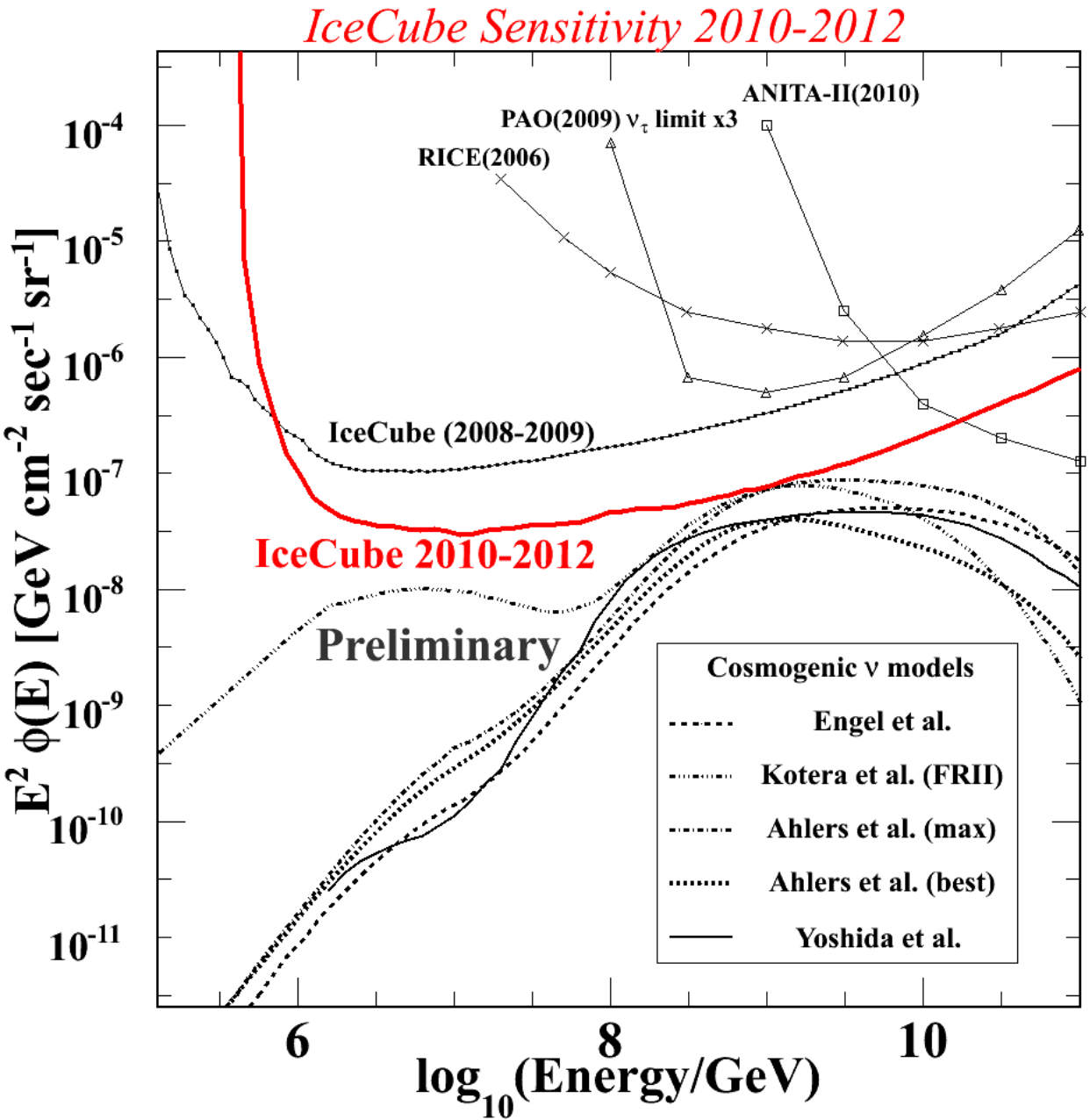


Effective Areas





IceCube UHE Sensitivity 2010-2012



- Significantly improved from the previous IceCube results
- The world's best sensitivity!
- Will constrain (or detect) the neutrino fluxes down to mid-strong cosmological evolution models

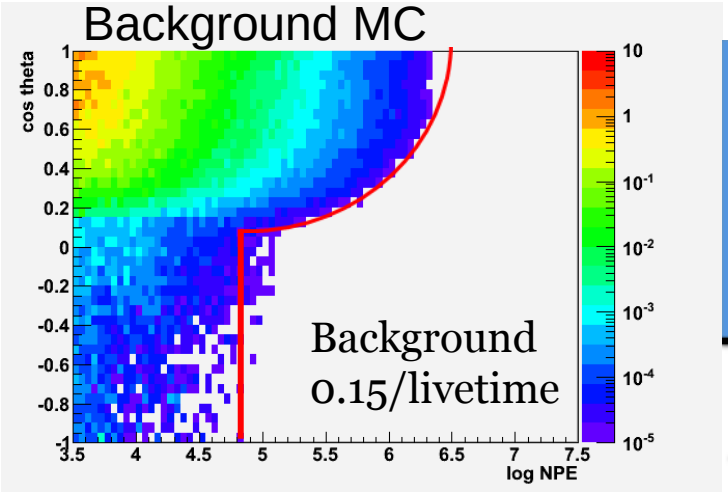
Summary

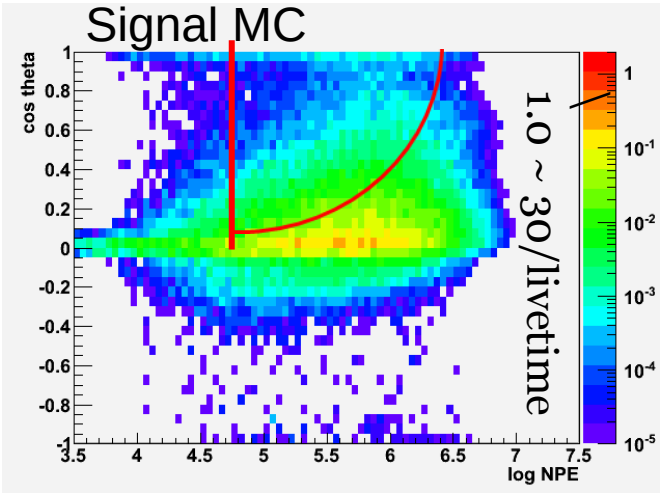
- Searched for neutrinos with PeV and greater energies in nearly full 2 years of the IceCube data
- Two candidate events observed
  - PeV to 10PeV energy cascade-channel neutrino events (CC/NC interactions within the detector)
- Likely to be beyond the conventional atmospheric neutrinos
- Hints for the PeV events origin from different energy-region / channels are also coming soon!
  - More cascade event sensitive analysis
  - Lower energy regions for the spectral transition
- Statistical confirmation foreseen with an independent sample
- **We are into very interesting era of neutrino astrophysics!**

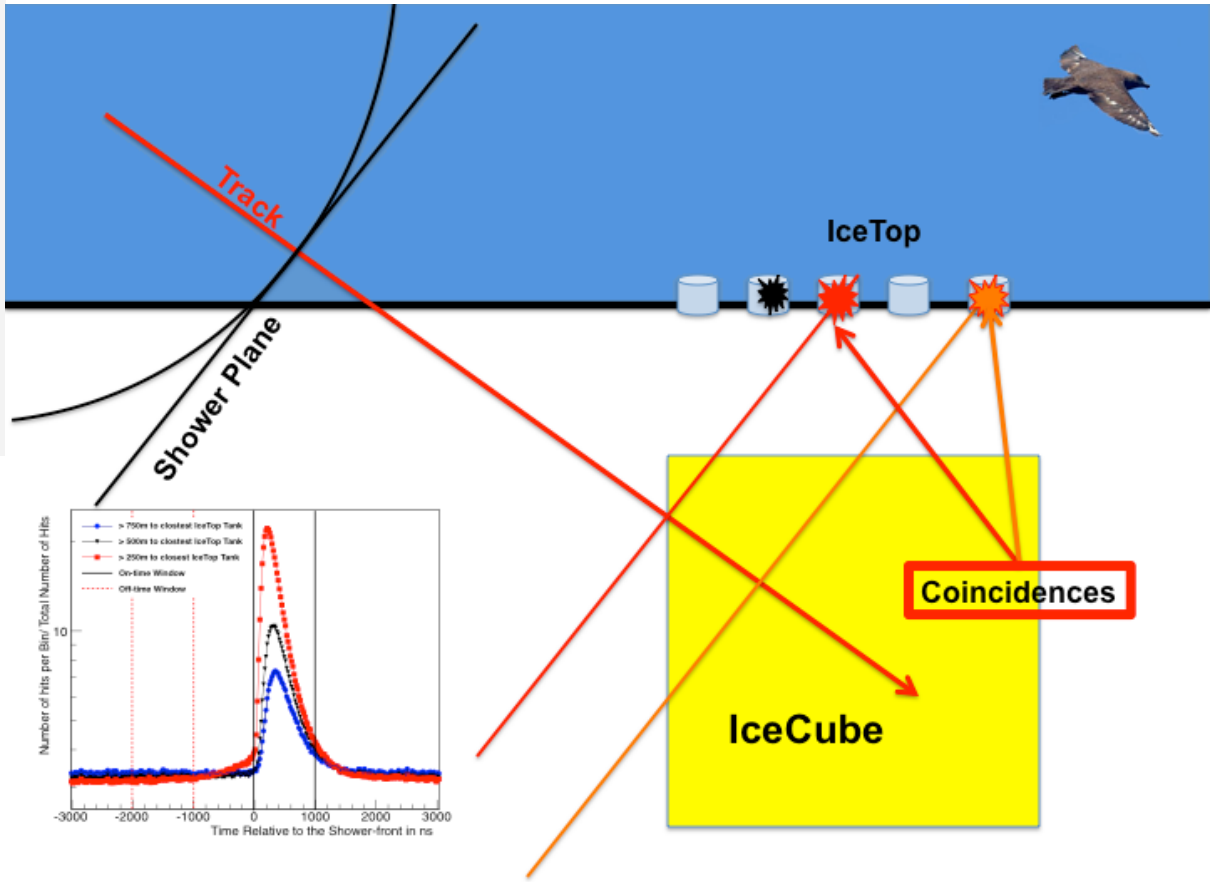
Backup

Background Veto with IceTop

Downward-going region is airshower induced muon background dominated

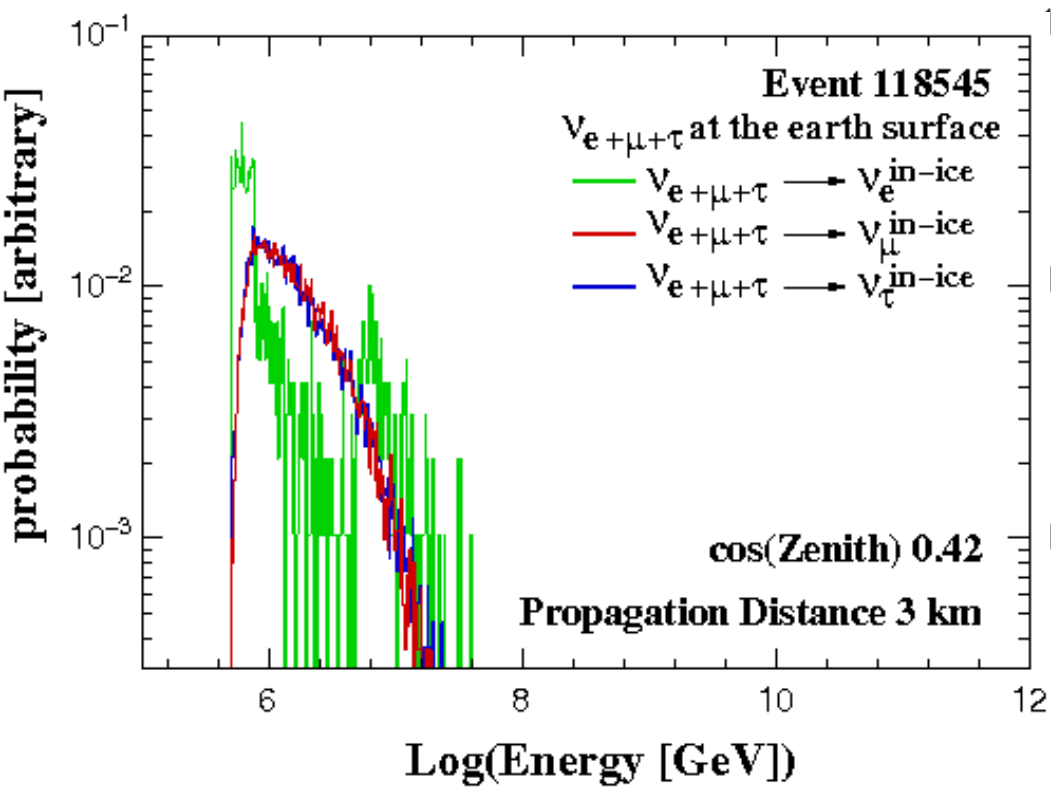


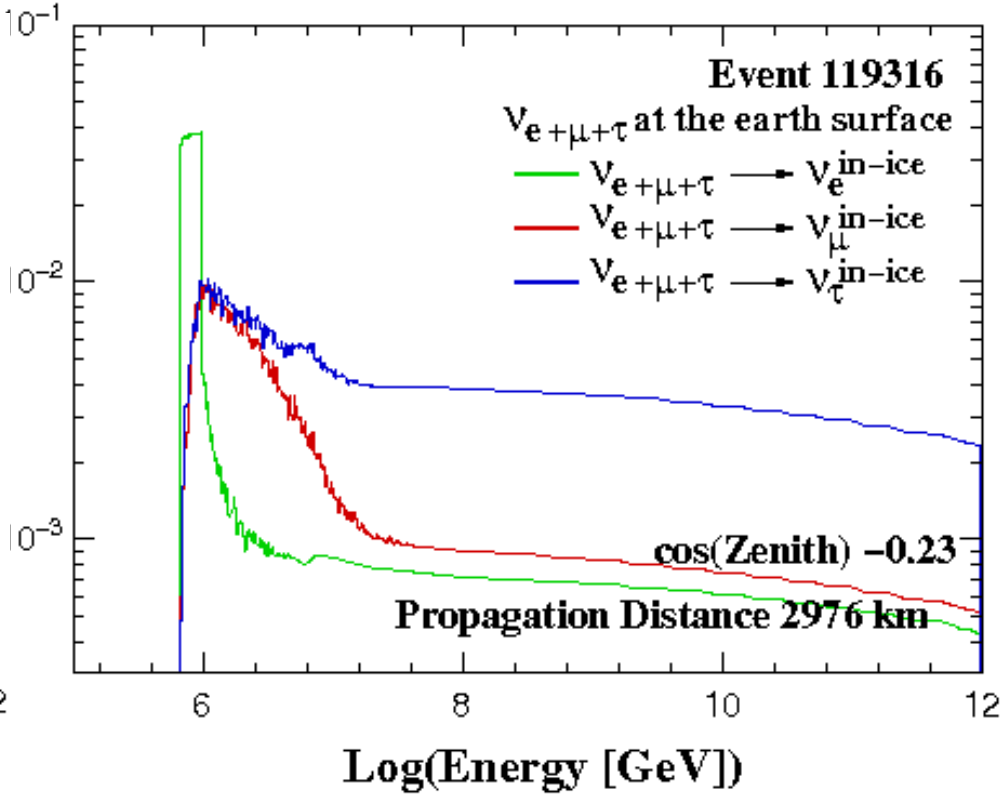




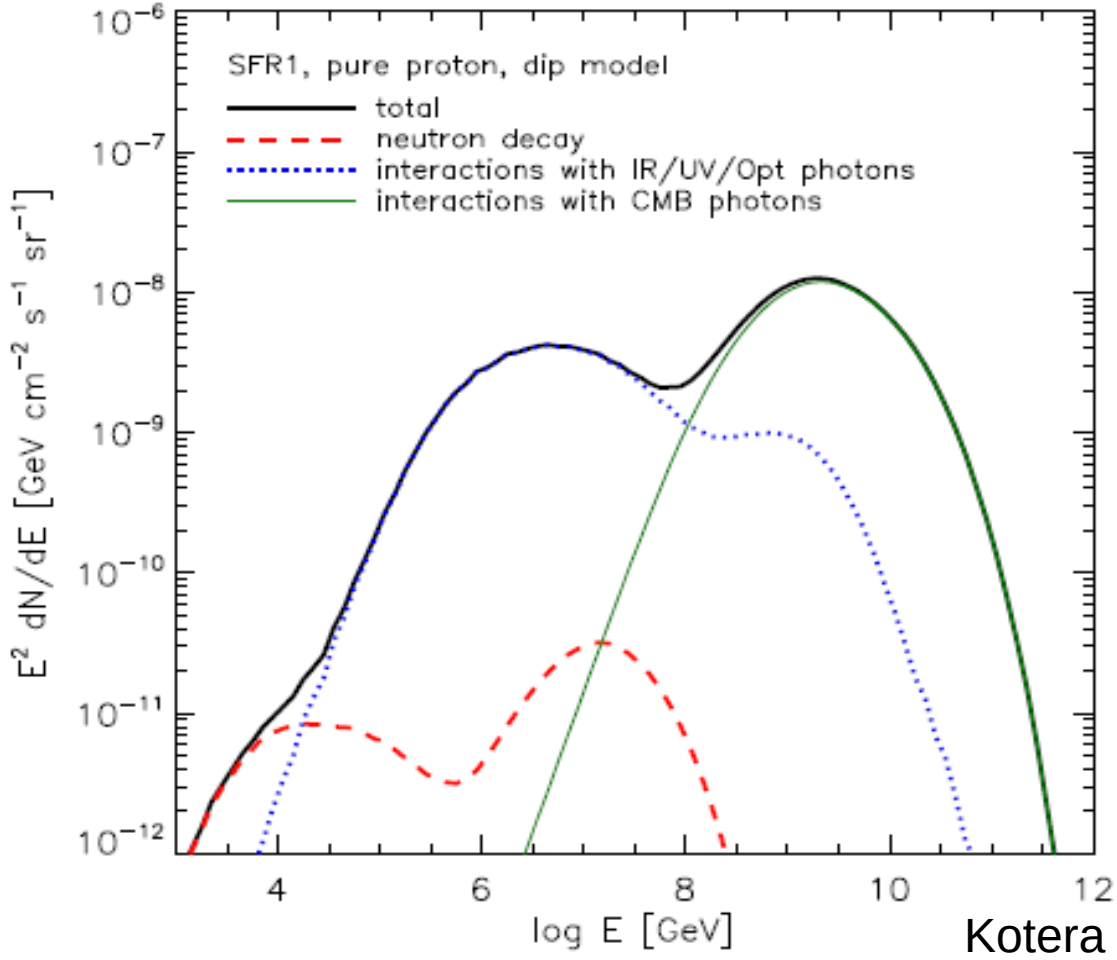
Surface Energy Distribution of Flavor Dependence

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.

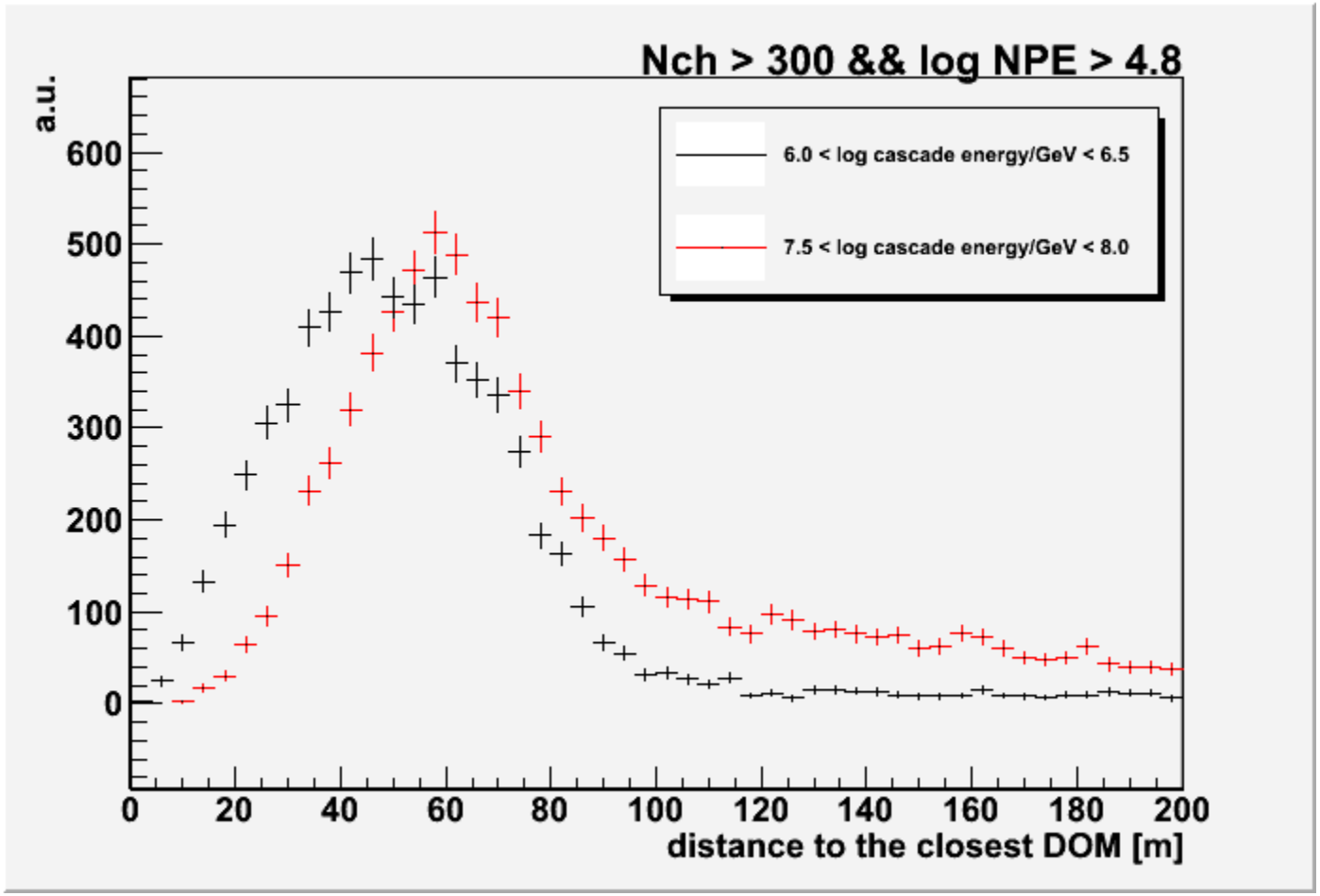




Contributions from IR/O, CMB and neutron decay



Kotera et al. JCAP (2010)


Nch > 300 && log NPE > 4.8
a.u.
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
180
200
distance to the closest DOM [m]
6.0 < log cascade energy/GeV < 6.5
7.5 < log cascade energy/GeV < 8.0

Possible Scenarios Near Term Beyond Neutrino2012

- Hardware issue (so far NO supportive material)
- Atmospheric muon induced (so far NO supportive material)
- Atmospheric conventional ν (different knee-models/compositions)
- Atmospheric prompt ν (different knee-models/compositions)
- Neutrinos with Glashow resonance
- GZK neutrinos from Opt/IR/UV interaction
- GZK neutrinos from CMB
- Neutron decay from dis-integrated heavy cosmic-rays
- Other astrophysical models
- …
- For the final upperlimit results in E > 10^8GeV, threshold may be finalized using re-optimization / re-unblinding procedure

should be excluded as experiment

Full 5comp sample on the way, Adding more current MC help to confirm?

Need more simulation sample (requested)

Further energy scale studies needed

P-values
Intensities