Searches for Astrophysical Neutrinos with IceCube

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24th Rencontres de Blois
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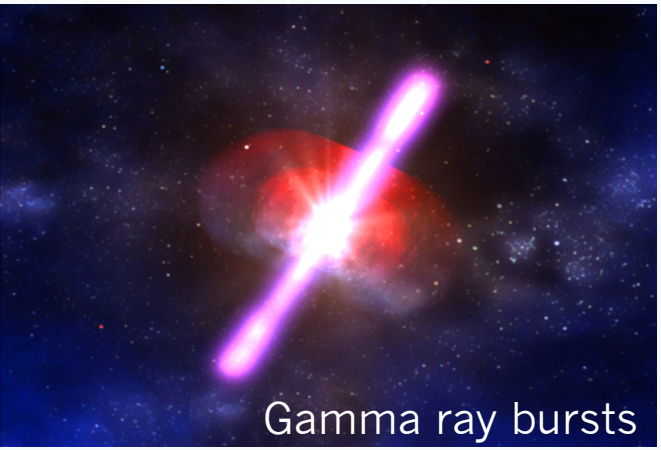
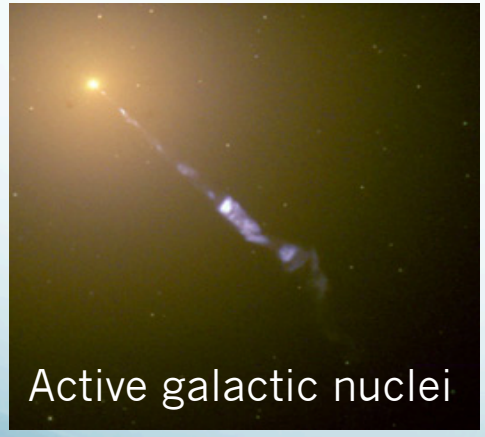
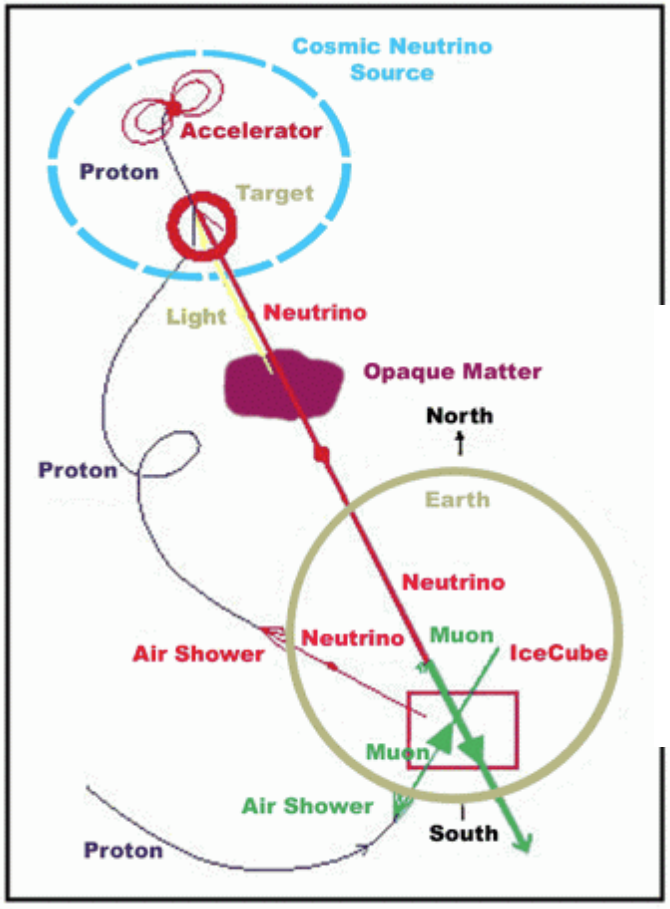
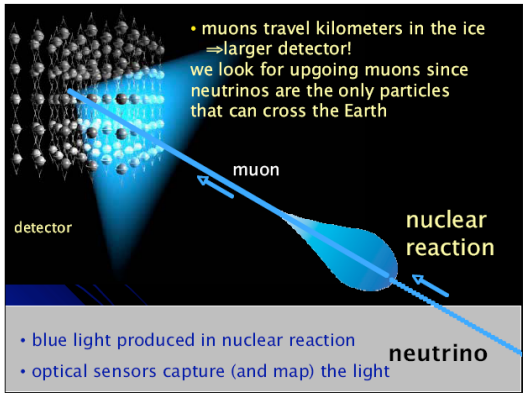
Neutrino Astronomy







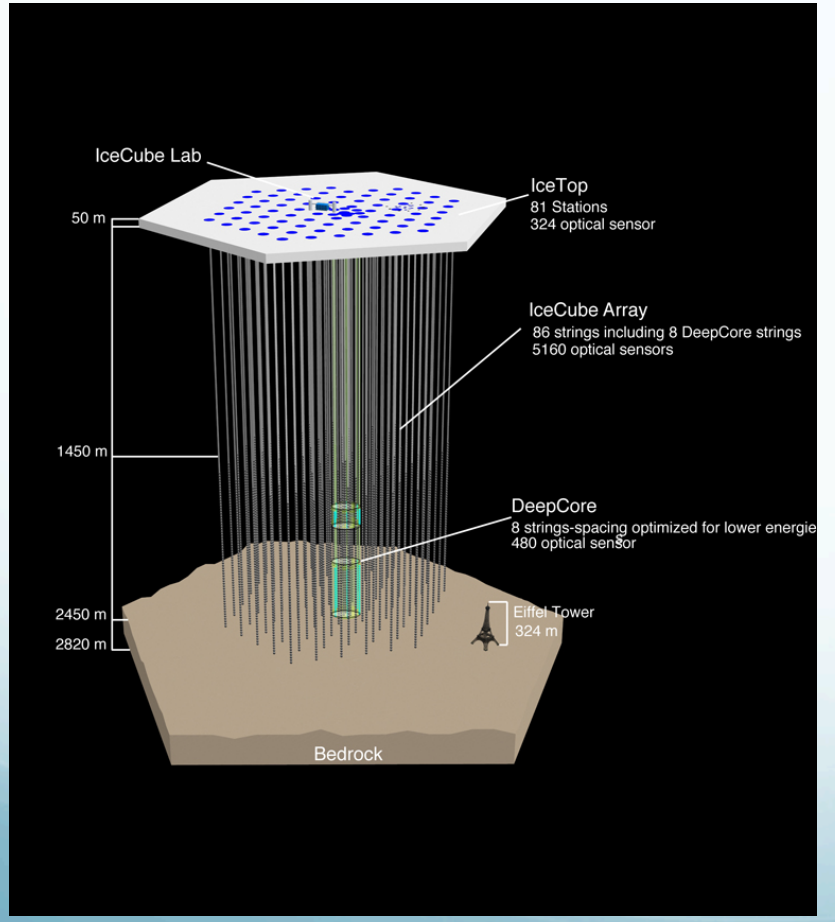
Sources of the highest energy cosmic rays are also potential neutrino sources



Large detector required for neutrino astronomy

The IceCube Detector

Location: Amundsen-Scott South Pole Station, Antarctica

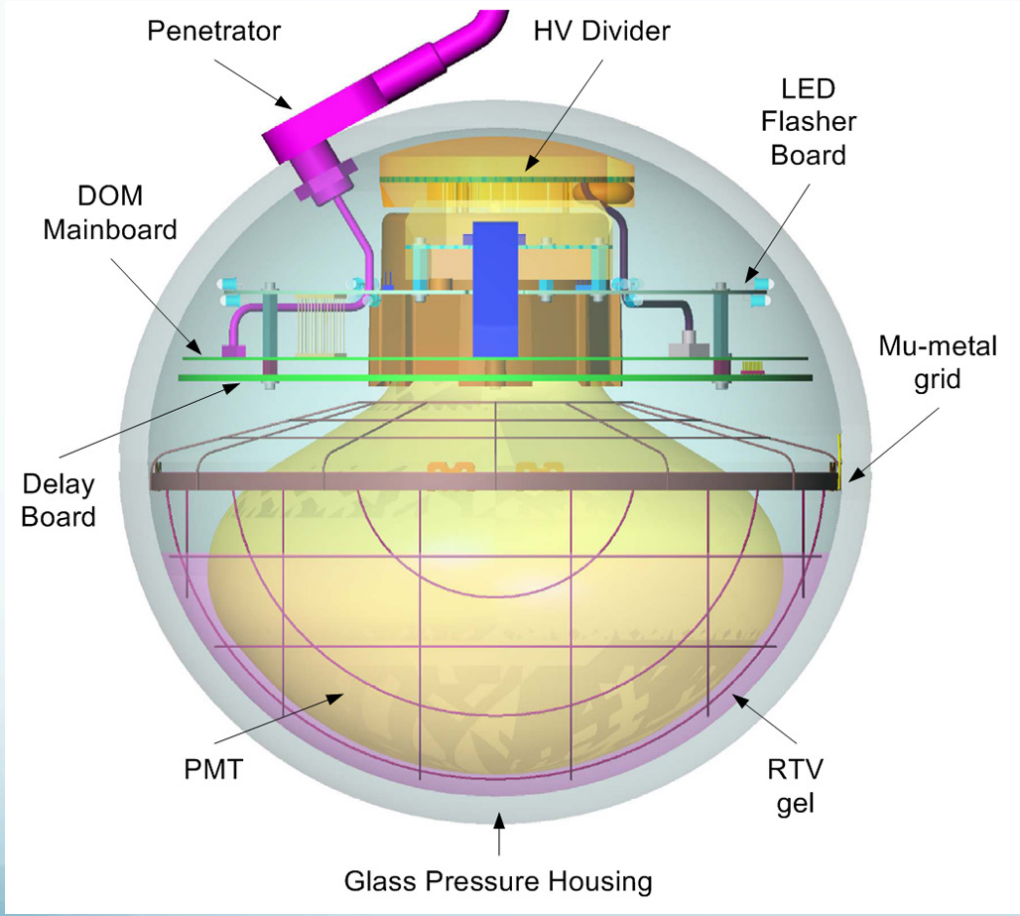


- IceCube construction completed December 2010
  - 86 in-ice strings
    - 60 Digital Optical Modules (DOMs) per string
    - DOMs deployed between 1450 and 2450 m deep
    - Innermost strings form the densely instrumented "DeepCore" array
  - 81 IceTop surface stations
    - 2 tanks per station

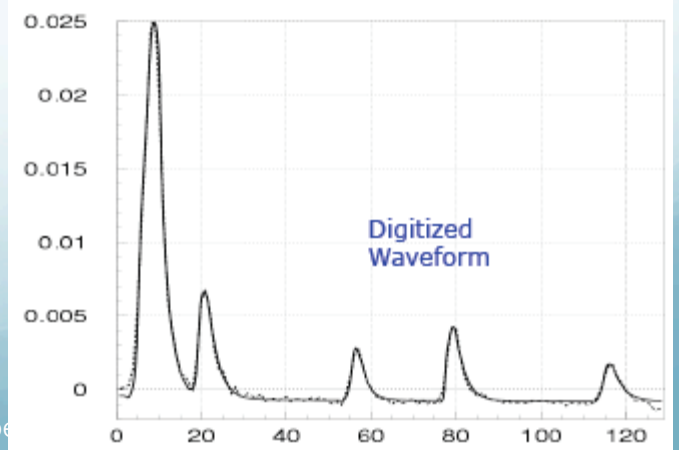
IceCube data taken during construction

2006-7 data set – IC9
2007-8 data set – IC22
2008-9 data set – IC40
2009-10 data set– IC59
2010-11 data set – IC79
Final configuration, 2011-present – IC86

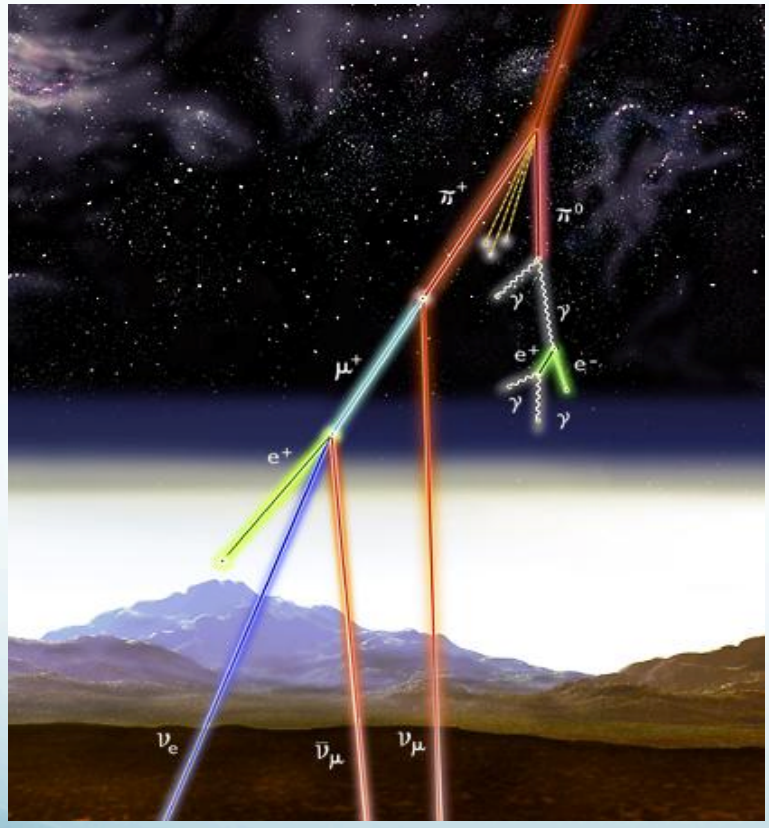
The IceCube DOM

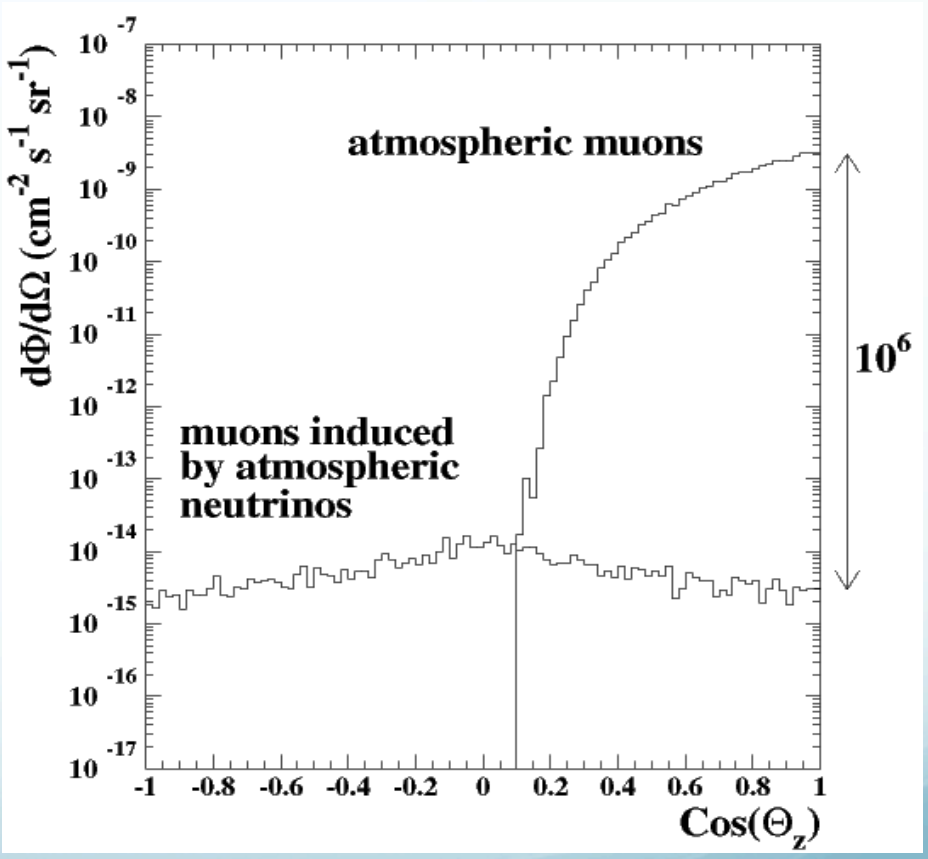


- **PMT waveform digitization in-ice**
- **On-board flasher LEDS for calibration**
- **Time calibration from surface GPS**



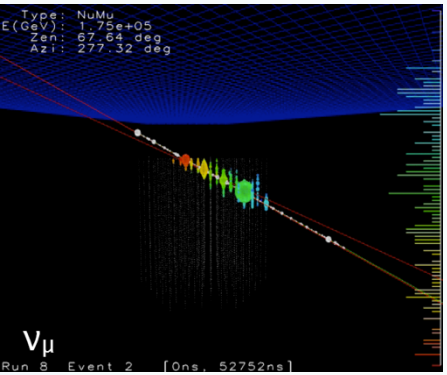
Backgrounds



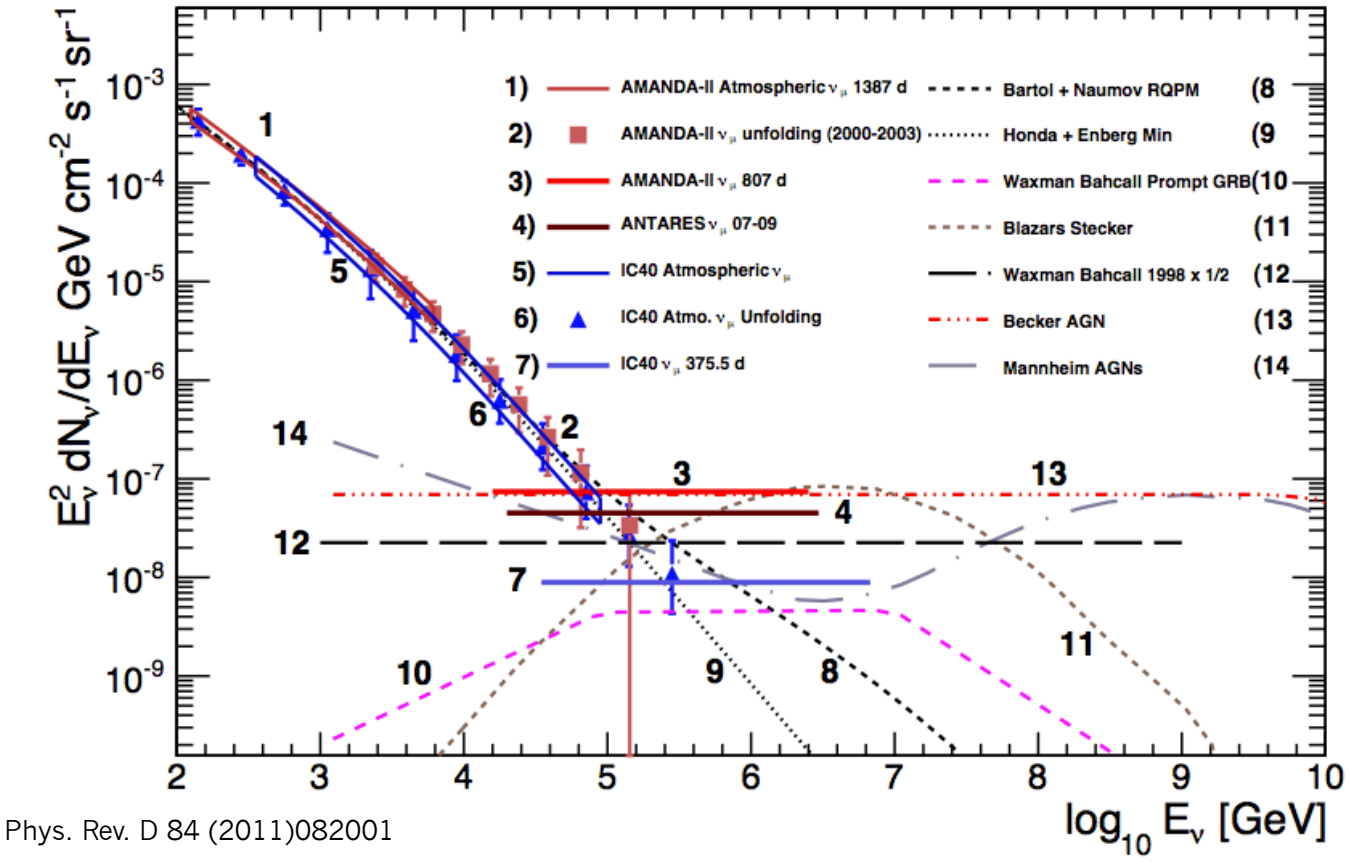


Upgoing events **Downgoing events**

Diffuse Flux, muon neutrinos



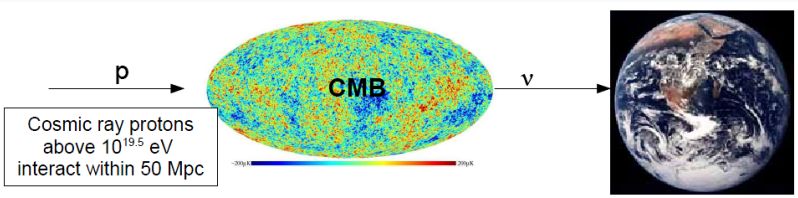
Simulated muon neutrino "track" in IceCube



Phys. Rev. D 84 (2011)082001

Limits from search for excess of muon neutrinos above atmospheric spectrum, all directions

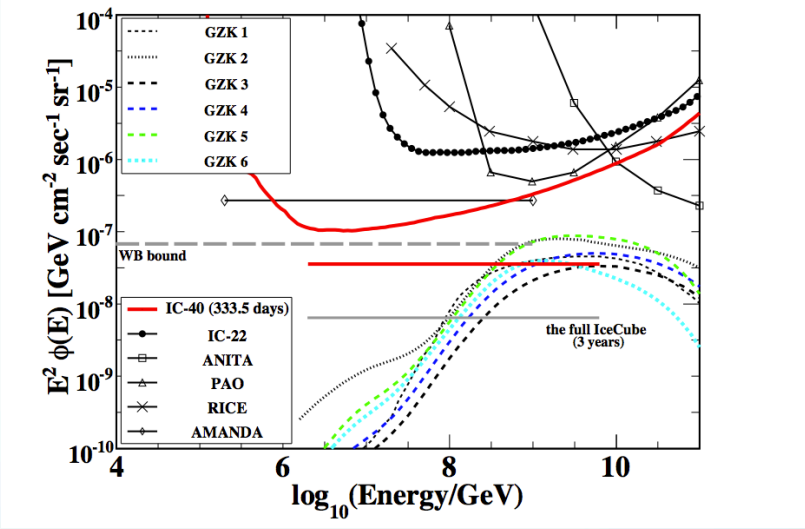
Limits on GZK Neutrinos



$$\gamma_{\mathrm{CMB}} + p \rightarrow \Delta^{+} \rightarrow p + \pi^{0}$$

$$\gamma_{\mathrm{CMB}} + p \rightarrow \Delta^{+} \rightarrow n + \pi^{+}.$$

GZK neutrinos expected from cosmic ray interaction with cosmic microwave background



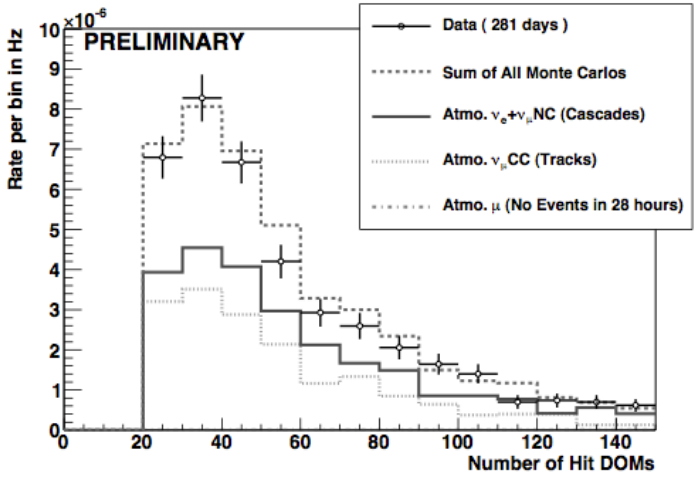
Phys.Rev.D83:092003(2011); Phys.Rev.D84:079902(2011)

IC40 data constrains GZK models with the highest flux predictions

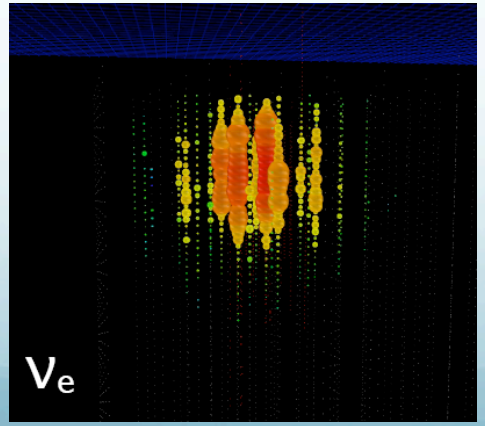
Sensitivity will improve with IC86

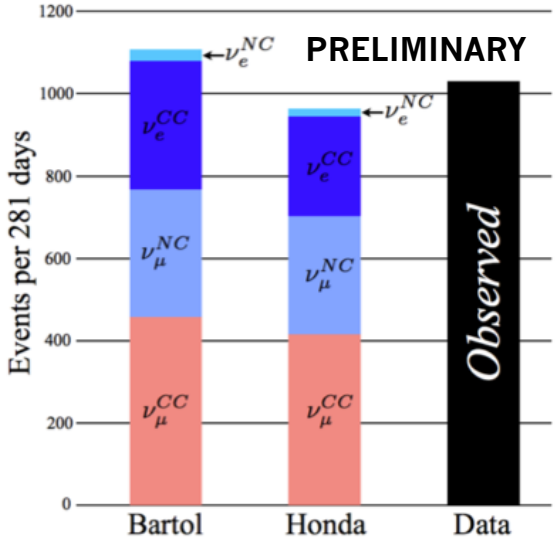
Diffuse Flux: cascades

- **Cascades are the signature of neutral current, ν_e and ν_τ**
- **First observation of atmospheric neutrino-induced cascades in IC79 with DeepCore**



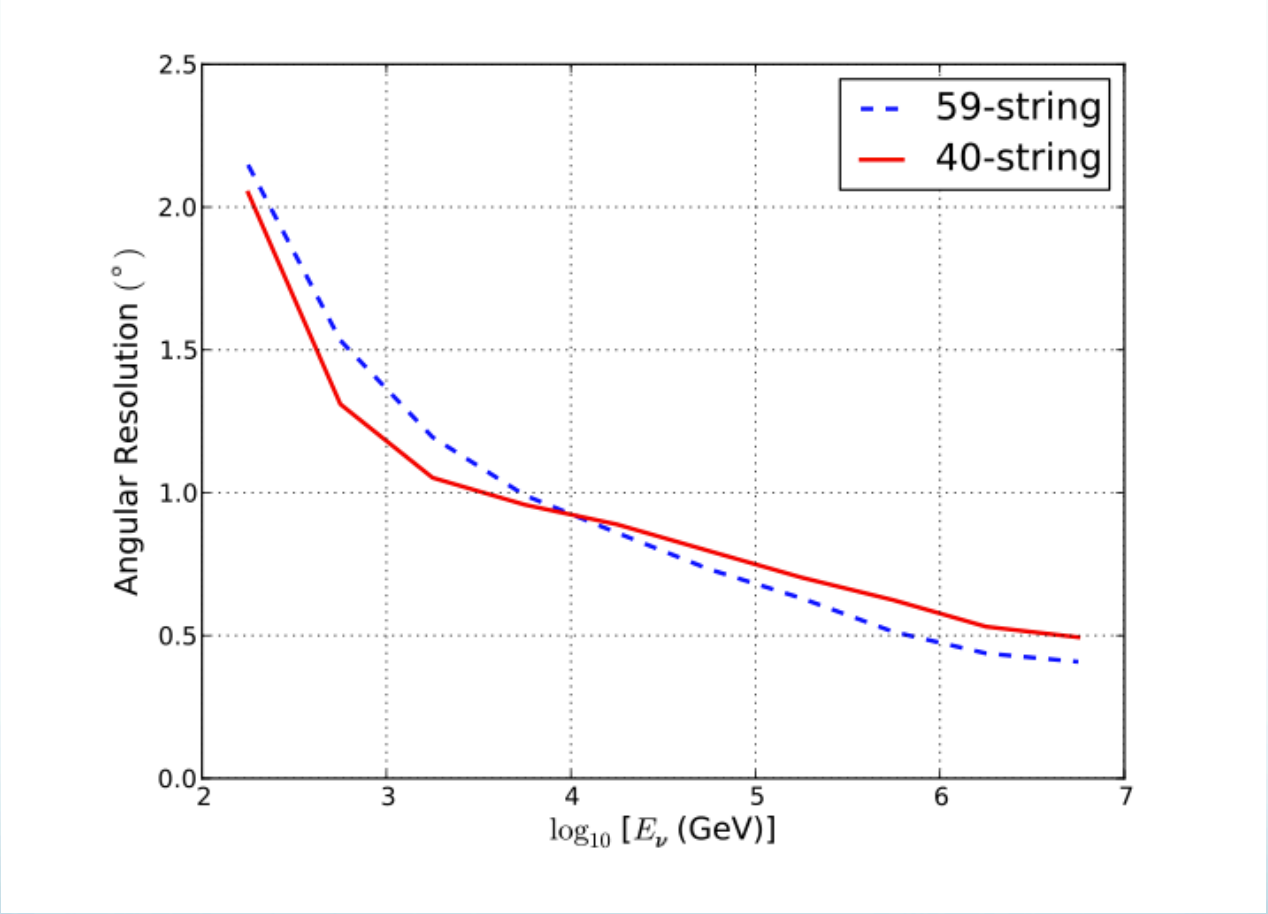
Simulated electron neutrino "cascade" in IceCube





Chang Hyon Ha, TAUP 2011

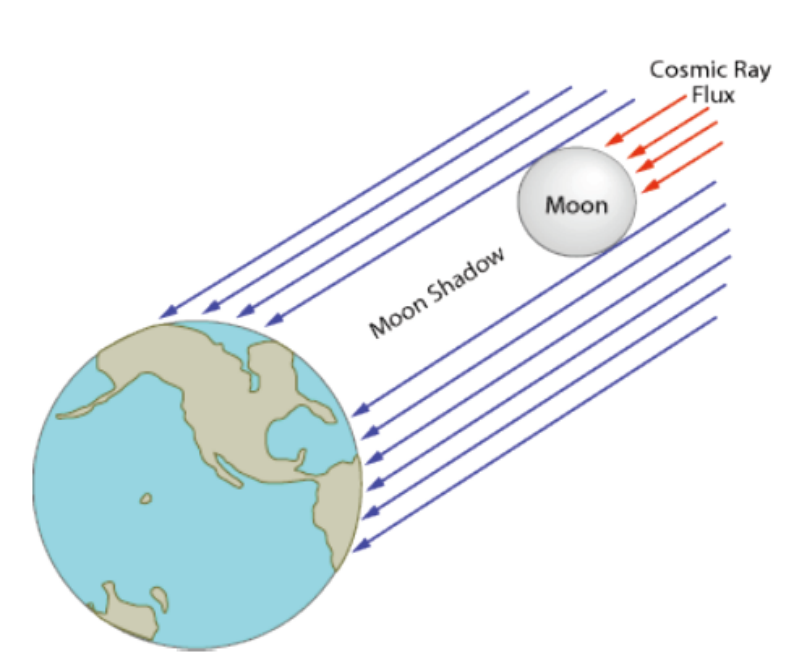
Pointing Resolution IC40 and IC59

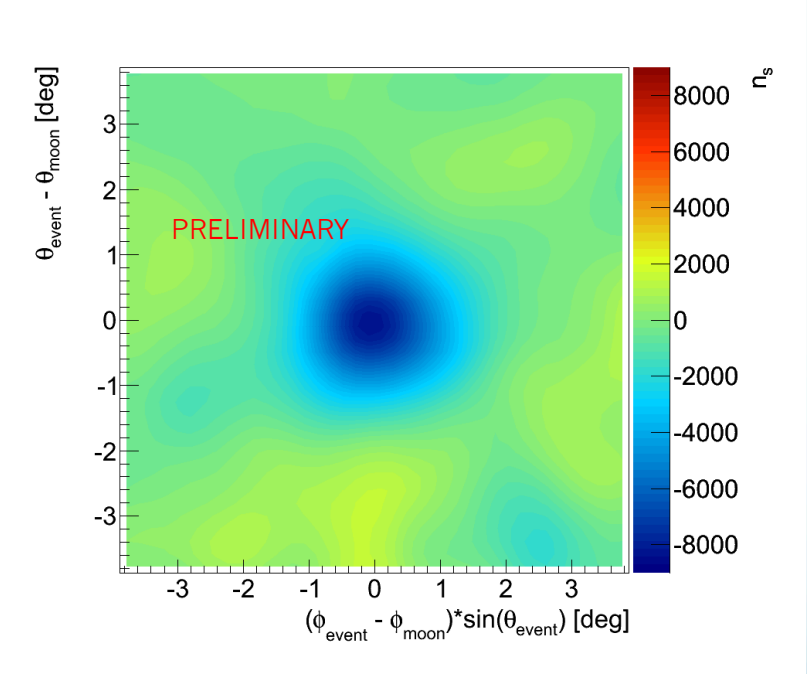


ICRC 2011

Moon shadow

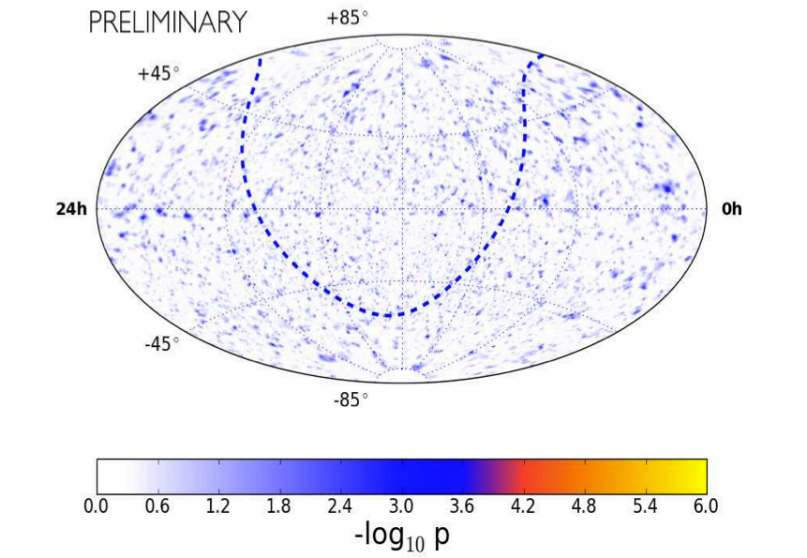
Proof of concept for IceCube pointing: look for deficit in cosmic rays from the direction of the Moon

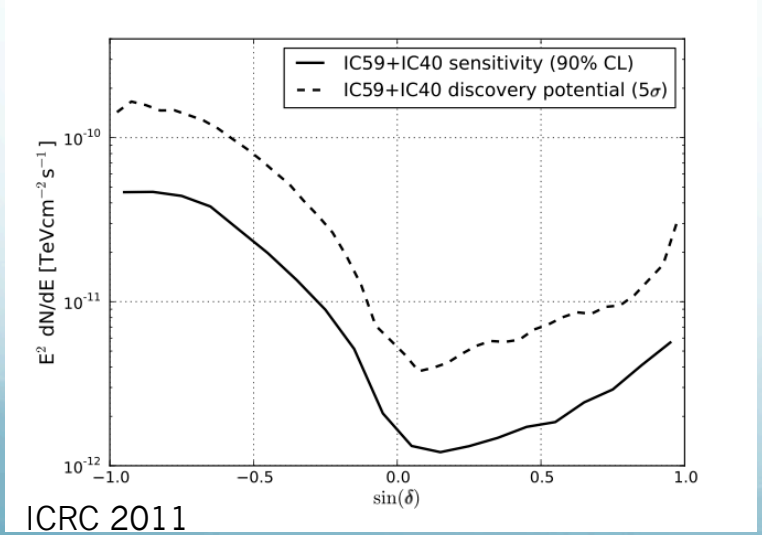




12 σ deficit from the moon shadow in the 59-string detector

Point Source, IC40+IC59

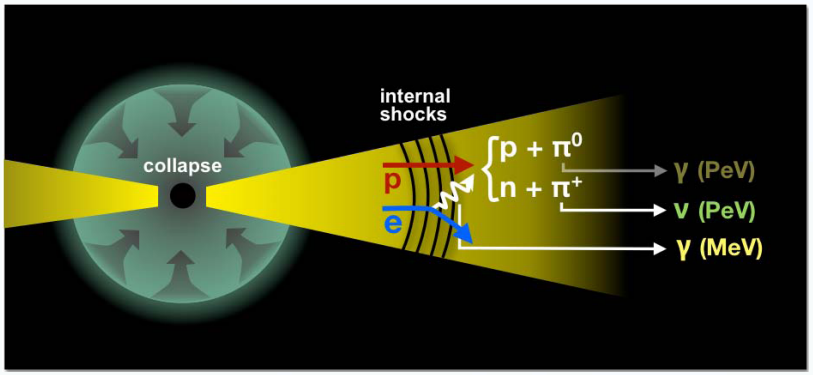




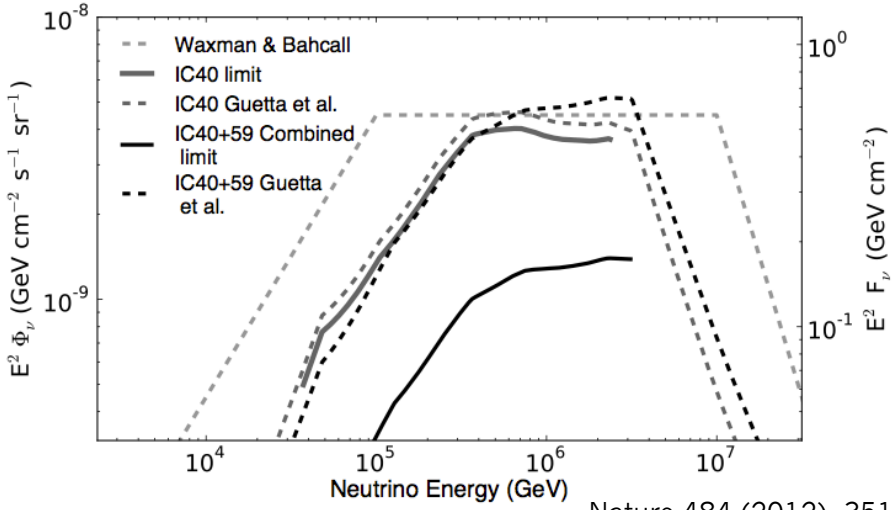
ICRC 2011

- Data from April 2008 – May 2010
- Muon neutrino events from northern hemisphere (TeV-PeV)
- High energy cosmic ray muons from southern hemisphere (PeV – EeV)
- Brightest spot at RA 75.45°, dec -18.15°
  - No close candidates
  - Post trial p-value of 67%

Gamma Ray Bursts

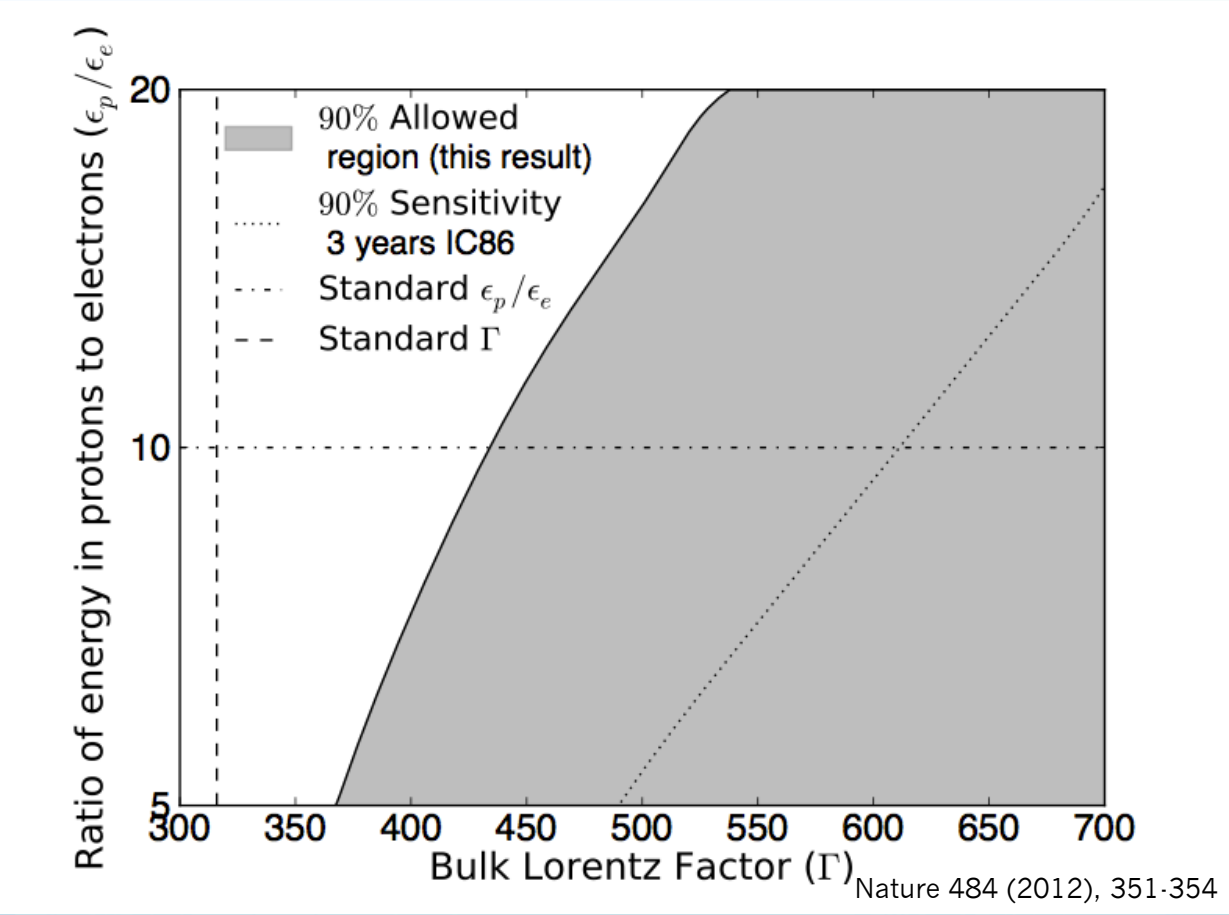


- Fireball model of cosmic ray acceleration in GRB predicts corresponding flux of neutrinos
- GRBs reported by GRB Coordinates Network
- 117 GRBs from IC40 (northern hemisphere only)
- 190 GRBs from IC59 (northern and southern hemispheres)
  - 9 not included due to detector construction/calibration downtime
  - 2 GRBs included from IC59 commissioning phase
- No muon neutrino events on-time (0.1-100 s) and on-source (within 10°)
  - 8.4 events expected based on gamma ray spectra of the bursts



Nature 484 (2012), 351-354

Gamma Ray Bursts

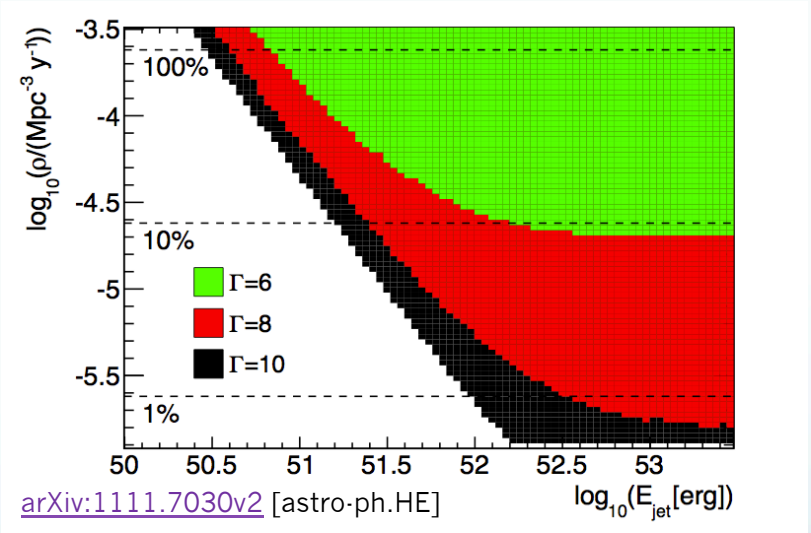


Nature 484 (2012), 351-354

Serious constraint on GRBs as the source of the highest energy cosmic rays

Optical Follow Up

- **Muon neutrino "multiplets" from IceCube transmitted to ROTSE, PTF optical telescopes**
  - **2 neutrinos within 100 s and 4° of each other**
- **Optical follow up data from IC40+IC59 set limits on neutrinos from supernova jets**
- **Follow-up programs in place with SWIFT, MAGIC, Veritas for gamma ray and X-ray follow up**



Limits on "choked jet" supernova model from IC40 and IC59

Summary

- **IceCube construction is complete**
- **Analysis of data from construction phase has already yielded interesting limits from diffuse searches and optical follow-up**
- **No events observed from gamma ray bursts, serious constraint on fireball model for cosmic ray acceleration**
- **Other ongoing analyses include cosmic rays, neutrino oscillation, indirect dark matter detection**