

Neutrino Astronomy at the South Pole

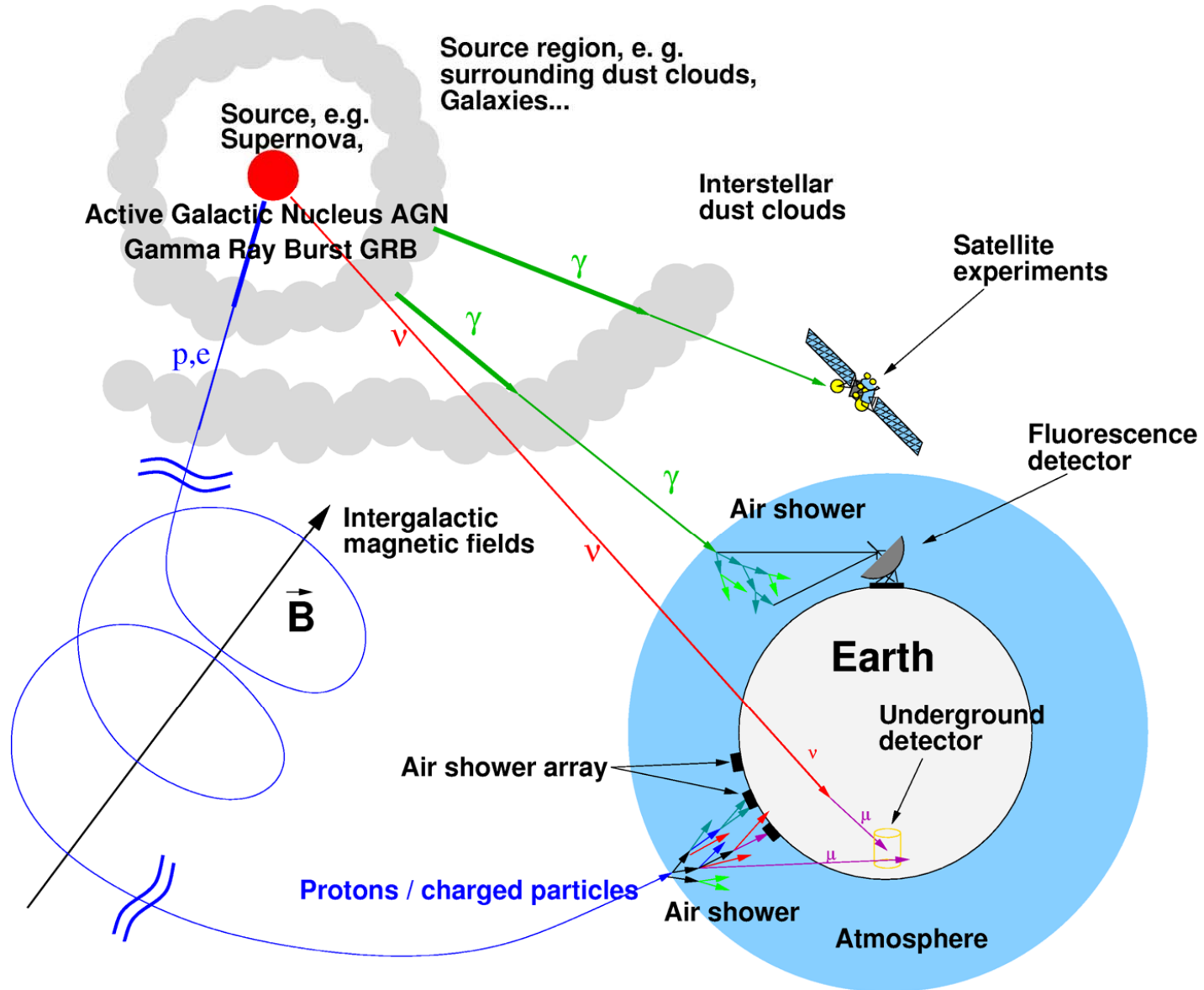
Latest results from IceCube

Kurt Woschnagg
UC Berkeley

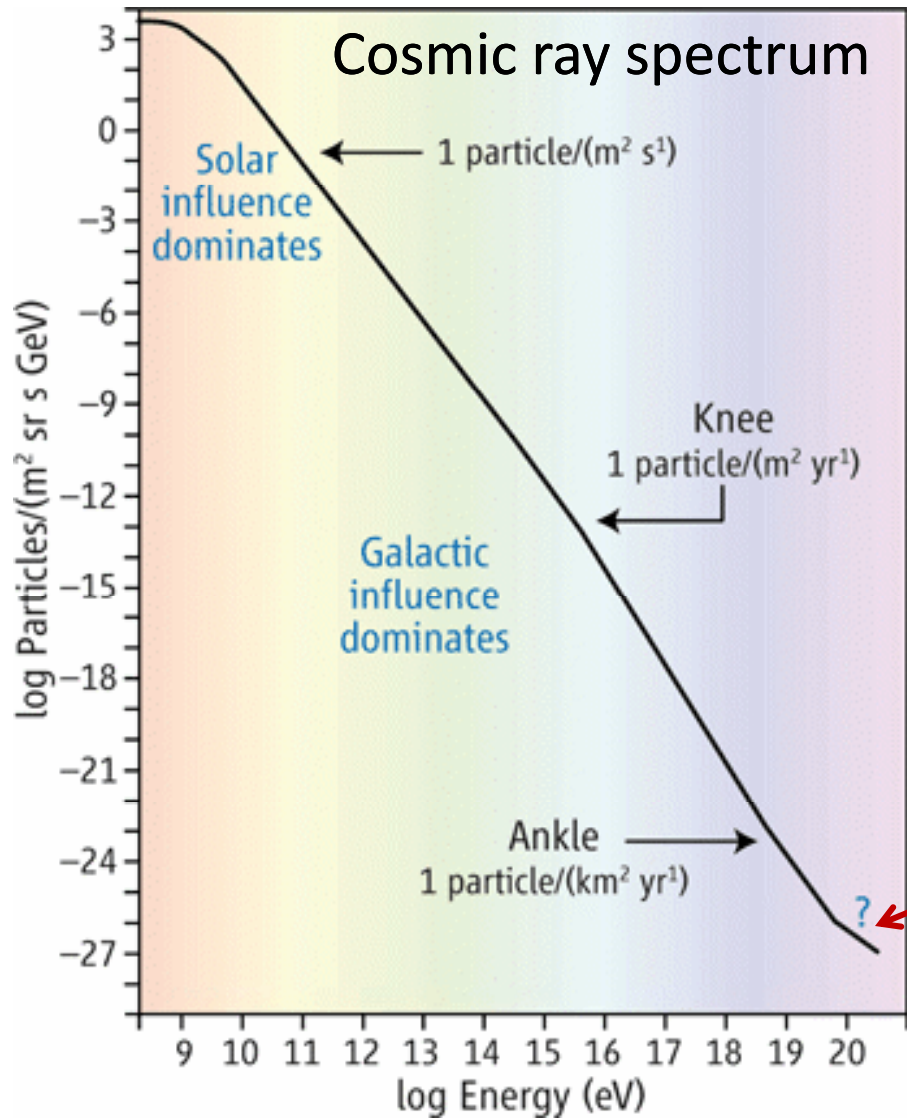
SLAC Summer Institute
August 3, 2011



Neutrinos as Cosmic Messengers



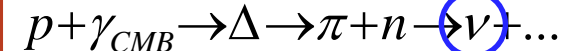
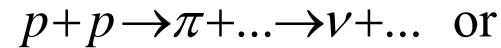
Neutrinos and the Origin of Cosmic Rays



Galactic: SN remnants

Extragalactic:
AGNs / GRBs / Other

We expect high-energy neutrinos from the same sources:



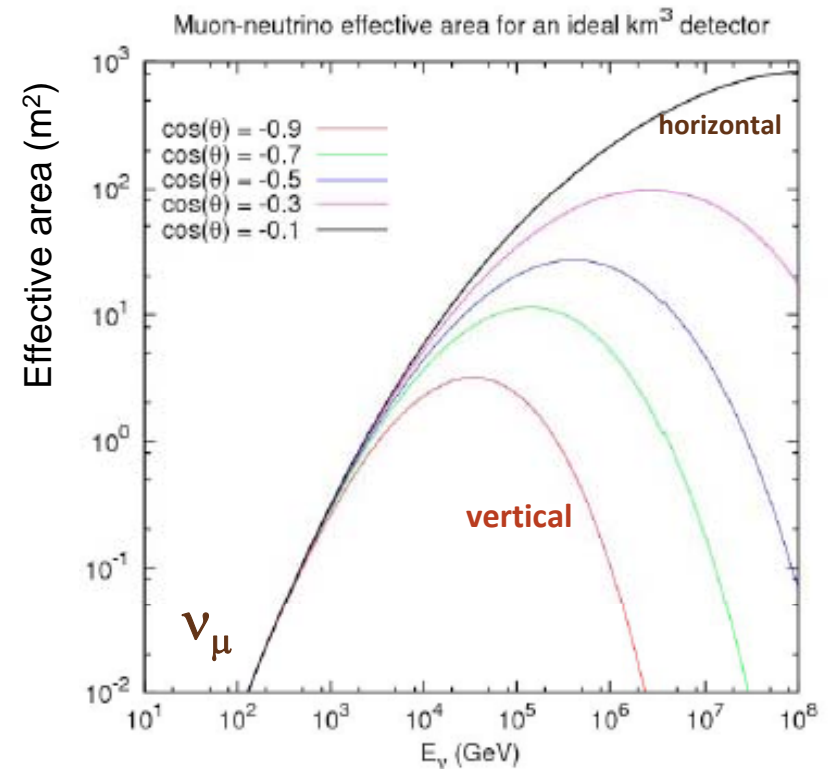
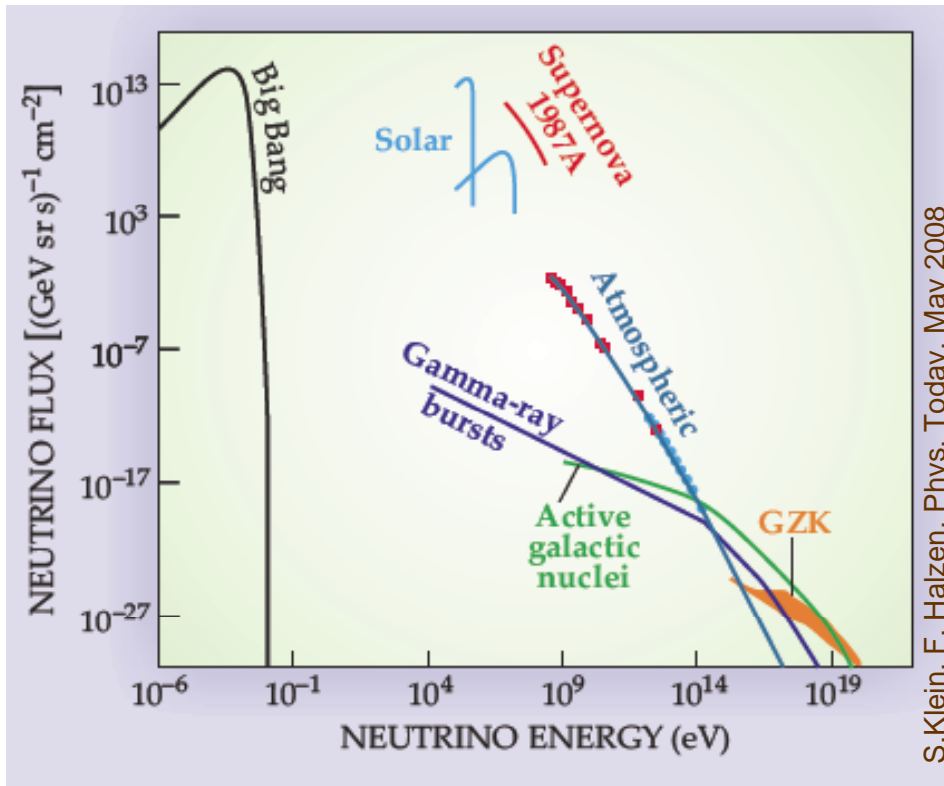
$$E_p > 6 \times 10^{19} \text{ eV} \quad \text{GZK cutoff}$$

Greisen, Zatsepin, and Kuzmin (1966)

GZK neutrinos are “guaranteed”

Size matters: need for a km³ neutrino detector

Rate = Neutrino flux x Neutrino Effective Area
 = Neutrino flux x Neutrino Cross Section x Absorption in Earth
 x Size of detector x (Range of muon for ν_μ)



Expected GZK neutrino rates in 1 km³ detector: ~ 1 per year

Amundsen-Scott Station (US)



Counting house

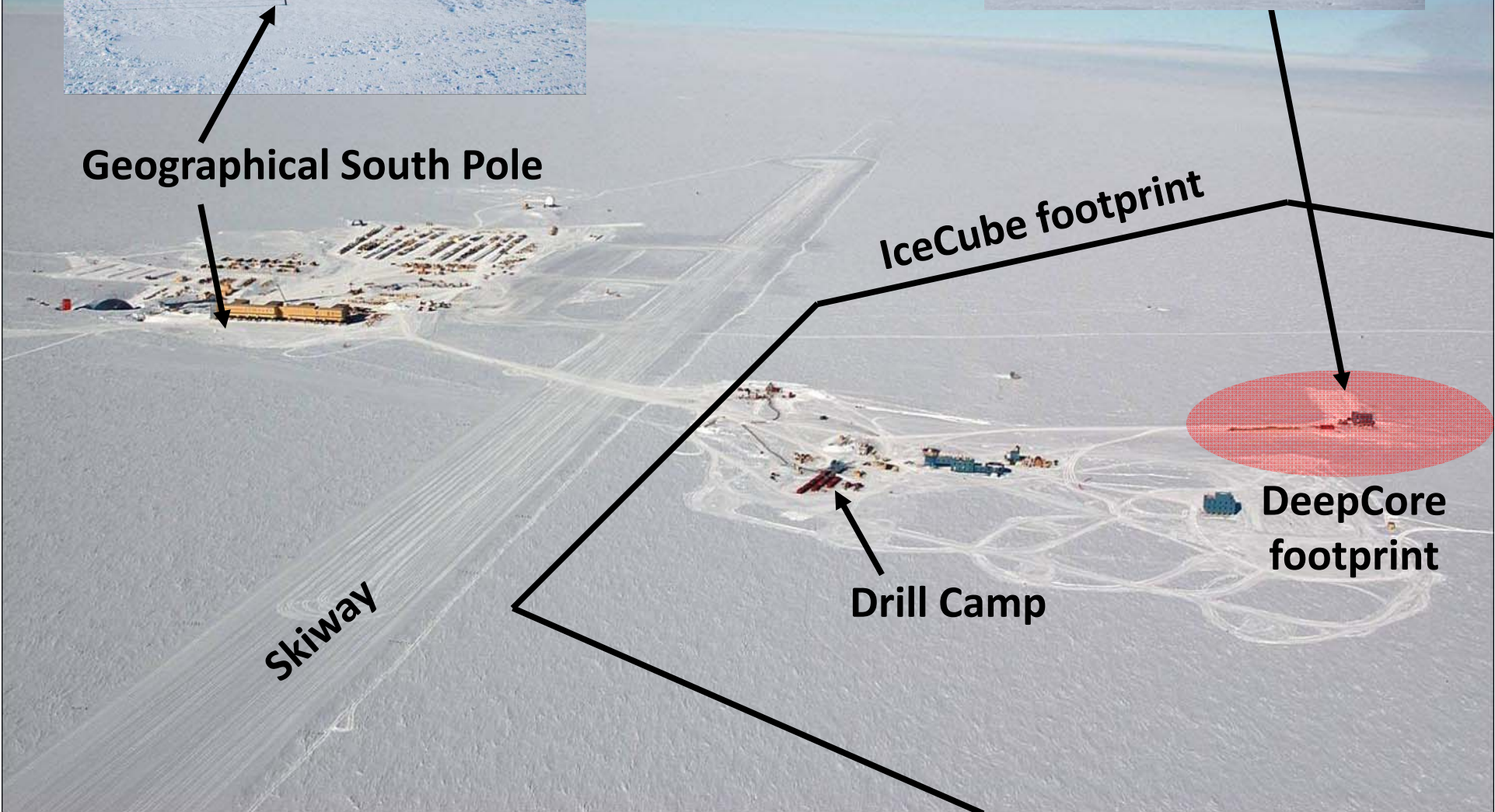
Geographical South Pole

IceCube footprint

DeepCore footprint

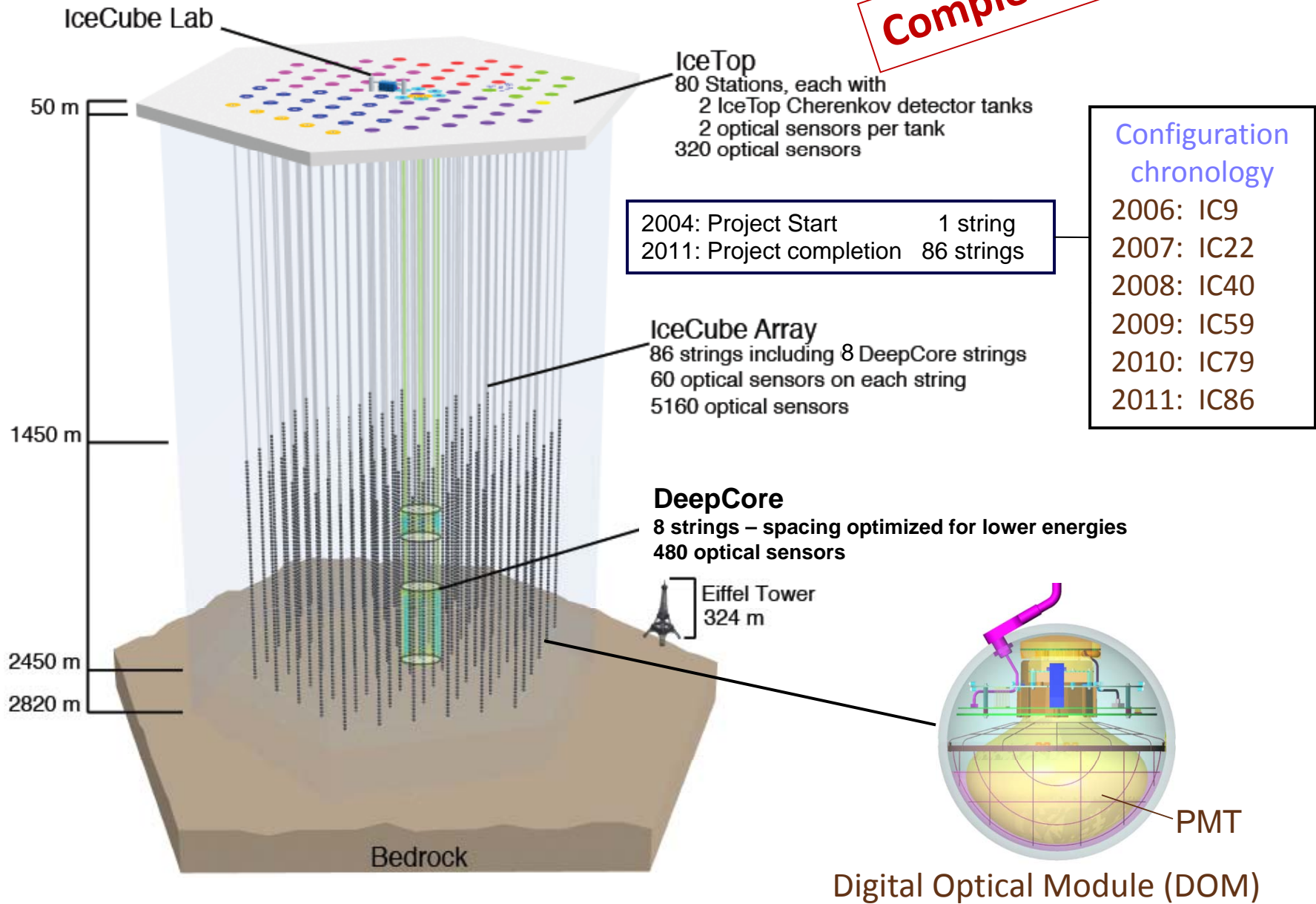
Drill Camp

Skiway



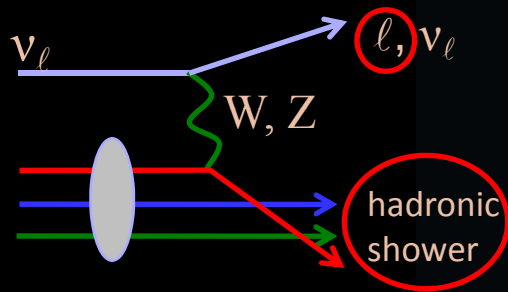
The IceCube Neutrino Observatory

Completed: Dec 2010



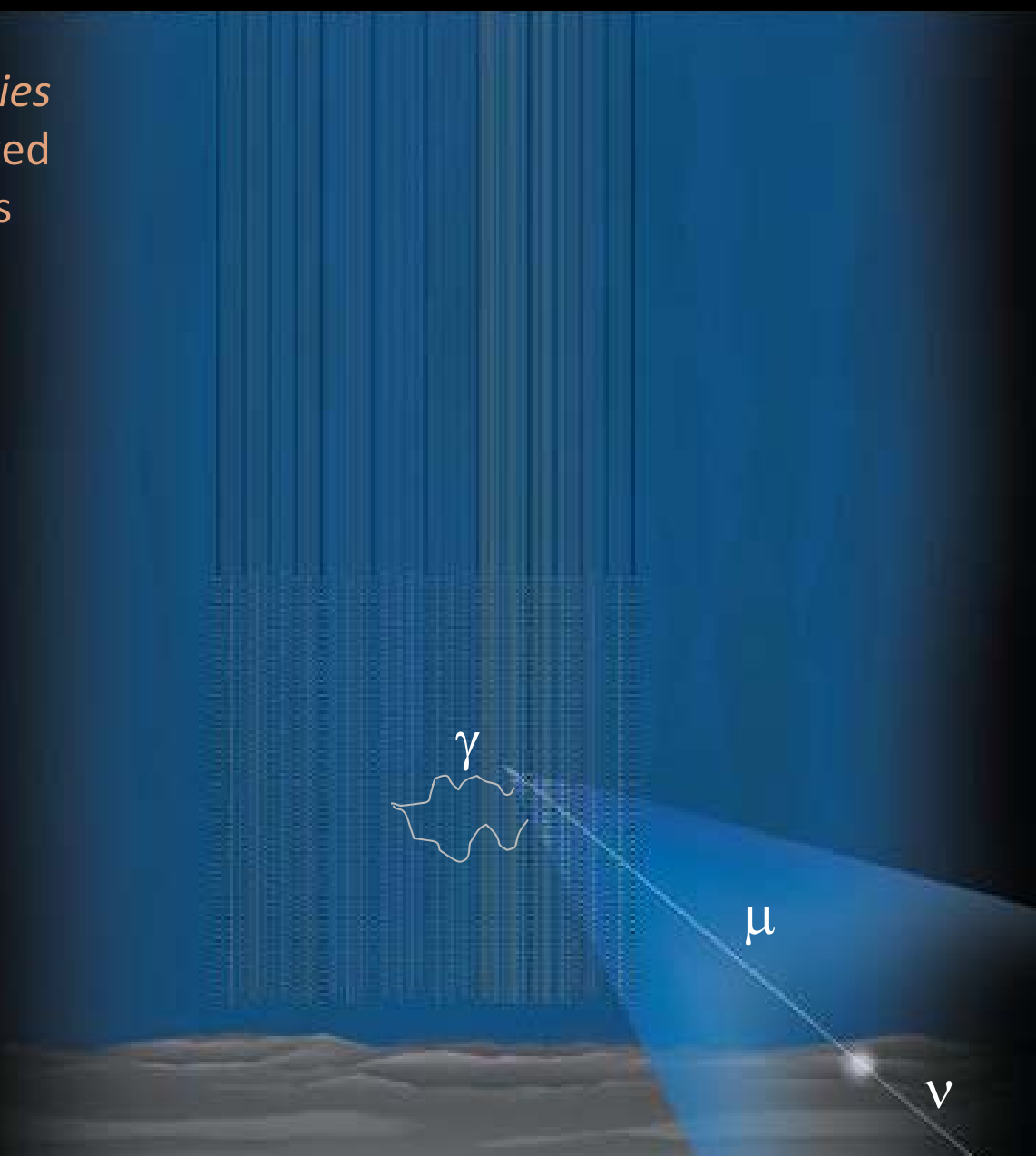
Neutrino Detection Principle

Observe the charged *secondaries* via Cherenkov radiation detected by a 3D array of optical sensors

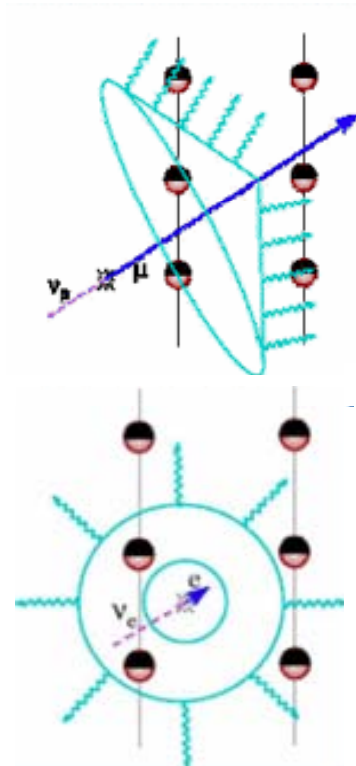
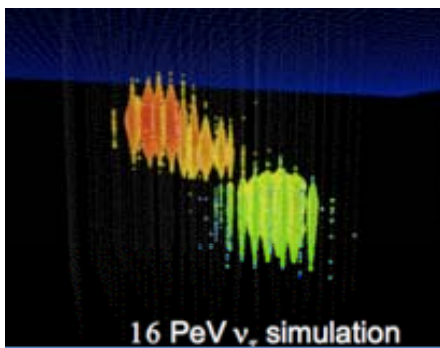
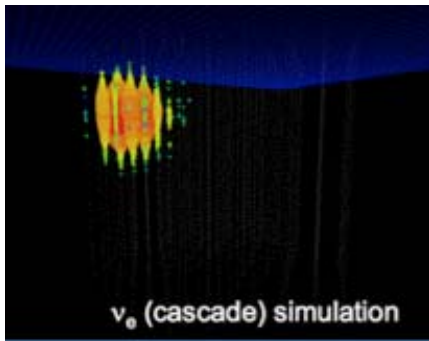
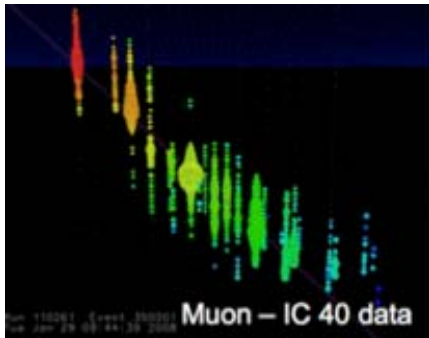


Need a huge volume (km^3) of an optically transparent detector material

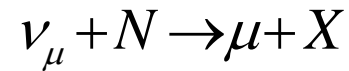
Antarctic ice is the most transparent natural solid known (absorption lengths up 200 m)



Neutrino Event Signatures



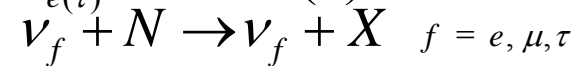
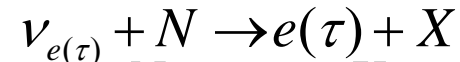
Tracks



- pointing resolution $\sim 1^{\circ}$

Cascades

- e-m and hadronic cascades



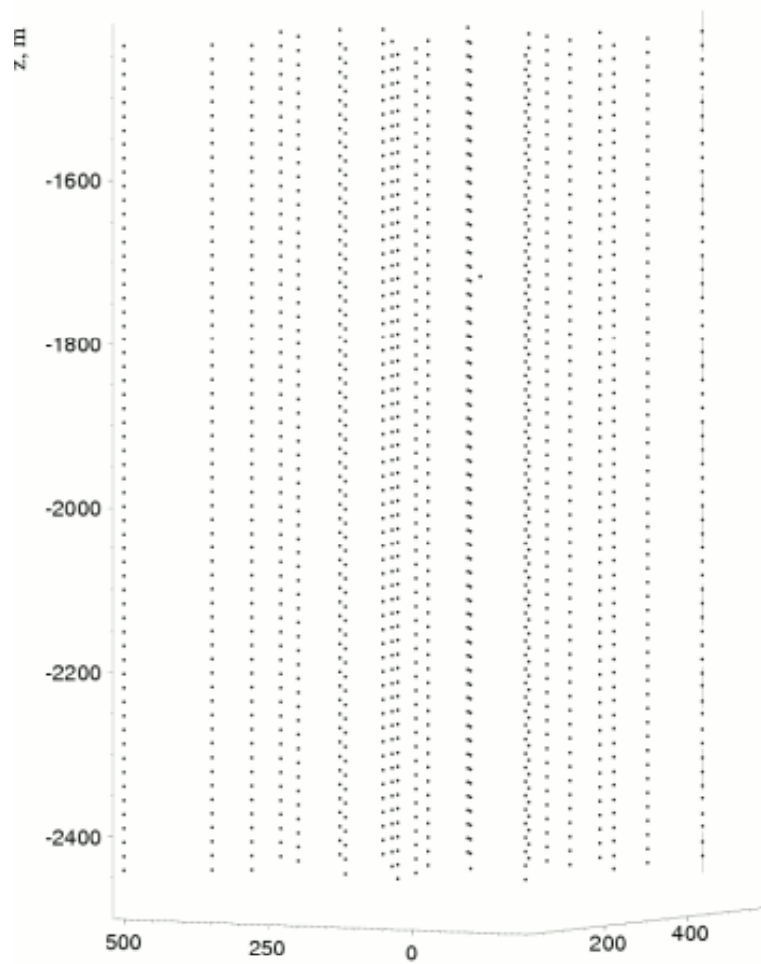
- energy resolution 10% in $\log(E)$

Composites

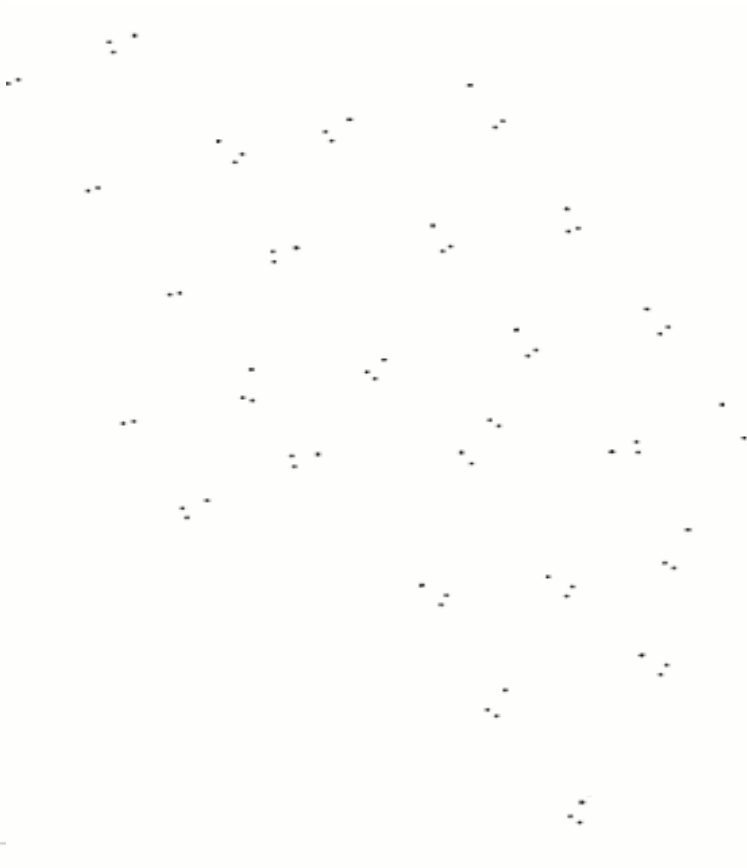
- starting tracks
- tau double bangs
- good directional and energy resolution

Up-going muon: signature of ν_μ event

IC22



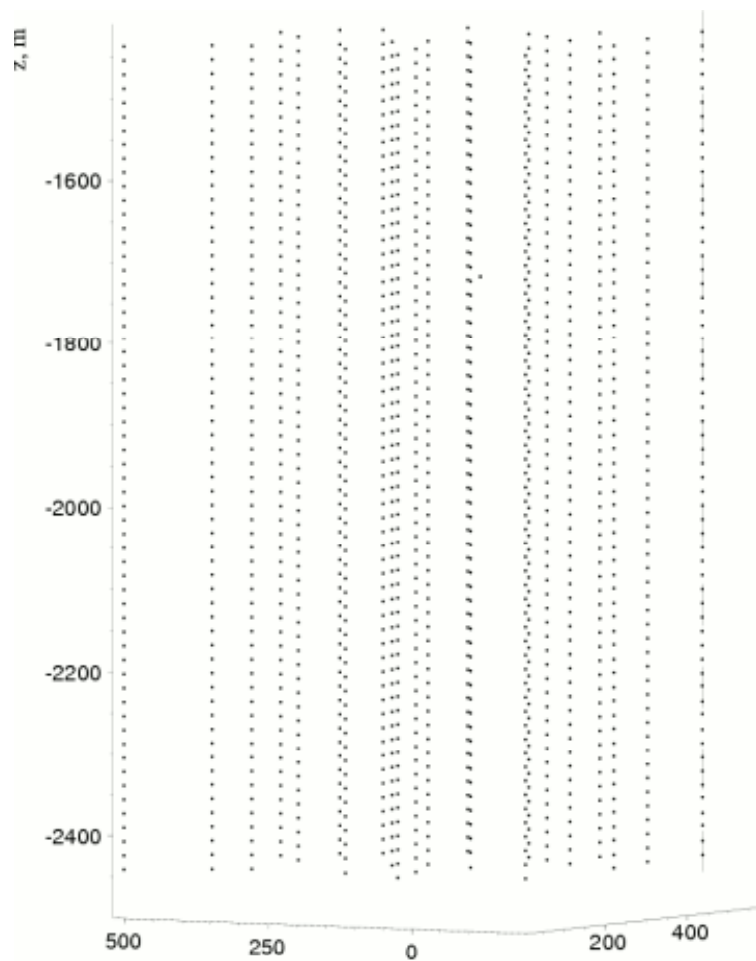
run 109457 event 5720360



run 109457 event 5720360

Cascade candidate: signature of ν_e event IC22

Reconstructed energy = 134 TeV



run 109682 event 6298338

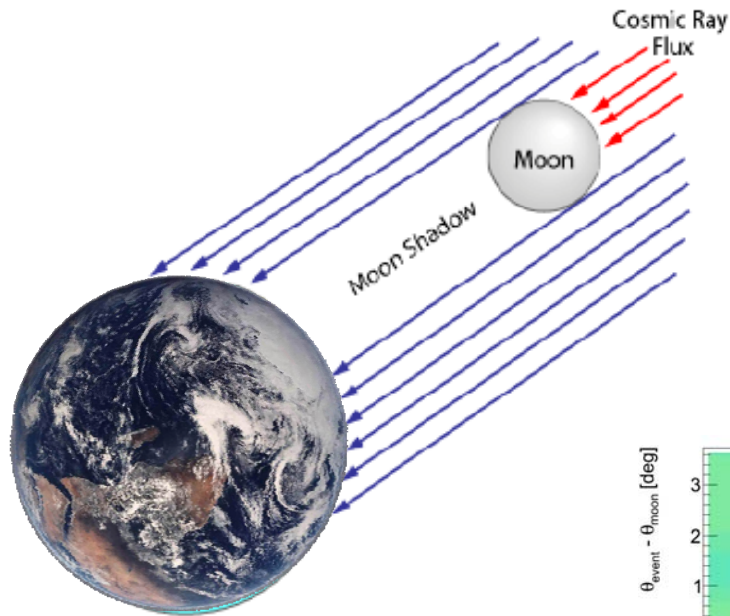


run 109682 event 6298338

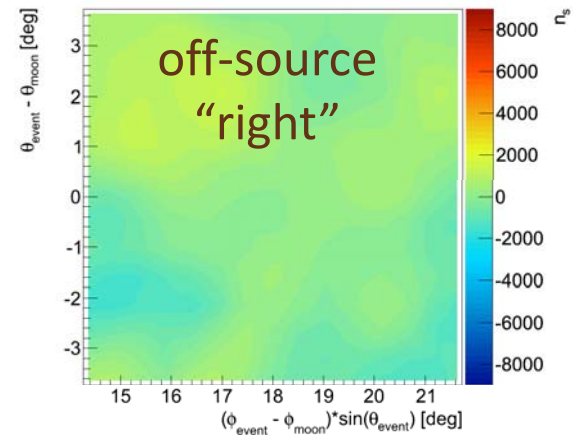
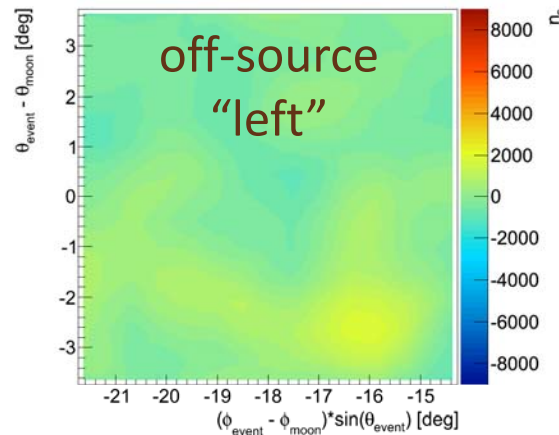
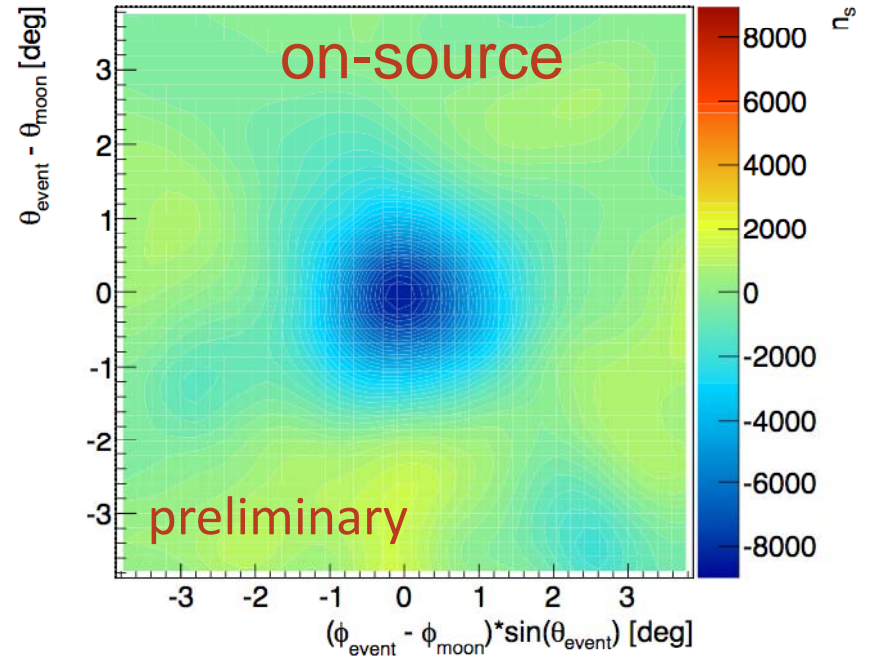
In the Shadow of the Moon

IC59

Cosmic rays blocked by the moon cause point-like deficit in angular distribution of down-going muons in the detector



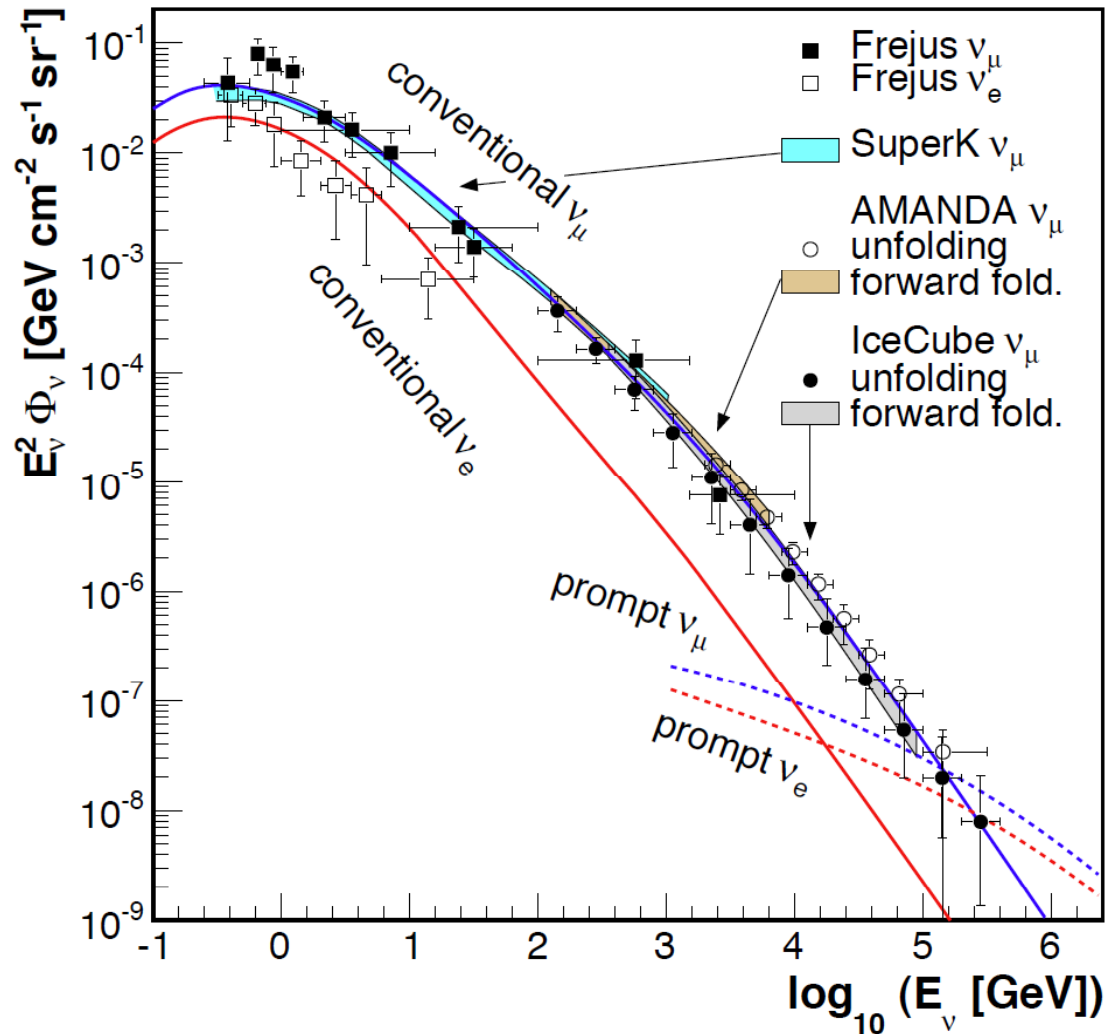
Moon shadow seen with $\sim 10\sigma$
Systematic pointing error $< 0.1^\circ$
Verification of PSF for track reco.



Need high statistics and good angular resolution!

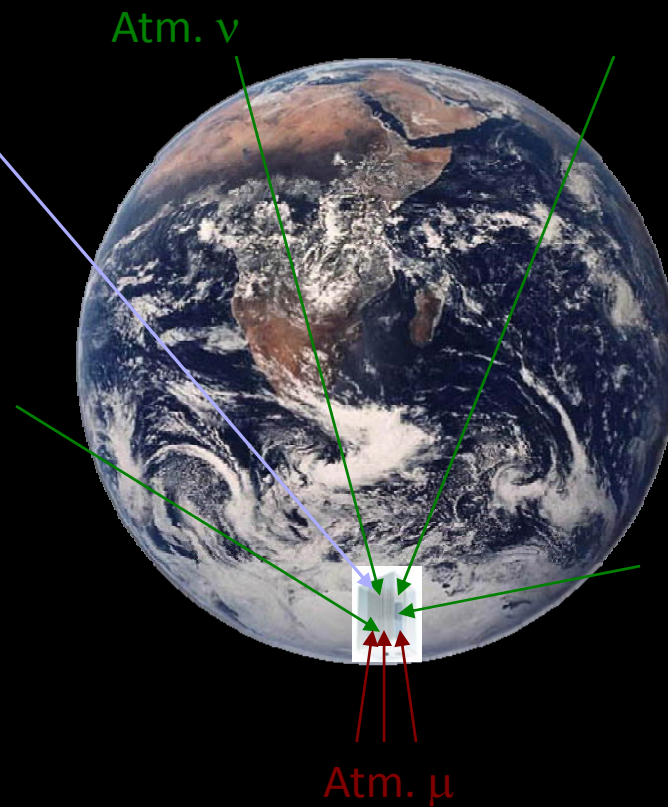
IceCube ν_μ spectrum up to 400 TeV

Phys. Rev. D83 (2011) 012001



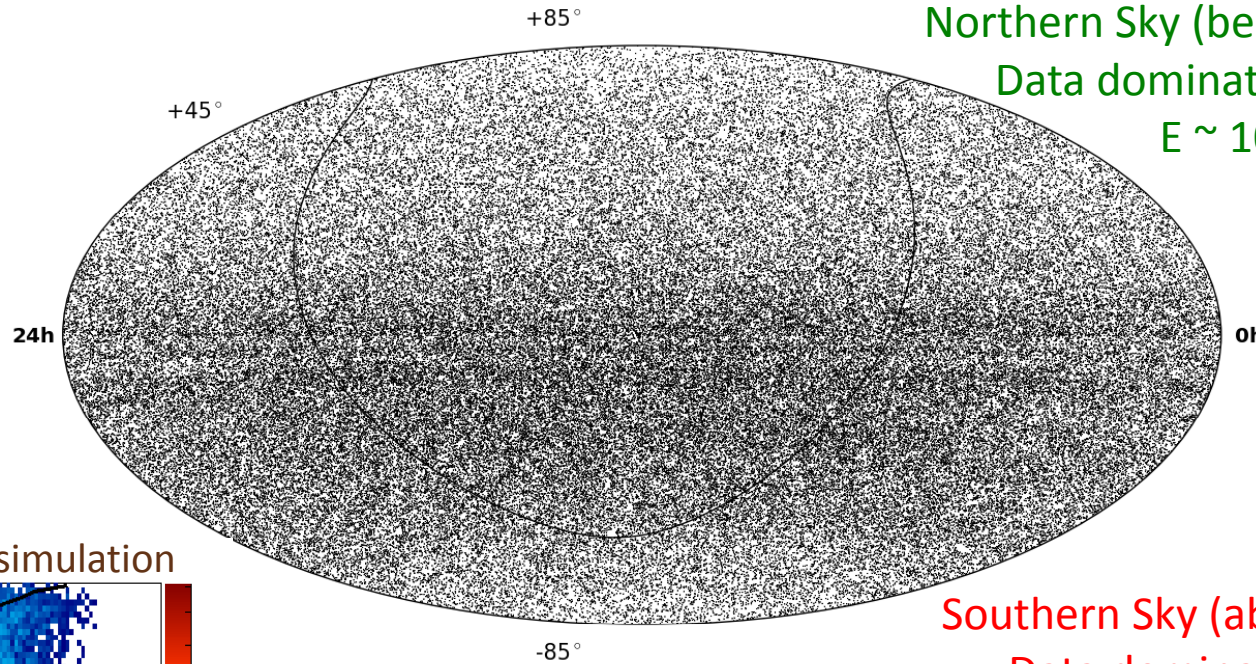
Search for Neutrino Point Sources

Search for an excess of astrophysical neutrinos from a common direction over a background of atmospheric neutrinos



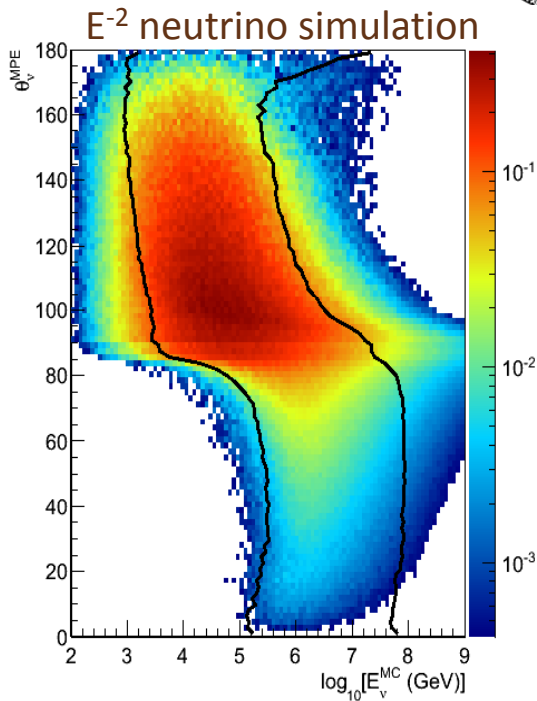
All-Sky Point Source Search

IC40+IC59



Northern Sky (below the horizon)
Data dominated by atmos. ν 's
 $E \sim 10$'s - 100 's of TeV

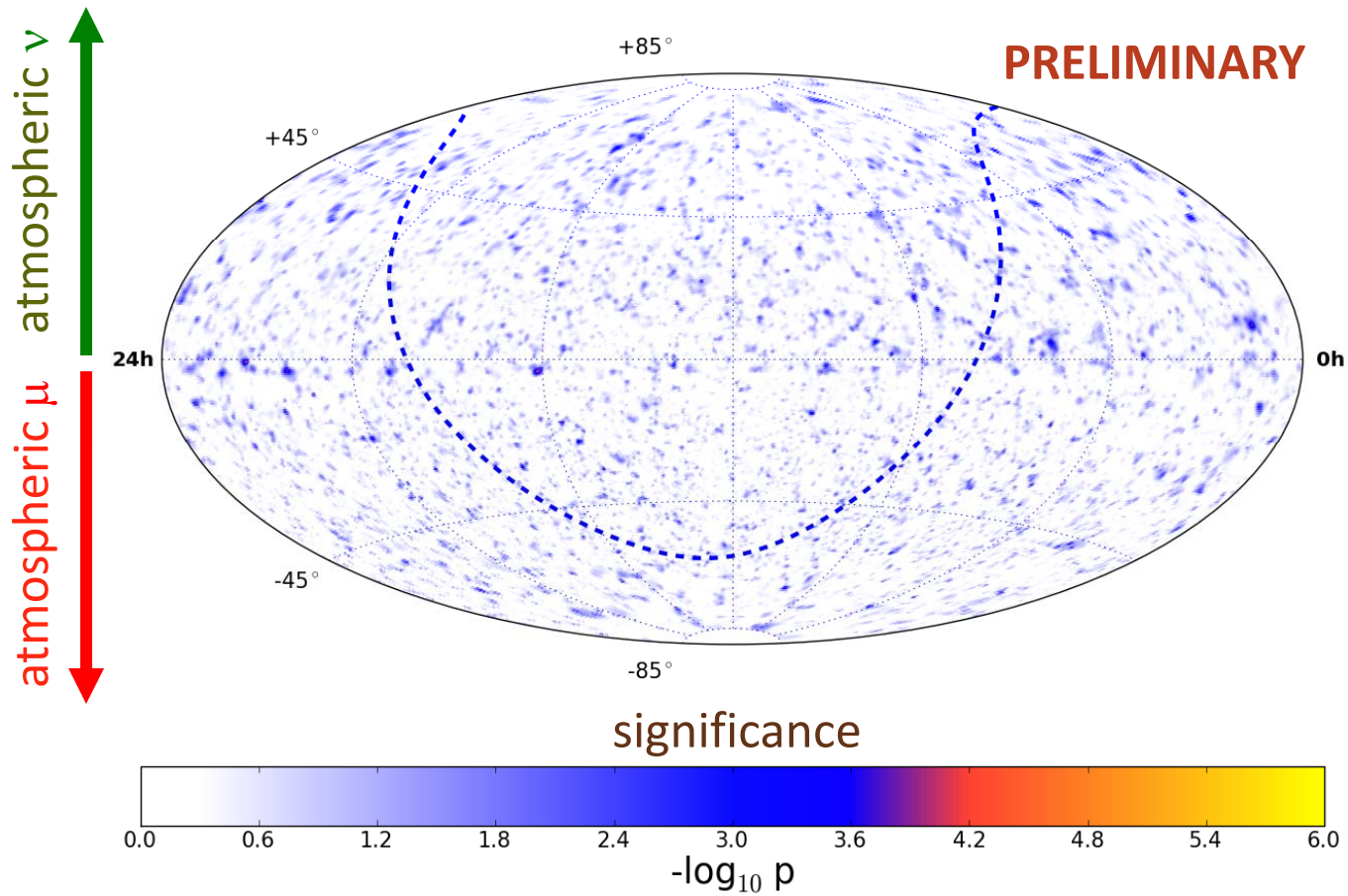
Southern Sky (above the horizon)
Data dominated by atmos. μ 's
 $E > \text{PeV}$, increasing with angle



More than 107,000 events:
43,339 upgoing + 64,230 downgoing
Livetime: 348 days (IC59) + 375 days (IC40)

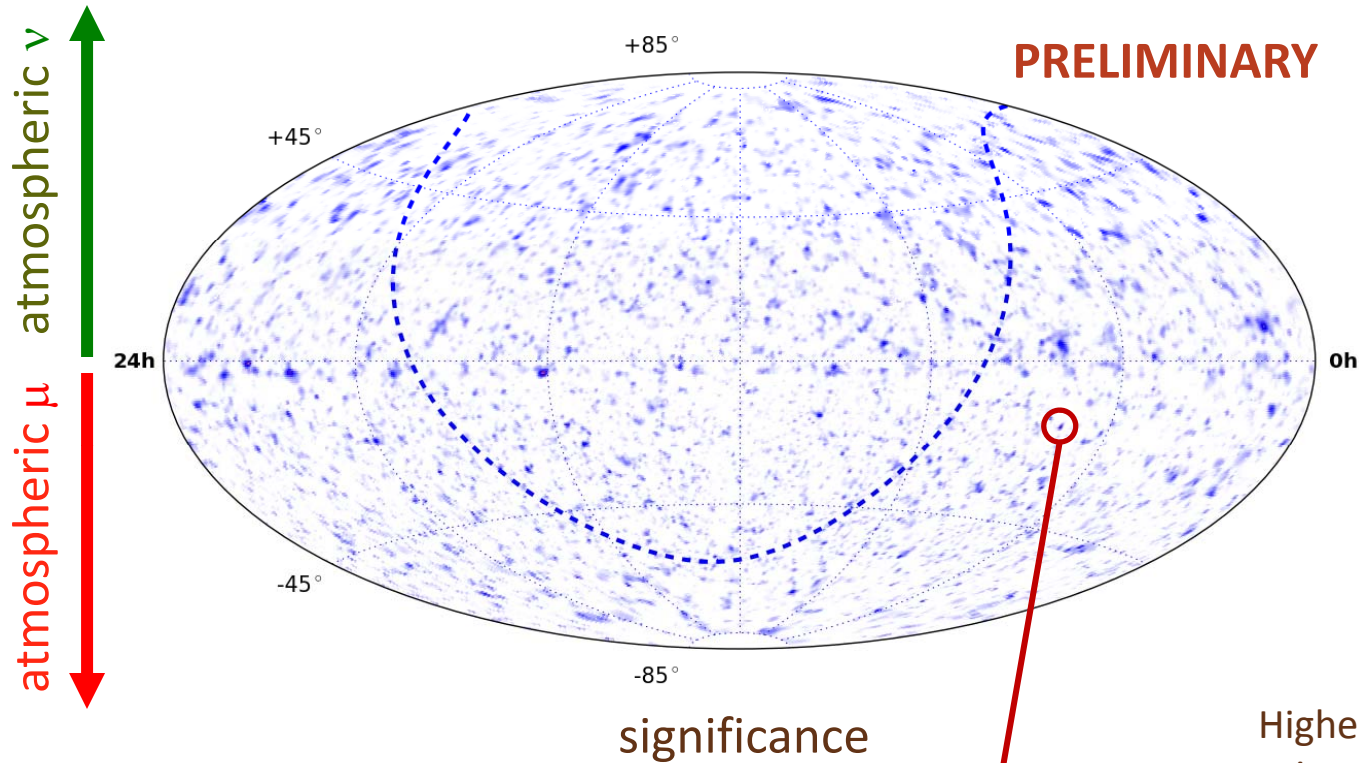
All-Sky Point Source Search

IC40+IC59



All-Sky Point Source Search

IC40+IC59

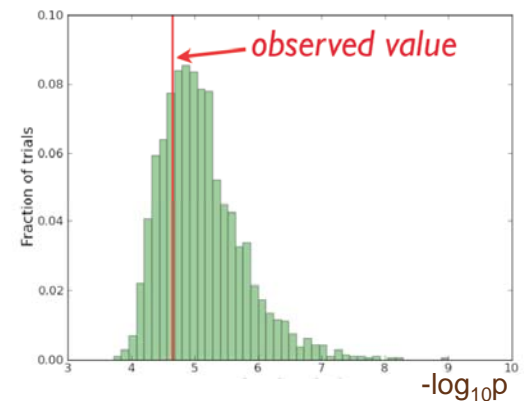


Hottest spot
(Ra=75.45, Dec=-18.15)

$-\log_{10}p = 4.65$
 $nSrc_{best} = 18.3$
 $\gamma_{best} = 3.9$

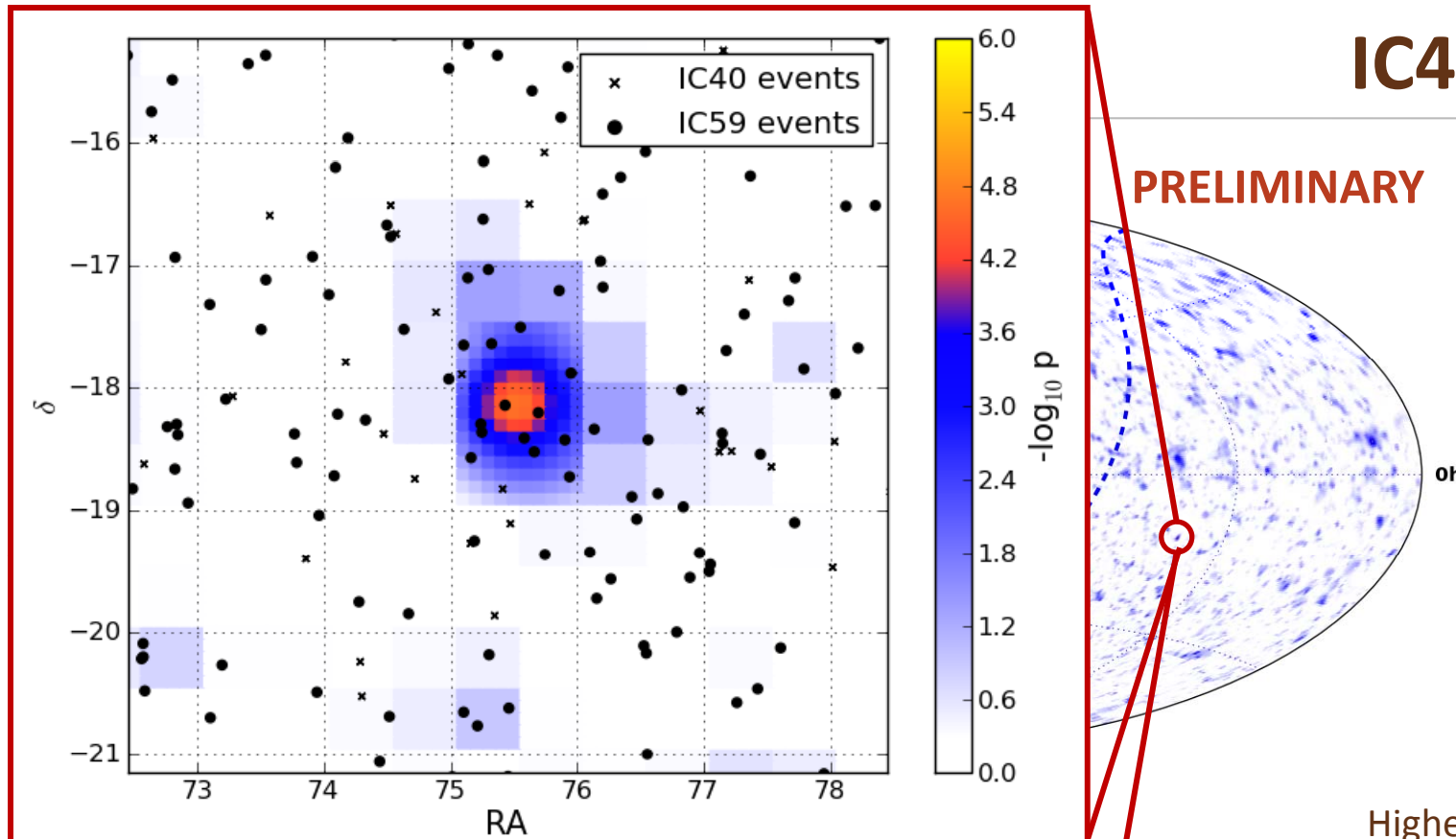
Not significant: 74.2% of trials have significance \geq hottest spot

Highest significance in azimuthally scrambled skymaps (2000 trials)



IC40+IC59

PRELIMINARY

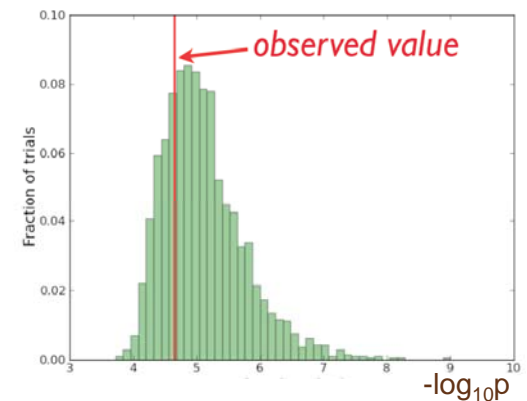


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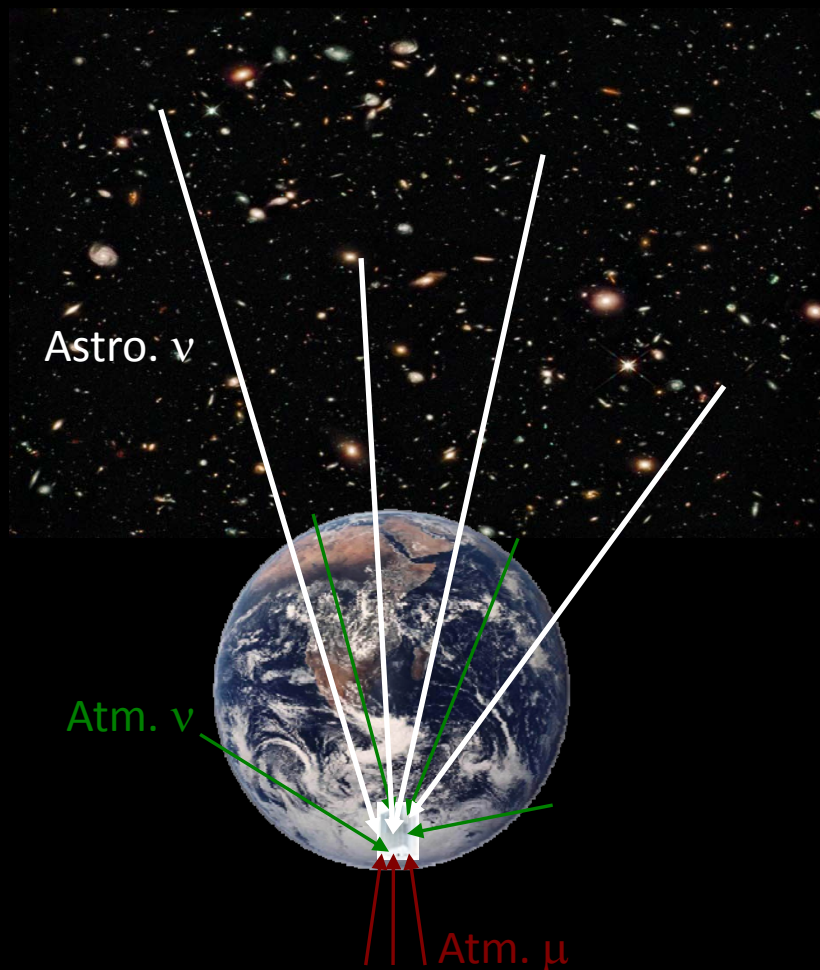
Highest significance in azimuthally scrambled skymaps (2000 trials)



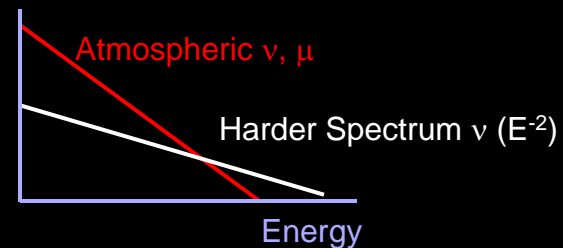
Searches for a Diffuse Neutrino Flux

Diffuse Flux = effective sum from all (unresolved) extraterrestrial sources (e.g., AGNs)

Possibility to observe diffuse signal even if flux from any individual source is too weak for detection as a point source



Search for excess of astrophysical neutrinos with a harder spectrum than background atmospheric neutrinos



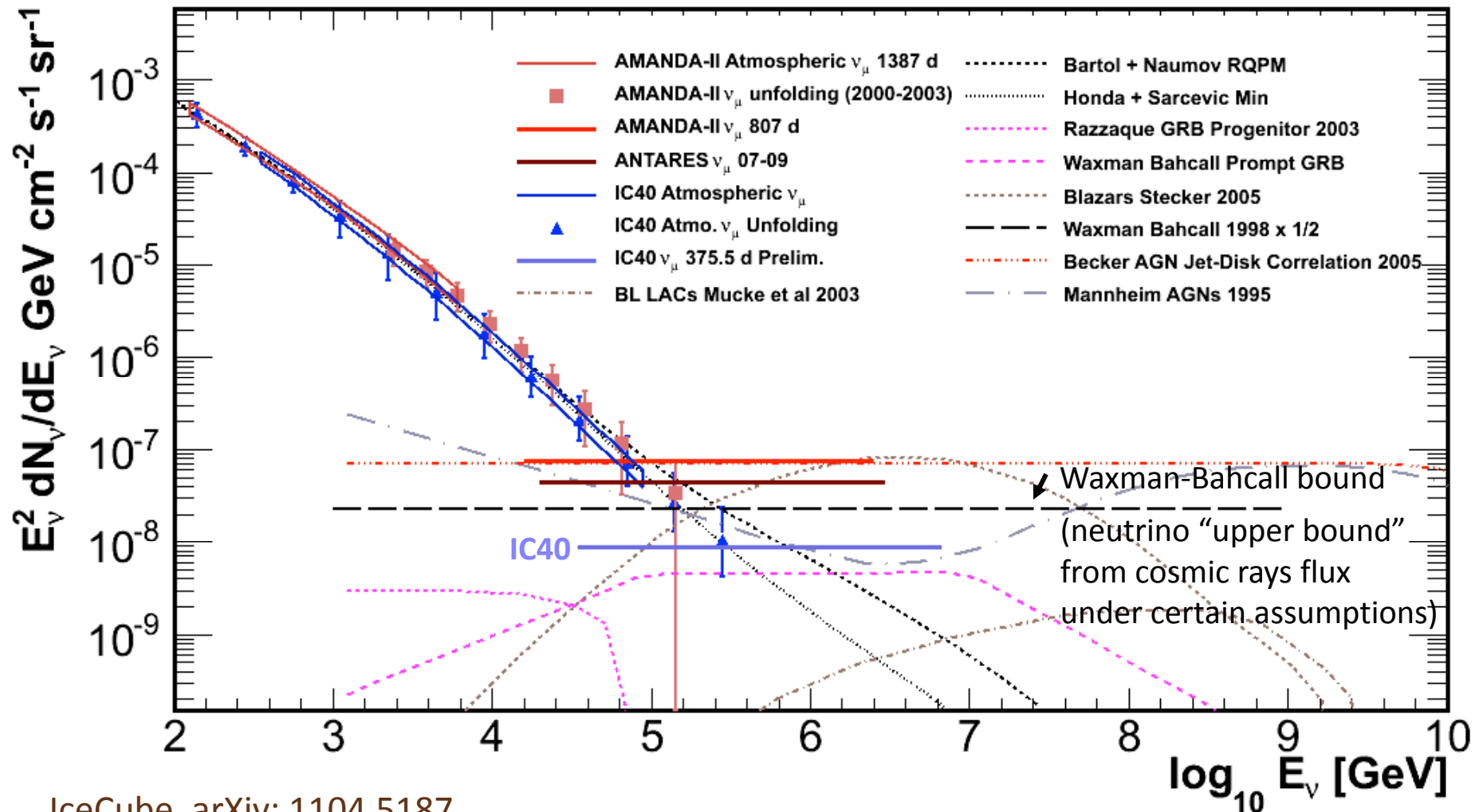
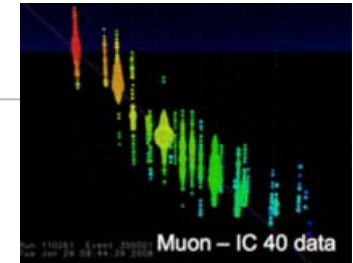
Advantage over point source search:
can detect weaker fluxes

Disadvantages:
high background
must simulate background precisely

Sensitive to all three neutrino flavors

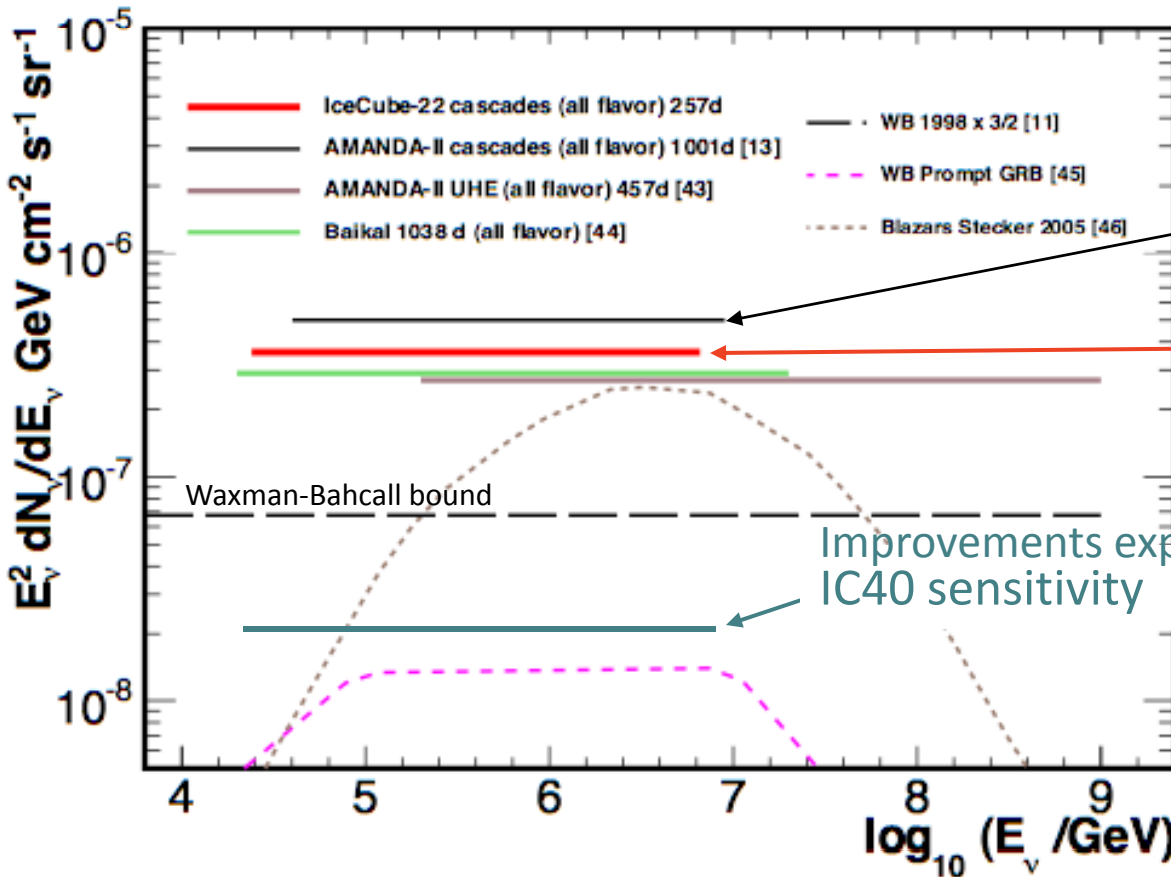
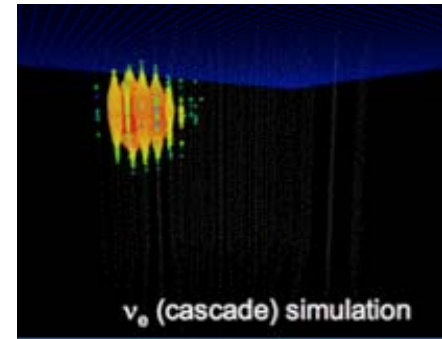
Limits on a diffuse muon neutrino flux

Experimental upper limits on the diffuse flux of muon neutrinos from sources with $\Phi \sim E^{-2}$ energy spectrum



Limits on a diffuse neutrino flux: cascades

Experimental upper limits on the diffuse flux of neutrinos from sources with $\Phi \sim E^{-2}$ energy spectrum



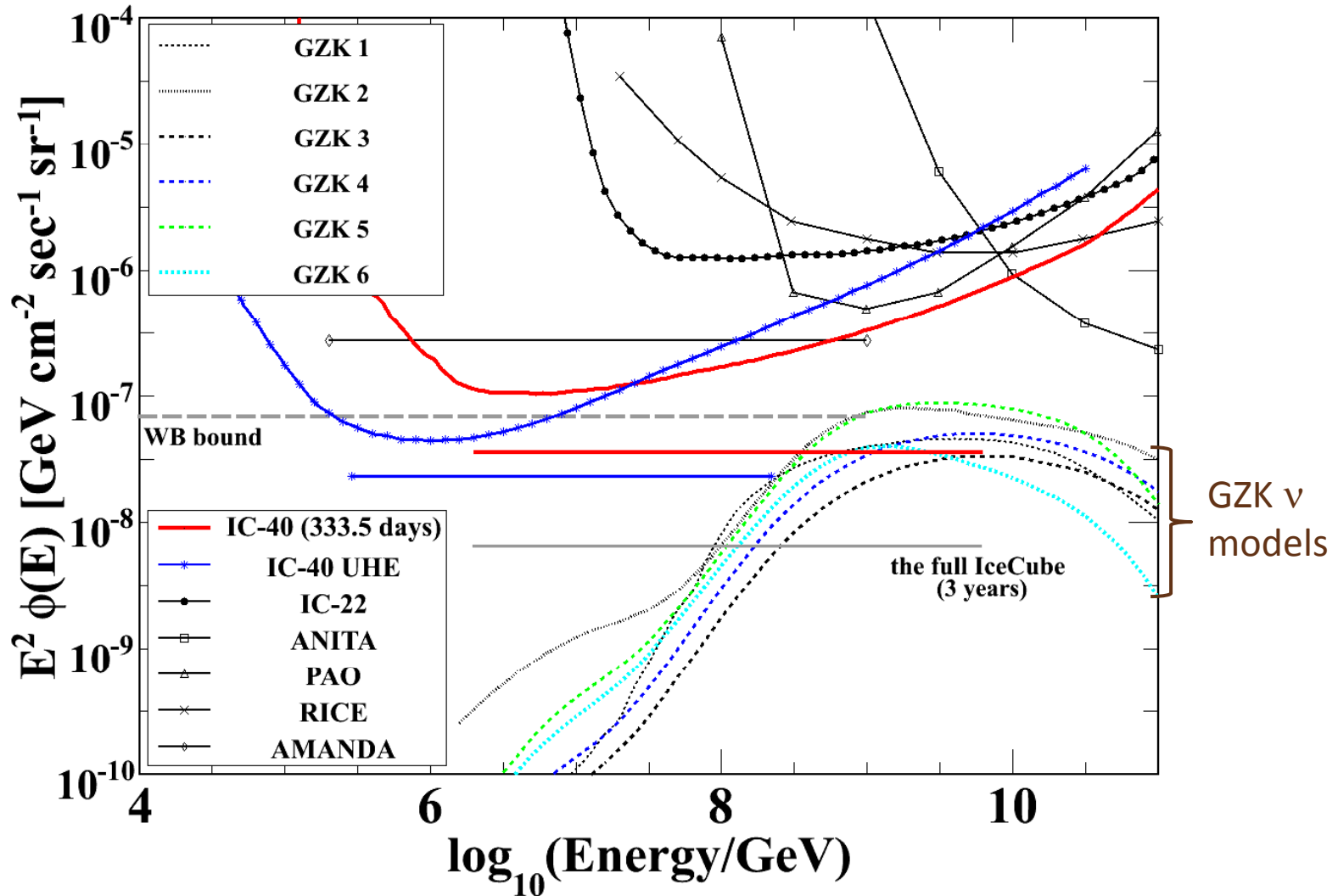
AMANDA (1001d)
Astropart. Phys. 34 (2011) 420

IC22 (257d)
arXiv: 1101.1692

Improvements expected with a larger detector
IC40 sensitivity (337d)

Extremely High-Energy Cosmic Neutrino Fluxes

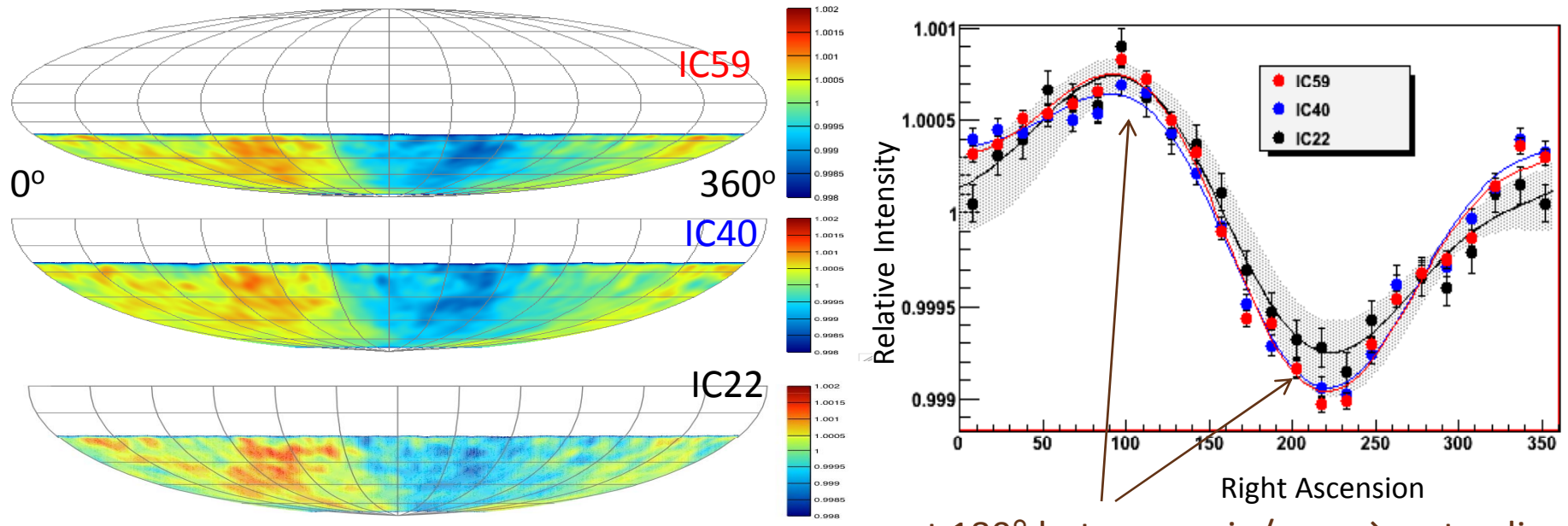
Phys. Rev. D83 (2011) 092003



The world's best all-flavor ν upper limits to date from 10^6 to 10^{10} GeV

Cosmic Ray Anisotropy

Observation of **anisotropy** in the arrival directions of cosmic rays

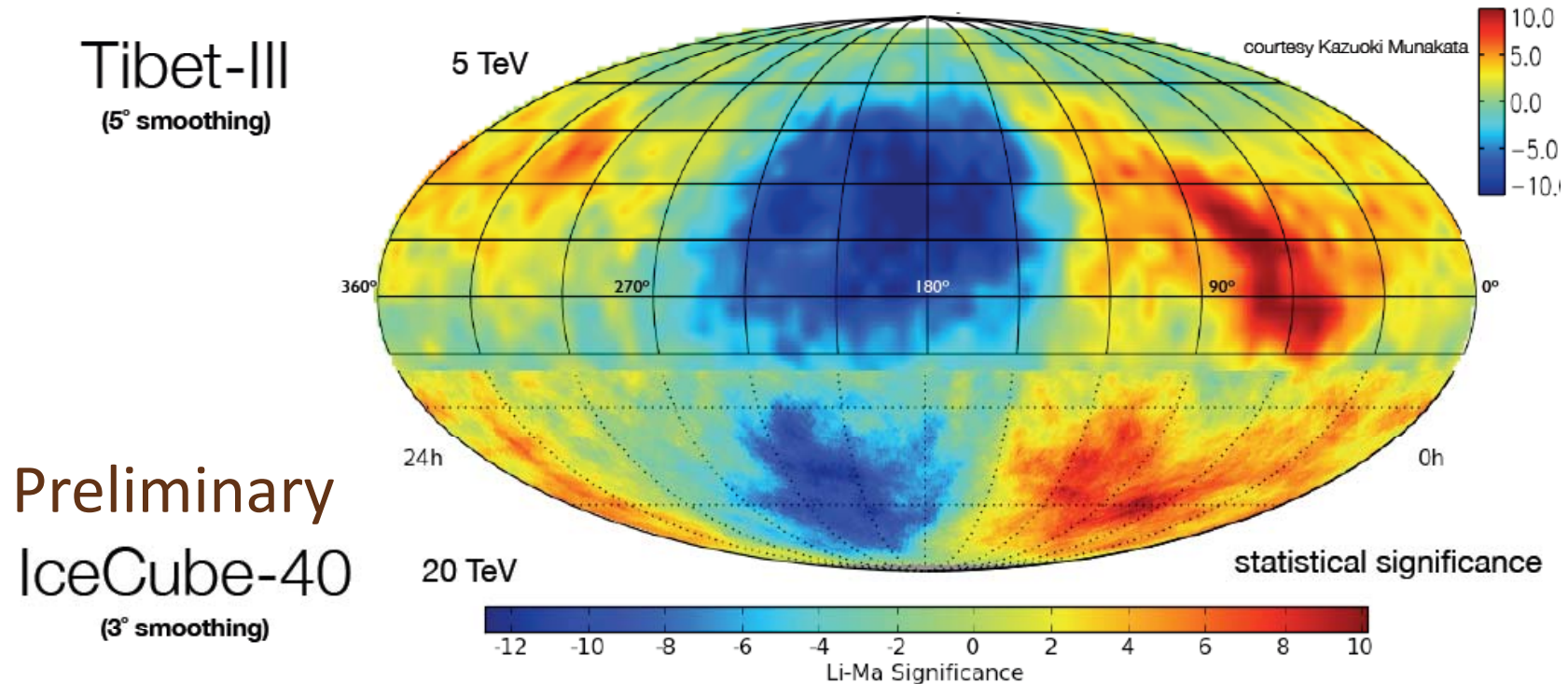


not 180° between min/max → not a dipole

Year	Rate (Hz)	LiveTime	CR Median Energy	Median Angular Resolution	Events
2007 (IC22)	240	~226 days	~19 TeV	3°	$4 \cdot 10^9$
2008 (IC40)	780	~324 days	~19 TeV	3°	$1.9 \cdot 10^{10}$
2009 (IC59)	1200	~324 days	~19 TeV	3°	$3.3 \cdot 10^{10}$

Cosmic Ray Anisotropy

Anisotropy seen in Southern Sky by IceCube is continuation of anisotropy seen in Northern Sky



Cause of anisotropy not known. Speculations include:

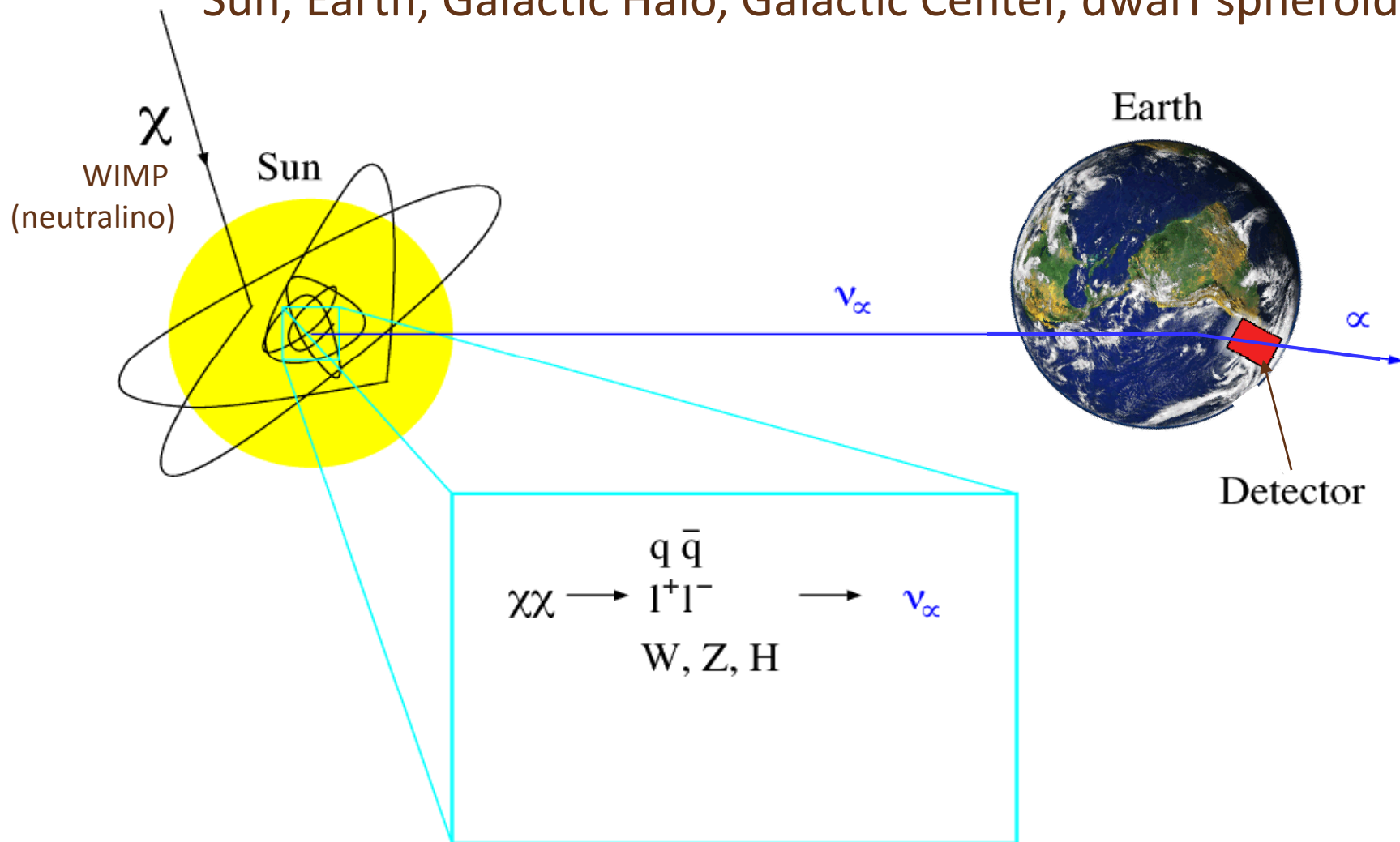
- Isolated nearby and recent SNR (unlikely)
- Configuration of magnetic fields in or near solar system
- Compton-Getting effect (not consistent with data)

Further studies of anisotropy vs energy, angular scale, time variability, spectral properties, ...

Indirect Dark Matter Searches

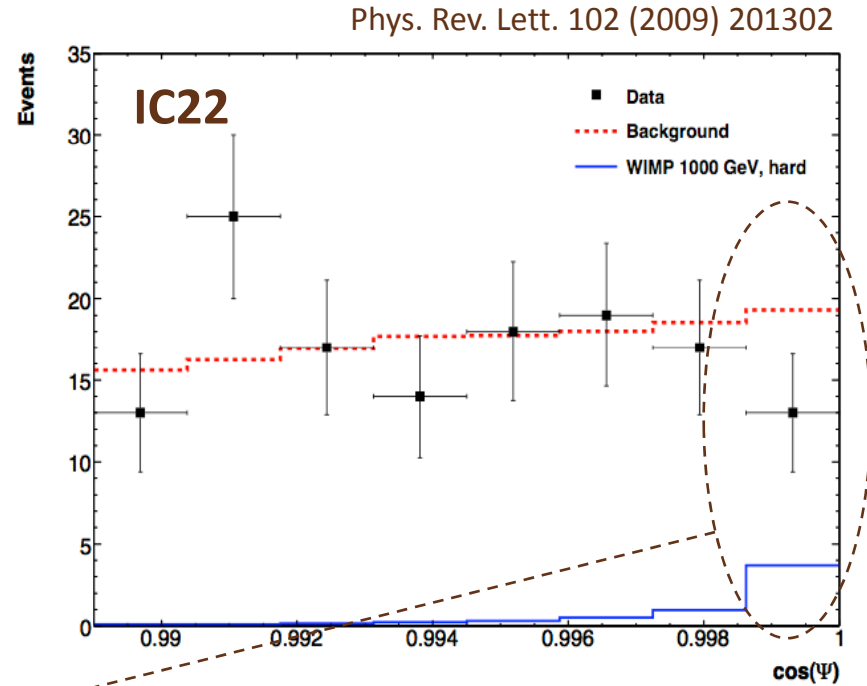
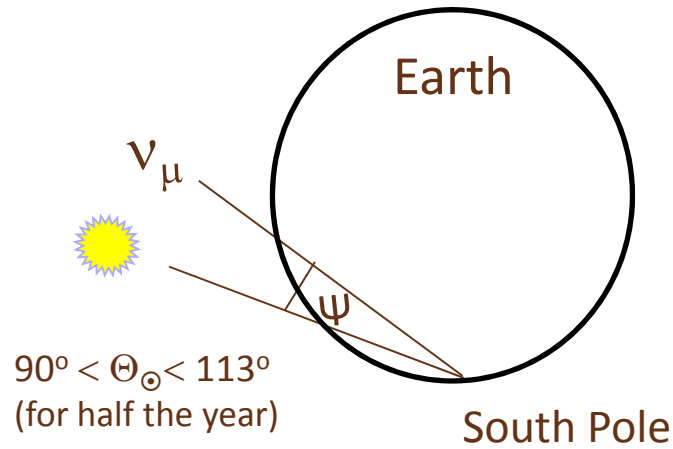
Search for neutrinos from objects where Dark Matter can have accumulated gravitationally over the evolution of the Universe:

Sun, Earth, Galactic Halo, Galactic Center, dwarf spheroids...



Indirect Dark Matter Search: Solar WIMPs

Data collected when the Sun is below the horizon at South Pole



No excess of events from the Sun, observation consistent with the expected background

⇒ upper limit on the number of signal events at 90% CL : μ_s

⇒ 90% CL limit on the neutrino to muon conversion rate:

$$\Gamma_{\nu \rightarrow \mu} = \frac{\mu_s}{V_{eff} \times T}$$

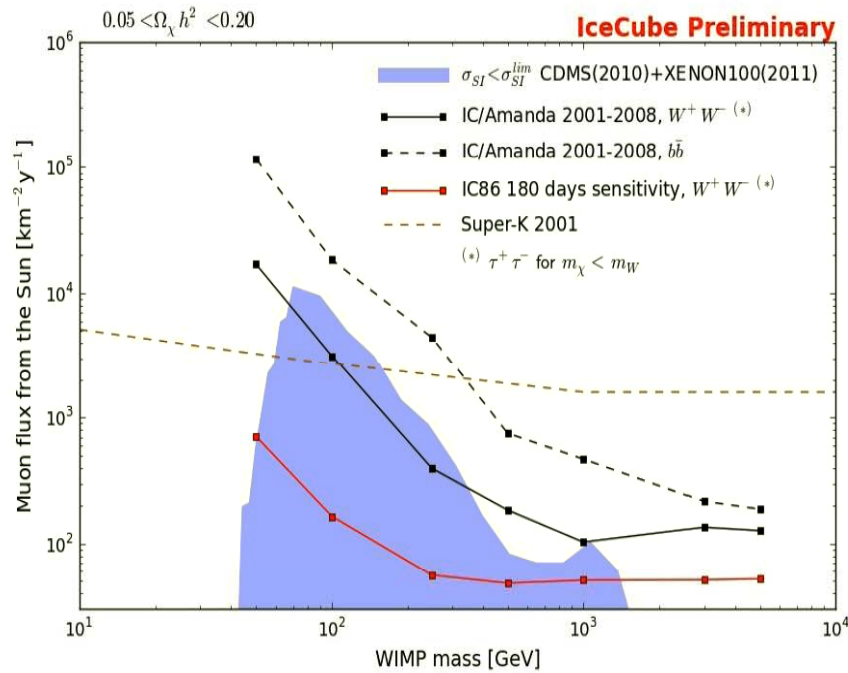
⇒ 90% CL limit on the neutralino annihilation rate in the Sun:

$$\Gamma_A = \kappa^{-1}(\chi) \times \Gamma_{\nu \rightarrow \mu}$$

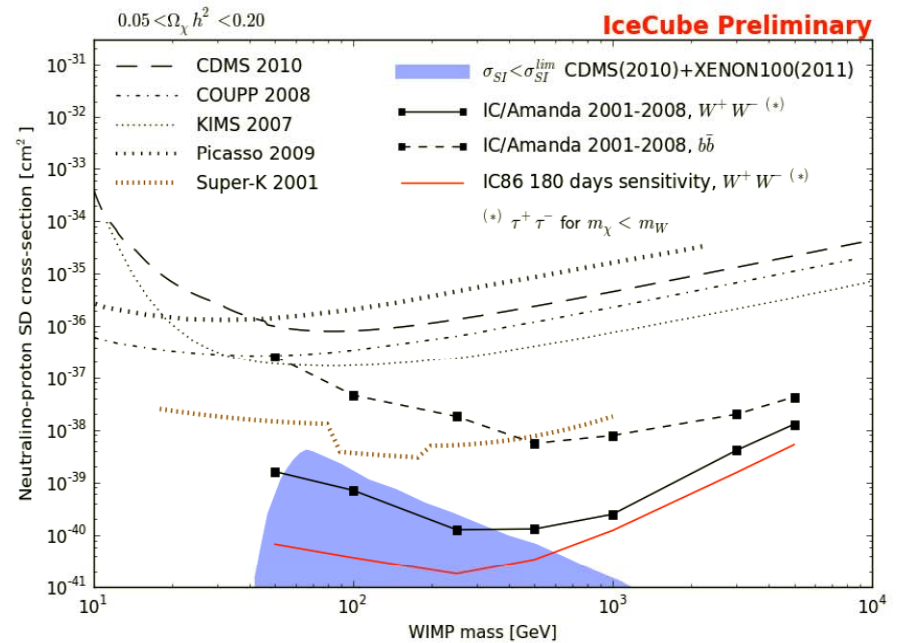
Indirect Dark Matter Search: Solar WIMPs

IceCube/AMANDA results from 1065 days of livetime between 2001-2008

90% CL **muon flux limit** from the Sun
(compared to MSSM scans)



90% CL **neutralino-p Xsection limit**
(compared to MSSM scans)

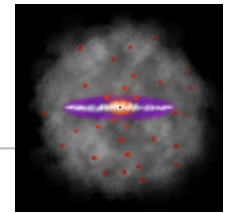


$$\Phi_\mu \rightarrow \Gamma_A \rightarrow C_c \rightarrow \sigma_{\chi p}$$



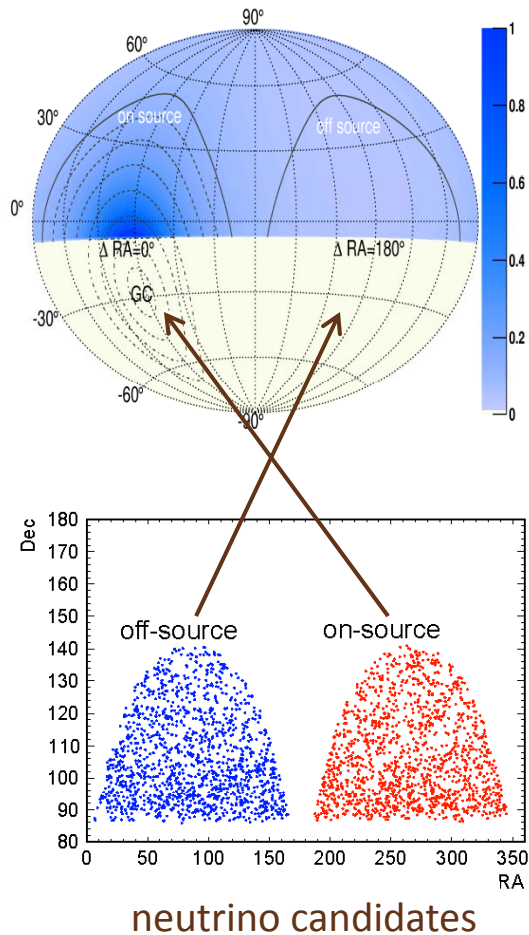
(particle physics and solar model)

Indirect Dark Matter Search: Galactic Halo

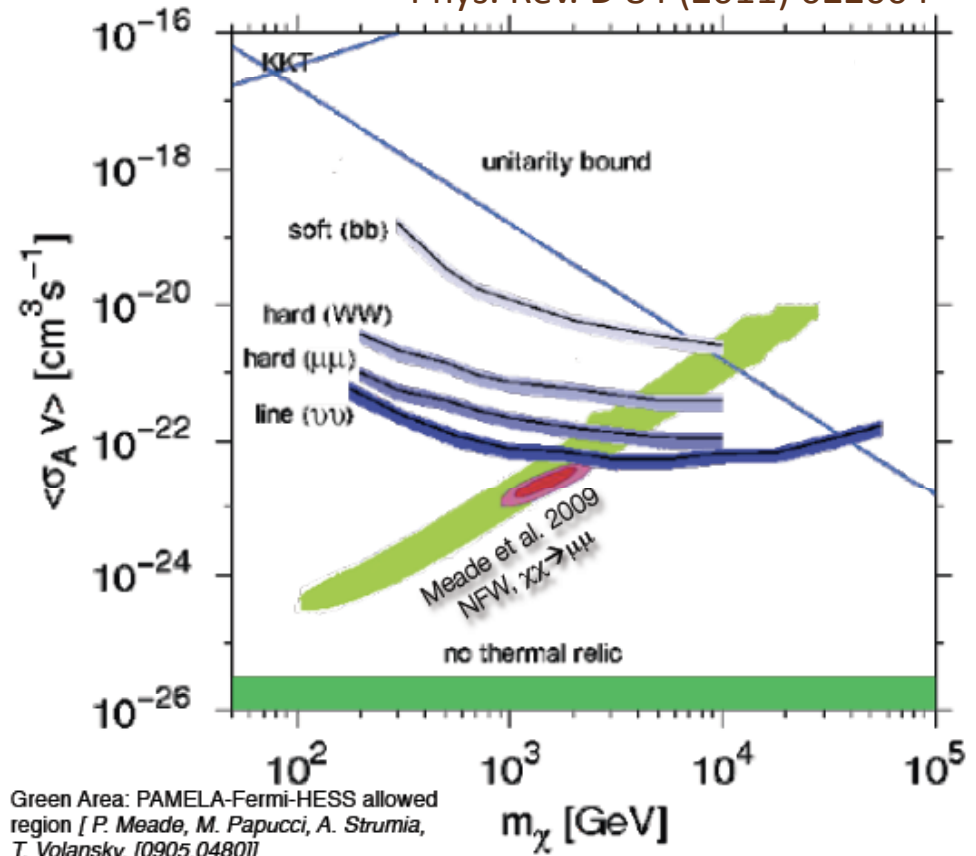


IC22 (275 days)

Expected relative neutrino flux from DM self-annihilation in GH

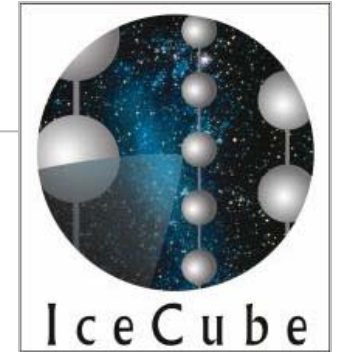


Phys. Rev. D 84 (2011) 022004



No observed excess over background

Summary



IceCube Neutrino Observatory completed

The era of km³ neutrino astronomy has begun

Physics run with complete detector started in May, 2011

100,000+ high-energy neutrinos on the books

No astrophysical neutrino sources detected yet

Increased sensitivity at lower energies with DeepCore

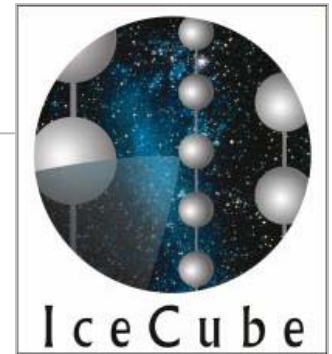
Lots of physics to come:

- cosmic ray spectrum • cosmic ray composition • cosmic ray anisotropies • atmospheric neutrinos (prompt component, oscillations, effects of quantum gravity, sterile neutrinos, ...) • neutrino point sources • gamma ray bursts • GZK neutrinos • multimessenger approaches • diffuse ν fluxes • dark matter • magnetic monopoles • supernova bursts • shadow of the moon • atmospheric physics • glaciology • climatology • new technologies for highest energies (radio, acoustics)

The IceCube Collaboration

<http://icecube.wisc.edu>

36 institutions, ~250 members



Canada

University of Alberta

US

Bartol Research Institute, Delaware
Pennsylvania State University
University of California - Berkeley
University of California - Irvine
Clark-Atlanta University
University of Maryland
University of Wisconsin - Madison
University of Wisconsin - River Falls
Lawrence Berkeley National Lab.
University of Kansas
Southern University, Baton Rouge
University of Alaska, Anchorage
University of Alabama, Tuscaloosa
Georgia Tech
Ohio State University

Barbados

University of West Indies

Sweden

Uppsala Universitet
Stockholms Universitet

UK

Oxford University

Germany

Universität Mainz
DESY-Zeuthen
Universität Dortmund
Universität Wuppertal
Humboldt-Universität zu Berlin
MPI Heidelberg
RWTH Aachen
Universität Bonn
Ruhr-Universität Bochum

Belgium

Université Libre de Bruxelles
Vrije Universiteit Brussel
Universiteit Gent
Université de Mons-Hainaut

Switzerland

EPFL, Lausanne

Japan

Chiba University

New Zealand

University of Canterbury

ANTARCTICA

Amundsen-Scott Station