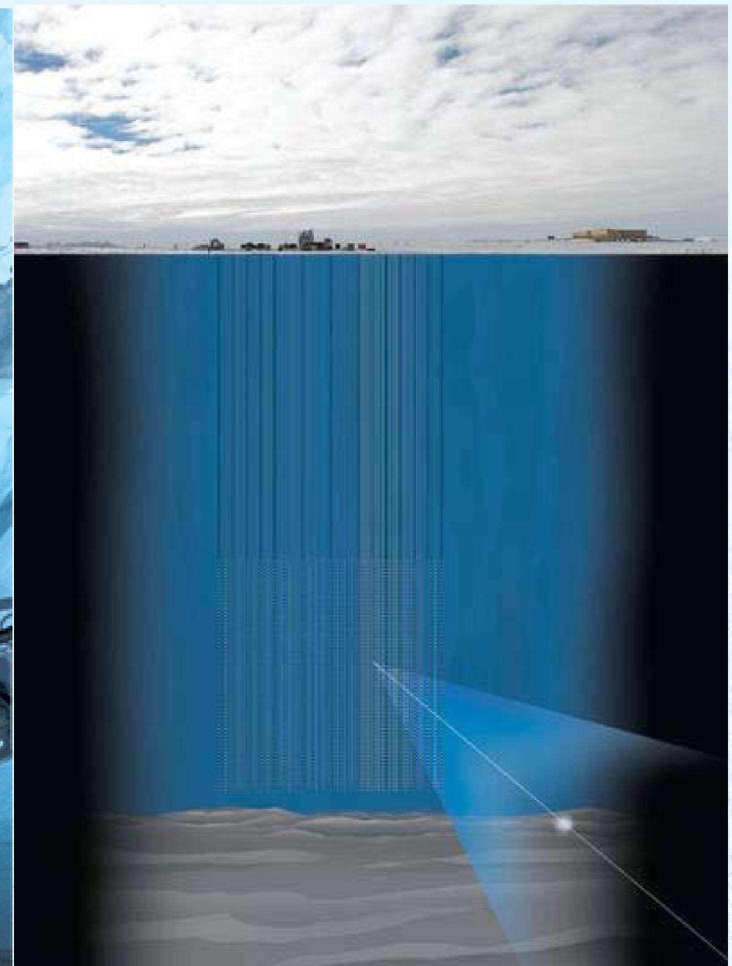
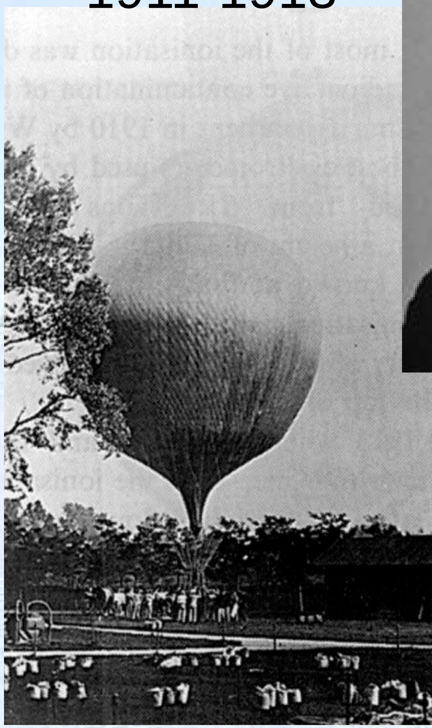
Recent results from IceCube

Kirill Filimonov, University of California, Berkeley, for the IceCube Collaboration

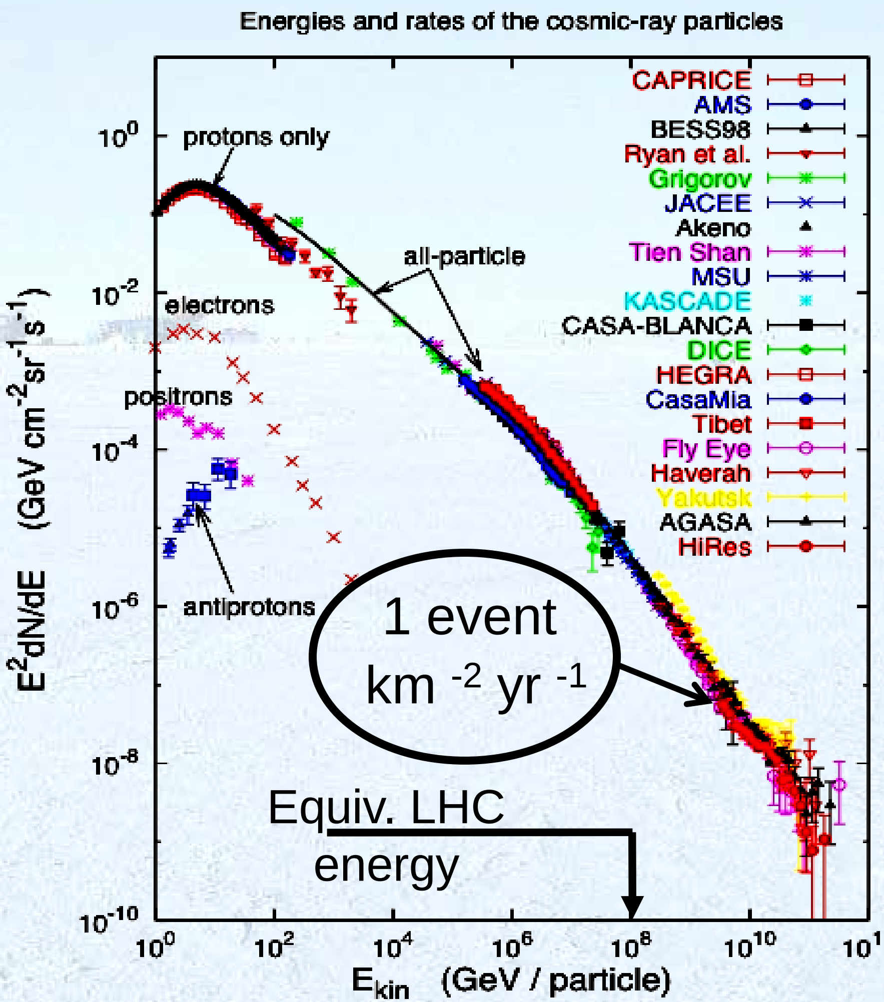


Cosmic rays: a 100 year-old mystery

Balloon flights
1911-1913

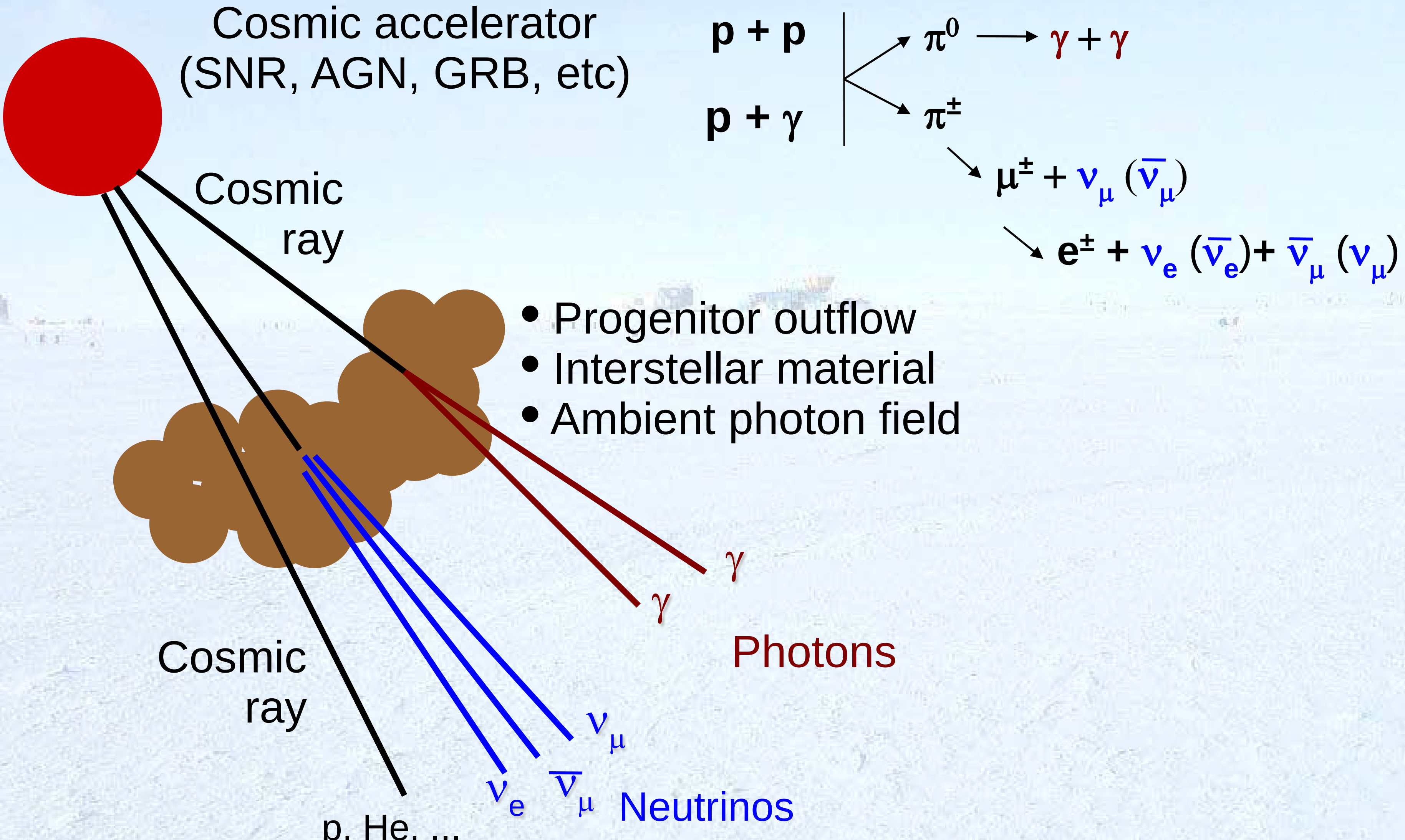


Victor Hess
Nobel 1936

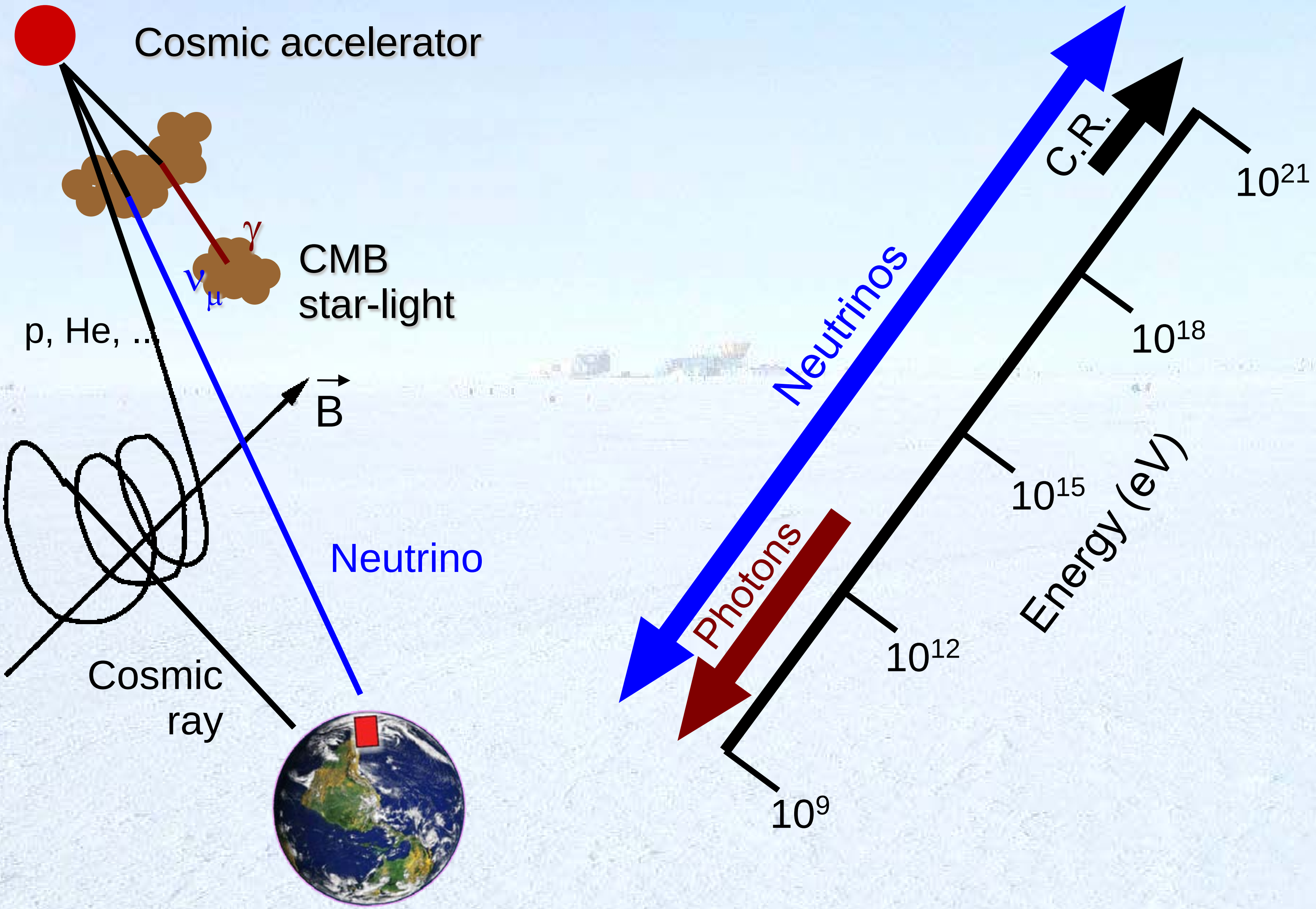


Power law over many decades

Cosmic ray – γ-ray – Neutrino connection

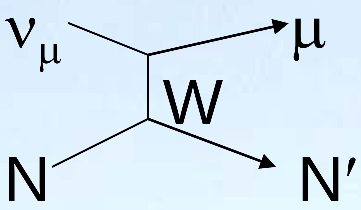


Neutrinos as Astronomical Messengers

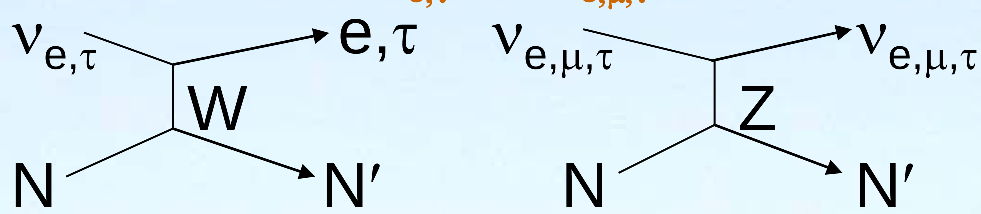


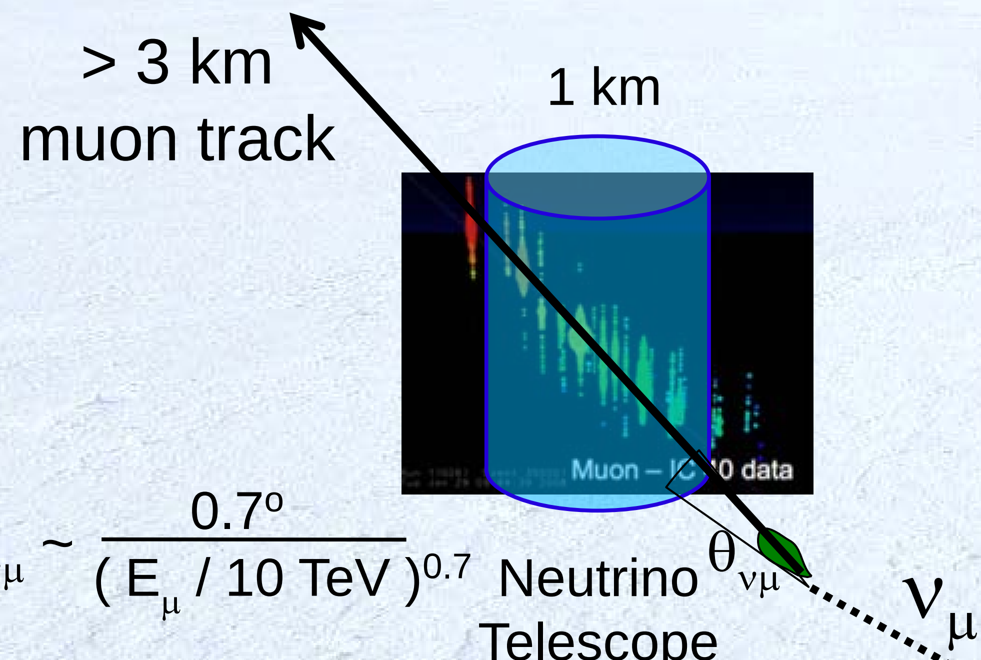
Neutrino interaction with matter

μ tracks (ν_μ)

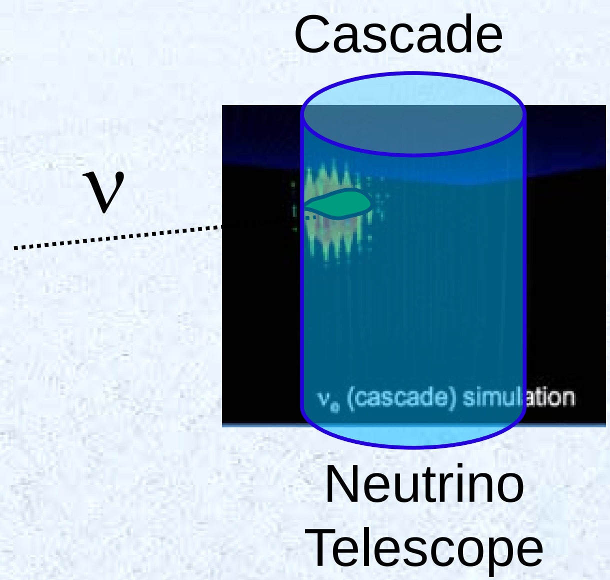


Cascades ($\nu_{e,\tau}$ CC, $\nu_{e,\mu,\tau}$ NC)

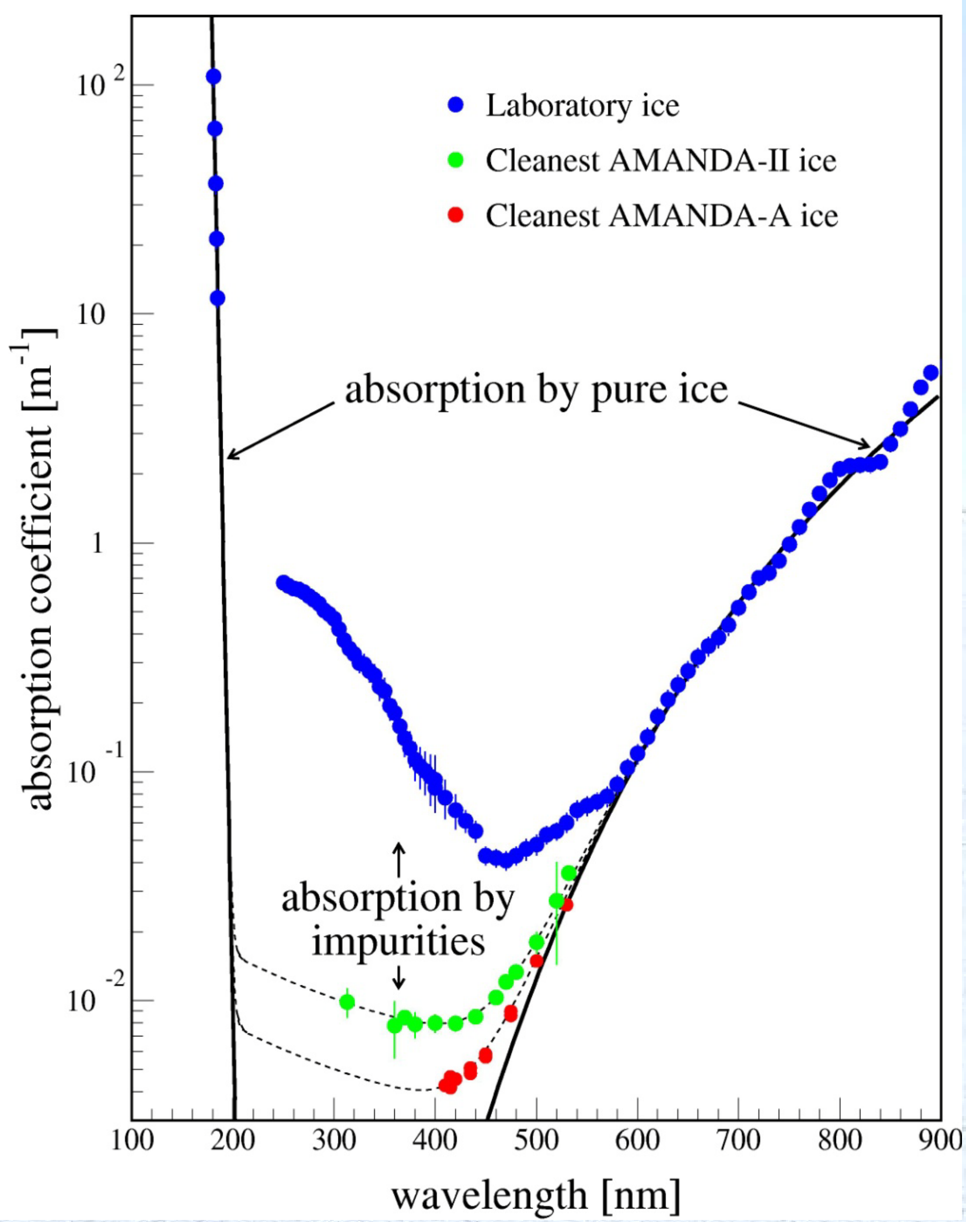




$$\theta_{\nu\mu} \sim \frac{0.7^o}{(E_\mu / 10\ \text{TeV})^{0.7}}$$



Why the South Pole?



Antarctic Ice is the most transparent natural solid known

Average optical ice parameters:

λ_{abs} ~ 110 m @ 400 nm
λ_{sca} ~ 20 m @ 400 nm

THE ICECUBE COLLABORATION

http://icecube.wisc.edu

39 institutions, 250 members

Canada:
University of Alberta

USA:
Bartol Research Institute, Delaware
Pennsylvania State University
UC Berkeley
UC 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
SUNY at Stony Brook

Barbados:
University of West Indies

Sweden:
Uppsala Universitet
Stockholm Universitet

UK:
Oxford University

Germany:
Universität Mainz
DESY-Zeuthen
Universität Dortmund
Universität Wuppertal
Universität Berlin
MPI Heidelberg
RWTH Aachen
Bonn
Bochum

Japan:
Chiba university

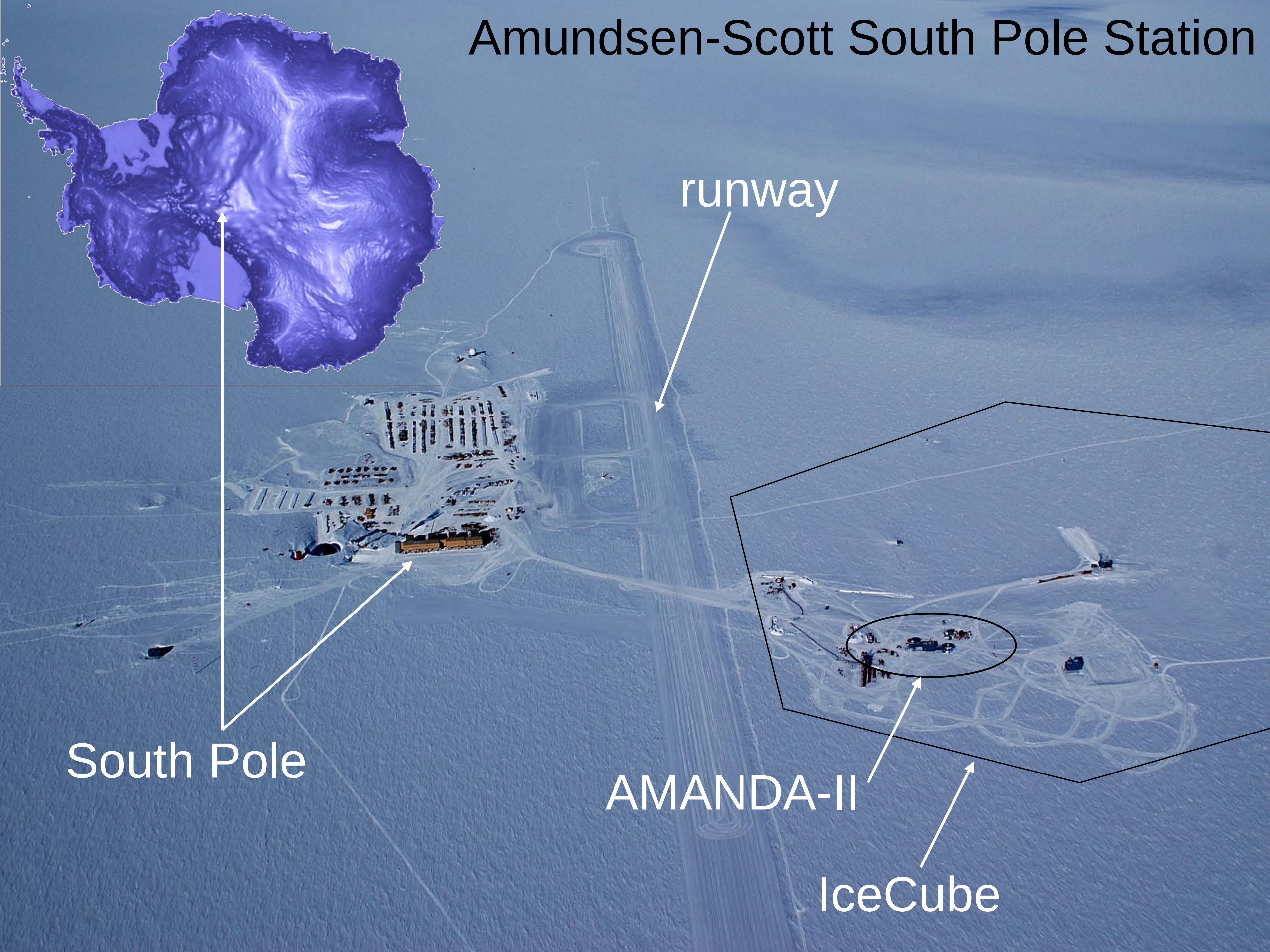
Belgium:
Université Libre de Bruxelles
Vrije Universiteit Brussel
Universiteit Gent
Université de Mons-Hainaut

Switzerland
EPFL, Lausanne
University of Geneva

New Zealand:
University of Canterbury

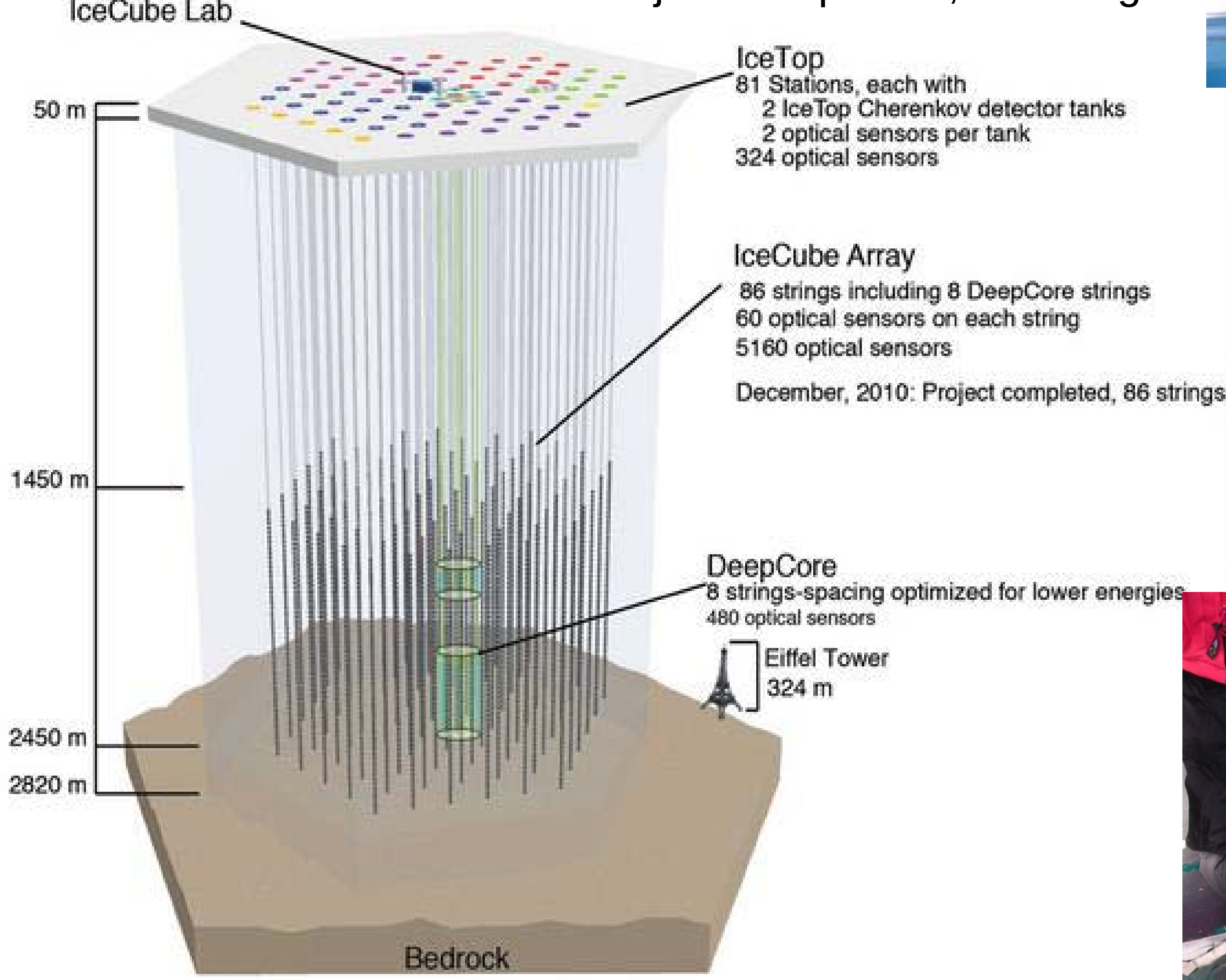
ANTARCTICA
Amundsen-Scott Station

Australia:
University of Adelaide


Amundsen-Scott South Pole Station
runway
South Pole
AMANDA-II
IceCube

IceCube

2004 Project Start, 1 string
2011 Project completion, 86 strings



Digital
Optical
Module

Digital Optical Module

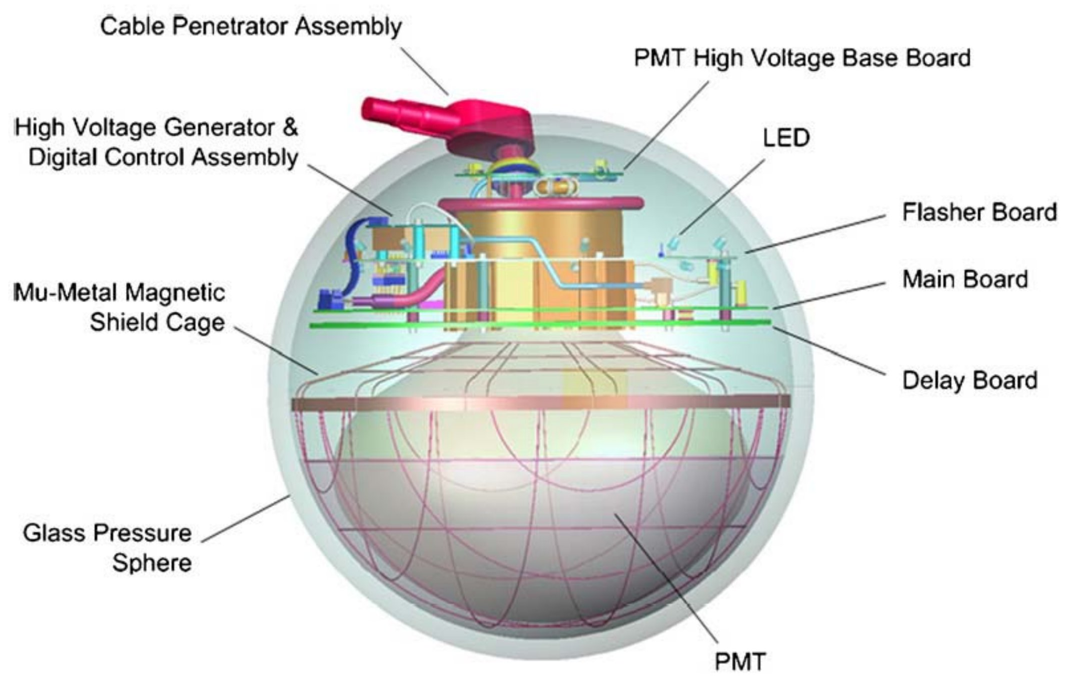
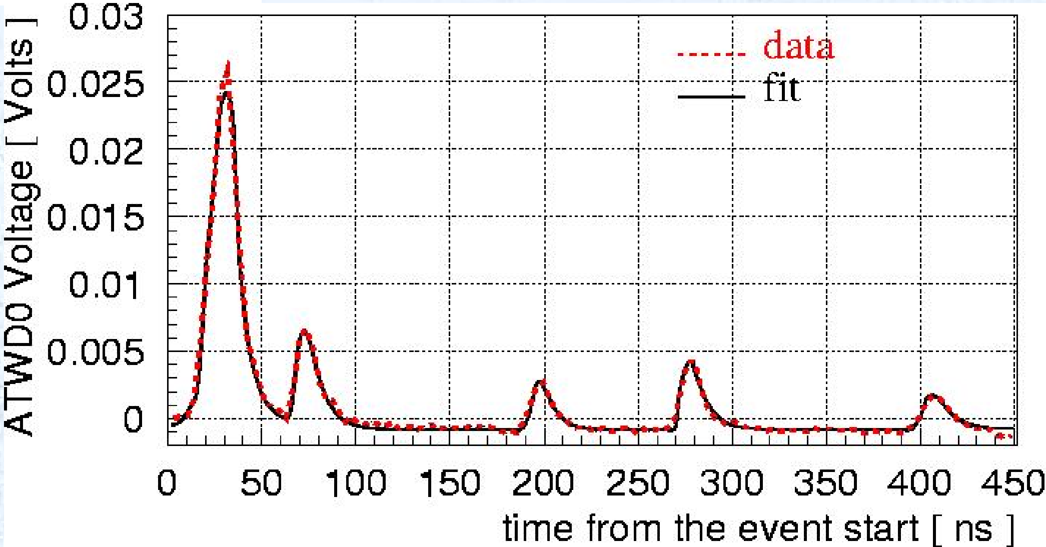


Fig. 3. A schematic view of an IceCube digital optical module.

DOM+Main Board - a complete data acquisition system

- internal digitization (waveform digitizers) and time stamping
- the photonic output signals from the PMT
- wide dynamic range: from single p.e. to thousands p.e.
- performs PMT gain and time calibration
- power consumption 3W, deadtime < 1%, dark noise rate < 400 Hz



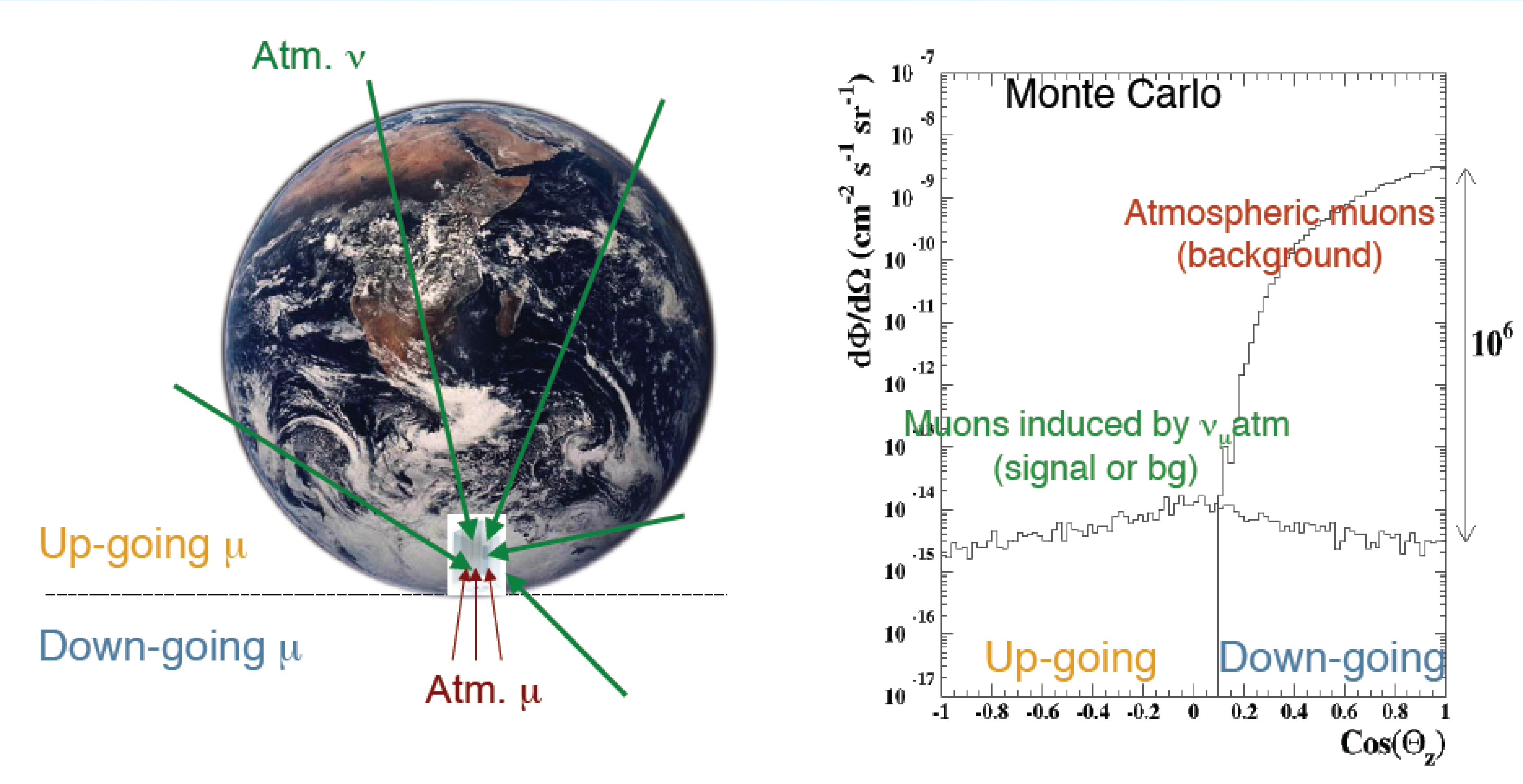
IceCube Detector Status, Rates

Strings	Data (year)	Livetime	μ rate (Hz)	HE ν rate (per day)
AMANDAII(19)	2000-2006	3.8 years	100	5 / day
IC40	2008-09	375 days	1100	38 / day
IC59	2009-10	360 days	1900	129 / day
IC79	2010-11	1 year	2250	
IC86	2011-	13 days	2700	

DeepCore Completed → IC79

IC86 Run Start on May 13, 2011

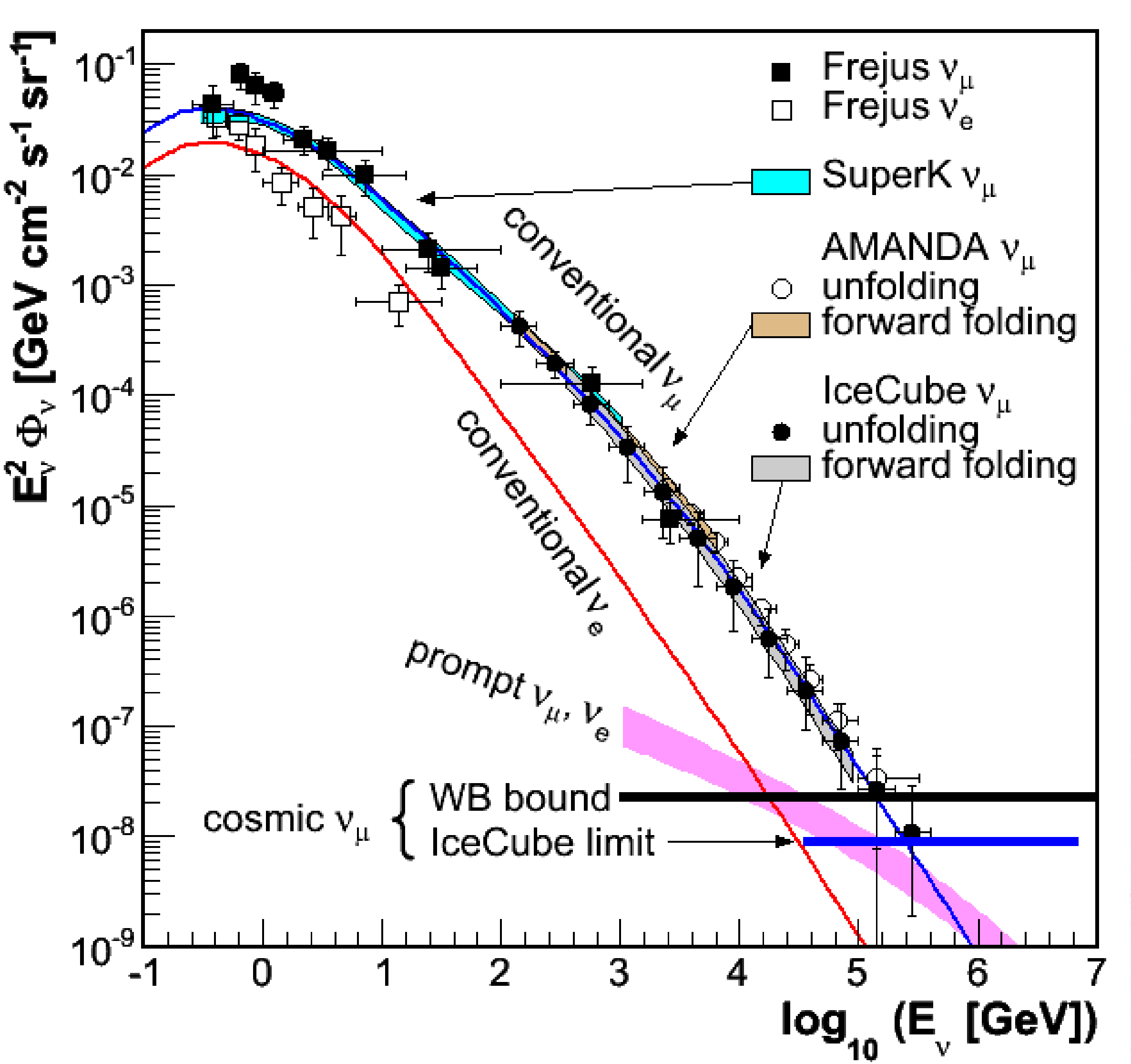
Background rejection



- Atmospheric ν: $dN/dE \sim E^{-3.7}$ background ν
- Prompt atmospheric ν: $dN/dE \sim E^{-2.8}$ background ν
- Extraterrestrial ν: $dN/dE \sim E^{-2.0}$ (model) signal ν

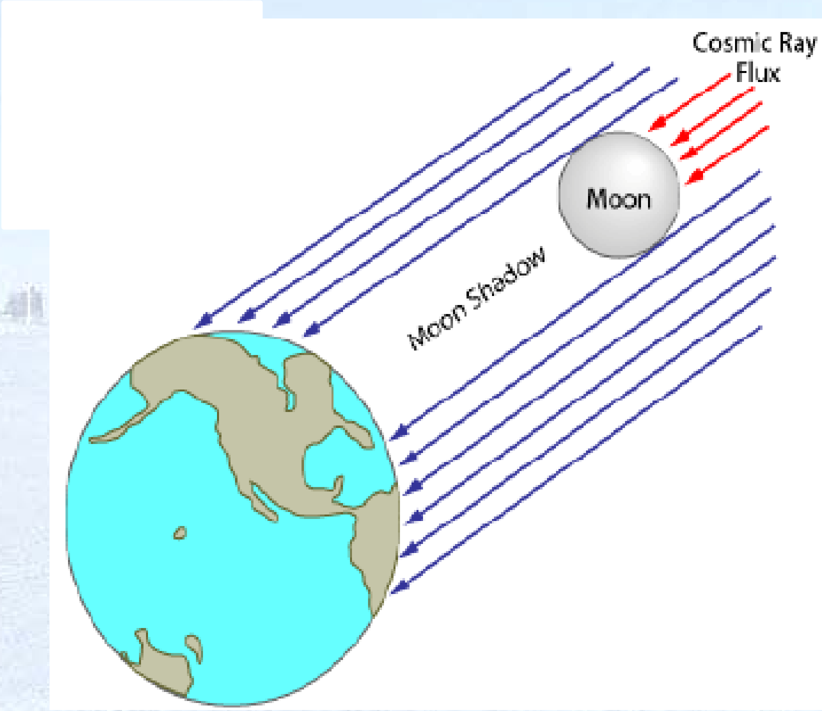
Atmospheric muon neutrino spectrum

- IC40: 13,000 high-energy (E>100 GeV) atmospheric ν_μ (95% purity)
- Flux consistent with previous measurement (Phys.Rev.D83:012001,2011)



Moon Shadow

• Cosmic rays blocked by the moon lead to a point-like deficit in the distribution of down-going muons in the detector.



Moon Shadow

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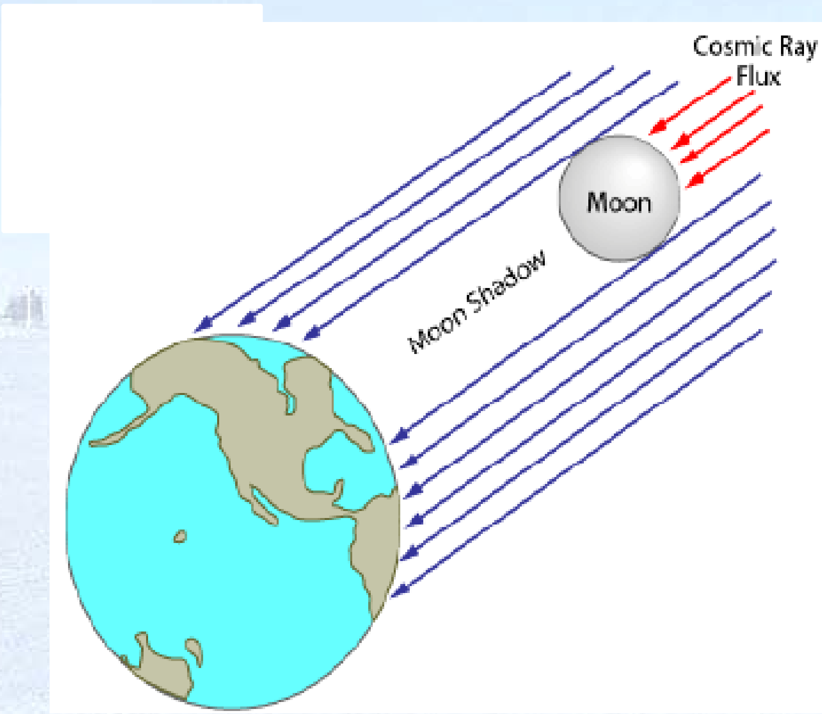
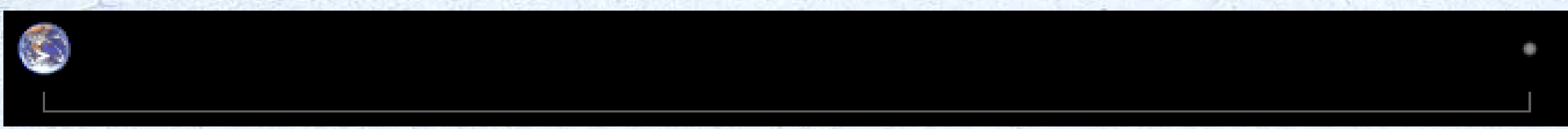
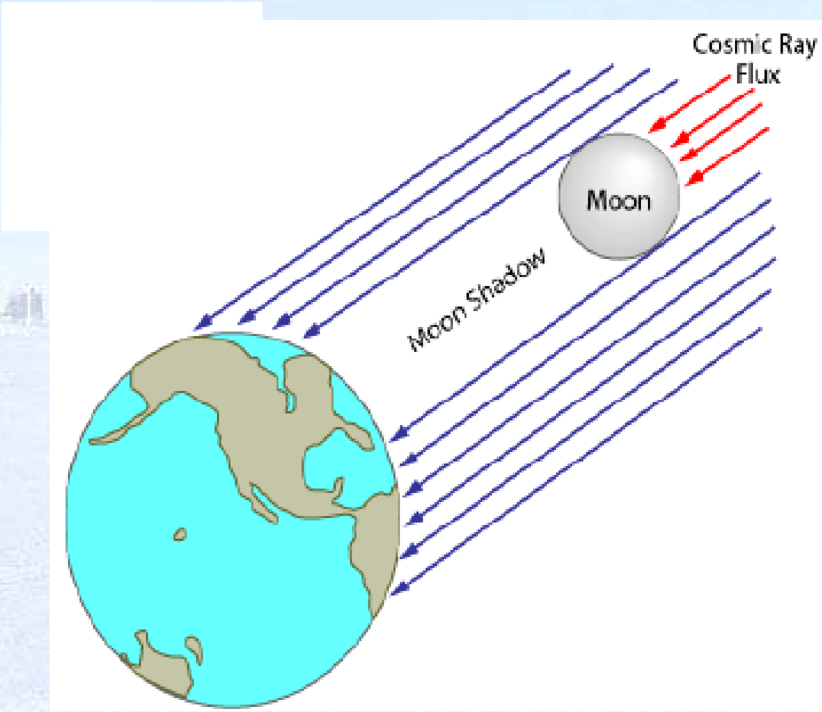


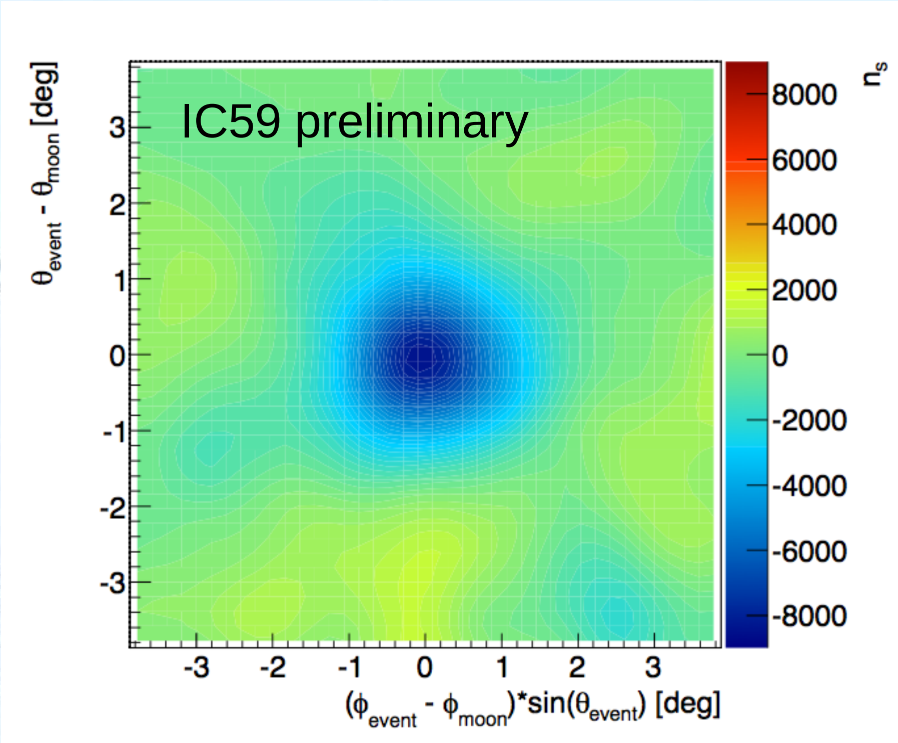


Need high statistics and good angular resolution!

Moon Shadow

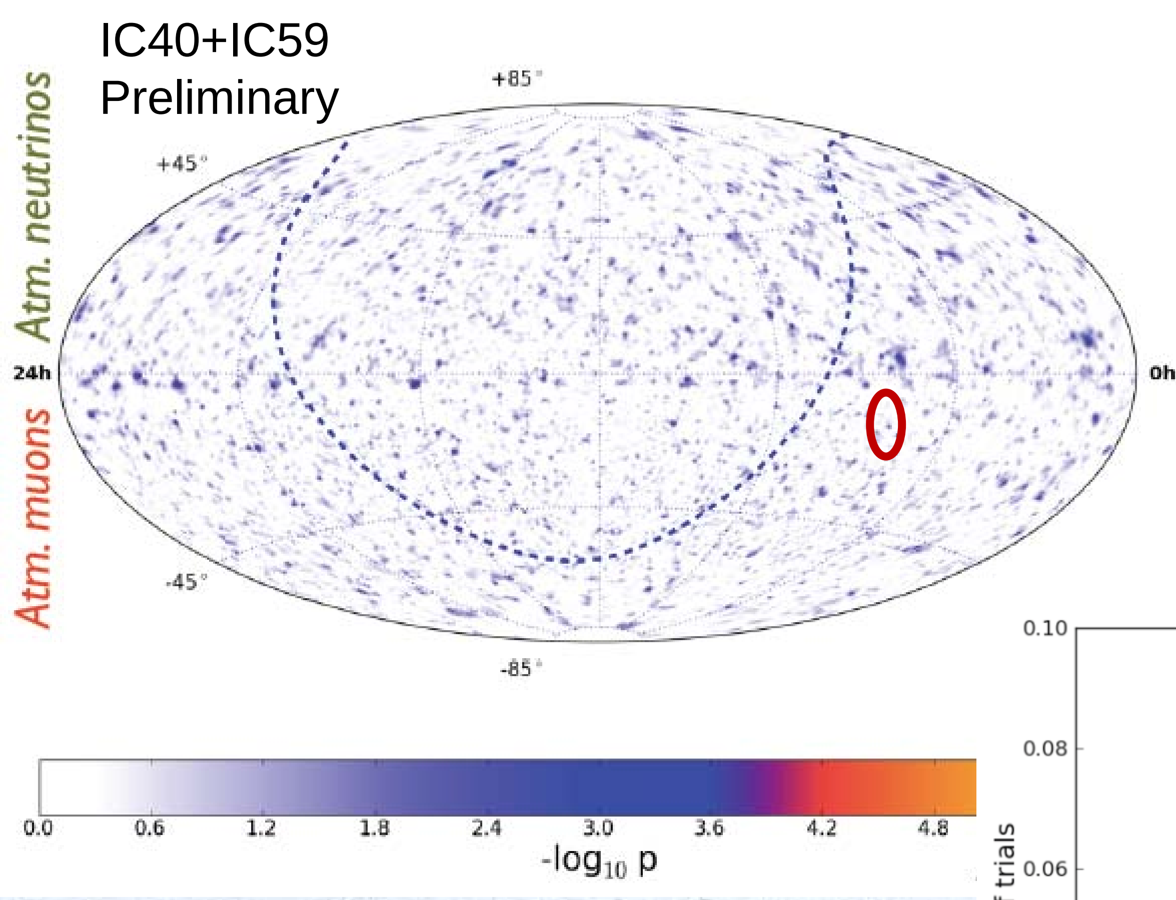
• Cosmic rays blocked by the moon lead to a point-like deficit in the distribution of down-going muons in the detector.

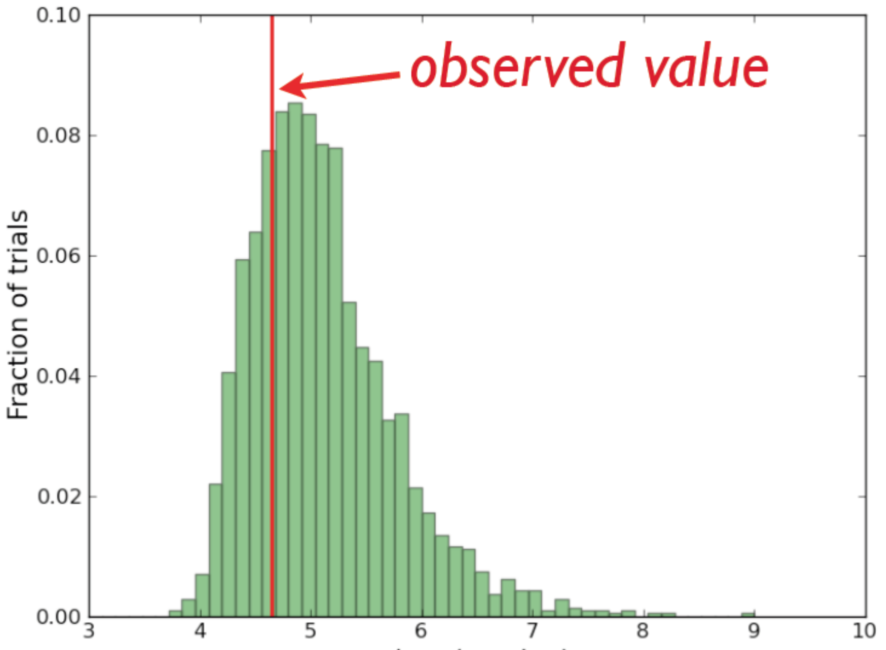




• Moon shadow seen with ~10σ
• Systematic pointing error less than 0.1°

Search for point sources: all-sky



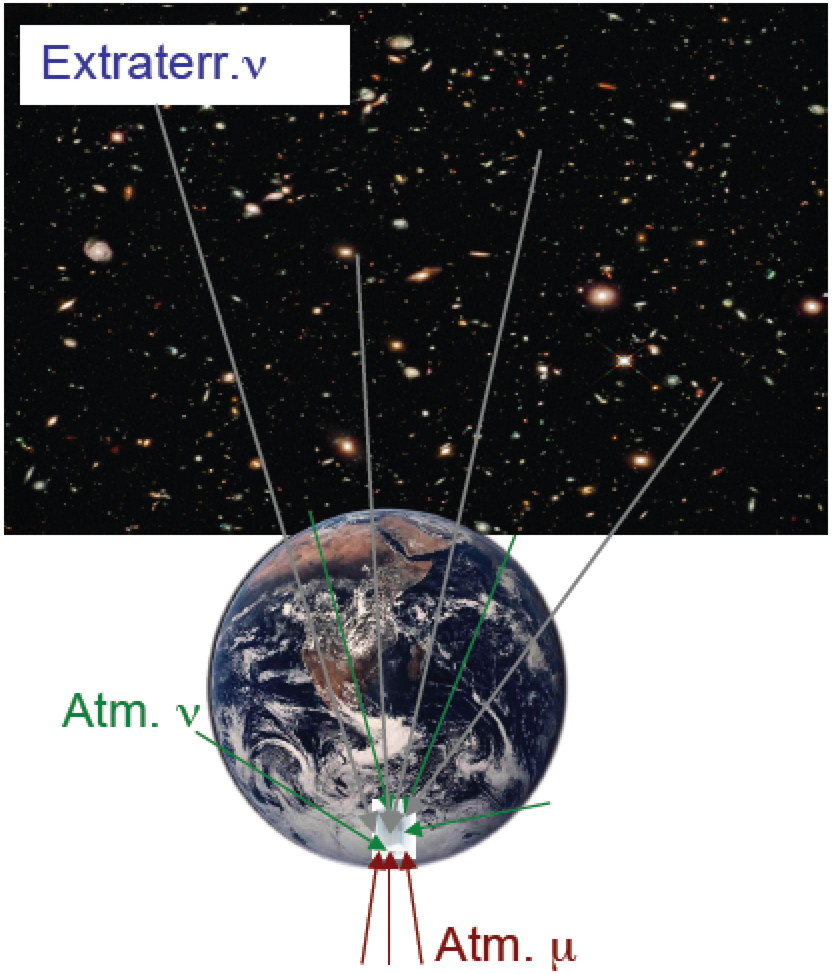


107,569 neutrino candidates (64,230 atm. μ from southern hemisphere)

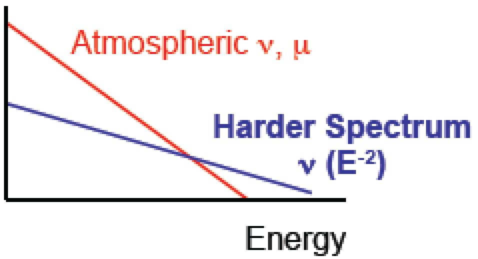
- Hottest spot (Ra=75.45, Dec=-18.15) not significant: 75.4% of trials have p-value value equal or lower than the observed one

Search for Diffuse Neutrino Fluxes

Diffuse flux = effective sum from all (unresolved) extraterrestrial sources (e.g.AGNs)
Possibility to observe diffuse signal even if flux from an individual source is too small to be detected by point source techniques.



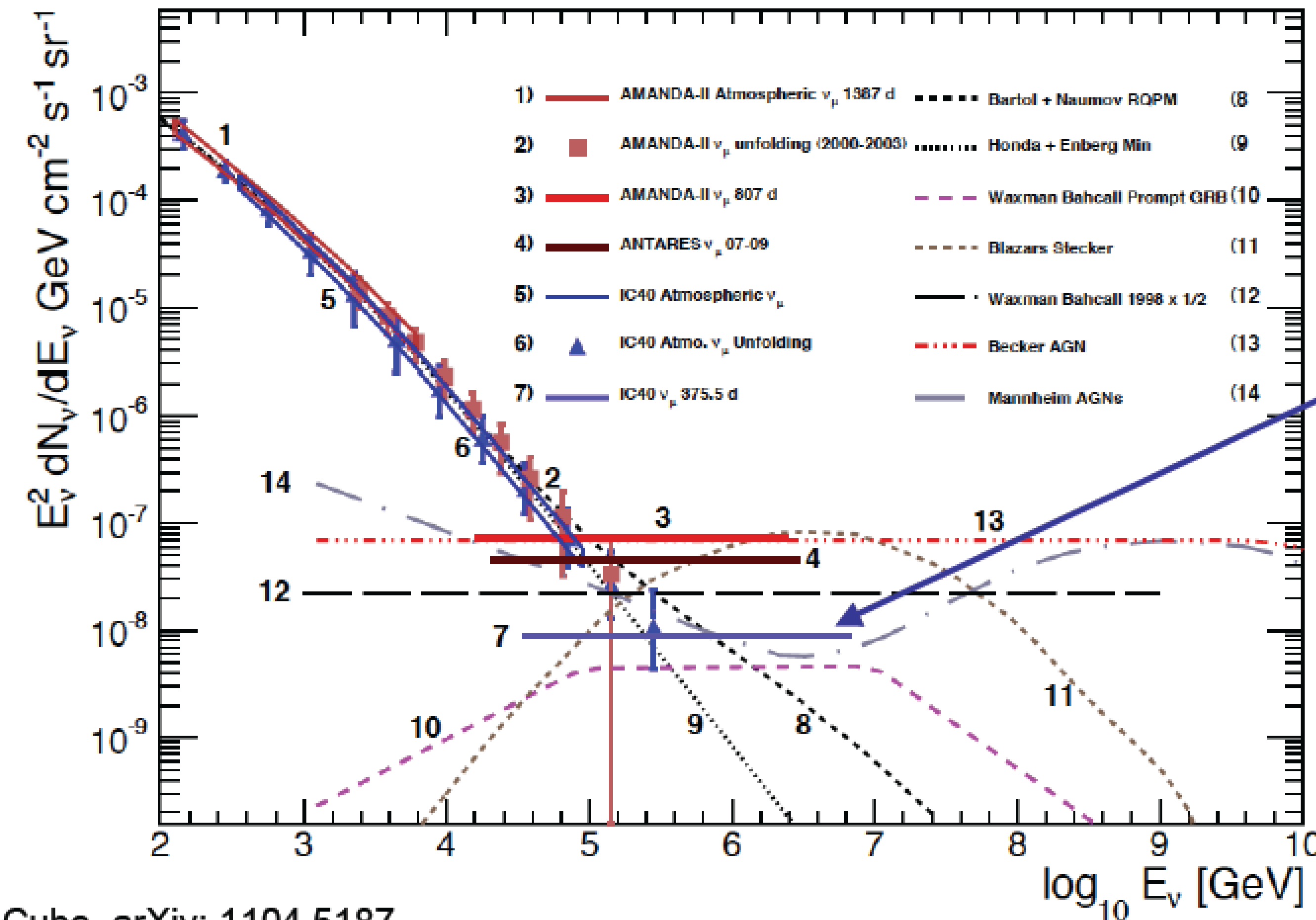
- Search for excess of astrophysical neutrinos with a harder spectrum than background atmospheric neutrinos



- Advantage over point source search: can detect weaker fluxes
- Disadvantage: high background
- Sensitive to all three flavors of neutrinos

Search for Diffuse Neutrino Fluxes

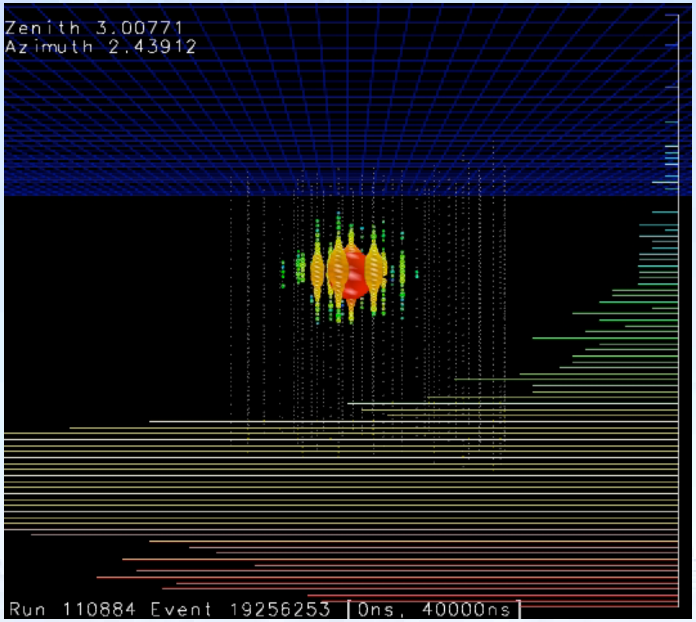
Experimental upper limits on the diffuse flux of neutrinos from sources with $\Phi \sim E^{-2}$ energy spectrum

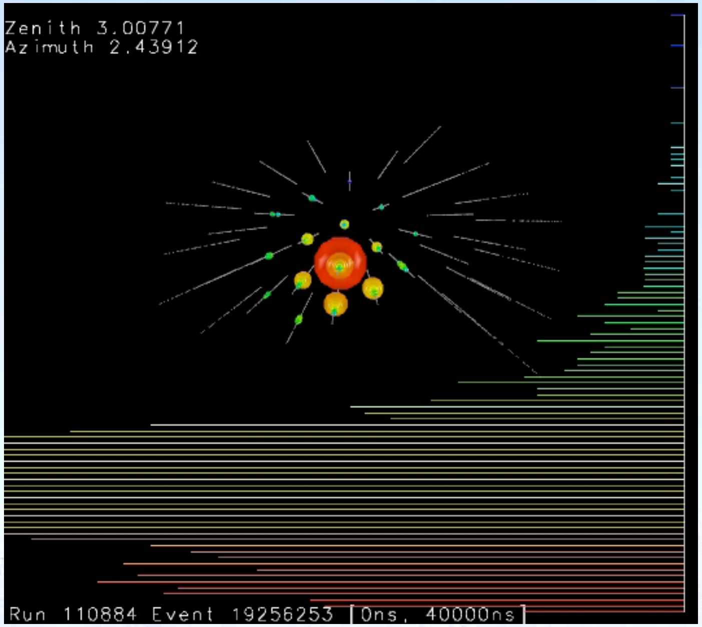


Below the Waxman - Bahcall bound

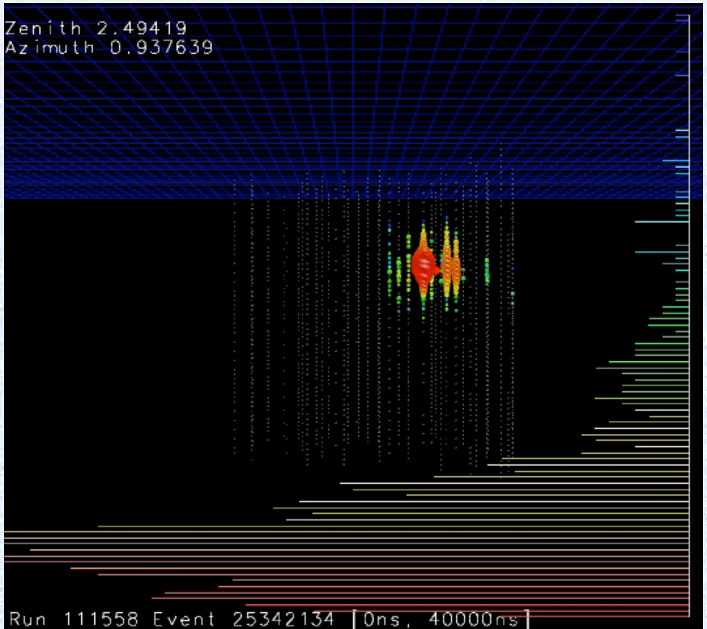
IceCube, arXiv: 1104.5187

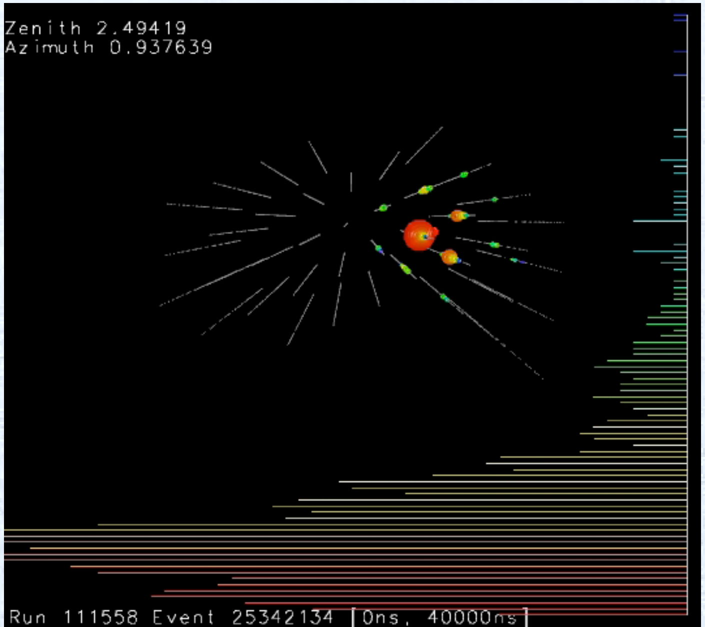
IC40 high-energy cascade search





E= 175 TeV

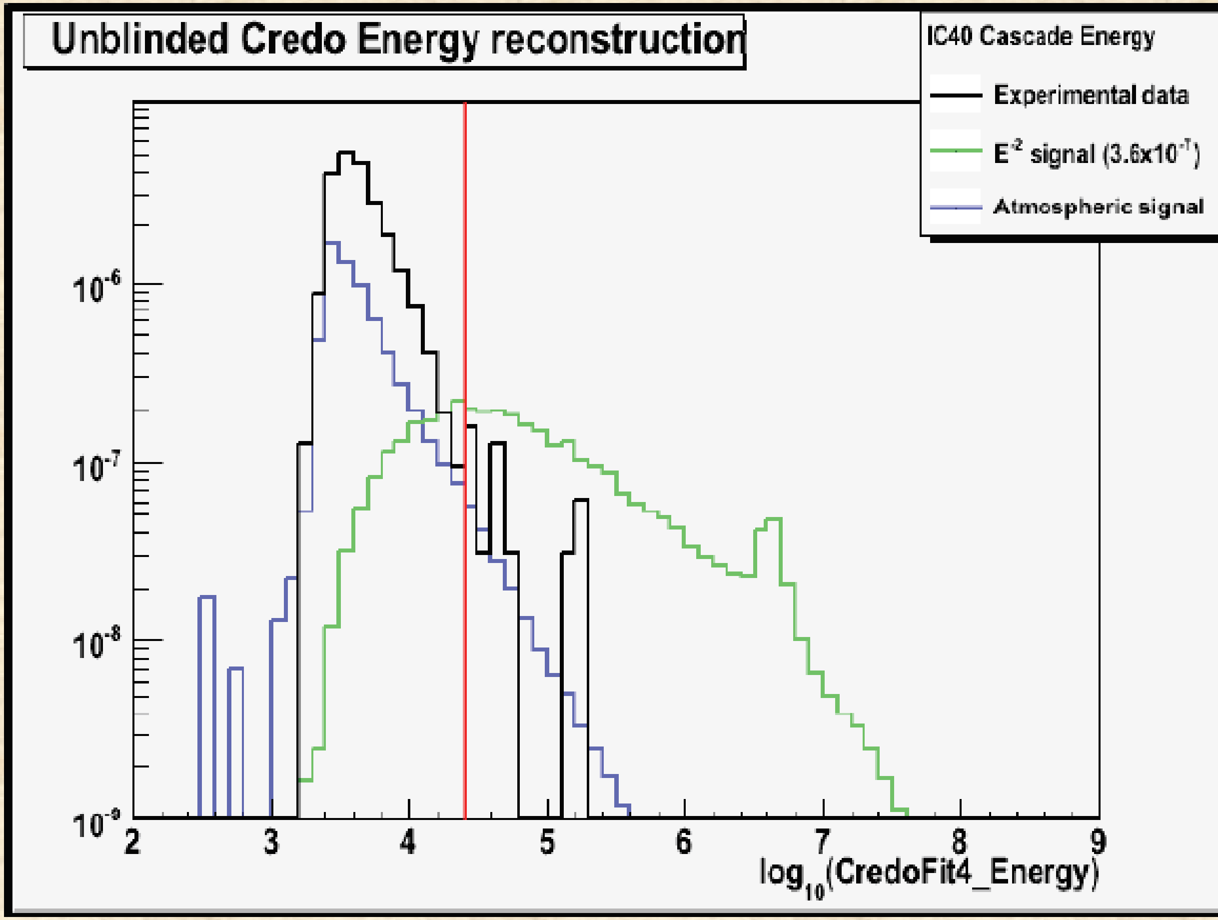




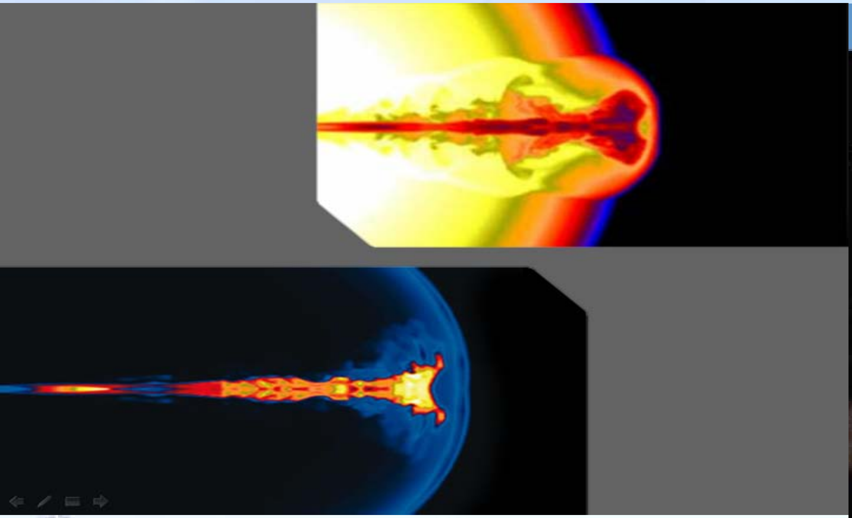
E= 45 TeV

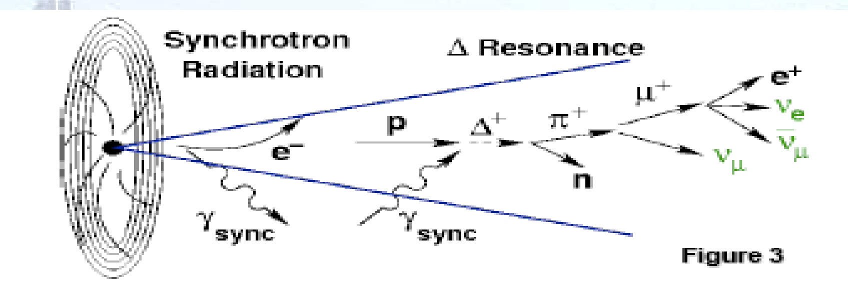
IC40 high-energy cascade search (preliminary)

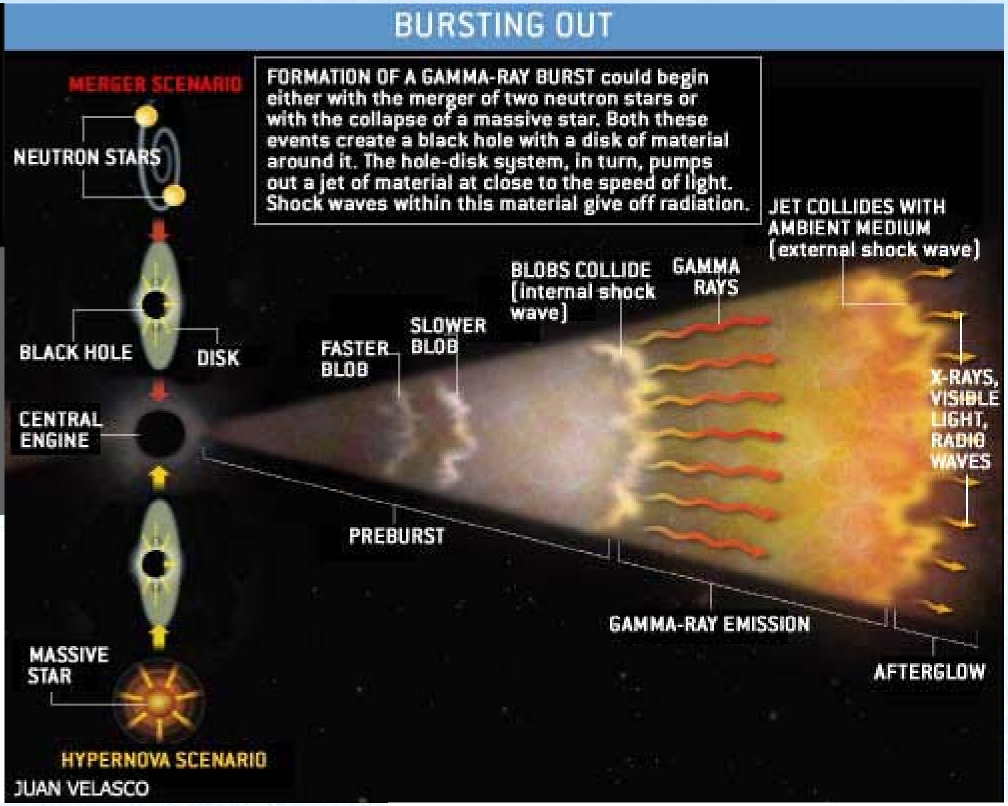
- 14 events pass cuts
- Detailed examination of the 14 events indicates ~4 events look like background from high energy cosmic rays
- Generating more monte carlo to make a better estimate for CR backgrounds and expected number of atmospheric neutrino events



Gamma-Ray Bursts

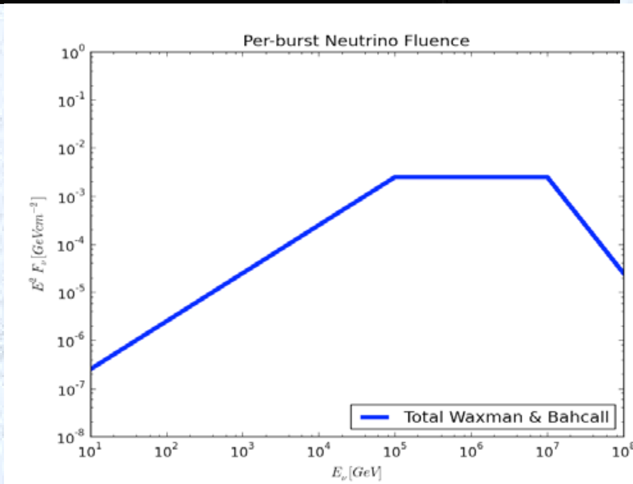






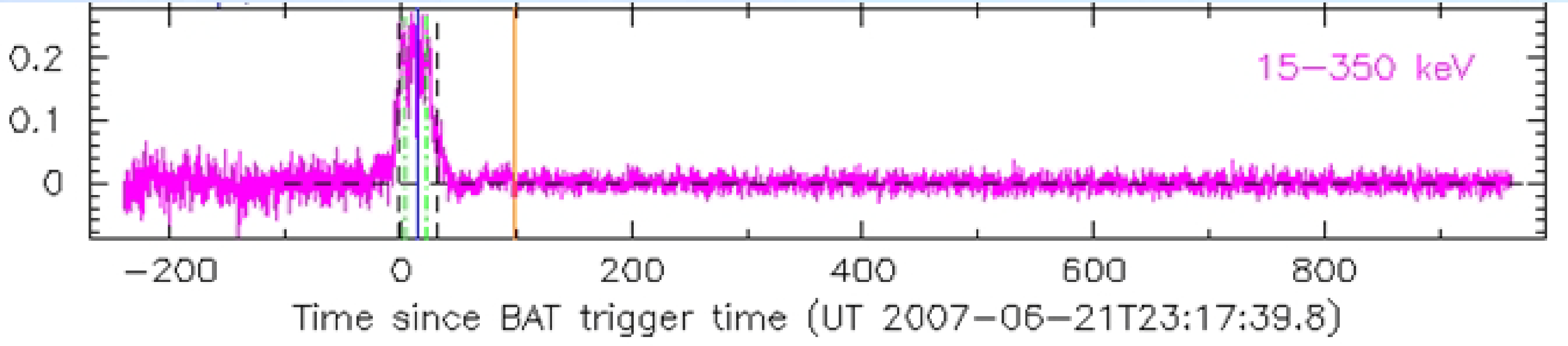
Fireball model:

- Internal shocks in GRBs → acceleration for UHECRs.
- Neutrino production in *γ*-hadron interactions in fireball



GRB Analysis method

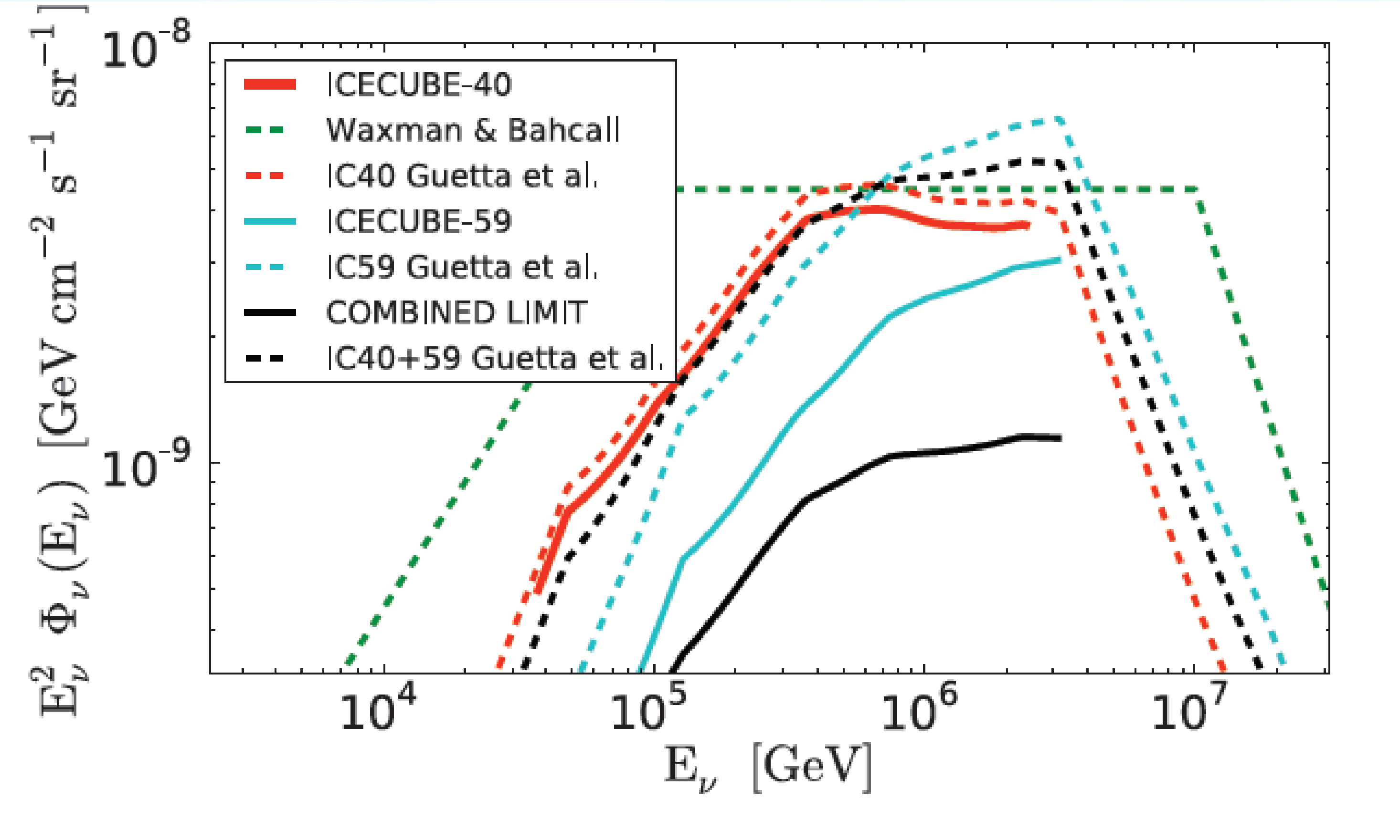
Use satellite measurements as trigger:



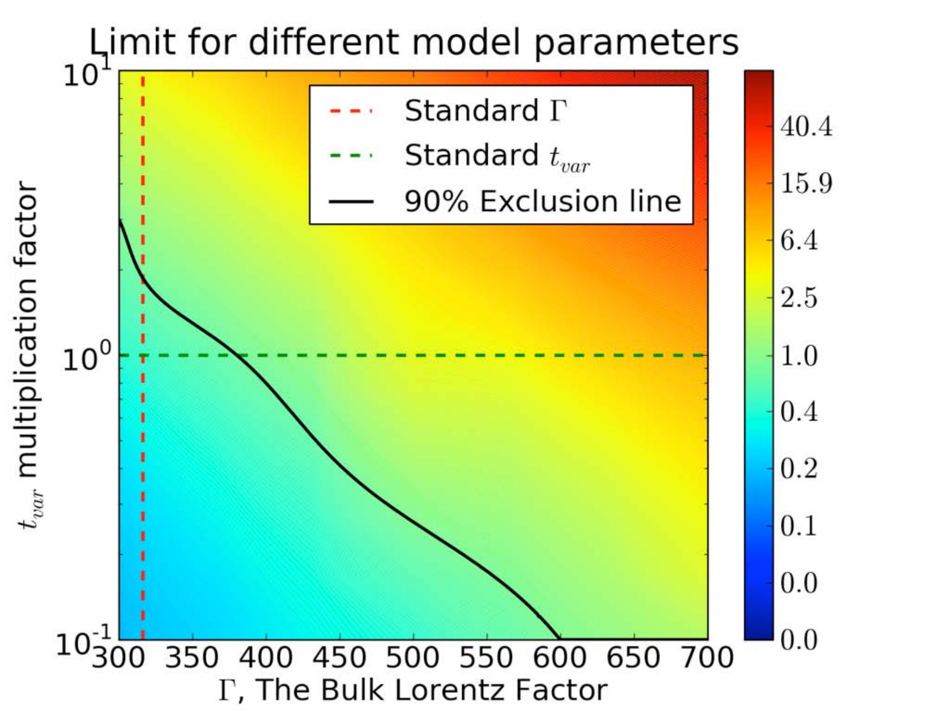
Look for neutrinos in the direction of GRB in a short (seconds to minutes) time window….

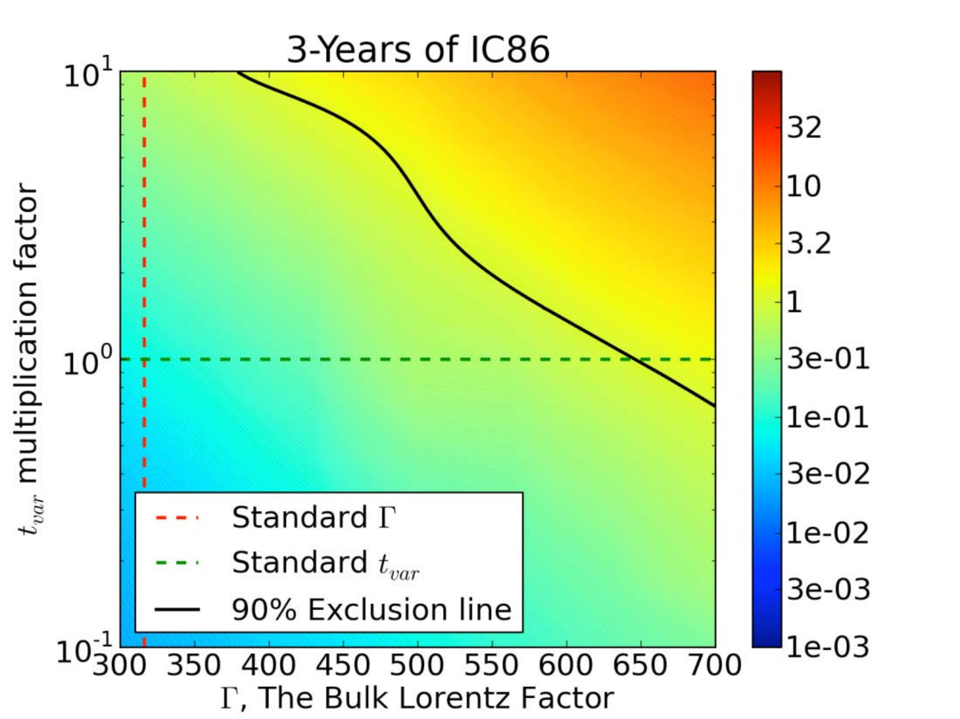
Search for neutrinos from GRBs, results

IC40: 117 Bursts
IC59: 109 Bursts (preliminary)
23 events at WB flux were expected, 0 observed



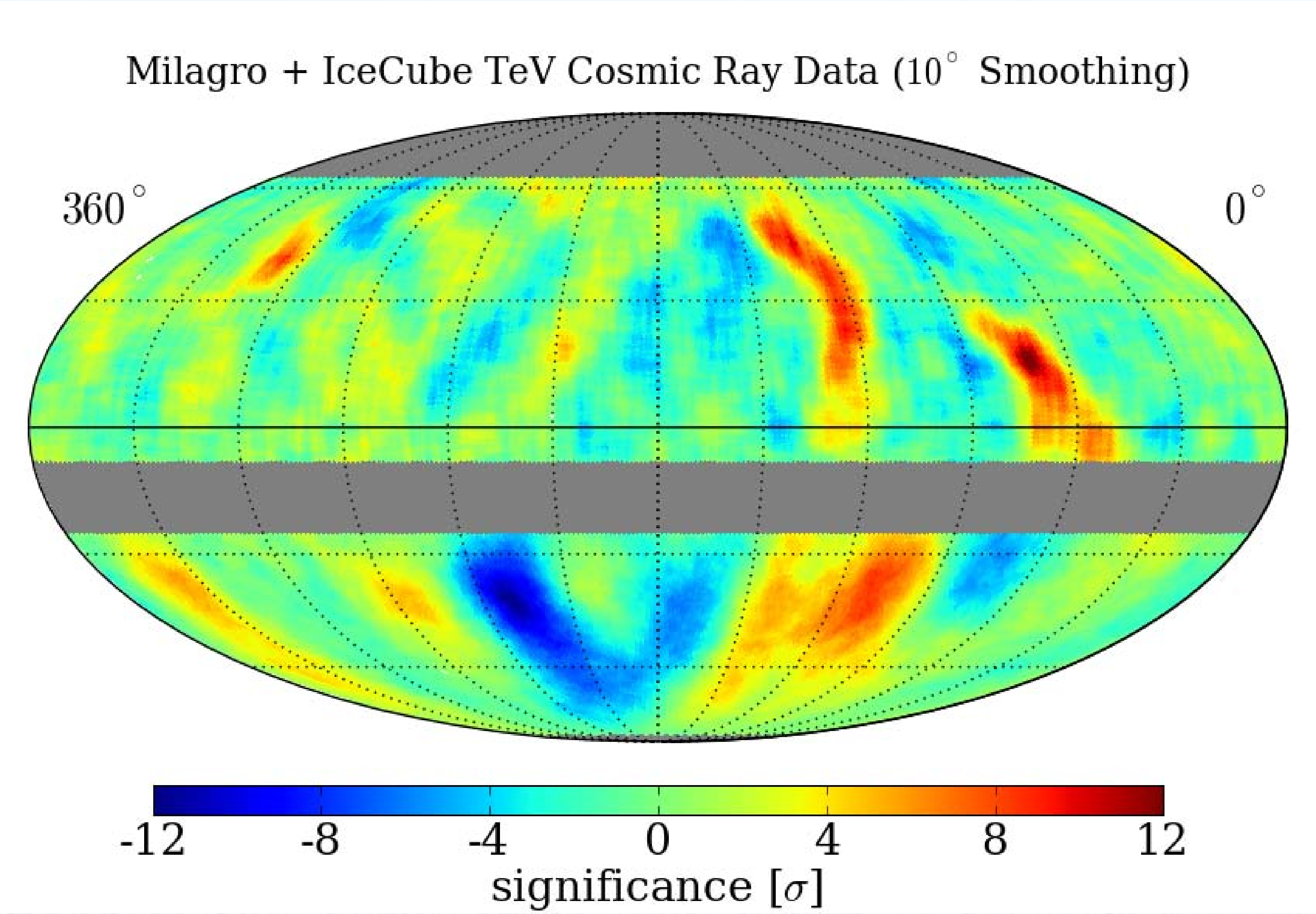
Search for neutrinos from GRBs, future





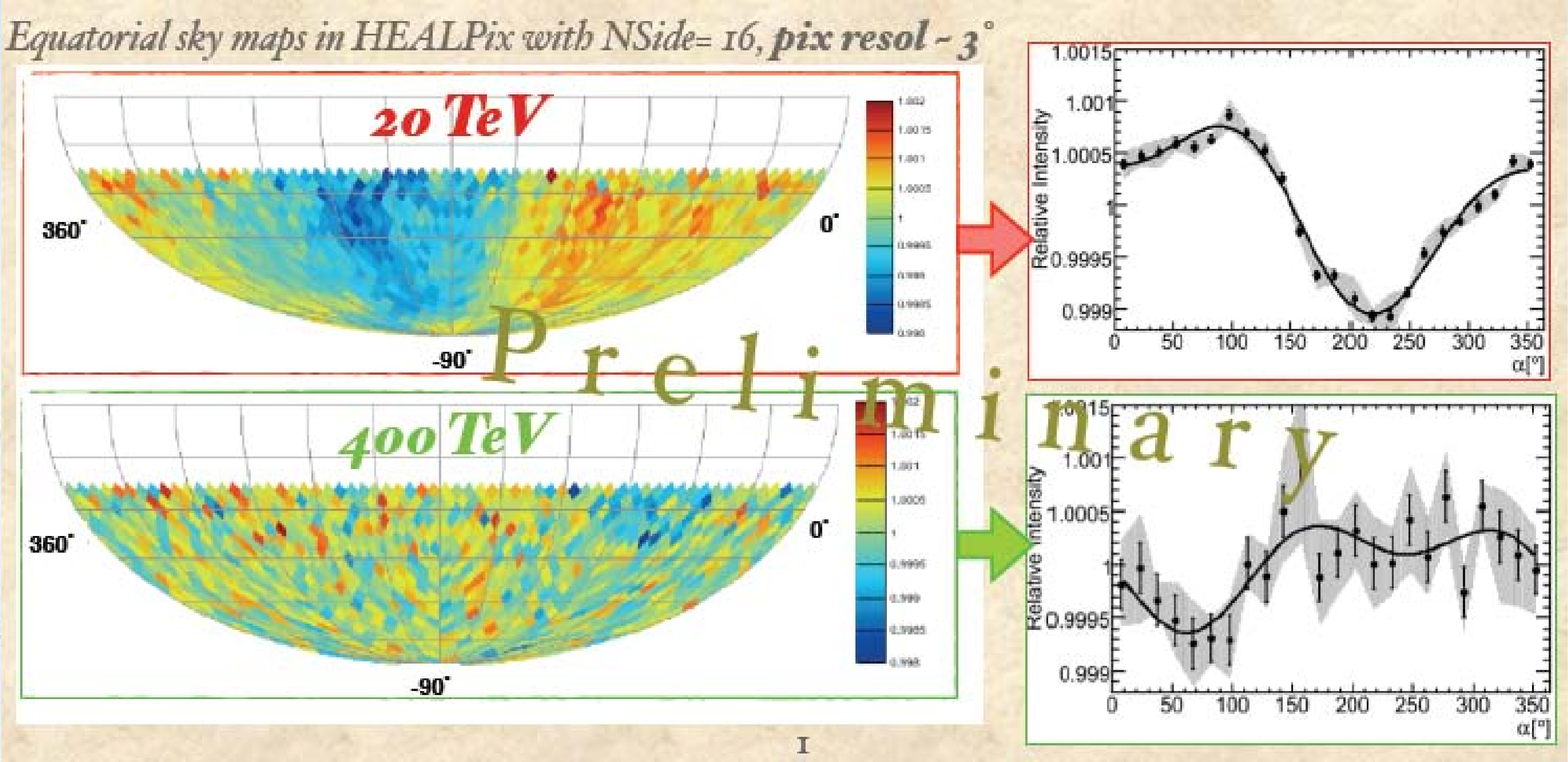
In 3 years IceCube will rule out fireball model or establish GRBs are not the only sources of UHECRs

Large-scale anisotropy of cosmic rays at 20 TeV



Astrophys.J.740:16,2011

Cosmic Ray Anisotropy at 400 TeV



arXiv:1109.1017

Origin of the anisotropy remains a mystery

Summary

- IceCube detector completed construction Dec 2010
  - Run start May 13, 2011
  - The era of km^3 neutrino astronomy has begun!
- The 40 and 59 string data have already surpassed the expected performance of the full IceCube on a number of searches
- No neutrinos seen from GRB
  - Setting important limits on astrophysics of fireball model
- No sources of high energy extraterrestrial neutrinos found as of today
- The sensitivity increases with the detector size, the data taking and analyses techniques

cosmic ray (CR) spectrum, • CR composition • CR anisotropies • atmospheric neutrinos (oscillations,effects of quantum gravity, …) • neutrino point sources • gamma ray bursts •multimessenger approaches • diffuse ν fluxes • dark matter • magnetic monopoles • supernova bursts • shadow of the moon • atmosphere physics • glaciology • new technologies for highest energies (radio, acoustics) • DeepCore and low-energy analyses•