IceCube Neutrino Observatory

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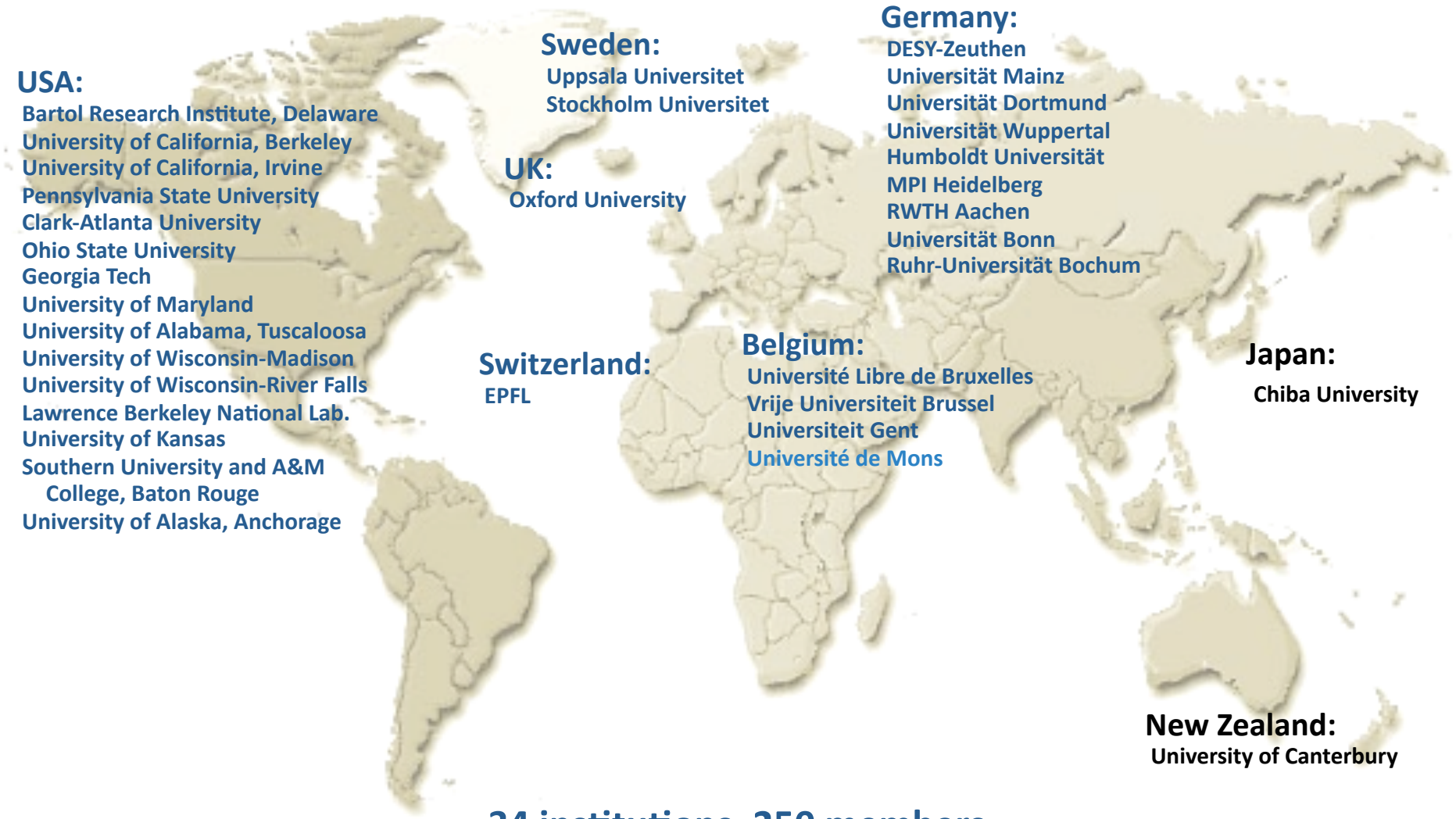
for the IceCube Collaboration

High Energy Phenomena in Relativistic Outflows II
Buenos Aires, Argentina 10/27/2009

The IceCube Collaboration



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

Sweden:
- Uppsala Universitet
- Stockholm Universitet

UK:
- Oxford University

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

Switzerland:
- EPFL

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

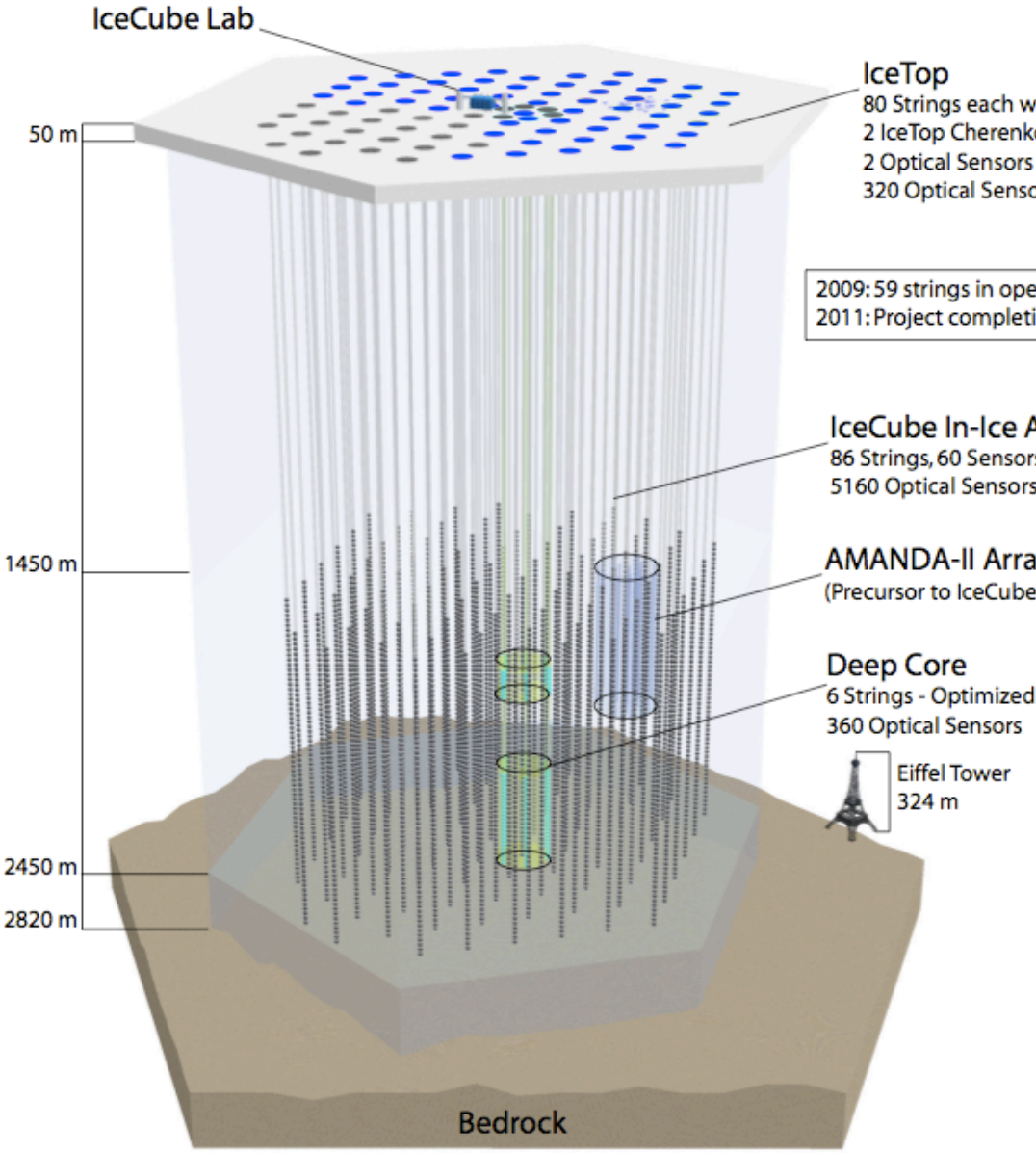
Japan:
- Chiba University

New Zealand:
- University of Canterbury

34 institutions, 250 members

http://icecube.wisc.edu

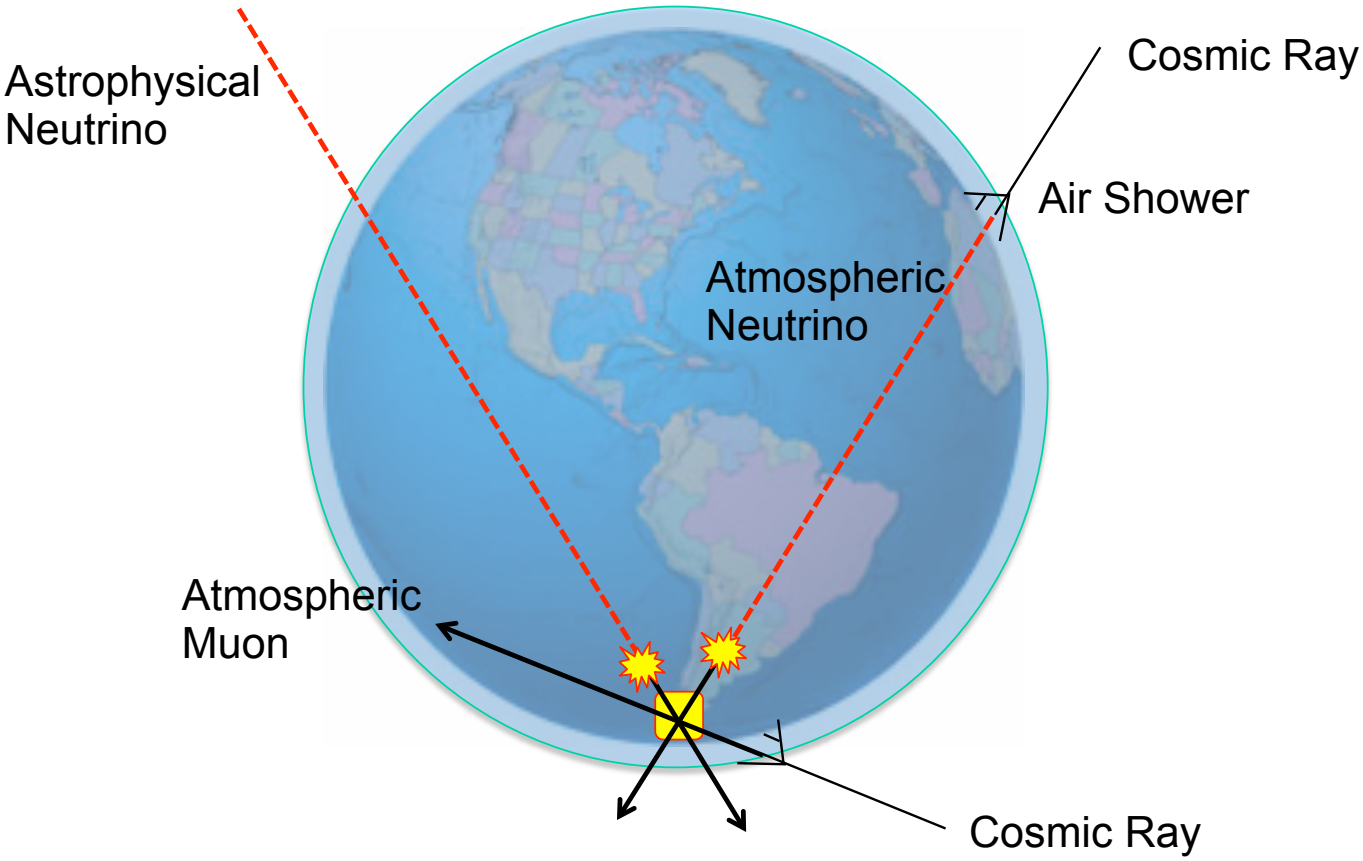
IceCube Detector



- When completed (2011) IceCube volume will reach 1 km^3 (80 strings + 6 additional strings for Deep Core).
  - 80 strings ~ 125 m apart
  - 60 DOMs/string at 17 m vertical spacing
- 59 strings Livetime : 96 %

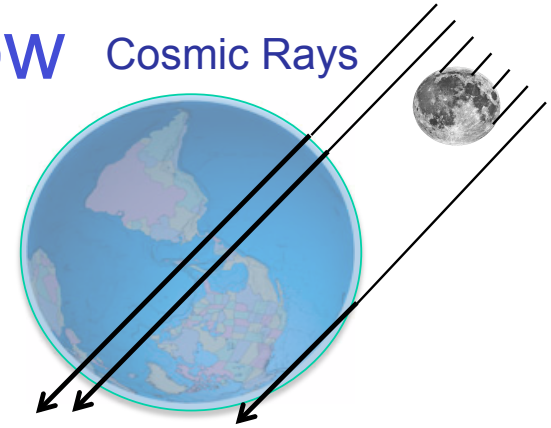
Year	Strings	Livetime (days)	ν rate (1/day)
2006	9	137	1.7
2007	22	275	28
2008	40	~365	110
2009	59	~365	160
2011	86	~365	220

Cosmic Ray Detection

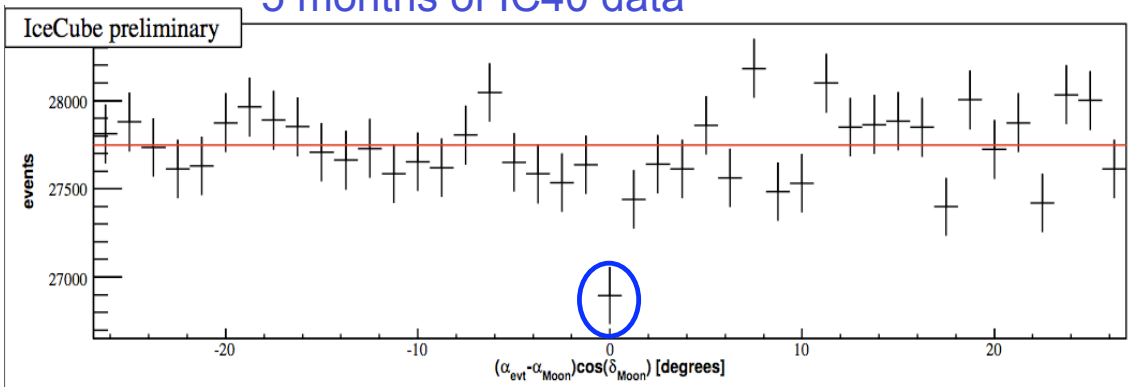


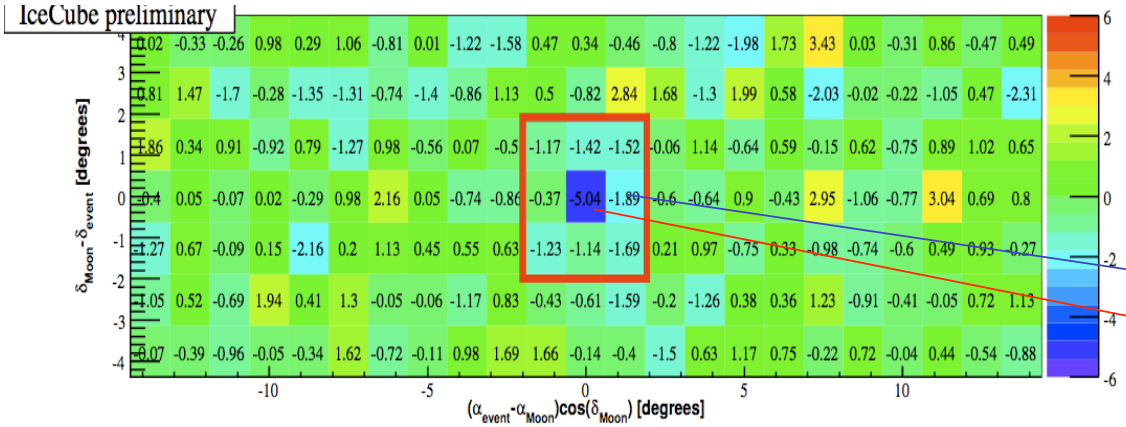
- Use large volume of material (~1 km^3 of ice) to improve chance of neutrino interaction inside the detector
- Data is dominated by a large background of cosmic ray muons.

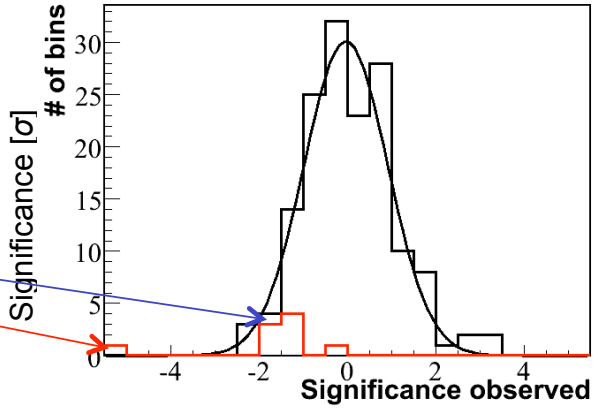
Observation of the Moon Shadow



5 months of IC40 data

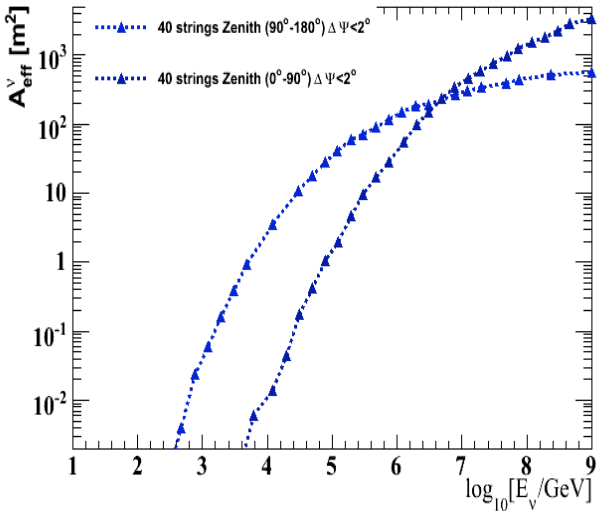






- The moon causes a small deficit in the flux of TeV cosmic rays
- There should be a corresponding deficit in atmospheric muons detected near the location of the moon
- Moon provides an excellent “test beam” Size (0.5°)
- Median primary energy at 30 TeV
- Deficit is 5σ (~900 events of ~28000)
- Verification of angular resolution and absolute pointing.
- More statistics will allow study of angular response function

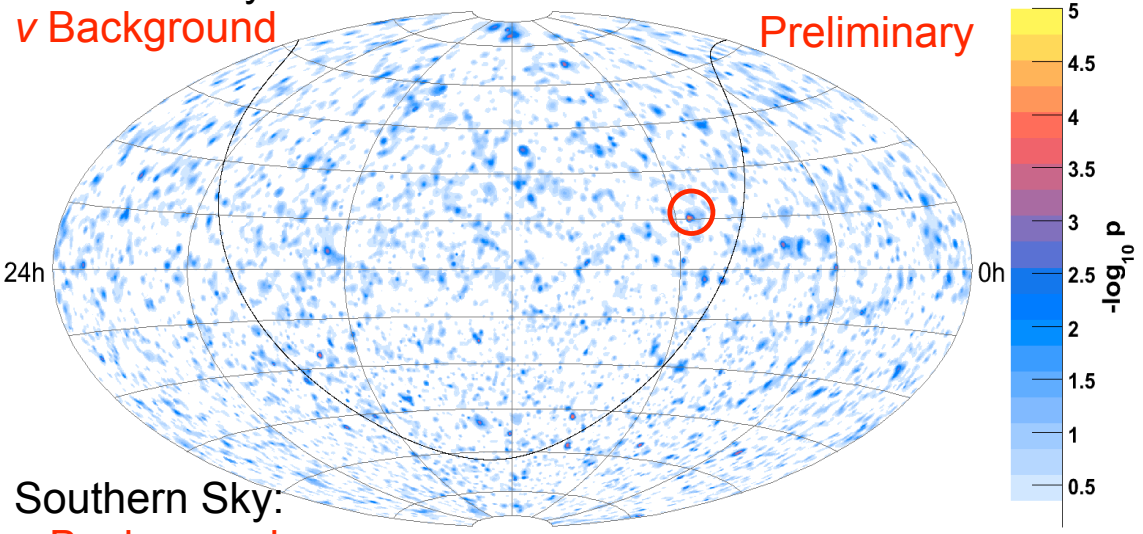
Search for point source



J. Dumm et al., ICRC 2009 (Lodz)

Northern Sky:
ν Background

Preliminary



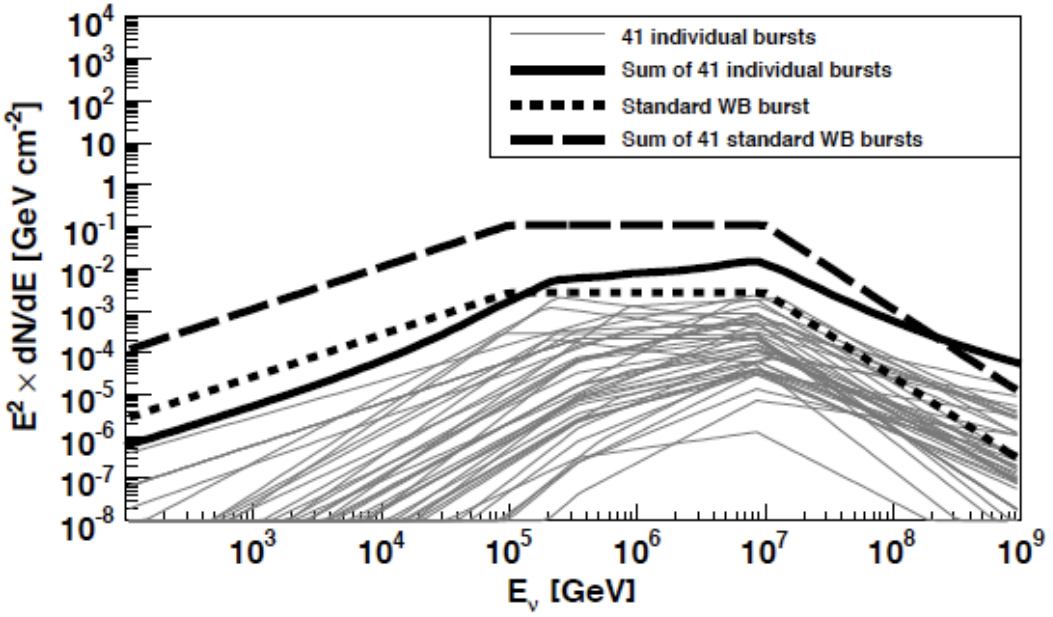
Southern Sky:
μ Background

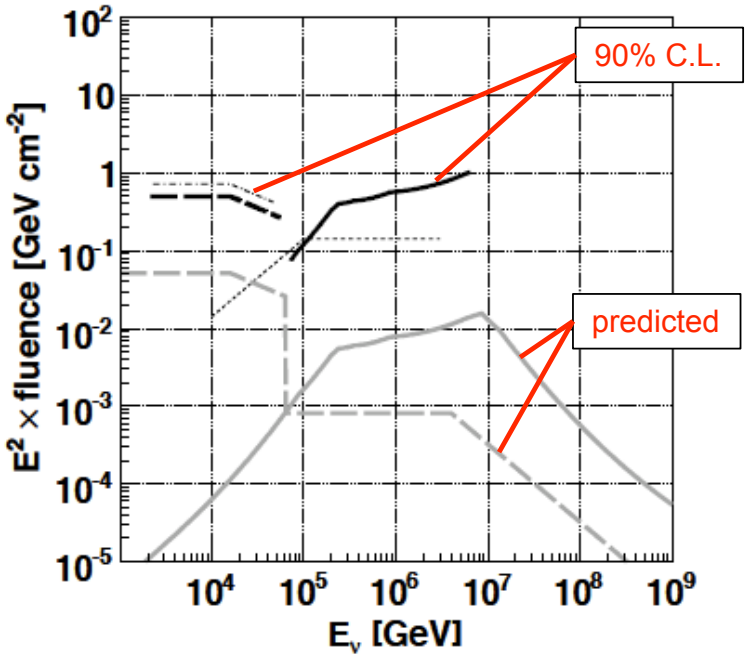
- 40-string (6 months) All sky search
- Livetime: 175.5d;
- 17777 events (6796 up, 10981 down)
- Hot spot at α = 7h 40m, δ = 15.4°
- Pre-trial log10(p-value) = 4.43
- Post-trials p-value after R.A. scrambling = 61% (all sky)

Not Significant.

Gamma Ray Bursts (22 strings)

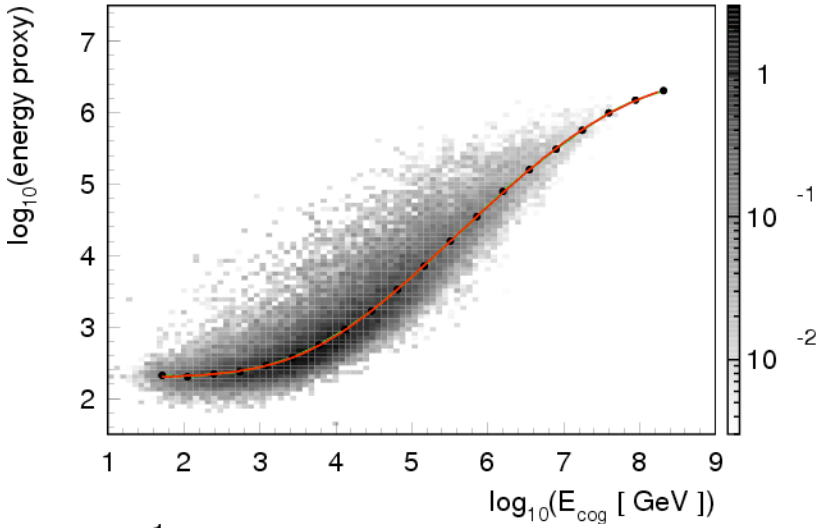
A. Kappes et al., ICRC 2009 (Lodz)

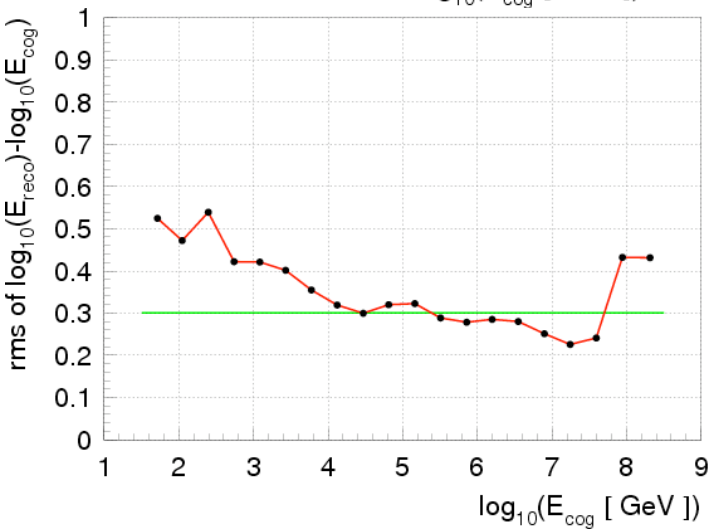


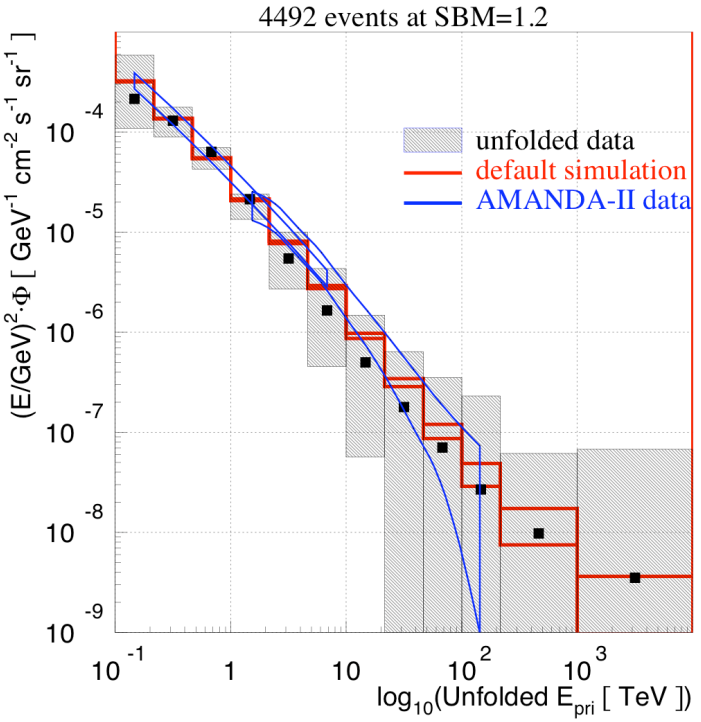


- Source stacking: 41 GRBs observed by SWIFT, etc., summed to estimate a total neutrino flux
- Upper limits set for precursor, prompt neutrino flux
- Full detector: 90% chance for 5σ GRB neutrino observation within 2 years (assuming Waxman-Bahcall flux)

22-String Atmospheric Neutrino Results







- IC-22 string analysis
- 4492 neutrino events at high purity (>95%)
- Muon energy resolution: ~0.3 in log(E)

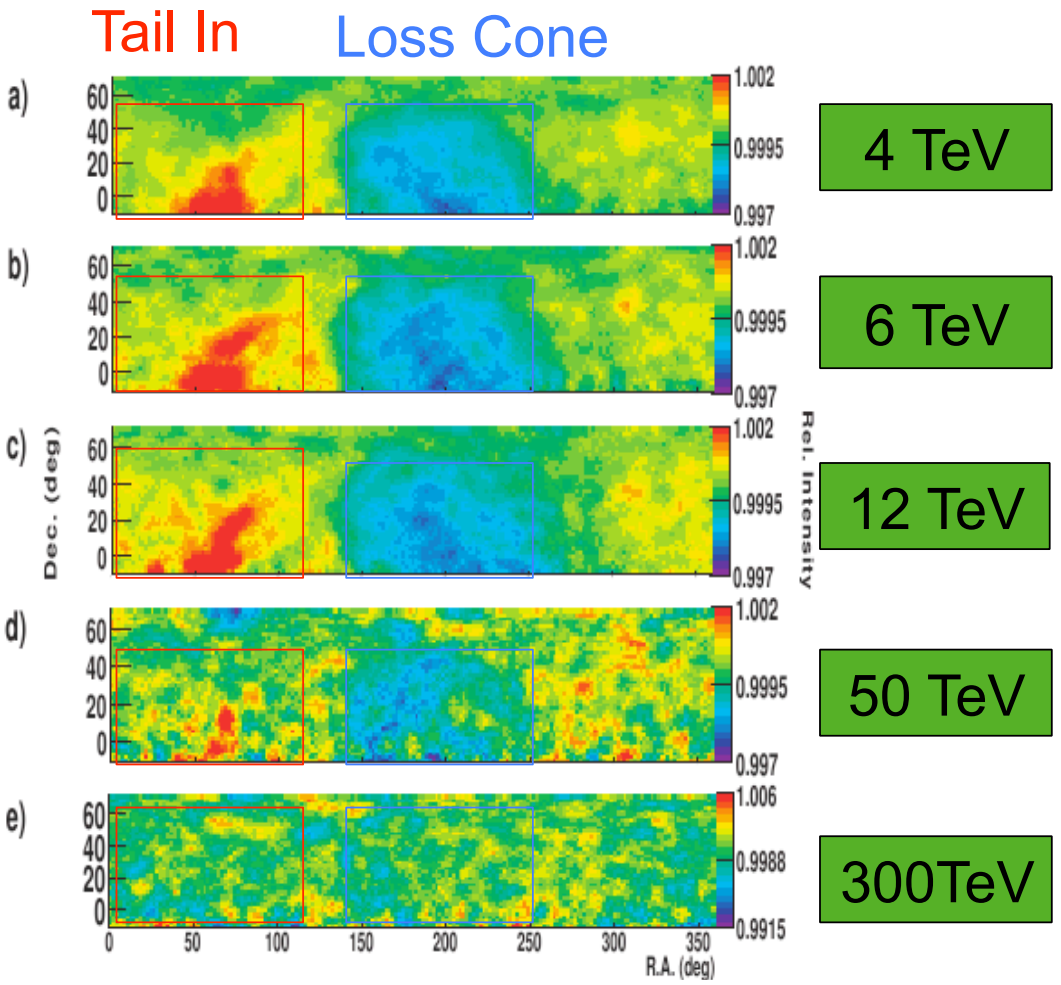
Still working to reduce systematic uncertainties of energy/depth dependence

Large scale cosmic ray anisotropy

Motivation

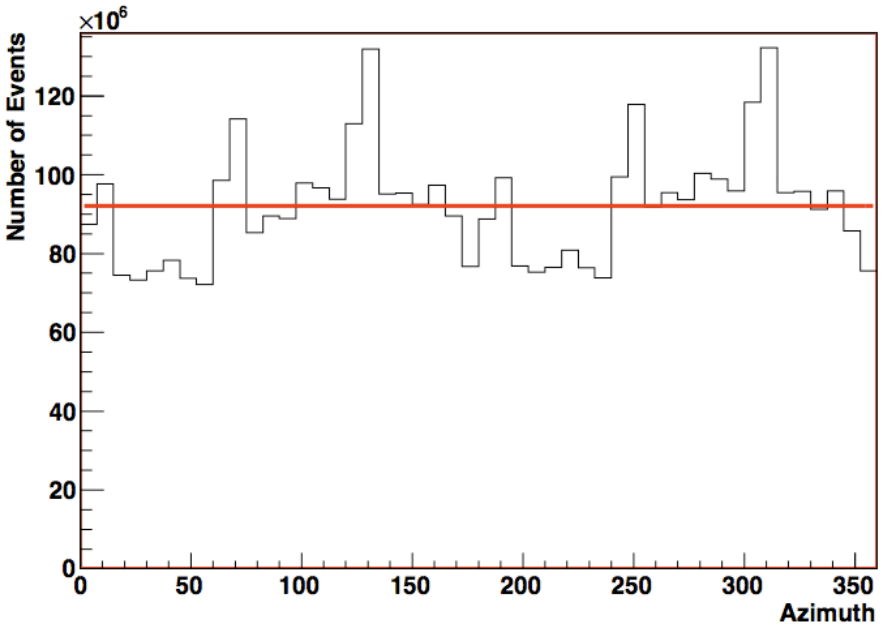
- Heliomagnetic sphere and heliomagnetotail.
- Compton Getting Effect
- Local structure of interstellar magnetic field.
- Nearby young sources of cosmic rays?

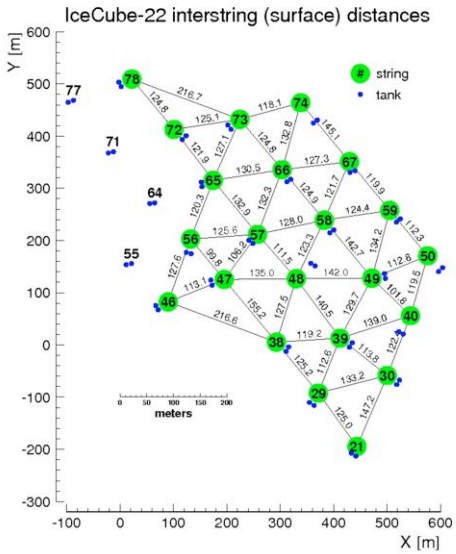
Source of the anisotropy is not understood



Science Vol. 314. no. 5798, pp. 439 - 443

Azimuthal Normalizing

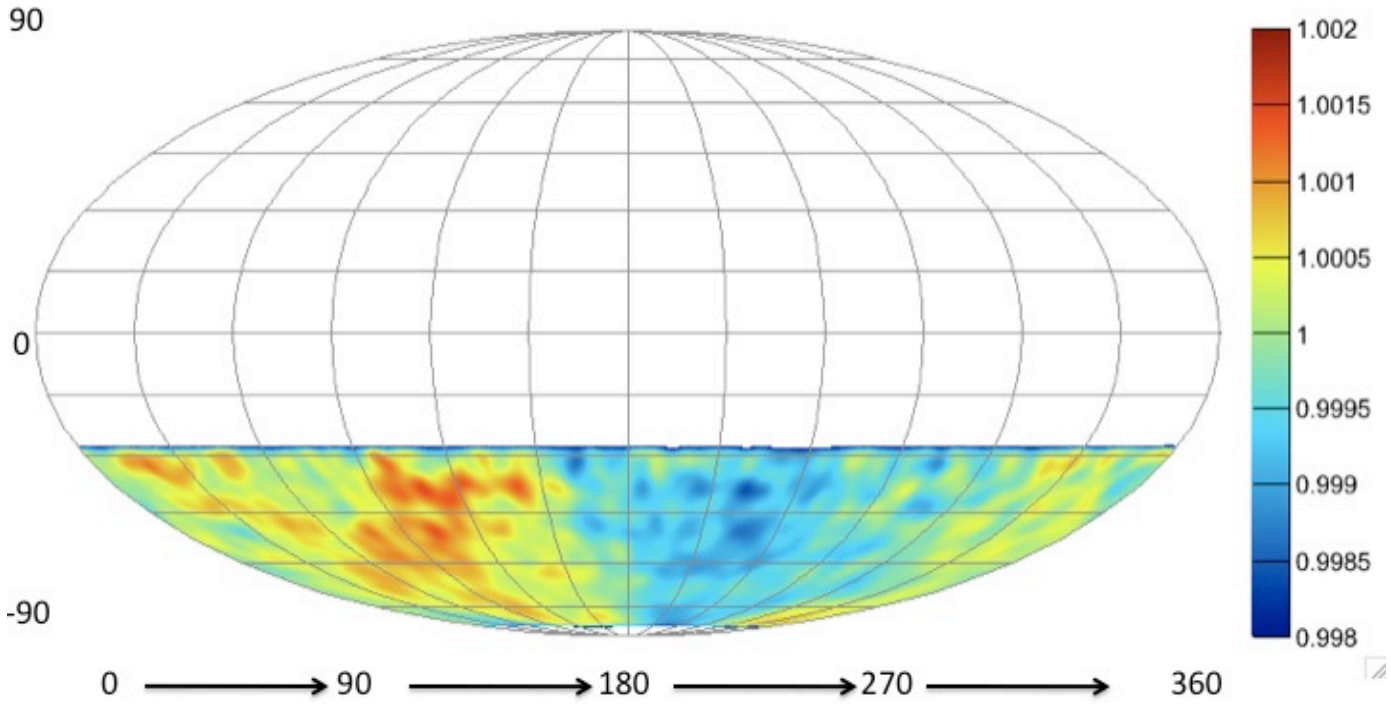


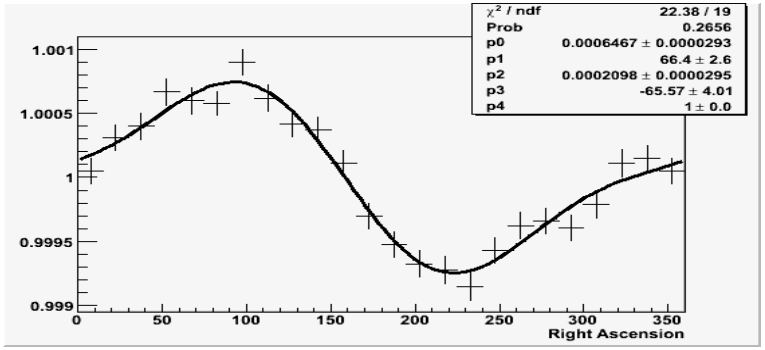


- Muon events after quality cuts: 4.3×10^9 during 226 days livetime: 3° angular resolution, 14 TeV median energy
- Azimuthal distribution of arrival directions strongly affected by 22-string geometry
- Looking for a 0.1% effect; don't want local asymmetry to show up in final skymap
- Solution: reweight each event to flatten the azimuth distribution

IceCube 22 string Skymap

Equatorial coordinates



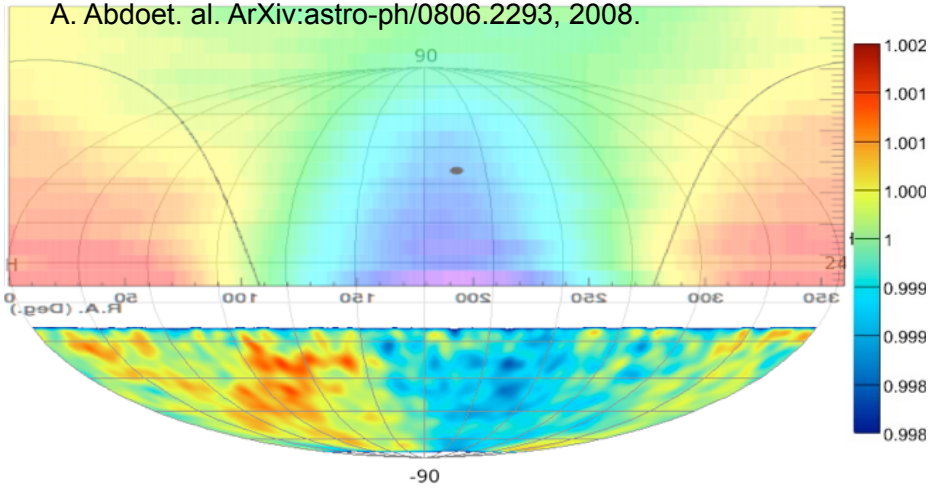


- *1-d projection of the Equatorial relative intensity skymap*

- The fitting function is the first and second order harmonic function in the form of Amp* Cos (RA-φ)

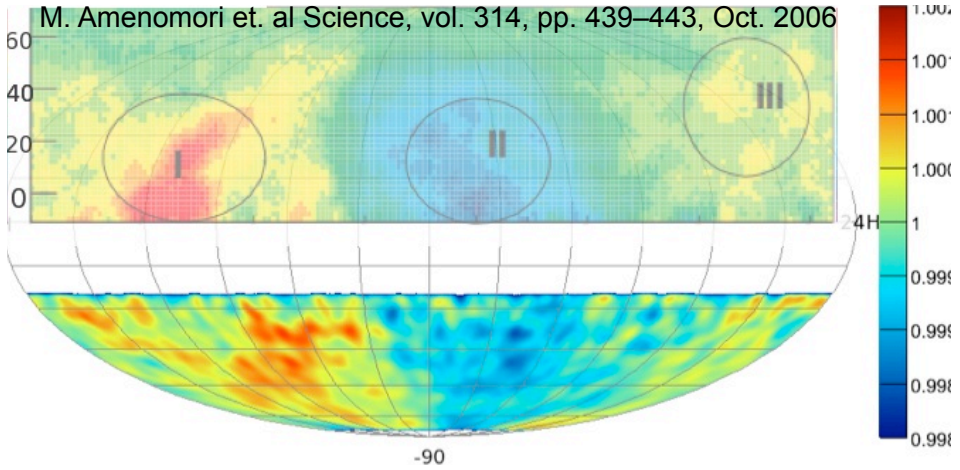
Comparison with Tibet array and Milagro

A. Abdoet. al. ArXiv:astro-ph/0806.2293, 2008.



IceCube & Milagro

M. Amenomori et. al Science, vol. 314, pp. 439–443, Oct. 2006



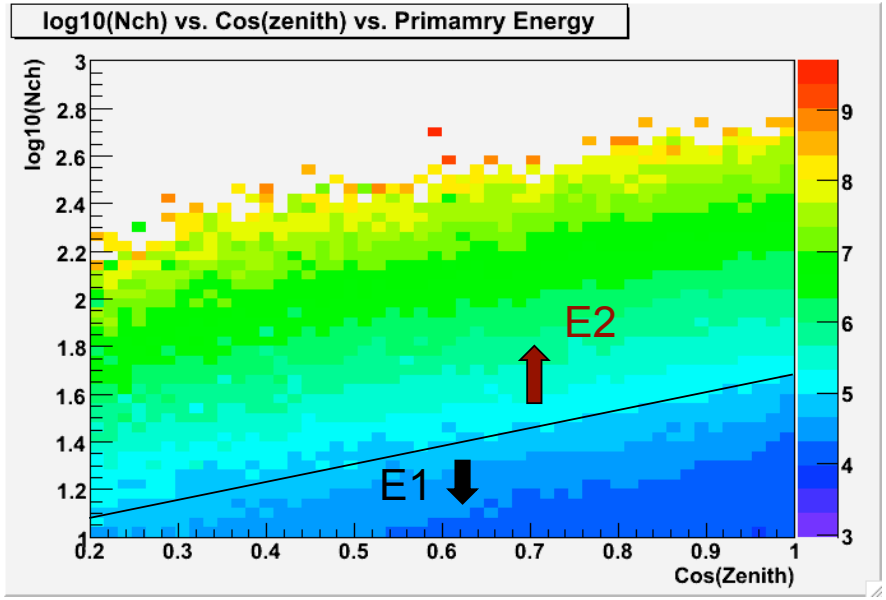
IceCube & Tibet Array

Anisotropy is a continuation of previously measured large scale anisotropy observed in northern locations.

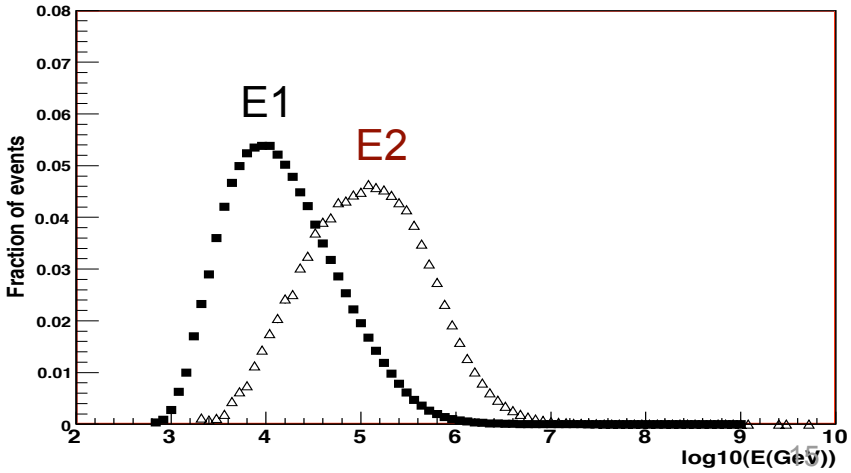
Source of the observed anisotropy?

Energy Estimation

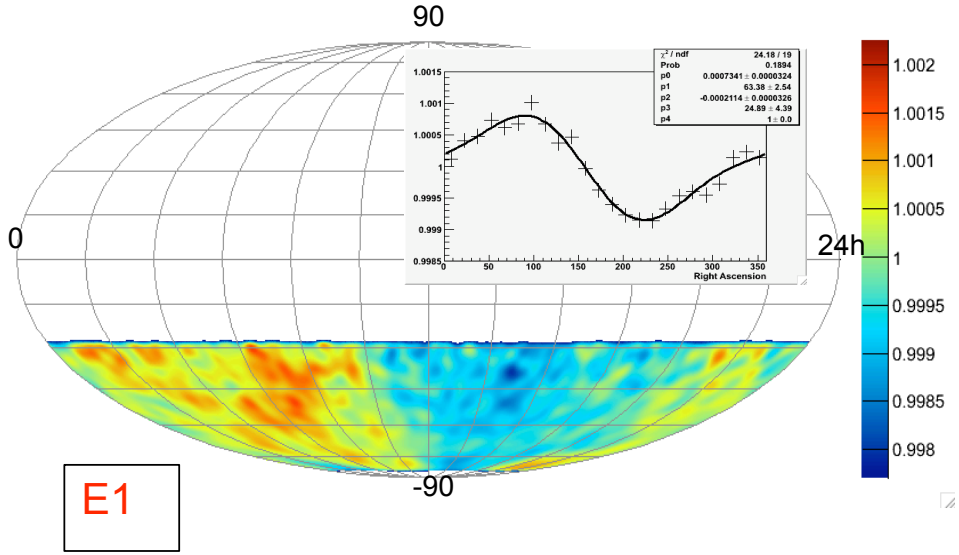
- Energy is not directly measured.
- Energy is estimated using Energy proxy from simulation.

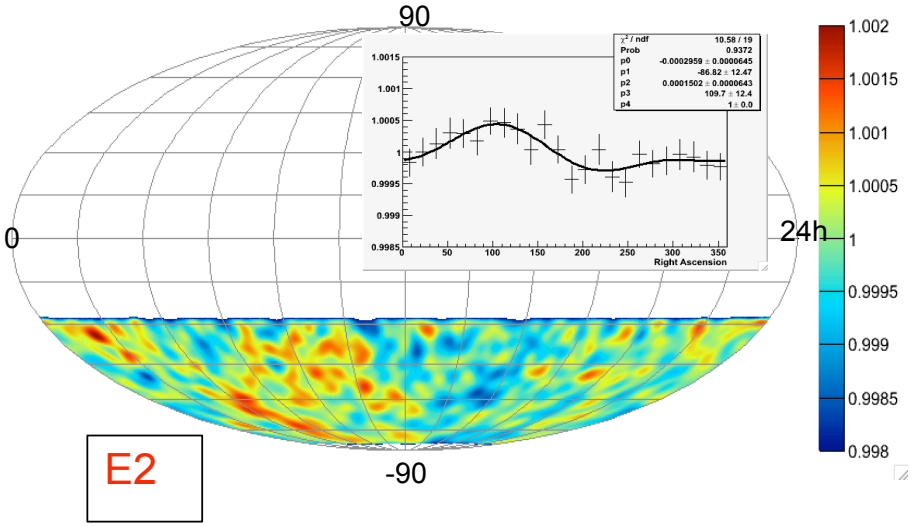


Median Energy	Number of events	68% of events lie between
12 TeV (E1)	3.3×10^{9}	12 - 60 (TeV)
126 TeV (E2)	9.6×10^{8}	25 - 500 (TeV)



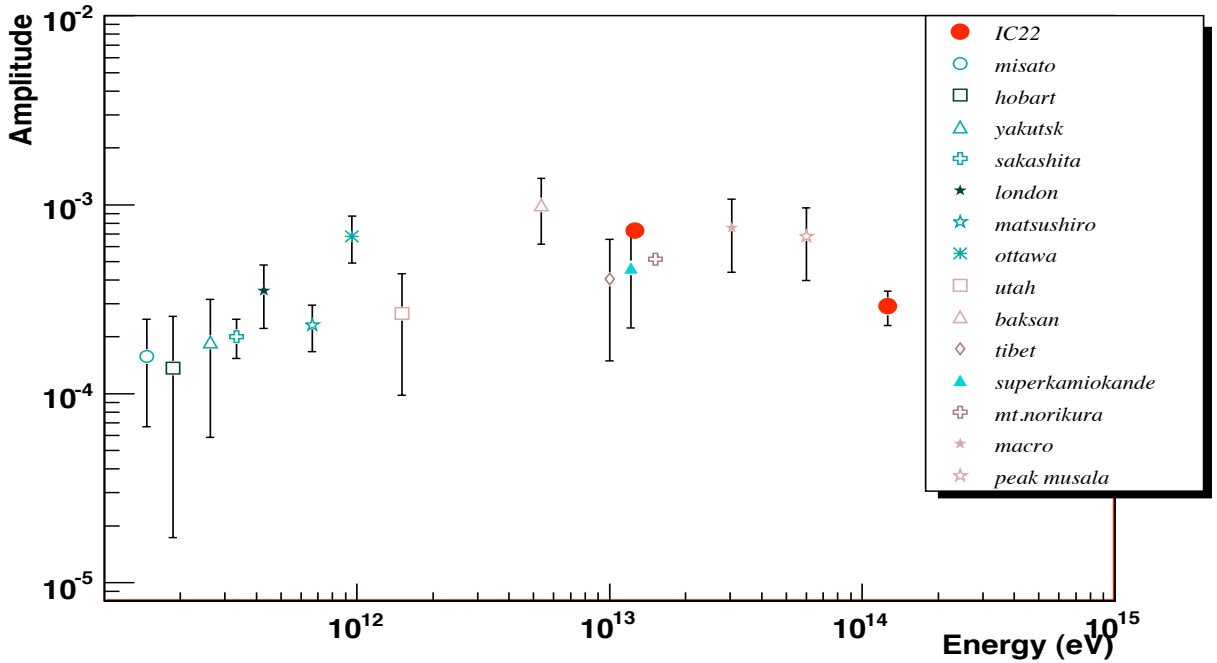
Energy Dependence skymaps





Median Energy	Number of events	Amplitude	Phase
12 TeV (E1)	3.3×10^{9}	7.3±0.3	63.4±2.6
126 TeV (E2)	9.6×10^{8}	2.9±0.6	93.2±12

Amplitude energy dependence



- In the energy range 10-100 TeV Amplitude shows a decrease in value at higher energies.

Toward Explanation

Local Interstellar Magnetic Field

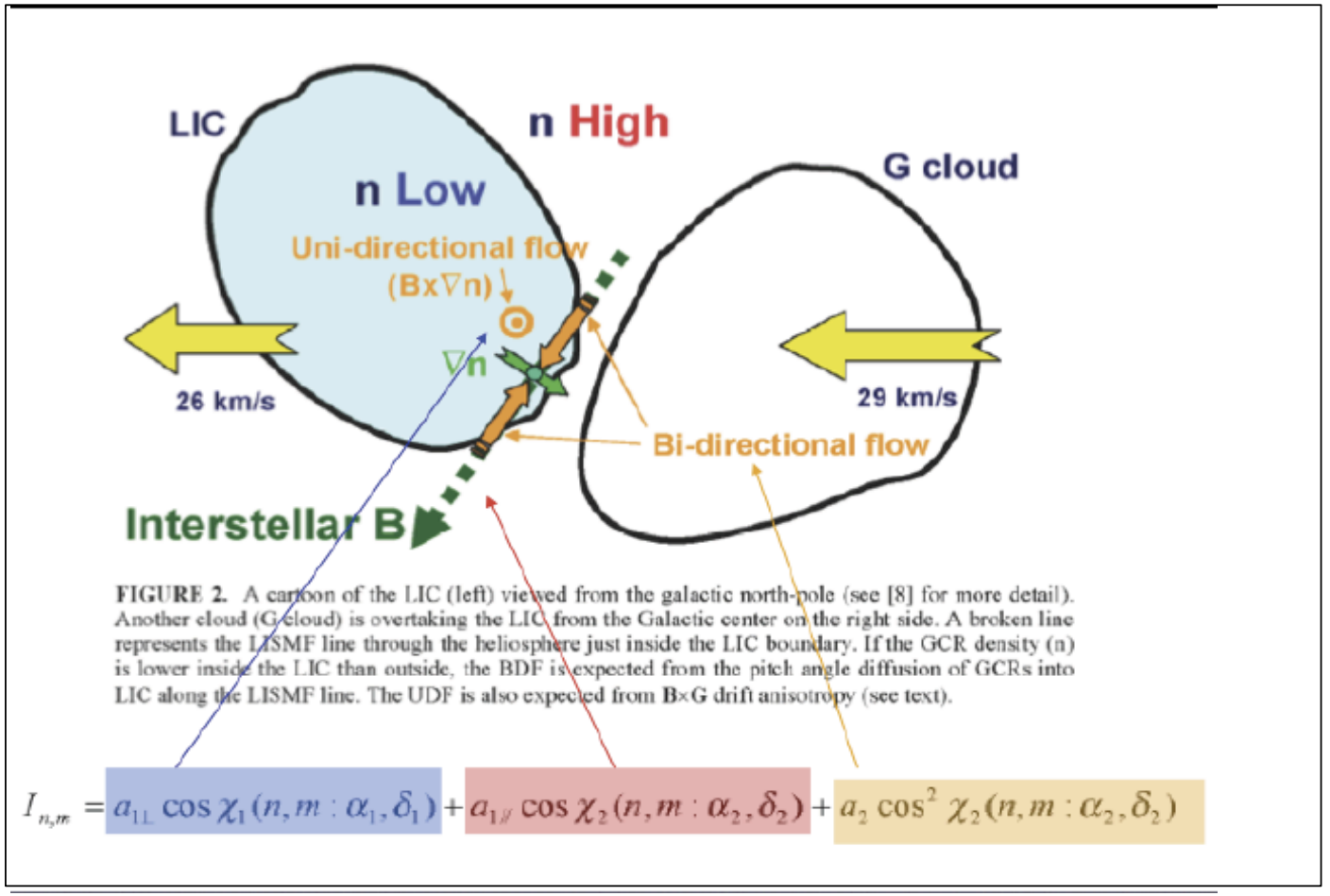


FIGURE 2. A cartoon of the LIC (left) viewed from the galactic north-pole (see [8] for more detail). Another cloud (G-cloud) is overtaking the LIC from the Galactic center on the right side. A broken line represents the LISMF line through the heliosphere just inside the LIC boundary. If the GCR density (n) is lower inside the LIC than outside, the BDF is expected from the pitch angle diffusion of GCRs into LIC along the LISMF line. The UDF is also expected from B×G drift anisotropy (see text).

$$I_{n,m} = a_{1\perp}\cos\chi_1(n,m:\alpha_1,\delta_1) + a_{1//}\cos\chi_2(n,m:\alpha_2,\delta_2) + a_2\cos^2\chi_2(n,m:\alpha_2,\delta_2)$$

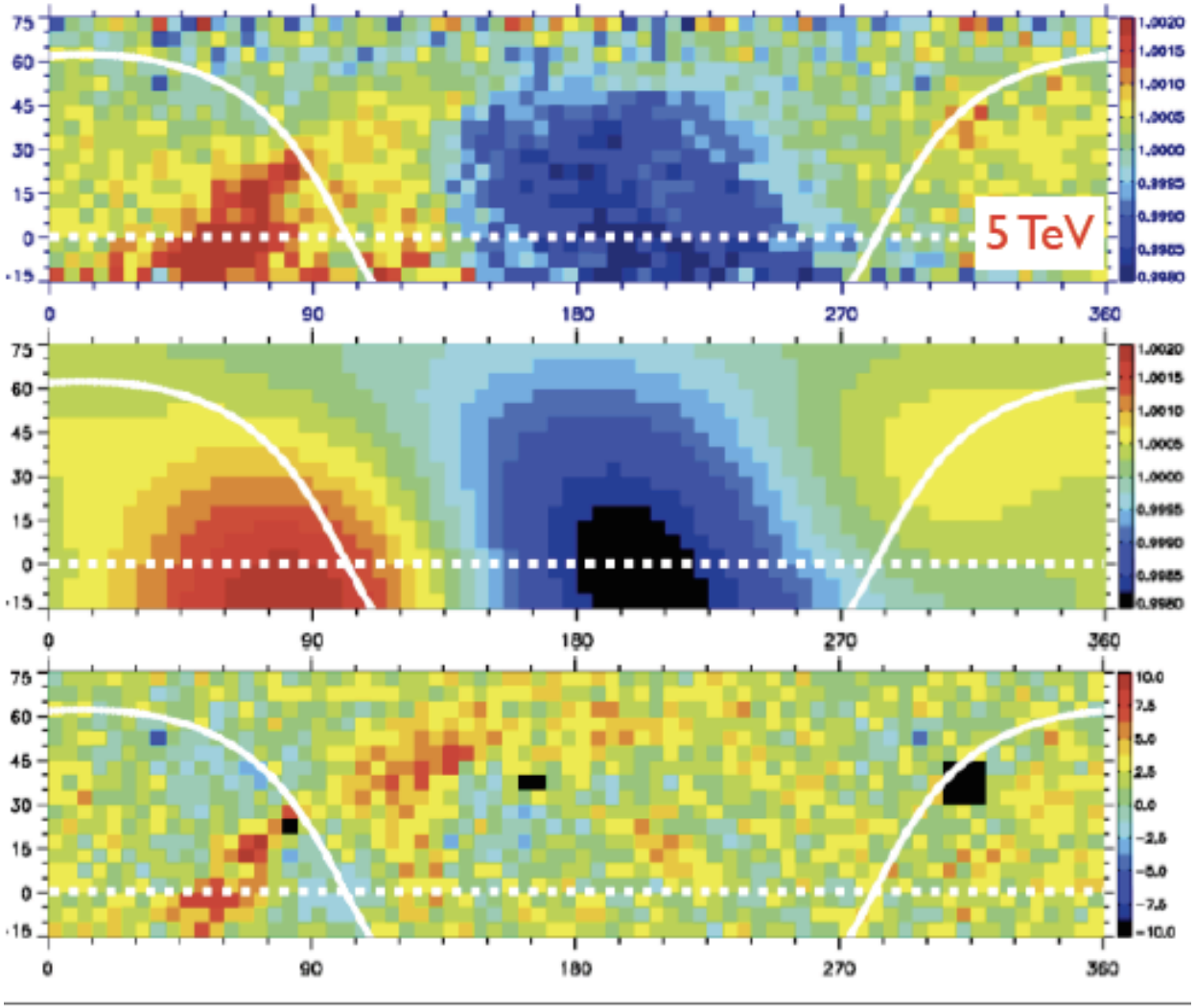
M. Amenomori *et. al*. ICRC 2007 Proceedings

Tibet Array Model Fit to Data

Data

Model

Residual skymap



M. Amenomori *et. al*. ICRC 2007 Proceedings

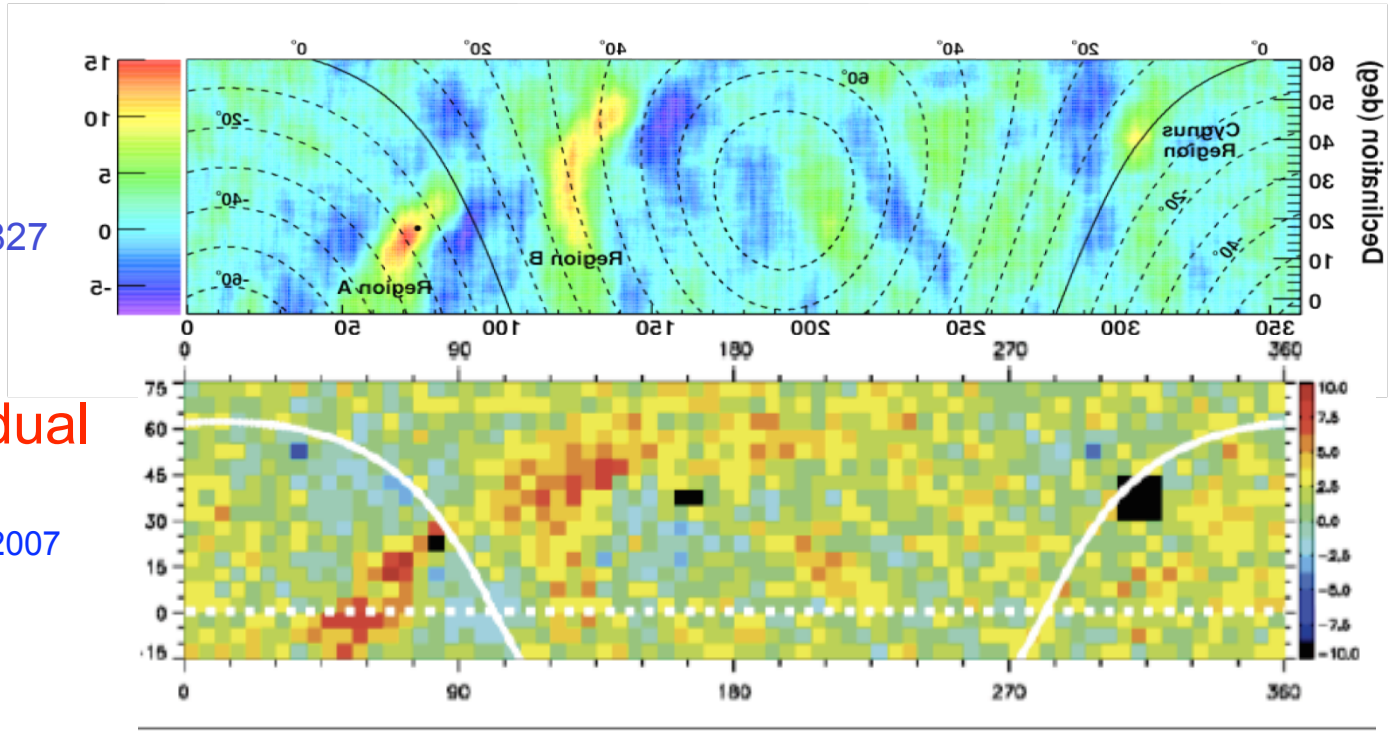
Nearby sources of Cosmic Ray

Milagro (1TeV)

Abdo *et. Al.* Arxiv:0801.3827

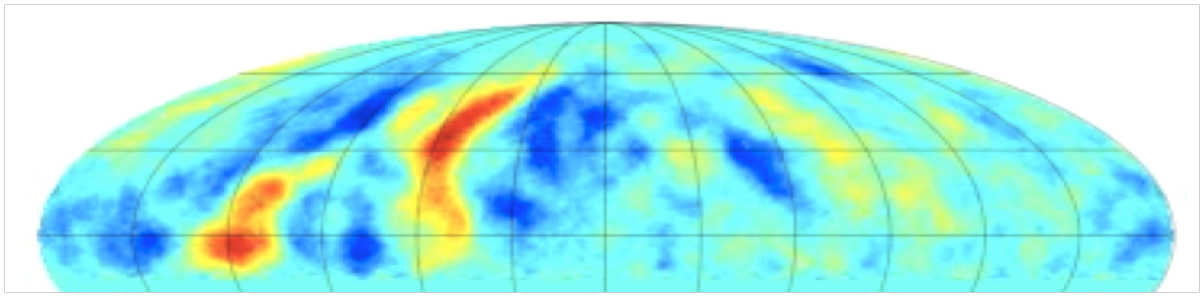
Tibet Array residual skymap (5 TeV)

M. Amenomori *et. al*. ICRC 2007 Proceedings

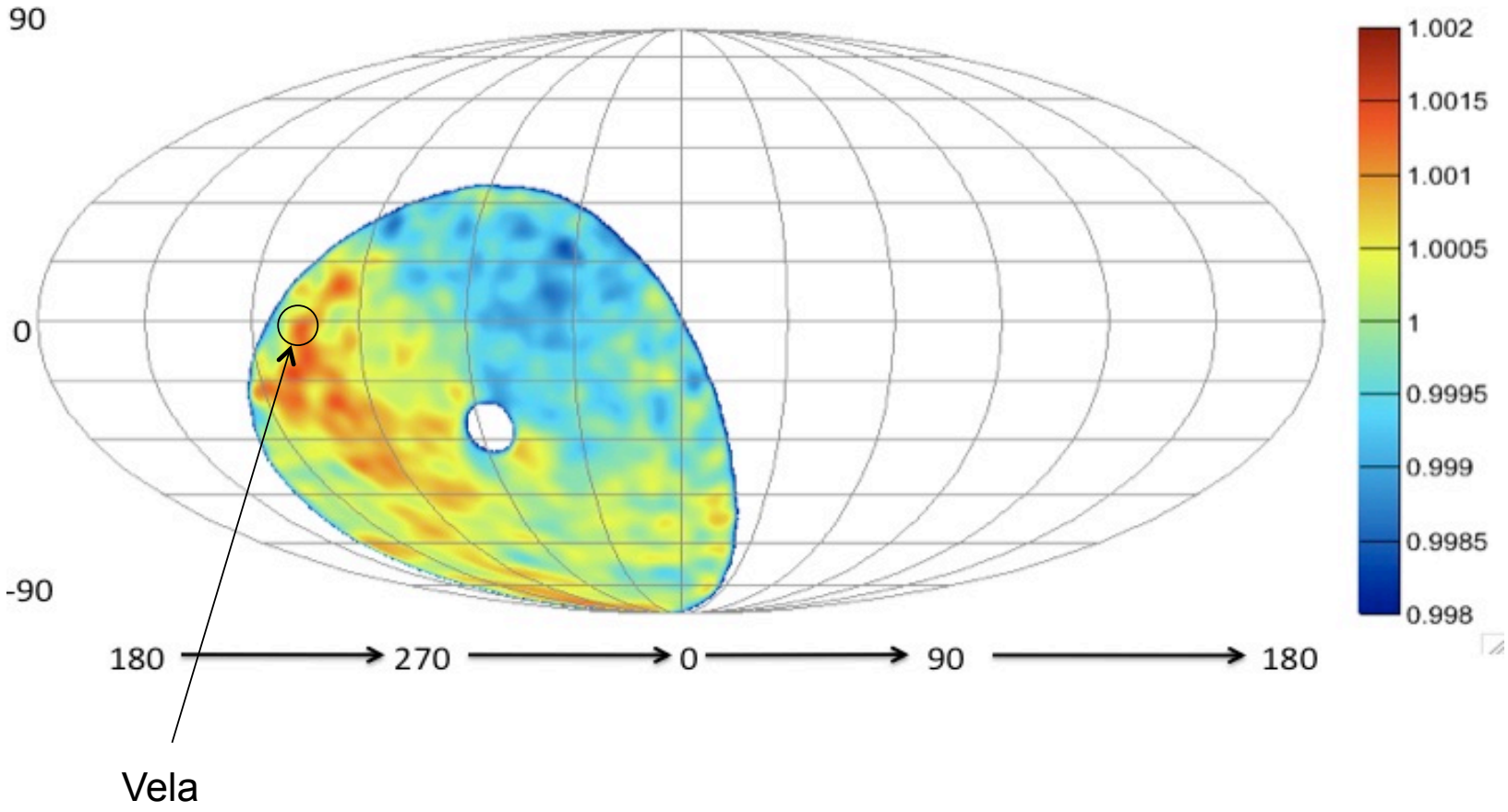


Argo (2 TeV)

S. Vernetto *et. al*. ICRC 2009 Proceedings



Galactic coordinates



Nearby sources of cosmic rays effect on the anisotropy?

Conclusion

- IceCube is currently deployed at the South Pole with 59 operating string
- The completed detector (2011) will comprise 86 strings
- Current results:
  - *A priori* source searches indicate no significant point sources
  - Flux limits set for neutrinos from GRBs
  - Atmospheric neutrino spectrum measured
  - Significant large-scale clustering of charged cosmic rays.
    - First skymap reporting a significant large scale anisotropy in the southern hemisphere sky. (In process to be submitted to APJ Letters)
    - IceCube skymap is consistent with Large scale anisotropy results reported by previous experiments looking at the northern hemisphere sky.
    - Source for large scale anisotropy is unknown

First look at IceCube 40 string 08-09