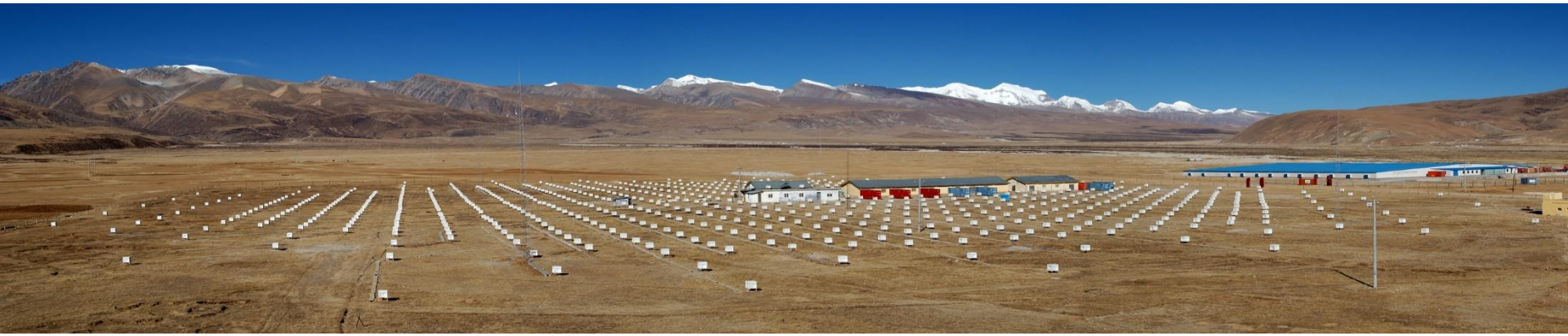
Observations of the Cosmic Ray Anisotropy at PeV with the Tibet Air Shower Array

Yi Zhang

Institute of High Energy Physics, CAS, China
On behalf of the Tibet Asγ Collaboration



Cosmic Ray Energy Spectrum

- **Spectral features (knee, ankle)**
  Acceleration mechanisms & propagation effects

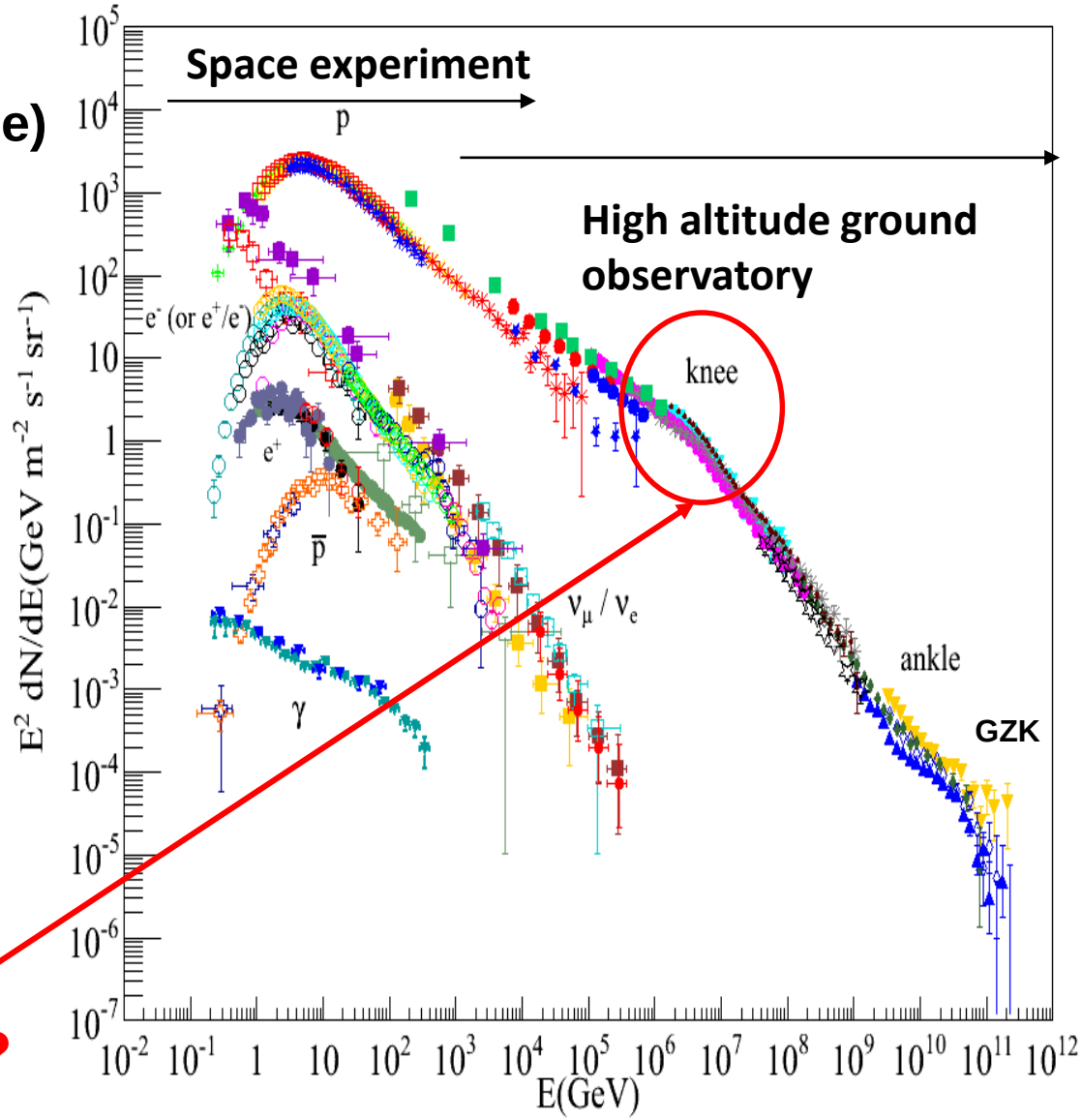
- **Below the knee**
  Galactic origin. SNs...

- **Above the ankle**
  Extragalactic, AGNs…

- **Composition** (TeV)**:**
  Mainly proton, 0.1% electron
  a few γ、 ν 、 $\bar{p}$ . . .

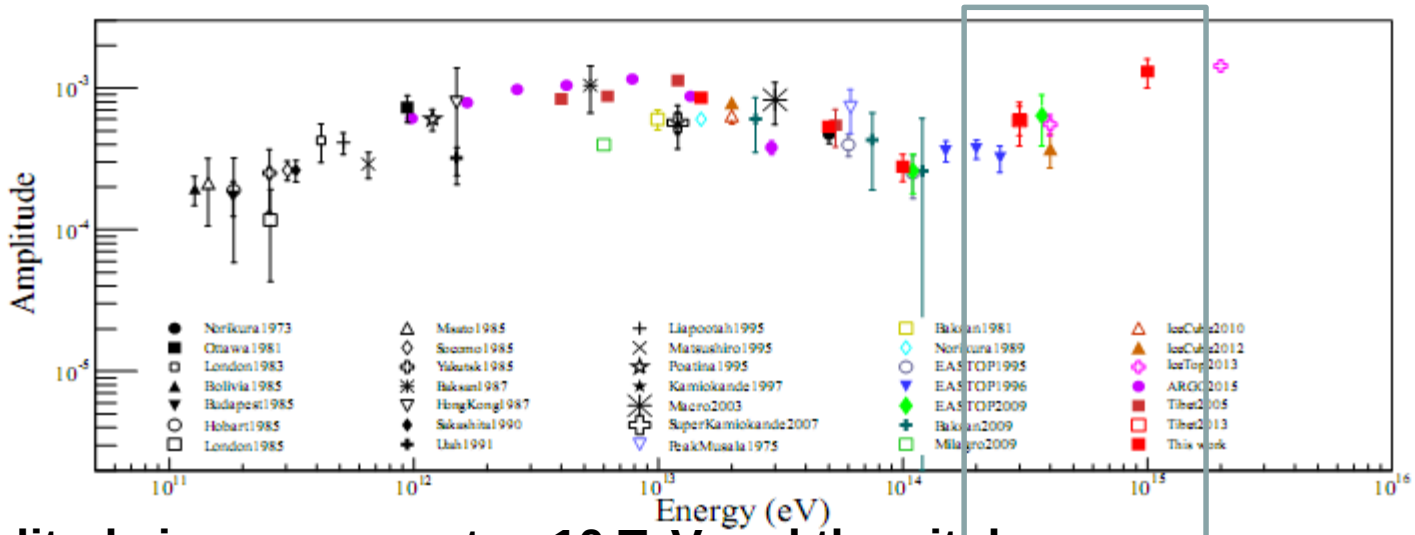
- 0.1% **anisotropy @ TeV**

CR anisotropy @ PeV???

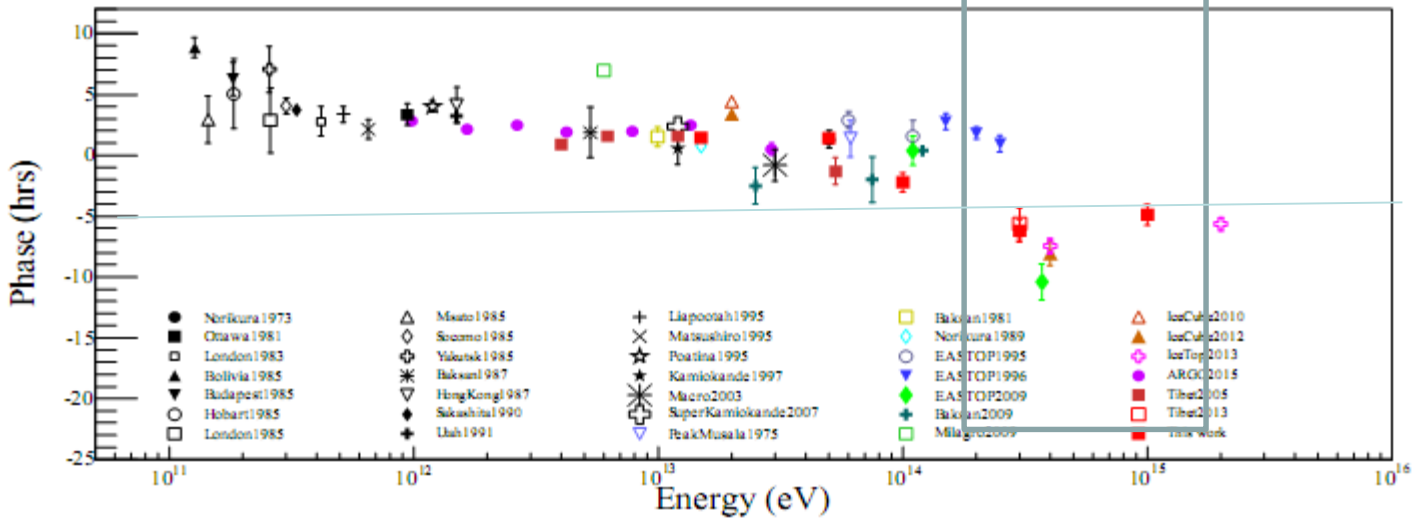


The energy dependences of amplitude and phase

Amplitude & phase of first-order harmonic function (dipole)

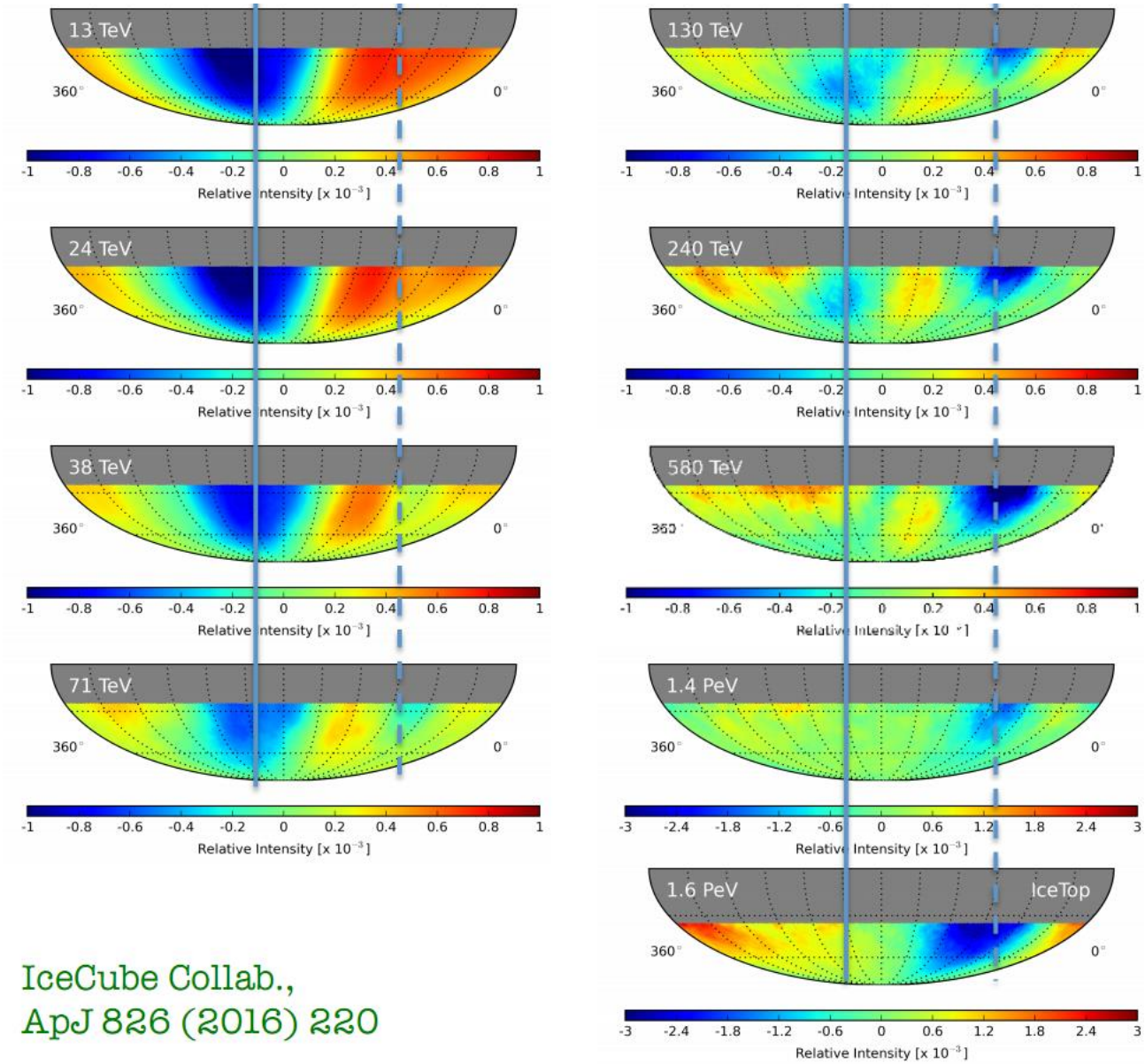


The amplitude increases up to ~10 TeV and then it decreases



The phase of dipole, a suddenly change, Hundreds of TeV

Energy dependence in southern hemisphere



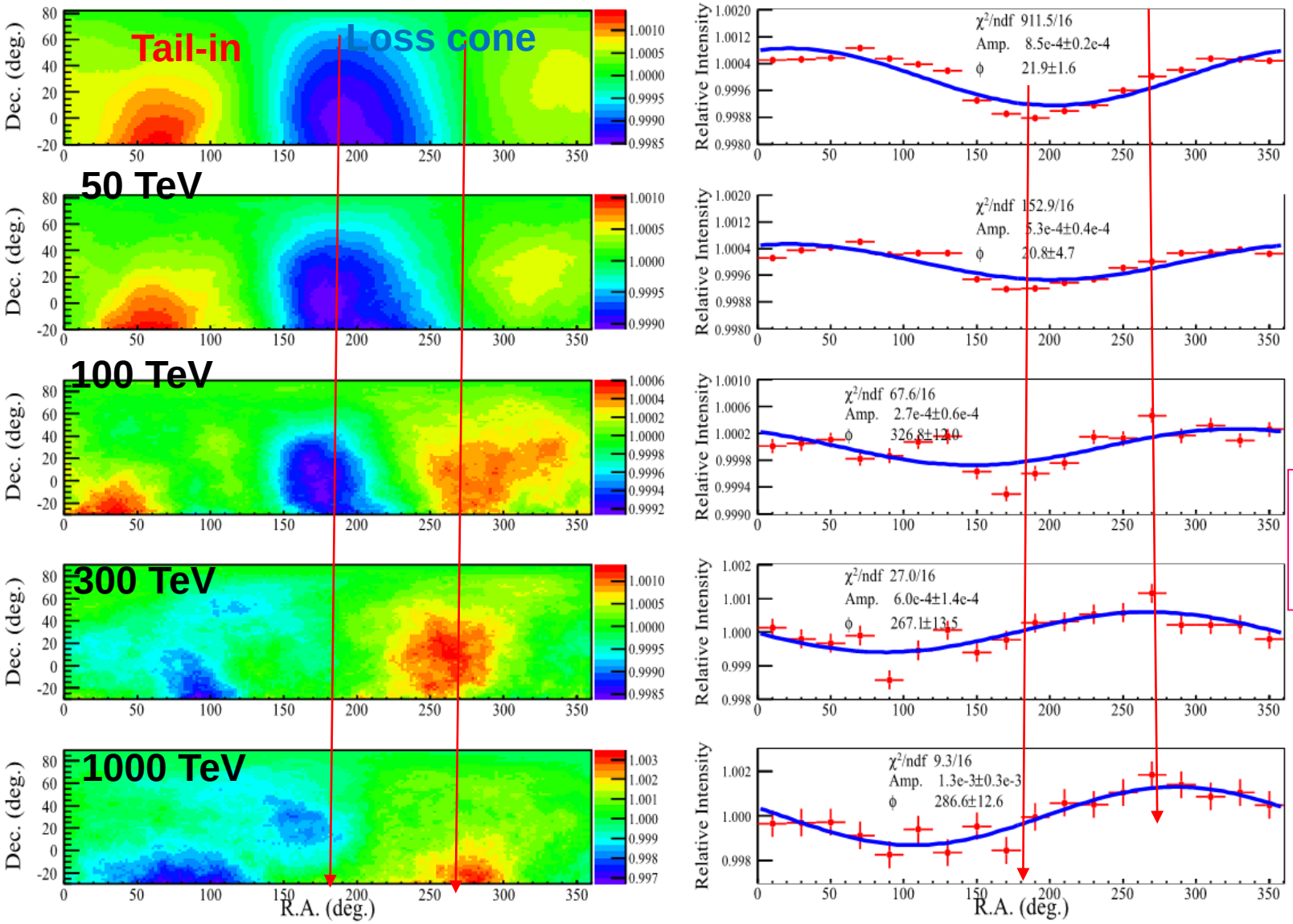
Phase Shift

Hundreds of TeV

IceCube Collab.,
ApJ 826 (2016) 220

Energy dependence of the cosmic ray anisotropy in northern hemisphere

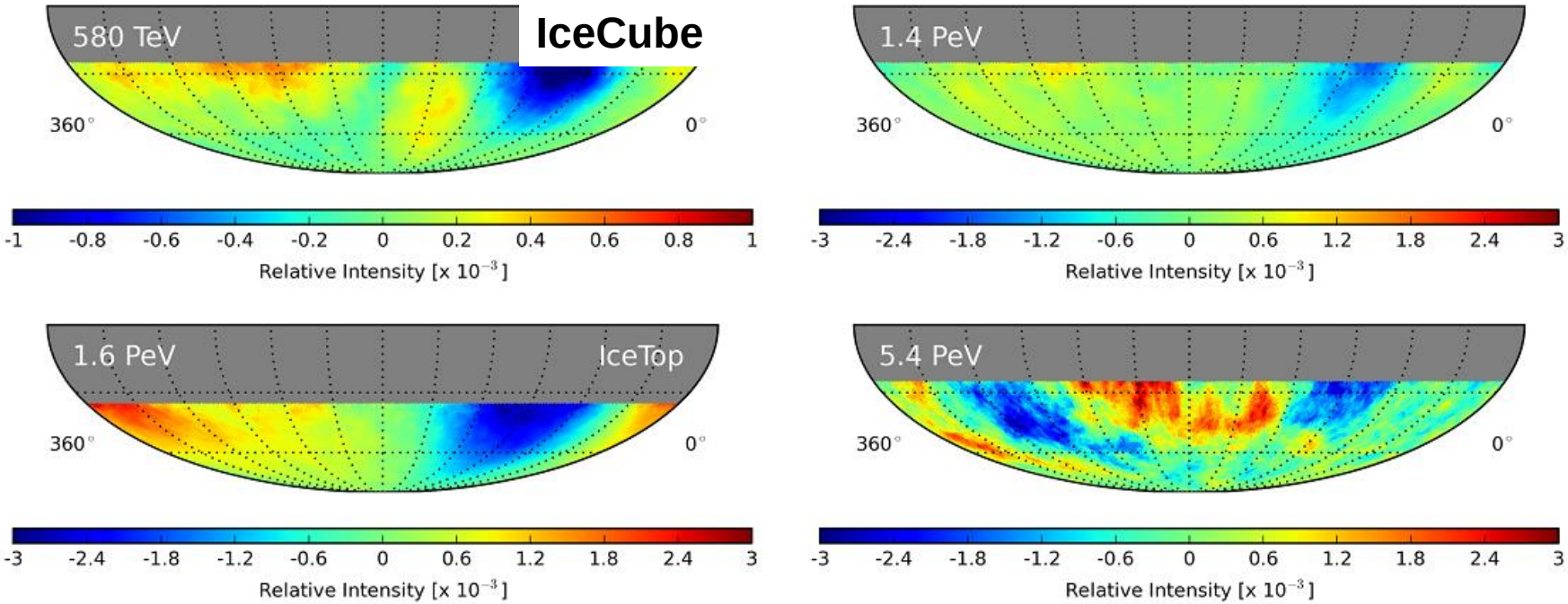
Also by ARGO



Phase Shift

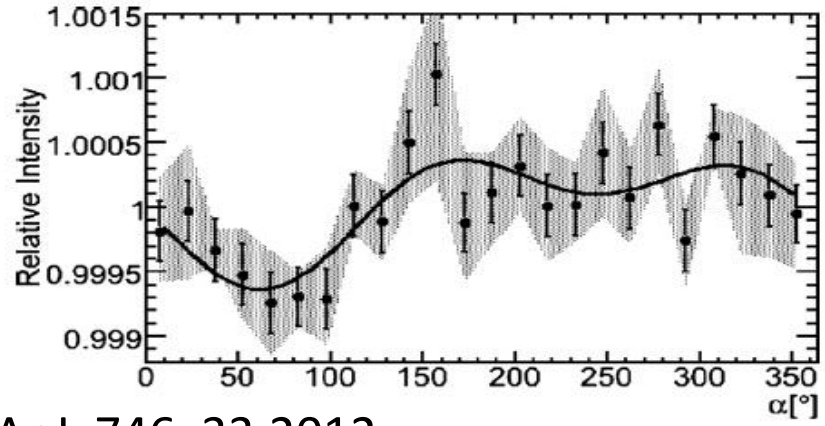
Amenomori, et al. 2017, ApJ, 836, 153

PeV anisotropy in Southern hemisphere



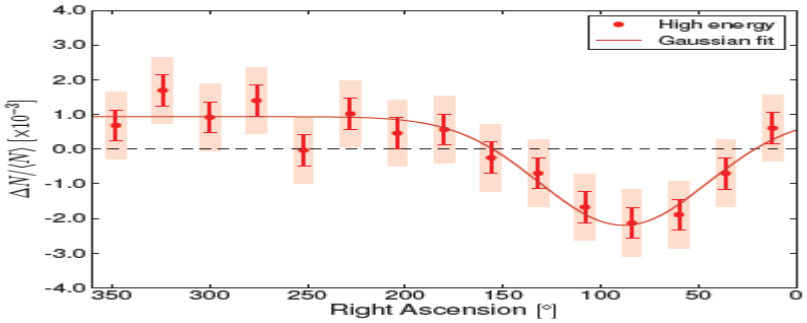
ApJ **826**, (2016) 220

IceCube



ApJ, 746, 33,2012

IceTop



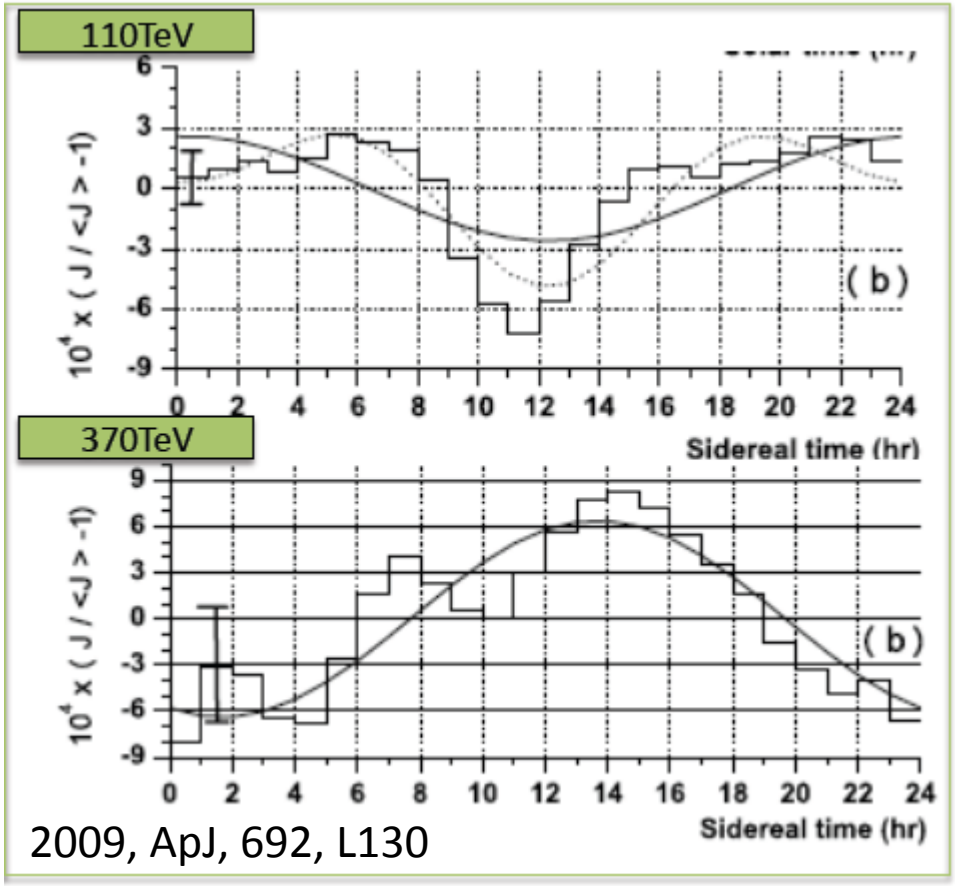
ApJ, 765, 55, 2013

Not a dipole

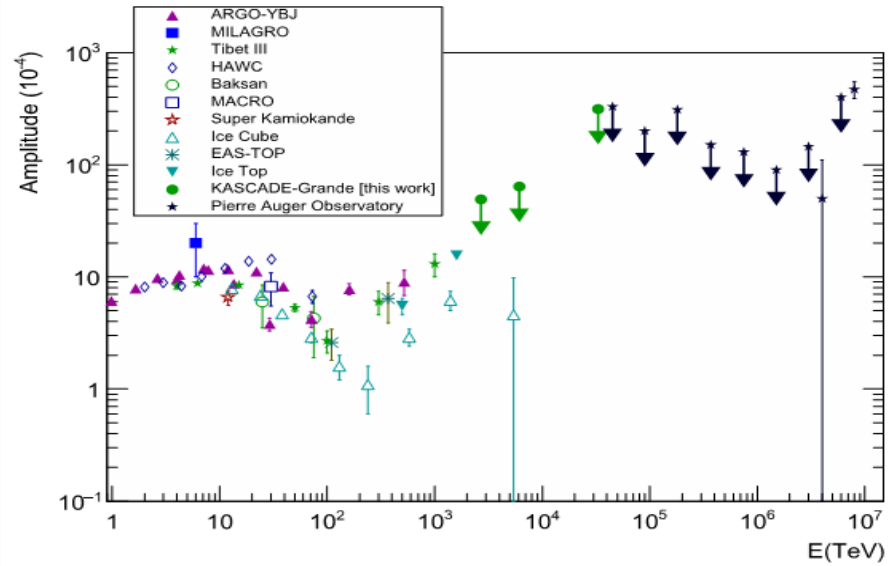
Experiments results in Northern hemisphere

EAS-TOP: sharp increase in the anisotropy for primary energies of ~370 TeV

KASCADE: upper limit from 2.7-33 PeV



2009, ApJ, 692, L130



D. Apel, et al. 2019, The Astrophysical Journal 870, 91

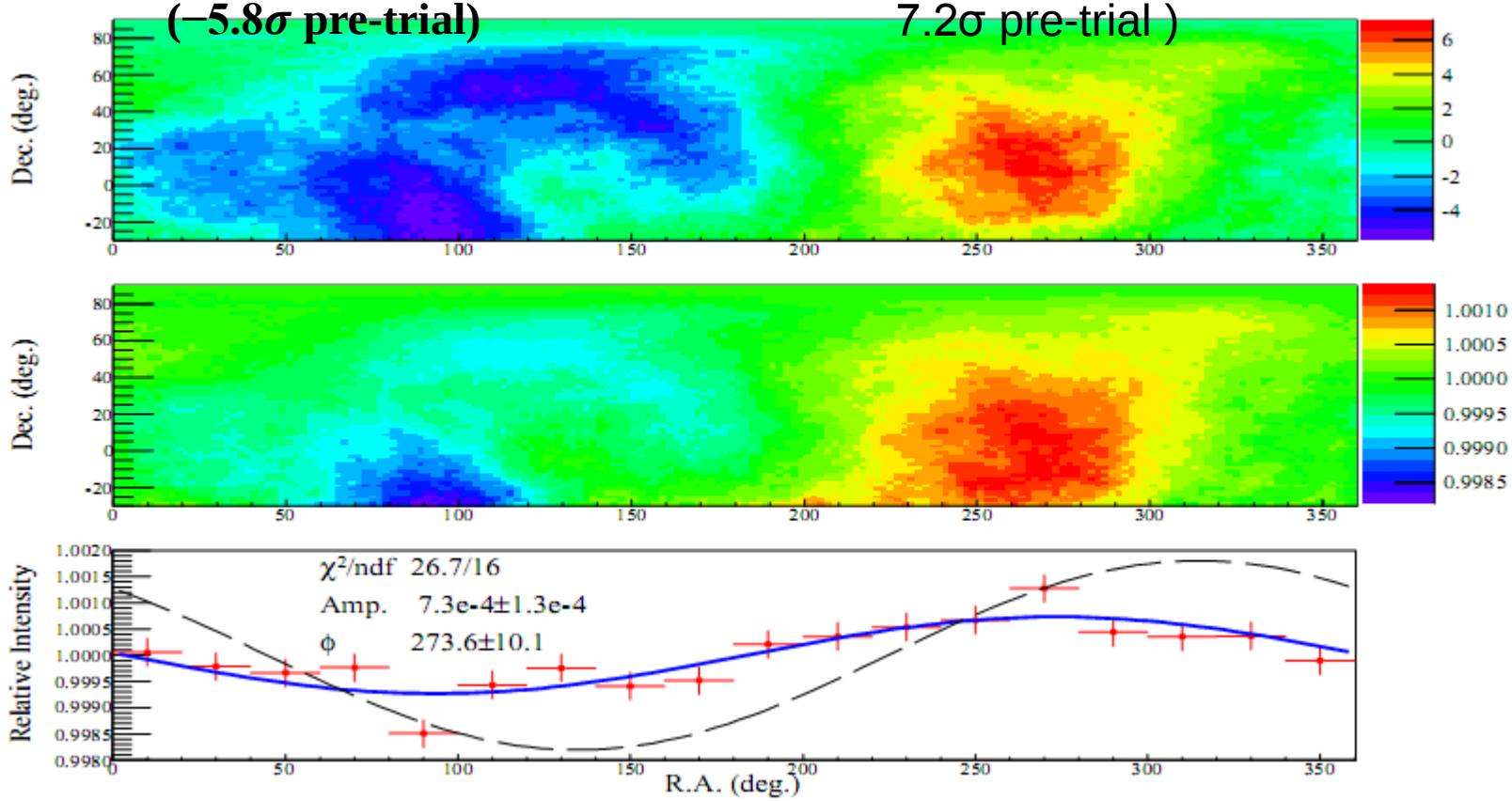
$$A^I_{\rm sid} = (6.4 \pm 2.5) \times 10^{-4}$$

$$\phi^I_{\rm sid} = (13.6 \pm 1.5) \text{ hr LST}$$

300TeV anisotropy by Tibet air shower array

A deficit region
(−5.8σ pre-trial)

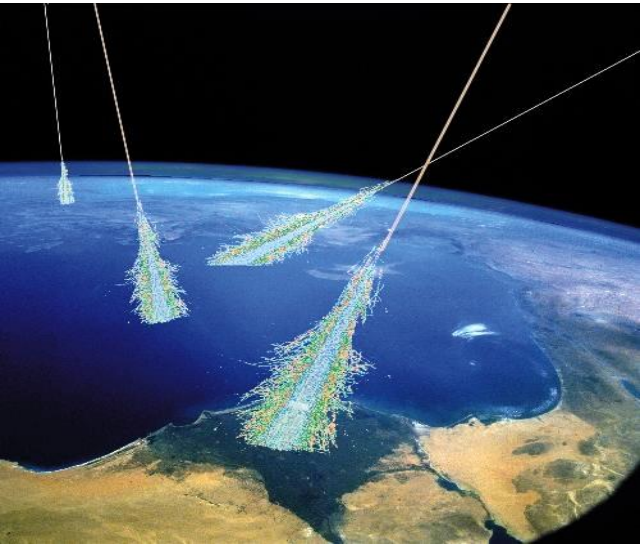
Excess region
7.2σ pre-trial)

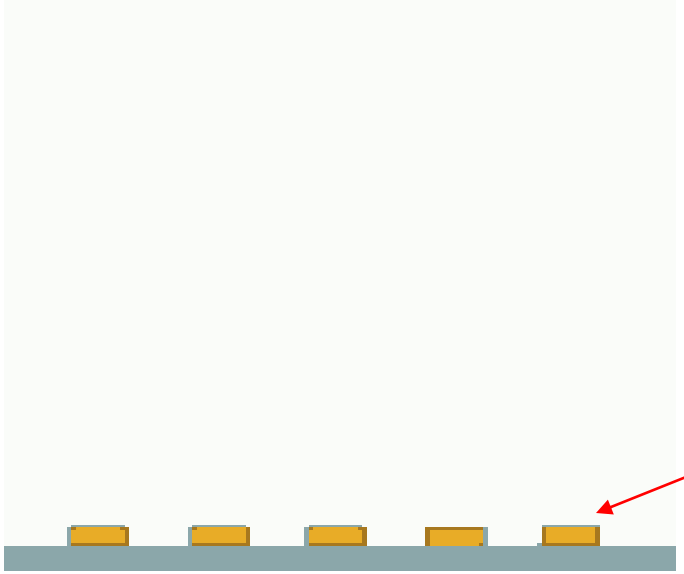


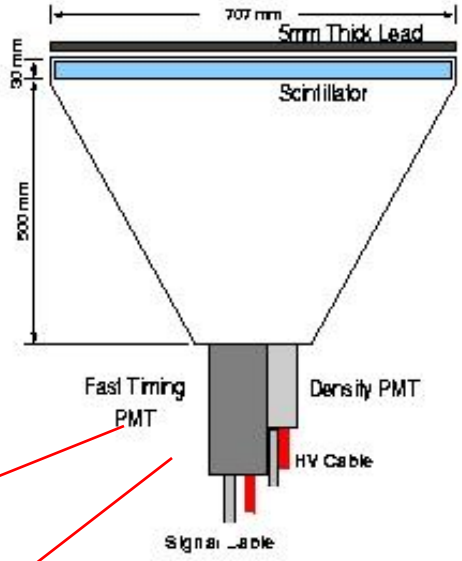
Expected Compton-Getting effect due to the solar motion around galactic center.

Amenomori, et al. 2017, ApJ, 836, 153

Yangbajing Observatory

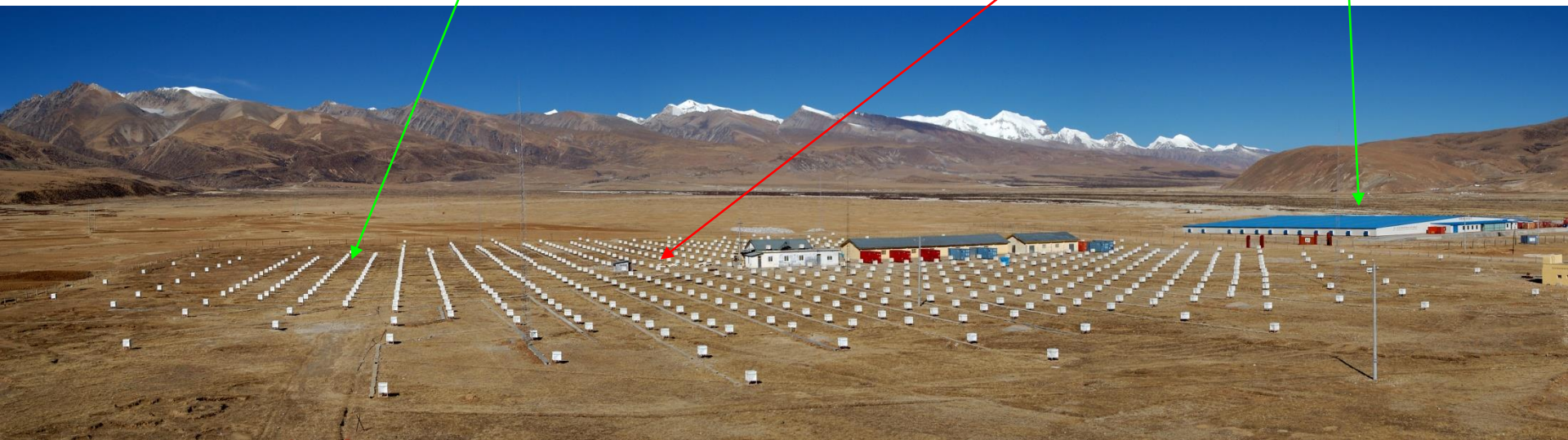






Tibet ASγ array

ARGO Hall



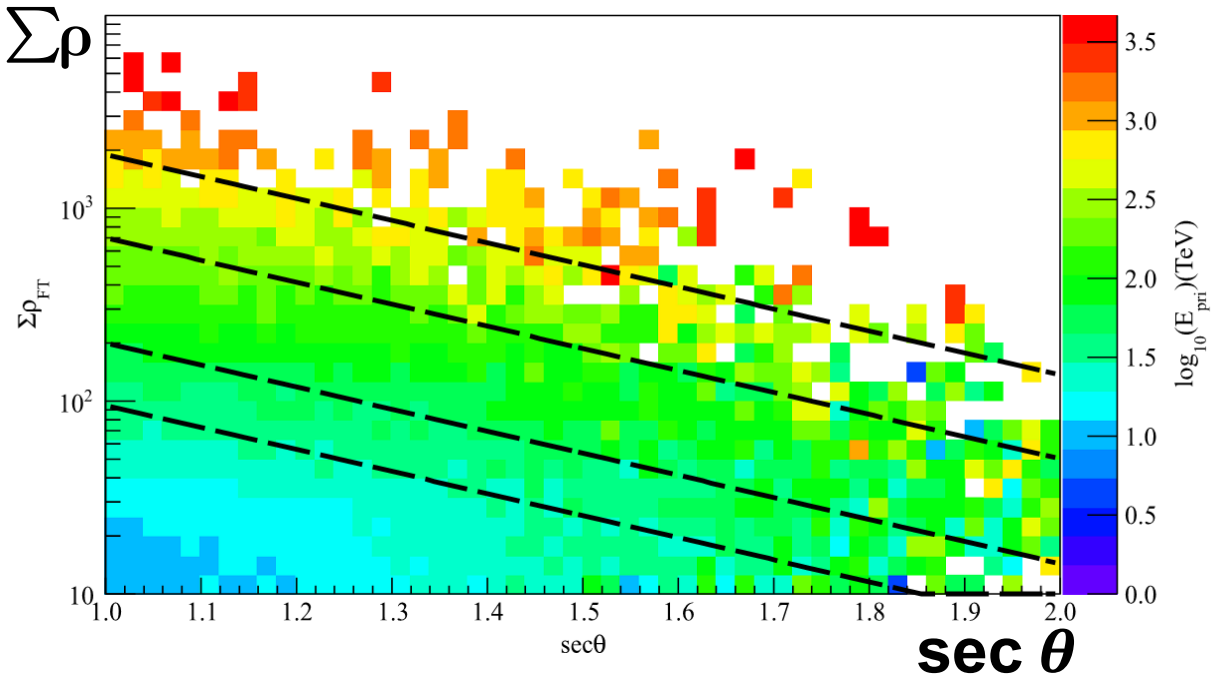
Tibet ASγ Experiment

Tibet China (90.522°E, 30.102°N) 4300 m a.s.l., since **1989**

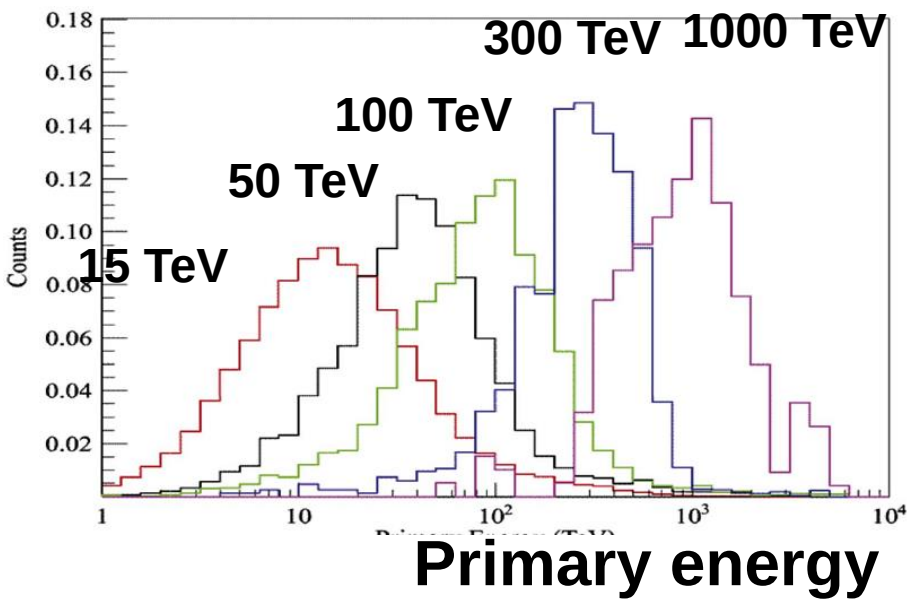
Number of Scinti. Det. 0.5 m^2 x 789
F.O.V. ~2 sr
Covering Area ~37,000 m^2
Angular resolution: ~0.3 degree (cosmic ray)

	Previous [1] ***ApJ* 836, (2017) 153.**	**This work ICRC2019-488**
Configuration	Tibet II	Tibet II
collected period	1995.10-2010.2	1995.10-2010.2, 2014.2-2017.5
Events@ 300TeV	2.7×10^8	3.6×10^8
Events@ 1 PeV	5.7×10^7	7.8×10^7

Energy determination

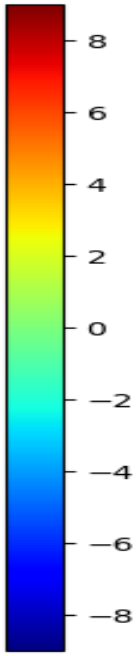


Two-dimensional selection criterion

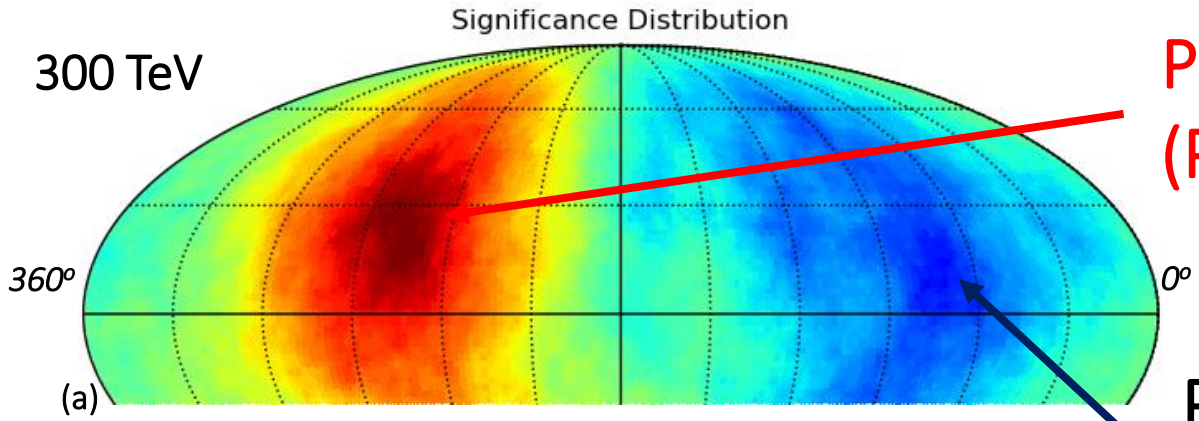


Energy distribution at five data sets

Significance map at 300 TeV and 1 PeV



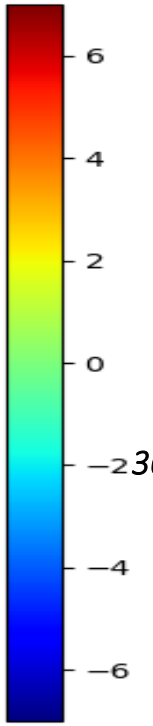
300 TeV



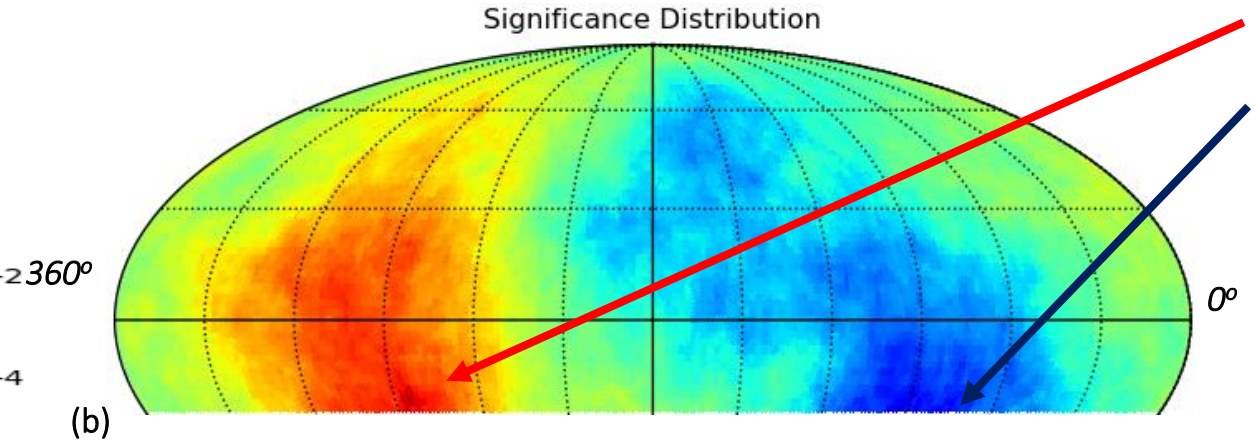
Optimized smooth radius: 40°

Pre-trial: 9.7 σ;
(Post-trial: 8.3σ)

Pre-trial: -6.7 σ;
(Post-trial: -4.6σ)



1 PeV

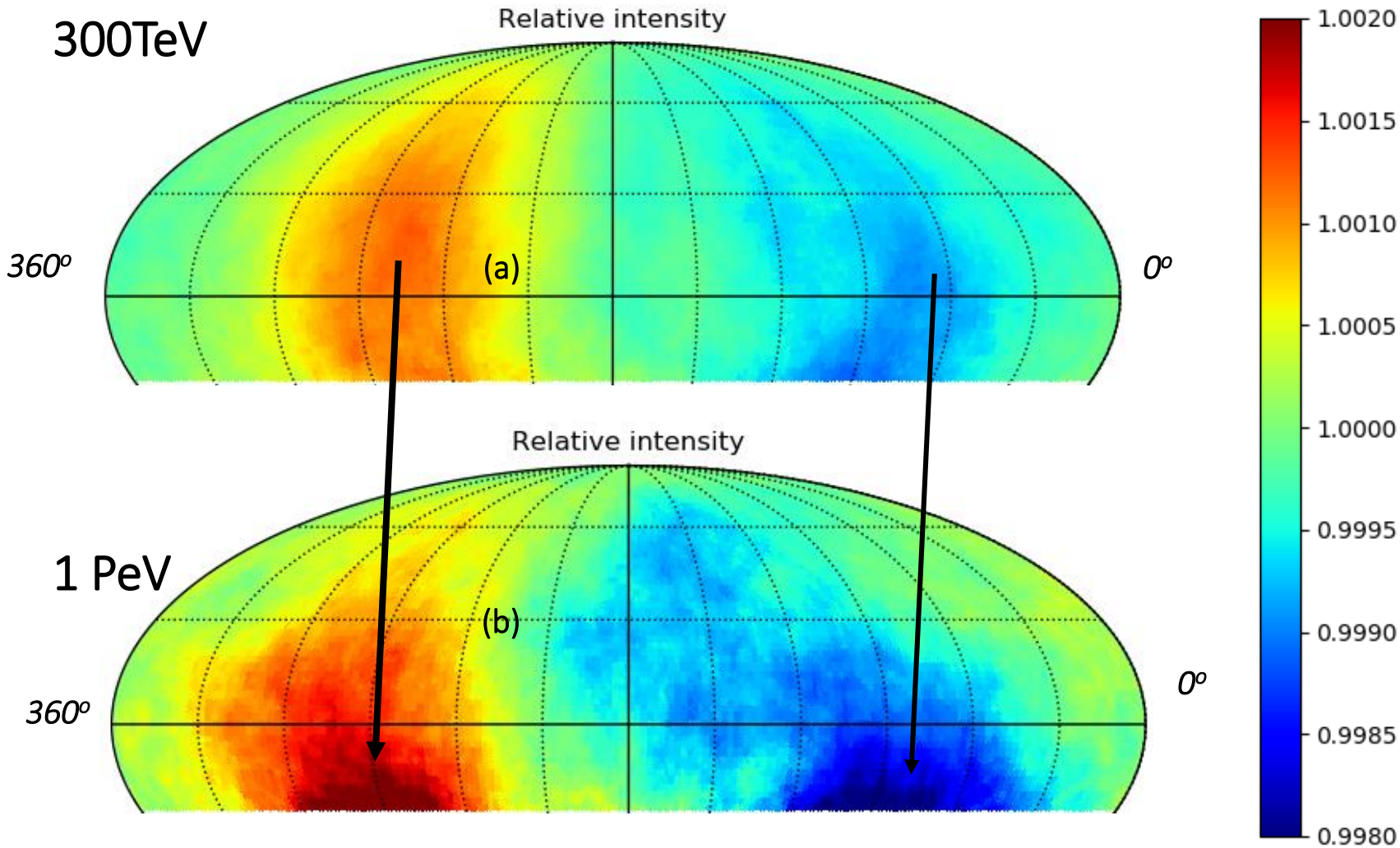


Same smooth radius: 40°

Pre-trial: 6.3 σ;

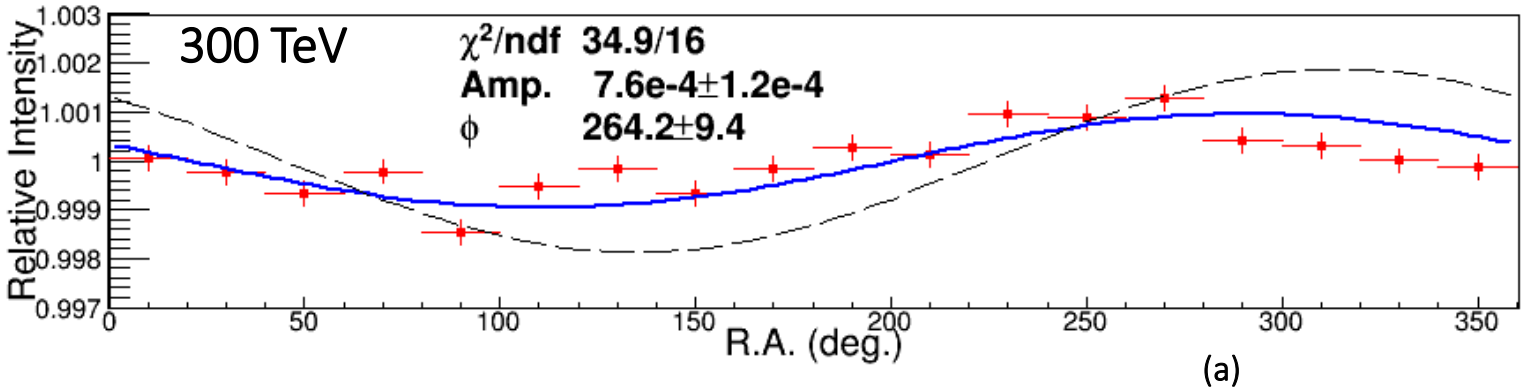
Pre-trial: 5.6 σ;

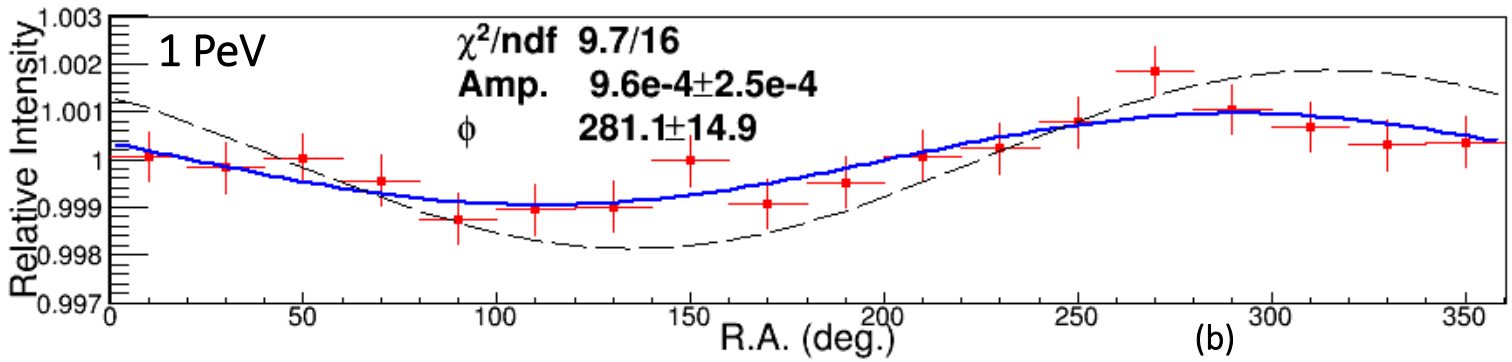
Relative intensity map at 300 TeV and 1 PeV



Hot spots shift?

One dimensional projection at 300 TeV and 1 PeV

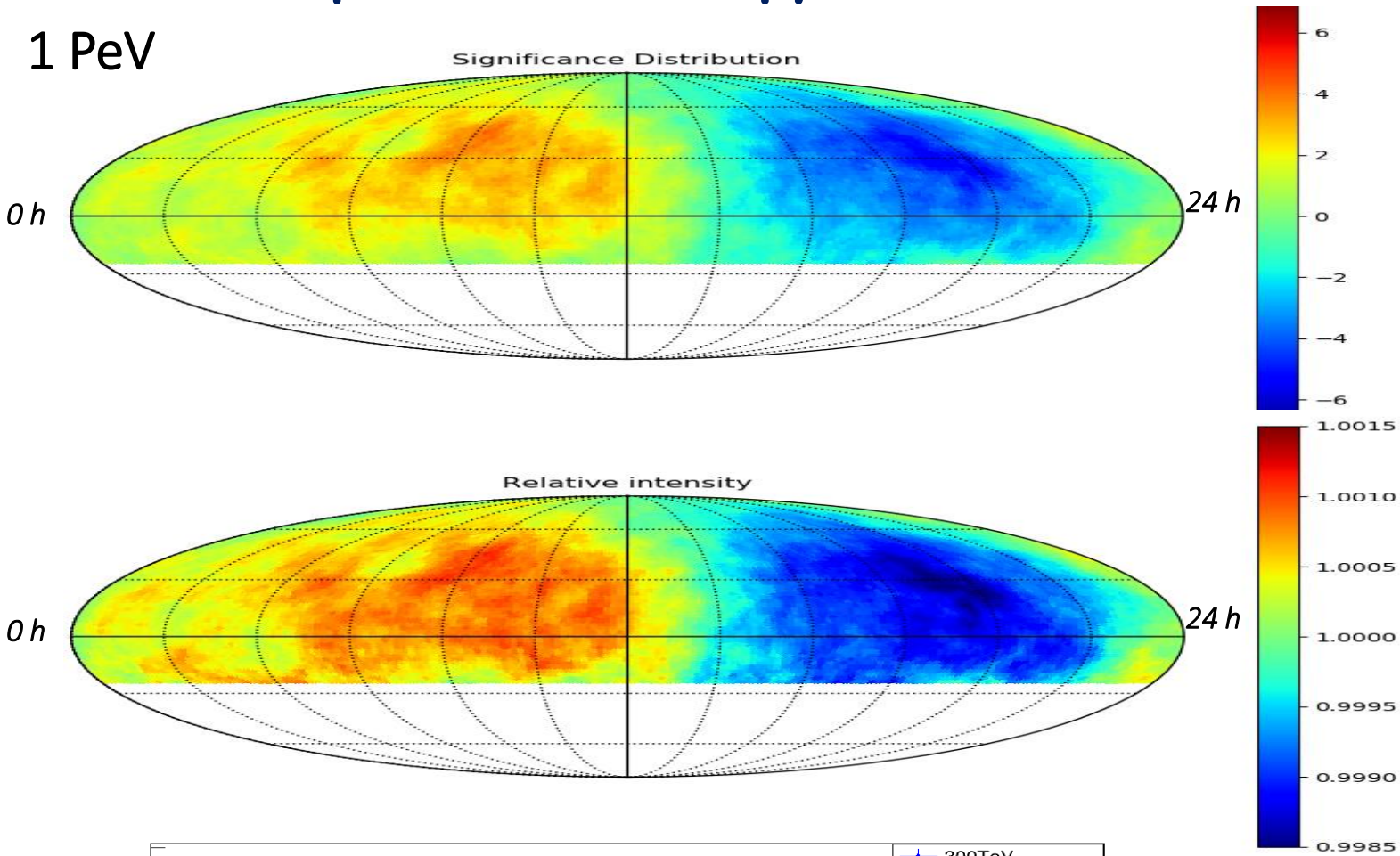


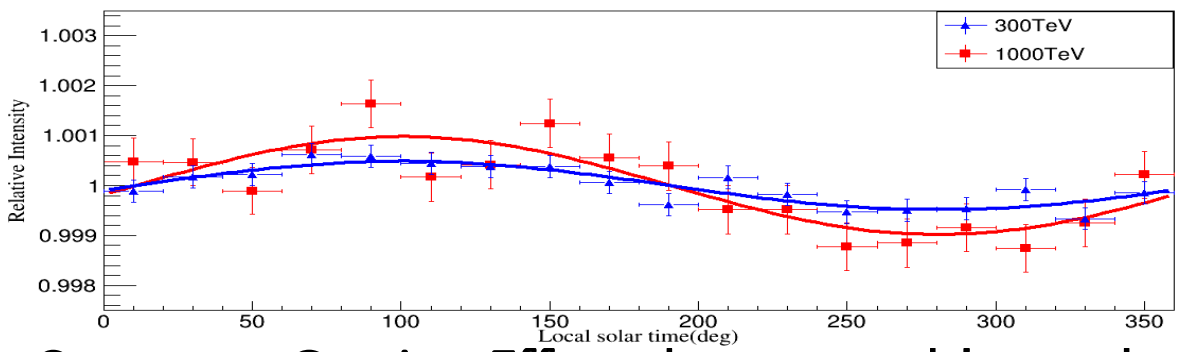


A dipole? Same phase

Expected anisotropy in Local solar time

1 PeV





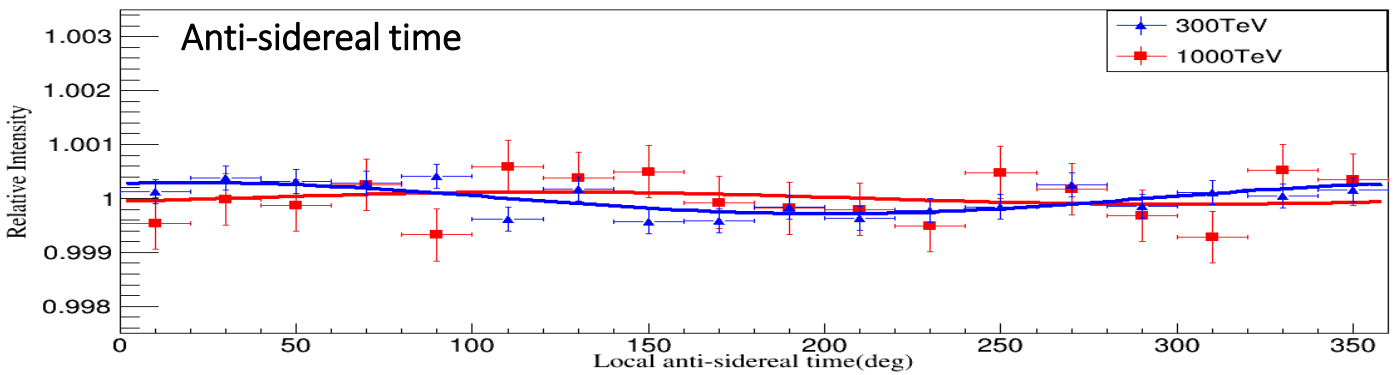
$\chi^2/\mathbf{ndf}$ 10.3/16

Amp. 8.8e-4 $\pm$2.5e-4

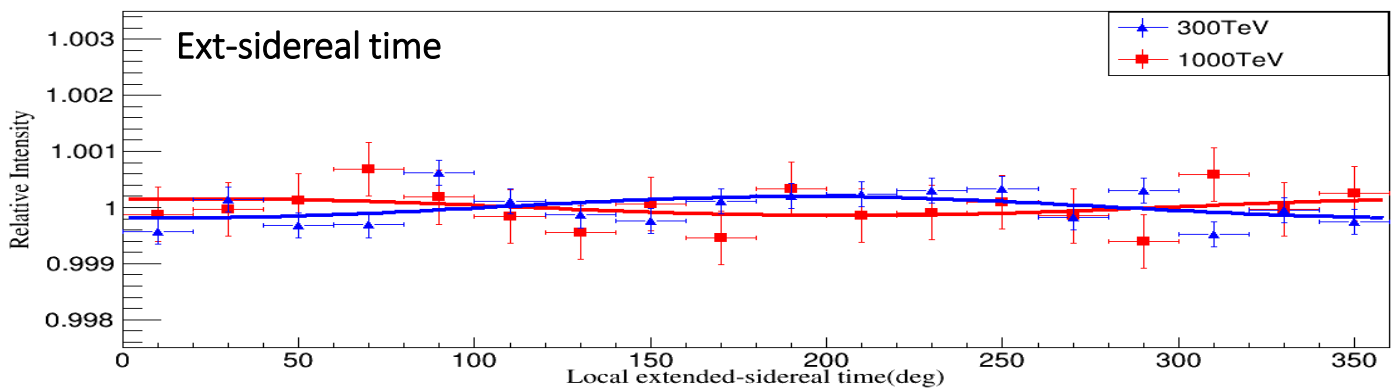
ϕ 97.7 $\pm$16.1

Compton-Getting Effect due to earth's revolution around the Sun

Systematic uncertainty

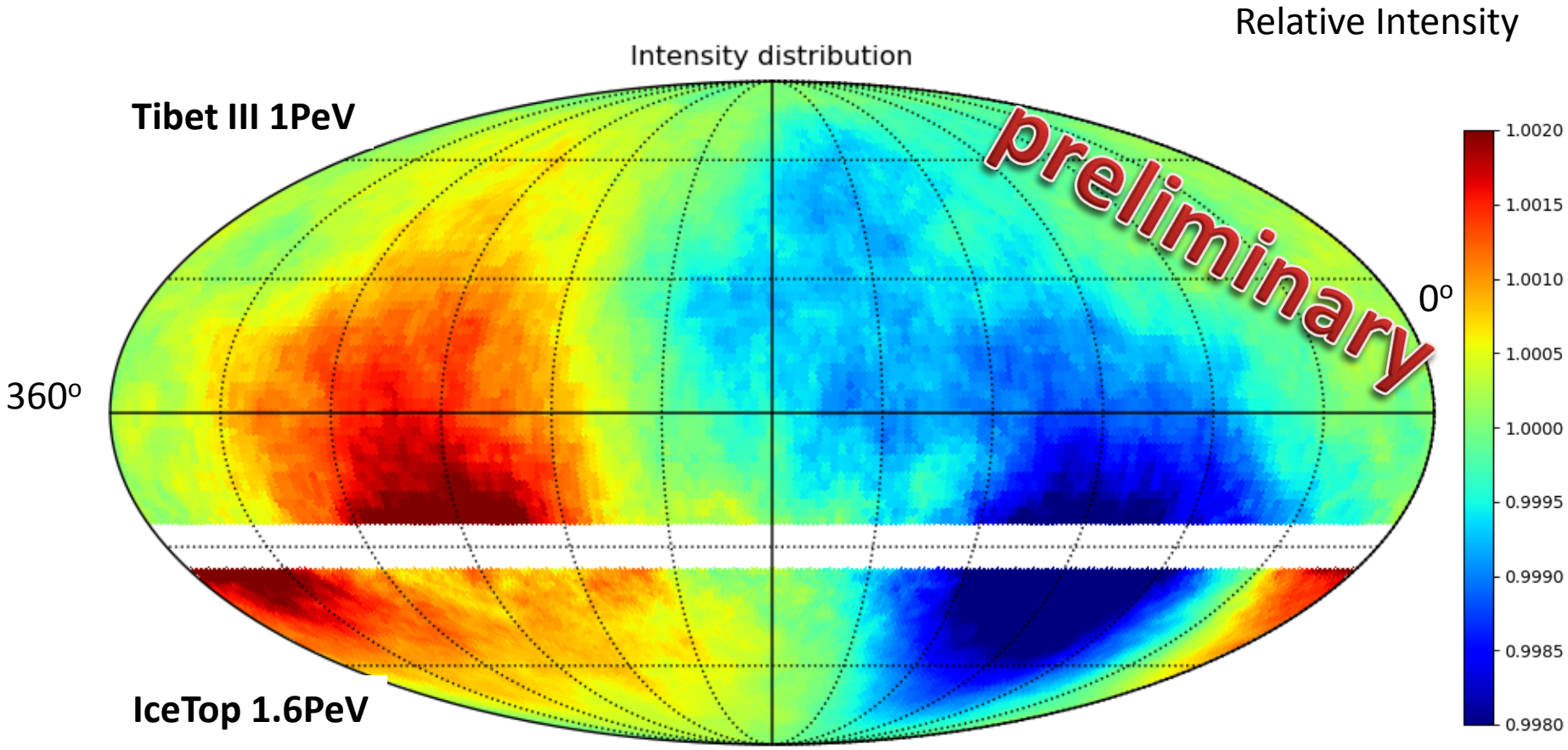


$\chi^2/\mathbf{ndf}$ 11.8/16
Amp. 1.1e-4 $\pm$2.5e-4
ϕ 142.4 $\pm$124.9

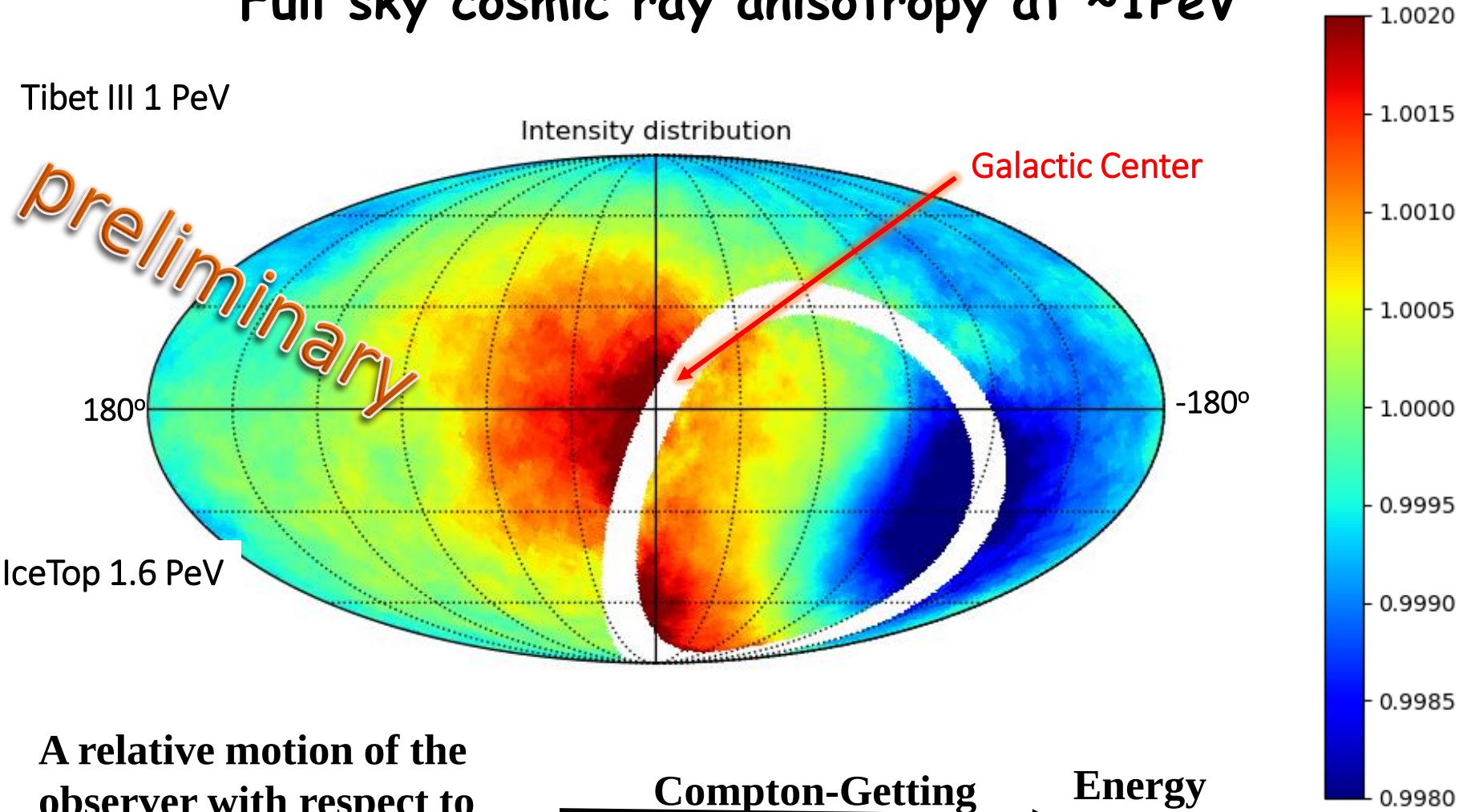


$\chi^2/\mathbf{ndf}$ 7.6/16
Amp. 1.1e-4 $\pm$2.5e-4
ϕ 338.8 $\pm$135.8

Full sky cosmic ray anisotropy at ~1PeV



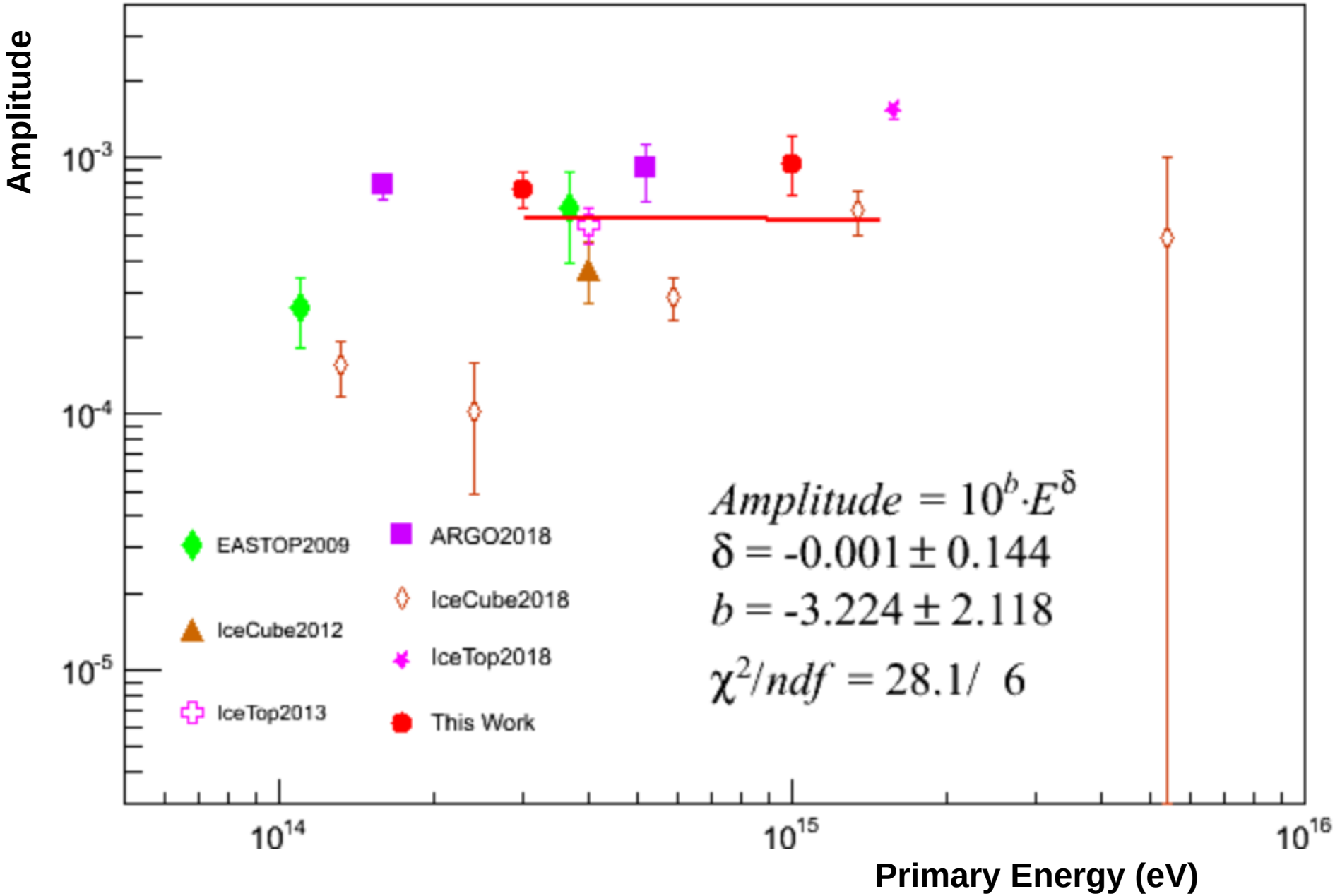
Full sky cosmic ray anisotropy at ~1PeV



A relative motion of the observer with respect to the cosmic-ray plasma → **Compton-Getting effect?** → **Energy independent**

Source distribution mainly in the disk → **CR diffusion** → **Rigidity dependent**

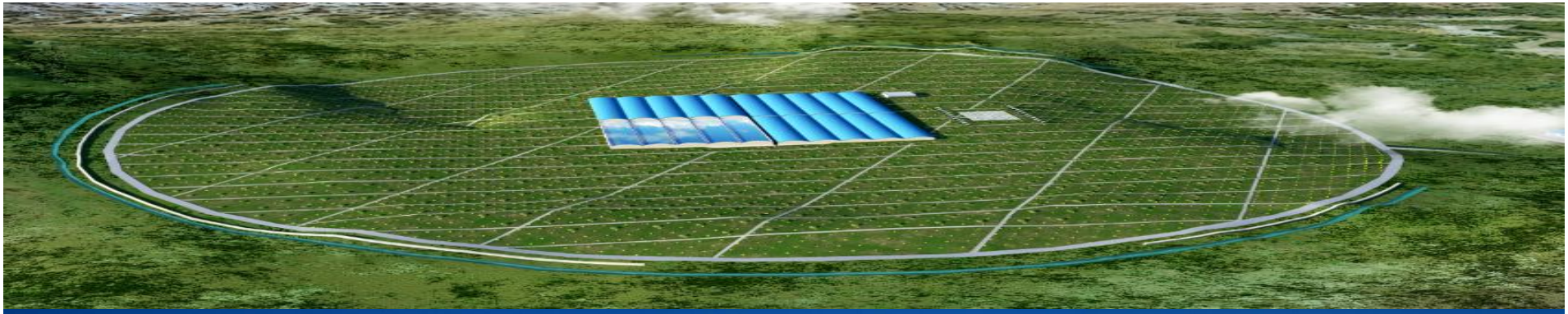
Energy dependences from 300 TeV to 1 PeV



Summary

- A significant excess (6.3σ)and a deficit (-5.6 σ) at PeV are observed by Tibet ASγ experiment in the northern hemisphere .
- The anisotropy in local solar time, anti-sidereal and extended-sidereal time are investigated.
- A full sky anisotropy map at 1 PeV is obtained.
- More statistics and observations…
- Study of the rigidity evolution could be helpful.

Thanks for your attention!

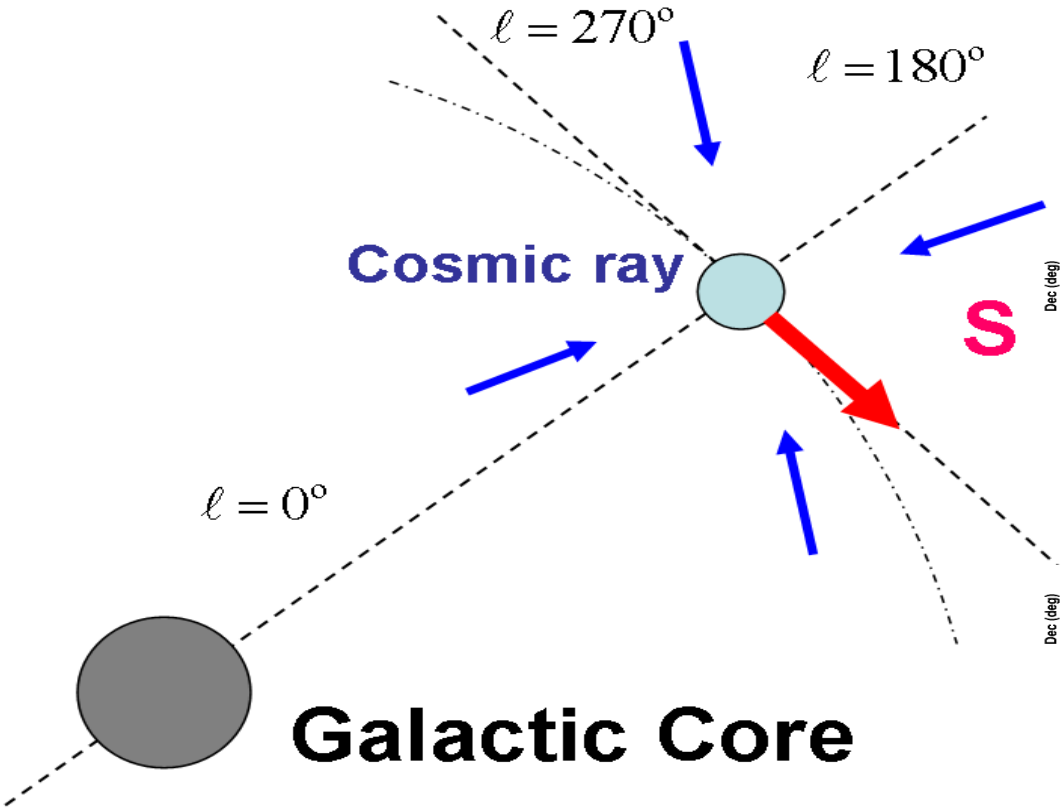


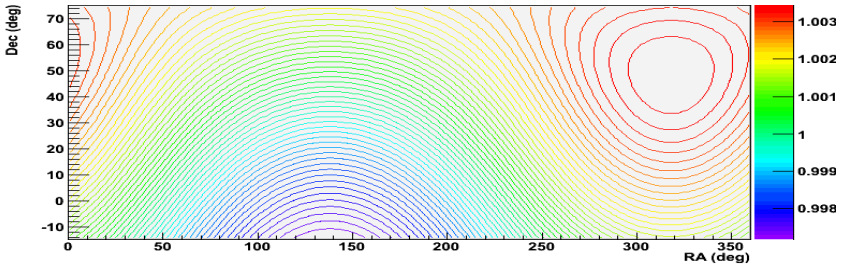
Compton-Getting Effect

Due to the solar motion around galactic center

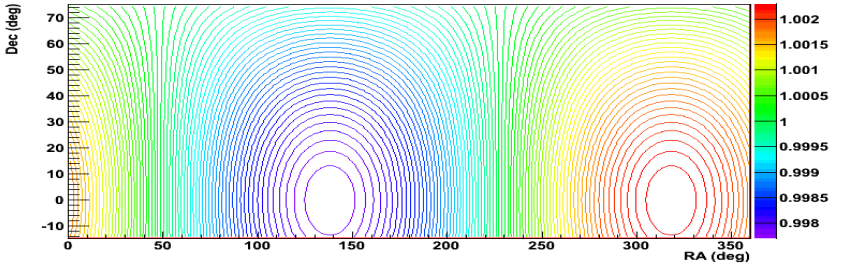
$j \propto E^{-\alpha}$ **V=220km/s,** $\alpha = 2.7$

$$\frac{\Delta I}{\langle I \rangle} = (\alpha + 2)\frac{v}{c}\cos\theta$$



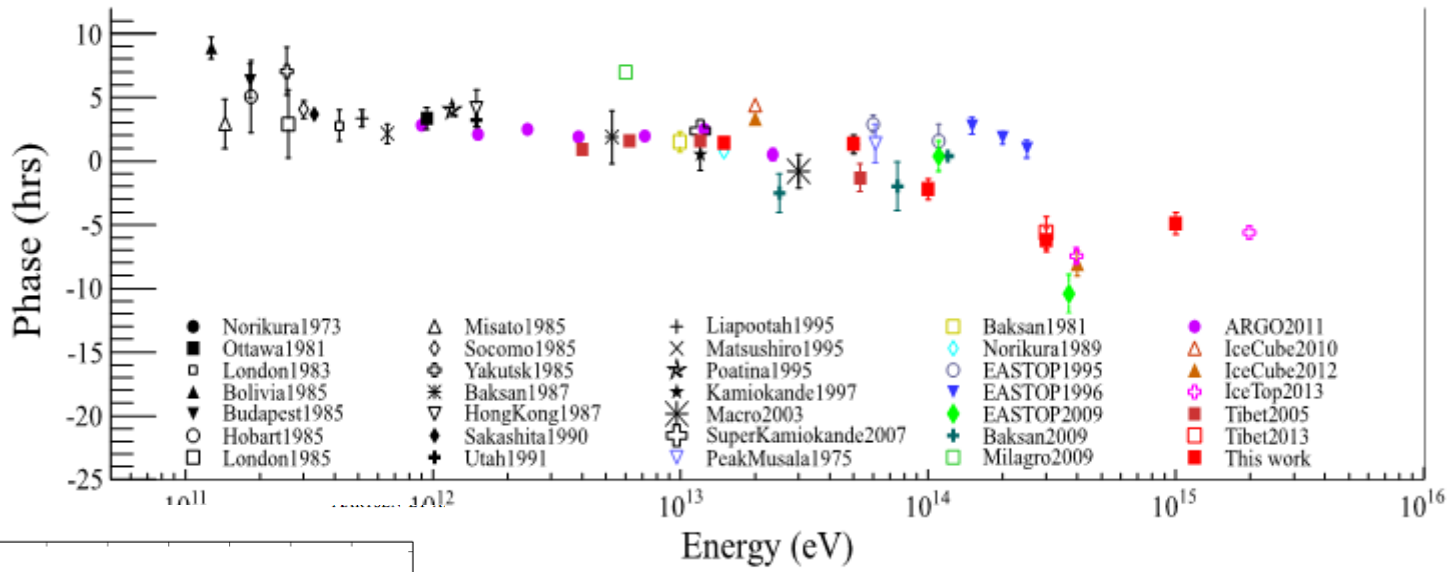


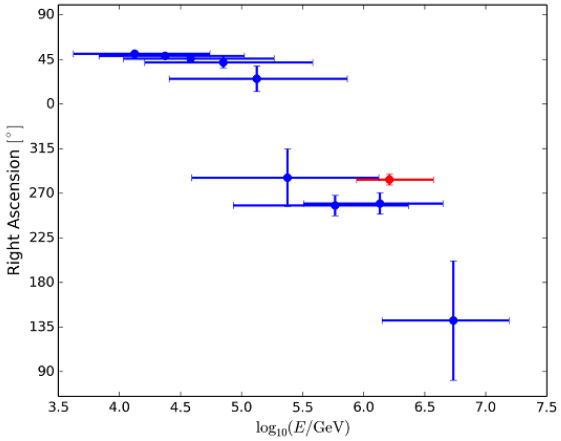
Expected dipole effect



We could observe

A.H. Compton and I.A. Getting, Phys. Rev. **47**, 817(1935)


Phase (hrs)
Energy (eV)
Norikura1973
Ottawa1981
London1983
Bolivia1985
Budapest1985
Hobart1985
London1985
Misato1985
Socomo1985
Yakutsk1985
Baksan1987
HongKong1987
Sakashita1990
Utah1991
Liapootah1995
Matsushiro1995
Poatina1995
Kamiokande1997
Macro2003
SuperKamiokande2007
PeakMusala1975
Baksan1981
Norikura1989
EASTOP1995
EASTOP1996
EASTOP2009
Baksan2009
Milagro2009
ARGO2011
IceCube2010
IceCube2012
IceTop2013
Tibet2005
Tibet2013
This work


Right Ascension [°]
$\log_{10}(E/\mathrm{GeV})$