Recent results from the Tibet ASγ experiment and related topics

Masato TAKITA (ICRR, Univ. of Tokyo)

For the Tibet ASγ Collaboration

October 8, 2019 @CRA2019,
GSSI Conference Center, L'Aquila, Italy

The Tibet ASγ Collaboration

M. Amenomori(1), Y.-W. Bao(2), X. J. Bi(3), D. Chen(4), T. L. Chen(5), W. Y. Chen(3), Xu Chen(3), Y. Chen(2), Cirennima(5), S. W. Cui(7), Danzengluobu(5), L. K. Ding(3), J. H. Fang(3,6), K. Fang(3), C. F. Feng(8), Zhaoyang Feng(3), Z. Y. Feng(9), Qi Gao(5), Q. B. Gou(3), Y. Y. Guo(3), Y. Q. Guo(3), H. H. He(3), Z. T. He(7), K. Hibino(10), N. Hotta(11), Haibing Hu(5), H. B. Hu(3), J. Huang(3), H. Y. Jia(9), L.Jiang(3), H.-B. Jin(4), F. Kajino(12), K. Kasahara(13), Y. Katayose(14), C. Kato(15) S. Kato(16), K. Kawata(16), W. Kihara(15), Y. Ko(15), M. Kozai(17), Labaciren(5), G. M. Le(18), A. F. Li(19,8,3), H. J. Li(5), W. J. Li(3,9), Y.-H. Lin(3,6), B. Liu(2), C. Liu(3), J. S. Liu(3), M. Y. Liu(5), W. Liu(3), Y.-Q. Lou(20), H.Lu(3), X. R. Meng(5), H. Mitsui(14), K. Munakata(15), H. Nakada(14), Y. Nakamura(3), H. Nanjo(1), M. Nishizawa(21), M. Ohnishi(16), T. Ohura(14), S. Ozawa(22), X. L. Qian(23), X. B. Qu(24), T. Saito(25), M. Sakata(12), T. K. Sako(16), Y. Sengoku(14), J. Shao(3,8), M. Shibata(14), A. Shiomi(26), H. Sugimoto(27), W. Takano(10), M. Takita(16), Y. H. Tan(3), N. Tateyama(10), S. Torii(28), H. Tsuchiya(29), S. Udo(10), H. Wang(3), H. R. Wu(3), L. Xue(8), K. Yagisawa(14), Y. Yamamoto(12), Z. Yang(3), Y. Yokoe(16), A. F. Yuan(5), L. M. Zhai(4), H. M. Zhang(3), J. L. Zhang(3), X. Zhang(2), X. Y. Zhang(8), Y. Zhang(3), Yi Zhang(3), Ying Zhang(3), S. P. Zhao(3), Zhaxisangzhu(5) and X. X. Zhou(9)

(1) Department of Physics, Hirosaki University, Hirosaki 036-8561, Japan
(2) School of Astronomy and Space Science, Nanjing University, Nanjing 210093, China
(3) Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
(4) National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China
(5) Physics Department of Science School, Tibet University, Lhasa 850000, China
(6) University of Chinese Academy of Sciences, Beijing 100049, China
(7) Department of Physics, Hebei Normal University, Shijiazhuang 050016, China
(8) Department of Physics, Shandong University, Jinan 250100, China
(9) Institute of Modern Physics, SouthWest Jiaotong University, Chengdu 610031, China
(10) Faculty of Engineering, Kanagawa University, Yokohama 221-8686, Japan
(11) Utsunomiya University, Utsunomiya 321-8505, Japan
(12) Department of Physics, Konan University, Kobe 658-8501, Japan
(13) Shibaura Institute of Technology, Saitama 337-8570, Japan
(14) Faculty of Engineering, Yokohama National University, Yokohama 240-8501, Japan
(15) Department of Physics, Shinshu University, Matsumoto 390-8621, Japan
(16) Institute for Cosmic Ray Research, University of Tokyo, Kashiwa 277-8582, Japan
(17) Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (ISAS/JAXA), Sagamihara 252-5210, Japan
(18) National Center for Space Weather, China Meteorological Administration, Beijing 100081, China
(19) School of Information Science and Engineering, Shandong Agriculture University, Taian 271018, China
(20) Physics Department, Astronomy Department and Tsinghua Center for Astrophysics, Tsinghua-National Astronomical Observatories of China joint Research Center for Astrophysics, Tsinghua University, Beijing 100084, China
(21) National Institute of Informatics, Tokyo 101-8430, Japan
(22) Advanced ICT Research Institute, National Institute of Information and Communication Technology, Koganei 184-8795, Japan
(23) Department of Mechanical and Electrical Engineering, Shandong Management University, Jinan 250357, China
(24) College of Science, China University of Petroleum, Qingdao, 266555, China
(25) Tokyo Metropolitan College of Industrial Technology, Tokyo 116-8523, Japan
(26) College of Industrial Technology, Nihon University, Narashino 275-8576, Japan
(27) Shonan Institute of Technology, Fujisawa 251-8511, Japan
(28) Research Institute for Science and Engineering, Waseda University, Tokyo 169-8555, Japan
(29) Japan Atomic Energy Agency, Tokai-mura 319-1195, Japan

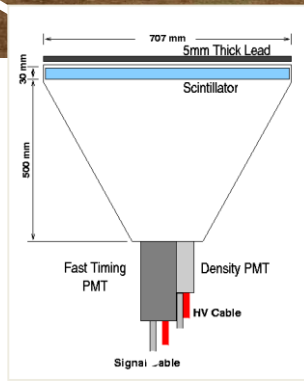
Outline

- Tibet ASγ Experiment (Multi-purpose)
- Gamma-ray observation
- Cosmic-ray anisotropy measurement
- Sun shodow observation to probe solar MFs

Skipped in this talk are:

- Chemical composition study around Knee
- Hadronic interaction tests using air shower data
- Summary

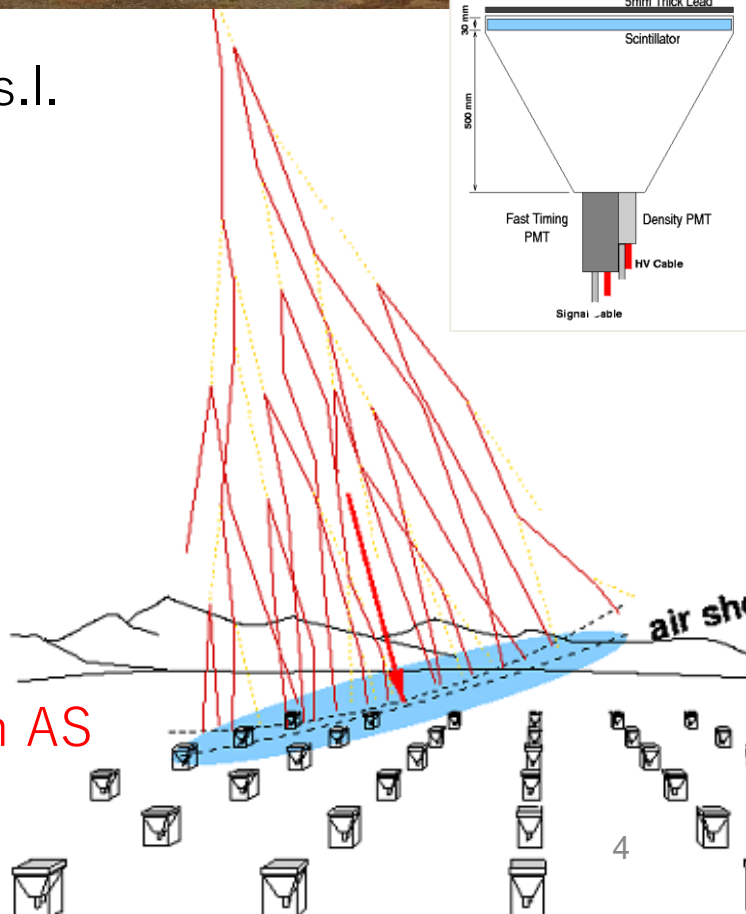
Tibet Air Shower Array



- Site: Tibet (90.522°E, 30.102°N) 4,300 m a.s.l.

Present Performance

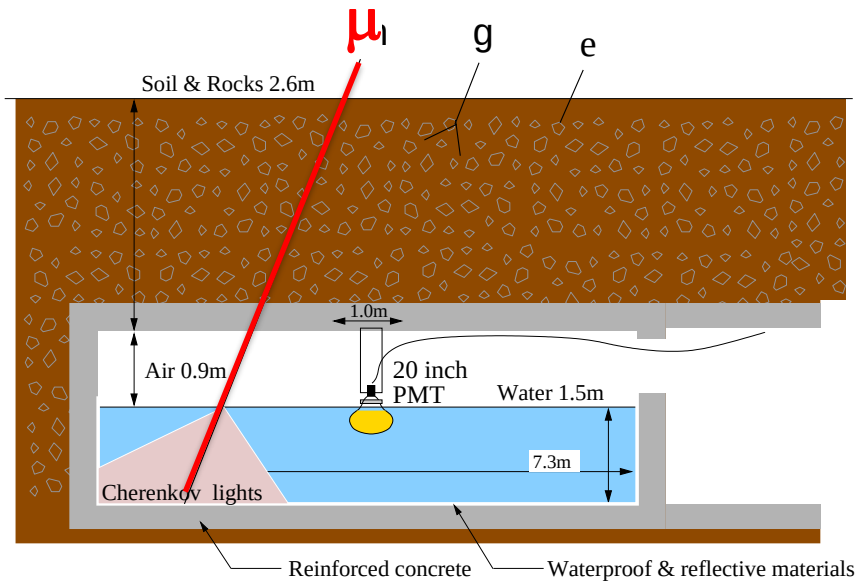
# of detectors	0.5 m^2 x 597
Effective area	~65,700 m^2
Angular resolution	~0.5° @10TeV
	~0.2° @100TeV
Energy resolution	~40%@10TeV γ
	~20%@100TeV γ

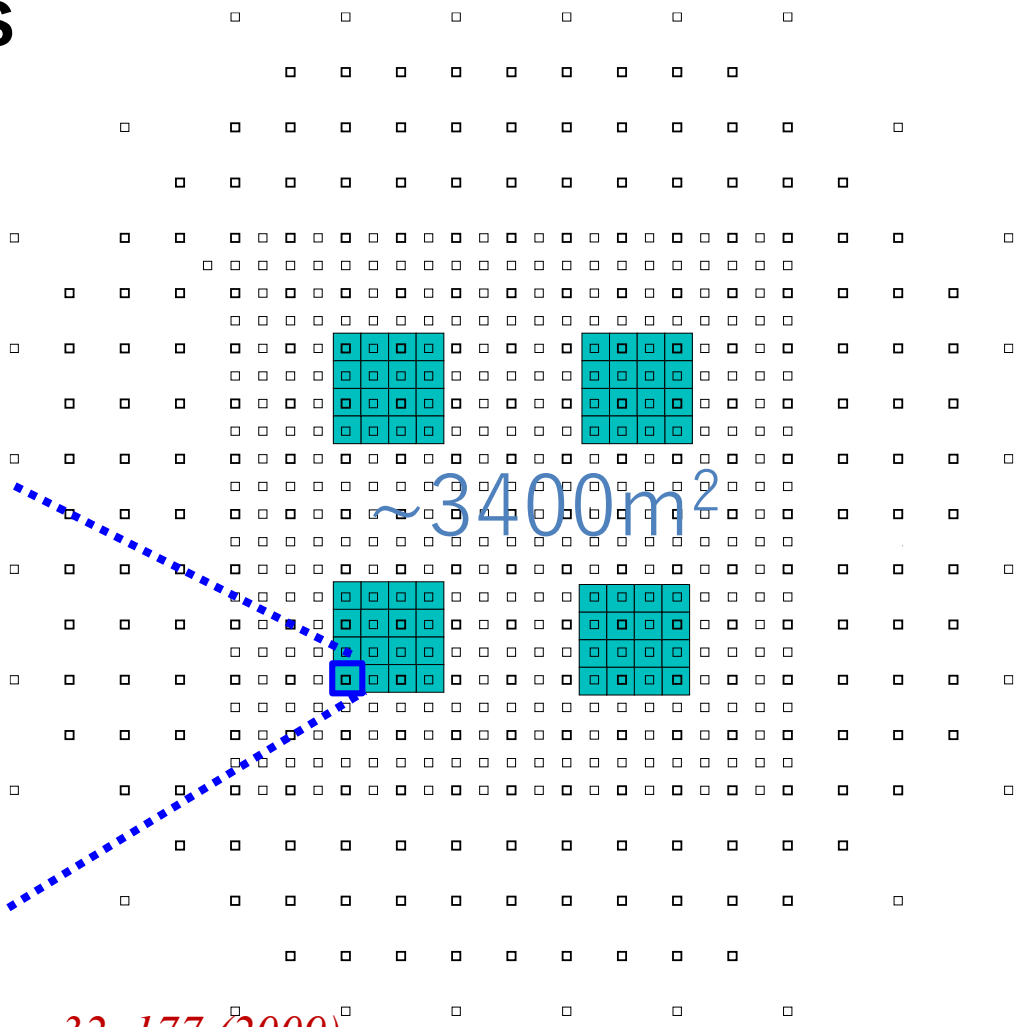


→Observation of secondary (mainly $e^{+/-}$, γ) in AS
Primary energy : 2nd particle densities
Primary direction : 2nd relative timings

Underground Water Cherenkov Muon detectors

- ✓ 2.4m underground (~515g/cm^2 ~19X_0)
- ✓ 4 pools, 16 units / pool
- ✓ 7.35m × 7.35m × 1.5m deep (water)
- ✓ 20" ΦPMT (HAMAMATSU R3600)
- ✓ Concrete pools + white Tyvek sheets





Basic idea: T. K. Sako et al., Astropart. Phys. 32, 177 (2009)

Measurement of # of μ in AS → γ／CR discrimination

DATA: February, 2014 - May, 2017 Live time: 719 days

Gamma rays

Viewpoint: Highest Energy Astrophysical Photons Detected

Rene A. Ong, Department of Physics and Astronomy, University of California, Los Angeles, CA, USA

July 29, 2019 • *Physics* 12, 87

PHYSICAL REVIEW LETTERS **123,** 051101 (2019)

Editors' Suggestion | Featured in Physics

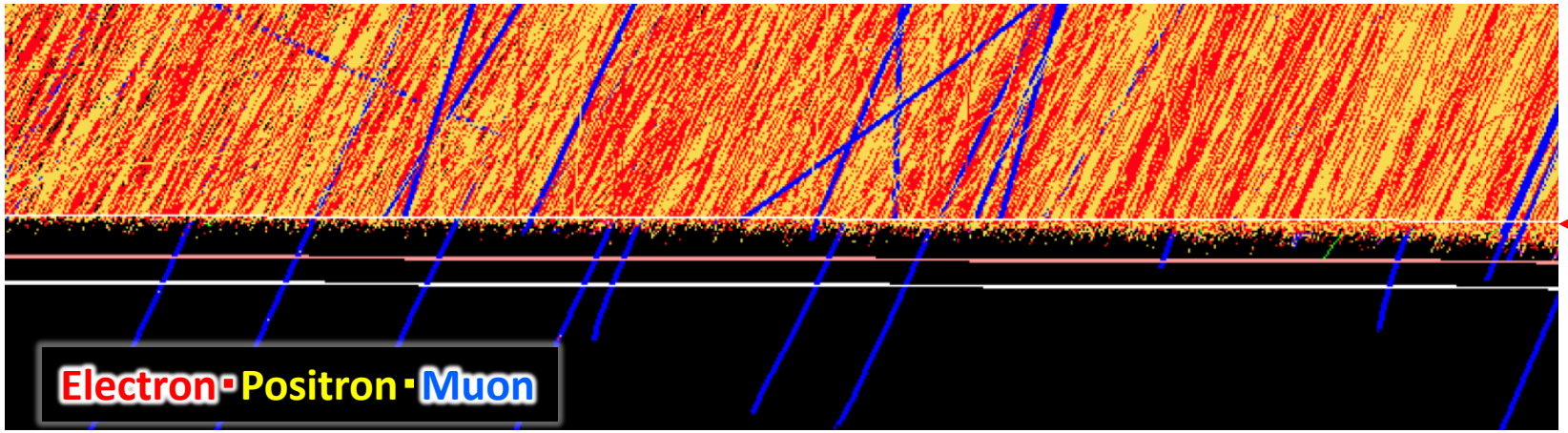
Received April 4, 2019, accepted June 13, published July 29, 2019 in PRL

First Detection of Photons with Energy beyond 100 TeV from an Astrophysical Source

M. Amenomori,[1] Y. W. Bao,[2] X. J. Bi,[3] D. Chen,[4] T. L. Chen,[5] W. Y. Chen,[3] Xu Chen,[3,6,†] Y. Chen,[2] Cirennima,[5] S. W. Cui,[7] Danzengluobu,[5] L. K. Ding,[3] J. H. Fang,[3,6] K. Fang,[3] C. F. Feng,[8] Zhaoyang Feng,[3] Z. Y. Feng,[9] Qi Gao,[5] Q. B. Gou,[3] Y. Q. Guo,[3] H. H. He,[3] Z. T. He,[7] K. Hibino,[10] N. Hotta,[11] Haibing Hu,[5] H. B. Hu,[3] J. Huang,[3,§] H. Y. Jia,[9] L. Jiang,[3] H. B. Jin,[4] F. Kajino,[12] K. Kasahara,[13] Y. Katayose,[14] C. Kato,[15] S. Kato,[16] K. Kawata,[16,*] M. Kozai,[17] Labaciren,[5] G. M. Le,[18] A. F. Li,[19,8,3] H. J. Li,[5] W. J. Li,[3,9] Y. H. Lin,[3,6] B. Liu,[2] C. Liu,[3] J. S. Liu,[3] M. Y. Liu,[5] Y.-Q. Lou,[20] H. Lu,[3] X. R. Meng,[5] H. Mitsui,[14] K. Munakata,[15] Y. Nakamura,[3] H. Nanjo,[1] M. Nishizawa,[21] M. Ohnishi,[16] I. Ohta,[22] S. Ozawa,[13] X. L. Qian,[23] X. B. Qu,[24] T. Saito,[25] M. Sakata,[12] T. K. Sako,[16] Y. Sengoku,[14] J. Shao,[3,8] M. Shibata,[14] A. Shiomi,[26] H. Sugimoto,[27] M. Takita,[16,‡] Y. H. Tan,[3] N. Tateyama,[10] S. Torii,[13] H. Tsuchiya,[28] S. Udo,[10] H. Wang,[3] H. R. Wu,[3] L. Xue,[8] K. Yagisawa,[14] Y. Yamamoto,[12] Z. Yang,[3] A. F. Yuan,[5] L. M. Zhai,[4] H. M. Zhang,[3] J. L. Zhang,[3] X. Zhang,[2] X. Y. Zhang,[8]

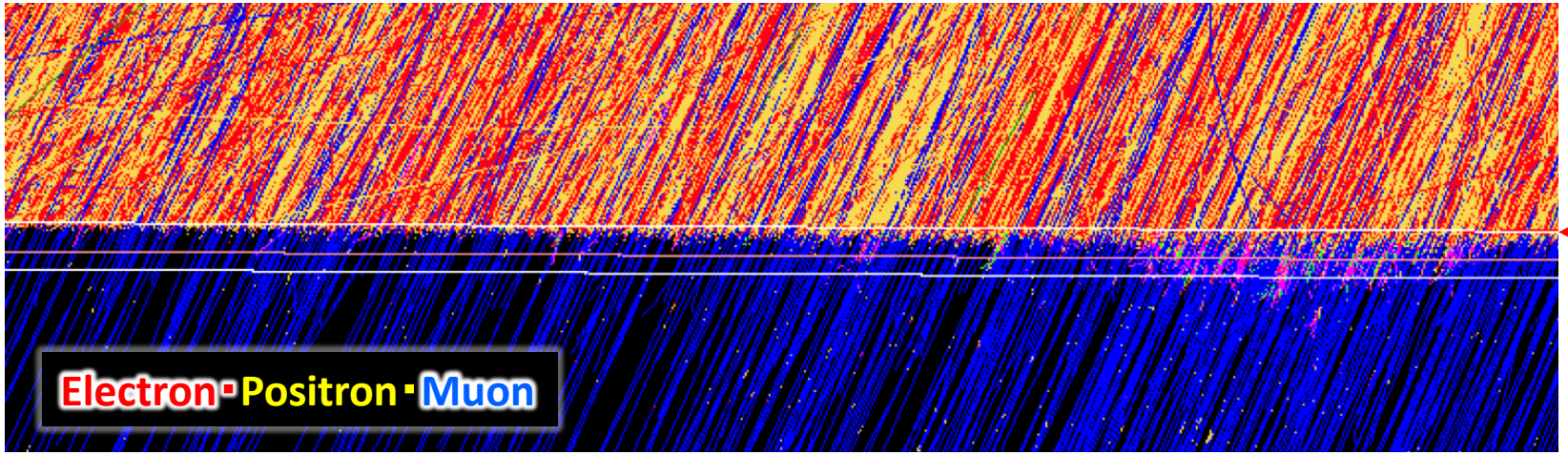
Muons in Air Shower

Simulated by COSMOS



ground

200TeV Gamma-ray induced AS



ground

200TeV Proton induced AS

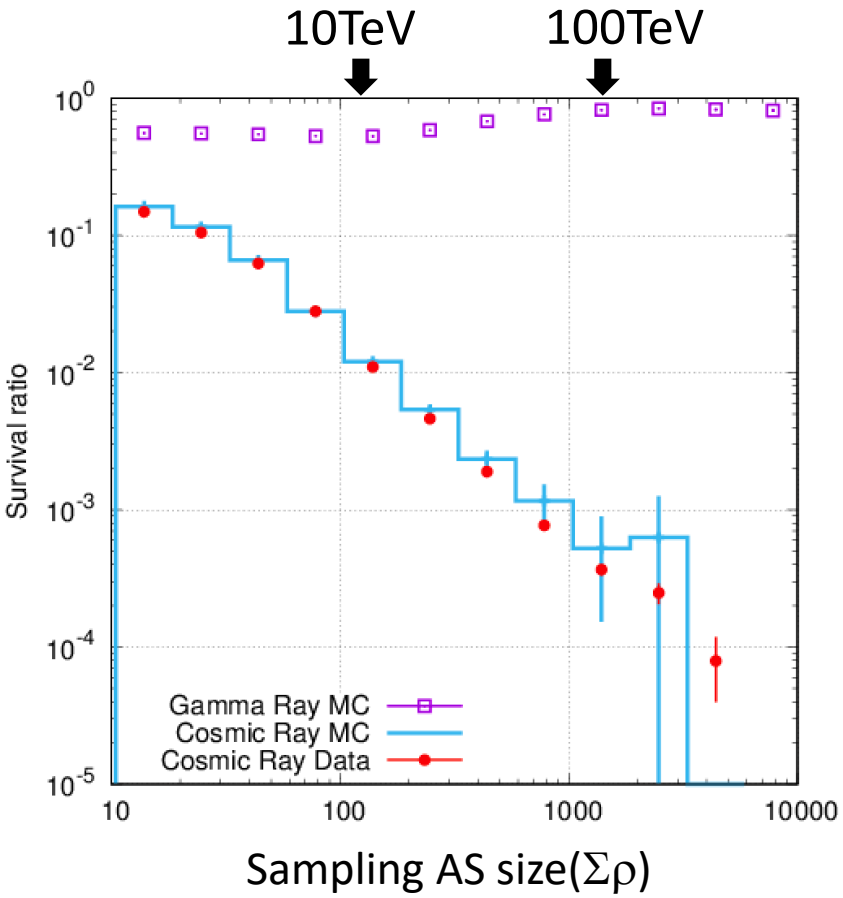
E (Σρ) vs. Nμ Plot

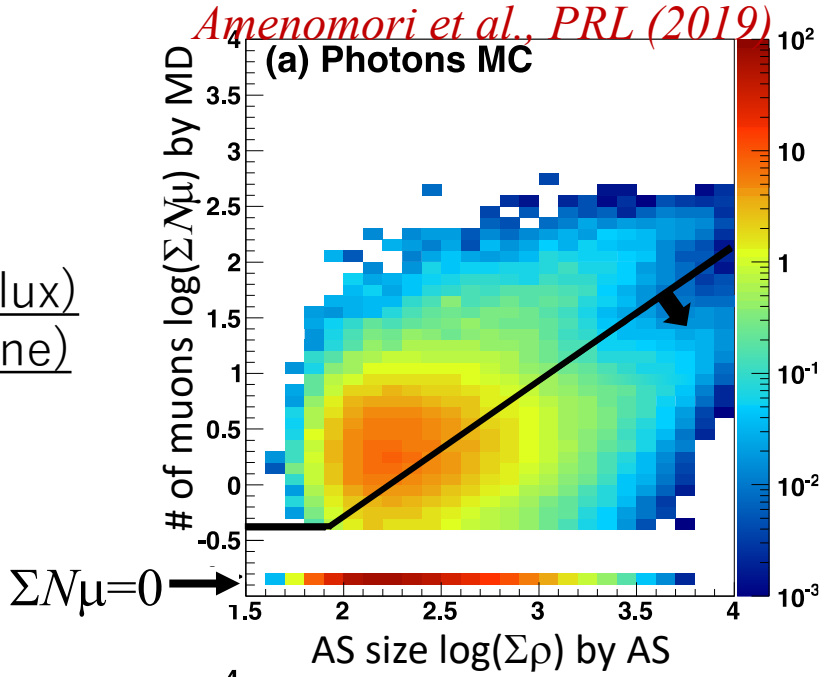
Amenomori et al., PRL (2019)

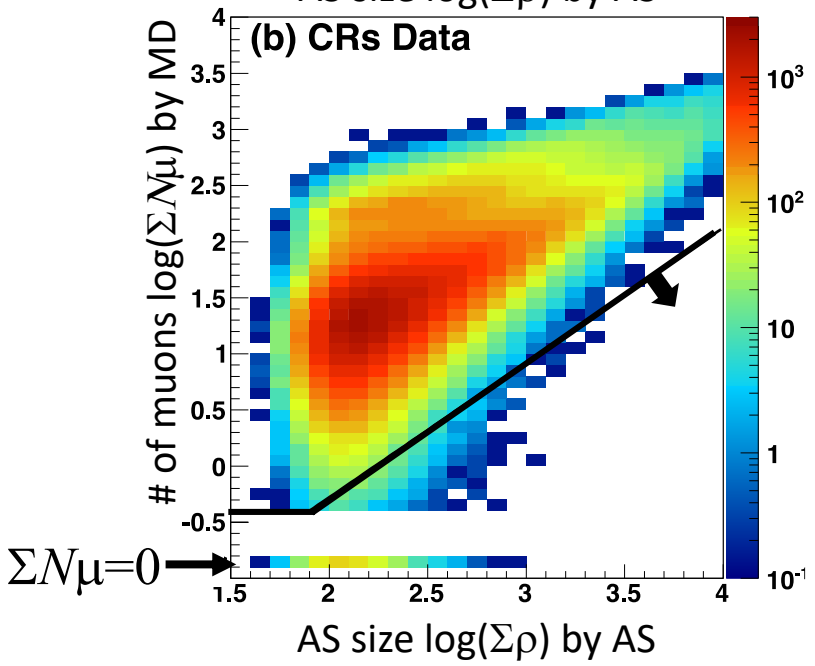
→Optimization of cut

Gamma: MC sample (Crab orbit & Crab Flux)

CR : DATA(excluding Crab and Galctic plane)

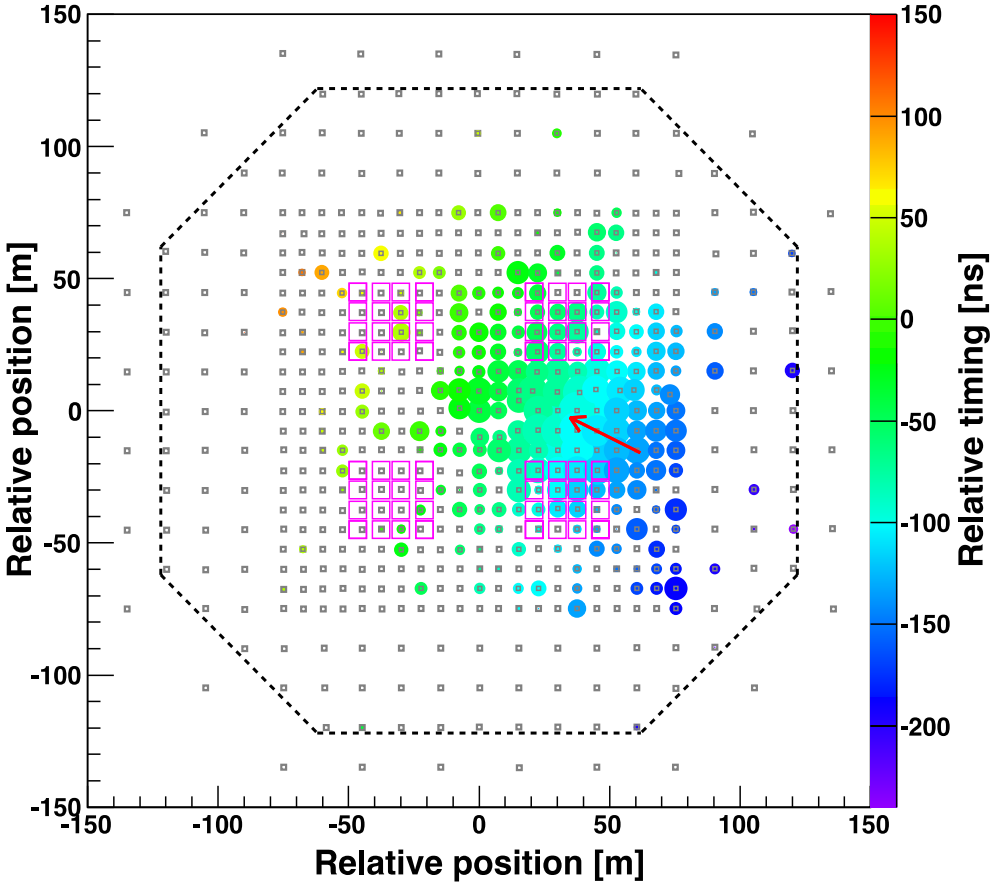


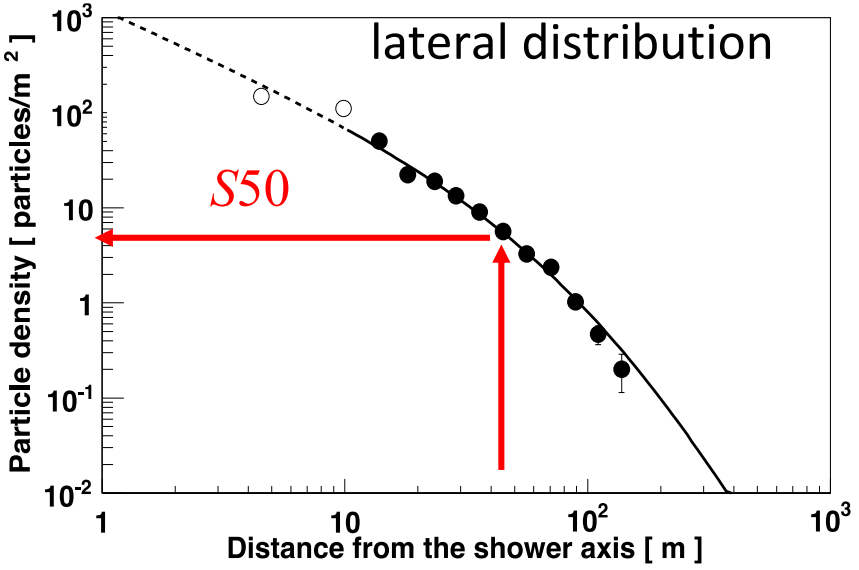




After Nμ cut,~99.9% CR rejection & ~90% γ efficiency @100 TeV

Gamma-like Event from the Crab





circle size ∝ log(# of detected particles)

circle color ∝ relative timing [ns]

fitting with NKG function

➡ E_{rec} ($S50$, θ)

$\Sigma\rho$ (from AS array) : 3256

$\Sigma N\mu$ (MD) : 2.3

zenith angle : 29.8°

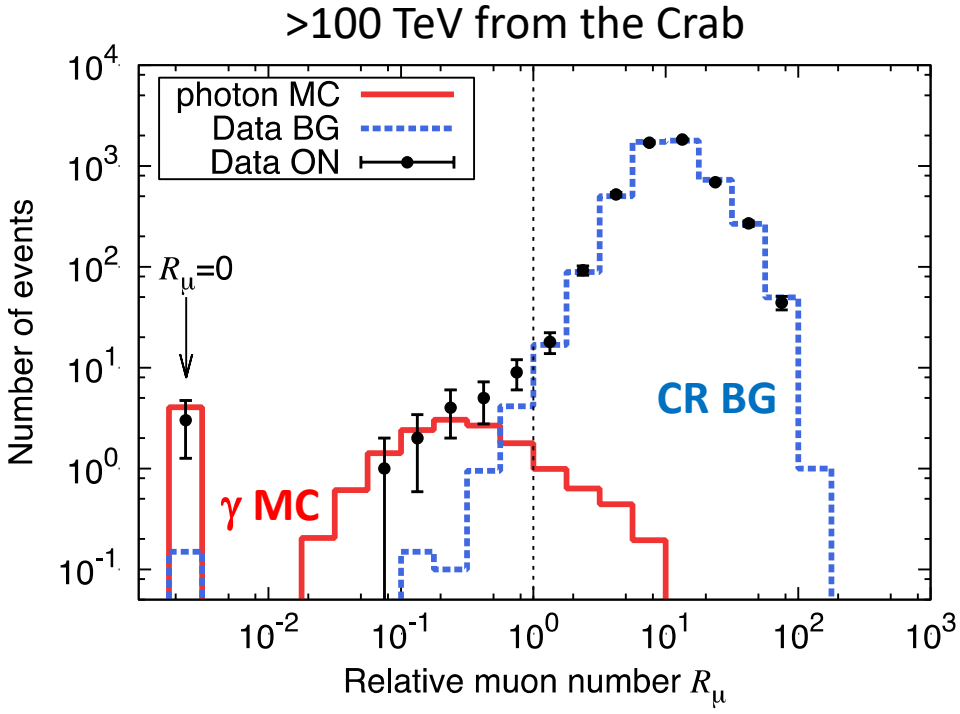
E_{rec} : $251\ ^{+46}_{-43}$ TeV

Amenomori et al., PRL (2019)

$S50$ improves E resolutions (10 - 1000 TeV)

→ ~40%@10 TeV , ~20%@100 TeV

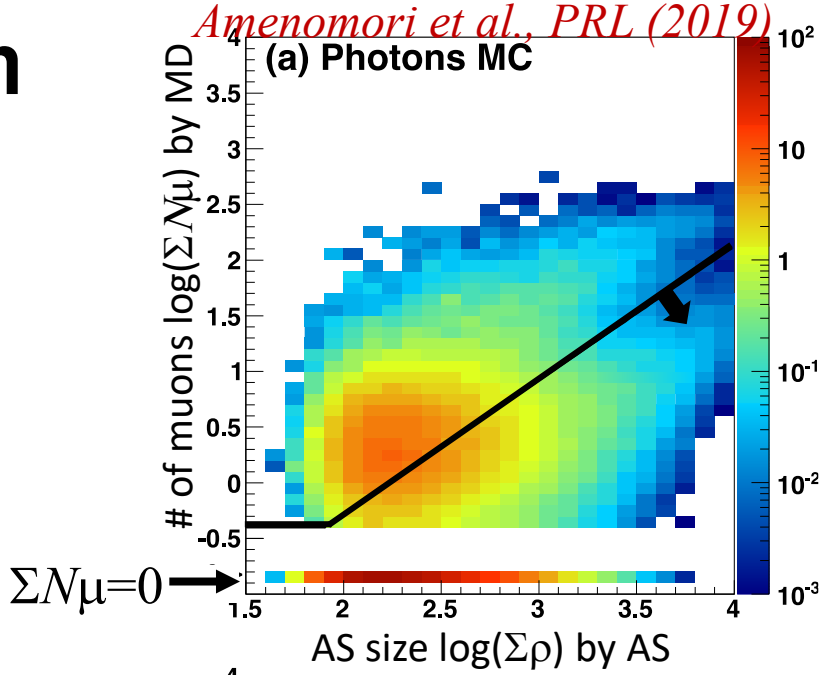
Muon Distribution in Crab Direction

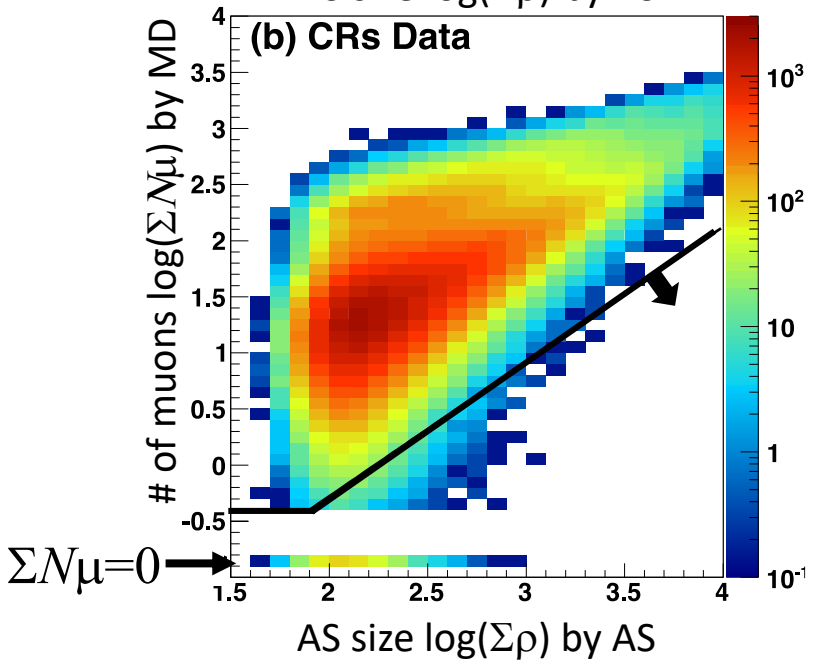


$$R\mu = \frac{\text{Observed \# of muons}}{\text{\# of muons at the cut value}}$$

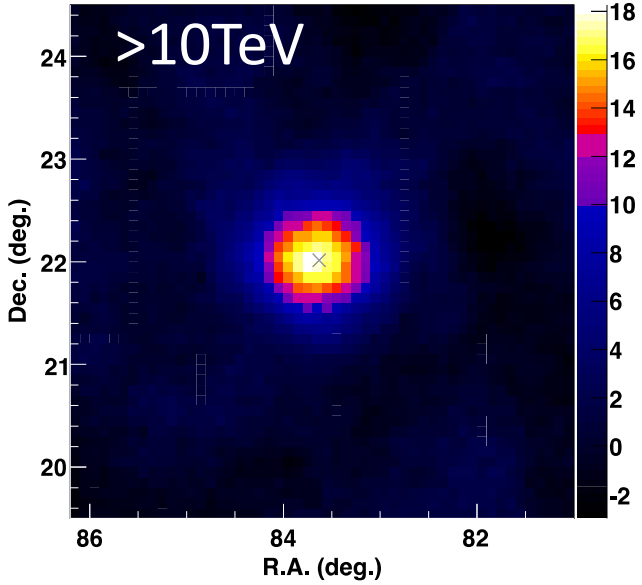
Amenomori et al., PRL Supplemental Material (2019)

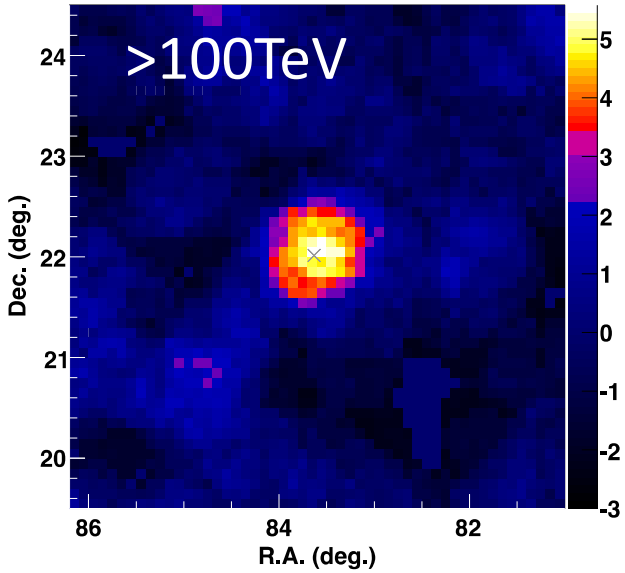
Amenomori et al., PRL (2019)



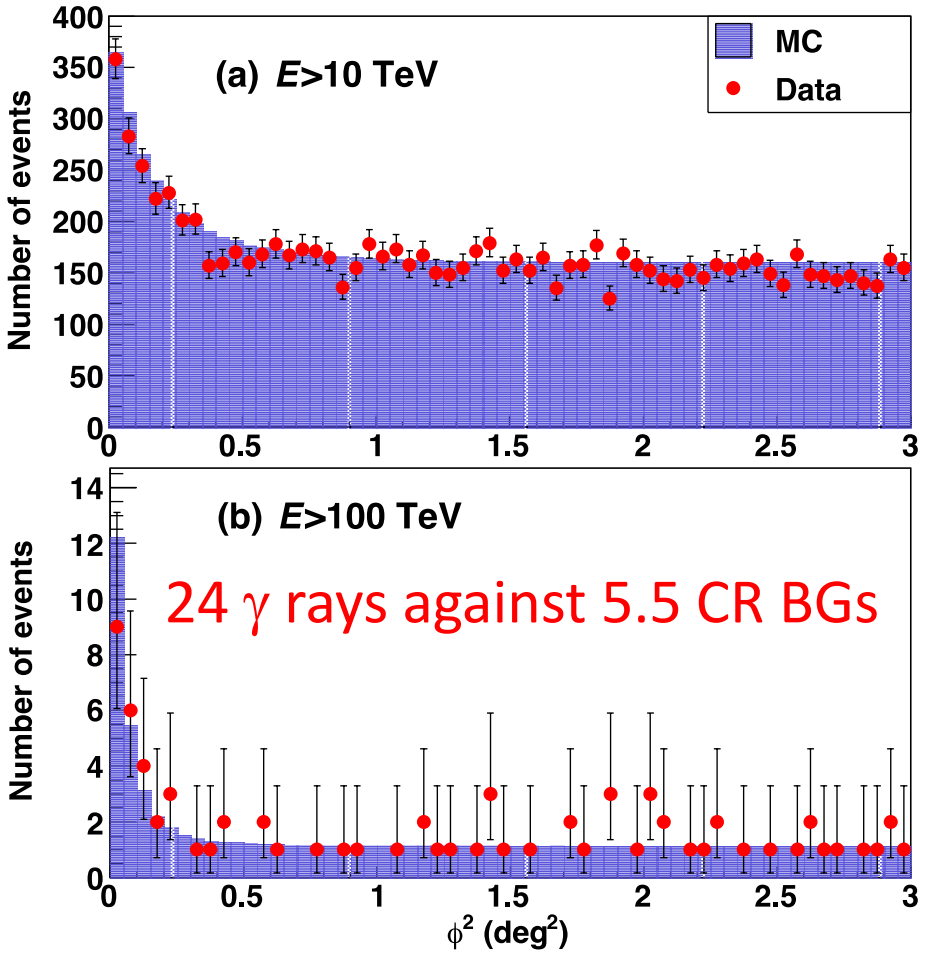


Gamma-ray Emission from Crab





Data vs MC

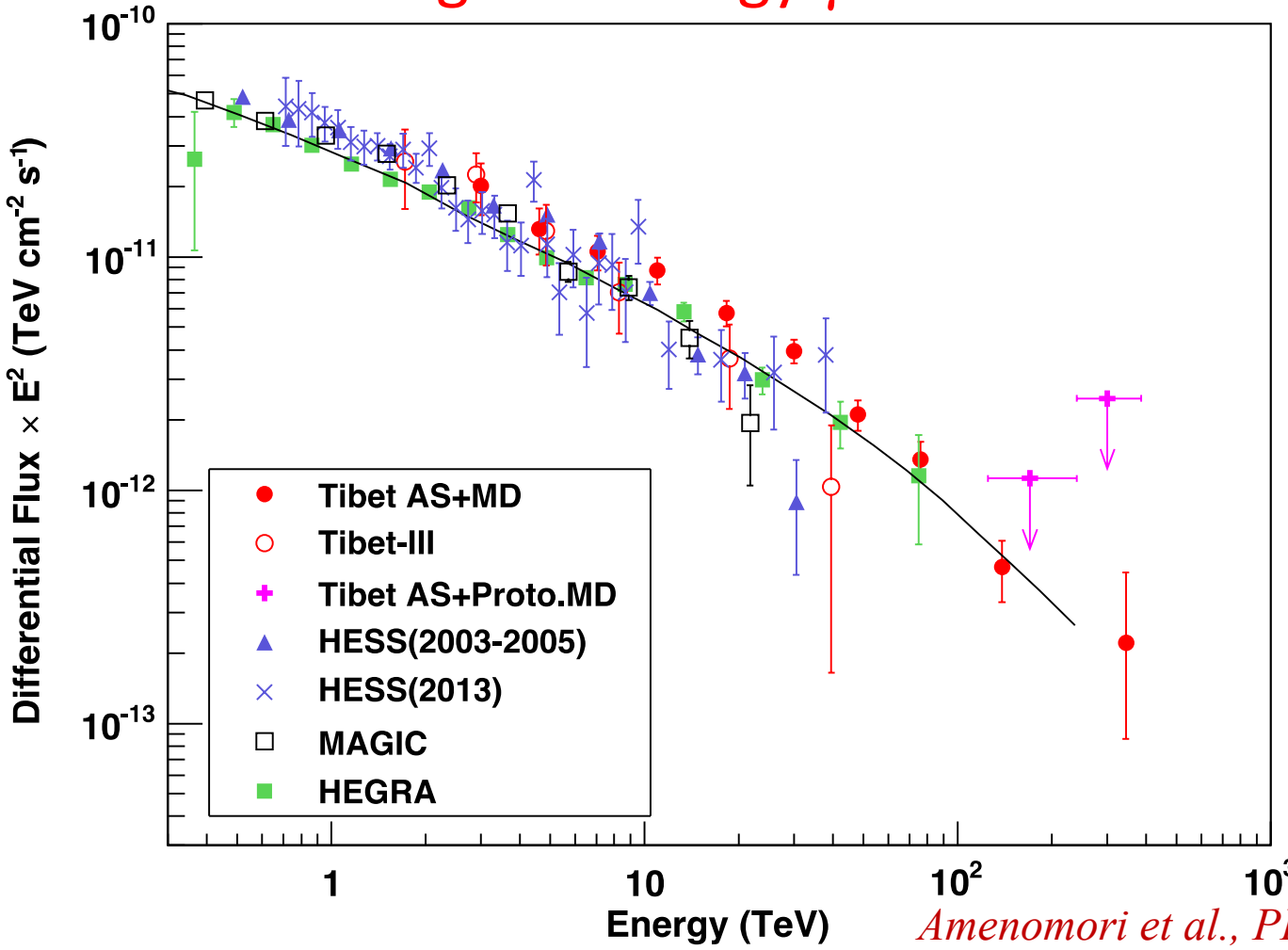


First Detection of Sub-PeV γ (5.6σ)

Amenomori et al., PRL
Supplemental Material (2019)

Energy spectrum of the Crab

The highest energy γ ~450 TeV



Amenomori et al., PRL (2019)

Thick curve： the expected flux by the inverse Compton model normalized to HEGRA data *Aharonian+, ApJ, 614, 897 (2004)*

Viewpoint: Highest Energy Astrophysical Photons Detected

Rene A. Ong, Department of Physics and Astronomy, University of California, Los Angeles, CA, USA

July 29, 2019 • *Physics* 12, 87

PHYSICAL REVIEW LETTERS **123,** 051101 (2019)

Editors' Suggestion | Featured in Physics

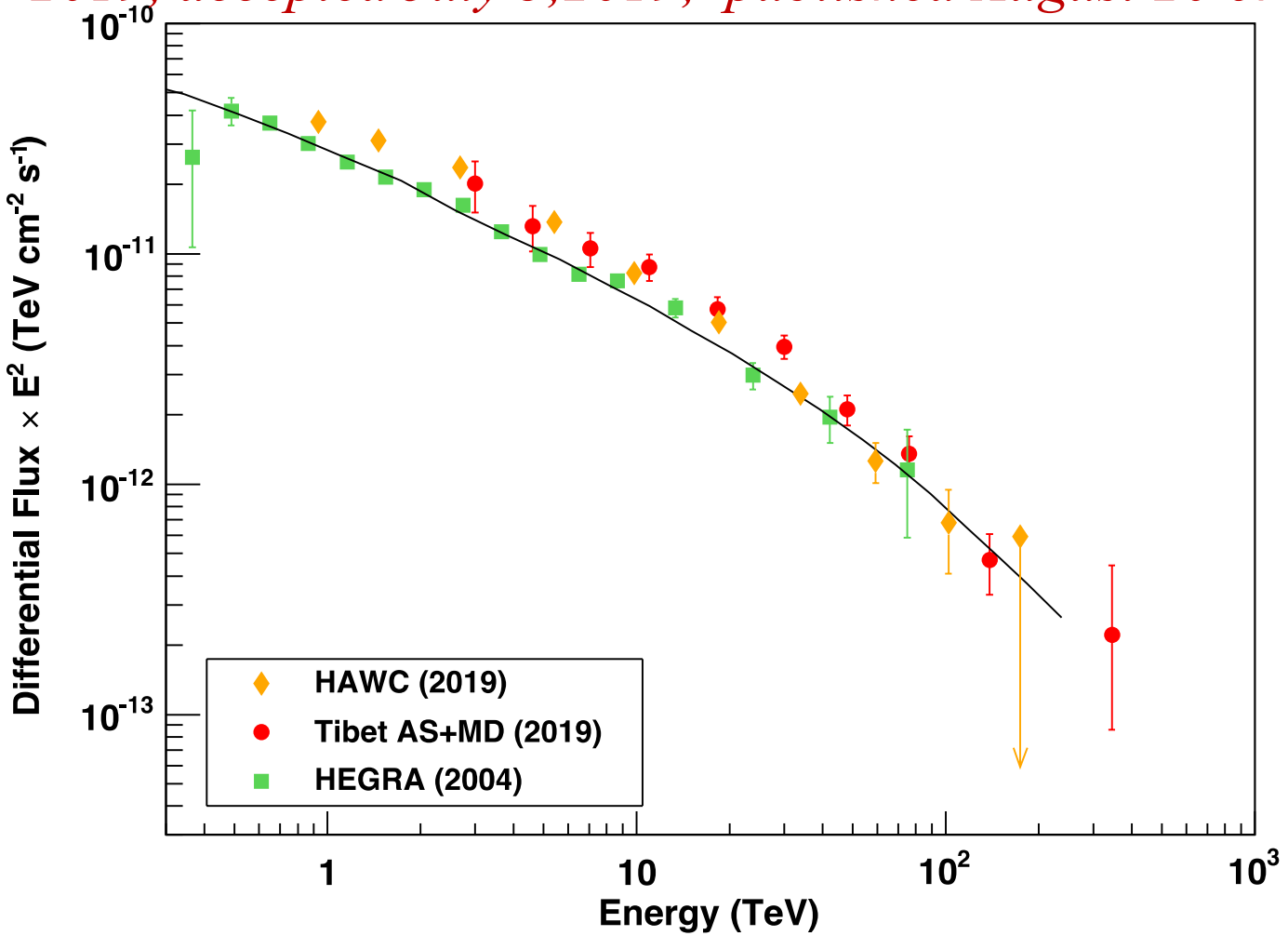
Received April 4, 2019, accepted June 13, published July 29, 2019 in PRL

First Detection of Photons with Energy beyond 100 TeV from an Astrophysical Source

M. Amenomori,[1] Y. W. Bao,[2] X. J. Bi,[3] D. Chen,[4] T. L. Chen,[5] W. Y. Chen,[3] Xu Chen,[3,6,†] Y. Chen,[2] Cirennima,[5] S. W. Cui,[7] Danzengluobu,[5] L. K. Ding,[3] J. H. Fang,[3,6] K. Fang,[3] C. F. Feng,[8] Zhaoyang Feng,[3] Z. Y. Feng,[9] Qi Gao,[5] Q. B. Gou,[3] Y. Q. Guo,[3] H. H. He,[3] Z. T. He,[7] K. Hibino,[10] N. Hotta,[11] Haibing Hu,[5] H. B. Hu,[3] J. Huang,[3,§] H. Y. Jia,[9] L. Jiang,[3] H. B. Jin,[4] F. Kajino,[12] K. Kasahara,[13] Y. Katayose,[14] C. Kato,[15] S. Kato,[16] K. Kawata,[16,*] M. Kozai,[17] Labaciren,[5] G. M. Le,[18] A. F. Li,[19,8,3] H. J. Li,[5] W. J. Li,[3,9] Y. H. Lin,[3,6] B. Liu,[2] C. Liu,[3] J. S. Liu,[3] M. Y. Liu,[5] Y.-Q. Lou,[20] H. Lu,[3] X. R. Meng,[5] H. Mitsui,[14] K. Munakata,[15] Y. Nakamura,[3] H. Nanjo,[1] M. Nishizawa,[21] M. Ohnishi,[16] I. Ohta,[22] S. Ozawa,[13] X. L. Qian,[23] X. B. Qu,[24] T. Saito,[25] M. Sakata,[12] T. K. Sako,[16] Y. Sengoku,[14] J. Shao,[3,8] M. Shibata,[14] A. Shiomi,[26] H. Sugimoto,[27] M. Takita,[16,‡] Y. H. Tan,[3] N. Tateyama,[10] S. Torii,[13] H. Tsuchiya,[28] S. Udo,[10] H. Wang,[3] H. R. Wu,[3] L. Xue,[8] K. Yagisawa,[14] Y. Yamamoto,[12] Z. Yang,[3] A. F. Yuan,[5] L. M. Zhai,[4] H. M. Zhang,[3] J. L. Zhang,[3] X. Zhang,[2] X. Y. Zhang,[8]

Comparison with HAWC (3.3σ>100 TeV)

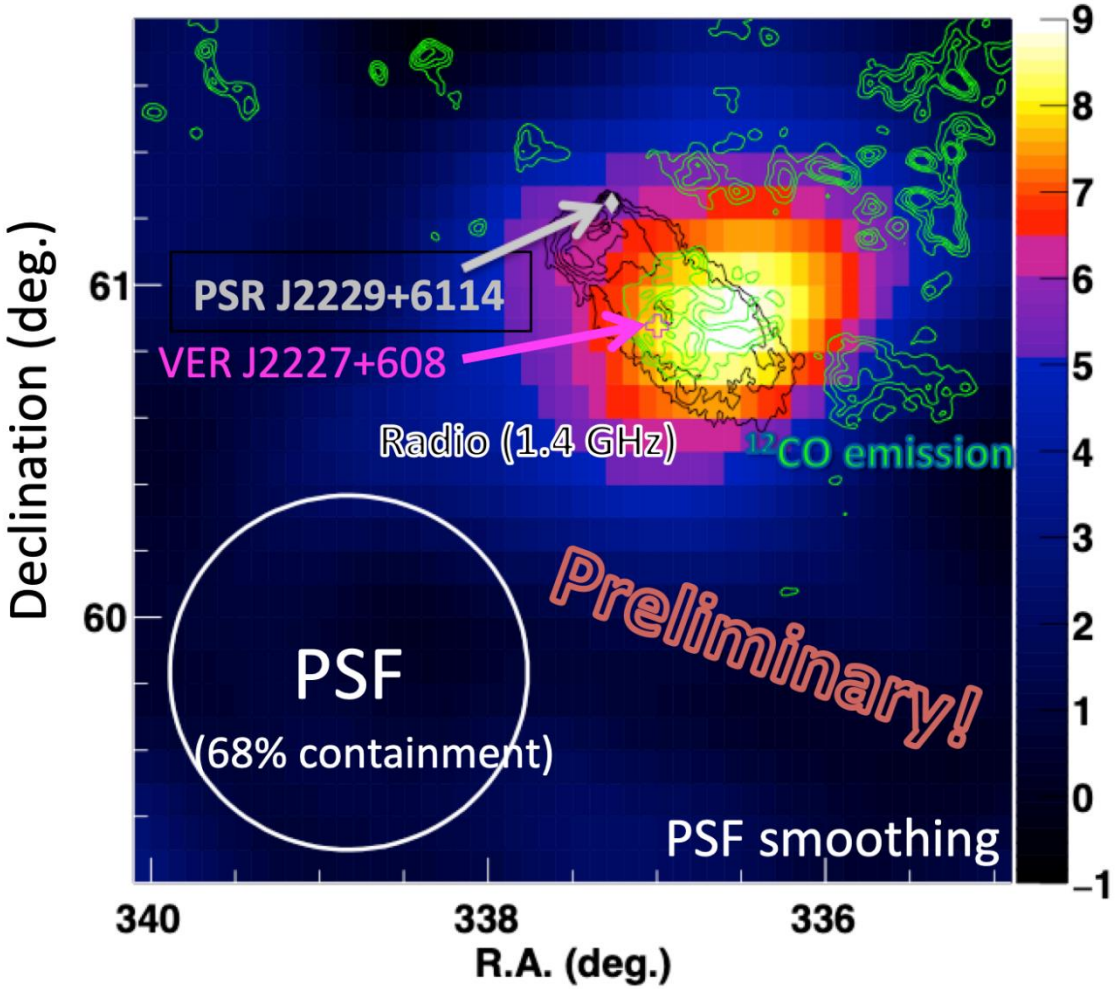
Abeysekara et al. ApJ 881:134 (pp1-13), Received May 28, 2019, accepted July 3,2019, published August 20 or 21, 2019



Thick curve： the expected flux by the inverse Compton model normalized to HEGRA data *Aharonian+, ApJ, 614, 897 (2004)*

SNR G106.3+2.7

$E > 10$ TeV

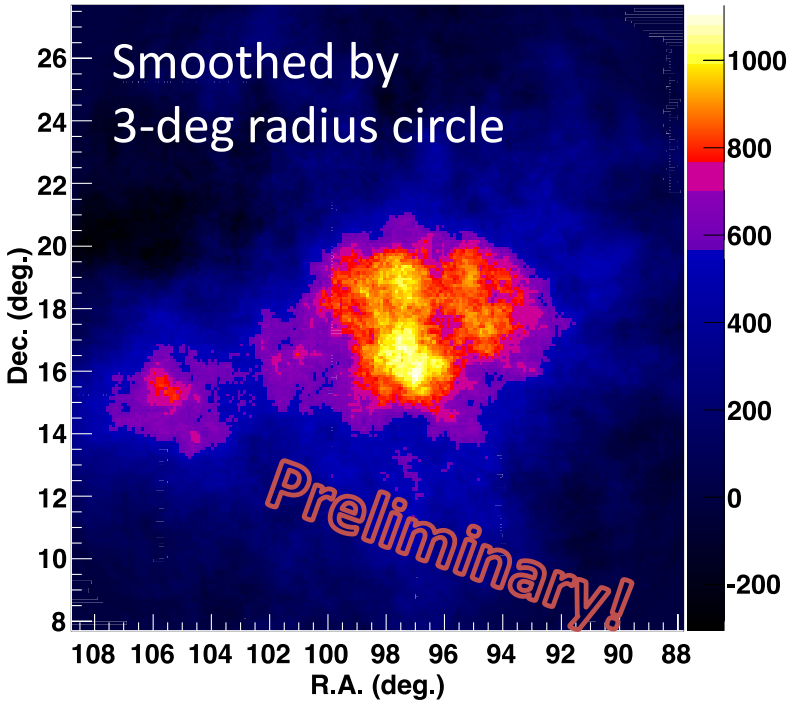


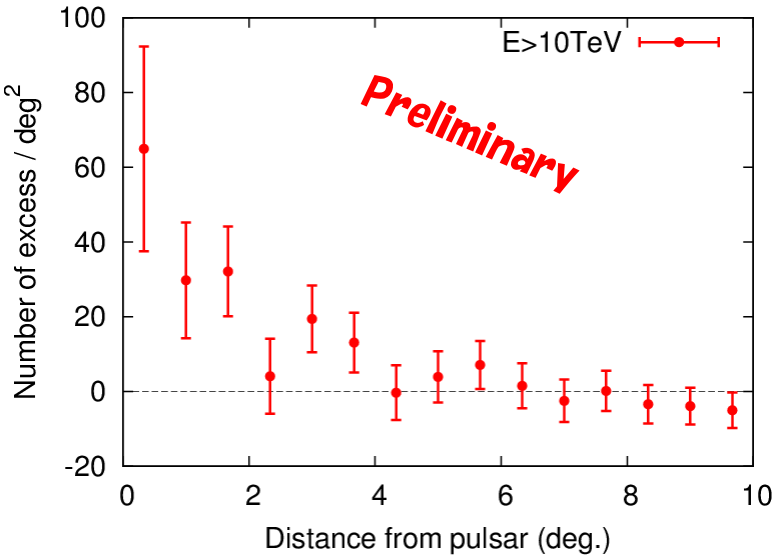
- ✓ Tibet emission centroid coincident with molecular cloud indicated by CO emission contours ※consistent with VERITAS
- ✓ spectrum under analysis

T. K. Sako ICRC2019 #778

Geminga

$E > 10$ TeV



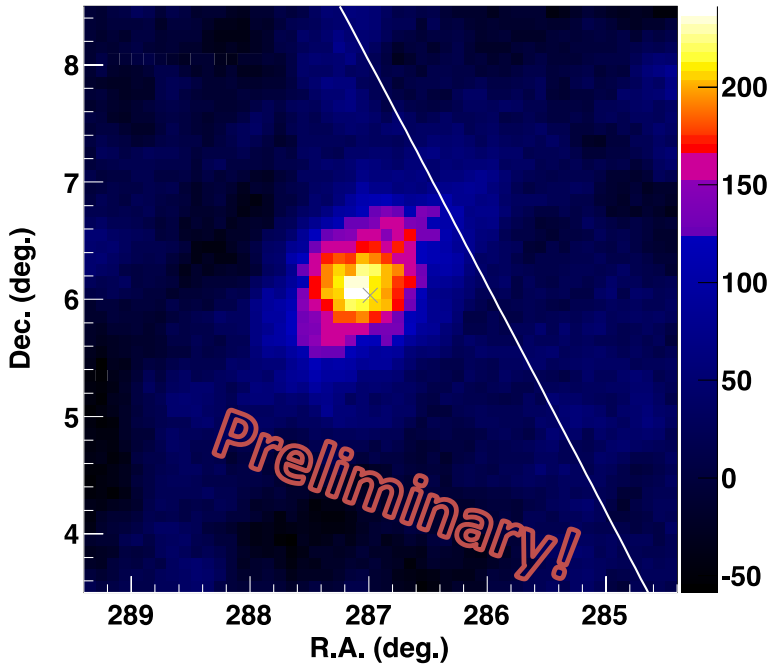


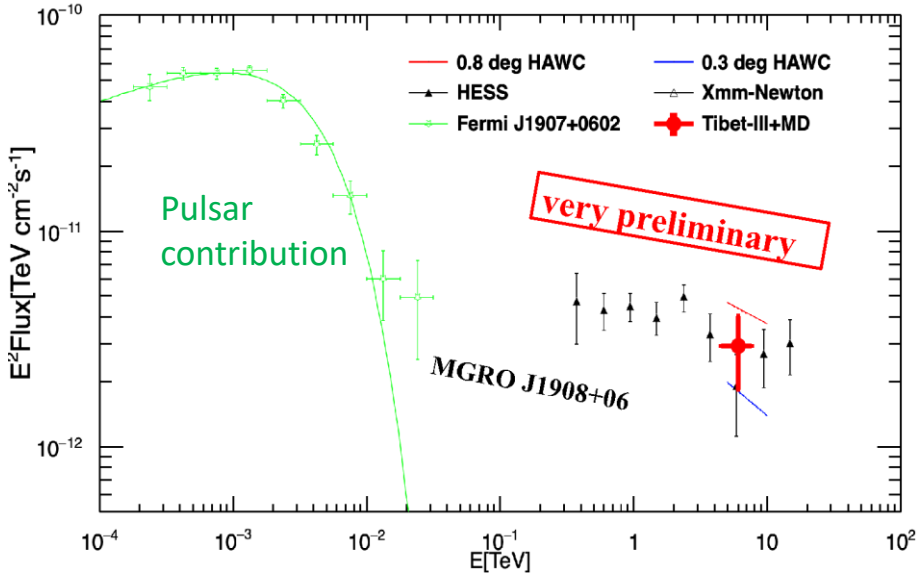
- ✓ Very extended source → Consistent with HAWC
- ✓ Spectrum under analysis

Katayose ICRC2019 #770

MGRO J1908+06

$E > 10$ TeV



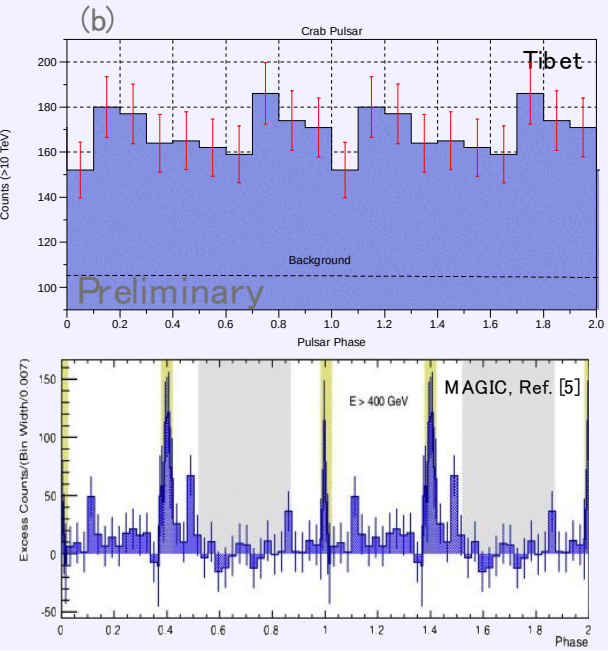


- ✓ Flux below 10 TeV is consistent with VERITAS
- ✓ Spectrum under analysis

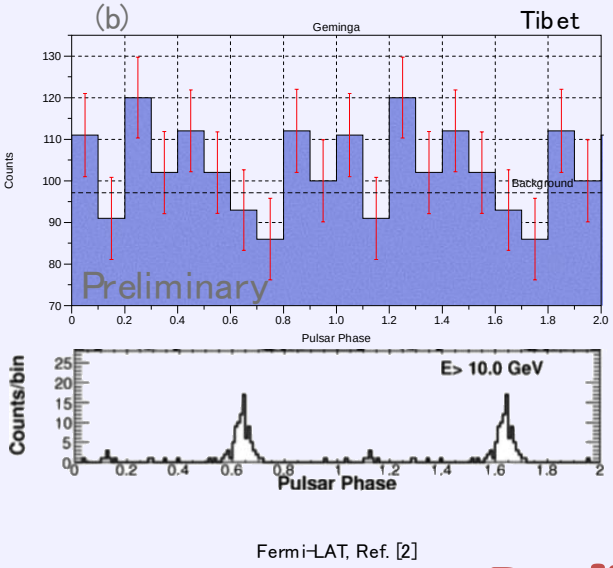
D. Chen ICRC2019 #648

Pulsar Analysis (>10TeV)

Crab pulsar

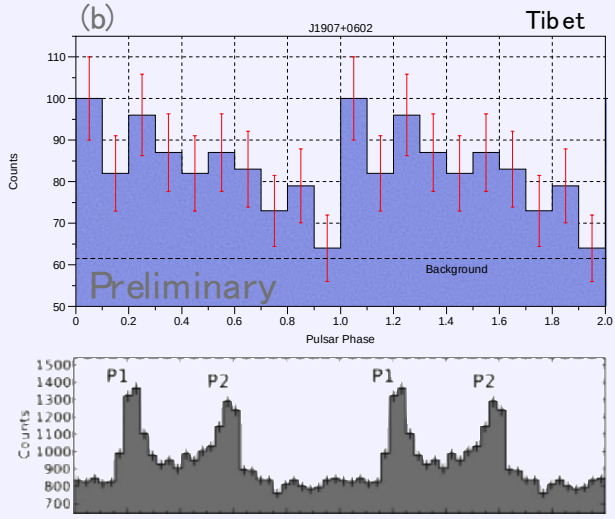


Geminga pulsar



Fermi-LAT, Ref. [2]

PSR J1907+0602



Fermi-LAT, Ref. [3]

Preliminary!

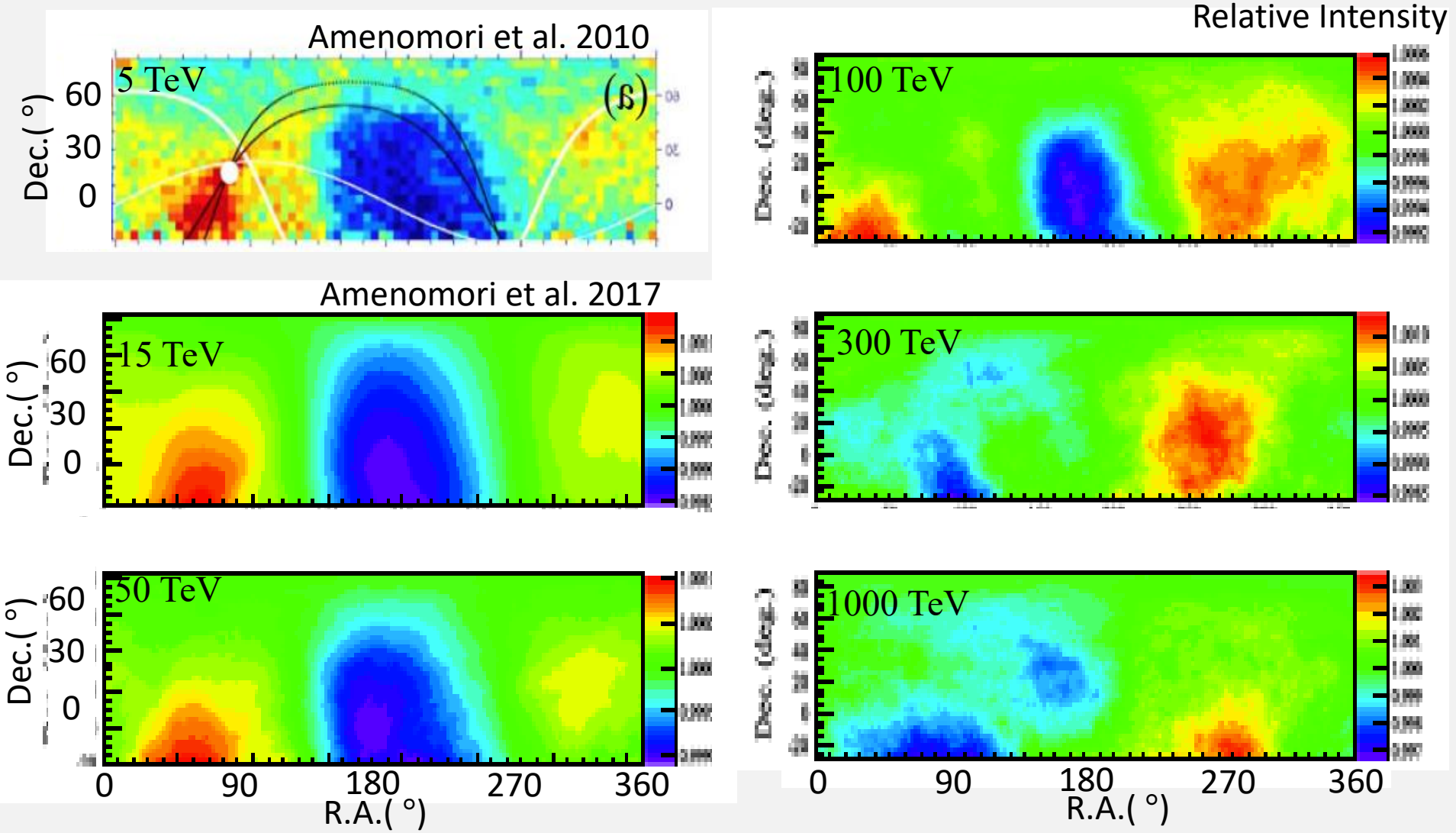
- ✓ No significant pulsed signals are found
- ✓ Under analysis around 100 TeV

Hibino ICRC2019 #695

Cosmic Ray Anisotropy

Previous Result observed by Tibet ASγ

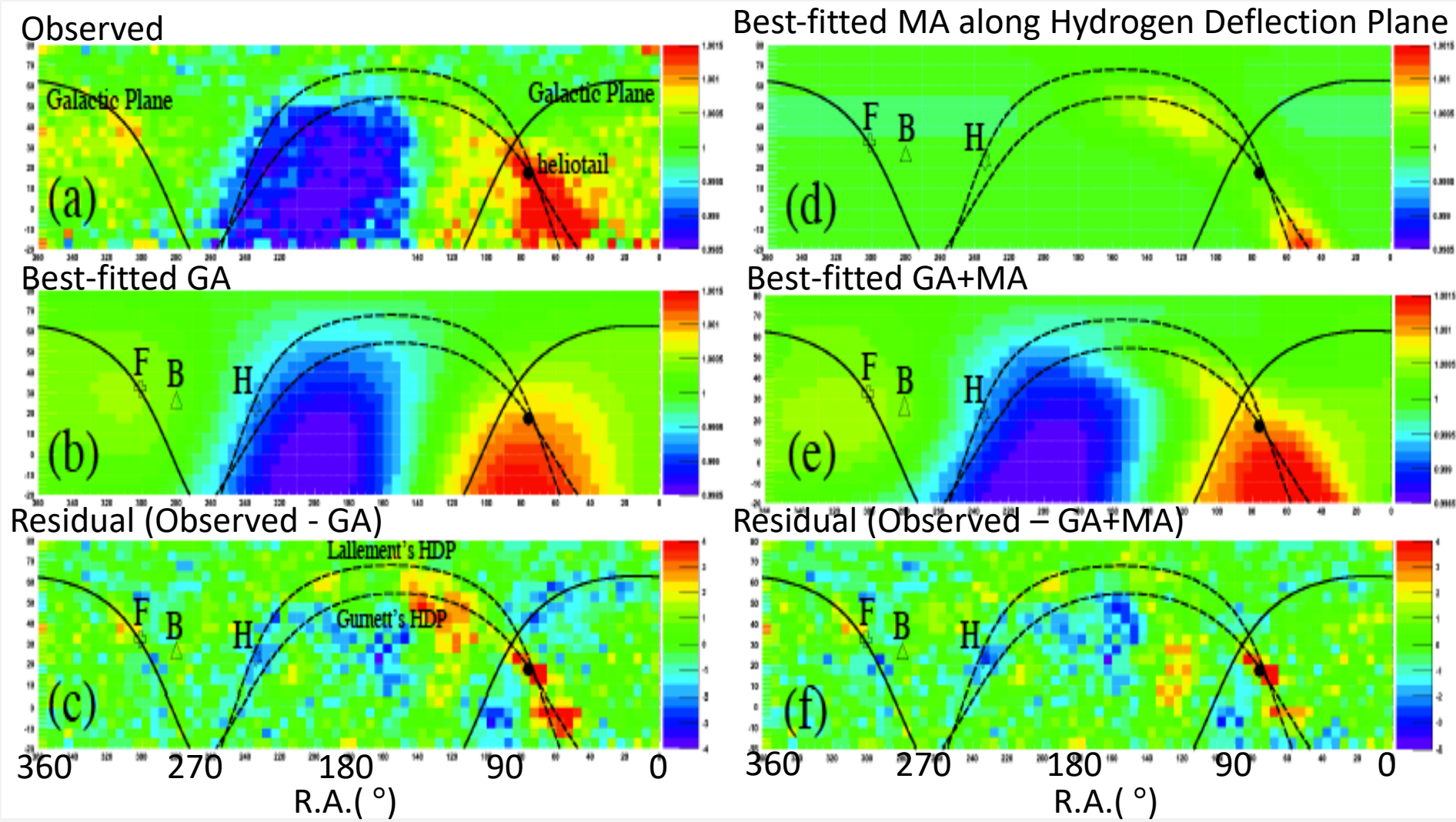
Sidereal anisotropy of cosmic ray including gamma ray/electron/positron at multi TeV – PeV



Previous Result observed by Tibet ASγ

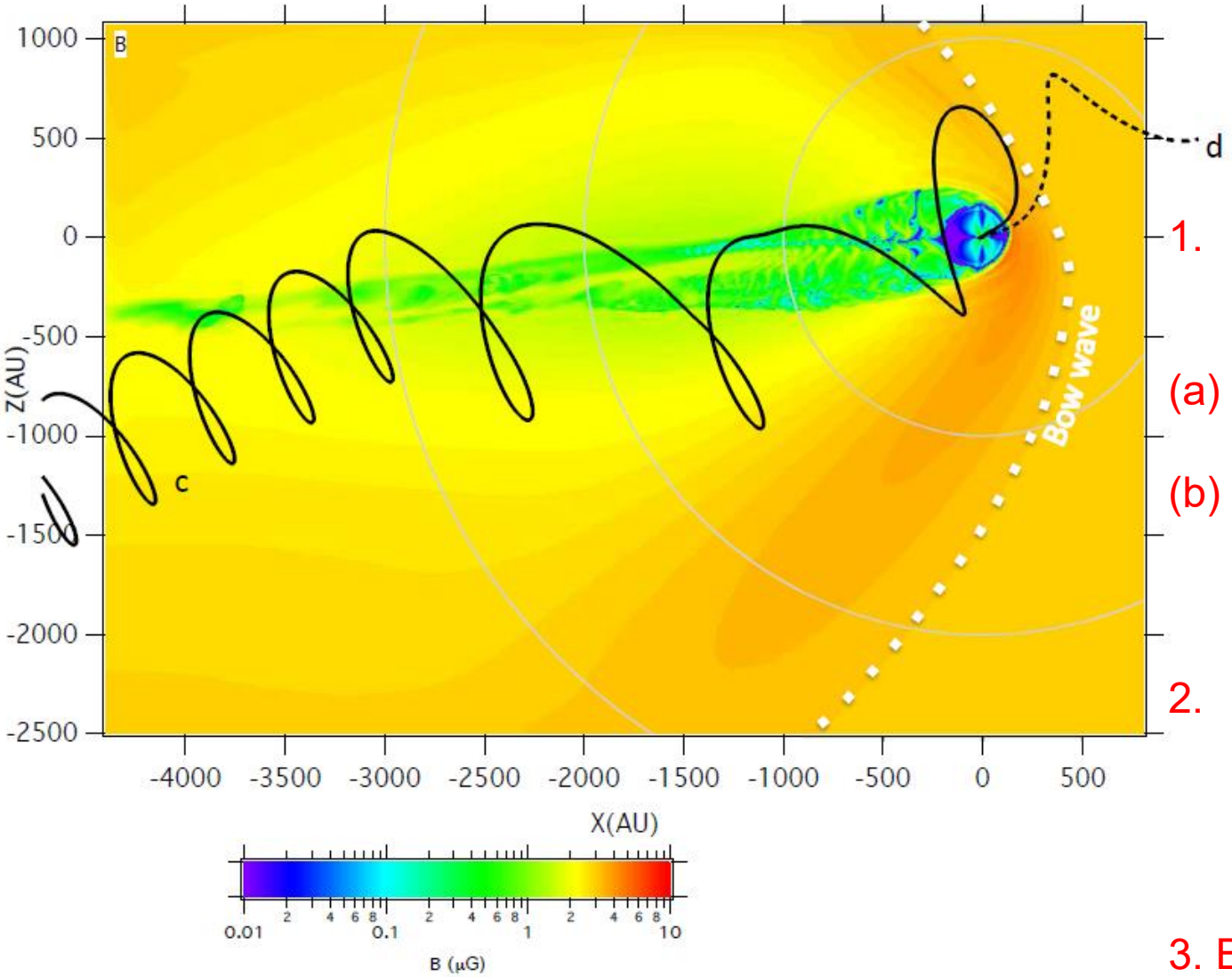
In multi TeV region, we found global anisotropy (1st and 2nd: GA) and middle scale anisotropies (MA)

Amenomori et al. 2010



Heliospheric “distortion” model

M. Zhang+ (J. of Physics conf. ser. 767 012027 2016)



1. Original anisotropy in ISM assumed

(a) B in ISM

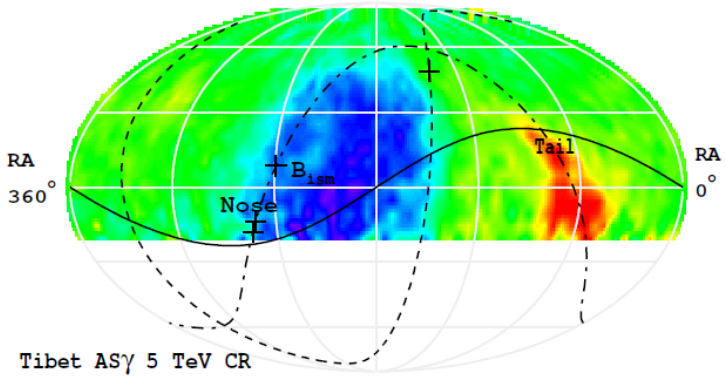
(b) 1st & 2nd harmonics + particle density gradient

2. Fit data to anisotropy simulated by MHD heliospheric distortion model

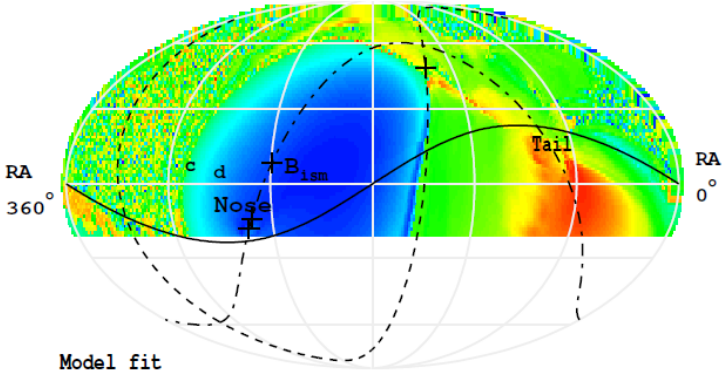
3. Best fit original anisotropy in ISM inferred

Heliospheric “distortion” model

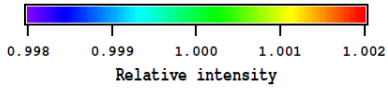
M. Zhang+ (J. of Physics conf. ser. 767 012027 2016)

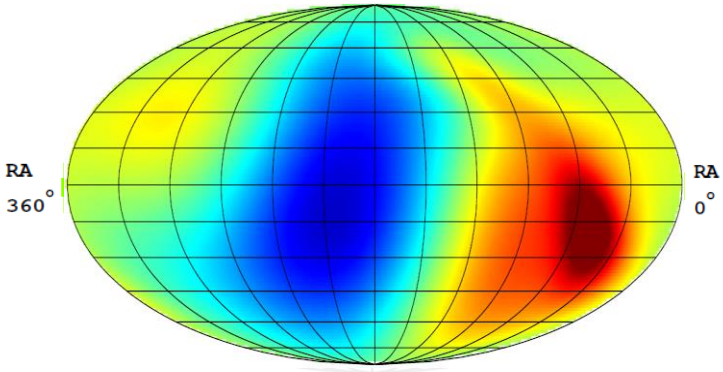


Tibet ASγ 5 TeV CR
Anisotropy measurement

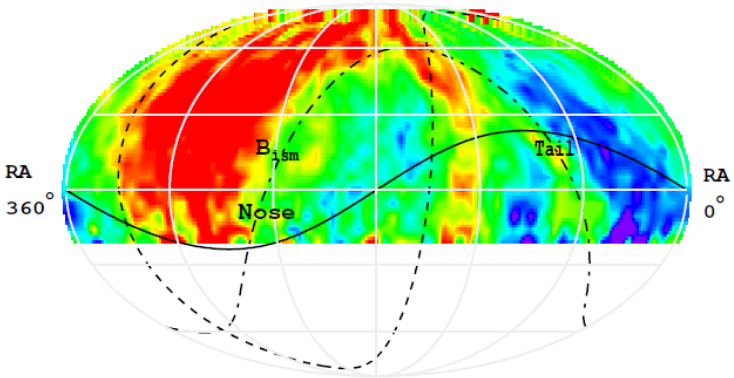


Model fit

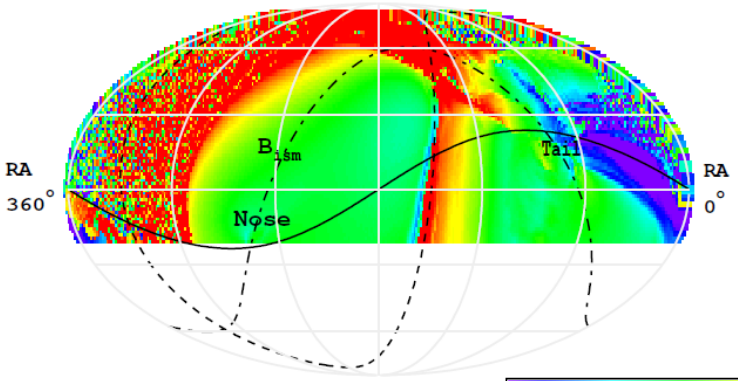




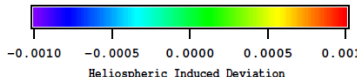
Inferred anisotropy in ISM



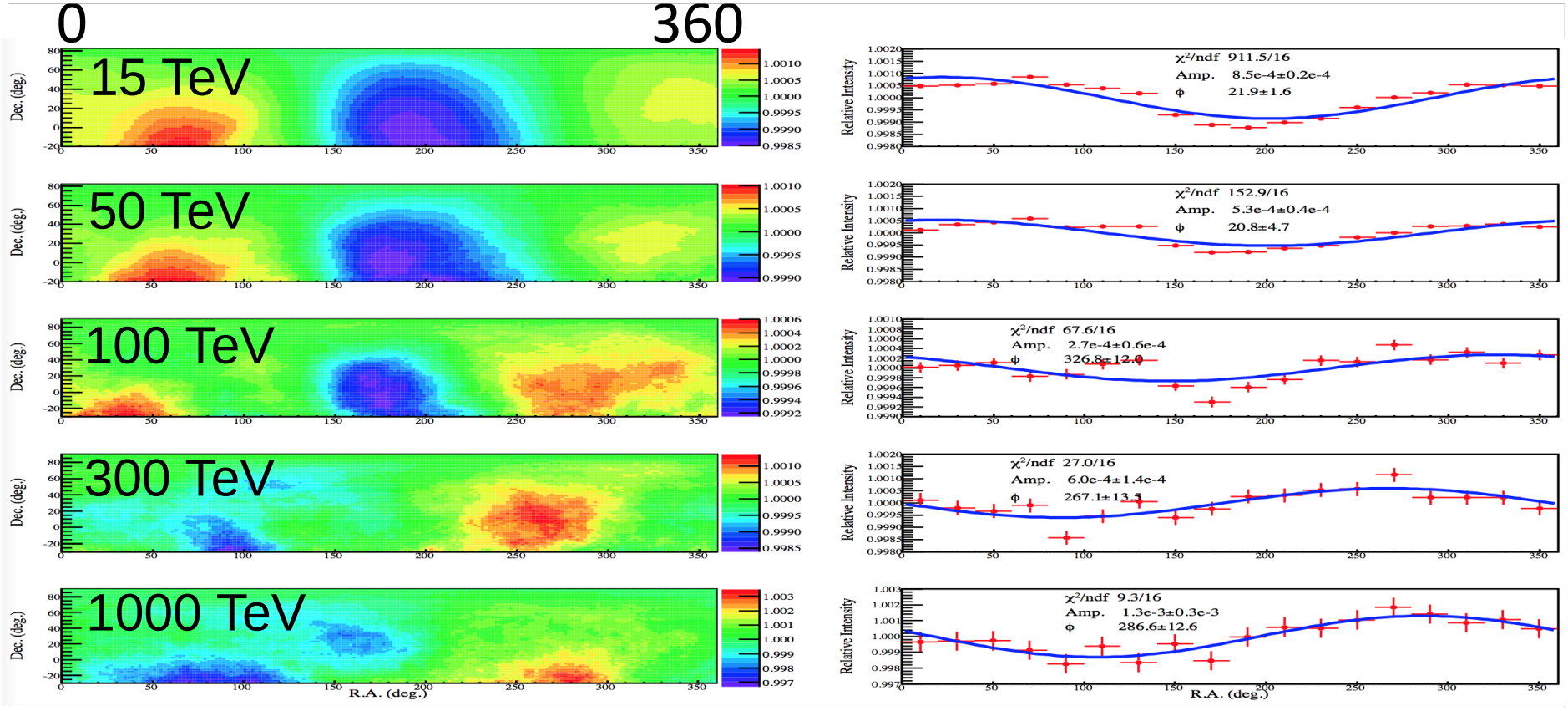
Measurement - inferred ISM



Model - Inferred ISM



10-1000TeV Sidereal Anisotropy (Tibet in the northern sky)



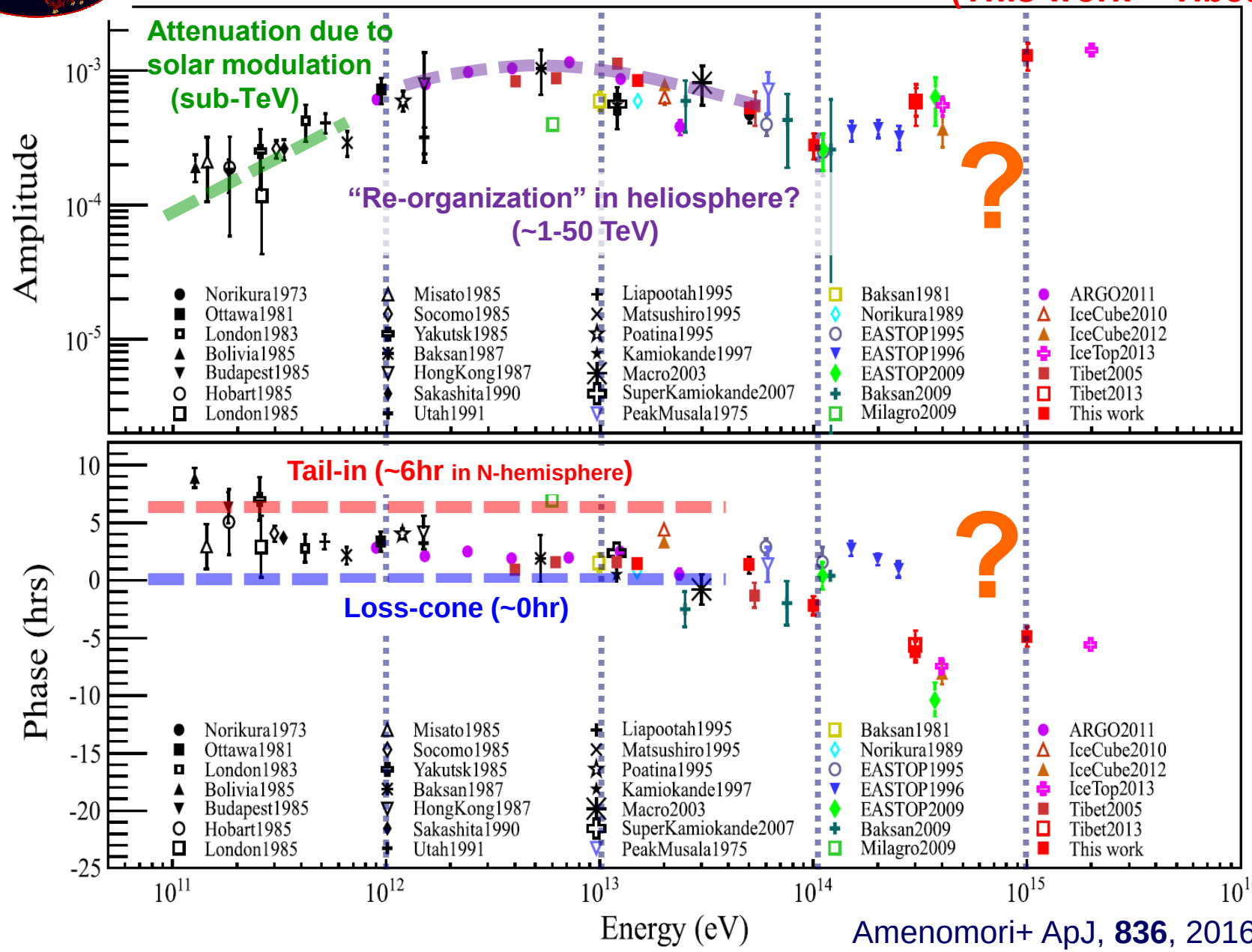
M. Amenomori et al, ApJ, 836, 153-1-7, (2017)

Yi Zhang ICRC2019 #488

>300 TeV new component!, consistent with IceCube >400 TeV

Sidereal diurnal anisotropy of CRs

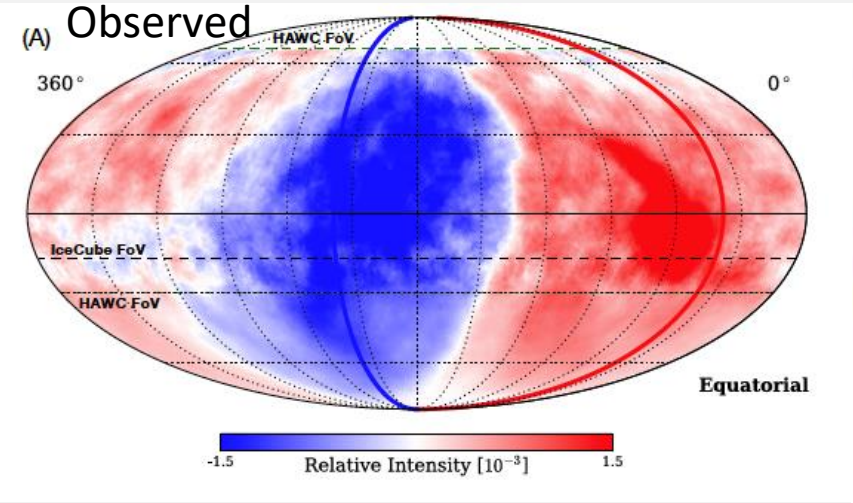
(This work = Tibet)

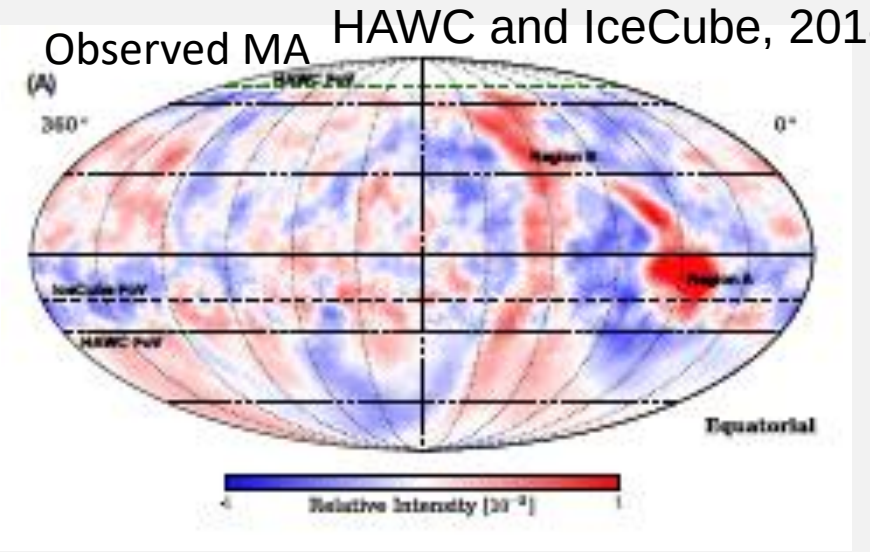


Amenomori+ ApJ, **836**, 2016, 153

Previous Results observed by other experiment

- ARGO, HAWC, and other experiments reported the results in multi TeV – serval tens TeV region consistent with Tibet ASγ (Bartoli et al.2013,2018, Abeysekara et al. 2014,2018)
- All sky map observed by HAWC & IceCube at 10TeV

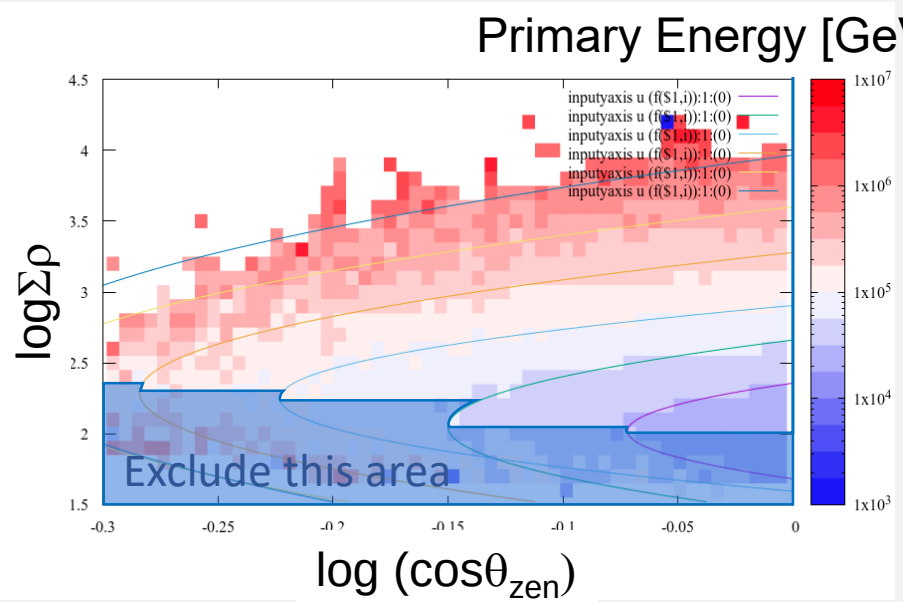




Still unknown what causes these sidereal anisotropies.
Observing sidereal anisotropies of cosmic ray and gamma ray/electron/positron separately will provide the new information around our solar system.

Event Selection

- Period : 2014 February - 2017 May (Live time : 719 days)
- Event selection
  - Zenith angle $\theta \leq 60^{\circ}$
  - Shower core locates in inner area
  - Four-fold coincidence (each array recorded more than 1.25 particles)
- Event selection for High Energy
  - More than 16 detectors used in the air shower reconstruction
  - $\sum\rho$ (the sum of particle density) selection



Total Events

After Event Selection

Number of Events : 2.740×10^9

Mode Energy : >20 TeV

Analysis Method & Cut Condition

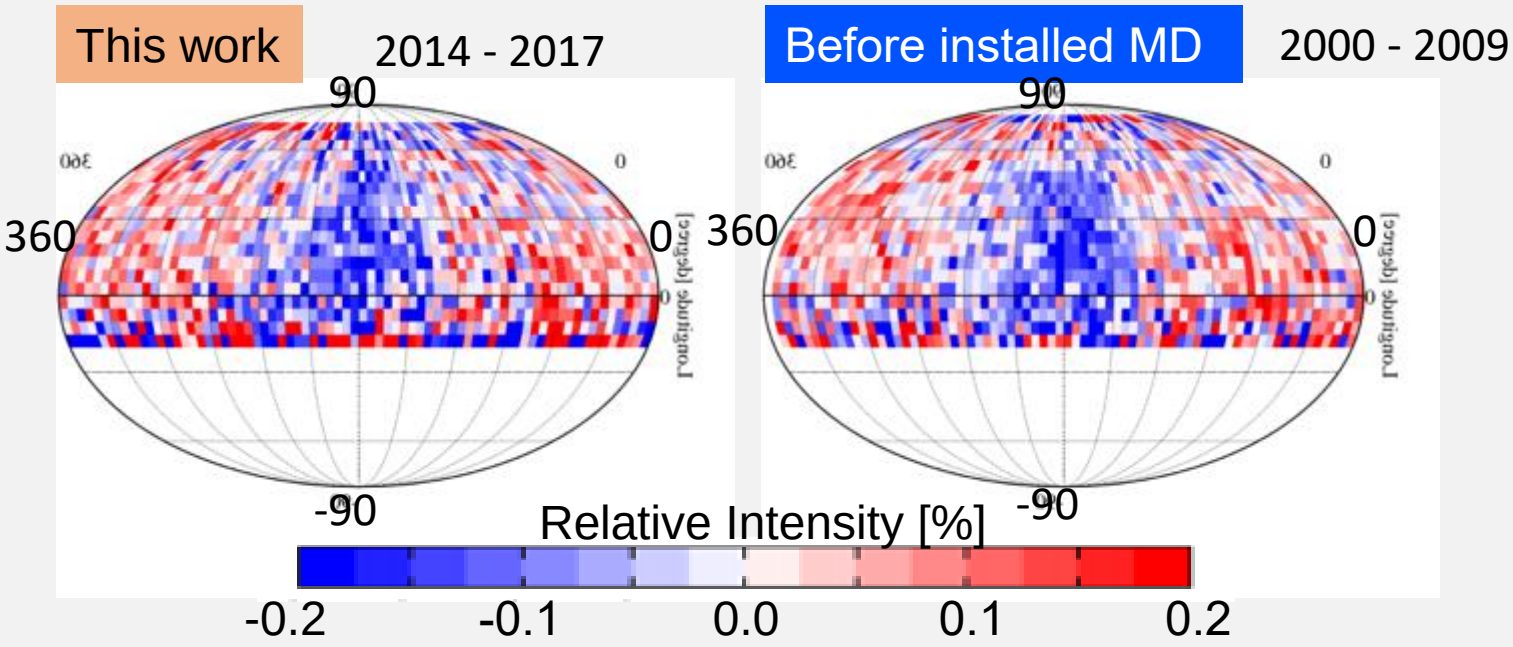
To exclude the γ ray (electron and positron) like event,
We introduced the additional cut

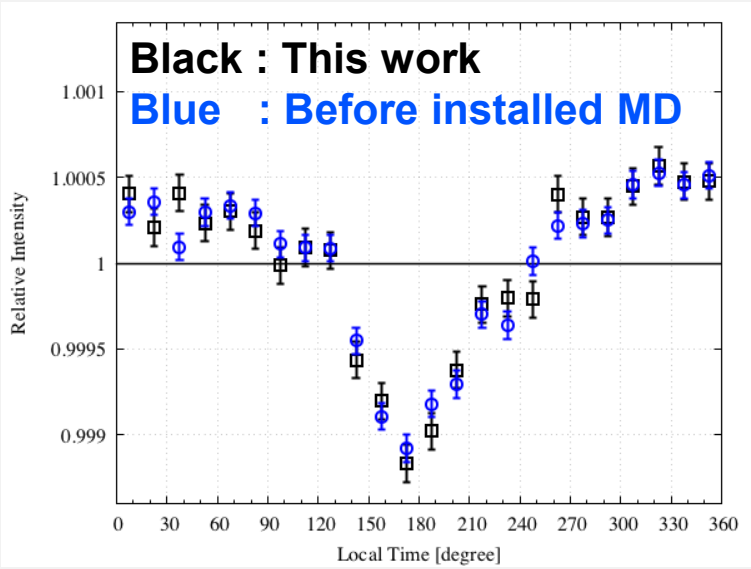
sum of number of μ-on detected by MD (ΣN_μ) >1

Total Events	μ–on Rich Events
After event Selection	After event Selection
Number of Events : 2.740×10^9	Number of Events : 2.716×10^9
Mode Energy : >20 TeV	Mode Energy : >20 TeV

0.024×10^9 (~0.86%) events excluded as γ ray like events

Comparison with before MD installation



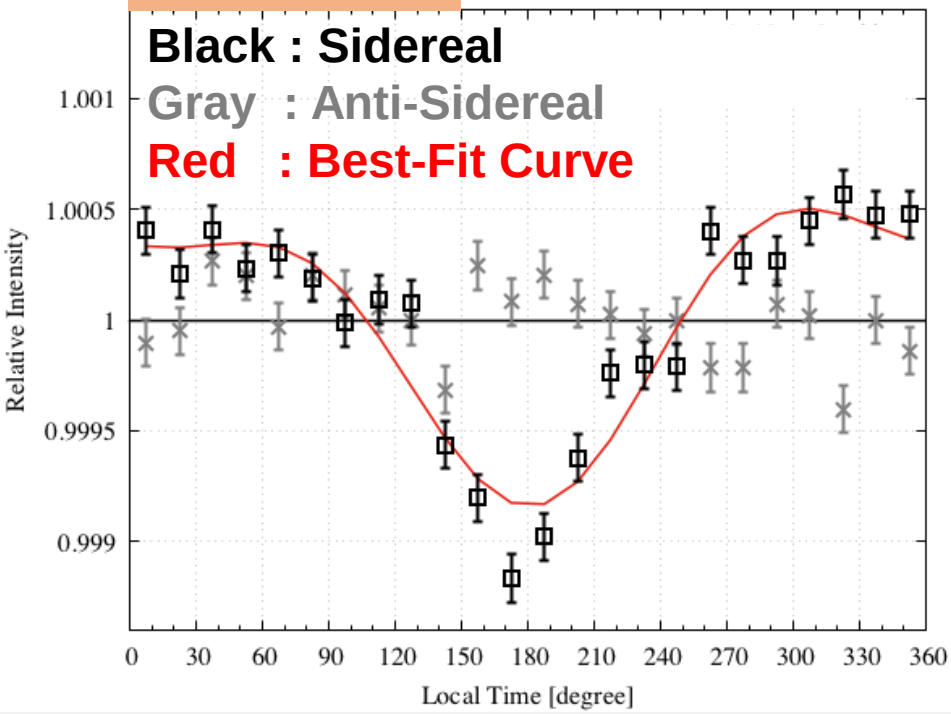


This result is consistent with the result before installed MD.
Tibet ASγ provide the equable data identically before installed MD.

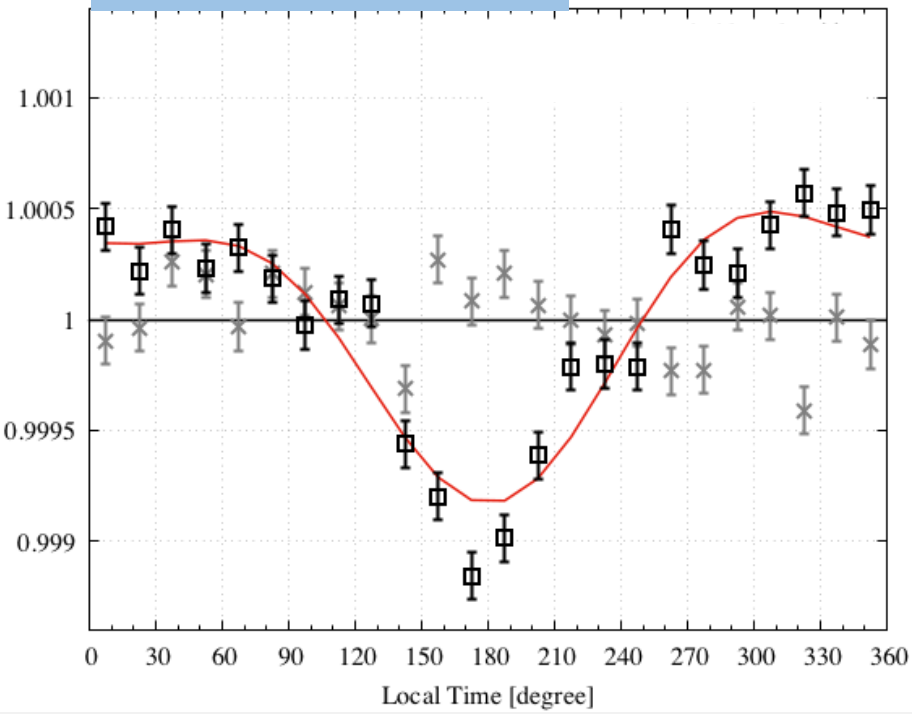
Result of Sidereal Anisotropy (1D)

Energy ::>20 TeV

Total Events



μ–on Rich Events



Fitting with 1st & 2nd harmonics $I(\alpha) = 1 + a_1 \cos(\alpha - \phi_1) + a_2 \cos(2\alpha - \phi_2)$

	a_i[%]	ϕ_i[°]
1st	0.060 ± 0.003	355.0 ± 2.9
2nd	0.025 ± 0.003	94.3 ± 3.4

	a_i[%]	ϕ_i[°]
1st	0.059 ± 0.003	355.5 ± 3.0
2nd	0.024 ± 0.003	93.4 ± 3.6

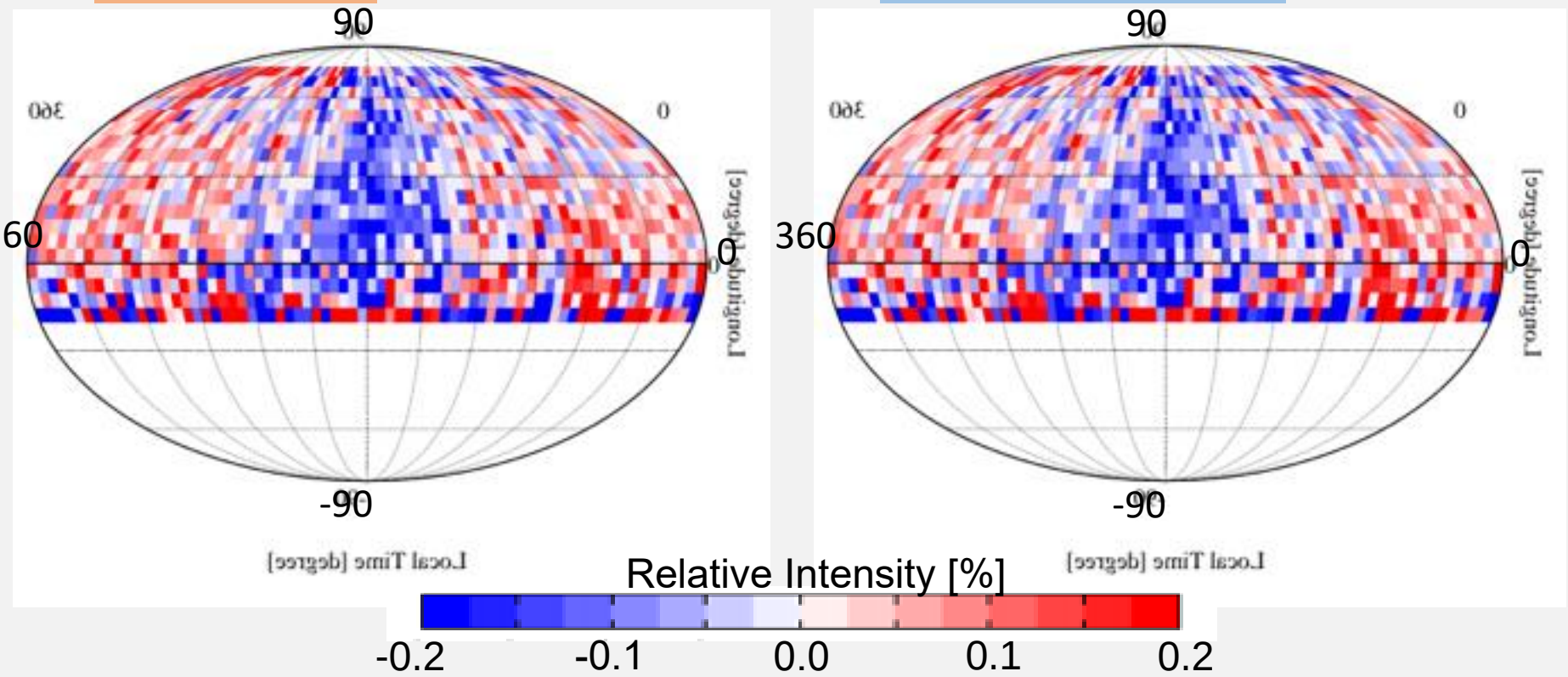
The EM components do not influence sidereal 1D projection.

Result of Sidereal Anisotropy (2D) Observed

Energy ::>20 TeV

Total Events

μ–on Rich Events



μ–on Rich Events consistent with Total Events

Fit with the 1st & 2nd anisotropy model denoting as

$$I(\alpha,\delta) = 1 + A_1 \cos(D(\alpha,\delta,;\alpha_1,0)) + A_2 \frac{2}{3}\cos^2(D(\alpha,\delta;\alpha_2,\delta_2)$$

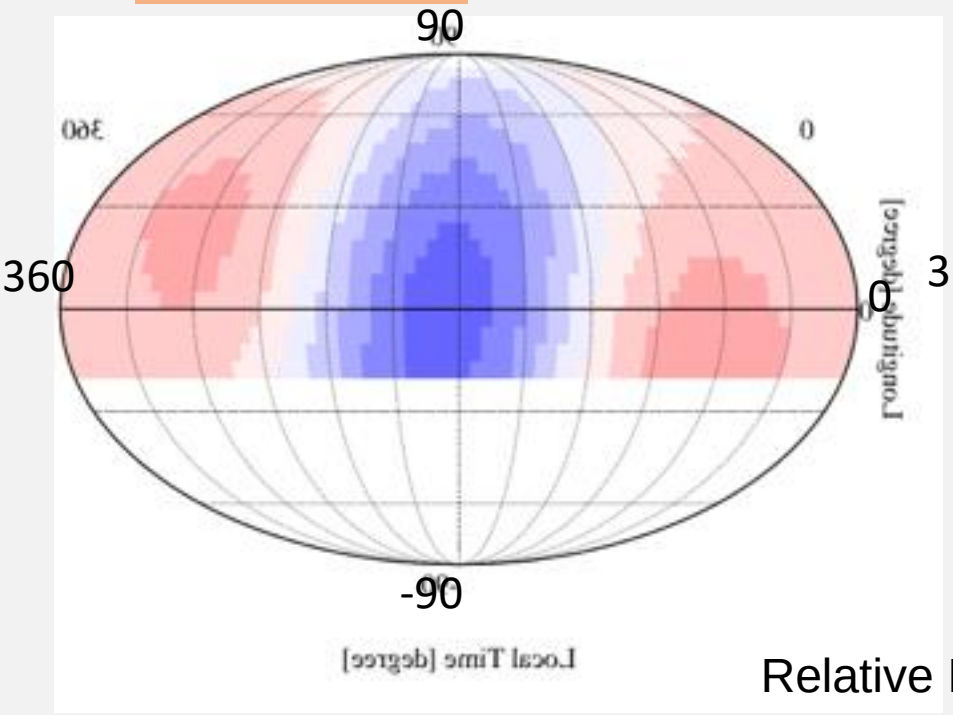
$D(\alpha,\delta;\alpha_i,\delta_i)$:Distance from peak direction / Best fit parameter $A_1, \alpha_1, A_2, \alpha_2, \delta_2$

Result of Sidereal Anisotropy (2D)

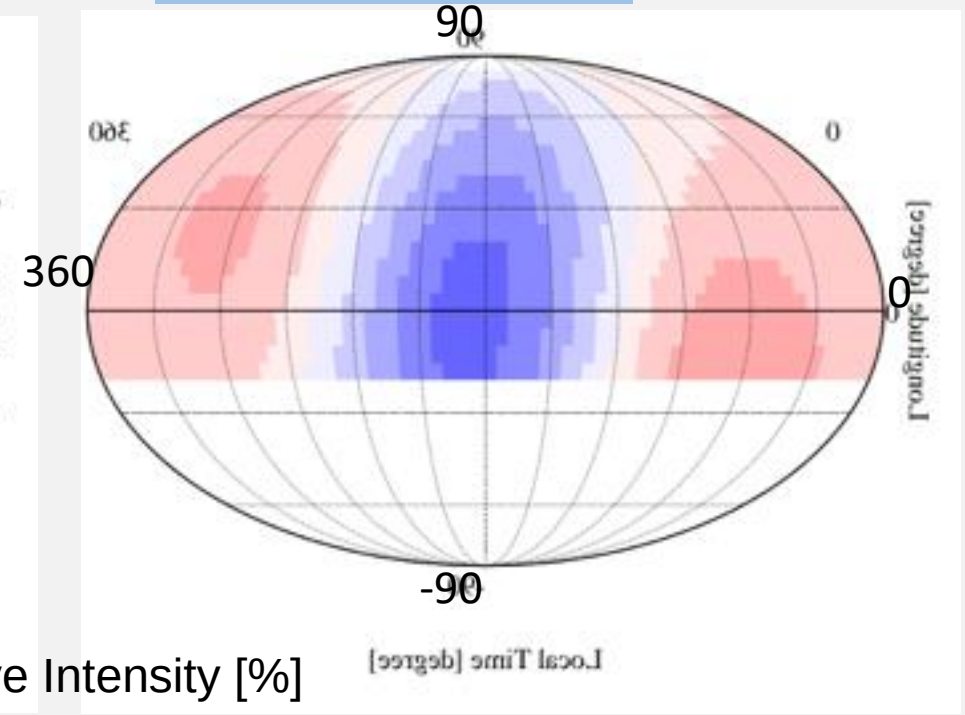
Energy ::>20 TeV

Best Fit Model

Total Events



μ–on Rich Events



Relative Intensity [%]

-0.2 -0.1 0.0 0.1 0.2

$$I(\alpha,\delta) = 1 + A_1 \cos(D(\alpha,\delta;\alpha_1,0)) + A_2 \frac{2}{3}\cos^2(D(\alpha,\delta;\alpha_2,\delta_2))$$

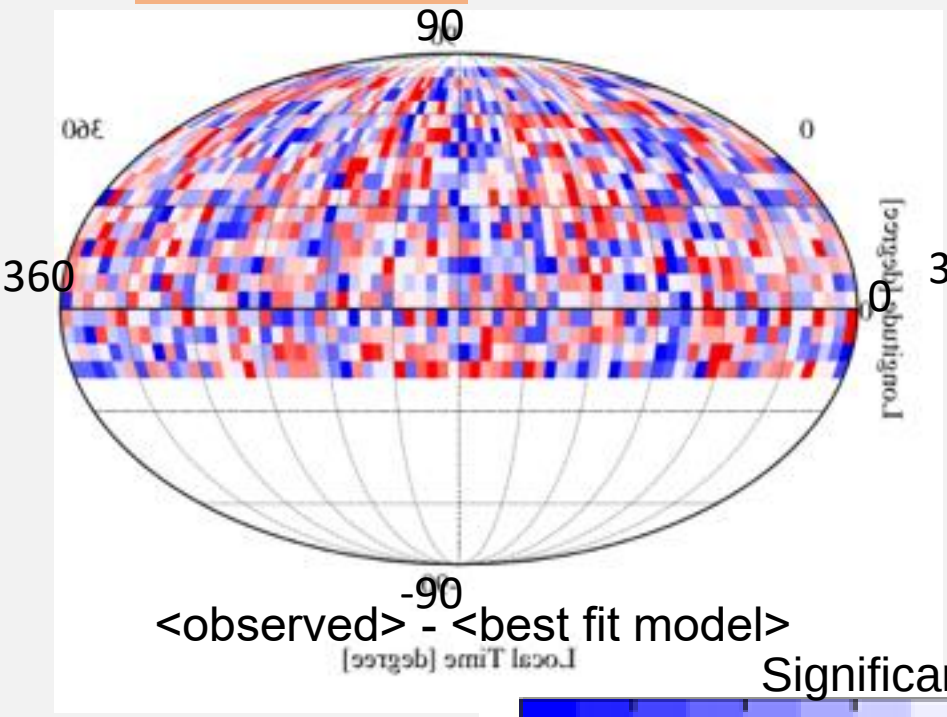
	A_i[%]	α_i[°]	δ_i[°]	χ^2/d. o. f
1st	0.075 ± 0.004	9.6 ± 5.0		1455.9/
2nd	0.054 ± 0.006	94.1 ± 3.2	−15.6 ± 5.1	1435

	A_i[%]	α_i[°]	δ_i[°]	χ^2/d. o. f
1st	0.075 ± 0.004	10.3 ± 4.8		1464.3/
2nd	0.052 ± 0.006	93.2 ± 3.4	−16.5 ± 5.3	1435

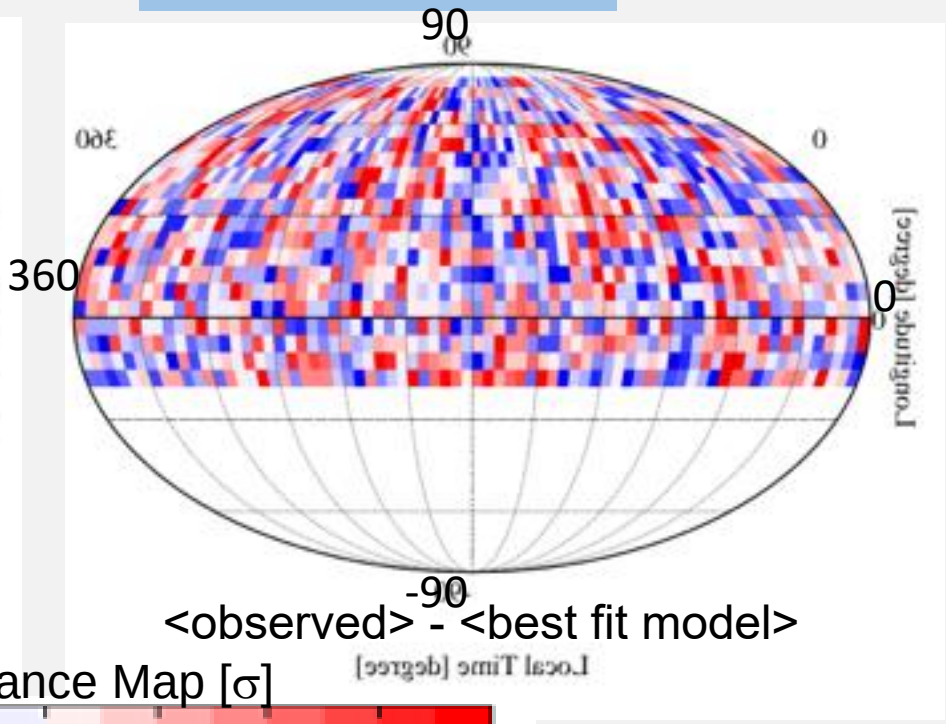
Result of Sidereal Anisotropy (2D) Residual

Energy ::>20 TeV

Total Events



μ–on Rich Events



Significance Map [σ]

-2 -1 0 1 2

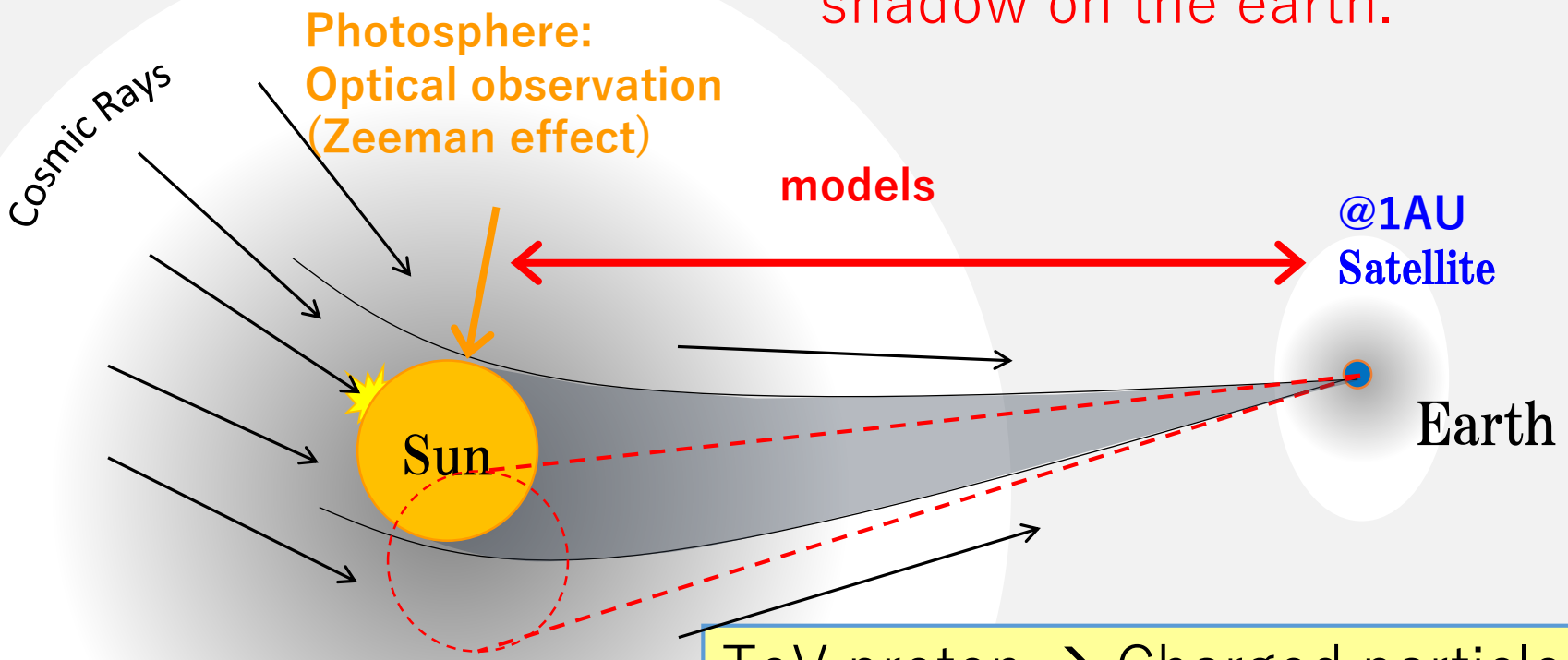
No difference is identified in
the best fit parameters & the residual map.

The EM components do not influence
large & middle scale anisotropies at >20 TeV.

Sun Shadow

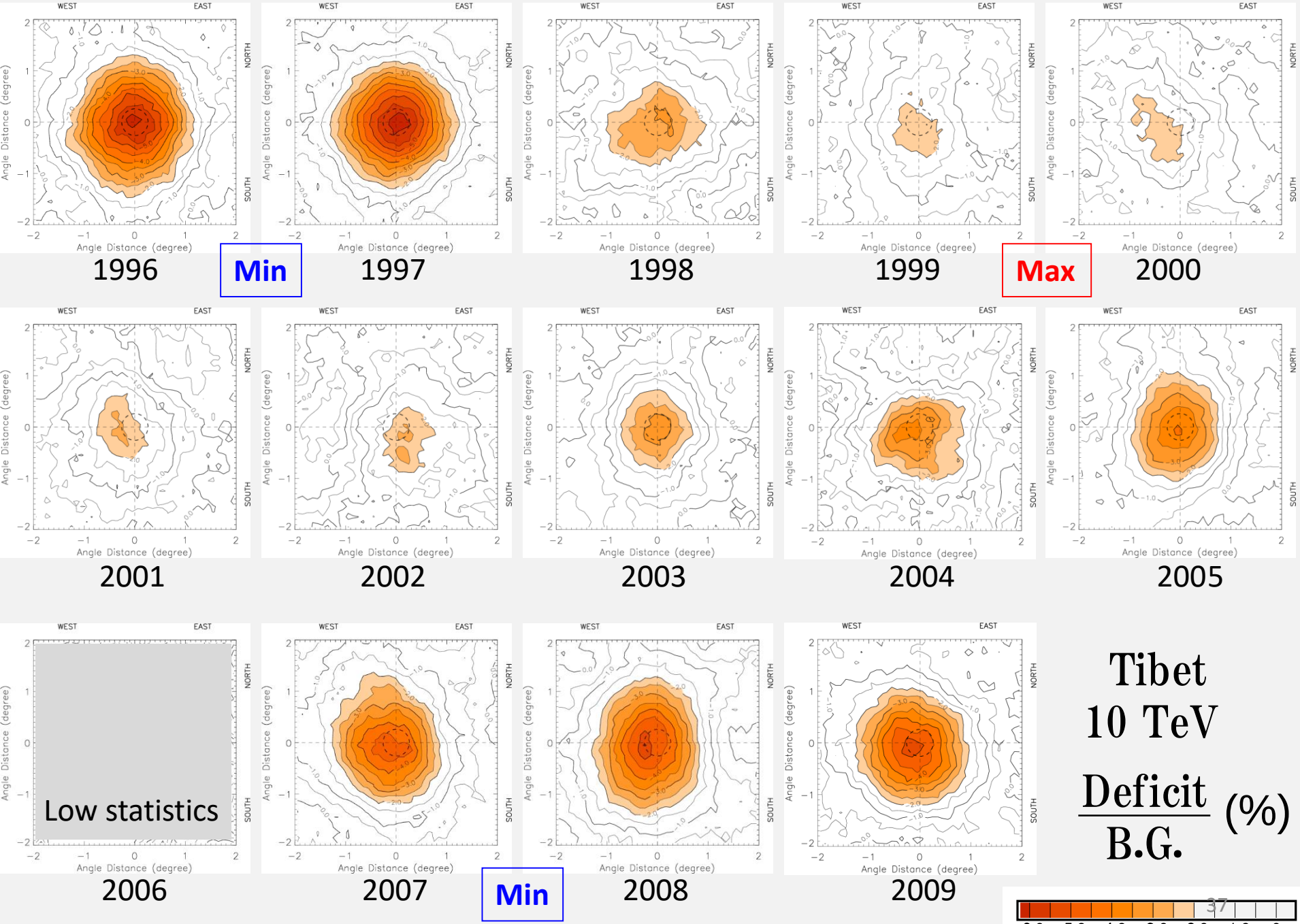
Sun Shadow

Sun blocks VHE cosmic rays, and cast the cosmic-ray shadow on the earth.



TeV proton → Charged particle
Gyroradius
～7.4AU (B=30μG near the earth)
～0.16$R_\odot$(B=300mG near the sun)

→ Sun shadow provides unique method to probe solar MFs experimentally.

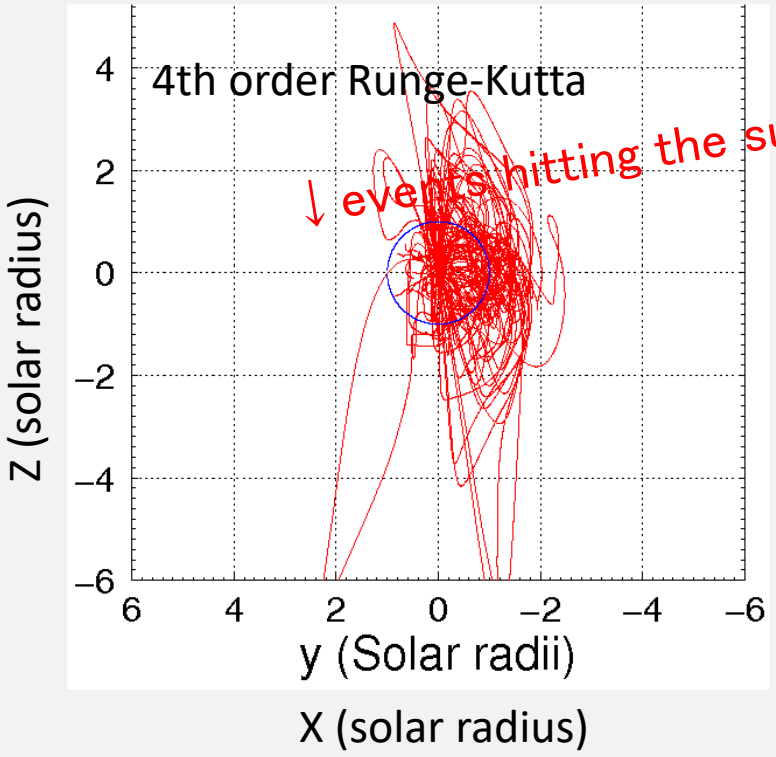

WEST
EAST
NORTH
SOUTH
Angle Distance (degree)
1996
Min
1997
1998
1999
Max
2000
2001
2002
2003
2004
2005
Low statistics
2006
2007
Min
2008
2009
Tibet
10 TeV
Deficit / B.G. (%)
−6.0 −5.0 −4.0 −3.0 −2.0 −1.0 0

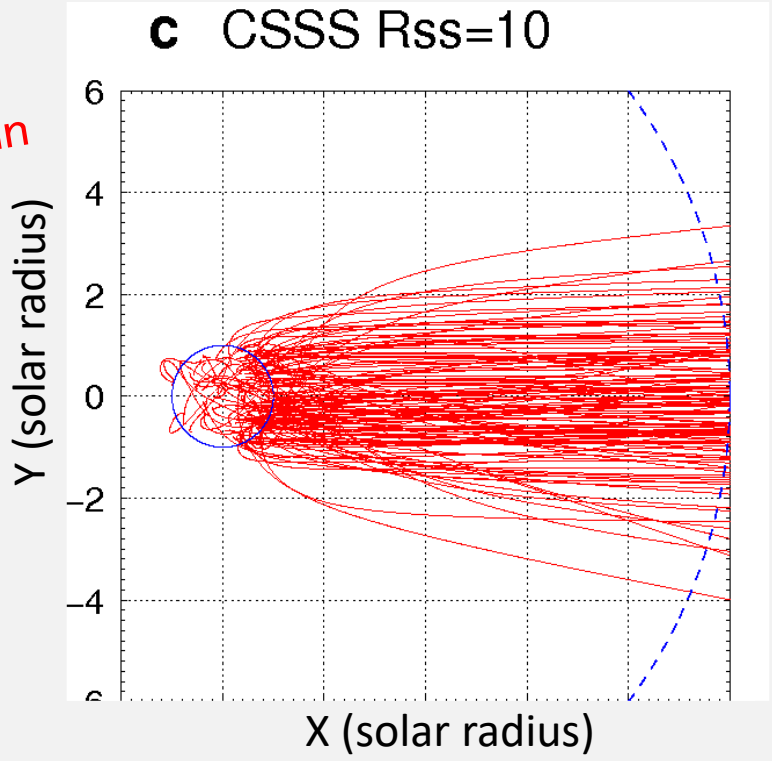
MC Simulation of Sun Shadow

- Anti-particles are shot back to the Sun from the Earth assuming CR spectra, compositions, detector responses

- Particle trajectories are traced assuming the solar MFs between the Sun and the Earth

-> Events hitting the sun reconstruct the Sun shadow



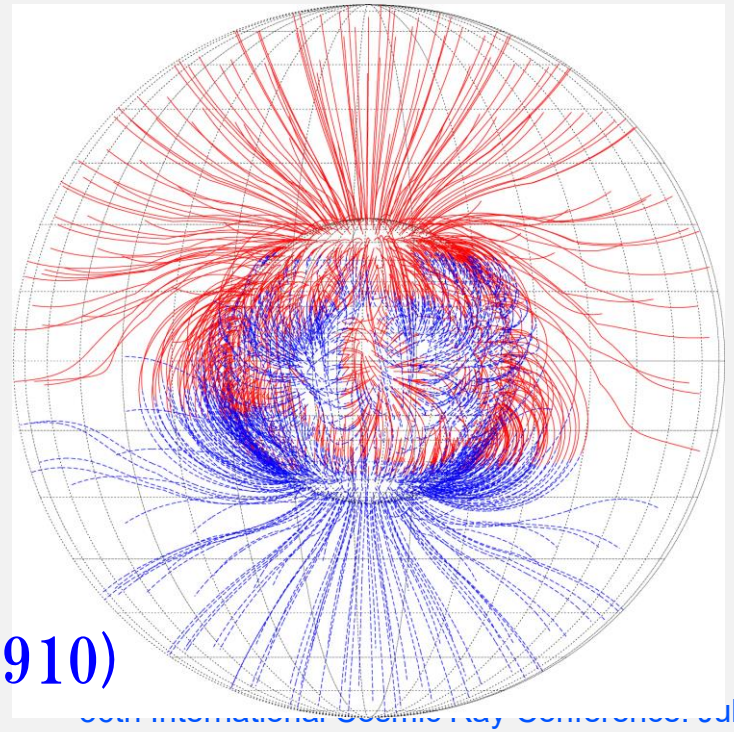


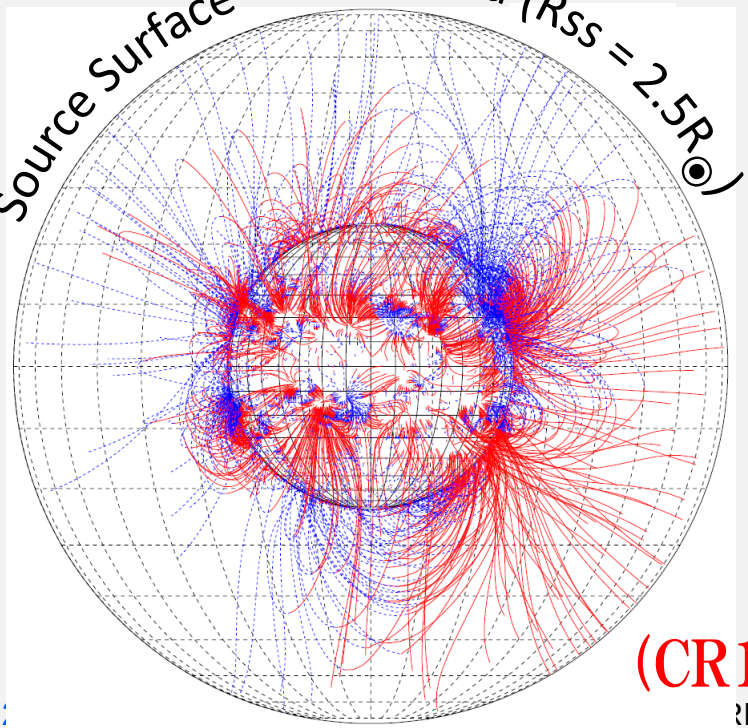
Time Dependent Coronal MF

Corona -> potential field models *(PSSS and CSSS)*
Extrapolated from the photospheric MFs measured by
Kitt Peak (KPVT/SOLIS) in each Carrington rotation (~27 days)

IMF -> Parker spiral model with latitude dependence
of the solar wind velocity taken into account.

Geomag.-> Dipole model



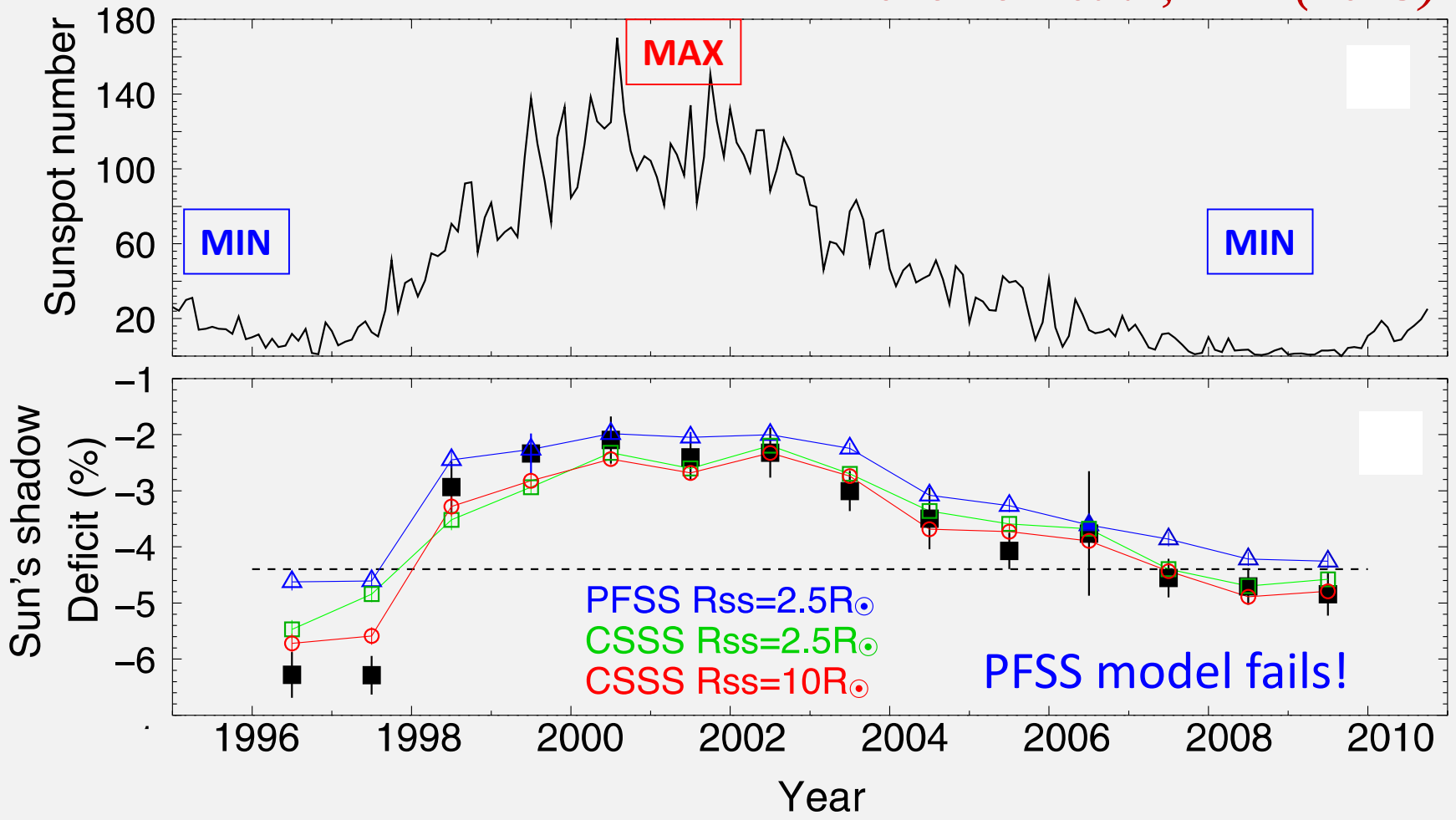


1996
(CR1910)

2001
(CR1978)

Evaluation Solar MF models

Amenomori et al, PRL (2013)



- ✓ 5オギGユ┗Uカ├ユ_9 GメU9カ 9ホチオGユカカUヌ9チユホユ_ヂイU QU_ガオギ
- ✓ First demonstration to evaluate the coronal MF models

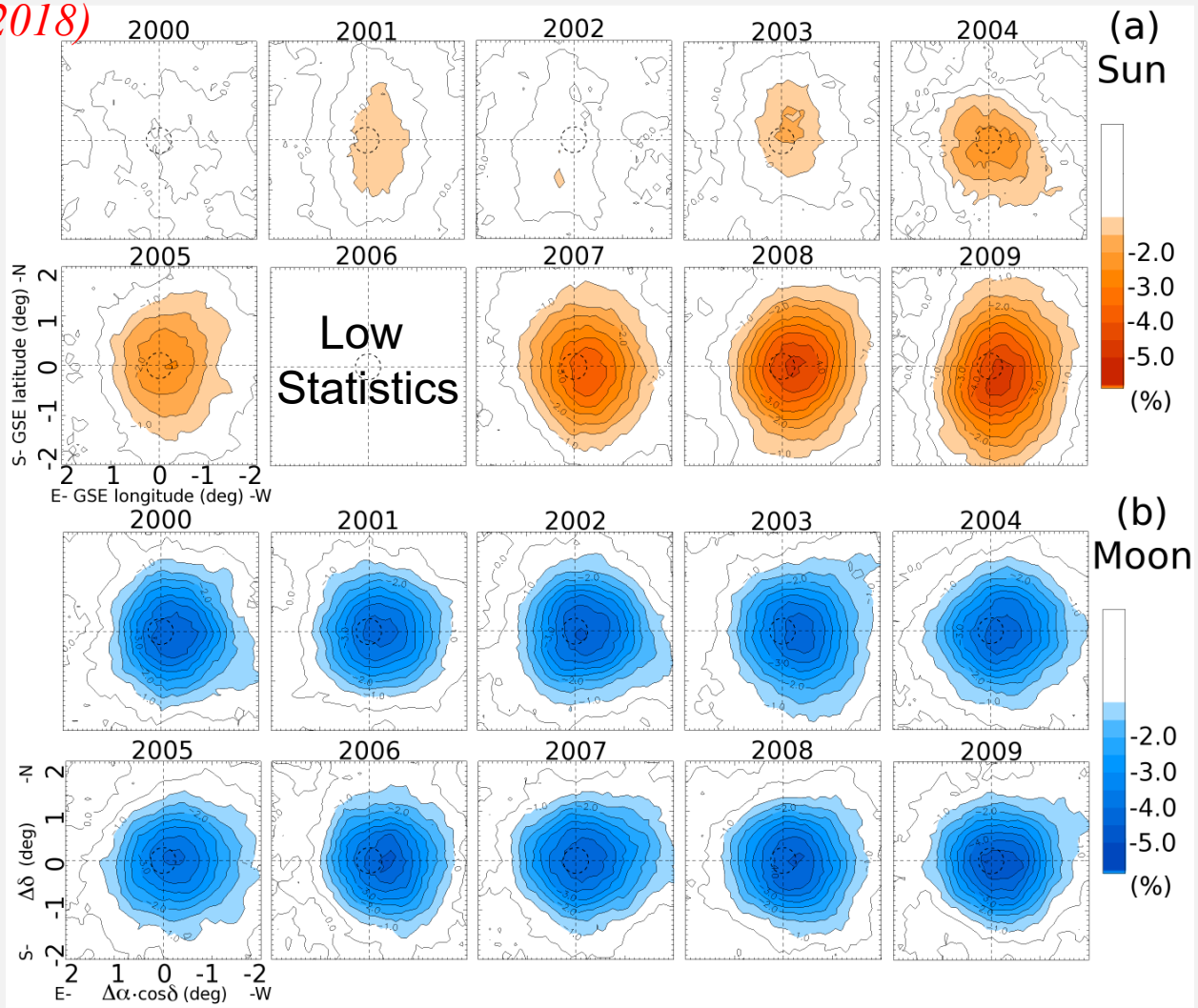
→ A clear solar-cycle variation of the deficits
CRs are scattered by solar magnetic field.

Amenomori et al., ApJ, 860,13 (2018)

Sun

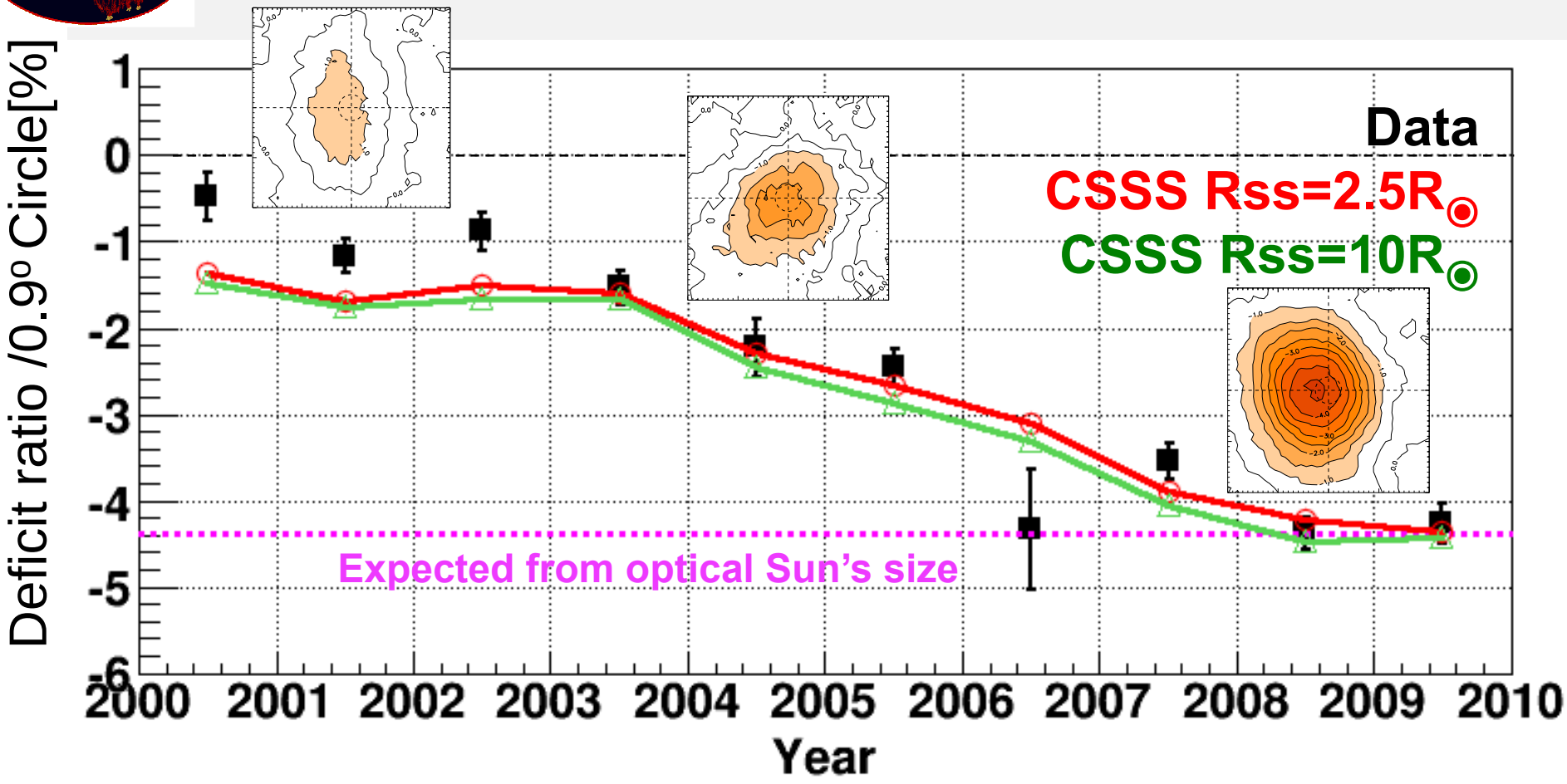
2000-2009
Tibet-III
(>3TeV)

Moon



→ Shift westward by geomagnetic field
Detector stability calibration

Deficit – Obs/MC **All Data** - 3 TeV



χ^2 test :

χ^2 / dof = 32.1 / 10 (3.4σ)

χ^2 / dof = 46.9 / 10 (4.8σ)

*only stat. error

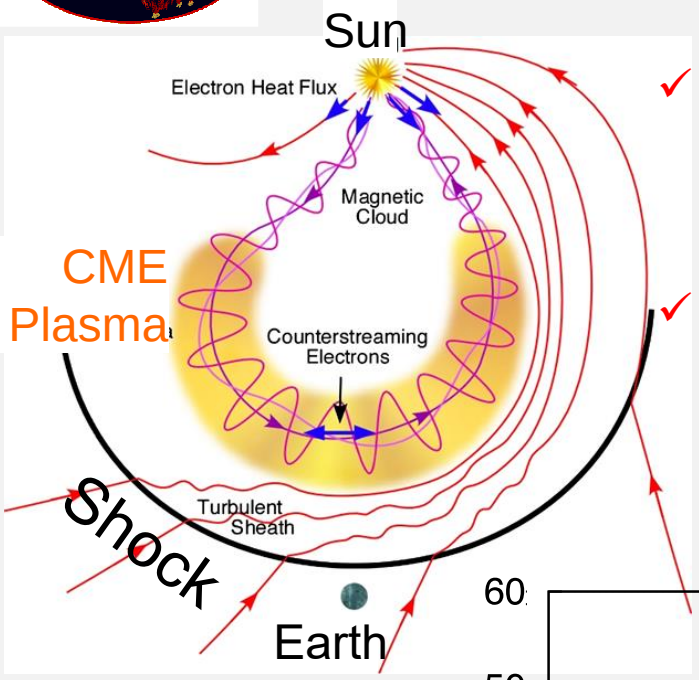
/{{{ QユUギ ホユヂ ヵU廿ヵユQ ¦ GU
L U双9ヂ ヂイU ギユ双9ヵ へ 9┘水へ ¦ へ

Influence of CMEs?

/a9 /9ヂ9ヌユィ

http://www.srl.caltech.edu/ACE/ASC/DATA/level3/icmetable2.htm

Richardson & Cane, Solar Phys (2010)



✓ wGイ9ヵQギュホ ろ /9ホU /9ヂ9ヌユィ

で/a9 ヰ又9ギへ 9 オホ_ユヵへ 9ヲオユホ ユFギUヵ┗UQ 9ヂヂイU U9ヵヂイ

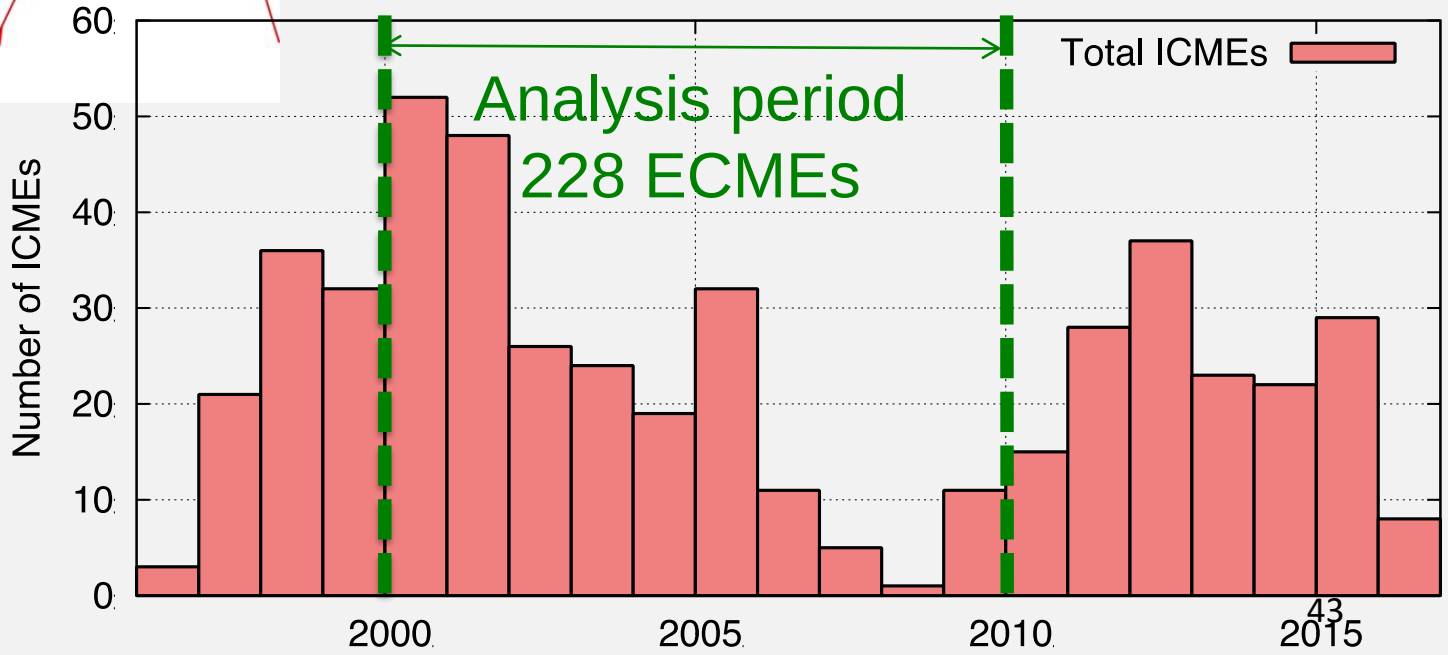
でOnly Earth-directed CMEs (ECMEs) are listed

✓ 9┛Gヌ┆QU ヂヵ9ホギオヂヰUヵオユQギュ_ 9/a9ギ _ヵユへ ヂイU 9ホ9ヌ┣ギオギ

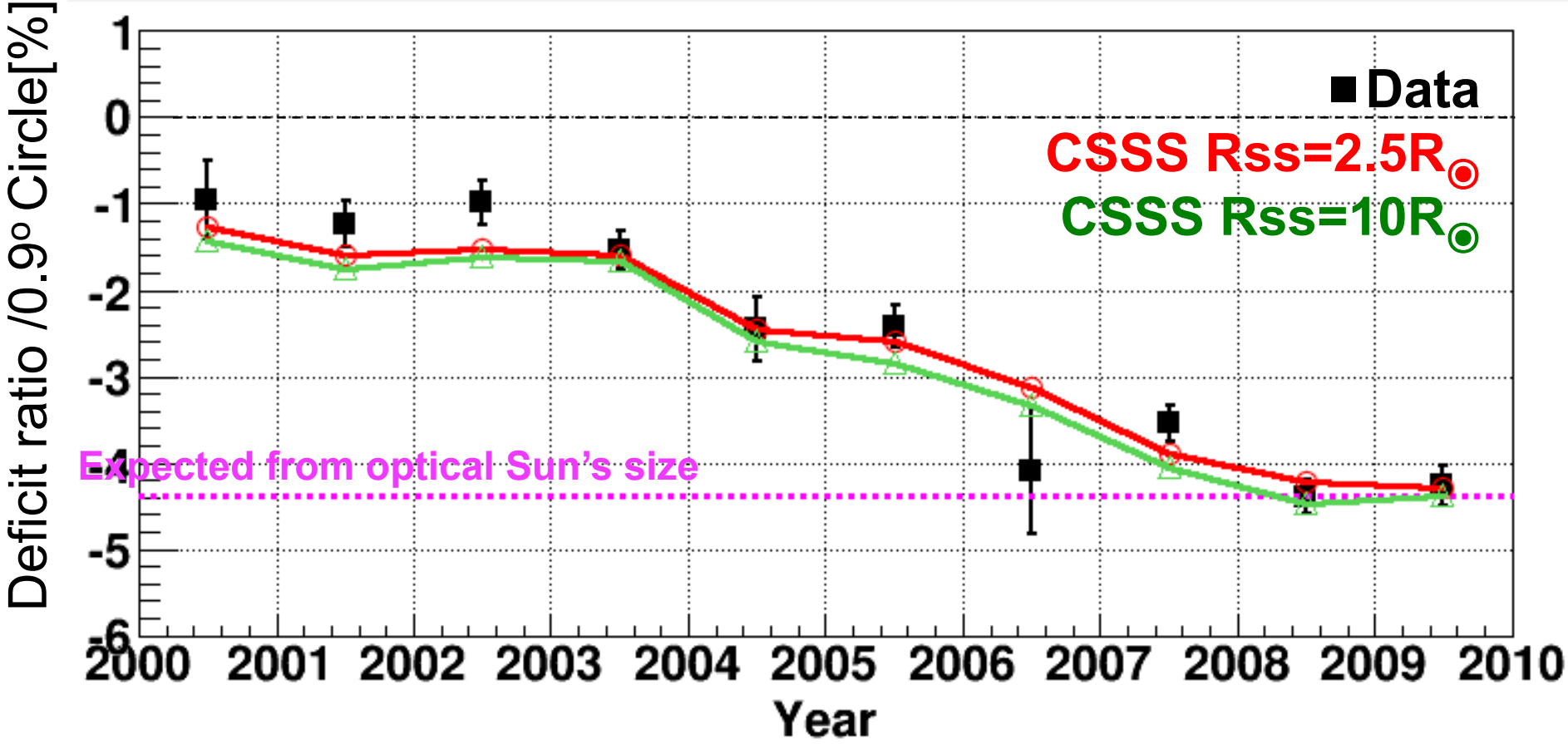
で9/a9 ギヂ9ヵヂオギヂイU Uヵ┆ヰヲオユホ ヲホへ U 9ヂヂイU {┆ホ

で9/a9 UホQ オギ ヰ又9ギへ 9 UホQ 9ヂヂイU U9ヵヂ侍

で9/a9 ヂヵ9ホギオヂヰUヵオユQ オギりヲ ワQ9┣ギ土



Deficit – Obs/MC **Exclude ECMEs** - 3 TeV



χ^2 test :

χ^2 / dof = 12.2 / 10 (0.6σ

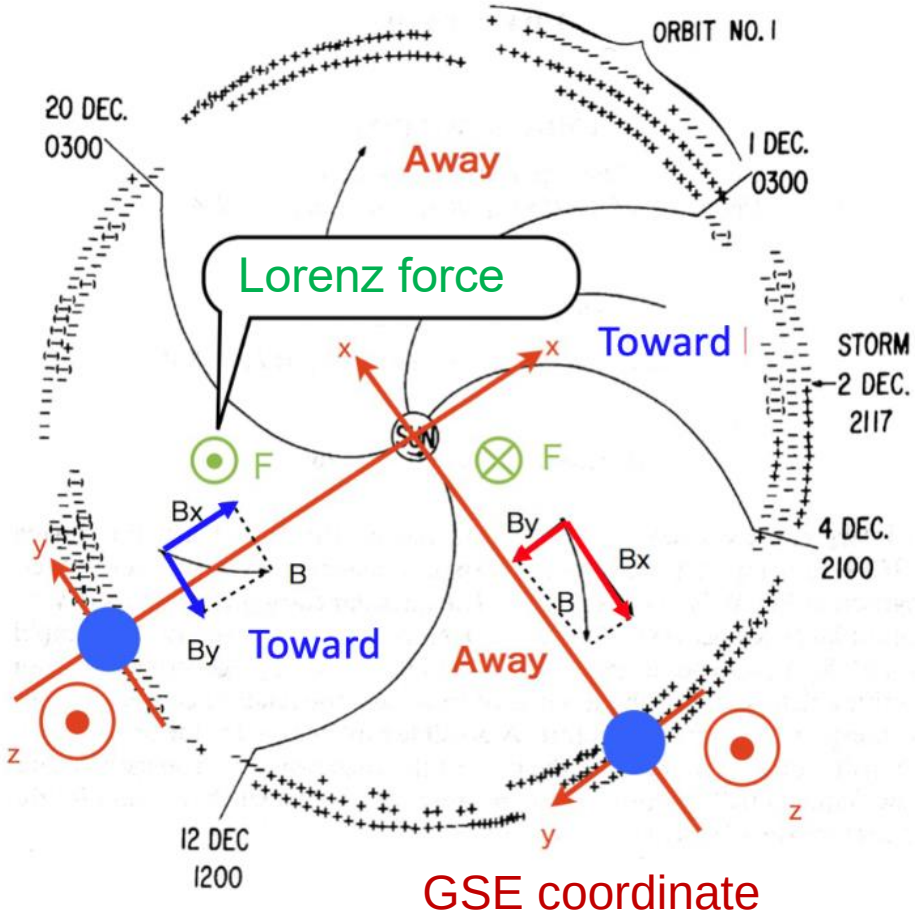
χ^2 / dof = 21.0 / 10 (2.0σ

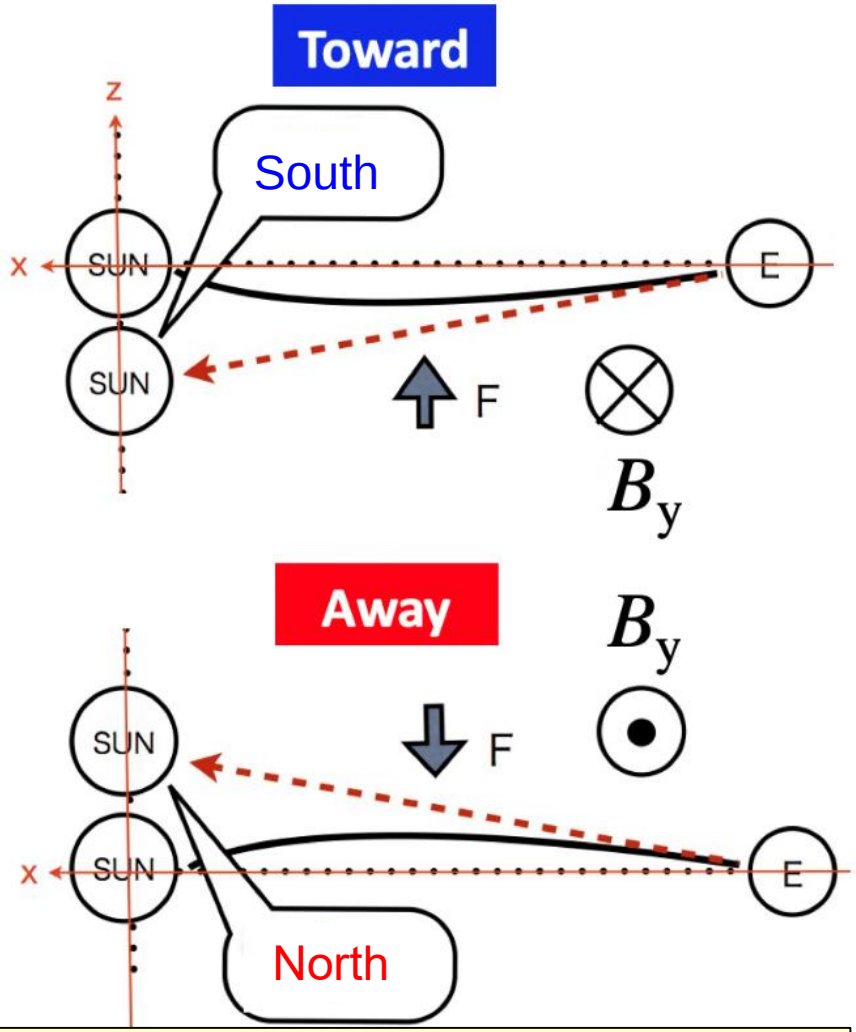
*only stat. error

Exclude ECMEs → CSSS works

First evidence for influence of ECMEs on the Sun shadow at 3 TeV

Indirect Measurement of IMF

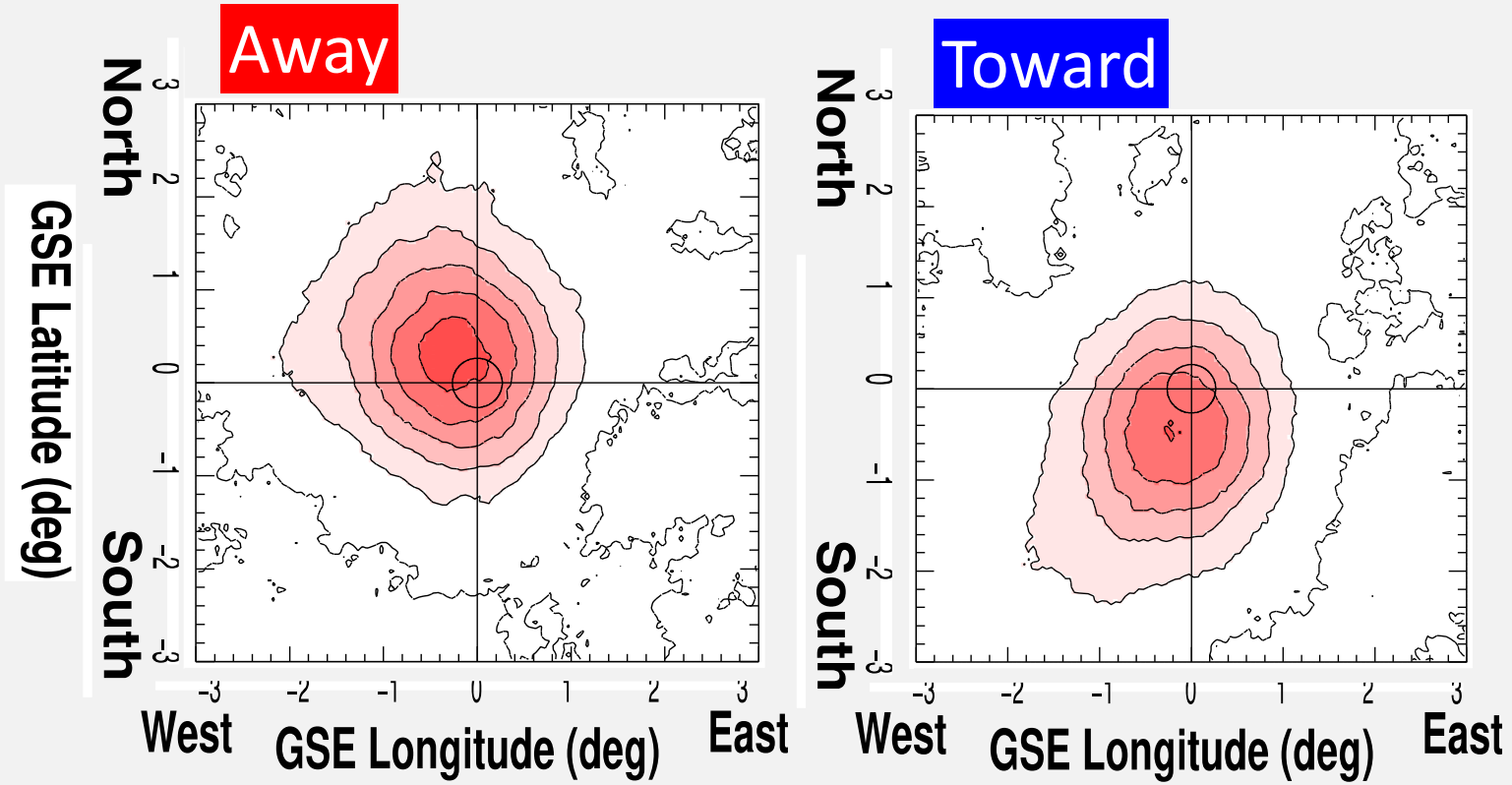




Sector structures (Toward/Away) in the IMF→ Spiral structure makes B_x and B_y
→ B_y shifts the Sun shadow to South / North at Toward / Away sector

Indirect Measurement of IMF

Amenomori et al., PRL (2018)

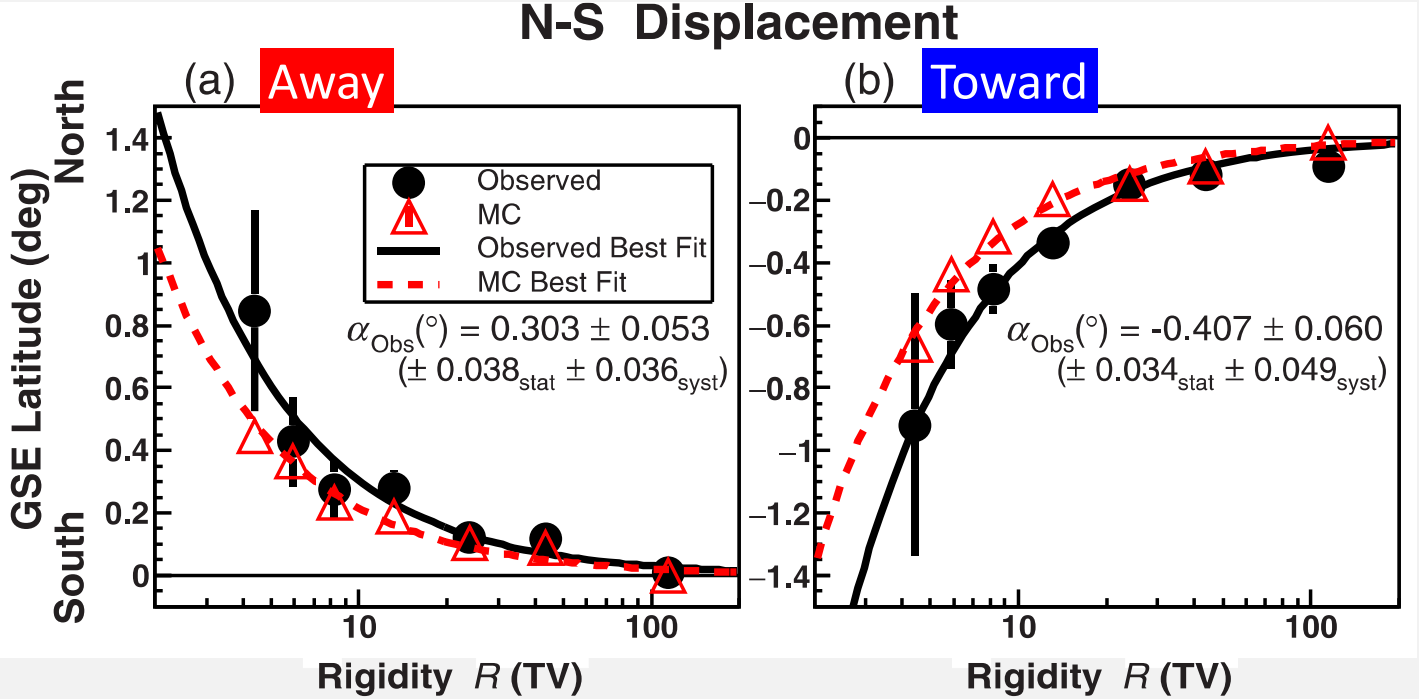


Amount of the shift is proportional to total B_y b/w Sun and Earth

→ Indirect measurement of IMF

Indirect Measurement of IMF

Amenomori et al., PRL (2018)



North-South displacement

Observed/Model ratio :

Away : $1.54 \pm 0.21_{stat} \pm 0.20_{syst}$

Toward : $1.62 \pm 0.15_{stat} \pm 0.22_{syst}$

→ MF in model is underestimated

Possible reasons:
- Potential field model?
- Systematic difference in photospheric MF measurements? (Input of the potential field models)

Summary

- Gamma-ray astronomy from TeV to sub-PeV

→ Crab: First detection of γ rays > 100 TeV observed (5.6σ)
Highest energy photon ever observed: 450 TeV
Opened a new energy (sub-PeV) window in astronomy!

→ Other interesting sources under study

- Cosmic-ray anisotropy measurement

→ ~10 TeV: :Reasonably explained by heliospheric modulation model & Original anisotropy in ISM inferred
→ >100 TeV: Different from ~10 TeV anisotropy, why?
Original anisotropy change in ISM?

→ (γ, e^{+-}) NOT contributing to CR anisotropy > 20 TeV

- Sun shadow measurement

→ IMF vs Sun shadow, CME vs Sun shadow