The anisotropy of cosmic ray observed by Tibet ASγ with muon detector

Yoshiaki Nakamura

Key Laboratory of Particle Astrophysics,

the Institute of High Energy Physics, Chinese Science Academy.

Tibet ASγ Collaborations

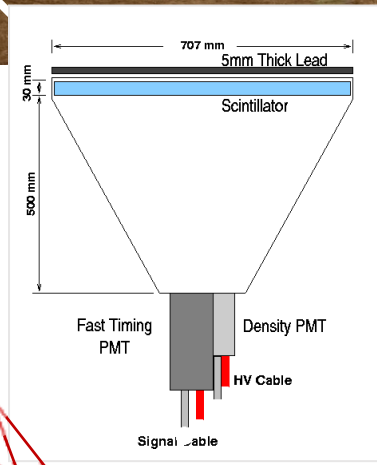
M. Amenomori,[1] Y.-W. Bao,[2] X. J. Bi,[3] D. Chen,[4] T. L. Chen,[5] W. Y. Chen,[3] Xu Chen,[3] Y. Chen,[2] Cirennima,[5] S. W. Cui,[7] Danzengluobu,[5] L. K. Ding,[3] J. H. Fang,[3,6] K. Fang,[3] C. F. Feng,[8] Zhaoyang Feng,[3] Z. Y. Feng,[9] Qi Gao,[5] Q. B. Gou,[3] Y. Y. Guo,[3] Y. Q. Guo,[3] H. 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 AS+MD
- Previous Result
- Event Selection
- Comparison with before MD installation
- Result of Sidereal Anisotropy (1D)
- Result of Sidereal Anisotropy (2D)
- Summary

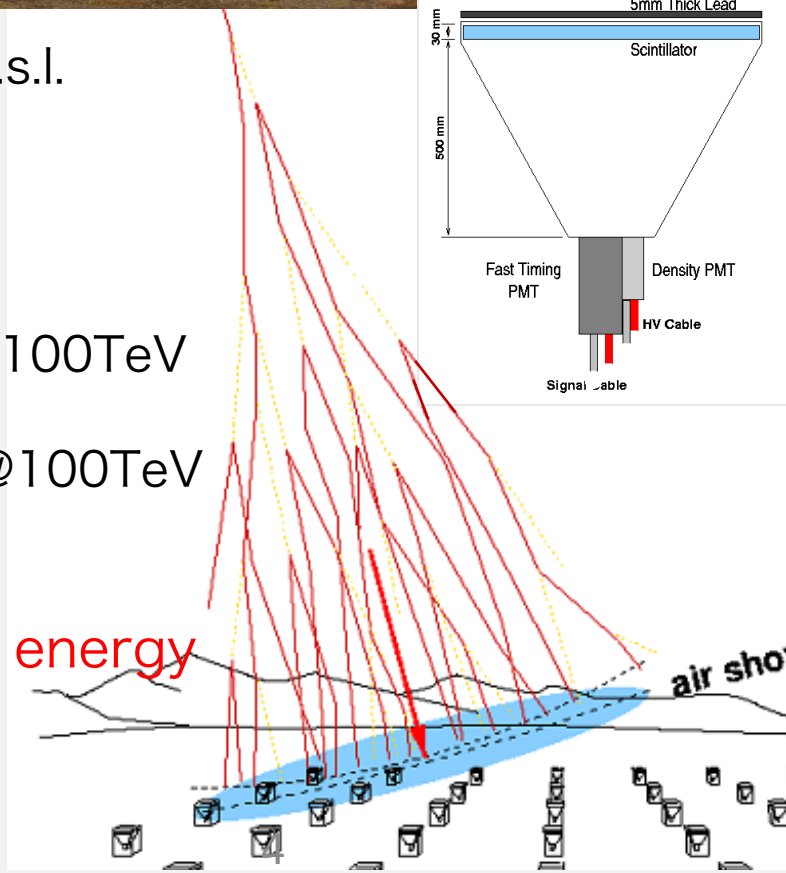
Tibet Air Shower Array



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

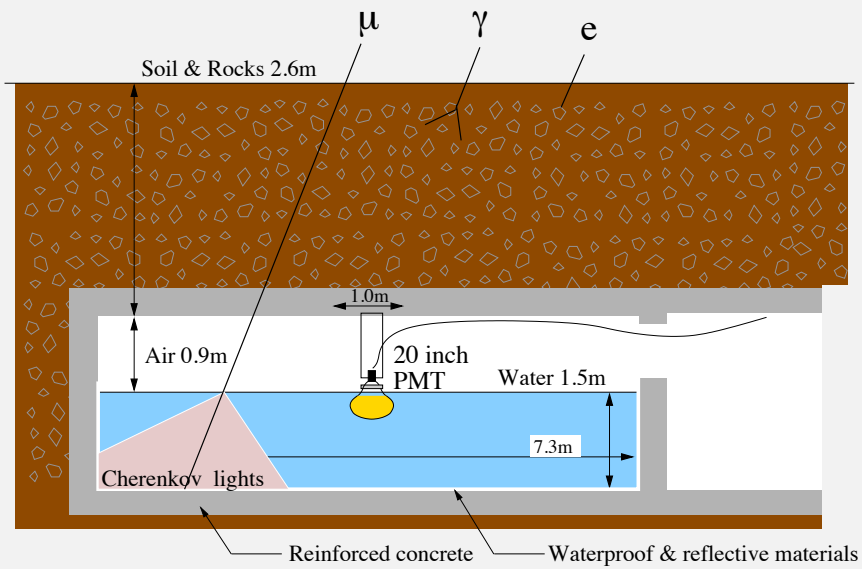
- scintillation counters 0.5 m^2 x 597
- coverage area ~65,700 m^2
- angular resolution ~0.5°@10TeV
  ~0.2°@100TeV
- energy resolution ~40%@10TeV
  ~20%@100TeV

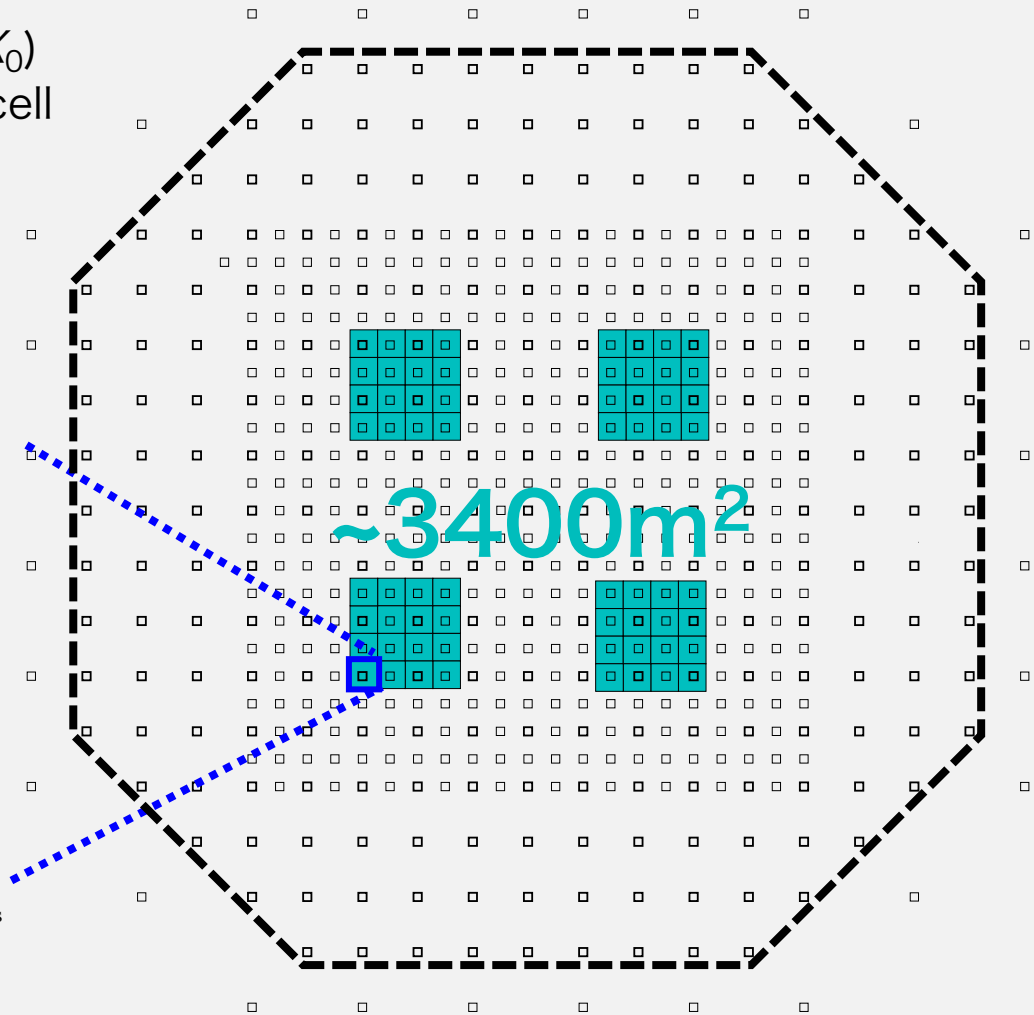
2nd particles timing ➡ arrival direction
2nd particles energy deposit ➡ primary energy



Water Cherenkov Muon Detector Array

- ✓ 2.4m underground (515g/cm^2 ~19X_0)
- ✓ 7.35m x 7.35m x 1.5m-deep water cell x 64
- ✓ 20"ΦPMT (HAMAMATSU R3600)
- ✓ Concrete pools + Tyvek sheets



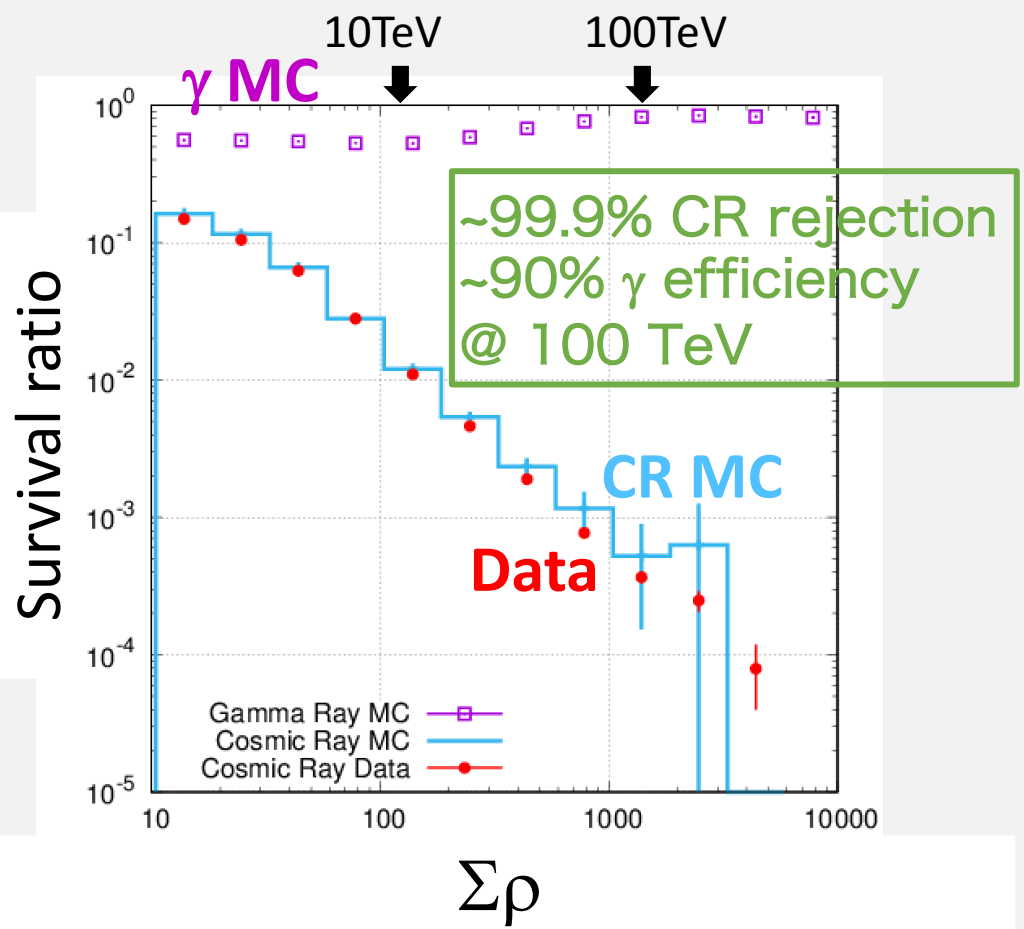


Measurement of number of muons in air shower
➡γ／CR discrimination

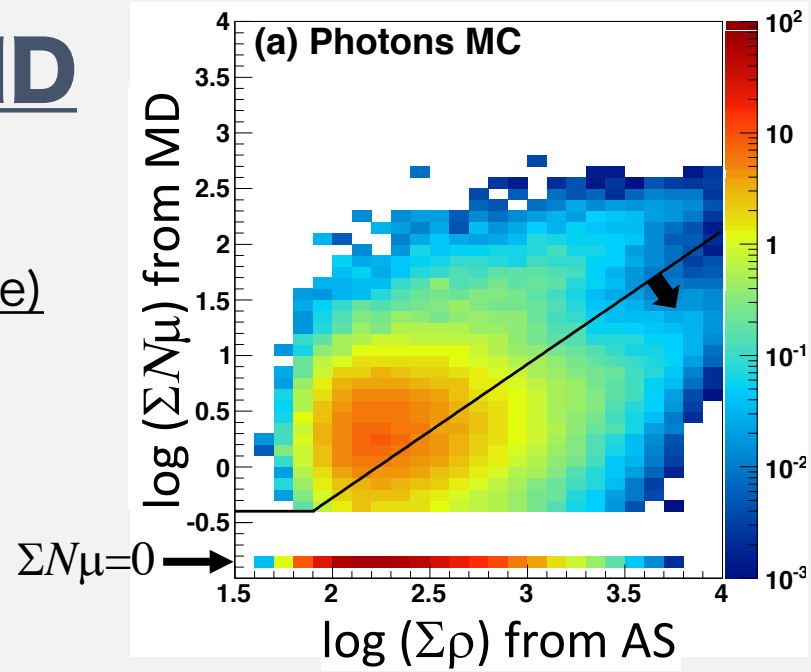
Event selection by MD

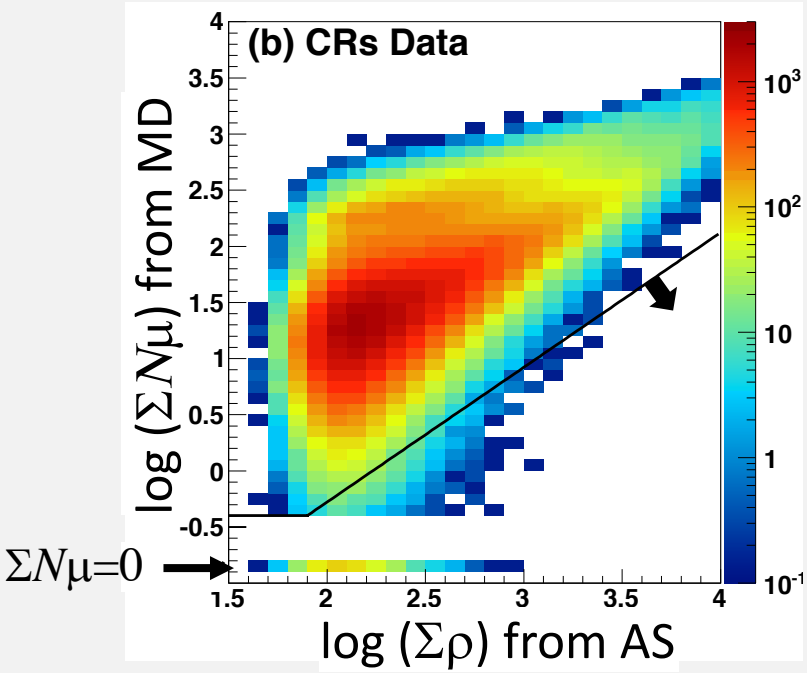
Optimization of N_μ cut

γ : MC sample (Crab orbit & Crab flux)
CR : Data (excluding Crab & Galactic Plane)



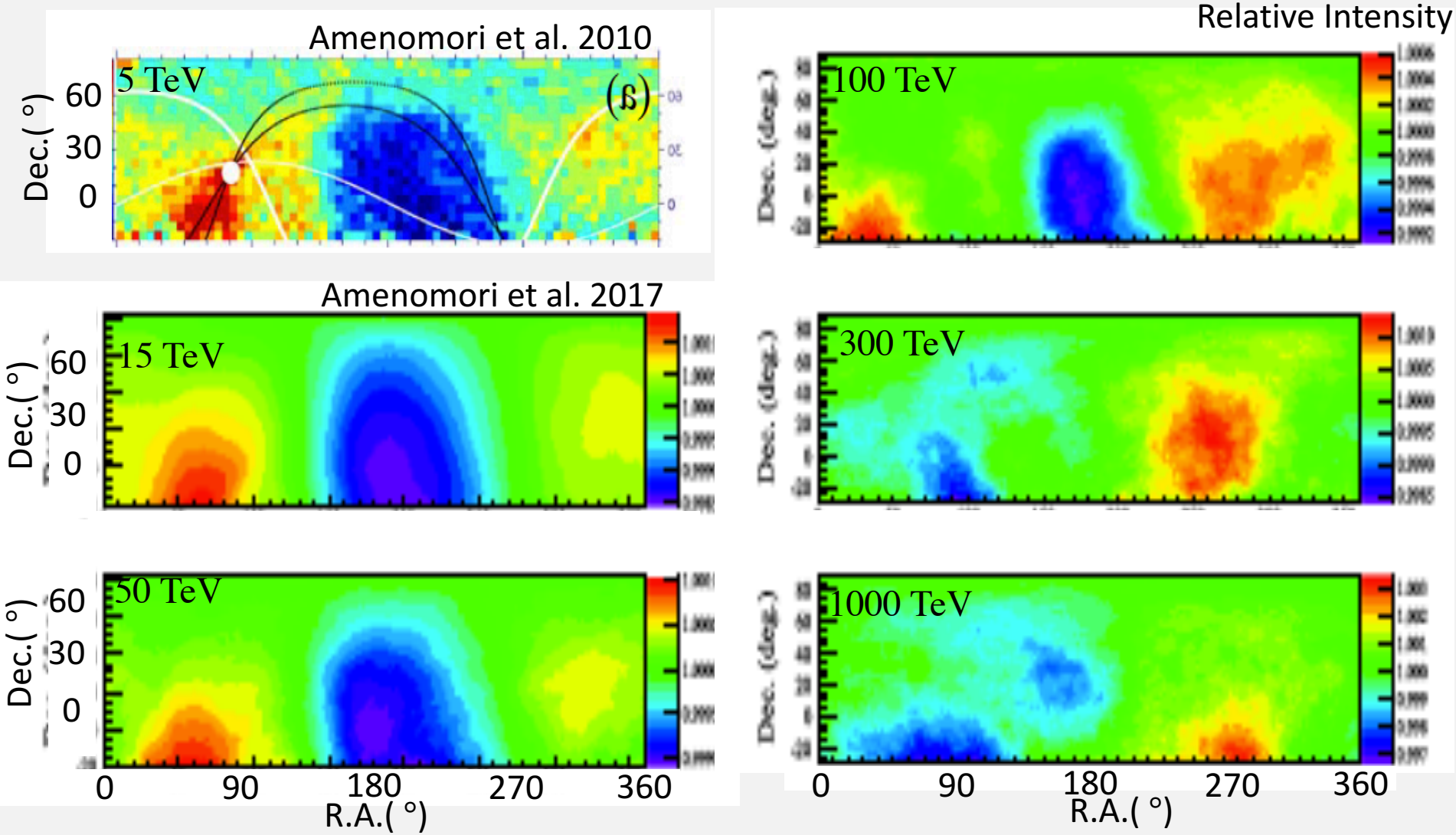
(Sum of particle densities by all AS counters)





Previous Result observed by Tibet ASγ

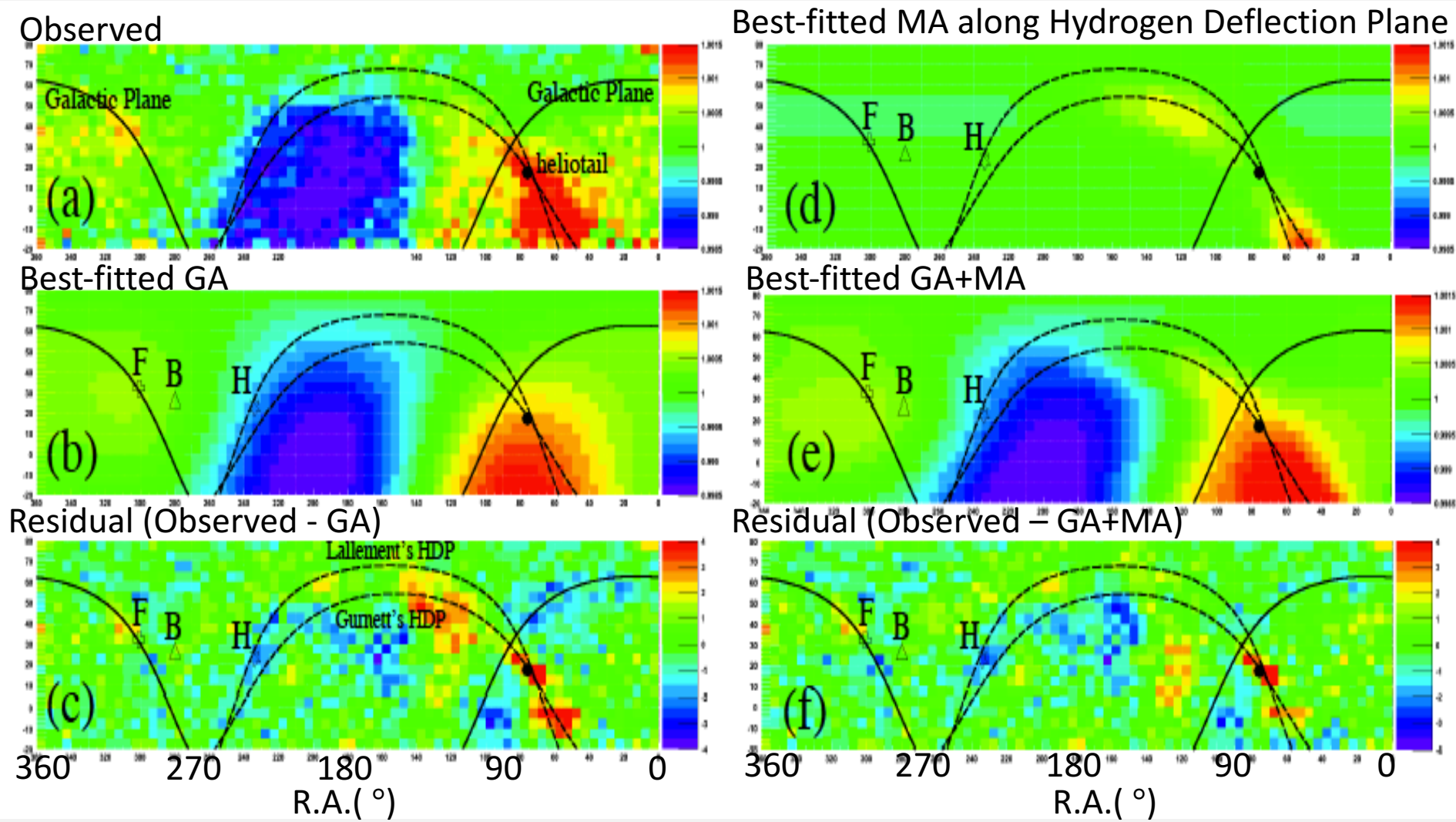
Sidereal anisotropy of cosmic ray including gamma ray/electron/positron at multi TeV – PeV



Previous Result observed by Tibet ASγ

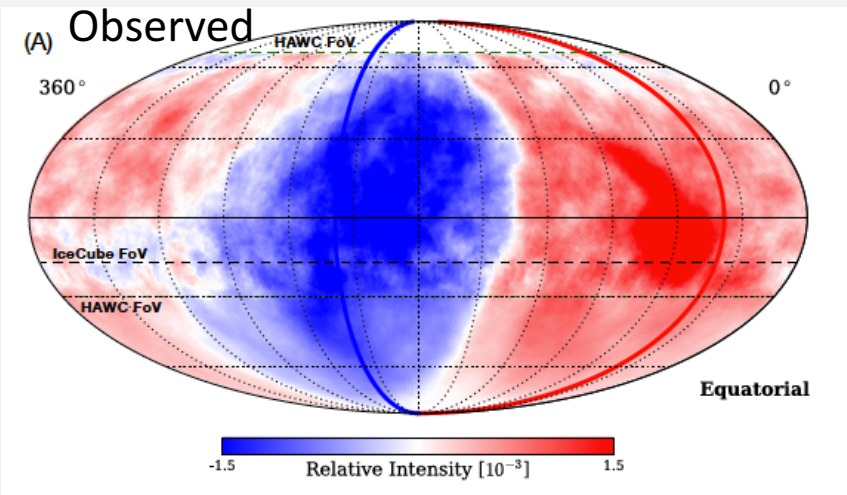
In multi TeV region, we found global anisotropy (1st and 2nd: GA) and middle scale anisotropies (MA)

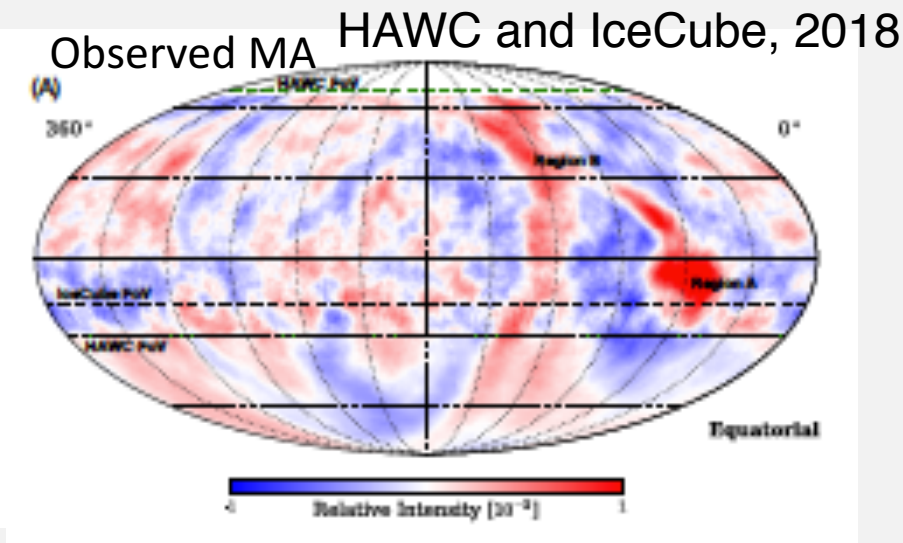
Amenomori et al. 2010



Previous Result 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

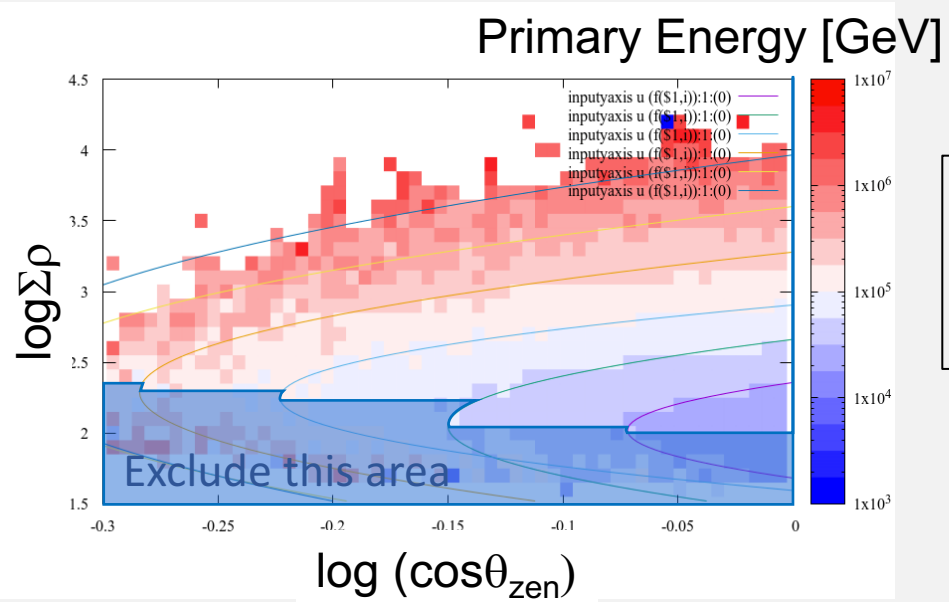




Still unknown what causes these sidereal anisotropies.
Observing sidereal anisotropies of cosmic ray and gamma ray/electron/positron separately will provide the new information around our solar system.

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

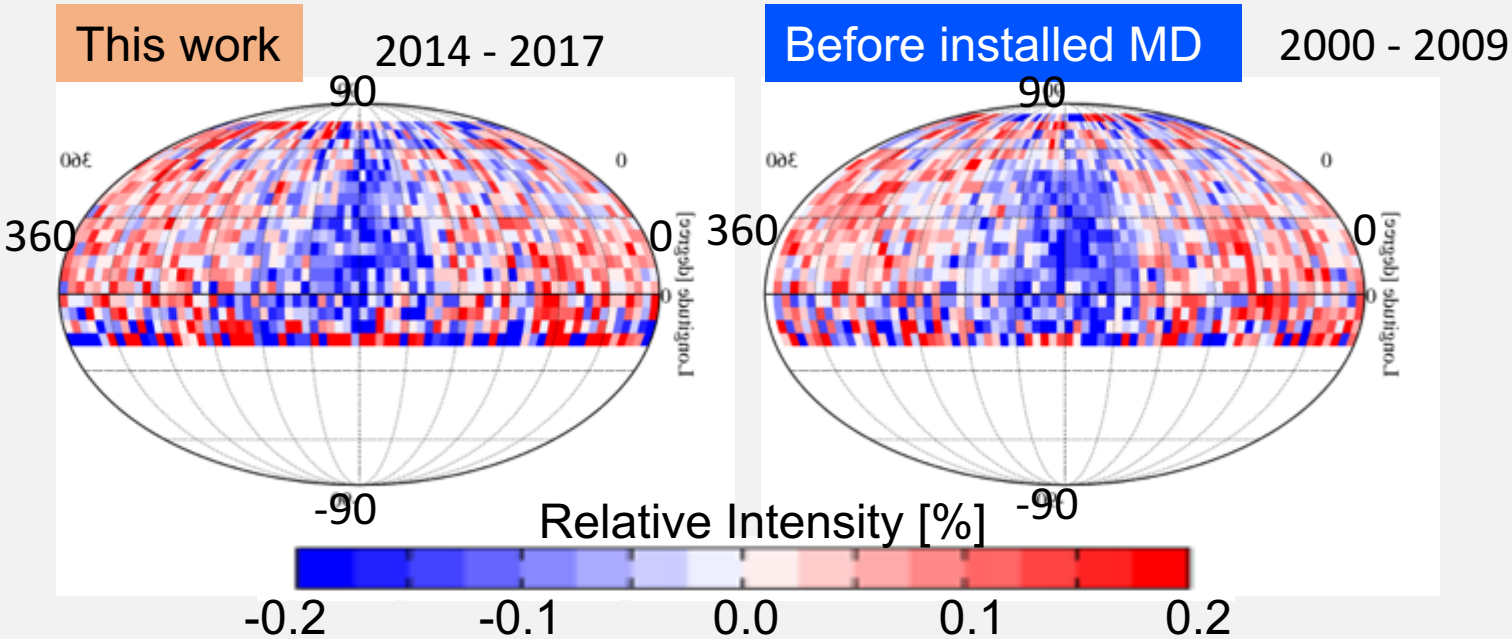
To exclude the γ ray (electron and positron) like event,
We introduced the additional cut

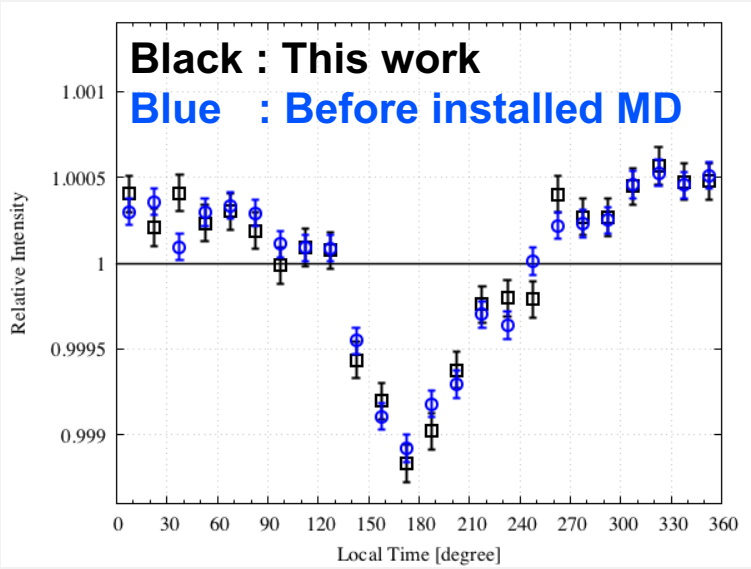
sum of number of μ-on detected by MD (ΣN_μ) >1

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



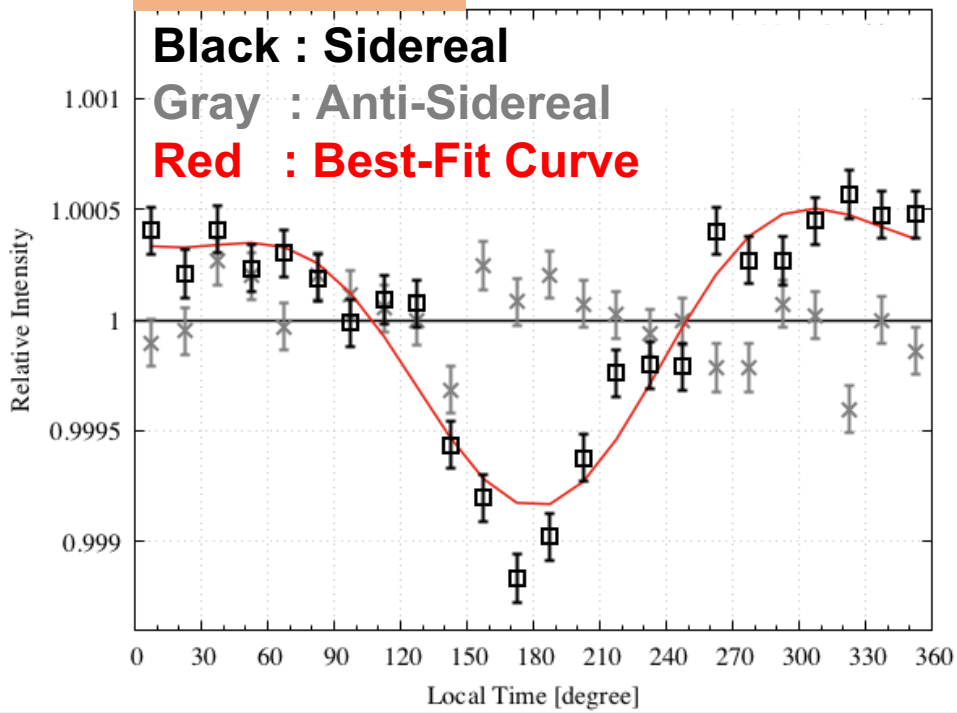


This result is consistent with the result before installed MD.
Tibet ASγ provide the equable data identically before installed MD.

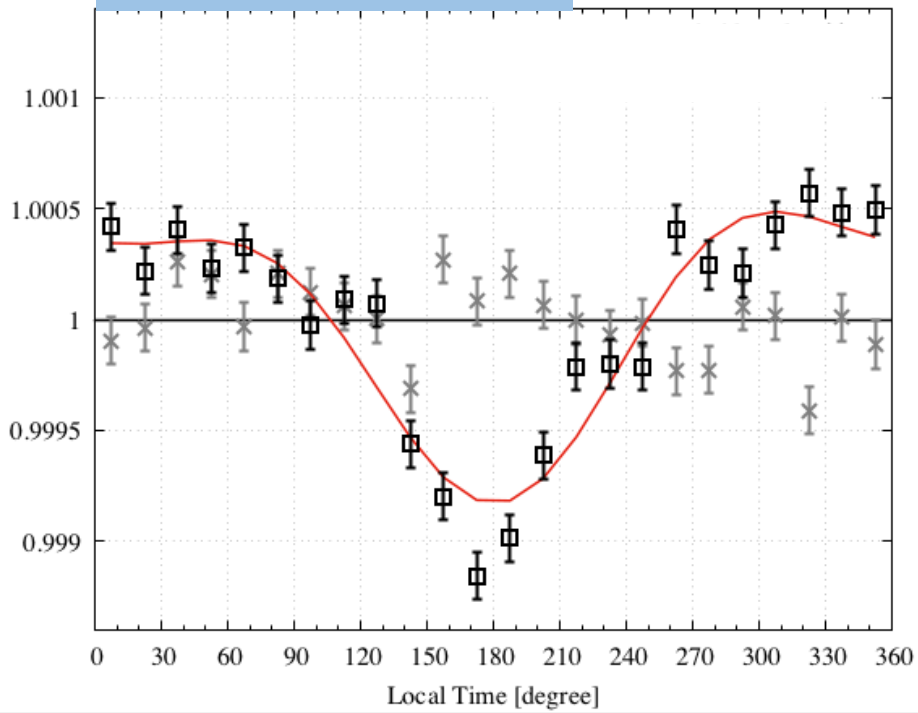
Result of Sidereal Anisotropy (1D)

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

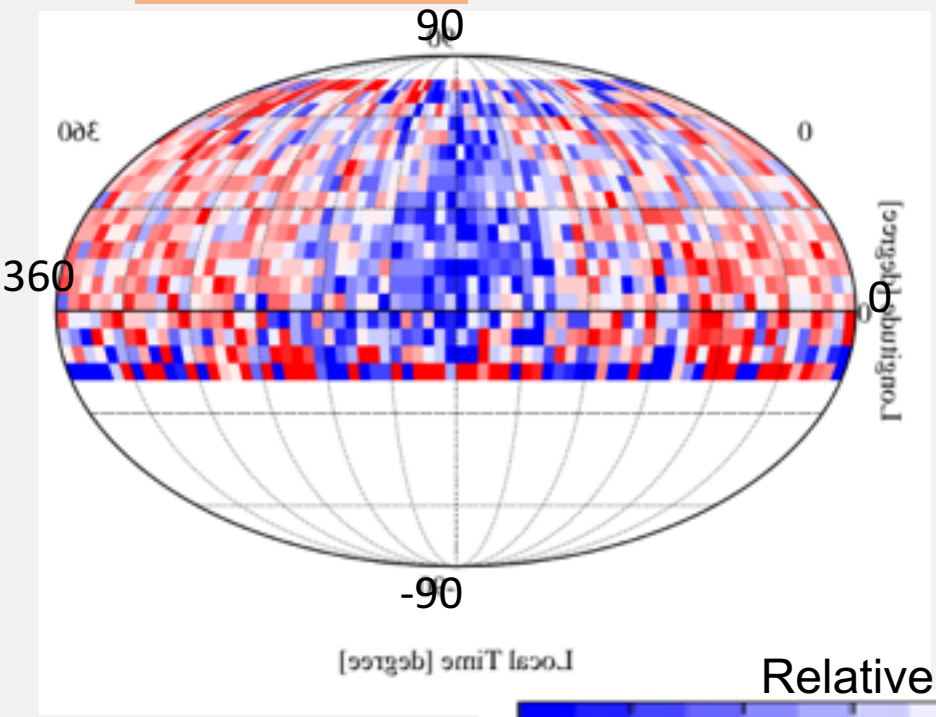
The EM components do not influence sidereal 1D projection.

Result of Sidereal Anisotropy (2D)

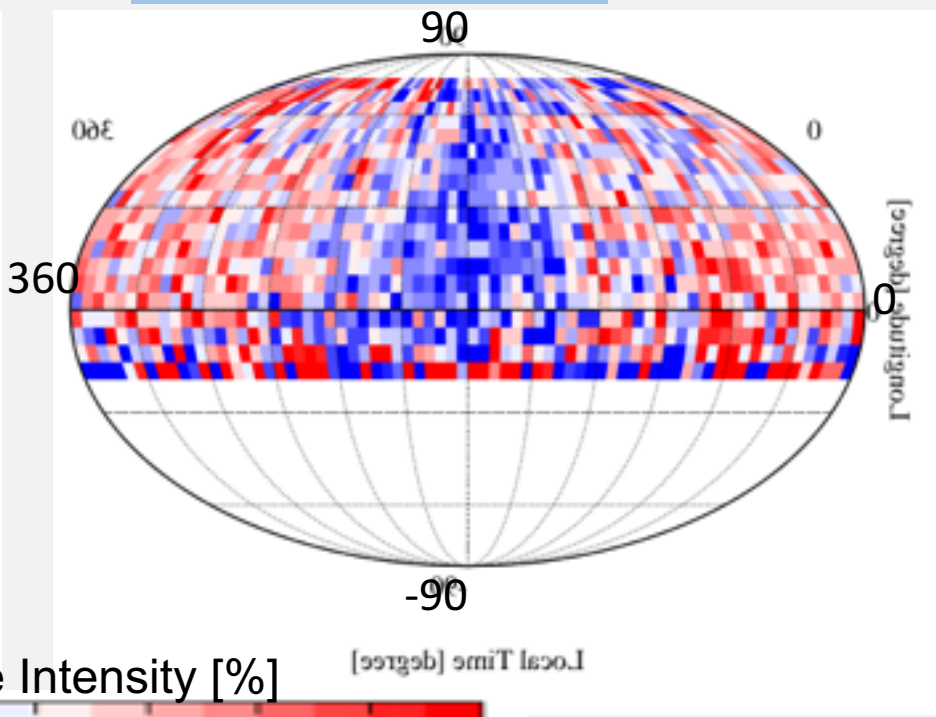
Energy ::>20 TeV

Observed

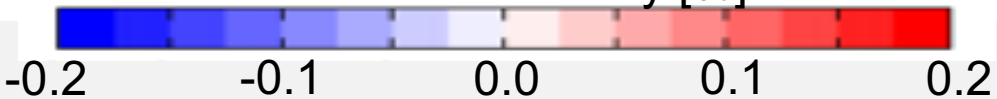
Total Events



μ–on Rich Events



Relative Intensity [%]



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 $A_1, \alpha_1, A_2, \alpha_2, \delta_2$

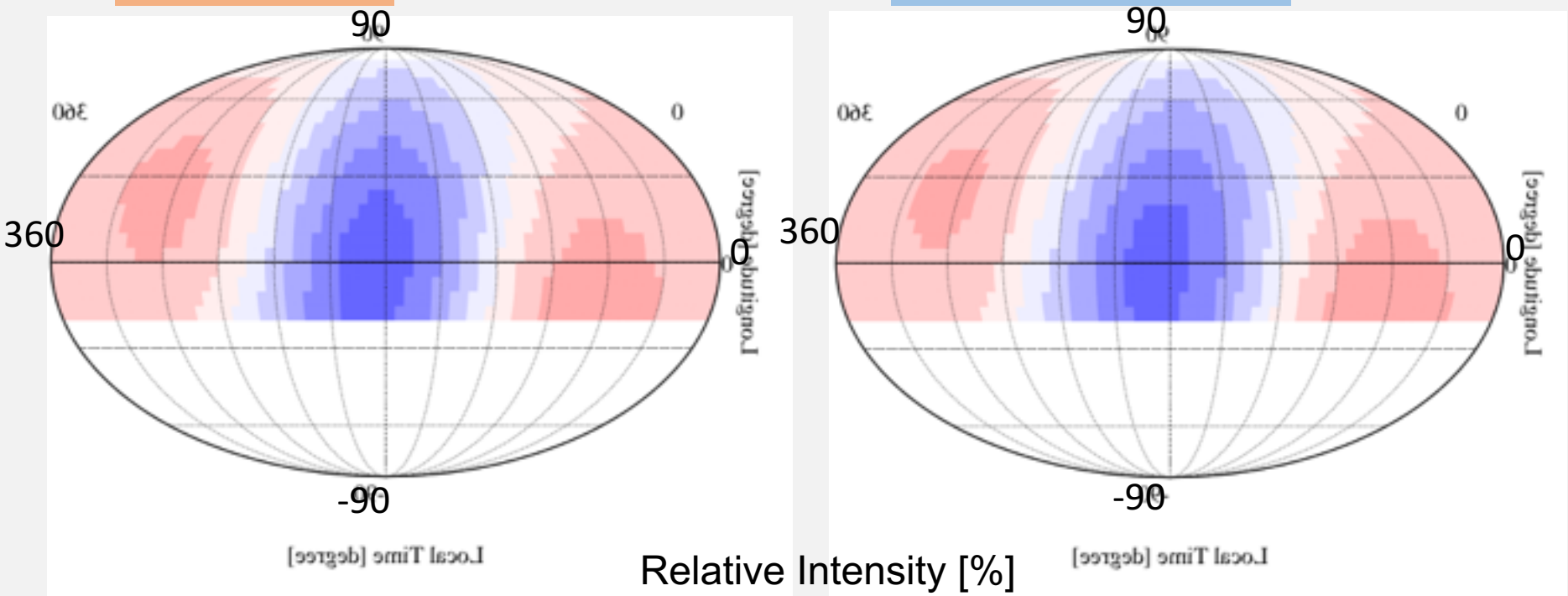
Result of Sidereal Anisotropy (2D)

Energy ::>20 TeV

Best Fit Model

Total Events

μ–on Rich Events



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

	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

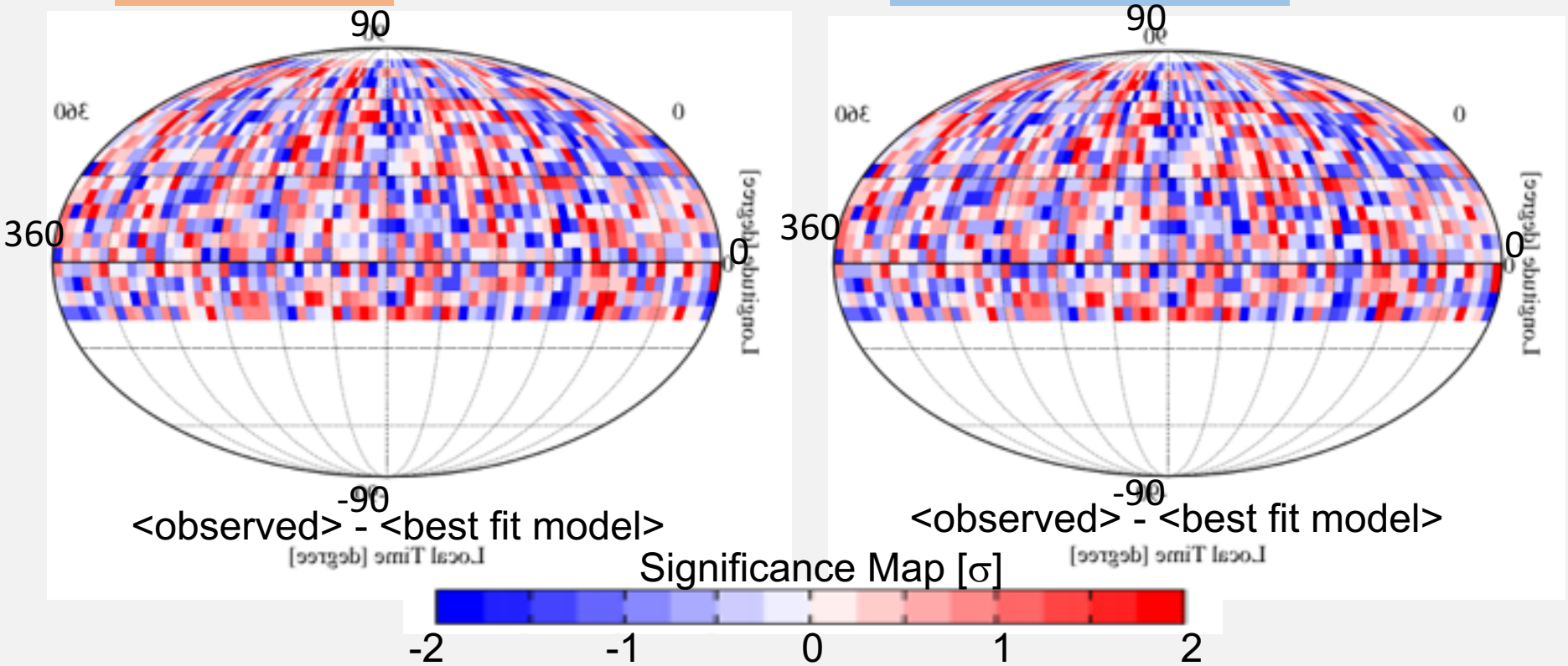
	A_i[%]	α_i[°]	δ_i[°]	χ^2/d. o. f
1st	0.075 ± 0.004	10.3 ± 4.8		1464.3/
2nd	0.052 ± 0.006	93.2 ± 3.4	−16.5 ± 5.3	1435

Result of Sidereal Anisotropy (2D) Residual

Energy ::>20 TeV

Total Events

μ–on Rich Events



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.

Summary

- We calculated the sidereal anisotropy at >20 TeV observed by Tibet AS+MD, and compared the result of total events and mu rich events (0.86% gamma like events excluded)
- Sidereal anisotropy of μ rich events is consistent with total events' one.
- EM components do not influence large and middle scale sidereal anisotropy of total events in this energy region.

Future plan

- Other energy region.
- sidereal anisotropy of μ poor events

Thank you!