チベット空気シャワー実験と 100TeV領域ガンマ線観測

Masato Takita (ICRR, Univ. of Tokyo)

for The Tibet ASγ Collaboration

~ contents ~

- What we have done
- What we should do next
- 100TeV source search
- Towards higher sensitivity
  (Next talk by Kawata san)

August 31, 2006
「宇宙線の起源、… 100TeV領域ガンマ放射天体の観測」 研究会 at ICRR

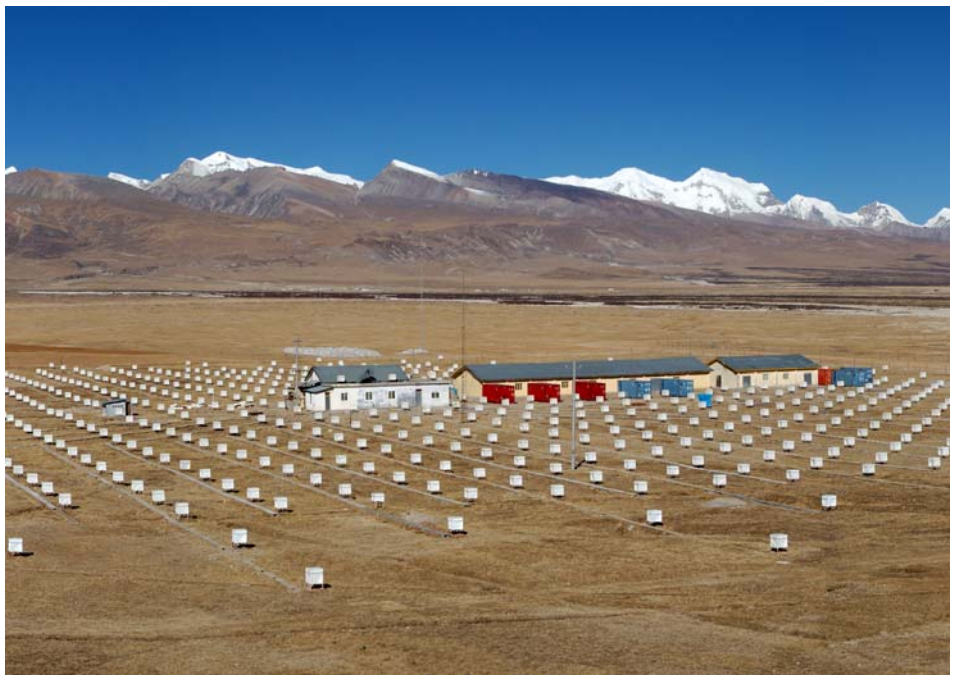
The Tibet ASγ Collaboration (China-Japan joint experiment)

M. Amenomori(a), S. Ayabe(b), X.J. Bi(c), D. Chen(d), S.W. Cui(e), Danzengluobu(f), L.K. Ding(c), X.H. Ding(f), C.F. Feng(g), Zhaoyang Feng(c), Z.Y. Feng(h), X.Y. Gao(i), Q.X. Geng(i), H.W. Guo(f), H.H. He(c), M. He(g), K. Hibino(j), N. Hotta(k), Haibing Hu(f), H.B. Hu(c), J. Huang(l), Q. Huang(h), H.Y. Jia(h), F. Kajino(m), K. Kasahara(n), Y. Katayose(d), C. Kato(o), K. Kawata(l), Labaciren(f), G.M. Le(p), A.F. Li(g), J.Y. Li(g), H. Lu(c), S.L. Lu(c), X.R. Meng(f), K. Mizutani(b,q),J. Mu(i), K. Munakata(o), A. Nagai(r), H. Nanjo(a), M. Nishizawa(s), M. Ohnishi(l), I. Ohta(t), H. Onuma(b), T. Ouchi(j), S. Ozawa(l), J.R. Ren(c), T. Saito(u), T. Y. Saito(l), M. Sakata(m), T. K. Sako(l), T. Sasaki(j), M. Shibata(d), A. Shiomi(l), T. Shirai(j), H. Sugimoto(v), M. Takita(l), Y.H. Tan(c), N. Tateyama(j), S. Torii(q), H. Tsuchiya(w), S. Udo(l), B. Wang(i), H. Wang(c), X. Wang(l), Y.G. Wang(g), H.R. Wu(c), L. Xue(g), Y. Yamamoto(m), C.T. Yan(l), X.C. Yang(i), S. Yasue(x), Z.H. Ye(p), G.C. Yu(h), A.F. Yuan(f), T. Yuda(j), H.M. Zhang(c), J.L. Zhang(c), N.J. Zhang(g), X.Y. Zhang(g), Y. Zhang(c), Yi Zhang(c), Zhaxisangzhu(f) and X.X. Zhou(h)

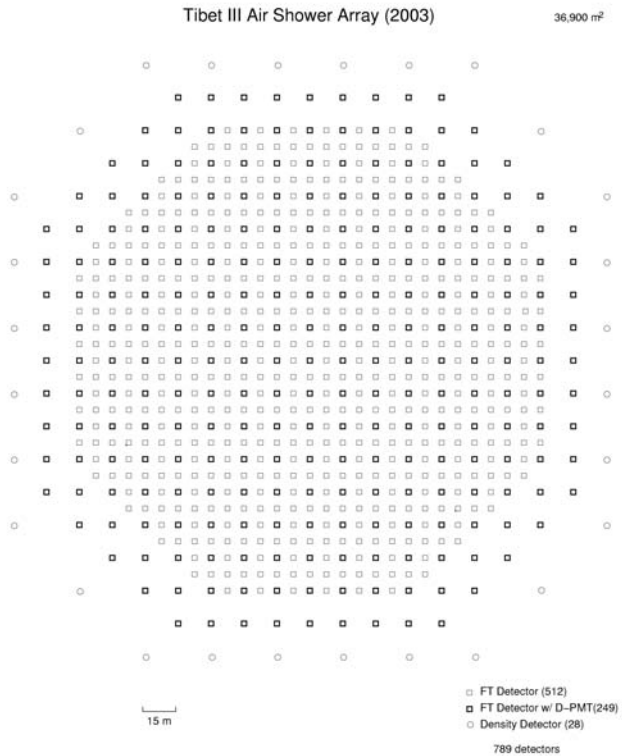
(a) Department of Physics, Hirosaki University, Hirosaki 036-8561, Japan
(b) Department of Physics, Saitama University, Saitama 338-8570, Japan
(c) Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
(d) Faculty of Engineering, Yokohama National University, Yokohama 240-8501, Japan
(e) Department of Physics, Hebei Normal University, Shijiazhuang 050016, China
(f) Department of Mathematics and Physics, Tibet University, Lhasa 850000, China
(g) Department of Physics, Shandong University, Jinan 250100, China
(h) Institute of Modern Physics, South West Jiaotong University, Chengdu 610031, China
(i) Department of Physics, Yunnan University, Kunming 650091, China
(j) Faculty of Engineering, Kanagawa University, Yokohama 221-8686, Japan
(k) Faculty of Education, Utsunomiya University, Utsunomiya 321-8505, Japan
(l) Institute for Cosmic Ray Research, University of Tokyo, Kashiwa 277-8582, Japan
(m) Department of Physics, Konan University, Kobe 658-8501, Japan
(n) Faculty of Systems Engineering, Shibaura Institute of Technology, Saitama 337-8570, Japan
(o) Department of Physics, Shinshu University, Matsumoto 390-8621, Japan
(p) Center of Space Science and Application Research, Chinese Academy of Sciences, Beijing 100080, China
(q) Advanced Research Institute for Science and Engineering, Waseda University, Tokyo 169-8555, Japan
(r) Advanced Media Network Center, Utsunomiya University, Utsunomiya 321-8585, Japan
(s) National Institute for Informatics, Tokyo 101-8430, Japan
(t) Tochigi Study Center, University of the Air, Utsunomiya 321-0943, Japan
(u) Tokyo Metropolitan College of Industrial Technology, Tokyo 116-8523, Japan
(v) Shonan Institute of Technology, Fujisawa 251-8511, Japan
(w) RIKEN, Wako 351-0198, Japan
(x) School of General Education, Shinshu University, Matsumoto 390-8621, Japan

Tibet Airshower Array

Tibet III (37000m^2)



Yangbajing (4,300m a.s.l.=606g/cm^2), Tibet, China



~3 TeV

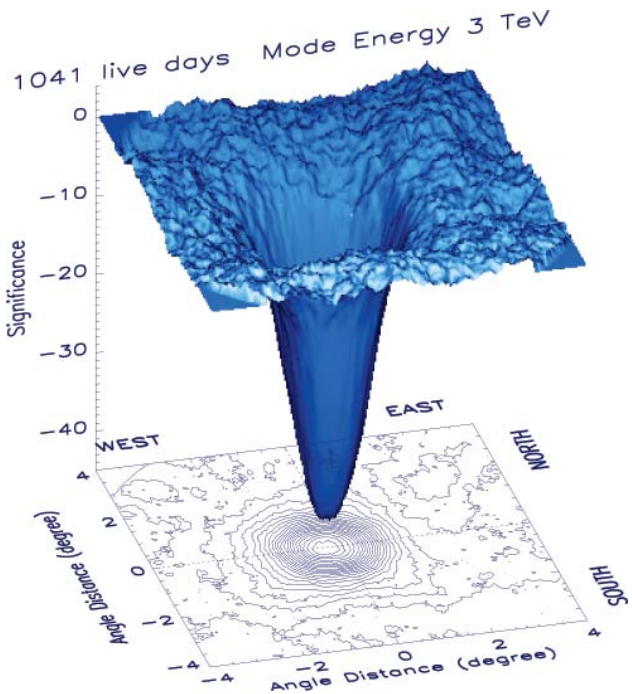
Angular Resolution

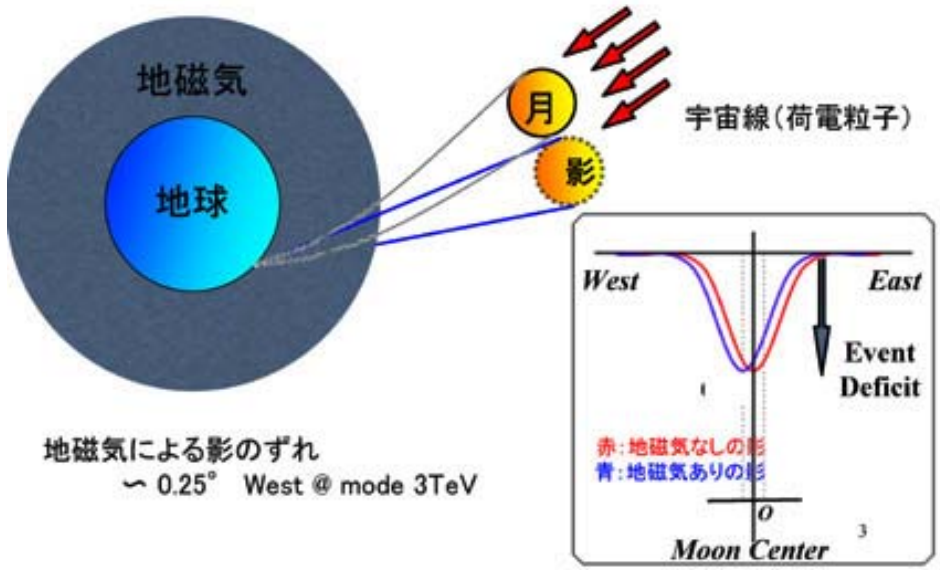
~0.9 deg @3TeV

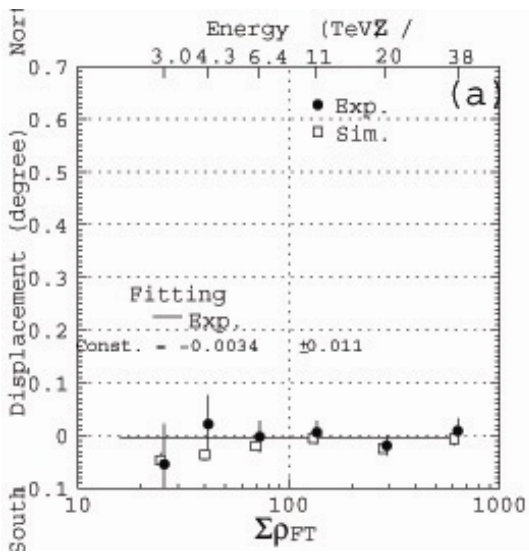
Trigger Rate

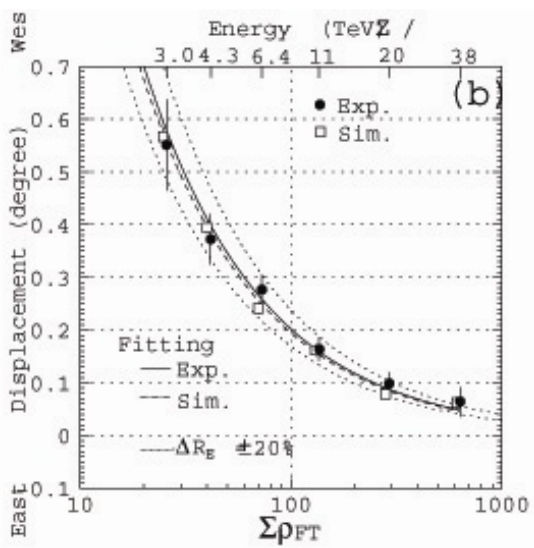
~1700 Hz

Moon's Shadow and Geomagnetic Field







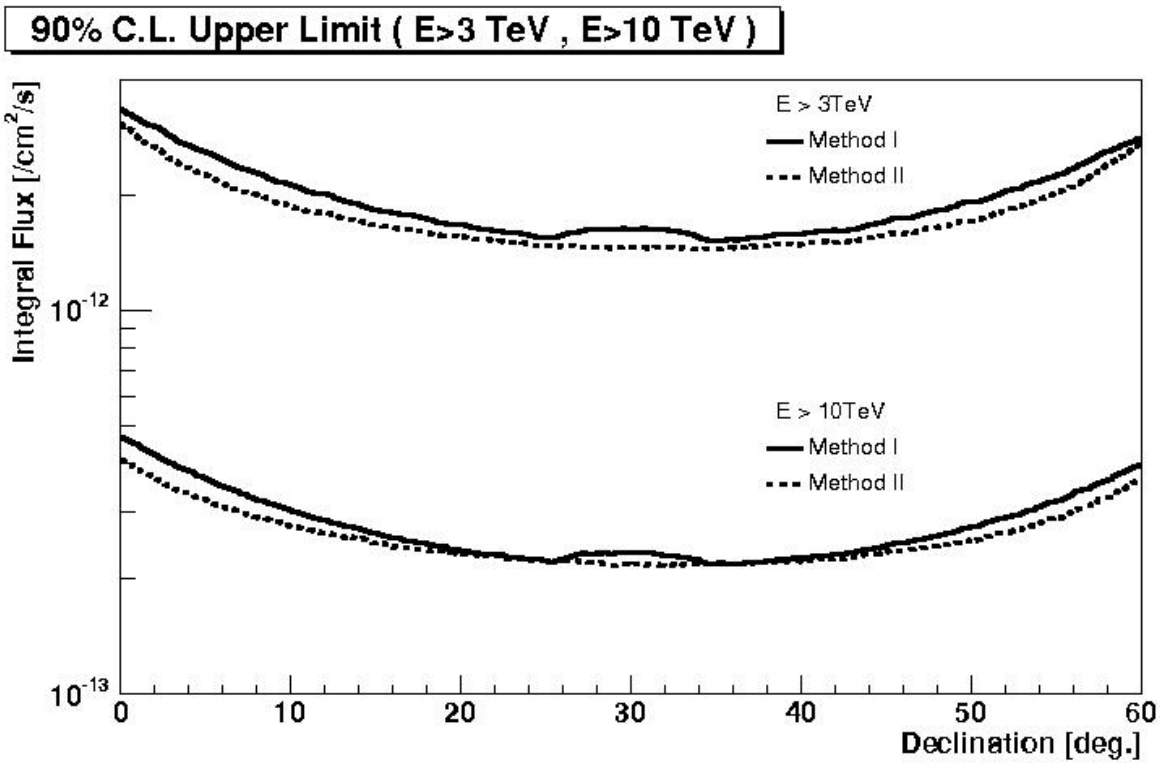


Observed Moon's shadow

North-south deviation

Westward shift

Northern Sky TeV γ-ray Source Search



No new steady bright point source (like Crab) found

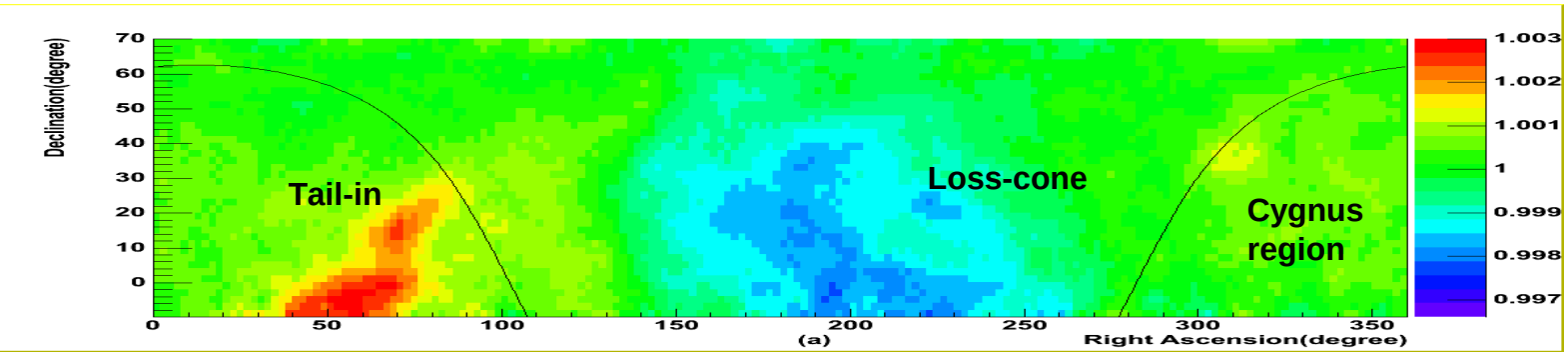
0.3 to 0.6 Crab

Flux upper limit

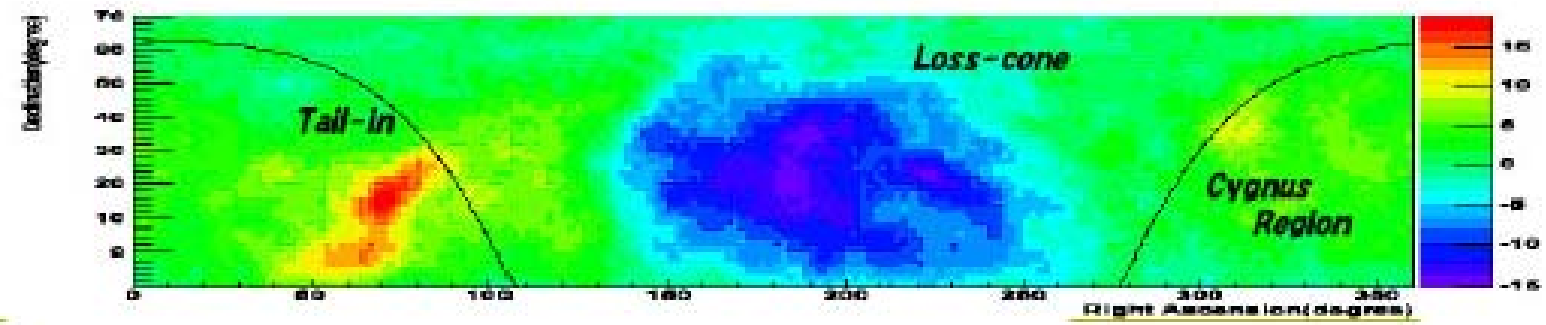
@90% CL

ApJ, 633, 1005-1012, (2005)

Multi-TeV Cosmic Ray Anisotropy at Sidereal Time



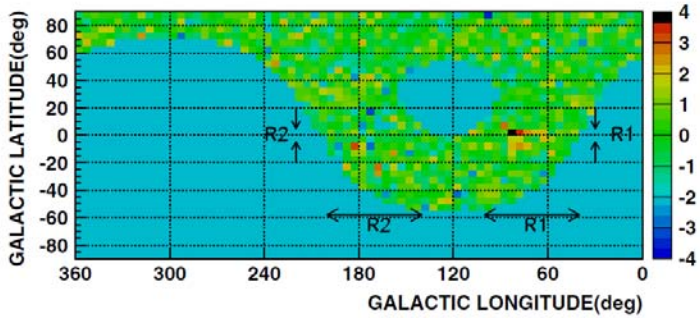
Relative Intensity (%) to CR

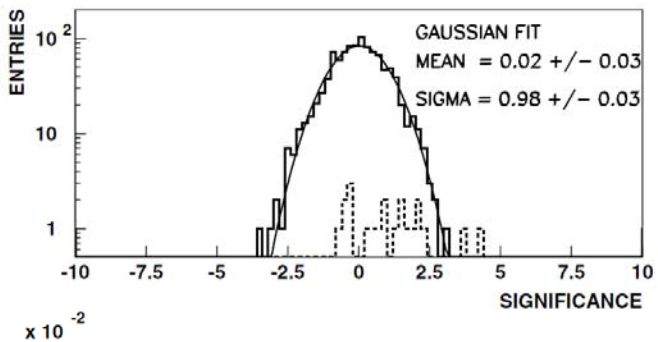


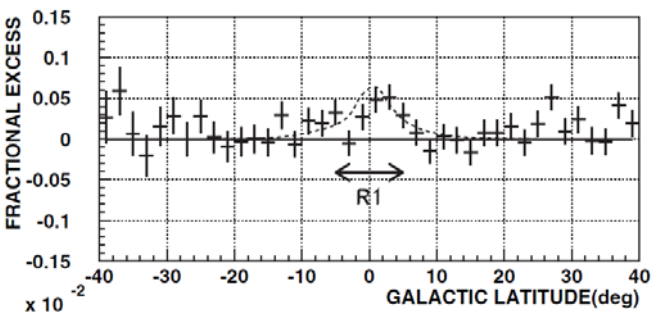
Excess(σ)

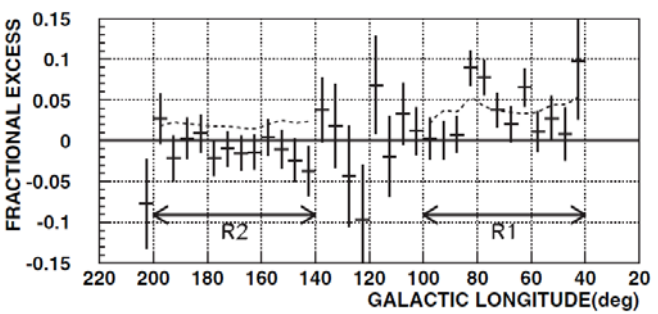
(ICRC2005, vol 2, 49-52)

Three calendar years data starting July 2000





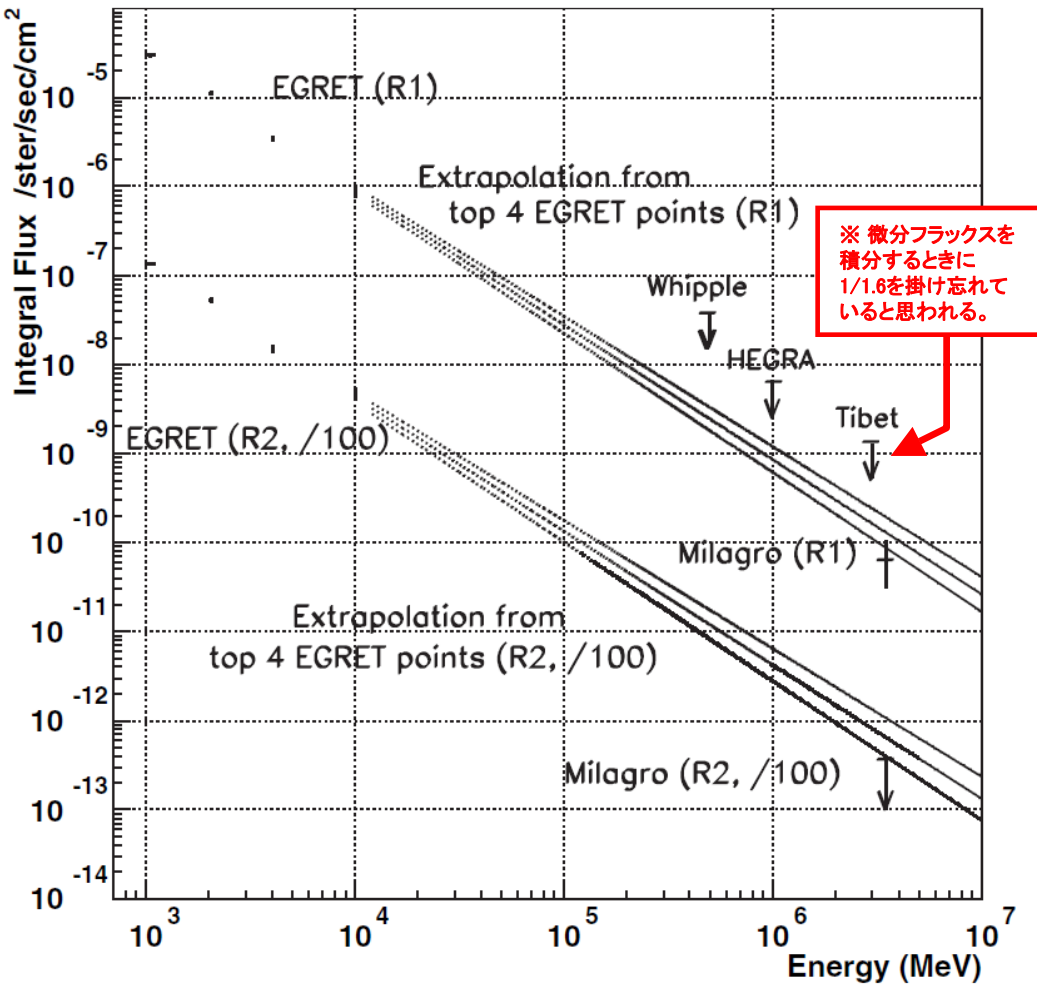




Milagro Paper

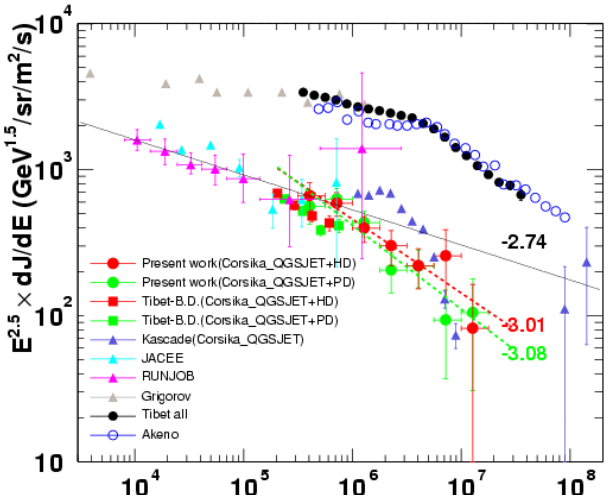
PRL **95,** 251103 (2005)

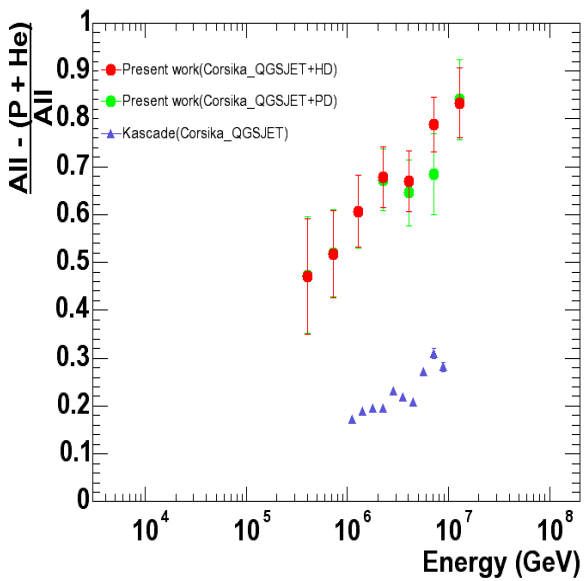
PHYSICAL



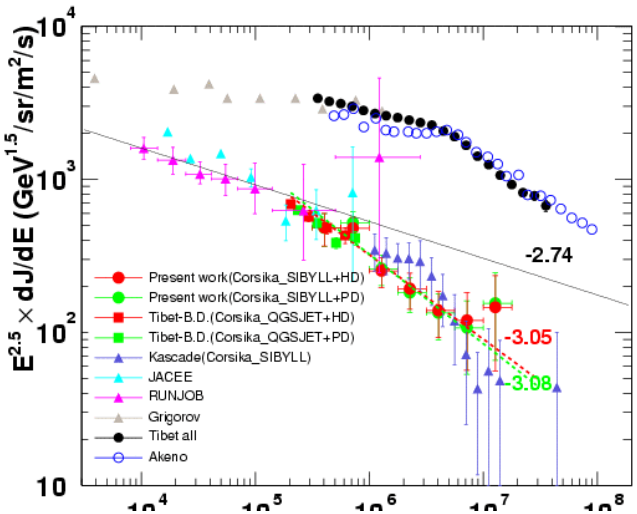
Primary Cosmic Ray Energy Spectrum

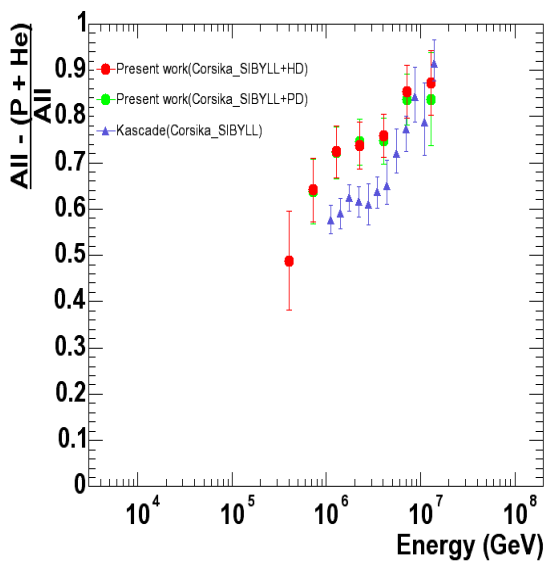
CORSIKA_QGSJET





CORSIKA_SIBYLL





Proton Spectrum

Small Model Dependence

(30 %)

$$\frac{\text{All} - (\text{p+He})}{\text{All}}$$

PL B632 (2006)58-64

Cf. Talks by M. Shibata

What we have found out:

Crab, Mrk501 , Mrk421 observed, but

No new steady bright TeV γ-ray point source found

Possible diffuse γ-ray signal from Cygnus region?

P, He, all-particle E-spectrum (Galactic cosmic rays accelerated to the knee region ~10^{15} eV)

What we should do next:

1. 100 TeV (10 – 1000 TeV) region γ-ray astronomy

   Where do galactic cosmic rays under knee come from?

2. E-spectrum of heavy component around ‘ knee’

   All-particle knee = CNO? Fe knee?

   (Cf. M.Shibata’s talk)

100TeV γ-ray search

Cosmic Rays are accelerated at least up to 10^{15} eV in Our Galaxy.

- 100 TeV gamma-rays should be emitted at the sources via the decay of pions produced by interaction between accelerated nuclei and ambient matters.
- Electrons can also produce 100 TeV gamma-rays by IC scattering.

< Cassiopeia A; Chandra X-ray Observatory >

Introduction

Tibet AS array		IACT
1° (~3TeV) 0.2° (~100TeV)	Angular Resolution	~0.1°
40,000m^2	Effective Area	~50,000m^2
~90%	Duty cycle	~10%
2 sr	Field of View	0.02 sr

<Tibet Air Shower Array>

<H.E.S.S.>

Tibet Air Shower Array

Scintillation Counter Array

(a) **Detector#: 533 (until 2002), 789(now)**

In this talk, 533 detectors used to keep the data consistency.

Effective area ~22,000 m^2 (now, 37,000 m2)

(b) Angular Resolution ~ 0.2^o @ 100 TeV region

(c) Modal Energy ~ 3 TeV

In this talk, events with > 500 particles detected are used

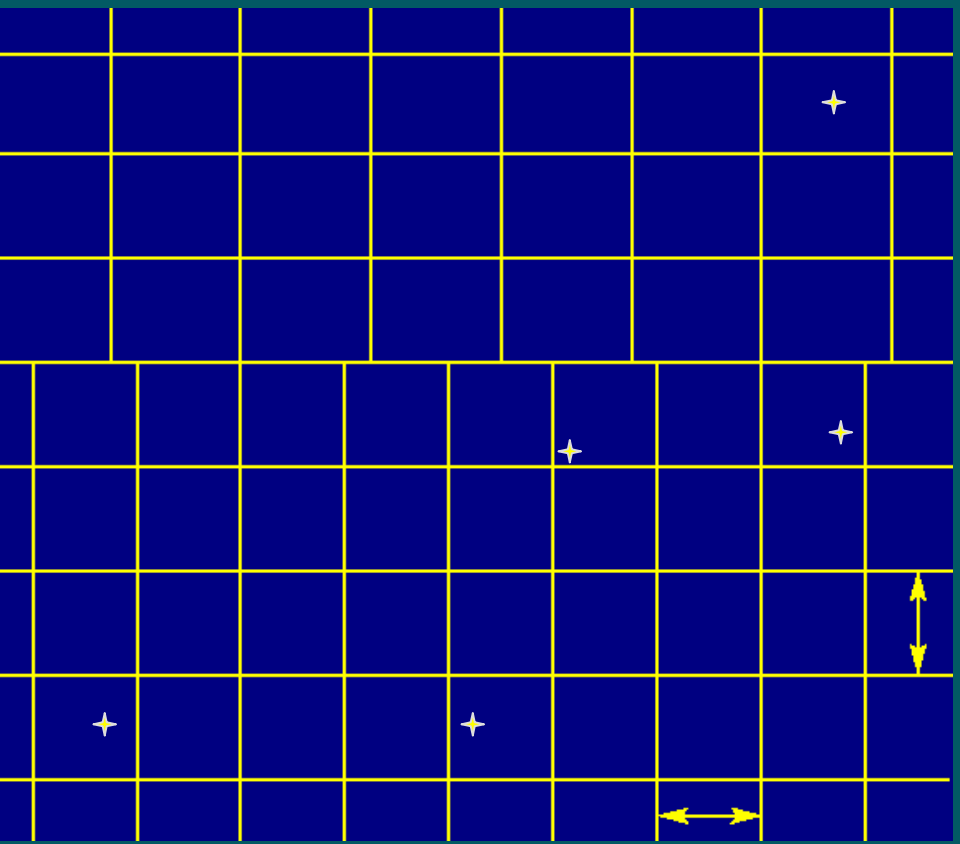
Modal Energy ~ 100 TeV on this selection

Observational Condition

Period : Nov. 1999 to Nov. 2005
Live time : 1318.9 days
Effective Area: 22,000 m^2

Modal Energy: ~100 TeV
Zenith Angle : <= 50 [deg]
Declination : -10 ~ +70 [deg]

Sky map binning



#Rectangular bins $(\Delta\alpha \times \Delta\delta)$

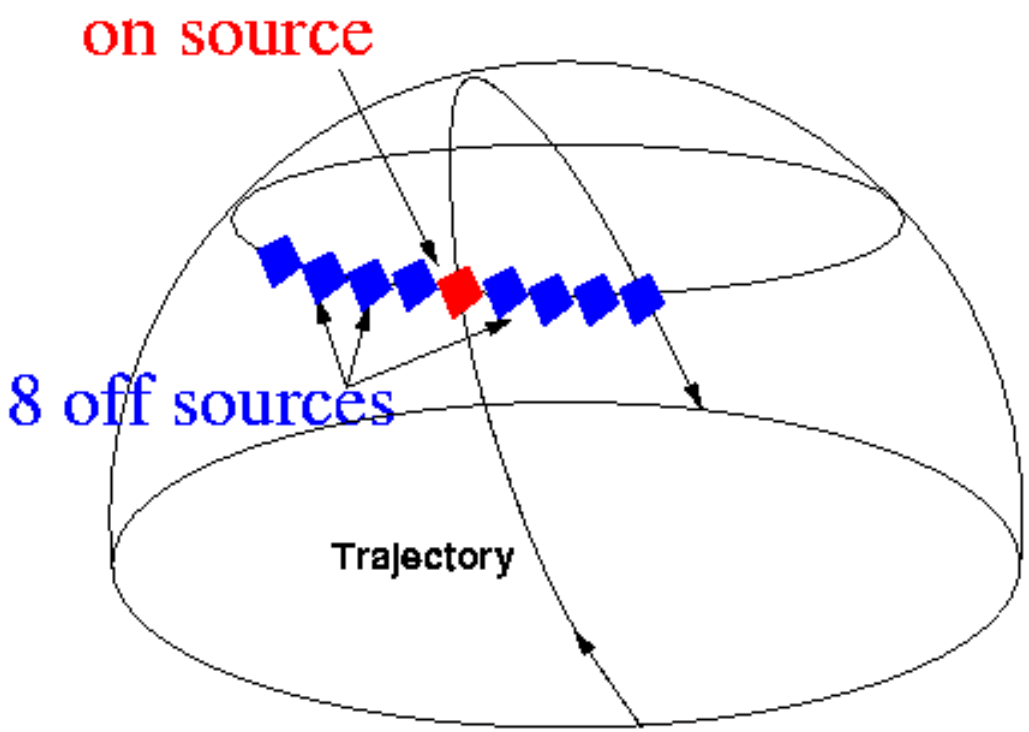
#Non-overlapping

#Constant Solid Angle $(\Omega \approx 7.5 \times 10^{-5}[sr])$

$\Delta\delta = 0.5^o$

$\Delta\alpha \approx 0.5^o / \cos(\delta)$

Equi-zenith Method



Estimate the number of BG events by using 8 equi-zenith-angle windows

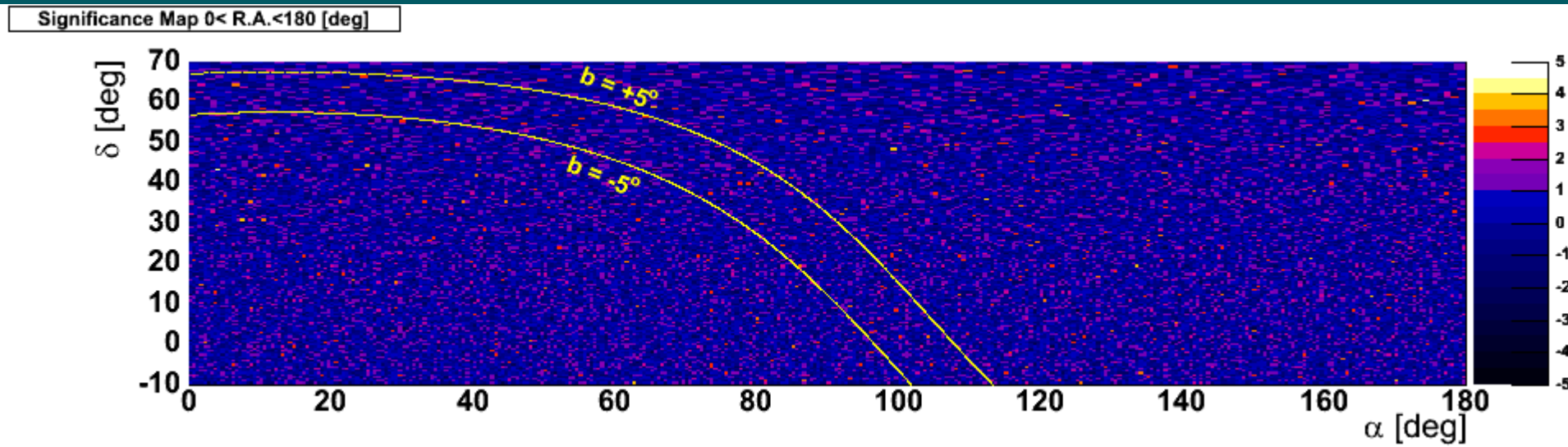
Significance of Excess

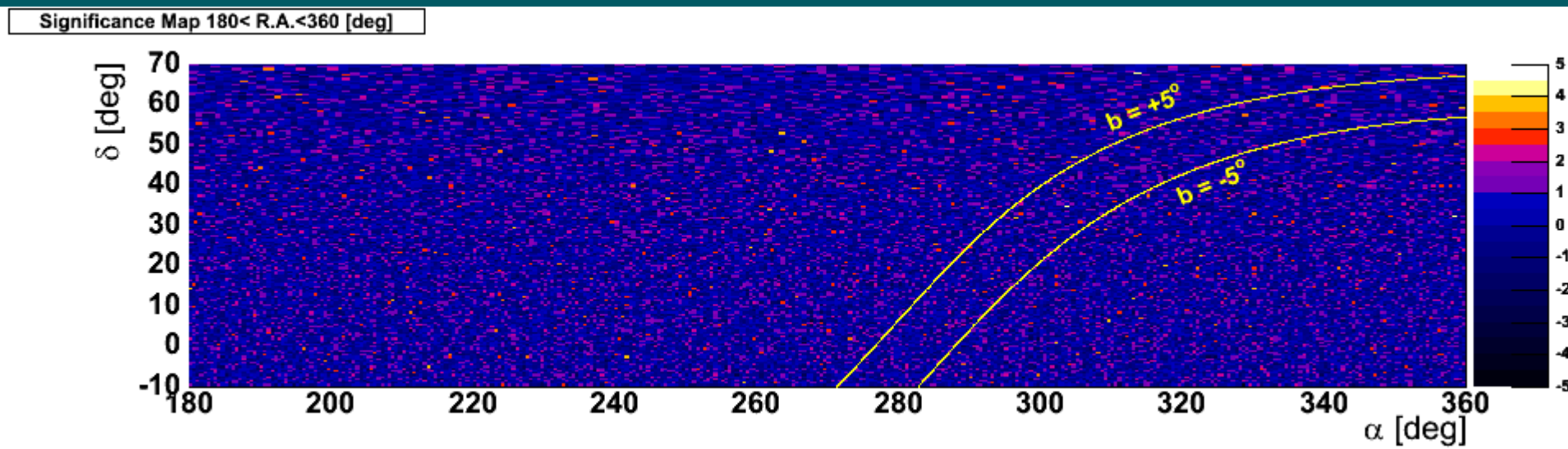
$$\sigma = \sqrt{2} * \sqrt{N_{on} \ln\left[\frac{1+\alpha}{\alpha}\left(\frac{N_{on}}{N_{on}+N_{off}}\right)\right] + N_{off} \ln\left[(1+\alpha)\left(\frac{N_{off}}{N_{on}+N_{off}}\right)\right]}$$

$$\alpha = 0.125$$

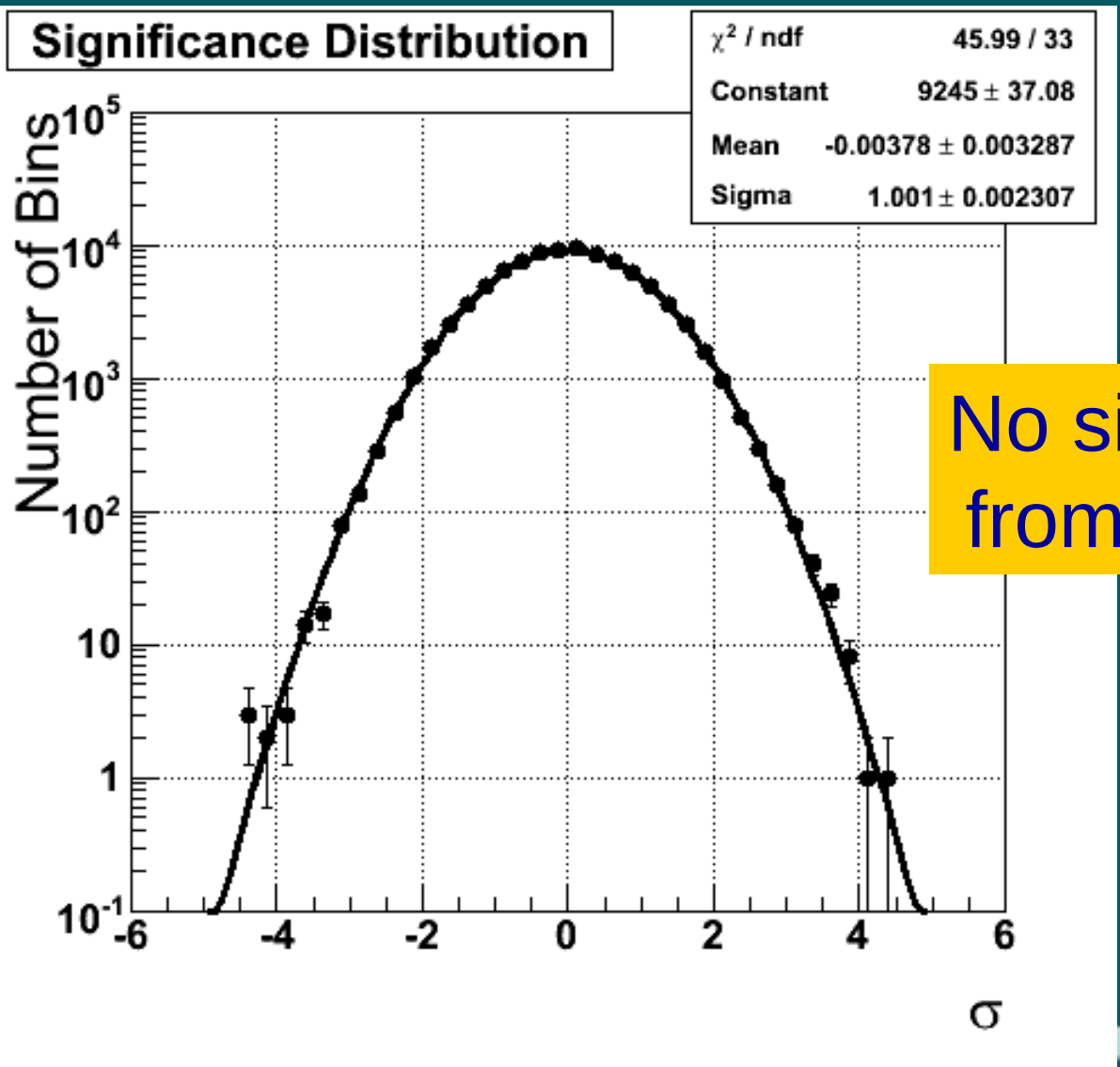
Li-Ma (17), [ApJ vol.272, 317; 1983]

Significance Map



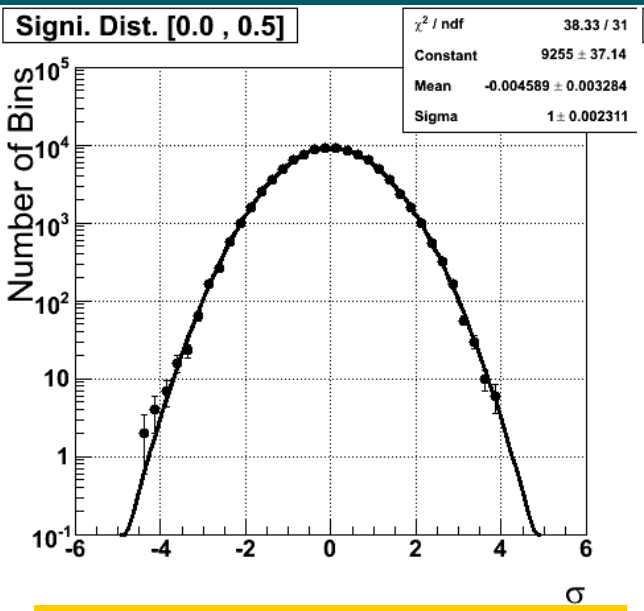


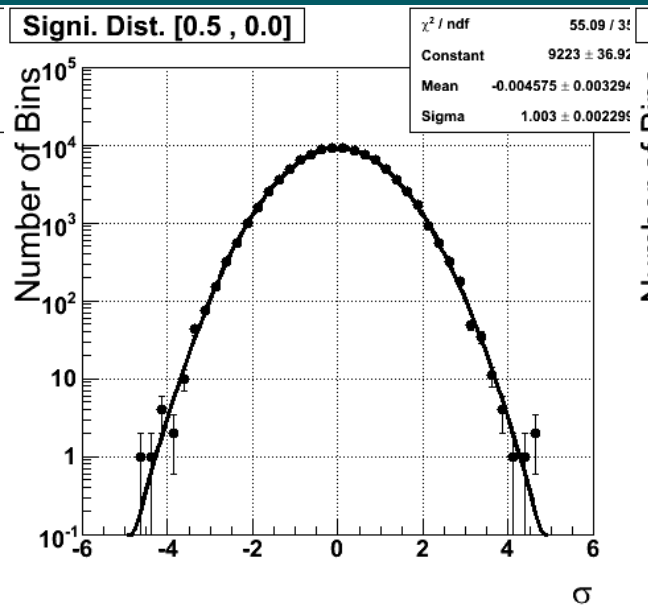
Significance Distribution

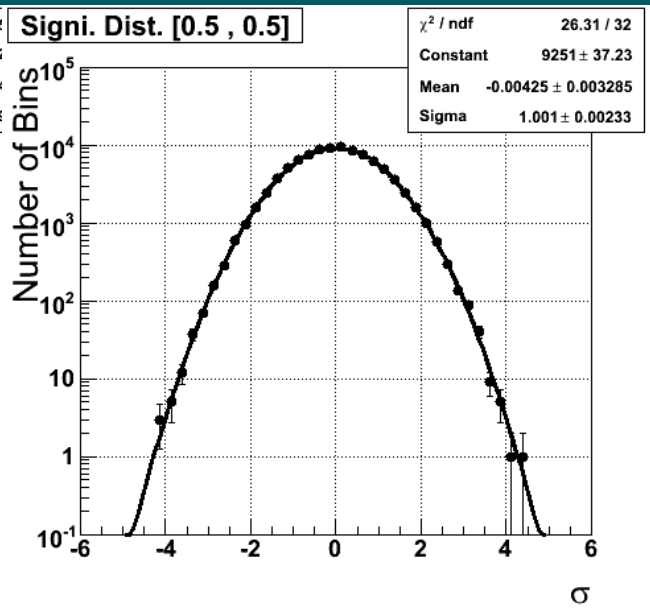


No significant Deviation from Normal Gaussian

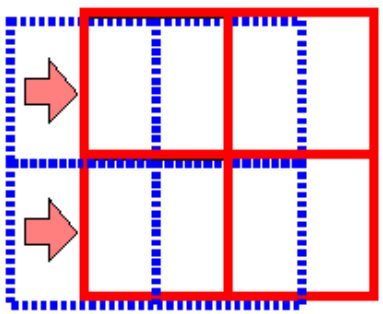
Different Binning



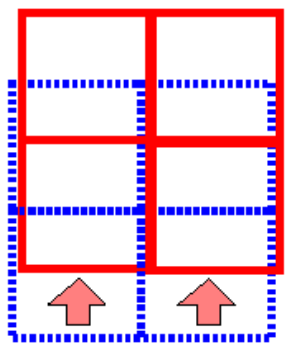




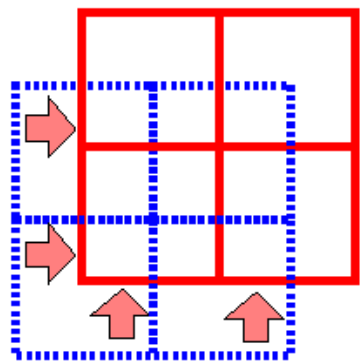
Half-Bin-Slid in R.A. direction



Half-Bin-Slid in Dec. direction



Half-Bin-Slid In R.A. and Dec. directions



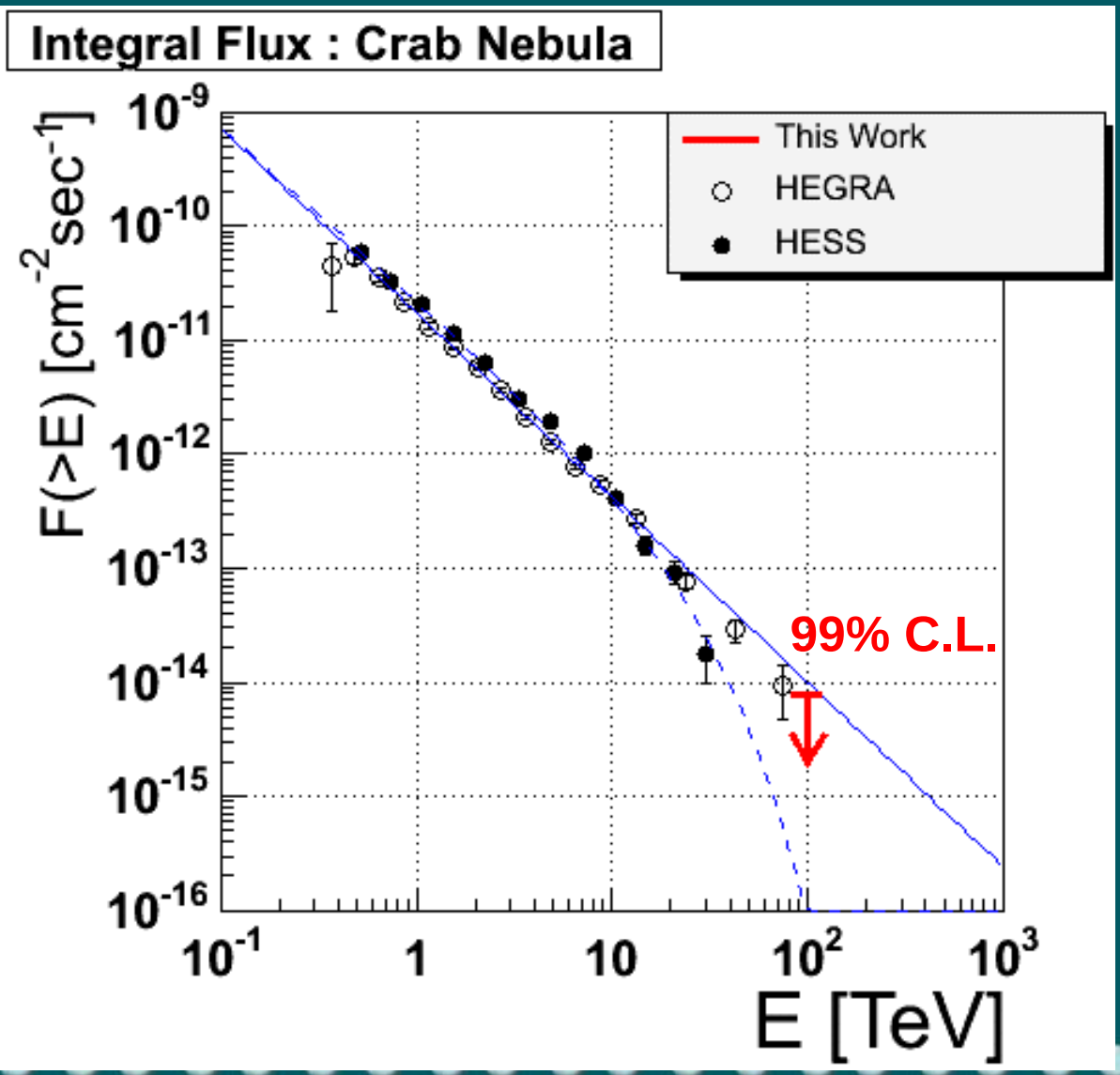
Excess from Known TeV Sources

	α	δ	N_{on}	N_{bg}	σ
1ES1959	300.00	+65.15	745	733.9	0.39
LS I +61	40.13	+61.23	832	913.4	-2.58
Cas A	350.85	+58.82	1059	1018.4	1.19
1ES2344	356.77	+51.71	1267	1255.1	0.32
H1426	217.14	+42.68	1522	1490.1	0.78
TeV2032	307.99	+41.50	1560	1510.4	1.20
Mrk 501	253.47	+39.76	1550	1542.6	0.18

Excess from Known TeV Sources

	α	δ	N_{on}	N_{bg}	σ
Mrk 421	166.12	+38.22	1521	1543.5	-0.54
1ES1218	185.34	+30.18	1411	1396.9	0.36
Crab	83.63	+22.02	1434	1472.5	-0.95
M 87	187.71	+12.39	1126	1154.4	-0.79
J1837	279.46	-6.99	376	371.4	0.23
J1834	278.68	-8.80	344	347.1	-0.16

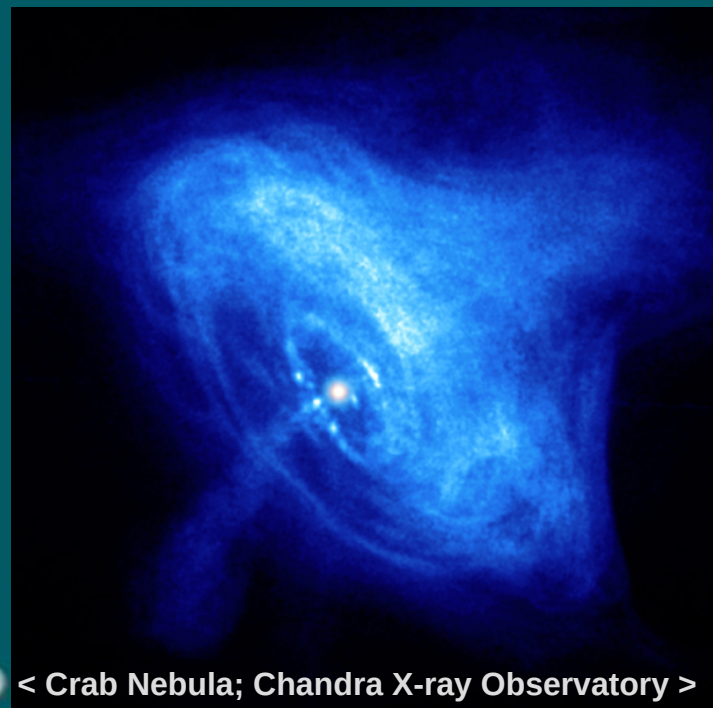
Crab (83.63,+22.02)



Γ =2.62

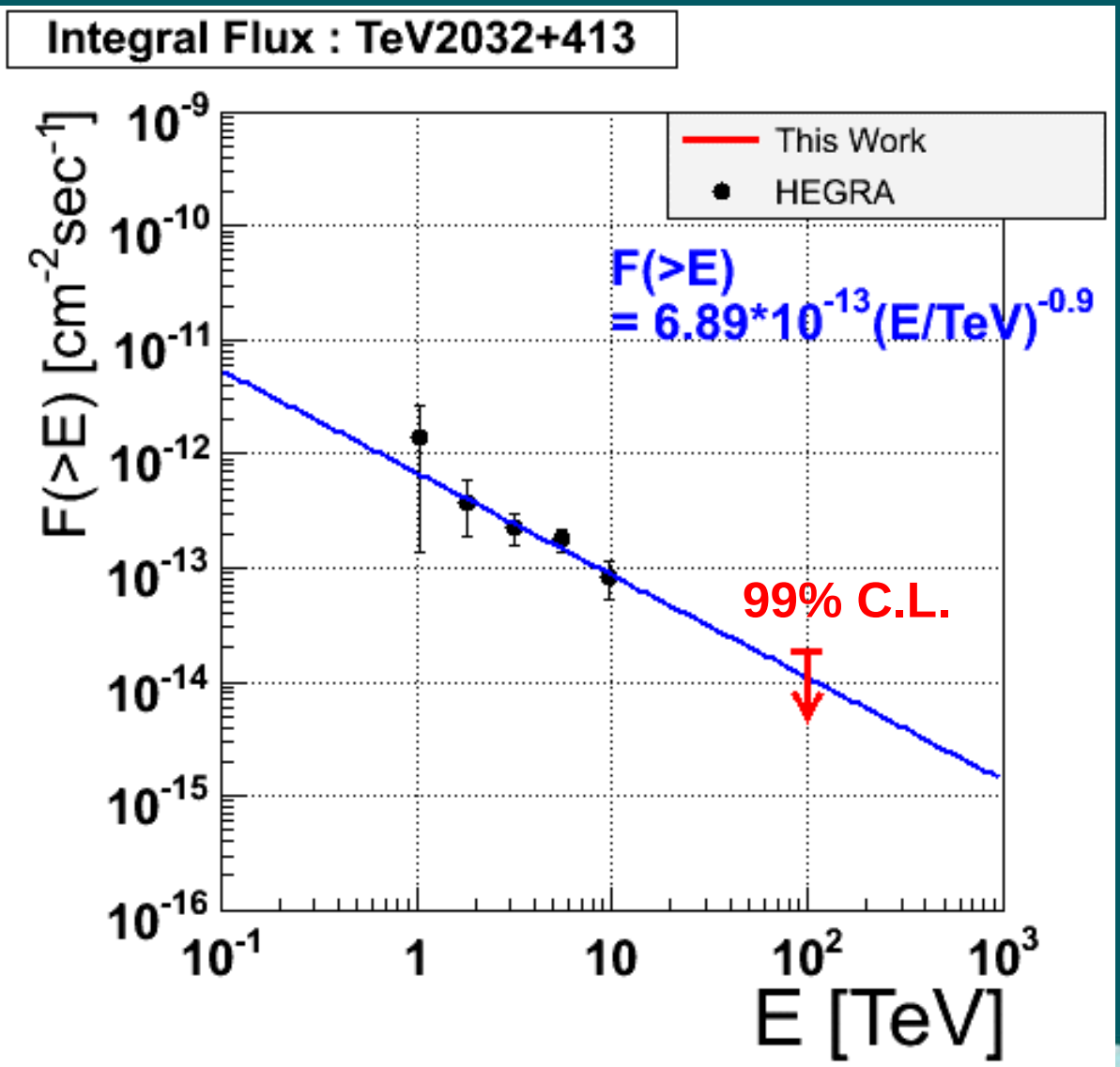
99% C.L. Flux U.L. above 100 TeV is

8.0 e-15 [cm^{-2} sec^{-1}]



< Crab Nebula; Chandra X-ray Observatory >

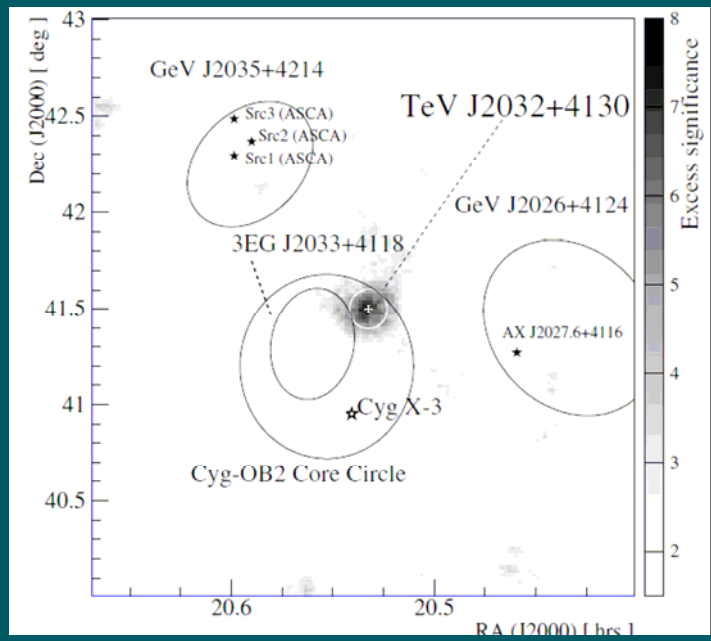
TeV2032+413 (307.98, +41.50)



Γ = -1.9

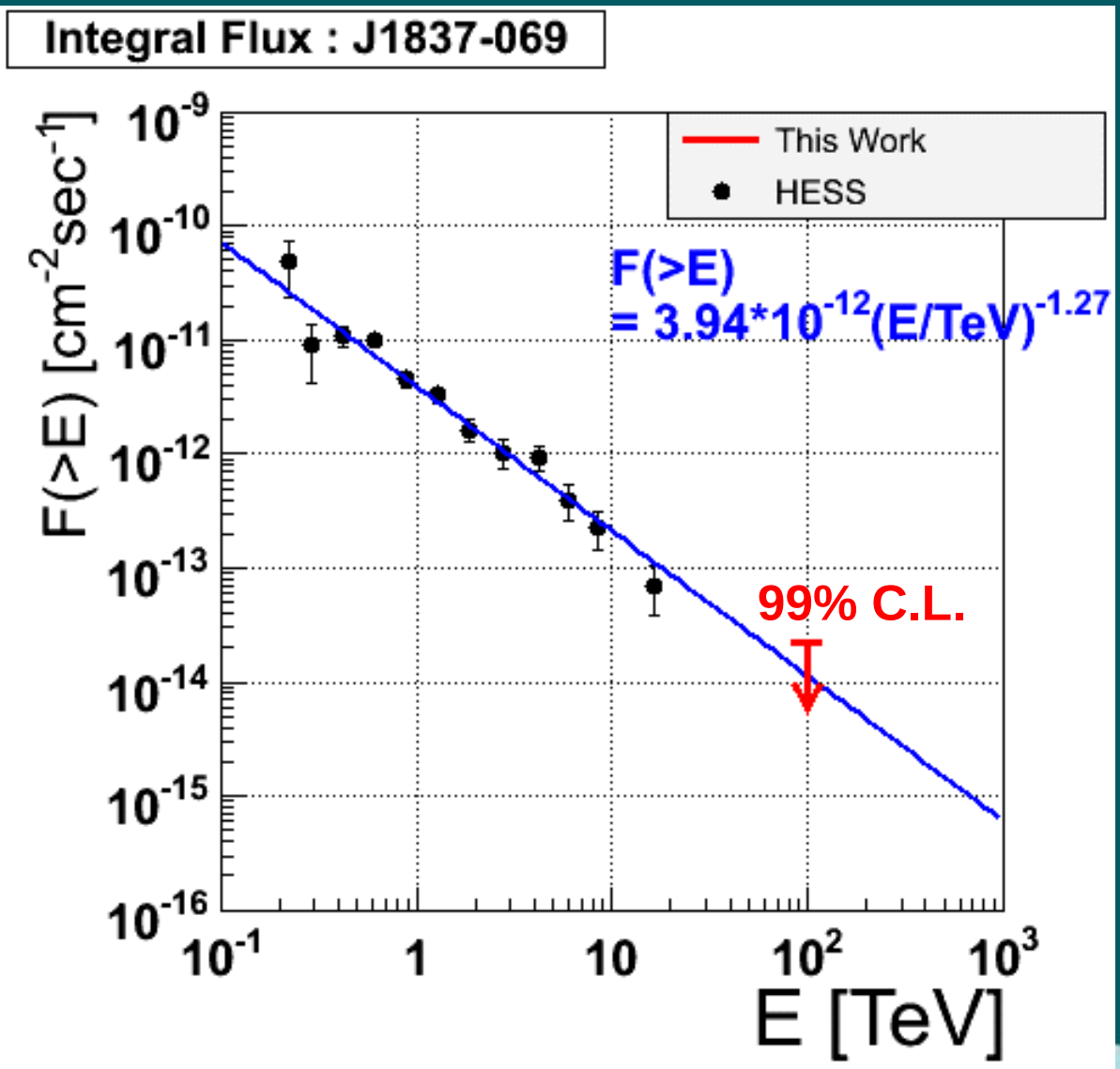
99% C.L. Flux U.L. above 100 TeV is

1.9 e-14 [cm^{-2} sec^{-1}]



< Aharonian et al., A&A 431(2005) >

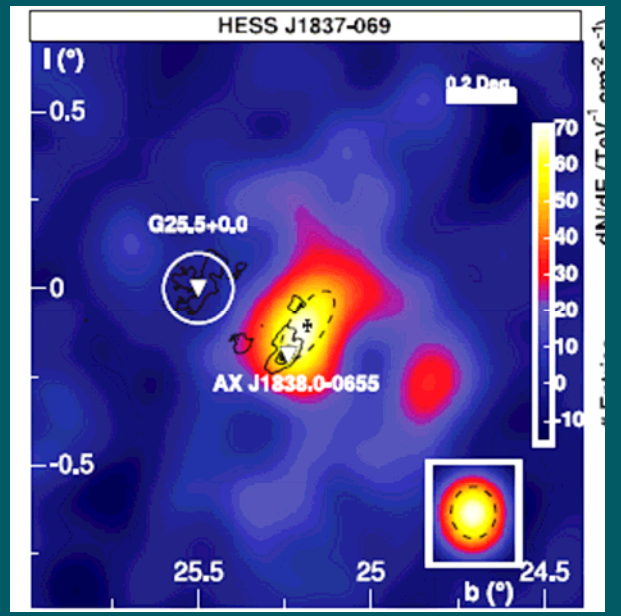
J1837-069 (279.46 -6.99)



Γ = -2.27

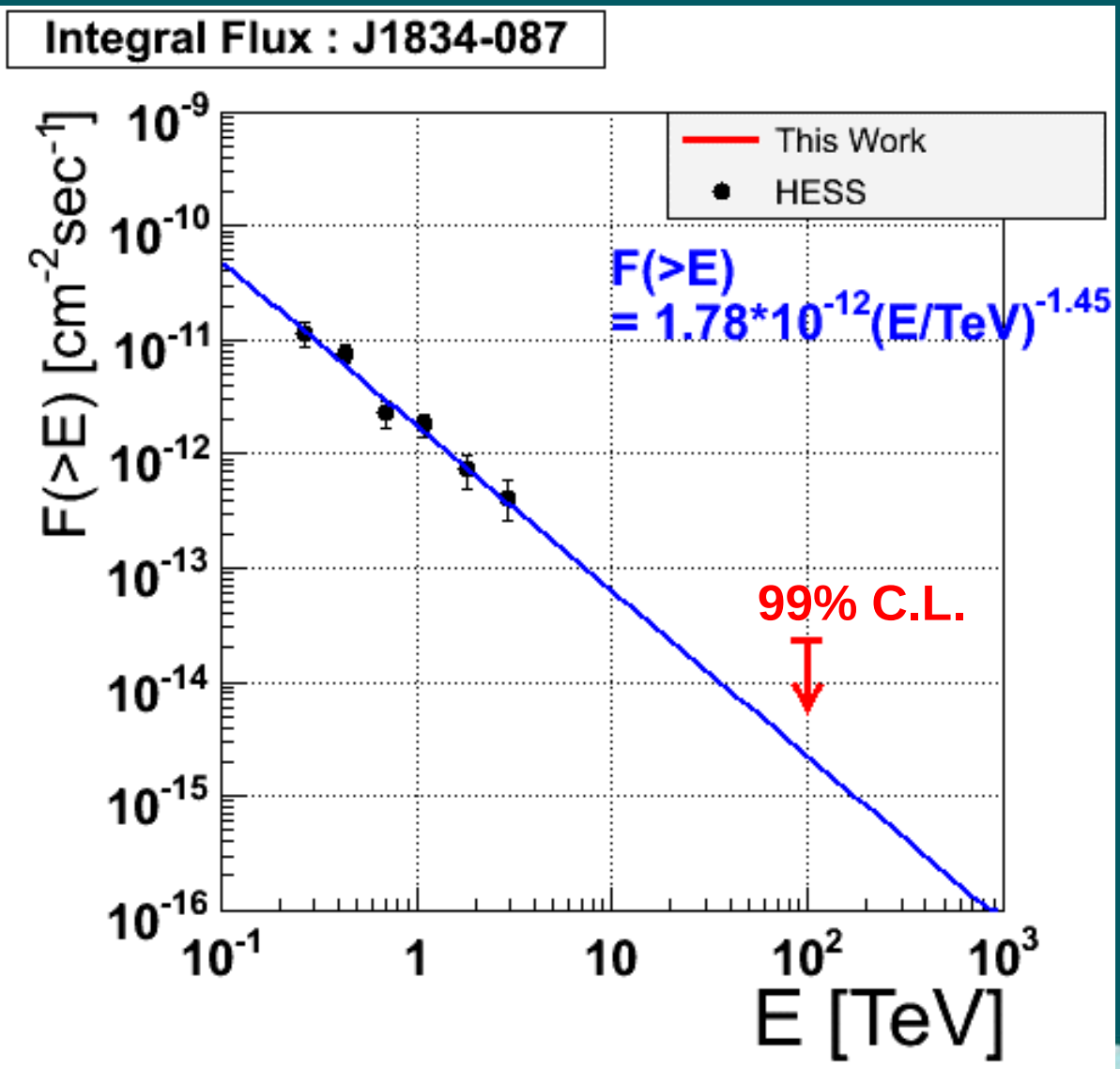
99% C.L. Flux U.L. above 100 TeV is

2.2 e-14 [cm^{-2} sec^{-1}]



< Aharonian et al., ApJ 636(2006) >

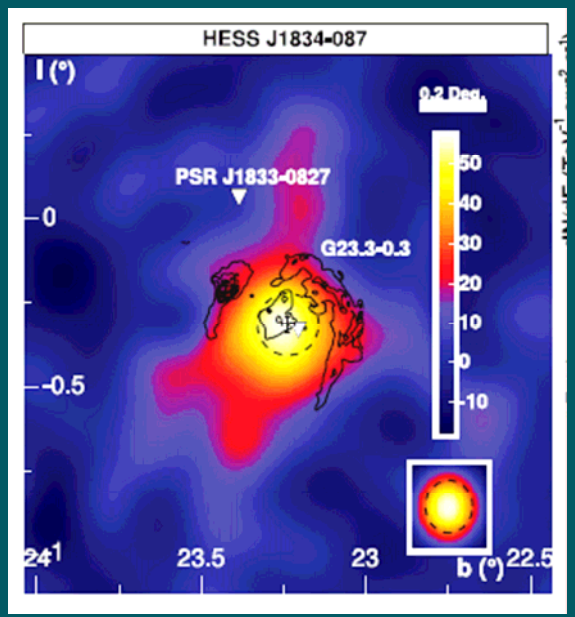
J1834-087 (278.68 -8.80)



Γ = -2.45

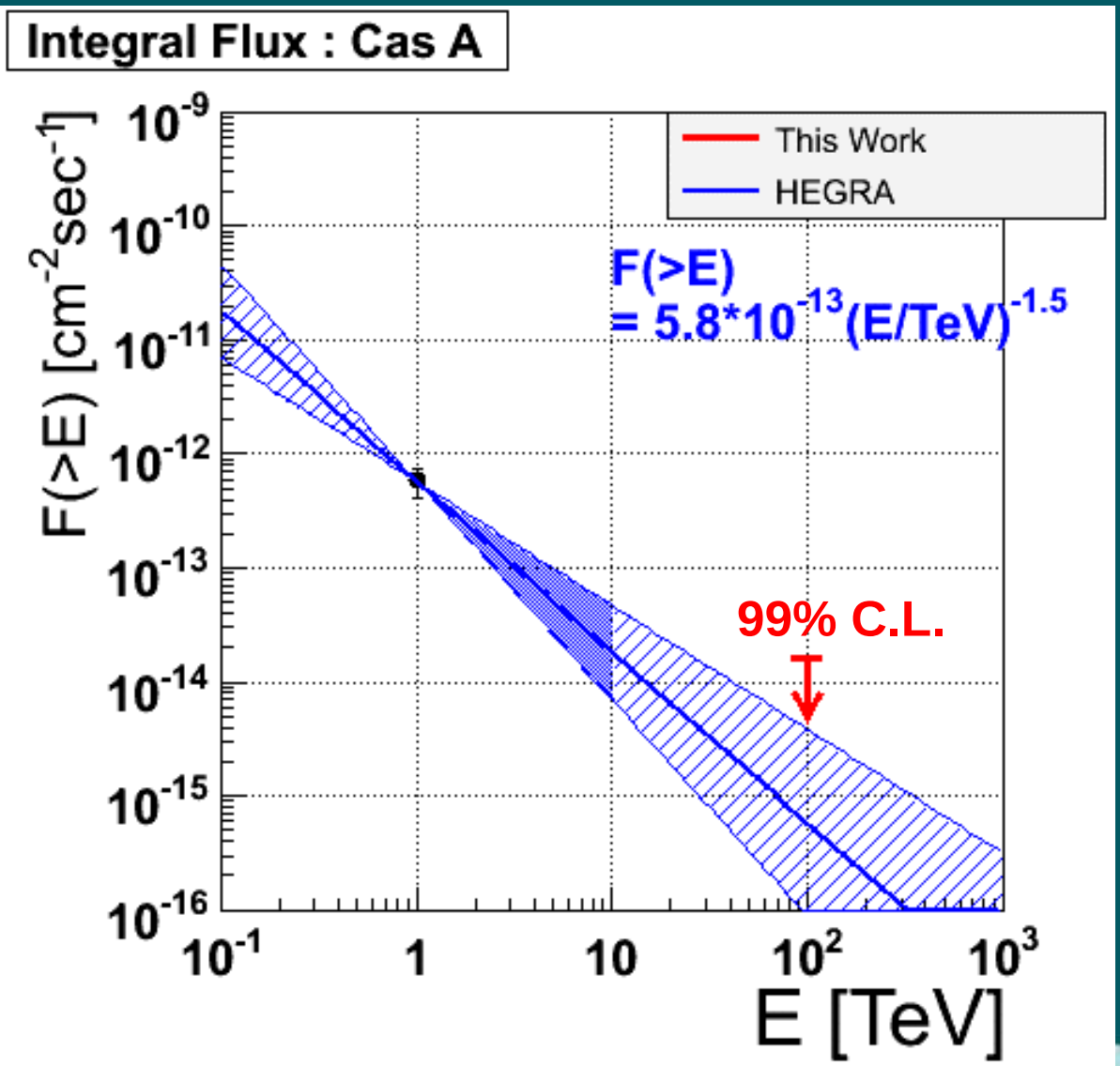
99% C.L. Flux U.L. above 100 TeV is

2.3 e-14 [cm^{-2} sec^{-1}]



< Aharonian et al., ApJ 636(2006) >

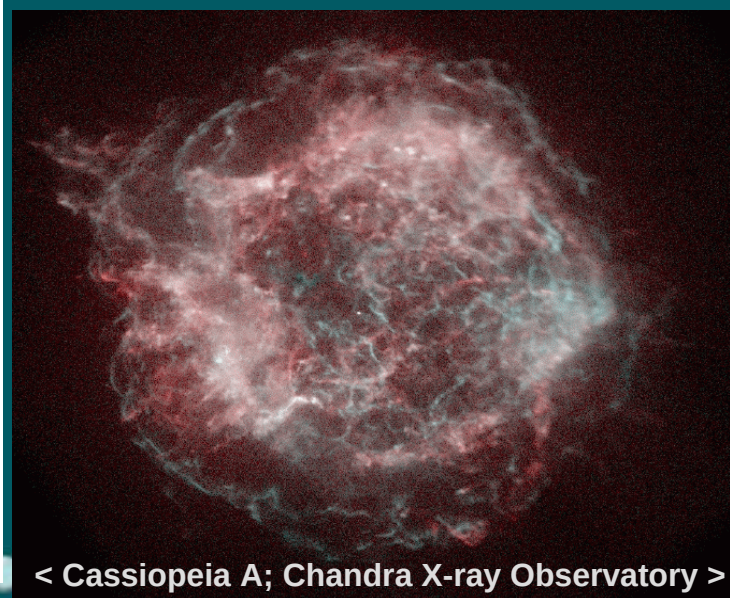
Cassiopeia A (350.85, +58.82)



Γ = -2.45

99% C.L. Flux U.L. above 100 TeV is

1.6 e-14 [cm^{-2} sec^{-1}]



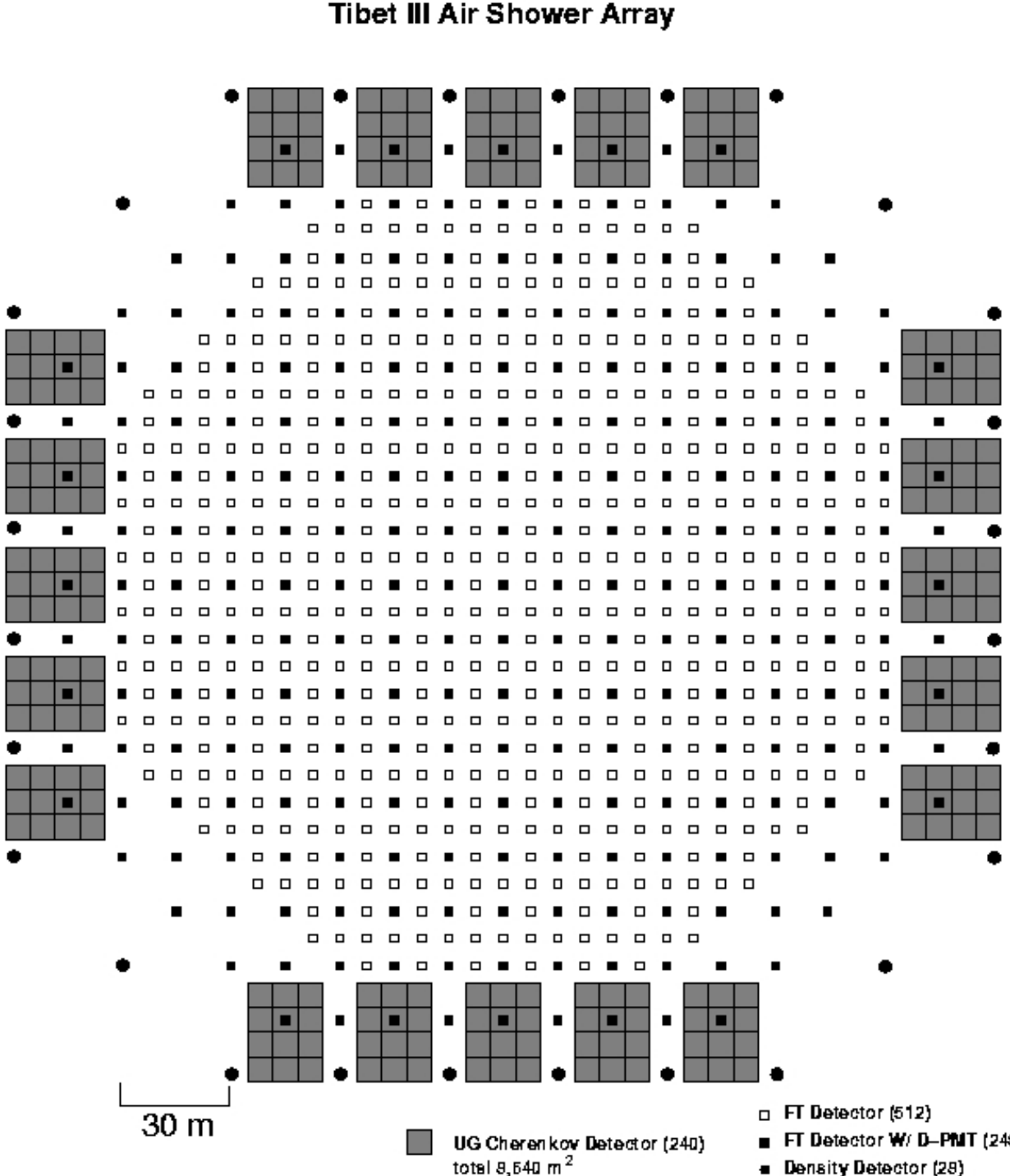
< Cassiopeia A; Chandra X-ray Observatory >

Towards Higher Sensitivity

Let's see 100 TeV-region gamma rays by Tibet-III (AS) + a large underground muon detector array (MD) (8640m^2 in total)!

Origin of cosmic rays and acceleration mechanism and limit at SNRs.

Diffuse gamma rays could be detected.


Tibet III Air Shower Array
30 m
UG Cherenkov Detector (240)
total 8,640 m 2
FT Detector (512)
FT Detector W/ D–PMT (249)
Density Detector (28)

Conclusions

- We couldn’t find any new source at 100 TeV region.
- We set upper limits on several objects above 100 TeV, though they are all consistent with extrapolations from lower energies.

- Next Project (Tibet MD) will improve our sensitivity by a factor of ?? -> Next talk (Kawata)