チベット高原での高エネルギー宇宙線の研究

瀧田正人　東京大学宇宙線研究所

平成18年度共同利用成果発表会

@宇宙線研究所　15/12/2006

(For the Tibet AS γ collaboration)

平成18年度チベット実験関係の共同利用研究採択課題一覧

1. チベット高原での高エネルギー宇宙線の研究
（瀧田正人　東京大学宇宙線研究所）

2. 宇宙線による太陽の影を用いた太陽周辺磁場の時間変動の研究
（西澤正己　国立情報学研究所人間・社会情報研究系）

3. 一時的または定常的ガンマ線放射の点源天体の探索
（坂田通徳　甲南大学理工学部）

4. Knee領域一次宇宙線組成の研究
（柴田槇雄　横浜国立大学大学院工学研究院）

5. Sidereal daily variation of ~10TeV galactic cosmic ray intensity observed by the Tibet air shower array
(宗像一起　信州大学理学部）

チベットグループ共同利用研究
経費執行状況

校費:　申請額495万円　->　配分額220万円

2002年に完成したTibet-IIIの維持・運転及び
将来計画のためのR＆D費用の一部に使用。

旅費:　申請額890万円　->　配分額370万円

宇宙線研での研究打ち合わせ

チベット出張海外旅費

The Tibet ASγ Collaboration

Papers (in refereed journals):

- Are protons still dominant at the knee of the cosmic-ray energy spectrum?, Phys. Lett B632, 58-64, (2006)
- Anisotropy and Corotation of Galactic Cosmic Rays, Science 314, 439-443, (2006)
- Variation of Sun shadow in the solar cycle 23 observed with the Tibet air shower array, Advances in Space Research, 38, 936-941 (2006).
- Primary proton spectrum around the knee observed by the Tibet air-shower experiment, Advances in Space Research, 37, 1938-1943 (2006)
- Flux upper limits of diffuse TeV gamma rays from the Galactic plane using the effective area of the Tibet-II and -III arrays, Advances in Space Research, 37, 1932-1937 (2006)
- Underground Water Cherenkov Muon Detector Array with the Tibet Air Shower Array for Gamma-Ray Astronomy in the 100-TeV region, Astrophys. Space Sci., accepted

International Conference

- COSPAR2006 (Beijing, China 2006) 3 talks
- ECRS2006 (Lisbon, Poutugal 2006) 2 posters
- The Multi-Messenger Approach to Unidentified Gamma-Ray Sources:3rd Workshop on the Nature of Unidentified High-Energy Sources (Barcelona, Spain 2006) 1 poster
- ISVHECRI2006 (Weihai, China 2006) 5 talks and 2 posters
- TEXAS symposium2006 (Merbourne, Australia 2006) 3 posters
- Locating PeV Cosmic-Ray Accelerators: Future Detectors in Multi-TeV Gamma-Ray Astronomy (Adelaide, Australia 2006) 2 talks
- Suzaku symposium (Kyoto, Japan 2006) 1 poster

研究目的

大気チェレンコフ望遠鏡と相補的な
広視野(約2sr)連続観測高エネルギー宇宙線望遠鏡

3～100TeVの高エネルギーガンマ線放射天体の
探索、10^{14} ～10^{17}の一次宇宙線の観測から、
宇宙線の起源、加速機構の研究を行う。

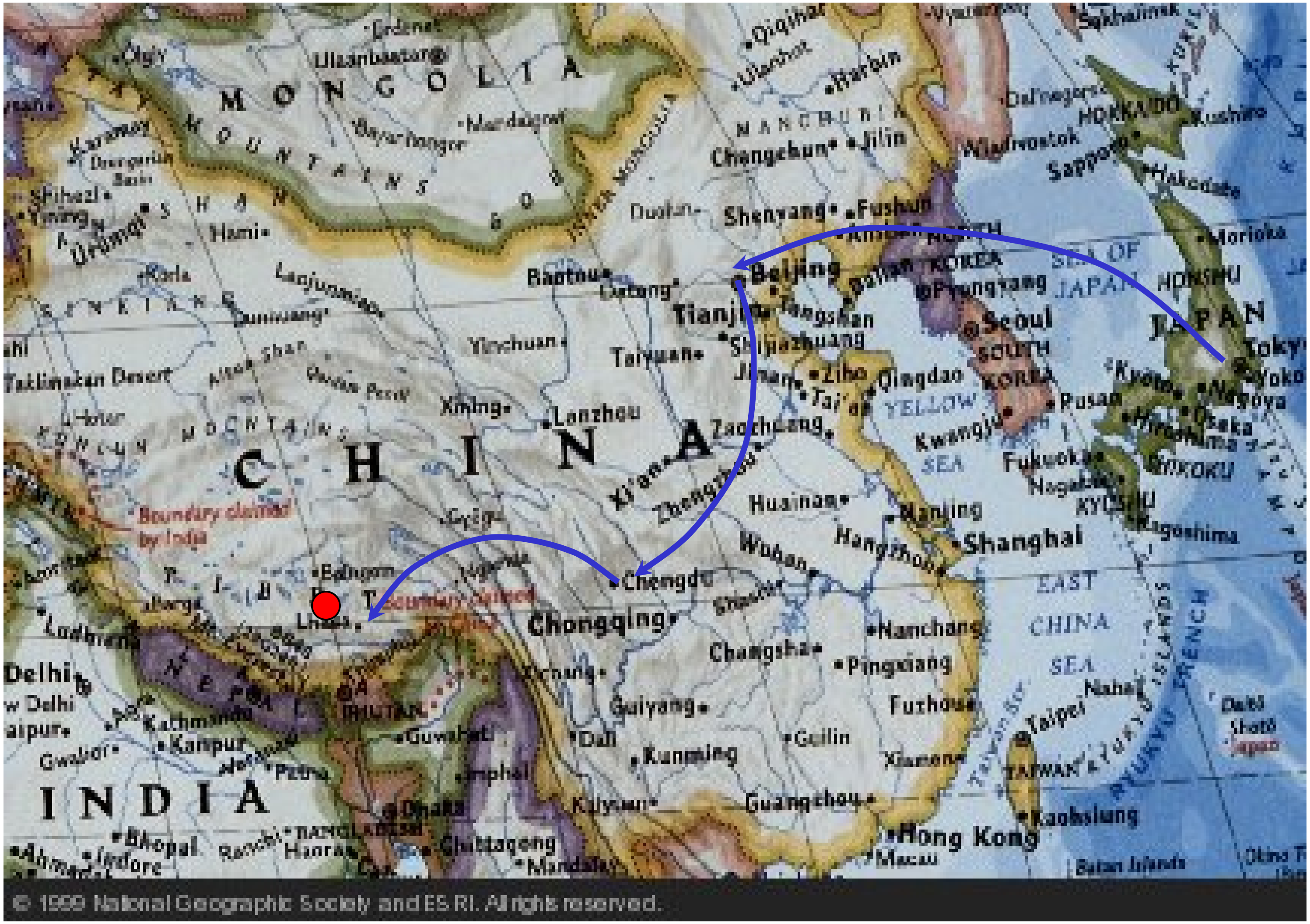
太陽活動期における“太陽の影”
(太陽による宇宙線の遮蔽効果)を観測し、
太陽近傍および惑星間磁場の大局的構造を知る。

The Tibet ASγ Collaboration

M.Amenomori,[1] S.Ayabe,[2] X.J.Bi,[3] D.Chen,[4] S.W.Cui,[5] Danzengluobu,[6] L.K.Ding,[3] X.H.Ding,[6] C.F.Feng,[7] Zhaoyang Feng,[3] Z.Y.Feng,[8] X.Y.Gao,[9] Q.X.Geng,[9] H.W.Guo,[6] H.H.He,[3] M.He,[7] K.Hibino,[10] N.Hotta,[11] HaibingHu,[6] H.B.Hu,[3] J.Huang,[12] Q.Huang,[8] H.Y.Jia,[8] F.Kajino,[13] K.Kasahara,[14] Y.Katayose,[4] C.Kato,[15] K.Kawata,[12] Labaciren,[6] G.M.Le,[16] A.F. Li,[7] J.Y.Li,[7] Y.-Q. Lou,[17] H.Lu,[3] S.L.Lu,[3] X.R.Meng,[6] K.Mizutani,[2,18] J.Mu,[9] K.Munakata,[15] A.Nagai,[19] H.Nanjo,[1] M.Nishizawa,[20] M.Ohnishi,[12] I.Ohta,[21] H.Onuma,[2] T.Ouchi,[10] S.Ozawa,[12] J.R.Ren,[3] T.Saito,[22] T.Y.Saito,[23] M.Sakata,[13] T.K.Sako,[12] T.Sasaki,[10] M.Shibata,[4] A.Shiomi,[12] T.Shirai,[10] H.Sugimoto,[24] M.Takita,[12] Y.H.Tan,[3] N.Tateyama,[10] S.Torii,[18] H.Tsuchiya,[25] S.Udo,[12] B. Wang,[9] H.Wang,[3] X.Wang,[12] Y.G.Wang,[7] H.R.Wu,[3] L.Xue,[7] Y.Yamamoto,[13] C.T.Yan,[12] X.C.Yang,[9] S.Yasue,[26] Z.H.Ye,[16] G.C.Yu,[8] A.F.Yuan,[6] T.Yuda,[10] H.M.Zhang,[3] J.L.Zhang,[3] N.J.Zhang,[7] X.Y.Zhang,[7] Y.Zhang,[3] Yi Zhang,[3] Zhaxisangzhu,[6] and X.X.Zhou[8]

(1) Dep. of Phys., Hirosaki Univ., Hirosaki, Japan
(2) Dep. of Phys., Saitama Univ., Saitama, Japan
(3) Key Lab. of Particle Astrophys., IHEP, CAS, Beijing, China
(4) Fac. of Eng., Yokohama National Univ., Yokohama , Japan
(5) Dep. of Phys., Hebei Normal Univ., Shijiazhuang, China
(6) Dep. of Math. and Phys., Tibet Univ., Lhasa, China
(7) Dep. of Phys., Shandong Univ., Jinan, China
(8) Inst. of Modern Phys., South West Jiaotong Univ., Chengdu, China
(9) Dep. of Phys., Yunnan Univ., Kunming, China
(10) Fac. of Eng., Kanagawa Univ, Yokohama, Japan
(11) Fac. f of Educ., Utsunomiya Univ., Utsunomiya, Japan
(12) ICRR., Univ. of Tokyo, Kashiwa, Japan
(13) Dep of Phys., Konan Univ., Kobe, Japan
(14) Fac. of Systems Eng., Shibaura Inst. of Tech., Saitama, Japan
(15) Dep. of Phys., Shinshu Univ., Matsumoto, Japan
(16) Center of Space Sci. and Application Research, CAS, Beijing, China
(17) Phys. Dep. and Tsinghua Center for Astrophys., Tsinghua Univ., Beijing, China
(18) Advanced Research Inst. for Sci. and Engin., Waseda Univ., Tokyo, Japan
(19) Advanced Media Network Center, Utsunomiya University, Utsunomiya, Japan
(20) National Inst. of Info., Tokyo, Japan
(21) Tochigi Study Center, Univ. of the Air, Utsunomiya, Japan
(22) Tokyo Metropolitan College of Industrial Tech., Tokyo, Japan
(23) Max-Planck-Institut fuer Physik, Muenchen, Germany
(24) Shonan Inst. of Tech., Fujisawa, Japan
(25) RIKEN, Wako, Japan
(26) School of General Educ.,Shinshu Univ., Matsumoto, Japan

Our site : Tibet



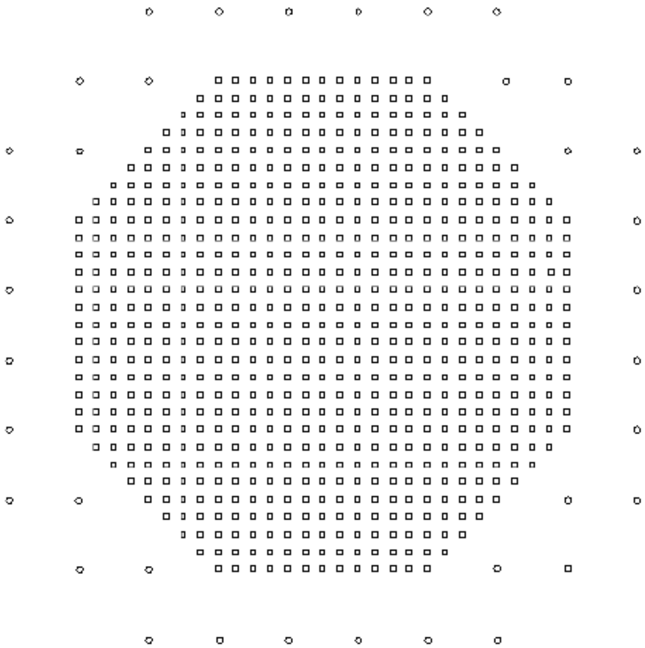
Yangbajing , Tibet, China

90°53**E**,   30°11**N**,   4,300 m a.s.l. (606g/cm^2)

Tibet Airshower Array

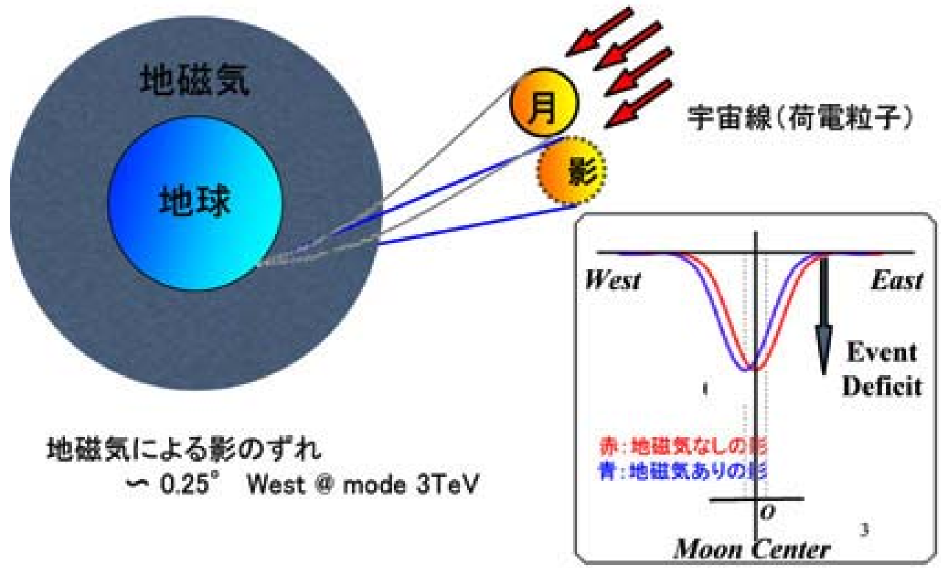
Tibet III (37000m^2)

Yangbajing (4300a.s.l.=606g/cm^2), Tibet, China

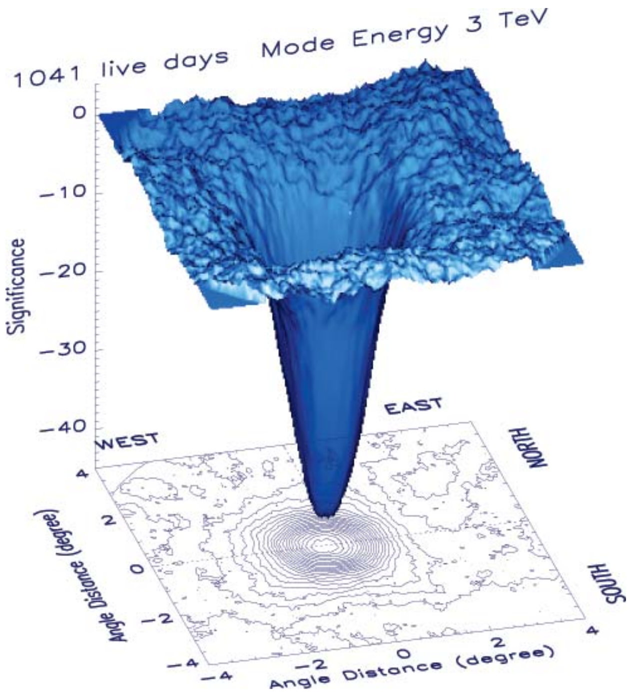


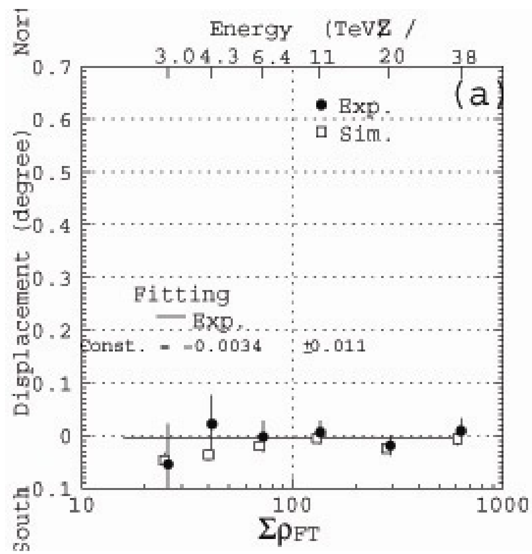
Total 789 detectors
Mode Energy
~3 TeV
Angular Resolution
~0.9 deg @3TeV
Trigger Rate
~1700 Hz

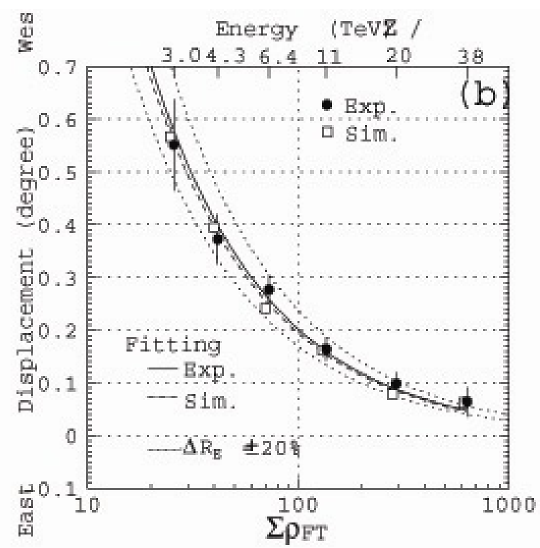
月の影
と
地磁気効果



地磁気による影のずれ
〜 0.25°　West @ mode 3TeV



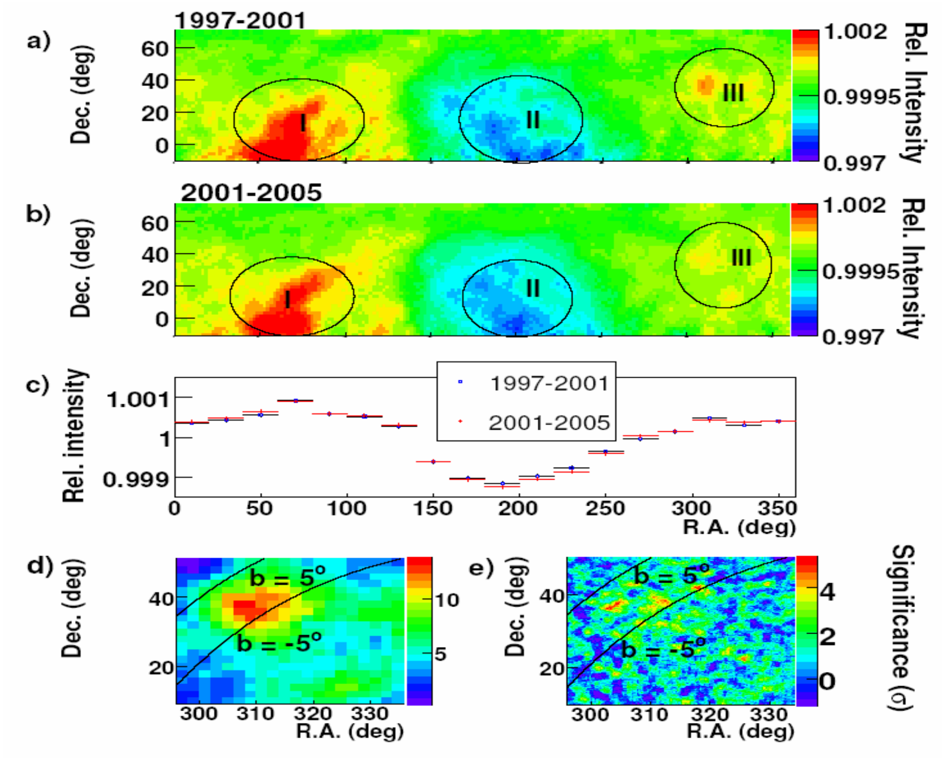


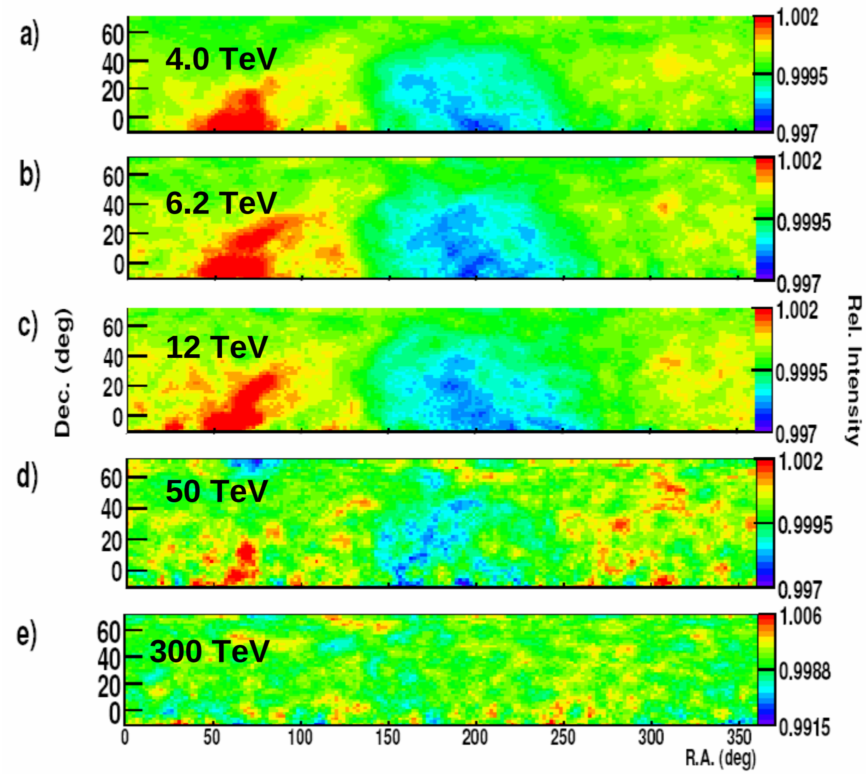


観測された月の影　　影の南北のズレ　　影の西へのズレ

Anisotropy of galactic cosmic rays

I: tain-in, II:loss cone, III: Cygnus





i) No significant temporal variation

ii) <u>New Anisotropy in the Cygnus region</u>

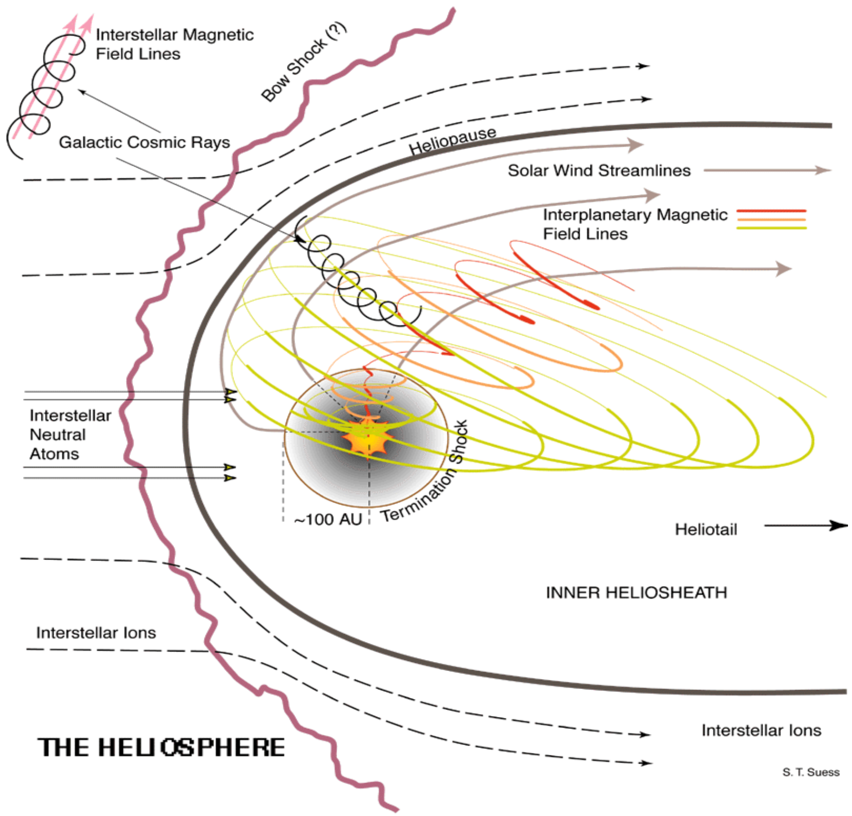
iii) Corotation (CR and Galaxy)

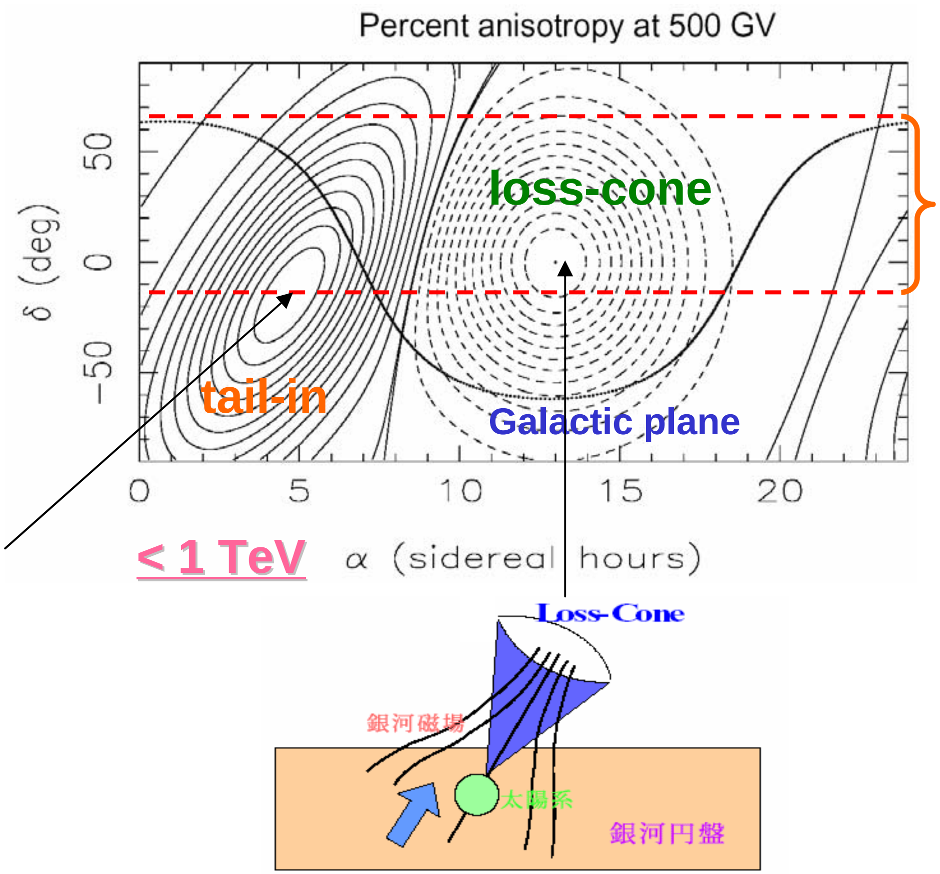
iv) <u>Anisotropy fade away ~ 300 TeV?</u>

Science, **V**<u>314</u>, pp.439 – 443 (**2006**)

Tail-in and loss-cone model of the anisotropy

Ref: K. Nagashima, K. Fujimoto, R.M. Jacklyn, J. Geophys. Res. V**103**, 17429 (1998).





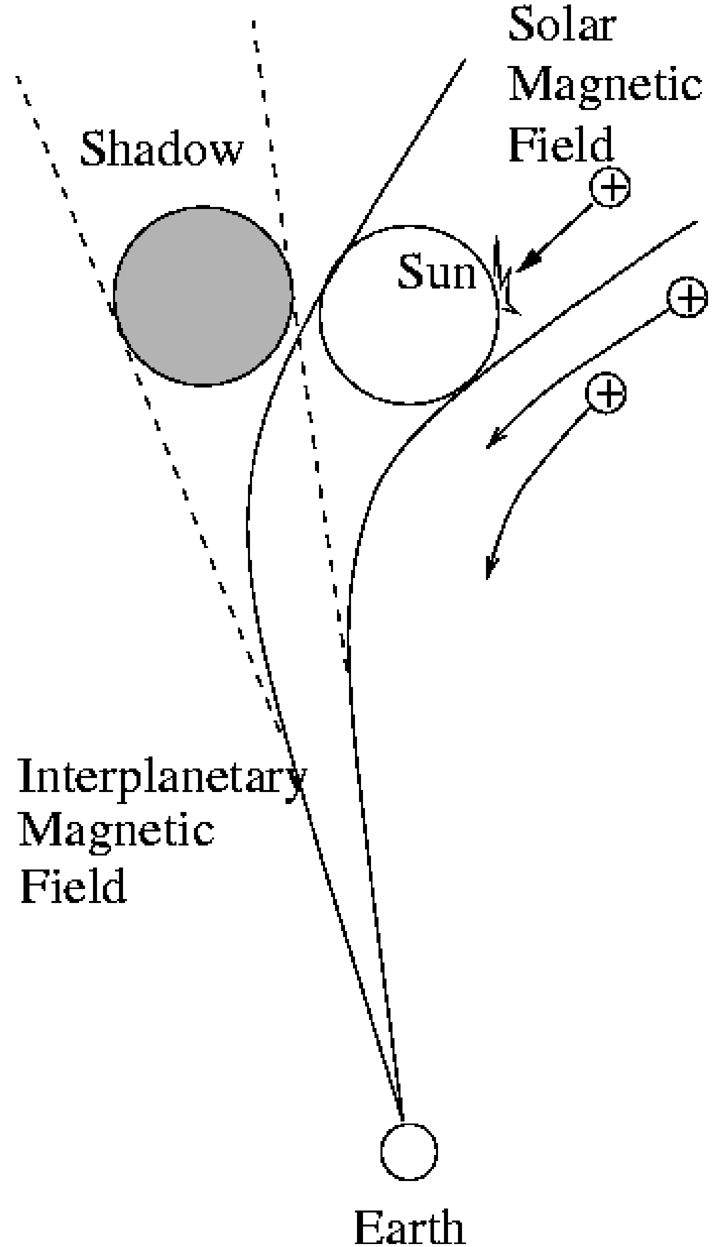
1) Heliospheric magnetic field is not enough for TeV CR anisotropy.
2) TeV CR anisotropy might be caused by the Local Interstellar Could (~ a few pc).

R_L ~ 0.01pc (for 10TeV proton in 1mG)

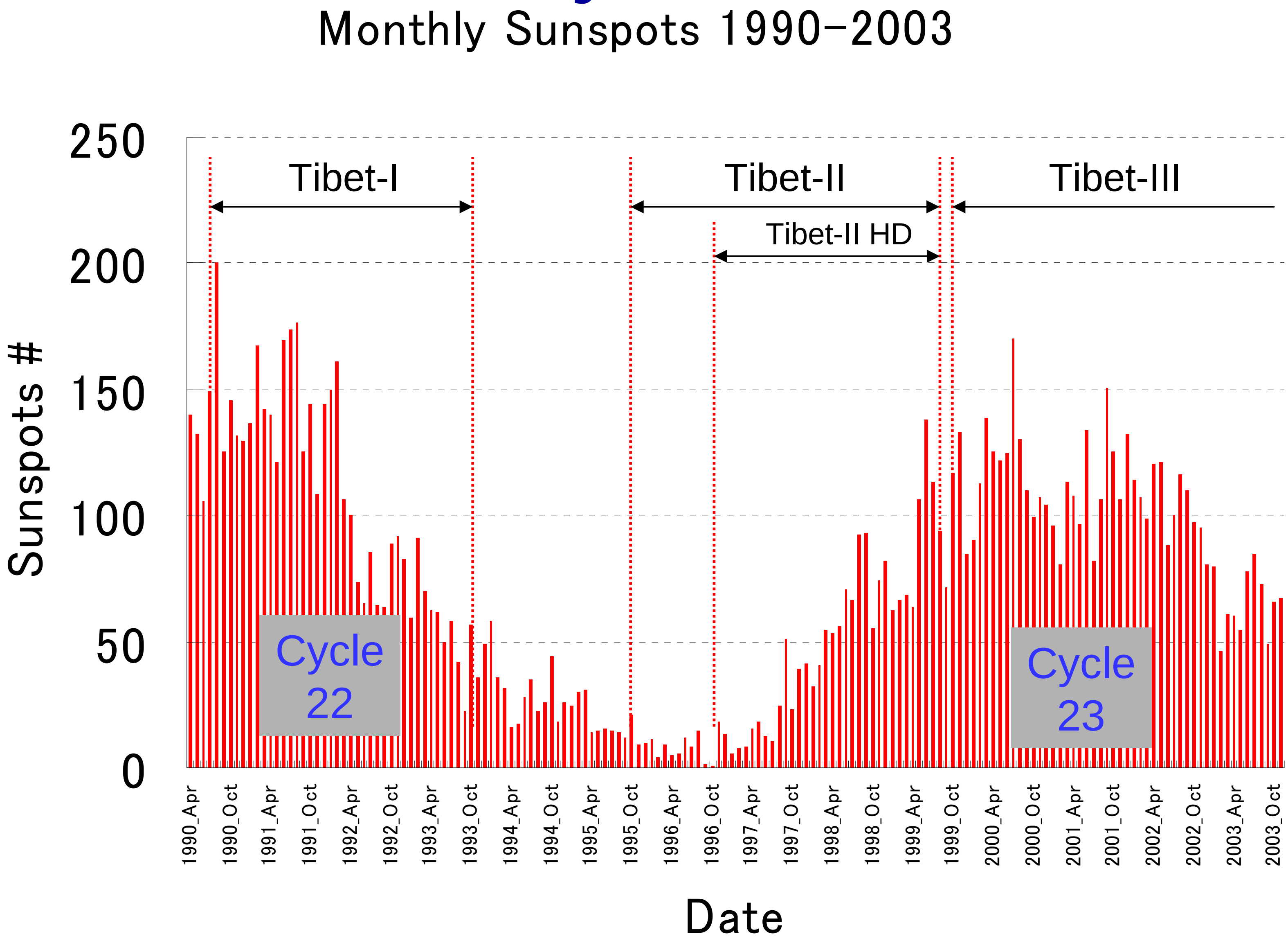
惑星間磁場　太陽の影

宇宙線は太陽によって遮蔽される。
正電荷をもった宇宙線は
太陽磁場、惑星間磁場によって
曲げられ、観測される“へこみ”は
磁場の変動によって“移動”する。

太陽活動は11年周期で極大期を迎え、
磁場の変動も活発になる。
この“へこみ”の“移動”を観測すること
によって、太陽磁気圏の大局的磁場構造
を知ることができる。

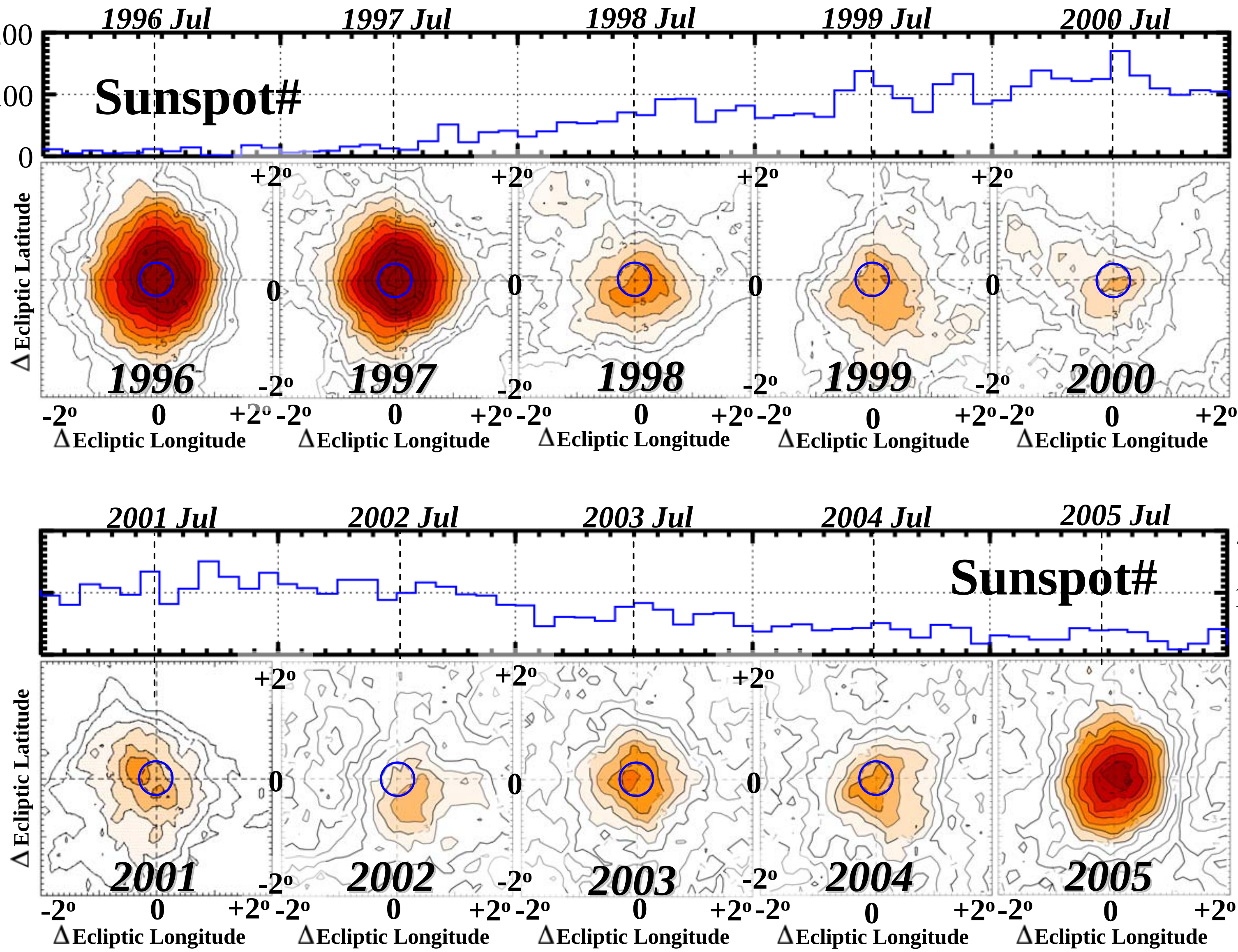


Solar Activity – Sunspots (Monthly)



Observation – Sun Shadow

Anti-correlation between Sun shadow and sun spot # @ 10 TeV



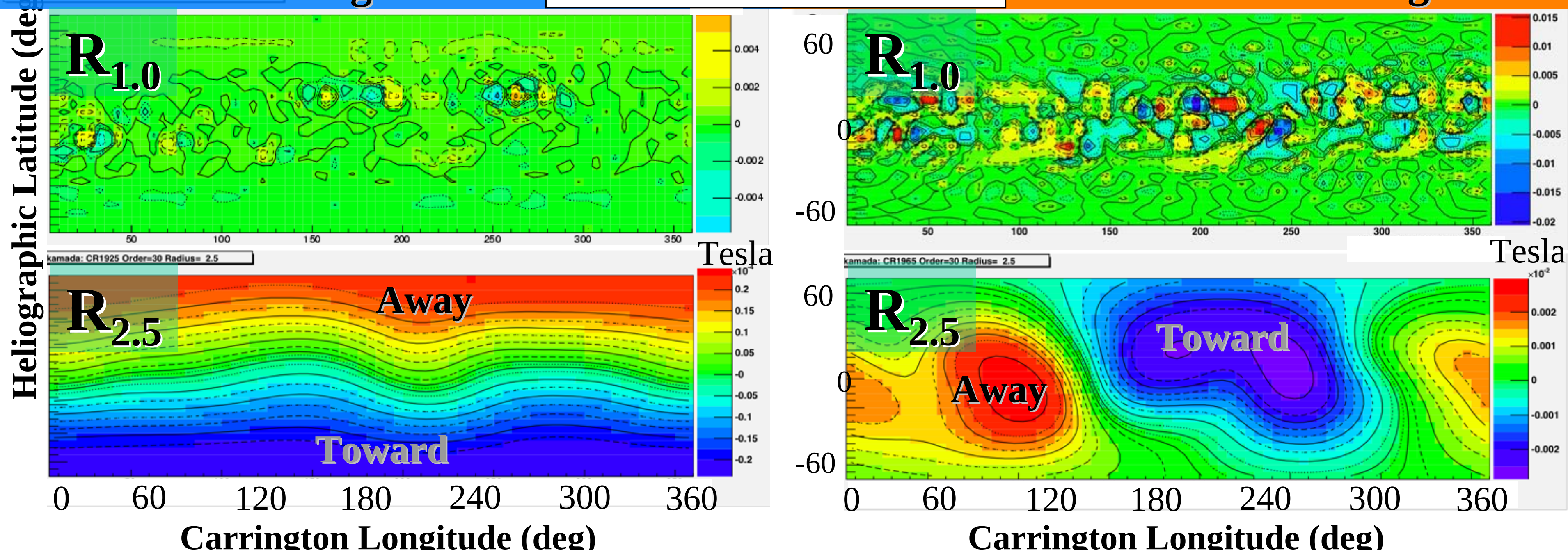
Potential Field Source Surface Model

- **Radial Field model by Hakamada, Chubu U.**
- scalar potential in the coronal magnetic field
  - expansion by spherical harmonics（order: ***n***）
- Assumption
  - No coronal current (no influence on magnetic field)
  - Scalar potential(@$R_{2.5}$)＝0 (to prevent troidal magnetic field)
  - Only radial component at the solar surface

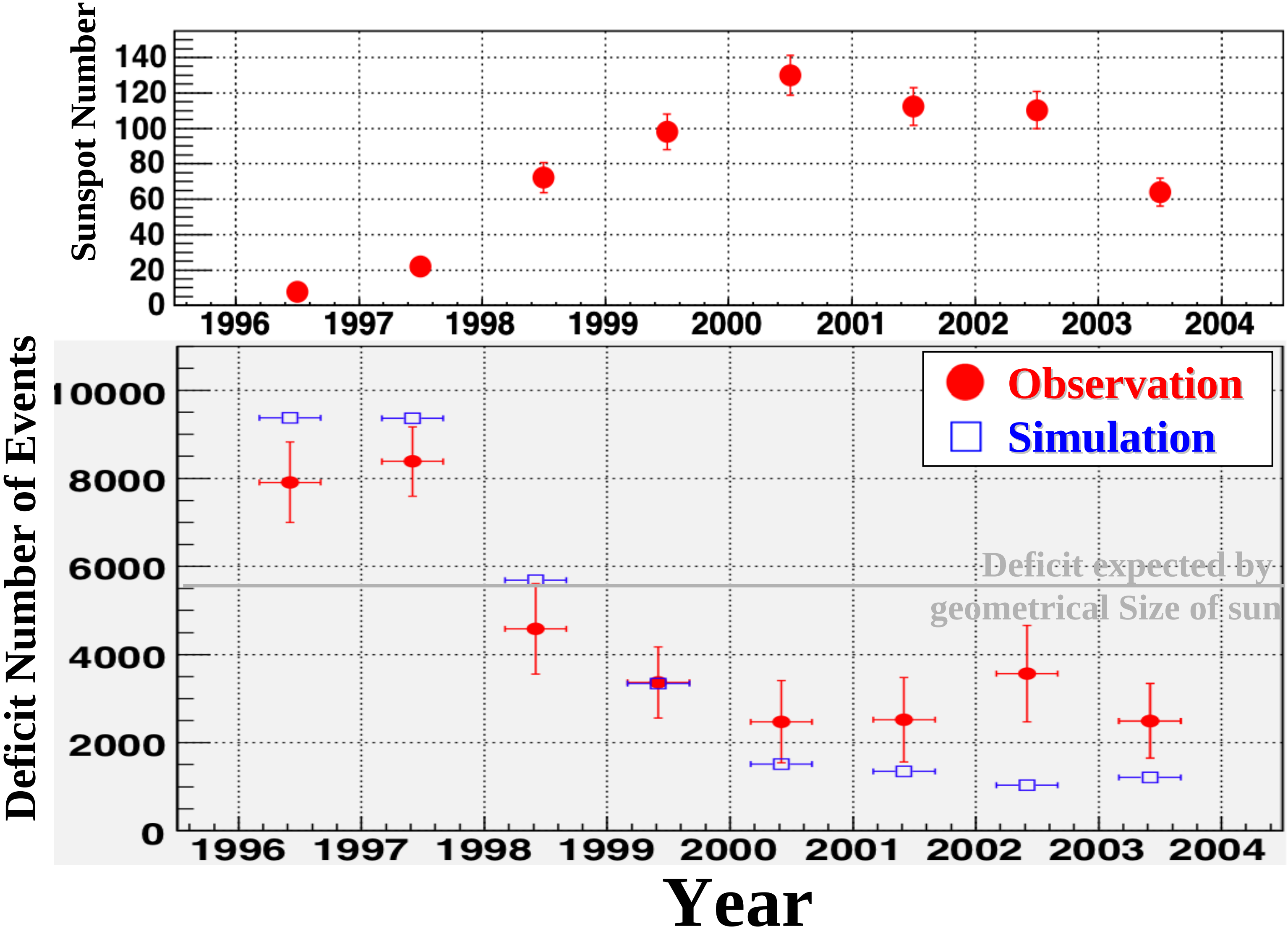
Solar Minimum
CR1925 / Jul.-Aug. 1997

Synoptic Chart for Radial component (n≦30)

Solar Maximum
CR1965 / Jul.-Aug. 2000



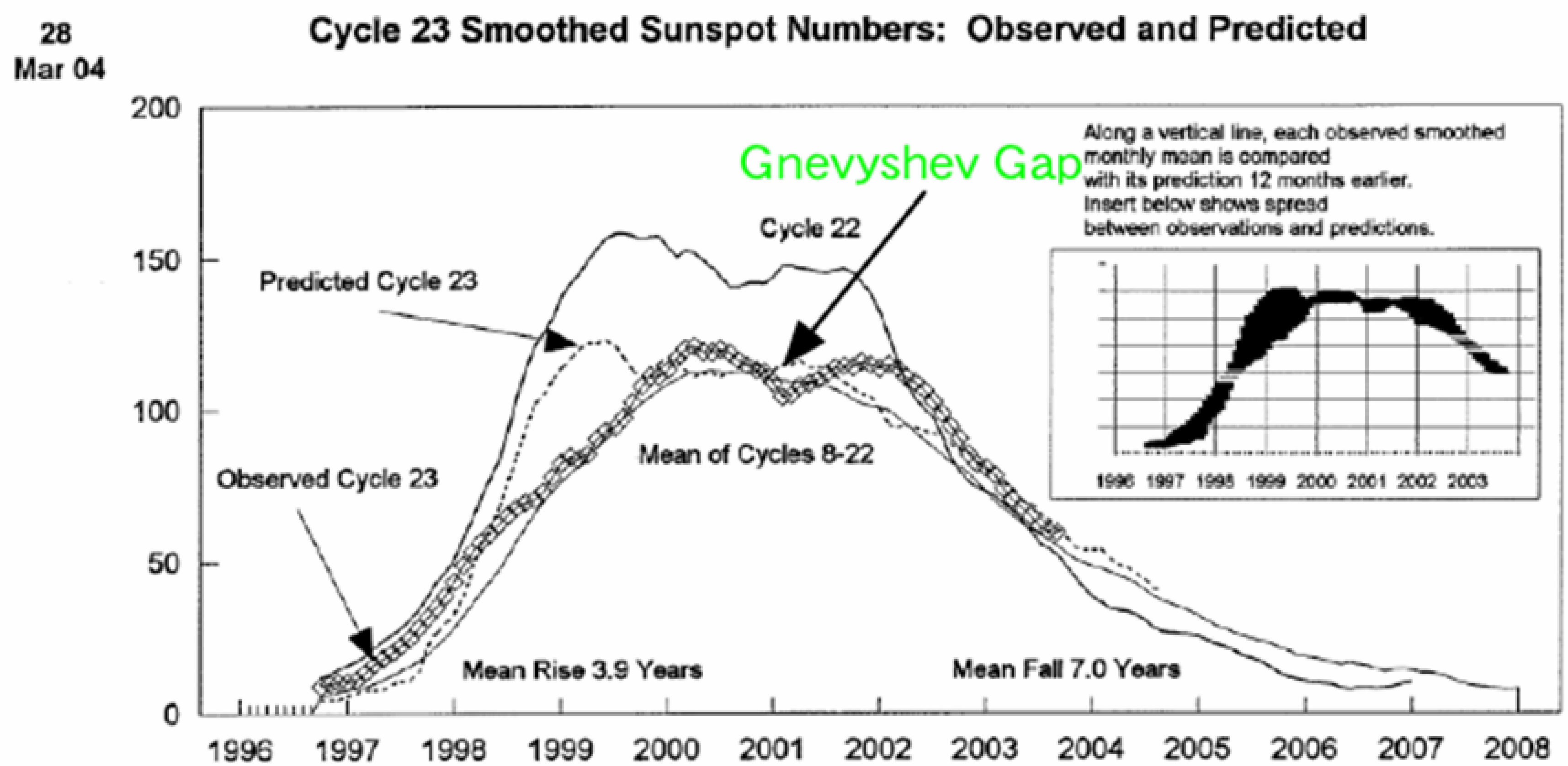
Yearly Variation of Deficit within 3^{o} around the apparent sun's direction @ 10 TeV



Sun spot#

Sun shadow

$\chi^2 = 17.71$
d.o.f. = 8
(2.0 σ)

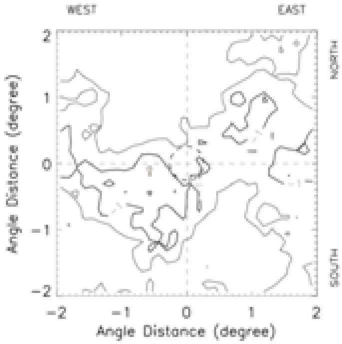


ref: Solar-Geophysical Data. (www.ngdc.noaa.gov)

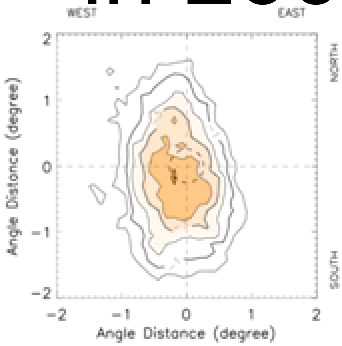
Yearly change of Sun shadow（1996–2005）, 3TeV

Gnevyshev gap

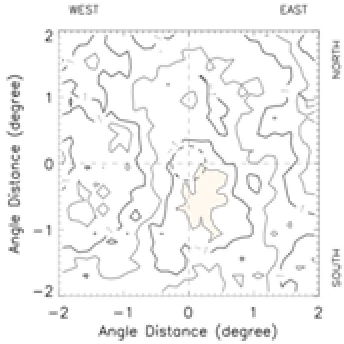
in 2001



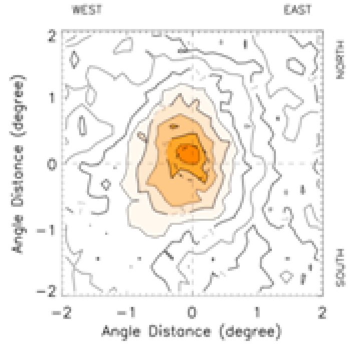
2000(Tibet-III)



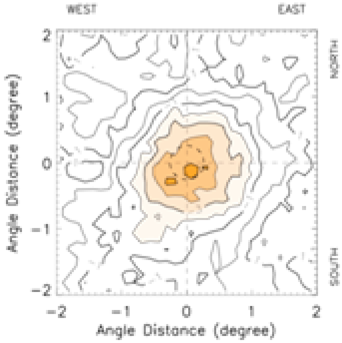
2001(Tibet-III)



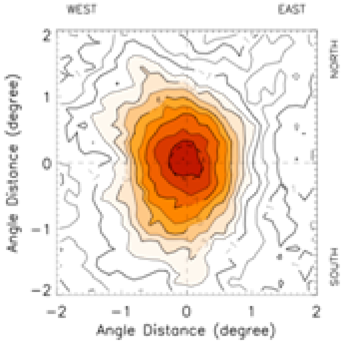
2002(Tibet-III)



2003(Tibet-III)



2004(Tibet-III)



2005(Tibet-III)

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?

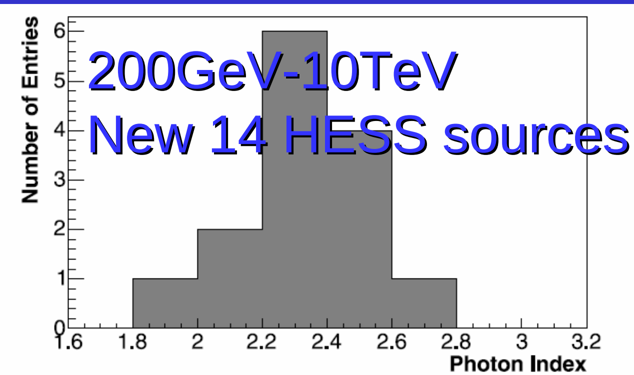
2. E-spectrum of heavy component around ‘ knee’

   All-particle knee = CNO? Fe knee?

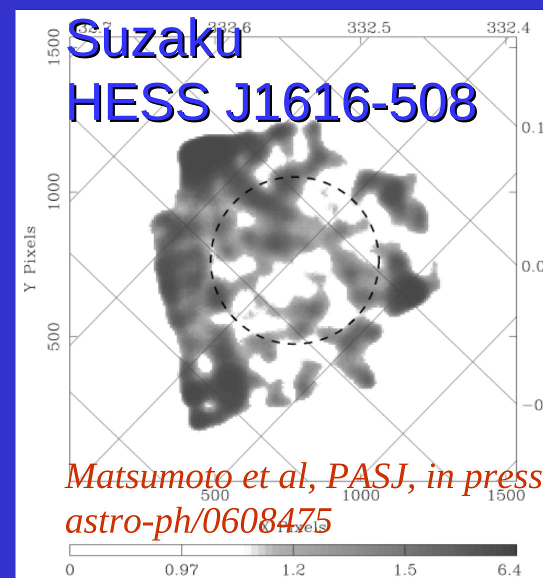
1. 100 TeV γ-ray astronomy

Cosmic ray	Acceleration	Origin
New 14 HESS sources	Hard spectral indices	Faint in other wavelengths
Theoretical possibility	• π^0 decay • IC* • …	• Old SNR *Yamazaki et al, MNRA, 371, 1975 (2006)* • Asymmetric PWN *Blondin et al, ApJ, 563, 806 (2001)* • …
Key observation	**100 TeV region**	**Wide sky survey**

* >100TeV IC is difficult
due to sync. cooling & KN effect

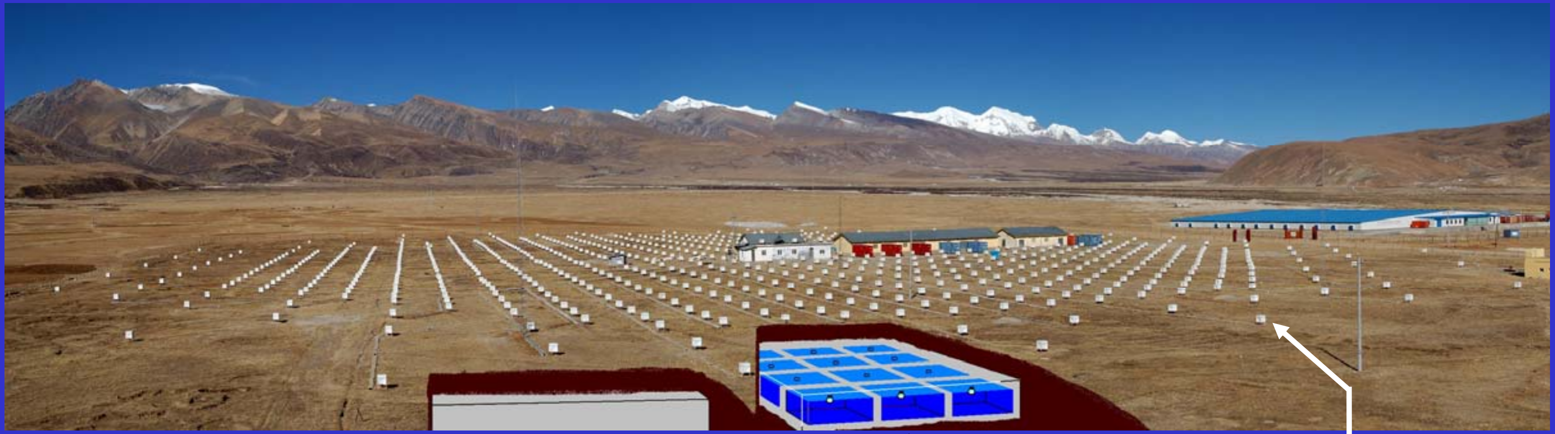


Aharonian et al, ApJ, 636, 777 (2006)
FIG. 8.—Distributions of the photon index of the new sources. The mean photon index is 2.32 with an rms of 0.2.



Matsumoto et al, PASJ, in press
astro-ph/0608475

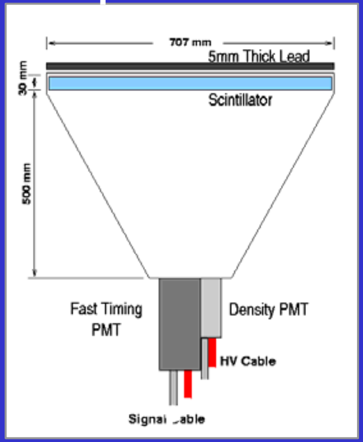
Tibet Air Shower (AS) Array



Tibet Muon Detectors (Image)

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

- Number of Scinti. Det. 0.5 m^2 x 789
- Effective Area for AS ~37,000 m^2 ⇨ ~50,000 m^2
- Energy region ~TeV - 100 PeV
- Angular Resolution (Gamma) ~0.4 @10 TeV, ~0.2 @100 TeV
- Energy Resolution (Gamma) ~70% @10 TeV, ~40% @100TeV
- F.O.V. ~2 sr



Tibet Muon Detector (MD) Array

7.2m x 7.2m x 1.5m depth Water pool

20”ΦPMT x 2 (HAMAMATSU R3600)

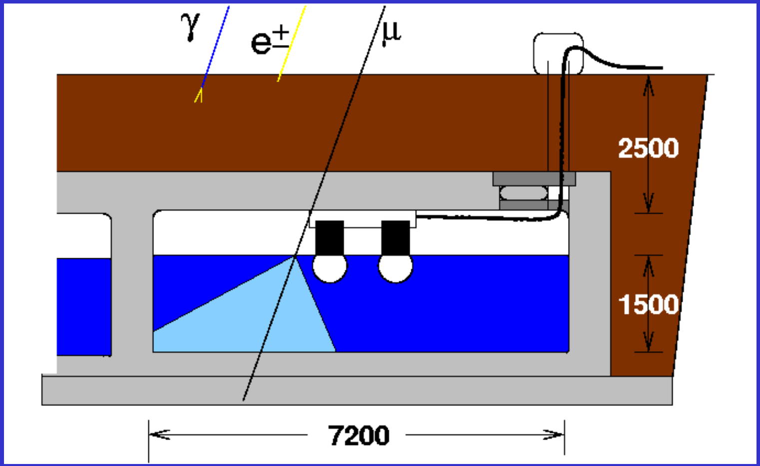
Underground 2.5m (~515g/cm^2~19X_0)

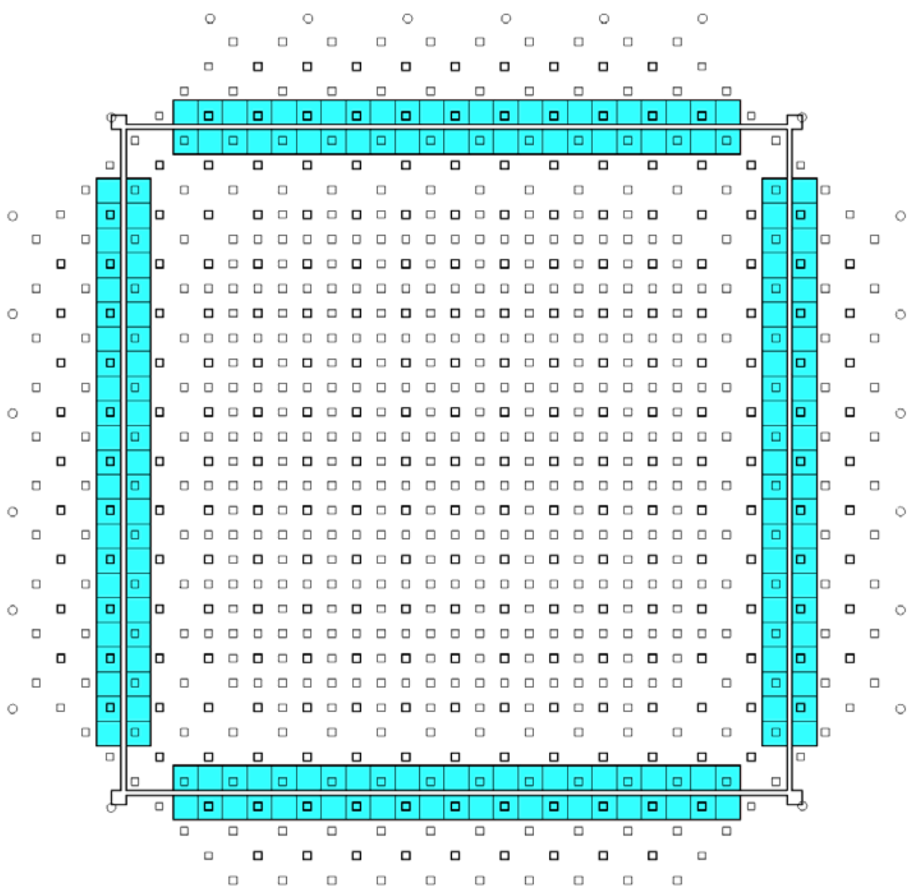
Material:

- Concrete pool
- White epoxy resin paint

184 detctors

Total 9540 m^2



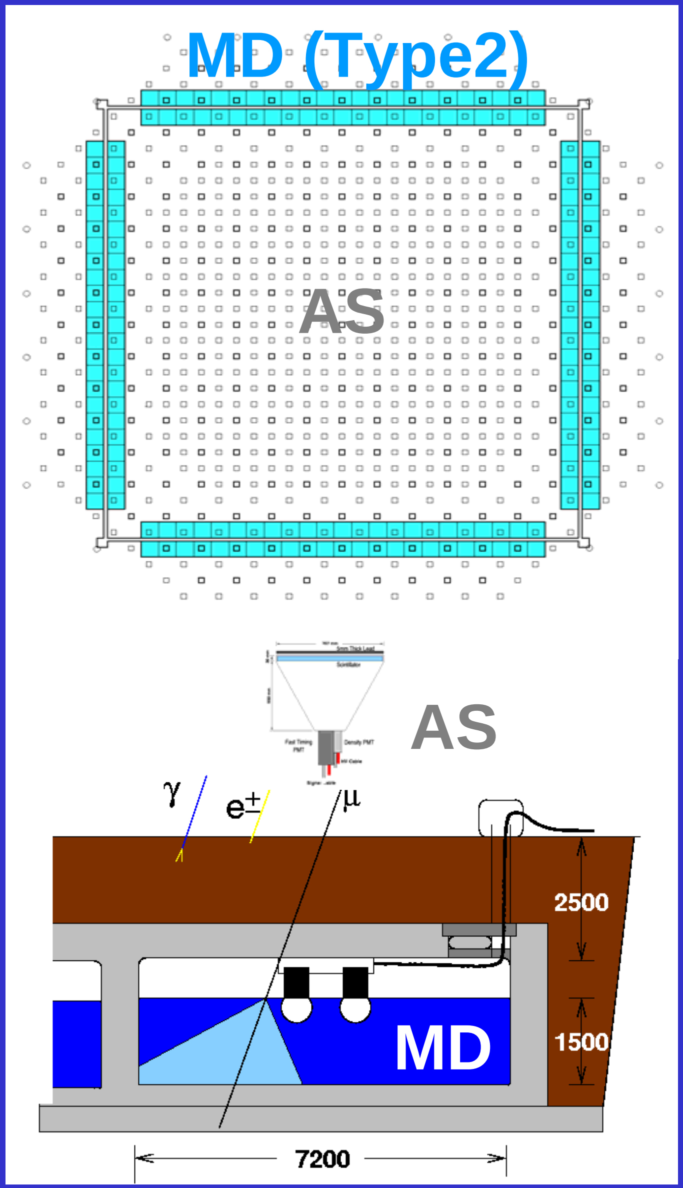


Future AS+MD Array (Type 2)

Counting the number of muons accompanying an air shower

Gamma/Hadron separation

Sensitivity Simulation



- Air Shower Generation - Corsika Ver.6.204
  CR: 0.3TeV-10PeV, Crab Orbit
  Chemical components
  Interaction model: QGSJET01c
  Gamma: 0.3TeV-10PeV, Crab Orbit
  $E^{-2.6}$
  Core position:
  Throw randomly within 300m radius

- Scintillation det. (Tibet AS) - Epics UV8.00
  Estimate energy, direction, core position, …

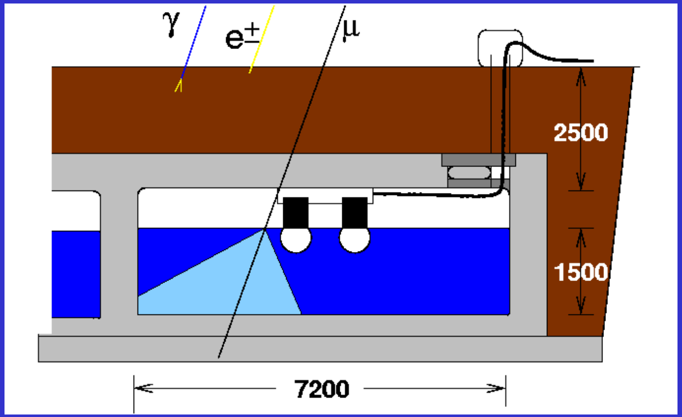
- Soil + Cherenkov det. (Tibet MD) - GEANT4 8.0
  Reflectance at walls 70%
  Att. length ~40m@400nm (Dependant on wave length)
  Quantum Eff. ~20%@400nm (Dependant on wave length)

- Accidental muons
  300 Hz/m^2 x 9540m^2 x 200 ns
  = ~0.57 muons/an air shower
  (Poisson noise distribution)

Water Cherenkov Technique

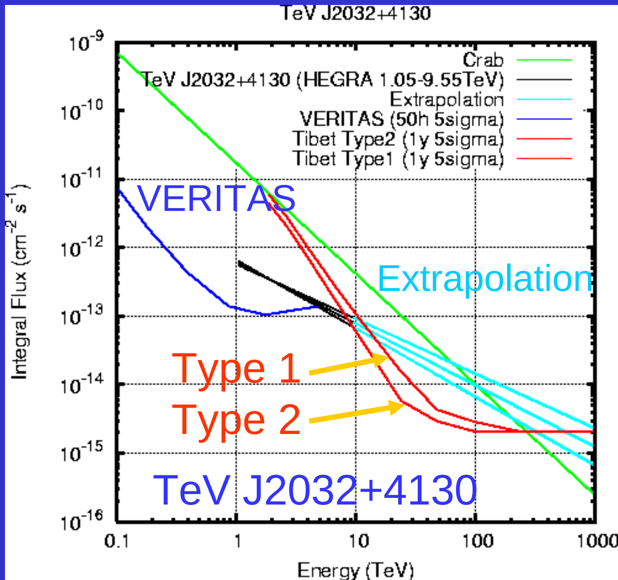
- Already established technique
- High cost performance
- Easy to design long path length detector
- Cherenkov threshold (electron 750keV in the water)

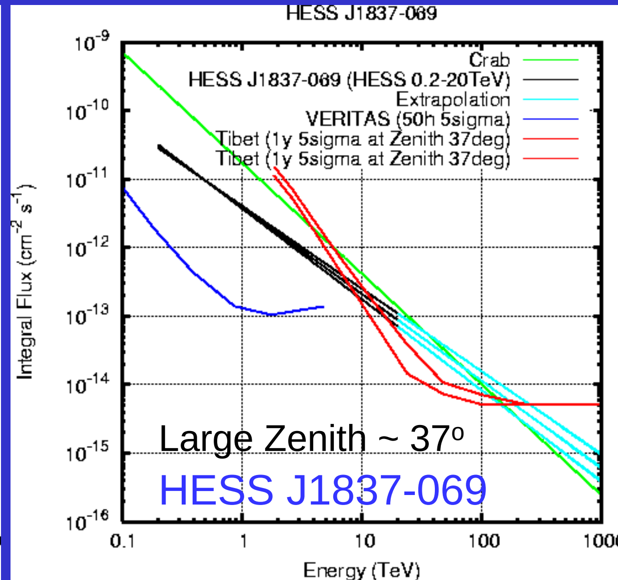
⇨ High rejection power for low energy $e^{+/-}$ & γ
Good technique for muon detection

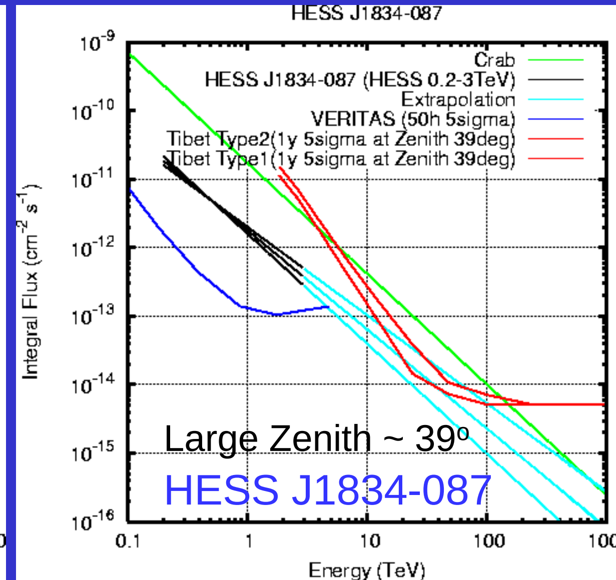


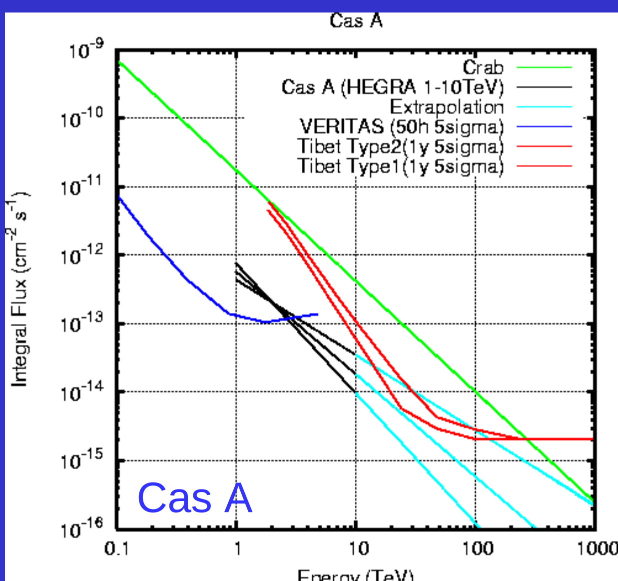
	Milagro	SK (Anti)	Tibet MD
PMT	8”ΦPMT	8”ΦPMT	20”ΦPMT
Detector Area	80mx60m Depth8m (Upper4800m^2 /Lower2000m^2)	All Surface ~7400m^2 Thickness ~2.5m	9540m^2 Depth1.5m
Unit	1PMT@2.8m × 2.8m	2PMTs@6m^2	2PMTs@52m^2
Photo-Coverage	0.4%	0.52%	0.75%
Number of PMTs	Upper: Depth 1.4m, 450 Lower: Depth 6.0m, 273	1885	368

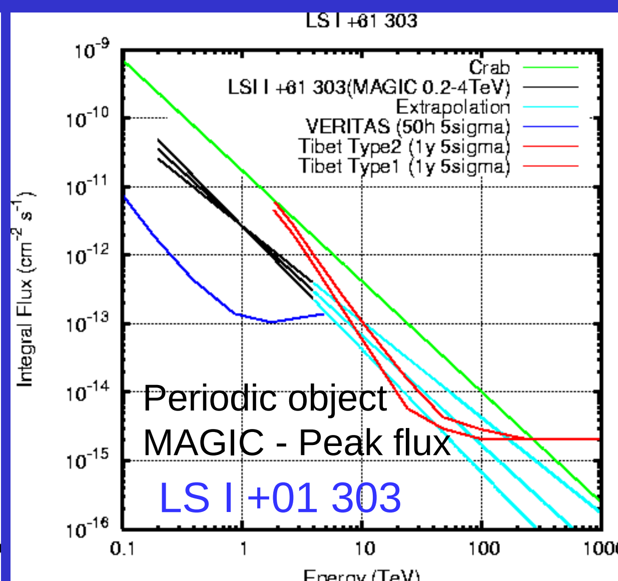
Known Galactic Sources in the Northern Sky

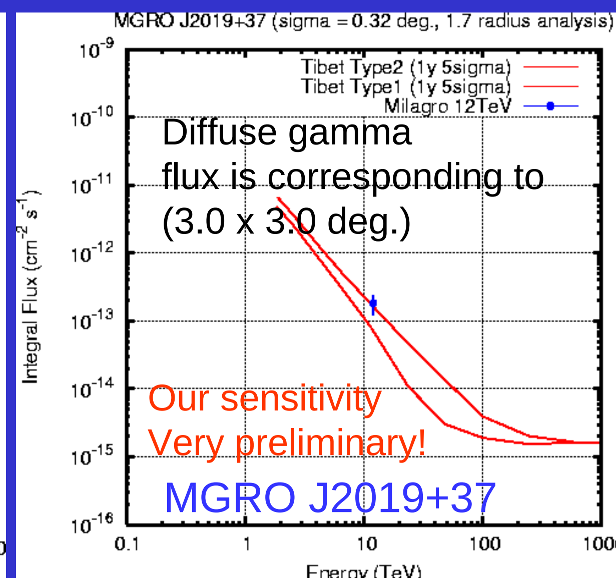




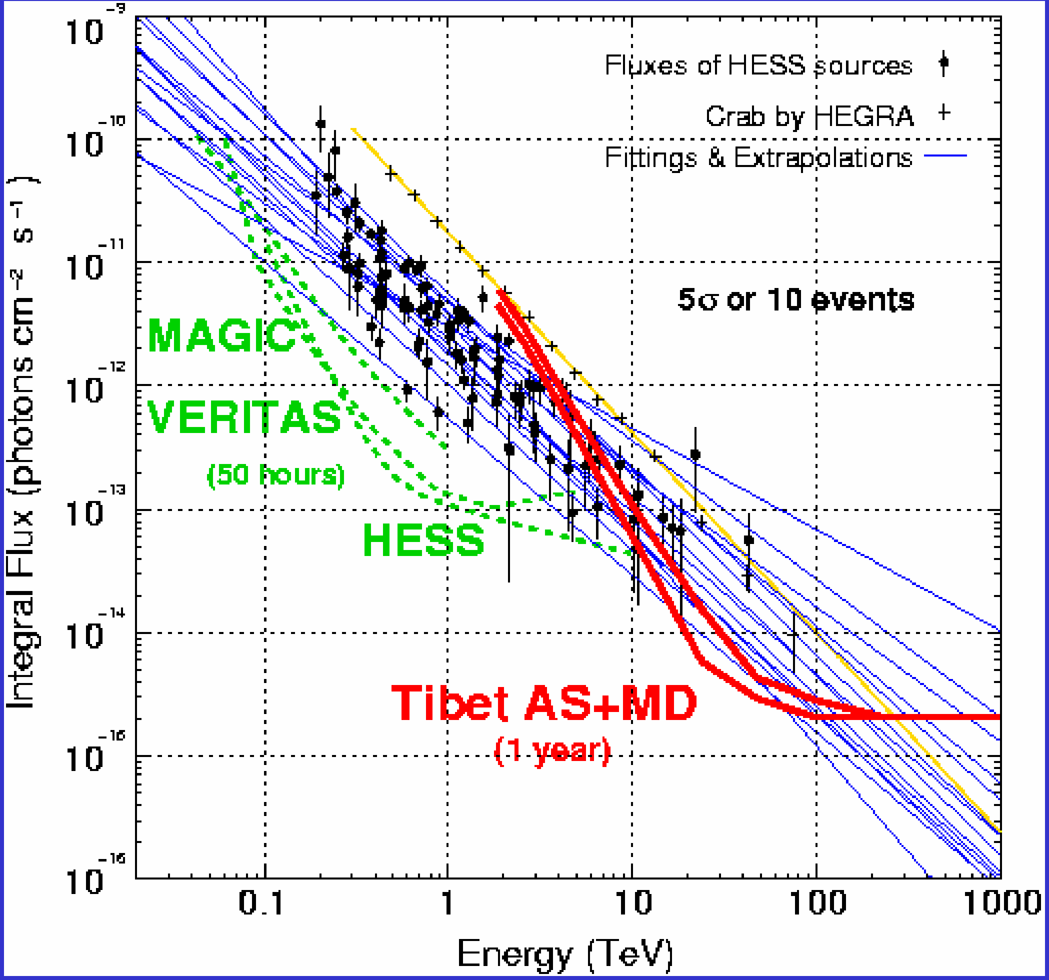








How Many New Sources?



Aharonian et al, ApJ, 636, 777 (2006)

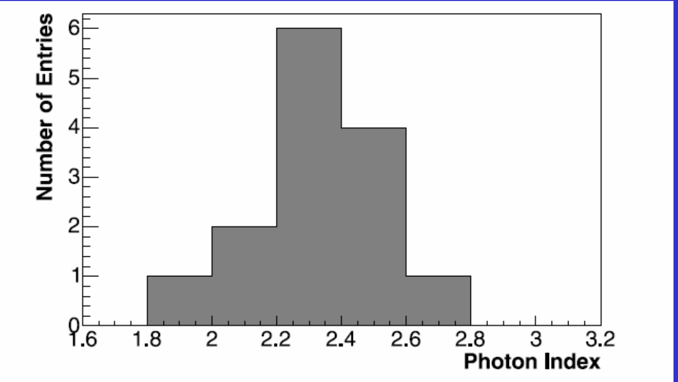


FIG. 8.—Distributions of the photon index of the new sources. The mean photon index is 2.32 with an rms of 0.2.

Induces are harder

(If it is constructed
at southern hemisphere)
Most of new HESS sources
detectable by Tibet AS+MD

6. Summary

- **Tibet MD Project**

  50,000 m^2 Tibet air shower array +
  9,540 m^2 Water cherenkov muon detector array

  ⇒ ~5M US\$ - 100 TeV gamma-ray wide sky survey.

- **Sensitivity simulation**

  Detailed simulation was done (two configurations).
  F(>100TeV) ~2 x 10^{-15} cm^{-2} s^{-1} (1 calender year, 5σ or 10 events).
  Improve sensitivity by an order of magnitude.
  Inner MDs are very important.

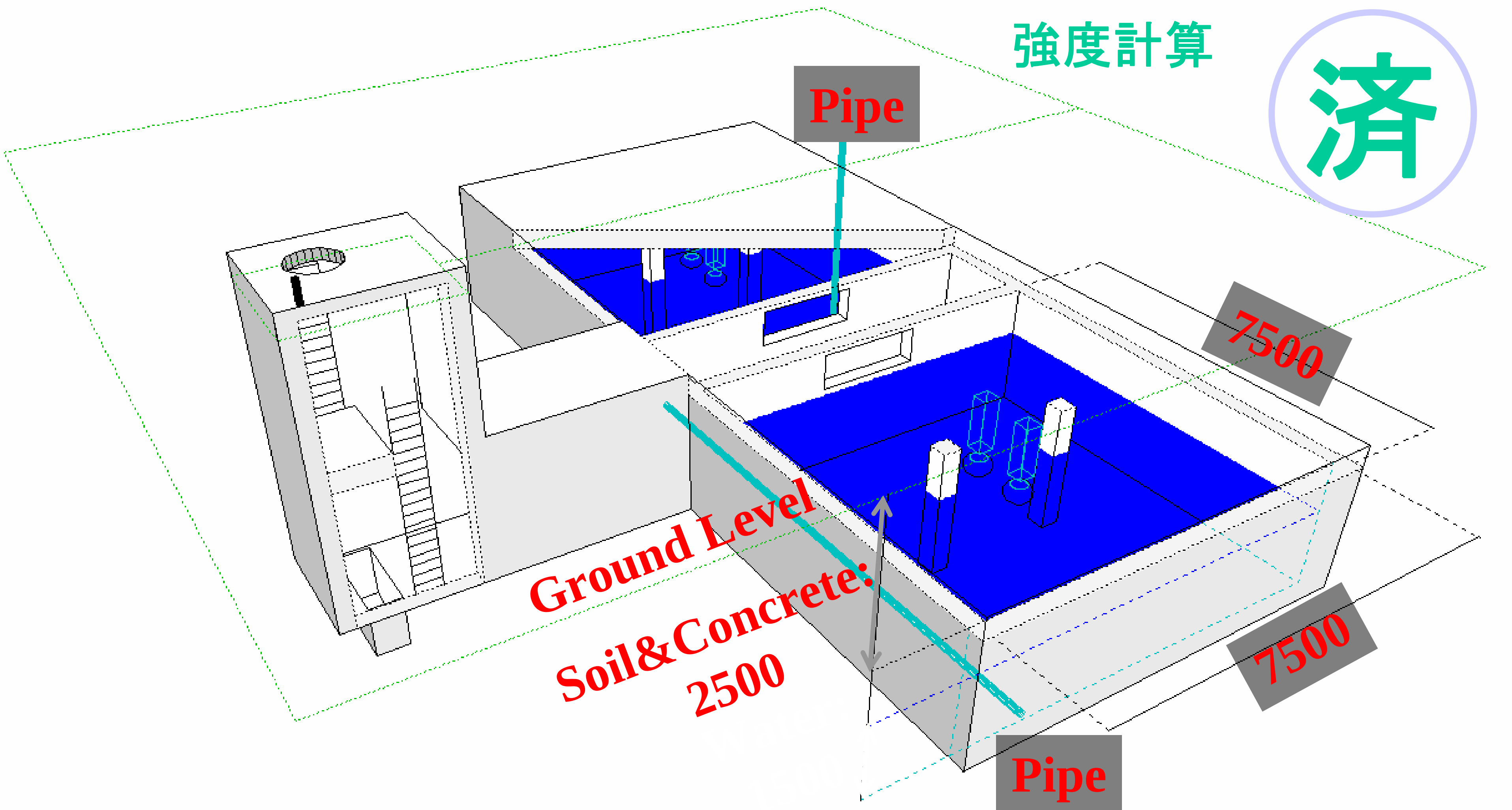
- **Candidates of 100 TeV sources in the northern sky**

  Promising: Crab, TeV J2032+4130,
  HESS J1837-069, MGRO J2019+37
  Interesting: Cas A, HESS J1834-089, LS I +61 303
  (Need several years)

+ ~ several to ~10 new sources?

プロトタイプ MD

MD:（7.5m×7.5m, 水深 1.5m, 20ΦPMT（R3600）x 2）x　2 台

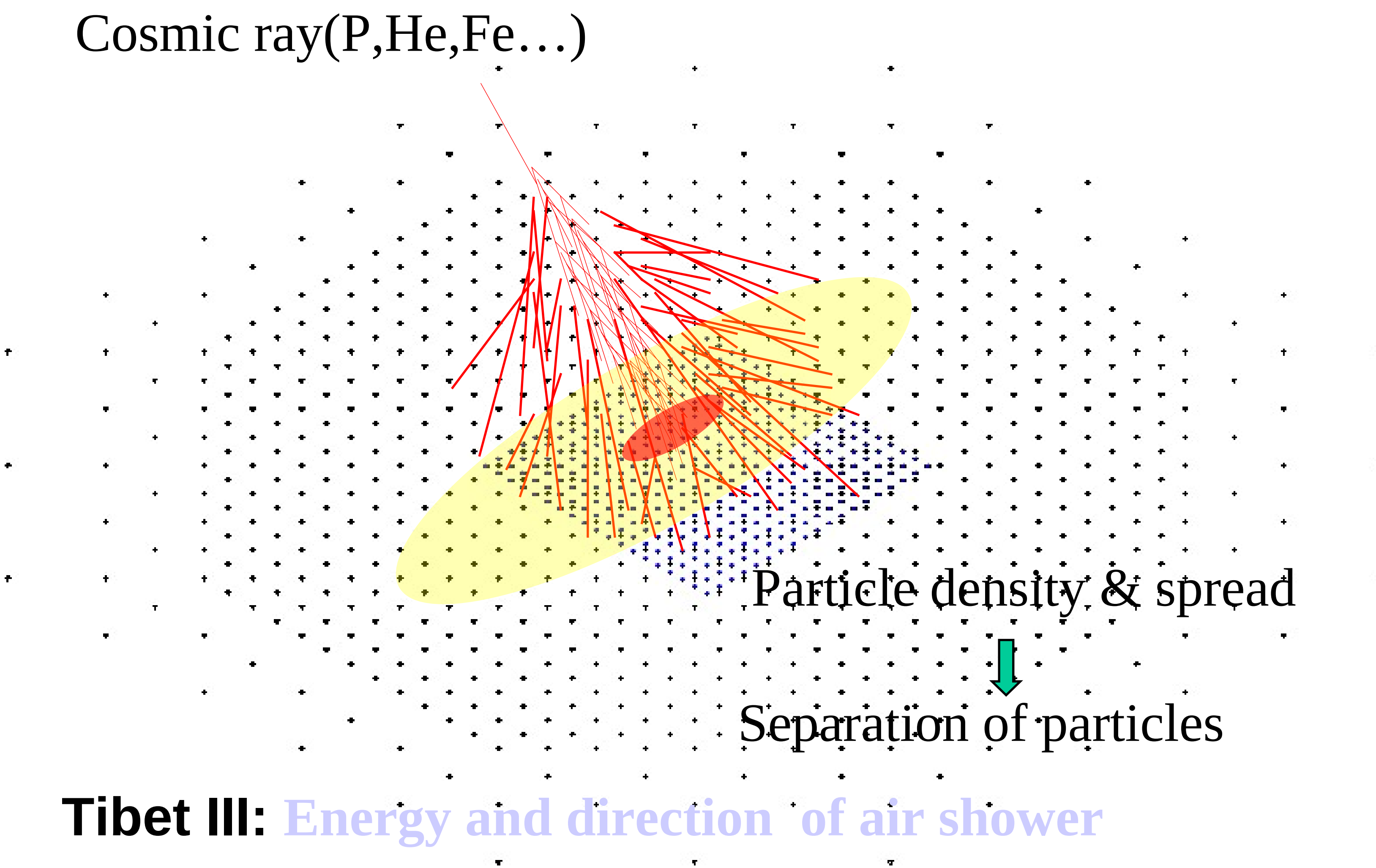


2. Next phase of Tibet hybrid exp. YAC

Yangbajing Air shower Core detector

- Measure the energy spectrum of the main component at the knee.
- Detector：Low threshold BD grid ＋AS array。
- Observe energy flow of AS core within several x 10m from the axis.

YAC array

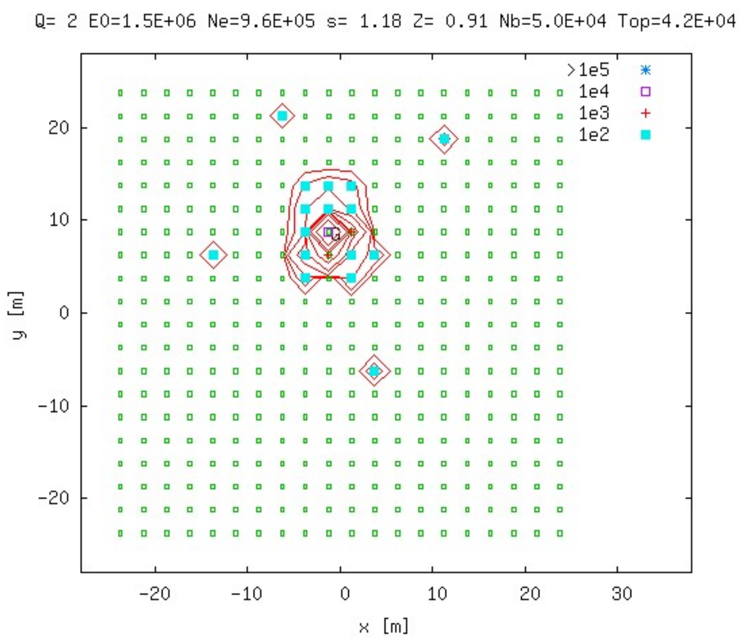


Tibet III: **Energy and direction of air shower**

Design of YAC

40cm x 50cm, 20x20 channels

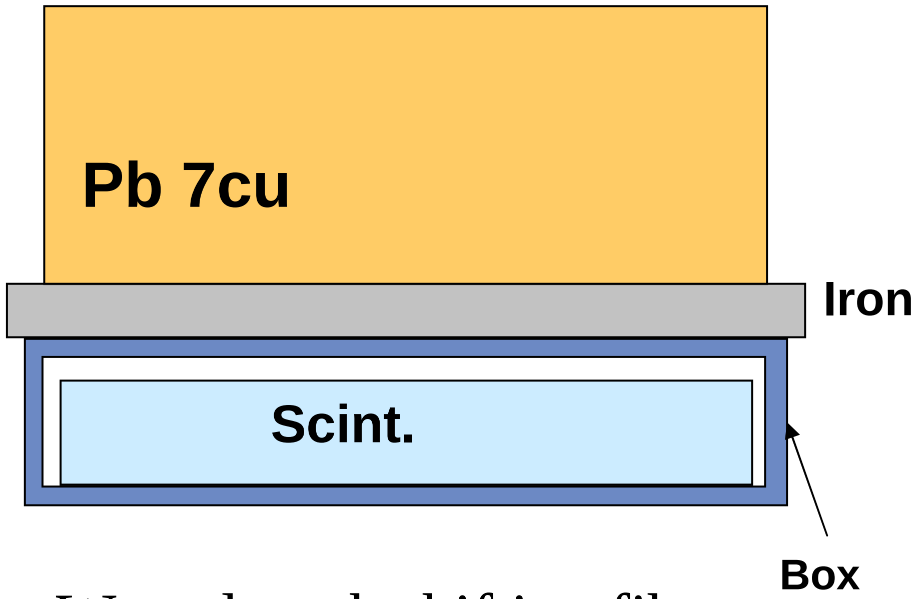
S=5000m^2



3.75m spacing 400ch

N_b>100, any 5

(>30GeV)



Wave length shifting fiber

+ 2 PMTs

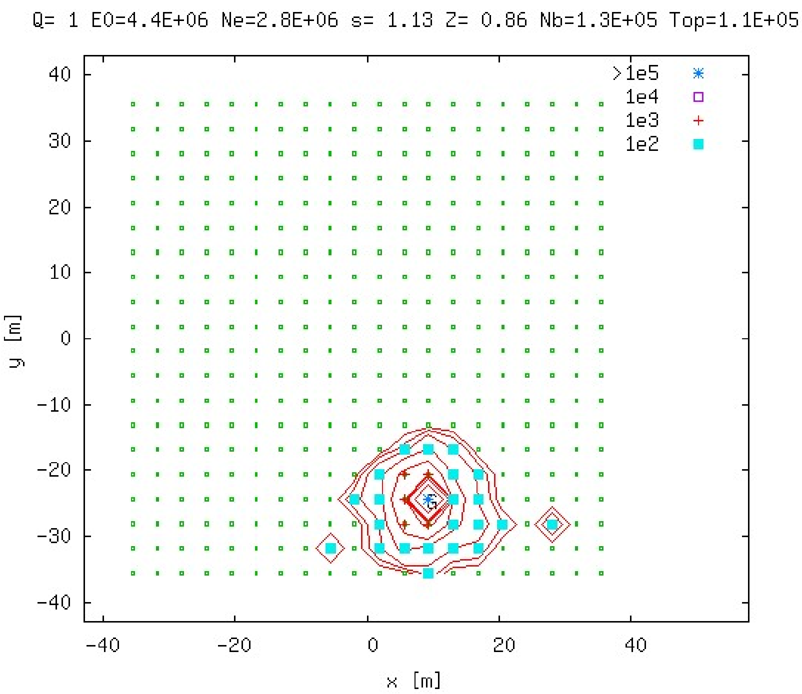
(Low gain & High gain)

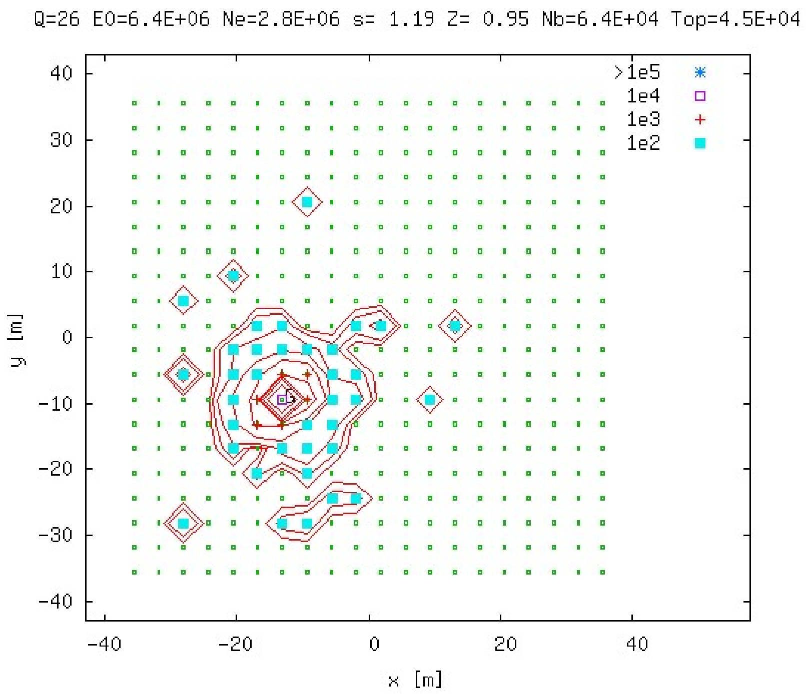
$10^2 < N_b < 10^6$

MC Event Map

Proton

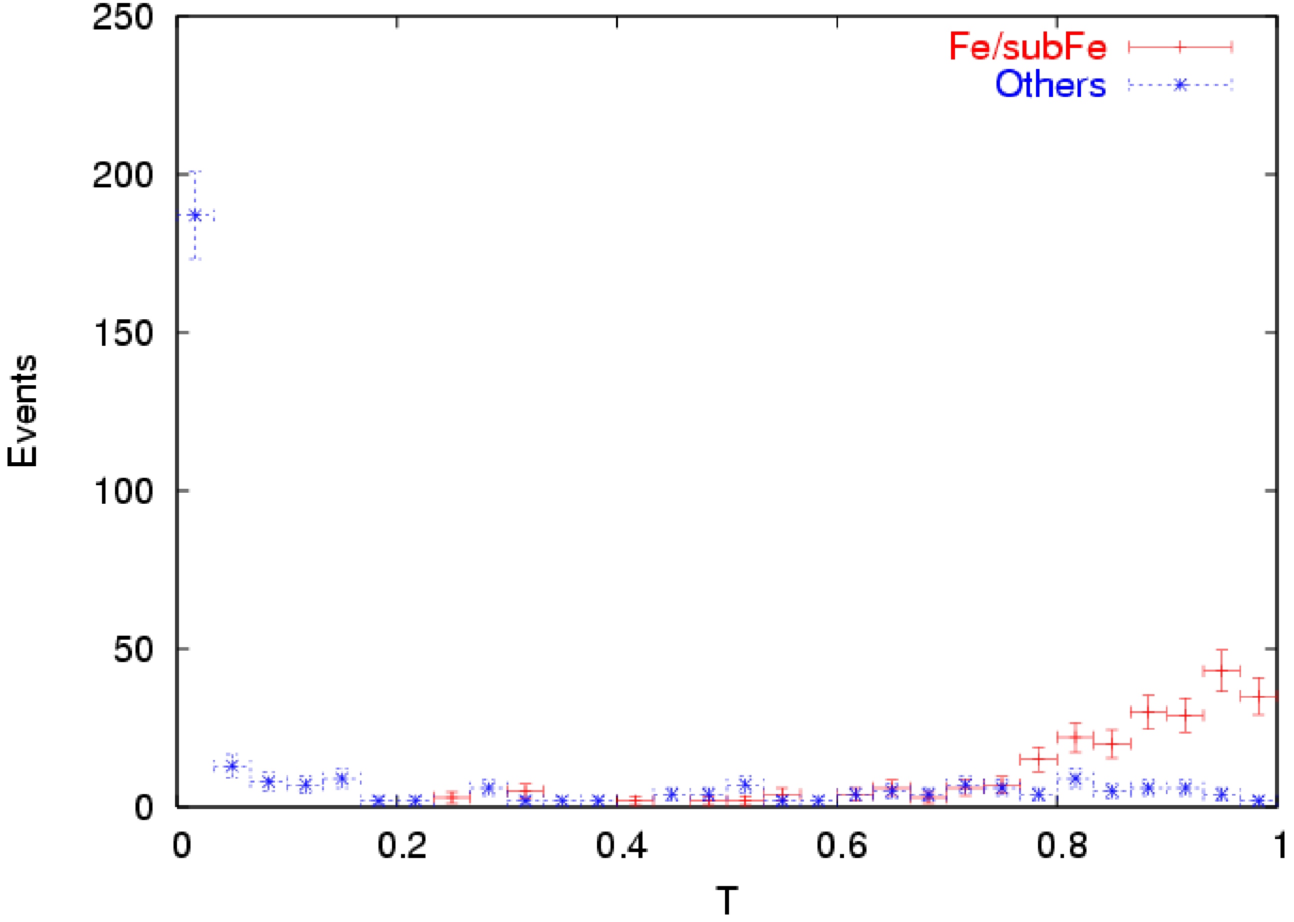
Fe



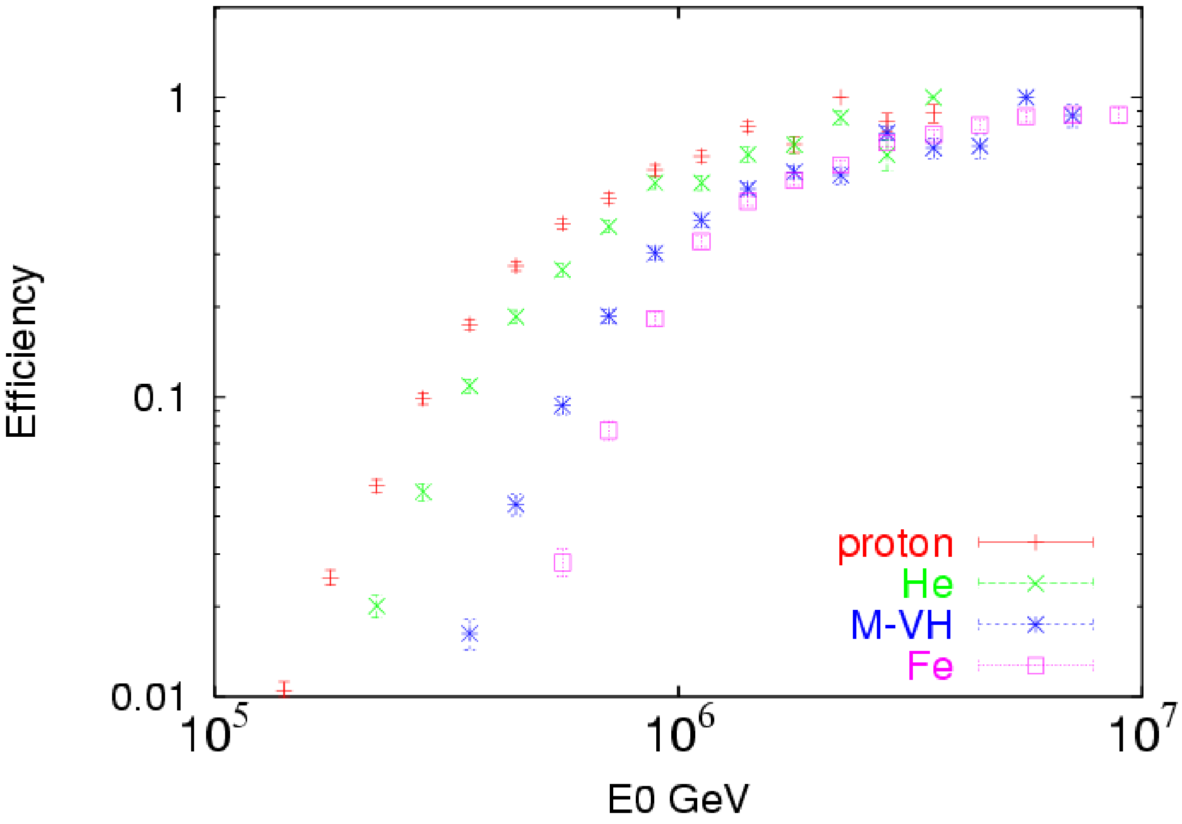


Separation of Fe by YAC（use ANN）

Iron and others



Detection efficiency of YAC



Expected results by YAC