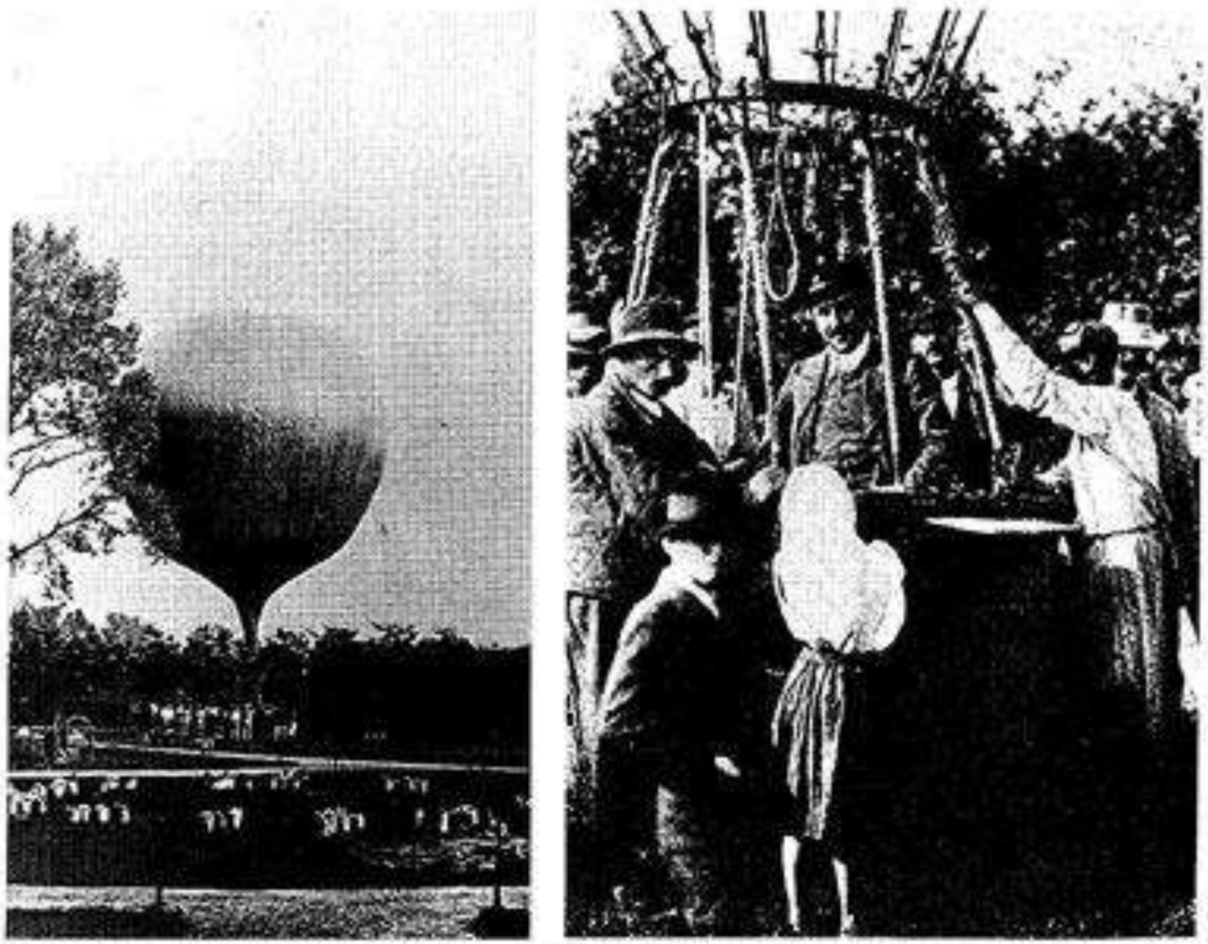
ガンマ線・宇宙線物理

副題：Tibet ASγ 実験により
宇宙線の起源・加速機構・伝播
の解明に挑む

瀧田正人, ICRR, U. of Tokyo

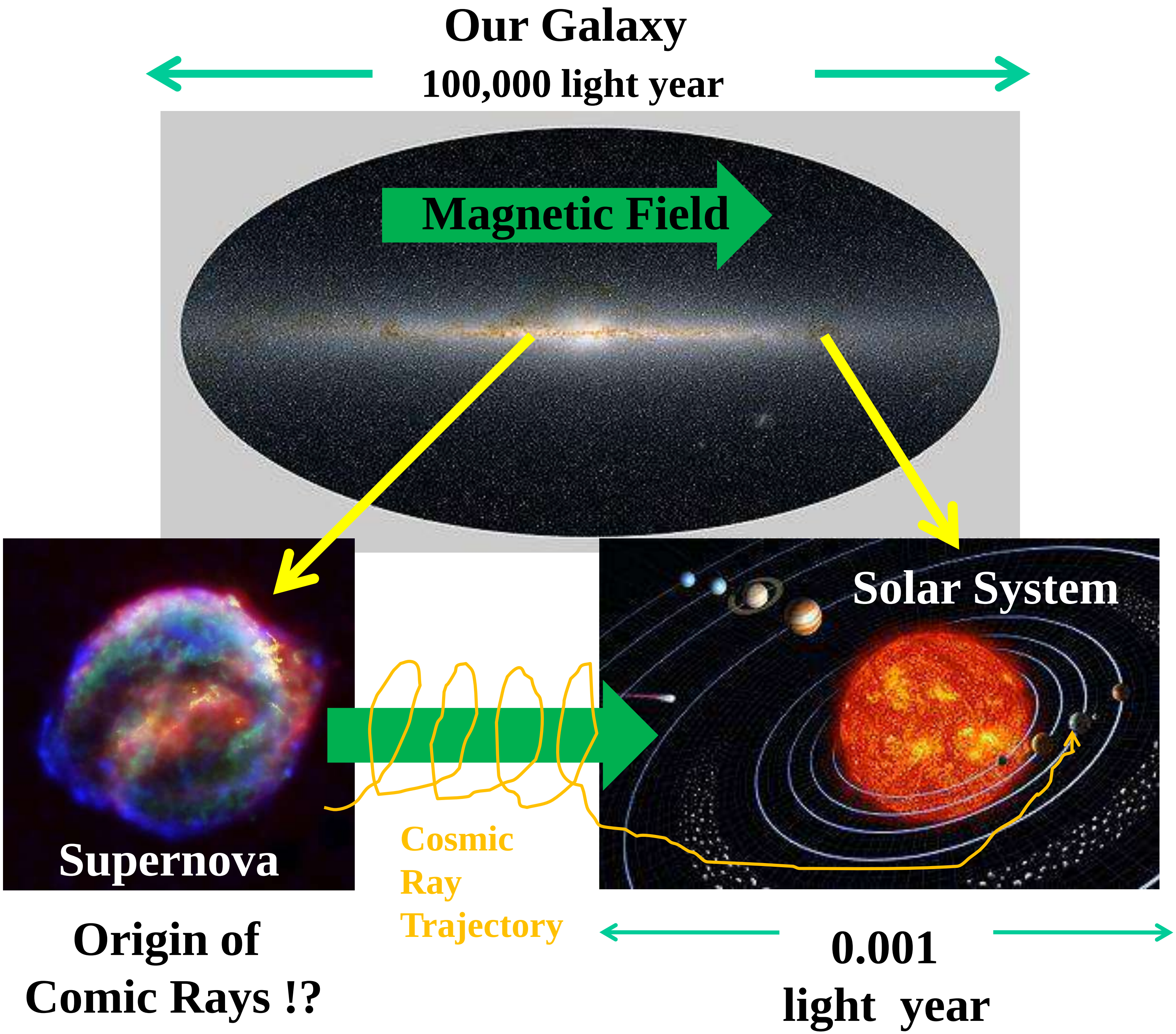
Spring School, @ICRR U. of Tokyo,
9/Mar/2018

Discovery of cosmic rays by Victor HESS (in 1912) getting on a balloon

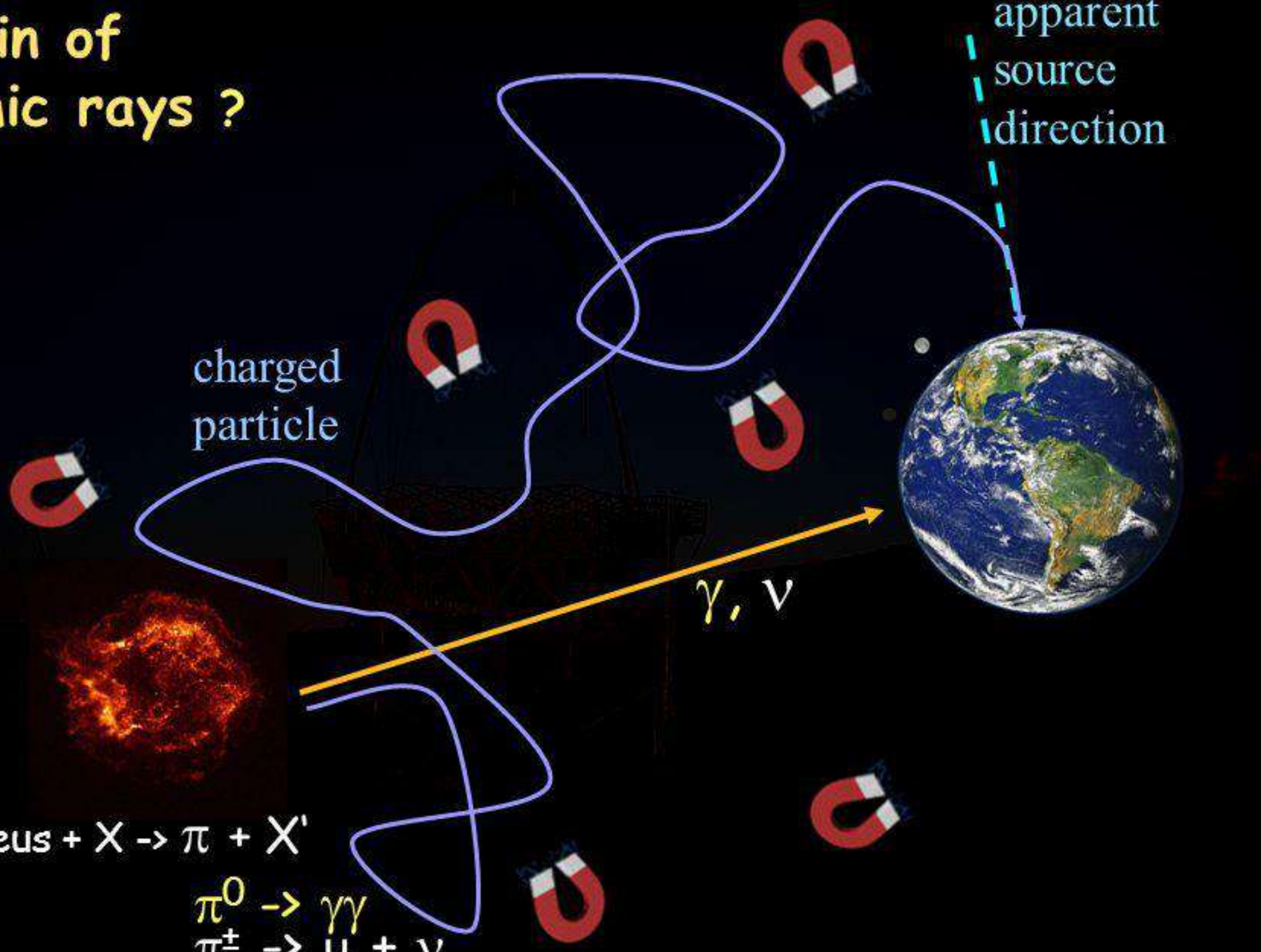


(a) (b)

Cosmic rays: Particles from outer space (H, He, C, N, O,…Fe nuclei)


Our Galaxy
100,000 light year
Magnetic Field
Supernova
Solar System
Cosmic
Ray
Trajectory
Origin of
Comic Rays !?
0.001
light year

Origin of cosmic rays ?



nucleus + X -> π + X'

$\pi^0 \rightarrow \gamma\gamma$

$\pi^{\pm} \rightarrow \mu + \nu$

$\mu \rightarrow e + \nu\nu$

チベット空気シャワー観測装置の研究目的

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、伝播の研究を行う。

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。

Our site : Tibet

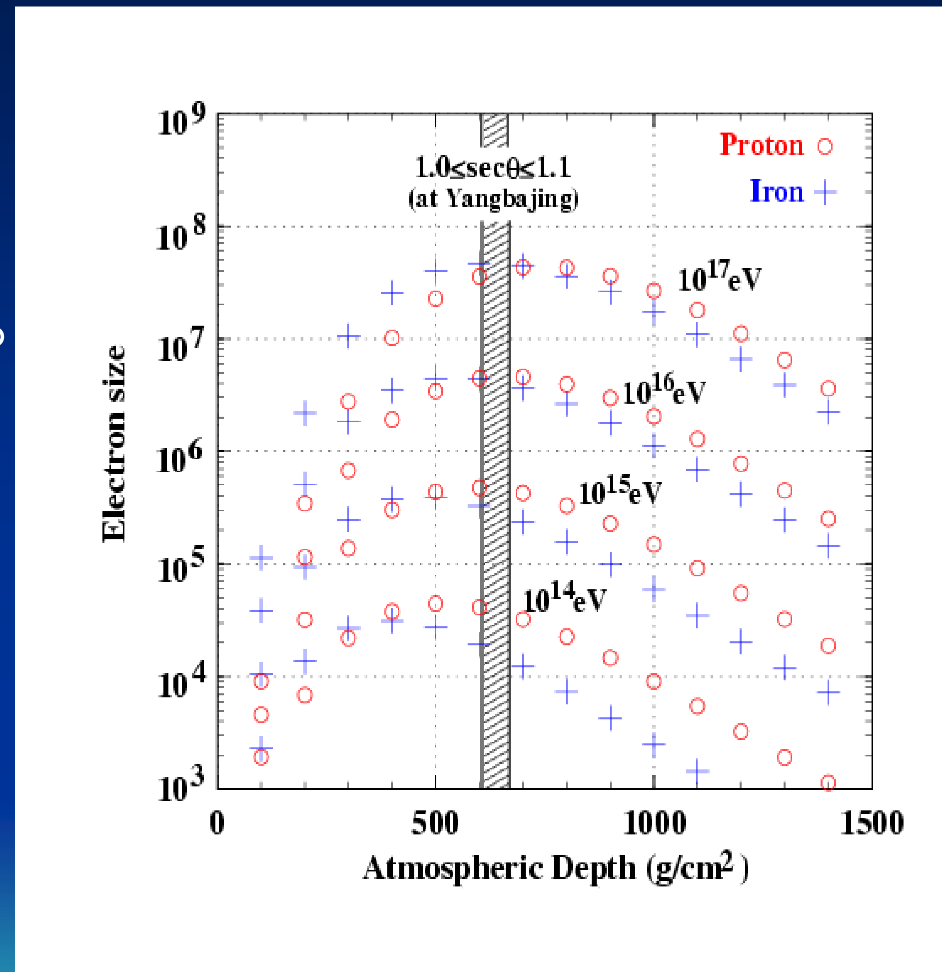
Yangbajing , Tibet, China

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

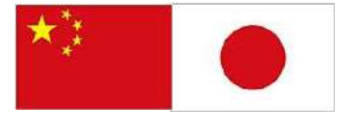
Why in Tibet?

1. 1-100TeV領域宇宙γ線
   ->大気中で減衰
   ->Sea Level に到達しない。

2. Knee領域宇宙線
   ->エネルギー決定精度の原子核依存性が少ない。



The Tibet ASγ Collaboration



M. Amenomori[1], X. J. Bi[2], D. Chen[3], T. L. Chen[4], W. Y. Chen[2], S. W. Cui[5], Danzengluobu[4], L. K. Ding[2], C. F. Feng[6], Zhaoyang Feng[2], Z. Y. Feng[7], Q. B. Gou[2], Y. Q. Guo[2], H. H. He[2], Z. T. He[5], K. Hibino[8], N. Hotta[9], Haibing Hu[4], H. B. Hu[2], J. Huang[2], H. Y. Jia[7], L. Jiang[2], F. Kajino[10], K. Kasahara[11], Y. Katayose[12], C. Kato[13], K. Kawata[14], M. Kozai[13], Labaciren[4], G. M. Le[2], A. F. Li[15,6,2], H. J. Li[4], W. J. Li[2,7], C. Liu[2], J. S. Liu[2], M. Y. Liu[4], H. Lu[2], X. R. Meng[4], T. Miyazaki[13], K. Munakata[13], T. Nakajima[13], Y. Nakamura[13], H. Nanjo[1], M. Nishizawa[17], T. Niwa[13], M. Ohnishi[14], I. Ohta[18], S. Ozawa[11], X. L. Qian[6,2], X. B. Qu[19,2], T. Saito[20], T. Y. Saito[21], M. Sakata[10], T. K. Sako[14], J. Shao[2,6], M. Shibata[12], A. Shiomi[22], T. Shirai[8], H. Sugimoto[23], M. Takita[14], Y. H. Tan[2], N. Tateyama[8], S. Torii[11], H. Tsuchiya[24], S. Udo[8], H. Wang[2], H. R. Wu[2], L. Xue[6], Y. Yamamoto[10], K. Yamauchi[12], Z. Yang[2], S. Yasue[25], A. F. Yuan[4], L. M. Zhai[2], H. M. Zhang[2], J. L. Zhang[2], X. Y. Zhang[6], Y. Zhang[2], Yi Zhang[2], Ying Zhang[2], Zhaxisangzhu[4], X. X. Zhou[7]

[1]Department of Physics, Hirosaki University, Japan
[2]Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, China
[3]National Astronomical Observatories, Chinese Academy of Sciences, China
[4]Department of Mathematics and Physics, Tibet University, China
[5]Department of Physics, Hebei Normal University, China [6]Department of Physics, Shandong University, China
[7]Institute of Modern Physics, SouthWest Jiaotong University, China
[8]Faculty of Engineering, Kanagawa University, Japan [9]Faculty of Education, Utsunomiya University, Japan [10]Department of Physics, Konan University, Japan
[11]Research Institute for Science and Engineering, Waseda University, Japan
[12]Faculty of Engineering, Yokohama National University, Japan
[13]Department of Physics, Shinshu University, Japan
[14]Institute for Cosmic Ray Research, University of Tokyo, Japan
[15]School of Information Science and Engineering, Shandong Agriculture University, China
[16]Saitama University, Japan
[17]National Institute of Informatics, Japan
[18]Sakushin Gakuin University, Japan
[19]College of Science, China University of Petroleum, China
[20]Tokyo Metropolitan College of Industrial Technology, Japan
[21]Max-Planck-Institut fuer Physik, Deutschland
[22]College of Industrial Technology, Nihon University, Japan
[23]Shonan Institute of Technology, Japan
[24]Japan Atomic Energy Agency, Japan
[25]School of General Education, Shinshu University, Japan

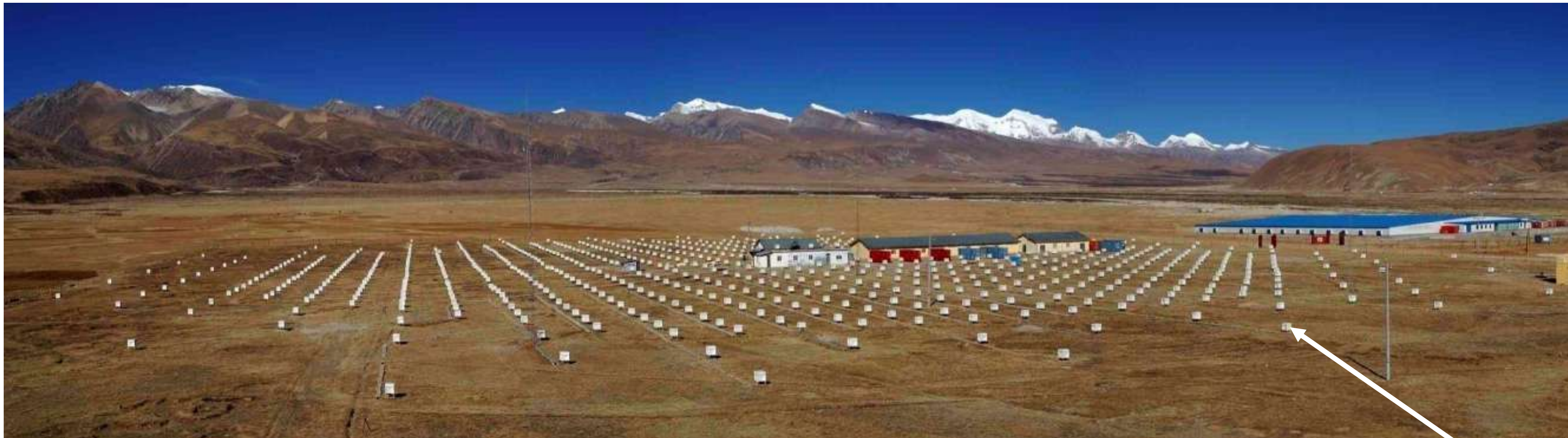
Yangbajing,
Tibet, China

4300 m a.s.l. = 606 g/cm^2

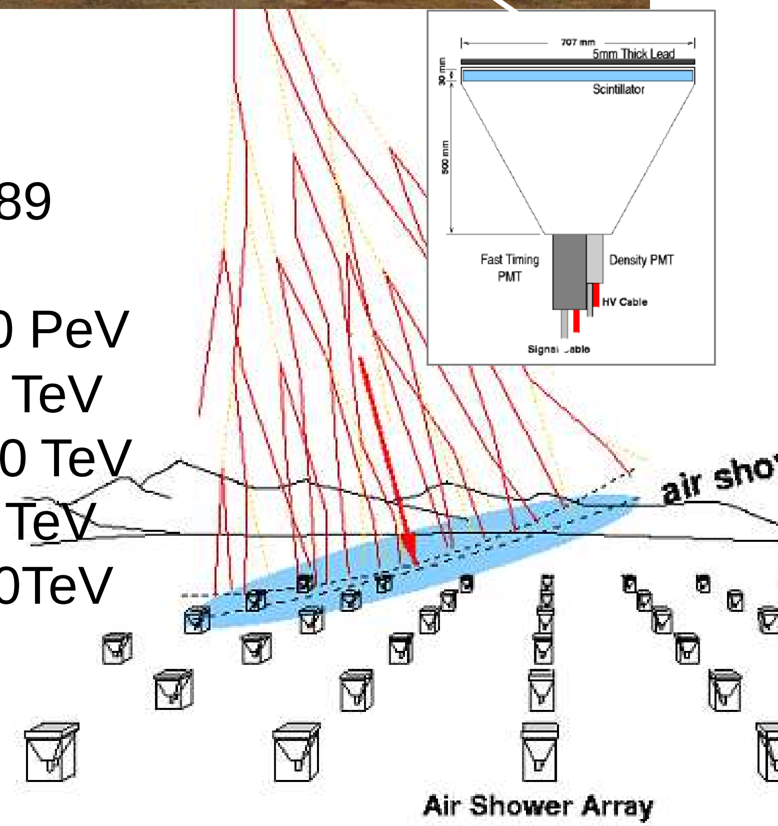
チベット空気シャワー観測装置

有効面積	37,000 m^2
検出器数	789台
観測エネルギー	10^{12} eV 以上
角度分解能	0.9度
観測頻度	毎秒1,700個

Tibet-III Air Shower (AS) Array

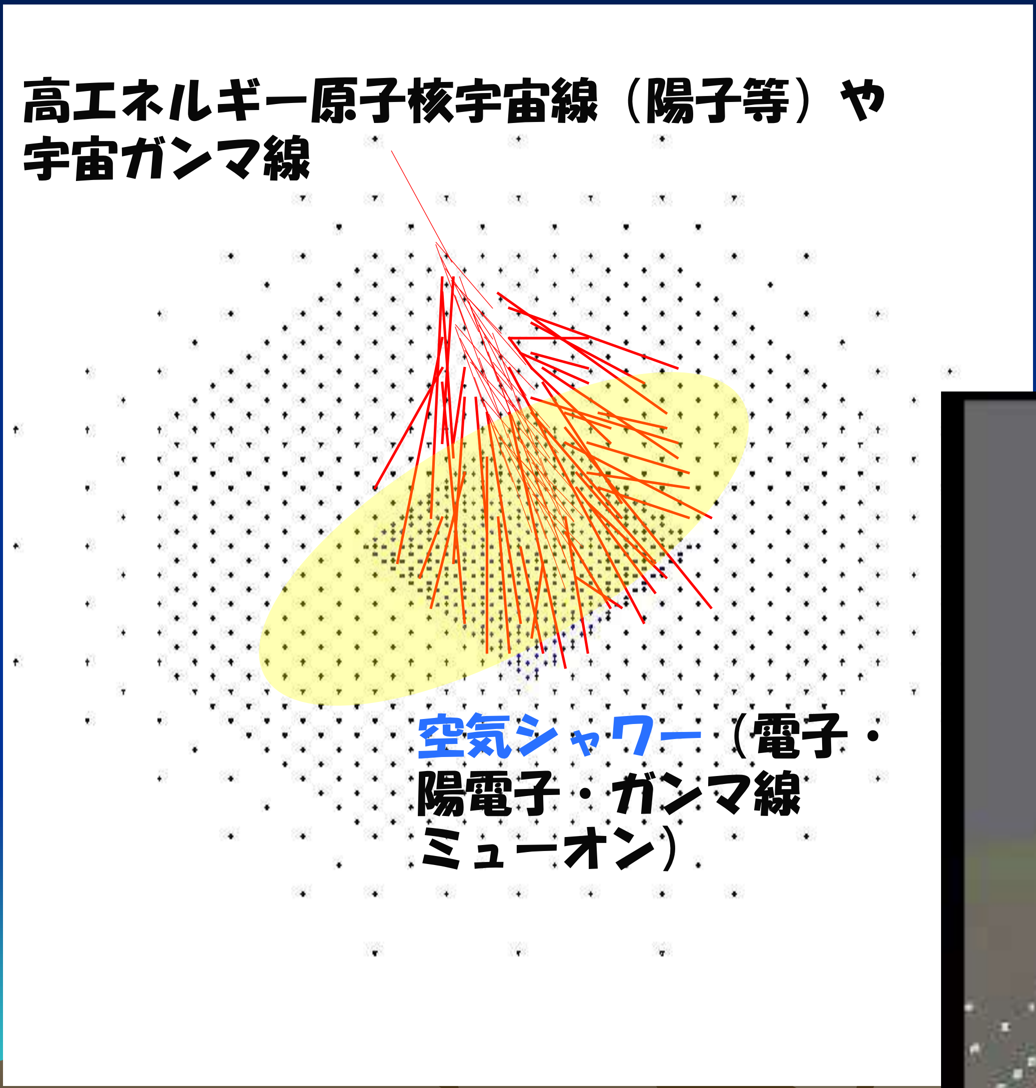


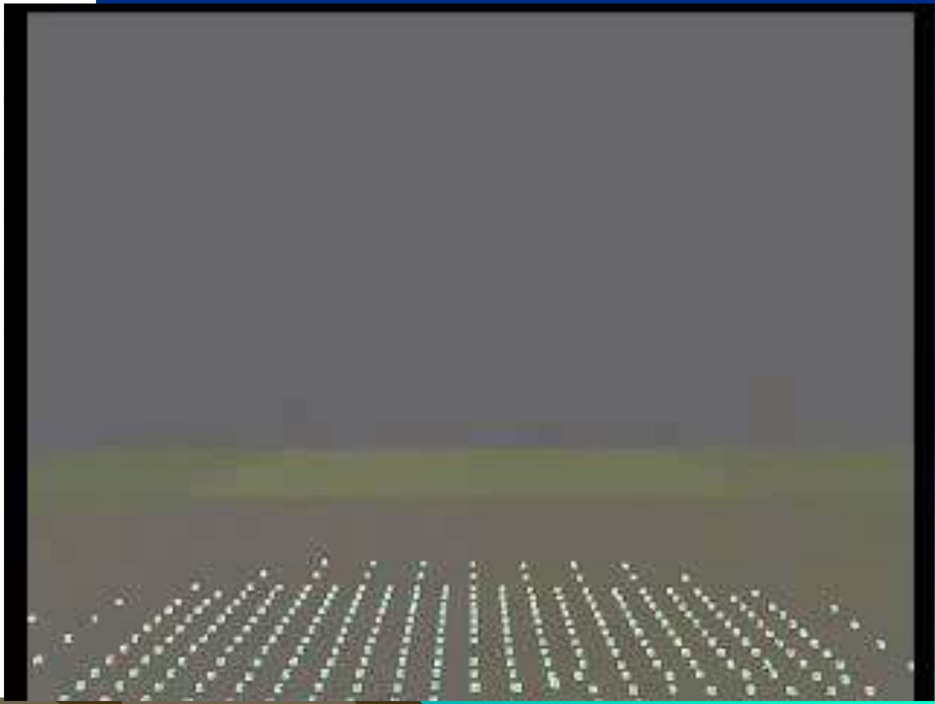
4,300 m a.s.l. (606 g/cm^2)



☐ Number of Scinti. Det.	0.5 m^2 x 789
☐ Effective Area for AS	~37,000 m^2
☐ Energy region	~3TeV - 100 PeV
☐ Angular Resolution (Gamma rays)	~0.4° @10 TeV ~0.2° @100 TeV
☐ Energy Resolution (Gamma rays)	~50% @10 TeV ~25% @100TeV
☐ F.O.V.	~2 sr

空気シャワー





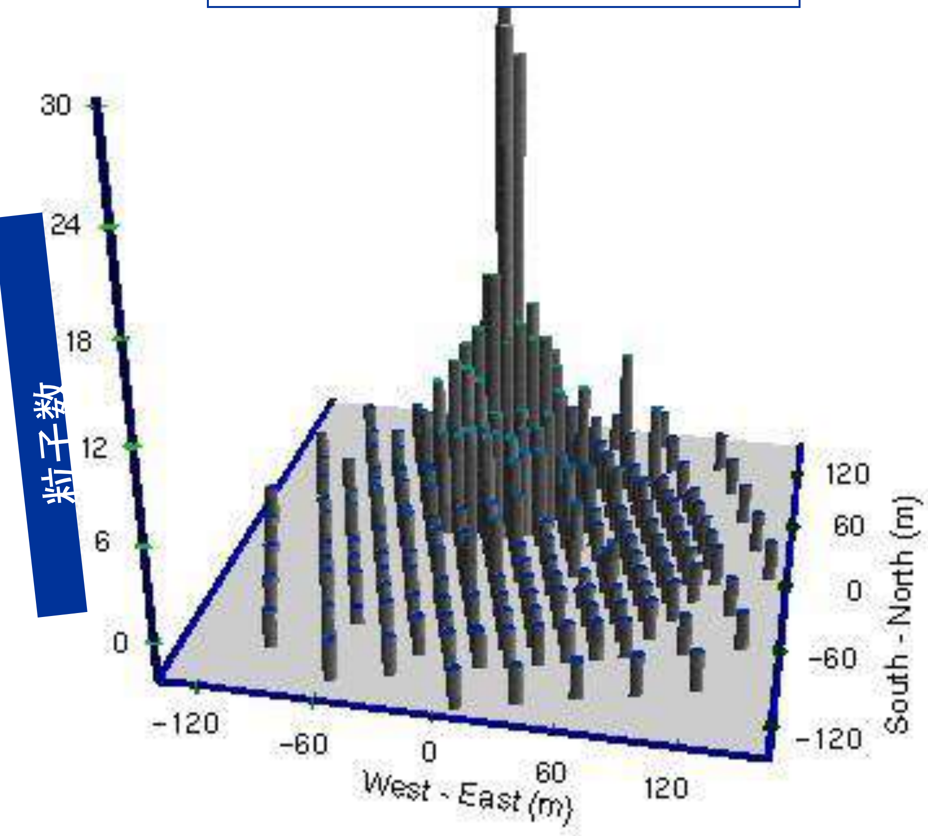
Air Shower Detection

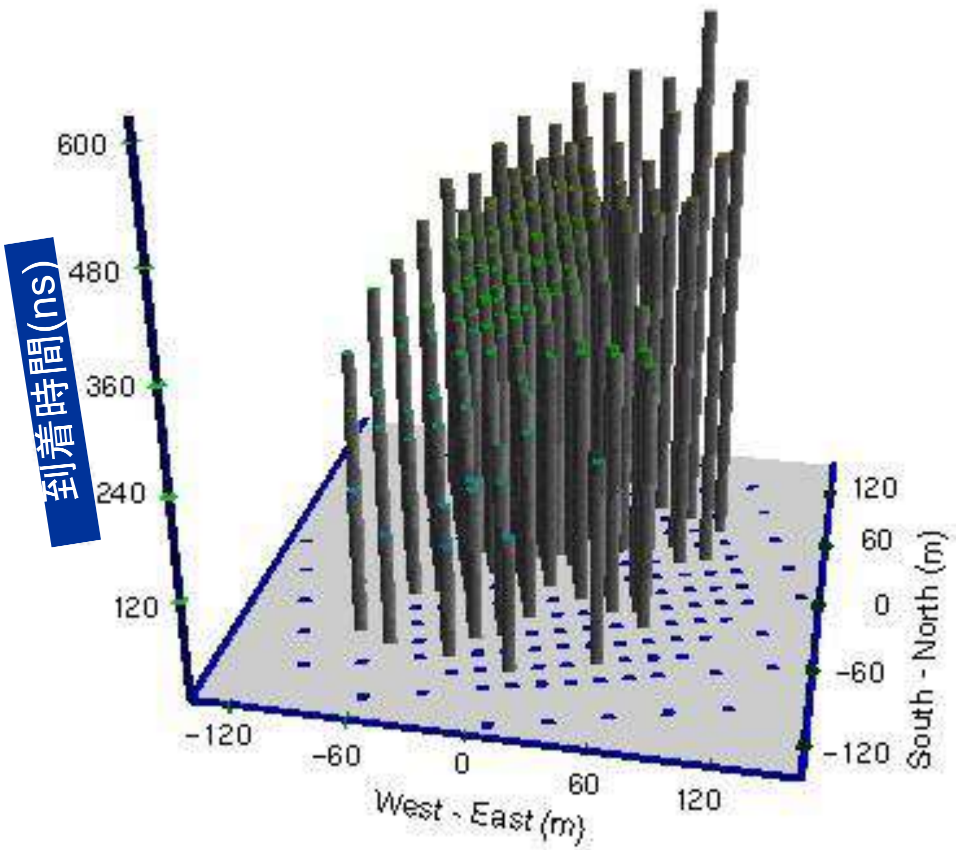
2nd particle density

Cosmic ray energy

2nd particle timing

Cosmic ray direction



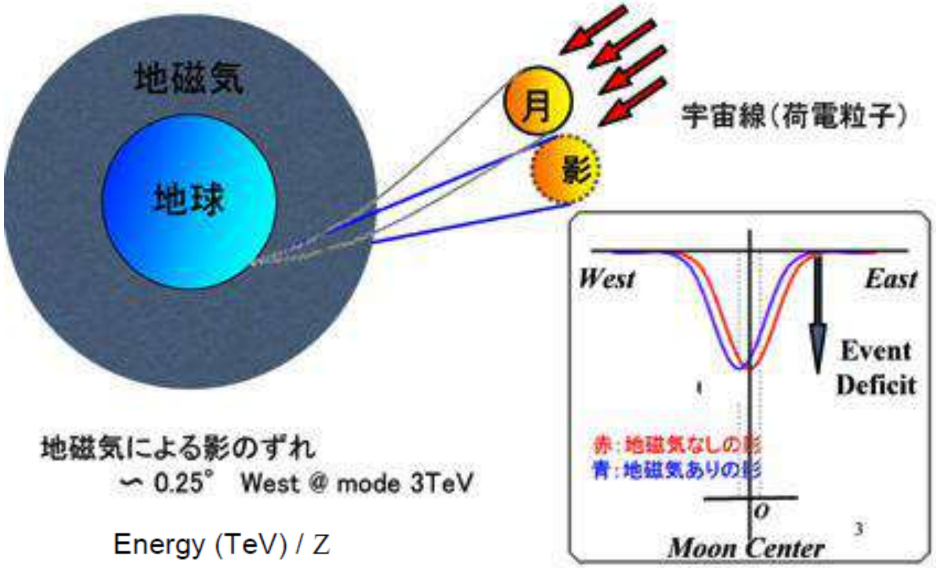


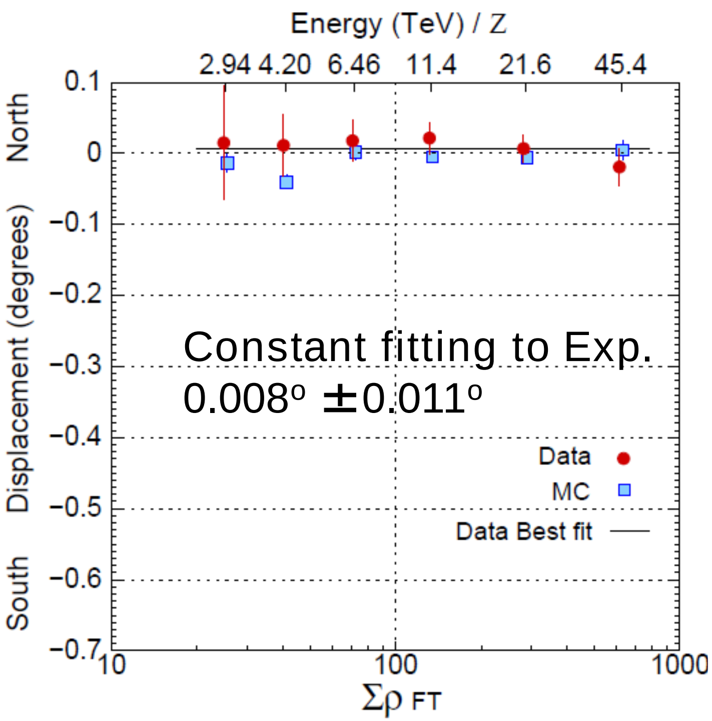
Air shower rate triggered by Tibet III ~1700Hz

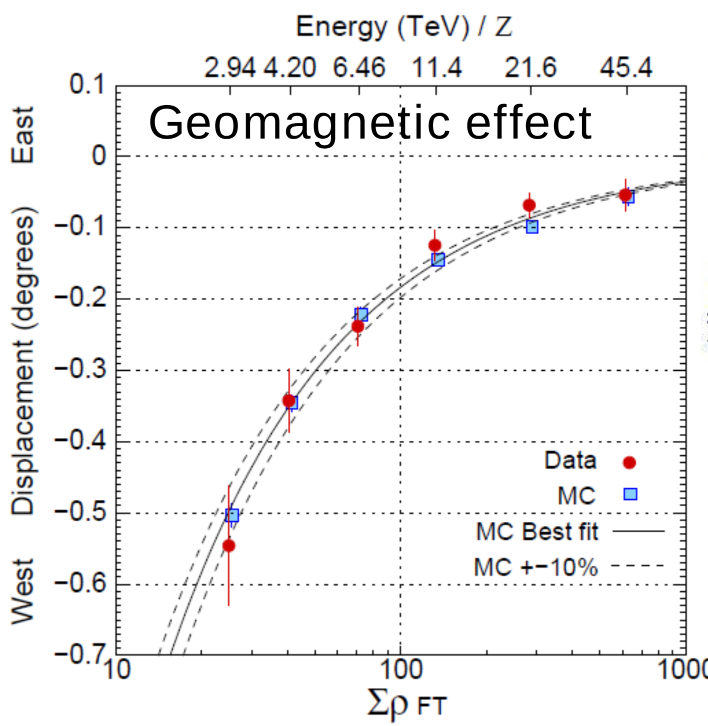
Performance by Moon's Shadow

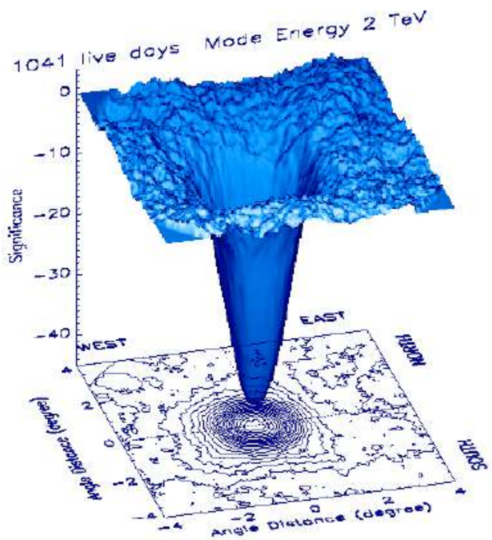
The Astrophysical Journal, 692, 61−72(2009)

- Absolute Energy Scale
- Angular Resolution
- Pointing Accuracy







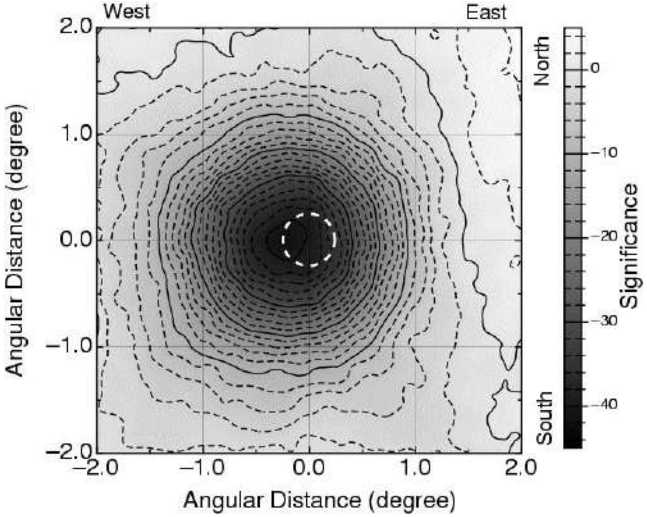


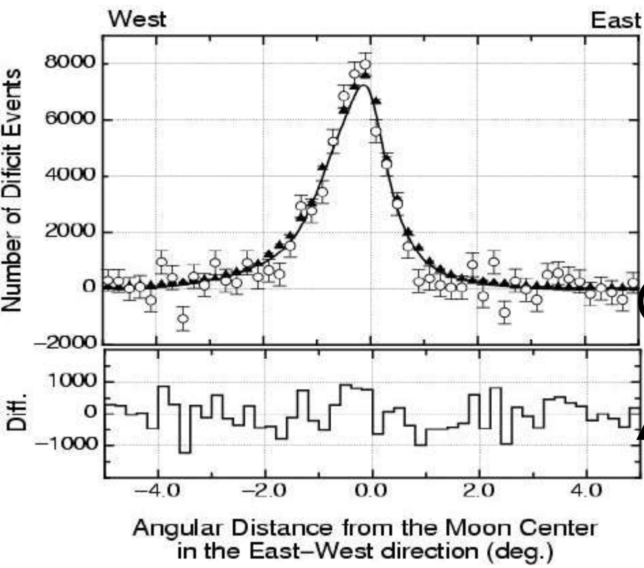
Pointing Error
< 0.011°

Absotute Energy Scale Error < 12%
+4.5%(±8.6stat.±6.7syst.)%

Search for TeV anti-protons by the Moon's shadow

3TeV 40σ





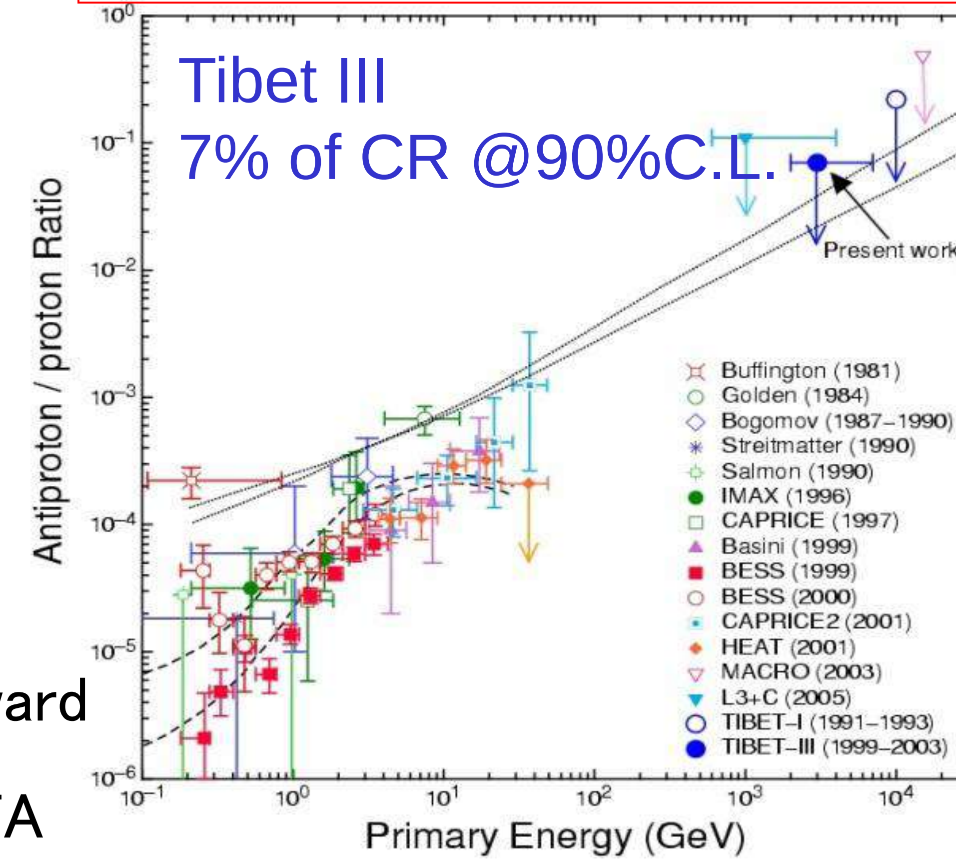
0.23°

Westward

○ :DATA

△ :MC

Amenomori et al.
Astroparticle Physics, 28, (2007) 137-142



Dashed line: leaky box

M.Simon et al. ApJ 499 (1998)250.

Dotted line: extragalactic anti-matter model

S.A. Stephan et al. Space Sci. Rev. 46 (1987) 31.

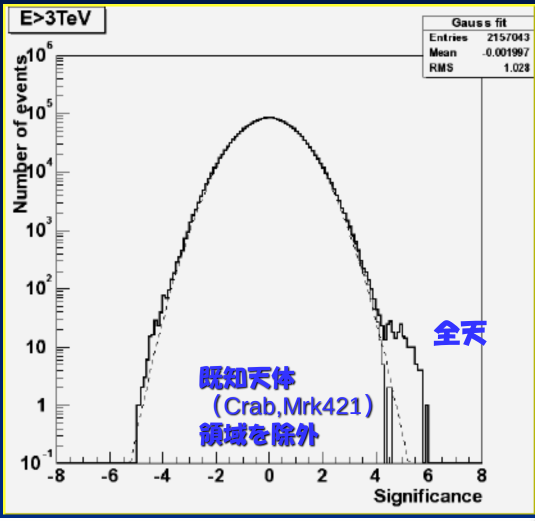
ガンマ線放射天体の探索

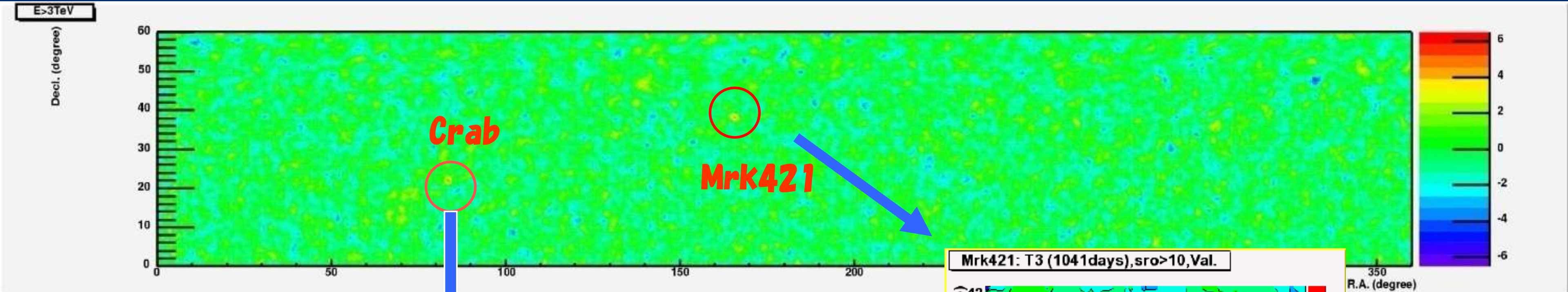
チベットで観測された点源

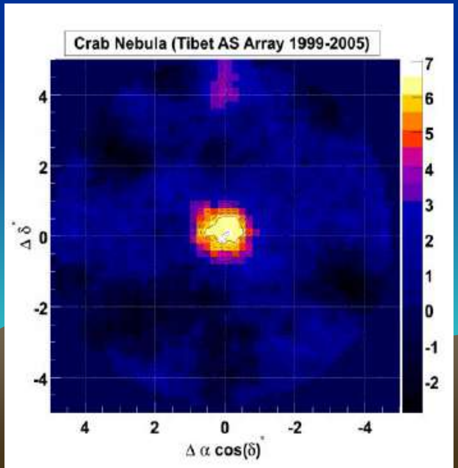
★　超新星残骸　かに星雲からの定常ガンマ線

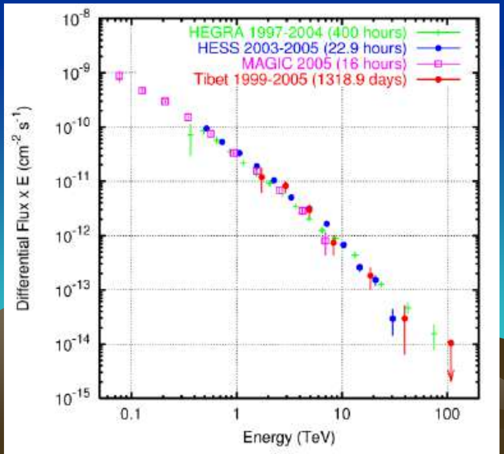
★　活動的銀河核　Mrk421, Mrk501からのフレアガンマ線

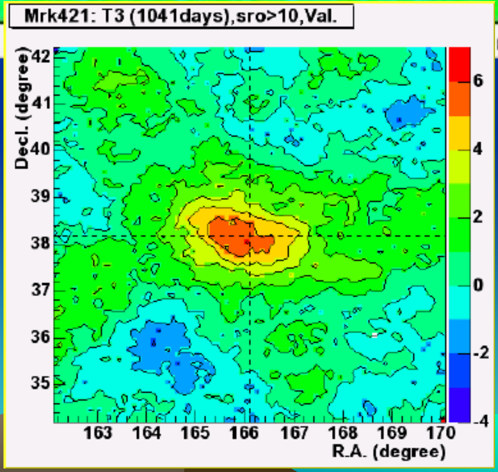
1999ー2003年　全北天探索









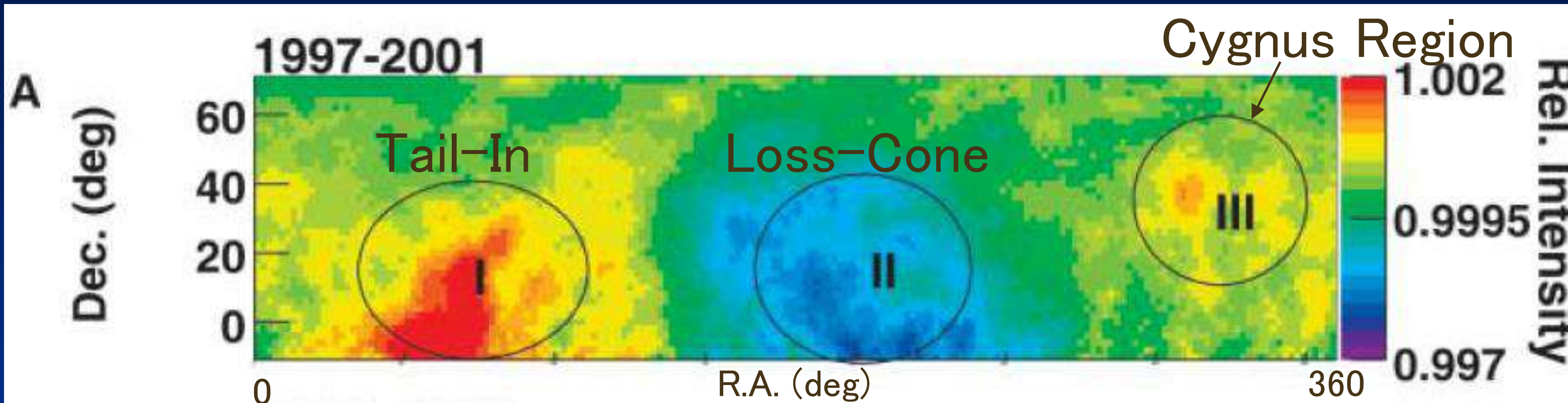


2000－2001年フレア

Cosmic Ray Anisotropy at multi-TeV energies（宇宙線）の伝播

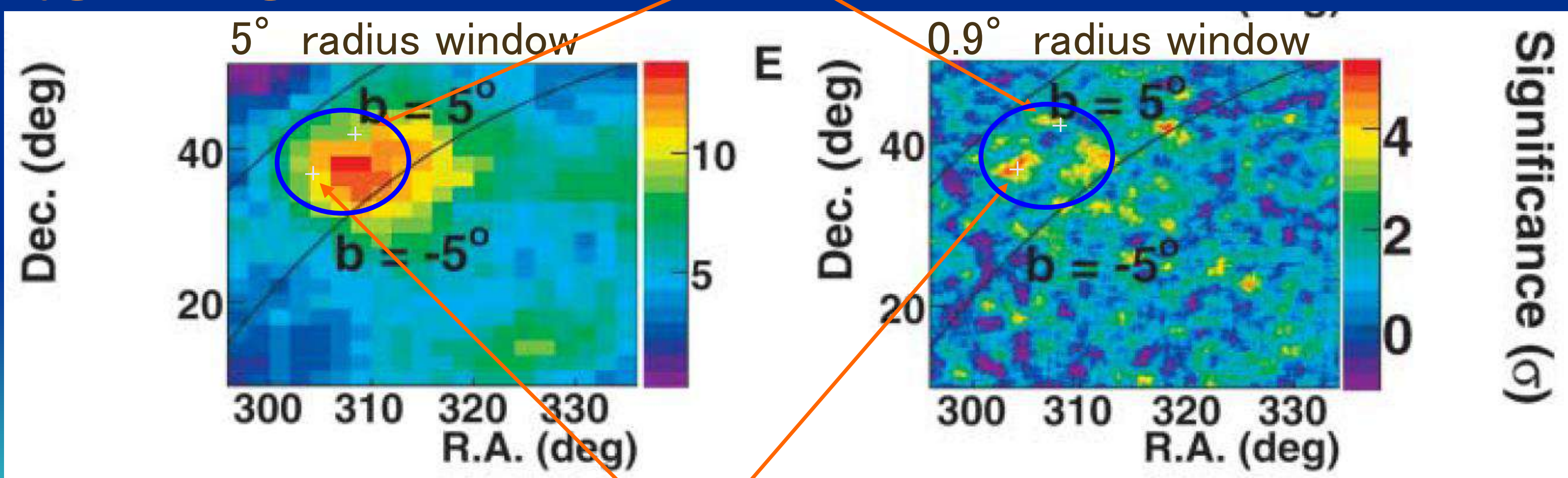
2D Large-scale Anisotropy Map

Amenomori et al, Science, 314, 439 (2006)



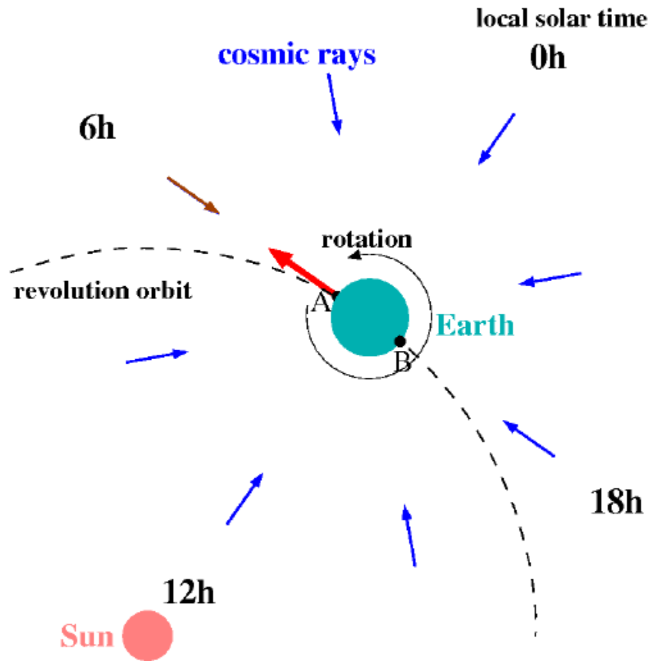
①MGRO J2033+42

Cygnus Region

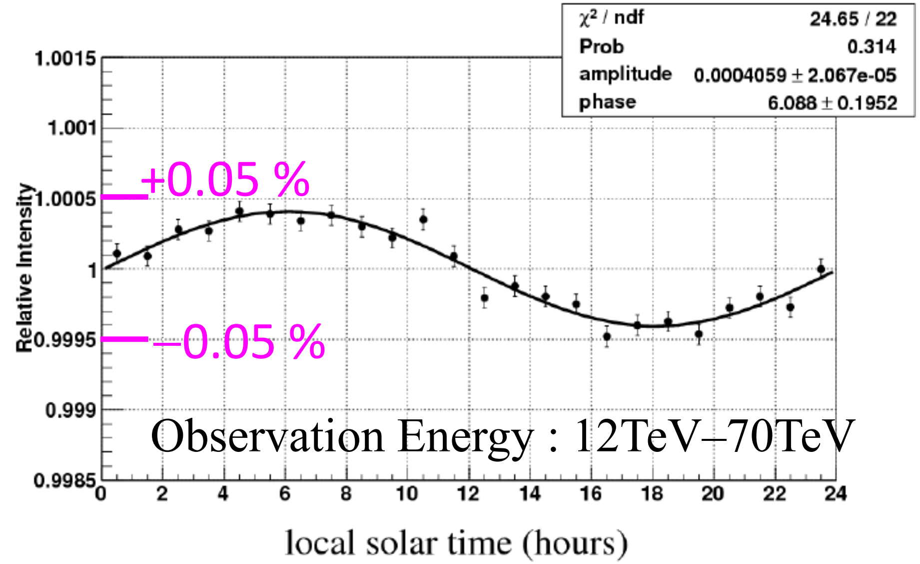


②MGRO J2019+37

Compton-Getting Anisotropy at Solar Time Frame



Amenomori et al., ApJL, 672 (2008) L53



Expected Amplitude 3.86×10^{-2} % Phase 6 [hr]

Data Amplitude $(4.06 \pm 0.21) \times 10^{-2}$ % Phase 6.1 ± 0.2 [hr]

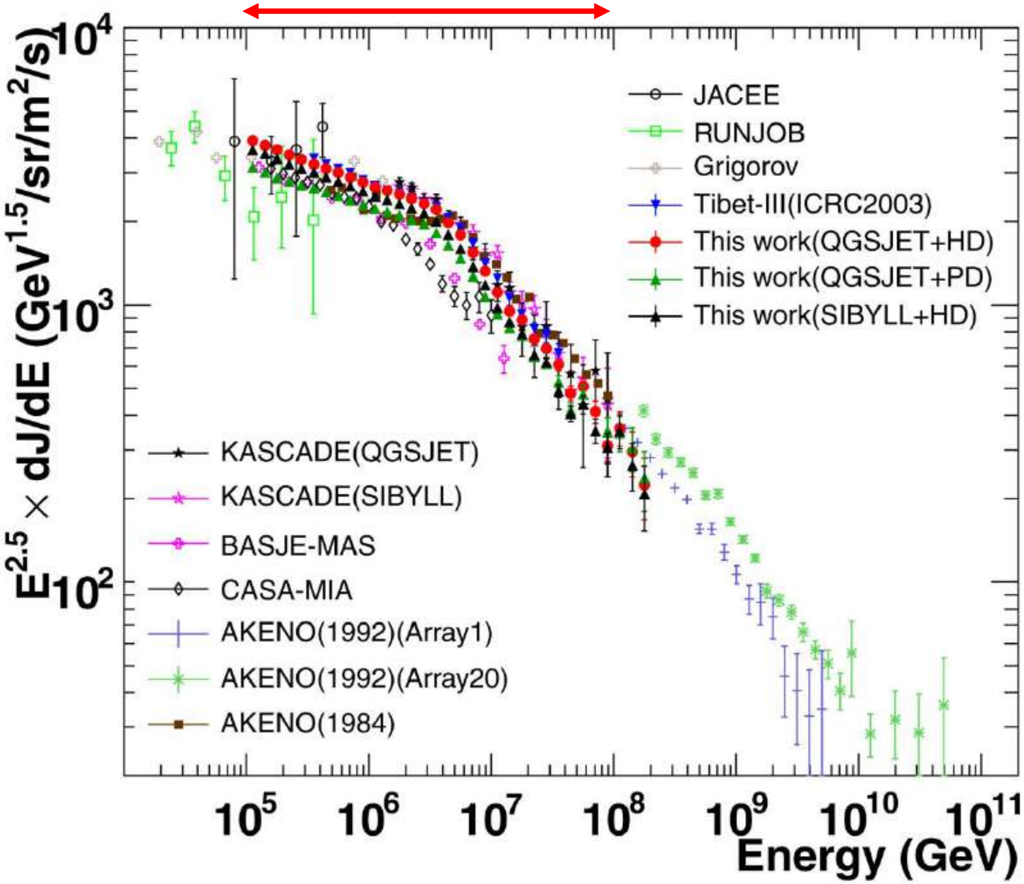
➡ **CG detected at 19.6σ consistent with expected**

- Reliability and calibration for sidereal anisotropy (~ 0.01%)
- Only Tibet ASγ experiment showing a clear sinusoidal curve

All Particle Energy Spectrum in the Knee region

Amenomori *et al.*,
ApJ, 678, 1165 (2008)

10^{14}eV ～ 10^{17}eV (3 orders)

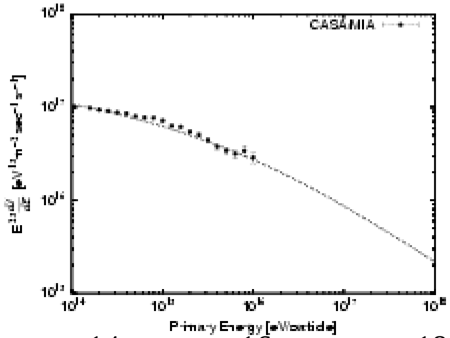


Model	Index of spectrum	Energy range (eV)
QGSJET +HD	−2.67±0.01	< 10^{15} eV
	−3.10±0.01	> 4×10^{15} eV
QGSJET +PD	−2.65±0.01	< 10^{15} eV
	−3.08±0.01	> 4×10^{15} eV
SIBYLL +HD	−2.67±0.01	< 10^{15} eV
	−3.12±0.01	> 4×10^{15} eV

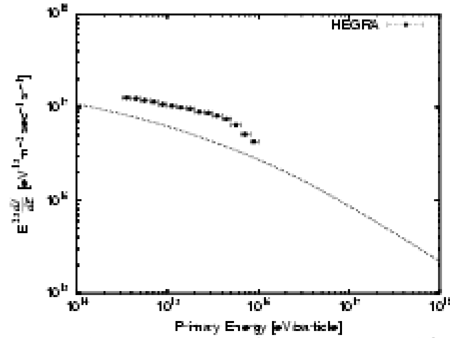
All particle spectrum around the knee

(Slide from M.Shibata, Y.N.U.)

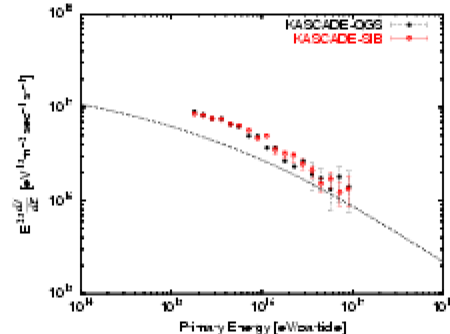
CASA/MIA HEGRA KASCADE



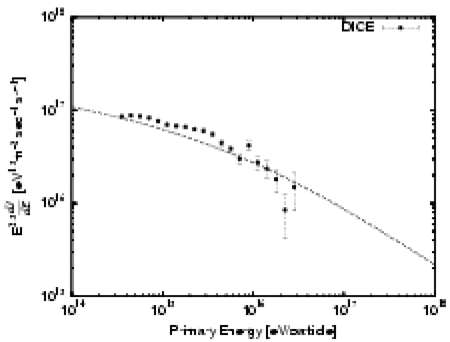
10^{14} 10^{16} 10^{18}



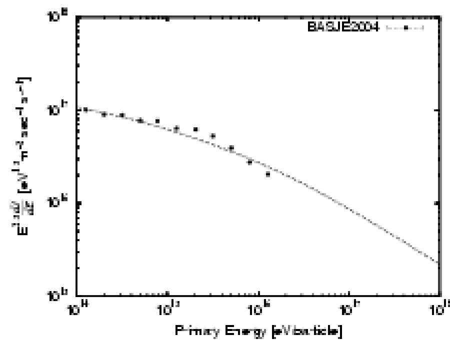
10^{14} 10^{16} 10^{18}



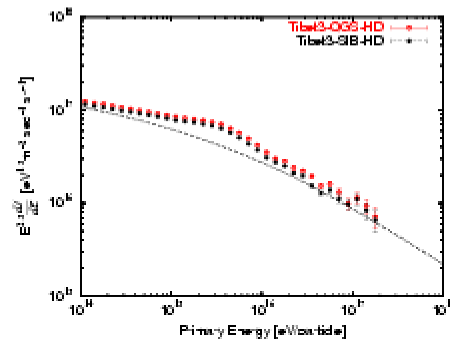
10^{14} 10^{16} 10^{18}



10^{14} 10^{16} 10^{18}



10^{14} 10^{16} 10^{18}

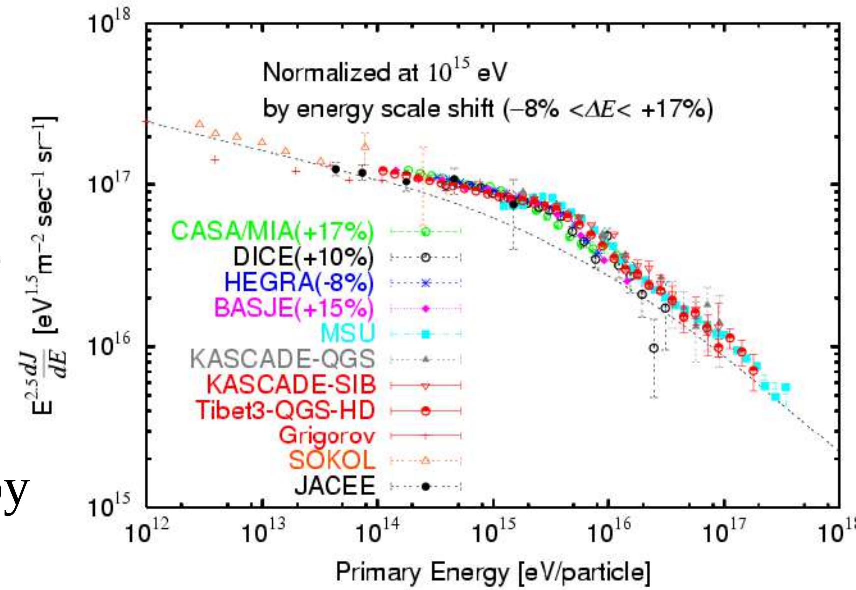


10^{14} 10^{16} 10^{18}

DICE BASJE TIBET

Extra component

All data agree if we apply energy scale correction within 20% by normalizing to direct observations.

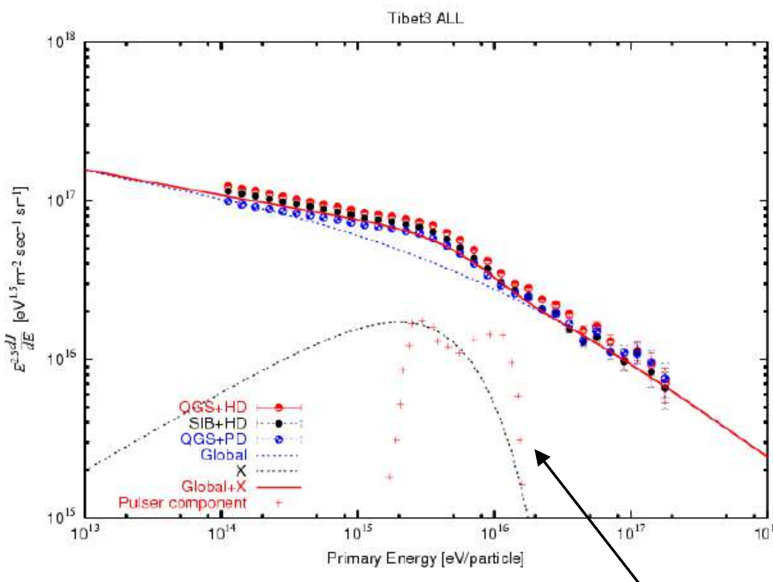


Extra component can be approximated by

$$E^{-2}\exp[-\frac{E}{4\mathrm{PeV}}],$$

suggesting **nearby source(s).**

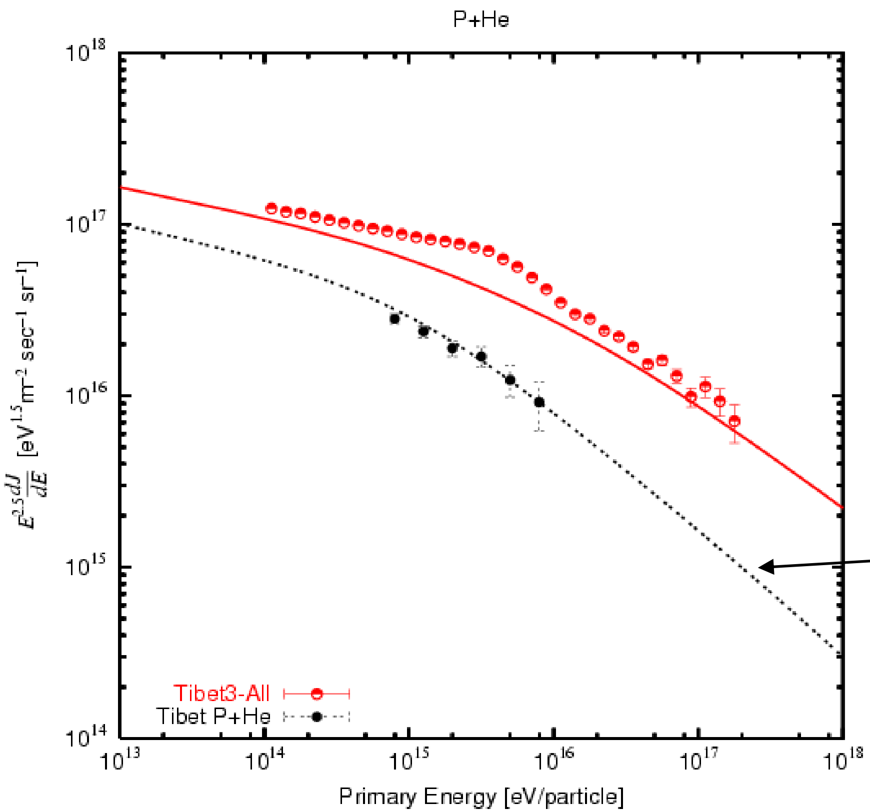
Since P and He component do not show the excess at the knee, the extra component should be attributed to heavy element such as Fe.



(W.Bednarek and R.J.Protheroe ,2002,APh)

(Slide from M.Shibata, Y.N.U.)

Tibet P +He spectrum does not show excess at the knee

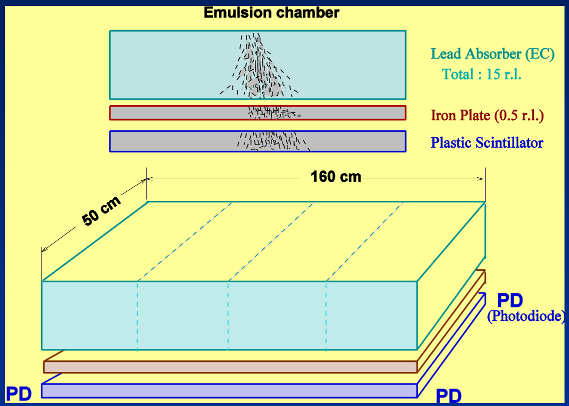


Tibet All particle Data vs. Expected by multiple source model

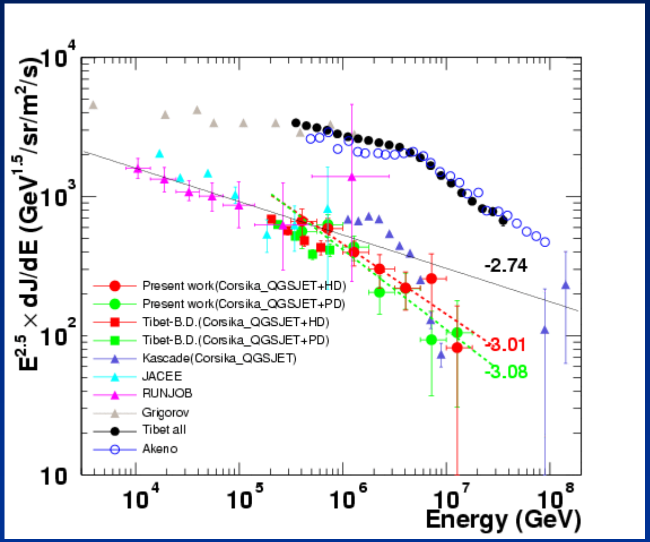
P+He Data vs. Expected by multiple source model

(Slide from M.Shibata, Y.N.U.)

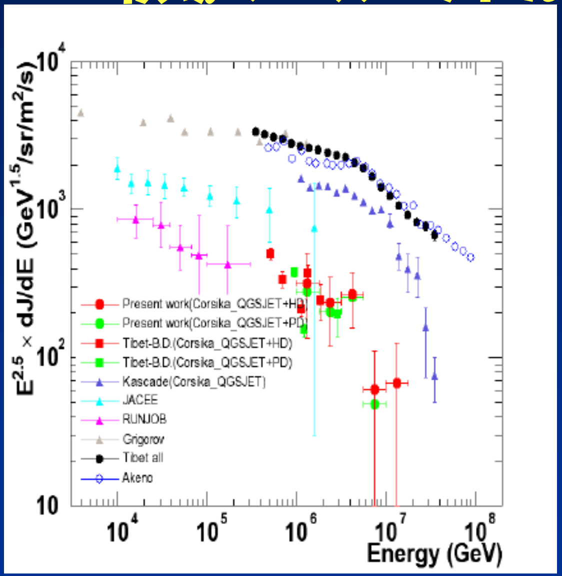
一次宇宙線陽子・Ｈｅ成分の観測



Knee領域の陽子スペクトル

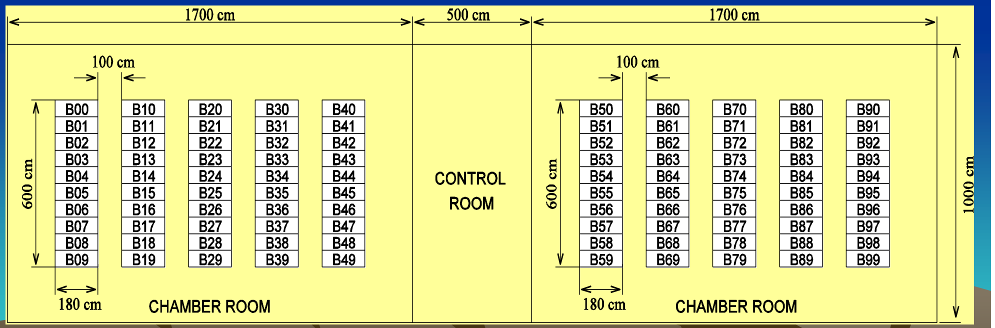


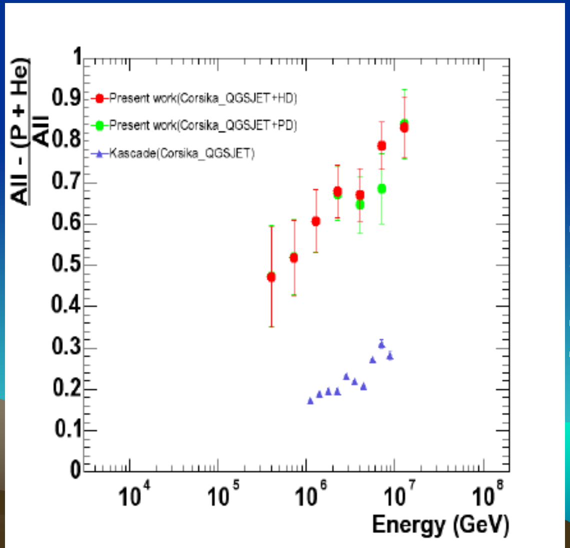
Knee領域のHeスペクトル



Burst検出器：100台

検出器総面積：80㎡





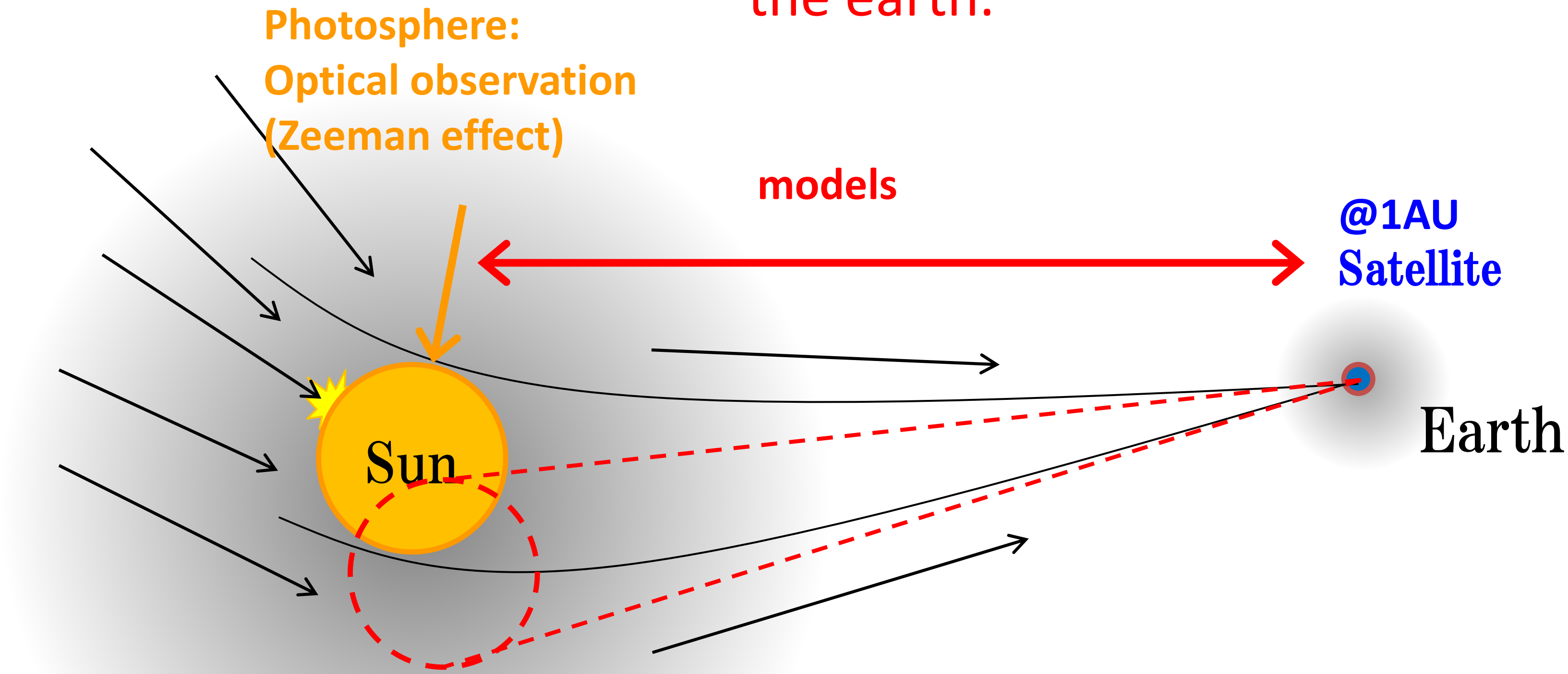
エネルギーが高いと

重粒子の割合が増加

Sun Shadow

Sun Shadow

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



TeV proton --> Charged particle

Larmor radius

~ 7.4AU (B=30μG near the earth)

$\sim 0.16 R_{\odot}$(B=300mG near the sun)

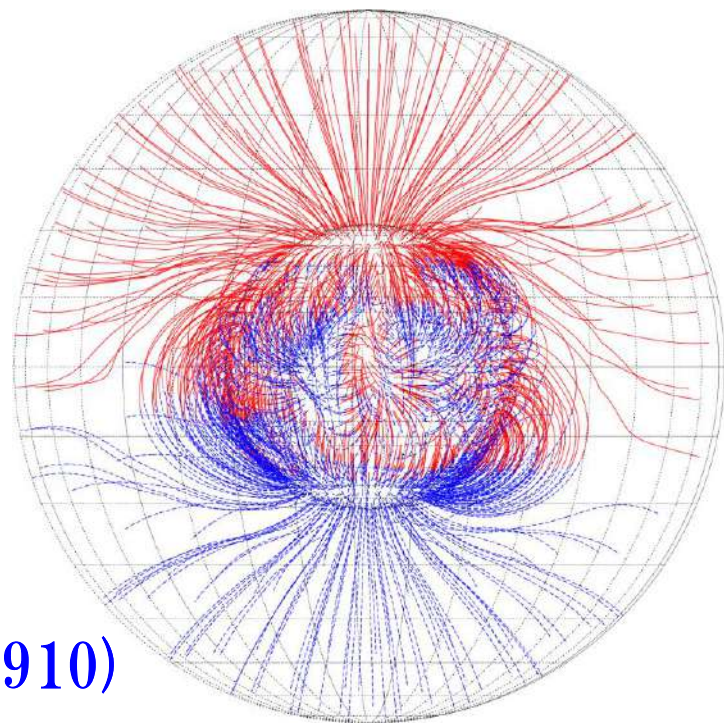
→ Probe of the solar MFs !

Magnetic Fields between Sun and Earth

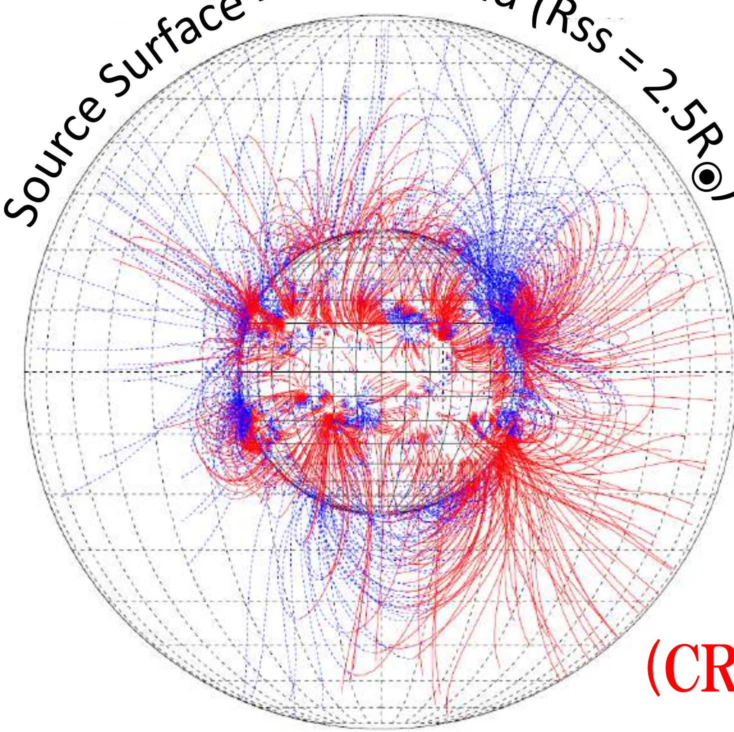
Corona -> Source Surface model *Zhao & Hoeksema, JGR (1995)*
(CSSS well reproduces the Tibet-II sun shadows)
Derived from the magnetogram measured by
Kitt Peak (KPVT / SOLIS) in each C.R.

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

Geomag.-> Dipole model



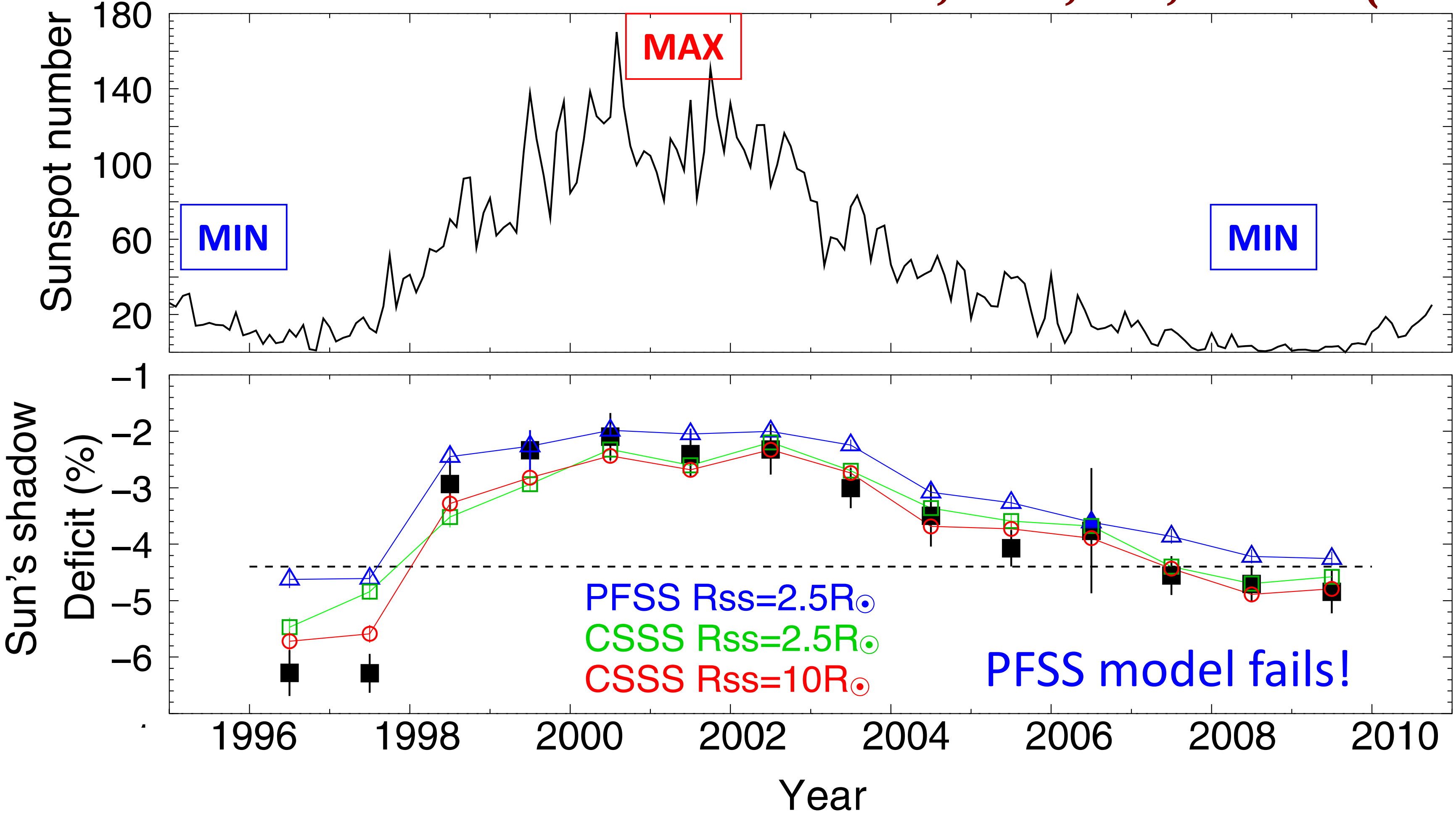
1996
(CR1910)



2001
(CR1978)

Past Results (Tibet-II >10TeV)

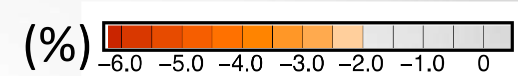
Amenomori et al, PRL, 111, 011101 (2013)

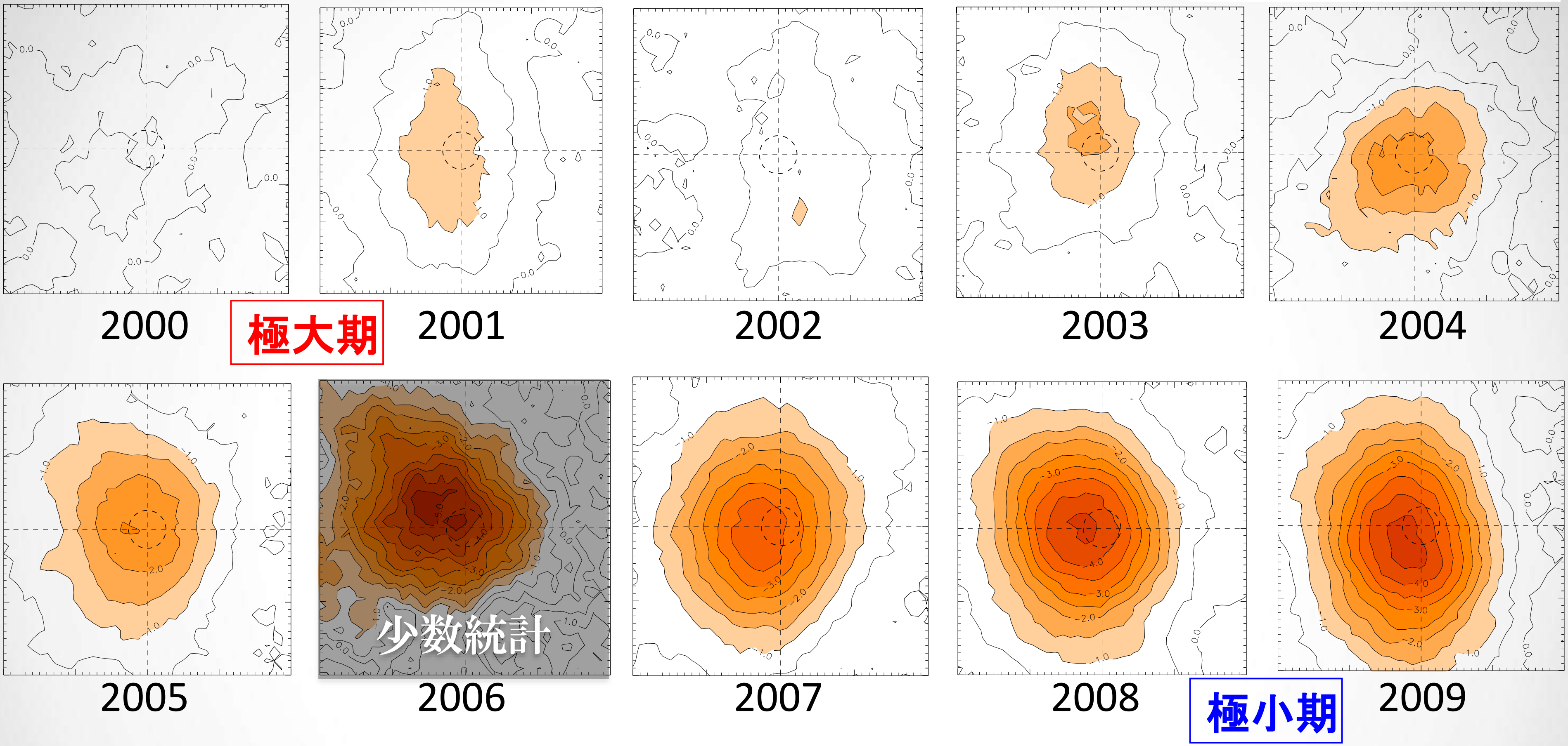


- ✓ Discovery of a clear anti-correlation of the deficits with SN
- ✓ Comparison b/w coronal MF models (PFSS/CSSS)

太陽の影の観測 > 3 TeV

川田、他、submitted(2016)

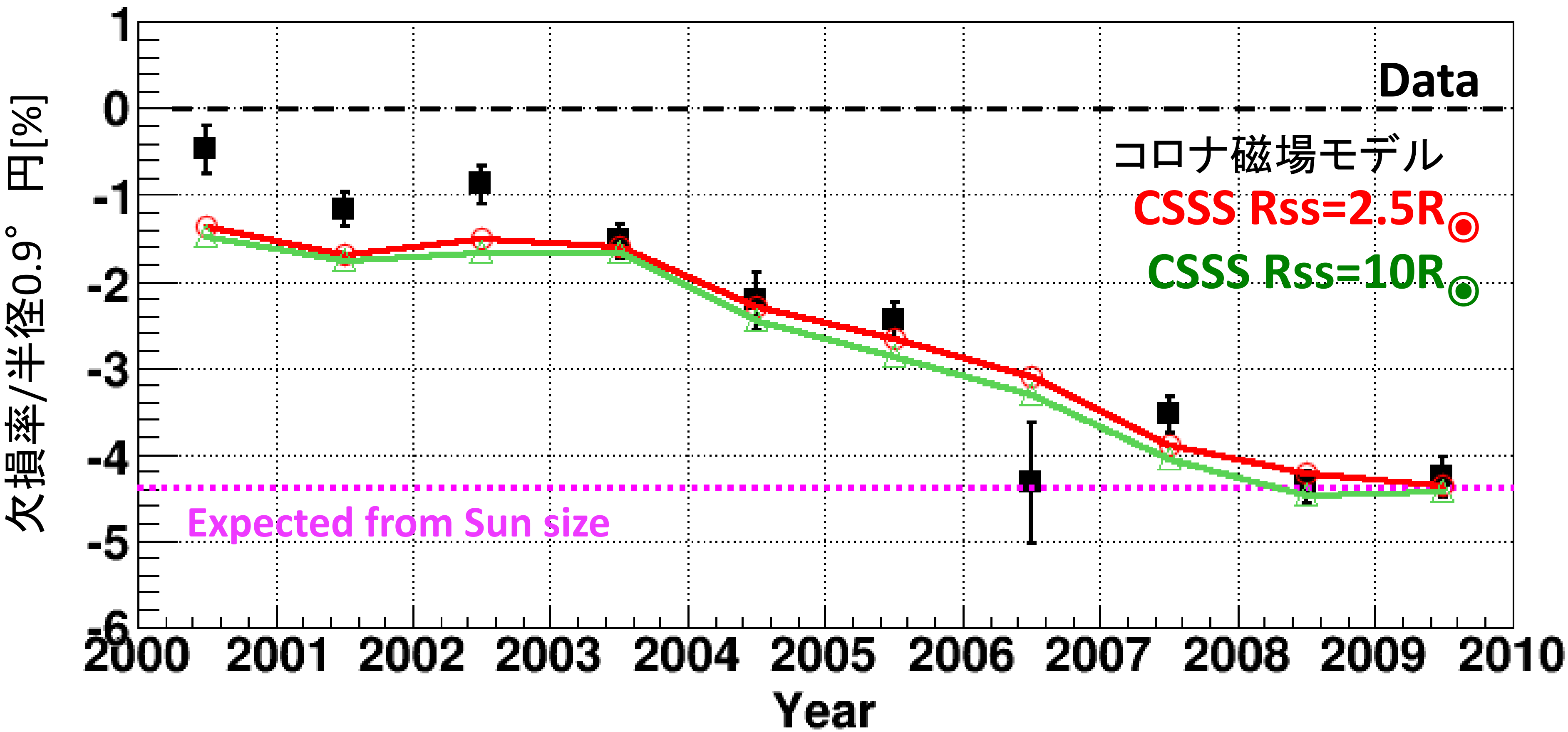




- ✓ Tibet-III (>3TeV) 2000年-2009年(10年間)
- ✓ 太陽方向を中心にした4°×4°の欠損率マップ
  (欠損率 = 欠損量／バックグラウンド [%])
  → 太陽活動と反相関：極大期は浅く、極小期は深い

川田、他、submitted (2017)

影の深さの変化 全期間 - 3 TeV



CSSSは極大期を再現しない？

χ^2 / dof = 32.1 / 10 (3.4σ)

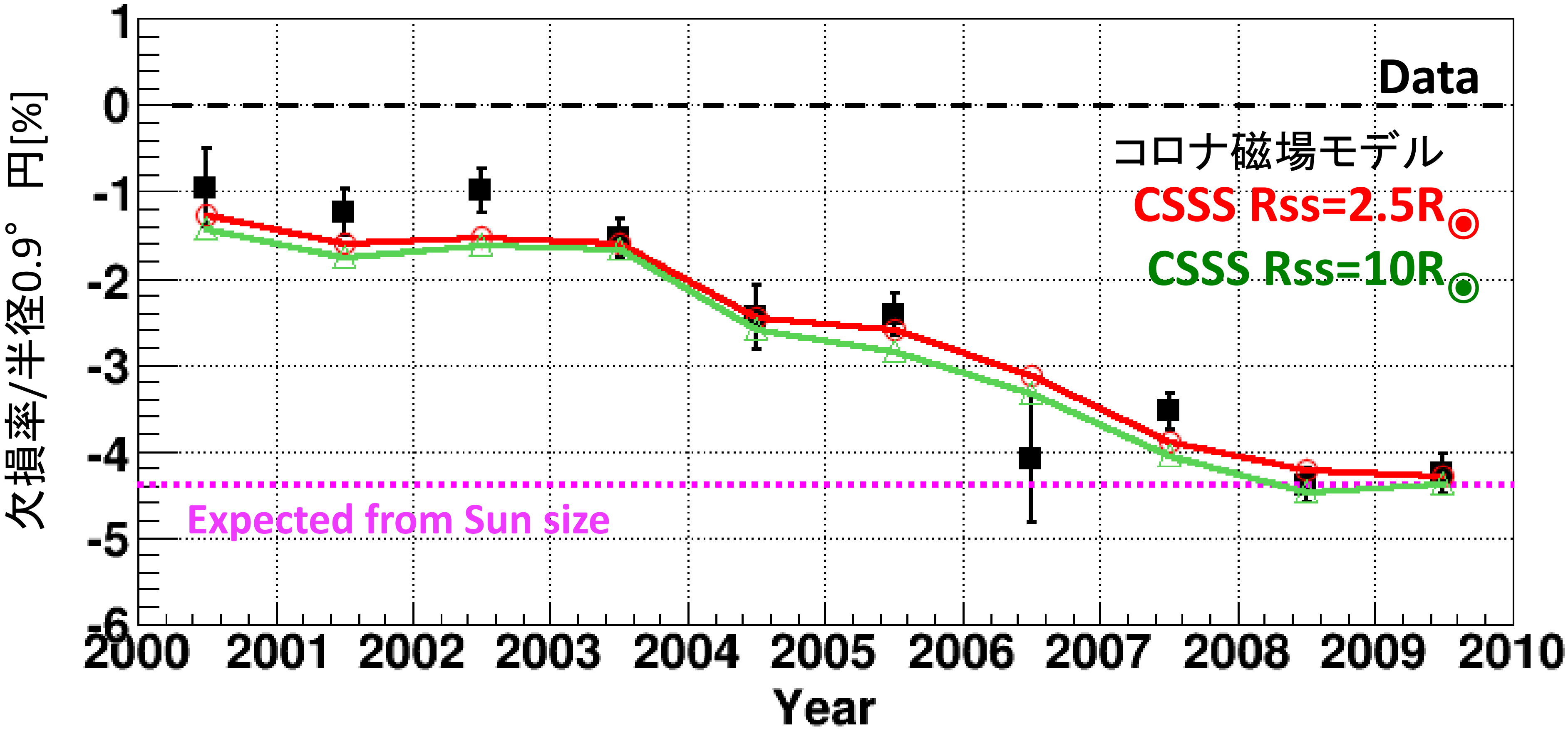
χ^2 / dof = 46.9 / 10 (4.8σ)

※統計誤差のみ

CMEの影響を調査

川田、他、submitted (2017)

影の深さの変化 CME発生期間を除く



Paper in preparation

χ^2 / dof = 12.2 / 10 (0.6σ)

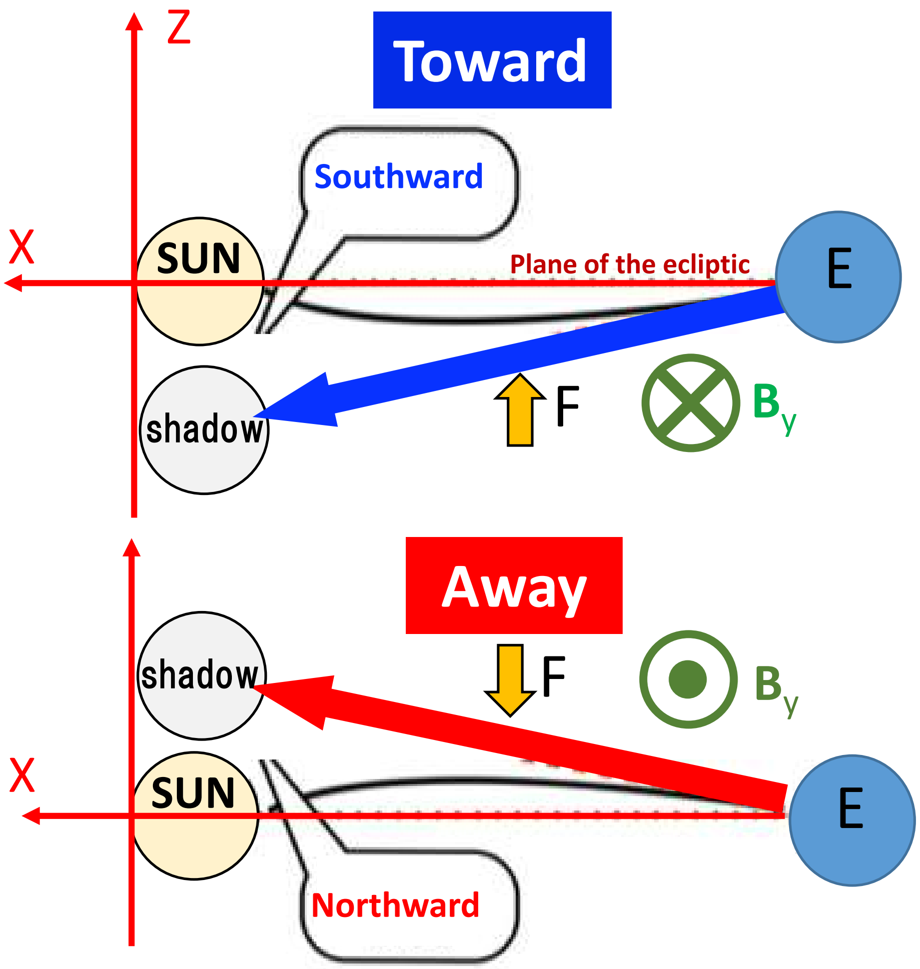
χ^2 / dof = 21.3 / 10 (2.0σ)

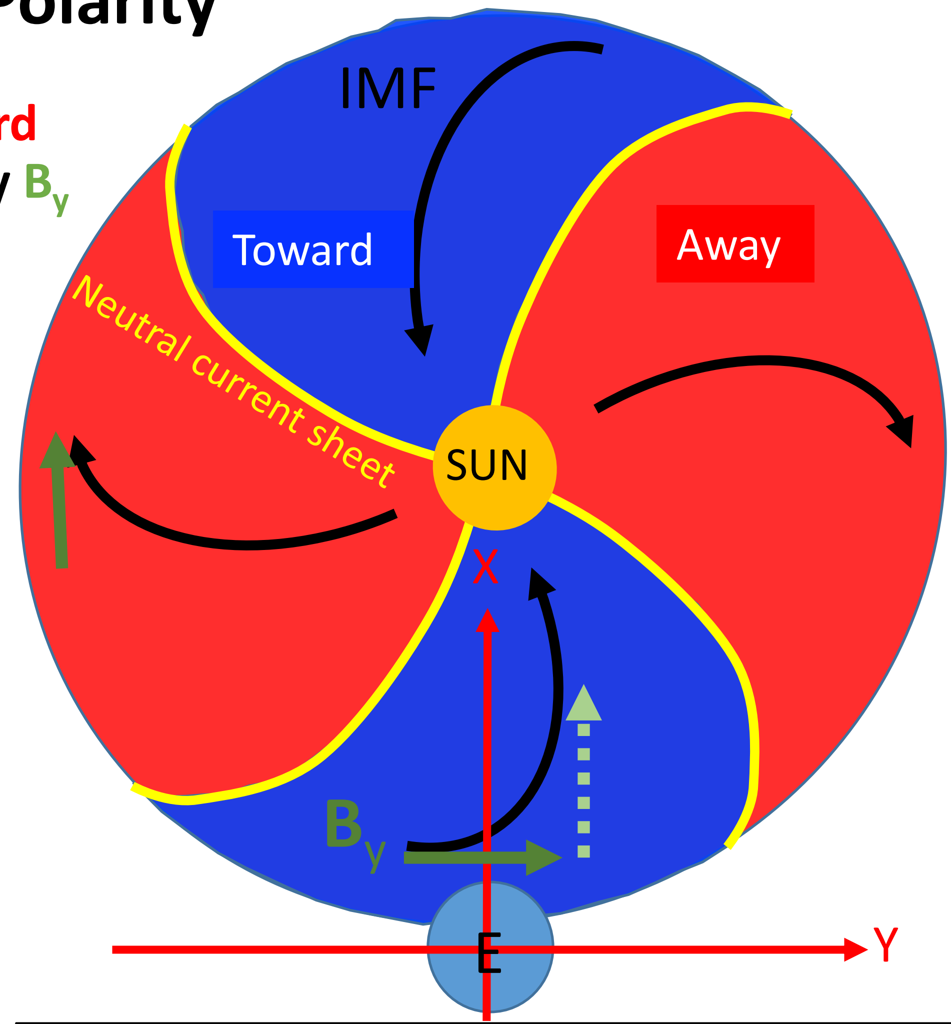
※統計誤差のみ

活動期で影が深くなる
CSSSは再現
→ 磁場モデルにはCME等の
短期変動は考慮されない

Sun’s Shadow and IMF Sector Polarity

- The Sun’s shadow is deflected northward (southward) in Away (Toward) sector by B_y





Assignment of the sector polarity with B_x & B_y observed two days later

$B_x < 0$ & $B_y > 0$ => Away

$B_x > 0$ & $B_y < 0$ => Toward

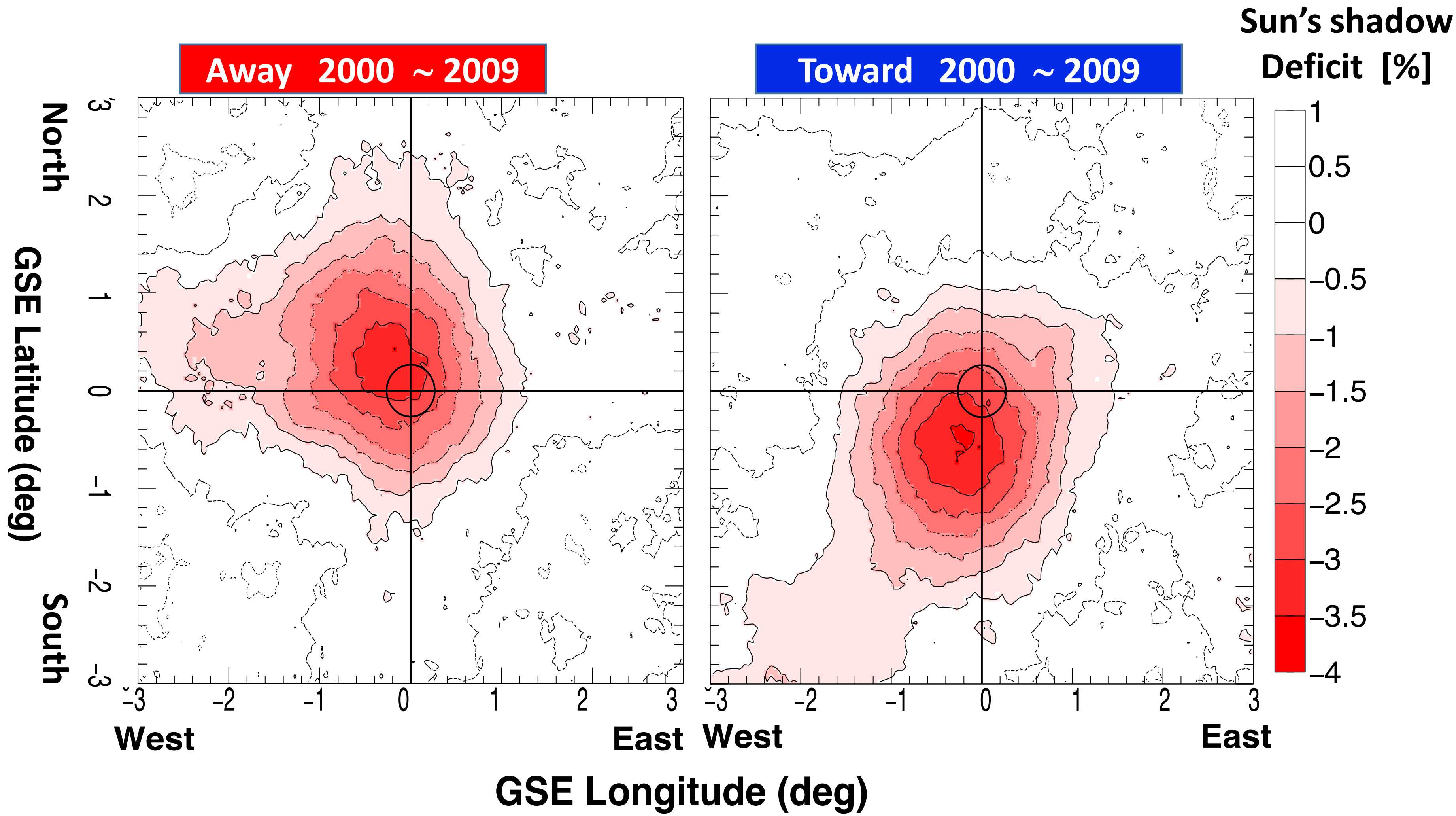
Data Selection (Tibet-III)

1. **Between 2000 and 2009 (only summer)**
2. **Zenith angle < 40°**
3. **Divide AS events into 7 energy bins according to the shower size : $\Sigma\rho_{FT}$**

7 energy bins		IMF sector polarity	
		Away	Toward
$\Sigma\rho_{FT}$	Rigidity[TV]	number of events	
17.8~31.6	4.4	2.7×10^6	3.2×10^6
31.6~56.2	5.9	8.8×10^5	1.0×10^6
56.2~100	8.2	2.1×10^5	2.4×10^5
100~215	13.1	4.2×10^4	5.0×10^4
215~464	24.0	6.1×10^3	7.2×10^3
464~1000	43.7	7.0×10^2	8.5×10^2
1000~	115	9.2×10^1	1.1×10^2

Observed Sun's shadow @13TV

- **The center of Sun's shadow clearly deviates from the center of the Sun.**
- **North-South(N-S) displacement in Away(Toward) sector is Northward (Southward).**

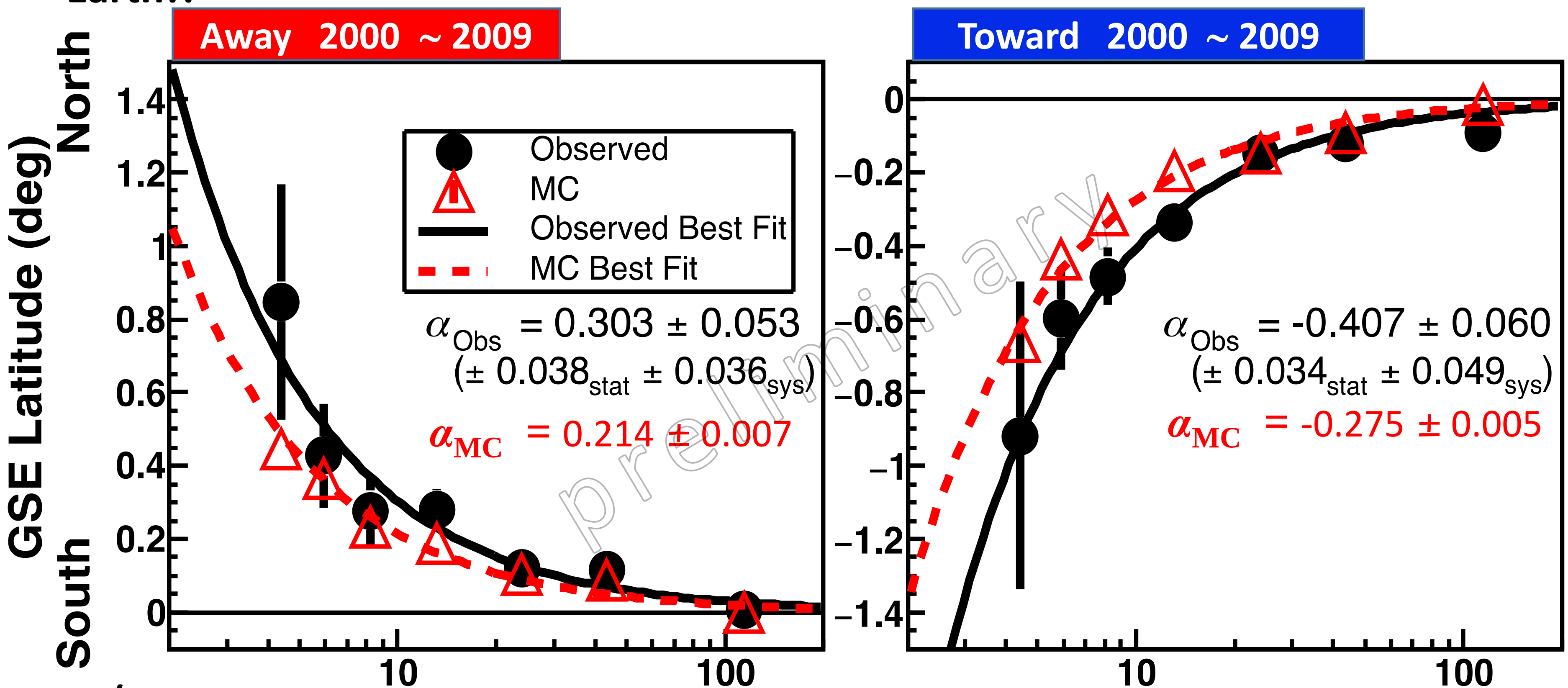


- **Westward displacement is mainly due to the deflection in the geomagnetic field, as observed in the Moon's shadow.**

Tibet-III : North – South Displacement of the Sun's Shadow

- **Rigidity (E/Ze) Dependence of N-S displacement, fitted by $f(R) = \alpha/(R/10[TV])$, fitting parameter: α denoting displacement angle at 10TV**
- **Our MC simulation underestimates α in both sectors!**

⇒the solar magnetic field model underestimates IMF strength between Sun and Earth!?



B_{obs}/B_{model}=

($1.54 \pm 0.21_{stat} \pm 0.20_{sys}$) (Away)

($1.62 \pm 0.15_{stat} \pm 0.22_{sys}$) (Toward)

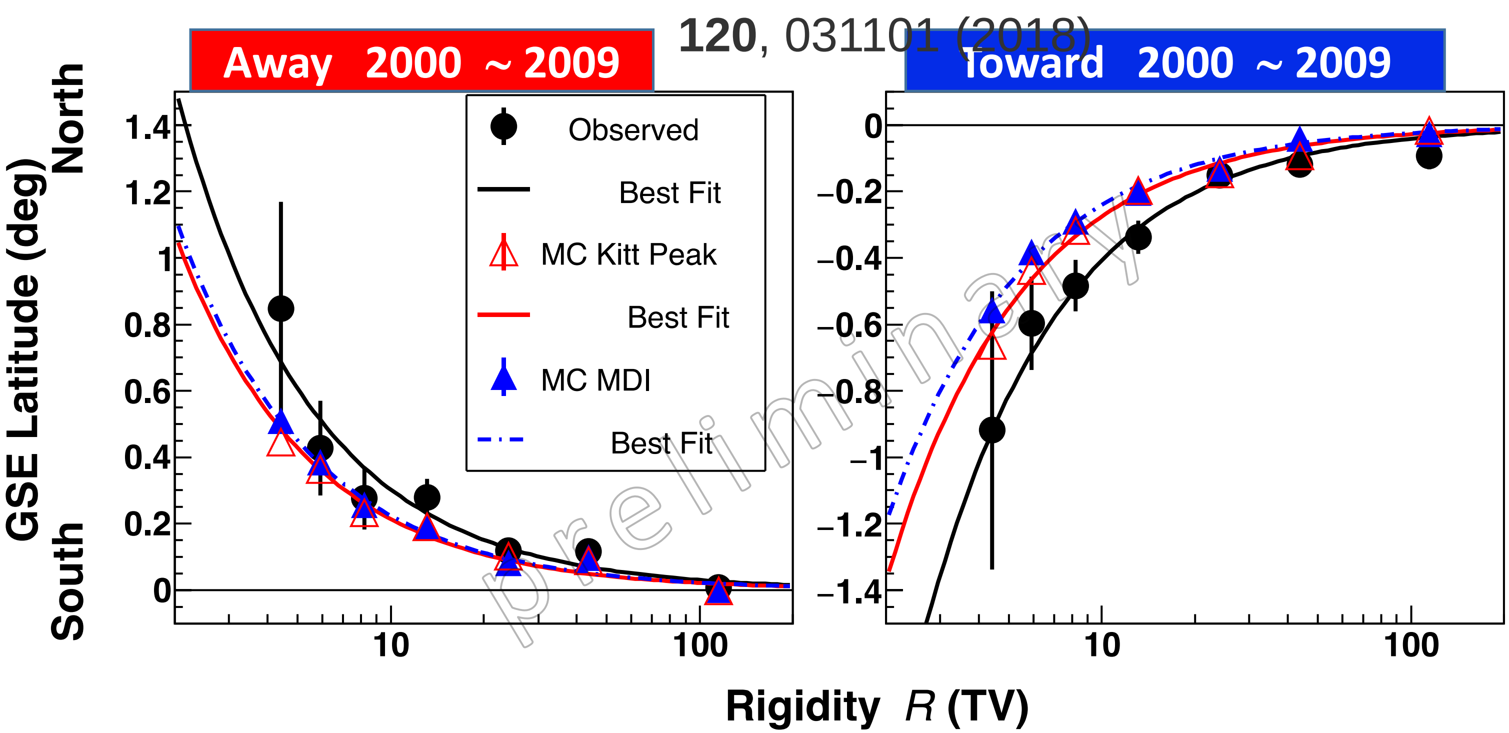
Discussions

M. Amenomori et al., PRL **120**, 031101 (2018)

- **The solar magnetic field model underestimates N-S displacement observed by Tibet-III, by underestimating the IMF strength**
- **Possible sources of this underestimation**
  - ◆ **underestimation of photospheric magnetic field ?**

    ; **photospheric field strength observed by MDI is 1.80 ± 0.20 times larger than Kitt peak used in our simulations (Riley *et. al.* 2014)**

    => But, the underestimation of α is not improved in simulations even with MDI
  - ◆ **refinement of the coronal magnetic field model needed? <= more likely**



これまでわかった事:

1. Several bright TeV γ point sources !

   Possible diffuse γ signal from Cygnus region?!

2. P, He, all-particle E-spectrum (Galactic cosmic rays accelerated to the knee region)

   エネルギーと共に重粒子の割合が増加

これからするべき事:観測装置の感度向上

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

   Where do galactic cosmic rays under knee come from? (Tibet-III + MD) -> PeVatron(宇宙線の起源)

2. Chemical composition (p ?, Fe?) (Tibet-III + YAC)

   p & Fe knee－＞if Z(原子番号)倍－＞SNR加速

□ Next Plans（南北両天での広視野連続観測）

1. 北半球 （チベットでon-going）

Tibet AS + MD + YAC EXPERIMENT

Gamma ray: Tibet Muon Detector (MD)

Cosmic Rays: Tibet Yangbajing Air shower Core detector (YAC-II)

2. 南半球（ボリビアで計画中）

ALPACA PROJECT

Tibet AS + MD: 100 TeV γ-ray astronomy

Let's see 100 TeV-region (10-1000TeV) gamma rays by

Tibet-III (AS) + a large underground

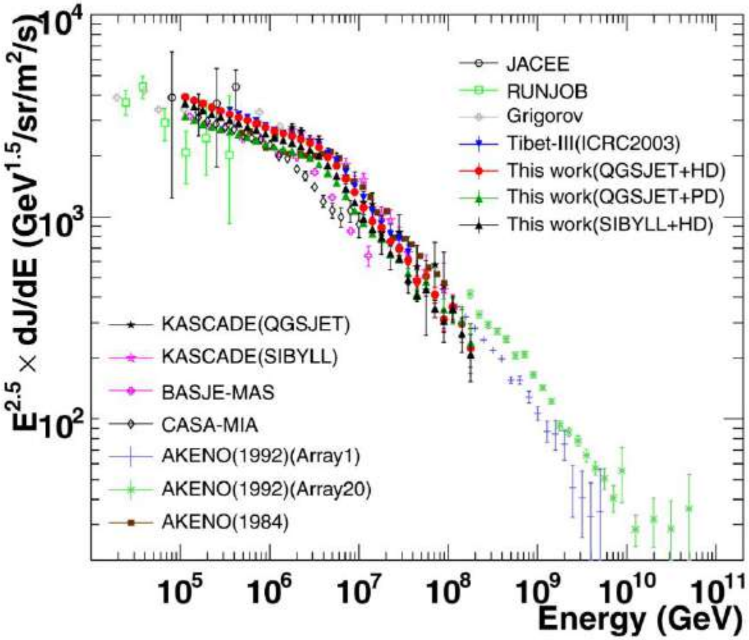
muon detector array (MD)

100 TeV以上の ガンマ線を観測できれば世界初

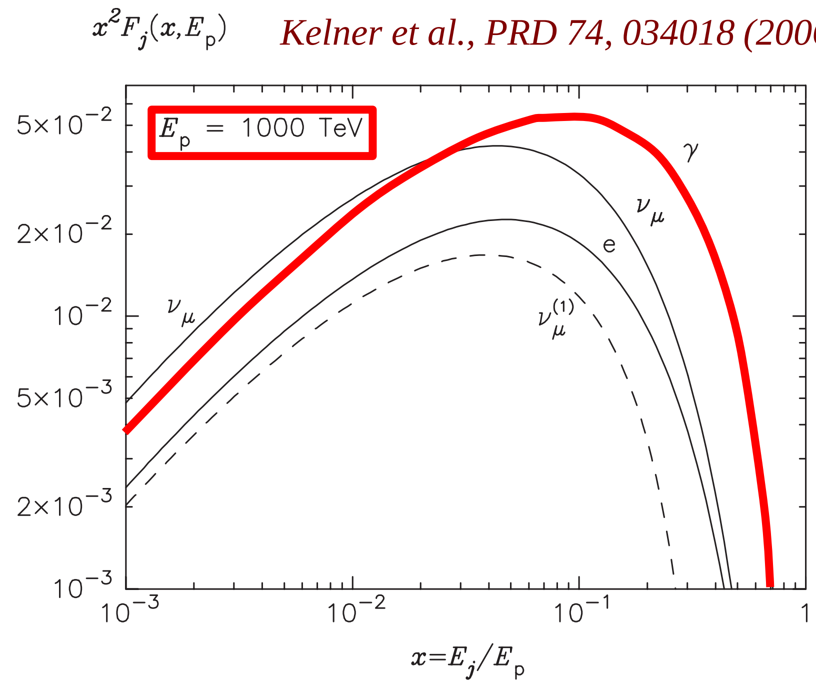
>Origin of cosmic rays and acceleration mechanism and limit at SNRs.

>Diffuse gamma rays

Origin of Cosmic Rays at the Knee



Kelner et al., PRD 74, 034018 (2006)



宇宙線スペクトル

✓ＳＮＲなどでの(斜め)衝撃波加速により宇宙線を100~数1000TeV程度まで加速可能

✓Knee~４PeVまでは銀河系内起源？

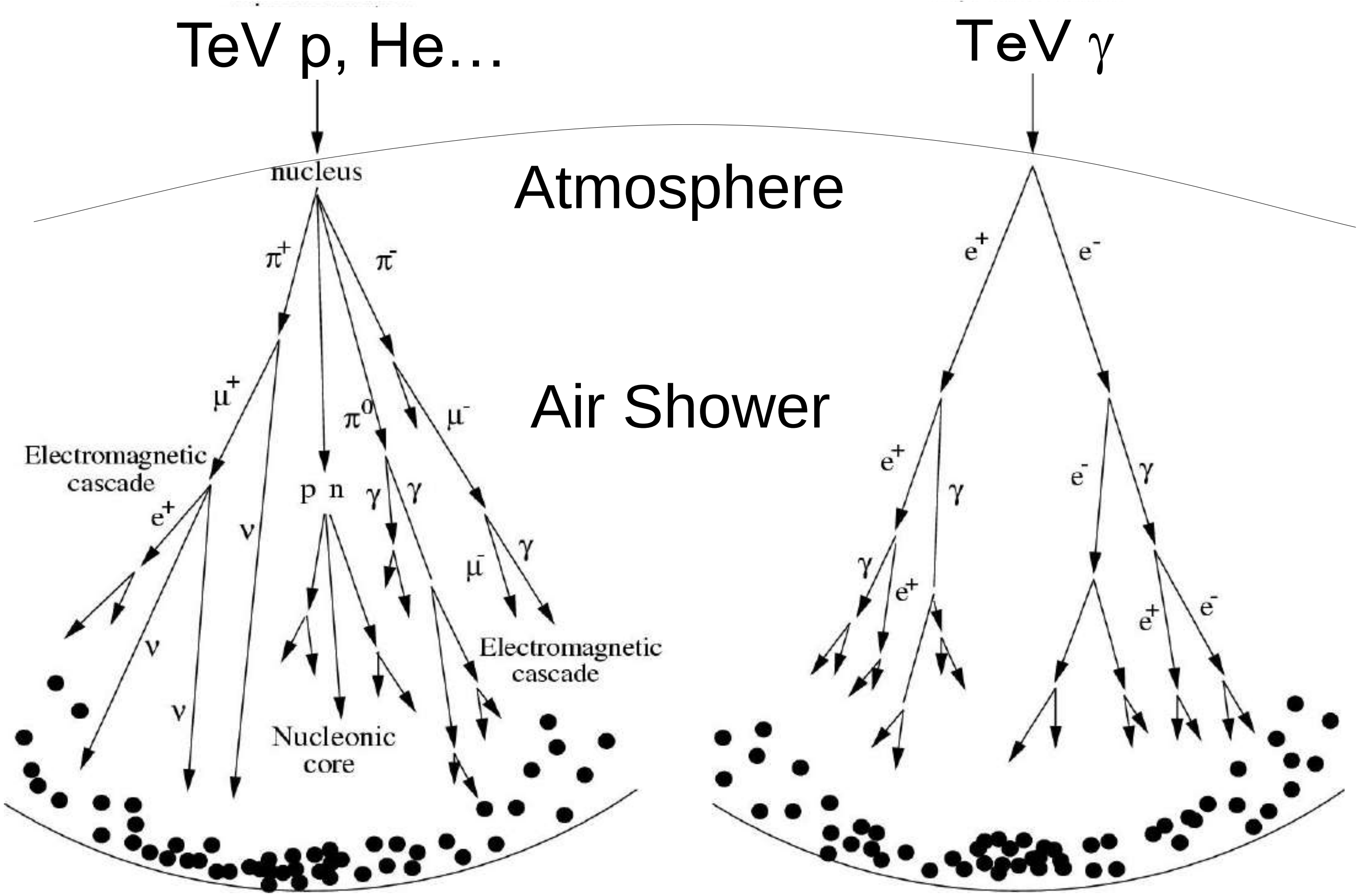
ガンマ線スペクトル

✓ 宇宙線＋星間物質→π^0＋…→2γ

✓ 陽子の最大エネルギーの一桁下のガンマ線・ニュートリノが生成

PeV宇宙線を加速している天体 = PeVatron
CMBによる吸収で銀河系内または超近傍天体

p/γ discrimination by muons

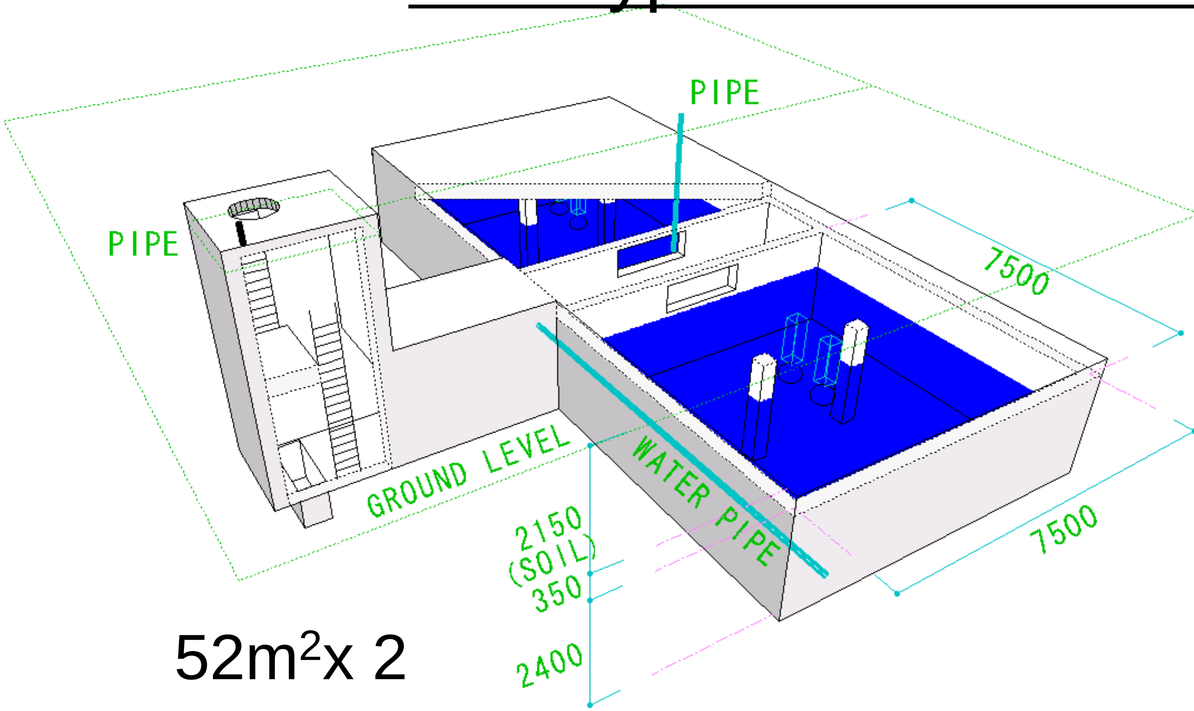


Number of muons（<100 m from core, 4300m a.s.l.）

100TeV Proton
~50

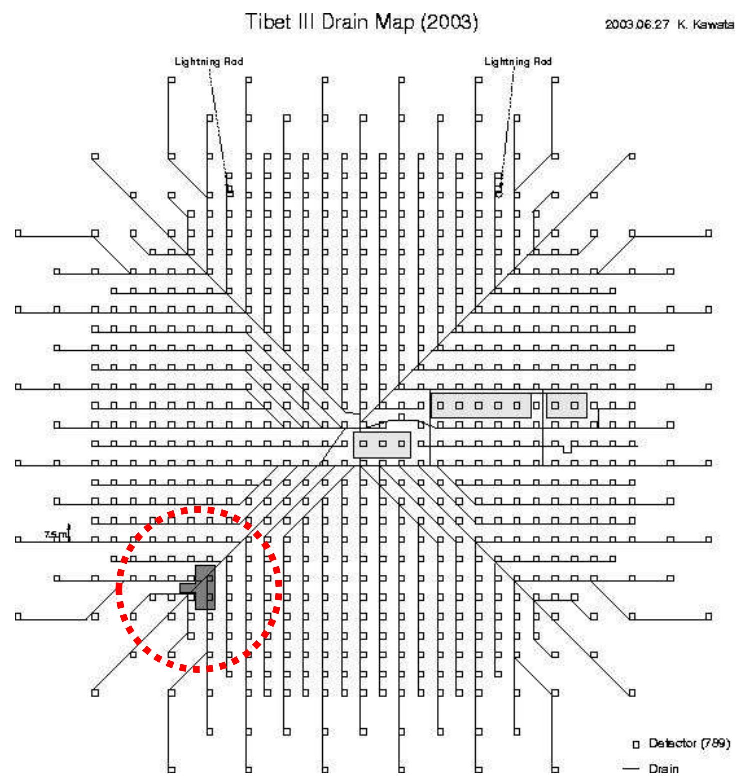
100TeV Gamma
~1

Prototype Muon Detector in Tibet

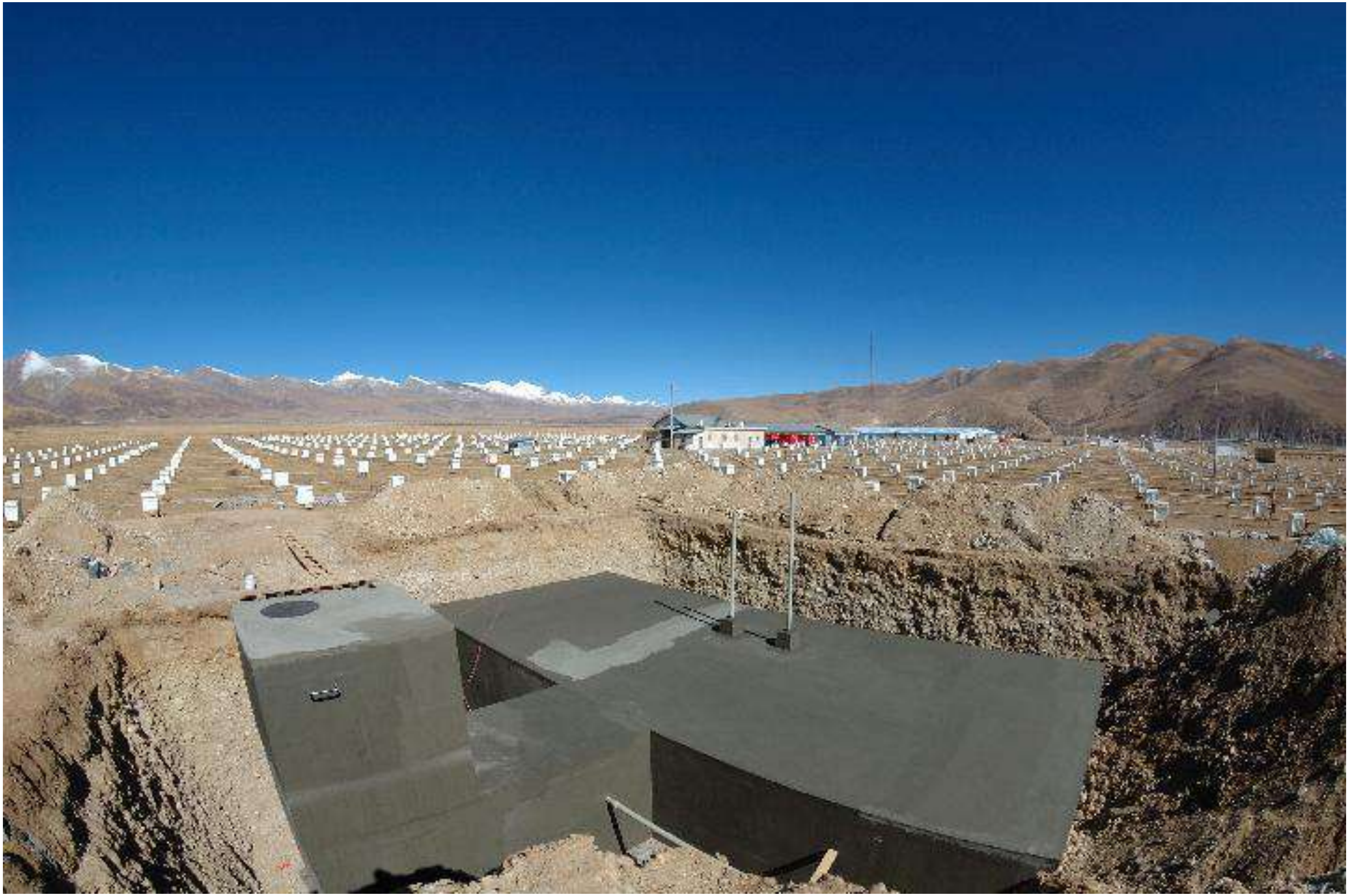


Construction from
Sep. 2007
Data taking from
Dec. 2007

$52m^2$x 2



- Construction feasibility in Tibet ?
- MC simulation OK?
- γ observation above multi 100 TeV



16 November, 2007 Prototype Muon Detector

Prototype Muon Detector after backfilling

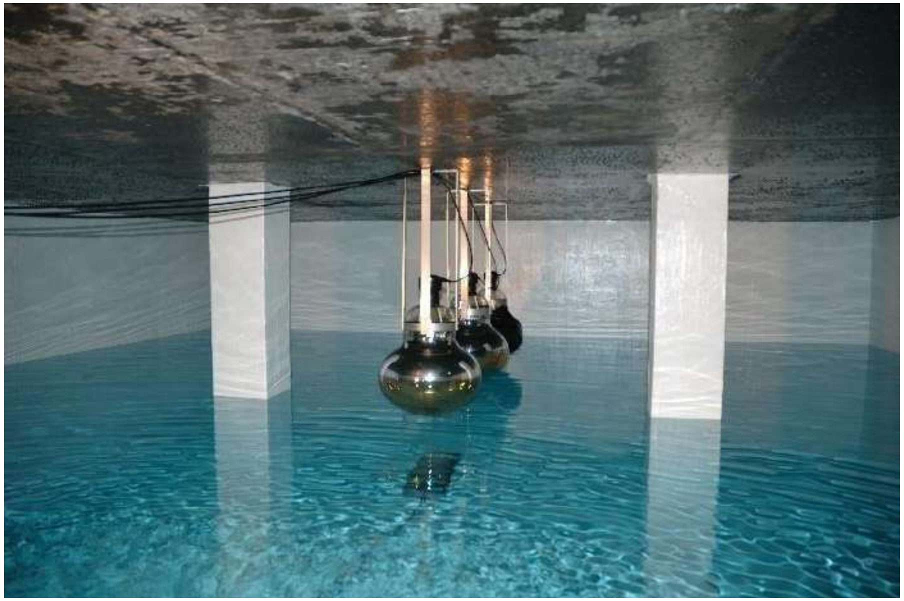
Inside of the Prototype MD

Clear underground water
from a nearby well

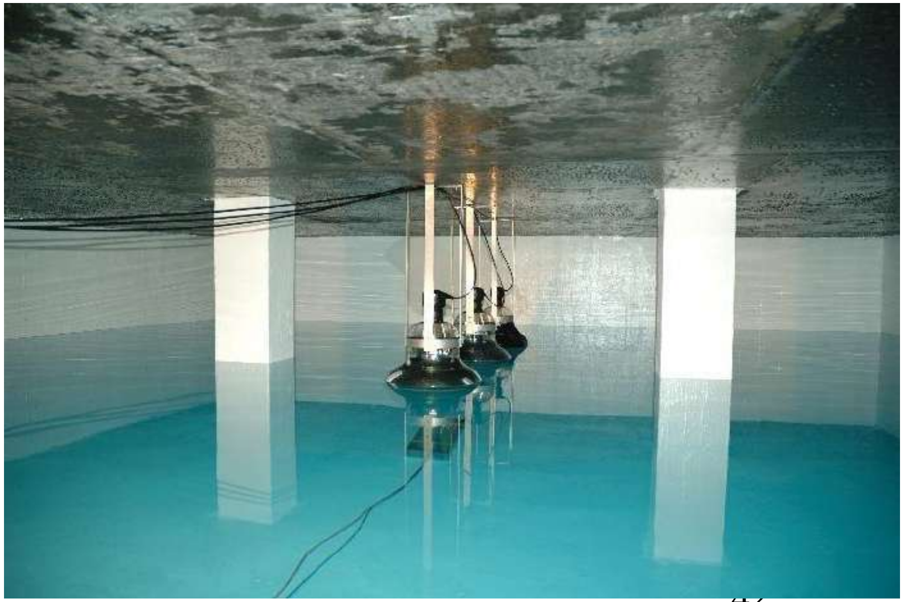
20”ϕ PMT x 3:
(Normal gain x 2, 1/100 gain x 1 for test)

Water depth : 1.5 m

White paint



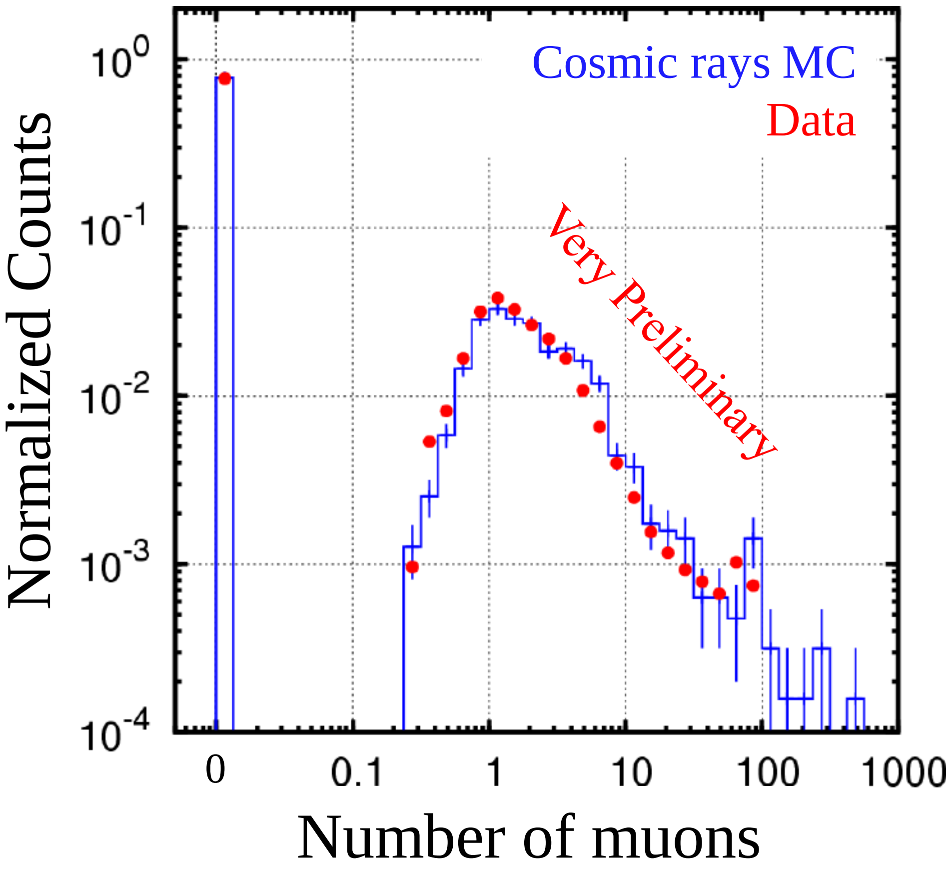
Pouring very clear well-water



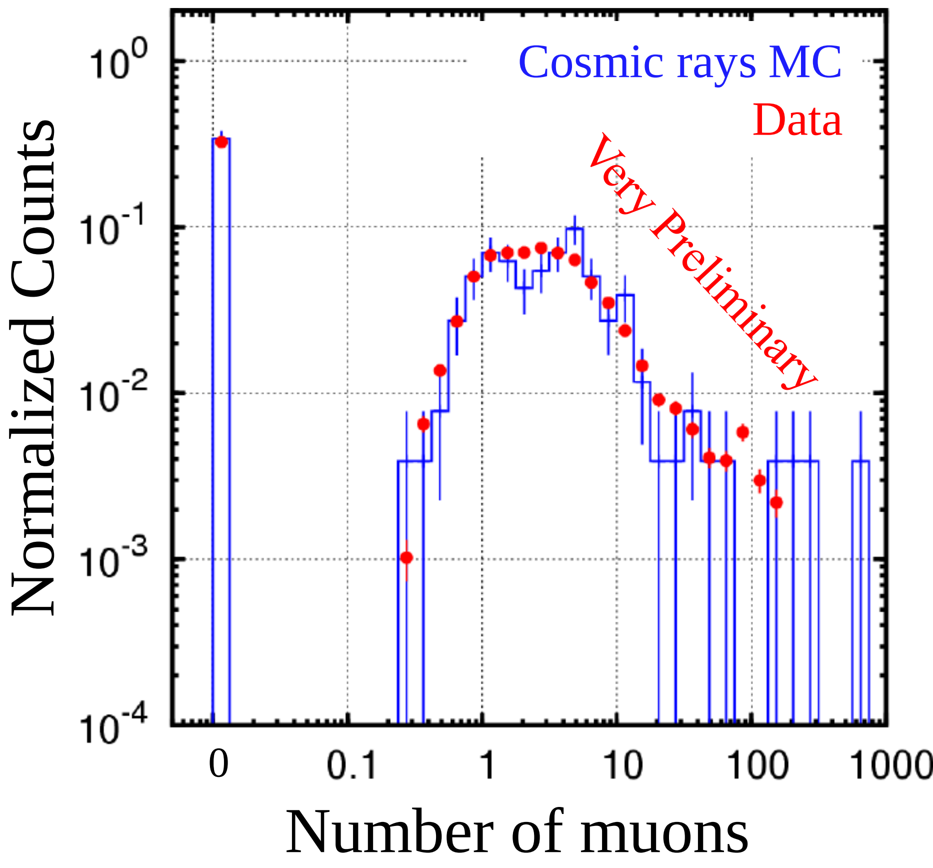
Filled up water 1.5 m in depth

Number of muons

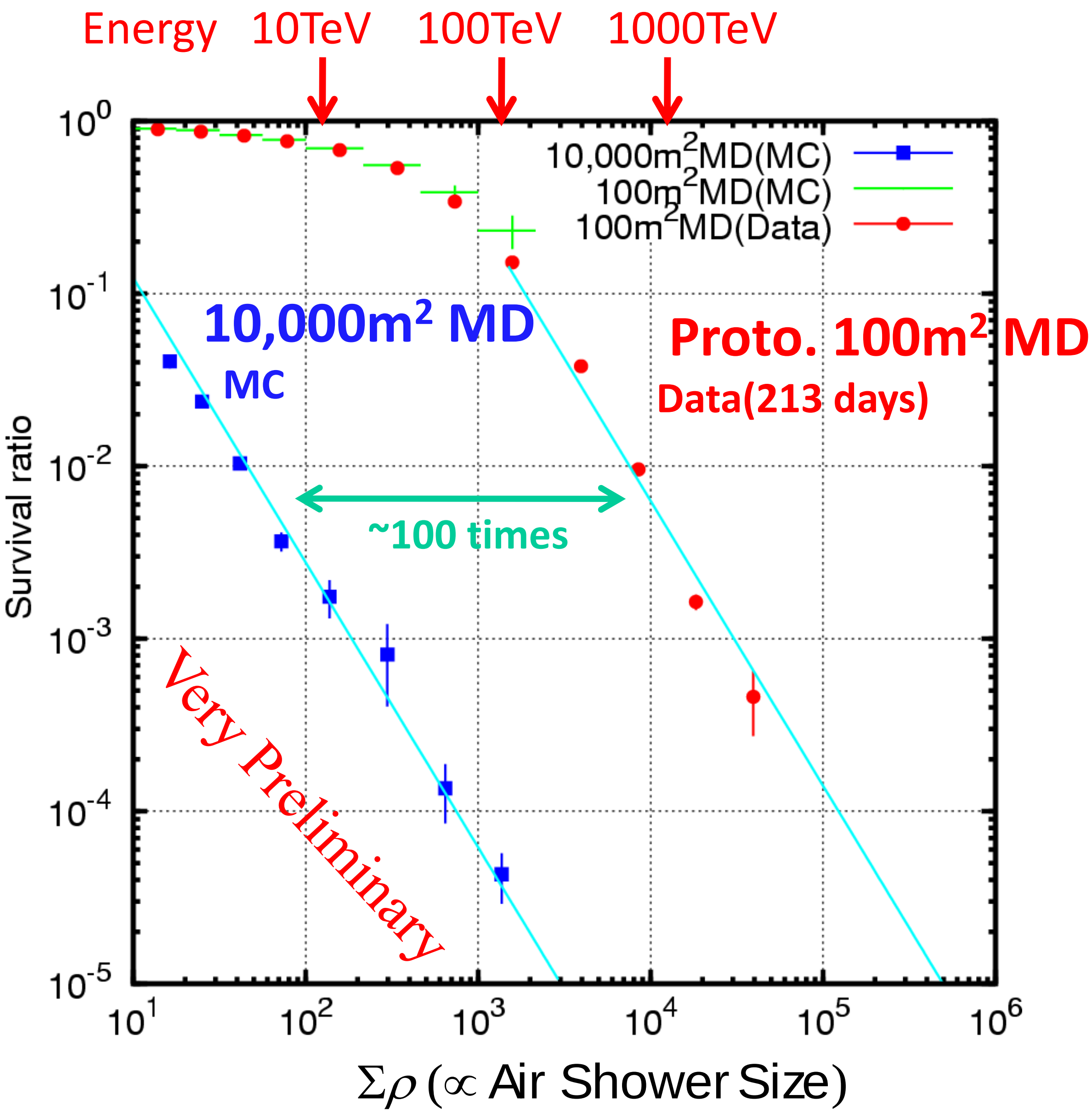
~10 TeV Air Showers



~100 TeV Air Showes



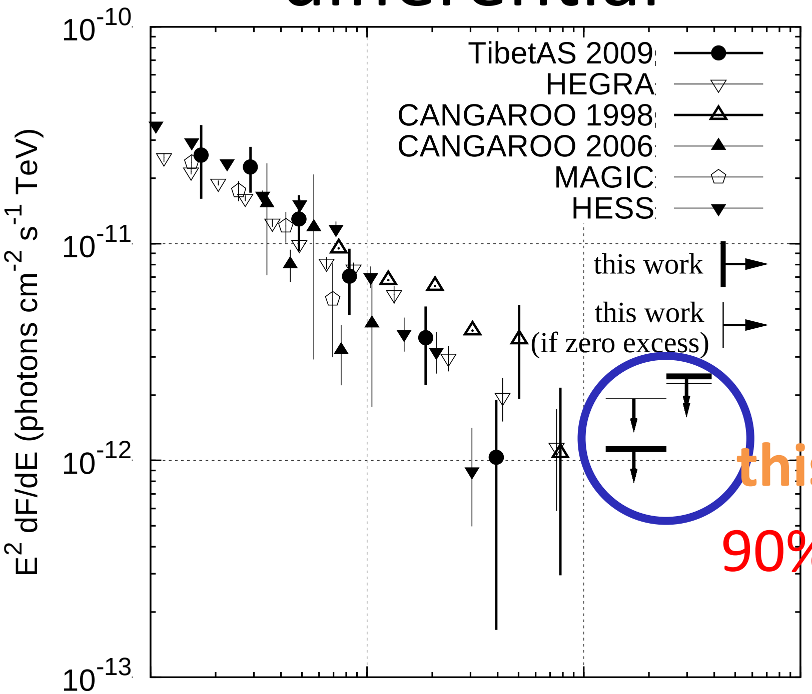
Cosmic Ray (Nucleus) Survival Ratio



Upper limits on the Crab Nebula flux > 100 TeV
(100m^2 Proto-type MD)

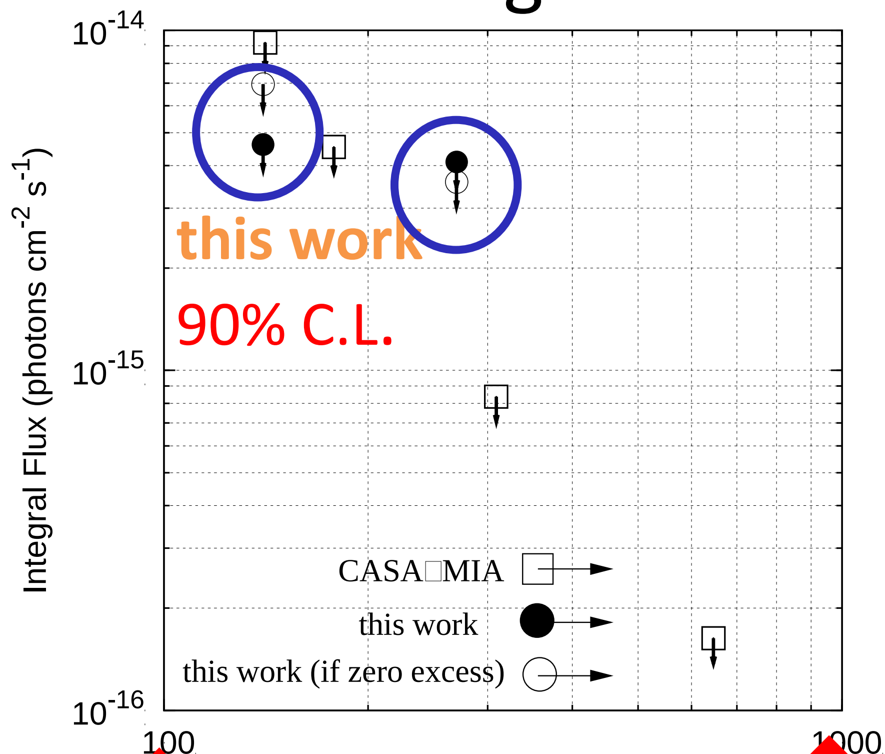
Amenomori M. et al., 2015, ApJ, 813, 98

differential



100 TeV **1000 TeV**

integral



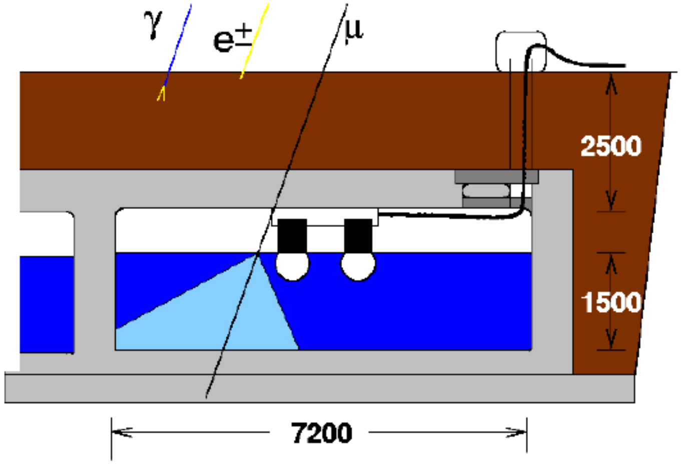
100TeV **1000 TeV**

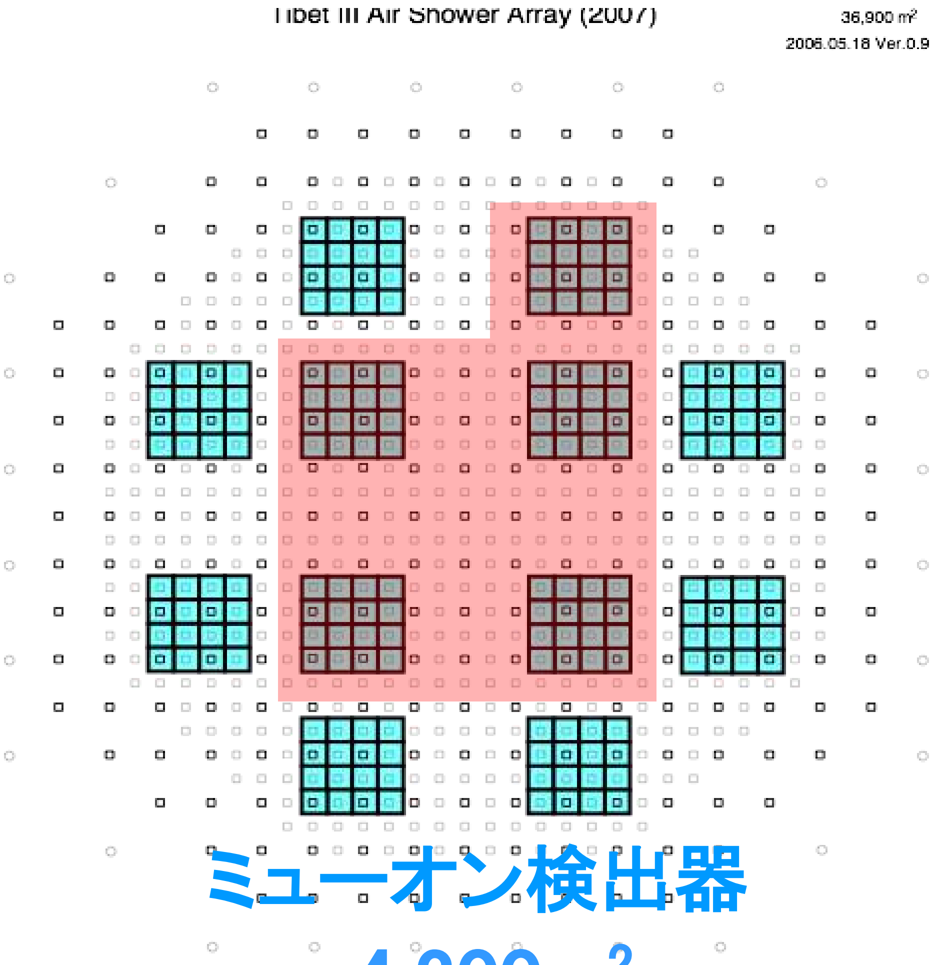
Amenomori et al. 2009, ApJ, 692, 61
Aharonian et al. 2004, ApJ, 614, 897
Tanimori et al. 1998, ApJ, 492, L33
Enomoto et al. 2006, ApJ, 638, 397
Albert et al. 2008, ApJ, 674, 1037
Aharonian et al. 2006, A&A, 457, 899

Borione et al. 1997, ApJ, 481, 313

チベット水チェレンコフミューオン観測装置 (Tibet MD)

地下 2.5m (物質厚 ~ 515g/cm^2 ~19X_0)
7.2m×7.2m×水深1.5m　水槽　192台
20”ΦPMT　2本 (HAMAMATSU R3600)
水槽材質:コンクリート
　　　　　白色反射材





→空気シャワー中のミューオン数を測定し、ガンマ線／核子選別

原子核起源空気シャワーを99.9%以上除去 (>~100TeV)

MD construction scene

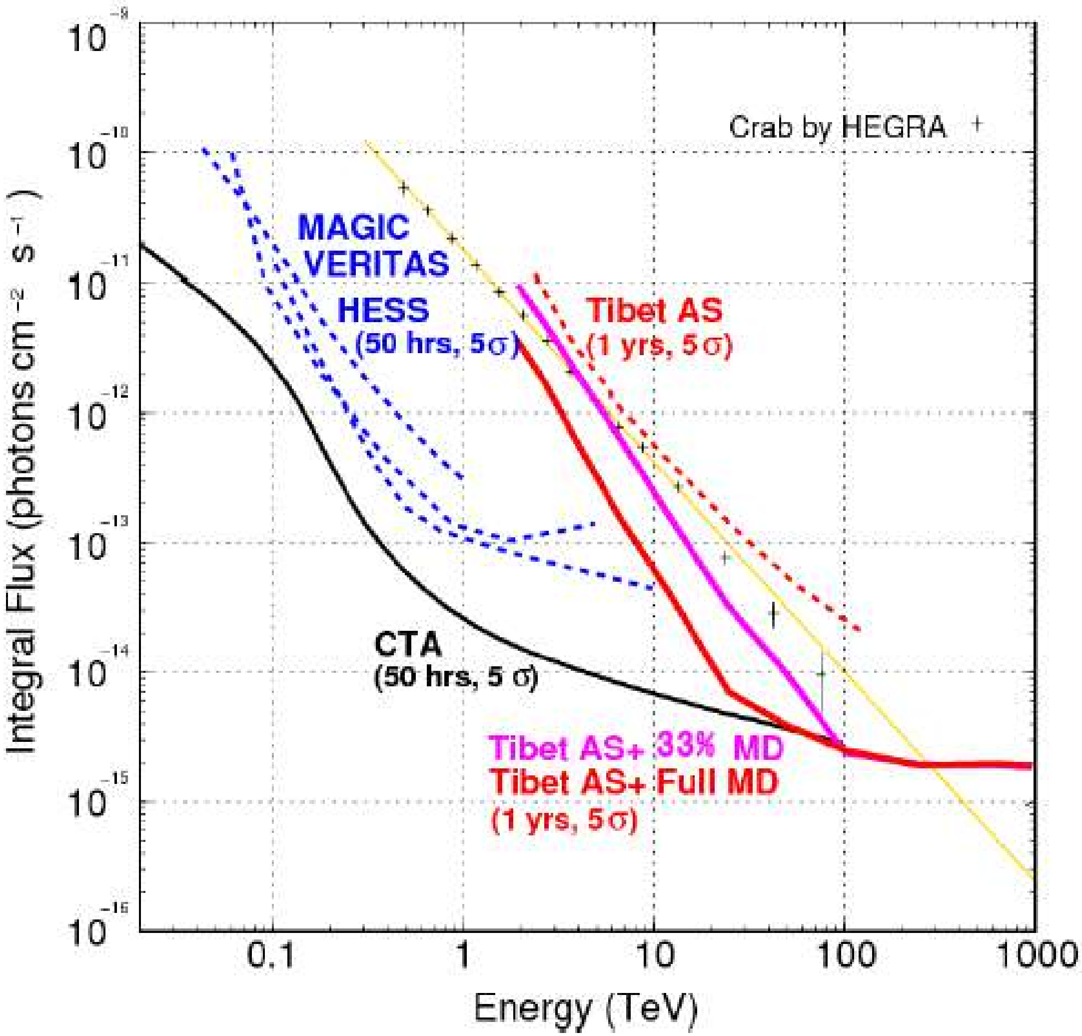
Installing a 20 inch PMT in a MD cell.

Tyvek sheet walls and two 20 inch PMTs


2013/10/10
Image © 2014 CNES / Astrium

2013/10/10
4,200m2
地下施設
Image © 2014 CNES / Astrium

Sensitivity to γ-ray point sources (AS 1yr/ IACT 50hrs, 5σ or 10 ev)



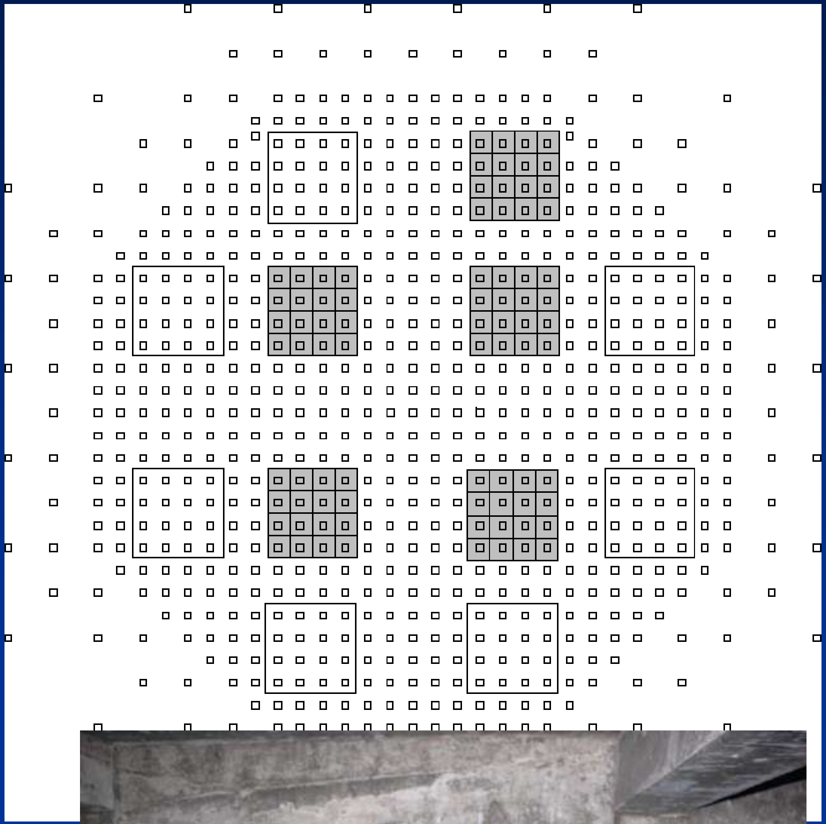
+Full MD

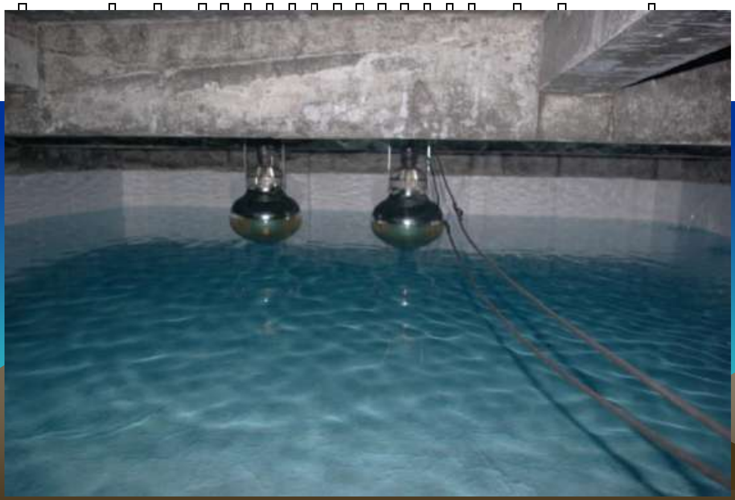
X ~10 @10TeV
X ~10 @100TeV

+1/3 MD

X 3~4 @10TeV
X ~10 @100TeV

MDの建設風景





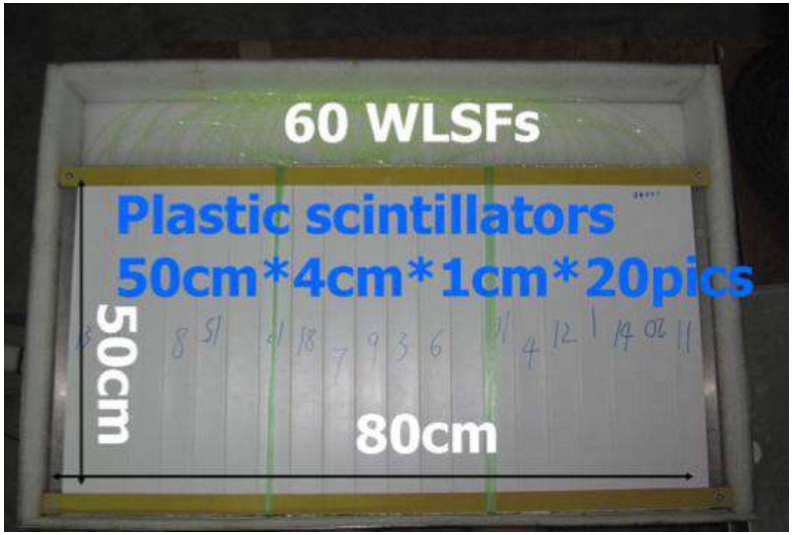
MD ～4000 m^2

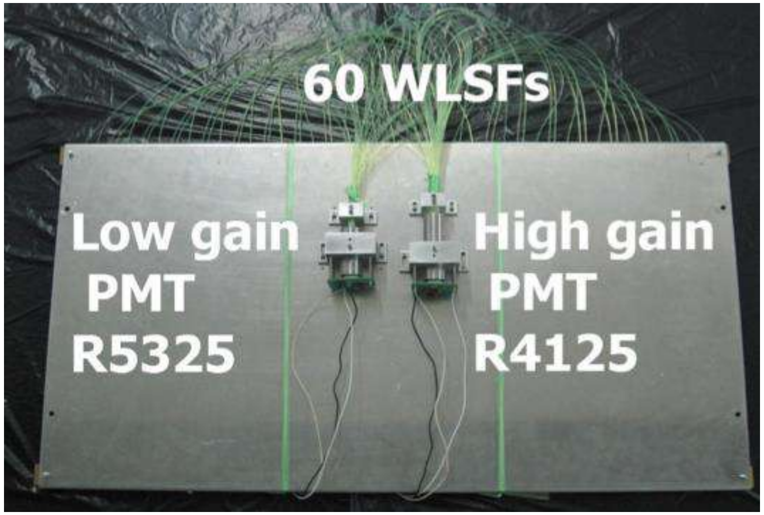
2014年度稼働開始

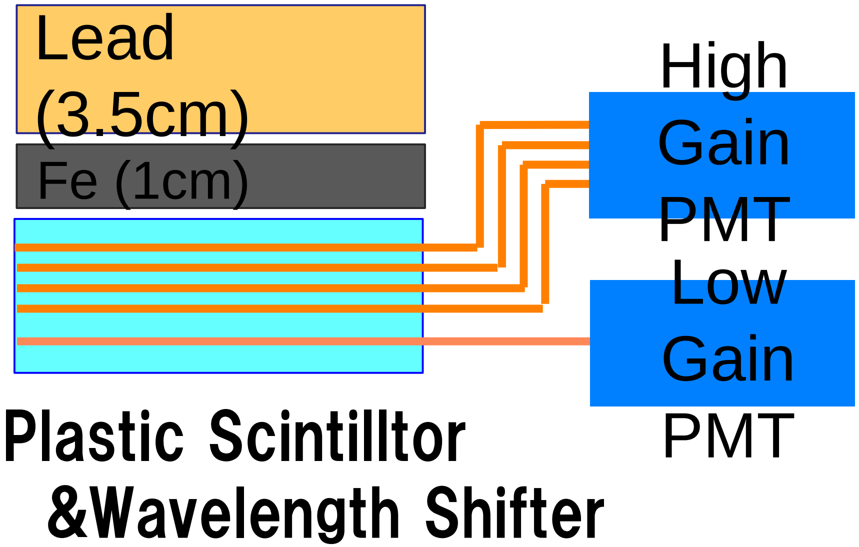
PeVatronを探せ！

YAC計画（Yangbajing Airshower Core detectors）Towards Chemical compositin and energy spectrum measurement in the Knee Energy Region

YAC-II (Yangbajing Air-shower Core) detectors for chemical composition study in Knee region

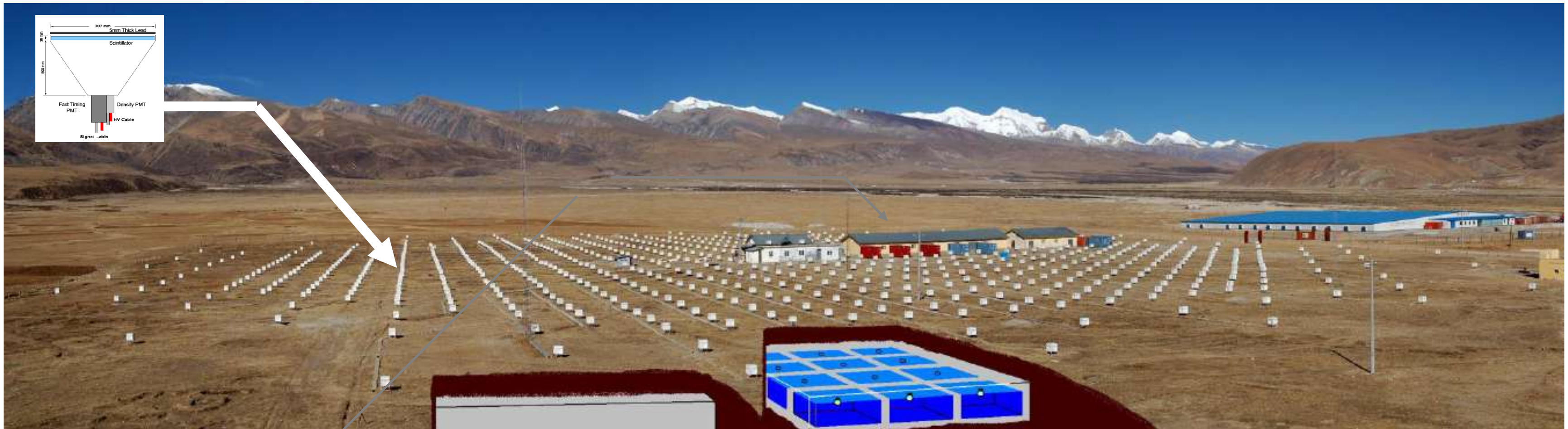


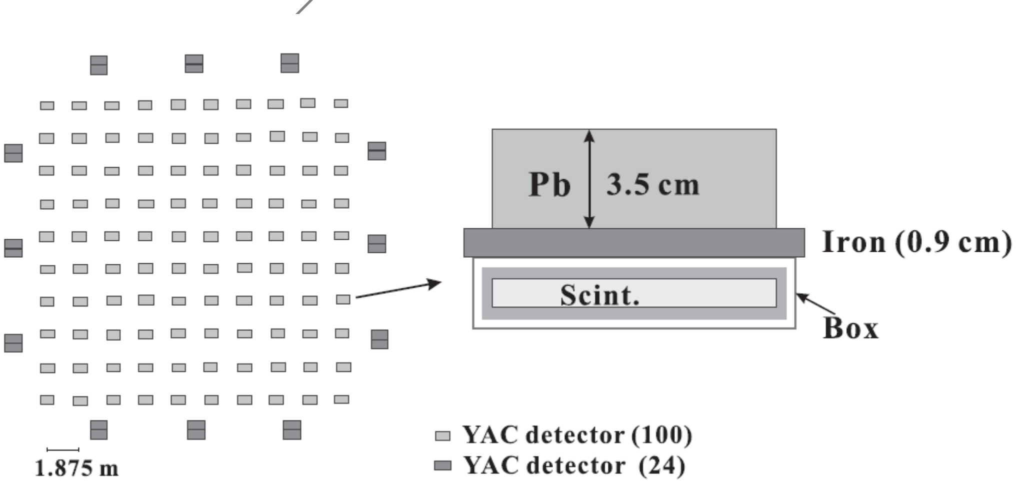


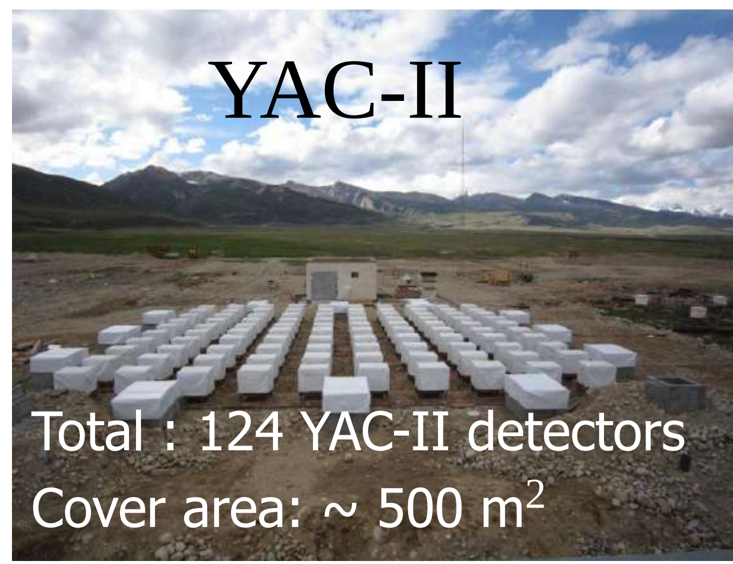


2PMTs cover 1~10^6 particles

YAC-II started in 2014, accumulating data

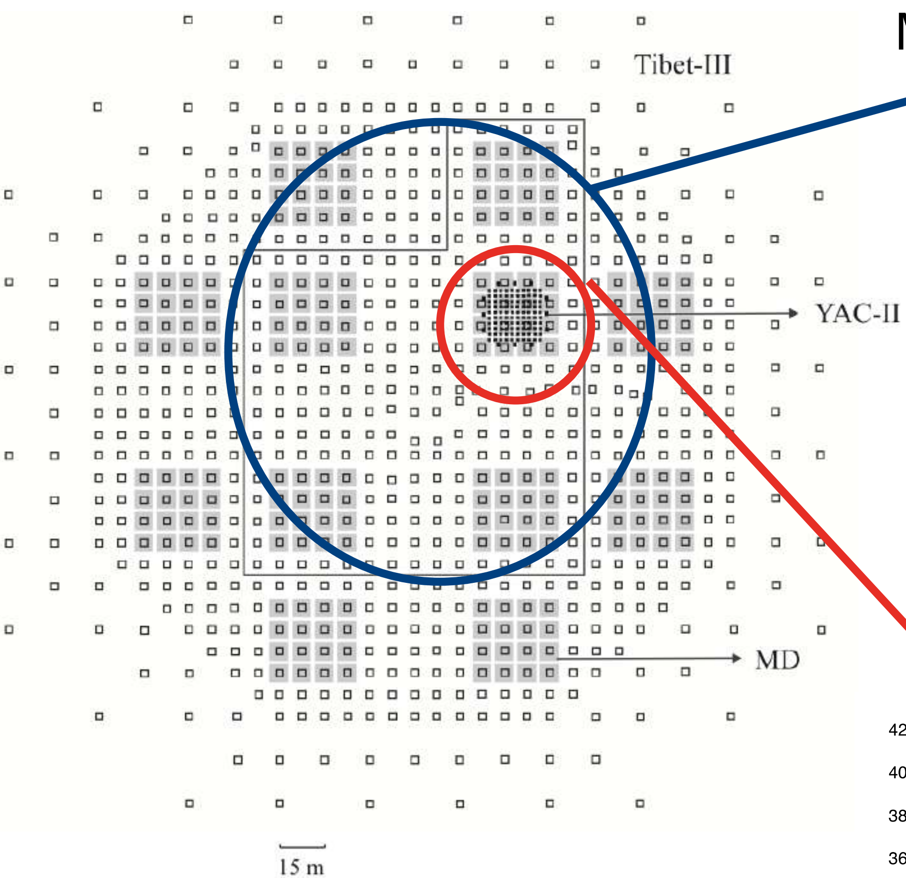




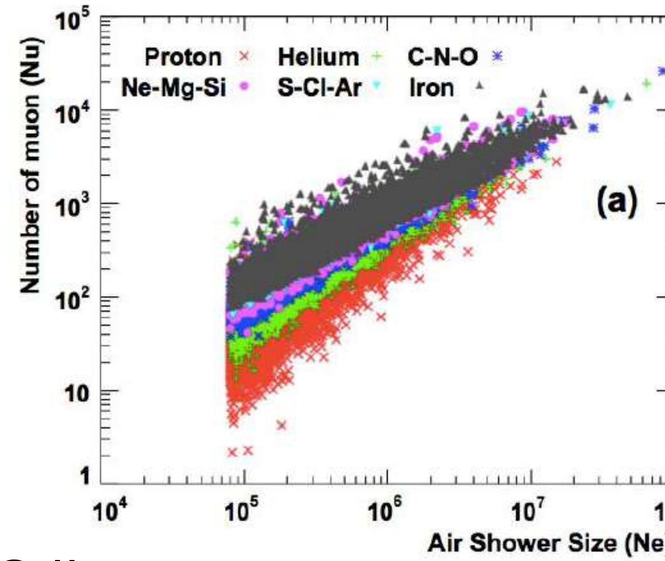


Tibet-III + YAC-II + MD (MC) for Knee Study

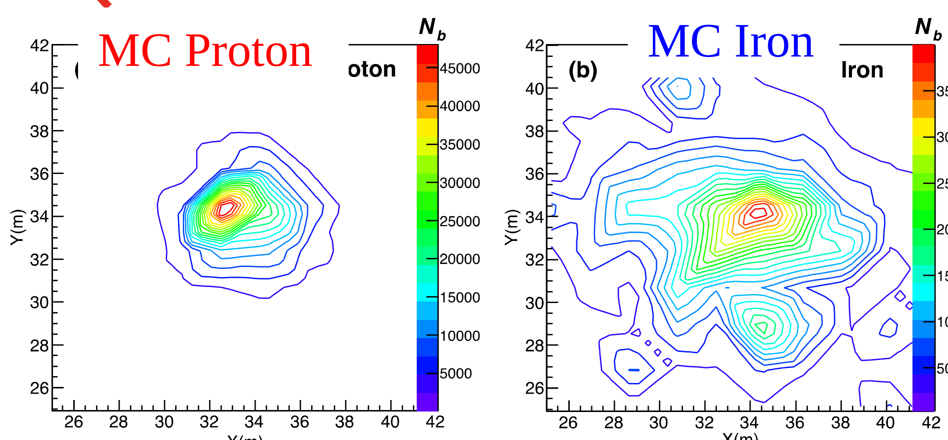
Muon Detector



MC Ne-Nμ Plot

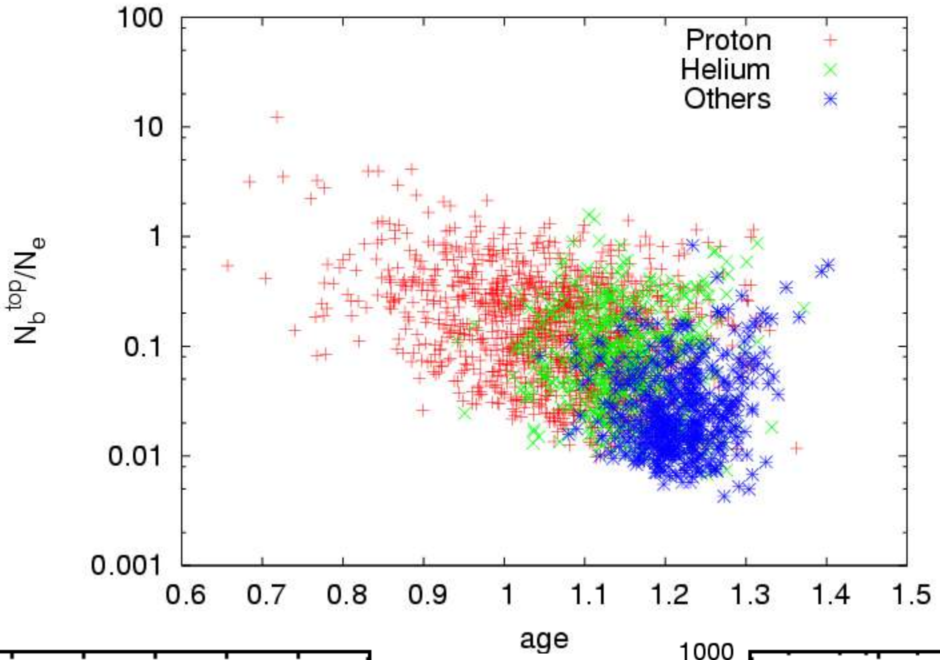


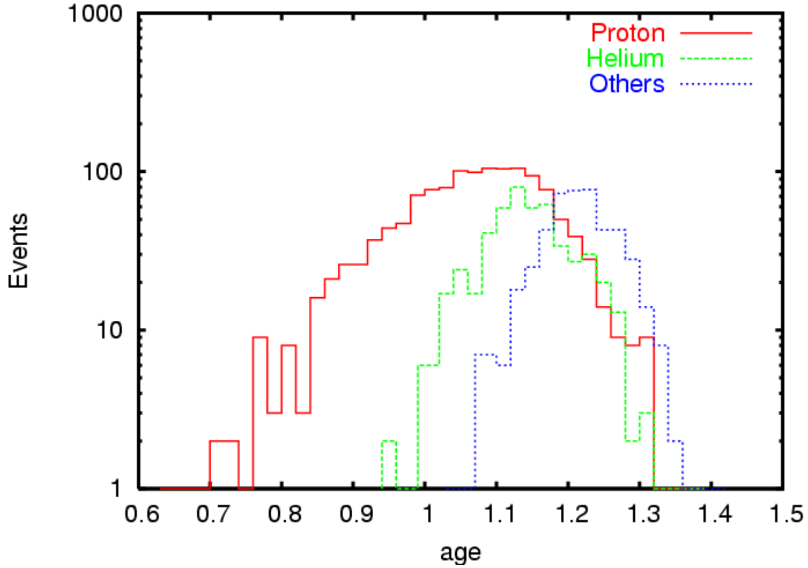
YAC-II

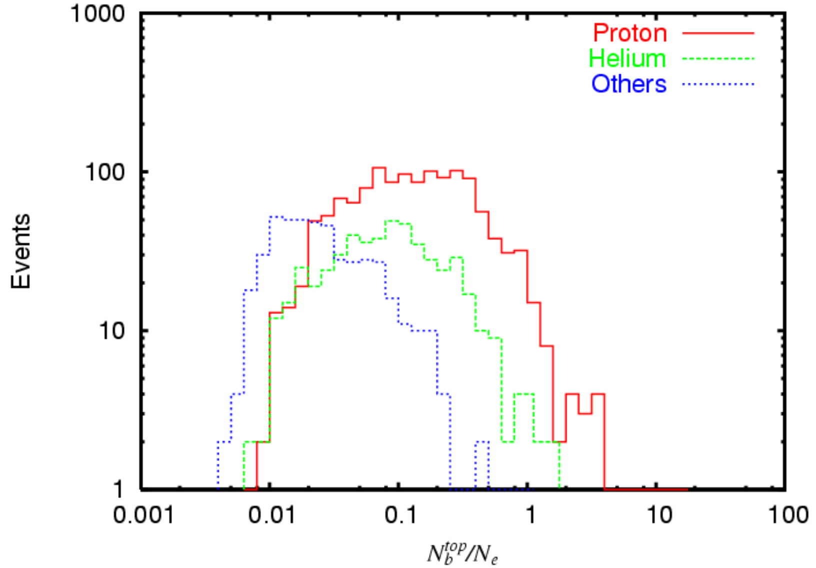


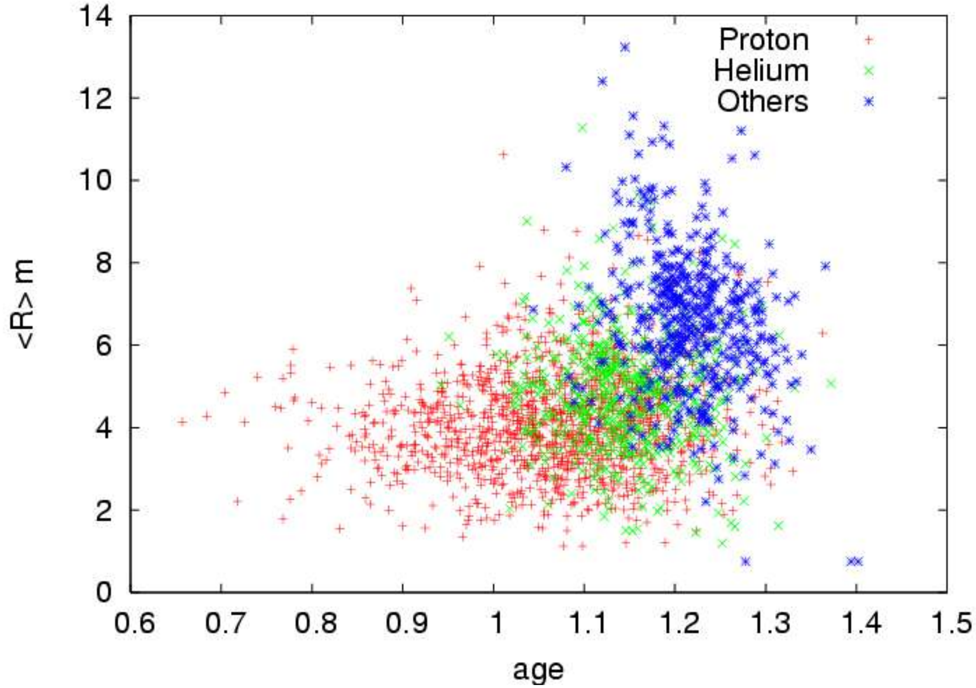
J.Huang et al,Astropart.Phys. 66 (2015) 18-30

Features of YAC-II observables

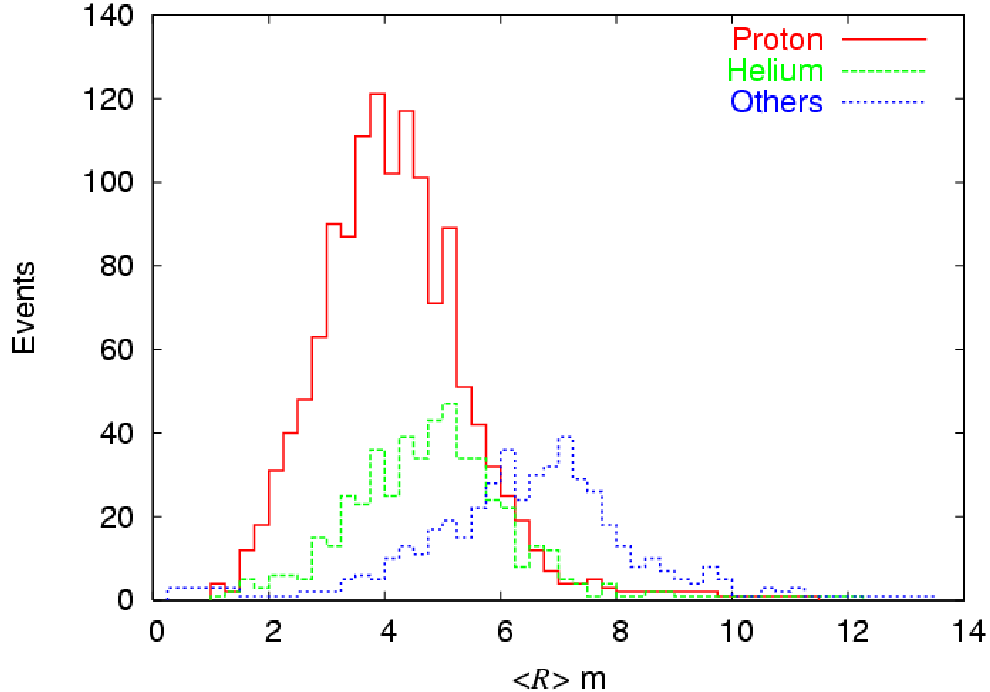








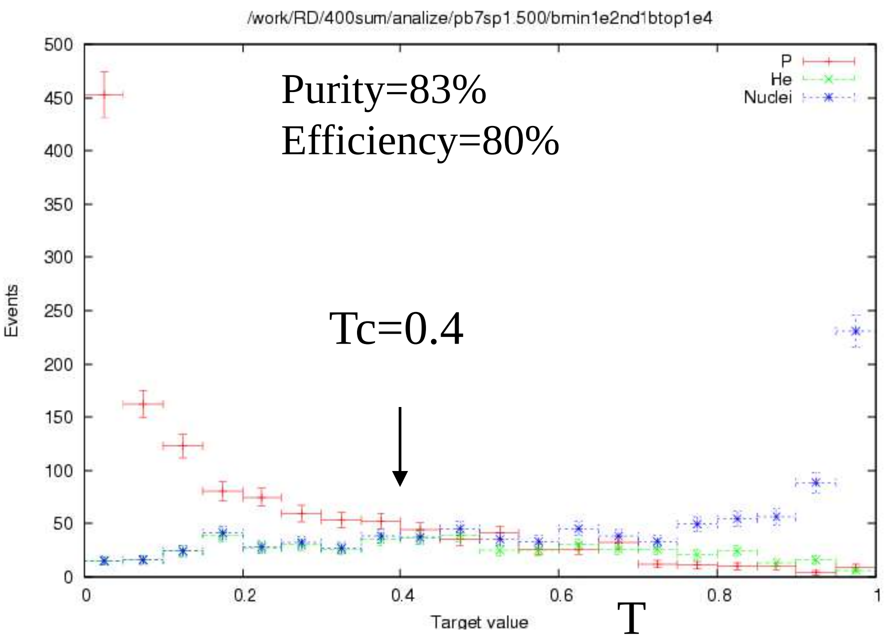
Proton
Helium
Others
<R> m
age



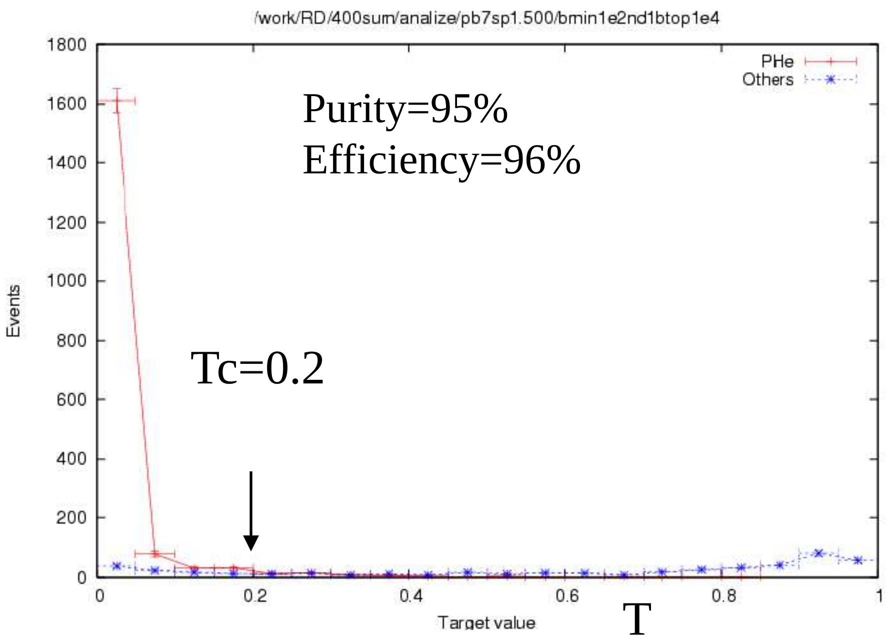
Proton
Helium
Others
Events
<R> m

ANN output

Proton separation



P+He separation

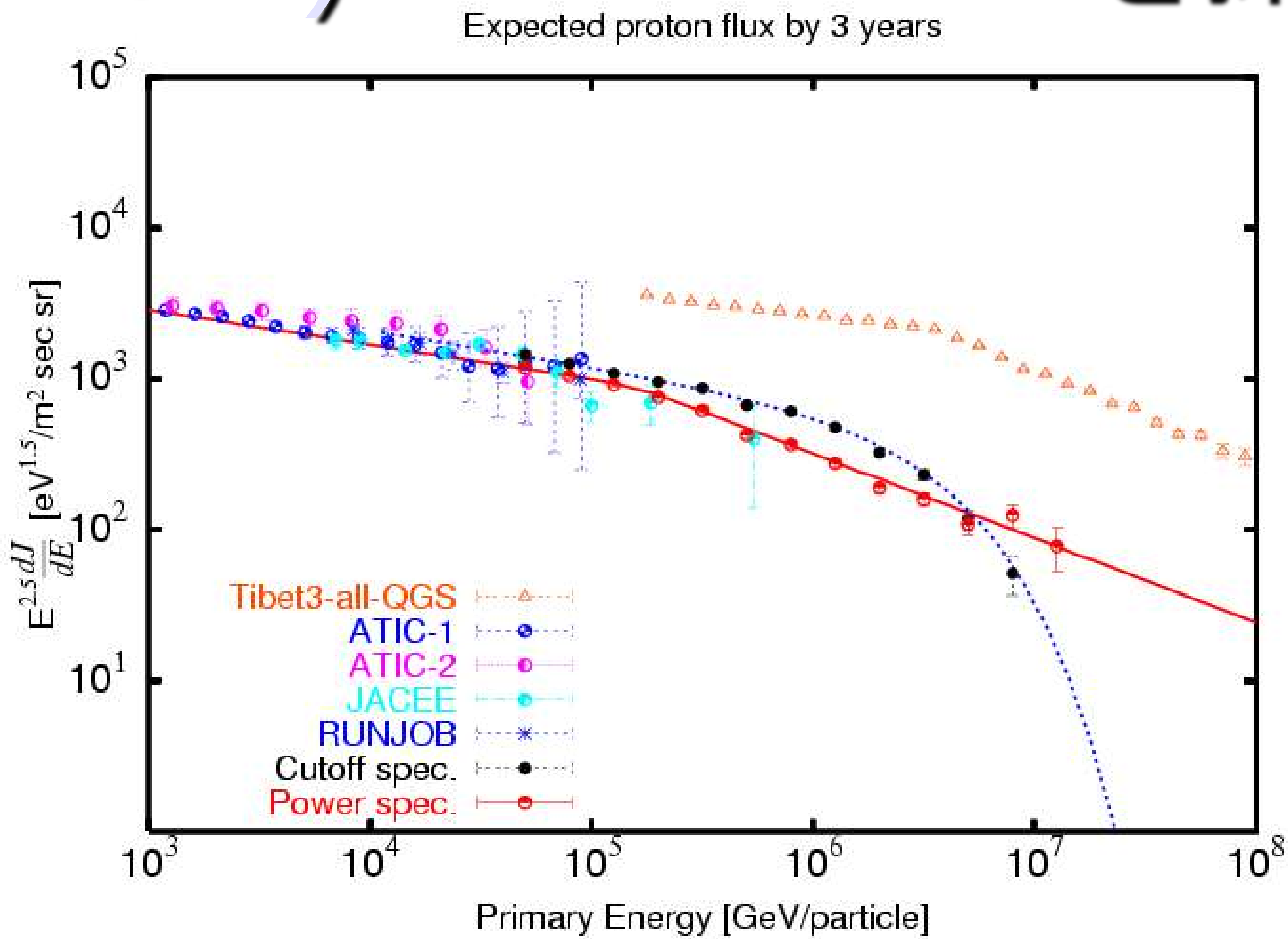


Contamination is exclusively by helium nuclei.
The fraction of helium events missidentified as protons is about 40% of helium events by Tc=0.4.

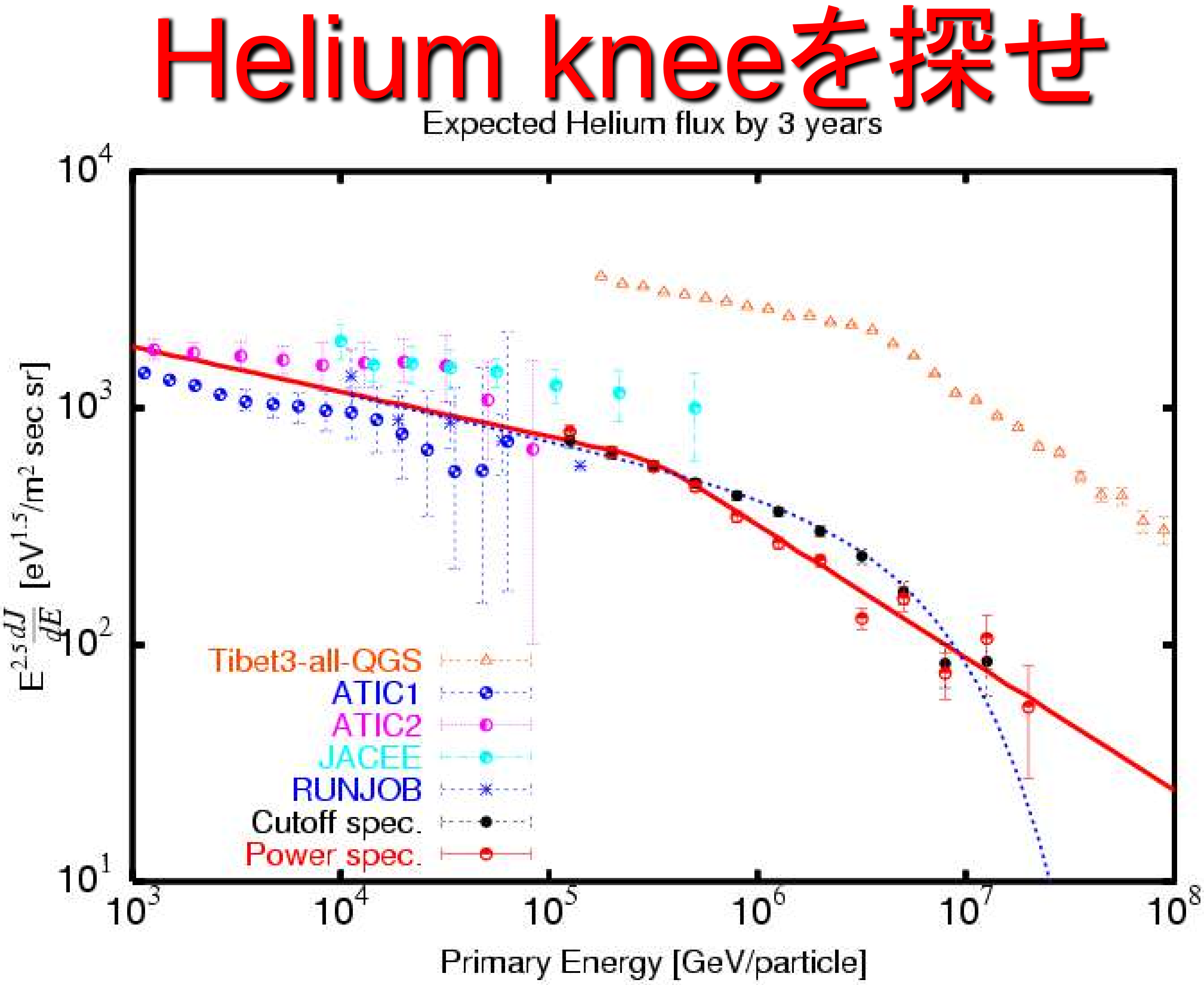
20% of heavier nuclei than helium contaminates to P+He region.

Expected proton spectrum (YAC-II)

Proton kneeを探せ



Expected He Spectrum (YAC-II)



The ALPACA Experiment　計画

Andes

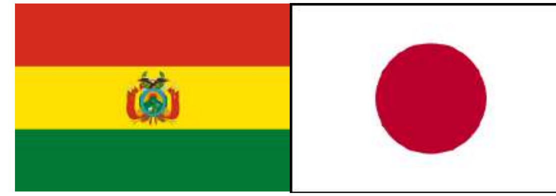
Large area

PArticle detector for

Cosmic ray physics and

Astronomy

The ALPACA Collaboration



IIF, UMSA, Bolivia

Martin SUBIETA, Rolando TICONA, Hugo RIVERA,
Mirko RALJEVICH, Javier QUISPE, Pedro MIRANDA

Faculty of Education, Utsunomiya Univ., Japan

Naoki HOTTA

Japan Atomic Energy Agency, Japan

Harufumi TSUCHIYA

Dept. of Physics, Shinshu Univ., Japan

Kazuoki MUNAKATA, Chihiro KATO

ICRR, Univ. of Tokyo, Japan

Masato TAKITA, Munehiro OHNISHI,
Kazumasa KAWATA, Takashi K. SAKO

College of Industrial Technology, Nihon Univ., Japan

Atsushi SHIOMI

Tokyo Metropolitan College of Industrial Tech., Japan

Toshiharu SAITO

National Inst. of Informatics, Japan

Masaki NISHIZAWA

RIKEN, Japan

Norio TAJIMA

Faculty of Engineering, Kanagawa Univ., Japan

Kinya HIBINO, Shigeharu UDO

Faculty of Engineering, Yokohama National Univ., Japan

Yusaku KATAYOSE

College of Engineering, Chubu Univ., Japan

Akitoshi OSHIMA, Shoichi SHIBATA

Faculty of Engineering, Aichi Inst. of Tech., Japan

Hiroshi KOJIMA

Graduate School of Science, Osaka City Univ., Japan

Shoichi OGIO, Yoshiki TSUNESADA

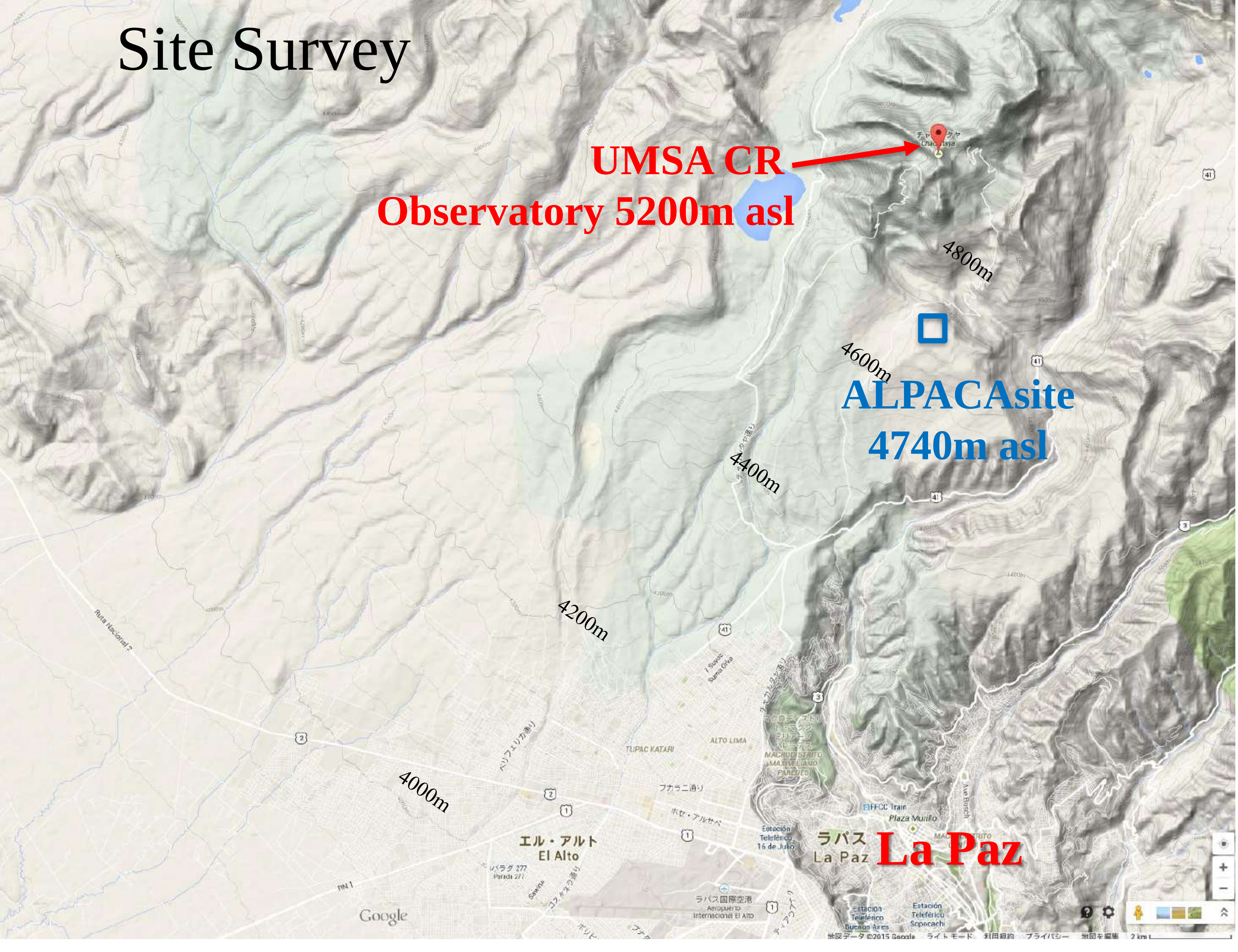
Japan some BASJE +
some GRAPES-3＋
some Tibet ASγ

Bolivia: Universidad Mayor De San Andres

ALPACA Site

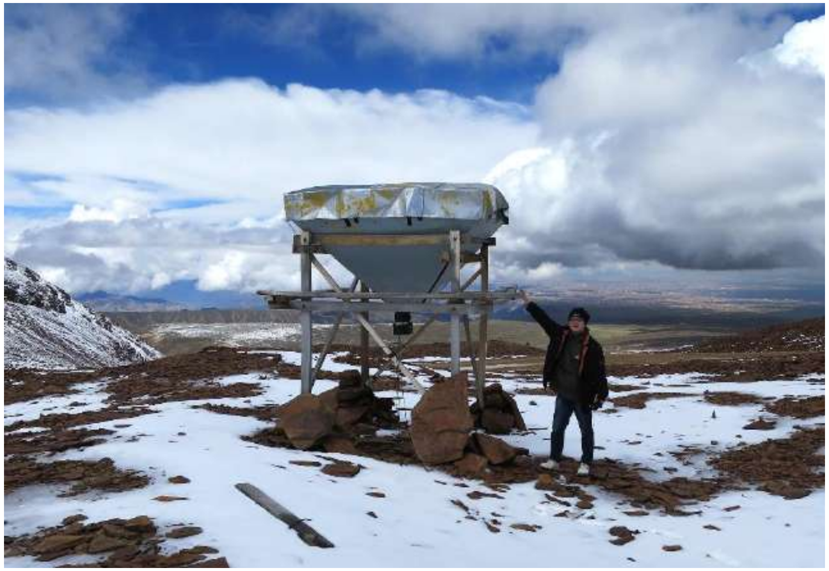
Mt. Chacaltaya, Bolivia

Site Survey


UMSA CR
Observatory 5200m asl
ALPACAsite
4740m asl
La Paz
4800m
4600m
4400m
4200m
4000m
エル・アルト
El Alto
ラパス
La Paz
Google

UMSACosmic Ray Laboratory

- ✓ Mt Chacaltaya(5,200m asl)
- ✓ CR Lab at the highest altitude
- ✓ Discovery of pion
  C. F. Powell in1947 (1950 Nobel Prize)



Main purpose of ALPACA

- 100 TeV γ-ray astronomy in South
- Locating origin of comic rays

by detecting cosmic 100 TeV gamma rays
from cosmic ray accelerator in our galaxy:

PeVatrons!

Why in Bolivia

- Flat land at high altitude: (> 4000m)

  Cosmic rays absorbed in atmosphere before reaching sea level

- Galactic Center: Observable in the southern hemisphere (not in the northern hemisphere)

  Most promising candidate of the origin of cosmic rays

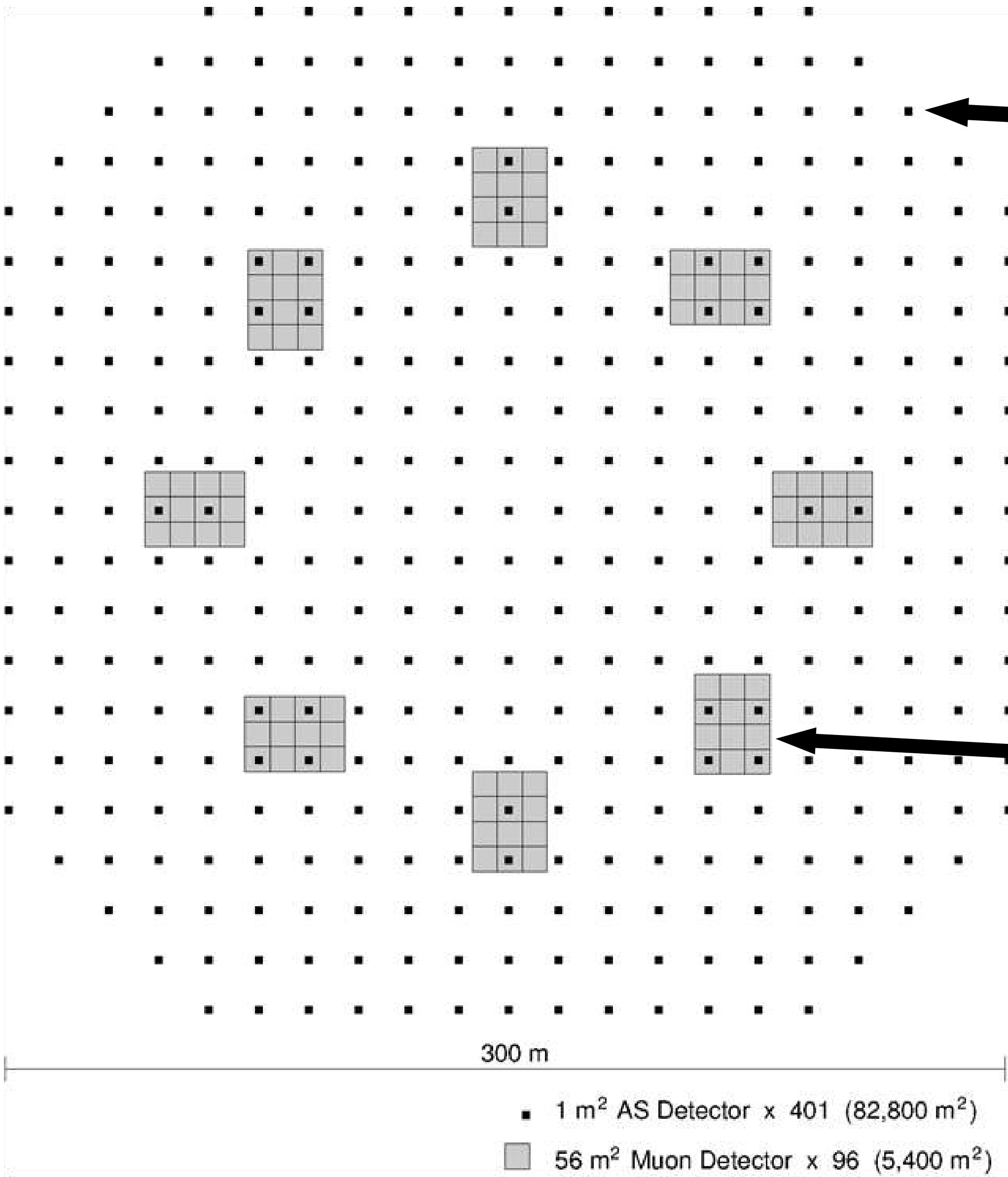
- Long-term collaboration between Bolivia and Japan (Good infrastructure: Electricity, water, road,...)

  Since 1962 in the field of cosmic rays, for example, BASJE

Experimental Cite : Cerro Estuqueria
（500m x 500m flat within ~+- 1 deg.)

4,740 m above sea level (16˚23’S, 68˚08’W)

Schematic view of ALPACA



Air
Shower
Array

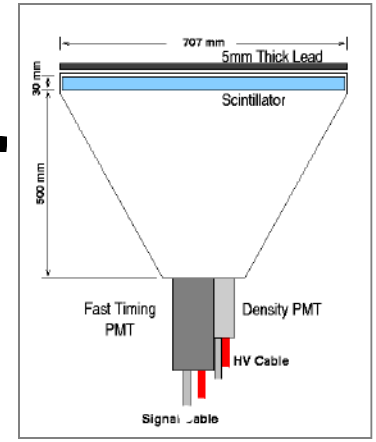


Image of 1m^2 plastic scintillation detector

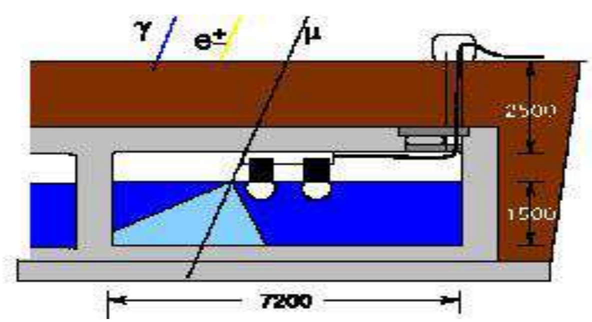
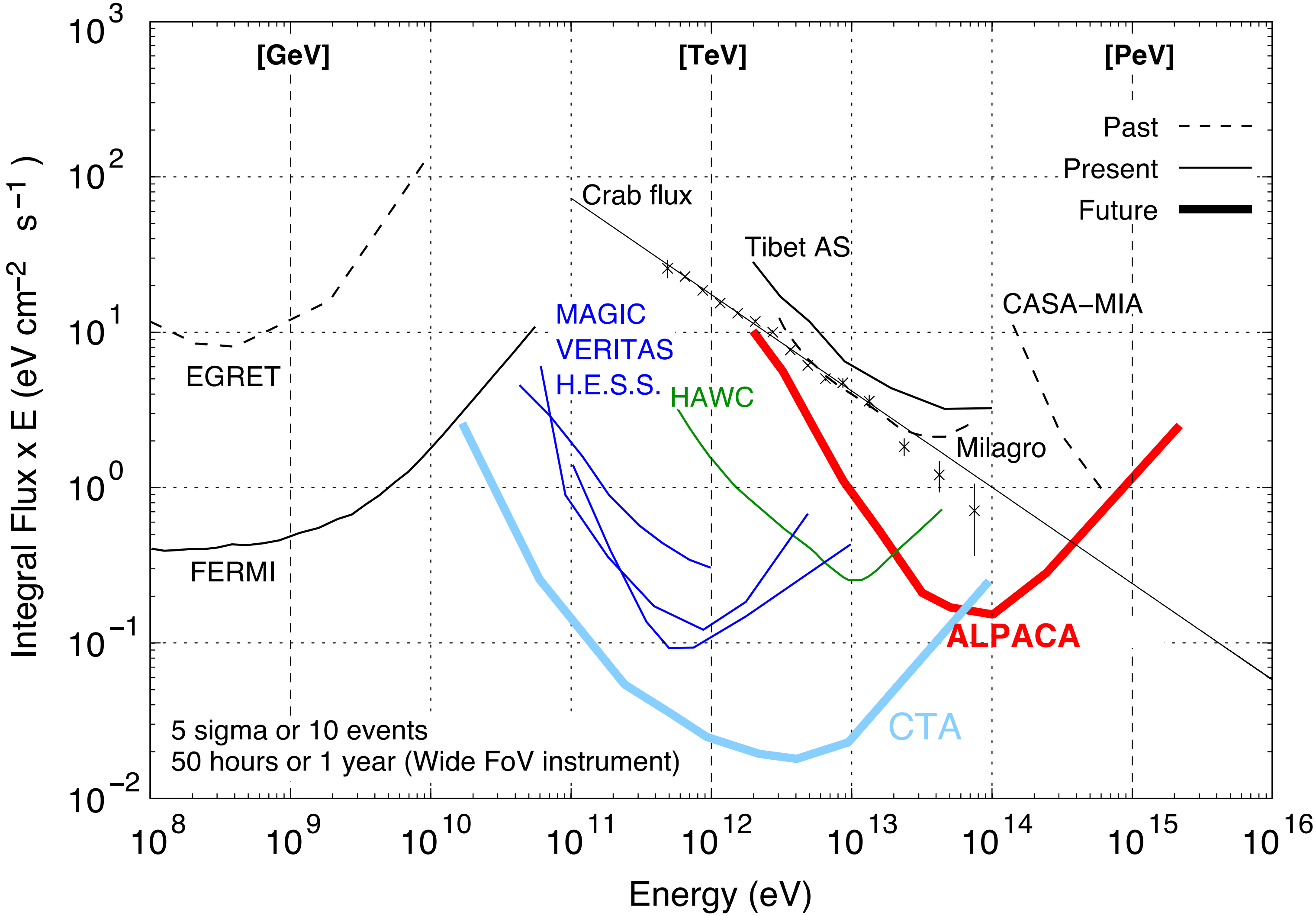


Image of unit (56m^2) underground water Cherenkov muon detector

Sensitivity to point-like γ-ray sources



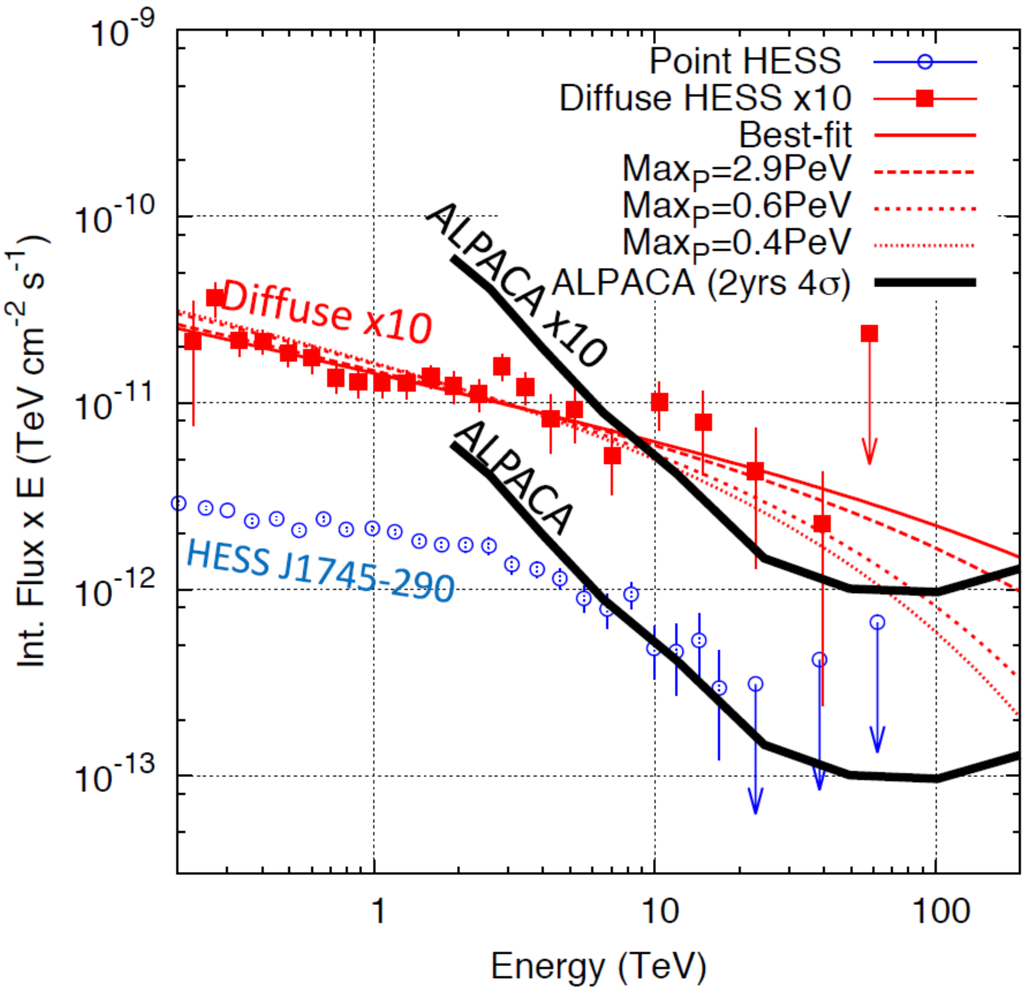
CTA Review by Kubo (JPS 2015)

M.Daniel, Proc. of 28th Texas Sympo. (2015)

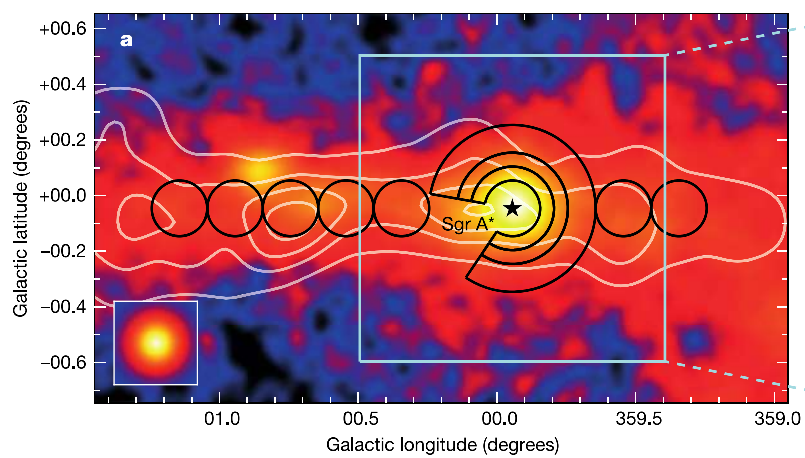
Target γ Sources

- Galactic Center
- Fermi Bubbles
- Young SNR
- Other Galactic Point-like Sources
- Nearby Extragalactic Sources

Galactic Center as PeVatron?



- ✓ Detection of diffuse component
- ✓ >100TeV γ−ray expected
- ✓ PeVatron candidate

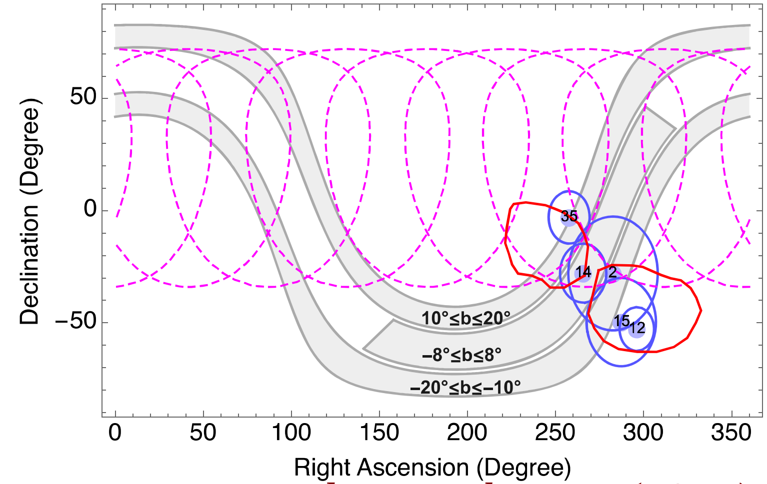


Abramowski, et al, Nature (2016)

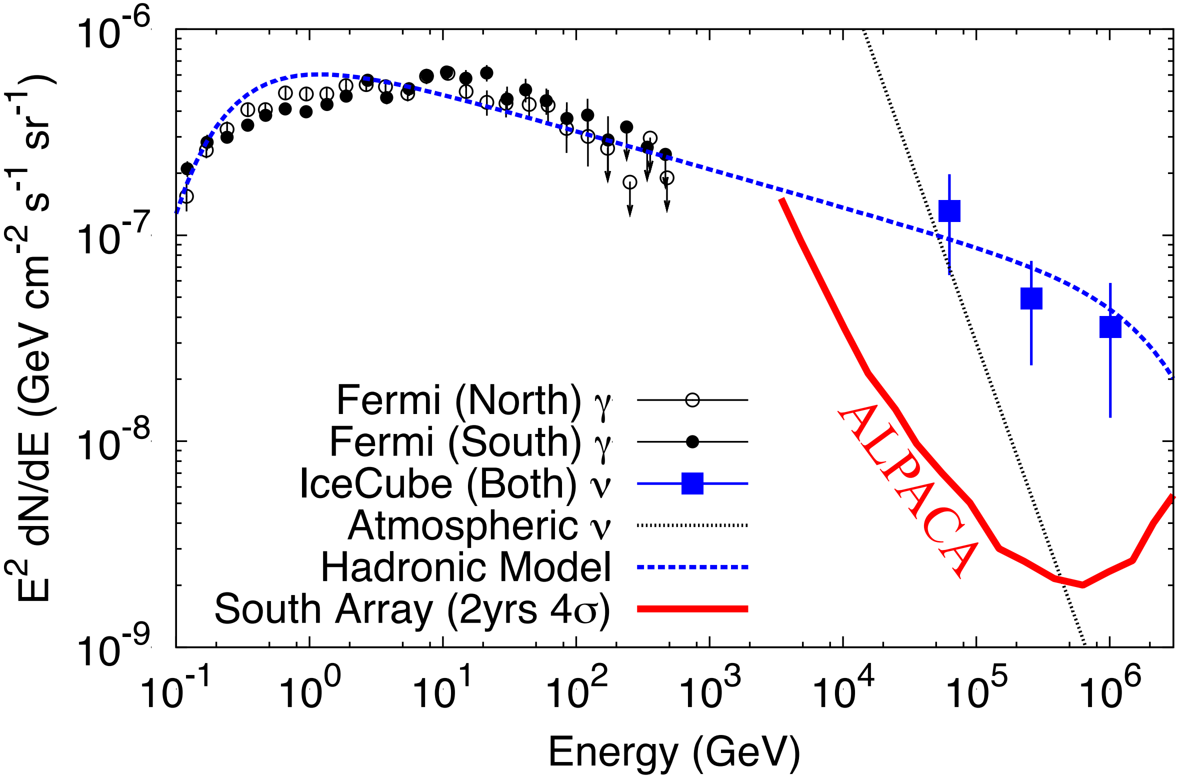
$\delta \sim -29°$

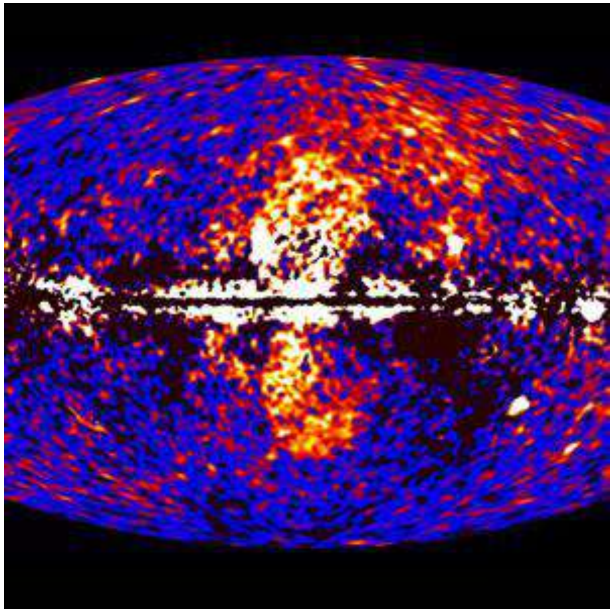
Fermi Bubbles

- ✓ sub-PeV γ rays expected, if sub-PeV ν's detected by IceCube are of hadronic origin.
- ✓ Fermi Bubbles: Very extended (~0.8sr) γ-ray sources difficult for IACTs to cover them all.



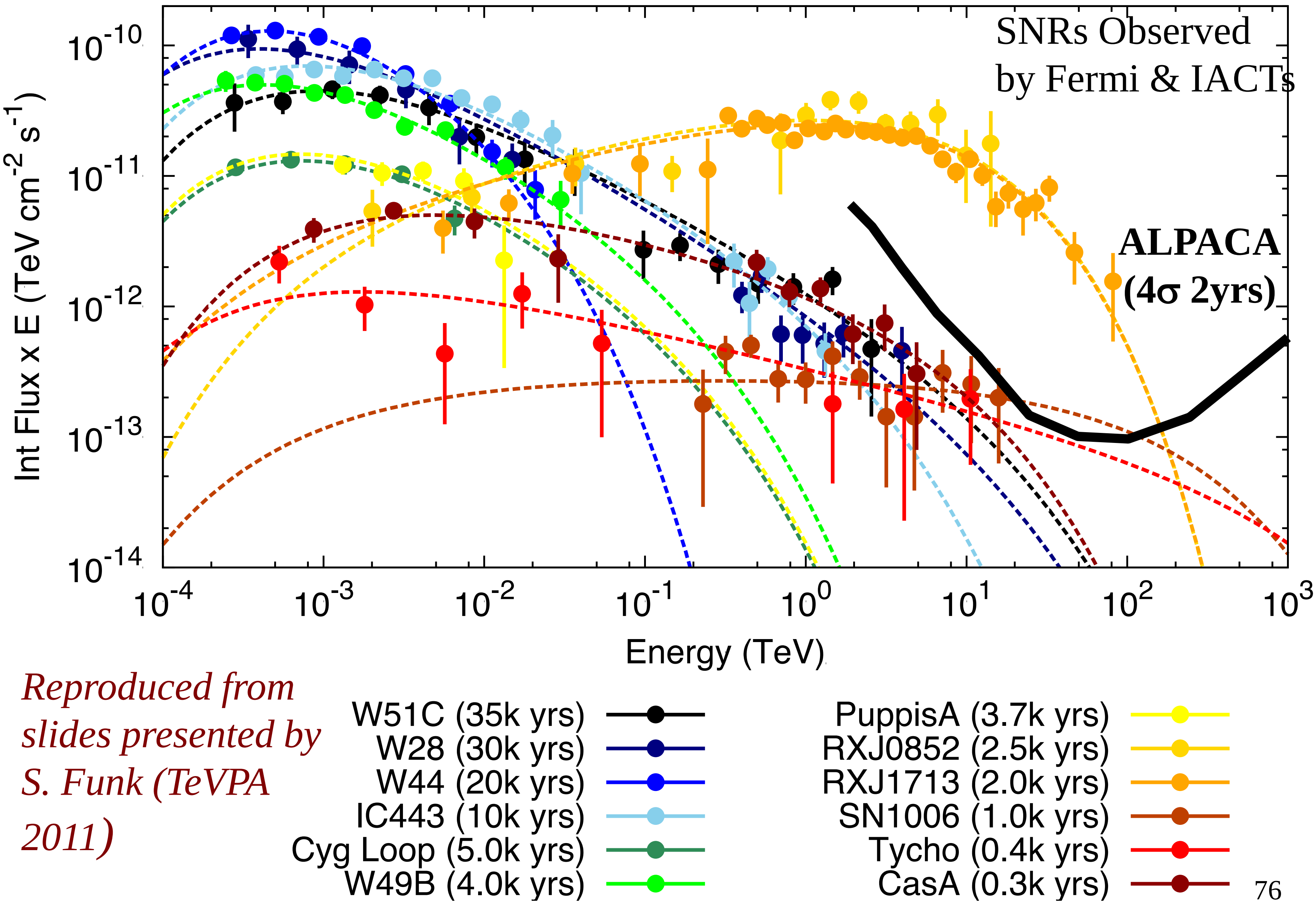
C. Lunardini, et al, PRD (2015)





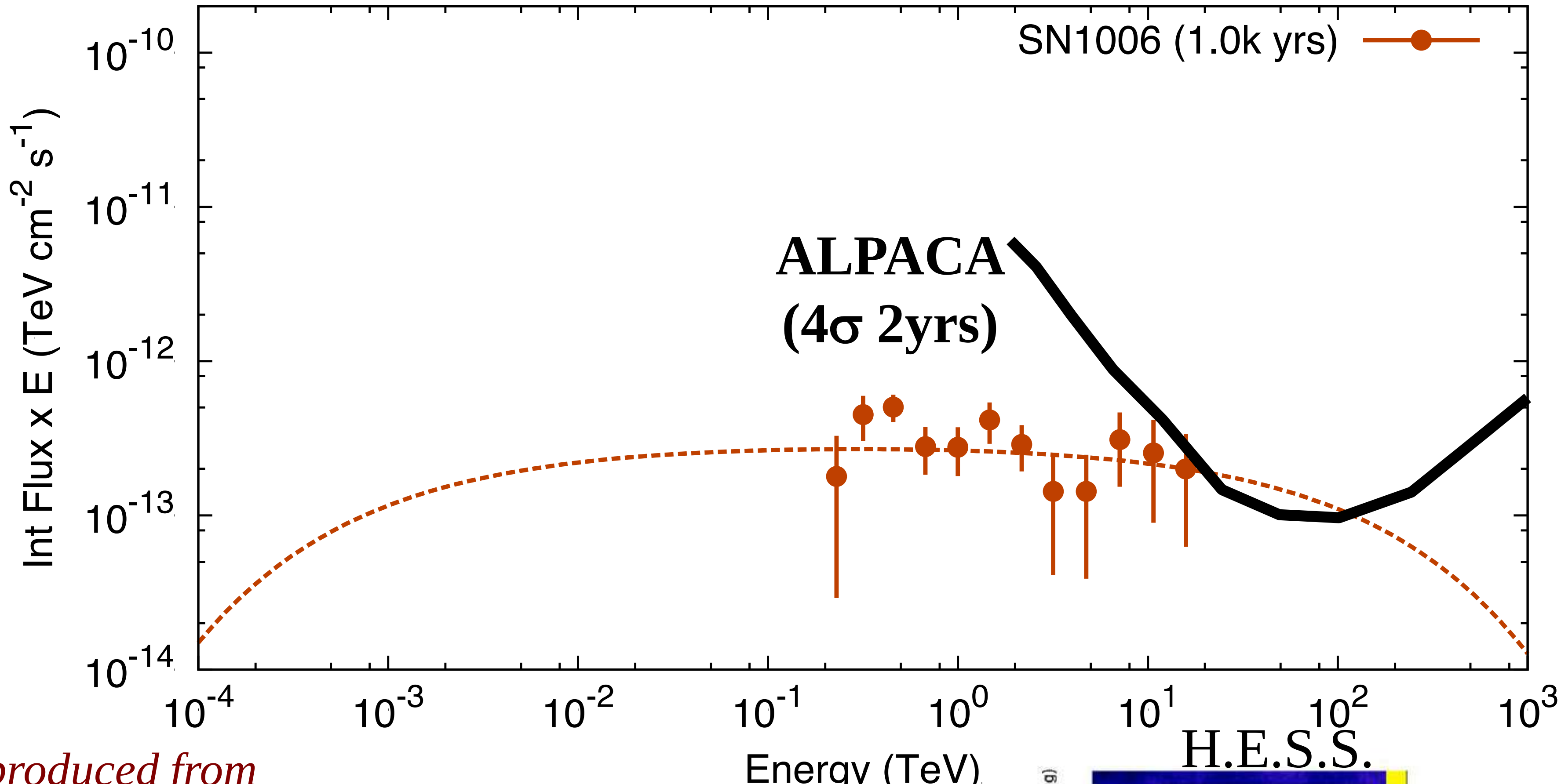
Bubbles observed by Fermi-LAT

Young SNRs



Reproduced from slides presented by S. Funk (TeVPA 2011)

Young SNRs



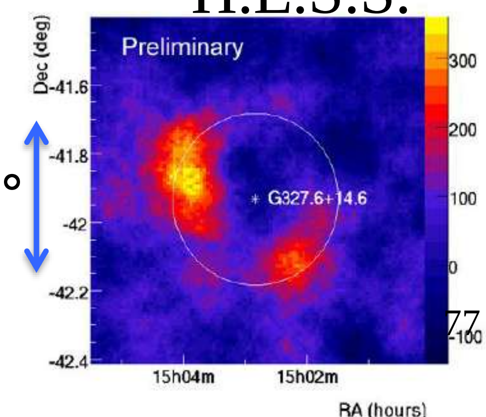
Reproduced from slides presented by S. Funk (TeVPA 2011)

SNRs Observed by Fermi & IACTs

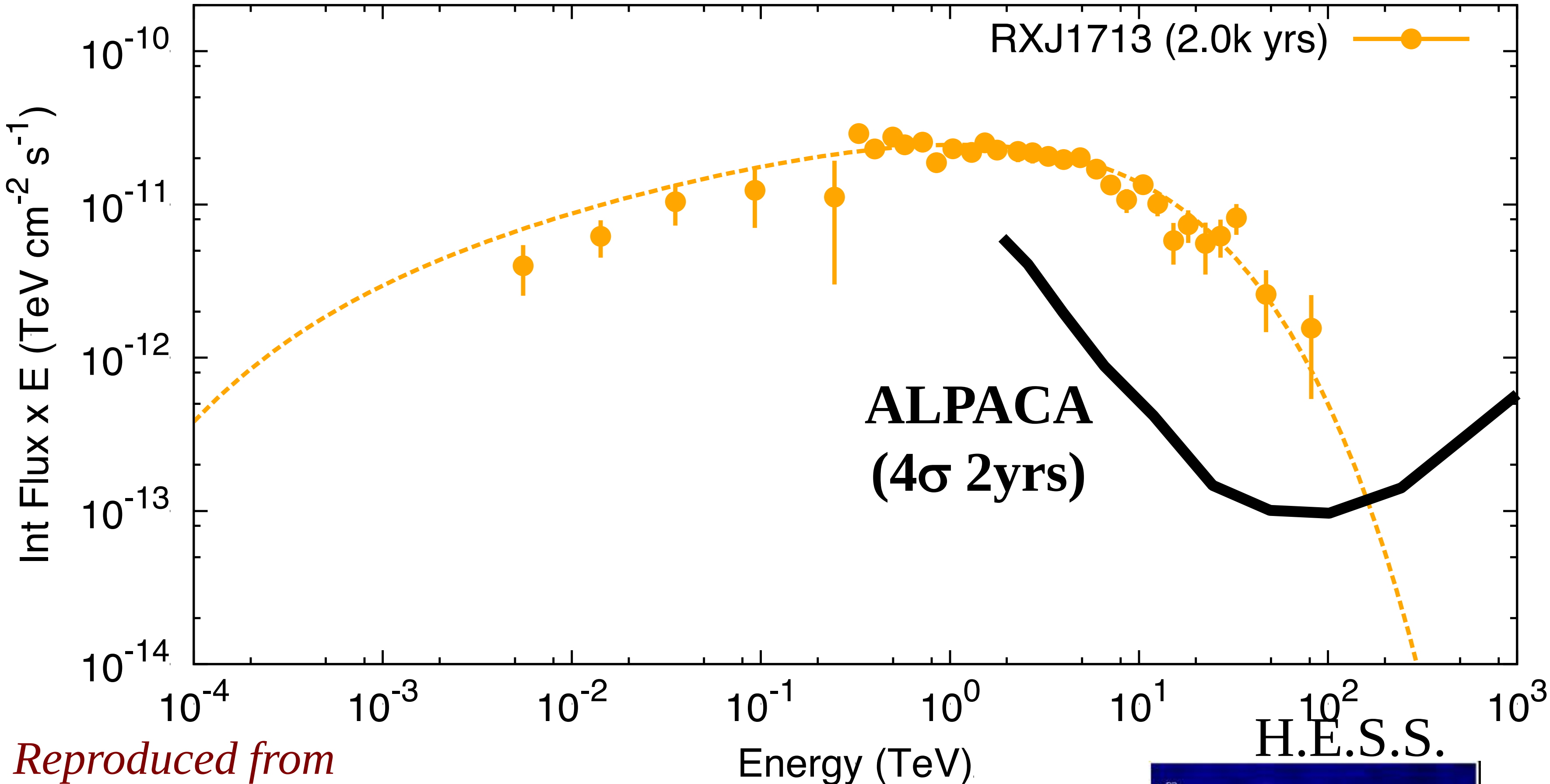
δ ~ -42°

H.E.S.S.

0.4°



Young SNRs



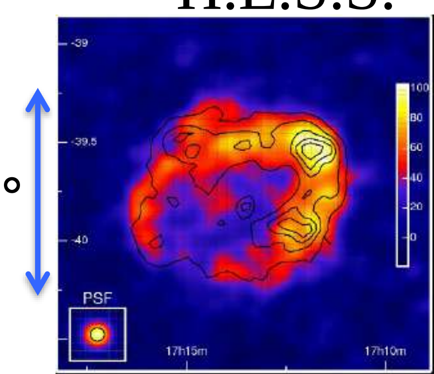
Reproduced from slides presented by S. Funk (TeVPA 2011)

SNRs Observed
by Fermi & IACTs

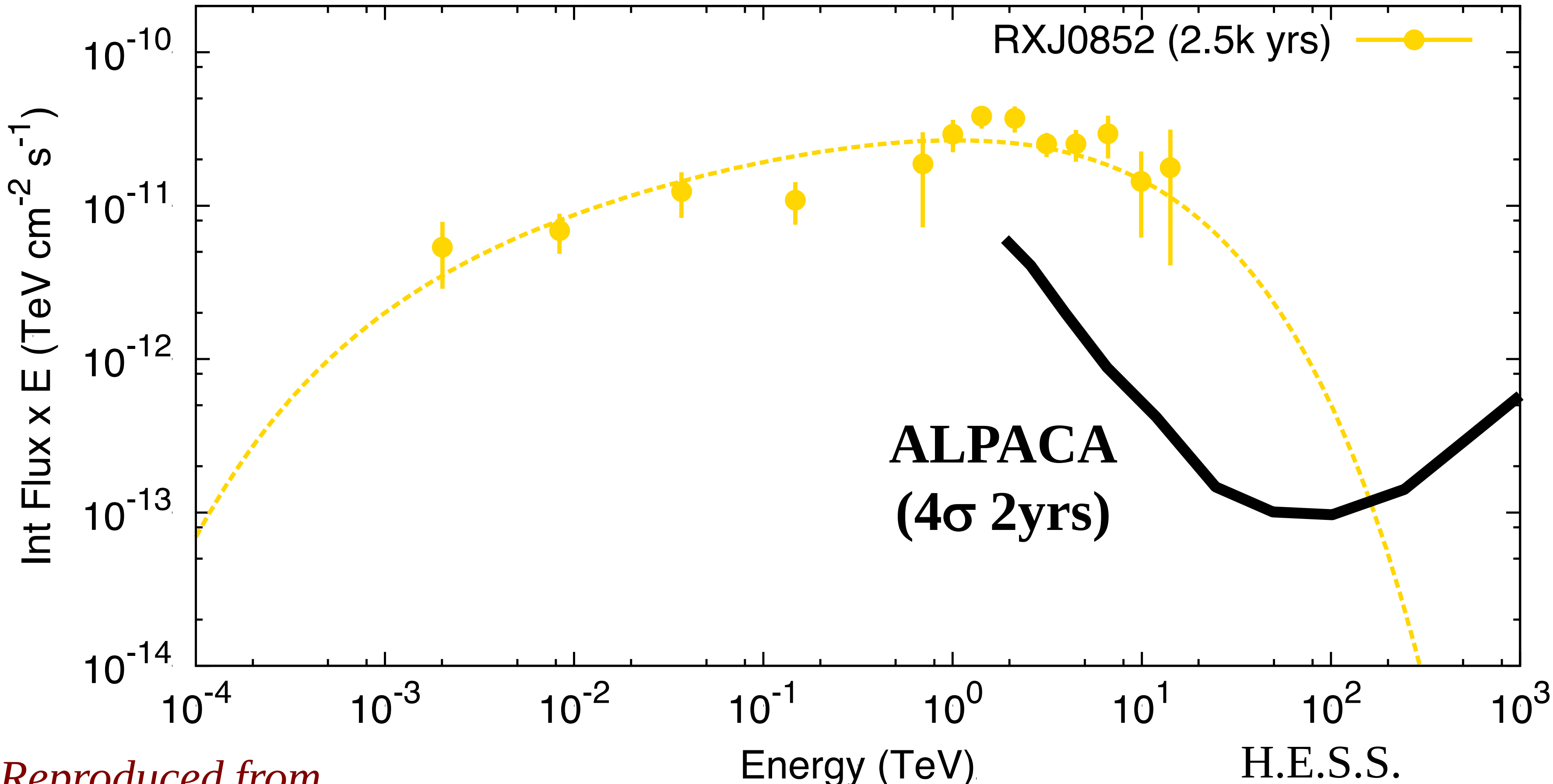
δ ~ -40°

H.E.S.S.

1.0°



Young SNRs



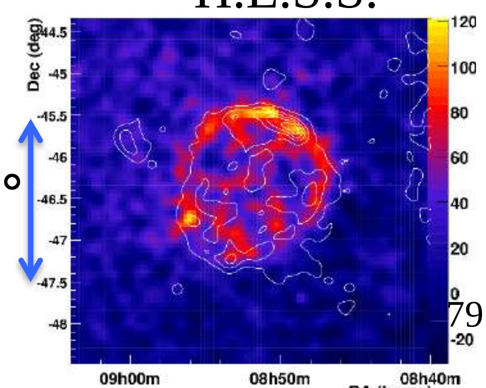
Reproduced from slides presented by S. Funk (TeVPA 2011)

SNRs Observed by Fermi & IACTs

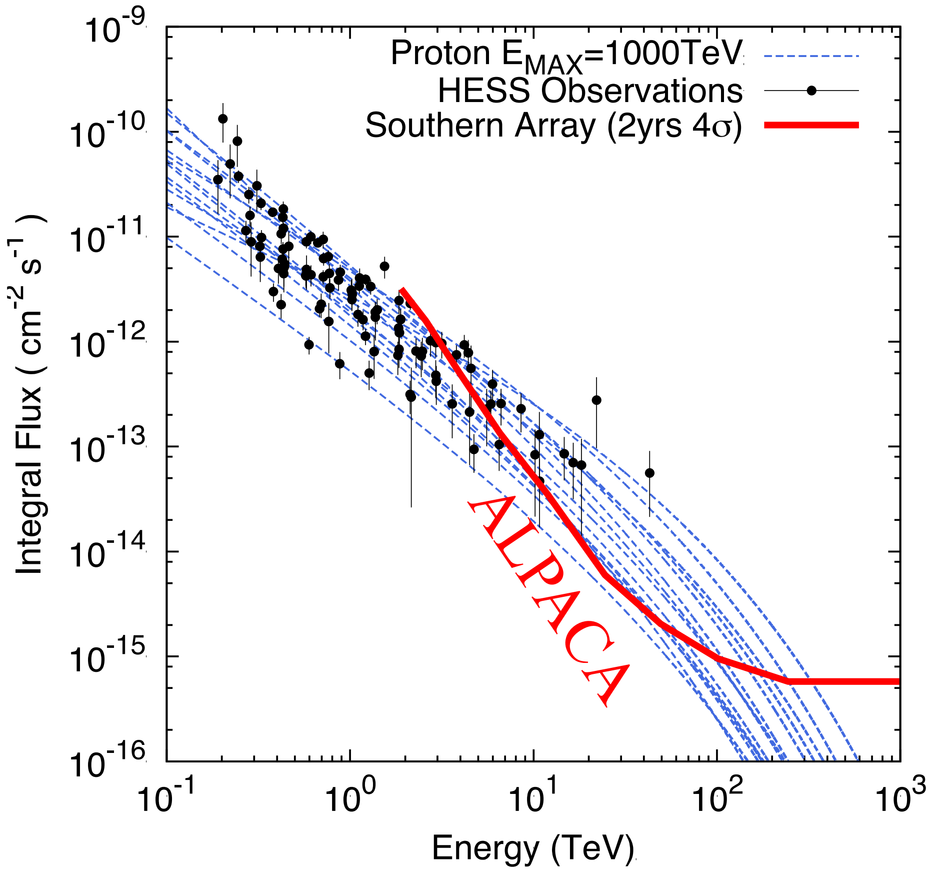
$\delta \sim -46°$

H.E.S.S.

2.0°



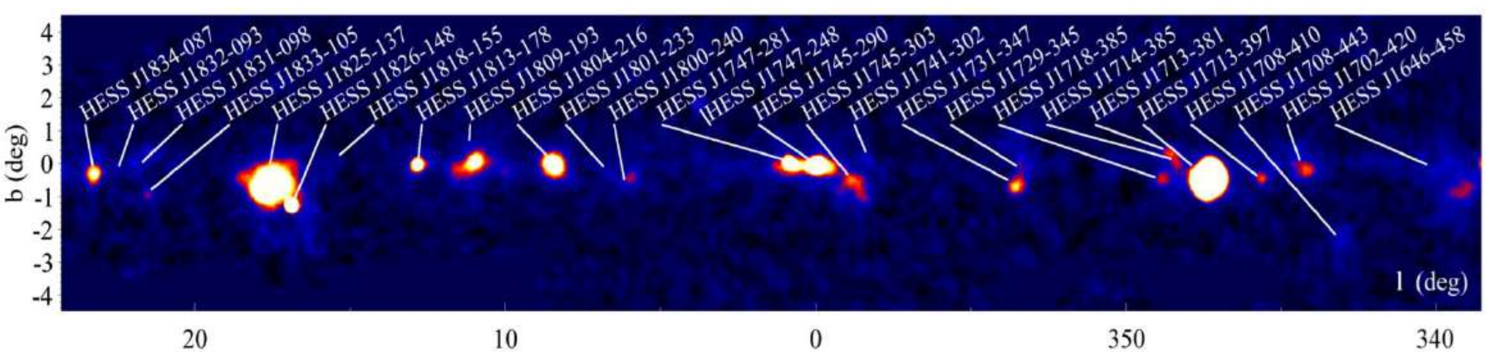
Other Galactic Sources



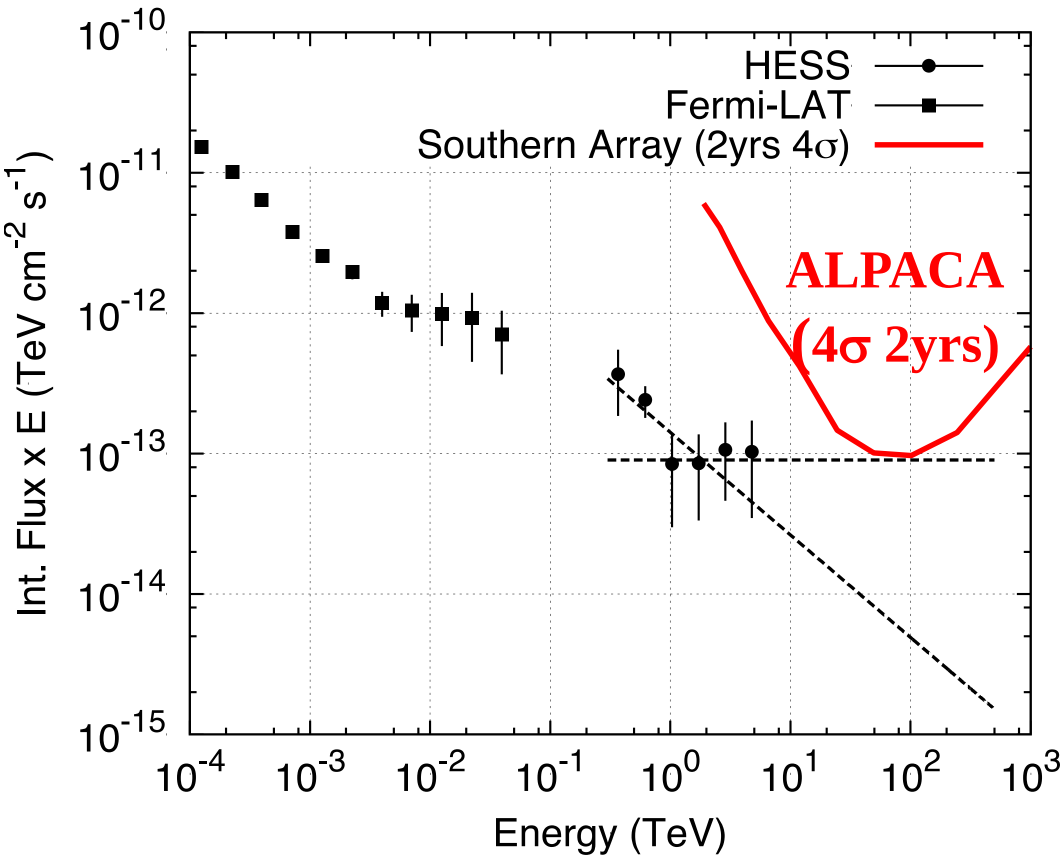
- ✓ More than dozen sources
- ✓ Many sources are dark in other wave length → Dark particle accelerator
- ✓ Many candidate of PWN (excess is located near pulsar)

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

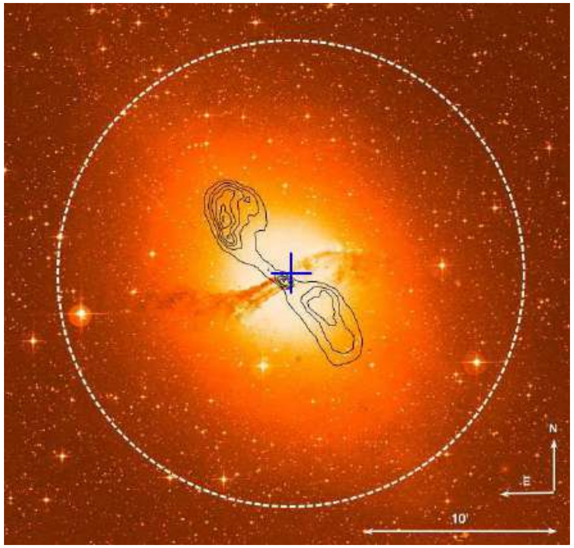
- ✓ Diffuse γ from Galactic plane



Nearby Extragalactic Source CenA



- ✓ Distance: 3.8Mpc very nearby!
- ✓ Relativistic jet
- ✓ Flat spectrum above TeV region?
- ✓ No significant time variation?



Aharonian et al, ApJ, 695, L40 (2009)
Sahakyan, et al, ApJ, 770, L6(2013)

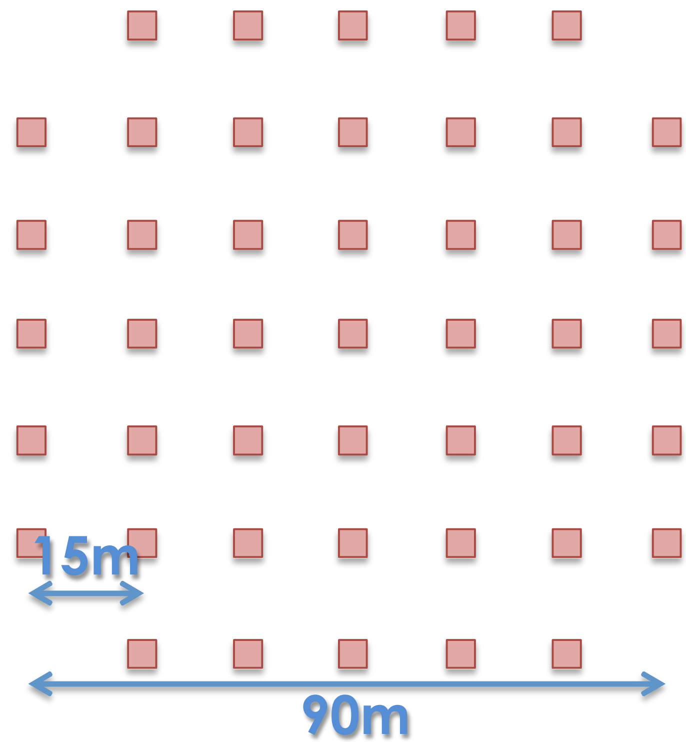
$\delta \sim -43°$

ALPAQUITA AS ARRAY

Proto-type ALPACA air shower array (~1/10 scale of ALPACA AS)
Construction: Scheduled in 2018

- $1m^2$ x 5cm Plastic scintillators: 45 detectors with 15m spacing (area: 7,650 m^2)
- 2-inch PMT H7195 (H1161 equivalent)
- Electronics: VME DAQ system + HV (CAEN A7030YP) +
  Front-end T-Q (REPIC) + TDC (CAEN V1190A)

$1m^2$ Detector



Thank you for your attention!

ALPAQUITA (~1/10 AS) will be constructed in 2018

End