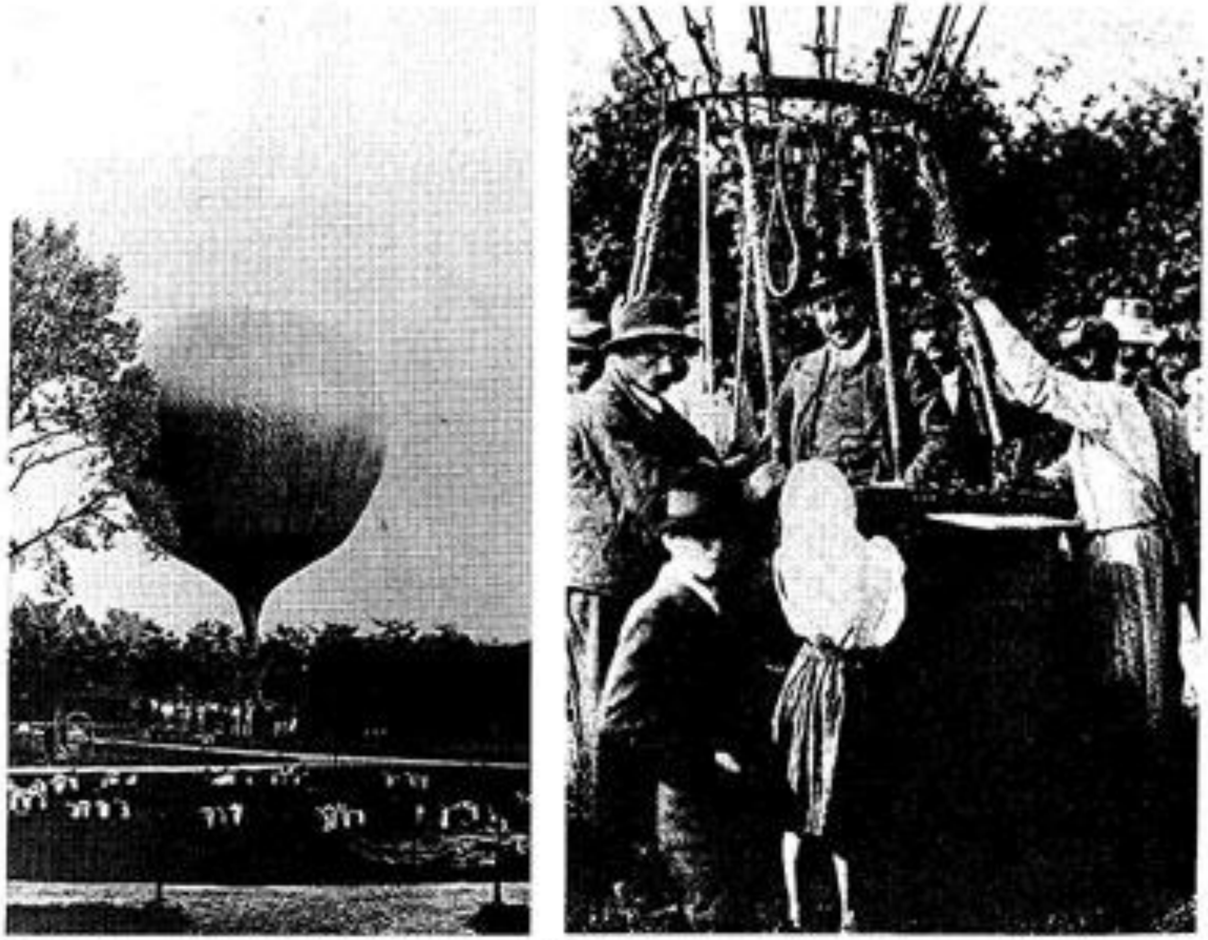
ガンマ線・宇宙線物理

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

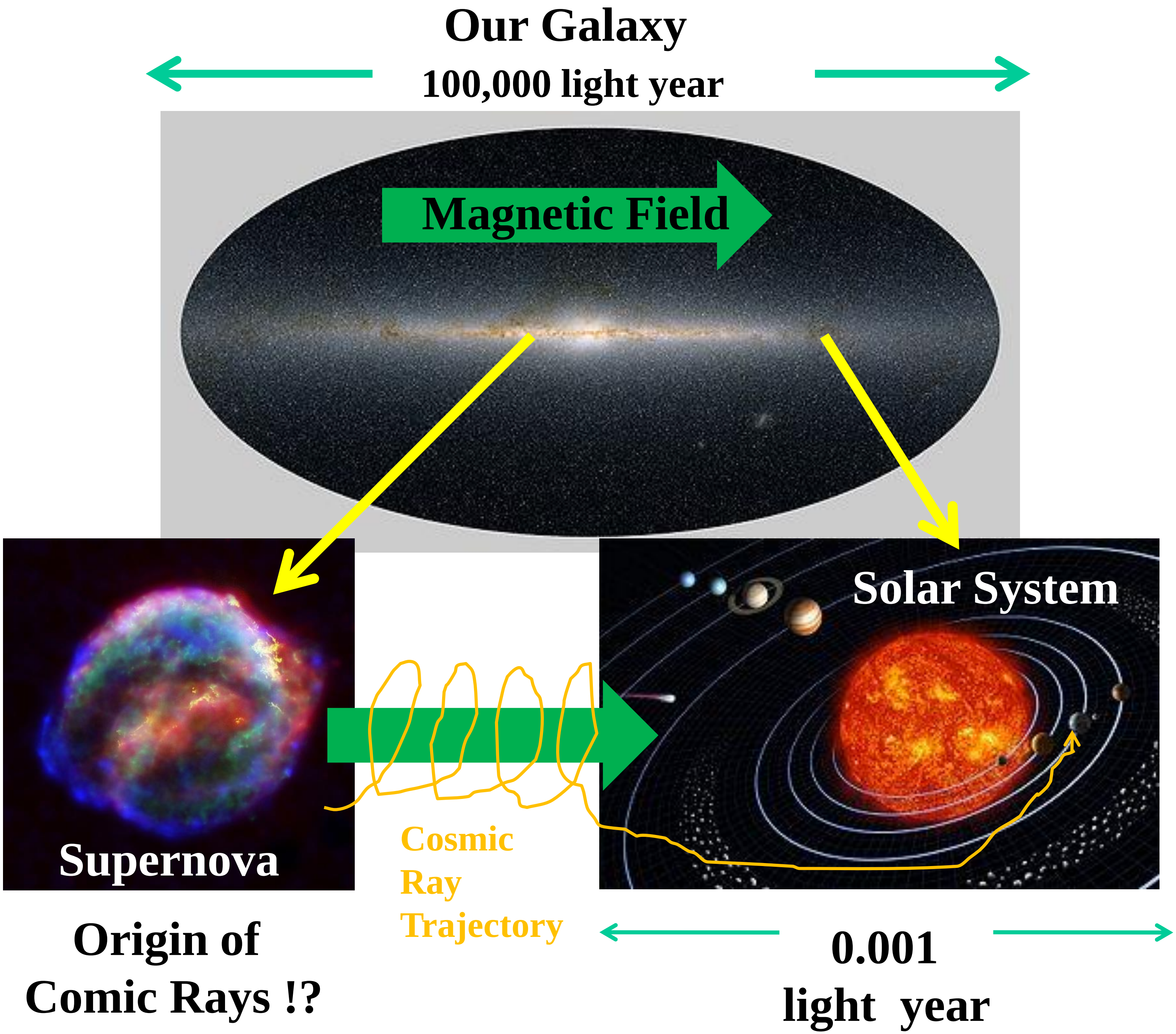
Spring School, @ICRR U. of Tokyo,
8/Mar/2019

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

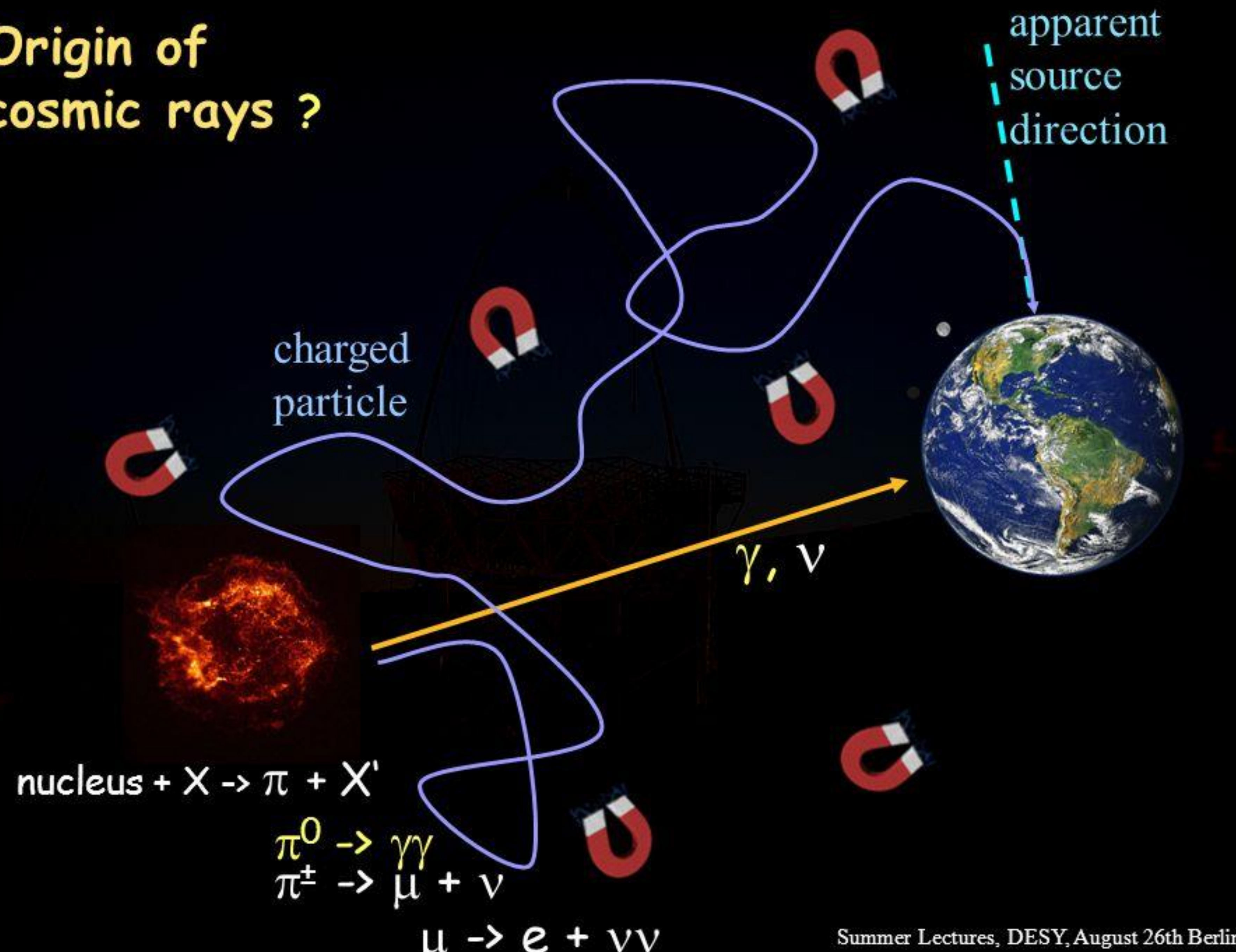


(a) (b)

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 ?



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

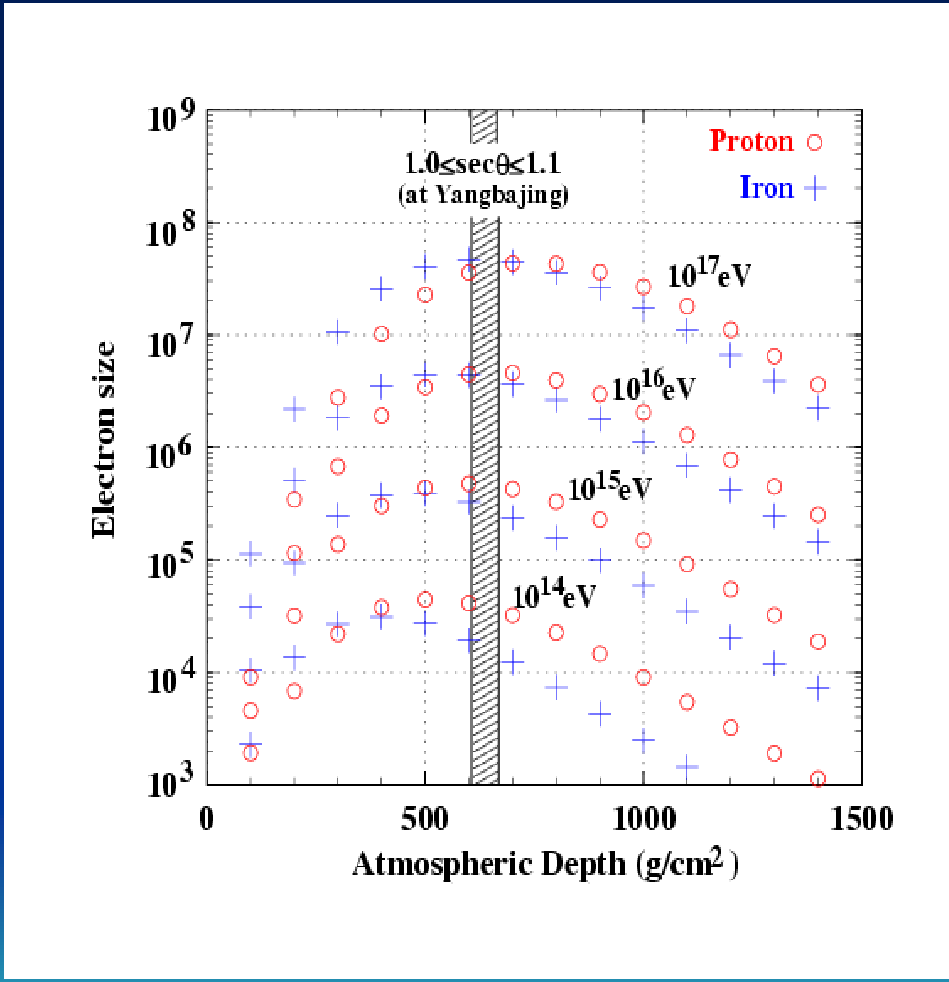
Yangbajing , Tibet, China

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

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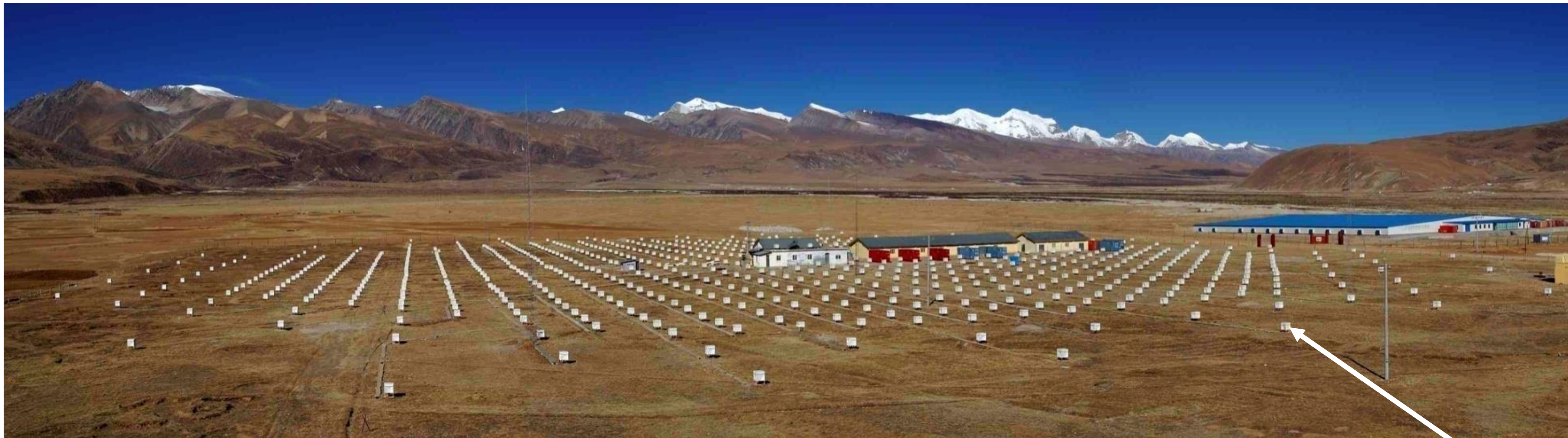
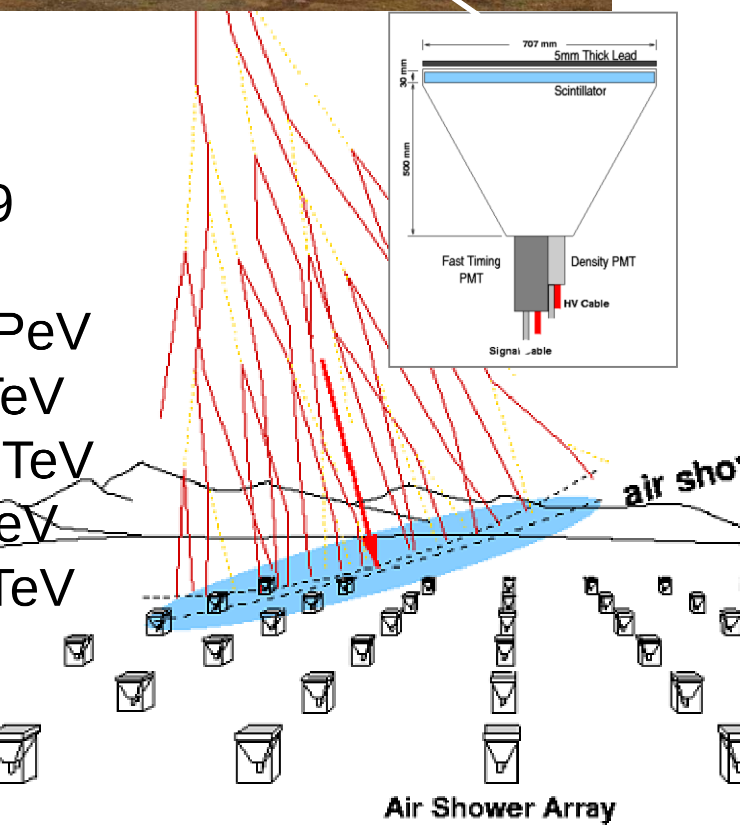
[23]Shonan Institute of Technology, Japan
[24]Japan Atomic Energy Agency, Japan
[25]School of General Education, Shinshu University, Japan

Tibet-III Air Shower (AS) Array

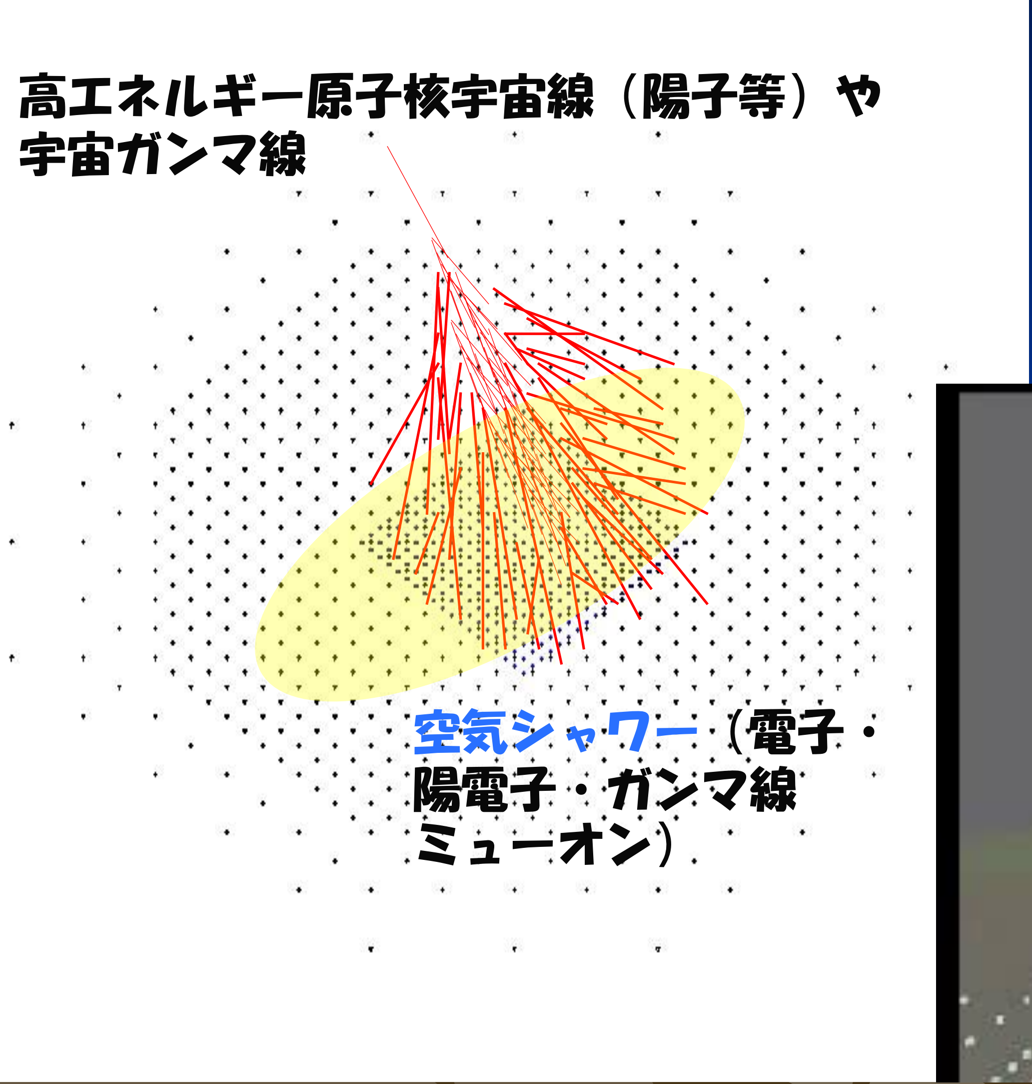


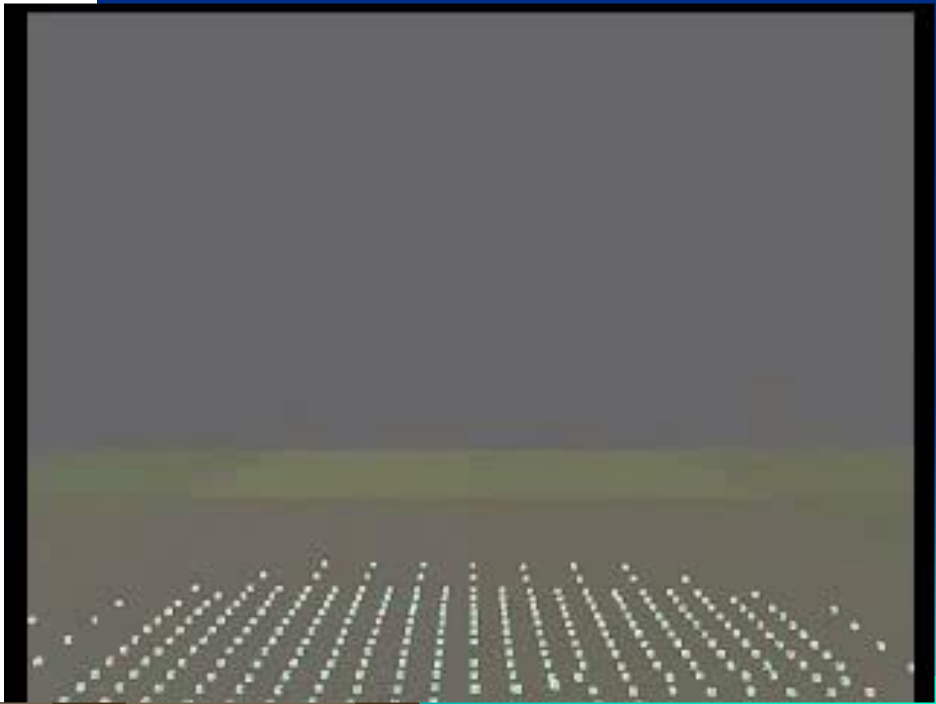
4,300 m a.s.l. (606 g/cm^2)



☐ 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 ~20% @100TeV
☐ F.O.V.	~2 sr
☐ Trigger Rate	1.7 KHz

空気シャワー





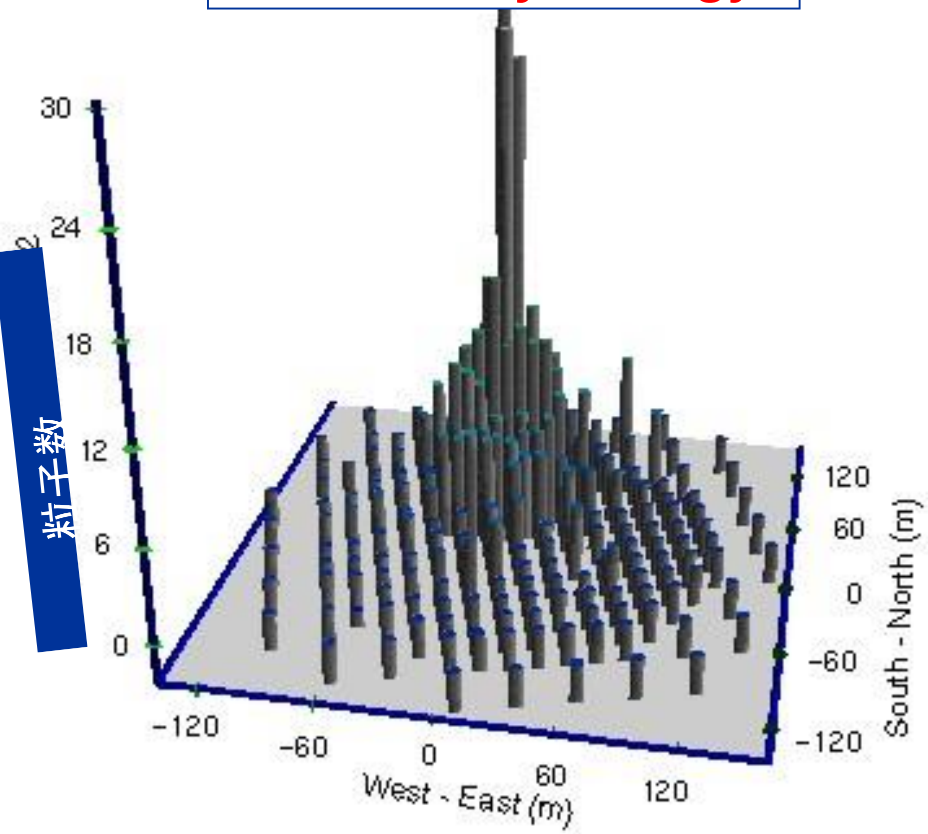
Air Shower Detection

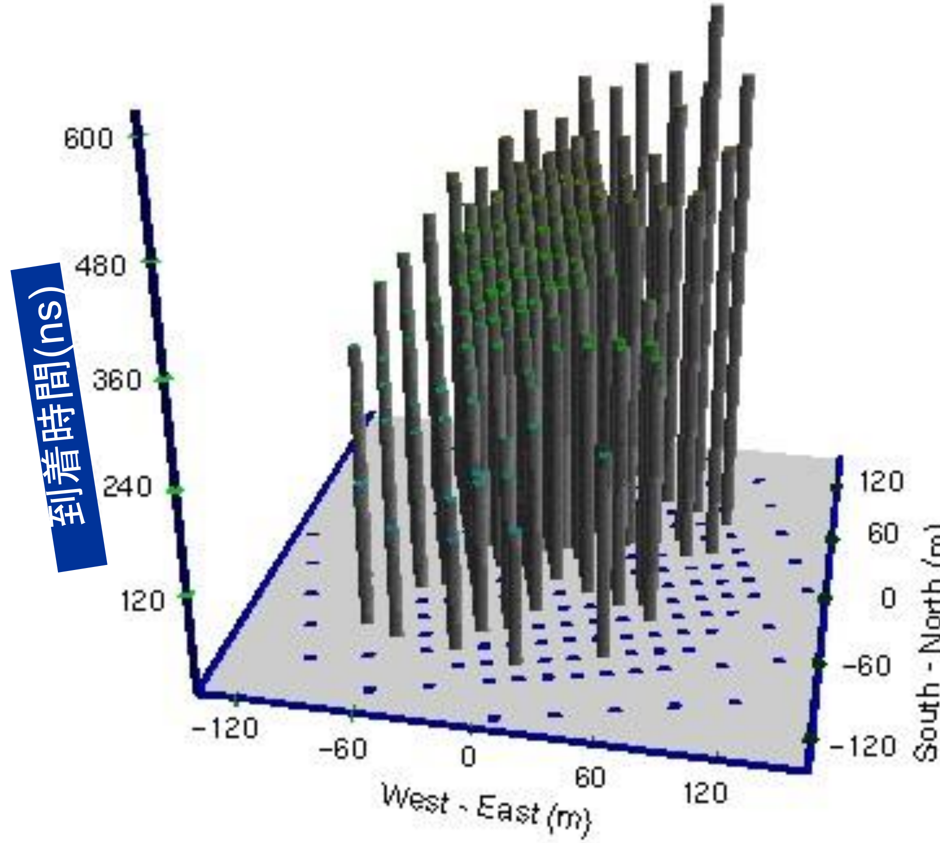
2nd particle density

Cosmic ray energy

2nd particle timing

Cosmic ray direction



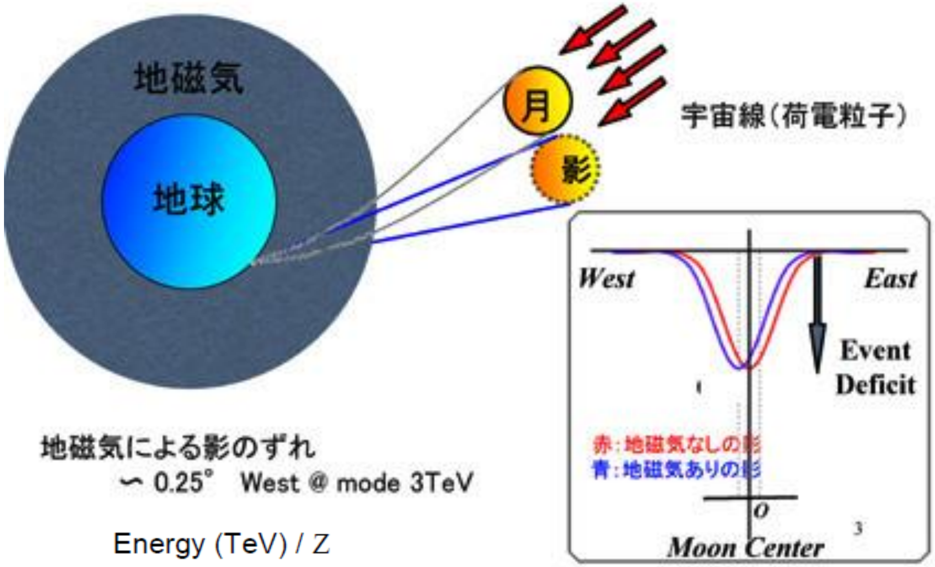


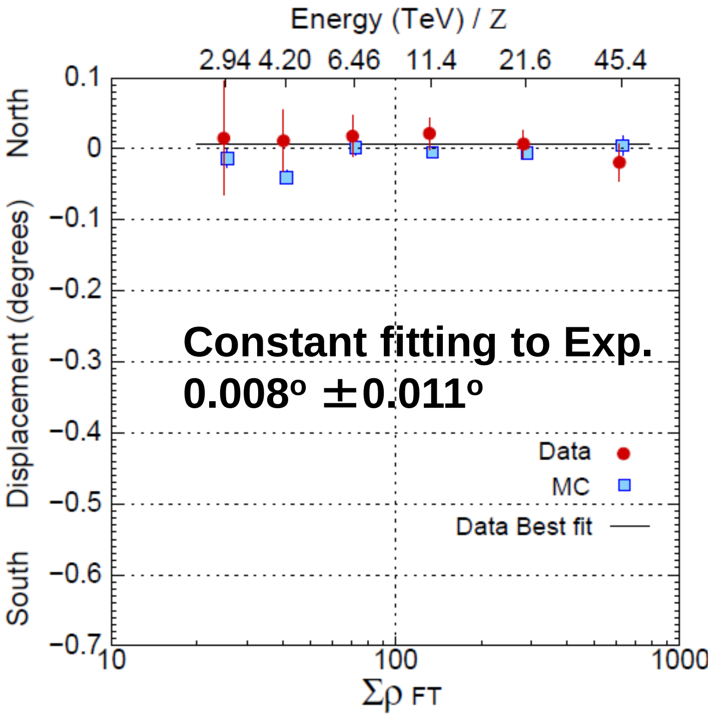
Air shower rate triggered by Tibet III ~1700Hz

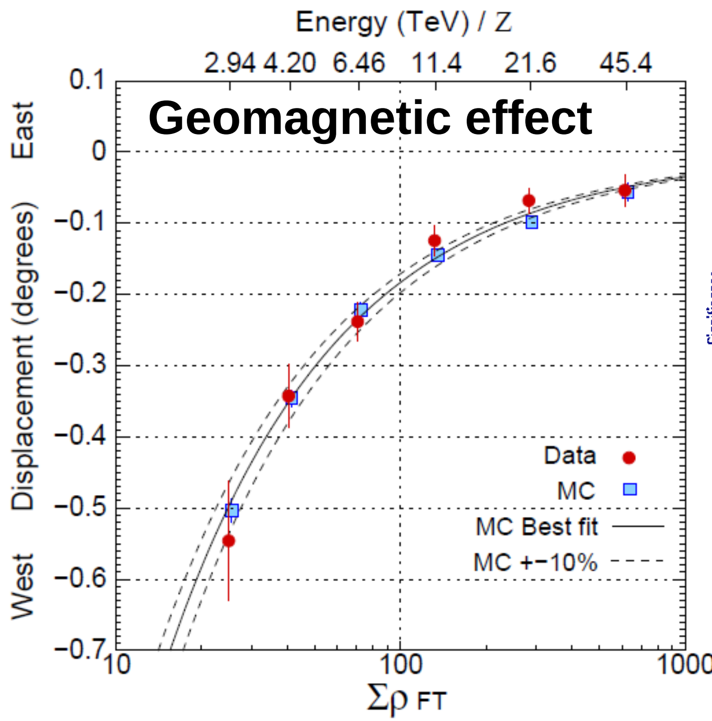
Performance by Moon's Shadow

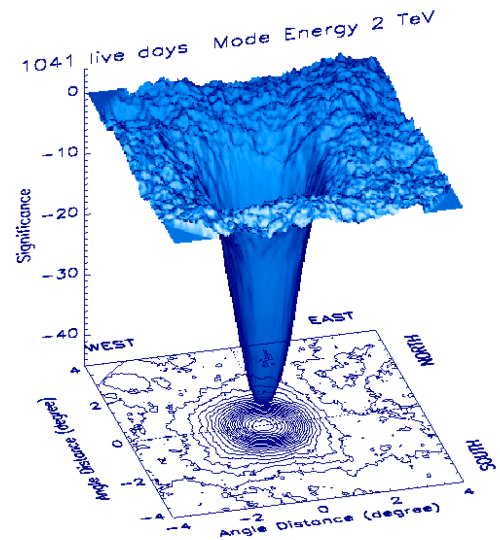
The Astrophysical Journal, 692, 61–72(2009)

- Absolute Energy Scale
- Angular Resolution
- Pointing Accuracy









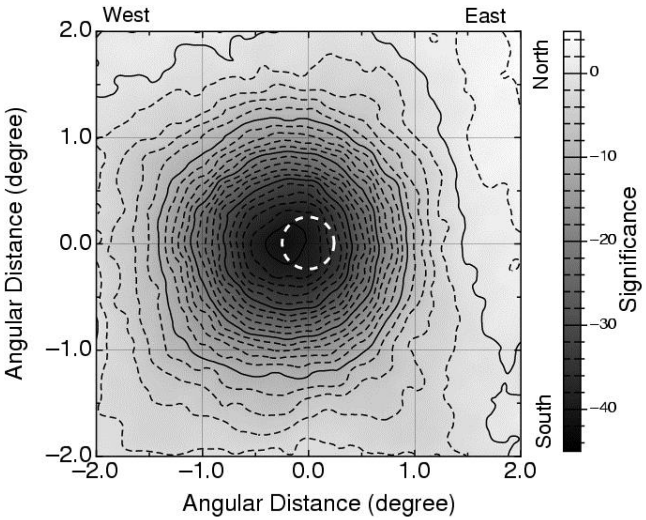
Pointing Error < 0.011°

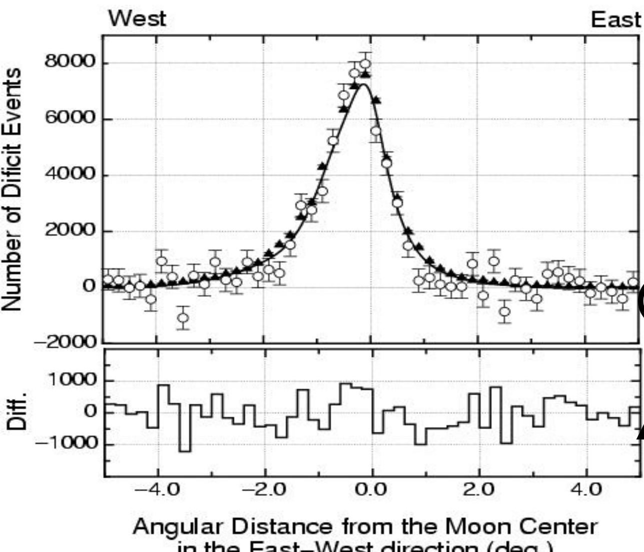
Absotute Energy Scale Error < 12%
+4.5%(±8.6stat.±6.7syst.)%

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

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

3TeV 40σ



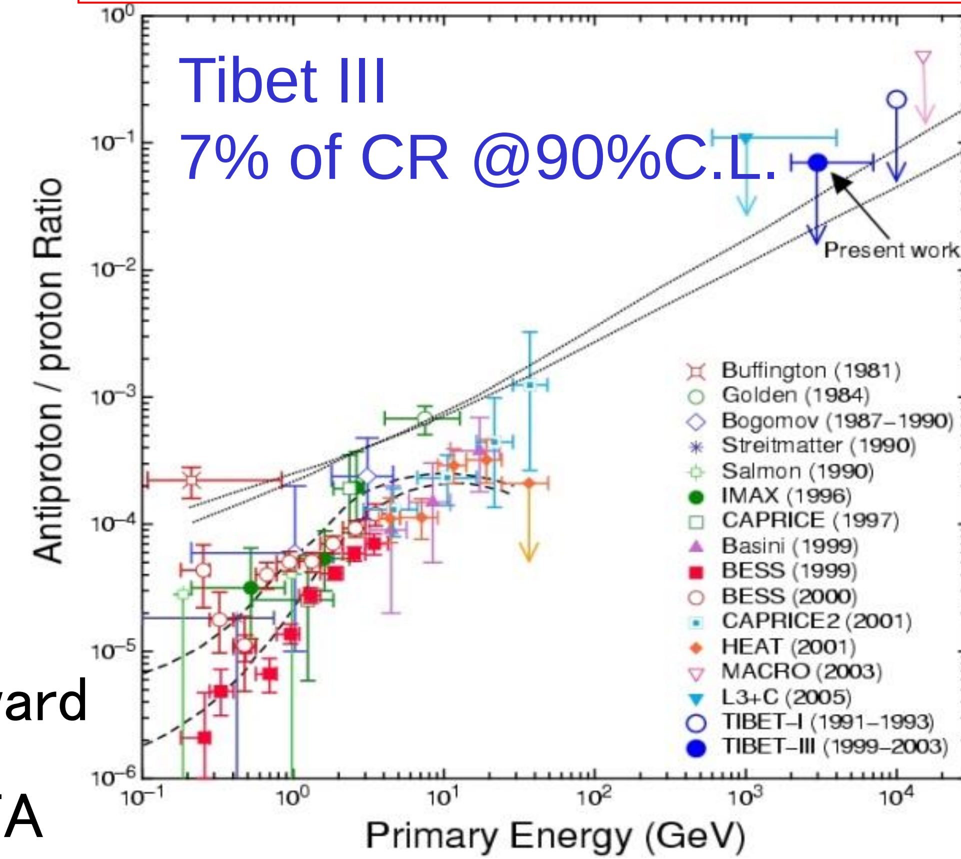


0.23°

Westward

○ :DATA

△ :MC



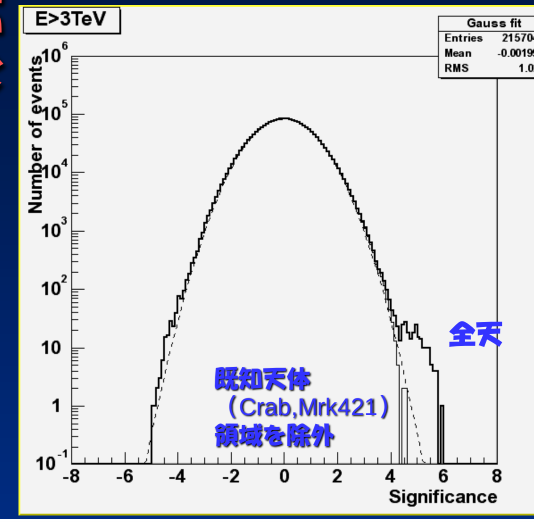
Dashed line: leaky box

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

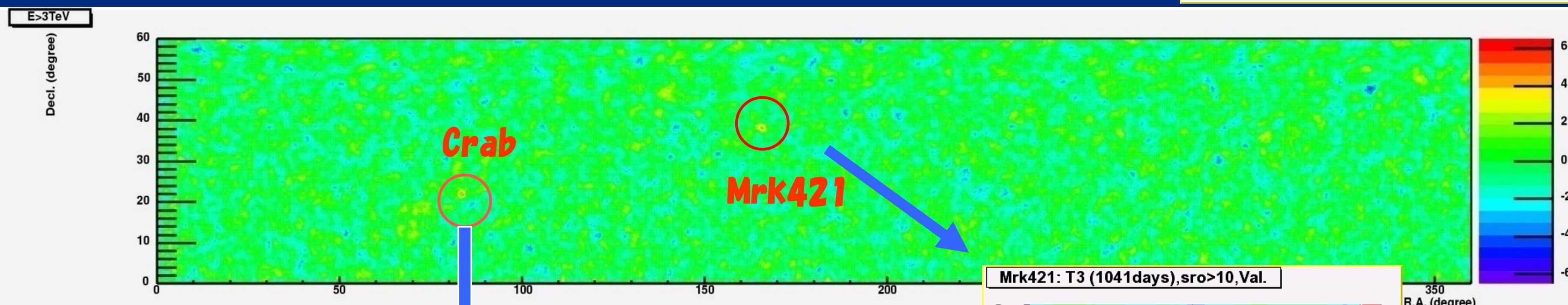


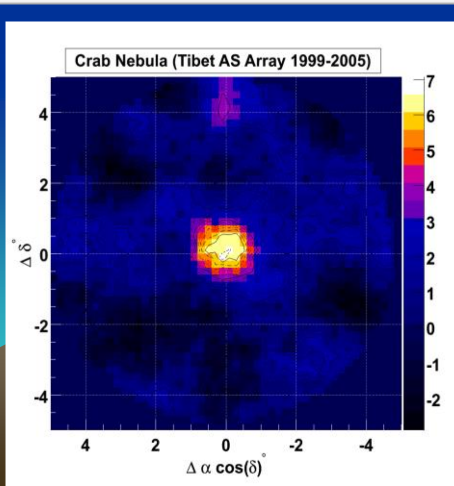
チベットで観測された点源

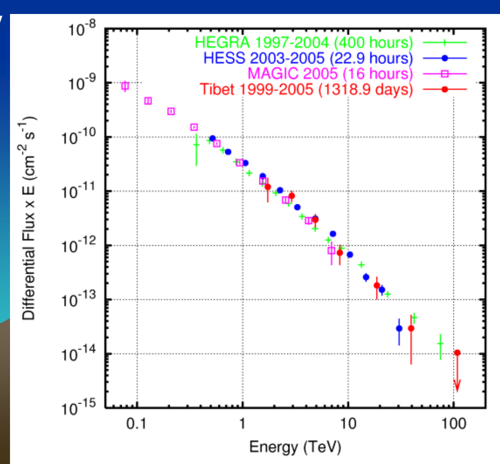
★　超新星残骸　かに星雲からの定常ガンマ線

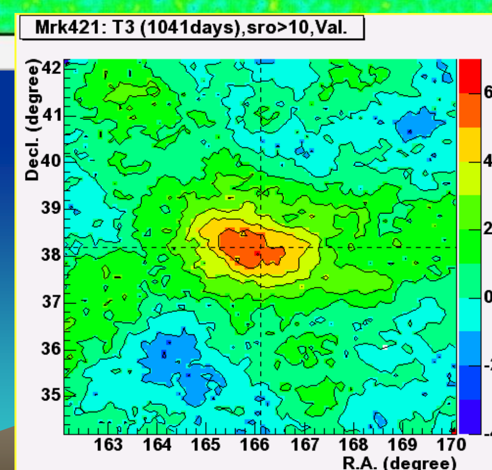
★　活動的銀河核　Mrk421, Mrk501からのフレアガンマ線

1999－2003年　全北天探索







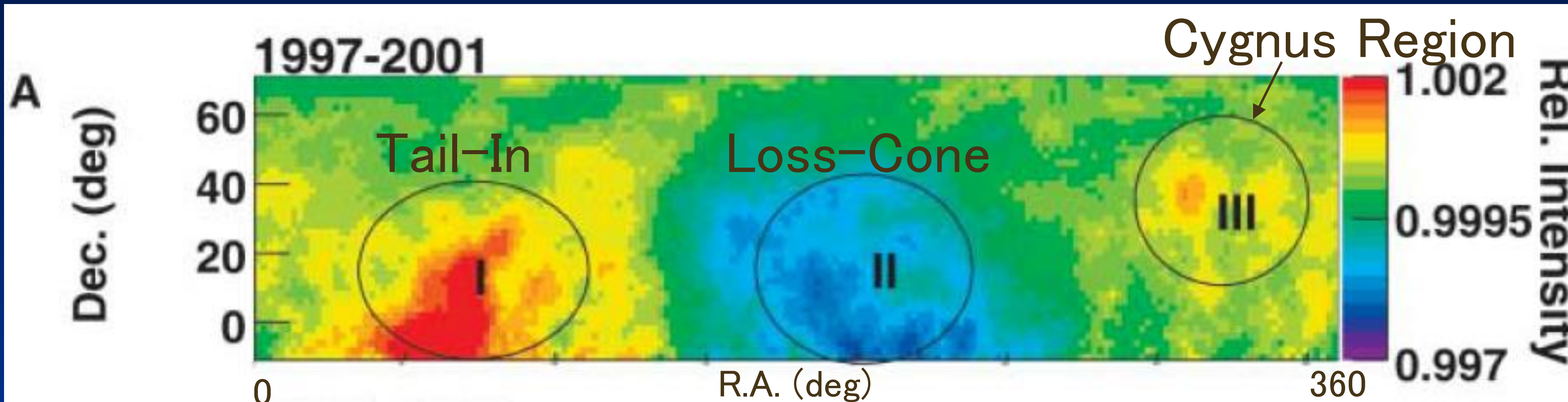


2000－2001年フレア

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

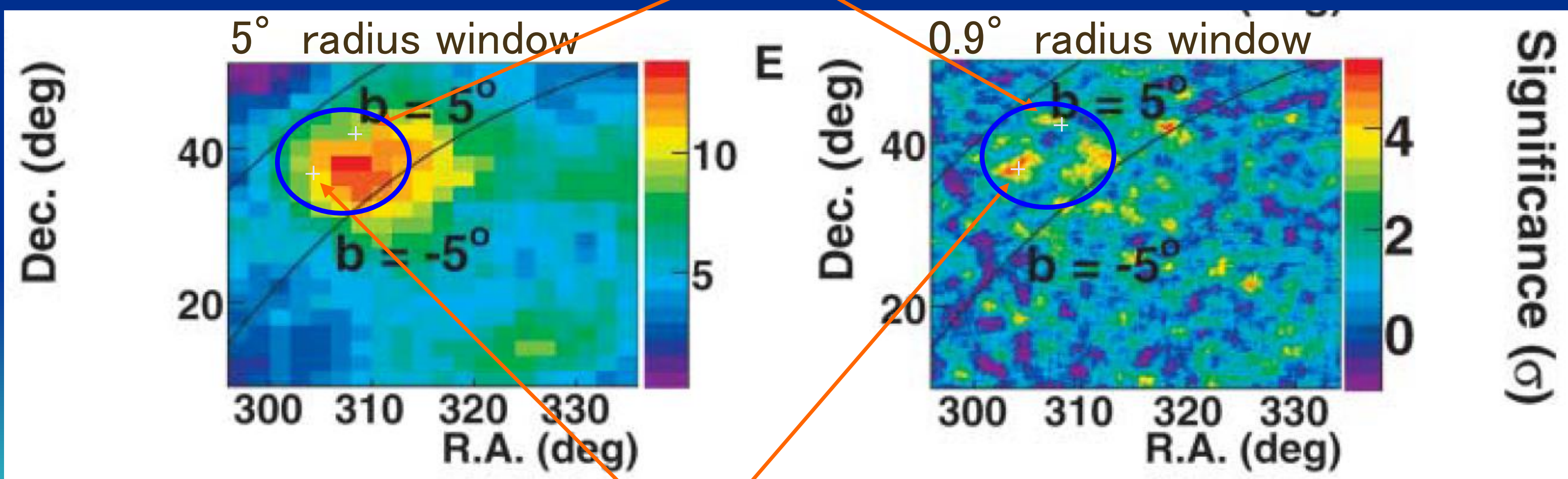
2D Large-scale Anisotropy Map

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



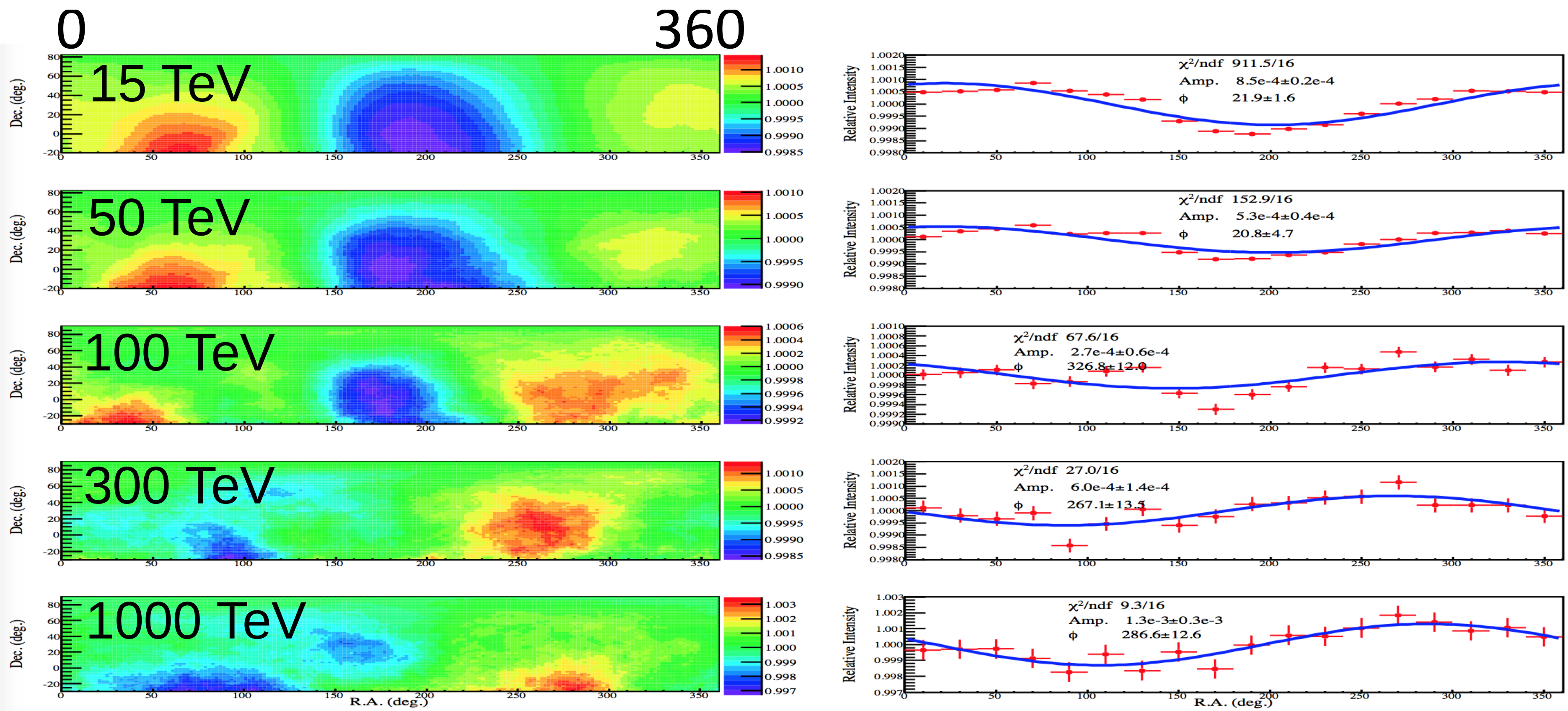
①MGRO J2033+42

Cygnus Region



②MGRO J2019+37

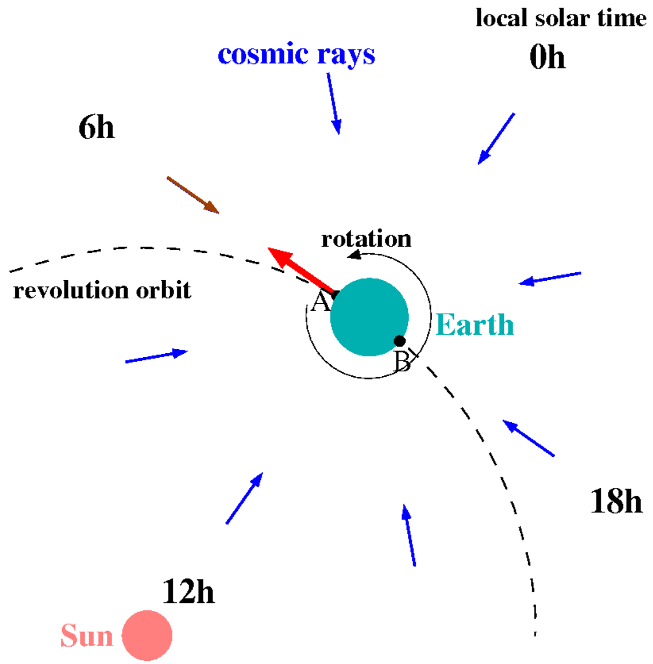
10-1000TeV CR Sidereal Anisotropy (Tibet)



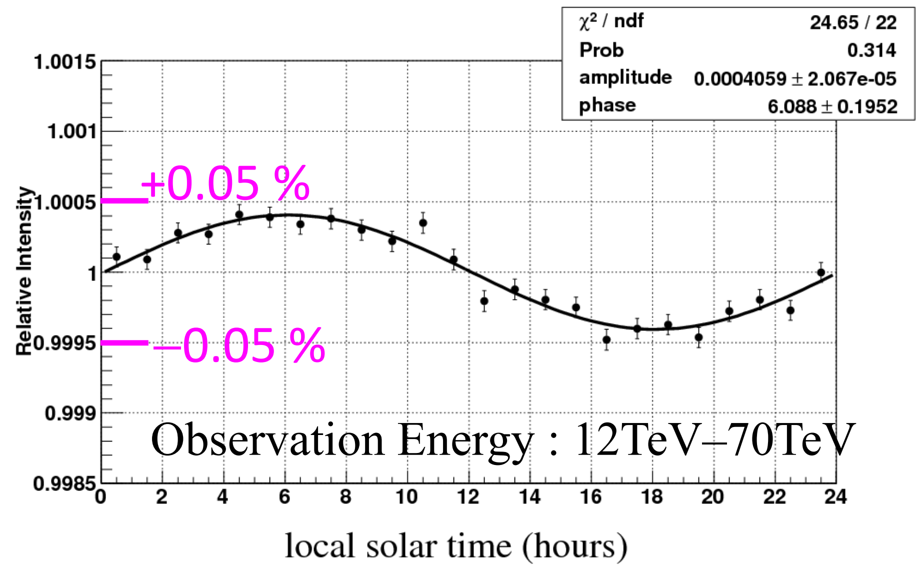
M. Amenomori et al, ApJ, **836**, 153-1-7, (2016)

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

Compton-Getting Anisotropy at Solar Time Frame



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



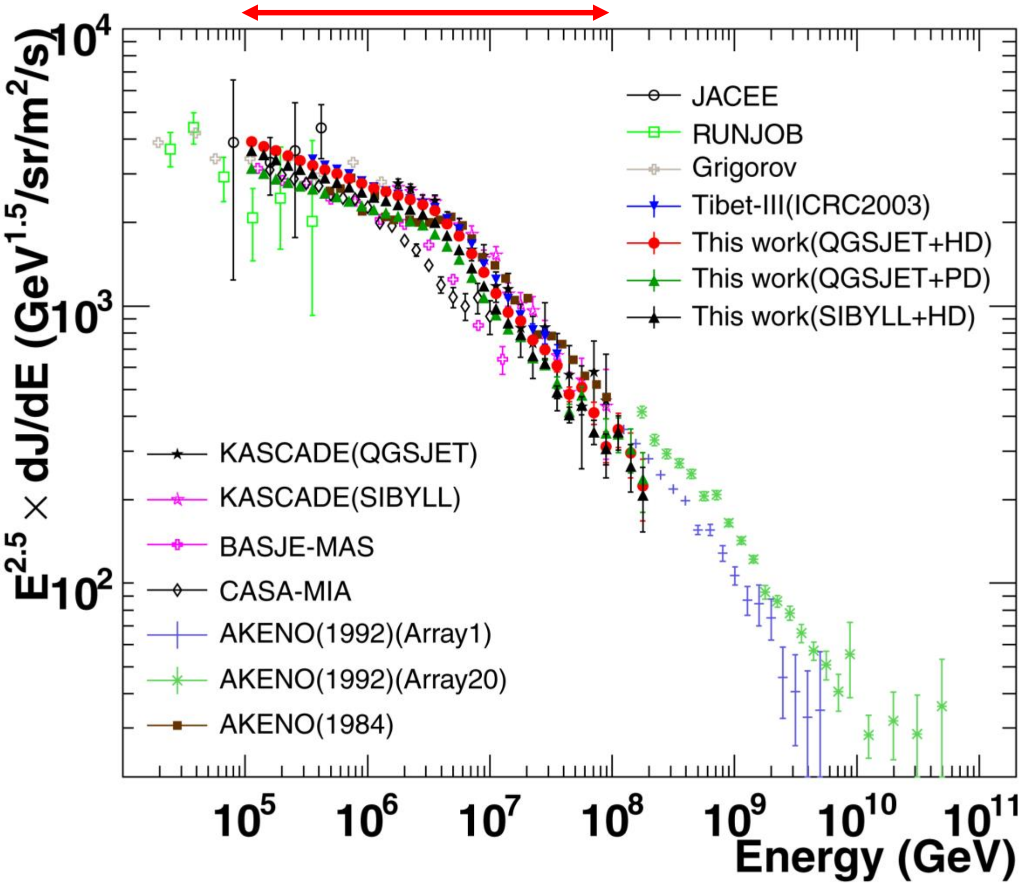
Expected	Amplitude 3.86 x 10^{-2} %	Phase 6 [hr]
Data	Amplitude (4.06 ±0.21) x 10^{-2} %	Phase 6.1±0.2 [hr]

➡ **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

10^{14}eV ～ 10^{17}eV (3 orders)



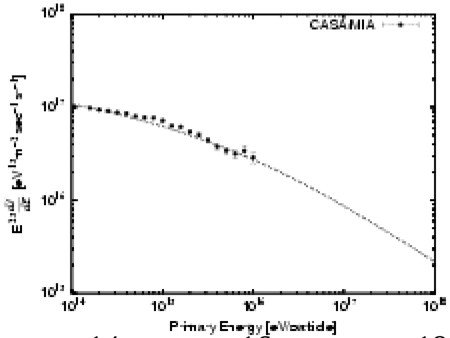
Amenomori *et al.*,
ApJ, **678**, 1165 (2008)

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

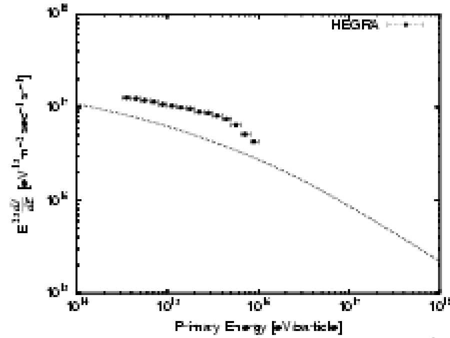
All particle spectrum around the knee

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

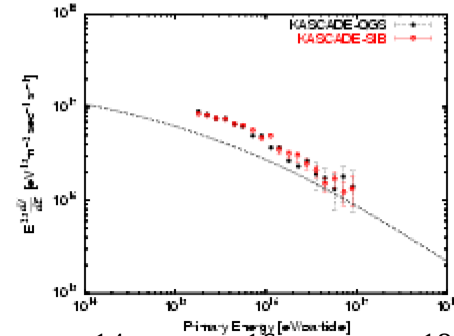
CASA/MIA HEGRA KASCADE



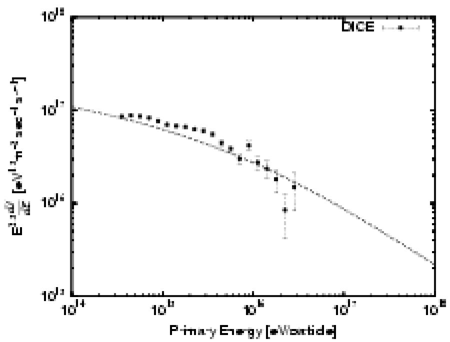
10^{14} 10^{16} 10^{18}



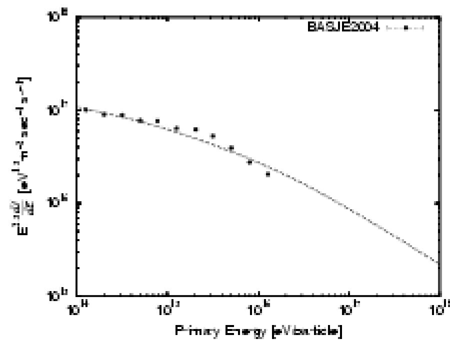
10^{14} 10^{16} 10^{18}



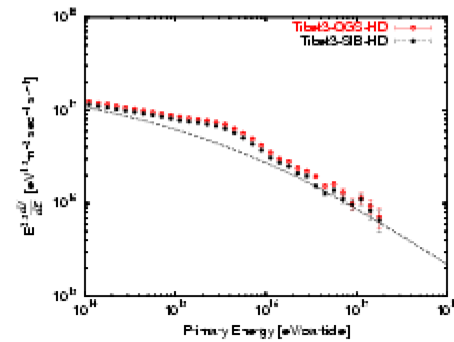
10^{14} 10^{16} 10^{18}



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



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

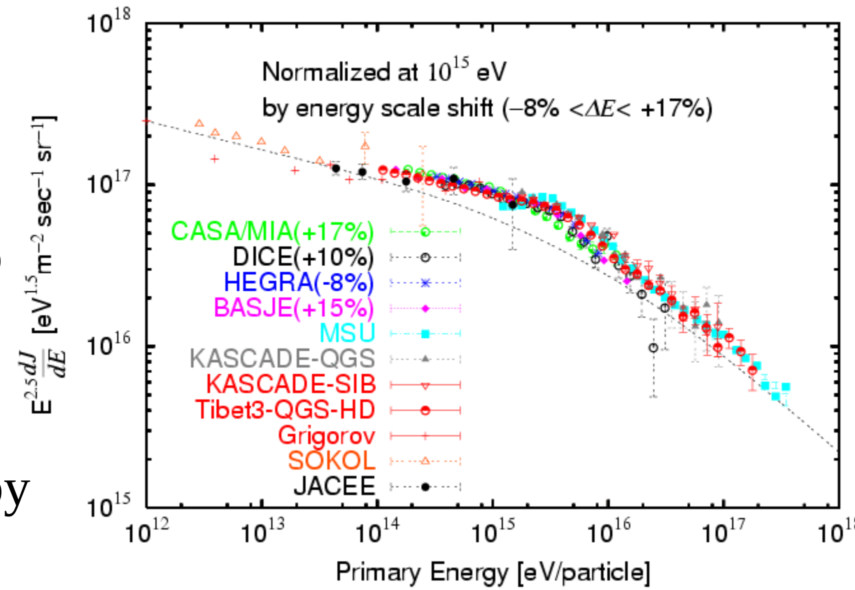


10^{14} 10^{16} 10^{18}

DICE BASJE TIBET

Extra component

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

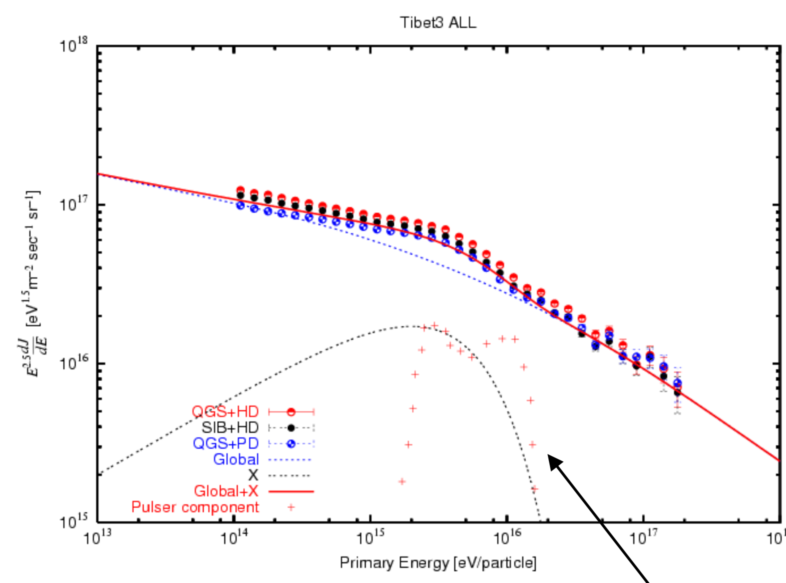


Extra component can be approximated by

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

suggesting **nearby source(s).**

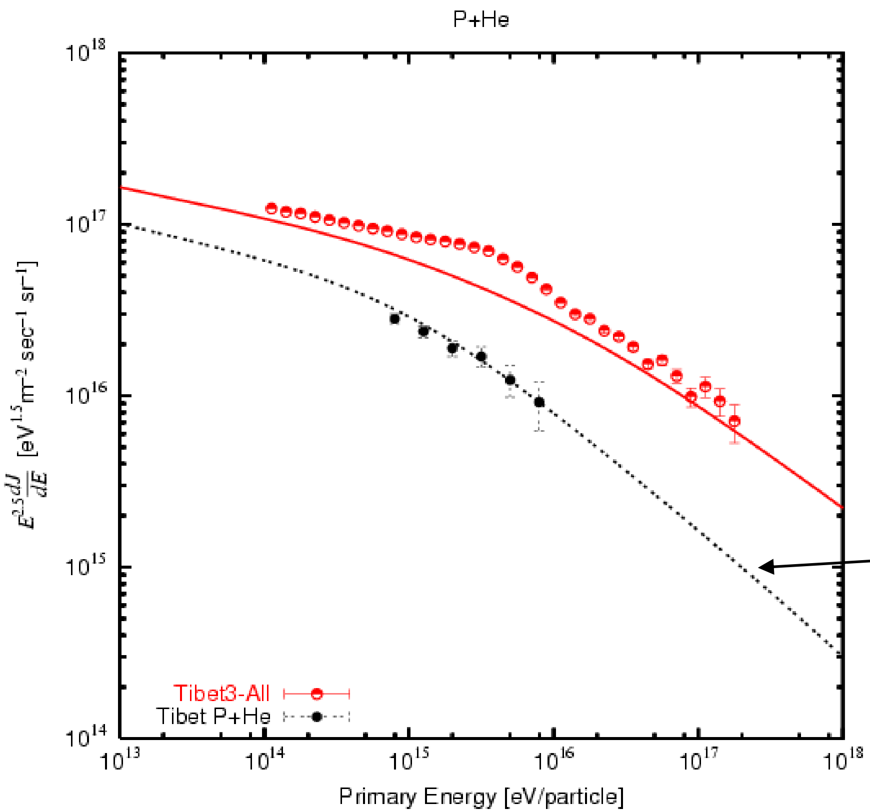
Since P and He component do not show the excess at the knee, the extra component should be attributed to heavy element such as Fe.



(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

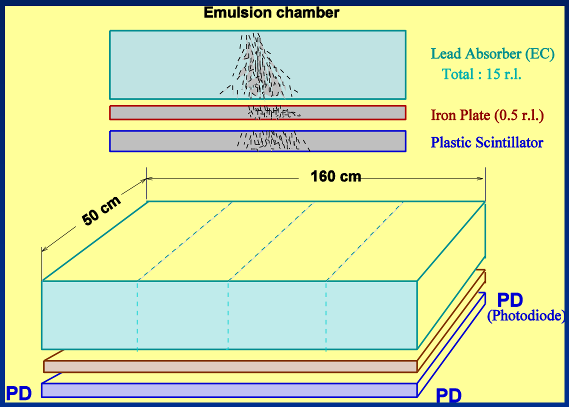


Tibet All particle
Data vs. Expected by multiple source model

P+He
Data vs. Expected by multiple source model

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

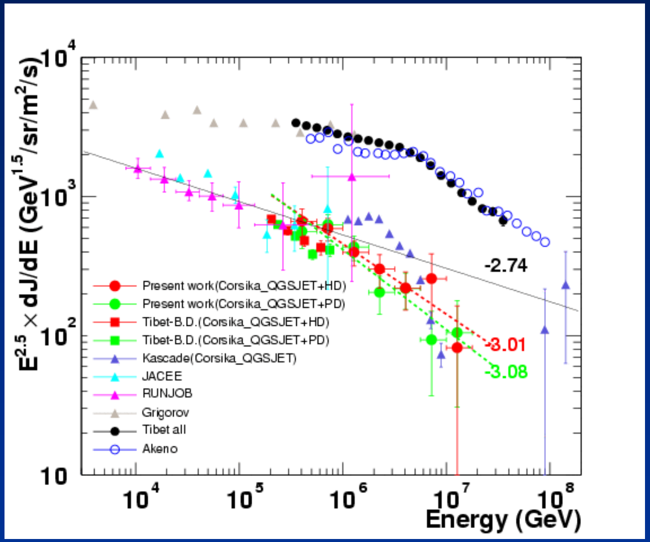
一次宇宙線陽子・Ｈｅ成分の観測



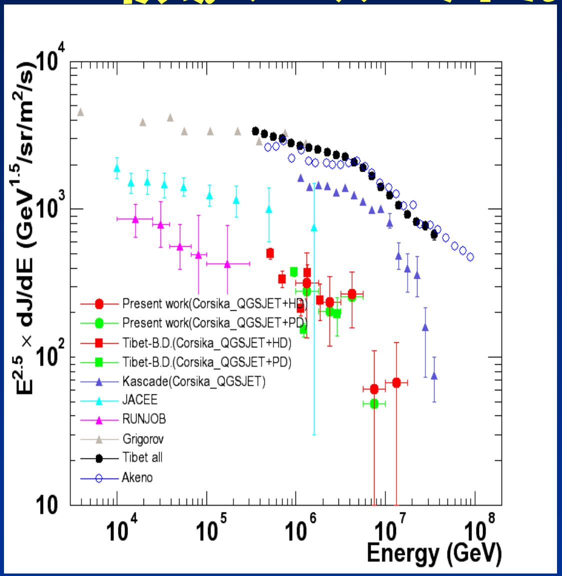
Burst検出器：100台

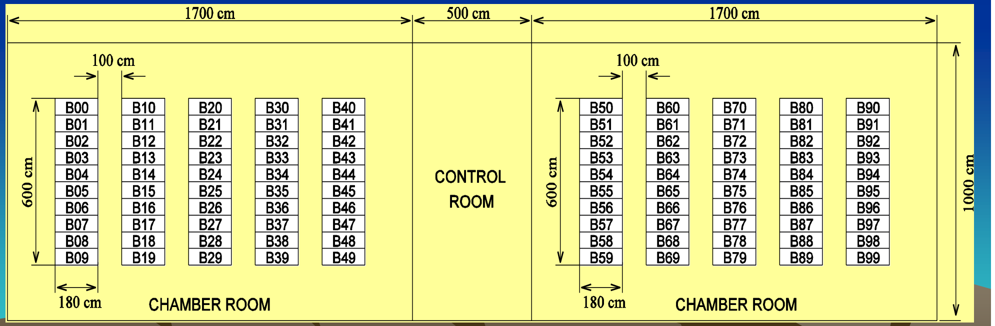
検出器総面積：80㎡

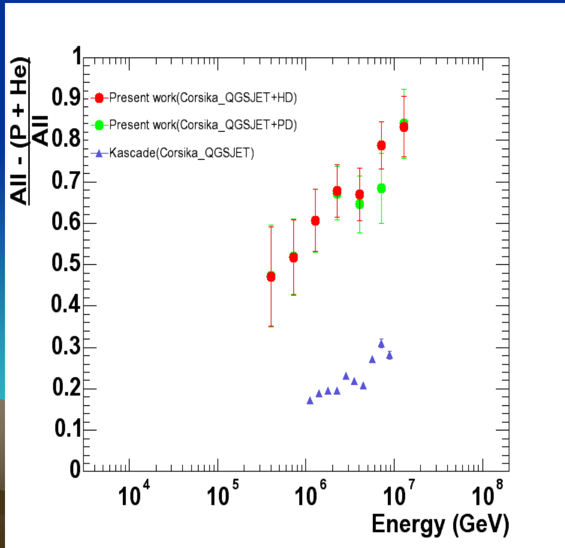
Knee領域の陽子スペクトル



Knee領域のHeスペクトル





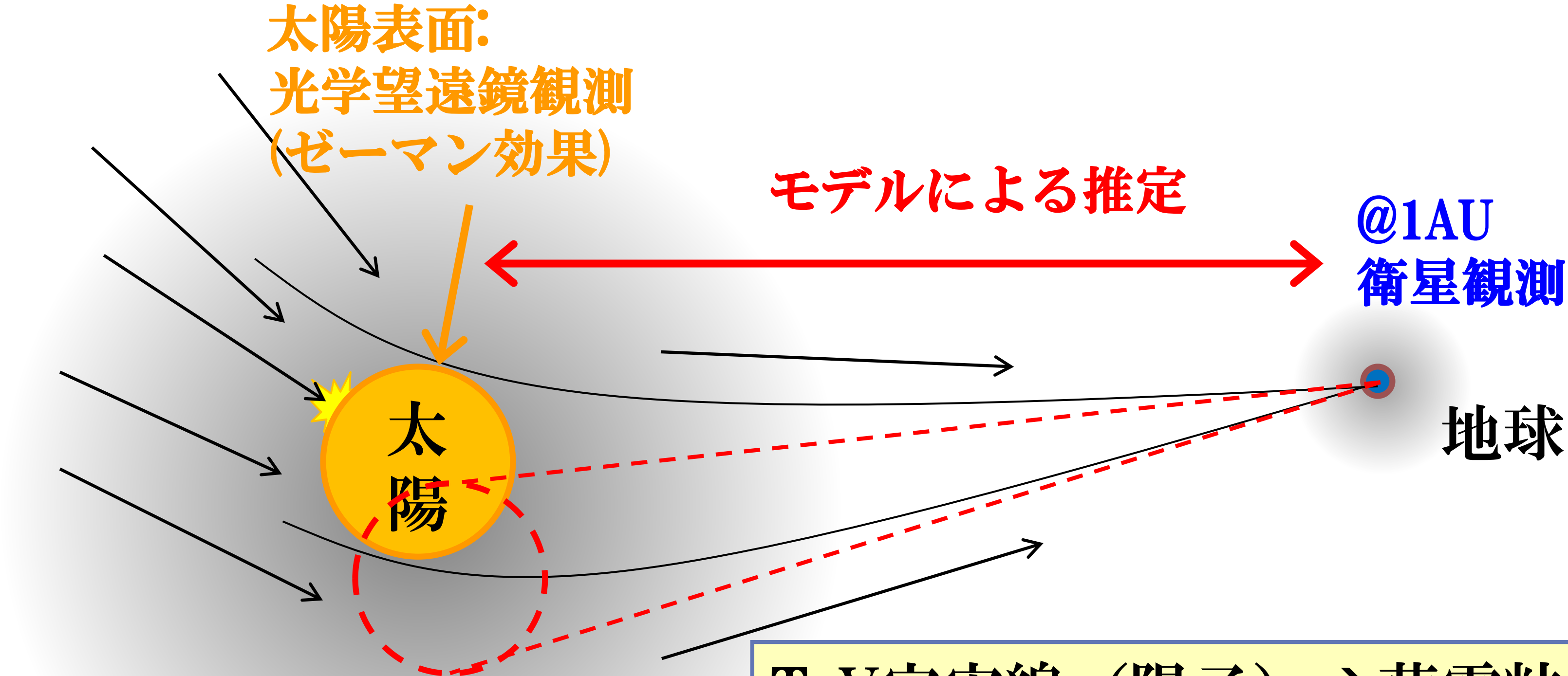


エネルギーが高いと

重粒子の割合が増加

「太陽の影」

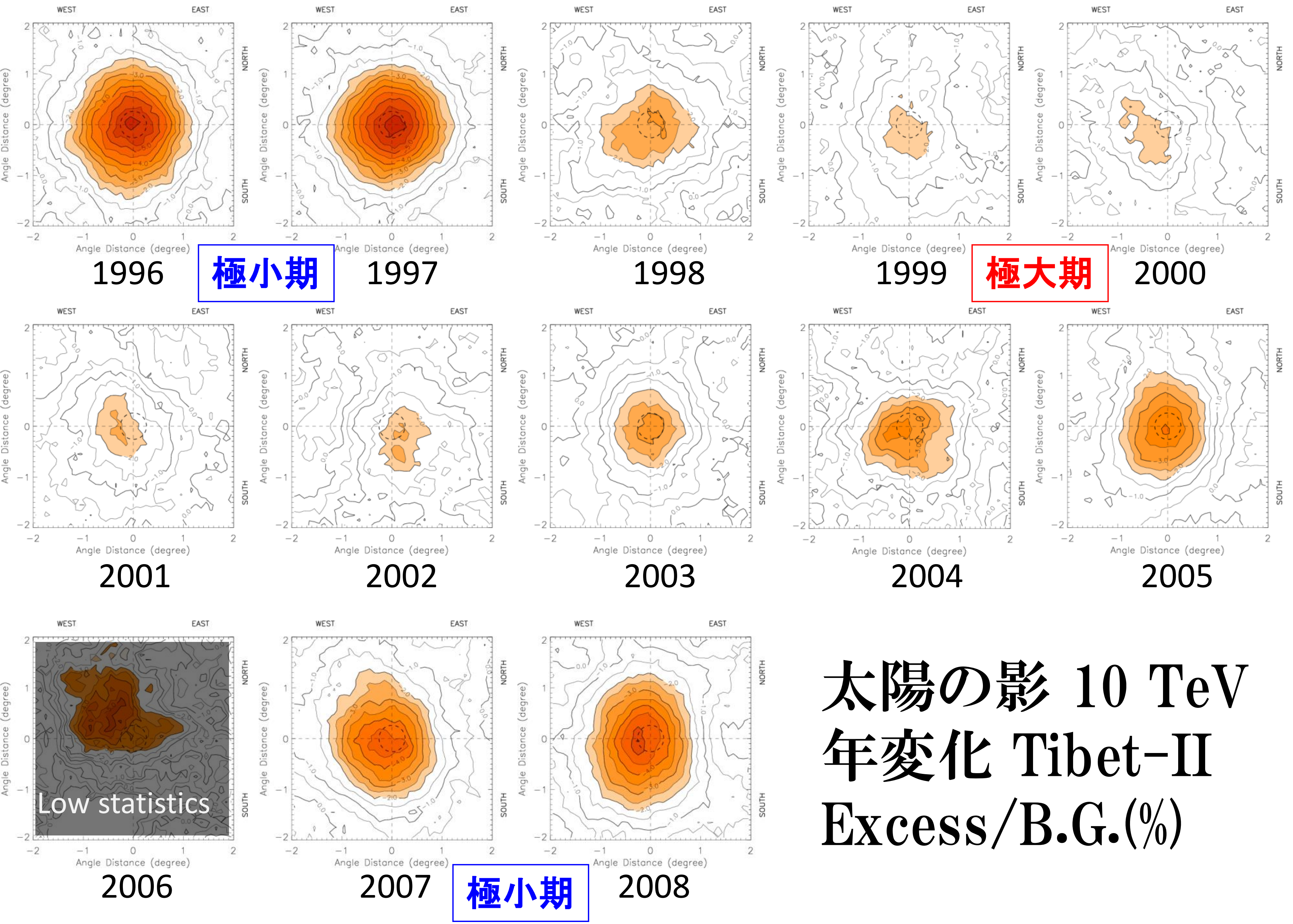
太陽による宇宙線の遮蔽



「太陽の影」の
深さ、方向、形に影響

TeV宇宙線（陽子）→荷電粒子
ラーモア半径
～7.4AU　(B=30μG 地球近辺)
～0.16$R_{\odot}$(B=300mG 太陽近辺)
→ 太陽磁場構造のプローブ！

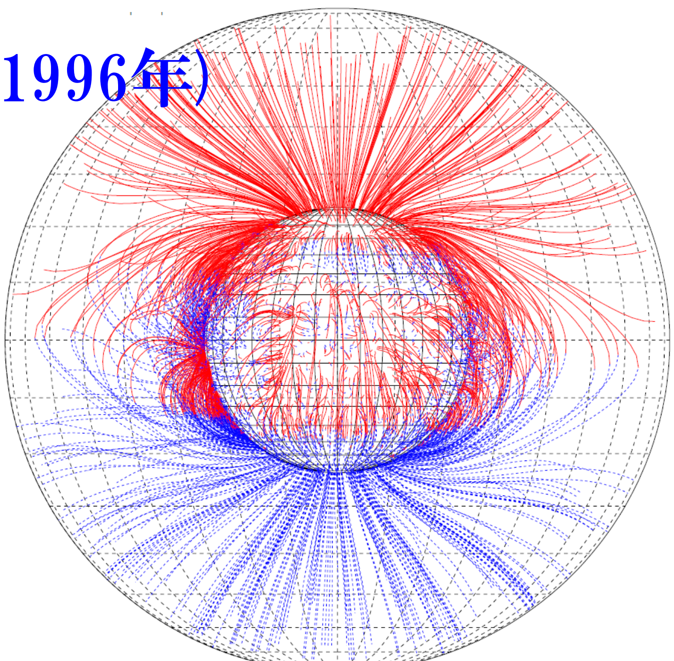
太陽の影 10 TeV 年変化 Tibet-II Excess/B.G.(%)



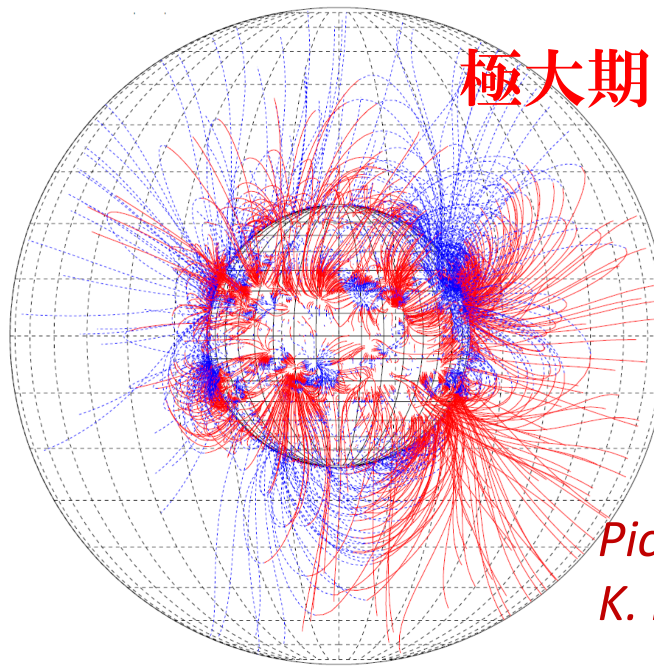
仮定する太陽圏の磁場

<u>コロナ磁場</u> → 2つのSource Surface モデル (PFSS / CSSS)
Kitt Peak の太陽表面磁場の観測から推測する
太陽の１自転周期(~27日)ごとの平均モデル
<u>惑星間磁場</u> → パーカー・スパイラルモデル
太陽風速度は名大IPS観測の緯度依存を考慮
<u>地磁気</u> → 双極子磁場モデル

極小期(1996年)
PFSS



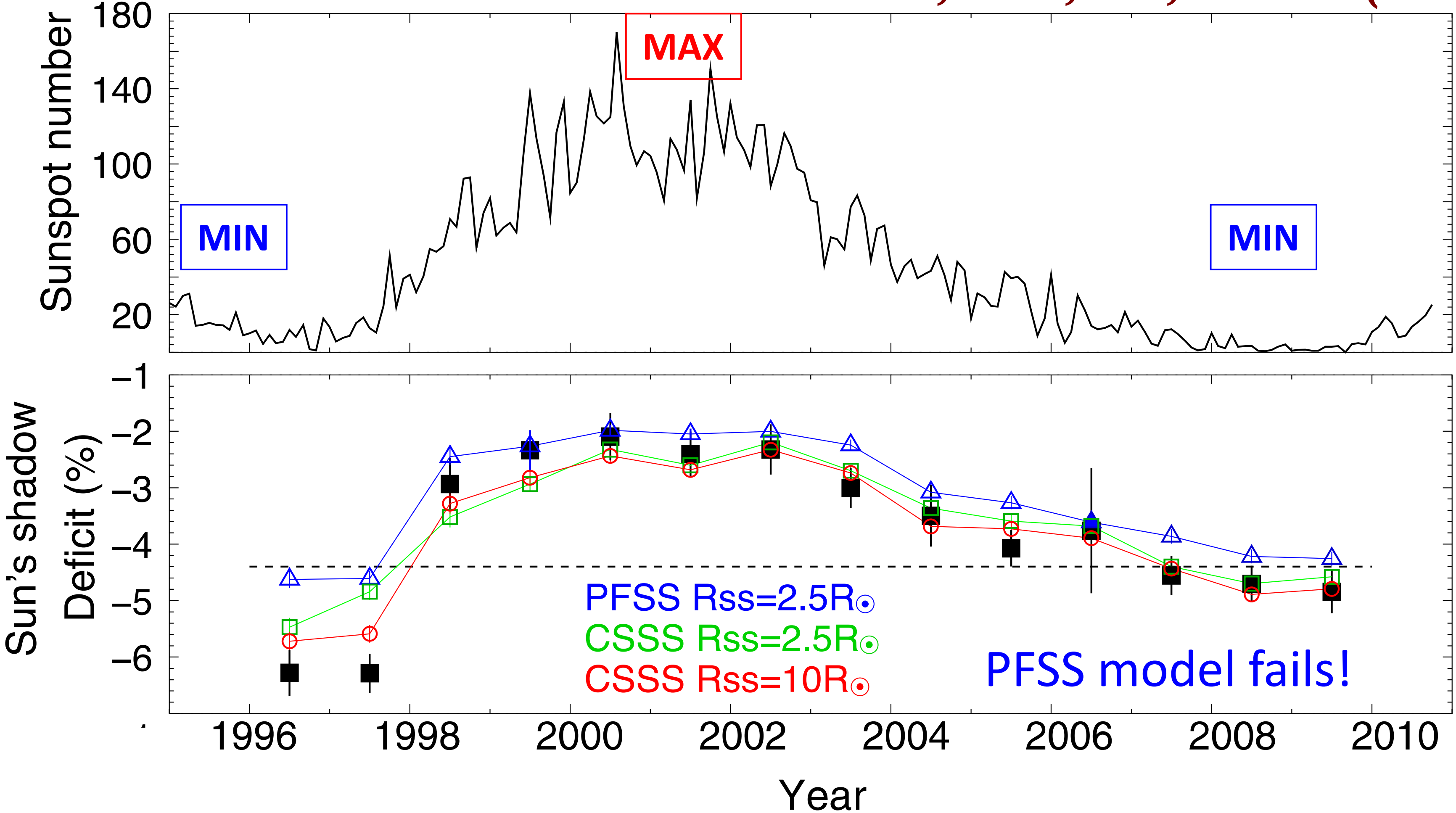
極大期(2000年)
PFSS



Pictures from
K. Hakamada

Past Results (Tibet-II >10TeV)

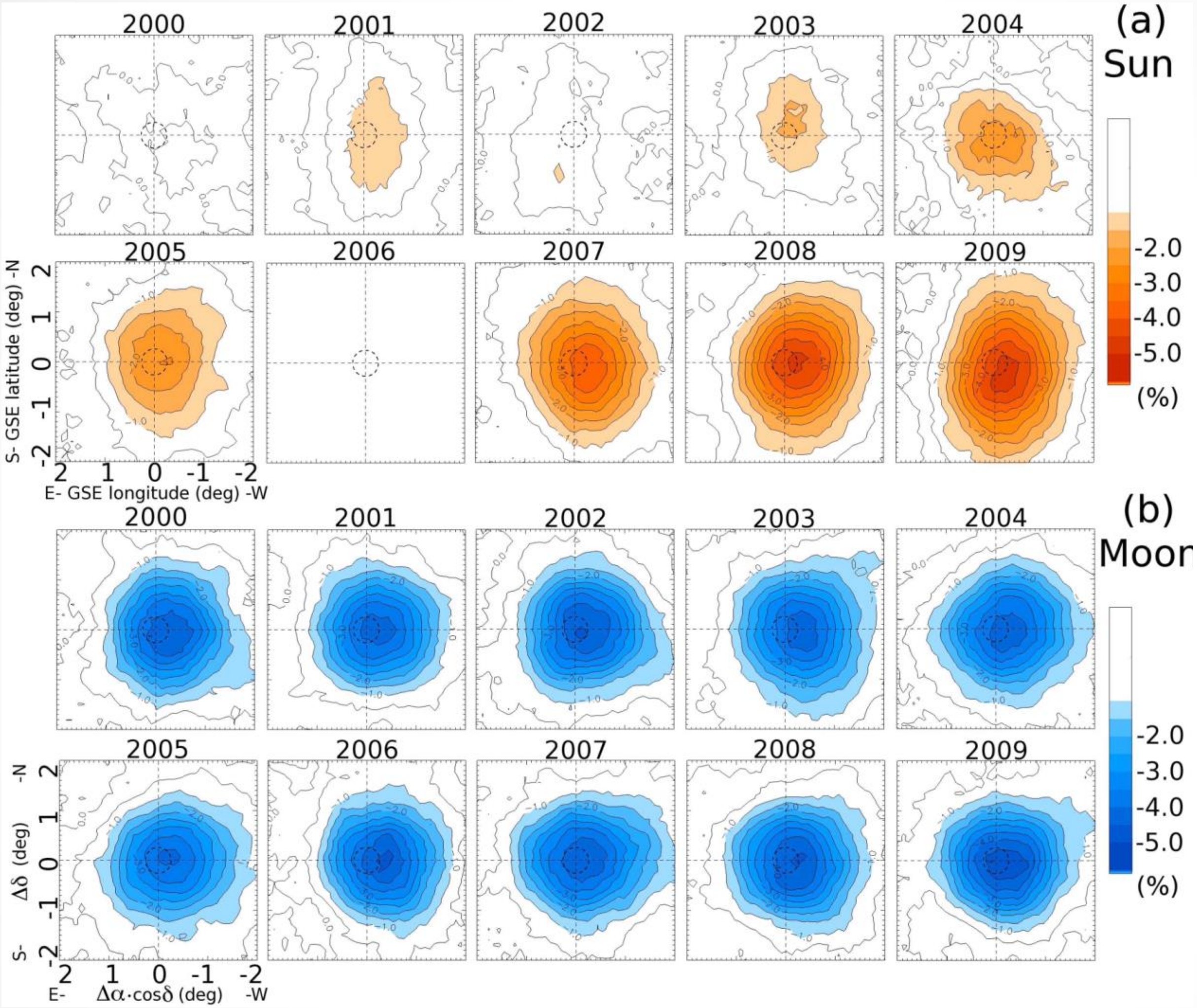
Amenomori et al, PRL, 111, 011101 (2013)



- ✓ 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 TeV領域

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

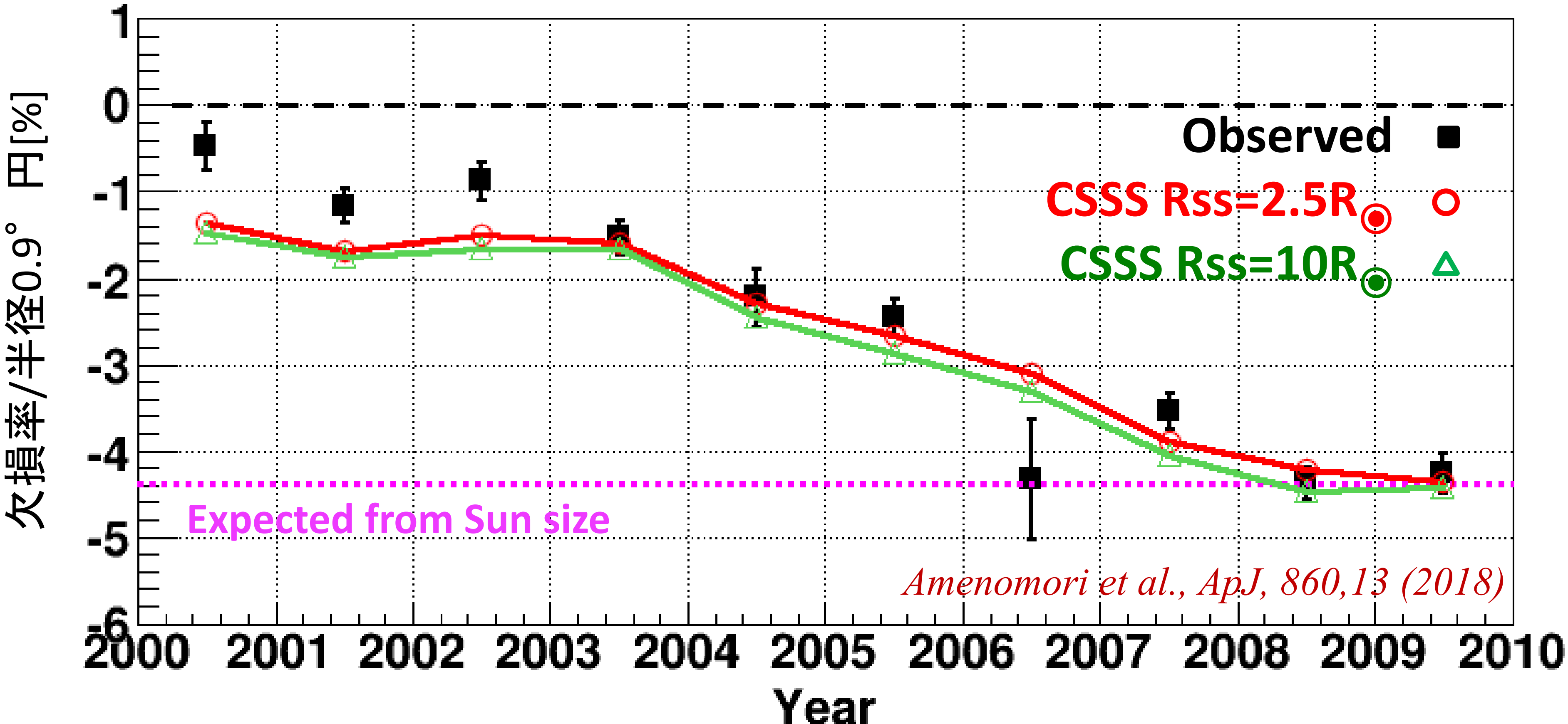


太陽の影
→太陽コロナ磁場
の影響で変動

月の影

- ✓ 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

影の深さの変化 全期間 - 3 TeV



χ^2 test :

χ^2 / dof = 32.1 / 10 (3.4σ)

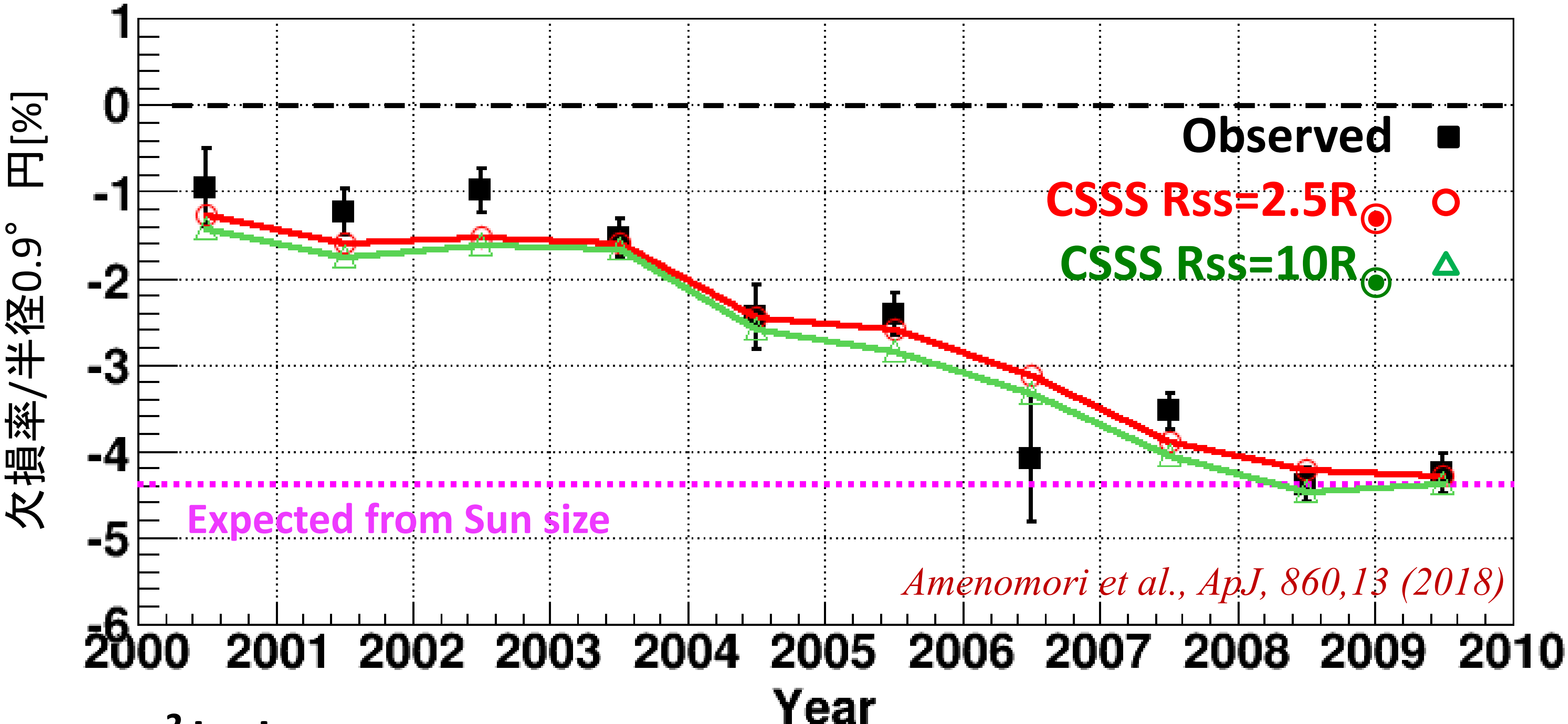
χ^2 / dof = 46.9 / 10 (4.8σ)

３TeV：CSSSは極大期を再現しない？
(10TeVはCSSSで良く再現されている)

Coronal Mass Ejection の影響？

Earth-directed CME catalog (Richardson & Cane 2010)

影の深さの変化 CME発生期間を除く



χ^2 test :

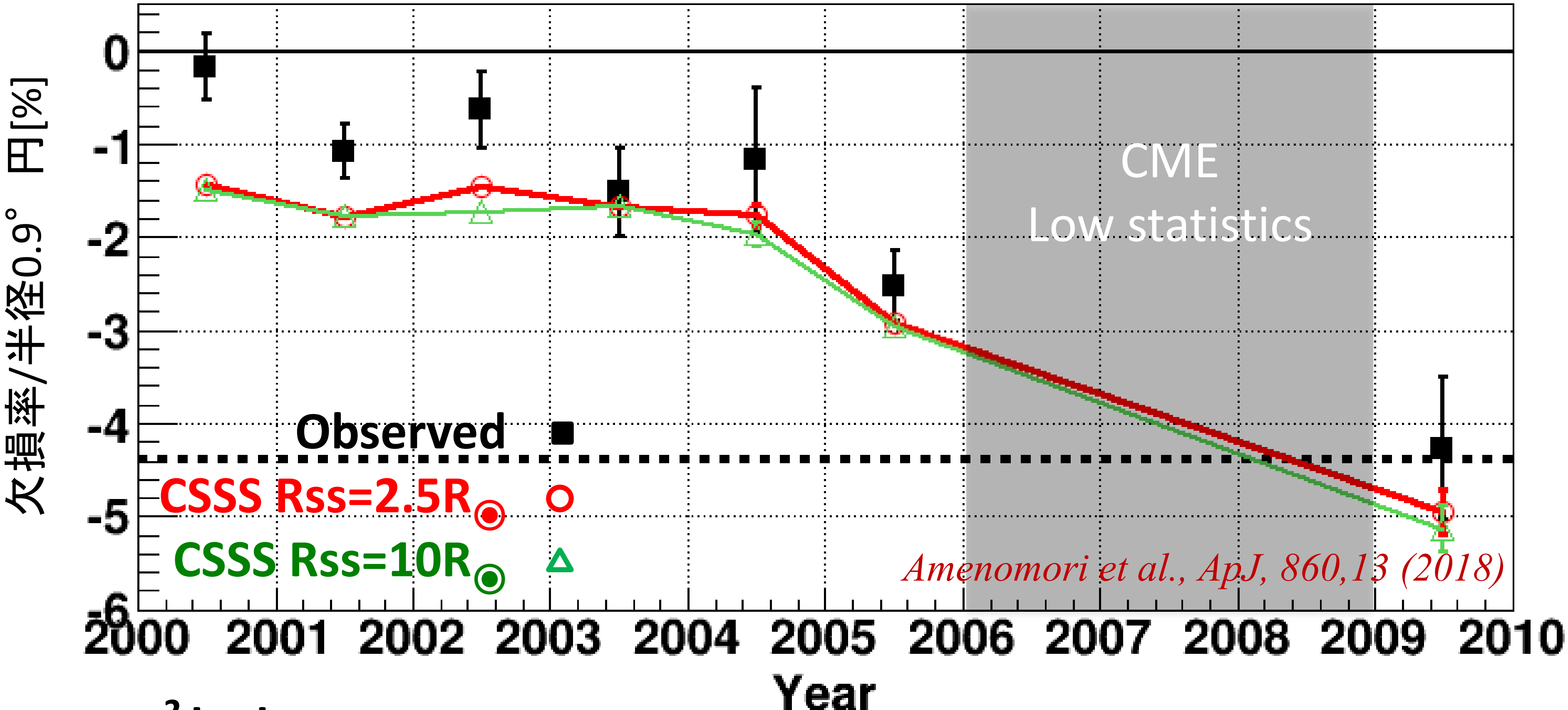
χ^2 / dof = 12.2 / 10 (0.6σ)

χ^2 / dof = 21.0 / 10 (2.0σ)

活動期ではCMEが多く影が深くなり
実験データを再現
→ 磁場モデルにはCME等の
　短期変動は考慮されない

Earth-directed CME catalog (Richardson & Cane 2010)

影の深さの変化 CME発生期間のみ



χ^2 test :

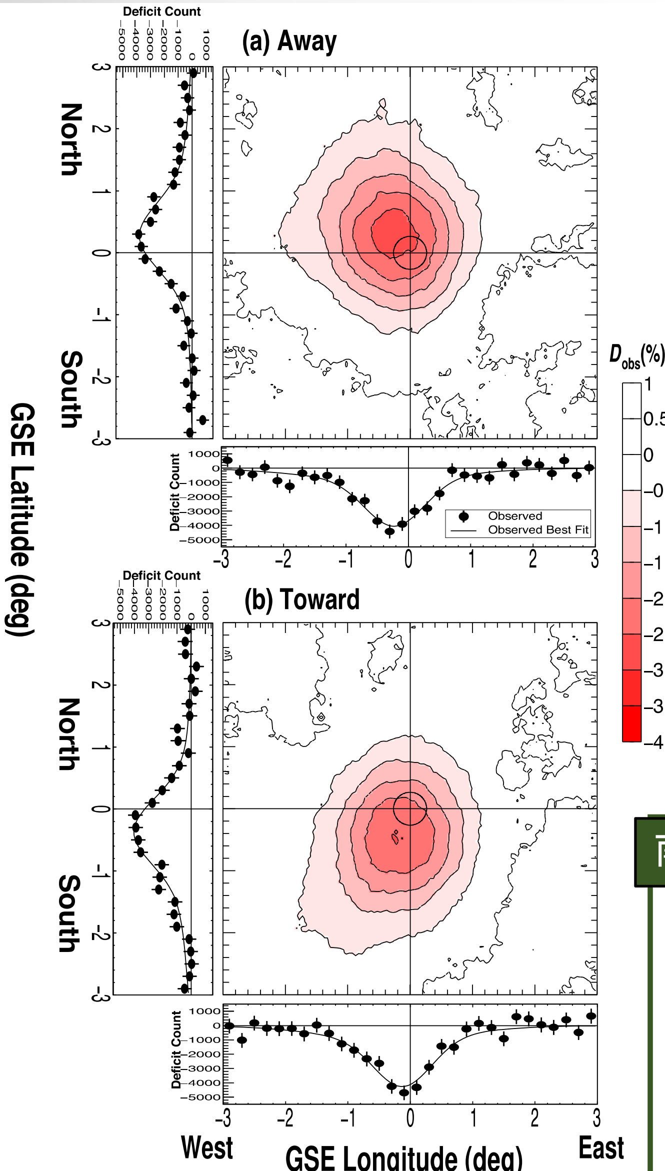
χ^2 / dof = 23.9 / 7 (3.0σ)

χ^2 / dof = 29.4 / 7 (3.7σ)

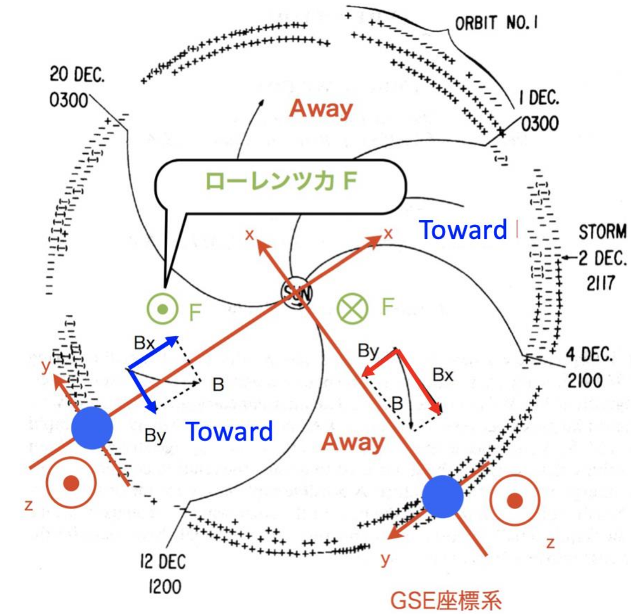
CMEは太陽の影を薄める効果
→ 将来的に宇宙天気予測が可能?

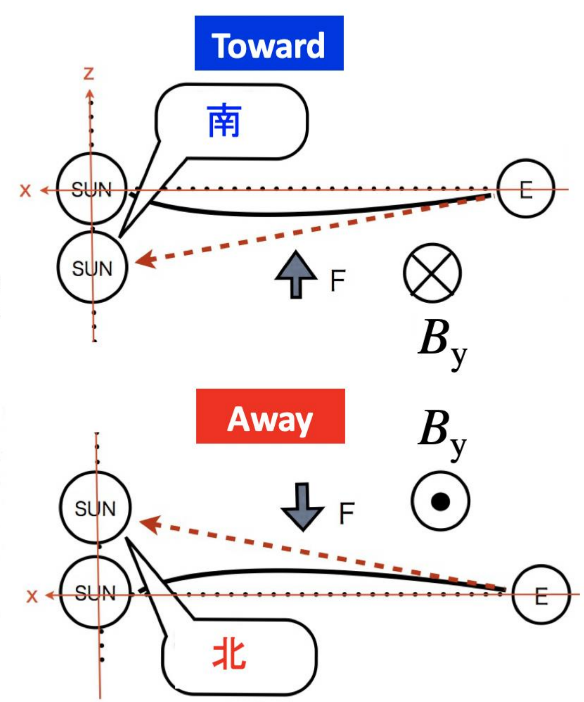
影の方向の観測 Toward/Away

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



惑星空間磁場の間接測定





南北

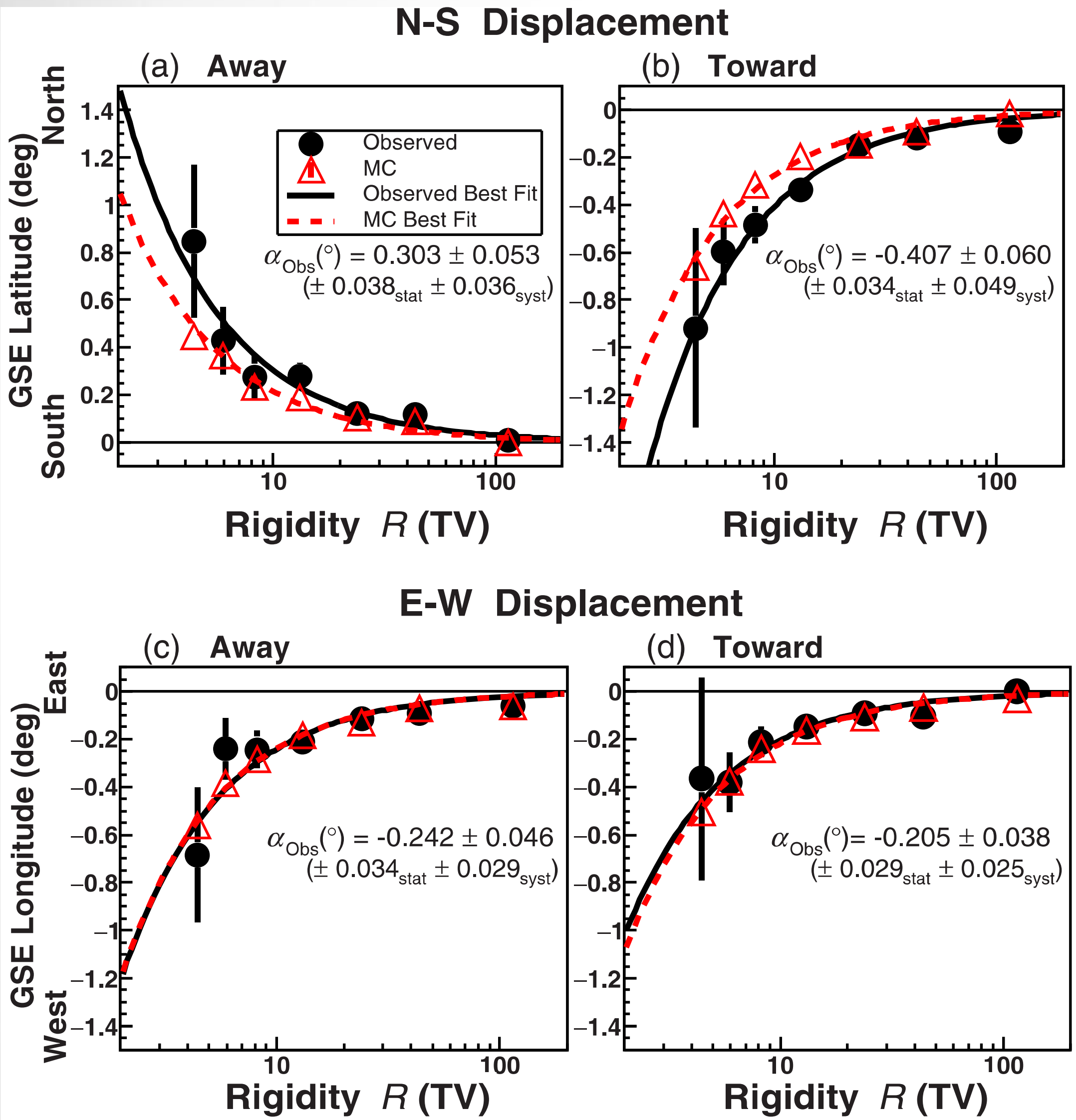
惑星間空間磁場(IMF)には、極性が逆の Away セクターと Toward セクターが存在し、磁場の#$ %&' (#の符号によって宇宙線の曲がる方向が逆になる

Toward'sector':') *+, - <0''=>'南向きのずれ

Away'sector':) *+, - >0'=>'北向きのずれ

影の方向の観測 Toward/Away

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



<u>南北方向のズレ</u>

Data/MC比 →

Away　: 1.54 ± 0.21_{stat} ± 0.20_{syst}

Toward : 1.62 ± 0.15_{stat} ± 0.22_{syst}

磁場モデルの問題か？
- ポテンシャルフィールドモデル
- 太陽表面磁場計測の系統誤差
(モデルへのインプット)

<u>東西方向のズレ</u>

→ ほとんど地磁気で説明できる

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

100 TeV領域 (10-1000TeV)ガンマ線天文学

By

Tibet-III (AS) + a large underground

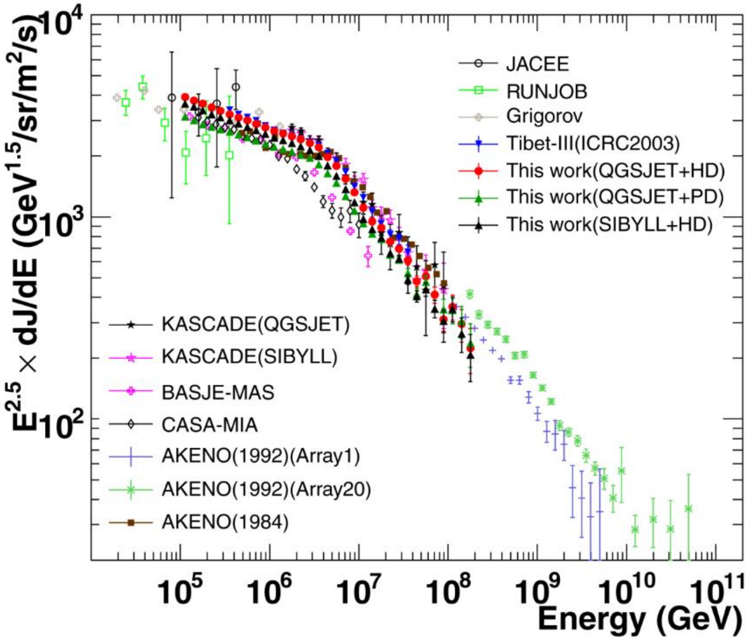
muon detector array (MD)

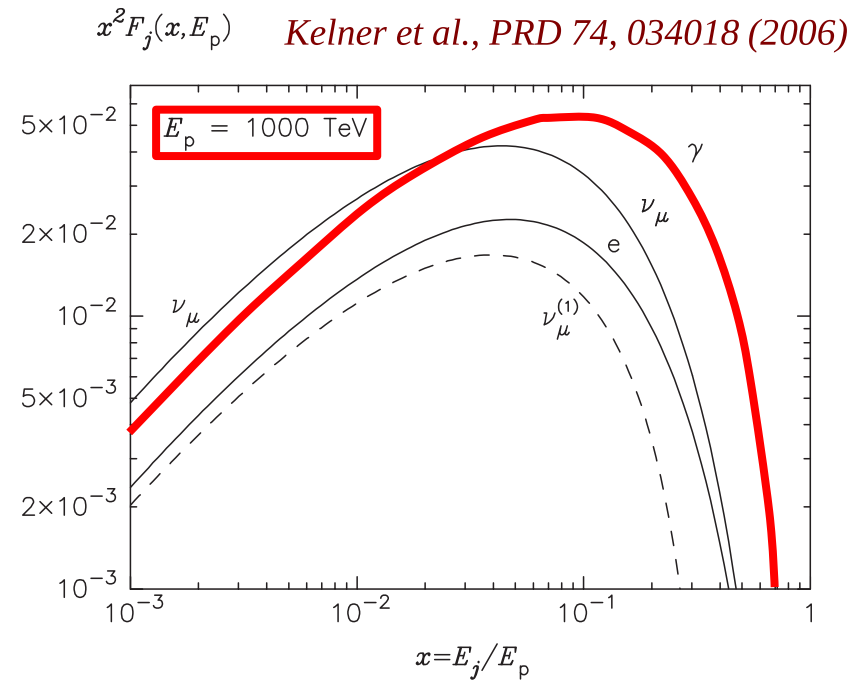
100 TeV以上の ガンマ線を観測できれば世界初

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

>Diffuse gamma rays

Origin of Cosmic Rays at the Knee





<u>宇宙線スペクトル</u>

✓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？

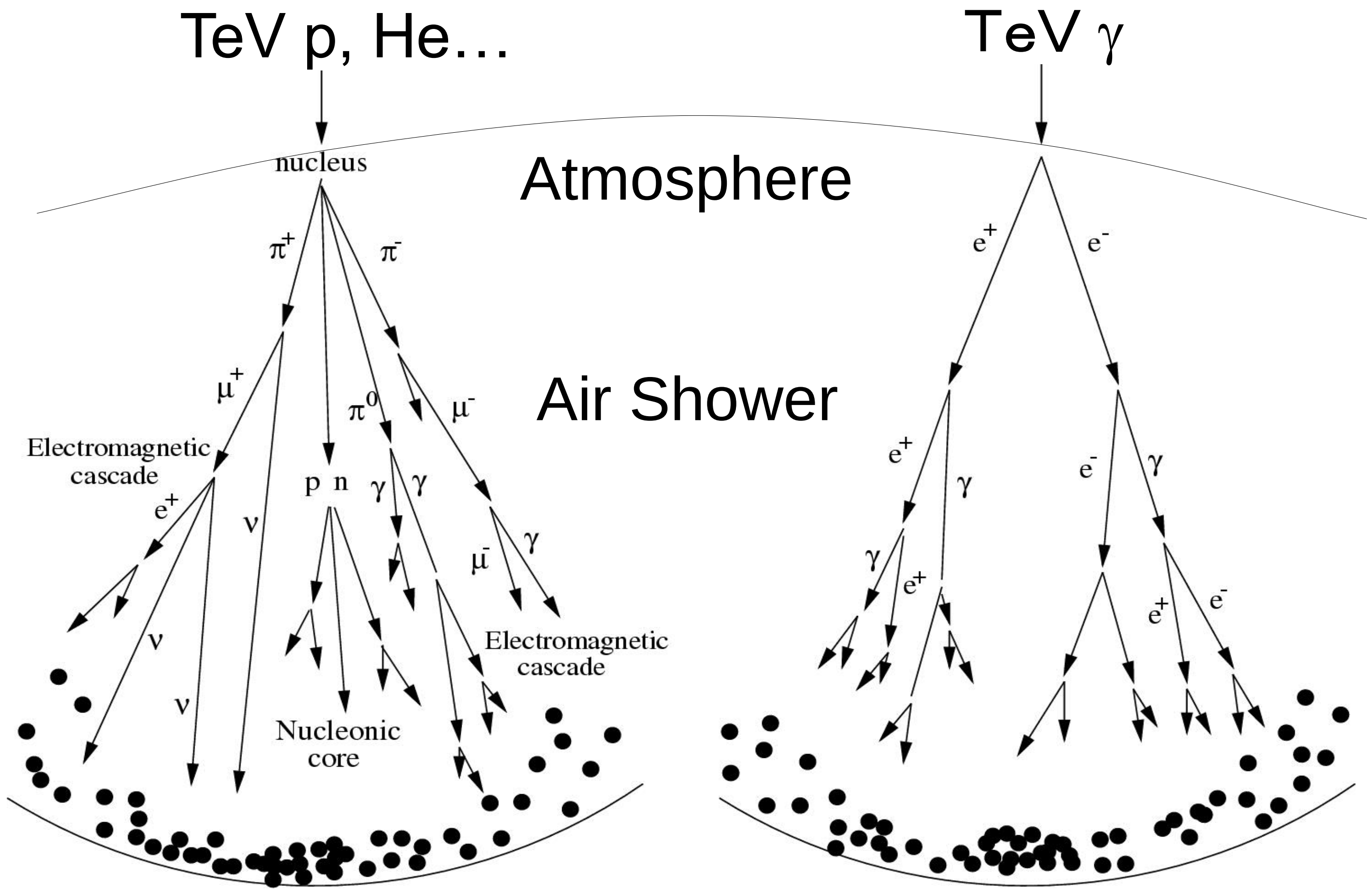
<u>ガンマ線スペクトル</u>

✓ 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

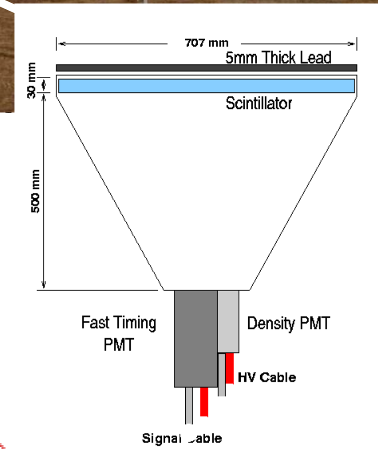


Number of muons（<100 m from core, 4300m a.s.l.）

100TeV Proton
~50

100TeV Gamma
~1

チベット空気シャワー観測装置 since 2014

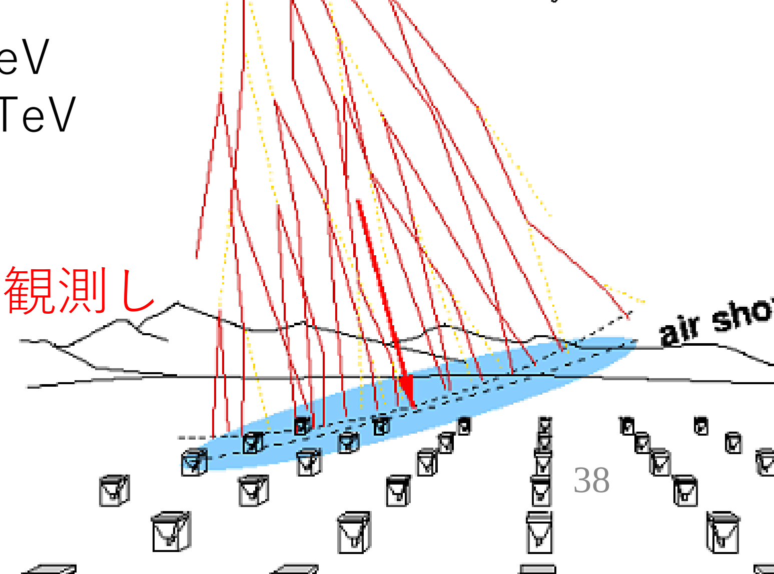


- チベット (90.522°E, 30.102°N) 標高4300 m

<u>現行スペック</u>

- シンチレーション検出器数　　0.5 m^2 x 597
- 空気シャワー有効面積　~50,000 m^2
- 観測エネルギー　　>TeV
- 角度分解能　　~0.5°　@10TeV
  　　~0.2°　@100TeV
- 視野　　~2 sr

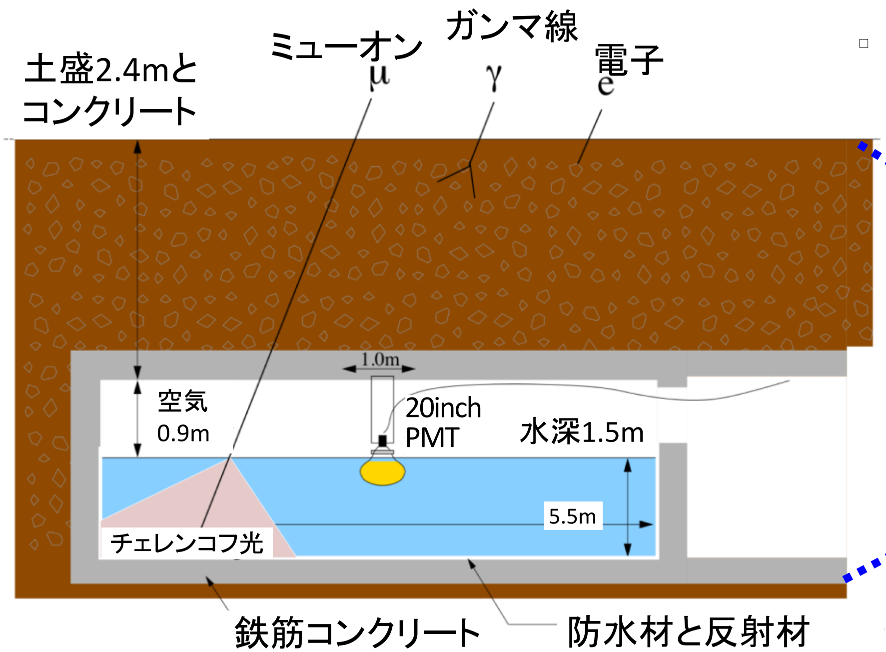
→空気シャワー中の二次粒子(主に$e^{+/-}$, γ)を観測し
一次宇宙線エネルギー、方向を決定

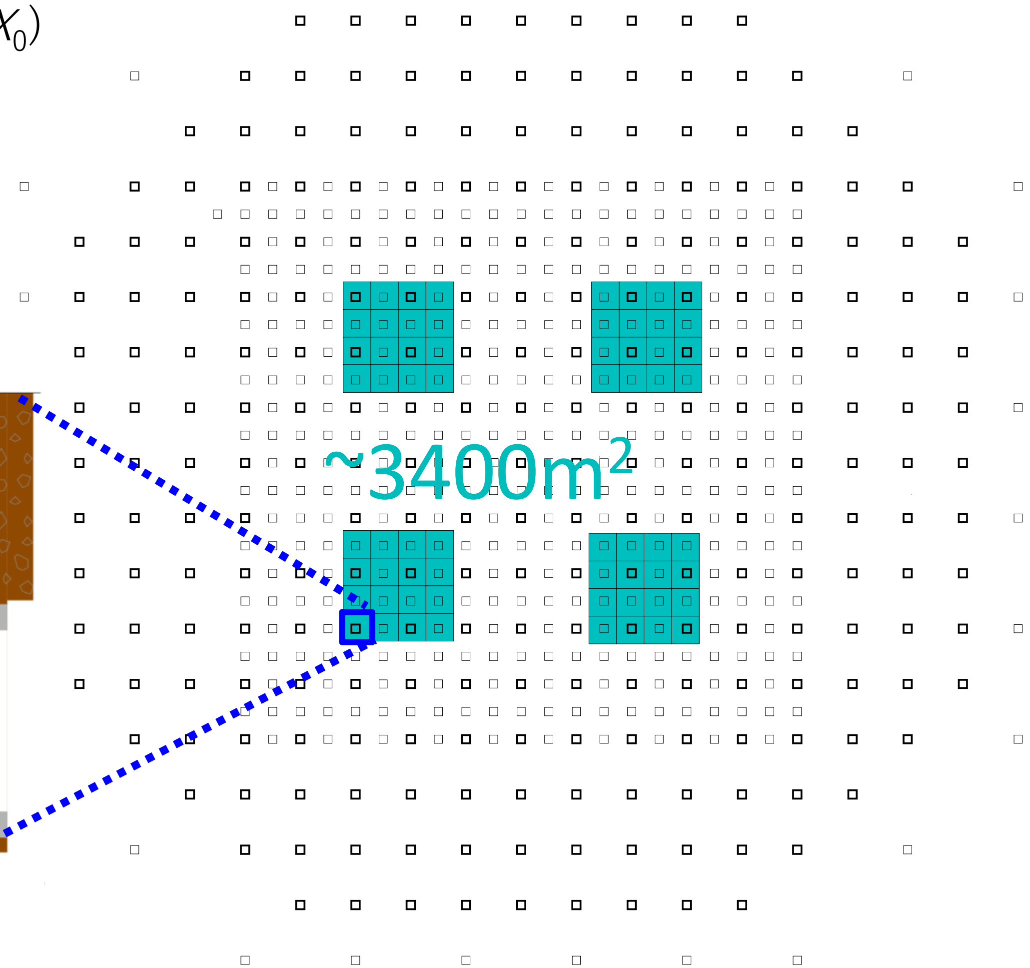


水チェレンコフ型ミューオン観測装置

Kawata et al., JPS meeting (2018)

- ✓ 地下 2.4m (物質厚 ~ 515g/cm2 ~19X_0)
- ✓ 7.35m×7.35m×水深1.5m　水槽
- ✓ 20”ΦPMT (HAMAMATSU R3600)
- ✓ 水槽材質：コンクリート+タイベック

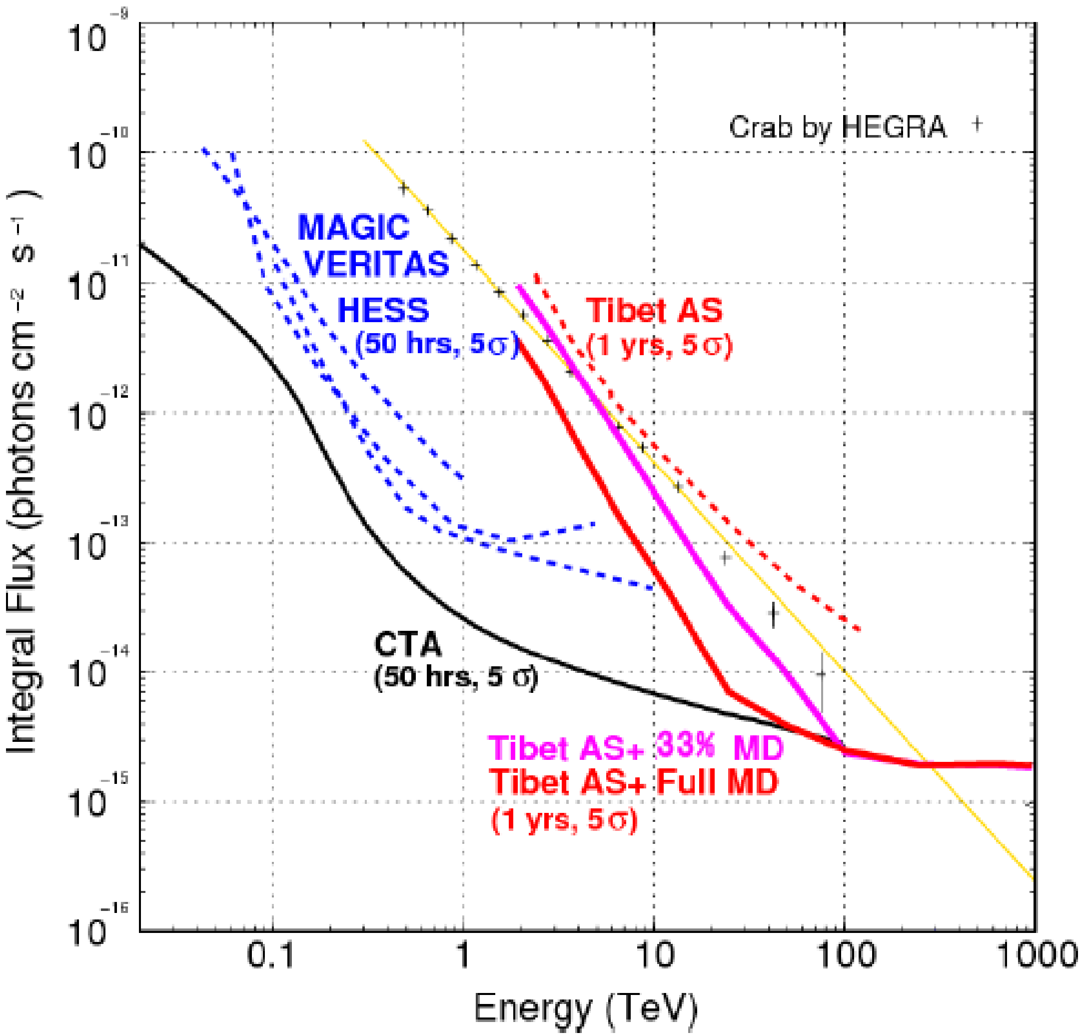




→空気シャワー中のミューオン数を測定し、ガンマ線／核子選別

2014年2月 ー 2017年5月　**有効観測時間：720日**

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



+Full:10000m^2 MD

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

+33%: 3400m^2 MD

X 3~4 @10TeV
X ~10 @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

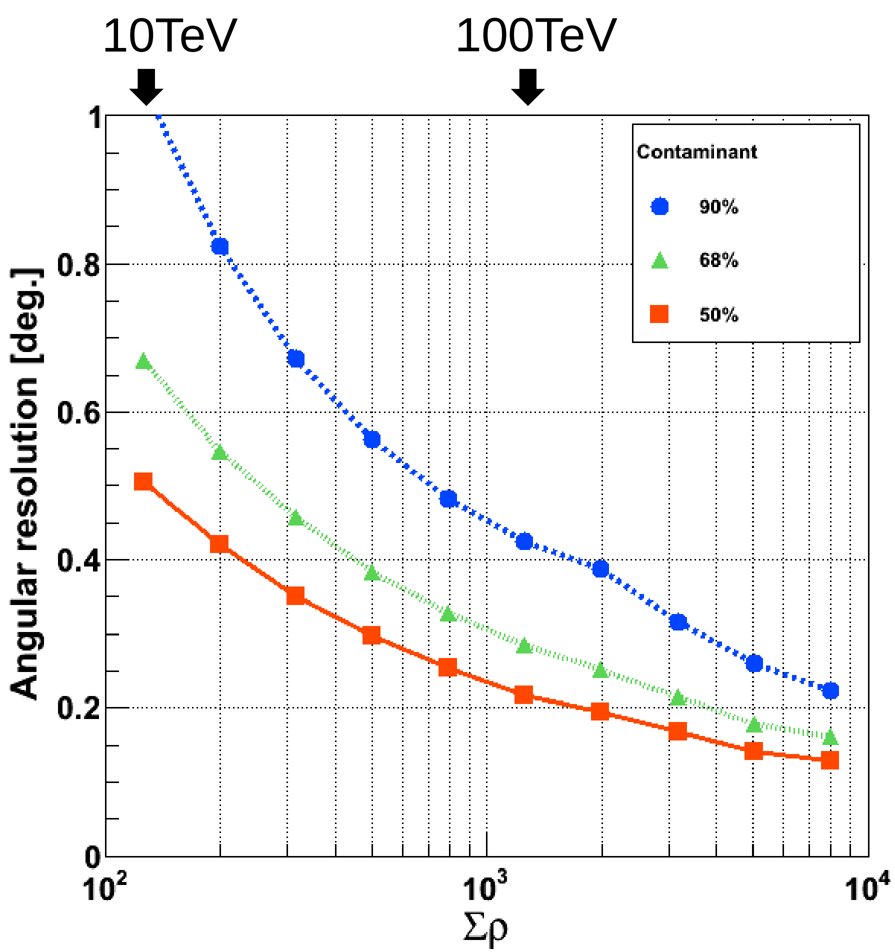
2013/10/10
3,400m2
地下施設
Image © 2014 CNES / Astrium

角度分解能・エネルギー分解能

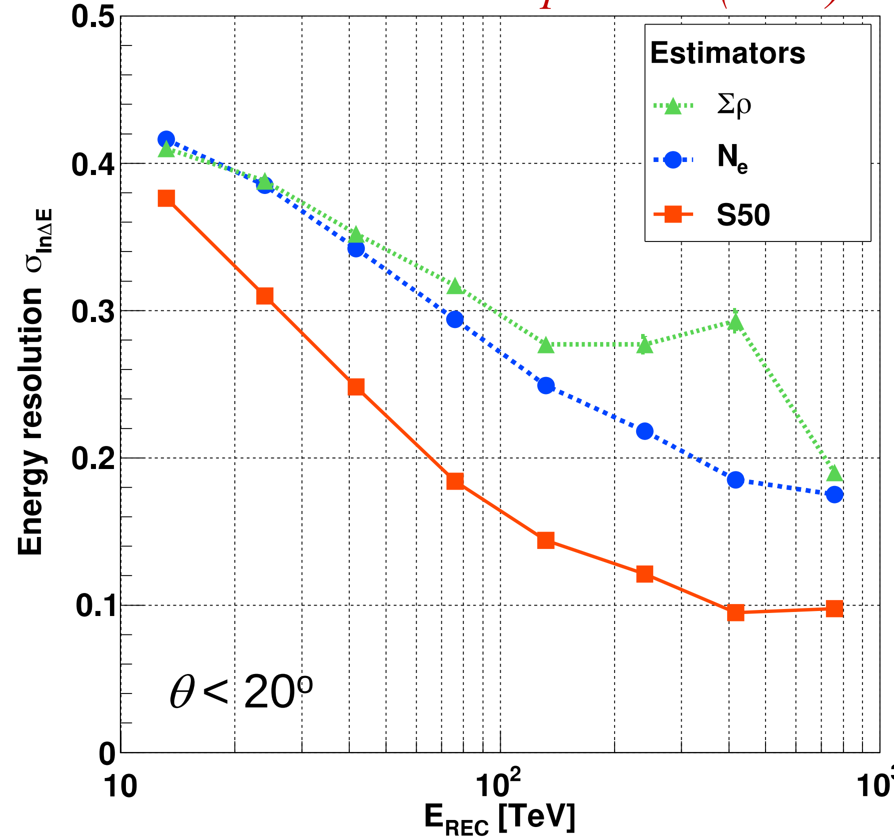
Kawata et al., JPS meeting (2018)

→ Full MCシミュレーションによる推定

✓ 空気シャワー生成：Corsika (ガンマ線、Crab軌道)
✓ シンチ検出器 & ミューオン検出器の応答：GEANT4

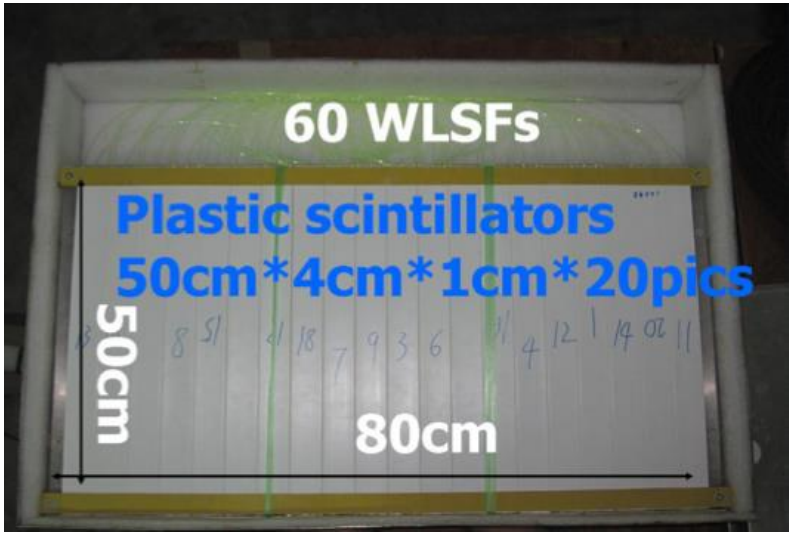


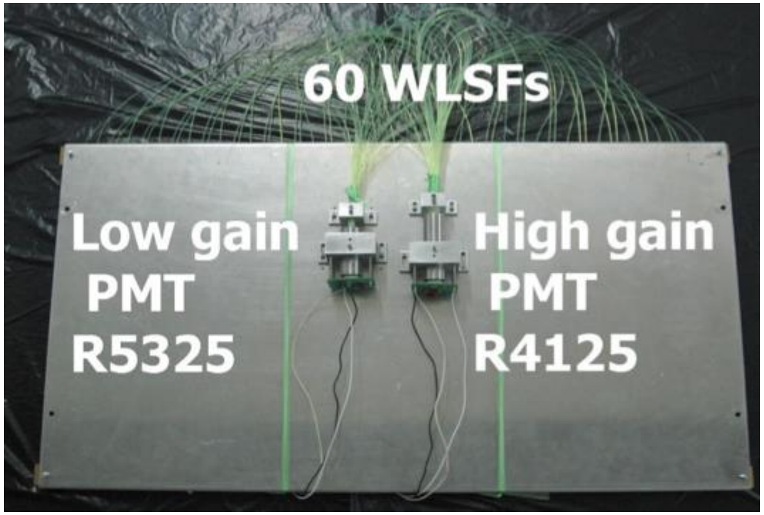
Kawata+ Exp Astron (2017)

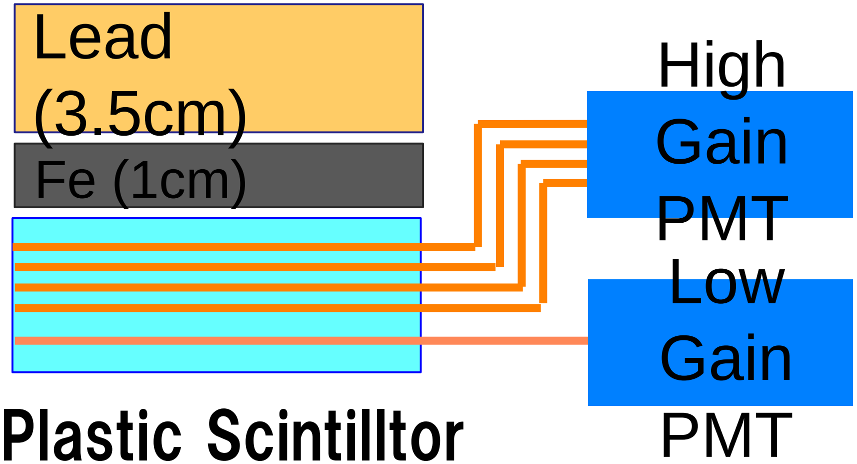


YAC計画（Yangbajing Airshower Core detectors）
Towards Chemical compositin and energy spectrum measurement in the Knee Energy Region

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



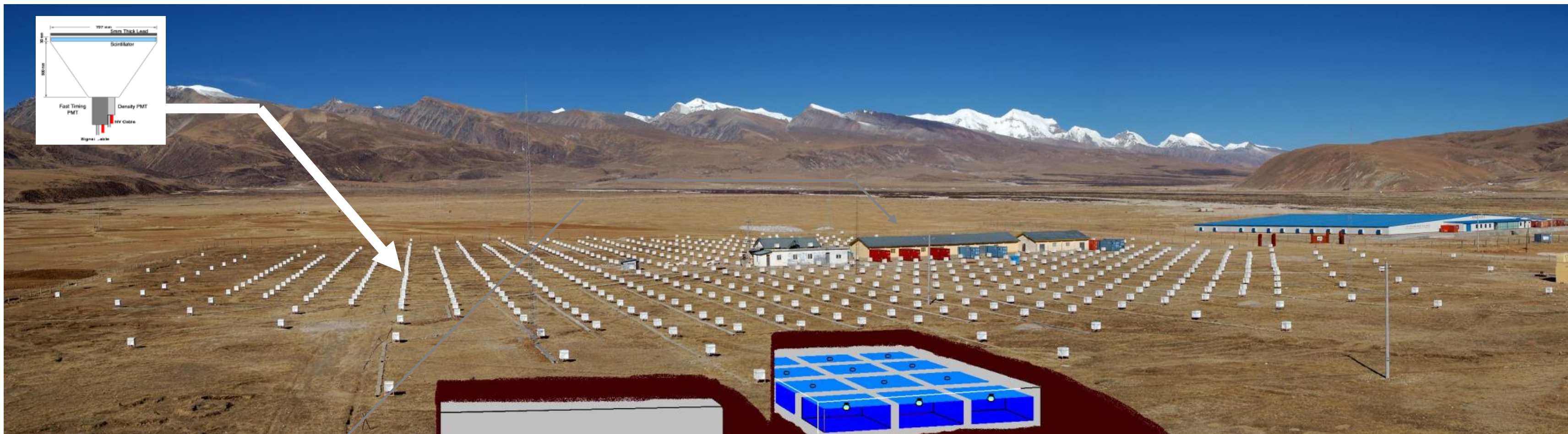


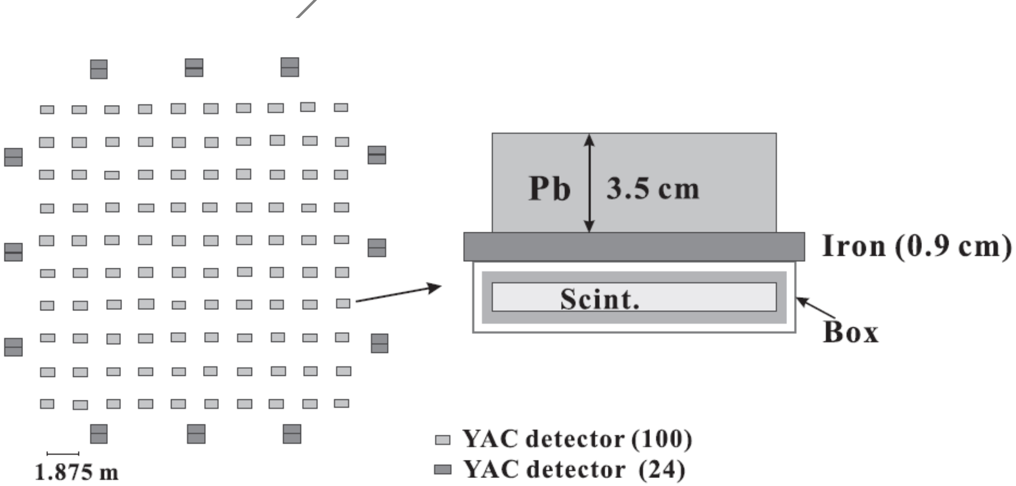


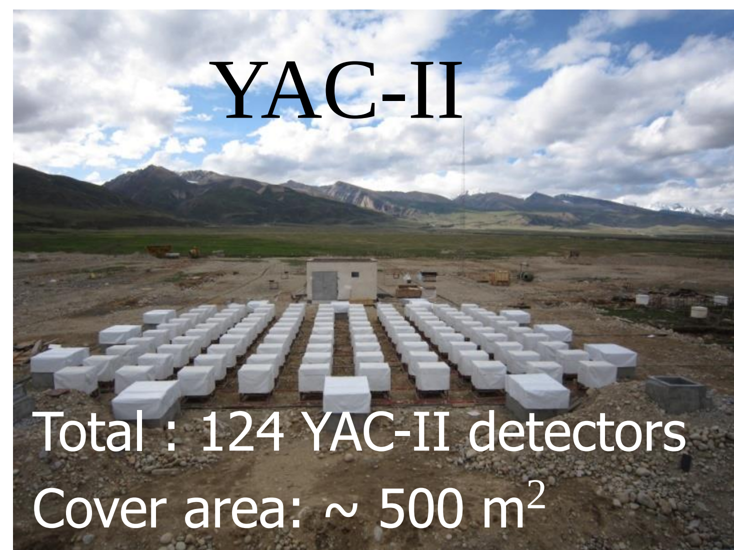
Plastic Scintilltor &Wavelength Shifter

2PMTs cover 1~10^6 particles

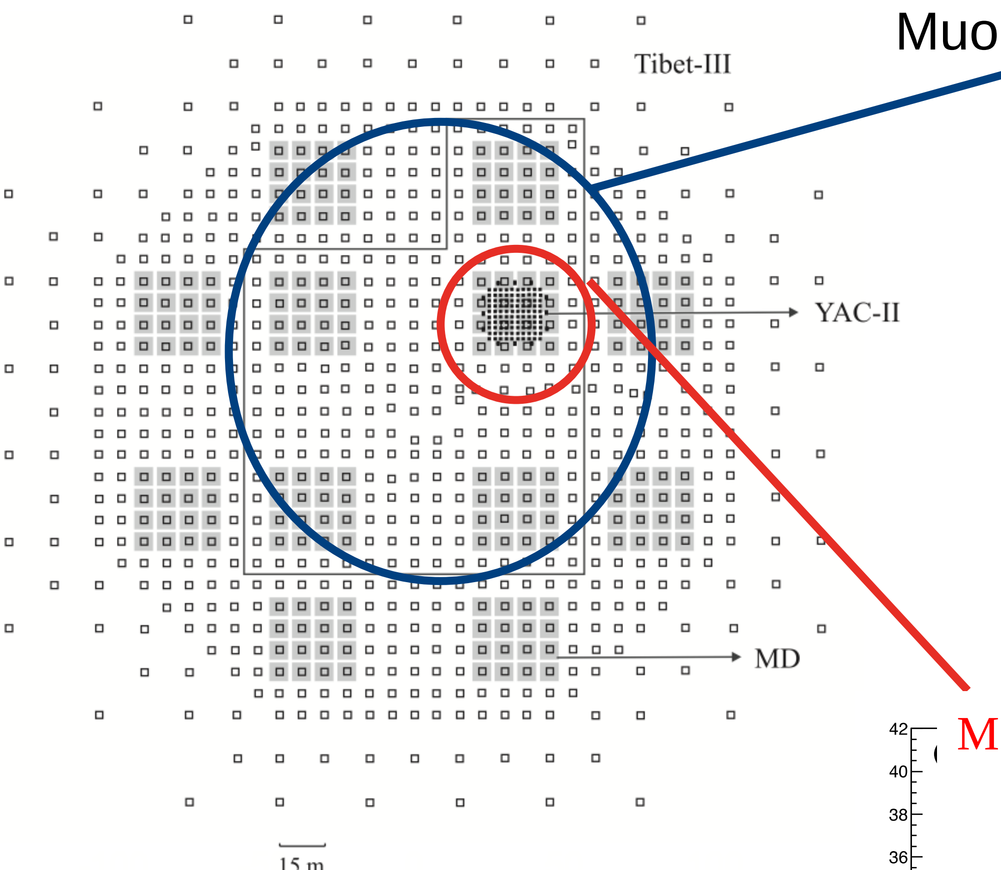
YAC-II started in 2014, accumulating data



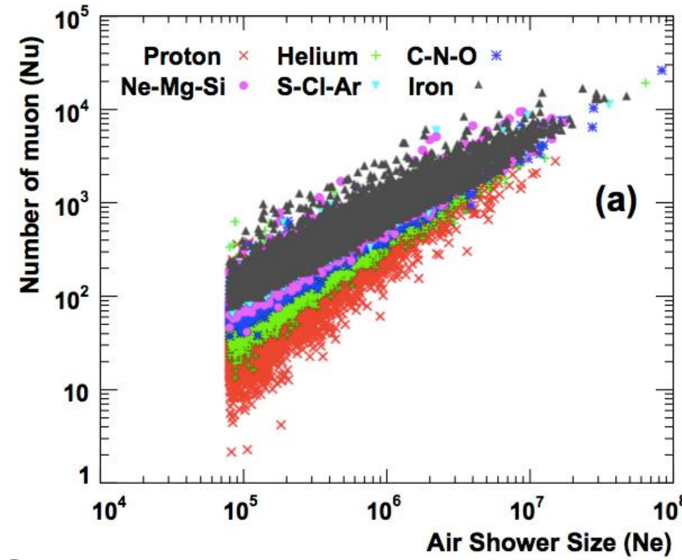




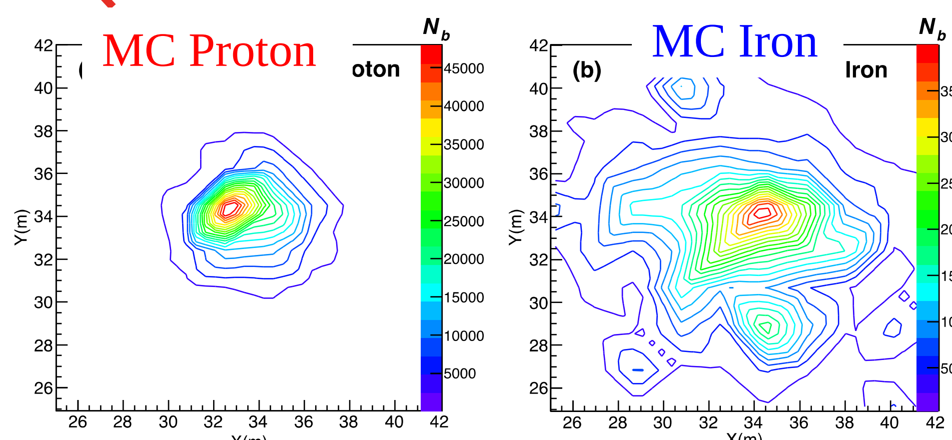
Tibet-III + YAC-II + MD (MC) for Knee Study



MC Ne-Nμ Plot

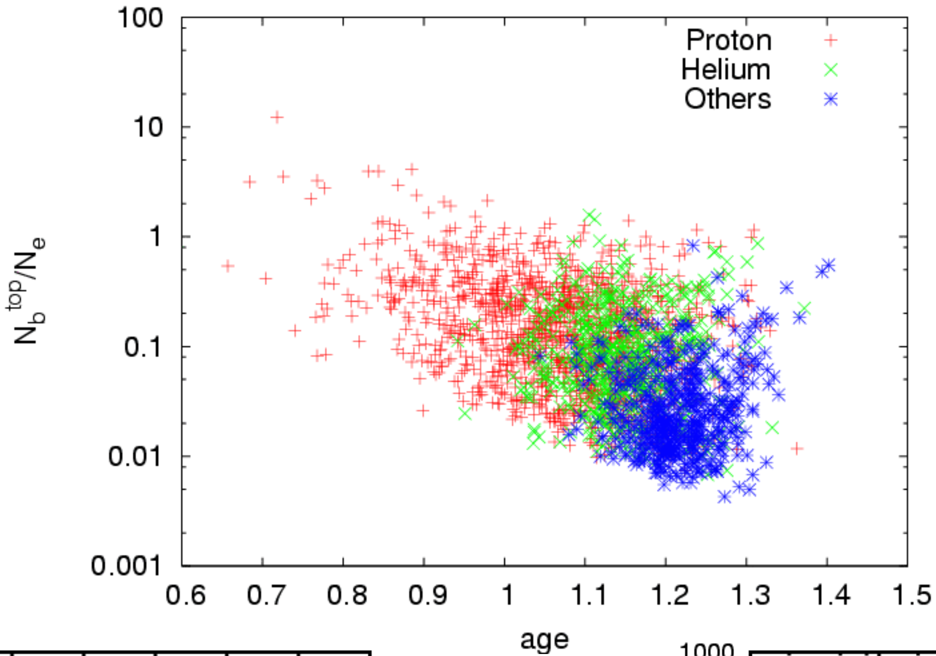


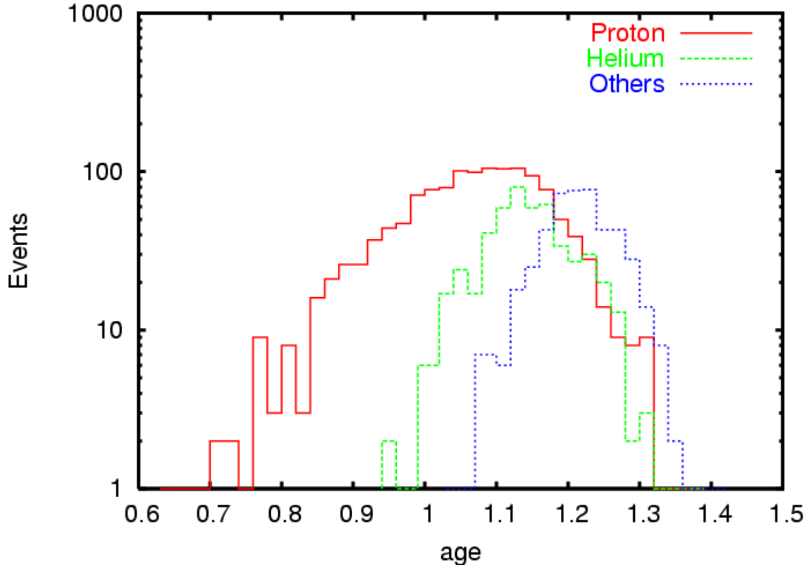
YAC-II

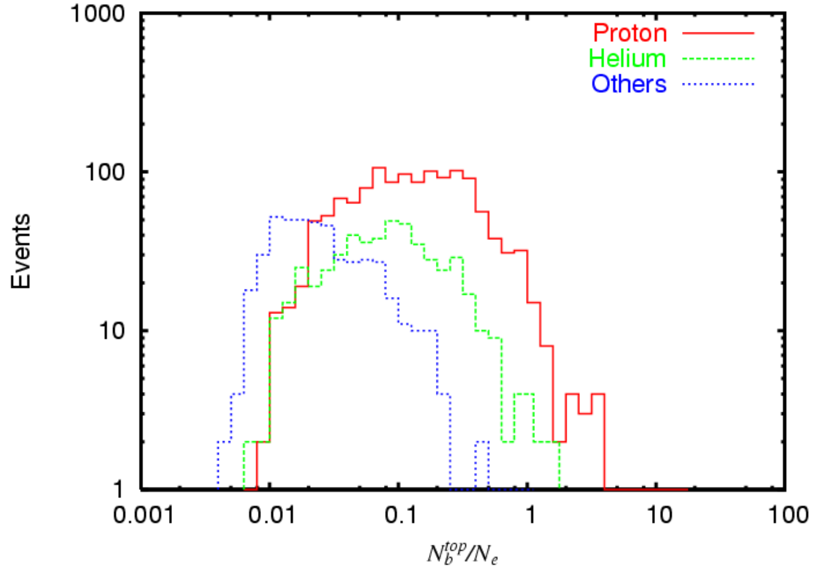


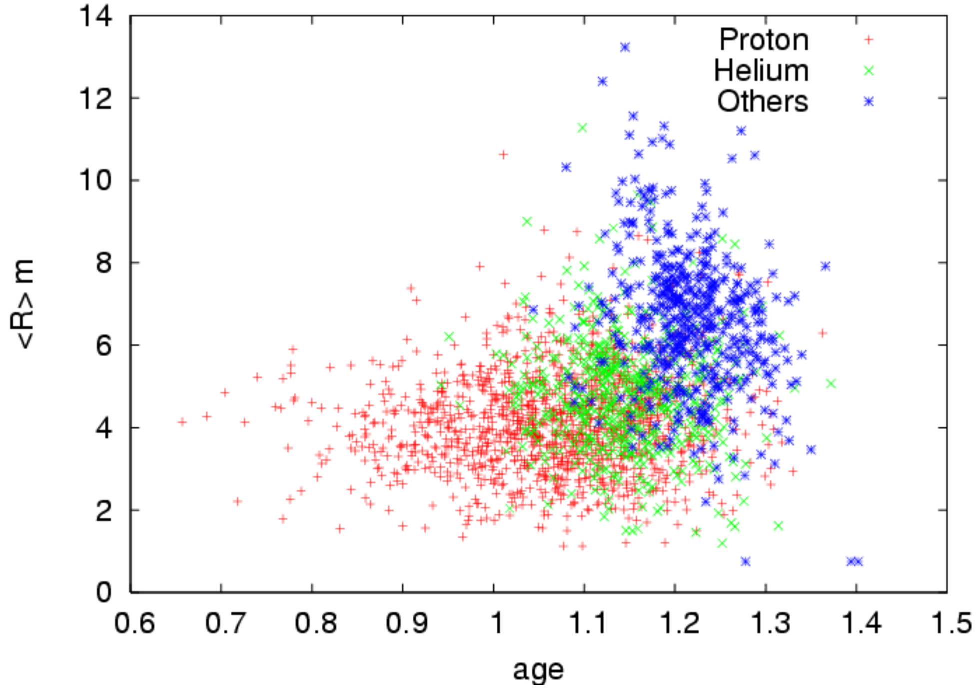
J.Huang et al,Astropart.Phys. 66 (2015) 18-30

Features of YAC-II observables

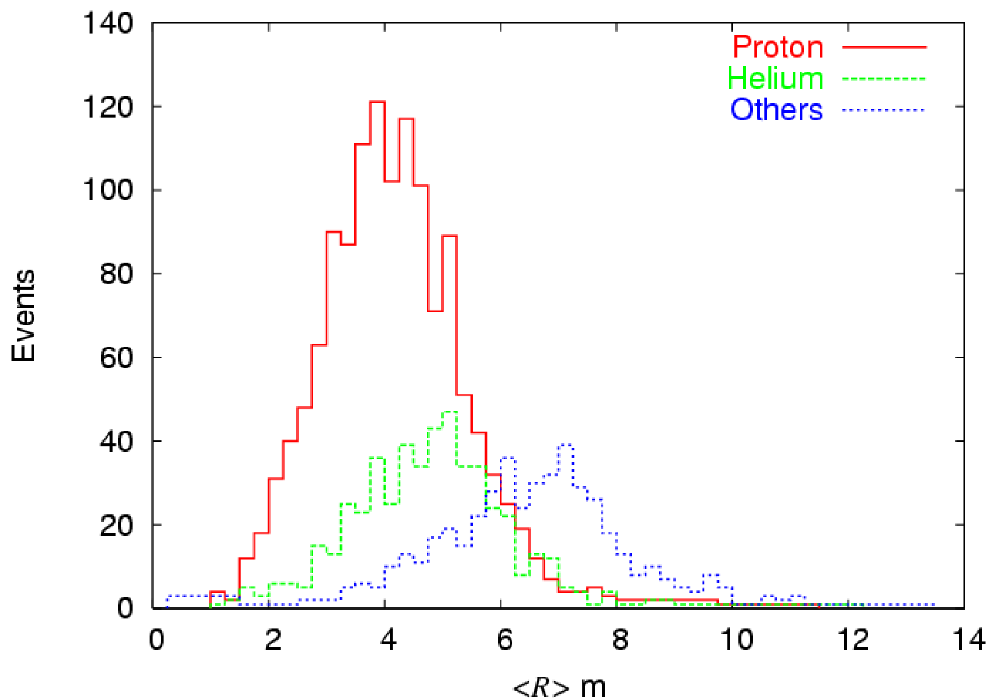








Proton
Helium
Others
<R> m
age

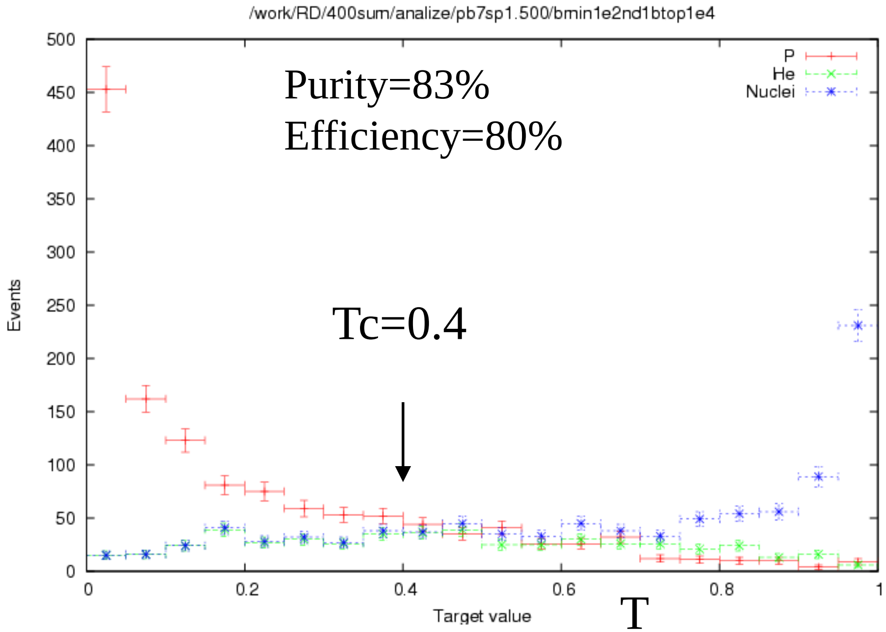


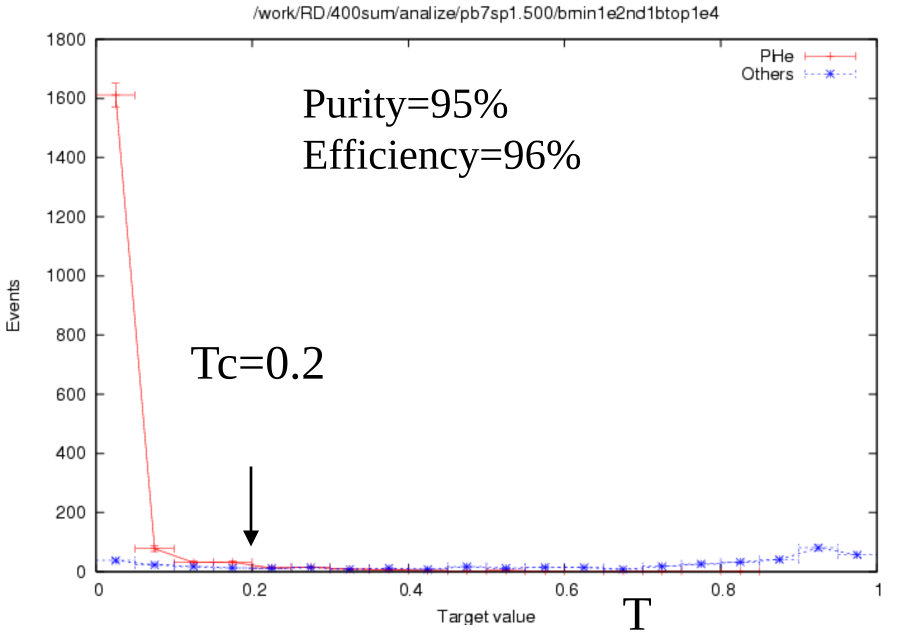
Proton
Helium
Others
Events
<R> m

ANN output

Proton separation

P+He separation

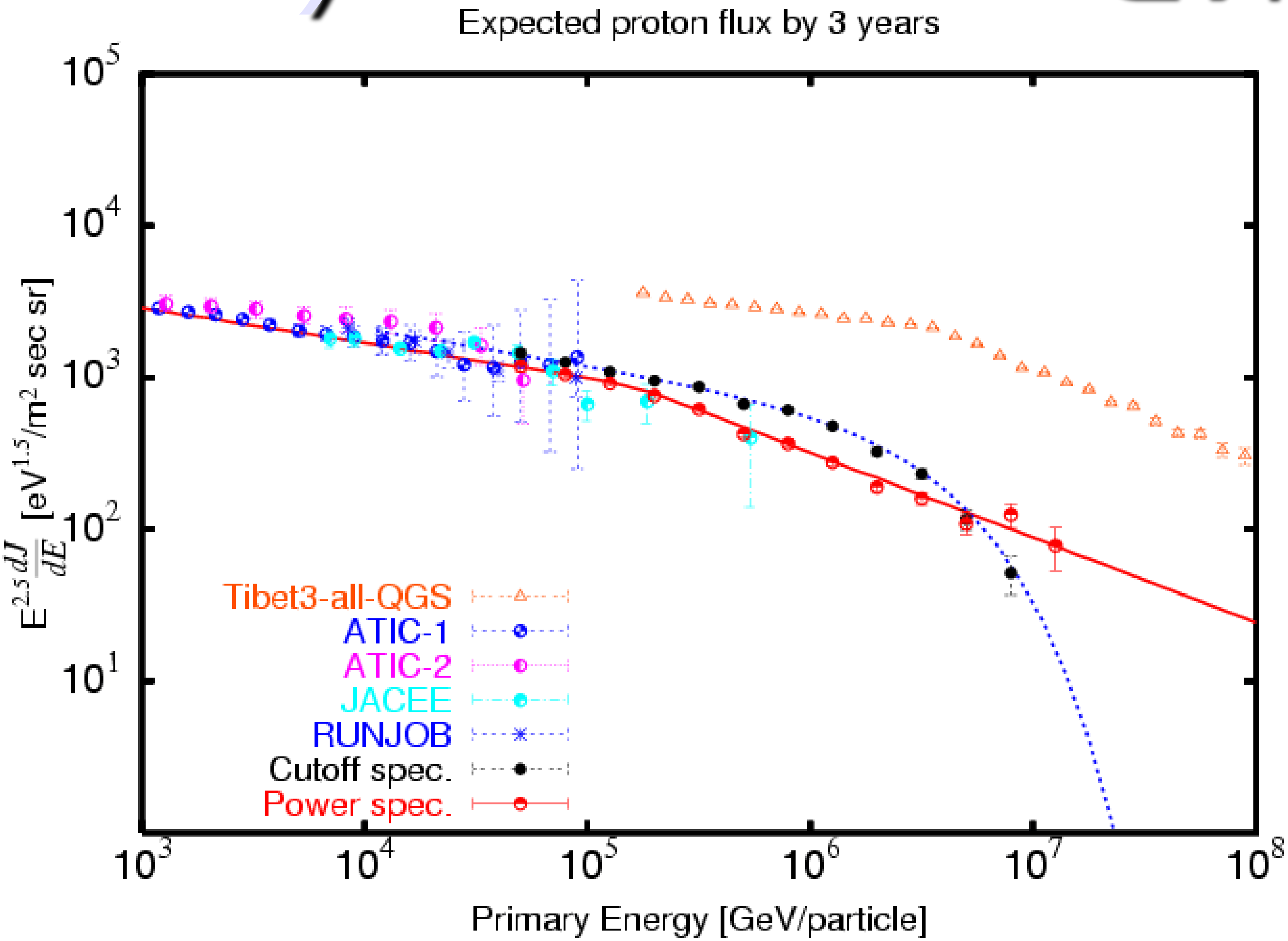




Contamination is exclusively by helium nuclei.
The fraction of helium events missidentified as protons is about 40% of helium events by Tc=0.4.

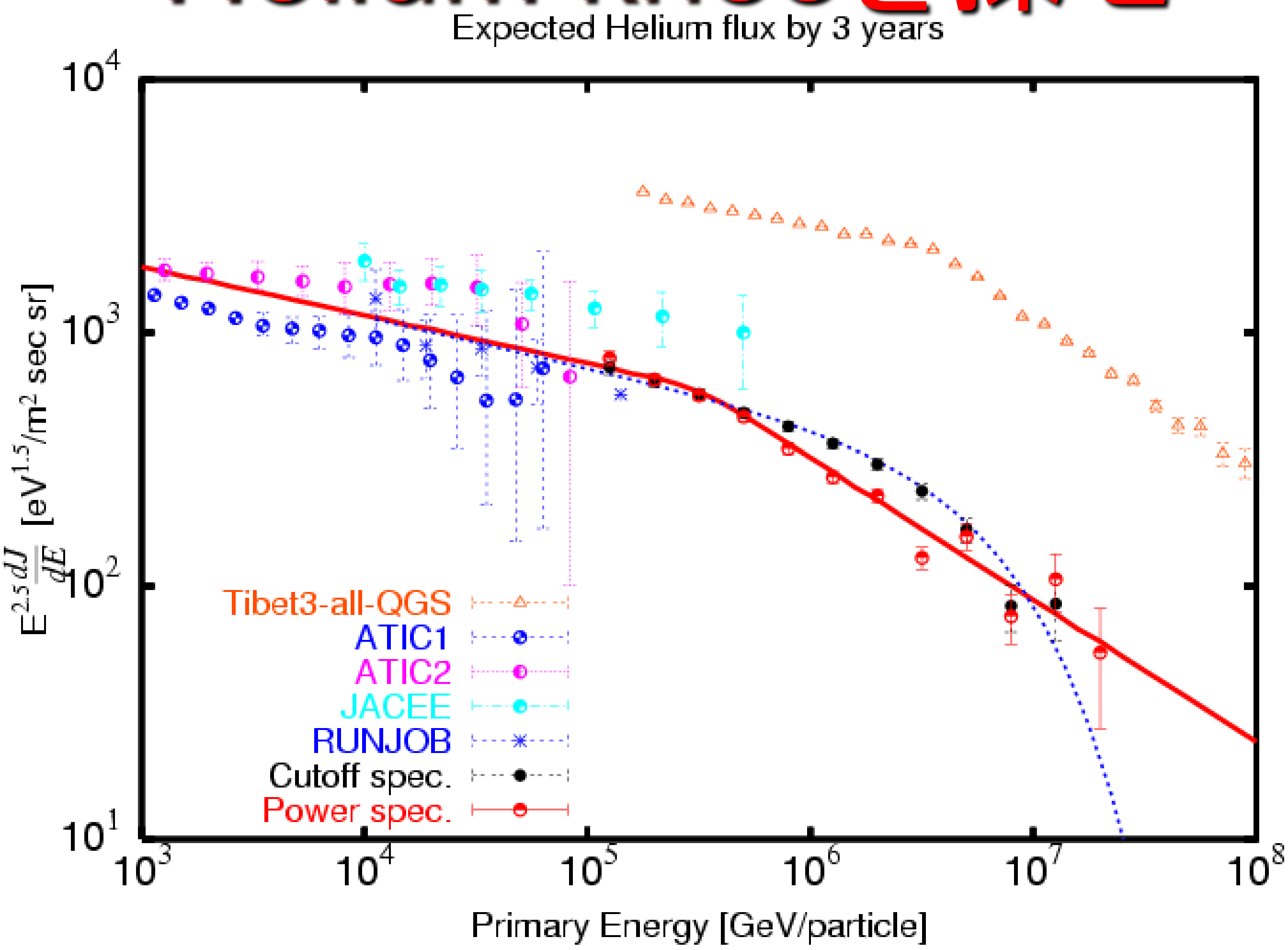
20% of heavier nuclei than helium contaminates to P+He region.

Expected proton spectrum (YAC-II) Proton kneeを探せ



Expected He Spectrum (YAC-II)

Helium kneeを探せ



The ALPACA Experiment

Andes

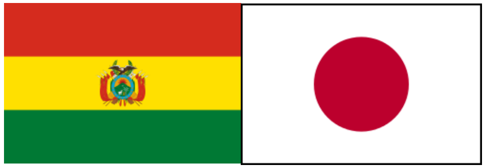
Large-area

PArticle detector for

Cosmic ray physics and

Astronomy

The ALPACA Collaboration



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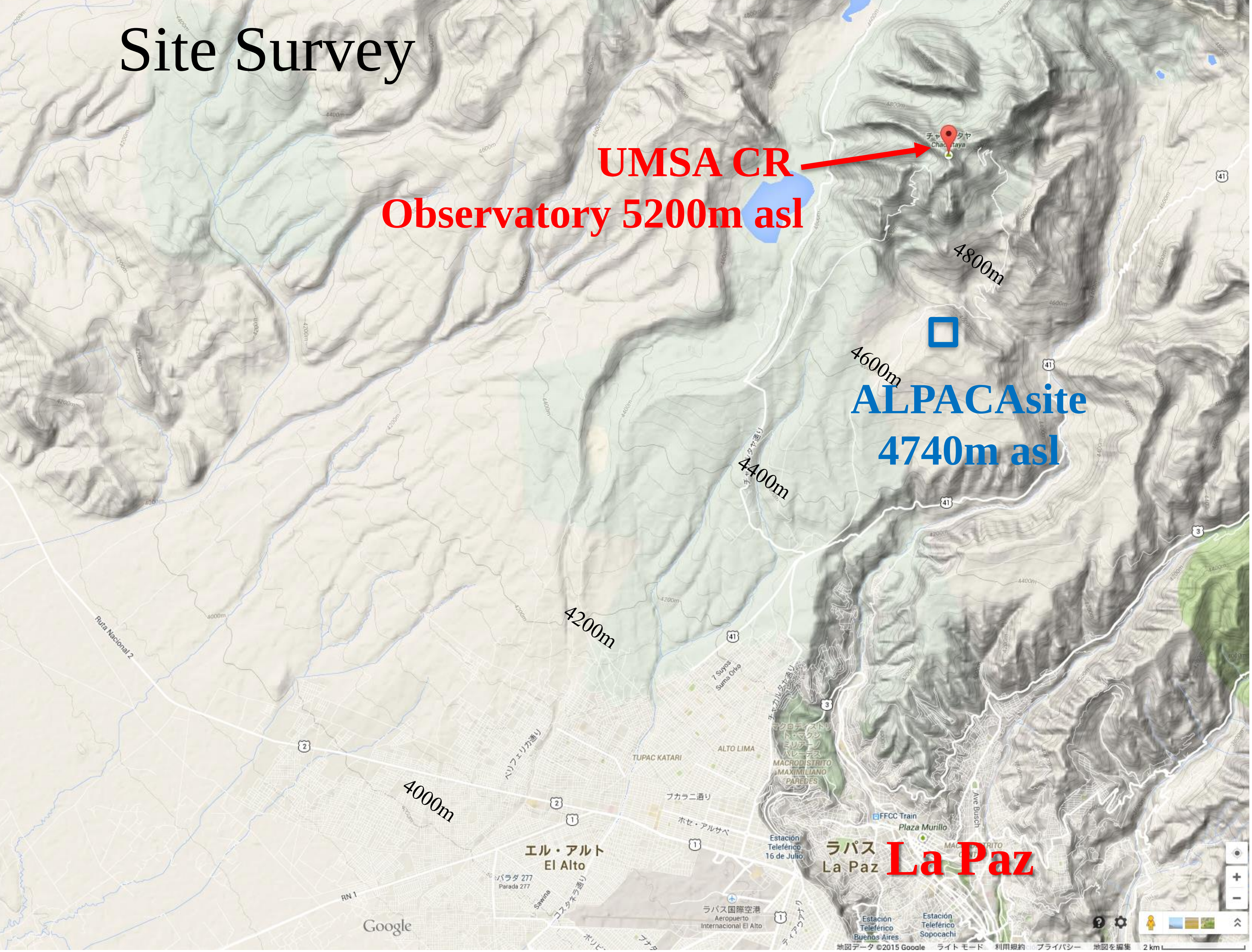
Institute of High Energy Physics, China
Yoshiaki NAKAMURA

ALPACA Site

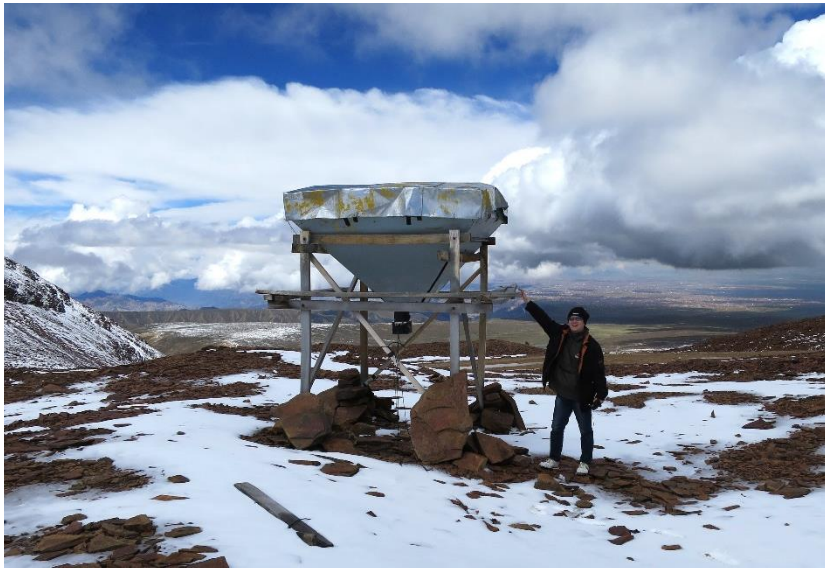
Mt. Chacaltaya, Bolivia

Site Survey


UMSA CR
Observatory 5200m asl
4800m
4600m
ALPACAsite
4740m asl
4400m
4200m
4000m
エル・アルト
El Alto
ラパス
La Paz
La Paz
Plaza Murillo
Google
地図データ ©2015 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,...)

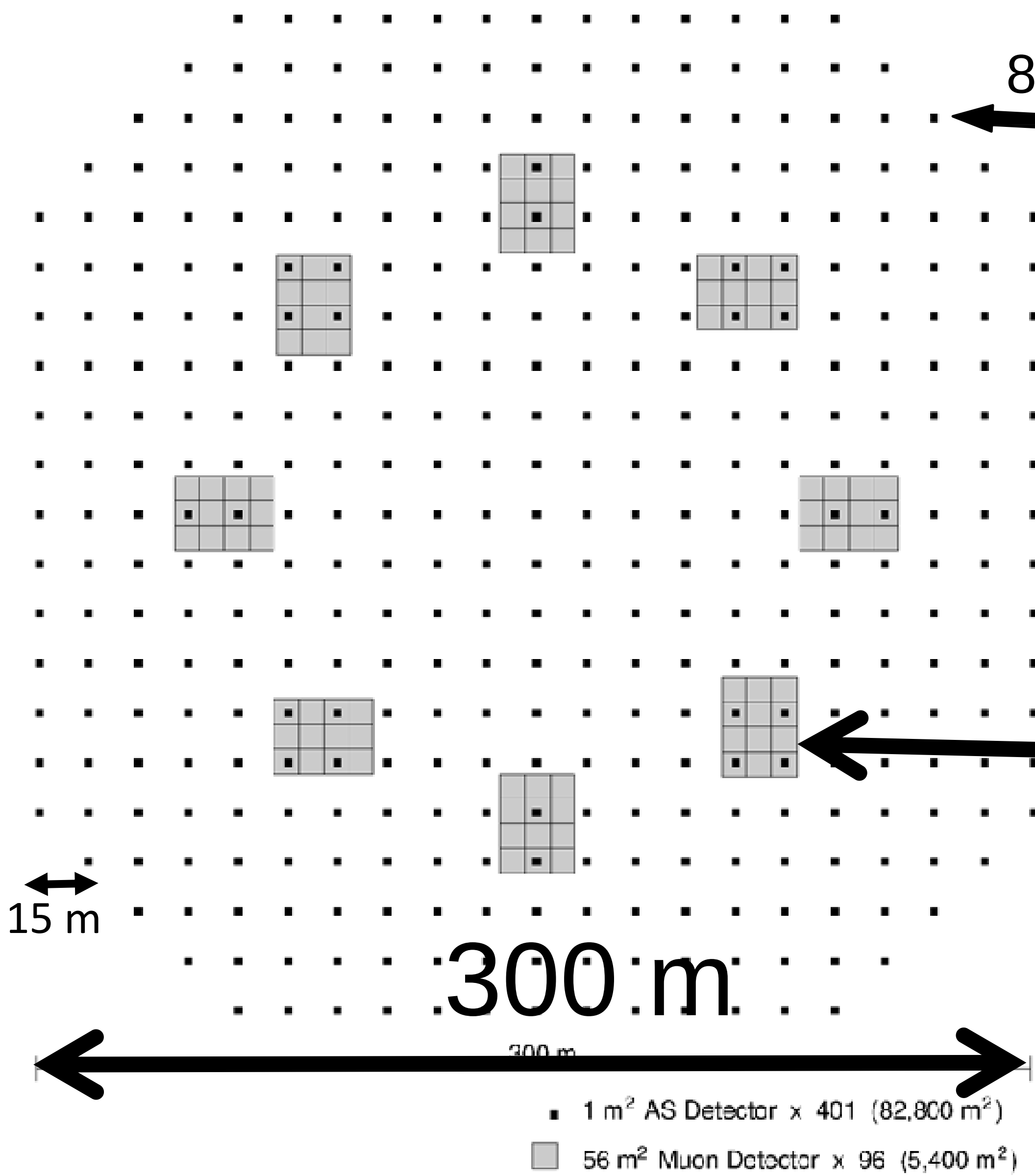
  Since 1962 in the field of cosmic rays, for example, BASJE

Observation Cite: **Chacaltaya Plateau**

500 m × 500 m flat within ± 1°

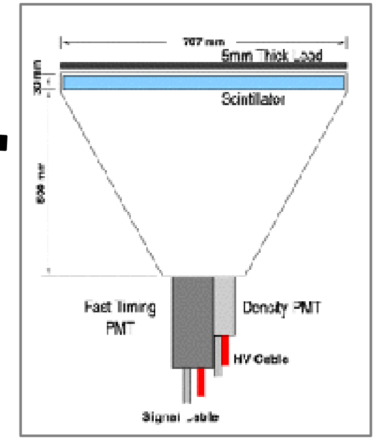
4,740 m above sea level (16° 23’S, 68° 08’W)

Schematic view of ALPACA



83,000 m^2

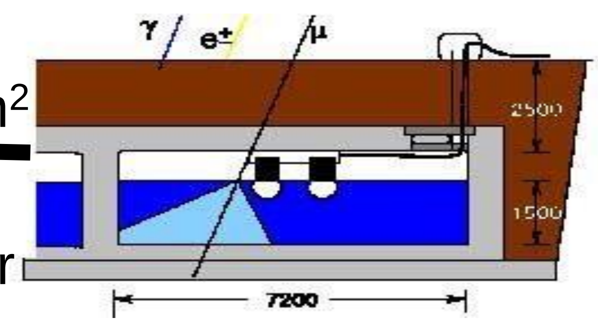
Air Shower Array



1m^2 plastic scintillation detector

5,400 m^2

Muon Detector Array

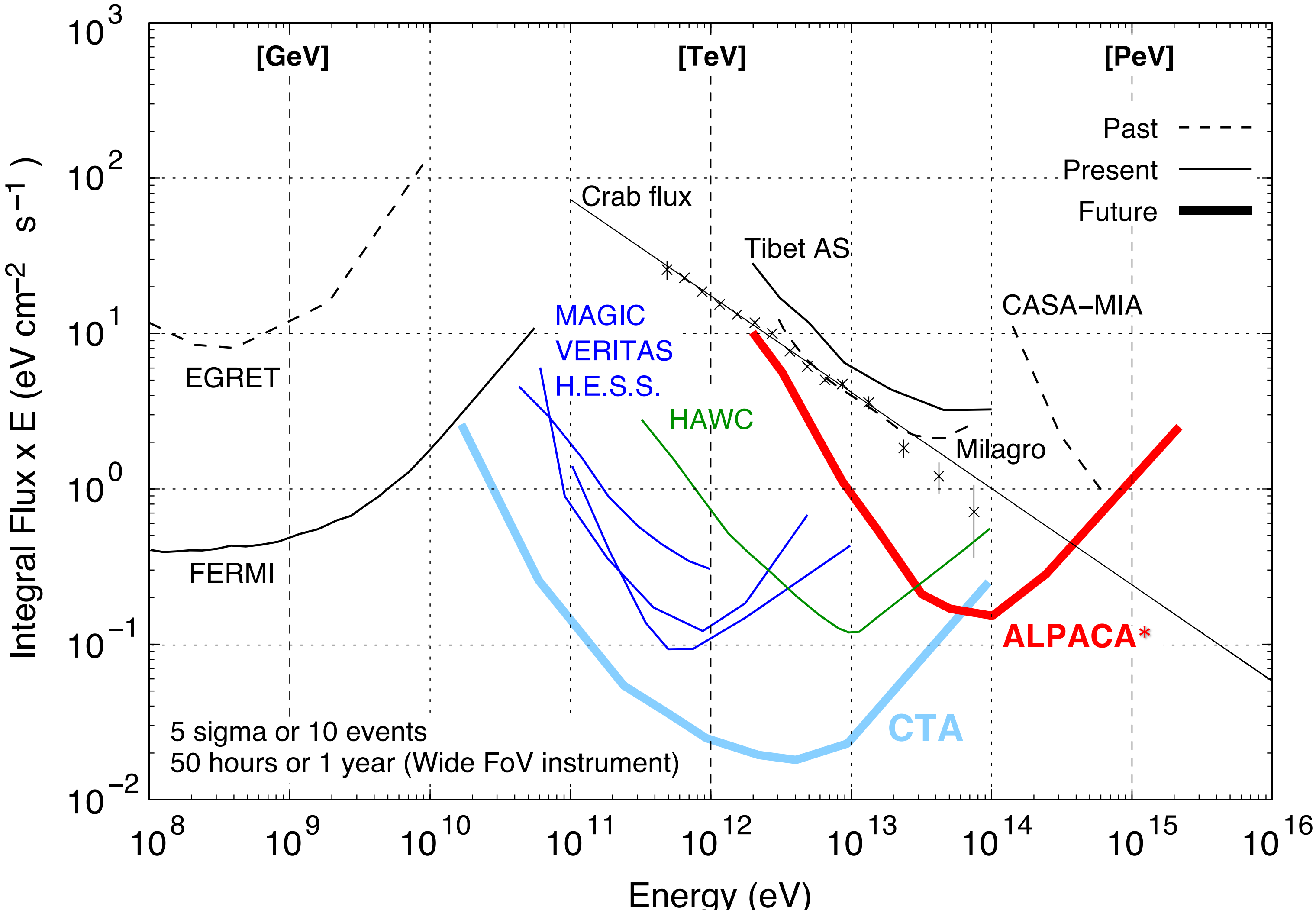


Underground water Cherenkov muon detector (56 m^2 / unit)

Performance of ALPACA air shower array

Location:	4,740 m above sea level (16°23' S, 68°08' W)
# of scintillation detectors	1 m^2 x 401 detectors
Effective area	~83,000 m^2
Modal energy	~5TeV
Angular resolution	~0.2° @100 TeV
Energy resolution	~20-25% @100TeV
Field of view	~2 sr

ガンマ線点源に対する感度



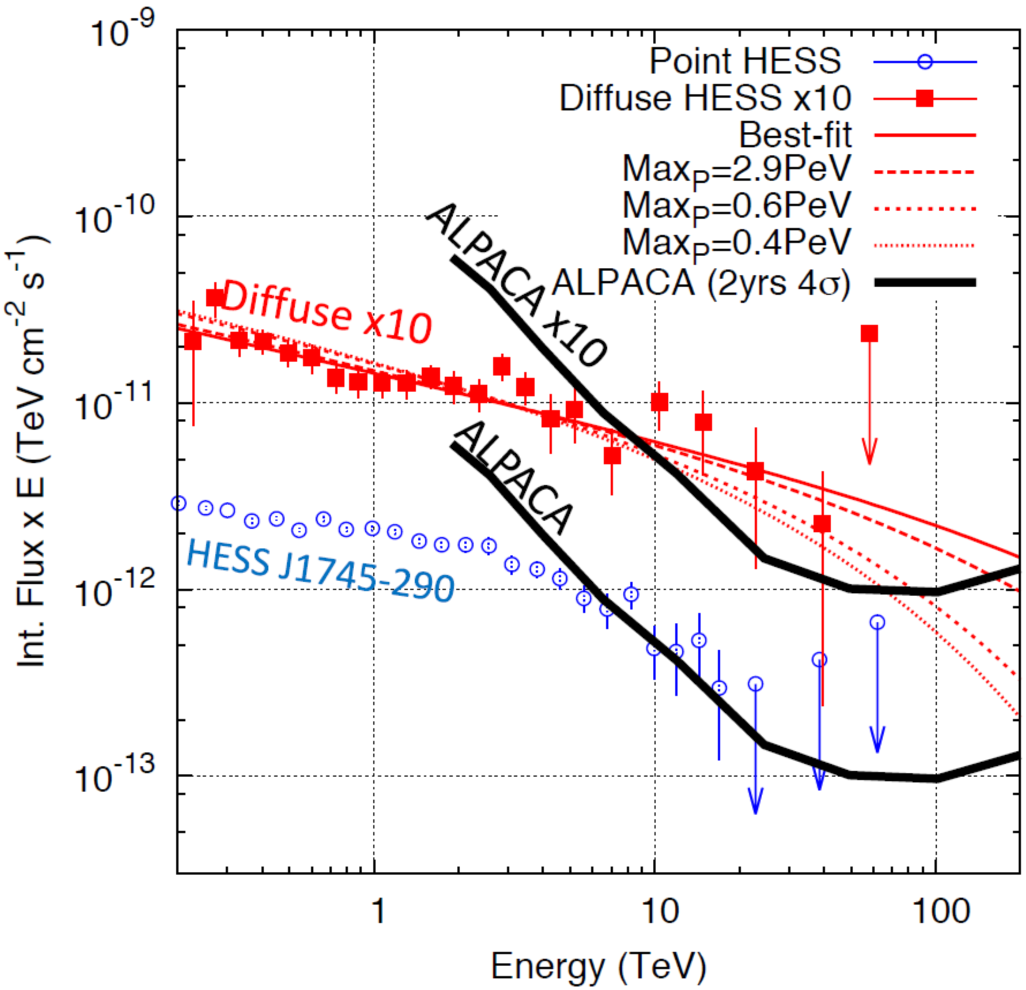
CTA Review by Kubo (JPS 2015)
M.Daniel, Proc. of 28th Texas Sympo. (2015)

*Based on MC Simulation
For the Tibet AS+MD

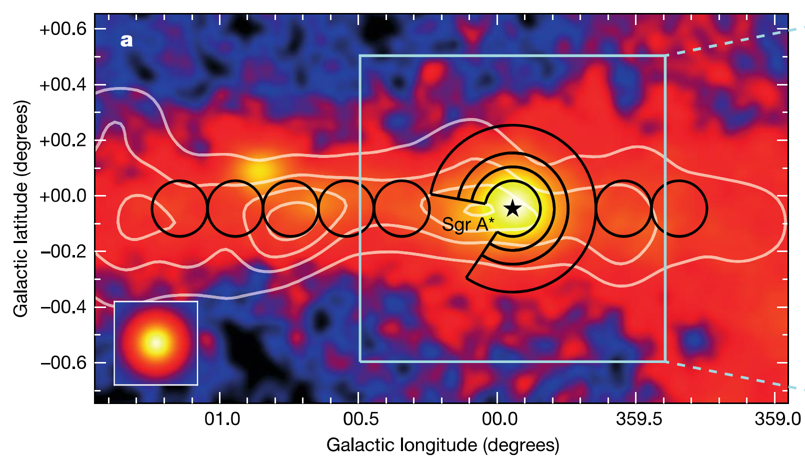
Target γ Sources

- 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

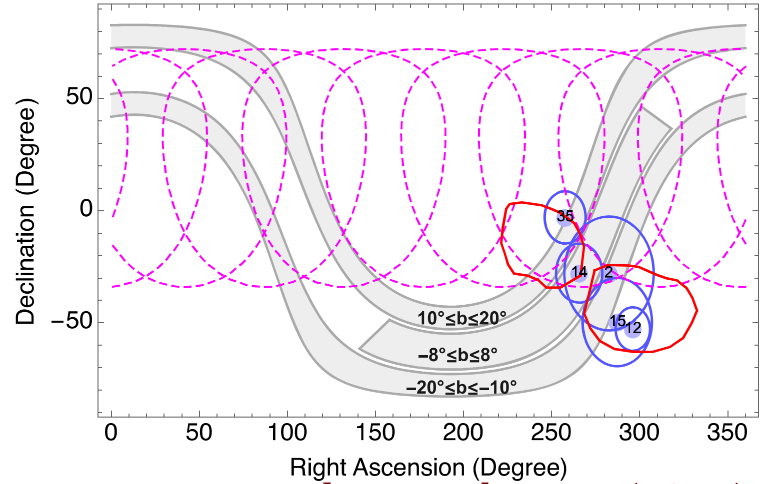


Abramowski, et al, Nature (2016)

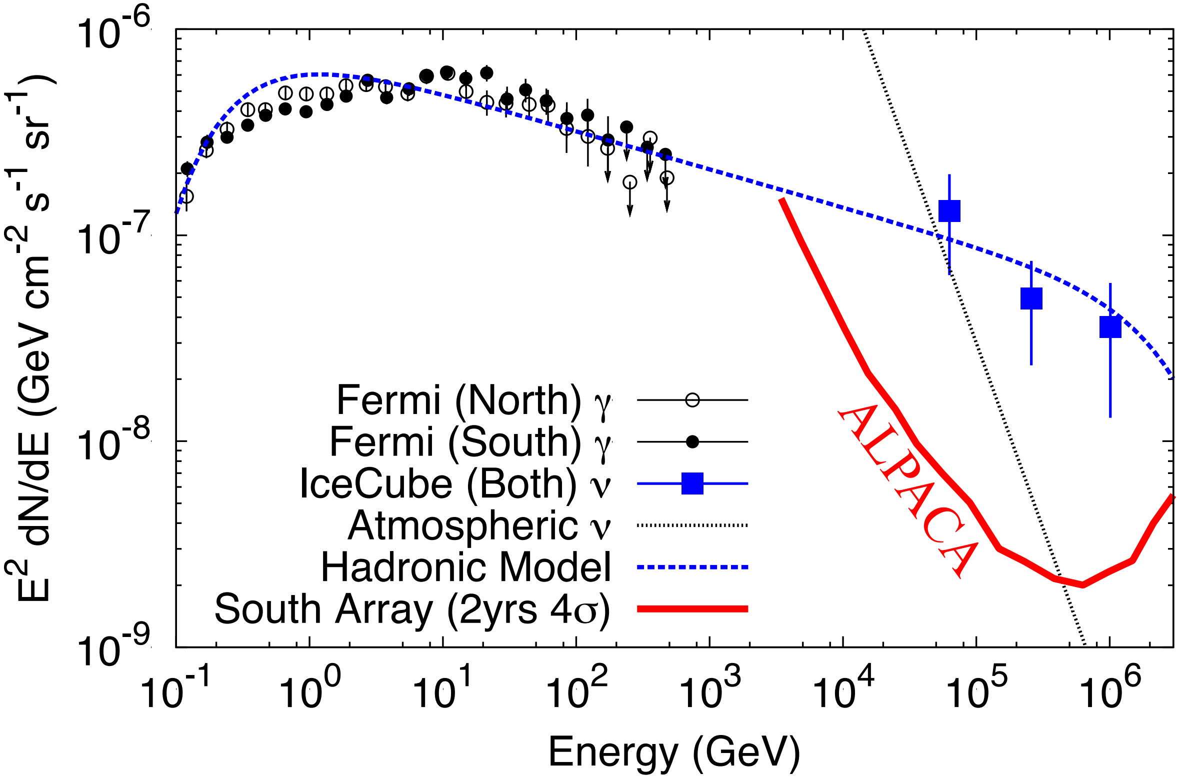
$\delta \sim -29°$

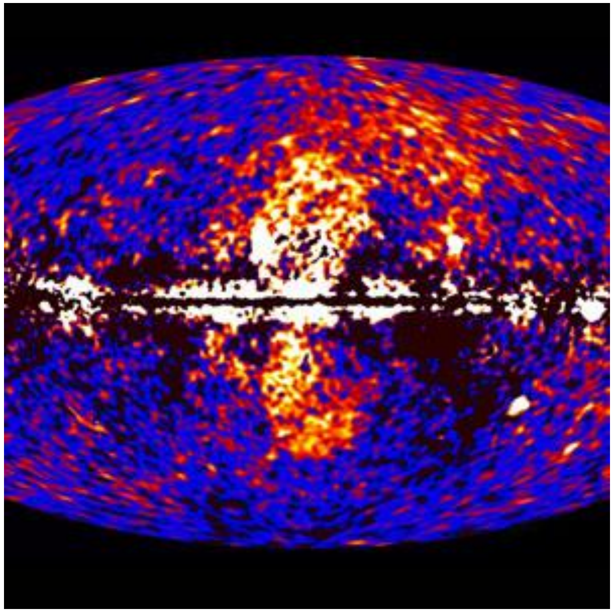
Fermi Bubbles

- ✓ 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.



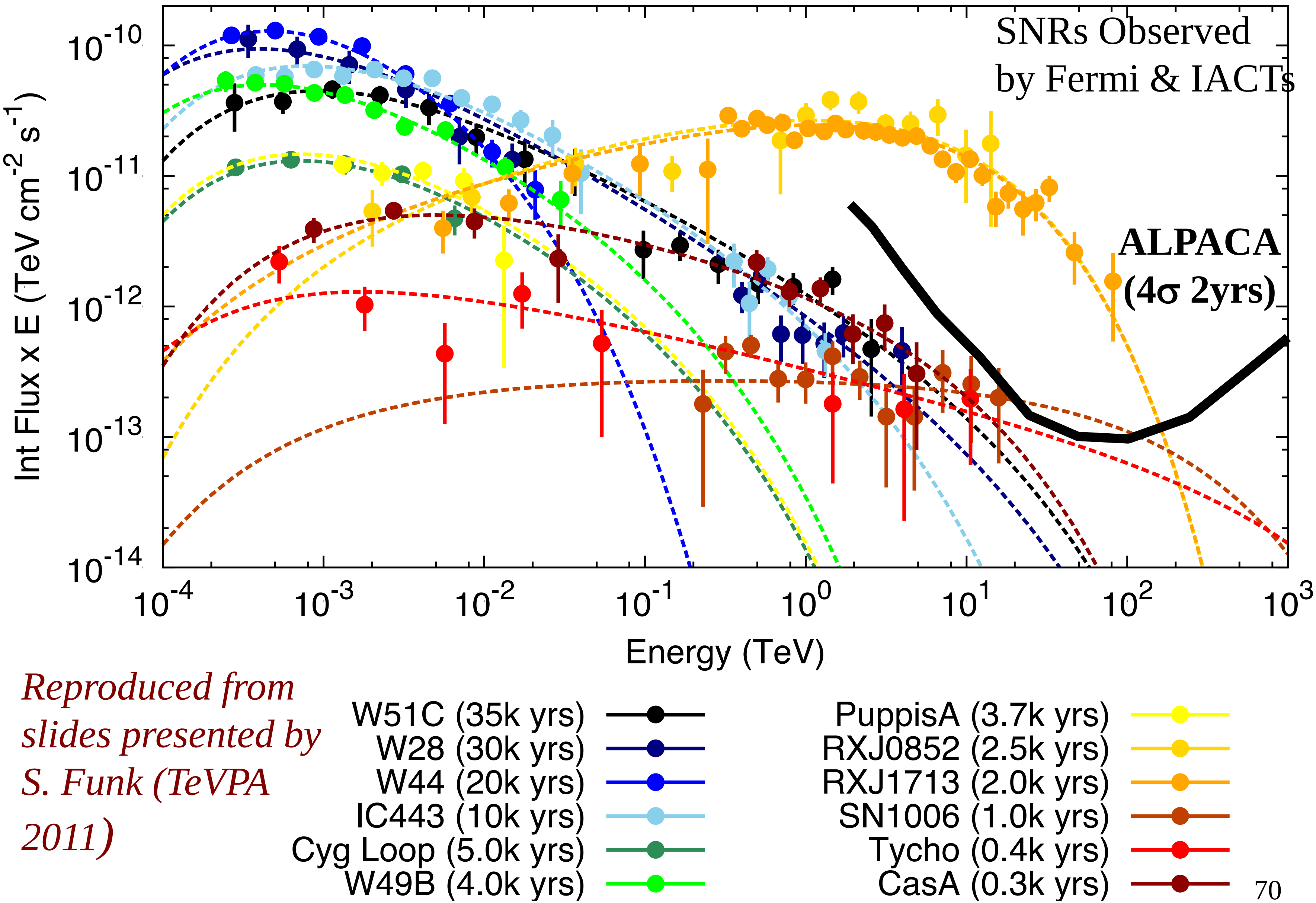
C. Lunardini, et al, PRD (2015)





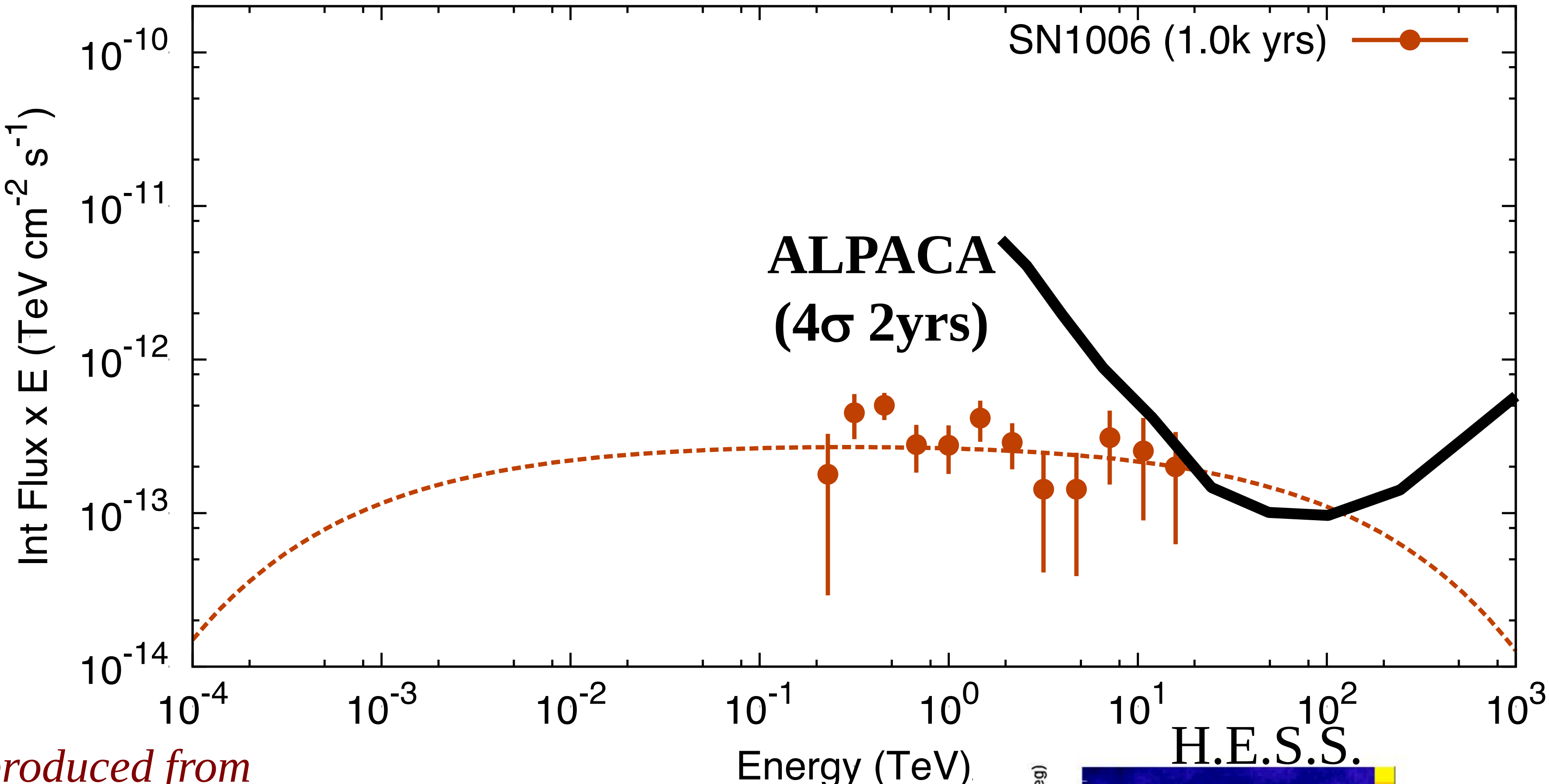
Bubbles observed by Fermi-LAT

Young SNRs



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

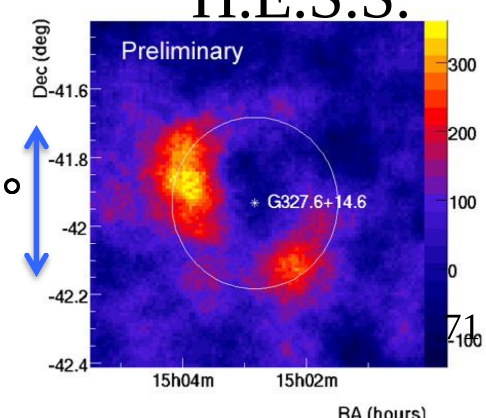
Young SNRs



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

H.E.S.S.

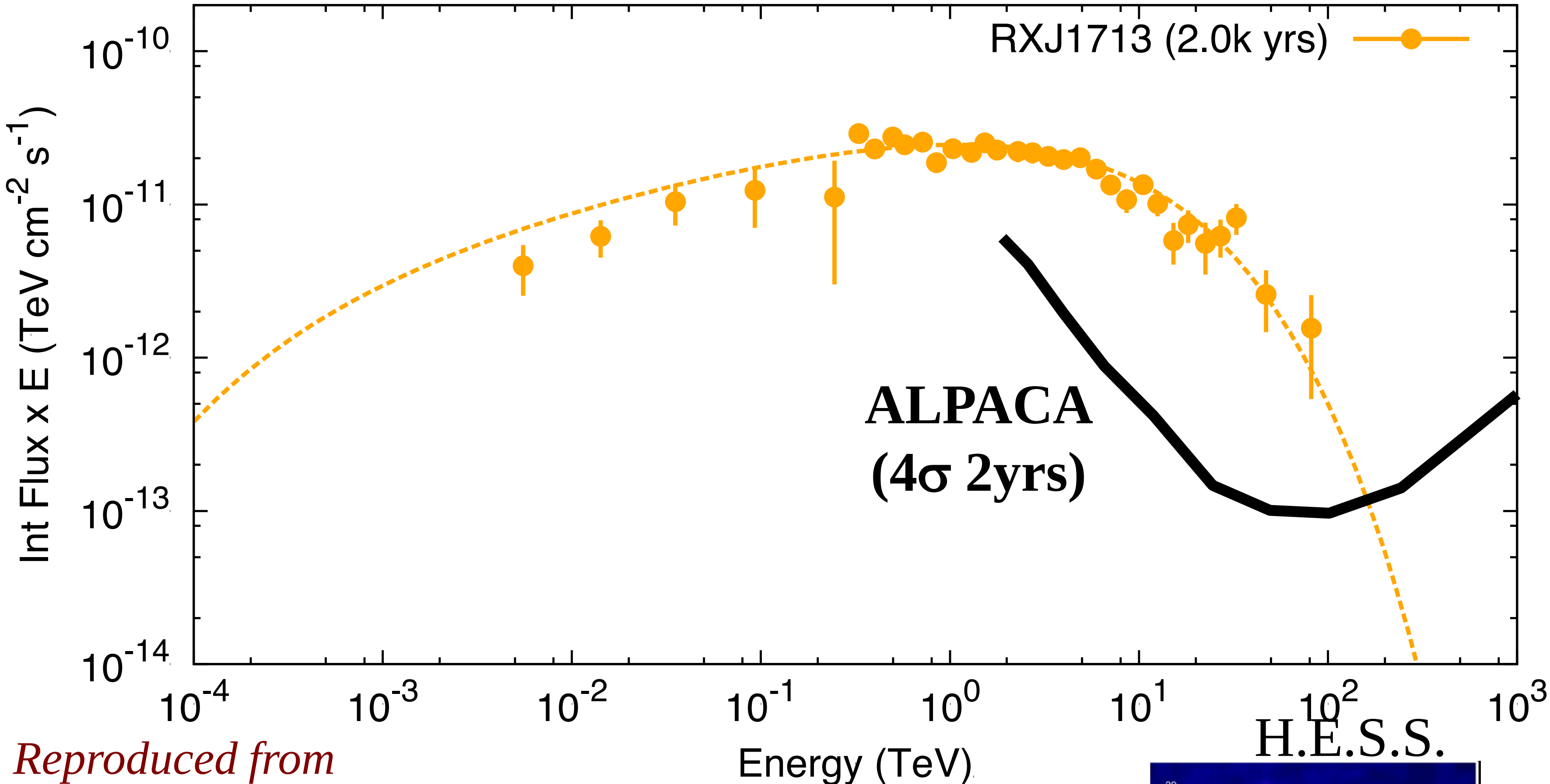
0.4°



SNRs Observed by Fermi & IACTs

δ ~ -42°

Young SNRs



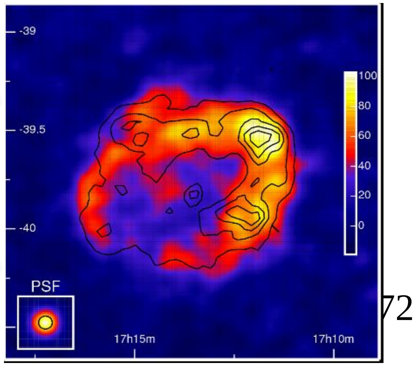
Reproduced from slides presented by S. Funk (TeVPA 2011)

SNRs Observed
by Fermi & IACTs

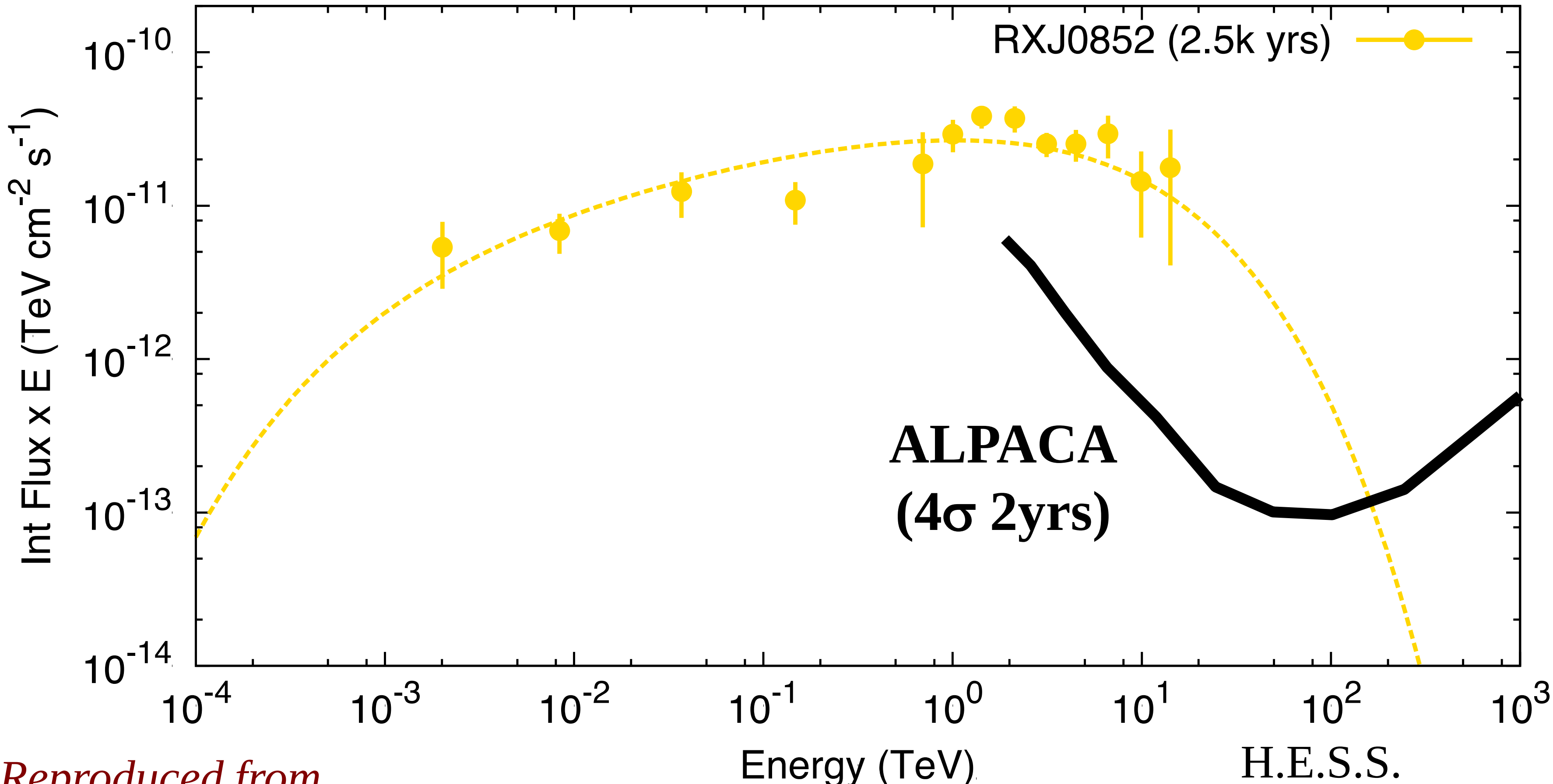
$\delta \sim -40^\circ$

H.E.S.S.

1.0°



Young SNRs

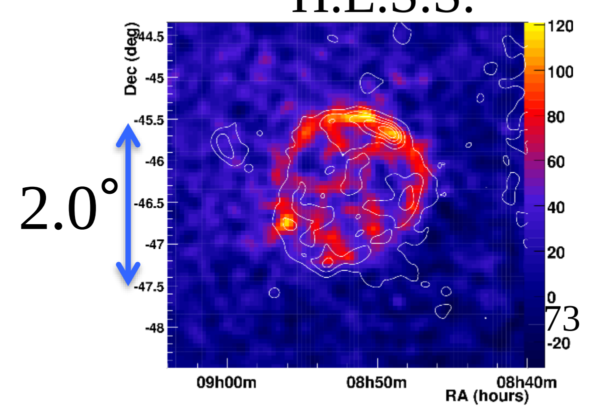


Reproduced from slides presented by S. Funk (TeVPA 2011)

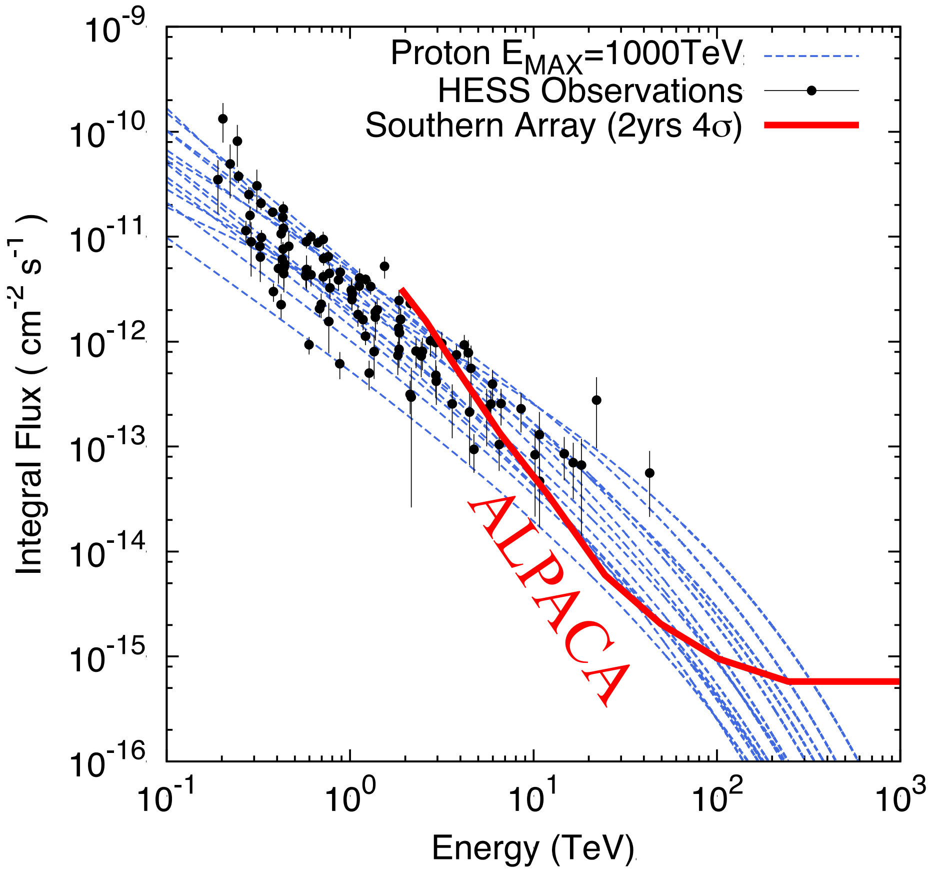
SNRs Observed
by Fermi & IACTs

$\delta \sim -46°$

H.E.S.S.



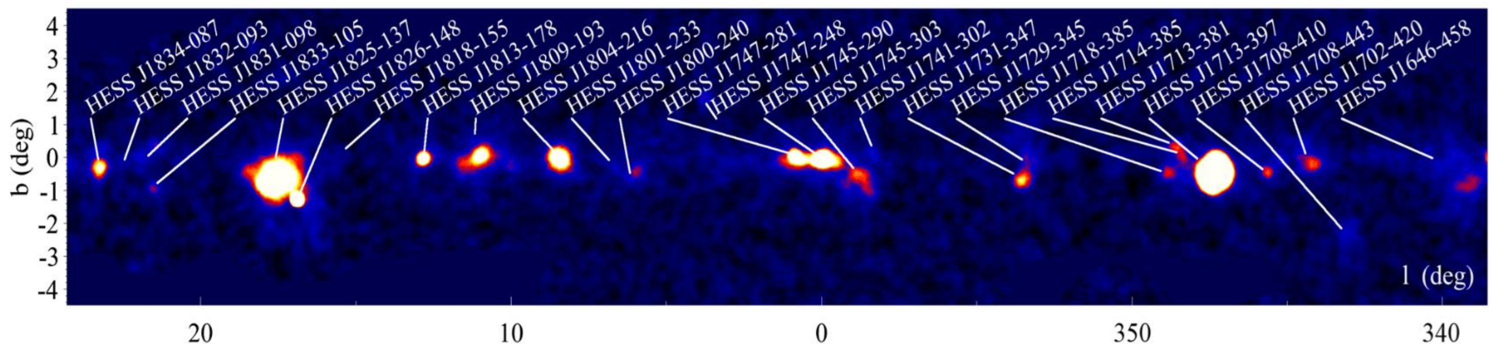
Other Galactic Sources



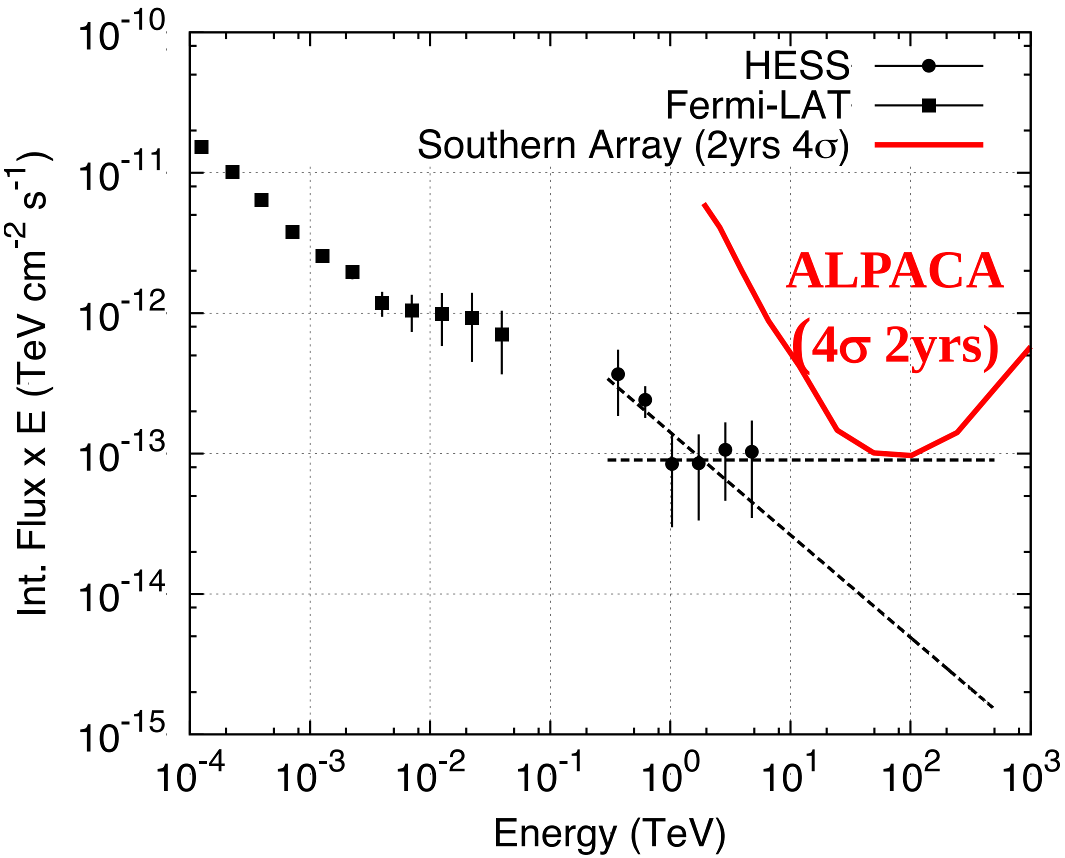
- ✓ More than dozen sources
- ✓ Many sources are dark in other wave length
  → Dark particle accelerator
- ✓ Many candidate of PWN (excess is located near pulsar)

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

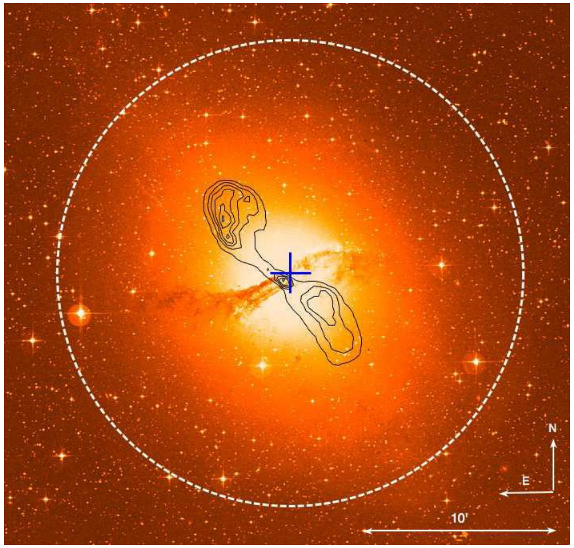
- ✓ Diffuse γ from Galactic plane



Nearby Extragalactic Source CenA



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

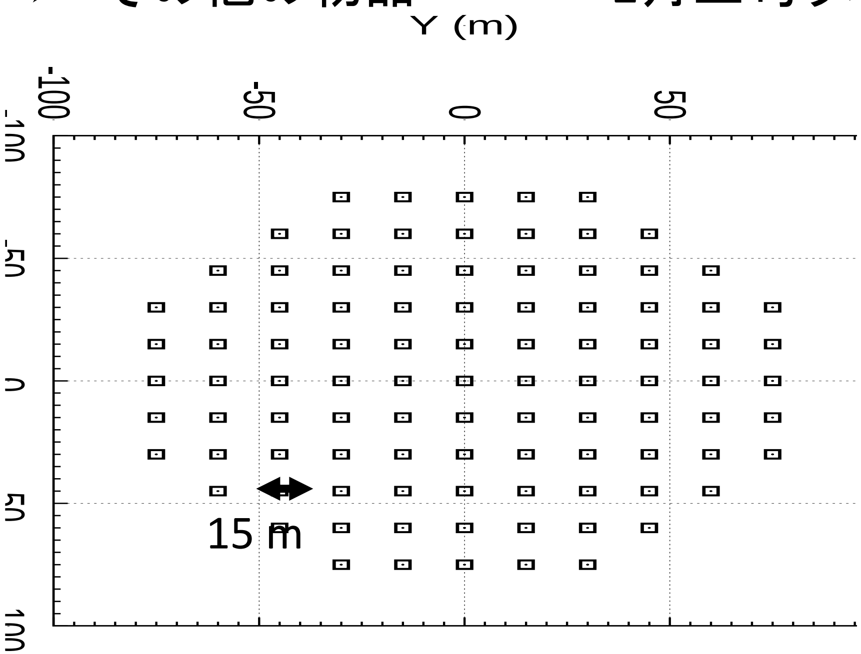


Aharonian et al, ApJ, 695, L40 (2009)
Sahakyan, et al, ApJ, 770, L6(2013)

$\delta \sim -43°$

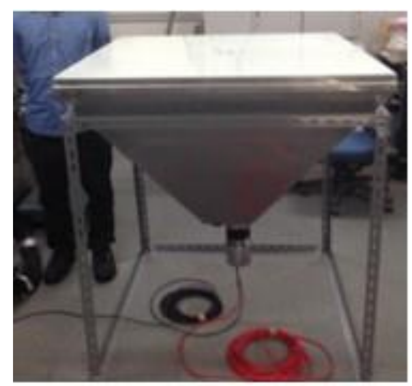
ALPAQUITA: prototype AS array

- 検出器台数　1.0 m^2 × 97
- 面積　~18,500m^2 (有効面積　12,600 m^2)
- インフラ (道路の整備、フェンス、建物、電気、インターネット、避雷針など)
  ー ボリビア側が準備中
- 検出器架台　ー ボリビアにて試作品すでに完成、2月ー3月に量産予定
- その他の物品　ー 2月上旬ラパス到着



← Detector deployment

↓ 1m^2 Detector



ALPAQUITA実験：物理目標

- 南天における宇宙線異方性の観測
  - IceCube　Eth=~10TeV (-90^{o}<Dec.<-20^{o})
  - ALPAQUITA Eth= ~5TeV (-70^{o}<Dec.<$+30^{o}$)

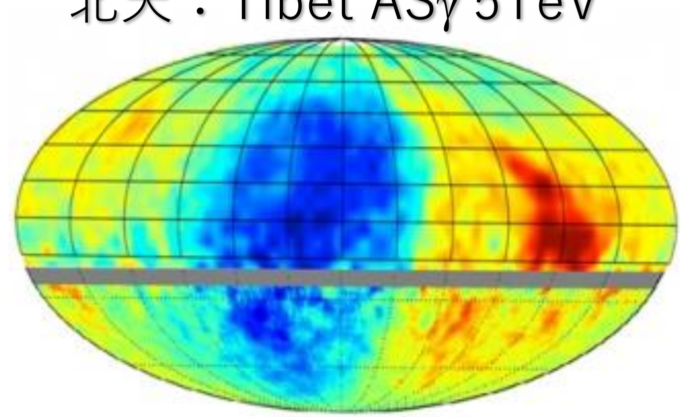
  → 銀河中心も含む赤緯での異方性解析

- 太陽(月)の影の観測
  - 赤道に近いので一年を通して観測可能
  - 月の影 ~15-20σ / year

- 雷と宇宙線の研究
  - 電場計と気象モニター

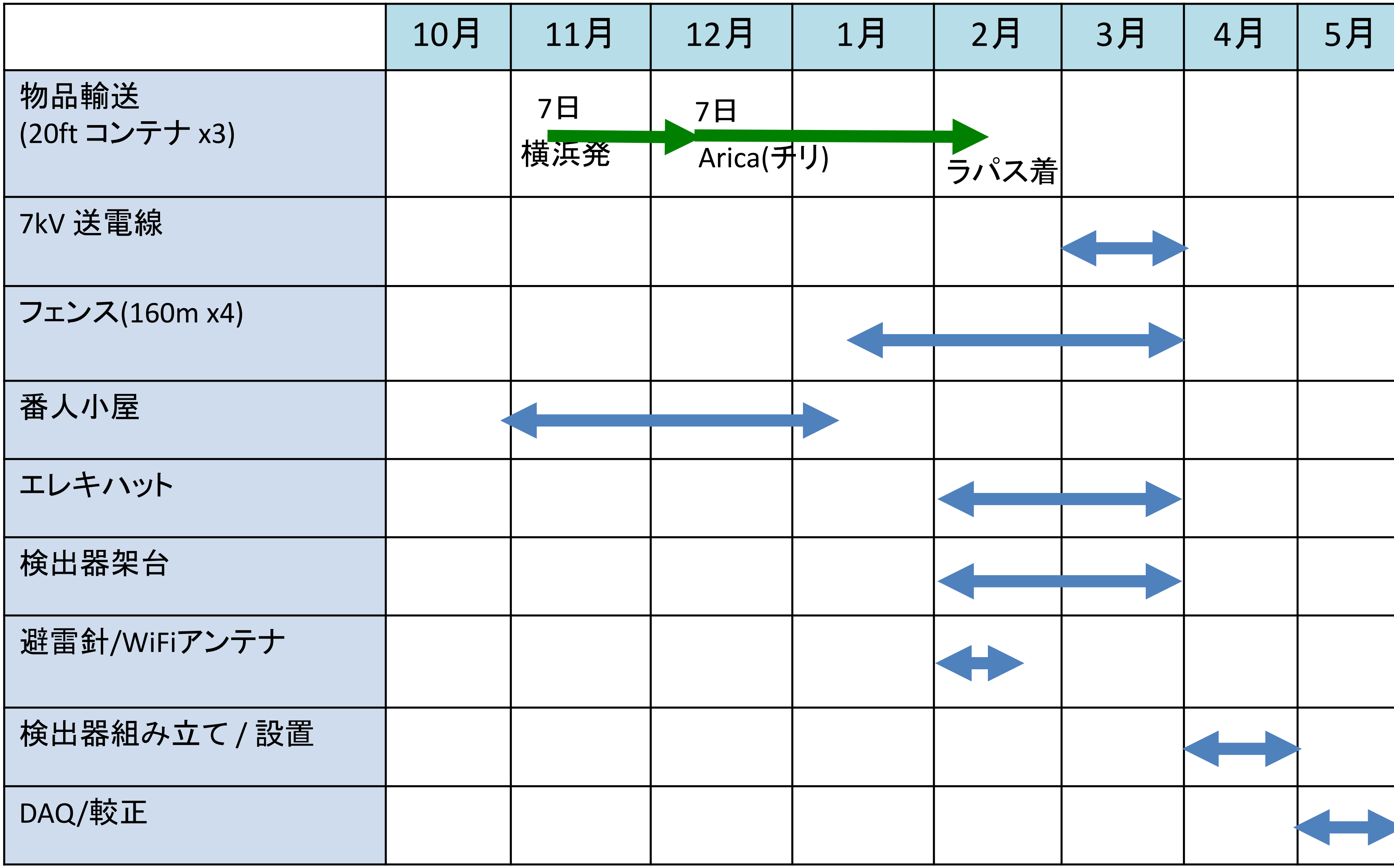
- 明るいガンマ線源の探索（上限値？）

北天：Tibet ASγ 5TeV

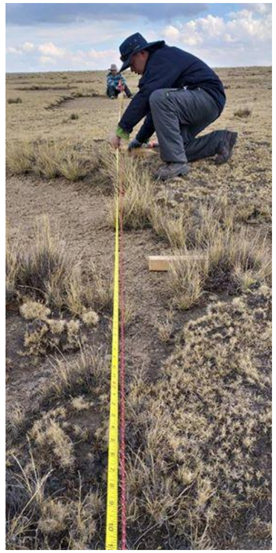


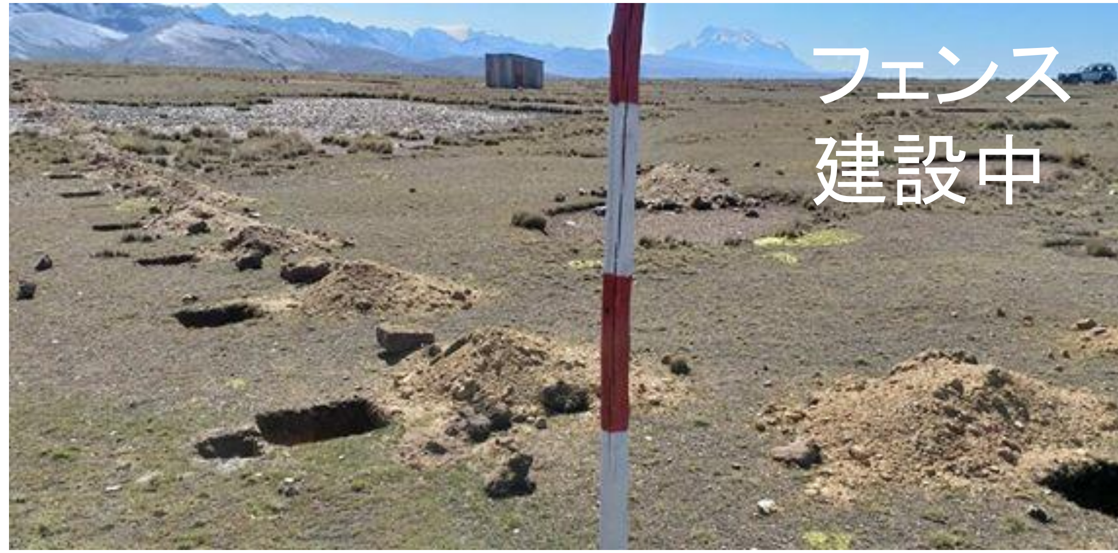
南天：IceCube 20TeV

ALPAQUITA スケジュール

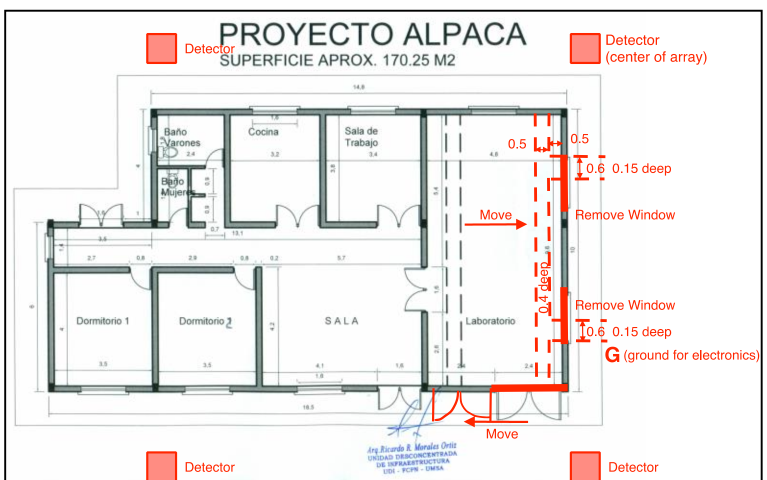


ALPAQUITA 現状 (1)

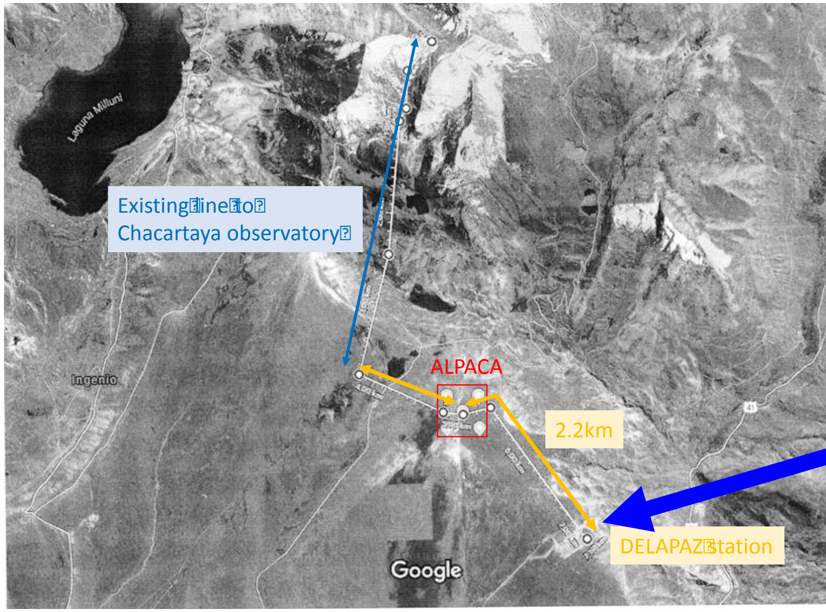




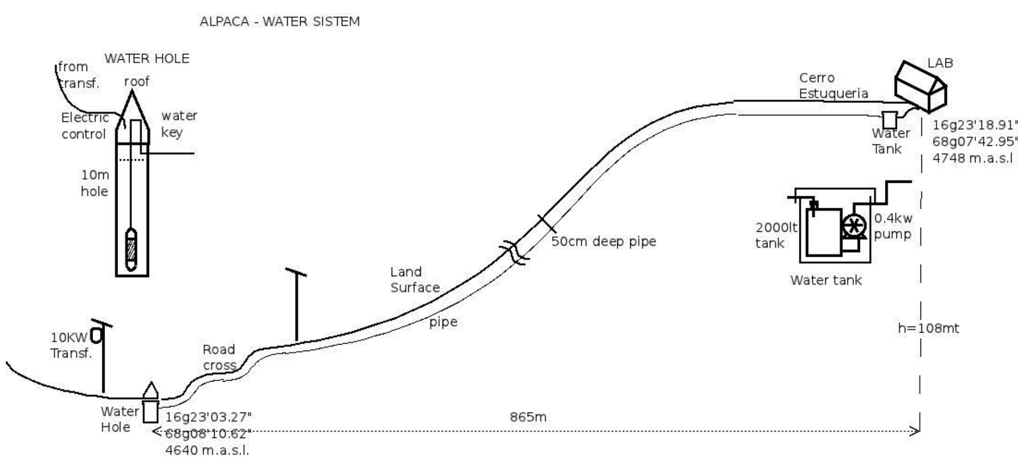
エレキハット 設計図面



ALPAQUITA 現状 (2)



水の供給

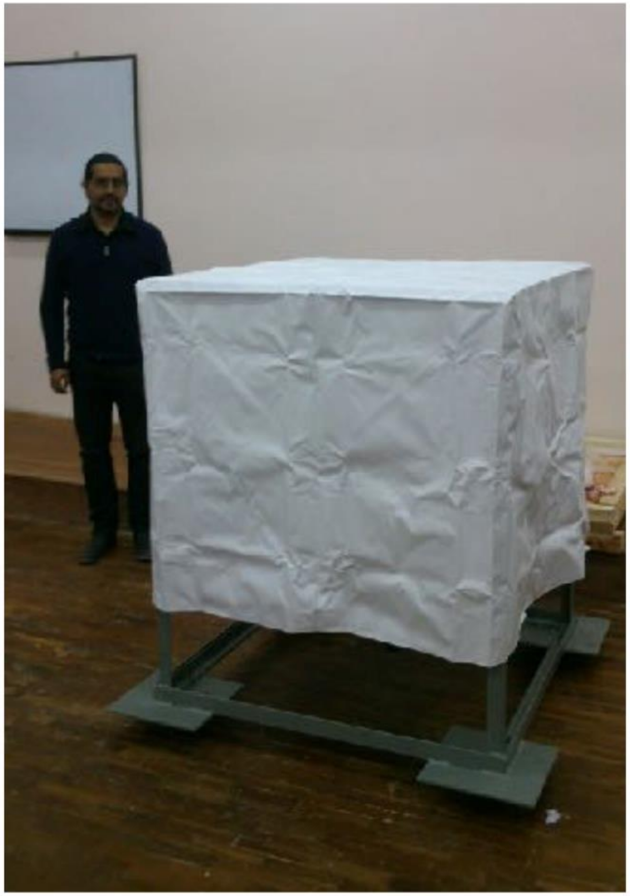


ALPAQUITA 現状 (3)

検出器架台

ボックス

カバー



まとめ

- Tibet ASγ 実験: チベット高原 標高4,300m on-going
  50,000m^2 AS + 3,400m^2 水チェレンコフ型MD

  ★ Targets
  10 - 1000 TeV gamma-ray astronomy (Northern sky)
  CR anisotropy, Chemical composition ~ 10^{15} eV, Sun shadow

- ALPACA計画: チャカルタヤ山 中腹 標高4,740m
  83,000m^2 AS + 5,400m^2 水チェレンコフ型MD

  ★ Targets
  10 - 1000 TeV gamma-ray astronomy (Southern sky)
  CR anisotropy, Chemical composition 10^{15} eV , Sun shadow

- ALPAQUITA: プロトタイプ空気シャワーアレイ
  1.0 m^2 × 97台、 ~18,000 m^2
  物品:2月上旬ラパス到着,インフラ整備:3月予定
  検出器設置、DAQ、較正作業:4月—5月
  → 5月データ取得開始予定

Thank you for your attention!

ALPAQUITA (~1/5 AS) will be constructed in 2019

End