

最高エネルギー宇宙線研究の 最新結果レビュー

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高エネルギーガンマ線でみる極限宇宙
2013

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まとめ

1. Telescope Array 実験の最新結果





Telescope Array Collaboration

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Telescope Array hybrid detector

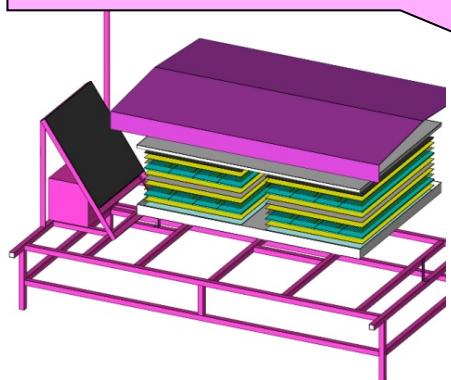
地表検出器 (SD)

シンチレーション検出器 507台

$3 \text{ m}^2 \times 1.2\text{cm} \times 2 \text{ layers}$

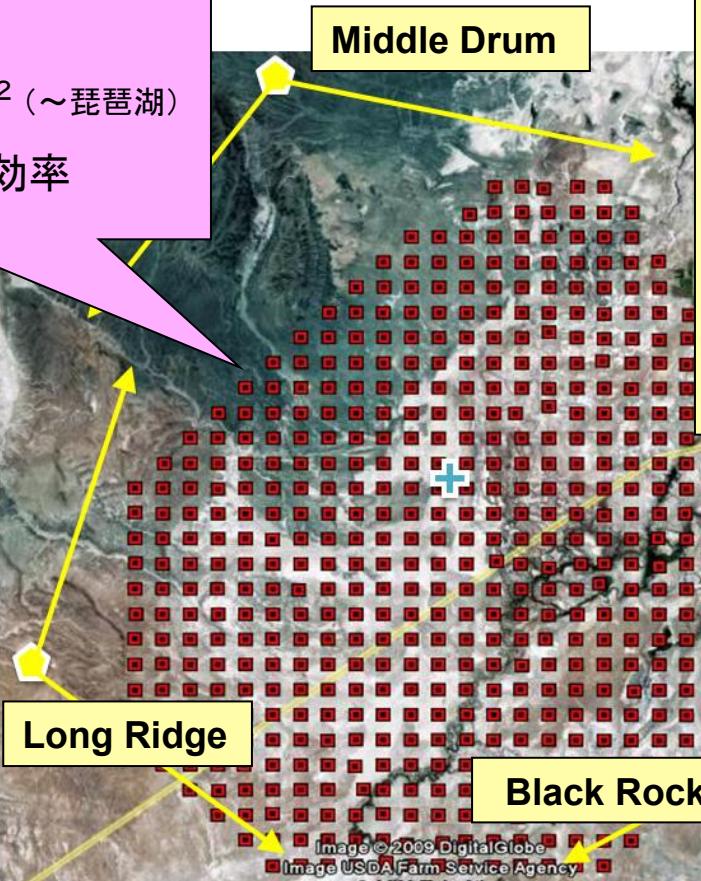
1.2 km 間隔, $\sim 700 \text{ km}^2$ (~琵琶湖)

$E > 10^{19} \text{ eV}$ で100%検出効率



ユタ州・ミラー郡 (北緯39.1°, 西経122.9°)

海拔~1400 m



大気蛍光望遠鏡 (FD)

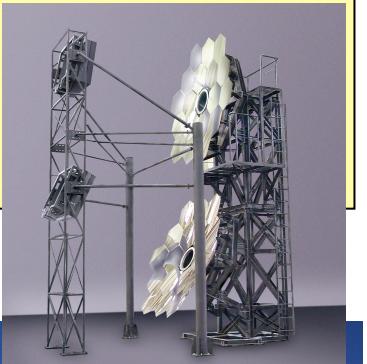
ステーション: 3ヶ所

望遠鏡: 12台(14台)／ステーション,

視野: $3^\circ - 33^\circ \times 108^\circ$

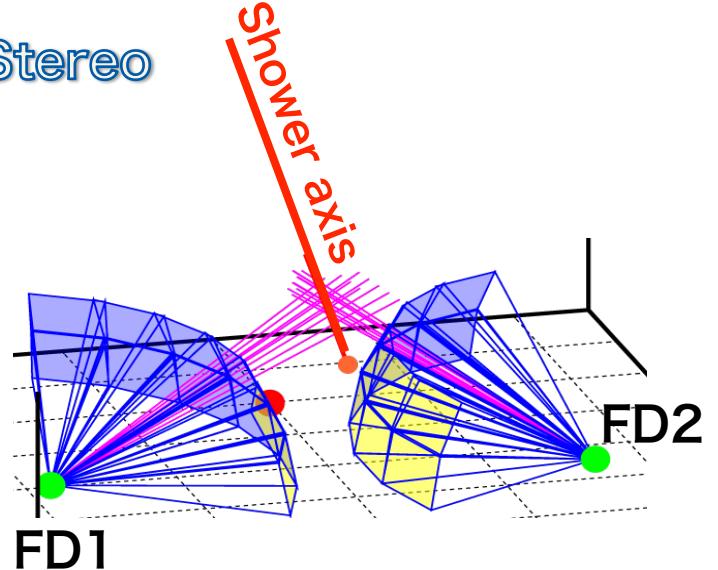
空間分解能: 1°

$\sim 35 \text{ km}$ 間隔



FD検出からイベント再構成

Stereo

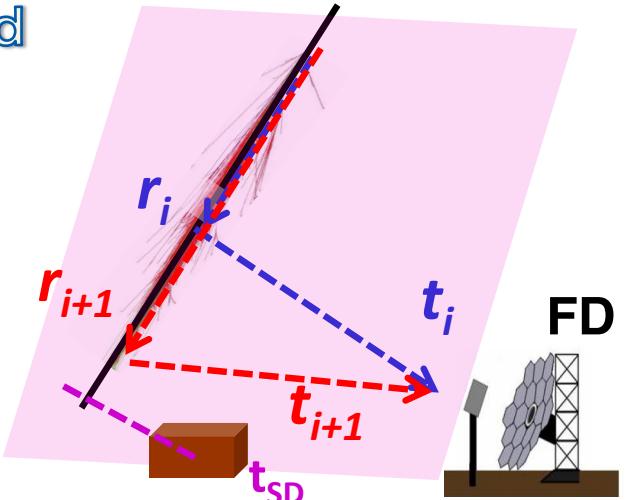


FD1

FD2

Timing Fitting

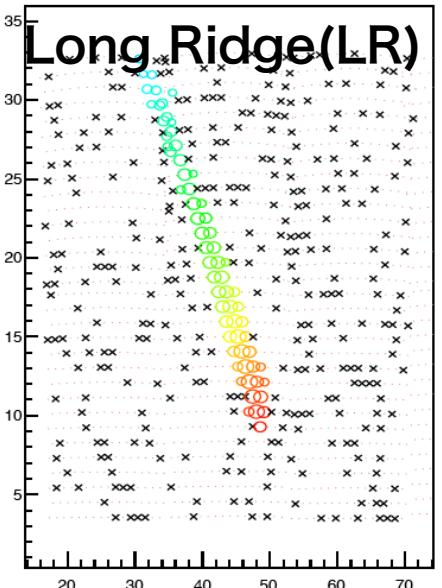
Hybrid



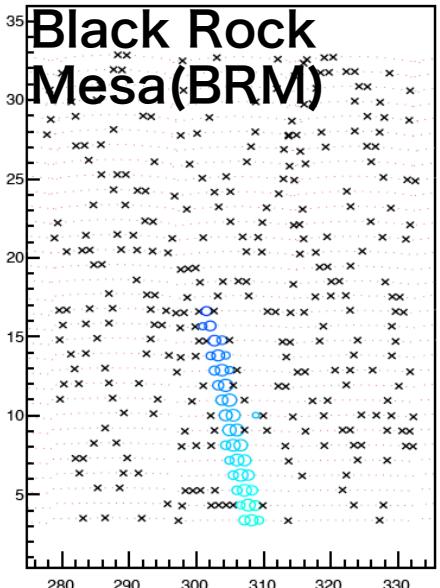
2013/09/03

$$\sigma X_{\max} \sim 20 \text{ g/cm}^2$$

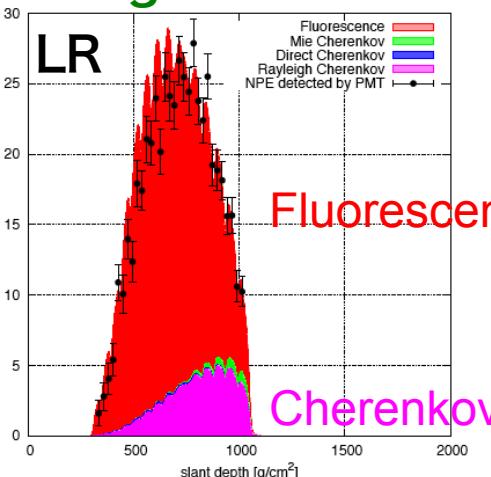
Camera images



Tsunesada (0769)



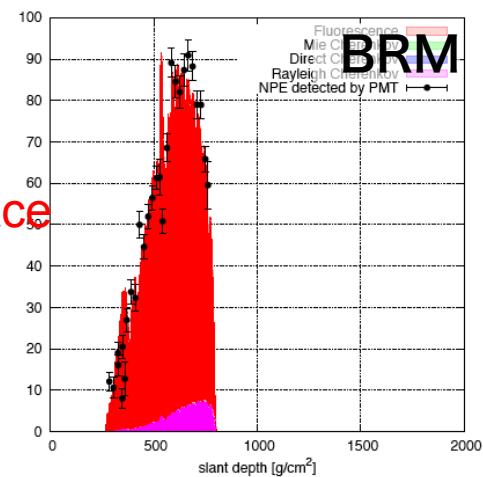
Longitudinal Profiles



Fluorescence

Cherenkov

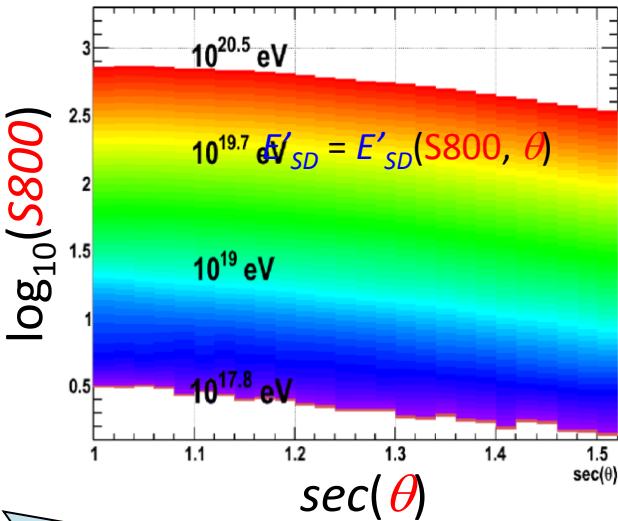
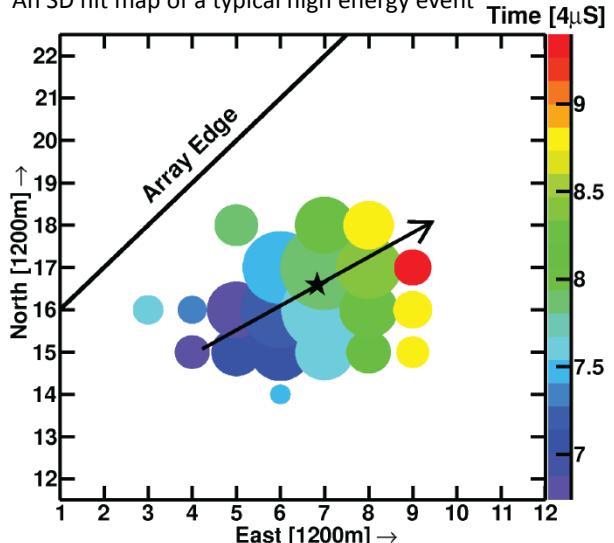
BRM



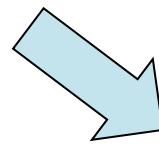


SDイベントに対するエネルギー決定

An SD hit map of a typical high energy event



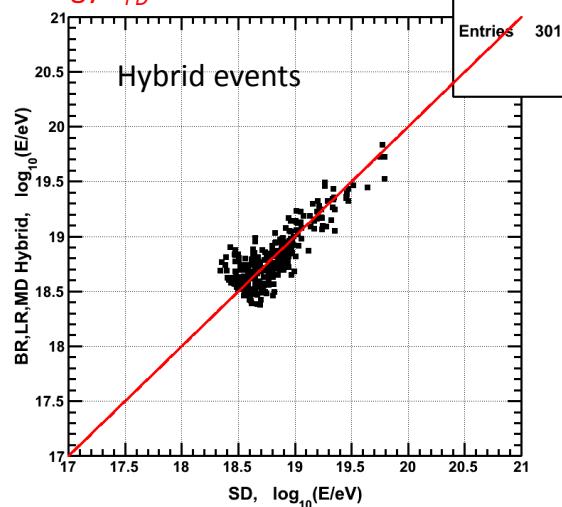
Sagawa(0128), Ivanov(0395)



(scaled to FD energy)

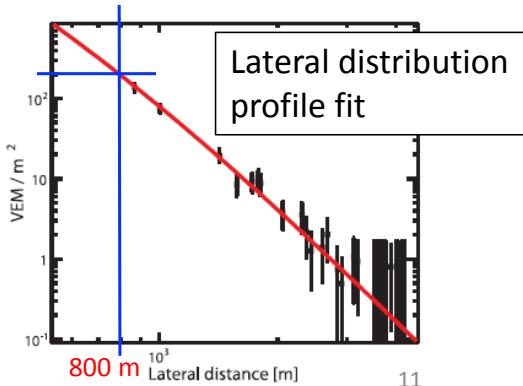
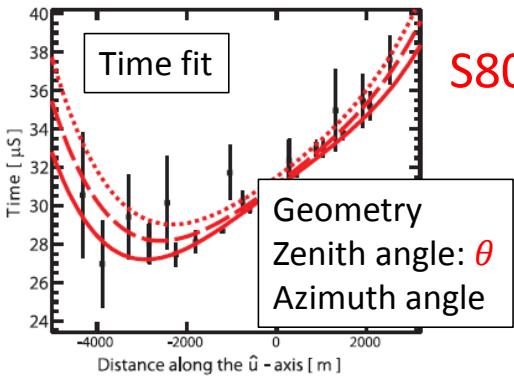
$$E_{SD} = E'_{SD} / 1.27$$

FD energy E_{FD}



SD energy E_{SD}

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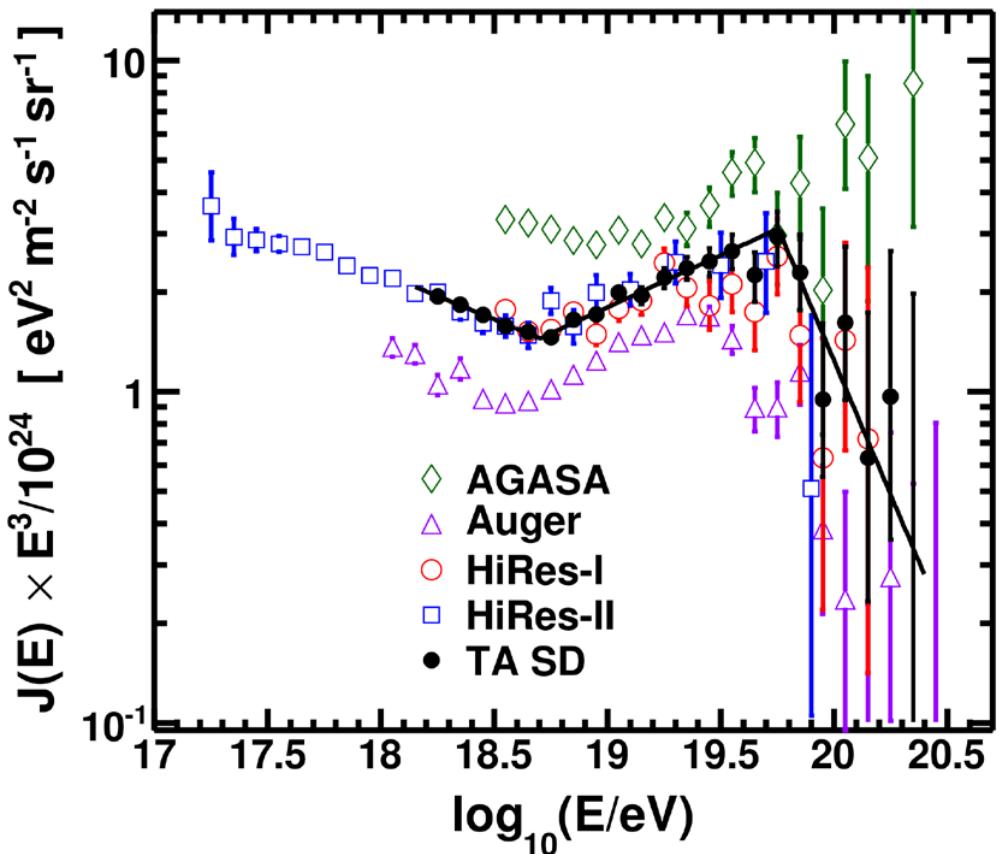
1.1 エネルギースペクトル





SD観測によるエネルギースペクトル

Sagawa(0128), Bergman(0221)



TA data

May, 2008 – May, 2013

Zenith angle < 45°

14787 ev. ($E > 10^{18.2}$ eV)

Exposure 4500 km² sr yr

Broken power law fit

$$\gamma_1 = -3.283 \pm 0.032$$

$$E_{\text{ankle}} = (5.04 \pm 0.27) \times 10^{18} \text{ eV}$$

$$\gamma_2 = -2.685 \pm 0.030$$

$$E_{\text{GZK}} = (5.68 \pm 1.05) \times 10^{19} \text{ eV}$$

$$\gamma_3 = -4.62 \pm 0.74$$

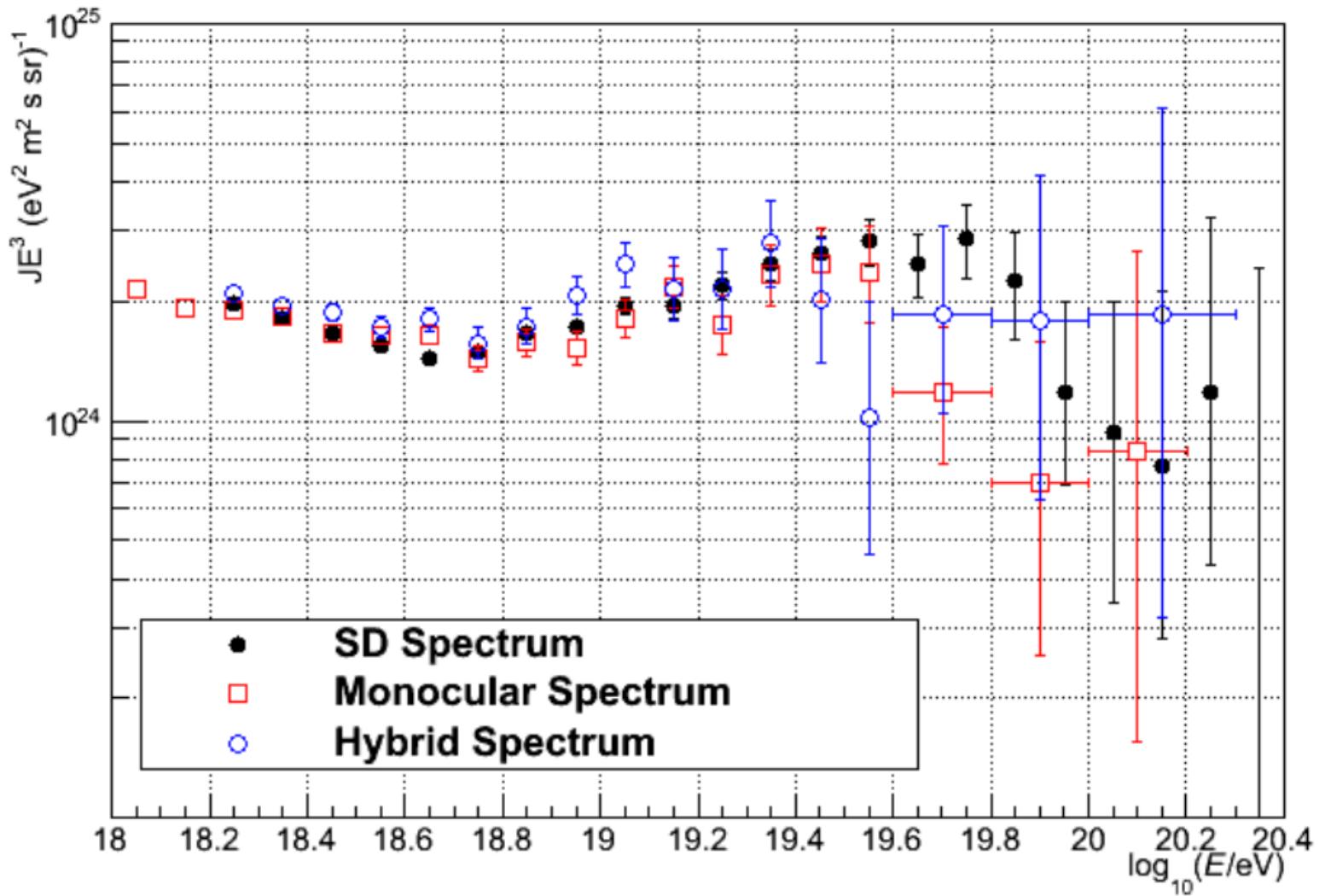
Steepening @ $E = 10^{19.8}$ eV :

$$N_{\text{exp}} = 68.1, N_{\text{obs}} = 26 \longrightarrow 5.74\sigma$$



SD、ハイブリッド、単眼FD観測によるスペクトル

Sagawa(0128), Bergman(0221)

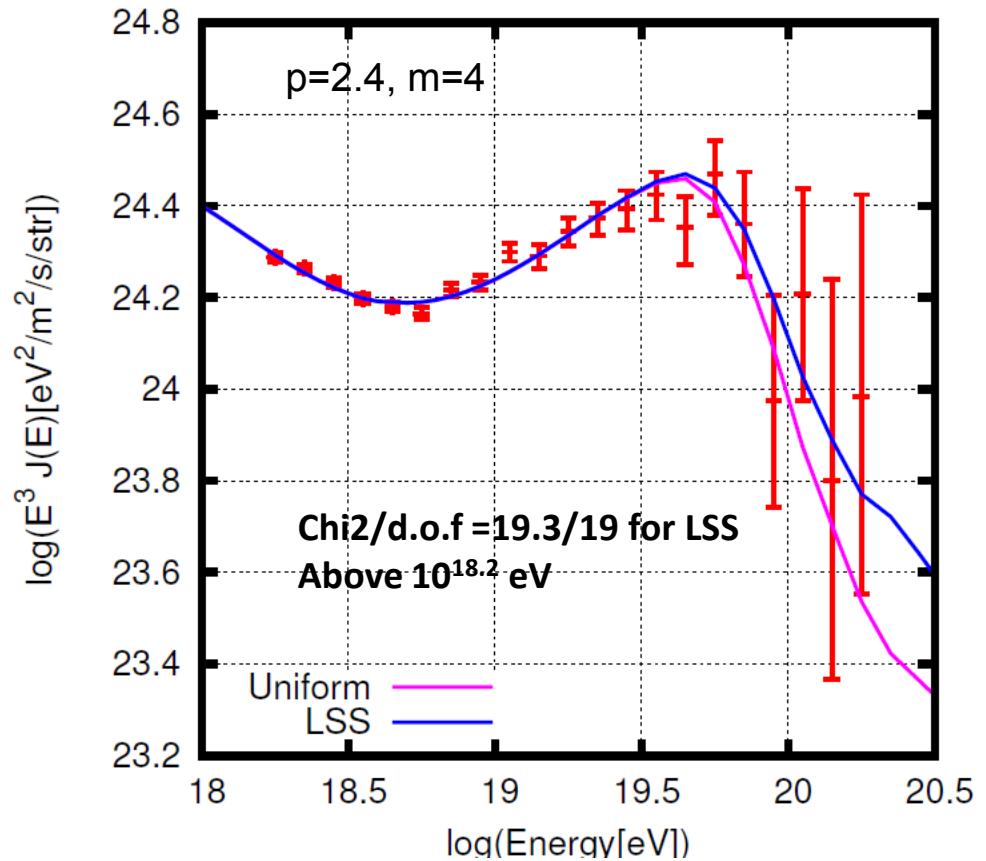


GZK機構モデルによるフィット

Free parameters: $E^{-\gamma}$, $(1+z)^m$

CRPropa v2.0, SOPHIA, IRB, LSS

Kido (0136)



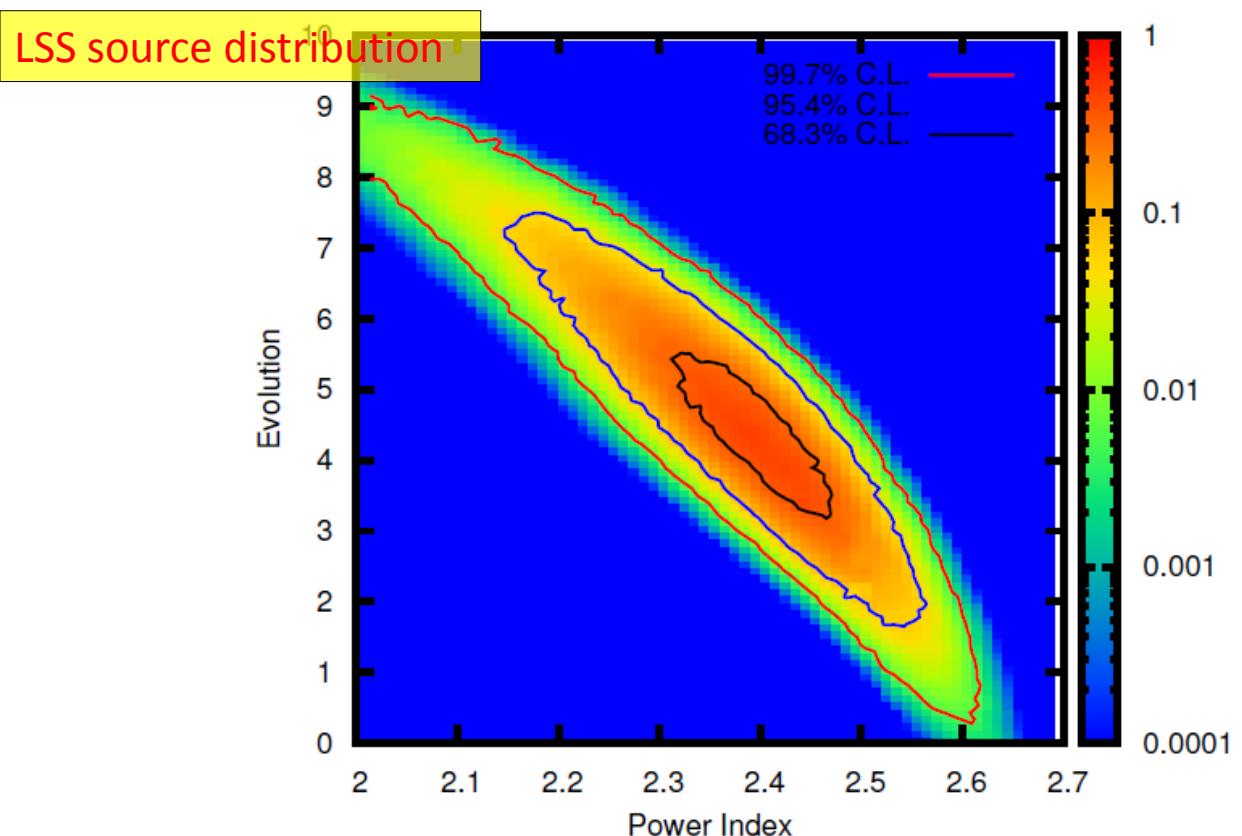


GZK機構モデルによるフィット

Free parameters: $E^{-\gamma}$, $(1+z)^m$

CRPropa v2.0, SOPHIA, IRB, LSS

Kido (0136)



$$\gamma = 2.39 \pm 0.08$$
$$m = 4.4 + 0.9 - 1.3$$

AGN: $m=5$ ($z < 1.7$)
(Hasinger et al. 2005)

GRB: $m=4.8$ ($z < 1$)
(Yuksel & Kstler 2007)

QSO: $m=3$ ($z < 1.3$)
(Waxman & Bahcall 2001)

1.2 化学組成





BRM+LR FDステレオ: 平均Xmax

Nov 2007 ~ Nov 2012: 5-year data

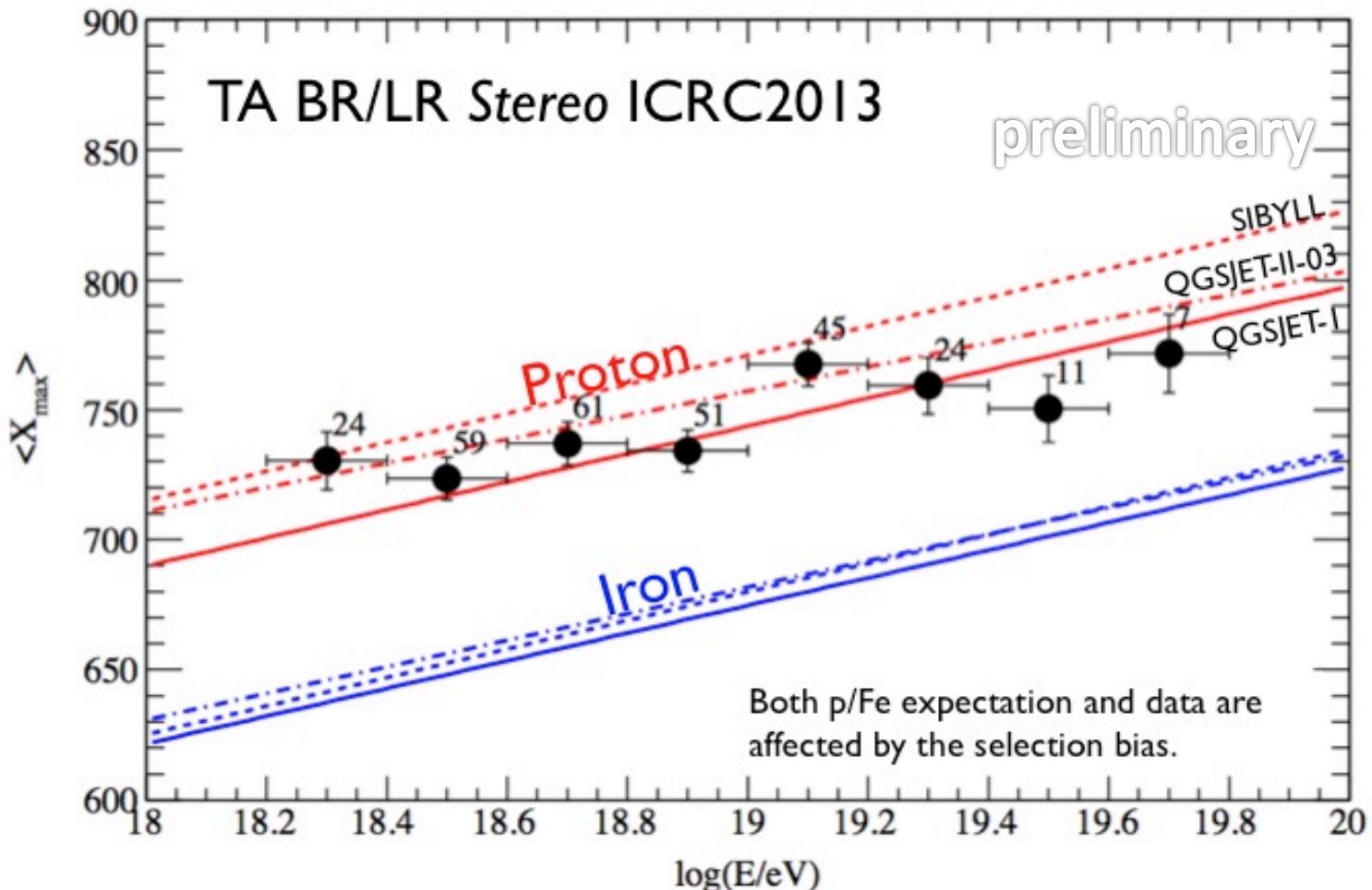
Tsunesada (0132), Tameda(0512)

Xstart/Xend definition change

Cut by minimum viewing angle (< 10deg)

Cut by angle btw Shower Detector Planes (SDPs) (< 10deg)

282 events in $E > 10^{18.2}$ eV



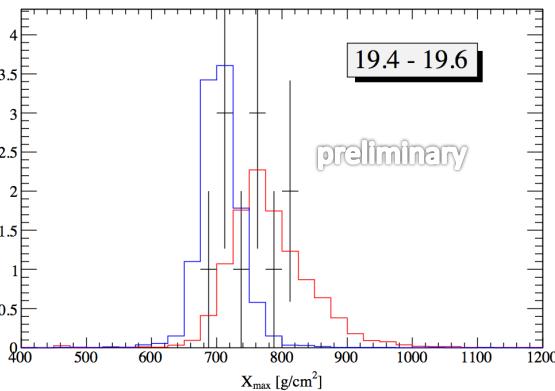
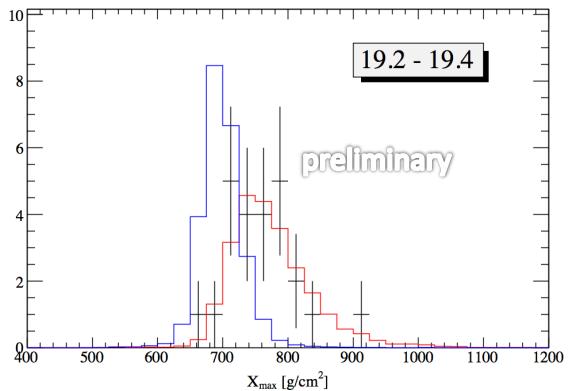
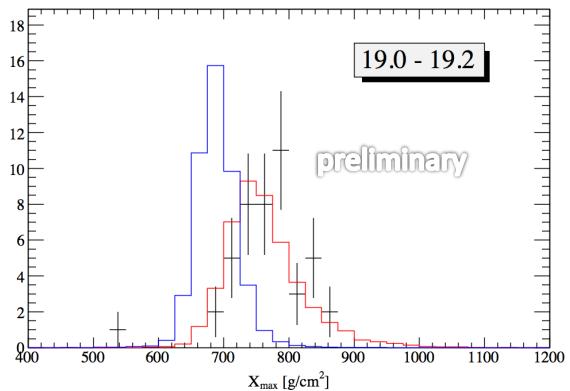
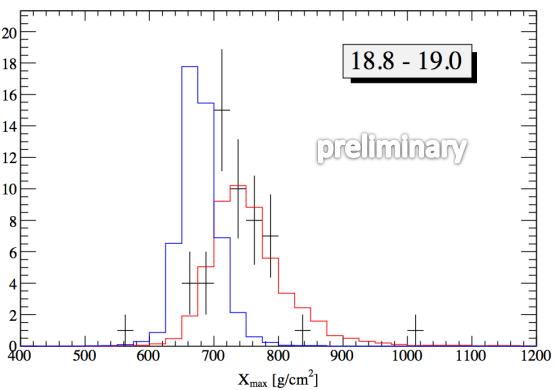
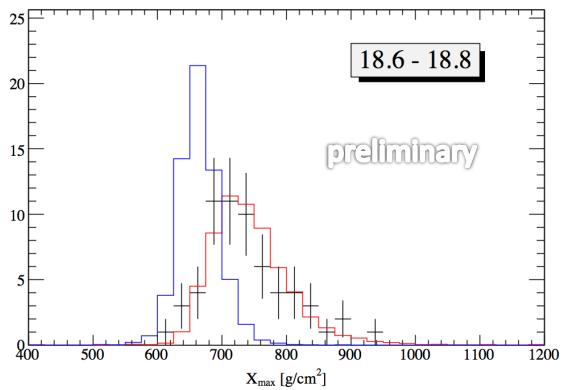
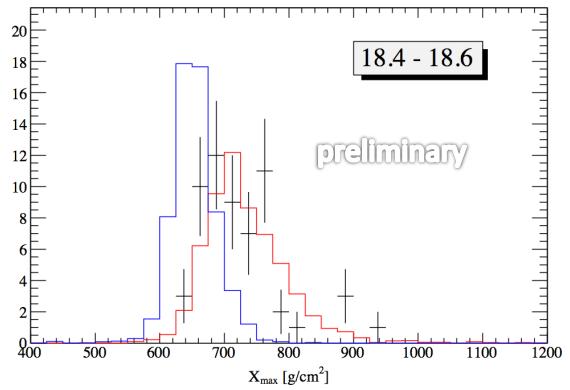


BRM+LR FDステレオ:Xmax分布とMCとの比較

Tsunesada (0132), Tameda(0512)

TA BR/LR Stereo ICRC2013

Proton
Iron

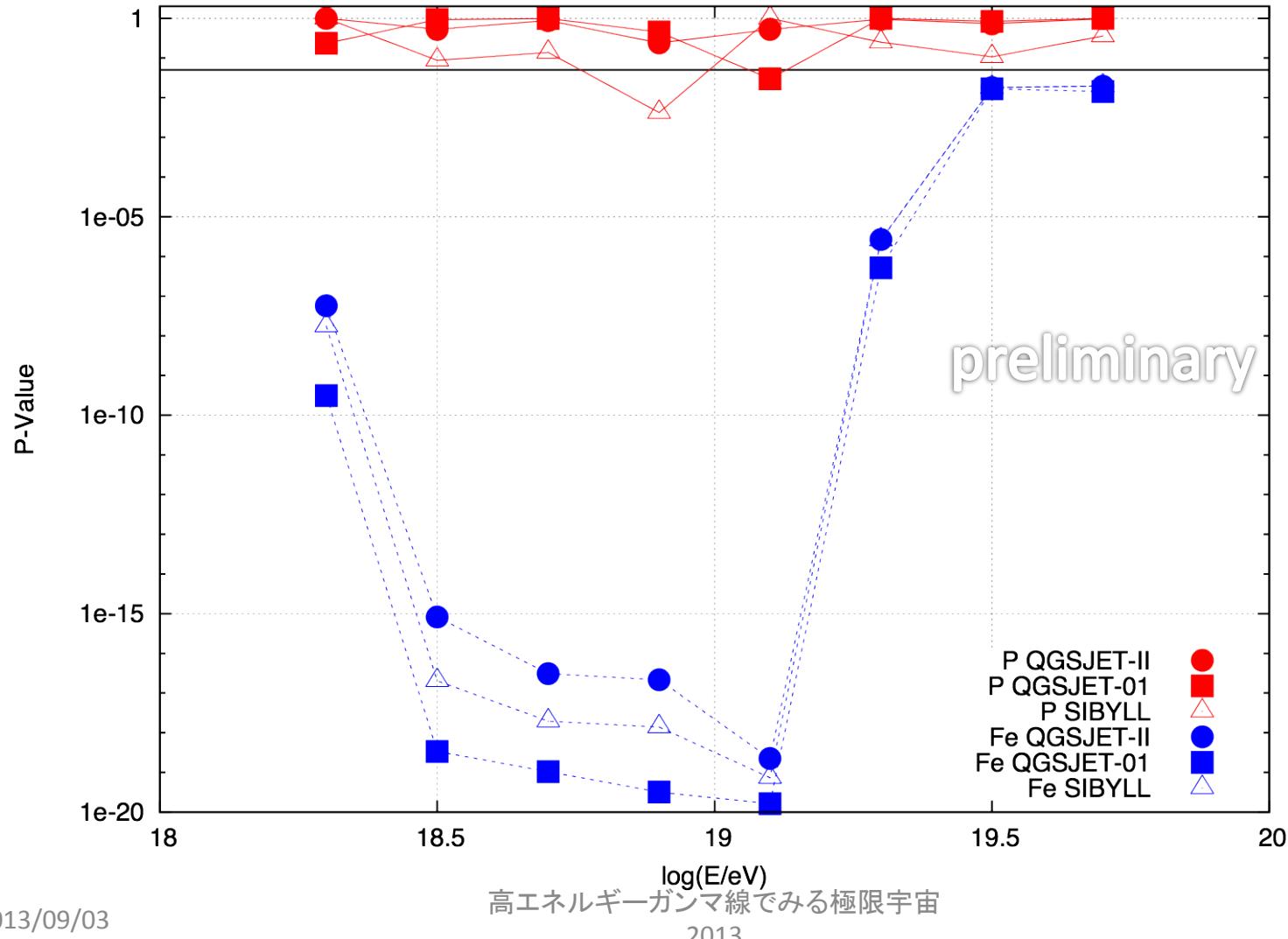




BRM+LR FDステレオ:Xmax分布の比較:KSテスト

Tsunesada (0132), Tameda(0512)

TA BR/LR Stereo ICRC2013



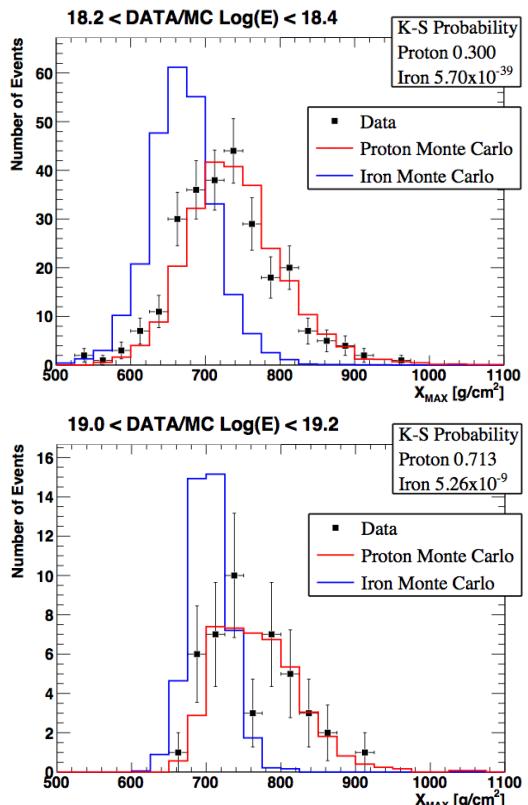
MD FD+SDハイブリットイベント:Xmax

MD-FD (refurbished HiRes-I detectors) + SD (≥ 3)

SDP by FD + SD shower core

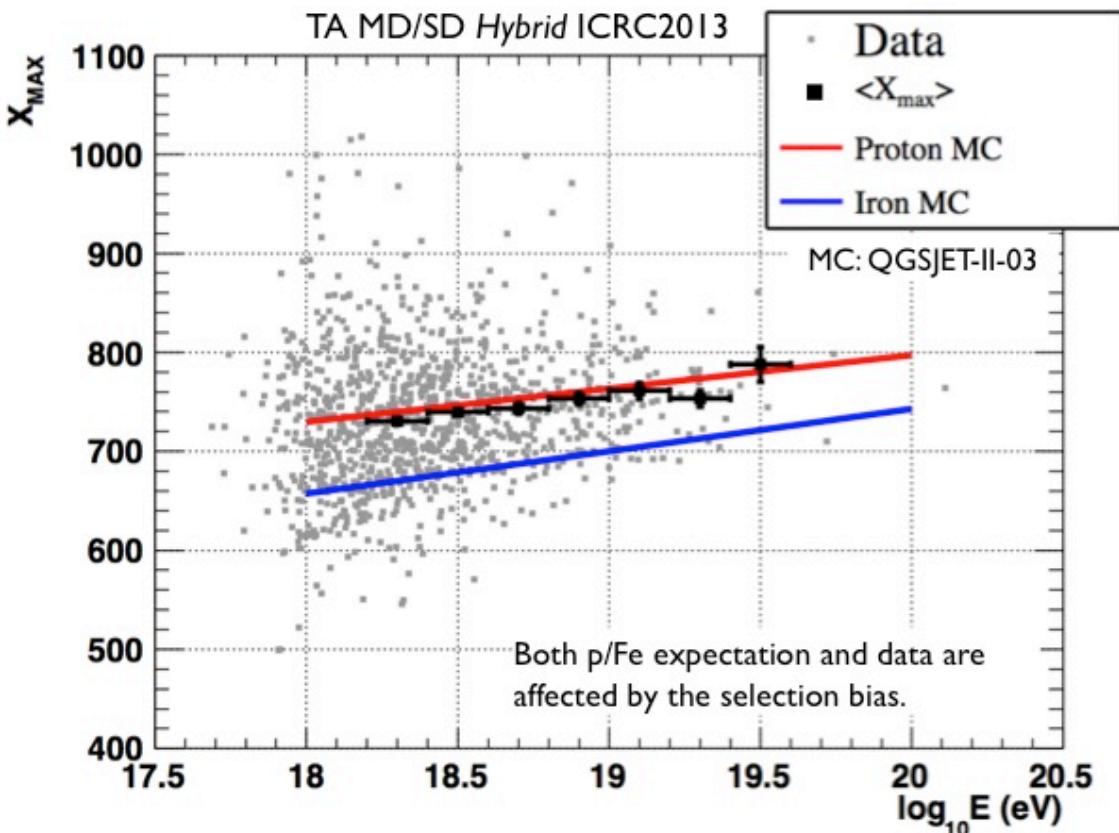
May 2008 ~ May 2012: 4-year data

~1000 events



Tsunesada (0132), Allen(0794)

TA MD/SD Hybrid ICRC2013



1.3 到来方向、異方性、起源天体





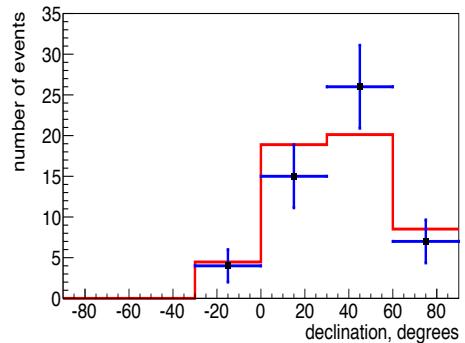
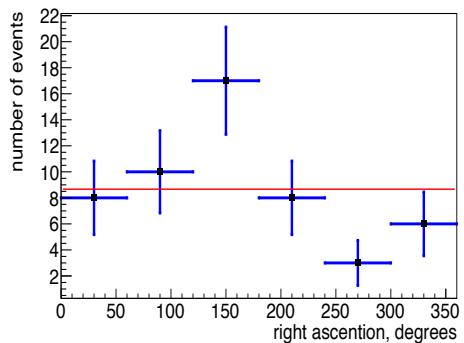
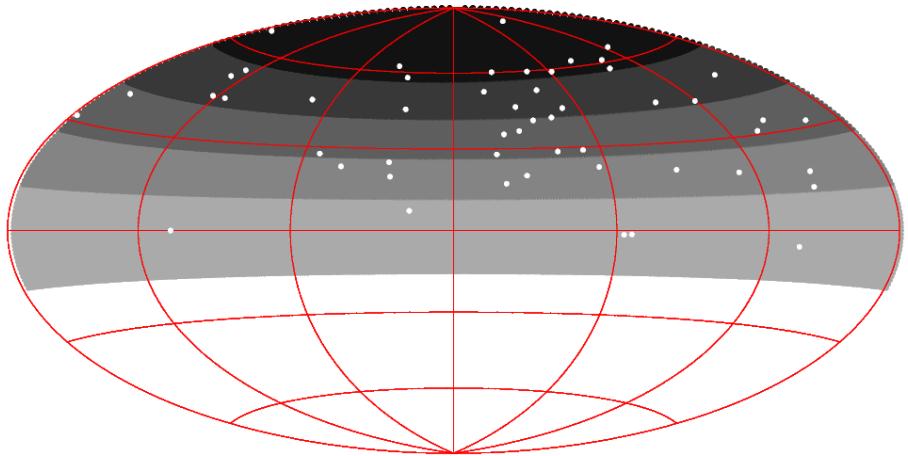
到来方向分布: 超銀河座標系

May 12, 2008 ~ May 4, 2013 (5 years)

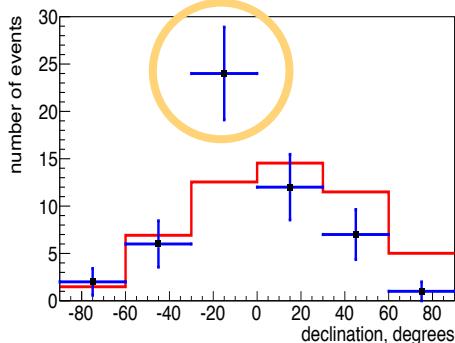
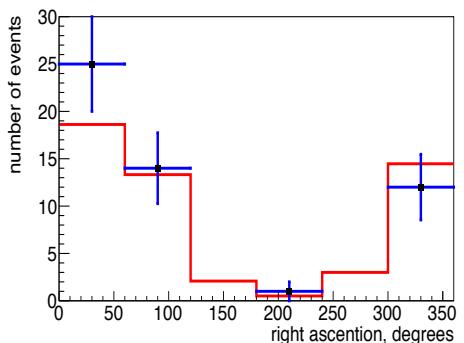
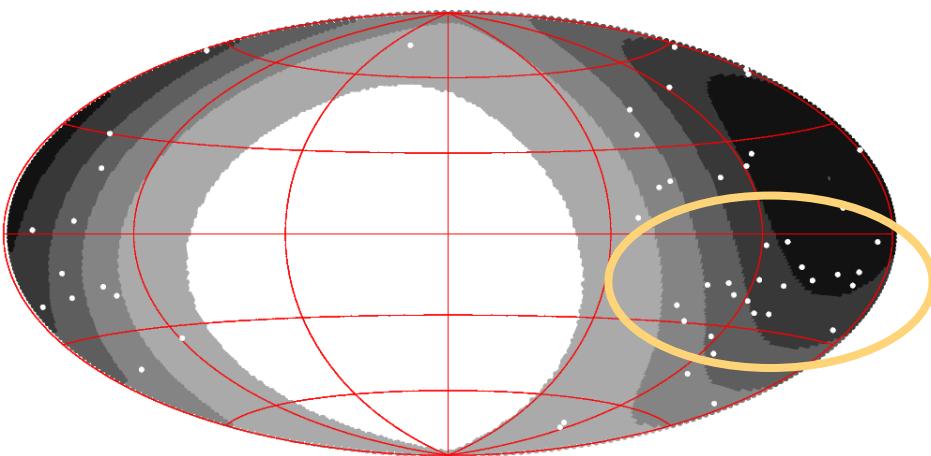
$E > 57 \text{ EeV}$, $\theta < 55^\circ$

Tinyakov(1033)

赤道座標系



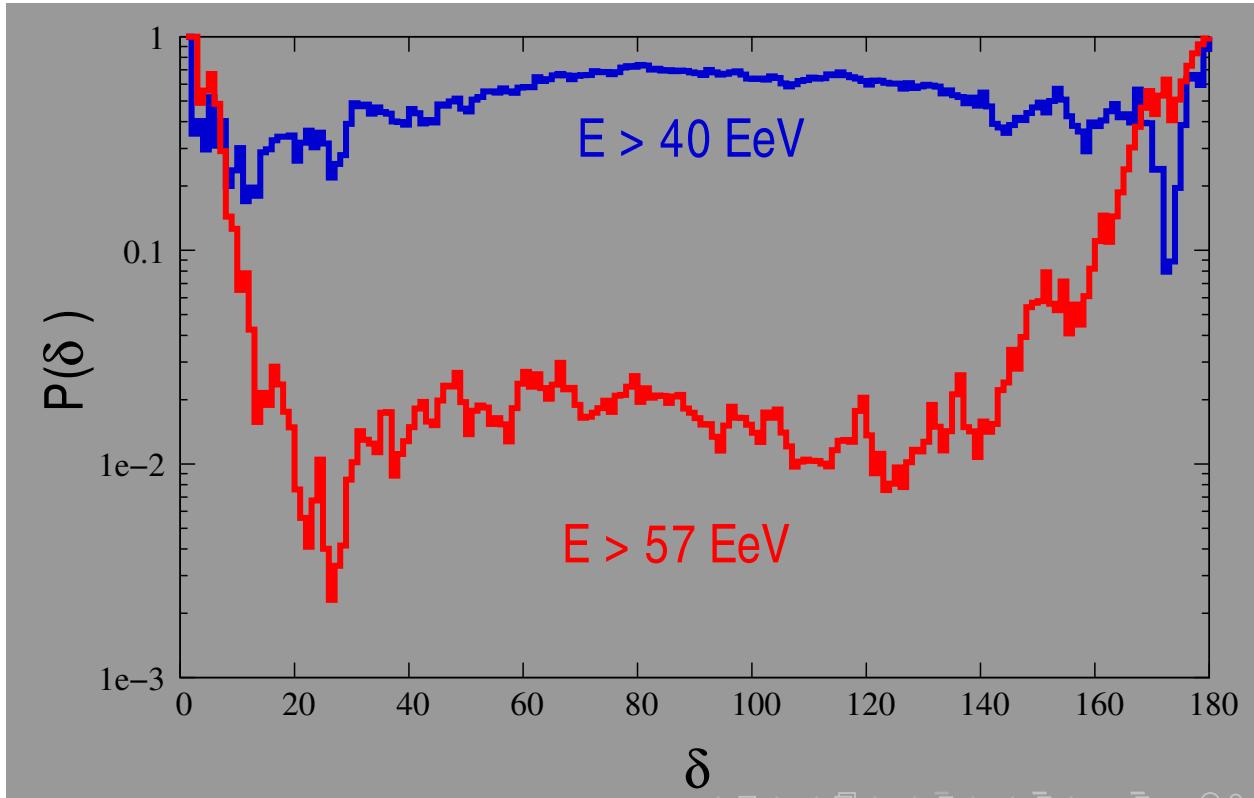
超銀河座標系



到来方向自己相關解析

- AGASA has reported clustering at 2.5° , $E > 40\text{EeV}$
- TA: Opairs found (1.5 expected from uniform)
 \Leftrightarrow no clustering at 2.5°
- Extend search for larger angles and higher energies:

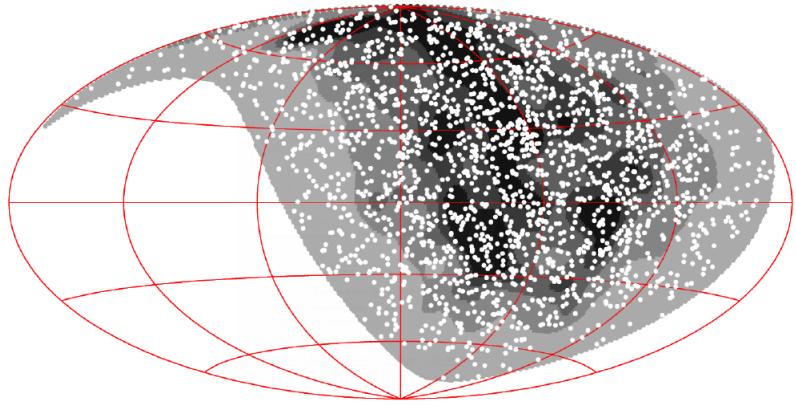
Tinyakov(1033)



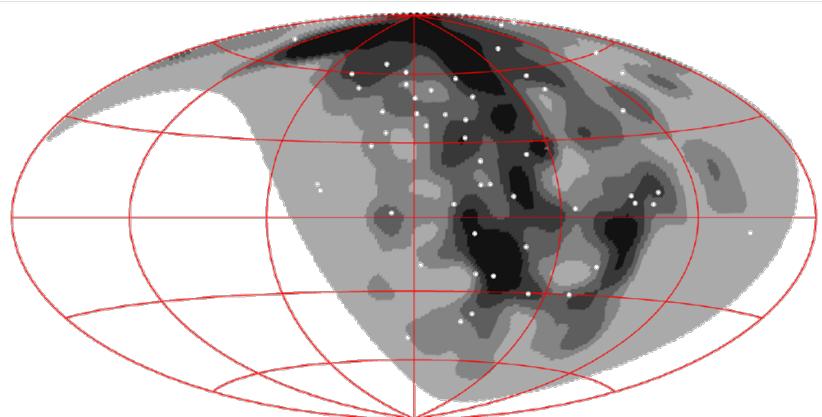


等方性／大規模構造との到来方向相関

$E > 10 \text{ EeV}$: 2130 ev.

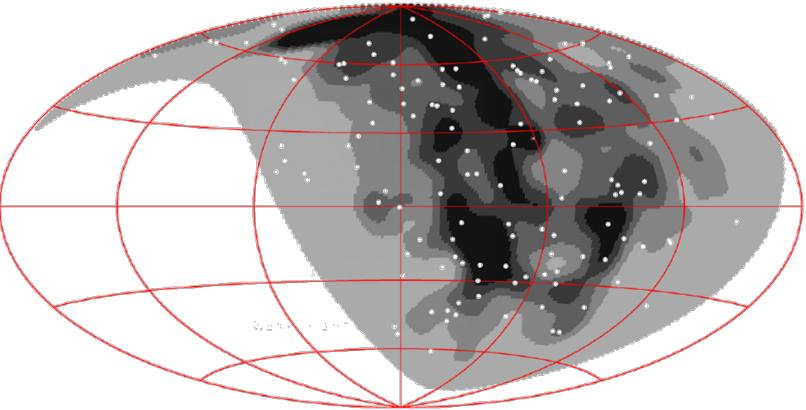


$E > 57 \text{ EeV}$: 52 ev.



Sagawa(0128), Tinyakov(0935, 1033)

$E > 40 \text{ EeV}$: 132 ev.



White dots: TA data with zenith angle $< 55^\circ$

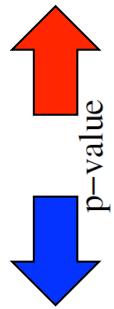
Gray patterns:
expected flux density from proton LSS
2MASS Galaxy Redshift catalog (XSCz)



等方性／大規模構造との到来方向相関

Sagawa(0128), Tinyakov(0935, 1033)

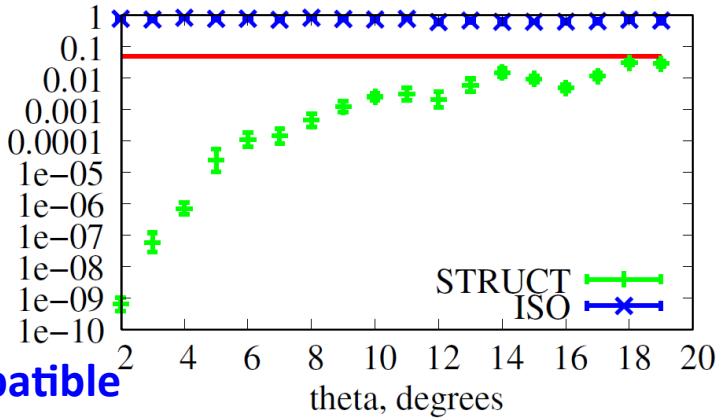
compatible



$E > 10 \text{ EeV}$

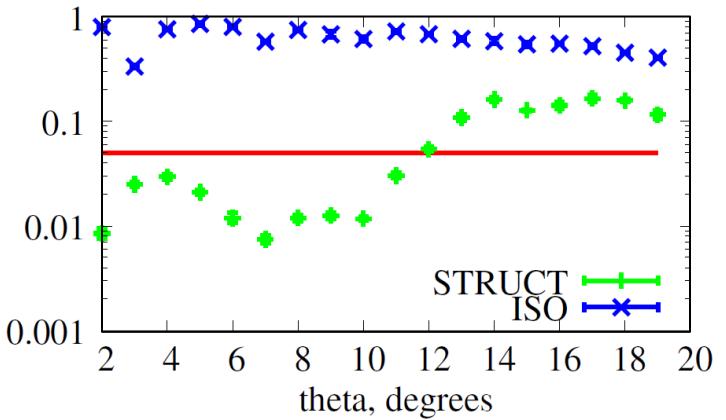
Not compatible

STRUCT ISO

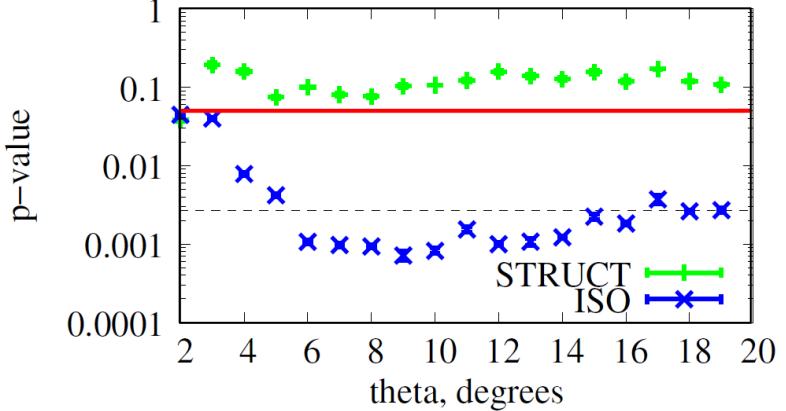


$E > 40 \text{ EeV}$

p-value



$E > 57 \text{ EeV}$



大規模構造との比較

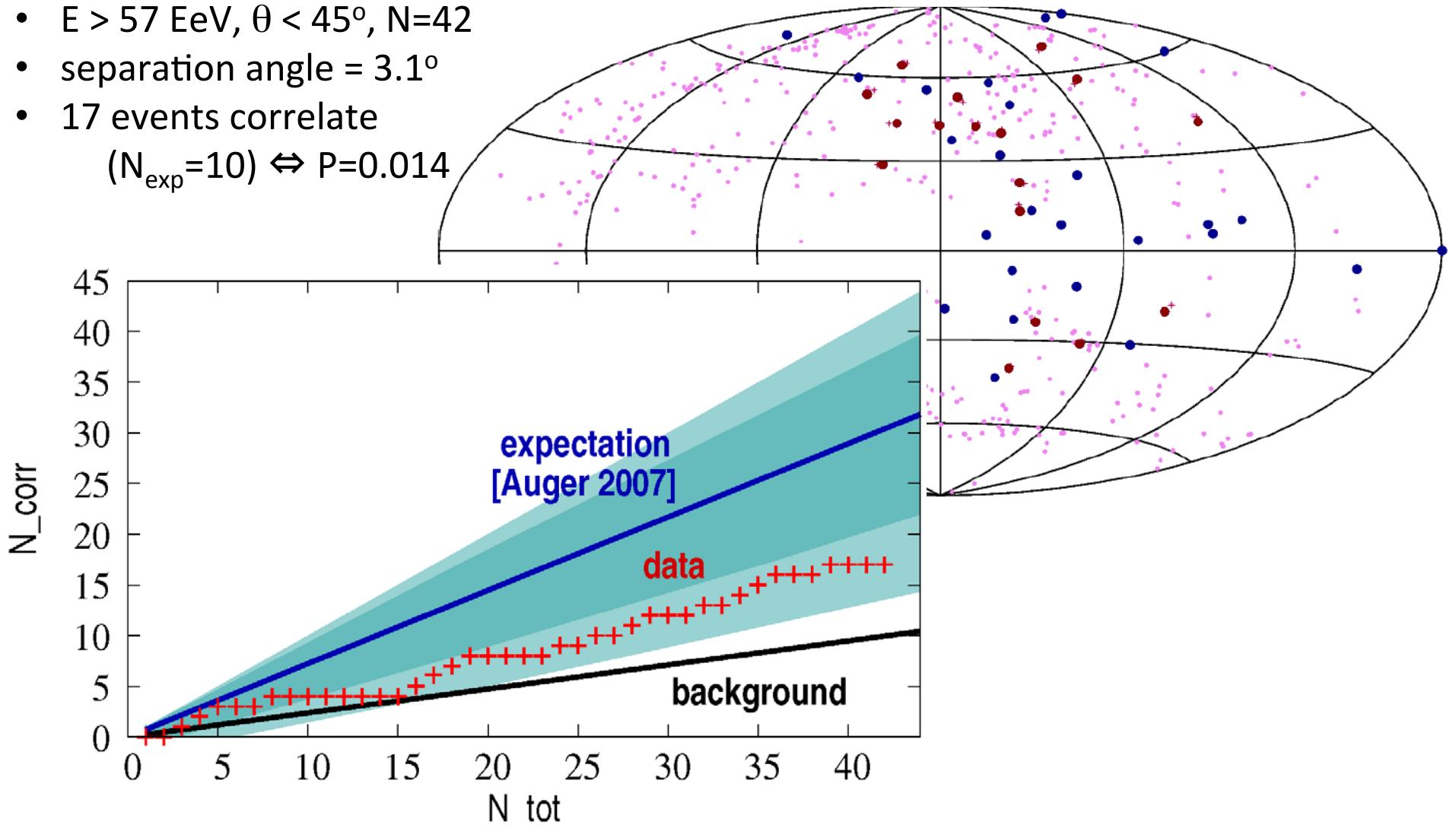
等方性との比較

smearing angle

AGNとの到来方向相関(PAO(2007)と同じ解析)

- 472 AGN from 2006 VCV, $z < 0.018$
- $E > 57 \text{ EeV}$, $\theta < 45^\circ$, $N=42$
- separation angle = 3.1°
- 17 events correlate
 $(N_{\text{exp}}=10) \Leftrightarrow P=0.014$

Sagawa(0128), Tinyakov(1033)





他の天体力タログ、エネルギーしきい値ではどうか？

arXiv:1308.5808, submitted to ApJ

- 3CRR, 2MRS, Swift BAT 58M, Swift BAT AGN, 2LAC, VCV 13th
- May 2008 – Sep 2011, $\theta < 45^\circ$, アレイの十分内側 → 57イベント $E > 40$ EeV
- スキャンされるパラメーター
 - ✓ $E \geq 40$ EeV
 - ✓ $z < 0.03$
 - ✓ $\phi = 1^\circ \sim 15^\circ$ (イベント到来方向と天体のなす角が ϕ 以下なら「方向相関」)
- 等方性を仮定したシミュレーションから確率を計算
→ 確率最小を与えるパラメーターセットを決定

Catalog	E_{th} [Eev]	Window	z	$k_{\text{corr}}/N_{\text{corr}}$	p_{iso}	P_{min}	P
Swift-BAT AGN	62.20	10.0°	0.020	17/17	0.52	1.3×10^{-5}	0.01
Swift-BAT 58M	57.46	11.0°	0.017	25/25	0.68	6.1×10^{-5}	0.04
2MRS	51.85	6.5°	0.005	29/31	0.62	8.5×10^{-5}	0.21
VCV 13 th	62.20	2.1°	0.016	8/17	0.14	8.6×10^{-4}	0.25
3CRR	66.77	2.0°	0.017	1/11	0.002	2.2×10^{-2}	0.75
2LAC	55.41	12.0°	0.018	2/23	0.069	2.1×10^{-1}	0.83



他の天体力学カタログ、エネルギーしきい値ではどうか？

arXiv:1308.5808, submitted to ApJ

k_{corr} : 天体と相関のあったイベント数

N_{corr} : エネルギーしきい値以上のイベント数

p_{iso} : 一様等方からの期待相関数(1イベントあたり)

P_{min} : 累積確率

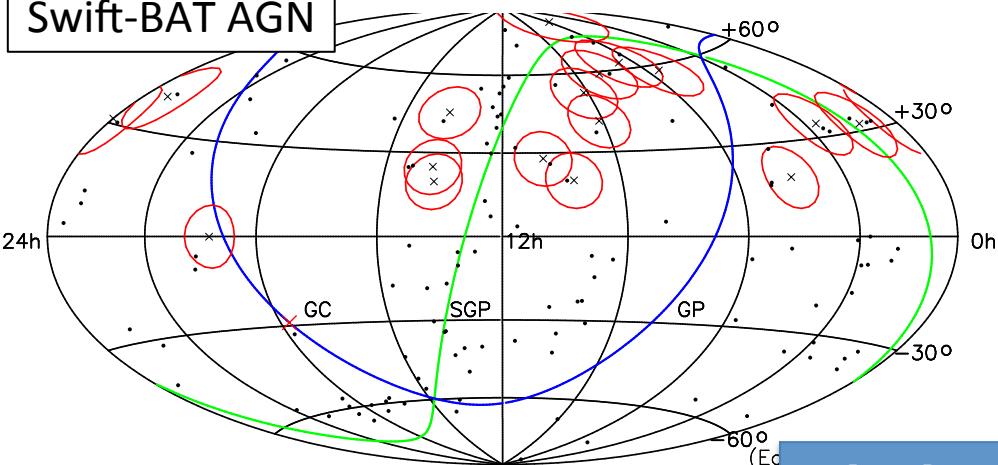
P : ペナルティで補正した P_{min}

Catalog	$E_{\text{th}}[\text{EeV}]$	Window	z	$k_{\text{corr}}/N_{\text{corr}}$	p_{iso}	P_{min}	P
Swift-BAT AGN	62.20	10.0°	0.020	17/17	0.52	1.3×10^{-5}	0.01
Swift-BAT 58M	57.46	11.0°	0.017	25/25	0.68	6.1×10^{-5}	0.04
2MRS	51.85	6.5°	0.005	29/31	0.62	8.5×10^{-5}	0.21
VCV 13 th	62.20	2.1°	0.016	8/17	0.14	8.6×10^{-4}	0.25
3CRR	66.77	2.0°	0.017	1/11	0.002	2.2×10^{-2}	0.75
2LAC	55.41	12.0°	0.018	2/23	0.069	2.1×10^{-1}	0.83



他の天体力カタログ、エネルギーしきい値ではどうか？

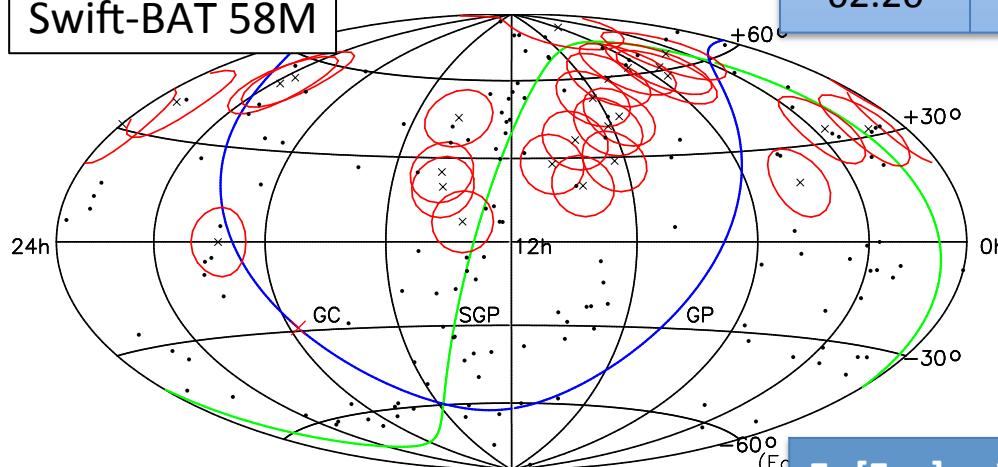
Swift-BAT AGN



arXiv:1308.5808, submitted to ApJ

$E_{\text{th}}[\text{Eev}]$	Window	z	$k_{\text{corr}}/N_{\text{corr}}$	P_{min}	P
62.20	10.0°	0.020	17/17	1.3×10^{-5}	0.01

Swift-BAT 58M



$E_{\text{th}}[\text{Eev}]$	Window	z	$k_{\text{corr}}/N_{\text{corr}}$	P_{min}	P
57.46	11.0°	0.017	25/25	6.1×10^{-5}	0.04

2013/09/03

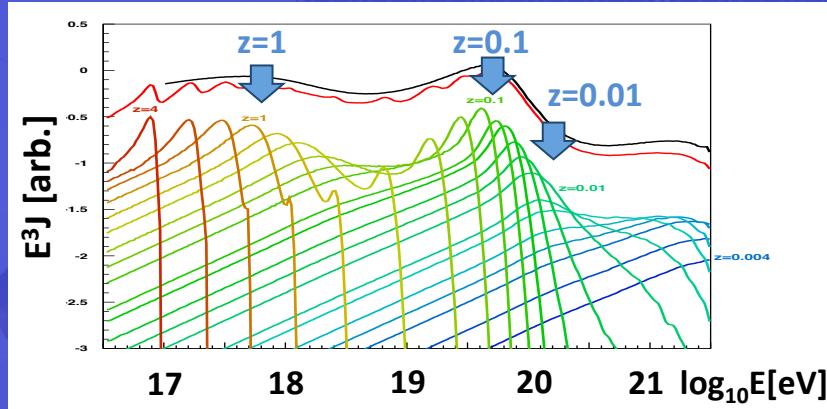
高工大

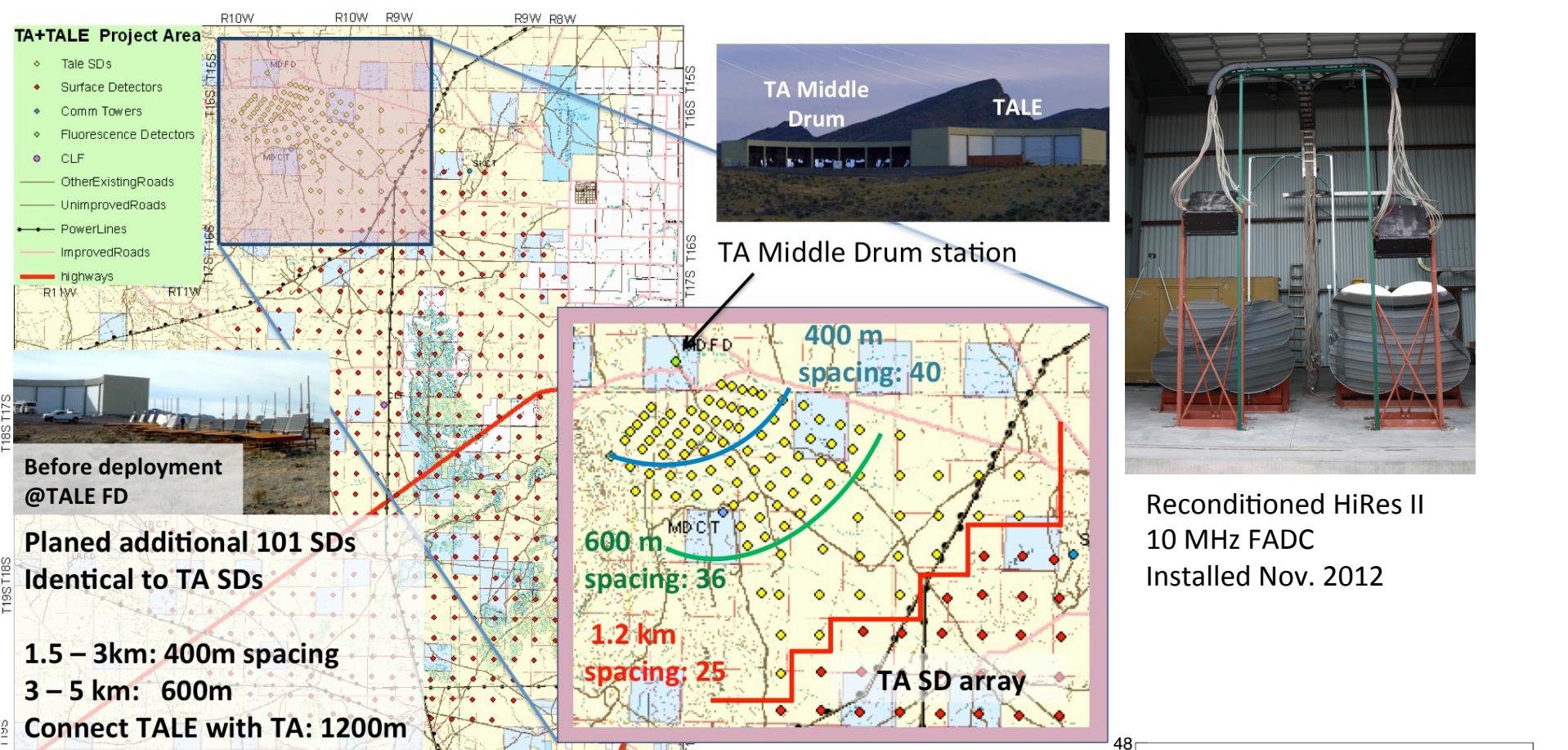
1. TA実験の最新結果：まとめ

- GZK機構によるdip、cut offによく一致
- $E_{SD} = E_{FD} \times 1.27$
- Xmax : $10^{18.2}$ eV以上では、「純粹陽子」と矛盾しない
- 最高エネルギー領域 ($E > \sim 60$ EeV) では、
 - 到来方向分布は「等方性」とは合わない
 - (統計的に有意ではないものの) 起源のヒント?
 - ✓ 超銀河座標系 $p \sim 0.003$
 - ✓ 自己相関 $p \sim 0.004 @ \delta = 20^\circ$
 - ✓ AGNとの相関 $p \sim 0.01$
 - ✓ $(1+z)^m$ (\leftarrow 低エネルギーでこそ！)

2. TA実験の将来計画

- TALE (TA Low energy Extension)+NICHE
 - Second knee、GCR/EGCR transition
 - $(1+z)^m$ 精密測定
 - EAS @ LHCエネルギー
- TA × 4
 - 世界最大級 ~ 3,000km²
 - 「異方性」に結論(→5σ)





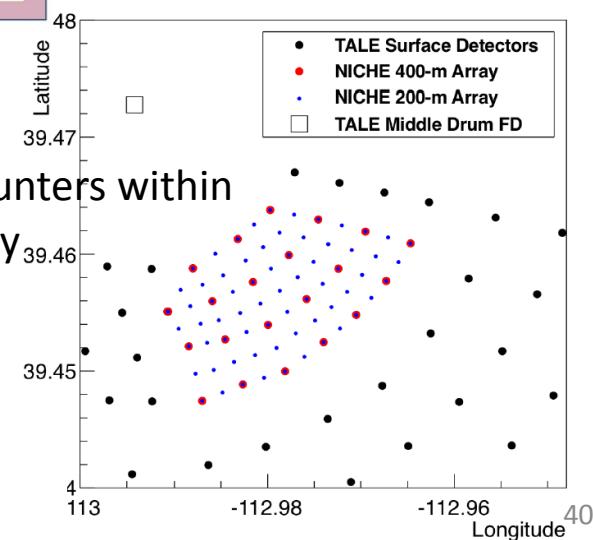
TALE: $10^{16.5} - 10^{19}$ eV
NICHE: $10^{15.5} - 10^{17}$ eV



TALE+NICHE

SO(0717), Krizmanic(0365)

Cherenkov counters within
TALE infill array





TA×4

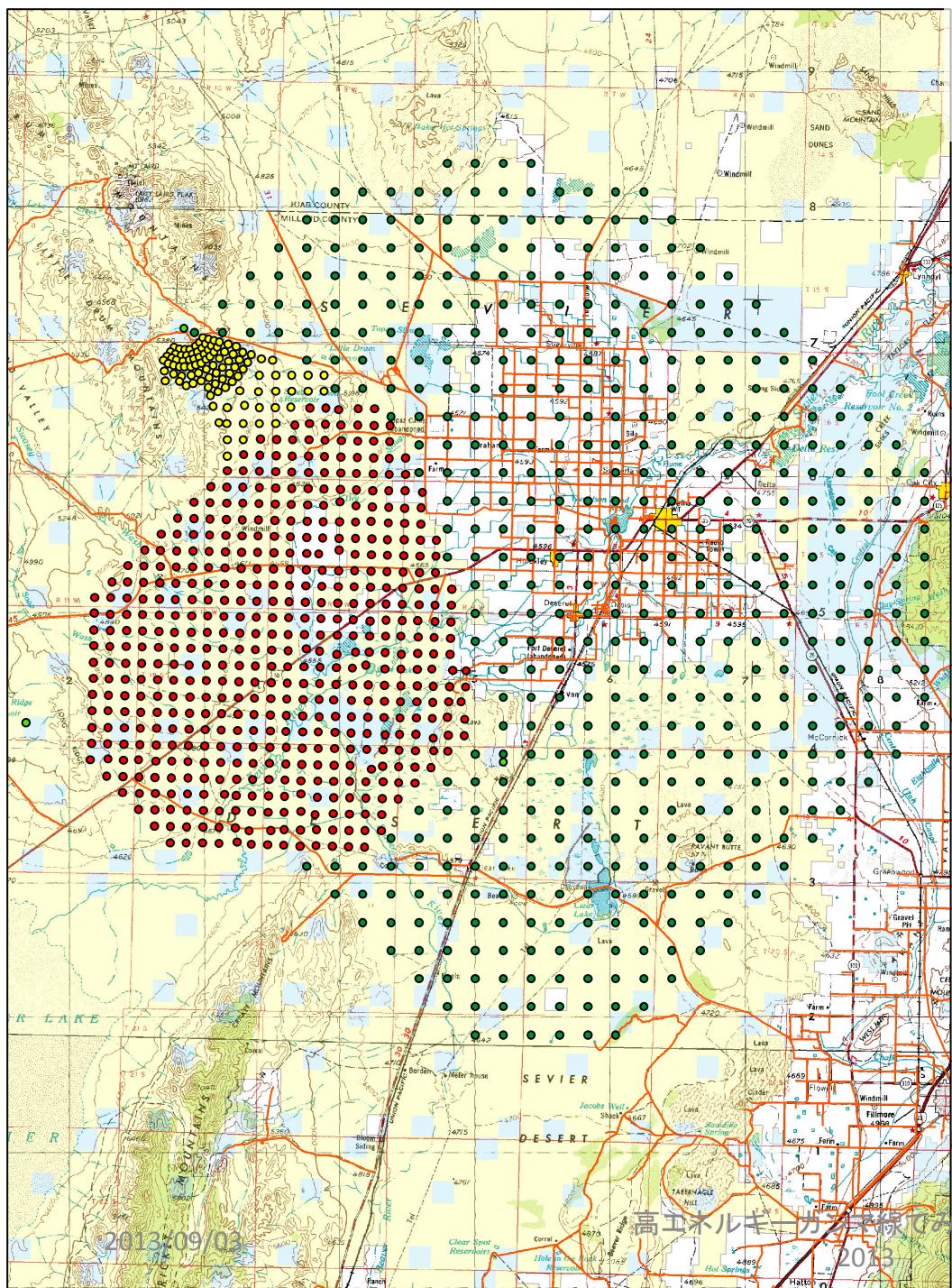
Sagawa(0121)

TA SDアレイを4倍に拡張 → ~ 3,000 km²

- 約500台のSDを追加 (2.08km間隔)
- 10台のFD(旧HiRes)を設置@BRM

2019年3月までに

- 20 TA years of SD
- 14 TA years of Hybrid



高エネルギーガンマ線である極限宇宙

2013

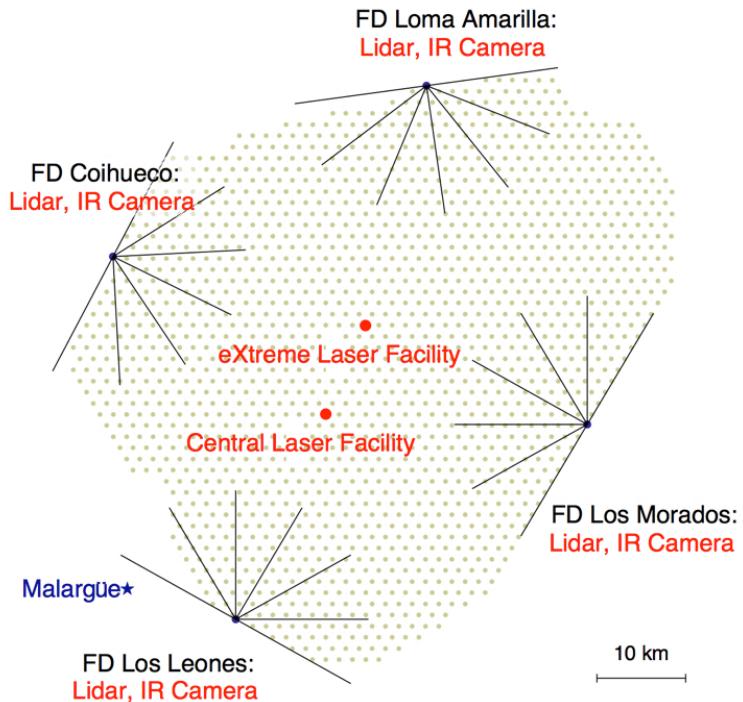
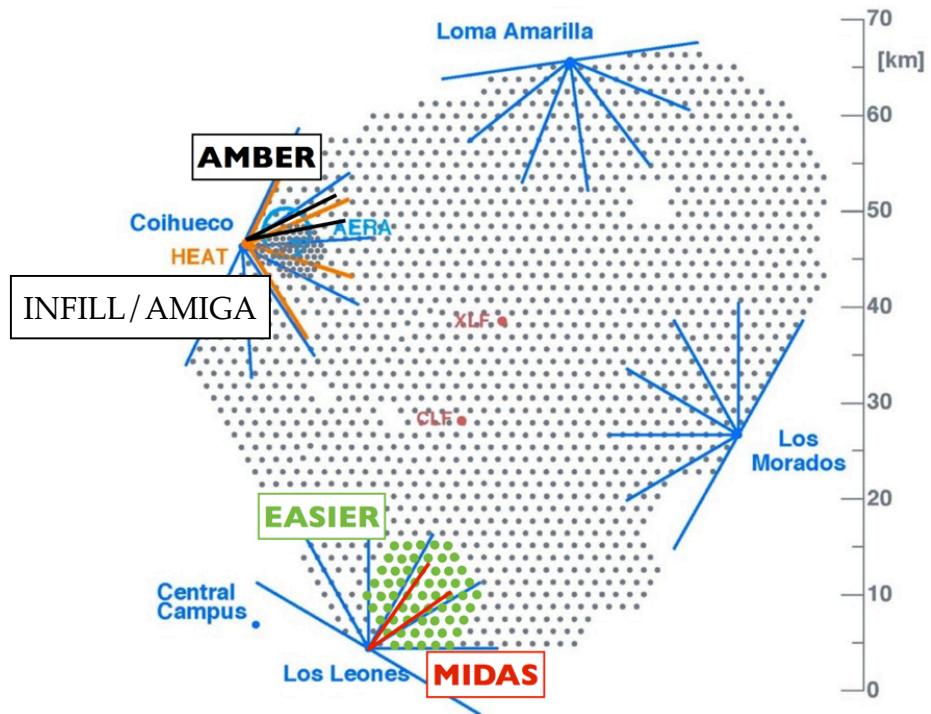
2013/09/03

3. Augerの最新結果



Pierre Auger Observatory

Letessier Selvon(1227)

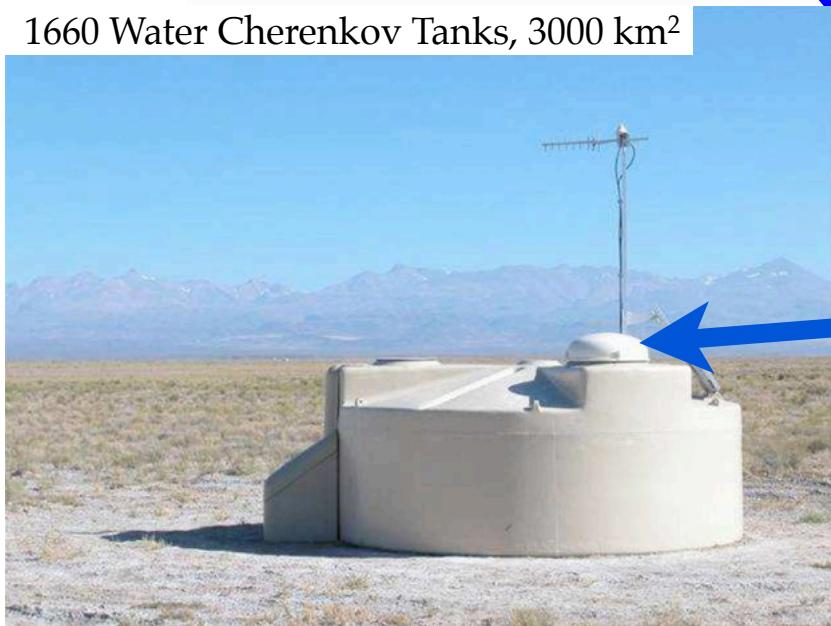


Pierre Auger Observatory

24+3 Telescopes, 4+1 sites

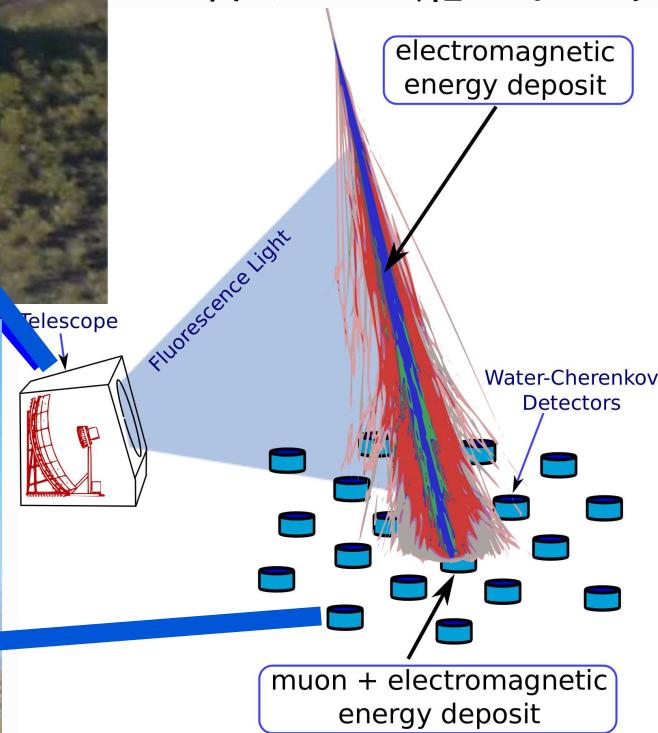


1660 Water Cherenkov Tanks, 3000 km²



AUGER
 OBSERVATORY

TA FDより広視野・大口径なので台数は少ない。
 +3台はHEAT(低エネルギー観測)用



水タンク検出器
 10m²、1.2m

2013/09/03

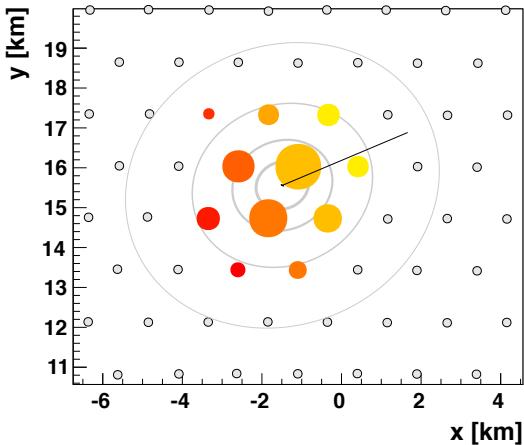
高エネルギーガンマ線でみる極限
 Letessier Selvon(1227)
 2013

Letessier Selvon(1227)

33

4つの異なる検出法／解析法で比較

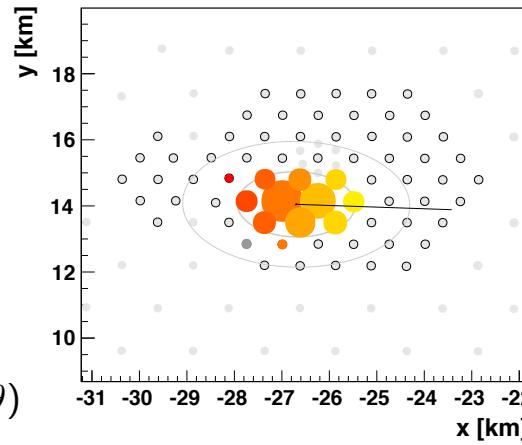
SD 1500 m, $\theta < 60^\circ$



Vertical events
 fully efficient:
 $E \geq 3 \text{ EeV}$
 energy estimator:
 S_{38}

$$S_{38} = S(1000)/\text{CIC}(\theta)$$

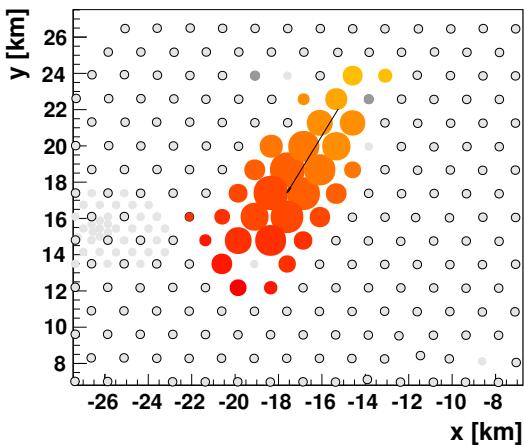
SD 750 m, $\theta < 55^\circ$



750 m events
 fully efficient:
 $E \geq 0.3 \text{ EeV}$
 energy estimator:
 S_{35}

$$S(450) \Rightarrow S_{35}$$

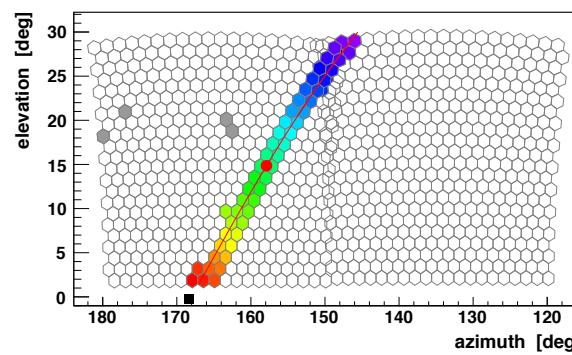
SD 1500 m, $62^\circ < \theta < 80^\circ$



Inclined events
 fully efficient:
 $E \geq 4 \text{ EeV}$
 energy estimator:
 N_{19}

$$N_{19}(E, A) = \rho_\mu / \rho_{\mu, 19}(x, y, \theta, \phi)$$

Hybrid (FD + 1 SD), $\theta < 60^\circ$

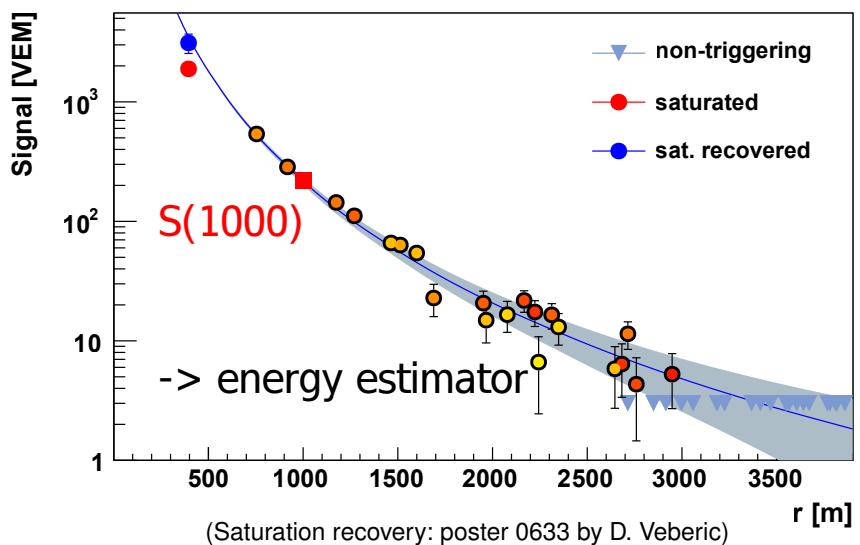
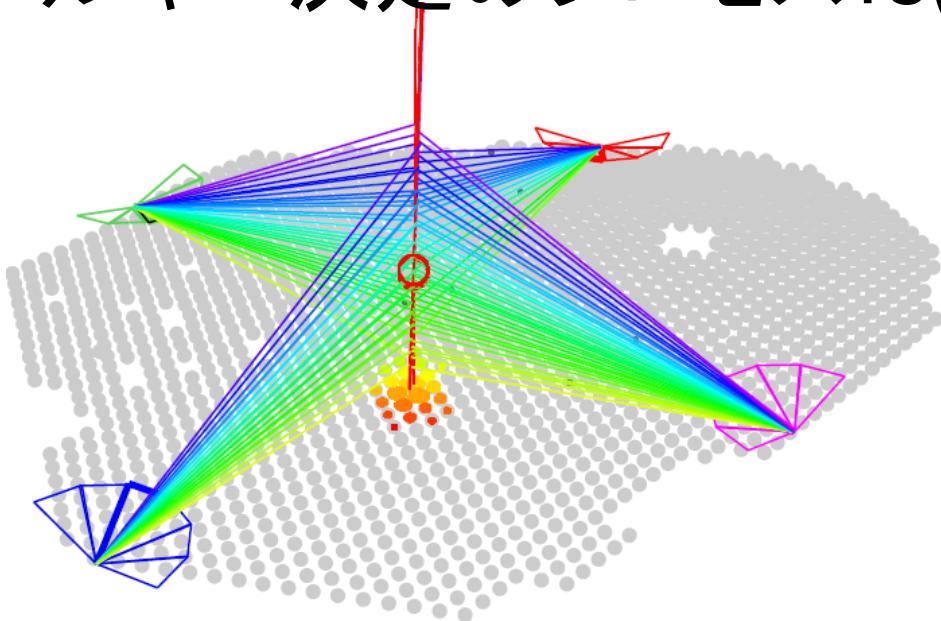


Hybrid events
 fully efficient:
 $E \geq 1 \text{ EeV}$
 energy meas.:
 E_{FD}

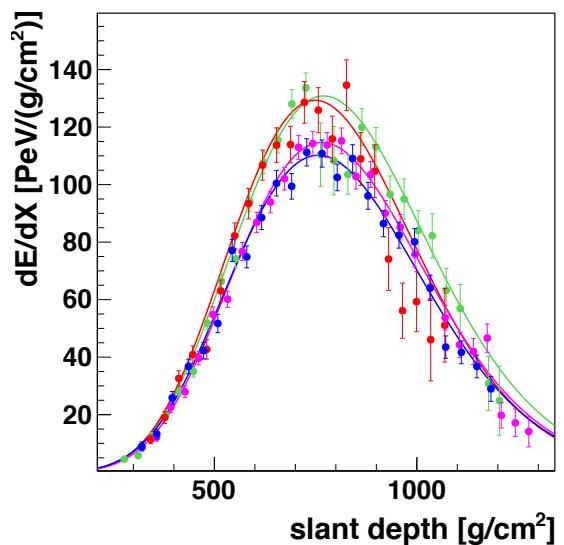
Schulz (0769)

エネルギー決定のプロセス: $S(1000) \rightarrow E_{FD}$ の場合

Schulz (0769)

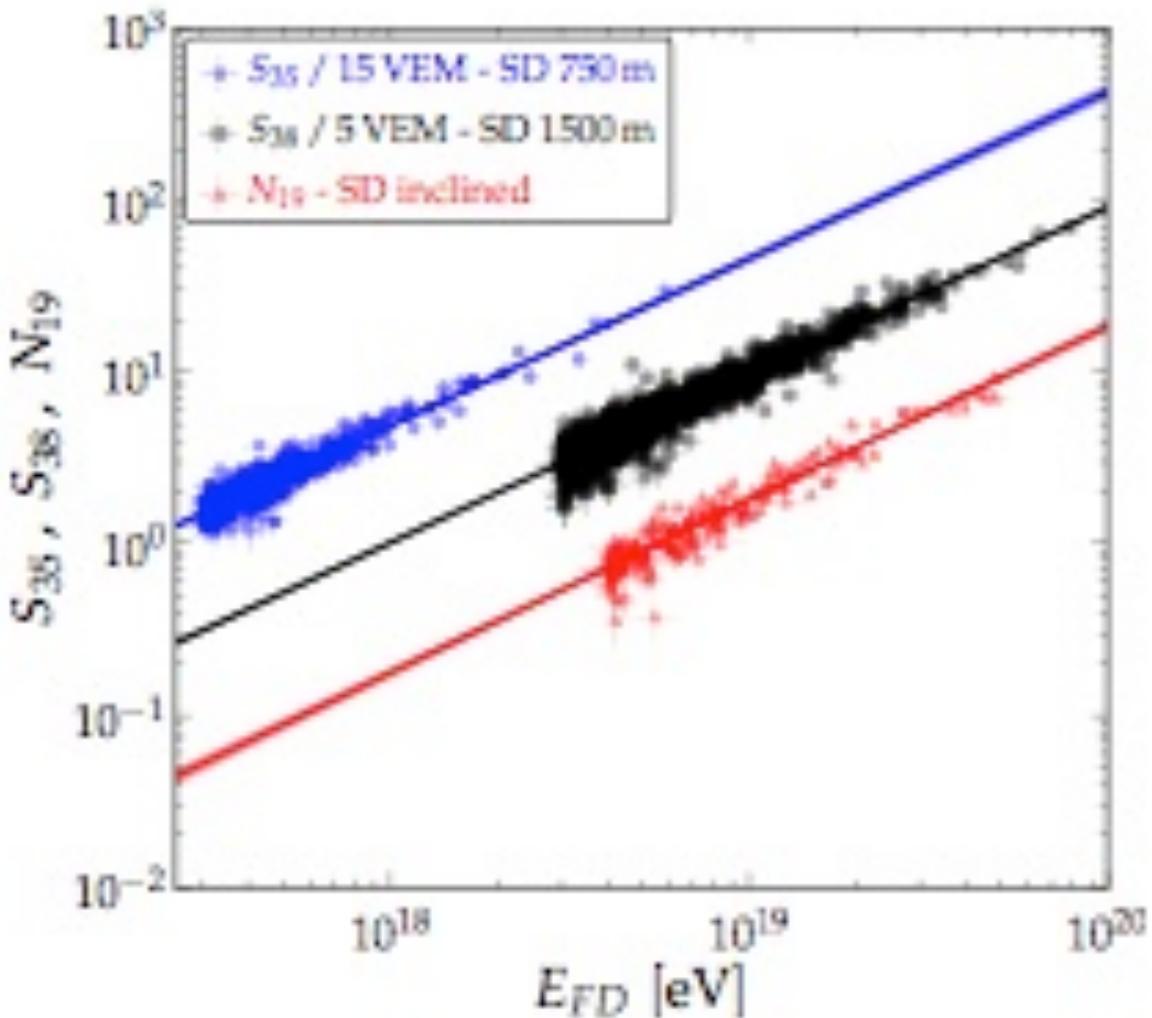


- Real event with $E = (76 \pm 2) \text{ EeV}$, $\theta = 54^\circ$
(Id: 201022604238)
- SD: Lateral distribution at optimal distance $S(r_{\text{opt}})$
- FD energy: \int Gaisser-Hillas + invisible energy ($\approx 10\%$)



エネルギー推定のプロセス: $S(1000) \rightarrow E_{FD}$ の場合

Schulz (0769)



エネルギーースケールを更新

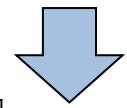
Verzi (0928)

(旧スケールでの系統誤差)

maximum change at 10^{18} eV

Absolute fluorescence yield	-8.2%
New opt. eff.	4.3%
Calibr. database update	3.5%
Sub total (FD cal.)	7.8%
Likelihood fit of dE/dX	2.2%
Folding with point. spr. func.	9.4%
Sub total (FD prof. rec.)	11.6%
Invisible energy	4.4%
Total	15.6%

Changes compatibles with the systematic uncertainties on the old energy scale



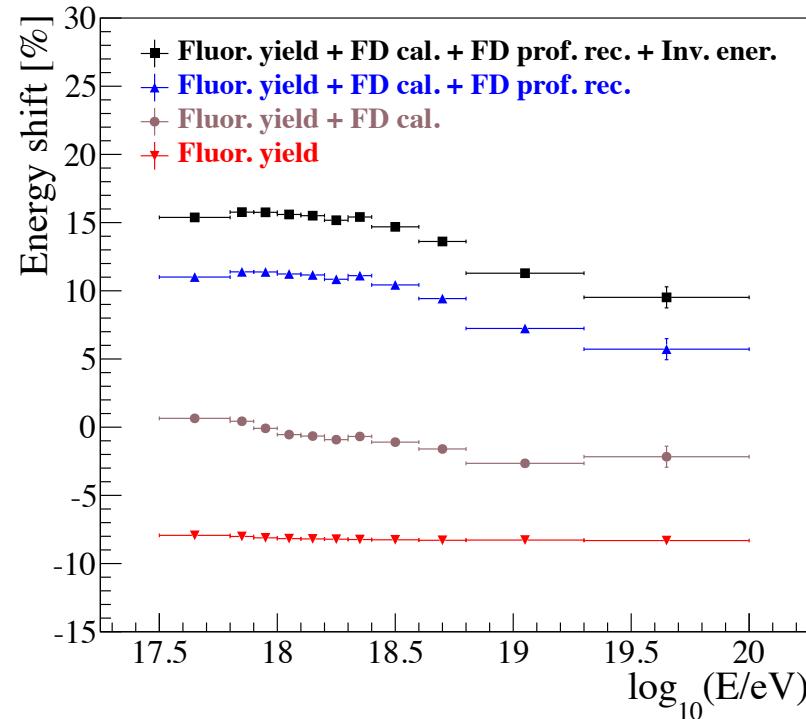
14%

9.5%

10%

4%

22%



エネルギー・シフトの
エネルギー依存性

16% ~ 10 %

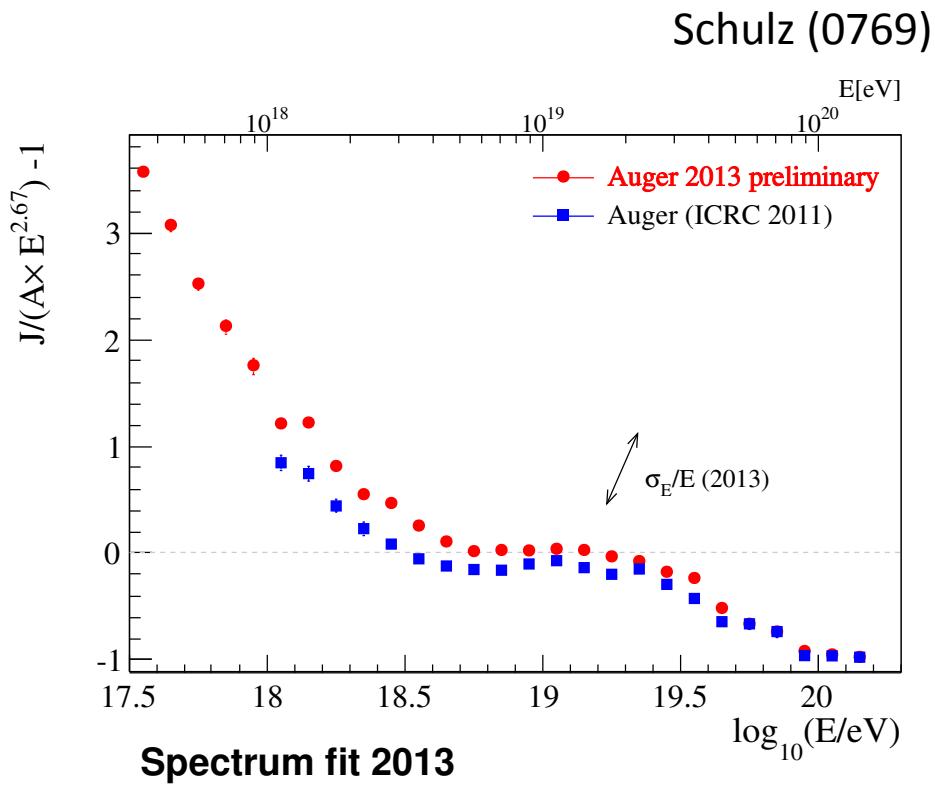
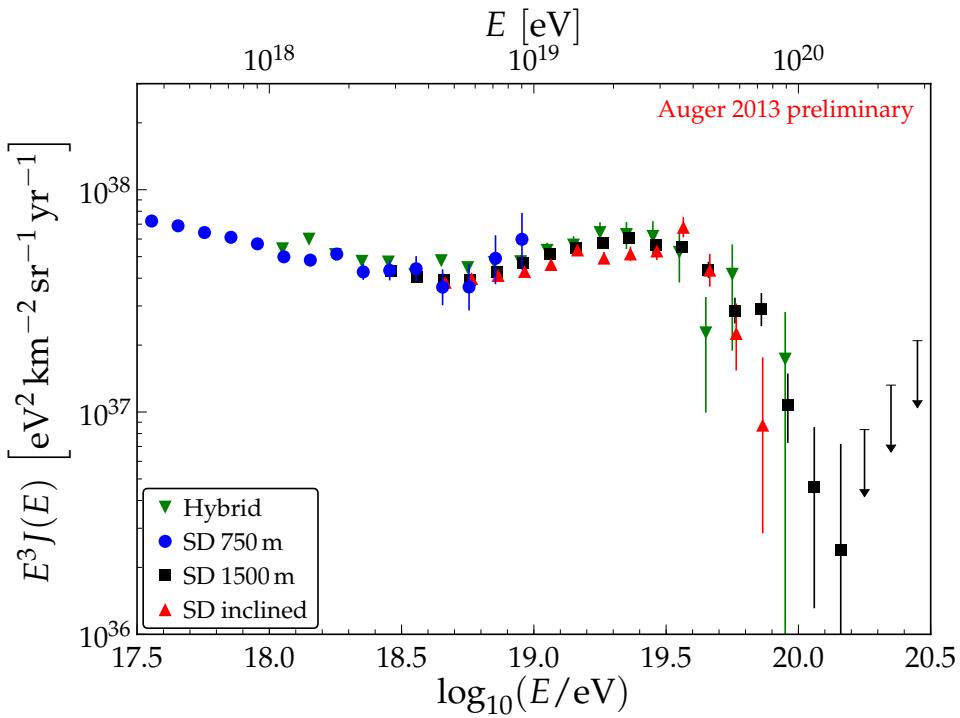
エネルギー推定の系統誤差

Absolute fluorescence yield	3.4%	
Fluores. spectrum and quenching param.	1.1%	
Sub total (Fluorescence Yield)	3.6%	14%
Aerosol optical depth	3% ÷ 6%	
Aerosol phase function	1%	
Wavelength dependence of aerosol scattering	0.5%	
Atmospheric density profile	1%	
Sub total (Atmosphere)	3.4% ÷ 6.2%	5% ÷ 8%
Absolute FD calibration	9%	
Nightly relative calibration	2%	
Optical efficiency	3.5%	
Sub total (FD calibration)	9.9%	9.5%
Folding with point spread function	5%	
Multiple scattering model	1%	
Simulation bias	2%	
Constraints in the Gaisser-Hillas fit	3.5% ÷ 1%	
Sub total (FD profile rec.)	6.5% ÷ 5.6%	10%
Invisible energy	3% ÷ 1.5%	4%
Statistical error of the SD calib. fit	0.7% ÷ 1.8%	
Stability of the energy scale	5%	
TOTAL	14%	22%

uncertainties on
previous energy
scale

improvement in each
sector with the
exception of FD cal.
(largest contribution)
work in progress to
reduce it

エネルギースペクトル



$$\log_{10}(E_a/\text{eV}) = 18.72 \pm 0.01$$

$$\gamma_1 = 3.23 \pm 0.01$$

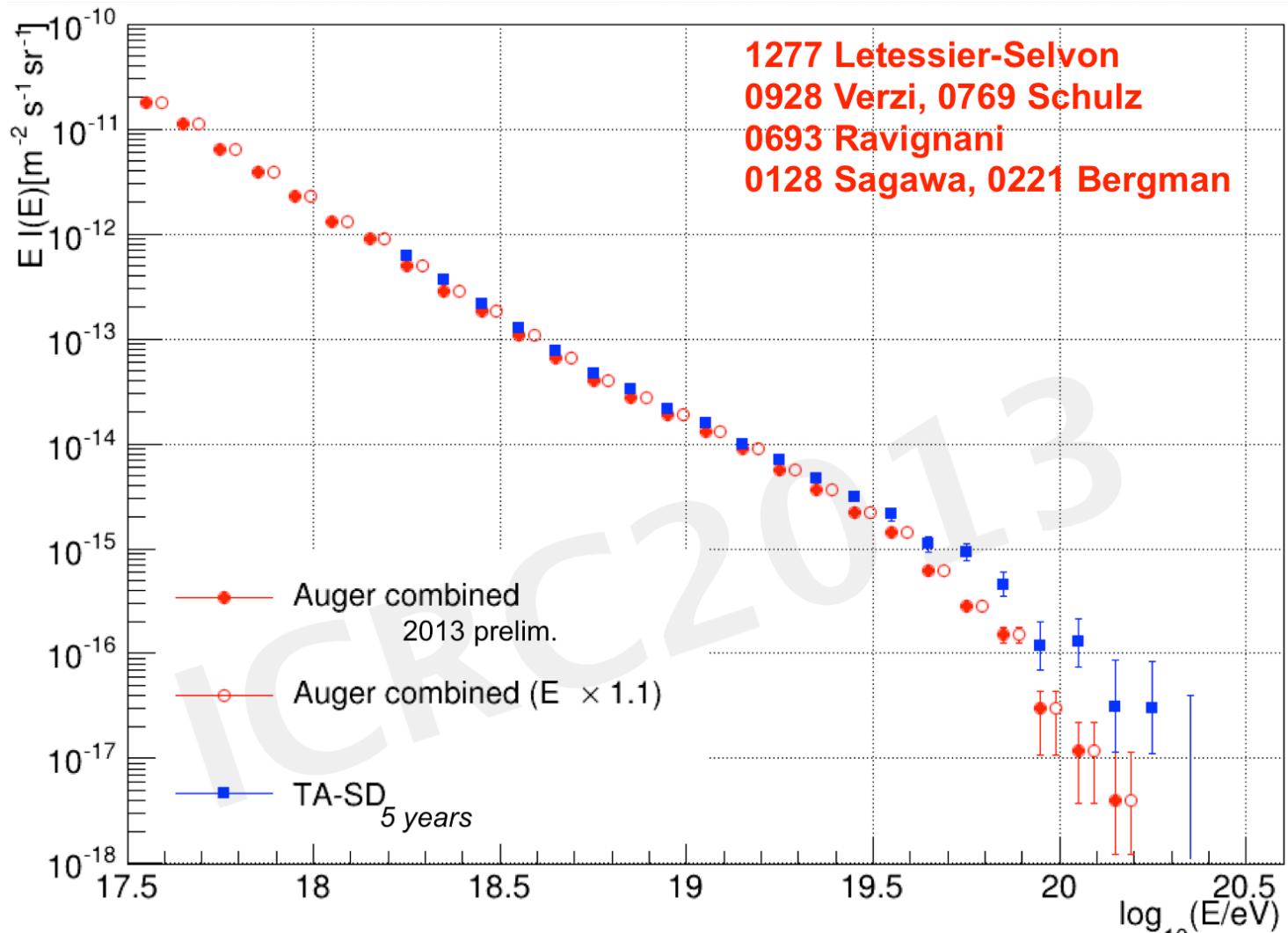
$$\gamma_2 = 2.63 \pm 0.02$$

$$\log_{10}(E_{1/2}/\text{eV}) = 19.63 \pm 0.01$$

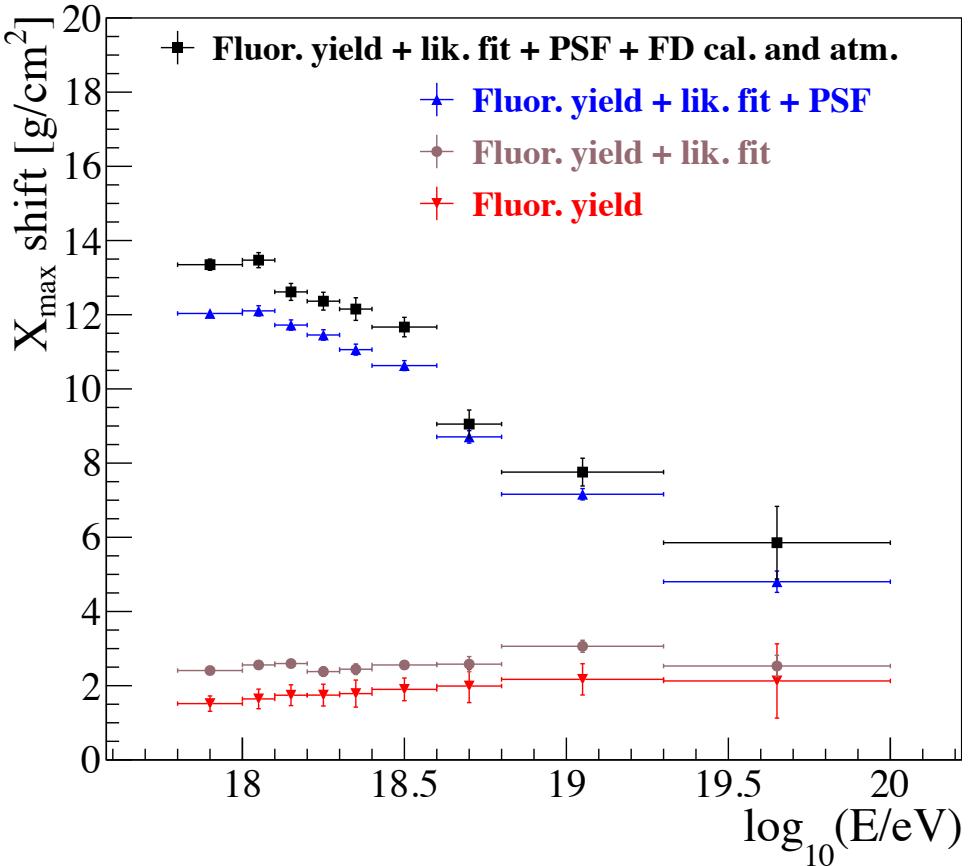
$$\log_{10} W_c = 0.15 \pm 0.01$$

エネルギースペクトル: TAとAugerの比較

Tsunesada (Rapporteur)

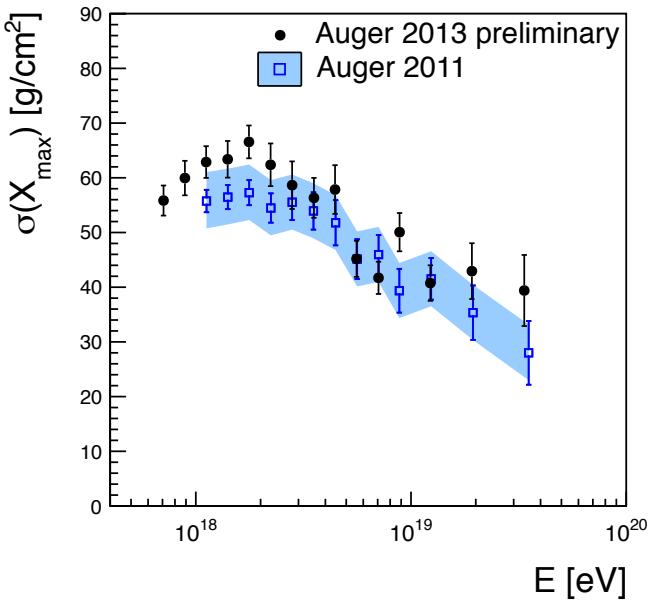
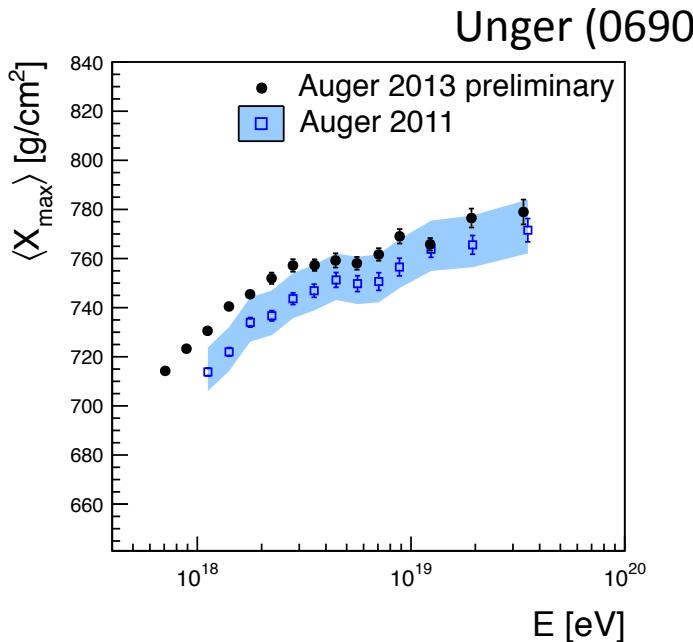


X_{max}に関するアップデート



2013/09/03

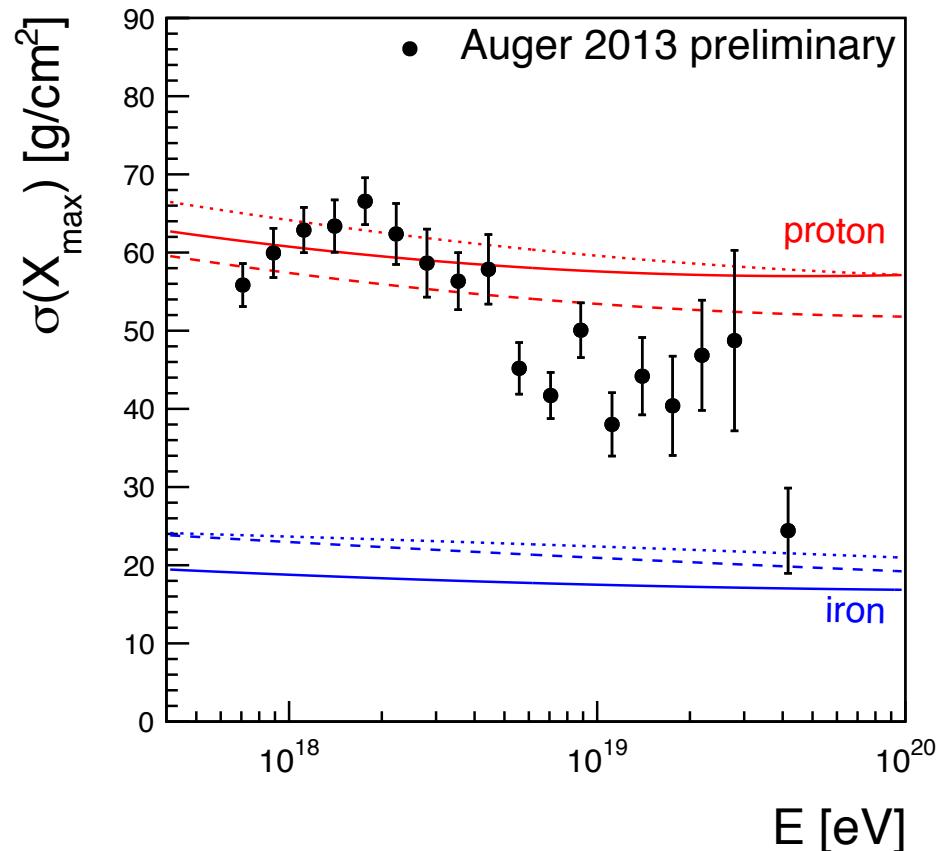
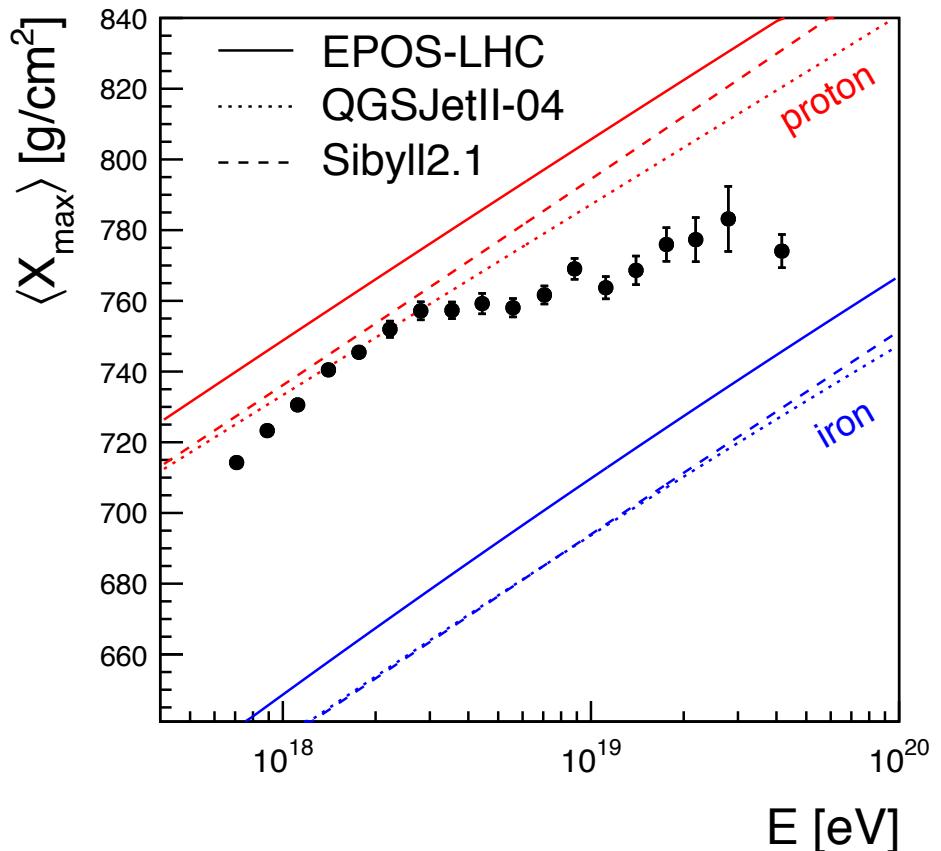
高エネルギーガンマ線でみる極限宇宙
 2013



Unger (0690)

FD+SDハイブリッド: 平均Xmaxと分布幅

Unger (0690)



FD+SDハイブリッド:<lnA>とその幅

Unger (0690)

$$\langle X_{\max} \rangle \approx \langle X_{\max}^p \rangle - D_p \langle \ln A \rangle$$

$$\sigma(X_{\max})^2 \approx \langle \sigma_i^2 \rangle + D_p^2 \sigma(\ln A)^2$$

$$\langle \ln A \rangle = \sum f_i \ln A_i$$

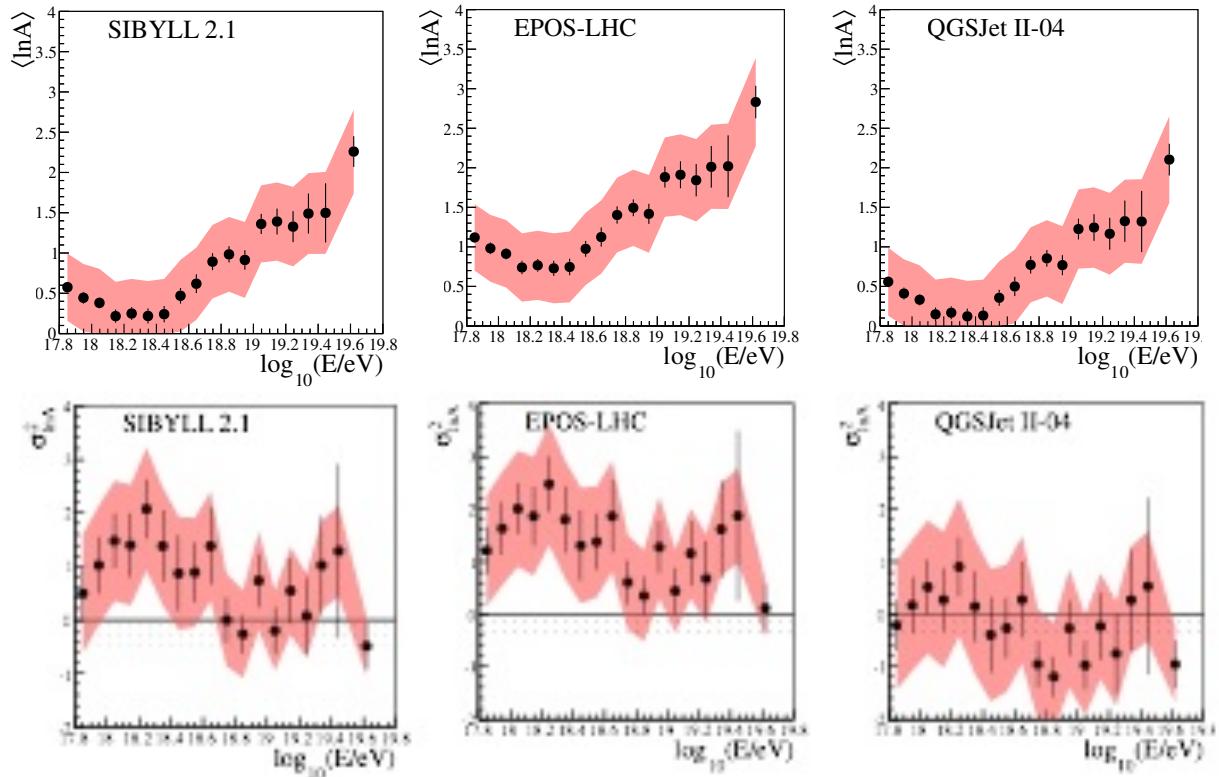
e.g. pure $p \rightarrow \langle \ln A \rangle = 0$, pure Fe $\rightarrow \langle \ln A \rangle \approx 4$, 50:50 p/Fe $\rightarrow \langle \ln A \rangle \approx 2$

$$\sigma(\ln A)^2 = \langle \ln^2 A \rangle - \langle \ln A \rangle^2$$

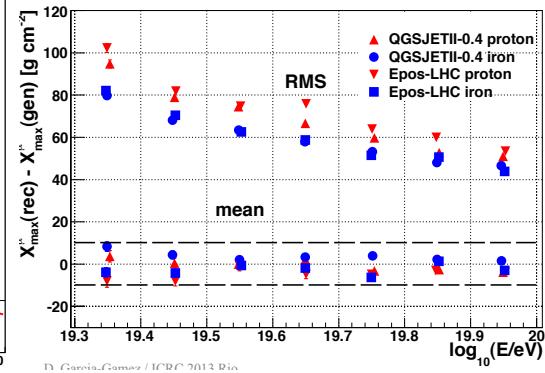
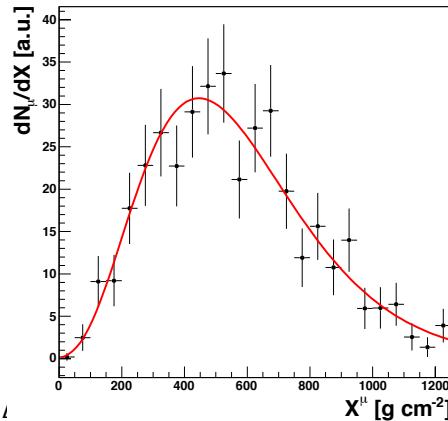
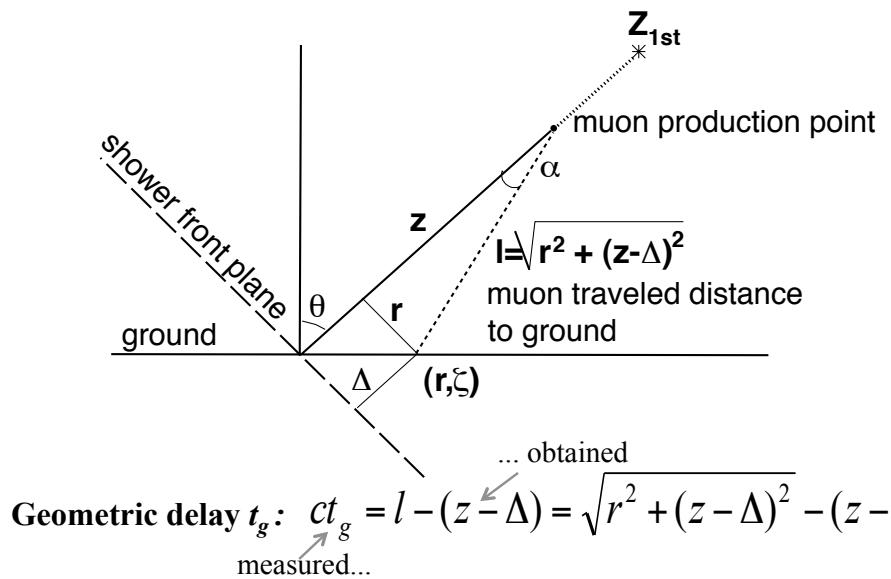
e.g. pure $p \rightarrow \sigma(\ln A)^2 = 0$, pure Fe $\rightarrow \sigma(\ln A)^2 = 0$, 50:50 p/Fe $\rightarrow \sigma(\ln A)^2 \approx 4$

$\langle \ln A \rangle$
medium \rightarrow light \rightarrow heavy ?

σ
mixed \rightarrow pure ?



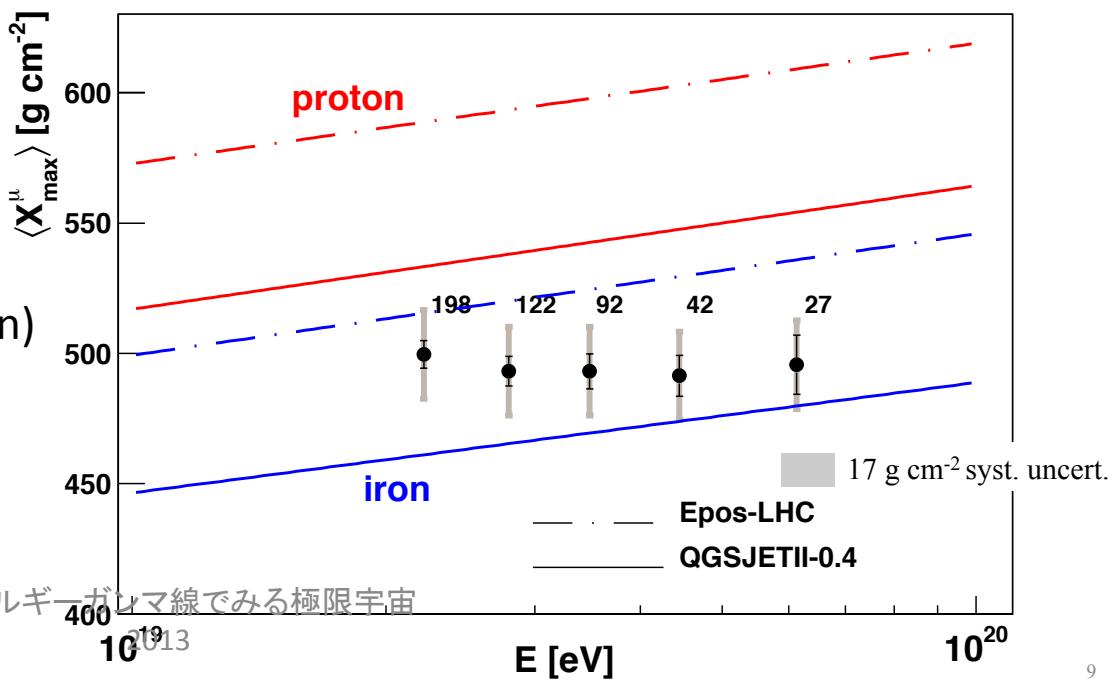
SDデータからMuonの発生高度を再構成



Example of a real event

$$z = \frac{1}{2} \left(\frac{r^2}{ct_g} - ct_g \right) + \Delta$$

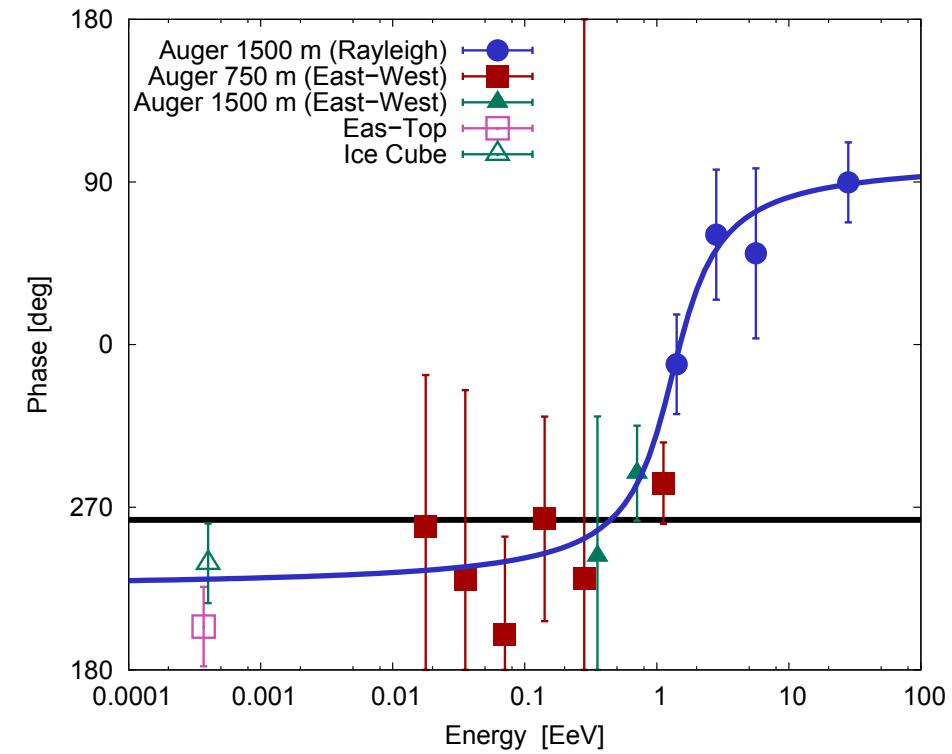
$S_{\text{th}} = 0.4\text{-}0.6 \text{ VEM}$ (avoid EM contamination)
 $\theta = 55^\circ\text{-}65^\circ$ (less EM, no θ dependence)
 $r > r_{\text{cut}}$, $r_{\text{cut}} = 1700\text{m}$ (reduce δX_{\max})



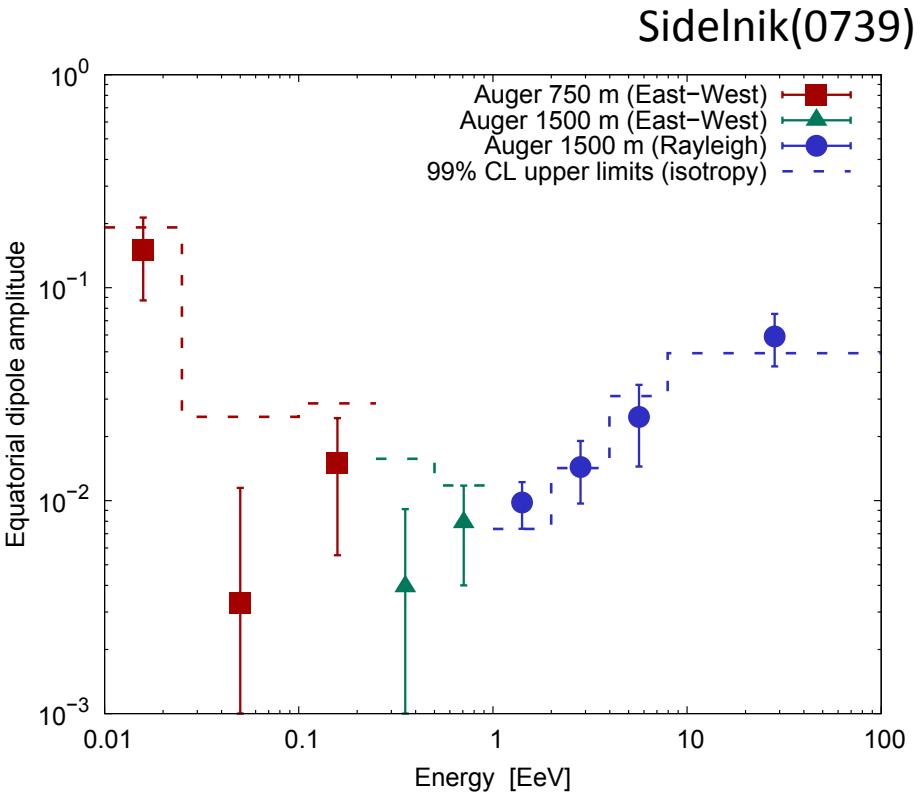
調和解析

Fourier coefficients $a = \frac{2}{N} \sum_{i=1}^N w_i \cos(\alpha_i)$, $b = \frac{2}{N} \sum_{i=1}^N w_i \sin(\alpha_i)$,
 Amplitude $r = \sqrt{a^2 + b^2}$ and phase $\varphi = \arctan\left(\frac{b}{a}\right)$

- ▶ Energy assignment corrected for weather and geomagnetic effects
- ▶ w_i accounting for the array growth, dead time and tilt of the array



Eas-Top: M. Aglietta *et al.* 2009 ApJ **692** L130
 IceCube: R. Abbasi *et al.* 2012 ApJ **746** 33

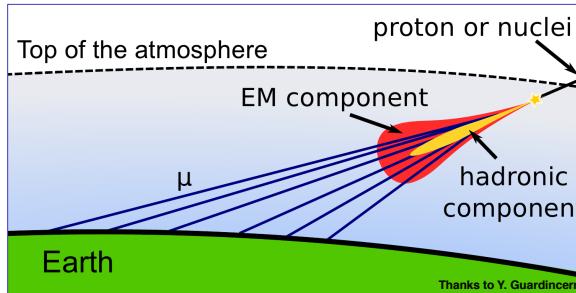


	ΔE [EeV]	N	$d_{\perp} \pm \sigma_{d_{\perp}}$ [%]	$\varphi \pm \Delta_{\varphi}$ [°]	$P(> d_{\perp})$ [%]	d_{\perp}^{iso} [%]	d_{\perp}^{ul} [%]
Infill	0.01 - 0.025	11819	15 ± 6.3	334 ± 25	5.9	19	28.6
East-West	0.025 - 0.1	428028	0.3 ± 0.8	122 ± 180	92	2.4	2.2
Method	0.1 - 0.25	223342	1.4 ± 0.9	277 ± 39	28	2.9	3.5
East-West	0.25 - 0.5	720224	0.4 ± 0.5	280 ± 180	75	1.6	1.5
Method	0.5 - 1	1081810	0.8 ± 0.4	258 ± 30	13	1.2	1.6
Modified	1 - 2	557829	1.0 ± 0.2	335 ± 14	0.03	0.7	1.5
	2 - 4	148790	1.4 ± 0.5	8 ± 19	0.9	1.4	2.5
Rayleigh	4 - 8	31270	2.5 ± 1.0	63 ± 25	5.5	3.1	4.8
	> 8	12292	5.9 ± 1.6	86 ± 16	0.1	4.9	9.4

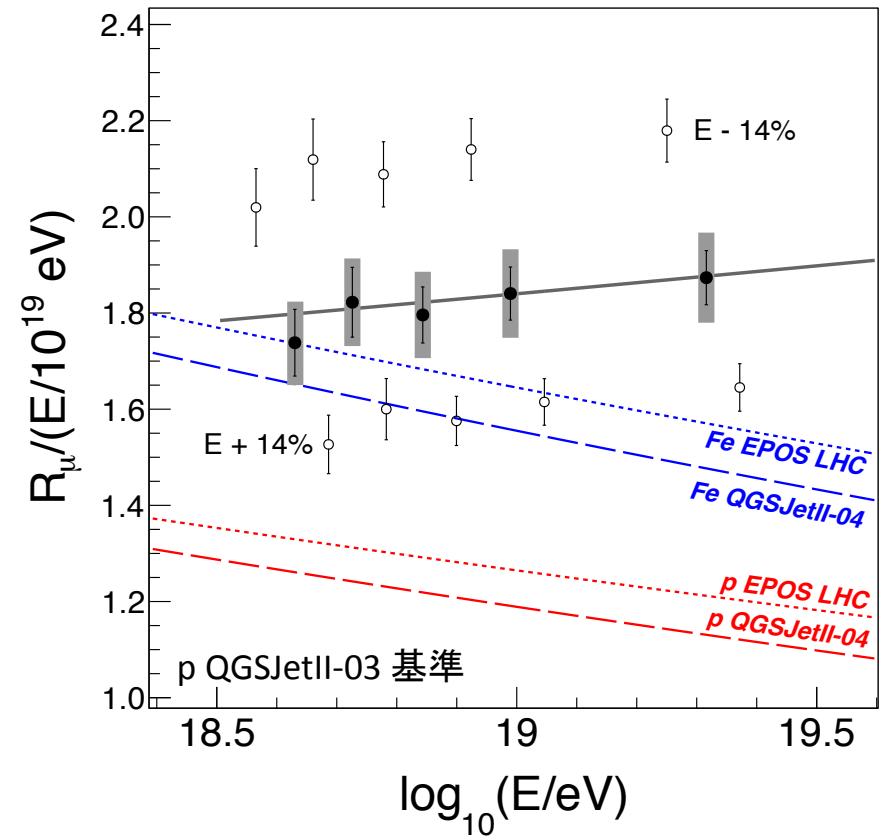
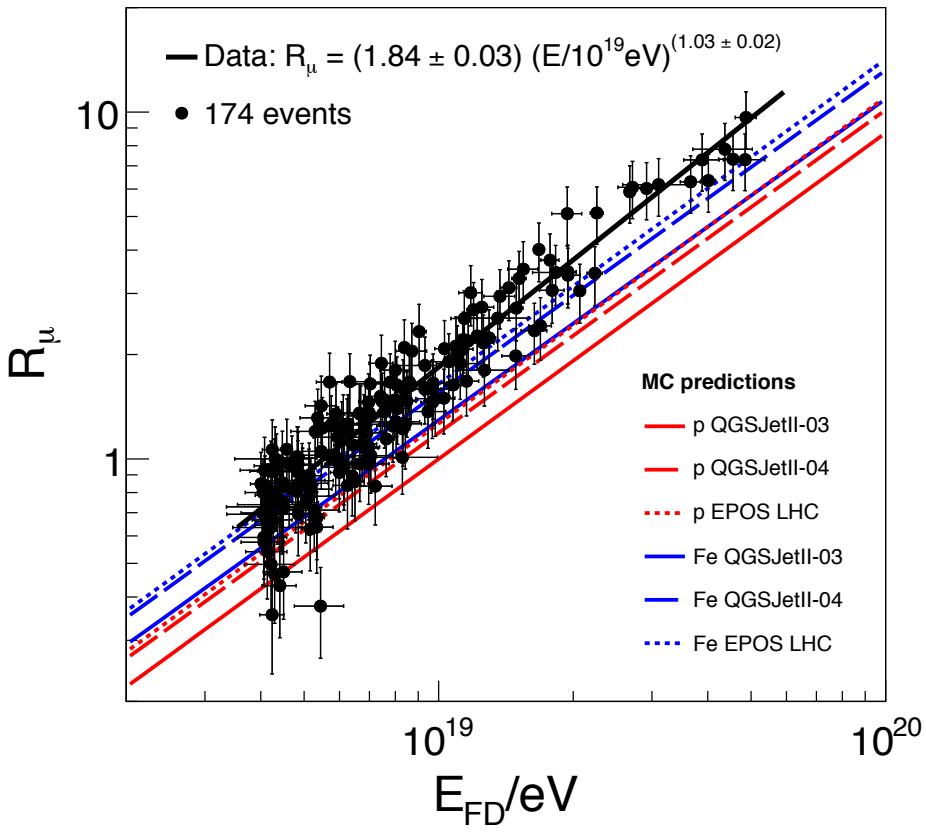
大天頂角シャワー

$$N_{19} = N_\mu / N_{\mu,19} \rightarrow R_\mu$$

(corrected the bias < 5% based on MC)



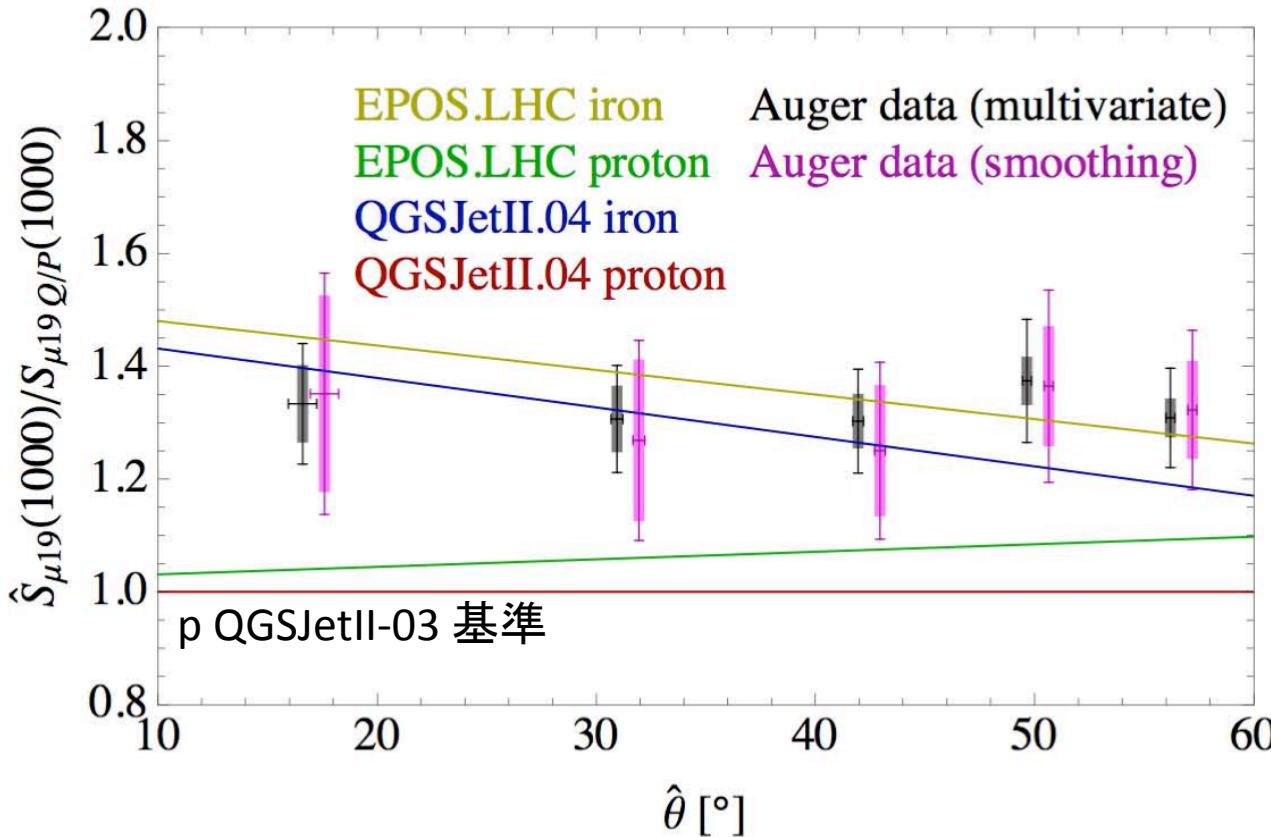
$62^\circ < \theta < 80^\circ$
 $\#SD \geq 4$
 Golden hybrid



SD信号波形から μ 比を見積もる@ 10^{19} eV

Muon signal rescaling wrt QGSJetII.04 proton

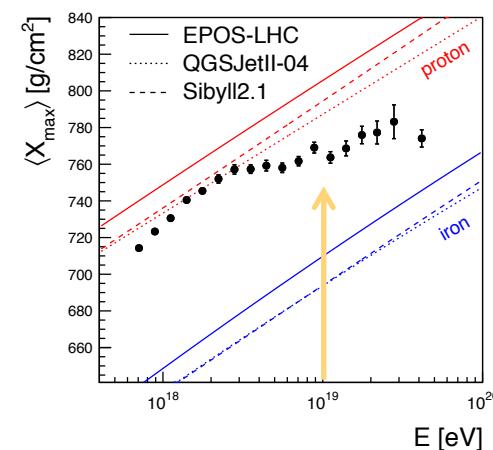
Kegl (0860)



1.33 ± 0.02 (stat.) ± 0.05 (sys.) (multivariate)

1.31 ± 0.02 (stat.) ± 0.09 (sys.) (smoothing)

$10^{18.98} \sim 10^{19.92}$ eV
 $r_{\text{core}} = 950 \sim 1050$ m



3. Augerの最新結果：まとめ

- エネルギースケールを更新 → TA寄りに
- dip、cut off。ただし、最高エネルギー端ではTAと異なる？
- $\langle \ln A \rangle$: medium → light → heavy？
- $\sigma(\ln A)$: mix → ~pure？
- 異方性位相のジャンプ@ 10^{18} eV
- ミューオン過剰: MCと合わない

4. TAとAugerの共同研究



TAとAugerの共同研究(1) : データ解析



ICRC
2013



Measuring Large-Scale Anisotropy in the
Arrival Directions of Cosmic Rays
Detected at the Telescope Array and the
Pierre Auger Observatory Above 10^{19} eV
(ICRC 0679)

Olivier Deligny¹, for the Telescope Array²
and the Pierre Auger Collaborations³

¹ IPN Orsay, CNRS/IN2P3 & Université Paris Sud

² <http://www.telescopearray.org/index.php/research-publications/conference-proceedings>

³ full author list: http://www.auger.org/archive/authors_2013_05.html

Deligny (0679)

TAとAugerの両方のデータを用いた
全天の異方性解析

UHECR2012 → ICRC2013 →
今後も継続する

Progress Towards Understanding the Analyses of Mass Composition Made by the Auger and Telescope Array Collaborations



PIERRE
AUGER
OBSERVATORY



William F. Hanlon¹
for the Telescope Array and Auger
Collaborations



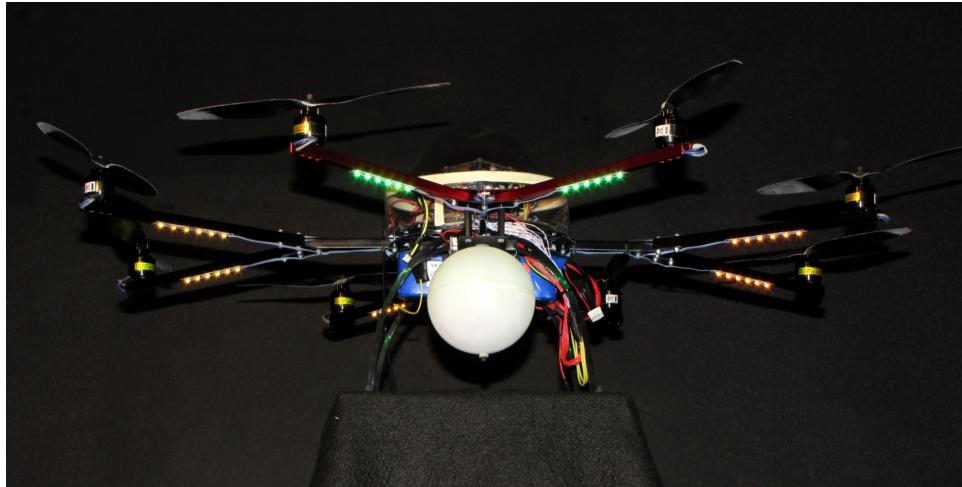
¹University of Utah, Department of Physics and Astronomy and
High Energy Astrophysics Institute.

Hanlon (0964)

Augerの結果を説明する「仮想的」組成
→ MCイベント生成
→ ハイブリッド再構成、Xmax解析

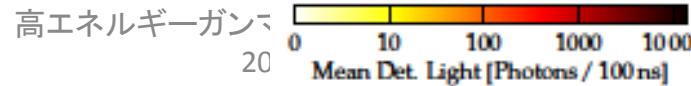
TA FDの分解能、再構成精度、バイアス
「TAはAugerと同じものを見ているのか？」という
問い合わせに答える

TAとPAOの共同研究(2) : 共通の光源による較正

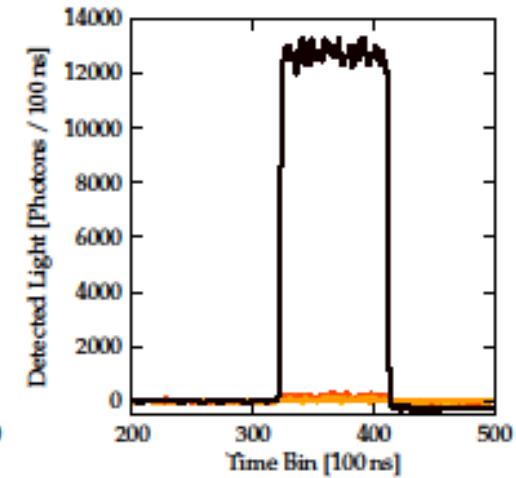


Flights @ TA-FD BRM : Oct 2012 & Mar 2013
@ Auger, Los Leones : Nov 2012

Event display @Auger



2013/09/03



全体のまとめ

- TAの結果:純陽子 + GZK機構と矛盾しない
- 最高エネルギー領域(~60EeV以上)では起源のヒント
- Augerはエネルギースケール、Xmax解析を更新
- TAとAugerは近づいたが、最高エネルギーでは合わない
- SDとFDのエネルギースケールの違い(TA)
- ミューオン過剰(Auger)
- TALE+NICHEによる広エネルギー拡張
- TA×4による異方性問題の解決 → 起源天体へ
- TAとAugerの共同研究