宇宙線・宇宙物理領域シンポジウム

「宇宙線のエネルギースペクトル再訪」

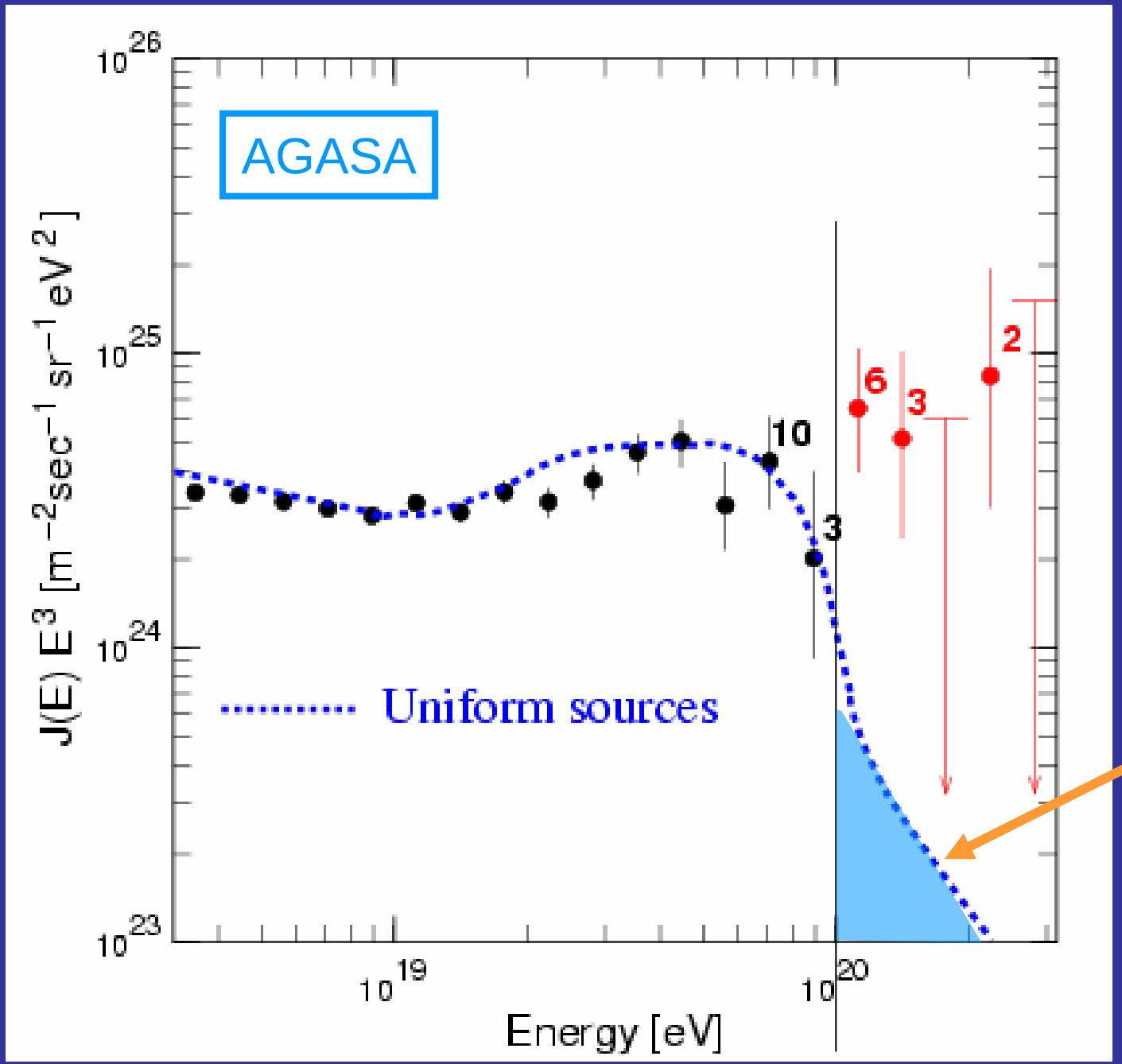
最高エネルギー宇宙線観測の現状

東大宇宙線研・福島正己

2005年9月14日

大阪市立大学・杉本キャンパス

MF7



~2 ev expected

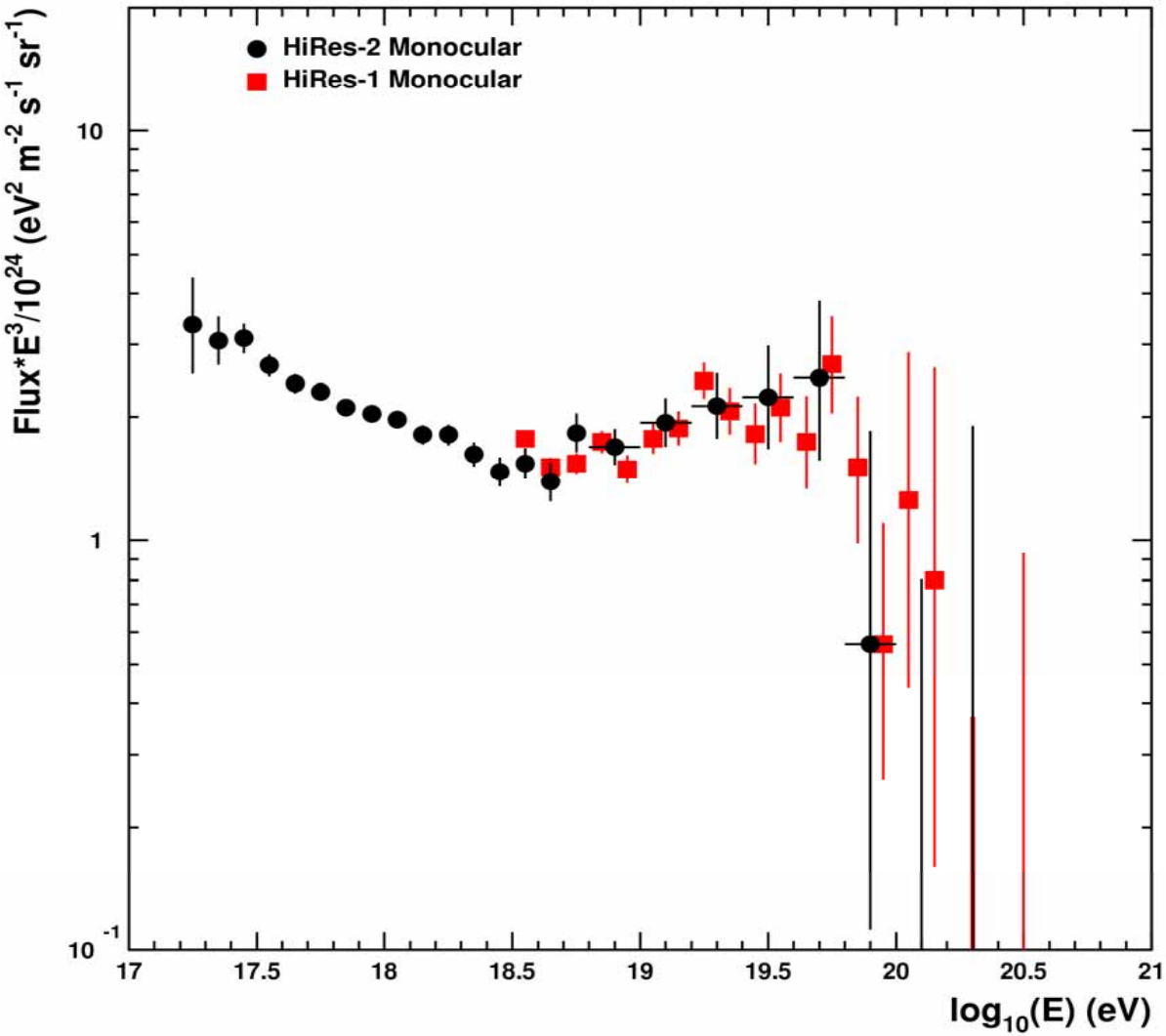
4.0 **σ**

MF7

AGASA 11 years result
10ev super GZK
10 ev found / 1.6 ev expected, 4.0 sigma rejection
5ev found / 1.0 expected, 2.6 sigma rejection if energy is -19% shifted down
福島正己, 2005/09/14

by S.Yoshida
@ 29th ICRC Pune
Rapporteur talk

HiRes (mono)



"GZK" Statistics

- Expect 42.8 events
- Observe 15 events
- ~5 σ

Bergman (this conference)

千葉大学
Chiba University

by M. Fukushima
@ 29th ICRC Pune

Telescope Array (TA)

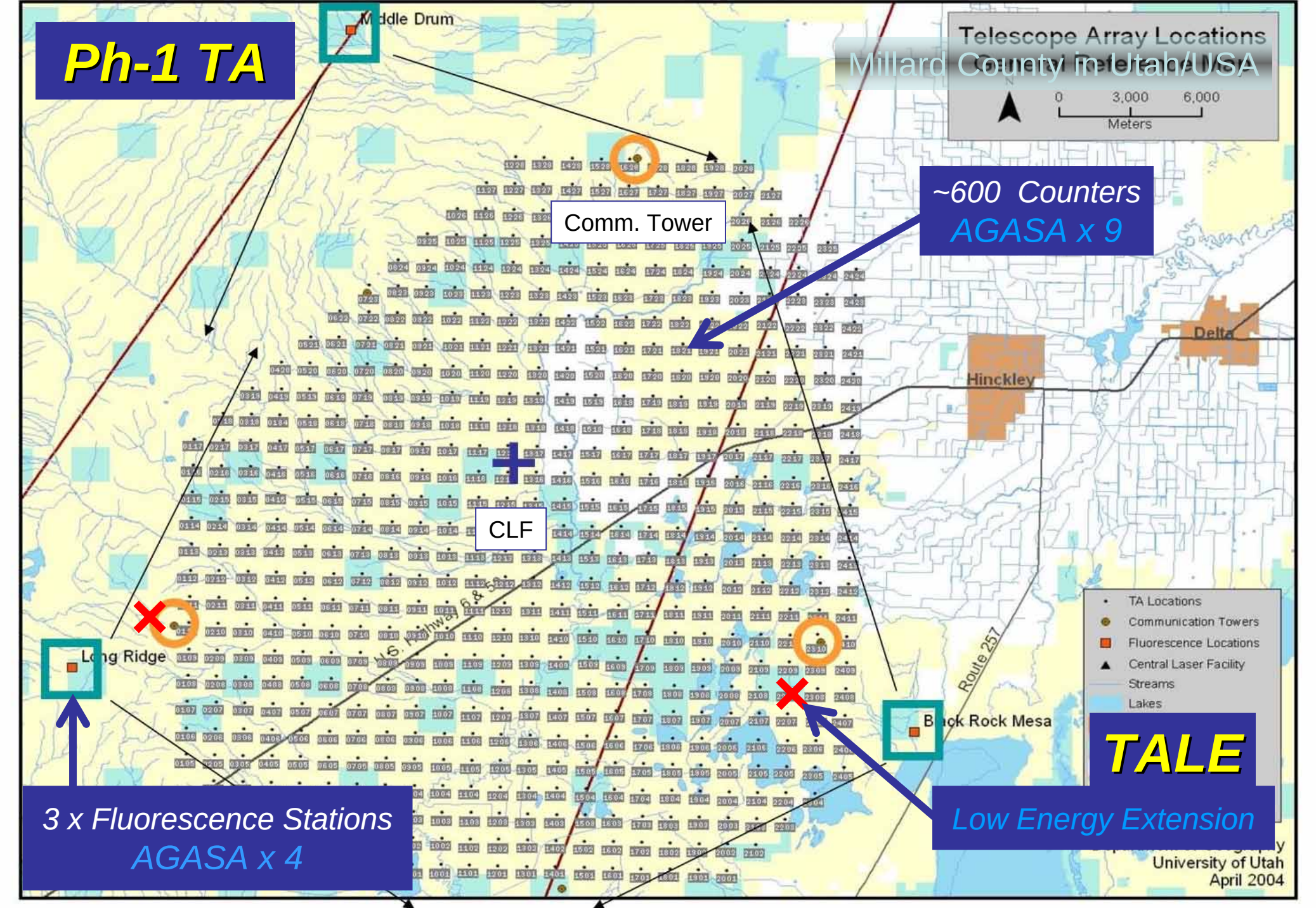
Originally planned as a large array of fluorescence telescopes to identify the origin of super-GZK cosmic rays.

HiRes mono spectrum suggested existence of GZK cutoff (27th ICRC @ Hamburg).

原因は *Physics? Method? Mistake?*

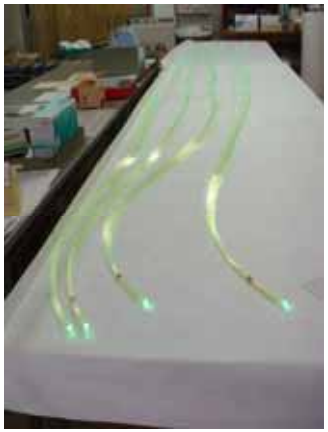
Critical look at systematics of SD (AGASA) and FD (HiRes) measurements became imperative.

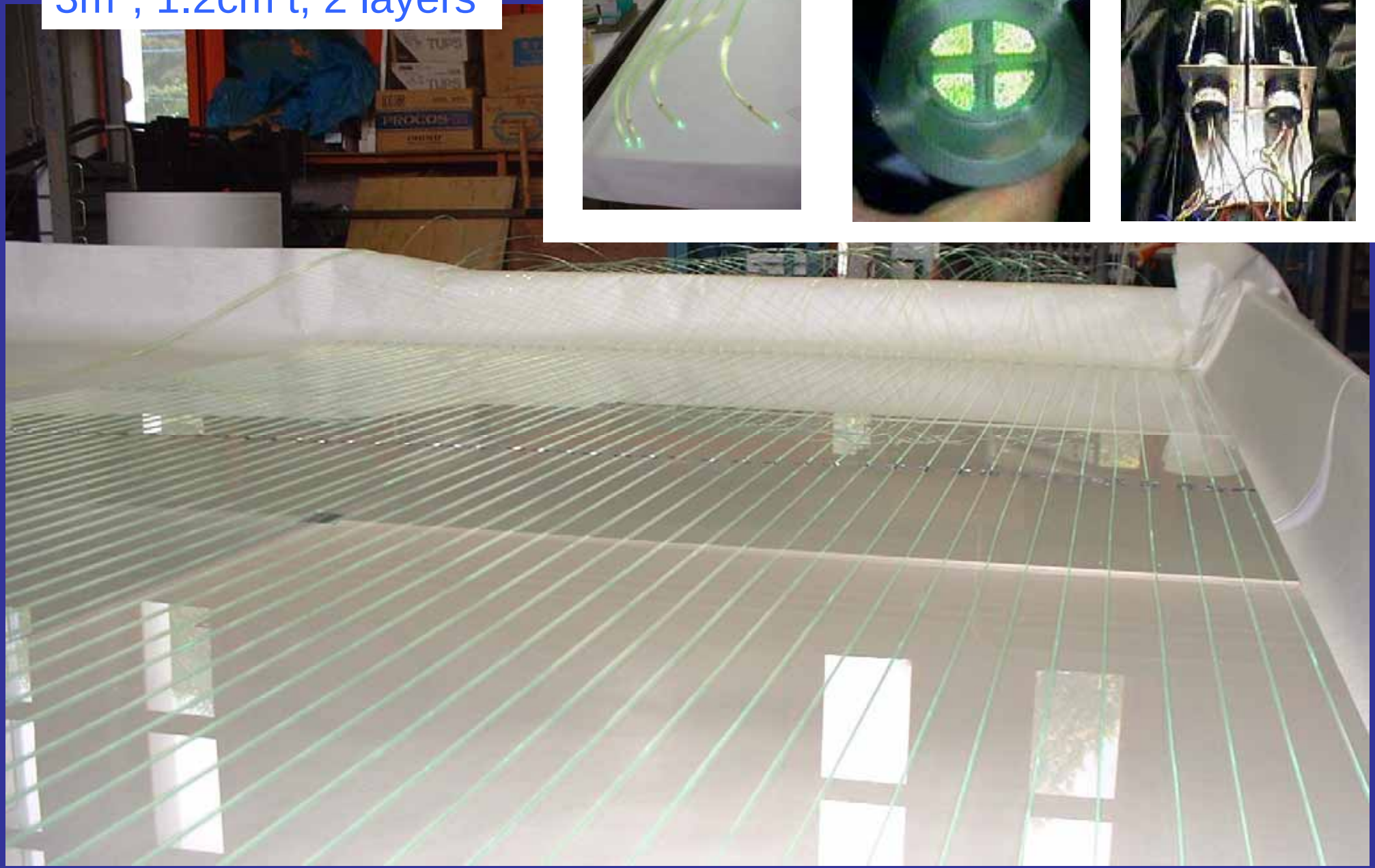
Phase-1 TA financed in 2003 (28th ICRC @ Tsukuba).

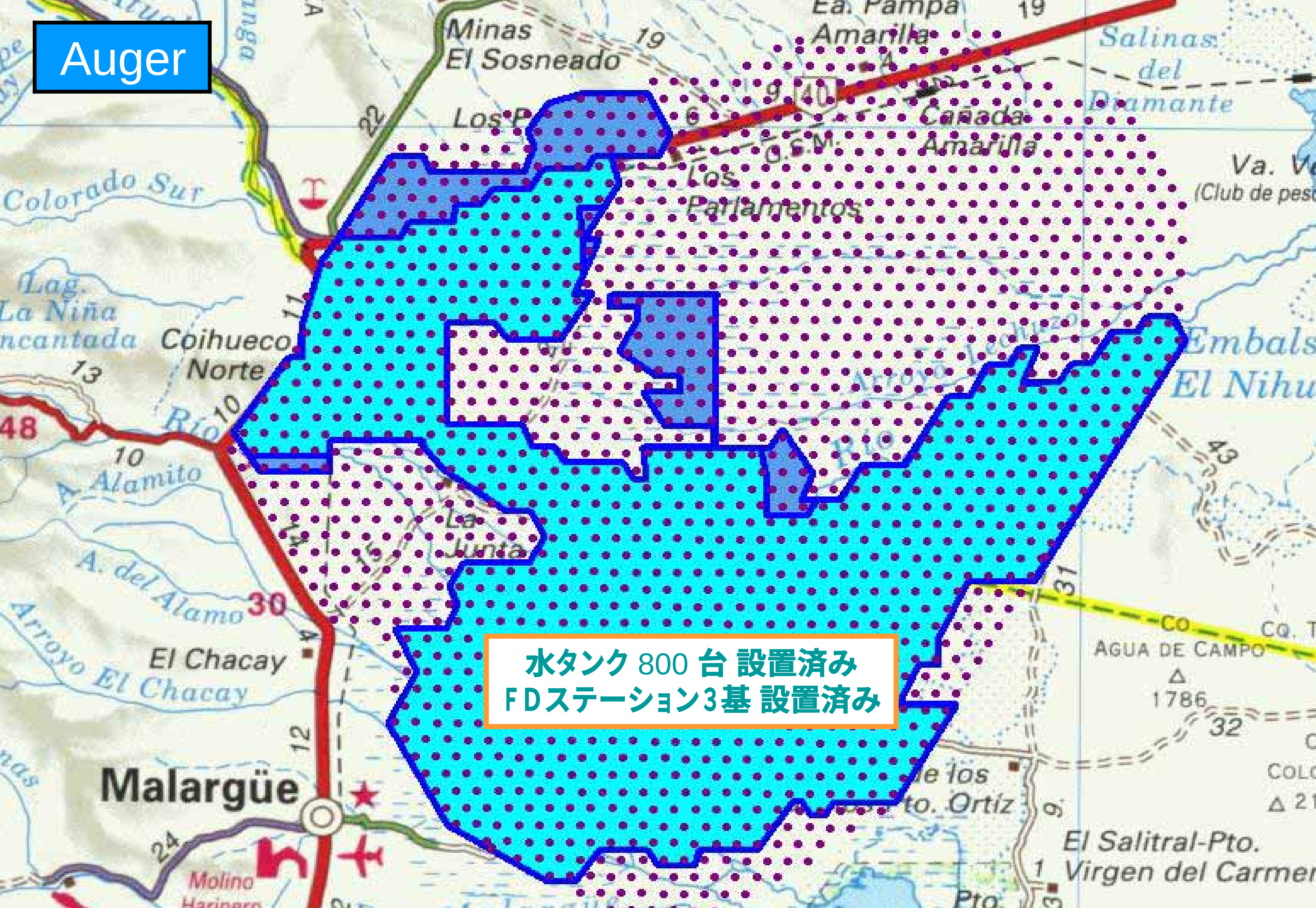

Ph-1 TA
Middle Drum
Telescope Array Locations
Millard County in Utah/USA
0 3,000 6,000
Meters
~600 Counters
AGASA x 9
Comm. Tower
CLF
Delta
Hinckley
Long Ridge
Black Rock Mesa
Route 257
U.S. Highway 6 & 50
TA Locations
Communication Towers
Fluorescence Locations
Central Laser Facility
Streams
Lakes
TALE
3 x Fluorescence Stations
AGASA x 4
Low Energy Extension
University of Utah
April 2004

18 SDs deployed in December 2004 for field test.

Plastic Scintillator
3m^2, 1.2cm t, 2 layers



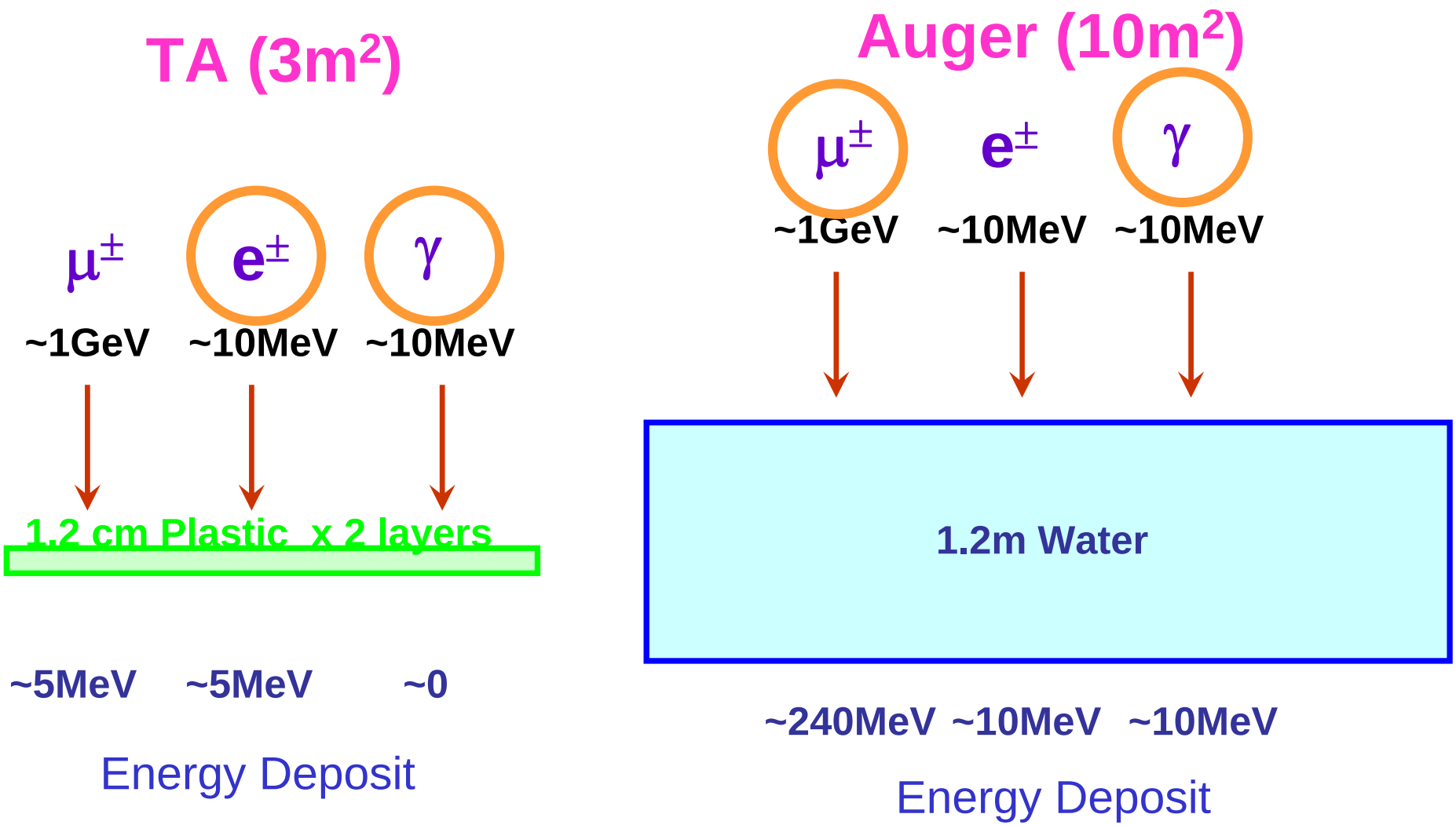




Auger
水タンク 800 台 設置済み
FDステーション3基 設置済み
Minas
El Sosneado
Ea. Pampa
Amarilla
Salinas
del
Diamante
Cañada
Amarilla
Los
Parlamentos
Va. Ve
(Club de pes
Colorado Sur
Lag.
La Niña
ncantada
Coihueco
Norte
Río
Arroyo El Lechuzo
Embals
El Nihu
A. Alamito
La
Junta
A. del Alamo
El Chacay
Arroyo El Chacay
AGUA DE CAMPO
1786
Malargüe
El Salitral-Pto.
Virgen del Carmen
Molino
Harinero

One of ~800 water tanks of Auger.

水タンク vs プラスチック (地表検出器レスポンス)



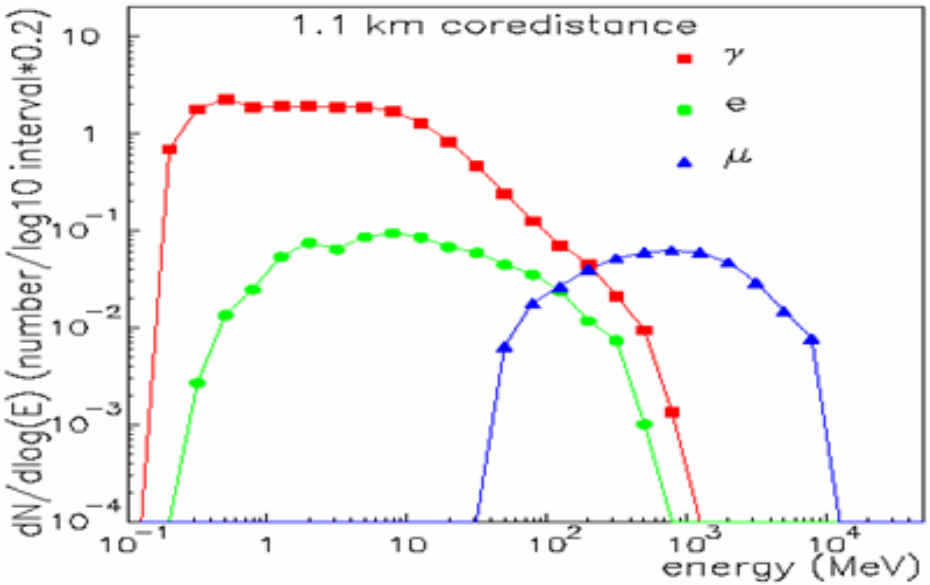


Figure 13: Energy spectra of ground particles.

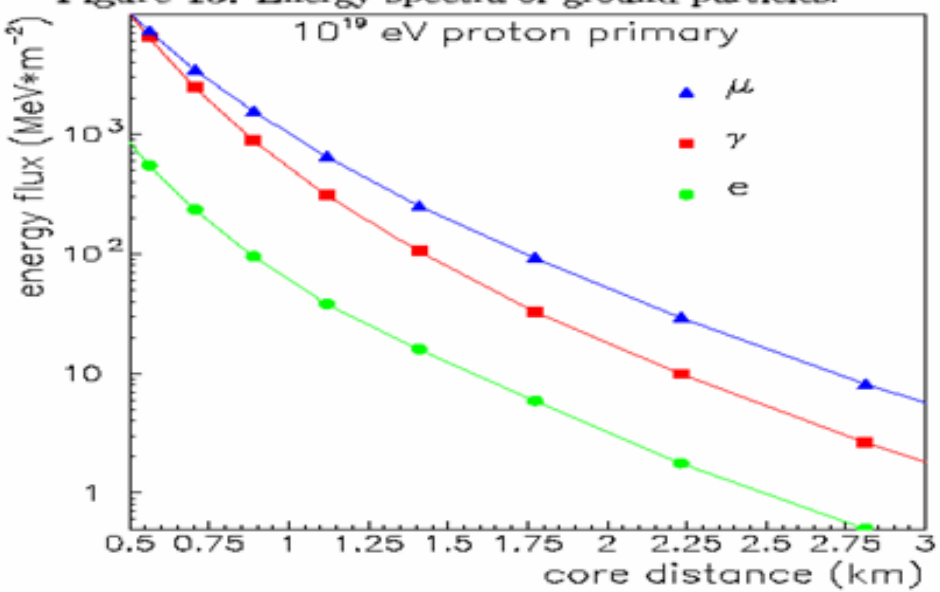
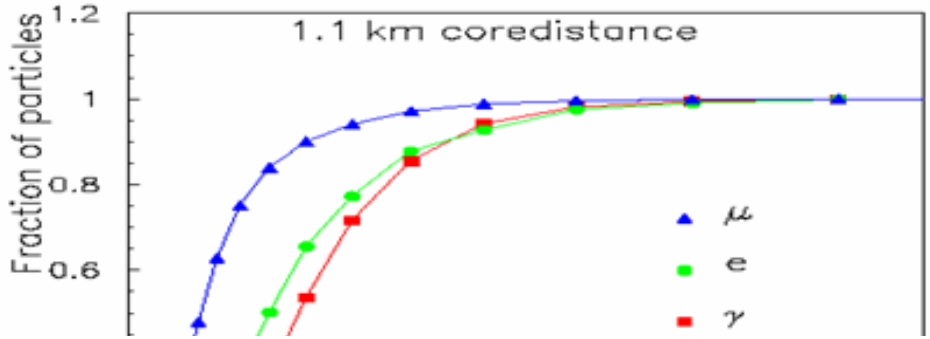


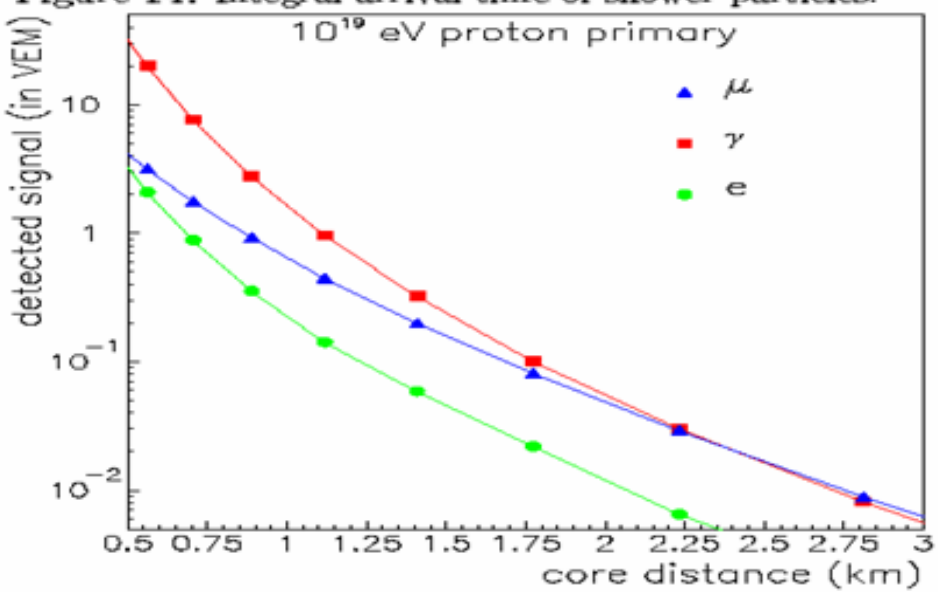
Figure 15: Lateral distribution of energy flux.



10^{19}eV proton shower による
水タンク信号波高 (MC)

time (μs)

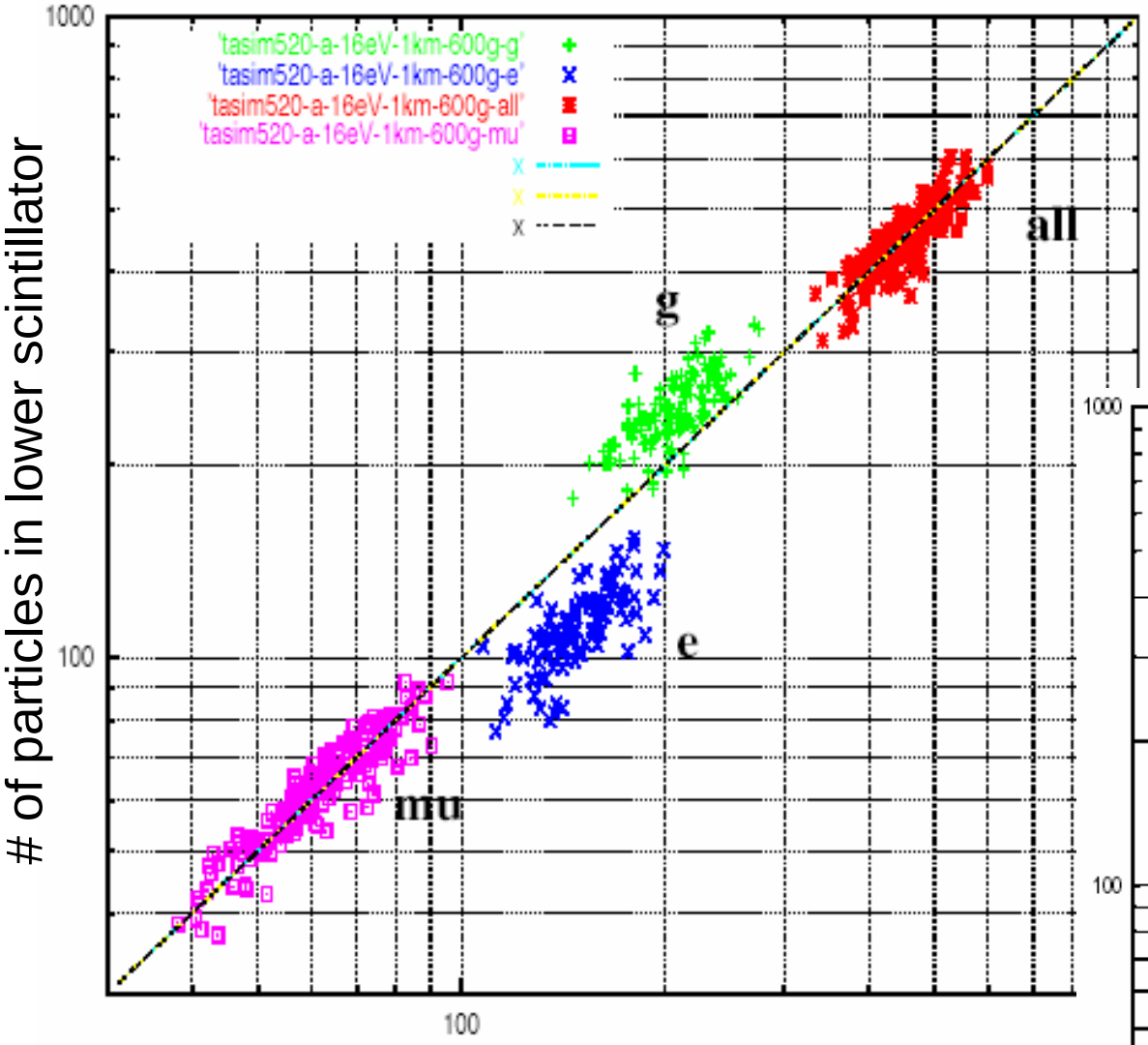
Figure 14: Integral arrival time of shower particles.



横軸：シャワー中心からの距離 (km)

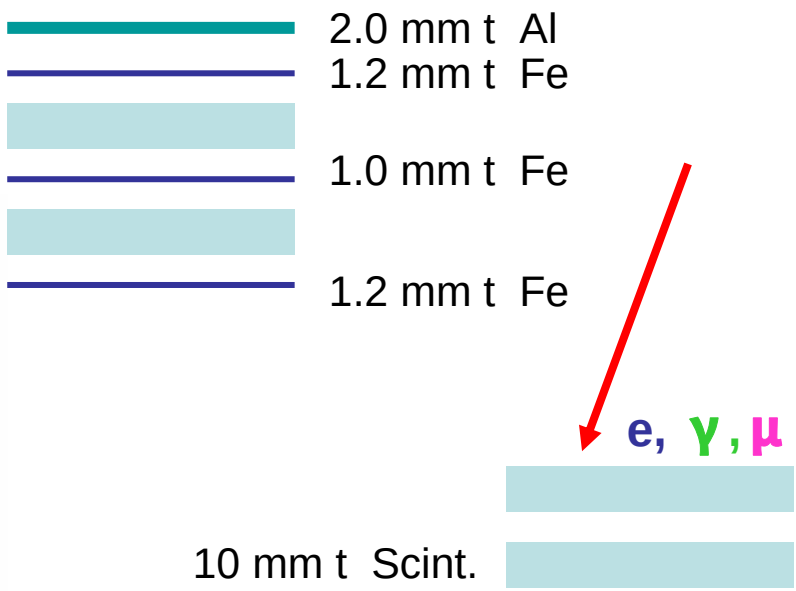
Expected Signal from e, γ, μ

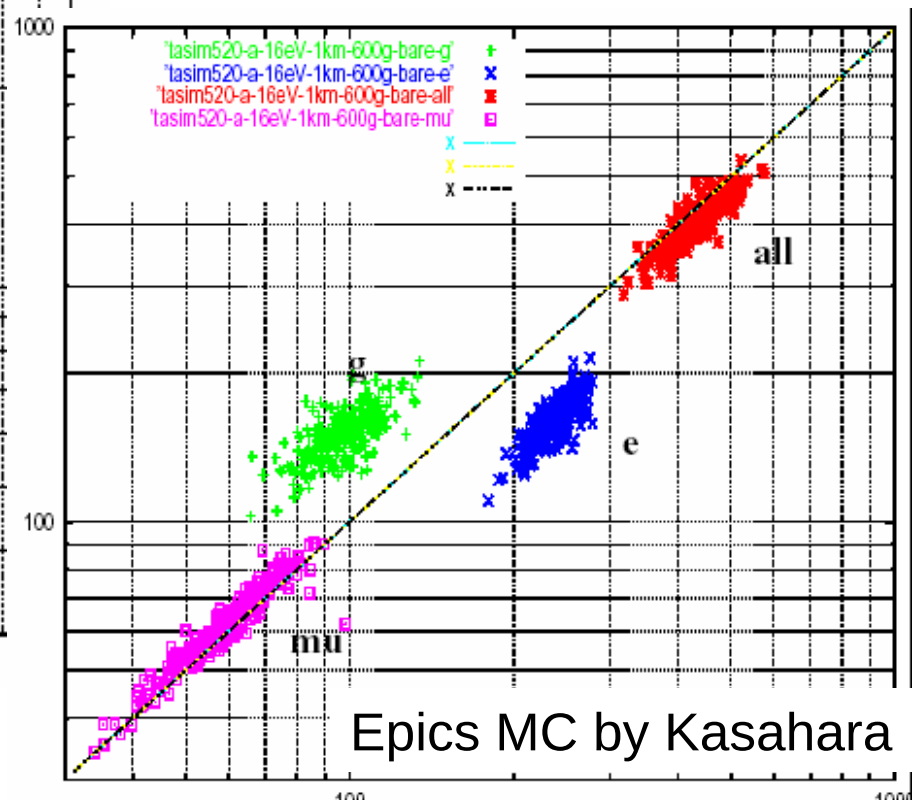
for 10^{20}eV proton shower on the ground & 1 km away from core



# of particles in lower scintillator

# of particles in upper scintillator





Epics MC by Kasahara

TA 地表検出器の特徴

Plastic Scintillator

- Conserve AGASA energy scale
- Sample electromagnetic shower (~90% of Eprimary)
  >>> less dependent on
  - primary composition
  - hadronic interaction @EHE

may vary over GZK energy

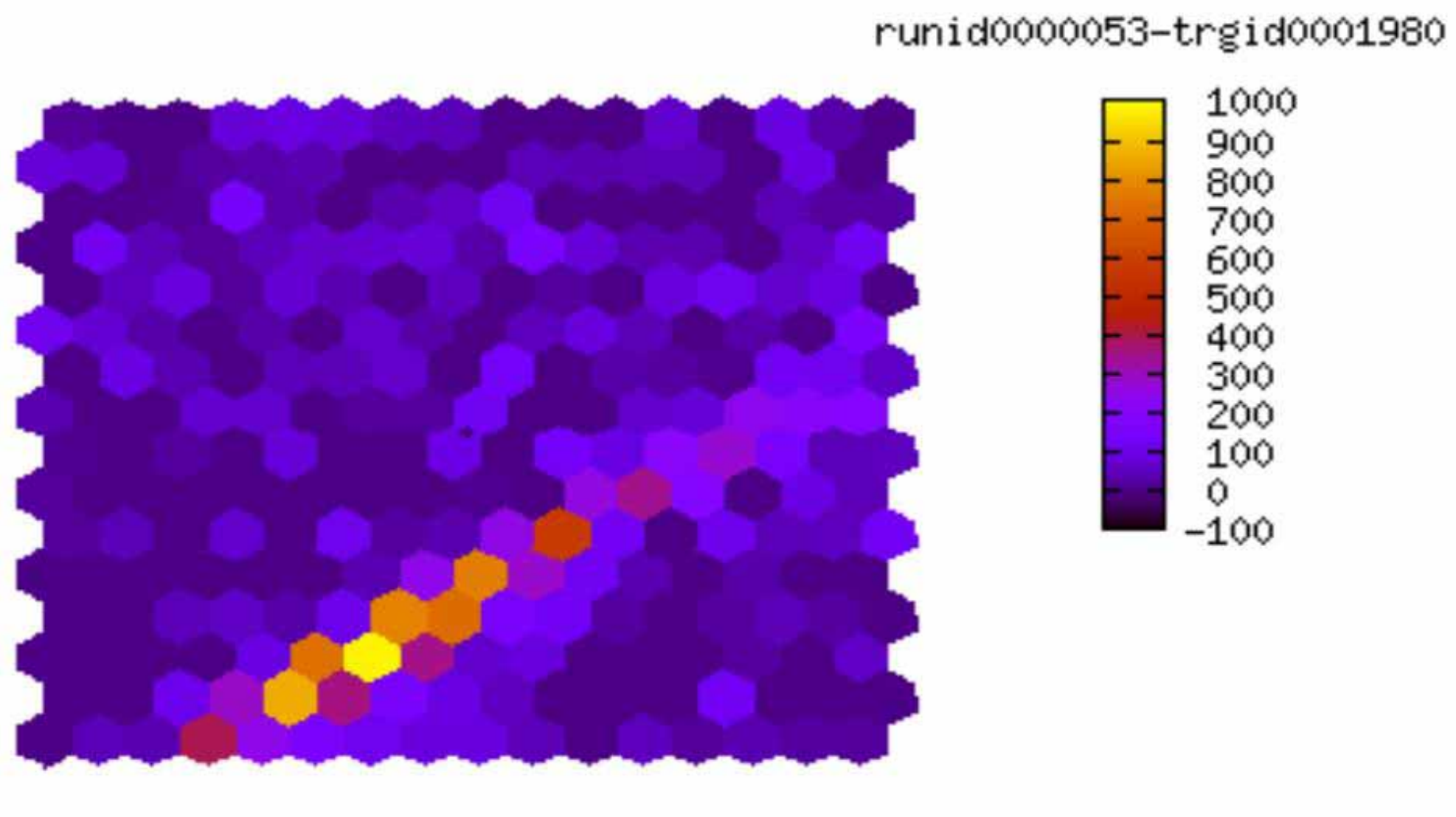
Two Layers

- trigger and calibration
- DAQ and local buffering
- wider dynamic range (MIPs)

~350 counters to be assembled in Japan, transported to Utah and deployed in JFY 2005

Construction of 1st FD station with 12 telescopes completed.

The 1st fluorescence event by test observation in Utah, July 2005



MF6

最高エネルギー宇宙線実験の現状 (@ Pune ICRC)

exp.	status	km^2
AGASA	stopped in Jan. 2004	100
HiRes	will be terminated in Mar. 2006	~300
Auger	half finished. completion in 2006	3,000
TA	being built. compl. in Mar. 2007	800
EUSO	not in space before 2012	~17,000

SD, FD > SD + FD > Super Detector (in space?)

MF6

exact area:
Auger=2964 km2 with 1600 ctrs, 1.5km triangle
TA=762 km2 with 576 ctrs, 1.2km mesh
HiRes r=30km2, duty=0.1
Euso 400km high, 60deg view, duty=0.1
　　230km radius on the ground

solid angle effect
zenith[0,45]=0.29
zenith[0,60]=0.5
zenith[0,90]=1　is not included (only AREA)
福島正己, 2005/09/14

Pune で

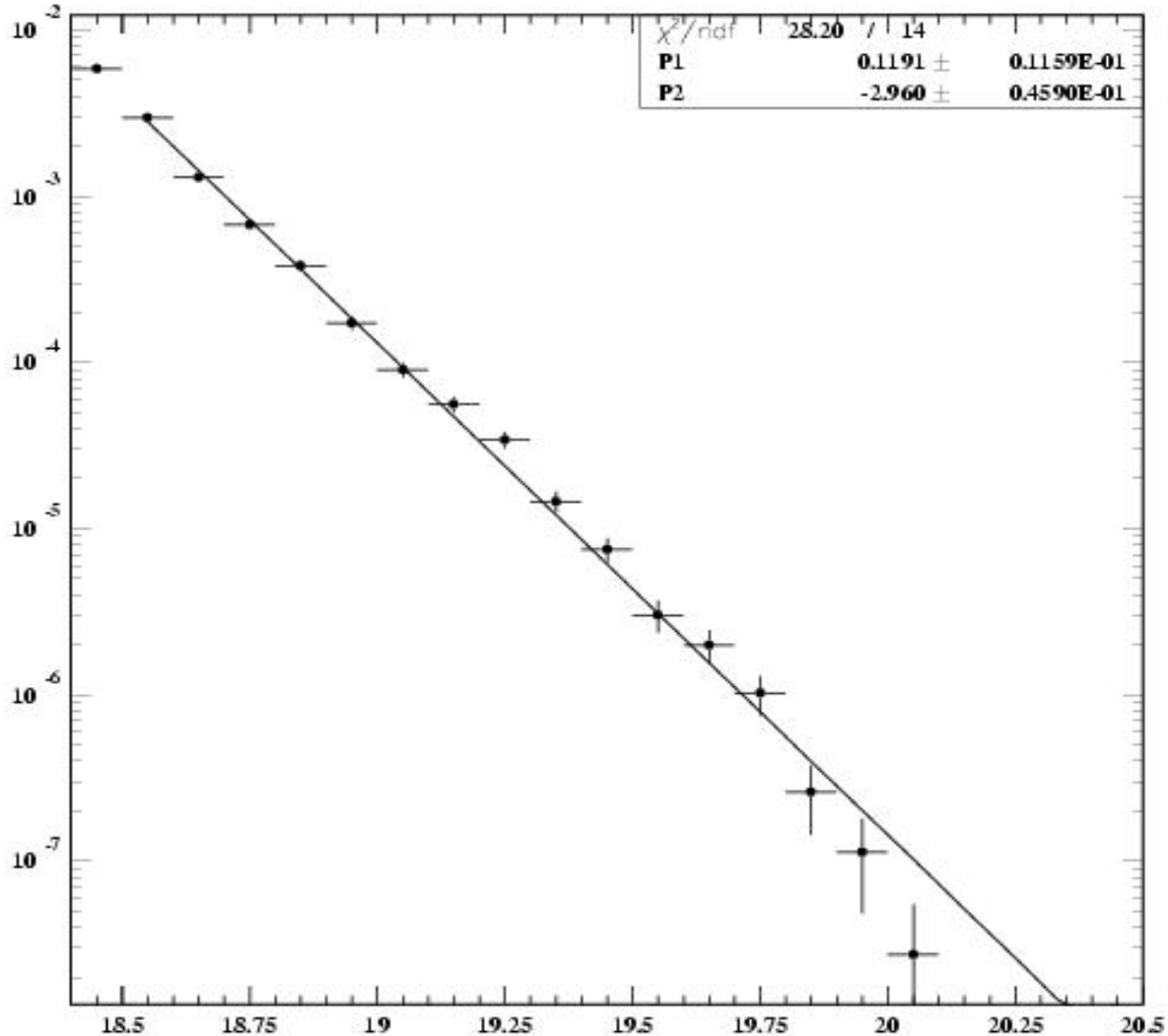
- HiRes stereo spectrum (prelim.)
- Auger hybrid spectrum (large sys. error)

が発表された。

by S.Yoshida
@ 29th ICRC Pune

HiRes Stereo Flux

- Fit to power law.
- Single index gives poor chi2
- Evidence for changing index

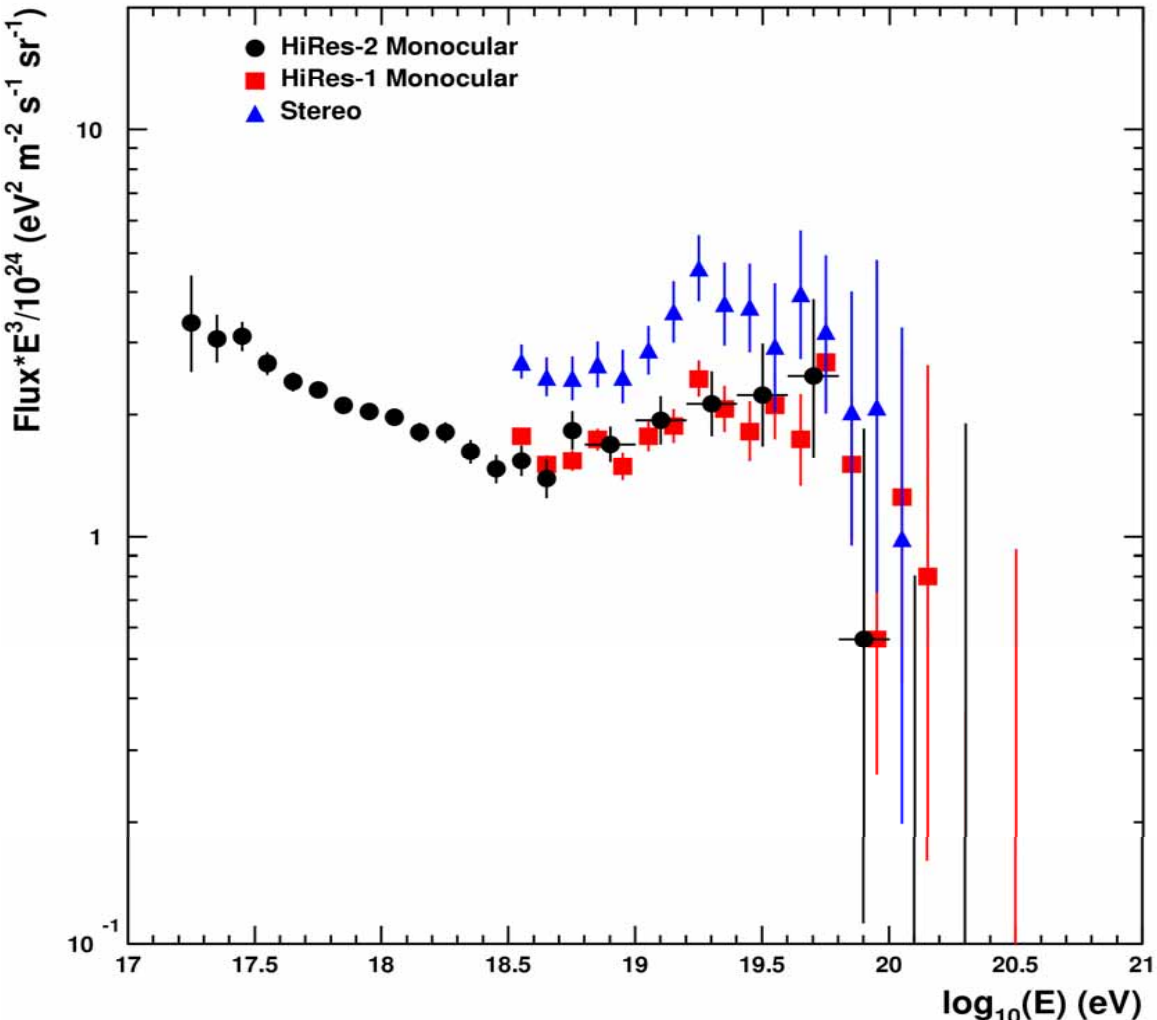


Wayne Springer (this conference)

by S.Yoshida
@ 29th ICRC Pune

HiRes Stereo (and others)

(Fukushima: HiRes STEREO DATA is NOT authorized by HiRes collab..)



Exhibits cutoff structure

Expect 33.7 events

Observe 9 events

~4.8σ

Some details DIFFERENT from mono!

The Mono spectrum may contain unknown syst.

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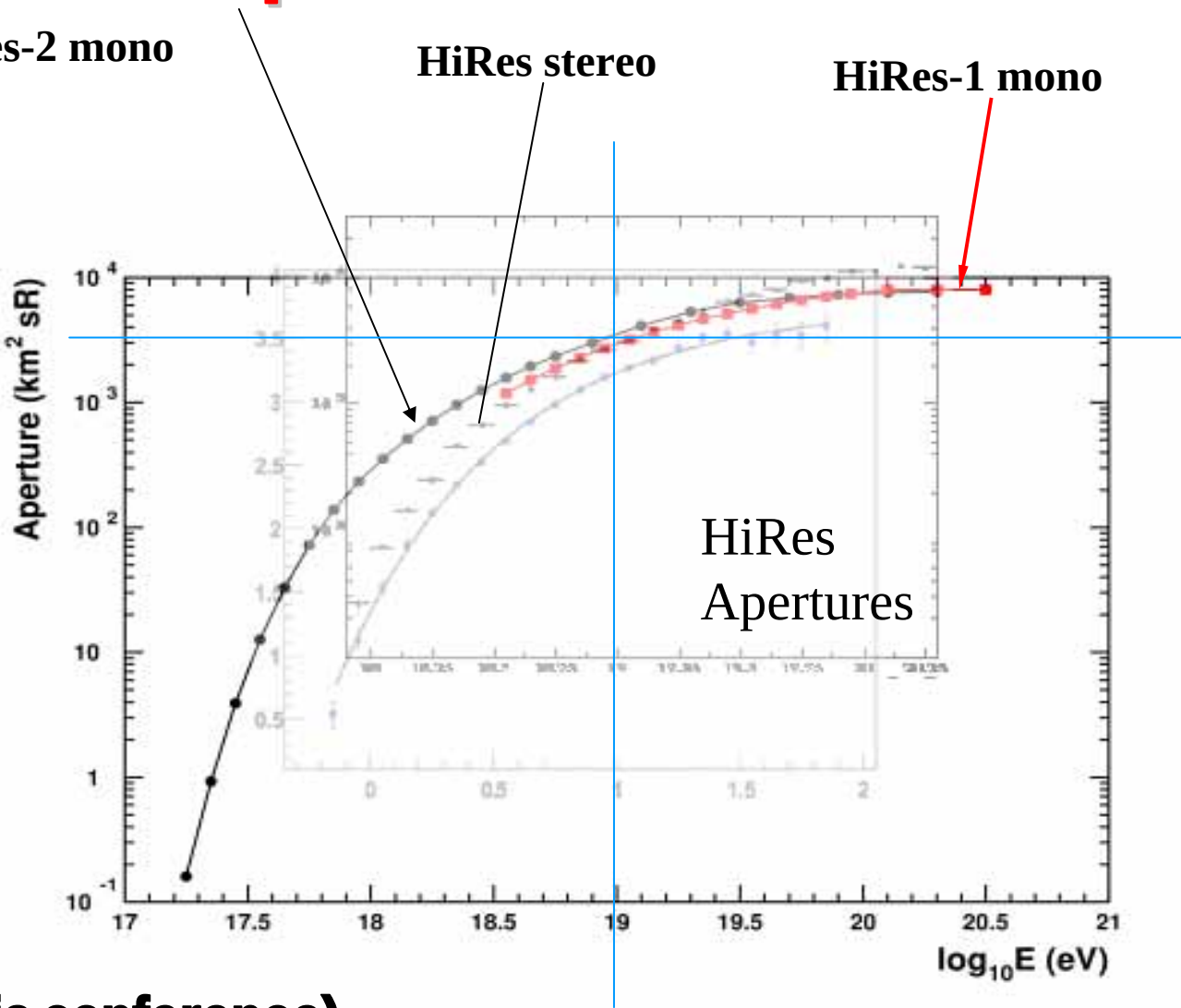
Chiba University

by S.Yoshida
@ 29th ICRC Pune

HiRes Aperture

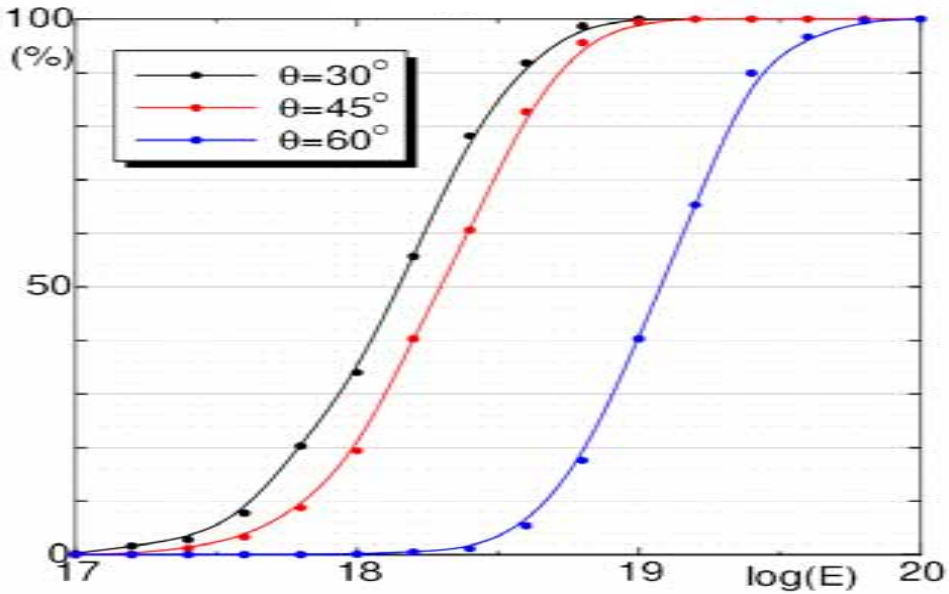
- **Stereo data**: best resolution, optimized for $E>3\times10^{18}$eV Uses time-dependent calibration of detector and atmosphere
- **HiRes-2 monocular**: car reach down to as low as $10^{17.2}$eV
- **HiRes-1 monocular** data began ~3 years earlier: largest statistics,
  - Uses profile constrained fit (PFC) unreliable $<10^{18.5}$eV

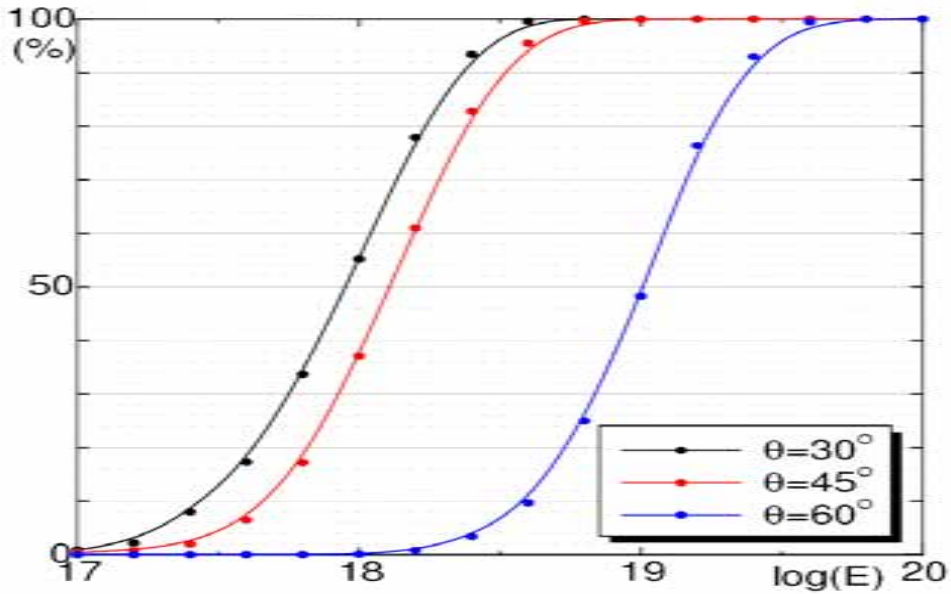


Wayne Springer (this conference)

Trigger Efficiency (# of hit ctr >= 4)

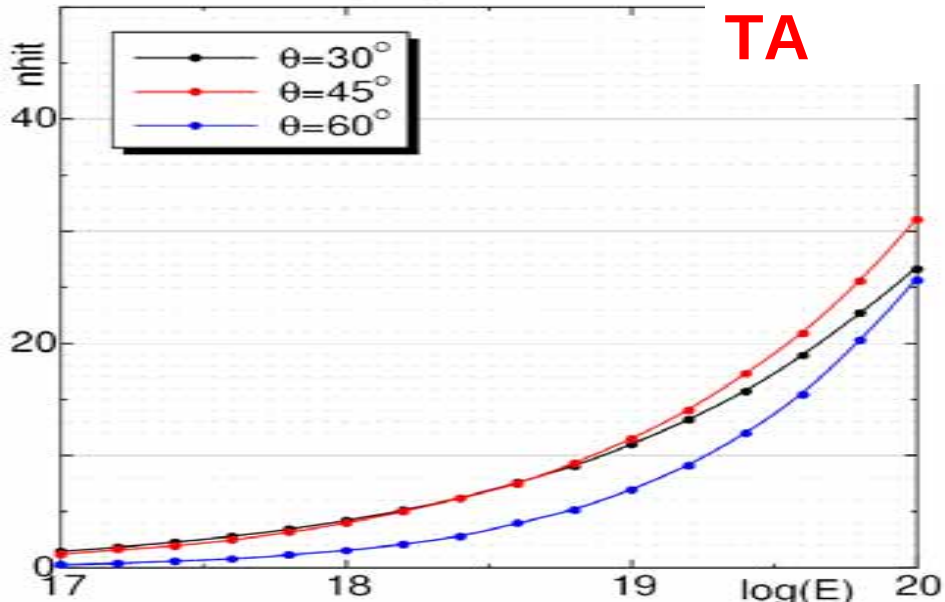
by Wada & Inoue



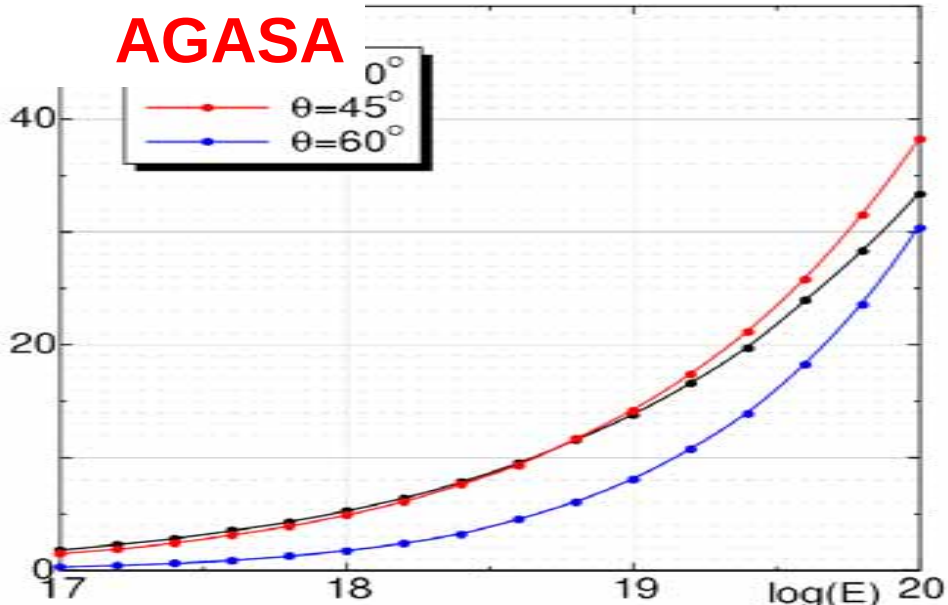


# of Hit counters 3m^2 , 1.2 km ⇔ 2.2m^2, 1.0 km spacing

TA

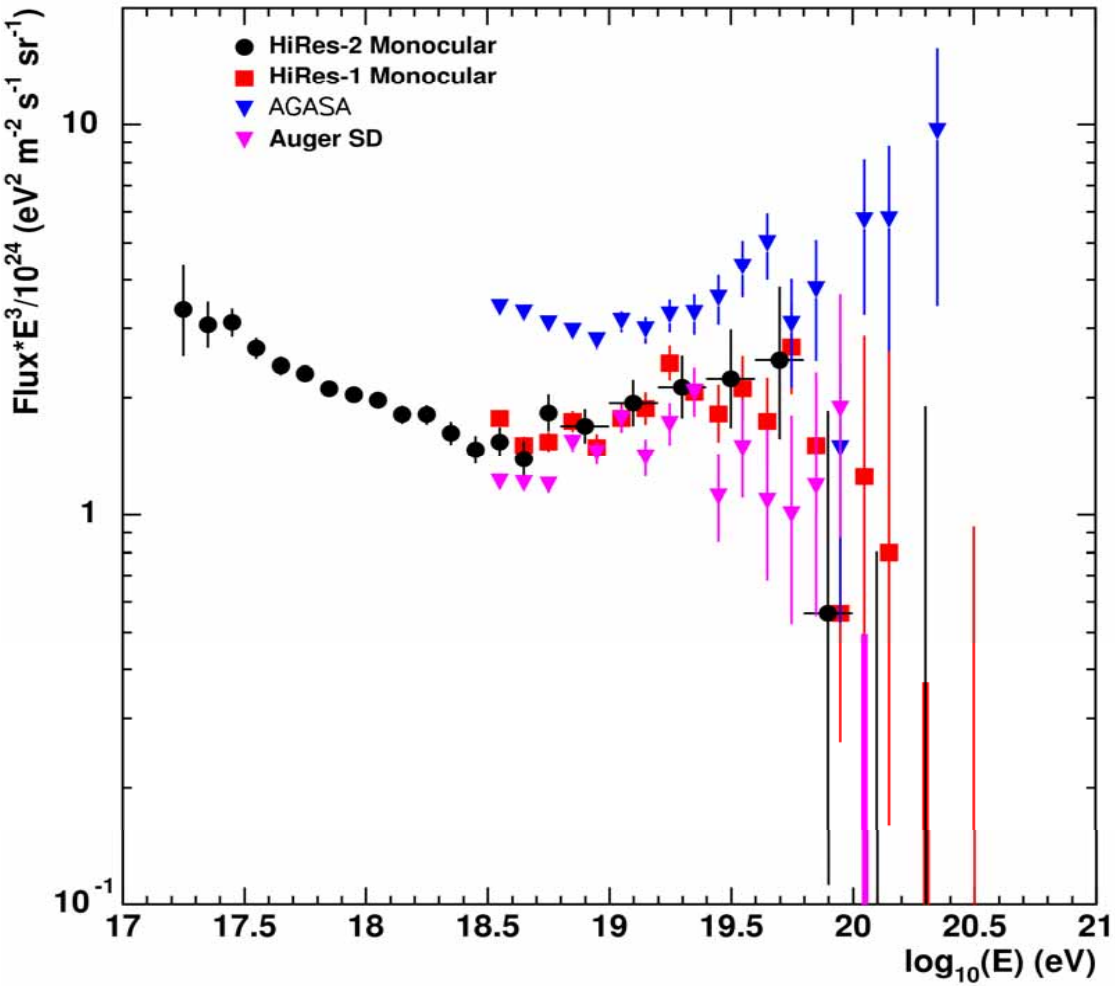


AGASA



by S.Yoshida
@ 29th ICRC Pune

Auger SD spectrum



Energy scale uncer. still large

~40 % in 100 EeV

improvement will come soon

PIERRE AUGER OBSERVATORY

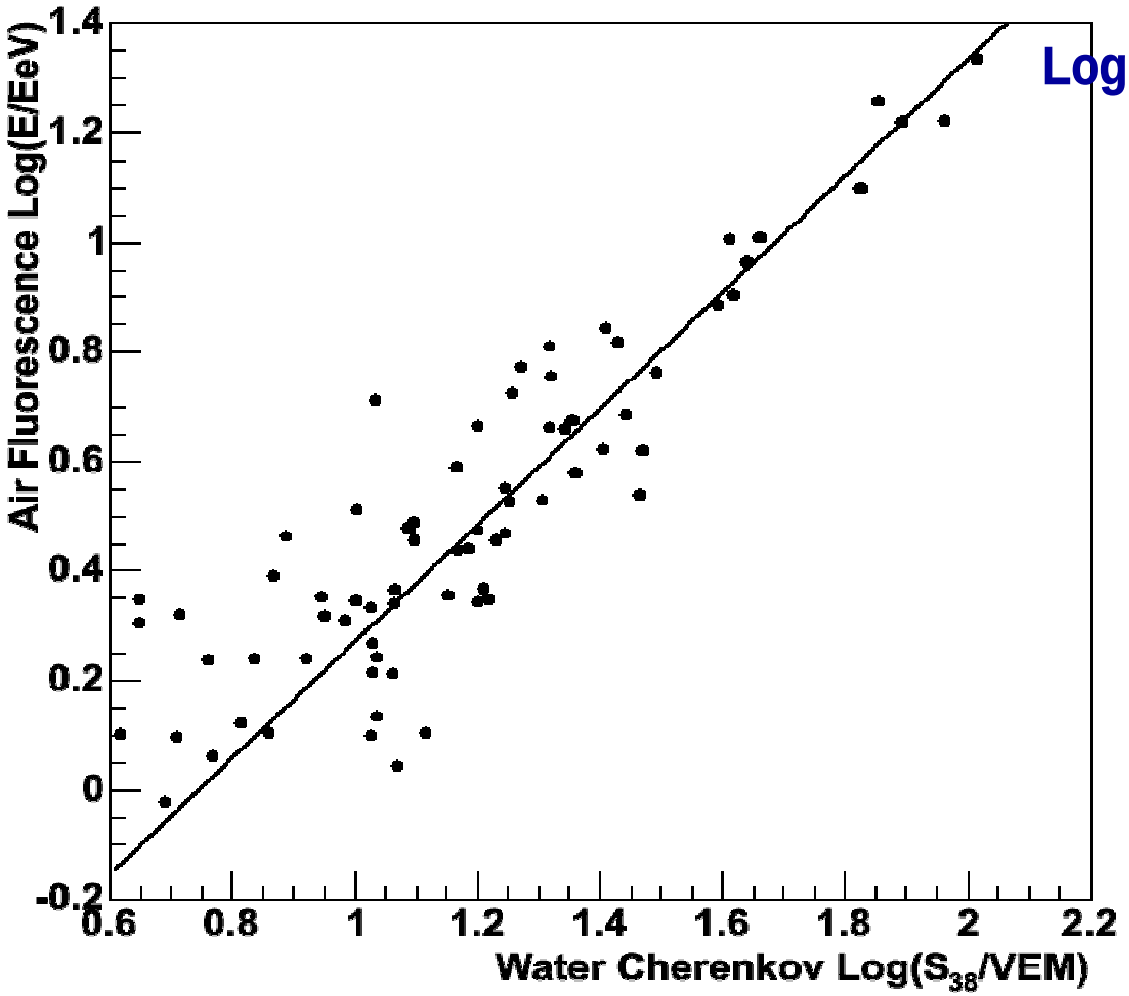
千葉大学 Chiba University

by S.Yoshida
@ 29th ICRC Pune

Auger Hybrid

PIERRE AUGER OBSERVATORY

Paul Sommers (this conference)



$\mathrm{Log}\,(E) = -0.79 + 1.06\,\mathrm{Log}(S_{38})$

$E = 0.16\ S_{38}^{1.06}$

(E in EeV, S_{38} in VEM)

Uncertainty in this rule increases from 15% at 3 EeV to 40% at 100 EeV

千葉大学 Chiba University

地表検出器のエネルギー決定は空気シャワーＭＣに依存する。

Energy estimator と primary energy の関係
e, μ, γ mixture　vs　測定器レスポンス

アクセプタンスは一定（天頂角４５°以下）

大気蛍光望遠鏡のエネルギーは実験的に決定できる。ただし

発光効率・大気透明度・望遠鏡定数などの
精度の良い較正・補正が必要。

ＳＤ ＋ ＦＤ Hybrid **同時測定は**

多くの問題を解決する。

ＳＤでスペクトルの形

(plastic vs water tank)

ＦＤでエネルギー決定

(Electron beam calibration)

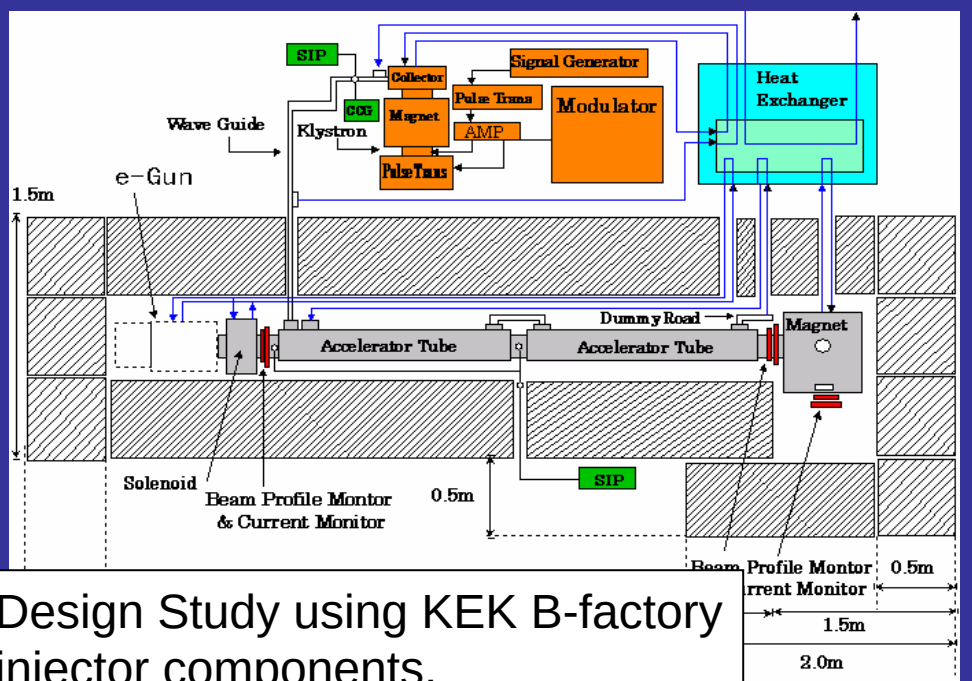
Electron Linac Beam for Energy Calibration

AF Source of
Known Total Energy

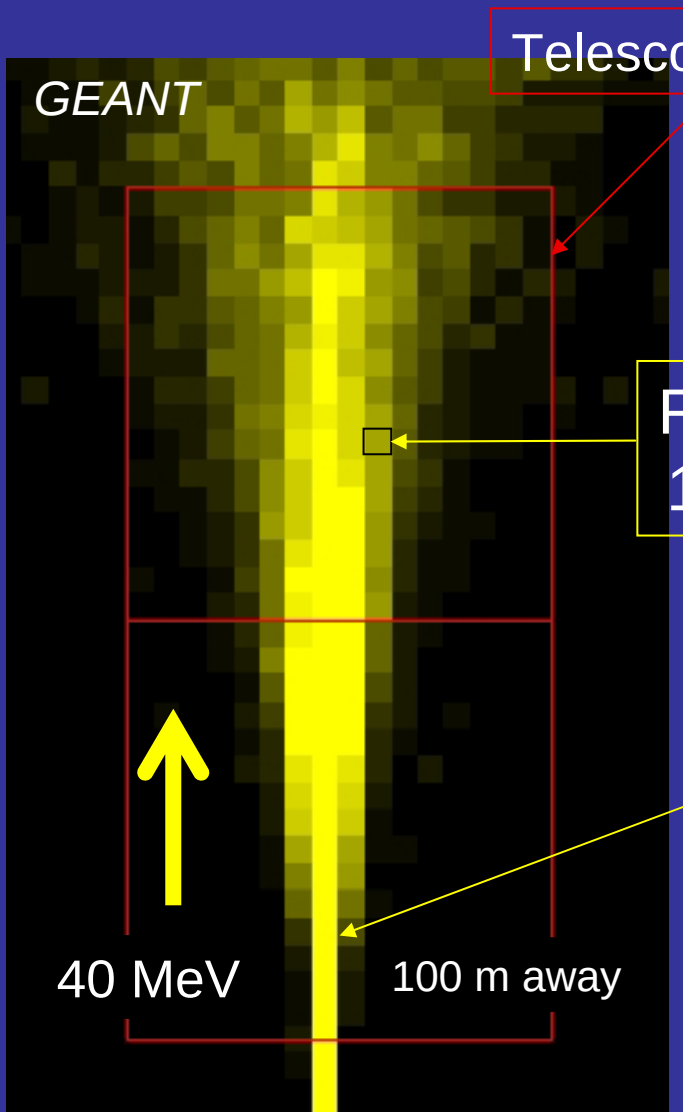
10^9 ppp ~ 4 x 10^{16} eV

Direct end-to-end calib.

From Energy Loss to ADC ch.



Design Study using KEK B-factory injector components.



まとめ

次期大型装置(TA & Auger) **は　ＳＤ＋ＦＤ**

- **ＳＤの規模を確保する（統計量）。**
- **ＦＤの絶対較正（エネルギー精度）。**

2007（**メキシコ　ＩＣＲＣ**）**までに**

南半球で、Ａｕｇｅｒ は　ｘ７　ＡＧＡＳＡ exposure
北半球で、TA**は**　x１ AGASA exposure

ＵＨＥＣＲのスペクトルについては、ほぼ結論が出る。