Telescope Array Experiment: Resent Status and Experimental Results

テレスコープアレイ実験による 北天極高エネルギー宇宙線観測の現状と最新結果

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on behalf of TA collaboration

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The Telescope Array experiment

Millard county, Utah, USA(39.1° N, 122.9° W) ~1400 m a.s.l.

Surface Detectors (SDs)

Scintillations detectors: 507

3 m^2 x 1.2cm x 2 layers

1.2 km separation, ~800km^2

E > 10^{19} eV

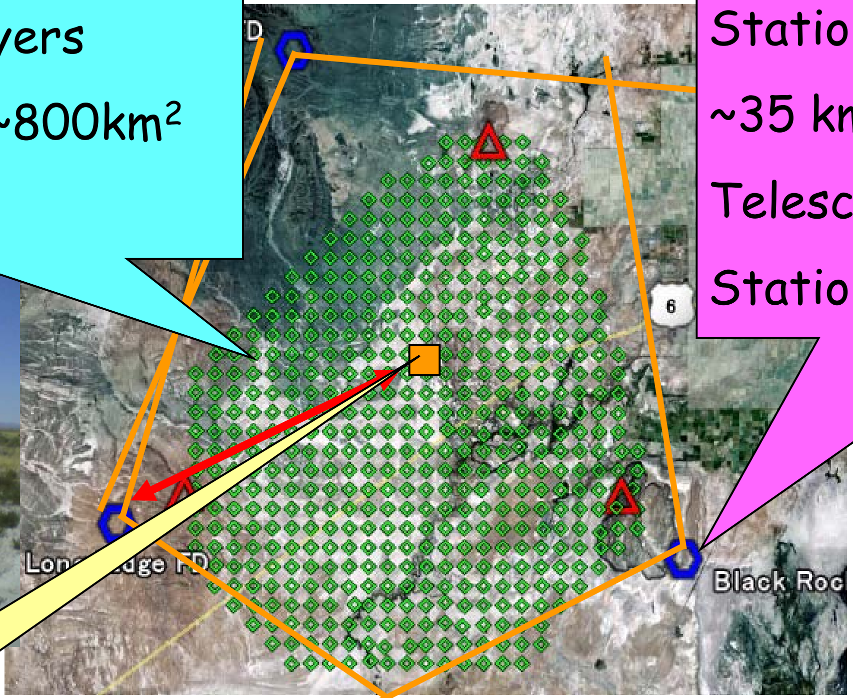
Fluorescence Detectors (FDs)

Stations: 3

~35 km separation

Telescopes: 12 / station

Station FOV: 3° – 33° x 108°



Central Laser
(~20 km)

From AGASA, HiRes to TA

■ Plastic Scintillator : from AGASA to TA

	area	thickness	readout	electronics	spacing
AGASA	2.2 m^2	50 mm	Direct PMT	Log Amp.	1.0 km
TA / SD	3.0 m^2	12 mm	WLS fiber	FADC	1.2 km

UHE spectra of AGASA should reproduce at TA.

■ Air Fluorescence Telescope : from HiRes to TA

same optics (1^0 pixel)	Mirror 5.2→6.8 m^2	Distance 12→30 km

3rd TA / FD station is a transfer of HiRes-1

UHE spectra of HiRes should reproduce at TA.

TA produces 2 independent energy spectra by SD & FD.

■ Akeno, Dugway and Millard: 37^0 - 40^0 N & 900 - 1300 m above sea.

研究資金

特定領域研究
「最高エネルギー宇宙線の起源」は2008年度で終了

特別推進研究
「**最高エネルギー宇宙線で探る宇宙極高現象**」が採択された。

- ✓ 2009年 – 2013年 の 5 年間
- ✓ TAの安定かつ能率的な運用
- ✓ 検出器の理解と精密較正
- ✓ データ解析と物理
- ✓ 研究成果の発表

基盤研究・萌芽的研究にて較正装置製作、検出法R&Dなど
東大宇宙線研共同利用費にて研究活動全般の支援

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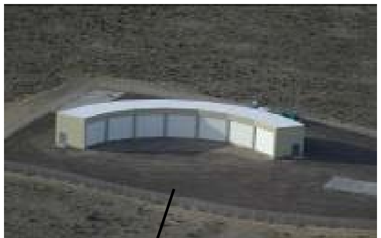
1. TA-FD
1-i. Performance, Calibration

H. Tokuno et al., 942, 31st ICRC
T. Tomida et al., 801, 31st ICRC
T. Shibata et al., 790, 31st ICRC

TA Fluorescence Detectors

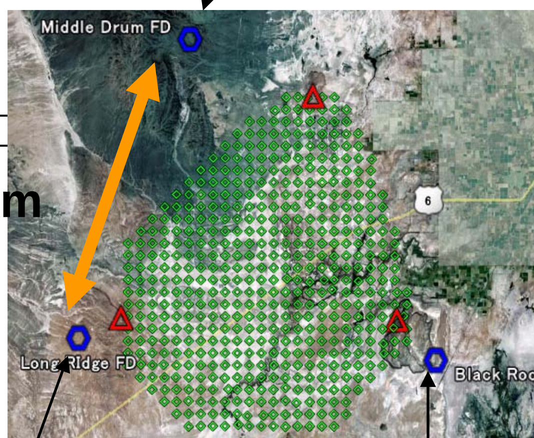
From HiRes

Middle Drum



14 cameras/station
256 PMTs/camera

5.2 m²



~30km

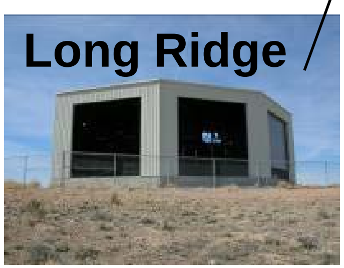
New FDs

256 PMTs/camera
HAMAMATSU R9508
FOV~15°x18°
12 cameras/station

6.8 m²

~1 m²

Long Ridge

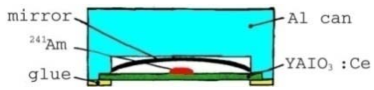


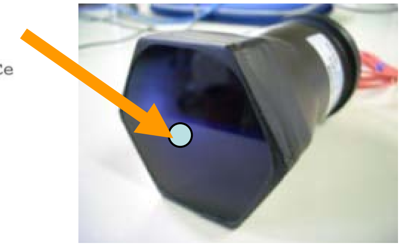
Black Rock Mesa

Gain Calibration

absolute light source in JPN
syst. err. +/-8% (preliminary)

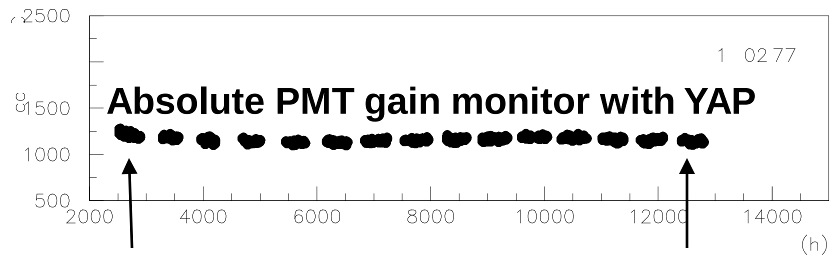
YAP ($YAlO_3$:Ce+^{241}Am)



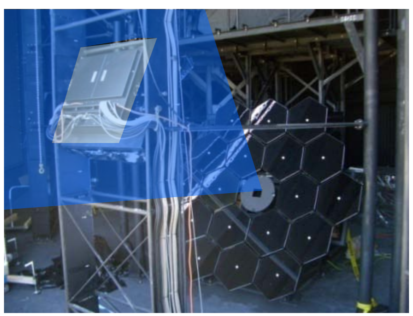


Standard PMT

standard PMTs installed

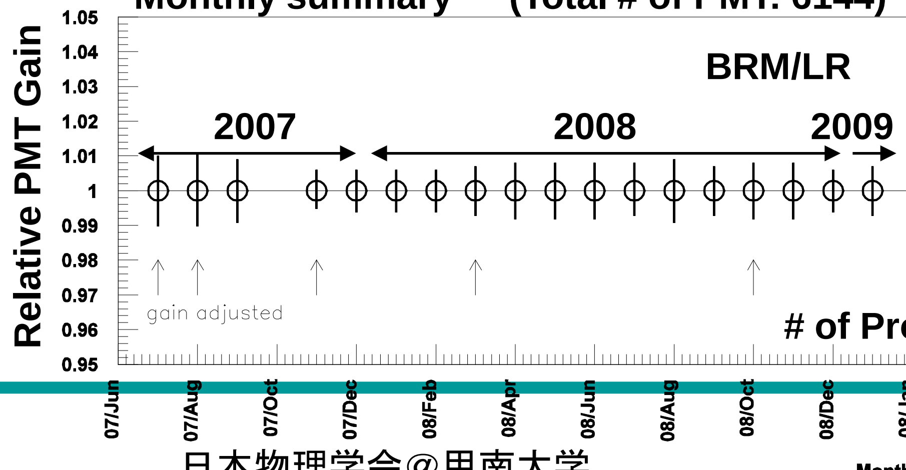


08Mar **09Apr**



relative gain adjusted

Monthly summary (Total # of PMT: 6144)



Error bars:
1sigma ~ 1%

# of Problematic PMTs: < 0.1%

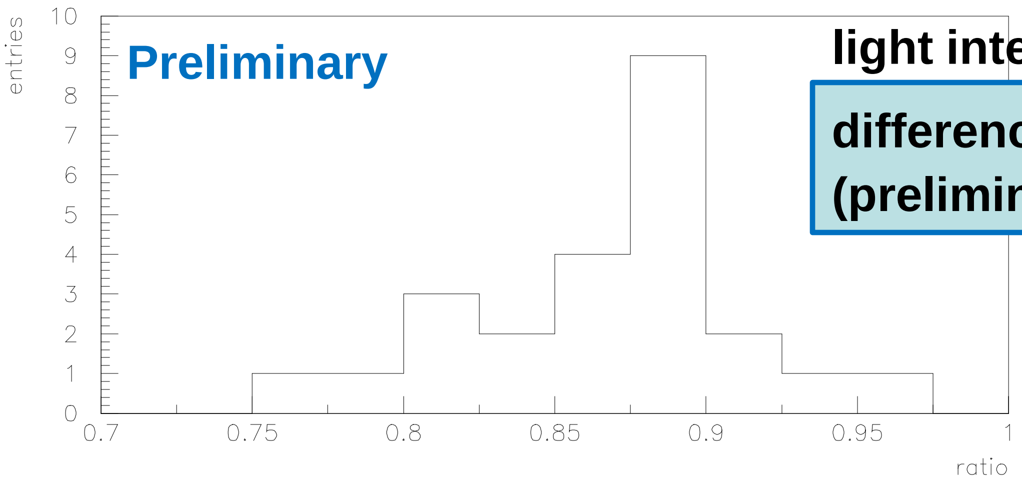
Gain Check

To compare absolute PMT gains of the three stations

RXF(Roving Xe flasher): an absolute calibrated light source of HiRes and MD

syst.+/-10%, stability +/-3%

May 2009　　BRM, LR 24 telescopes



Light intensity　measured / expected

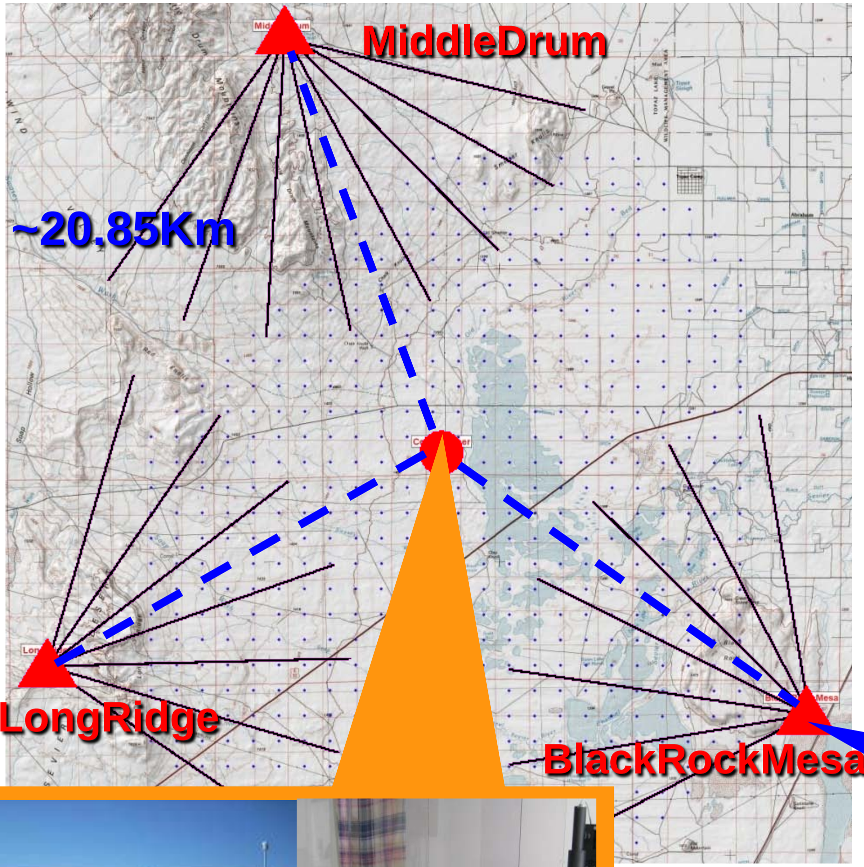
light intensities:

difference -12(+/-5)% (preliminary)

while absolute gain measurement in JPN

syst. err. ~+/-8% (preliminary)

Atmospheric Monitor



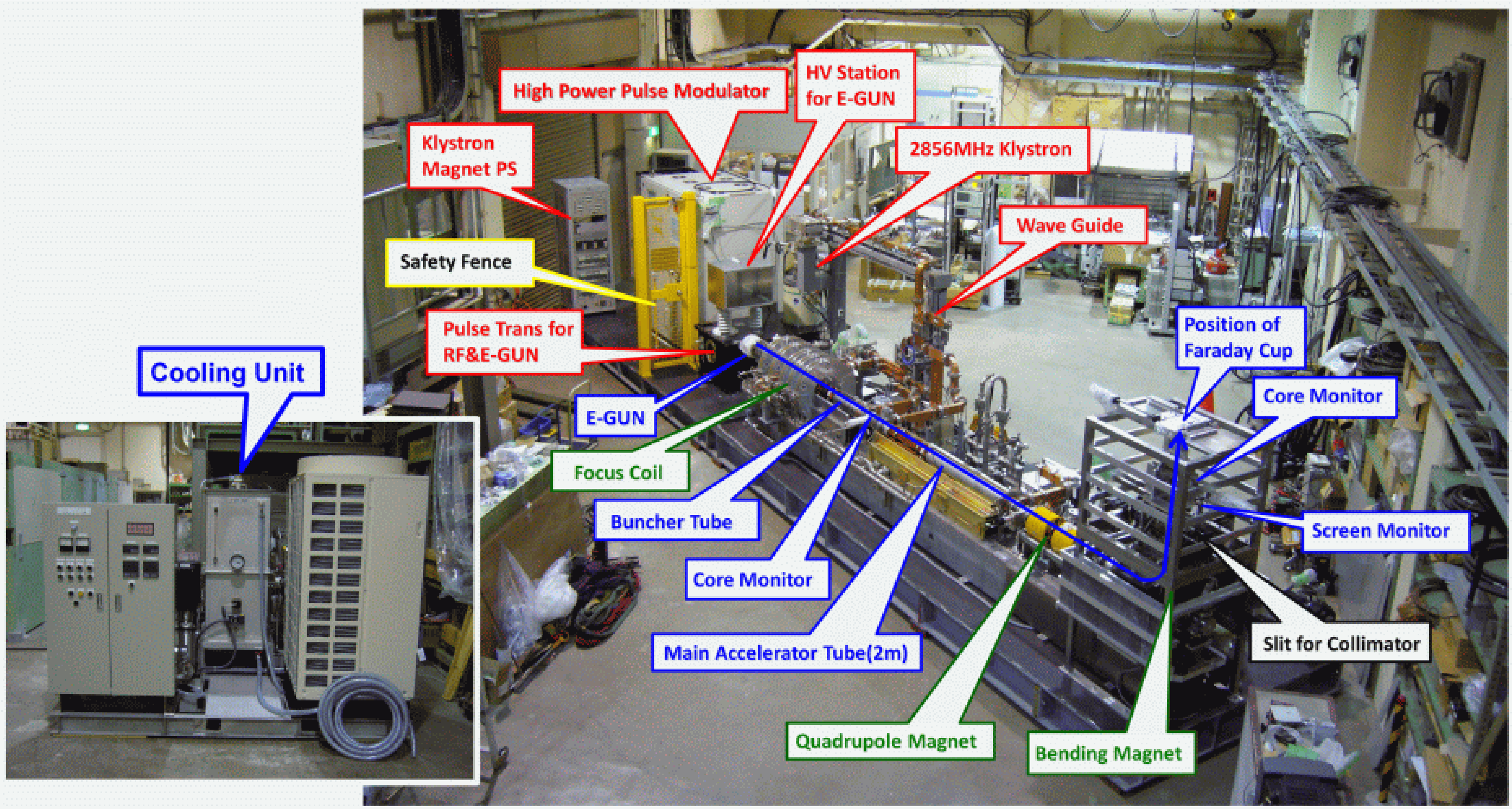
LIDAR :
measuring the back scatter light by own steerable system

IR camera :
take a Infra-Red picture to check the cloud covering

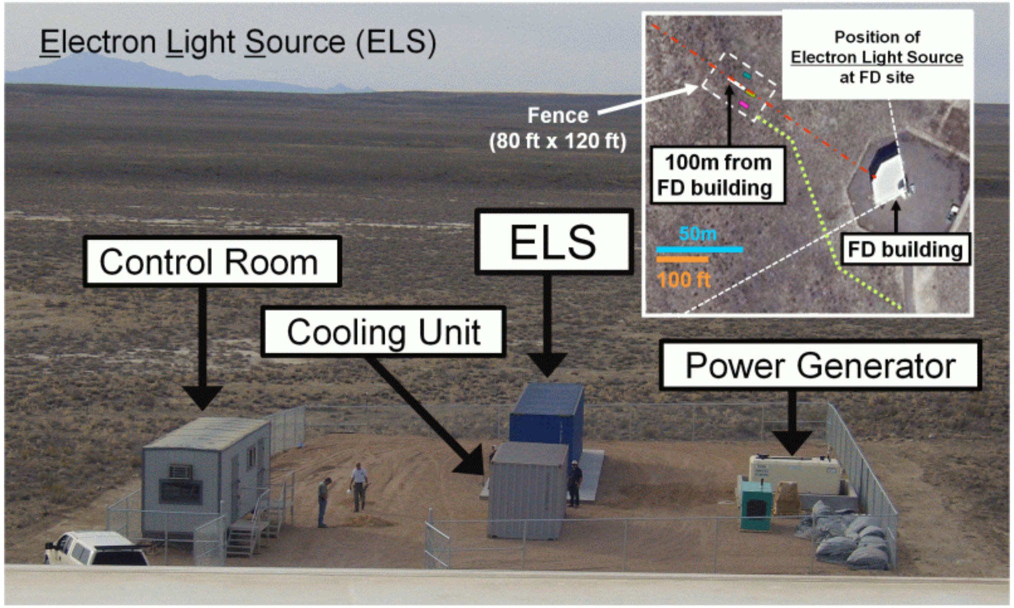
CLF :
measuring the side scatter light through FD telescopes

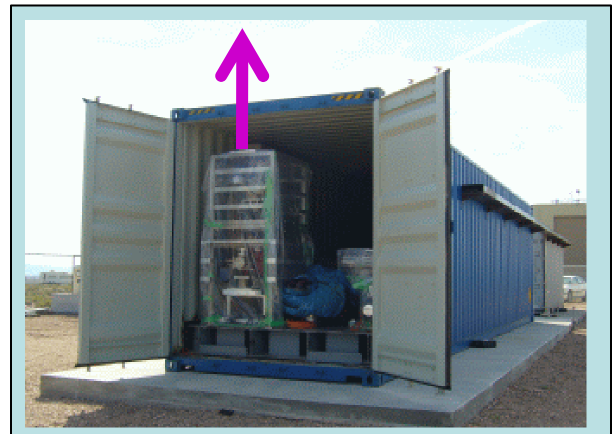
Electron Light Source (ELS)

Reconstruction of ELS was completed in KEK, Feb.'09



Installed ELS

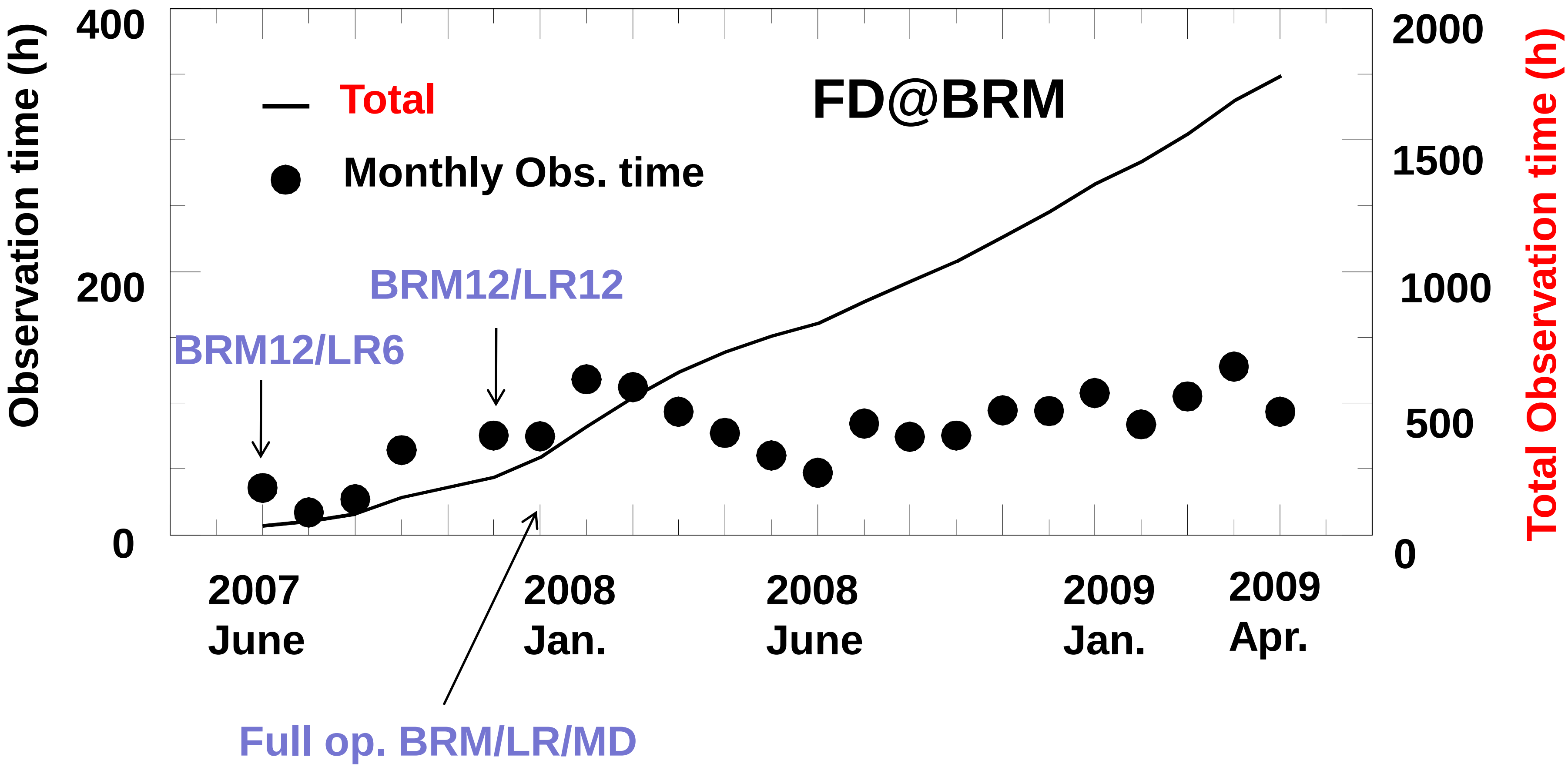




1. TA-FD
1-ii. Observations

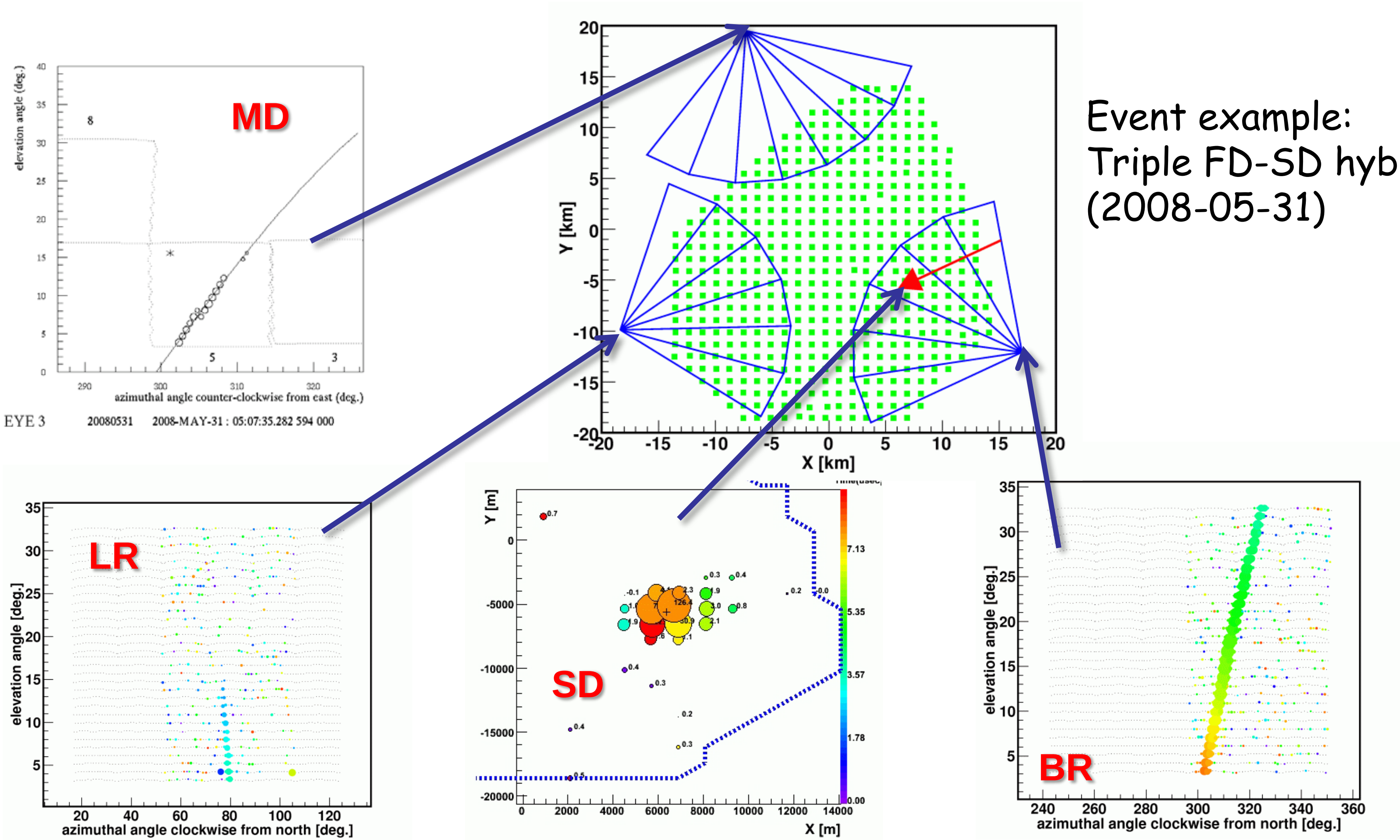
H. Tokuno et al., 942, 31st ICRC
D. Ikeda et al., 857, 31st ICRC

Observation Time



!! 2009 May ~: Remote Operation (LR site)

Hybrid event (sample)



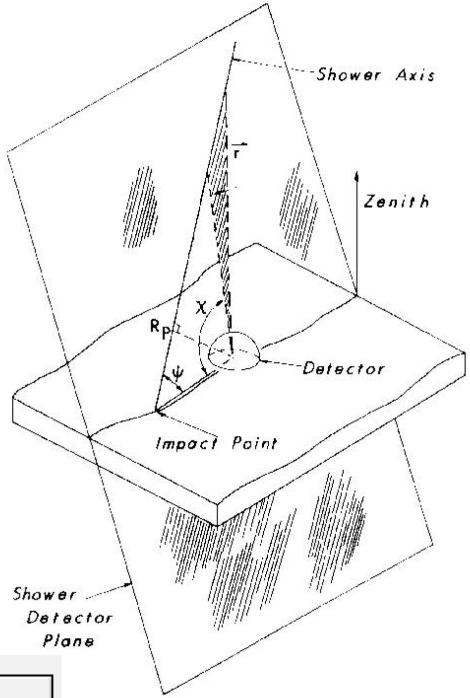
Event example:
Triple FD-SD hybrid
(2008-05-31)

1. TA-FD
1-iii. Analysis for BRM site

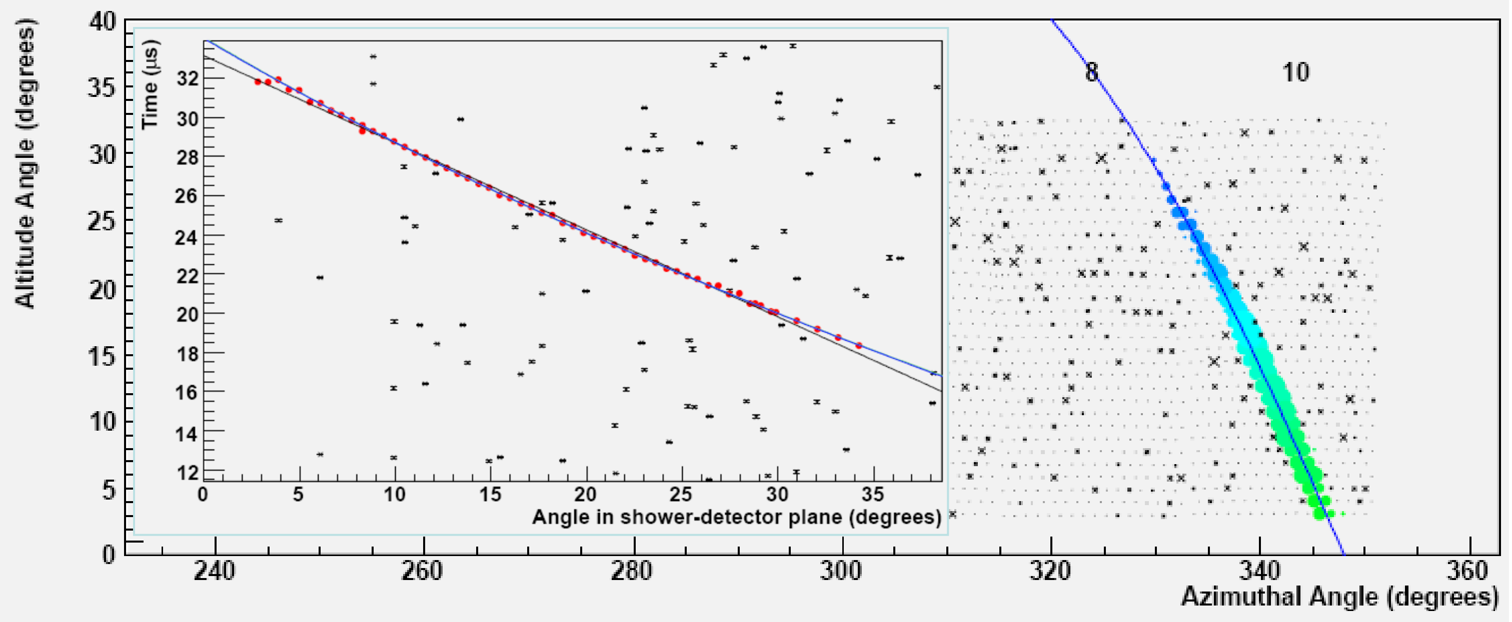
- Stereo, Hybrid, (Monocular) …..Japan-Korea
- Monocular, (Stereo)…..US

D. Bergman et al., 826, 31st ICRC

Monocular Analysis for BRM station

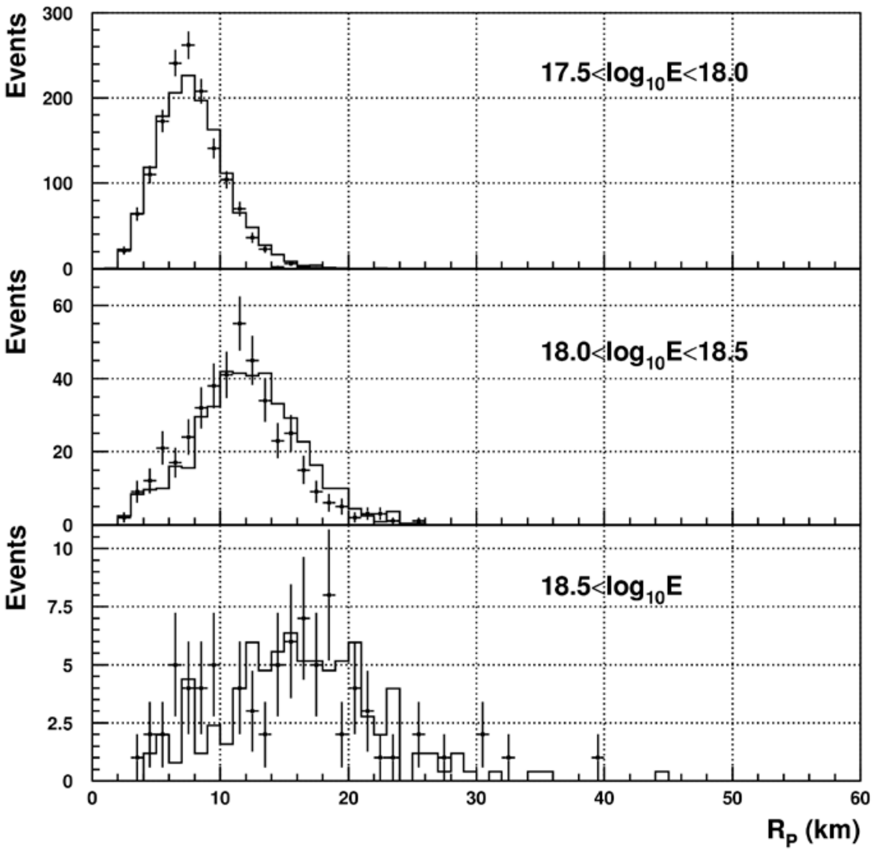


- Stereo
  - Reconstruct shower geometry by intersection of planes
  - Limited to area where detectors overlap
- Monocular
  - Use timing to reconstruct geometry
  - Larger energy range

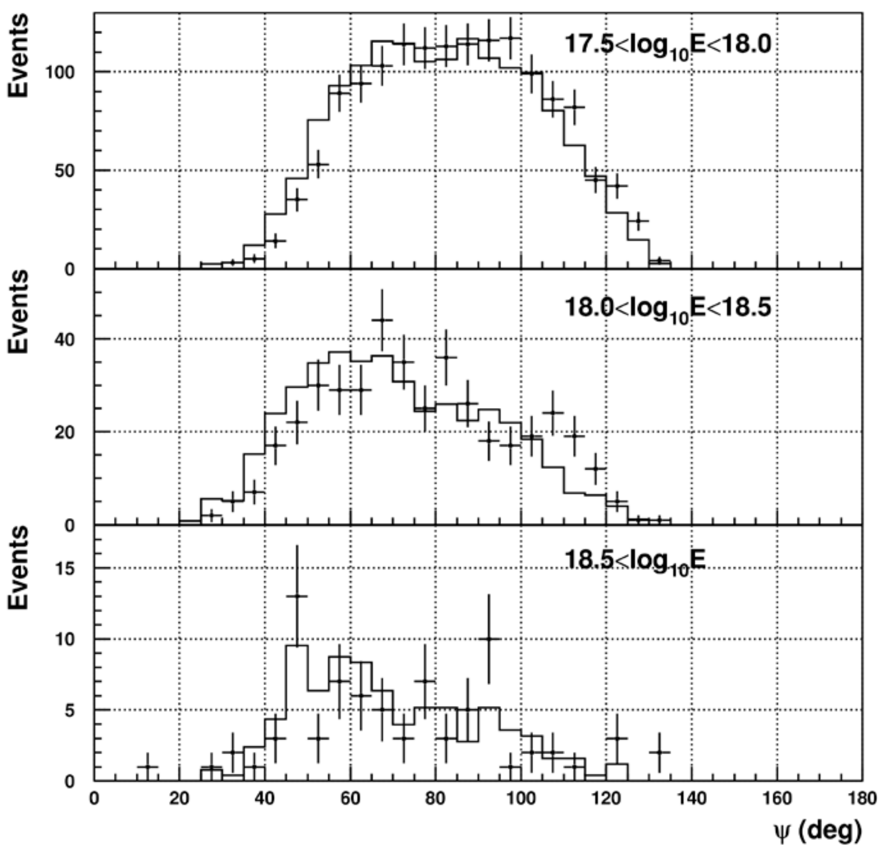


Data/MC Comparisons: Geometry

- Distance to Shower

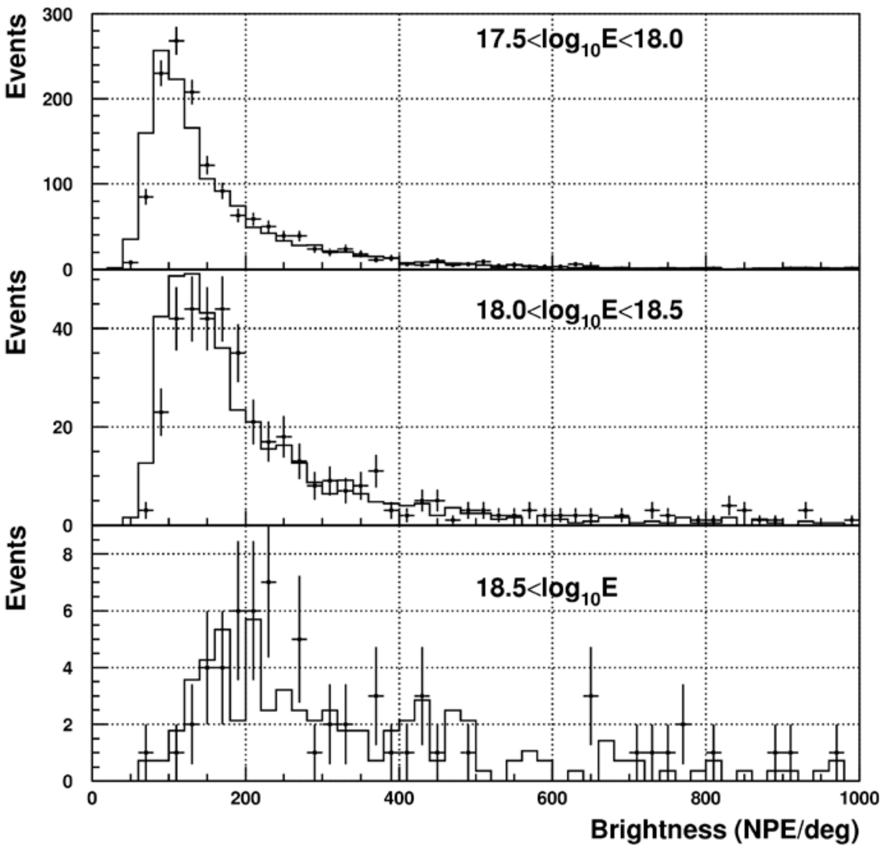


- Angle in Plane

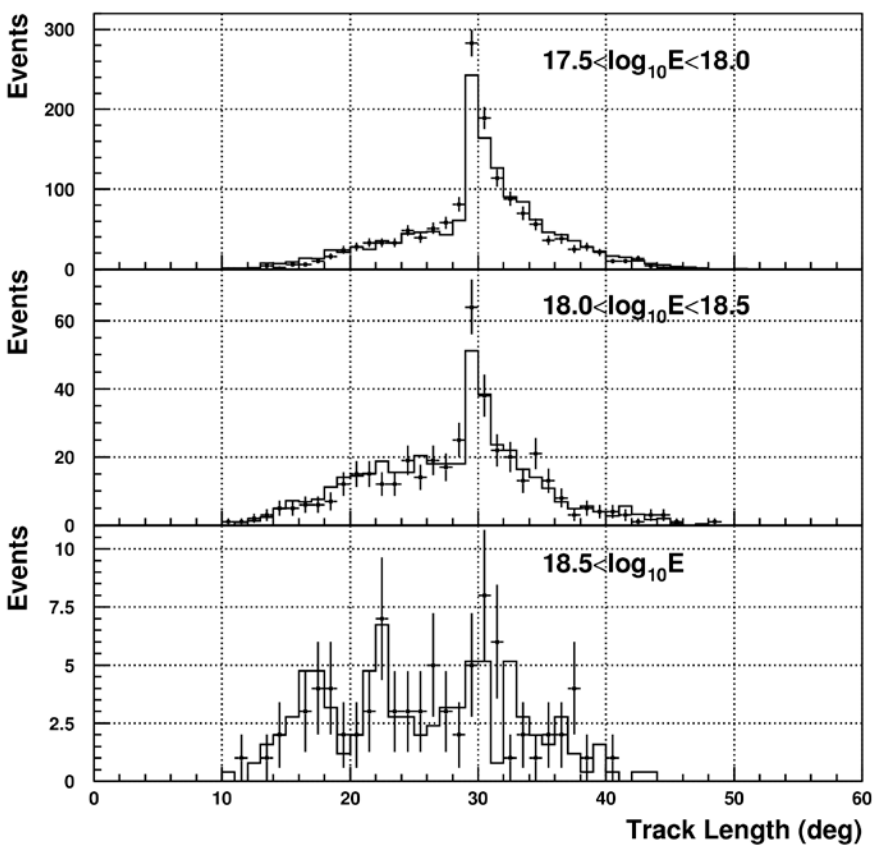


Data/MC Comparisons: Trigger

- Brightness



- Track Length



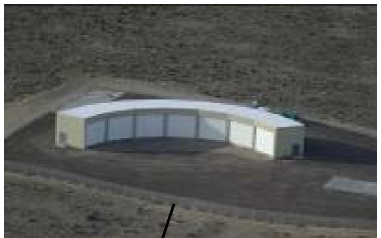
1. TA-FD
1-iv. Analysis for MD site

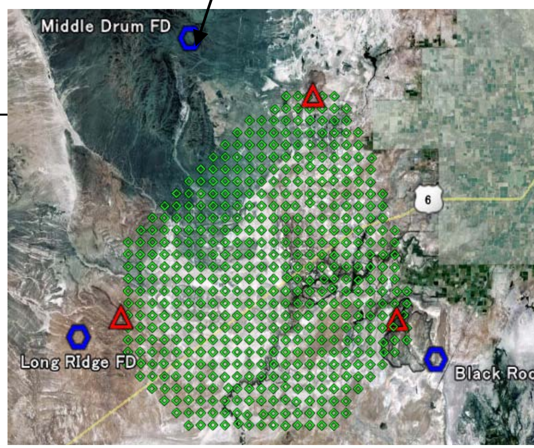
C. Jui et al., 1380, 31st ICRC

Middle Drum FD

From HiRes

Middle Drum





14 cameras/station
256 PMTs/camera

5.2 m²

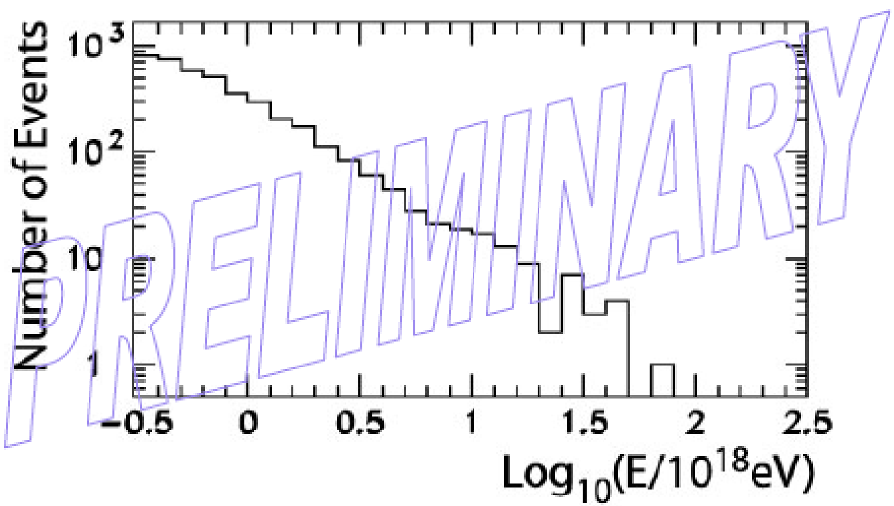
- Refurbished telescopes
- Sample-Hold elec.: 5.6us gate
- Turn on Nov. 2007
- Comparison of
  - ✓ MD ⇔ HiRes (*i.e.* TA ⇔ HiRes)
  - ✓ MD ⇔ BRM, LR (stereo events)
  - ✓ MD ⇔ BRM, LR (central laser shot)
  - ✓ MD ⇔ SD (hybrid events)

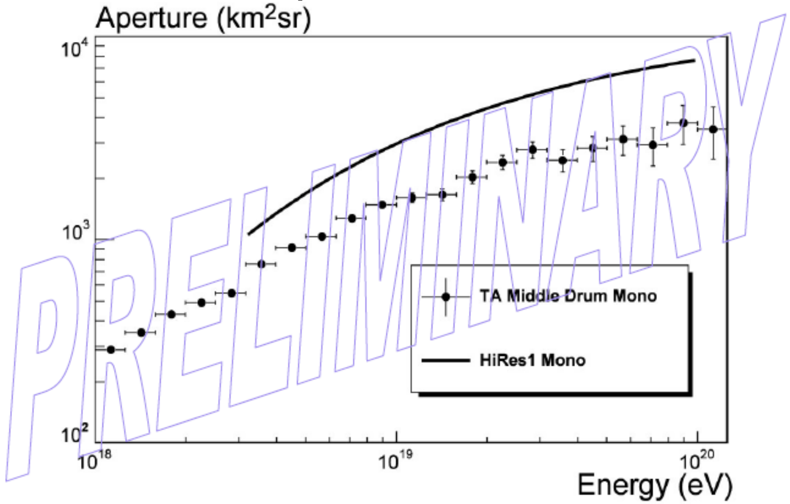
MD mono data set: MD 1st year on-time

- High energy aperture (> 10^{19} eV) ~ 1/2 HiRes-1
  - ✓ **Two ring configuration gives larger aperture than 1/3 HiRes-1**
  - ✓ **One year for running ~ 1/10 of HiRes-1 exposure @ 10^{19}eV**
  - ✓ **HiRes-1 exposure ~ 5 AGASA**
  - ✓ **One year of TA-MD ~ 1/2 AGASA**
- This data set is not quite big enough for GZK test !!
- MD integrated "mirror-hours" (14 mirrors)

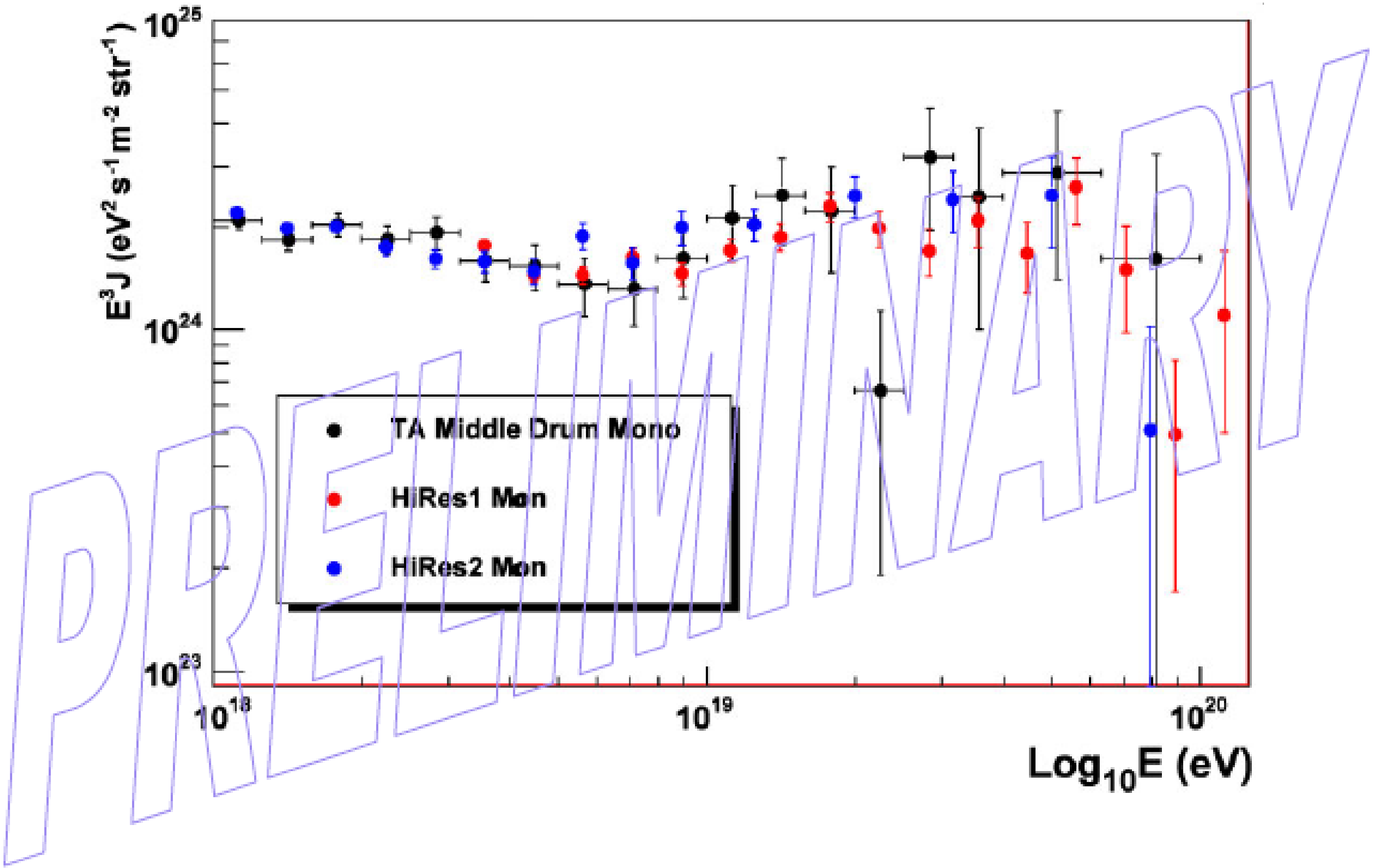
Dec. 16, 2007 – Dec. 07, 2008: ~ 13500 (= 964 hrs = 11%)

good weather: ~ 11000 (= 786 hrs = 9%)





TA-MD spectrum

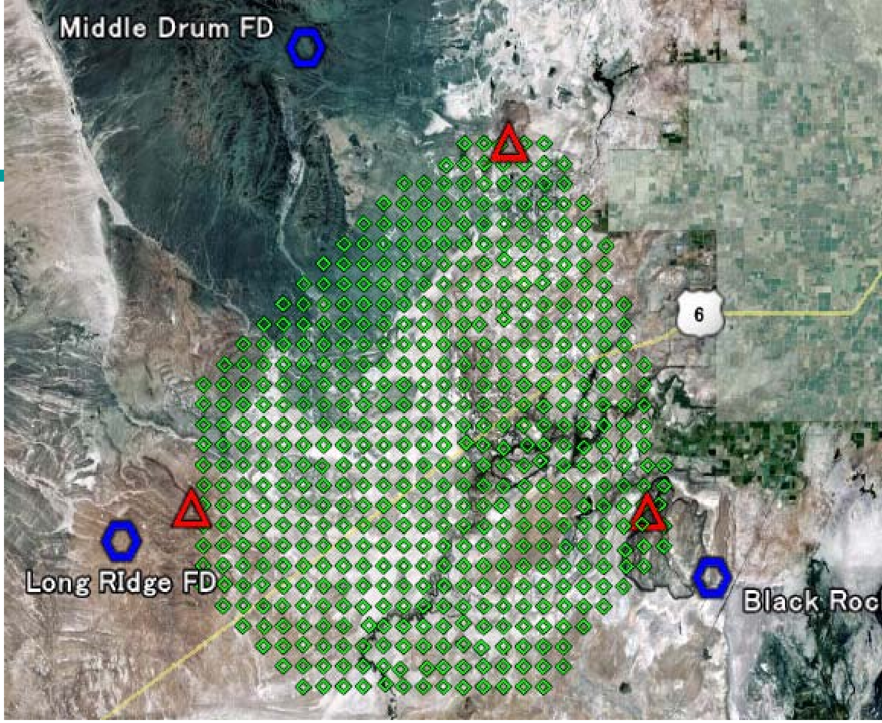


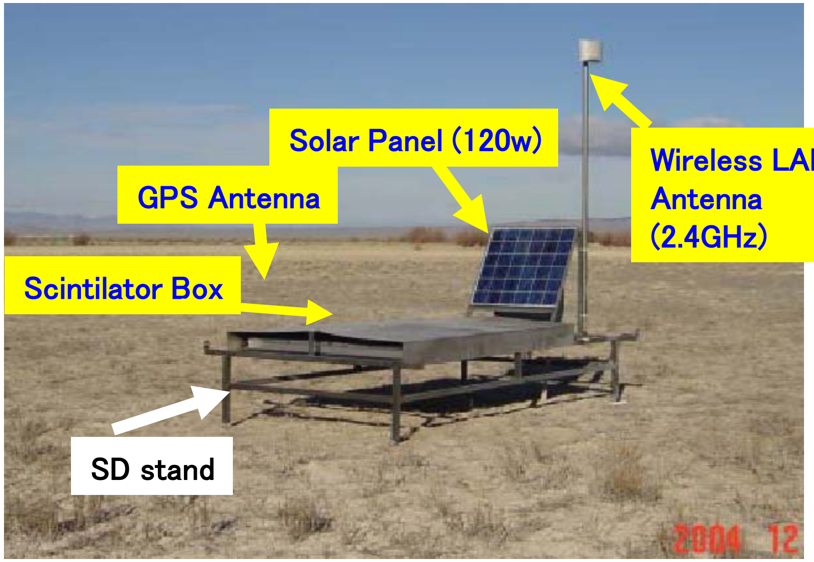
2. TA-SD
2-i. Performance, Calibration

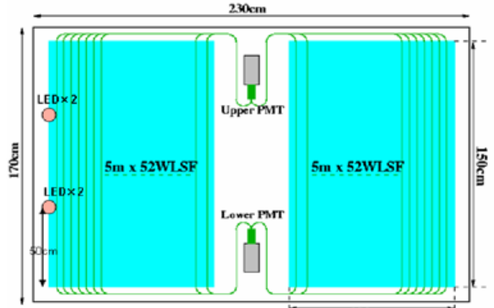
T. Nonaka et al., 974, 31st ICRC

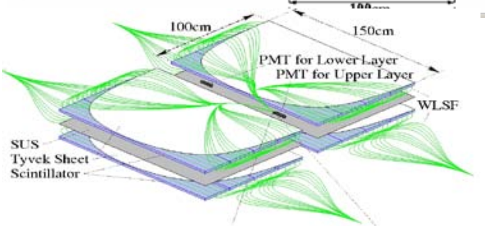
Surface Detectors

- Solar cell+ Battery
- Wireless LAN (2.4GHz) communication
- GPS 1pps pulse are common clock for SDs.
- 50Msps FADC recording



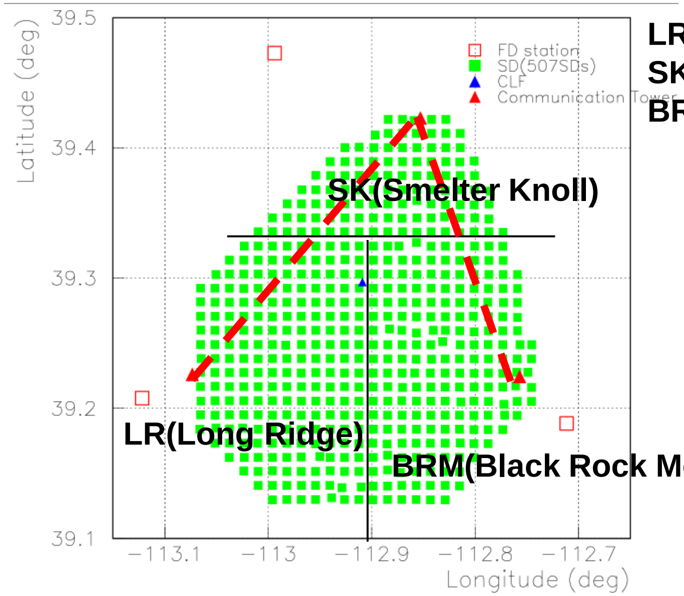




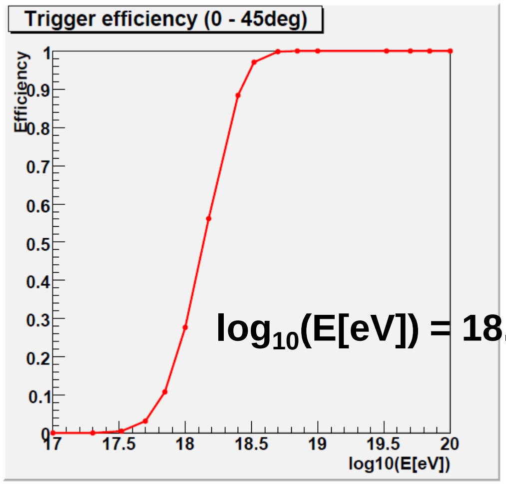


- Scintillator : 2layer of 3m^2 × 1.2cm (t)
- WLF read out of scintillation light
- PMT: 2× “ETL 9124SA”
- Power Base: 2× “ETL PS1806-2”
- Temperature /Humidity sensors.

Triggers



LR: 207SD
SK: 110SD
BRM: 190SD



$\log_{10}(E[eV]) = 18.7$ ~100%

●SD Trigger

0)Wave form recording (LV-0)
>1/3 mip signal ⇒ ~750counts/sec

1)List of large signal (LV-1)
>3 mip signal ⇒ ~20counts/sec

communication tower for array trigger

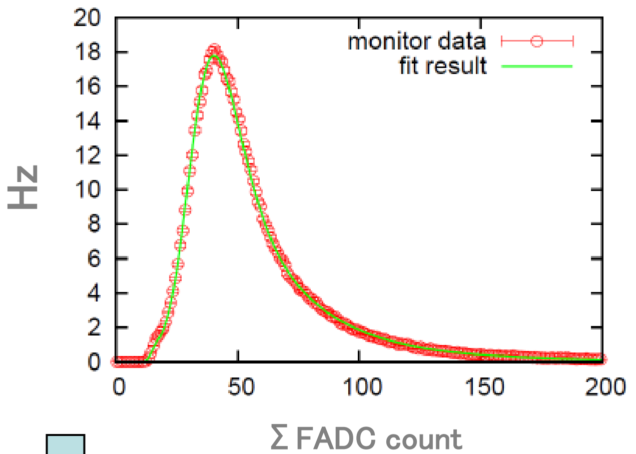
●Array Trigger：

＞3mip & 3 adjacent detectors
(coincidence in 8μsec)
（＋cross boundary trigger）

➔Wave forms >0.3mip, ±32μsec

➡ **~ 20 triggers/hr**

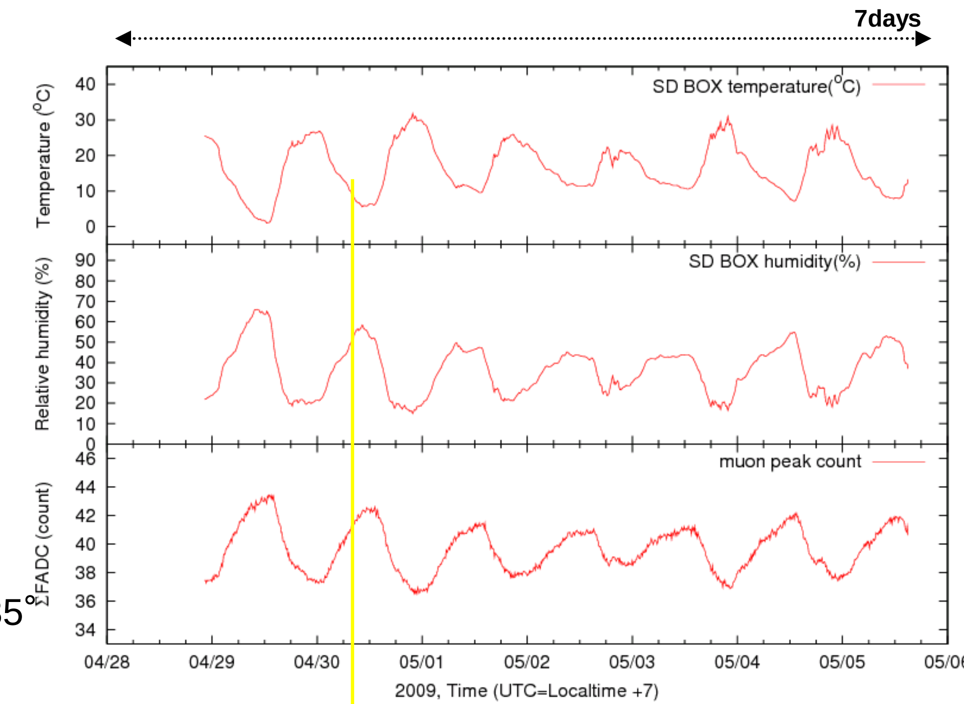
Muon peak monitoring



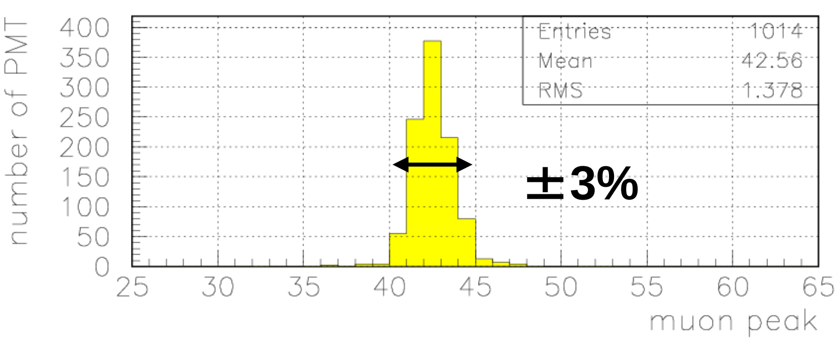
Monitored distribution (FADC)
fit by scaled energy deposit

Peak ～2.4MeV

1VEM ～ 2.03 MeV cos35°



2009/04/30 13:00-13:10 (UTC)



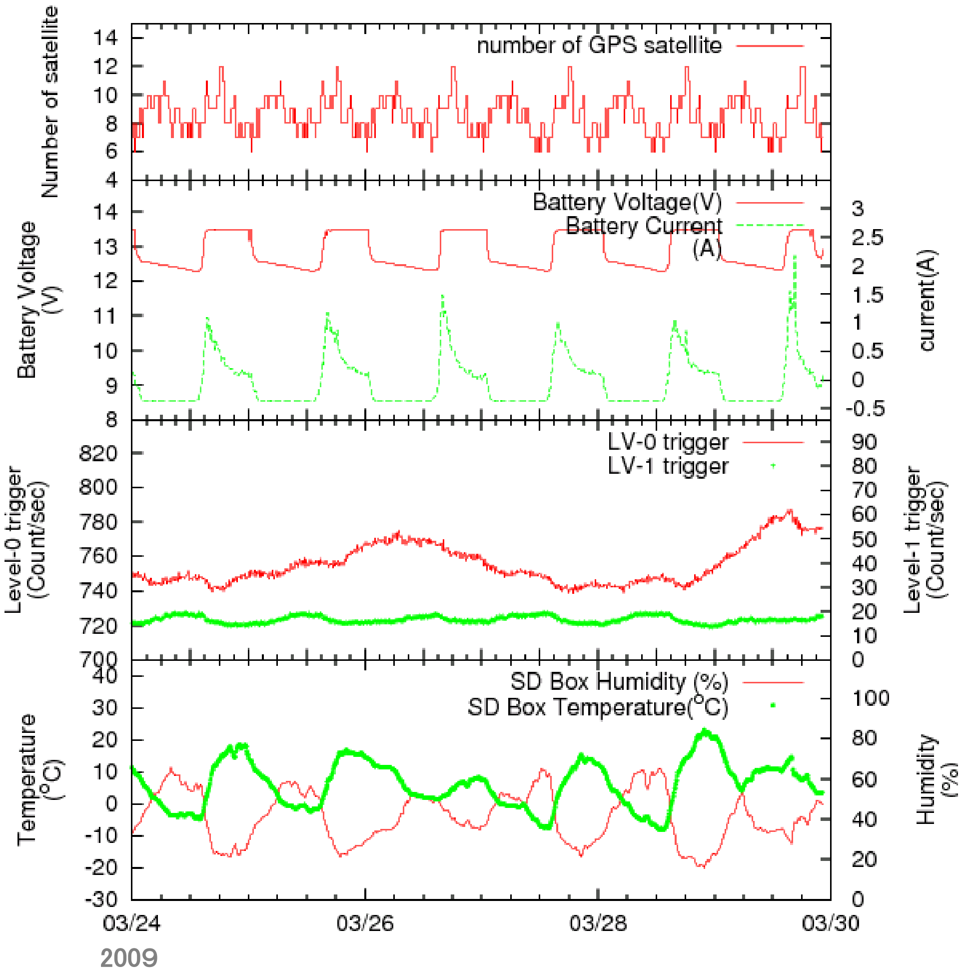
Temperature coefficient: ～ -0.8%/℃

(PMT –0.3% ,Fiber+Scinti –0.5%)

Variation of detector gain is tracked every 10 minutes

Detector status monitoring

Other diagnostic information → Provides detailed information for maintenances



Number of GPS satellites

Charging status
Battery voltage(V), Charging current(A)

Detector trigger rate
LV-0 (>~0.3mip), LV-1（>~3mip)

SD box humidity, temperature
Humidity(%), Temperature（℃)

Other : electronics board temperature, solar panel voltage, GPS antenna continuity, low voltages on electronics

2. TA-SD
2-ii. Observations

T. Nonaka et al., 974, 31st ICRC

Observation summary

2004-2006 : Mass production, Assembly of detector

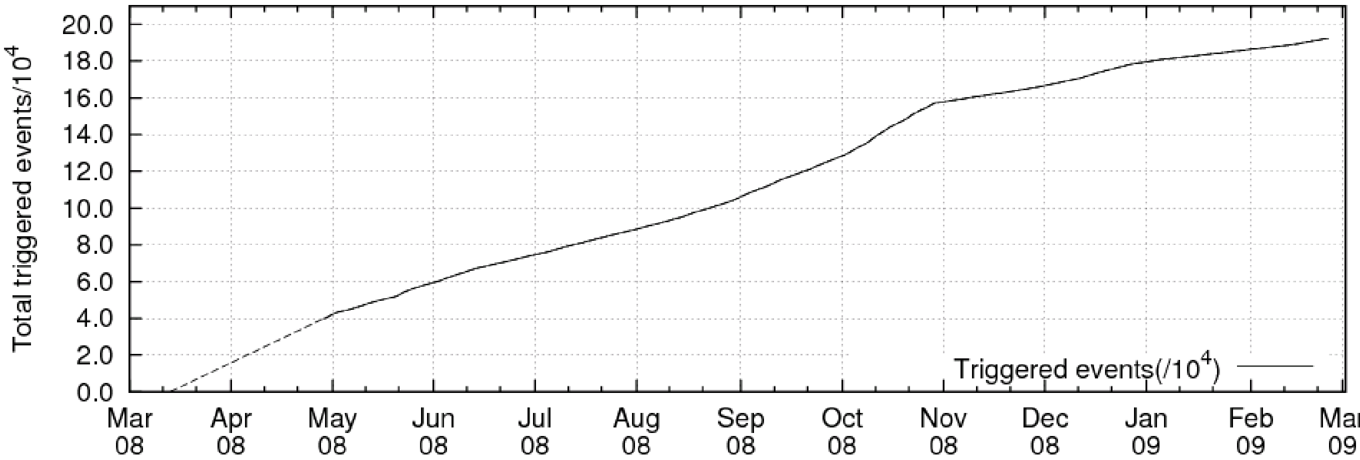
Oct.2006 : Deployment - (Feb.2007)

Jun.2007 : Observation with three small array.

(Tuning, Long distance communication)

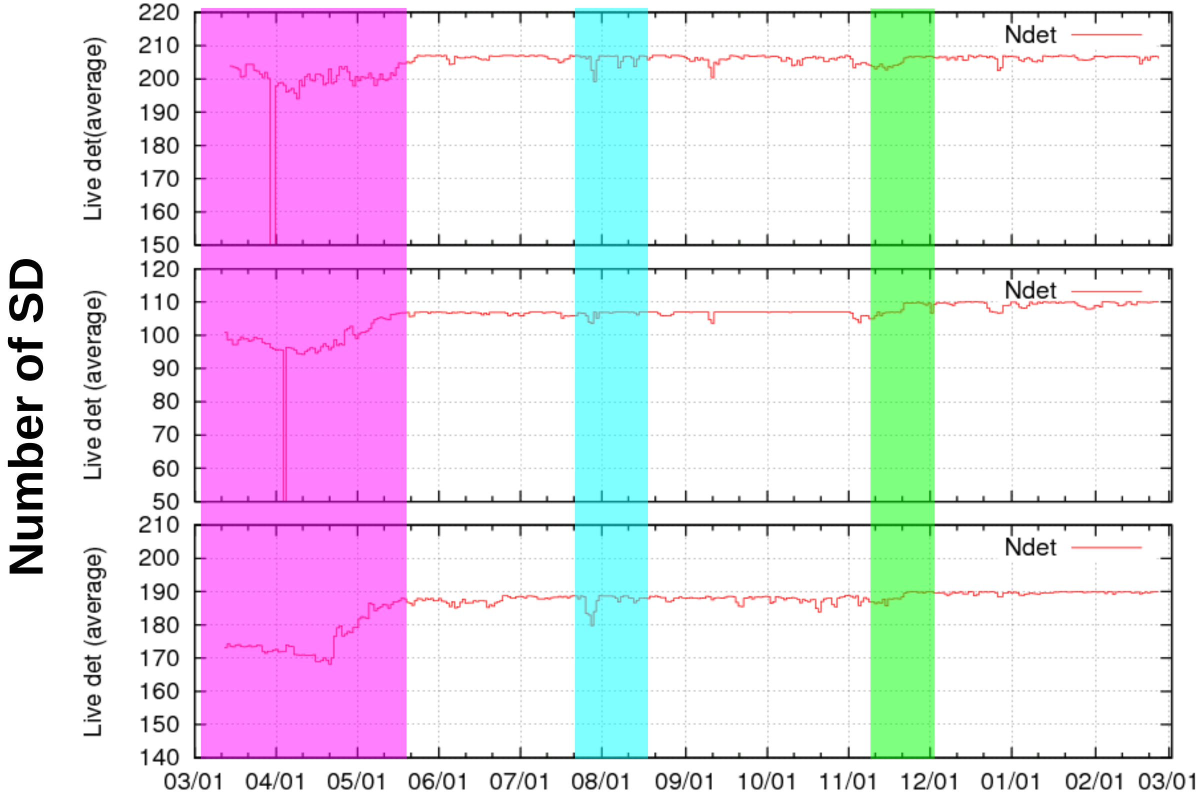
Mar.2008 : Start full operation

Nov.2008 : Cross boundary trigger



Running status

Available SDs：(∝communication status)



(05/17~)

Running time

LR:97%

SK:96%

BR:97%

Available SD：

>98%

2008

Tuning of antennas
Gain adjustment

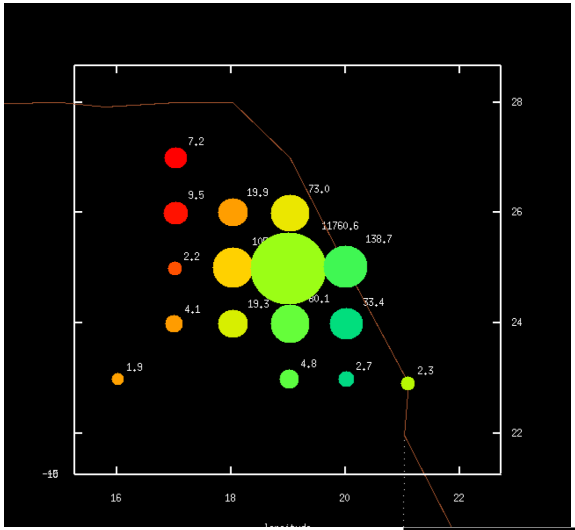
Bad weather

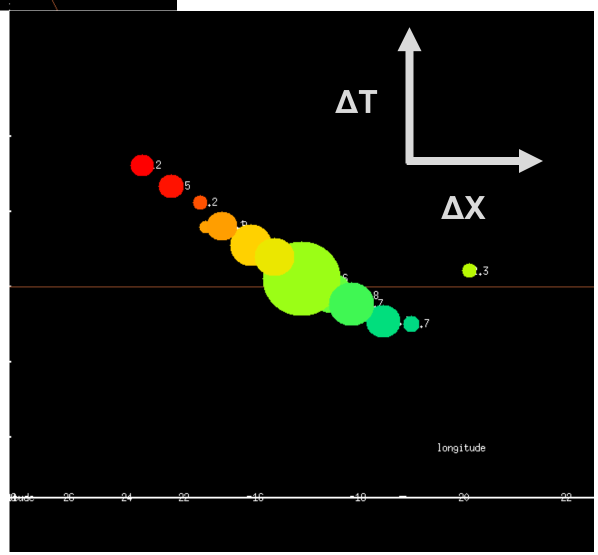
2009

+ repair of SD
Install of boundary trigger system

Recorded wave form example

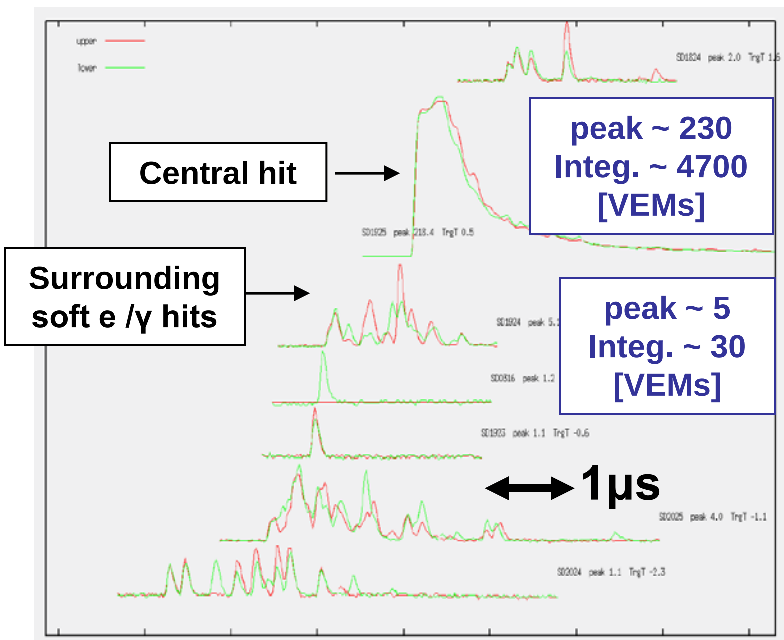
090301-135836





number = MeV energy deposit (av U+D)
~ 2.5 MeV for vertical mu

upper layer
lower layer

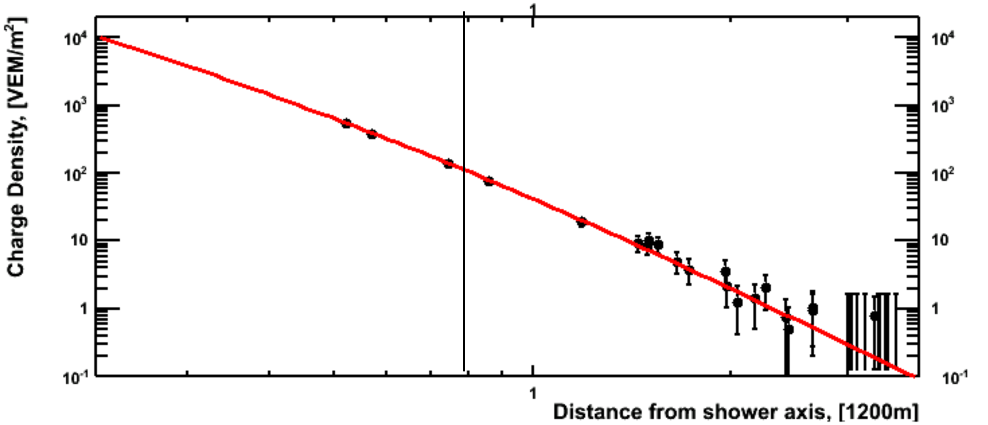


2. TA-SD
2-iii. S(800) distribution

- Lateral Distribution Function…..Japan
- $\boxed{\text{S(800)…..US}}$

A. Taketa, M. Fukushima, E. Kido, B. T. Stokes,
D. Ivanov et al., 855, 31st ICRC

Lateral Distribution Function(LDF) Fitting



r = 800m

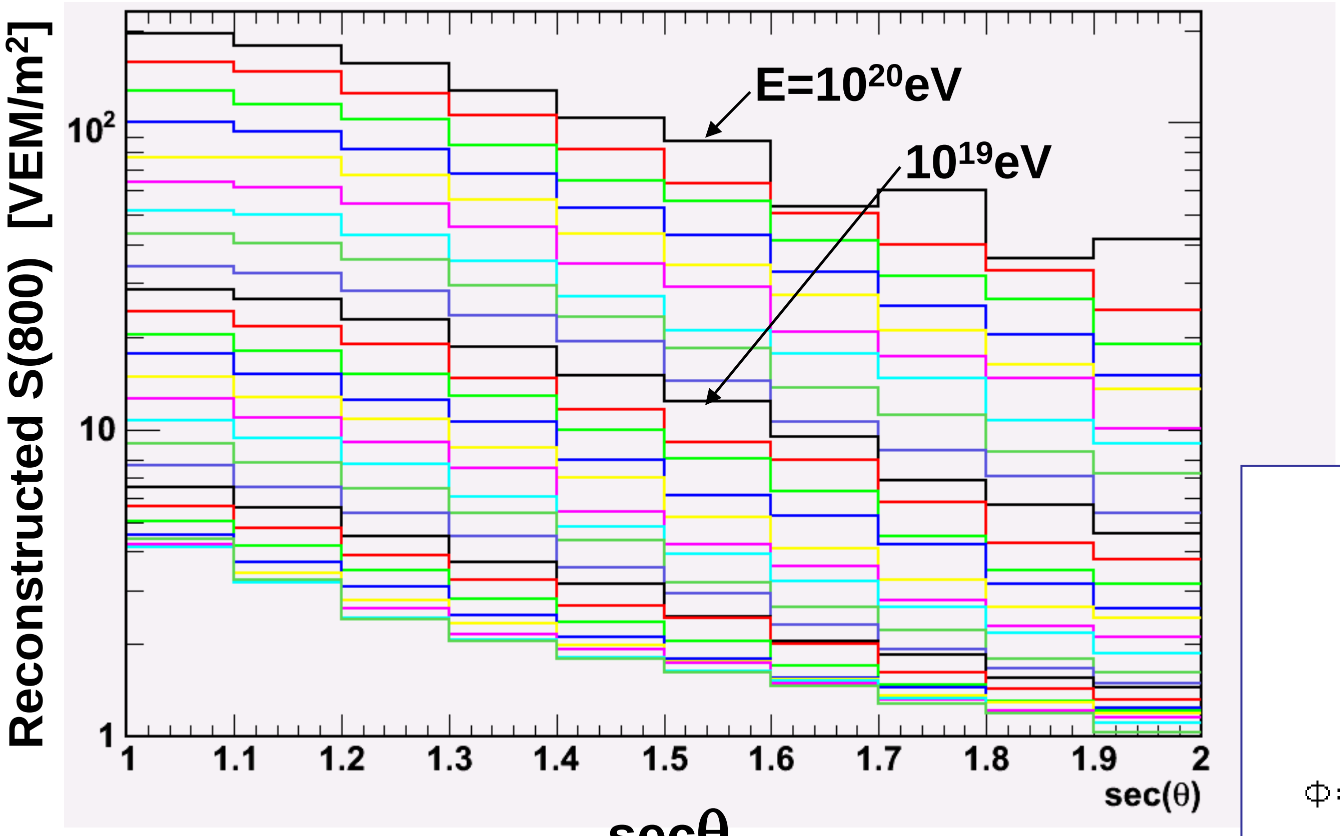
Fit with AGASA LDF

$$\rho(r) \propto \left(\frac{r}{R_M}\right)^{-1.2}\left(1+\frac{r}{R_M}\right)^{-(\eta-1.2)}\left\{1+\left(\frac{r}{1000}\right)^2\right\}^{-0.6}$$

$$\eta = (3.97 \pm 0.13) - (1.79 \pm 0.62)(\sec\theta - 1)$$

- **S(800) ⟶ Primary Energy**
- **Zenith attenuation by MC (not by CIC).**

Zenith attenuation of S(800)

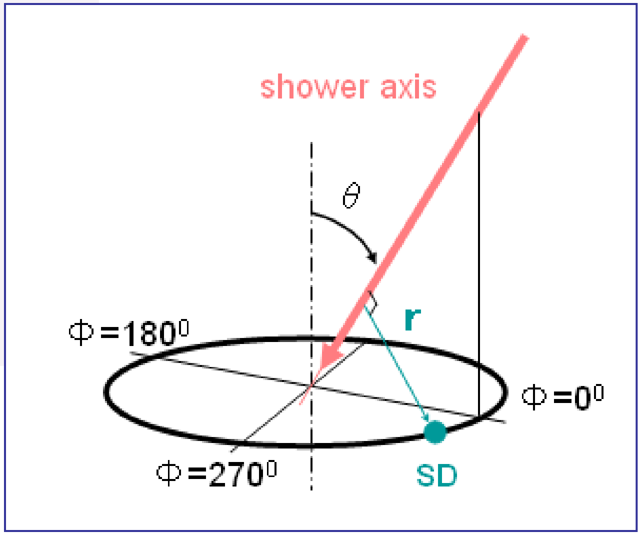


secθ

VEM = 2.05 MeV

dt-Corsika,

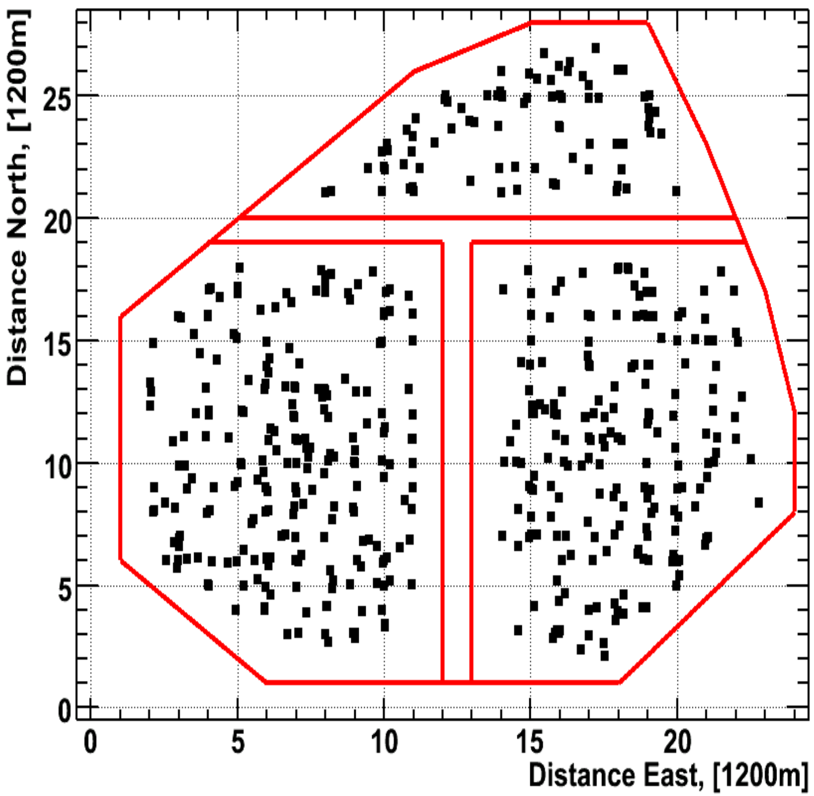
averaged over ϕ



Data Set, Core location

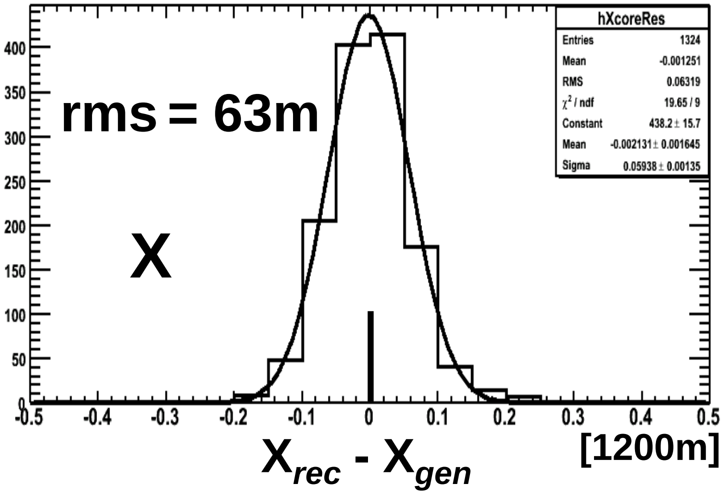
- May 11 - Nov. 10, 2008
- in 3 sub-arrays (~ 680 km^2 sr)
- ~ 1.0 x 10^{16} m^2 sr sec
- Good hits in time and space cluster.
- Number of hit SDs > 3
- $\chi^2 / N_{dof} < 4$
- Core : min. 1200m from array boarder
- $\theta < 45^0$
- Pointing resolution < 5^0
- S800 uncertainty < 25%

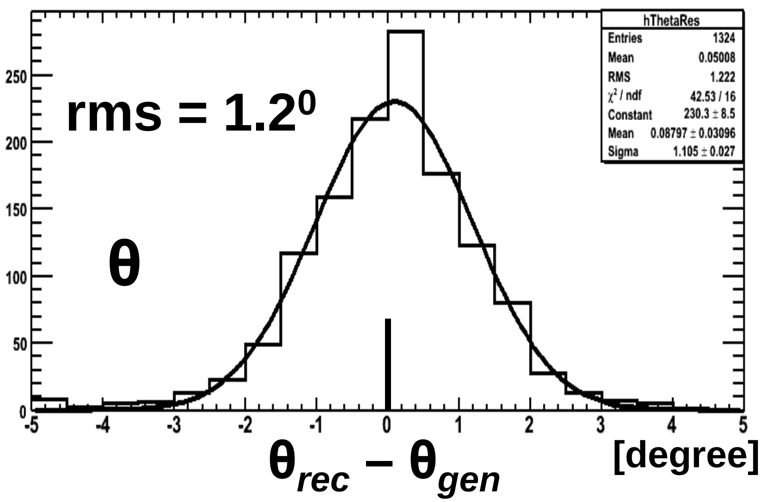
 # Event = 489
for
E > $10^{18.8}$ eV

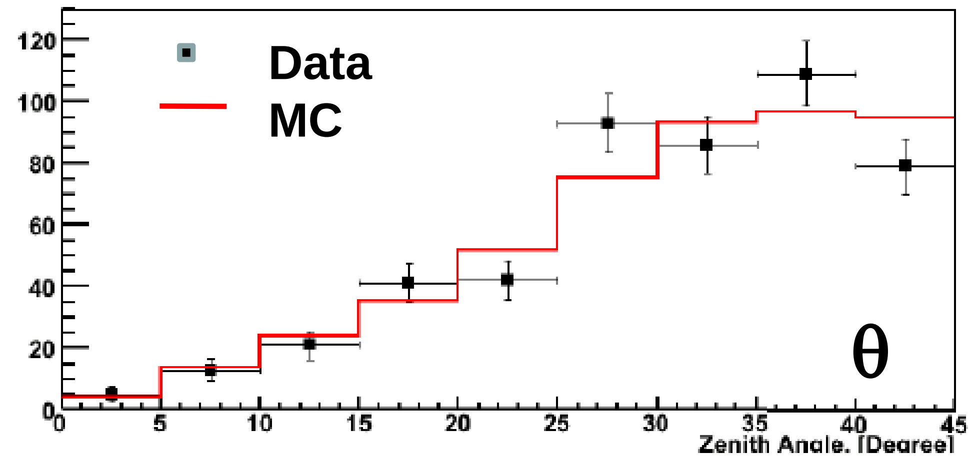


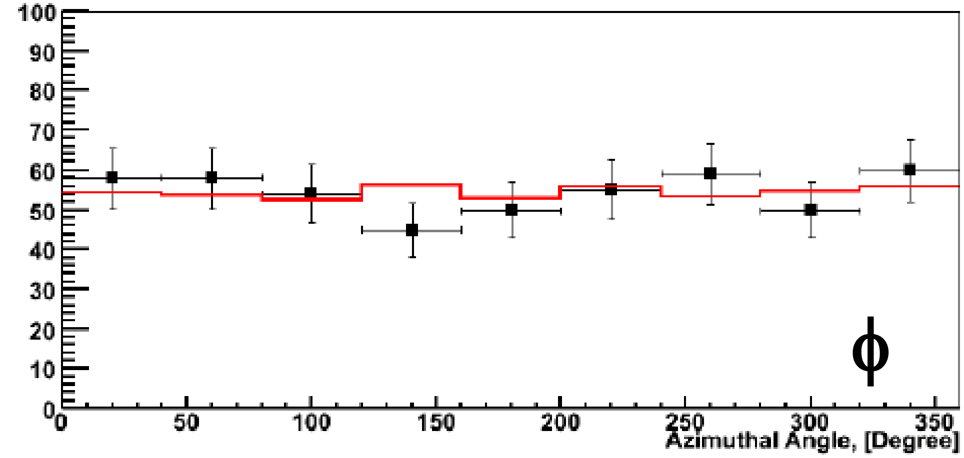
Reconstruction Accuracy: Geometry

MC by dt-Corsika

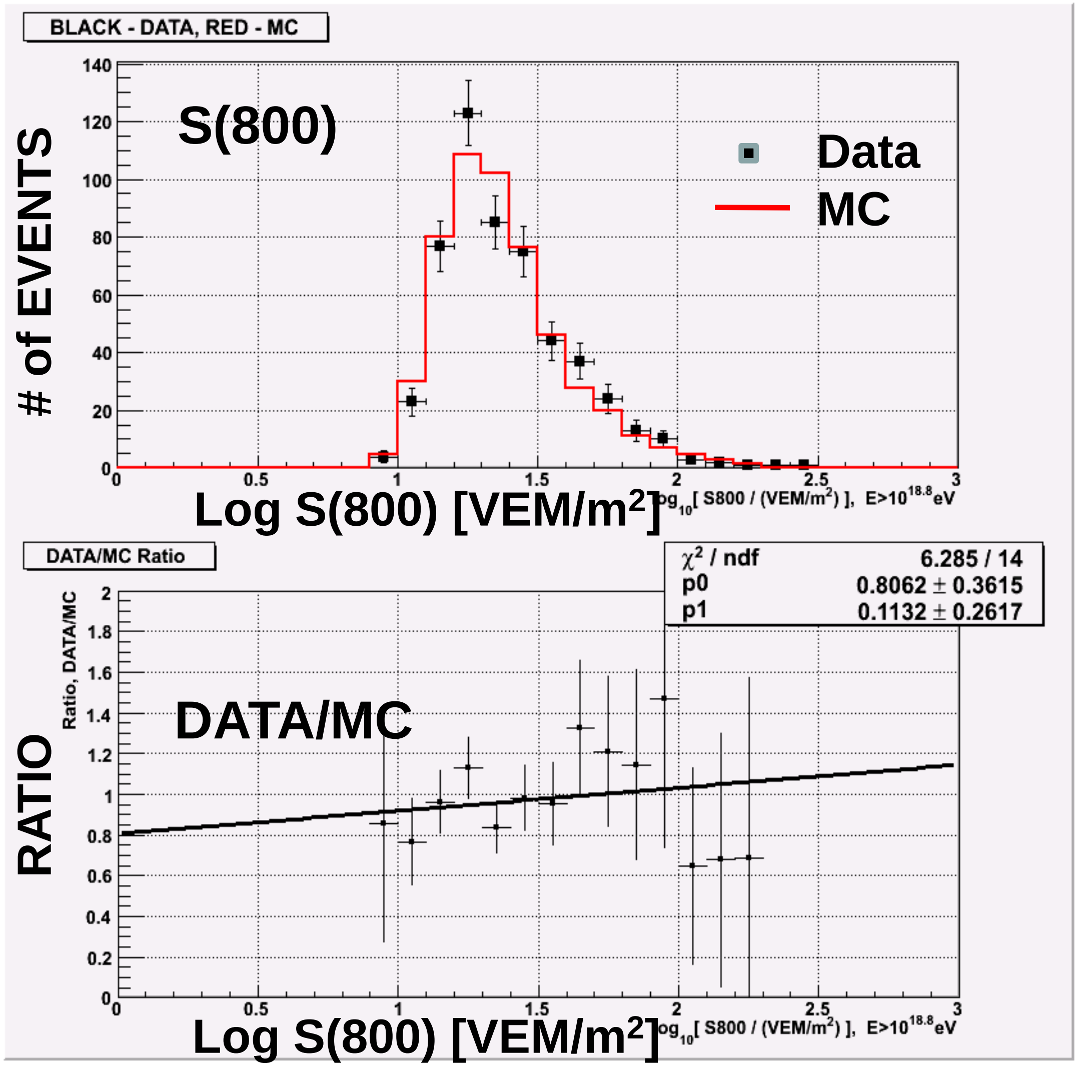








S(800) distribution



MC spectrum:

- $E^{-2.81}$ above ankle
  $E^{-3.25}$ below ankle
- ankle @ $10^{18.65}$ eV
- QGSJET2, proton
  dt-Corsika
- # event norm. to data

Data:

- May – Nov., 2008
- ~1.0×10^{16} m^2 sr s

2. TA-SD
2-iv. Arrival Direction Analysis

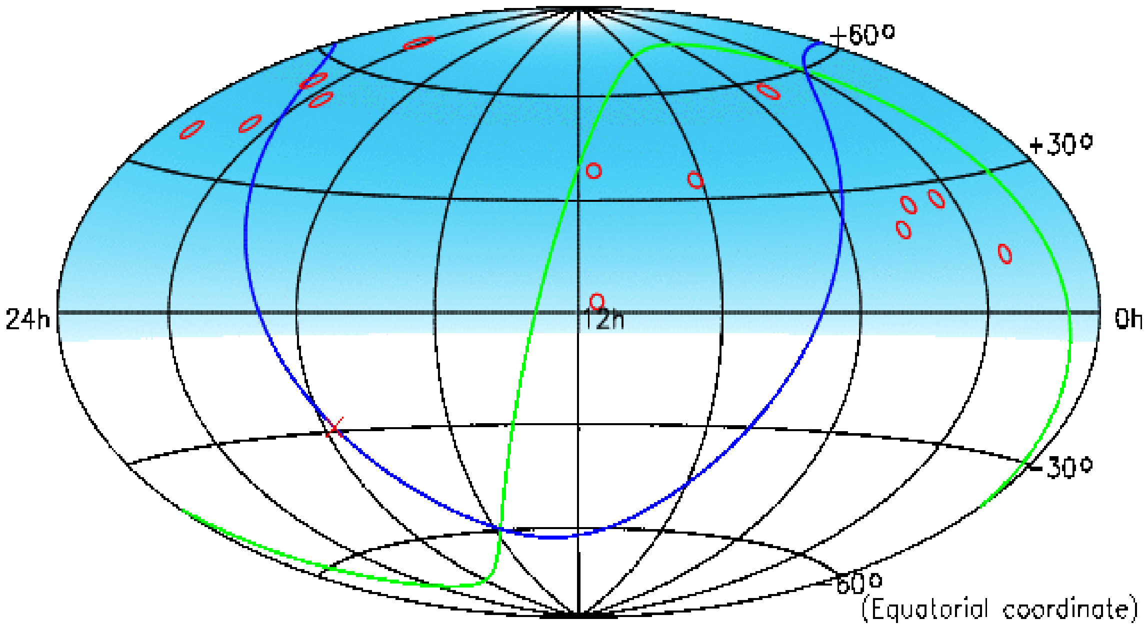
N. Sakurai et al., 709, 31st ICRC
I. Tkachev, P. Tinyakov et al., 714, 31st ICRC

Skymap (log E > 19.5)

Equatorial coordinate

May 11 2008 → Nov. 30 2008 (204days)

Zenith < 45deg.



…search correlation with candidate sources (AGN, BL Lac)

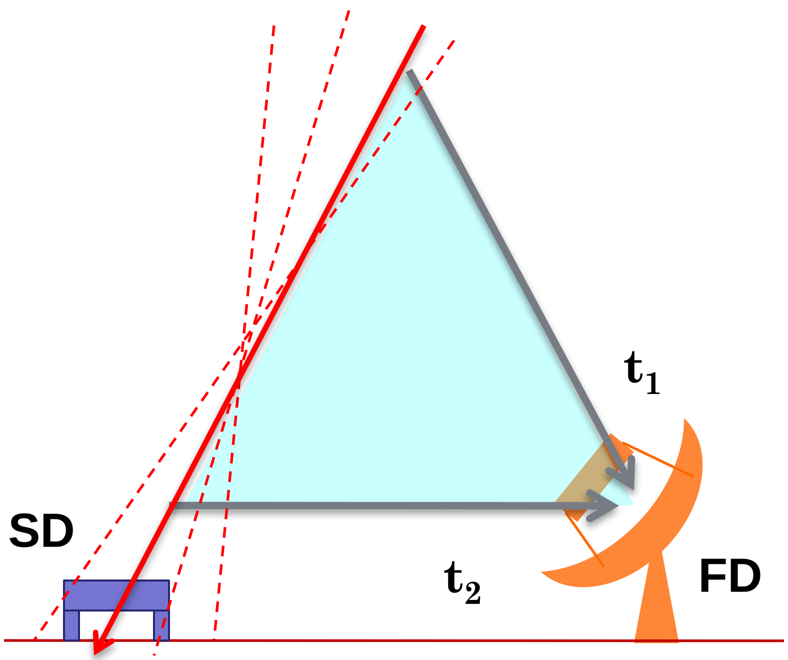
13 events are plotted.

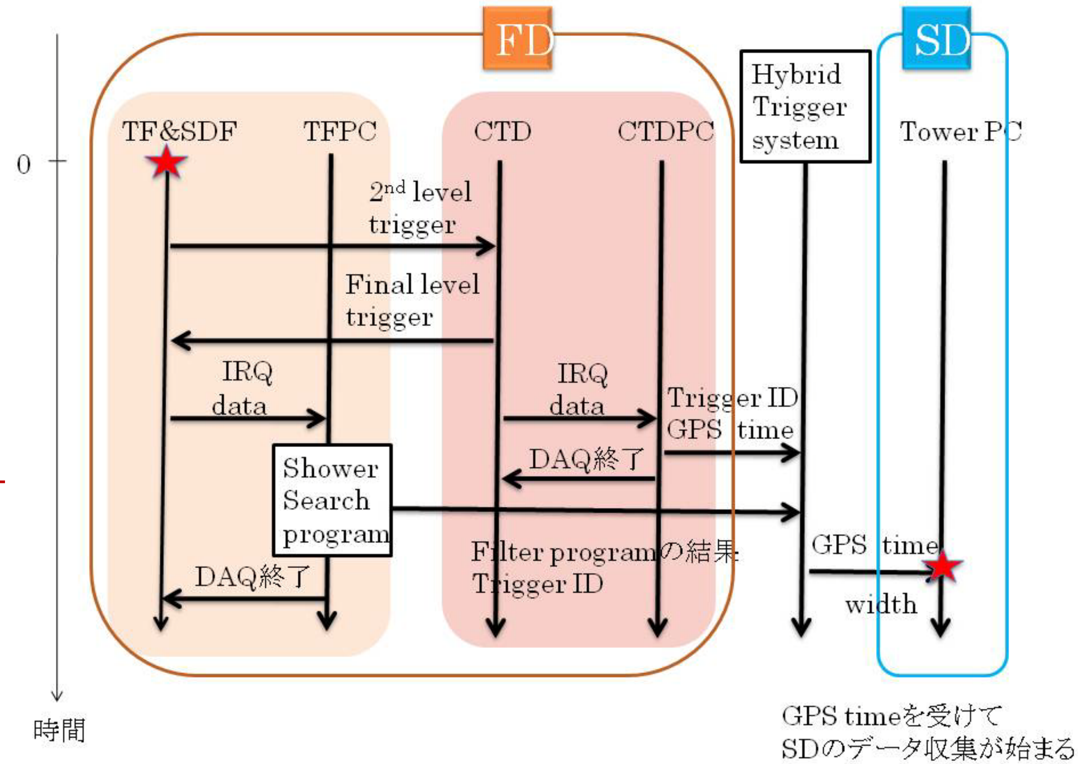
Cluster candidate ($\Delta\theta$< 2.0°) : 0 pairs

Expected # of clusters for random distribution : 0. ~ 0.3

3. Near Future Plan

Hybrid Trigger (FD triggers SD array)

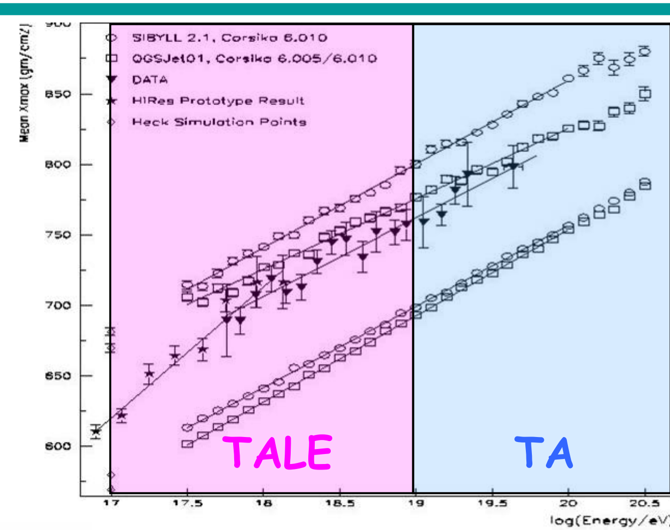


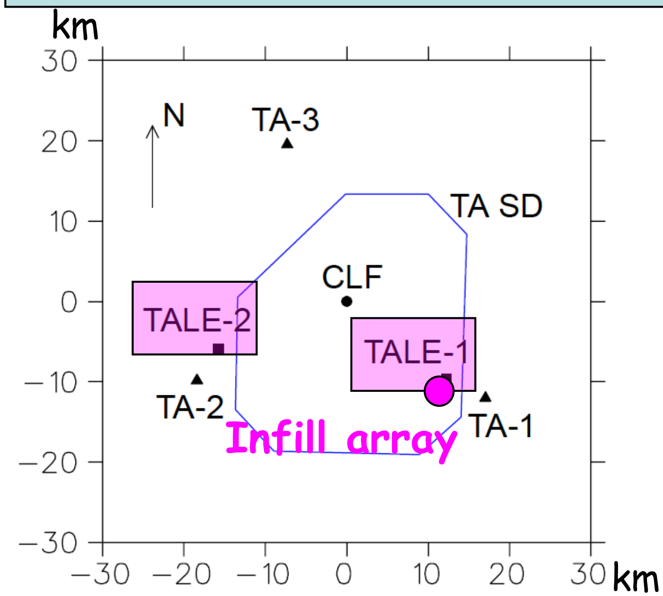


TA Low energy Extension (TALE)

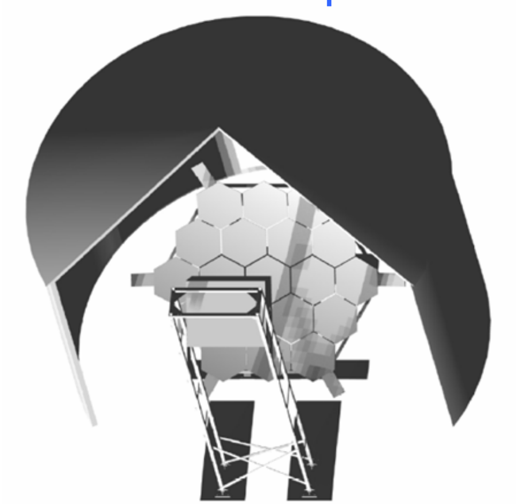
Hybrid observation of CR > 10^{17}eV

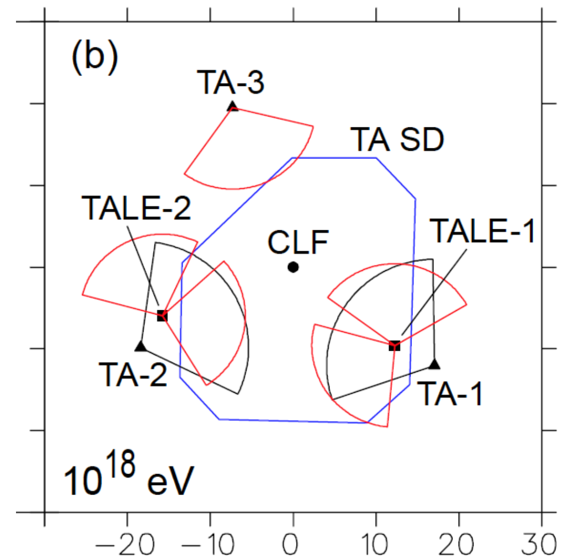
- ーHiRes II
- ーNewly Developed Telescopes for higher elev.
- ーInfill scintillation detectors (400 m spacing)
- ーTA type FD electronics





TALE Tower telescope





TALE station ⇔ TA station ~ 6 km

Summary

- ◆ In spring 2010　TA exposure will reach 1 x AGASA

- ◆Comparing MC programs
  - ✓CORSIKA de-thinning
  - ✓COSMOS
- ◆Test event reconstruction codes
  - ✓SD: S(800), Lateral Distribution Function
  - ✓FD: Inverse MC, Monocular, Stereo, etc.

- ◆Evaluate systematic errors
  - ✓Hadron Interaction, Composition, Reconstruction…
  - ✓ Atmosphere….
- ◆Check energy scale with SD/FD hybrid events
- ◆Improve calibrations

- ◆Near future
  - ✓Hybrid trigger　- for Mono-FD
  - ✓TA Low energy Extension