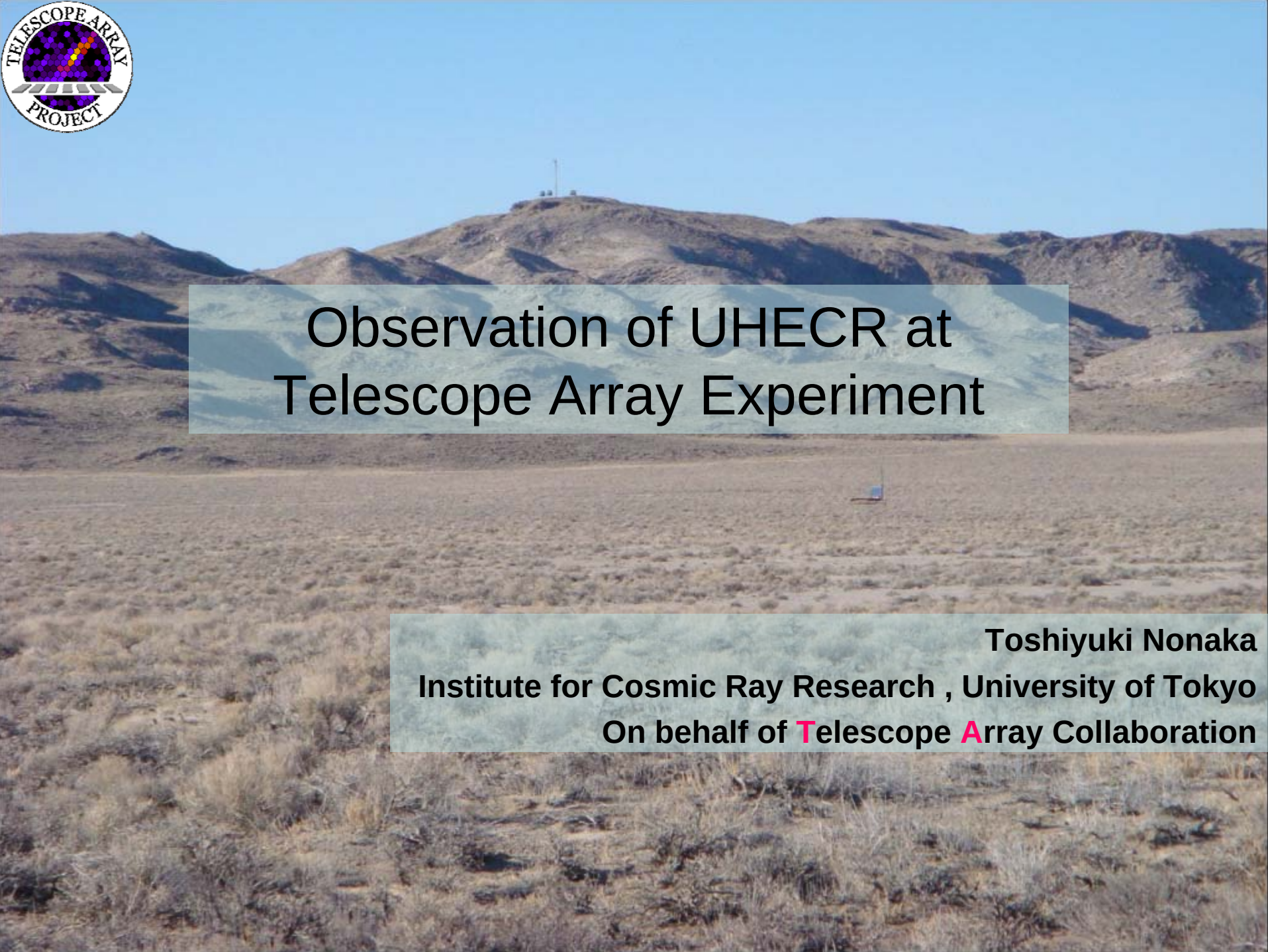


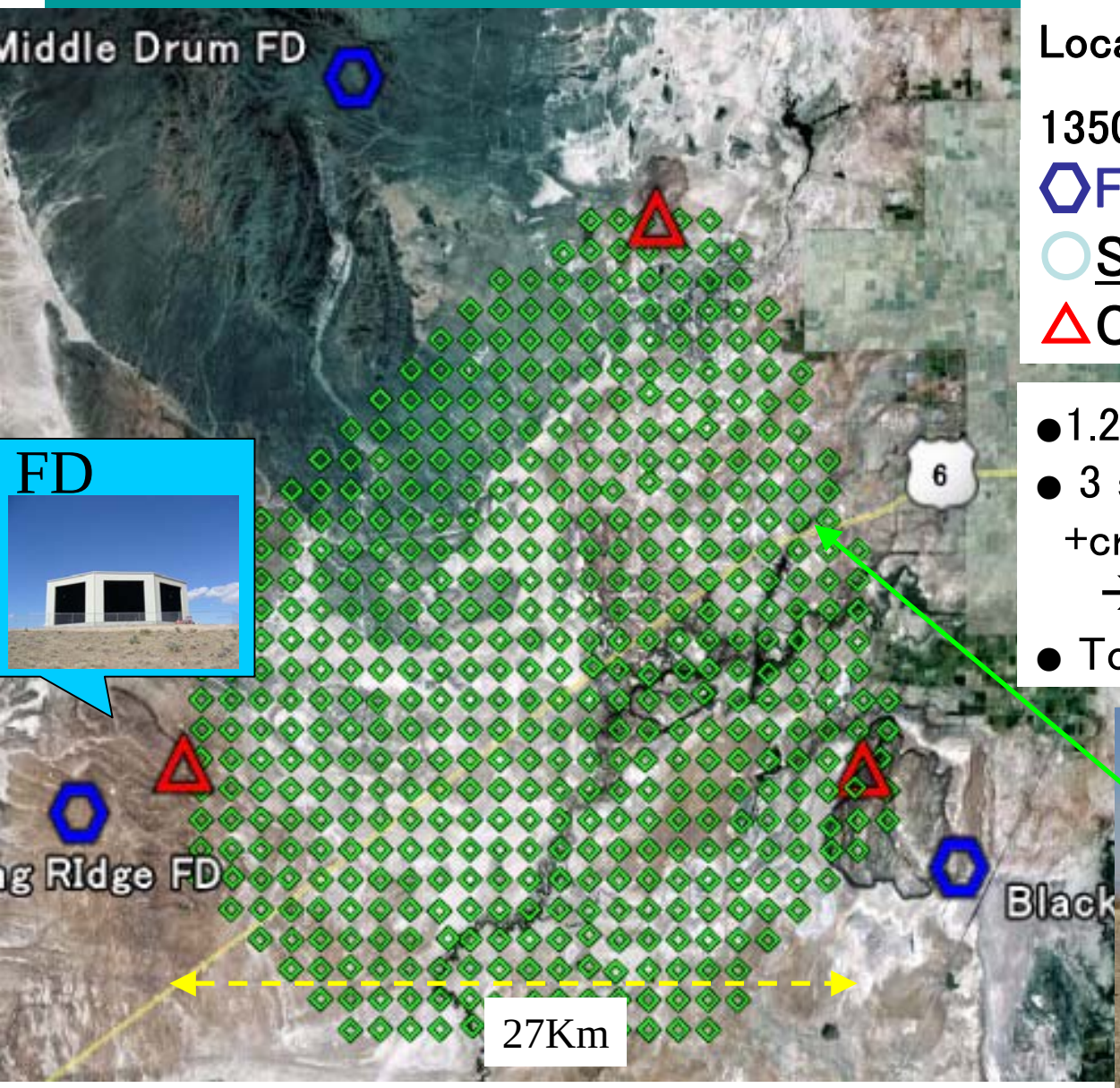
Observation of UHECR at Telescope Array Experiment

Toshiyuki Nonaka

Institute for Cosmic Ray Research , University of Tokyo

On behalf of Telescope Array Collaboration

Telescope Array Experiment



Location: N39.3° W112.9°

1350–1500m asl

⬡FD station (× 3station)

○Surface Array (507 SD)

△Communication tower

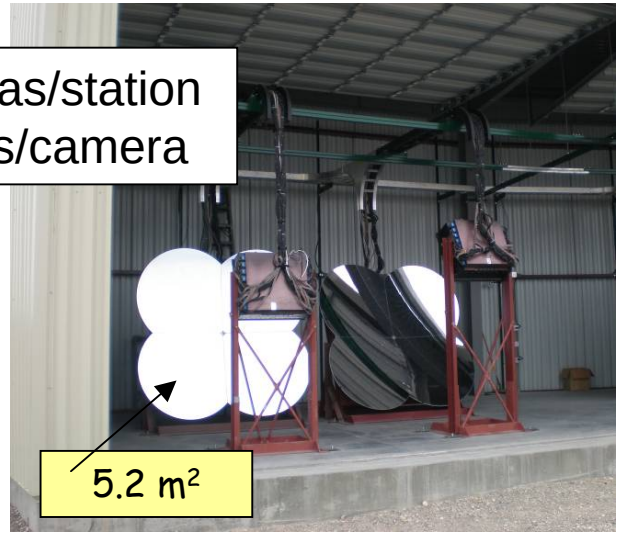
- 1.2 km grid SD (3m^2)
- 3 sub array :
  +cross boundary trigger
  →Total 507 SD
- Total detection area ～700km^2

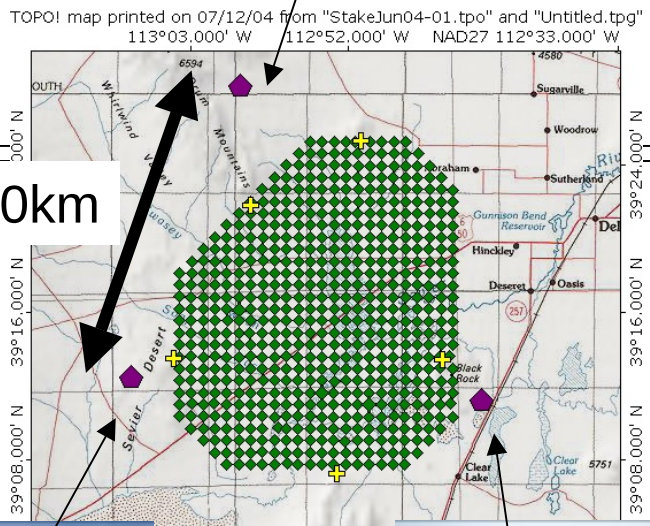
TA-FD

From HiRes

Middle Drum

14 cameras/station
256 PMTs/camera





~30km

New FDs

256 PMTs/camera
HAMAMATSU R9508
FOV~15x18deg
12 cameras/station

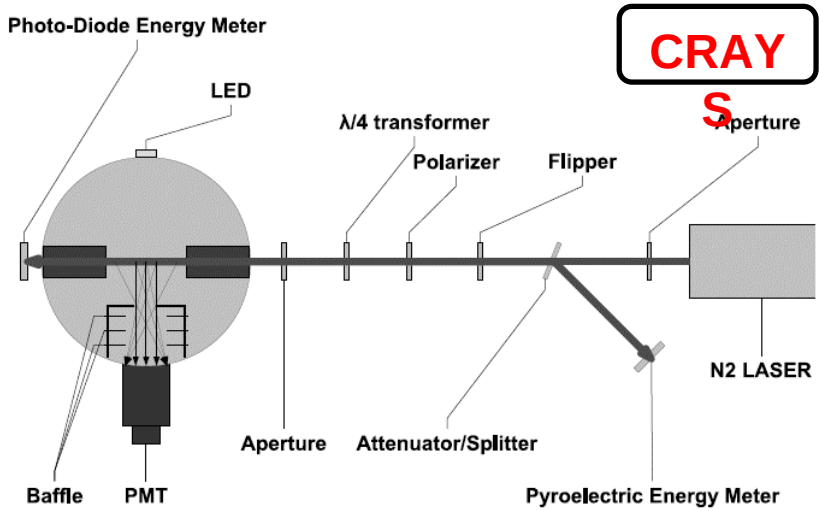
Telescope Calibration (PMT Gain)

Absolute gain: CRAYS

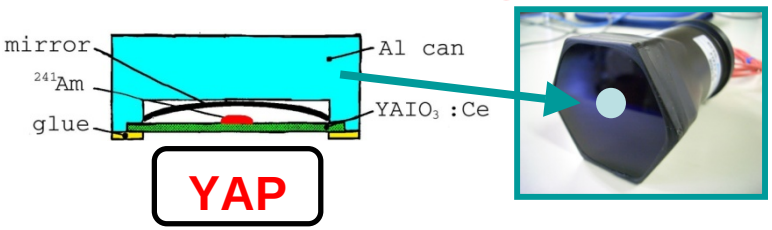
Three PMTs for each camera

Scattered Rayleigh photons
as an absolute light source

- 0.508 count / photons (337.1nm) @24degrees
- Systematic error: ~8%



YAP: Scintillator and RI
as a stable light source



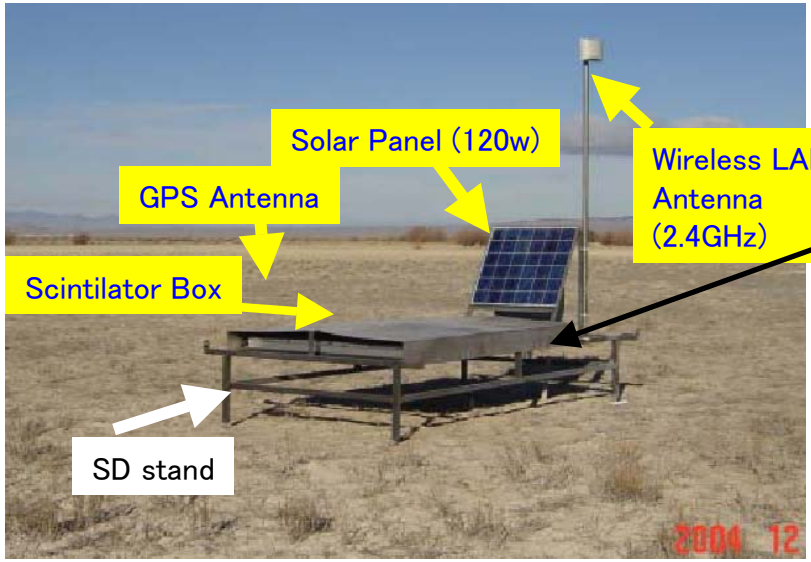
- Temperature dependence
  Measured by Incubator and LED
  ~-0.72%/degree

Relative gain: Xe flasher

Xe discharge flasher
as a uniform light source

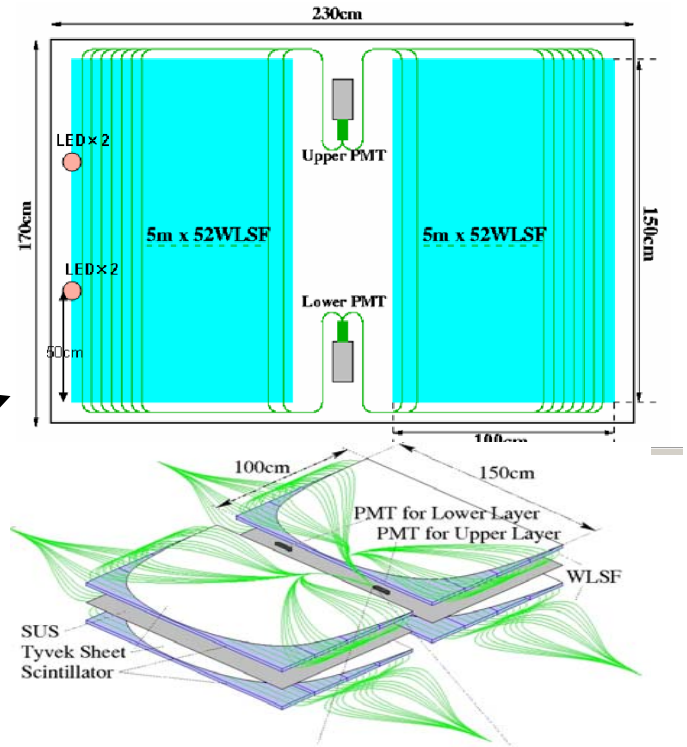
- Adjusted about 1% for all PMTs
- Monitoring in every 1hour

Telescope Array Surface Detector



- 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.



Surface Detector Calibration/Monitor

Calibration
- Muon Peak monitor (Count/MeV)
- pulse height monitor (Linearity)
- Internal clock speed (timing)

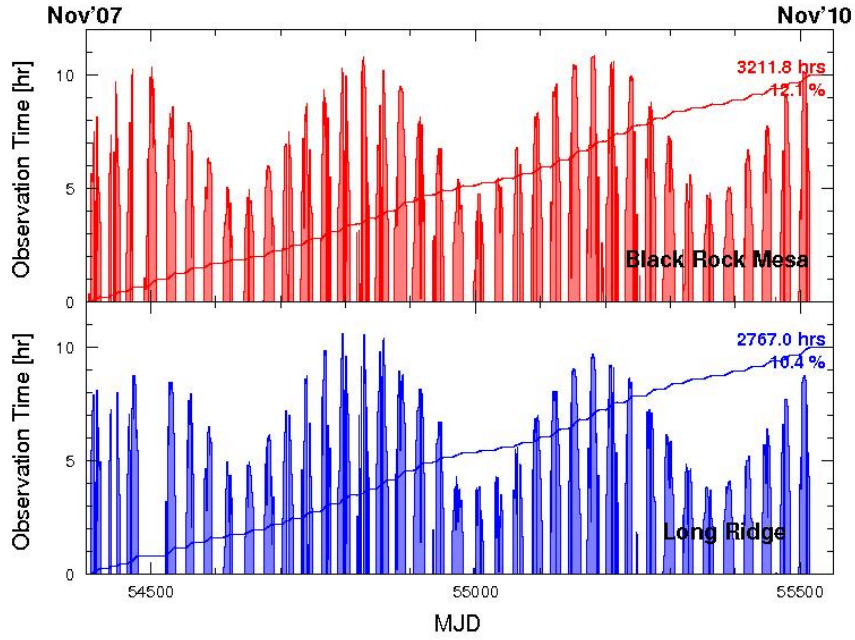
Status monitor
- Battery,Solar Panel Voltage Current monitor
- Rate monitor (> 0.3MIP, >3MIP)
- SD environment monitor
- Number of Satellite (GPS antenna status)

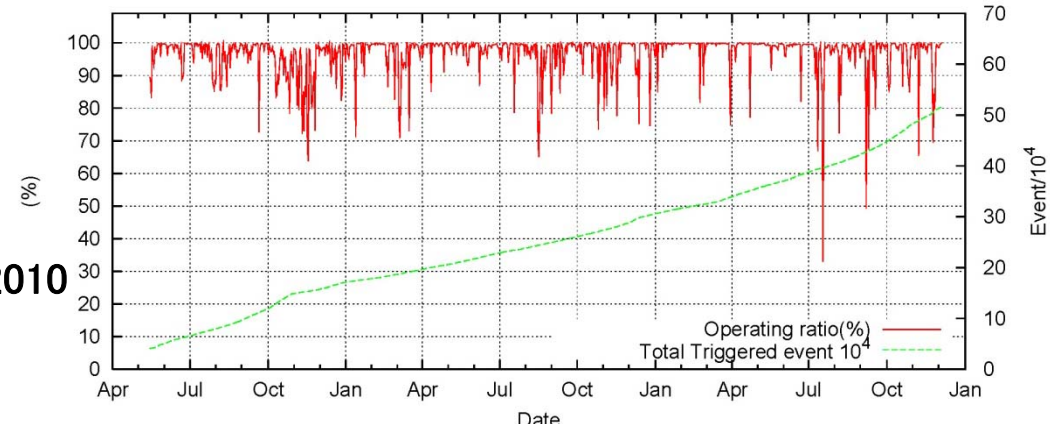
==List of monitoring items==

Item	Data	Resolution
MIP histogram	12bin sum of FADC count	1FADC count 10min
Pedestal histogram	8bin sum of FADC count	1FADC count 10min
Pulse height histogram	Maximum FADC count	32FADC count 10min
Total charge histogram	128bin sum of FADC cont	$\Delta \log_2(FADCsum) = 0.2$
Power Cycle data	Battery,Solar Panel (voltage , current)	1min
Environmental data	temp($^\circ C$,)hum(%) at SD	1min
Trigger rate	Level-0 , Level-1 trigger rate	1min
GPS status	number of satellite, Antenna status	10min

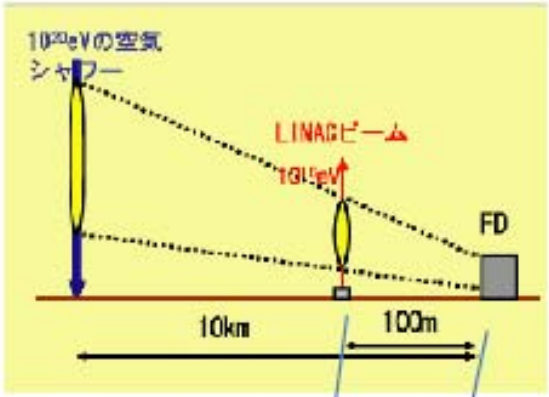
Operation status

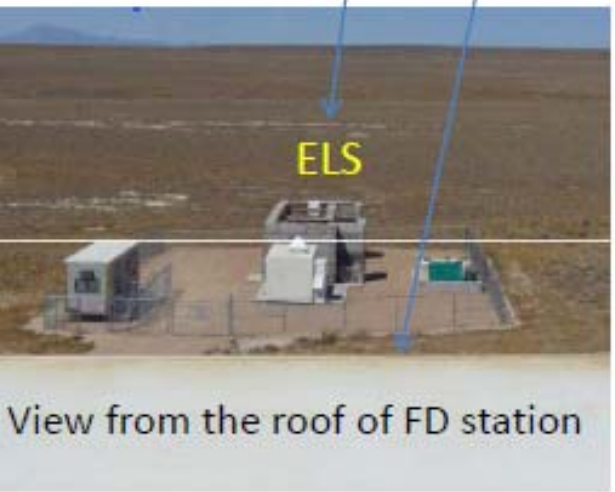
- ◇ FD full observation have started 2007 Dec
- ◇ SD full observation have started Mar.2008
  - →～700km^2 of detecting area
  - θ_{zenith} <45° ～100% efficiency at E>$10^{18.9}$eV
- ◇ Cross boundary Trigger Nov.2008
- ◇ Hybrid Trigger Sep.2010
- ◇ Monitoring
  - SD :detailed monitoring every 10min
  - FD :Atmospheric monitoring, PMT Gain montoring with Xenon light source,YAP pulser.
- ◇ Operation,stability
  - SD: Running ＞96% of duty cycle
    - ＞98% of counter is fine.
  - FD: ～ 7% of duty cycle,
- → Hybrid exposure ～1.5×10^2km^2・yr・sr @2010





First light from ELS

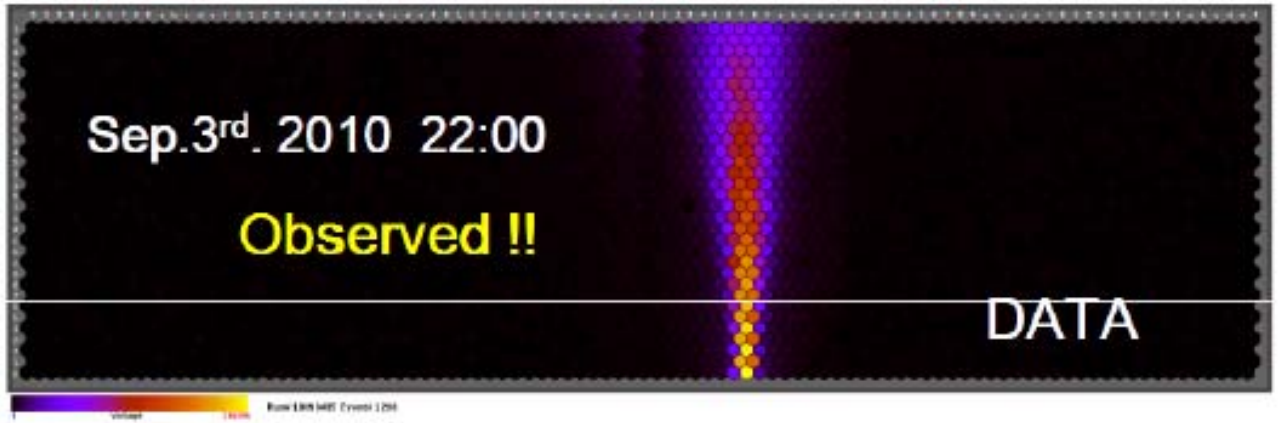


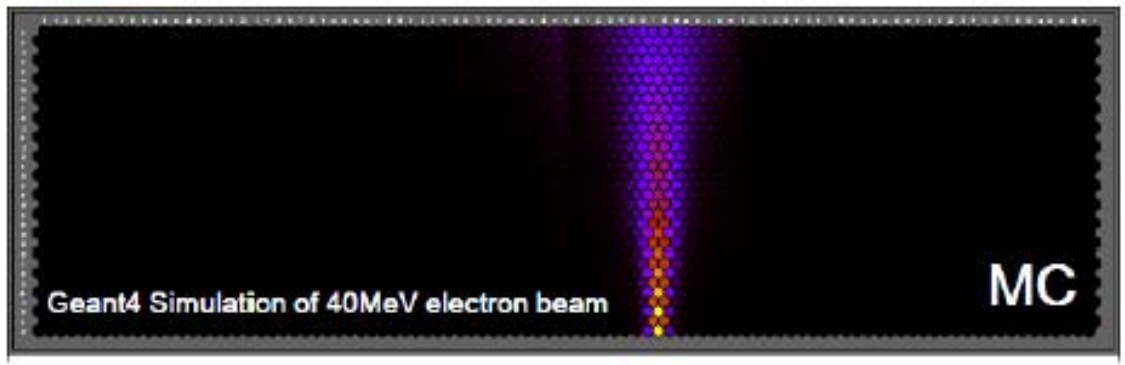


View from the roof of FD station

FD Observation

Sep.3rd.2010 Beam Shot into the Sky, and Observed by FD





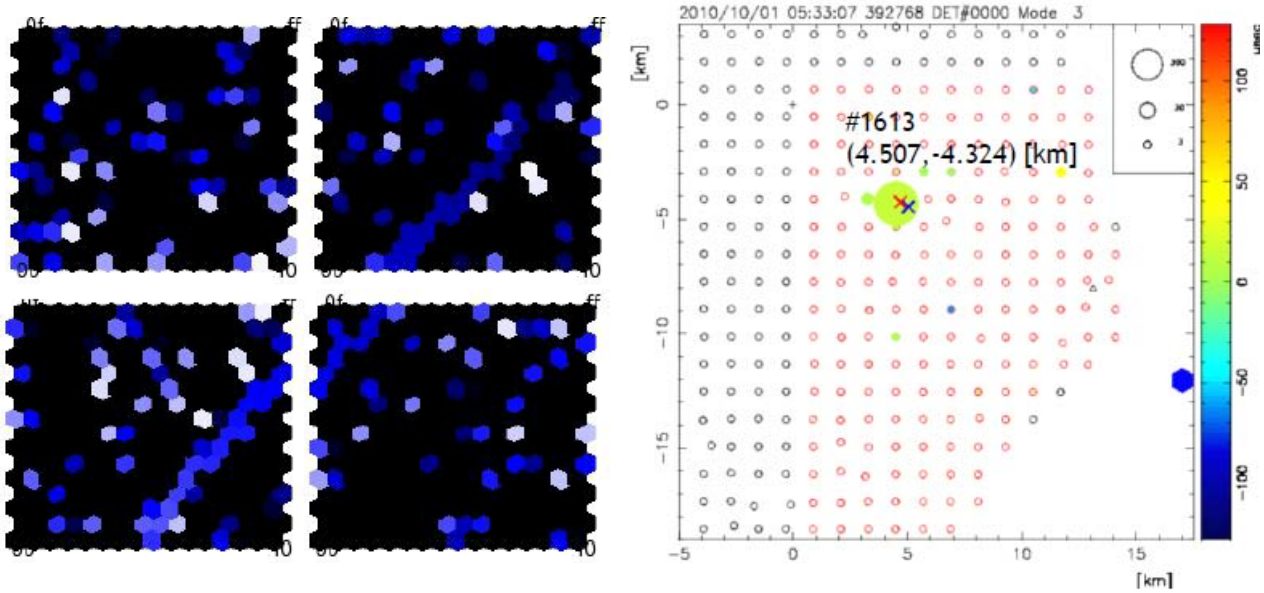
Hybrid trigger

Hybrid trigger:
When FD is triggered, FD requests the collection of signal (waveform) from SDs.

→ Obtain SD information at shower event with much lower than SD arrays threshold energy.
→ Increase accuracy of FD reconstruction at wide energy range.

Installed Sep 2010

The first hybrid trigger event



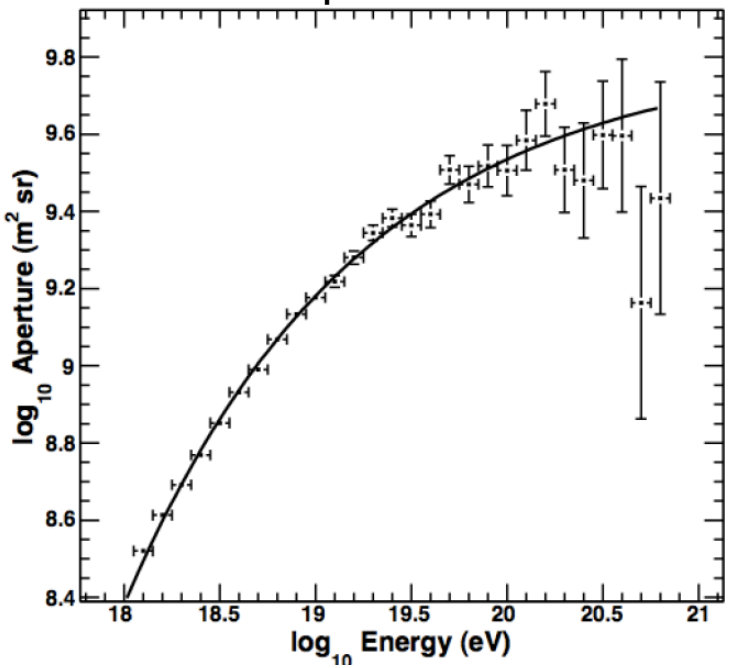
Energy Spectrum @TA MD,SD,Hybrid

MD mono energy spectrum

- **14 refurbish HiRes-1 telescopes & Electronics**
- **TAMD mono processing is identical to HiRes-1 monocular one.**
  - **Same program set, event selection, cuts**
  - **Using the same "average" atmospheric model**
- **The differences**
  - **the telescope location and pointing directions**
  - **Thresholds (~20% lower than HiRes-1)**

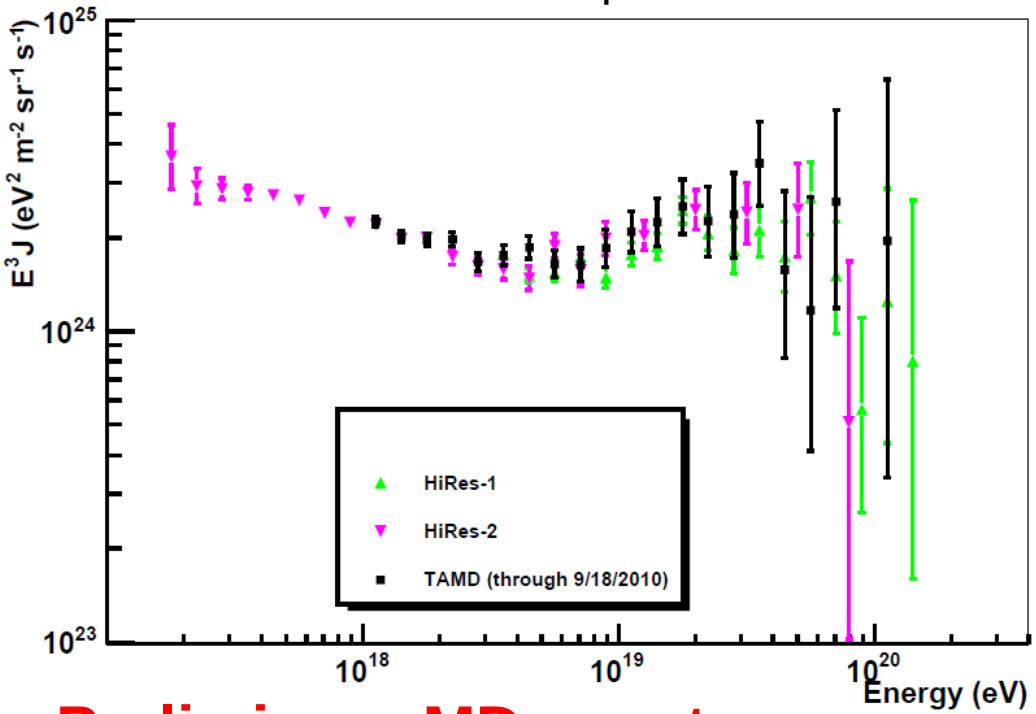
- Data: 2007/Dec~2008/Sep

Aperture



~1/2 HiRes (E>10^{19}eV)
~1/4 the exposure of HiRes-1

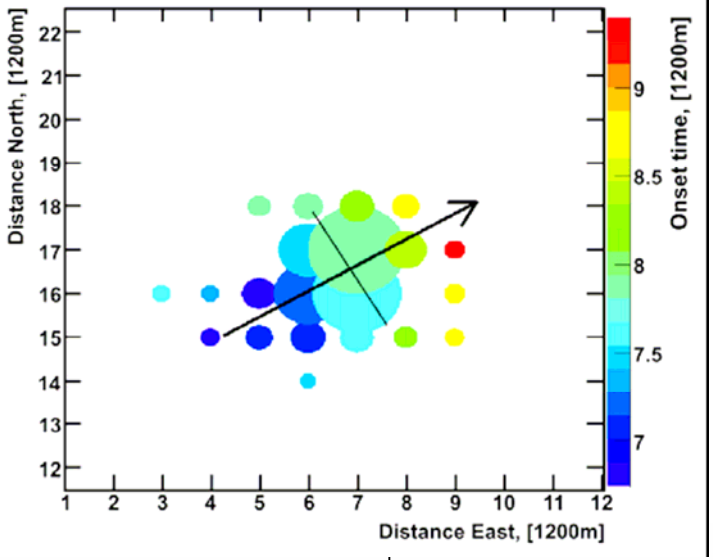
Spectra



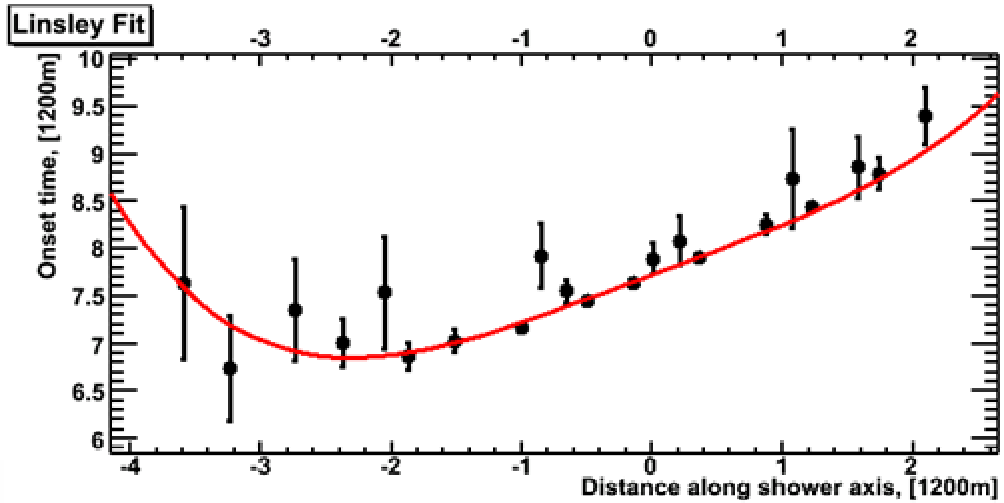
Preliminary MD spectrum in good agreement with HiRes

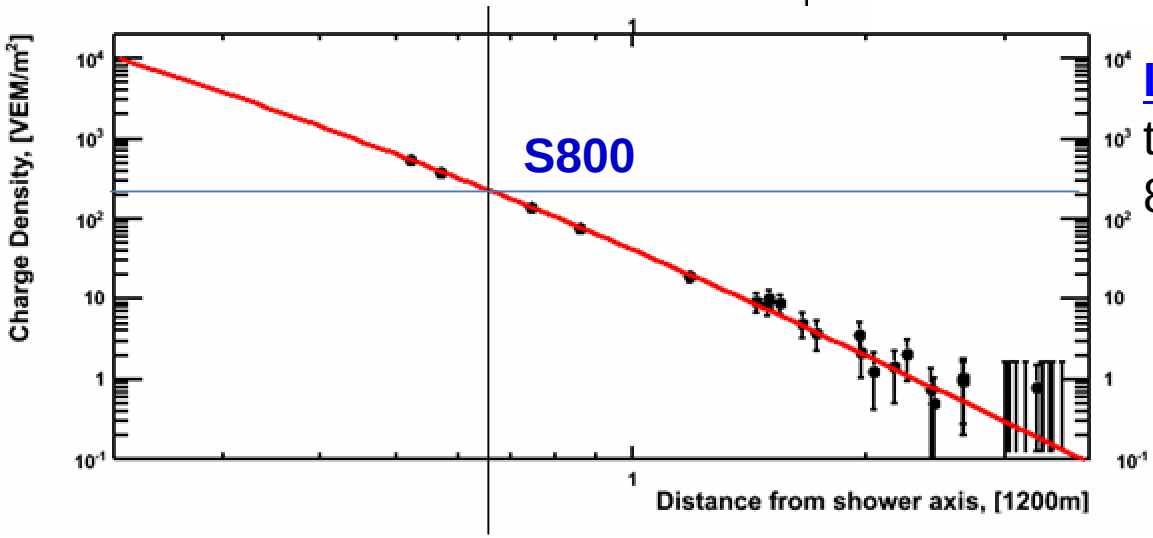
SD Event Reconstruction

2008/Jun/25 - 19:45:52.588670 UTC



Time fit to determine **geometry**
(modified Linsley)





Lateral Density Distribution Fit
to determine **S800** (charge density 800m from the shower axis)

Fit with AGASA LDF

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

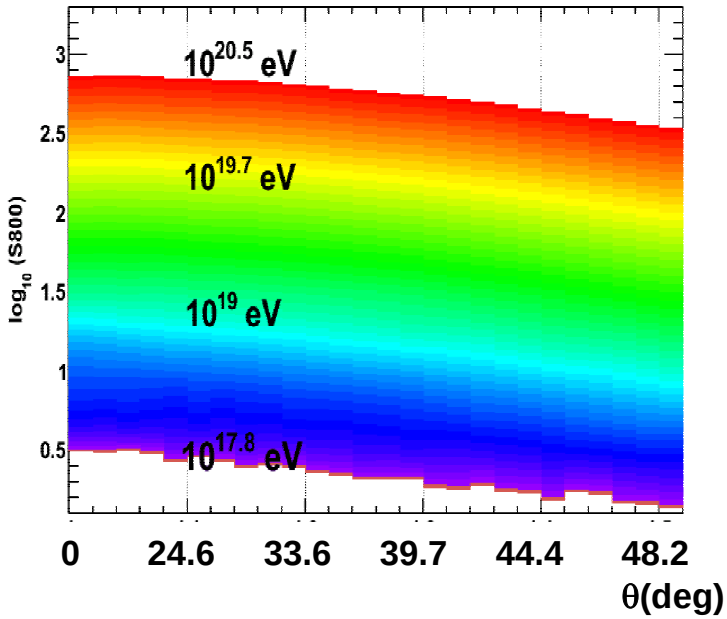
$$\eta = (3.97 \pm 0.13) - (1.79 \pm 0.62)\,(\sec\theta - 1)$$

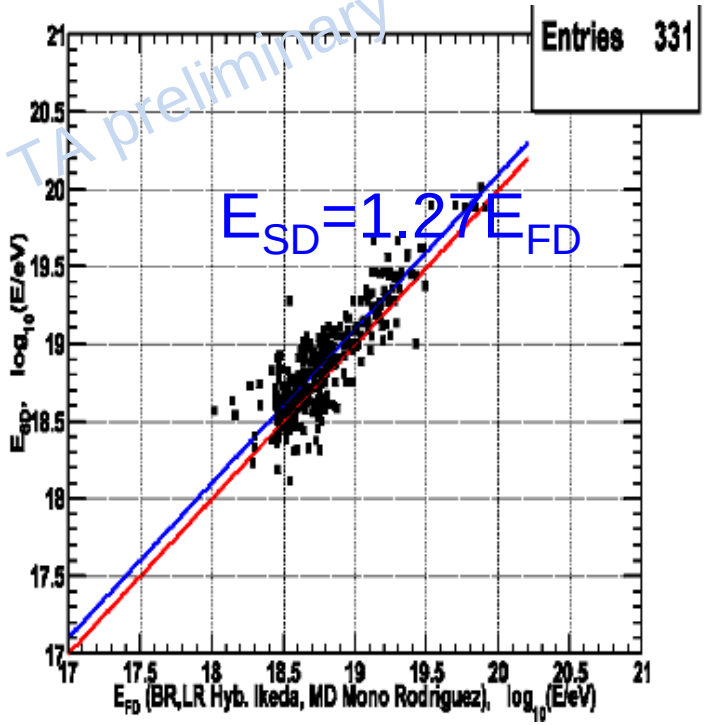
- S(800)→Primary Energy

r = 800m

SD Energy Estimation

Energy table from MC (First estimation)



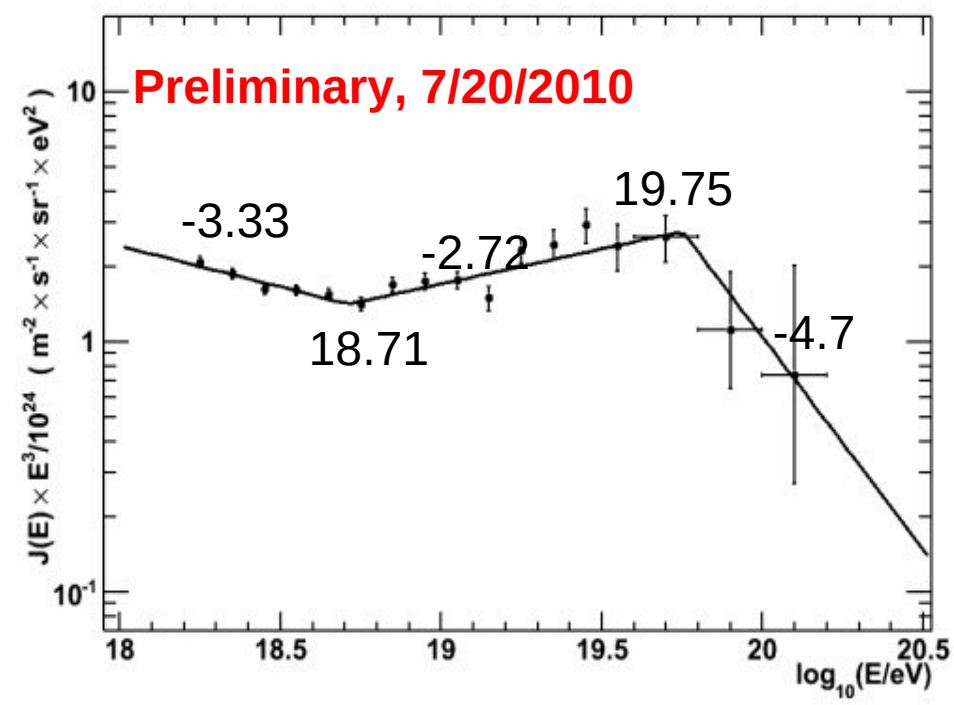


From reconstructed event, S800 , arrival direction(zenith angle) will be used for first estimation.
Event energy will be decided by applying calibration between FD and SD.

TA SD Spectrum

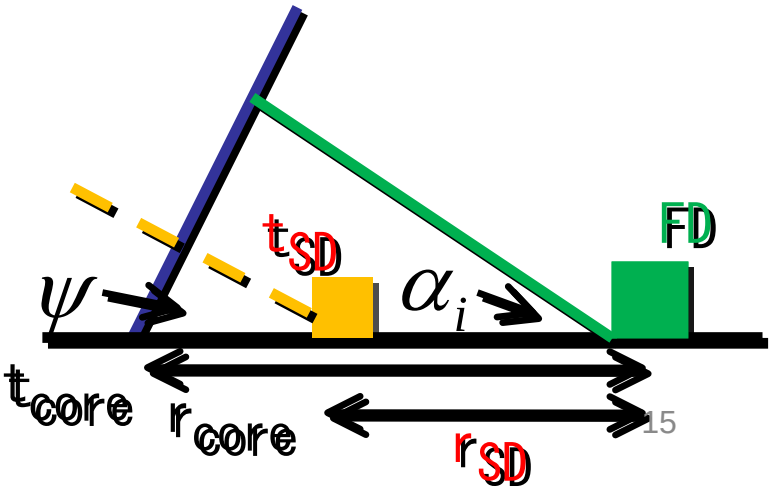
- May/2008 – Feb/2010 (~AGASA 13 years) Exposure ~1500km^2 sr yr
- Cuts:
  - LDF χ^2/ndf < 4.0
  - Border Cut > 1.2km
  - Zenith Angle < 45 degrees
  - Pointing direction uncertainty < 5 degrees
  - Fractional S800 uncertainty < 0.25

6264 events



TA FD-SD Hybrid Spectrum

<Air Shower Geometry> / <Longitudinal development>



Inverse Monte Carlo (IMC)

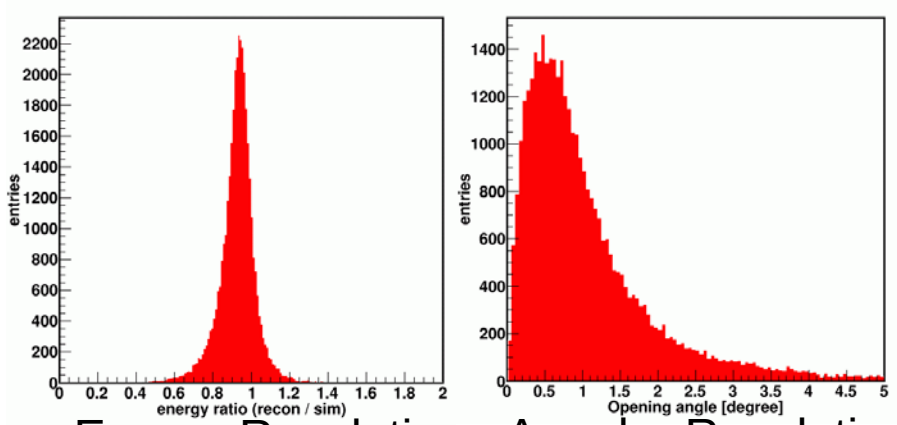
- Direct comparison b/w data and MC on cameras
- All of effect can be included.
- Database of detector response
  → High speed/statistics

- Xmax has to be observed
- Energy > $10^{18.65}$eV
- Zenith angle < 45 degree

Hybrid reconstruction

$$t_i = t_{core} + \frac{1}{c}\frac{\sin\psi - \sin\alpha_i}{\sin(\psi + \alpha_i)} r_{core}$$

$$t_{core} = t_{SD} + \frac{1}{c}(r_{core} - r_{SD})\cos\psi$$

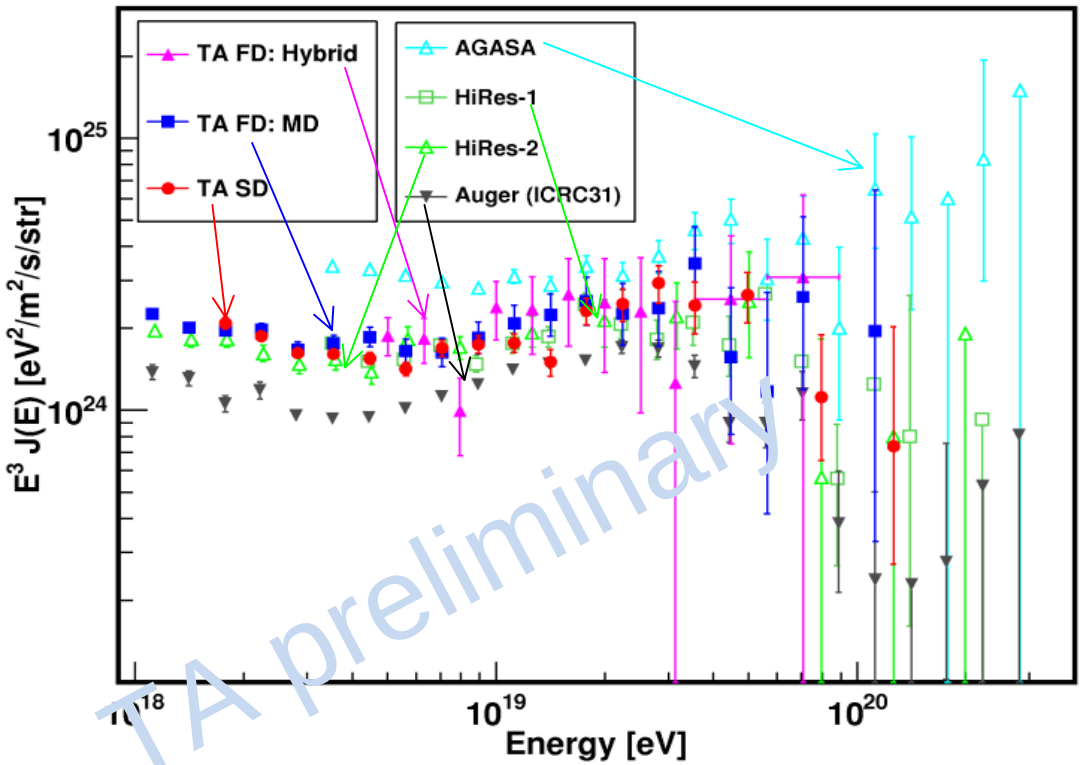


Energy Resolution ～8%

Angular Resolution ～1.1°

TA FD-SD Hybrid Spectrum

TA 1.5 years of hybrid events on BR and LR station



Systematic errors on Hybrid Spectrum

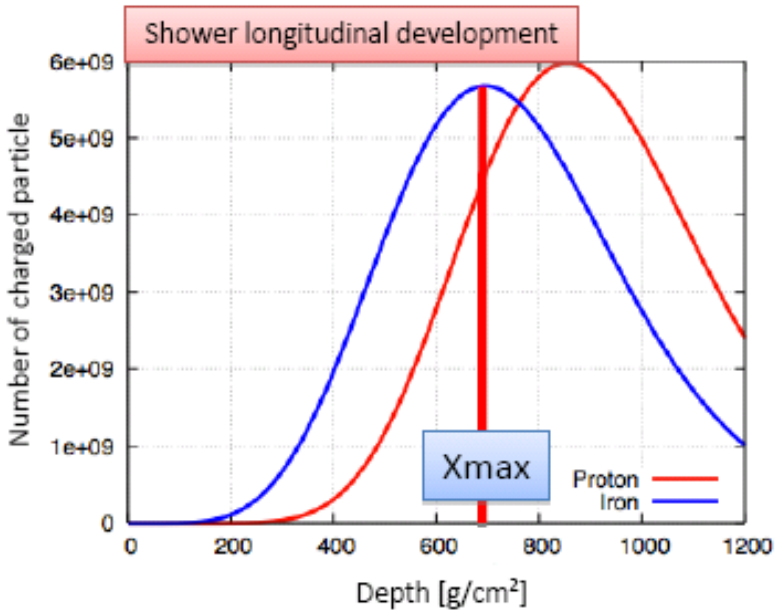
Item	Systematic error
Fluorescence yield	12%
Detector	10%
Atmosphere	11%
Primary particle mass	5%
MC correction	3%
Total	19%

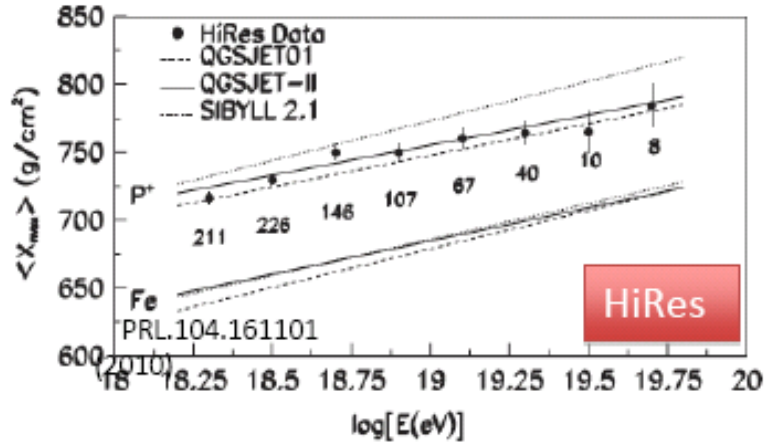
Chemical Composition @TA

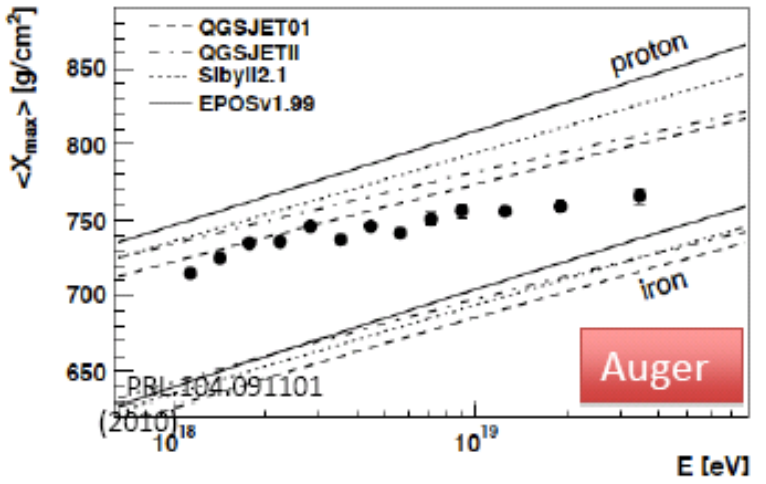
X_max method

X_max: slant depth(g/cm^2) at maximum development of shower

- Shower longitudinal development strongly depends on their primary particle type.
- FD observes shower development directly.
- Xmas is one of the most efficient parameter for determining primary particle type.







Stereo reconstruction

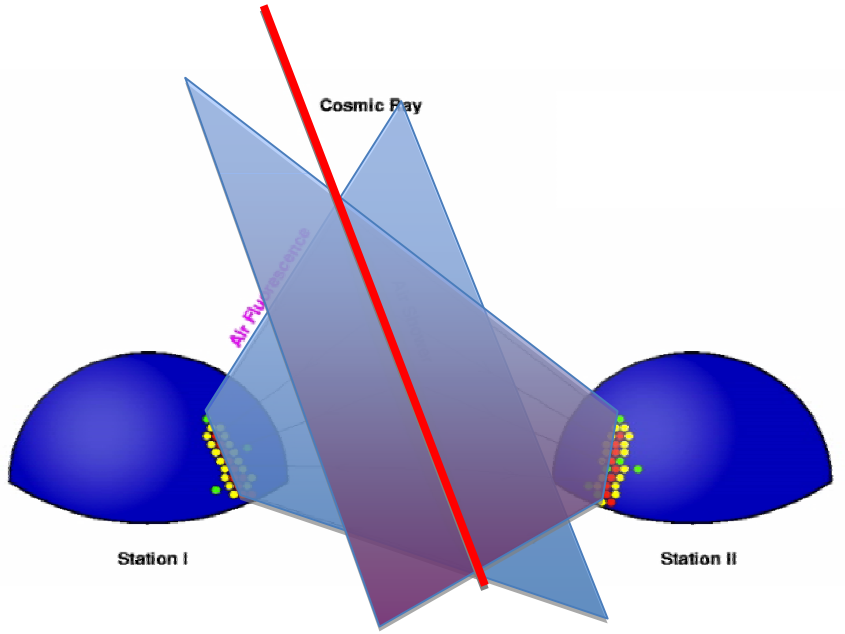
Determination by direction of the selected PMTs

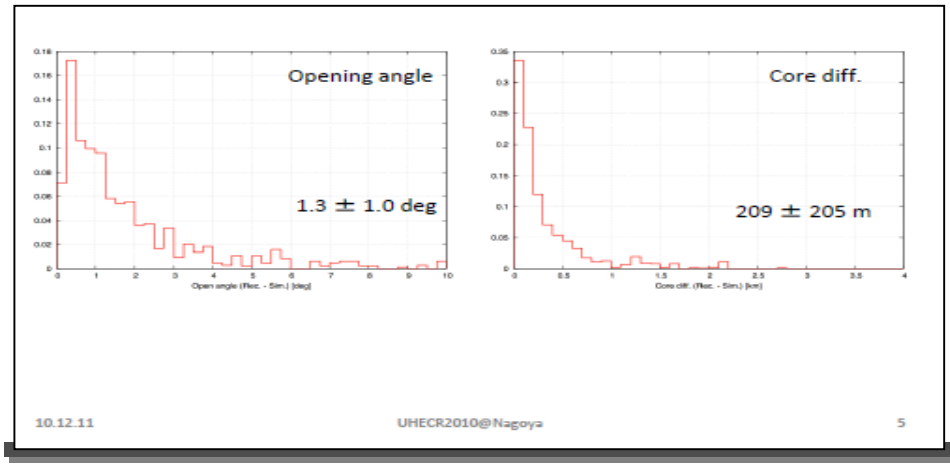
$$\sum_i w^i (\boldsymbol{n} \cdot \boldsymbol{k}^i)^2$$

n: Normal SDP vector
k^i: PMT direction vector

Intersect line of two SDPs

$$\boldsymbol{s} = \boldsymbol{n}_1 \times \boldsymbol{n}_2$$





Resolution @$10^{19\text{-}19.2}$eV

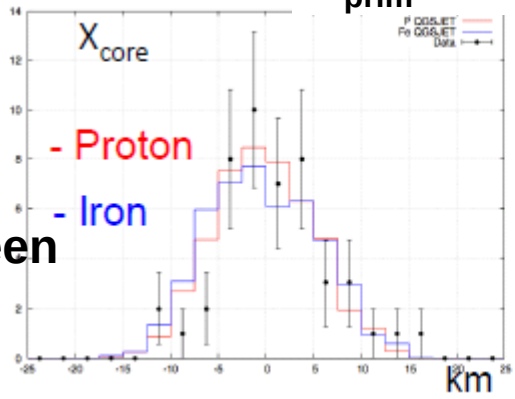
	Proton	Iron
ΔE/Esim	-0.8±8%	-6.2±5%
ΔXmax	-11±23g/cm^2	-11±15g/cm^2

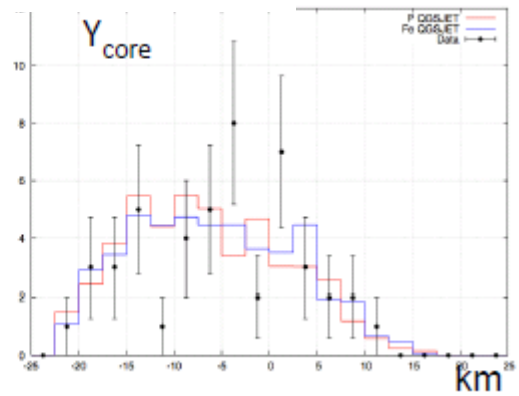
(QGSJET01)

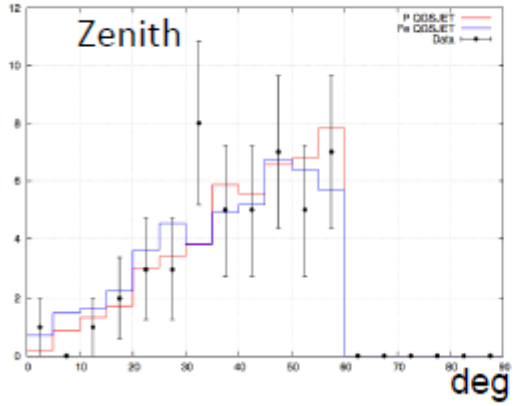
Data MC comparison (Stereo observation)

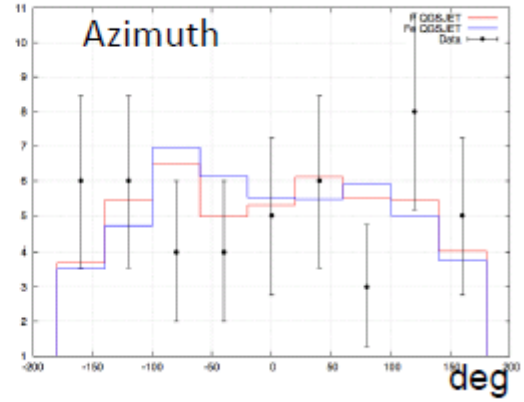
$E_{prim}=10^{18.8} \sim 10^{19.0}$ eV

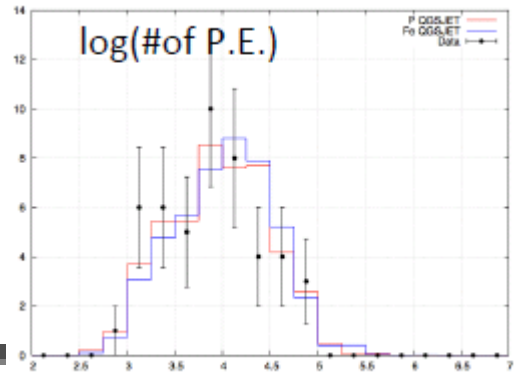
- Data and MC are compared
- No significant discrepancy are seen from data for both Proton and Iron case





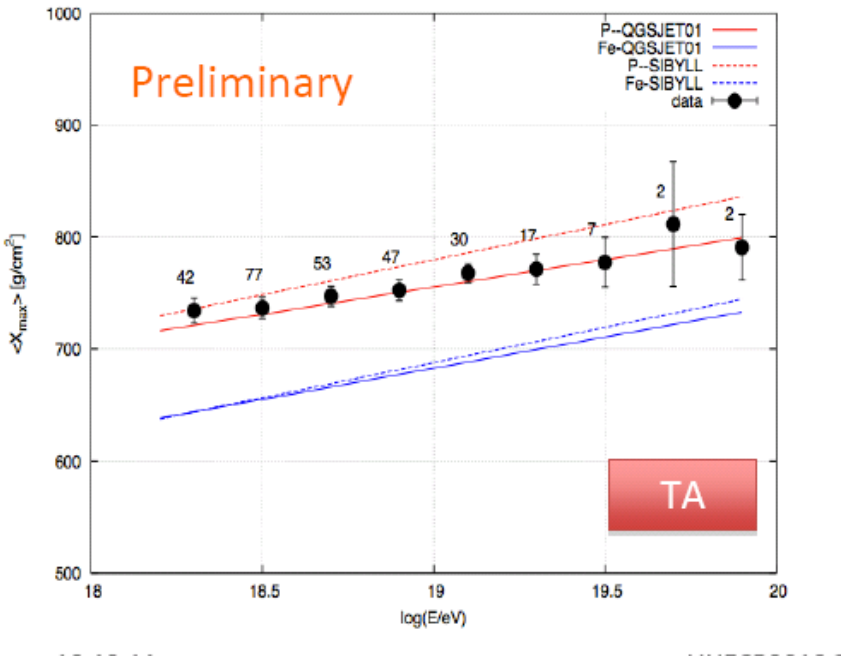


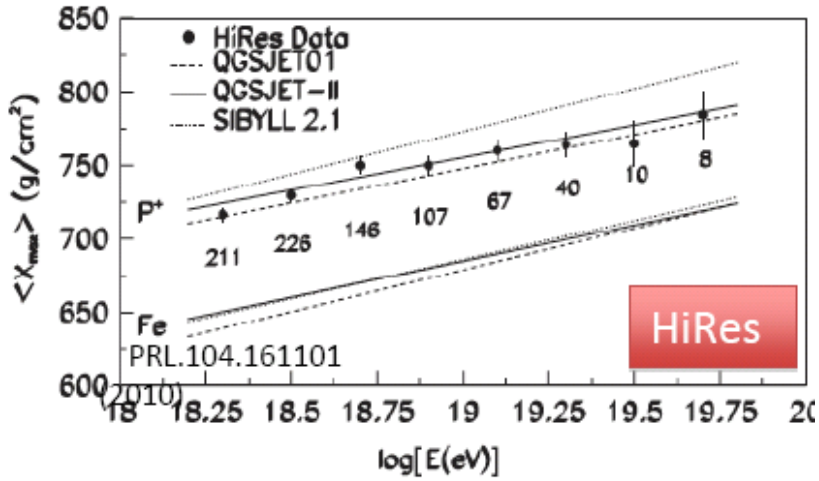




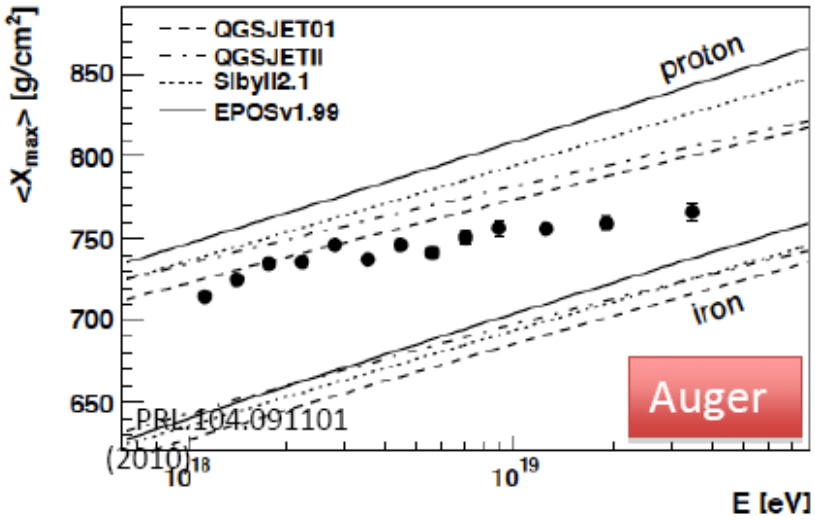
Average X_max

Observed <X_max> and MC event includes same detector bias.





PRL.104.161101 (2010)



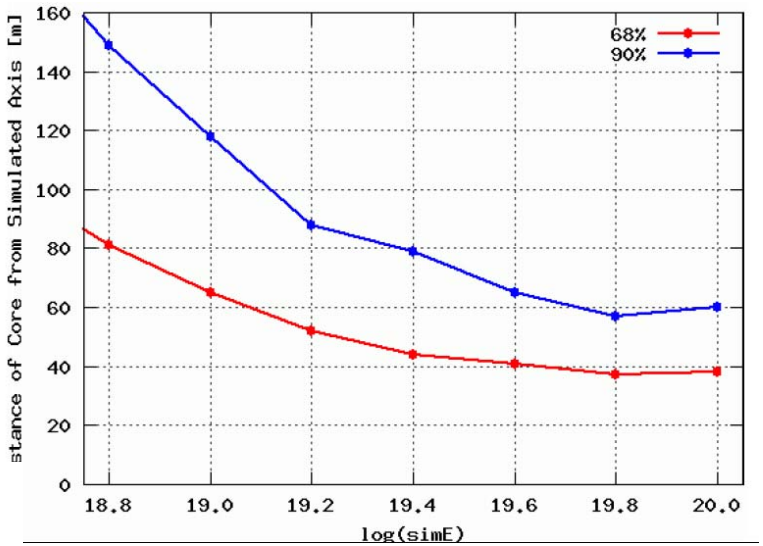
PRL.104.091101 (2010)

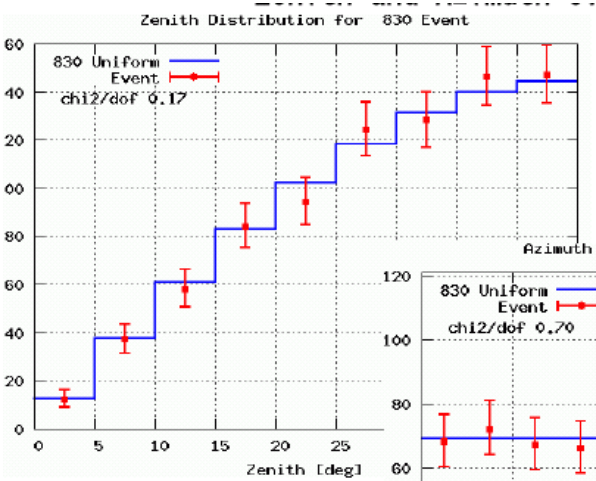
Anisotropy @TA

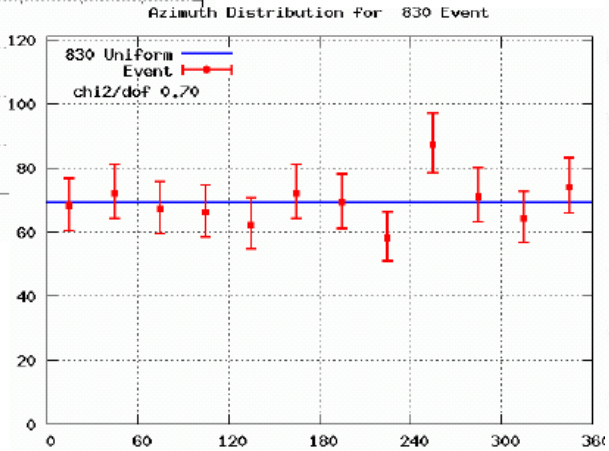
Auto Correlation study using SD data

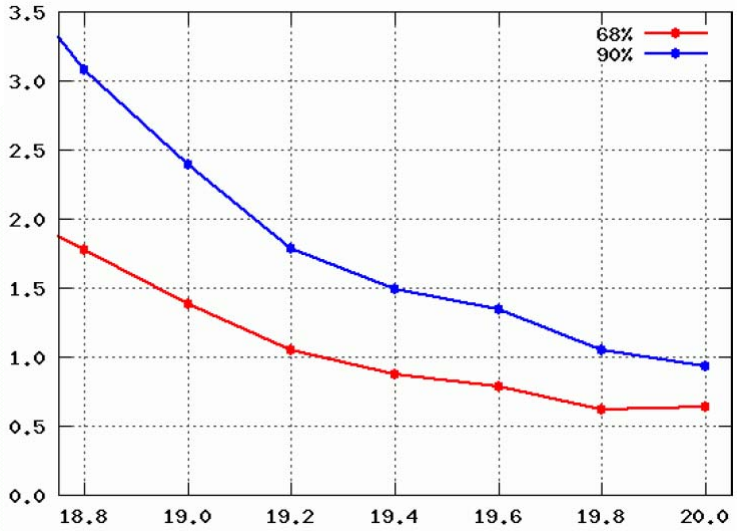
Data 2008/05/11-2010/09/07

E>10^{19}eV
830event
E>4×10^{19}eV
42event
Zenith <45°
Core location < Inside array (~600m)



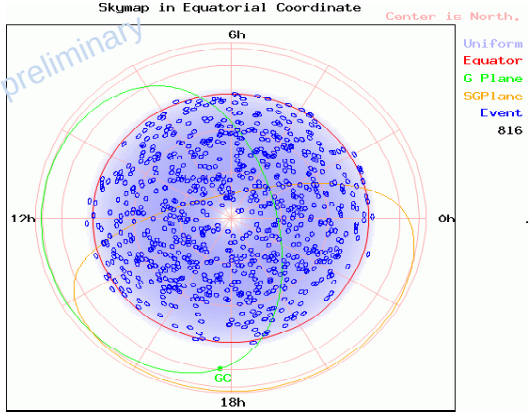


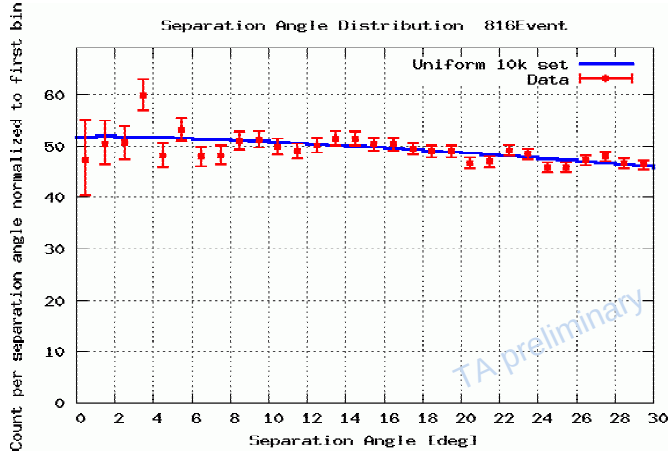




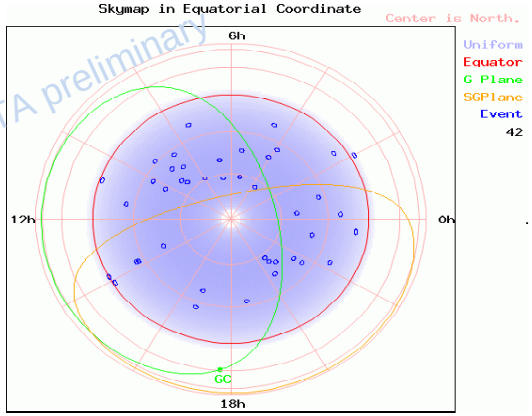
Auto Correlation study using SD data

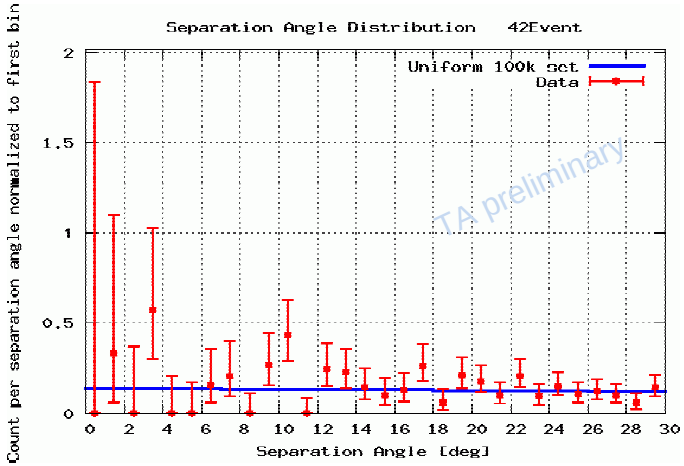
10EeV





40EeV





<2.5[deg] separation angle:
311 pairs (>10EeV) for 323 pairs expected from isotropy
1 pair (>40EeV) for 0.84 Pairs expected from isotropy

Summary: (2011/03/17)

◇ **TA full observation have started Mar.2008**

◇ Cross boundary Trigger Nov.2008

◇ Hybrid Trigger Sep.2010

◇ Operation,stability good. + Detailed Calibration and cross check tools.

Spectrum

◇ **MD, TA-Hybrid spectrum consistent with Hires1 2**

X_max

◇ **Chemical composition (stereo analysis) seems consistent with proton.**

Anisotropy

◇ **No small scale cluster of arrival direction were found. (>10EeV,>40EeV)**

Now, correlations with number of catalogue (eg, AGN) and Large Scale Structure(LSS) with consideration of Galactic Magnetic field model are going.