Result of Telescope Array

N. Sakurai
for Telescope Array collaboration

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Telescope Array

- The aims of TA are :
  - Measuring the UHE CR energy spectrum.
  - Studying the primary composition of UHE CR.
  - Searching the source of the ultra high energy cosmic ray.
- For these purpose, TA collaboration was forged by Members of AGASA and HiRes.
- Now, the collaboration members comes from Japan, US, Korea, Russia and China.

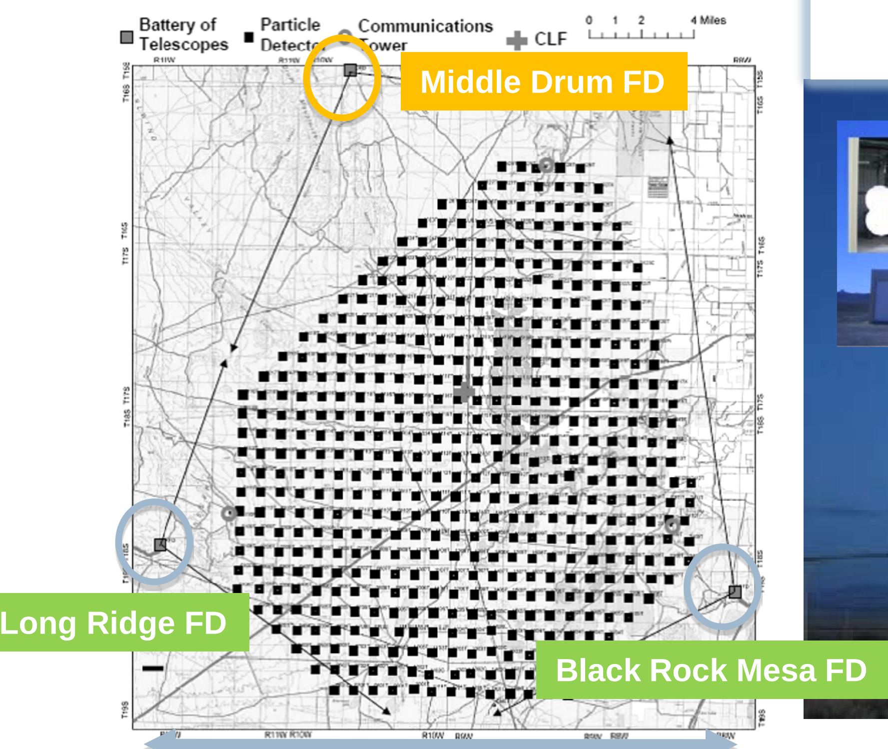
Telescope Array Collaboration

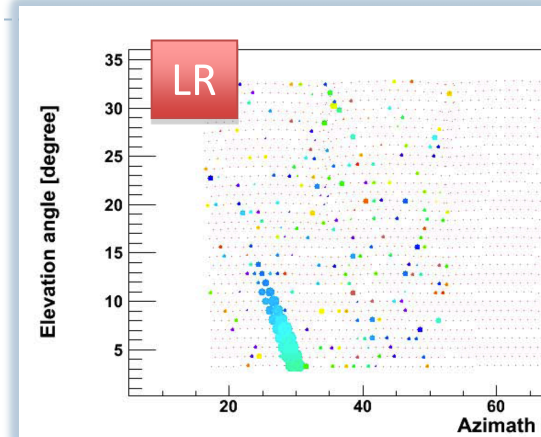
T Abu-Zayyad[1], R Aida[2], M Allen[1], R Azuma[3], E Barcikowski[1], JW Belz[1], T Benno[4], DR Bergman[1], SA Blake[1], O Brusova[1], R Cady[1], BG Cheon[6], J Chiba[7], M Chikawa[4], EJ Cho[6], LS Cho[8], WR Cho[8], F Cohen[9], K Doura[4], C Ebeling[1], H Fujii[10], T Fujii[11], T Fukuda[3], M Fukushima[9,22], D Gorbunov[12], W Hanlon[1], K Hayashi[3], Y Hayashi[11], N Hayashida[9], K Hibino[13], K Hiyama[9], K Honda[2], G Hughes[5], T Iguchi[3], D Ikeda[9], K Ikuta[2], SJJ Innemee[5], N Inoue[14], T Ishii[2], R Ishimori[3], D Ivanov[5], S Iwamoto[2], CCH Jui[1], K Kadota[15], F Kakimoto[3], O Kalashev[12], T Kanbe[2], H Kang[16], K Kasahara[17], H Kawai[18], S Kawakami[11], S Kawana[14], E Kido[9], BG Kim[19], HB Kim[6], JH Kim[6], JH Kim[20], A Kitsugi[9], K Kobayashi[7], H Koers[21], Y Kondo[9], V Kuzmin[12], YJ Kwon[8], JH Lim[16], SI Lim[19], S Machida[3], K Martens[22], J Martineau[1], T Matsuda[10], T Matsuyama[11], JN Matthews[1], M Minamino[11], K Miyata[7], H Miyauchi[11], Y Murano[3], T Nakamura[23], SW Nam[19], T Nonaka[9], S Ogio[11], M Ohnishi[9], H Ohoka[9], T Okuda[11], A Oshima[11], S Ozawa[17], IH Park[19], D Rodriguez[1], SY Roh[20], G Rubtsov[12], D Ryu[20], H Sagawa[9], N Sakurai[11], LM Scott[5], PD Shah[1], T Shibata[9], H Shimodaira[9], BK Shin[6], JD Smith[1], P Sokolsky[1], TJ Sonley[1], RW Springer[1], BT Stokes[5], SR Stratton[5], S Suzuki[10], Y Takahashi[9], M Takeda[9], A Taketa[9], M Takita[9], Y Tameda[3], H Tanaka[11], K Tanaka[24], M Tanaka[10], JR Thomas[1], SB Thomas[1], GB Thomson[1], P Tinyakov[12,21], I Tkachev[12], H Tokuno[9], T Tomida[2], R Torii[9], S Troitsky[12], Y Tsunesada[3], Y Tsuyuguchi[2], Y Uchihori[25], S Udo[13], H Ukai[2], B Van Klaveren[1], Y Wada[14], M Wood[1], T Yamakawa[9], Y Yamakawa[9], H Yamaoka[10], J Yang[19], S Yoshida[18], H Yoshii[26], Z Zundel[1]

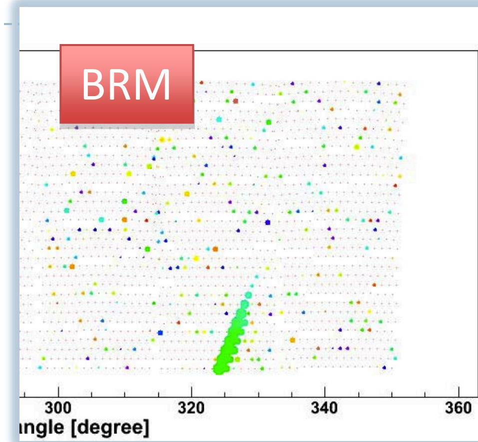
[1]University of Utah, [2]University of Yamanashi, [3]Tokyo Institute of Technology, [4]Kinki University, [5]Rutgers University, [6]Hanyang University, [7]Tokyo University of Science, [8]Yonsei University, [9]Institute for Cosmic Ray Research, University of Tokyo, [10]Institute of Particle and Nuclear Studies, KEK, [11]Osaka City University, [12]Institute for Nuclear Research of the Russian Academy of Sciences, [13]Kanagawa University, [14]Saitama University, [15]Tokyo City University, [16]Pusan National University, [17]Waseda University, [18]Chiba University [19]Ewha Womans University, [20]Chungnam National University, [21]University Libre de Bruxelles, [22]University of Tokyo, [23]Kochi University, [24]Hiroshima City University, [25]National Institute of Radiological Science, Japan, [26]Ehime University

Fluorescence Detector (FD)

- 2 FD stations (**BRM** & **LR**) are newly developed.
- 1 FD station (**MD**) consists of **HiRes-I** PMT/electronics and HiRes-II mirrors.
- FD operation started from Nov. 2007.

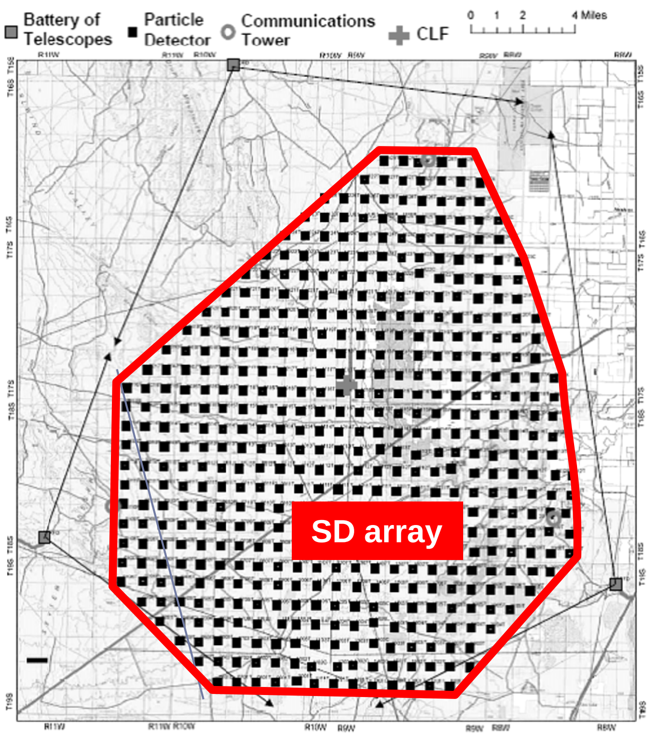


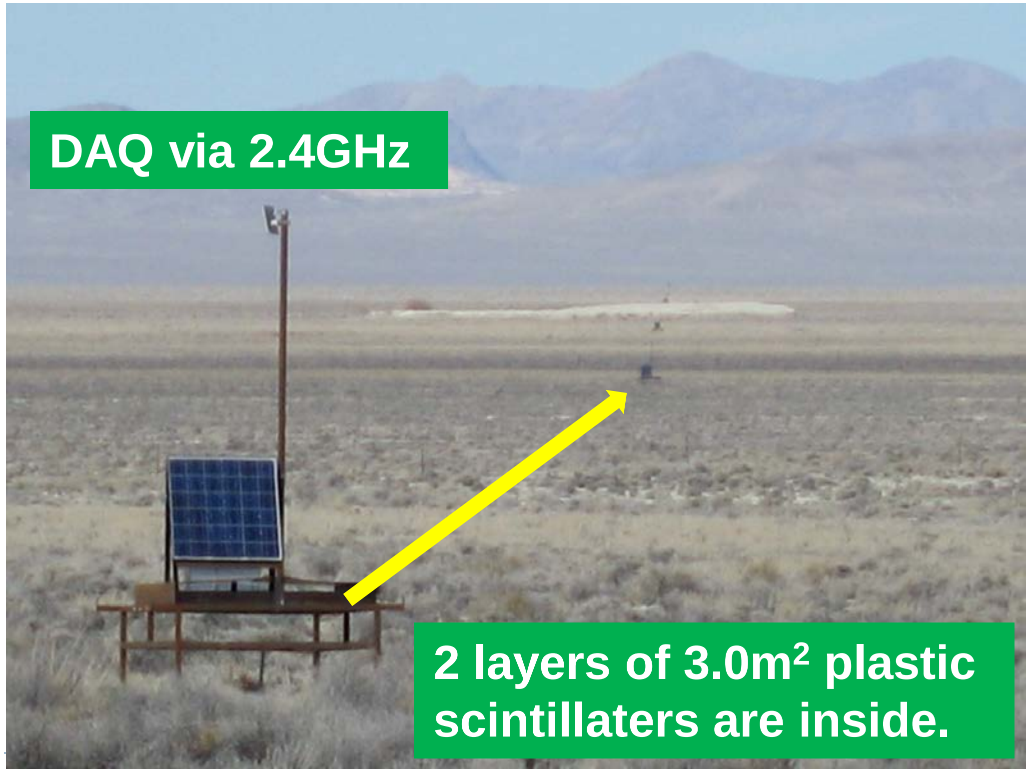




Surface Detector (SD)

- 507 SDs on 1.2 km grid
- Total detection area ~700 km^2
- SD operation started from Mar. 2008.
- More than 97% detectors are available over the operation.



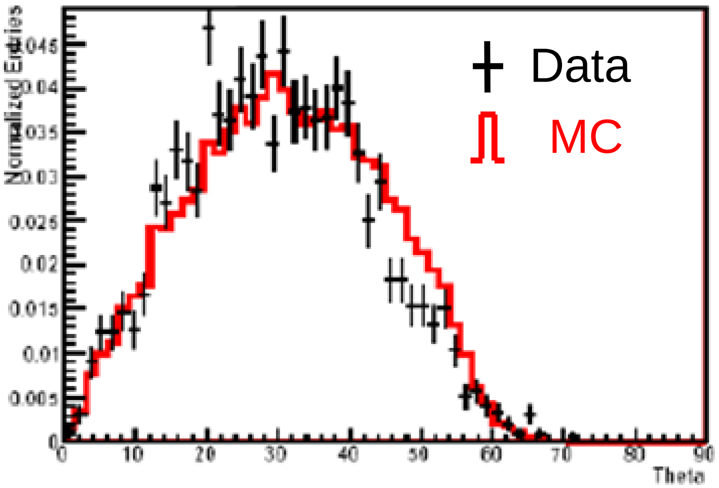


FD mono analysis

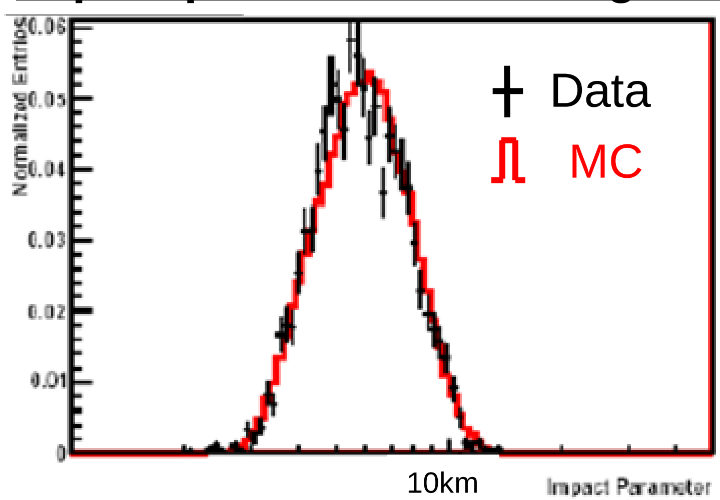
- "HiRes-I at MD" data analyzed by HiRes-I program.
  - Same electronics & PMT but FOV of mirrors are different (3 ^{o}~ 31^{o}).
  - Same program, same event reduction conditions.
  - Same average atmospheric model
  - Same fluorescence light yield.
    - Kakimoto(1996) + FLASH(2008)
  - Energy threshold is ~20% lower than HiRes-I.

FD mono data/MC comparison

Zenith angle 17.5<logE<18

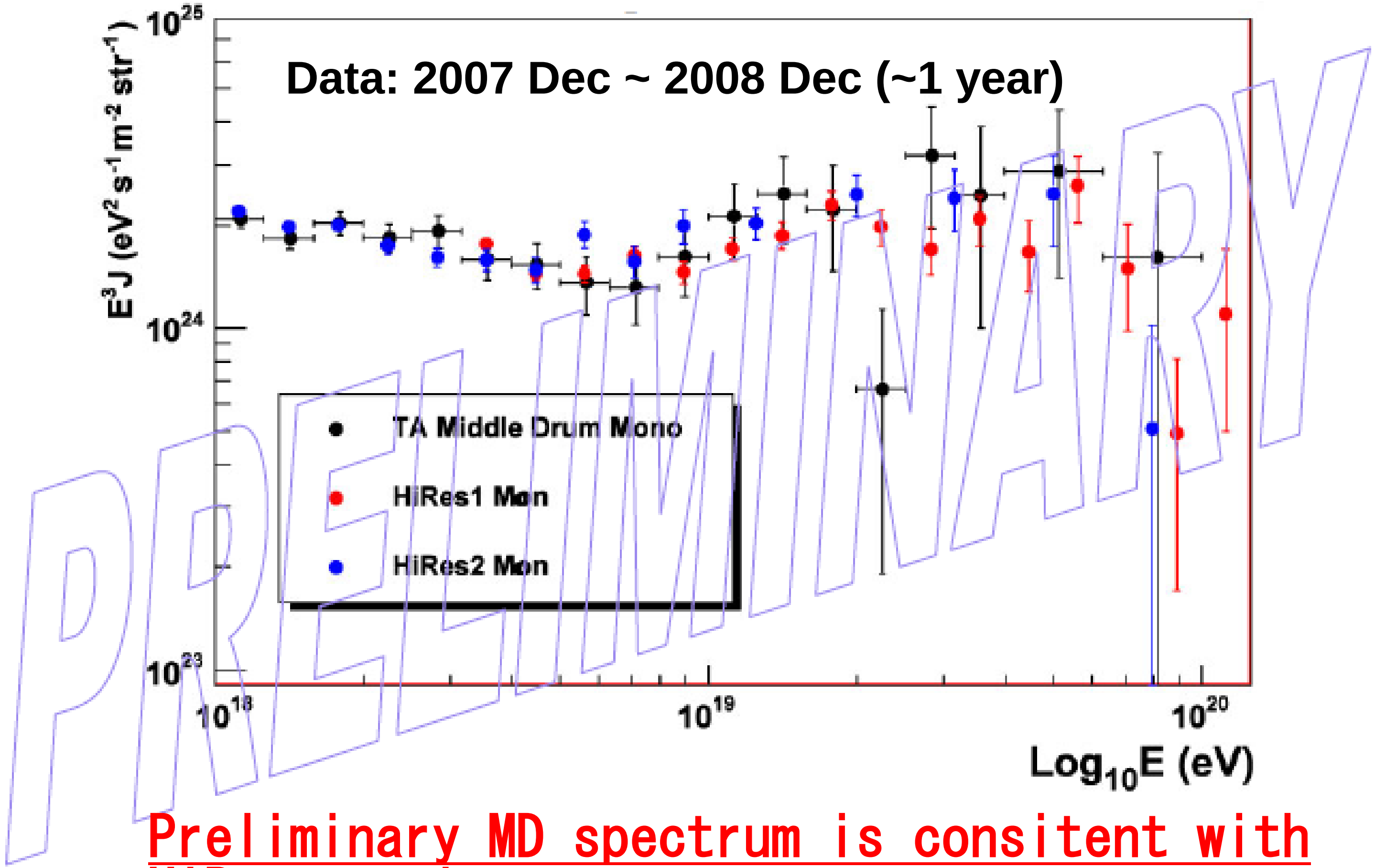


Impact parameter 17.5<logE<18



- Spectrum & composition are previously measured ones.
- FD-MD mono data processes are identical to HiRes-I mono data analysis.
- Both of Data & MC are analyzed by same program.

Energy spectrum (FD mono)



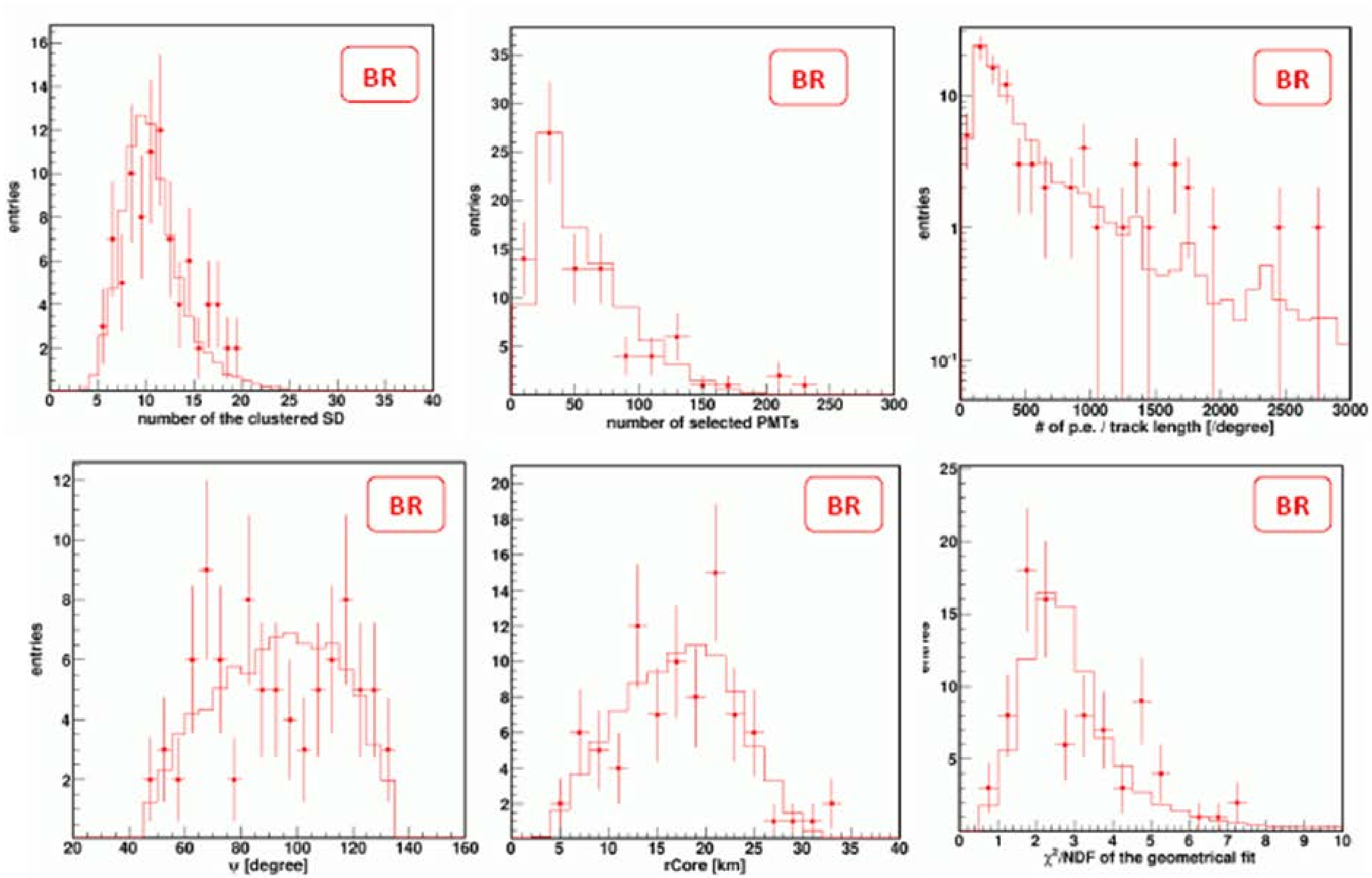
Preliminary MD spectrum is consitent with HiRes result.

Hybrid data analysis

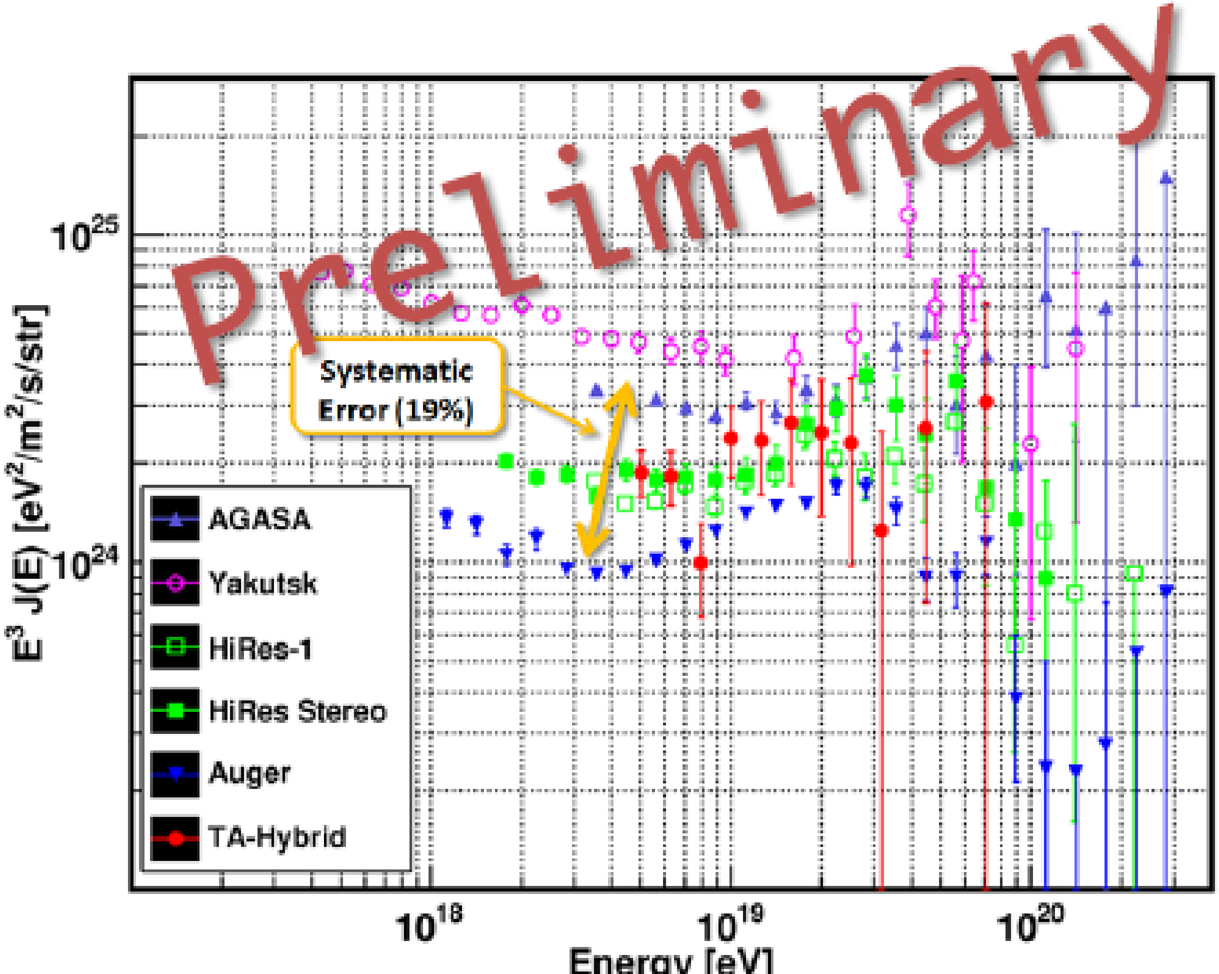
- Hybrid data = ("BRM-FD" + "LR-FD") ∩ SD
- Period : 2008 May.-2009 Sep.
- Geometry reconstruction
  - Both of SD data and FD data are used.
  - Geometry is well reconstructed.
- Longitudinal shower profile fit
  - Longitudinal development is determined by only FD data.
  - FD energy scale is used.
  - FLY : Kakimoto (1996) + FLASH(HiRes, MD-FD)

Hybrid data/MC comparison

- BR station
- Filled circles : data
- Histograms : MC



Energy spectrum (Hybrid data)



Systematic errors

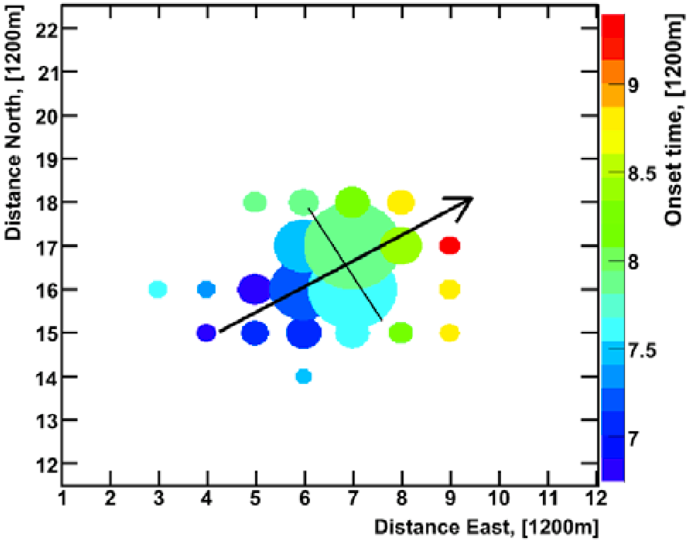
Item	Systematic error
Fluorescence yield	12%
Detector	10%
Atmosphere	11%
Primary particle mass	5%
MC correction	3%
Total	19%

SD data analysis

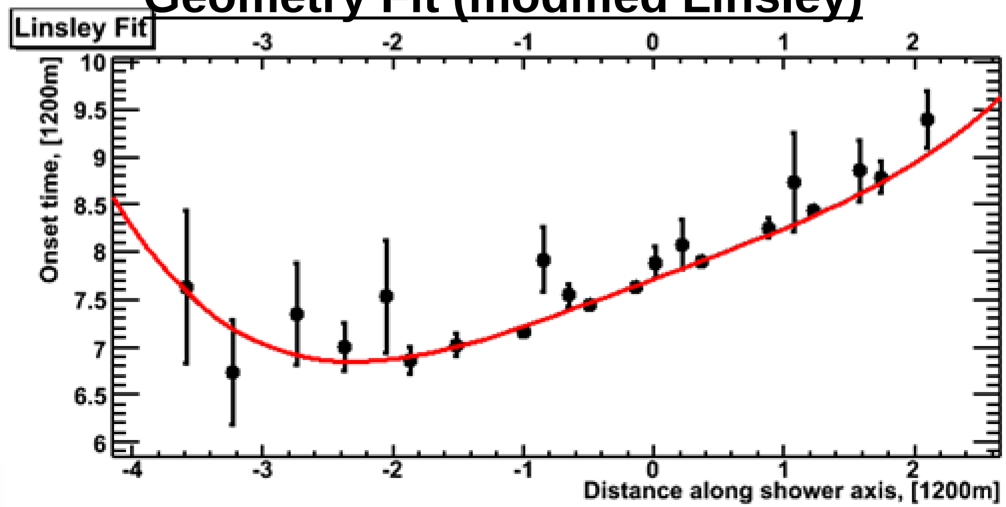
- Data: 2008 May - 2009Feb. (1.75yr)
  - 1500km^2 yr sr (~ 1AGASA)
- Data cuts:
  - Zenith angle < 45^o
  - Distance from the array border is >1200m
  - Bad quality events.
  - 6264 events remains after cuts.
- Reconstruction procedure :
  - Time fit for geometry reconstruction.
  - Lateral distribution fit to obtain the signal size at 800m from shower axis (S800).

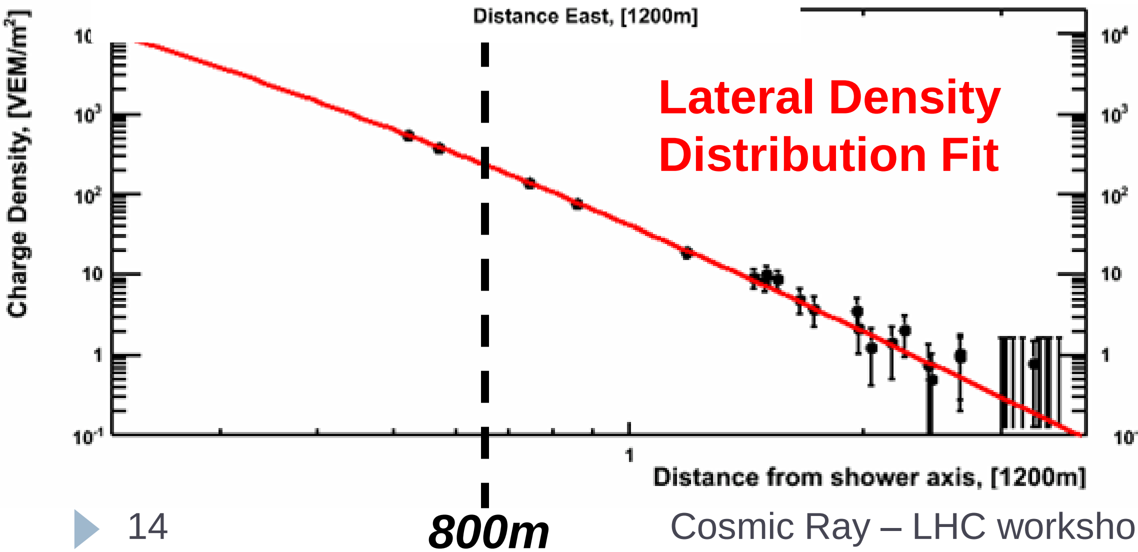
SD typical event example

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



Geometry Fit (modified Linsley)





Fit with AGASA LDF

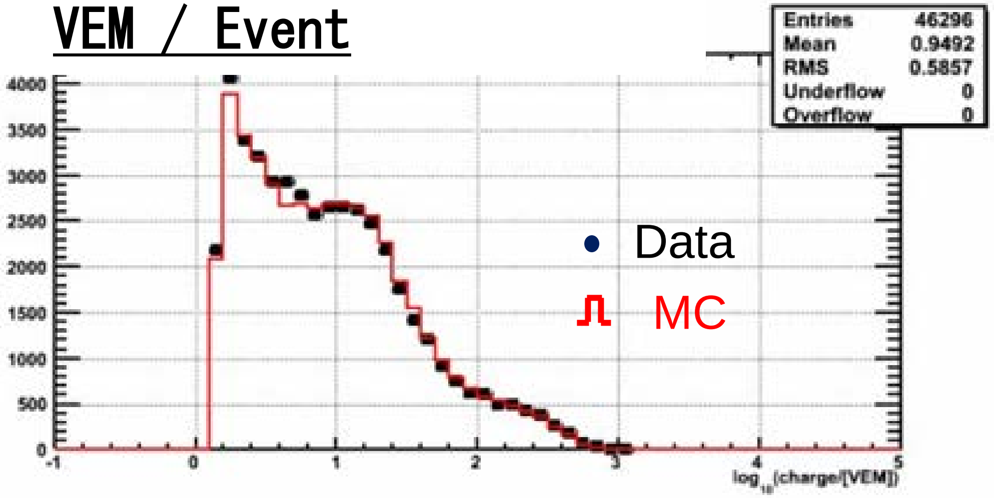
$$\rho(r) \propto \left(\frac{r}{R_M}\right)^{-1.2} \left(1 + \frac{r}{R_M}\right)^{-(\eta-1.2)} \left\{1 + \left(\frac{r}{1000}\right)^2\right\}^{-0.6}$$

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

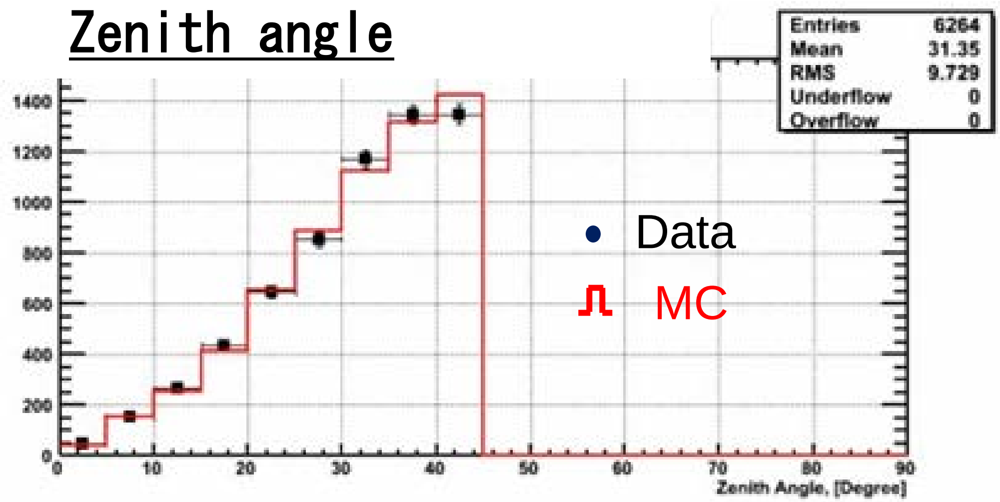
- S(800): Primary Energy
- Zenith attenuation by MC (not by CIC).

SD data/MC comparisons

VEM / Event



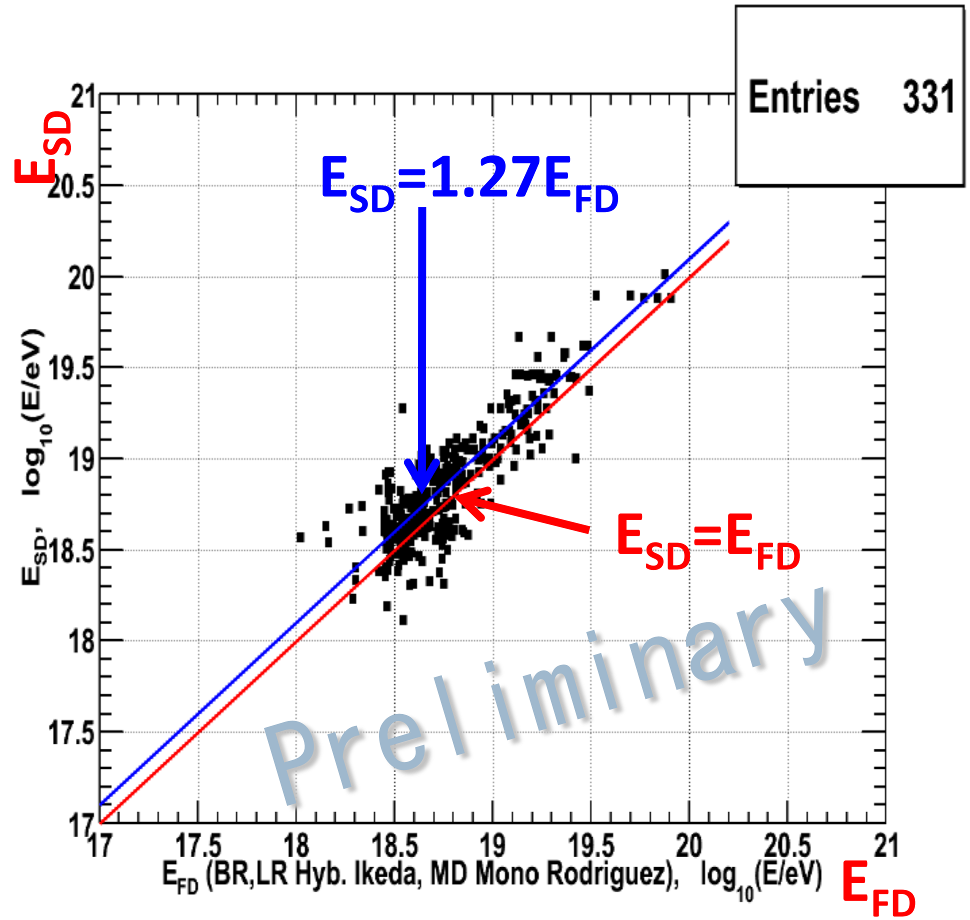
Zenith angle



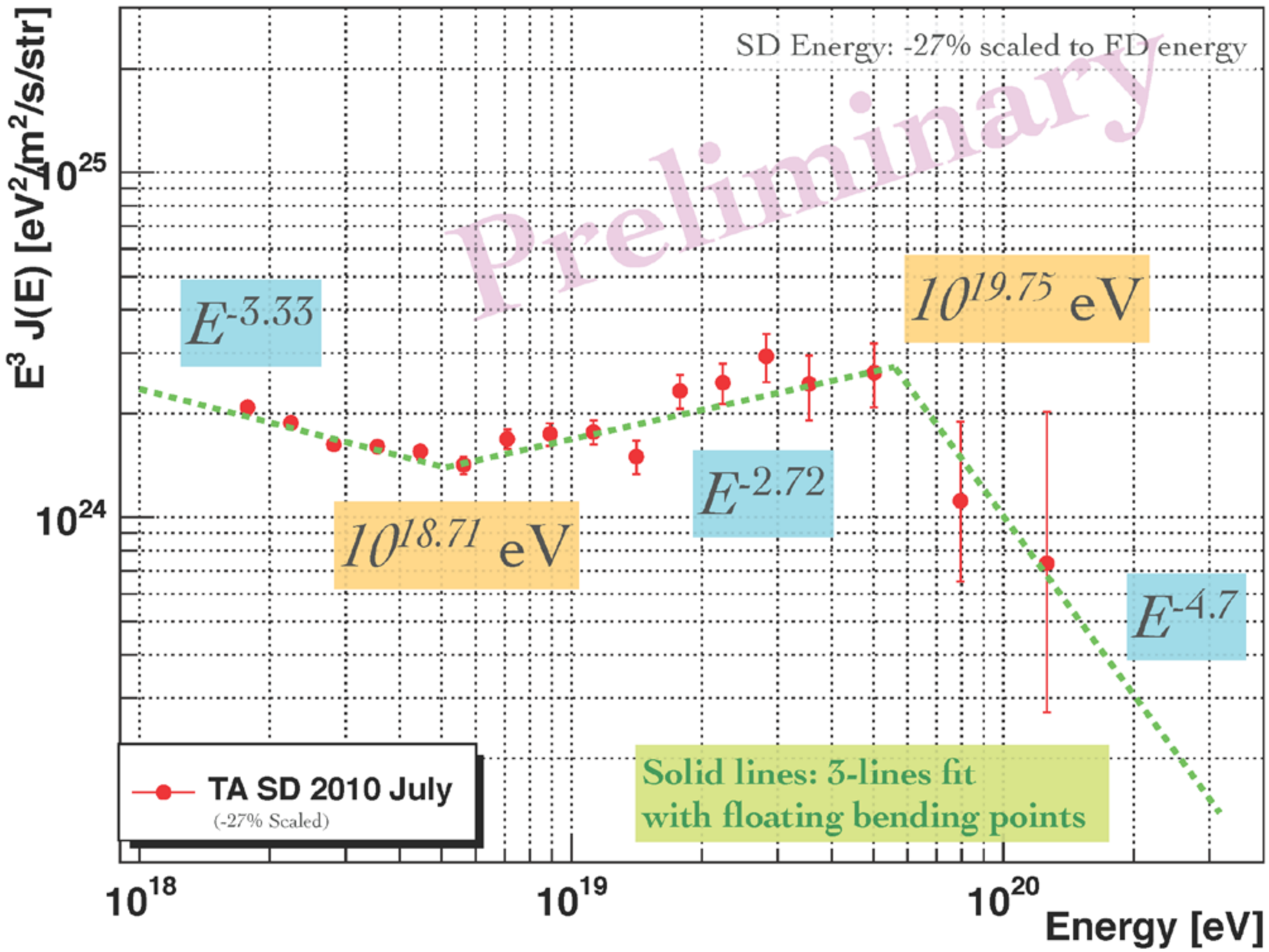
- Spectrum & composition are previously measured ones.
- COSIKA/QGSJet-II is used.
- Both of Data & MC are analyzed by same program.

TA energy scale (FD vs. SD)

- Energy scale is determined experimentally by FD.
- Set SD energy scale to FD energy scale using well-reconstructed events seen by both detectors:
- <u>27% renormalization.</u>
  - Systematic error is obtained as ~19% from "hybrid data analysis".



TA SD Spectrum

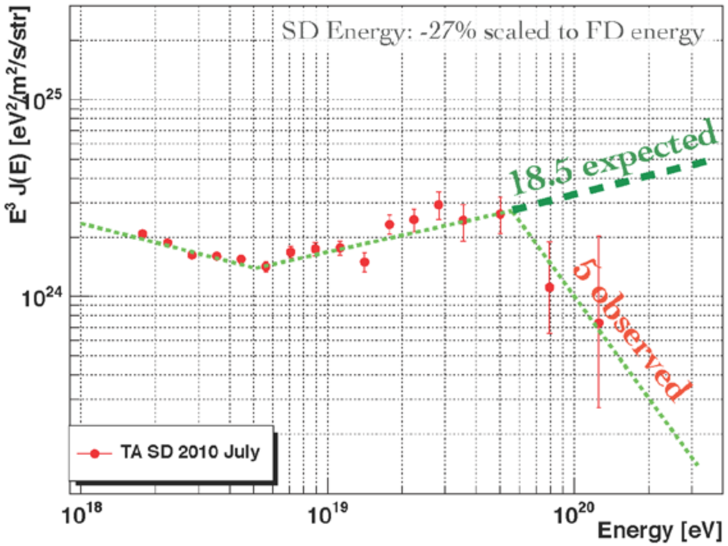


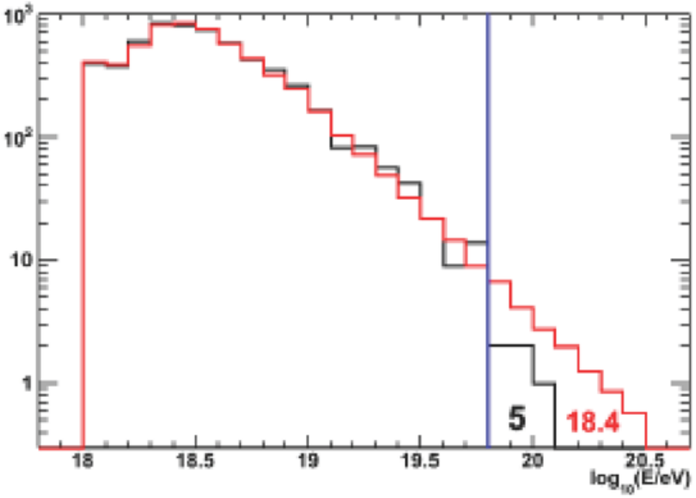
Significance of suppression

- Assuming no suppression and extend the broken power low fit beyond the cut off.
- # of events in $\log_{10}E$ bins after $10^{19.8}$eV.
  - Expected : 18.4 events
  - Observed : 5 events

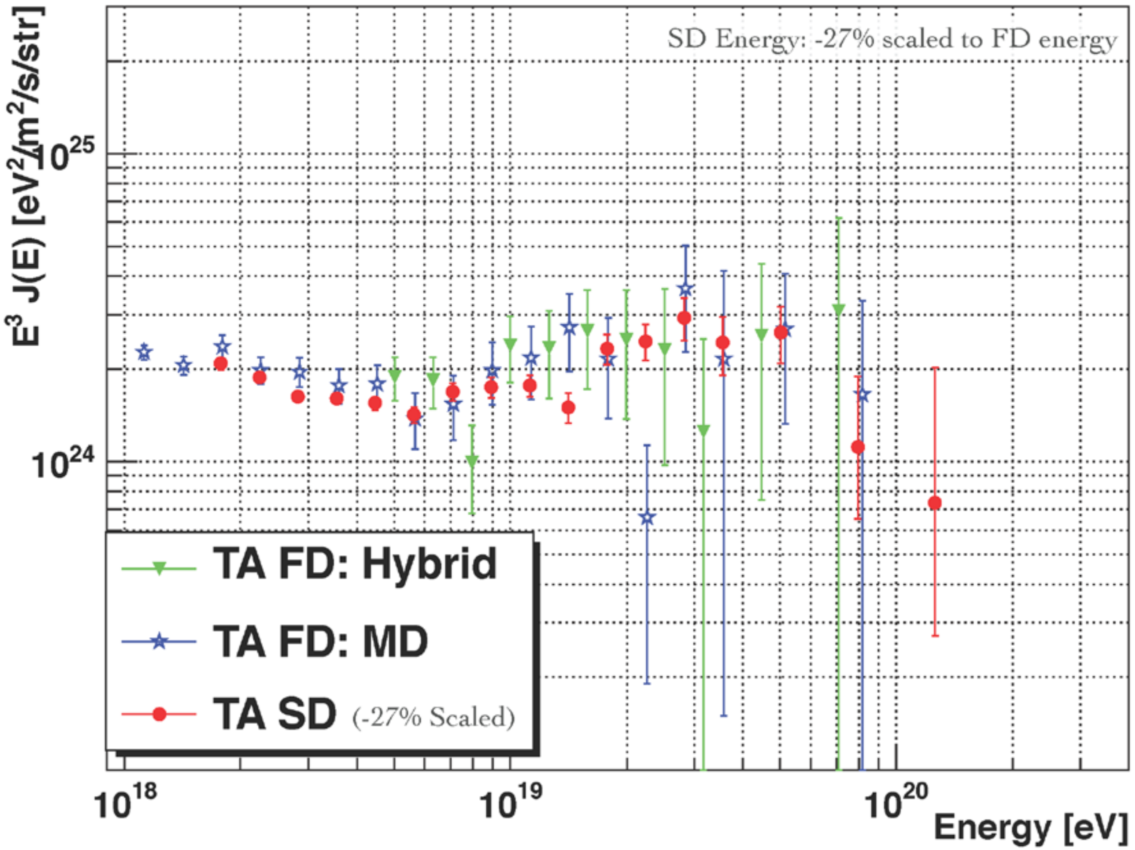
$$P = \sum_{i=0}^{5} Poisson(\mu = 18.4; i) = 2.41 \times 10^{-4}$$

(3.5σ)

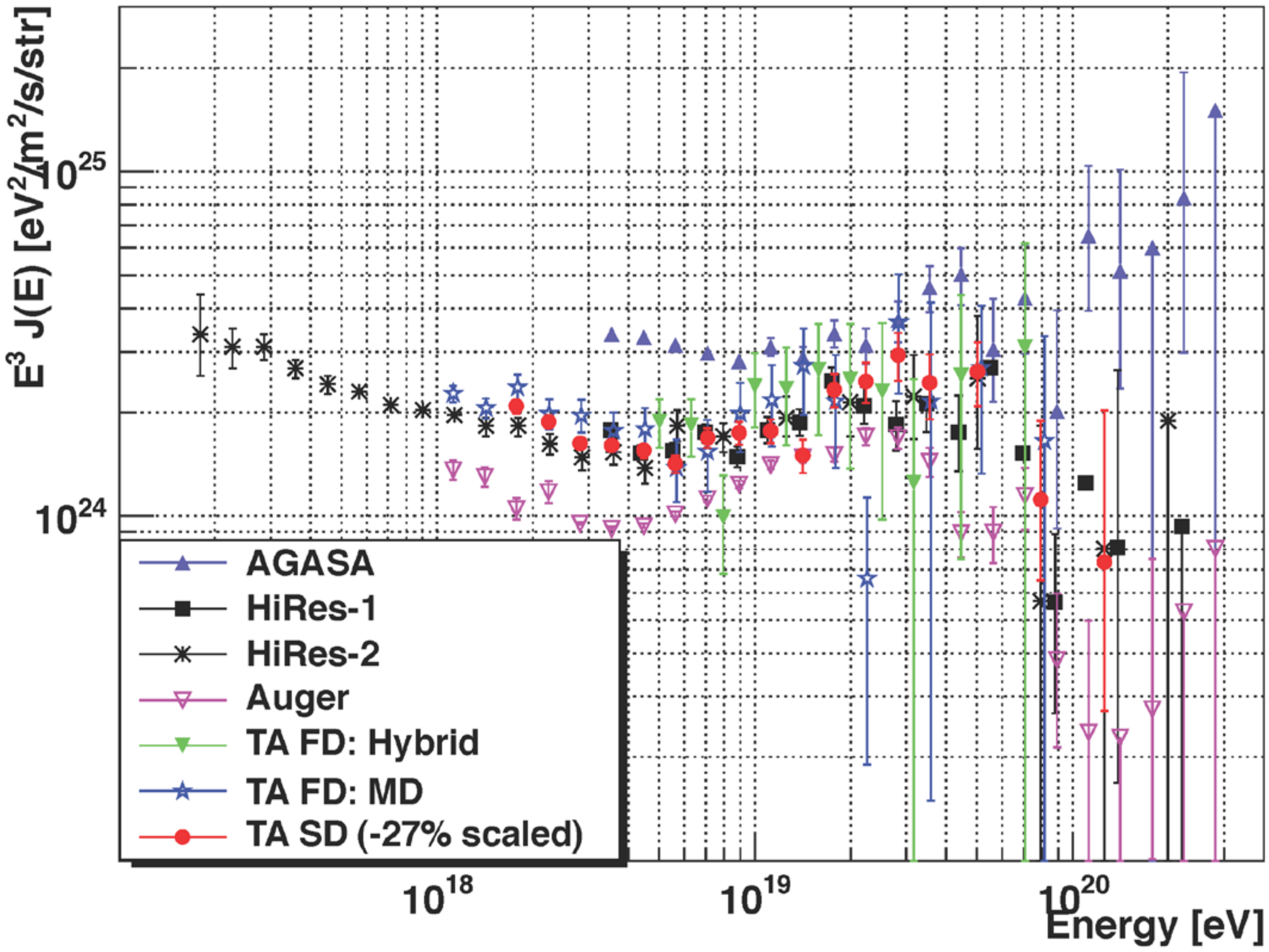




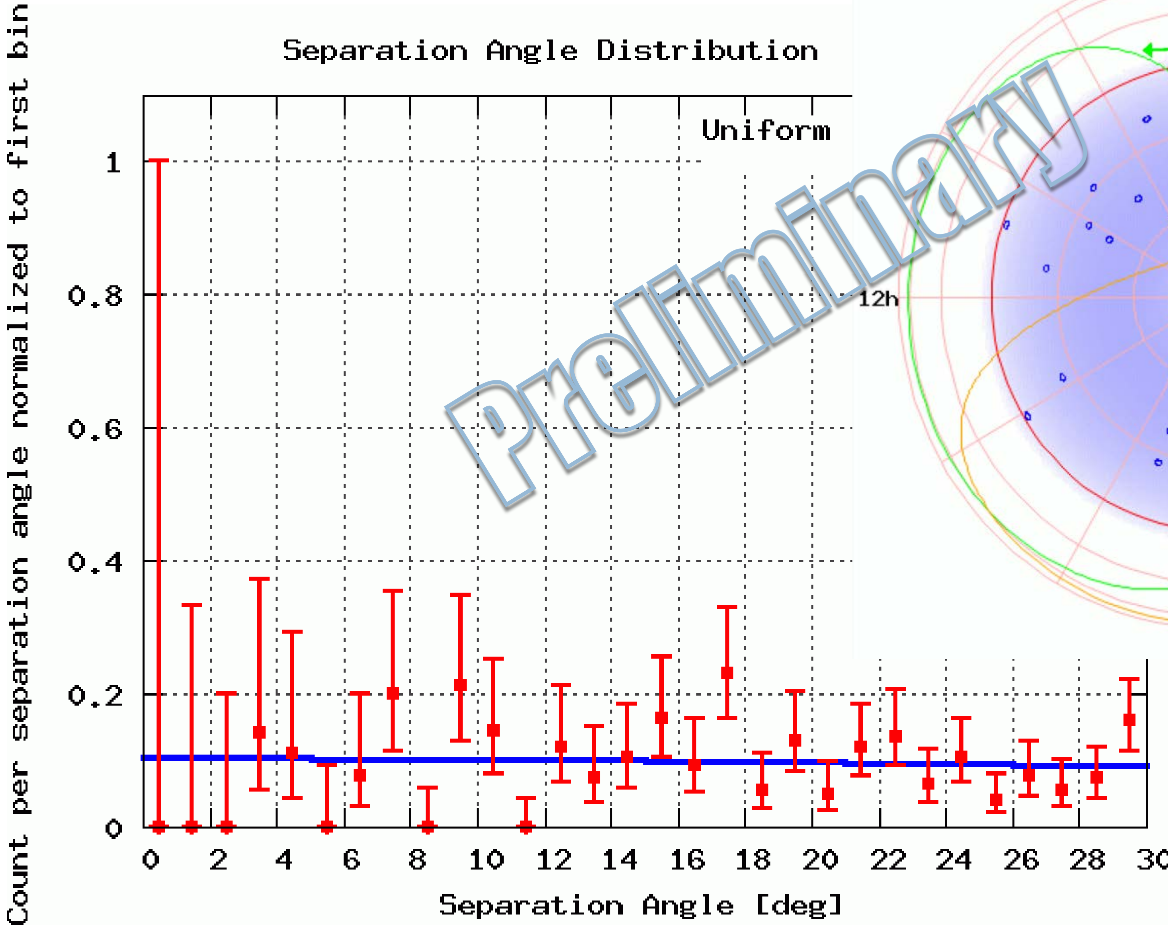
TA CR energy spectrum

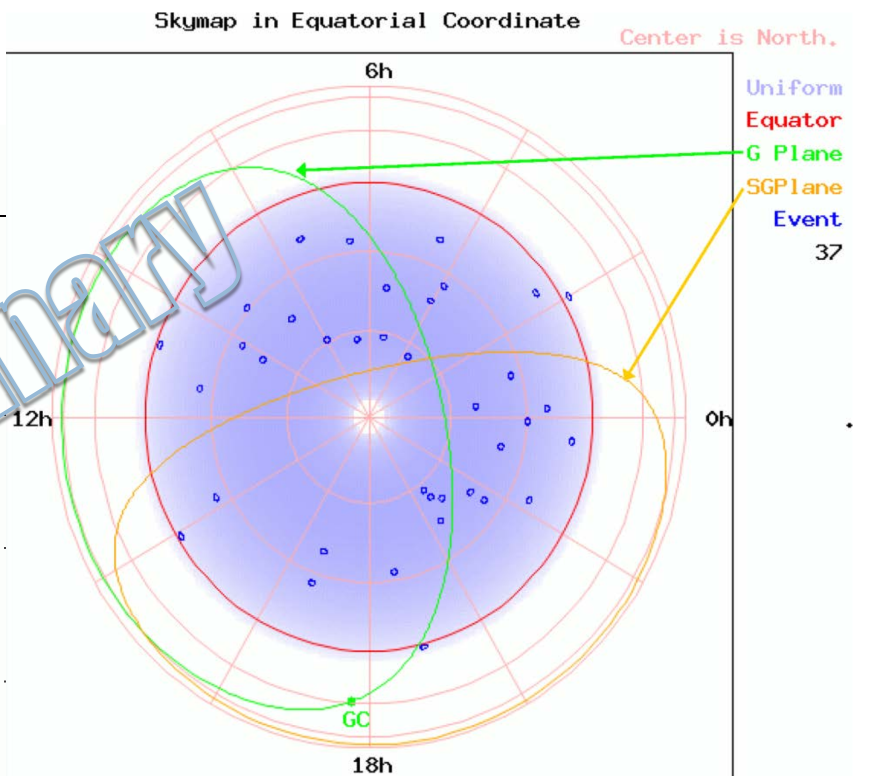


Spectrum comparison

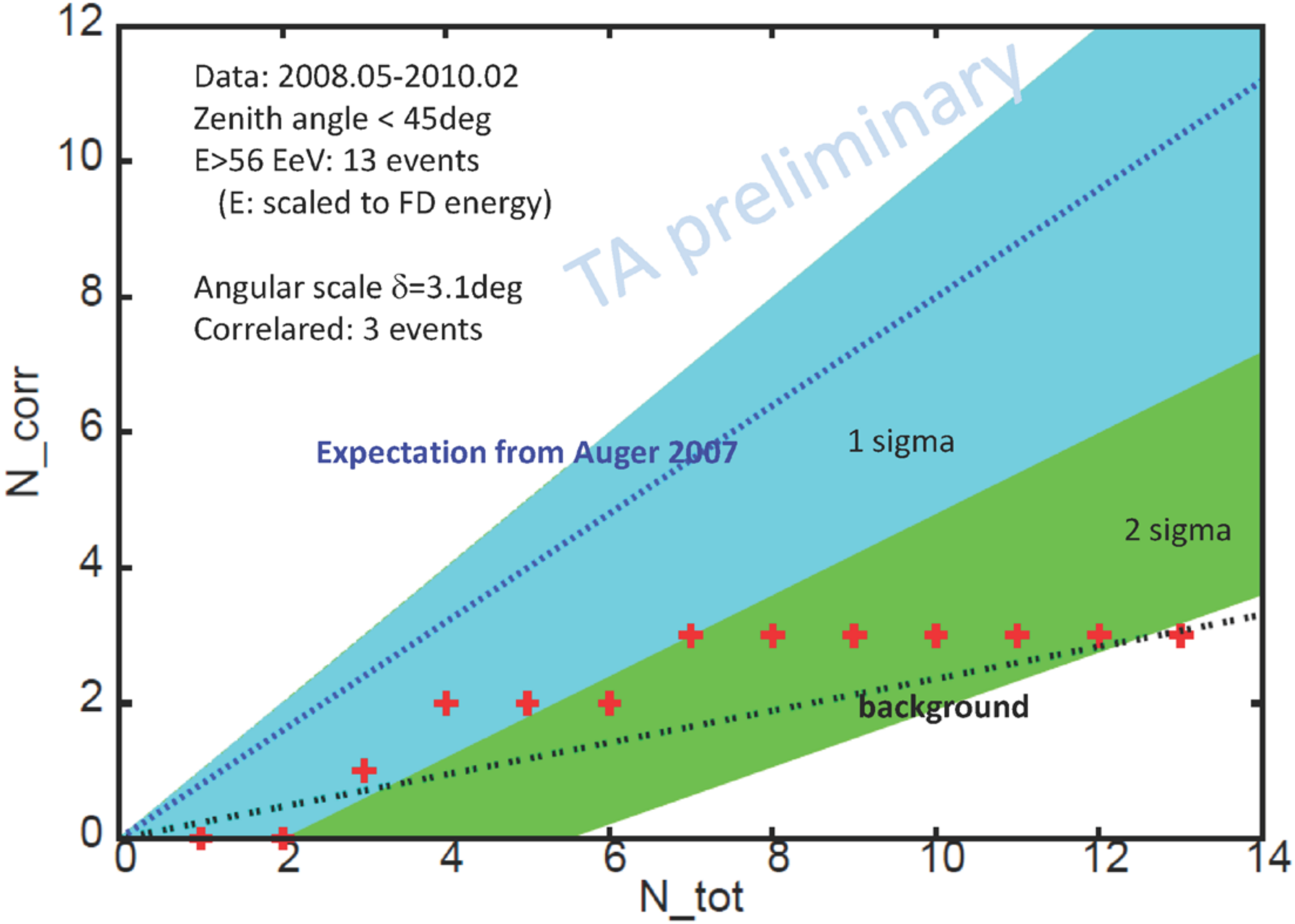


Skymap & autocorrelation (E>40EeV)



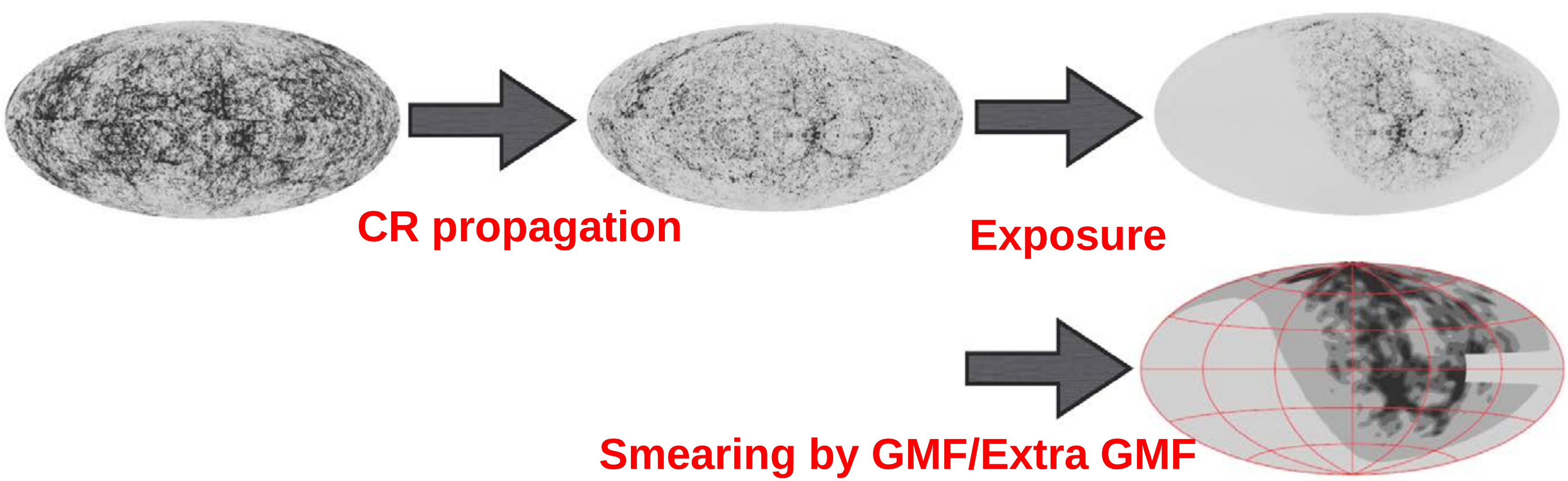


Correlation to AGNs

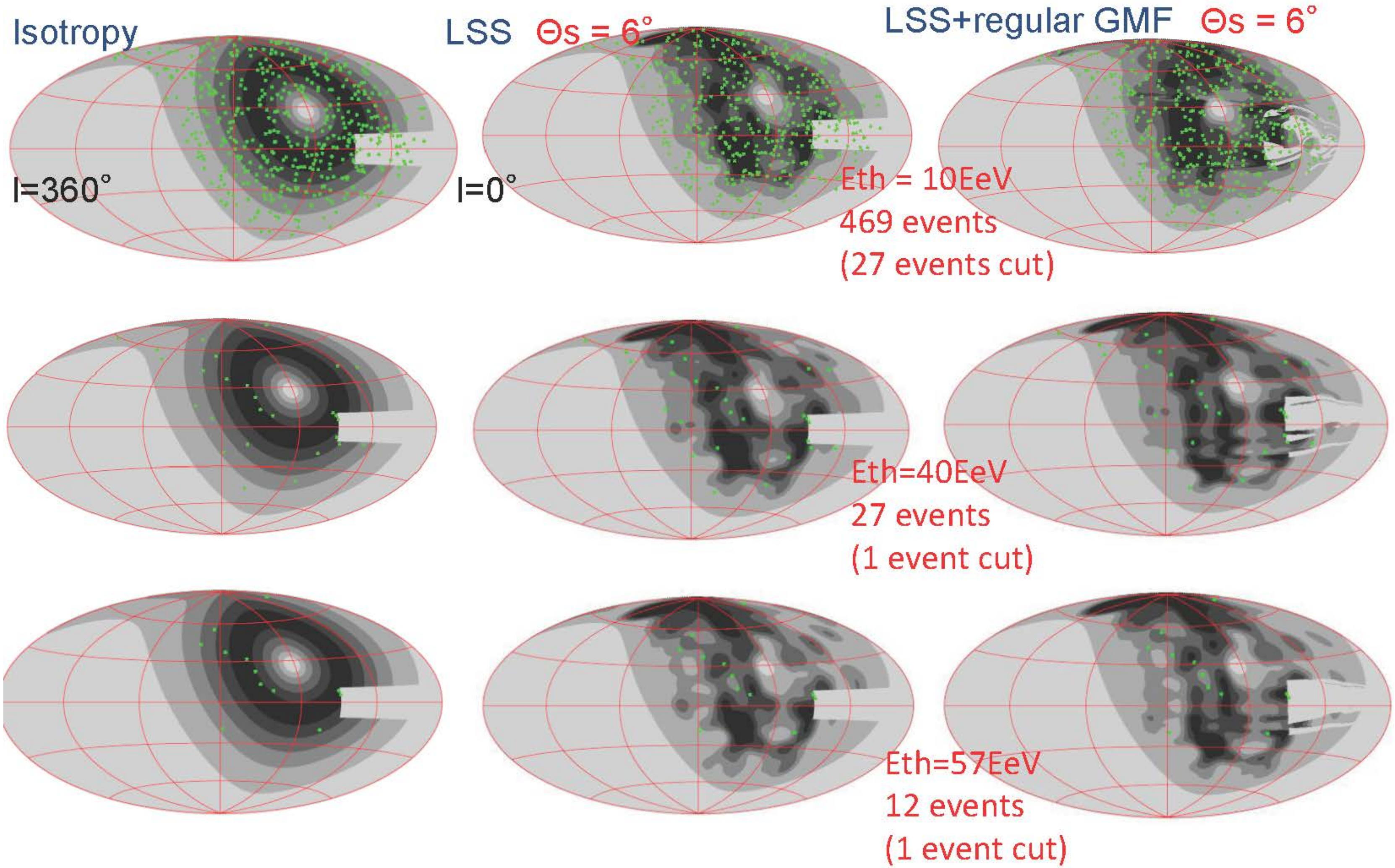


UHECR map from LSS

- Galaxy catalogue : 2Mass Extended Sources (XSCz)
  - $m<12.5$, $5 < D < 250$ [Mpc]
- Propagation : Interaction with CMB, 4π dilution
  - Assume same CR luminosity
  - Injection : photon, $E^{-2.2}$

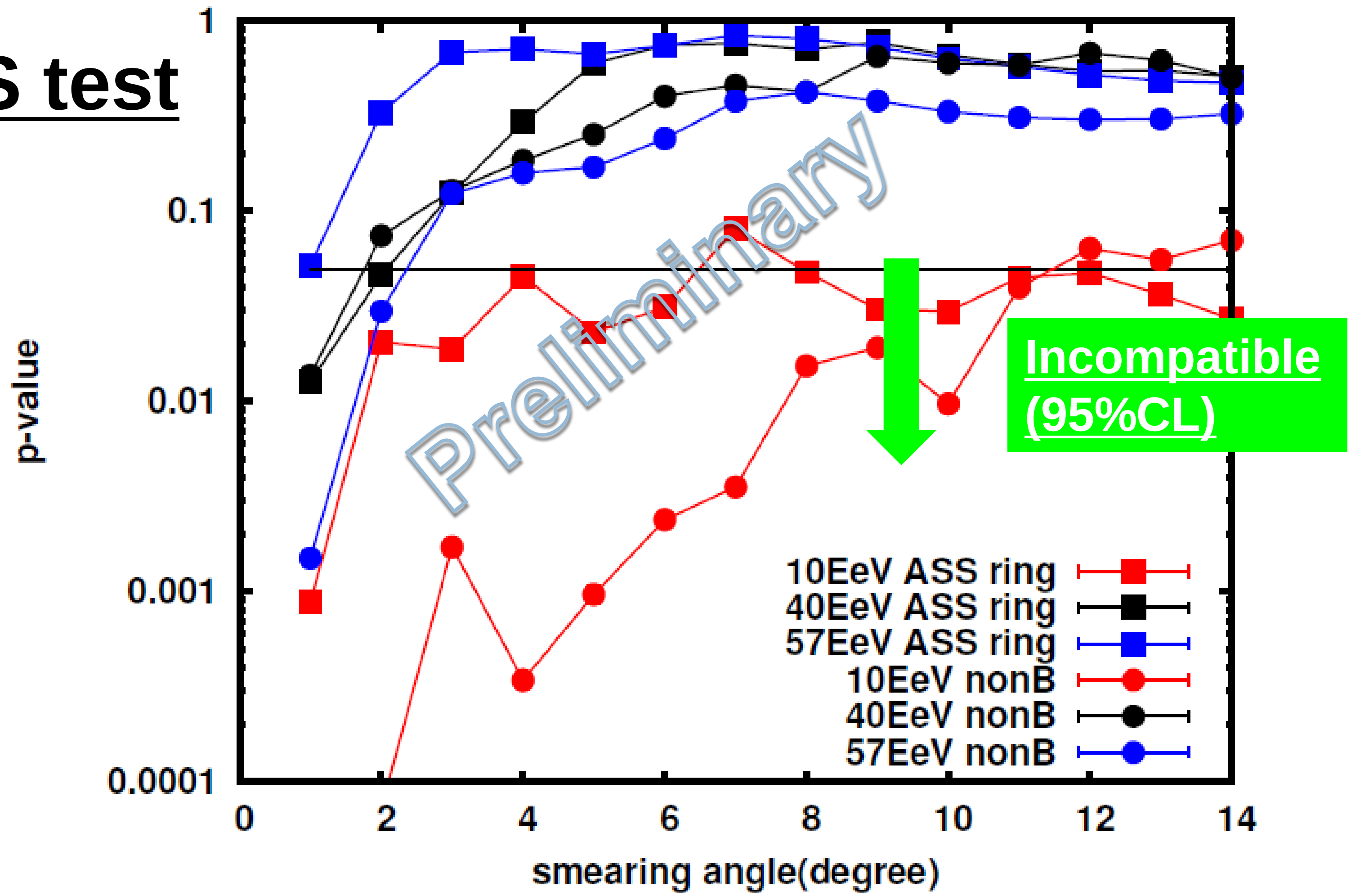


Skymap : LSS correlation



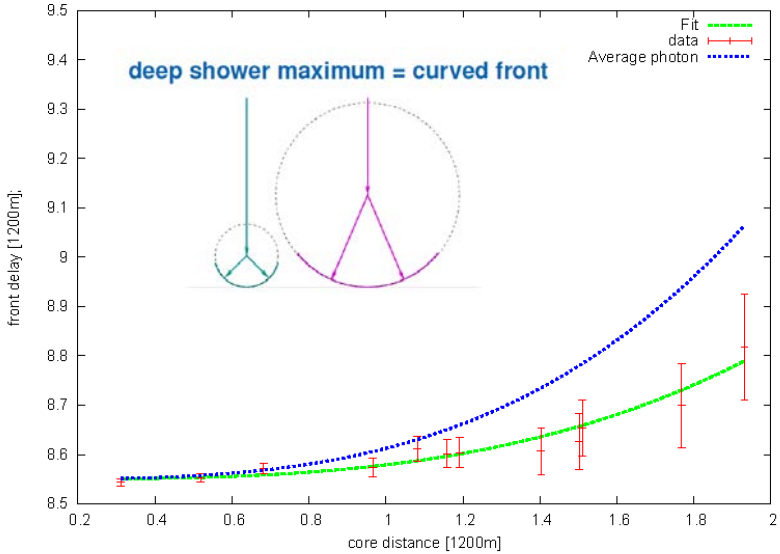
Hypothesis test

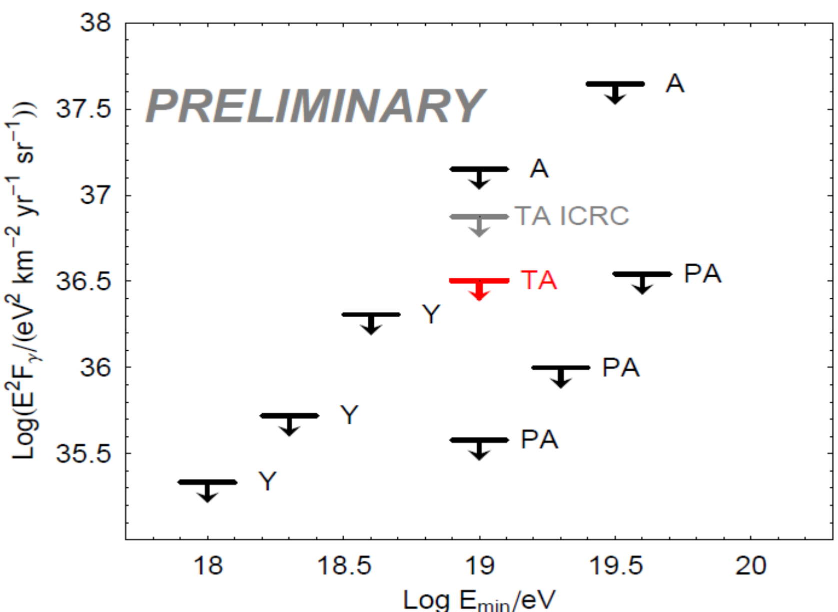
KS test



Incompatible with LSS correlation hypothesis for small smearing angle

UHE photon limit from SD data





- Photon showers
  - Deeply penetrated
  - Large curvature at the shower front.
- Event select conditions
  - $E\gamma > 10^{19}$eV
  - Zenith angle : $45^o < \theta < 60^o$
  - P/γ separation by MC studies.
  - Exposure : 158 [km^2 yr sr]
  - $F\gamma < 3.3 \times 10^{-2}$ [km^{-2} yr^{-1} sr^{-1}] **(95% CL)**

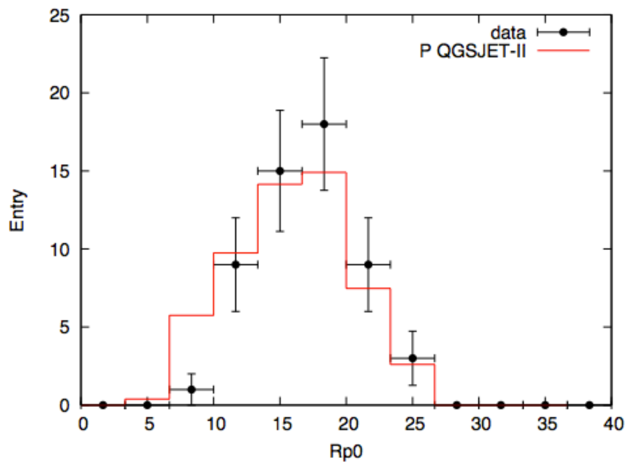
FD Stereo: Mass composition

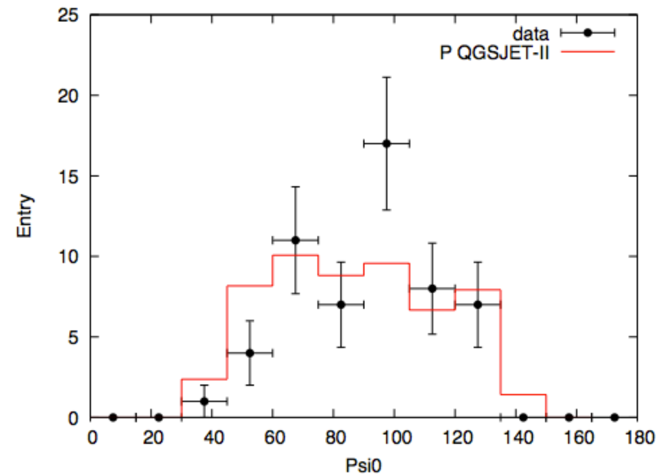
- Measure x_{max} for BRM/LR FD stereo events
- Apply strict quality cuts in order to improve x_{max} resolution
- Shower simulation
  - CORSIKA with QGSJET01, QGSJET-II, SIBYLL
  - Primary ; proton/iron
- Apply exactly the same procedure as with the data

Data/MC Comparisons

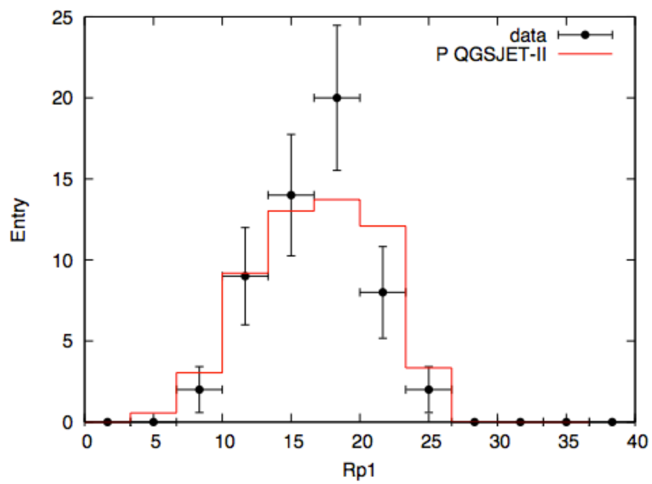
Impact parameter[km] **Azimuth angle [deg]**

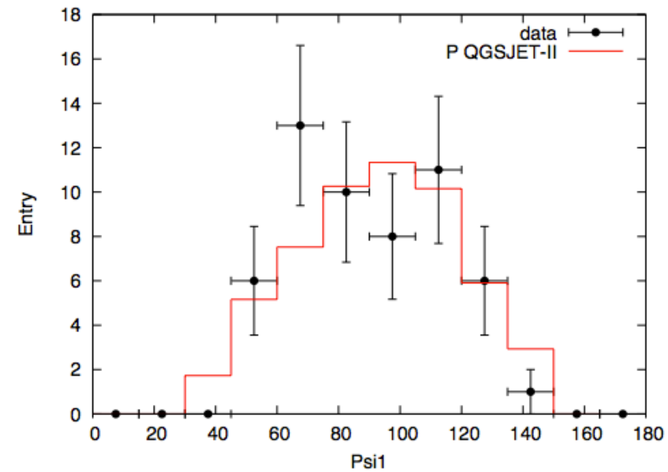
BRM



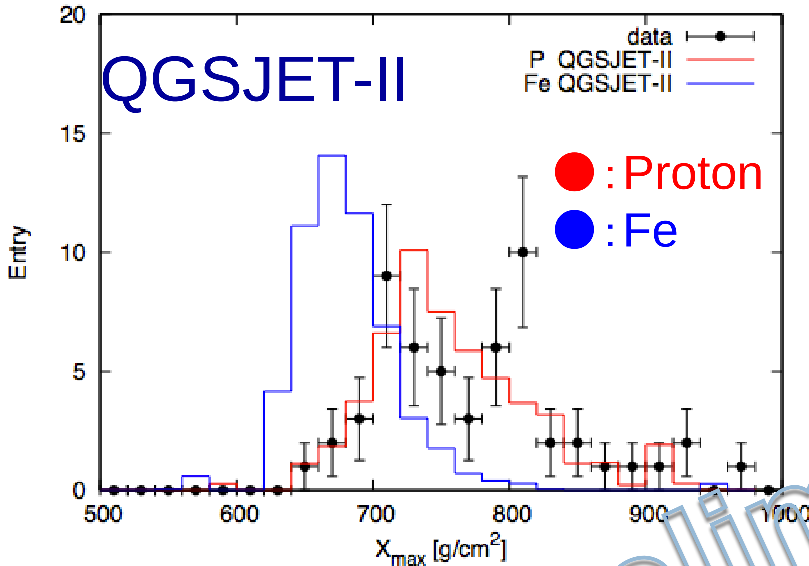


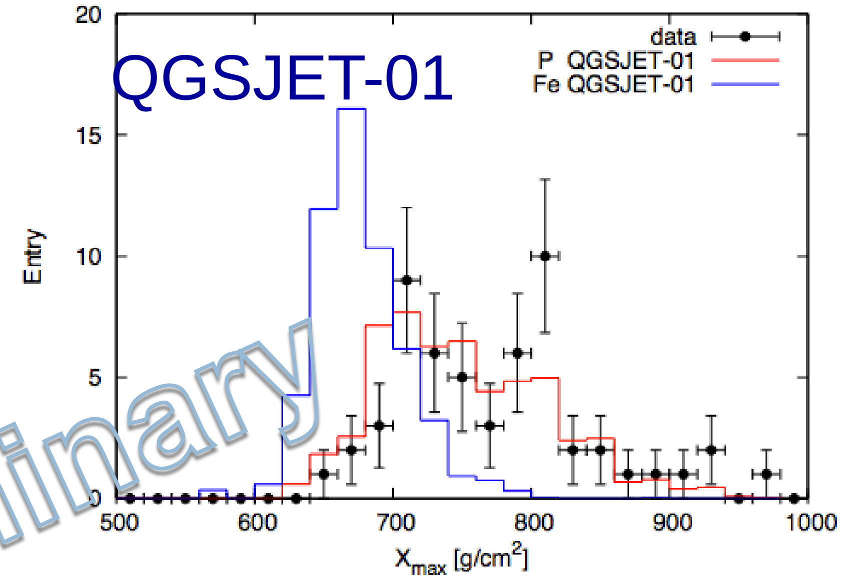
LR

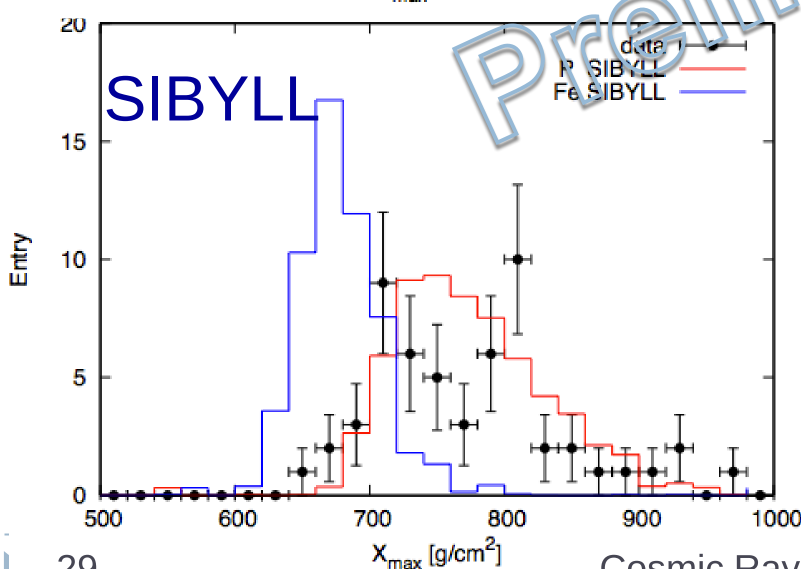




X_{max} Data/MC comparison



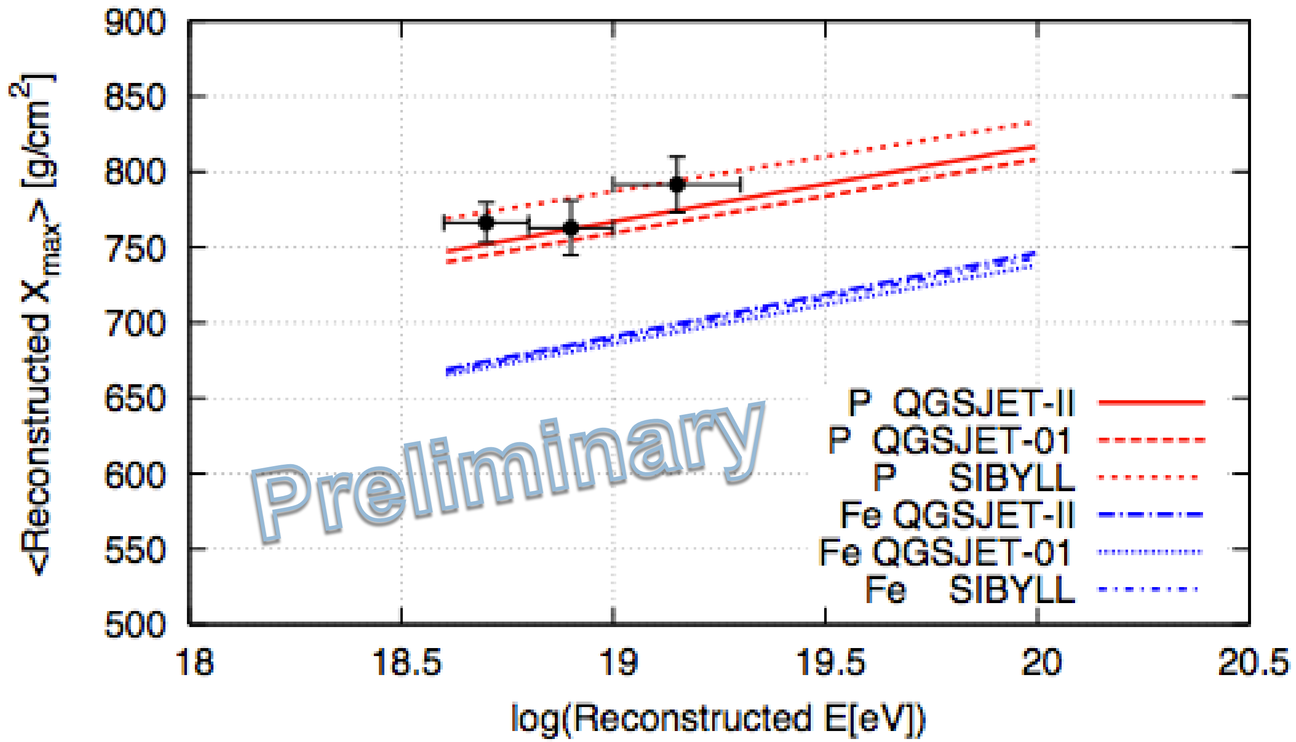




$\chi 2$/dof of each models

	QGSJET-II	QGSJET-01	SIBYLL
Proton	**1.44**	**1.06**	**1.63**
Iron	**55.54**	**56.67**	**85.71**

Energy averaged Xmax



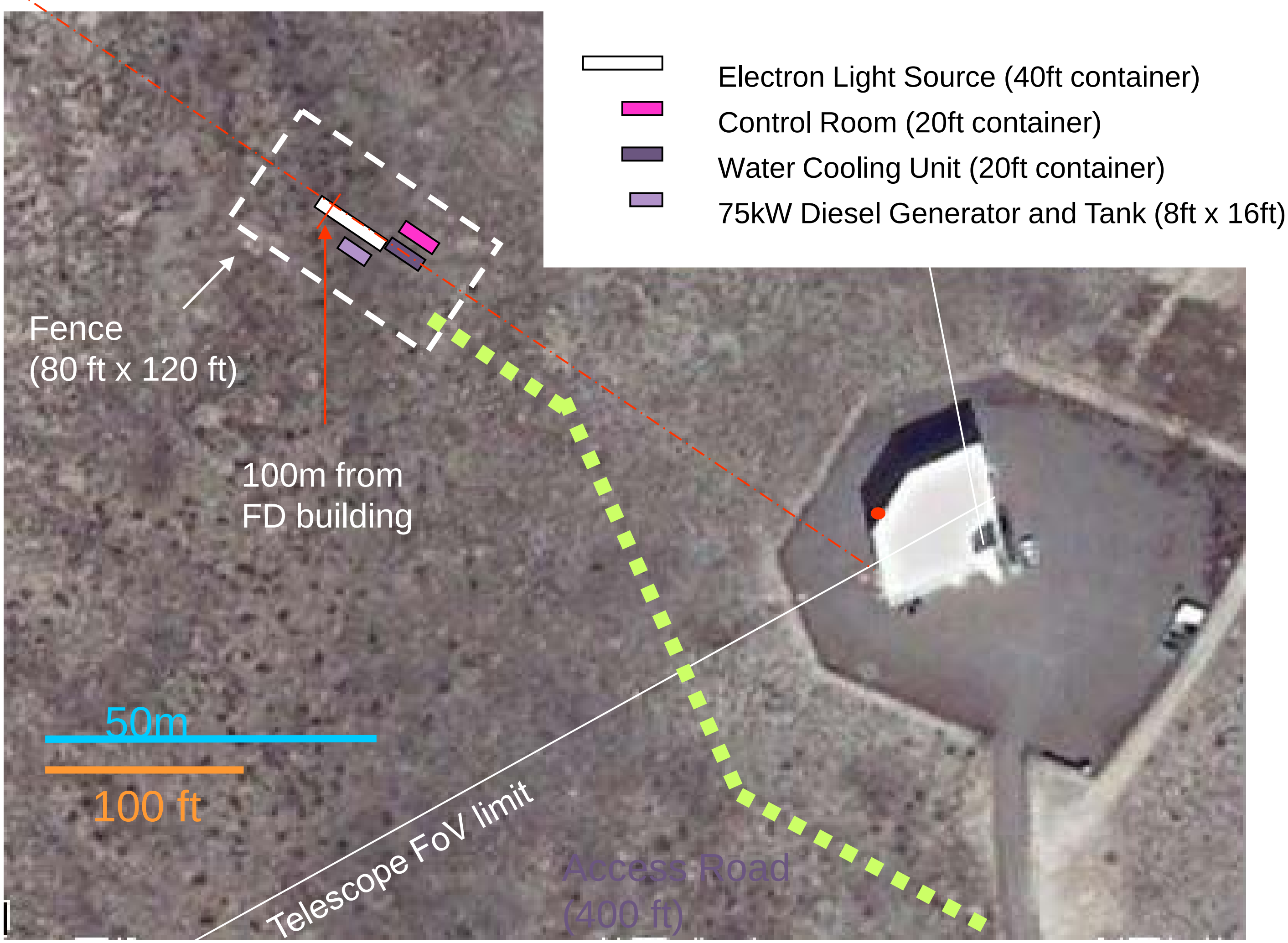
Preliminary result is consistent with proton hypothesis.

Near future prospects

- New calibration tool for FD (Electron light source) is installed and start shooting.
- Hybrid trigger is installed on Feb. 2010
  - SD array can be triggered by FD trigger too.
  - Energy threshold of hybrid data should become lower.
- Low energy extension is planed.
- Very preliminary study of TA-phase II

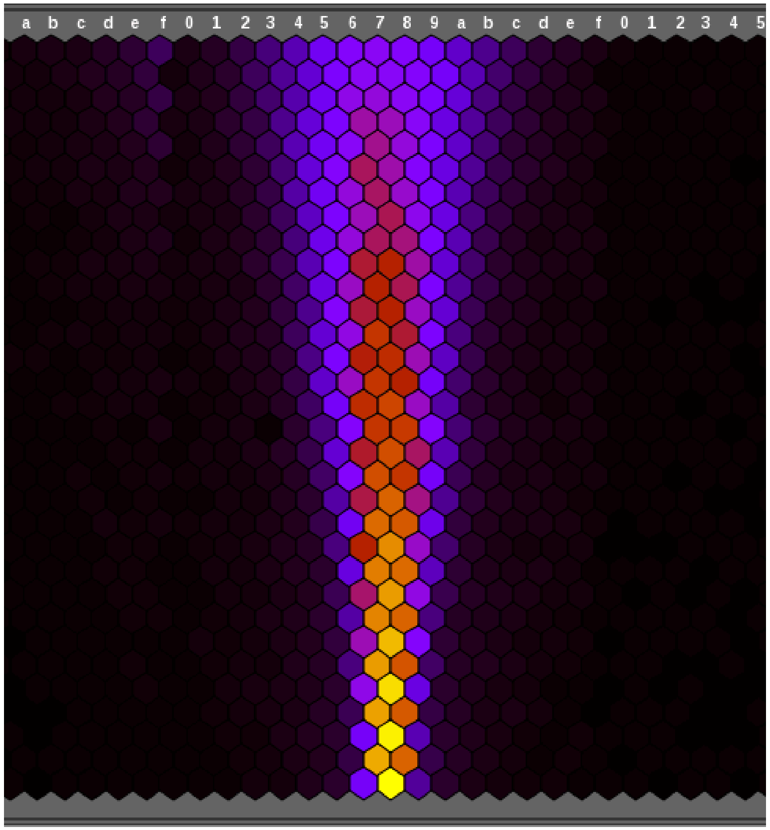
Electron Light Source (LINAC)

TA Electron Light Source @ BRM



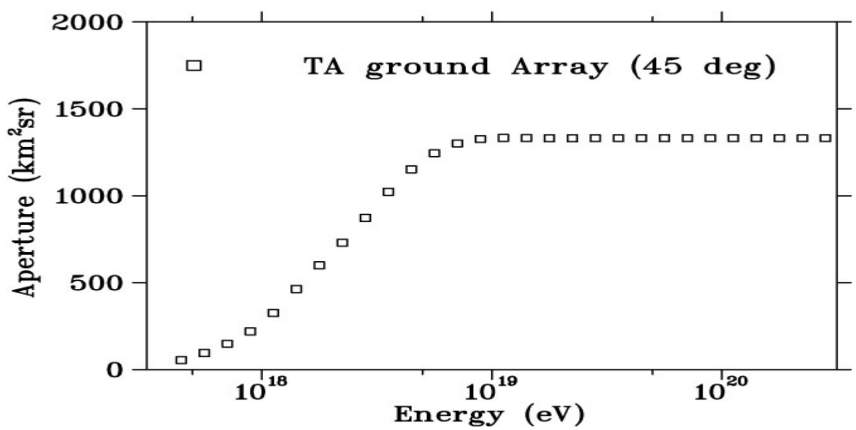
ELS in desert (Feb. 2010)

ELS First Light!!



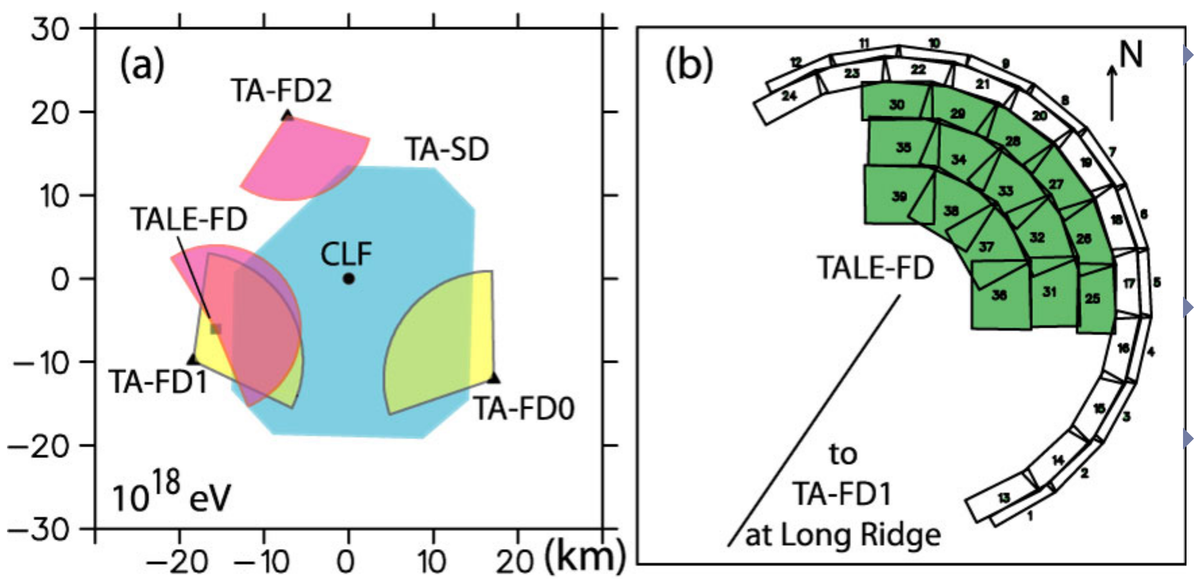
- First beam shot into the sky on Sep. 2010.
- Absolutely calibrated mono-energy (40MeV) e^- beam.
- Automatically takes into account fluorescence yield (λ) and detector efficiencies.
- Data analysis is now going on.

TA Low energy Extension (TALE)



Purpose is :

To lower the trigger threshold of TA to ~3×10^{16}eV for the measurements between galactic and extra-galactic regions.



- 4^{th} Fluorescence Station – 6 km separation
  - 24 telescopes (3-31° elevation) - "ring 1 & 2"
  - 15 large area Tower telescopes (31-73° elevation)
- Infill scintillator array 111 ($3m^2$/ea) detectors at 400 m spacing
- Graded muon array - 25 ($12m^2$ /ea) detectors, buried 3 m

Summary

- Operation of TA is quite stable.
- Preliminary results are shown:
  - FD-mono result is consistent with HiRes.
  - FD-SD hybrid result is also consistent with Hires.
  - Shape of energy spectrum from SD data also shows the suppression above $10^{19.75}$eV.
    - SD energy is scaled to FD energy scale.
  - Observed Xmax is consistent with the proton dominant case.
  - Arrival direction
    - No correlation with known sources.
    - No significant clusters
- More TA results are coming soon.