Recent Results and Plan from Telescope Array

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- TA Detectors
- Shower analysis
- Energy spectra
    - SD, FD, Hybrid…
- Mass composition
    - X_{max} analysis
- Anisotropy
    - AGN correlation
    - Large scale
- New Projects

IKEDA Daisuke

ICRR, University of Tokyo

for the Telescope Array Collaboration

The Telescope Array Collaboration

International collaboration that consists of about 140 researchers, 26 institutions from Japan/US/Korea/Russia/Belgium

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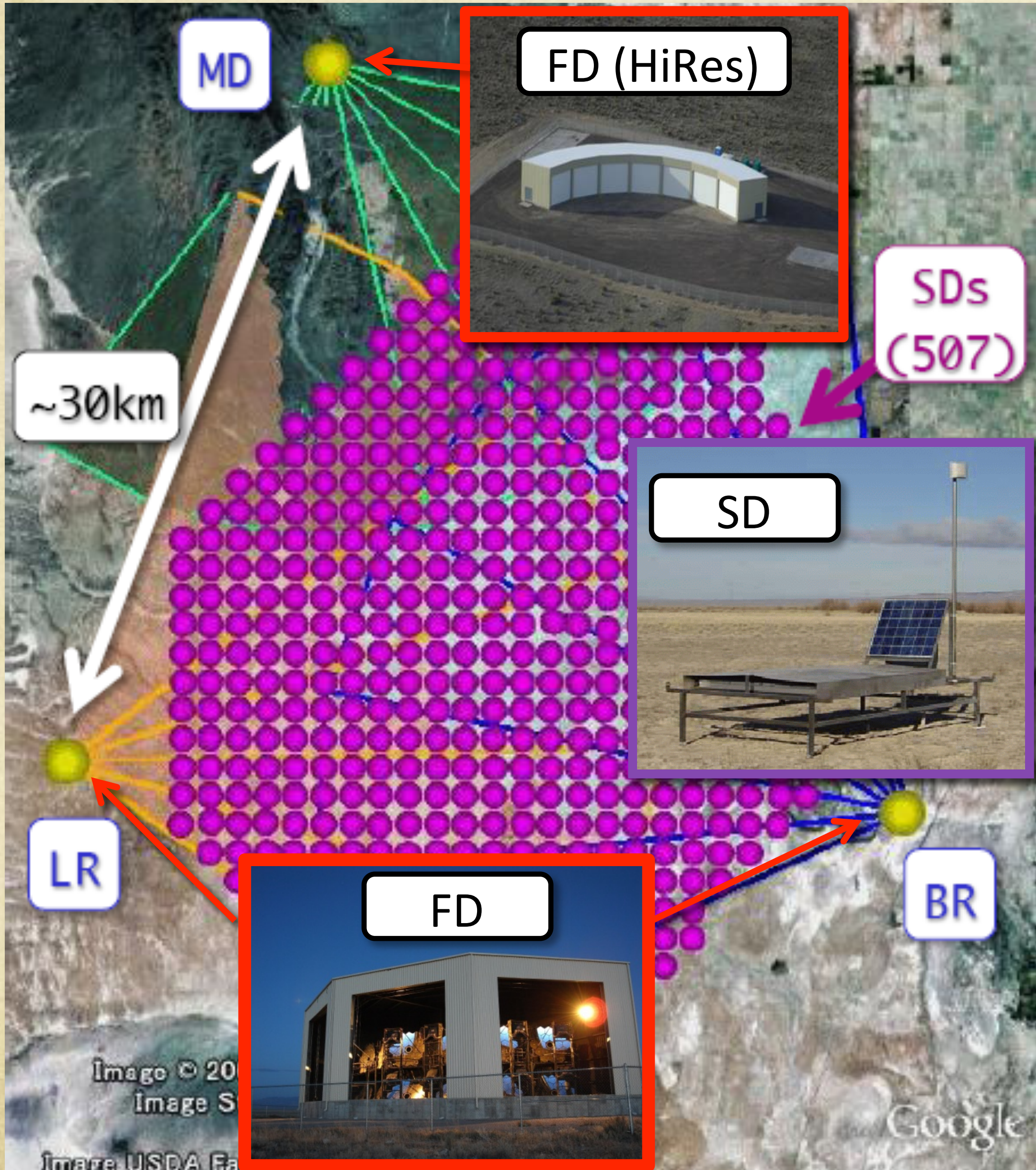
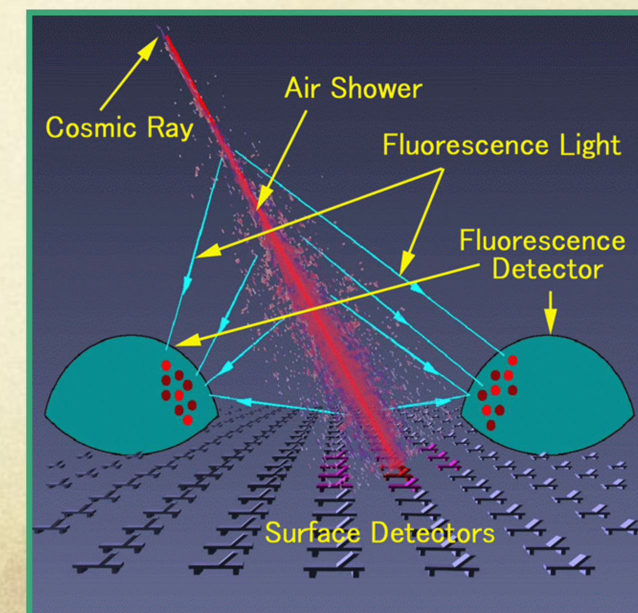
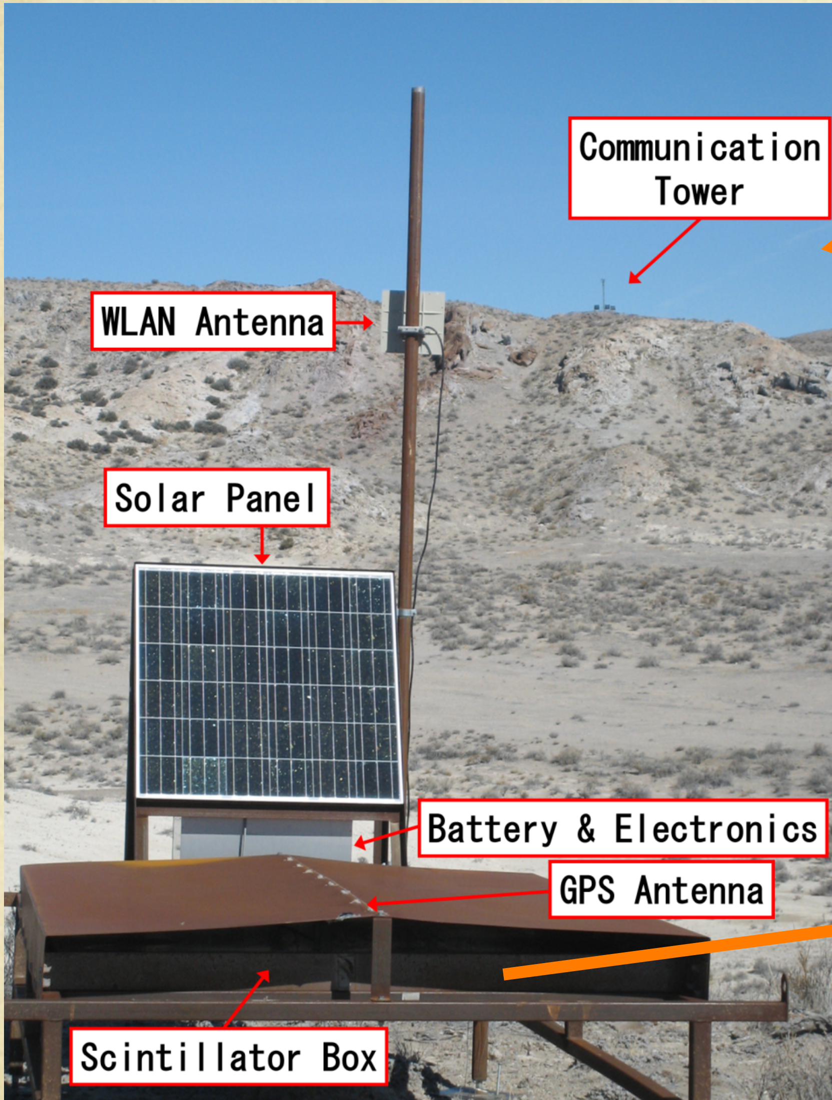
Telescope Array Experiment

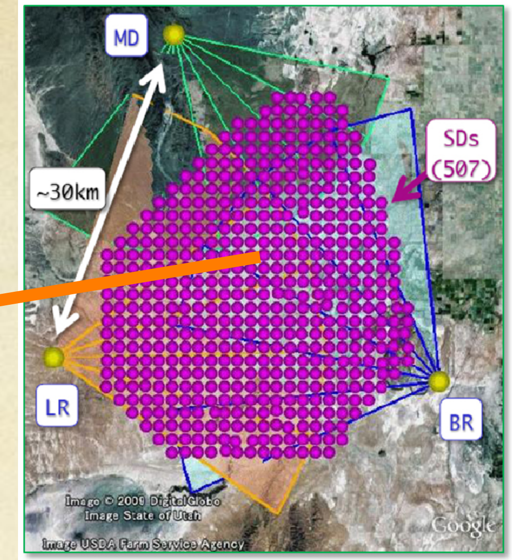


- Desert in Utah, US (1400m a.s.l.)
- 507 Surface Detectors (SDs)
  - 1.2km spacing
  - Two layer of plastic scintillator, $3m^2$, 1.2cm thickness
- 3 Fluorescence Detectors (FDs)
  - Middle Drum (MD) station is transferred from HiRes.
  - Black Rock (BR) and Long Ridge(LR) stations are newly built.
- FD observation : from Nov/2007
- SD observation : from Mar/2008

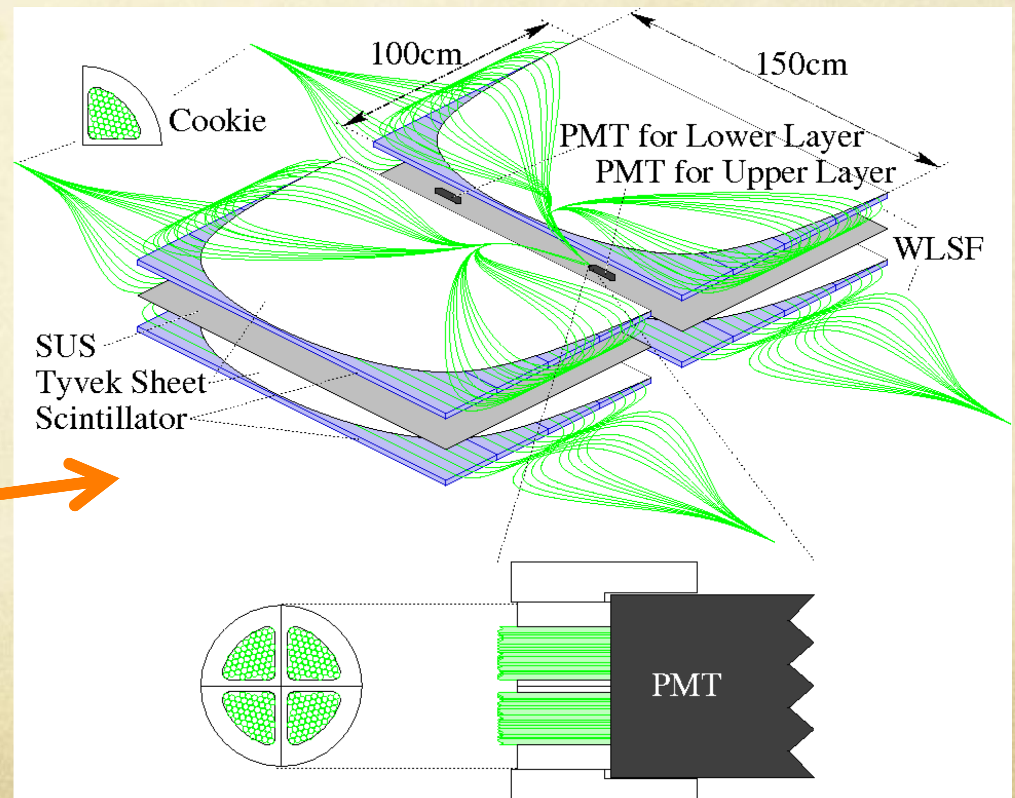


Surface Detector array

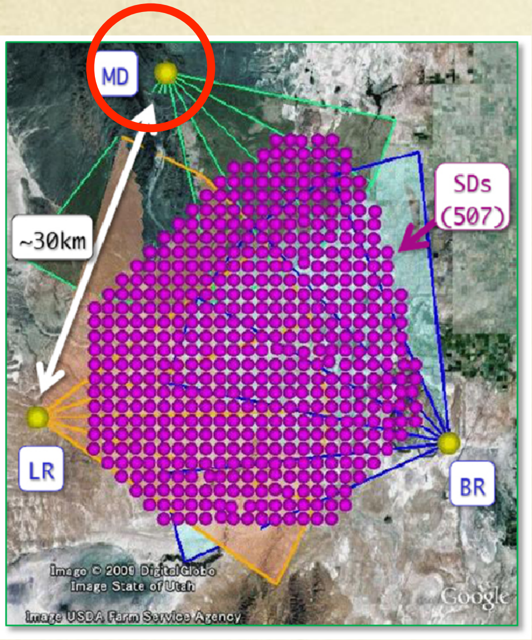




- Two layers of the 3m^2 plastic scintillators



Fluorescence Detector station at MD site

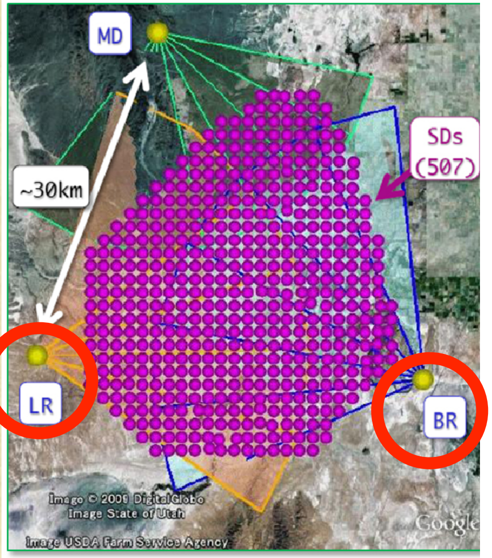


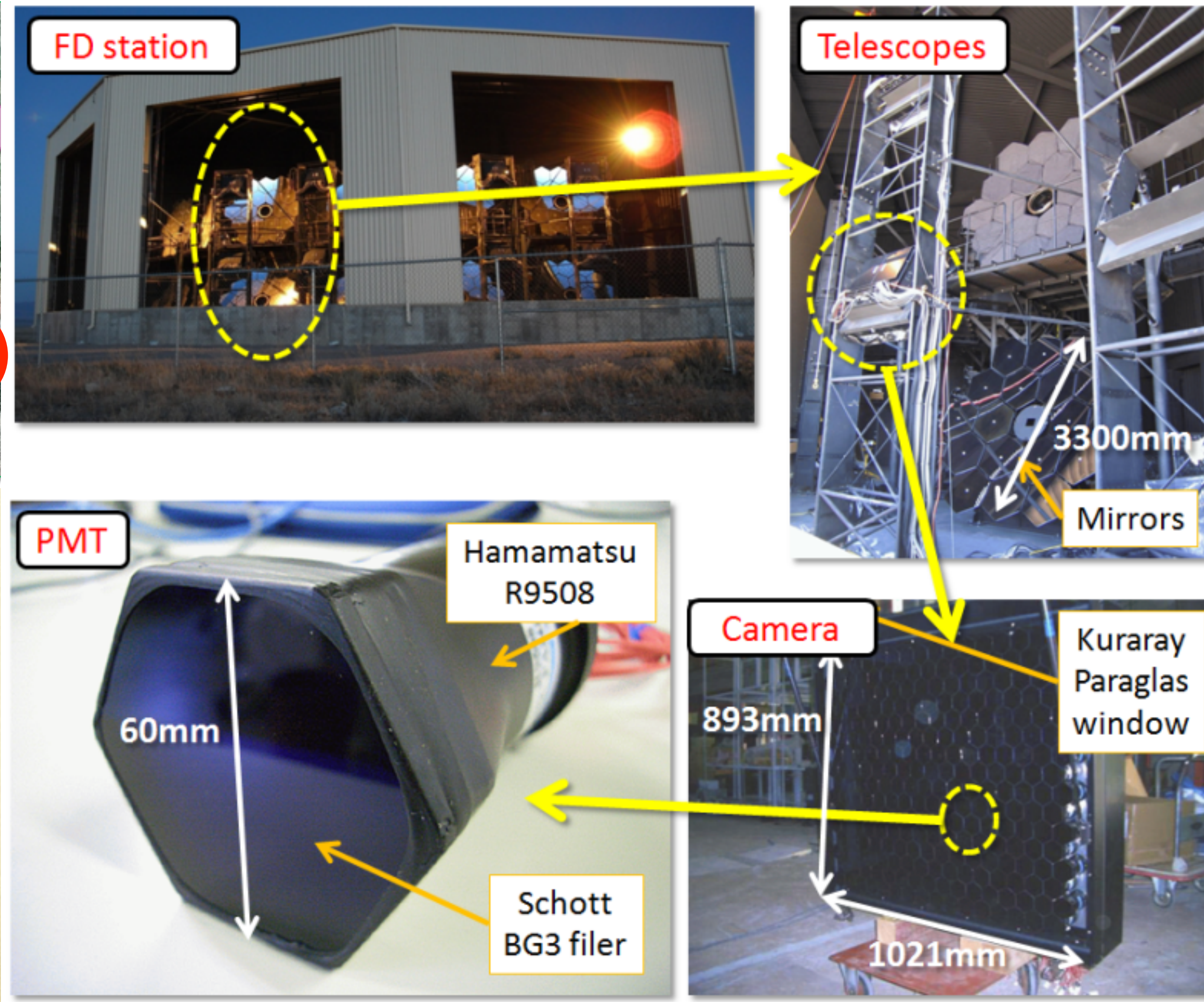
Transferred from HiRes

- 14 cameras/station
- 256 PMTs/camera
- 3^o-31^o elevation with 1^o pixel
- 114^o in azimuth
- $5.2m^2$ mirror
- S/H electronics

Fluorescence Detector station at BR/LR site

BR/LR site : new telescopes for TA





F.O.V of station:
- Elevation: 3~33°
- Azimuth: 108°

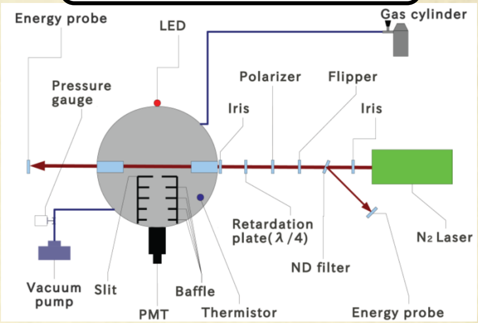
Calibrations for BR/LR

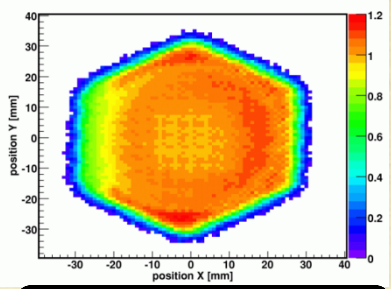
Detector:

•Absolute gain : CRAYS (~8%)
•Aging : YAP pulsar
•Relative gain : Xe flusher
•PMT uniformity : XY-scanner
•Temperature dependence : incubator and LED
•Mirror reflectance : spectrometer

~10%

CRAYS System



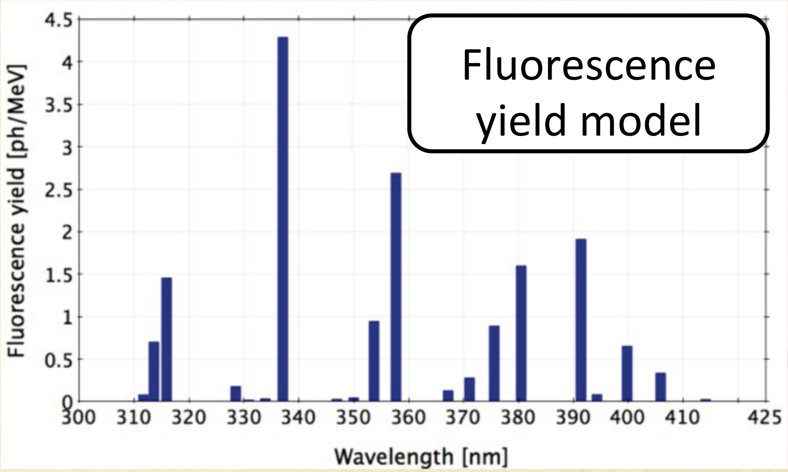


PMT Uniformity

Air showers:

•Fluorescence yield:
   •Spectral lines: FLASH
   •Absolute values: Kakimoto
 If TA model applied to Auger analysis,
   the energy increases by **~9%** (F. Arqueros).
•Cherenkov light: Nerling

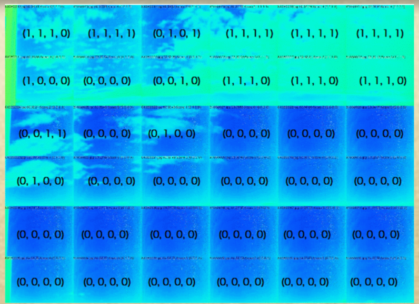
~11%



Atmosphere:

•Transparency : LIDAR
•Temp. , Pressure,... : Radiosonde
•Cloud : IR-Camera and Eye-check

~11%



Shower Analysis

Shower Analysis
- FD Monocular -

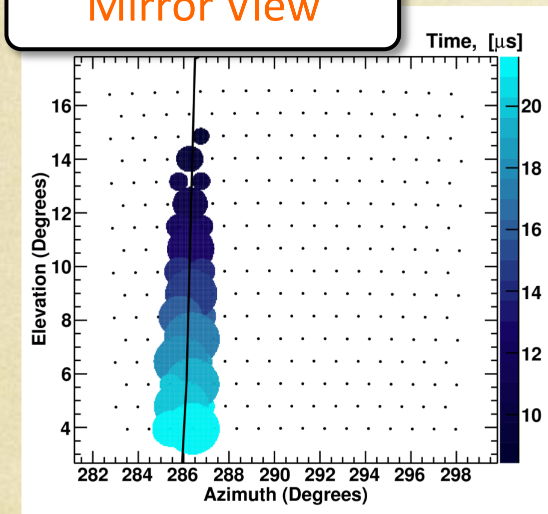
Data set for MD monocular analysis:

- 16/Dec/2007 – 16/Dec/2010 (3 years)
- ~1/3 of HiRes-1 observation

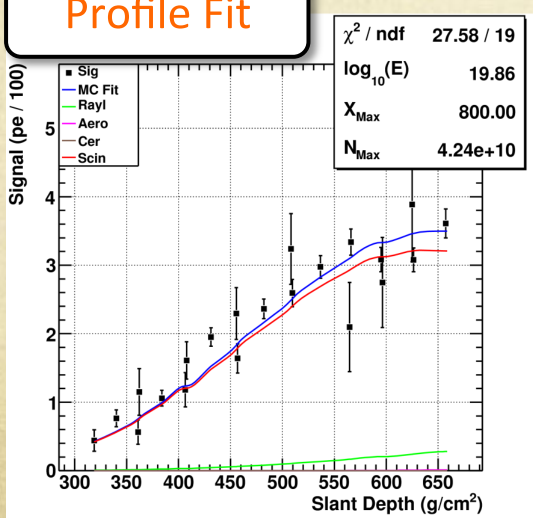
MD station: Transferred from HiRes-I

- Data analysis: Identical to HiRes-I monocular analysis
- Differences: Location, Direction, Trigger threshold…

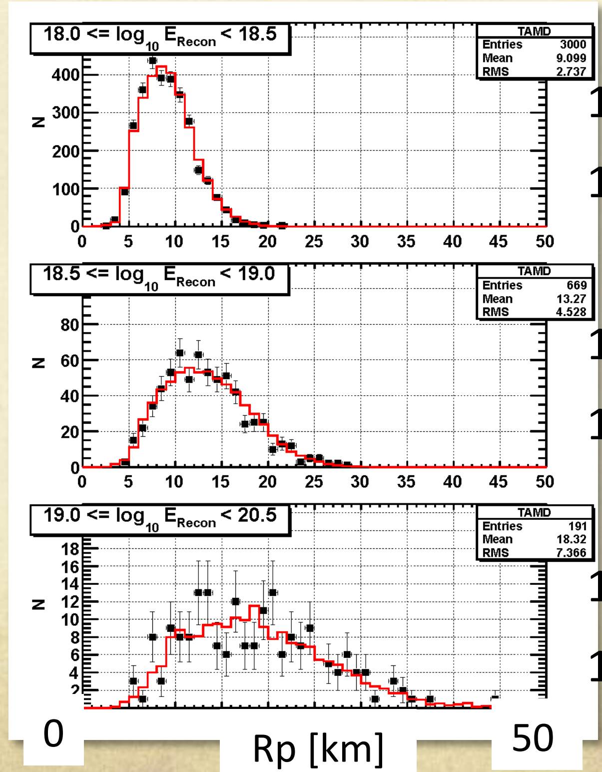
Mirror View



Profile Fit



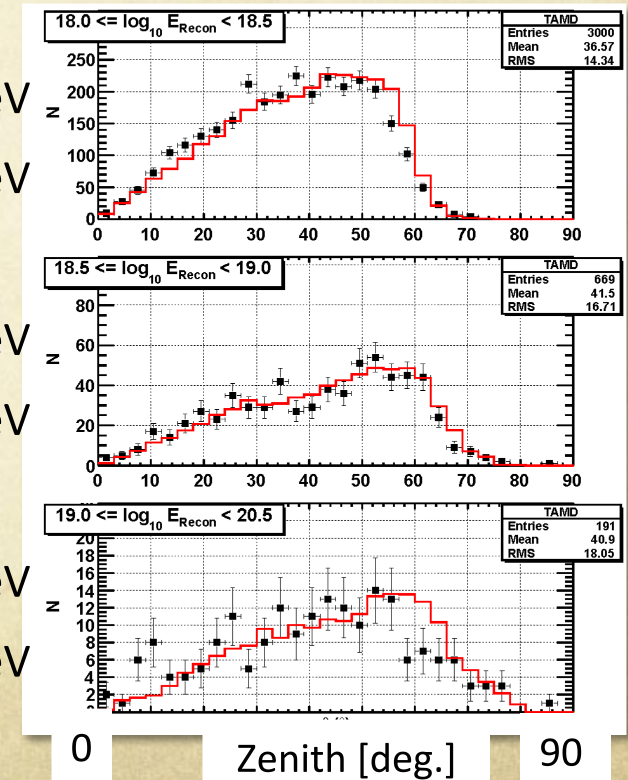
Data/MC comparison with Coriska, Proton



$10^{18.0}$eV ~ $10^{18.5}$eV

$10^{18.5}$eV ~ $10^{19.0}$eV

$10^{19.0}$eV ~ $10^{20.5}$eV



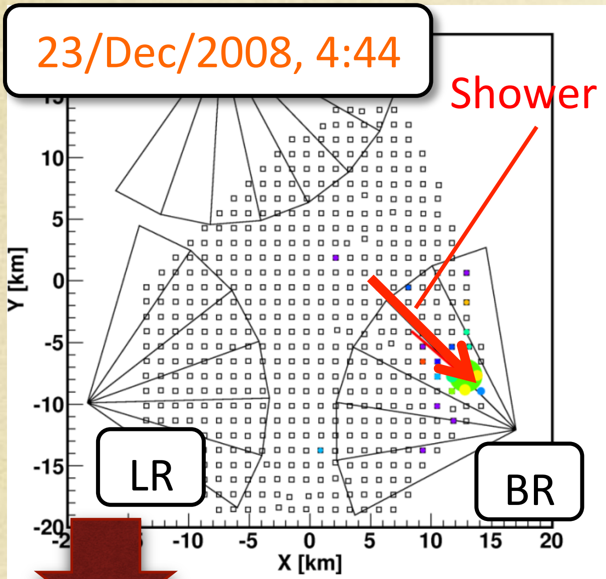
Shower Analysis - Hybrid -

Data set for BR/LR Hybrid analysis:
- 27/May/2008 – 07/Sep/2010 (~2.3 years)

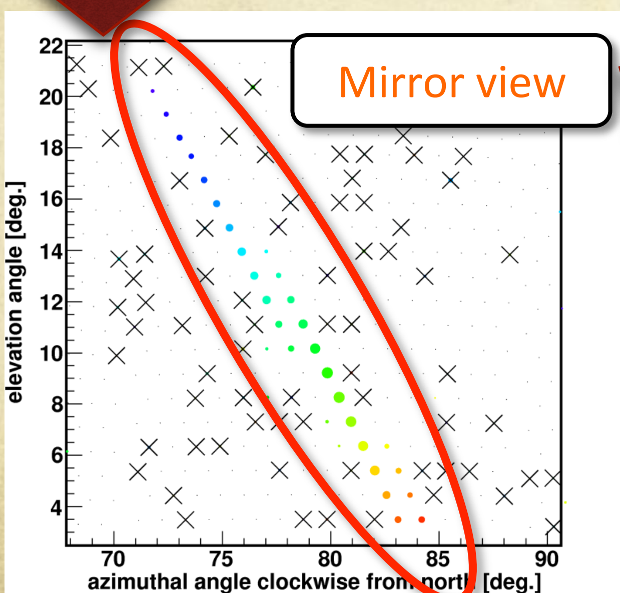
Geometry: FD+SD, Profile: FD

- Geometry: Traditional reconstruction of FD with timing of one SD (~0.9 deg.)
- Profile: Inverse Monte Carlo (~8%)

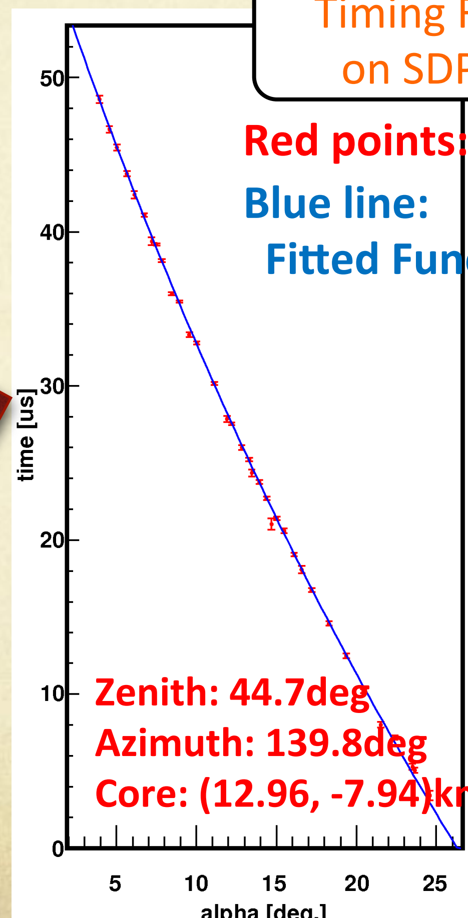
23/Dec/2008, 4:44



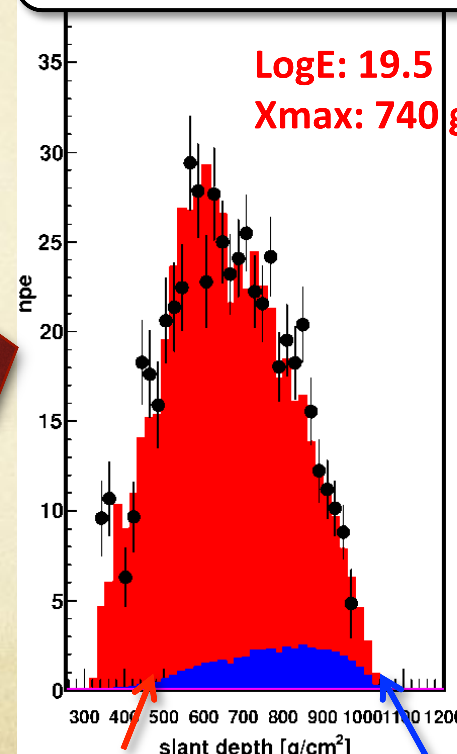
Mirror view



Timing Fit on SDP



Profile Fit by Inverse Monte Carlo

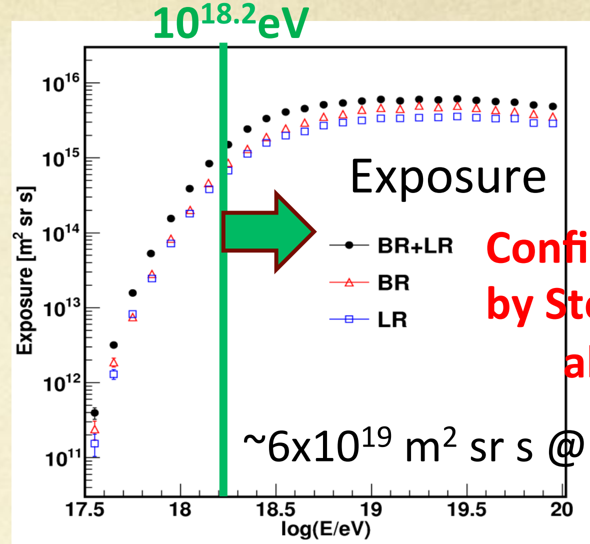


Shower Analysis - Hybrid -

Quality Cuts:

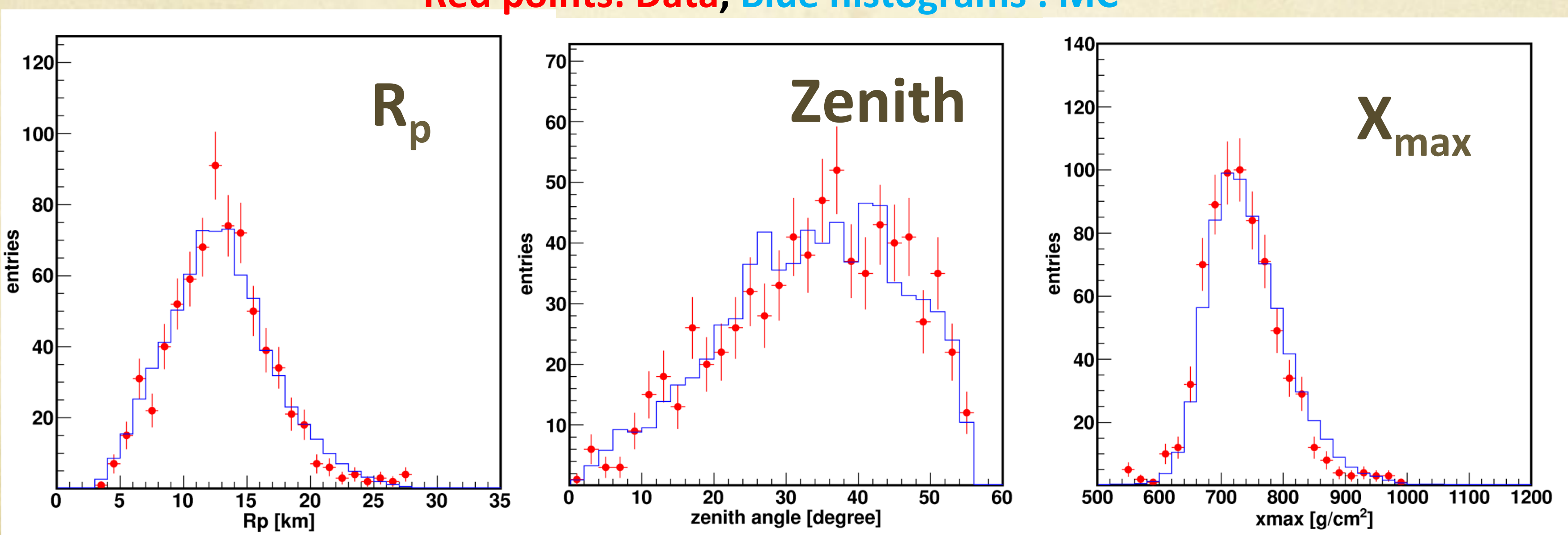
- # of PMTs > 20
- Core is inside the SD array
- Xmax observed
- Angle b/w telescope and shower > 20deg

avoid high Cherenkov fraction



Confirmed as "Proton" by Stereo X_{max} analysis above $10^{18.2}$eV

Red points: Data, Blue histograms : MC



Data and MC are in good agreement !!

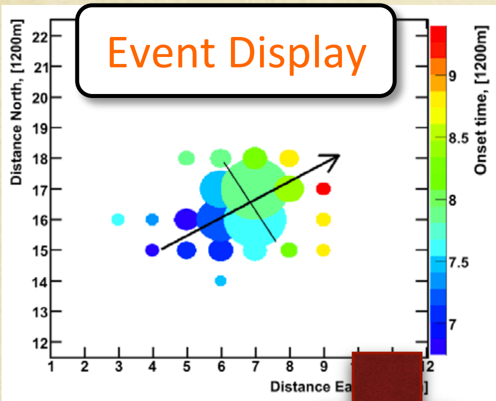
Shower Analysis
- SD -

Data set for SD analysis:
- 11/May/2008 – 01/May/2011 (3 years)

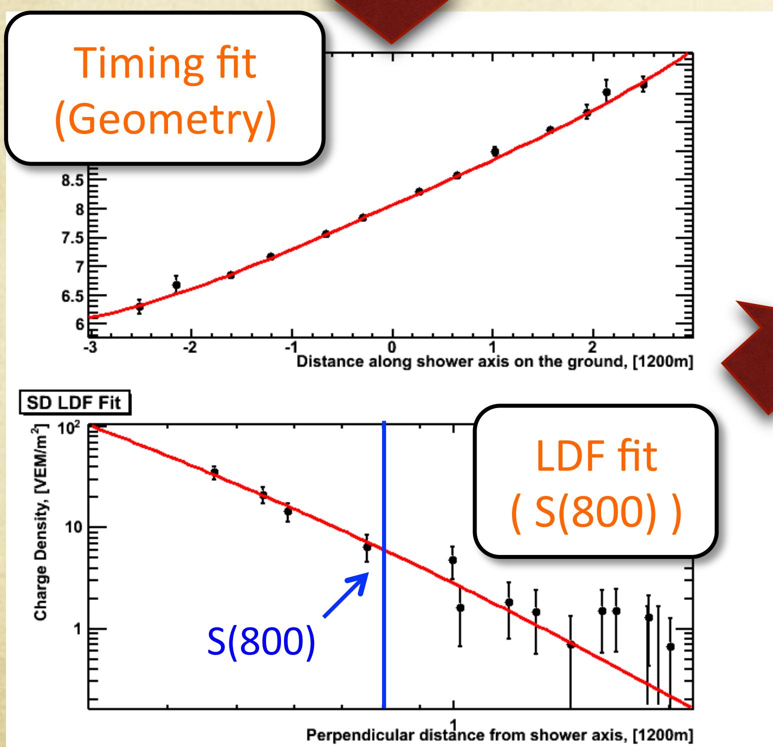
Lateral distribution at the ground

- Geometry: Time fit (~1.5deg.)
- Energy E_{SD}(MC): Primary estimated by S(800) and Zenith angle by using MC (~20%)

Event Display

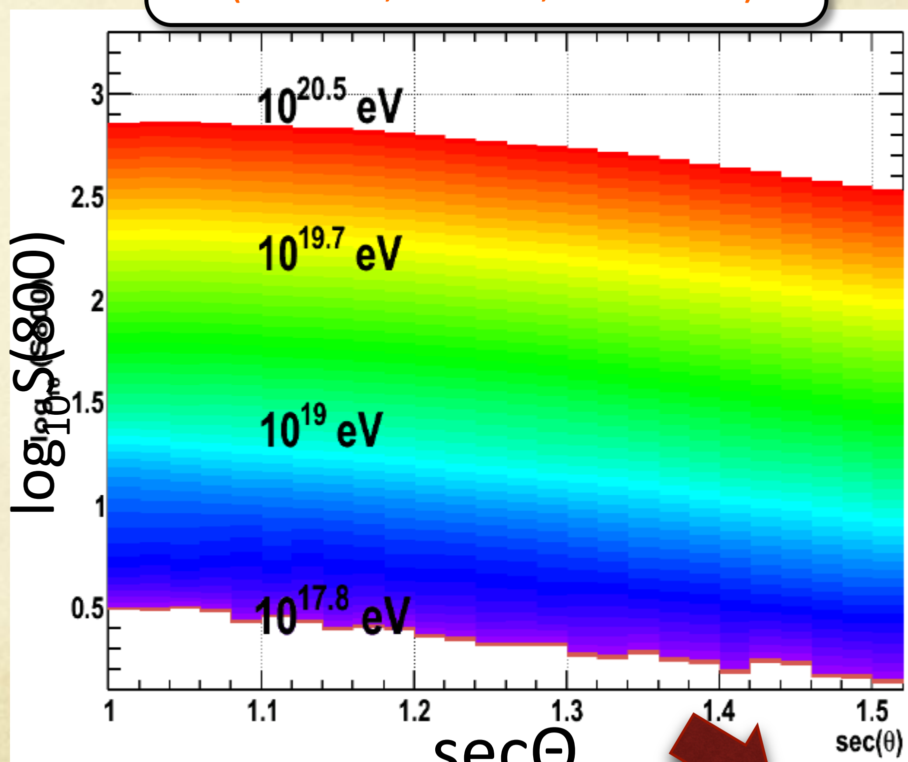


Timing fit
(Geometry)



LDF fit
(S(800))

Energy table from MC
(Corsika, Proton, QGSJet-II)

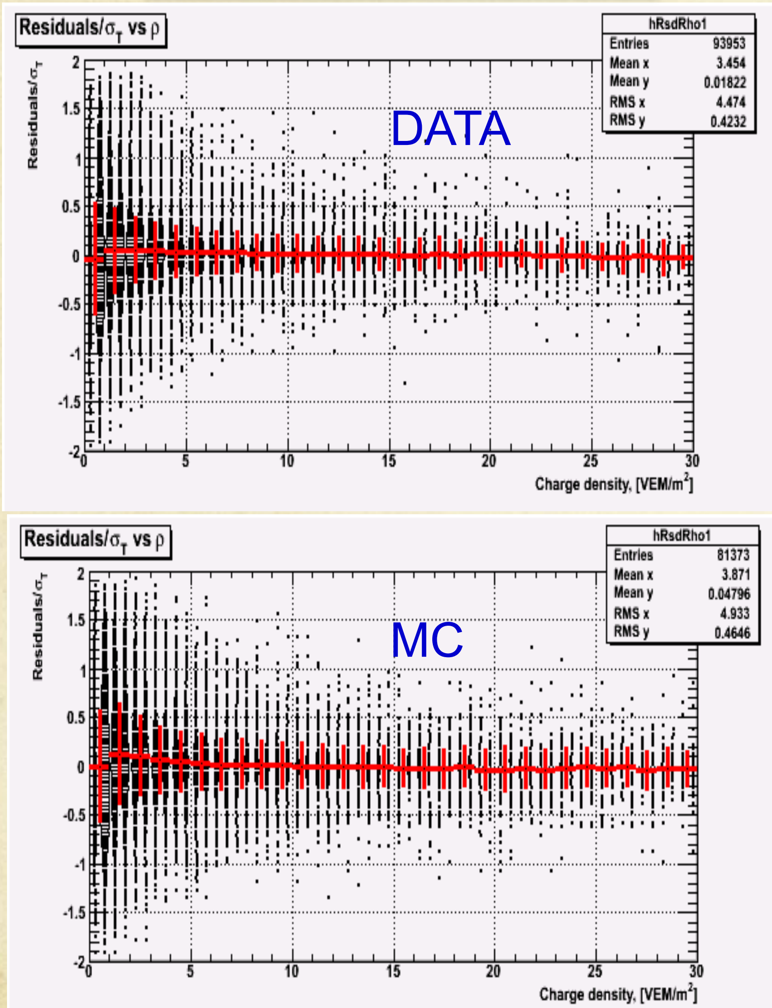


E_{SD}(MC)

Shower Analysis - SD -

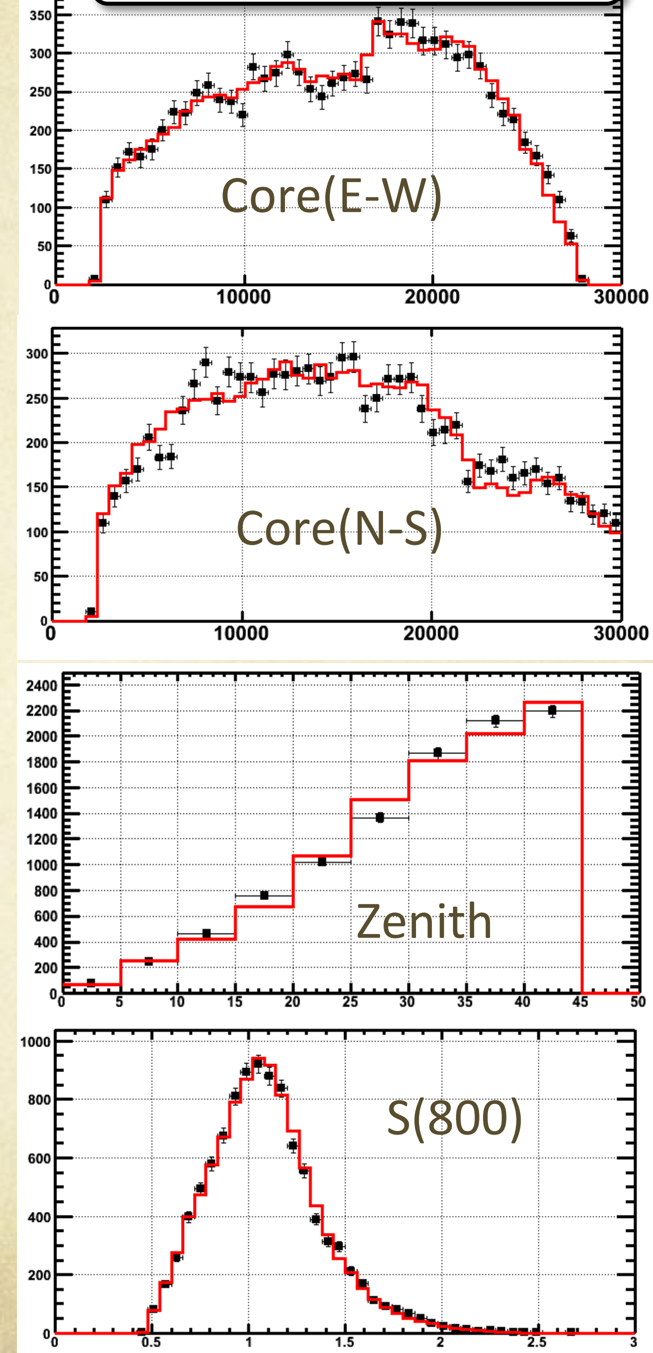
Lateral Distribution

Time fit residual over σ



Counter signal, [VEM/m^2]

Data/MC comparison



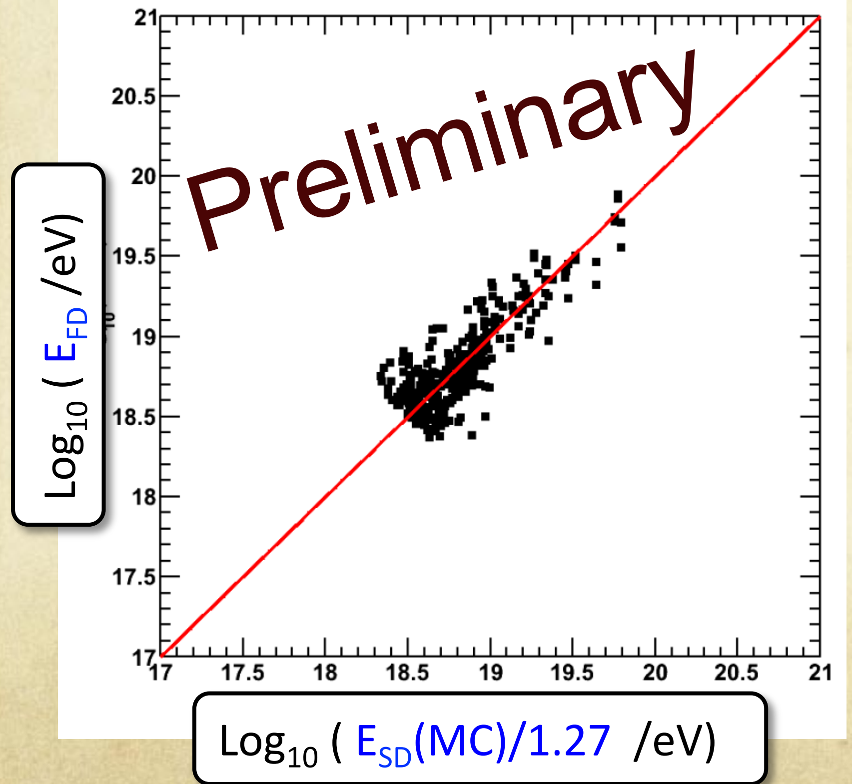
Data and MC are in good agreement !!

FD-SD Energy Scale

- Energy scales from MD and BR/LR are consistent
- We use the MD + BR/LR as a calorimetrically determined energy by FD
- By using well-reconstructed events from MD, BR/LR hybrid analysis and SD, we obtained

$$E_{SD} = 1.27 \times E_{FD}$$

- Set SD energy scale to FD energy scale with 27% renormalization.

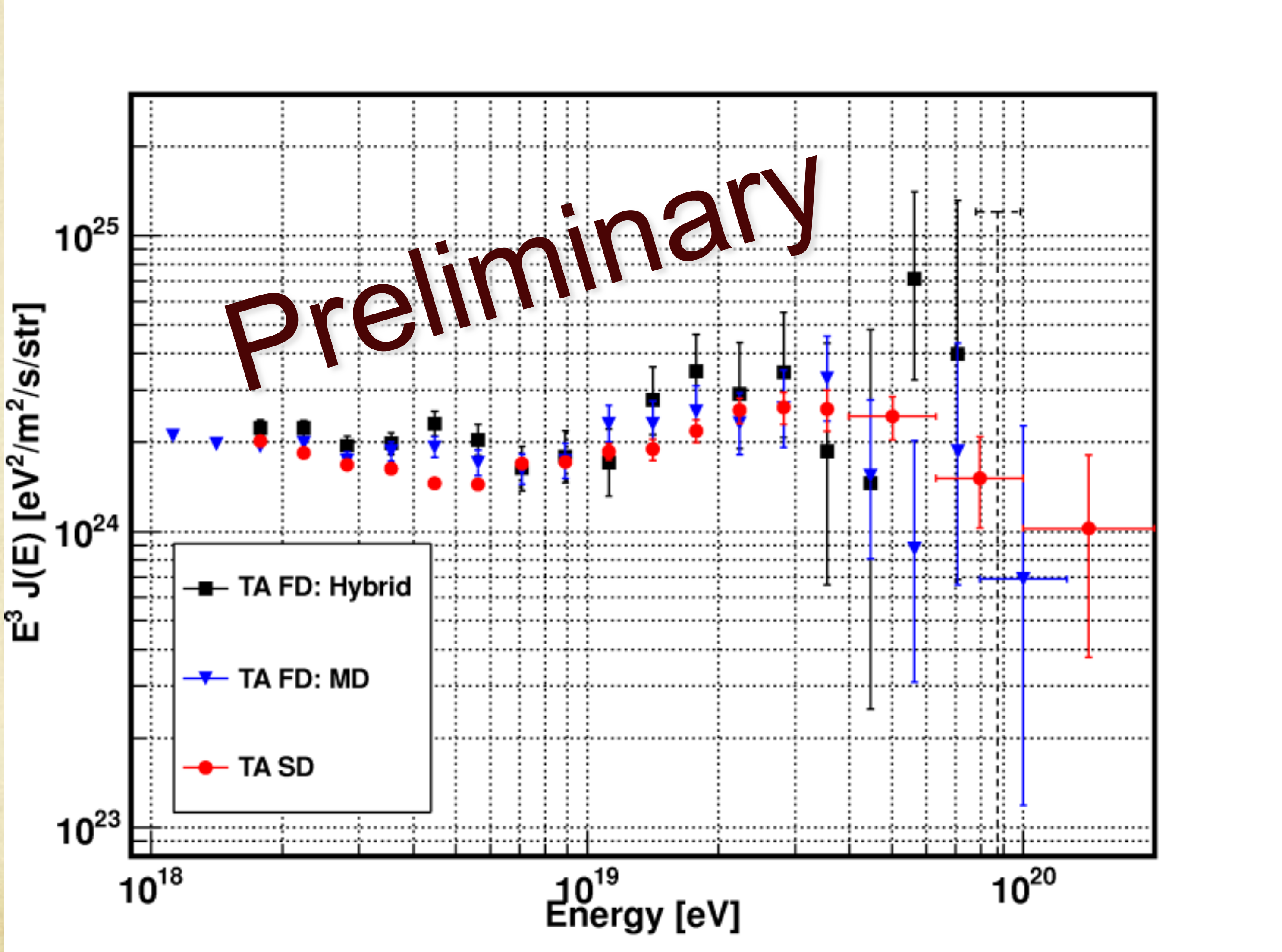


Systematic uncertainties for FD energy determination

Source	ΔE/E
Fluorescence yield	11%
Detector	10%
Atmosphere	11%
Reconstruction	10%
Total	21%

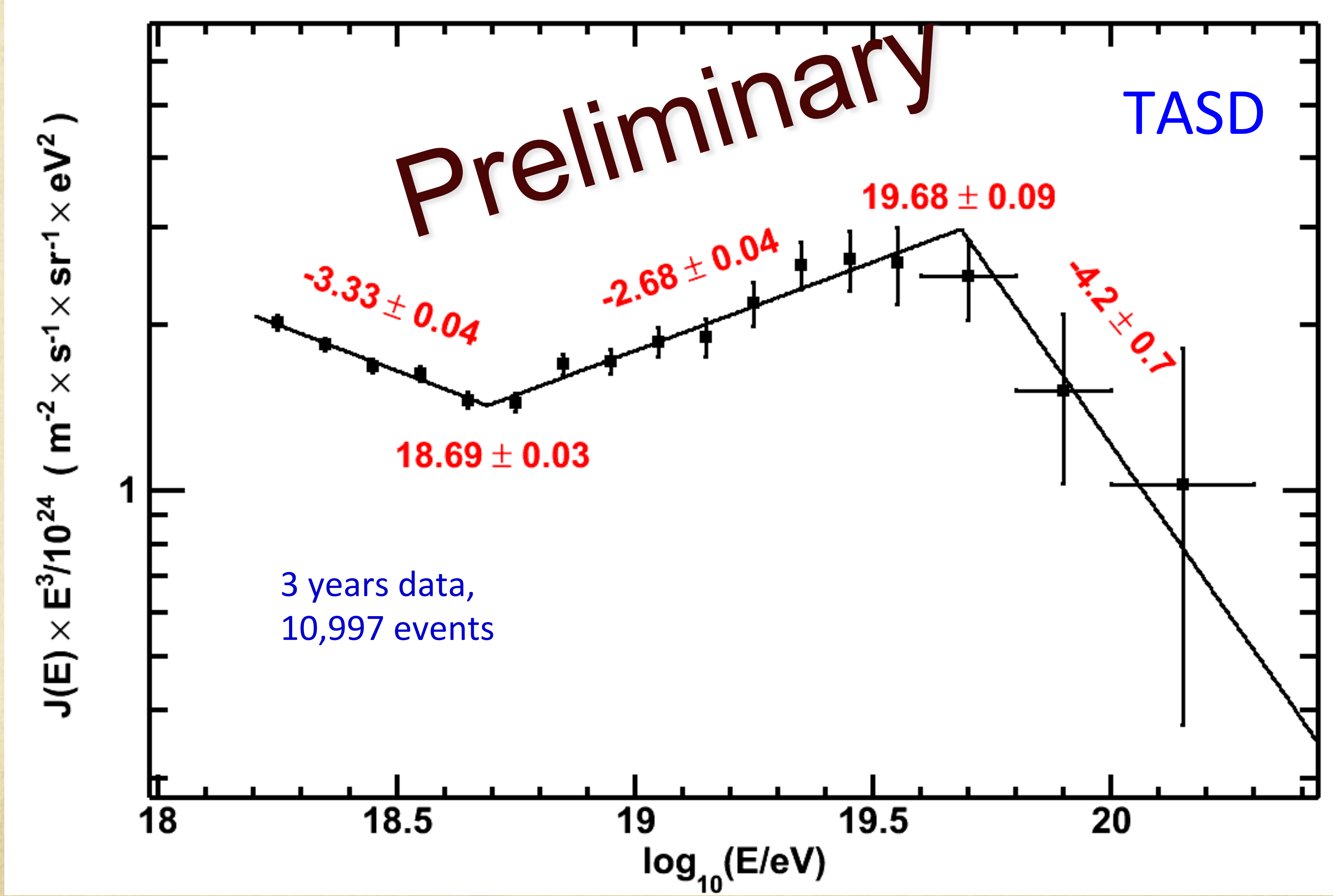
Energy Spectra

Energy spectra from TA

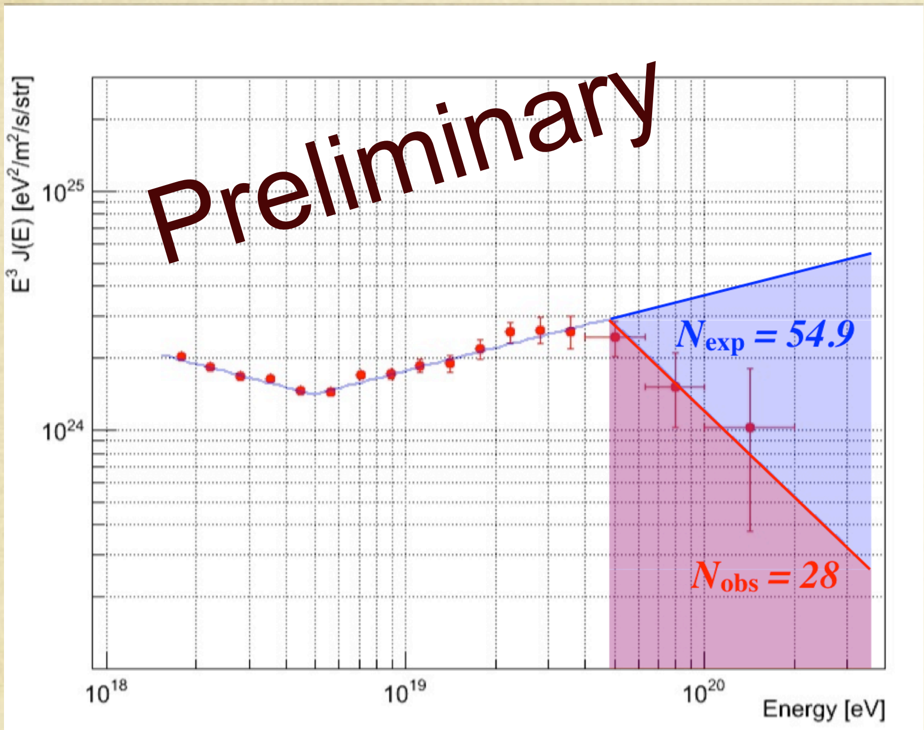


Three energy spectra from TA,
MD monocular, BR/LR hybrid, and SD are in good agreement.

Broken Power Low Fit



GZK suppression



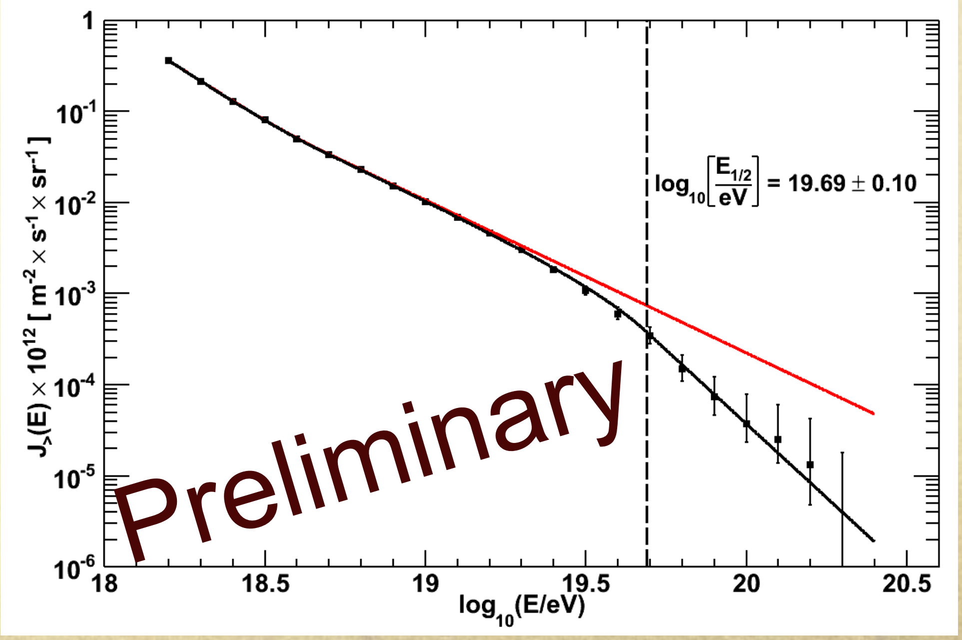
Significance of the suppression

Comparison with the expectation from the extended power low fit beyond the break point and data:

- # of expected events: **54.9**
- # of observed events: **28**

$$\sum_{i=0}^{28} Poisson(\mu = 54.9; i) = 4.75 \times 10^{-5}$$

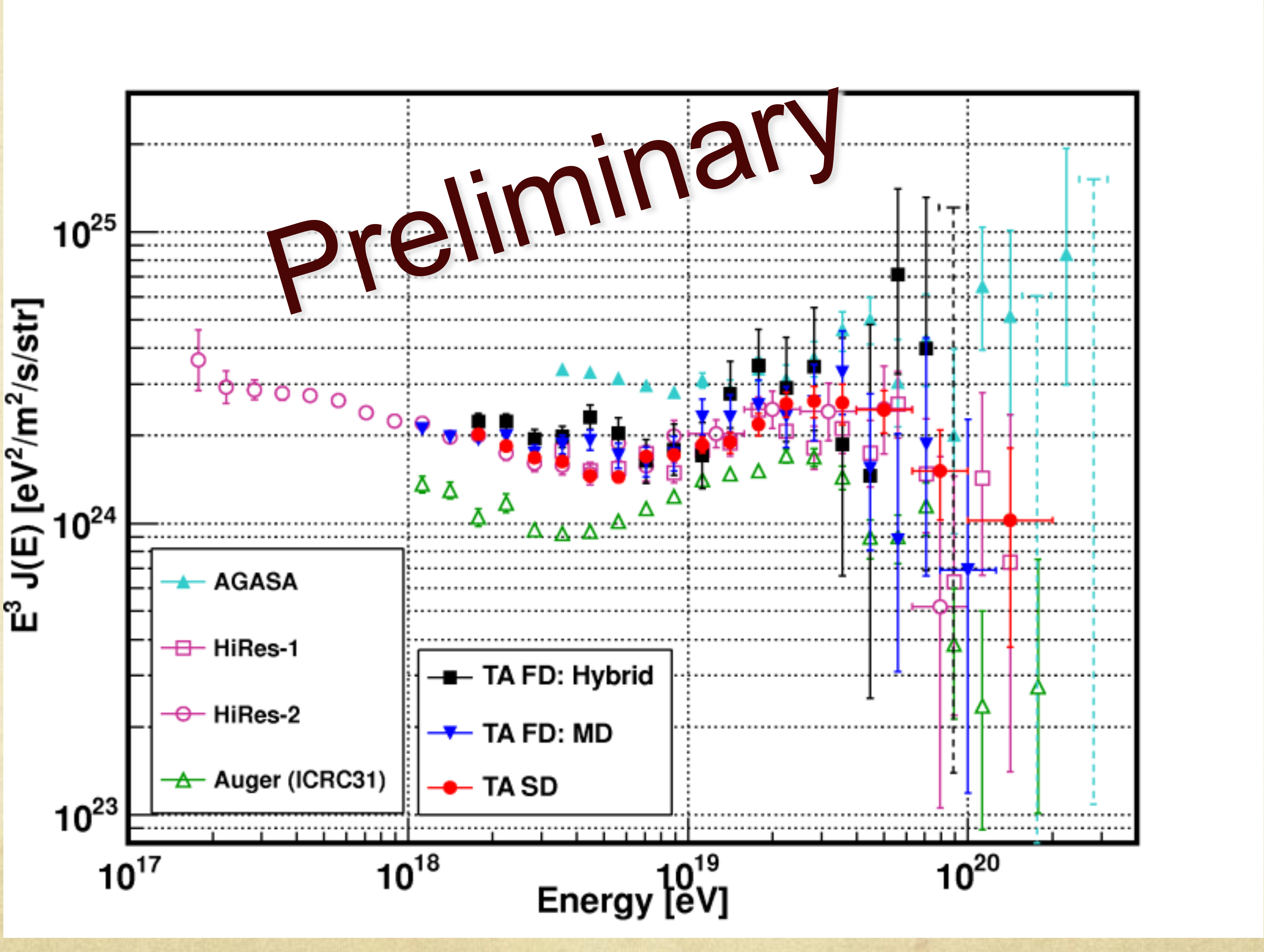
3.9σ



Integral Flux $E_{1/2}$

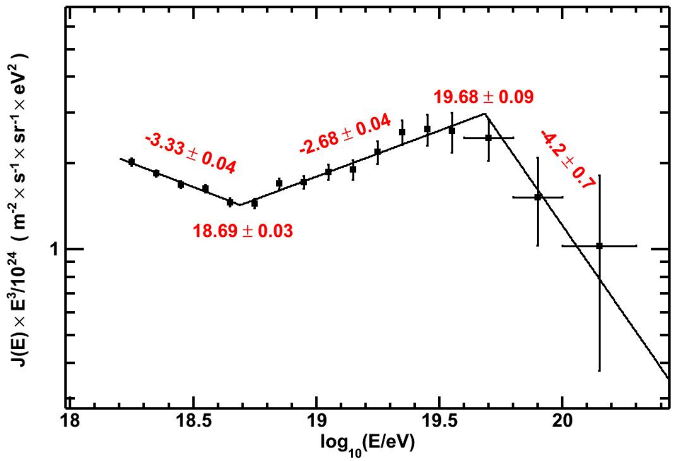
- $E_{1/2}$ = **$10^{19.69}$eV**
- Berezinsky et al. predict **$10^{19.72}$eV**

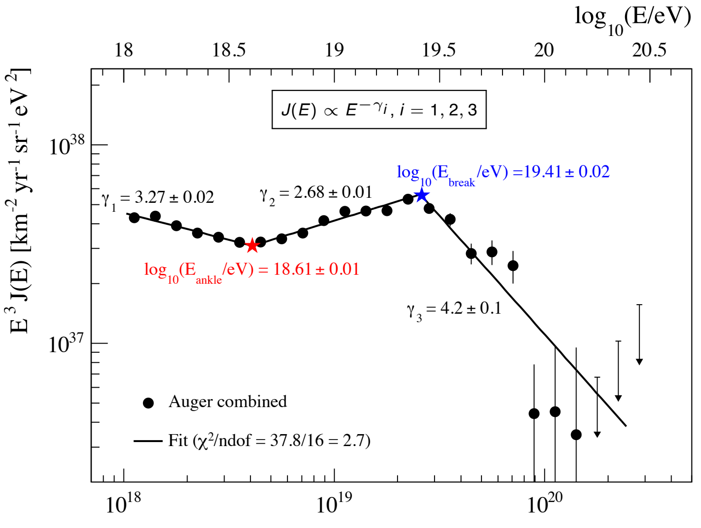
AGASA, HiRes, Auger, TA



TA spectra are consistent with HiRes. (-20% AGASA, +20% Auger)

Energy scale and Spectrum in TA, PAO

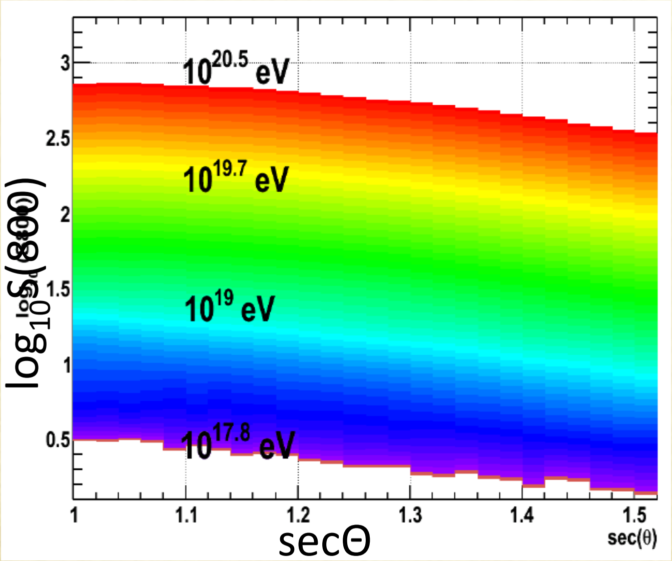




	TA	Auger
γ_1	3.33 ± 0.04	3.27 ± 0.02
γ_2	2.68 ± 0.04	2.68 ± 0.01
γ_3	4.2 ± 0.7	4.2 ± 0.1
$\lg(E_1/\mathrm{eV})$	18.69 ± 0.03	18.61 ± 0.01
$\lg(E_2/\mathrm{eV})$	19.68 ± 0.09	19.41 ± 0.02

Again FD - SD energy scale

- Energy scale issues in SD and FD have been left unresolved !!
  - The energy scale of SD is 27% larger than that of FD
  - It's consistent with the relation b/w AGASA and HiRes
- What's is problem ?

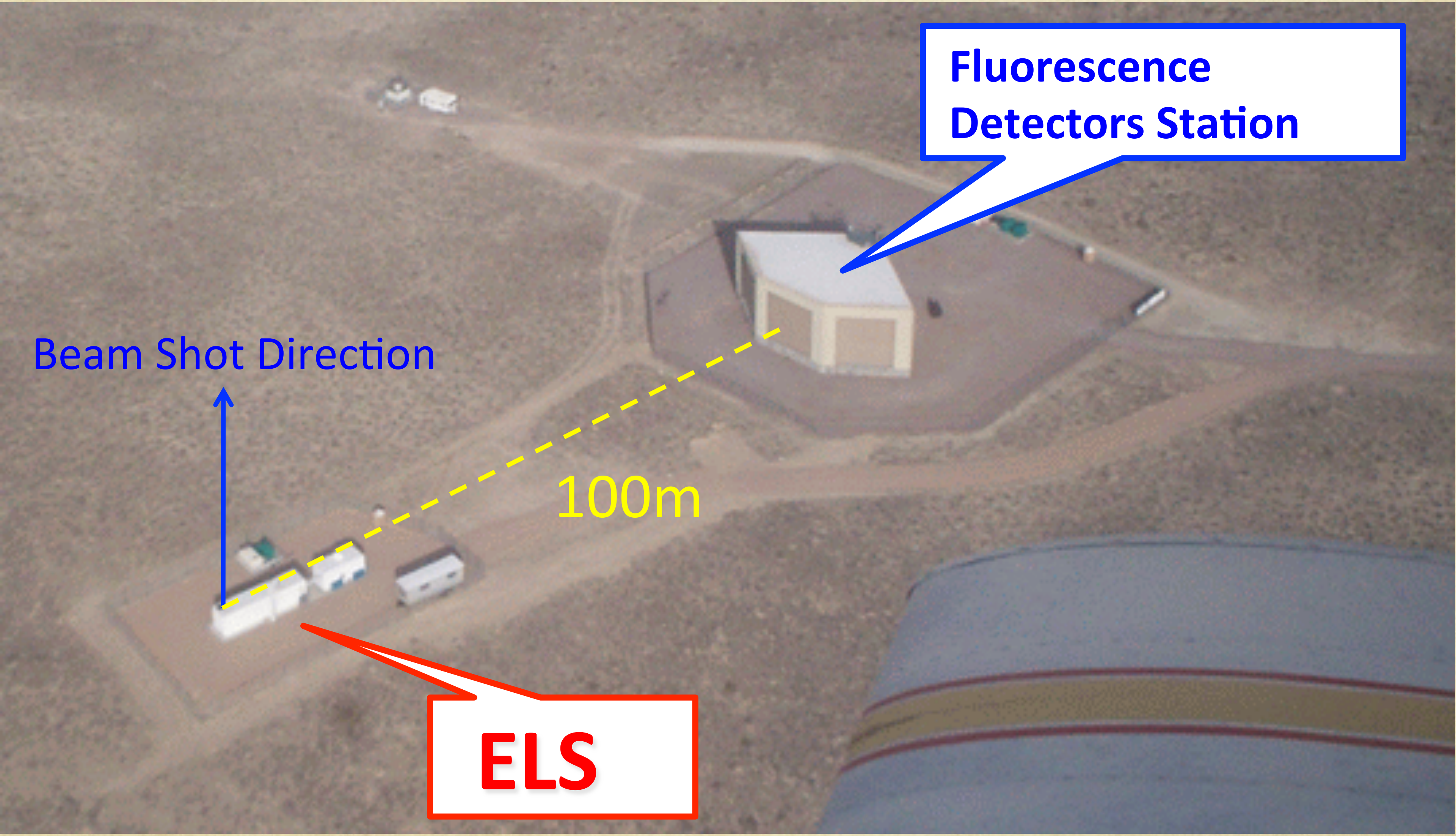


Source	ΔE/E
Fluorescence yield	11%
Detector	10%
Atmosphere	11%
Reconstruction	10%
Total	21%

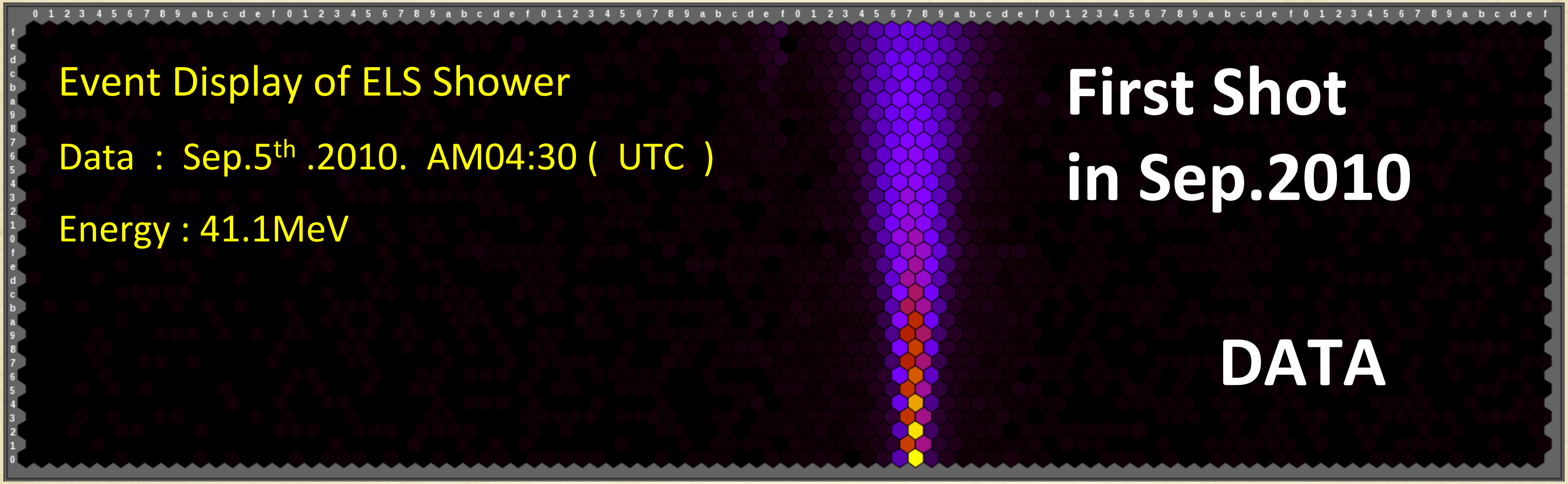
Model ? ⇨ LHCf !!

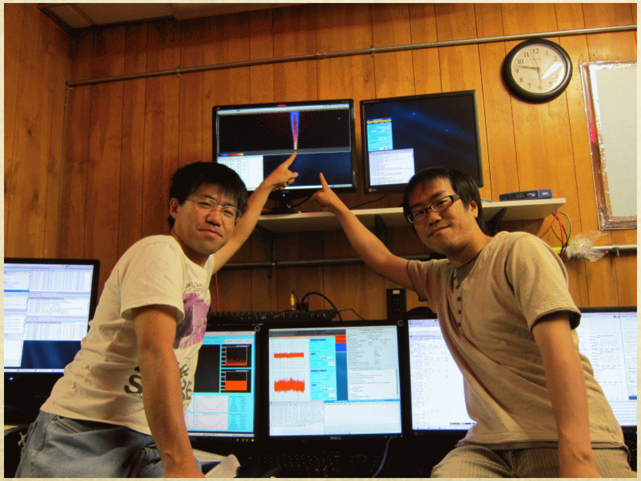
Measurement ? ⇨ ELS !!

Absolute energy calibration : ELS



First light of e- beam from ELS





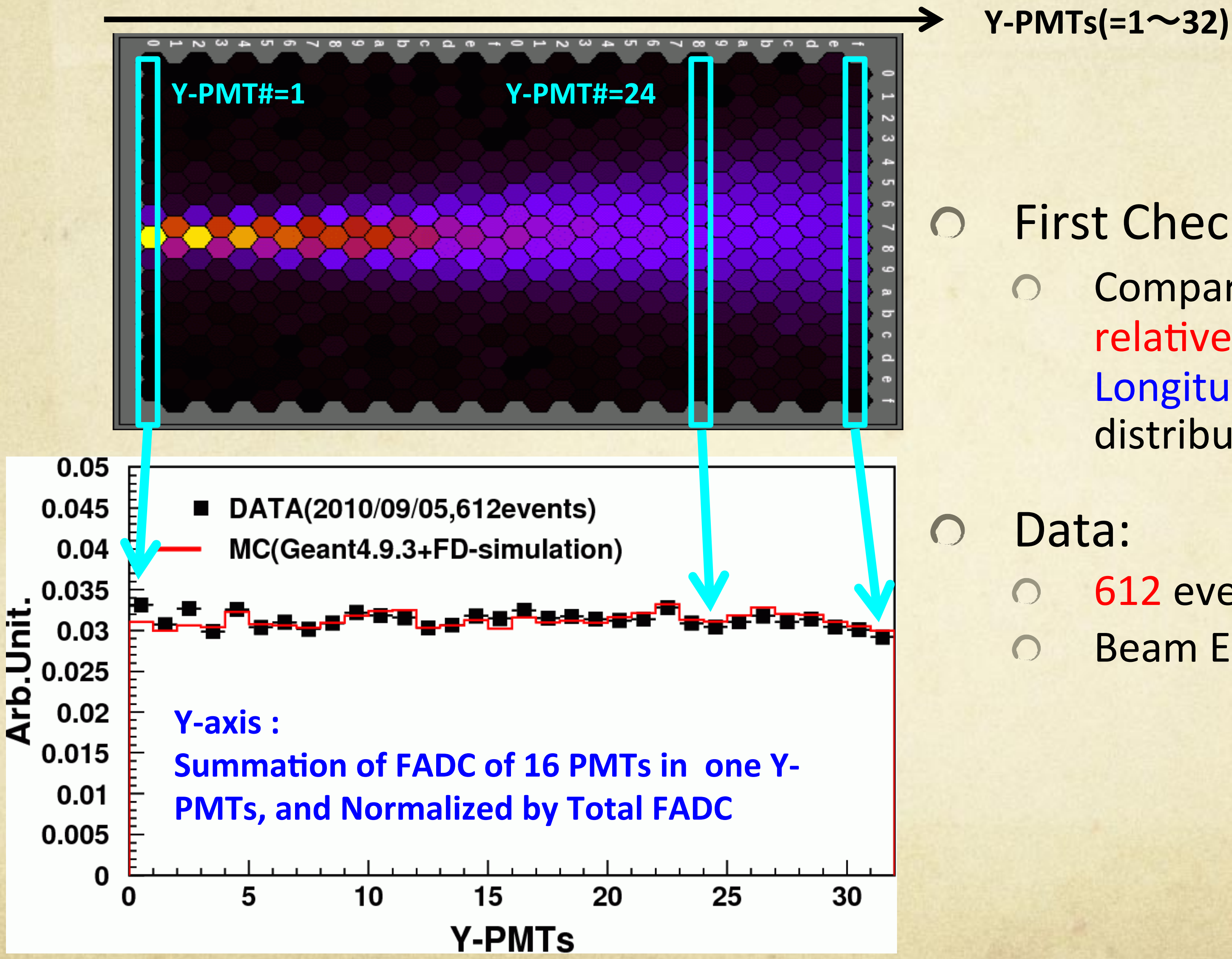
Beam Operation : Sep.2nd -4th

Beam shot into the Sky : Sep. 3rd and 4th

# of shot into the Sky: ~1800 pulses

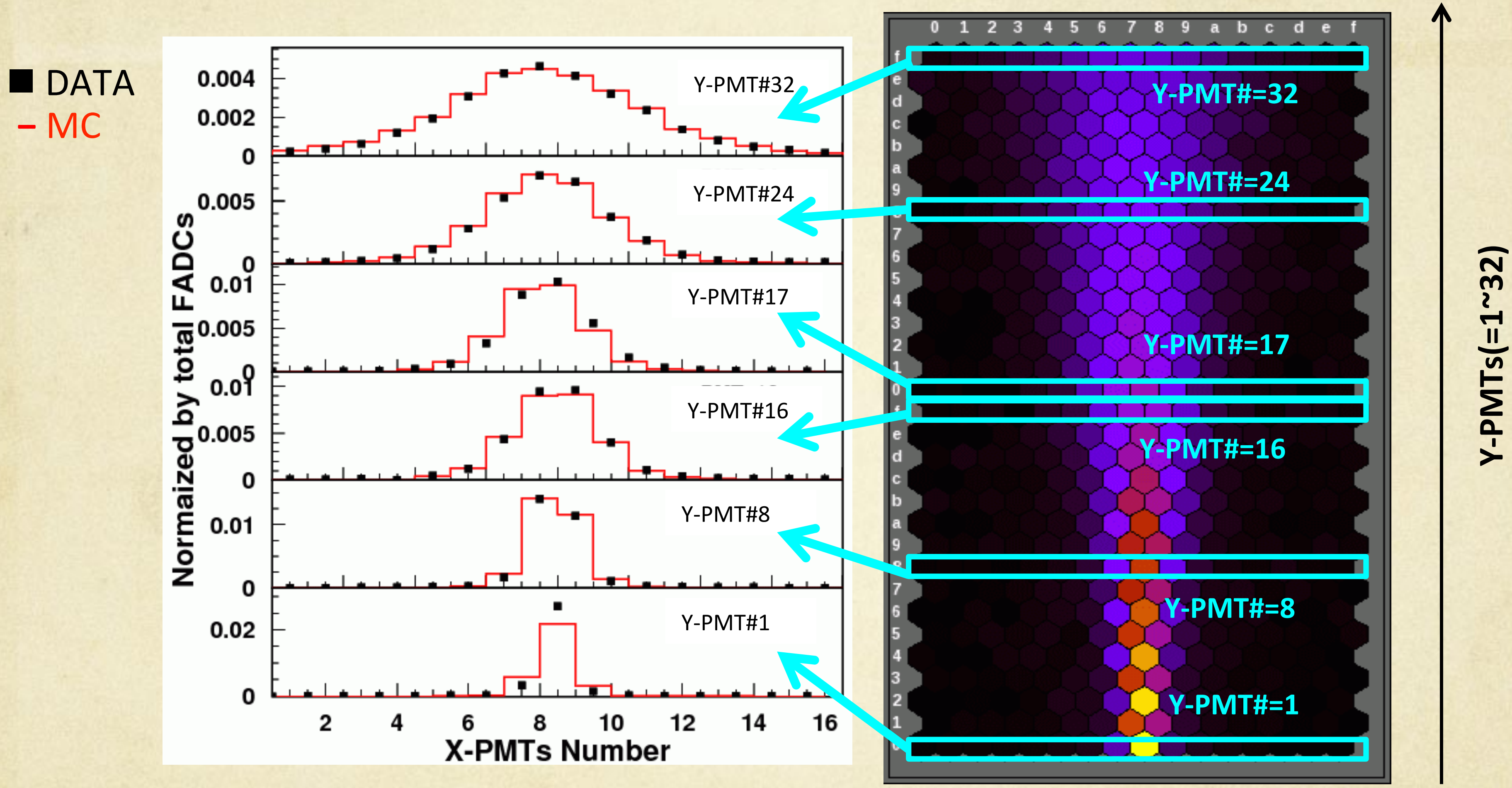
Output power = 41.1MeV×40~140pC/pulse×0.5Hz

ELS Analysis
- Longitudinal distribution-



- First Check:
  - Comparison with the relative values on Longitudinal/Lateral distributions
- Data:
  - 612 events (Sep/2010)
  - Beam Energy: 41.1 MeV

ELS Analysis
- Lateral distribution-



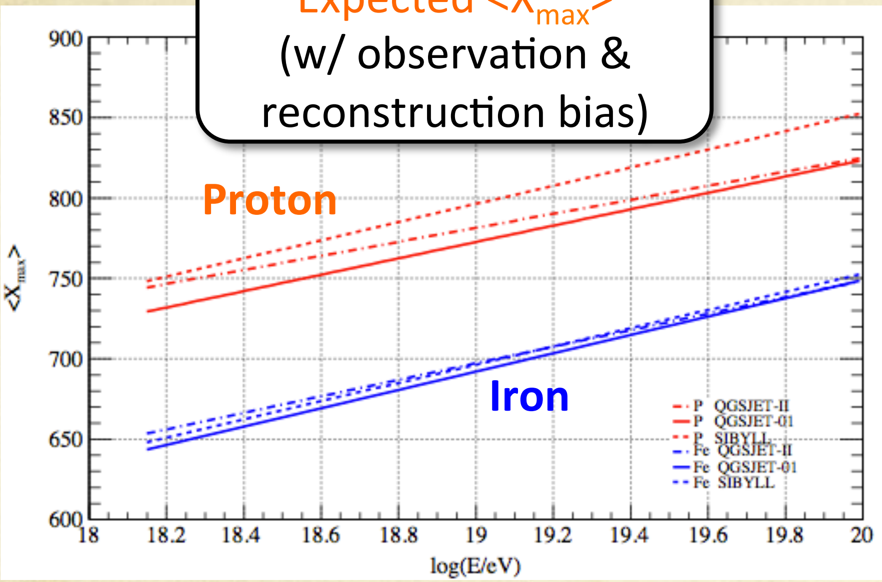
Data/MC are in good agreement !!

➡ Go to absolute calibration…

Mass Composition

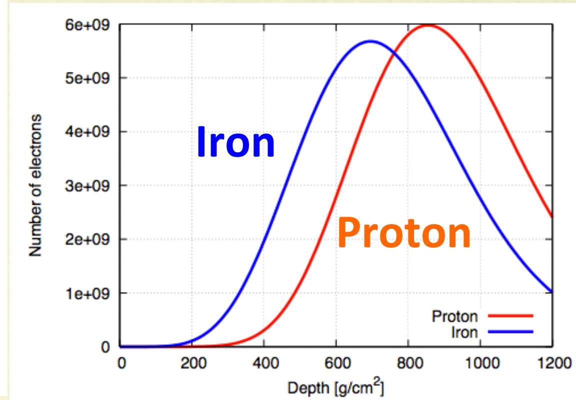
X_{max} analysis

Expected $\langle X_{max} \rangle$
(w/ observation & reconstruction bias)



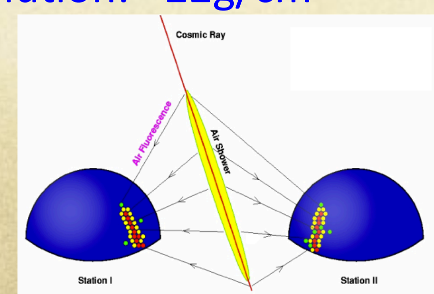
Shower longitudinal development depends on primary particles

- X_{max} is the most efficient parameter
- $\langle X_{max} \rangle$ and that's distribution are compared with Model prediction.

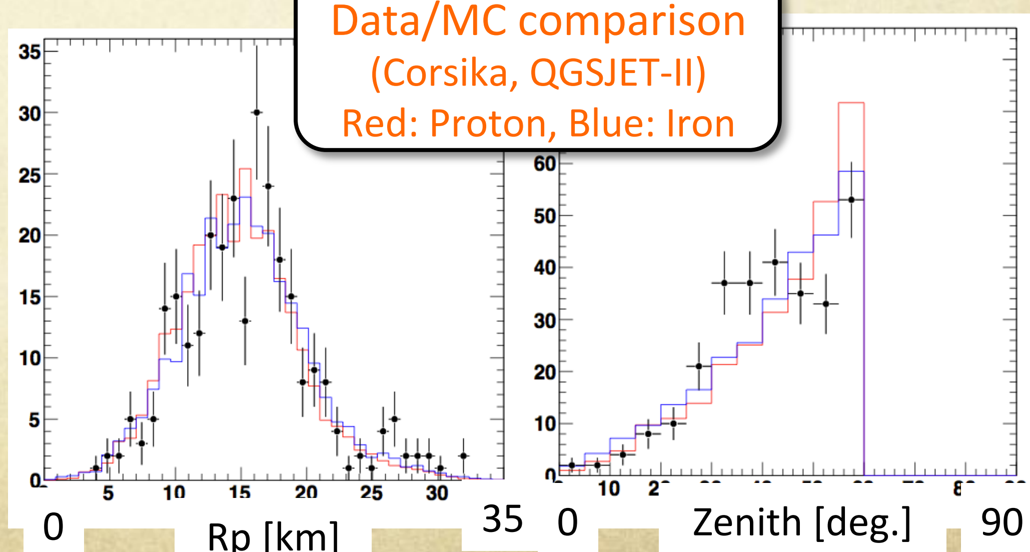


Stereo analysis on BR/LR

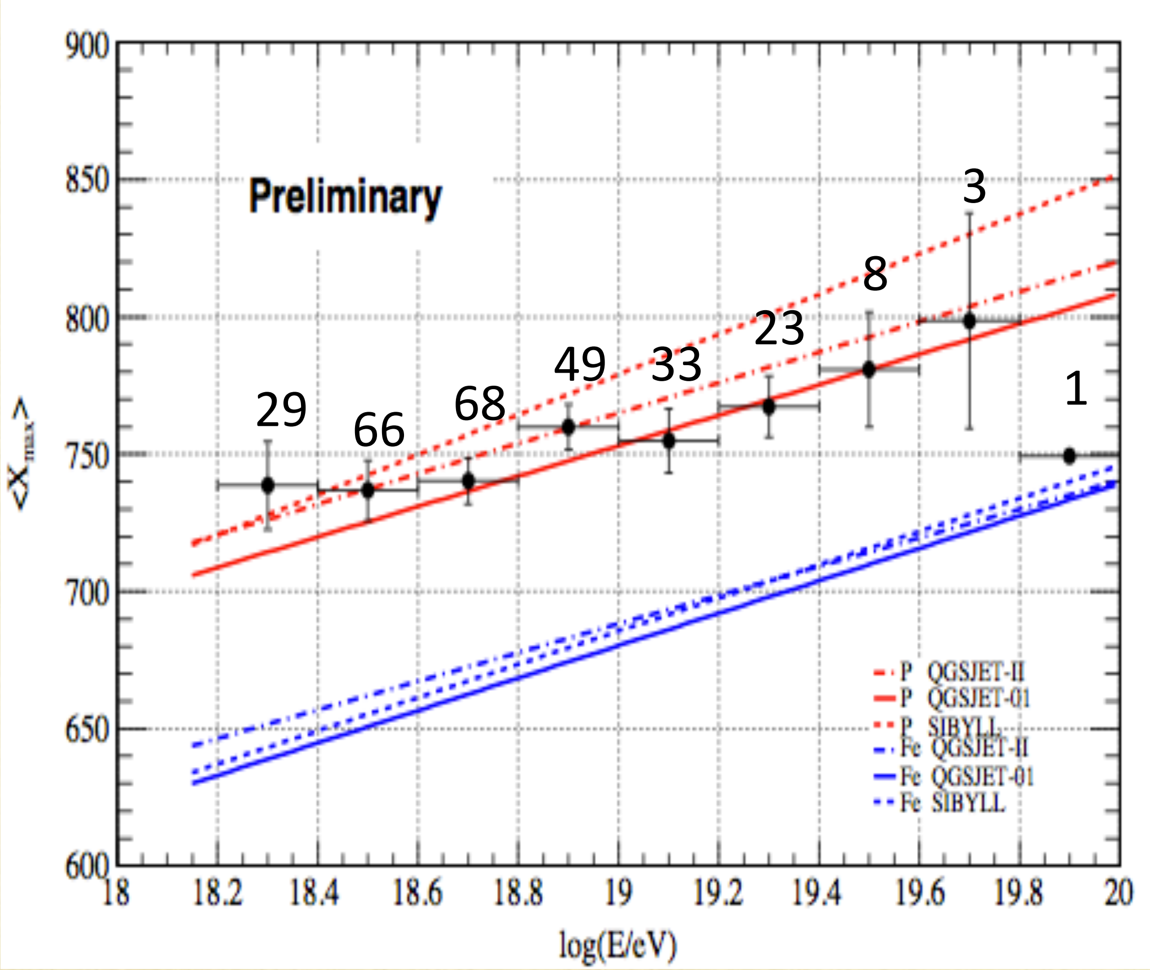
- Axis: Intersection of two Shower-Detector Plane
- Profile: Inverse Monte Carlo
  - X_{max} resolution: ~22g/cm^2

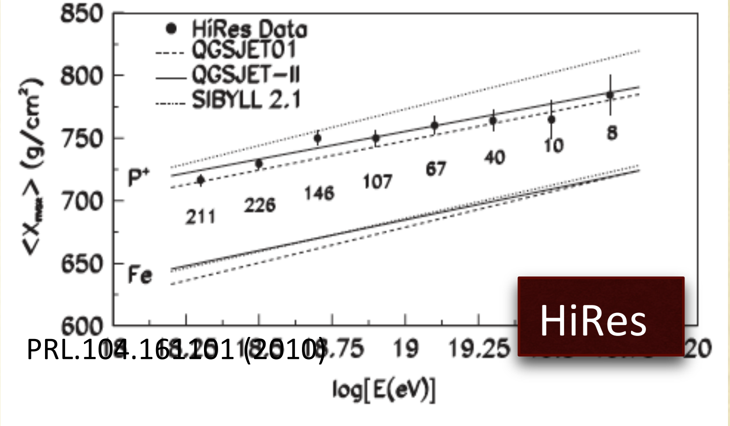


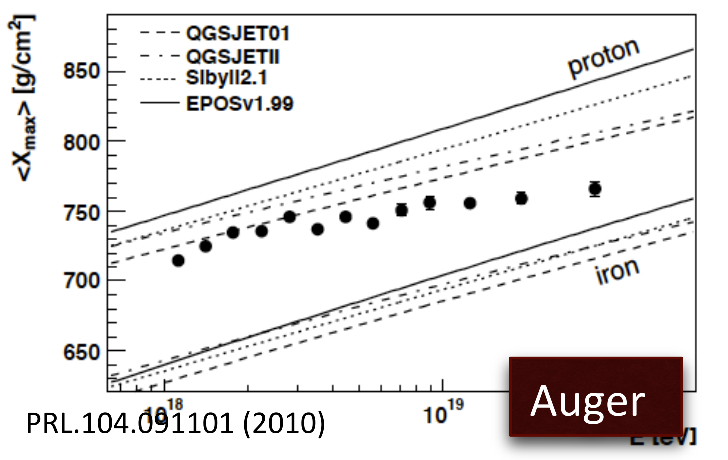
Data/MC comparison
(Corsika, QGSJET-II)
Red: Proton, Blue: Iron



Energy - <X_{max}>

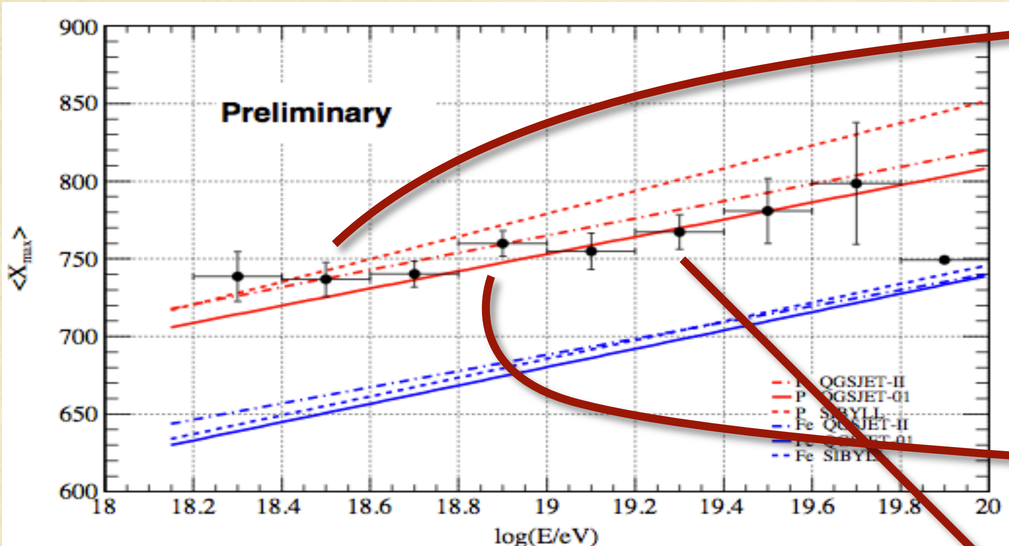


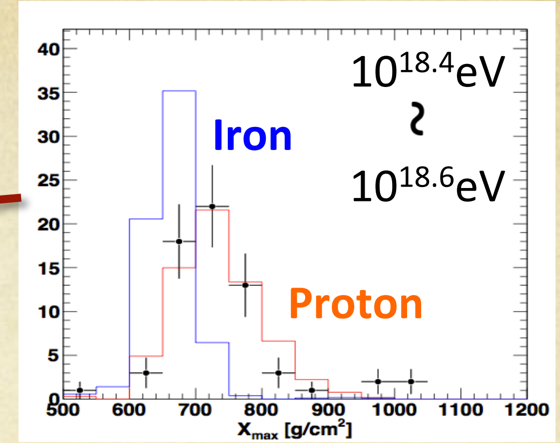


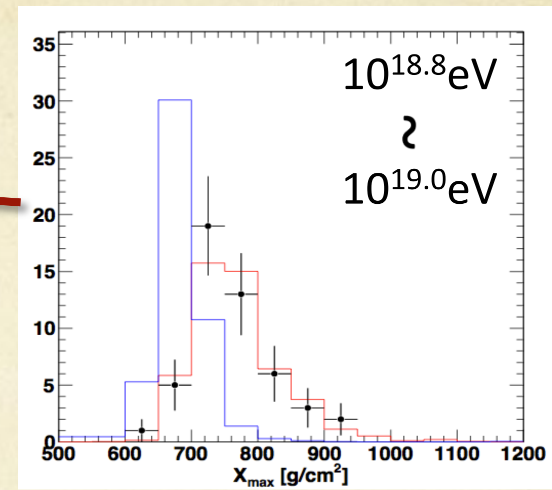


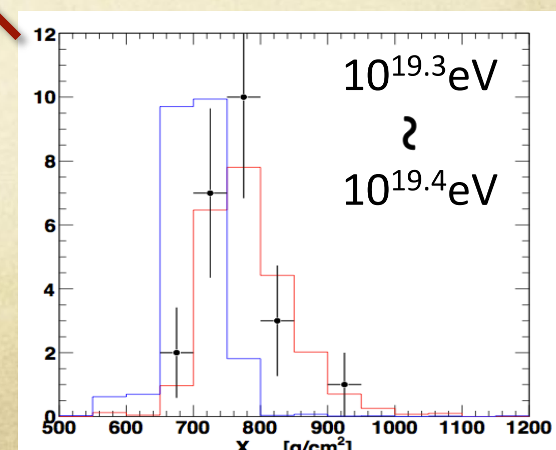
Data set : 2007/Nov – 2010/Sep

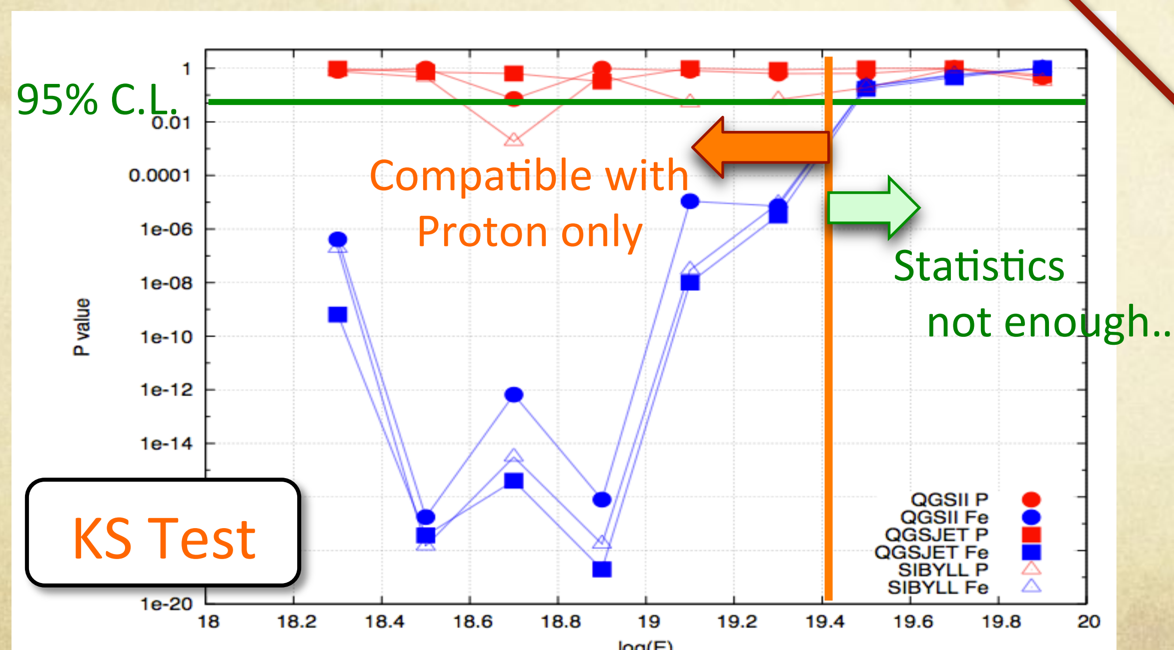
Distribution of X_{max} , KS Test





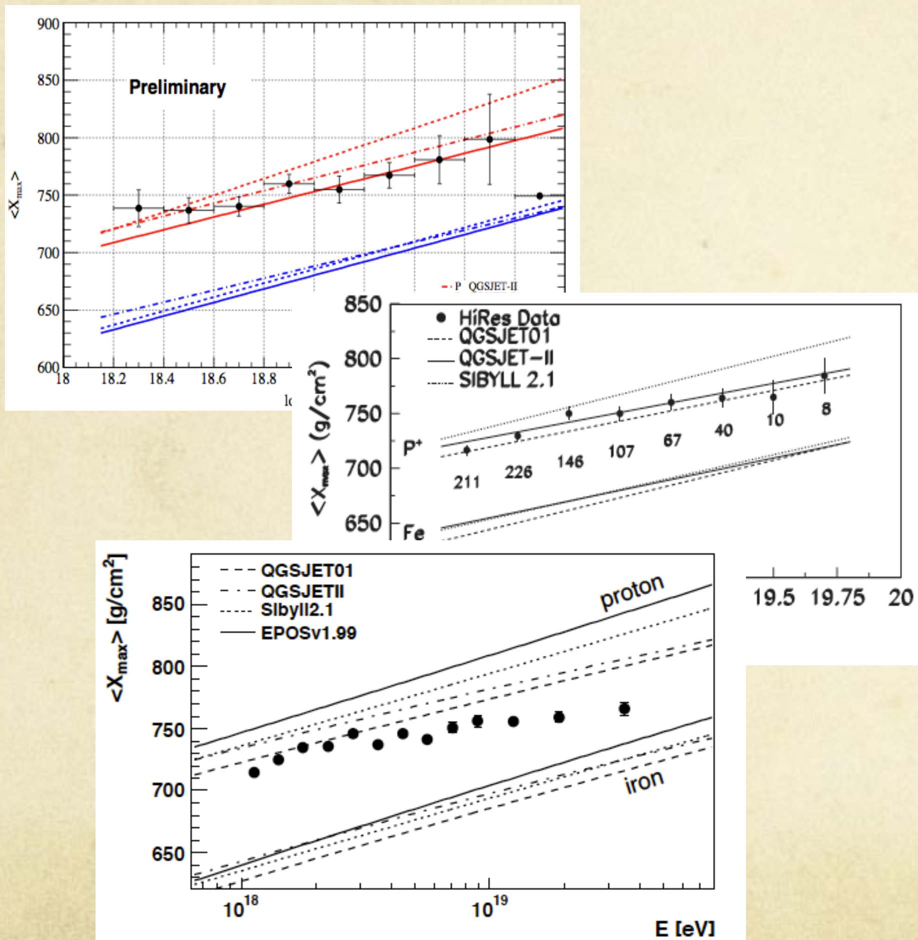




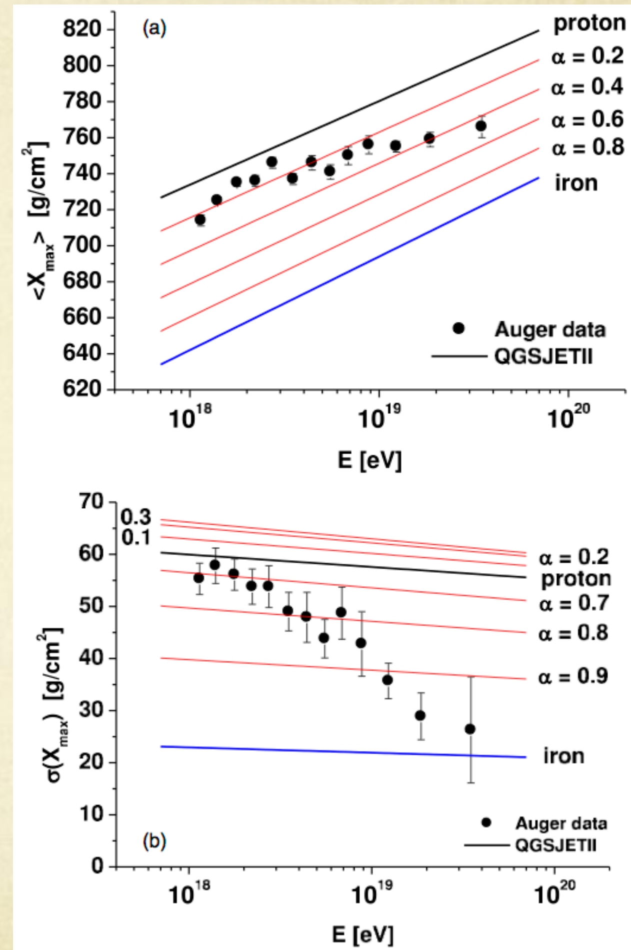


UHECR Composition

$\langle X_{max} \rangle$ in each measurement shows inconsistency ?



The fraction in Auger is not clear



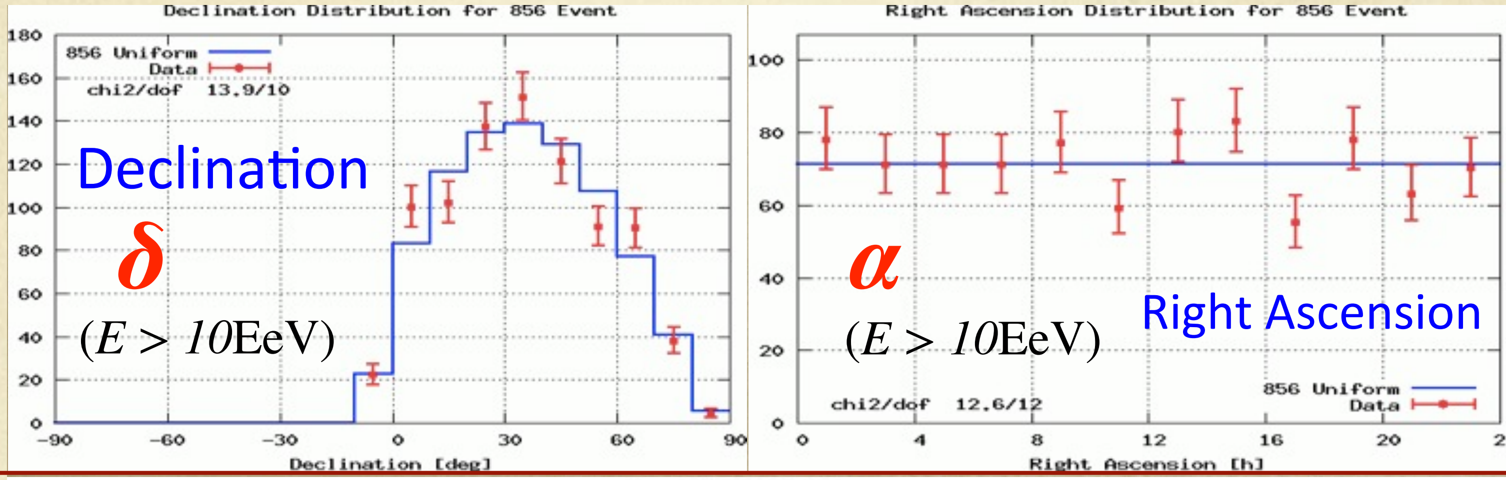
Analysis ?

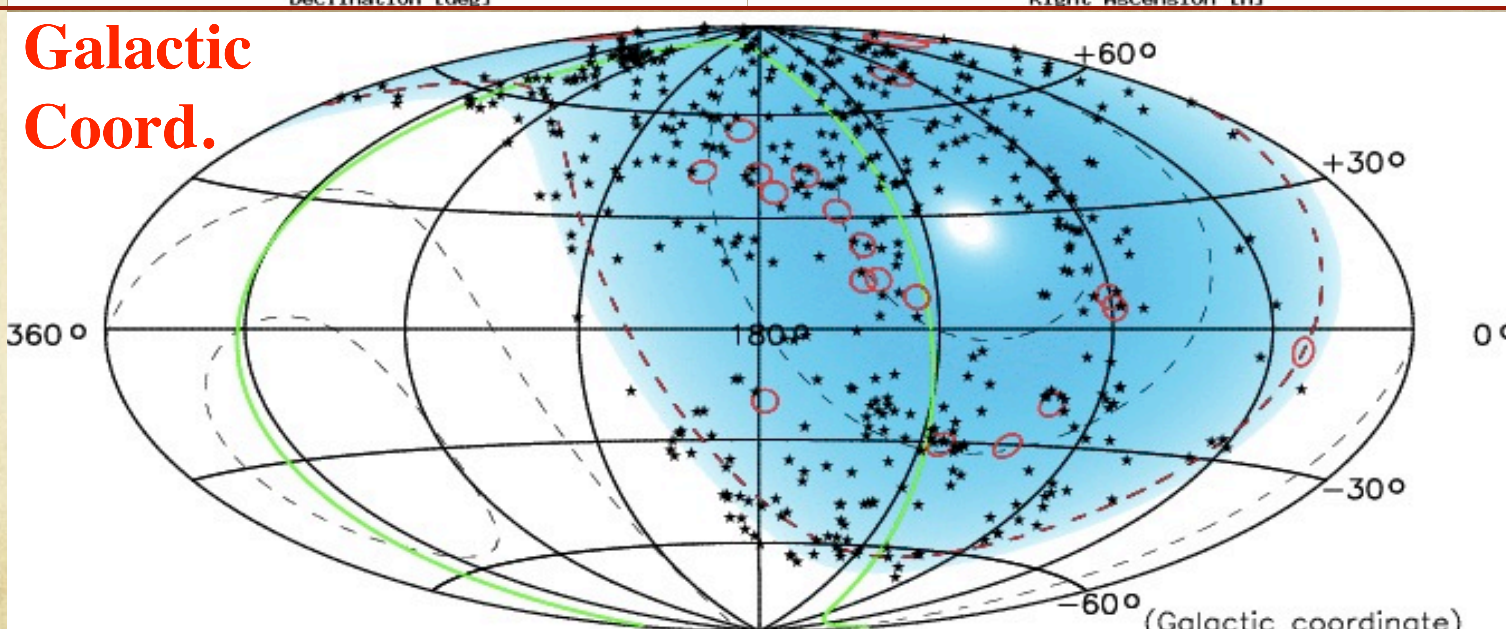
Model ?

Anisotropy

Event map

- Consistent w/ Isotropic distribution in (δ, α) (854 events, E>10 EeV)



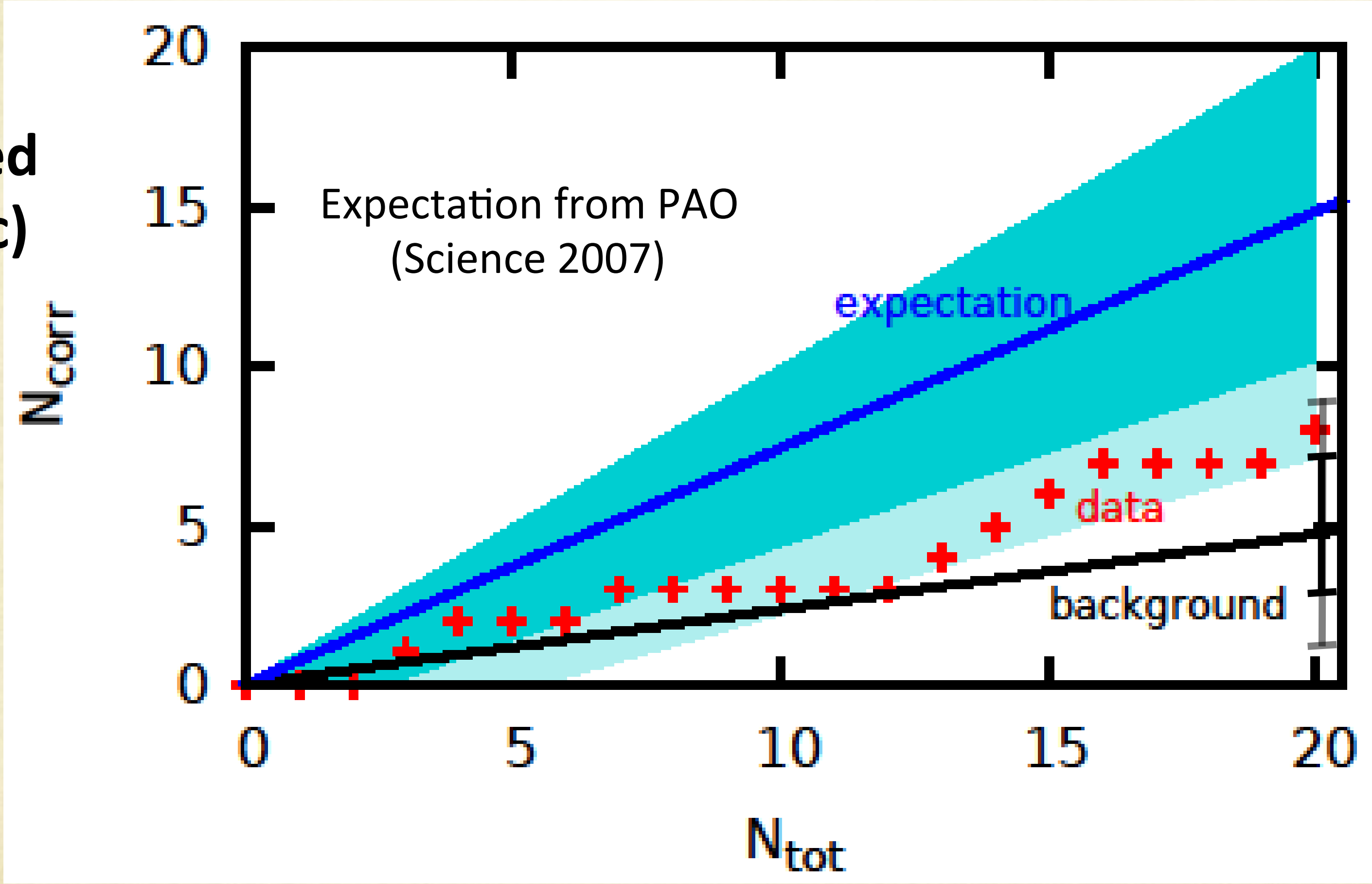


AGN and SD events (20 events, >57 EeV, 3.1 radii)

AGN correlation

Binomial correlation of SD events (>57EeV)
with AGNs in VCV catalog (Z<0.018, 3.1deg.)

8 of 20 correlated
(4.8 for isotropic)

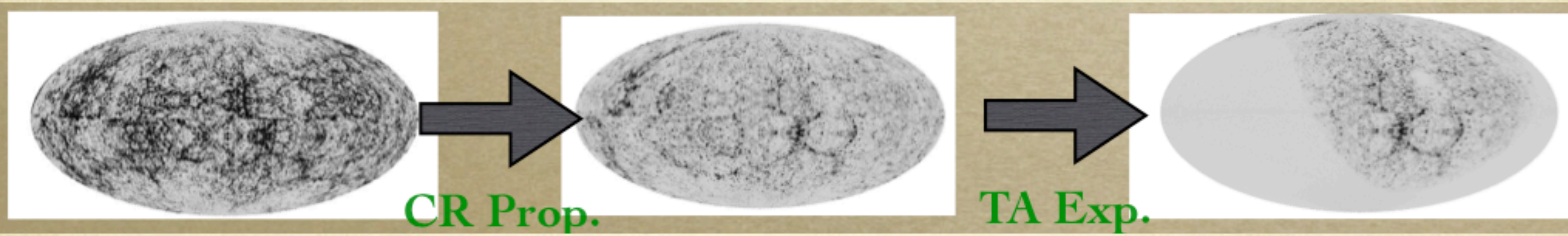


TASD data is consistent with Isotropic distribution

Large-Scale Anisotropy

2MASS catalog (5-250Mpc)
& uniform intensity (>250Mpc)

Proton ($E^{-2.2}$)
Interactions/redshift



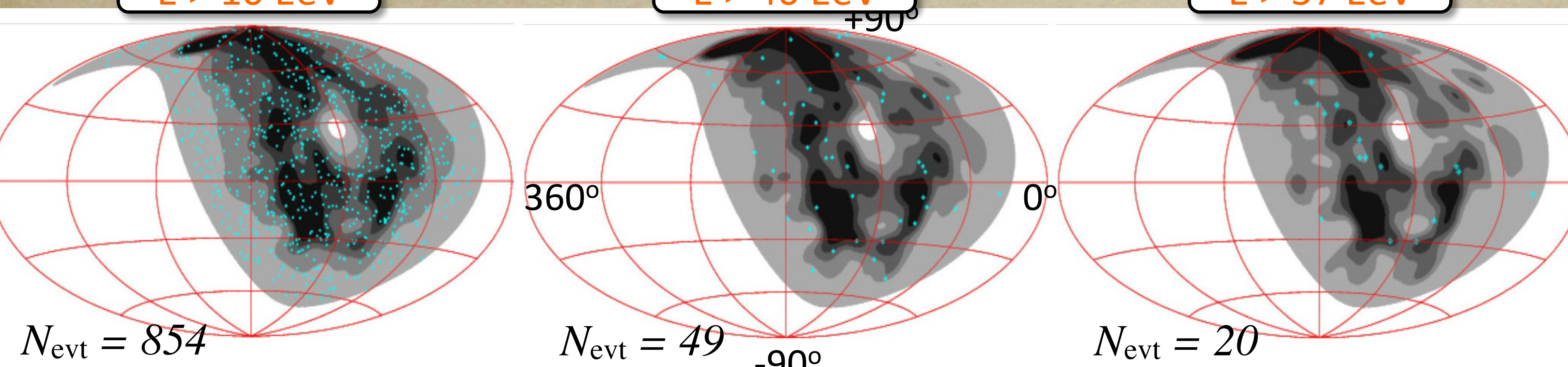
Smearing angle: Free parameter
GC region excluded
(|b| < 10deg, |l|<90deg)

Smearing

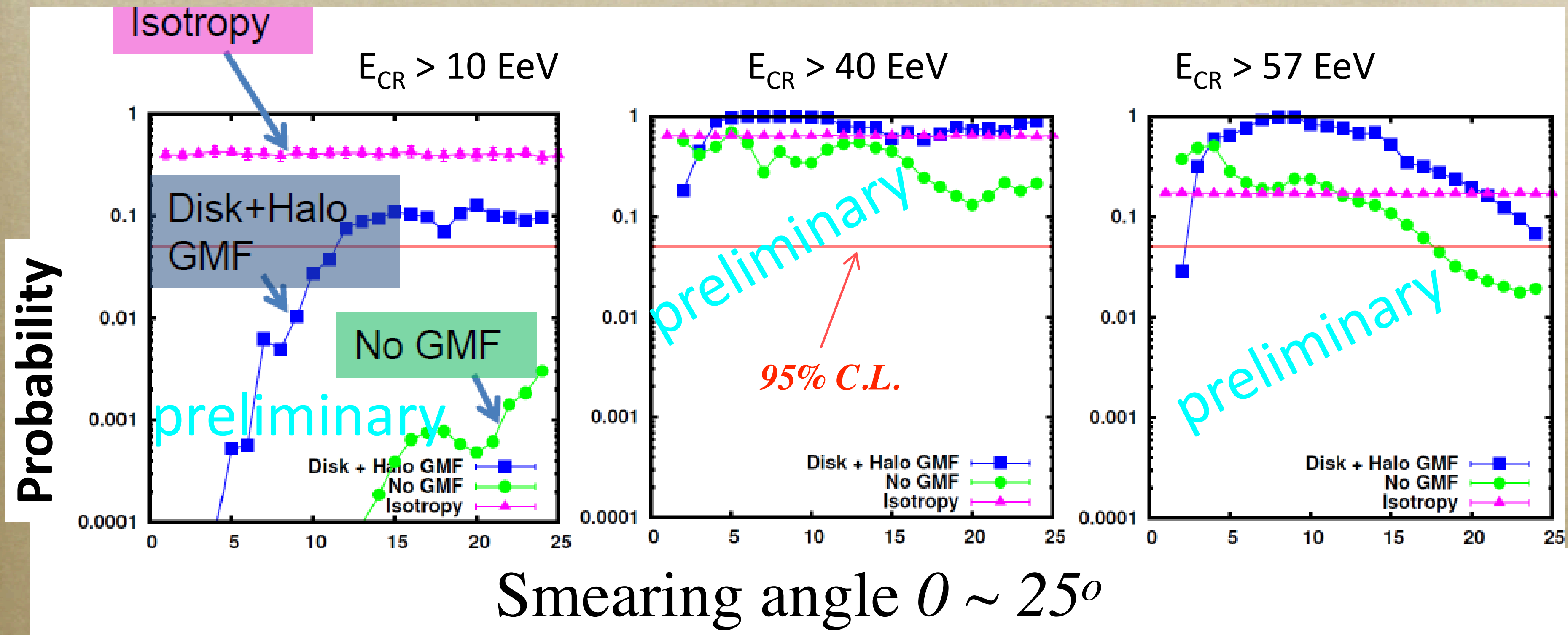
E > 10 EeV

E > 40 EeV

E > 57 EeV



TASD and LSS - KS Test -

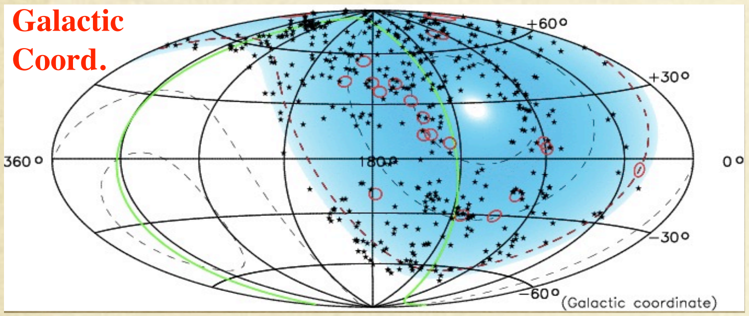


- Compatible with isotropy for all energy regions
- Compatible with the LSS hypothesis at 40/57 EeV w/ or w/o GMF
- NOT compatible with LSS for E>10 EeV,

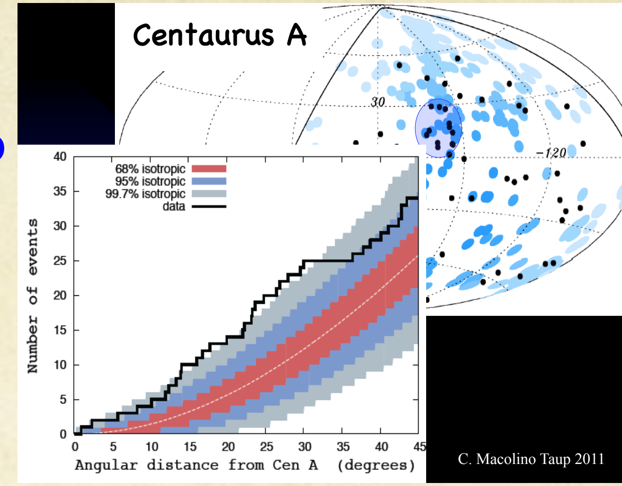
  w/o strong/extended halo field

UHECR (an)isotropy

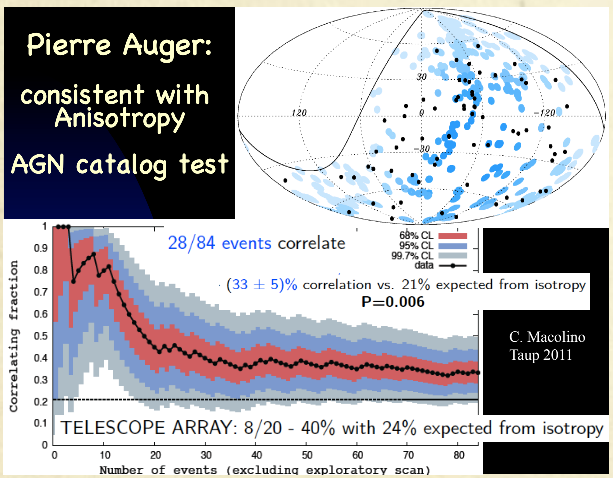
No clear Anisotropy signal yet !!



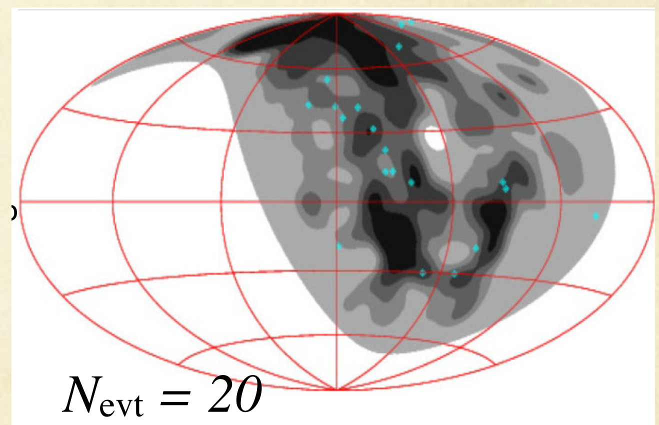
Cen A ?



AGN ?



LSS ?



- Energy Scale
- Composition

More statistics !!

New Projects

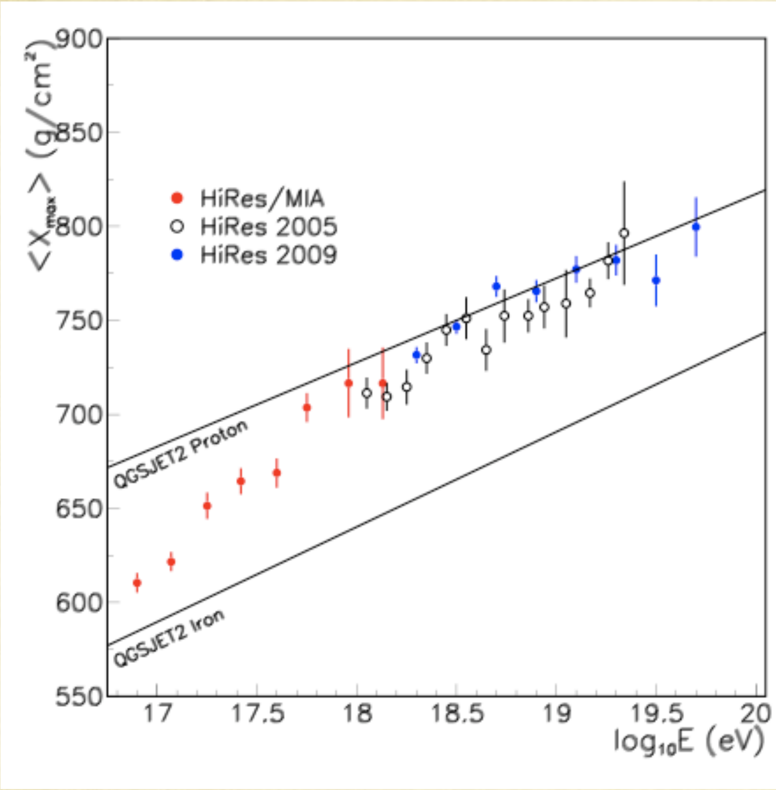
New Projects at the Telescope Array

- Telescope Array Low Energy Extension : TALE
  - Study CR spectrum, composition, anisotropy from $10^{16.5}$ eV to 10^{18} eV with hybrid detectors

Go to LHC energy !!

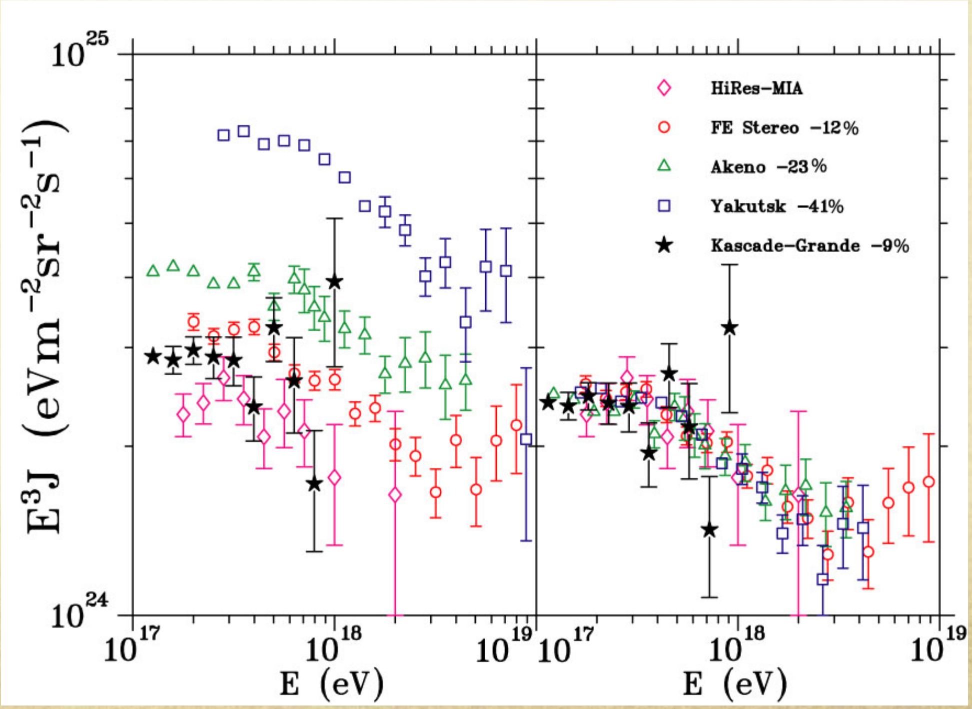
- R/D of new technique “Radio” for next Large Detector
  - Molecular Bremsstrahlung Radiation
    - To use 10-12GHz waves to detect molecular bremsstrahlung radiation from air shower electron components
  - Bi-Static Radar
    - To use 50MHz TV carrier waves to detect plasma produced by EAS in the atmosphere

TALE physics

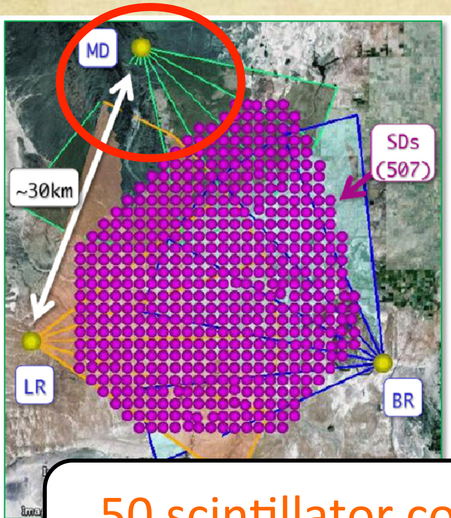


- Study reported but poorly known spectral features – "iron knee", "second knee", "galactic-extragalactic transition"

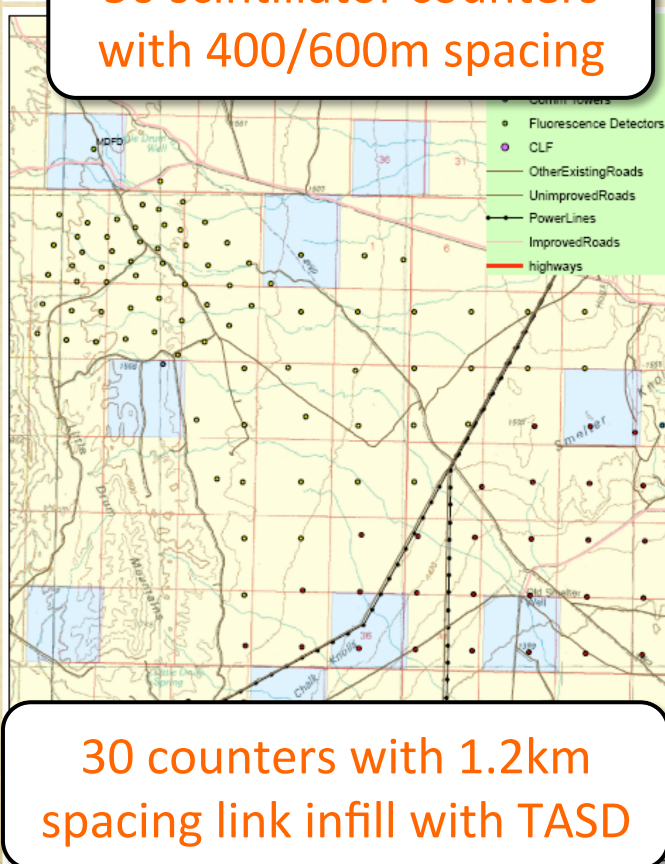
- Study EAS physics at same energy as LHC ($10^{16.5\text{-}17}$ eV)
  - Compare LHC validated proton MC with experimental EAS determination



TALE Detectors

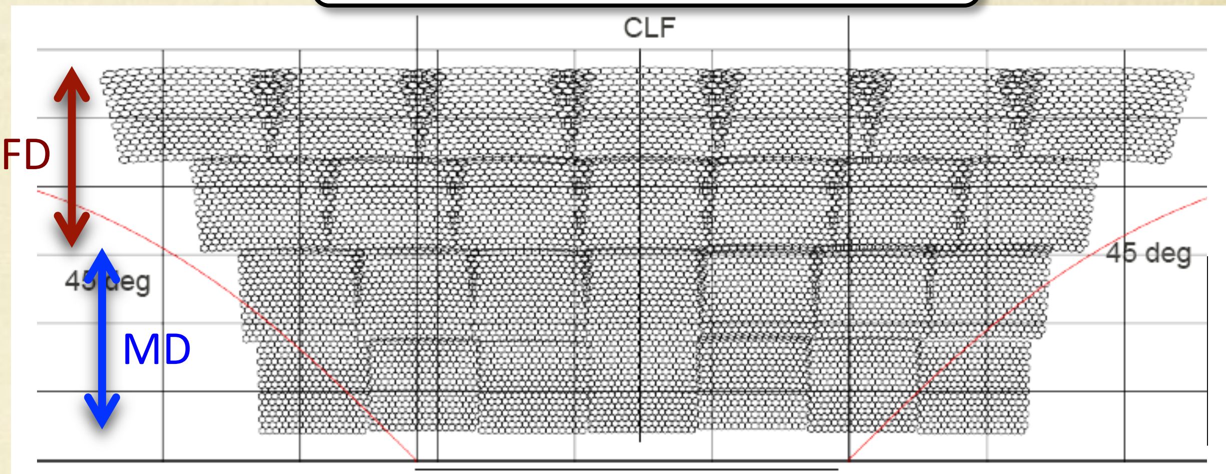


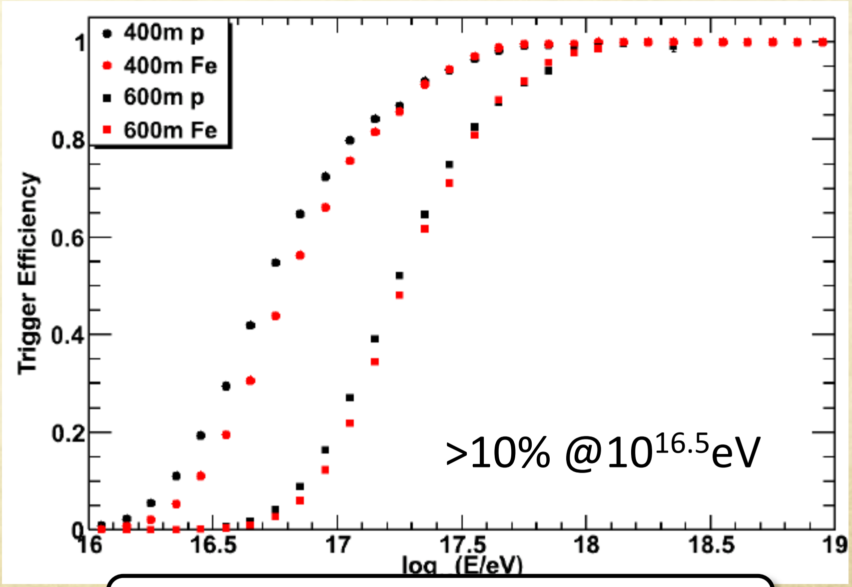
50 scintillator counters with 400/600m spacing



30 counters with 1.2km spacing link infill with TASD

F.O.V of TALE FD (~60deg.)



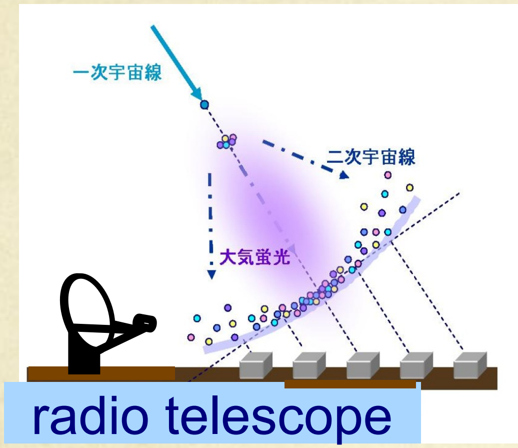


Trigger efficiency of TALE SD

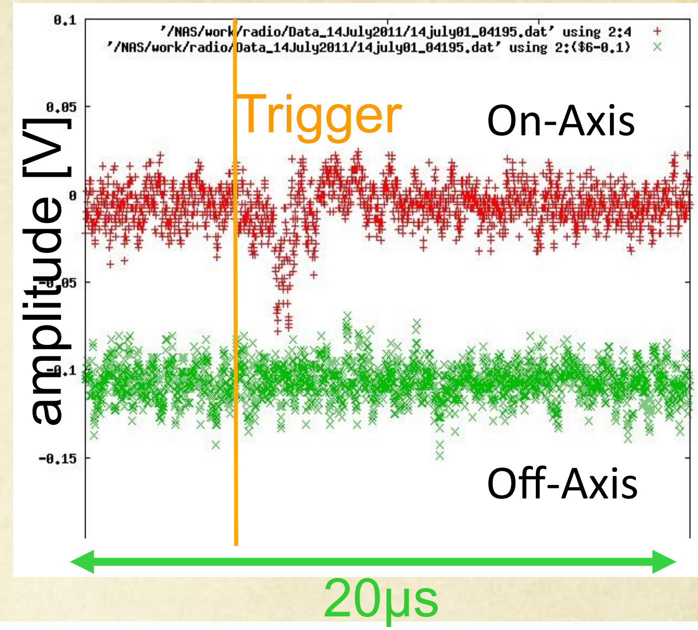
Molecular Bremsstrahlung Radiation

R/D project @OCU

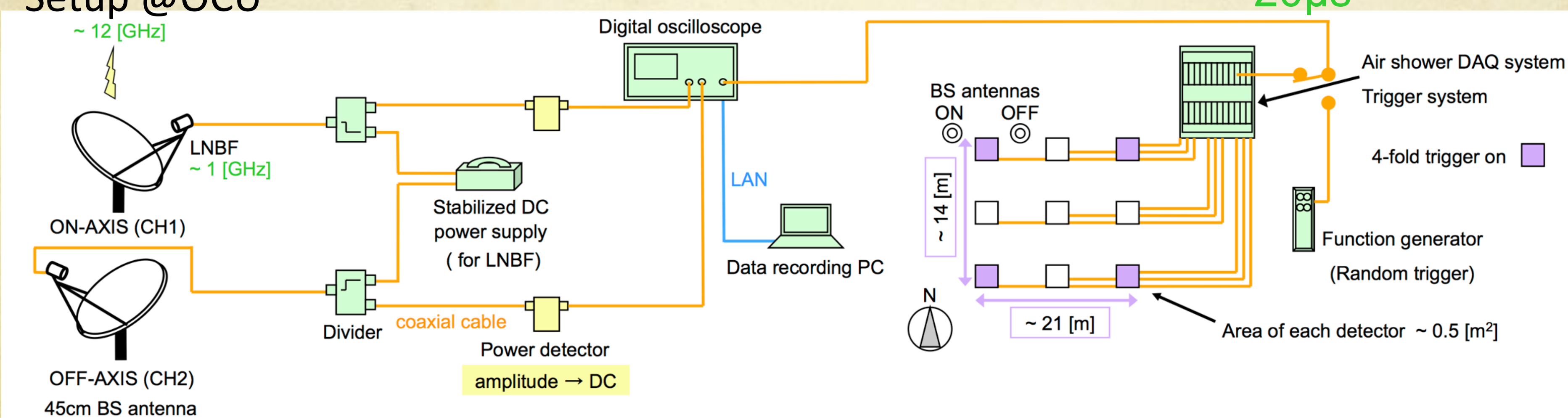
- Two antenna for 10-12GHz (ON/OFF – axis)
- Check the coincidence with SD signal



Signal candidate (???)

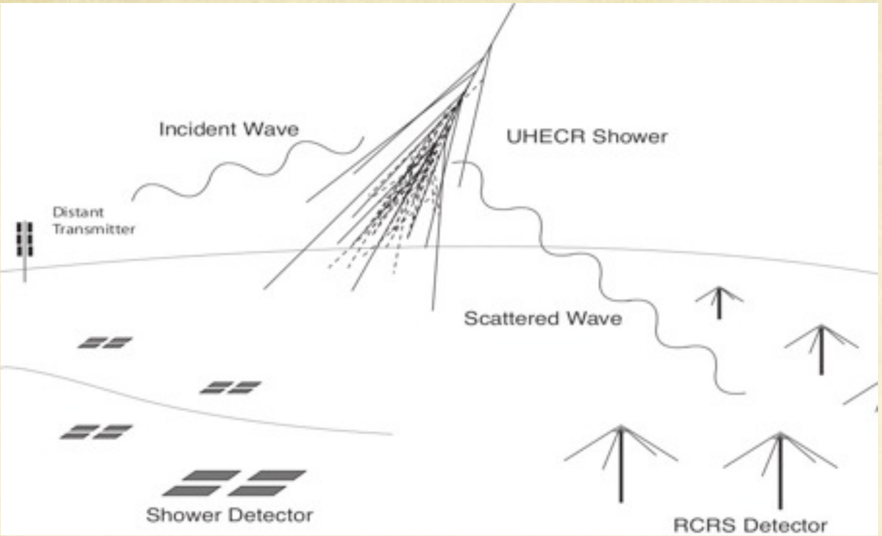


Setup @OCU

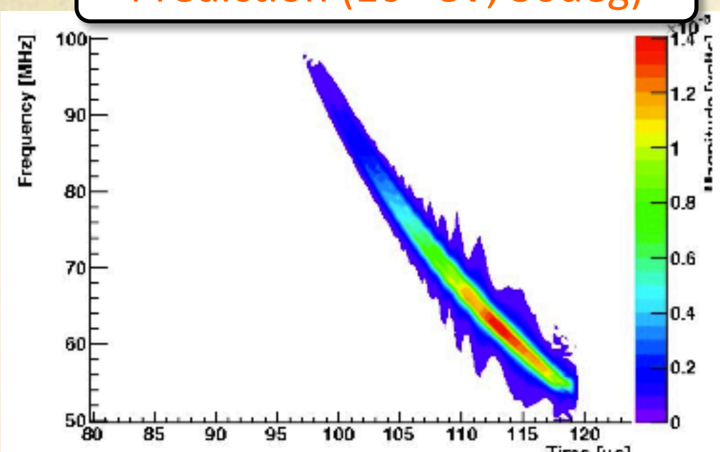


Go to TA site !!

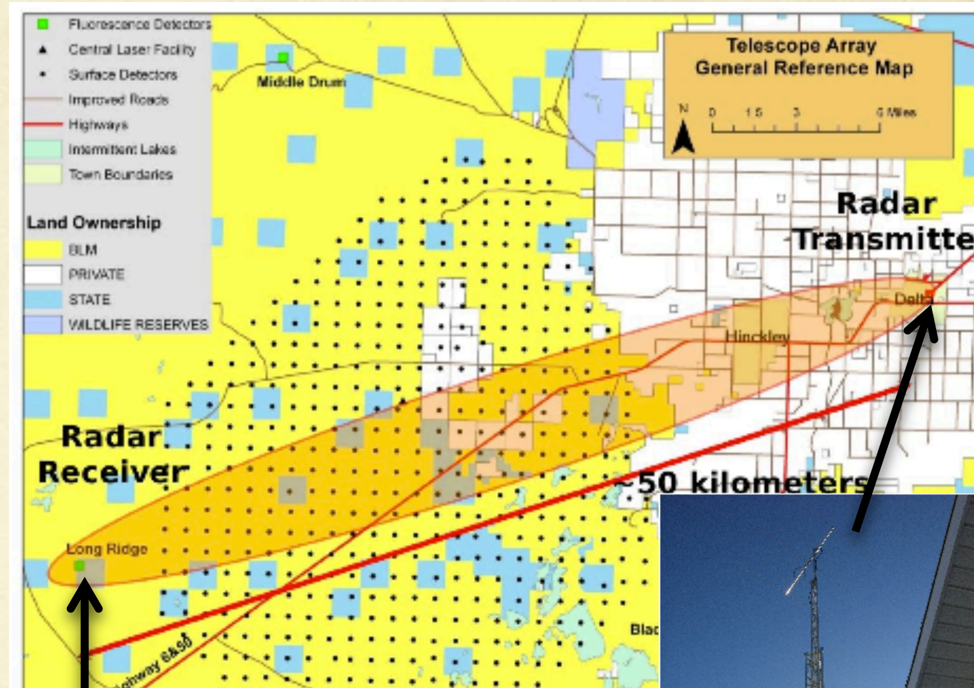
Bi-static Radar at Telescope Array

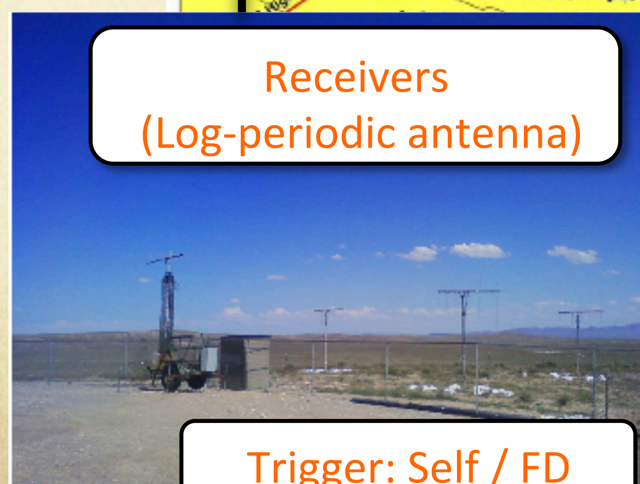


Prediction (10^{19}eV, 30deg)



"Chirp" : Unique signature for EAS
(Rapid movement of "target" produces Doppler-like shift)





Receivers
(Log-periodic antenna)

Trigger: Self / FD

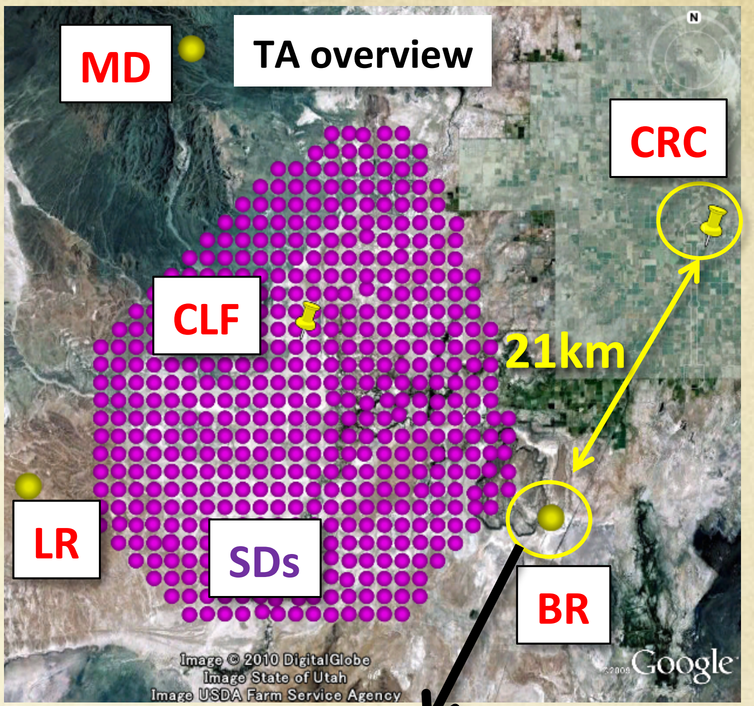
Transmitter (6m Yagi)
Power: 2kW -> 40kW

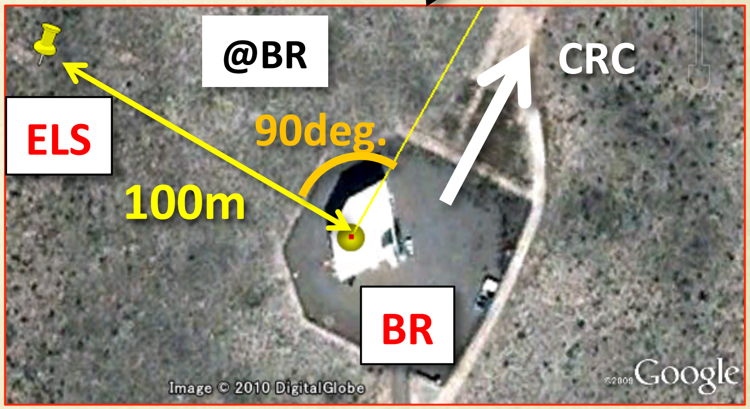
Calibration by ELS

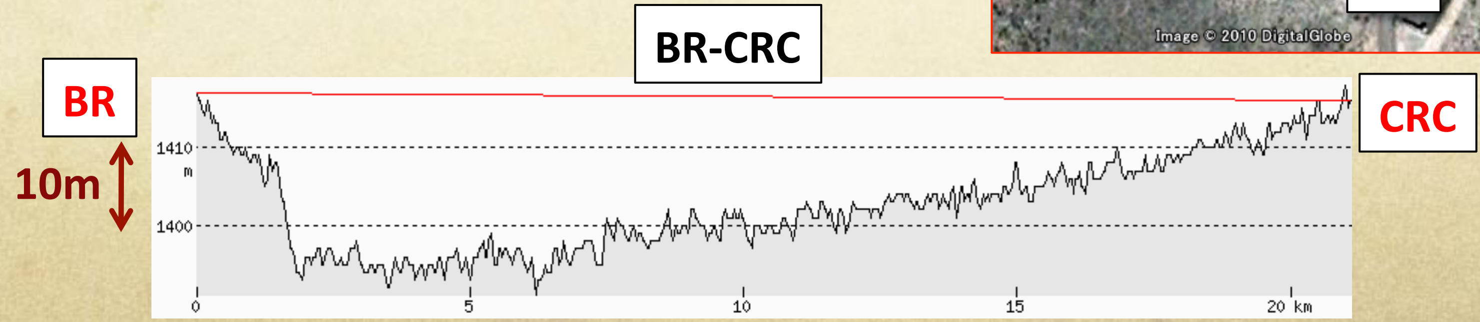
Bi-Static Radar

- Radio path: CRC - ELS – BR
- Confirmation of the technique
- Ratio of detected power from transmitter to received power from ELS gives cross-section
- Expected S/N: ~30 /1000shots (30min)

Bremsstrahlung Radiation technique will also use the ELS shower as a calibrator







In future…

To understand the origin of UHECR, we need more statistics.

- 10000 SDs ?
- Original TA (FD array) ?
- JEM-EUSO ?
- Radio technique ?
- Other method ?

We started to consider the next Large UHECR Observation !!

Conclusion

- Three years TA full operation
- Energy Spectrum:
  - MD, BR/LR, SD spectra are in good agreement
  - Consistent with HiRes
  - Suppression: 3.9 σ away from continued spectrum
- Composition: Proton dominant up to GZK break point
- Anisotropy: Compatible with both isotropy and AGN/LSS correlation hypothesis
  - Need more statistics
- New projects: TALE, Radio technique…