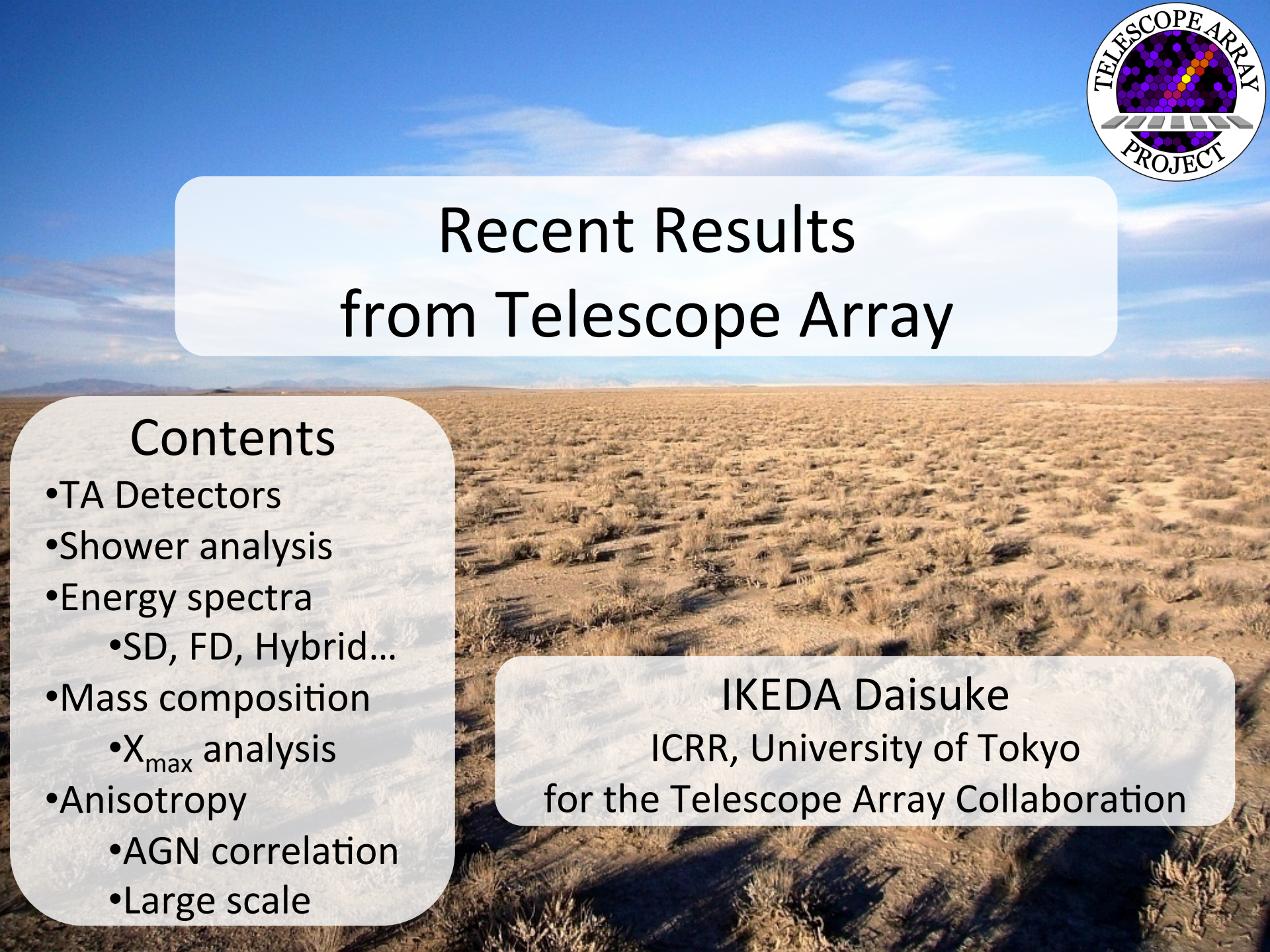


Recent Results from Telescope Array

Contents

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

IKEDA Daisuke
ICRR, University of Tokyo
for the Telescope Array Collaboration

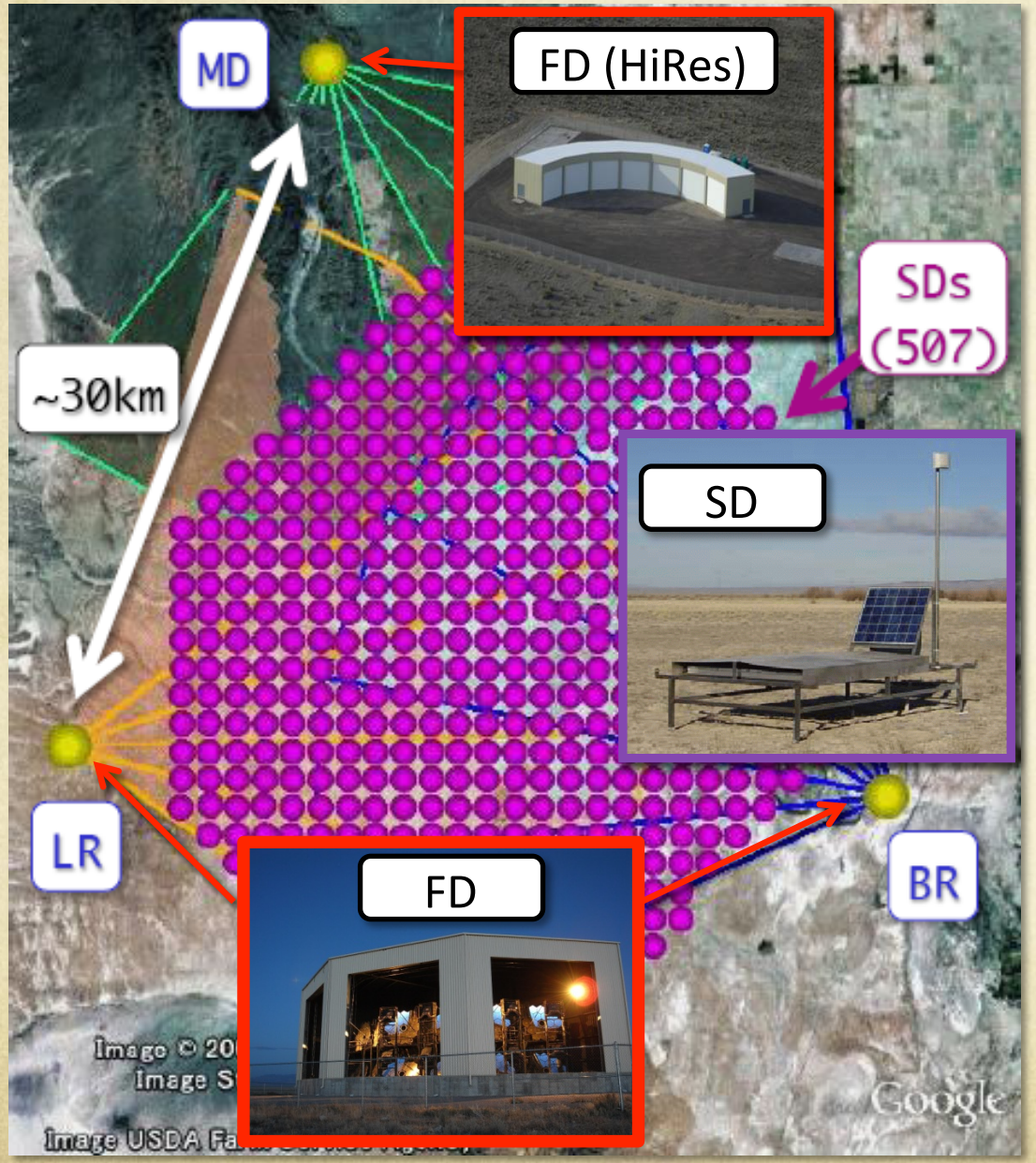
The Telescope Array Collaboration

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

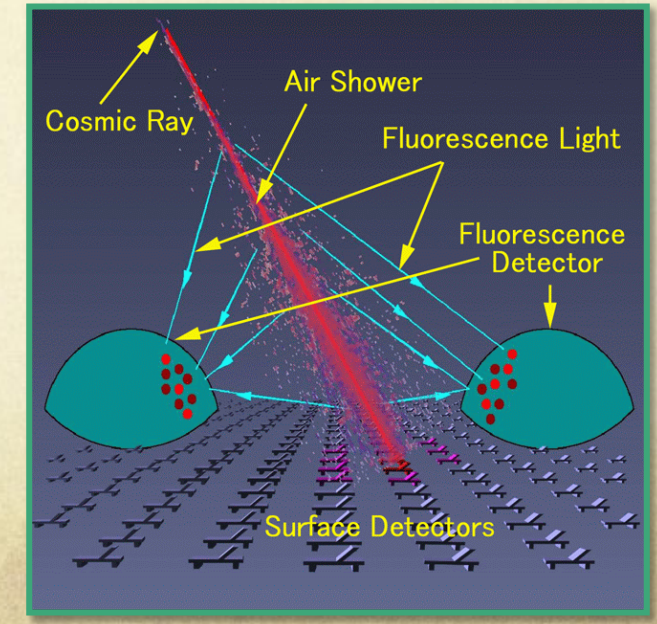
T Abu-Zayyad[1], R Aida[2], M Allen[1], R Azuma[3], E Barcikowski[1], JW Belz[1], T Benno[4], DR Bergman[1], SA Blake[1], O Brusova[1], R Cady[1], BG Cheon[6], J Chiba[7], M Chikawa[4], EJ Cho[6], LS Cho[8], WR Cho[8], F Cohen[9], K Doura[4], C Ebeling[1], H Fujii[10], T Fujii[11], T Fukuda[3], M Fukushima[9,22], 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[9], 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[1], TA Stroman[1], 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]

1University of Utah, High Energy Astrophysics Institute, Salt Lake City, Utah, USA
2University of Yamanashi, Interdisciplinary Graduate School of Medicine and Engineering, Kofu, Yamanashi,Japan
3Tokyo Institute of Technology, Meguro, Tokyo, Japan
4Kinki Unversity, Higashi Osaka, Osaka, Japan
5Rutgers University, Piscataway, USA
6Hanyang University, Seongdong-gu, Seoul, Korea
7Tokyo University of Science, Noda, Chiba, Japan
8Yonsei University, Seodaemun-gu, Seoul, Korea
9Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Chiba, Japan
10Institute of Particle and Nuclear Studies, KEK, Tsukuba, Ibaraki, Japan
11Osaka City University, Osaka, Osaka, Japan
12Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia
13Kanagawa University, Yokohama, Kanagawa, Japan
14Saitama University, Saitama, Saitama, Japan
15Tokyo City University, Setagaya-ku, Tokyo, Japan
16Pusan National University, GeumJeong-gu, Busan, Korea
17Waseda University, Advanced Research Institute for Science and Engineering, Shinjuku-ku, Tokyo, Japan
18Chiba University, Chiba, Chiba, Japan
19Ewha Womans University, Seodaaemun-gu, Seoul, Korea
20Chungnam National University, Yuseong-gu, Daejeon, Korea
21University Libre de Bruxelles, Brussels, Belgium
22University of Tokyo, Institute for the Physics and Mathematics of the Universe, Kashiwa, Chiba, Japan
23Kochi University, Kochi, Kochi, Japan
24Hiroshima City University, Hiroshima, Hiroshima, Japan
25National Institute of Radiological Science, Chiba, Chiba, Japan
26Ehime University, Matsuyama, Ehime, Japan

Telescope Array Experiment

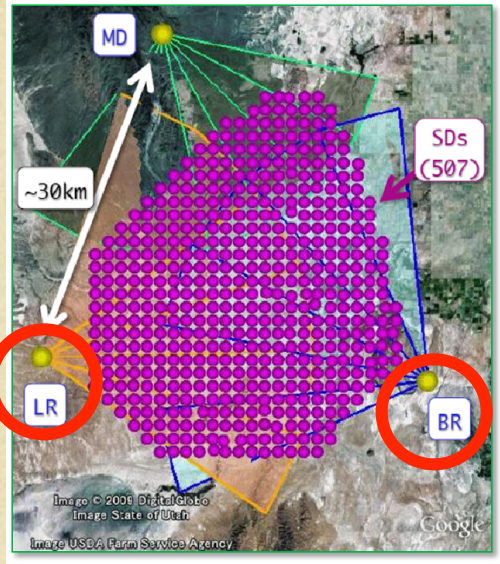


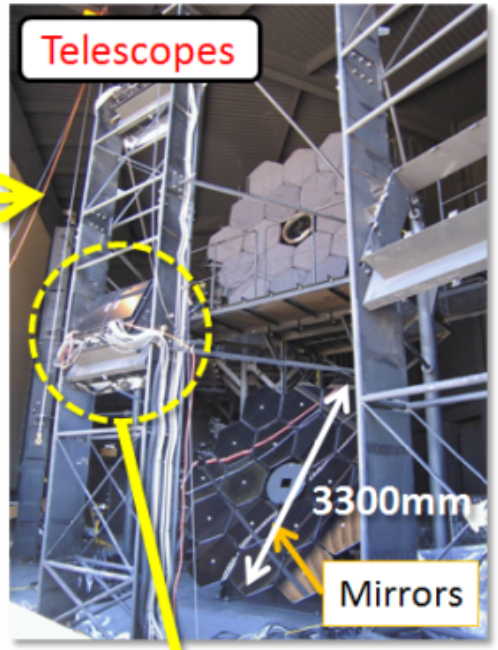
- Desert in Utah, US (1400m a.s.l.)
- 507 Surface Detectors (SDs)
  - 1.2km spacing
  - Two layer of plastic scintillator, $3m^2$, 1.2cm thickness
- 3 Fluorescence Detectors (FDs)
  - Middle Drum (MD) station is transferred from HiRes.
  - Black Rock (BR) and Long Ridge(LR) stations are newly built.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

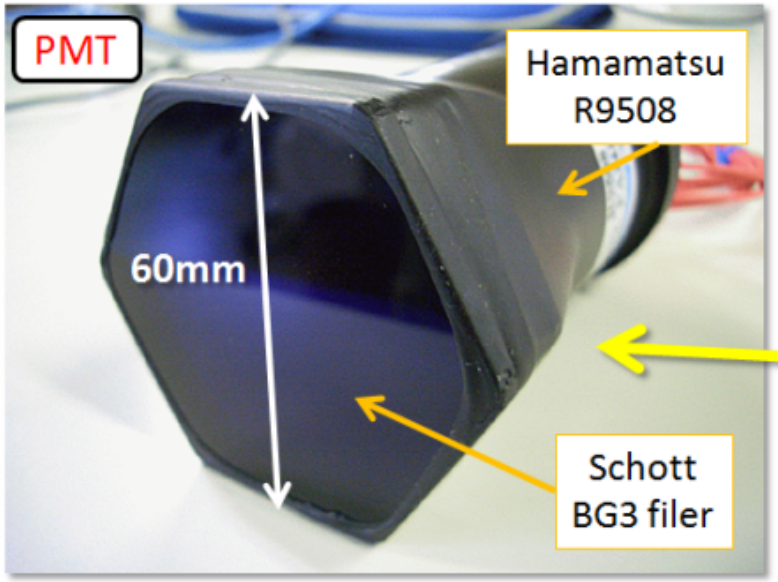


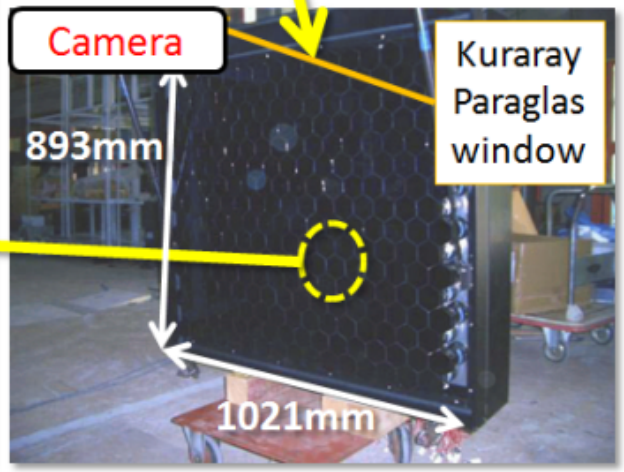
Fluorescence Detector station at BR/LR site

BR/LR site : new telescopes for TA





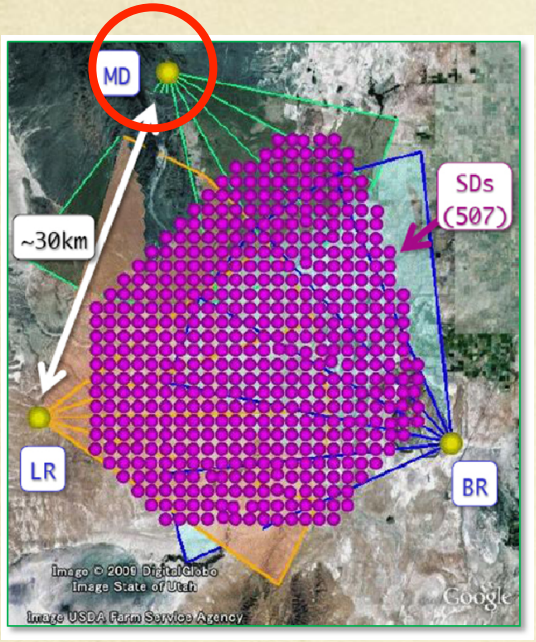




F.O.V of station:

- Elevation:3~33°
- Azimuth: 108°

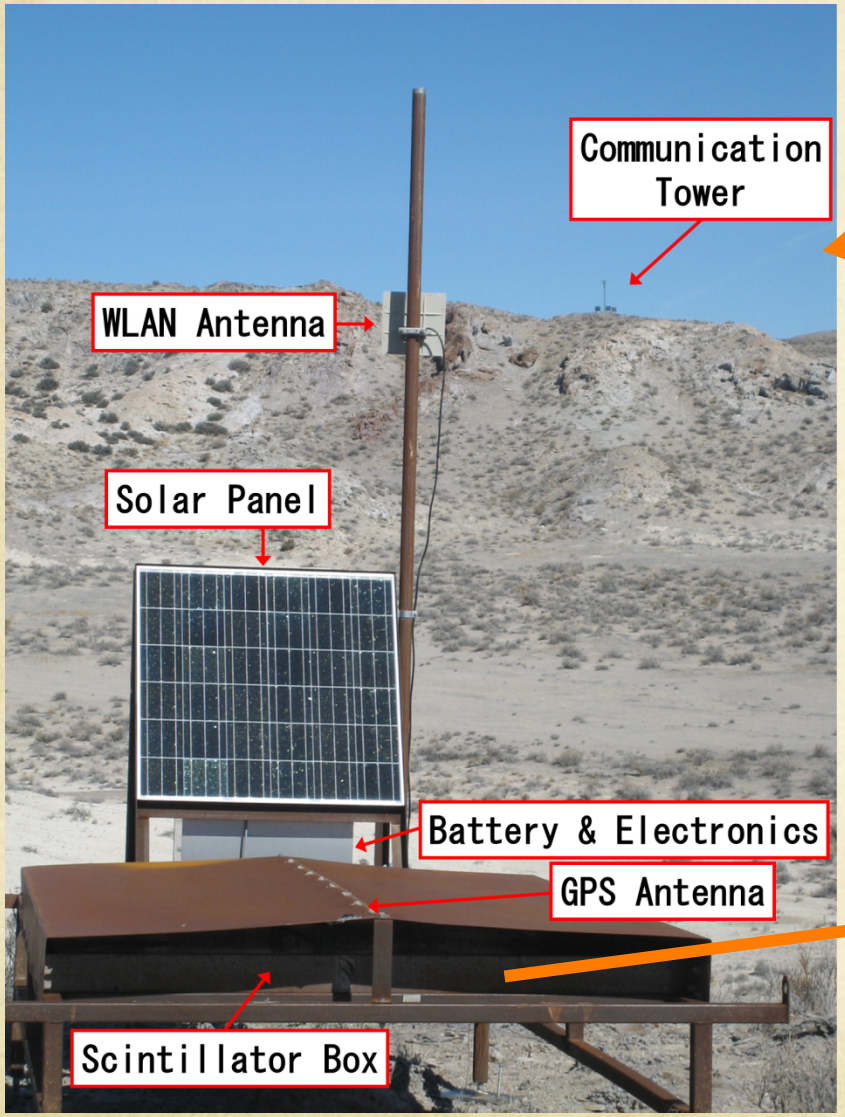
Fluorescence Detector station at MD site

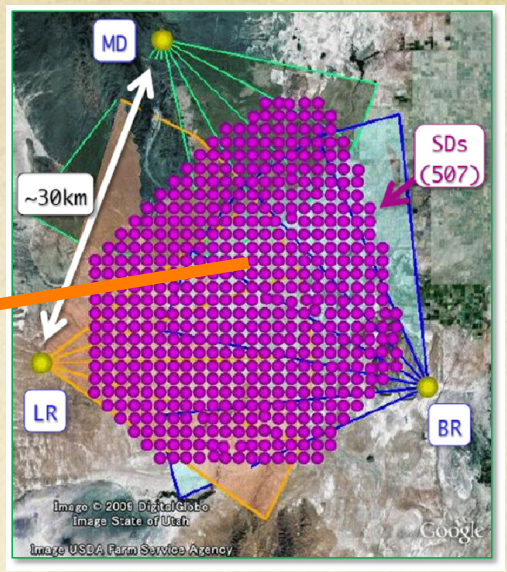


Transferred from HiRes

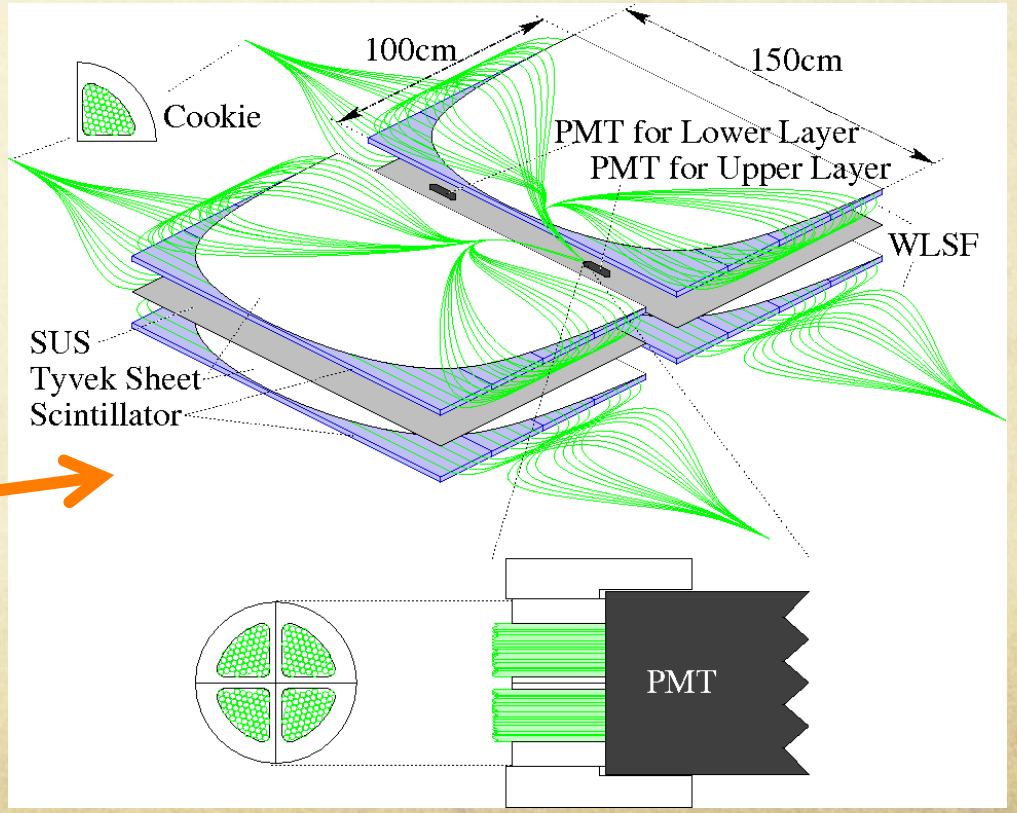
- 14 cameras/station
- 256 PMTs/camera
- 3^o-31^o elevation with 1^o pixel
- 114^o in azimuth
- $5.2m^2$ mirror
- S/H electronics

Surface Detector array





- Two layers of the 3m^2 plastic scintillators

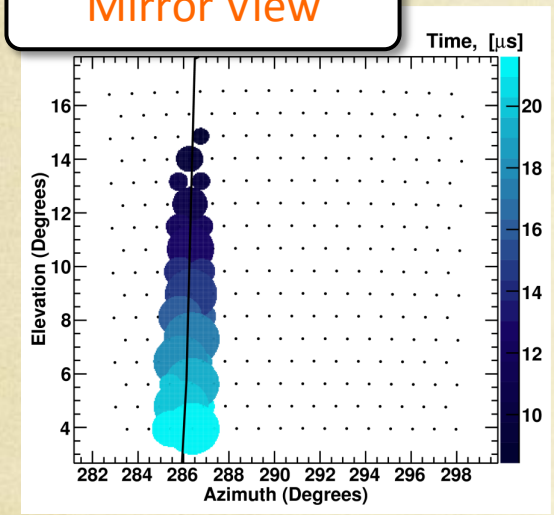


Shower Analysis

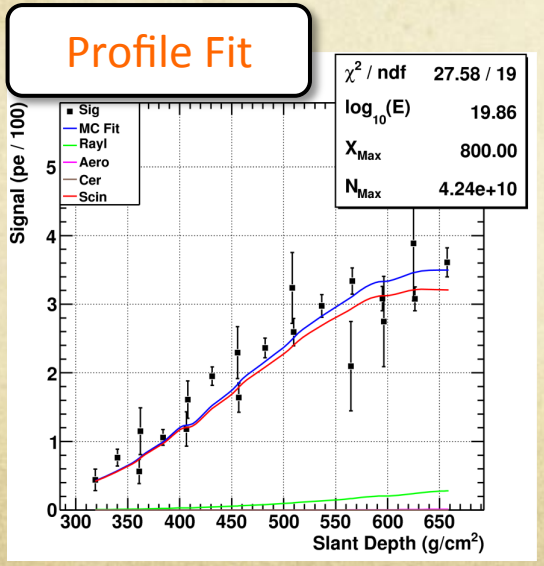
Shower Analysis
- FD Monocular -

Data set for MD monocular analysis:
- 16/Dec/2007 – 16/Dec/2010 (3 years)
- ~1/3 of HiRes-1 observation

Mirror View



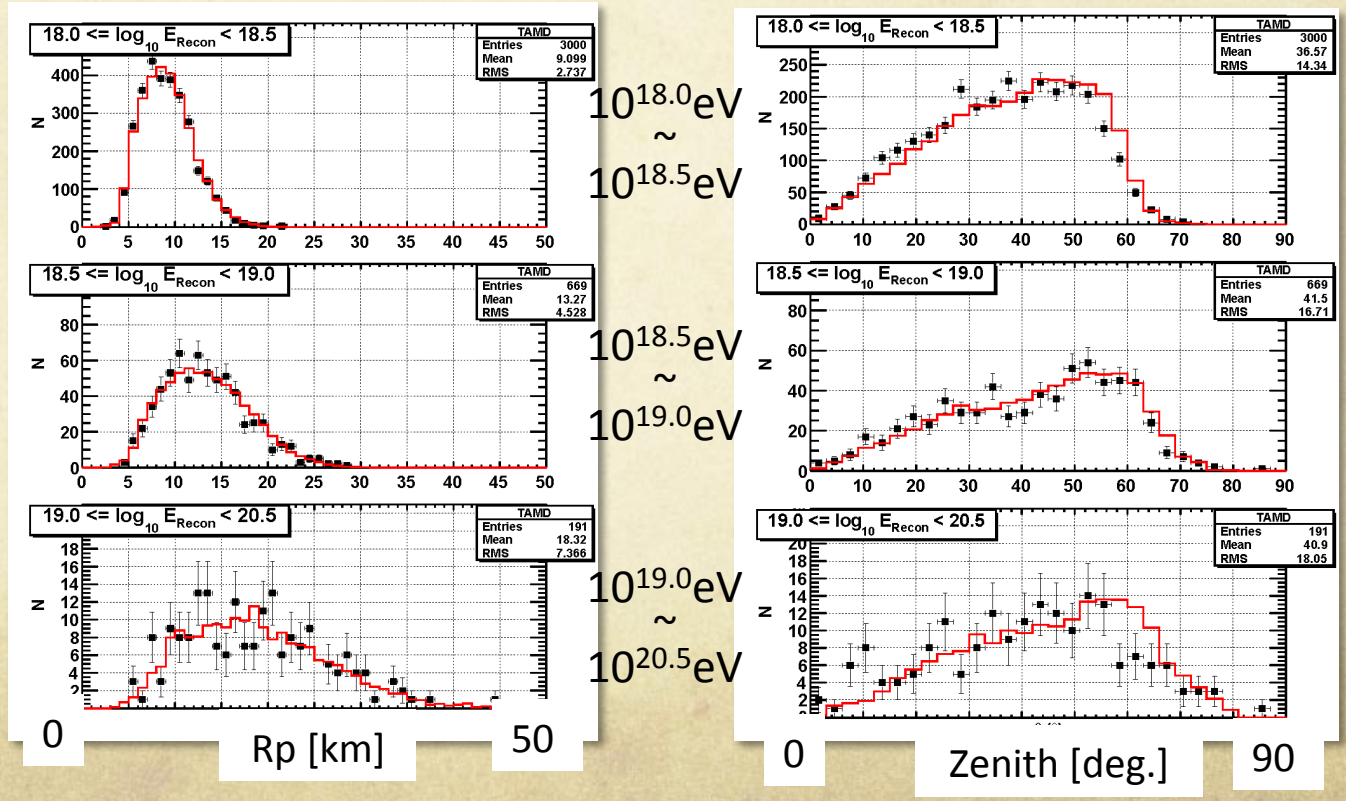
Profile Fit



MD station: Transferred from HiRes-I

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

Data/MC comparison with Coriska, Proton

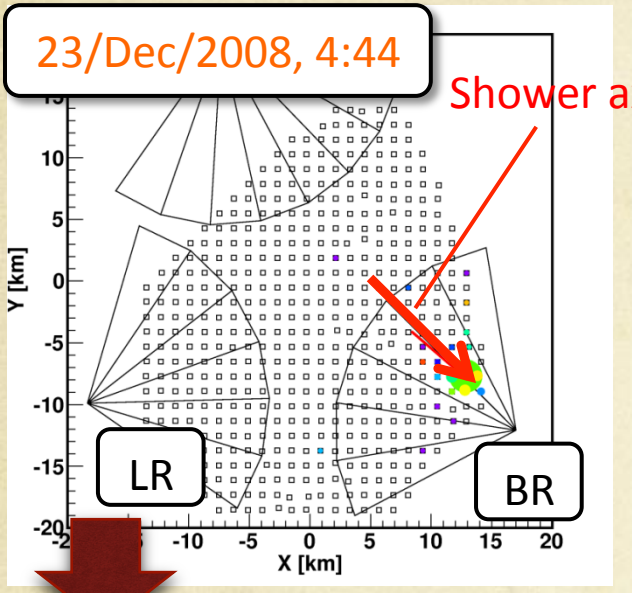


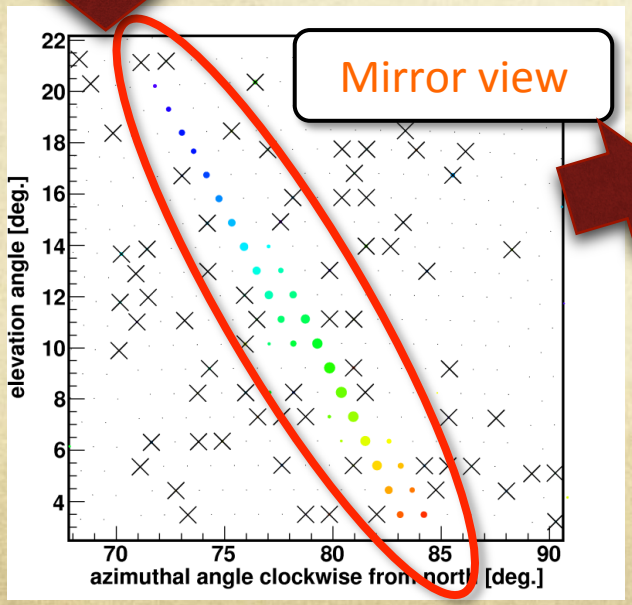
Shower Analysis
- Hybrid -

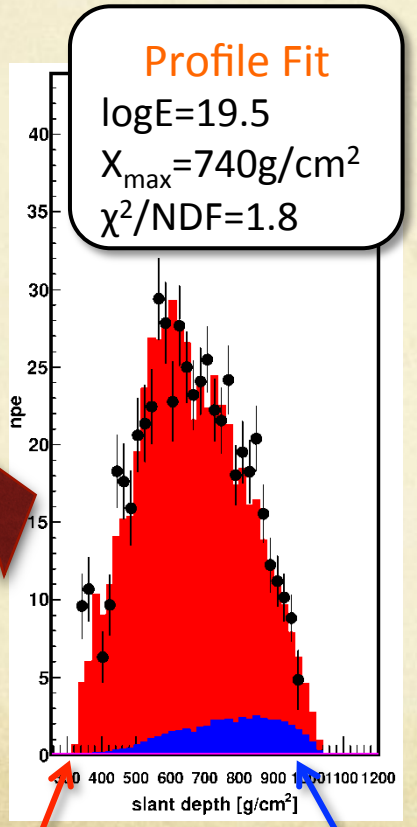
Data set for BR/LR Hybrid analysis:
- 27/May/2008 – 07/Sep/2010 (~2.3 years)

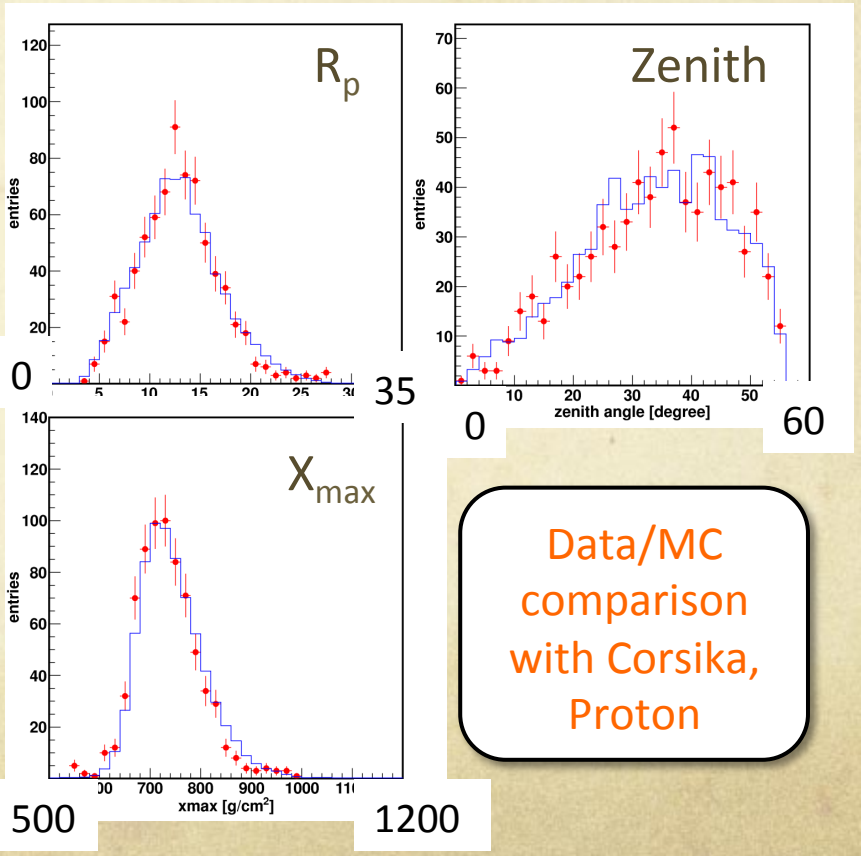
Geometry: FD+SD, Profile: FD

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









Data/MC comparison with Corsika, Proton

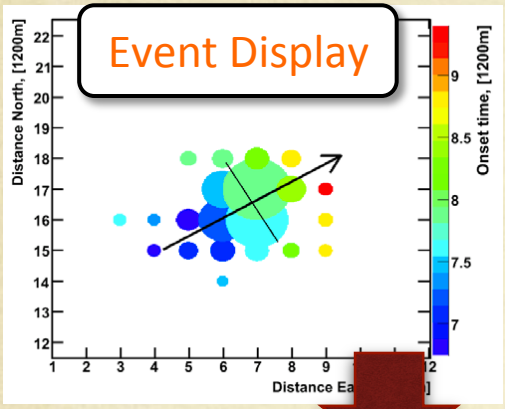
Shower Analysis
- SD -

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

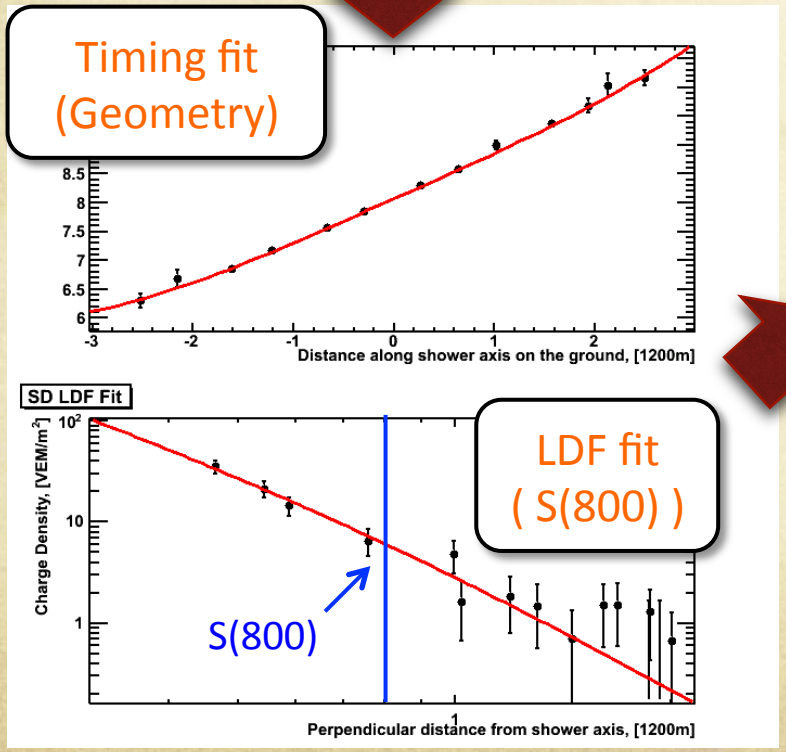
Lateral distribution at the ground

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

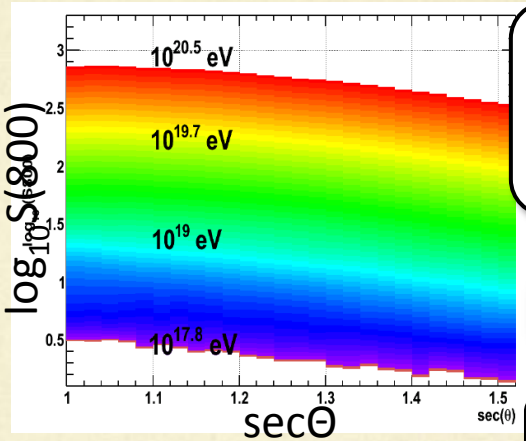
Event Display



Timing fit (Geometry)



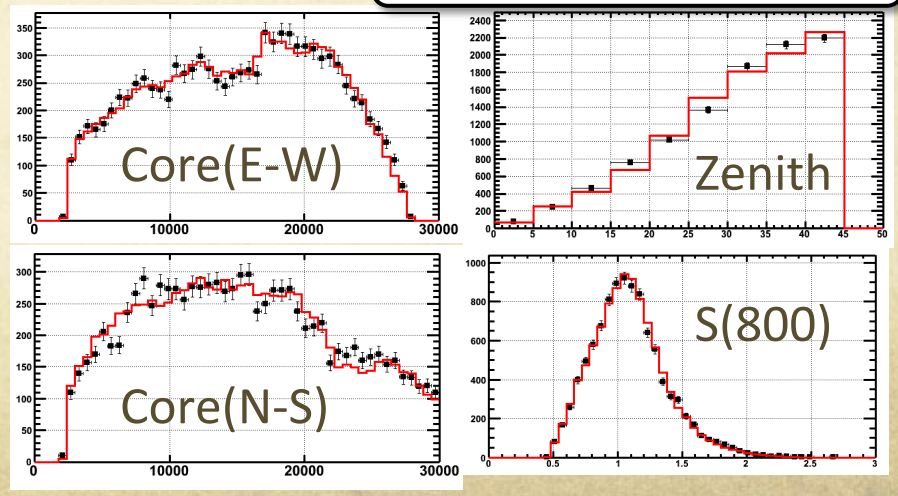
LDF fit (S(800))



Energy table Constructed from MC (Corsika, Proton)

E_{SD}(MC)

Data/MC comparison

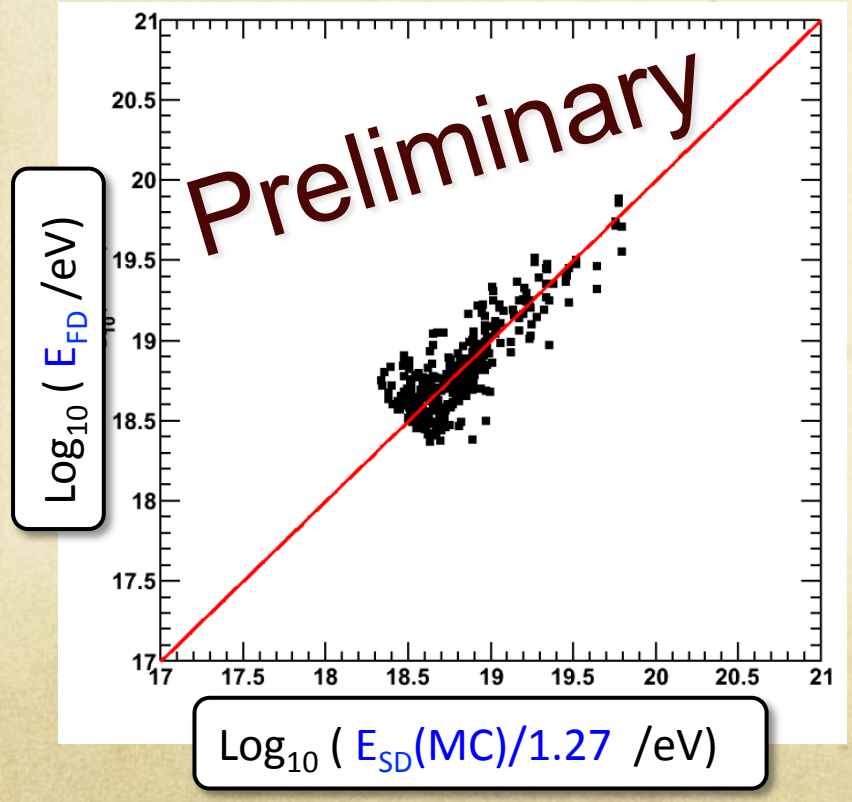


FD-SD Energy Scale

- 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 all 3 FDs and SD, we obtained

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

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

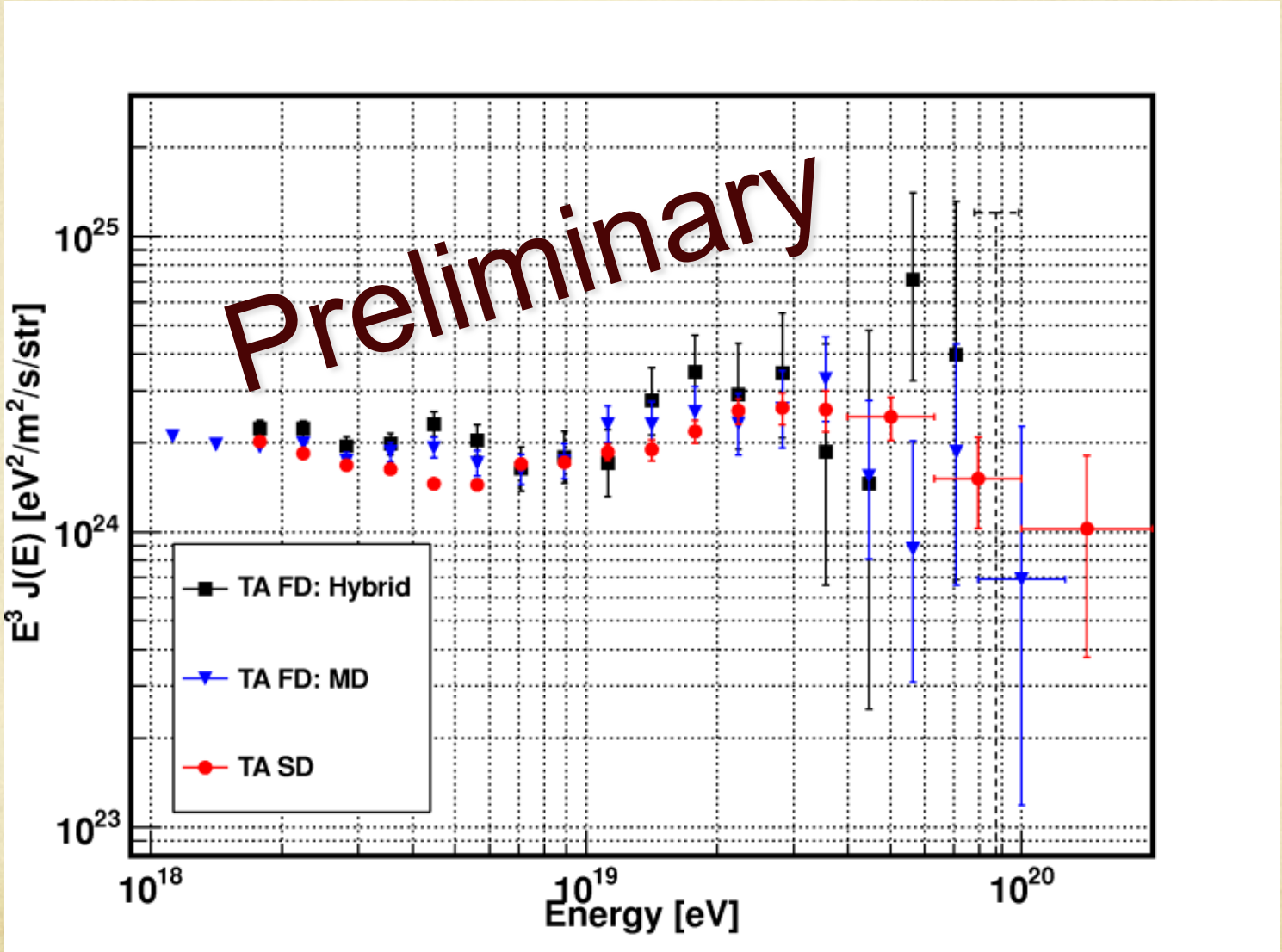


Systematic uncertainties for FD energy determination

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

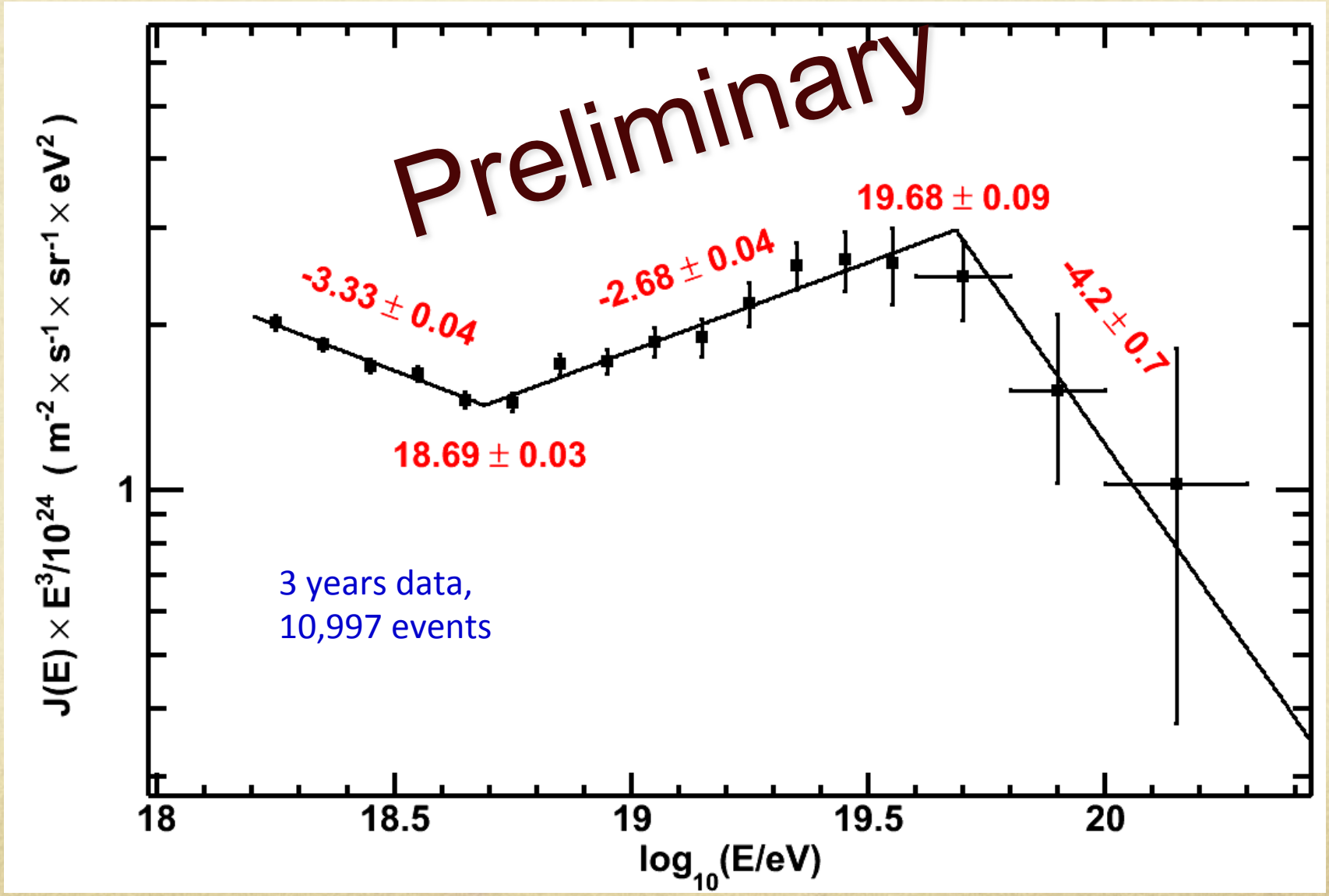
Energy Spectra

Energy spectra from TA

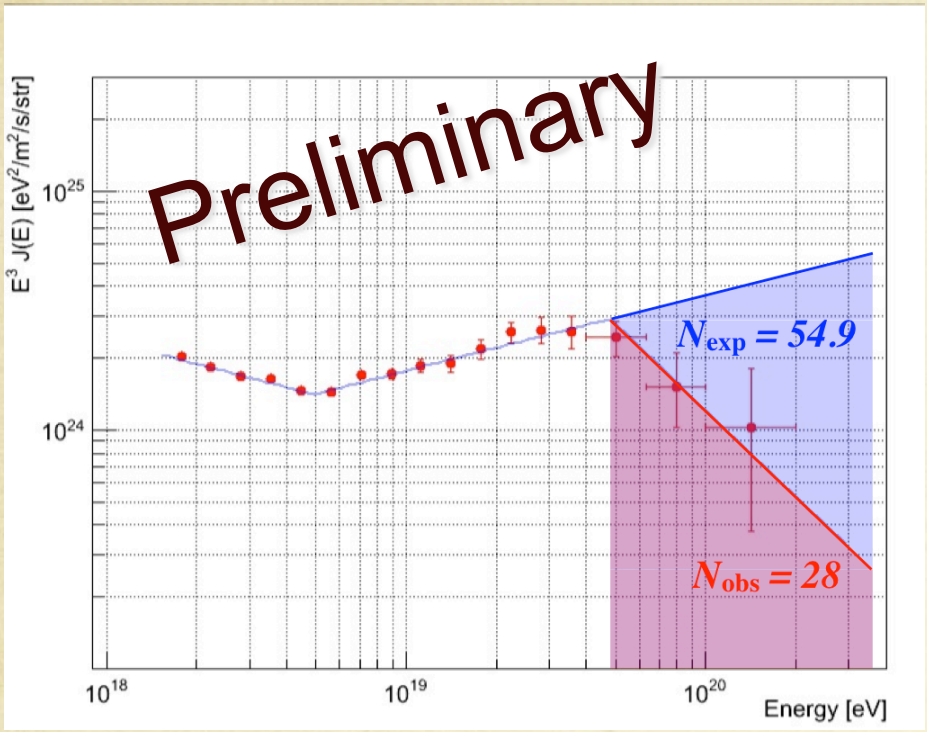


Three energy spectra from TA,
MD monocular, BR/LR hybrid, and SD are in good agreement.

Broken Power Low Fit



GZK Feature



Significance of GZK suppression

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

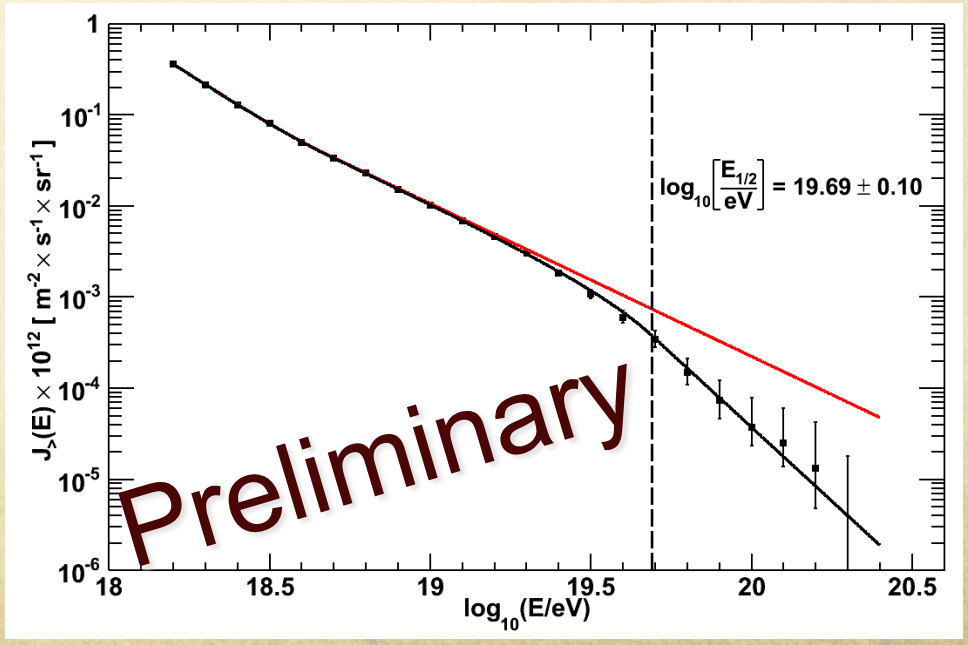
- # of expected events: **54.9**
- # of observed events: **28**

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

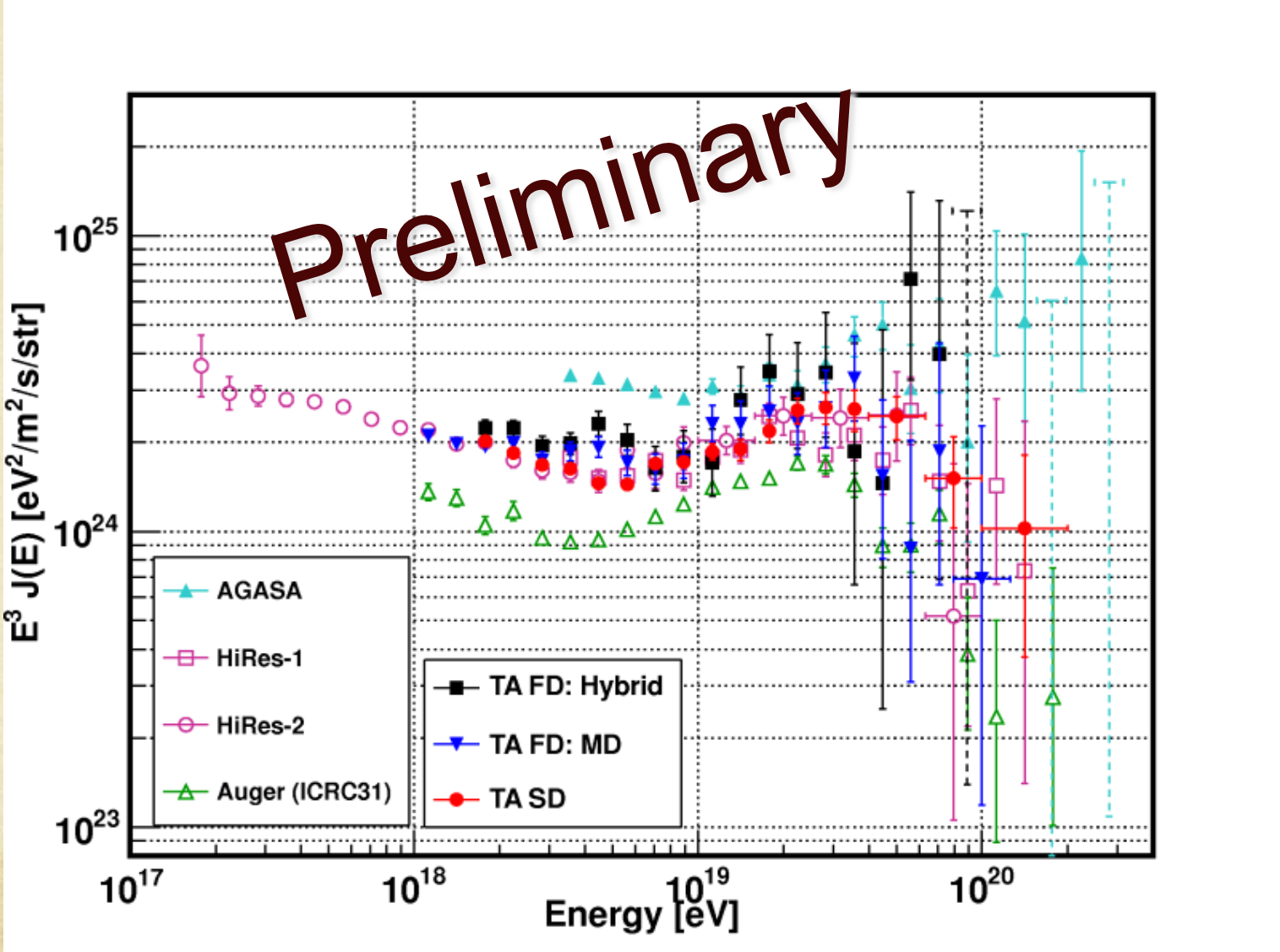
3.9σ

Integral Flux $E_{1/2}$

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



AGASA, HiRes, Auger, TA

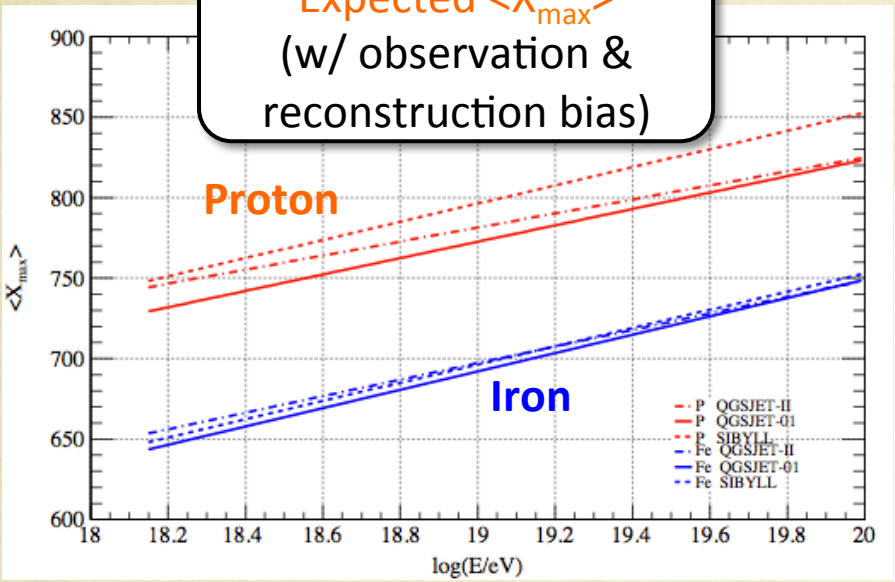


TA spectra are consistent with HiRes. (-20% AGASA, +20% Auger)

Mass Composition

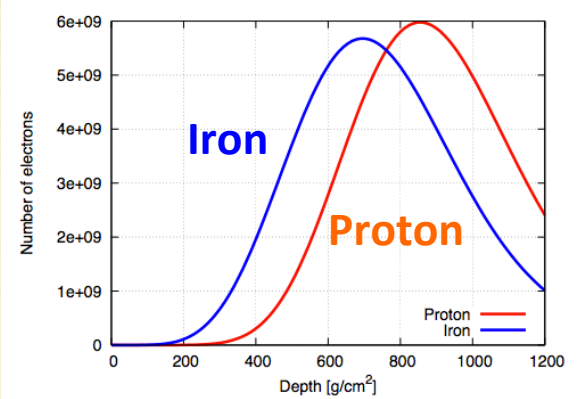
X_{max} analysis

Expected $<X_{max}>$ (w/ observation & reconstruction bias)



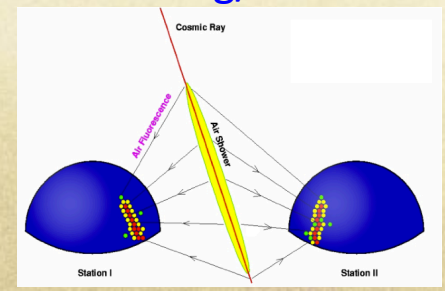
Shower longitudinal development depends on primary particles

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

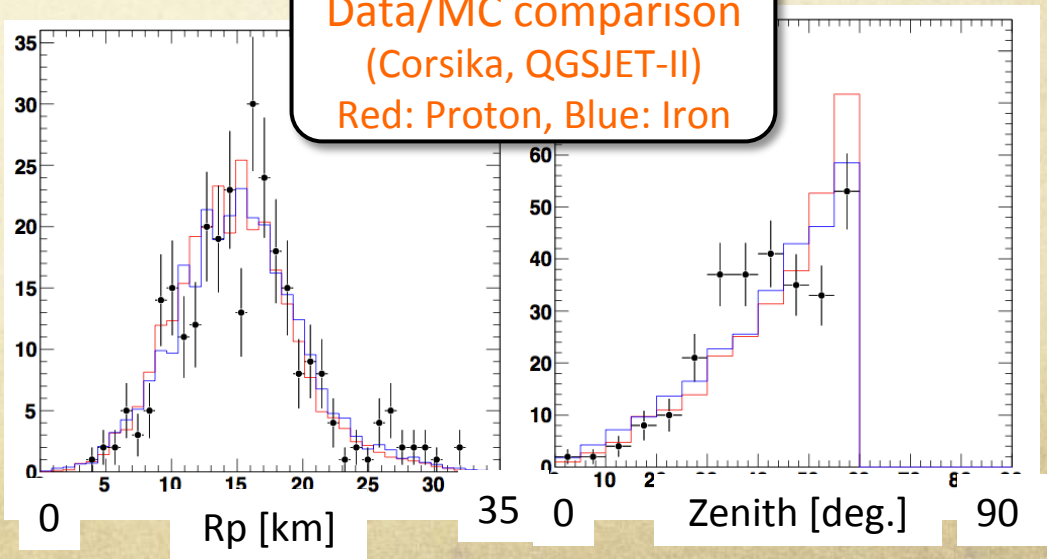


Stereo analysis on BR/LR

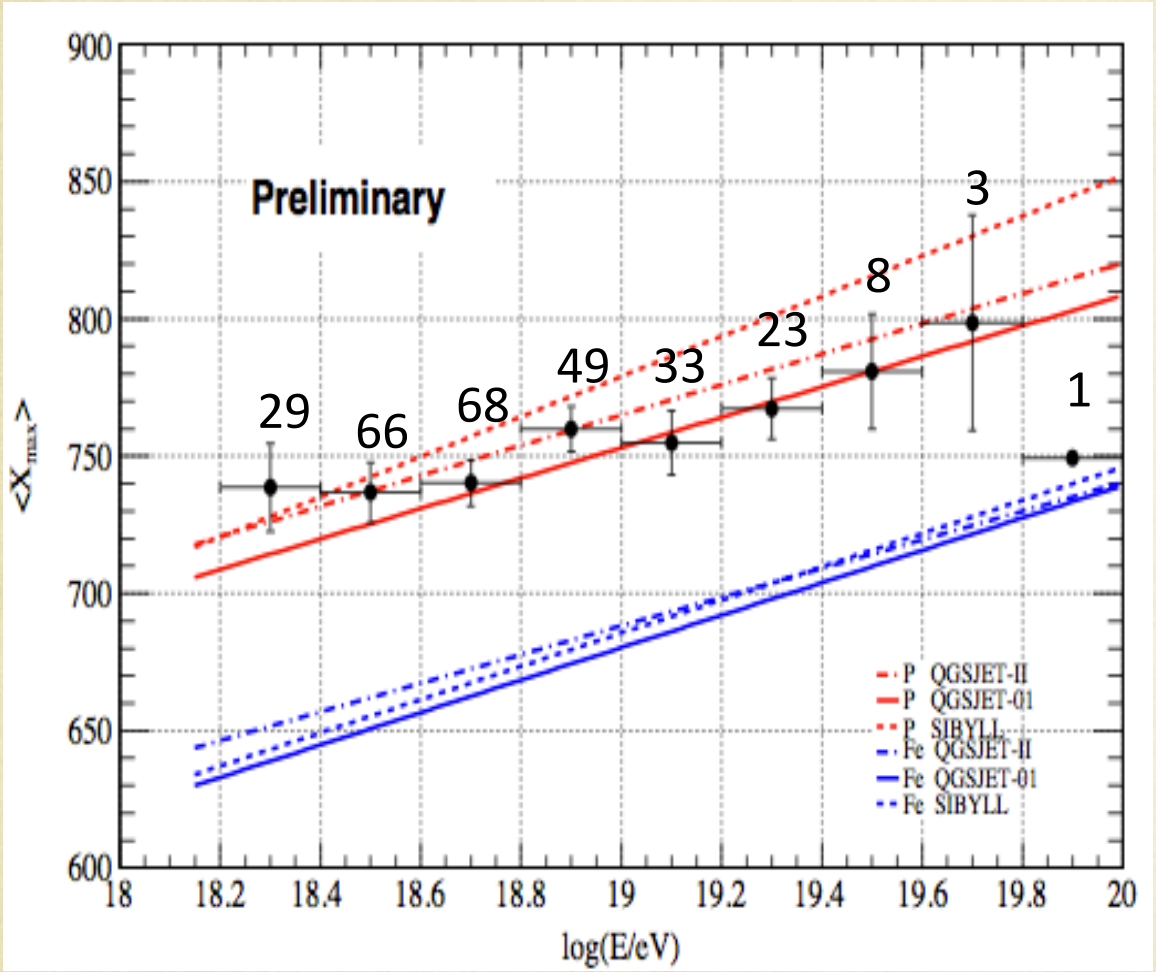
- Axis: Intersection of two Shower-Detector Plane
- Profile: Inverse Monte Carlo
  - X_{max} resolution: ~22g/cm^2

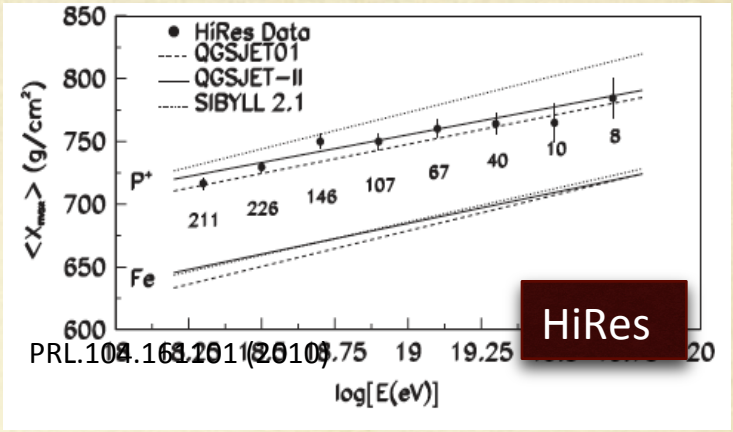


Data/MC comparison (Corsika, QGSJET-II) Red: Proton, Blue: Iron

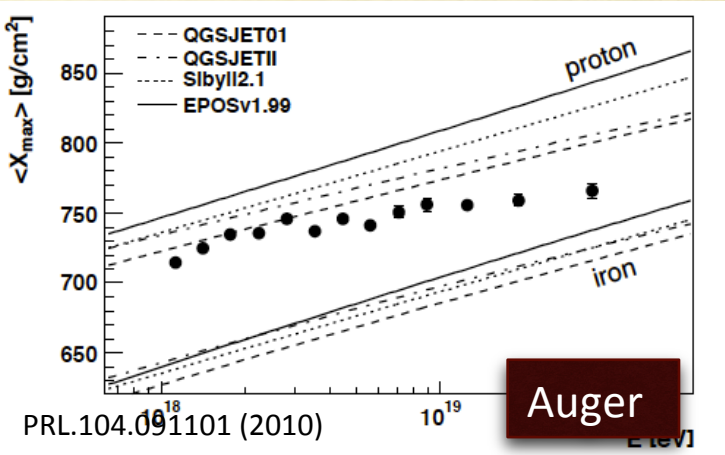


Energy - <X_{max}>





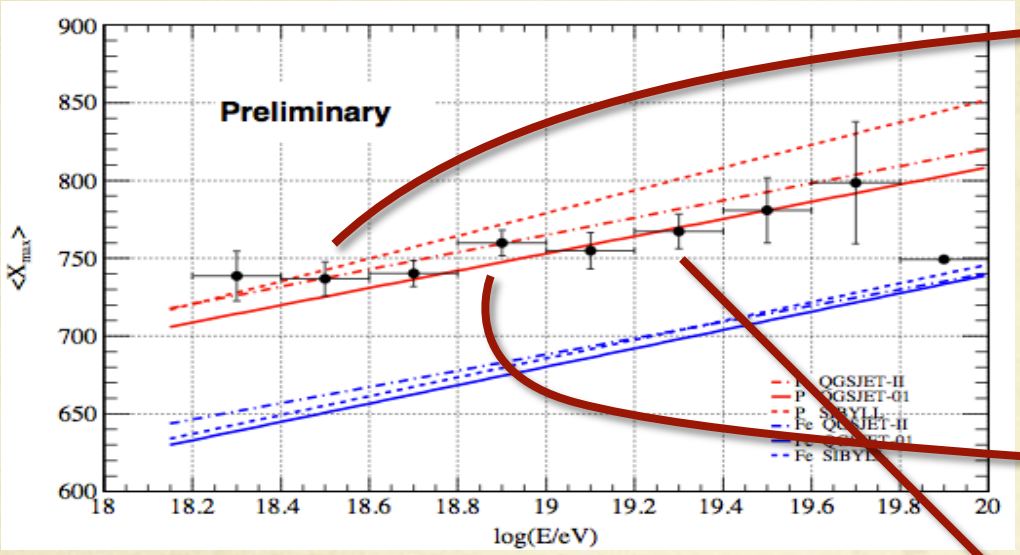
PRL.104.161101 (2010)

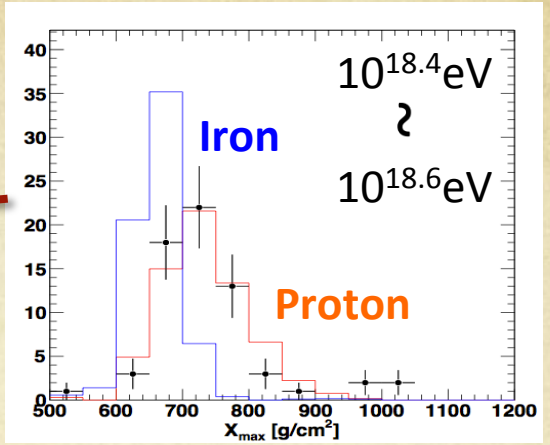


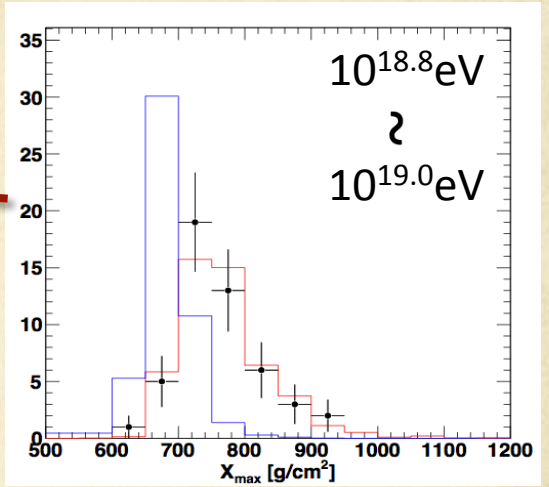
PRL.104.091101 (2010)

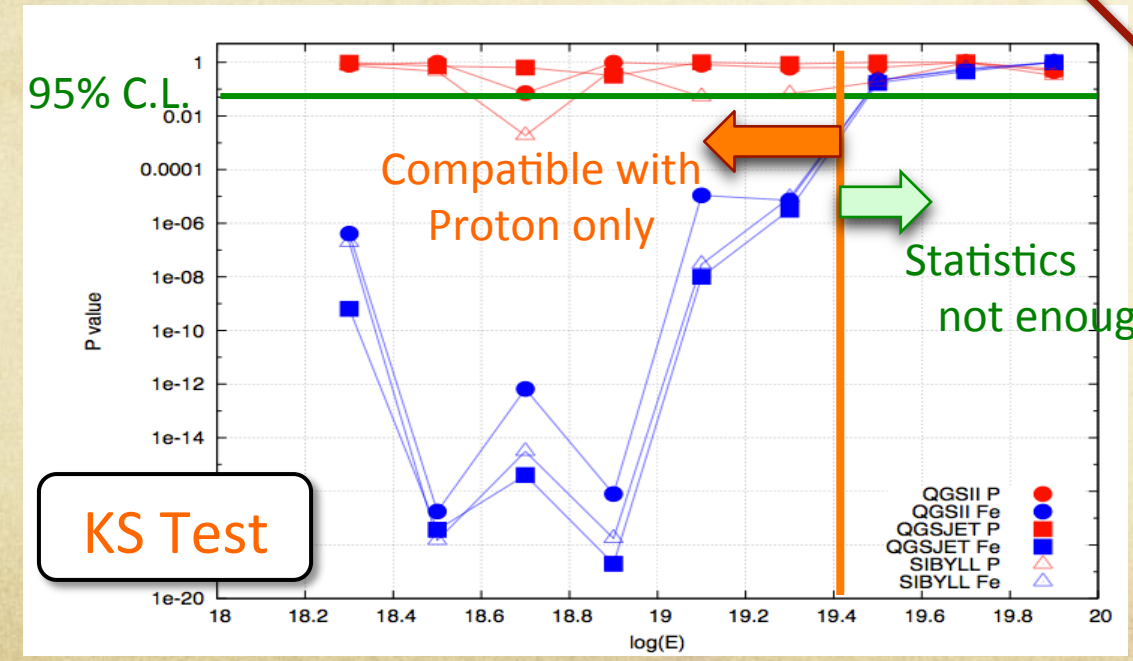
Data set : 2007/Nov – 2010/Sep

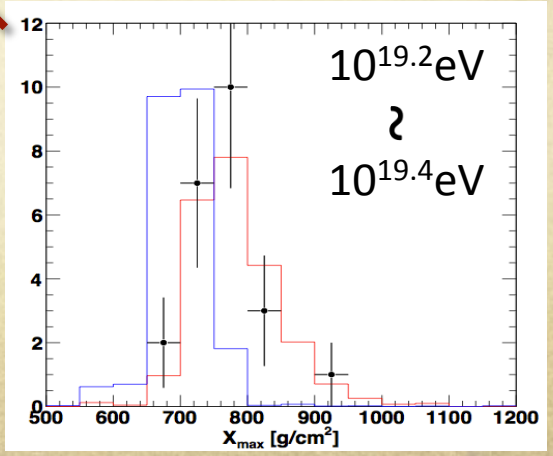
Distribution of X_{max}, KS Test







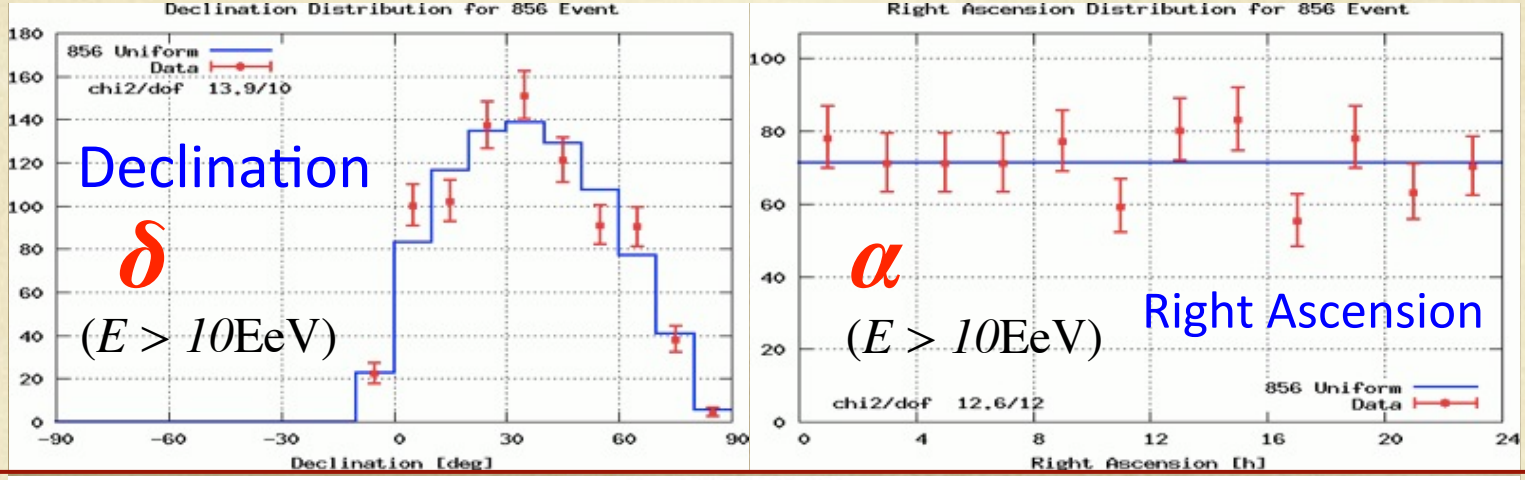


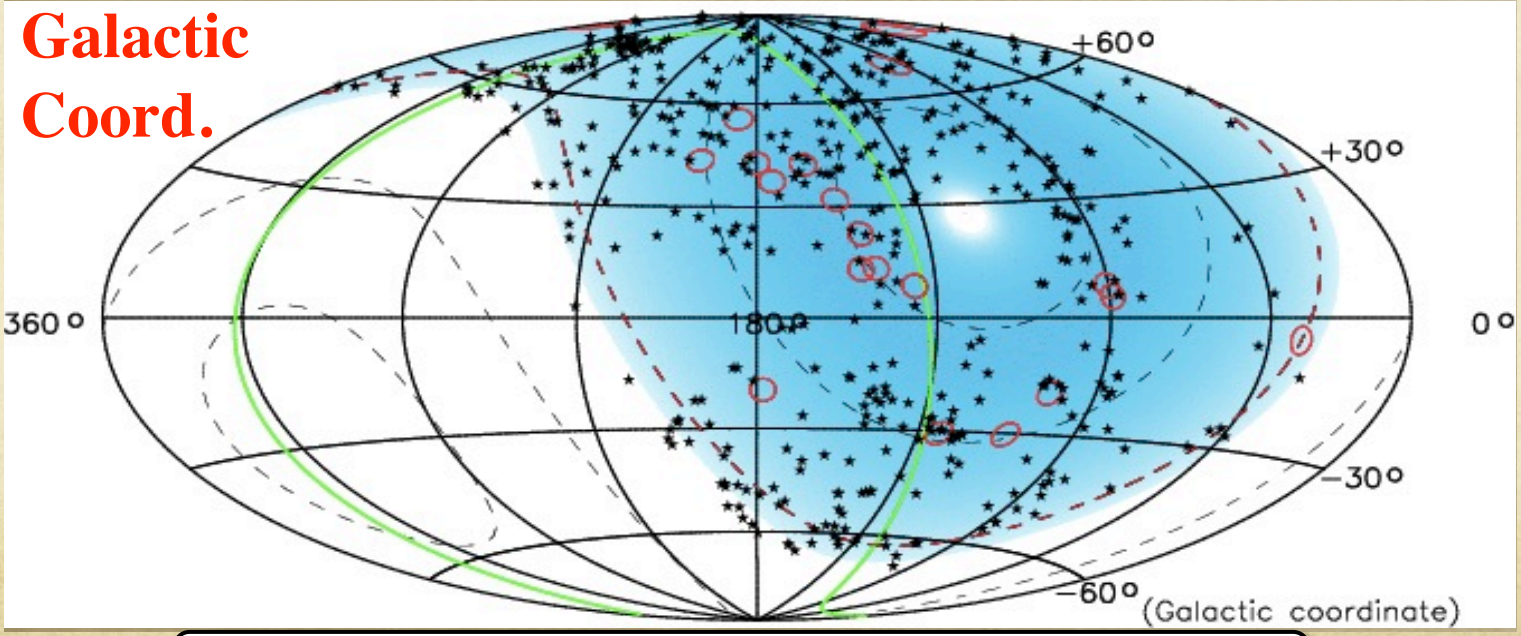


Anisotropy

Event map

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



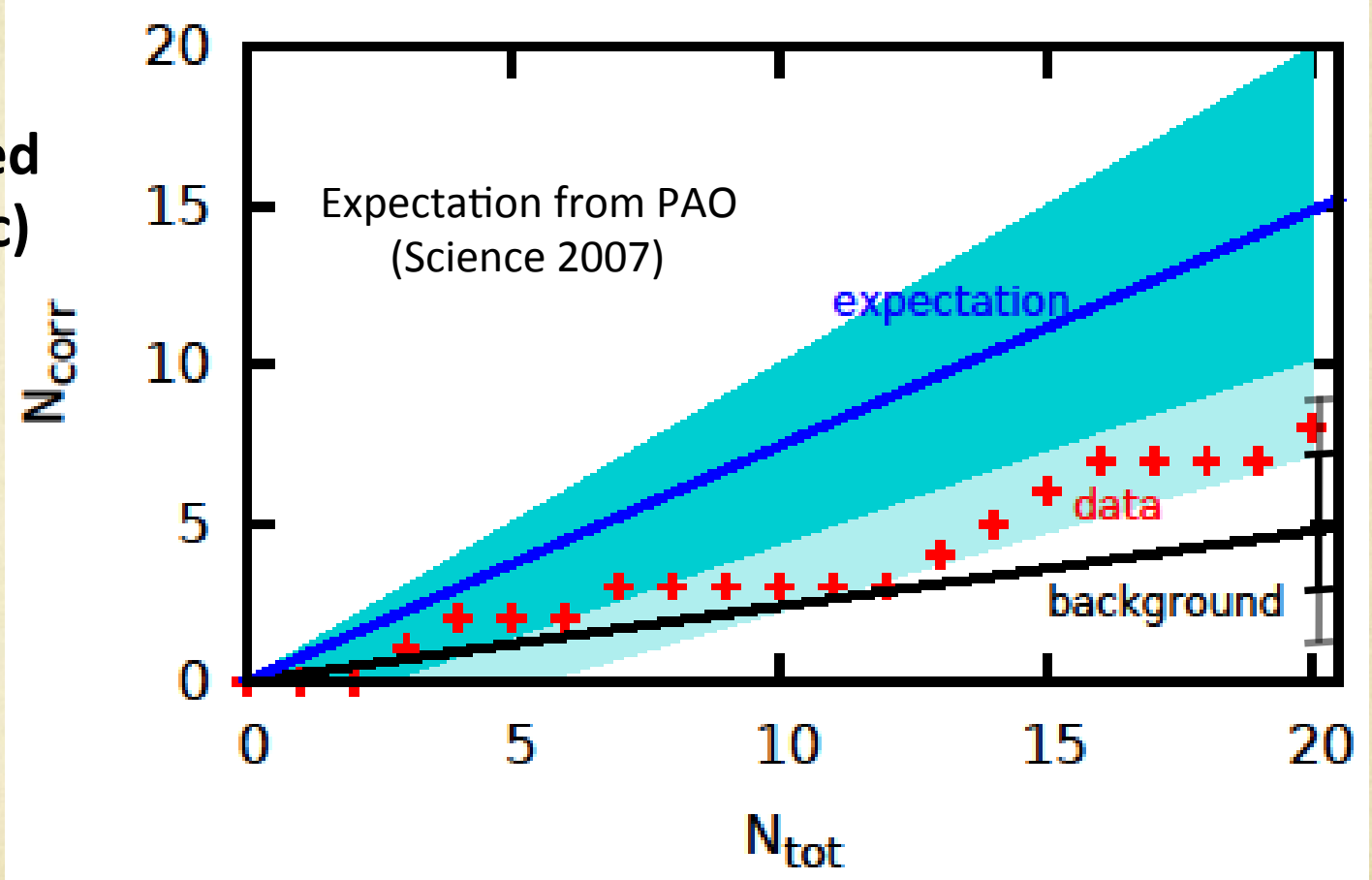


AGN and SD events (20 events, >57 EeV, 3.1 radii)

AGN correlation

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

8 of 20 correlated
(4.8 for isotropic)

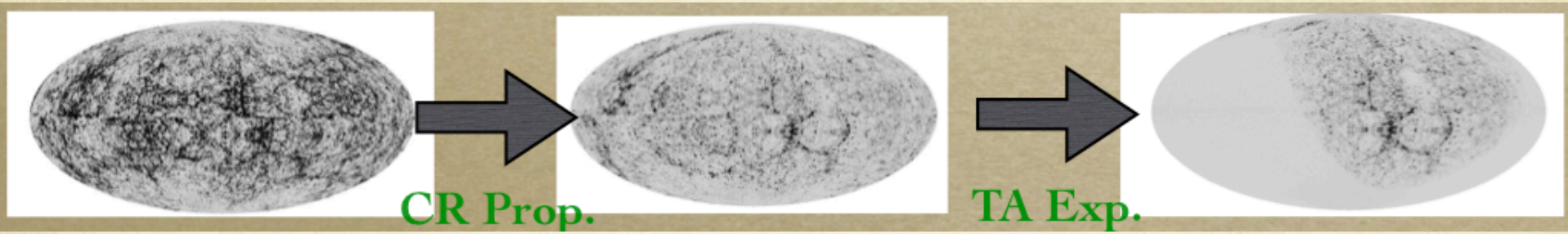


TASD data is consistent with Isotropic distribution

Large-Scale Anisotropy

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

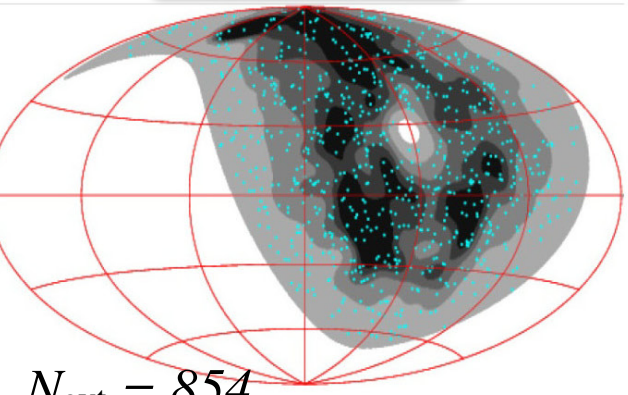
Proton ($E^{-2.2}$)
Interactions/redshift



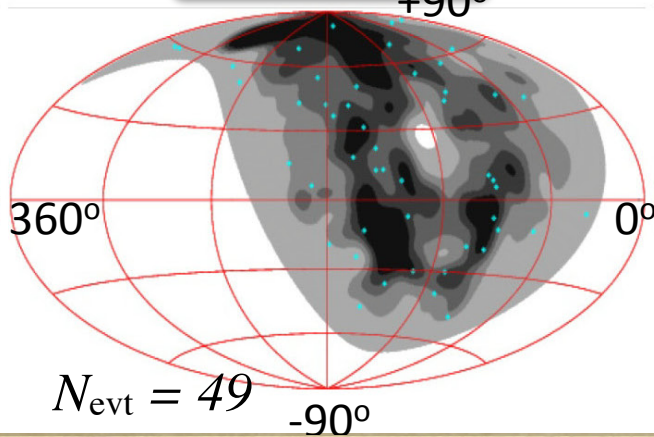
Smearing angle: Free parameter
GC region excluded
(|b| < 10deg, |l|<90deg)

Smearing

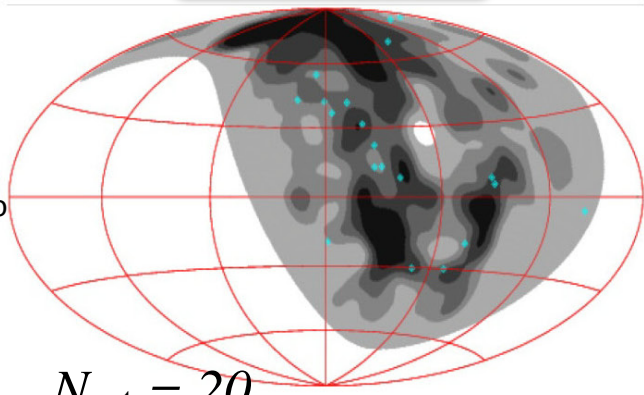
E > 10 EeV



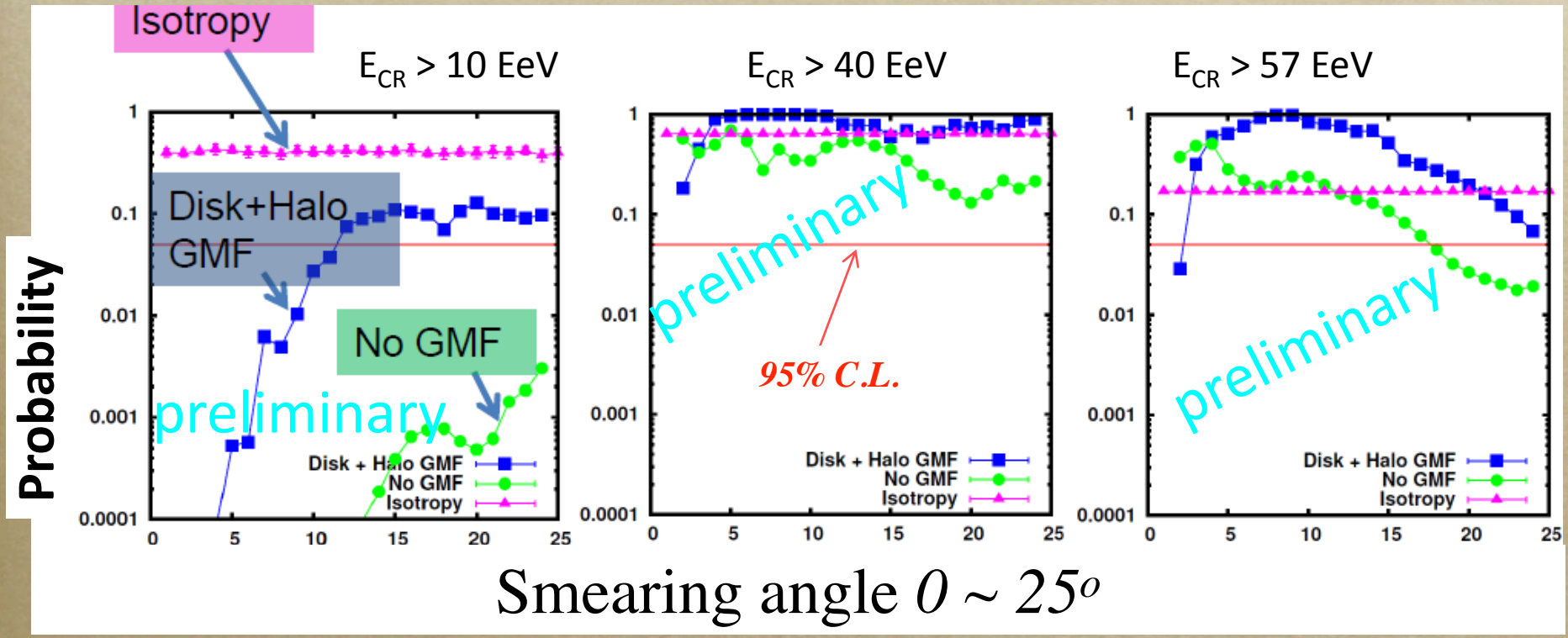
E > 40 EeV



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

Conclusion

- Three years TA full operation
- Energy Spectrum:
  - Consistent with HiRes
    - SD/FD energy scale difference
  - Break points: Ankle: $10^{18.69}$eV, GZK: $10^{19.68}$eV
  - 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
- Observation/Analysis in TA are still on-going.
- Future Plan: presentation by Pierre Sokolsky in this session