TELESCOPE ARRAY: LATEST RESULTS

P. Tinyakov[1,2]
for the Telescope Array Collaboration

[1]Université Libre de Bruxelles, Bruxelles, Belgium

[2]Institute for Nuclear Research, Moscow, Russia

Outline

Telescope Array detector

Spectrum

Chemical composition

Anisotropies

Photon limit

Conclusions

UHECR ground-based experiments

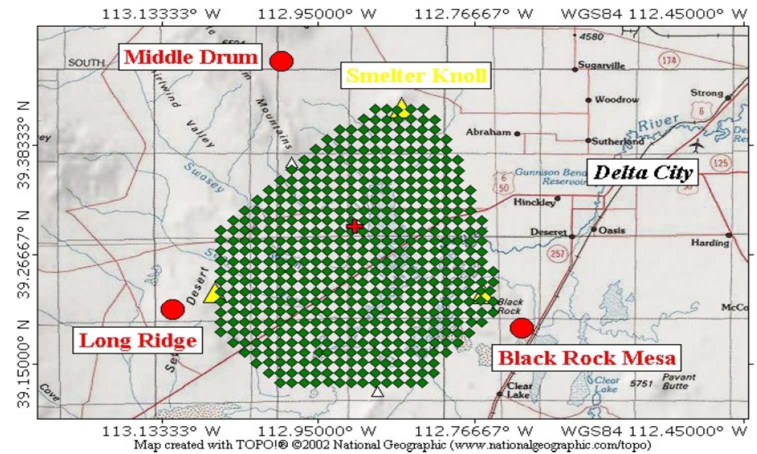
The Telescope Array collaboration

T. Abu-Zayyad[1], R. Aida[2], M. Allen[1], R. Azuma[3], E. Barcikowski[1], J.W. Belz[1],T. Benno[4], D.R. Bergman[5], S.A. Blake[1], O. Brusova[1], R. Cady[1], B.G. Cheon[6], J. Chiba[7], M. Chikawa[4], E.J. Cho[6], L.S. Cho[8], W.R. 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], S.J.J. Innemee[5], N. Inoue[14], T. Ishii[2], R. Ishimori[3], D. Ivanov[5], S. Iwamoto[2], C.C.H. 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], B.G. Kim[19],H.B. Kim[6], J.H. Kim[6], J.H. Kim[20], A. Kitsugi[9], K. Kobayashi[7], H. Koers[21], Y. Kondo[9], V. Kuzmin[12], Y.J. Kwon[8], J.H. Lim[16], S.I. Lim[19], S. Machida[3], K. Martens[22], J. Martineau[1], T. Matsuda[10], T. Matsuyama[11], J.N. Matthews[1], M. Minamino[11], K. Miyata[7], H. Miyauchi[11], Y. Murano[3], T. Nakamura[23], S.W. Nam[19], T. Nonaka[9], S. Ogio[11], M. Ohnishi[9], H. Ohoka[9], T. Okuda[11], A. Oshima[11], S. Ozawa[17], I.H. Park[19], D. Rodriguez[1], S.Y. Roh[20], G. Rubtsov[12], D. Ryu[20], H. Sagawa[9],N. Sakurai[9], L.M. Scott[5], P.D. Shah[1], T. Shibata[9], H. Shimodaira[9], B.K. Shin[6], J.D. Smith[1], P. Sokolsky[1], T.J. Sonley[1], R.W. Springer[1], B.T. Stokes[5], S.R. 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], J.R. Thomas[1], S.B. Thomas[1],T.A.Stroman[1], G.B. Thomson[5], 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 DETECTOR

TELESCOPE ARRAY HYBRID DETECTOR



- 507 scintillator detectors covering 680 km^2
- 3 fluorescence sites, 38 telescopes
- Surface detector fully operational from March 2008
- SD relative size: TA $\sim$ 9 $\times$ AGASA $\sim$ PAO/4

TA surface detectors

- Deployed with the spacing $\sim$ 1.2 km
- Powered by solar panels. Connected by radio.

TA Fluorescence Detectors

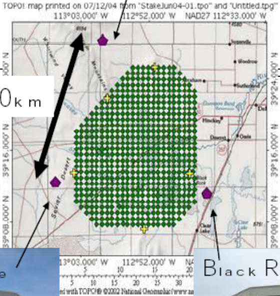
Refurbished from HiRes

Observation started Dec. 2007

Middle Drum

14 cameras/station
256 PMTs/camera

5.2 m^2



~30 km

Observation started Nov. 2007

Observation started Jun. 2007

New FDs

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

~1 m^2

6.8 m^2

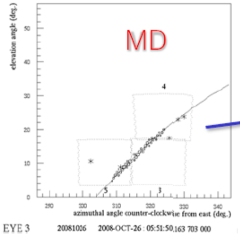
TELESCOPE ARRAY: LATEST RESULTS

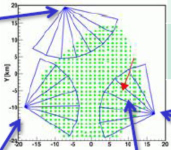
P. Tinyakov for the Telescope Array Collaboration

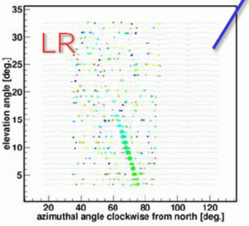
Hybrid event example

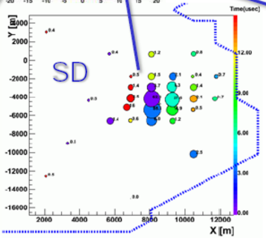
Triple FD Event (2008-10-26)

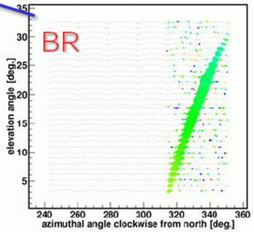
	θ[deg]	ϕ[deg]	X[km]	Y[km]
MD mono	51.43	73.76	7.83	-3.10
BR mono	51.50	77.09	7.67	-4.14
Stereo BR&LR	50.21	71.30	8.55	-4.88











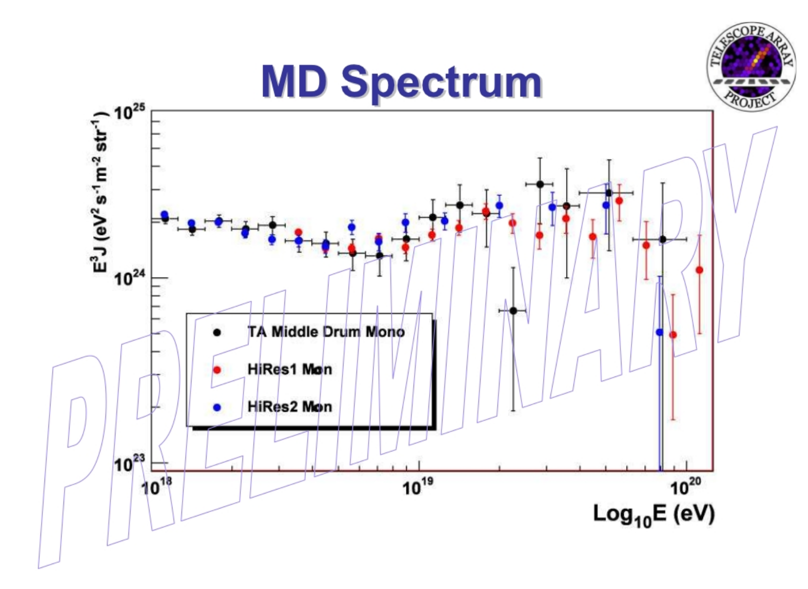
SPECTRUM

TA spectrum

TA measures spectrum by three techniques:

- Middle Drum fluorescence detector (FD-mono)
- Surface detector (SD)
- Hybrid (SD+FD)

FD-mono spectrum

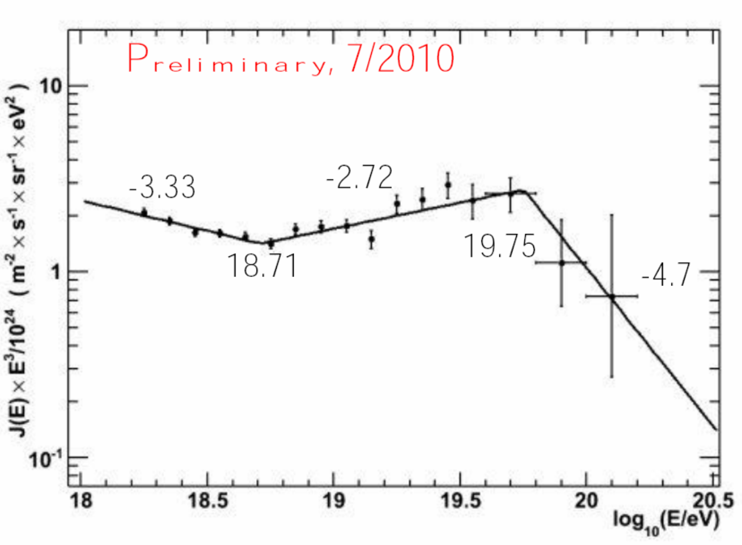


Surface detector spectrum

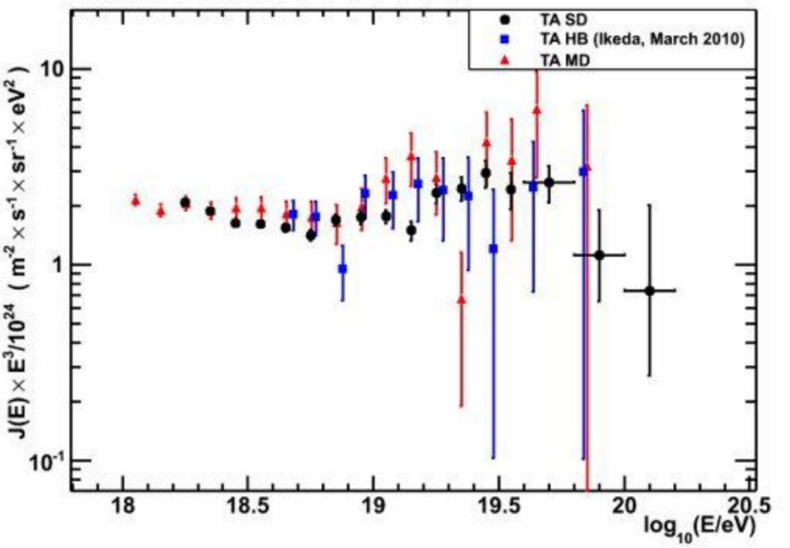
Dataset:

- Geometrical cuts:
  - $\theta < 45^\circ$
  - core inside the array, distance to border > 1200 m
- Cuts on reconstruction quality:
  - number of detectors hit ≥ 4
  - $\chi^2/d.o.f < 4.0$
  - pointing direction resolution $< 5^\circ$
  - fractional S_{800} uncertainty < 0.25
- 1.75 years, 6264 events after cuts

TA surface detector spectrum

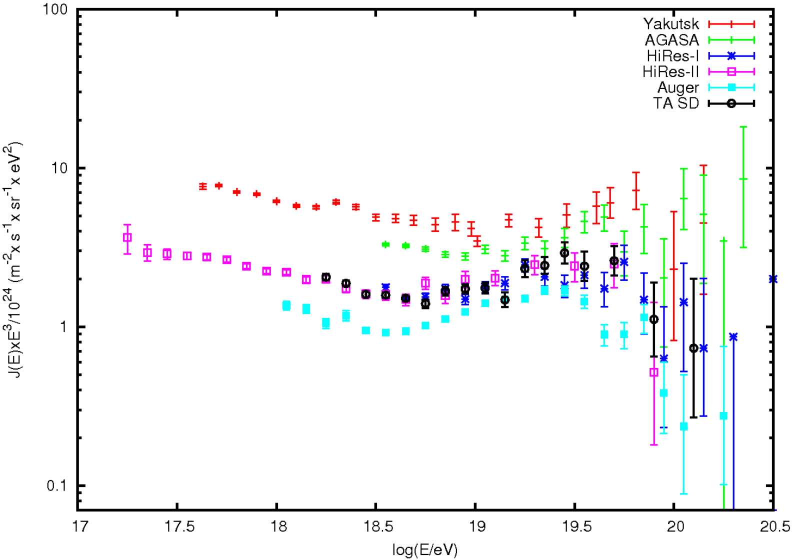


SD, FD-mono and hybrid spectra



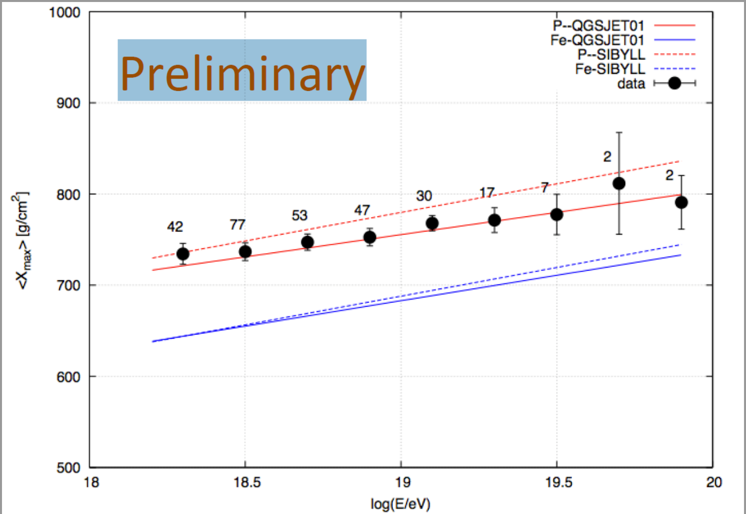
Note: SD energy normalized by 27% down

Comparison with other experiments



CHEMICAL COMPOSITION

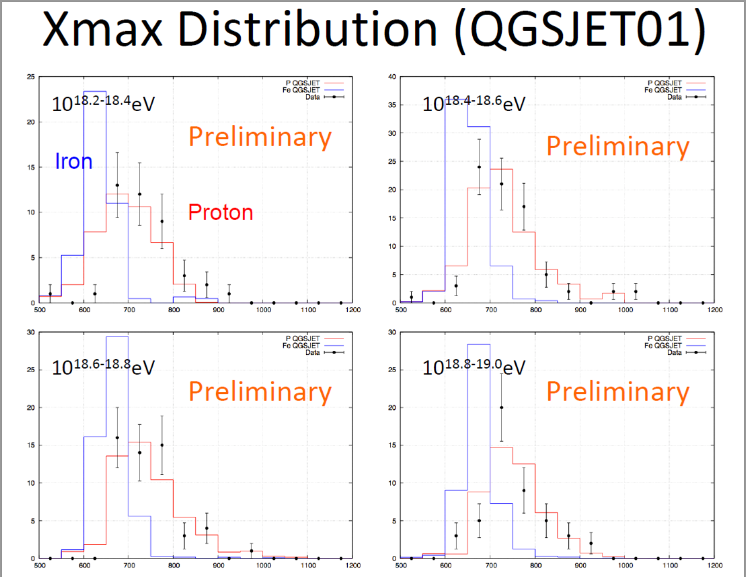
Telescope Array stereo result



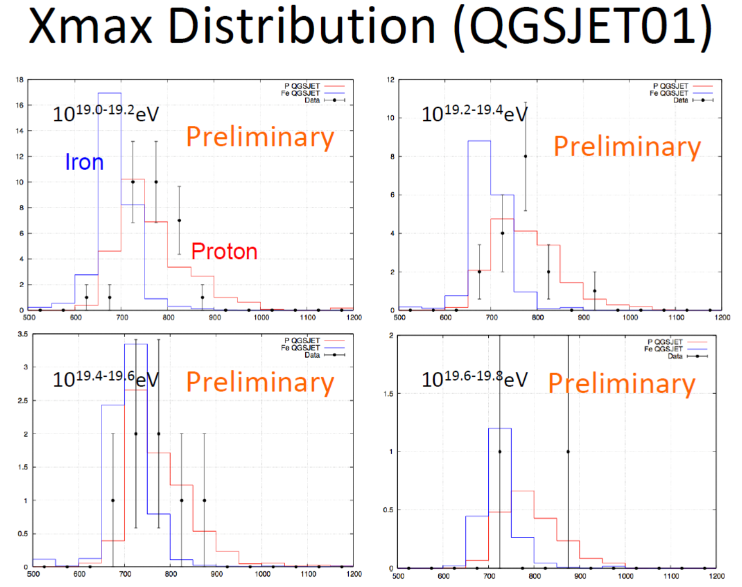
TA data favor protons

[Y. Tameda, UHECR-2010, Nagoya]

TA X_{max} distributions (I)

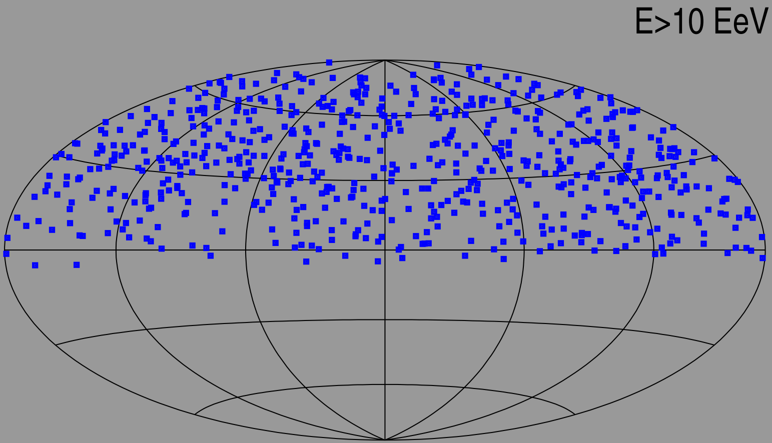


TA X_{max} distributions (II)



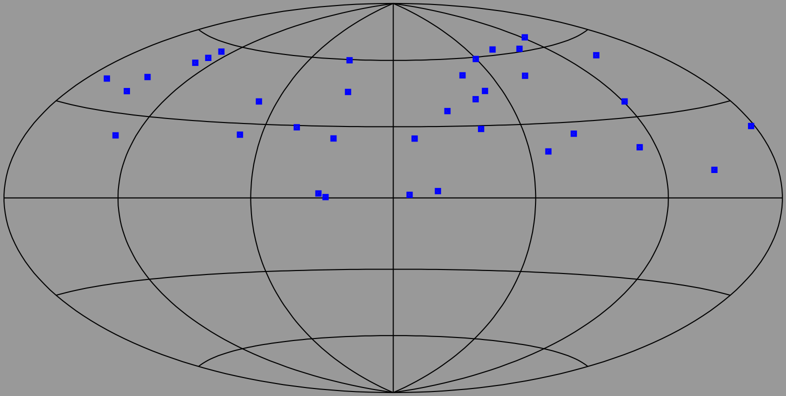
ANISOTROPIES

Sky distribution, $E > 10$ EeV



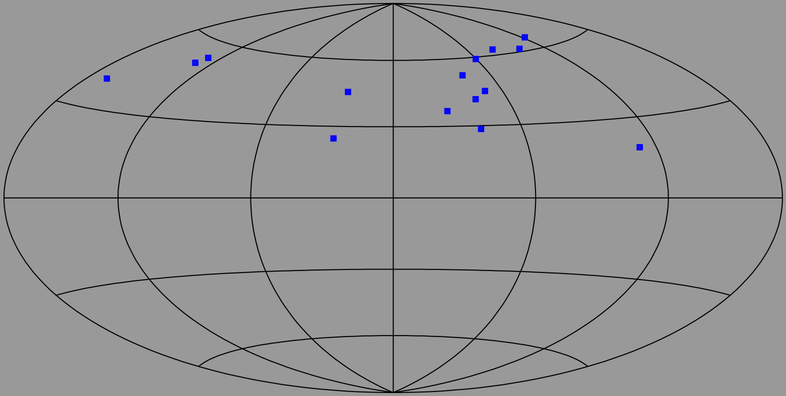
Equatorial coordinates, 655 events

Sky distribution, $E > 40$ EeV



Equatorial coordinates, 35 events

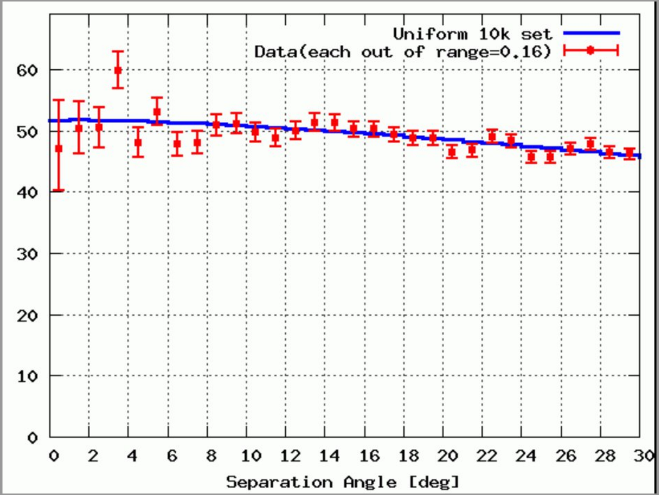
Sky distribution, $E > 57$ EeV



Equatorial coordinates, 15 events

Search for clustering at small scales

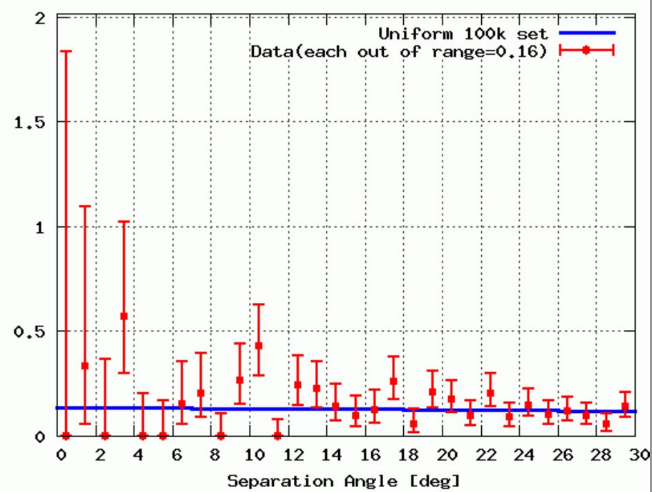
$E > 10$ EeV



$\Longrightarrow$ no excess over background

Search for clustering at small scales

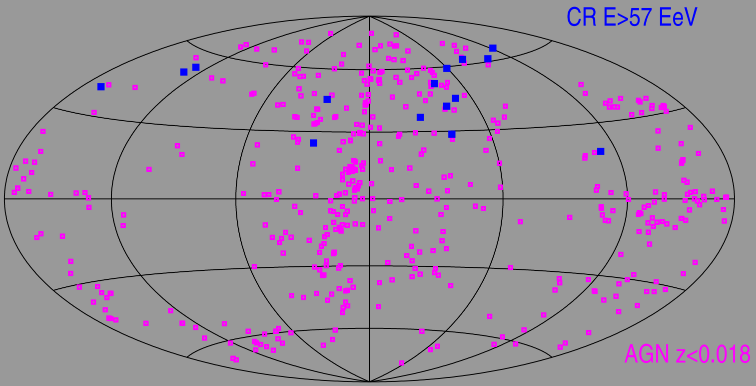
$E > 40$ EeV



$\Longrightarrow$ no excess over background

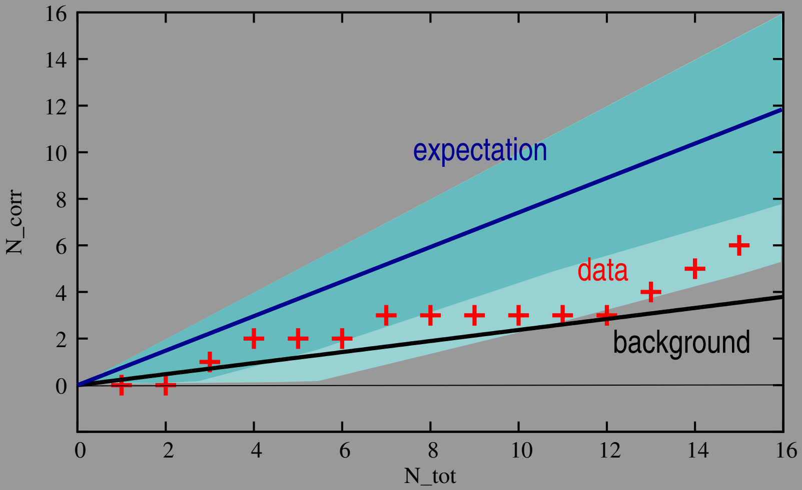
Test of correlations with AGN

- 472 AGN from 2006 Veron catalog with $z < 0.018$ ($D < 75$ Mpc)
- separation angle 3.1°



Equatorial coordinates

Test of correlations with AGN



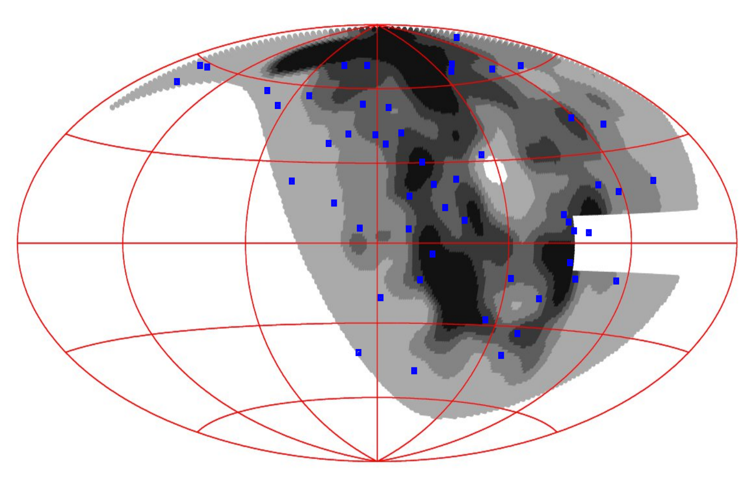
Currently: observed 6, background 3.6, $p = 16\% \Longrightarrow$ compatible with background

Correlation with LSS

- UHECR flux at high energies is expected to be anisotropic because matter distribution is not uniform at distances $\sim$ 100 Mpc
- The matter distribution can be modeled out to $\sim$ 250 Mpc from the XSCz catalog (*T. Jarrett, in preparation*) containing over 700 000 galaxies with spectroscopic redshifts
- From the matter distribution the UHECR flux map may be calculated and compared to observation
- This involves a single parameter — the smearing angle θ representing deflections in magnetic fields and finite angular resolution

Correlations with LSS

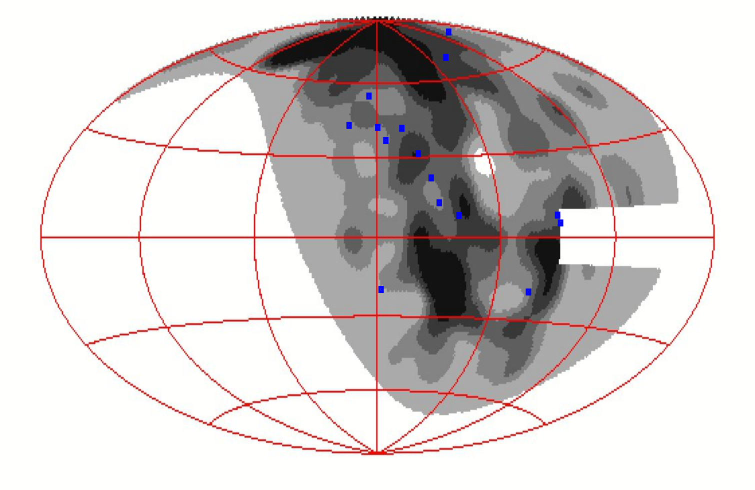
$E > 40$ EeV



Galactic coordinates

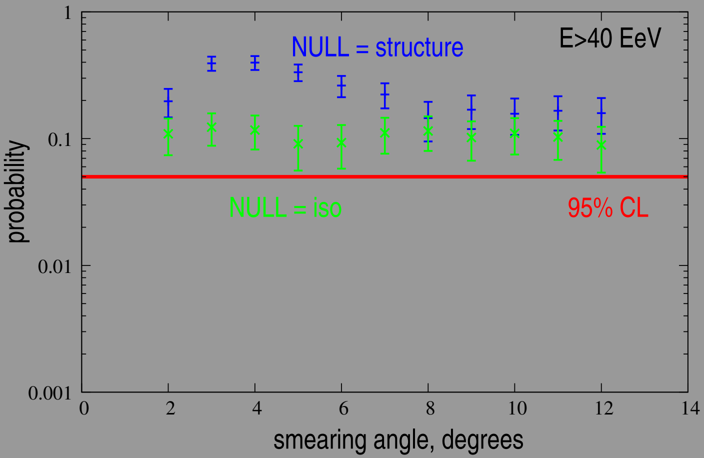
Correlations with LSS

$E > 57$ EeV



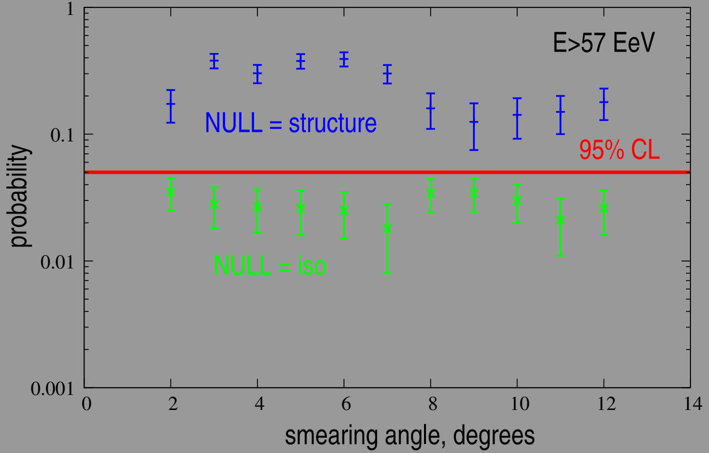
Galactic coordinates

Results of the statistical tests



Compatible with both structure and isotropy

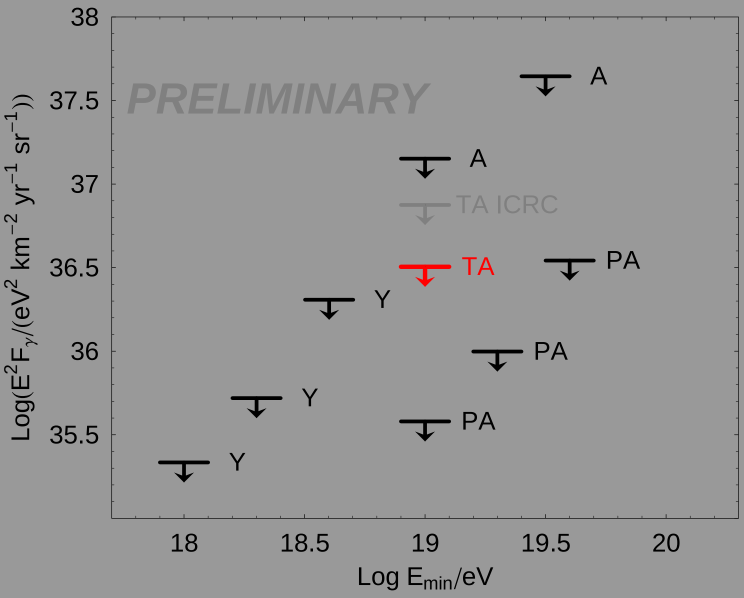
Results of the statistical tests



Compatible with structure
not compatible with isotropy @ 95%CL

PHOTON LIMIT

Photon flux limits



G.Rubtsov, JPS March 2010; Quarks'10

CONCLUSIONS

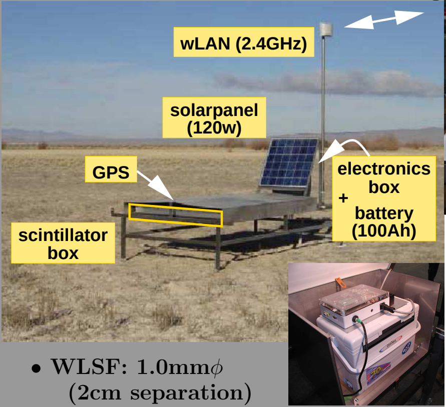
- TA observes the cut-off in the spectrum, significance currently is $\sim 3.5\sigma$
- TA data favor light composition at high energies (like HiRes, unlike Auger)
- Almost fully consistent with isotropy (except perhaps at $E > 57$ EeV)
  - no significant small-scale clustering
  - no significant correlation with AGN
  - no significant correlation with LSS

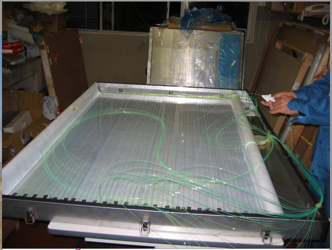
BACKUP SLIDES

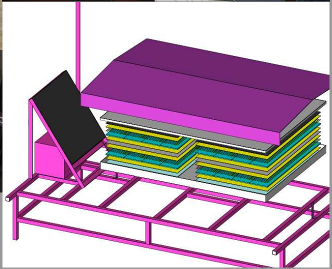
TA surface detector in detail

< Surface Detector >

~200kg



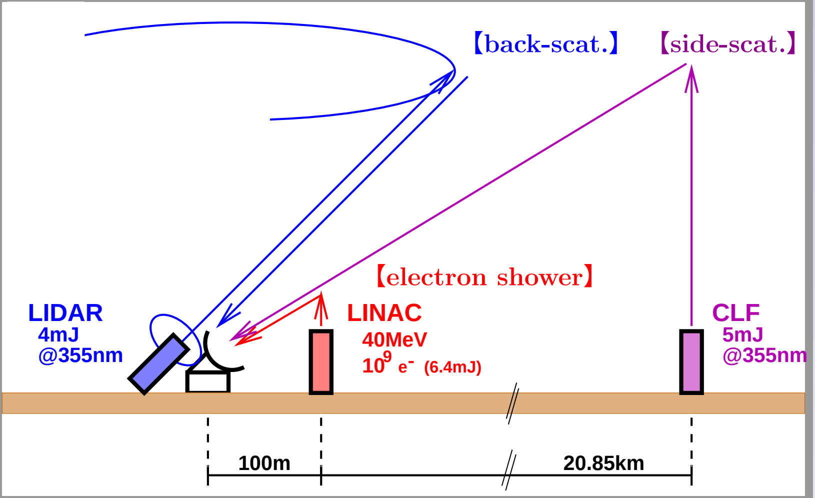




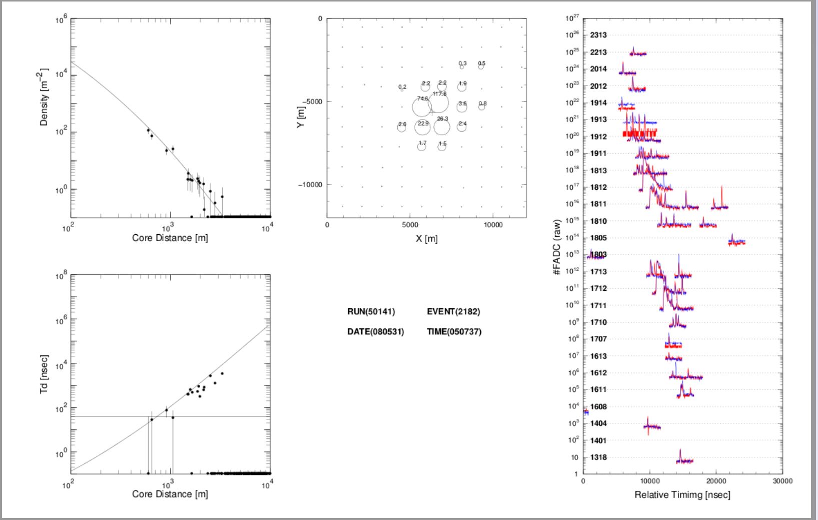
- WLSF: 1.0mmϕ
  (2cm separation)
- PMTs: ET 9123SA $\times$ 2
- 3m^2 (12mm $\times$ 2 layers)

atmosphere monitoring

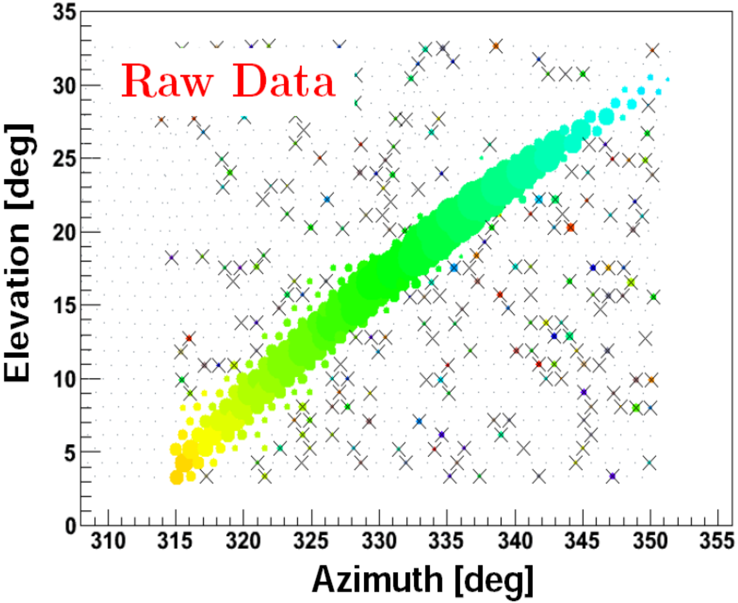
< Atmospheric Monitor (LIDAR, CLF) & LINAC >



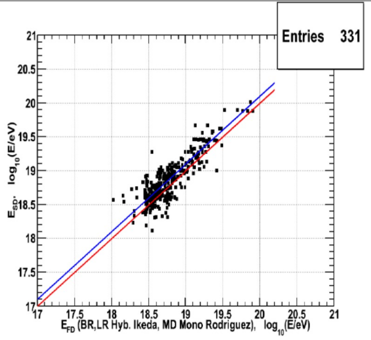
SD event example

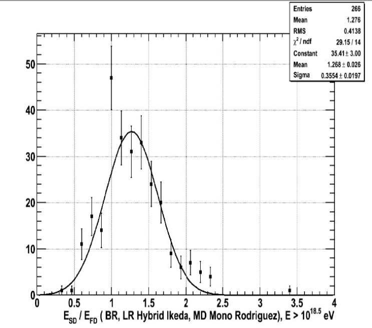


FD event example



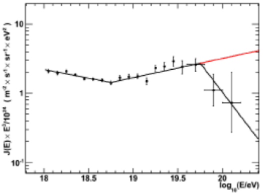
Energy scale

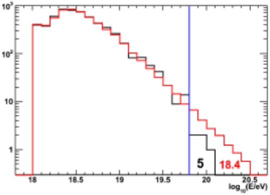




- SD energy: CORSIKA QGSJET-II full MC
- FD energy: MD mono, BRM, LR hybrid
- Result: $E = E_{SD}/1.27$

Statistical significance of GZK cut-off





- Assume no GZK cutoff and extend the broken power law fit beyond the break
- Apply this extended flux formula to the actual TASD exposure, find the number of expected events and compare it to the number of events observed in $\log_{10}E$ bins after $10^{19.8}$eV bin:
  - $N_{EXPECT} = 18.4$
  - $N_{OBSERVE} = 5$

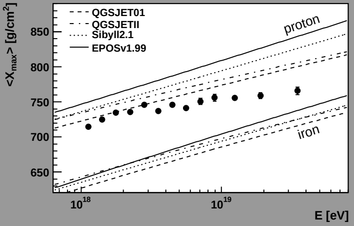
$$\mathrm{PROB} = \sum_{i=0}^{5} Poisson(\mu = 18.4; i) = 2.41 \times 10^{-4}$$

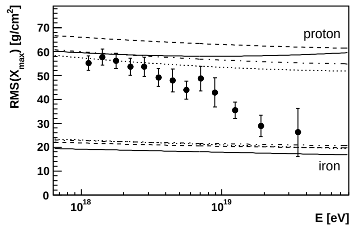
(3.5σ)

G.Thomson, ICHEP'10, Paris

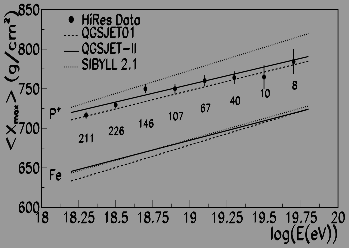
Auger & HiRES XMAX results

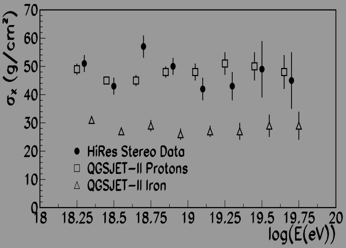
Auger: Phys.Rev.Lett.104.091101





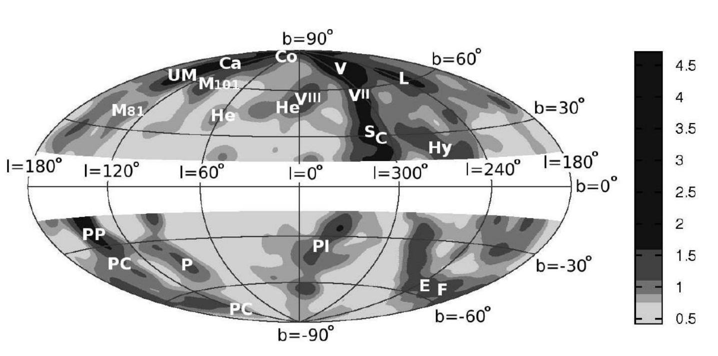
HiRES: Phys.Rev.Lett.104.161101





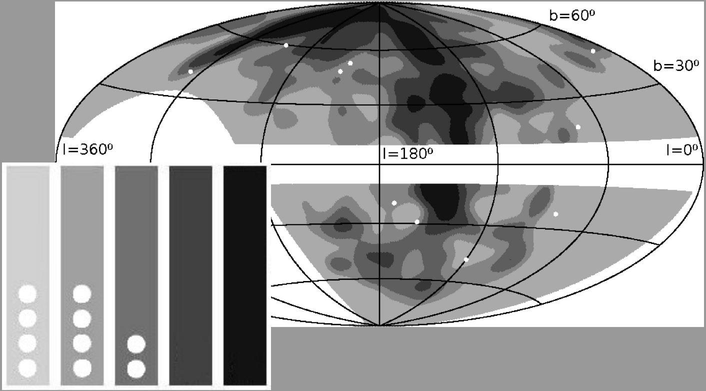
TELESCOPE ARRAY: LATEST RESULTS

P. Tinyakov for the Telescope Array Collaboration



C: Centaurus supercluster (60 Mpc); Ca: Canes I group (4 Mpc) and Canes II group (9 Mpc); Co: Coma cluster (90 Mpc); E: Eridanus cluster (30 Mpc); F: Fornax cluster (20 Mpc); He: Hercules superclusters (140 Mpc); Hy: Hydra supercluster (50 Mpc); L: Leo supercluster (130 Mpc), Leo I group (10 Mpc), and Leo II group (20 Mpc); M81: M81 group (4 Mpc); M101: M101 group (8 Mpc); P: Pegasus cluster (60 Mpc); PI: Pavo-Indus supercluster (70 Mpc); PC: Pisces- Cetus supercluster (250 Mpc); PP: Perseus-Pisces supercluster (70 Mpc); S: Shapley supercluster (200 Mpc); UM: Ursa Major supercluster (240 Mpc), Ursa Major North group (20 Mpc), and Ursa Major South group (20 Mpc); V: Virgo cluster (20 Mpc); VII: Virgo II group (20 Mpc); VIII: Virgo III group (20 Mpc).

The statistical test ("flux sampling")



- Events following the model would produce uniform distribution over the bands
- No binning is needed (on the picture it is for illustration only): two distributions may be compared by the KS test