TELESCOPE ARRAY: STATUS, RESULTS AND FUTURE PROSPECTS

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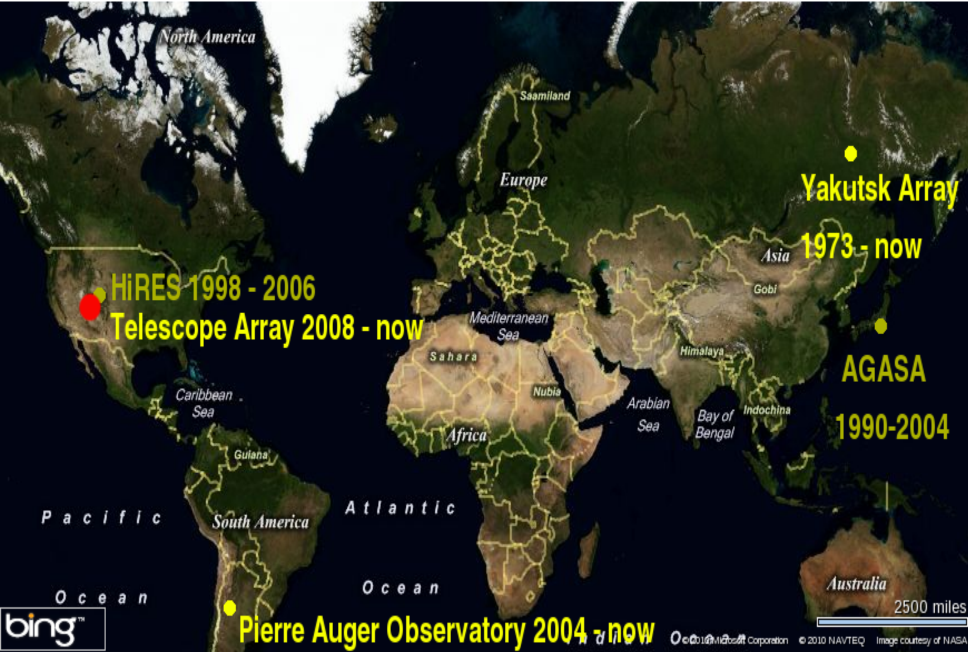
Outline

- Telescope Array detector
- Spectrum
- Composition
- Anisotropies
- Future TA
- Summary

Latest UHECR experiments



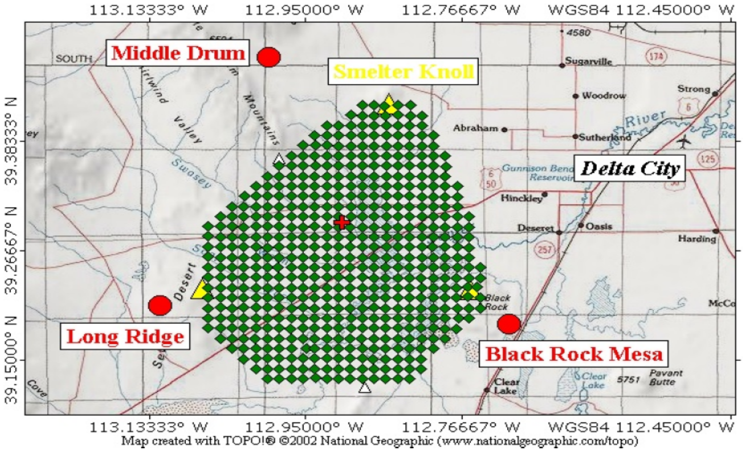
TELESCOPE ARRAY COLLABORATION

T. Abu-Zayyad[1], R. Aida[2], M. Allen[1], R. Anderson[1], R. Azuma[3], E. Barcikowski[1], J. W. Belz[1], D. R. Bergman[1], S. A. Blake[1], R. Cady[1], B. G. Cheon[4], J. Chiba[5], M. Chikawa[6], E. J. Cho[4], W. R. Cho[7], H. Fujii[8], T. Fujii[9], T. Fukuda[3], M. Fukushima[10,11], W. Hanlon[1], K. Hayashi[3], Y. Hayashi[9], N. Hayashida[10], K. Hibino[12], K. Hiyama[10], K. Honda[2], T. Iguchi[3], D. Ikeda[10], K. Ikuta[2], N. Inoue[13], T. Ishii[2], R. Ishimori[3], D. Ivanov[1,14], S. Iwamoto[2], C. C. H. Jui[1], K. Kadota[15], F. Kakimoto[3], O. Kalashev[16], T. Kanbe[2], K. Kasahara[17], H. Kawai[18], S. Kawakami[9], S. Kawana[13], E. Kido[10], H. B. Kim[4], H. K. Kim[7], J. H. Kim[1], J. H. Kim[4], K. Kitamoto[6], S. Kitamura[3], Y. Kitamura[3], K. Kobayashi[5], Y. Kobayashi[3], Y. Kondo[10], K. Kuramoto[9], V. Kuzmin[16], Y. J. Kwon[7], J. Lan[1], S. I. Lim[19], S. Machida[3], K. Martens[11], T. Matsuda[8], T. Matsuura[3], T. Matsuyama[9], J. N. Matthews[1], M. Minamino[9], K. Miyata[5], Y. Murano[3], I. Myers[1], K. Nagasawa[13], S. Nagataki[20], T. Nakamura[21], S. W. Nam[19], T. Nonaka[10], S. Ogio[9], M. Ohnishi[10], H. Ohoka[10], K. Oki[10], D. Oku[2], T. Okuda[22], A. Oshima[9], S. Ozawa[17], I. H. Park[19], M. S. Pshirkov[23], D. C. Rodriguez[1], S. Y. Roh[24], G. Rubtsov[16], D. Ryu[24], H. Sagawa[10], N. Sakurai[9], A. L. Sampson[1], L. M. Scott[14], P. D. Shah[1], F. Shibata[2], T. Shibata[10], H. Shimodaira[10], B. K. Shin[4], J. I. Shin[7], T. Shirahama[13], J. D. Smith[1], P. Sokolsky[1], B. T. Stokes[1], S. R. Stratton[1,14], T. Stroman[1], S. Suzuki[8], Y. Takahashi[10], M. Takeda[10], A. Taketa[25], M. Takita[10], Y. Tameda[10], H. Tanaka[9], K. Tanaka[26], M. Tanaka[9], S. B. Thomas[1], G. B. Thomson[1], P. Tinyakov[16,23], I. Tkachev[16], H. Tokuno[3], T. Tomida[27], S. Troitsky[16], Y. Tsunesada[3], K. Tsutsumi[3], Y. Tsuyuguchi[2], Y. Uchihori[28], S. Udo[12], H. Ukai[2], G. Vasiloff[1], Y. Wada[13], T. Wong[1], M. Wood[1], Y. Yamakawa[10], R. Yamane[9], H. Yamaoka[8], K. Yamazaki[9], J. Yang[19], Y. Yoneda[9], S. Yoshida[18], H. Yoshii[29], X. Zhou[6], R. Zollinger[1], and Z. Zundel[1]

- ∼ 140 collaborators from 29 Institutions in Belgium, Japan, Korea, Russia, USA

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.

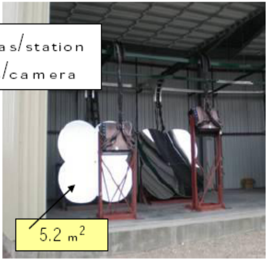
TA Fluorescence Detectors

Refurbished from HiRes

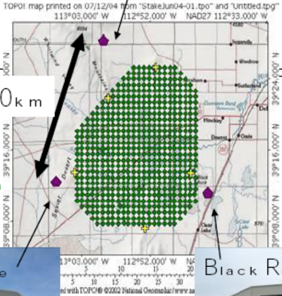
Observation started Dec. 2007

Middle Drum

14 cameras/station
256 PMTs/camera



5.2 m^2



~30km

Observation started Nov. 2007

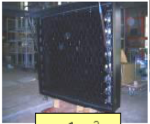
Long Ridge

Observation started Jun. 2007

Black Rock Mesa

New FDs

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



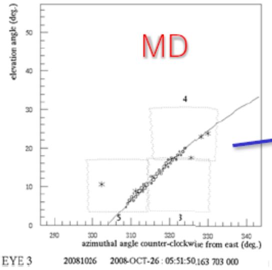
~1 m^2

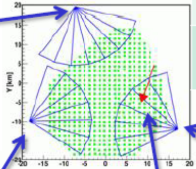
6.8 m^2

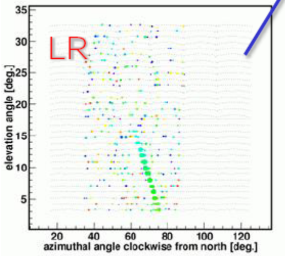
Hybrid event example

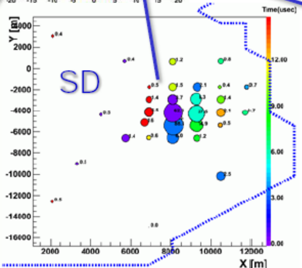
Triple FD Event (2008-10-26)

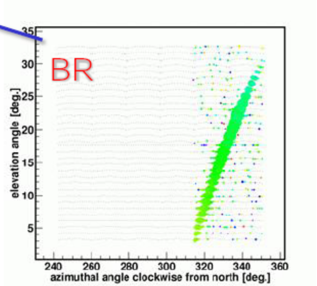
	θ[deg]	φ[deg]	X[km]	Y[km]
MD mono	51.43	73.76	7.83	-3.10
BR mono	51.50	77.09	7.67	-4.14
Stereo BR&LR	50.21	71.30	8.55	-4.88









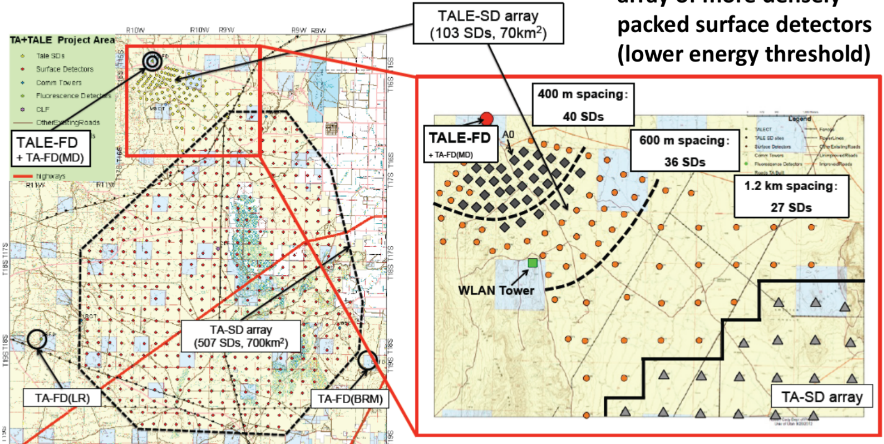


TA Low Energy Extension (TALE)

10 new telescopes to look higher in the sky (31-59°) to see shower development to much lower energies

[859- PoS 637] Poster 1 CR Track: CRIN Board #: 148
Presented by Shoichi OGIO on 30 Jul 2015
at 15:30

Infill surface detector array of more densely packed surface detectors (lower energy threshold)



SPECTRUM

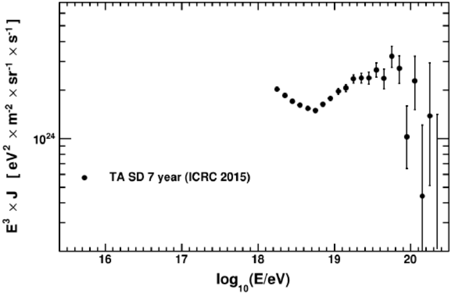
TA spectrum

TA measures spectrum by several techniques:

- Fluorescence detector (FD-mono) – at three stations independently + in stereo mode (FD-stereo)
- Surface detector (SD) – largest statistics
- Hybrid (SD+FD) – used for calibration
- TALE SD – low energies
- TALE Cherenkov – even lower energies

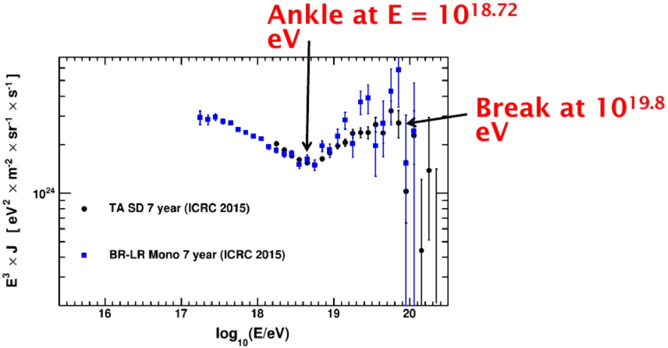
TA spectrum

TA SD, E > $10^{18.2}$ eV



TA spectrum

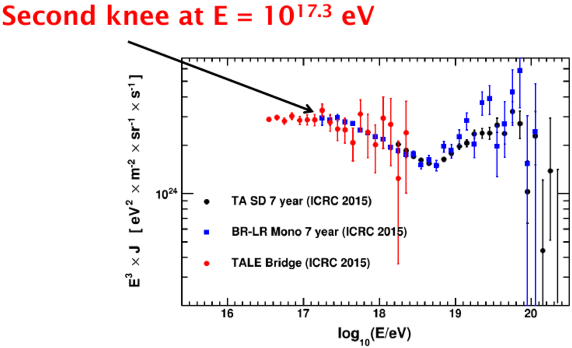
Add TA FD Mono, E > $10^{17.2}$ eV



Contribution **320**, "*Energy spectrum and Mass Composition Measured with the Telescope Array Fluorescence Detector Using a Monocular Analysis*", T. Fujii

TA spectrum

Add TALE FD Mono, $10^{16.5}$ eV < E < $10^{18.4}$ eV

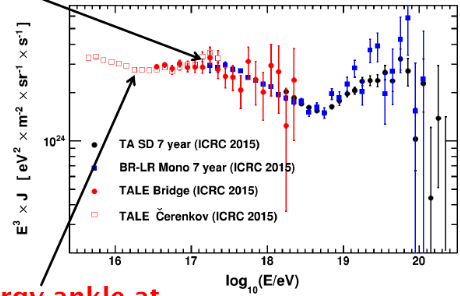


Contribution **445**, "*Fluorescence Detection of Cosmic Ray Air Showers with the Telescope Array Low Energy Extension*", Z. Zundel

TA spectrum

Add TALE Cherenkov, $10^{15.6}$ eV < E < $10^{17.4}$ eV

Second knee at E = $10^{17.3}$ eV



Low energy ankle at $10^{16.34}$ eV

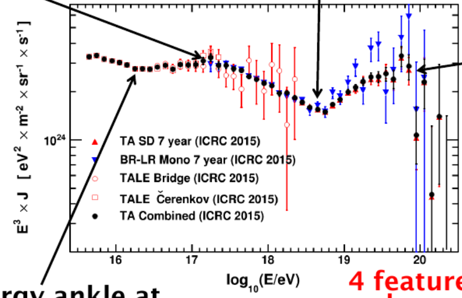
Contribution **422**, "*Cosmic Rays Energy Spectrum Observed by the TALE Detector Using Čerenkov Light*", T. AbuZayyad

Combined TA Spectrum

Second knee at E = $10^{17.3}$ eV

Ankle at E = $10^{18.72}$ eV

Break at $10^{19.8}$ eV

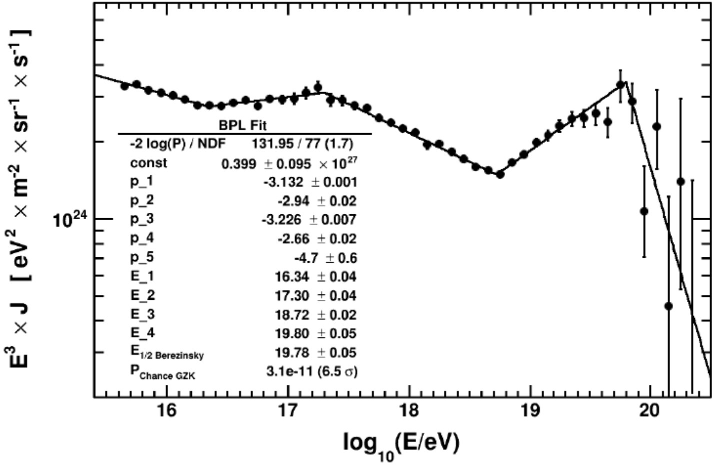


Low energy ankle at $10^{16.34}$ eV

4 features over 4.7 orders of magnitude in energy

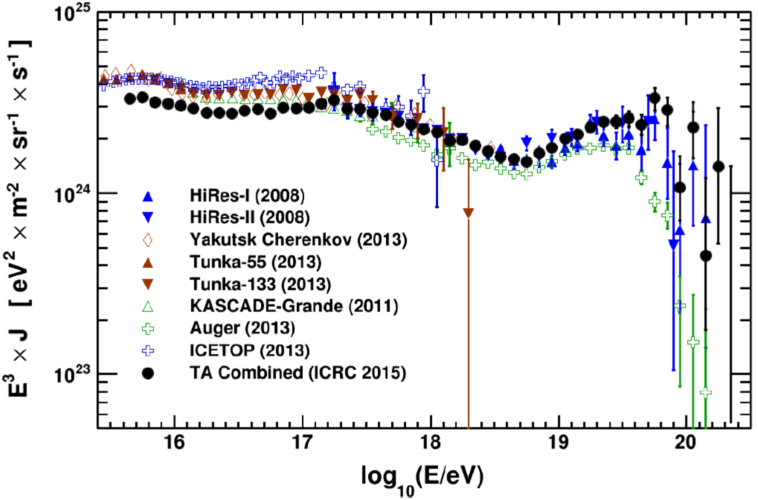
TA spectrum

Fit with power broken law



TA spectrum

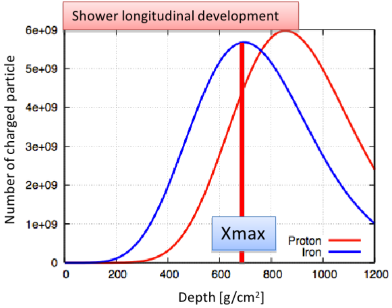
Comparison with other experiments



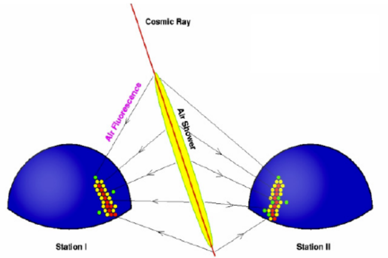
COMPOSITION

TA composition measurement

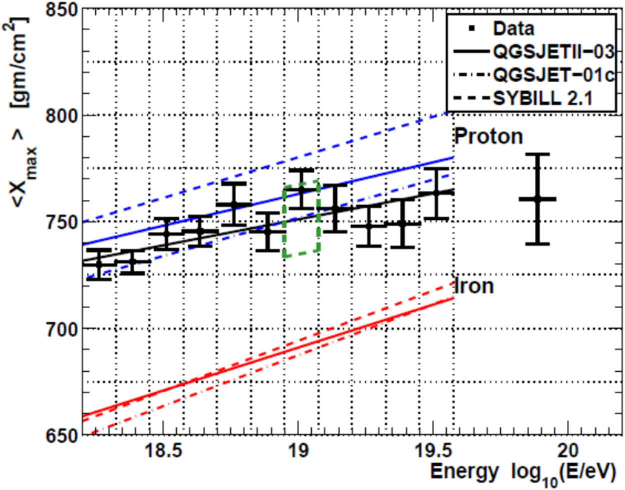
- Observable sensitive to composition: shower depth X_{max} $\Longrightarrow$ FD data only
- Difficult measurement:
  - large fluctuations, limited statistics
  - model uncertainties
  - biases in event selection
- TA strategy:
  - full MC simulation of the data analysis chain (including event selection)
  - prediction for different compositions
  - comparison to data



FD stereo analysis



Published Hybrid Composition (MD)

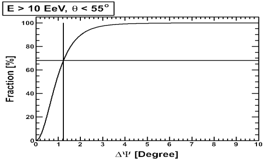


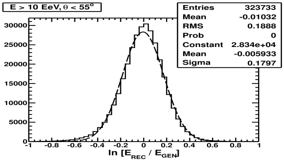
R. Abbasi *et al.* (TA Collaboration) Astropart Phys. (2014) **11** 004

ANISOTROPIES

Most recent “anisotropy” data set (SD)

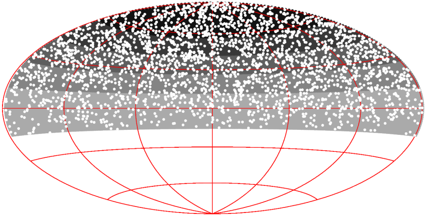
- covers the period 12.05.2008 — 11.05.2015 (full 7 years)
- zenith angle up to 55°, loose border cut
- geometrical acceptance; exposure $\sim$ 8600 km^2 yr sr
- 2996 above 10 EeV
- 210 above 40 EeV
- 83 above 57 EeV
- angular resolution: better than 1.5°
- energy resolution: $\sim$ 20%



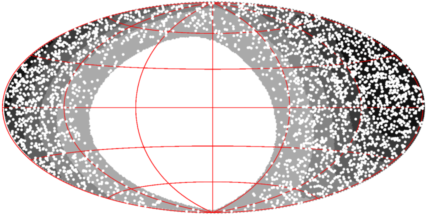


Global distributions

2996 events with $E > 10$ EeV



equatorial



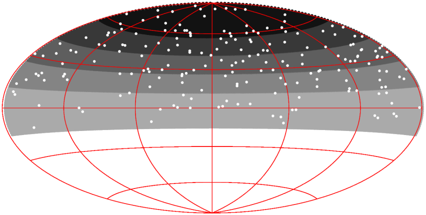
supergalactic

KS tests:

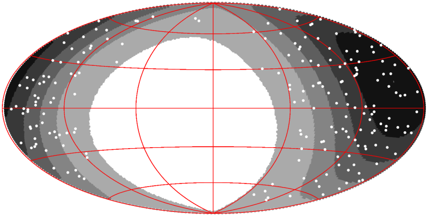
Frame	longitude	latitude
Equatorial:	0.19	0.58
Supergalactic:	0.54	0.17

Global distributions

210 events with $E > 40$ EeV



equatorial



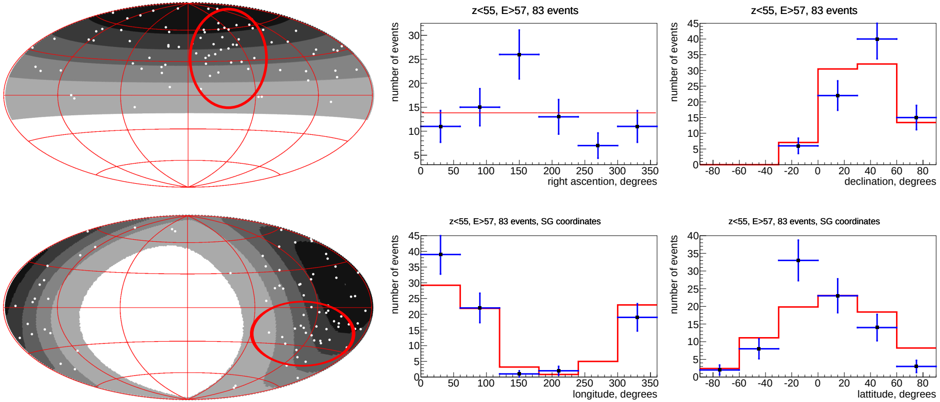
supergalactic

KS tests:

Frame	longitude	latitude
Equatorial:	0.12	0.63
Supergalactic:	0.74	0.15

Global distributions

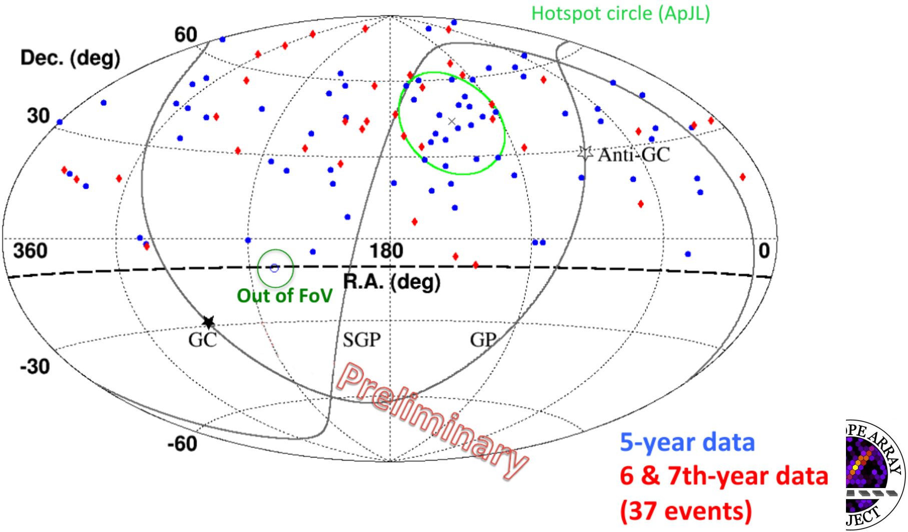
83 events with $E > 57$ EeV



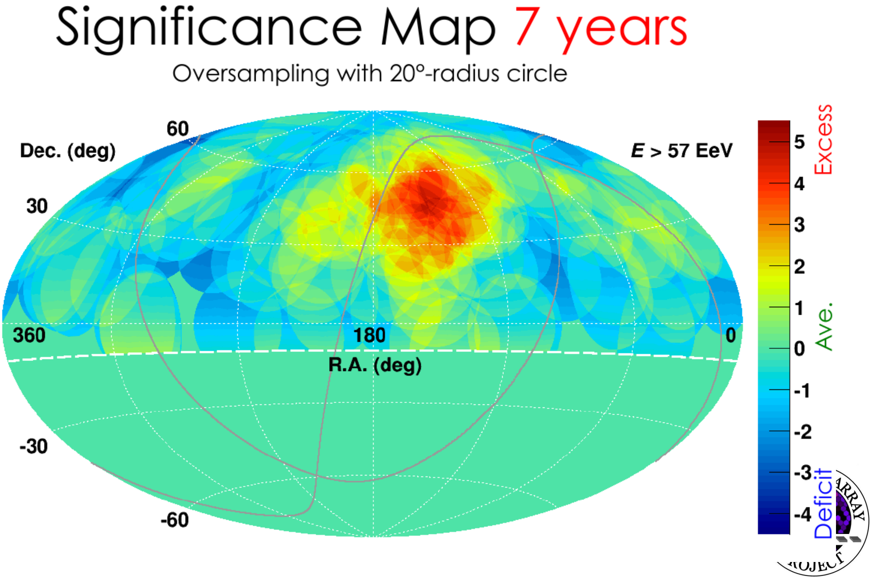
Frame	longitude	latitude
Equatorial:	0.07	0.04
Supergalactic:	0.01	0.03

HOT SPOT: 7 yr update

Same cuts as for 5yr; 109 events with $E > 57$ EeV in 7yr set



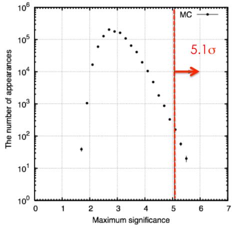
HOT SPOT: 7 yr update



HOT SPOT: 7 yr update

Significance calculation (same procedure as for 5

- oversampling at 15°, 20°, 25°, 30°, 35°, moving center
- Pre-trial: $P = 5.07\sigma$; $N_{\rm on} = 24$; $N_{\rm bg} = 6.88$;
  Post-trial $P = 3.7 \times 10^{-4}$ (3.4σ)
  $\Longrightarrow$ same as for 5 yr



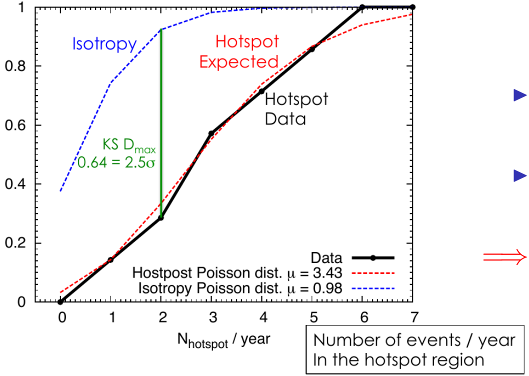
P = 367 / 1,000,000 trials
= 3.7×10^{-4} (3.4σ)

- Blind search with 2yr data (6th and 7th yr):
  expected in the spot region 2.31, observed 4, $P = 0.2$

Period	Total (>57EeV)	Hotspot Signals	B.G.	Chance Prob.	Center position (RA., Dec.)
6-th year	15	3	0.94	7%	146.7°, 43.2°
7-th year	22	1	1.37	74%	146.7°, 43.2°
6 & 7-th year	37	4	2.31	20%	146.7°, 43.2°

TELESCOPE ARRAY PROJECT

HOT SPOT: year-by-year statistics



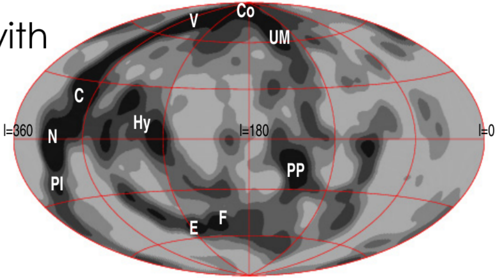
- Consider distribution of the number of events per year in the hot spot region.
- Build cumulative distribution
- Compare with signal and bg expectations

⟹ Compatible with signal;

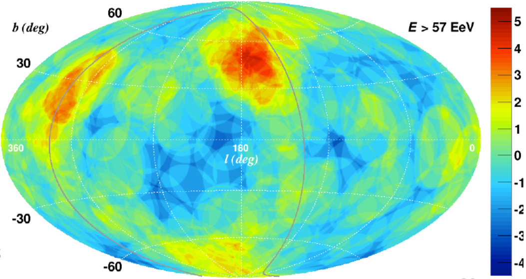
Not compatible with bg at 2.5σ CL

Adding Auger events

Comparison with Large-Scale Structure



Sky map of expected flux at E > 57 EeV (Galactic coordinates). The smearing angle is 6°. The letters indicate the nearby structures as follows: C: Centaurus supercluster (60 Mpc); Co: Coma cluster (90 Mpc); E: Eridanus cluster (30 Mpc); F: Fornax cluster (20 Mpc); Hy: Hydra supercluster (50 Mpc); N: Norma supercluster (65 Mpc); PI: Pavo-Indus supercluster (70 Mpc); PP: Perseus-Pisces supercluster (70 Mpc); UM: Ursa Major (20 Mpc); and V: Virgo cluster (20 Mpc).



TA 7 years + PAO 10 years

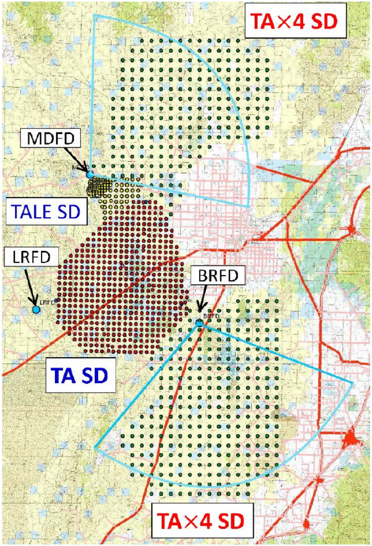
FUTURE TA

TA×4 project

- Quadrule TA SD (~3000 km^2)
  - 500 scintillator SDs
    2.08 km spacing
- 2 FD stations

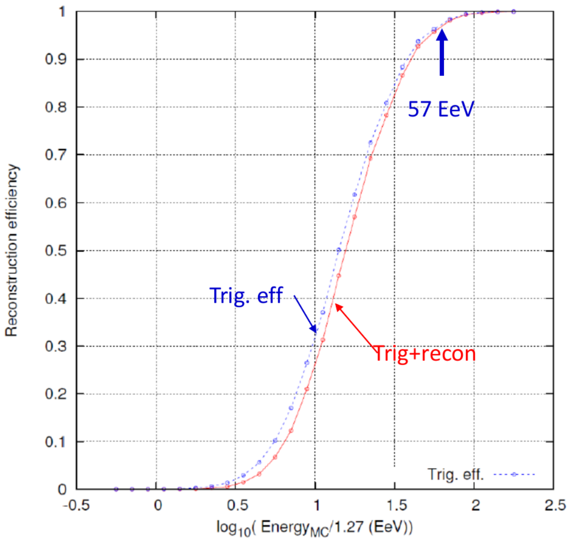
- Proposals
  - SD: approved in Japan in April 2015
  - FD: submit in US in October 2015

- Get 19 TA years of SD data by 2010
- Get 16.3 TA years of hybrid data
  - 2.7-year construction
    - TA in operation
  - 2.3-year observation



Efficiency for additional TA × 4 SD array

Differential for energies



Trigger condition
. 3 MIPS
. 3-fold SDs
. < 8x2.08/1.2usec

Reconstruction
. NSD≥ 4

TA SD reconstruction efficiency =100% for $E > 10^{19}$eV

SUMMARY

- Spectrum:
  - several features over 4.5 orders of magnitude in energy
  - ankle and GZK suppression energy are consistent with protons
- Composition:
  - consistent with protons; inconsistent with iron
- Anisotropy:
  - a hot spot at $E > 57$ EeV;
  - needs confirmation with higher statistics
  - presently consistent with LSS model + protons
- Future plans:
  - ground array TAx4 approved and is being constructed
  - proposal for complementary fluorescent detector is submitted