Telescope Array:

Hiroyuki Sagawa
(ICRR, Univ. of Tokyo)

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Outline

- TA, detectors
- TA results
  - Energy spectrum
  - Xmax … composition
  - Arrival directions … search for anisotropy
- Near-future and future plans
  - TA next 5 years
  - TALE
  - Next generation experiments
- Summary

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 [illegible], Y Kondo[9], V Kuzmin[12], YJ Kwon[8], JH Lim[16], SI L[illegible]uda[10], T Matsuyama[11], JN Matthews[1], M Minamino[11], [illegible]SW Nam[19], T Nonaka[9], S Ogio[11], M Ohnishi[9], H Ohoka[illegible], [illegible]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]

[1]University of Utah, [2]University of Yamanashi, [3]Tokyo Institute of Technology, [4]Kinki University, [5]Rutgers Univer[illegible]nsei University, [9]Institute for Cosmic Ra[illegible]Nuclear Studies, KEK, [11]Osaka City Univ[illegible]emy of Sciences, [13]Kanagawa Univer[illegible]National University, [17]Waseda University, [illegible]n National University, [21]University Libre de [illegible]hima City University, [25]National Institute of Radiological Science, Japan, [illegible]Ehime University

~140 collaborators

5 countries

(Japan, USA, Korea, Russia, Belgium)

26 institutions

Telescope Array Configuration

- Location
  - Utah, USA
  - 39.3oN., 112.9oW.
  - ~1400 m a.s.l.
- Surface Detectors (SD)
  - 507 scintillator detectors
  - 1.2 km spacing, 680 km^2
- Fluorescence Detectors (FD)
  - **3 FD stations**

Middle Drum (MD)
From HiRes

Observation since Dec.2007

~30 km

Full operation since May.2008

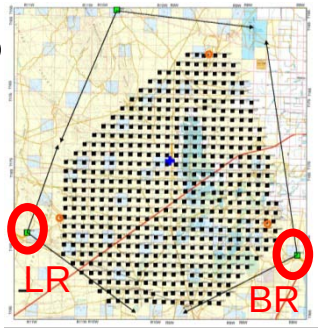
Long Ridge (LR)

Observation since Nov.2007

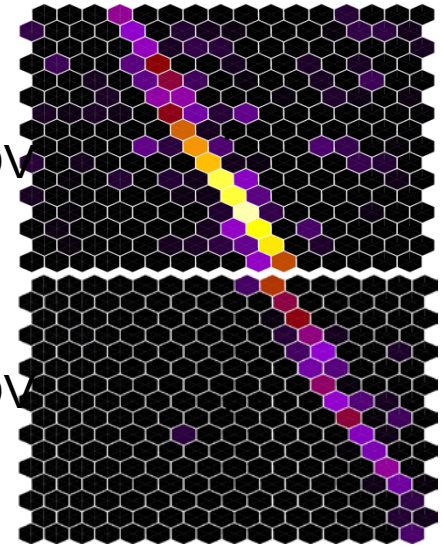
Black Rock Mesa (BR)

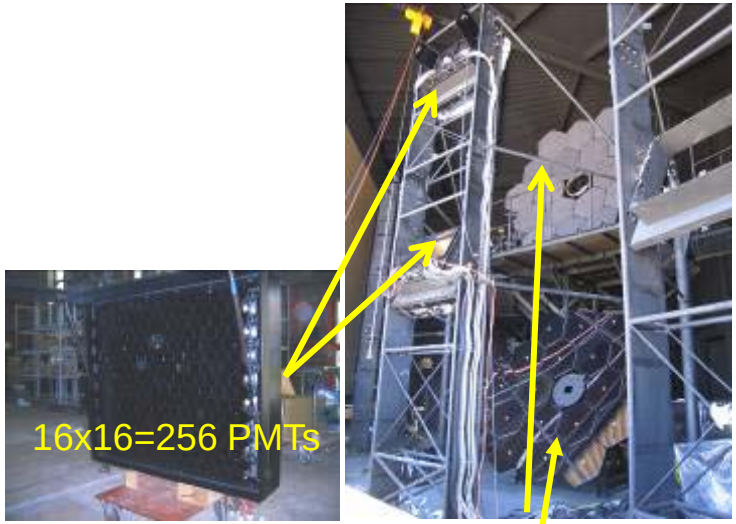
Observation since Jun.2007

TA Fluorescence Detectors BR/LR (new FDs)



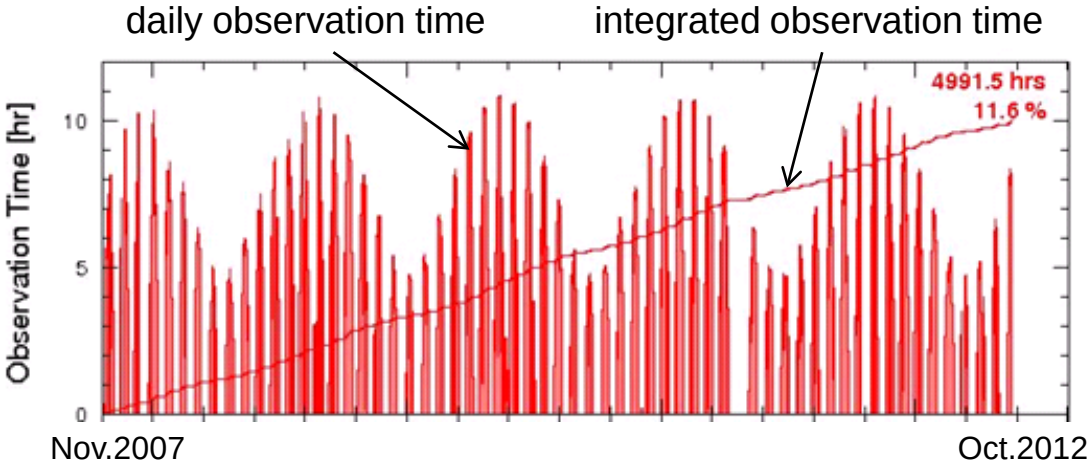
For each station
- 12 cameras
  - 256 PMTs/camera (HAMAMATSU R9508)
- FOV: 3-31° (elevation)
  108° (azimuth)



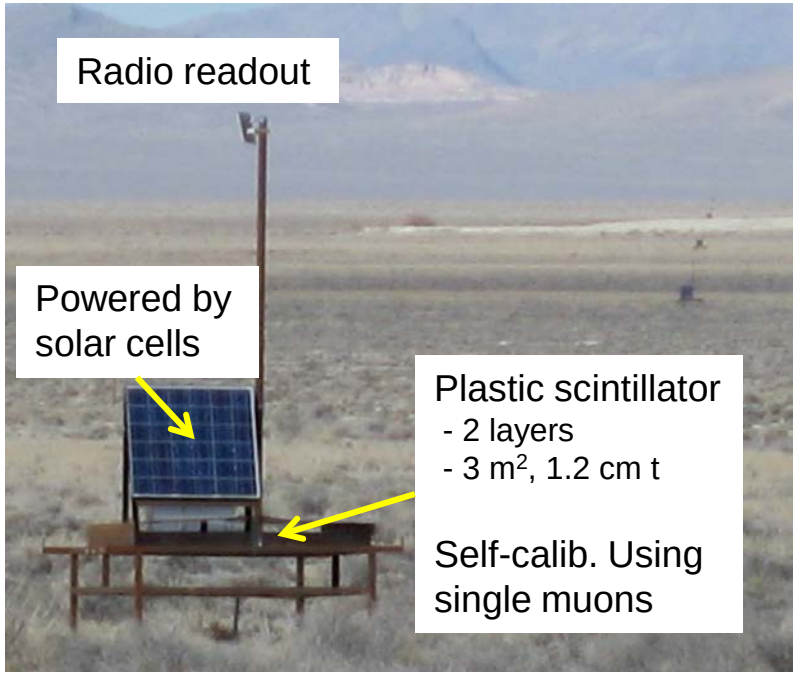


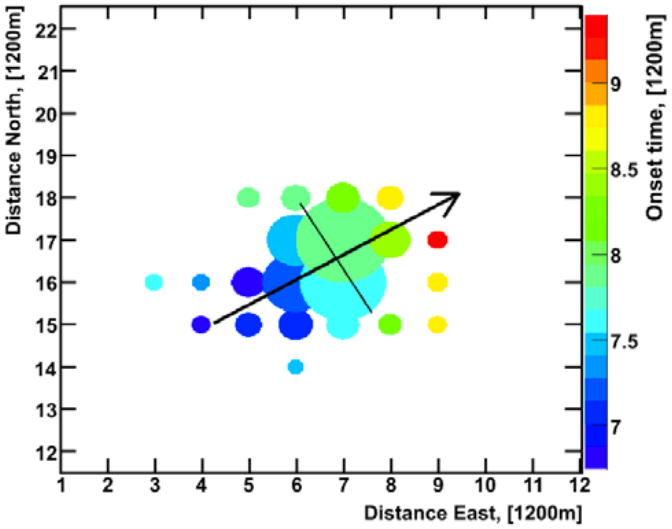
Camera box~1 m^2

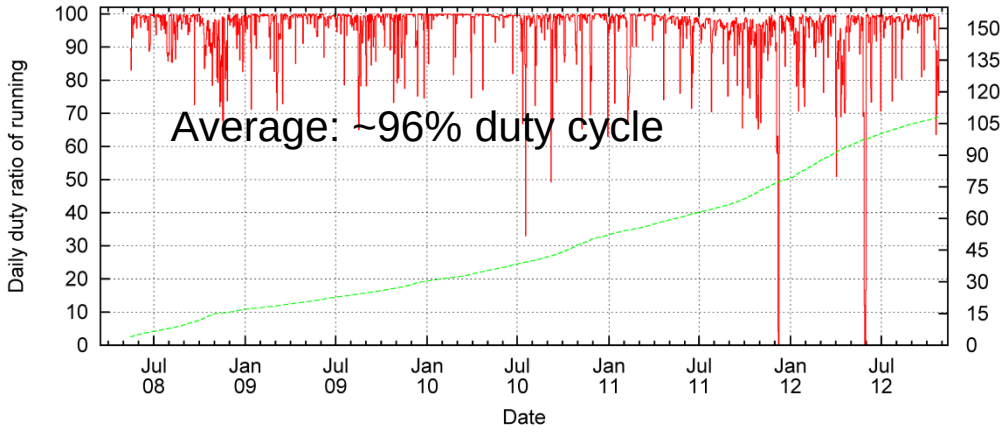
Mirror ~6.8 m^2

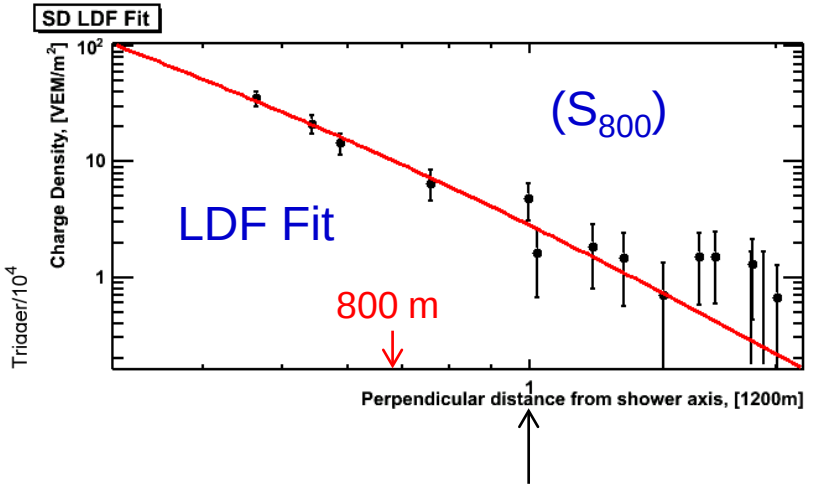


TA Surface Detector

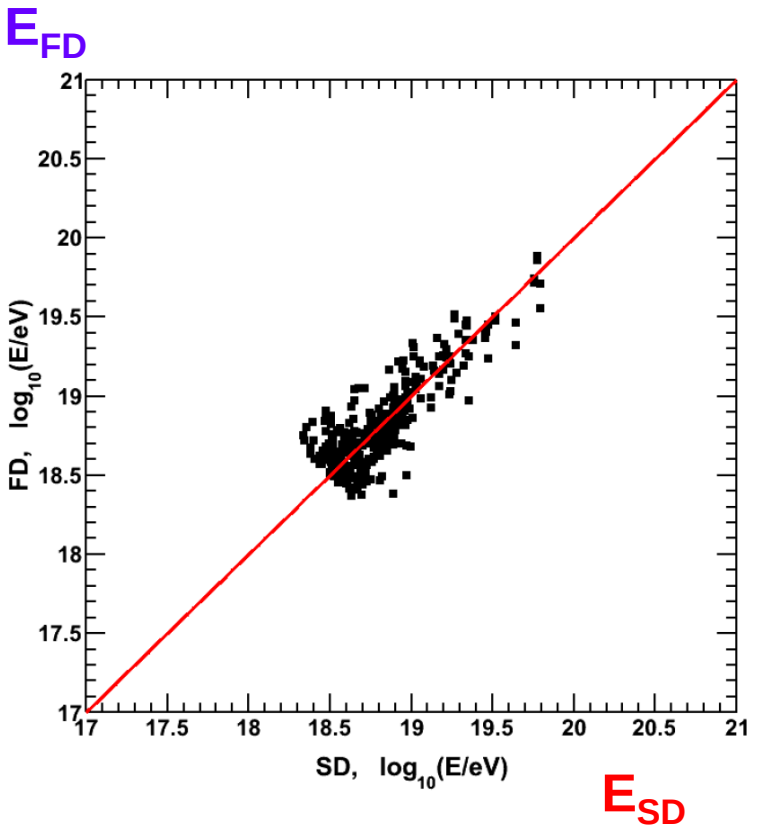








Energy Scale



- SD and FD energy
  - for hybrid events

$$\left\langle \frac{E'_{SD}}{E_{FD}} \right\rangle_{hyb} = 1.27$$

    - E'_{SD}: energy table from MC

$$E'_{SD}(S800, \theta)$$

      - θ: zenith angle
  - Rescale SD energy

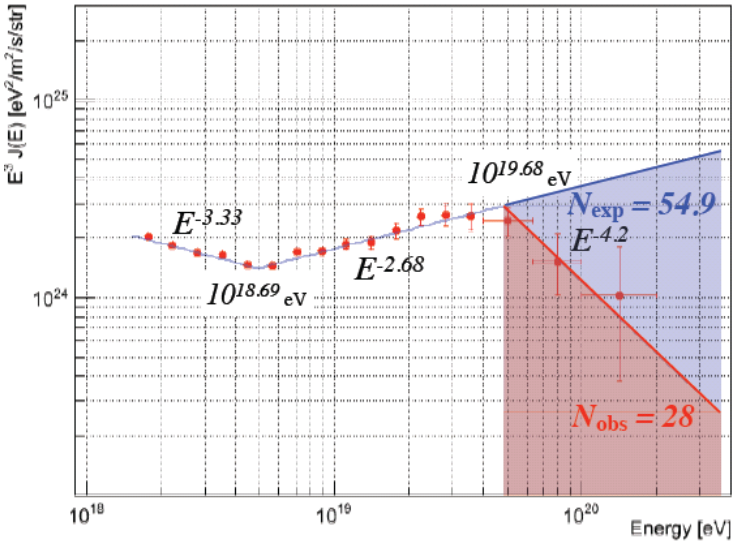
$$E_{SD} = \frac{1}{\left\langle \frac{E'_{SD}}{E_{FD}} \right\rangle_{hyb}} E'_{SD} = \frac{1}{1.27} E'_{SD}$$

Spectrum

- SD
- hybrid
- FD mono

TA Surface Detector Result

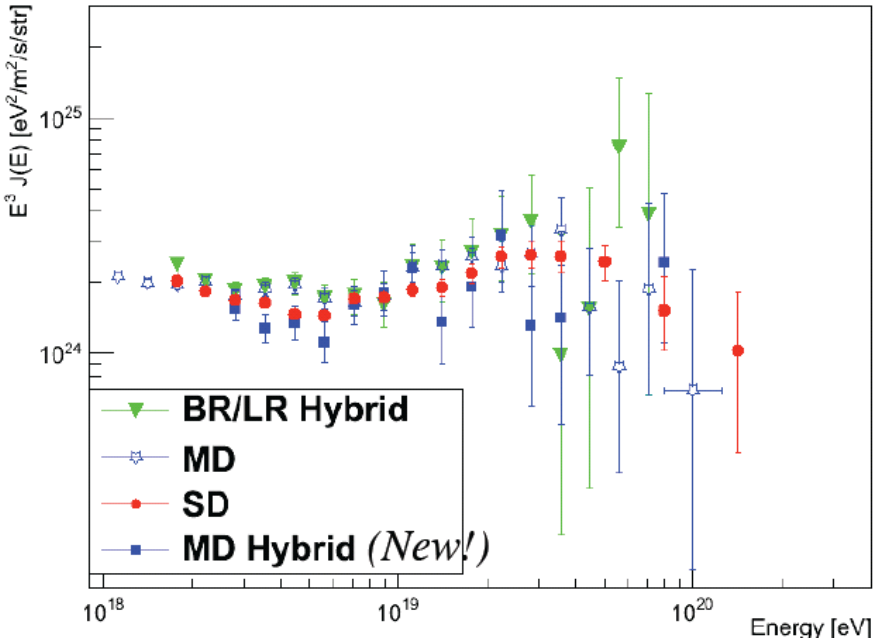
- Significance of the GZK suppression



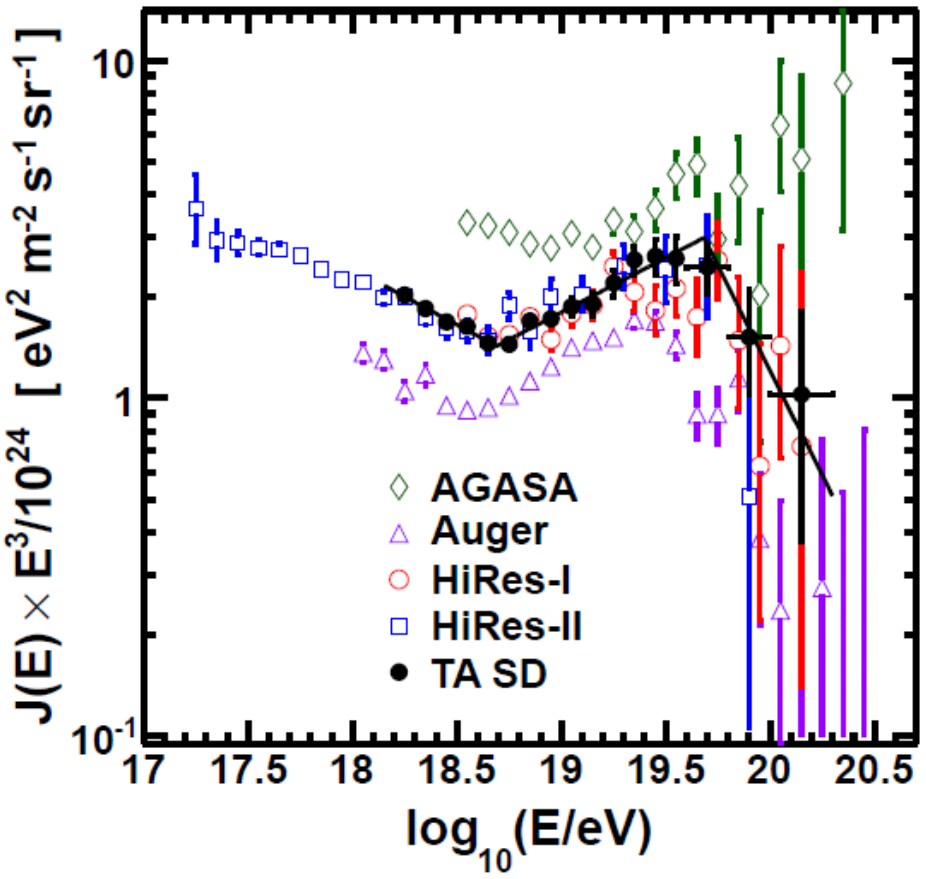
$$\mathrm{PROB} = \sum_{i=0}^{28} \mathrm{Poisson}(\mu = 54.9; i) = 4.75 \times 10^{-5}$$

(3.9σ)

- The TA spectra are consistent with each other.



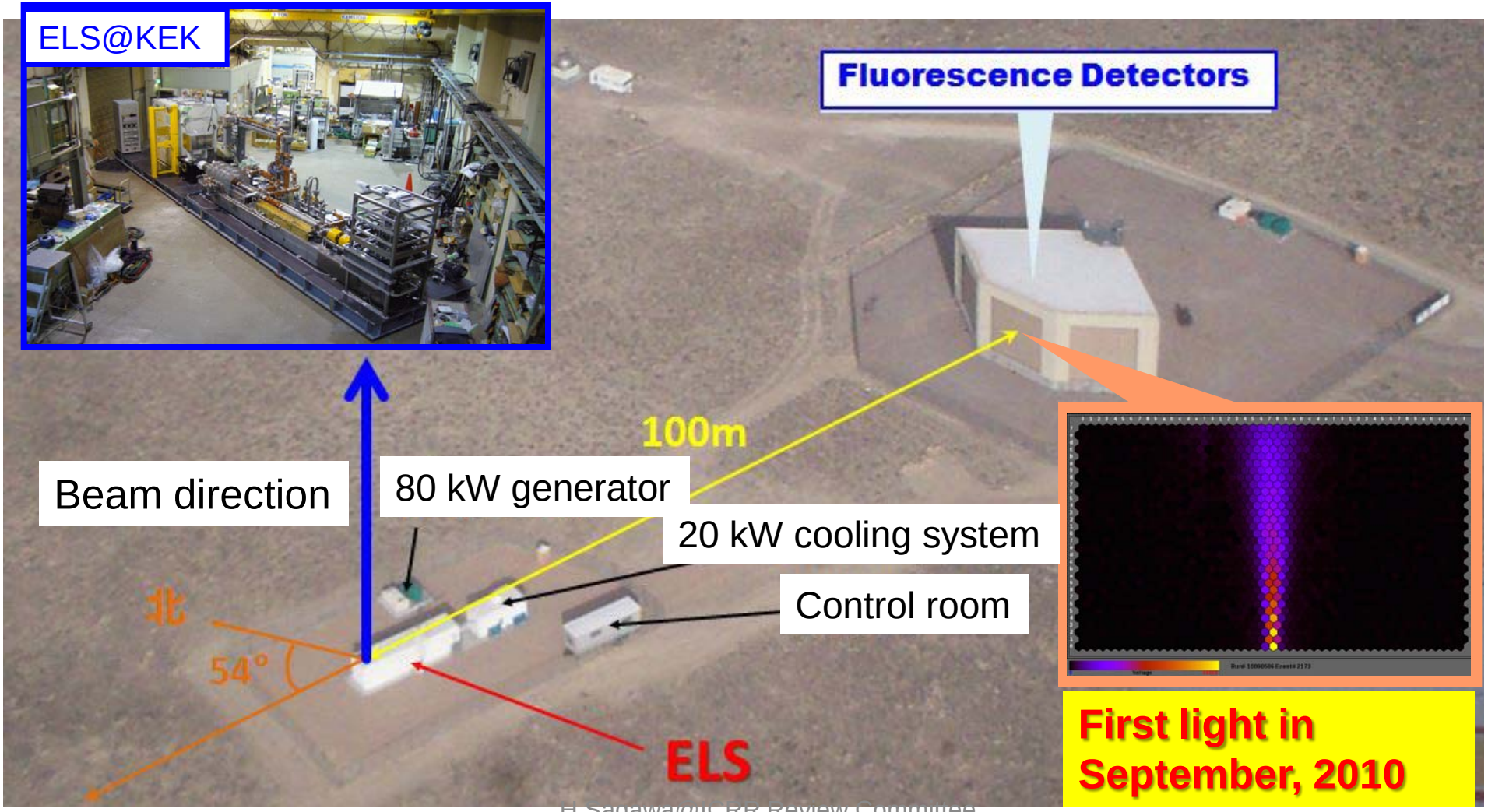
Spectrum



- Ankle: all experiments
- Suppression:
  - HiRes, Auger, TA
- TA SD spectrum is consistent with HiRes.
  - -20% (AGASA)
  - +20% (Auger)
    - ~20% total systematic uncertainty of energy both in TA and Auger

Electron Light Source (ELS)

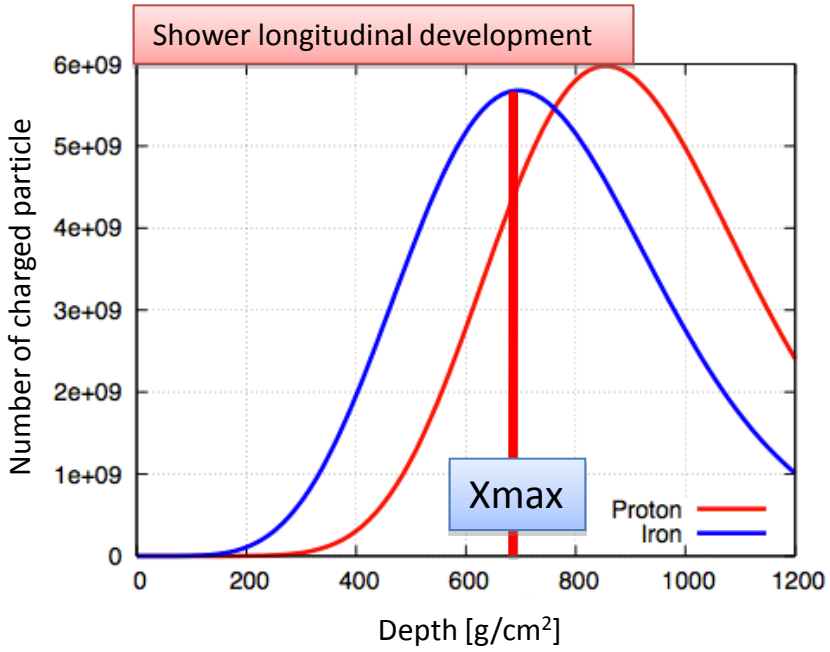
Source of electron beam = end-to-end energy calibration of FD



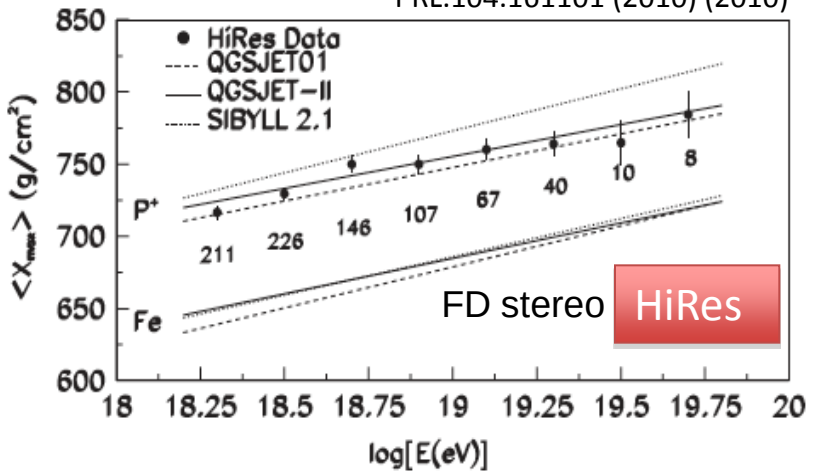
Output power=40 MeV×10^9e-/pulse×0.1-0.5 Hz, pulse width: 1μsec

Composition from X_{max}

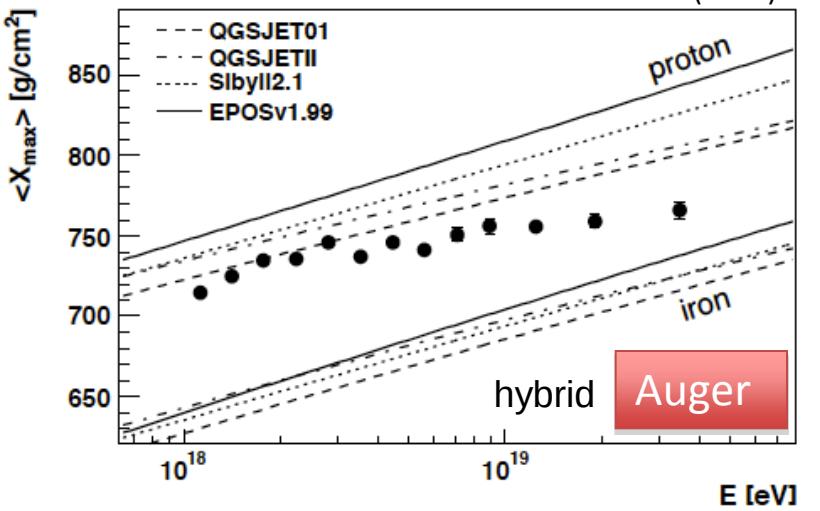
- Shower longitudinal development depends on primary particle type.
- FD observes shower development directly.
- Xmax is the most efficient parameter for determining primary particle type.



PRL.104.161101 (2010) (2010)

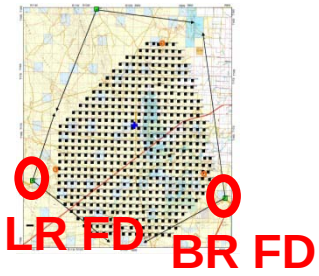


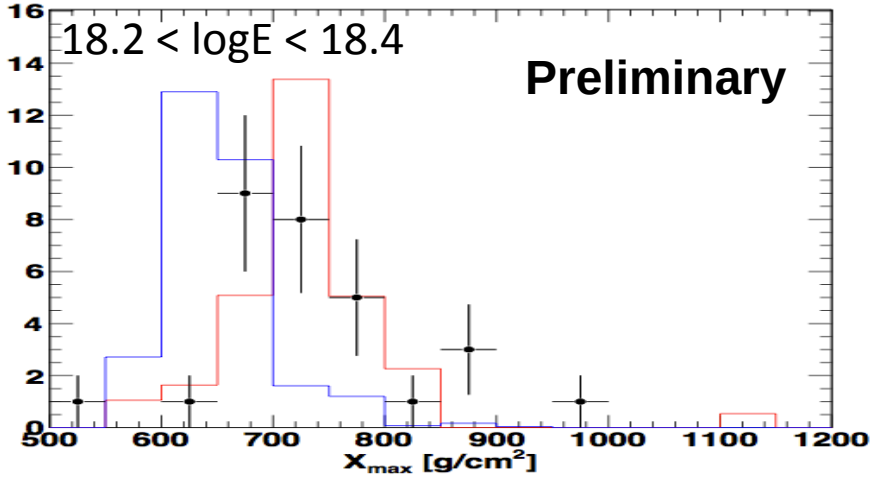
PRL.104.091101 (2010)

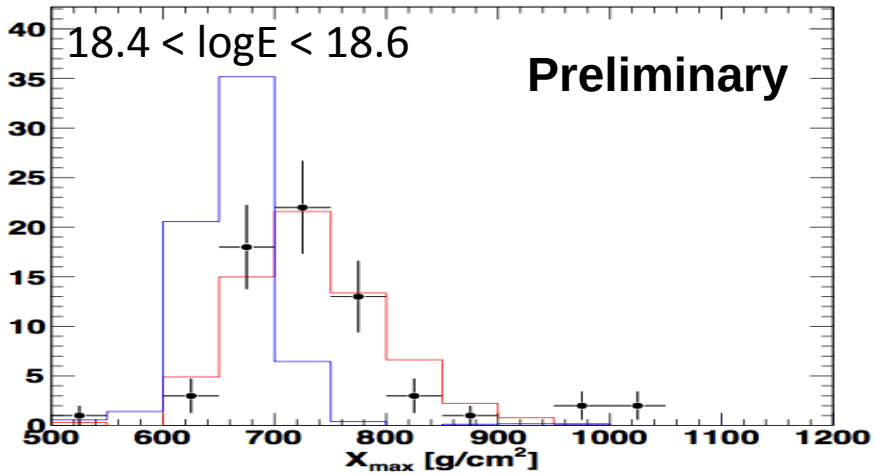


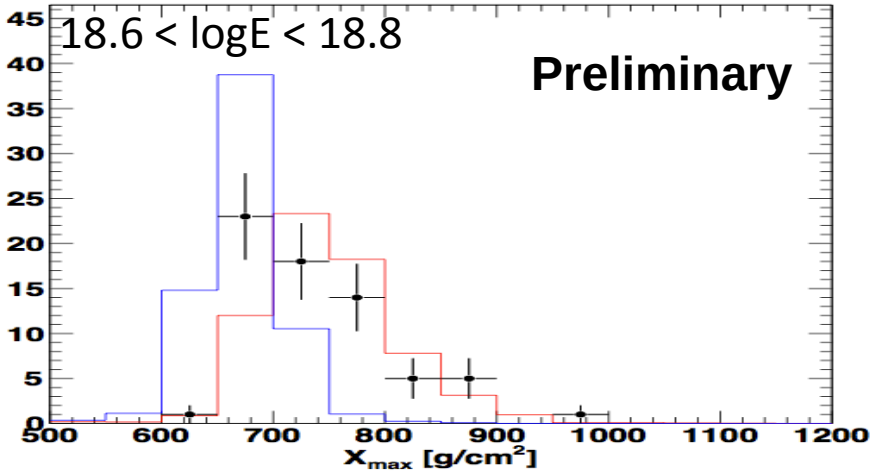
TA X_{max} dist. QGSJET-II

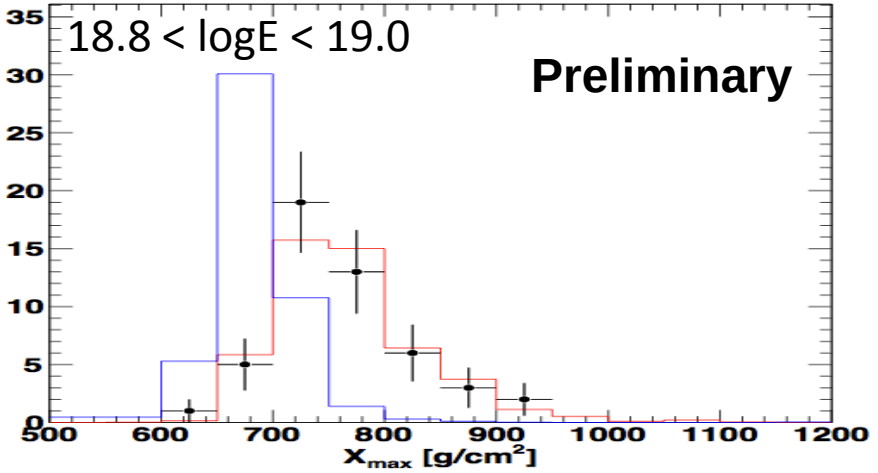
TA stereo data (2.9 years)











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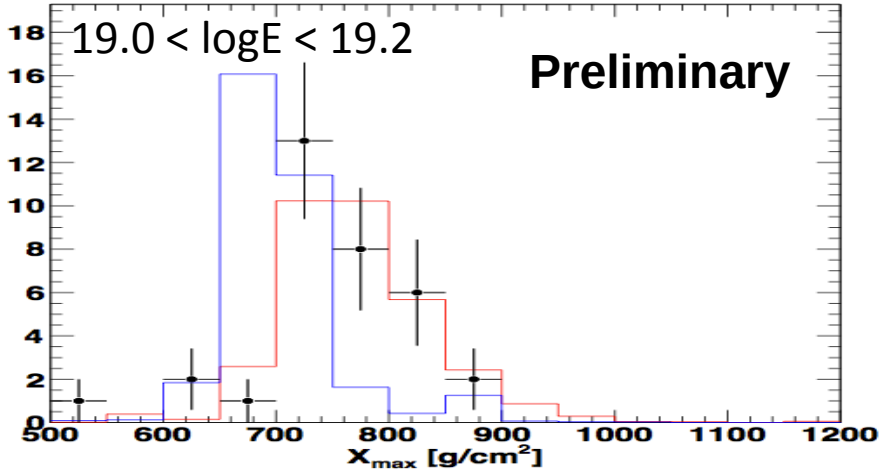
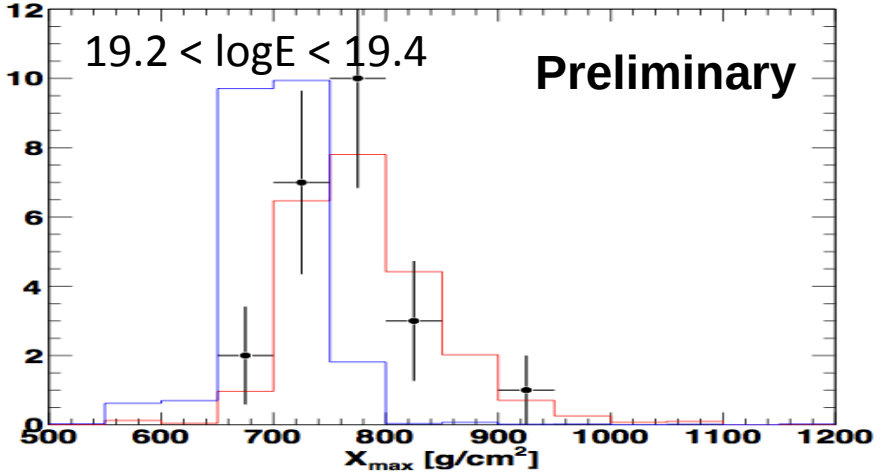
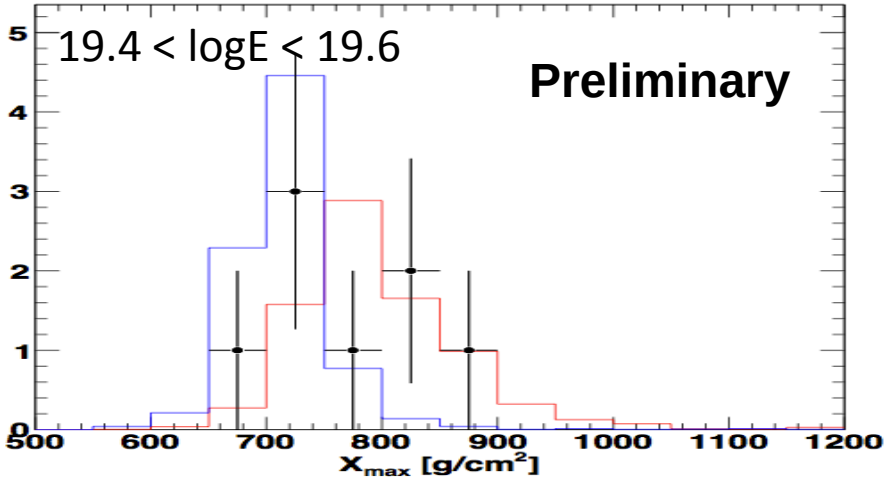
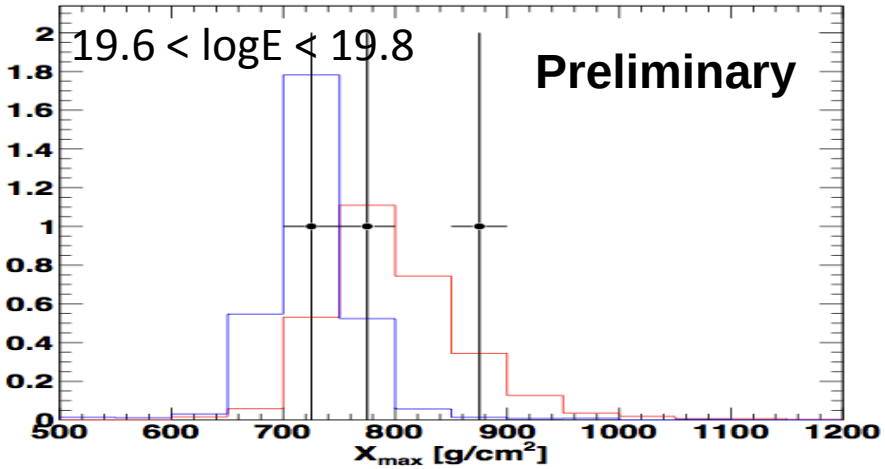


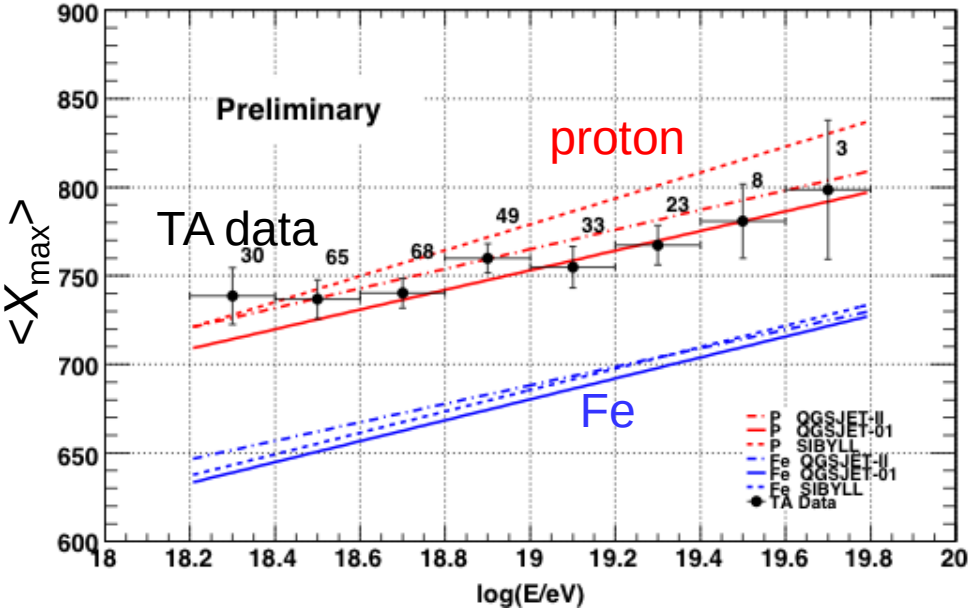




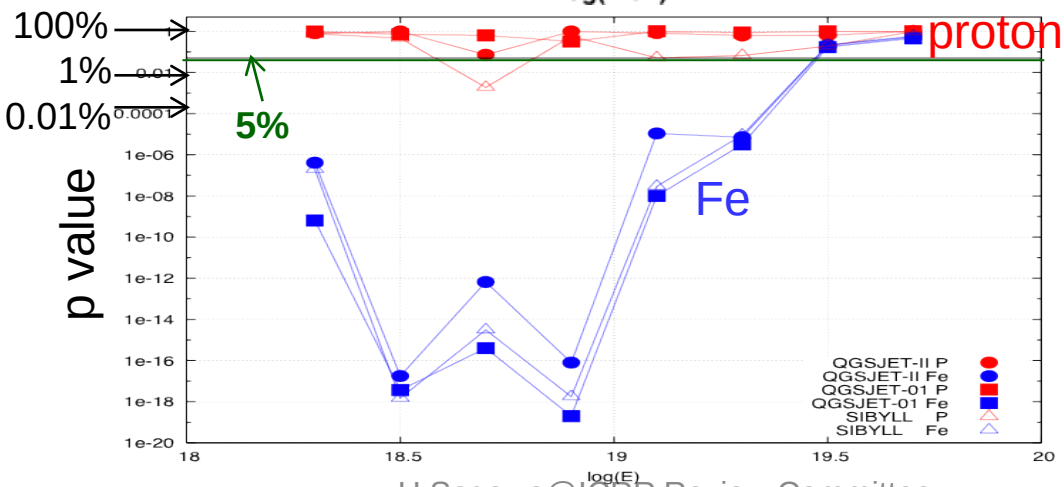


TA $<X_{max}>$ vs. Energy

TA stereo data (2.9 years)

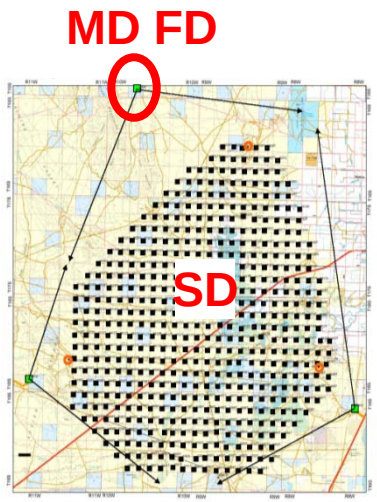


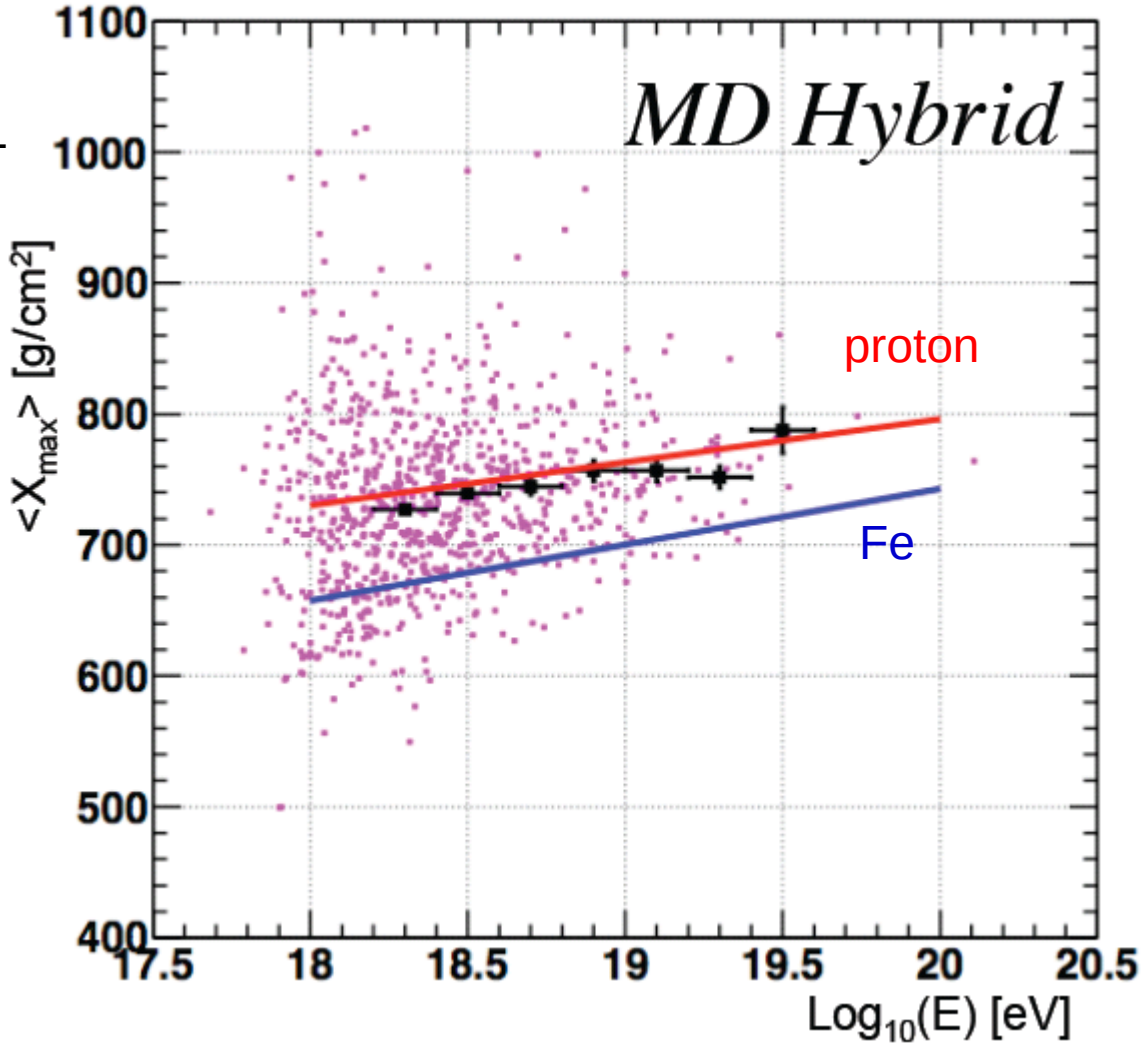
Consistent with proton
($E > 10^{18.2}$ eV)



TA $<X_{max}>$ vs. LogE

- 3.4 years of MD hybrid data
  - ➢May 11, 2008 – Sep 9, 2011





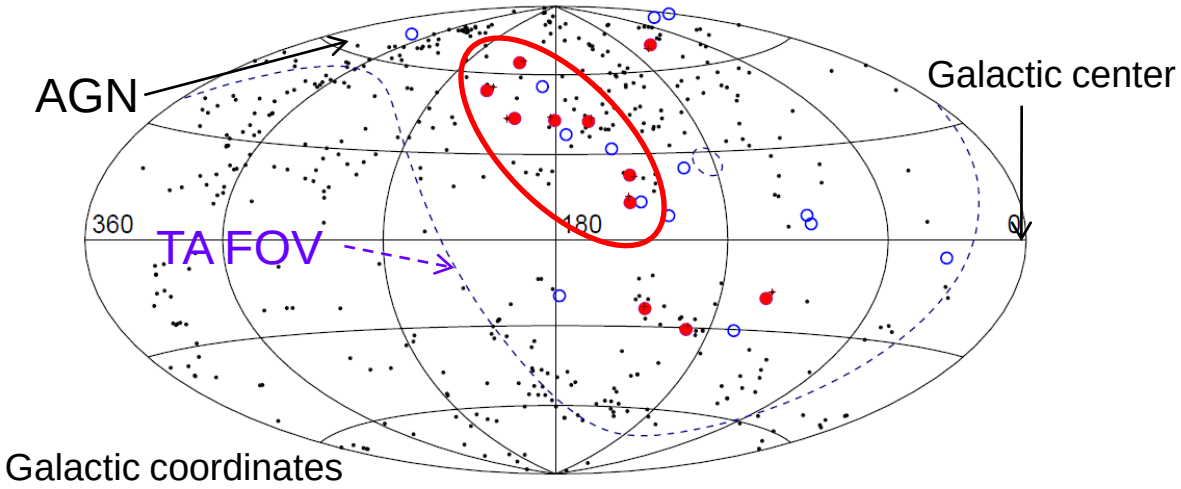
Arrival Direction Distributions

TA SD: May 11, 2008 – Sep 15 2011 (40 months)

- Correlations with AGN
- Auto-correlation
- Correlations with LSS

Correlations with AGNs

- AGN: z<0.018 (75 Mpc) from VCV catalog (dot)
- TA SD 25 events above 57 EeV (red + blue)
- 11 events within 3.1^{o} (red)

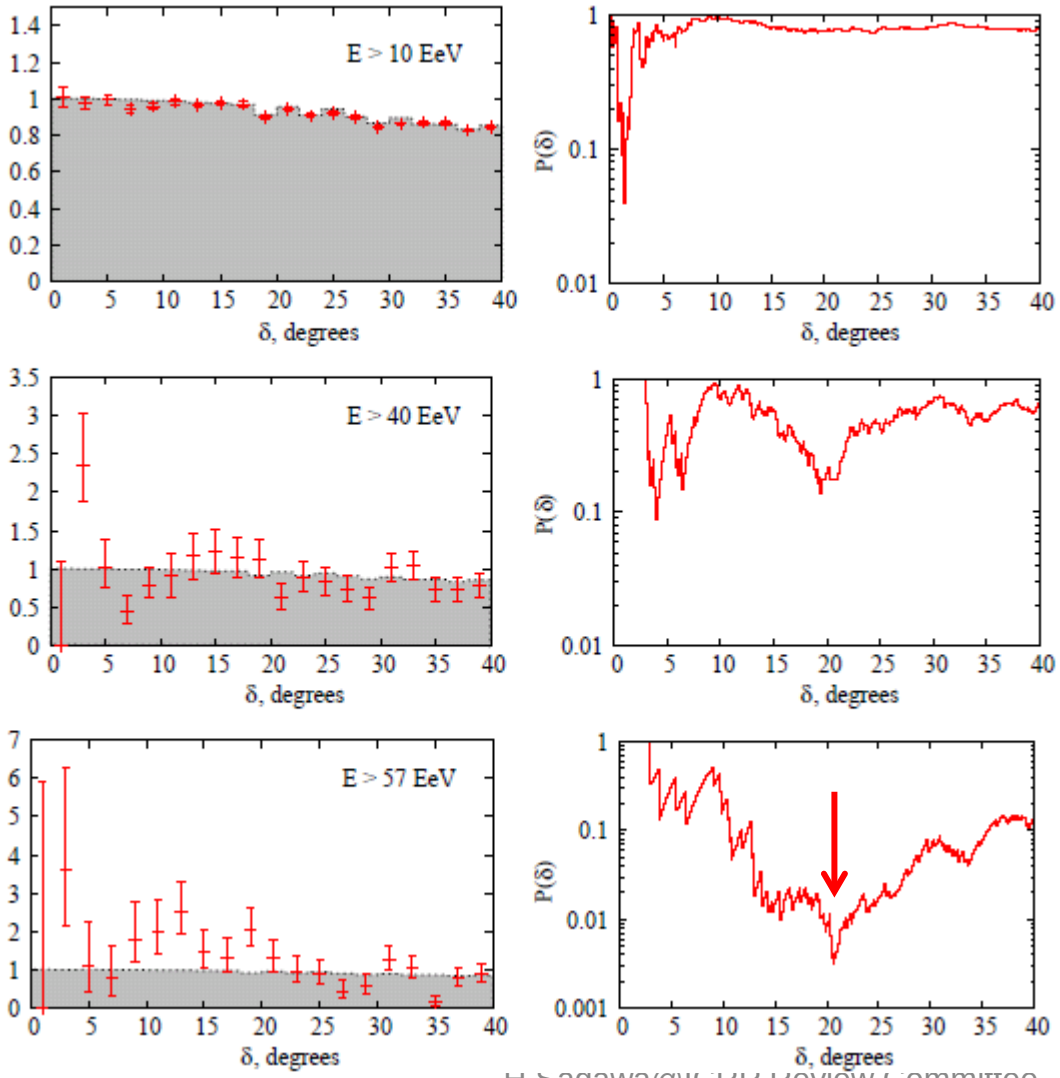


- The expected number of pairs for isotropy model: 5.9.
  - Chance probability to observe 11 events: 2%

- Auger (update incl. Jun.2011)
  (28 corr. Events)/(84 events)
  - Chance prob.=0.6%

Auto-correlation

The number of pairs with separation angle δ (normalized)



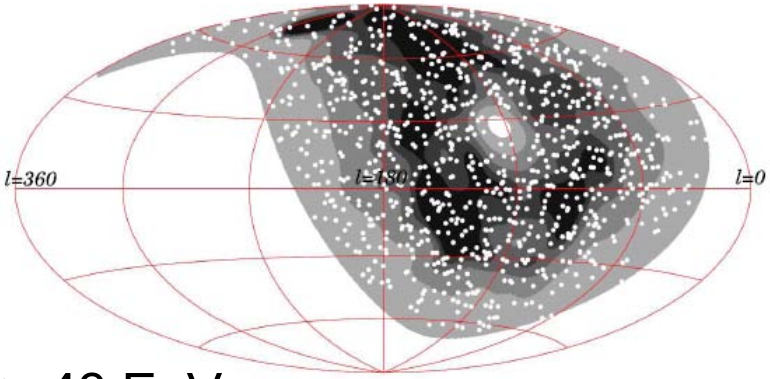
The probability that the excess of pairs (<δ) occurs in a uniform distribution

No clustering at angular scale of 2.5° or 0 – 40°

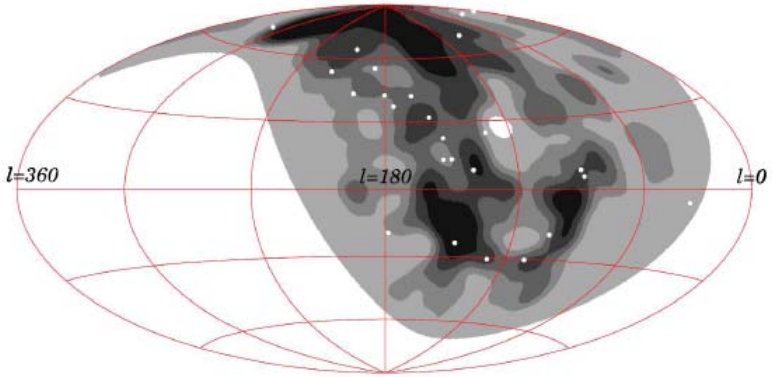
Small P(δ): departure from isotropy

Correlations with LSS
(skymaps of the expected flux with TA events)

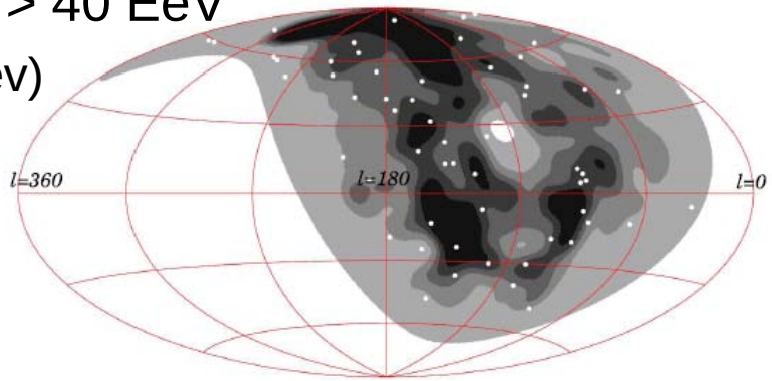
E > 10 EeV (988 ev)



E > 57 EeV (25 ev)



E > 40 EeV (57 ev)

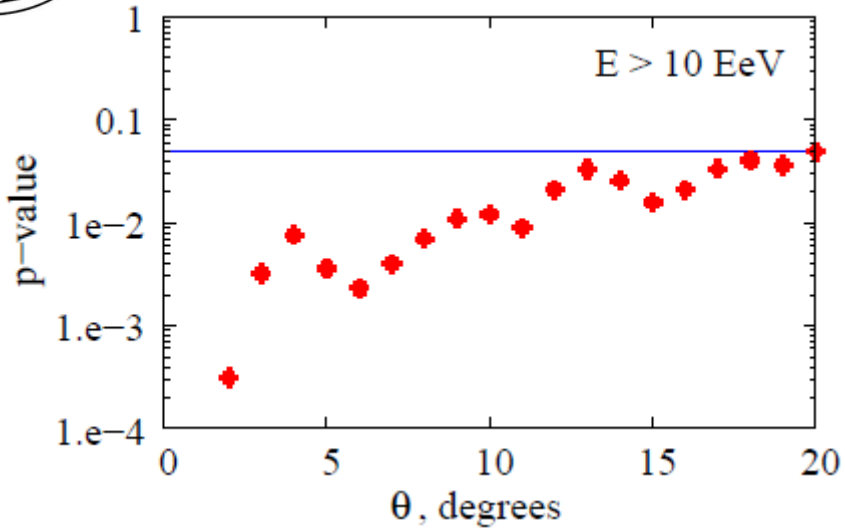


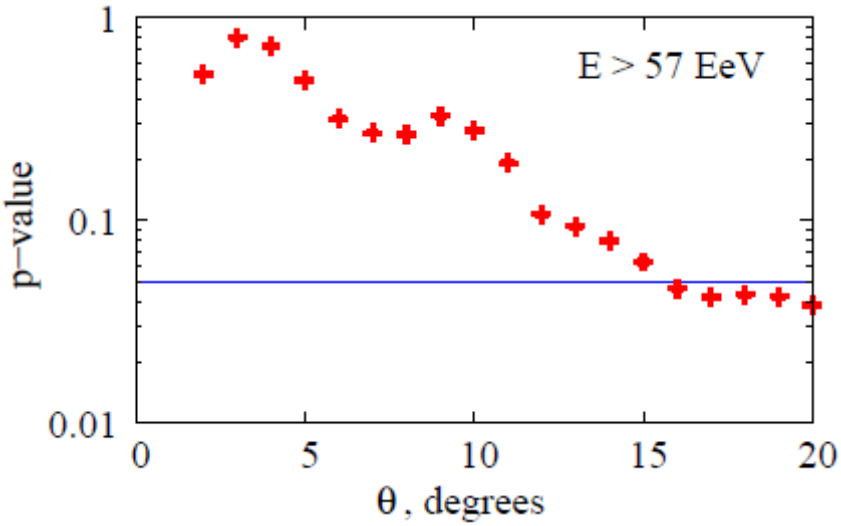
White dots: TA SD events

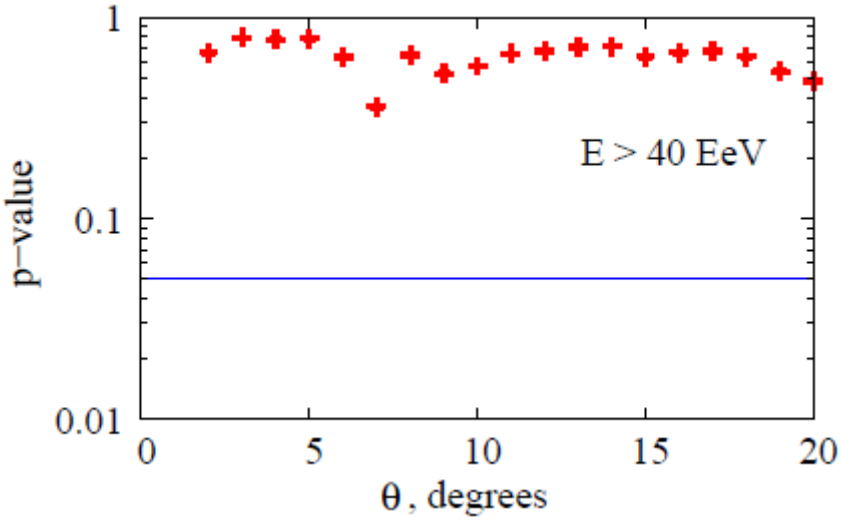
Smearing angle: Θs = 6°
Darkr: higher flux

Proton LSS model
Within 250 Mpc : 2MASS Extended source catalog
Beyond 250 Mpc: isotropy

Correlations with LSS







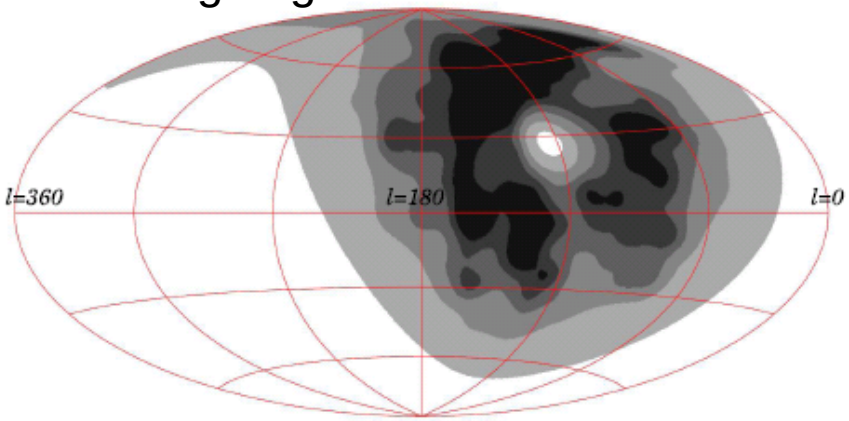
Consistent with LSS above 40 EeV, 57 EeV

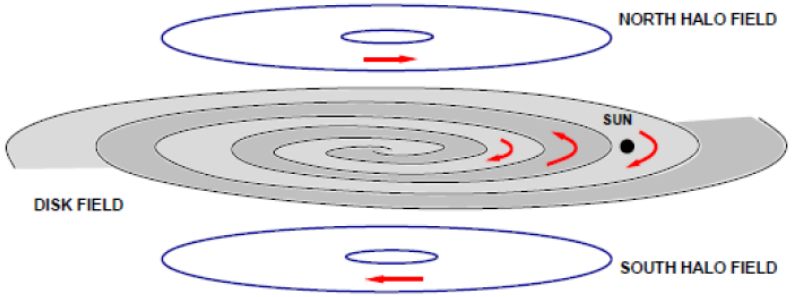
P-value for isotropic distribution
0.5 (E > 10 EeV)
0.9 (E > 40 EeV)
0.6 (E > 57 EeV)

Consistent with isotropy

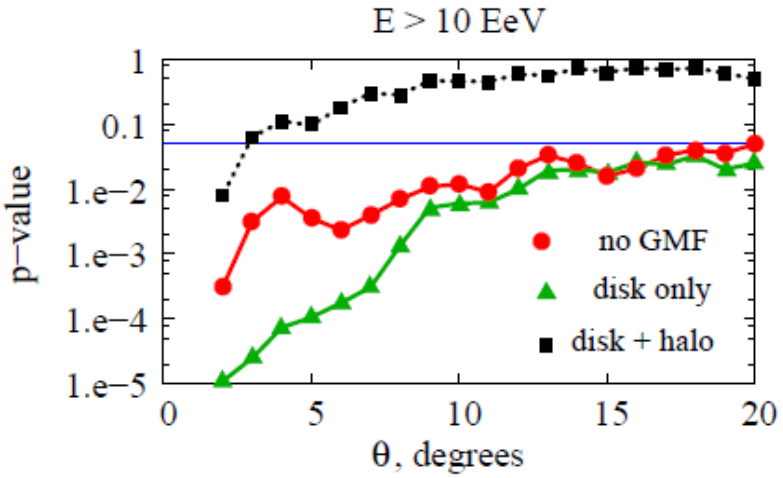
Correlations with LSS
[the sky map (<10EeV) with GMF]

Smearing angle 6^o





Strong/thick halo MG



Consistent with Galactic Magnetic Field (GMF) with **halo** (4μG, 1.5 kpc thick)

UHECR2012 symposium (CERN in Feb.)
Highlight: WORKING GROUP（WG）

WG from TA, Auger, HiRes, and Yakutsk

- UHECR spectrum
- UHECR anisotropy
- UHECR composition
- UHE multi-messenger
- Description of Modeling & air shower

Discuss the issues in advance (incl. analysis details)

Joint report from each WG at the symposium

After the symposium

- The WGs continue: formally and informally
- TA and Auger spokespersons: occasional skype meetings
- Auger's octocopter light source measurement with FD
  - TA site in October and Auger site in November
- TA and Auger joint anisotropy meeting: Jan.31/Feb.1

(Near) future plans

- TA next 5 years
  - Previous grant: Apr, 2003 - Mar, 2009
    - Construction + observation (~1-yr SD, 1.4 FD)
  - Current grant: Apr, 2009 - **Mar, 2014**
  - In Oct.2013, we will submit next proposal (Apr, 2014 – Mar, 2019).
- TA Low Energy Extension (TALE)
  - Ongoing, partially started
- Towards Larger aperture experiment
  - JEM-EUSO
  - Next generation ground-based experiment
- Associate experiments at TA site

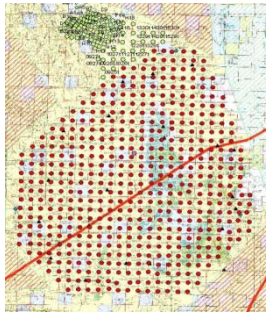
Options of TA next 5 years

- More statistics/Understand TA and Auger results

a) Current TA

(Operation~5M$)

SD: (1)+(5)+(5) =11 yrs
hyb:(1)+(5)+(5) =11 yrs



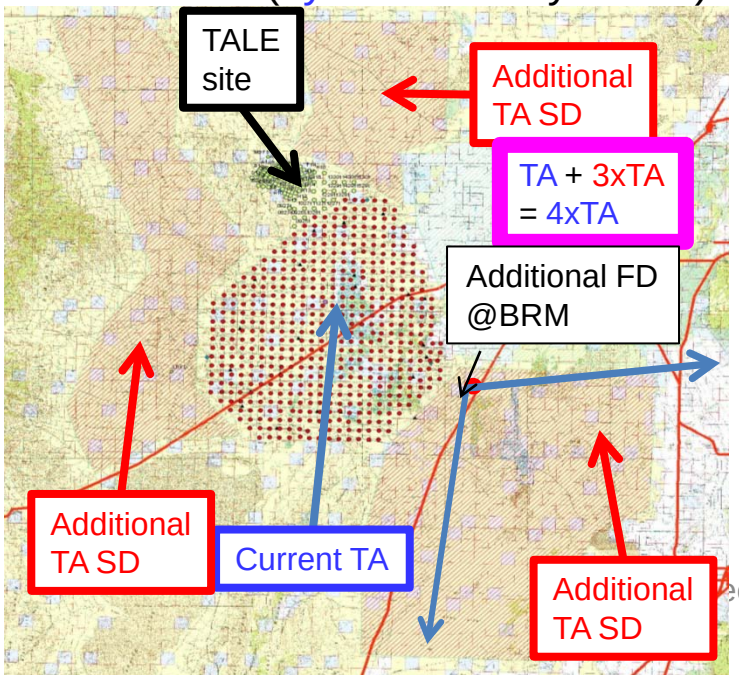
b) 4xTA SD

Additonal 500 SDs (~5M$)
with 2 km spacing ⟶ 3x TA SD

Additional 1 FD from HiRes II (US side)
for energy scale and hybrid analysis

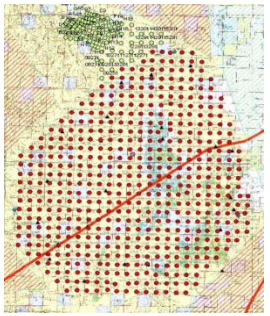
TA SD: (1)+(5)+(5+3yx3)=20 yrs
TA hyb:(1)+(5)+(5+3y) =14 yrs

(3y: assume 2-y const.)



c) Current TA + Det. exchange

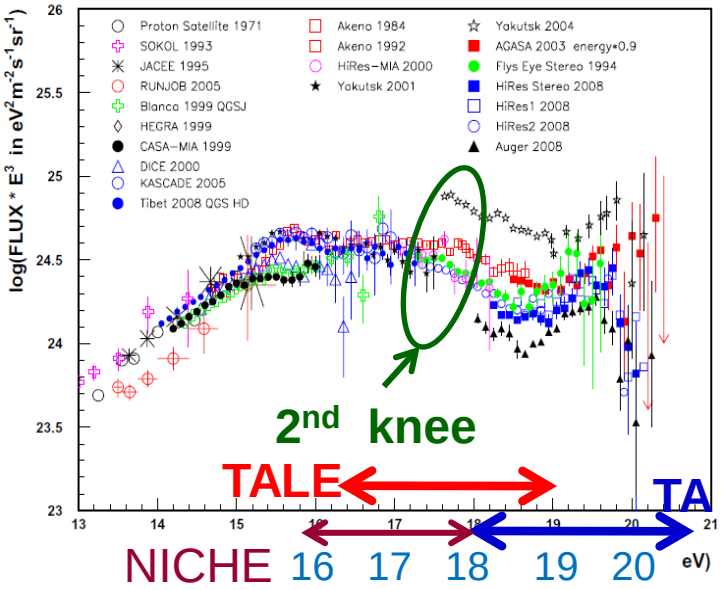
(Operation~5M$)



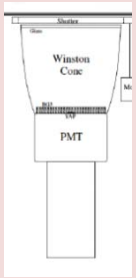
+

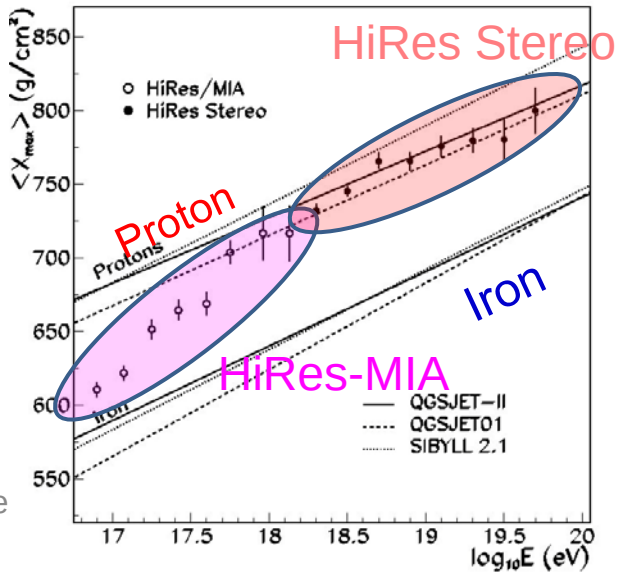
TA Low Energy Extension (TALE)

- Study at $10^{16.5}$ ~ 10^{19} eV
  - Change of composition?
  - Second knee
  - The galactic-extragalactic transition
  - LHC center-of-mass energy



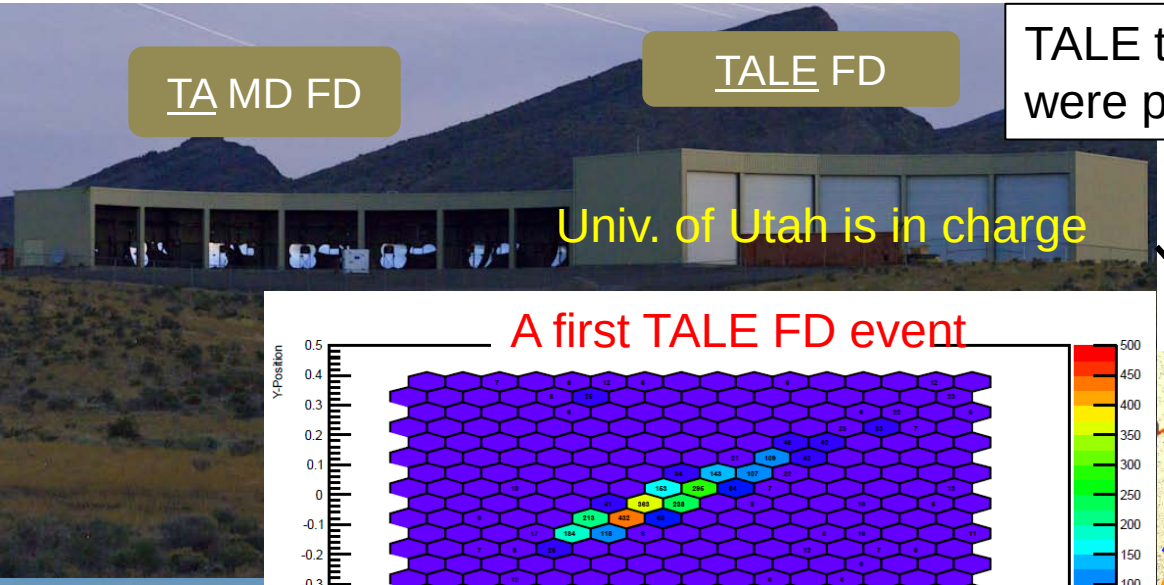
- NICHE (Non-Imaging CHErenkov array, $10^{15.8}$ – 10^{18} eV)
  - The proposal to NSF: submitted in Oct.2012 for Aug.2013 – Jul.2016





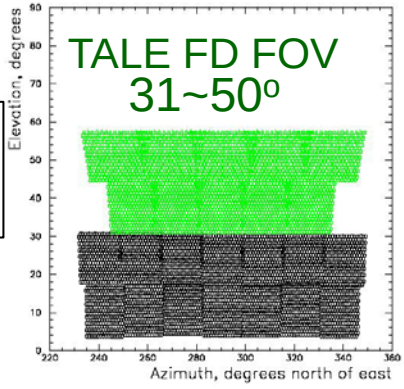
Energy and composition measurements with cross-calibration between TA and TALE, and TALE and NICHE over ~5-decade energy region ($10^{15.8}$ ~ >$10^{20.8}$ eV) with absolute end-to-end energy calibration of FD with ELS at TA

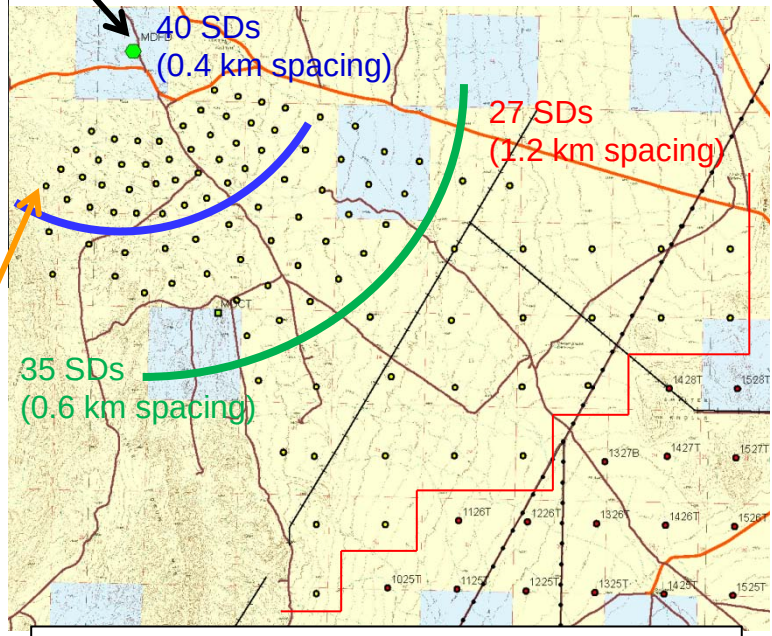
TALE detectors



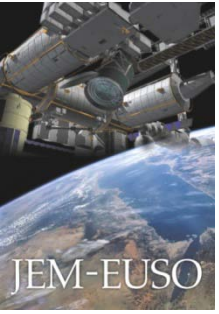
TALE telescopes were partially installed.

From HiRes II



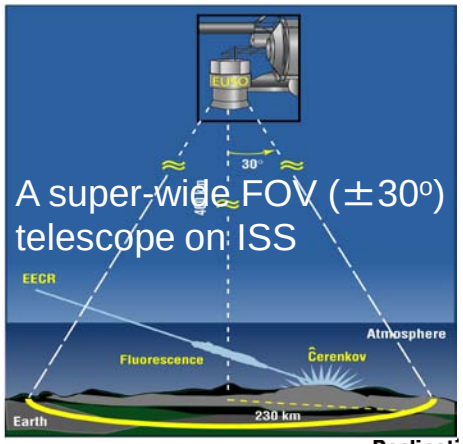


TALE FD and partially SD array will start operation next spring.

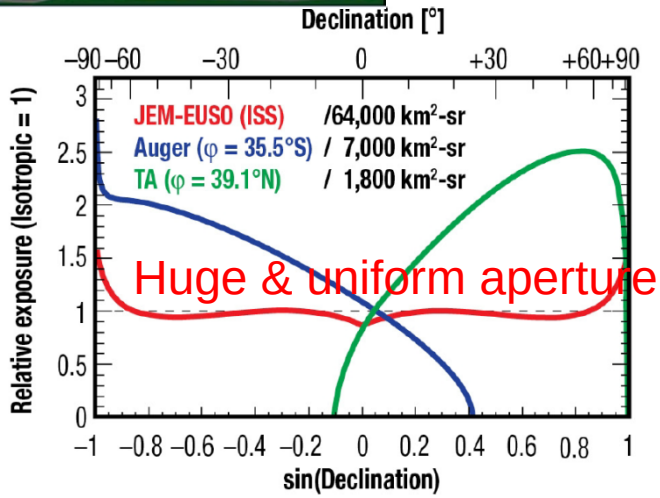


JEM-EUSO

Extreme **U**niverse **S**pace **O**bservatory onboard **J**apanese **E**xperiment **M**odule on International Space Station

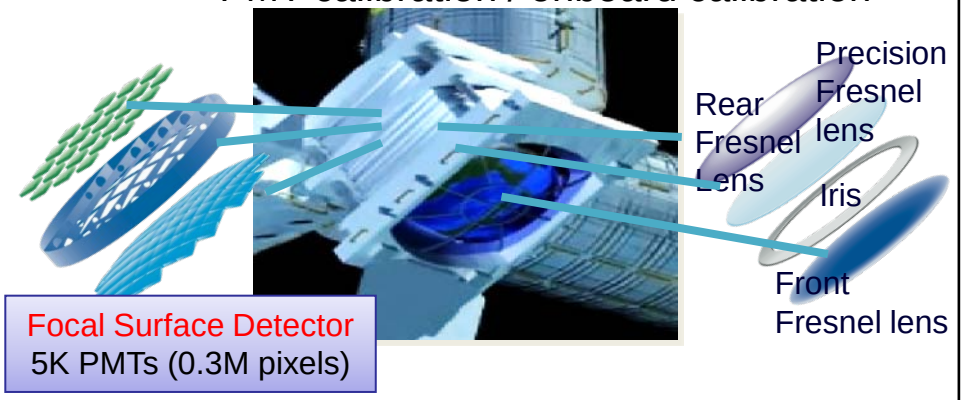


- Launching: 2017
- Mission lifetime: 3+2 years
- $E_{CR} > 5 \times 10^{19}$ eV
- Orbit: 400 km

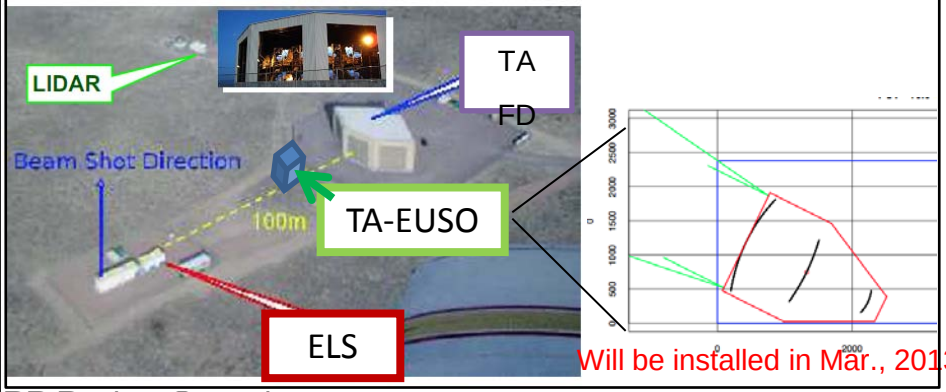


- ICRR TA group joined JEM-EUSO in Dec., 2012.

- Role sharing (technically/manpower)
  - PMT calibration / onboard calibration



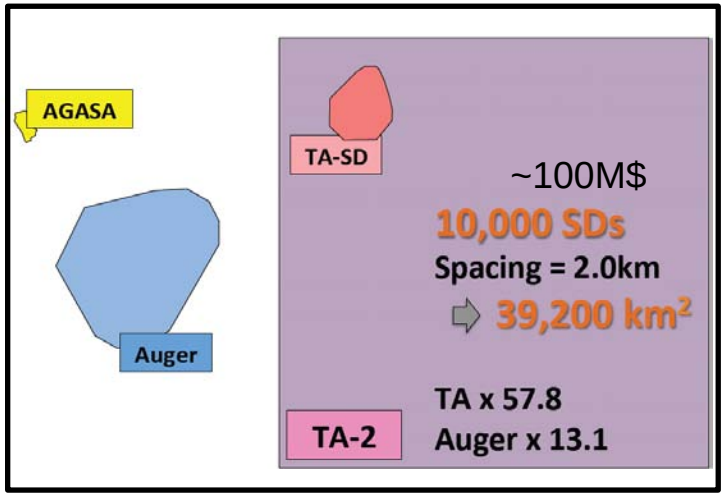
  - JEM-EUSO prototype (TA-EUSO) test at TA FD site



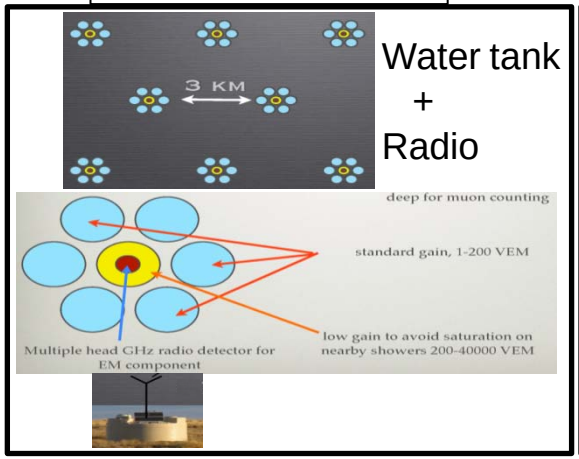
Will be installed in Mar., 2013

Next generation ground-based observatory

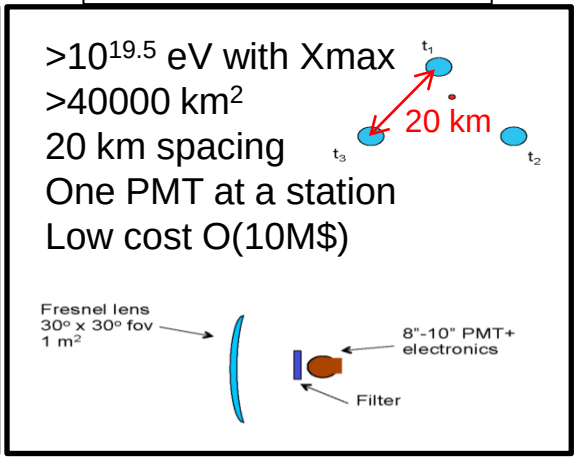
- Huge aperture
- Complementary to JEM-EUSO
  - better resolution for energy/direction/mass composition
  - Connection from highest to lower energy CRs
- New techniques: on-site check with FD and SD
- At UHECR2012 symposium, some ideas were proposed.



Multi-component



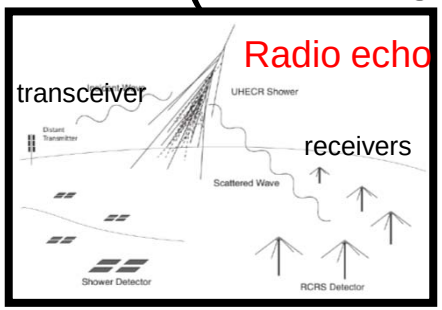
Low cost FD array

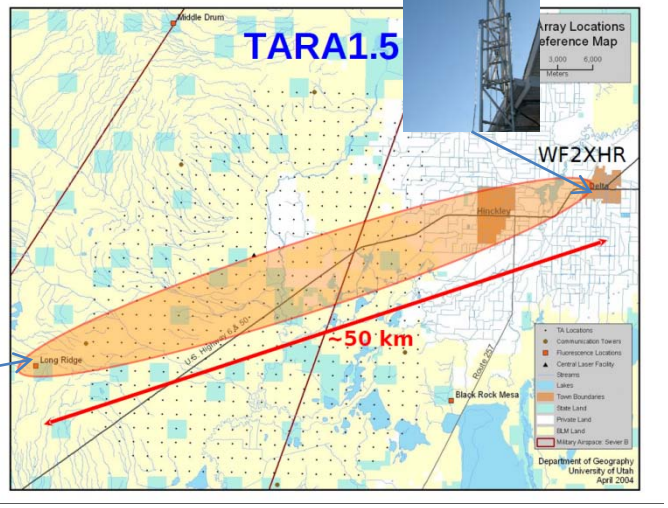


- To be examined worldwide

Associate experiments

- Radio detection test
  - TARA (TA RAdar)



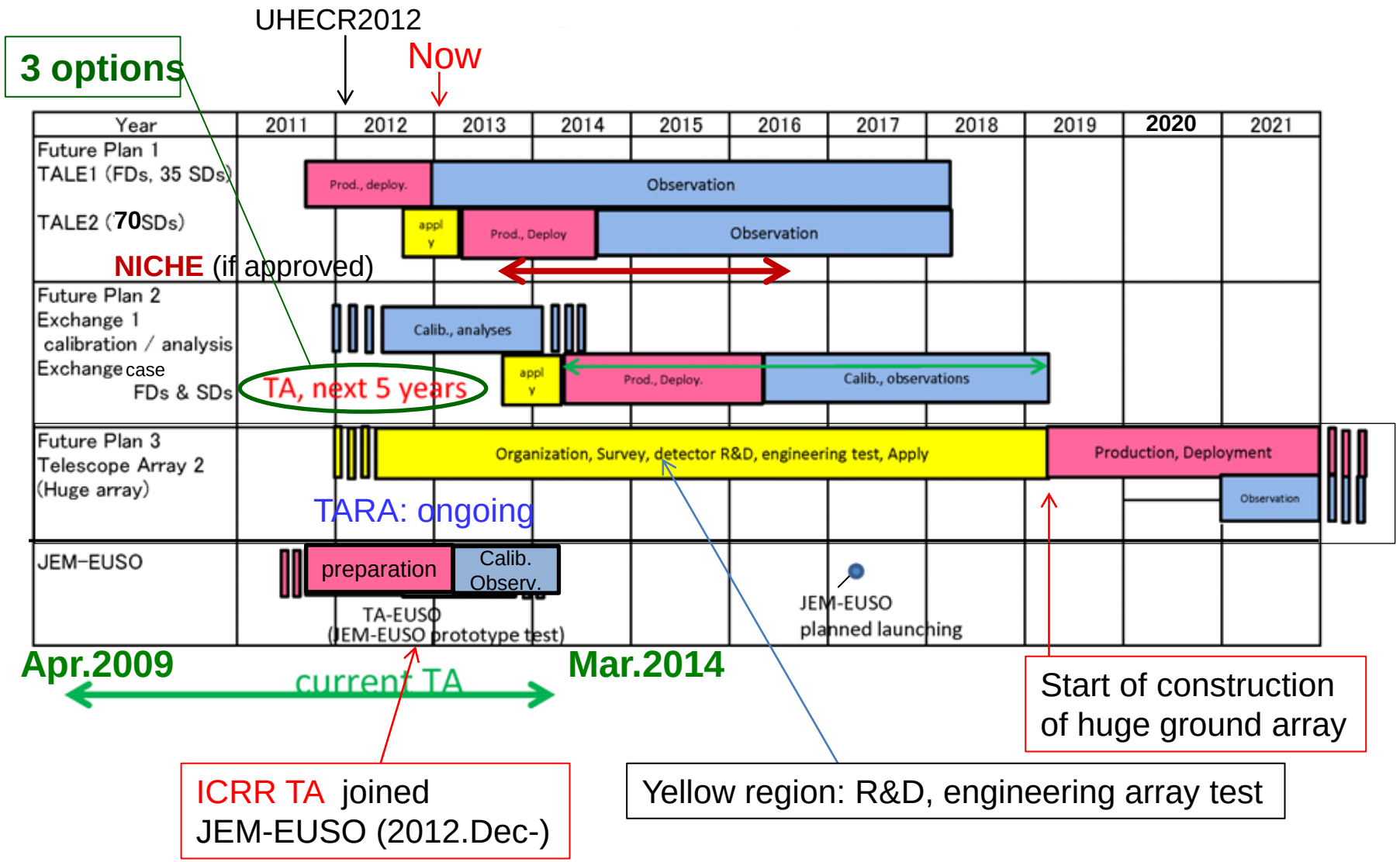


  - Bremsstrahlung detection: GHz
    - KIT/Chicago group from Auger
    - Konan Univ./Osaka City Univ. et al.

Mar, 2012

- TA-EUSO
- Octocopter light source measurement

A global plan



Summary

- TA experiment : running smoothly.
  - Recent results were presented.
    - Some hints of anisotropy
- TA next 5 years
  - Anisotropy/point source search, measurement of energy spectrum and mass composition by increasing statistics
  - Understand the results of TA and Auger (X_{max}, energy spectrum, arrival directions) by TA/Auger joint researches
- Energy, composition and anisotropy measurements over $10^{16.5}$ ($10^{15.8}$) ~ $10^{20.8}$ eV with TA and TALE (NICHE if approved) with absolute energy calibration with ELS at TA
  - TALE (on-going)
- Next generation CR observatory (space/ground)
  - ICRR TA group joined JEM-EUSO.
  - Next generation ground -based observatory: to be discussed worldwide
  - TARA (TA RAdar project): in the R&D stage in TA site.