Telescope Array Experiment

BK Shin on behalf TA collaboration

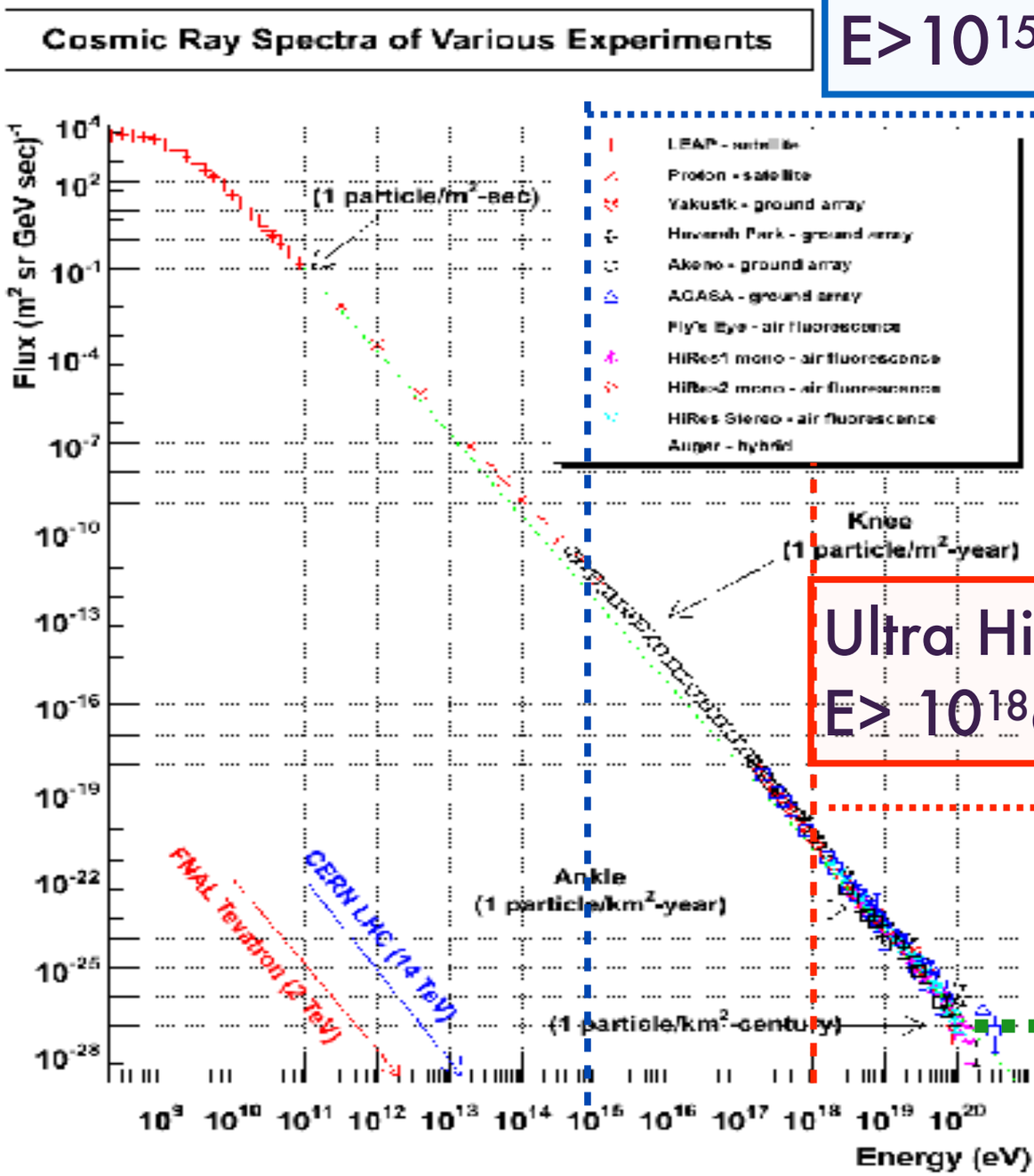
Osaka City University

2017/Oct/2nd CHEF 2017

Contents

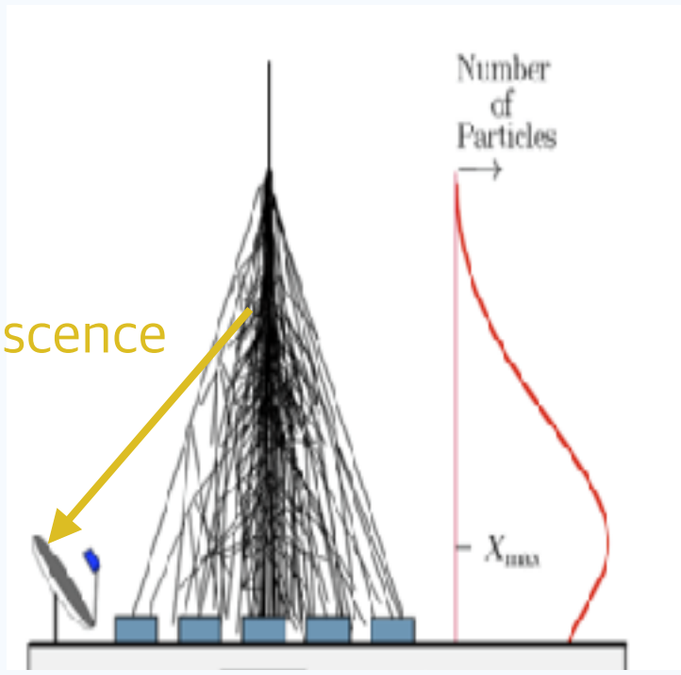
- Introduce of UHECR, Extensive Air shower
- Introduce of Telescope Array Experiment.
  - Fluorescence Detector , Surface detector Array
- Calibration Facilities
- Observation & Results
- Future and branch experiments

Cosmic Rays



Air Shower
$E>10^{15}$eV

Air Shower:CR interaction with air



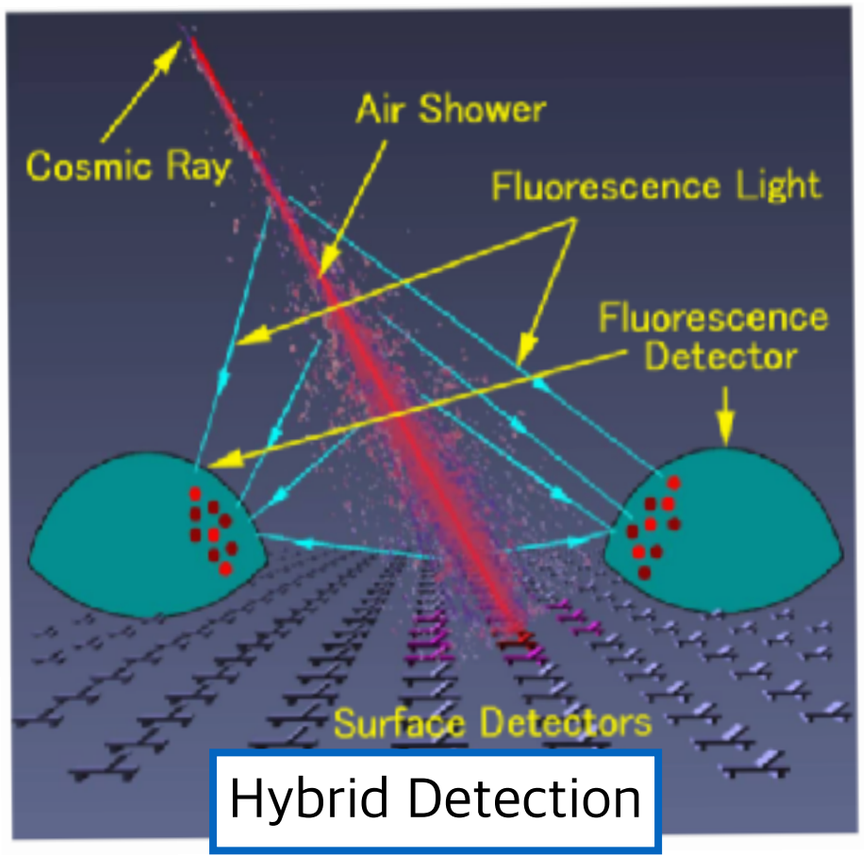
Ultra High Energy CR
$E> 10^{18}$eV

1 Particle/km² Century

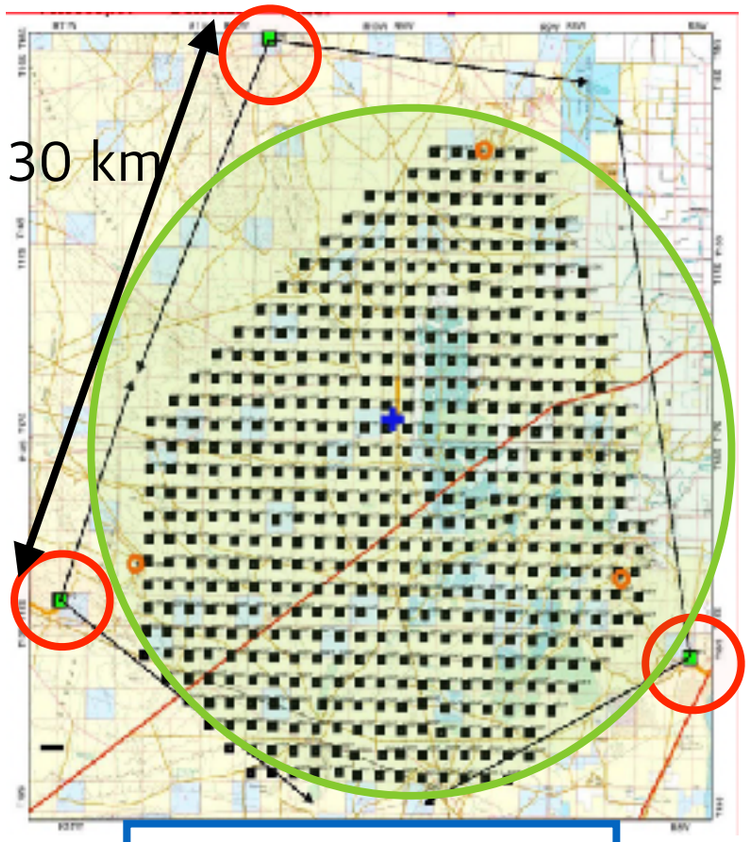
Huge Air Shower Observatory

Overview of TA Experiment

- **Physics goal : Research for UHECR**
  - Precise Measurement: Energy spectrum, Mass composition, Anisotropy
  - International collaboration: 5 countries, Japan, USA, Korea, Russia, Belgium
- Hybrid Observatory: 3 FD stations, an array with 507 SDs to cover 700 km^2 Aperture
- Site : Utah, USA
- Operated from 2008



Hybrid Detection



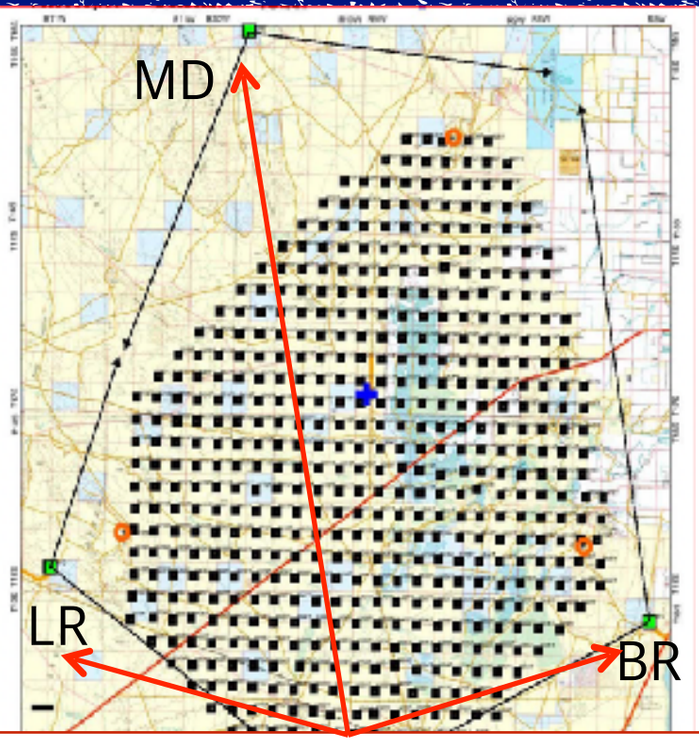
SD Array

FD station

TA Site in Utah, US

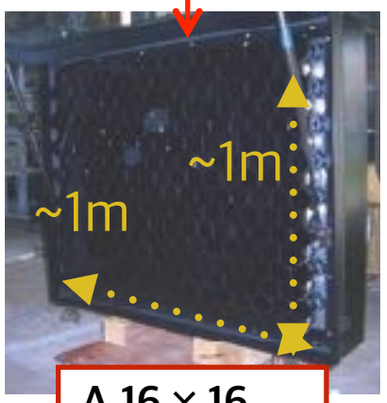
Fluorescence Detectors(FDs)

The TA has 3 stations of FD
AS Longitudinal property
Operation in Moonless night: 12% of duty

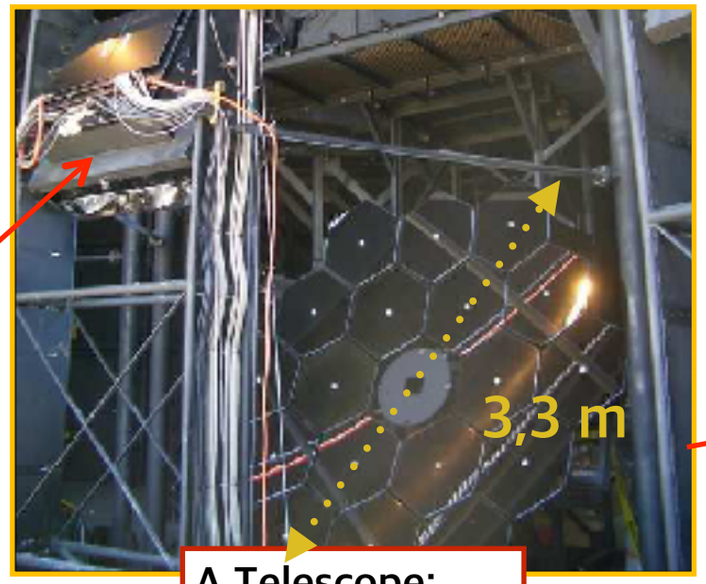


12 (BR,LR) or 14 (MD)Telescopes in a station
1 station cover 3°~33° in elev, 108° in azi

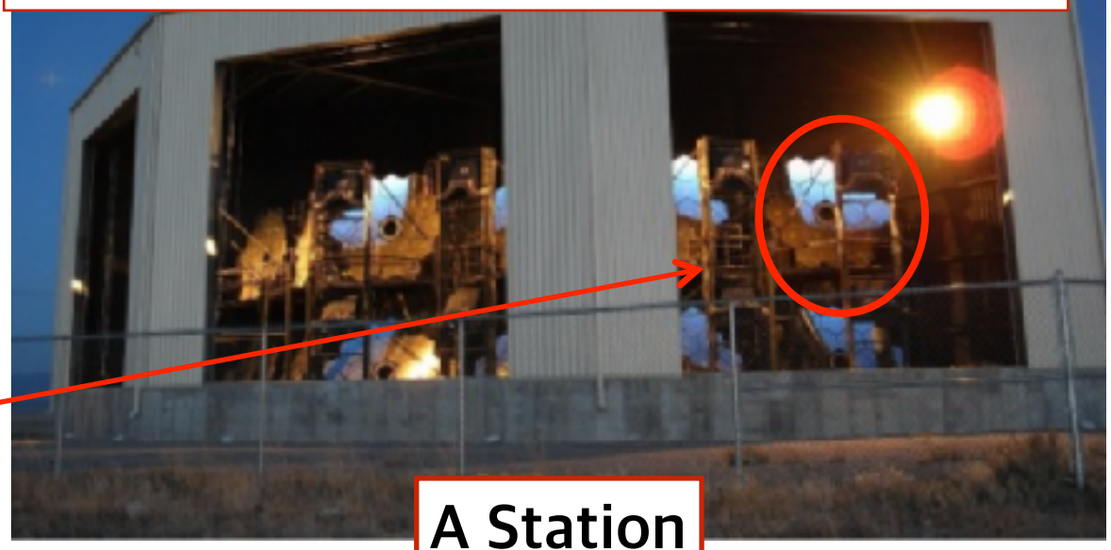

A PMT with a UV filter



A 16 × 16 PMT Camera



A Telescope: Camera & mirror

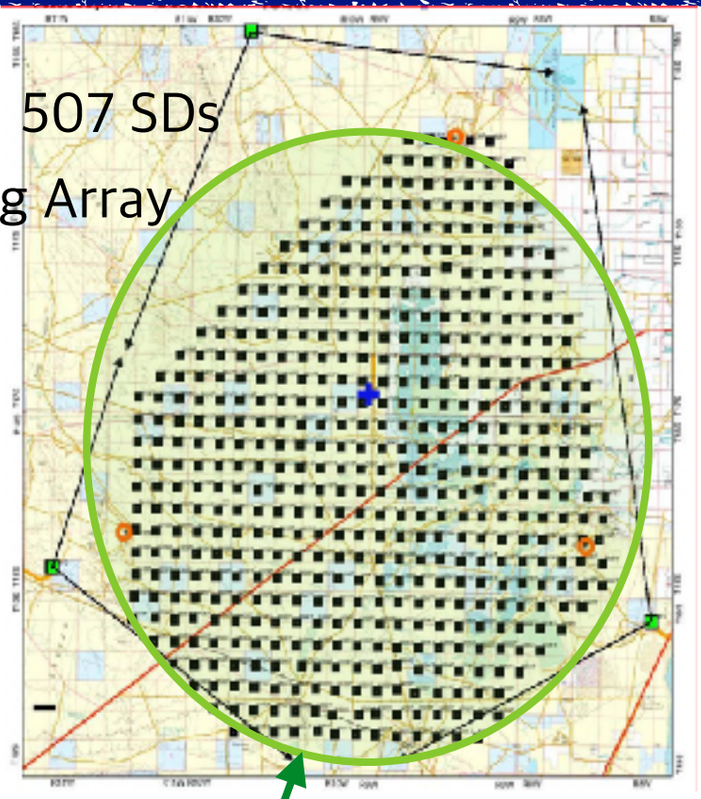

A Station

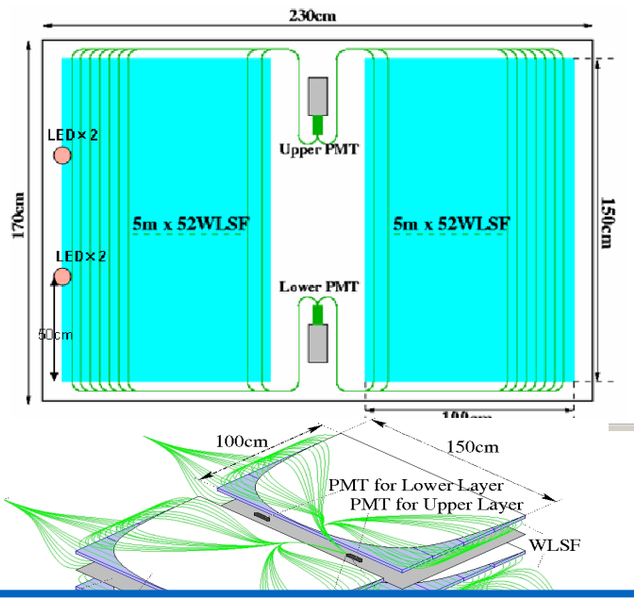
Surface Detector (SD) Array

507 of SDs with 1.2 km spacing.

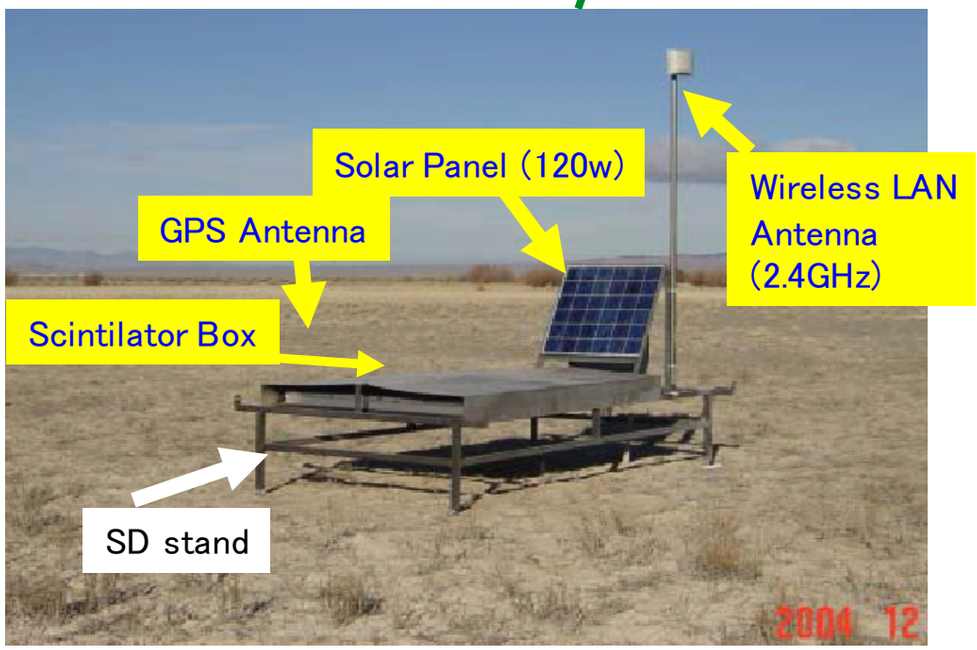
AS Lateral property on the ground.

Environment independent: Operation (Full time).



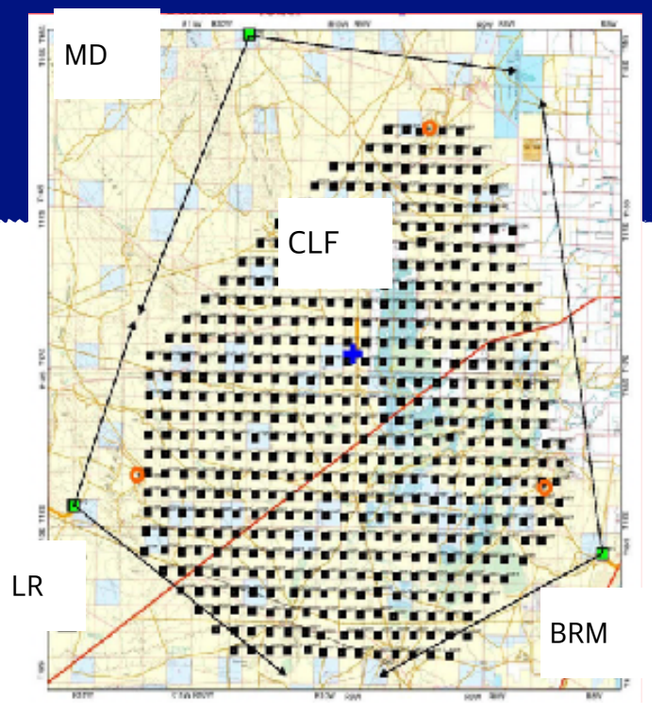


Consists PMT & Scintillation



Calibration Facilities

Calib: Laser Facilities

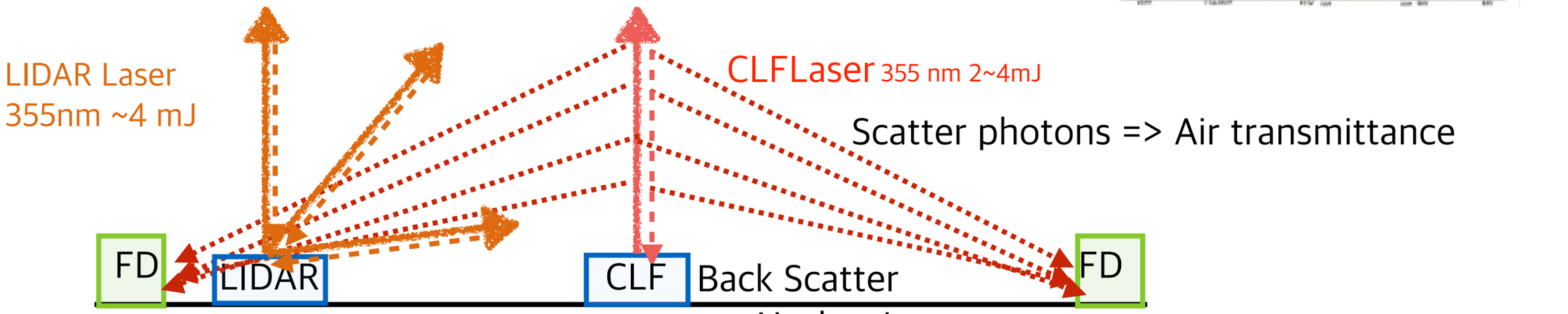


CLF: Position at centre position in TA site

Measurement of air transmittance.

Cross calibration between stations

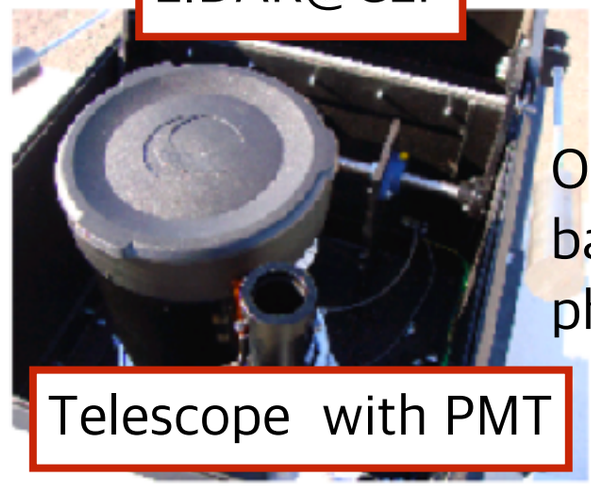
2 LIDARs: Measurement of air density



LIDAR@BRM

CLF

LIDAR@CLF



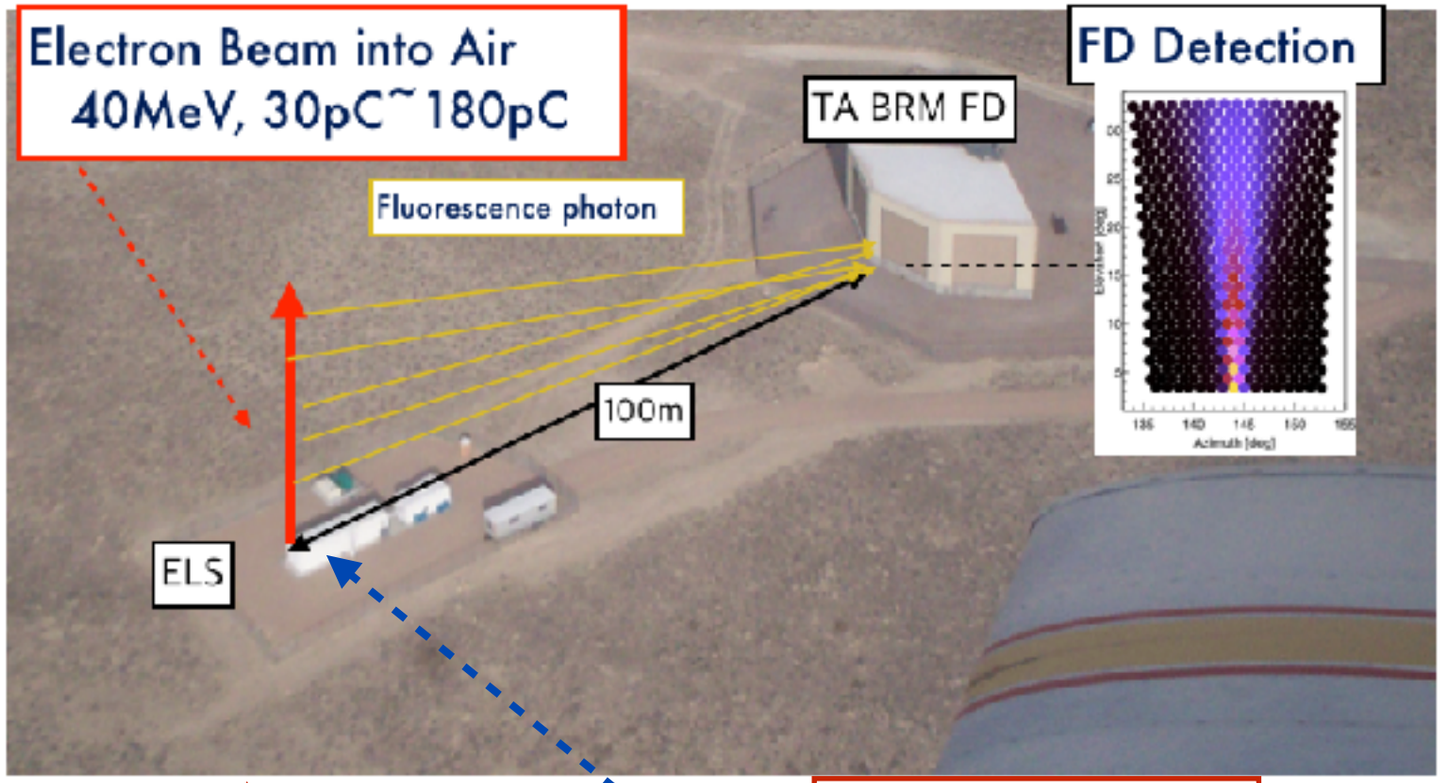
Observe backscatter photon

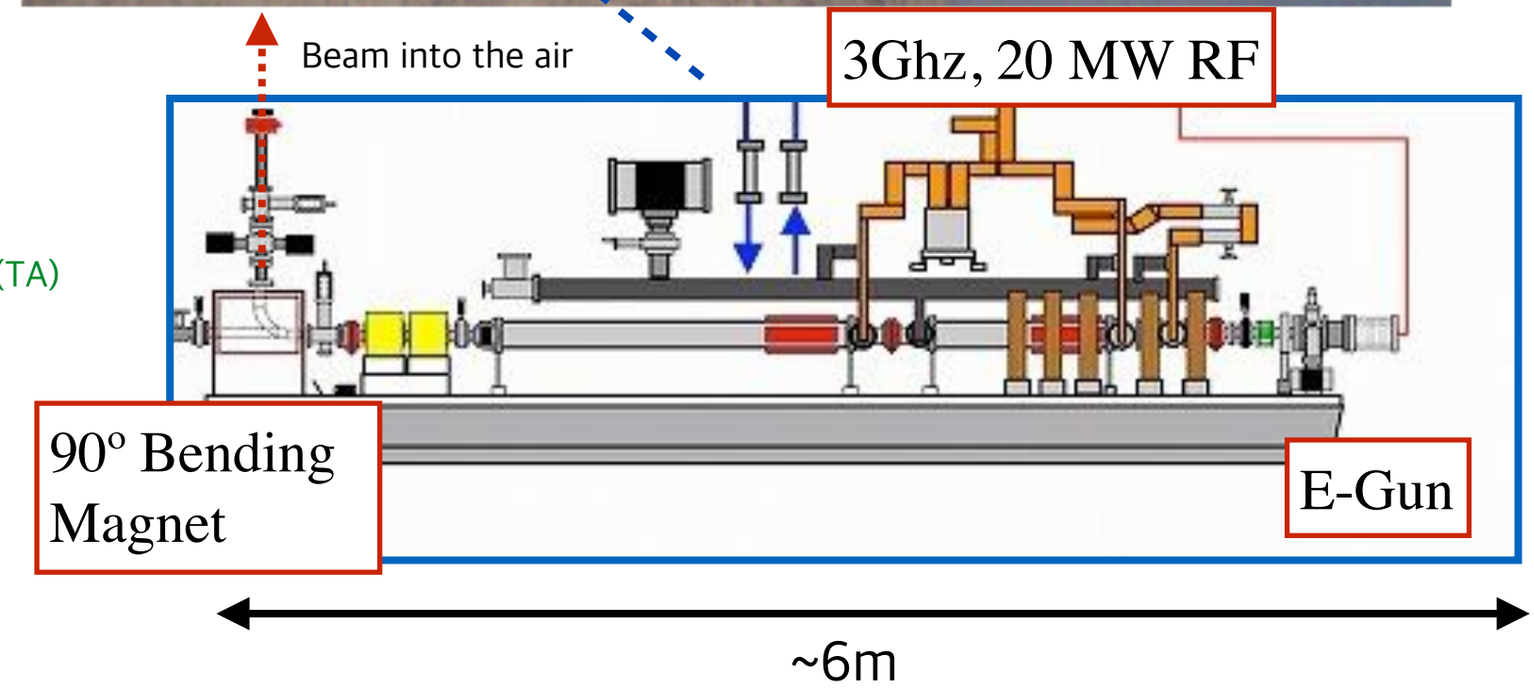
Telescope with PMT

Calib: Electron Light Source

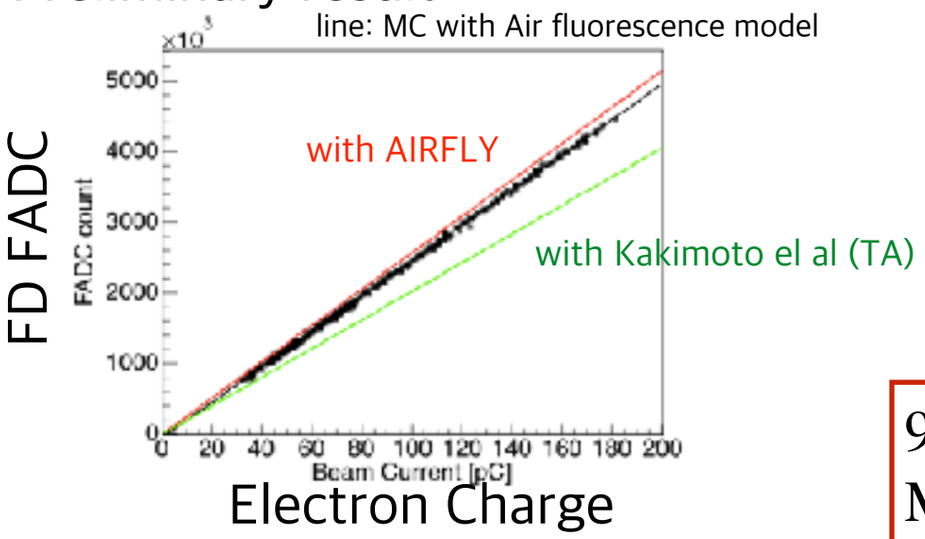
Energy calibration using electron linear accelerator Developed from KEK.

- Energy: 40 MeV/e-
- Charge: up to 180 pC
- 0.5 Hz shooting





Preliminary result



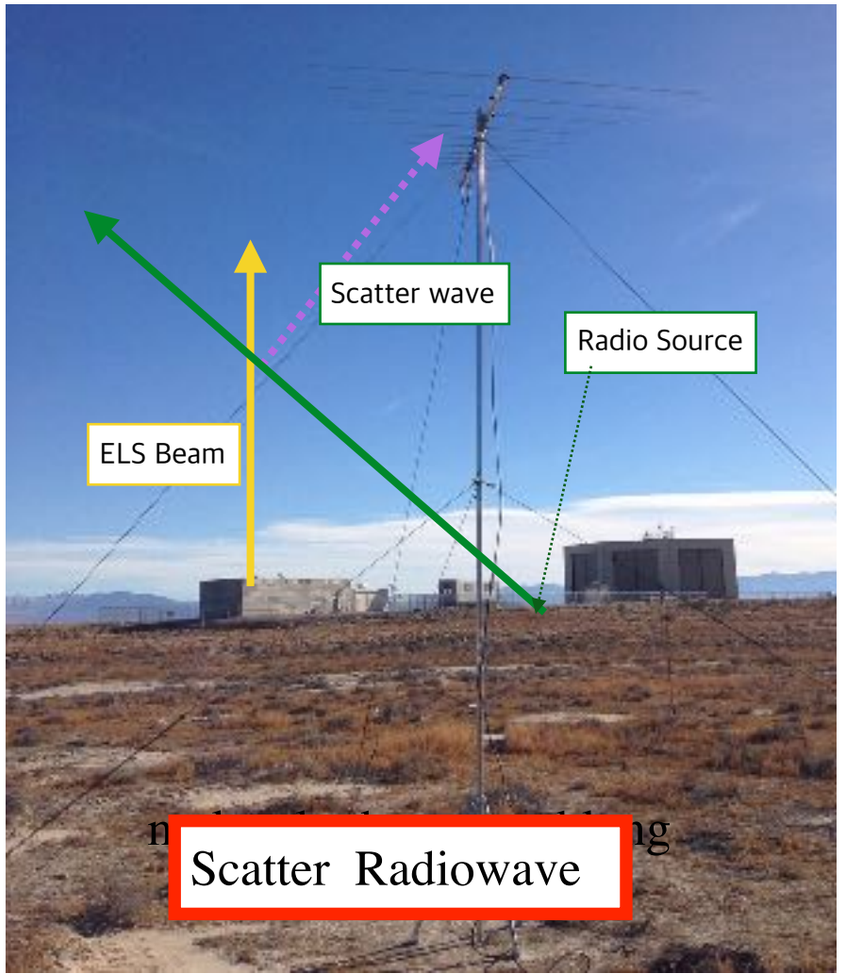
DATA/MC = ~1.2

ELS Applications

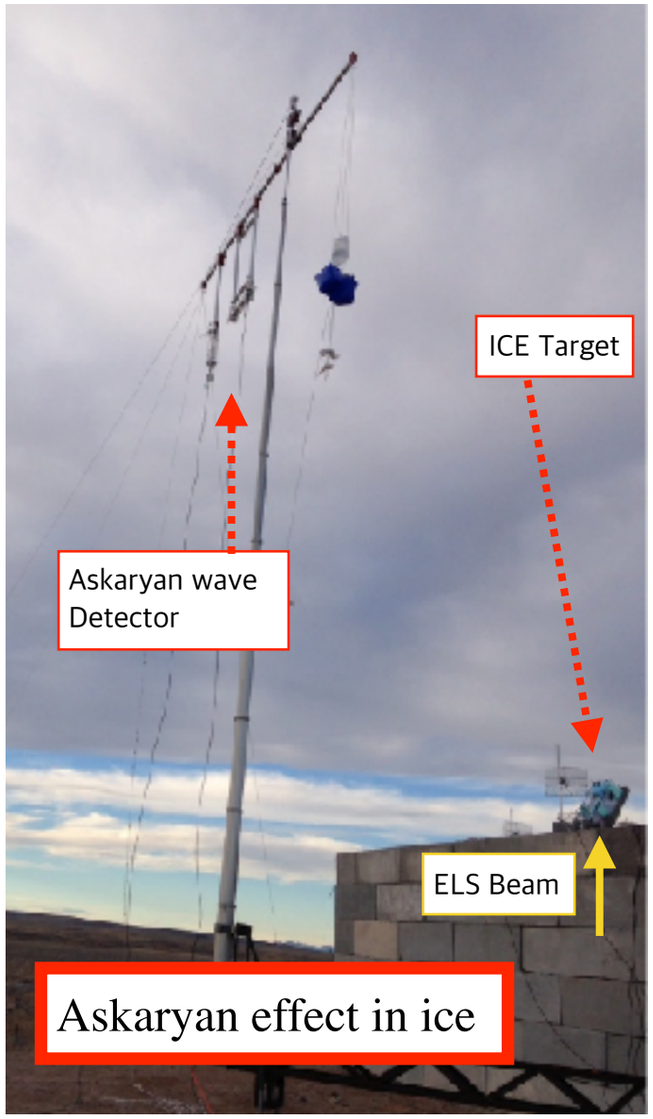
Detector R&D group test/calibrate their detector with ELS

- 4 of Radio type UHECR detector
- 2 FD type

EUSO-TA, FAST Telescope can be seen ELS beam.



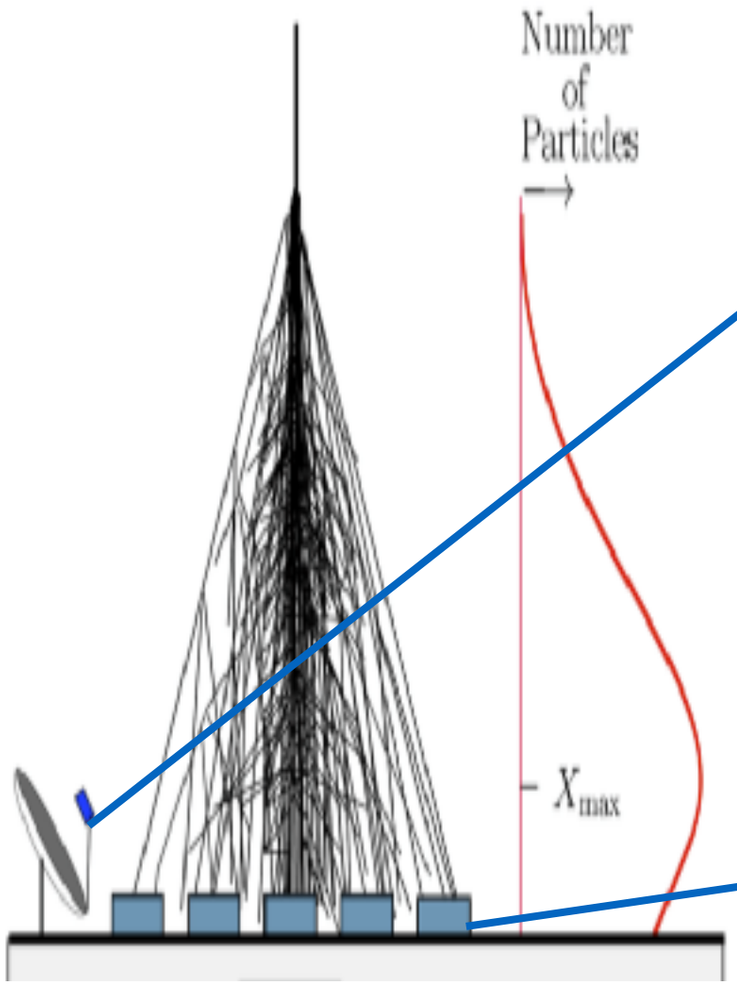
Scatter Radiowave



Askaryan effect in ice

Analysis & Result

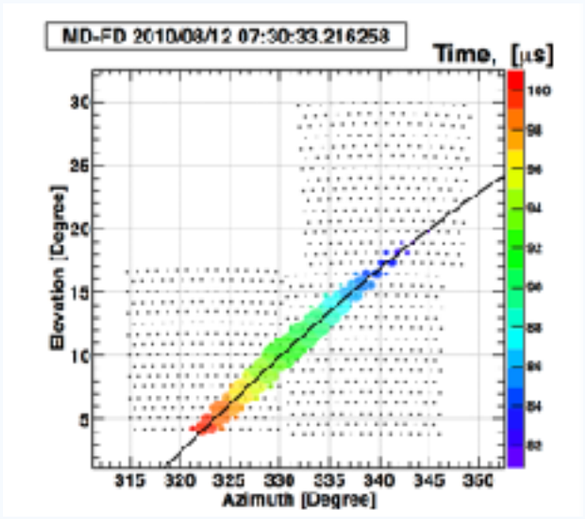
Observation Analysis

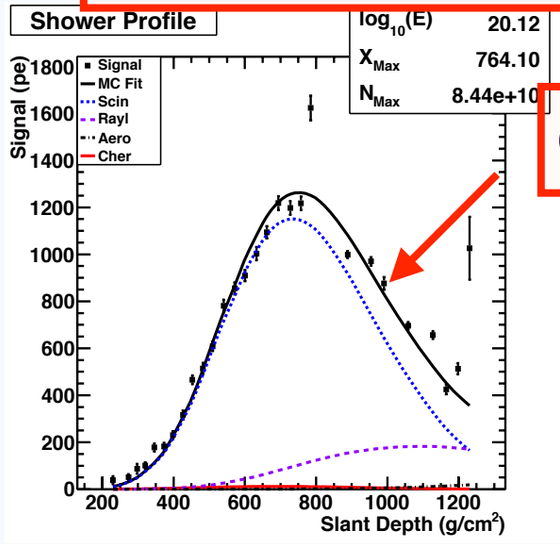


$X_{max.}$: Air Depth of maximum
N particle => Composition

Longitudinal Property (FD)

Higher accuracy Small statistics





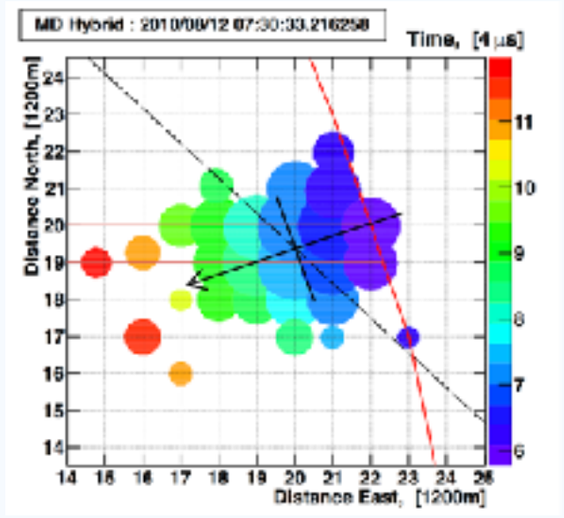
G-H Fomula

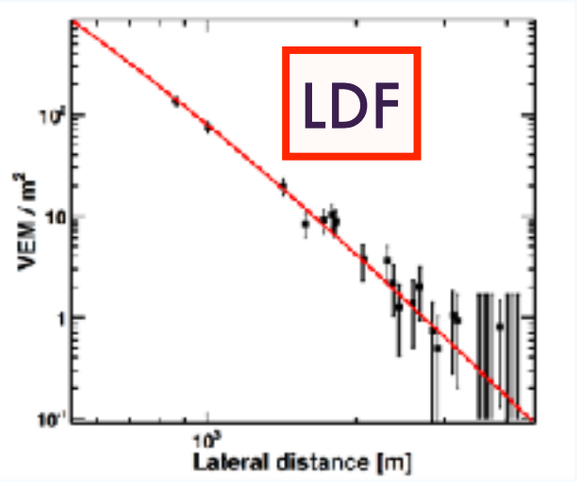
Energy
Xmax

Cross Check

Lateral Property (SD)

Less accuracy Higher statistics

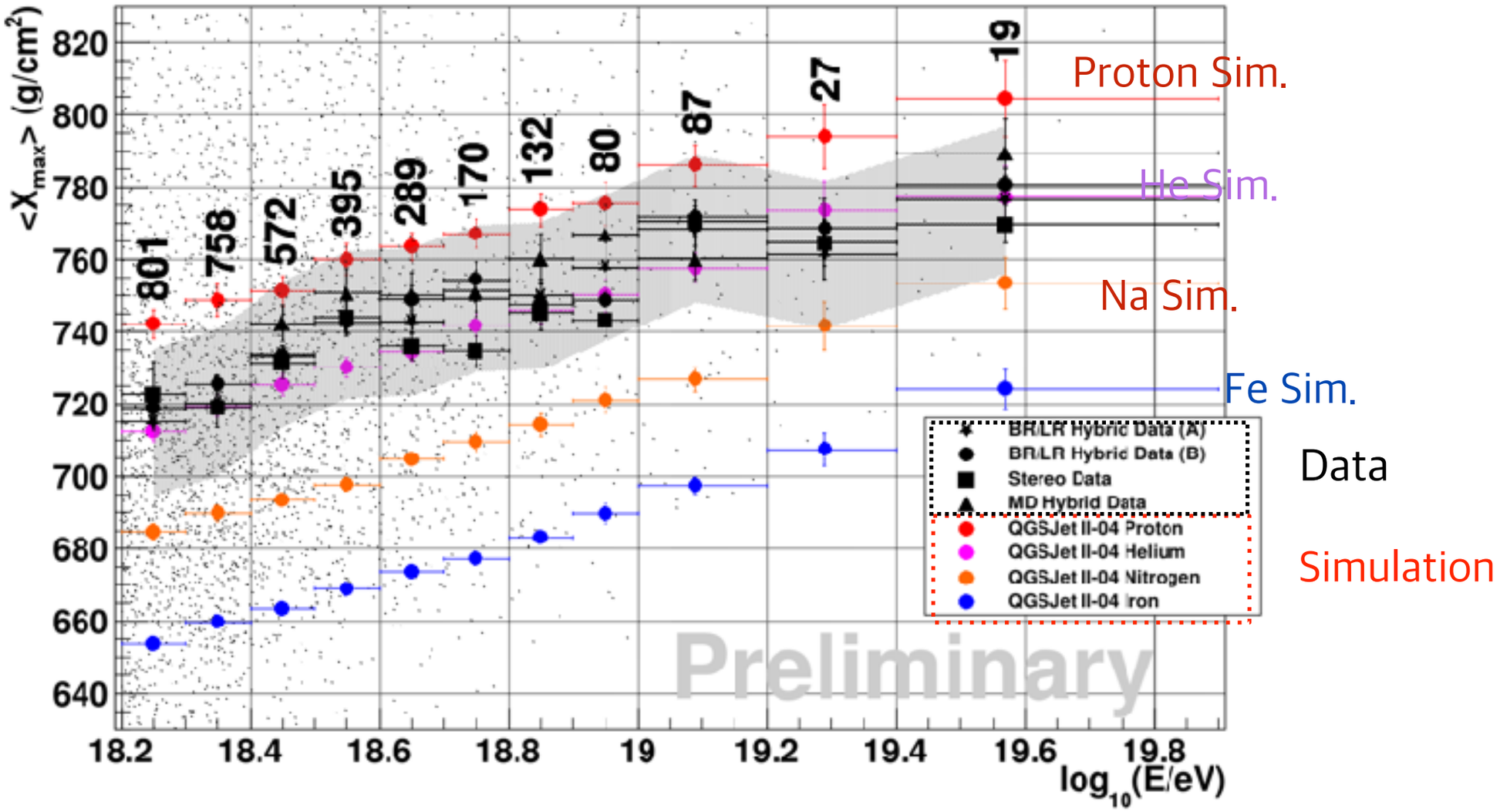




Energy

X_{max} : Composition Study

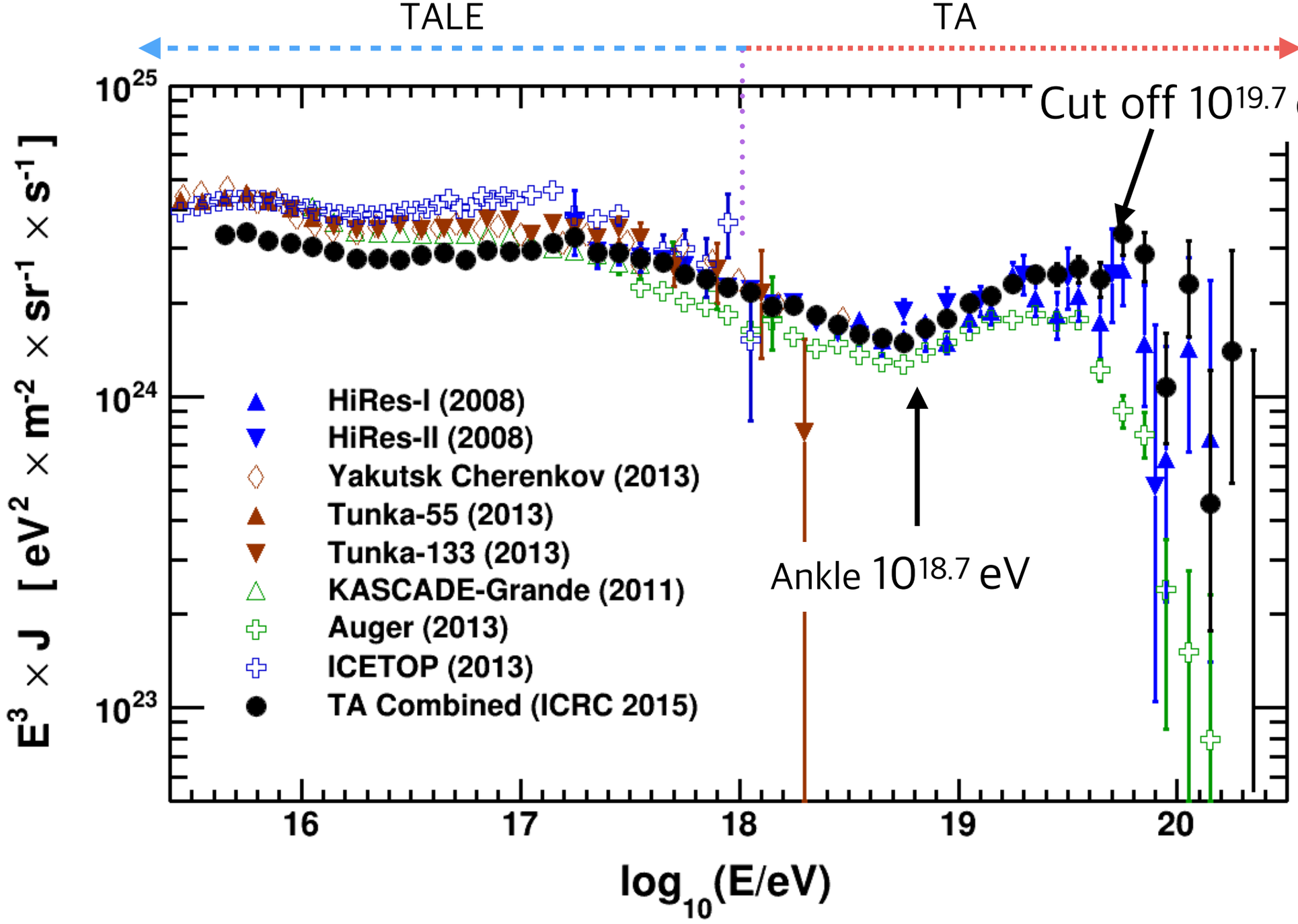
Xmax: Depend on Composition and Energy



E<$10^{19.6}$: Tendency of composition is close to proton

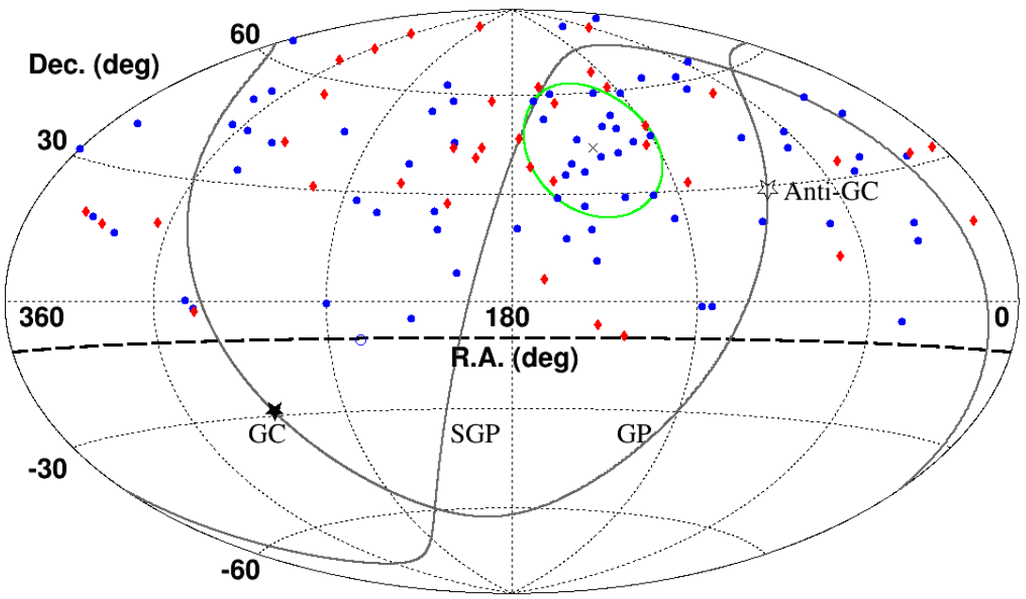
Agreement between results from data

Energy Spectrum

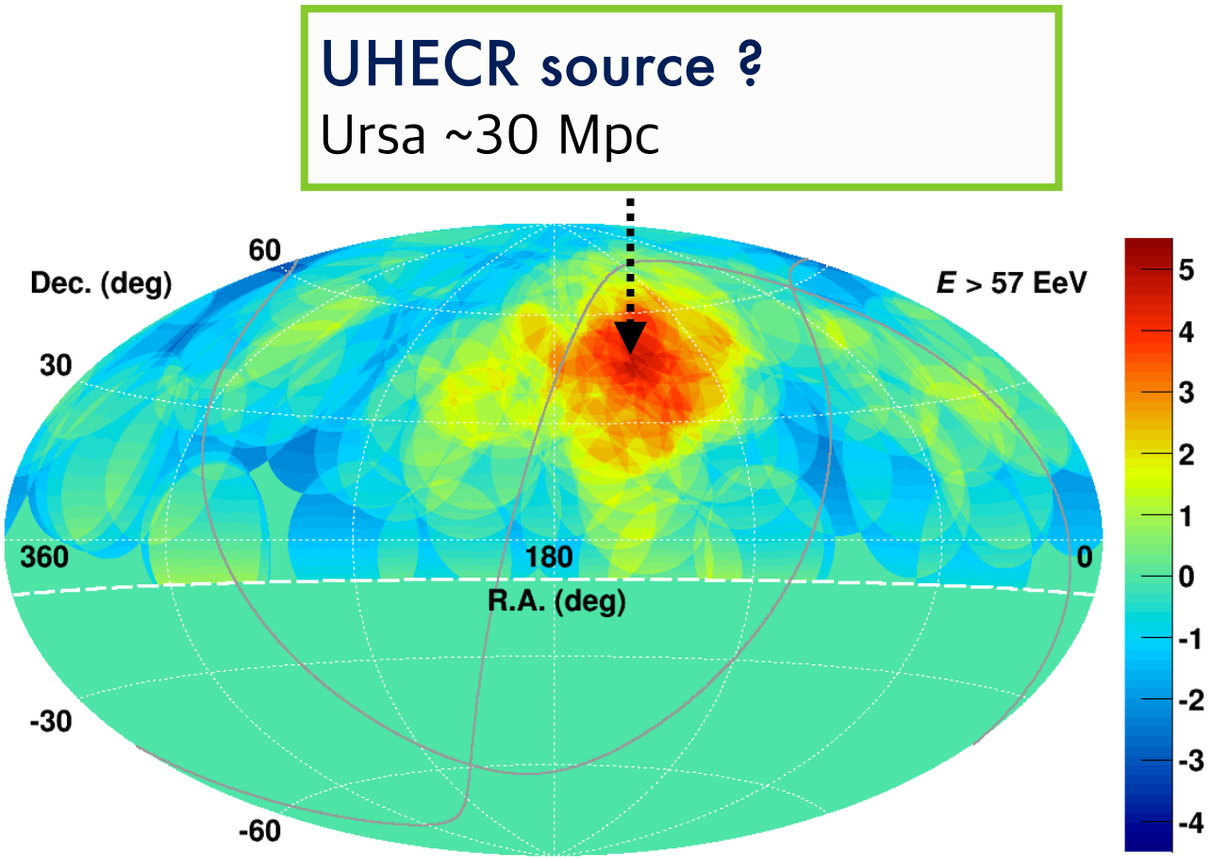


Anisotropy

Event $E>10^{19.7}$ eV



UHECR source ?
Ursa ~30 Mpc



First 5-year data (72 events) -- ApJ 790 L21 (2014)
New 2-year data (37 events) — Updated

Max significance **5.1**σ (N_{SIG} = 24, N_{BG}=6.88) for 7 years
Centered at R.A=148.4°, Dec.=44.5° (shifted from SGP by 17°)
Global Excess Chance Probability: 3.7×10^{-4} : 3.4s (~ same as first 5 years)

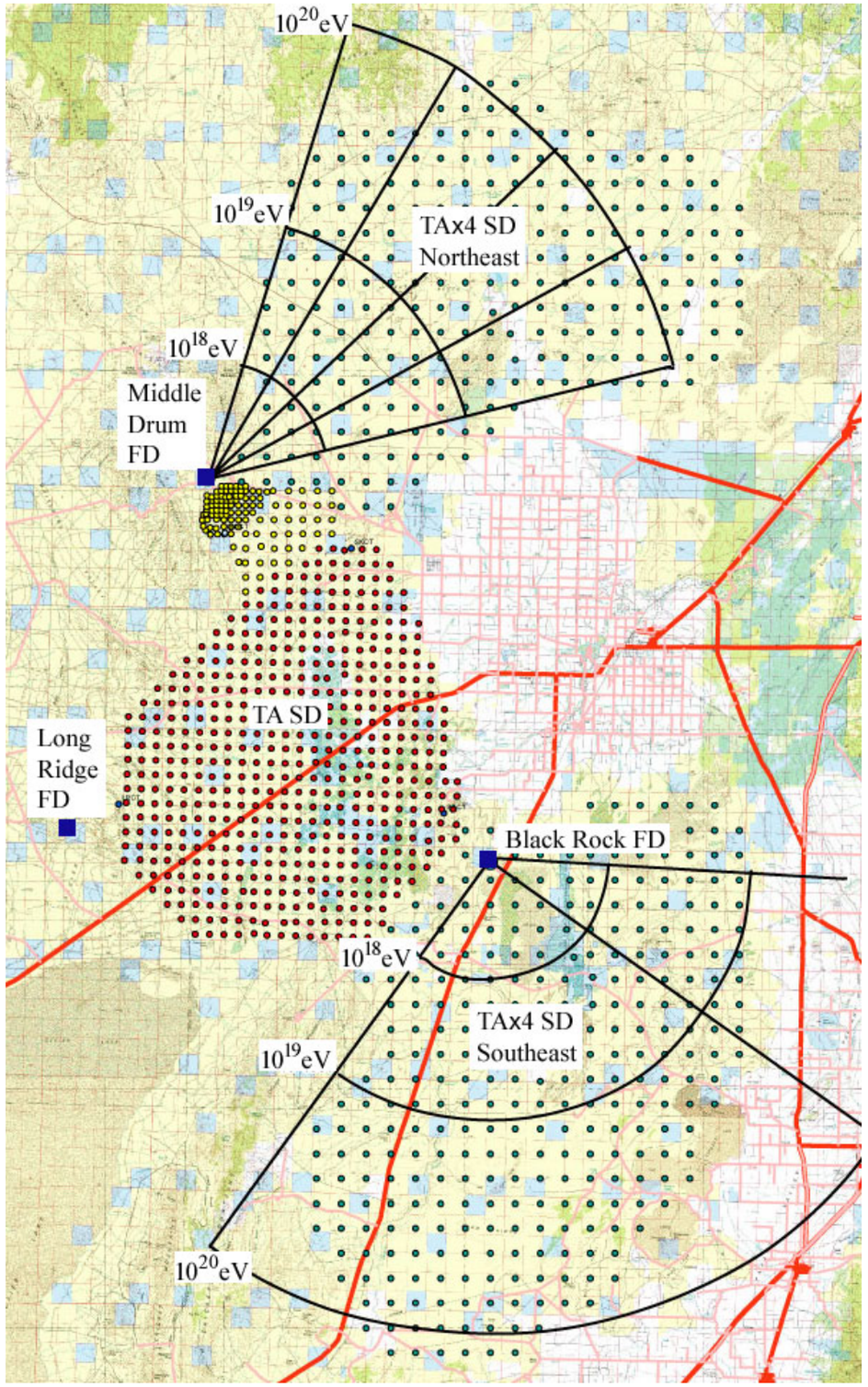
What is property energy spectrum and composition?

TA×4 Project

Target > 10^{19} eV
Aperture 700 km² → 3000 km²

500 SDs
- 2.1 km spacing
- First stage 173 SDs were prepared
  Start to deploy from next winter

2 FD stations:
- 12 telescopes
- North (MD) Station under construction.



TA Branches

- TALE: Lower Energy Extension.
  - Additional SD: 400m, 800m, 1200m spacing grid
  - A station of FD Looking 30~60°
  - E> 10^{16}eV
- TARA: Radio antenna array
  - Radio echo from UHECR
- NICHE: Cherenkov Detector Array
  - Cherenkov detector: 70m, 100m, 200m spacing grid
  - E> 10^{15} eV

Summary

- Telescope Array Experiments
  - UHECR: energy, composition ,anisotropy
  - 3 stations of FD, an Array with 507 SDs

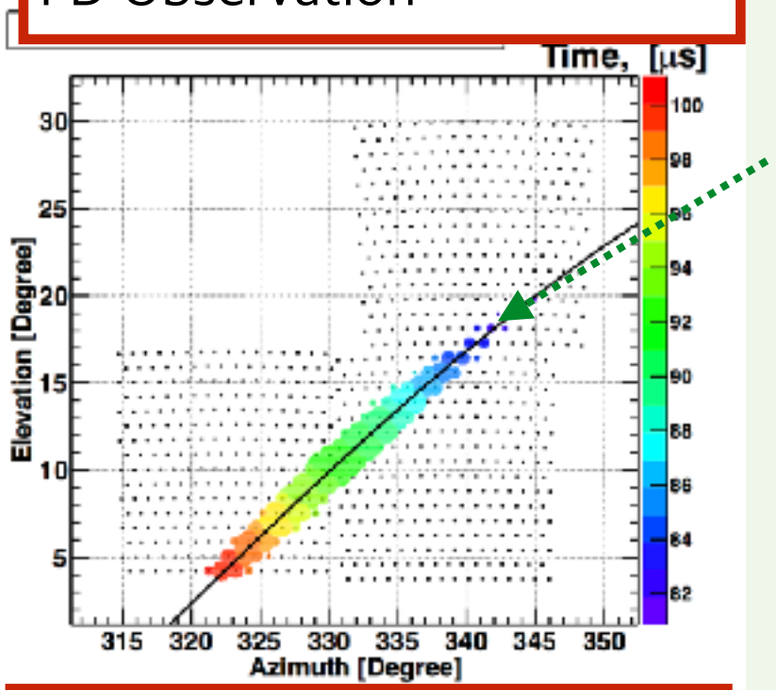
- Result:
  - Composition by Xmax: near proton ($E<10^{19.6}$ eV)
  - Spectrum: cut off $E\sim10^{19.7}$ eV
  - Anisotropy: ~5 sigma near Ursa cluster evidence of UHECR source ($E>10^{19.7}$ eV)

- TA×4 = Extension of Aperture 700 km^2 -> 3000 km^2

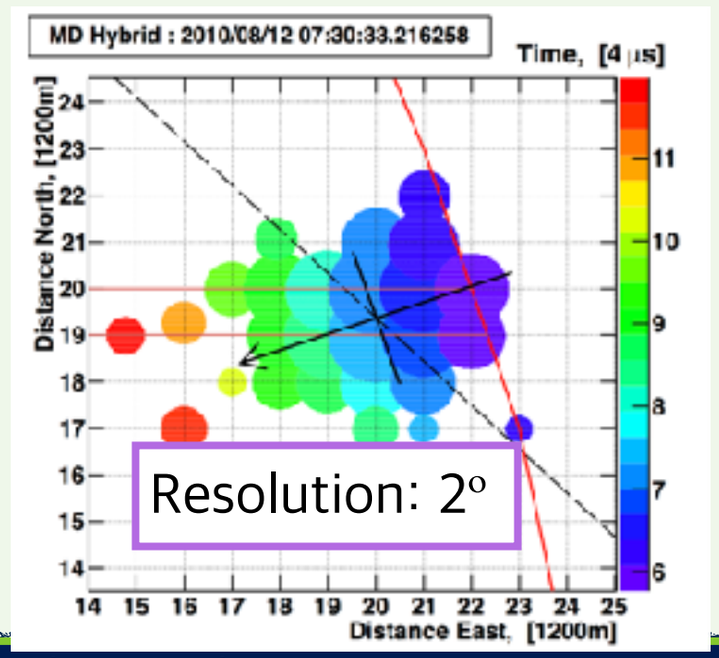
Backup

Observation & Axis Analysis

FD Observation



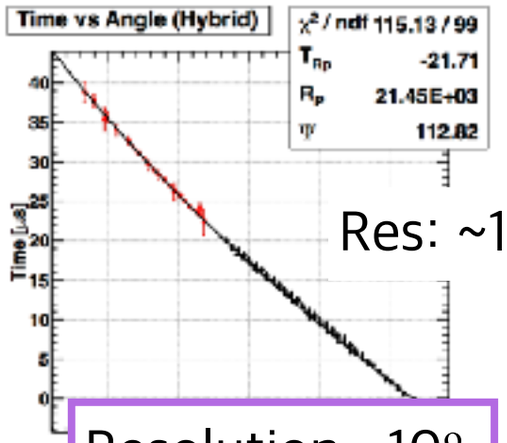
SD Observation



Resolution: 2°

FD Shower Geometry Analysis

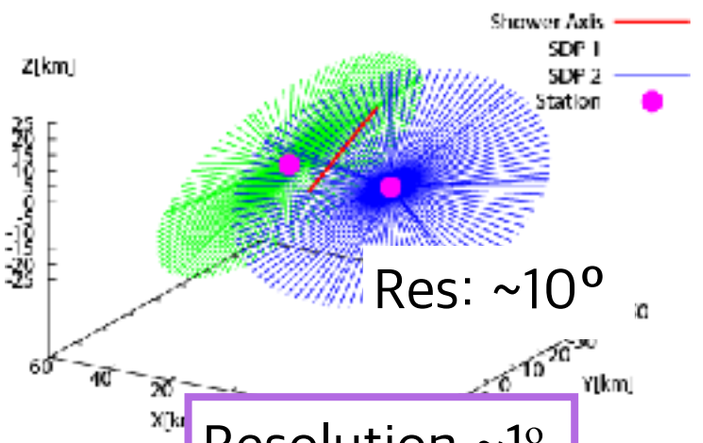
Monocular: Timing



Res: ~10°

Resolution ~10°

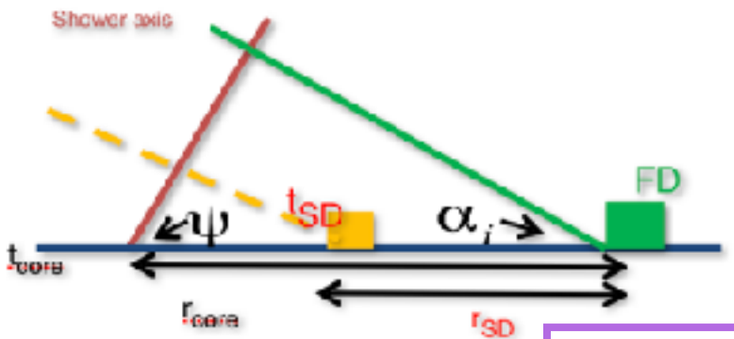
Stereo (2more FDs): intersection

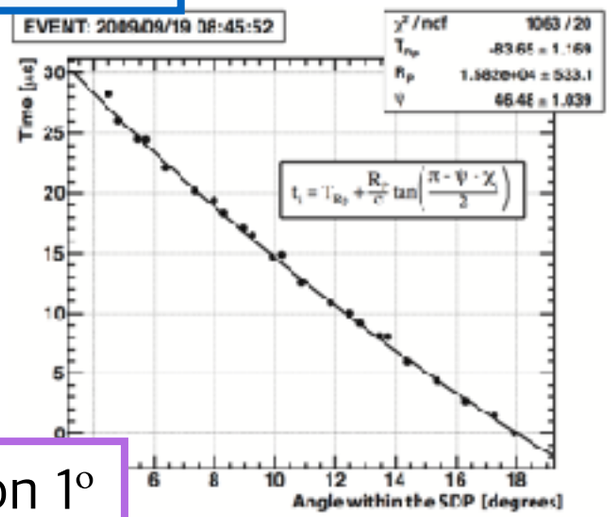


Res: ~10°

Resolution ~1°

Hybrid: Timing with SD Geometry



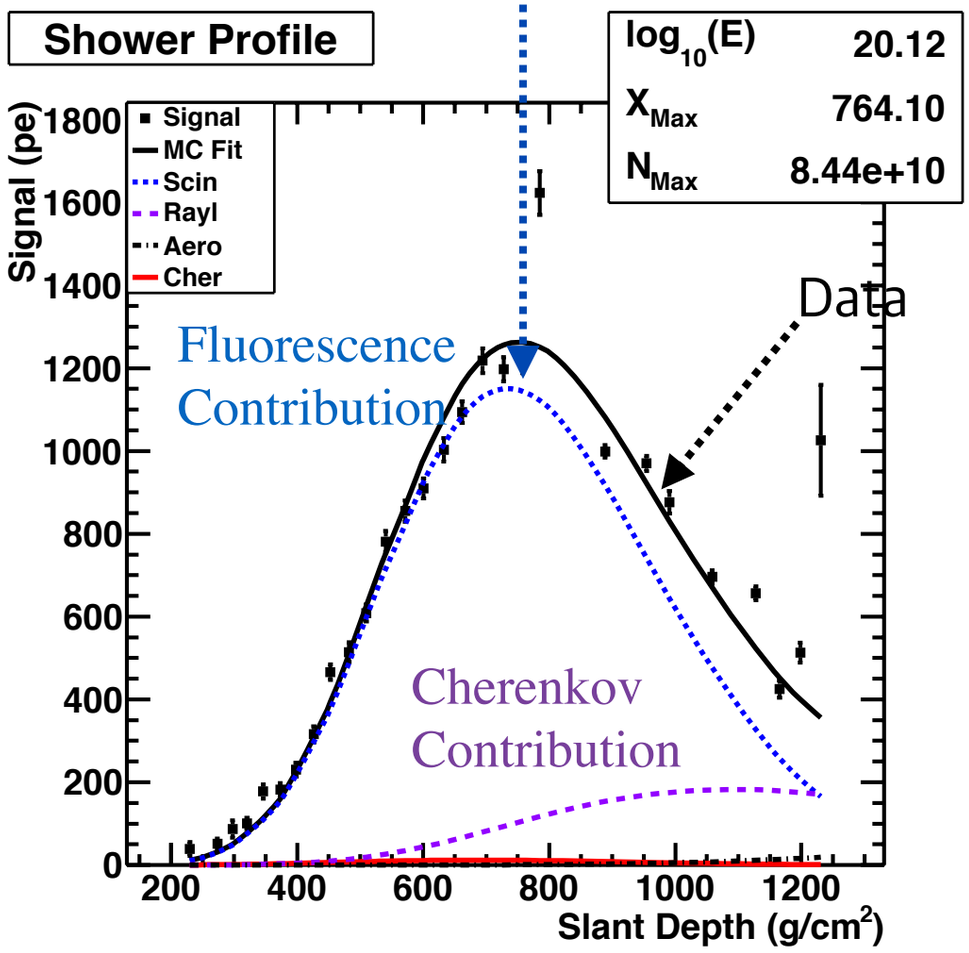


Resolution 1°

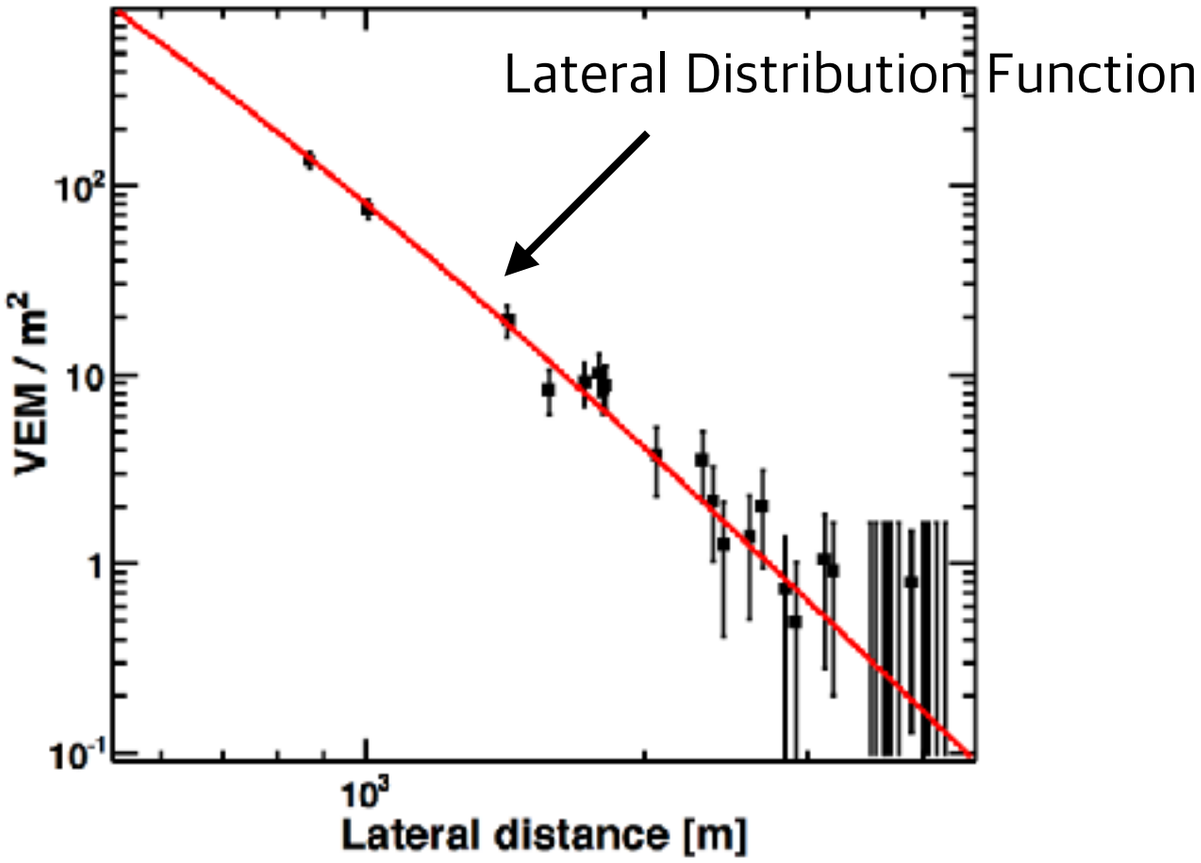
Analysis

FD/Hybrid Shower profile Recon.

G-H Formula



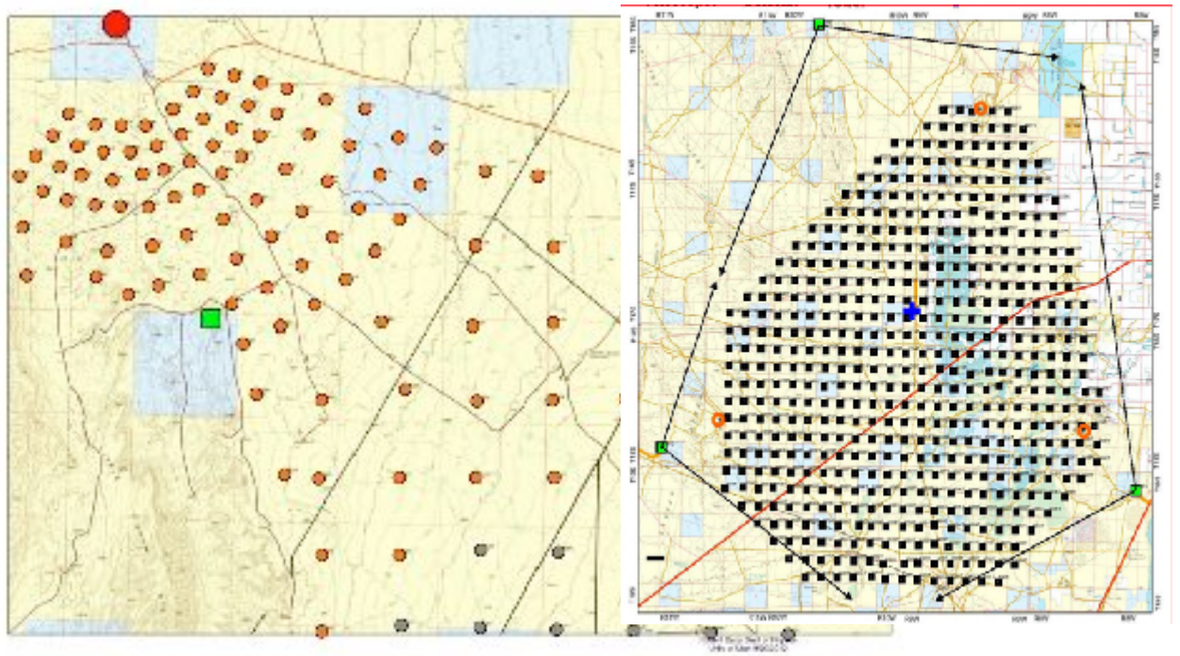
SD Energy estimation

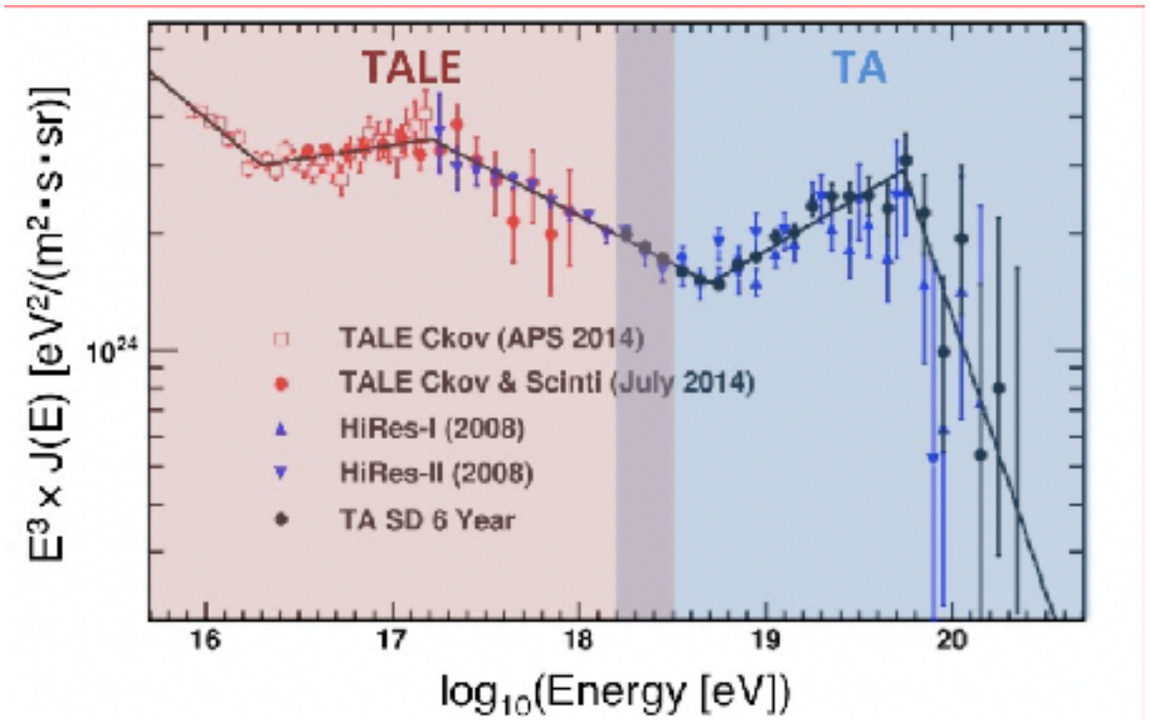


$X_{max.}$ => Composition
N_{max} => Energy
Shower axis => Arrival direction

TALE

TA Low energy Extension
- E > 10^{16}eV
- 1 station of FD : 30° ~ and 60° elev.
- 400m, 800m, 1.2 km grid array

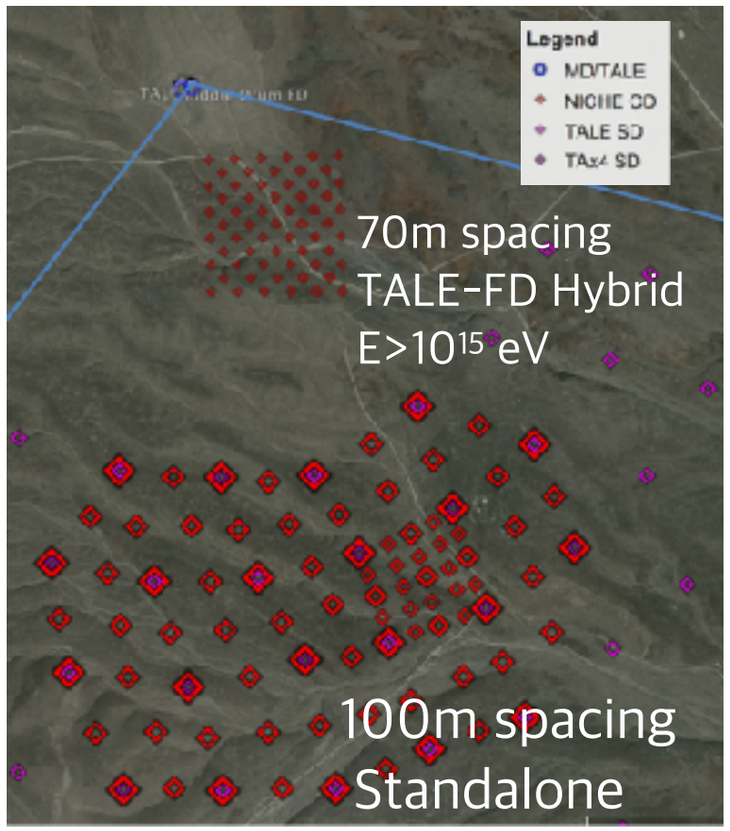


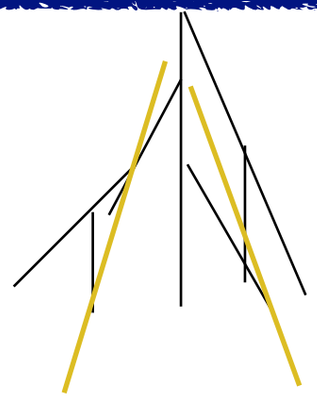


Same Type of TA SD and FD

NICHE

NICHE: Cherenkov Detection.
Energy: $>10^{15.5}$ eV
Sensitivity to composition





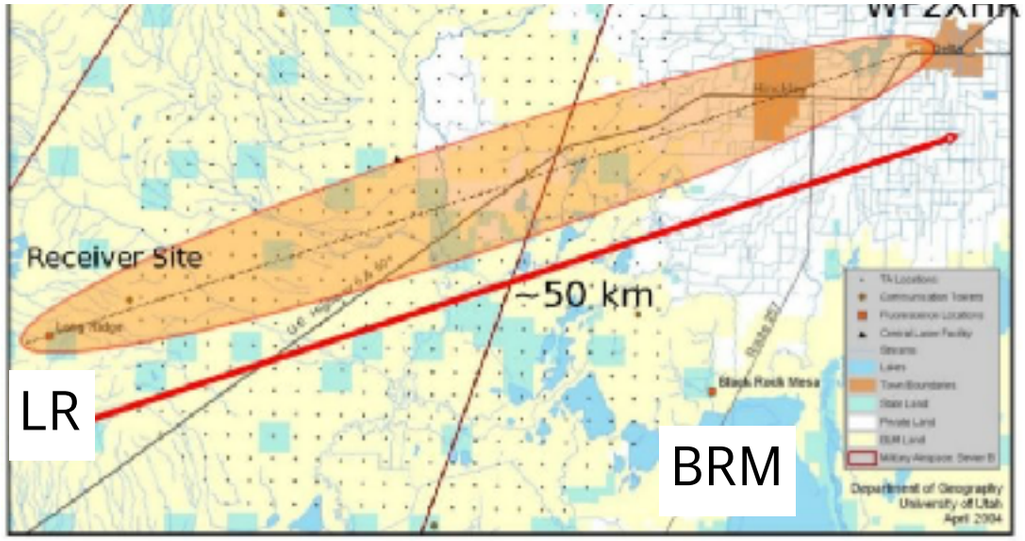
Cherenkov Detector

Now under construction.

TARA

TA Radio Array
– Radio echo from air shower
– Low cost detector Array
  Log-periodic antenna

TX RX



TX

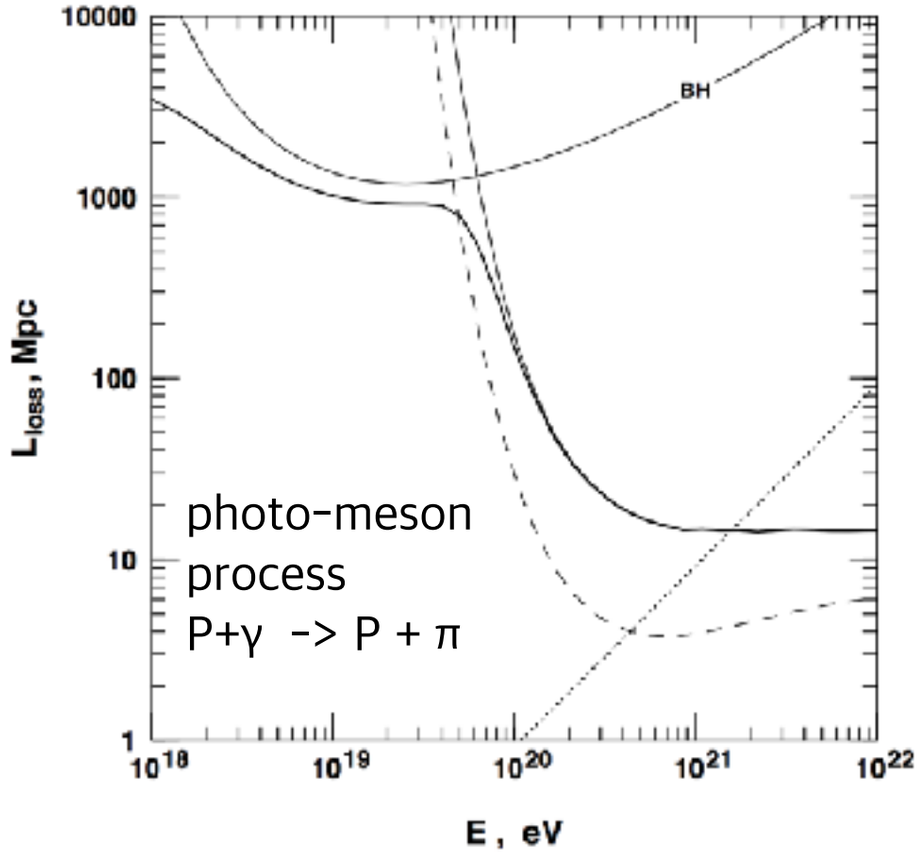
RX

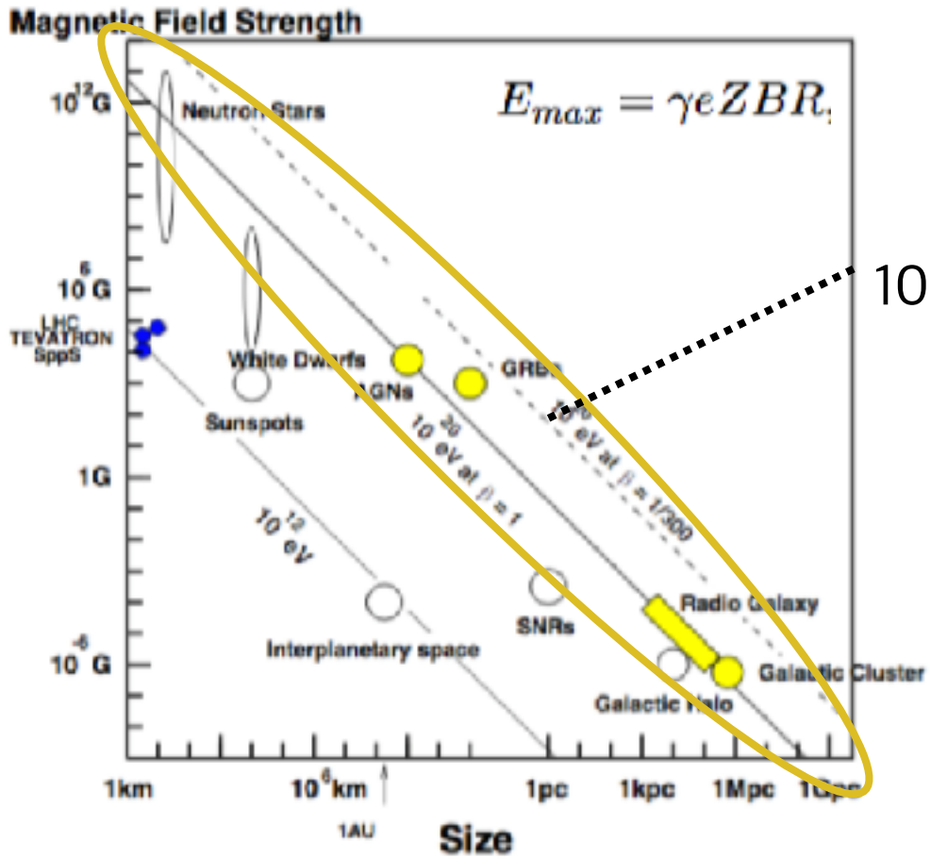
Energy Limit of UHECR

Greisen, Zatsepin and Kuzmin suggested the limit of CR energy by photo-meson process (1966)

Hillas suggested energy limit by acceleration by magnet of astronomic objects (1984)

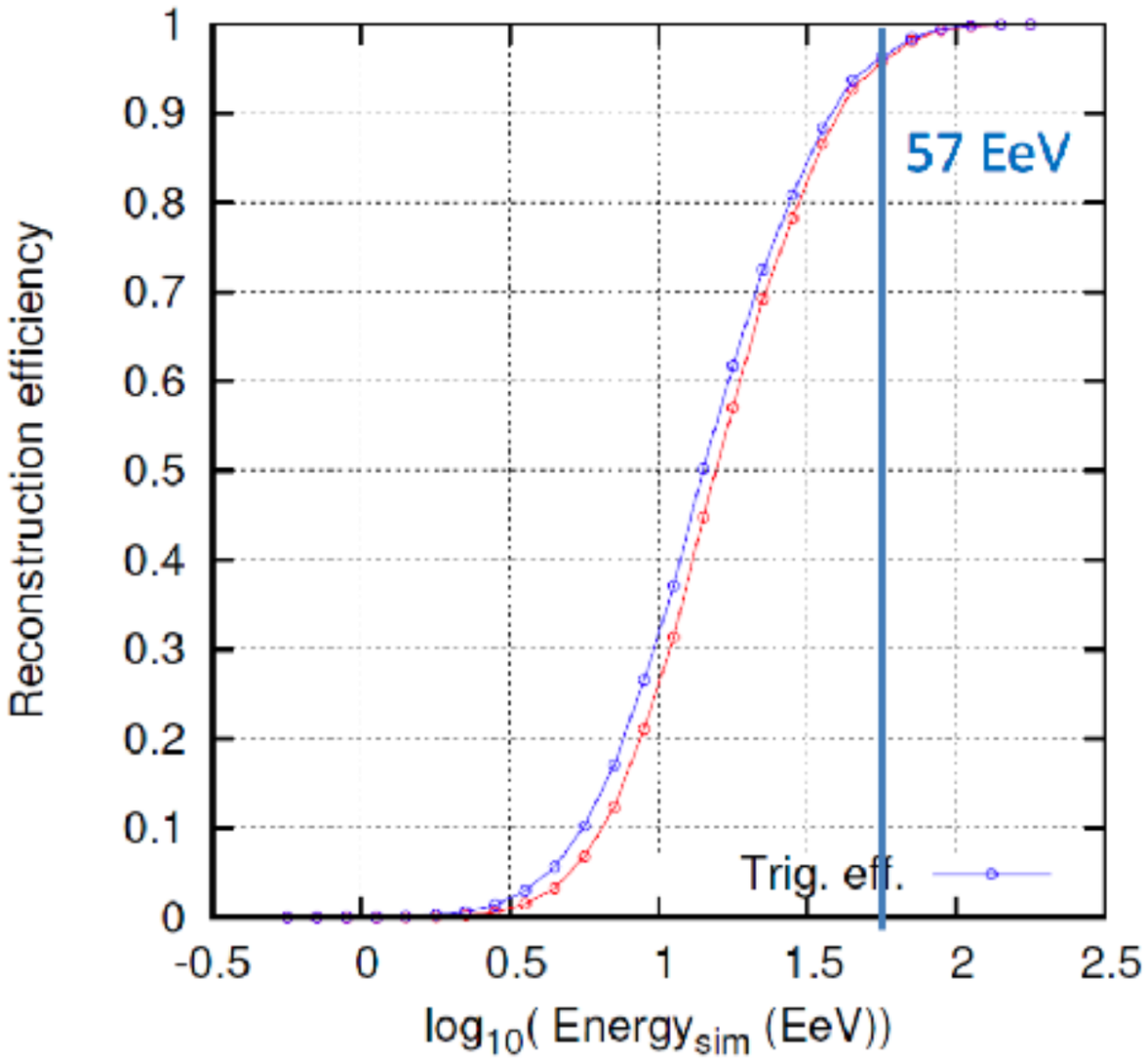
Bethe-Heitler process
P+γ -> P+2e

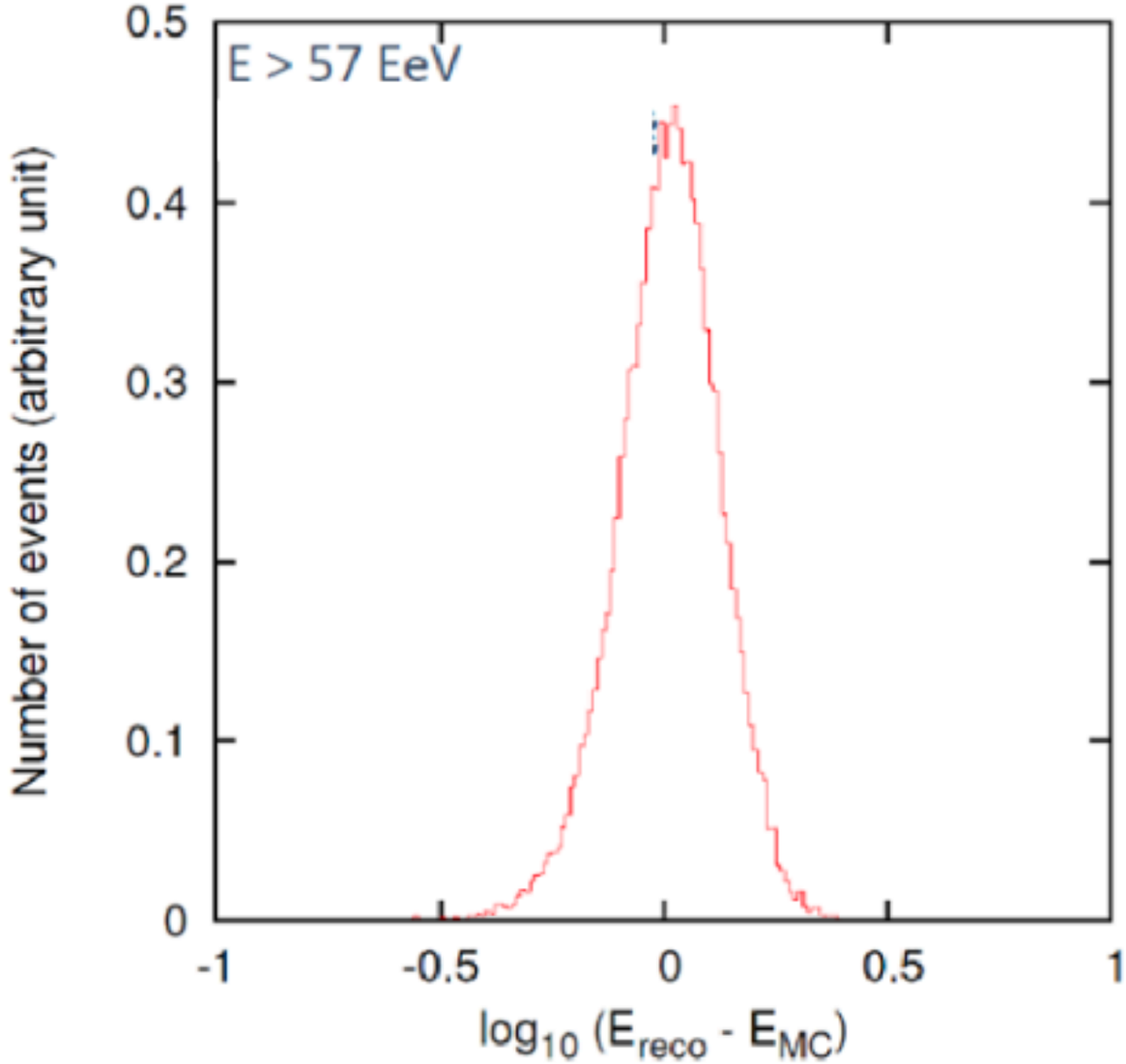




UHECR >10^{20} eV: Unknown Object and Placed in 100Mpc
Origin of Source??, Composition of UHECR??

Design of the TAx4 SD array

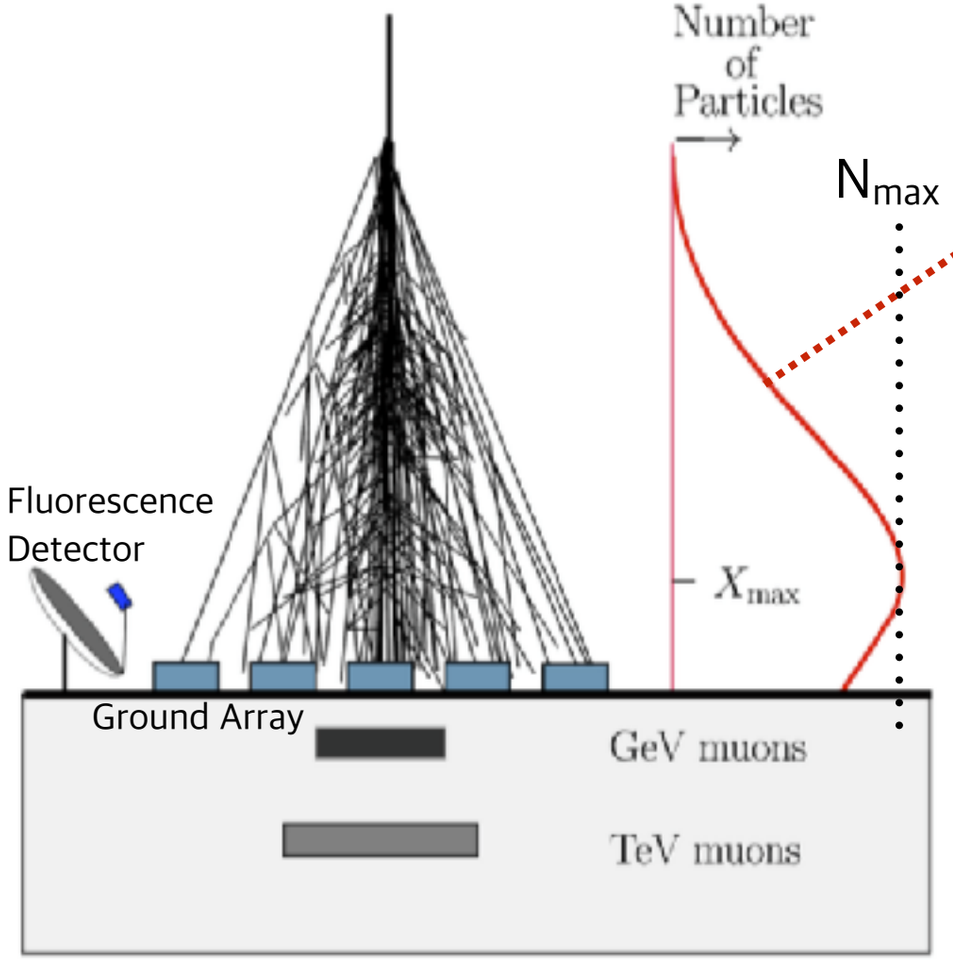




- E > 57 EeV: reconstruction efficiency > 95%
- Angular resolution: 2.2°
- Energy resolution: ~25%

Extensive Air Shower

EAS: Primary Cosmic-Rays interaction with air molecule



Gaisser-Hillas (G-H) formula

$$N(X) = N_{max}\left(\frac{X - X_0}{X_{max} - X_0}\right)^{\frac{X_{max}-X_0}{\lambda}} exp\left(\frac{X_{max} - X}{\lambda}\right)$$

N_{max} : Energy estimation

X_{max} : composition estimation

Observation methods

Ground Array: Lateral properties

Fluorescence telescope: Longitudinal properties