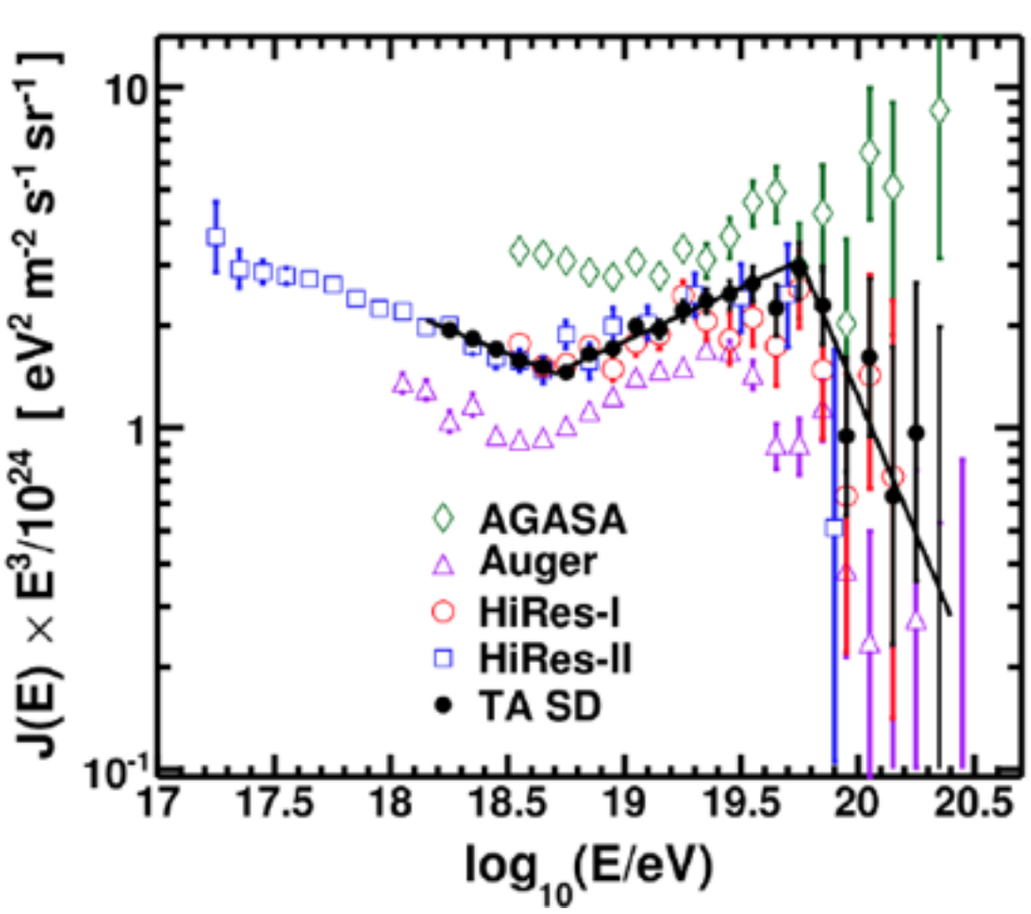
The Current Status of the Composition Measurements of UHECRs with TA

Y. Tameda

Intro.

What can **TA** contribute for the solution of UHECR's origin ?

- **TA** is confirming the shape of spectrum.
- The rest of important topics is **mass composition** and arrival direction study.



Mass composition of UHECRs

- Nucleus ? — (P, He, CNO, Fe or mixed ?)
  - Bottom up model
- Gamma ray, Neutrino ?
  - Top down model

Approaches to Mass composition of UHECRs

- Nucleus ?
  - Xmax analysis with **fluorescence detectors**.
- Gamma ray ?
  - Shower curvature analysis with **surface detectors**.
  - Xmax analysis with **FD**.
- Neutrino ?
  - Shower age analysis with **SD**.
  - Up-going shower search with **FD**.

Approaches to Mass composition of UHECRs

- Nucleus ?
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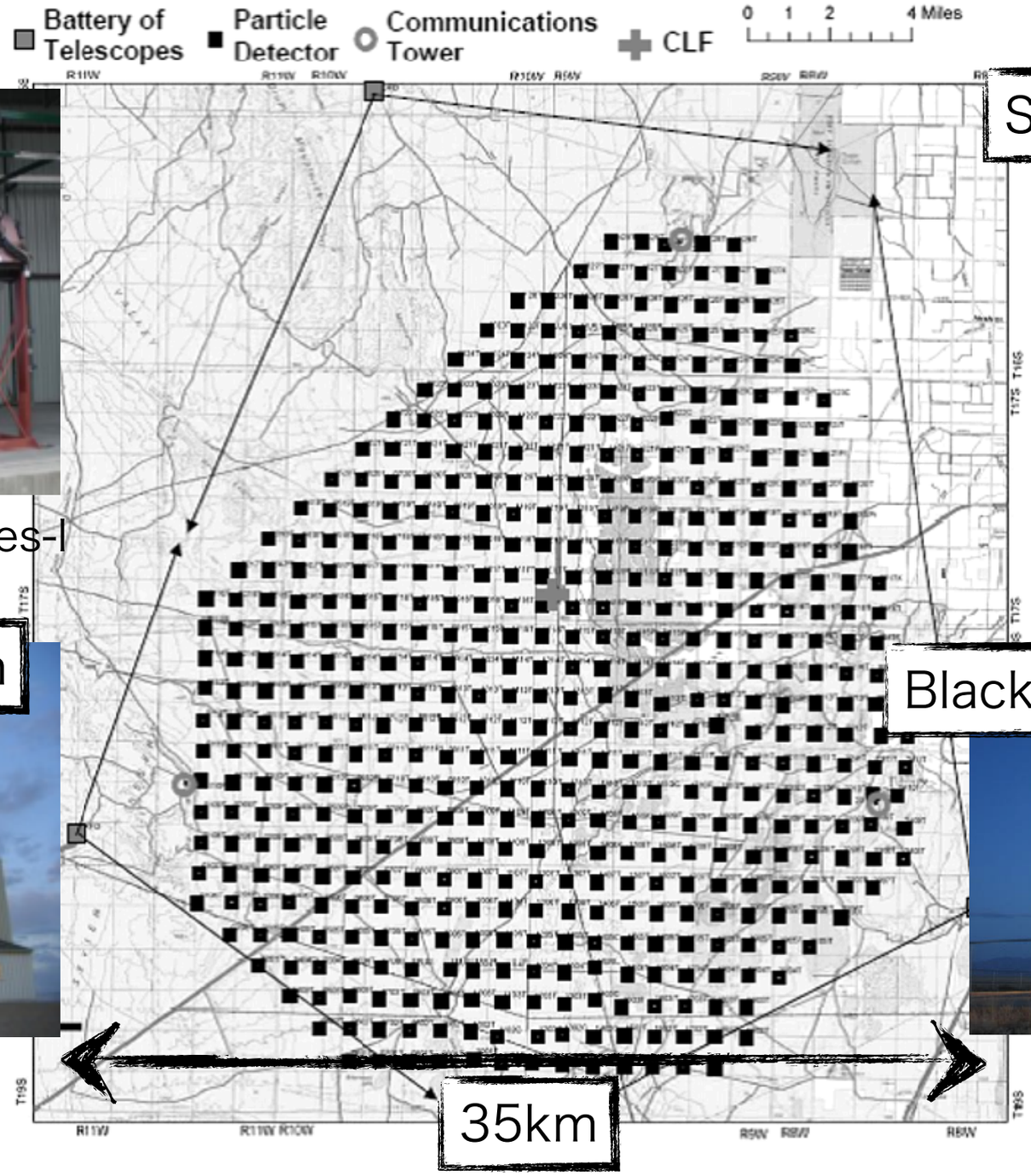
Telescope Array



FD (MD)

14 telescopes from HiRes-I

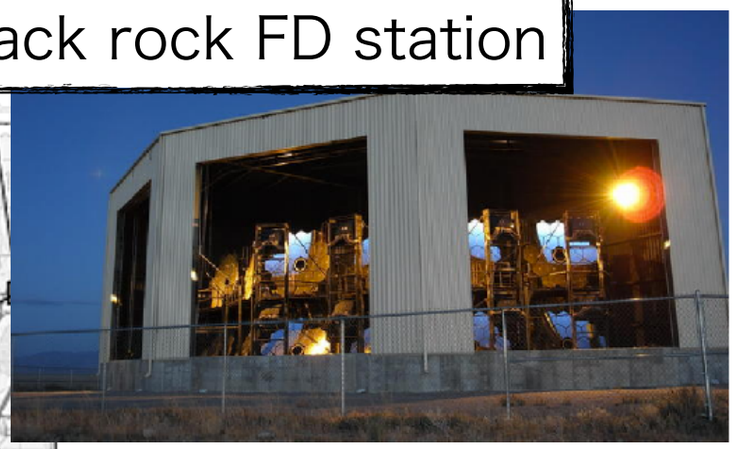
SD

507 plastic scintillation over 680 km²

Long Ridge FD station

12 telescopes

Black rock FD station

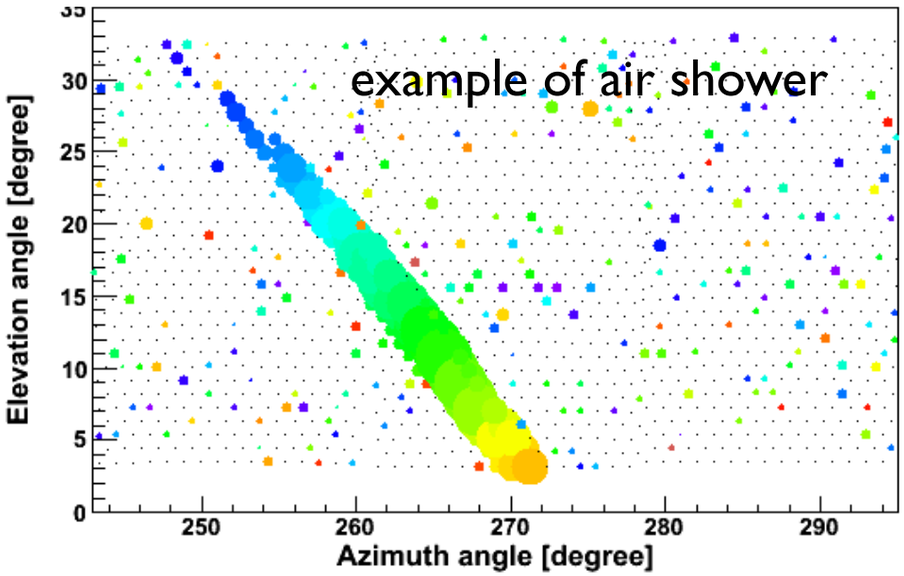


12 telescopes

Xmax analysis with

TA FD

FD Shower measurement



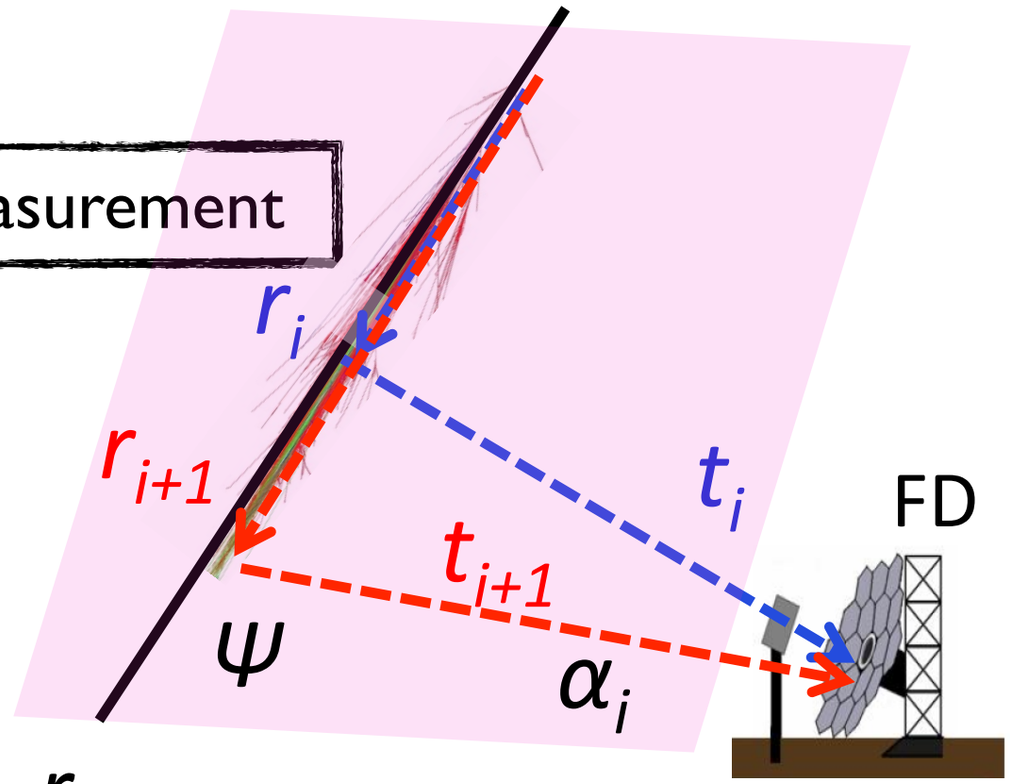
Shower Detector Plane(SDP)

$$\chi^2 = \sum_i w^i (\boldsymbol{n} \cdot \boldsymbol{k}^i)^2$$

n: vector of SDP

k^i: direction vector of ith PMT

Mono measurement



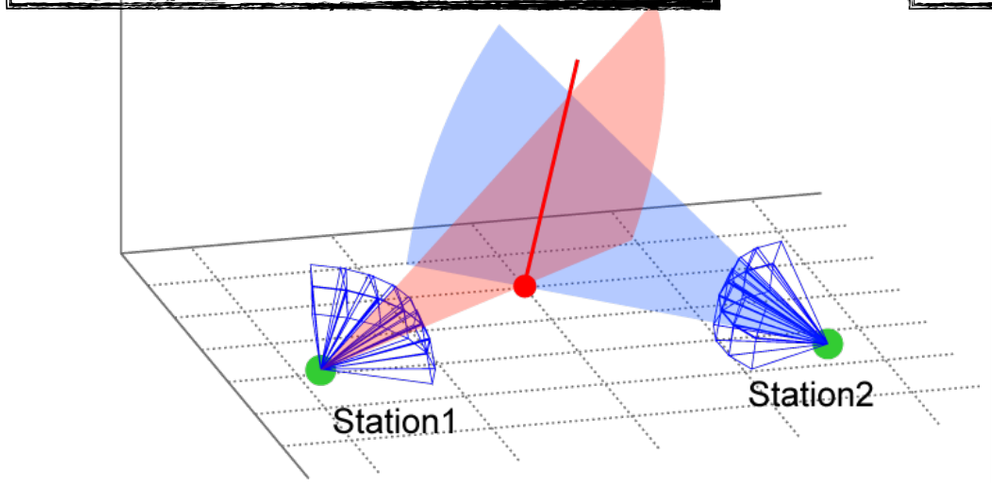
Determination of shower axis on SDP

$$t_i = t_{core} + \frac{1}{c}\frac{\sin\psi - \sin\alpha_i}{\sin(\psi + \alpha_i)} r_{core}$$

accuracy : 7.4 degree

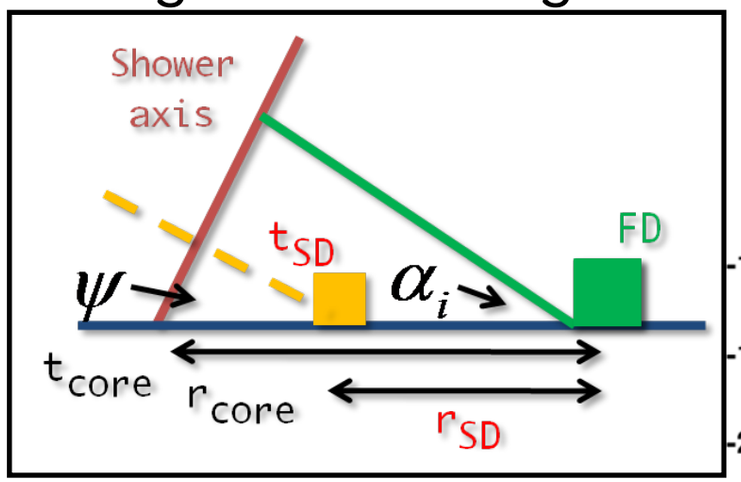
FD Shower measurement

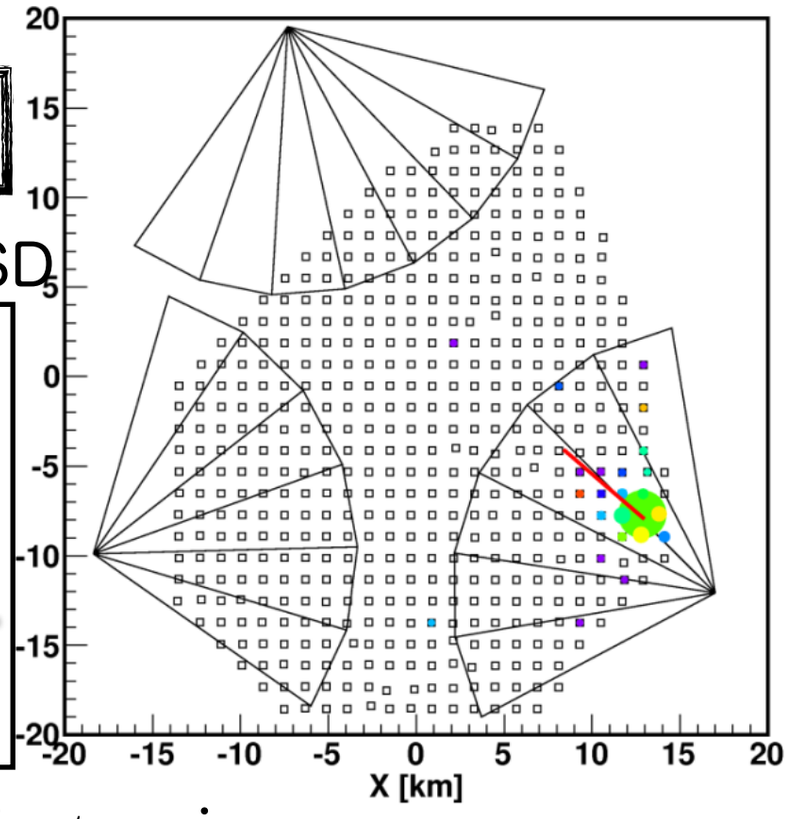
Stereo measurement



Hybrid measurement

using arrival timing on SD





Shower axis is determined as an intersection of SDPs

$$\boldsymbol{s} = \boldsymbol{n}_1 \times \boldsymbol{n}_2$$

n_i: vector of SDP

accuracy : 1.8 degree

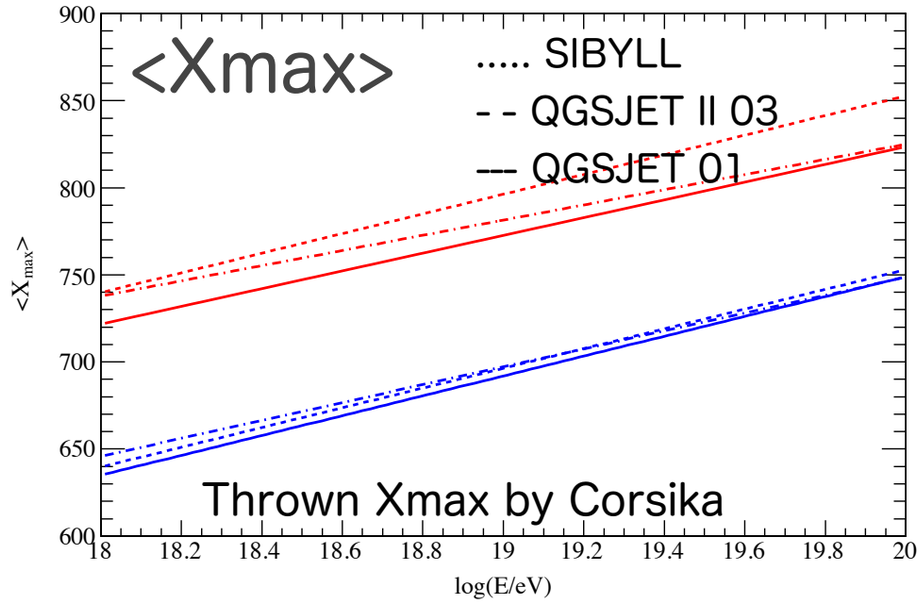
$$t_i = t_{core} + \frac{1}{c}\frac{\sin\psi - \sin\alpha_i}{\sin(\psi + \alpha_i)} r_{core}$$

$$t_{core} = t_{SD} + \frac{1}{c}(r_{core} - r_{SD})\cos\psi$$

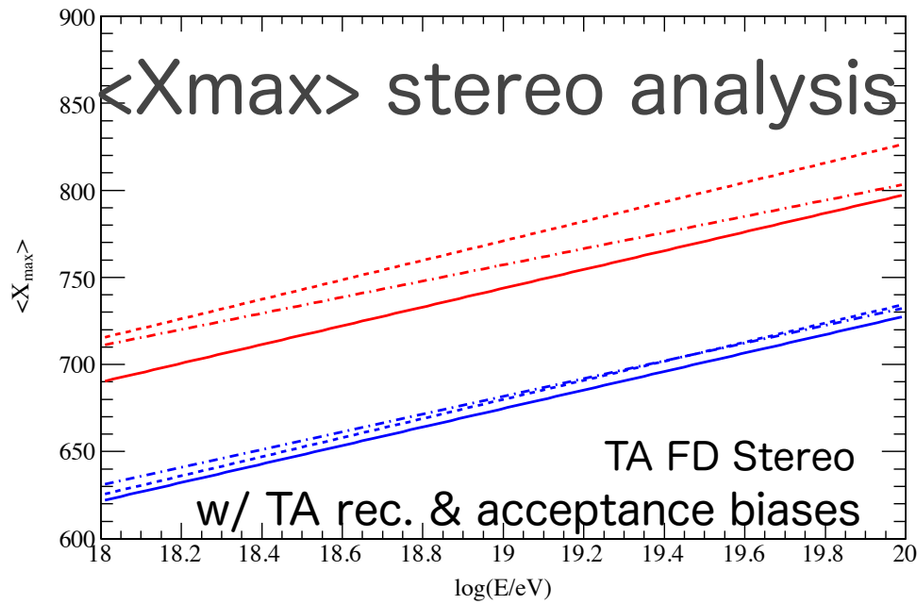
accuracy : 0.9 degree

Xmax analysis

- Xmax is still one of the best parameter to determine the mass composition.
- Comparison b/w Data and MC.
  - FD measurement is suffered from acceptance bias which should be taken into account.
- Shower simulation by CORSIKA
- Detector simulation
  - Check how does our detector simulation reproduce data well.
  - Bias estimation (Acceptance, Reconstruction)
- This analysis is based on the hadronic interaction model which is extrapolated from lower energy.

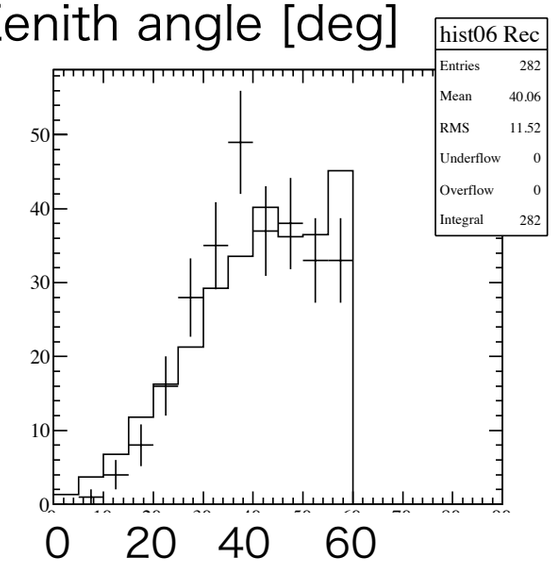


- Proton
- Fe

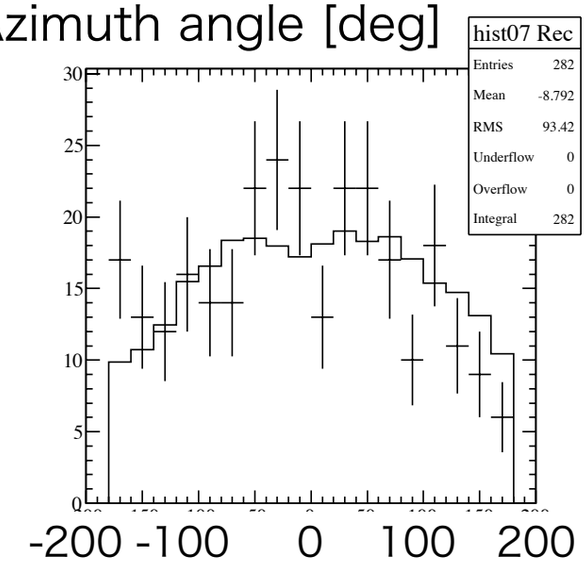


Various parameters Comparison b/w data and MC (TA FD stereo analysis)

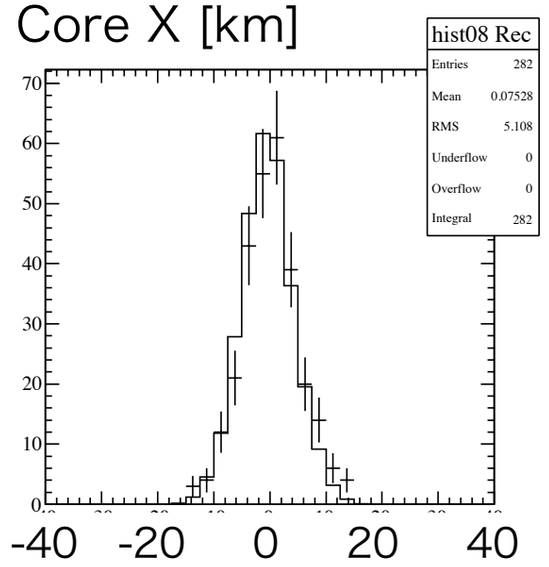
Zenith angle [deg]



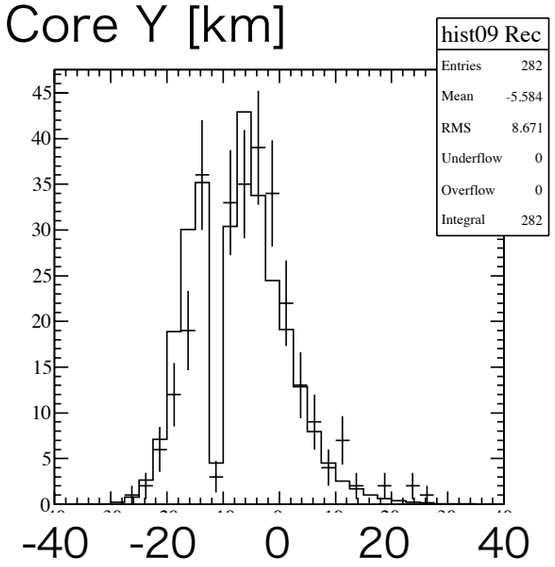
Azimuth angle [deg]



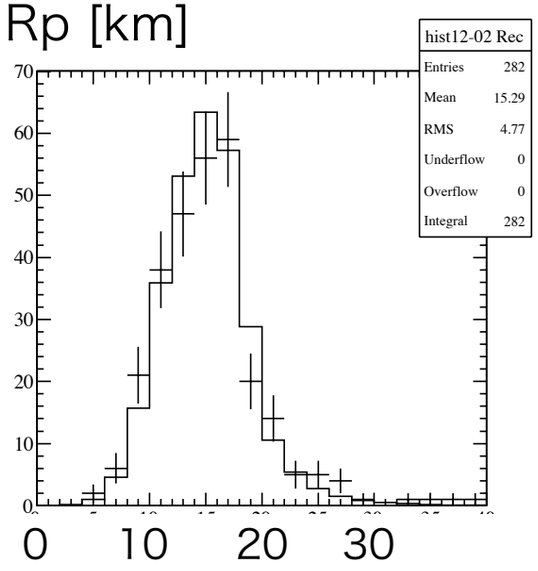
Core X [km]



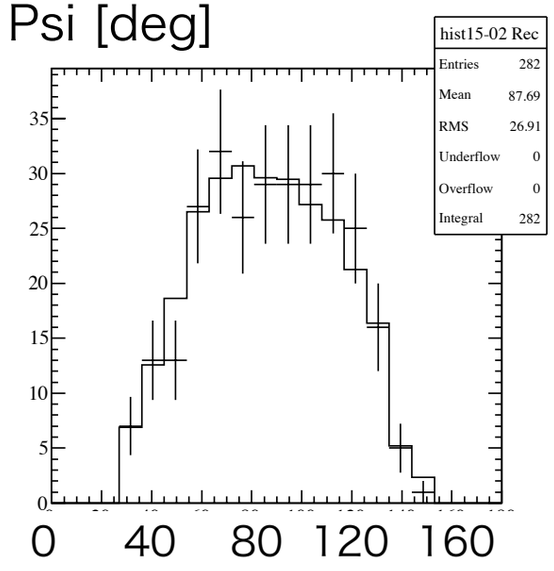
Core Y [km]



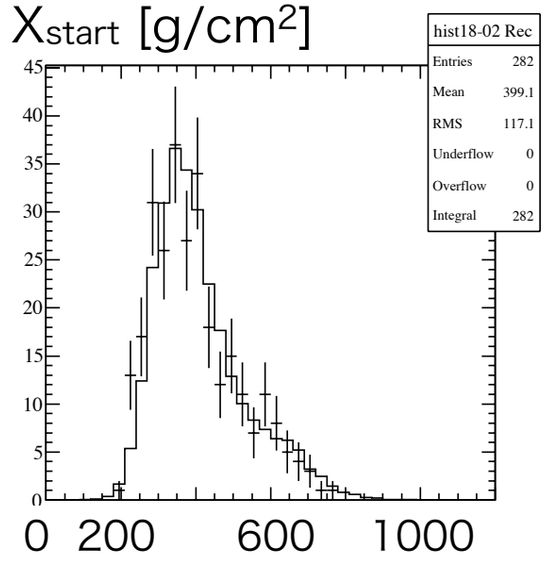
Rp [km]



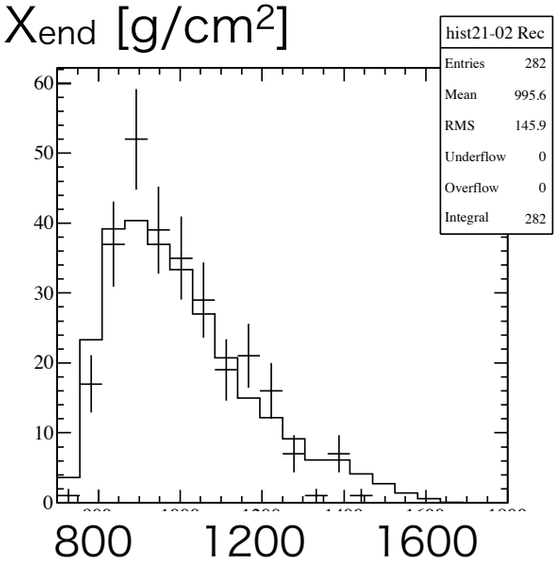
Psi [deg]



X_{start} [g/cm^2]

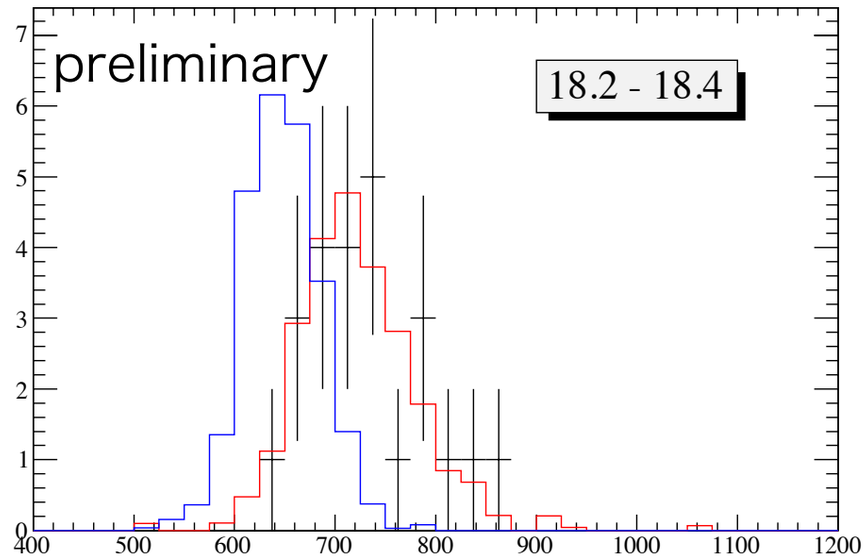


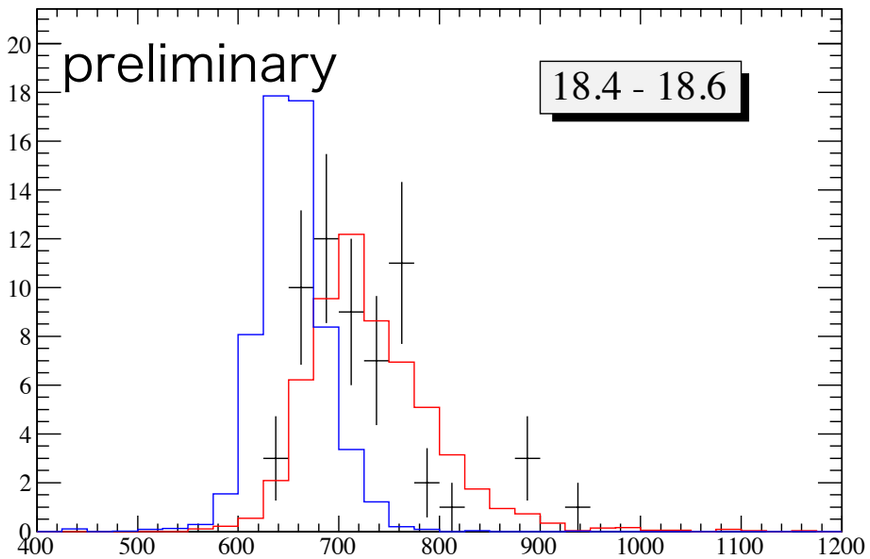
X_{end} [g/cm^2]

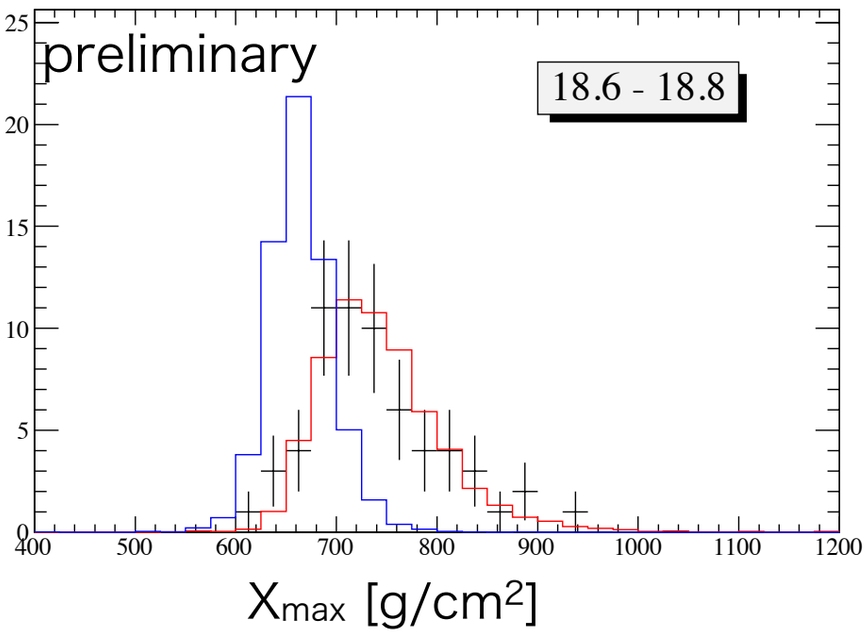


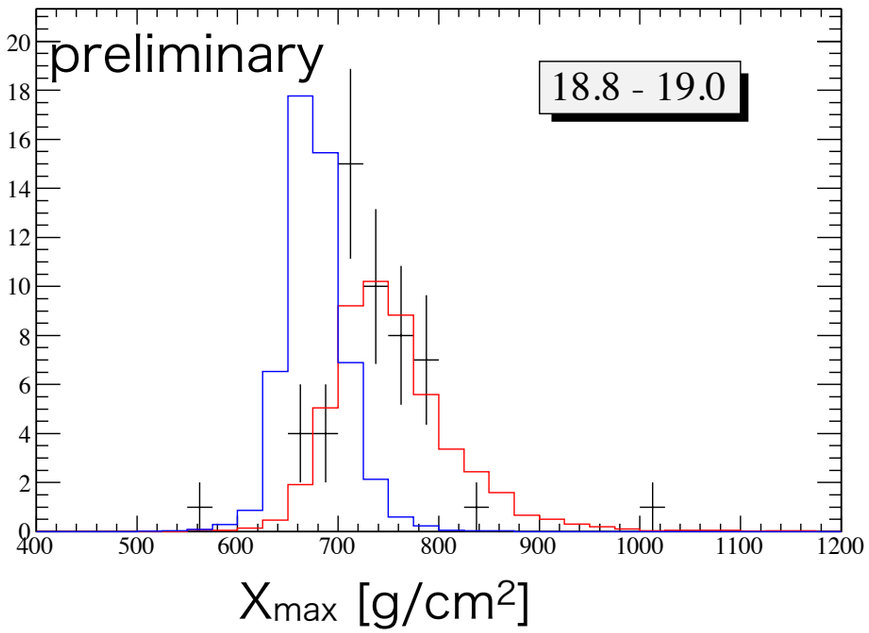
MC: QGSJET II 03, Proton

Xmax distribution (TA FD stereo)





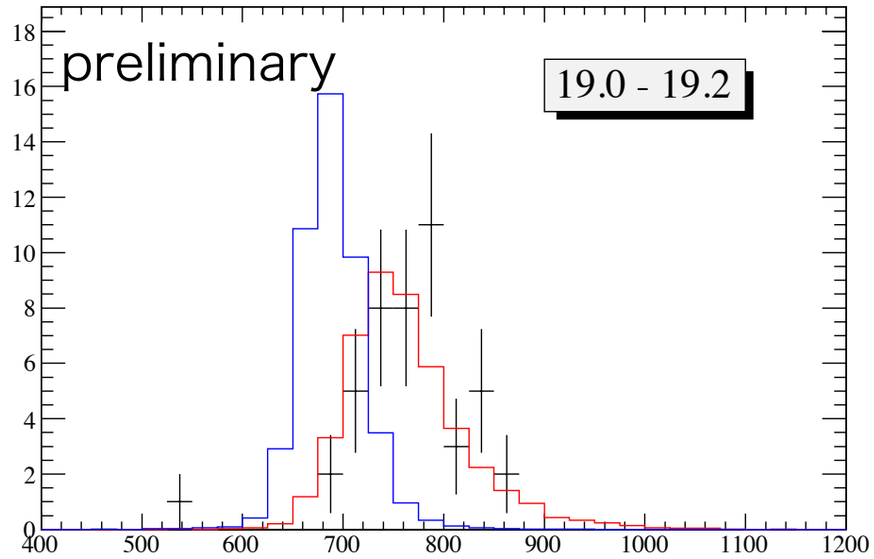


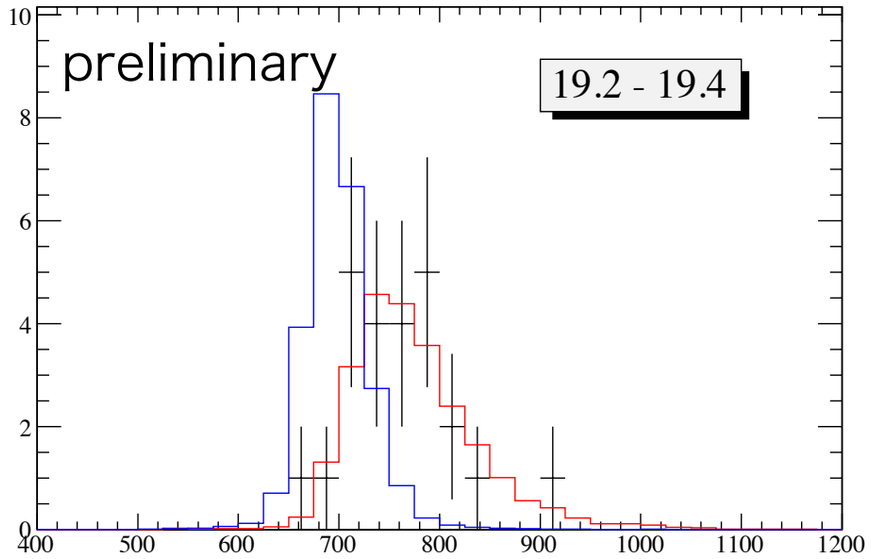


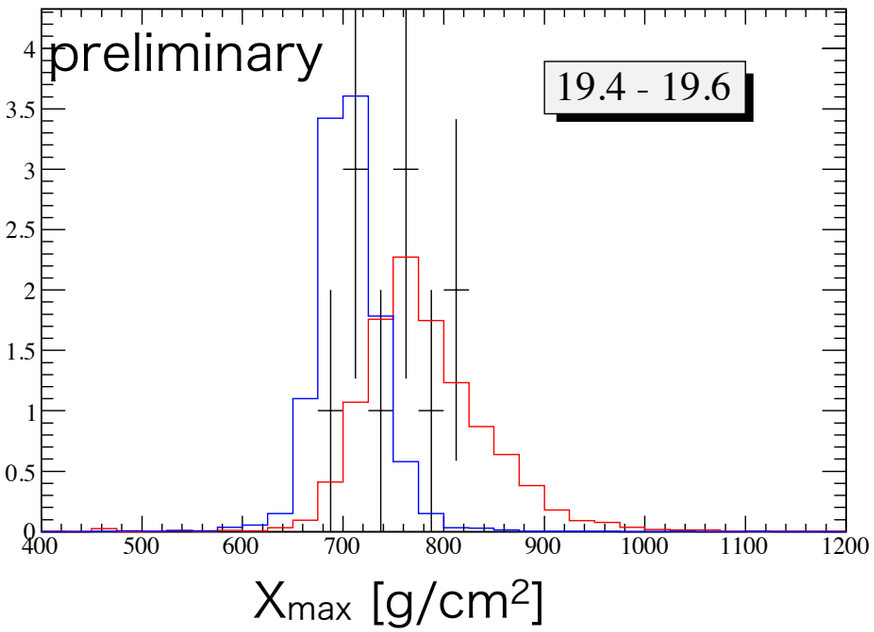
QGSJET-II-03

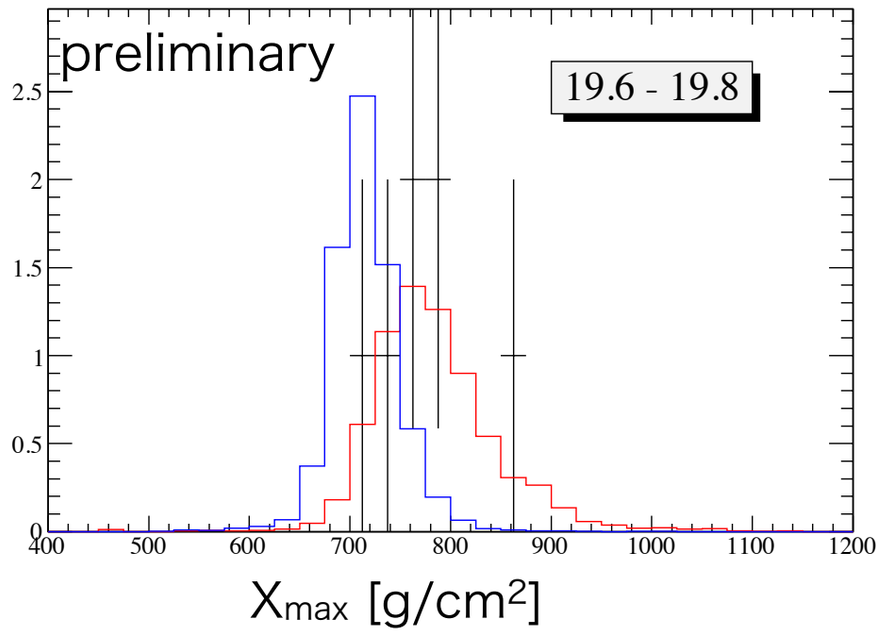
- Proton
- Fe

Xmax distribution (TA FD stereo)







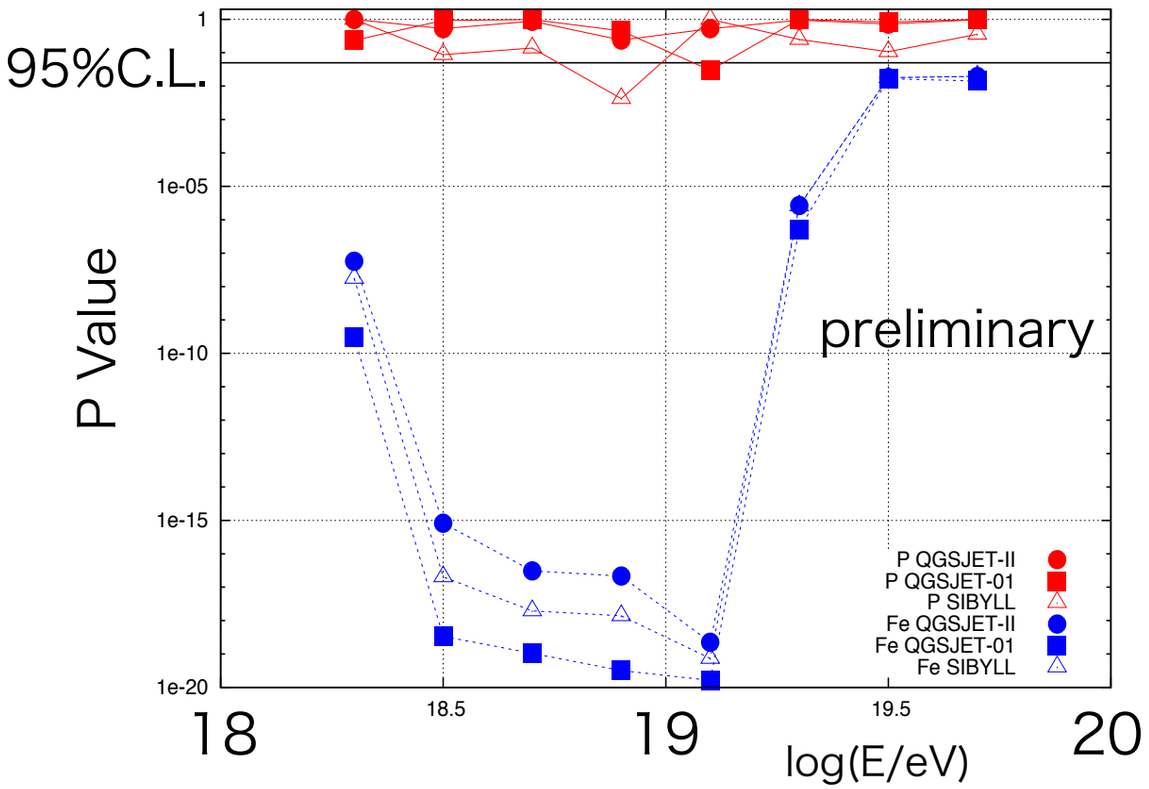


QGSJET-II-03

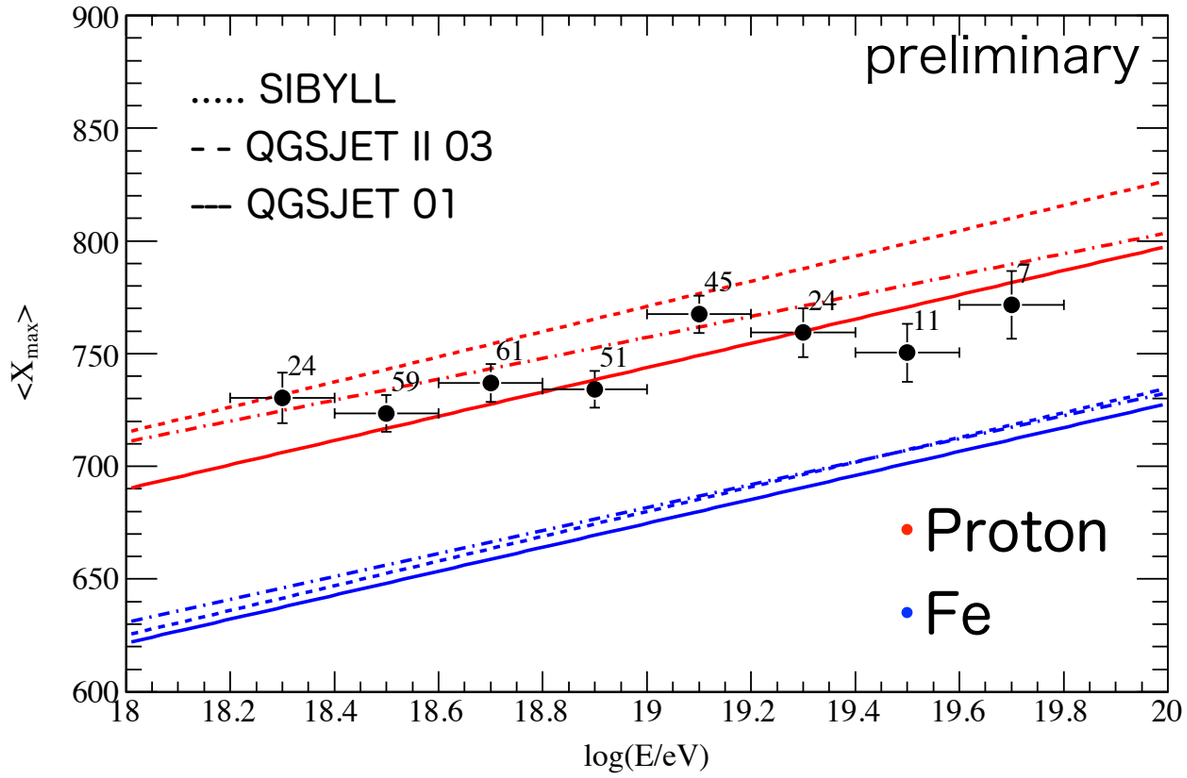
- Proton
- Fe

TA FD stereo: Xmax vs logE

K.S. test for Xmax distribution



Averaged Xmax



Y.Tameda ICRC 2013

K.S. test

K.S. test applies to Xmax distribution of each energy region.

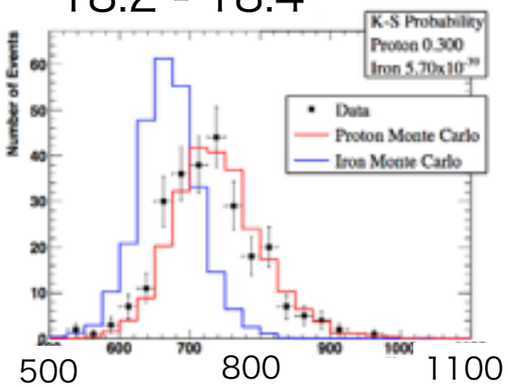
Fe model can be rejected with 95 % C.L.

Averaged Xmax

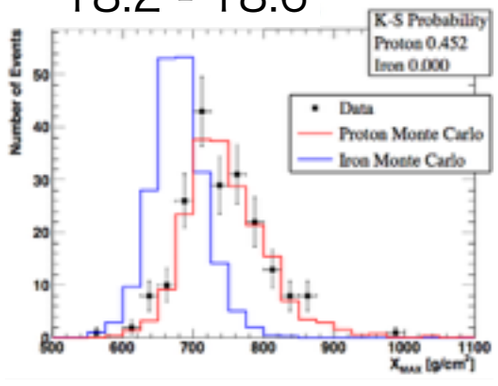
FD stereo data is consistent with QGSJET - proton model.

MD/SD Hybrid

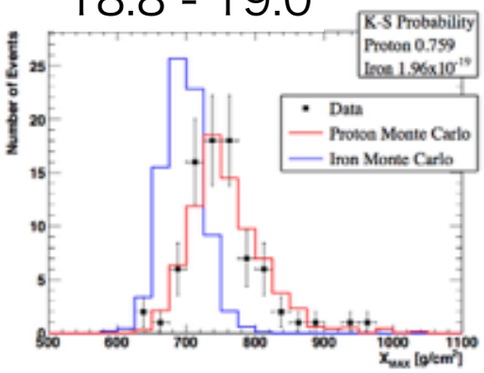
18.2 - 18.4



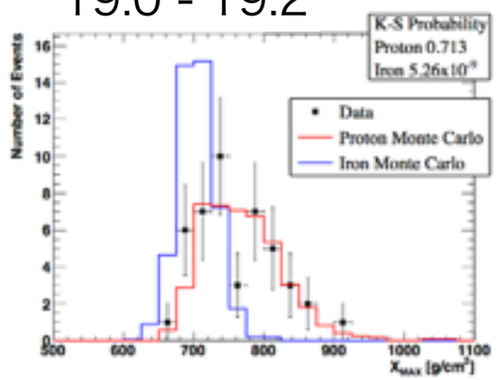
18.2 - 18.6



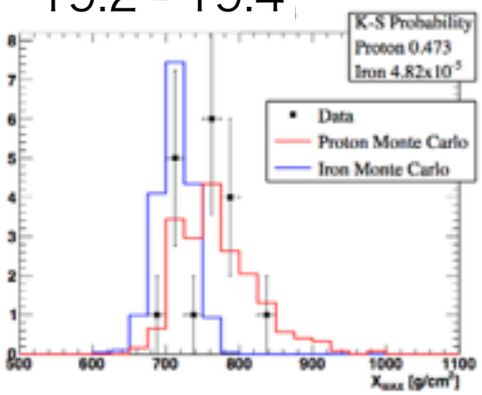
18.8 - 19.0



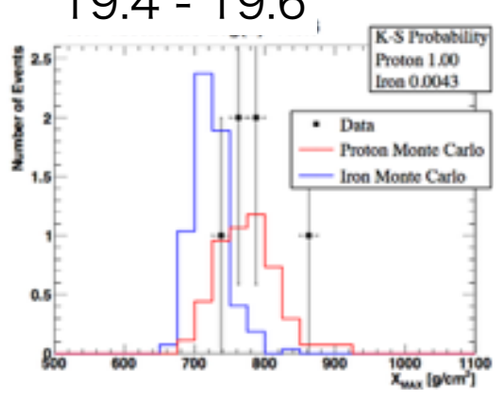
19.0 - 19.2

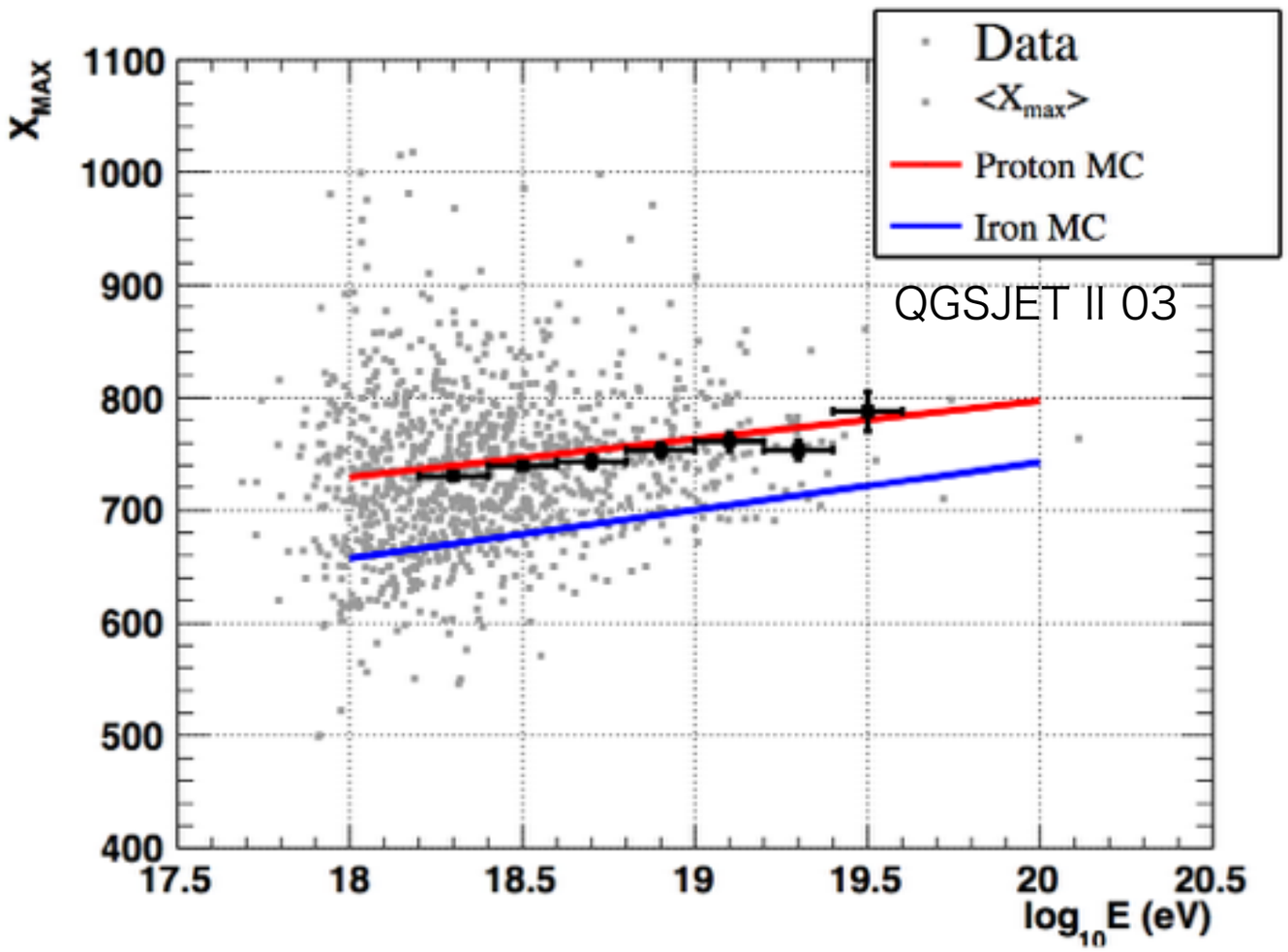


19.2 - 19.4



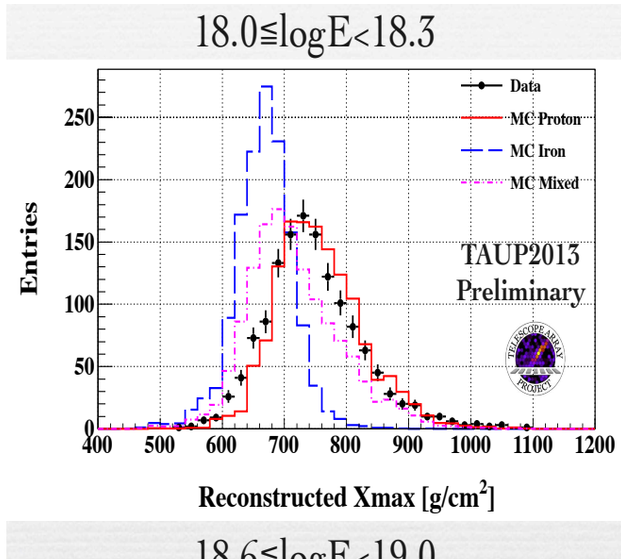
19.4 - 19.6

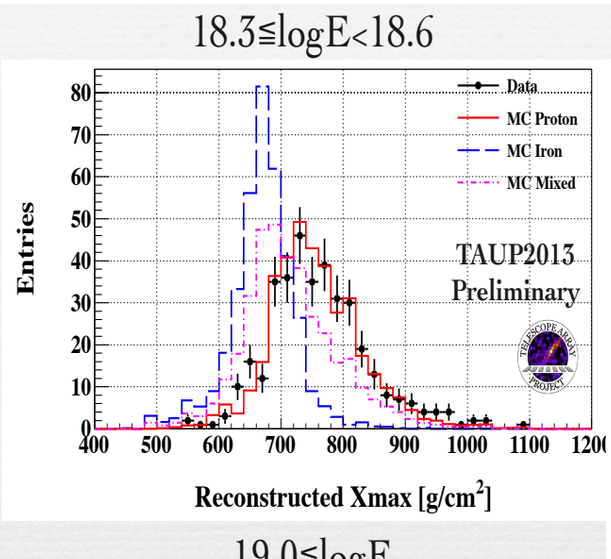


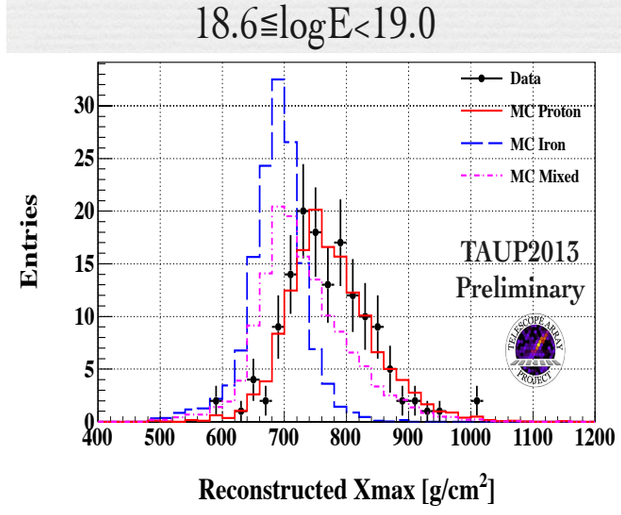


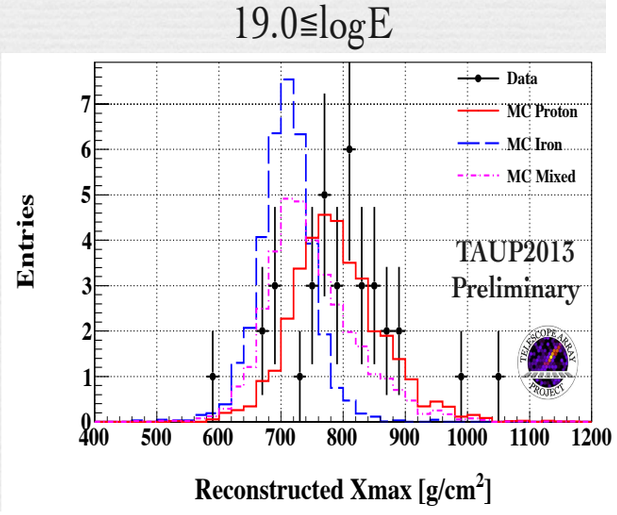
M. Allen, ICRC2013

TA FD mono

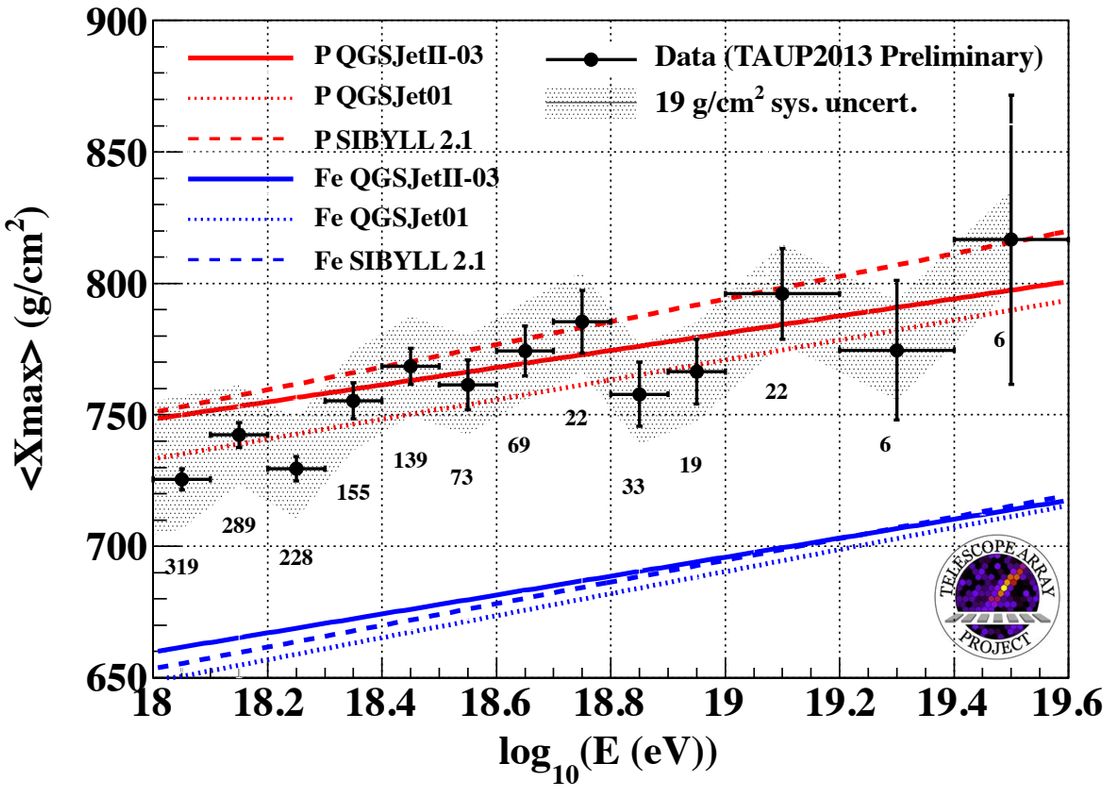








QGSJET II 03



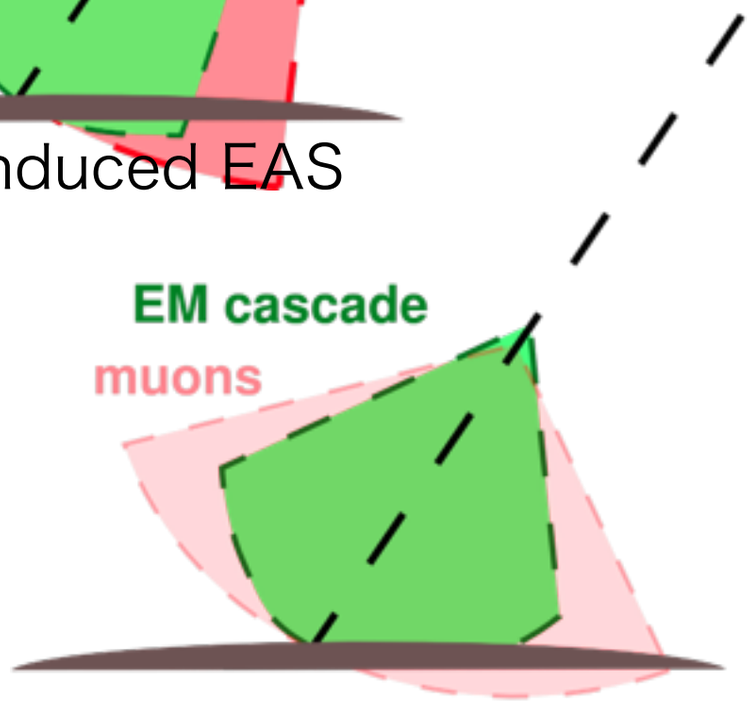
T. Fujii, TAUP2013

Gamma ray, neutrino search with TA SD

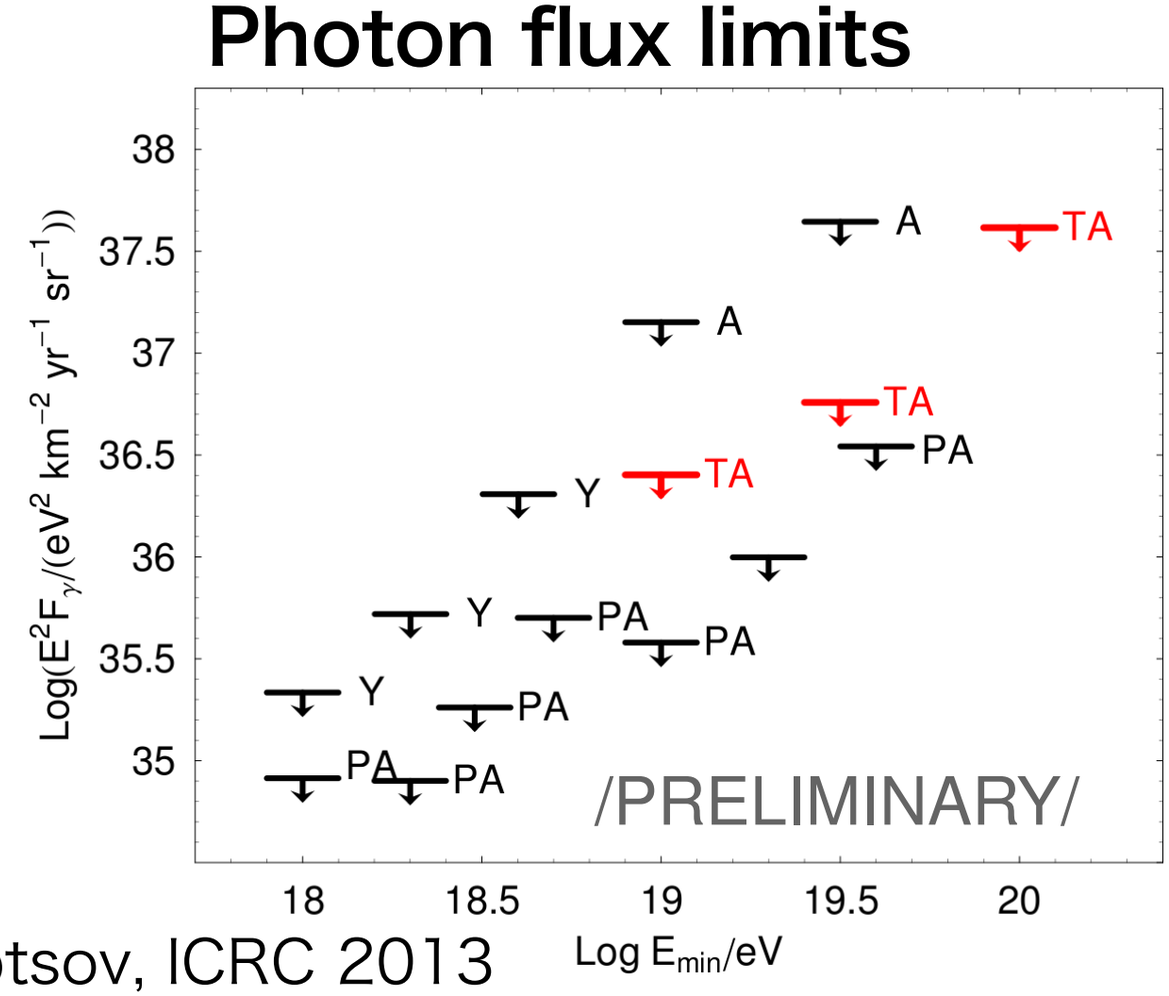
Gamma search

- Deep shower maximum and shortage of muons.
  - —> curved front.
- using Linsley's shower front curvature parameter "a ".

Proton-induced EAS



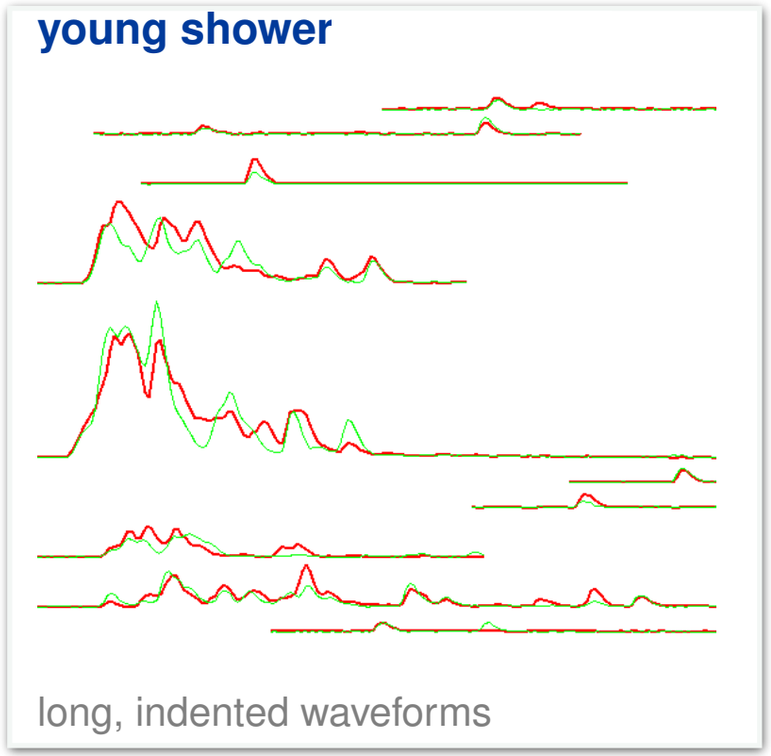
Gamma-induced EAS

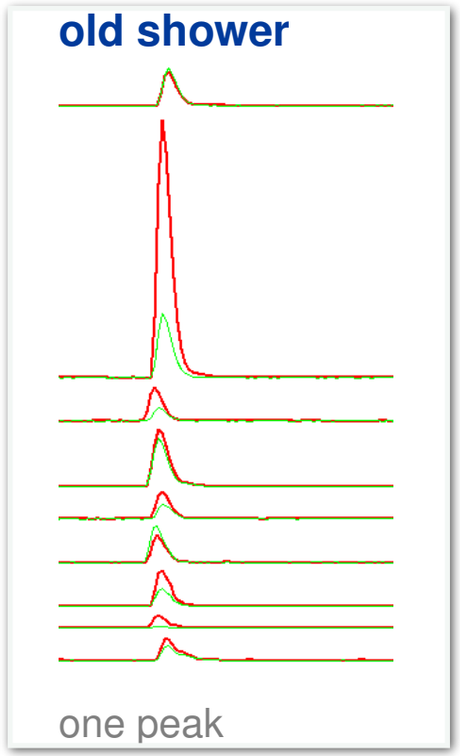


G. Rubtsov, ICRC 2013

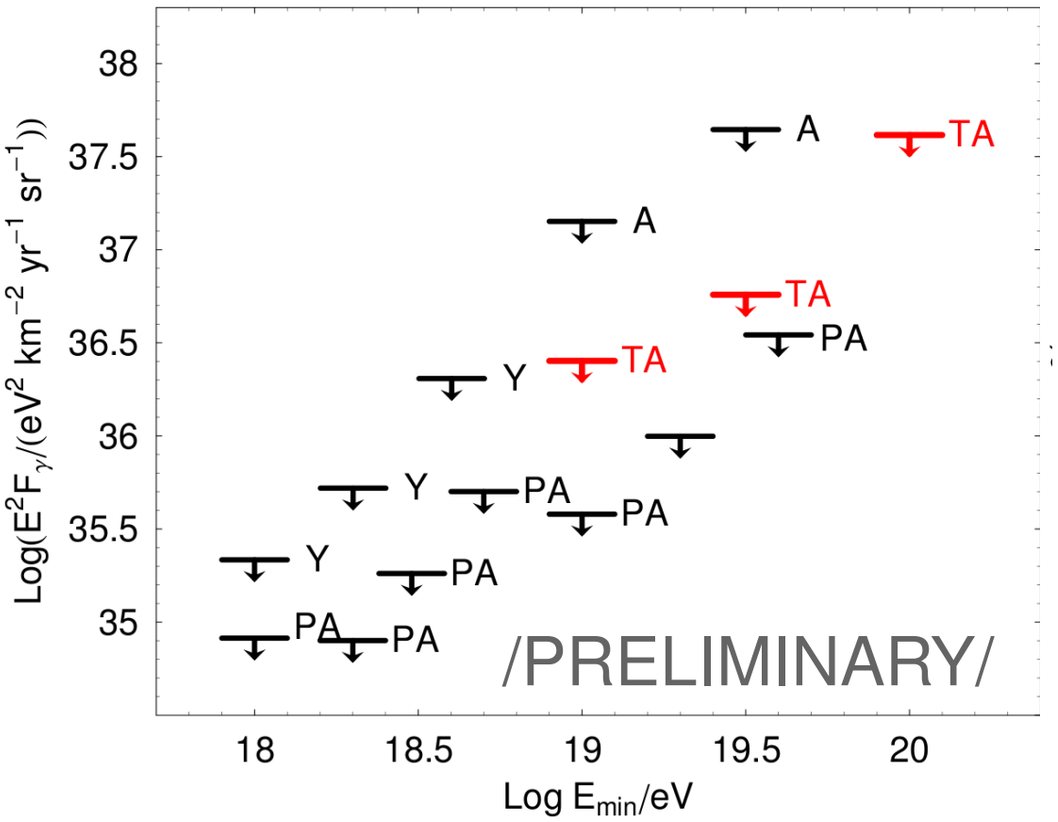
Neutrino search

- Neutrino produces very inclined young shower.
- Counting wave form peak per detector layer.





Neutrino flux limits



No neutrino candidate.

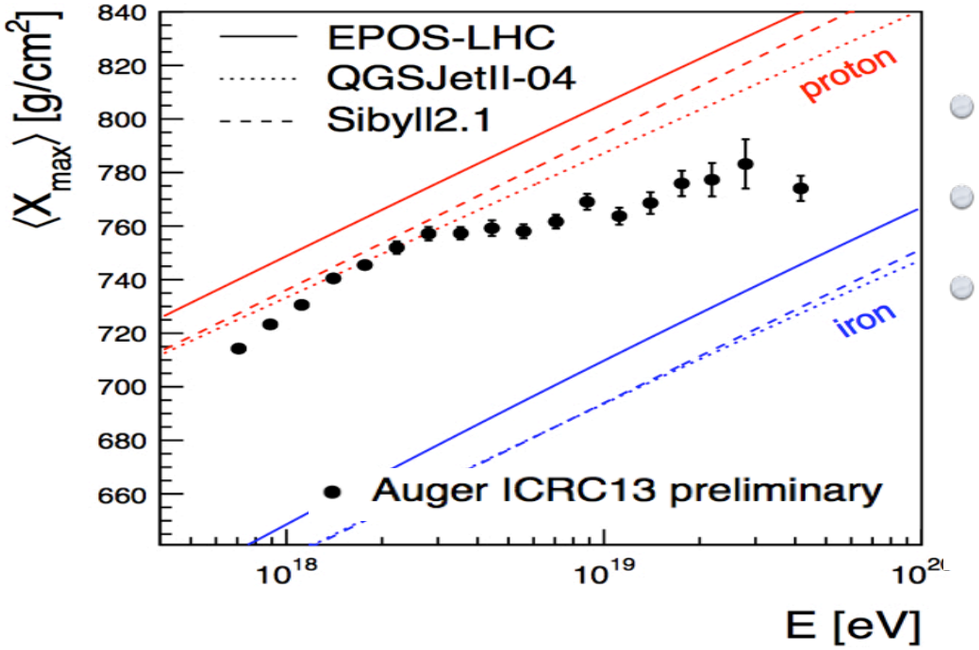
G. Rubtsov, ICRC 2013

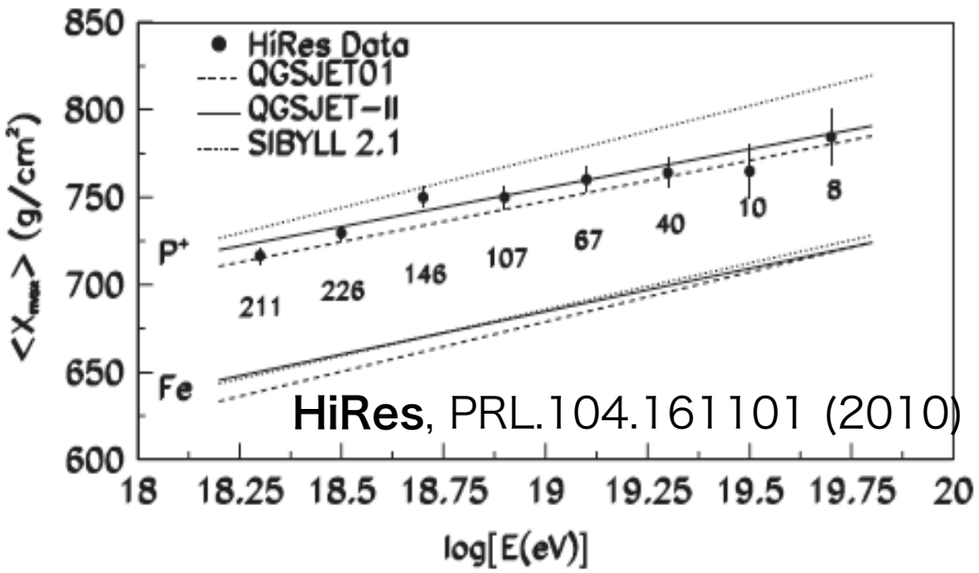
Mass composition of UHECRs

- Nucleus ? — (P, He, CNO, Fe or mixed ?)
  - Proton favor mass composition. (>$10^{18.3}$eV)
- Gamma ray, Neutrino ?
  - These don’t seem to be dominant component.

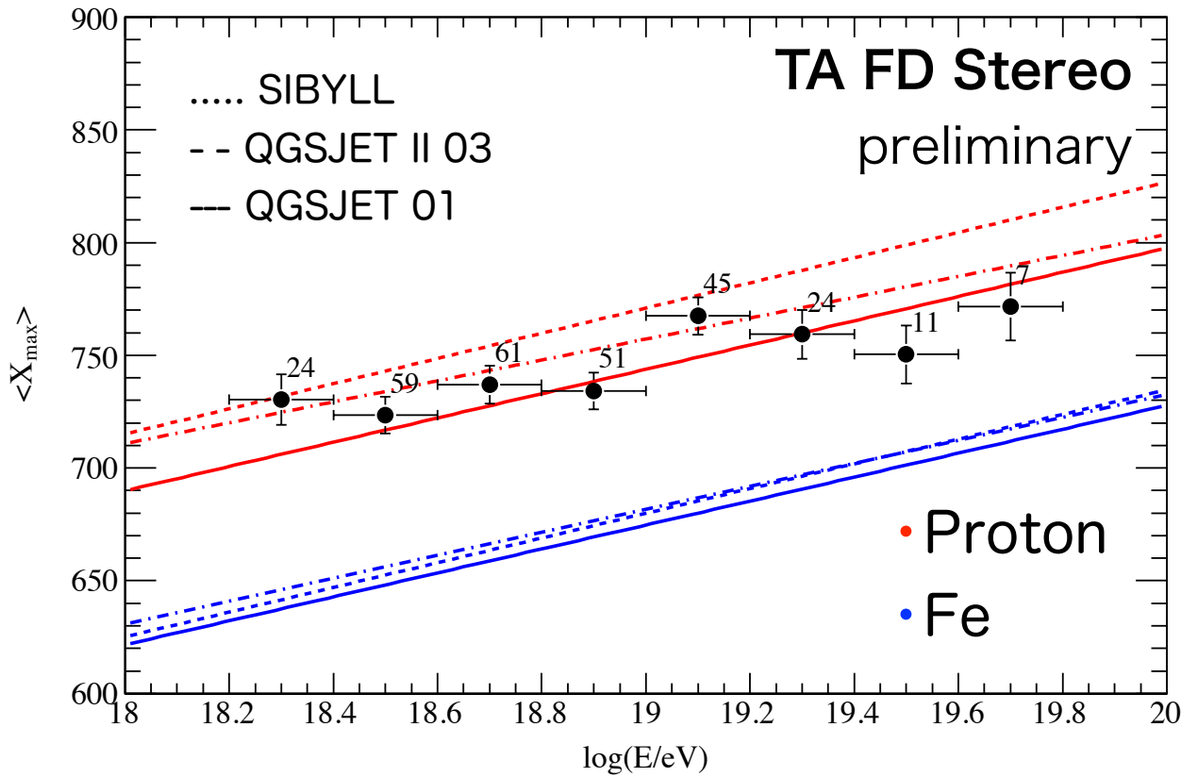
Next Step

How do we understand the differences of various experiments





- Averaged Xmax looks different.
- Un-biased (Auger) or biased analysis (TA, HiRes)
- Hadronic interaction model uncertainty



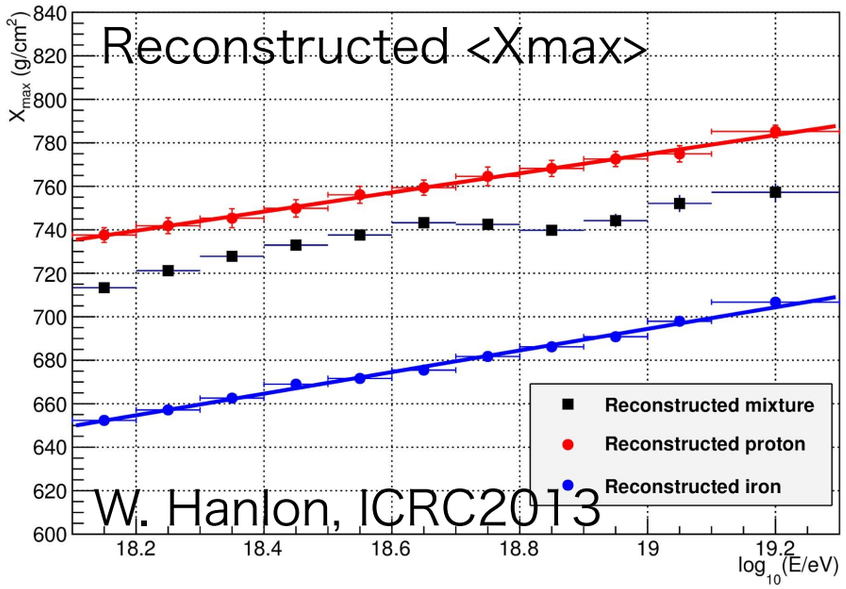
How do we understand the differences of various experiments

Analysis approach

Auger's 4 composition model is tested with TA simulation.

- H, He, N, Fe model
- with TA FD bias

TA analysis has enough resolution to distinguish Auger's 4 comp. model.



Common calibration source?

- We flied Auger octocopter light source at TA site.
- The light source is for the energy scale calibration, mainly.
- FD geometry (sensitive to Xmax observation) might be calibrated.

How do we understand the differences of various experiments

Analysis approach

Auger's 4 composition model is

test

TA a

distinguish Auger's 4 comp. model.

Common calibration source?

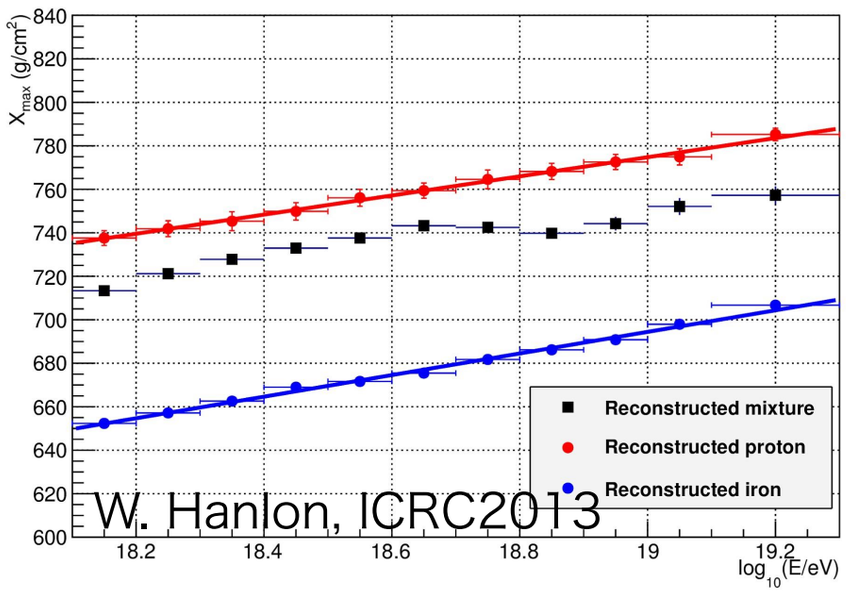
- We flied Auger octocopter light

ergy

max

ated.

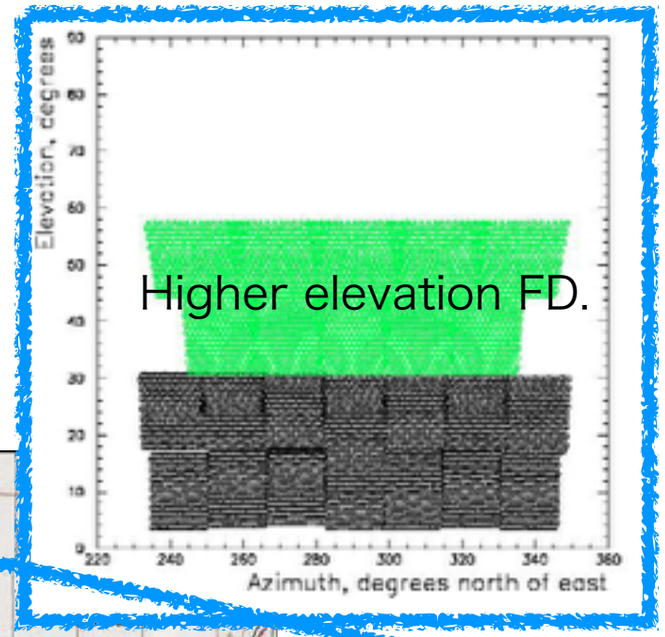
We need to work together to understand the detector and analysis procedure, each other.

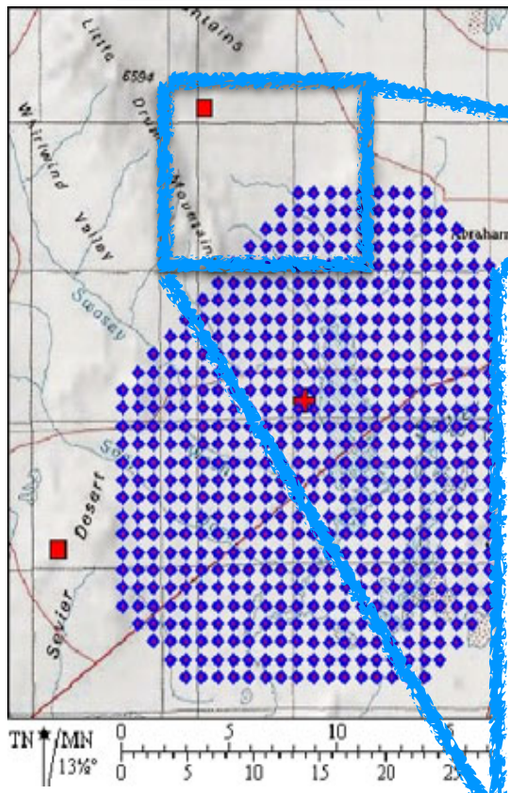


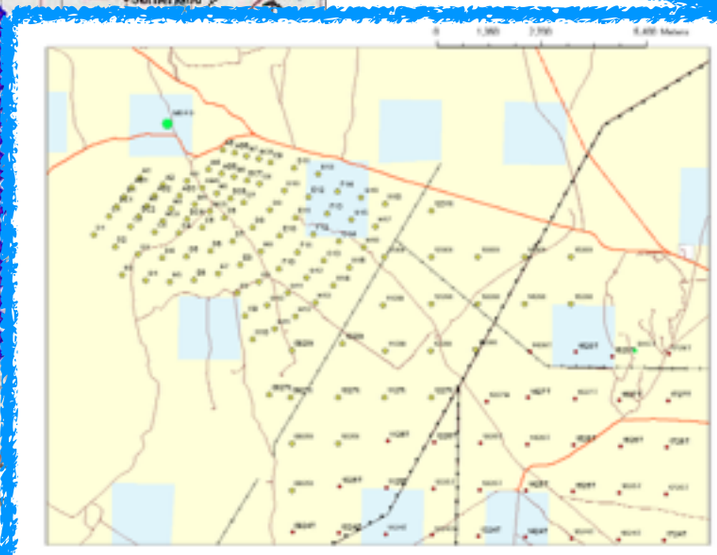
W. Hanlon, ICRC2013

TA extensions

- TA Low-energy Extension (TALE)
  - Physics @ $10^{16.5\text{-}19}$eV
    - **Galactic to Extra-galactic transition** (2nd knee and ankle, acceleration limit)
    - **Source evolution**
    - **Hadron interaction model**
  - Additionally install 10 FD telescopes and 105 SDs.
    - Construction of FDs complete.
    - All telescopes are operational.
    - 35 SDs are deployed.
- TARA (TA Radar)
- NICHE (Non-imaging CHErenkov array)







Summary

- TA composition
  - FD data is consistent with QGSJET-Proton model at least $10^{18.3}$ eV.
  - Gamma-ray and neutrino flux limit is estimated by SD data.
- UHECR composition is still not concluded.
  - Fundamentally, UHECR composition study has a uncertainty of the hadronic interaction model.
  - Differences of various experiments.
  - We have a pipe to contact each other to solve this topic.
- TA Extensions
  - TALE, TARA, NICHE, ⋯
- TA Extensions will help to understand the hadronic interaction model.