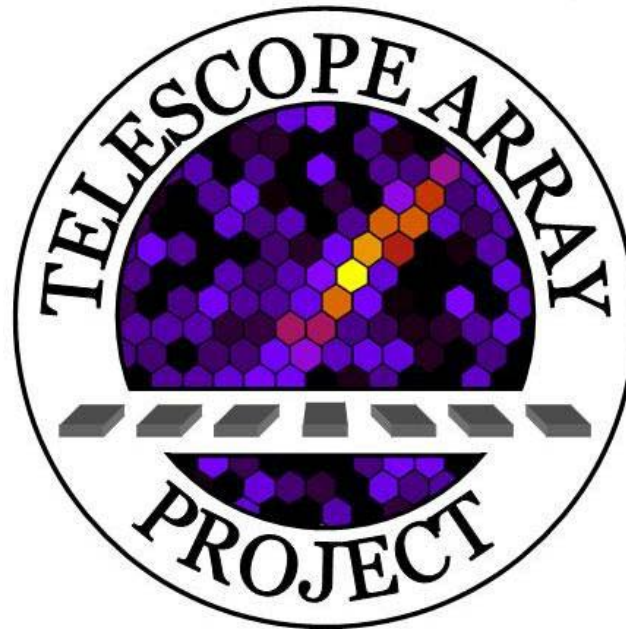


The Telescope Array Low-Energy Extension (TALE)



C. Jui

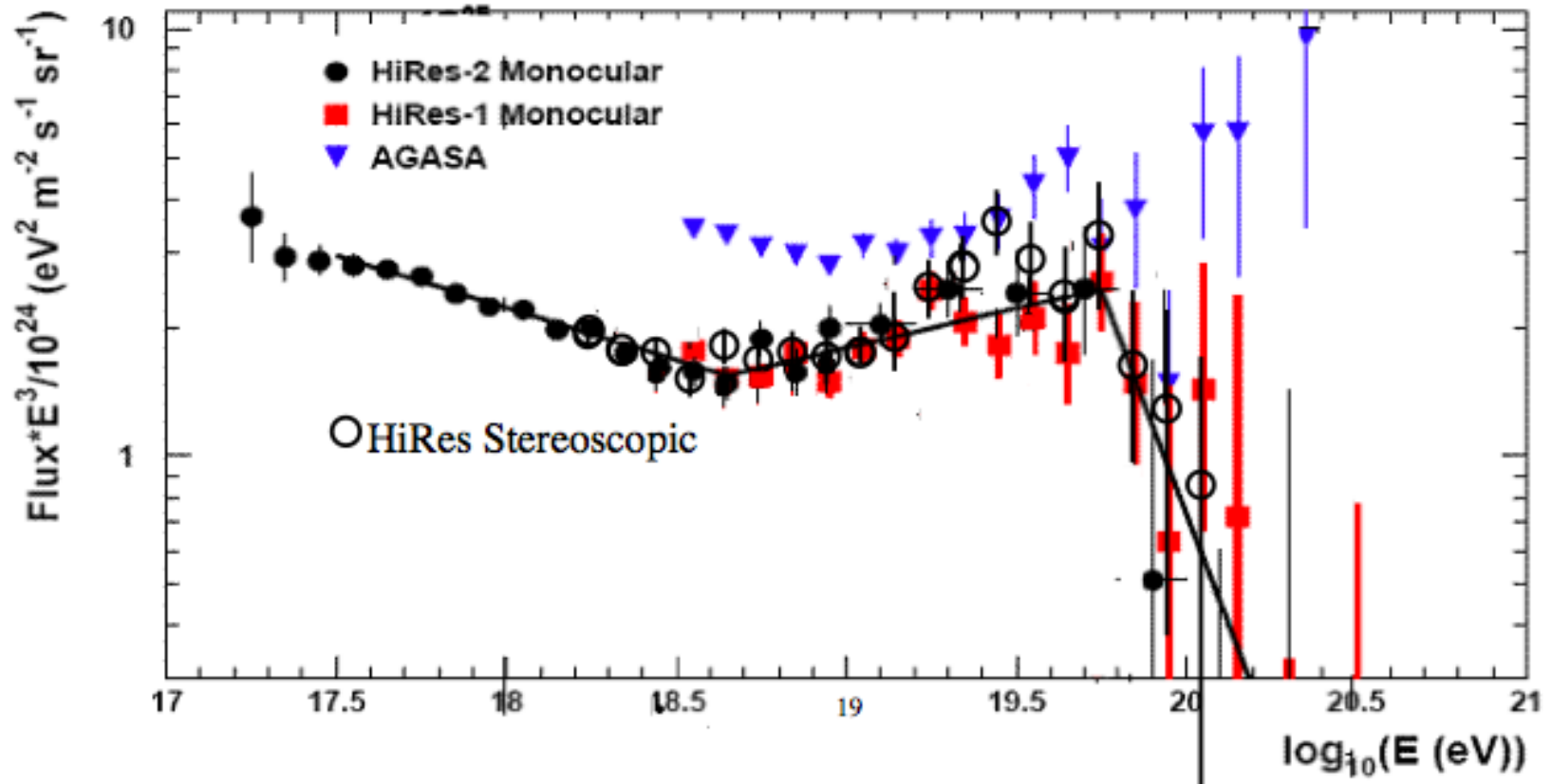
For the TA/TALE Collaboration

ISVHECRI, FNAL, July 1, 2010

Features in the UHECR spectrum:

The minority straight-forward View

- CMBR photons interact with cosmic ray protons:
 - Pion production makes the *GZK suppression*: $E < 6 \times 10^{19}$ eV if cosmic rays travel > 50 Mpc.
 - e^+e^- production: threshold $\sim 4 \times 10^{17}$ eV, excavates the **ankle**.
- Pair production pileup + galactic/extragalactic transition: the **second knee**.
- **Three** spectral features in the UHE regime.
- *But NO single experiment has measured all three features: the exact energies (or even the ratios) are not known; i.e., basic information is in doubt.*
- The field needs an experiment with **WIDE energy coverage!!** **good resolution!!** and **good systematics!!**

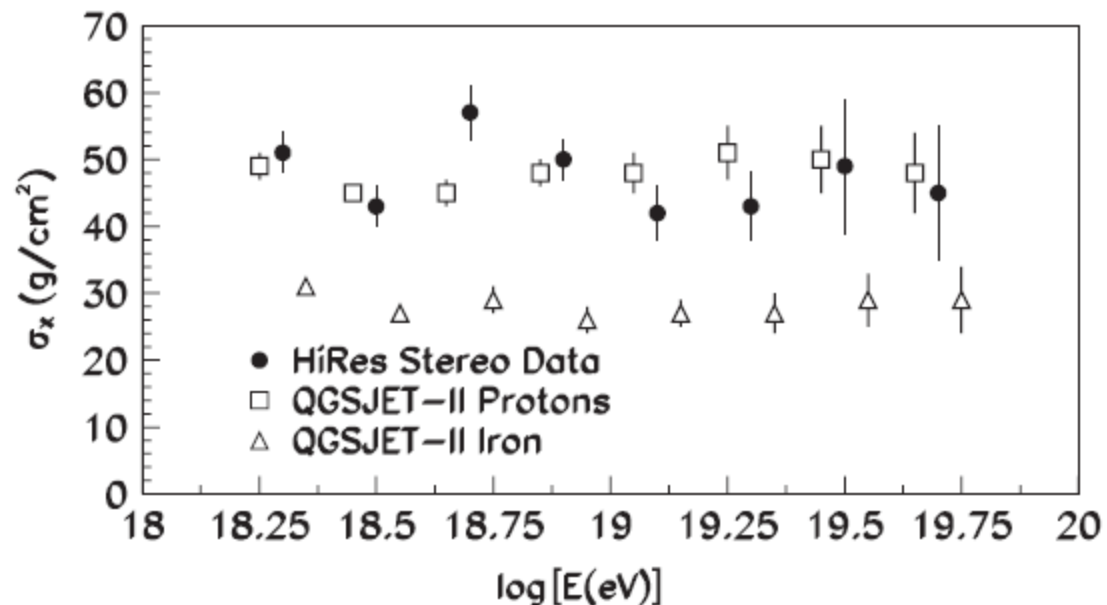
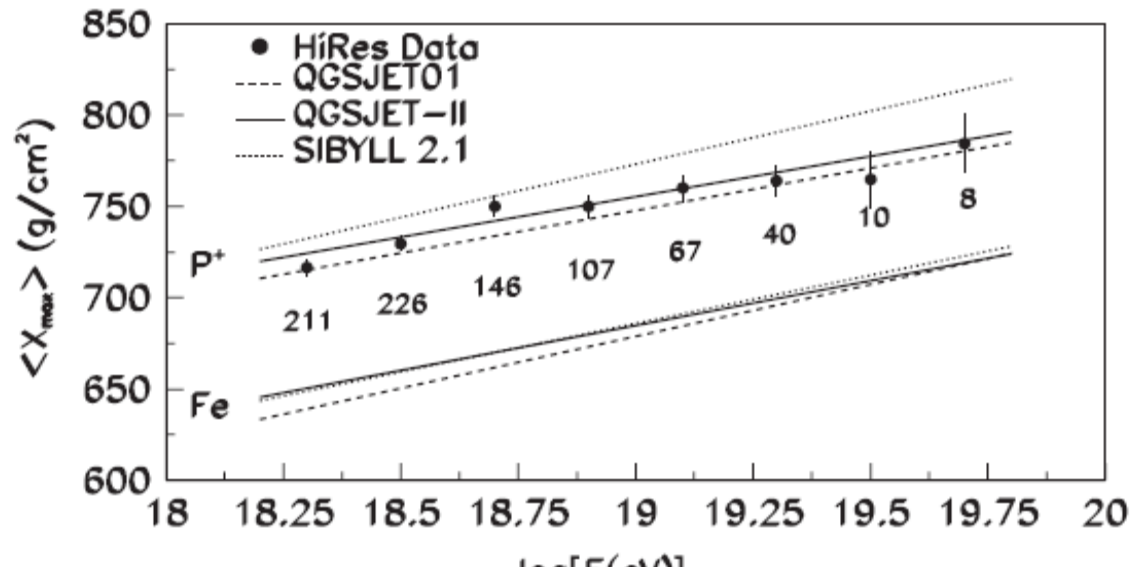


- HiRes was first to observe the GZK suppression
 - *Physical Review Letters* **100** (10): 101101 (5σ significance)
 - Confirmed in stereo spectrum (4σ significance)
- Ankle (“dip”) was also seen by HiRes

HiRes: GZK + Ankle = protons !?

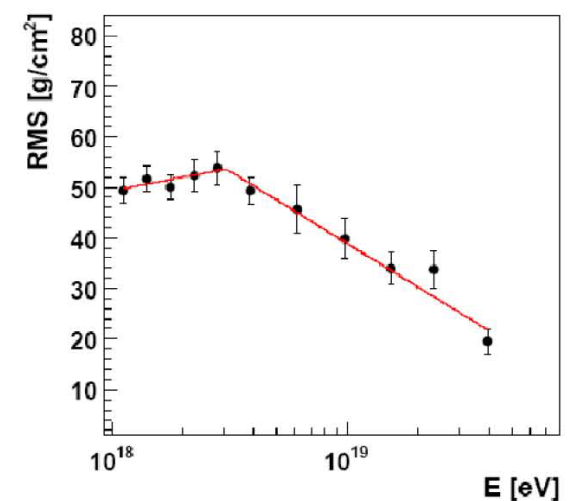
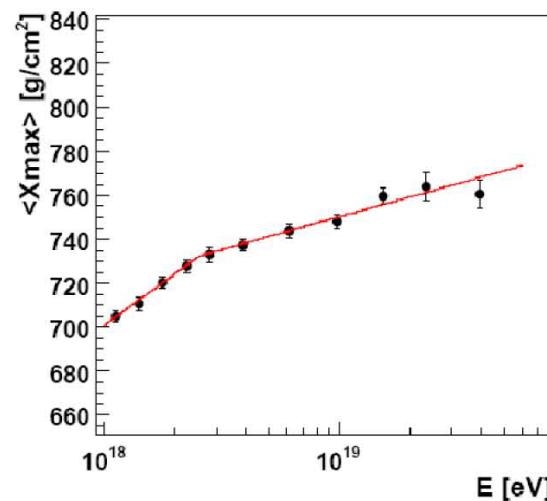
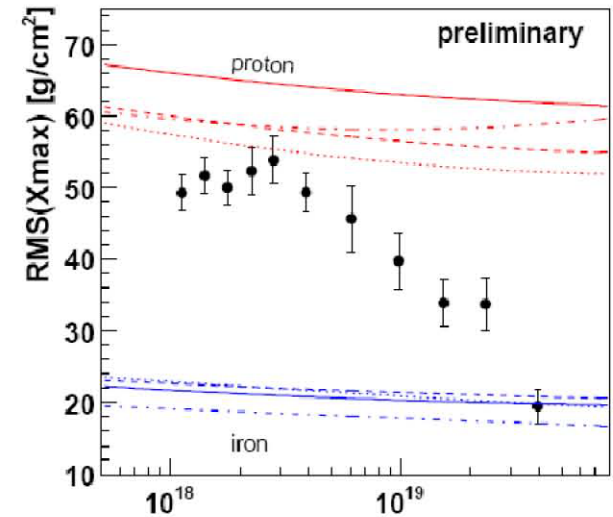
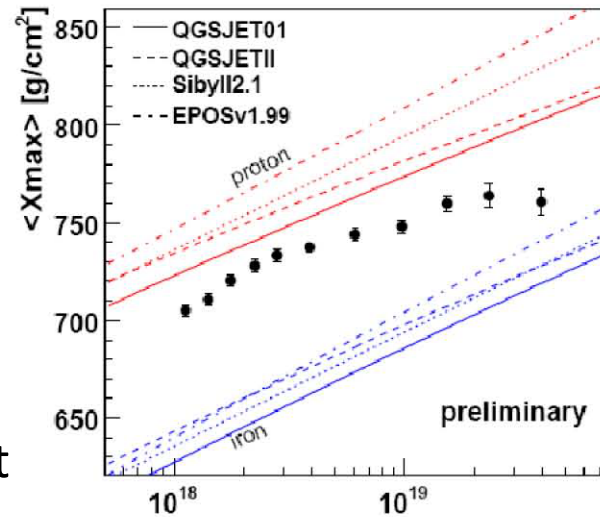
- The observation of the GZK and ankle features are consistent with proton dominated composition (e.g. Berezhinsky & Gazizov Phys Rev. D 74, 043005 2006)
- Comparison of HiRes $\langle X_{\max} \rangle$ vs. energy plot against hadronic models show a unchanging (from the slope), light composition

HiRes Result:
Phys Rev Lett. 104,
161101 (2010)

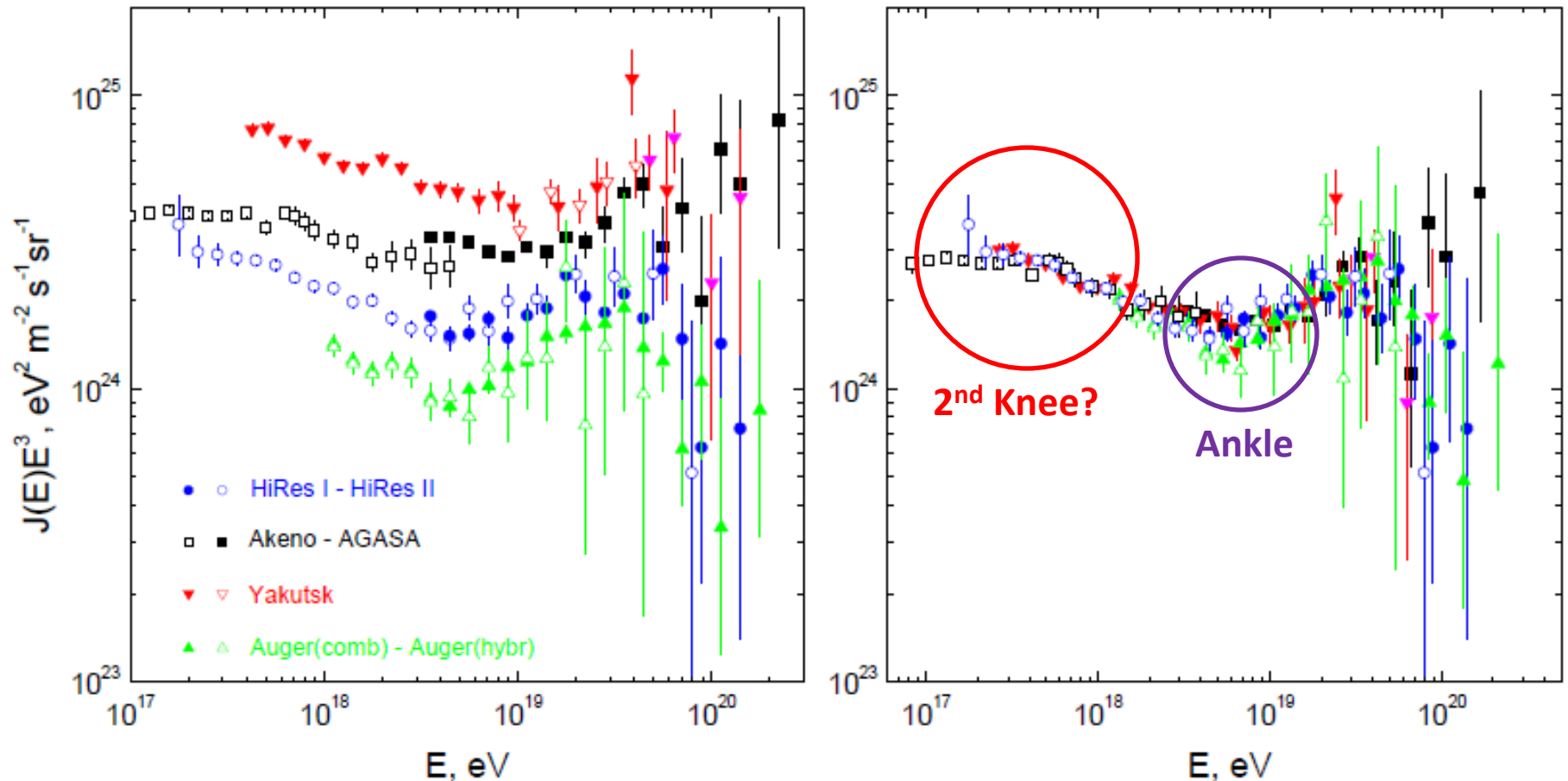


Gallup Poll Headline: Proton Dominance Approval Rating Down

- >60% of the UHECR field disagrees with proton dominance
- The popular interpretation seems to be that the breaks in these plots suggests transition to iron starting below the ankle
- The two-component interpretation of these plots are of course problematic: a 50%-50% mix of iron and proton would have RMS > $\sim 70 \text{ g/cm}^2$



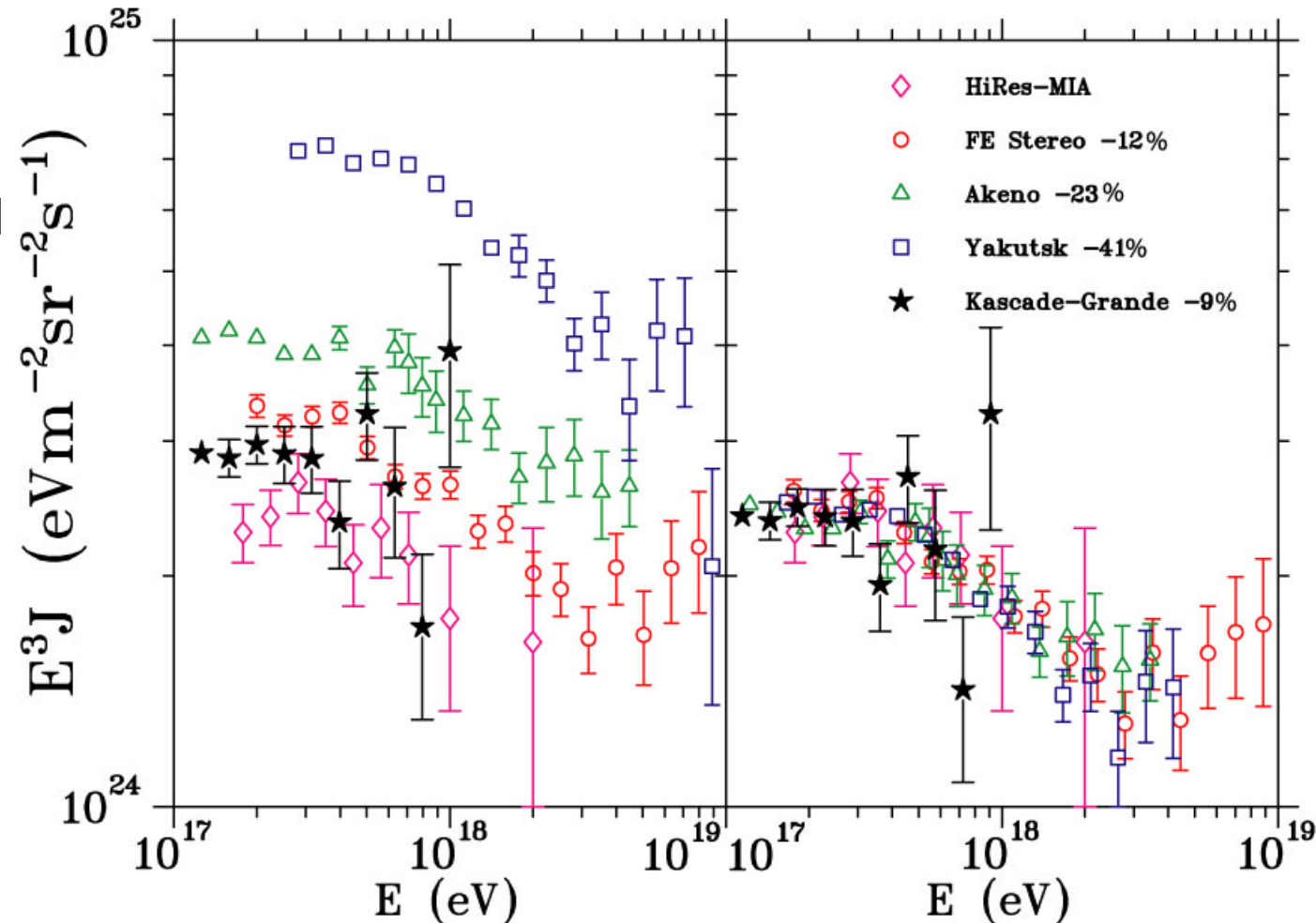
UHECR spectra consistency



- Nevertheless, the spectra from the four previous experiments can be made to agree both in **shape** and **normalization** by energy rescaling alone

The Second Knee

- The 2nd knee feature has been seen by 4 previous experiments
- Can make the spectra agree in normalization and in location of feature by adjusting energy scales
- Recent results from Cascade-Grande seems to run out of statistical power at the feature and is inconclusive



Galactic Sources

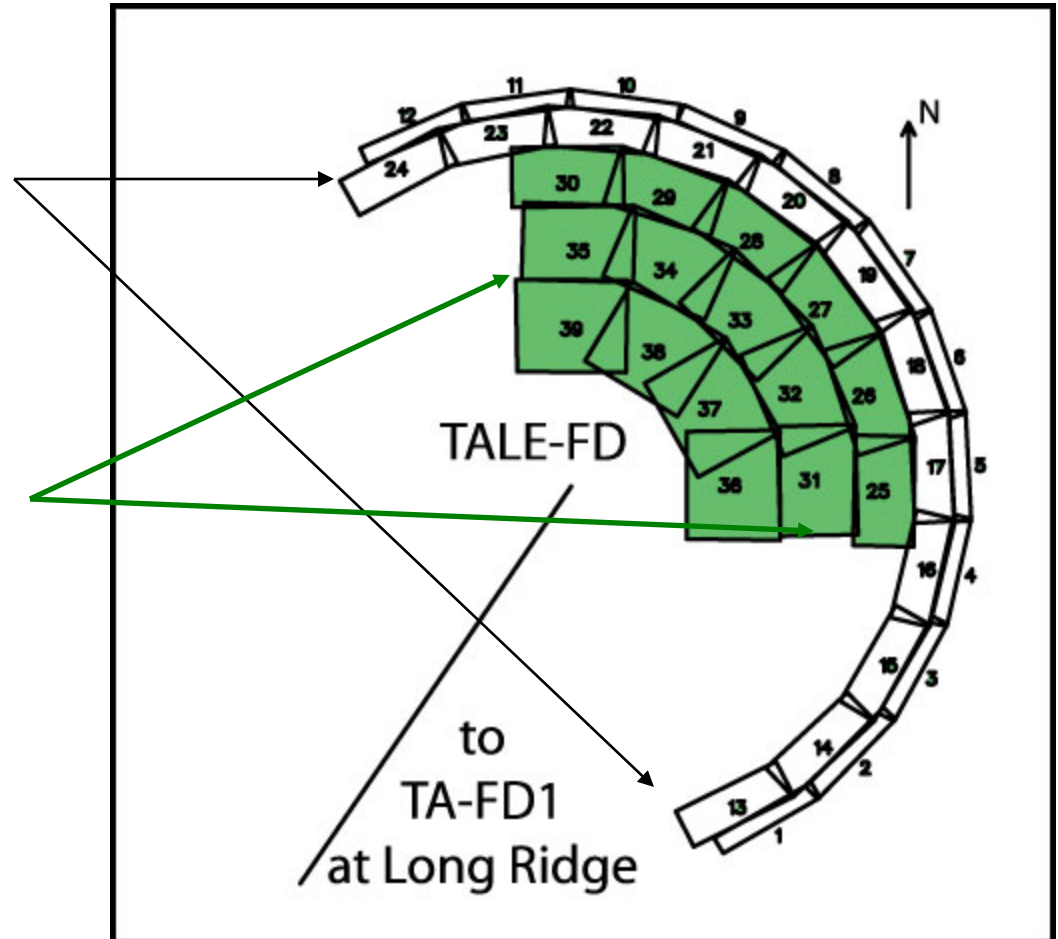
- While a minority of the UHECR field ($\sim 20\%$) might not agree that UHE cosmic rays are definitively correlated with AGN's, there appear to be consensus that there are Galactic sources of cosmic rays.
- Questions about Galactic sources:
 - What is the maximum energy they produce?
 - Is there anisotropy at 10^{18} eV?
- TA/TALE aim: attack these questions:
 - Measure spectrum and composition at lower energies where galactic contribution is larger.
 - Search for anisotropy along galactic plane, and just above the galactic center.
- X_{\max} is the variable that discriminates between p and Fe primaries.
- Fluorescence gives direct observation → best technique.
- Choose stereo and hybrid: each has x2 better X_{\max} resolution than mono.
- Paradoxical indication by HiRes+(HiRes-MIA) and Fly's Eye stereo:
 - “early” transition; i.e., below the ankle (HiRes)
 - “late” transition; i.e., above supernova capability (Fly's Eye + AUGER?).
- The next experiment needs a WIDE energy range.

TALE Design Criteria

- Second Knee region:
 - Transition from Galactic to extra-galactic flux?
 - The energy scale of this feature is uncertain (somewhere in the 10^{17} eV decade)
 - Need long lever arm below
- ➔ Hybrid measurements from $10^{16.5}$ - 10^{18} eV
- Ankle region:
 - Need better, and more stereo data than HiRes (HiRes sites were too far apart at 12.6 km)
- ➔ ~6 km site separation stereo measurements

TALE fluorescence

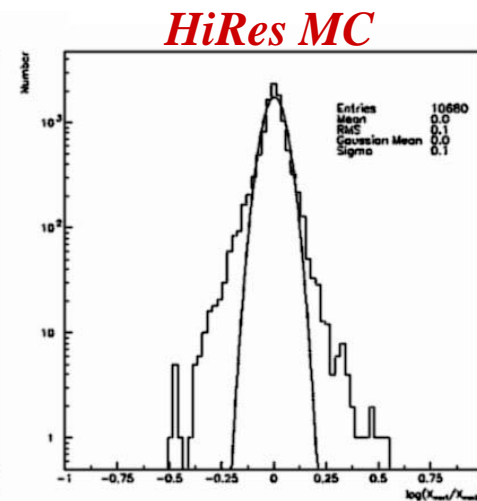
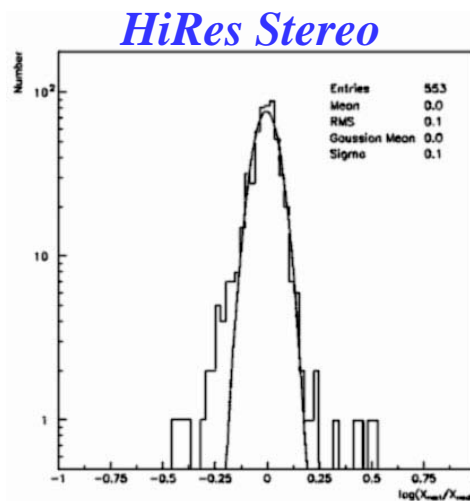
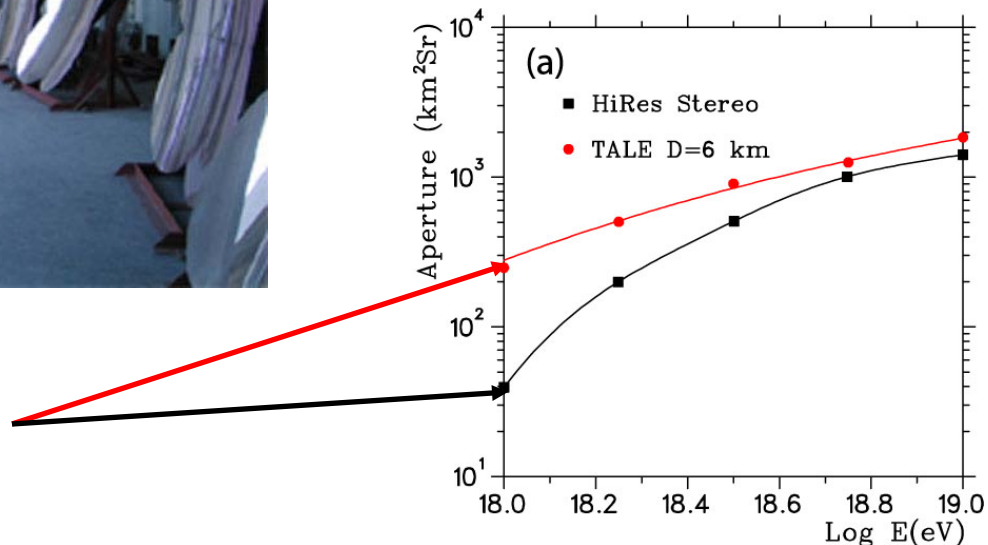
- The Fluorescence detectors of TALE consist of two overlapping components:
 - 24 telescopes viewing up to 31° in elevation to provide stereo coverage in conjunction with existing TA fluorescence station
 - 15 “Tower” telescopes with 4m diameter mirrors (~3 fold increase in light collection area from HiRes) and viewing up to 73° in elevation
- Uses refurbished HiRes-2 FADC electronics and PMTs
- Tower: new, larger mirrors and scaled up PMT clusters with Winston Cones





TALE Stereo

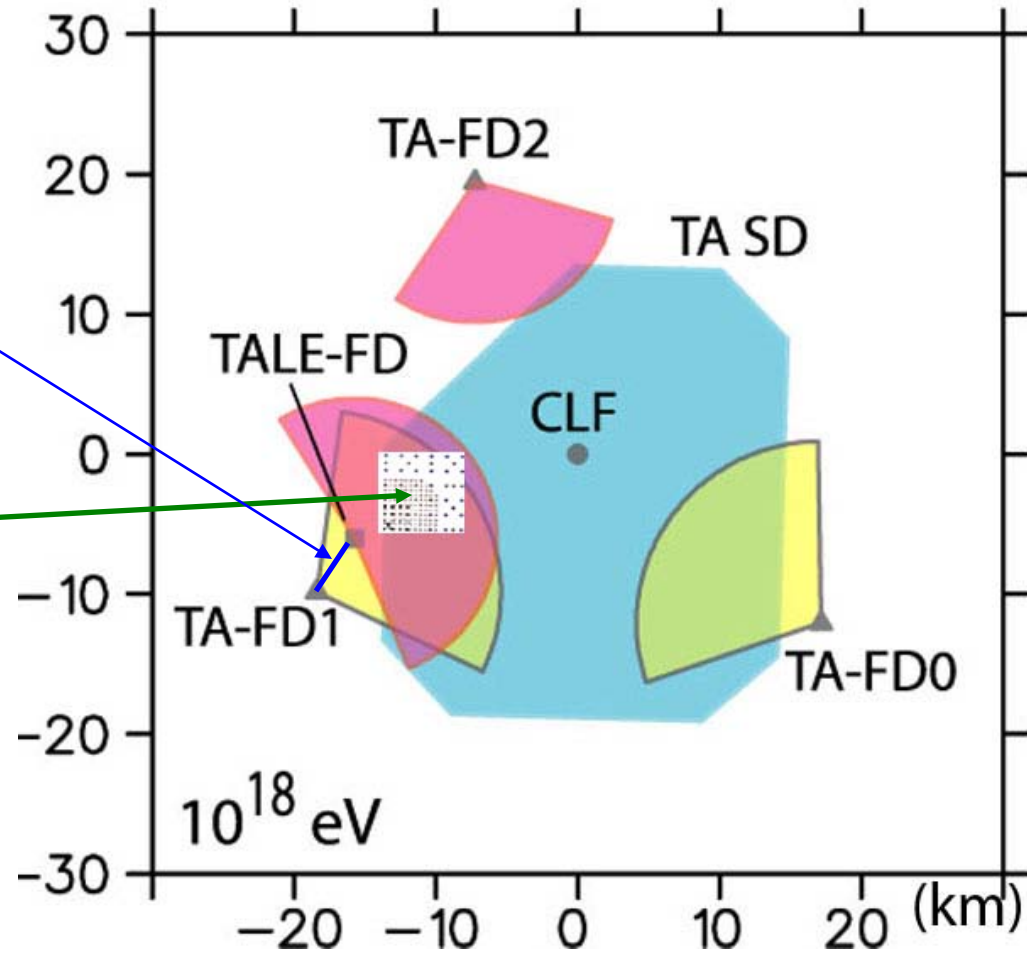
- Aperture is much flatter than the HiRes stereo aperture.
- Aperture at 10^{18} eV is $\sim 6\times$ that of HiRes stereo: comparable to hybrid aperture (*is there a systematic effect between stereo and hybrid composition measurements?*)
- **Stereo:** redundant measurement of shower properties (e.g. E and X_{\max}) which allows DIRECT validation of MC



$\text{Log}(X_{\text{MAX2}}/X_{\text{MAX1}})$

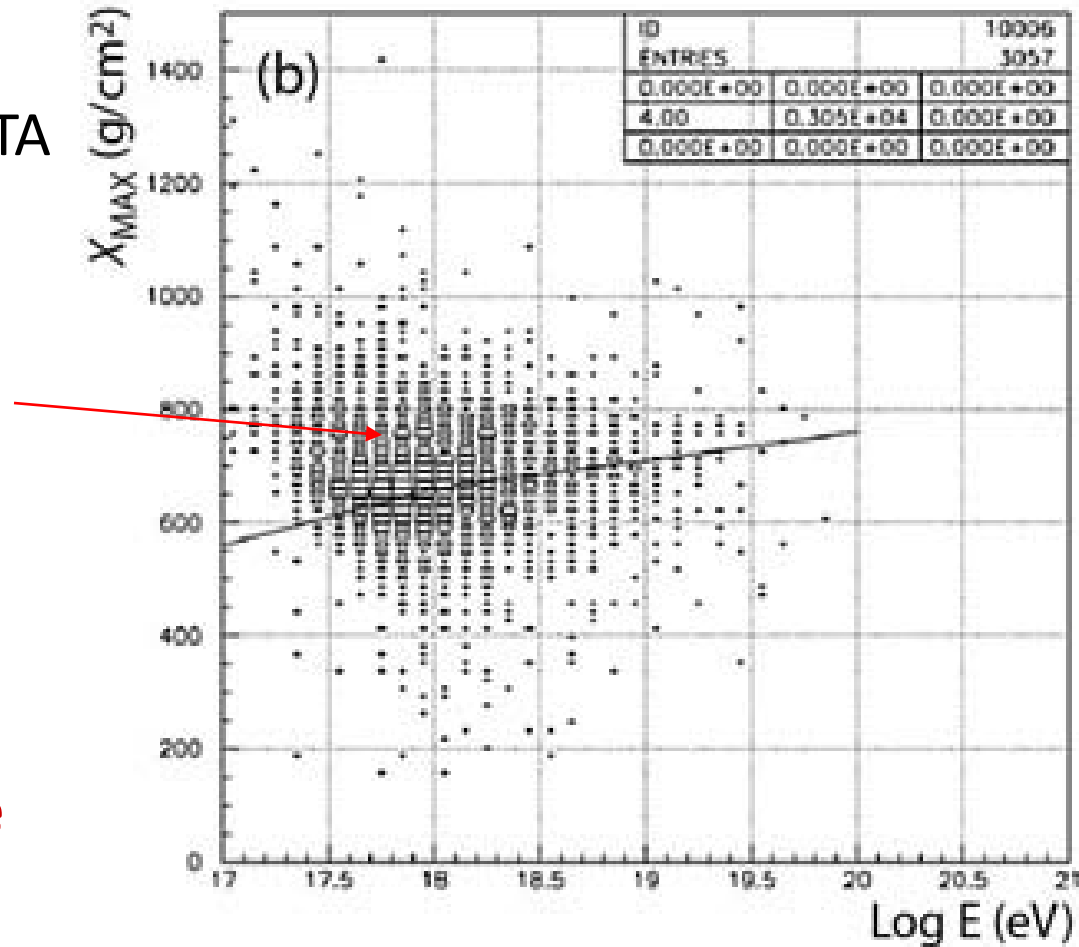
An example of TALE-FD placement

- Within the 4-7 km site separation window ideal for stereo fluorescence measurements in the 10^{18} - 10^{19} eV decade.
- Borders the periphery of the ground array where construction of infill arrays are possible (and needed)
- Availability of State Education trust Land (without BLM access and use constraints)



“31 Bias”: X_{max} below $\sim 10^{18}$ eV

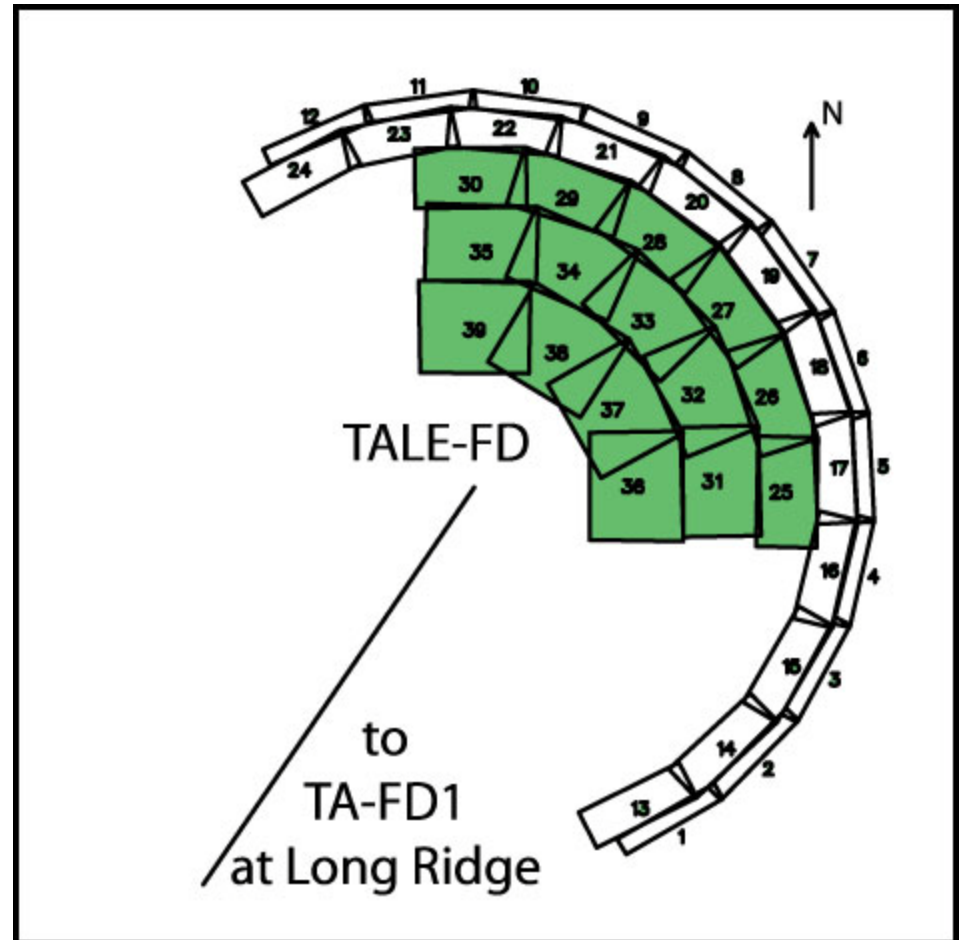
- X_{MAX} measurements below 10^{18} eV are beyond the scope of HiRes and Auger. TA is only a little better.
- Two-ring ($<31^\circ$ elevation) configuration introduces significant trigger bias toward low X_{max} (heavy composition) showers
- **TALE needs additional elements to cover this region, which contains the Second Knee Structure**



Data points show X_{MAX} of triggered events: Line gives measured/corrected $\langle X_{\text{MAX}} \rangle$

TALE Tower

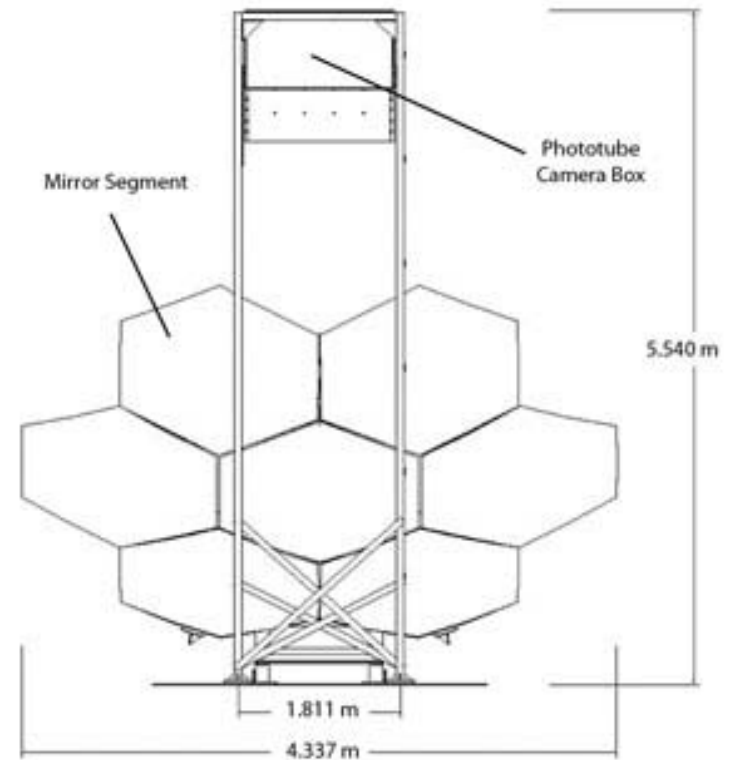
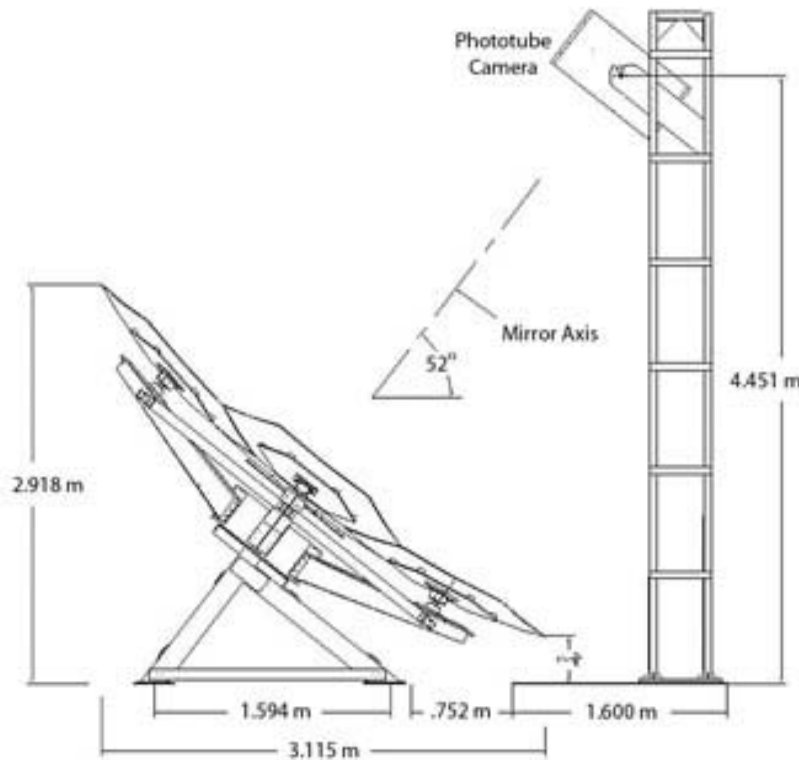
- The TALE Tower detector consists of 15 telescopes in its top three “rings”:
 - 6 (3) at 31-45°
 - 5 (3) at 45-59°
 - 4 (4) at 59-73°# in parenthesis shows the number of mirrors in the HiRes tower prototype at the same elevation
- The 6km telescopes also provide 16 telescopes directly below the top three rings compared to only 4 in the HiRes-prototype
- Stereo overlap with existing TA fluorescence Station validation of MC resolutions



Top view projection of the viewing solid angles of the TALE telescopes

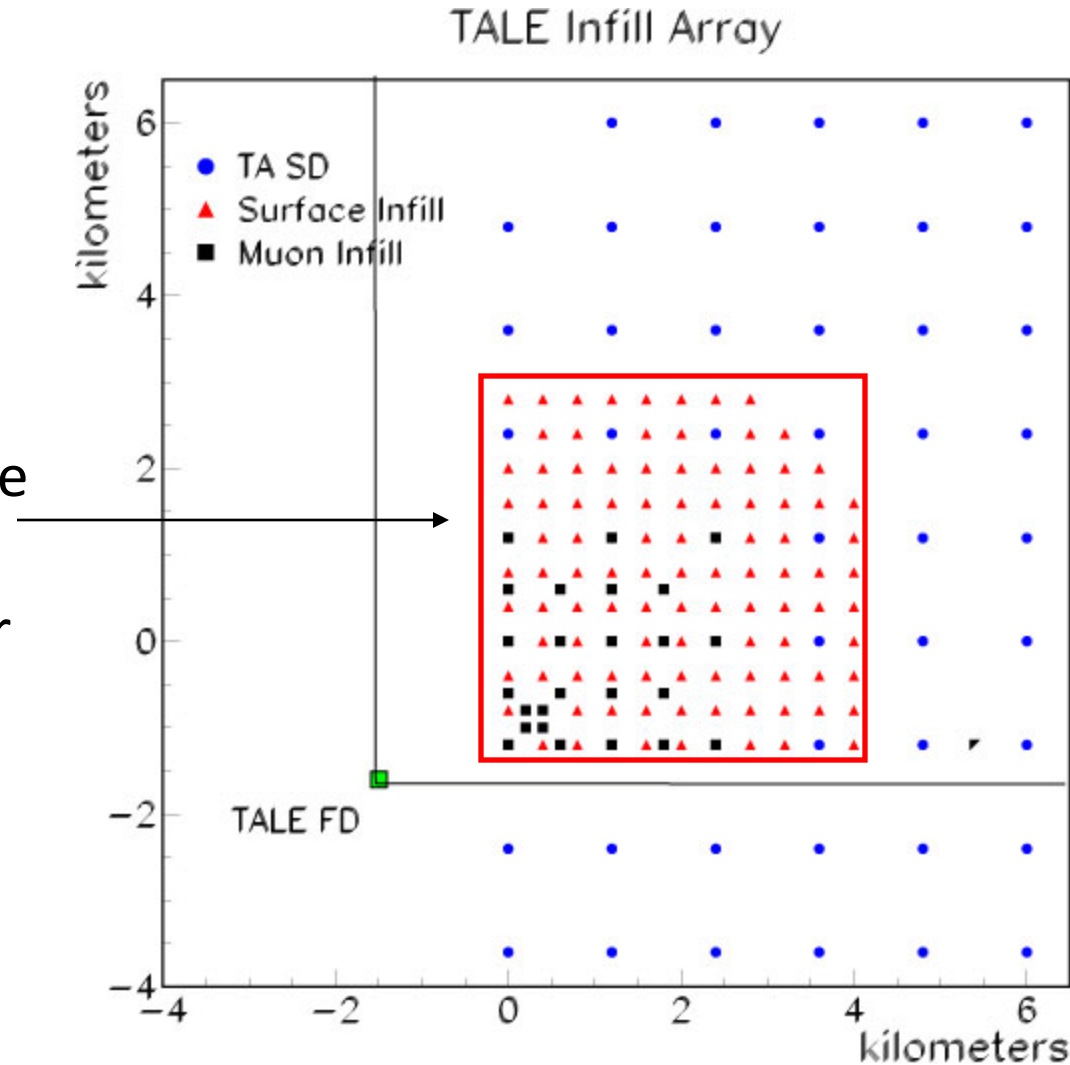
Tower Detector

- Use ~4 m diameter mirrors to **triple the collection area** over those of the re-deployed HiRes mirrors in the 6km stereo detector.
- **Eliminates trigger Xmax bias in the $10^{16.5}$ - $10^{18.0}$ eV range**
- Use scaled-up ~F1.1 optics identical to HiRes
- Re-use PMTs from HiRes telescopes
- Use **Winston cones** for light collection



Hybrid with Infill Array (Japan)

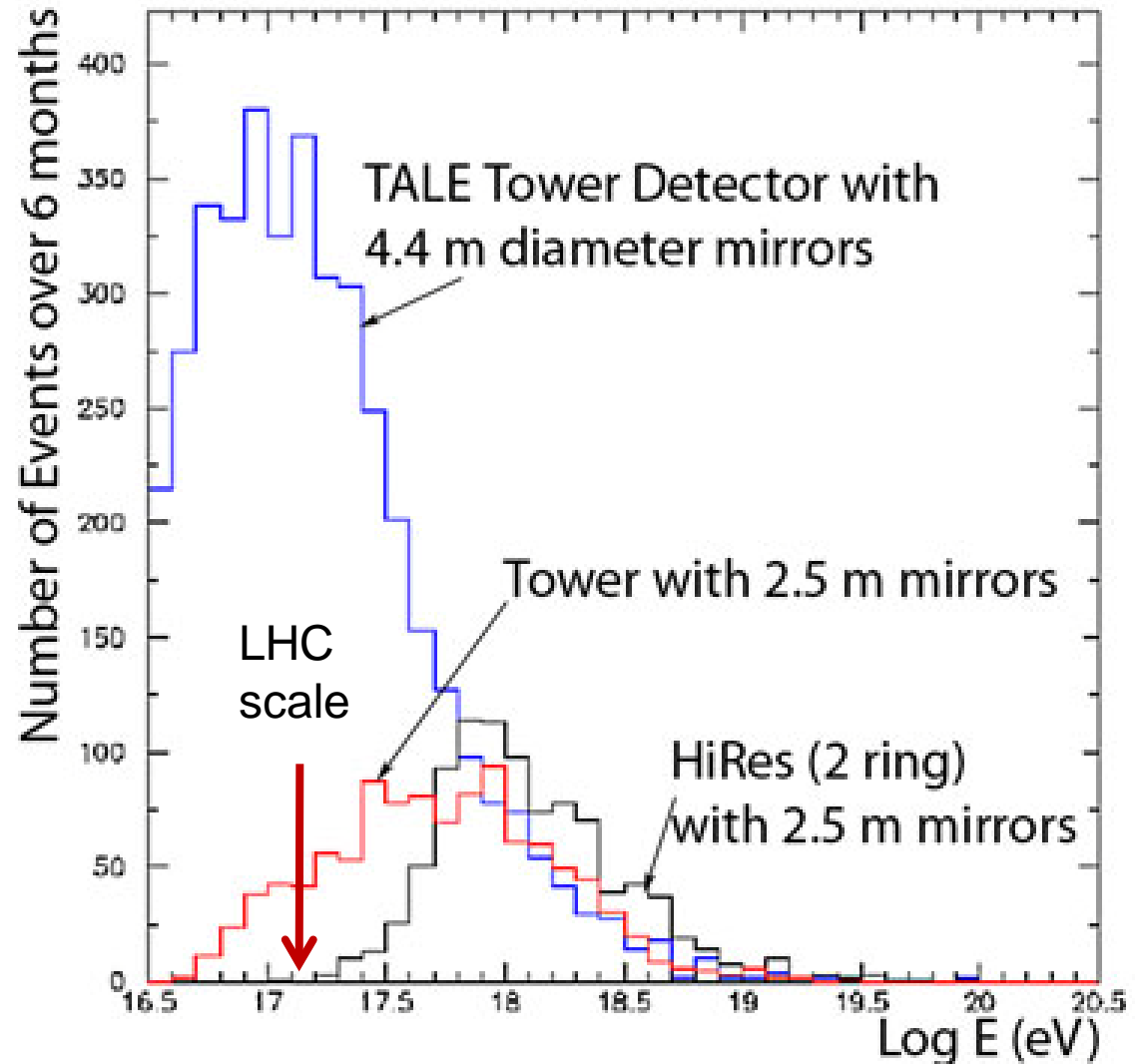
- Will place **111** additional surface array counters overlapping with main ground array: **4km x 4km**
- For the Tower detector these counters provide hybrid trajectory reconstruction for the lowest energy events that fall outside of the stereo overlap
- **25 muon detector array** placed in the “inner corner” of the infill array, **under 3m of packed soil**



This **2.5km x 2.5km** graded array is designed to work at **$10^{16.5}$ - 10^{18} eV**

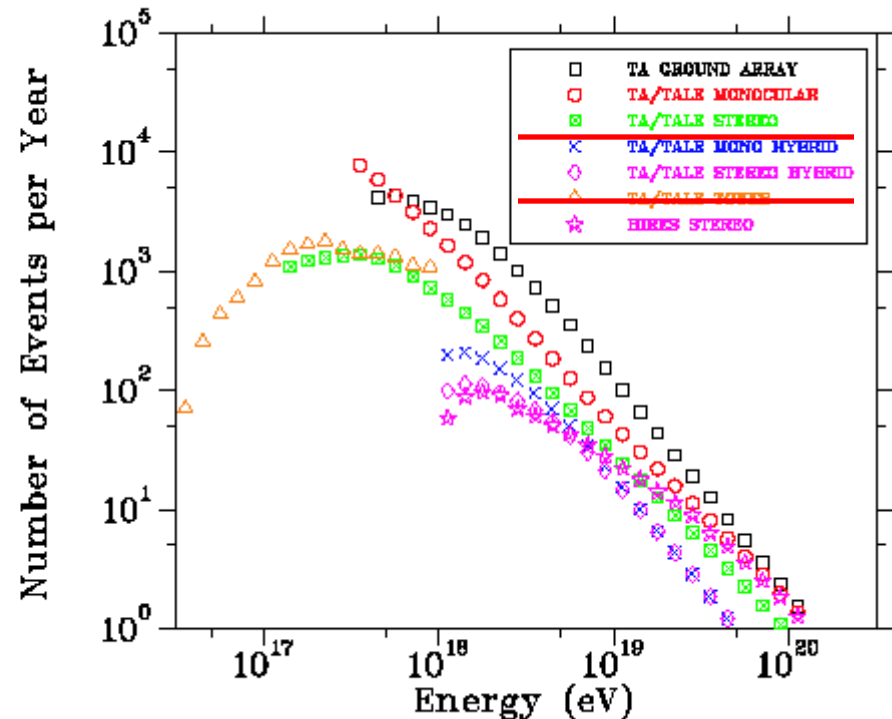
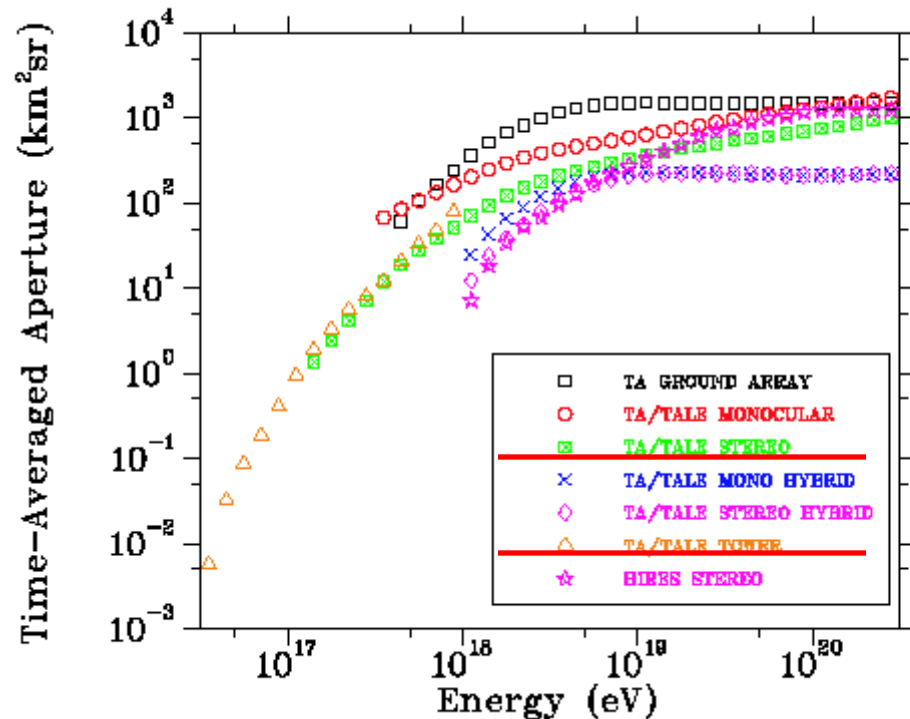
Improved Sensitivity

- The increased mirror size will improve substantially the sensitivity of TALE in the $10^{16.5}$ - $10^{17.5}$ eV energy decade
- Note the gain in sensitivity comes from the improvement in signal.
- Energy, angular and X_{\max} resolutions comparable to HiRes stereo or TA hybrid

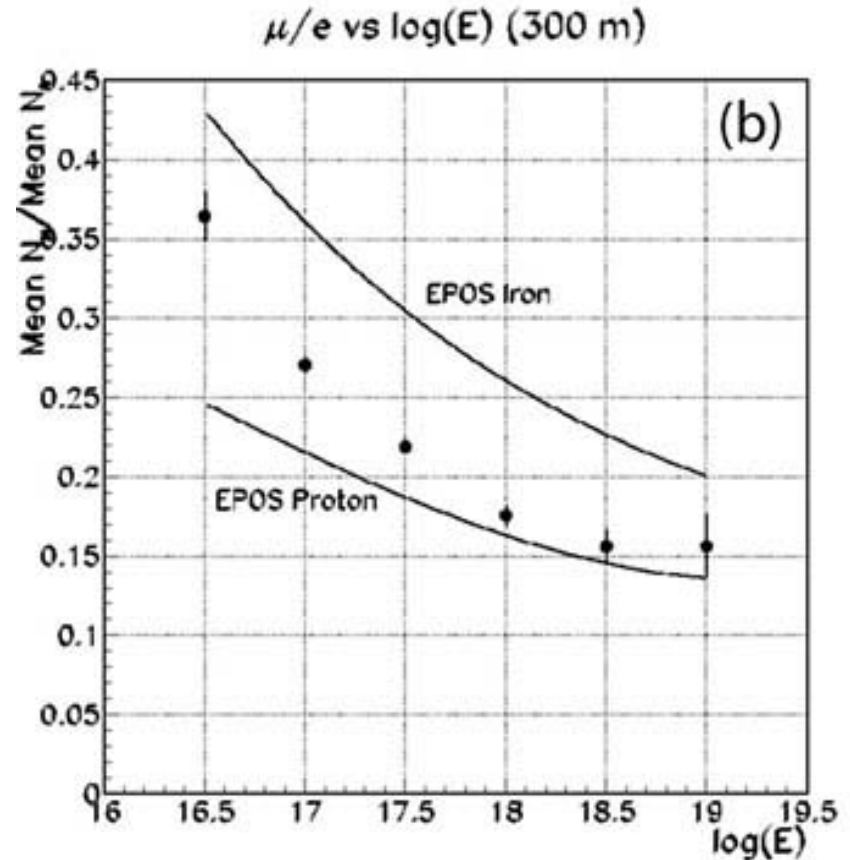
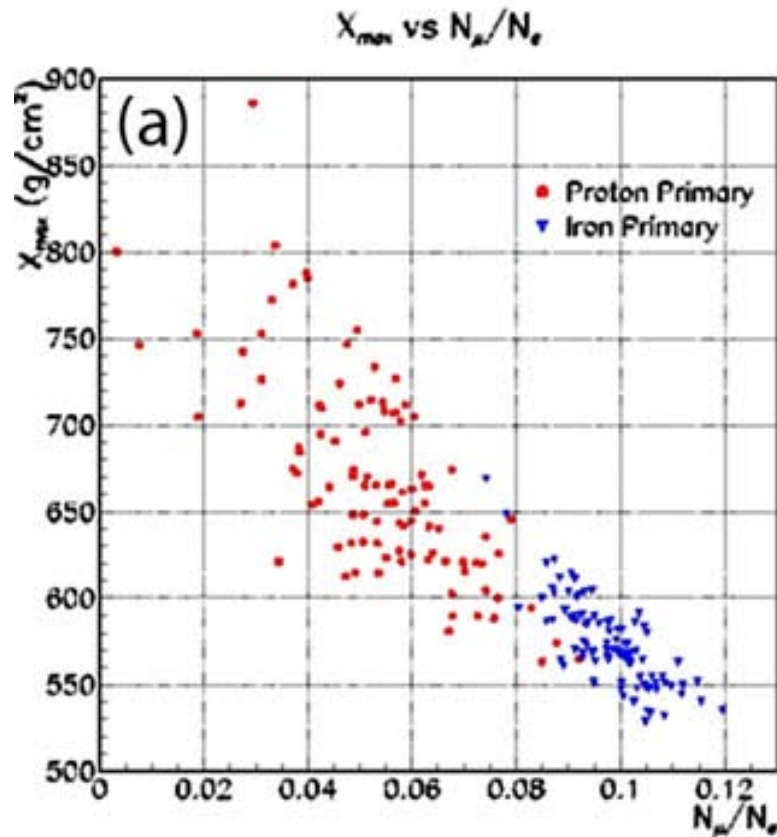


Aperture and Event Rate

- The TALE 6km stereo detector was designed for relatively flat aperture in the 10^{18} - 10^{19} eV decade
- The tower detector is specifically optimized to collect a maximum number of events in the 10^{17} - 10^{18} eV decade
- In both cases we will have long lever arms on either side of the spectral feature (ankle, 2nd knee) targeted



Composition via μ/e ratio



- Simulated 3-year TALE μ/e ratio ratio at 300m from core, at zenith angles of 25-35 degrees, for 10^{17} - 10^{18} eV decade: 50% protons at 10^{17} eV which increases to 80% protons at $10^{17.9}$ eV.
- The fit to the simulated data is shown with the curves for pure iron and proton CORSIKA w/ EPOS simulations.

TALE Summary

- In conjunction with TA, TALE provide overlapping (i.e. *cross-calibrated*) fluorescence (*stereo* or *hybrid*) coverage of cosmic rays from $10^{16.5}$ - $10^{20.5}$ eV
 - Single energy scale for the energy spectrum over four decades
 - X_{\max} composition measurement down to well below the “second knee” region
 - Anisotropy (with X_{\max} tagging)
- A Non-Imaging Cherenkov Experiment (NICHE) is being proposed to extend energy coverage of the TA Observatory down to below the knee