Cerenkov Events Seen by the TALE Air Fluorescence Detector

Tareq AbuZayyad
University of Utah

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Overview

- **TA L**ow **E**nergy extension (TALE) Fluorescence Detector.
- TALE Cerenkov Data Set.
- Monte Carlo and Event Reconstruction.
- Performance of Monocular Reconstruction.
- Summary and Outlook.

The Telescope Array Experiment

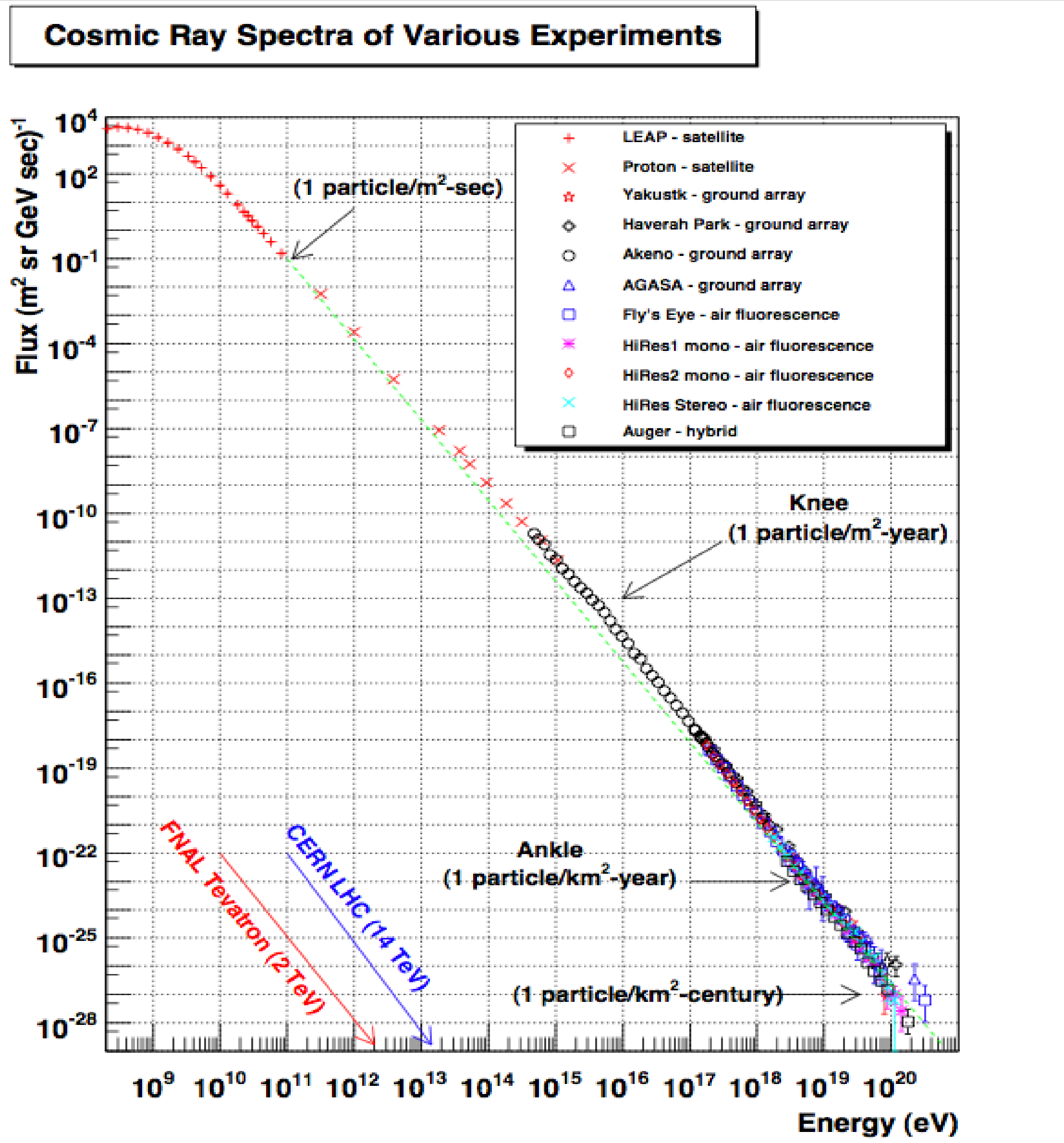
Telescope Array Collaboration

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 Kim[6], JH Kim[20], A Kitsugi[9], K Kobayashi[7], H Koers[21], Y Kondo[9], V Kuzmin[12], YJ Kwon[8], JH Lim[16], SI Lim[19], S Machida[3], K Martens[22], J Martineau[1], T Matsuda[10], T Matsuyama[11], JN Matthews[1], M Minamino[11], K Miyata[7], H Miyauchi[11], Y Murano[3], T Nakamura[23], SW Nam[19], T Nonaka[9], S Ogio[11], M Ohnishi[9], H Ohoka[9], T Okuda[11], A Oshima[11], S Ozawa[17], IH Park[19], D 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[5], 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 University, [6]Hanyang University, [7]Tokyo University of Science, [8]Yonsei University, [9]Institute for Cosmic Ray Research, University of Tokyo, [10]Institute of Particle and Nuclear Studies, KEK, [11]Osaka City University, [12]Institute for Nuclear Research of the Russian Academy of Sciences, [13]Kanagawa University, [14]Saitama University, [15]Tokyo City University, [16]Pusan National University, [17]Waseda University, [18]Chiba University [19]Ewha Womans University, [20]Chungnam National University, [21]University Libre de Bruxelles, [22]University of Tokyo, [23]Kochi University, [24]Hiroshima City University, [25]National Institute of Radiological Science, Japan, [26]Ehime University

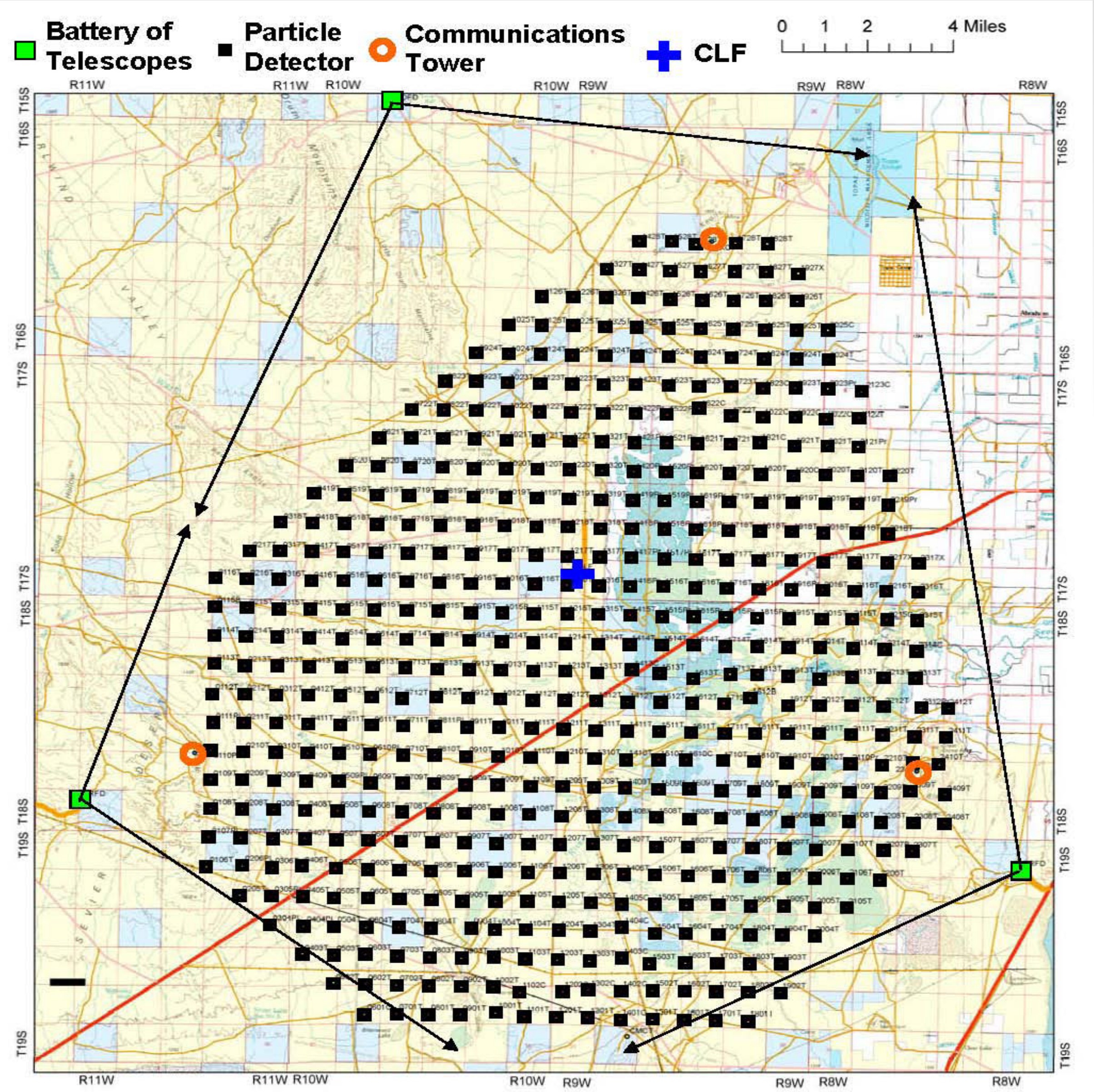
Telescope Array Experiment

- The Telescope Array (TA) experiment was originally designed for the study of ultra high energy (above ~1×10^{18} eV) cosmic rays.
- TA is a follow up experiment to AGASA/HiRes experiments with the goal of improving on both.
- TA Low Energy extension (TALE) aims to lower the energy threshold of the experiment to well below 10^{17} eV.



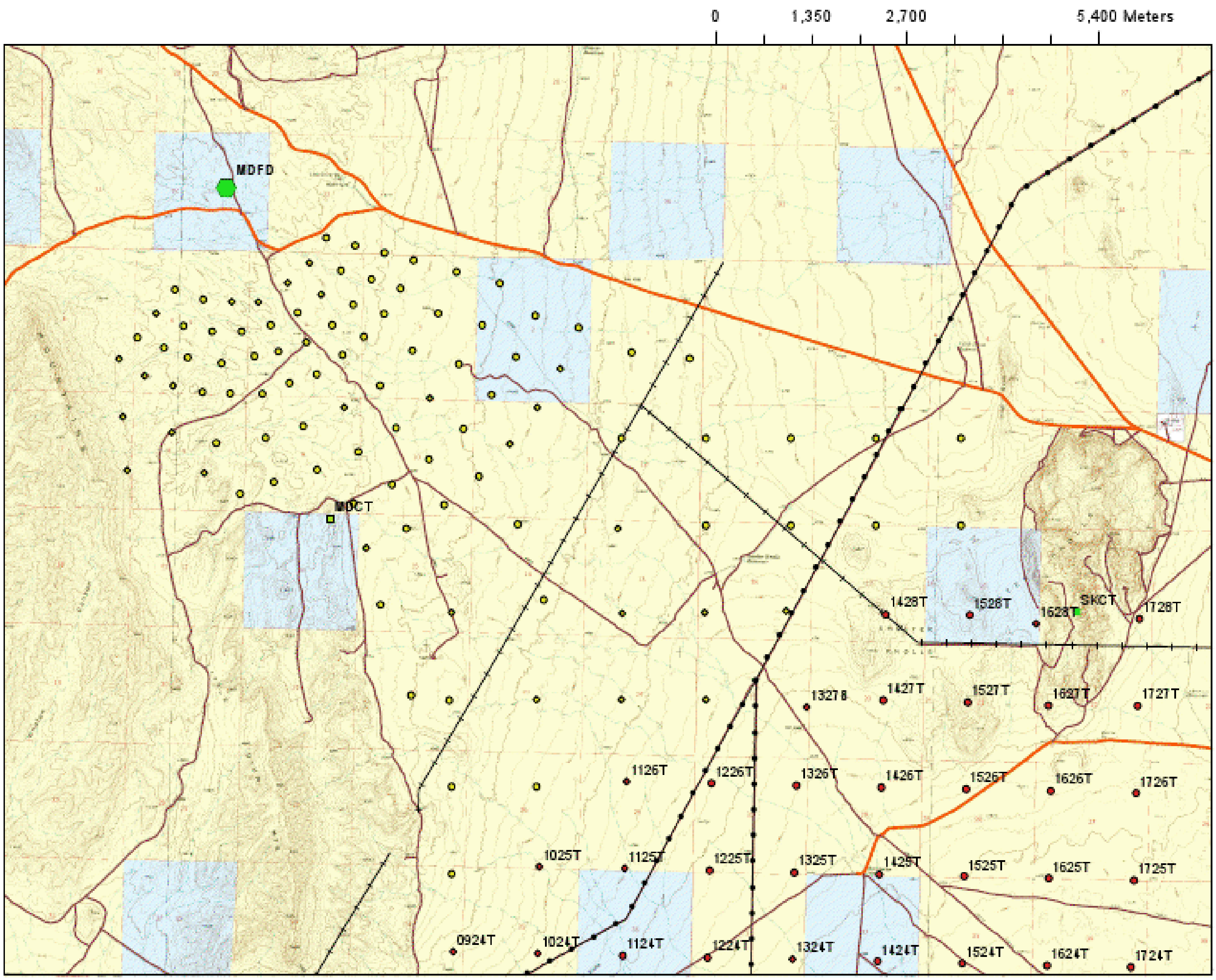
Telescope Array Experiment

- TA is located in Millard County, Utah, ~200 km southwest of Salt Lake City.
- Surface Detector: 507 scintillation counters 1.2 km spacing. (***run 24/7***)
- Three Fluorescence Detectors overlooking SD (***run only during moonless nights***):
  - Middle Drum (MD)
  - Black Rock (BR)
  - Long Ridge (LR)



TALE Surface Detector Infill Array

- Infill Array operates 24/7.
- However, when FD is on, we get the opportunity for hybrid observation.



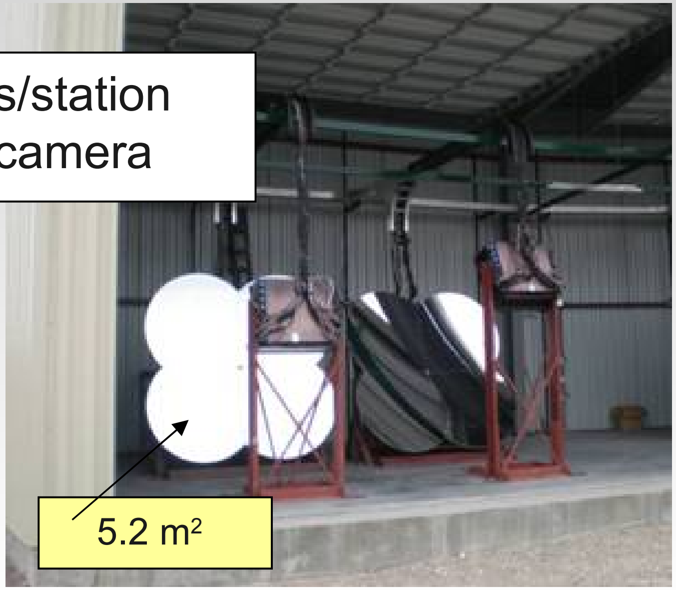
TA Fluorescence Detectors

Refurbished from HiRes

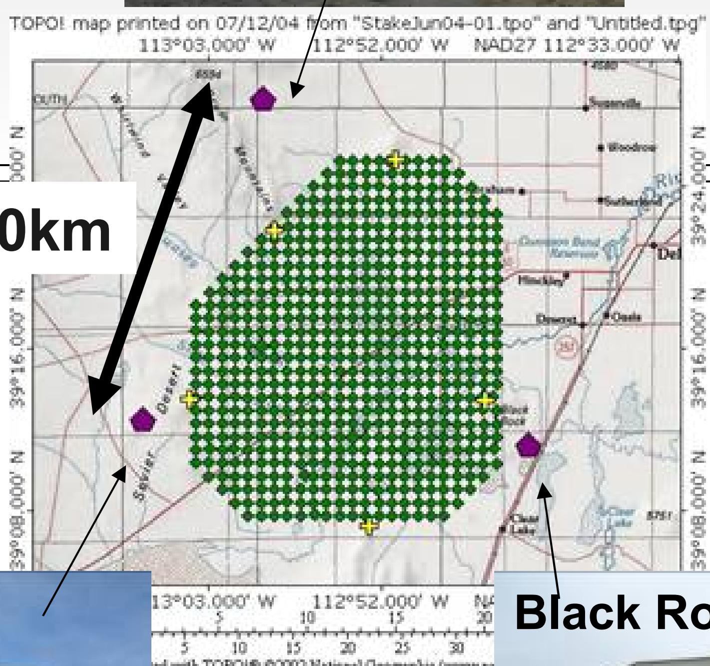
Observation started Dec. 2007

Middle Drum

14 cameras/station
256 PMTs/camera



5.2 m²



~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

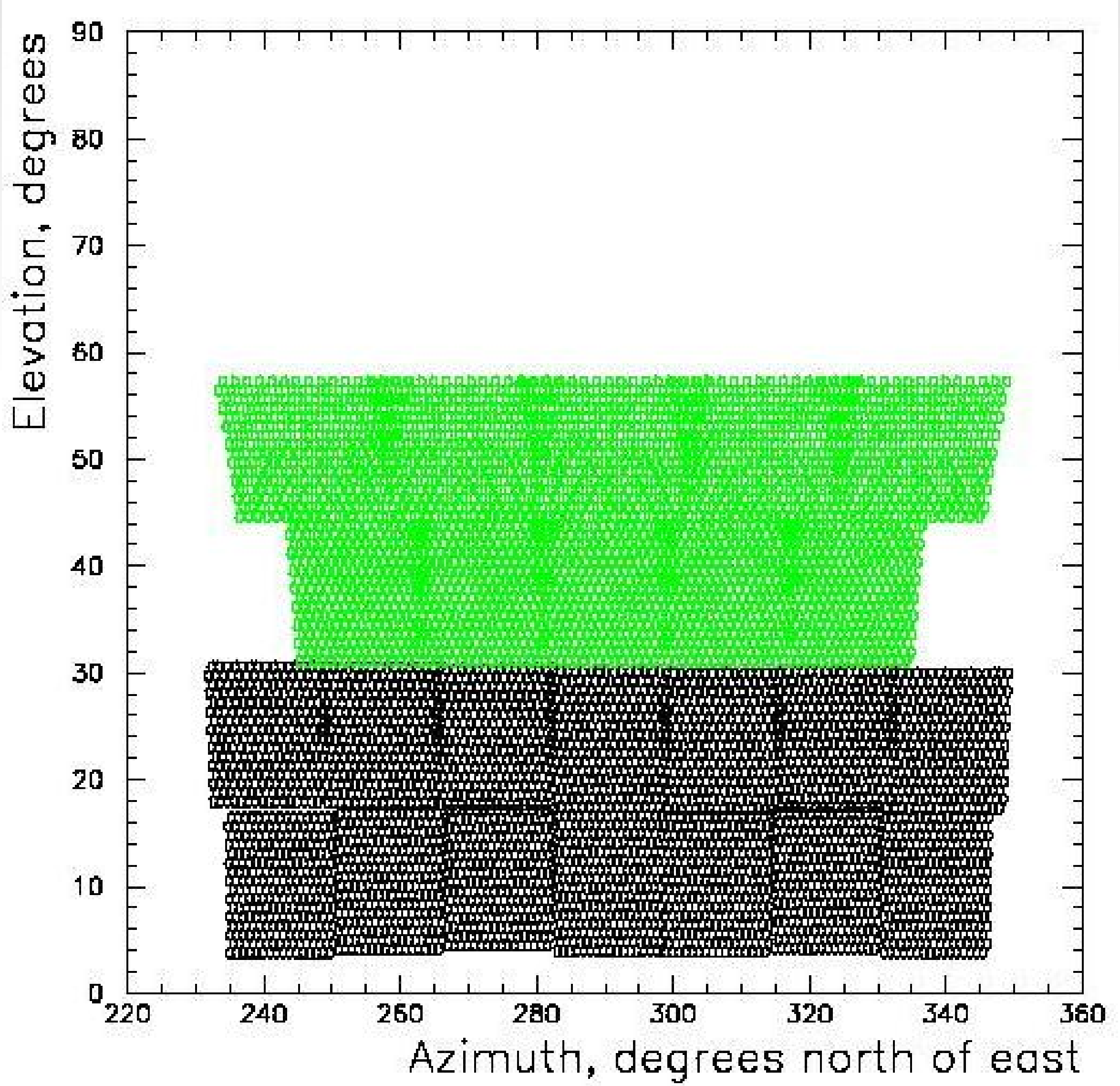
~1 m²

6.8 m²

Middle Drum TALE Observatory Site (14+10 Telescopes)

Middle Drum TA/TALE Viewing Range

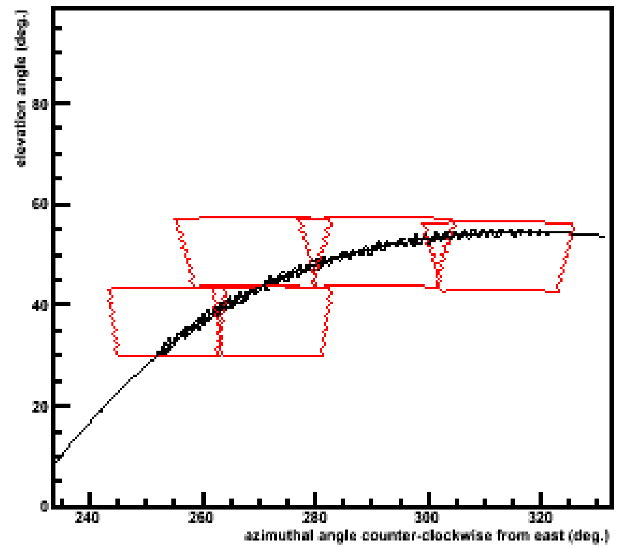
- TAMD + TALE
- 14 lower telescopes make up TA (Middle Drum) Detector.
- 10 higher telescope (new addition) make up the TA-Low Energy extension Detector.
- TALE telescopes equipped with (HiRes2) FADC electronics.

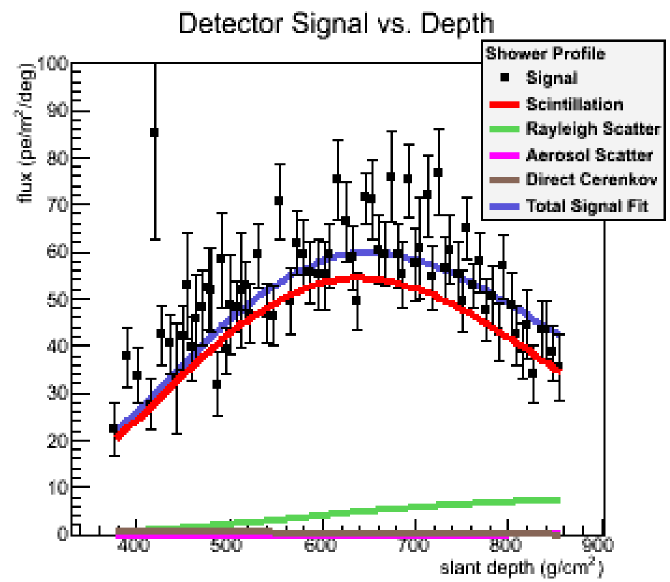


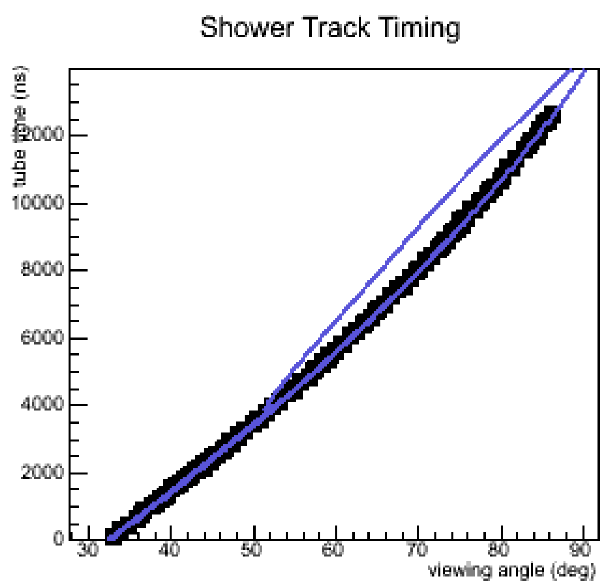
TALE Cerenkov Data Set

Example event TALE FD designed to look for

- Five (Err.. eight) telescope event.
- Event duration ~ few micro-seconds
- Angular extent long
- … in case hybrid then even better geometrical reconstruction
- Threshold ~3e16 eV







TALE event data

Event Starting: 7: 0:0.695370

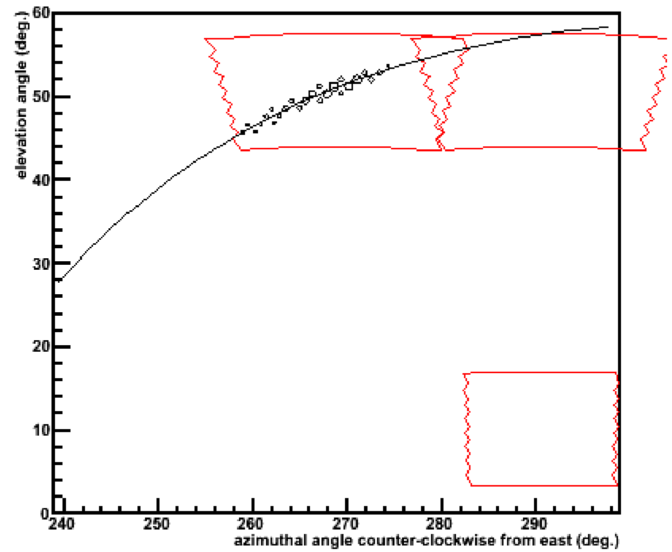
Energy: 0.530 EeV
Shower max size: 3.565e+08 particles
Shower max depth: 631.247 g/cm^2
Profile Fit χ^2/ndf: 1.2395

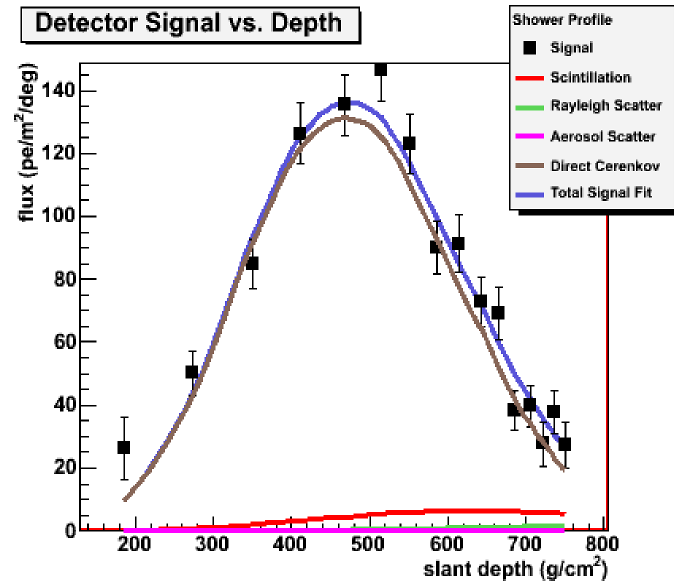
Rp Magnitude: 5.839 km
ψ angle: 55.1 degrees

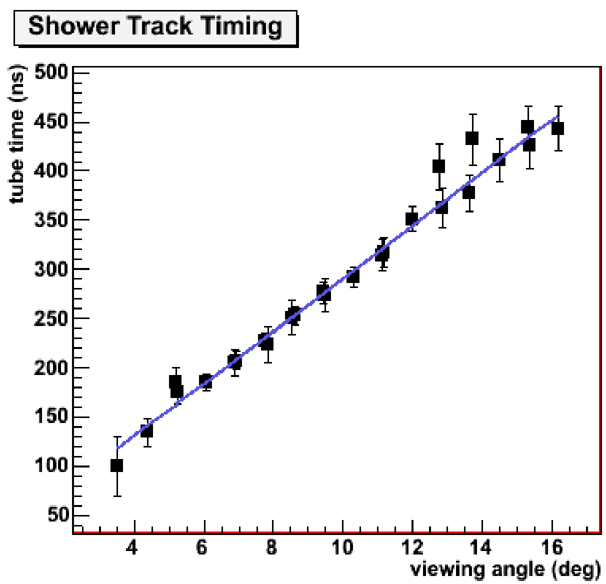
Shower azimuthal angle: 8.2 degrees
Shower zenith angle: 48.0 degrees
Angle to Magnetic field: 60.5 degrees

Example Cerenkov event seen by TALE FD

- Most are single telescope
- Event duration ~100ns - ~600 ns
- Angular extent short
- Unlikely to trigger surface detector
- Threshold ~3e15 eV







TALE event data

Event Starting: 0: 0:0.139663747441801

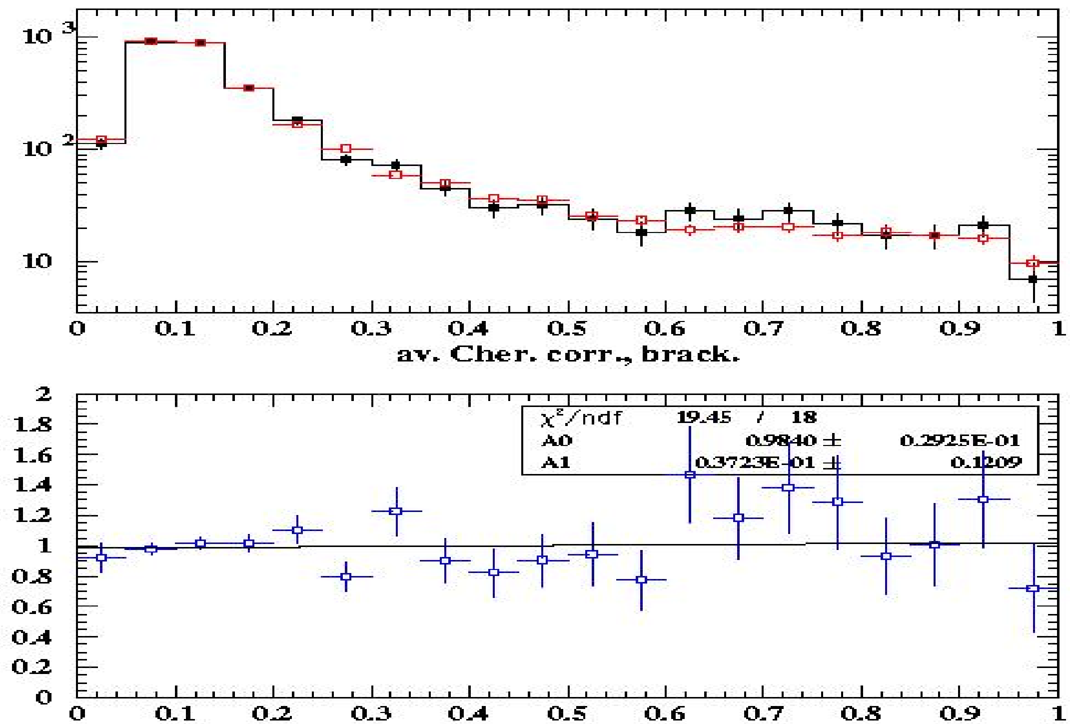
Energy: 9.241 PeV
Shower max size: 6.143e+06 particles
Shower max depth: 605.810 g/cm^2
Profile Fit χ^2/ndf: 0.7362

Rp Magnitude: 0.912 km
ψ angle: 106.9 degrees

Shower azimuthal angle: -80.1 degrees
Shower zenith angle: 35.0 degrees

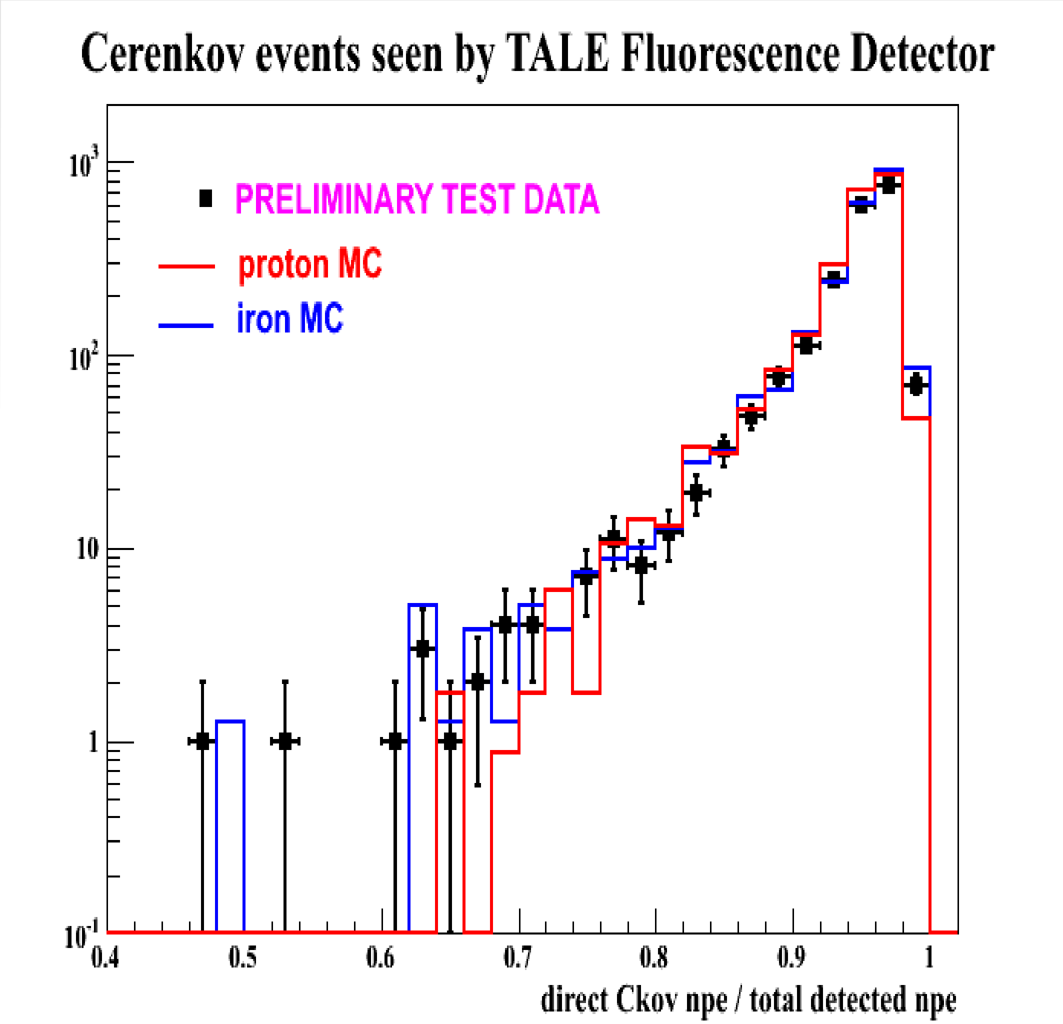
Cerenkov Contribution to Detected Signal

- HiRes-II event set.
- Most events have less than 20% contribution from direct ***and*** scattered Cerenkov light.



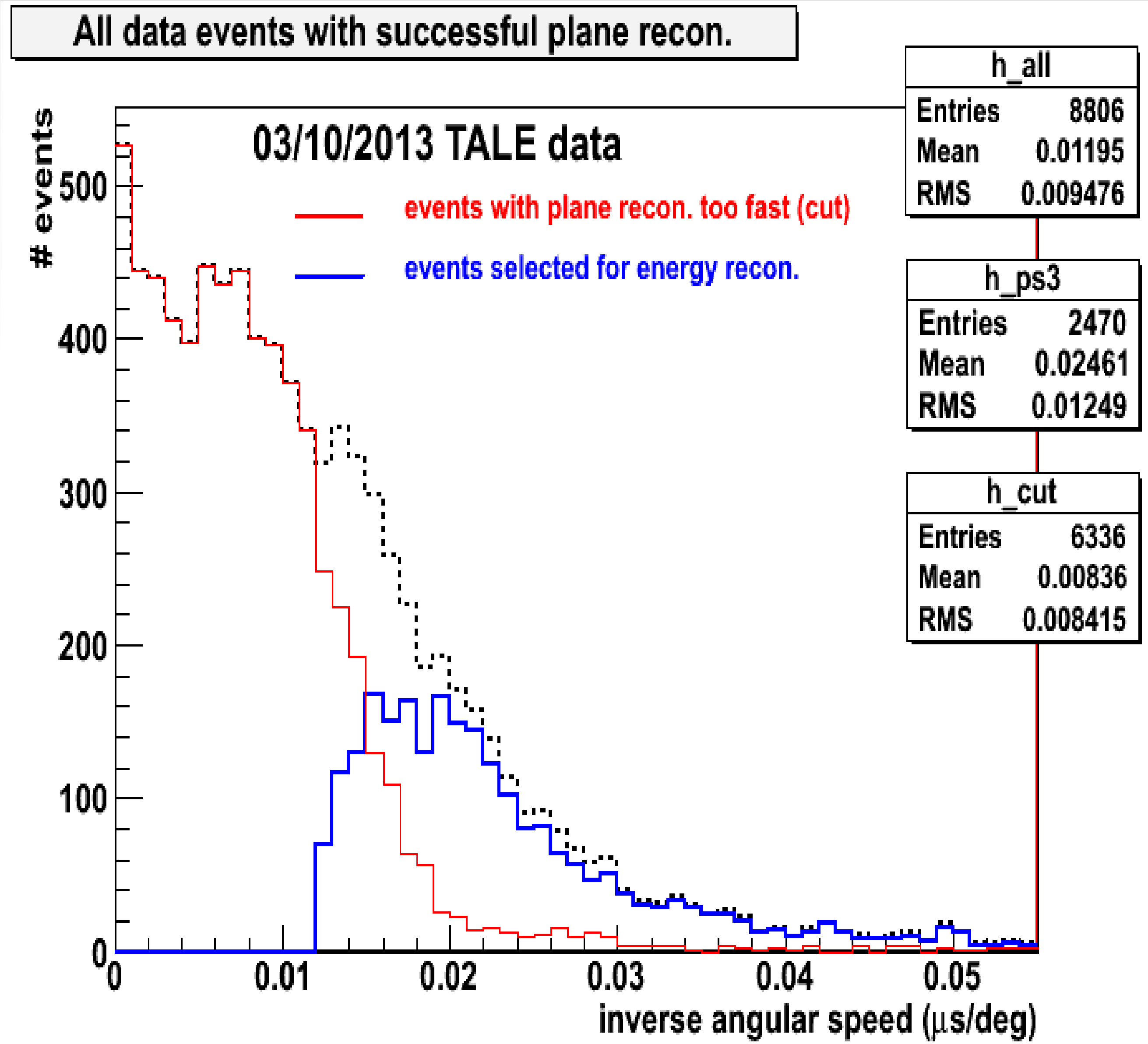
Cerenkov Contribution to Detected Signal

- TALE Cerenkov event set.
- Most events have more than 90% contribution from *direct* Cerenkov light.



Cerenkov events data rate

- Vast majority of triggered events are Cerenkov (lower energy).
- Still dominant, even after removing “Cerenkov Blasts”



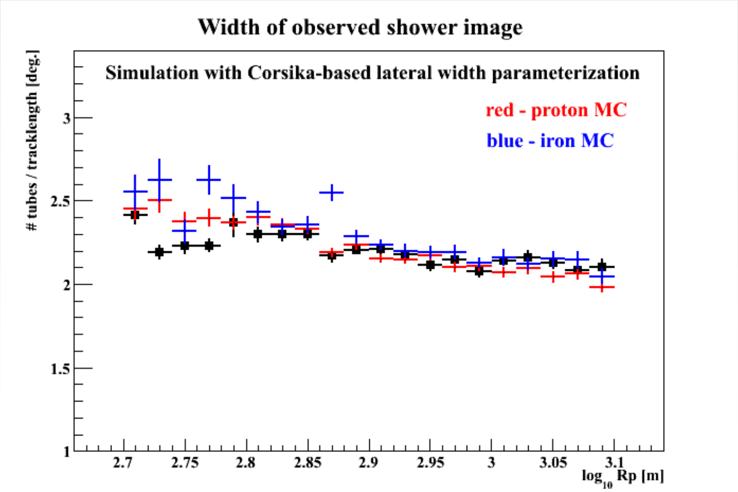
Monte Carlo and event Reconstruction

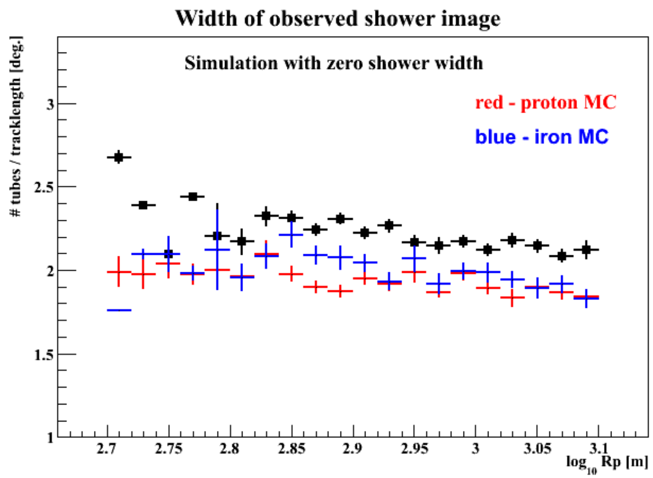
TALE fluorescence detector MC

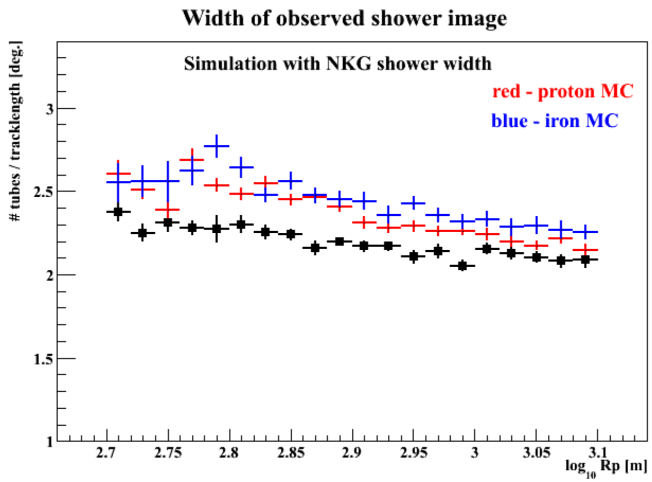
- Added support of TALE telescopes to existing MC code used by TA-MD detector for the past 6 yrs.
  - Identical optics; different electronics.
- An updated description of the shower lateral width was ***required*** for the treatment of Cerenkov events.
- Treatment of Cerenkov in detector MC is still under development.
- Testing / Verification studies are on-going.

Shower lateral width and image of observed events

- # triggered PMTs divided by angular tracklength

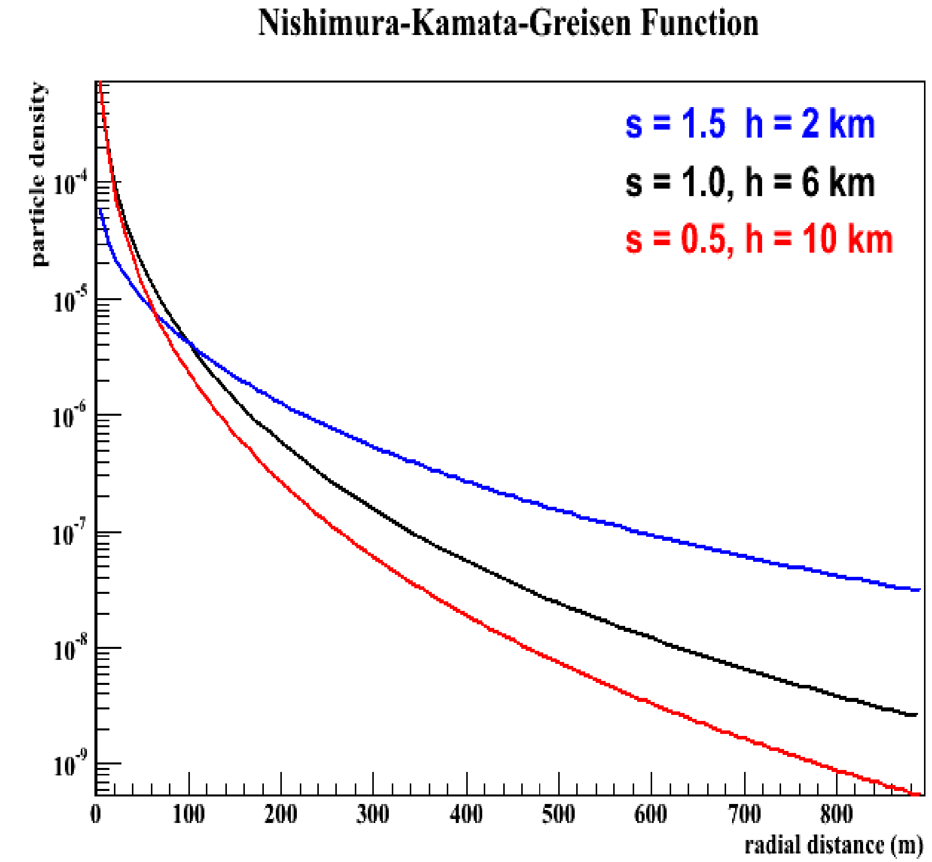






Lateral width of EAS

- Separate treatment for fluorescence and Cerenkov photons.
- Based on parameterizations in Lafebre et al. (arXiv:0902.0548)
- Fluorescence uses all particle NKG like function
- Cerenkov uses NKG like function for a fixed electron energy:
  - Age dependent
  - Altitude dependent
  - *Viewing angle* dependent

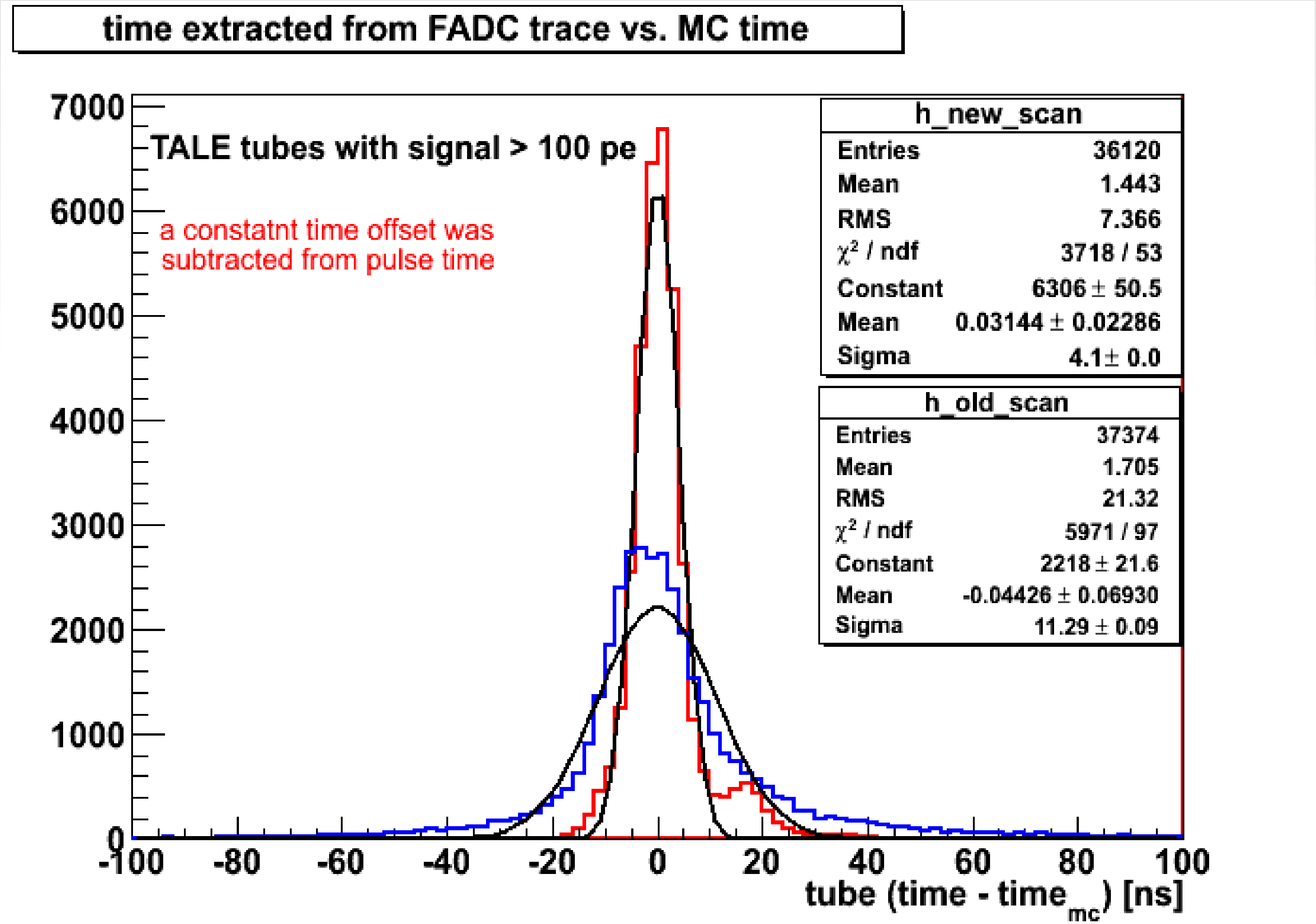


TALE fluorescence detector MC

- A different approach to simulating the detector response to Cerenkov light was also implemented:
- Corsika / IACT (arXiv:0808.2253 [astro-ph])
  - Full 3D MC shower development
  - Cerenkov photons production
  - Cerenkov photons detection (sphere surrounding telescope mirror)
- We can test our reconstruction code (and parameterizations) ***against an external, "true MC" simulation***.
- *Work in Progress, will report on in the future.*

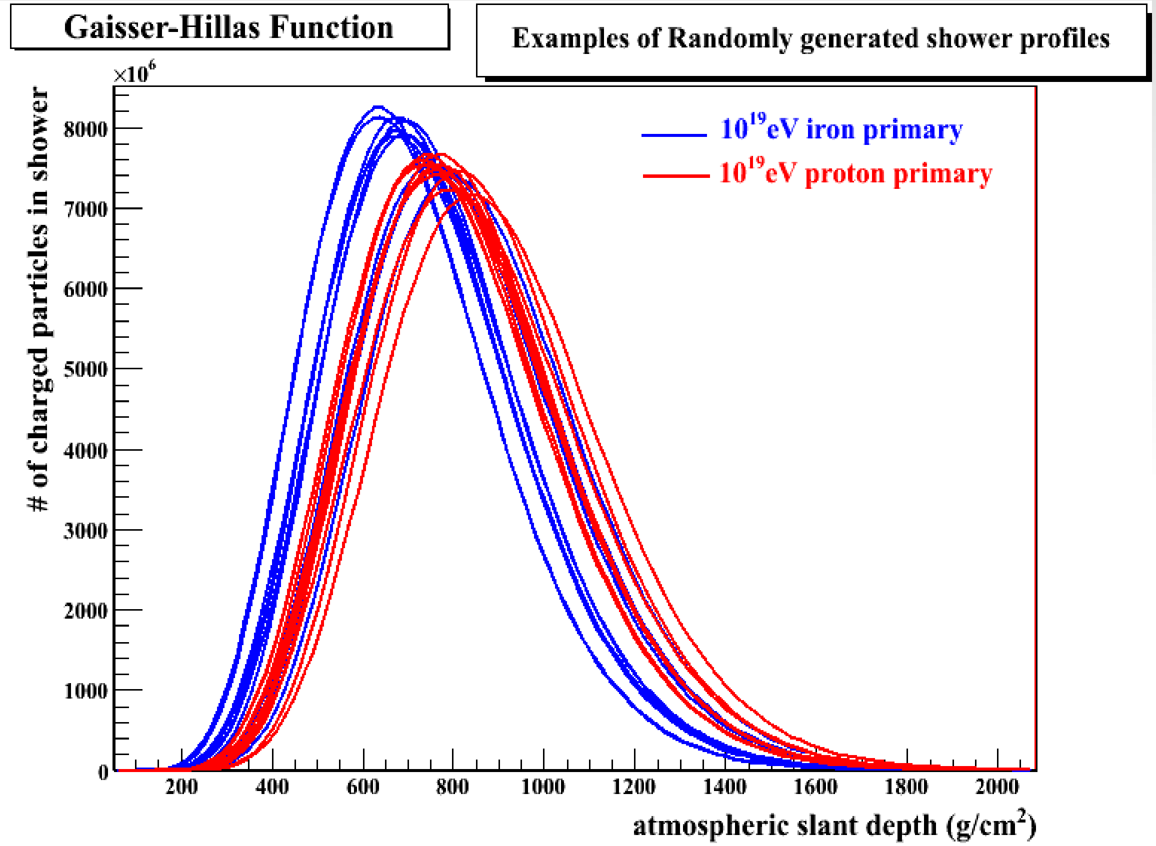
TALE Event Reconstruction (PMT Timing)

- Cerenkov events are “fast”. Need best possible timing
- TALE electronics has 100 ns FADC sampling
- Based on MC study: We can get ~5ns timing for bright signals and better than ~20ns for most/all tubes.



TALE Event Reconstruction (EAS Parameters)

- Primary particle energy (***E***)
- Shower Geometry:
  - A line segment from the top of the atmosphere, ~47km, to the ground. **Rp_vec**[3], **ut_hat**[3]
- Shower Longitudinal Profile:
  - Parametrization given by a Gaisser-Hillas function with four parameters (***N_max, x_0, x_max, lambda***)
  - ***x*** [g/cm²] is the atmospheric slant depth along the shower track.
  - ***N(x)*** is the number of charged particles at depth x
- A total of eight free parameters:
  - ***E*** → ***N_max***
  - ***ut_hat*** is a unit vector & is normal to ***Rp_vec***.



$$N(x) = N_{max} \times \left(\frac{(x - x_o)}{(x_{max} - x_o)} \right)^{\frac{(x_{max} - x_o)}{\lambda}} \times e^{\frac{(x_{max} - x)}{\lambda}}$$

TALE Event Reconstruction (Standard Procedure)

1) Fit Shower-Detector plane

2) Fit Rp, psi angle

- Monocular timing
- Monocular timing; with shower core location provided by Surface Detector.

3) Fit Shower profile and energy

- ***Geometry fixed*** by steps 1, 2
- GH lambda parameter typically fixed to a nominal value.

Reconstruction of TALE Cerenkov Events (Profile Constrained Fit)

1) Fit Shower-Detector plane

2) Fit Rp, psi angle

- Profile Constrained Geometry Fit (As in HiRes1 recon.):
    - ***Assume*** a known shower profile (xmax).
    - Scan psi angle, use timing for Rp determination.
    - For each trial geometry fit observed npe (i.e. profile fit)
    - Find best geometry for given shower profile.

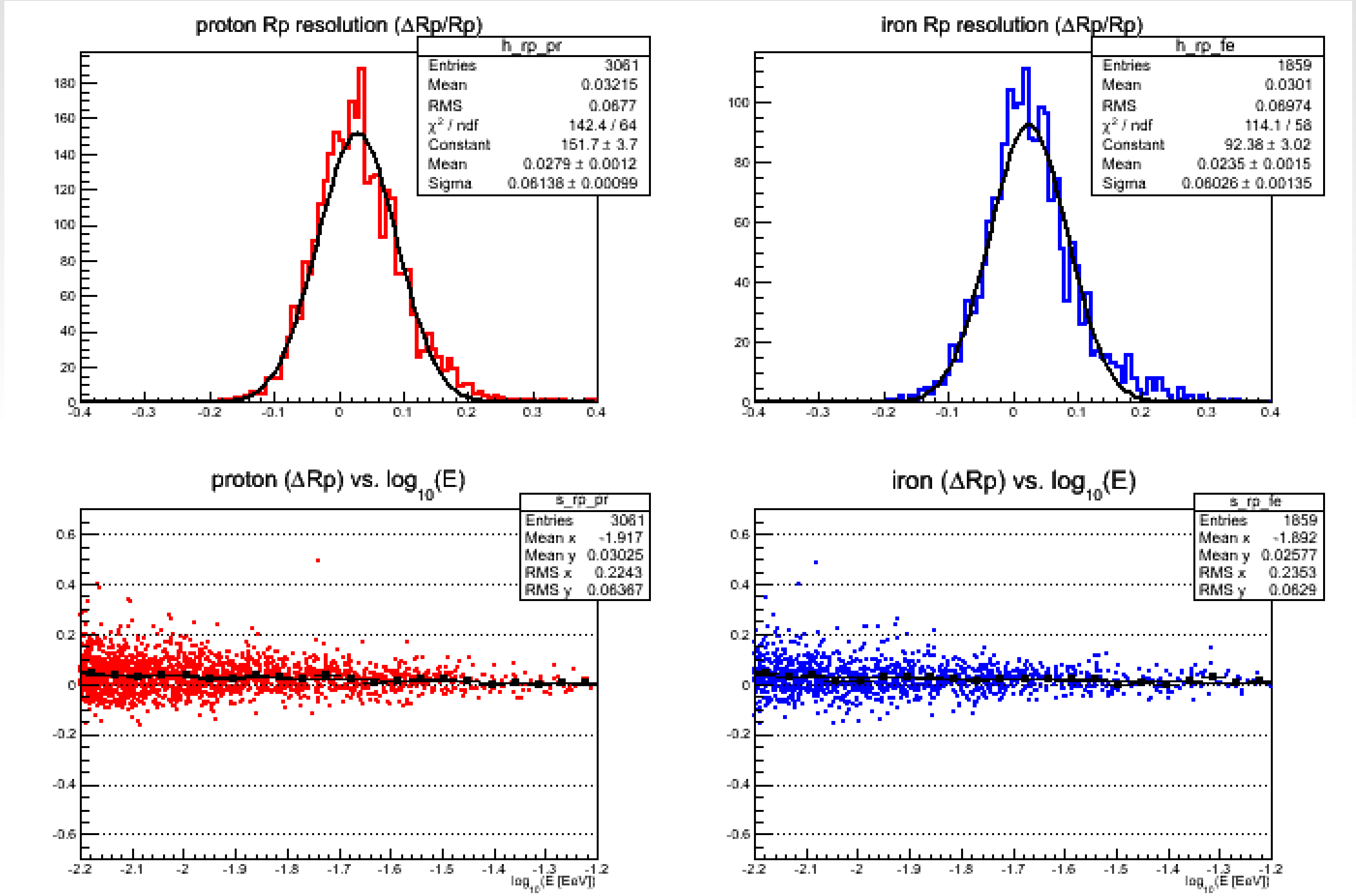
3) Fit Shower profile and energy

- ***Geometry fixed*** by steps 1, 2
- ***Release xmax*** parameter. Perform a standard profile fit.

Performance of Monocular Reconstruction

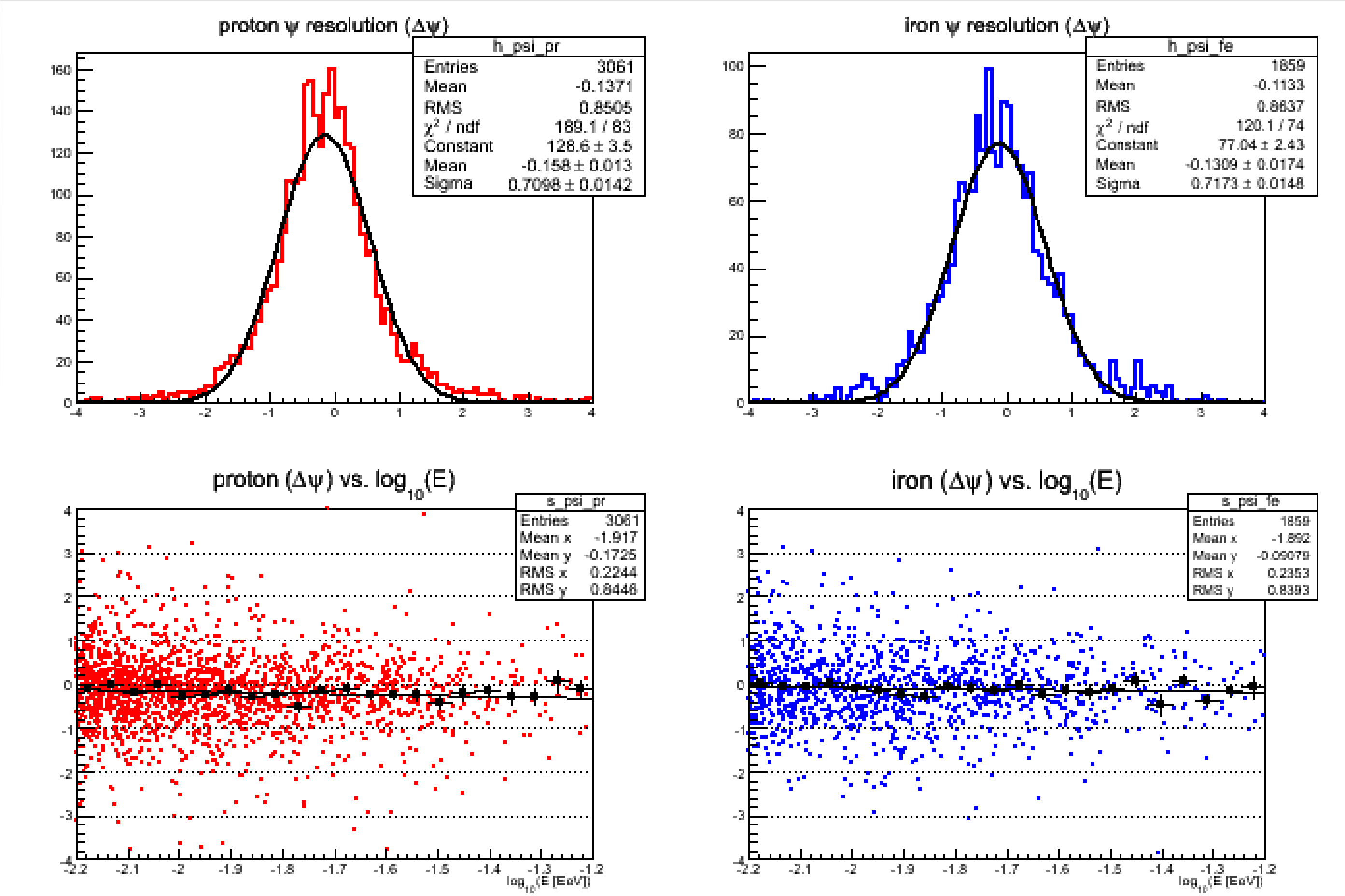
Shower Rp resolution

- Shower Impact parameter



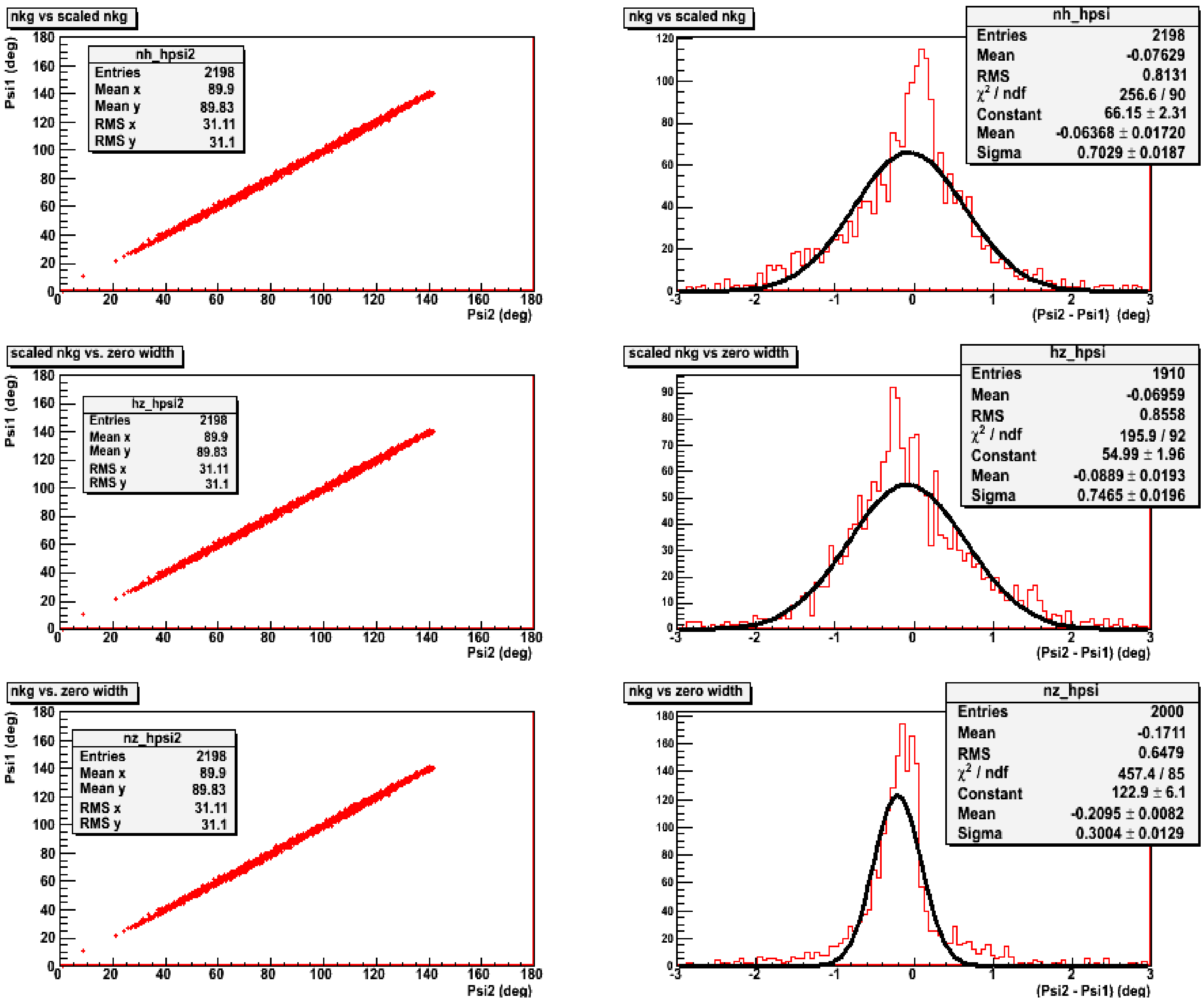
Shower psi angle resolution

- Shower Angle in the plane



Effect of changing lateral width in the reconstruction

- Real data reconstructed with three different assumptions about lateral width.
- Shown are differences in reconstructed psi from each fit.



Summary and Outlook

- We developed a new event reconstruction technique which allows us to use a Fluorescence detector as an Imaging Air Cerenkov Telescope
- The quality of the reconstruction and possible systematic effects are still under study.
- TALE as a Cerenkov detector can reach energies lower than 10^{16} eV with very high statistics.