Preliminary Search for Exotic Events
in the Auger Cosmic Ray Observatory Surface Detector Data

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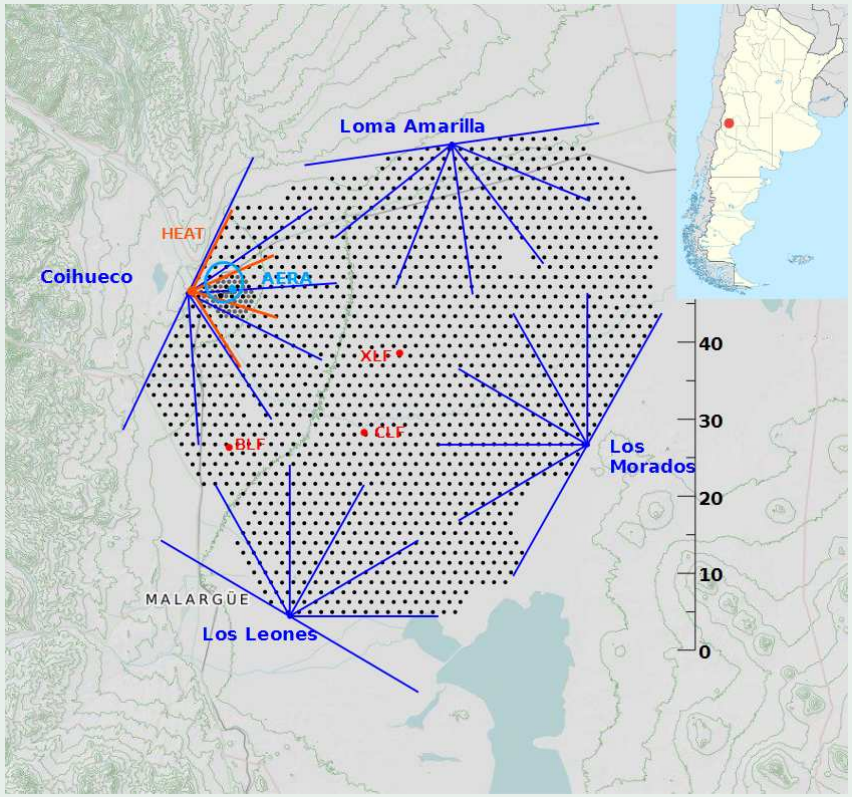
Pierre Auger Cosmic Ray Observatory

Detecting Ultra High Energy Cosmic Rays

- Hybrid Cosmic Ray Observatory
  - 1600 Surface Detectors, Cherenkov Water Tanks (SD)
  - 4 Fluorescence Detectors Stations (FD)
- Designed to detect Ultra High Energy Cosmic Rays
  - $E > 10^{18} eV (EeV)$
  - Examining the high end of the Cosmic Ray Spectra
- Detection Area of 3000 km^2

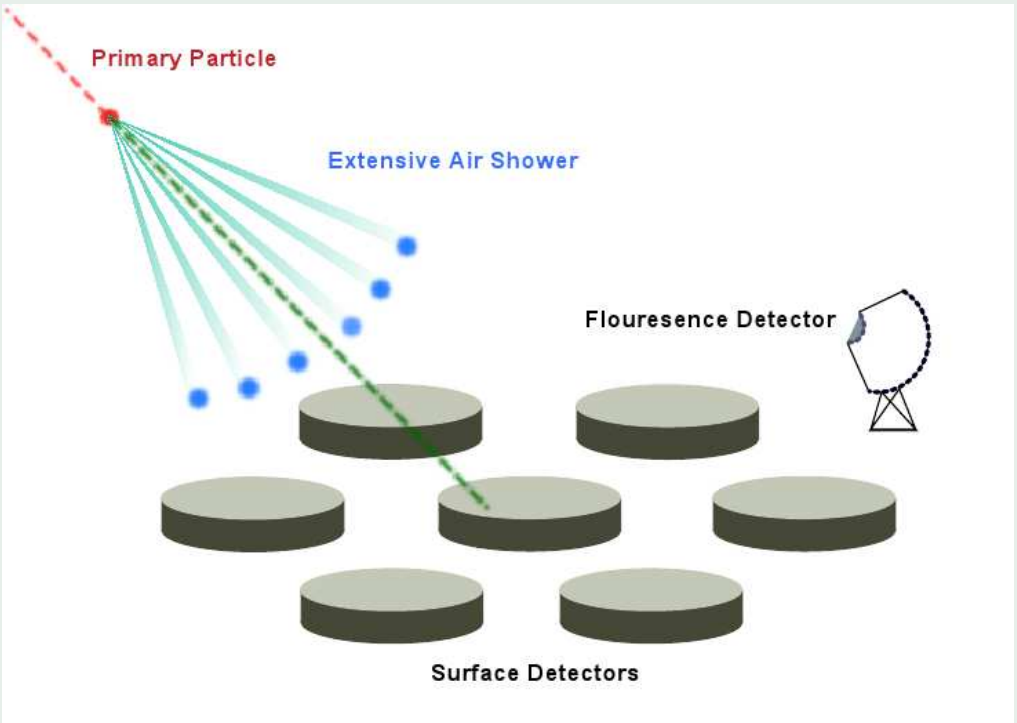
Auger Observatory Overview



Blue Dots are FD Stations **Black dots are SDs**.
Adopted From: Darko Veberic, Auger Collaboration, and http://en.wikipedia.org/wiki/Malargue

Cosmic Rays and Extensive Air Showers
Particle Interactions within the Atmosphere

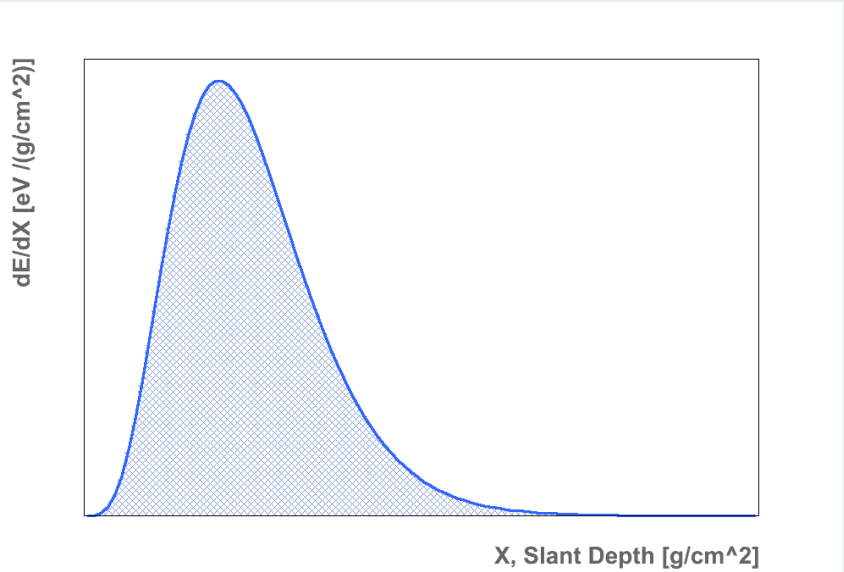
Cosmic Ray → Extensive Air Shower → Detection



- Primary particle enters the atmosphere
- Loses energy through the interactions within the atmosphere
  - Creates an Extensive Air Shower
- Secondary particle cascades are detected in the SDs & FDs

Longitudinal Development Profiles
Understanding the Particle's Interactions within the Atmosphere

Longitudinal Development Profile

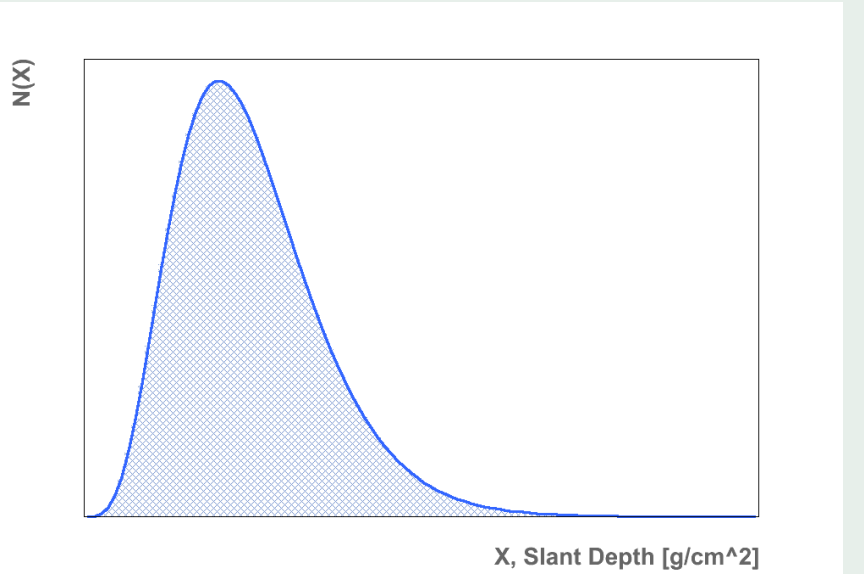


- $\frac{dE}{dX}$: The loss of energy of the Primary Particle to secondary particles at that slant depth.
- $X = \int \rho_{atmo}(s)\, ds$: Slant Depth. The amount of matter a particle will pass through as it propagates through the atmosphere. Zero is at the top of the atmosphere.

Giasser Hillas (GH) Function

$$N(X) = N_{max}\left(\frac{X - X_0}{X_{max} - X_0}\right)^{\left(\frac{X_{max}-X_0}{\lambda}\right)} \exp\left(\frac{X_{max} - X}{\lambda}\right) \quad (1)$$

Single Giasser Hillas Bump

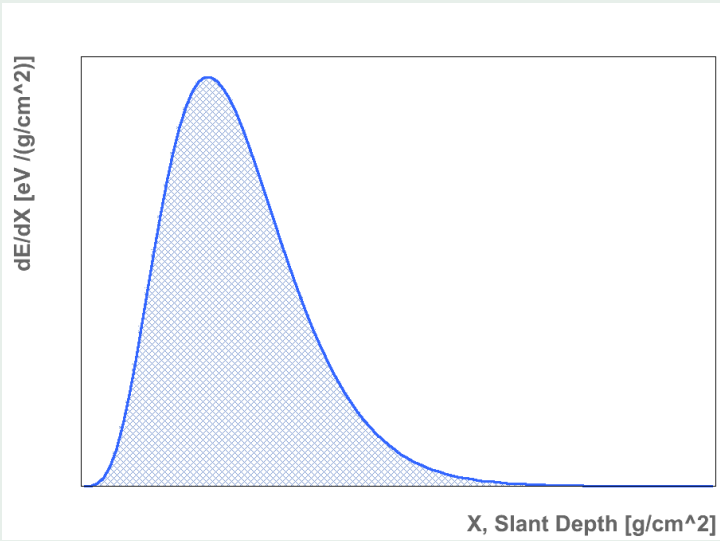


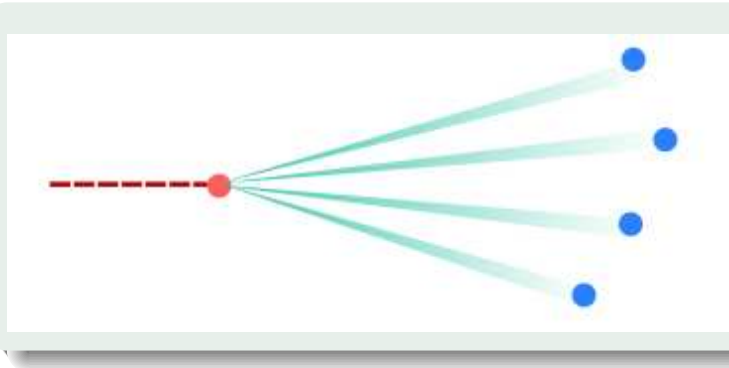
- N_{max} : Number of particles at the slant depth of shower maximum.
- X_0 : Slant depth of first interaction.
- X_{max} : Slant depth of shower maximum.
- λ : Shower decay length.

Exotic Events

Single Bump vs. Double Bump Shower Profiles

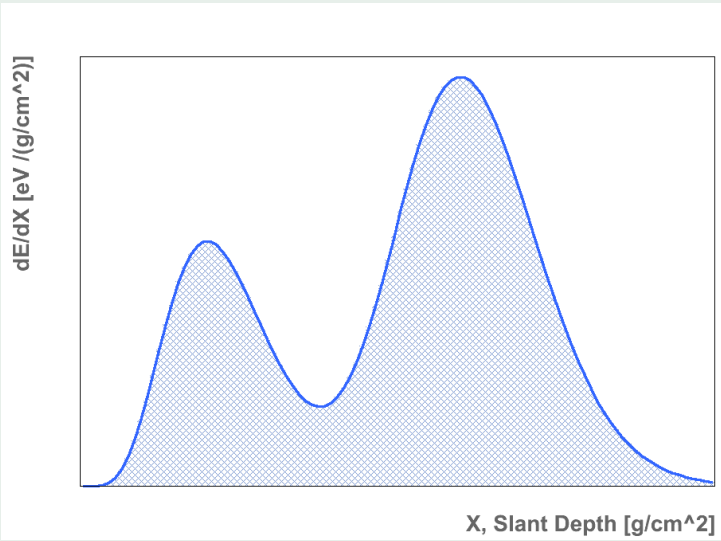
Normal Event

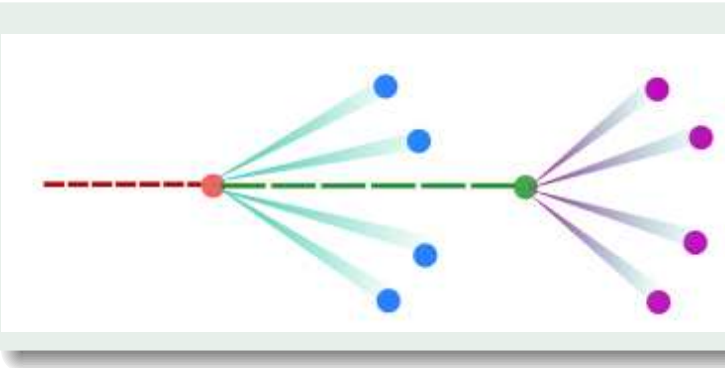




VS.

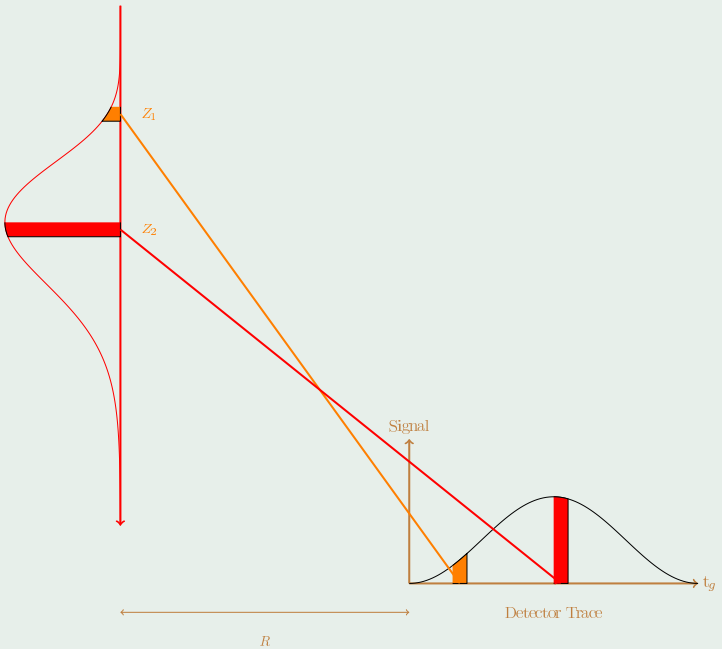
Exotic Event





Methods of Distinguishing Exotic Cosmic Ray Events
with Root & RooFit

Shower Profile Reconstruction



Credit: Niraj Dhital

Reconstructed the Longitudinal Shower Profile form each Events SD data. Using each tank's signal, time stamp, and geometry with respect to shower core, the position along the shower core that the particles arrived from was determined. Events used in reconstruction had E $>$ 8 EeV and a Zenith angle, $55^\circ < \theta_{\mathcal{Z}} < 80^\circ$.[1]

↓

Fitted each Event's shower profiles with GH function to determine fit parameters, their average values, and their standard deviations, σ.

↓

Constructed the Events' average shower profile from average fit parameters.

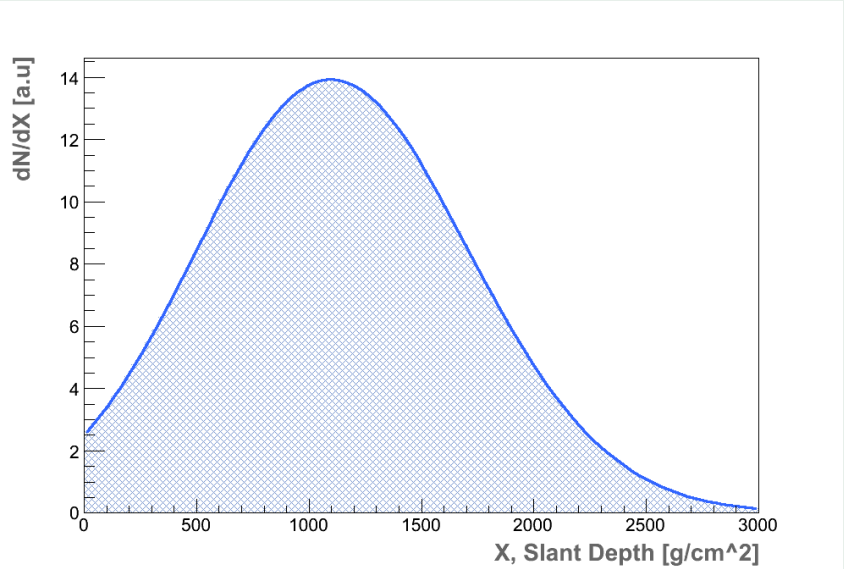
↓

Flagged Events with Fit Parameter $Xmax + 4\sigma$ from $\langle X_{max} \rangle$ as an Exotic Candidate.

[1] Modified versions of codes written by Niraj Dhital

Average Fitted Longitudinal Development Profile

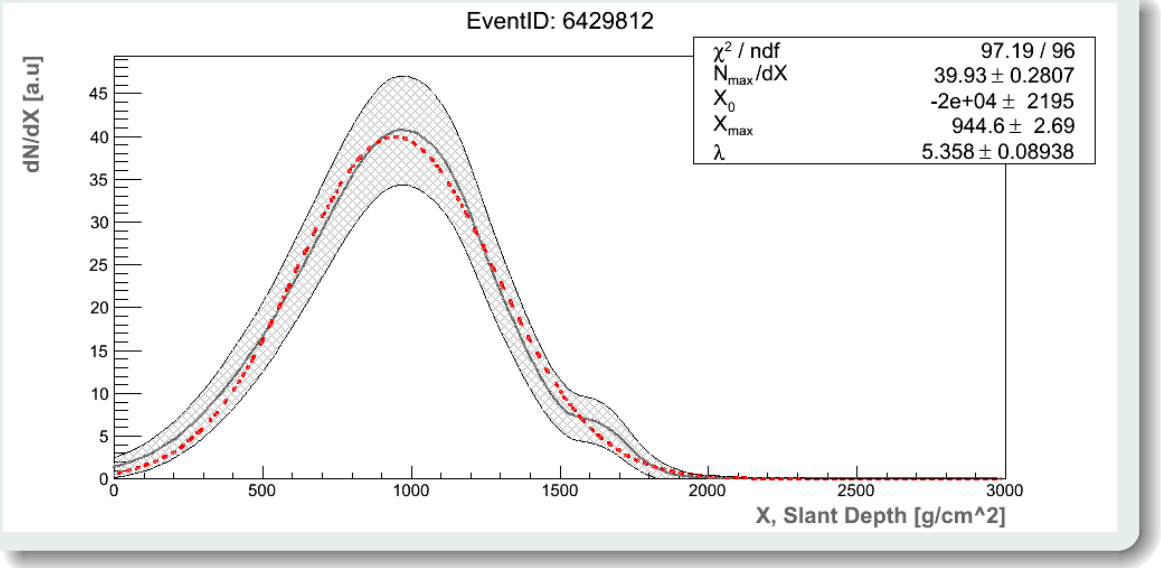
Average Event

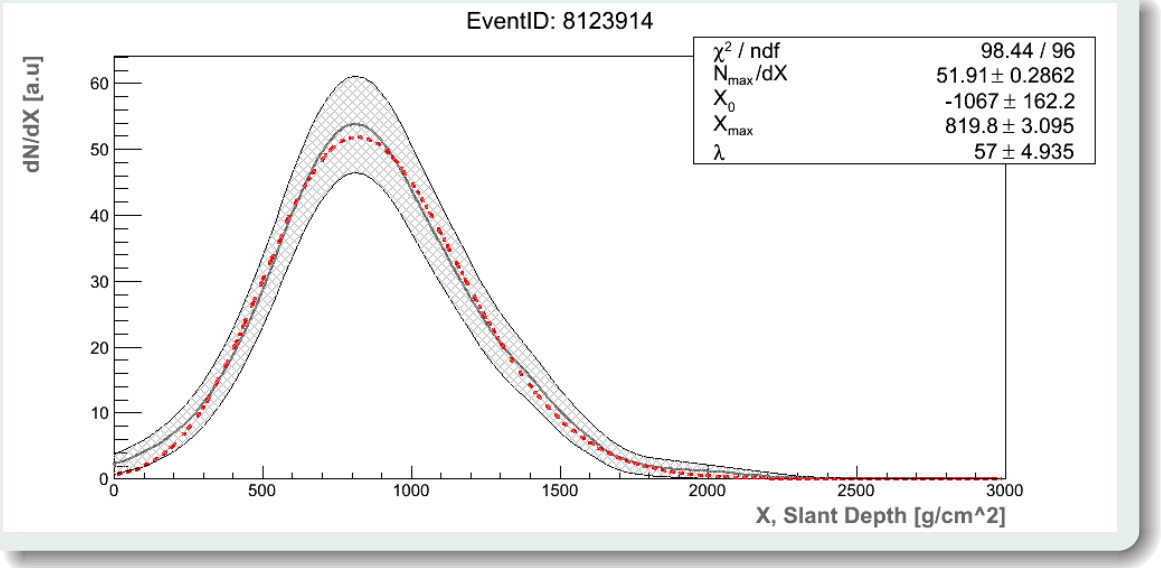


- $\left\langle \frac{dN_{max}}{dX} \right\rangle = 13.9 \pm 9.9 \ [a.u.]$
- $\langle X_0 \rangle = (-1.71 \pm .64) \cdot 10^5 \ [g/cm^2]$
- $\langle X_{max} \rangle = 1100 \pm 390 \ [g/cm^2]$
- $\langle \lambda \rangle = 20.1 \pm 40 \ [g/cm^2]$

Examples of Normal Events

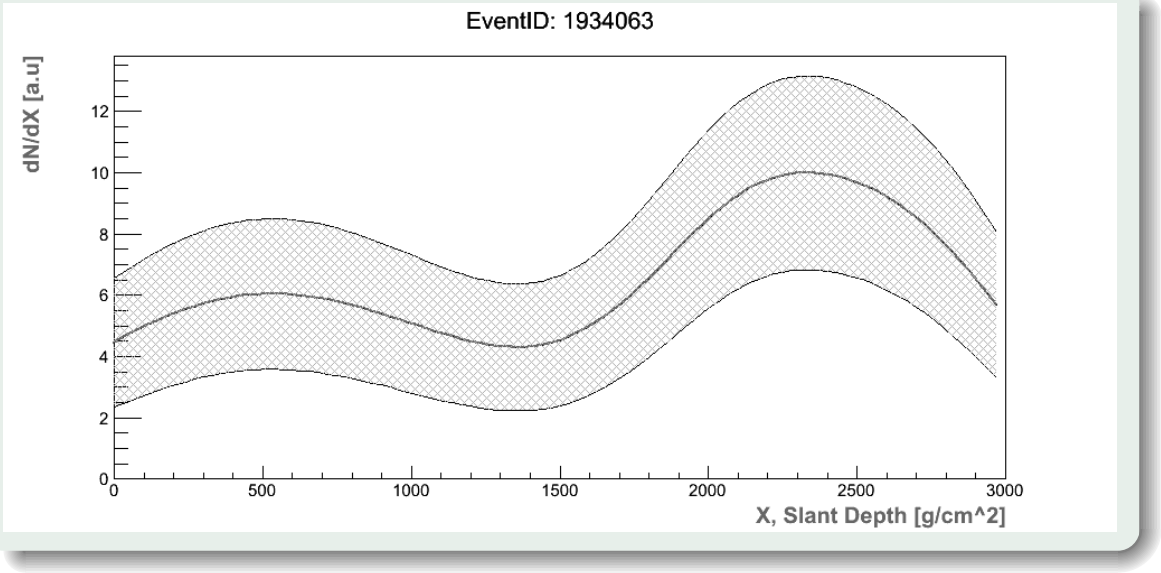
$\chi^2/NDF \approx 1$ & within 1 σ

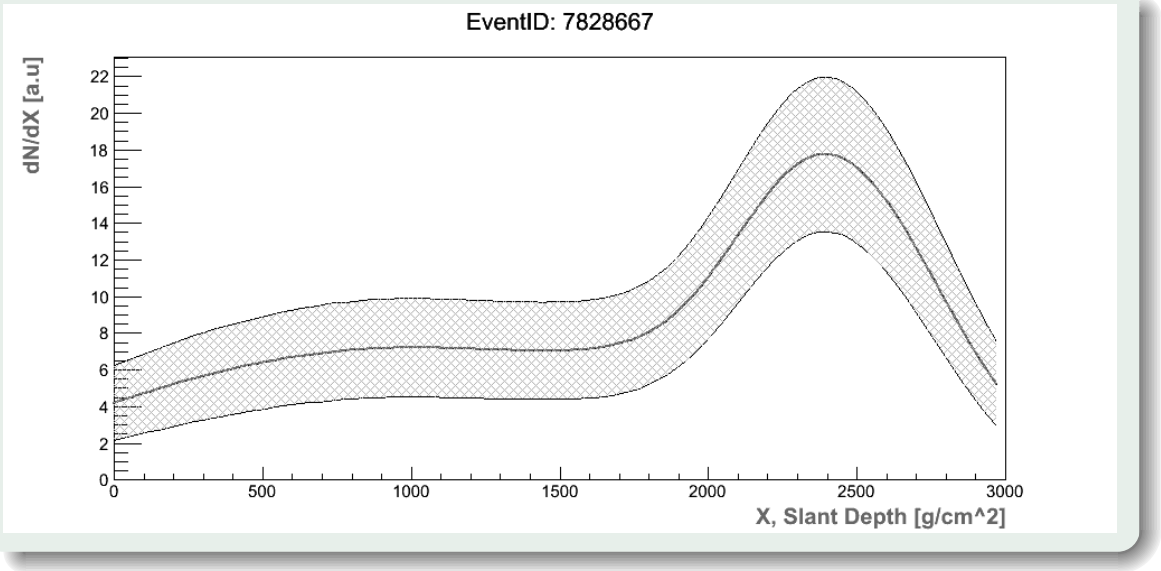




Exotic Events Candidates

Parameter $X_{max} + 4\sigma$ from $\langle X_{max} \rangle$





Conclusions & Further Work

- 50 Exotic Candidates were found out of 4571 Events.
- Further rigorous examination of these Exotic Candidates must be done.
  - Confirm these are not artifacts from Shower Profile Reconstruction.
  - Confirm these are not artifacts from shower geometry or triggering.
- Compare to Simulations of Exotic Events.

Acknowledgements and Sources

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- Tolga Yapici
- Auger Collaboration
- MTU Department of Physics

1 "Properties and performance of the prototype instrument for the Pierre Auger Observatory," J. Abraham et al. [Pierre Auger Collaboration], Nuclear Instruments and Methods, A523 (2004), 50.

2 "Proceedings of the 15th International Cosmic Ray Conference, 1326 Aug 1977"Gaisser, T.K.; Hillas, A.M. (1977). **8**. Plovdiv, Bulgaria. p. 353

3 "A Measurement of the average longitudinal development profile of cosmic ray air showers between 10^{17}eV and 10^{18}eV ," HIRES Collaboration (T. Abu-Zayyad et al.). Aug 2000. 28 pp.

Fit Parameter Histograms