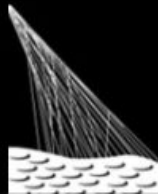


Analysis of an anomalous event

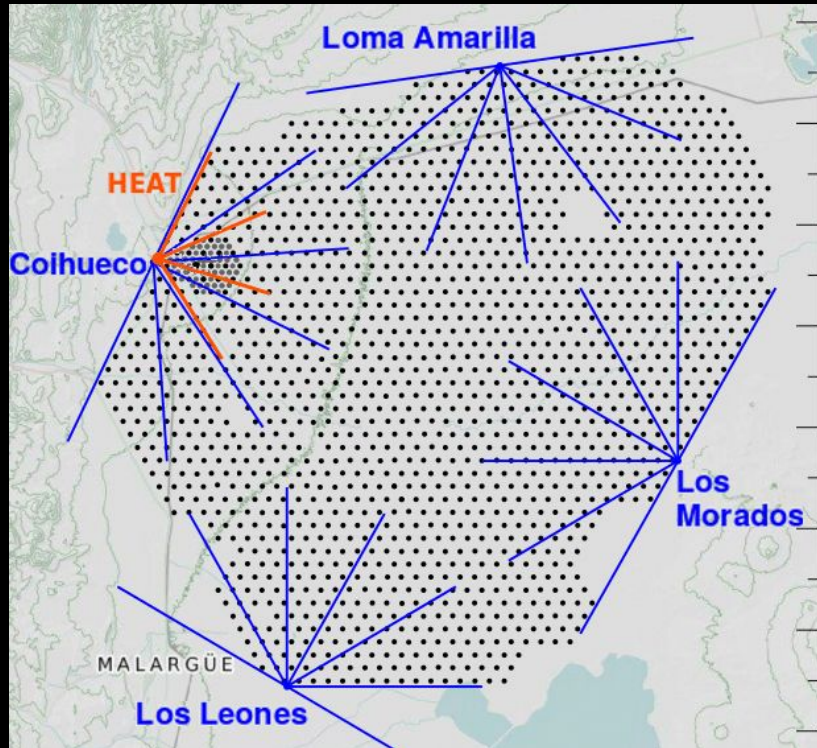
By Megha Mogarkar



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Pierre Auger Observatory



- The largest cosmic ray observatory in the world- spans over 3,000 square kilometers
- Purpose - understand the origin and properties of cosmic rays (UHECRs)

Auger Phase 2

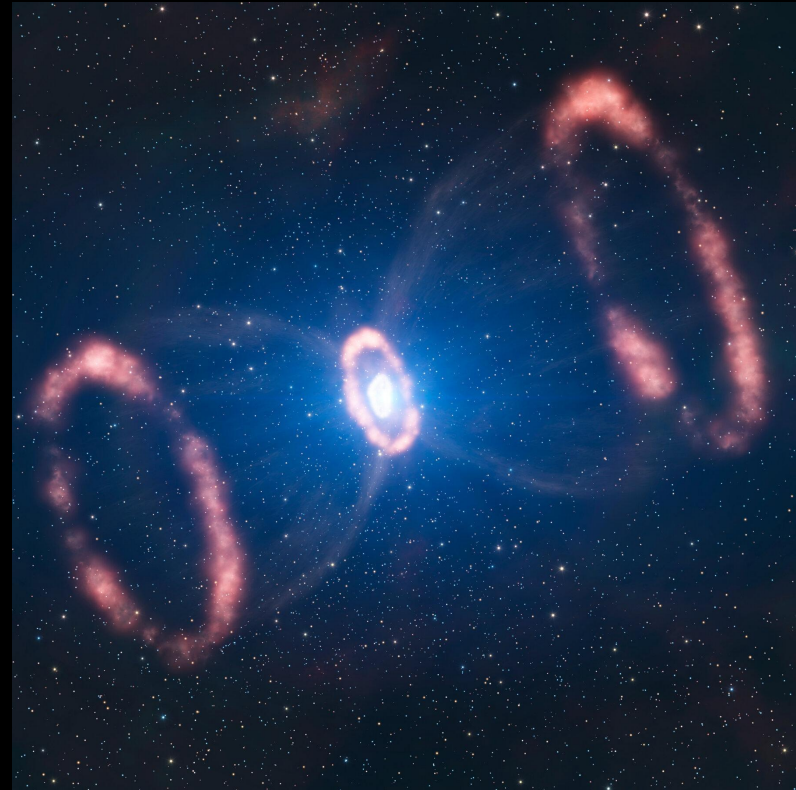
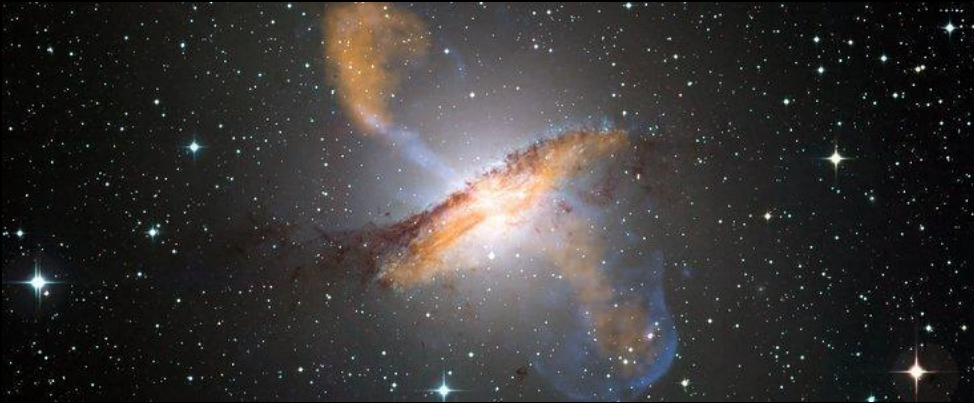


- Auger Phase 1 - Fluorescence detectors, Water cherenkov detectors
- Auger Phase 2 - Addition of Surface scintillator detectors, underground muon detectors, radio detectors

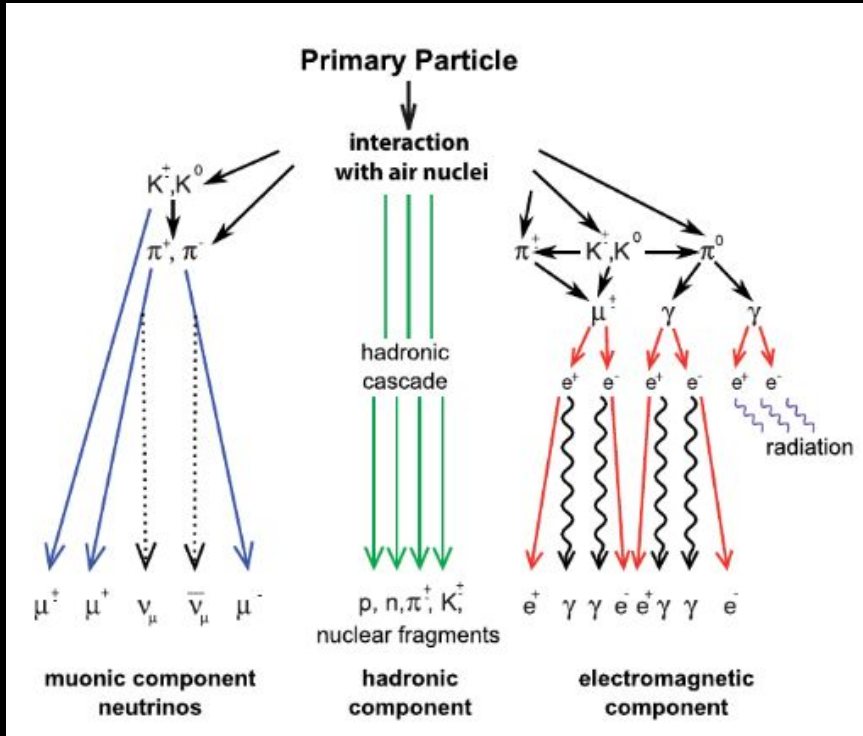
What is an Event?

Cosmic Rays

- Cosmic rays are high energy particles originating from outer space
- Origins eg. – supernovae, active galactic nuclei

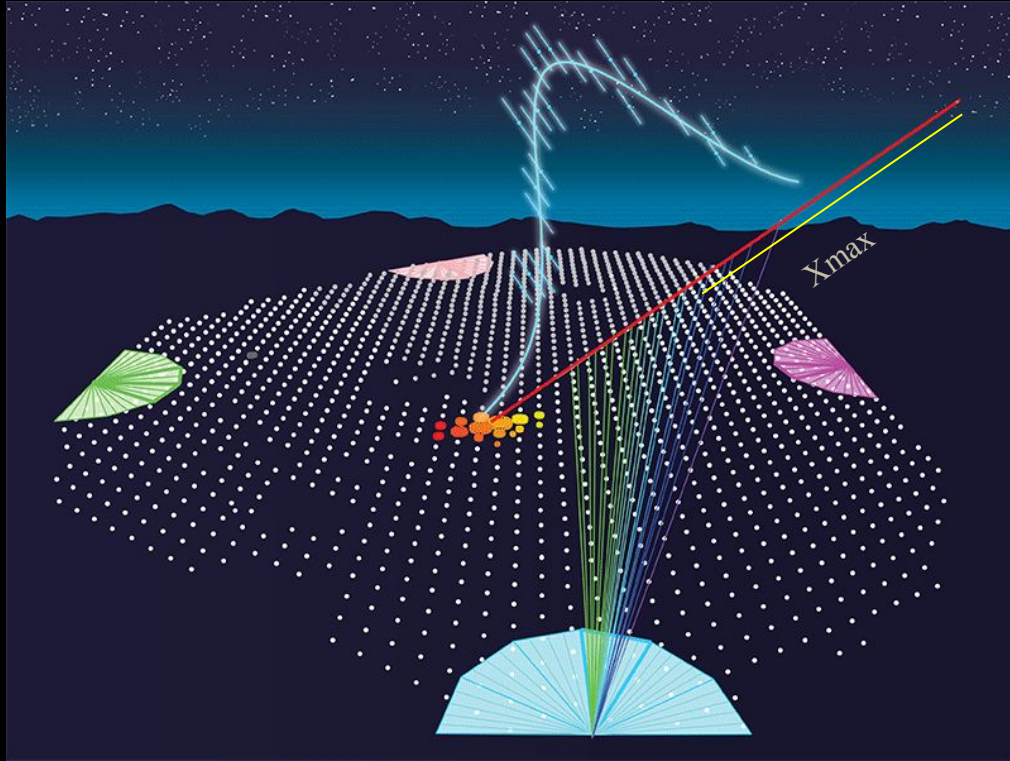


Extensive Air Showers (EAS)



- High energy cosmic rays (energies $\geq 10^{15}$ eV) coming to the Earth, interact with the earth's atmosphere producing cascades of particles
- My work - EAS in ultra high energy range ($> 10^{17}$ eV)

Extensive Air Showers

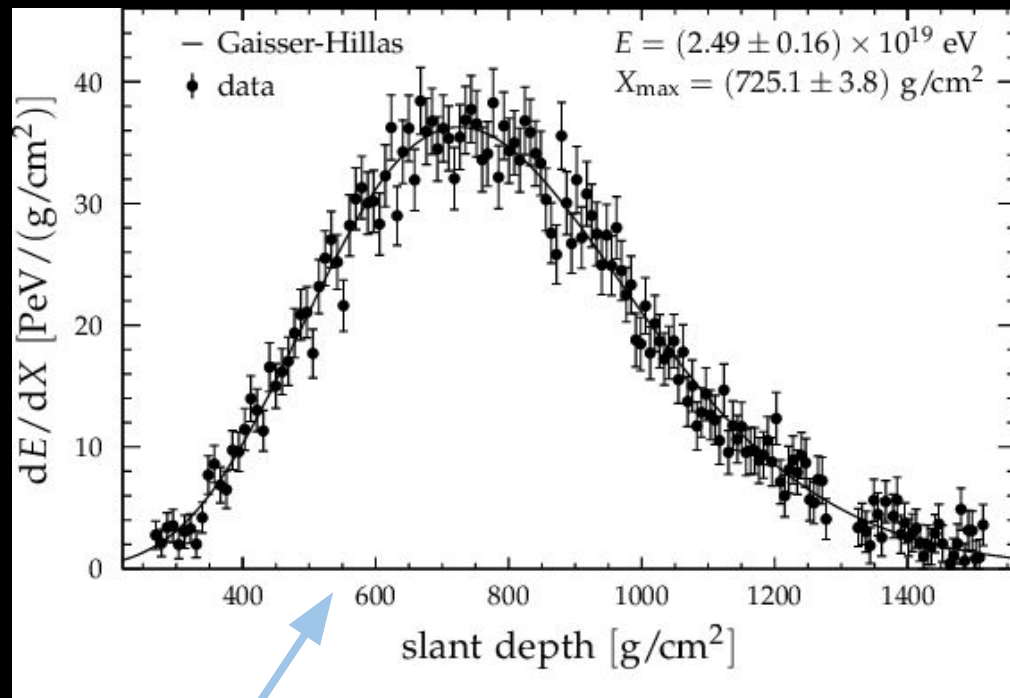
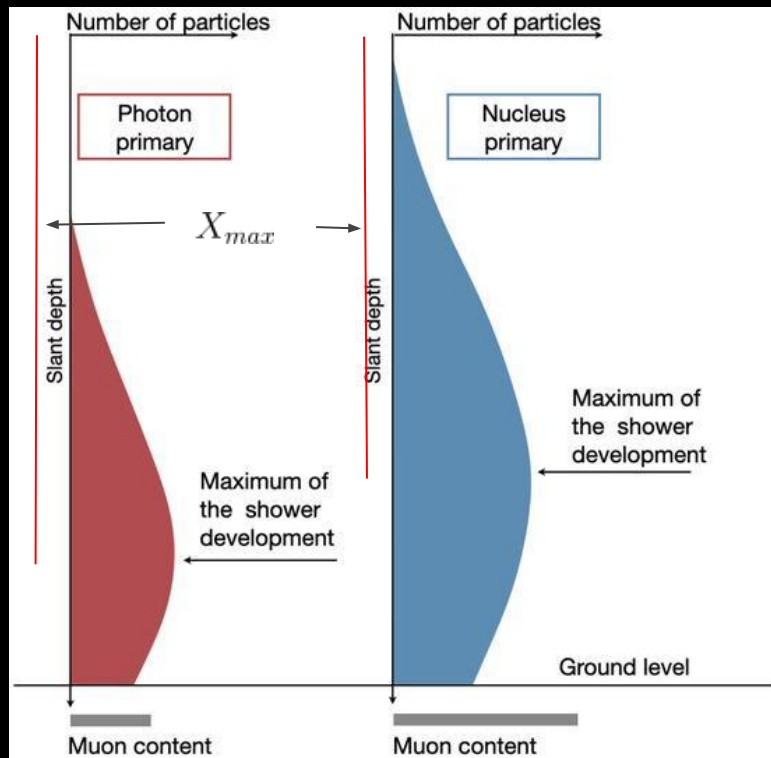


Hybrid detection of an extensive air shower at the Pierre Auger Observatory

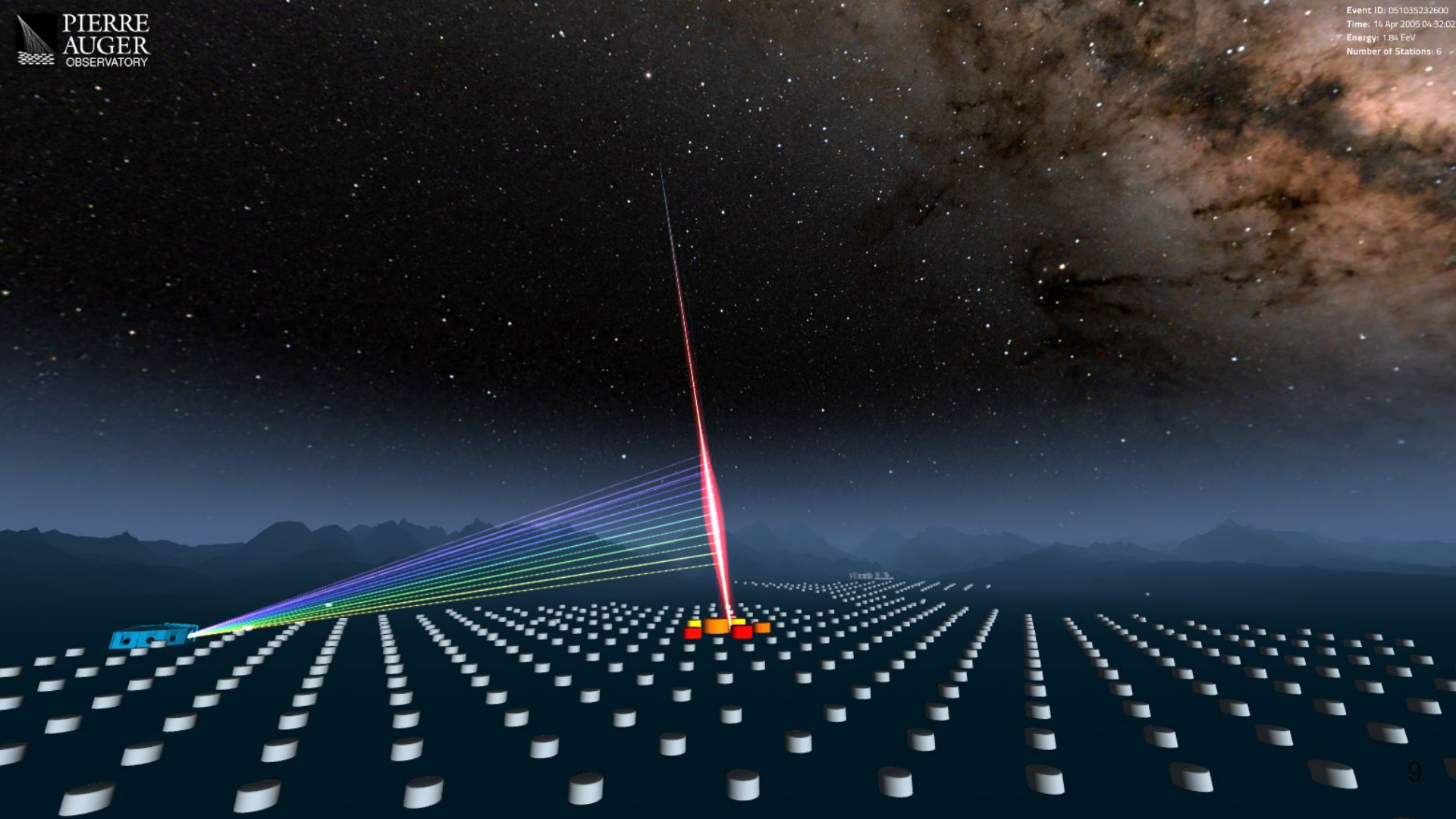
Key observables:

- Energy of the primary particle
- Arrival direction
- Mass composition: determined from observables like depth of maximum development (X_{max}) and muon content.

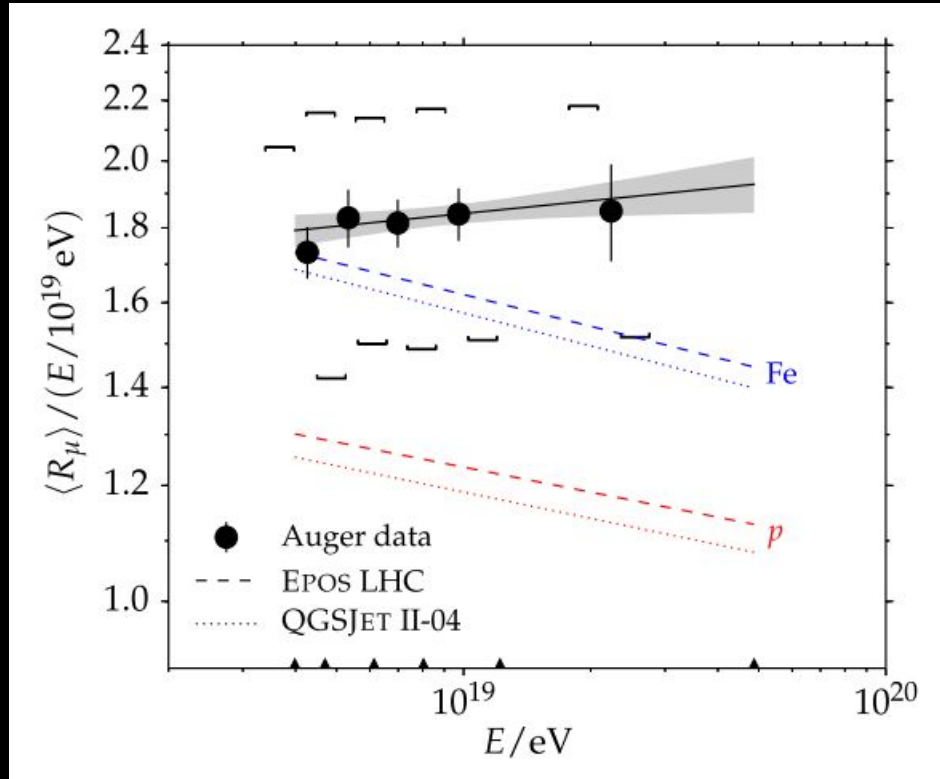
More about Xmax



Longitudinal profile



Muon Puzzle

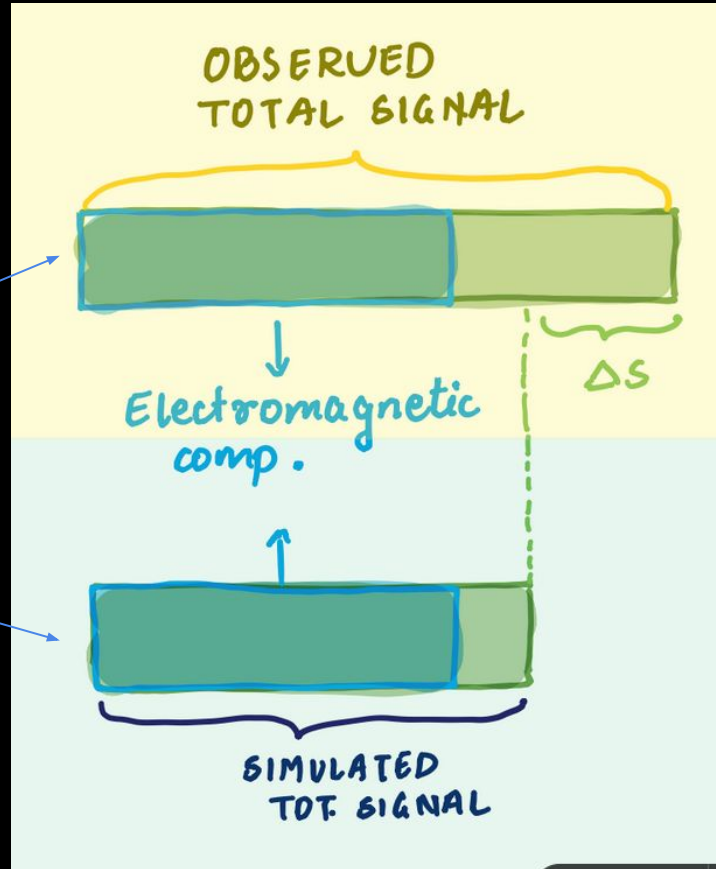


What is it?

- Discrepancy between the number of muons observed in EAS and the predictions made by current hadronic interaction models (off by 30% to 60%)
- This issue becomes more significant at highest energies ($\geq 10^{18}\text{eV}$)

What is the method
of analysis?

Top-Down chain



Longitudinal profile
match => EM signal
match

Objective: To account
for muon puzzle in
the reconstructions

Main Softwares:
Auger Offline
Framework ;
CORSIKA

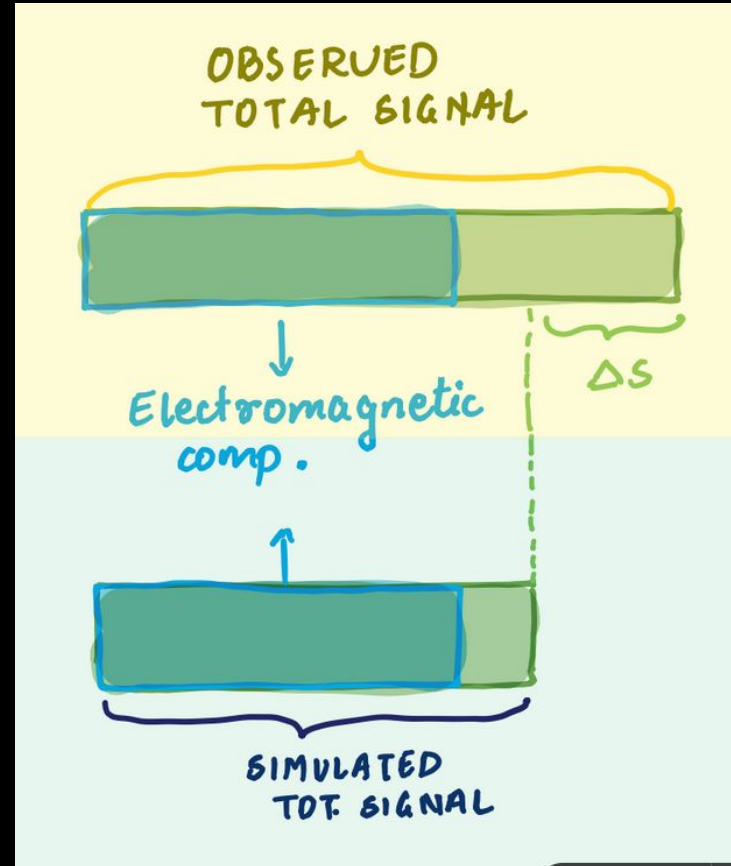
Top-Down chain

$$S \equiv S_{1000}$$

$$\Delta S = S_{data} - S_{TD}$$

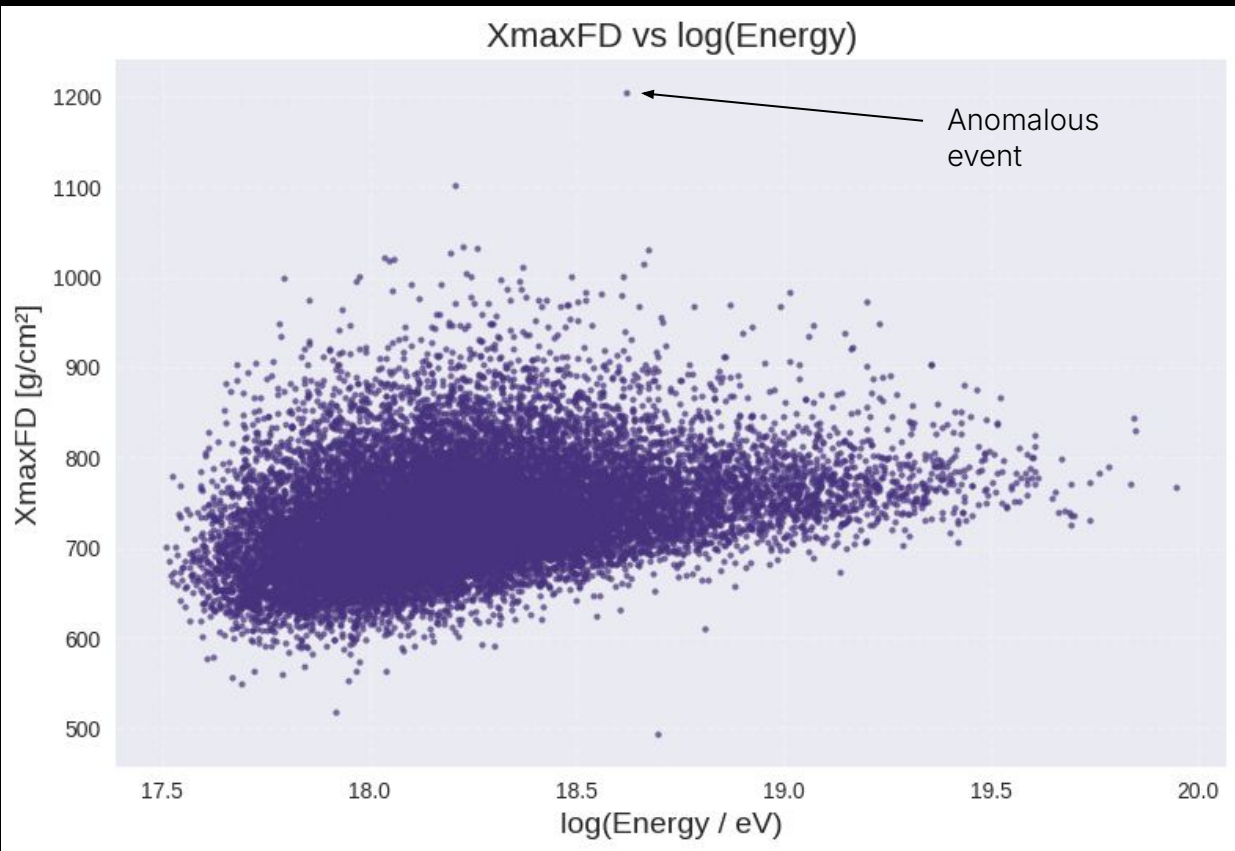
$$S_{\mu,data} = S_{\mu,sim} + \Delta S$$

$$R_{\mu} = 1 + \frac{\Delta S}{S_{\mu sim}}$$



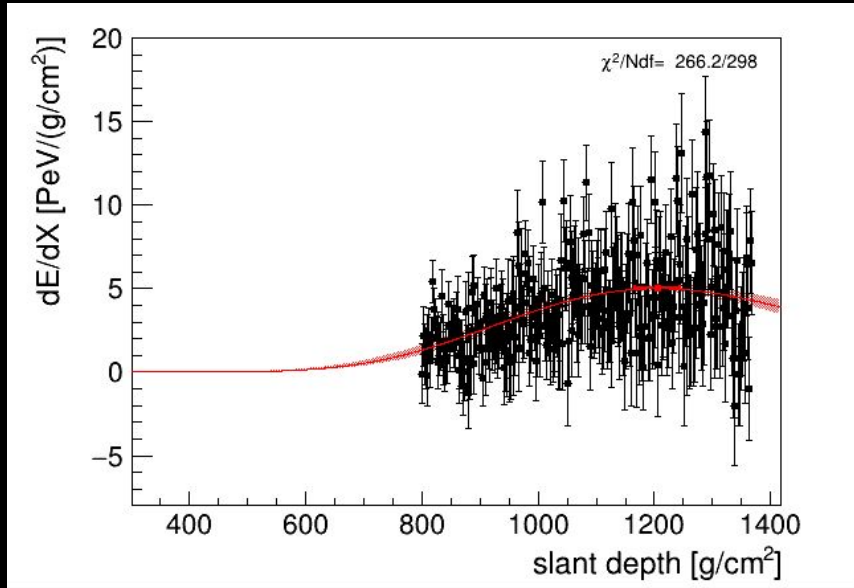
What is the
anomalous event?

Distribution of X_{max} with respect to Energy



- It lies significantly above the average trend for its energy, indicating a very deep shower.
- Analyzed event is found to have an X_{max} significantly ($> 3\sigma$) above the average trend for its energy

The Deep Event

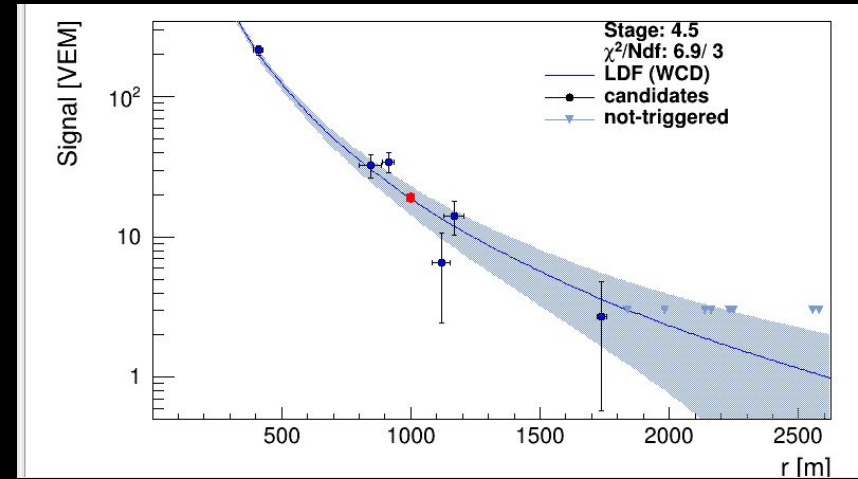


$S_{1000} = 19.0 \pm 1.6 (\pm 0.3) \text{ VEM}$

$$E = (4.15 \pm 0.39 \pm 0.32) \times 10^{18} \text{ eV}$$

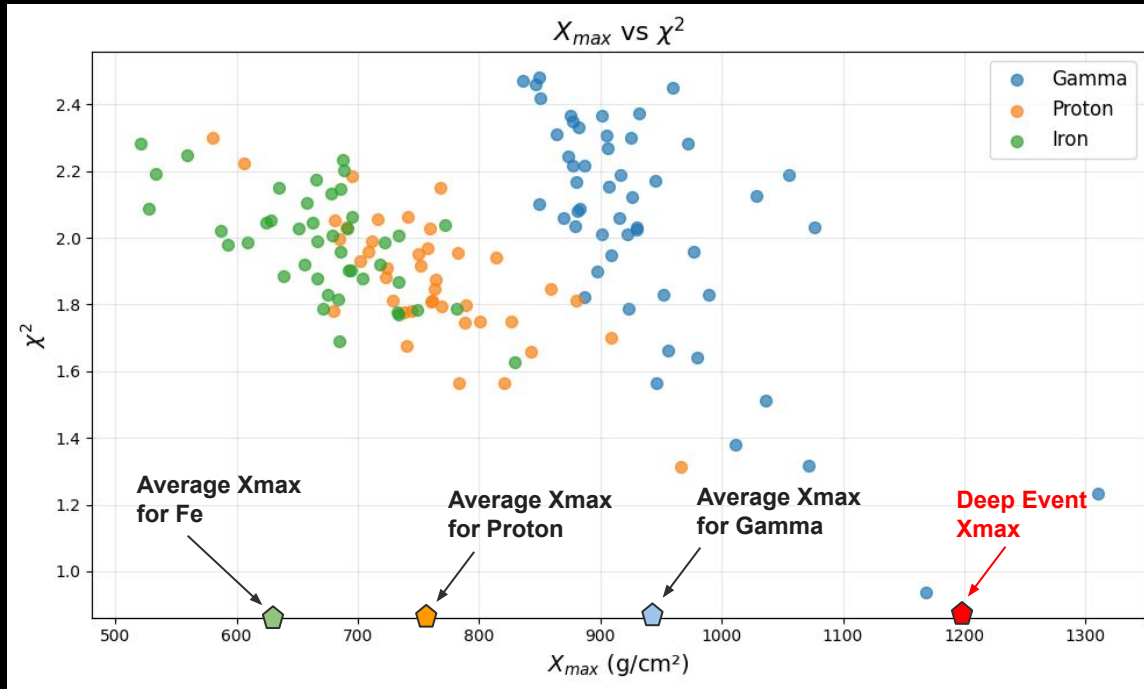
$$X_{\text{max}} = 1205 \pm 38 \text{ g}/\text{cm}^2$$

$$(\theta, \phi) = (53.3 \pm 0.6, 355.0 \pm 0.6) \text{ deg}$$



The Analysis

Applying Top-Down to Deep Event



100 1-D simulations for different primary particles and comparison of their χ^2 values with respect to X_{max} .

Narrowing down primary particle:

CONEX simulations:

- The χ^2 vs X_{max} graphs were compared to decide on primary particles for simulations.
- Model used: EPOS-LHC; CORSIKA version: 7.7
- The event best fits lighter primaries
- Need to make changes to the pipeline to simulate this event

Results

$$S_{\mu,obs} = 14.99 \pm 0.48 VEM$$

$$R_{\mu,proton} = 1.41 \pm 0.31$$

$$R_{\mu,photon} = 3.10 \pm 0.30$$

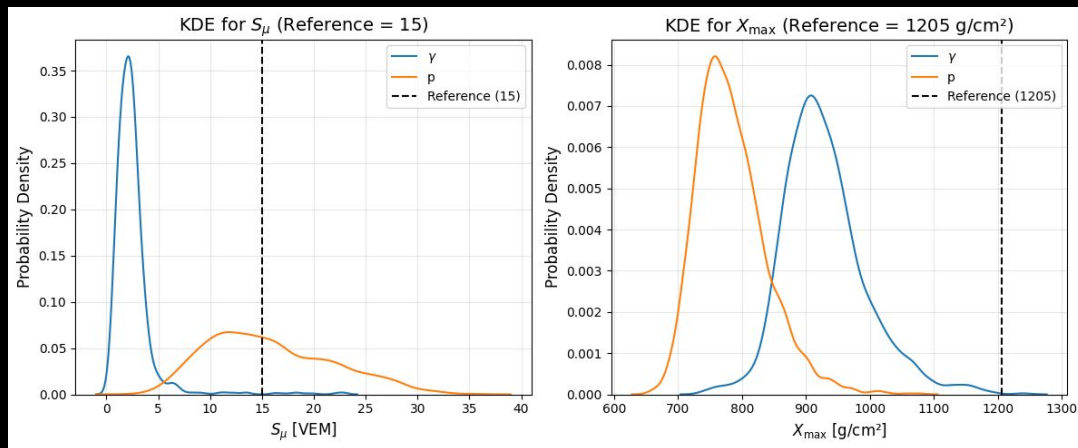
Conclusions from calculation:

- The muon content is significantly high for it to be a photon primary particle
- There is an unusually large discrepancy between the observed signal and the reconstructed signal for photon showing disagreement with the photon assumption.

Results

Comparison with a standard set of simulations in the energy range $10^{18.5} - 10^{19.0} eV$

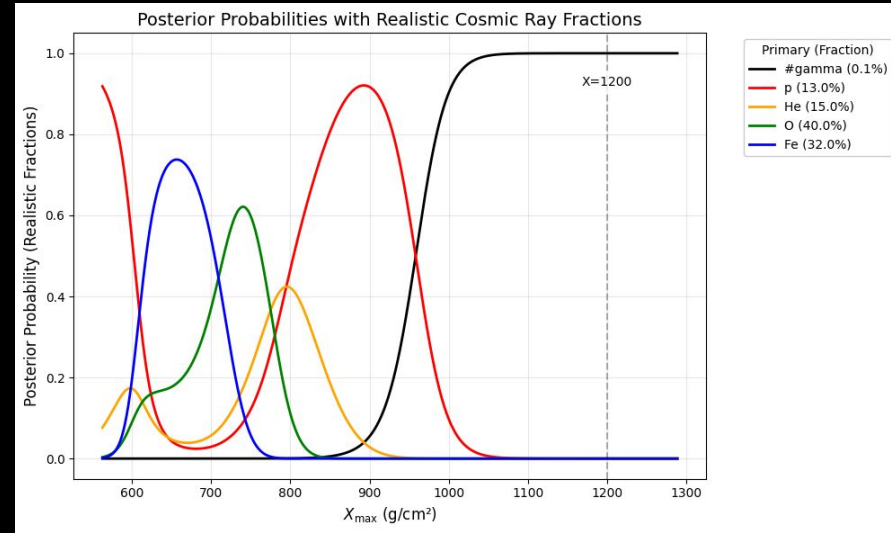
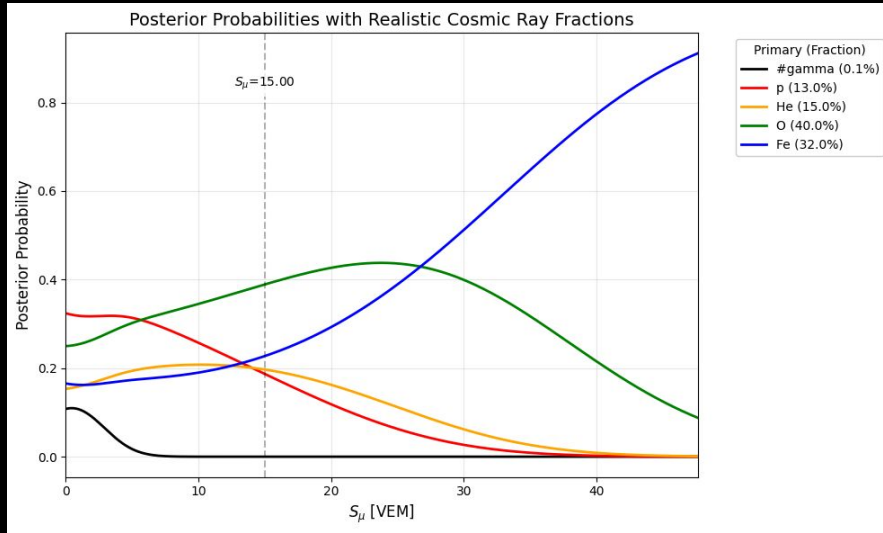
- X_{max} lies on the edge of distribution for photons
- But S_{μ} value lies in the hadron distribution range



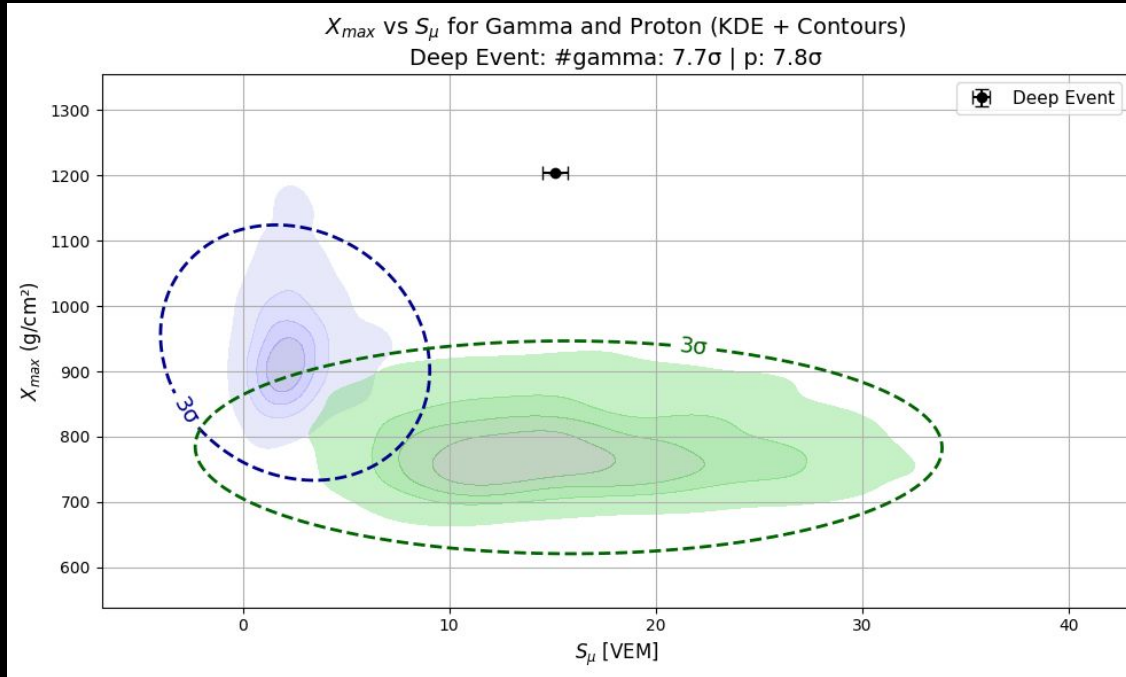
Results

Posterior probabilities using

$$p_j(X_{\max}) = f_j \mathcal{P}_j(X_{\max}) / \sum_j f_j \mathcal{P}_j(X_{\max})$$



Results



Conclusion:

- Comparison with standard simulations is inconclusive
- The calculations from top-down analysis favor a proton (hadronic) primary rather than a photon

Further...?

- The deep event as a neutrino primary assumption
 - Further modifications required to the pipeline
- Auger Phase 2 data analysis using top-down:
 - In the process of these modifications - involves new versions of softwares, containers and testing

Summary

- Deep Event - has largest X_{\max} observed by the Pierre Auger Observatory
- It's analysis by Top-down required modifications to the chain
- Analysis involved assumption of primary particles - chosen: proton and photon
- Muon content and Rescaling factor calculated
- Results - It favors hadronic primaries more than photon
- Comparison with simulations was inconclusive
- Next work involves neutrino primary assumption and Phase 2 data analysis

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