



Pierre Auger Observatory Results

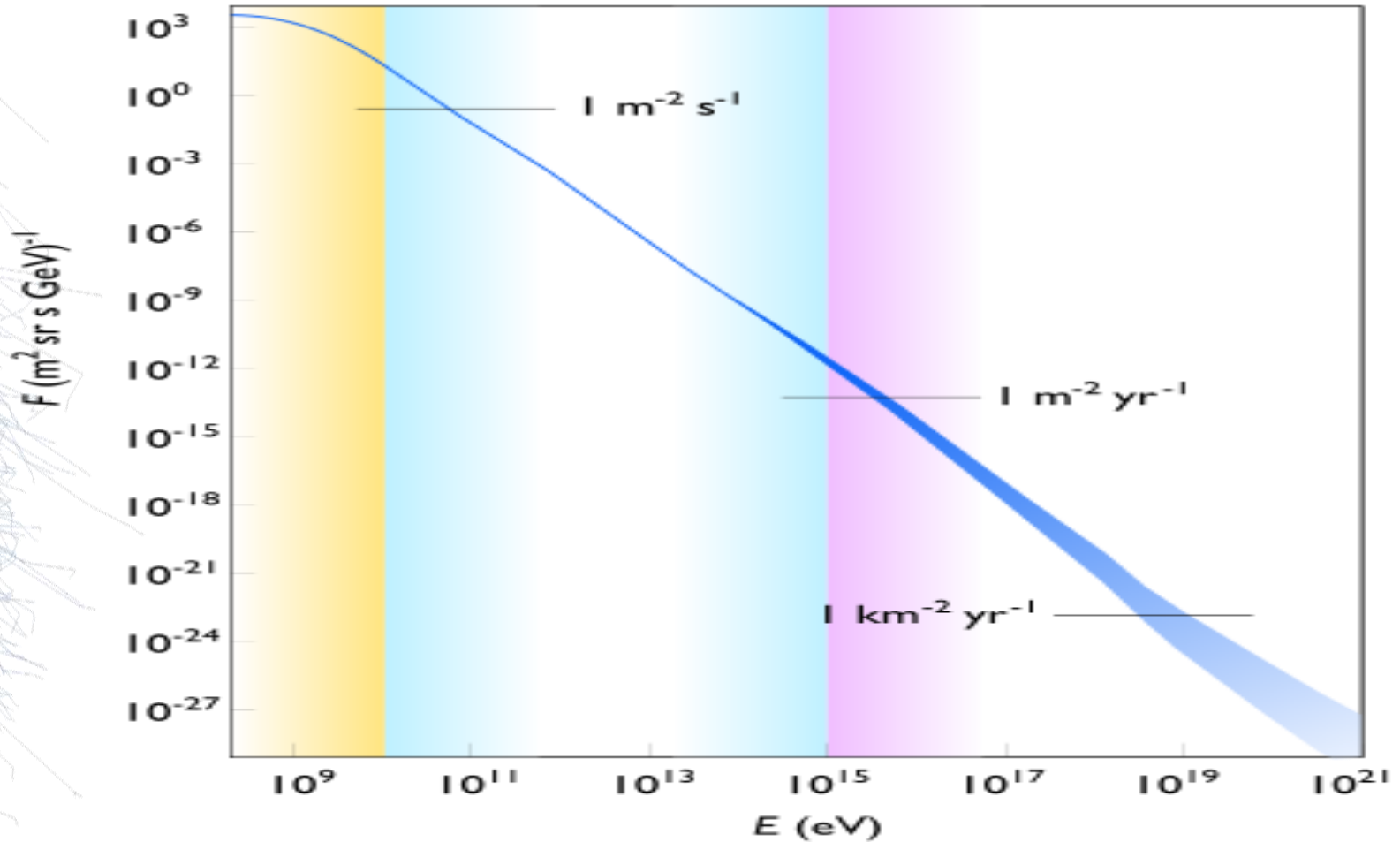
Ruben Conceição

for the Pierre Auger Collaboration



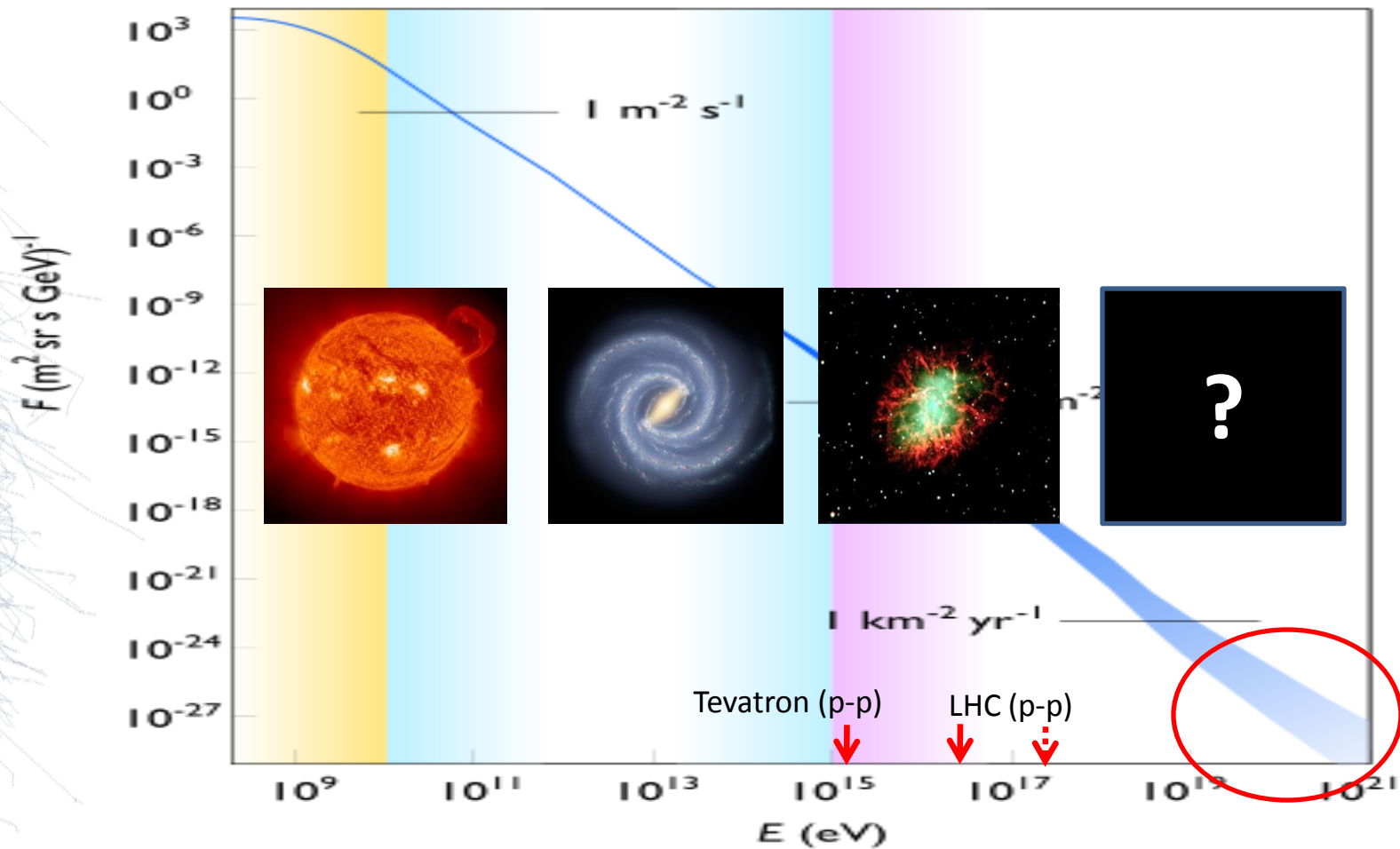
Ultra High Energy Cosmic Rays

Cosmic ray spectrum



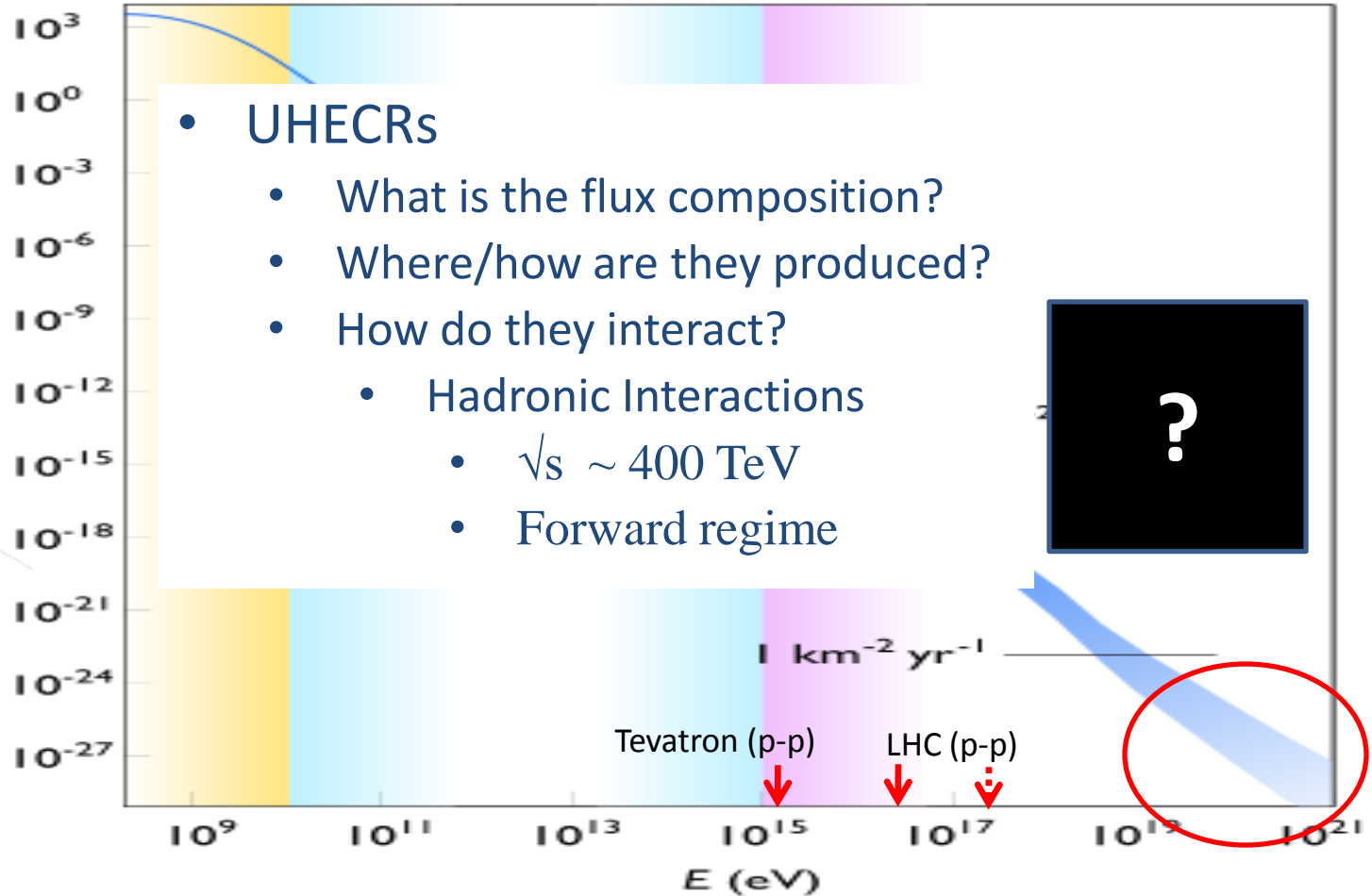
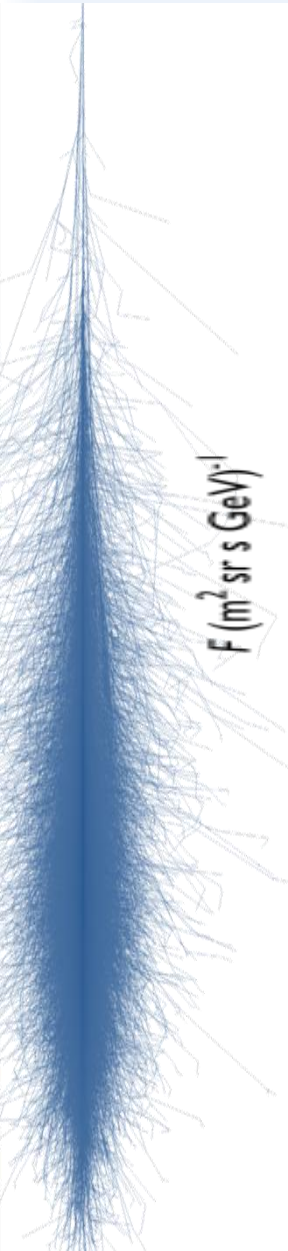
Ultra High Energy Cosmic Rays

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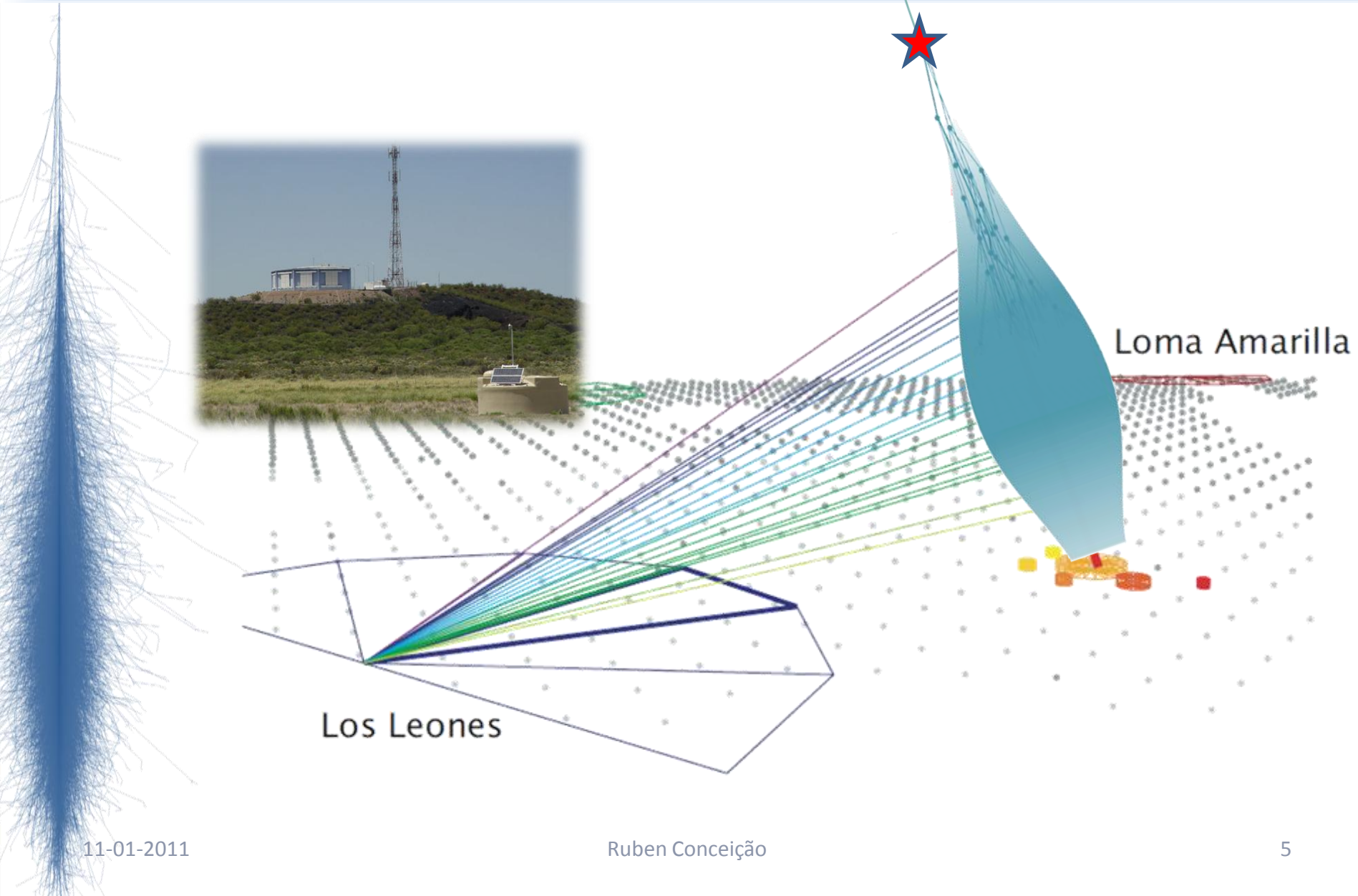


Ultra High Energy Cosmic Rays

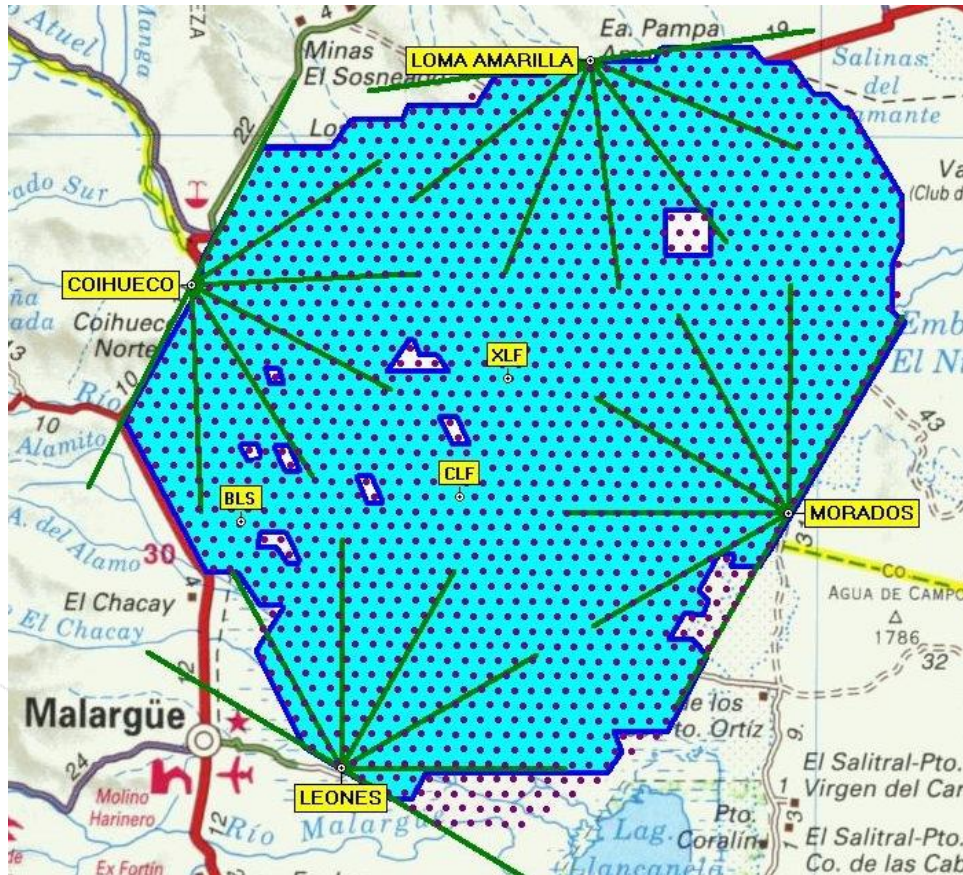
Cosmic ray spectrum



Pierre Auger Observatory



Pierre Auger Observatory

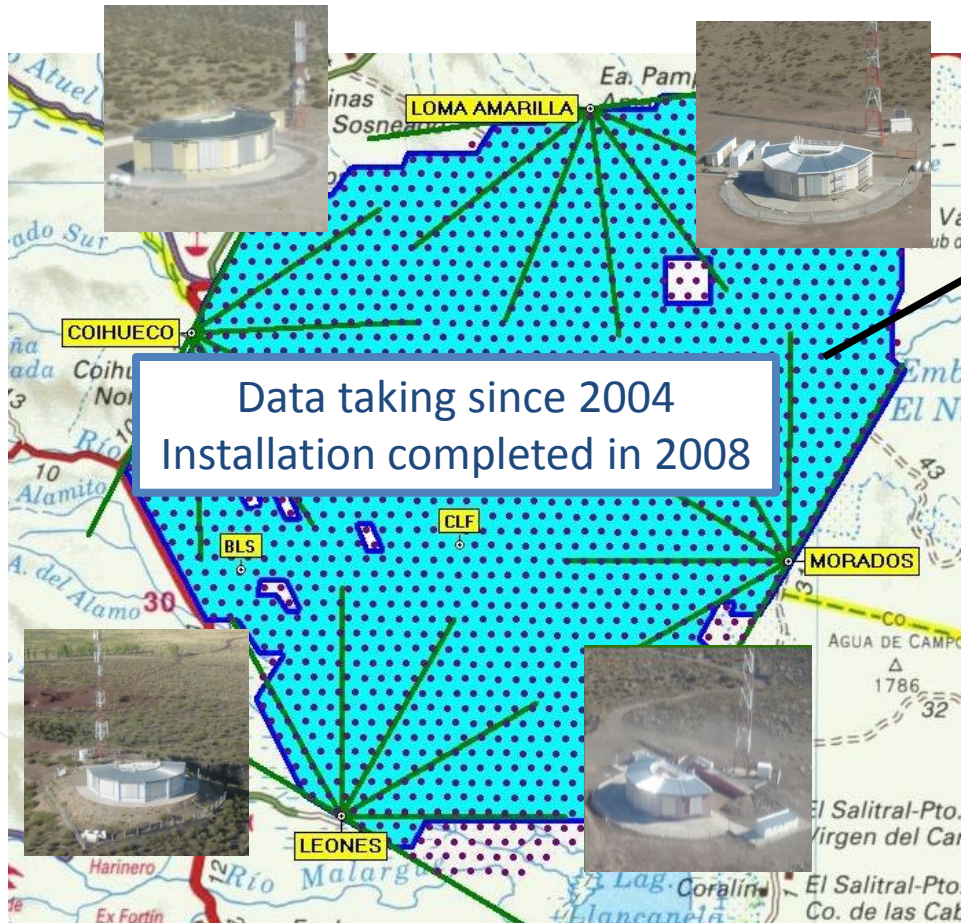


- ~ 1600 Surface Detector (SD) Stations
- 1.5 km spacing
- 3000 km²

- 4 Fluorescence Detectors (FD)
- 6 x 4 Telescopes



Pierre Auger Observatory



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Surface Detector

- Cherenkov water tanks
- Detect charge particles at the ground
- 100% duty cycle
- Provides large statistics



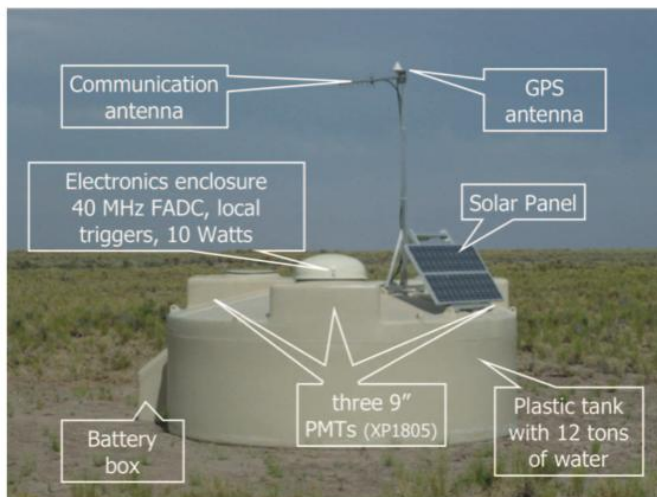
Fluorescence Detector

- Telescopes FoV $30^\circ \times 30^\circ$
- Only works in moonless nights
- ~ 13% duty cycle
- More direct information



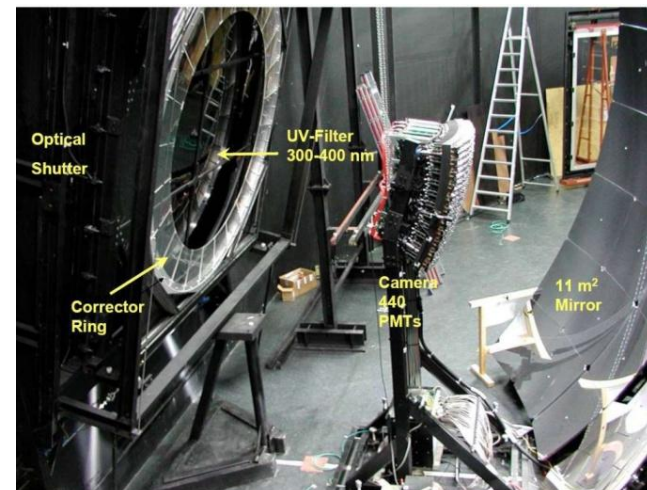
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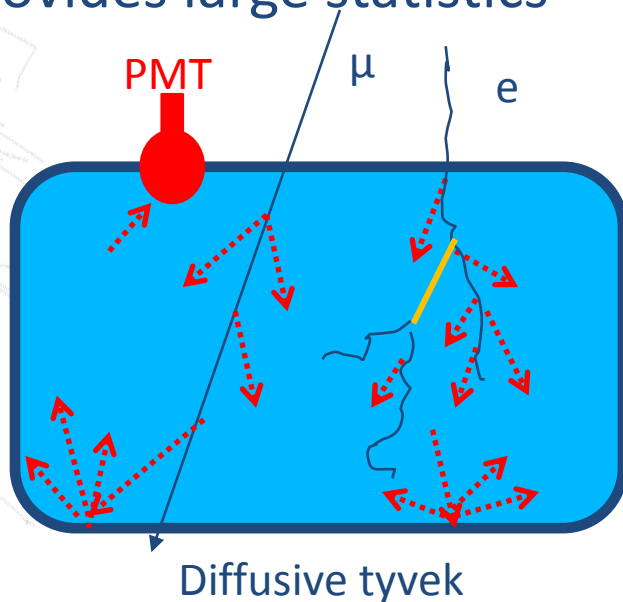
Fluorescence Detector

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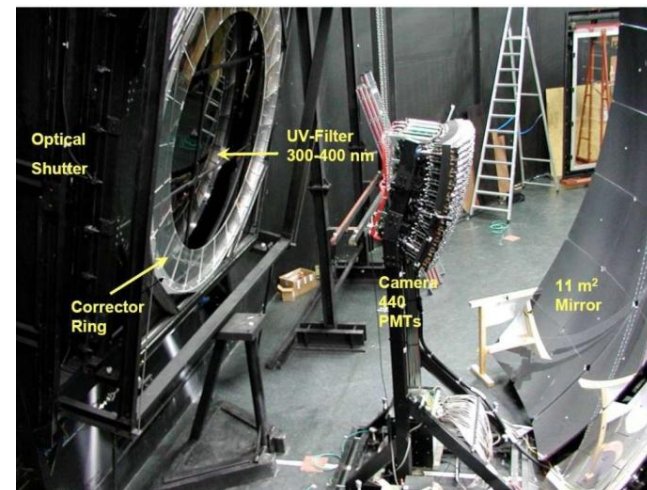
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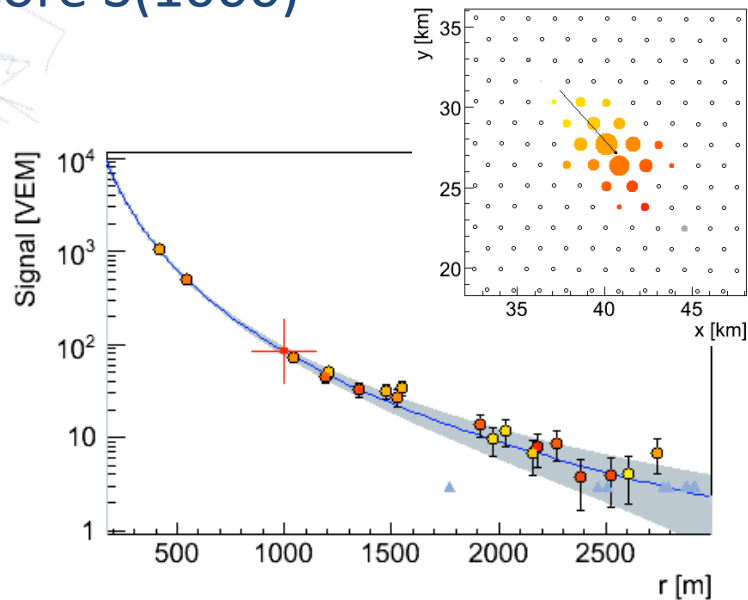
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Event Reconstruction

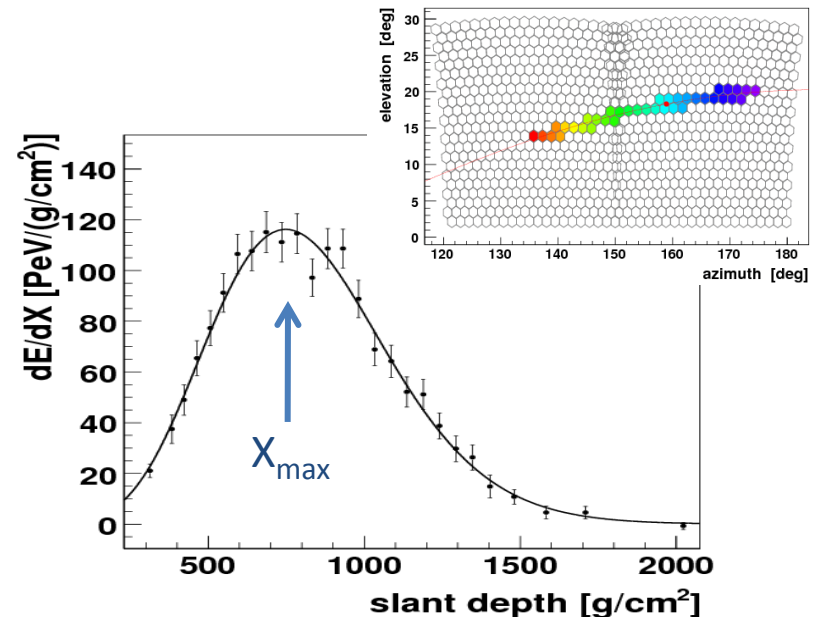
Surface Detector

- Tank hit time gives shower direction
- Energy is obtained using the signal measured at 1000 meters from the shower core $S(1000)$



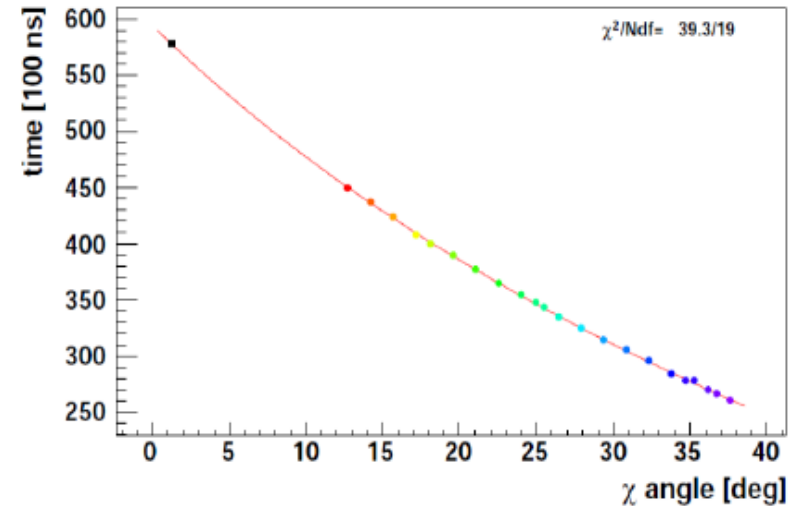
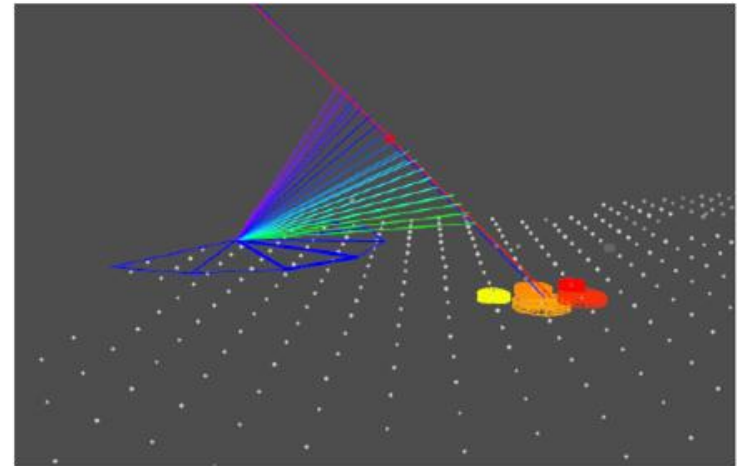
Fluorescence Detector

- Evolution seen in camera gives the shower geometry
- Energy is calculated by integrating the longitudinal profile



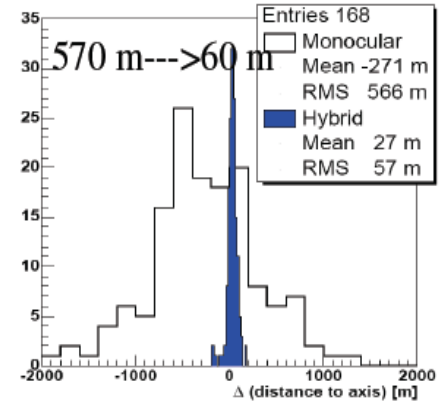
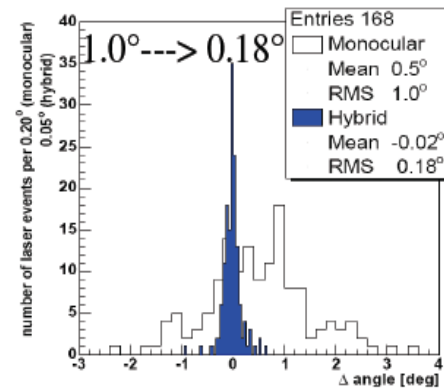
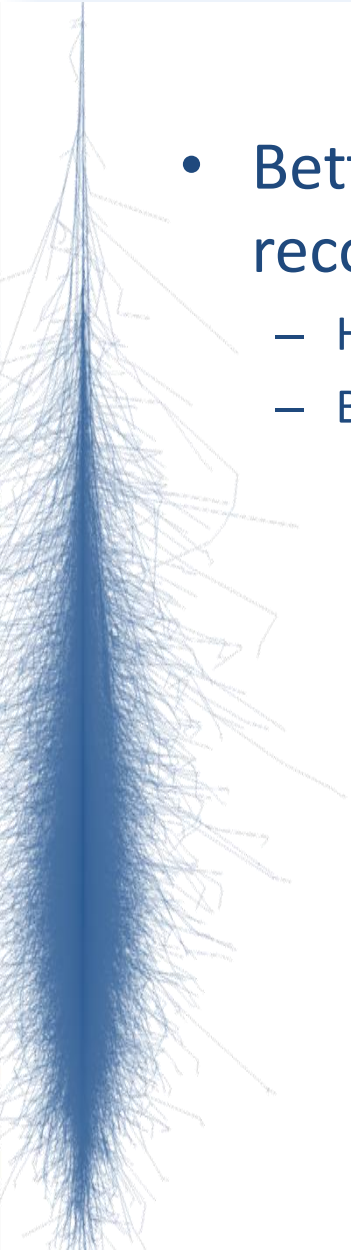
Hybrid Technique

- Better geometry reconstruction
 - Higher X_{\max} resolution
 - Better energy reconstruction



Hybrid Technique

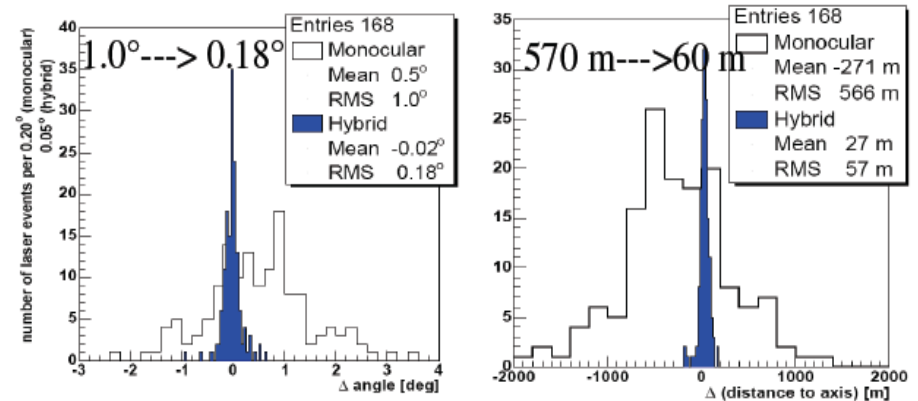
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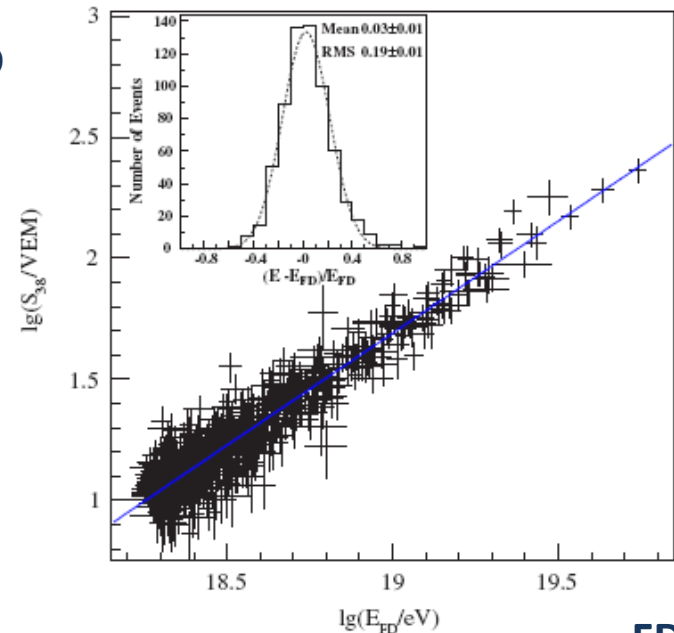
Hybrid Technique

- Better geometry reconstruction
 - Higher X_{\max} resolution
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- Calibration of SD with FD
 - Reduced systematics (22 %)
 - Calibration done with data to be independent of hadronic interaction models
 - Energy resolution 17%



SD



FD

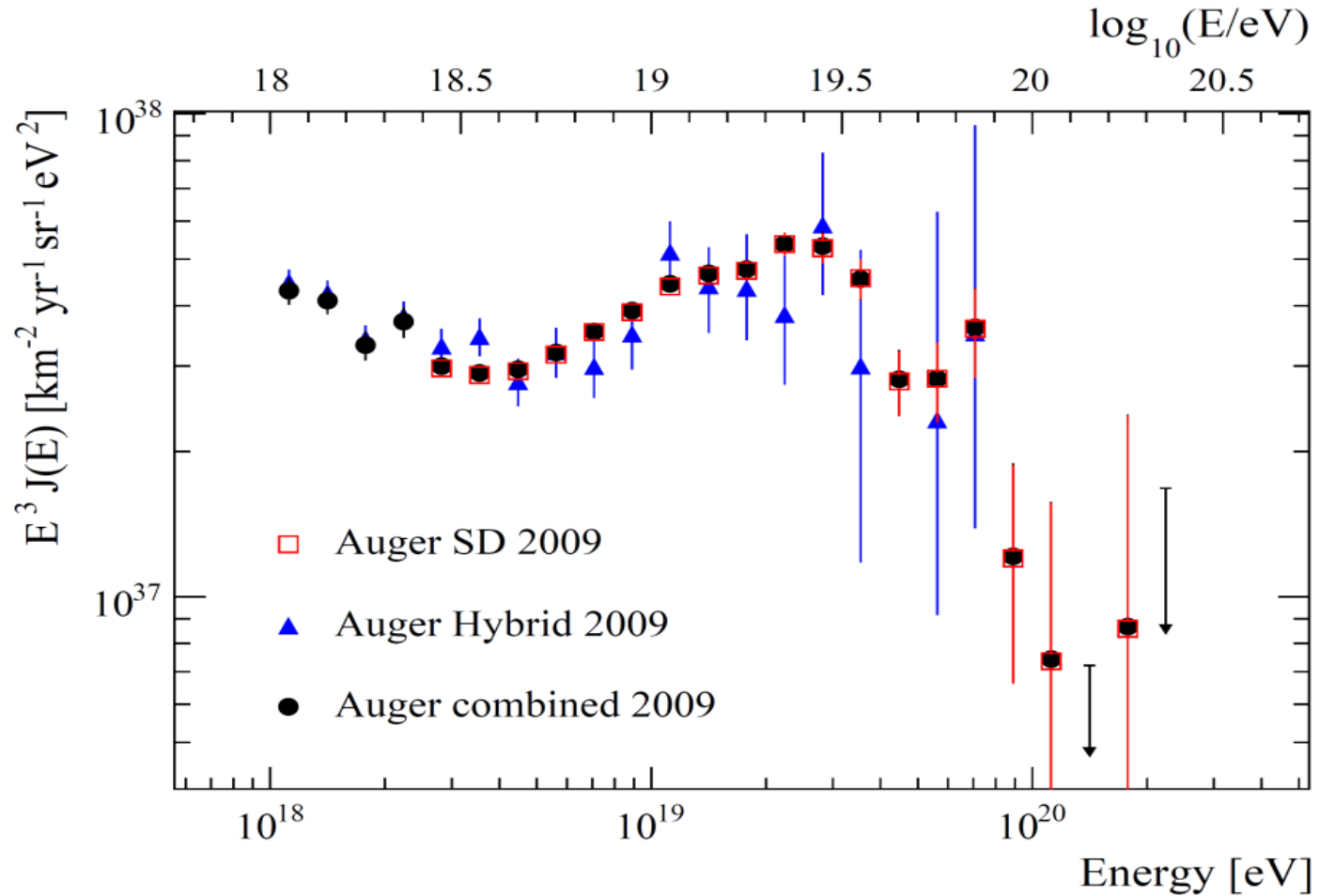
Energy Spectrum

– FD

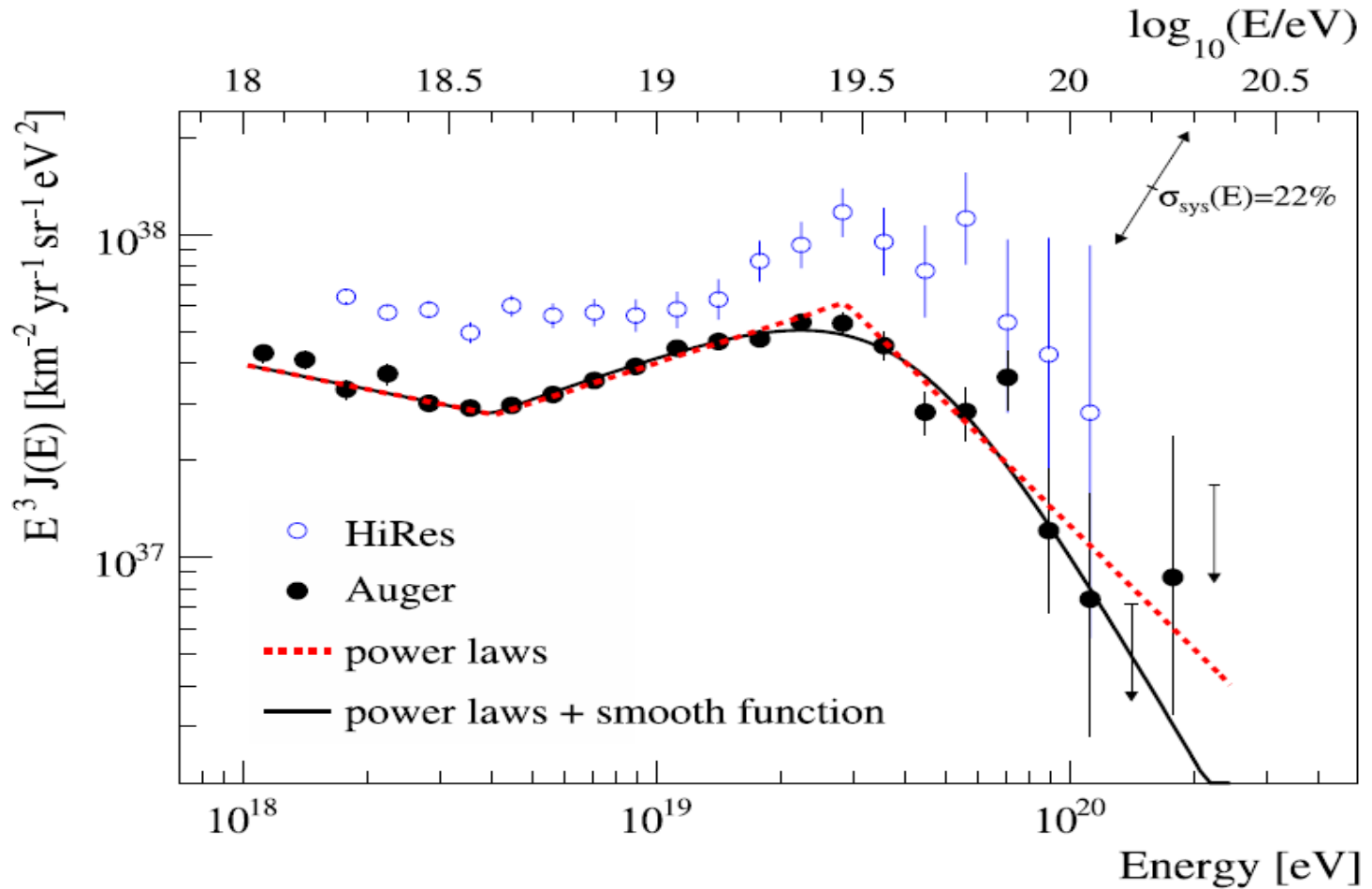
- Lower energy range

– SD

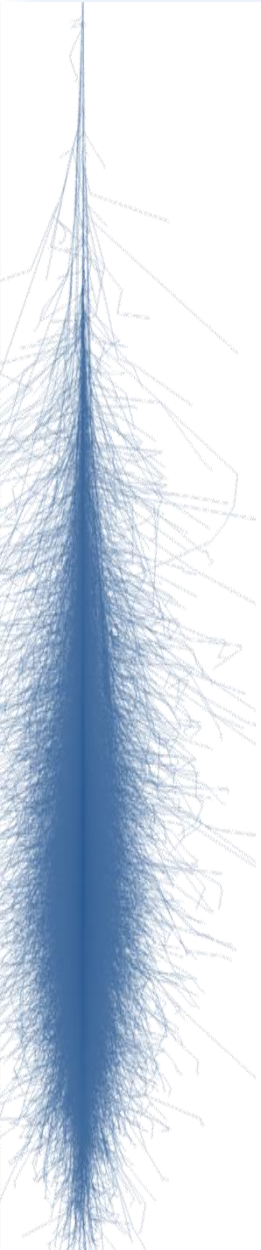
- higher exposure



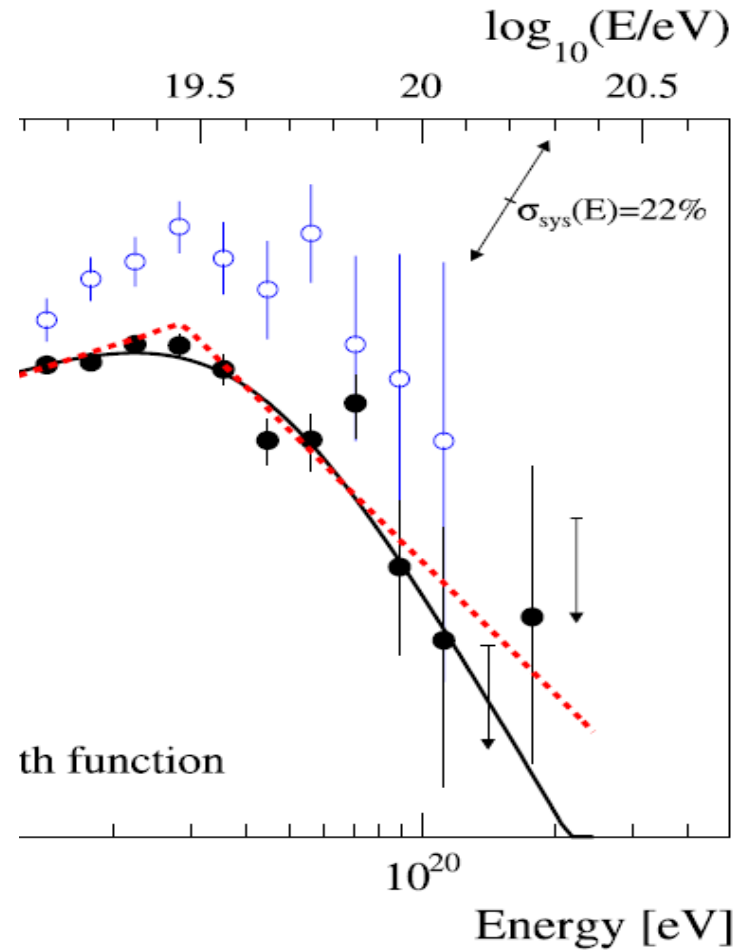
Energy Spectrum



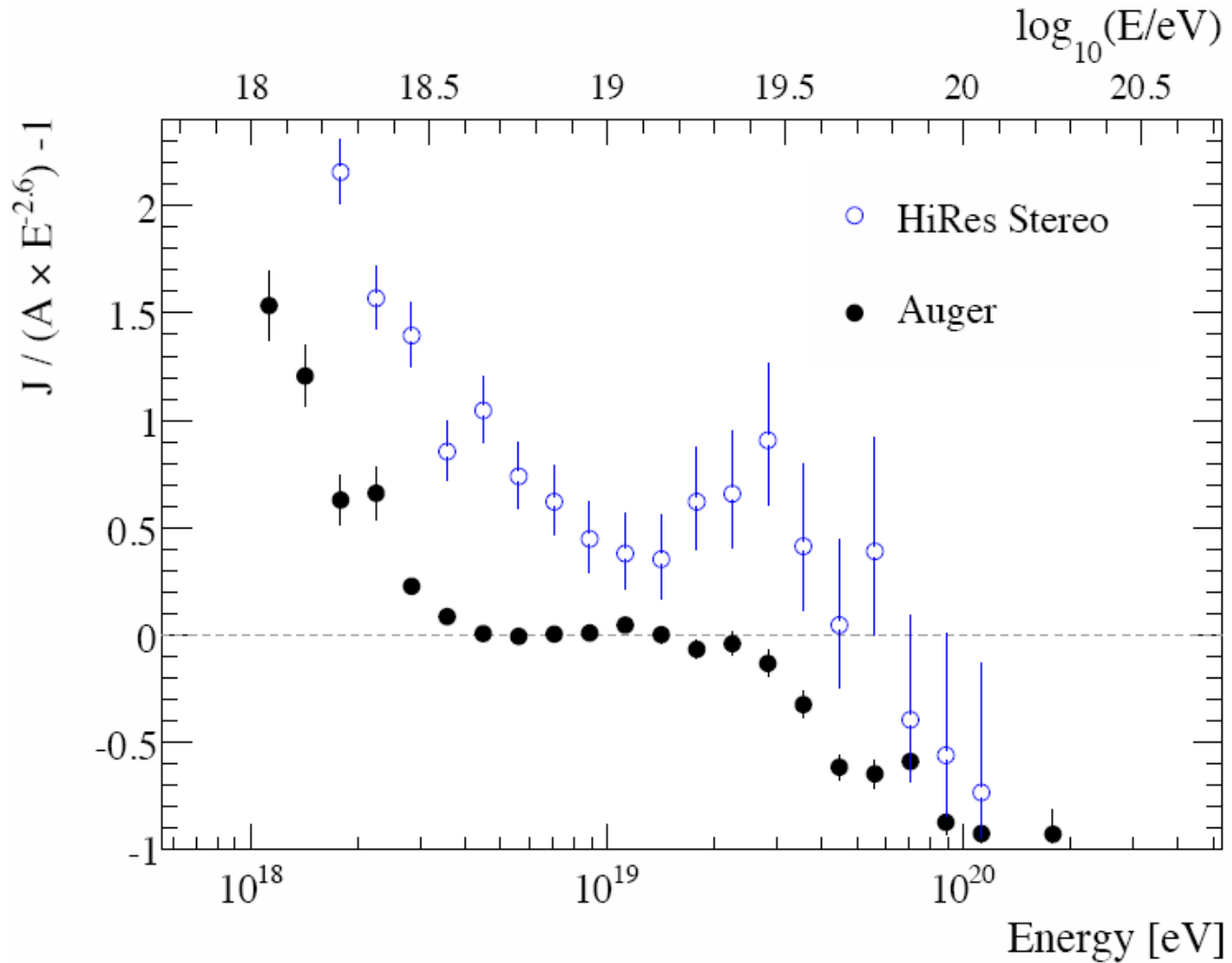
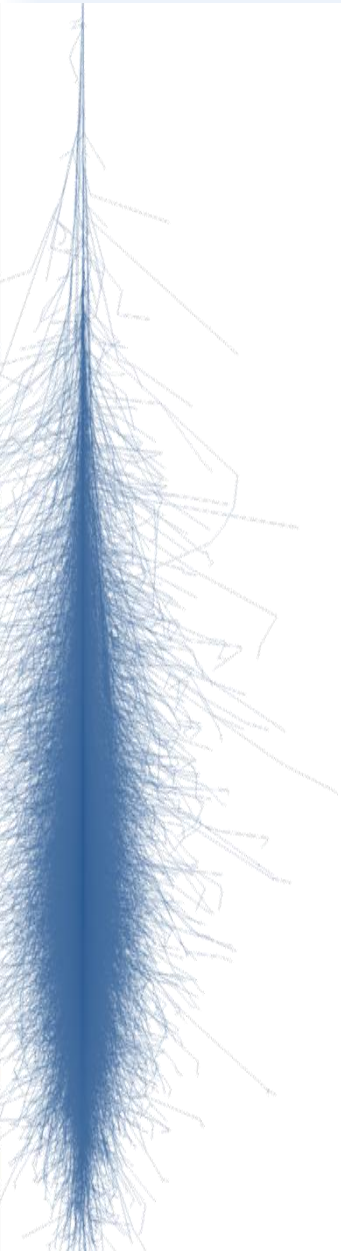
Energy Spectrum



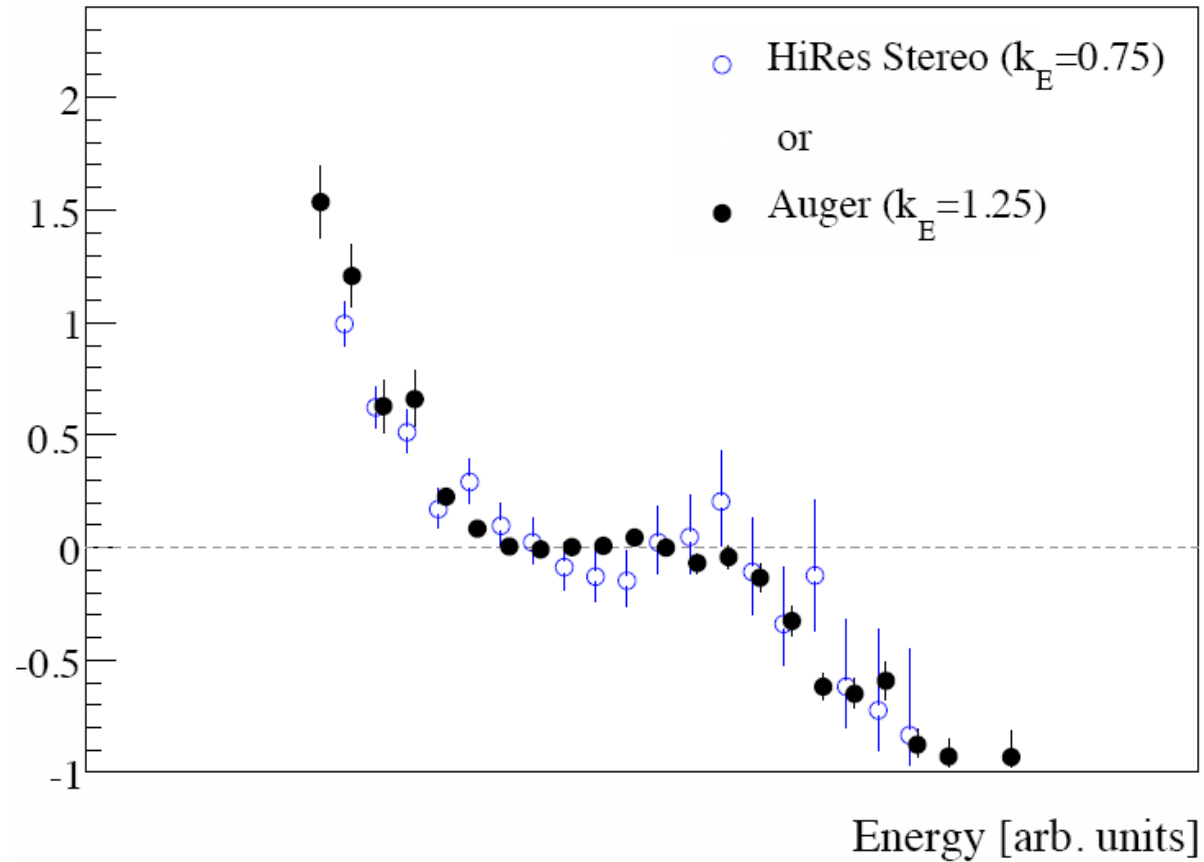
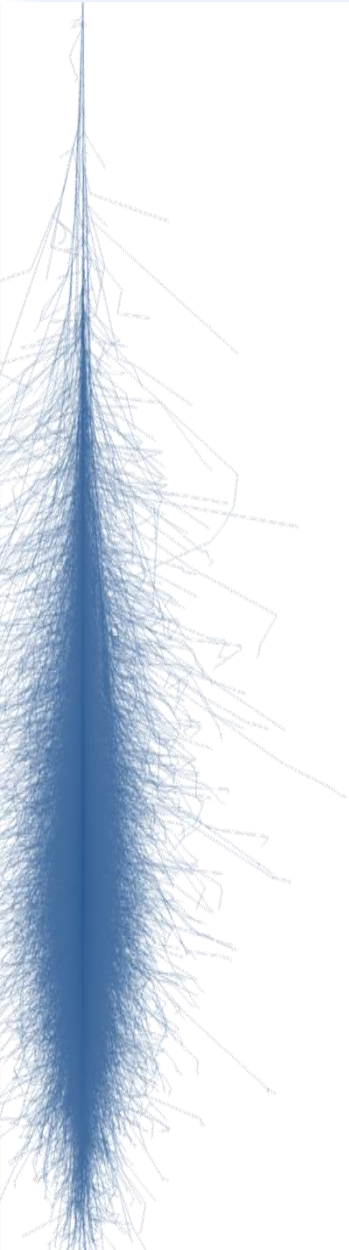
- Auger data shows a flux suppression at the highest energies
 - Cutoff significance $> 20 \sigma$
- This feature is compatible with:
 - GZK cutoff
 - Cosmic ray interaction with CMB through Δ resonance
 - Sources running out of power



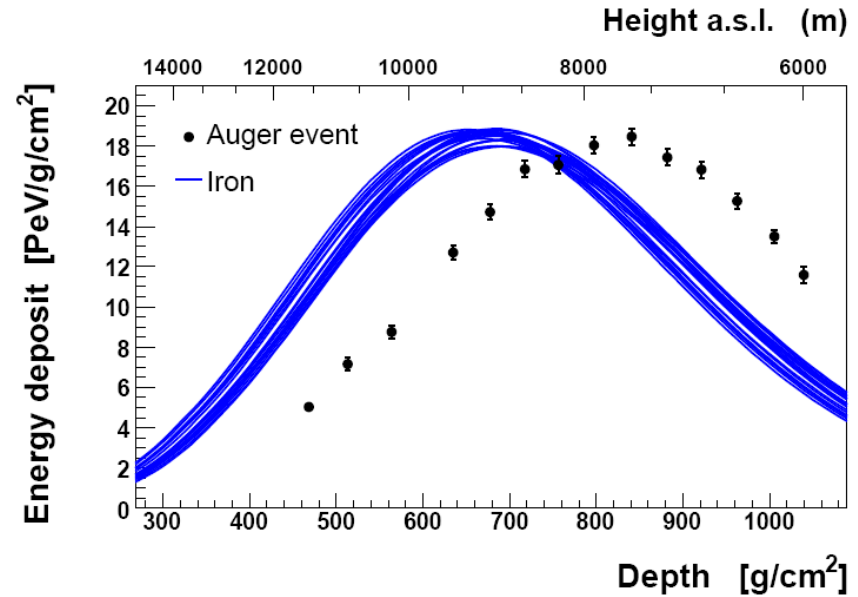
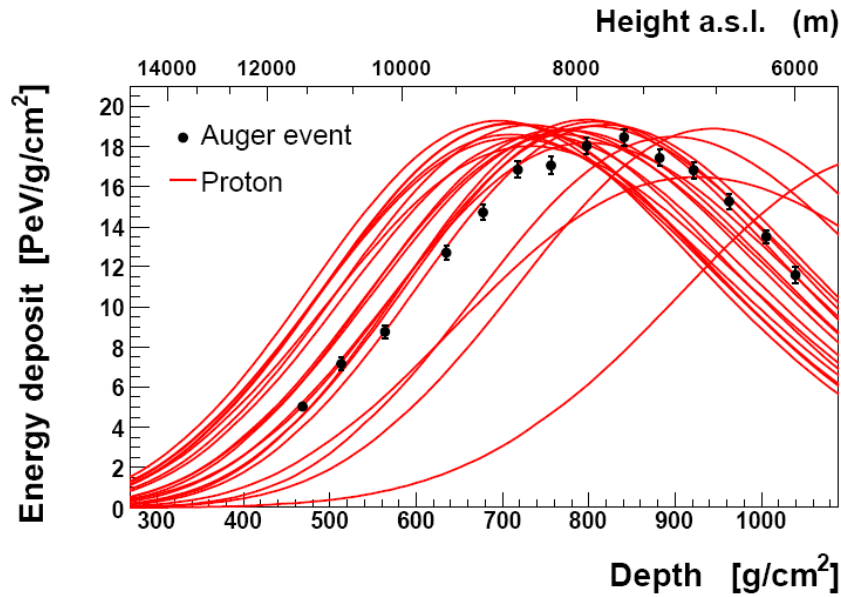
Comparing energy spectrum



Comparing energy spectrum

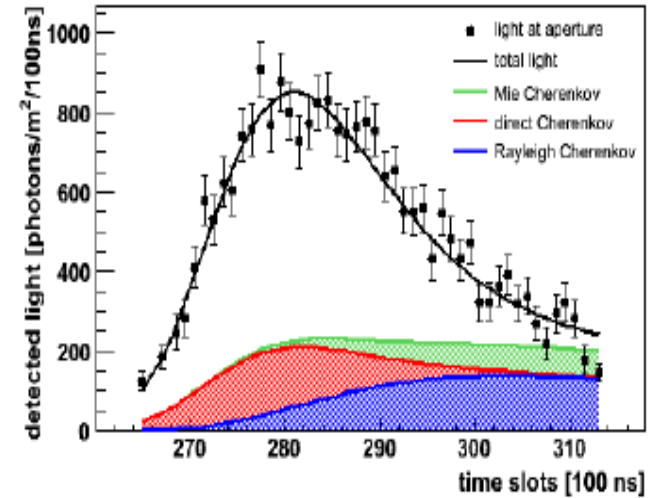
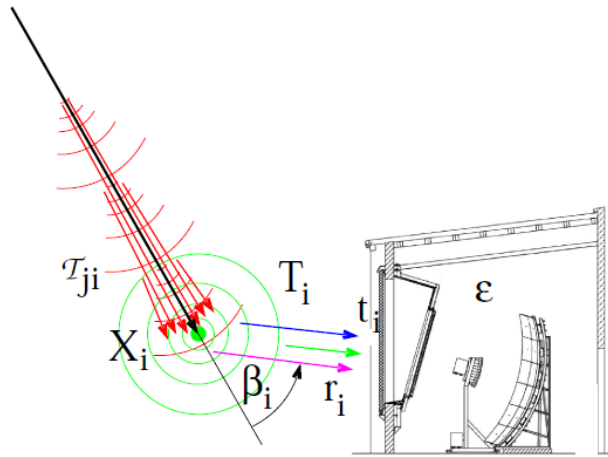


Composition Variables



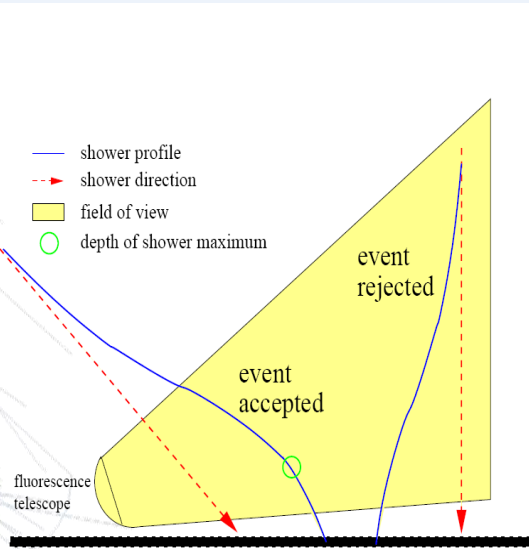
- The moments of the X_{\max} distribution (mean and RMS) are sensitive to primary composition
- As the iron showers spend more energy their mean X_{\max} and shower to shower fluctuations are smaller

Analysis procedure



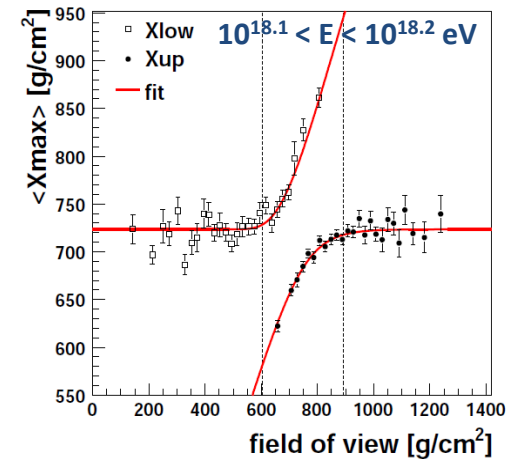
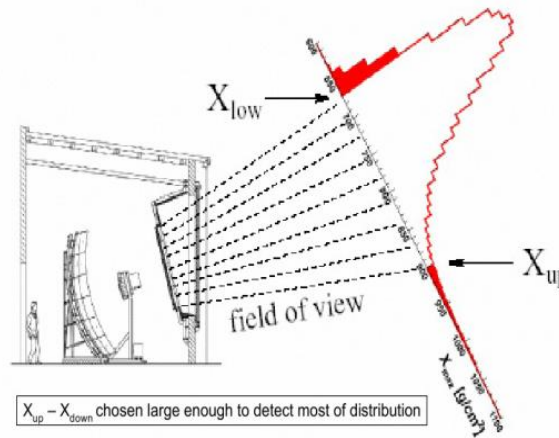
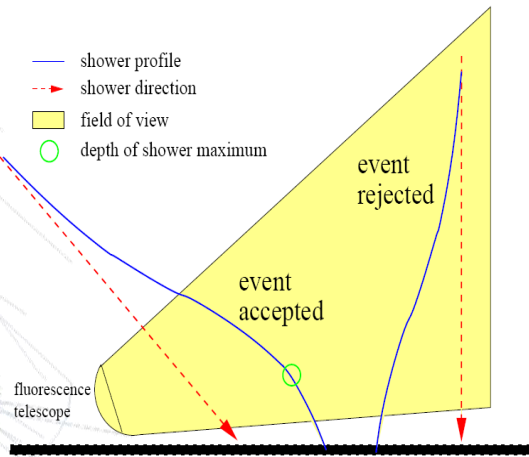
- Shower reconstruction accounts for different types of light and propagation
 - Fluorescence light: isotropic emission
 - Cherenkov light: beamed emission
 - Cherenkov scattering
 - Rayleigh
 - Mie (aerosols)

Analysis procedure



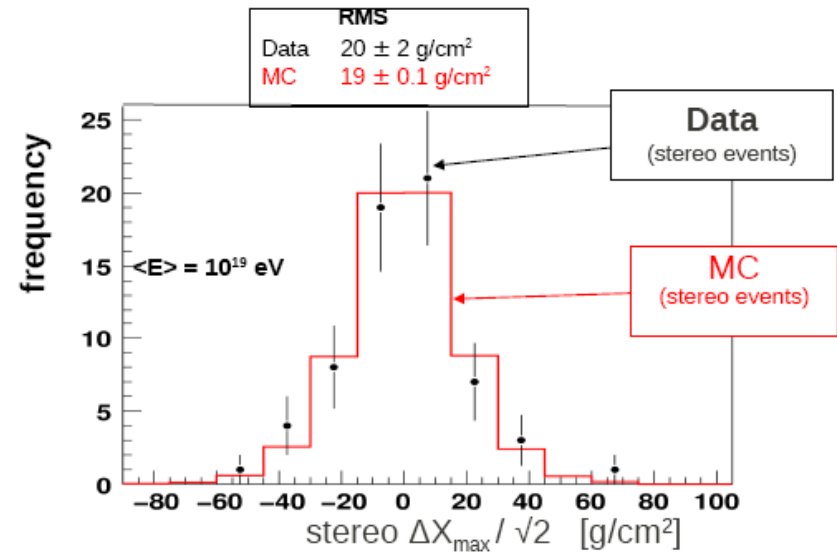
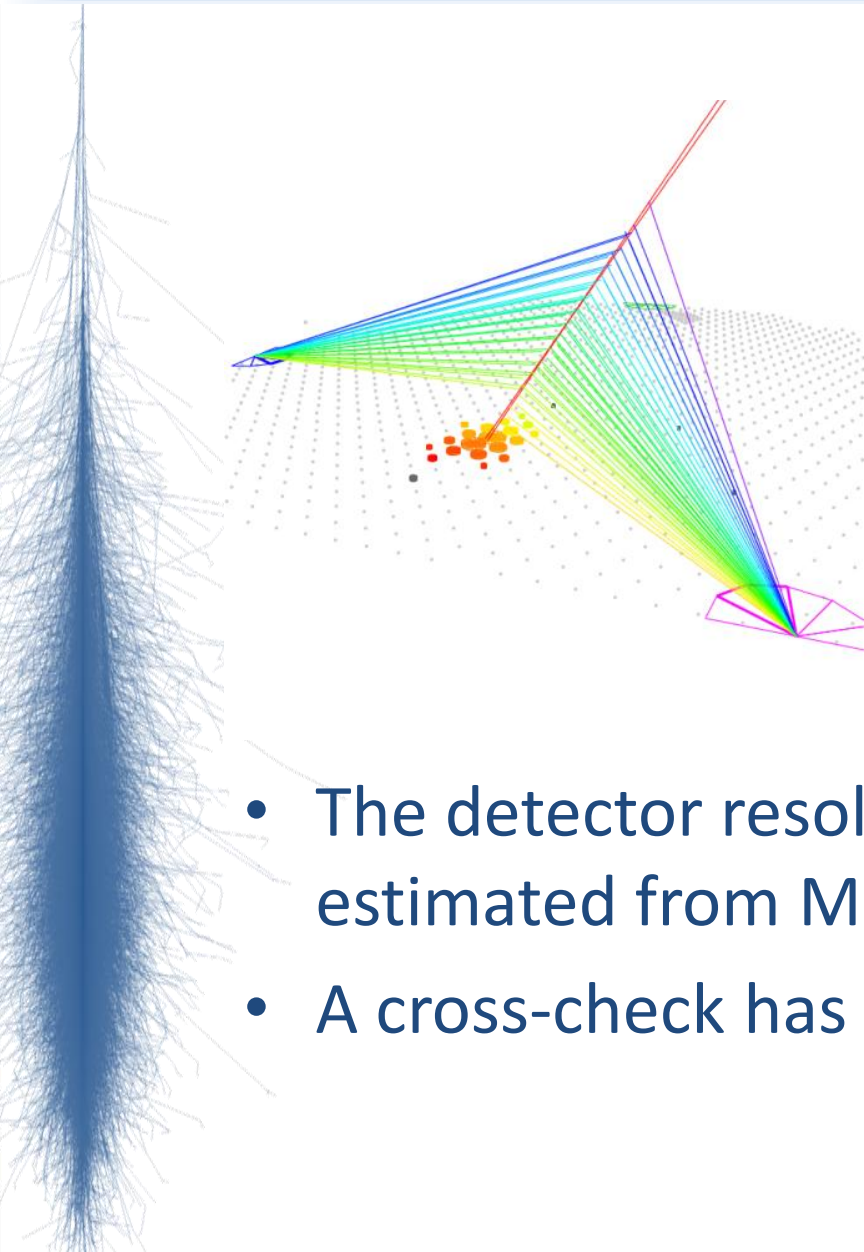
- Apply quality cuts to reconstructed events
 - Atmospheric monitoring
 - Good geometrical reconstruction
 - X_{\max} in the FoV
 - ...

Analysis procedure



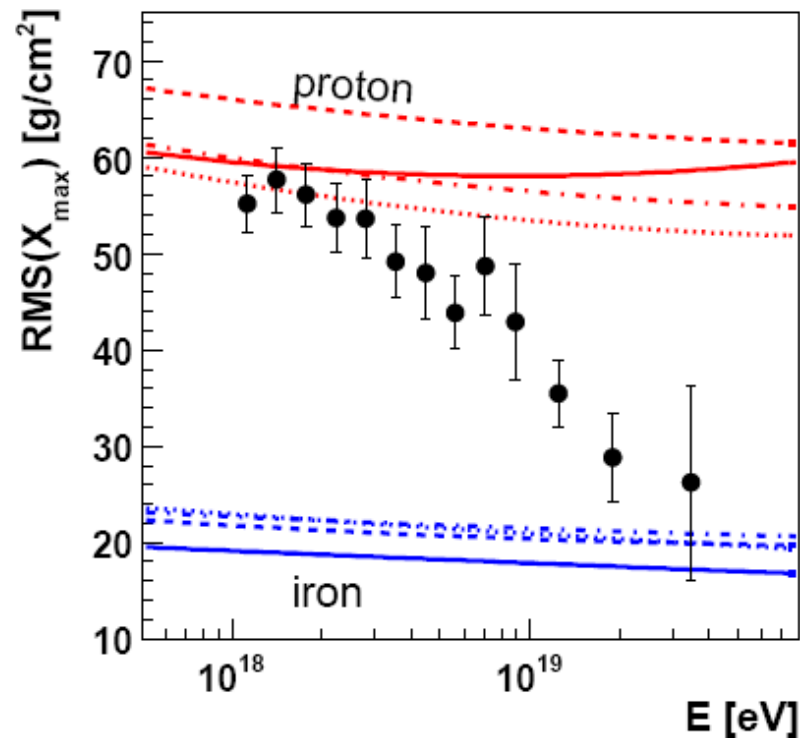
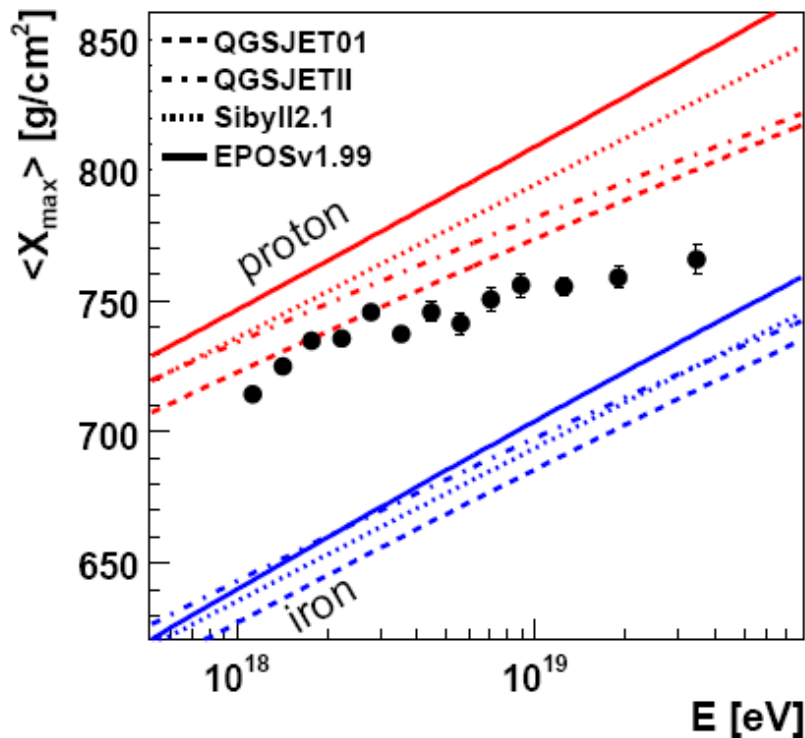
- Apply quality cuts to reconstructed events
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 - Good geometrical reconstruction
 - X_{\max} in the FoV
 - ...
- Apply anti-bias cuts (X_{low} ; X_{up})
 - Cuts derived from data

Resolution of the reconstructed X_{\max}



- The detector resolution for X_{\max} has been estimated from MC simulations to be 20 g cm^{-2}
- A cross-check has been done with *stereo events*

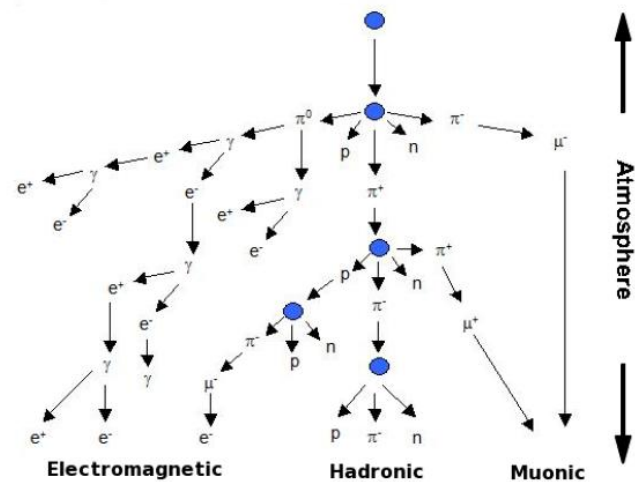
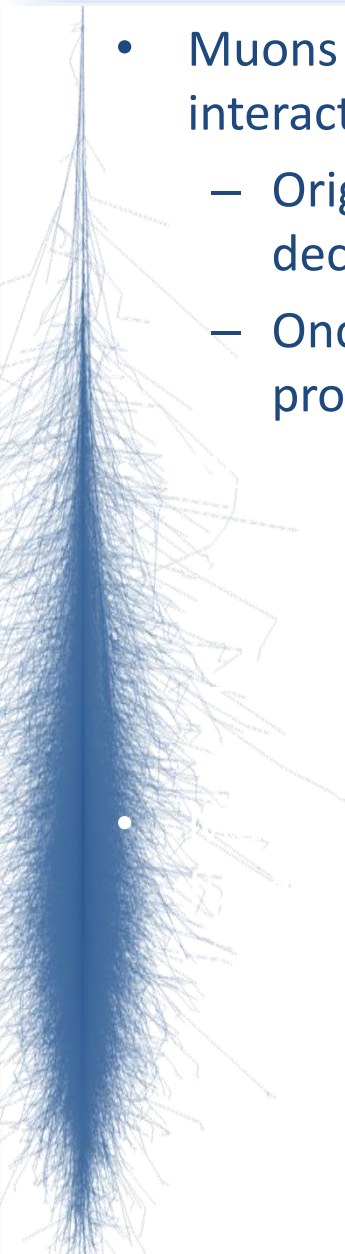
Moments of the X_{\max} distribution



- As energy increases data seems to favour a heavier composition
- A change on the primary cross-section or on the hadronic models may produce the same effect

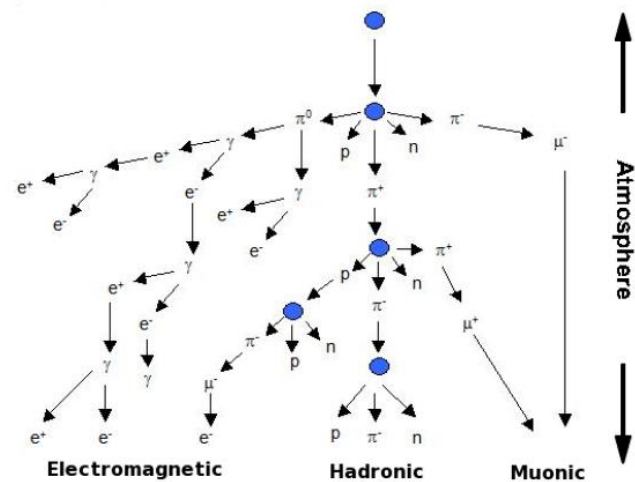
Other shower observables

- Muons are very sensitive to hadronic interactions
 - Originated essentially from the decay of charged pions
 - Once produced they have a large probability to reach the ground



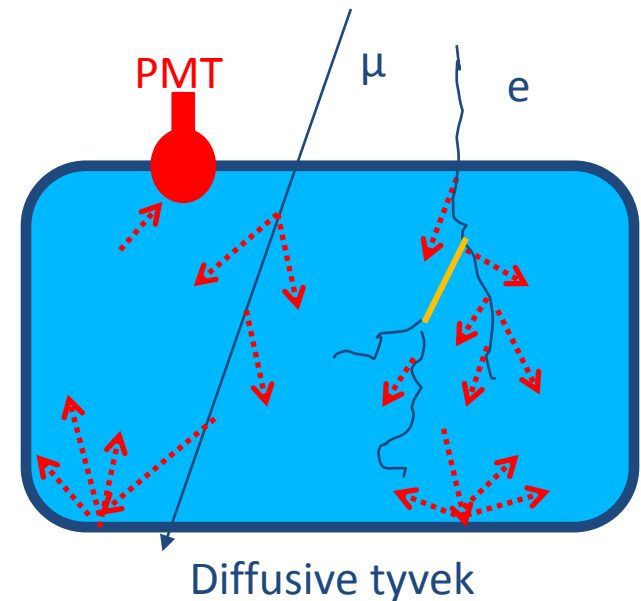
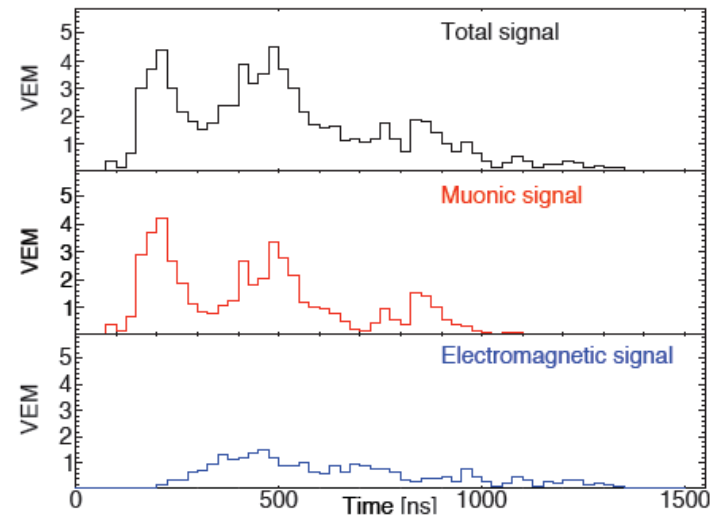
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- Number of muons can be measured in:
 - Vertical showers (indirect)
 - $\theta < 60^\circ$
 - Inclined showers (direct)
 - R. Vázquez talk



Other shower observables

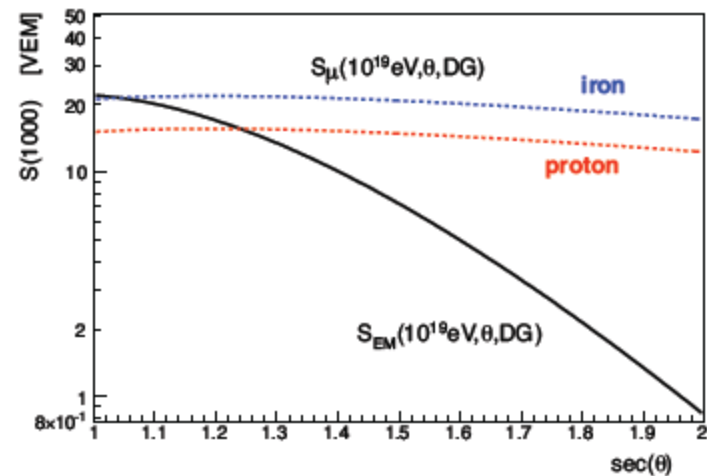
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 - R. Vázquez talk
- Measurement of the muon density at a fixed core distance:
 - Analysis of the time trace:
 - **Muon counting**
 - Prompt peak signal
 - **Smoothing method**
 - Estimate the e.m. signal



Other shower observables

- Exploit the **universality** features of the e.m. shower component

$$S_{MC}(E, \theta, \langle X_{\max} \rangle) = S_{EM}(E, \theta, DX) + N_{\mu}^{\text{rel}} S_{\mu}^{\text{QGSII,p}}(10^{19} \text{ eV}, \theta, DX)$$



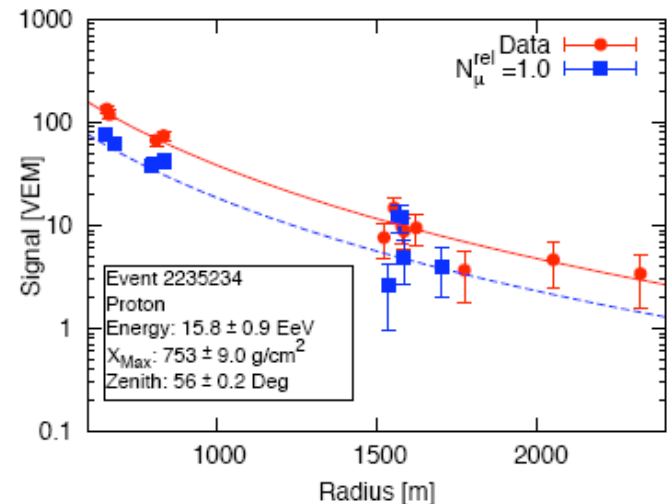
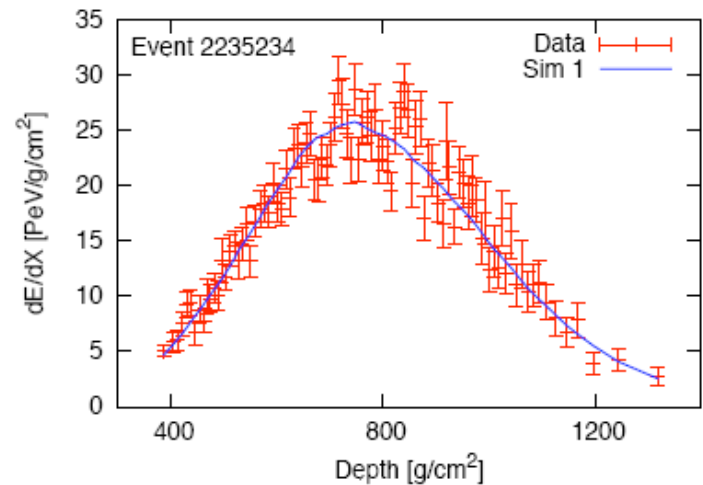
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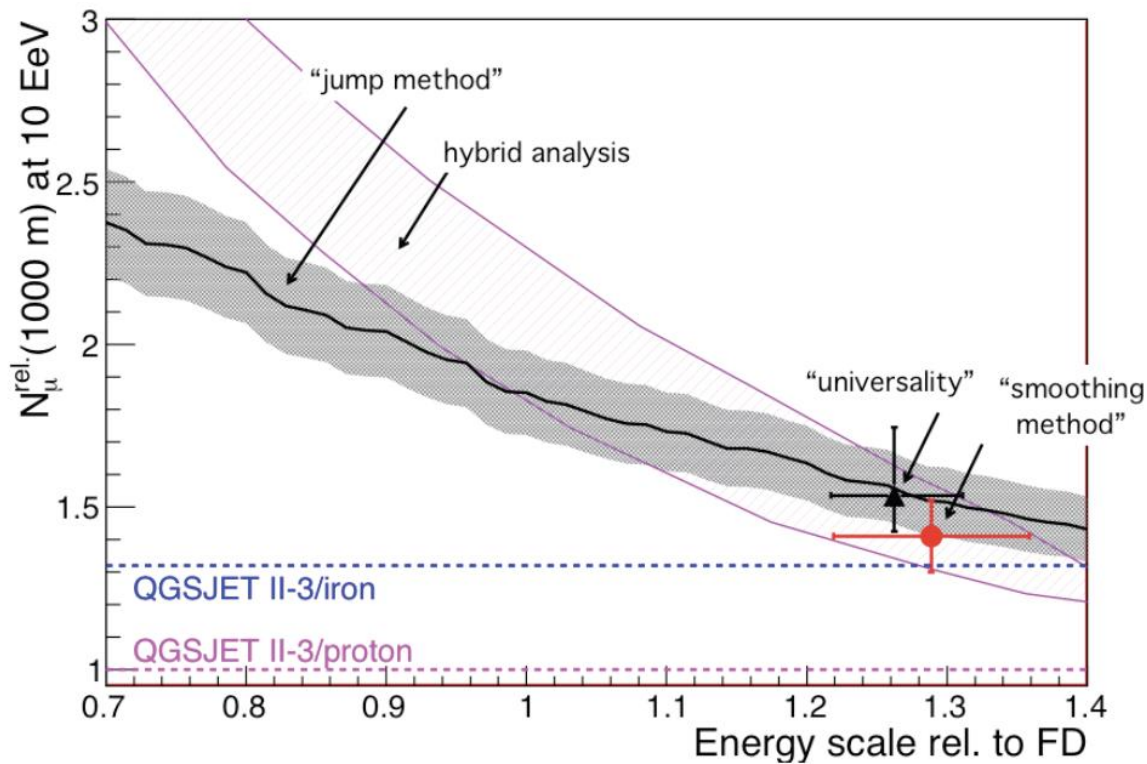
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- **Hybrid events**

- Reproduce the data e.m. longitudinal profile with simulation
- Compare signal at the ground MC/data




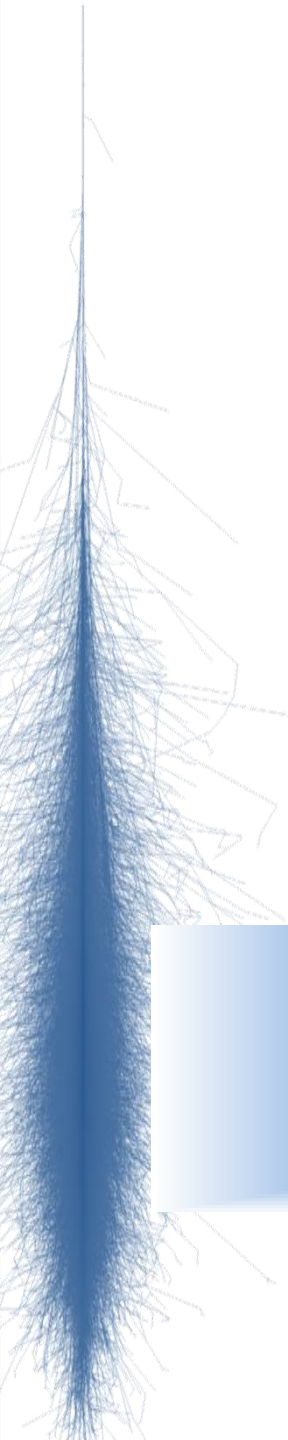
Number of Muons in EAS



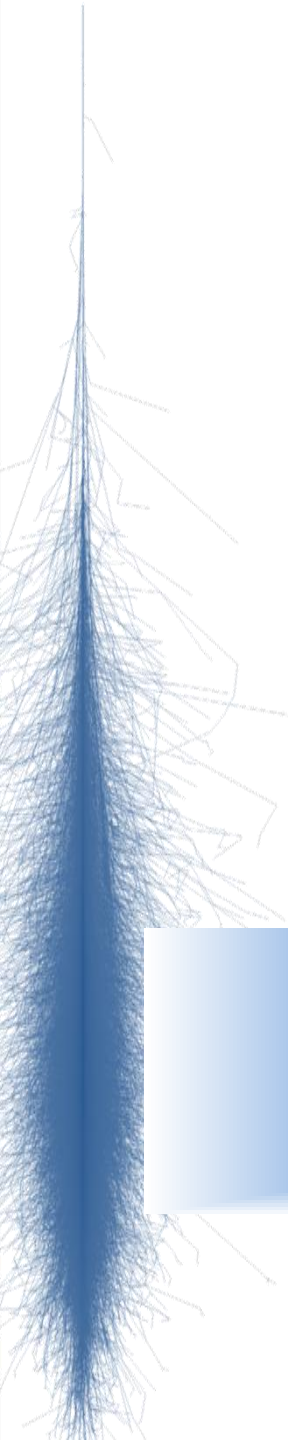
- All methods show that there is a **muon deficit** in MC simulations
 - $E_{\text{LAB}} \simeq 10^{19}$ eV ($\sqrt{s} \simeq 140$ TeV for proton primaries)
- Additionally an increase on the FD energy scale of $\sim 26\%$ is preferred
 - Compatible with FD systematic uncertainty of 22%

Conclusions

- 
- The Pierre Auger Observatory is working smoothly at full acceptance.
 - **Energy spectrum** measured with high statistics
 - Ankle structure determined with high definition
 - A suppression, compatible with the GZK cutoff, is observed at the highest energies ($> 20 \sigma$)
 - Observation of a change in the **shower development with energy**
 - Mass composition?
 - Cross-section or Hadronic models?
 - Data shows a deficit of **muons** in Hadronic models
 - An update of the Pierre Auger Observatory results will be shown in ICRC 2011 Beijing

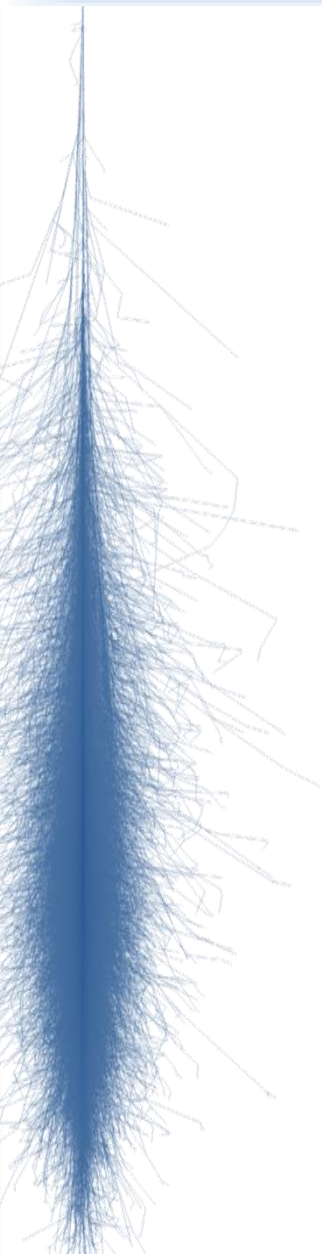


END



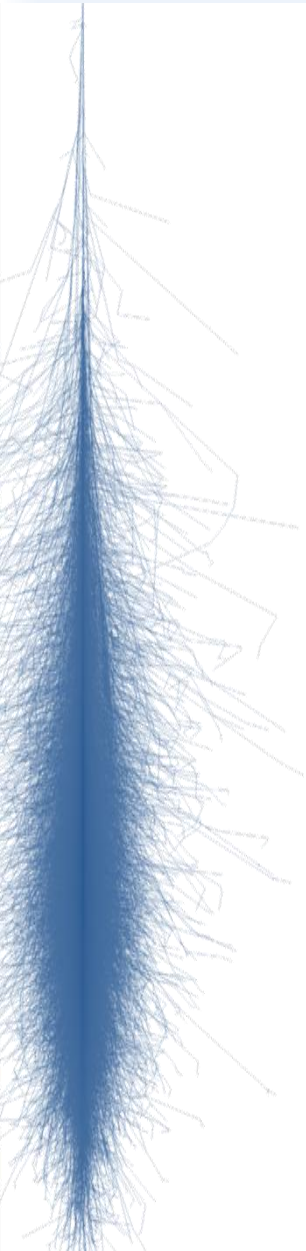
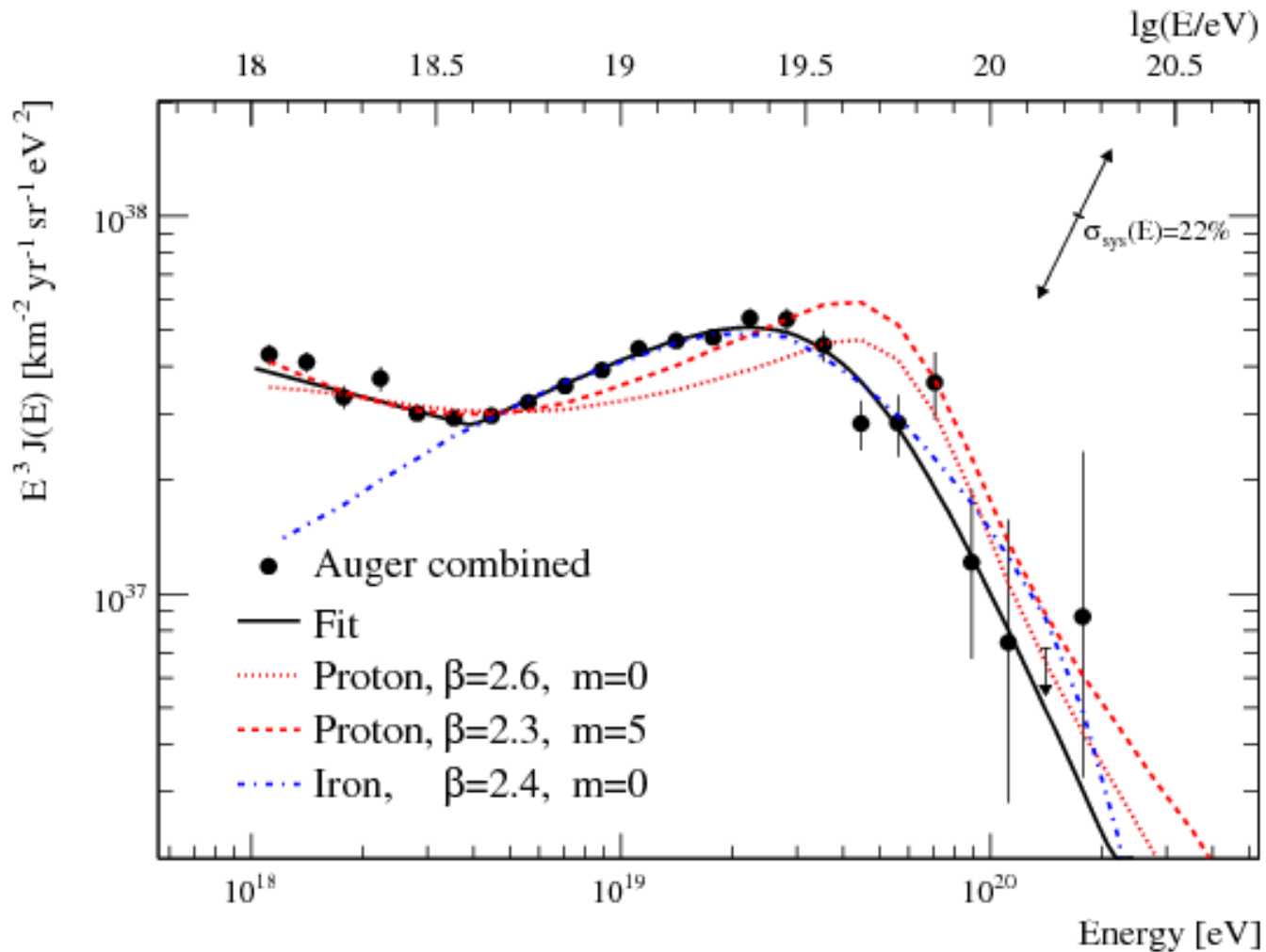
BACKUP SLIDES

FD systematics

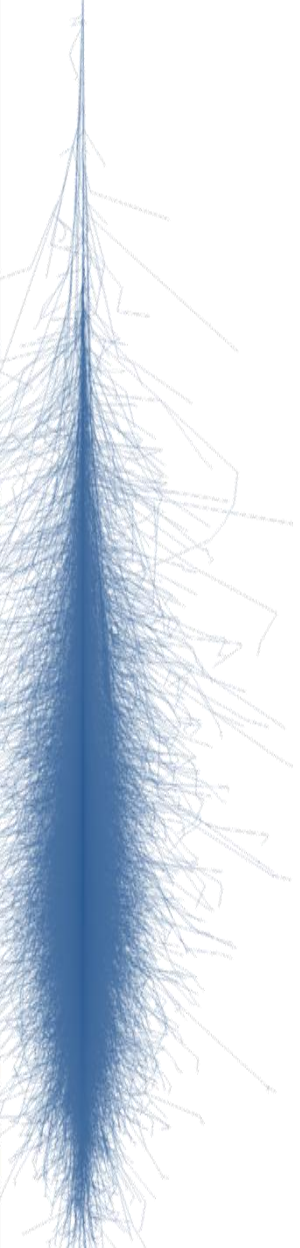
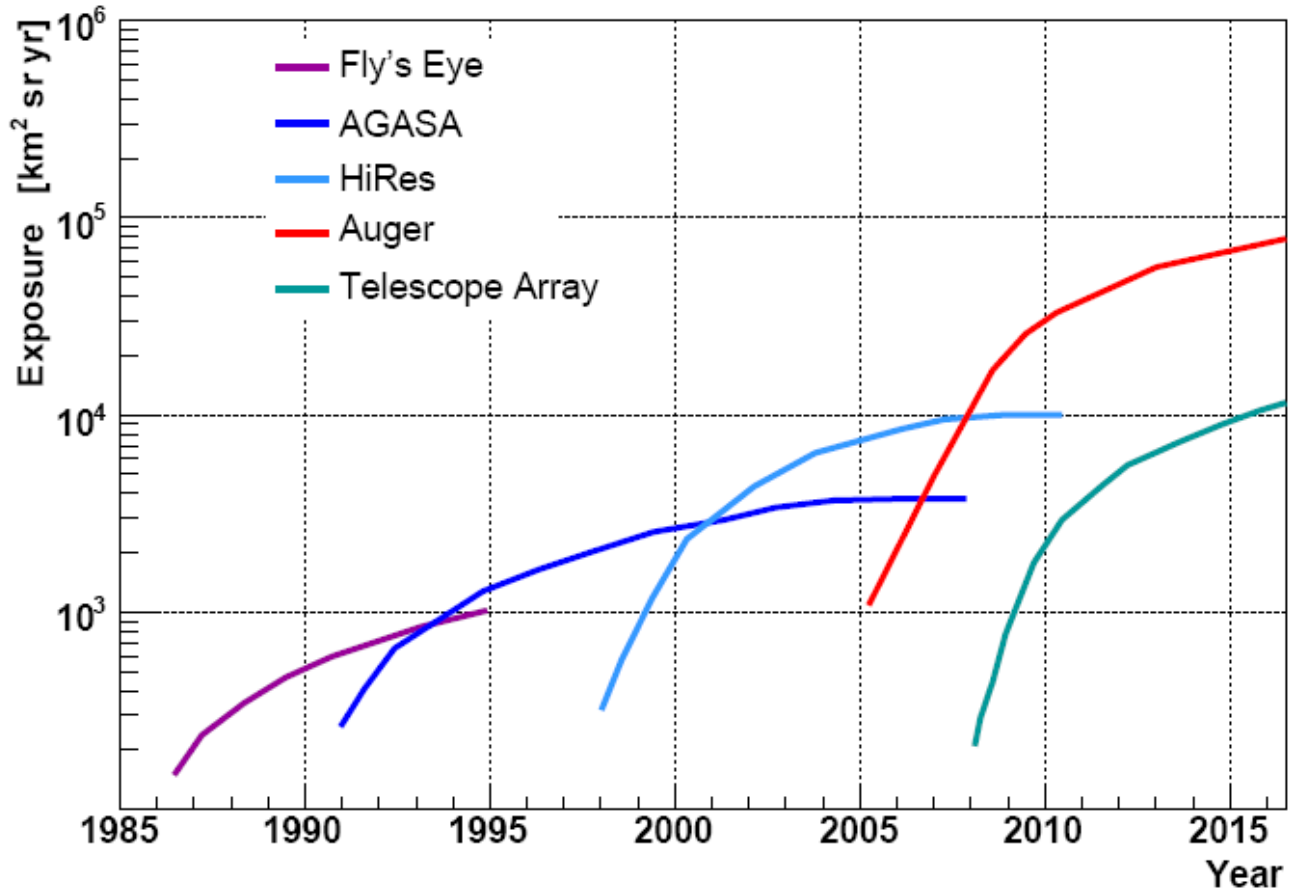


Uncertainty (%)	Source
14	Absolute fluorescence yield
10	Reconstruction of the longitudinal shower profile
9	Absolute calibration of the fluorescence telescopes
7	Aerosol optical depth
5	Water vapour quenching
4	Invisible energy
3	Wavelength dependent response
1	Molecular optical depth
1	Multiple scattering models
22	Total

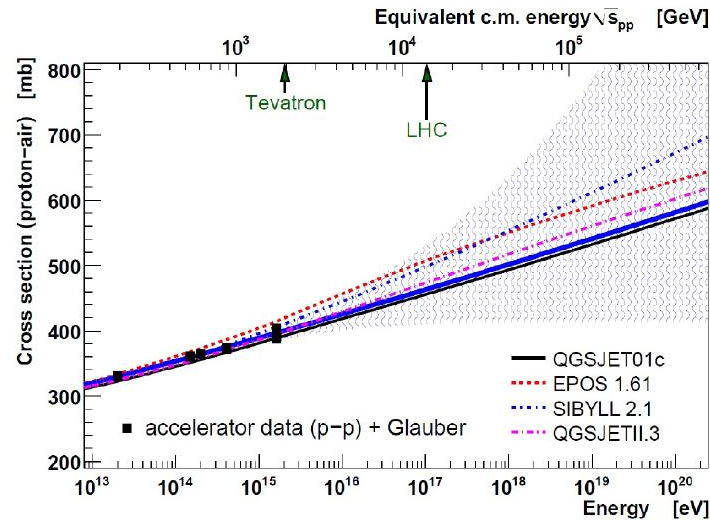
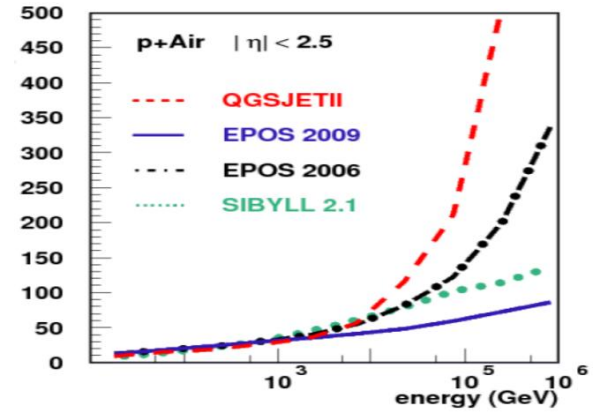
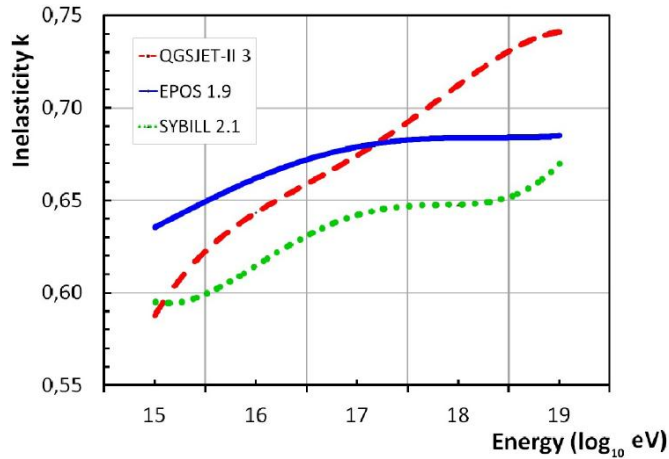
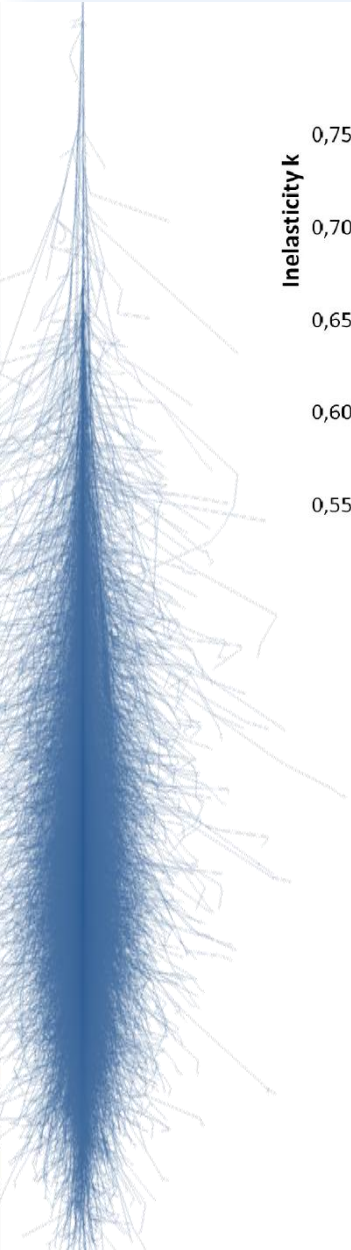
Composition from the energy spectrum



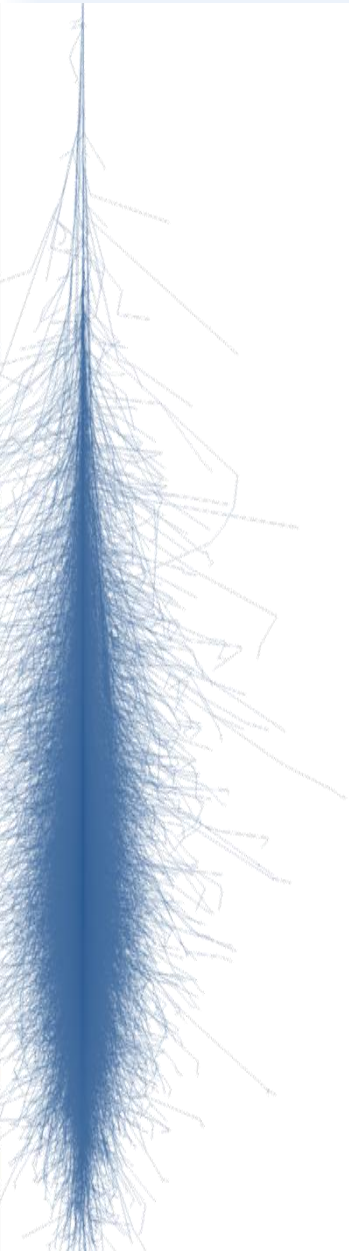
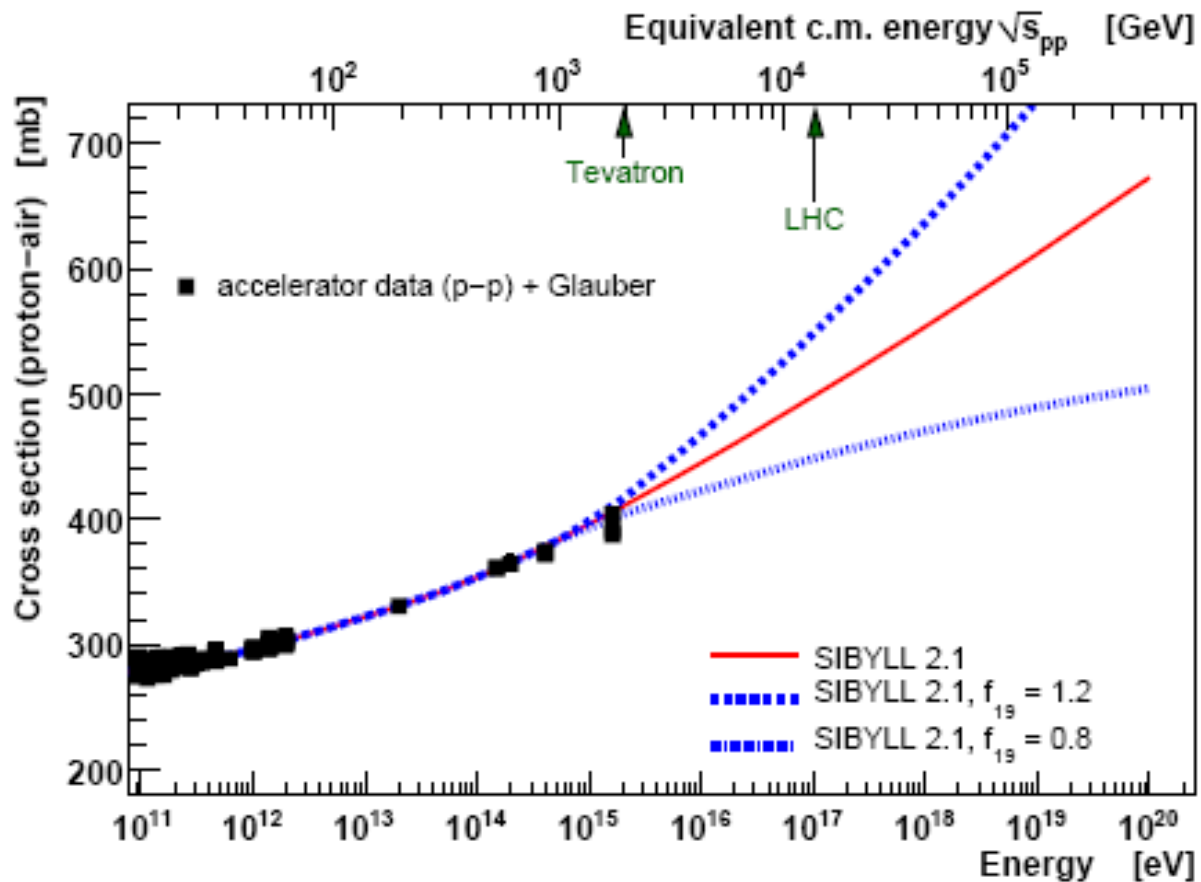
Experiments Exposure



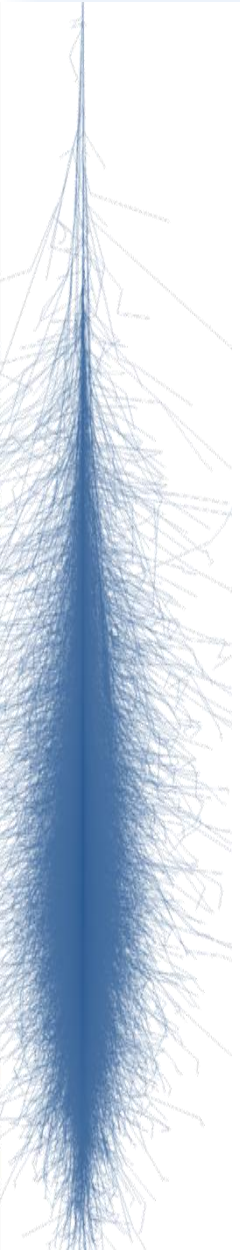
Interactions parameters



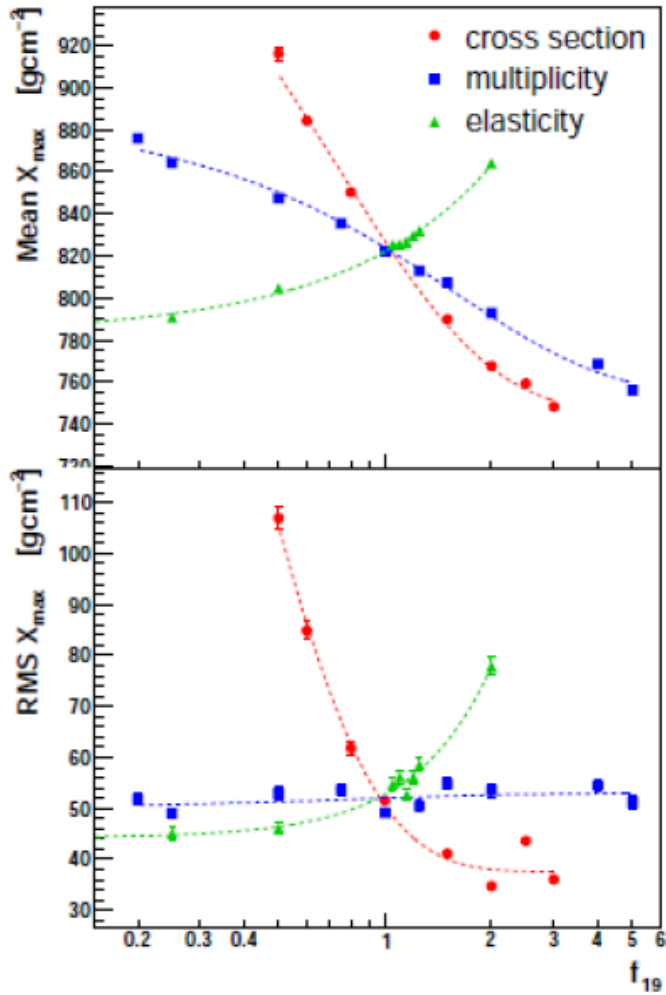
Changing interaction parameters



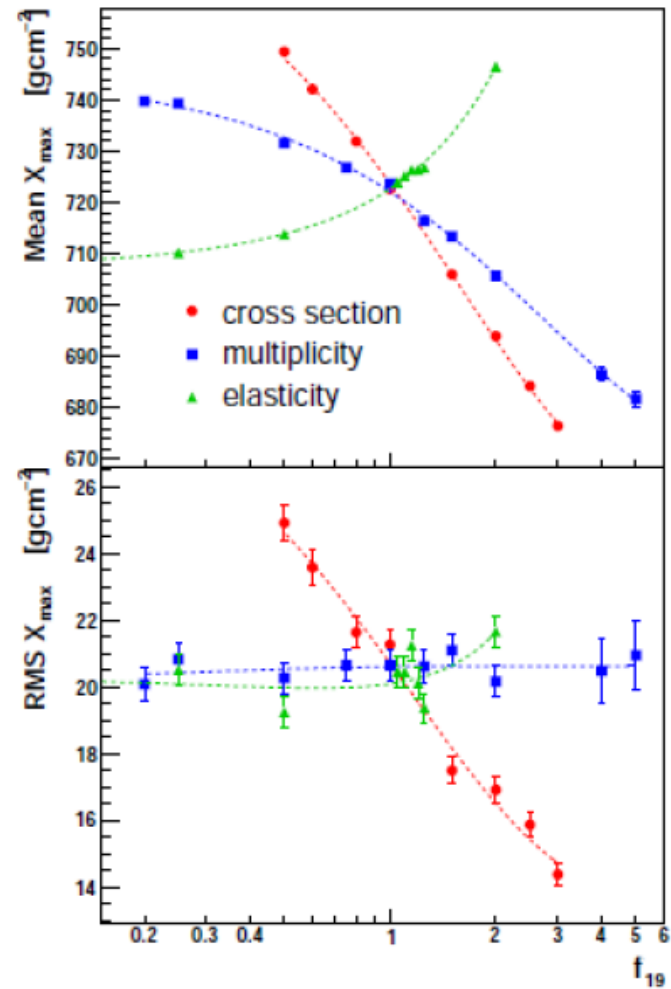
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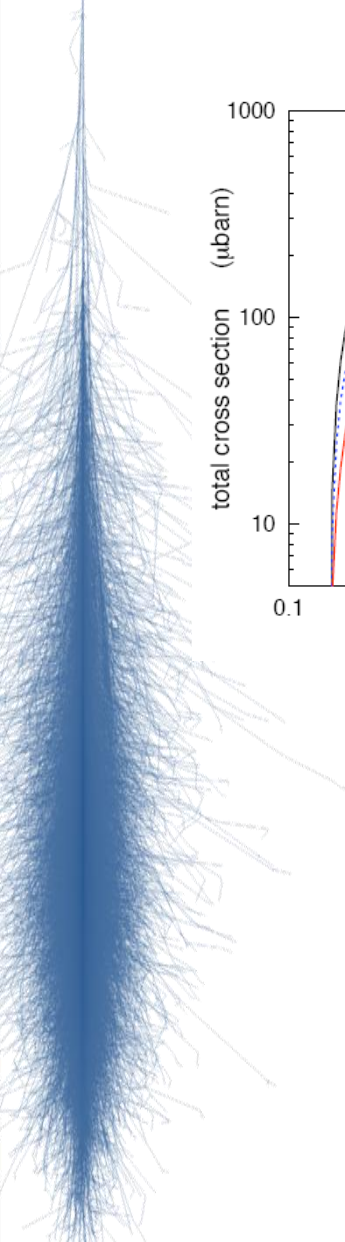
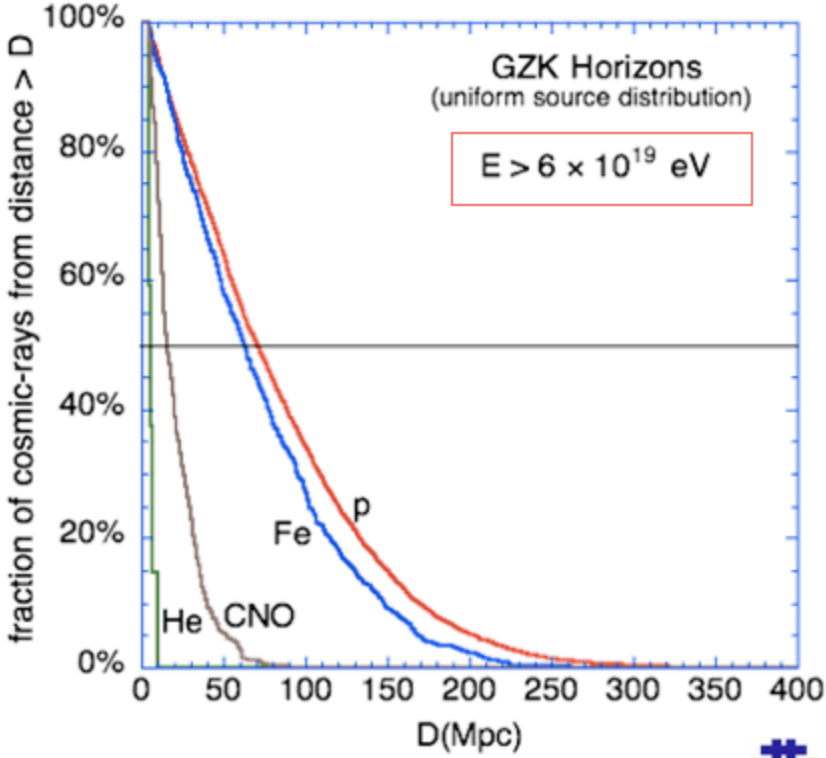
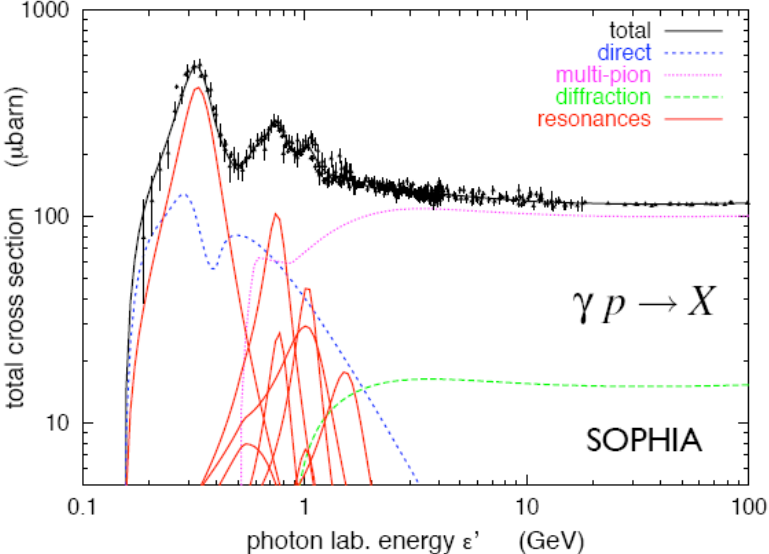
Proton



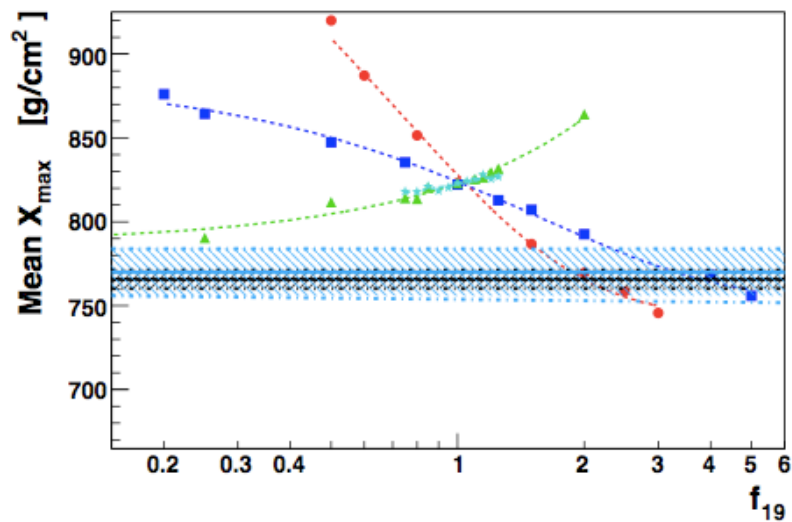
Iron



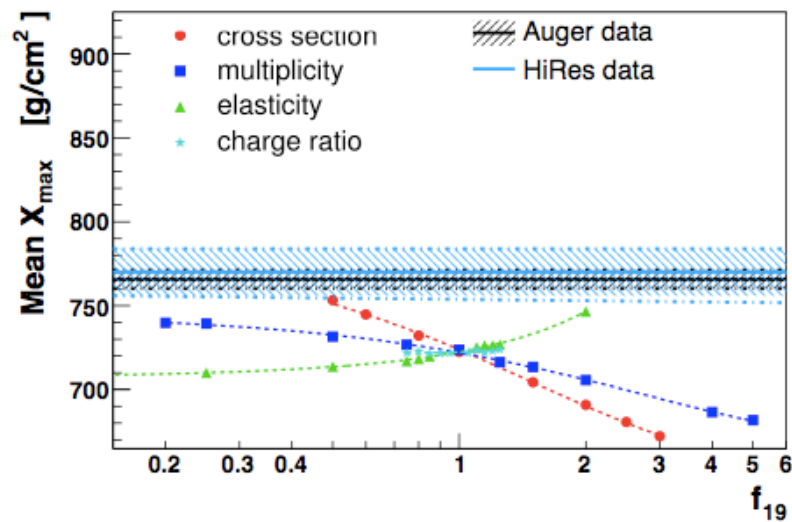
GZK effect



Changing interactions parameters



Proton



Iron

