Highest energy astro-particle physics with the Pierre Auger Observatory

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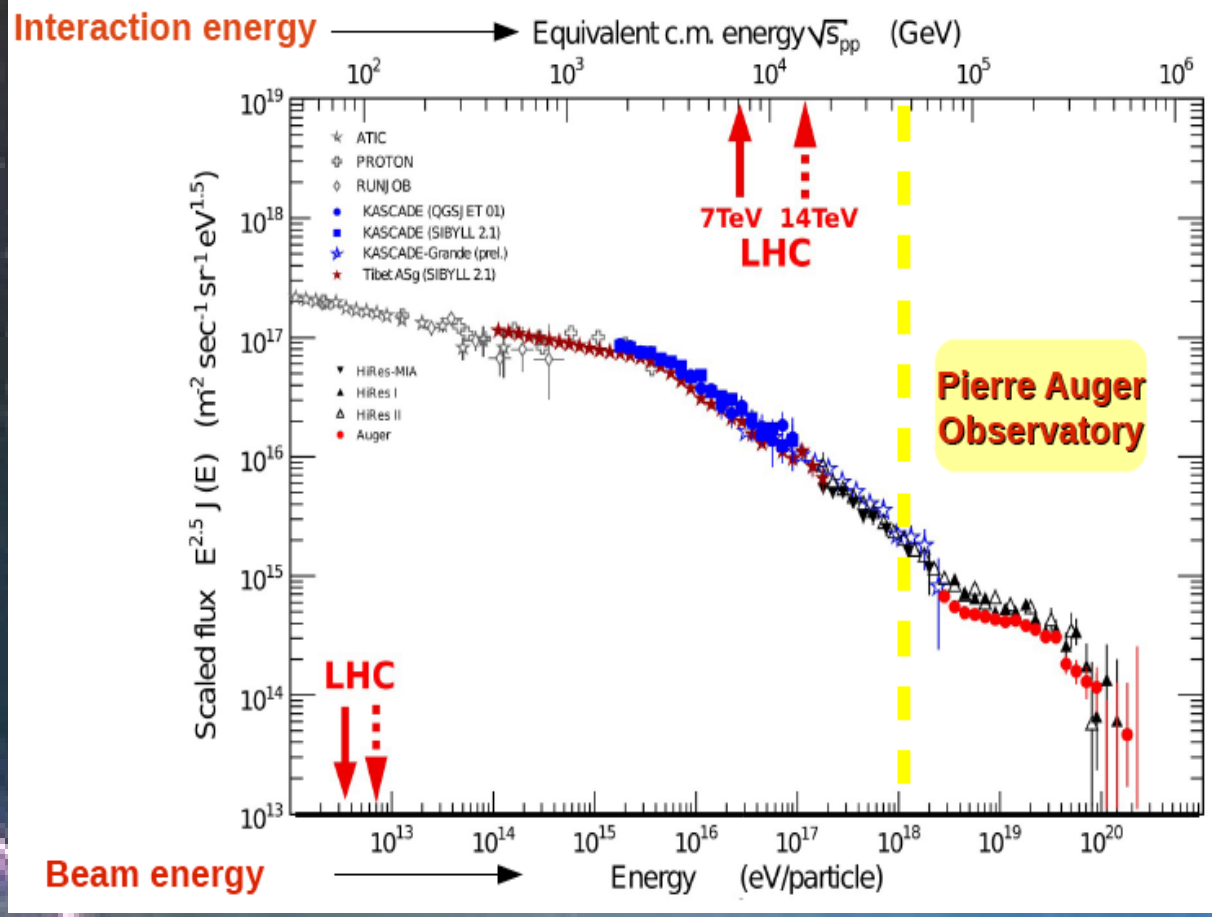
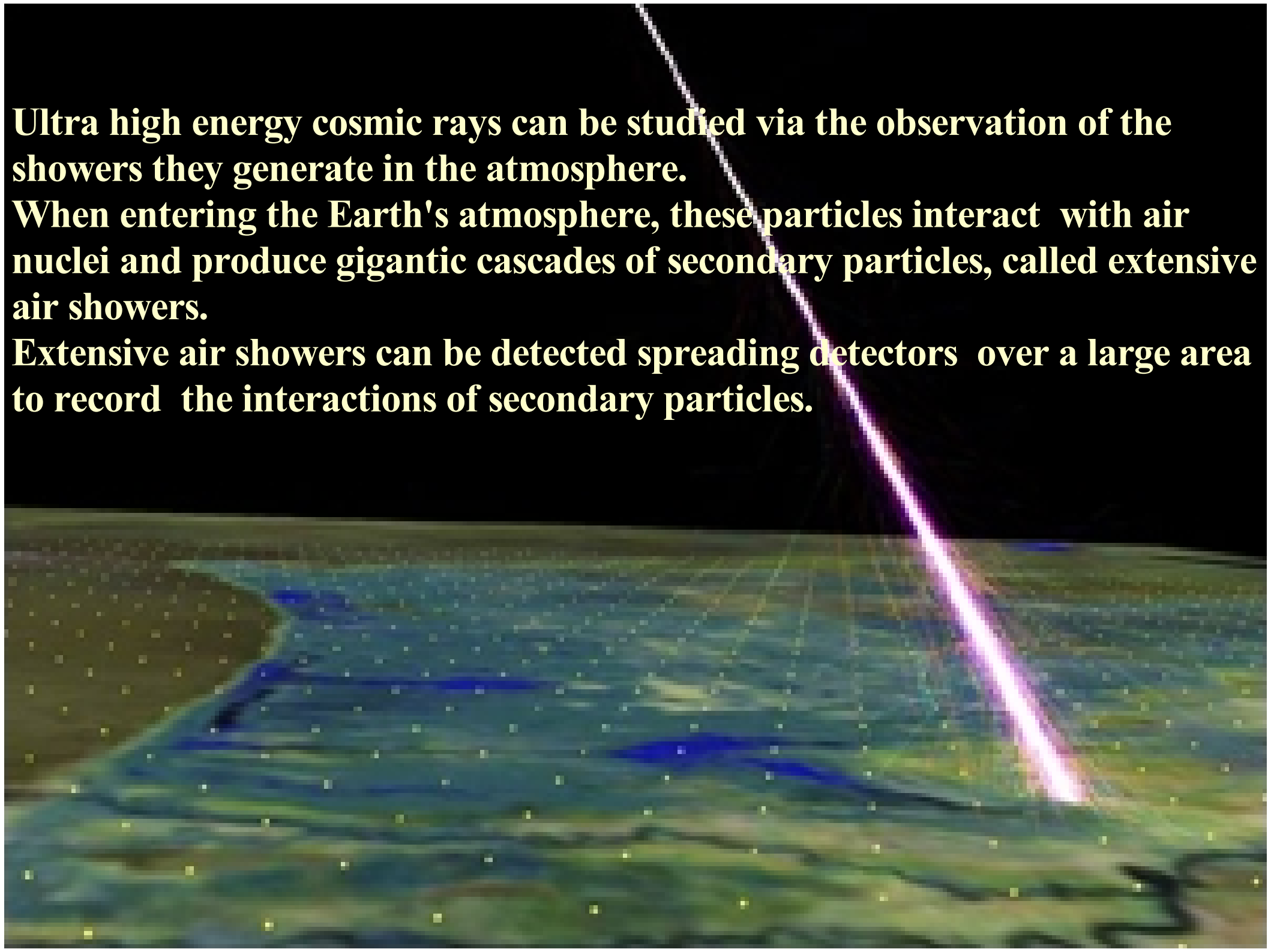
September 3-7, PIC 2013, Beijing, China



Astroparticles offer a new path of research in the field of particle physics, allowing investigations at energies outstanding the possibilities of accelerators .

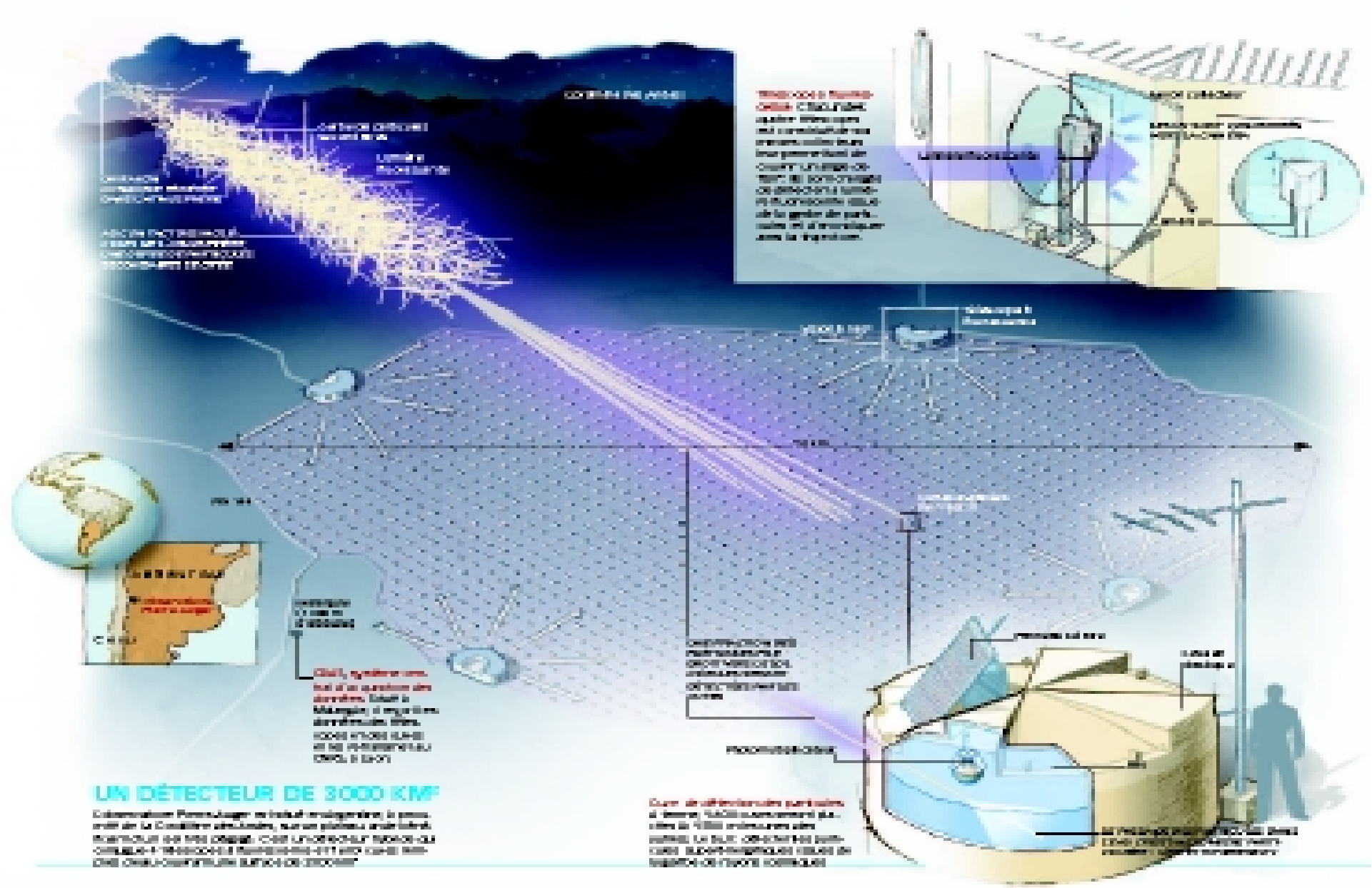
The earth is constantly being bombarded by particles, cosmic rays, coming from space.

These cosmic particles provide a beam at energies higher than any man-made accelerator, but at a very low rate.

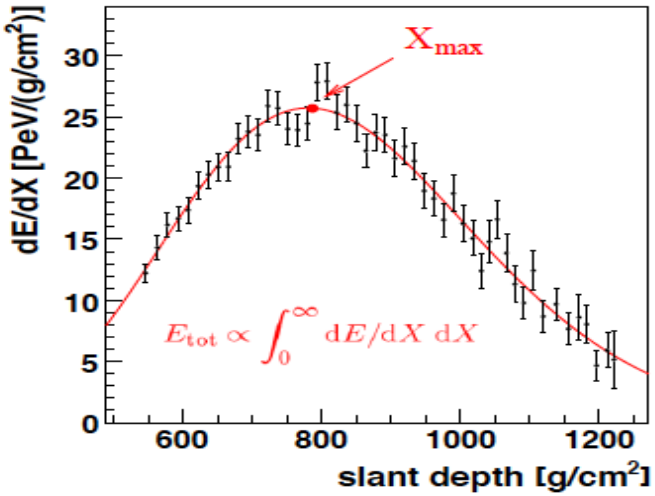

Ultra high energy cosmic rays can be studied via the observation of the showers they generate in the atmosphere.
When entering the Earth's atmosphere, these particles interact with air nuclei and produce gigantic cascades of secondary particles, called extensive air showers.
Extensive air showers can be detected spreading detectors over a large area to record the interactions of secondary particles.

Pierre Auger Observatory

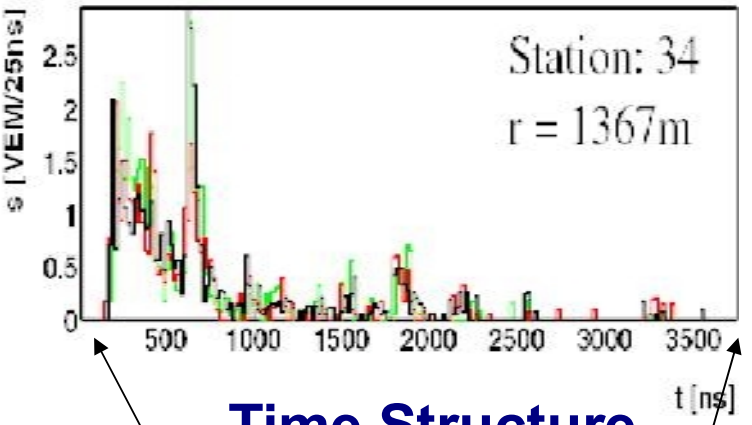
A unique and powerful design to observe ultra high energy cosmic rays and probe particle interactions at the highest energies



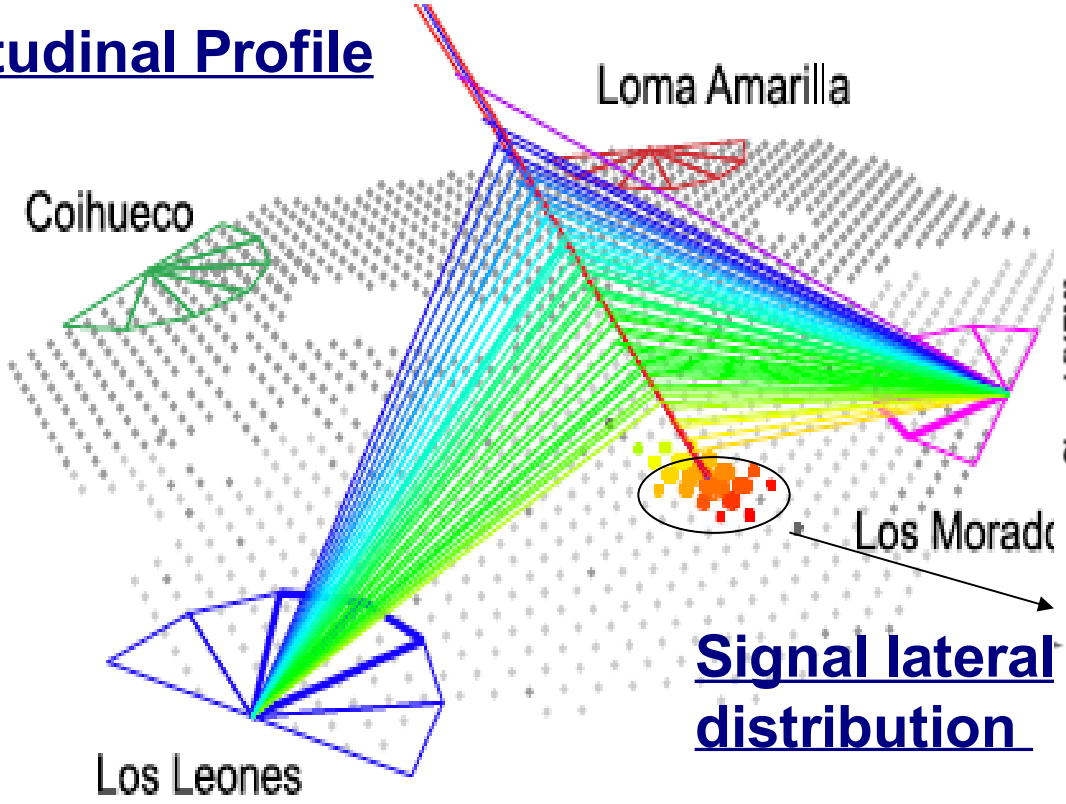
Extensive air shower observables



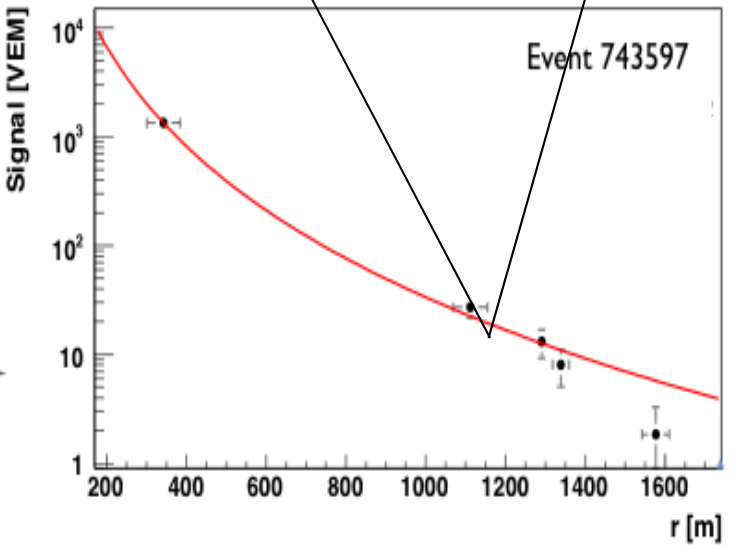
Longitudinal Profile



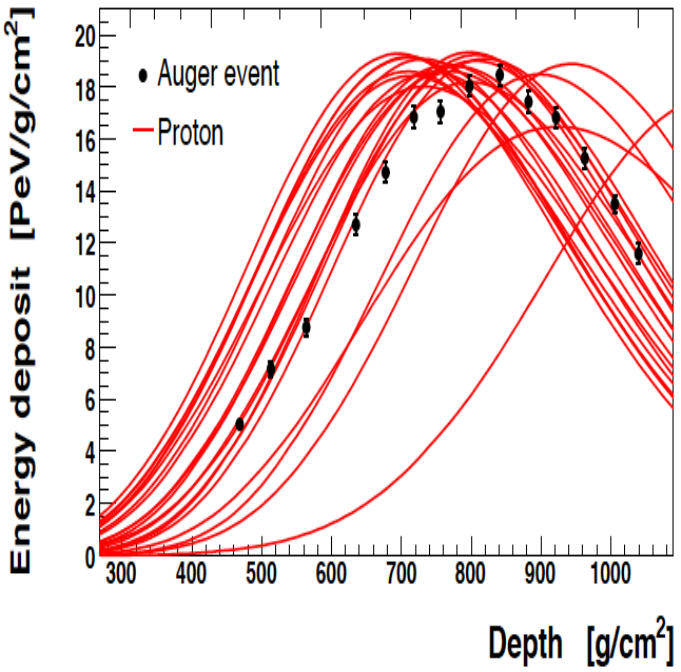
Time Structure

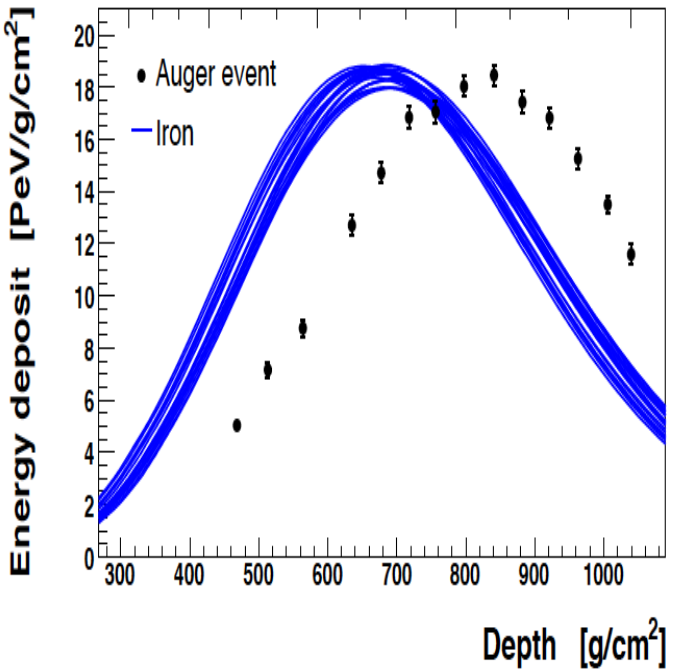


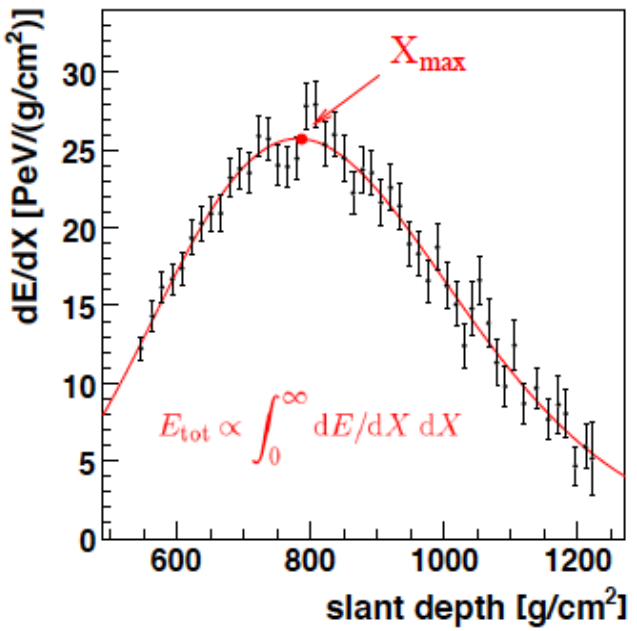
Signal lateral distribution

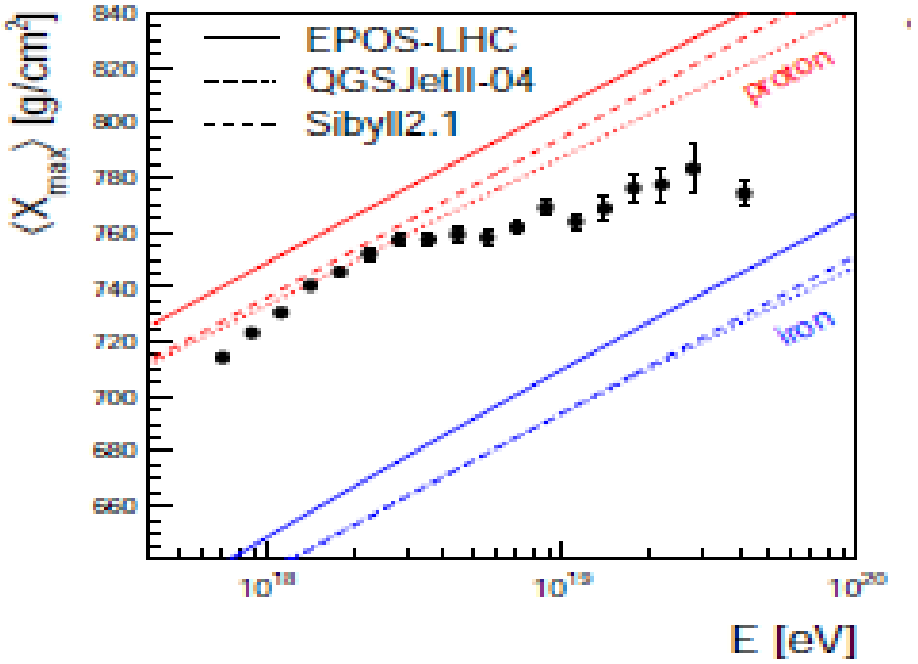


Longitudinal shower profile: mass composition





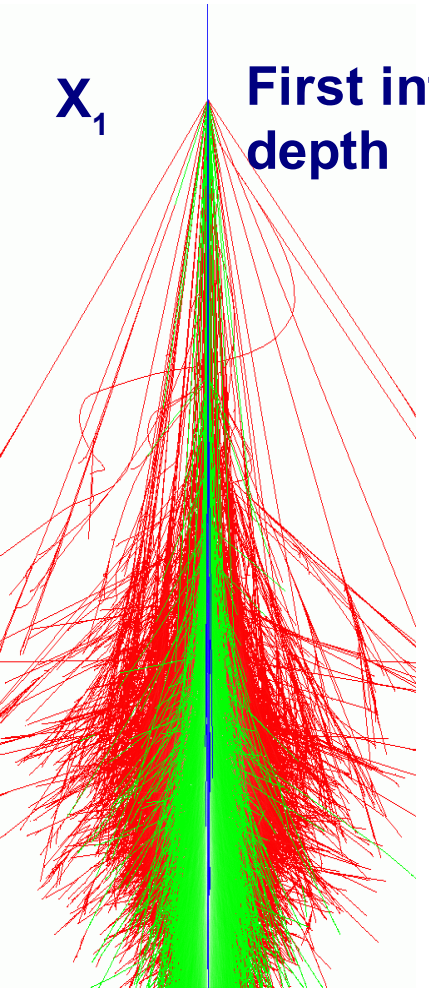




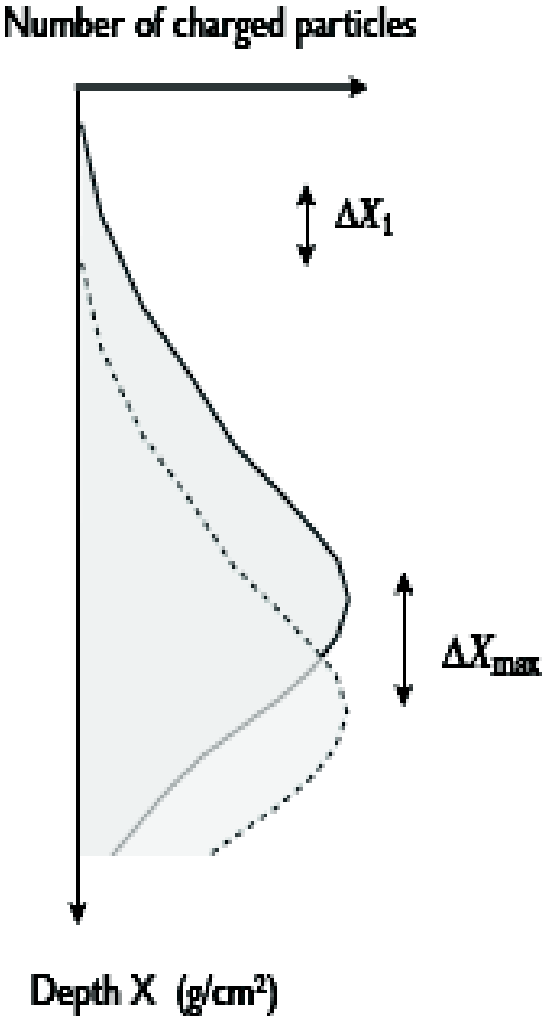
Energy: energy deposit profile integral (E_{cal})

Mass composition: mean and fluctuations of depth of maximun development of the shower (X_{max})

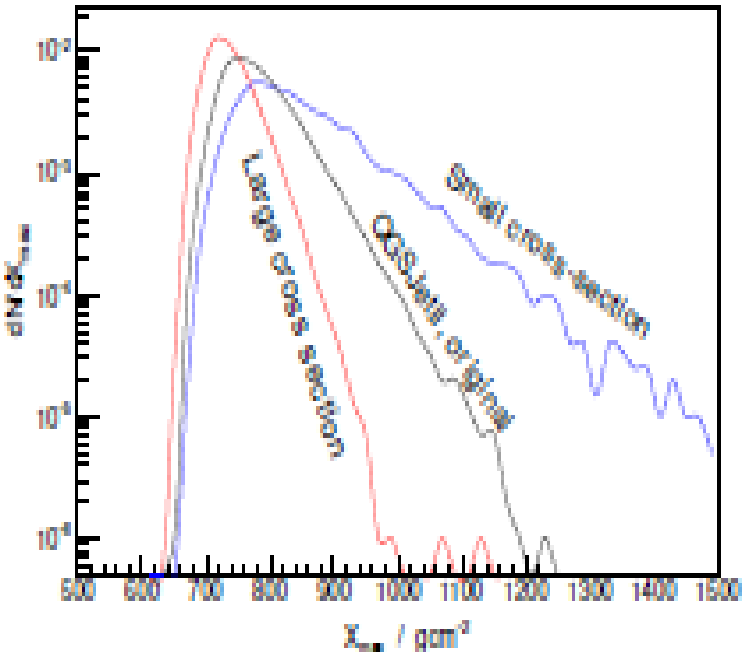
Proton-air cross section from air showers



X_1 First interaction depth



X_{max} distributions



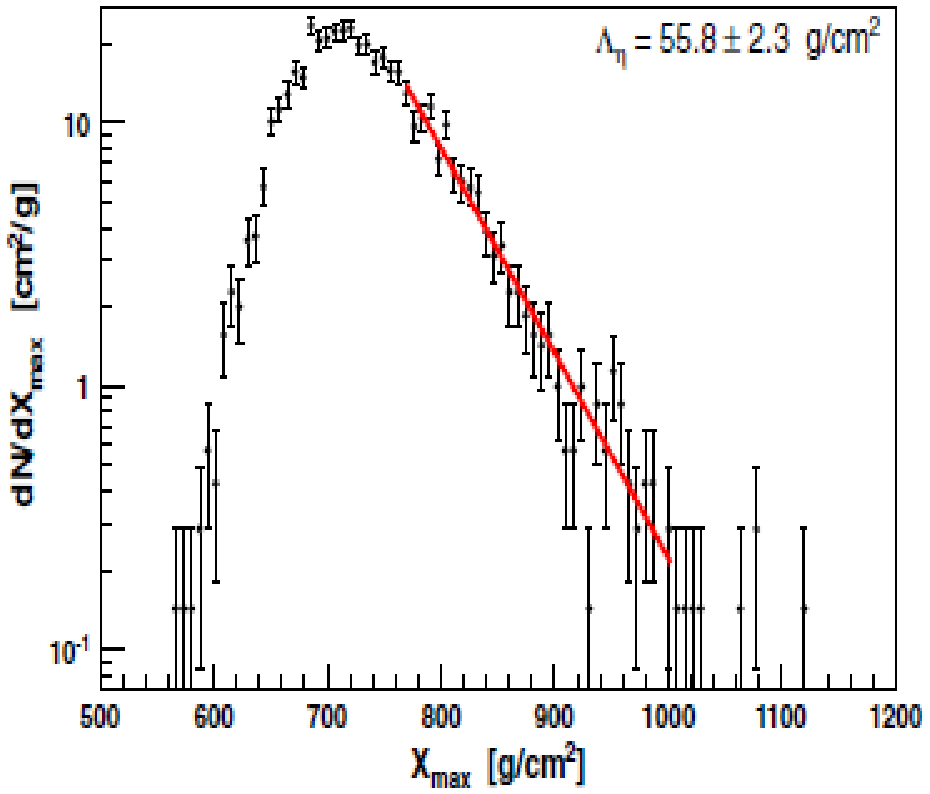
X_1 is not measured directly.

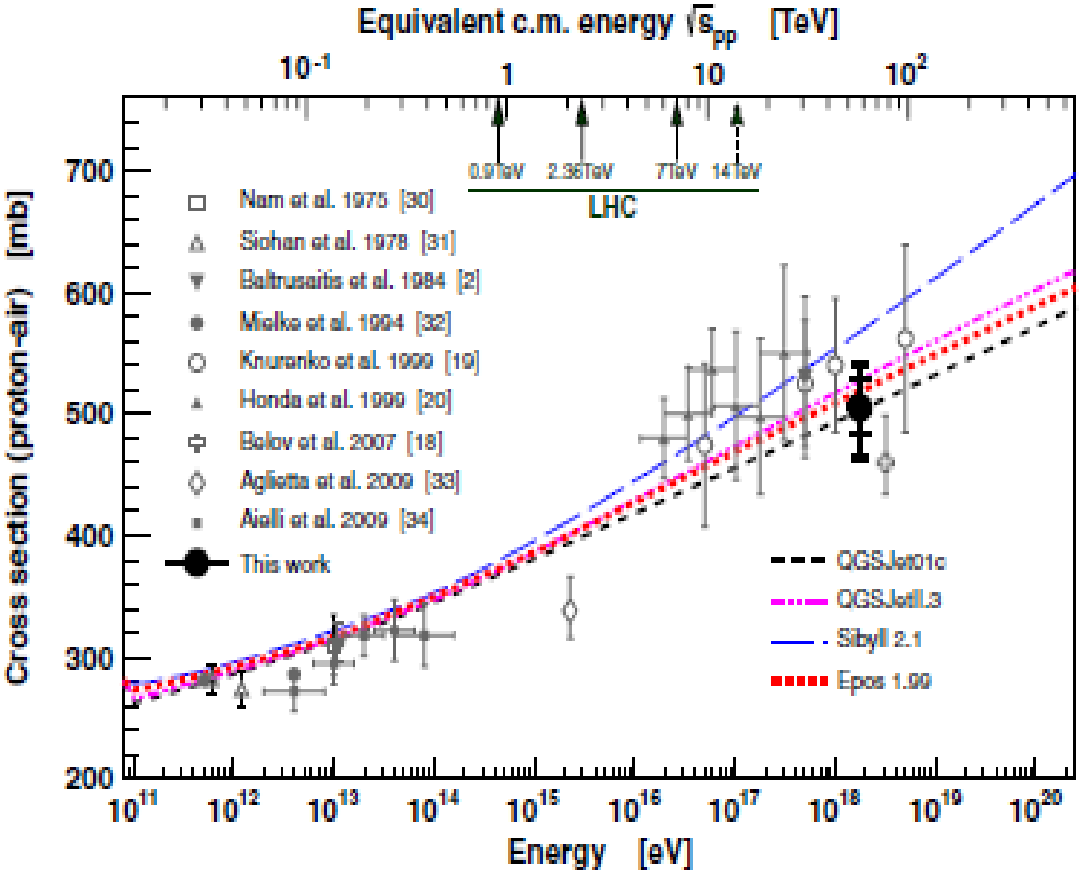
Use fluctuations in shower development

X_{max} distribution tail sensitive to cross section

Proton-air cross section of particle production

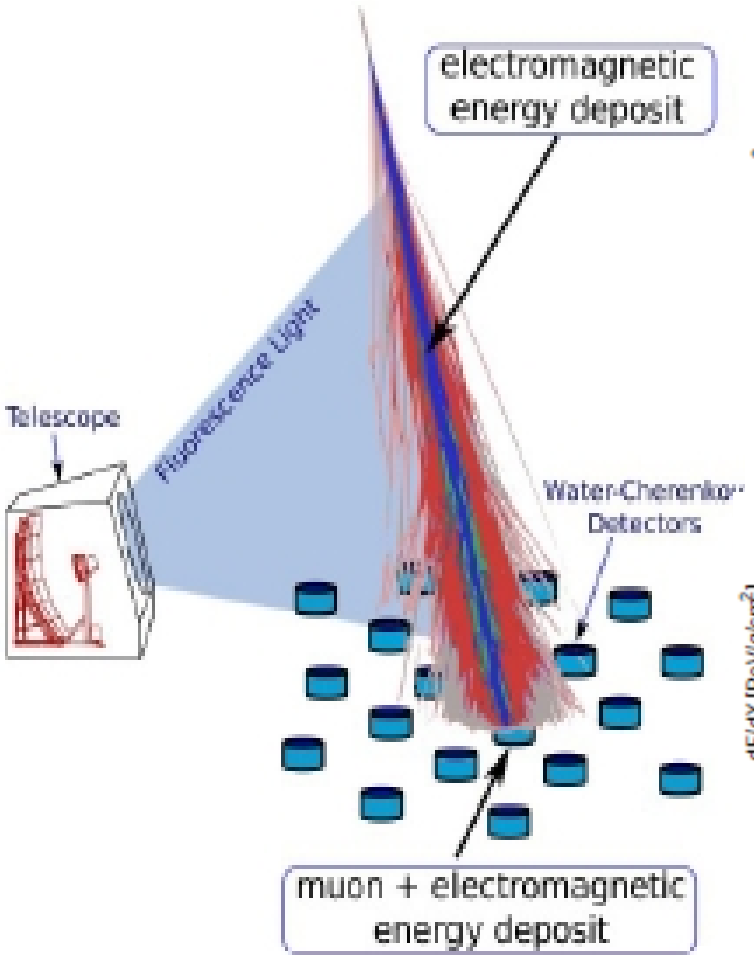
Selection of proton by selecting very deep showers

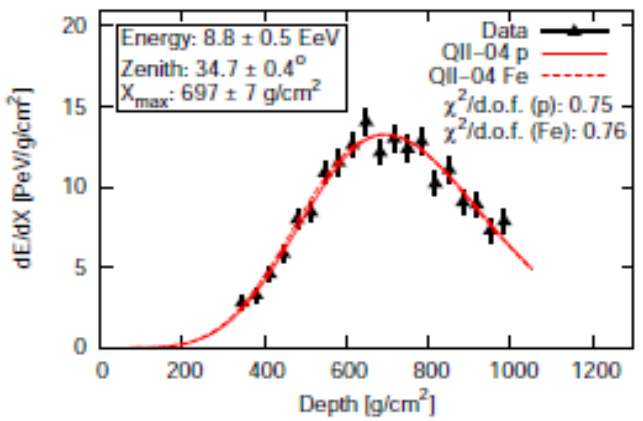


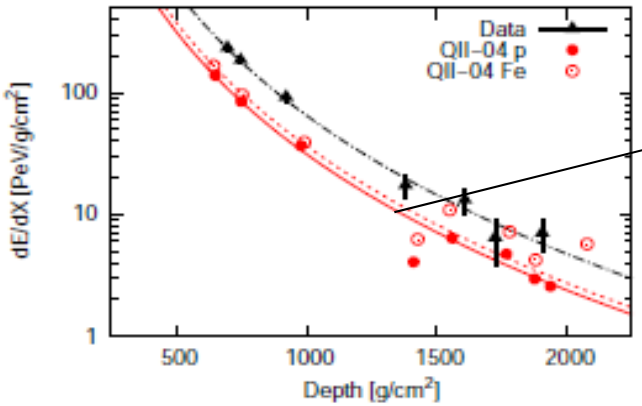


$$\sigma^{\mathrm{prod}}_{p\text{-air}} = [505 \pm 22(\mathrm{stat})^{+28}_{-36}(\mathrm{syst})]\ \mathrm{mb}$$

Longitudinal profile and ground signal missmatch?



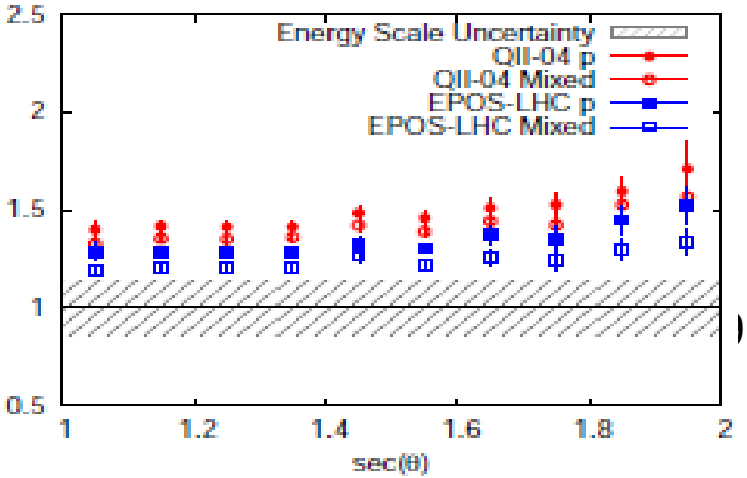




Find simulations that match the measured longitudinal profile for each event, and compare ground signals.

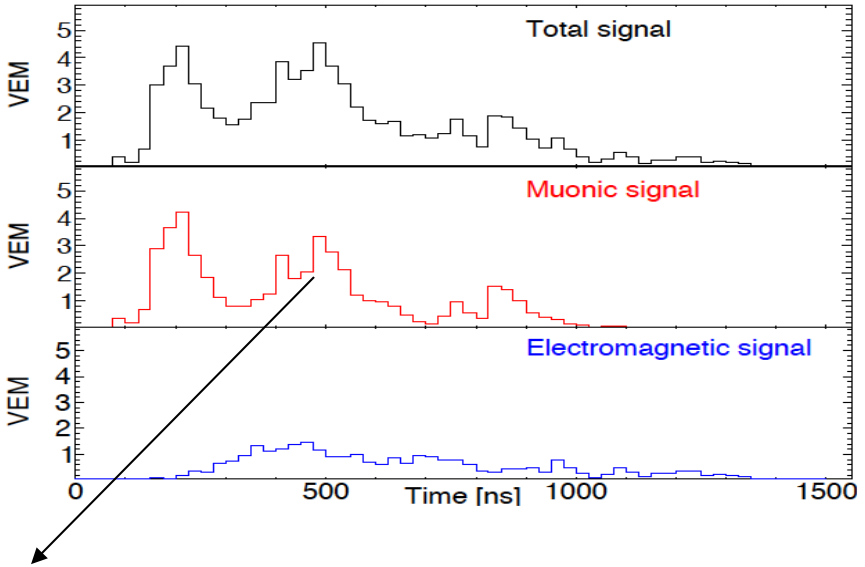
Ground signal from MC models is too low

$$\frac{S(1000)\ \text{observed}}{S(1000)\ \text{predicted}}$$



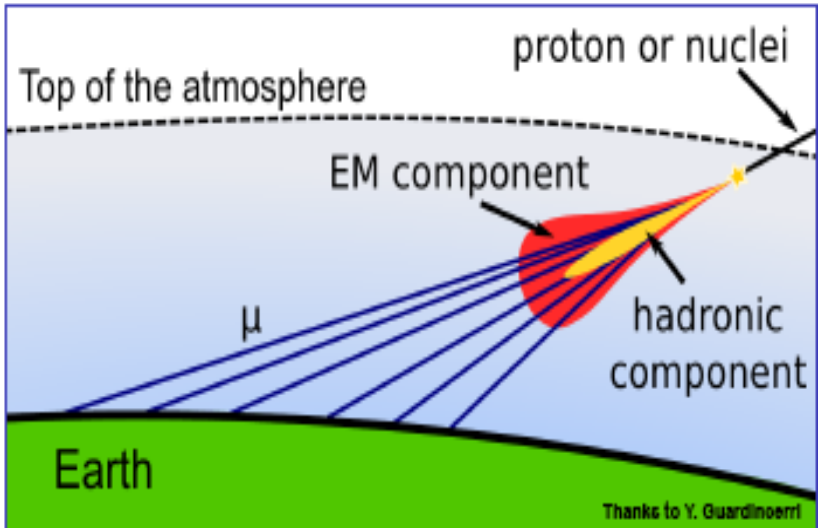
Independent confirmation with other observables

From signal time structure at 10 EeV



Muons stand above smooth electromagnetic component in FADC traces

From inclined showers



Above 62 deg muon dominate the recorded signals

Magnitud of muon fraction is comparable with predictions for iron showers.

Xmax distribution at 10 EeV is not compatible with iron composition.

Signal is not well described by MC simulations

Summary

- Energy reach of cosmic rays exceeds by far that of colliders.
- Proton-air cross-section measured with the Pierre Auger Observatory hybrid data at centre of mass energy per nucleon 57 TeV.
- Deviations found if longitudinal profile and surface detector signals are compared. Significant muon deficit in predictions.
- Realistic treatment of the mass composition do not remove the muon discrepancy. Hadronic shower at least 1.3 to low in post LHC models.
- Multiple methods reach the same conclusion : models do not accurately described muon signal (FADC traces, inclined showers, hybrid events)
- Measurements of extensive air showers at ultra-high energies can have an impact on understanding hadronic interactions at energies beyond what is accessible at accelerators.