Identifying cosmic rays
through particle detection at the Earth's surface

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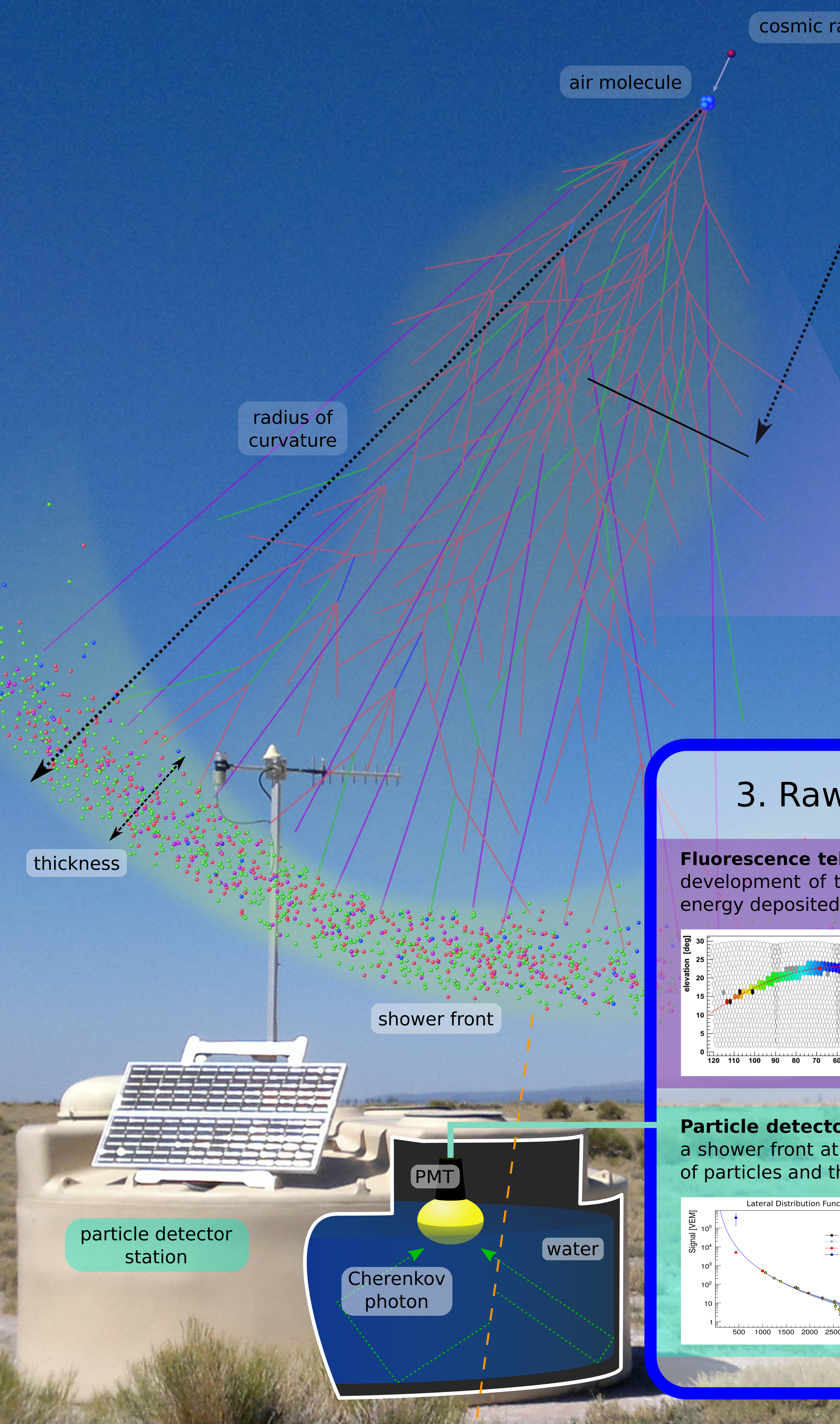
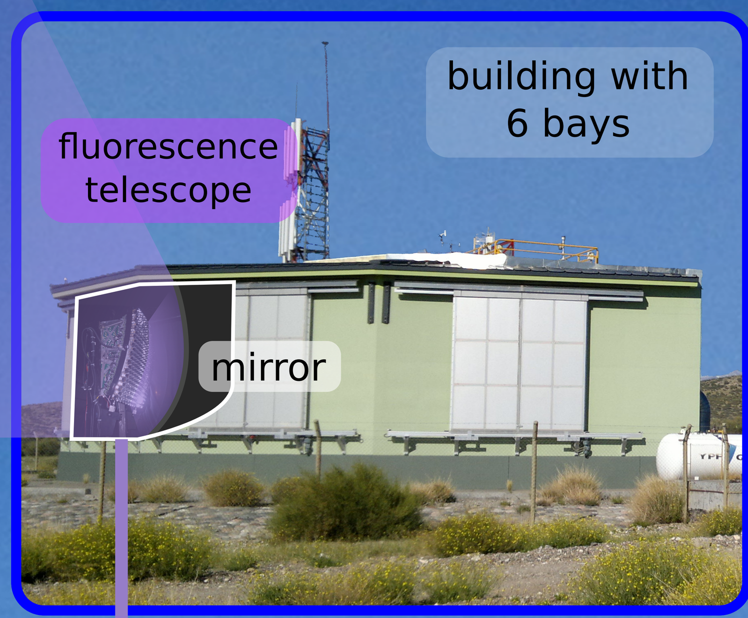




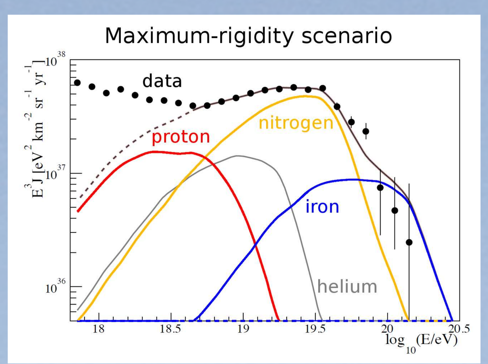
1. Motivation

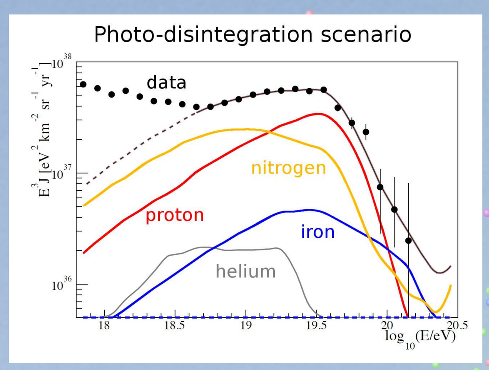
Cosmic rays are particles that, travelling throughout the universe, can reach the Earth's atmosphere with energies up to 10^{20} eV.

The nature and the origin of these particles is unknown.

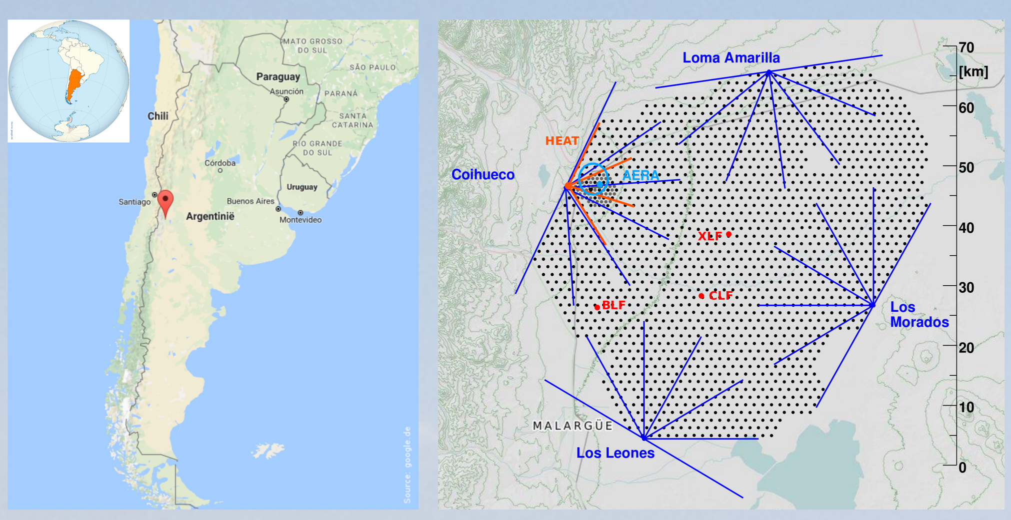
Charged cosmic rays are deflected by the (extra)galactic magnetic fields. Particles with lower charge (or lighter mass) are weakly bent and can be used to identify the origin. Neutral particles are not deflected and point directly to the source.

We present two methods to discriminate between light and heavy nuclei and to search for neutral cosmic rays (photons).





2. Pierre Auger Observatory



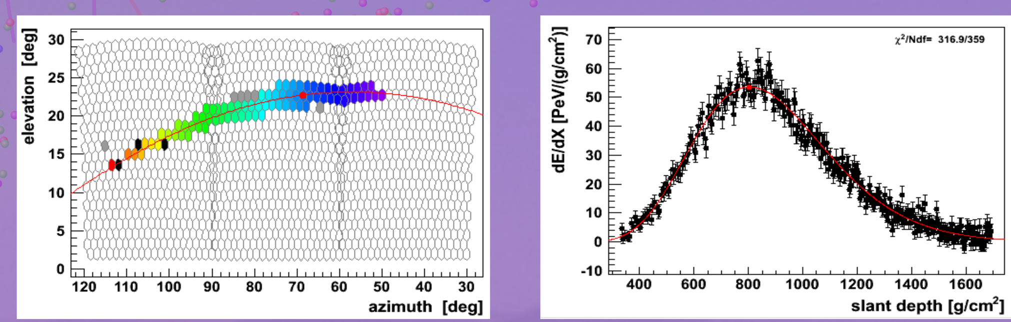
The **Pierre Auger Observatory** covers an area of 3000 km² (bigger than the province of South Holland) and is fully efficient for cosmic rays above $3{\cdot}10^{17}$ eV.

27 **fluorescence telescopes** on 4 sites, collect the light produced by the air molecules when excited by the cosmic shower during clear, dark nights. **Uptime: ~13%**.

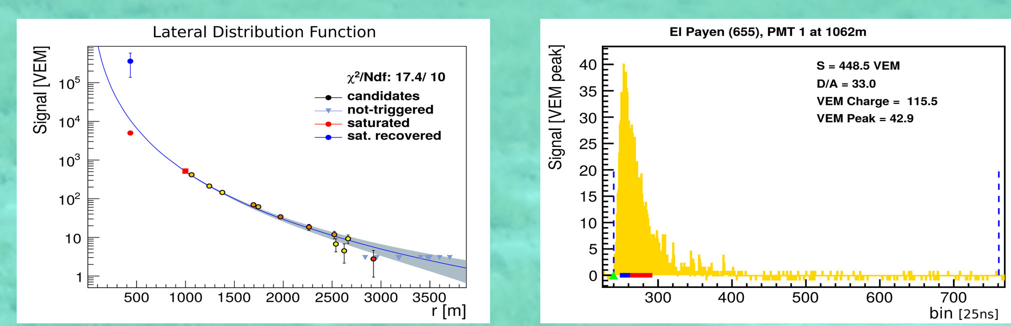
1660 water-Cherenkov **particle detectors** sample the shower footprint at ground. **Uptime: 100%**.

3. Raw Measurements

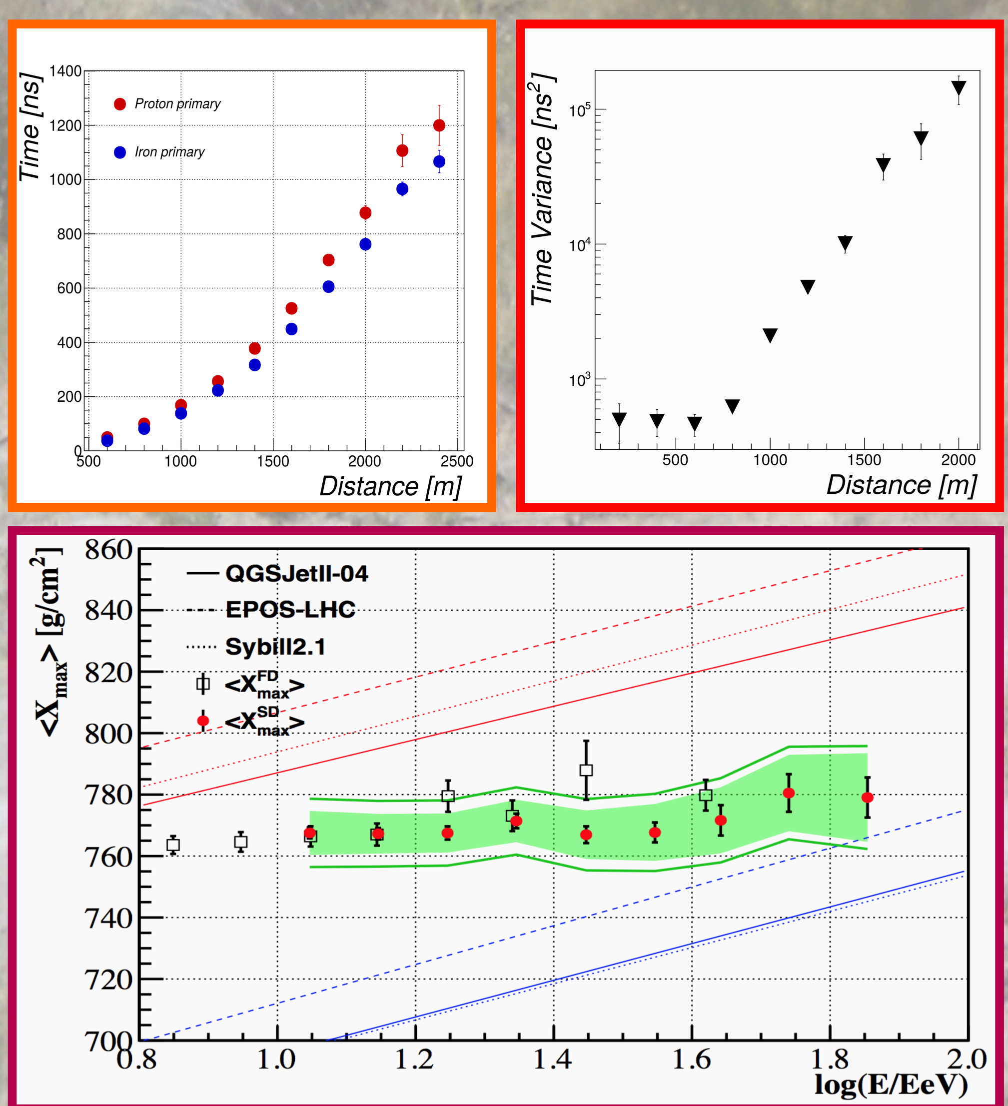
Fluorescence telescopes measure the longitudinal development of the shower in air and estimate the energy deposited at each position in atmosphere.



Particle detectors sample the particle densities of a shower front at ground, by measuring the number of particles and their arrival times.



4a. Curvature Analysis



Idea:
Different cosmic nuclei induce air showers with different **arrival times** for the shower particles at ground.

Method:
With fully simulated showers it is possible to properly estimate the arrival **time uncertainties**, fit the curvature and find a value for X_{max}.

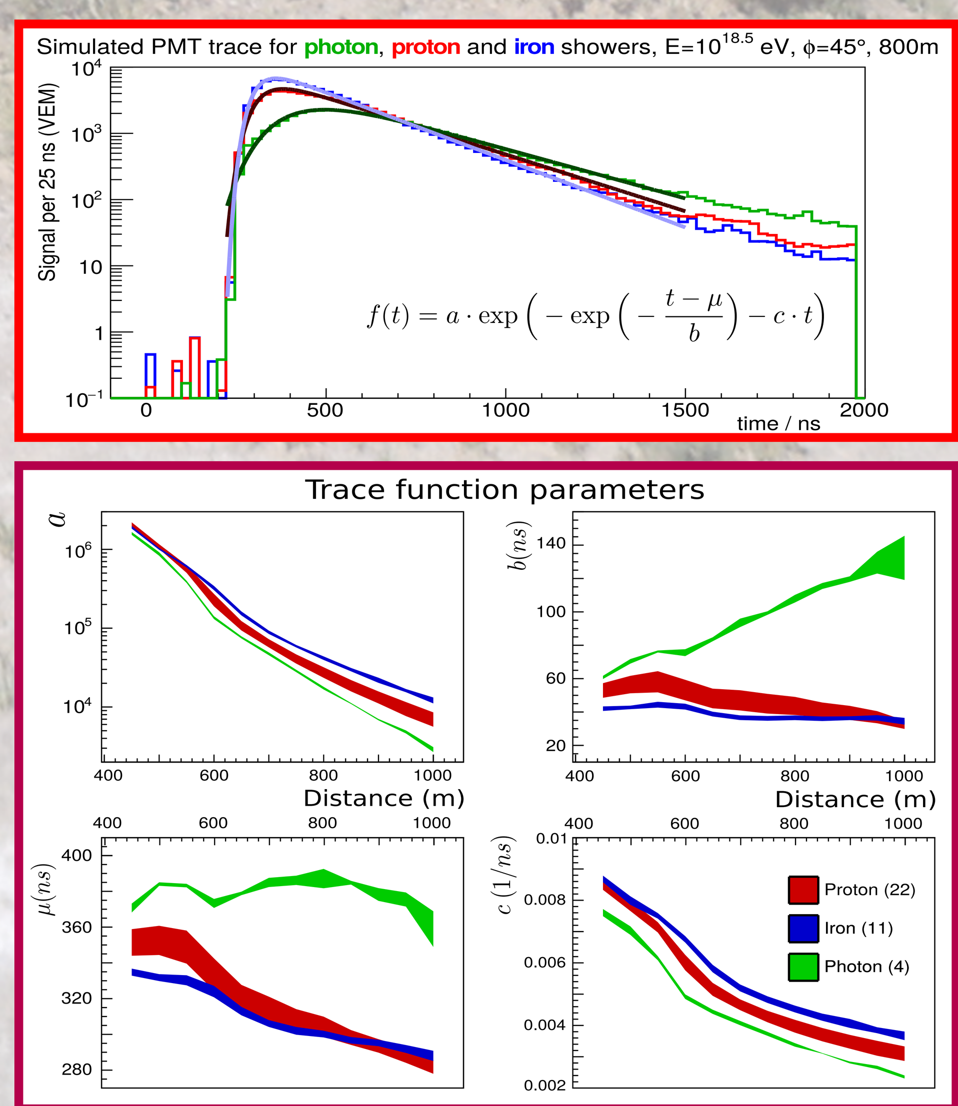
Results:
The average X_{max} is determined from the surface detector data (red points) and compared with the predicted composition for pure proton and iron. The average mass **composition** is found to become **heavier** at the highest energies.

4b. Shower Front Shape Analysis

Idea:
Distinction of cosmic ray type (primary particle of an air shower) by analysing the **shower front characteristics**, using the signal time information.

Method:
We have made full air shower simulations with detector reconstruction and analyzed **PMT responses** for different primaries.

Results:
We found a formula with 4 free parameters, which discribes the PMT trace. 2 of these parameters show a good separation between the different primaries and can be used for further **mass composition** studies.



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