Cosmic Ray Detection

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December 2022

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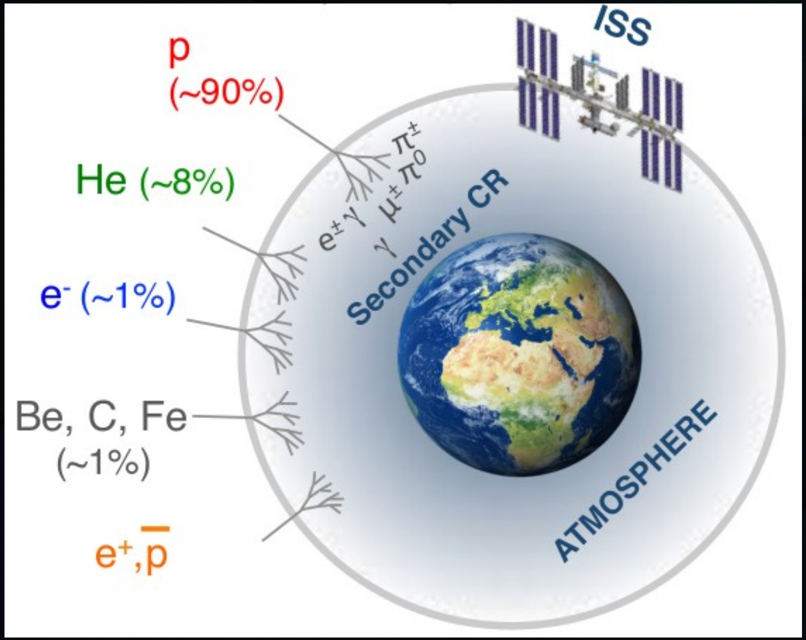
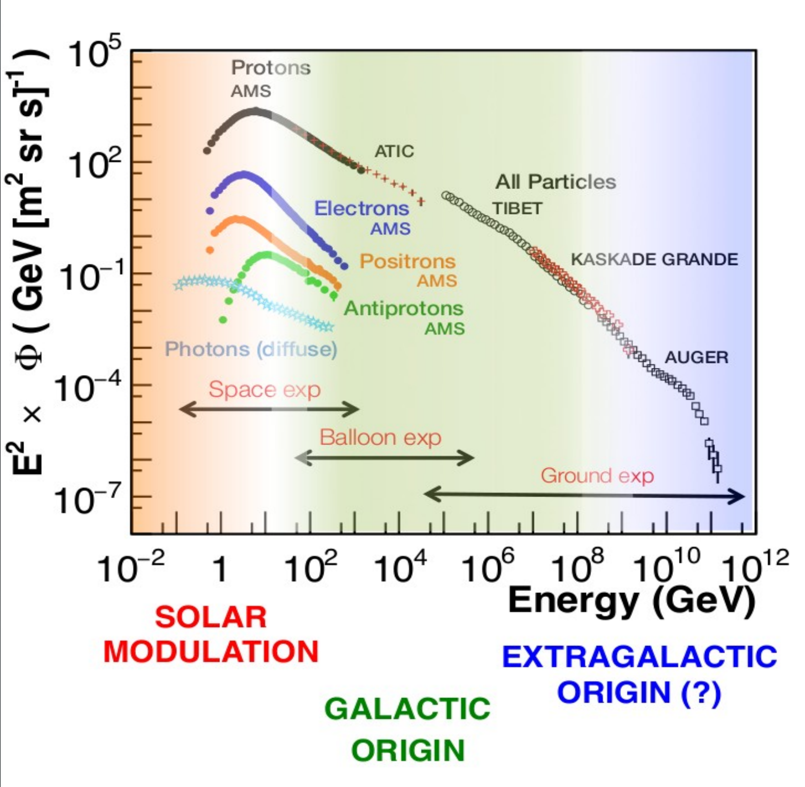
Outline

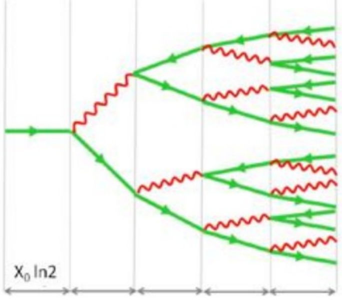
- I. What are Cosmic Rays?
- II. How we can detect CR?
- III. Direct detection.
- IV. Indirect detection

What are Cosmic Rays





EM and hadronic shower



d=	1	2	3	4	5
N=	2	4	8	16	32
E=	1/2	1/4	1/8	1/16	1/32

The electron losses half of his energy when : $R = X_0 \ \ln(2)$

Define the scale variables: $t = z/X_0 \quad y = E_0/E_c$

Total number of produced electrons after z = n R : $N(z) = 2^n$

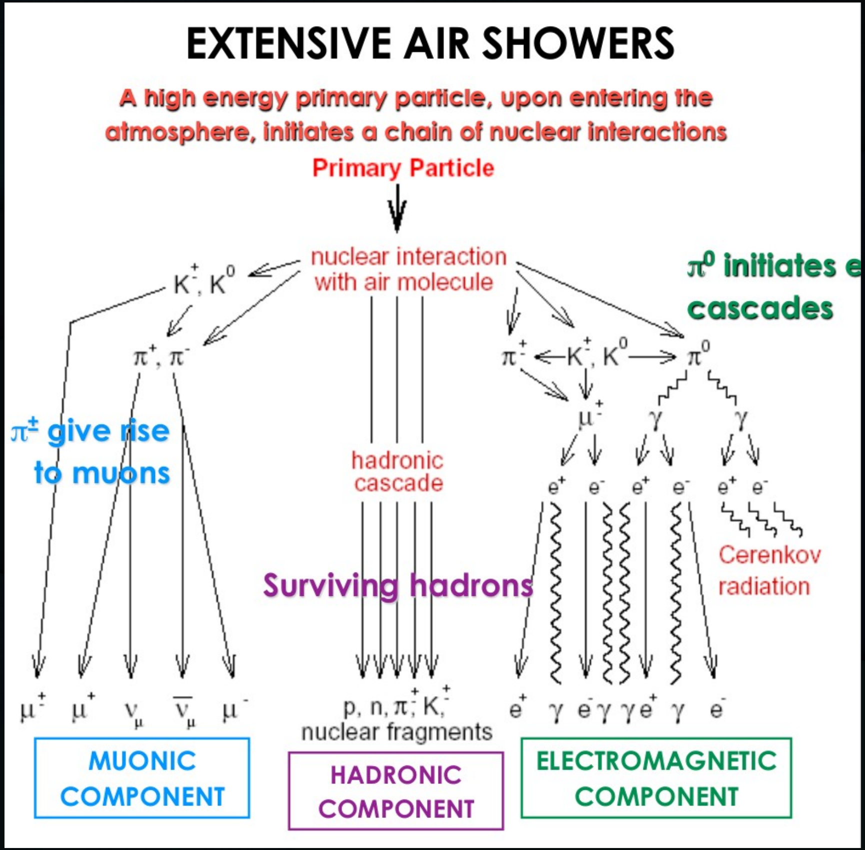
Mean energy for each particle : $E(z) = E_0/2^n$

Particle creation in shower stops when E < Ec : $n_c = \frac{1}{\ln 2} \ \ln\left(\frac{E_0}{E_c}\right)$

Maximum depth : $z_{max} = X_0 \ \ln\left(\frac{E_0}{E_c}\right)$

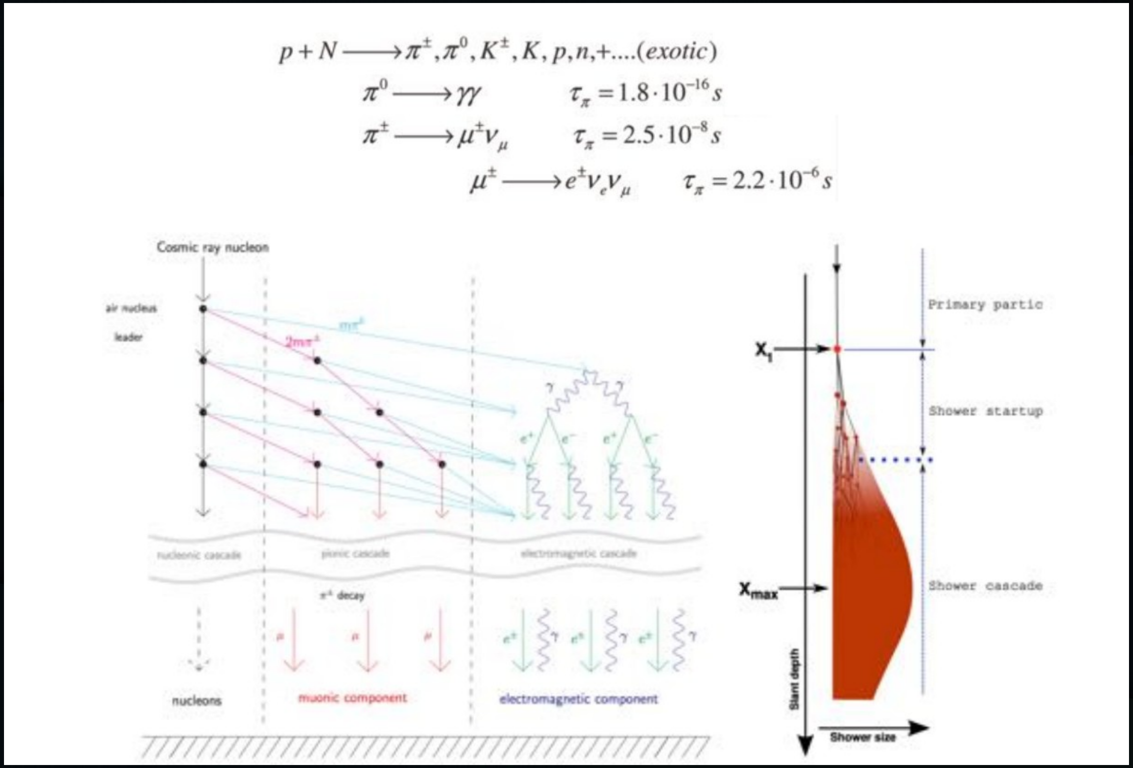
Numer of particle at zmax : $N_{max} = E_0/E_c$

Fig. 4.2. Toy model evolution of an electromagnetic cascade. At each step of the cascade the number of particles is multiplied by two, through either pair creation or single photon bremsstrahlung. Backward arrows indicate a positron positron, as in Feynman diagrams. The evolution stops when individual particle energies fall below the critical energy E_c. The number N of particles at each step d and the average particle energy E in the Heitler's model are also indicated. Adapted from [4ww01]

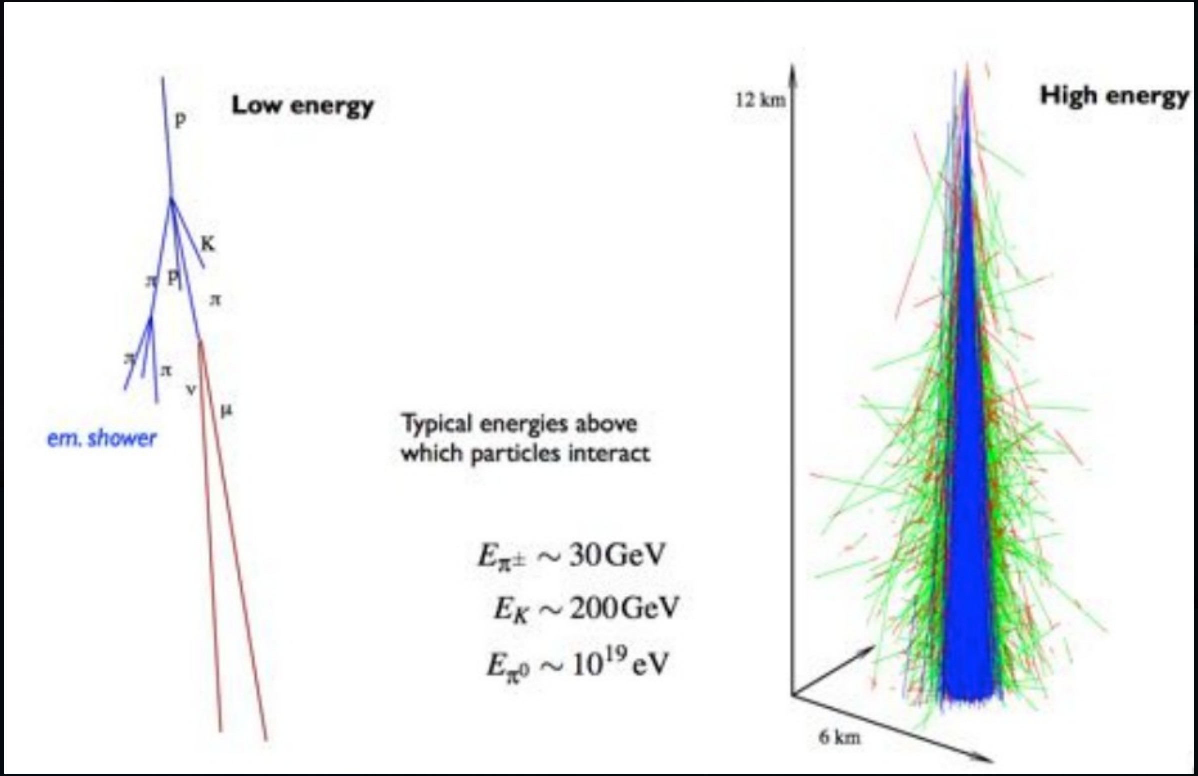


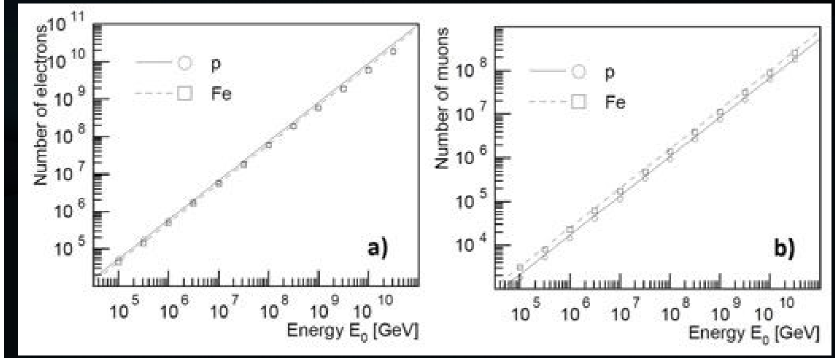
EM and hadronic shower

- After each interaction, the primary nucleon carries a fraction 1-f of its initial energy E_0 , and the rest f is distributed to the N_π pions.
- After k interactions, the primary carries $(1-f)^k E_0$ energy. The rest is spread among N_π pions, each having around $E_0/(N_\pi)^k$
- Muons are produced by decaying low energy pions.
- Electrons are produced by the decay of π_0.

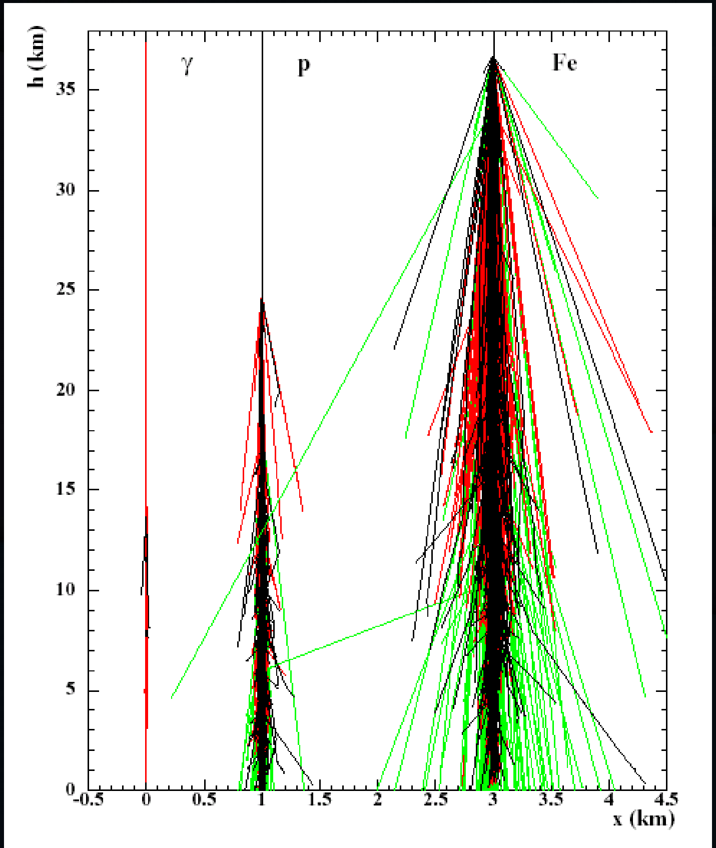


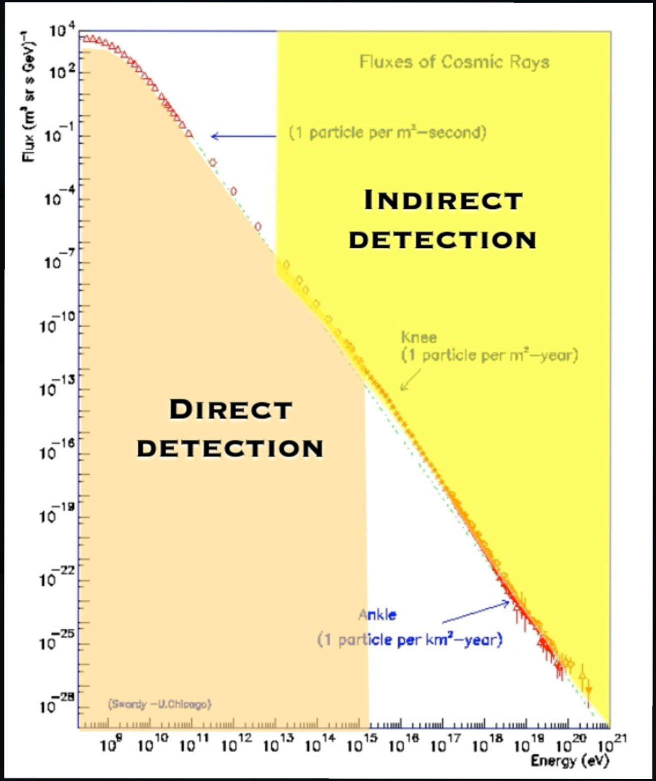
Extensive Air Shower



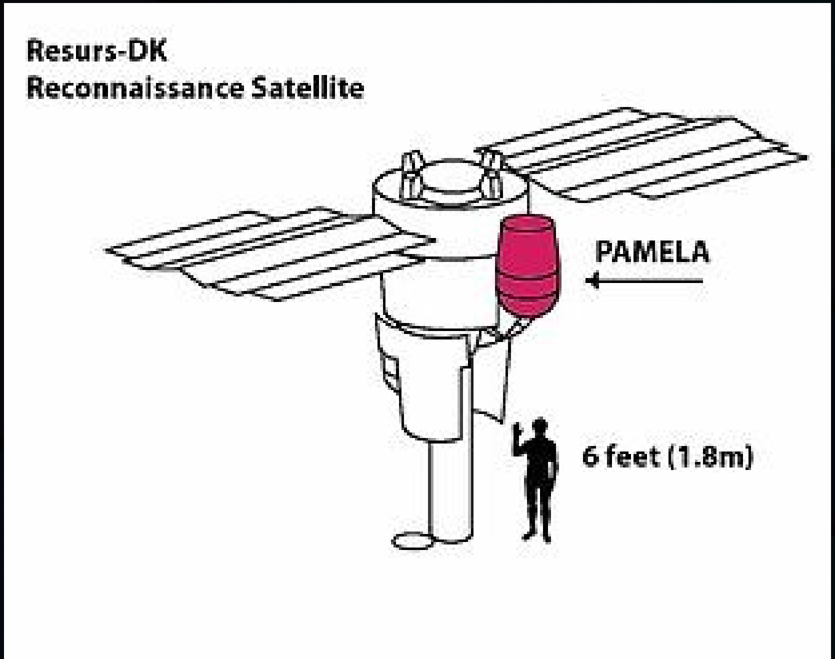


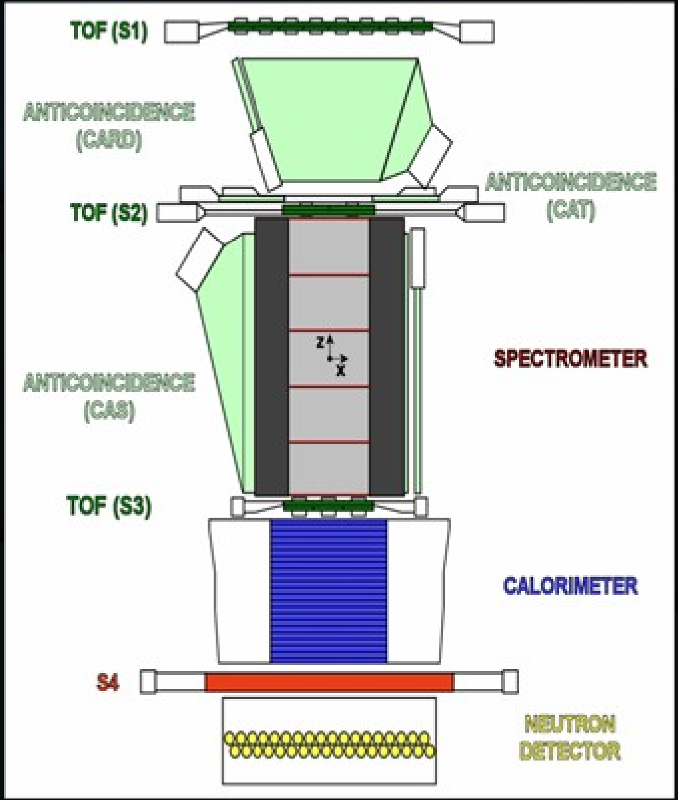
Extensive Air Shower





PAMELA detector



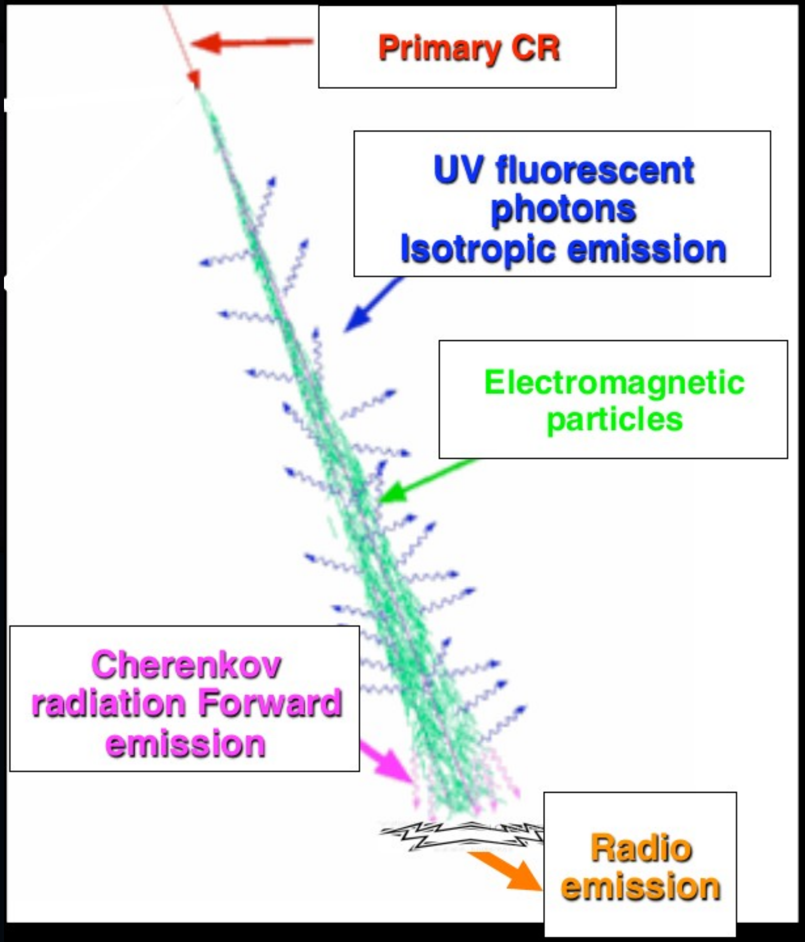


Indirect detection

- When rare high energy cosmic rays enter the atmosphere, they initiate particle showers. Secondary particles may reach the ground and be detected by ground experiments. The atmosphere is used as a huge Calorimeter.

- High energy CR fluxes are faint, so we need large (up to O(1000) km^2) collection areas to maximize the statistics. Luckily, showers may extend over more than $100m^2$.

Different kinds of radiation in EAS



Cherenkov radiation: Electrons and positrons in the shower travel faster than the speed of light in air and emit Cherenkov radiation, mostly in the forward direction

Fluorescence radiation: The passage of air shower e.m. particles in atmosphere results in the excitation of the gas molecules (mostly nitrogen). Some of this excitation energy is emitted in the form of isotropic visible and UV radiation.

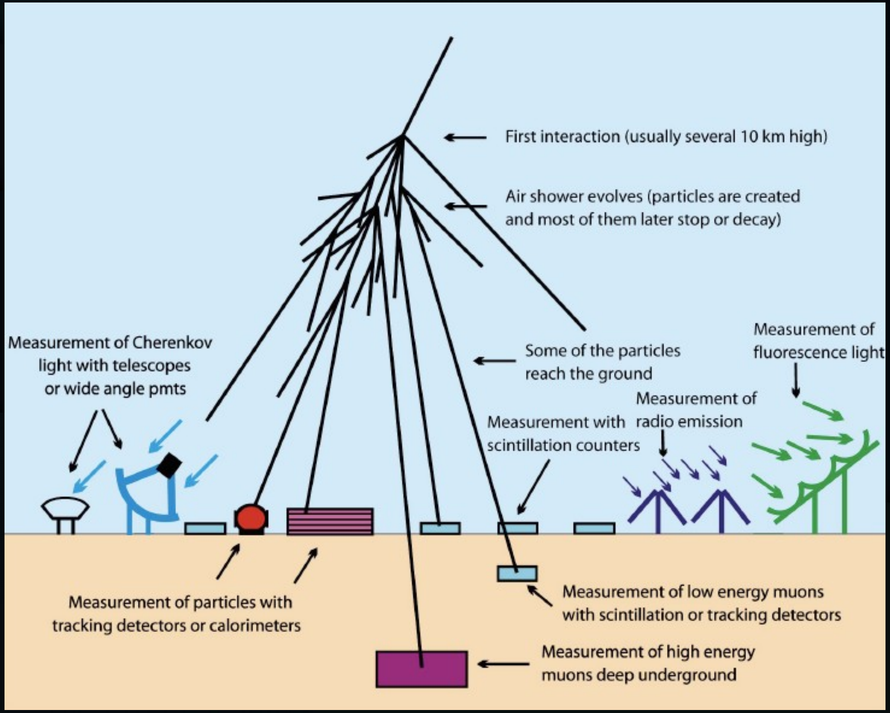
Radio emission: Air shower electrons and positrons are deflected in the Earth's magnetic field. Because of their relativistic velocities, they emit synchrotron radiation, beamed very sharply downwards, at radio frequencies below 100 MHz. Many sparkles together produce a bright radio flash

Different detectors for different EAS observables

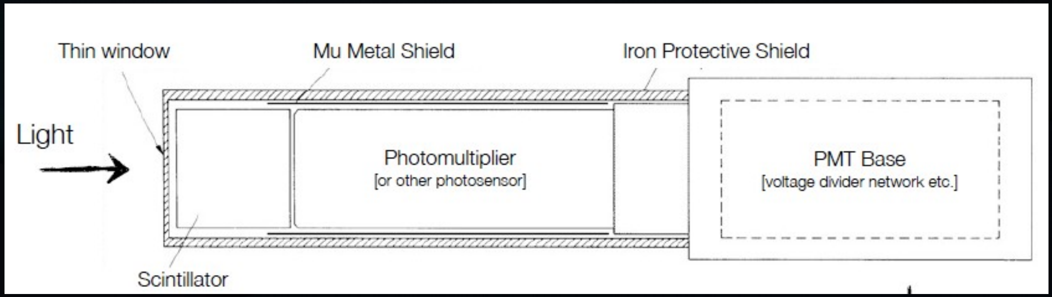
- **Extensive showers are detected combining the measurements of several detector units spread over a wide area (array)**
- **Different detectors are used depending on the observable to be measured**
- **If possible, the measurement of more than one observable provides an improvement in the primary particle property accuracy**

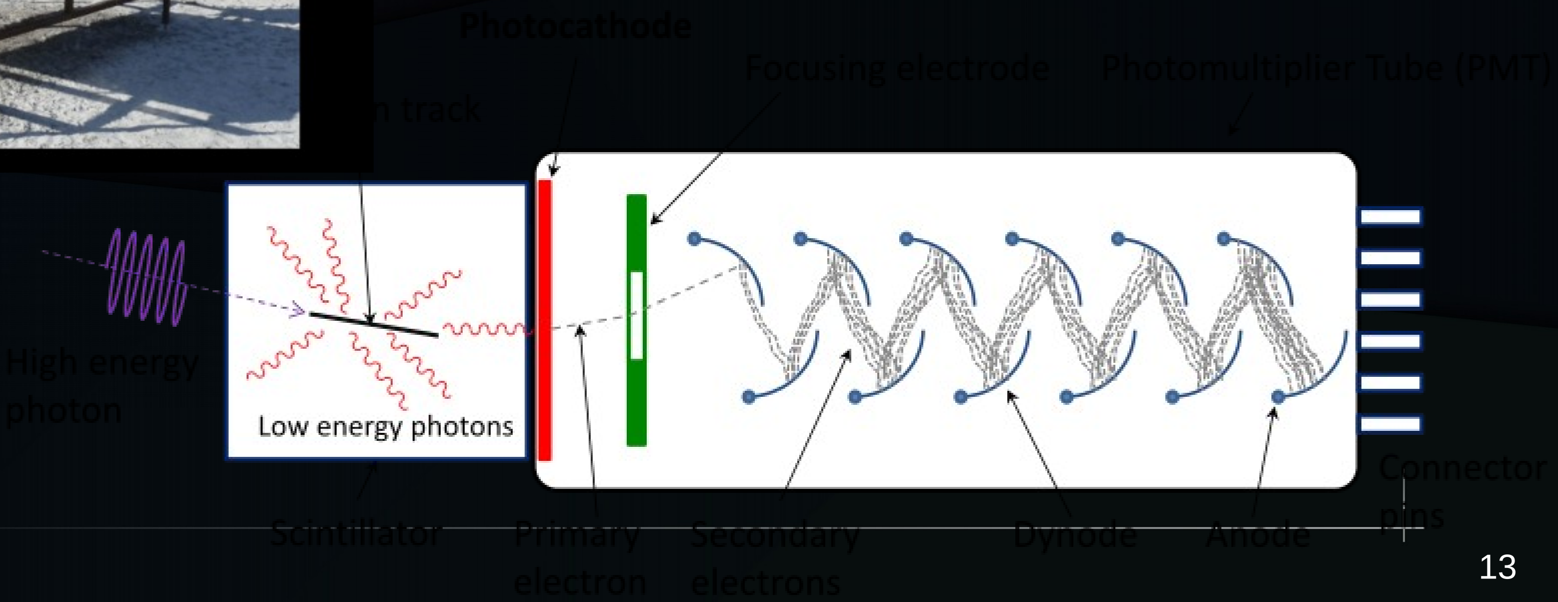
Typical detectors used:

- **Cherenkov telescope**
- **Fluorescence telescope**
- **Muon detectors**

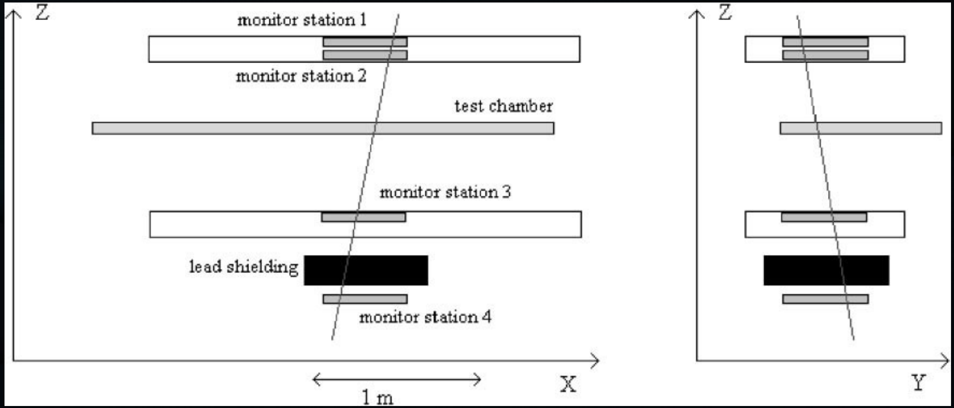


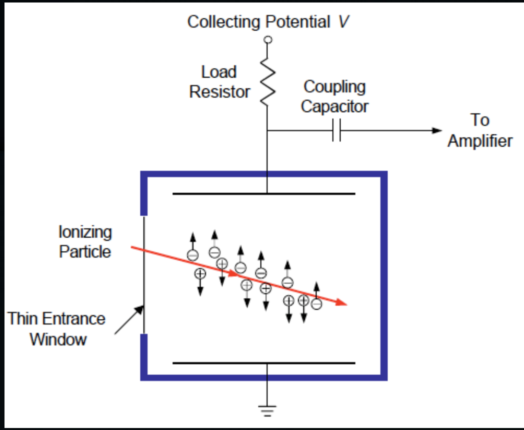
Scintilator



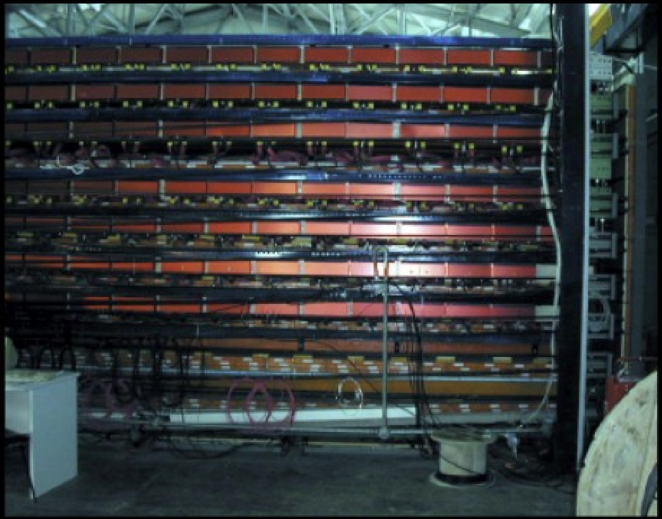


Resistive Plate Chamber(RPC)

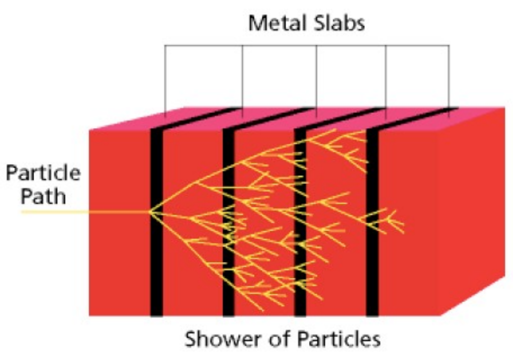




Calorimeter



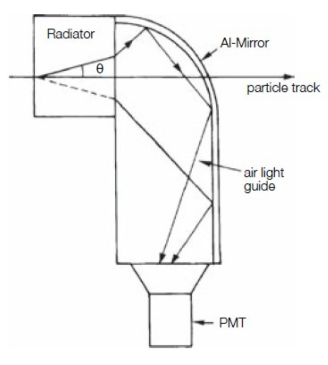
CALORIMETERS (FOR MUONS & HADRONS)

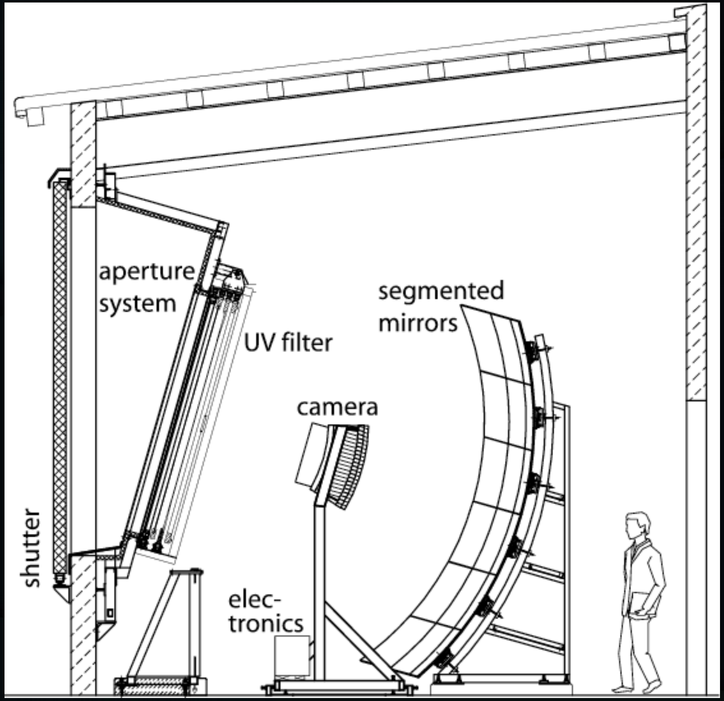


CALORIMETERS

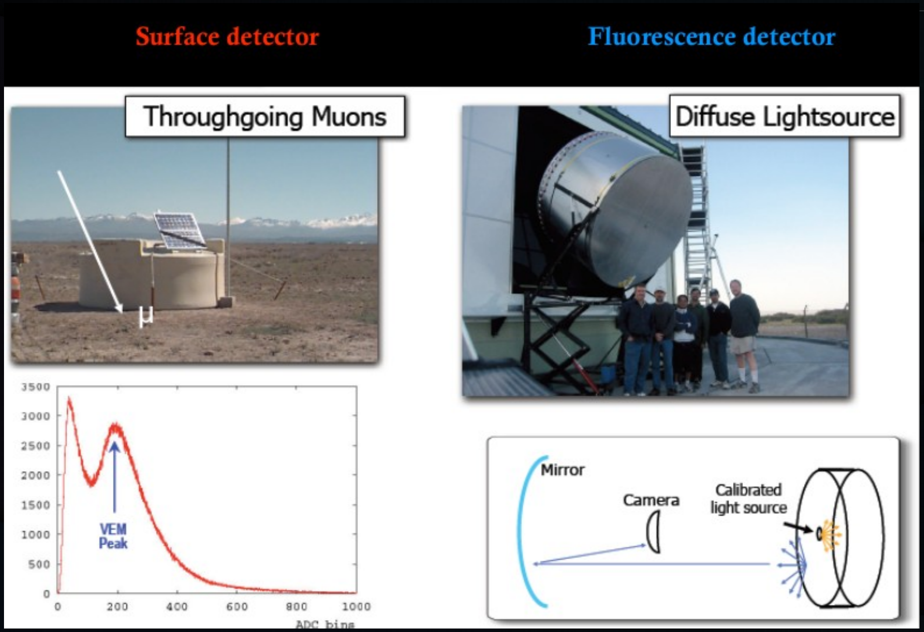
Cherenkov telescope

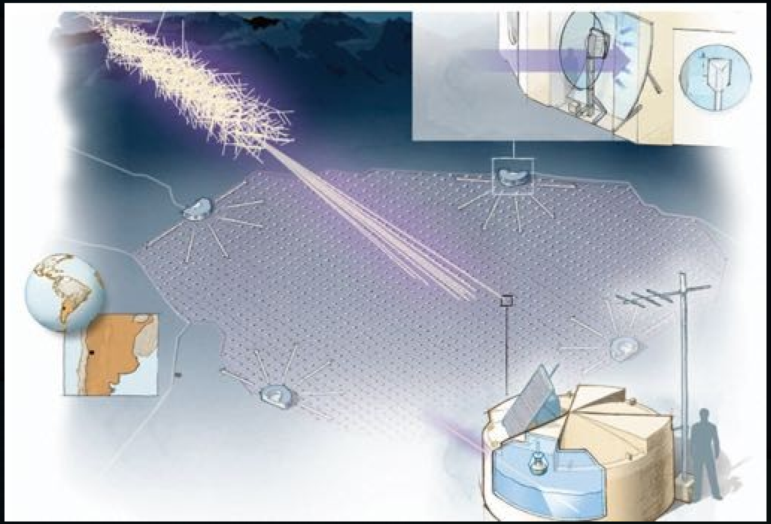
The light from Cherenkov or fluorescence emission is collected by a mirror or a lens and imaged on to a camera made by photosensors (PMTs). Each PMT receives light coming from a specific region of the sky.
When an EAS crosses the field of view of the telescope, It triggers some of the PMTs. Each triggered PMT records the trigger time and the intensity of the signal.



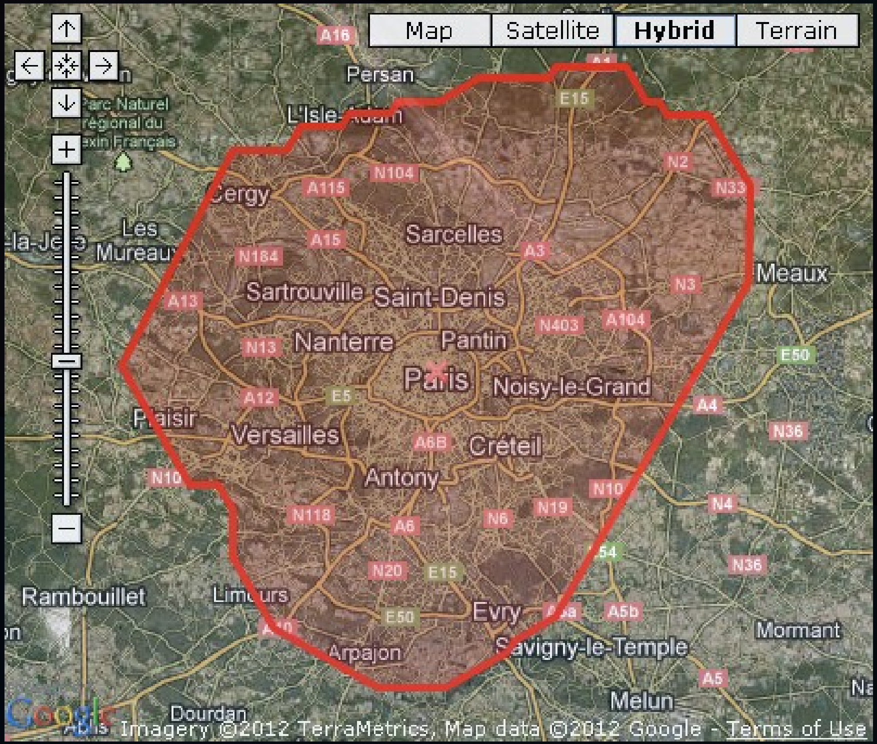


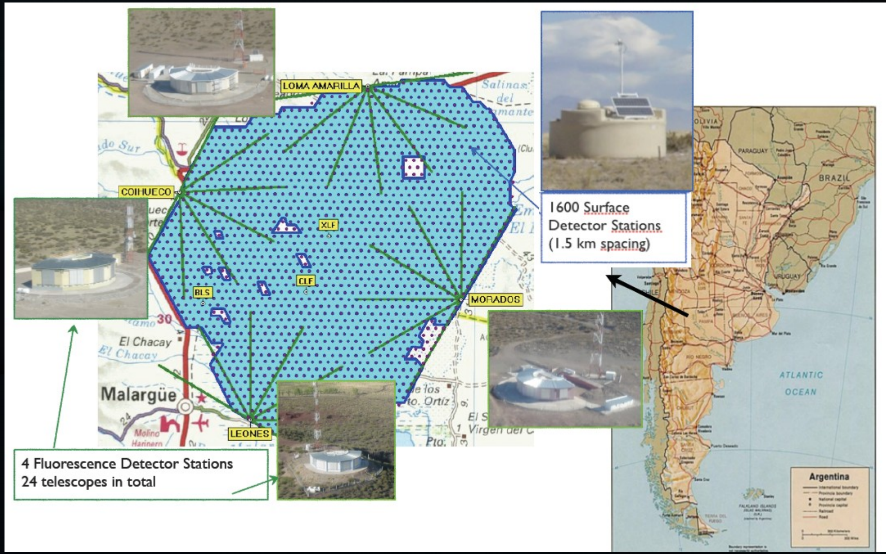
Pierre Auger telescope





Pierre Auger telescope

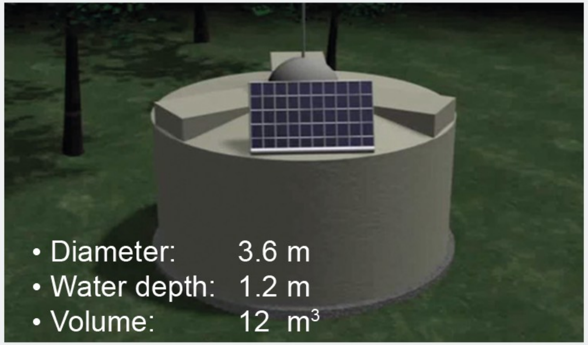


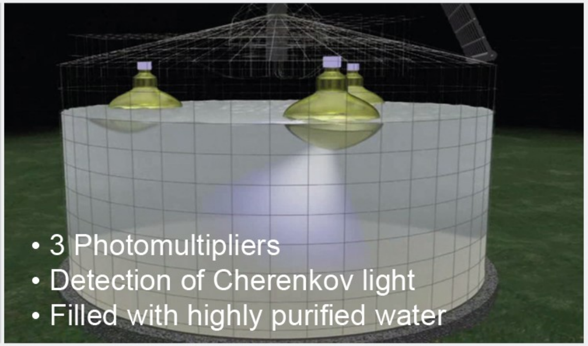


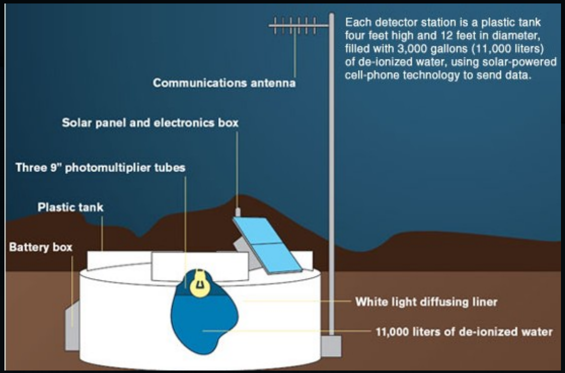
Surface detector

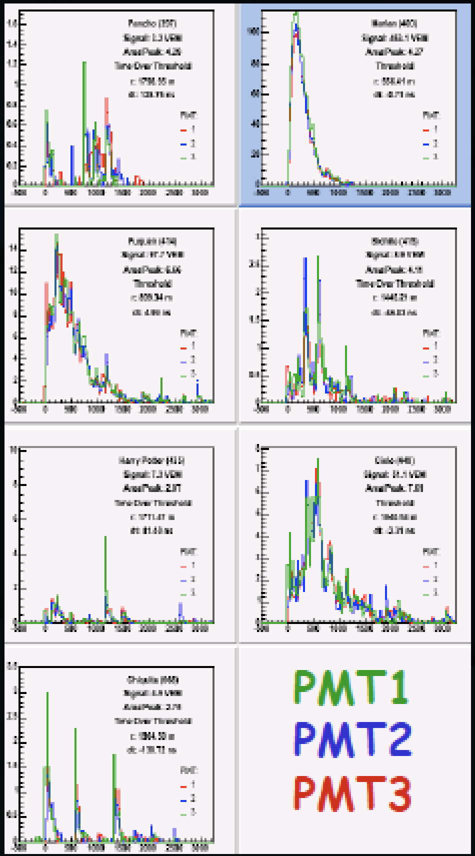
Surface Detector

1,660 surface detector stations
(1,500 m apart from each other)



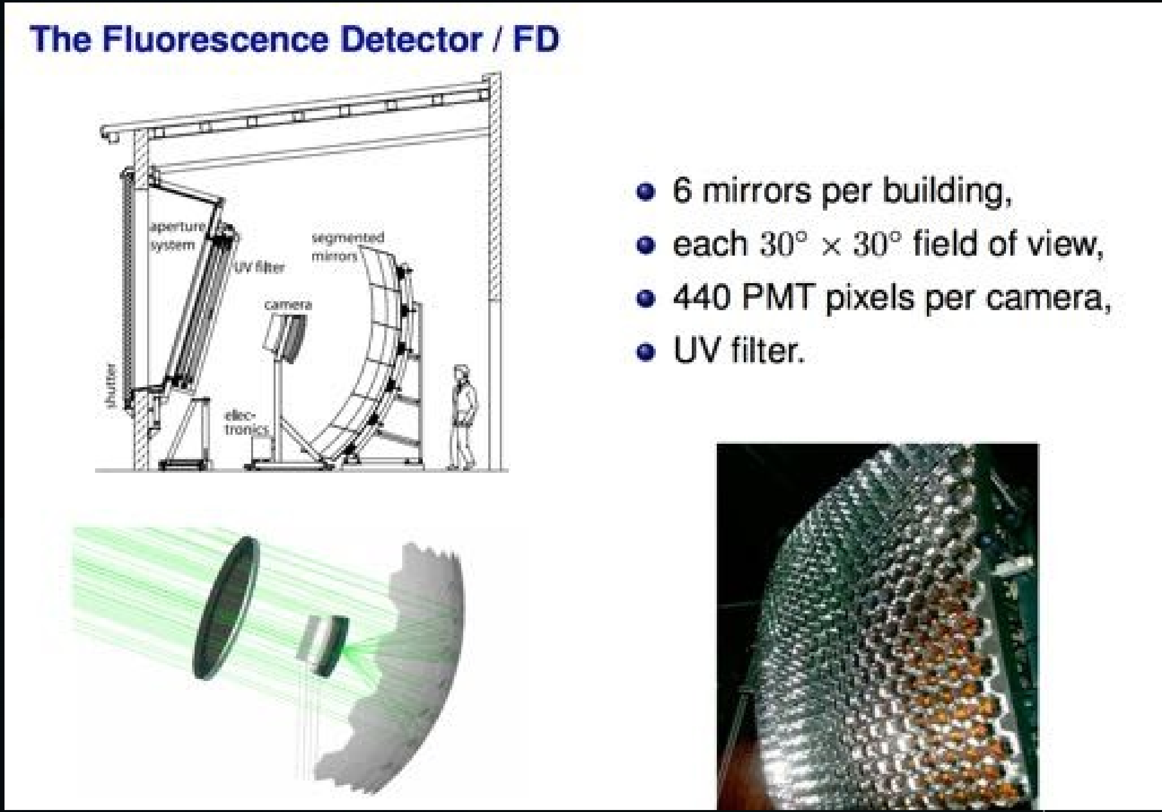






Fluorescence Detector

Charged particles from EAS interact with Nitrogen molecules in air . The Nitrogen molecules get excited and they emit (when returning to their ground state) a typical radiation in the wavelength range between 300 nm to 400 nm.). Fluorescene radiation (commonly called fluorescence light) is emitted isotropically. It can travel several kilometers throught the atmosphere and detected by an optical telescope, i.e., mirrors and PMTs, typically, equipped with fast response electronics (fluorescence detectors).



Pierre Auger telescope

surface detectors	fluorescence detectors
LATERAL SPREAD	**LONGITUDINAL PROFILE**
⊕ 100% duty cycle	⊖ 10-15% duty cycle (clear, moonless nights)
⊕ acceptance = geometric	⊖ acceptance depends on distance and atmosphere
⊖ only last stage of shower development observed	⊕ full observation of longitudinal shower development
⊖ energy scale model dependent	⊕ (almost) model independent

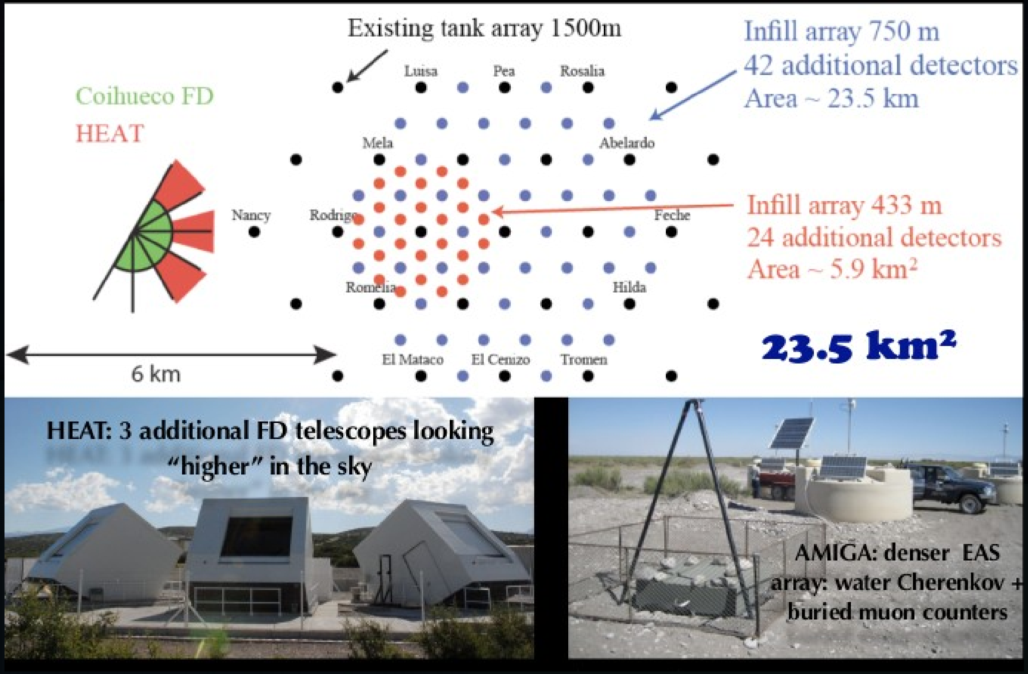
→ combine two complementary techniques: Auger hybrid detector

Results

- The result showed that the directions of origin of the 27 highest-energy events were correlated with the locations of active galactic nuclei (AGNs).
- data from 12 years of observations enabled the discovery of a significant anisotropy of the arrival direction of cosmic rays at energies above 10^{18} ev. This supports that extragalactic sources (i.e. outside of our galaxy) for the origin of these extremely high energy cosmic rays.

Future

1) the surface detectors will be enhanced by scintillation detectors and radio antennas.
2) two higher-density nested arrays of surface detectors will be combined with underground muon counters.



Thanks for listening!

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