

# Cosmic Ray Mass Composition & Energy Spectrum measurement around $10^{17}$ eV energies

## Cosmic Ray Physics

Cosmic rays are high energy particles traveling in universe

- proton, nucleus (up to Fe), electron, etc.

Power law nature (arrival rate  $\propto E^{-3}$ )

- 1 particle/m<sup>2</sup> / 1yr @  $10^{15}$  eV
- 1 particle/km<sup>2</sup>/1yr @  $10^{18}$  eV
- 1 particle/km<sup>2</sup>/100yr @  $10^{20}$  eV

Unknown sources

- believe Galactic origin  $E < \sim 10^{17}$  eV
- Above are extra-galactic

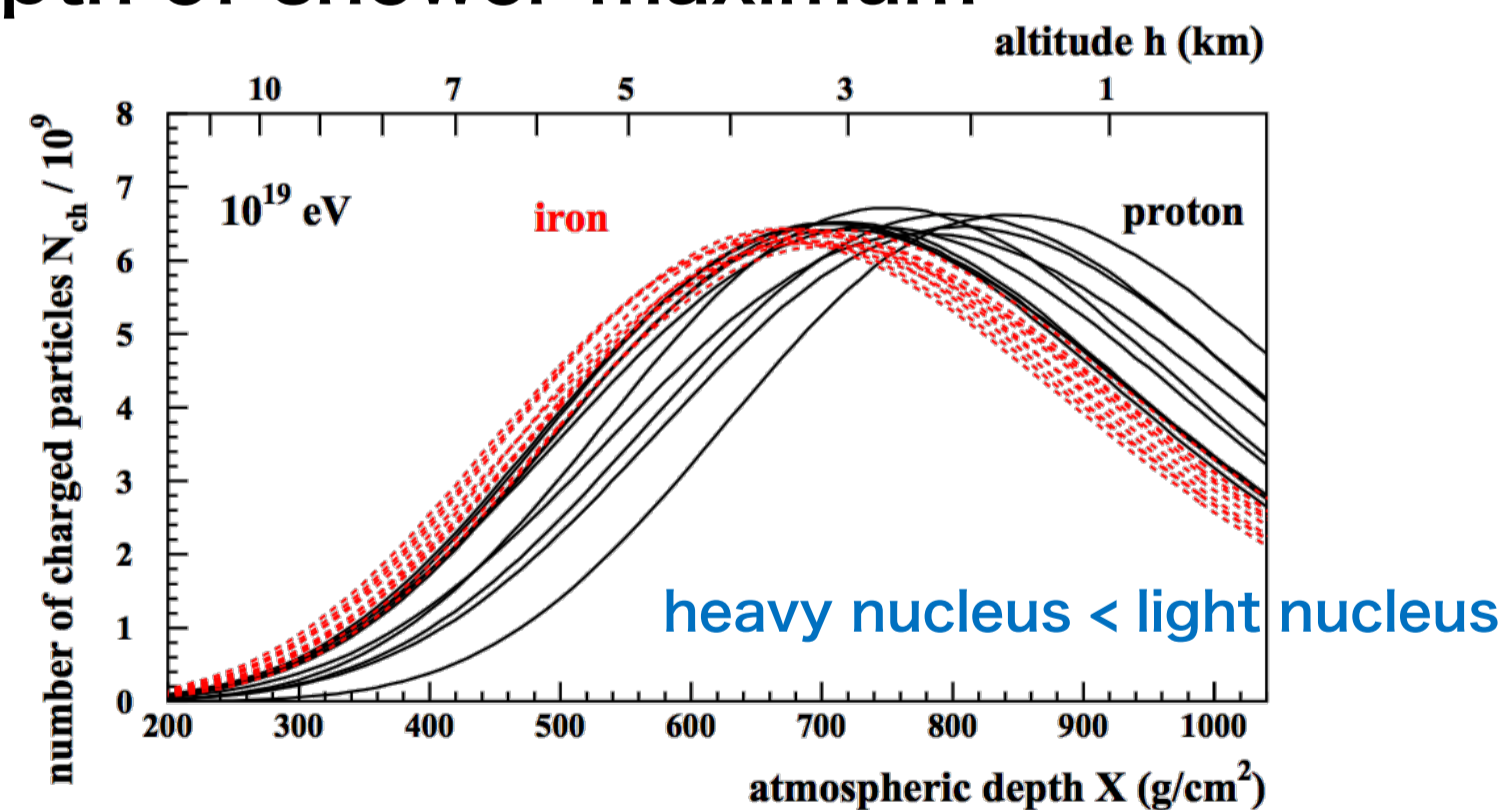
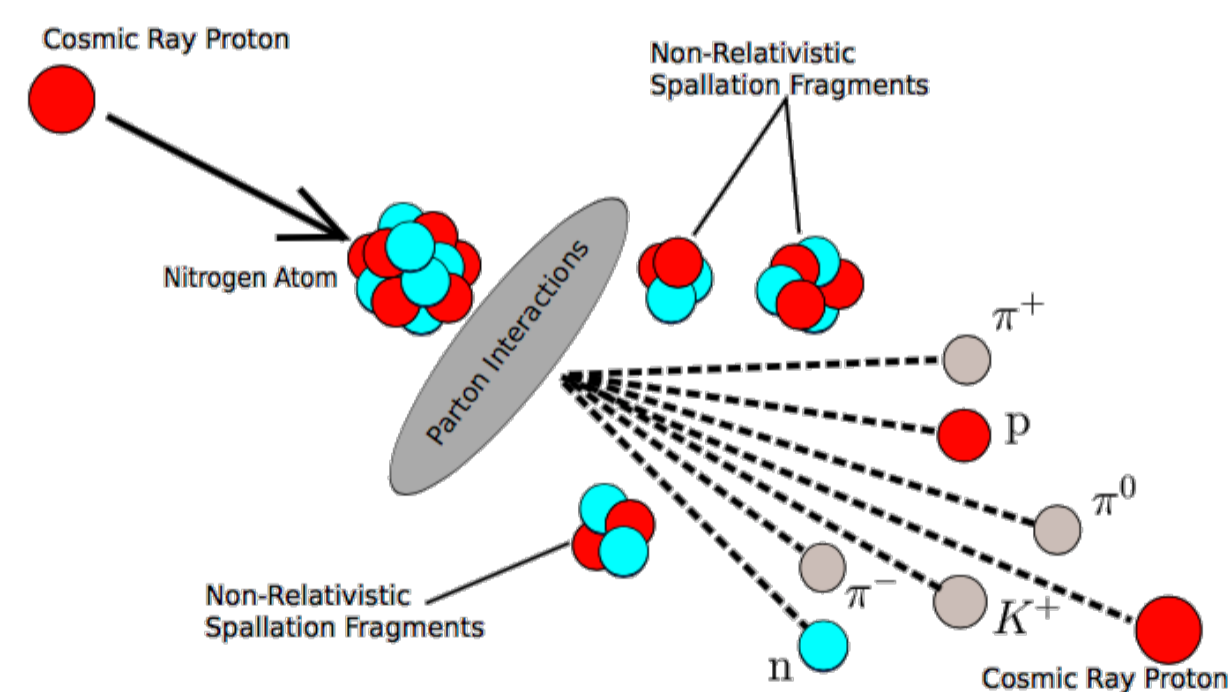
Highest energy by accelerator:  $10^{13}$  eV

Direct measured  $E < 10^{12}$  eV with satellite

Indirect measured  $E > 10^{12}$  eV at ground

Generate air shower in the atmosphere

- Interact with atmospheric molecules
- Produce huge number of particles
- nucleus differences appear in the depth of shower maximum

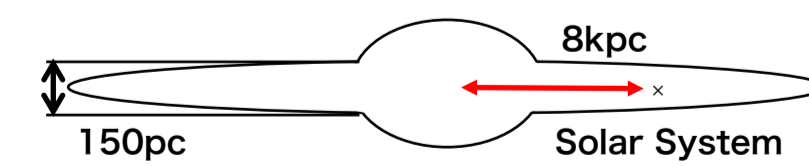


Galactic to Extra-Galactic??

- Maximum energy trapped in our Galaxy depends on charge

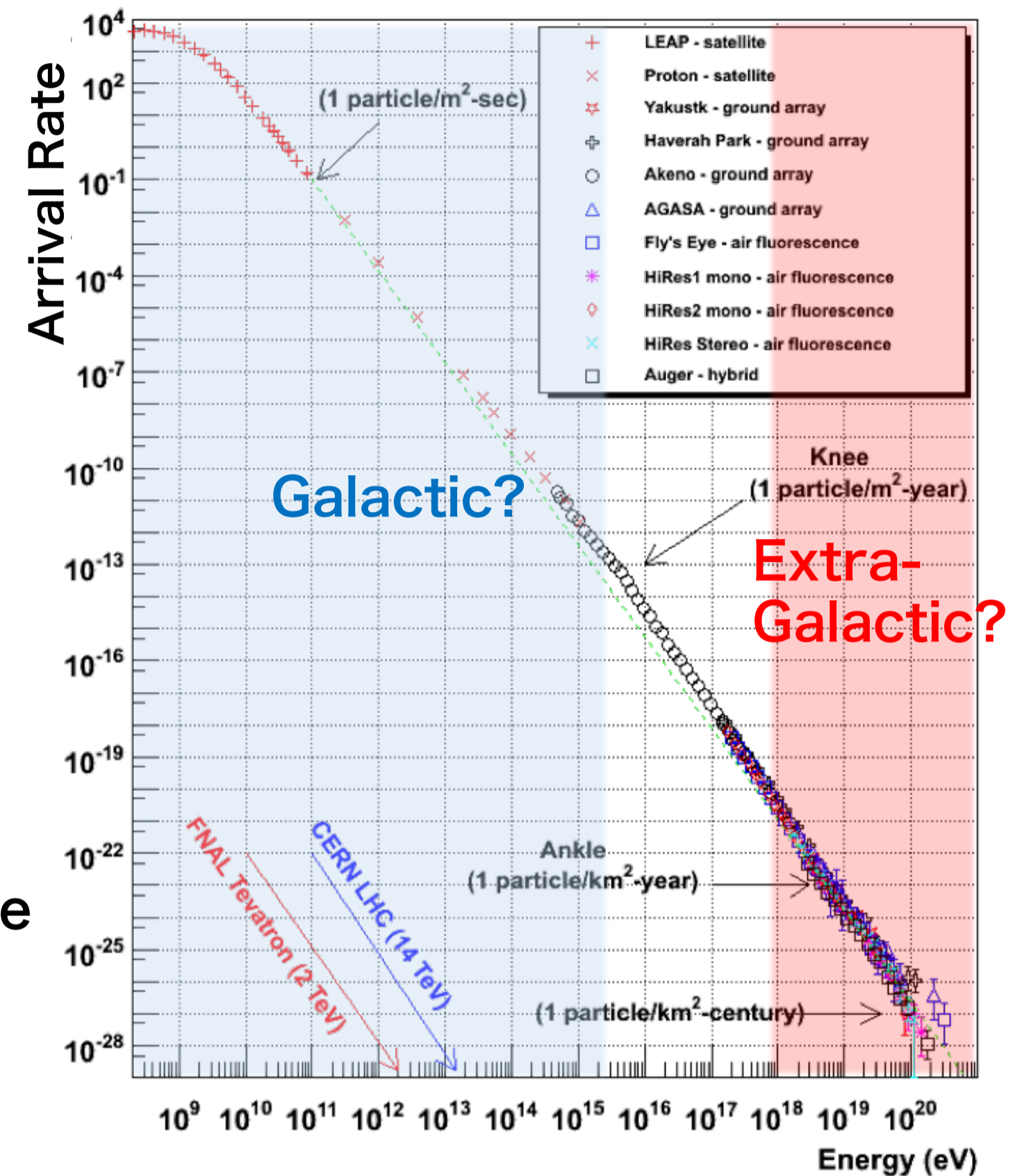
$$E \sim Z \times \left( \frac{R}{100 \text{ pc}} \right) \times \left( \frac{B}{1 \mu\text{G}} \right) \times 10^{15} \text{ eV}$$

Image of Galaxy, edge on



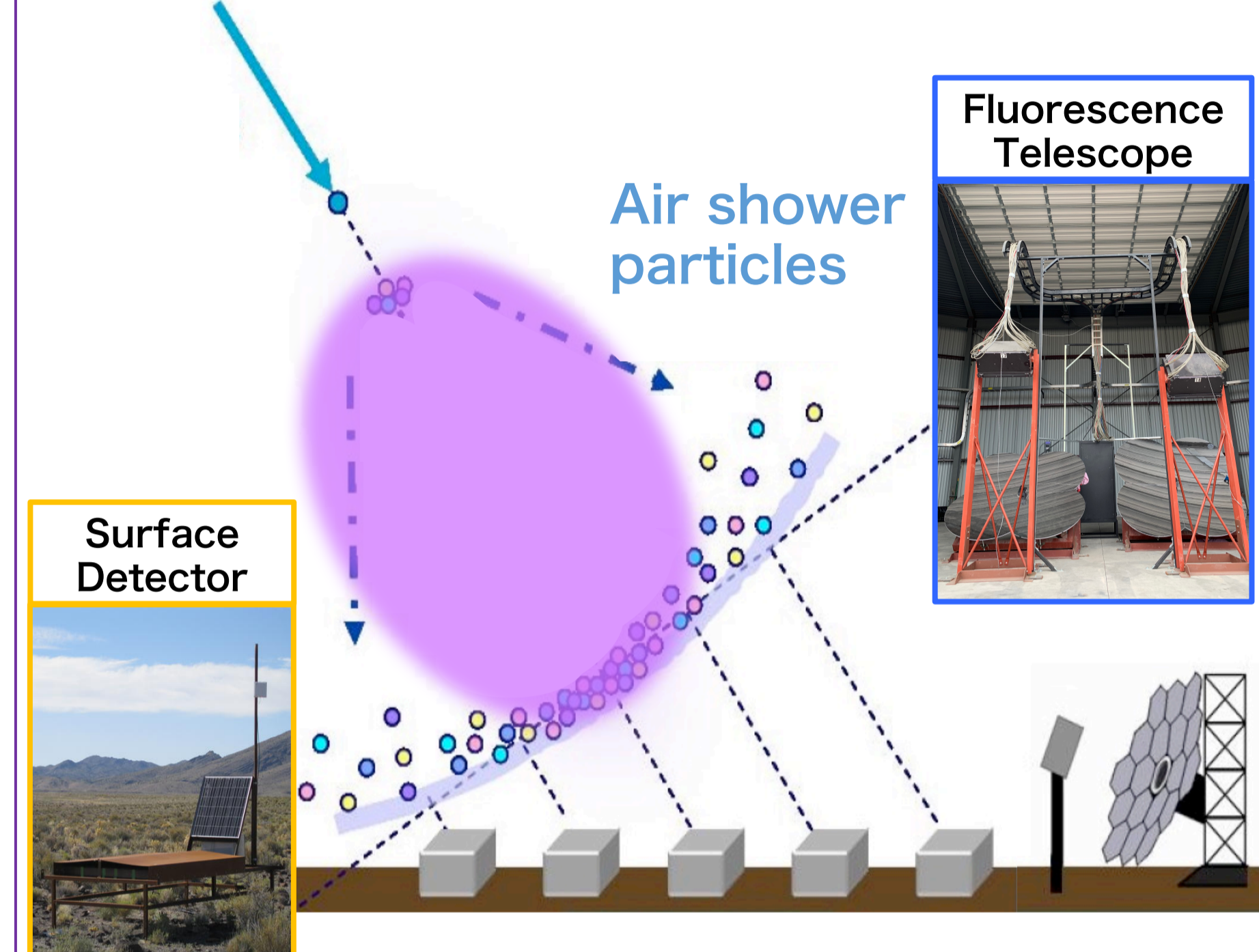
- E: cosmic ray energy
- Z: cosmic ray charge
- R: Size of Galaxy,  $\sim 150\text{pc}$  ( $\sim 500\text{ly}$ )
- B: Galactic Magnetic strength,  $\sim 3\mu\text{G}$
- for proton:  $\sim 4.5 \times 10^{15}$  eV ??
- for iron :  $\sim 1.2 \times 10^{17}$  eV ??
- Above is extragalactic proton again ??

**Broken structures can be explained proton and iron escape??**



## Air Shower Detection

Cosmic Ray particle



**Surface Detector Array, SDs**  
Surface Detector Array sample the lateral distributed of charged particles induced by primary cosmic ray at the ground in order to determine the energy and arrival direction of cosmic ray.

**Air Fluorescence light**  
An Extensive Air Shower excited molecular nitrogen, which de-excites and emits fluorescence photons isotropically.

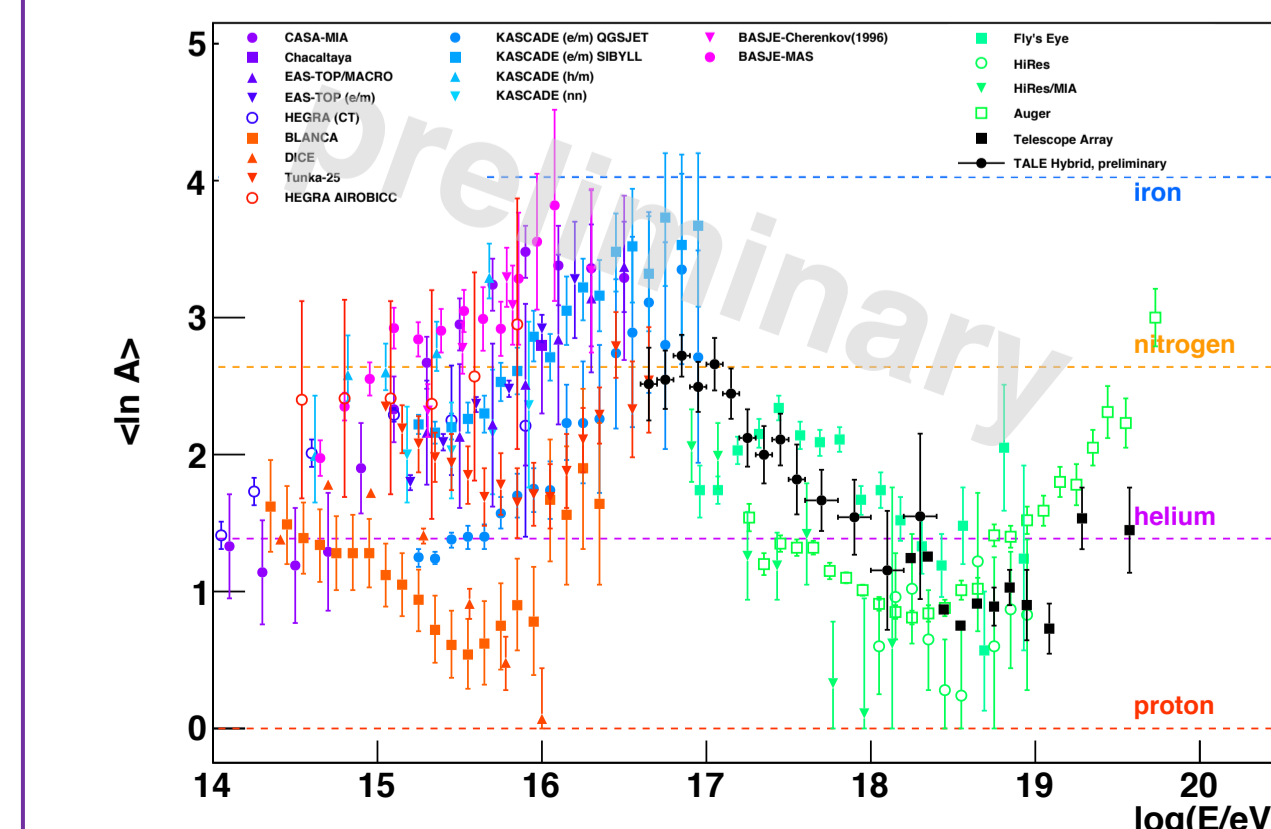
**Air Cherenkov light**  
The Cherenkov light emitted by electrons moving down through the atmosphere. The Cherenkov light is beamed forward in a cone around the direction of the particle.

**Fluorescence Detector, FD**  
The air fluorescence and Cherenkov photons are collected by optical instruments of FD. An advantage by the FD technique is to observe the shower longitudinal profile and measure the shower energy calorimetrically.

## Mass Composition & Energy Spectrum measurement

Mean logarithmic Atomic number  $\langle \ln A \rangle$  vs. Cosmic ray Energy

- Black points: this work
- Heavy mass composition @  $10^{17}$  eV
- Drastically changes to
- Light mass composition  $E > 10^{17}$  eV



Cosmic Ray Energy Spectrum multiplied  $E^3$  to arrival rate to clearly seen fine structures

- Magenta points: this work
- Broken feature are observed @  $\sim 10^{17}$  eV

