UW Madison Colloquium March 98.

The Highest Energy Cosmic Rays and the Auger Project

Talk outline:

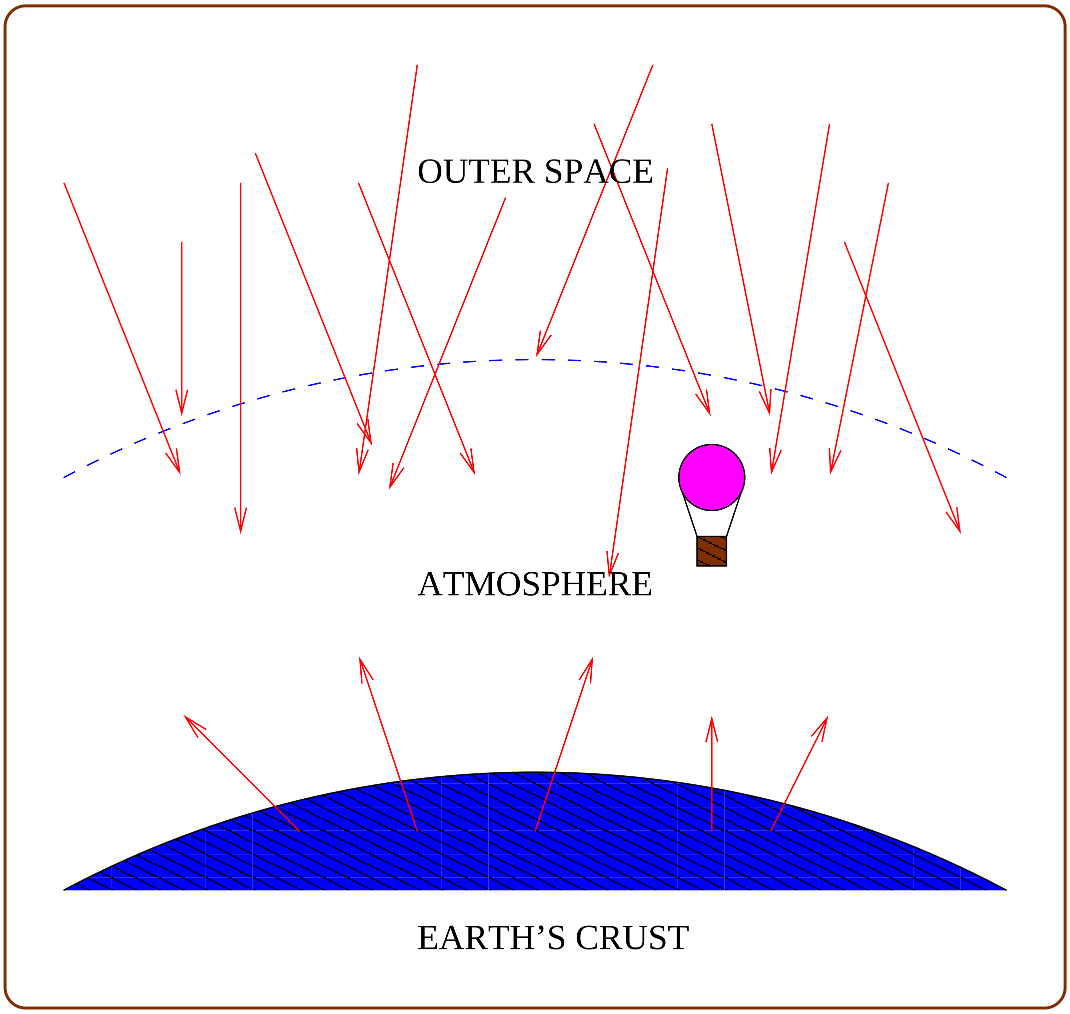
- Discovery of Cosmic Rays and Air Showers
- Anatomy of an air shower
- Detection Techniques
  - Ground Arrays
  - Fluorescence Detectors
- What we know about cosmic rays
- Highest Energy Events are interesting.
- The Auger Observatory - a hybrid detector
- Conclusions

Clem Pryke - University of Chicago

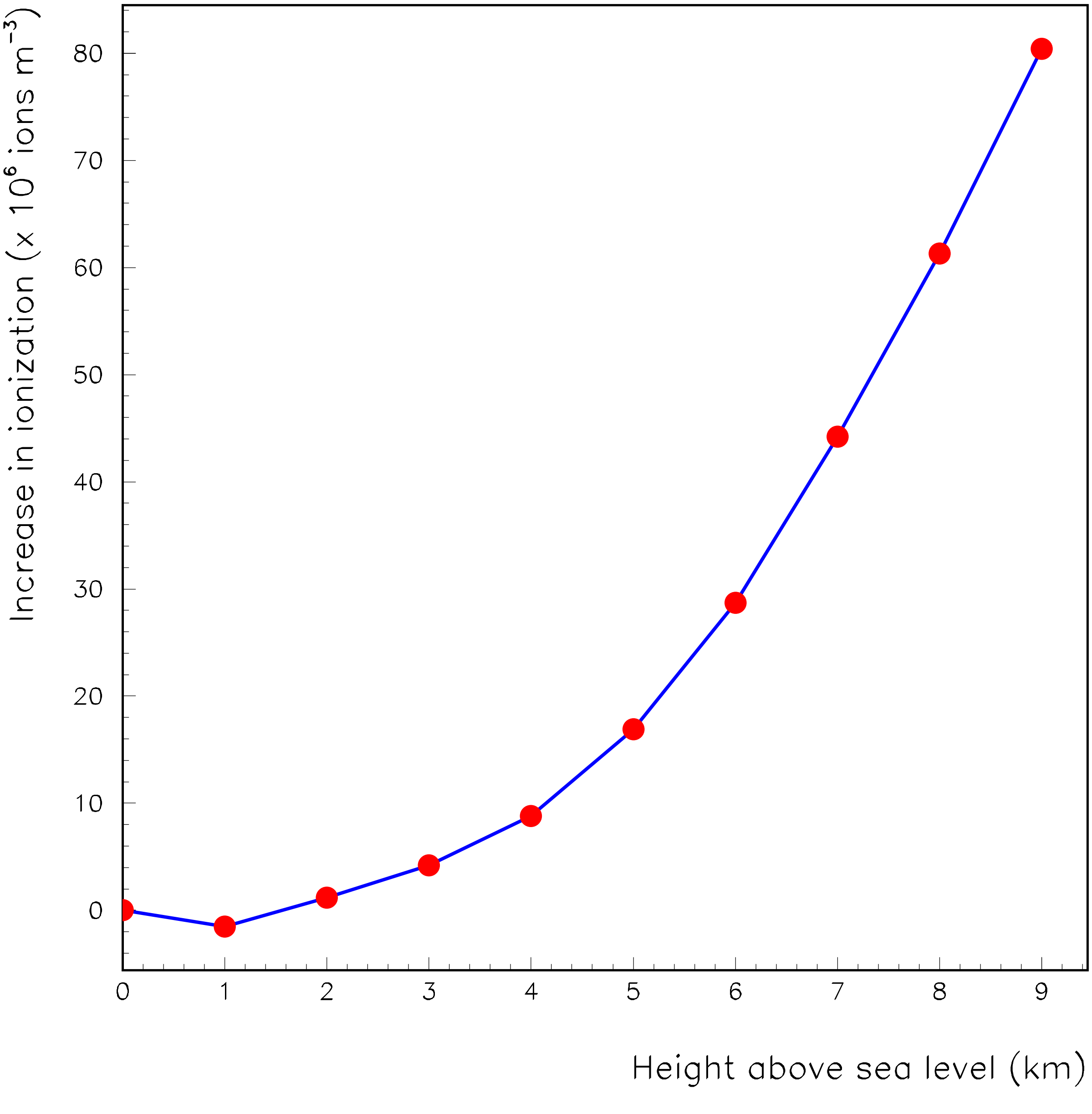
Discovery of Cosmic Rays

- Victor Hess showed in 1912 that ionization of the atmosphere increases $\uparrow$ with altitude. (Expected to decrease if due to radioactivity of Earth's crust).

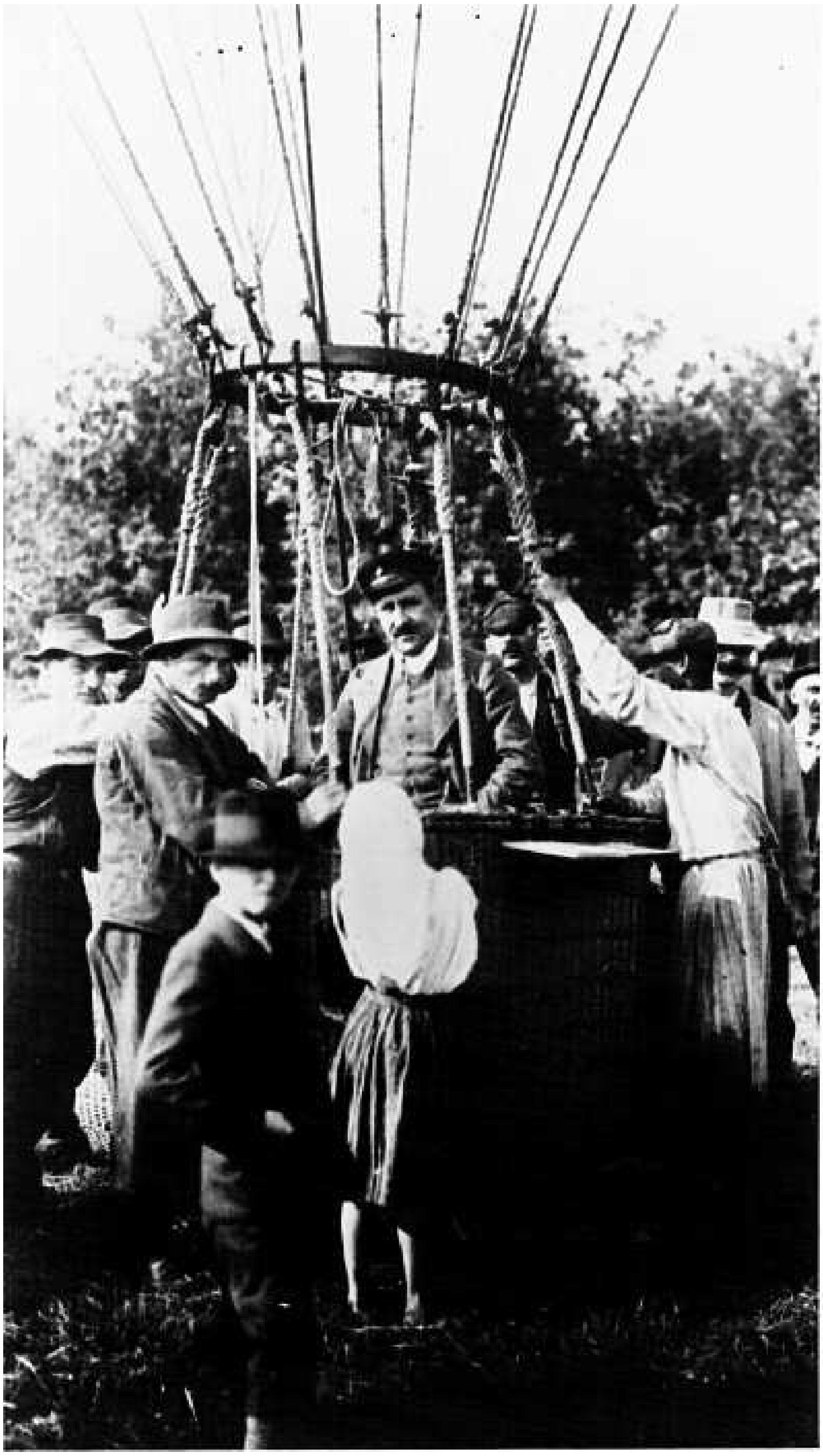
- Correct inference $\Rightarrow$ Radiation enters our atmosphere from above.



Balloon flight of Kolhorster 1914

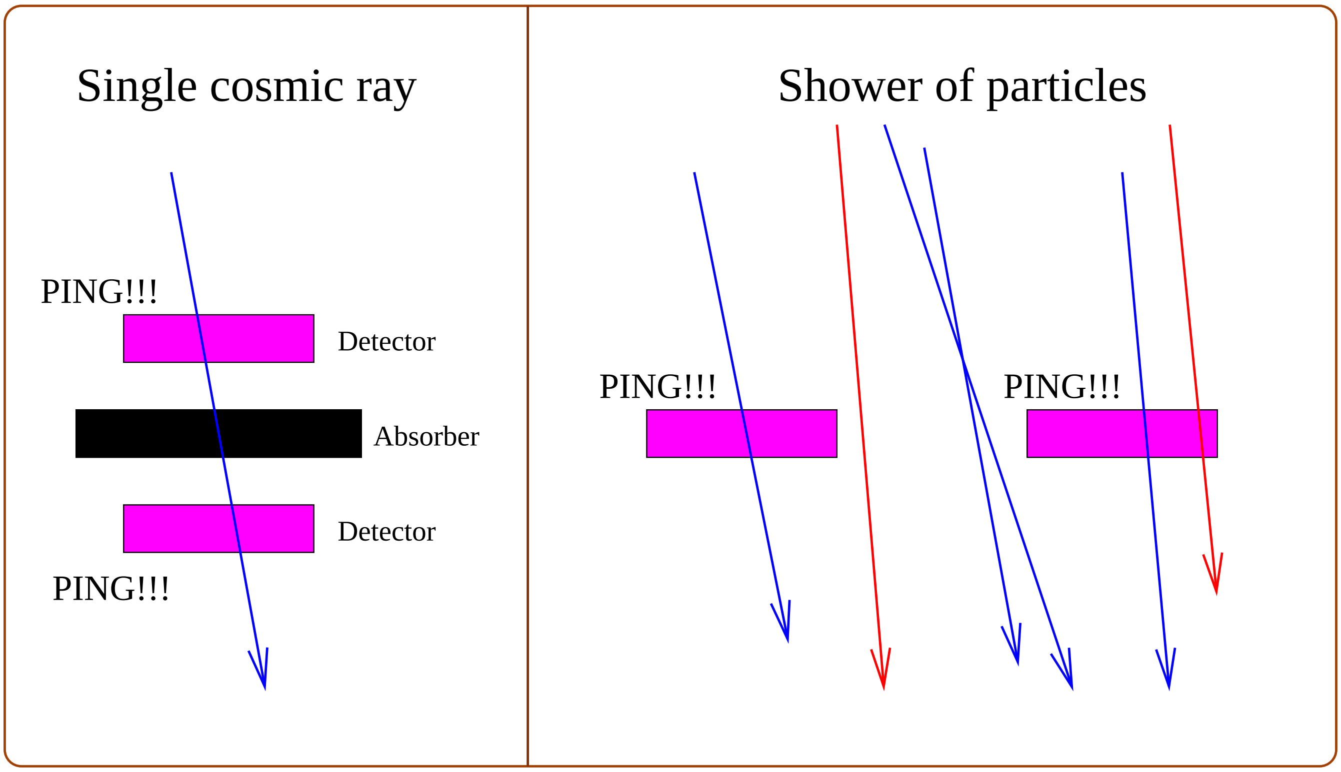


Hess after a successful flight



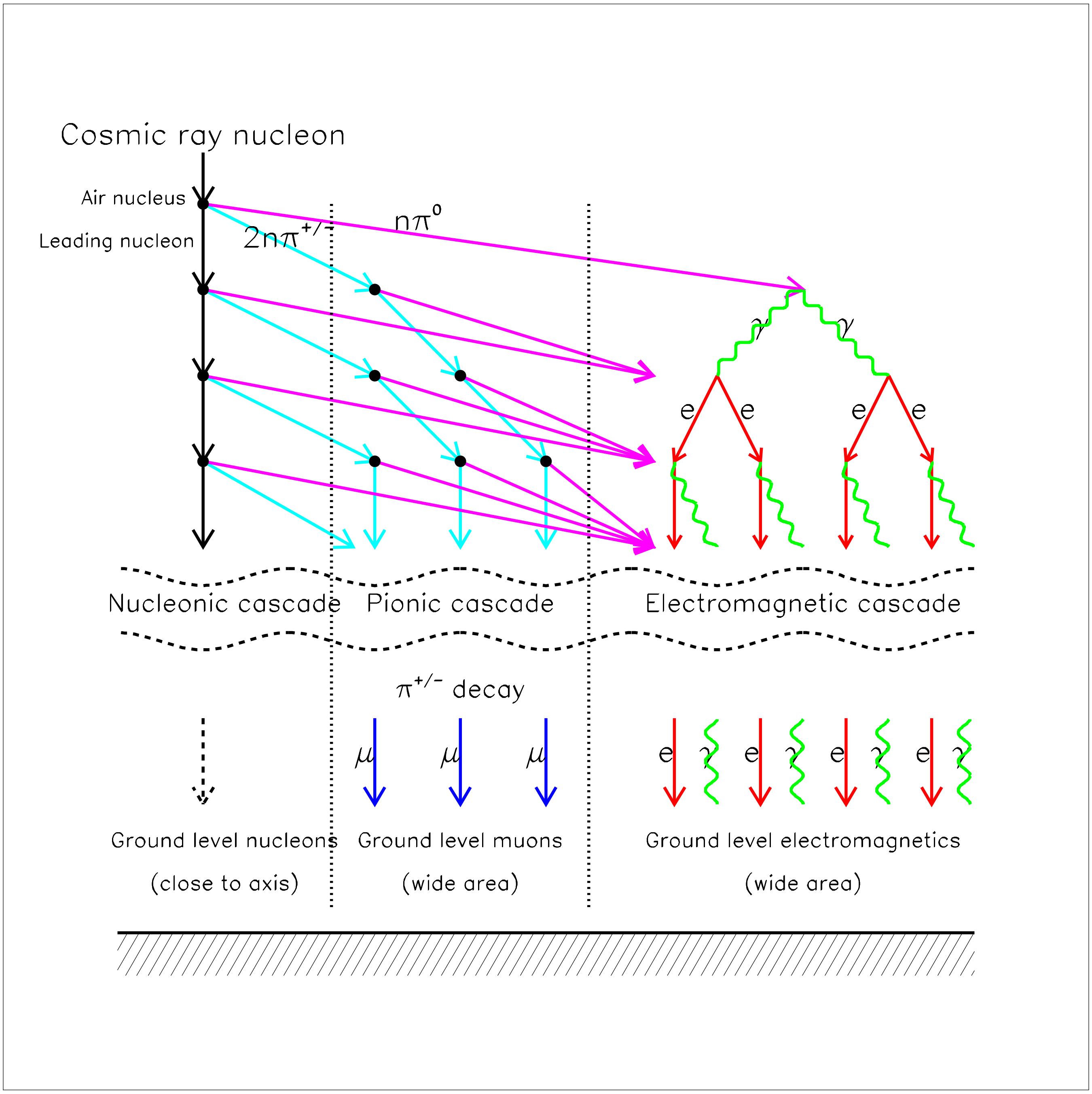
Discovery of Air Showers

- In late 1930's by Frenchman Pierre Auger
- Using newly invented coincidence circuit (μ sec)
- Detectors on top of each other fire together $\Rightarrow$ due to single particles.
- Separated detectors fire together $\Rightarrow$ showers of particles.

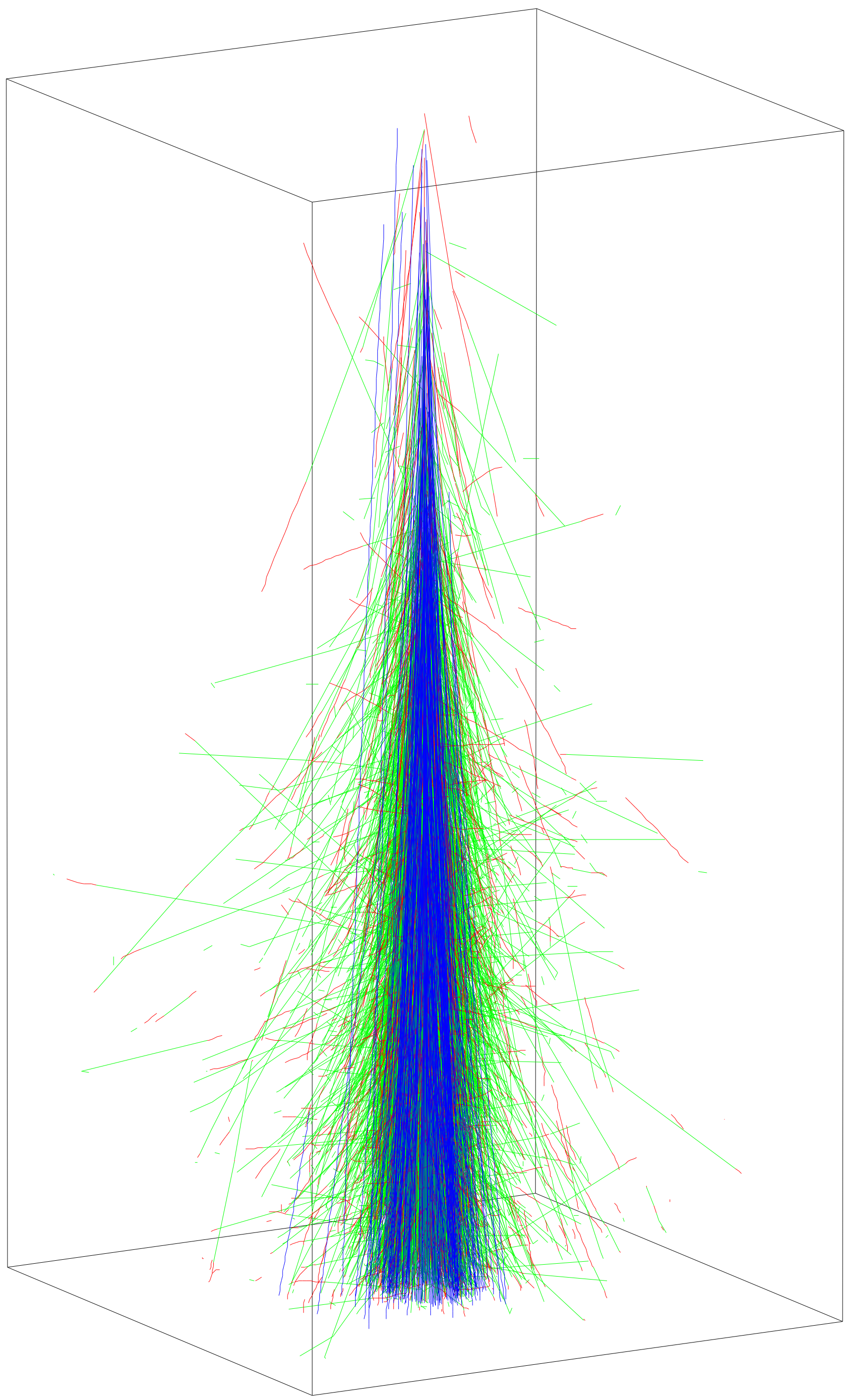


- Inference: Showers of secondary particles.
  Over 300 meter baseline $\Rightarrow 10^{15}$ eV primary!

Anatomy of an Air Shower



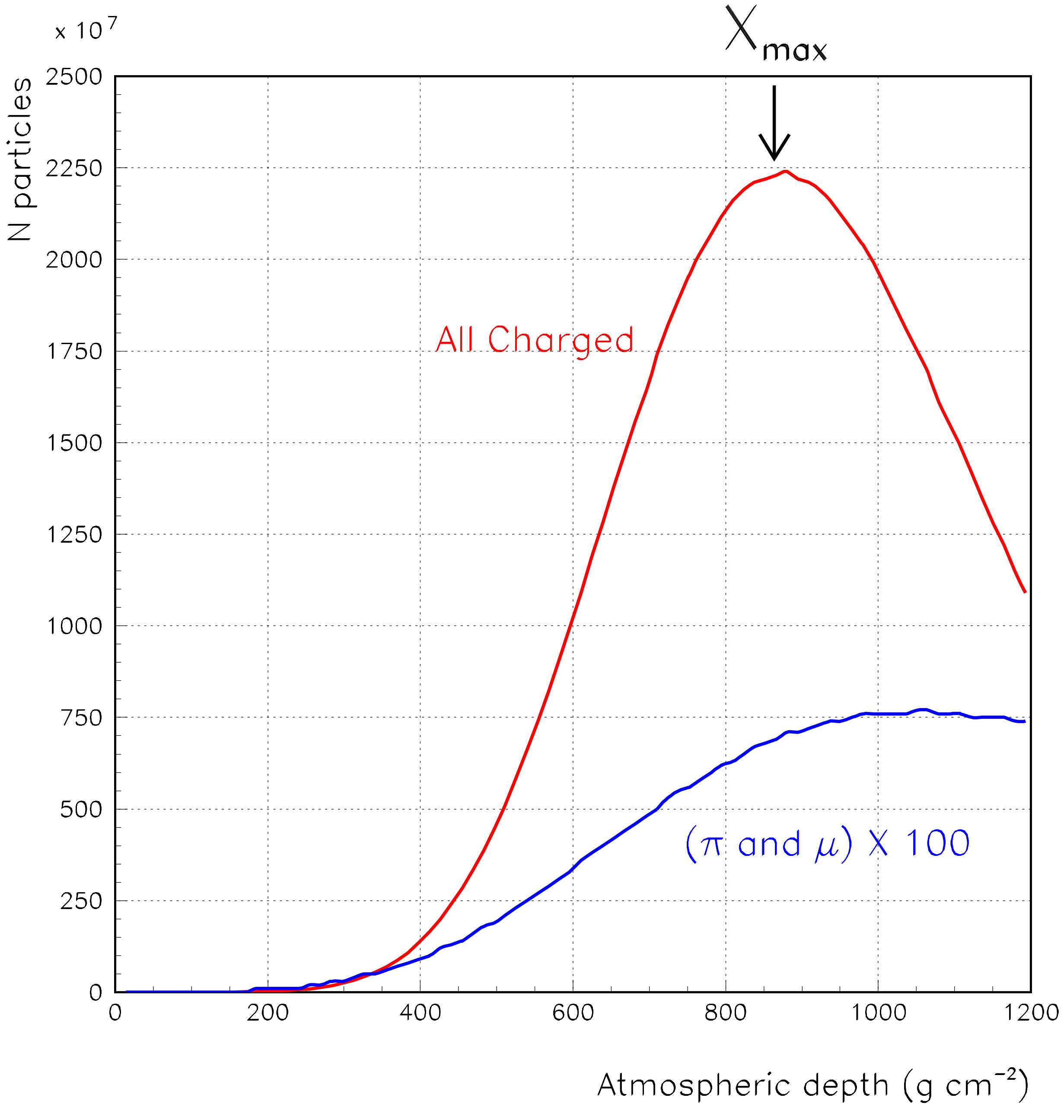
Air Shower Simulation



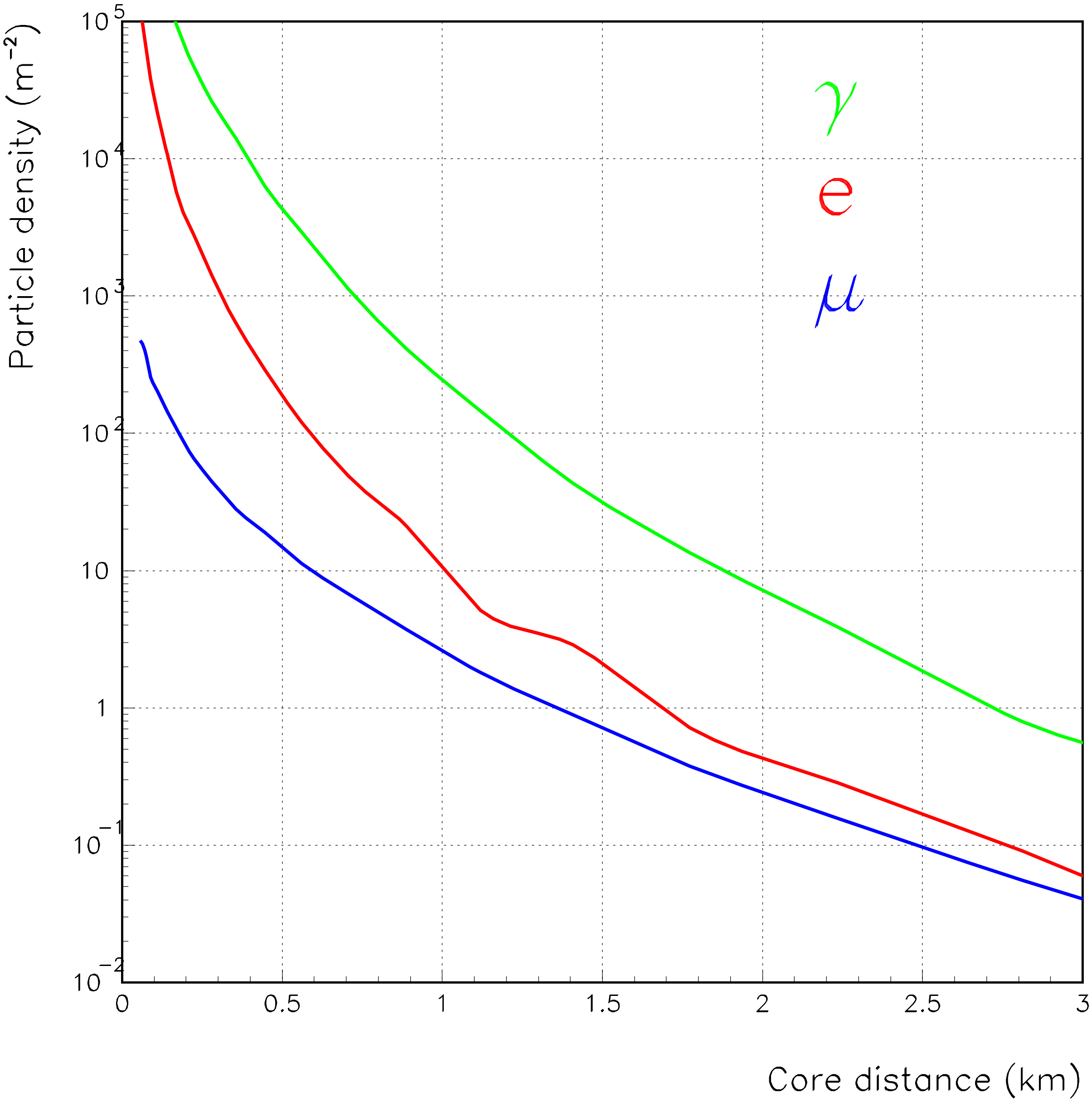
Frame box: 6 x 6 x 12 km high.

Color code: γ, e, μ.

Longitudinal Distribution



Lateral Distribution

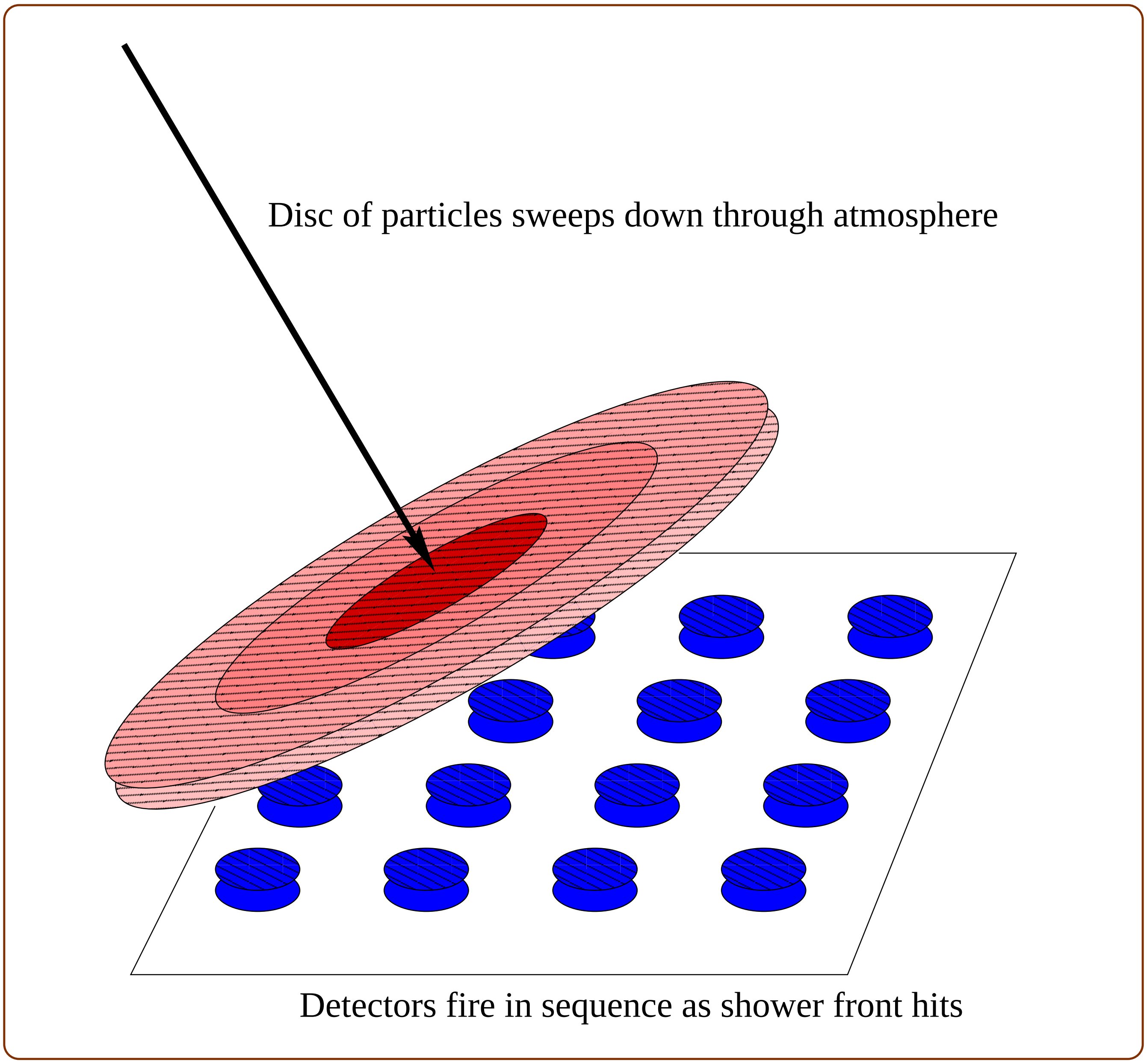


Detection Techniques

- Ground Arrays
  - Original technique (developed in the 50's).
  - Measure the Lateral Distribution at Ground Level.
- Fluorescence Detectors
  - Atmosphere as remote sensing calorimeter.
  - Measure the Longitudinal Distribution.

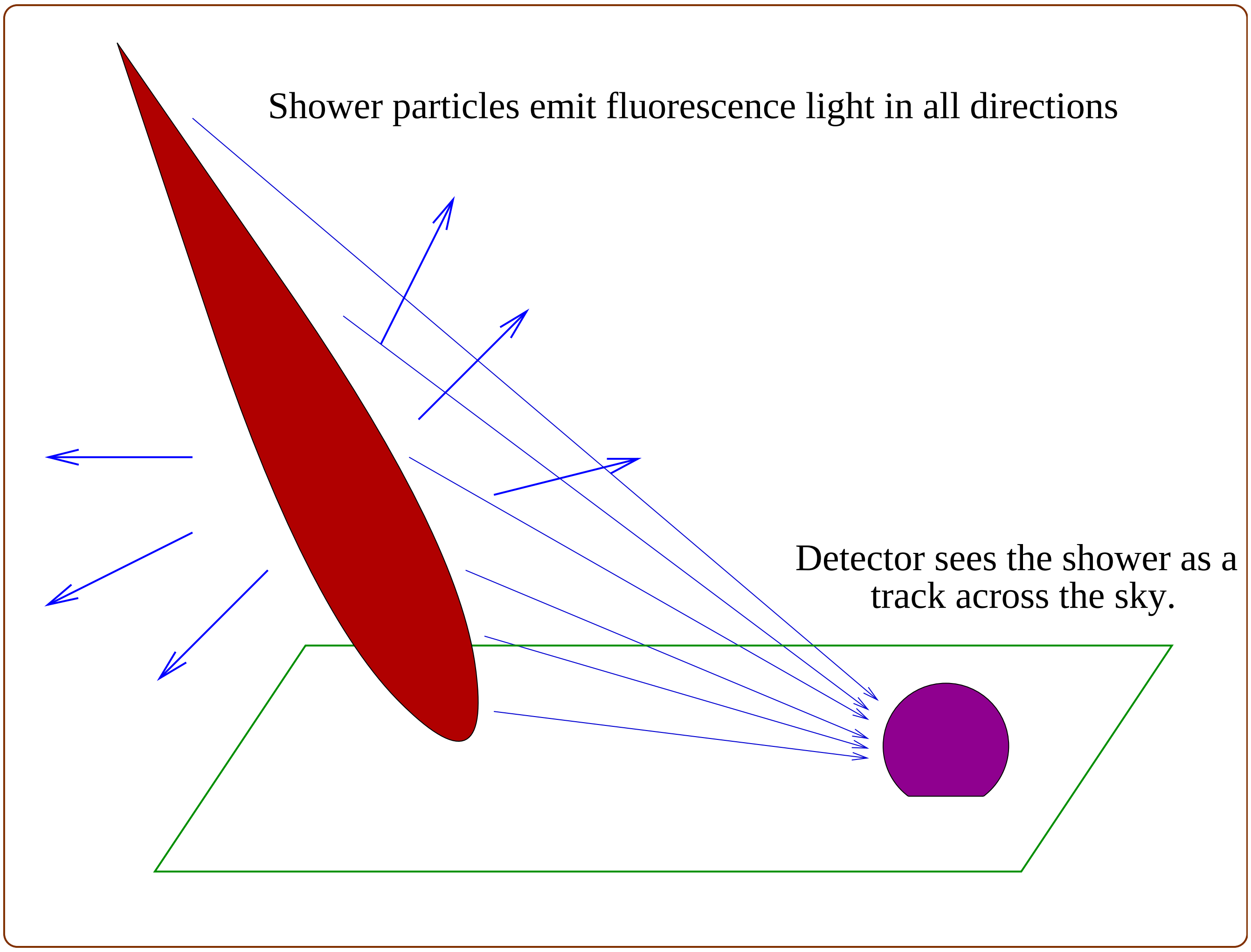
Ground Array Technique

- Incidence angle found from timing.
- Primary energy inferred from particle density pattern on the ground.



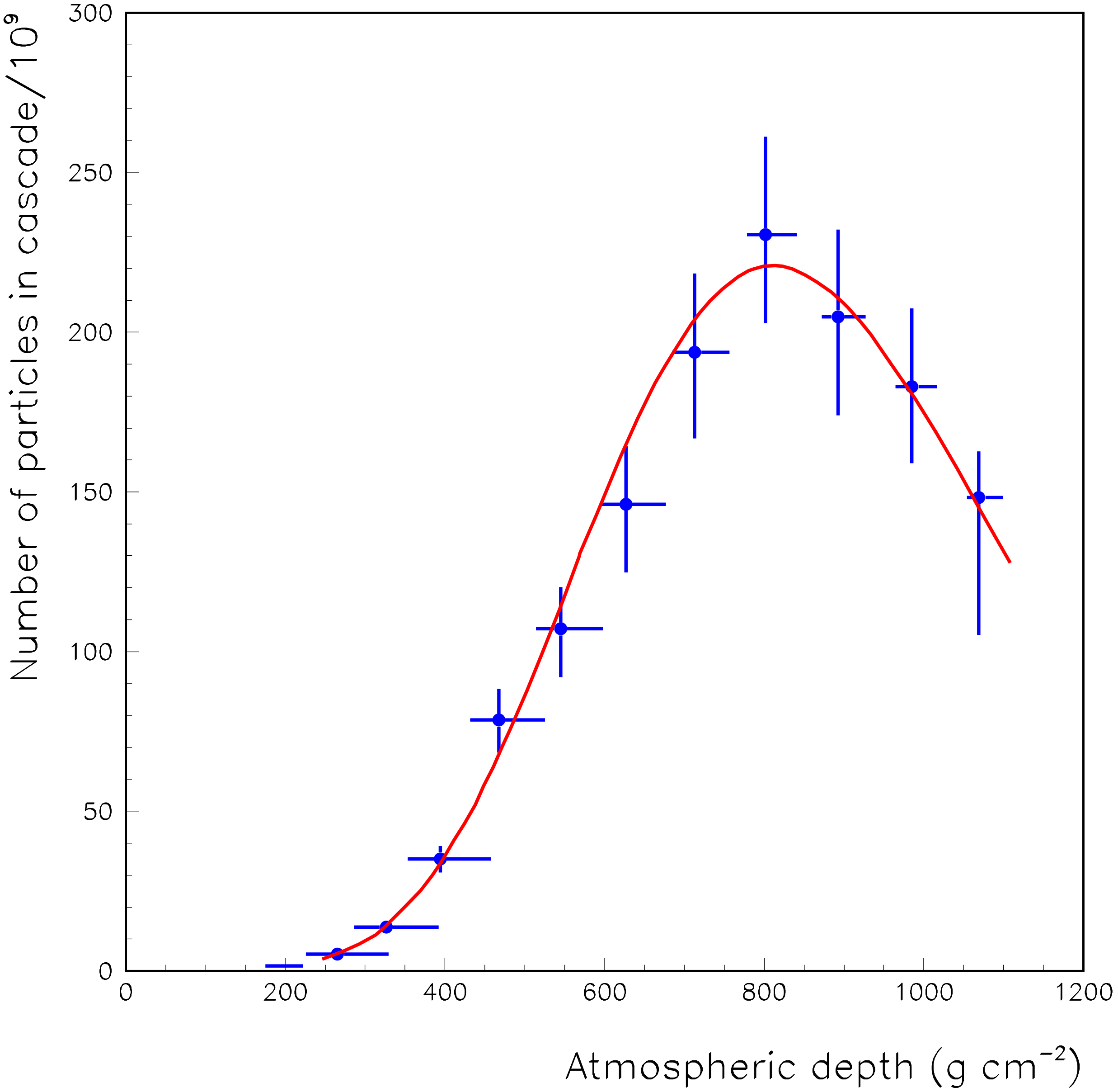
Fluorescence Detectors

- Incidence angle found from geometry+timing (geometry alone for stereo).
- Primary energy inferred from integral of longitudinal profile $\Rightarrow$ Solid calorimetric lower limit on primary energy.



Fly's Eye 3×10^{20} eV Event

$\approx$ 200 billion particles at cascade maximum!



What We Know and Don't Know about Cosmic Rays

A flux of relativistic particles striking the upper atmosphere with a power-law energy spectrum: $\frac{dN}{dE} \propto E^{-2.5}$

Up to 10^{14} eV - Below the "Knee":

- Direct observations possible — we know "everything". Particle types well measured: 2% electrons, 85% protons, 12% alpha particles, 1% heavier nuclei.

- Plausible source theory: Supernova shock acceleration.

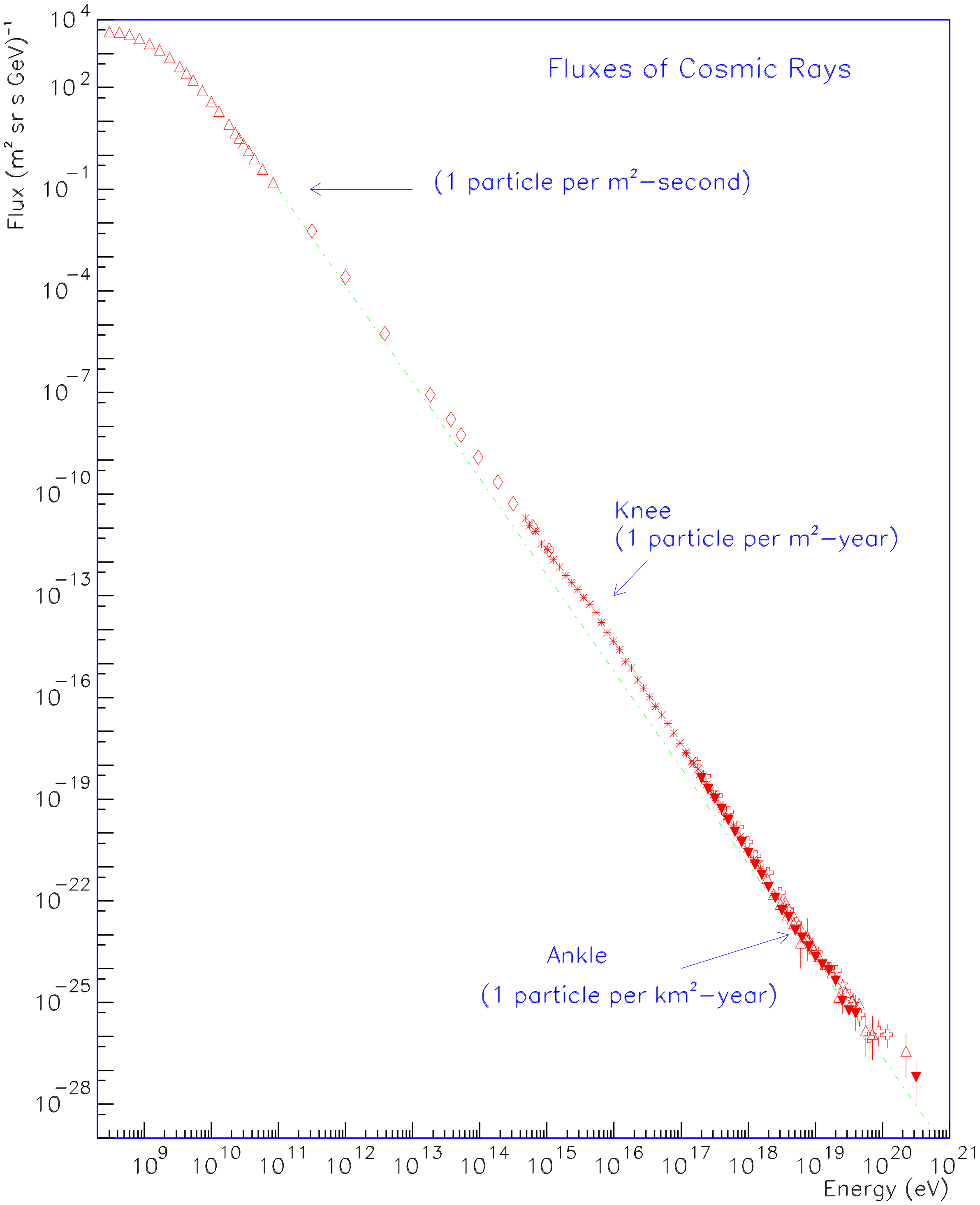
Above 10^{14} eV - "Knee" region and above:

- Only indirect (Air Shower) observations. We know energy spectrum but composition measurement hard.

- Supernova acceleration should cut off at $\sim 10^{16}$ eV.

- Origin of $E > 10^{16}$ eV a mystery.

The Cosmic Ray Energy Spectrum



Why are the Highest Energy Events Interesting?

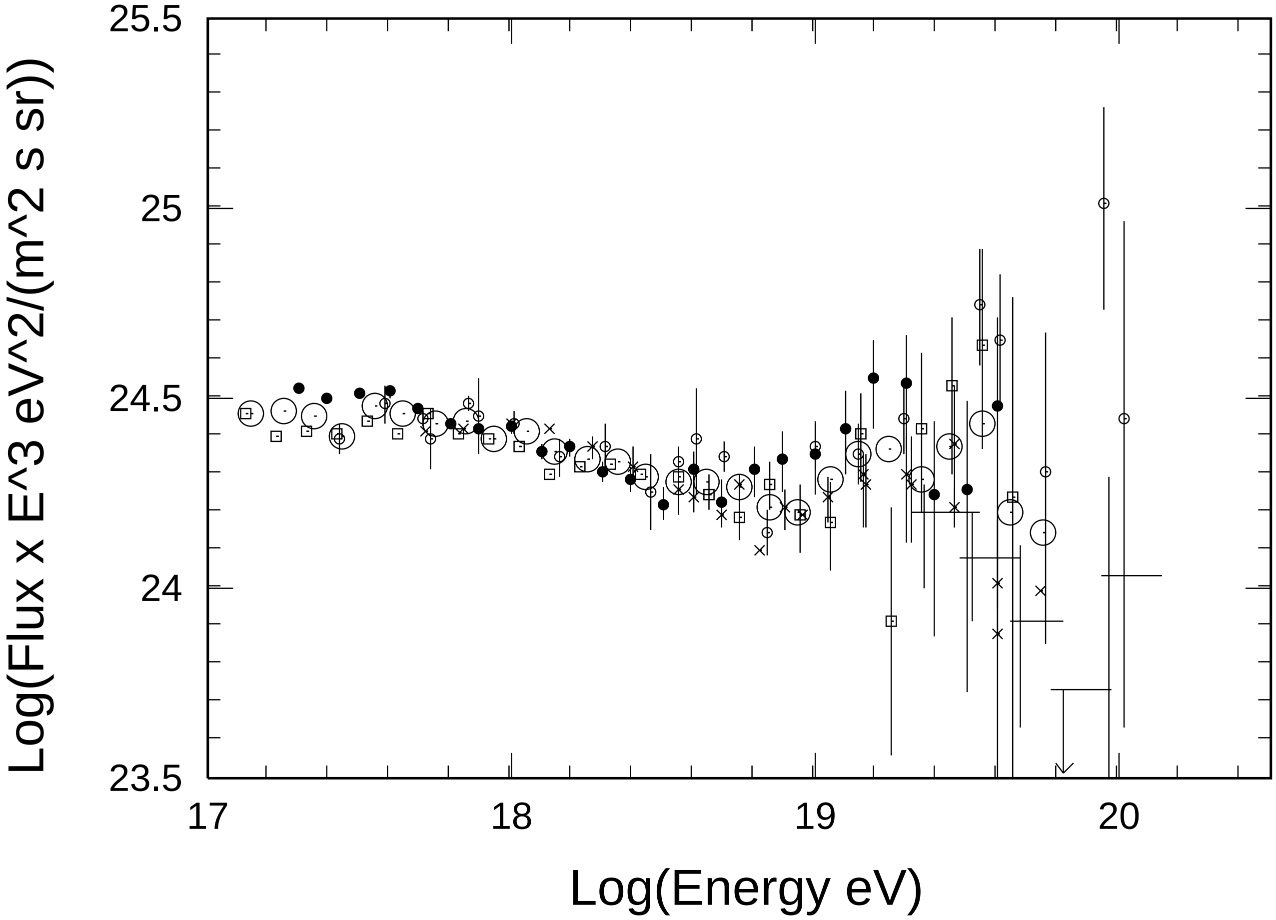
- Tantalizing hints of structure in the energy spectrum with agreement between different expt. Extragalactic component emerging? $\rightarrow$ evidence for composition change also...

- At $> 5 \times 10^{19}$ eV photo-pion production with Cosmic Microwave Background photons means sources must be < 50 Mpc.

- Magnetic deflections should be small $\Rightarrow$ no obvious candidates for events so far.

- Great difficulty constructing source models using even most extreme astrophysical objects.

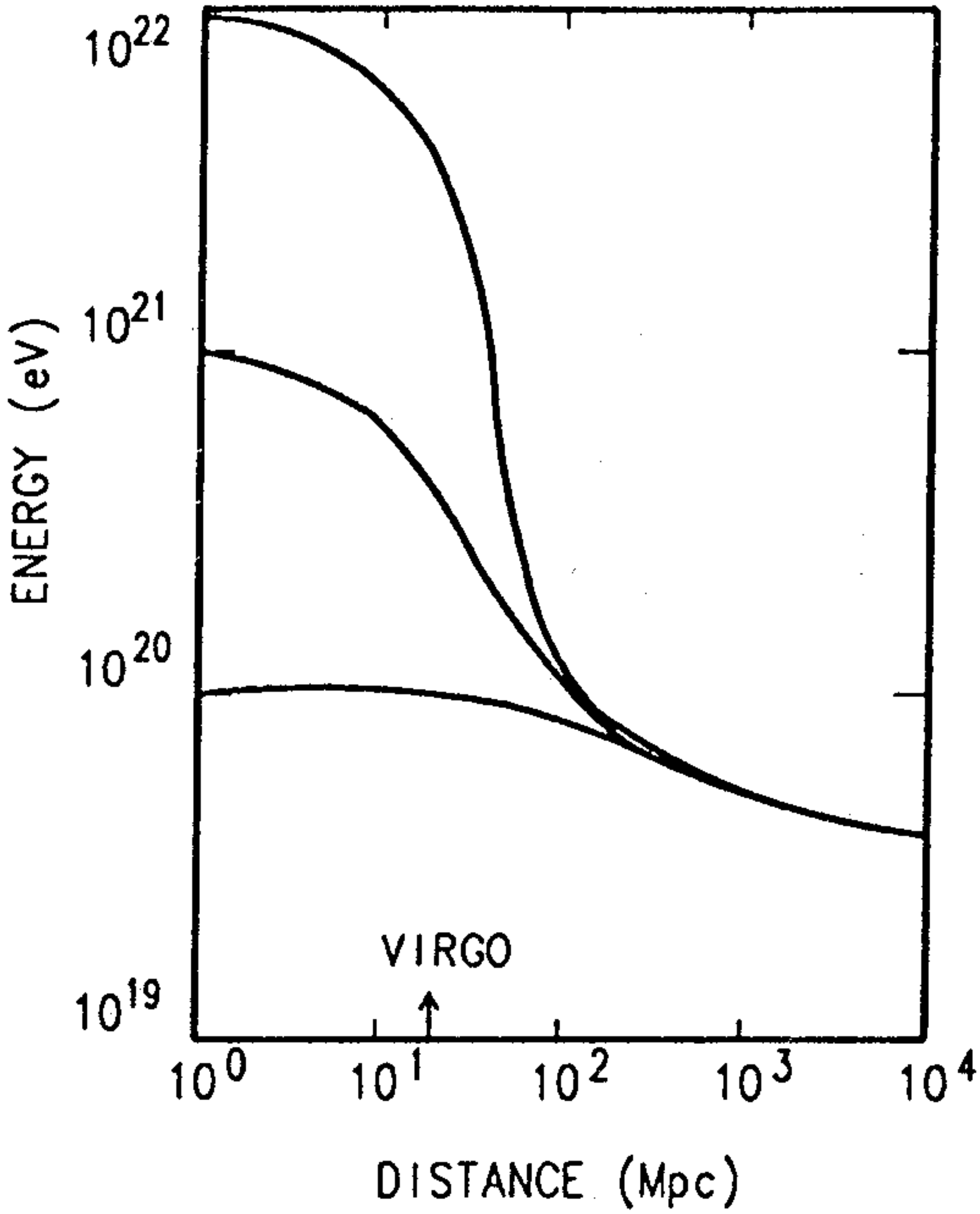
Top end of the Energy Spectrum



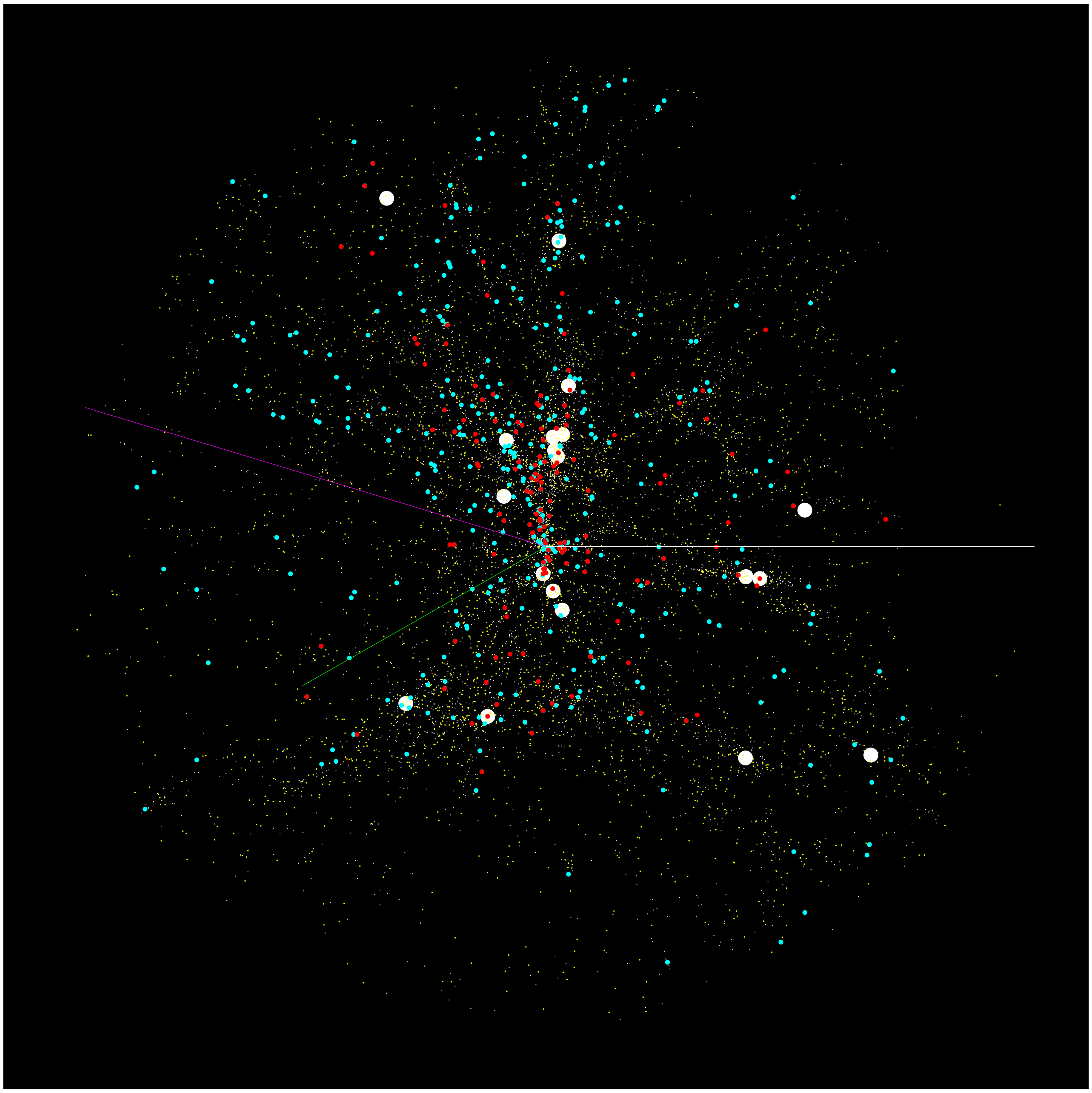
4 experiments: $\sim$ 15% energy scale shifts.

CMB cutoff

$$p + \gamma_{2.7K} \rightarrow n + \pi^+$$



Sources Not Obvious



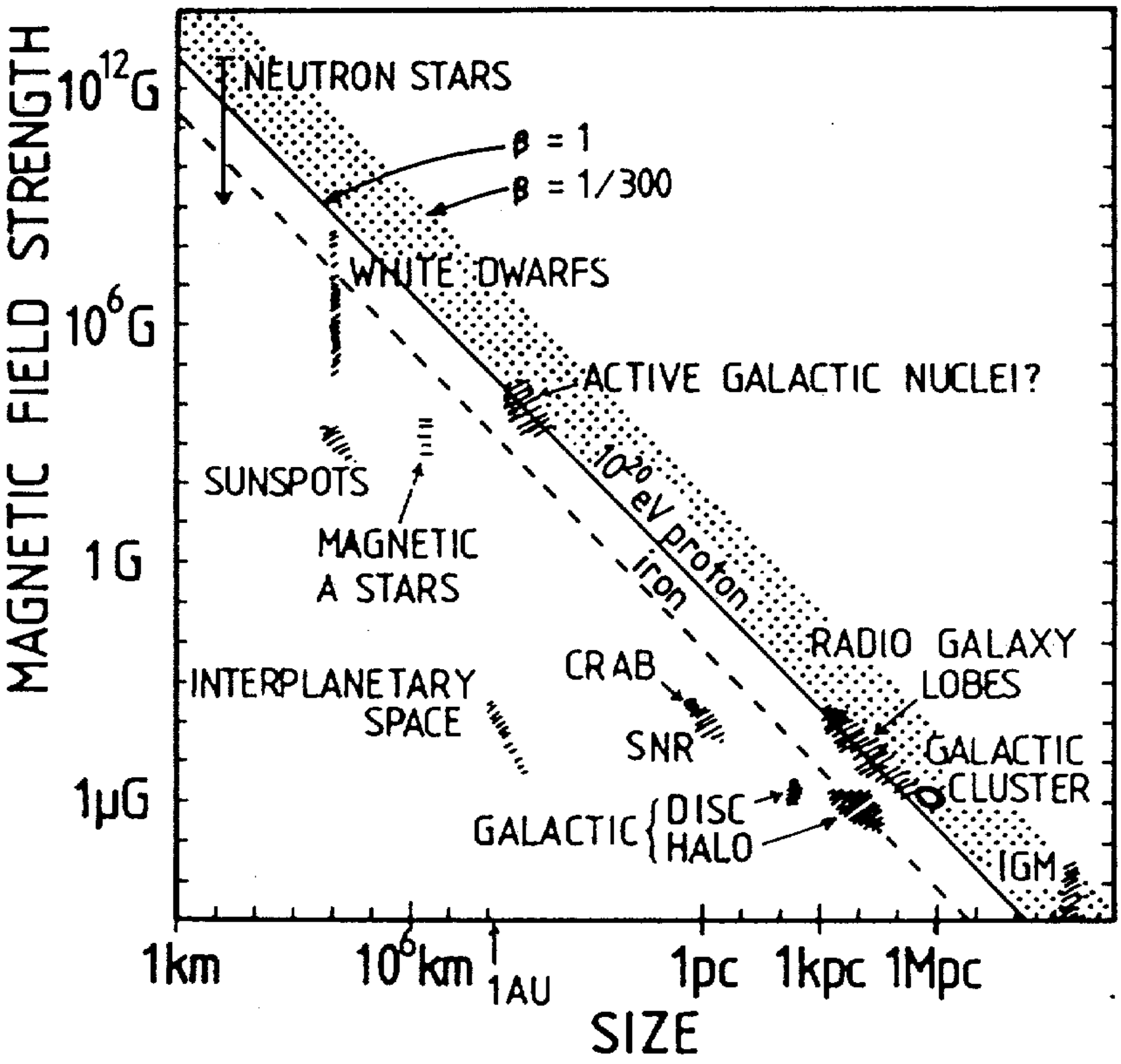
Fly's Eye 3×10^{20} eV, AGASA 2×10^{20} eV

See this image rotate at:

http://aupc1.uchicago.edu/p̃ryke/auger/arrival_dir

Magnetic Field Constraint

$$r_{pc} \approx \frac{E_{10^{15}\ eV}}{Z B_{\mu G}}, \; r_{Mpc} \approx \frac{E_{10^{18}\ eV}}{Z B_{nG}}$$



The Auger Observatory — A Hybrid Detector

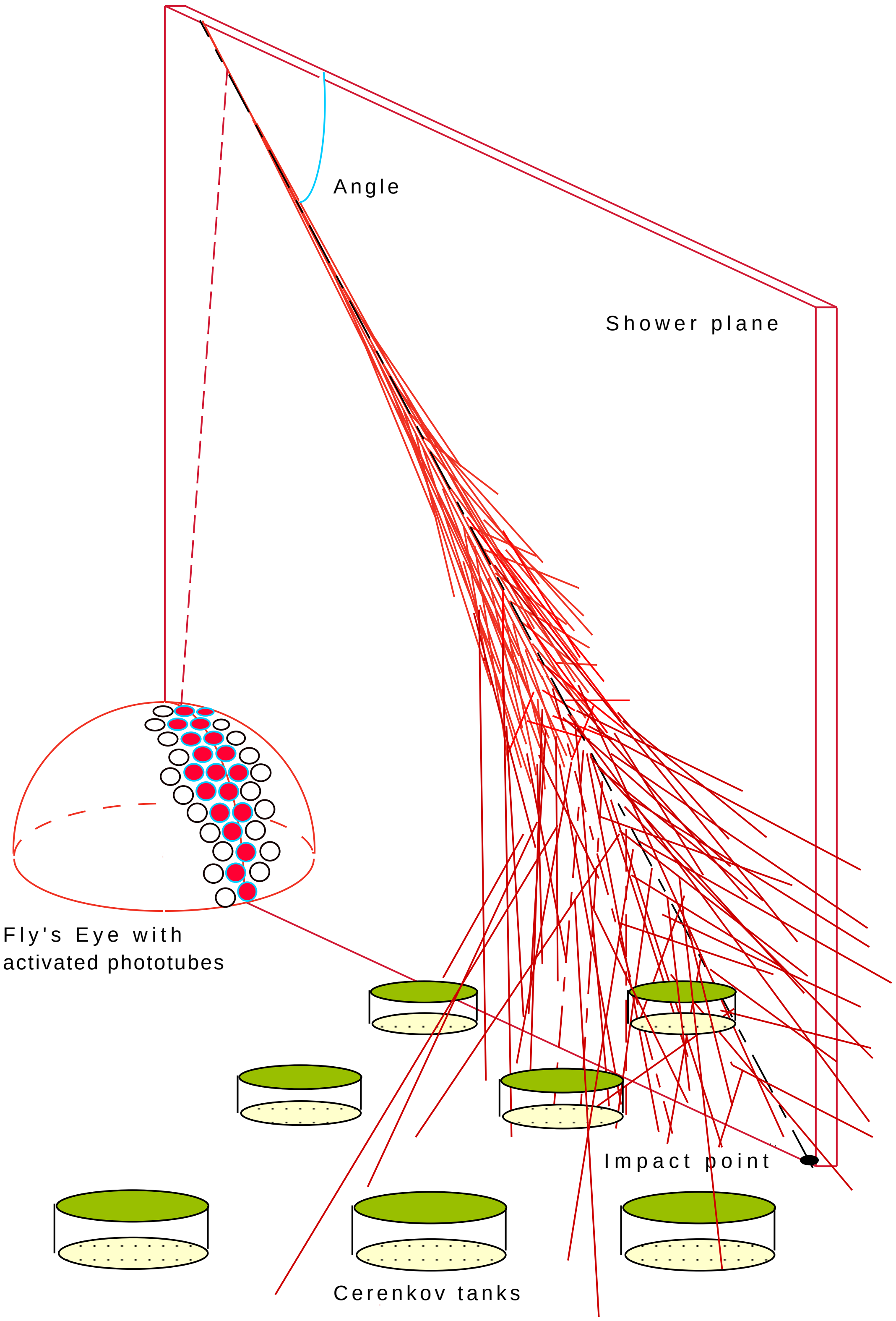
Key Objectives:

- To harness the power of both available techniques in a hybrid instrument. Increase confidence in results!

- To collect a statistically significant sample of events at the Highest Energies. ~ 100 events per year at $E > 10^{10}$ eV requires $\sim 10^4$ km^2 sr aperture.

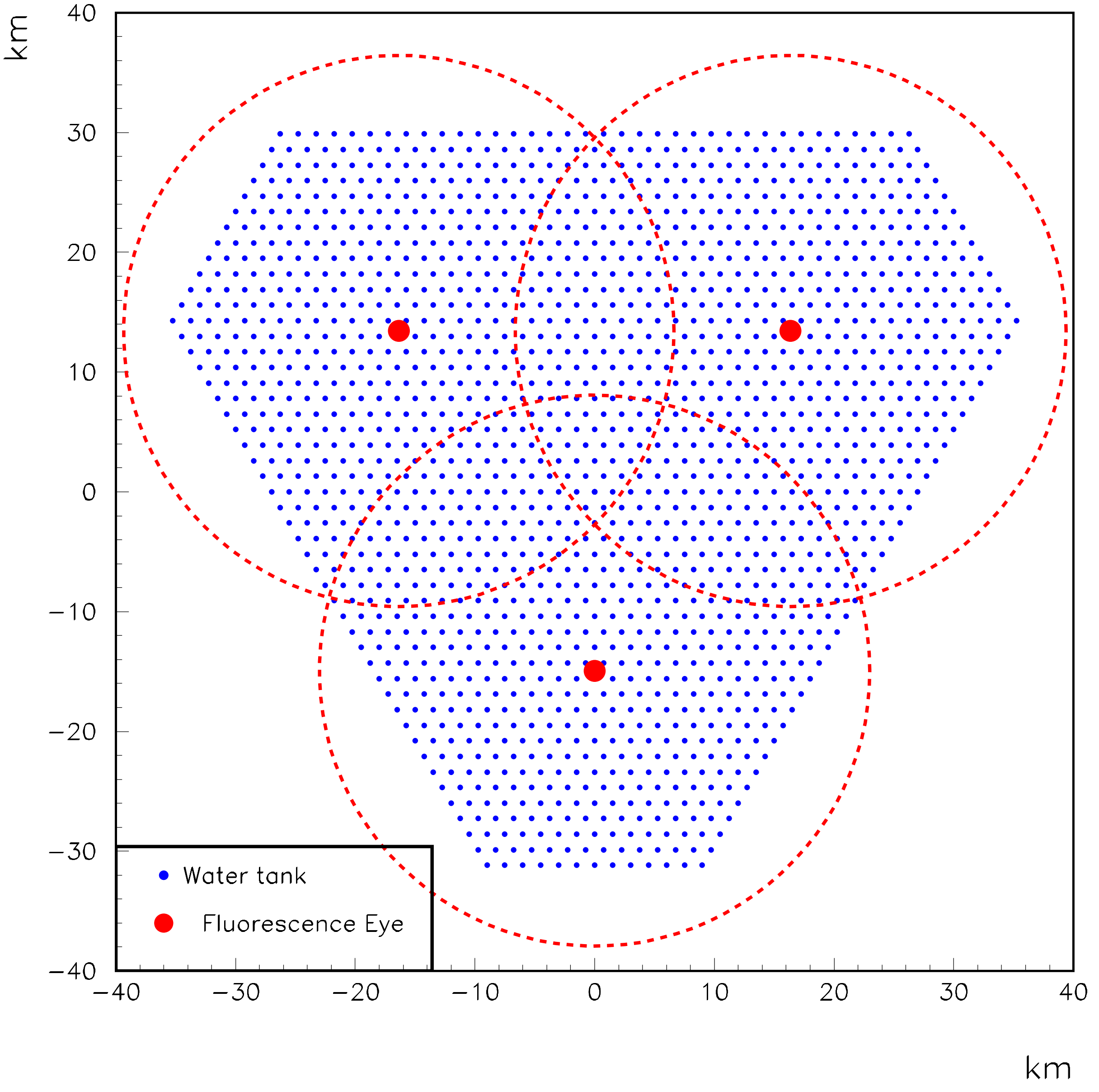
- Survey the whole sky $\Rightarrow$ Twin detectors in the northern and southern hemispheres.

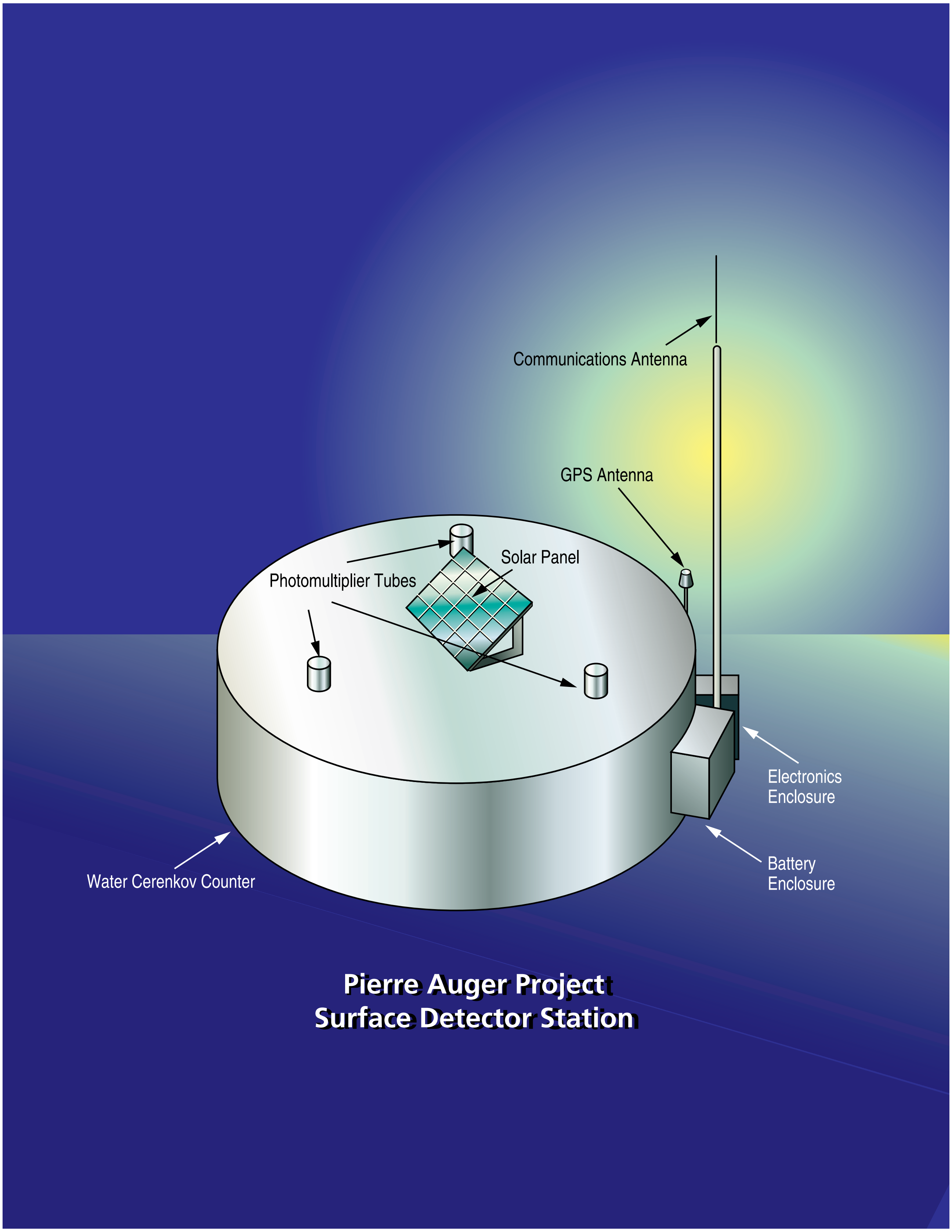
Hybrid Detection



The Proposed Auger Arrays

- 1600 water Čerenkov tanks spread over 3000 km^2
- Overlooked by 3 fluorescence detectors.




Communications Antenna
GPS Antenna
Solar Panel
Photomultiplier Tubes
Electronics Enclosure
Battery Enclosure
Water Cerenkov Counter
Pierre Auger Project
Surface Detector Station

Conclusions

- The Highest Energy cosmic rays are a challenge to our understanding of Astrophysics $\Rightarrow$ they demand to be studied!

- Conceptual design is complete - Engineering is under way.

- Sites have been chosen: Utah USA, and Mendoza Argentina.

- A large, highly international collaboration has been formed under the leadership of Jim Cronin, U of Chicago.

- Funding is being sought - large fraction already in place.

[Find these transparencies through:

http://aupc1.uchicago.edu/auger.html]