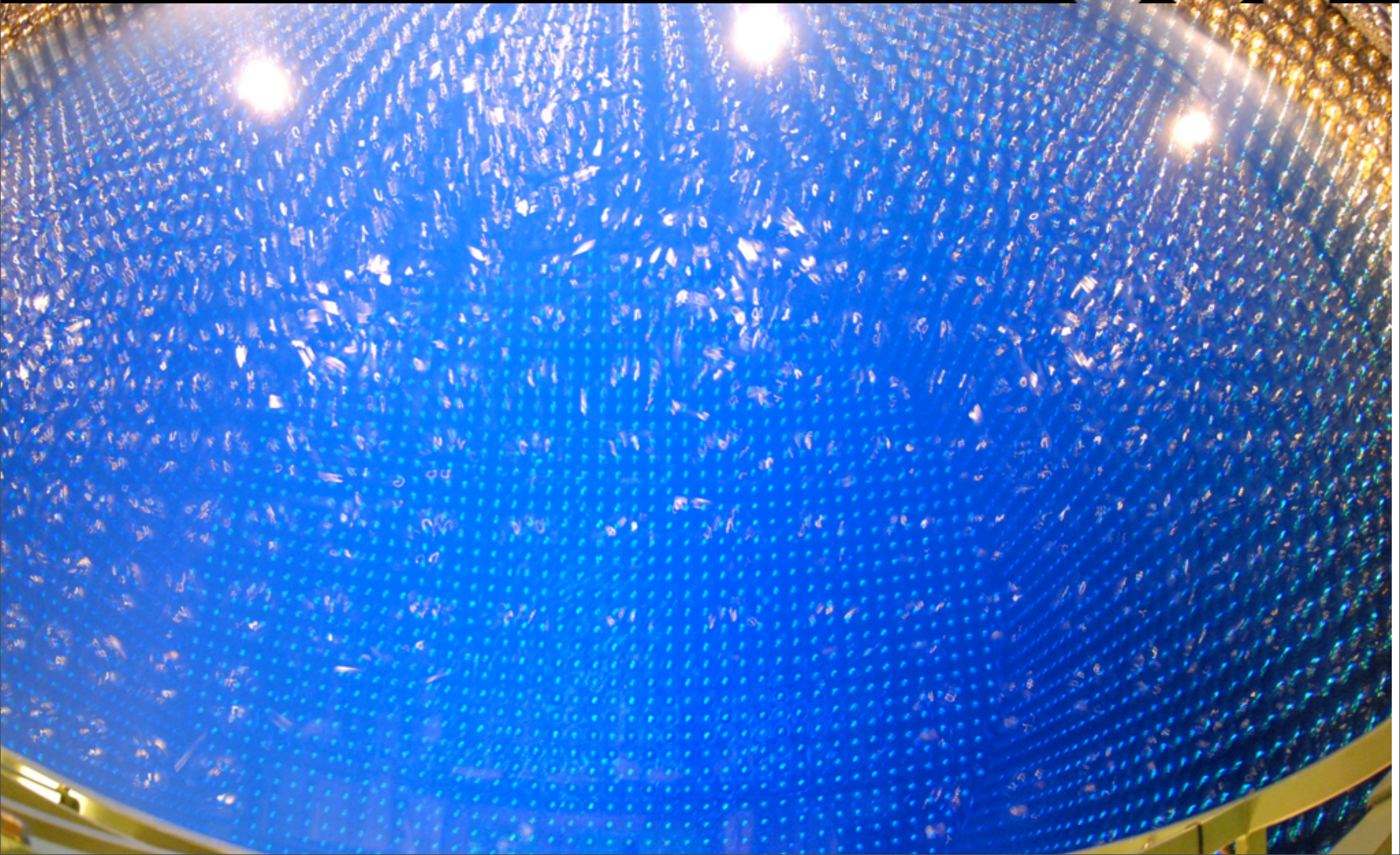
Cherenkov Detectors



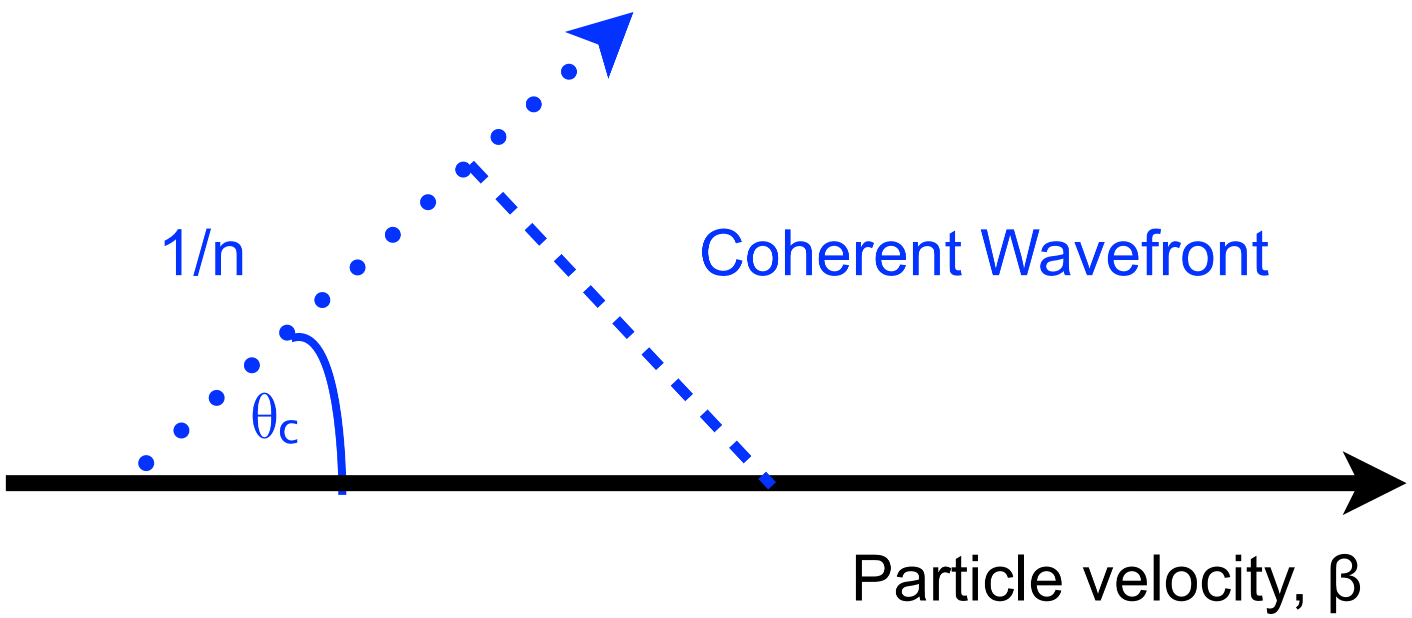
Aside: Particle Identification

- So far we have concentrated on various ionisation tracking detectors that relied on photographs and hand scanning.
  - Identify particles based on curvature and amount of ionisation
- More generally how do we identify particles (i.e. tell the difference between a proton and electron or pion and muon)
  - Charge
  - Type of interactions (hadron vs lepton)
  - Mass
- To determine mass we need to measure (or determine) any two of
  - Energy, momentum, velocity

Cherenkov Radiation

- A charged particle radiates if its velocity is greater than the local phase velocity of light
- The radiation is coherent at a particular angle relative to the direction of the particle

$$\cos\theta_c = \frac{1}{\beta n}$$



$$\frac{d^2N}{dx d\lambda} = \frac{2\pi\alpha z^2}{\lambda^2}\left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right) \qquad N_{\mathrm{p.e.}} = L\frac{\alpha^2 z^2}{r_e\, m_e c^2}\int \epsilon(E)\, \sin^2\theta_c(E) dE\ ,$$

- Discovered in 1934 by Cherenkov and Vavilov, described in 1937 by Frank and Tamm

Cherenkov Counter

- Cherenkov counters were used for
  - "The efficient detection and fast counting of single charged particles at energies in excess of the Cherenkov threshold (Cherenkov counters have an extremely rapid rate of response and at the same time suffer no paralysis effects)."

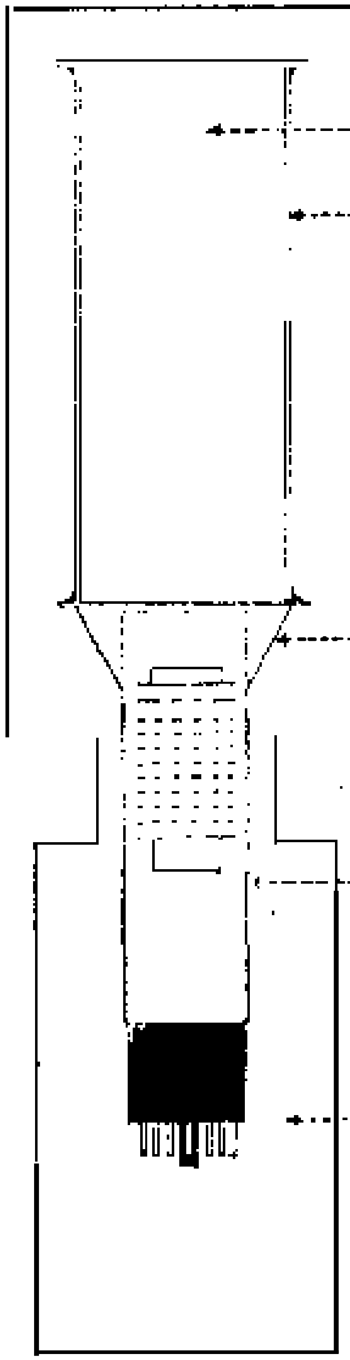
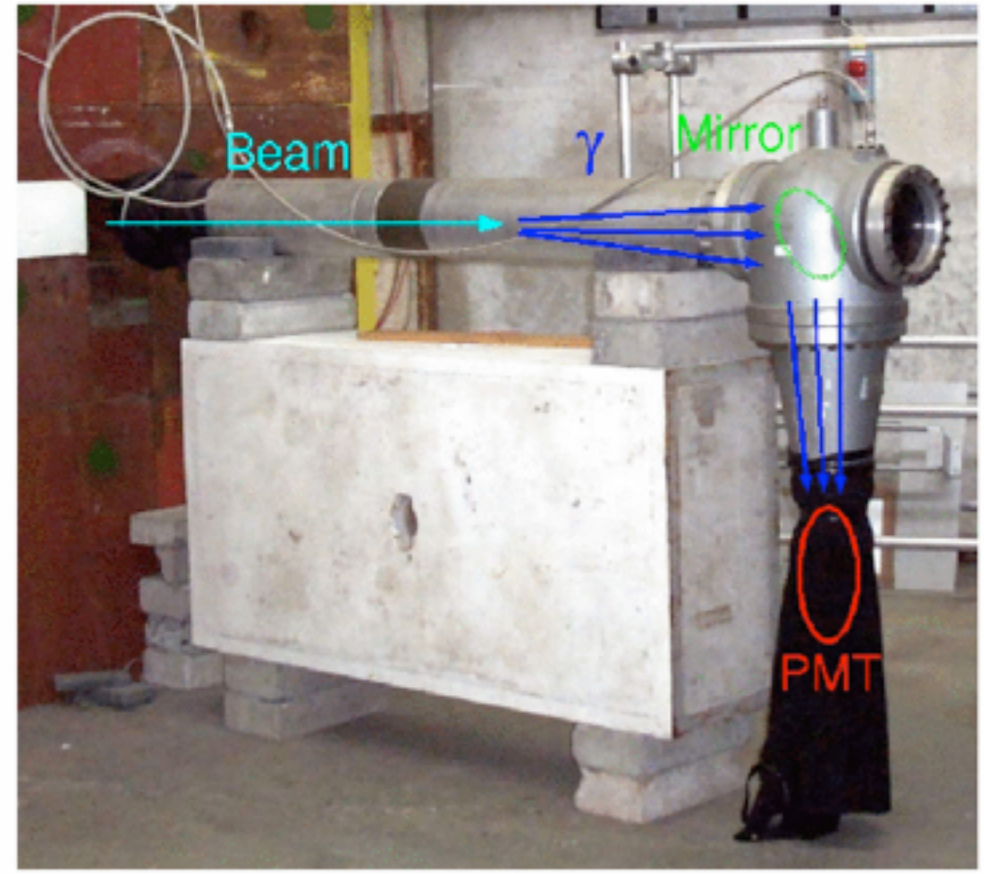
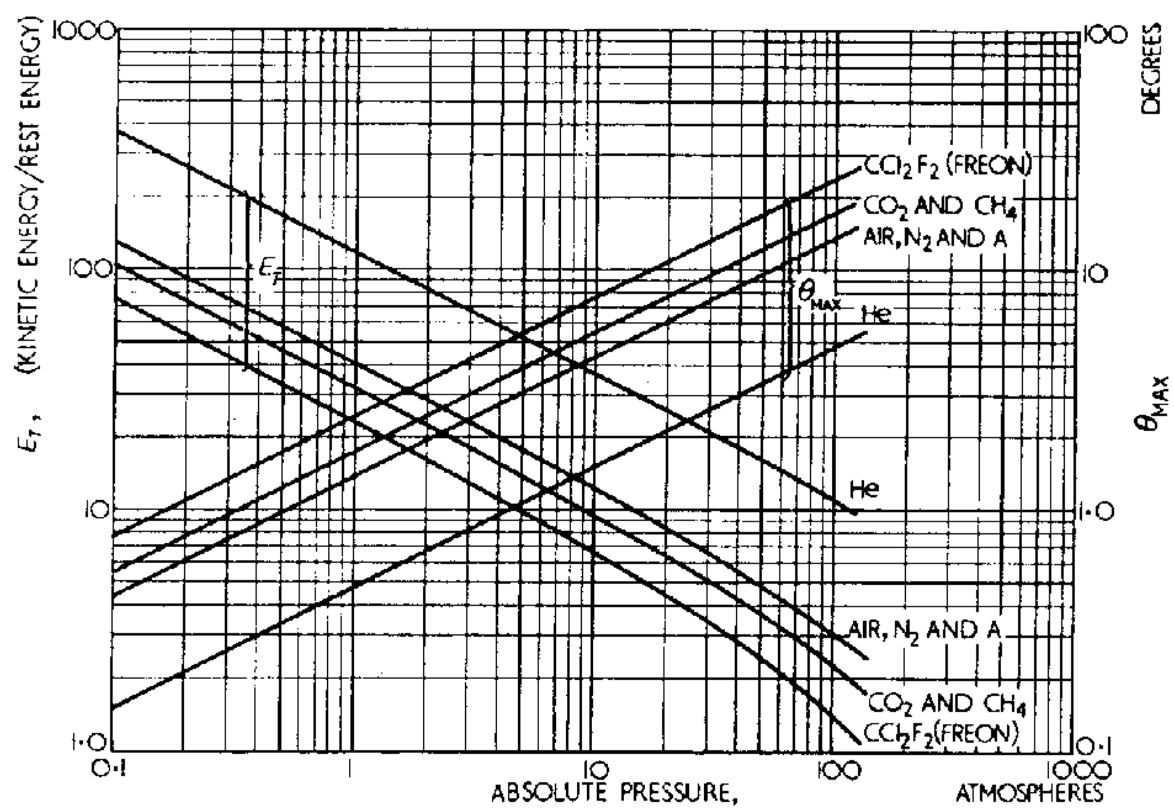


FIG. 3. Jelley's nonfocusing water Čerenkov counter. The first really successful Čerenkov counter. The MgO cone allows light to strike the photocathode from the back side. The black paint on the outside of the tube must be removed for this purpose.

Threshold Cherenkov

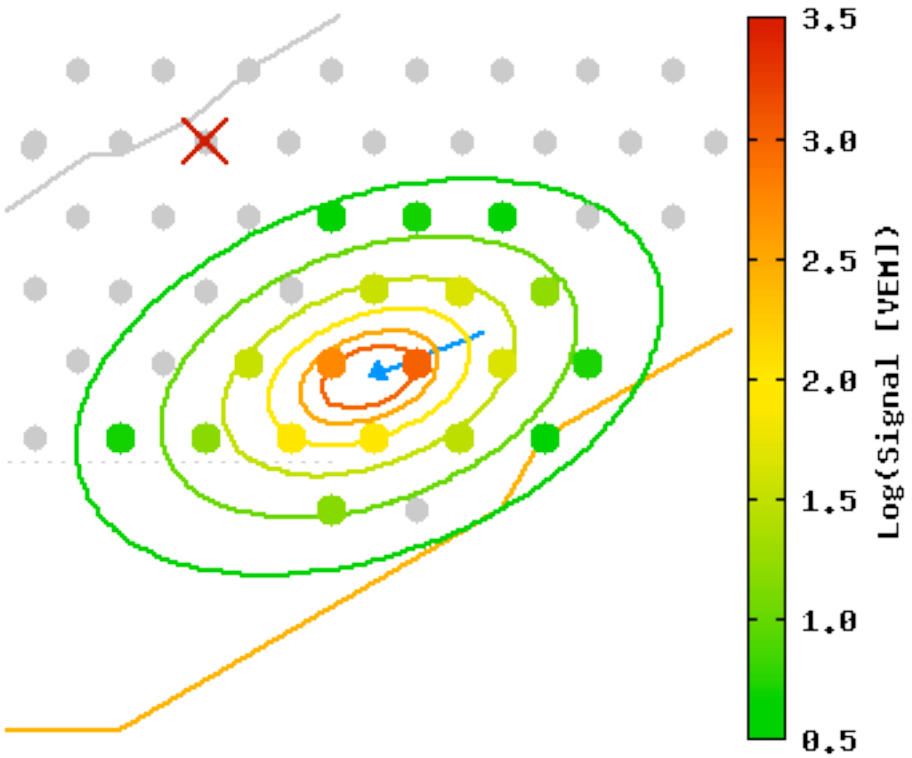
- Cherenkov light is only produced by particles above a velocity threshold
- Can use Cherenkov detectors to identify different particles with same momentum
- CO^2 is commonly used in threshold Cherenkov detectors, changing pressure changes the threshold velocity

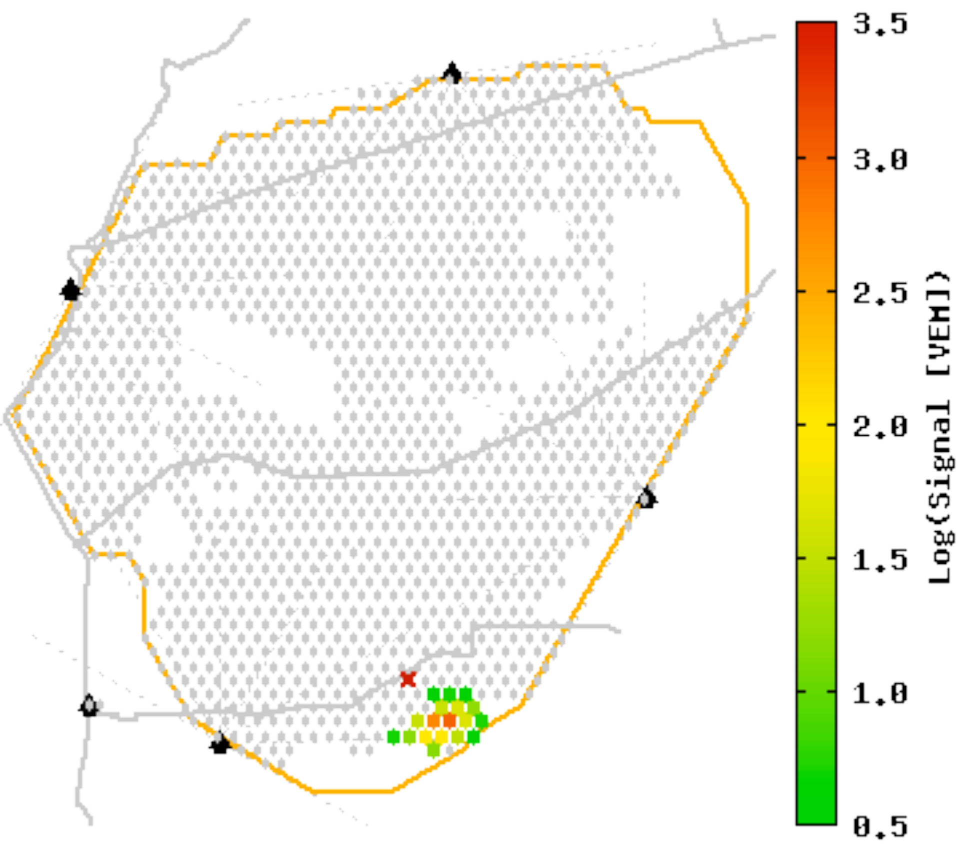




The Auger Observatory

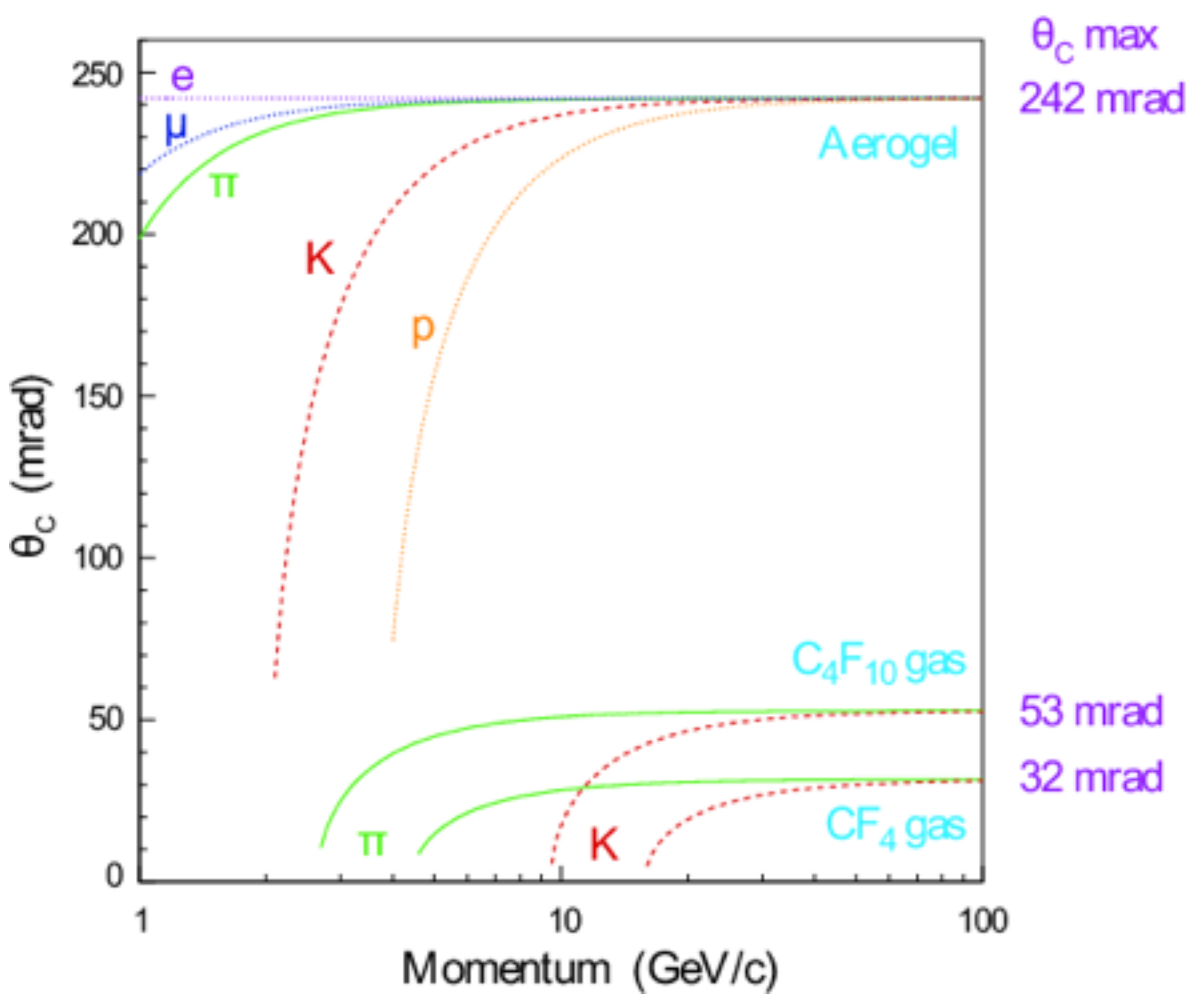
- Water Cherenkov counters are still at the forefront of the investigation of ultra-high energy cosmic rays with the Auger experiment

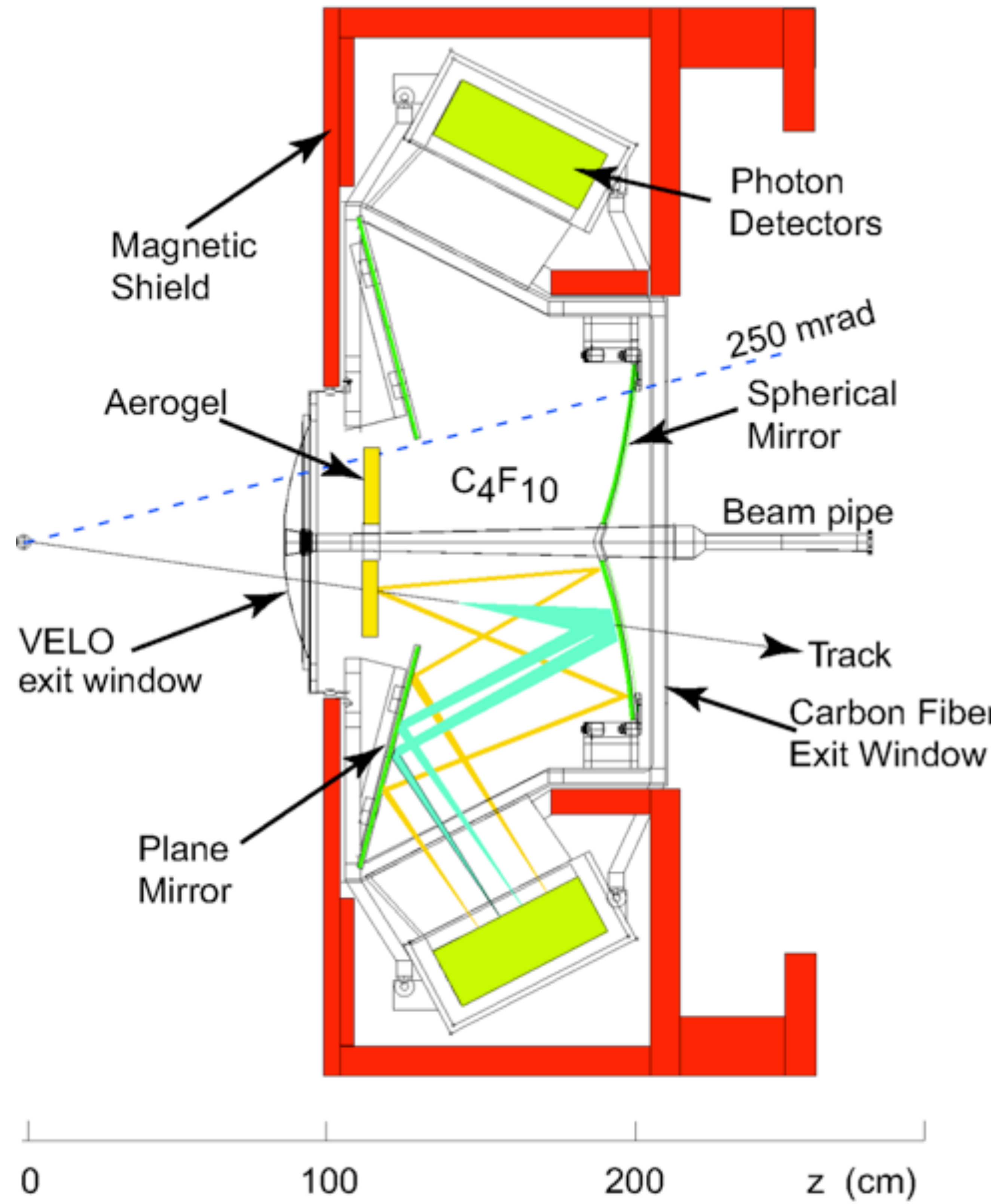




Ring-Imaging Cherenkov

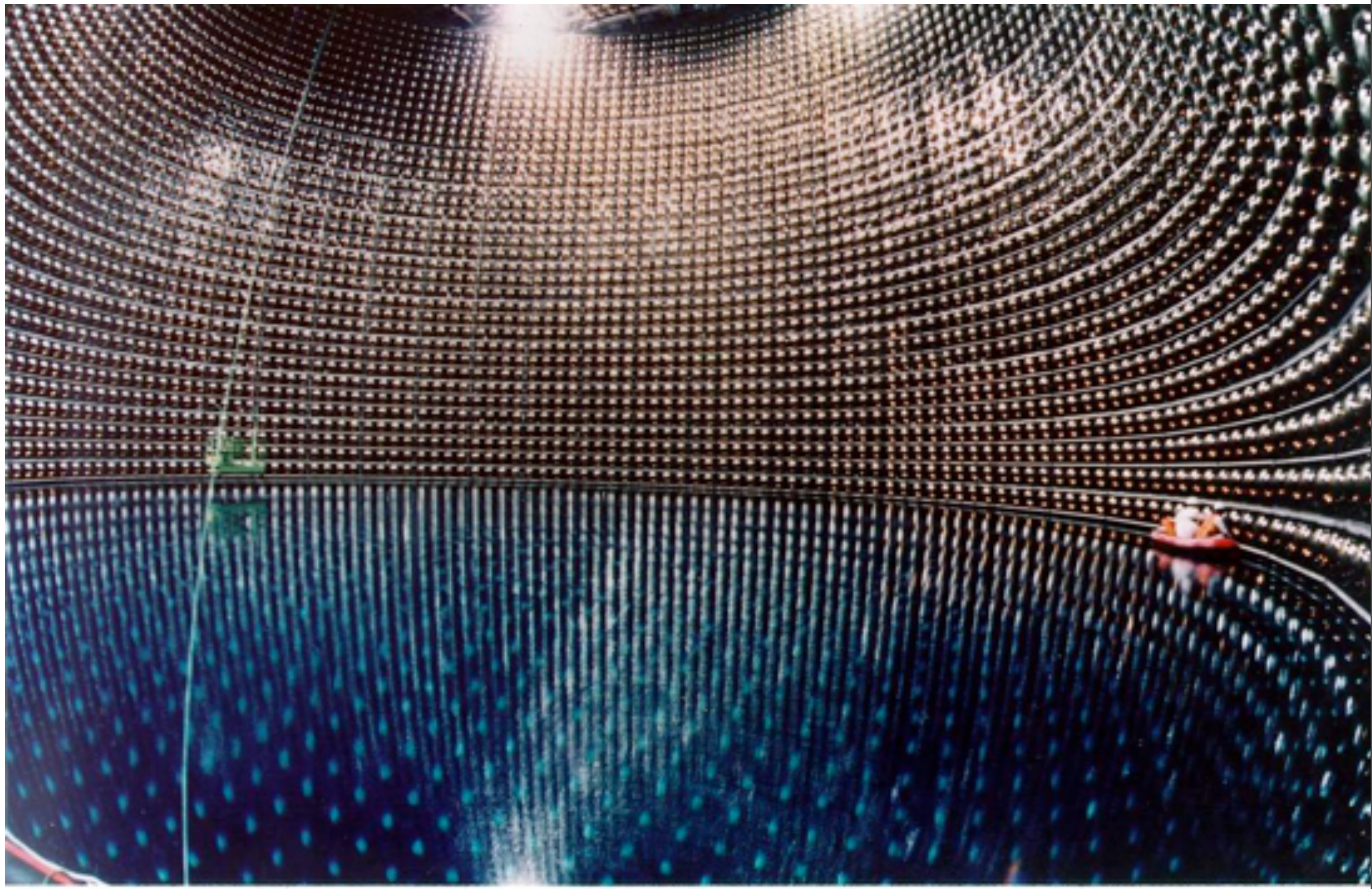
- Used in modern experiments (such as LHCb) to identify particles by imaging the Cherenkov ring

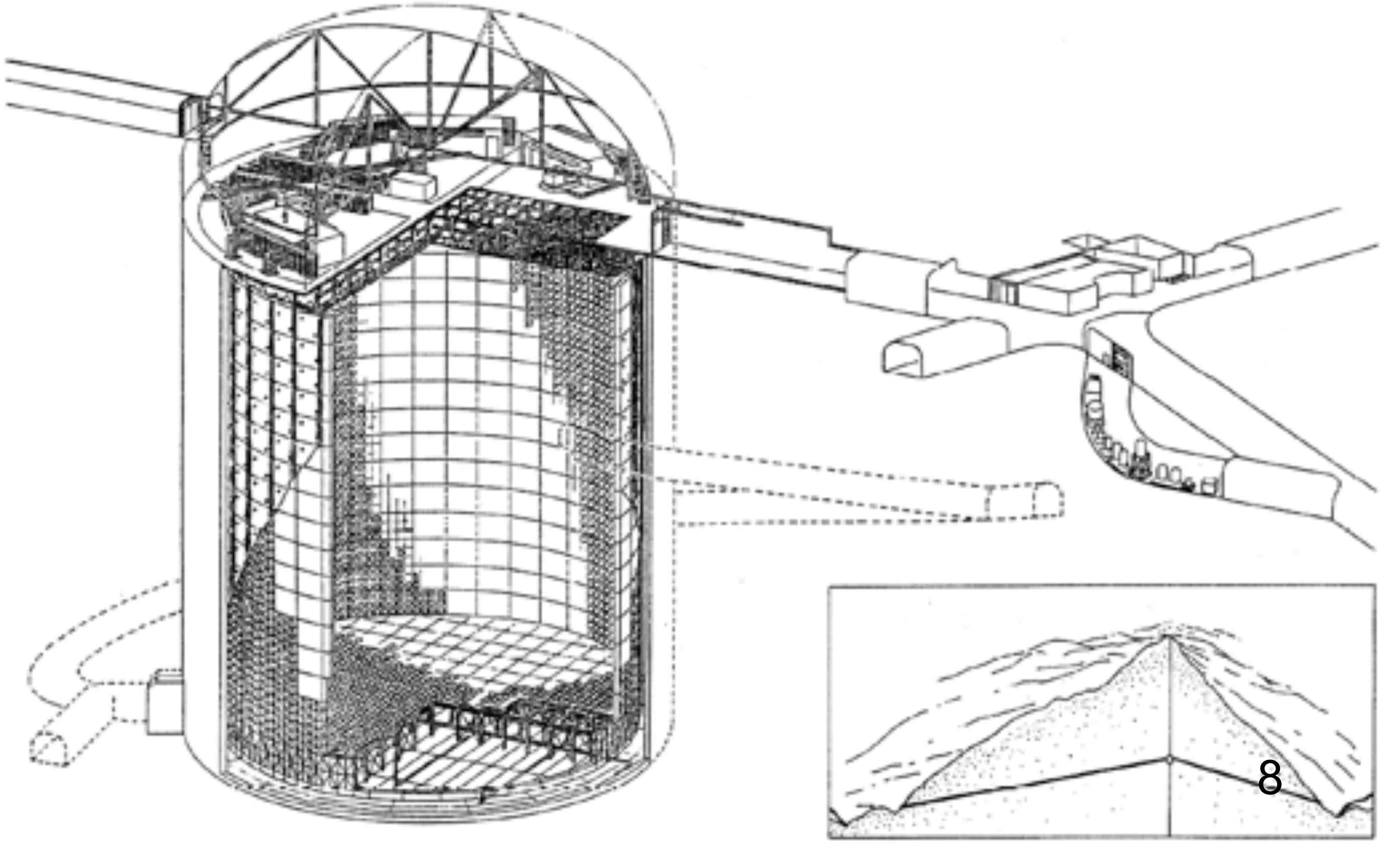




Water Cherenkov

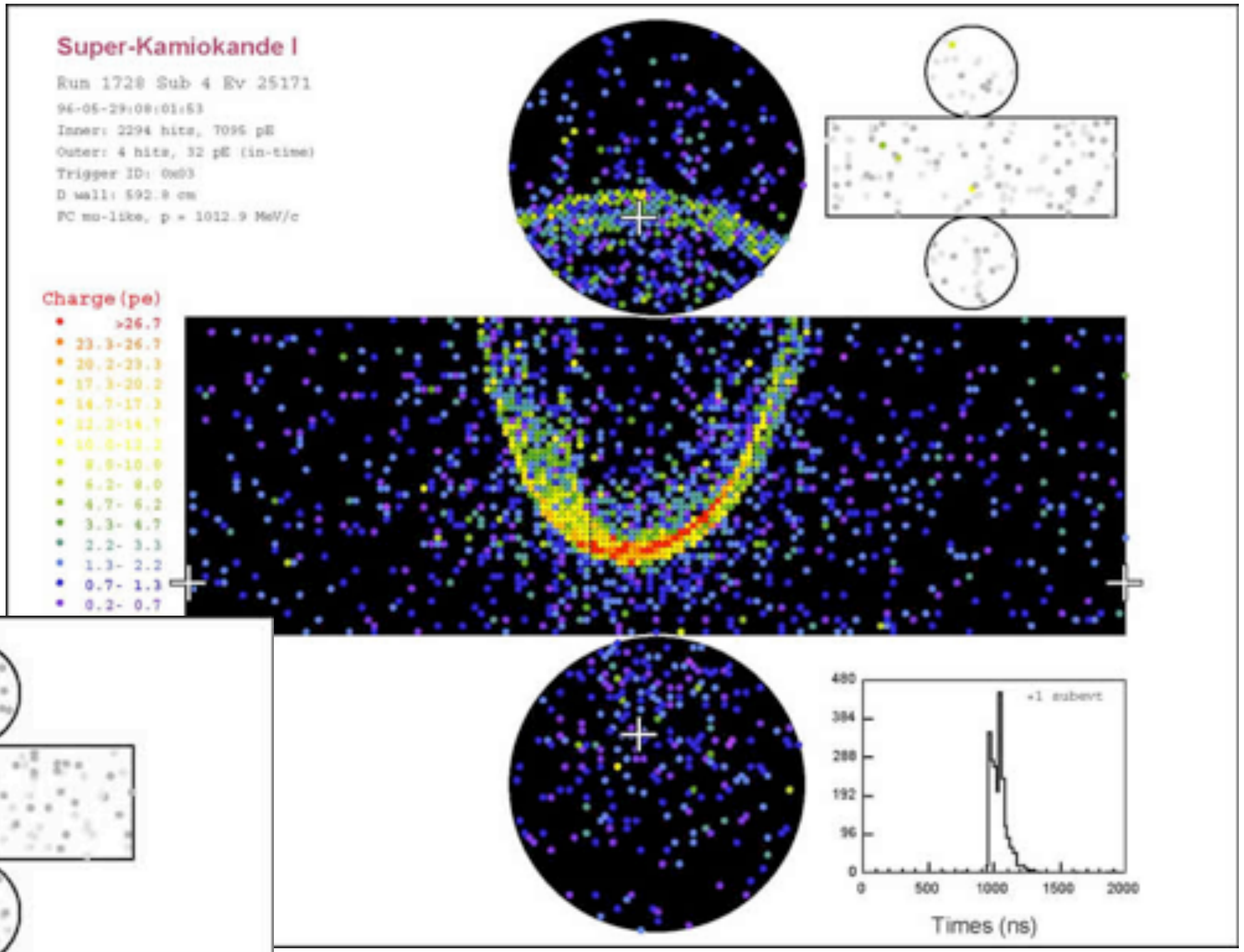
- Super Kamiokande is an example of a water cherenkov neutrino detector
- Responsible for the discovery of the only physics beyond the standard model... neutrino mass and oscillations

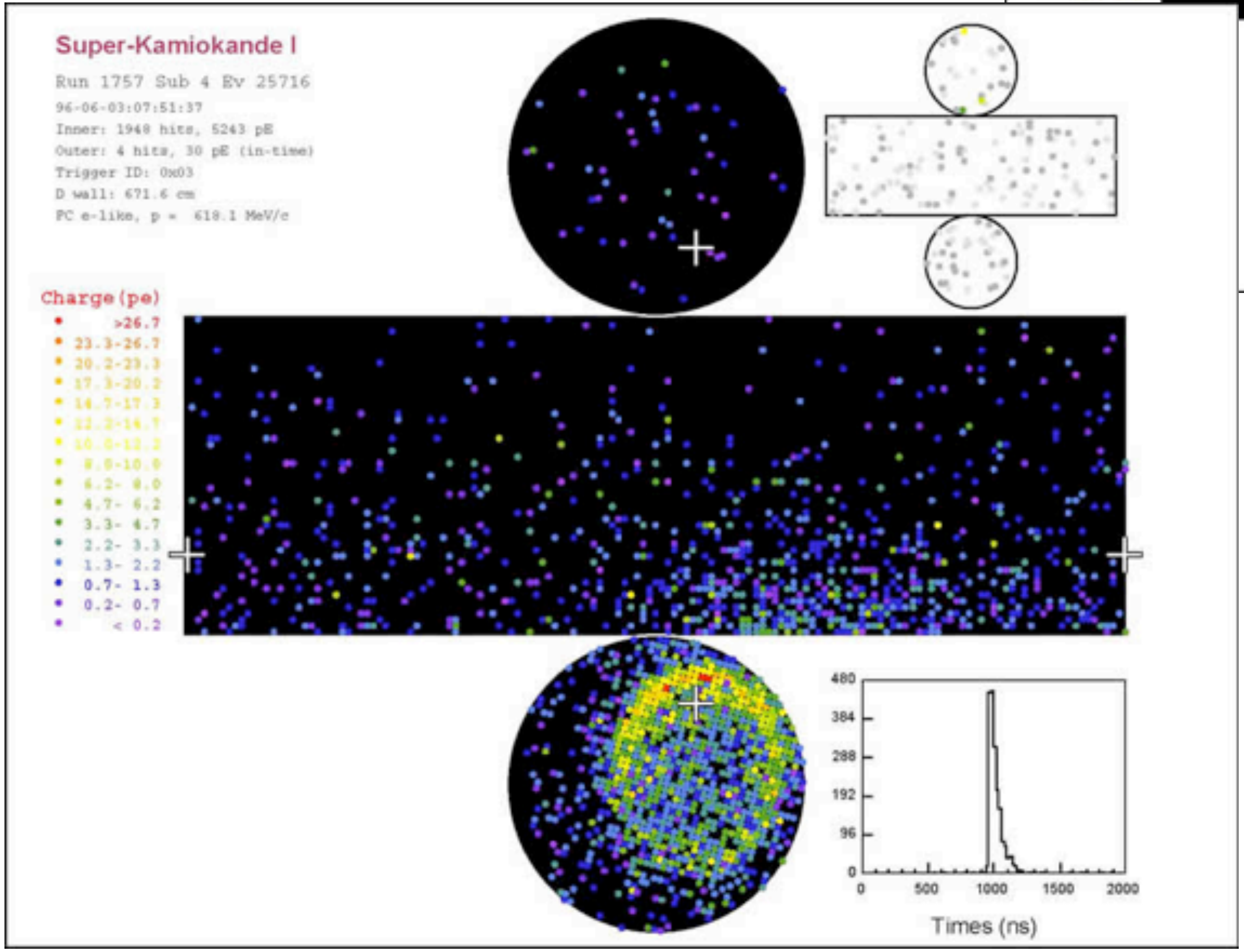




Super Kamiokande

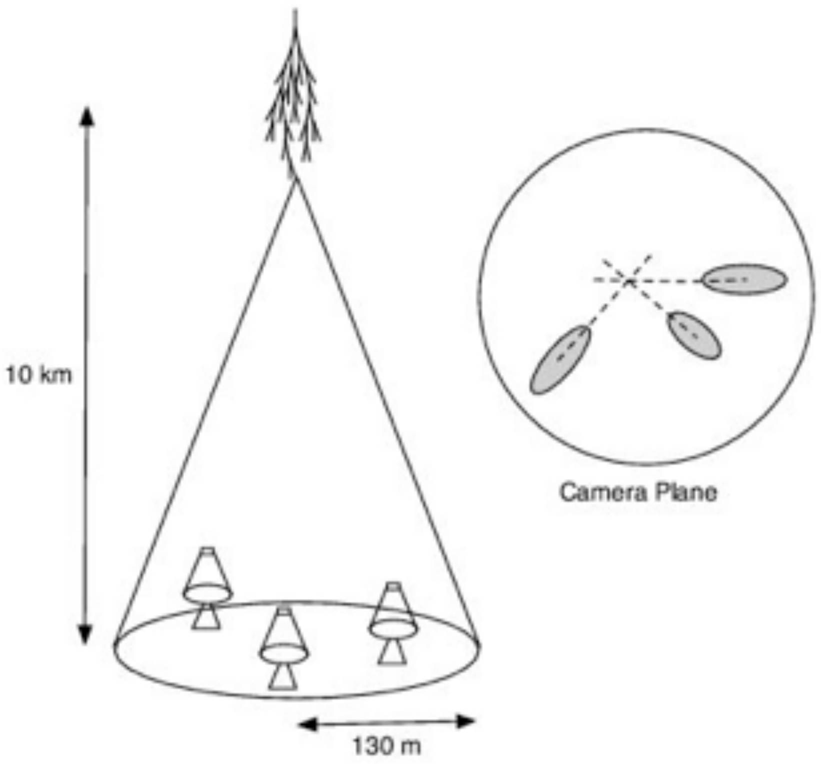
- Can separate electron and muon events by looking for the 'fuzzy' electron ring





Imaging Atmospheric Cherenkov

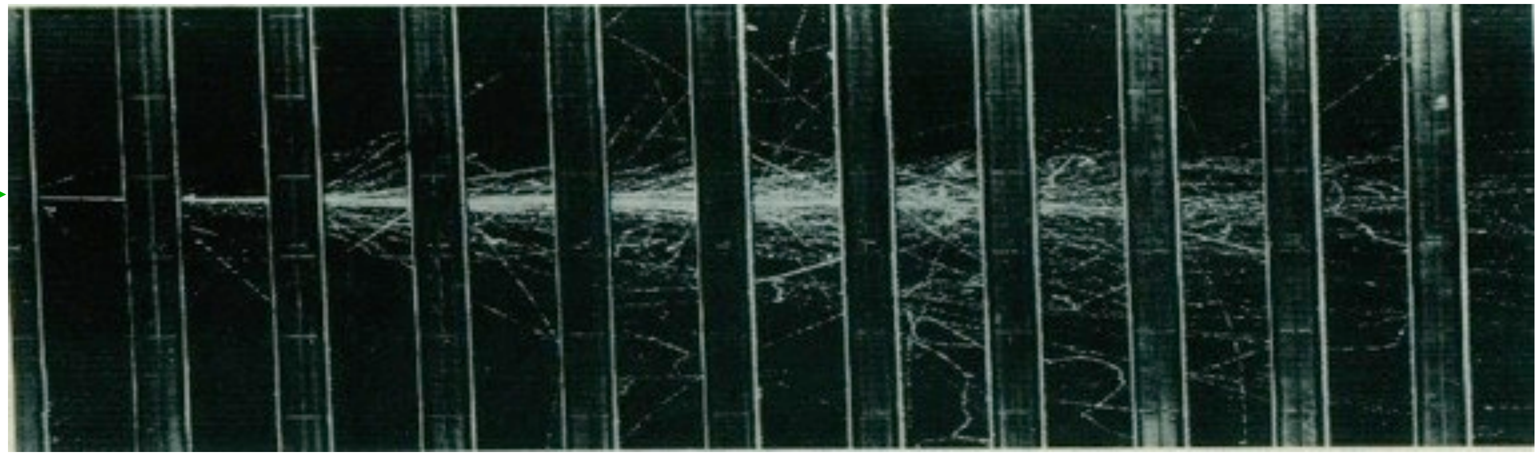
- Imaging atmospheric Cherenkov telescopes, such as Veritas, HESS, Magic, CTA image gamma ray induced showers in the atmosphere



Radio Cherenkov -- The Askaryan Effect

- In 1962 Gurgen Askaryan hypothesised coherent radio transmission from EM cascades in a dielectric:

$e^{\pm}$ or γ



Typical Dimensions:
$L \approx 10$ m
$R_{Moliere} \approx 10$ cm

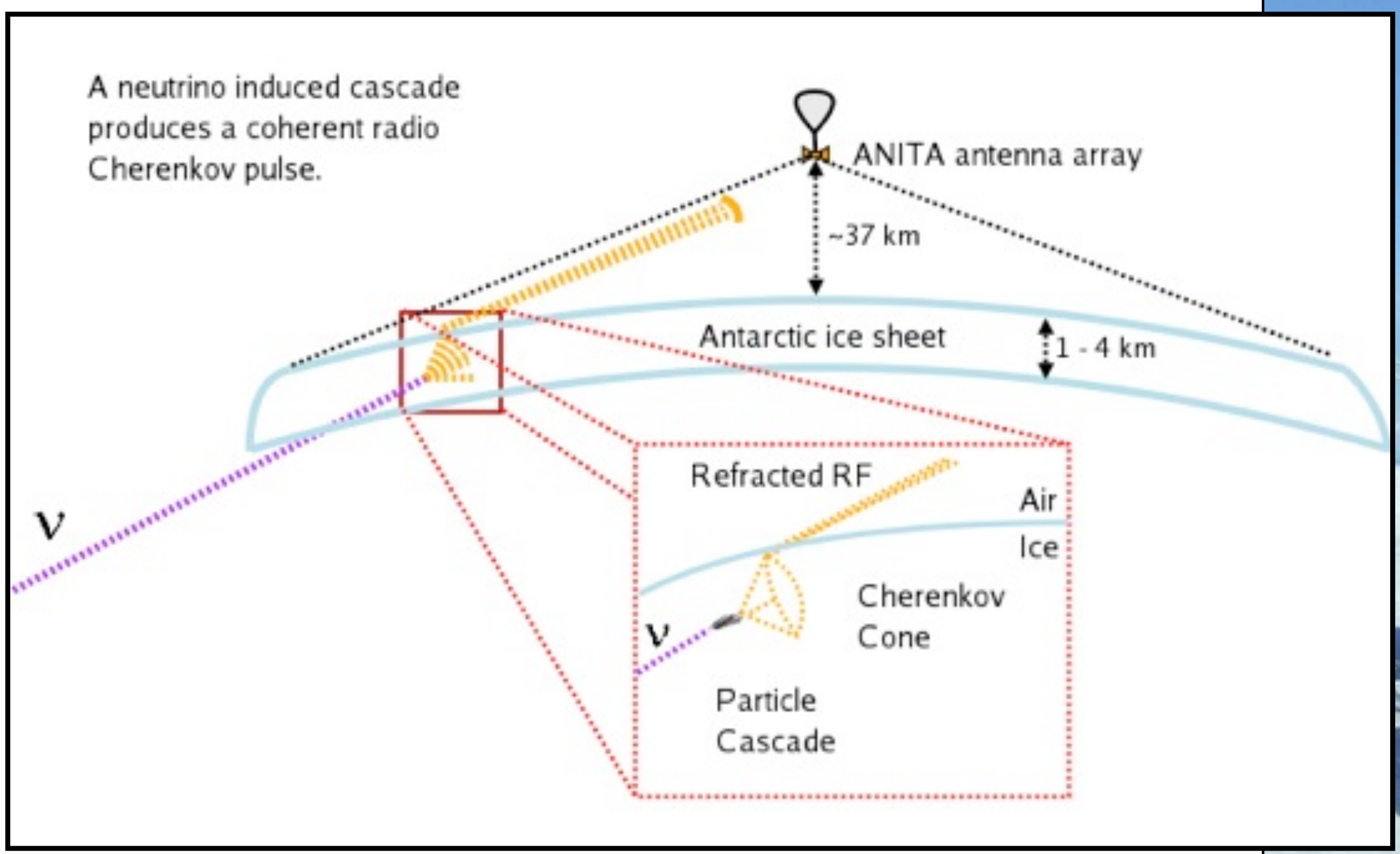
– 20% Negative charge excess:
  - Compton Scattering: □ $+ e^-_{(rest)} \Rightarrow \gamma + e^-$
  - Positron Annihilation: $e^+ + e^-_{(rest)} \Rightarrow \gamma$

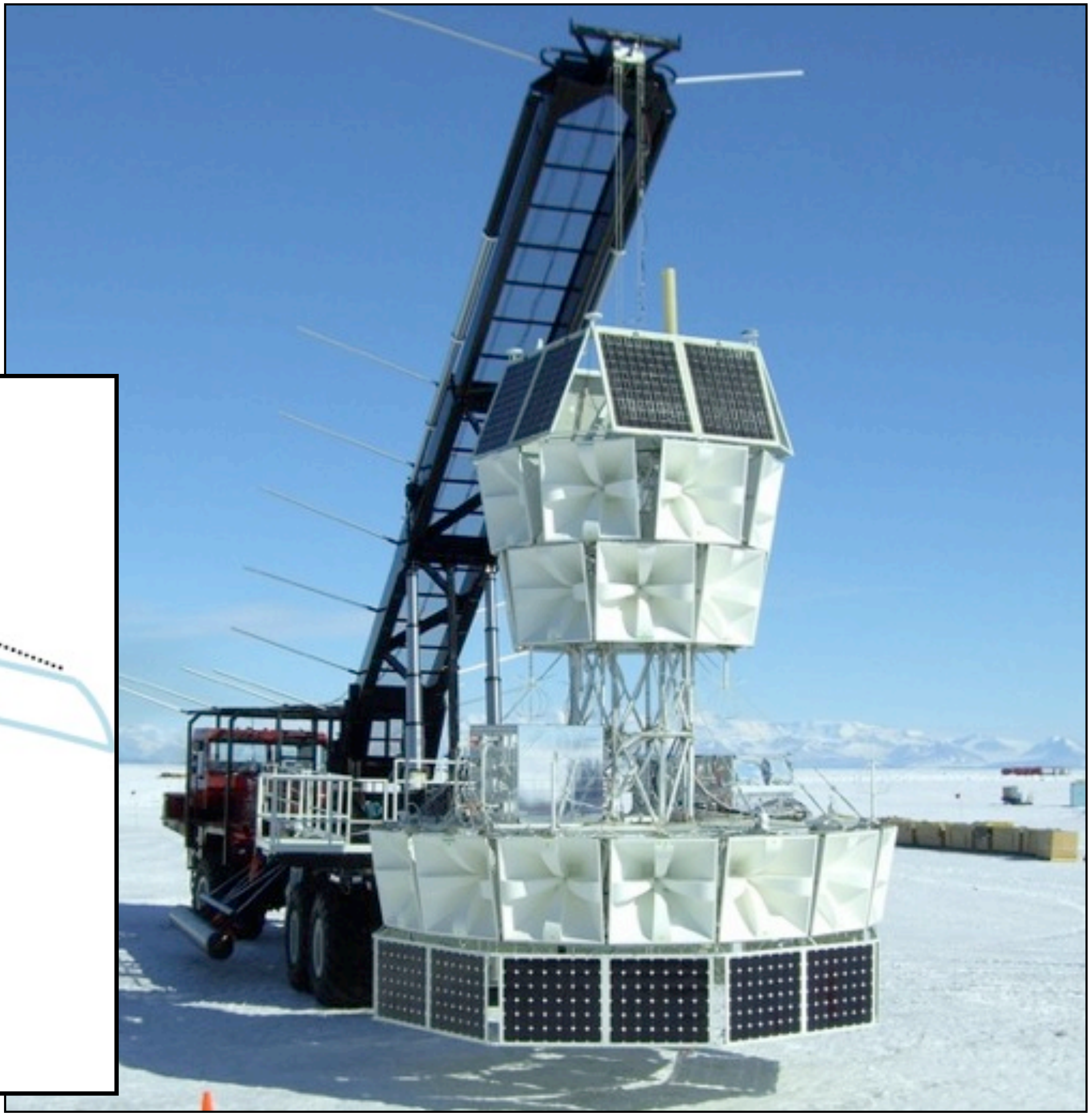
– Excess travelling with, $v > c/n$
  - Cherenkov Radiation: $dP \propto \nu \, d\nu$

– For $\lambda > R$ emission is coherent, so $P \propto E^2_{shower}$

ANITA

- The ANtarctic Impulsive Transient Antenna
  - A balloon borne experiment
    - 32 dual polarization antennas
    - Altitude of 37km (120,000 ft)
    - Horizon at 700km
    - Over 1 million km^3 of ice visible





Only top of Cherenkov cone escapes ==> vertically polarised E-field at payload

References

- Cherenkov, P. A. 1934. Dokl. Akad. Nauk SSSR 2:451
- Vavilov, S. I . 1934. Dokl. Akad. Nauk SSSR 2:457
- Jelley, J. V. 1955 Br. J. Appl. Phys. 6 227
- Google:
  - Auger Observatory
  - Super Kamiokande
  - HESS, Magic, Veritas, Milagro
  - LHCb RICH
  - ANITA