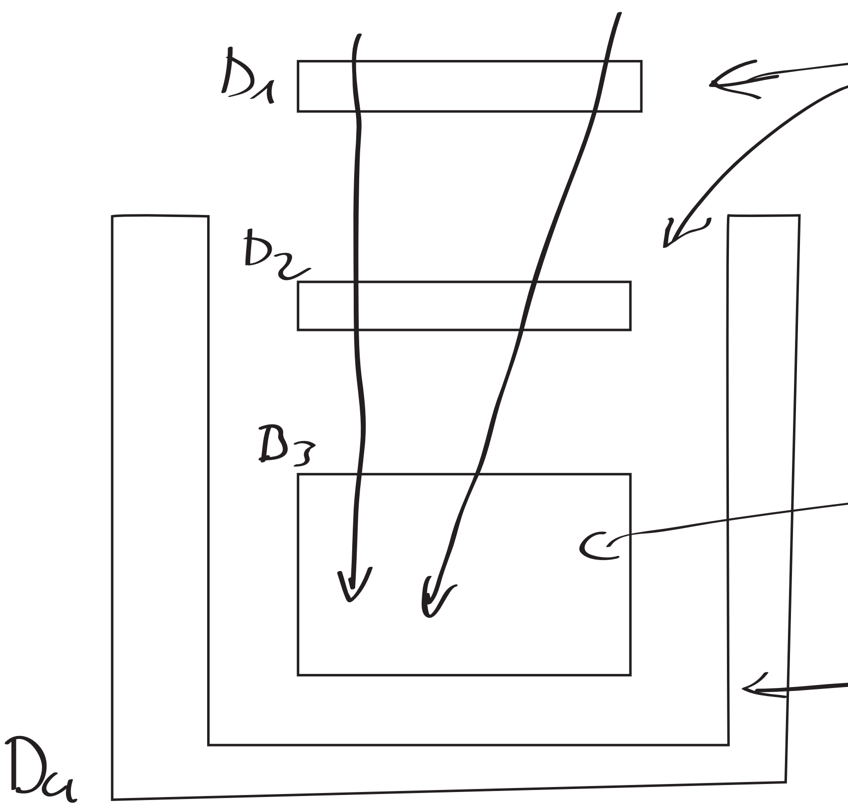
Direct measurement of cosmic rays

put detectors for particles above the atmosphere on satellites or balloons to directly measure the properties of cosmic rays

problem: mixture of different particles with different energies impinging on the detector from different directions

=> a combination of different detectors is required, operated in coincidence

classical set-up



Si detectors
thin, good E-resolution

scintillator
high density

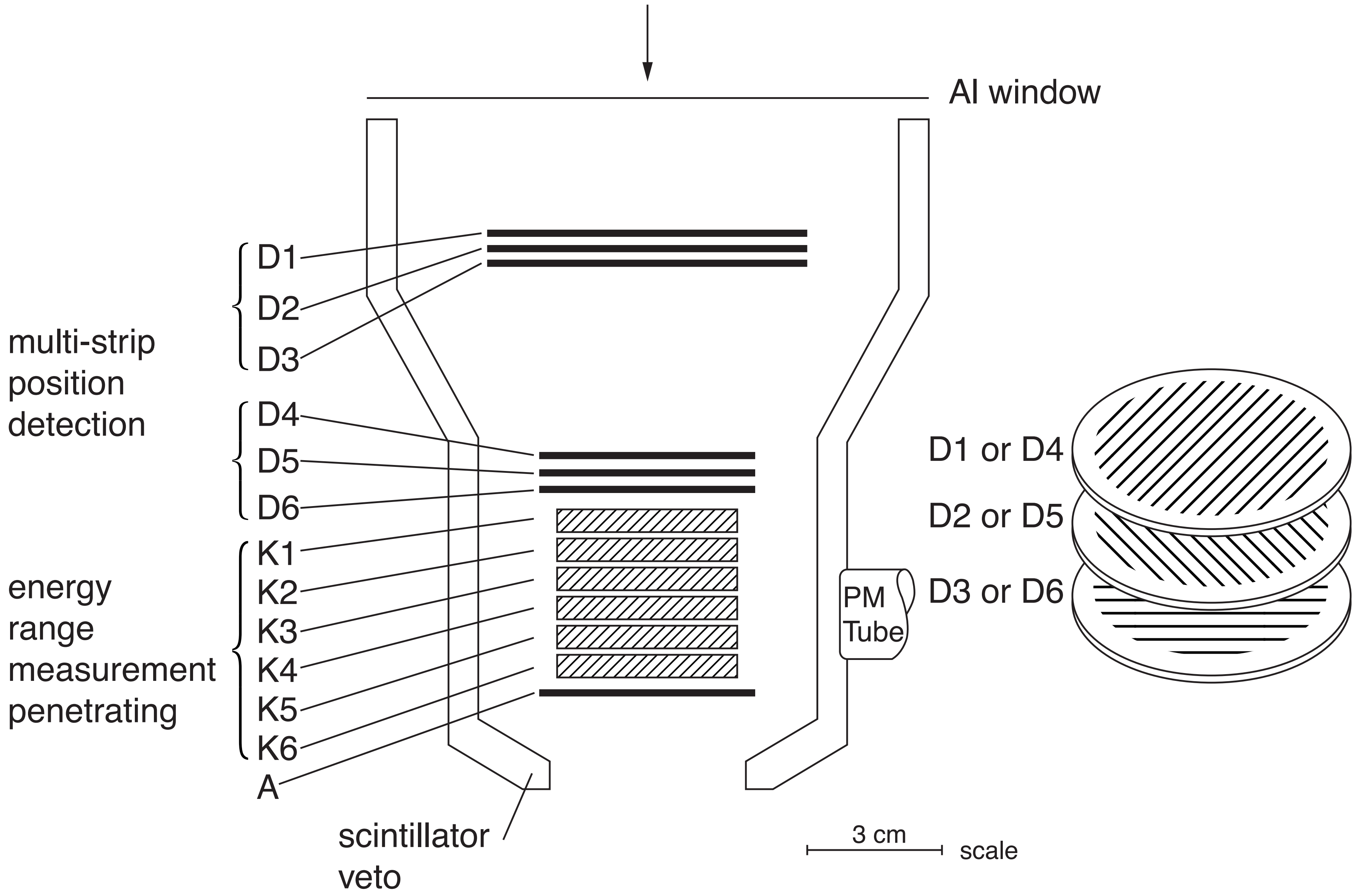
veto
anti-coincidence counter

particle telescope

signal in D_1 & D_2 & D_3

but not in D_4

Ulysses High Energy Telescope (HET)



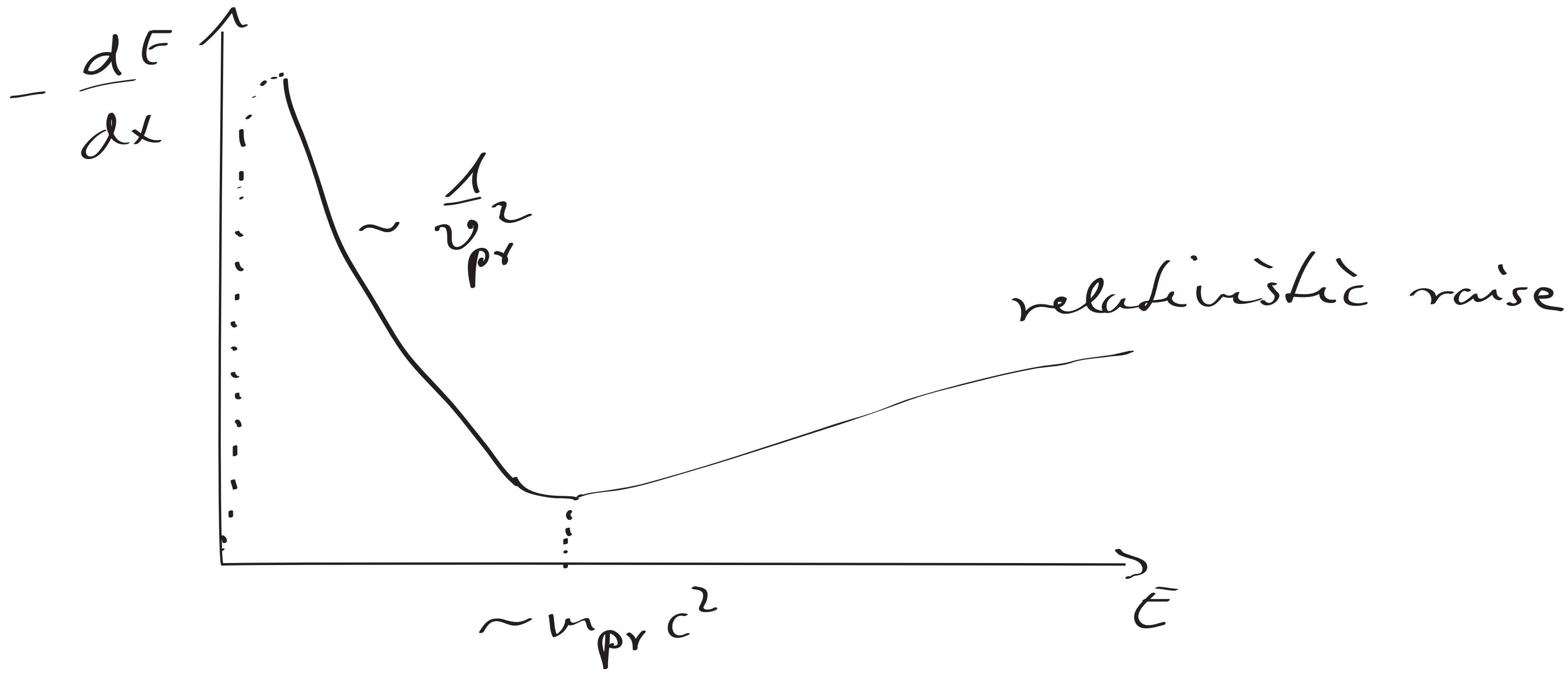
in which energy range can we use such a detector?

- the E has to be large enough to cross $D_1 + D_2$ and impinge on D_3
- but low enough to be absorbed in D_3

particles loose energy through ionization described by Bethe Bloch formula

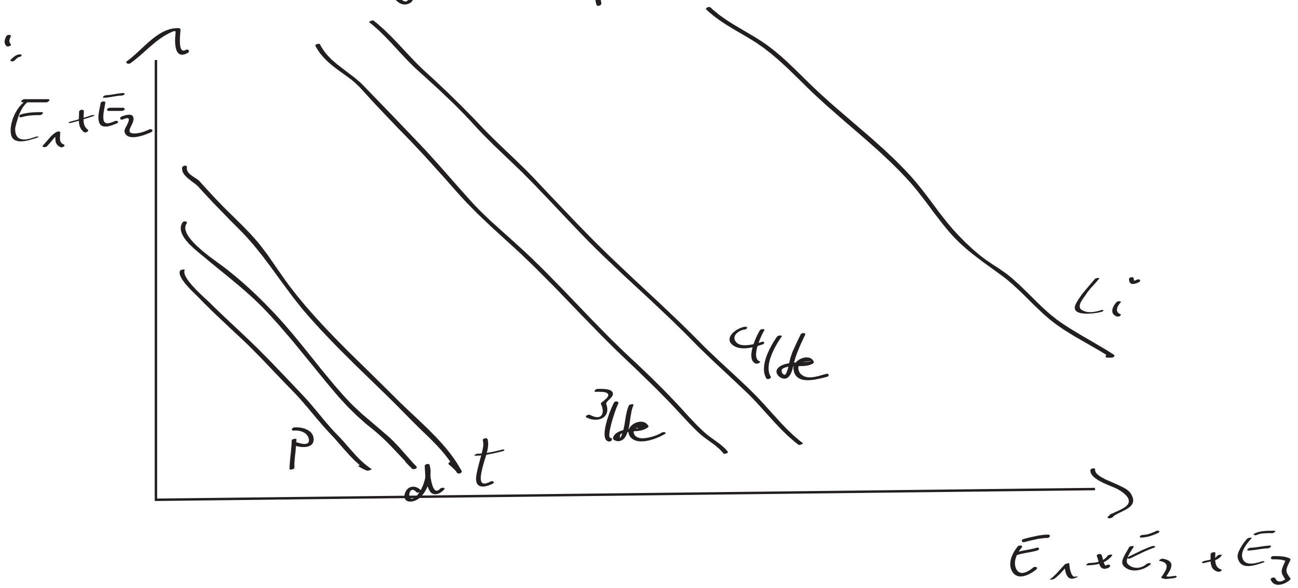
$$-\frac{dE}{dx} = \frac{z_{pr}^2 \cdot 4\pi \cdot N_A \cdot e^4 \cdot z_{abs}}{v_{pr}^2 \cdot m_e \cdot A_{abs}} \left(\ln \frac{2 m_{pr} \cdot v_{pr}^2}{I(1-\beta_{pr}^2)} - \beta_{pr}^2 \right)$$

$$\propto \frac{z_{pr}^2}{v_{pr}^2} \propto z_{pr}^2 \frac{m_{pr}}{E_{pr}^{kin}}$$

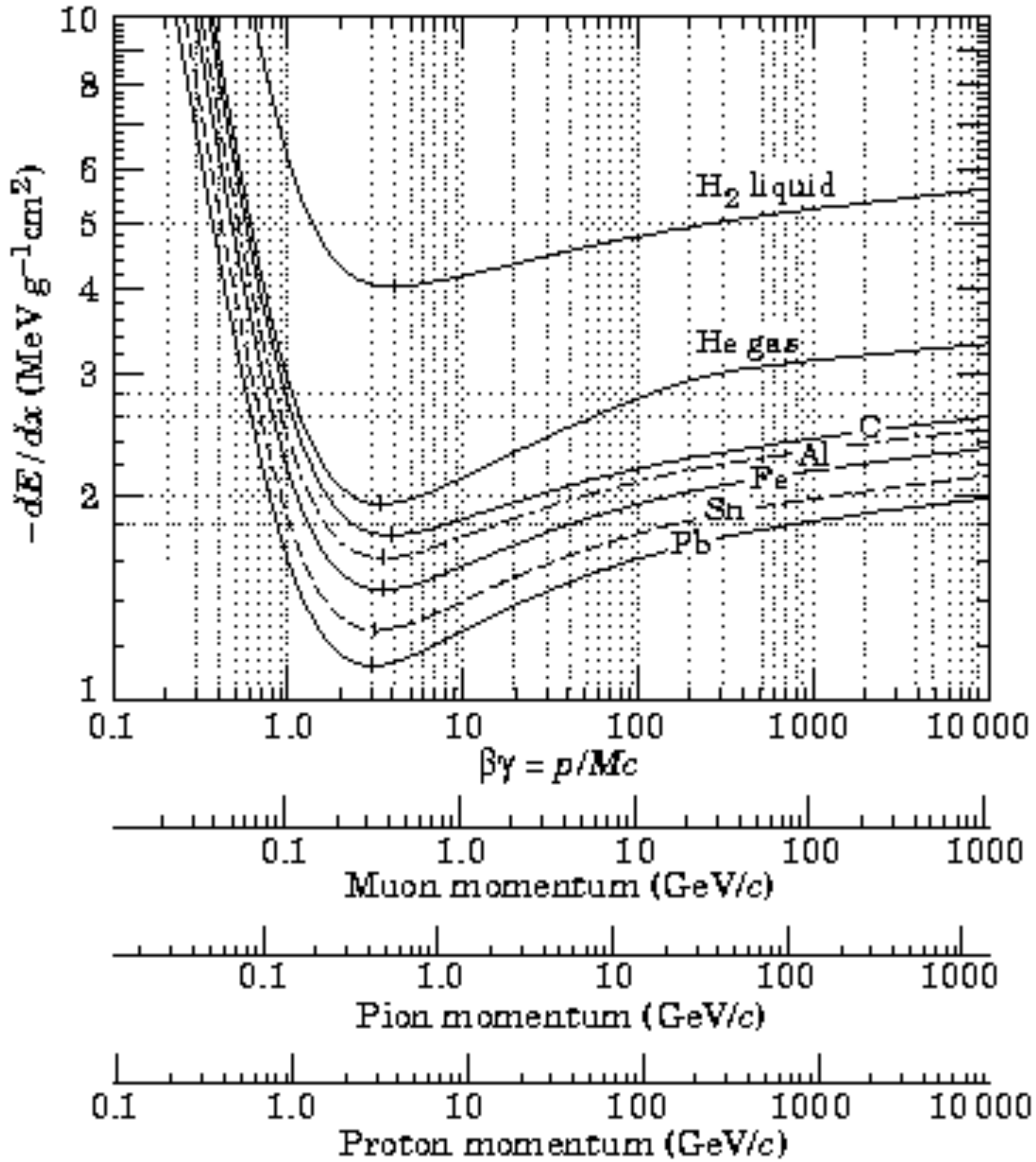


total energy of particle $E_1 + E_2 + E_3$

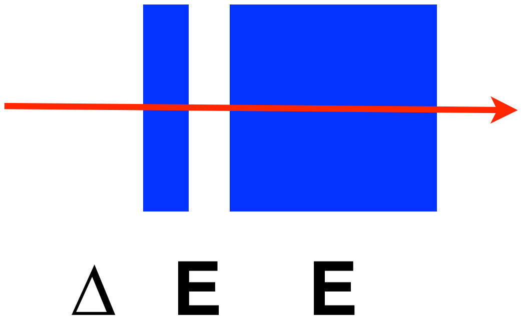
expect:

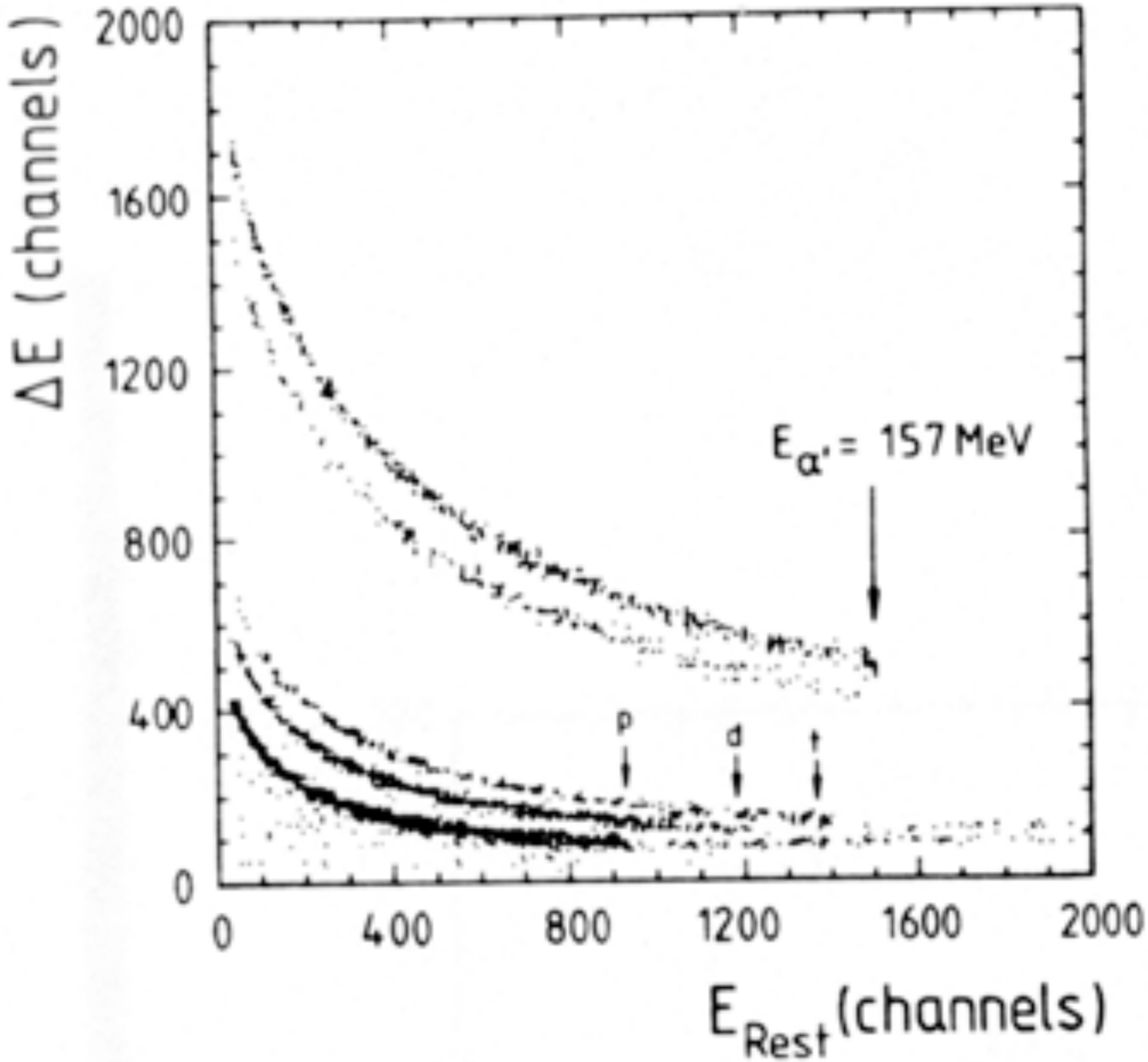


specific energy loss
Bethe Bloch formula

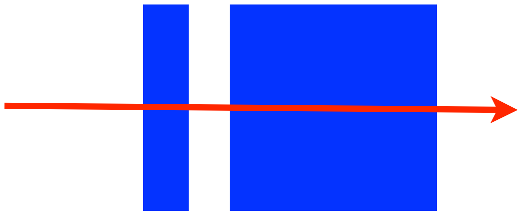


particle identification

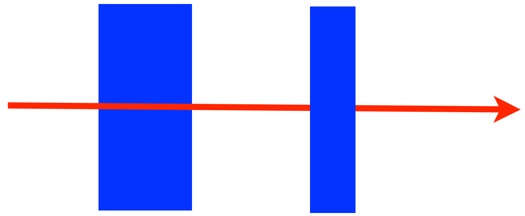




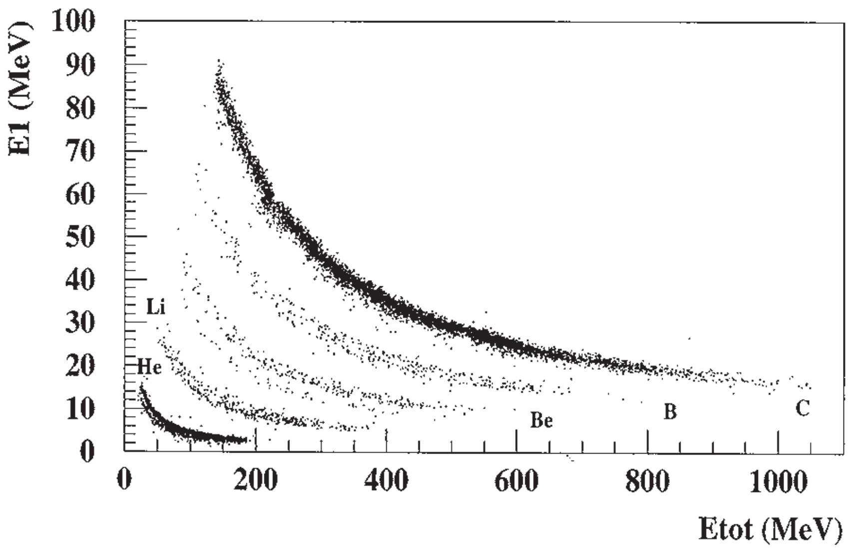
particle identification



Δ E E



Δ E₁ Δ E₂



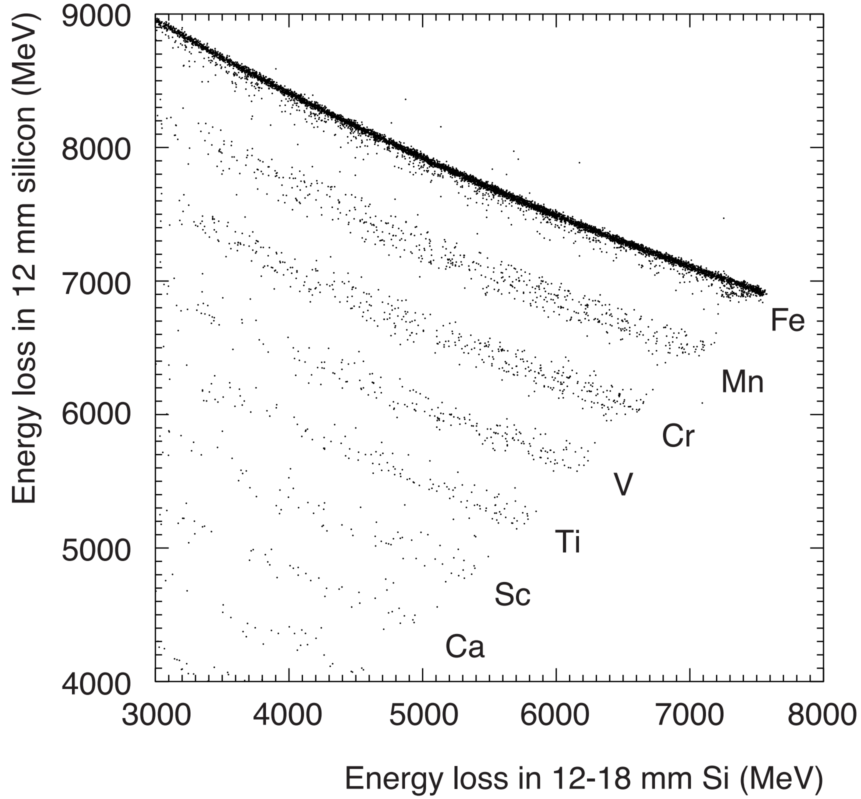
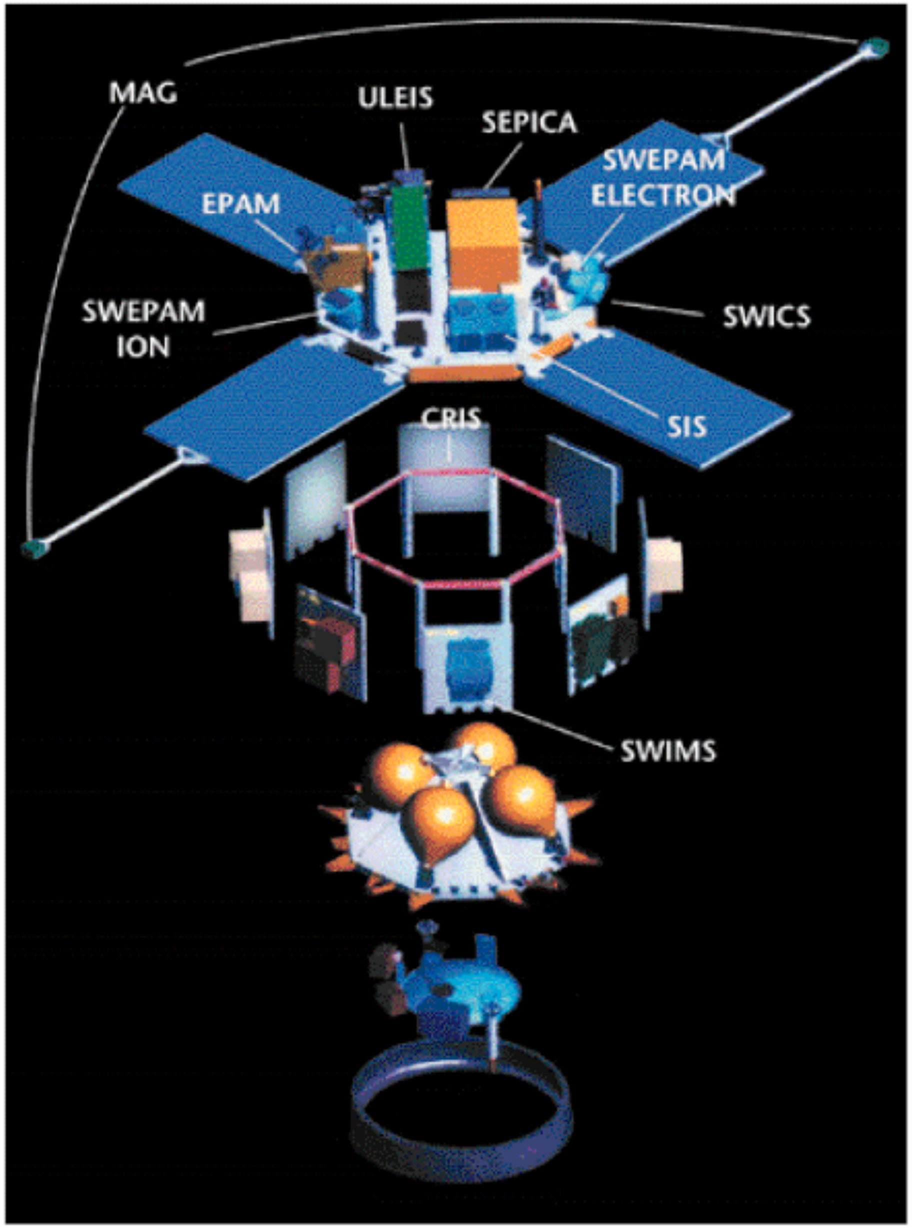


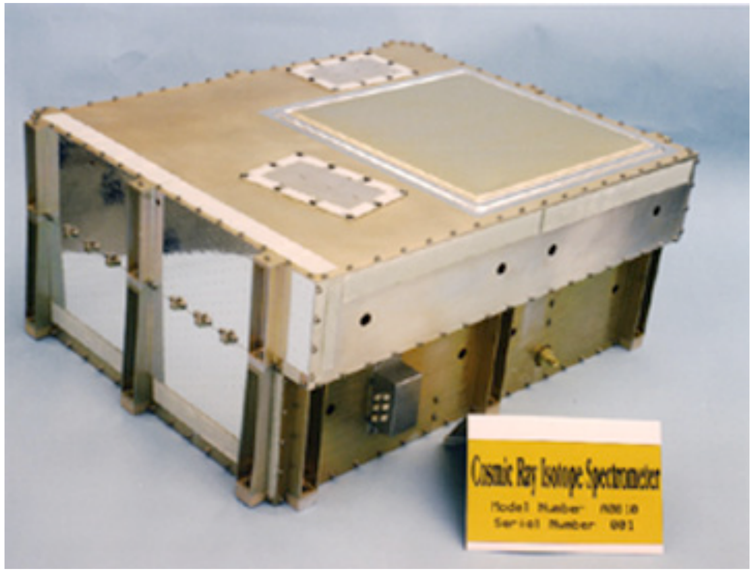
Fig. 3.4. *Left*: Energy loss in the first plane (E1) vs. total energy (E_{tot}) detected by the NINA telescope for particles fragmented from a ^{12}C test beam [8]. *Right*: Scatter plot of ΔE in 12 mm Si vs. ΔE in the following 6 mm Si from calibration of the CRIS instrument in an ^{56}Fe beam [5]

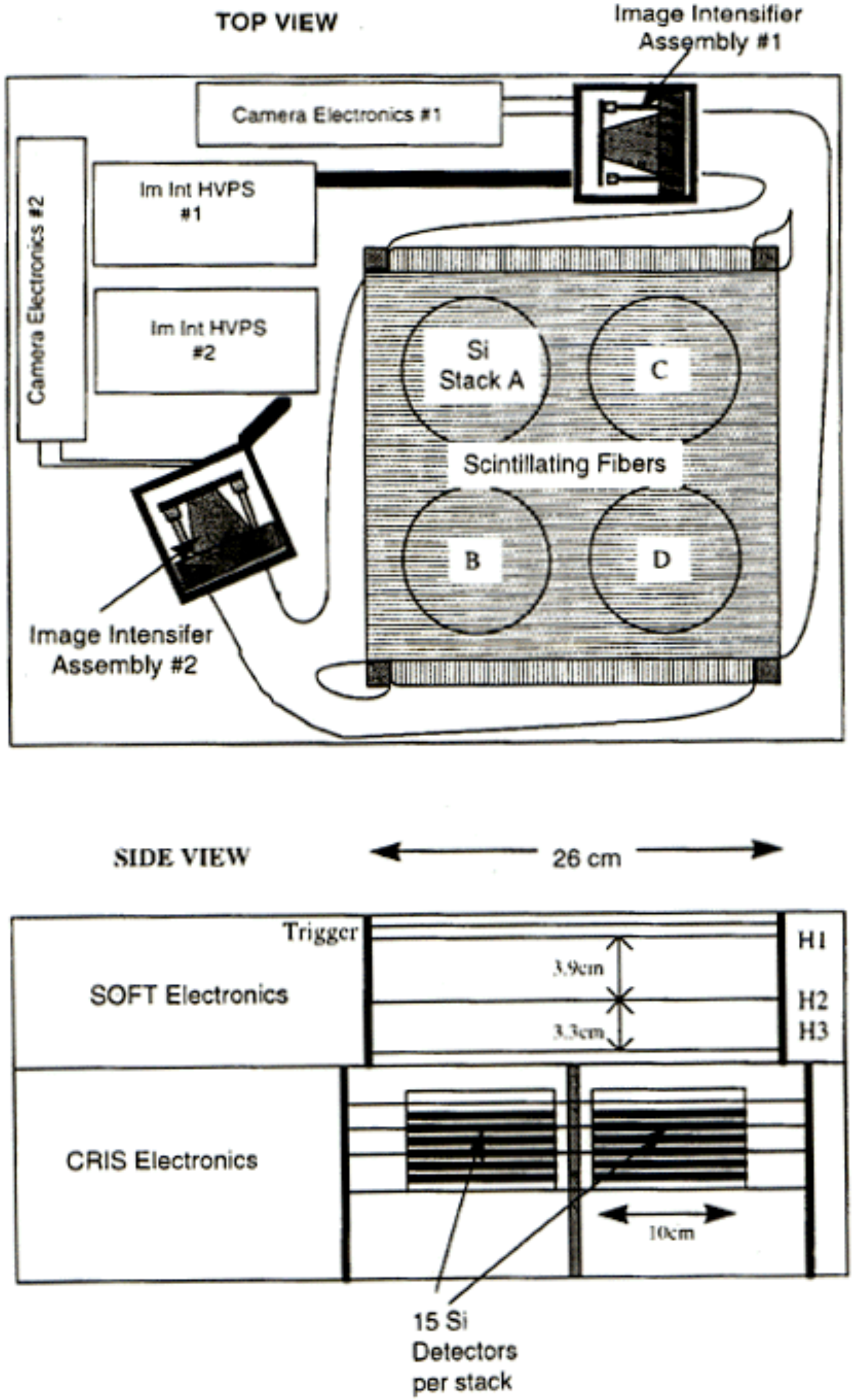
Advanced Composition Explorer (ACE)



NASA / Goddard Space Flight Center; Start: 25.8.97,
9 wissensch. Instrumente (156 kg) ; 90% duty cycle
$1 \leq Z \leq 28$; 1 keV $\leq E \leq 600$ A·MeV

CRIS: The Cosmic Ray Isotope Spectrometer

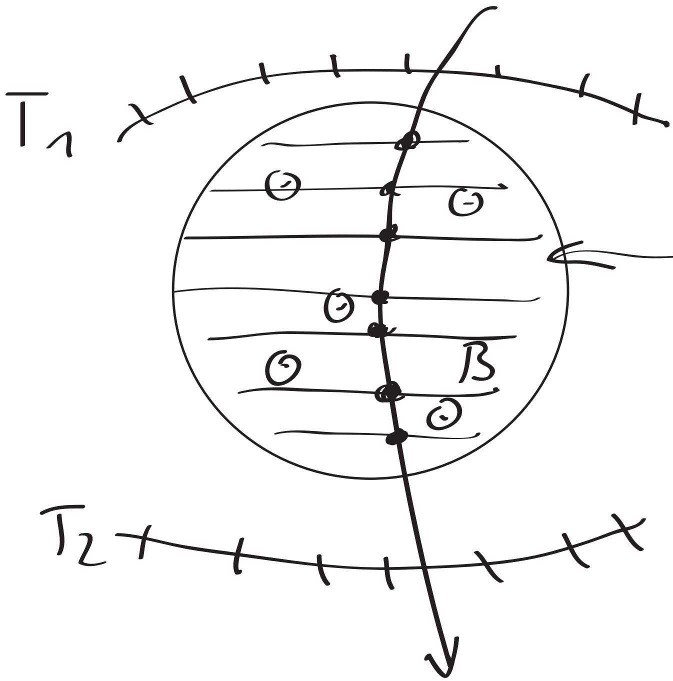




this technique works up to several 100 MeV/nucleon since the particles have to be absorbed

For higher energies up to ~ 1 TeV one can use

<u>magnet spectrometer</u>



segmented counter (scintillator)

e.g. wire chamber
Si strip detector
high spatial resolution

T_1 & T_2 time of flight (TOF) measurements

-> direction

need high time resolution

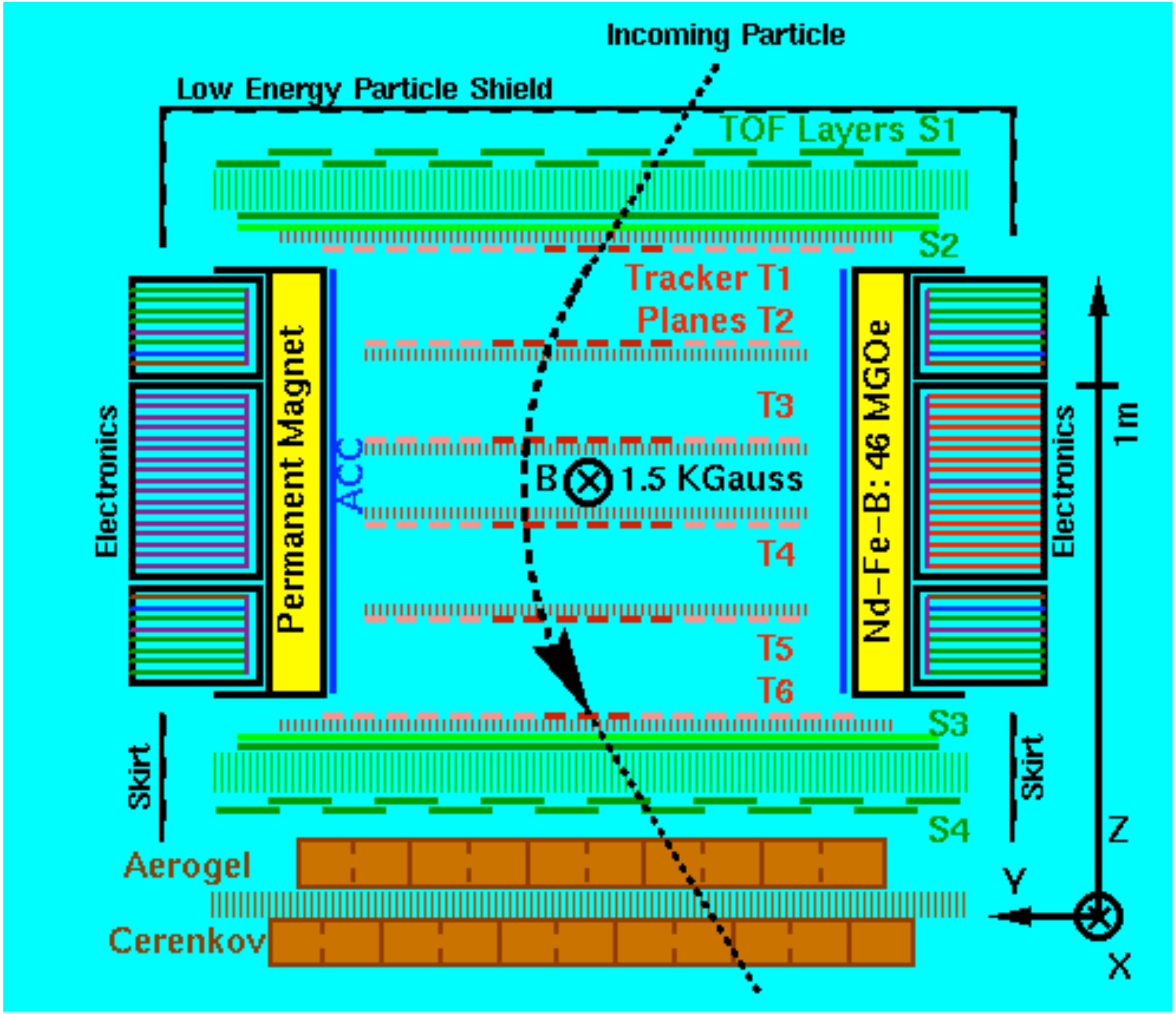
track reconstruction ⟶ curvature ρ

$$\frac{m v^2}{\rho} = v \cdot B \cdot Z \Rightarrow p = B \cdot \rho \cdot Z$$

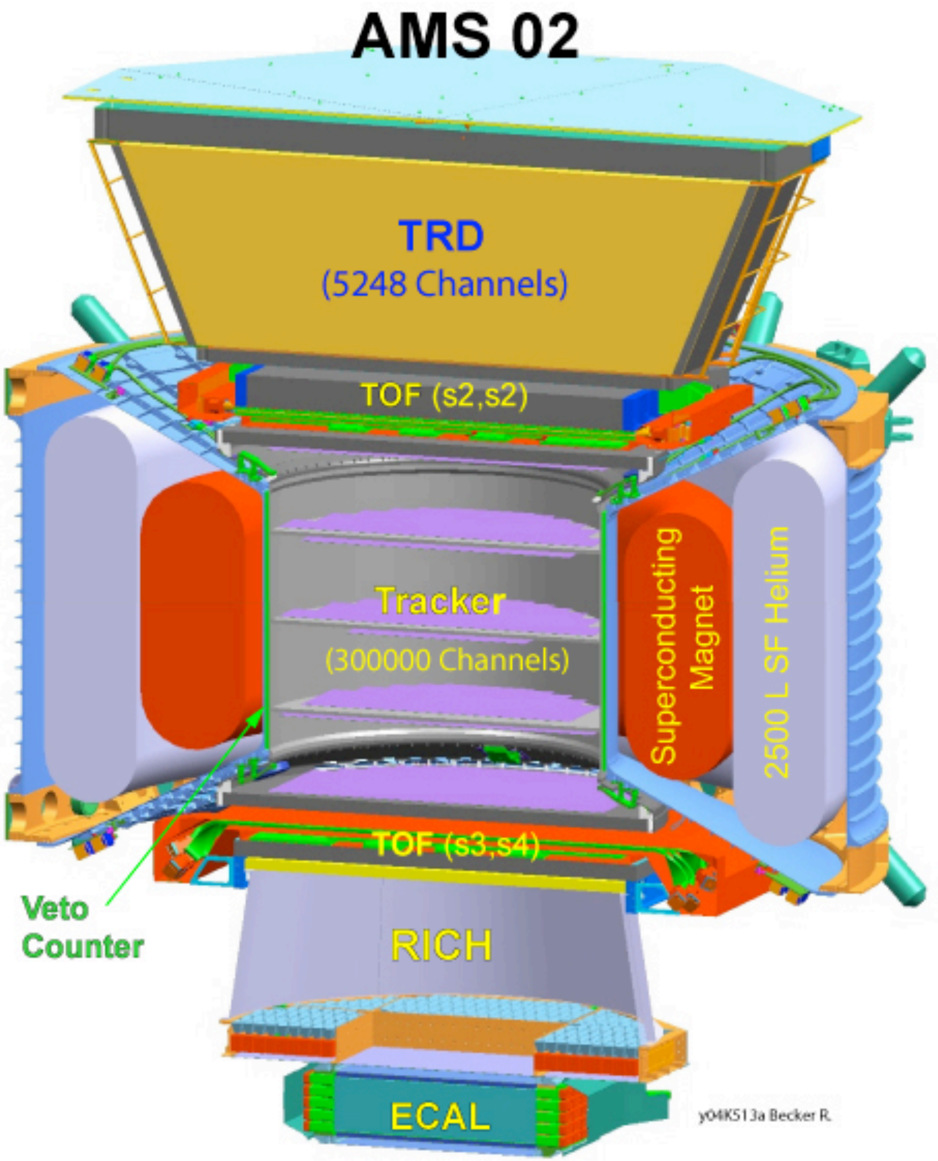
Z is determined from signal in scintillator

($\propto Z^2$)

Alpha Magnetic Spectrometer - AMS



Alpha Magnetic Spectrometer - AMS

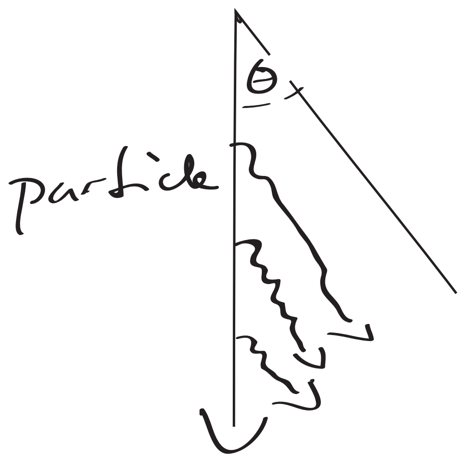


Alpha Magnetic Spectrometer - AMS

Čerenkov detector

charged particle in a medium with refractory index n moves with a velocity $v > \frac{c}{n}$

$\longrightarrow$ Čerenkov radiation



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

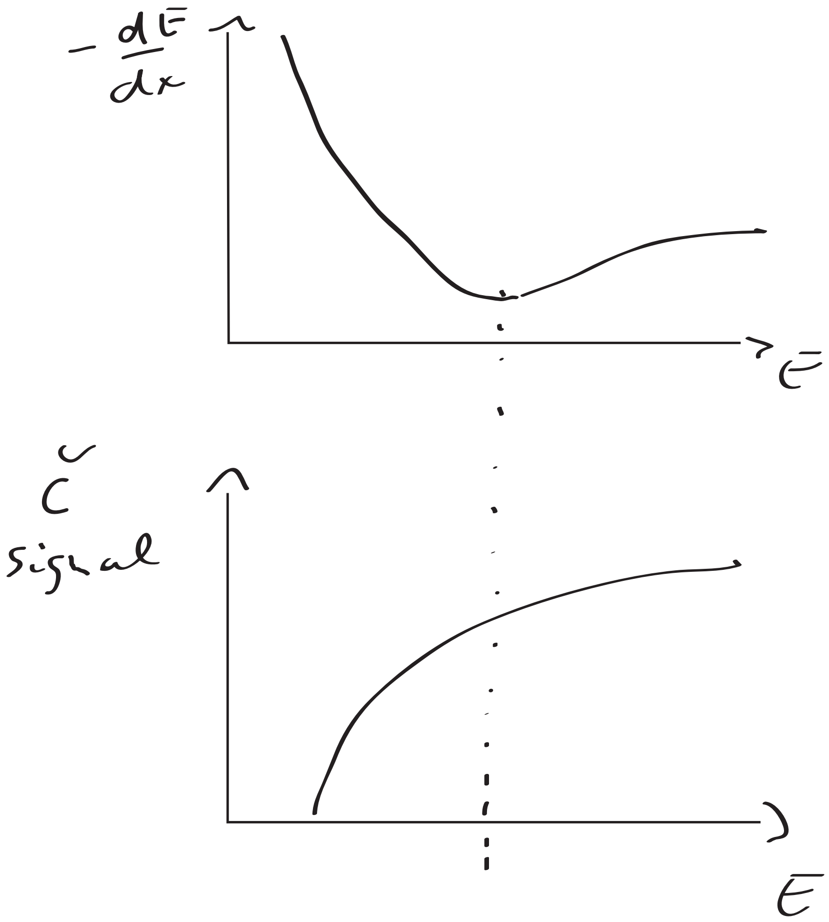
$$\Rightarrow \theta_c = \arccos \frac{1}{n}$$

$n > 1 \Rightarrow$ threshold energy

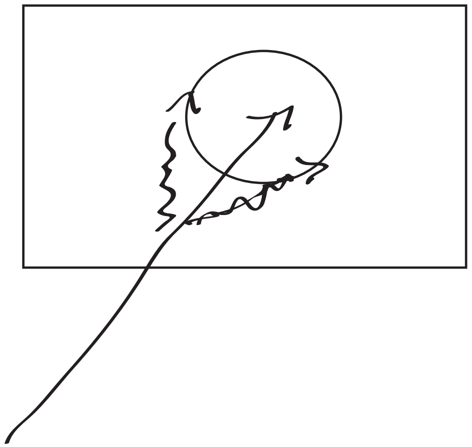
$$\gamma_{th} = \frac{1}{\sqrt{1-\beta_{th}^2}} = \frac{1}{\sqrt{1-\frac{1}{n^2}}} = \frac{E_{th}}{m_0 c^2}$$

- threshold detector

with a Čerenkov detector low-E particles can be identified



– ring imaging Čerenkov counter (RICH)



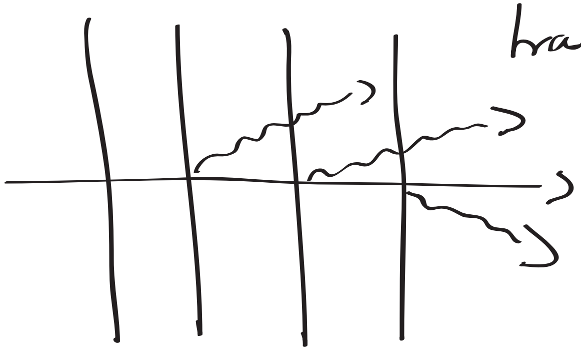
⇒ measure β from θ_c

Transition radiation detectors

below Č threshold

charged particles traverse a border between two media with different dielectric properties

⟶ transition radiation (Ginzburg 1946)



transition radiation (x-ray photons)

radiated $E \propto \gamma$

-> energy measurement

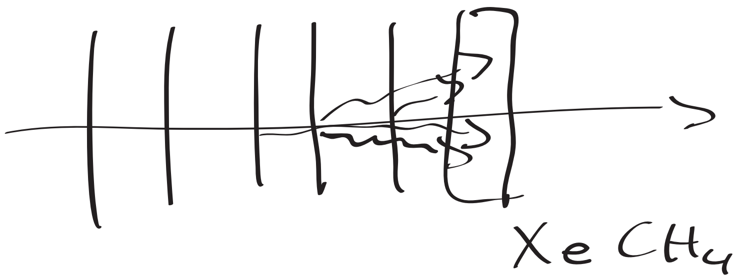
measurement of the x-ray photons

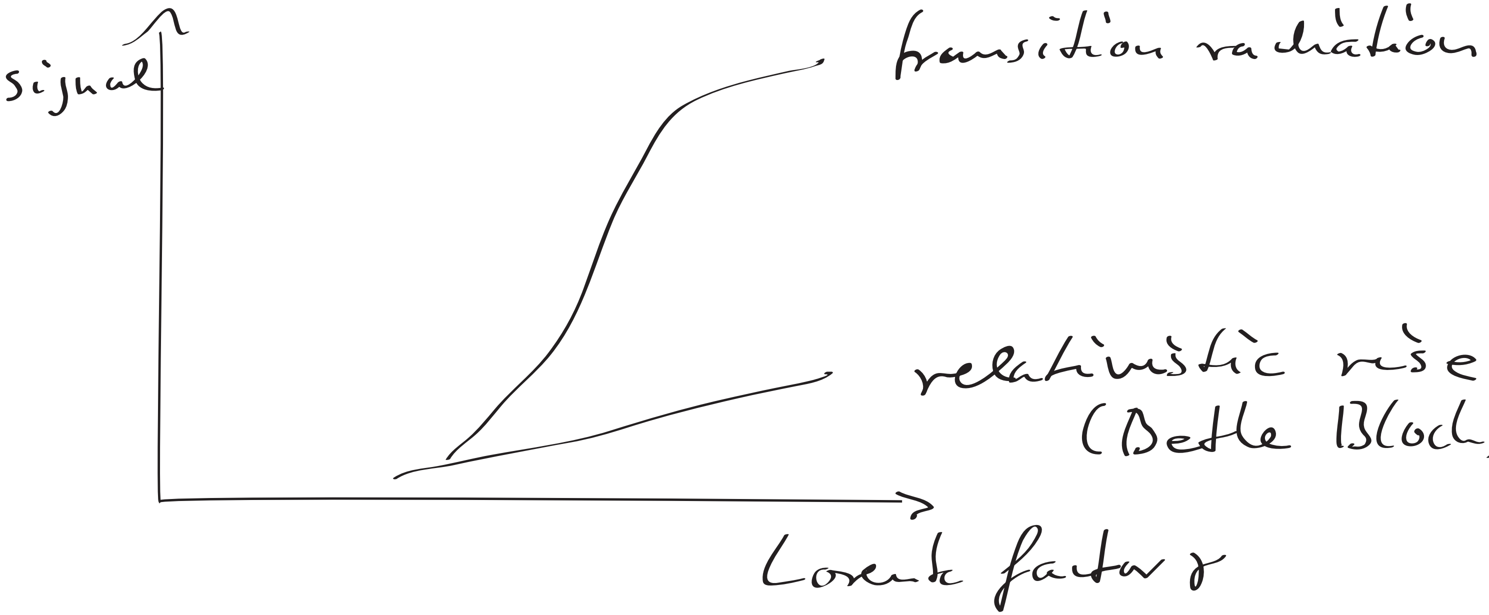
e.g. with MWPC (multiwire proportional chamber)

photoelectric effect $\sigma \sim Z^5$

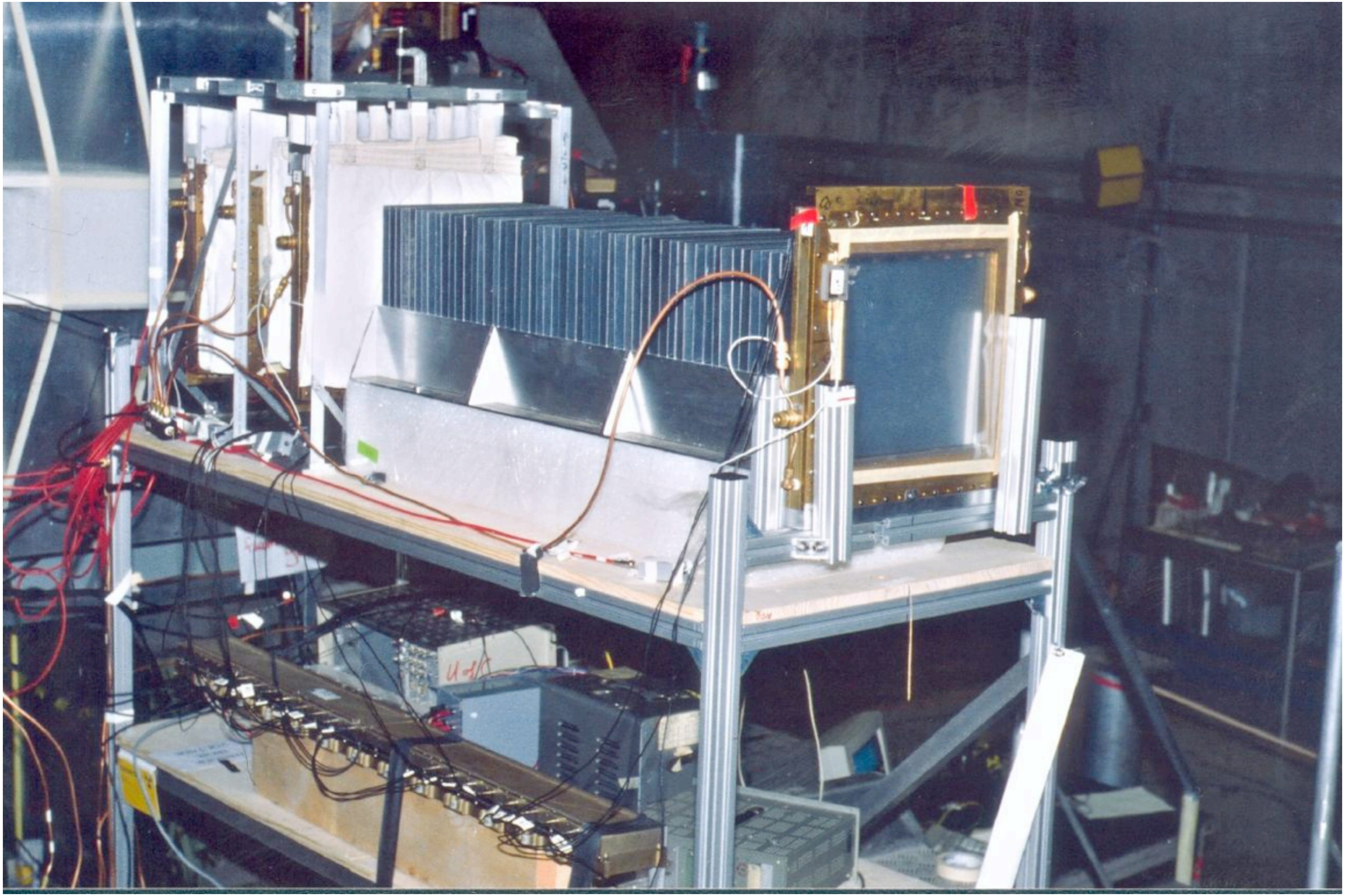
-> big cross section for gas with large Z

-> Xe


Xe CH4


signal
transition radiation
relativistic rise
(Bethe Bloch)
Lorentz factor γ

TRD test at CERN



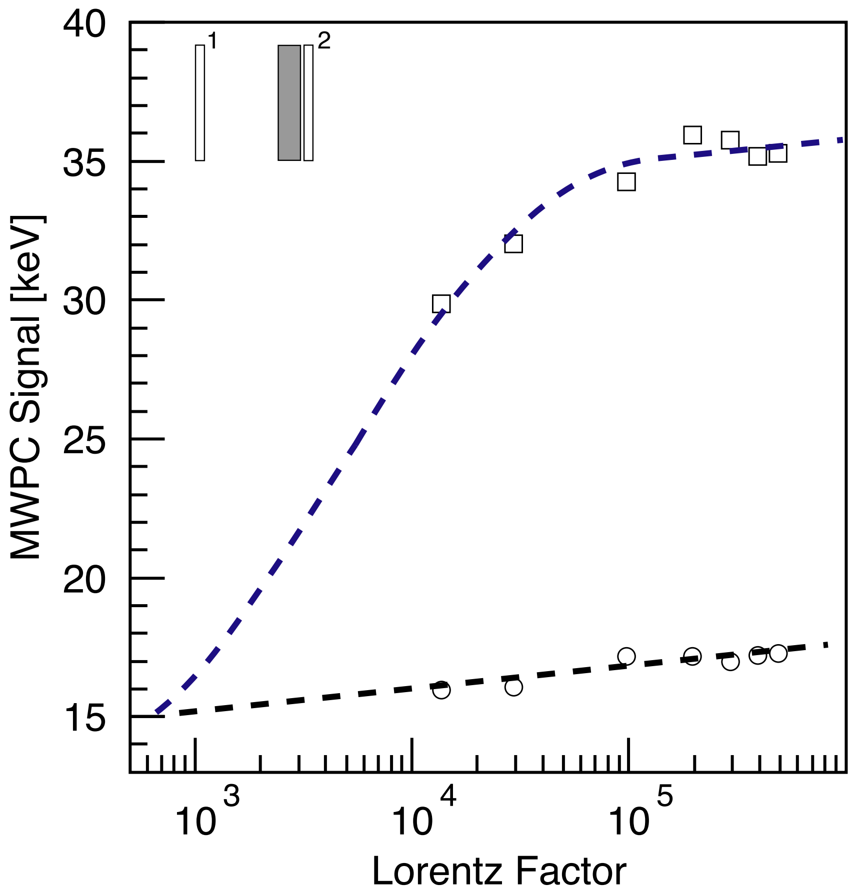
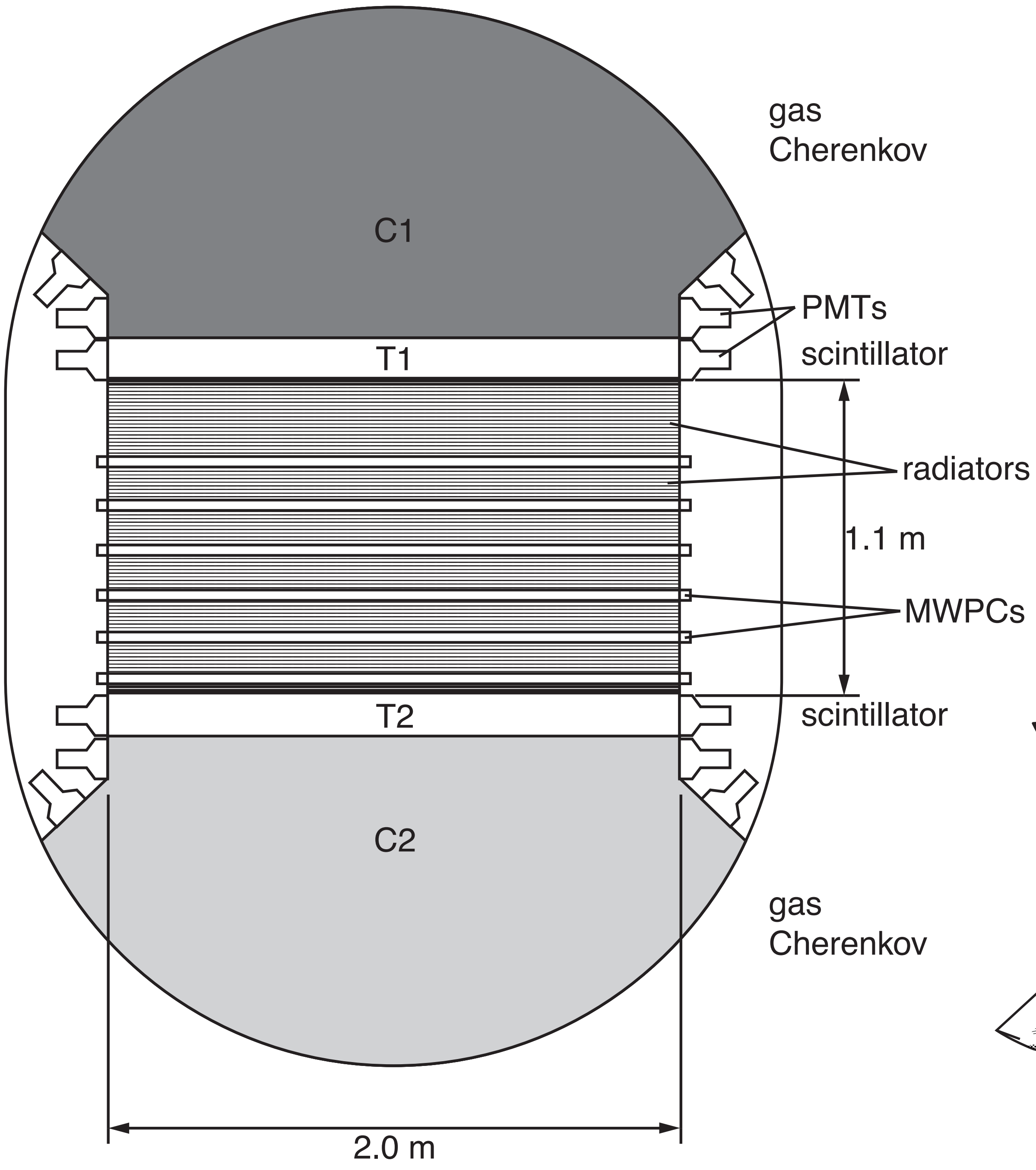
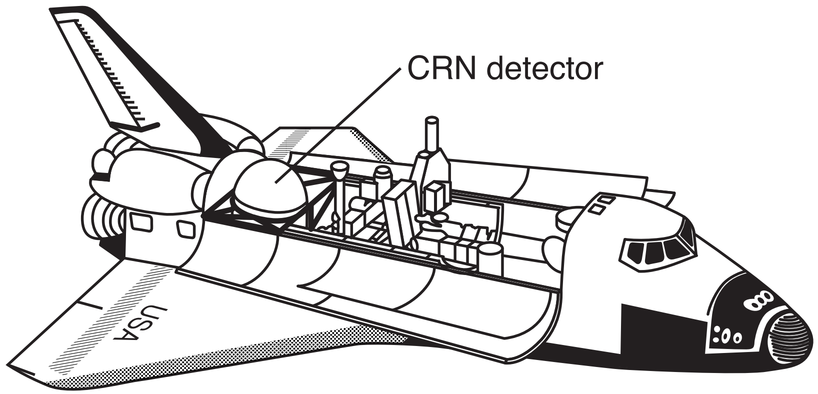


Fig. 8. Average detector signal versus Lorentz factor for a CRN-like radiator configuration. The open circles are data from MWPC 1, and the open squares are from MWPC 2, as shown in the inset schematic. The dashed lines serve to guide the eye.

Transition
Radiation
Detector

Cosmic Ray Nuclei instrument - CRN



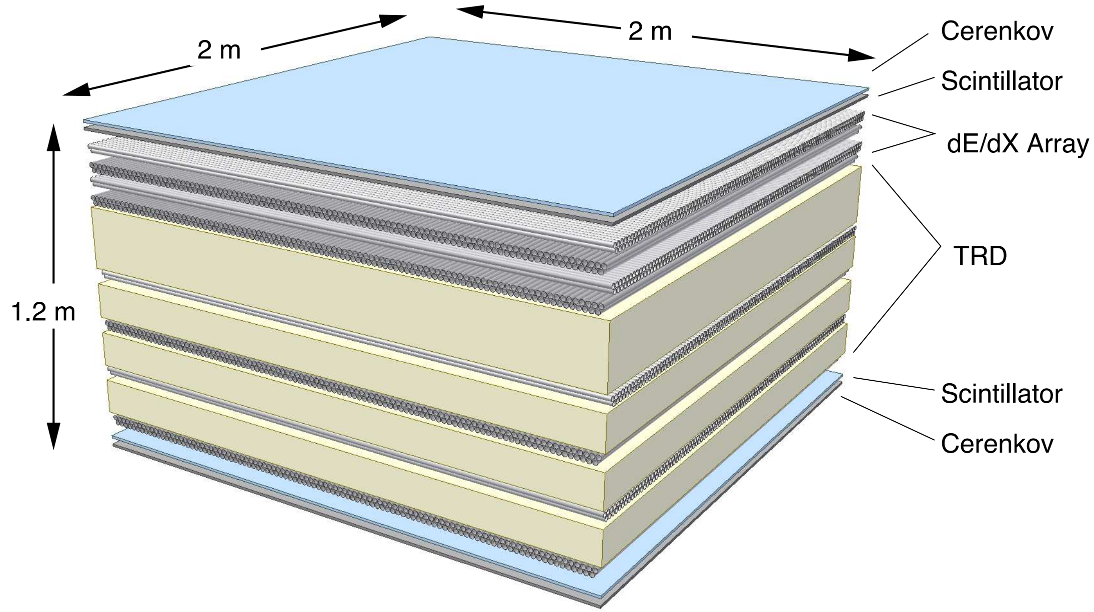


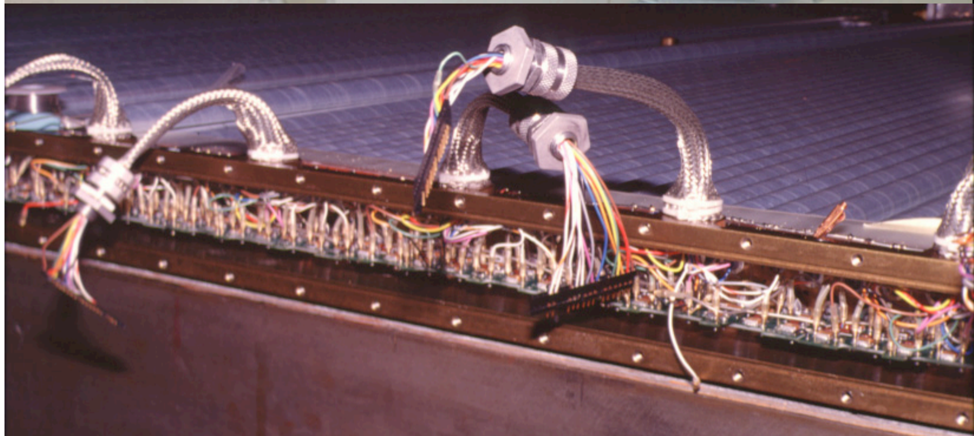
Challenger 1985

TRACER experiment

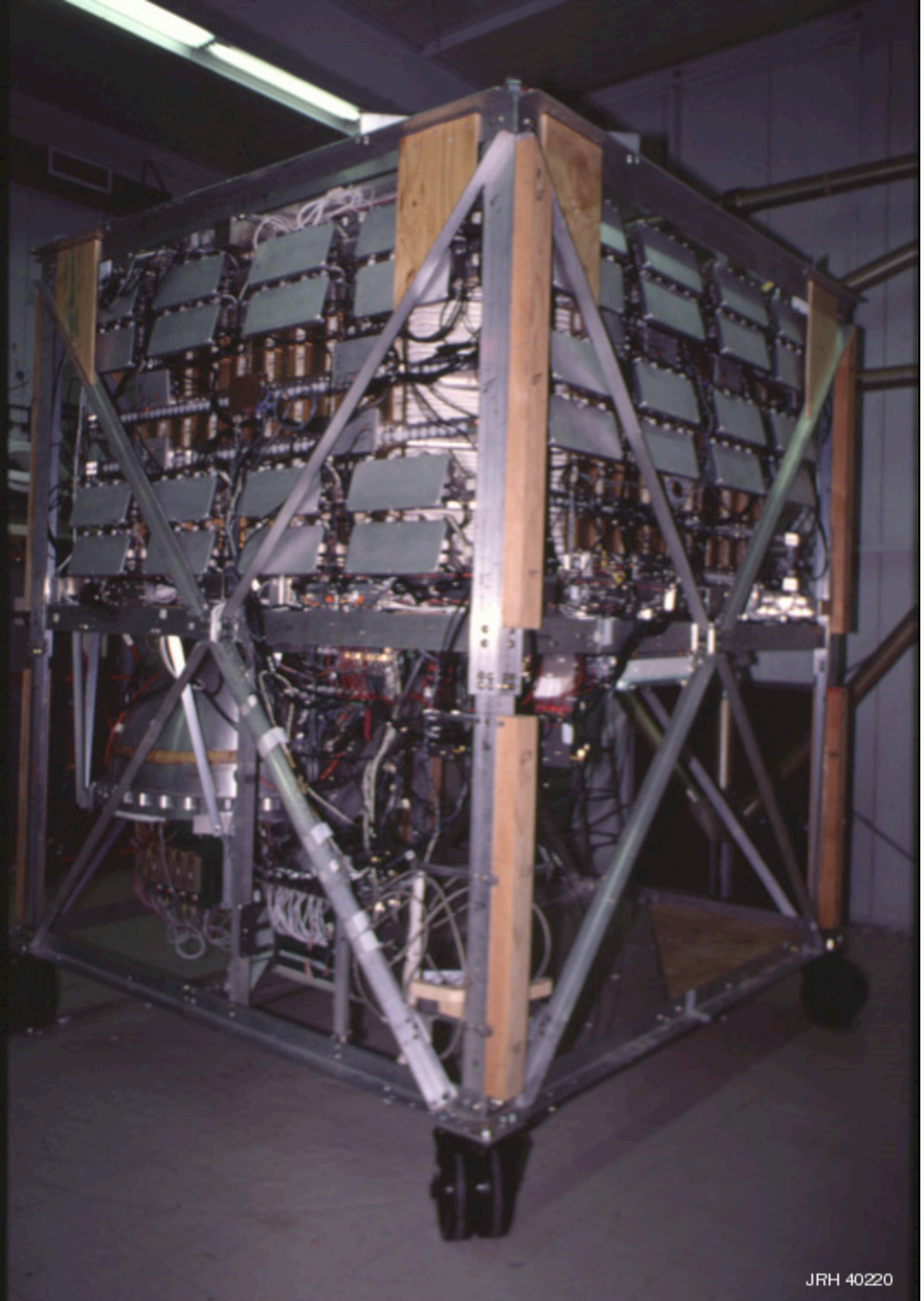
TRACER Overview

- Two pairs of Cerenkov and Scintillation Detectors
- 1600 Proportional Tubes (2cm × 2m) in 16 Layers
  - Upper 8 Layers: dE/dX in Gas (dE/dX array)
  - Lower 8 Layers: dE/dX+TR (TRD)





JRH 38201

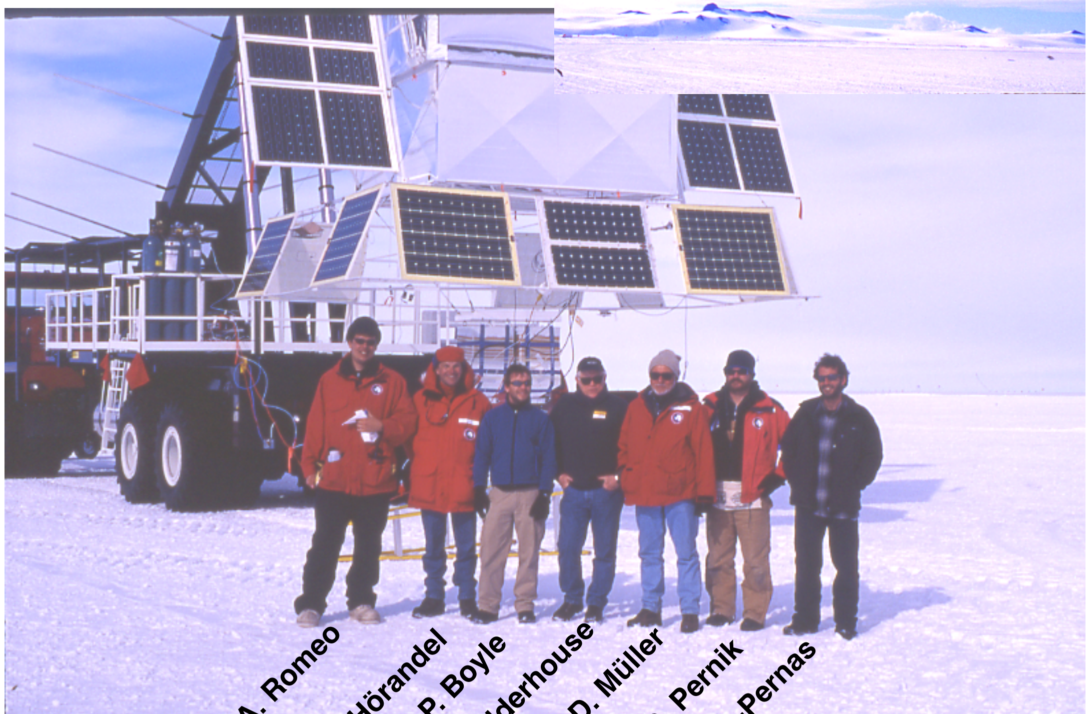


JRH 40220

TRACER Experiment - Mc Murdo, Antarctica

flight: 12. – 26. December 2003 **~ 40 km (3-5 g/cm²)**

TRACER Experiment



TRACER Experiment - Mc Murdo, Antarctica
flight: 12. – 26. December 2003 ~ 40 km (3-5 g/cm²)

balloon

filled with $10^6\,m^3$ He

ϕ 130 m

total mass ~5 t

flight altitude ~40 km $(3-5\,g/cm^2)$

charge measurement

$$\frac{dE}{dx} \propto Z^2$$

$$Z \propto \sqrt{\text{signal in scintillator}}$$

TRACER - measured charge distribution

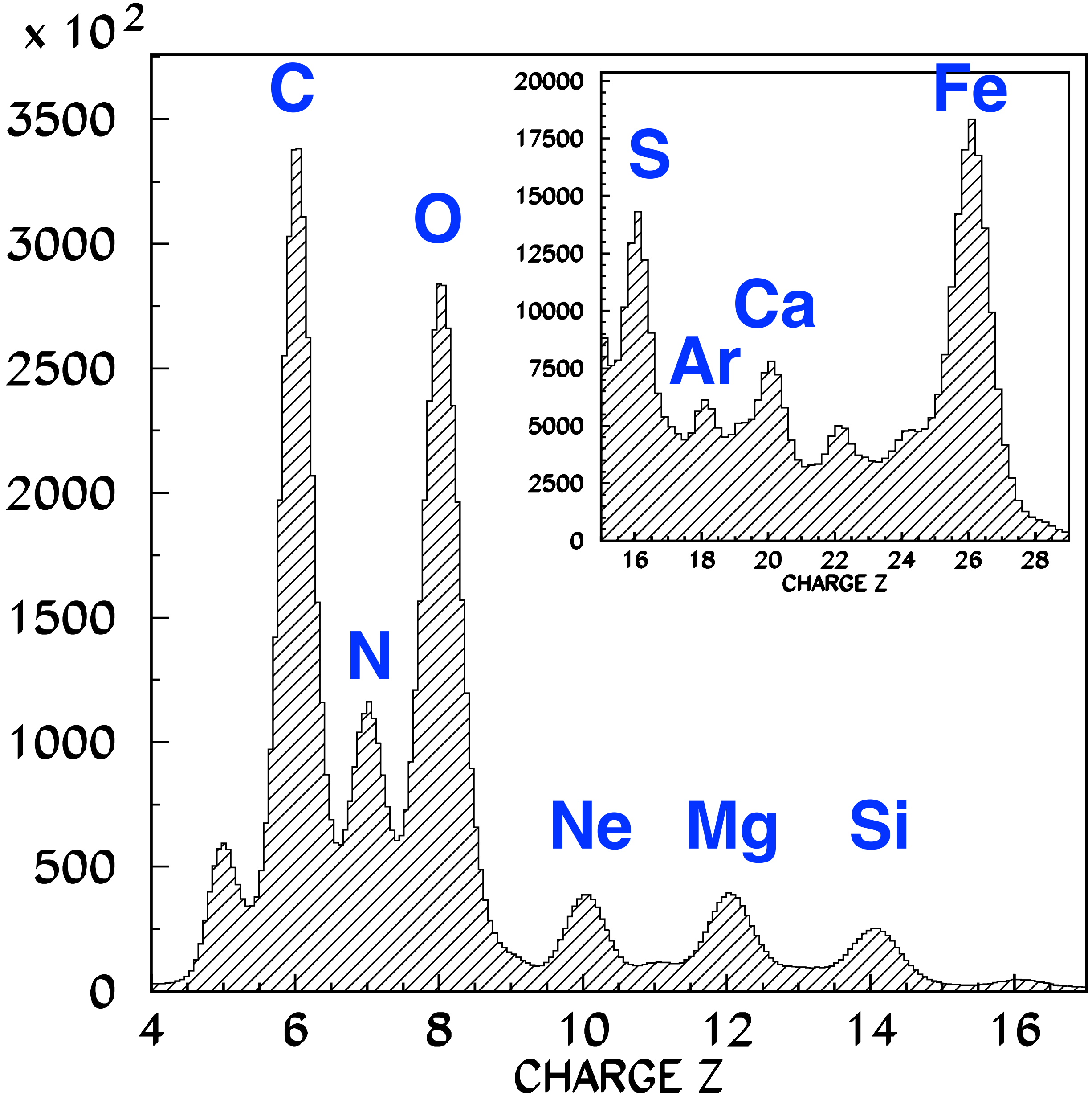


FIG. 5.—Charge histogram for all events measured in flight.