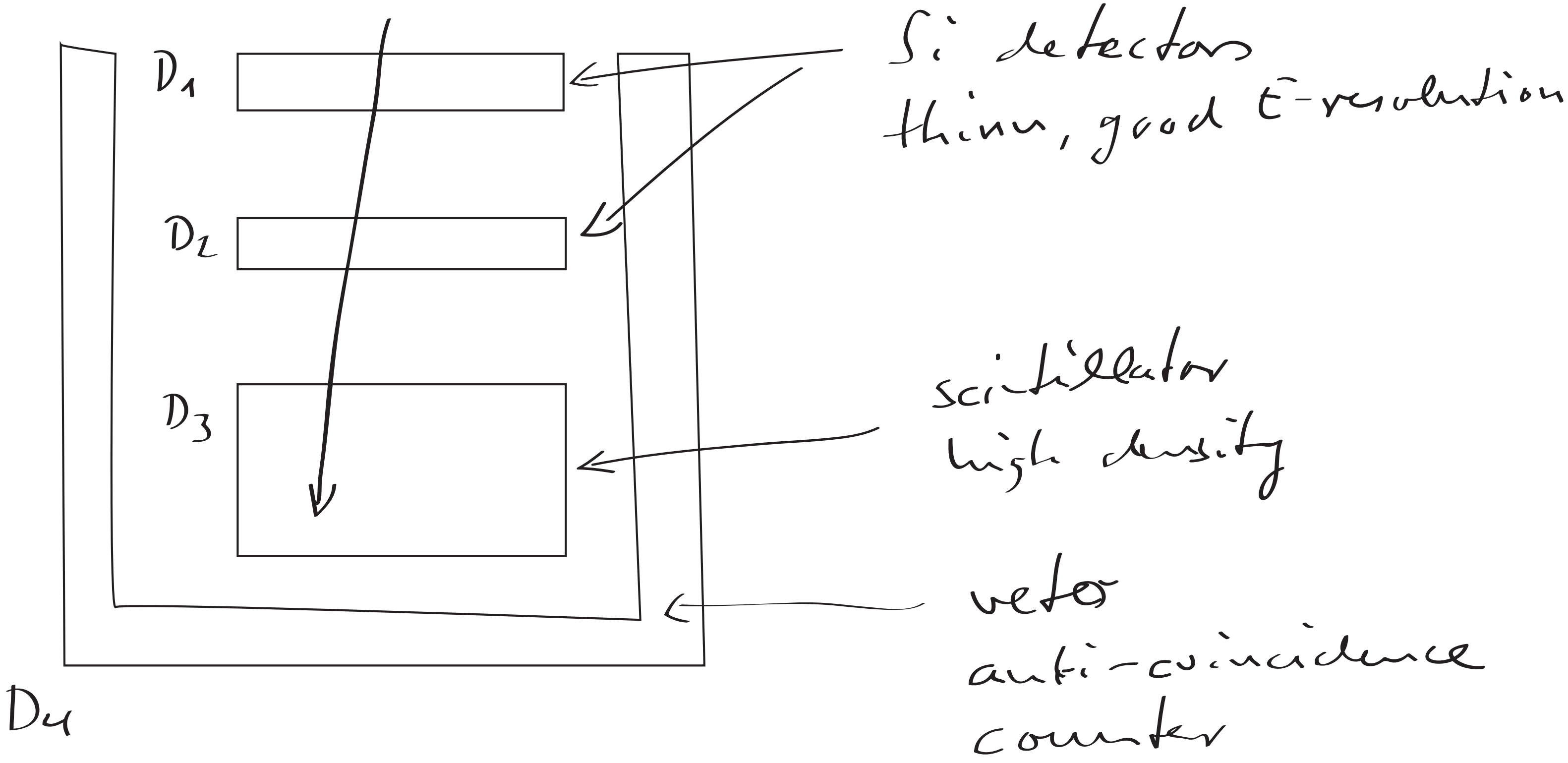
# Direct measurement of Cosmic Rays

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 setup

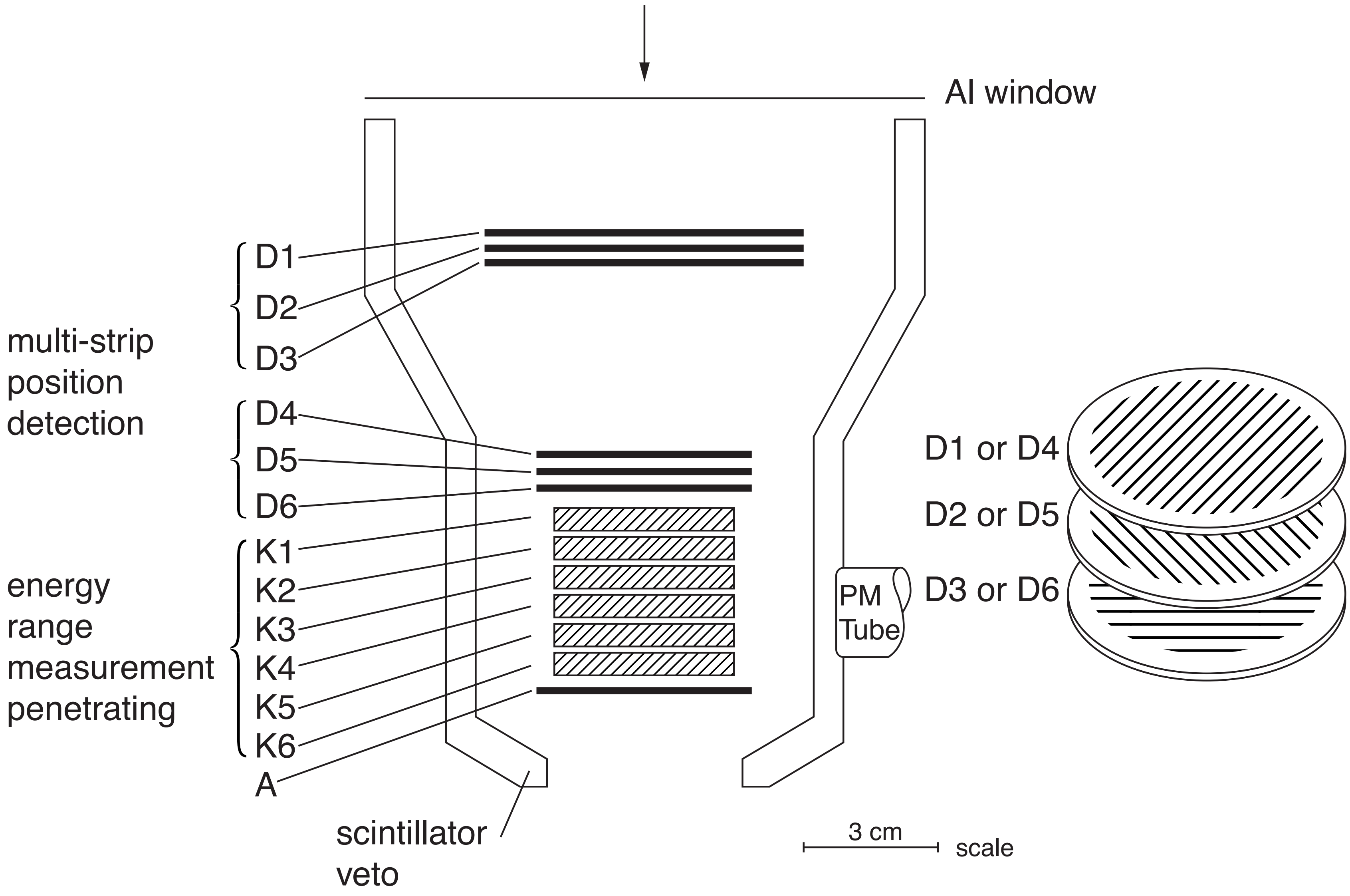



particle telescope

signal in $D_1$ & $D_2$ & $D_3$

but not in $D_4$

# Ulysses High Energy Telescope (HET)



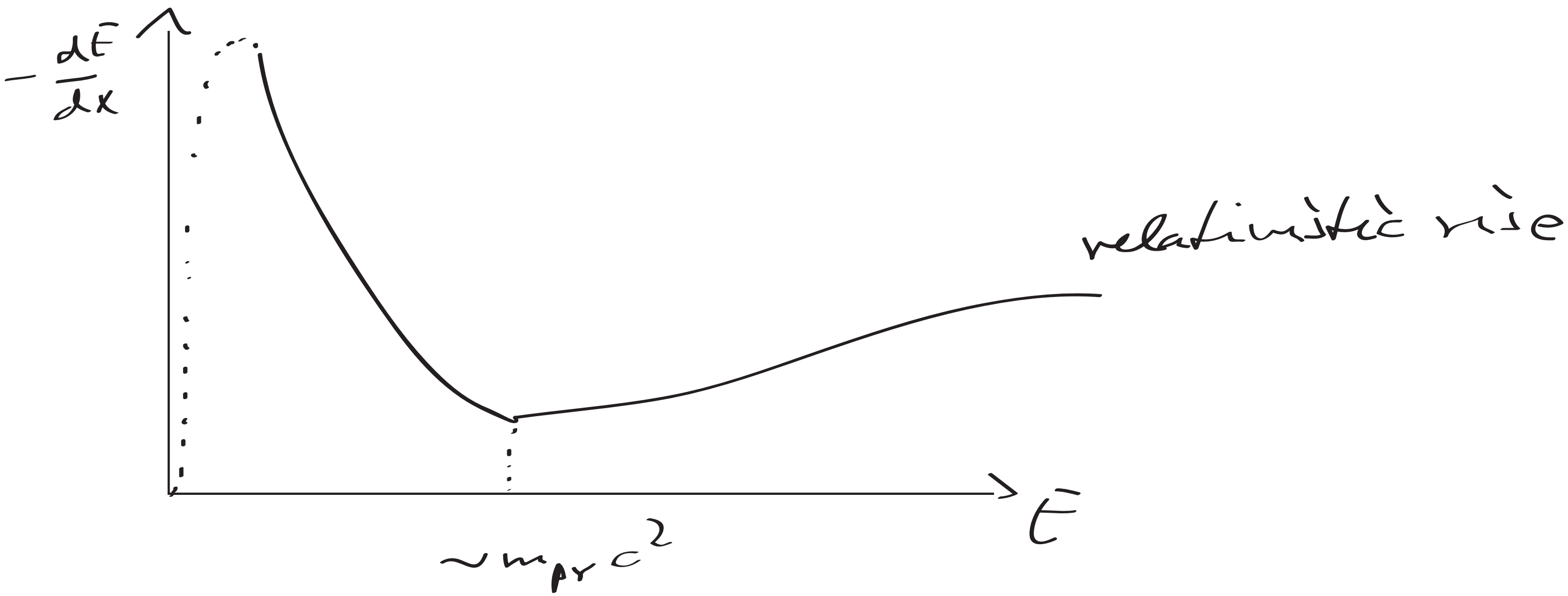
in which energy range can we use such a detector?

- 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 $D_3$

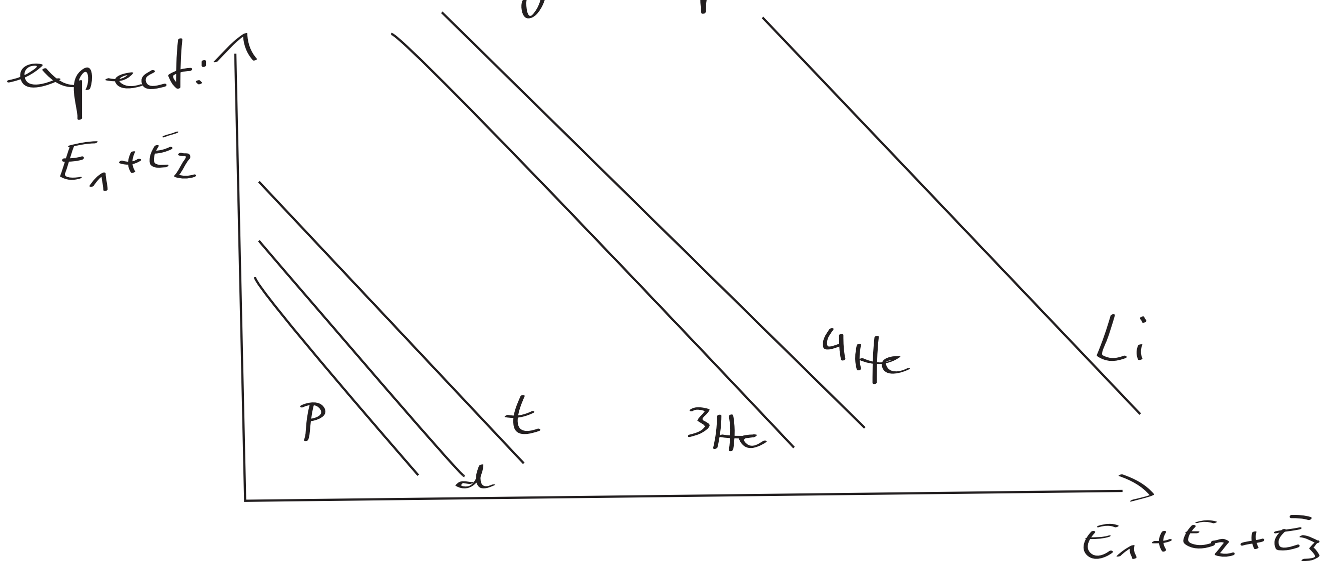
particles loose energy through ionization described by the Bethe Bloch formula

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

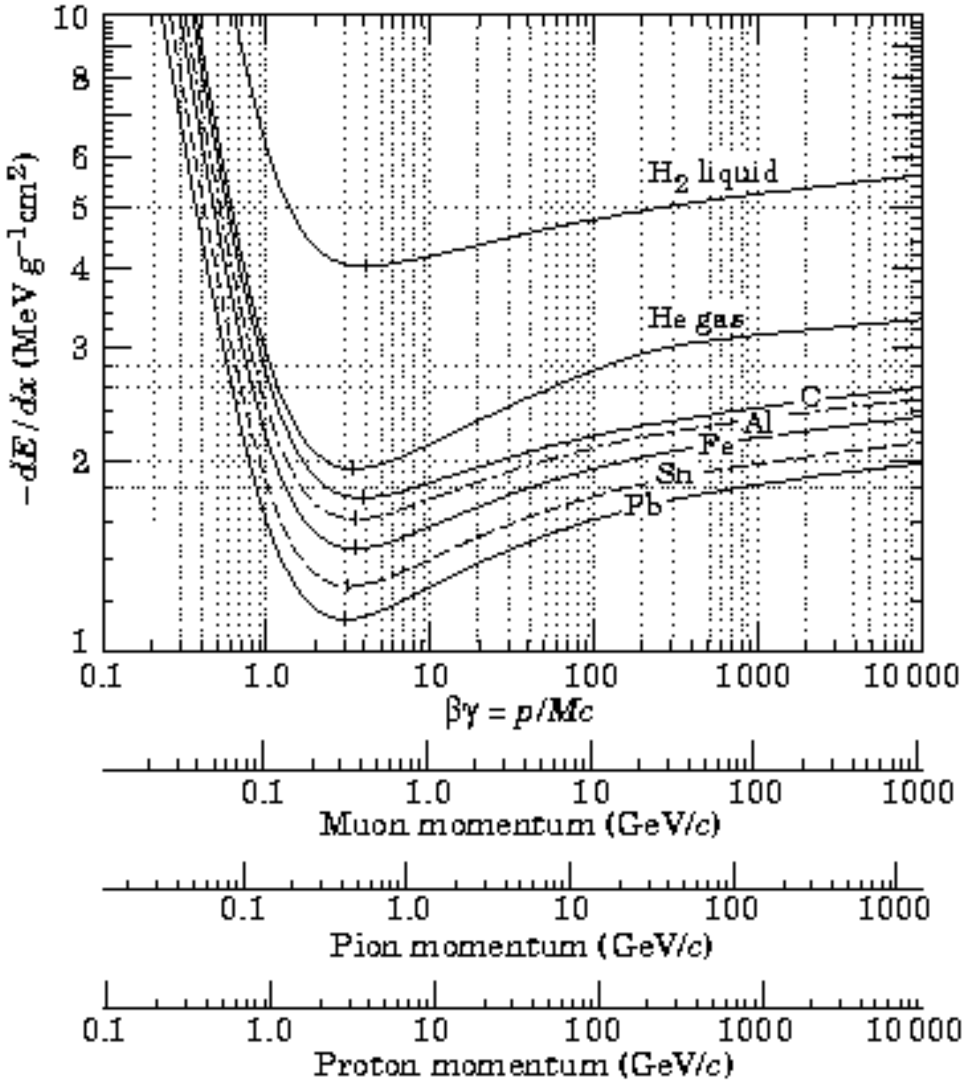
$$\propto \frac{z_{pr}^2}{v_{pr}^2} \qquad \propto z_{pr}^2 \frac{m_{pr}}{E_{pr}^{kin}}$$



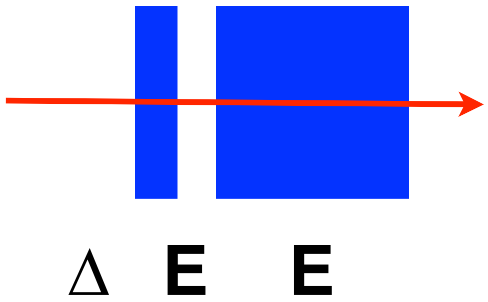

total energy of particle $E_1 + E_2 + E_3$

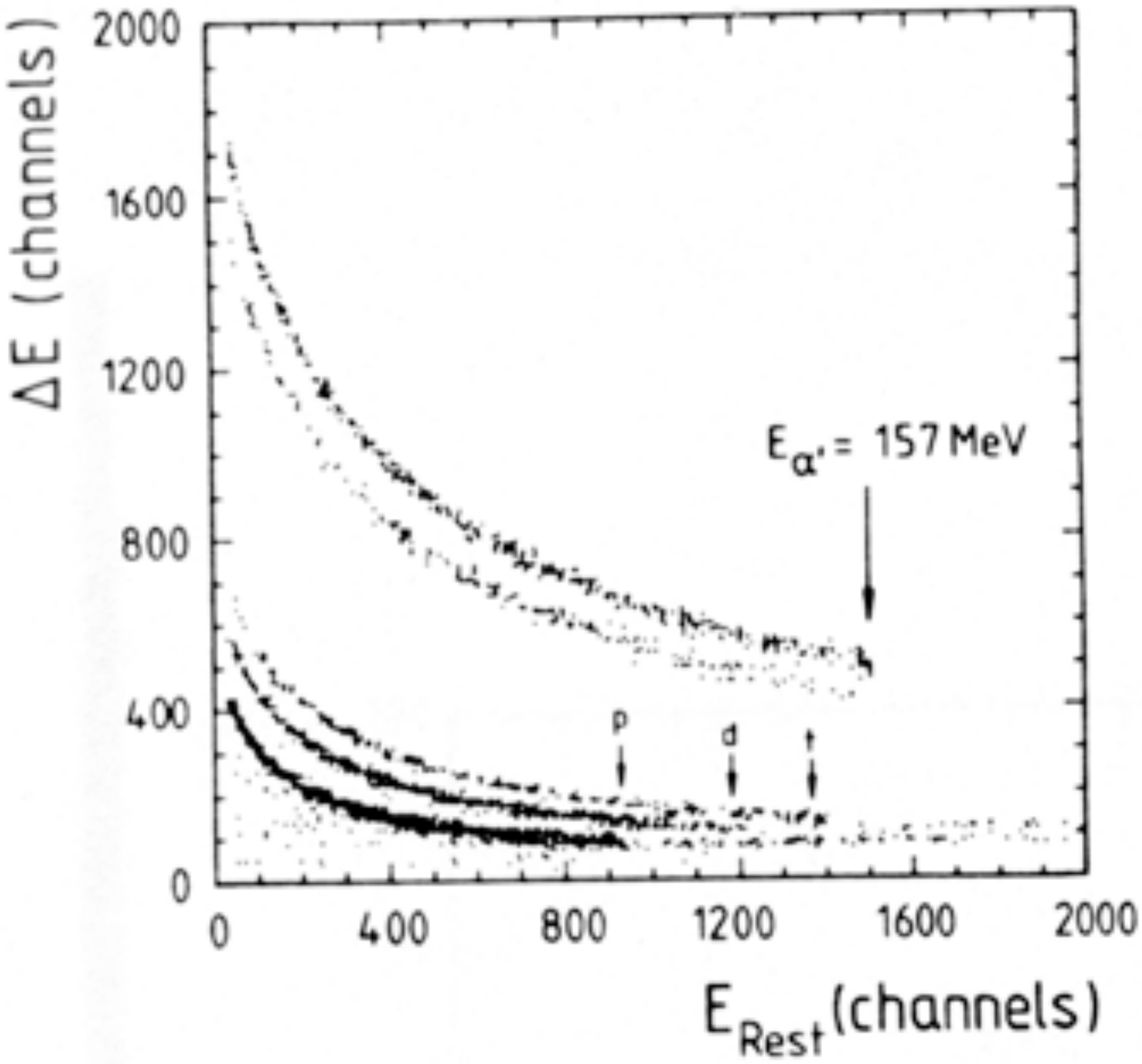


# specific energy loss
# Bethe Bloch formula

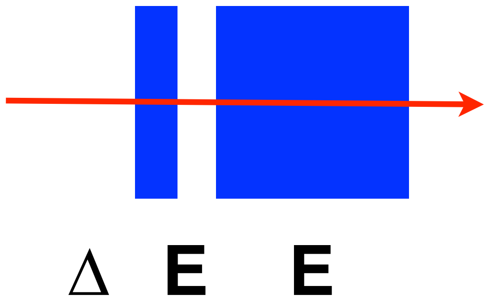


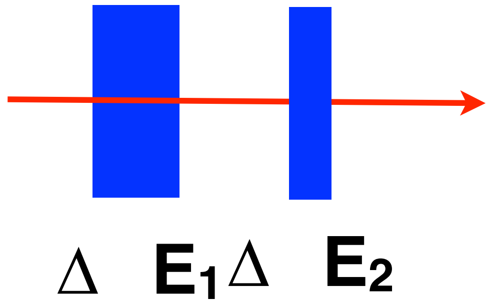
# particle identification

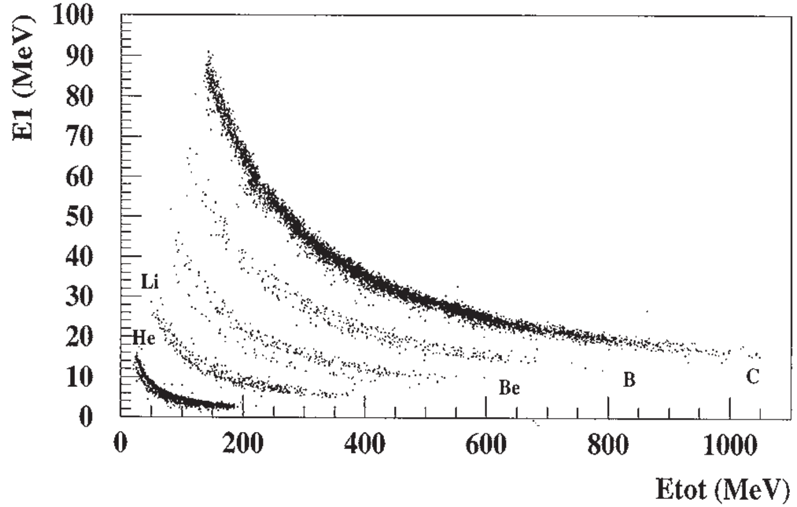


# particle identification



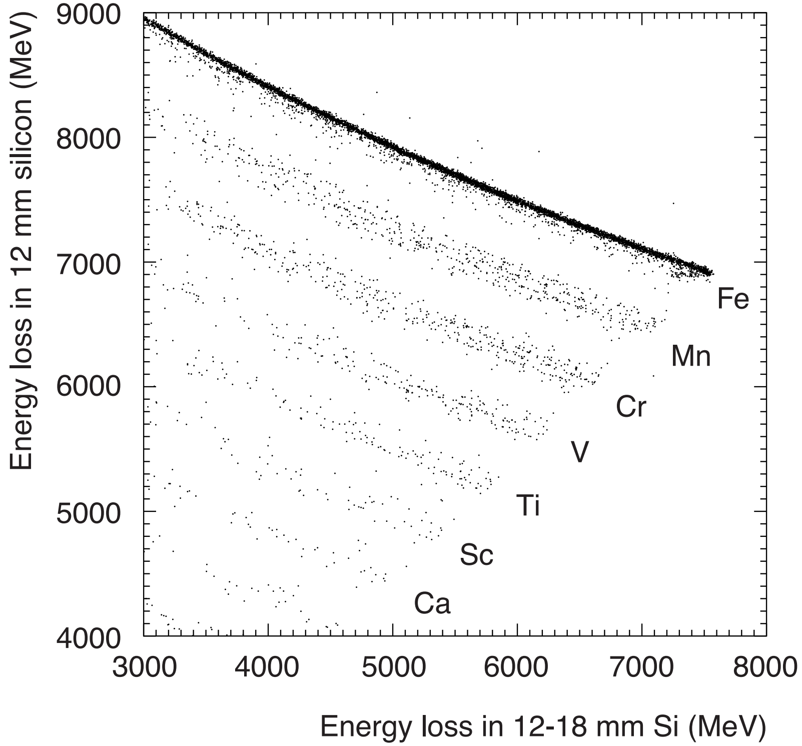
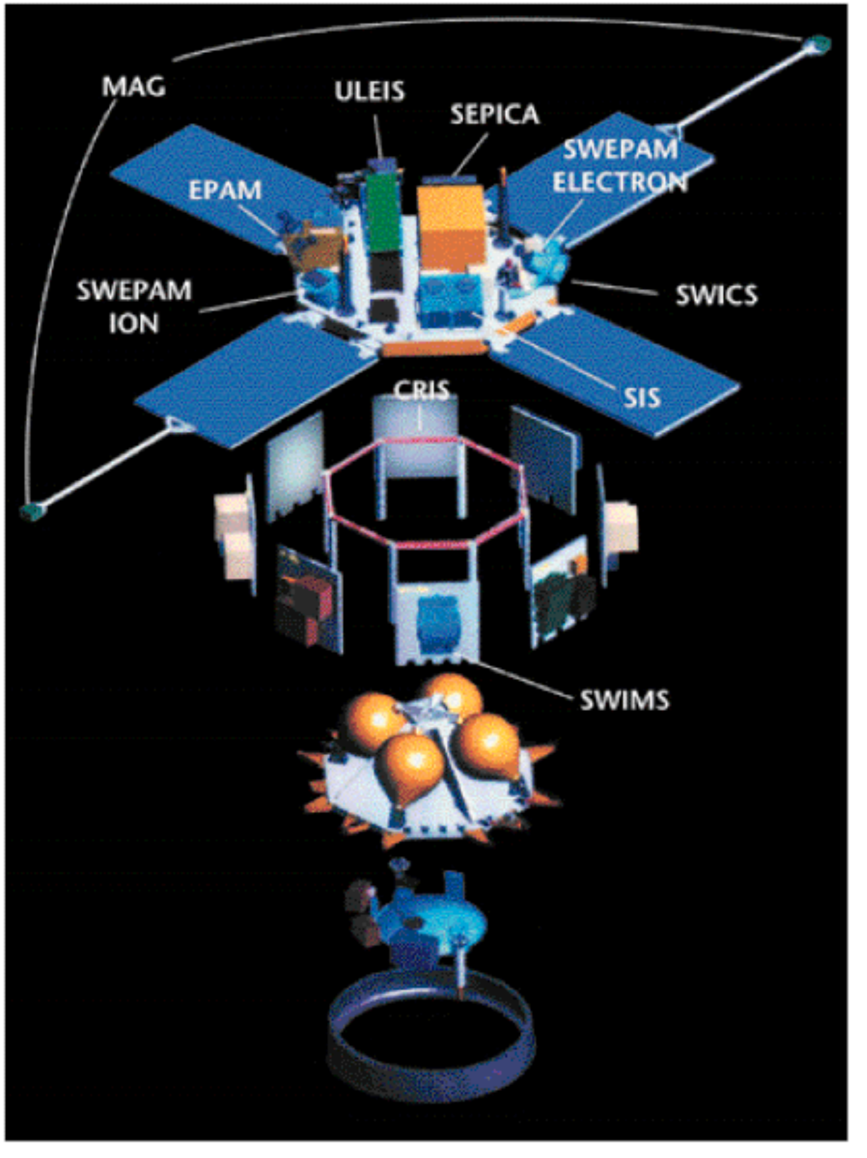



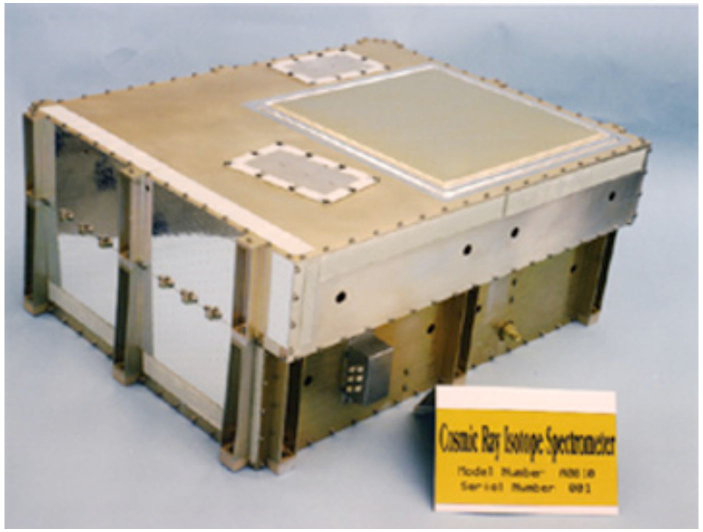

**Fig. 3.4.** *Left*: Energy loss in the first plane (E1) vs. total energy ($E_{tot}$) detected by the NINA telescope for particles fragmented from a $^{12}C$ test beam [8]. *Right*: Scatter plot of $\Delta E$ in 12 mm Si vs. $\Delta E$ in the following 6 mm Si from calibration of the CRIS instrument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

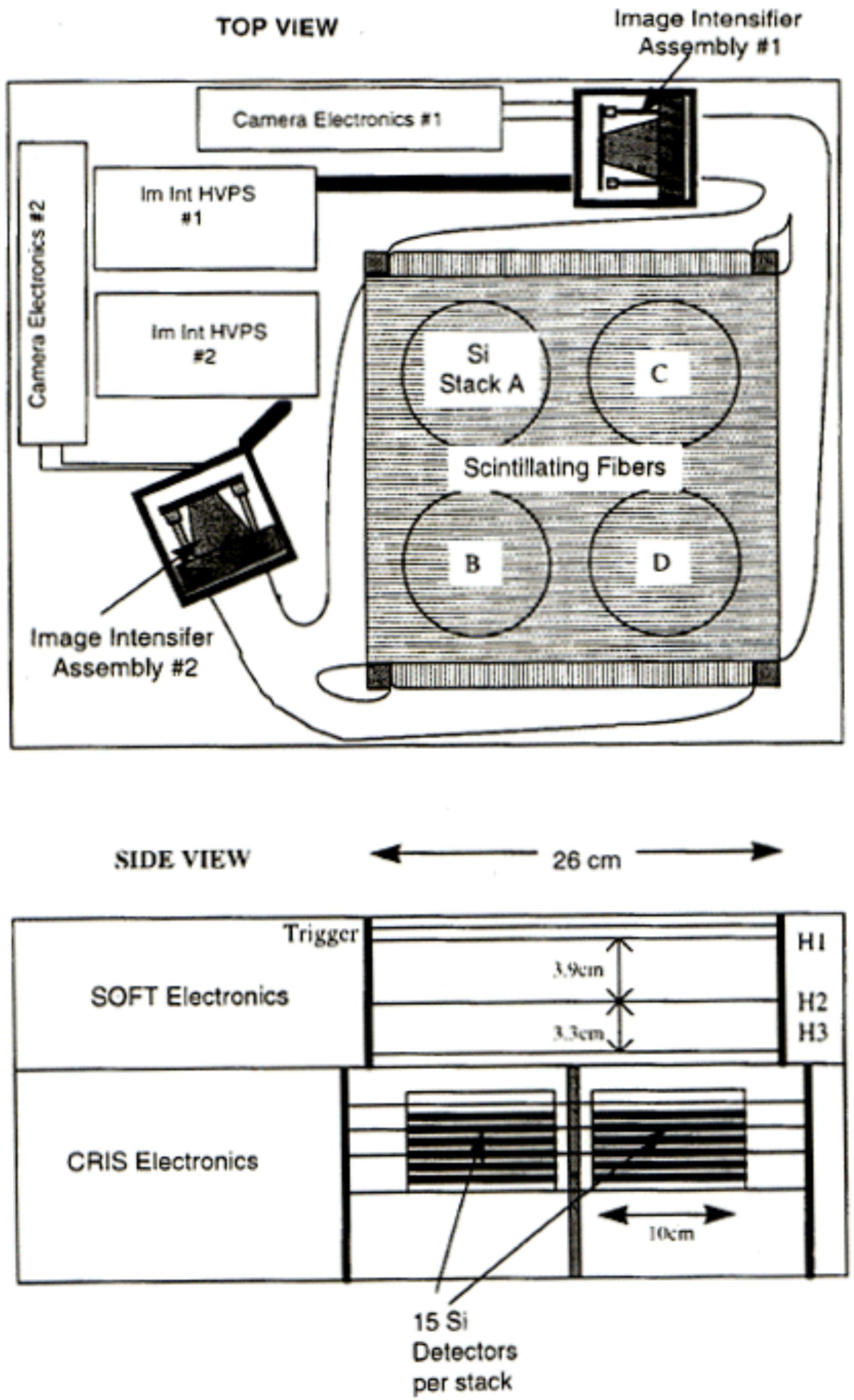
# Advanced Composition Explorer (ACE)




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

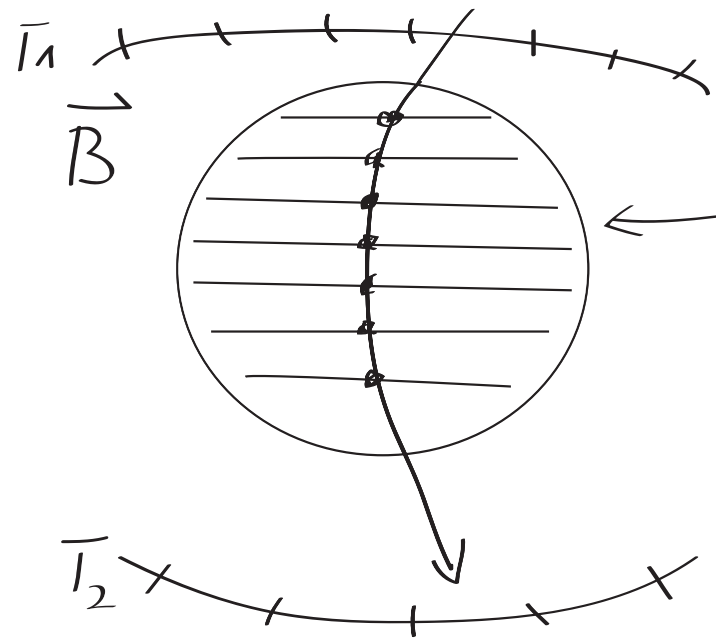


this technique works up to several 100 MeV/nucleon since the particles have to be absorbed

For higher energies up to $\sim 1$ TeV one can use

**magnet spectrometer**




segmented counter (scintillator)

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

$T_1$ & $T_2$ time of flight (TOF) measurements

→ direction

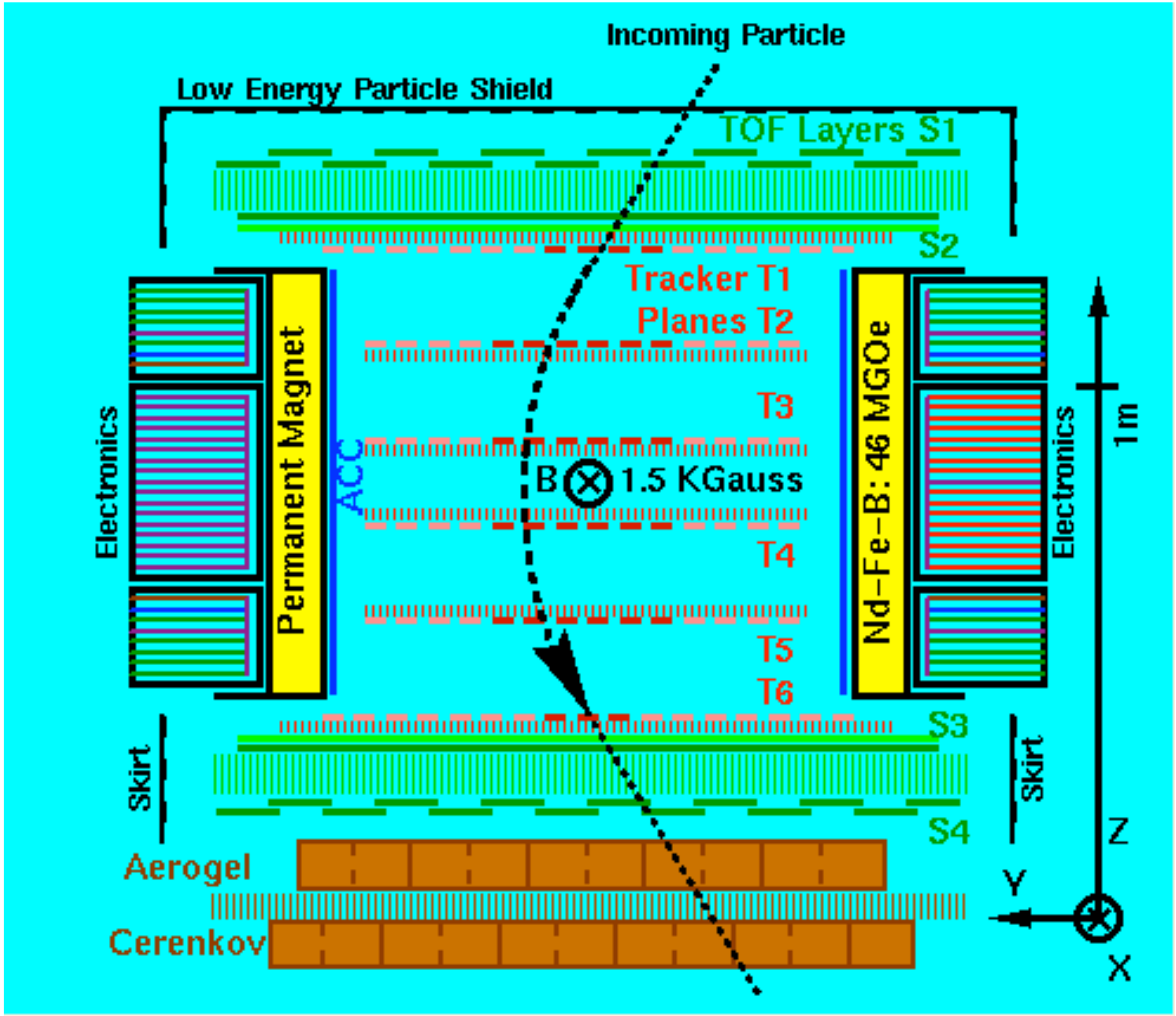
need high time resolution

track reconstruction → curvature $\rho$

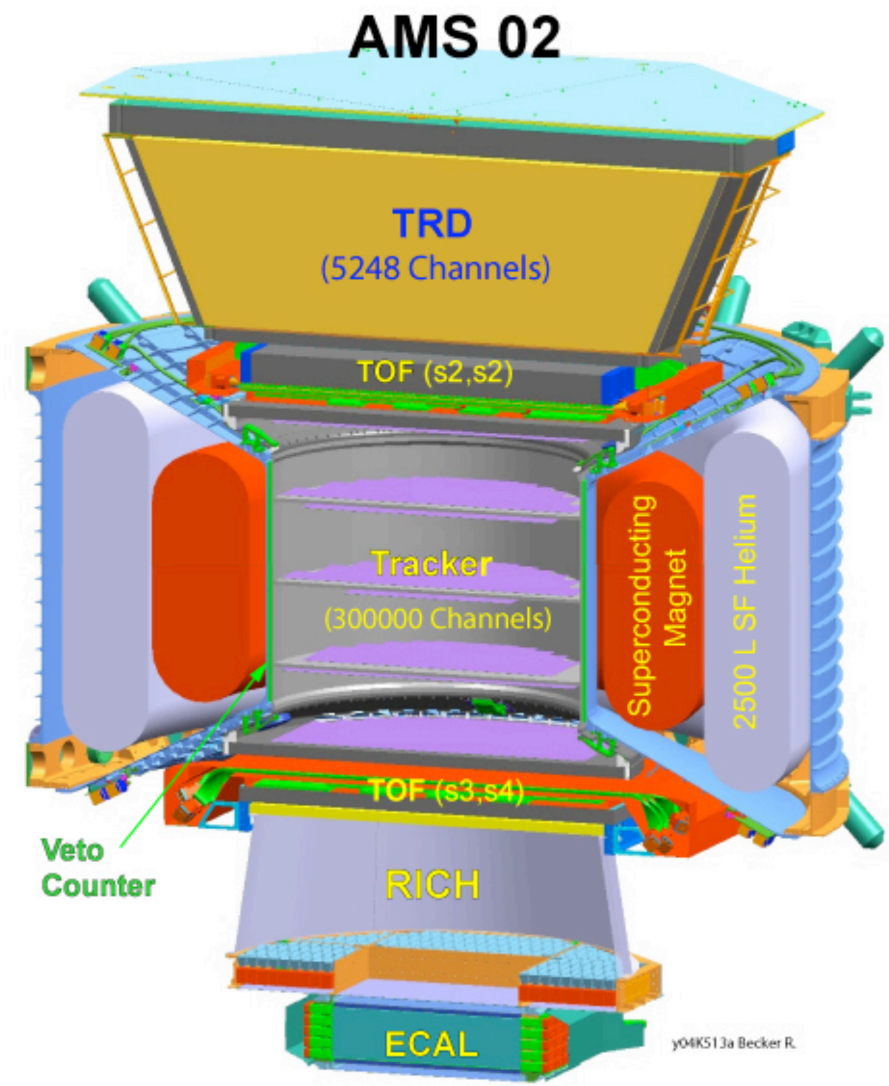
$$\frac{m v^2}{\rho} = v \cdot B \cdot z \Rightarrow p = B \cdot \rho \cdot z$$

$z$ is determined from signal in scintillator ($\propto z^2$)

# Alpha Magnetic Spectrometer - AMS



# Alpha Magnetic Spectrometer - AMS

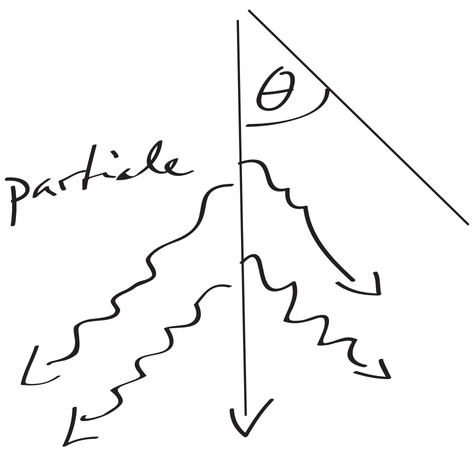


# Alpha Magnetic Spectrometer - AMS

# Čerenkov detector

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

→ Čerenkov radiation




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

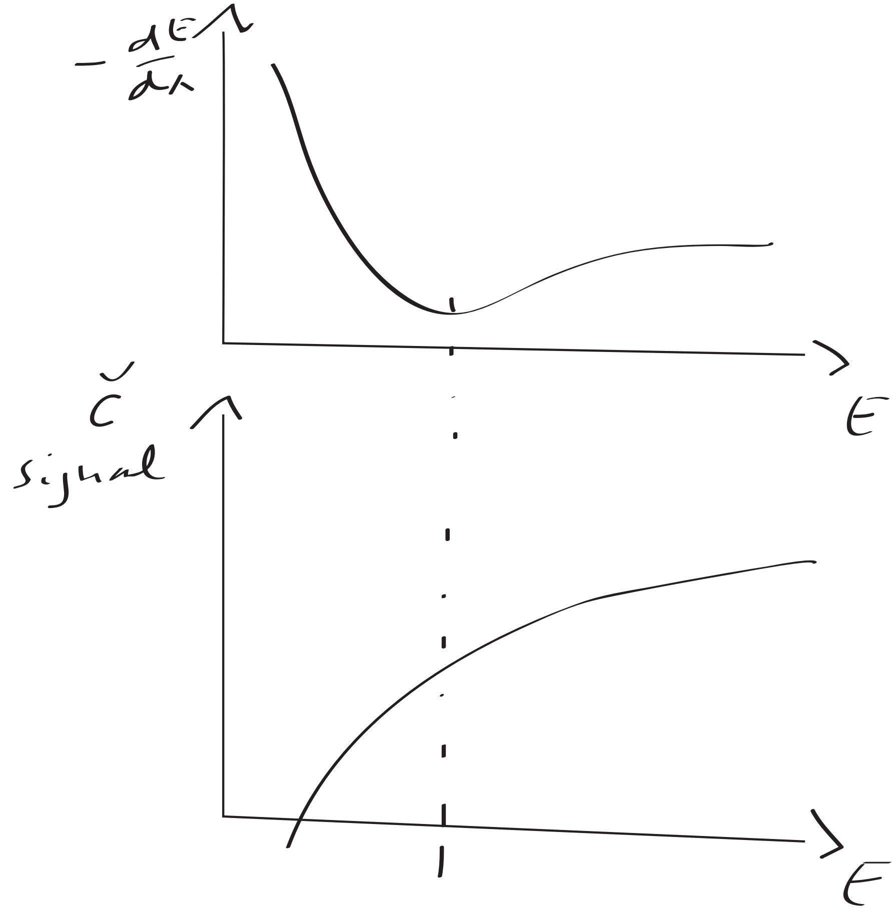
$$\Rightarrow \theta_C = \arccos \frac{1}{n}$$

$n > 1 \Rightarrow$ threshold energy

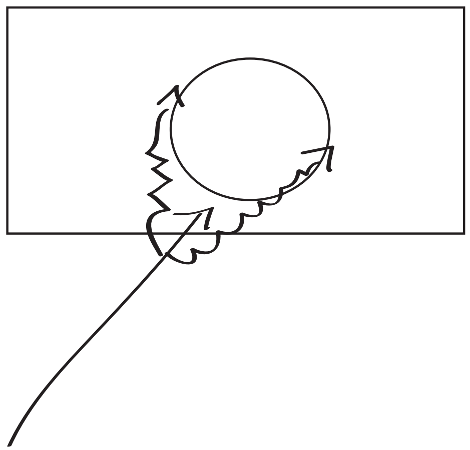
$$\gamma_{th} = \frac{1}{\sqrt{1-\beta_{th}^2}} = \frac{1}{\sqrt{1-\frac{1}{n^2}}} = \frac{E_{th}}{m_0 c^2}$$

threshold detector

with a Čerenkov detector low-E particles can be identified



- ring imaging Čerenkov counter (RICH)



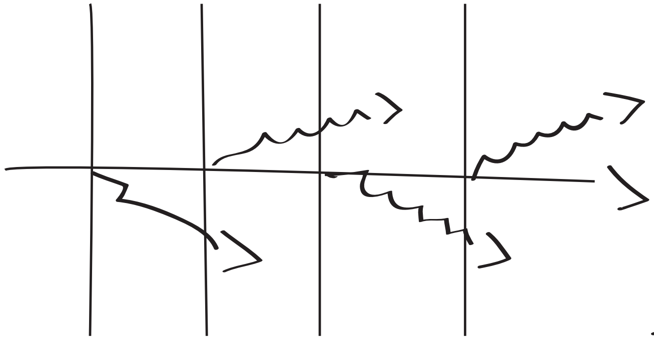
=> measure $\beta$ from $\Theta_c$

## Transition radiation detectors

below Č threshold

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

→ transition radiation (Ginzburg 1946)



transition radiation (x-ray photons)

particle

radiated $E \propto \gamma$

→ energy measurement

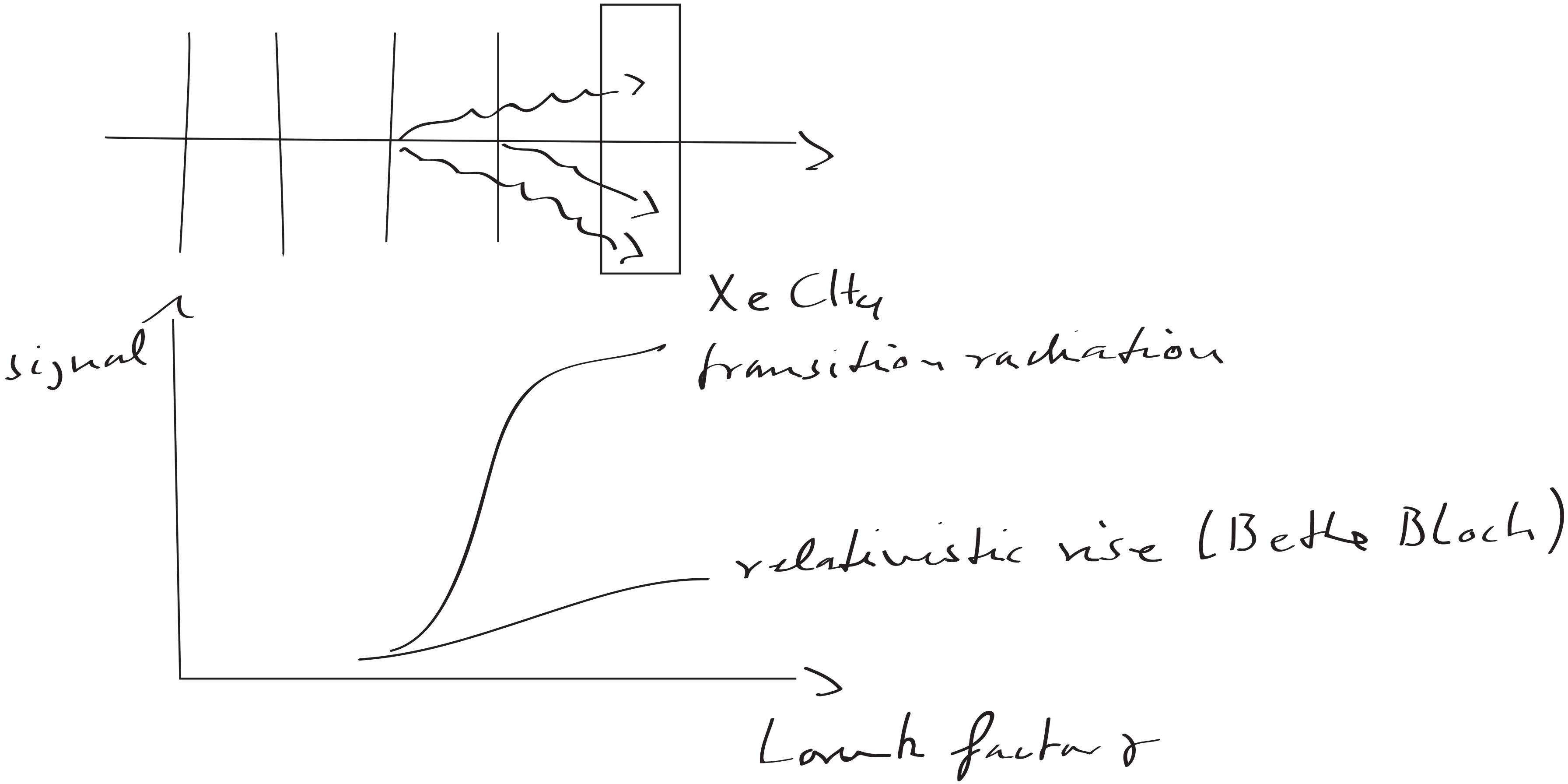
measurement of the x-ray photons

e.g. with MWPC (multi wire proportional chamber)

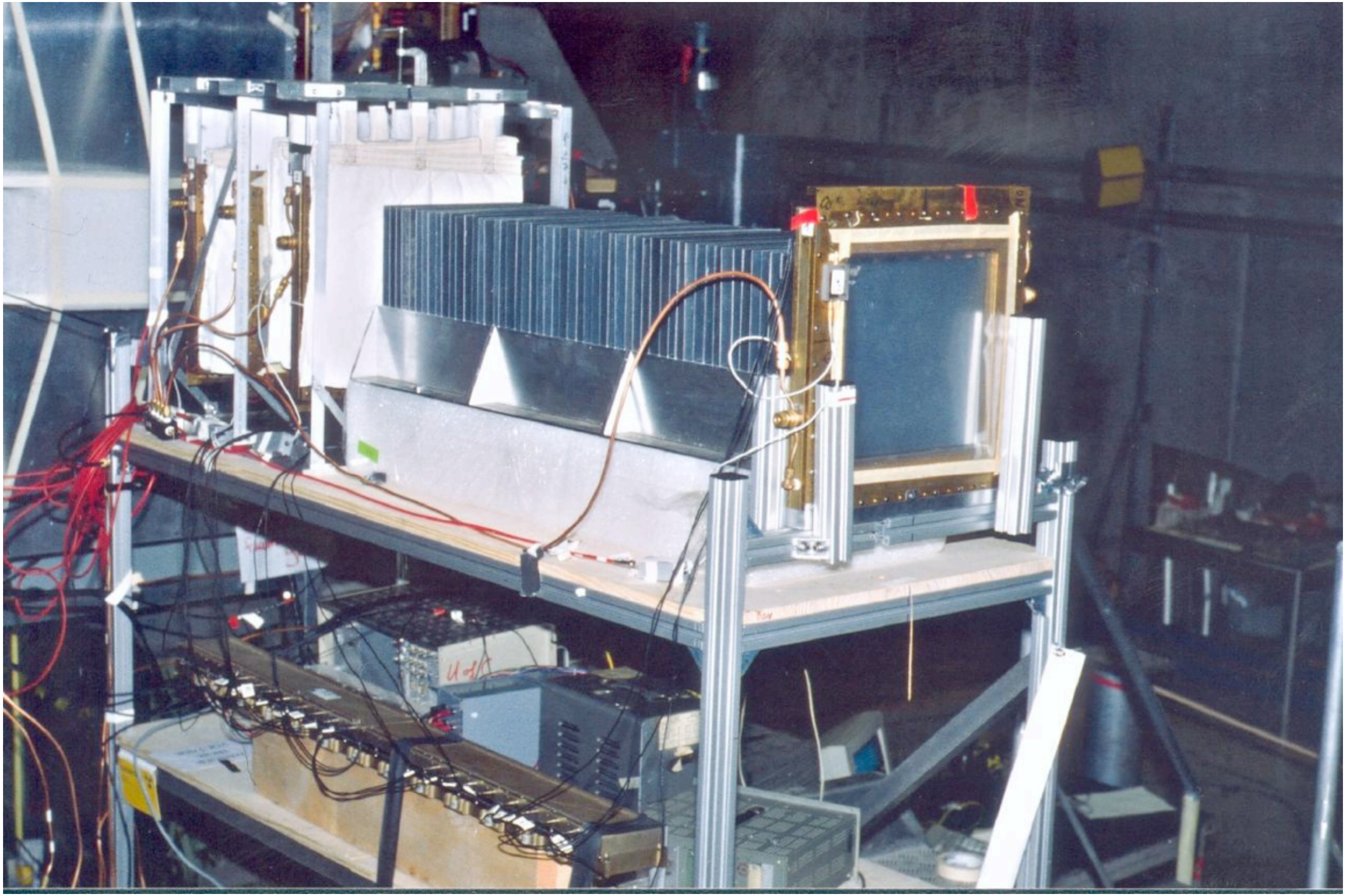
photoelectric effect $\sigma \propto Z^5$

→ big cross section for gas with large Z

→ Xe


Xe CH4
transition radiation
signal
relativistic rise (Bethe Bloch)
Lorentz factor γ

# TRD test at CERN



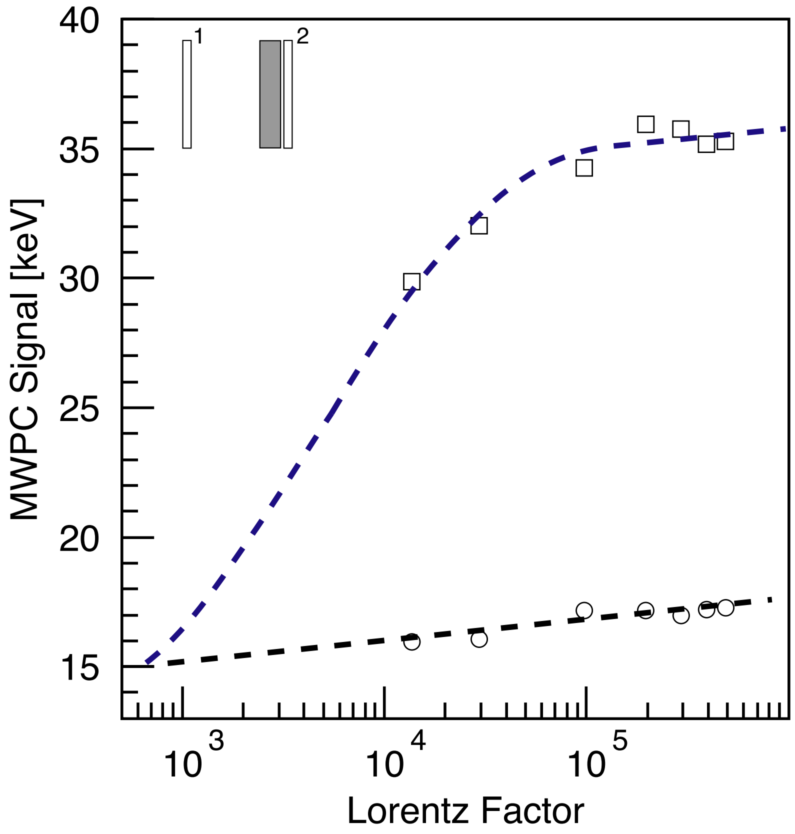
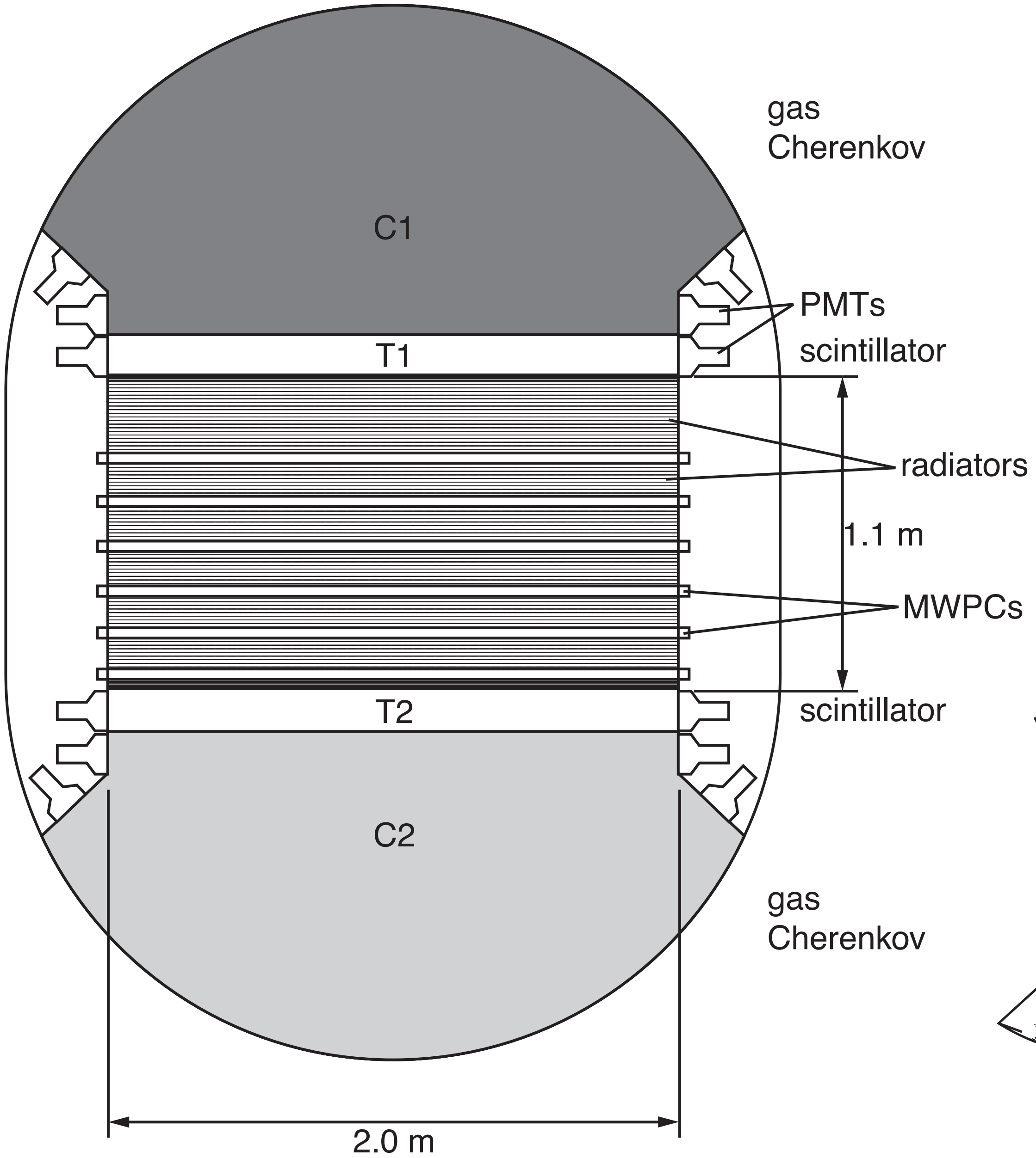
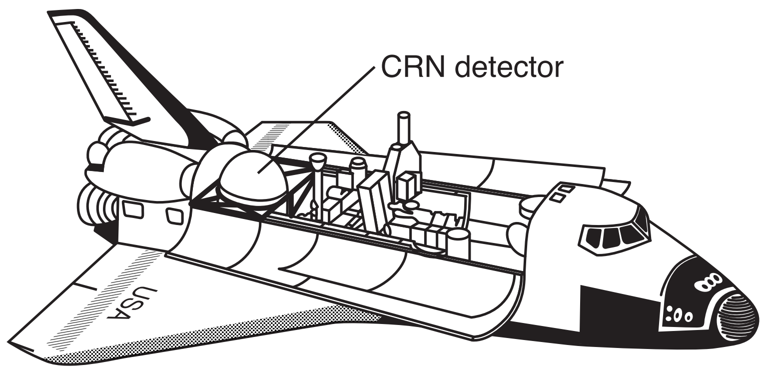



Fig. 8. Average detector signal versus Lorentz factor for a CRN-like radiator configuration. The open circles are data from MWPC 1, and the open squares are from MWPC 2, as shown in the inset schematic. The dashed lines serve to guide the eye.

**Transition**
**Radiation**
**Detector**

# Cosmic Ray Nuclei instrument - CRN



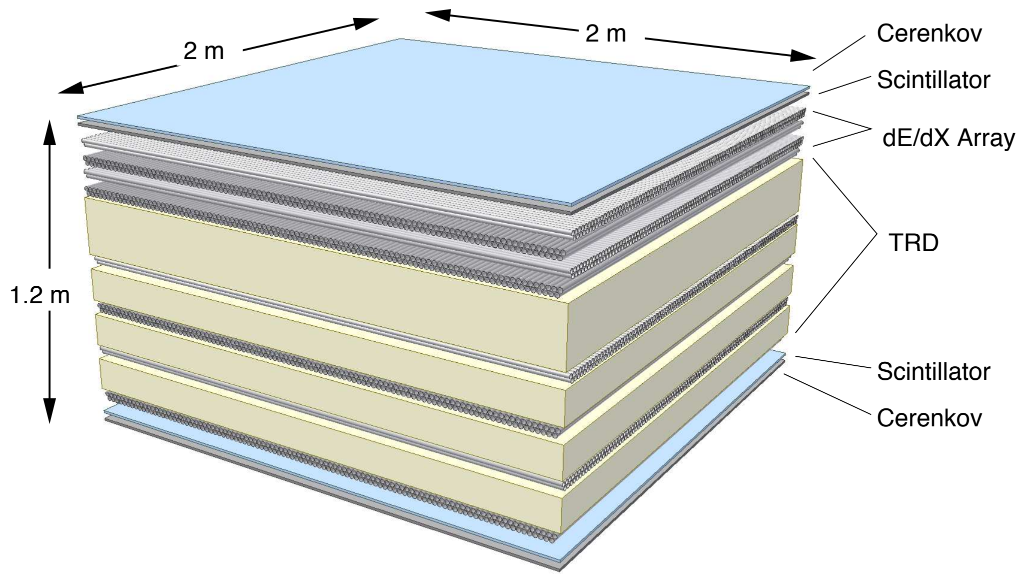



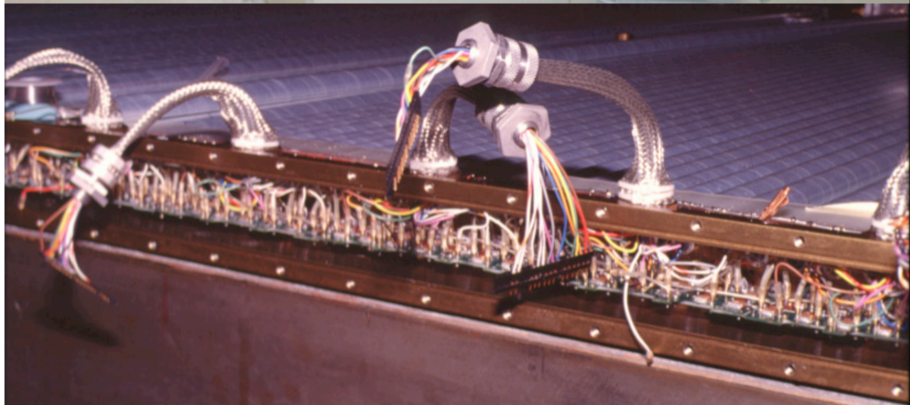

**Challenger 1985**

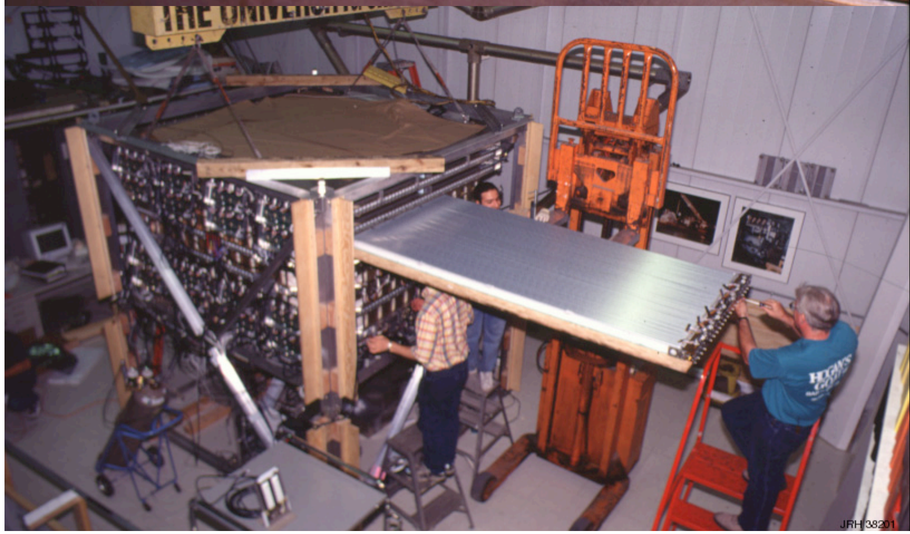
# TRACER experiment

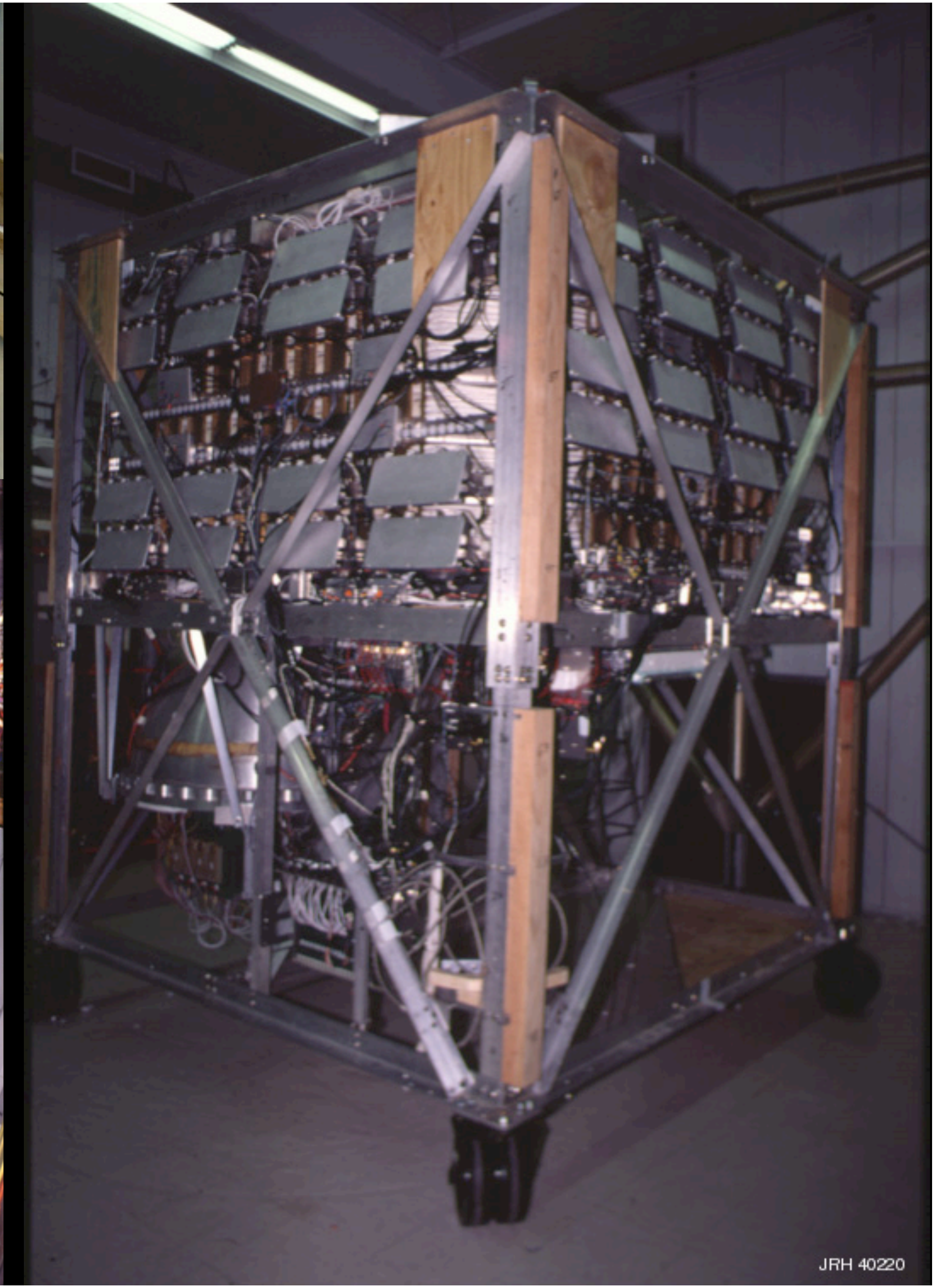
## TRACER Overview

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





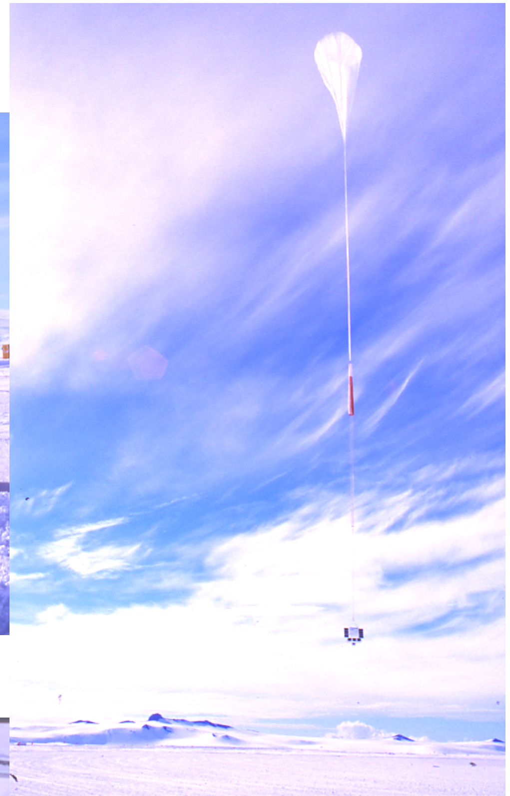

JRH 38291

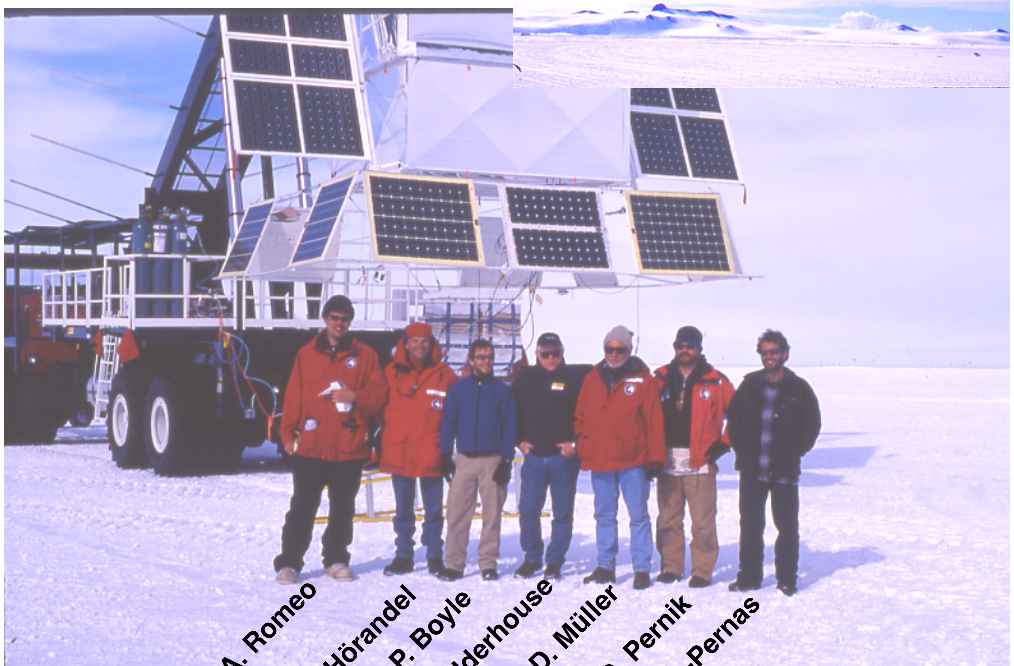

JRH 40220

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



# TRACER Experiment





A. Romeo
J.R. Hörandel
P. Boyle
G. Kelderhouse
D. Müller
D. Pernik
M. Ave-Pernas

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

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

$\phi$ 130 m

total mass ~ 5 t

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

<u>charge measurement</u>

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

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

# TRACER - measured charge distribution

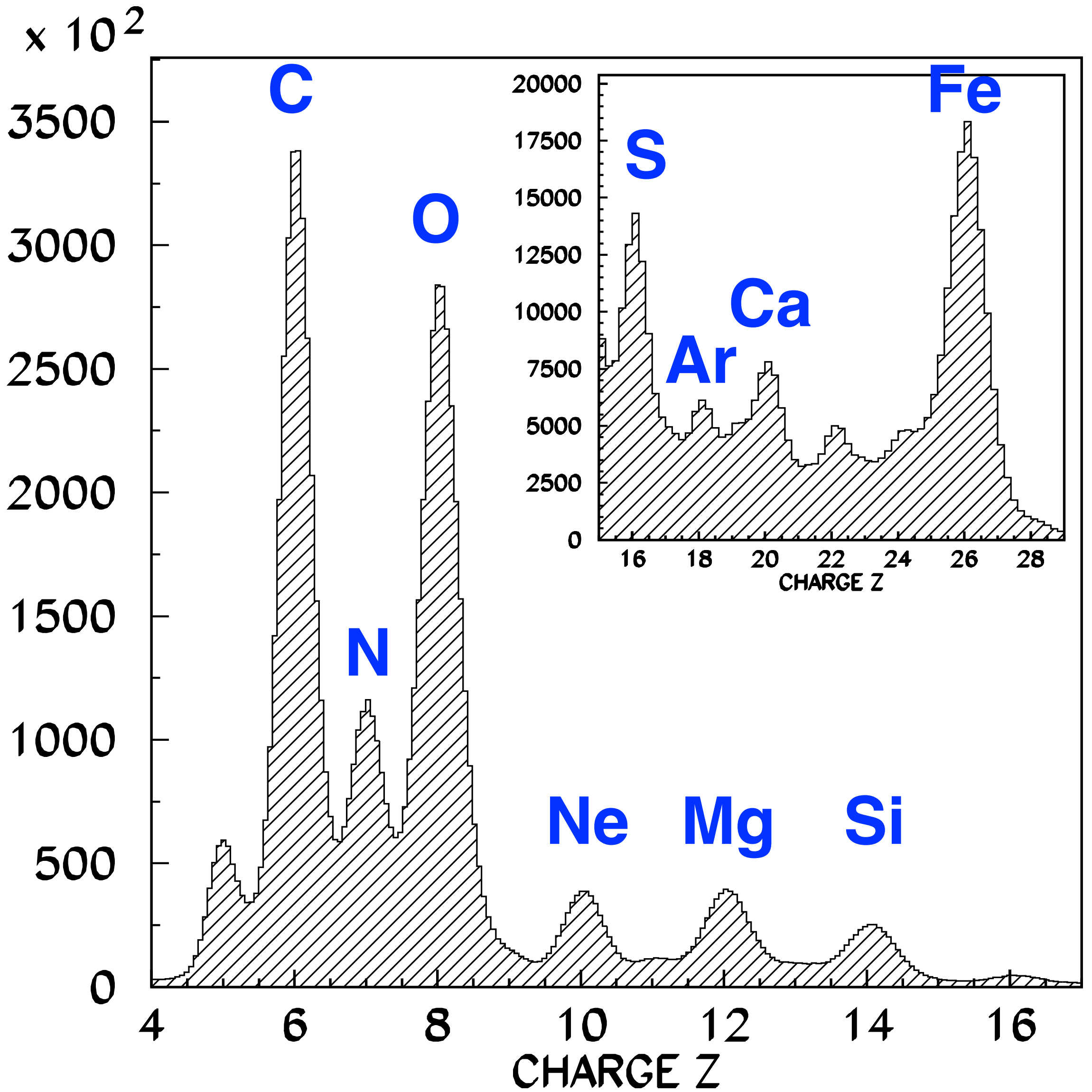



FIG. 5.—Charge histogram for all events measured in flight.