From First TR Studies to HELIOS TRD

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Outline

- Context
- Spatial separation of TR and dE/dx
- Cluster Counting method
- HELIOS TRD
  - Design
  - Performance
- Conclusions

The Q-method

- Boris Dolgoshein got interested in TR studies in late seventies
  - At that time the dominant method was a simple total charge measurement (the Q-method) when both dE/dx and TR were measured together
  - Q-method drawbacks:
    - Integration time of readout electronics has to be much longer than a total drift time (~1 microsecond)
      - impossible to use TRD in fast trigger
    - The dE/dx fluctuations are not suppressed, which worsens the TRD rejection capabilities

TR R&D for HELIOS

- Before that B. Dolgoshein was involved in the τ-experiment at IHEP, Protvino, which detected excess of prompt muons
  - Other experiments detected prompt lepton excess as well
    - The proposed HELIOS experiment at CERN was to resolve the prompt lepton puzzle
      - It became a largest CERN SPS collaboration at time (about 200 physicists)
- Lepton trigger was required for HELIOS
  - Can the TRD be used for the trigger?
- A series of R&D studies were conducted to improve the TR detection methods
  - These studies investigated differences in transverse and longitudinal ionization deposition in the gas from the dE/dx and TR

Angle Between Particle Track and TR (Transverse Separation)

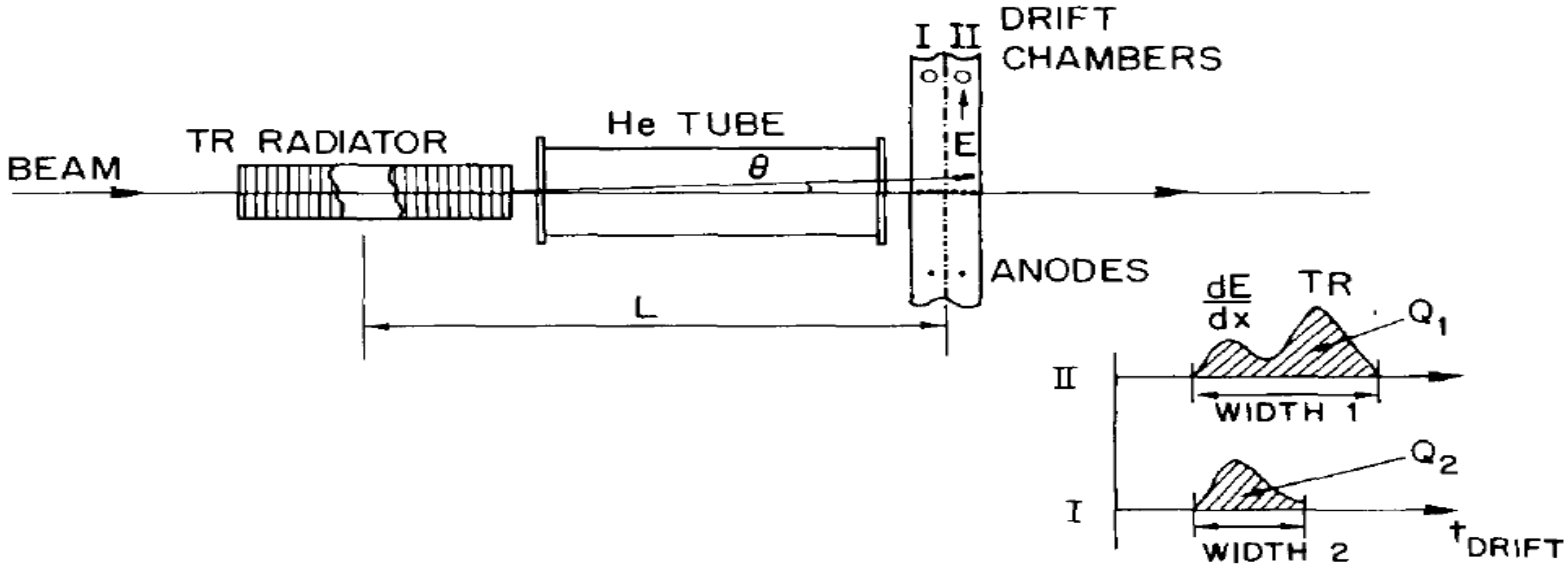
Three mechanisms for angular separation:

1. Angular emission of TR is rather small ~1/gamma
2. Multiple scattering in the radiator

   for e at 2 Gev/c the MS angle is ~10 times larger than the TR emission angle

3. Deviation of the charged particle in a magnetic field
   - This method of separation dE/dx and TR requires a long distance between the radiator and a chamber and therefore can not be compact
   - Nevertheless it may be used under specific conditions,
     - especially if radiator is installed in the magnetic field

Typical experimental setup to use differences in dE/dx and TR emission angles in respect to a particle track from NIM 180(1981) 409
The measurements used both total charge and a transverse width of a signal (as an angular information) to improve the TRD rejection



Experimental set-up. The picture at lower right illustrates the transverse drift method of the detection TR

In the experiment only one radiator-chamber module was installed at the beam, measurements were used to calculate pi-K and pi-e rejection for multi-chamber setup

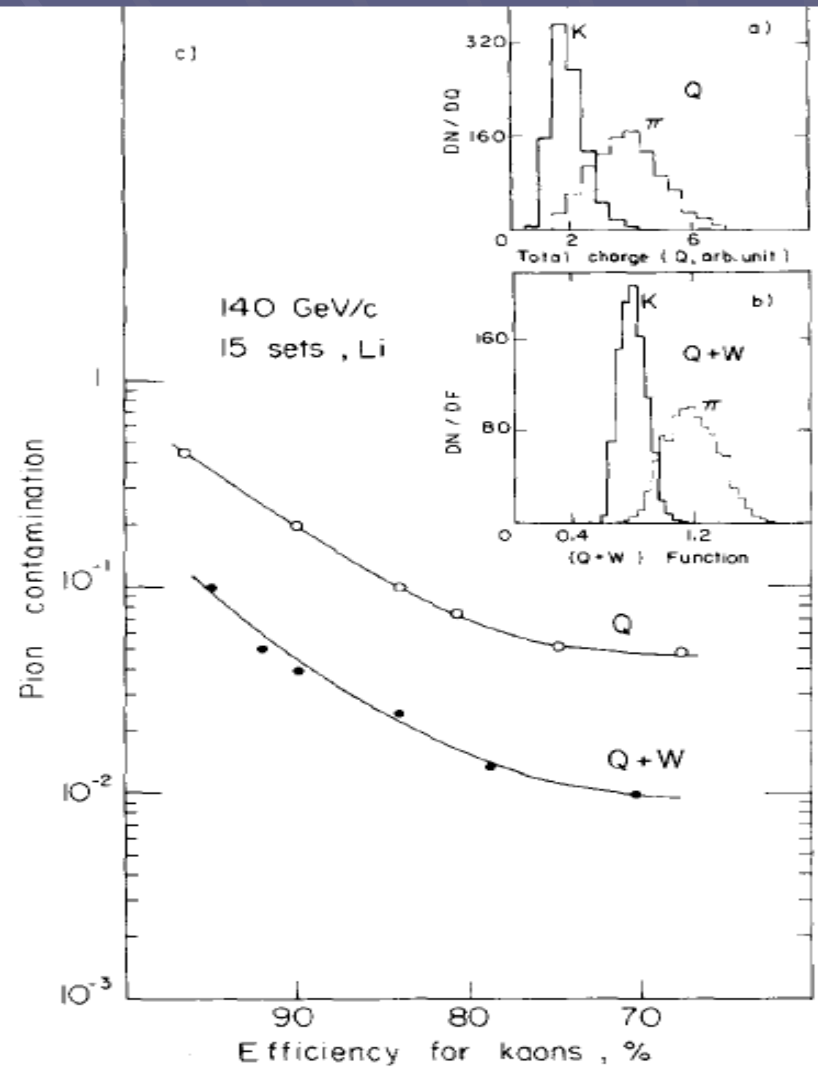


Fig. 6. Pion–kaon separation by two methods (Q, and $Q + W$)

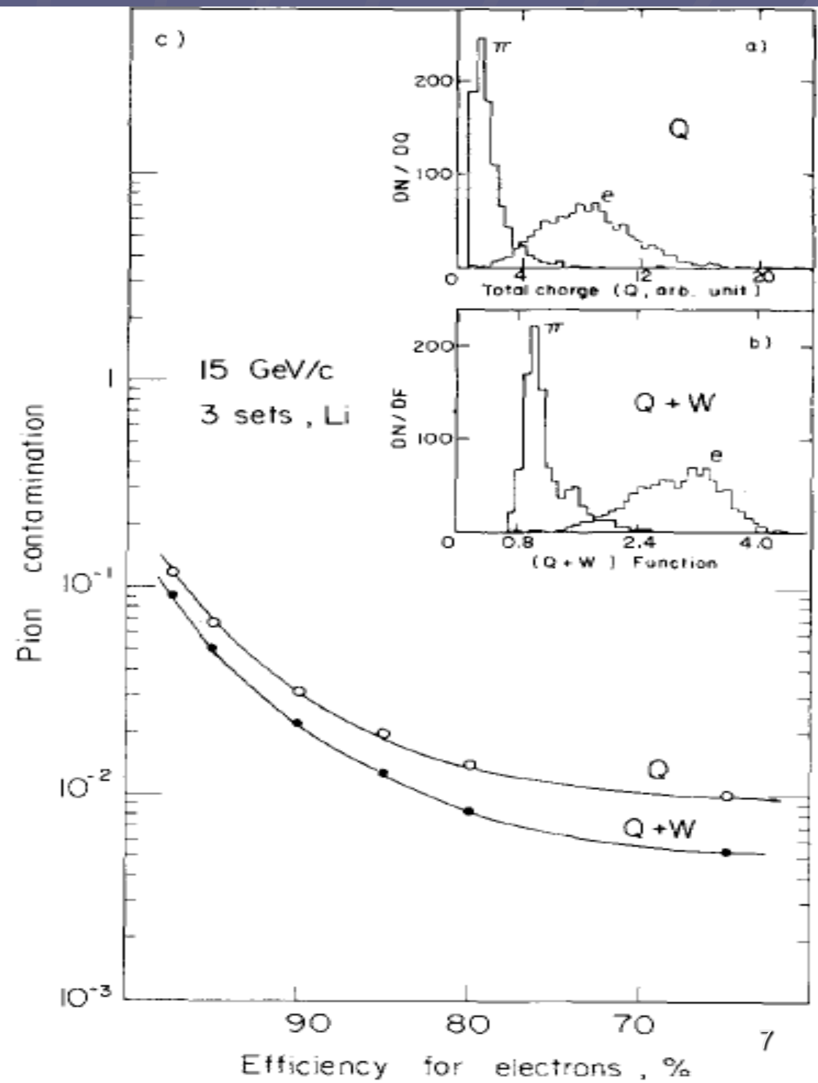


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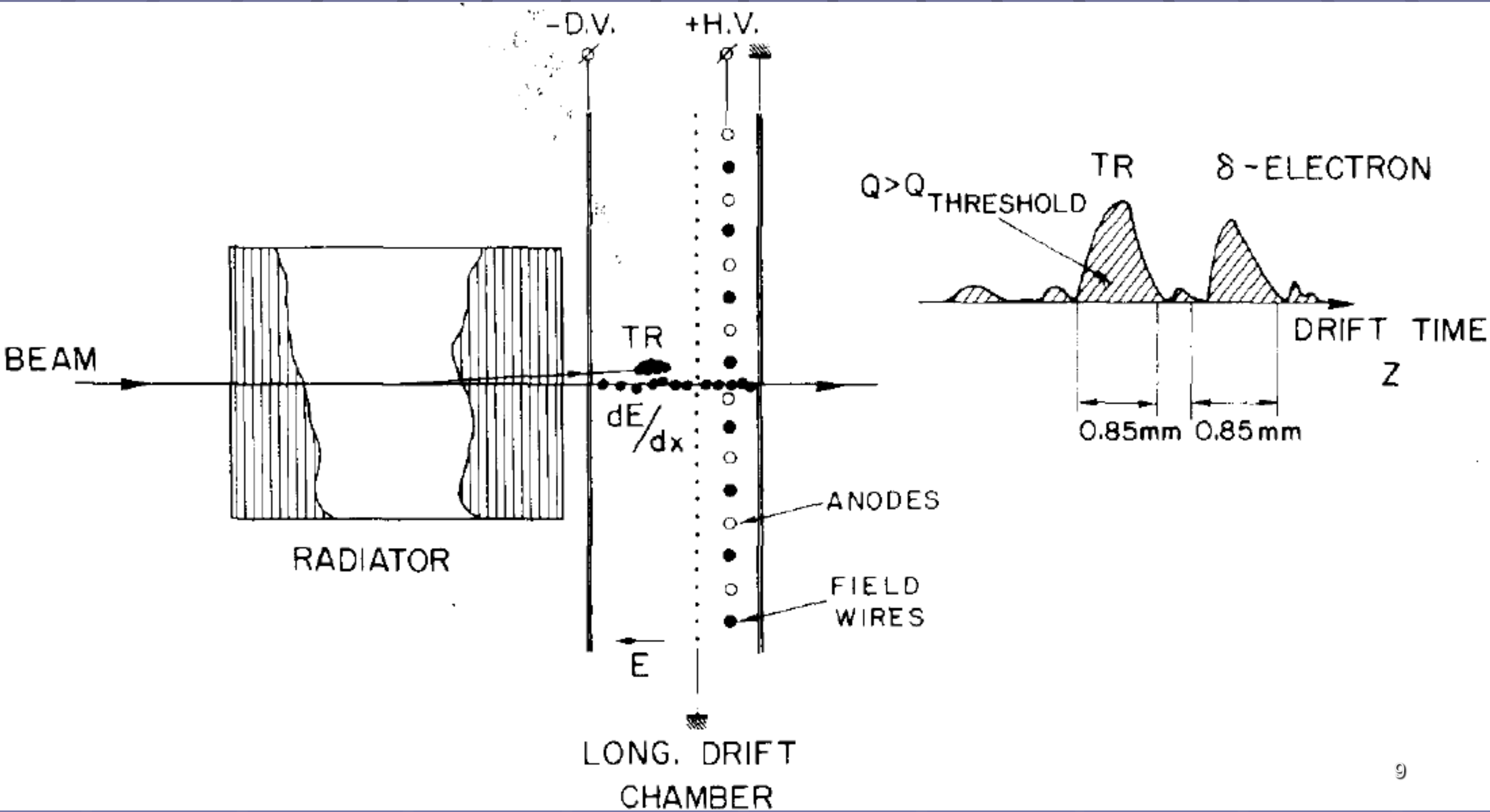
Fig. 7. Electron–pion separation by methods Q, and $Q + W$

Cluster Detection along Particle Ionization Track

- Ionization density is different for particles and TR photons:
  - Particle ionization is distributed uniformly along the track (except the δ-e)
  - Ionization from TR photons in the gas is localized in a small space, which produces clusters of charge
    - In addition TR photons are not uniformly absorbed along the drift distance, but are located mostly near the input window

For the first time the cluster method was used in the paper NIM 180 (1981) 413



Experimental Setup

Radiator – 30 micron lithium, 200 micron gap in He

Longitudinal drift chamber

- drift space: 10 mm
- anode-cathode gap: 3 mm
- anode spaced by 6 mm
- gas gain: 10^4

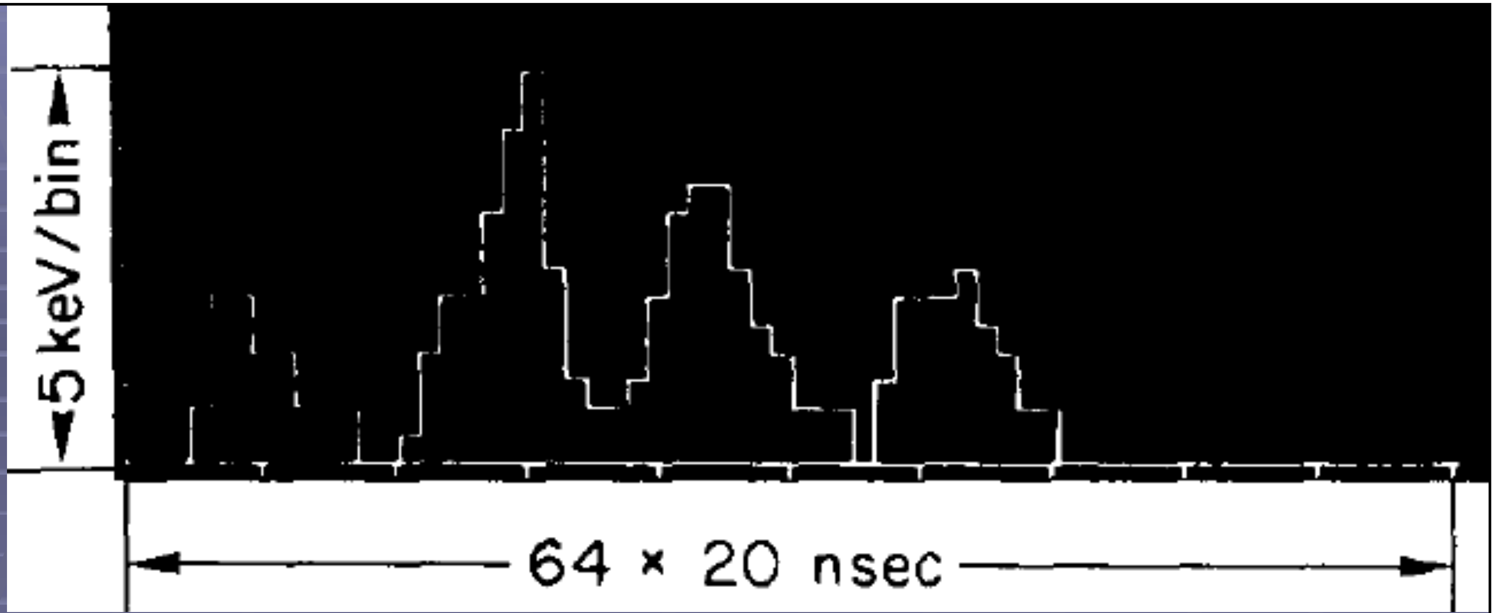
Gas: 70%Xe+30%CO2, at Edrift=0.65 kV/cm

- i/vdrift=116 ns/mm

Readout included fast amplifier and 64x20 ns FADC

20 m long Cherenkov counter provided tagging of 40-140 Gev pi (98% of the beam) or 15 Gev e (50%)

Typical event for 15 Gev e



Cluster distribution along track for 1000 events

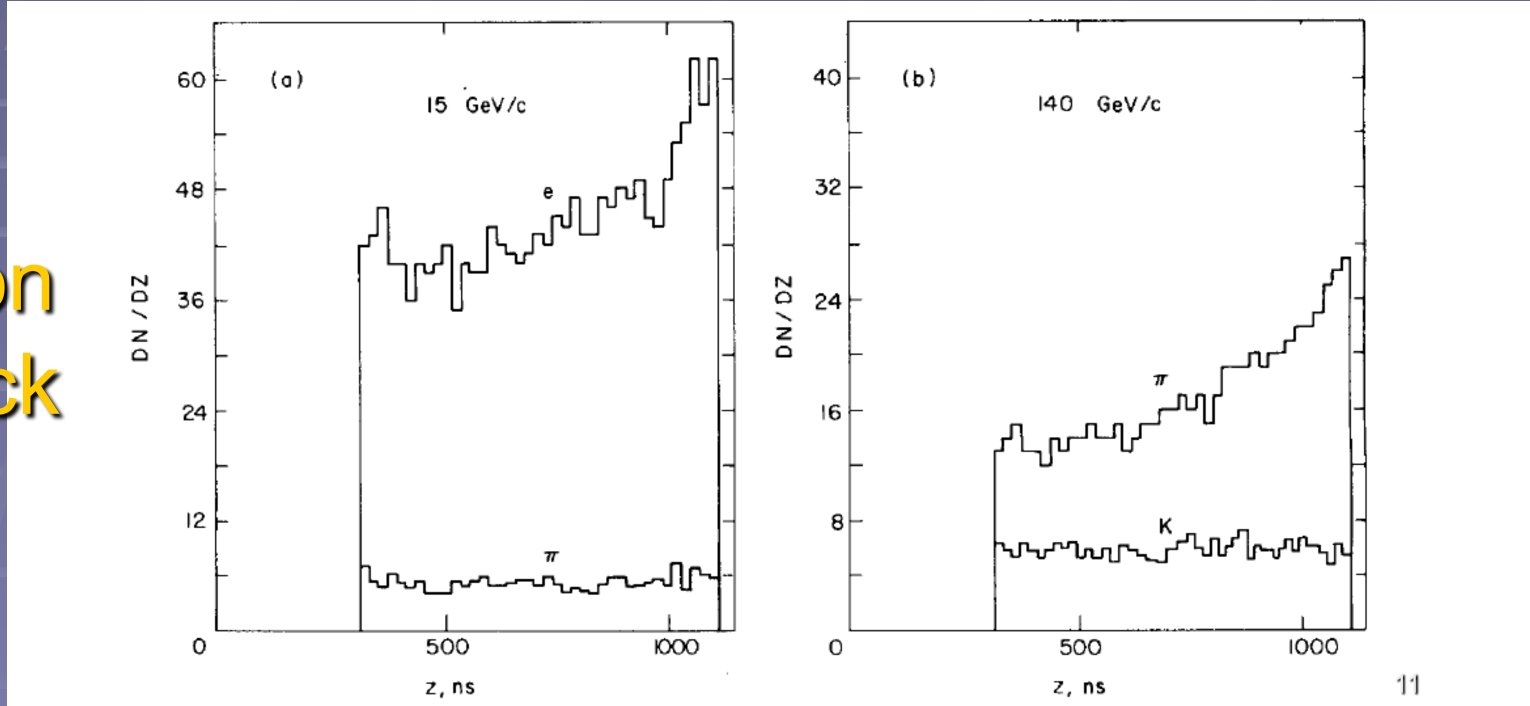


Fig. 4. The distribution of cluster number with energy $E_{cl} \geqslant 2$ keV along the track, for 1000 incident particles. One bin in the histogram represents 170 μm.

All Methods Were Used for Particle Identification

- Conventional (Q)
  - total charge measurement
- Cluster-counting (N)
  - N=N(Ecl>Ethr)
- Maximum likelihood method (W)
  - W(Ecl,z) is a probability of cluster creation with energy Ecl at gas depth z

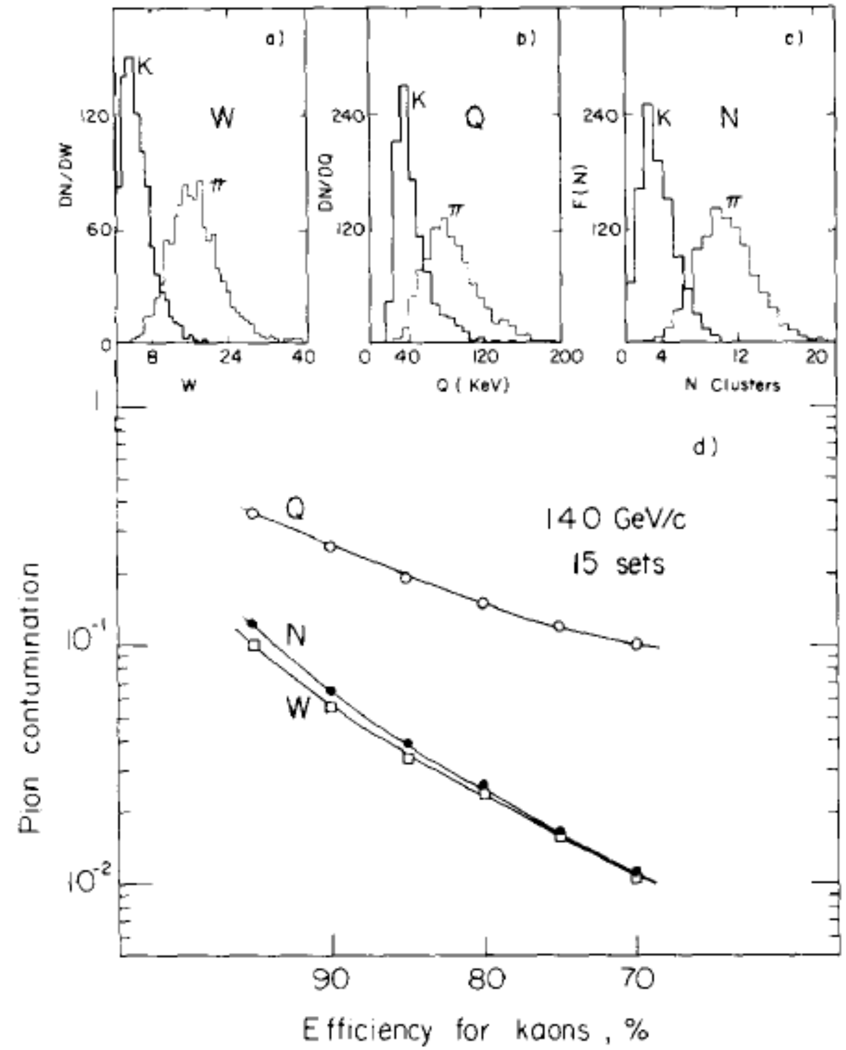


Fig. 7. Pion–kaon separation by different methods, with the "free bin" method of cluster definition: (a) Identification function method, *W*. (b) Total energy measurement, *Q*. (c) Cluster counting, *N*.

Conclusions of the Study

- Cluster counting method (N) is superior to the total charge method (Q)
- However, in this study the gas thickness in the chamber was not optimal for the Q-method
- Likelihood method (W) did not show a large enough improvement to became practical

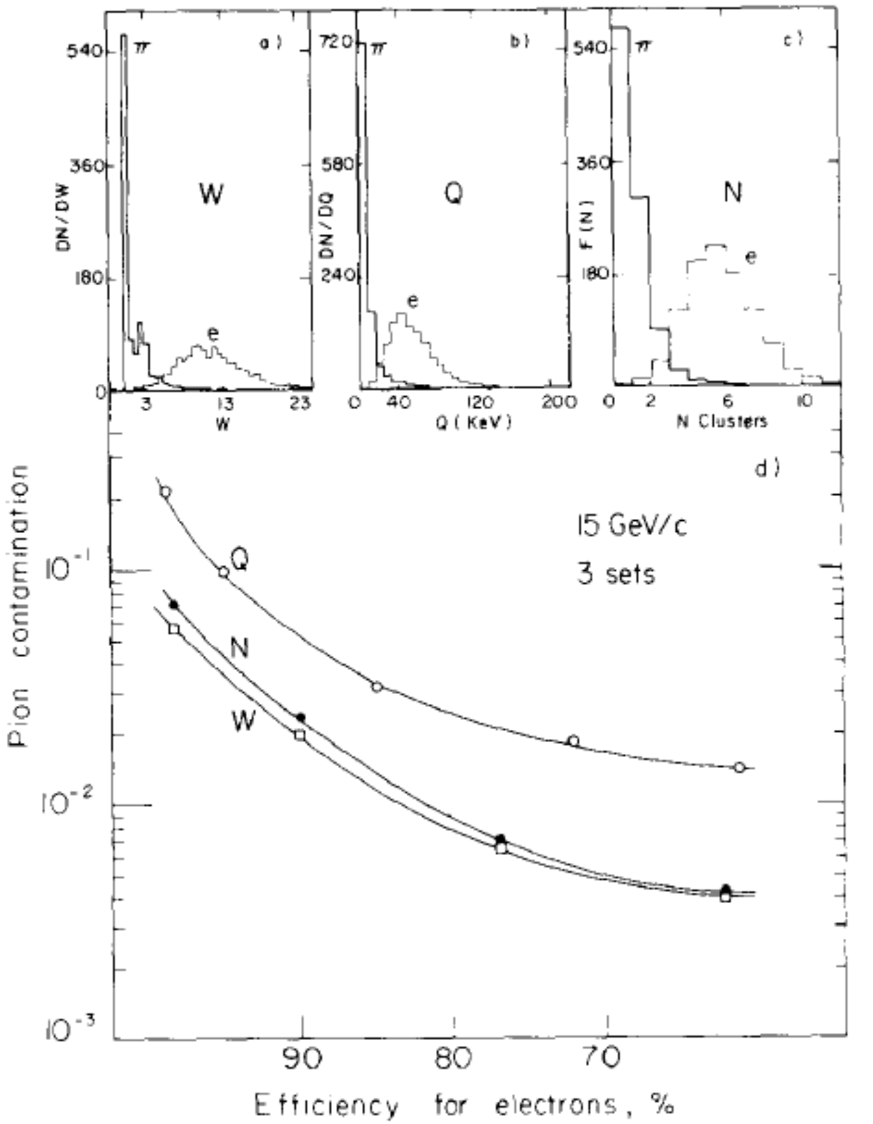
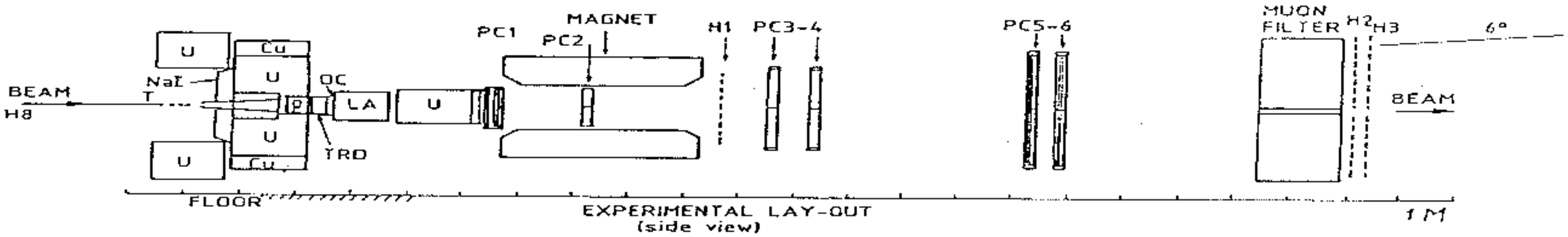
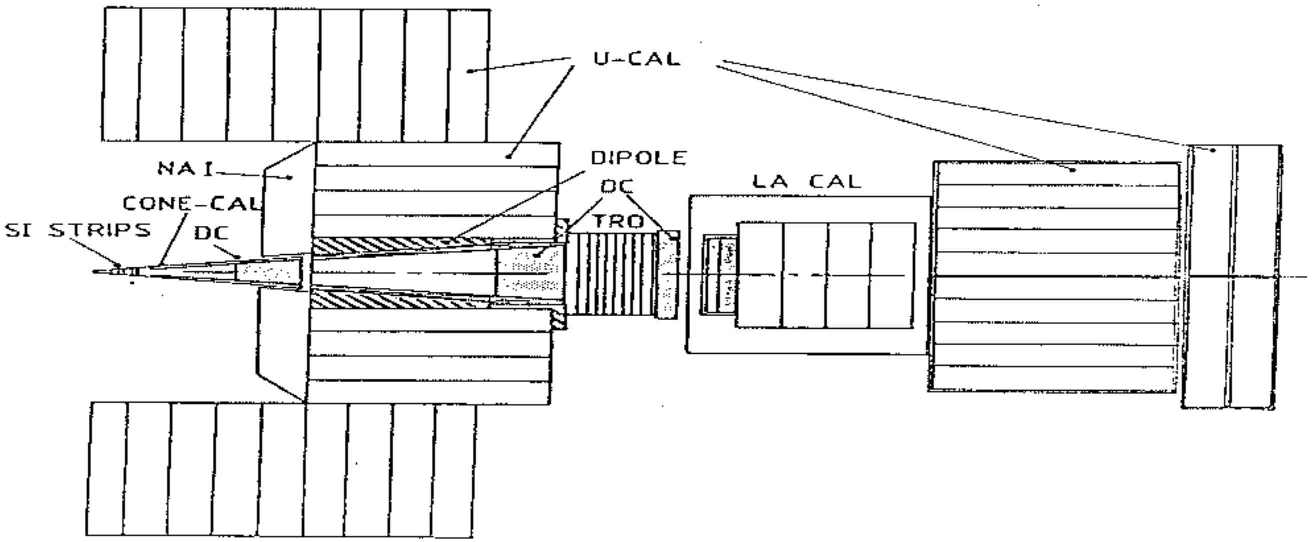


Fig. 8. Pion–electron separation by means of three methods (Q, N, W), using the "free bin" method of cluster definition.

NA-34 EXPERIMENT HELIOS
(High Energy Lepton and Ion Spectrometer)

Prompt lepton trigger requires highly sensitive electron identification
For electron trigger both a U Liquid Ar Calorimeter and a TRD were used





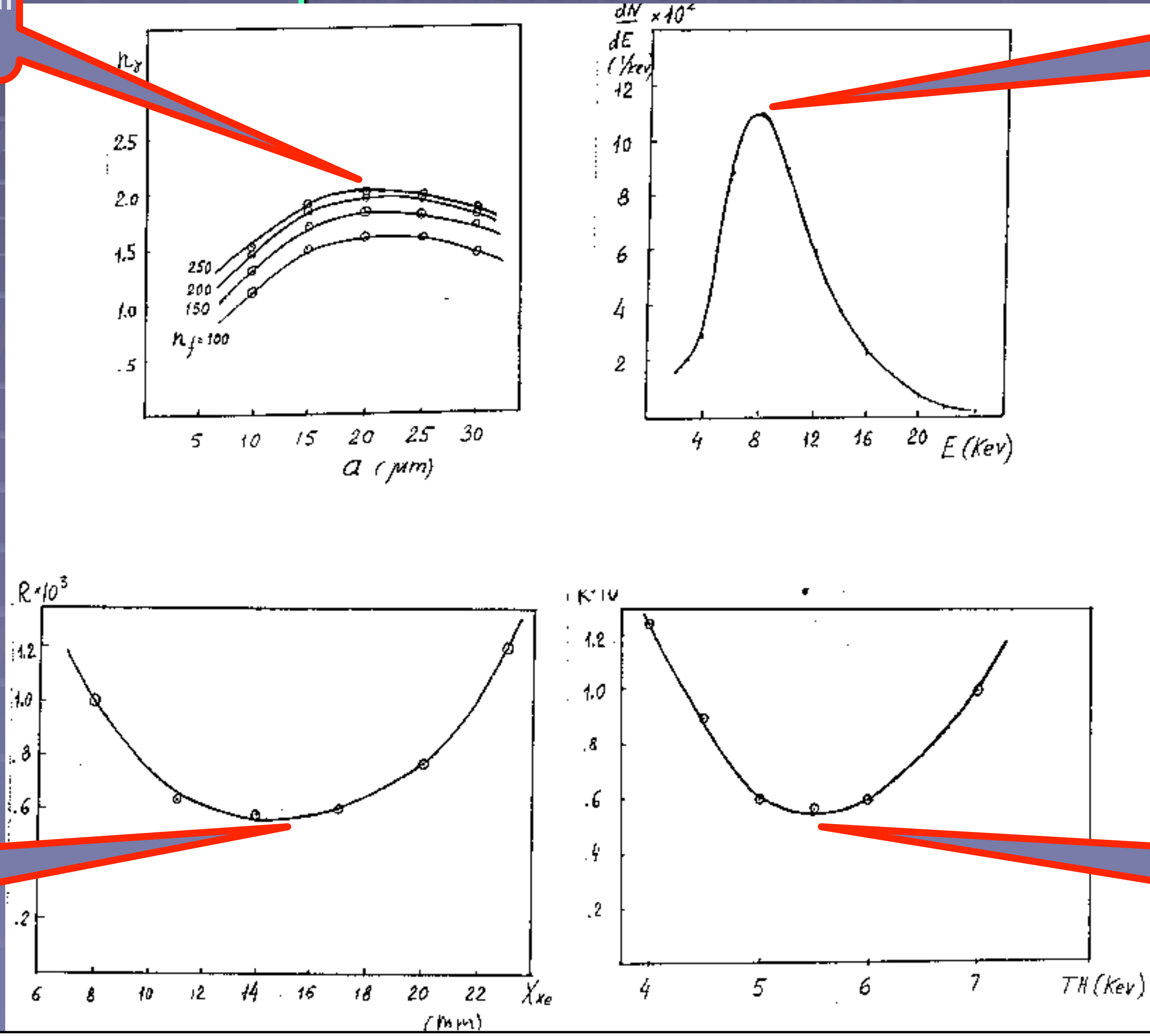
Cluster counting was implemented for the first time in a TRD of the physics experiment HELIOS (NA-34)

- Also HELIOS was the first example, where TRD is used at the same time as a tracker
- TRD has eight radiator-detector modules with anode and cathode strips readout, its total length was 70 cm
- Every radiator has length 64 mm and contains 250 polypropylene (CH2) foils
  - The thickness of 150 nearest to chamber foils was 20 micron, the rest foils were 30 micron thick
  - Gap between foils – 230 micron
- Such foils configuration increased TR yield by 6%

Here we present some results of optimization parameters of radiator

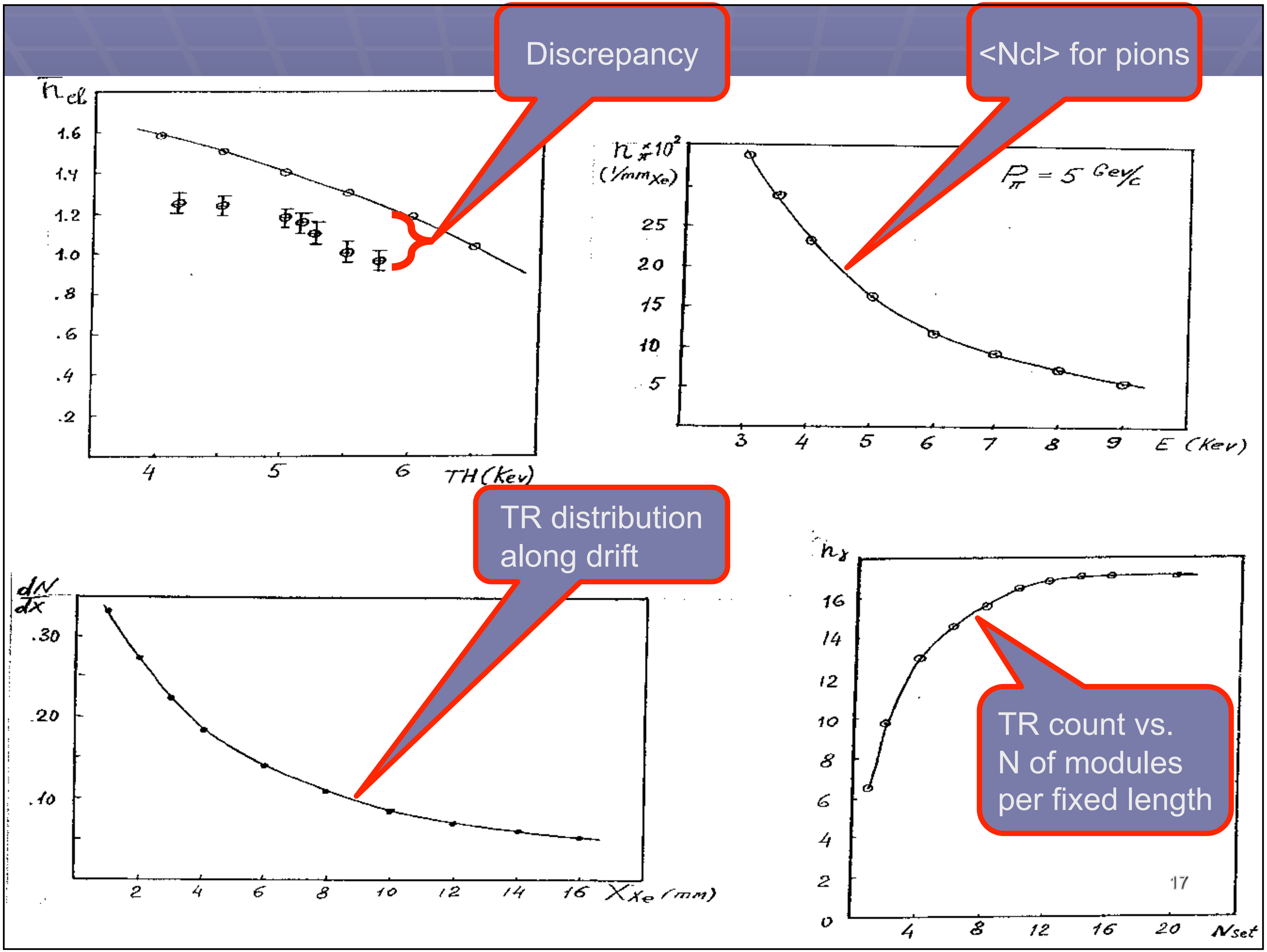
Optimal foil thickness

Peak TR energy



Optimal Xe gap

Optimal E-thresh


Discrepancy
<Ncl> for pions
TR distribution along drift
TR count vs. N of modules per fixed length
TH (Kev)
E (Kev)
$P_\pi = 5$ Gev/c
X_{Xe} (mm)
N_{set}

HELIOS TR Chamber

The longitudinal drift chamber is more suitable for ionization cluster counting:
-clusters concentrate in a small space defined mainly by diffusion
- clusters that arise from TR and delta-e, dE/dx practically do not contribute to a total charge of cluster

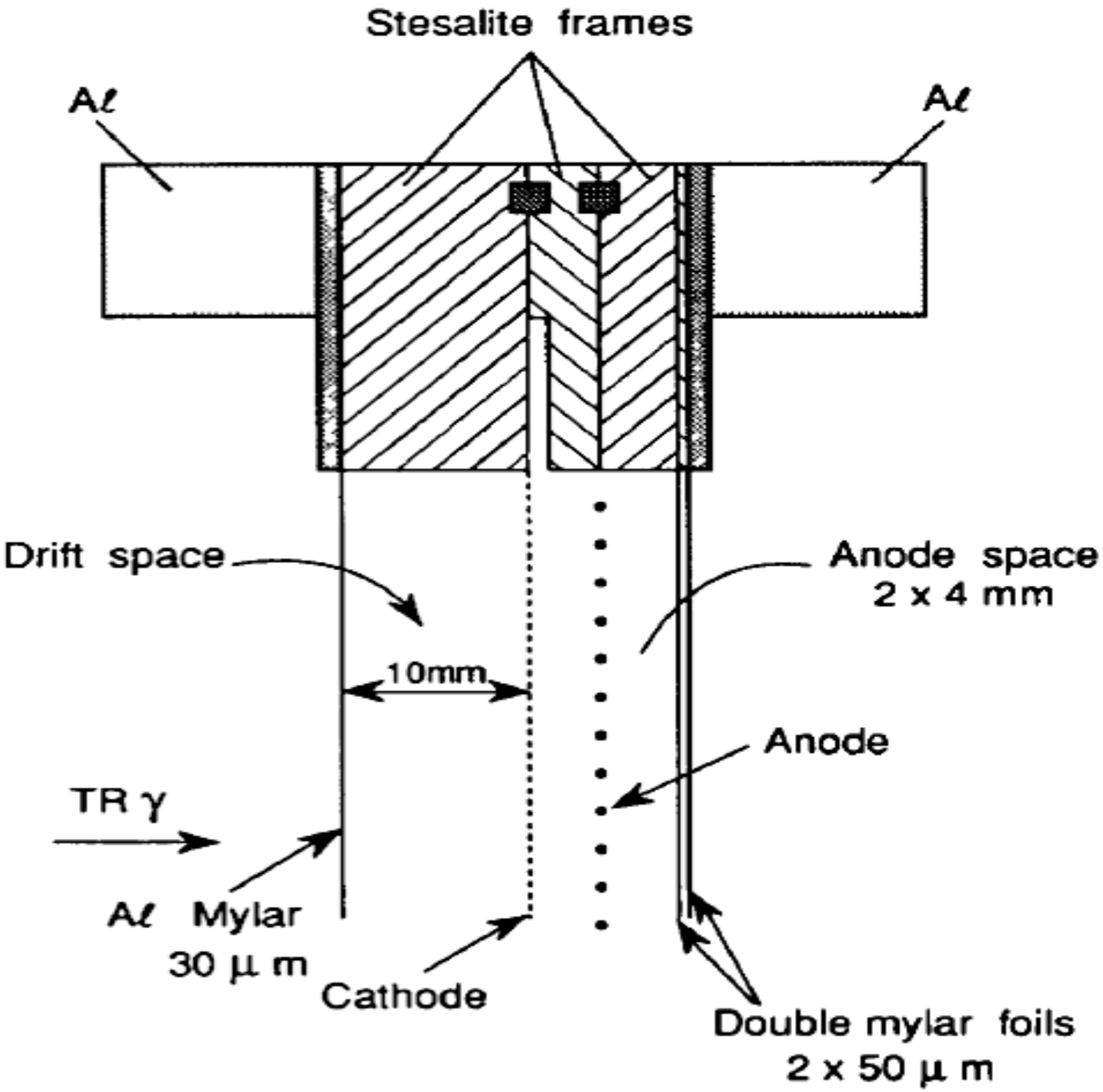
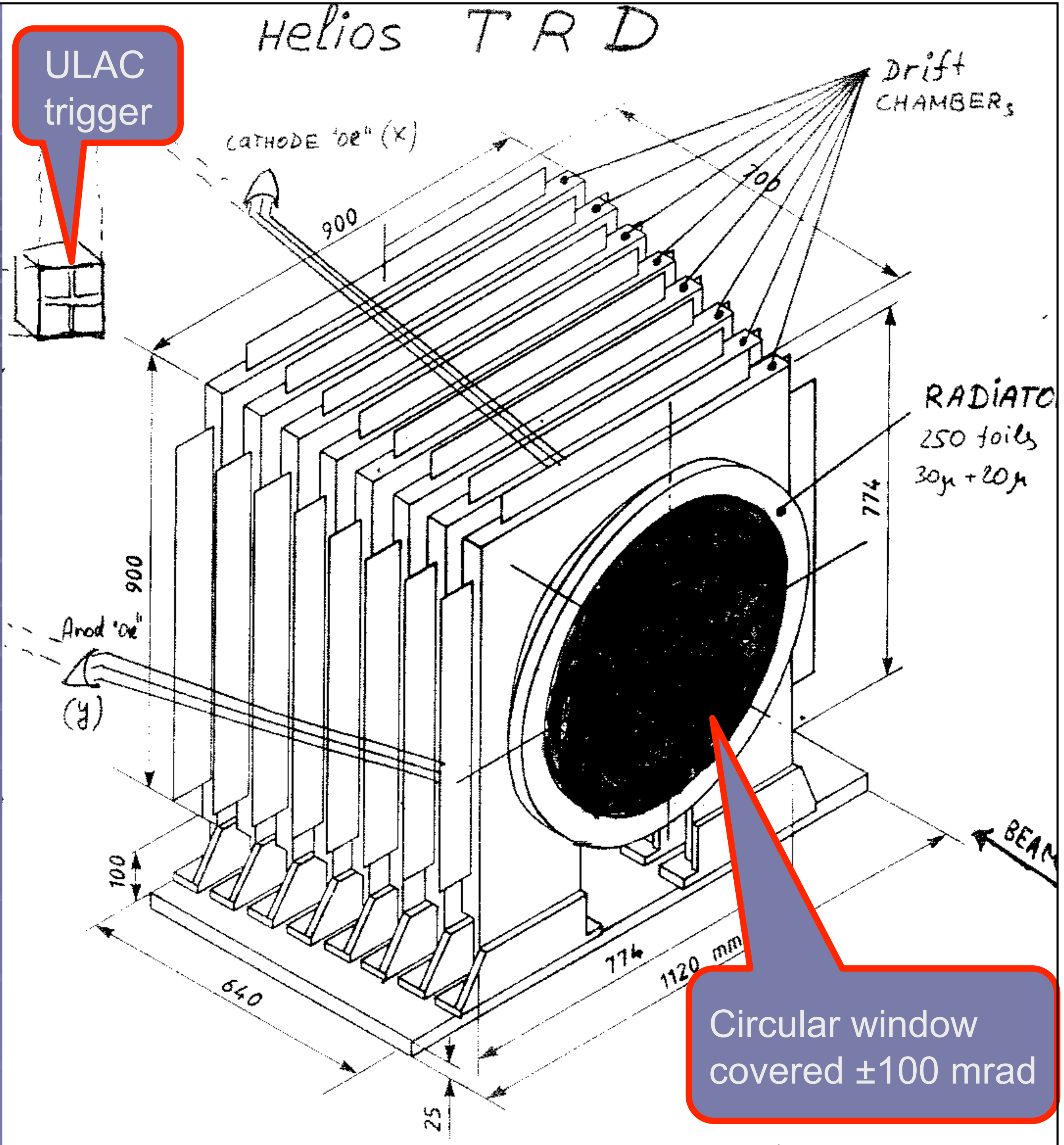
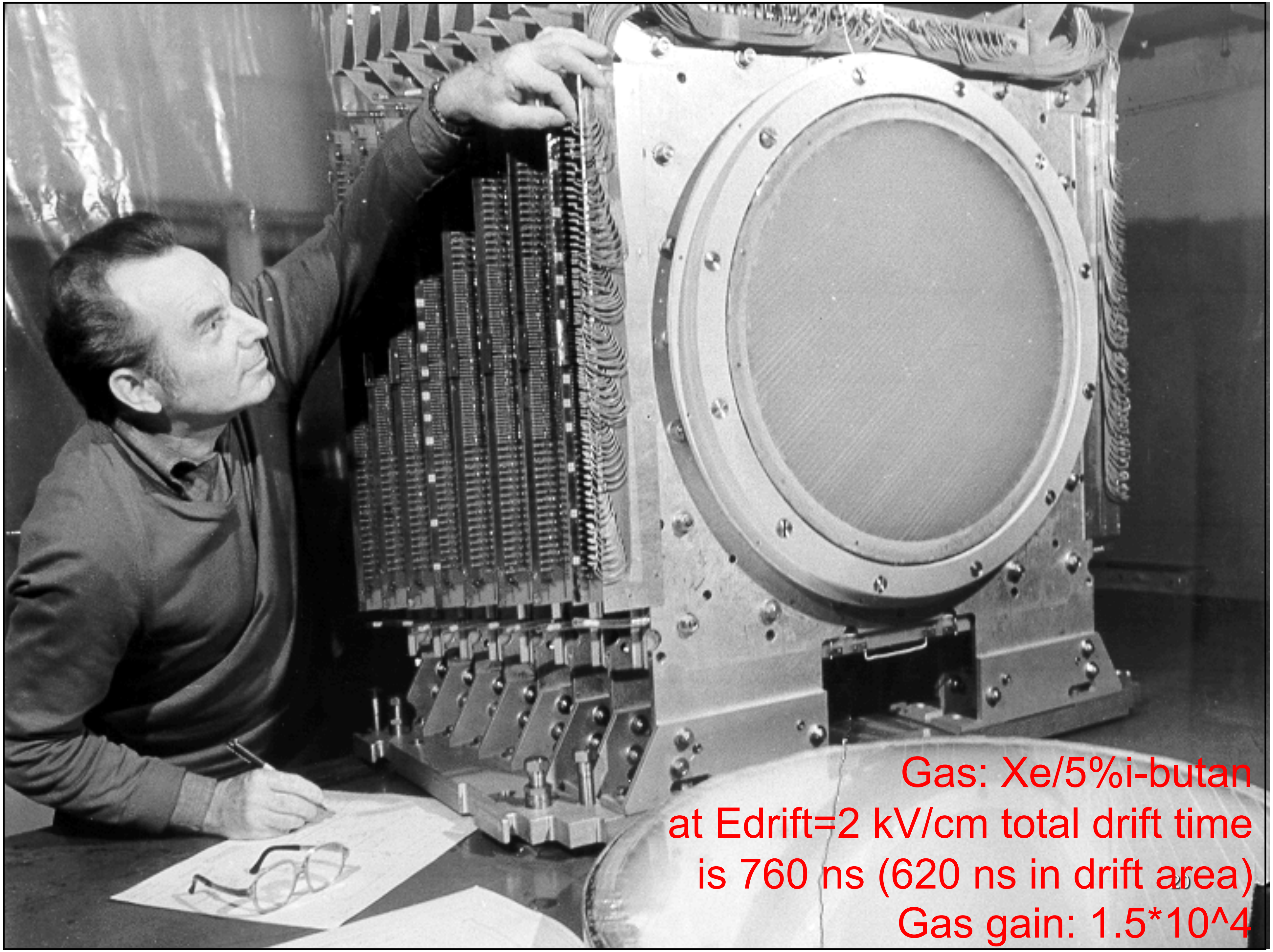


Fig. 34. The design of HELIOS TR chamber with the double cathode window: the internal window is flat; the sag of the external window does not influence the uniformity of the cathode–anode field.

HELIOS TRD had projection geometry in order to point to the 50 micron target Therefore anode and cathode pitches were varied from module to module: 2.3 mm to 2.8 mm for anode wires, 4.6 mm to 5.6 mm for cathode strips




Gas: Xe/5%i-butan
at Edrift=2 kV/cm total drift time
is 760 ns (620 ns in drift area)
Gas gain: 1.5*10^4

TRD Performance at High Multiplicities

- So far we discussed isolated particles
  - In real experiments the multiplicity of secondary particles is high and the rejection power of TRD is quite different
- In this case it is needed to localize the particle track and count one or two clusters nearest to anode and cathode
  - For best results in offline external drift chambers and Si-pad detector were involved for targeting
- Optimal width of ‘counting clusters road’ contain two anode and one cathode (for one anode –20% clusters are lost)
  - Even in this case the probability to find more than one particle in one TRD element was still high
    - This is main reason a degradation rejection power under this condition
- Next two slides show some results obtained in HELIOS experiment

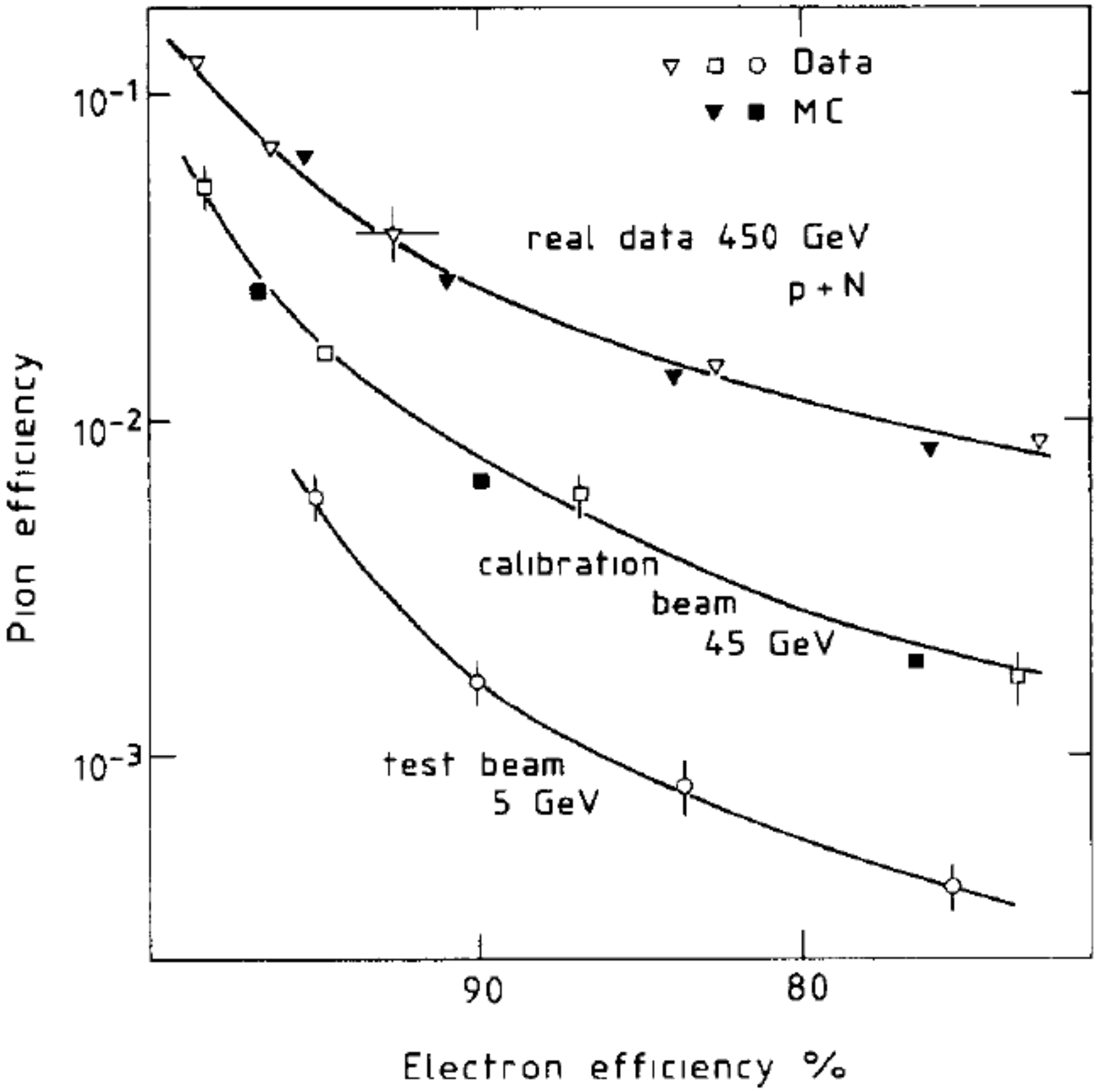


Fig. 51. Pion suppression of the HELIOS TRD under different conditions.

Nevertheless rejection of HELIOS TRD in case p-Be interaction at 450 GeV/c still is 2.5*10^-2
It provided a pure enough sample of non–isolated electrons

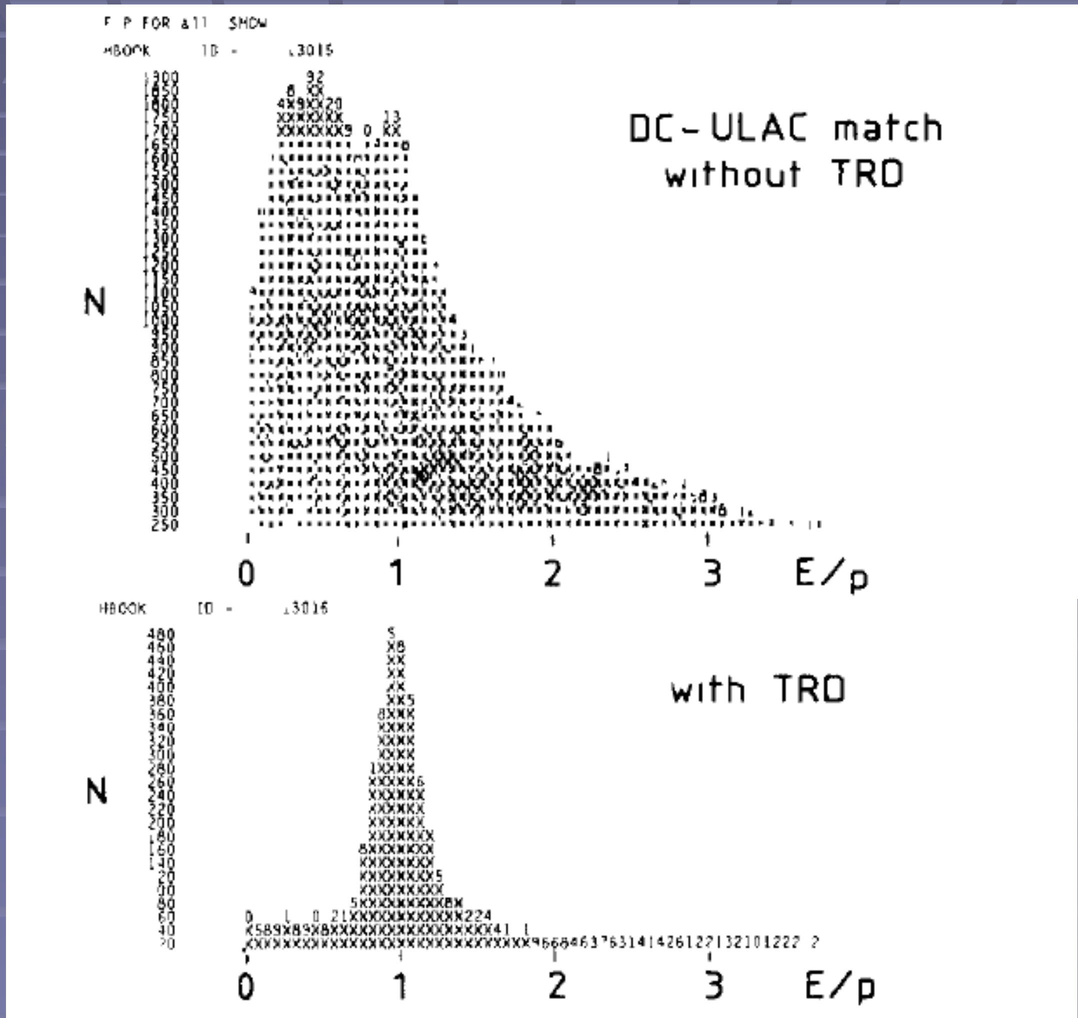


Fig. 52. Cleaning of electron candidates as seen without TRD (a) and with the HELIOS TRD (b) in p + Be interactions.

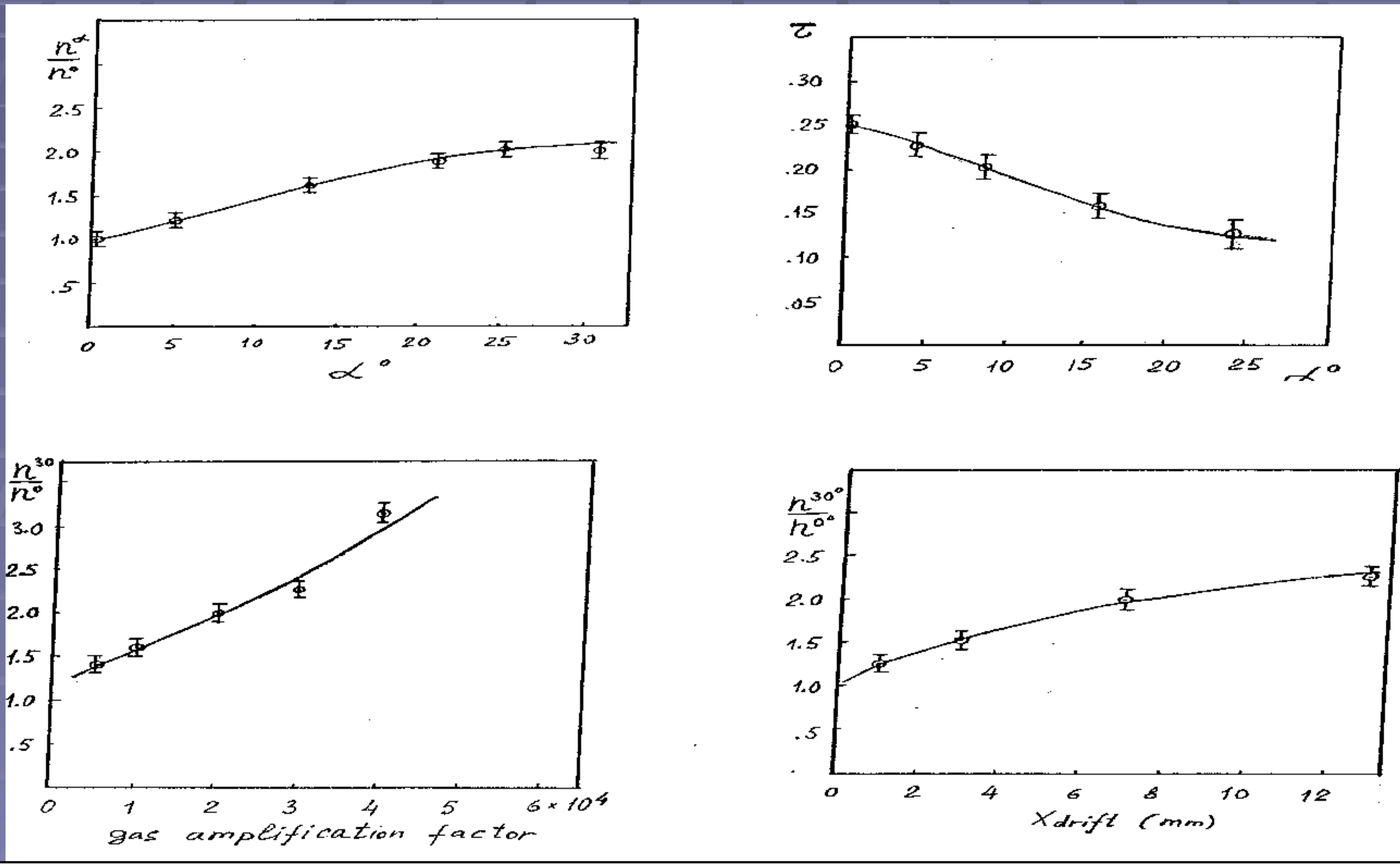
Conclusions

- R&D studies led by B. Dolgoshein developed TRD techniques for HELIOS
  - A successful use of TRD in HELIOS paved a roadmap for further TRD/tracker development for the LHC
    - A subject of A. Romaniuok talk at this session

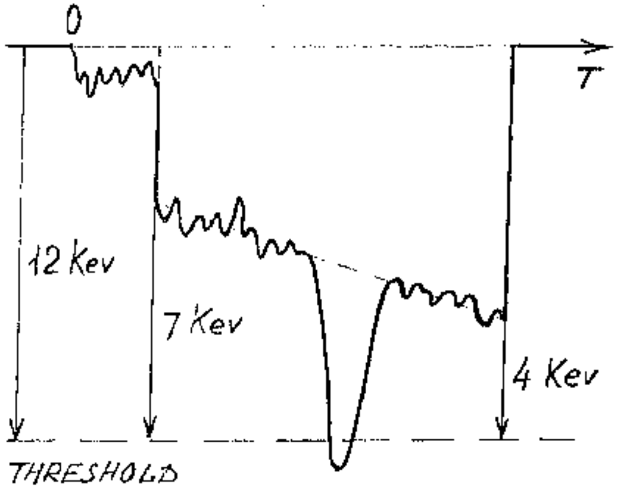
APPENDIX

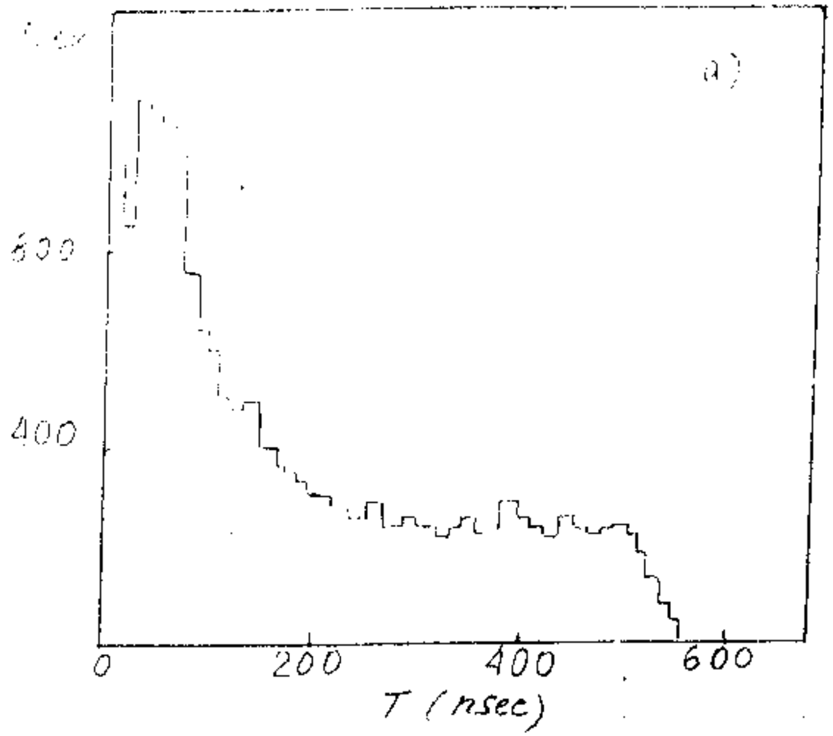
Cluster Counting Details

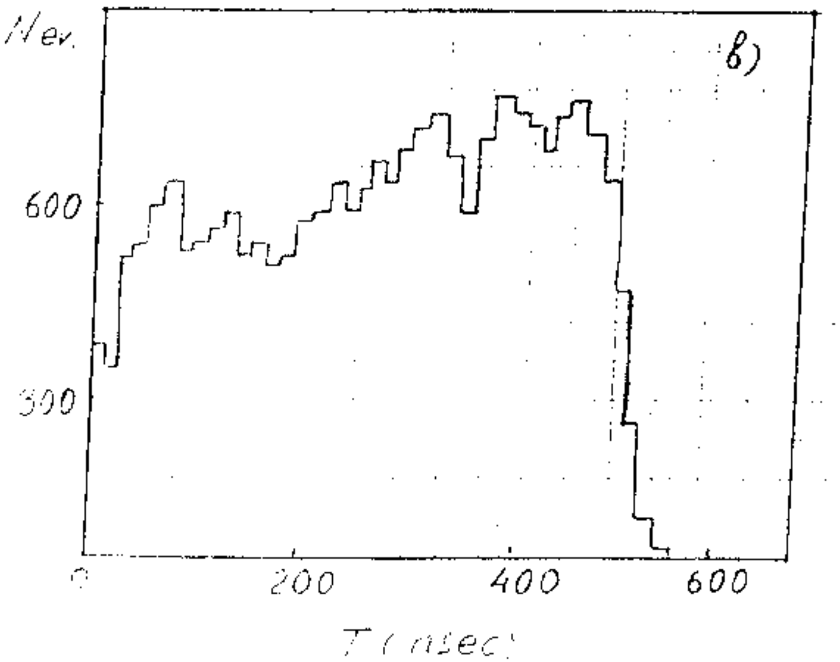
In wire chamber track ionization collected in a small region of the anode wire. After multiplication a density of positive charge is big enough to suppress gas gain. This local charge effect depends on gas gain and a track slope in the chamber.



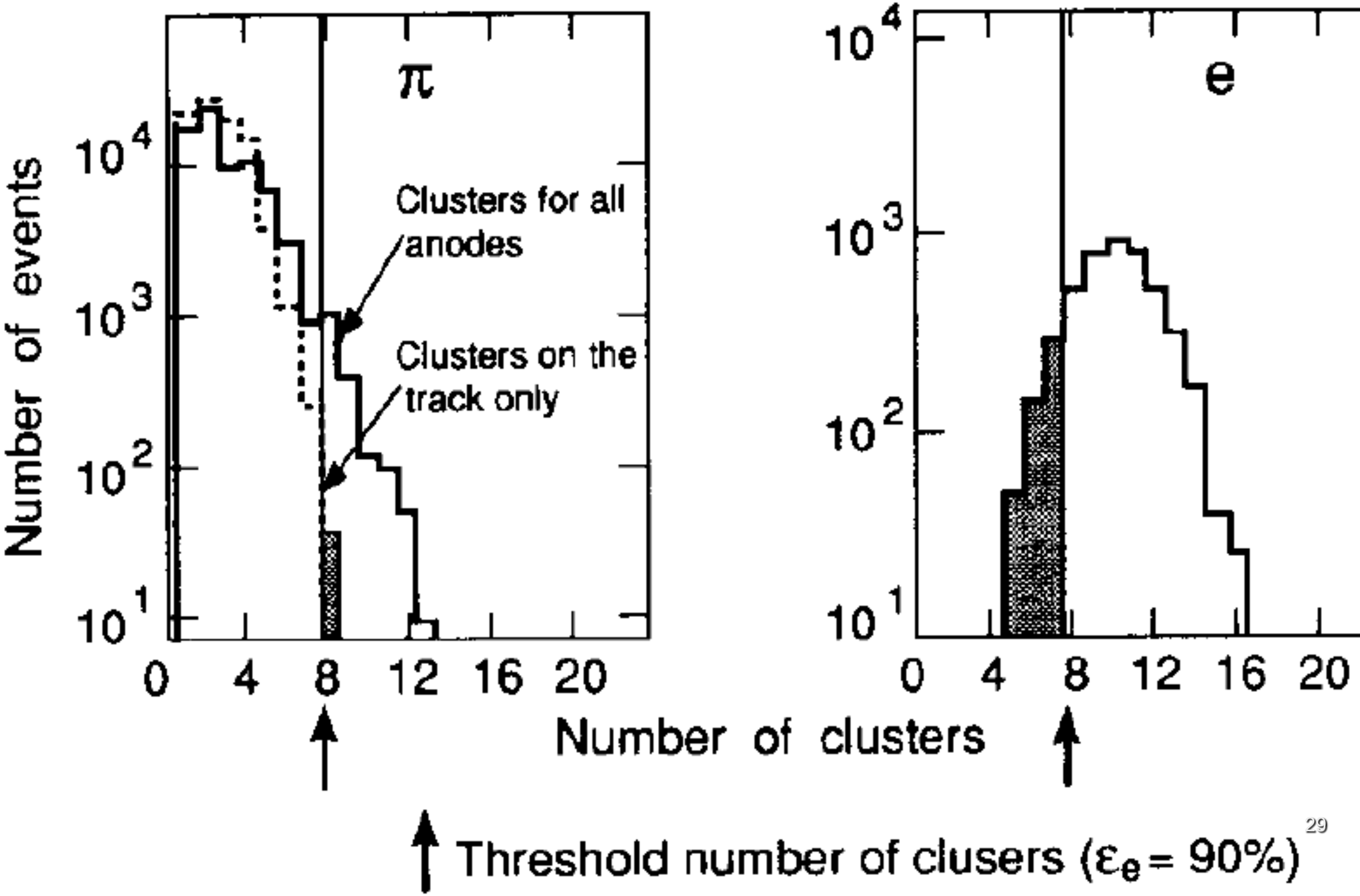
Positive charge is accumulated by dE/dx as well by clusters. The previous clusters on the track create some dead time (tau) for registration of subsequent one.
Effect of charge from dE/dx look like smooth drop gas gain and therefore smooth increase cluster threshold during drift.
Space charge very negatively affects on the clusters registration ability, especially take in to account that most TR photons absorb near input window of chamber.
To compensate space charge the floating threshold was used. High threshold (12KeV) was kept all time. Promptly after pretriger threshold jumped to 7 KeV, than smoothly dropped to 4 KeV and at the end of drift time returned to high threshold again. This simple method improve rejection power of TRD on factor 5.


0
T
12 Kev
7 Kev
4 Kev
THRESHOLD


a)
600
400
0
200
400
600
T (nsec)


Nev.
b)
600
300
200
400
600

Below some beam-test results are shown
For all of them a floating threshold was used



All anodes – number cluster from all anodes should be > THR.
Trigger mode – number anode and cathode clusters should be > THR
Off-line mode - a maximum-likelihood method, using two-dimensional distribution cluster on anodes and cathodes.

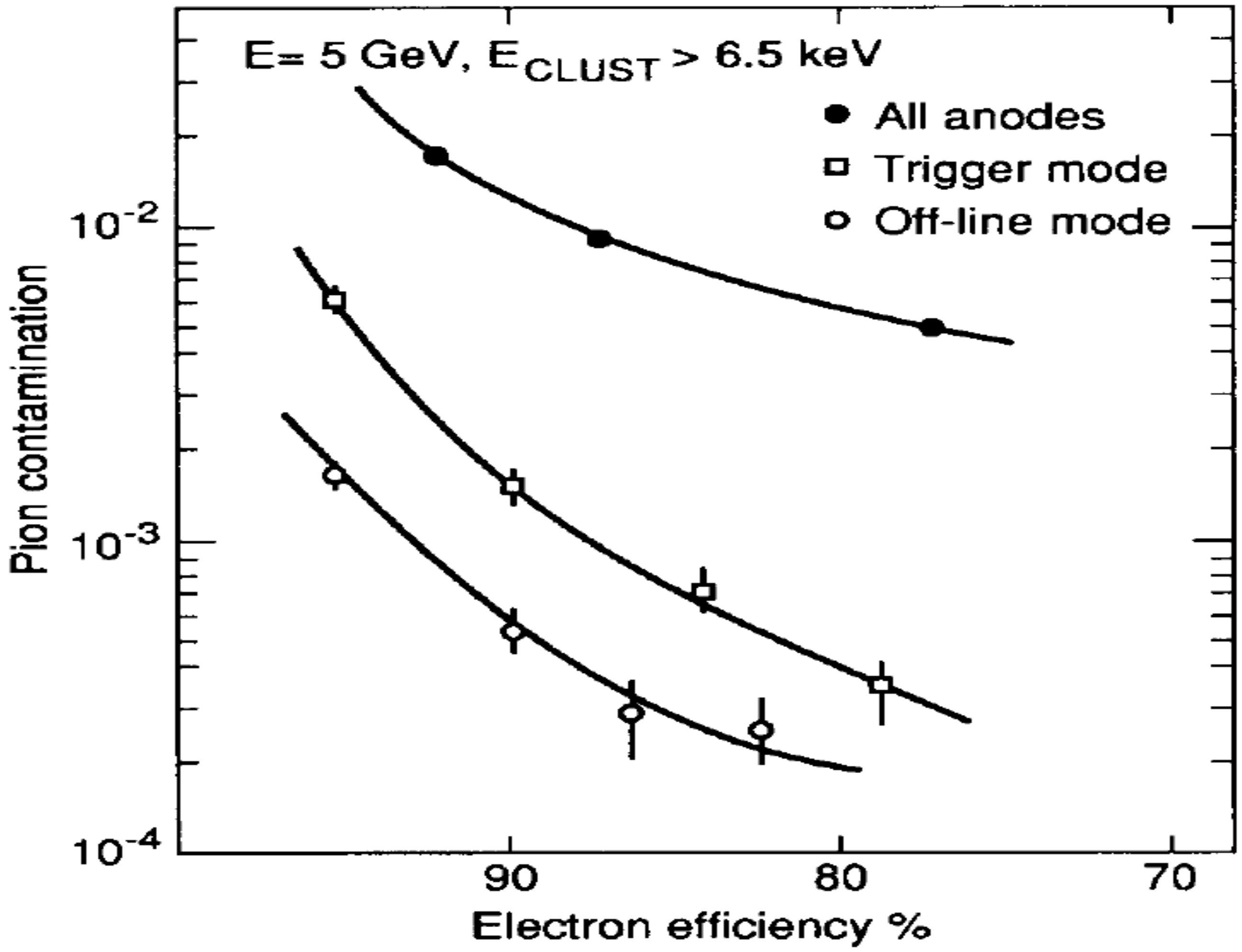


Fig. 46. Rejection power of the HELIOS TRD for different methods of analysis.

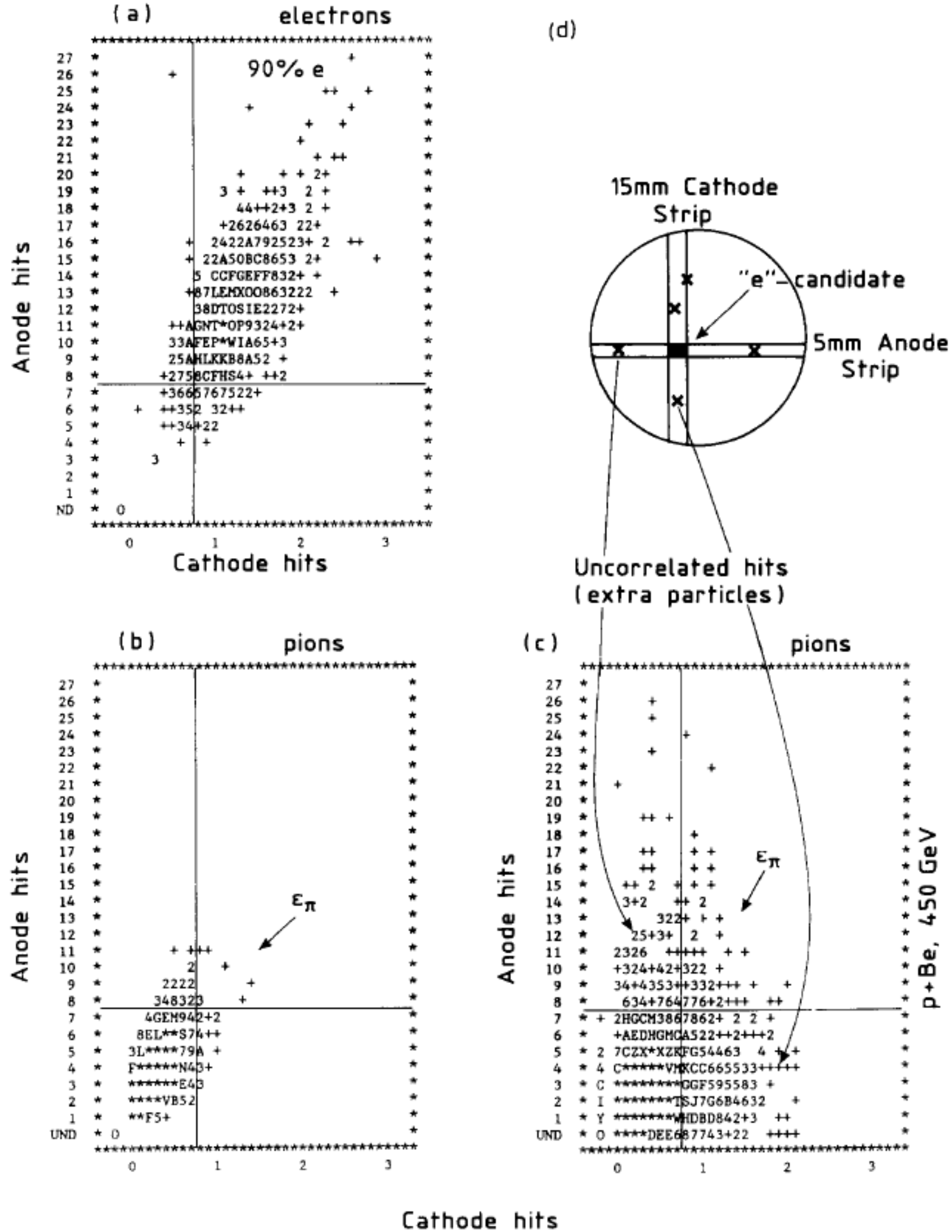


Fig. 50. Scatter plots (anode hits versus cathode hits) for isolated electrons (a), isolated pions (b) and pions inside secondaries produced by p + Be interactions (c). The straight lines correspond to 90% electron efficiency (upper left-hand section).

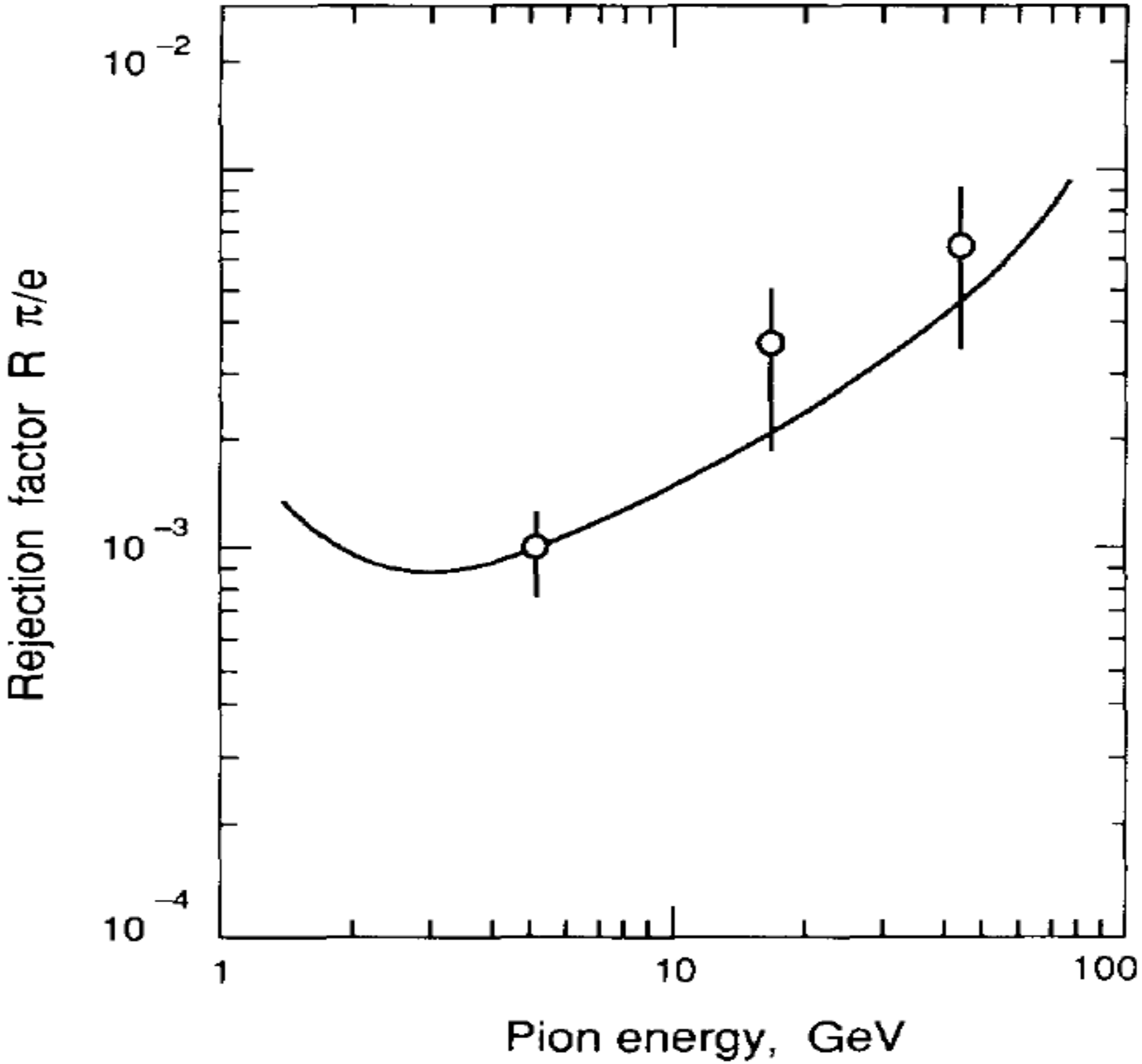


Fig. 47. Energy dependence of the rejection power $R_{\pi/c}$ (HELIOS TRD). The solid curve presents the expectation of TR theory, normalized at 5 GeV.