Particle Identification

ICFA 2001

Faure, South Africa, March 28, 2001

Jürgen Engelfried[1]

(Instituto de Física, Universidad Autónoma de San Luis Potosí, Mexico)

Outline

- Introduction
- Transition Radiation Detectors
- Ring Imaging Cherenkov Detectors – RICH
- Summary

[1] jurgen@ifisica.uaslp.mx, http://www.ifisica.uaslp.mx/~ jurgen

Tom Ypsilantis 1928-2000

Introduction

In this class: Only identification of charged particles

What is Particle Identification?

Two major applications:

1. Beam Particle Identification (Fixed Target)
2. Identification of decay products

In both cases the momentum of the particle is known

1. By beamline elements (only small momentum bin)
2. Measured by a magnetic spectrometer (wire chambers)

$\Longrightarrow$ Particle Identification reduces to measure the velocity (this class) or the total energy (calorimetry class) or specific energy loss (dE/dx).

Reconstruction of Λ_c^+

- Λ_c^+ consists of (udc) quarks
- Mass $m_0 = 2.285\,\mathrm{GeV}/c^2$ (remember: proton $0.938\,\mathrm{GeV}/c^2$)
- Lifetime: $\tau = 2.1 \cdot 10^{-13}\,\mathrm{sec}$
- Decays to $\Lambda_c \rightarrow pK^-\pi^+$ in $4.4\,\%$ of the time.
- Only in 1 out of 1000 collisions a charm quark gets produced.

Special Theory of Relativity:

$$
\begin{aligned}
E &= m \cdot c^2 \\
m &= m_0 \cdot \gamma \\
\gamma &= \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{E \cdot c^2}{m_0} \\
p &= m \cdot v \approx m_0 \cdot \gamma \cdot c \\
\text{Time dilation:} \quad t &= t_0 \cdot \gamma \\
\text{Mean flight path:} \quad L &= c \cdot \tau \cdot \gamma
\end{aligned}
$$

$\Longrightarrow$ A Λ_c^+ with momentum $200\,\mathrm{GeV}/c$ flies on average $5.4\,\mathrm{mm}$
$\Longrightarrow$ Do a Fixed Target Experiment
But even there we cannot observe a Λ_c directly

What do we do?

- Measure type, direction, momentum, and charge of all decay products
- Apply momentum and energy conservation to "interesting" decay vertex and calculate energy and momentum of hypothetical mother particle
- Transform into rest system of mother particle to obtain rest mass
- Do this for a lot of events, fill histogram with results

Measuring direction and decay vertex

- Use silicon microstrip detectors

Measuring momentum and charge

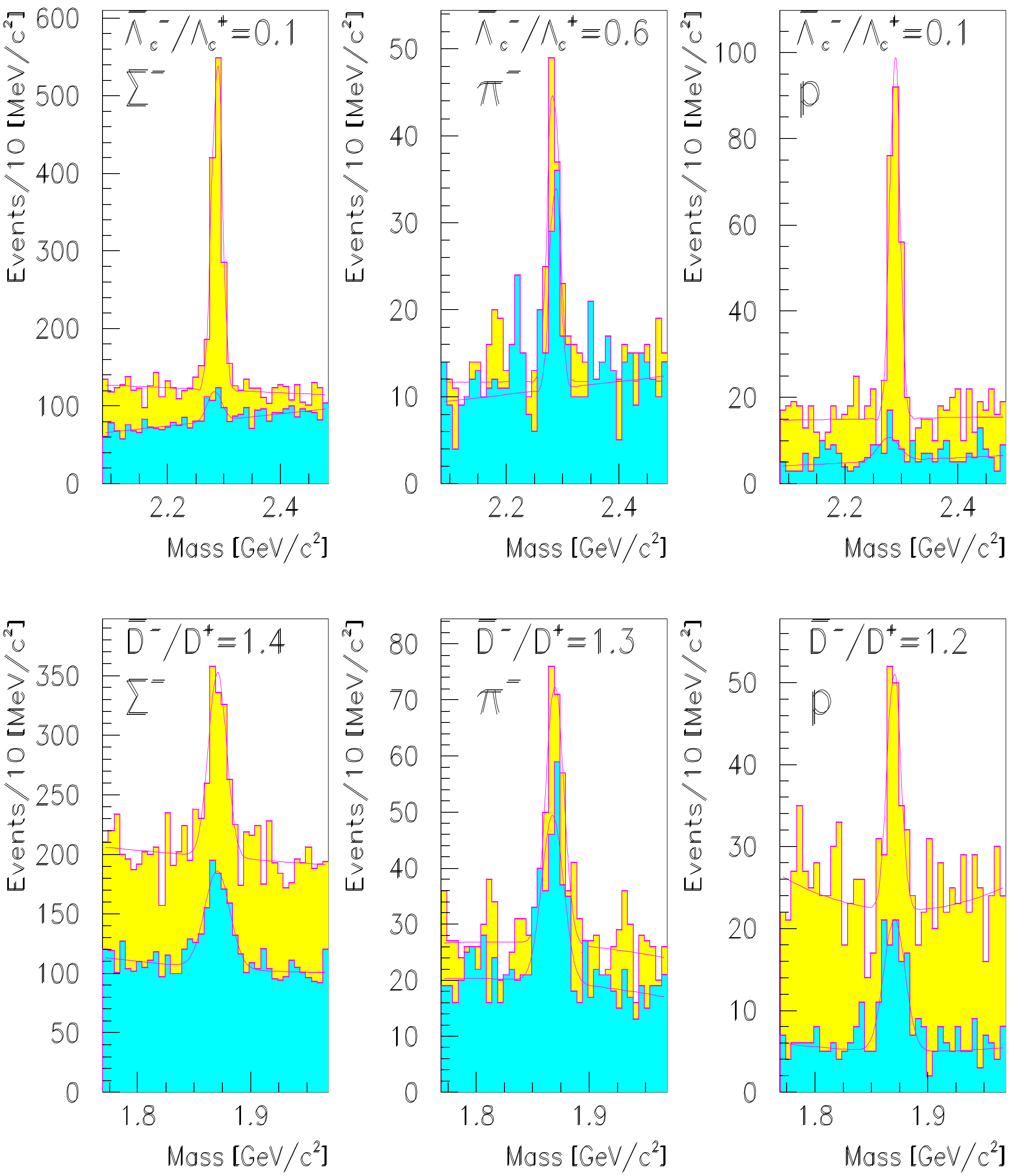
- Deflection in magnetic field, measure track angles before and after with wire chambers

Measuring type (is it a proton?)

- Measure total energy in calorimeter, calculate mass
- Measure velocity with Cherenkov effect

PRELIMINARY SELEX Production Comparison

Sample cuts: $x_F > 0.3$ and $L/\sigma > 8$



“Simple” Methods of Particle Identification
Time–of–flight (TOF)

- Put two Scintillation Counters at a known distance
- Measure time difference between the two signals

Extremely good time resolution: 150 psec.
Maximum distance: $\approx 10\,\mathrm{m}$ (detector), $\approx 100\,\mathrm{m}$ (beamline).
$\Longrightarrow$ Can measure difference between Kaons and Pions up to a few GeV/c
Also has problem at higher rate and/or multiple particles hitting the same scintillator

Transition Radiation Detectors (TRD)

Radiation is emitted by a charge particle if:

1. $v > c/n$: Cherenkov radiation (see later)
2. $\vec{v}/c_{\mathrm{ph}} = \vec{v} \cdot n/c$ changes
   (a) $|\vec{v}|$ changes: Bremsstrahlung
   (b) direction of $\vec{v}$ changes: Synchrotron radiation
   (c) n changes: Transition Radiation

Transition Radiation: Reformation of particle field while traveling from medium with $\epsilon = \epsilon_1$ to medium with $\epsilon = \epsilon_2$.

Energy of radiation emitted at a single interface

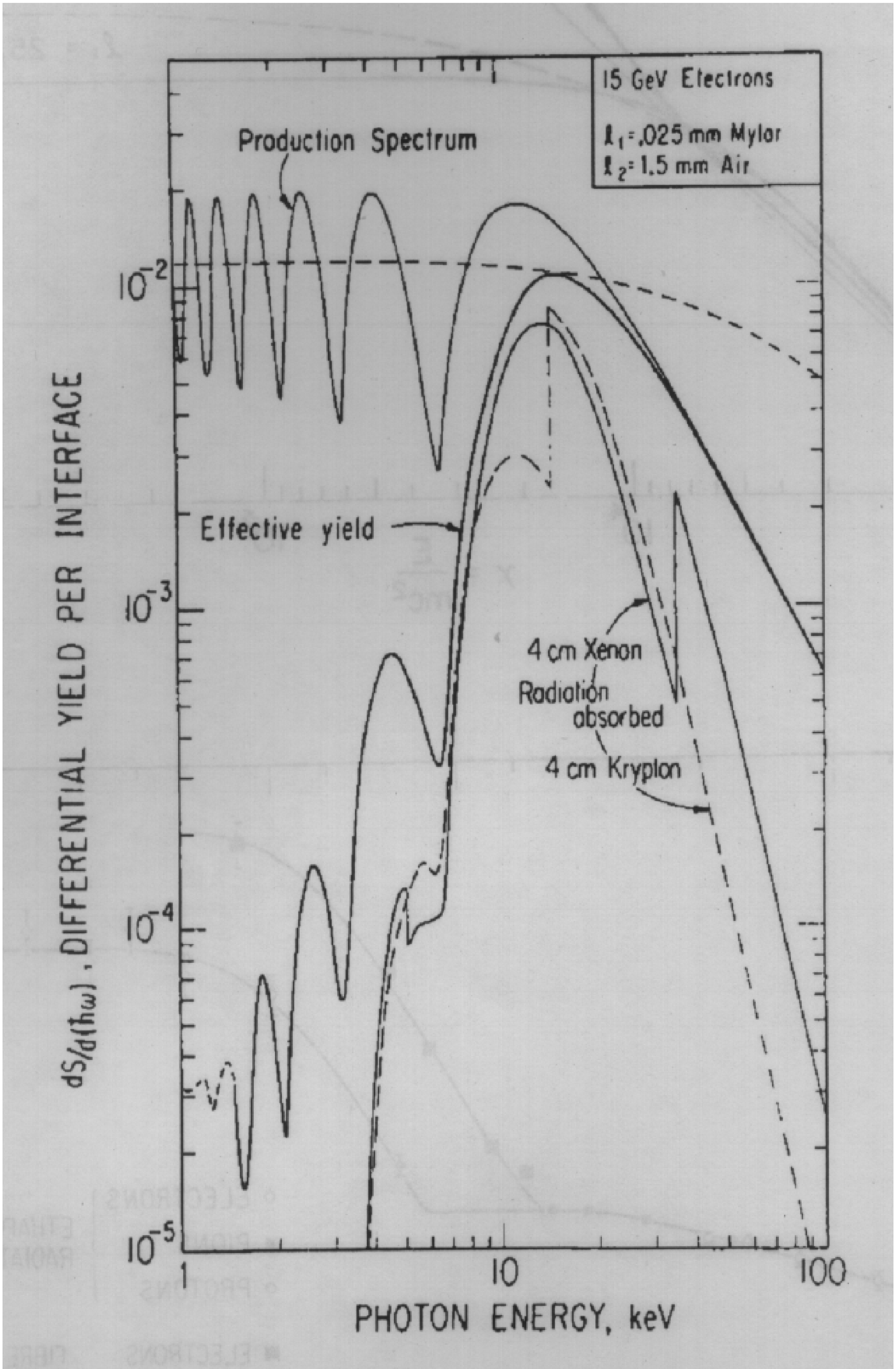
$$S = \frac{\alpha \hbar Z^2}{3} \frac{(\omega_1 - \omega_2)^2}{\omega_1 + \omega_2} \gamma$$

$\alpha = 1/137$, ω_1, ω_2 plasma frequencies, $\gamma = E/mc^2$.
Typical values: Air $\omega_1 = 0.7\,\mathrm{eV}$, polypropylene $\omega_2 = 20\,\mathrm{eV}$

Spectral and angular dependence of Transition Radiation:

$$\frac{d^2}{d\vartheta d\omega} = \frac{2e^2}{\pi c} \left(\frac{\vartheta}{\gamma^{-2} + \vartheta^2 + \omega_1^2/\omega^2} - \frac{\vartheta}{\gamma^{-2} + \vartheta^2 + \omega_2^2/\omega^2} \right)^2$$

$\Longrightarrow$ Most of radiation in cone with half angle $1/\gamma$: forward in particle direction.


15 GeV Electrons
ℓ_1 = .025 mm Mylar
ℓ_2 = 1.5 mm Air
Production Spectrum
Effective yield
4 cm Xenon
Radiation absorbed
4 cm Krypton
dS/d(ħω), DIFFERENTIAL YIELD PER INTERFACE
PHOTON ENERGY, keV

From figure:

1. Large photon energies $\omega > \gamma\omega_2 \approx 20 - 30\,\text{KeV}$: large drop of intensity $\propto \gamma^4/\omega^4$
2. Medium energies $\gamma\omega_1 < \omega < \gamma\omega_2$: Logarithmic decrease with ω
3. Small energies $\omega < \gamma\omega_1 \approx 1\,\text{KeV}$: intensity almost constant

Probability to emit a KeV photon $\approx 10^{-2} \Longrightarrow$ Need a lot of interfaces: stack of radiator foils.
Consequences:

- Need minimum foil thickness so particle field reaches new equilibrium
- Transition $\omega_1 \to \omega_2$ and $\omega_2 \to \omega_1$ equal $\Longrightarrow$ Interference effects (min and max in fig)
- Equally spaced foils: Interference between amplitude of different foils
- Finite thickness of foils: re-absorption of radiation ($\propto Z^5$): Low Z materials.

Typical values used in TRDs:
Thickness: $30\,\mu$m, distance: $300\,\mu$m, materials: mylar, CH_2, carbon fibers, lithium.

Detection of Transition Radiation

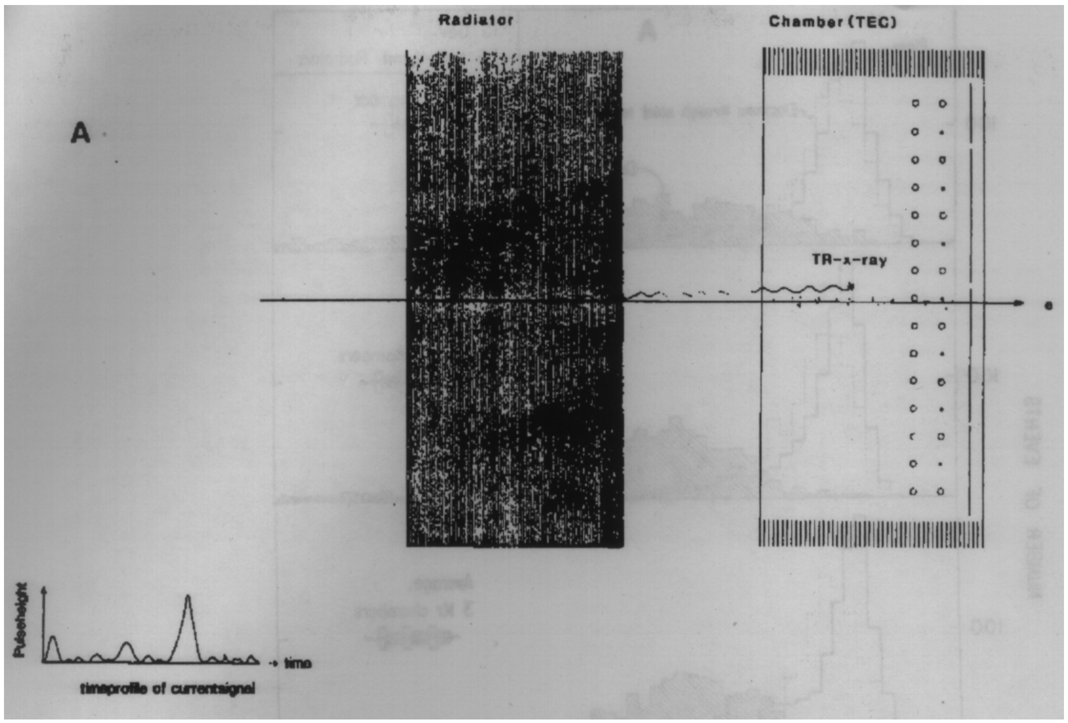
X-rays emitted under small angle to particle track

$\Longrightarrow$ X-ray detector sees X-rays and particle dE/dx together.

Typical dE/dx in gas detectors: some KeV/cm and Landau distributed

$\Longrightarrow$ Signals from dE/dx and X-ray similar

Detector: Use "thin" MWPC, with Xenon or Krypton, several (10) radiator / chamber units to beat Landau



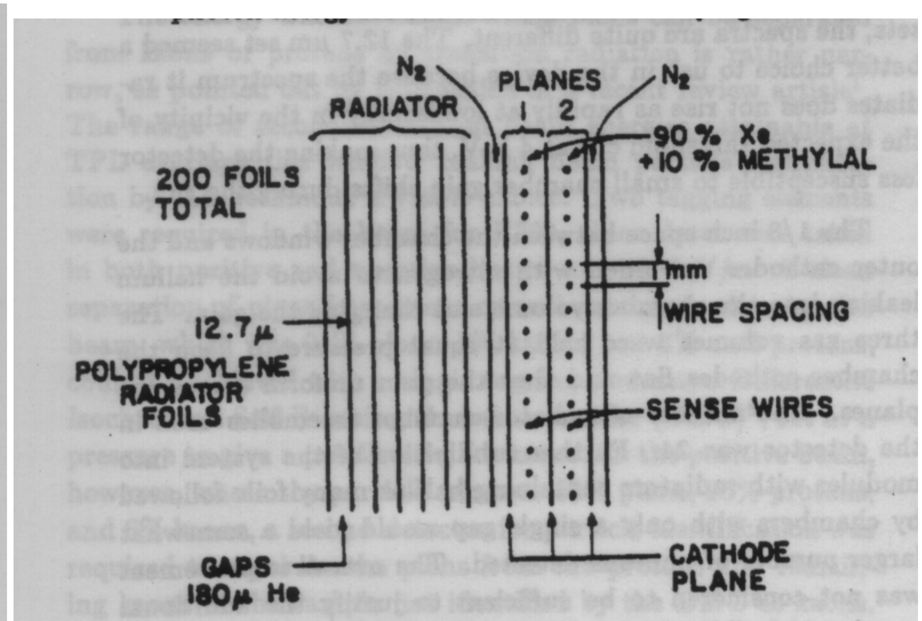
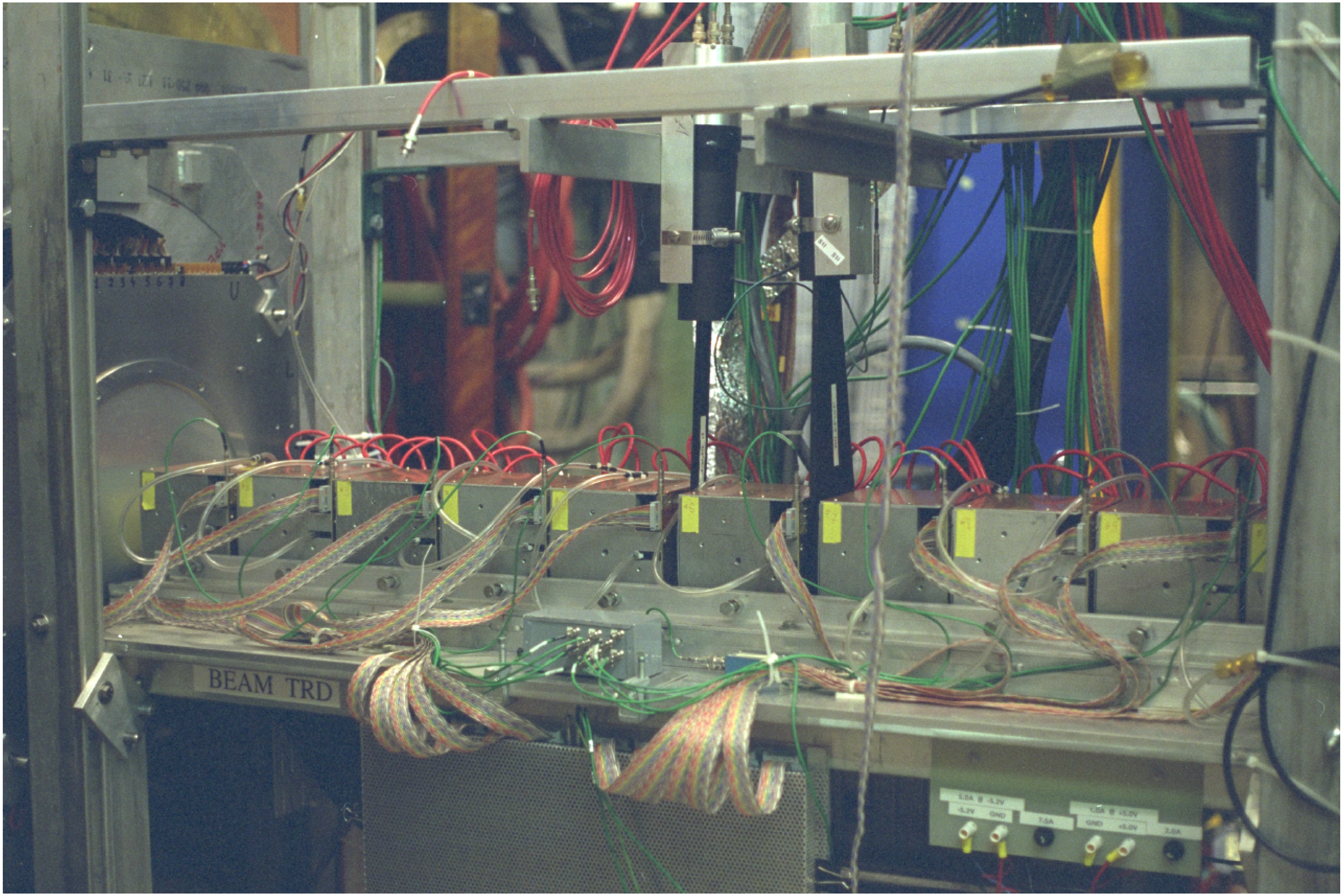
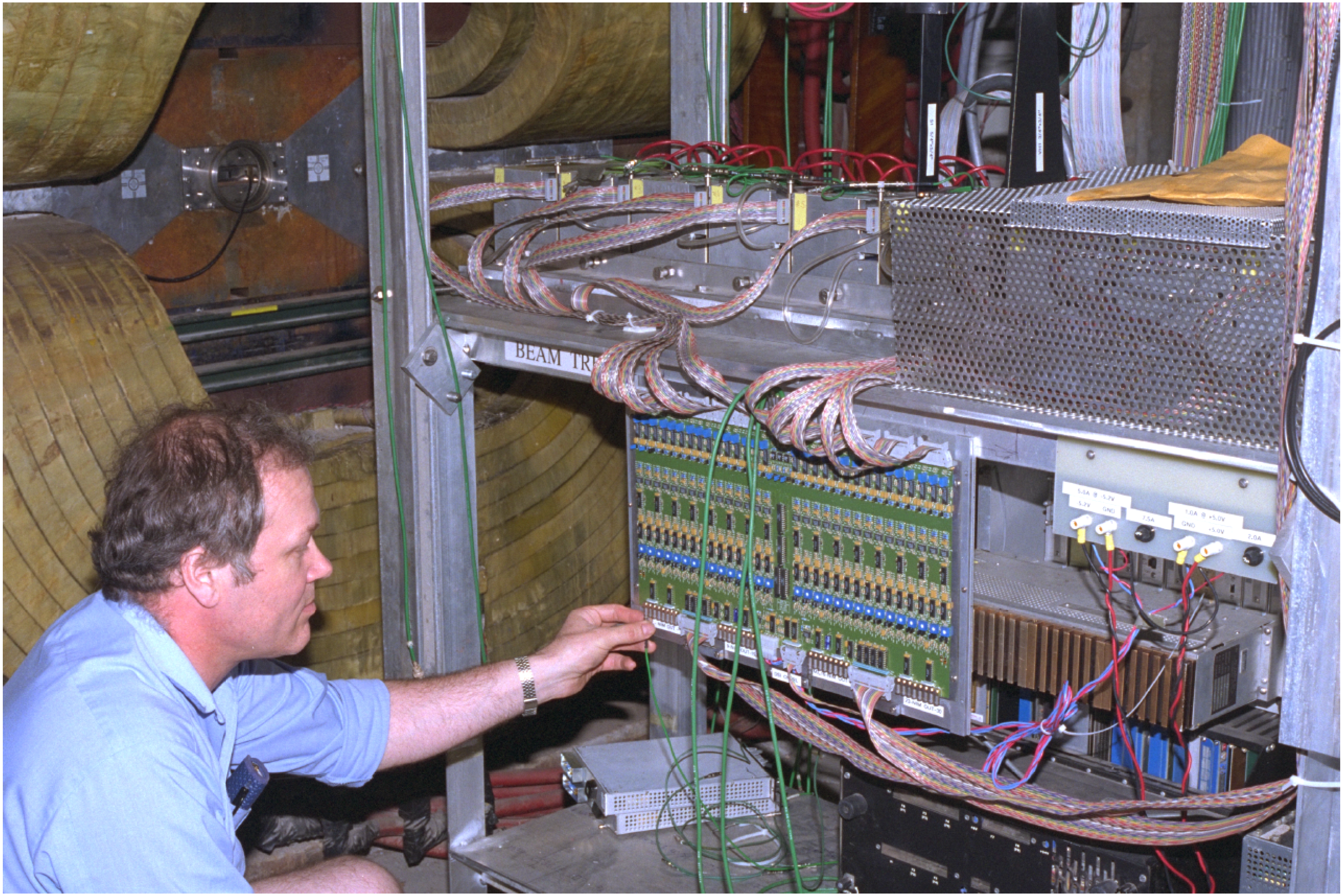
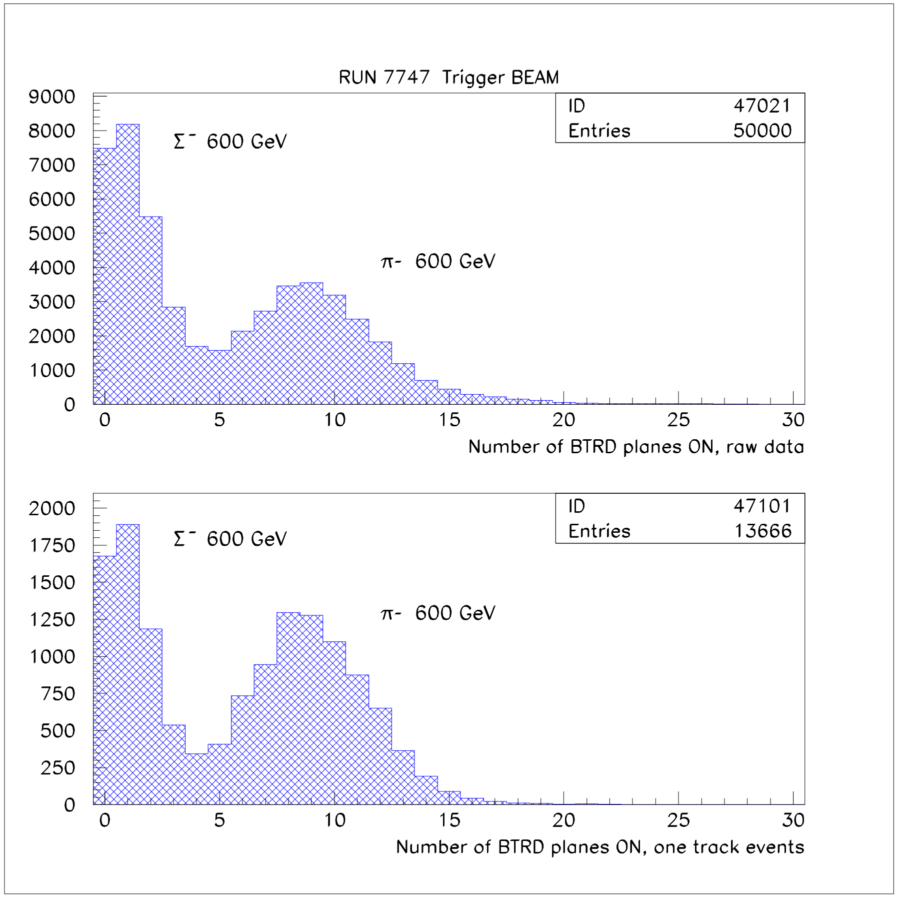


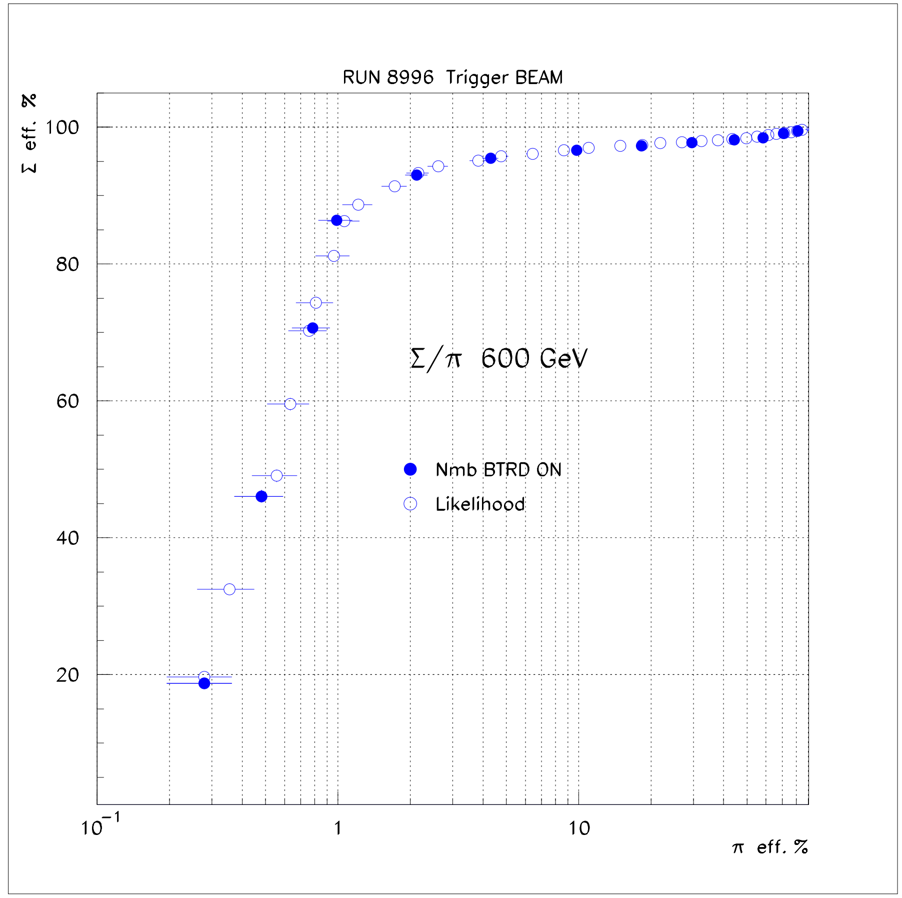
Fig 4. Schematic of a radiator-chamber module showing the final design parameters discussed in the text.

Two identification methods: Charge integration, Cluster counting


BEAM TRD


BEAM TR


RUN 7747 Trigger BEAM
ID 47021
Entries 50000
Σ⁻ 600 GeV
π- 600 GeV
Number of BTRD planes ON, raw data
ID 47101
Entries 13666
Σ⁻ 600 GeV
π- 600 GeV
Number of BTRD planes ON, one track events


RUN 8996 Trigger BEAM
Σ eff. %
Σ/π 600 GeV
Nmb BTRD ON
Likelihood
π eff. %

Cherenkov Radiation

A charged particle with a velocity v larger than the velocity of light in a medium emits light.

Angle of emmission: $$\cos\theta_c = \frac{1}{\beta\, n} = \frac{1}{\frac{v}{c}\, n}$$

Number of photons: $$\frac{d^2N}{dEdl} = \frac{\alpha}{\hbar c}\left(1 - \frac{1}{(\beta n)^2}\right) = \frac{\alpha}{\hbar c}\sin^2\theta_c$$

$$\frac{d^2N}{d\lambda dl} = \frac{2\pi\alpha}{\lambda^2}\sin^2\theta_c$$

First (obvious) application: Threshold Cherenkov Detectors

For fixed momentum and only 2 particles to separate (beam line)

More than 2 particles and/or wider momentum range: Several counters at different thresholds

NUCLEAR INSTRUMENTS AND METHODS 9 (1960) 55–66; NORTH-HOLLAND PUBLISHING CO.

A NEW TYPE OF ČERENKOV DETECTOR FOR THE ACCURATE MEASUREMENT OF PARTICLE VELOCITY AND DIRECTION*

ARTHUR ROBERTS

Department of Physics[**]*, University of Rochester*

Received 22 June 1960

A new type of Čerenkov radiation detector is proposed, in which the light emitted by a single particle traversing a radiator is imaged, by means of a lens or mirror focused at infinity, on the cathode of an image-intensifier tube. The image is a ring, whose diameter measures accurately the Čerenkov cone angle, and thus the particle velocity. In addition the coordinates of the center of the circular image accurately indicate the orientation of the particle trajectory, though not its position. The sensitivity of presently available systems of cascaded image-intensifier tubes allows the photographic recording of the image produced by a single particle. The system is inherently insensitive to background noise. It can observe simultaneously several incident particles whose directions span a wide angle. It may be gated with microsecond coincidence resolving times. It can use condensed or gaseous radiators; with the former, chromatic dispersion is likely to limit the accuracy. For gas radiators, the attainable accuracy of velocity determination is estimated as $\delta\beta = \pm 0.0002$ or better; the accuracy of track orientation ± 0.001 radians. The range of velocity and orientation simultaneously observable depends on the angular field of view of the objective. Sources of error, the precision attainable, the design of practical systems and some possible applications are discussed.

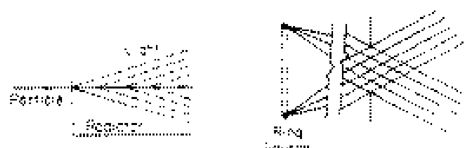
1. Introduction

The Čerenkov light emitted by a fast-moving particle consists of rays parallel to the elements of a right circular cone. As observed by a detector, it seems to originate from a ring source at infinity whose angular diameter is that of the cone (Fig. 1). It has justly been likened to the light from a ring of faint stars. If such light is collected by a telescope objective, an image of the ring is formed in the focal plane with a diameter given by

$$D = 2f \tan\theta \qquad (1)$$

where f is the focal length of the objective, and θ is the half-angle of the cone of light.

Precisely such an arrangement may be used to collect the Čerenkov radiation from a fast particle, as shown in Fig. 2. The light emitted by the particle may all be collected in a ring image. In principle, a photographic plate could then record the particle's passage, but the light emitted is of course far too weak to allow the photography of single particles. However, existing image-intensifier tubes, as now used in cascade for scintillation track-imaging, can record such ring images. Fig. 3 shows such a cascade system.



(a) (b)

Fig. 1. (a) Čerenkov radiation emitted by a fast particle traversing a radiator lies on a circular cone of parallel rays [illegible] the particle path. (b) The light from a ring source at infinity, after passing through an aperture, also lies on a cone of parallel light, which may be focused to a ring image by a lens or mirror objective.

One can construct in this way a Čerenkov detector that measures accurately both the particle velocity,—even at very high speeds ($\beta \approx 0.99$),—and the direction of motion of the particle. Furthermore, these measurements may be made on particles entering a large radiator at

* [illegible]

** [illegible]

[illegible] 31 (1960) [illegible]

[illegible] 6 (1960) [illegible]

NUCLEAR INSTRUMENTS AND METHODS 142 (1977) 377-391 ; © NORTH-HOLLAND PUBLISHING CO.

PHOTO-IONIZATION AND CHERENKOV RING IMAGING

J. SEGUINOT* and T. YPSILANTIS†

CERN, Geneva, Switzerland

Received 17 December 1976

We have investigated the photo-ionization process in gases and shown that single photon pulse counting in multiwire proportional chambers (MWPC) is possible with about 50% quantum efficiency for photons above 9.5 eV. An application of this technique in imaging the Cherenkov ultra-violet (UV) radiation is presented.

1. Introduction

The Cherenkov radiation effect in an optical medium allows a precise determination of the velocity β [or $\gamma = (1-\beta^2)^{-\frac{1}{2}}$] of a charged particle passing through the medium. From the Cherenkov relation[1]

$$\cos\theta = 1/\beta n, \tag{1}$$

where θ is the emission angle of the Cherenkov light and n the refractive index of the optical medium, we find

$$\frac{\Delta\beta}{\beta} = \left[\tan^2\theta\,(\Delta\theta)^2 + \left(\frac{\Delta n}{n}\right)^2\right]^{\frac{1}{2}}, \tag{2}$$

with $\Delta\beta$, $\Delta\theta$ and Δn the r.m.s. error in the measurement of β, θ and n respectively. Litt and Meunier[2] show that with a "differential isochronous self collimating" type Cherenkov counter (DISC) a resolution of $\Delta\beta/\beta \approx 10^{-7}$ is possible. This corresponds to a γ resolution of $\Delta\gamma/\gamma = [illegible]\,\Delta\beta/\beta = 0.4\%$ at $\gamma = 200$. In such counters the Cherenkov photons emitted at different points along the particle's straight line trajectory are focused by a reflective mirror (radius R, focal length $f = \frac{1}{2}R$) to give a circular ring image of radius r at the mirror focal plane. In the small angle approximation the focal surface is a plane and the radius of the ring image is

$$r = f\tan\theta. \tag{3}$$

The angle determination in DISC is obtained by using an annular diaphragm of radius r at the mirror focal plane. Photomultipliers (PMs) located behind the diaphragm detect the transmitted photons. For optimal resolution additional optical elements are added to correct for chromatic dispersion due to the variation of n with the energy of the emitted photons. Obviously a DISC type counter can only be used in collimated beams so that the source of Cherenkov radiation is along the optical axis of the device. Furthermore, the counter is not continuously sensitive in β and responds only to particles having a preset value of β (i.e. Cherenkov light which passes through the annulus). Such counters are suitable for velocity (mass) selection in collimated (momentum analyzed) primary particle beams but completely unsuitable for velocity measurement of secondary particles emerging from an interaction. The phase space occupied by these particles is large whereas the phase space acceptance of DISC is small.

A secondary particle detector may be imagined (see fig. 1) as consisting of a spherical mirror of radius R whose centre is the source of secondary particles (target) and a spherical detector surface at radius $\frac{1}{2}R$ with the Cherenkov radiating medium

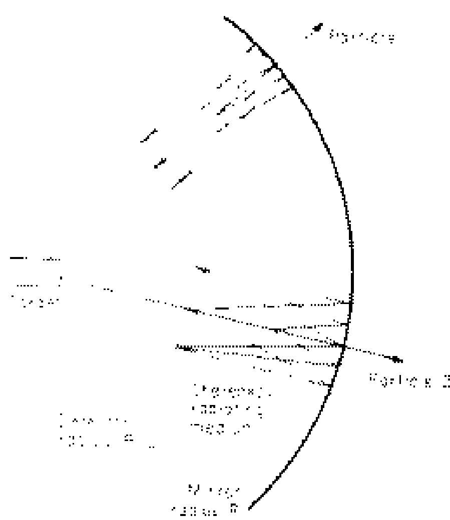
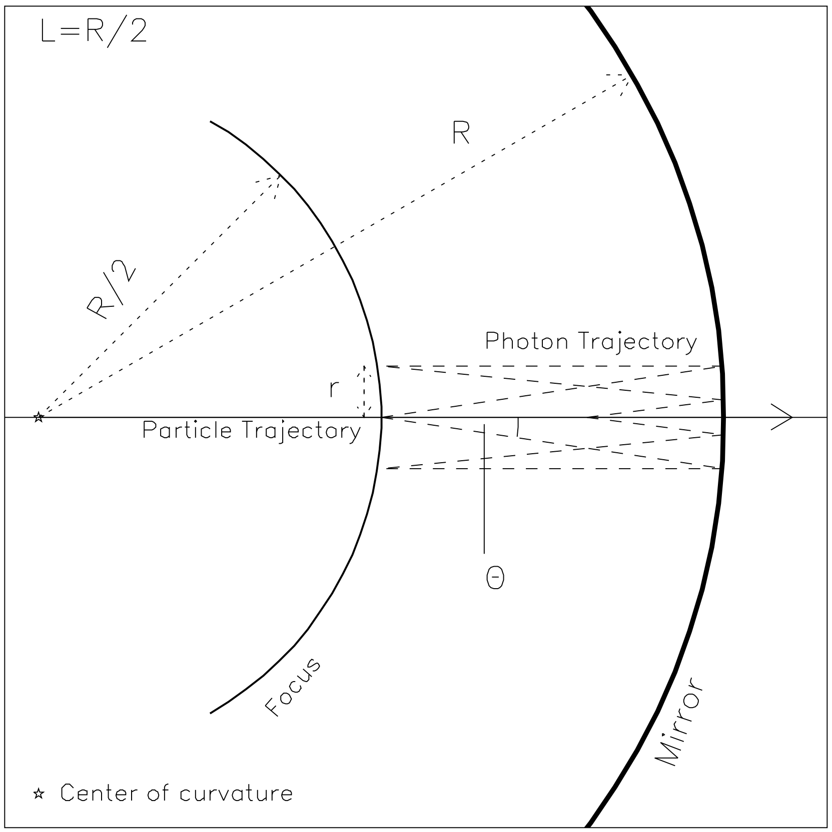


Fig. 1. Schematic large phase space acceptance Cherenkov ring imaging detector.

* [illegible] CNRS (France).
† [illegible] C.E.N. Saclay, France.

Ring Imaging Cherenkov – The Basics



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

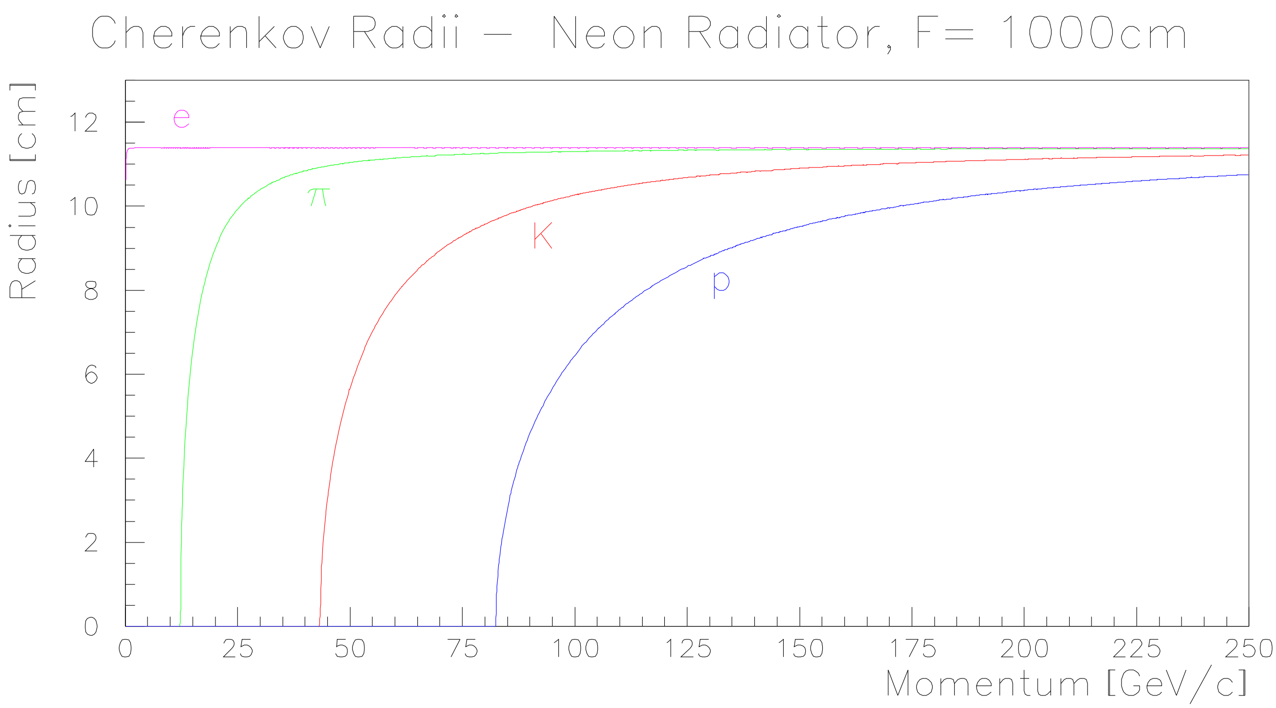
$$r = F \cdot \theta_c = \frac{R}{2} \cdot \theta_c$$

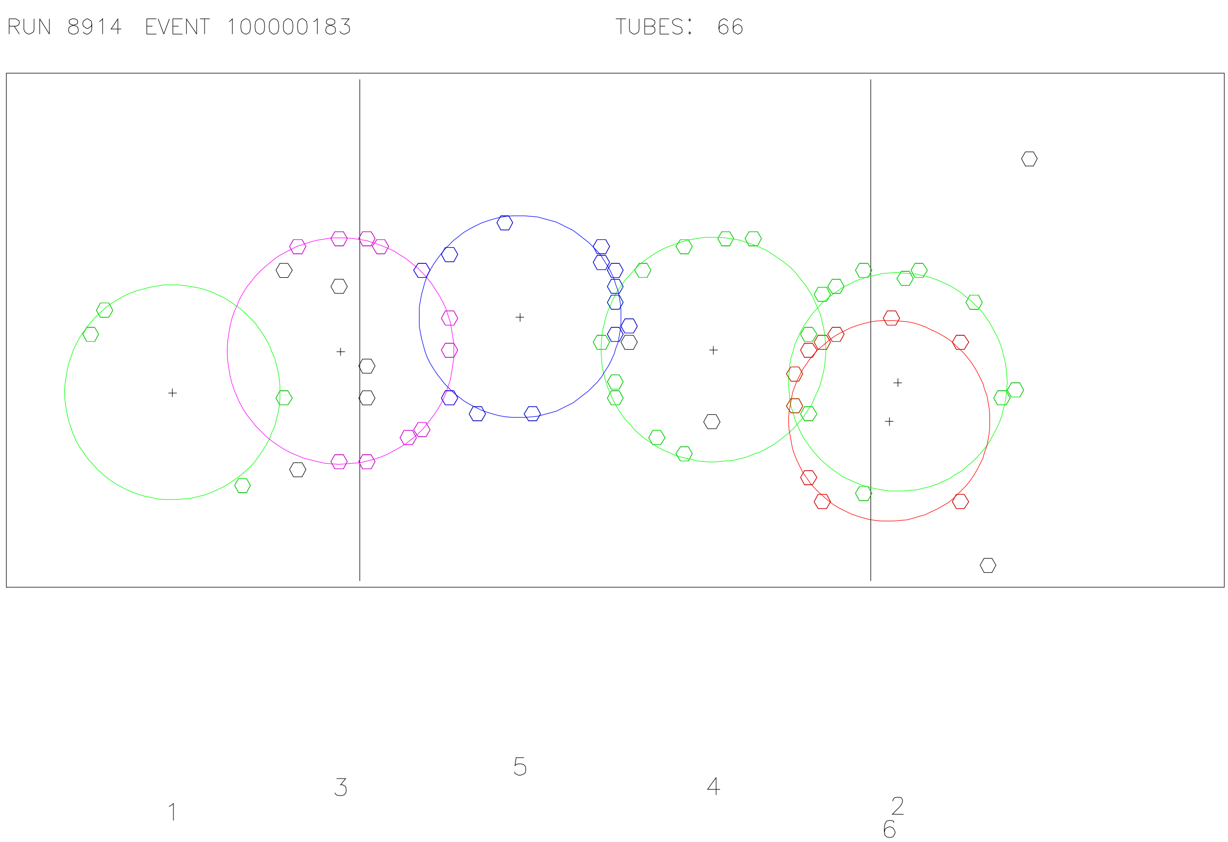
$$N_{ph} = N_0 \cdot L \cdot \sin^2\theta_c$$

θ_c: Cherenkov angle
β: velocity
n: refractive index
r: Radius of ring on focal surface
R: Radius of curvature of spherical mirror(s)
F: Focal length ($F = R/2$)
L: Radiator length (usually $L = F$)

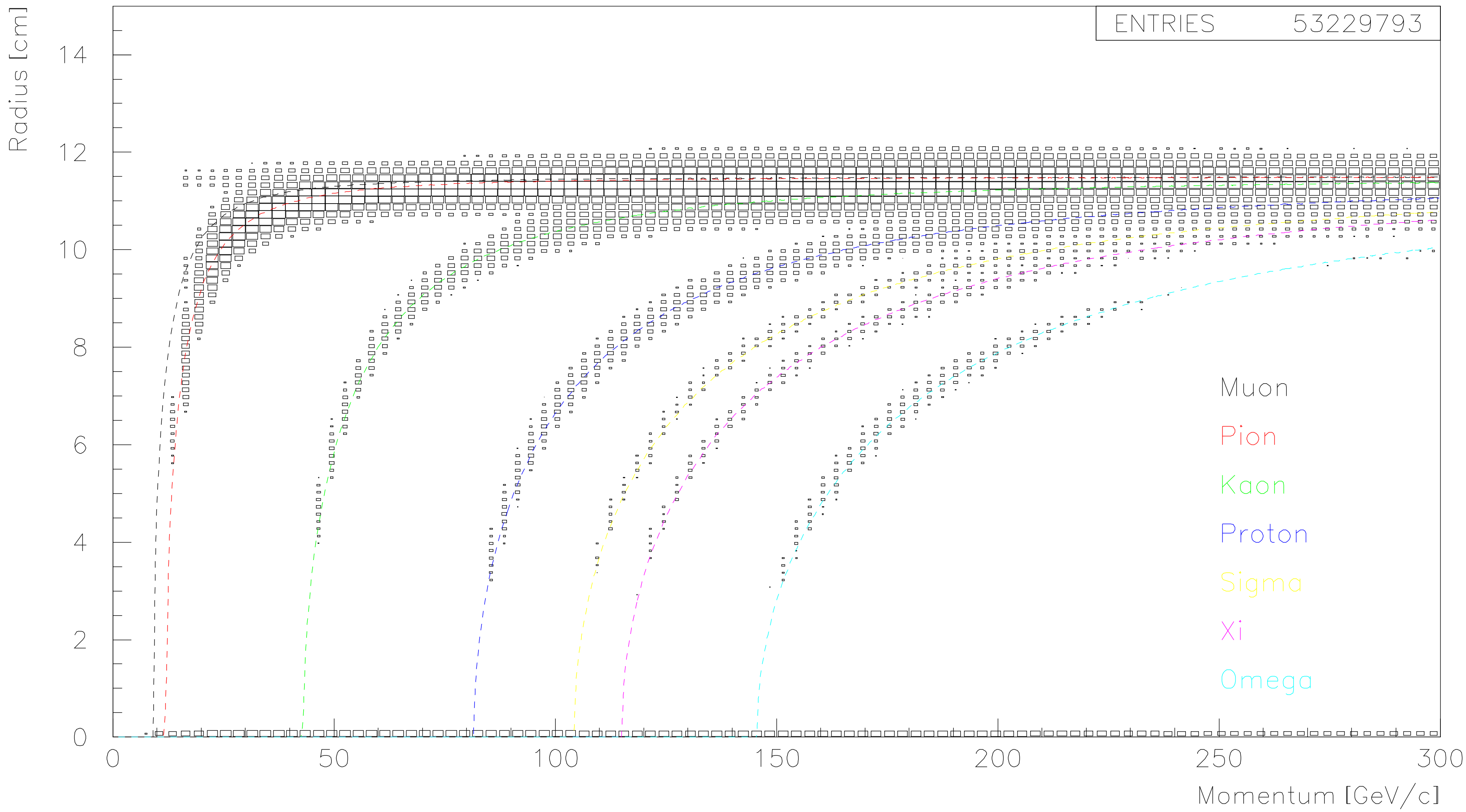
Parallel particles have the same ring image

$$r = \frac{R}{2}\sqrt{2 - \frac{2}{n}\sqrt{1 + \frac{m^2c^2}{p^2}}}$$





SELEX RICH: Particle Id negative tracks



Short History of RICHes

First Generation: Beginning of 1980's.
Examples: Omega RICH (WA69, WA82), E653 RICH.

Second Generation: End-of 80's beginning of 90's.
Examples: Upgraded Omega RICH (WA89, WA94), Delphi, SLD–GRID, CERES.

Third Generation: Mid-End 90's.
Examples: SELEX RICH, Hermes, Hera-B.

New Generation: BaBar–DIRC, PHENIX, CLEO–III

Future: ALICE, LHC–B, BTeV, CKM, ...

RICH – The Reality

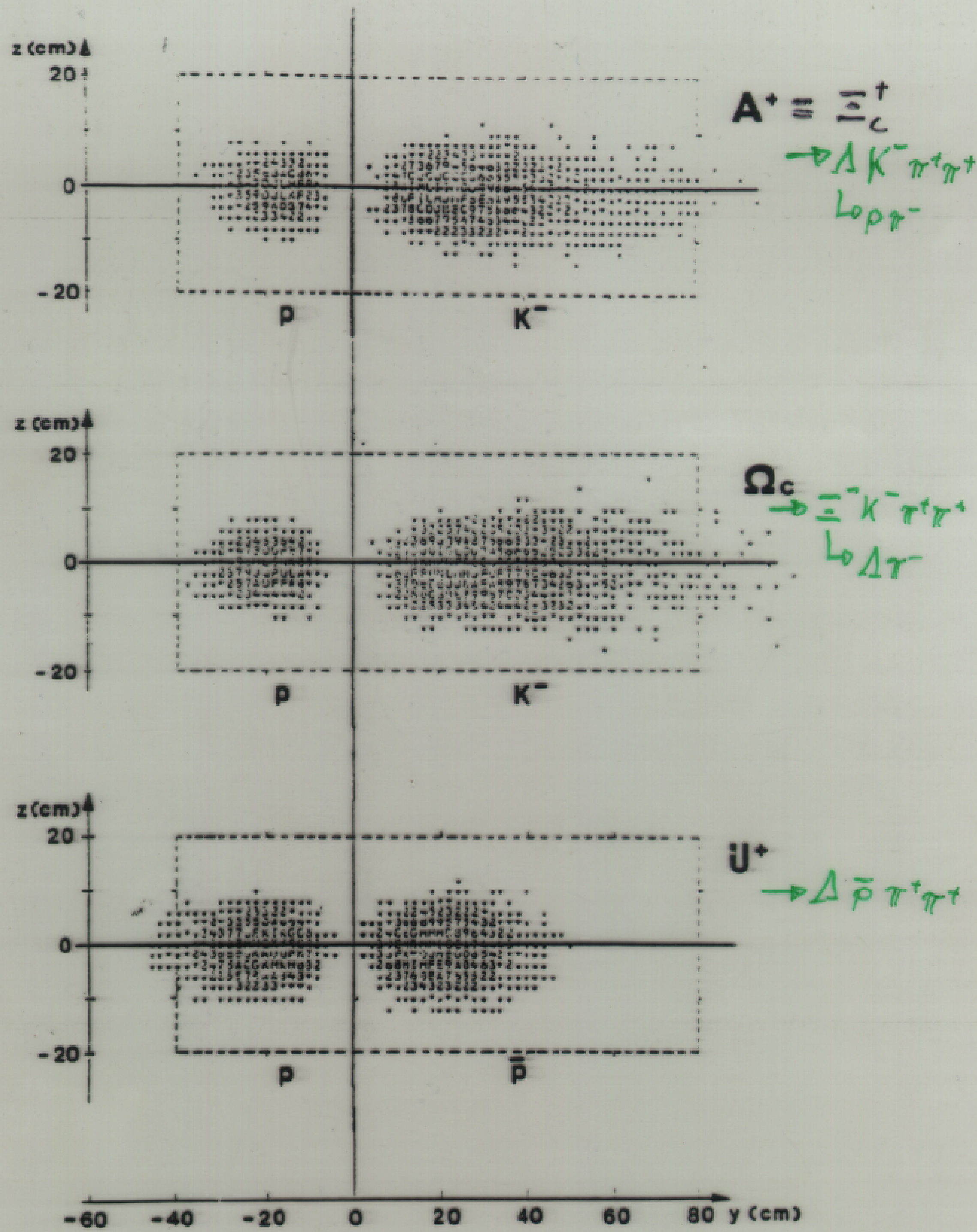
- Center of ring depends on track angle $\Longrightarrow$ large detector surface (up to square meters)
- good resolution of photon position $\Longrightarrow$ large number of "pixels" (up to 100000 or more)
- Spectrum of Cherenkov photons

$$\frac{dN}{d\lambda} = \frac{2\pi\alpha}{\lambda^2} L \sin^2 \theta_c$$

$\Longrightarrow$ Ultraviolet

- refractive index $n = n(\lambda) \Longrightarrow$ Chromatic dispersion
- Detection of UV-photons: convert photon in electron (photoeffect)
  1. small (up to a few thousand) number of pixels: Photomultipliers
  2. large number of pixels or area: Time Expansion Chambers with TEA or TMAE
- When using TEC: particle pass through the chambers: dE/dx
- When using TEC: response (memory) time limit rate

Distribution of Ring Centers



WA89 Proposal

Fig.20

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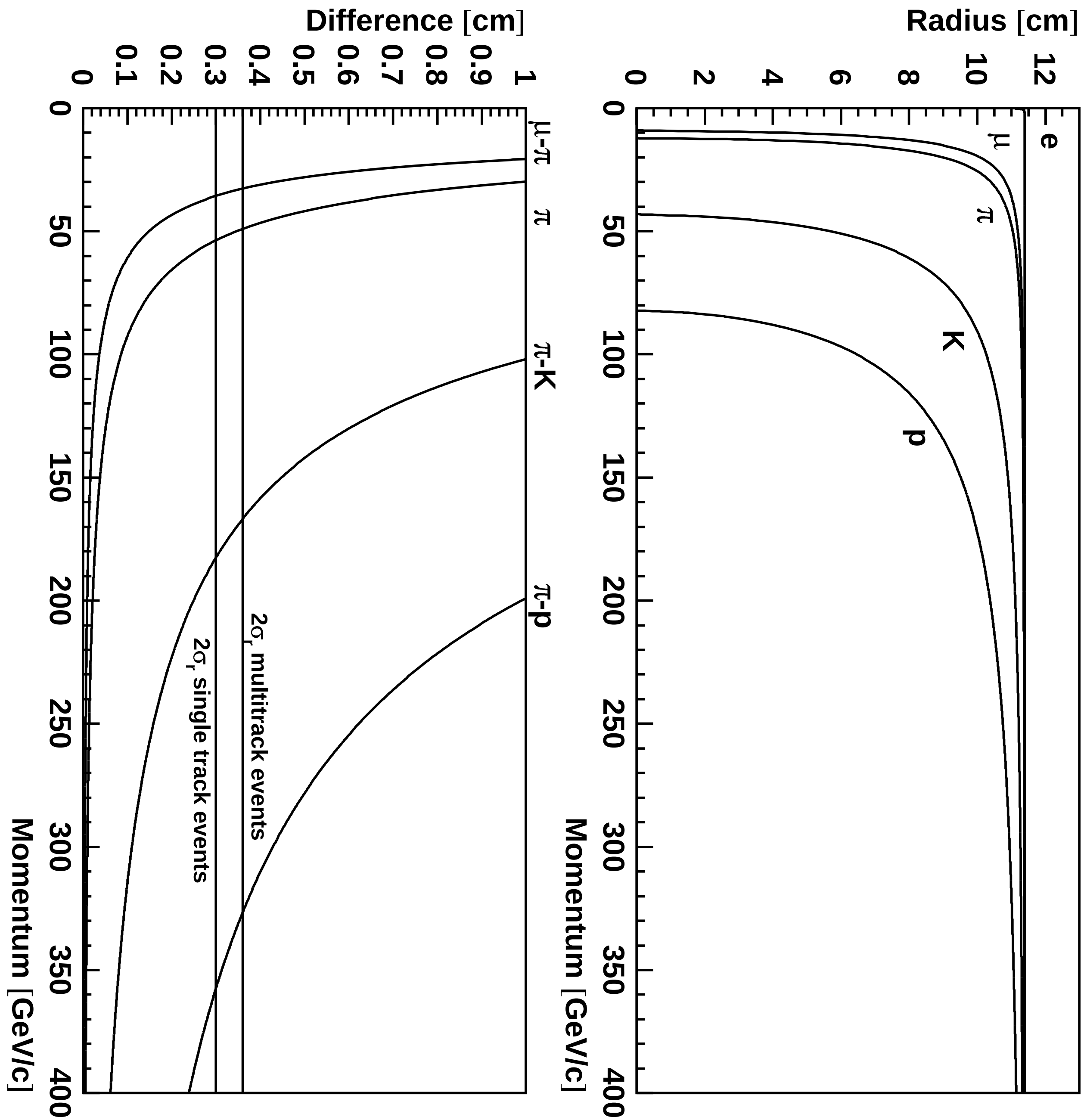

Radius [cm]
e
μ
π
K
p
Momentum [GeV/c]
Difference [cm]
μ-π
π
π-K
π-p
$2\sigma_r$ multitrack events
$2\sigma_r$ single track events
Momentum [GeV/c]

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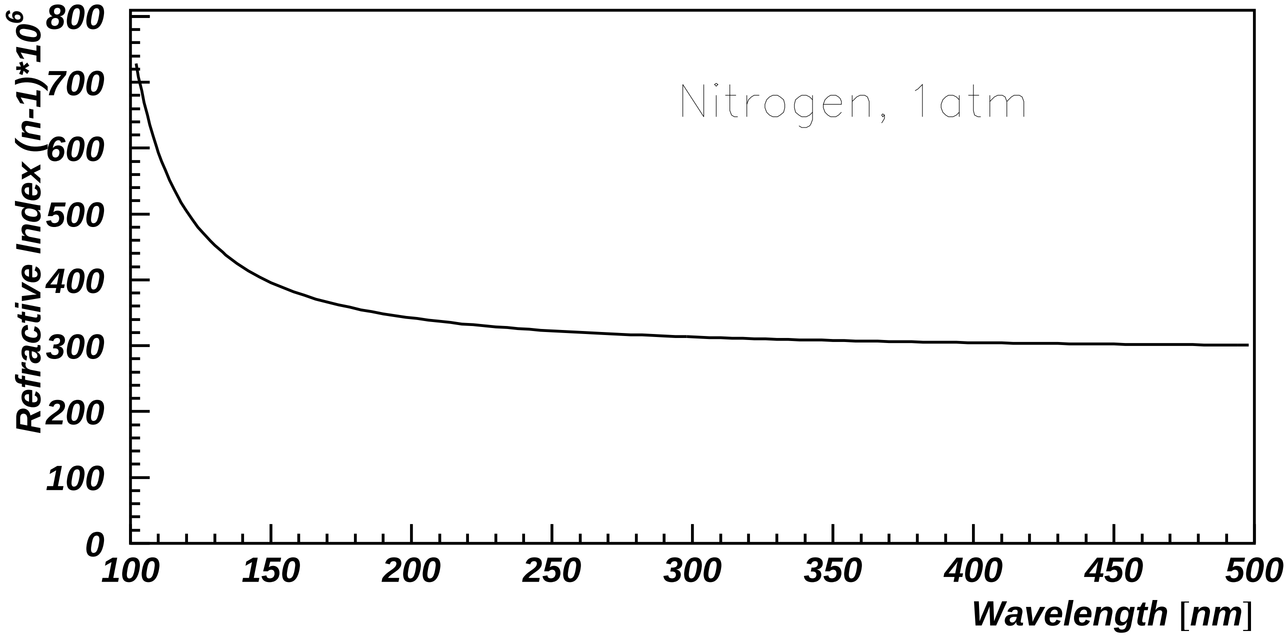
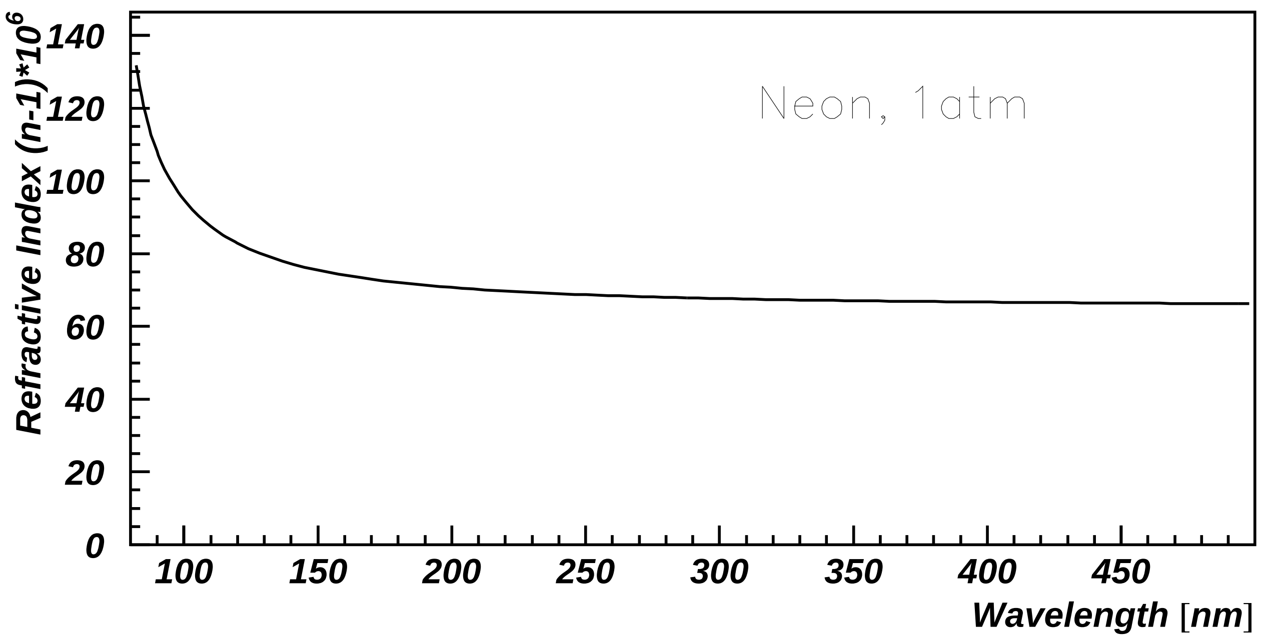

Nitrogen, 1atm
Refractive Index (n-1)*10^6
Wavelength [nm]
0
100
200
300
400
500
600
700
800
100
150
200
250
300
350
400
450
500


Neon, 1atm
Refractive Index (n-1)*10^6
Wavelength [nm]
0
20
40
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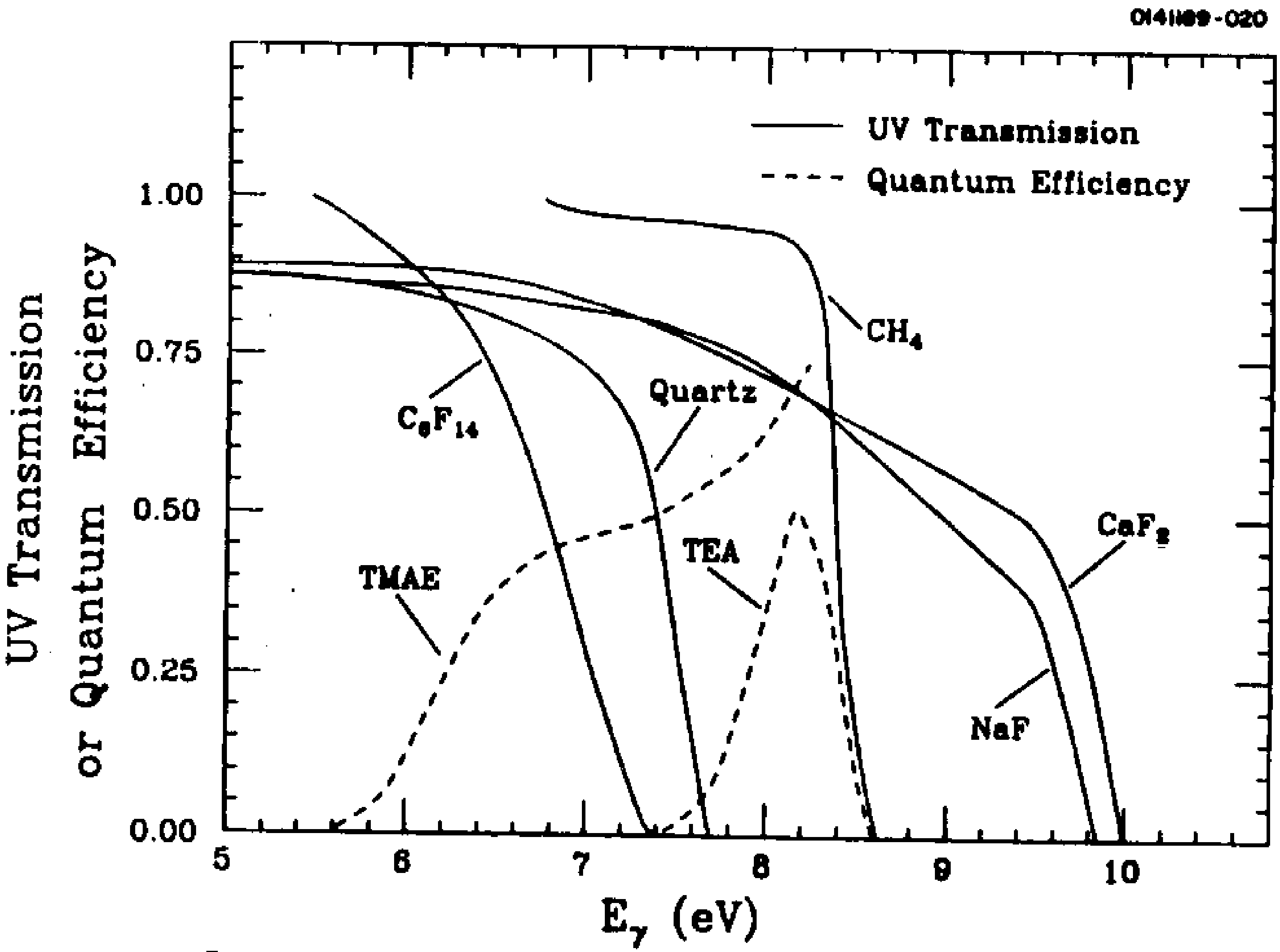
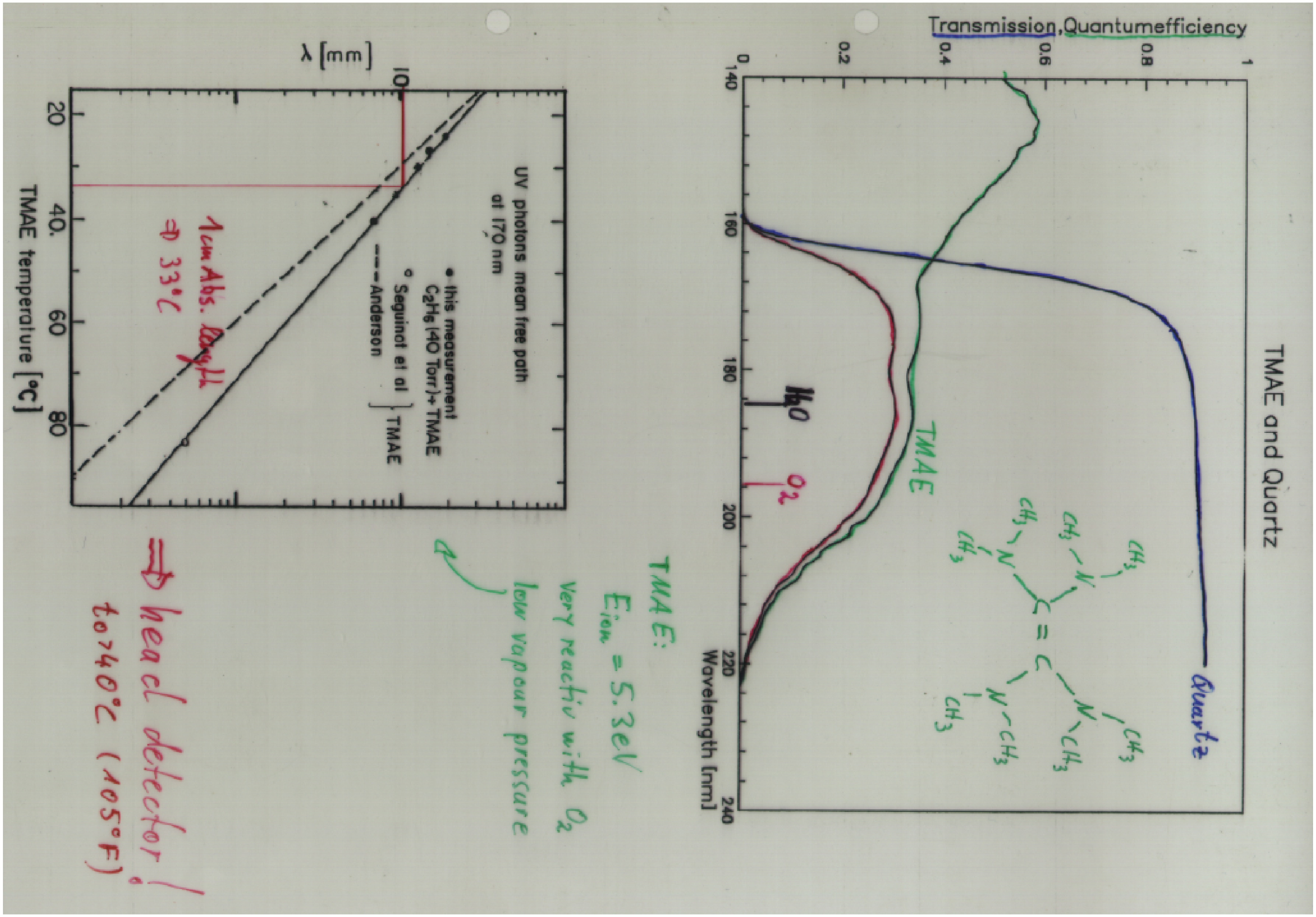


Figure 13: Photon transmission and photoionization quantum efficiency for various CRID materials as function of photon energy in the UV range. (Reproduced from



TMAE and Quartz
Transmission, Quantumefficiency
Wavelength [nm]
Quartz
TMAE
H_2O
O_2
UV photons mean free path at 170 nm
• this measurement C_2H_6 (40 Torr)+ TMAE
° Seguinot et al
--- Anderson
TMAE
λ [mm]
TMAE temperature [°C]
1cm Abs. length ⇒ 33°C
TMAE:
$E_{ion} = 5.3eV$
very reactiv with O_2
low vapour pressure
⇒ heat detector!
to 40°C (105°F)

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- Spectrum of Cherenkov photons

$$\frac{dN}{d\lambda} = \frac{2\pi\alpha}{\lambda^2} L \sin^2\theta_c$$

  $\Longrightarrow$ Ultraviolet

- refractive index $n = n(\lambda) \Longrightarrow$ Chromatic dispersion
- Detection of UV-photons: convert photon in electron (photoeffect)
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  2. large number of pixels or area: Time Expansion Chambers with TEA or TMAE
- When using TEC: particle pass through the chambers: dE/dx
- When using TEC: response (memory) time limit rate

WA89: A Hyperon Beam Experiment at the CERN-SPS Using the Omega Facility

Bologna Univ./INFN, CERN, Genoa Univ./INFN Grenoble Univ./IN2P3, Heidelberg MPI, Heidelberg Univ., Mainz Univ., Moscow Lebedev Phys. Inst.

Bologna
A. Forino, R. Gessaroli, P Mazzanti, A. Quareni-Vignudelli, F. Viaggi

CERN
F. Antinori, W. Beusch, J.P. Dufey, B.R. French, P. Grafström

Genoa Univ./INFN
M. Dameri, R.B. Hurst, B. Osculati, L. Rossi, G. Tomasini

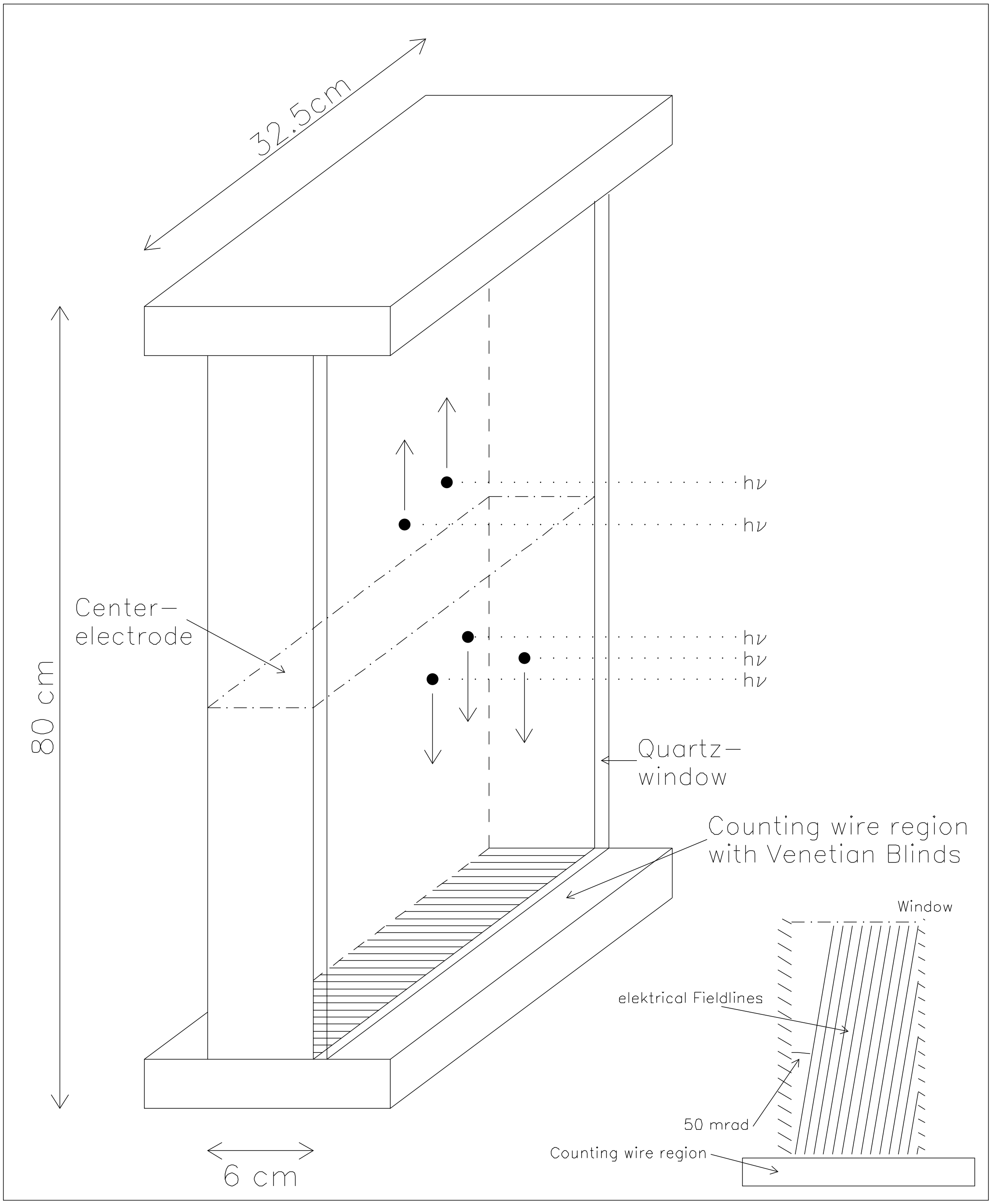
Grenoble Univ./IN2P3
D. Barberis, C. Bérat, M. Buénerd, F. Charignon, J. Chauvin, J.T. Hostachy, Ph. Martin, M. Rey–Campagnolle, R. Touillon

Heidelberg MPIfK
E. Albertson, K.-H. Brenzinger, W. Brückner, F. Dropmann, S.G. Gerassimov, M. Godbersen, T. Kallakowsy, R. Michaels, S. Paul, B. Povh, K. Röhrich, A. Trombini, A. Wenzel, R. Werding

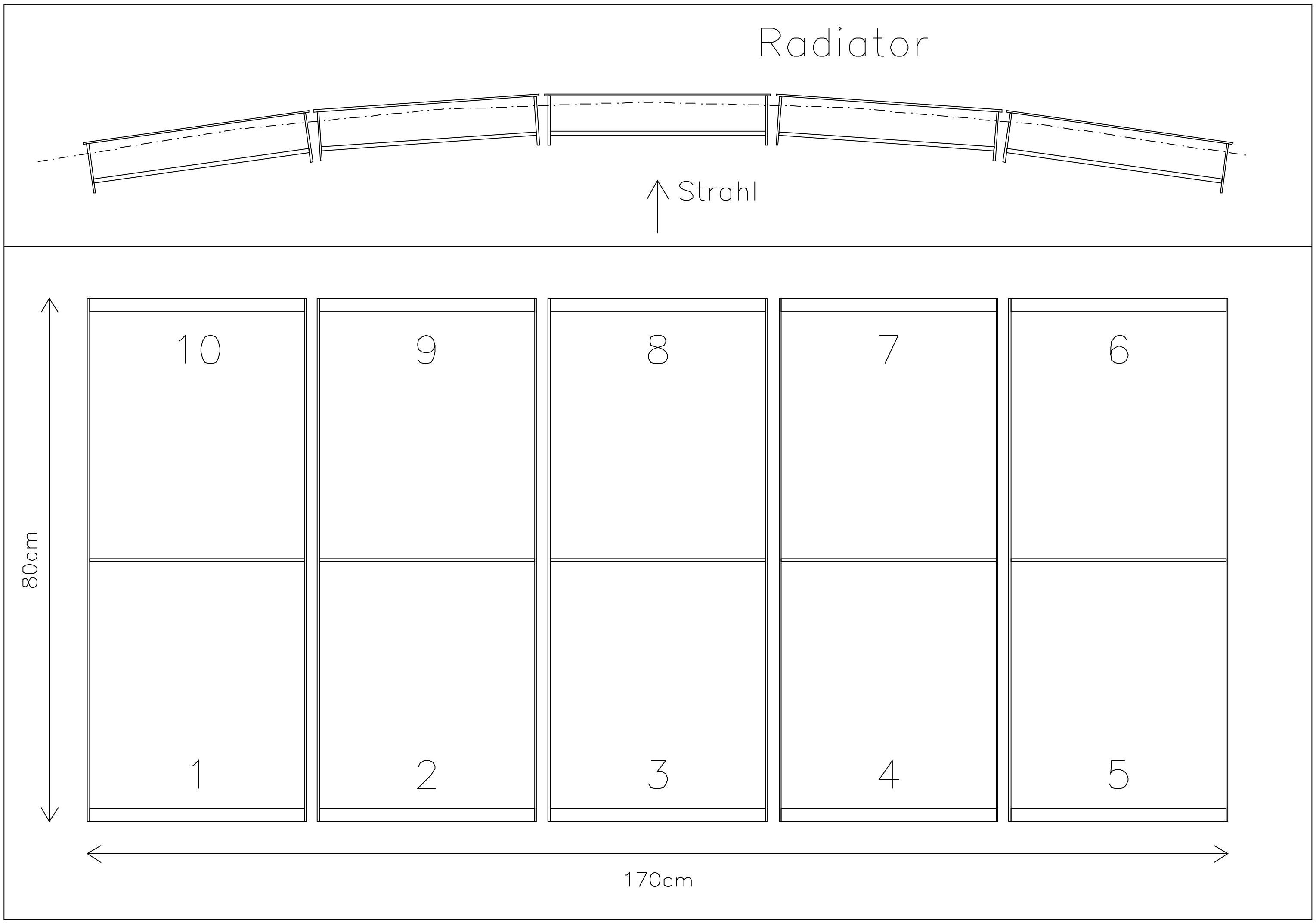
Heidelberg Univ.
J. Engelfried, F. Faller, J. Heintze, S. Kluth, S. Ljungfelt, P. Lennert, K. Martens, H. Rieseberg, H.-W. Siebert, A. Simon, G. Wälder

Mainz Univ., Inst. of Nucl. Physics
E. Chudakov, U. Müller, G. Rosner, H. Rudolf, B. Volkemer, Th. Walcher

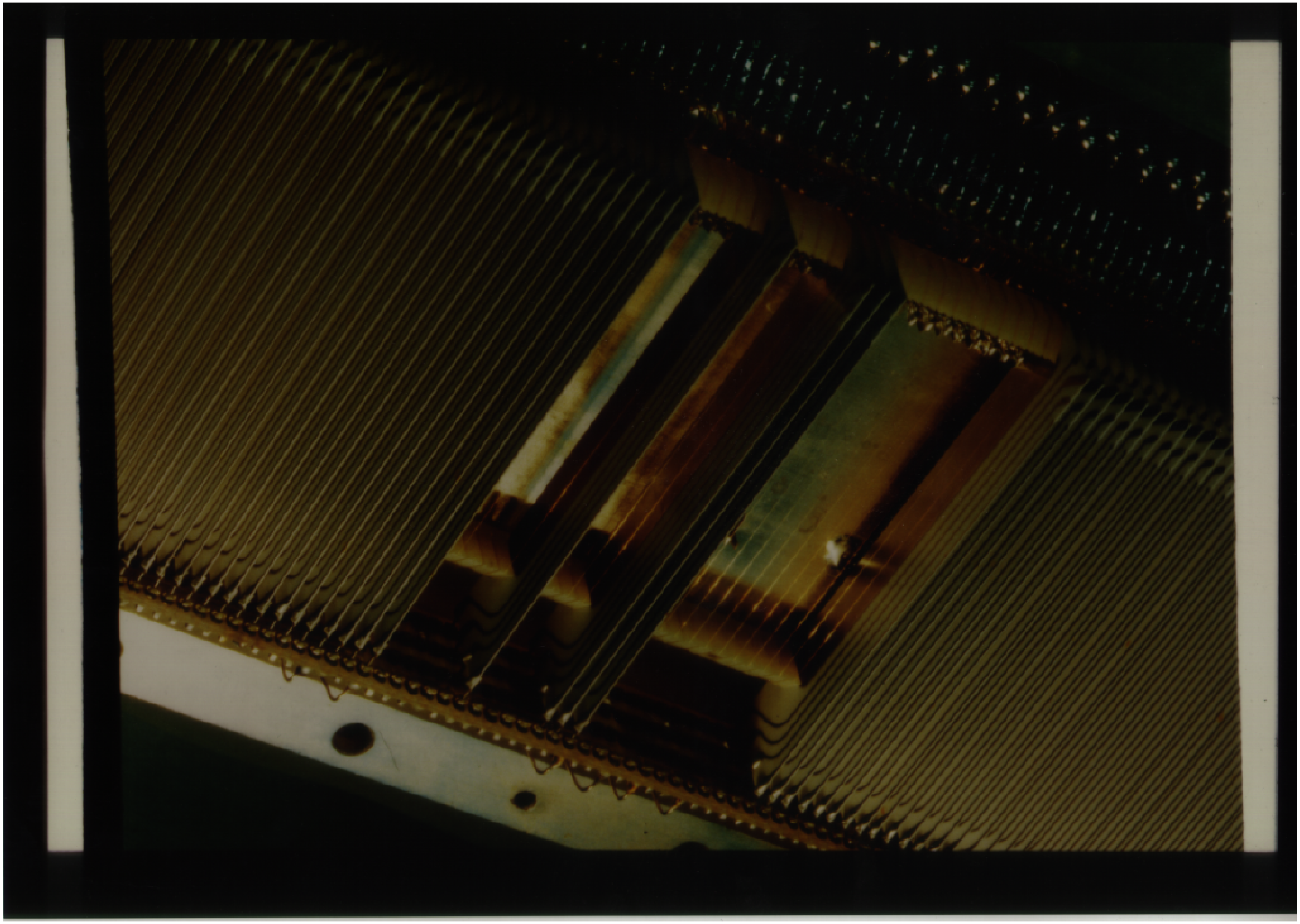
Moscow Lebedev Phys. Inst.
M.I. Adamovich, Yu.A. Alexandrov, S.P. Kharlamov, L.N. Malinina, N.G. Peresadko, M.V. Zavertyaev



Counting gas: Ethan + TMAE, 1 KV/cm, 5 cm/μsec


Radiator
Strahl
10
9
8
7
6
1
2
3
4
5
80cm
170cm


TOP



Nuclear Instruments and Methods in Physics Research A 343 (1994) 279–283
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Particle identification with the RICH detector in experiment WA89 at CERN **

U. Müller [a,*], J. Engelfried [b,1], S.G. Gerassimov [c,2], K. Martens [b], R. Michaels [c,3], H.-W. Siebert [b], G. Wälder [a]

[a] Institut für Kernphysik, Univ. Mainz, Germany
[b] Physikalisches Institut, Univ. Heidelberg, Germany
[c] Max-Planck-Institut für Kernphysik, Heidelberg, Germany

The RICH detector in the hyperon beam experiment WA89 at the CERN-SPS is used for identification of π, K and p/p̄ out of Σ⁻–N reactions. Methods for reduction of charged particle background in the detector are discussed. An algorithm for particle identification was developed and tested on a sample of Λ → pπ decays. A separation of p and π with 90% efficiency and a rejection by a factor of 10 or more at a momentum of 150 GeV/c was achieved.

1. Introduction

We report on algorithms used for particle identification with the upgraded Omega RICH detector [1] in the hyperon beam experiment WA89 [2] at the CERN-SPS.

Cherenkov light is generated in a nitrogen radiator $(n-1 = 290 \times 10^{-6})$ of length $L \approx 5$ m and detected in a set of five drift chambers, covering a total active surface of 3.6×0.75 m² with a maximum drift path of 41 cm. Photoelectrons are counted on 1280 wires with a pitch of 2.54 mm, equipped with multihit TDCs. The overall spatial accuracy is $\sigma = 2.8$ mm for single electrons, corresponding to an angular resolution of 0.56 mrad [3]. The counting gas is ethane saturated with TMAE at 30°C. Fig. 1 shows an on-line display of one event in the RICH of the 1991 beamtime. This display contains the signals observed in the chambers, the particle impacts extrapolated from the spectrometer, and the predicted rings for the mass hypotheses π, K, and p. Also the momenta and charges of the tracks are given. Cherenkov photon signals along the predicted rings are clearly seen. We also note two half-rings in the centre from an out-of-time beam particle or e⁺e⁻ pair.

In the following, we present data analysis methods to reduce the background from charged tracks and other sources, and to identify particles with high efficiency and low probability of misidentification.

2. Background reduction

A charged particle traversing the drift chamber volume produces a few hundred electrons, which give a signal with high amplitude on several (typically three) adjacent wires. In addition, these large signals may produce electronic cross talk to neighbouring channels and signals due to δ rays or photon feedback. All these effects combined lead to a cluster of observed hits around the charged particle impact point.

In the raw data, information about a second discriminator threshold which is higher than the one used for single electron signals is available for each group of eight neighbouring wires [4]. This is used in the first step of background subtraction to suppress all hits with high amplitudes which may stem from a traversing charged particle.

In the second step, clusters of at least four neighbouring hits are removed from the data. The distance for individual hits to be considered as neighbours has to be at most two wirespacings (0.508 cm) in the y direction and 1.0 cm in z (electron drift) direction. These numbers were tuned to give the best compro-

* Corresponding author.
** Work supported by the Bundesministerium für Forschung und Technologie under contract numbers 05 5HD15I, 06 HD524I, and 06 MZ5265 TP2.
1 Now at Fermilab, Batavia, IL, USA.
2 On leave from Lebedev Inst., Moscow, Russian Federation.
3 Now at CEBAF, Newport News, VA, USA.

SSDI 0168-9002(93)E1168-W

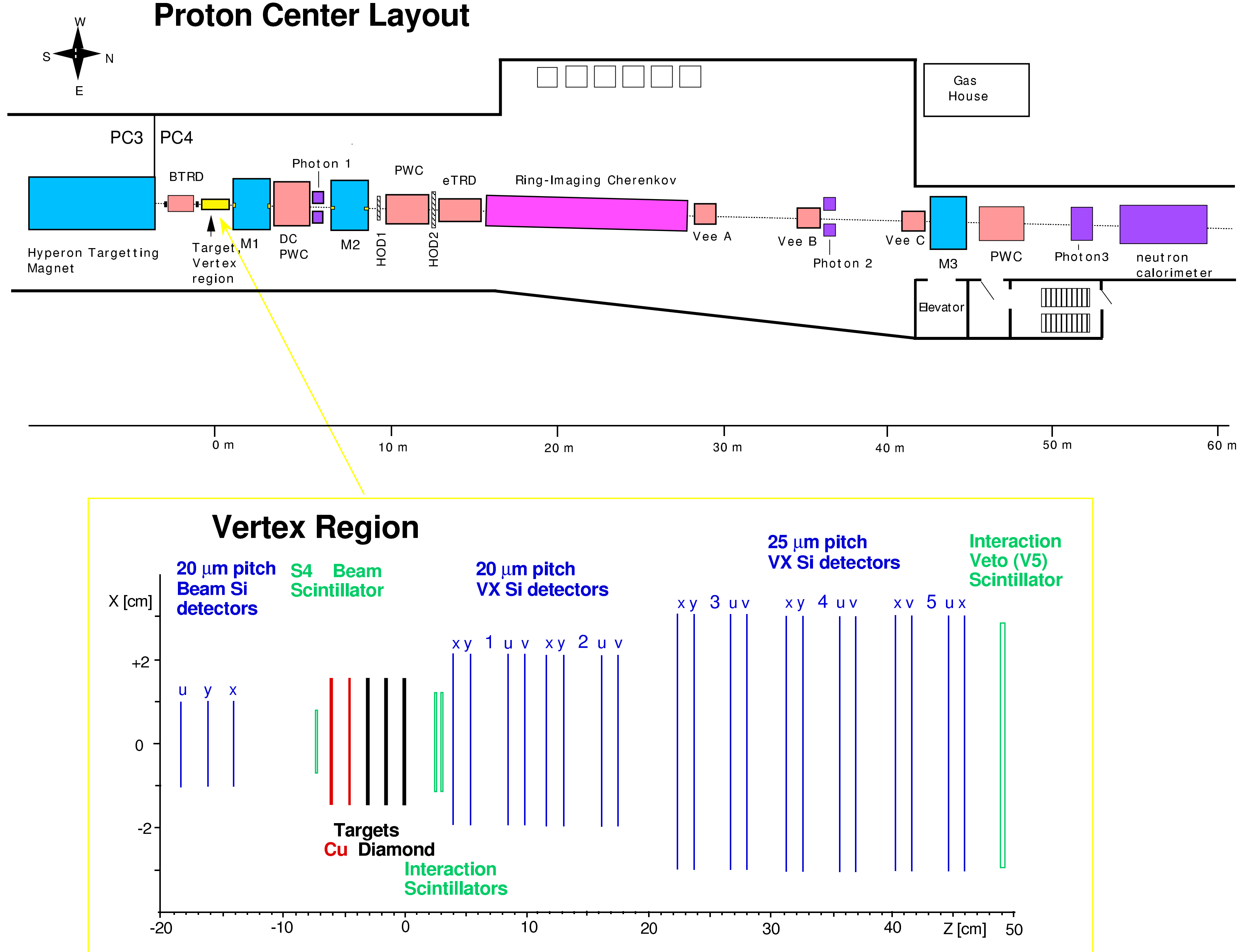
Particle Identification Algorithm

- only discrete particle masses: e, μ, π, K, p, Σ, etc.
- Track parameter and momentum known
  $\Longrightarrow$ Calculate ring radius for each hypothesis
- "Compare" measured and expected rings for each hypothesis with a maximum likelihood method
- for identification, make cuts on likelihood ratios

The SELEX Collaboration

G.P. Thomas
Ball State University, Muncie, IN 47306, U.S.A.
E. Gülmez
Bogazici University, Bebek 80815 Istanbul, Turkey
R. Edelstein, S.Y. Jun, A.I. Kulyavtsev[1], A. Kushnirenko, D. Mao[1], P. Mathew[2], M. Mattson, M. Procario[3], J. Russ, J. You[4]
Carnegie-Mellon University, Pittsburgh, PA 15213, U.S.A.
A.M.F. Endler
Centro Brasiliero de Pesquisas Físicas, Rio de Janeiro, Brazil
P.S. Cooper, J. Kilmer, S. Kwan, J. Lach, E. Ramberg, D. Skow, L. Stutte
Fermilab, Batavia, IL 60510, U.S.A.
V.P. Kubarovsky, V.F. Kurshetsov, A.P. Kozhevnikov, L.G. Landsberg, V.V. Molchanov, S.B. Nurushev, S.I. Petrenko, A.N. Vasiliev, D.V. Vavilov, V.A. Victorov
Institute for High Energy Physics, Protvino, Russia
Li Yunshan, Mao Chensheng, Zhao Wenheng, He Kangling, Zheng Shuchen, Mao Zhenlin
Institute of High Energy Physics, Beijing, P.R. China
M.Y. Balatz[5], G.V. Davidenko, A.G. Dolgolenko, G.B. Dzyubenko, A.V. Evdokimov, M.A. Kubantsev, I. Larin, V. Matveev, A.P. Nilov, V.A. Prutskoi, A.I. Sitnikov, V.S. Verebryusov, V.E. Vishnyakov
Institute of Theoretical and Experimental Physics, Moscow, Russia
U. Dersch[6], I. Eschrich[7], I. Konorov[8], H. Krüger[9], J. Simon[10], K. Vorwalter[11]
Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany
I.S. Filimonov[5], E.M. Leikin, A.V. Nemitkin, V.I. Rud
Moscow State University, Moscow, Russia
A.G. Atamantchouk, G. Alkhazov, N.F. Bondar, V.L. Golovtsov, V.T. Kim, L.M. Kochenda, A.G. Krivshich, N.P. Kuropatkin, V.P. Maleev, P.V. Neoustroev, B.V. Razmyslovich, V. Stepanov, M. Svoiski, N.K. Terentyev[12], L.N. Uvarov, A.A. Vorobyov
Petersburg Nuclear Physics Institute, St. Petersburg, Russia
I. Giller, M.A. Moinester, A. Ocherashvili, V. Steiner
Tel Aviv University, 69978 Ramat Aviv, Israel
J. Engelfried[4], A. Morelos
Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico
M. Luksys
Universidade Federal da Paraíba, Paraíba, Brazil
V.J. Smith
University of Bristol, Bristol BS8 1TL, United Kingdom
M. Kaya, E. McCliment, K.D. Nelson[13], C. Newsom, Y. Onel, E. Ozel, S. Ozkorucuklu, P. Pogodin
University of Iowa, Iowa City, IA 52242, U.S.A.
L.J. Dauwe
University of Michigan-Flint, Flint, MI 48502, U.S.A.
M. Gaspero, M. Iori
University of Rome “La Sapienza” and INFN, Rome, Italy
L. Emediato, C.O. Escobar[14], F.G. Garcia[4], P. Gouffon, T. Lungov[15], M. Srivastava, R. Zukanovich-Funchal
University of São Paulo, São Paulo, Brazil
A. Lamberto, A. Penzo, G.F. Rappazzo, P. Schiavon
University of Trieste and INFN, Trieste, Italy

Selex (E781)
Proton Center Layout



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Nuclear Instruments and Methods in Physics Research A 431 (1999) 53–69

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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The SELEX phototube RICH detector

J. Engelfried[a,*,1], I. Filimonov[b,2,3], J. Kilmer[a,1], A. Kozhevnikov[c,3], V. Kubarovsky[c,3], V. Molchanov[c,3], A. Nemitkin[b,3], E. Ramberg[a,1], V. Rud[b,3], L. Stutte[a,1]

[a] *Fermi National Accelerator Laboratory, Batavia, IL, USA*
[b] *Moscow State University, Moscow, Russia*
[c] *Institute for High Energy Physics, Serpukhov, Russia*

Received 6 November 1998

Abstract

In this article, construction, operation, and performance of the RICH detector of Fermilab experiment 781 (SELEX) are described. The detector utilizes a matrix of 2848 phototubes for the photocathode to detect Cherenkov photons generated in a 10 m neon radiator. For the central region an N_0 of 104 cm^{-1}, corresponding to 13.6 hits on a $\beta = 1$ ring, was obtained. The ring radius resolution measured is 1.6%. © 1999 Published by Elsevier Science B.V. All rights reserved.

1. Introduction

The Fermilab experiment E781 (SELEX): a segmented large x_F Baryon spectrometer [1,2], which took data in the 1996/1997 fixed target run at Fermilab, is designed to perform high statistics studies of production mechanisms and decay physics of charmed baryons such as Σ_c, Ξ_c, Ω_c and Λ_c. The physics goals of the experiment require good charged particle identification to look for the different baryon decay modes. One must be able to separate π, K and p over a wide momentum range when looking for charmed baryon decays like $\Lambda_c^+ \rightarrow pK^-\pi^+$.

A RICH [3] detector with a 2848 phototube photocathode array has been constructed [4,5] to do this. The detector begins about 16 m downstream of the charm production target, with two analysis magnets with 800 MeV/c p_t-kick each in-between, and is surrounded by multi-wire proportional and drift chambers which provide particle tracking. The average number of tracks reaching the RICH is about 5 per event. First results from this detector can be found in Ref. [6].

* Corresponding author. Now at Instituto de Física, Universidad Autonoma de San Luis Potosí, Manuel Nava # 6, Zona Universitaria, 78240 San Luis Potosi, Mexico. Tel.: + 52-48-262362; fax: + 52-48-133874 e-mail; jurgen@fnal.gov.

1 Work supported by the US Department of Energy under contract NO. DE-AC02-76CHO3000.

2 Deceased.

3 Supported by the Russian Ministry of Science and Technology.

PII: S0168-9002(99)00043-1

SELEX RICH Vessel and Gas System

Vessel: 10.3 m long

2.4 m diameter (50 m^3)

Gas: Neon @ 1 atm

closed volume ($\Rightarrow$ constant refractive index)

Filling:

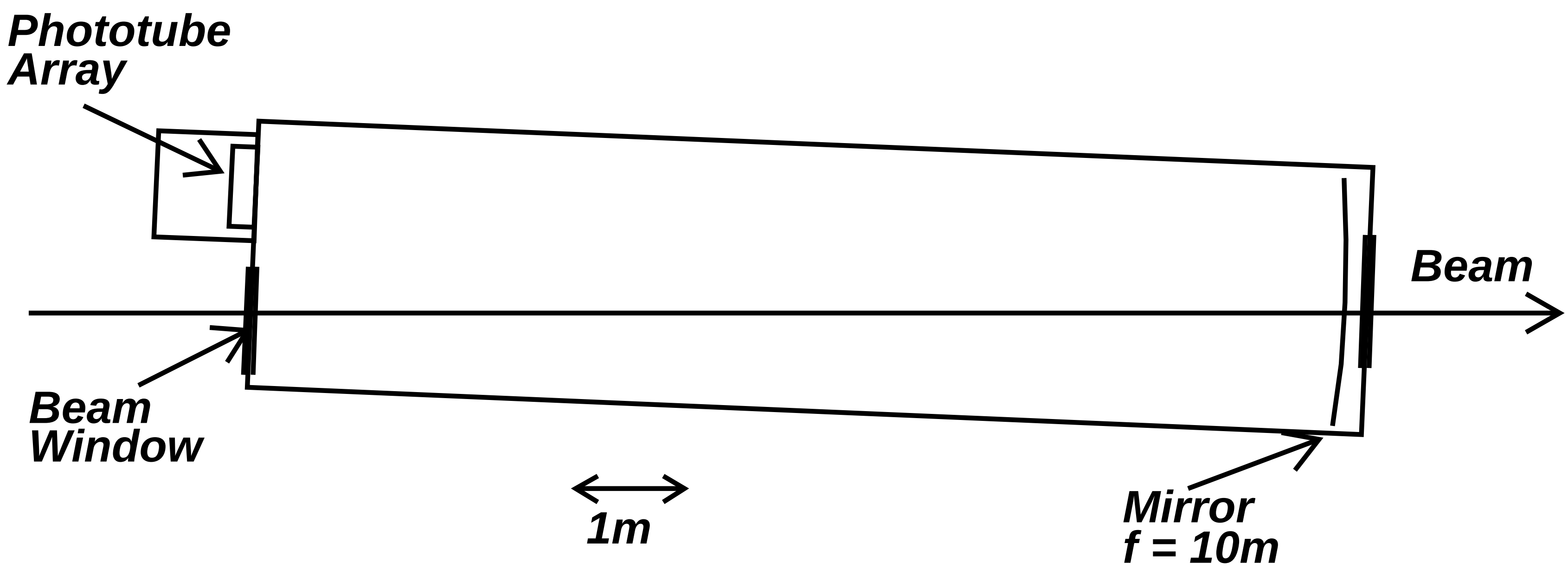
– purge with CO_2 ($\approx$ 1 day)

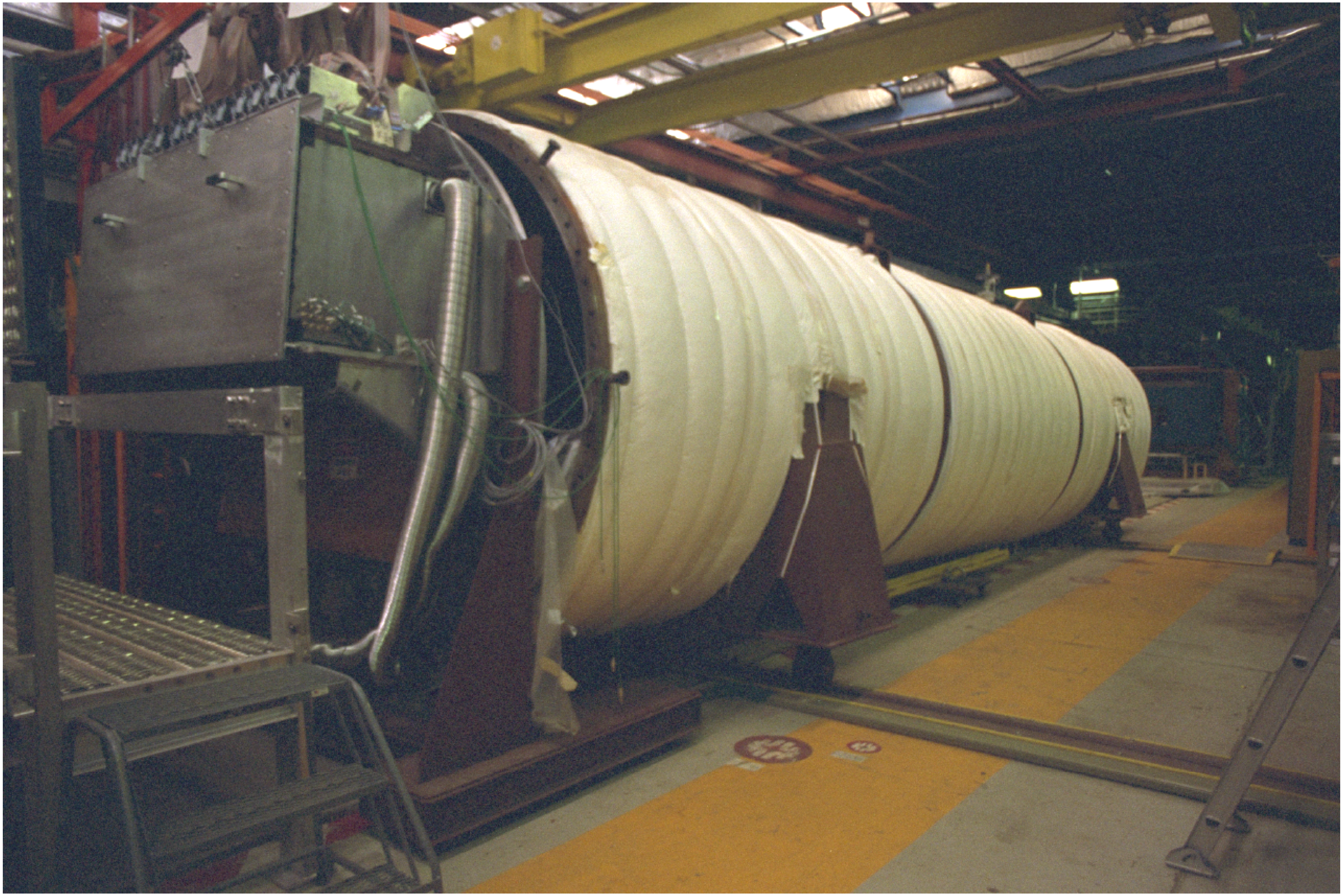
– freeze out CO_2, replace with Ne

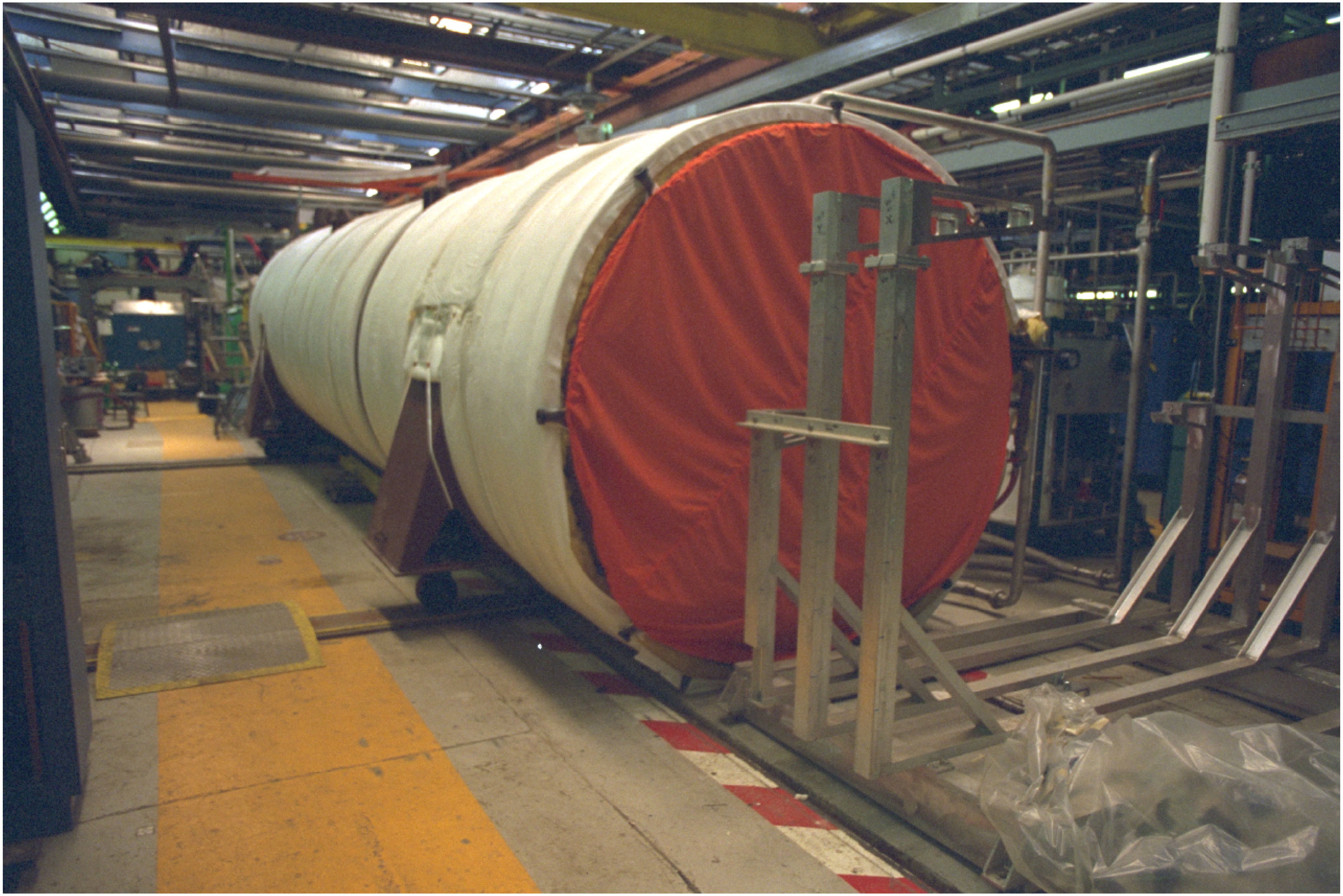
– remove remaining O_2 and water

– started with 3 ppm O_2

– after 15 months: (20 ± 12) ppm


Phototube
Array
Beam
Window
1m
Mirror
f = 10m
Beam





SELEX RICH Mirrors

Spherical, nominal 20 m Radius
16 hexagonal mirrors, 46 cm tip to tip

- Glass
  - low expansion glass (Schott Tempax), 10 mm thick.
  - Polished to 19.82 m ± 5 cm
  - Measured with Ronchi Method (NIMA 369 (1996) 69-78)
- Coating
  - Aluminum, with MgF_2 overcoating (Acton)
  - Reflectivity $> 85\,\%$ at 160 nm
- Mounting
  - 3 point mount
  - Ball bearing, double differential screw
  - Honeycomb panel with carbon fiber matrix
- Alignment
  - Theodolite with Laser in Center of Curvature
  - Vessel movable on wheels lateral to beam

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Nuclear Instruments and Methods in Physics Research A 369 (1996) 69–78

A method to evaluate mirrors for Cherenkov counters

Linda Stutte*, Jürgen Engelfried, James Kilmer
Fermi National Accelerator Laboratory[1], P.O. Box 500, Batavia, IL 60510, USA

Received 19 June 1995

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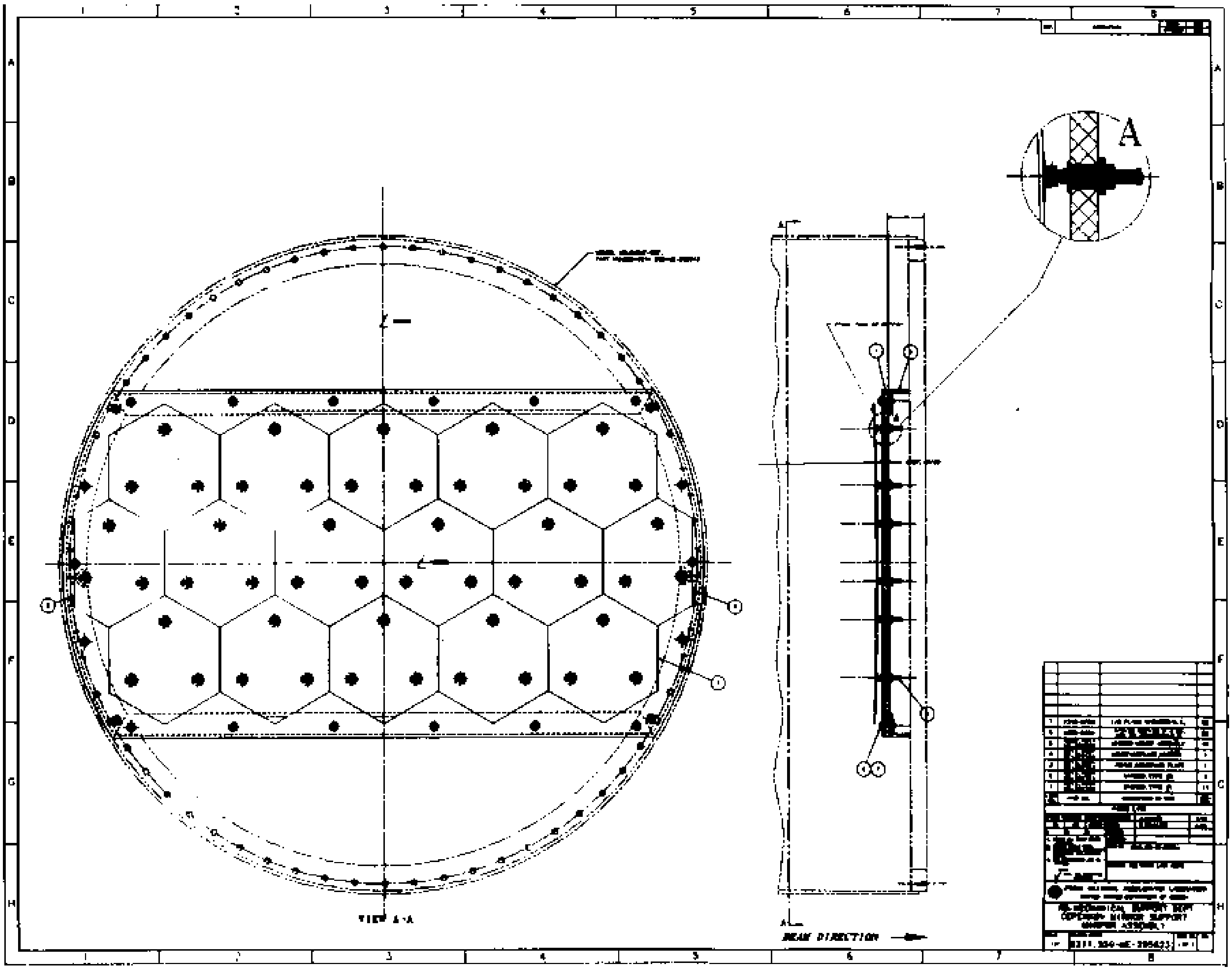
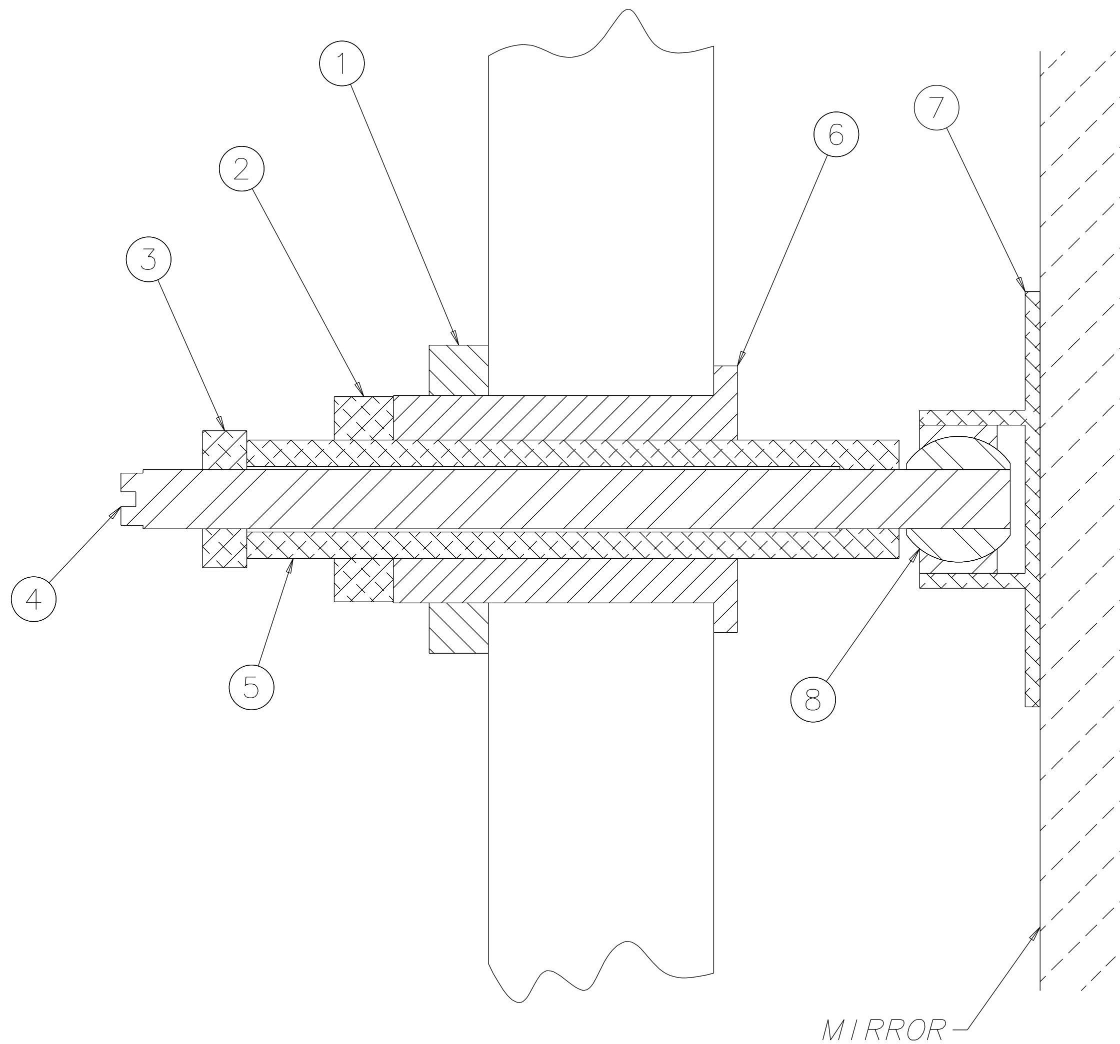
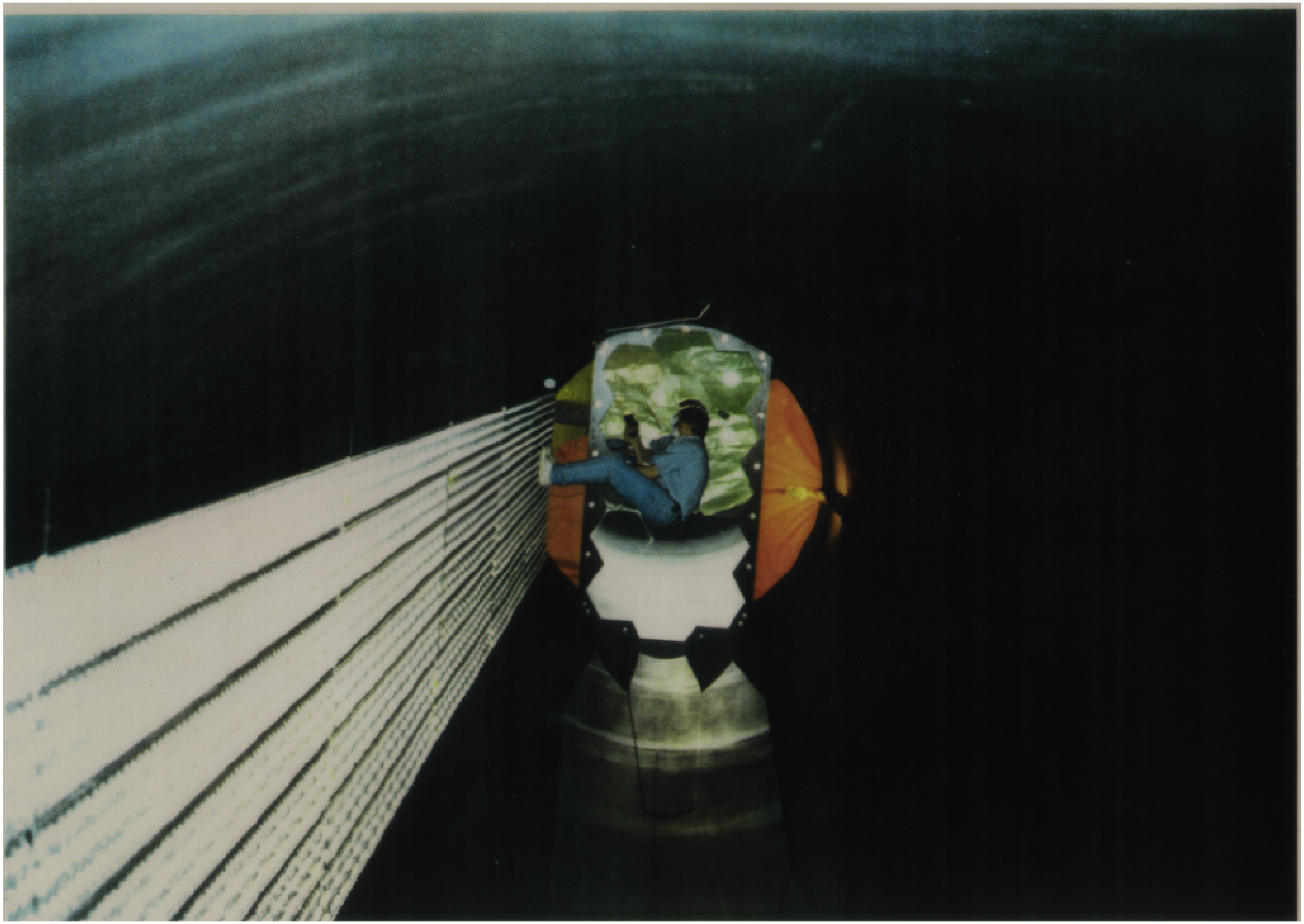
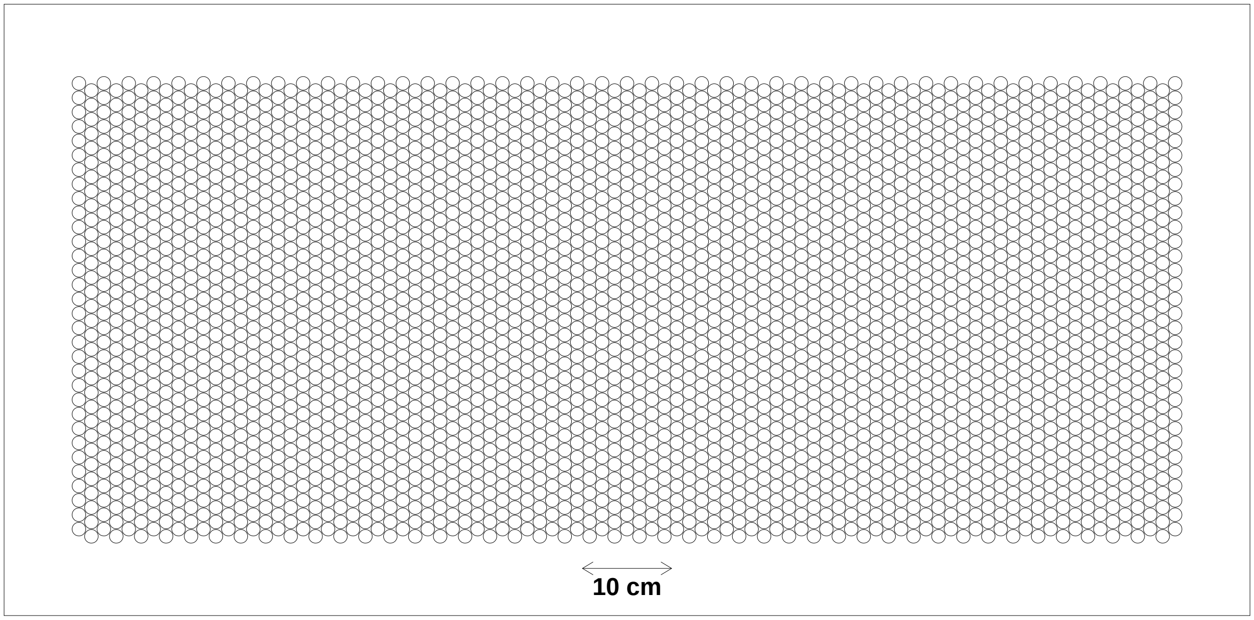

A
VIEW A-A
BEAM DIRECTION


1
2
3
4
5
6
7
8
MIRROR

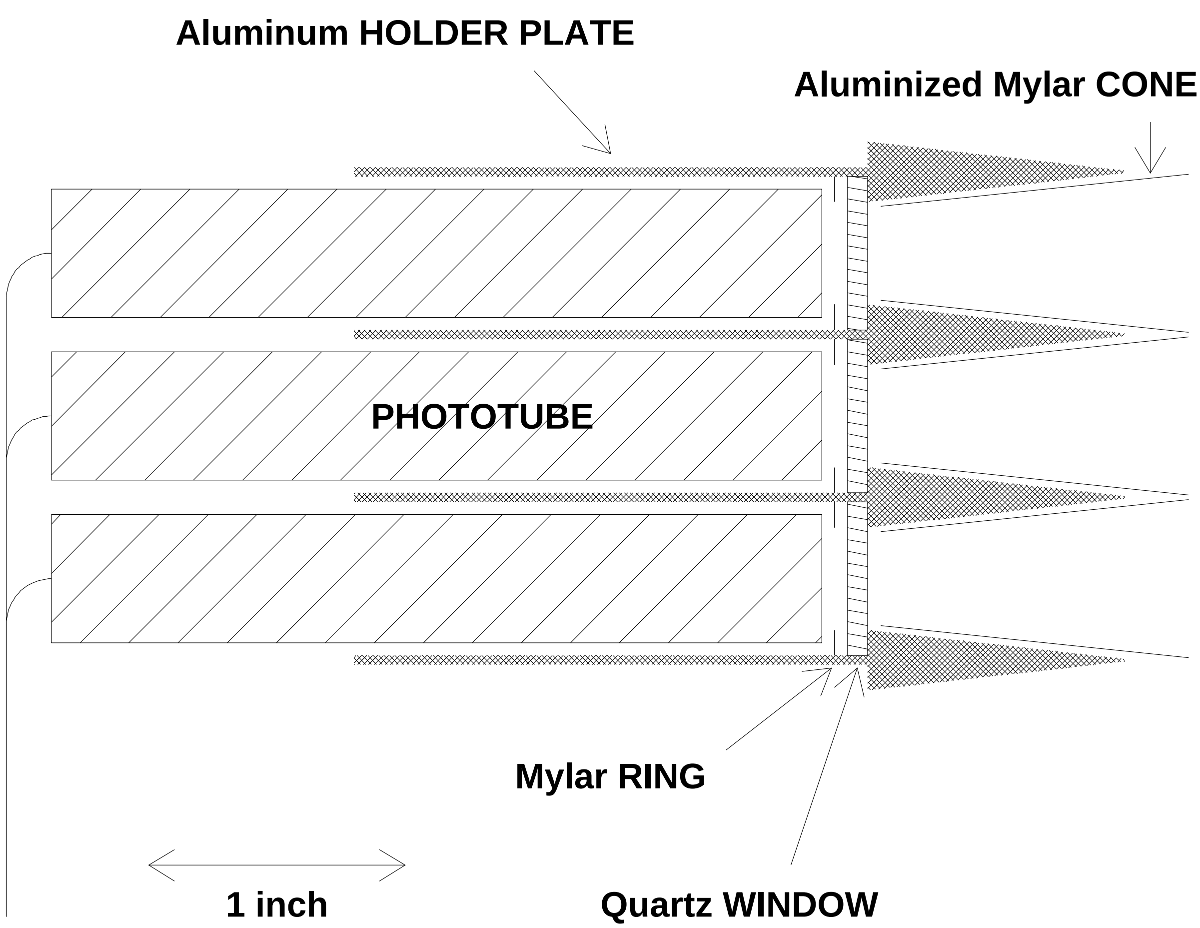


SELEX RICH Photon Detection

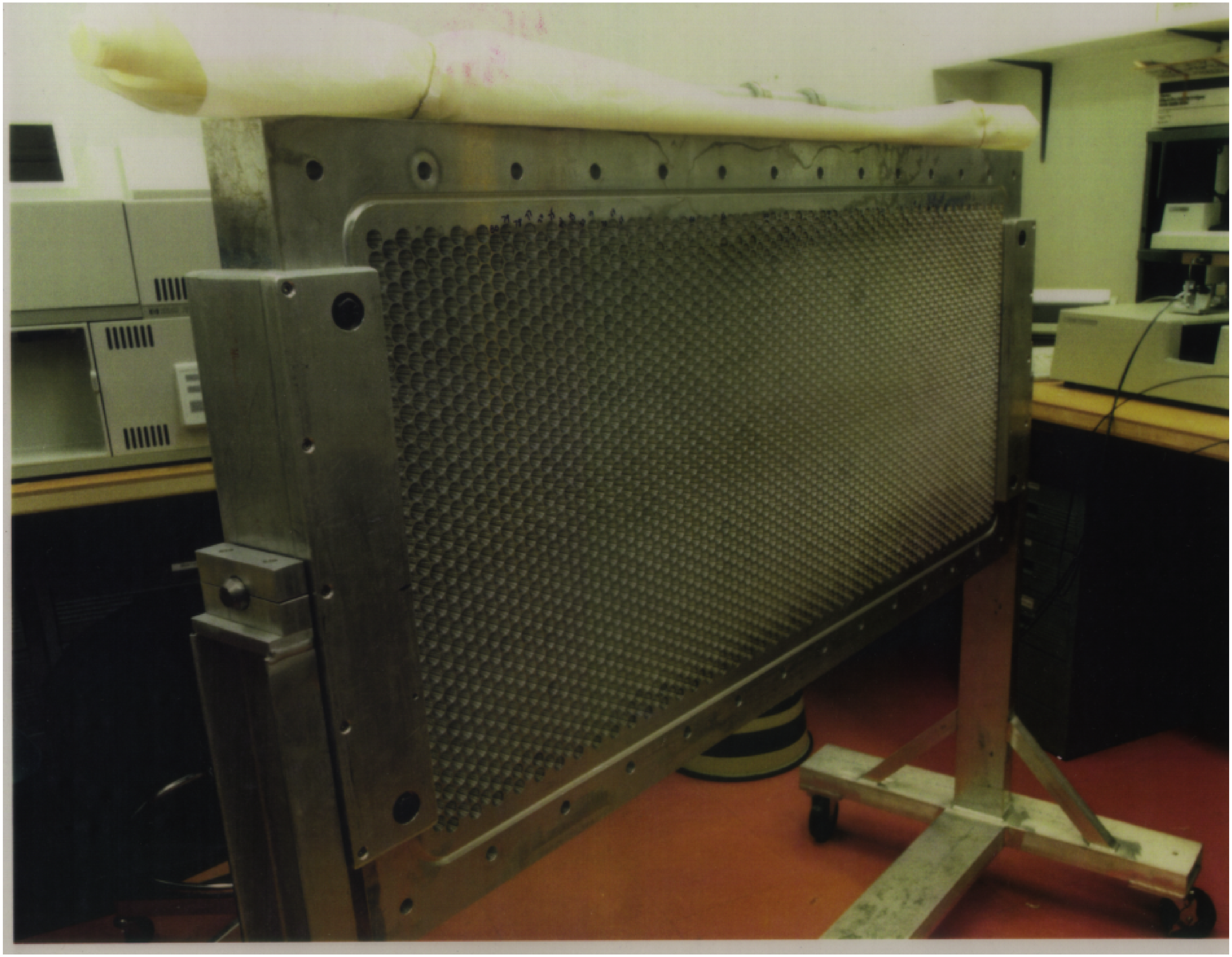
- Photomultiplier Holder
  - Aluminum plate, 2848 (89×32) holes
  - individual quartz windows as gas seal
  - aluminized mylar Winston cones
- Photomultipliers
  - $\frac{1}{2}$" diameter, Photocathode 10 mm
  - 608 Hamamatsu R760
  - 2240 FEU60 (with wavelength shifter)
  - all PM measured to find operating voltage
  - groups of 32 run on same HV
- High Voltage
  - Operating Voltage 900 V...1900 V
  - 6 HV Supplies
  - Zener Box (á la "Berkeley Cow"), 96 outputs
- Crates with Hybrid Chips
  - Hybrids contain Amplifier, Discriminator, diff. ECL Driver
- Readout: CROS PWC System
  - Integration time 170 nsec



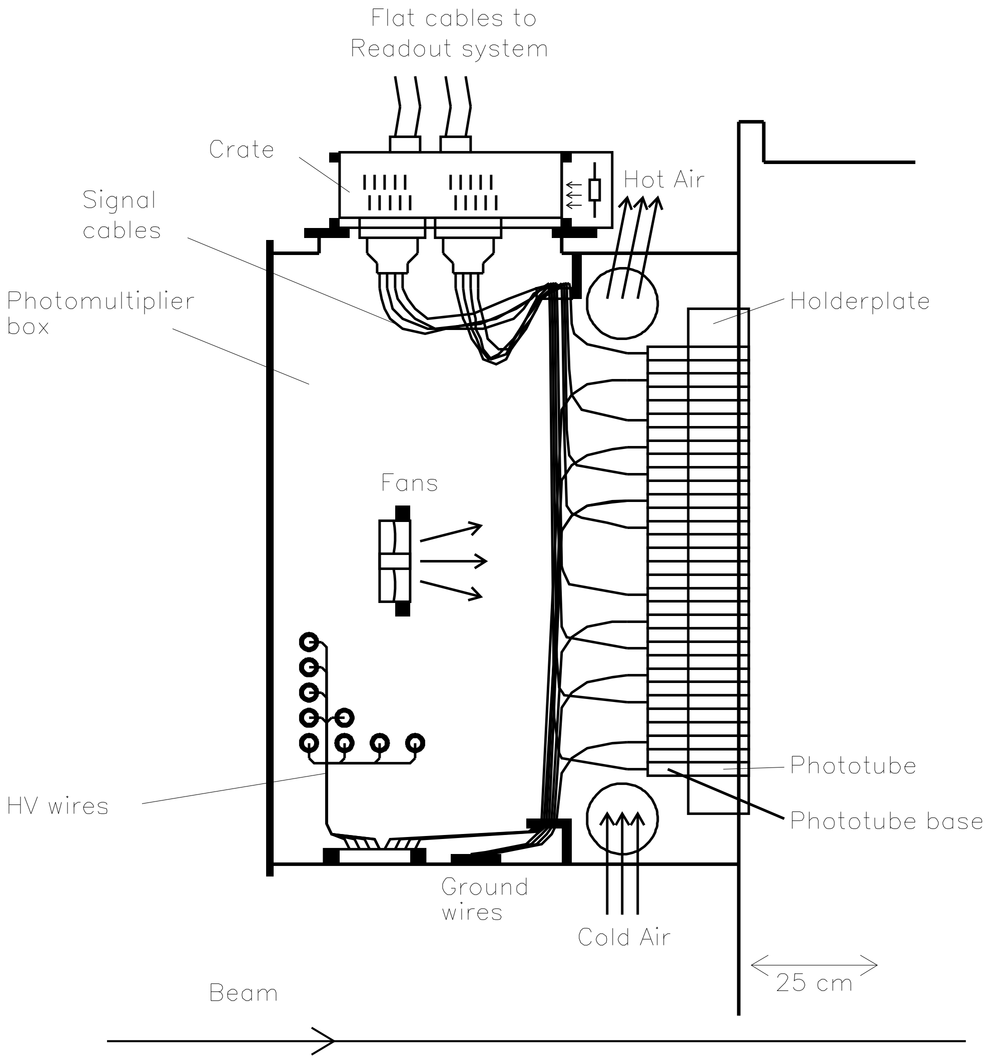
10 cm

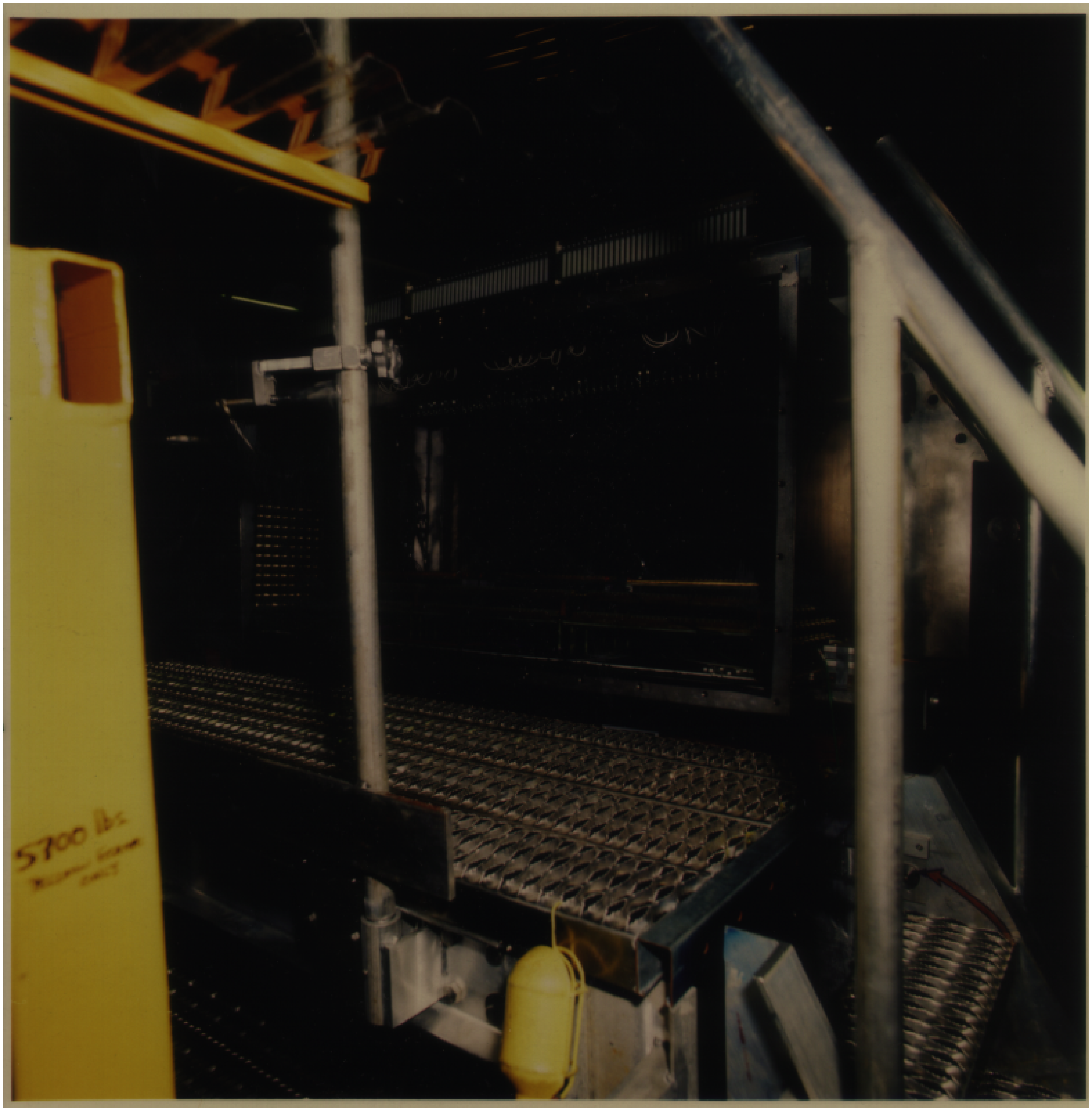


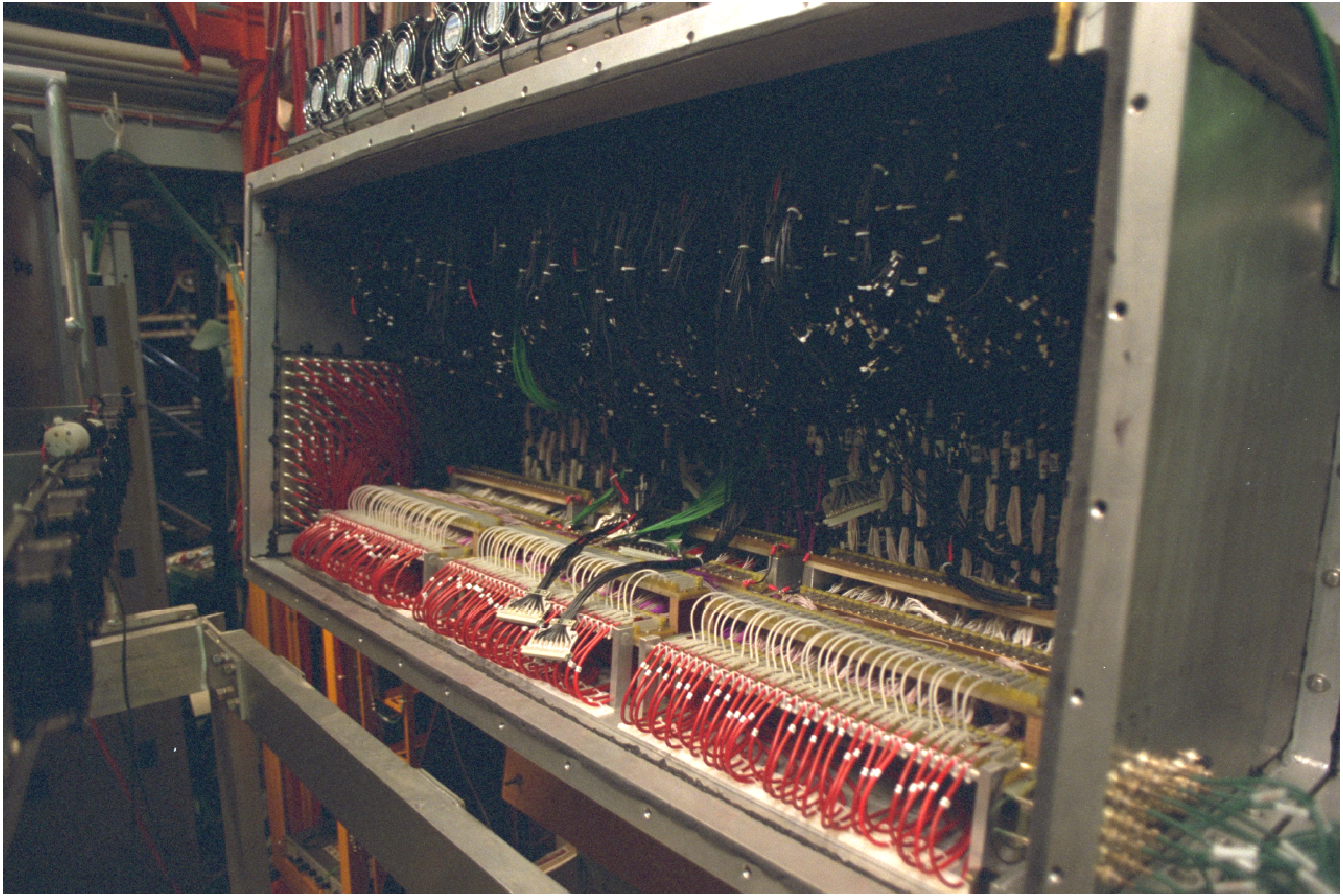
Aluminum HOLDER PLATE
Aluminized Mylar CONE
PHOTOTUBE
Mylar RING
1 inch
Quartz WINDOW



SELEX RICH PM Box

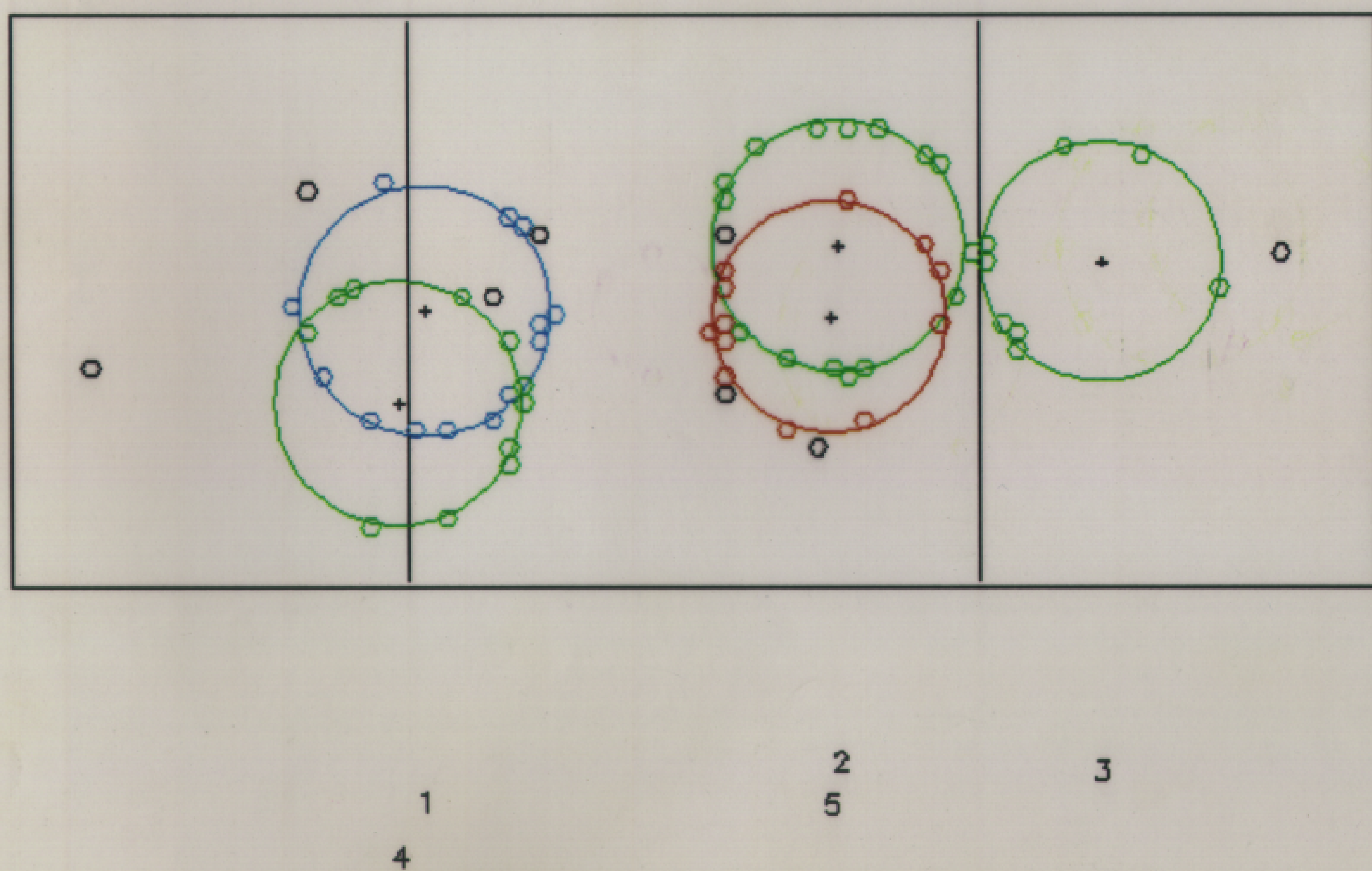



5700 lbs



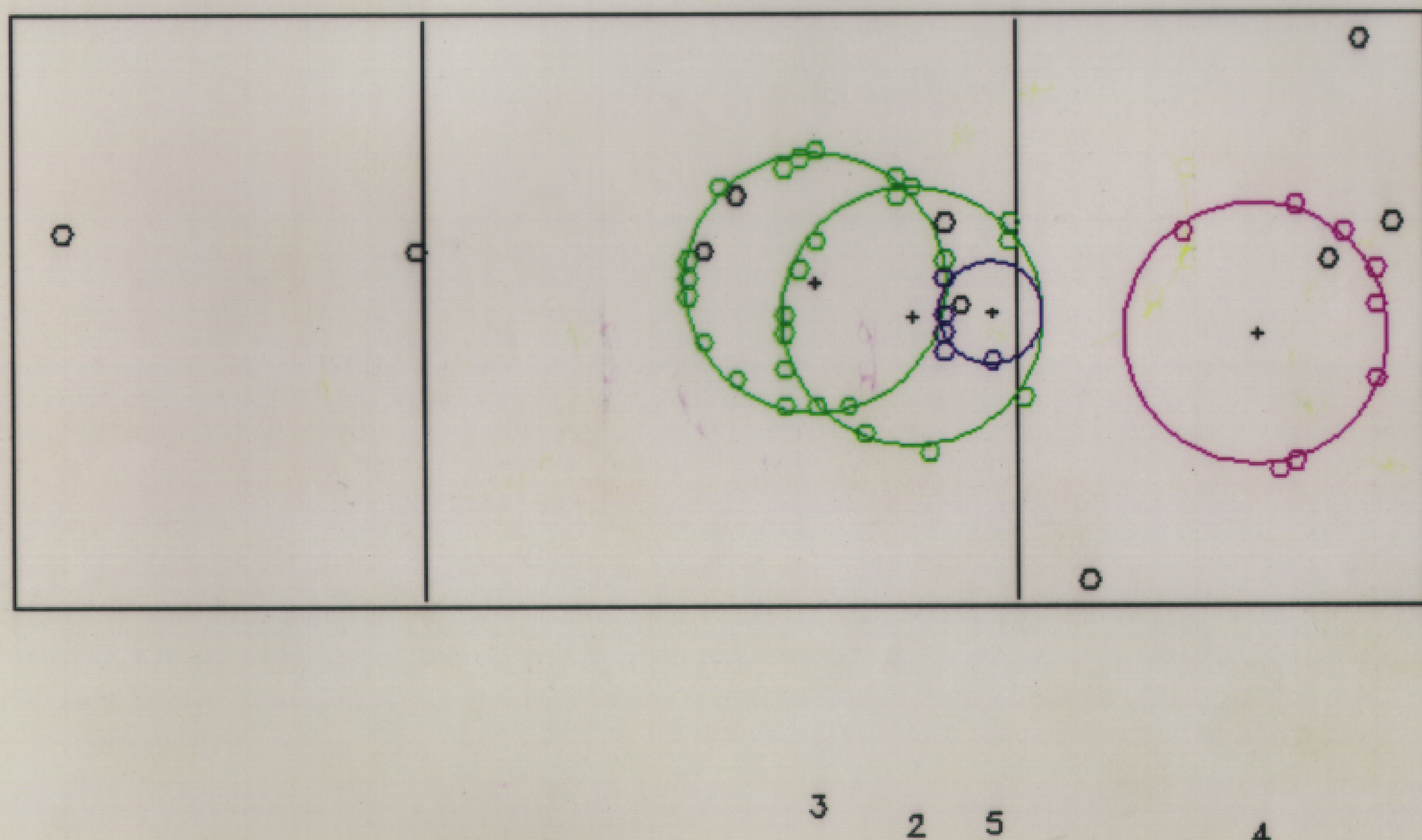
trk	momnt	pid	pckge	stat	gam	bckg	e	muon	pion	kaon	p	sigma
1	71.4	5	rich	8	-1.00	0.00	0.79	1.00	0.88	0.00	0.00	0.00
2	-136.8	9	rich	8	-1.00	0.00	0.88	0.96	1.00	0.00	0.00	0.00
3	-38.1	9	rich	8	-1.00	0.00	0.00	0.06	1.00	0.00	0.00	0.00
4	50.0	8	rich	8	-1.00	0.00	0.24	0.81	1.00	0.00	0.00	0.00
5	-107.7	12	rich	8	-1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00

RUN 1755 EVENT 10000030 TUBES: 67

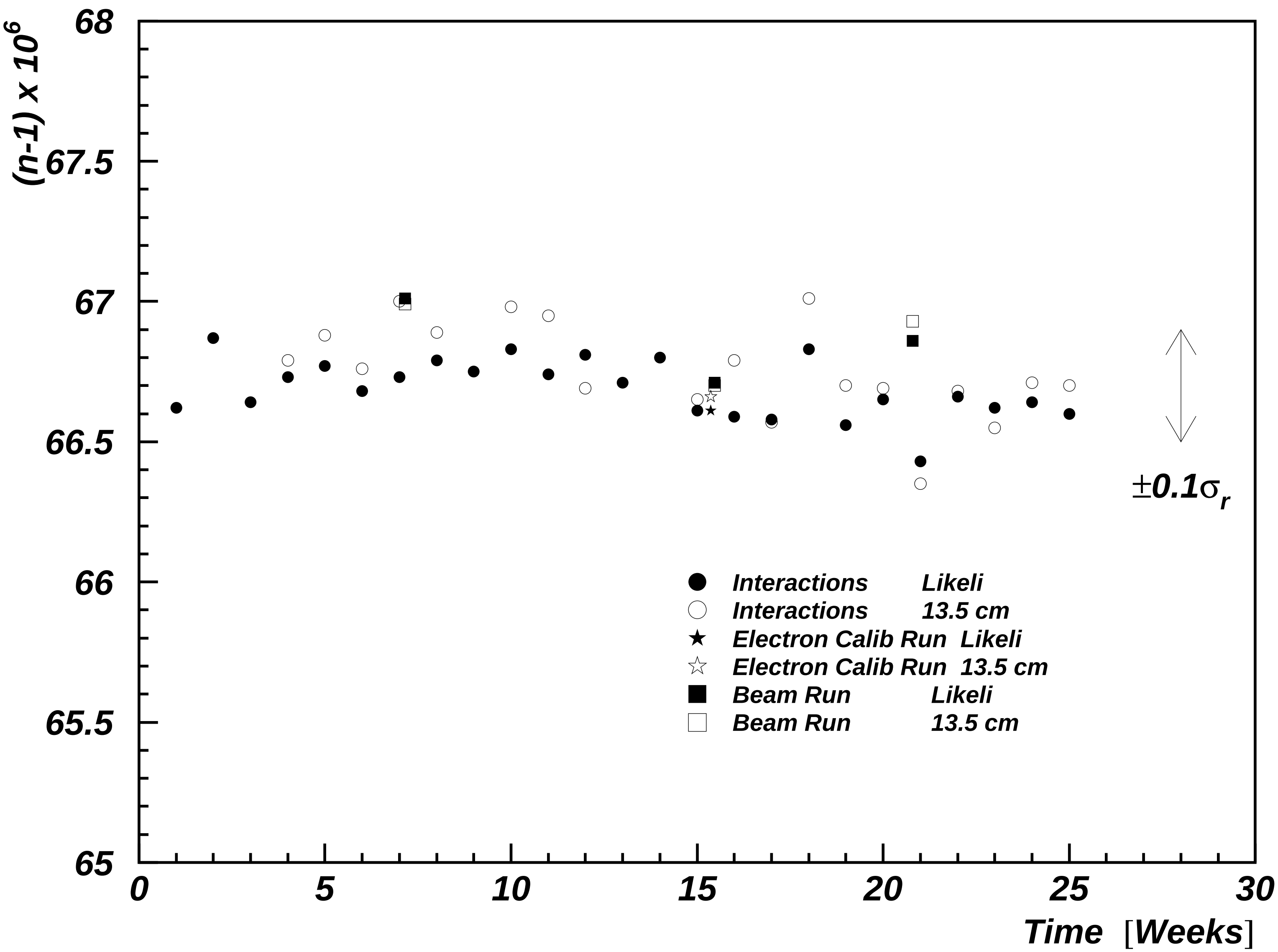


trk	momnt	pid	pckge	stat	gam	bckg	e	muon	pion	kaon	p	sigma
2	-81.9	9	rich	8	-1.00	0.00	0.75	0.96	1.00	0.00	0.00	0.00
3	-120.2	9	rich	8	-1.00	0.00	0.61	0.82	1.00	0.00	0.00	0.00
4	-22.5	3	rich	8	-1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
5	-88.1	15	rich	8	-1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00

RUN 1755 EVENT 110000004 TUBES: 49

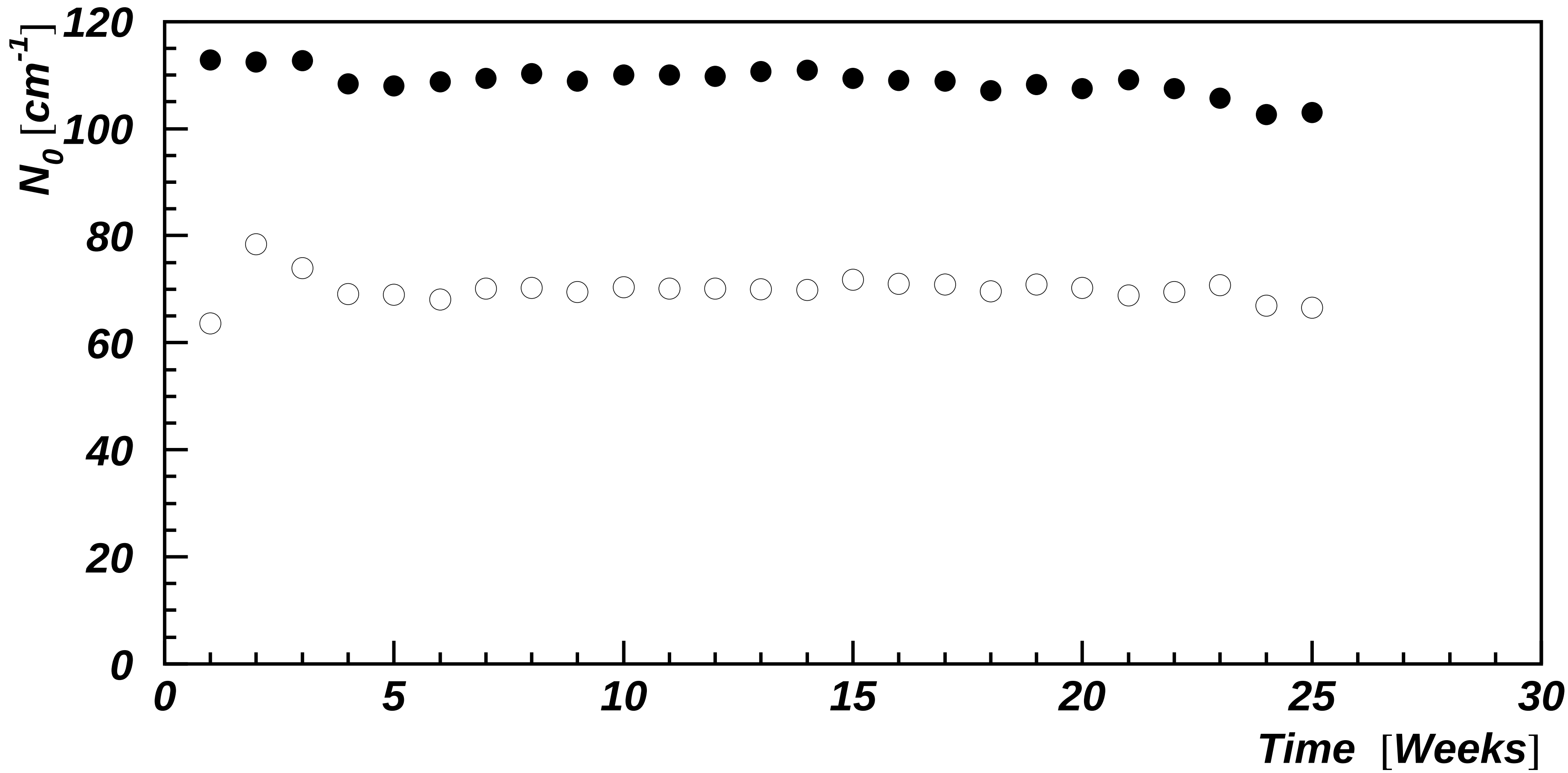


SELEX RICH Stability – Refractive Index



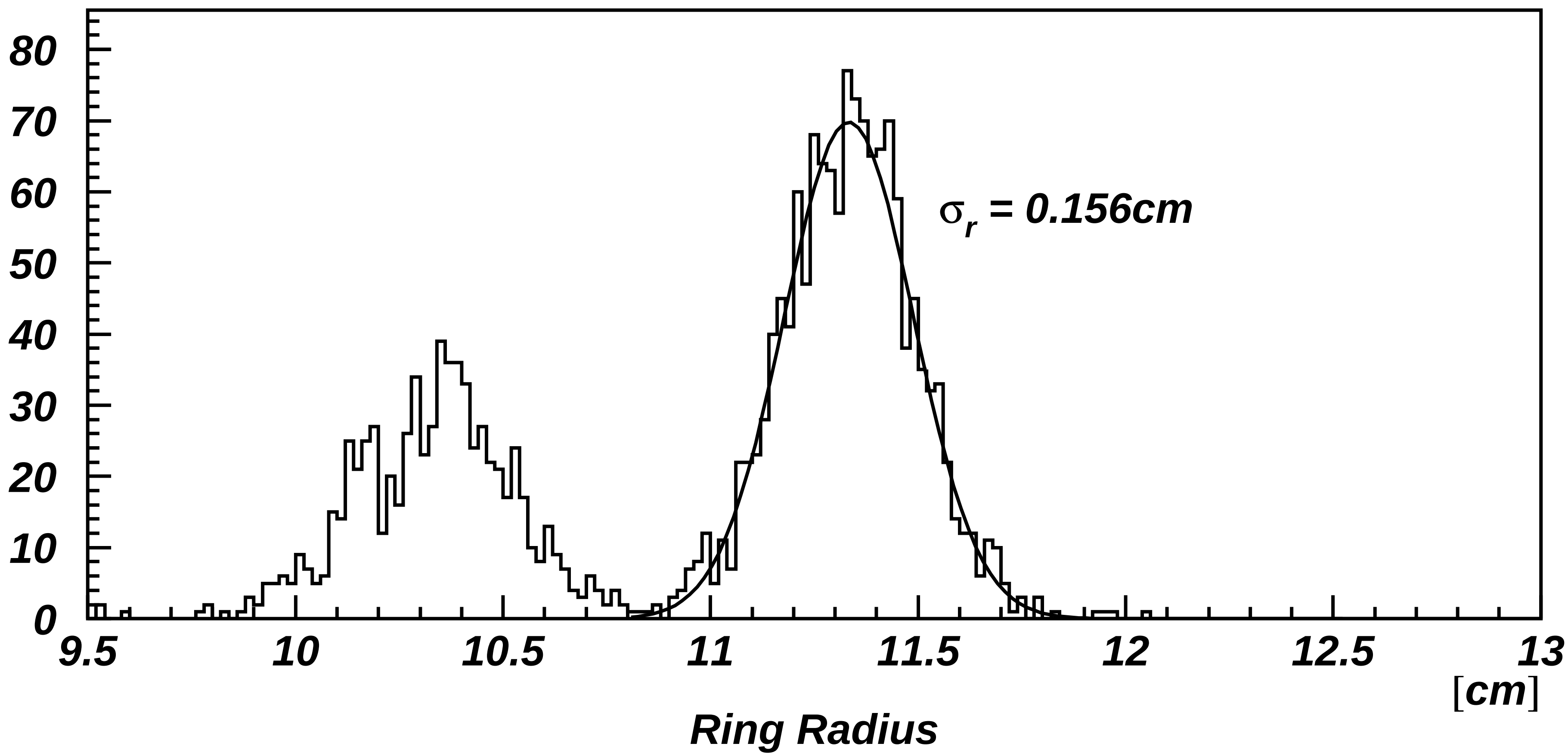
SELEX RICH Stability – N_0

$$N_{\mathrm{ph}} = N_0 \cdot L \cdot \sin^2 \theta_c$$

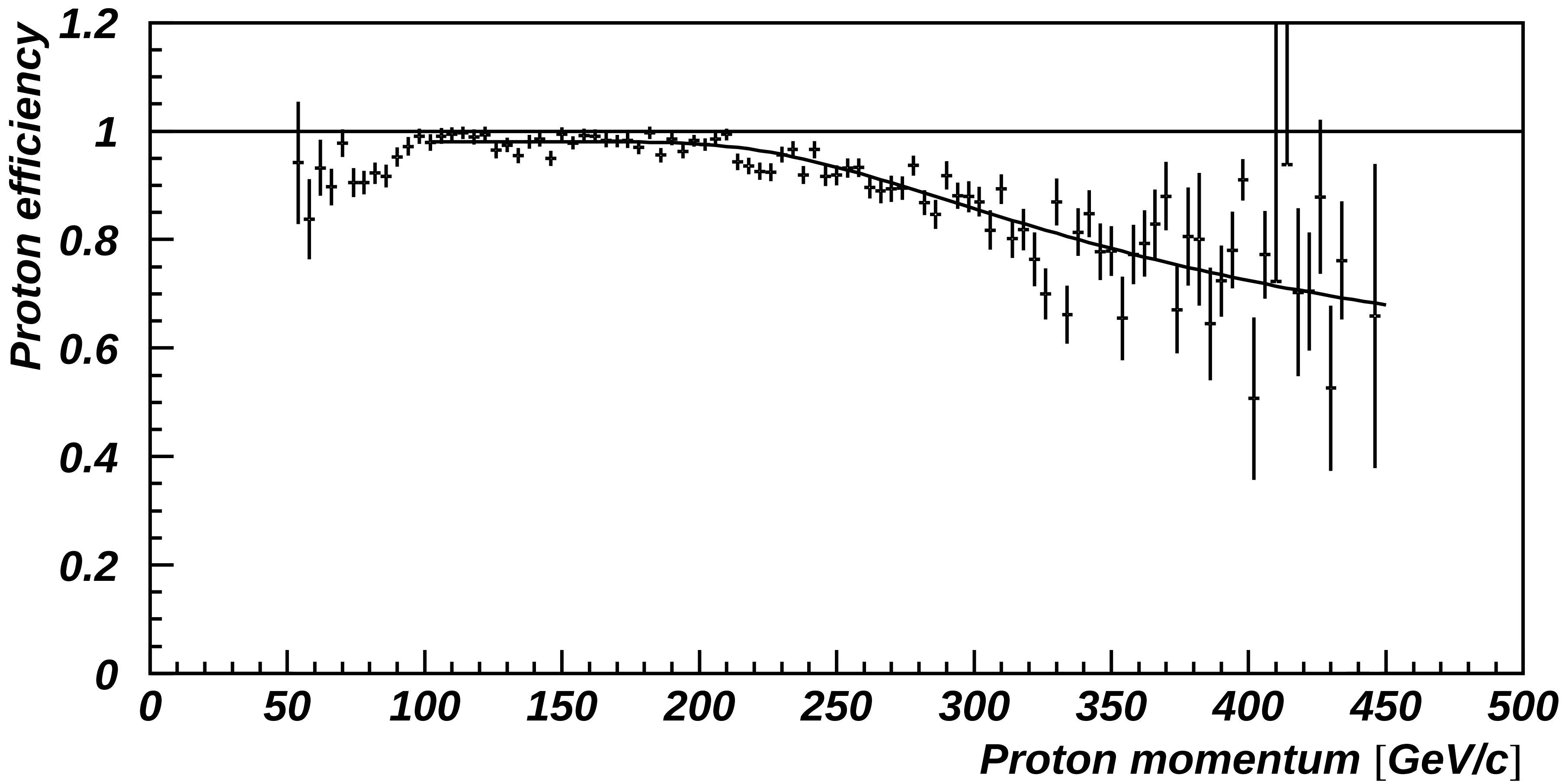


SELEX RICH Separation

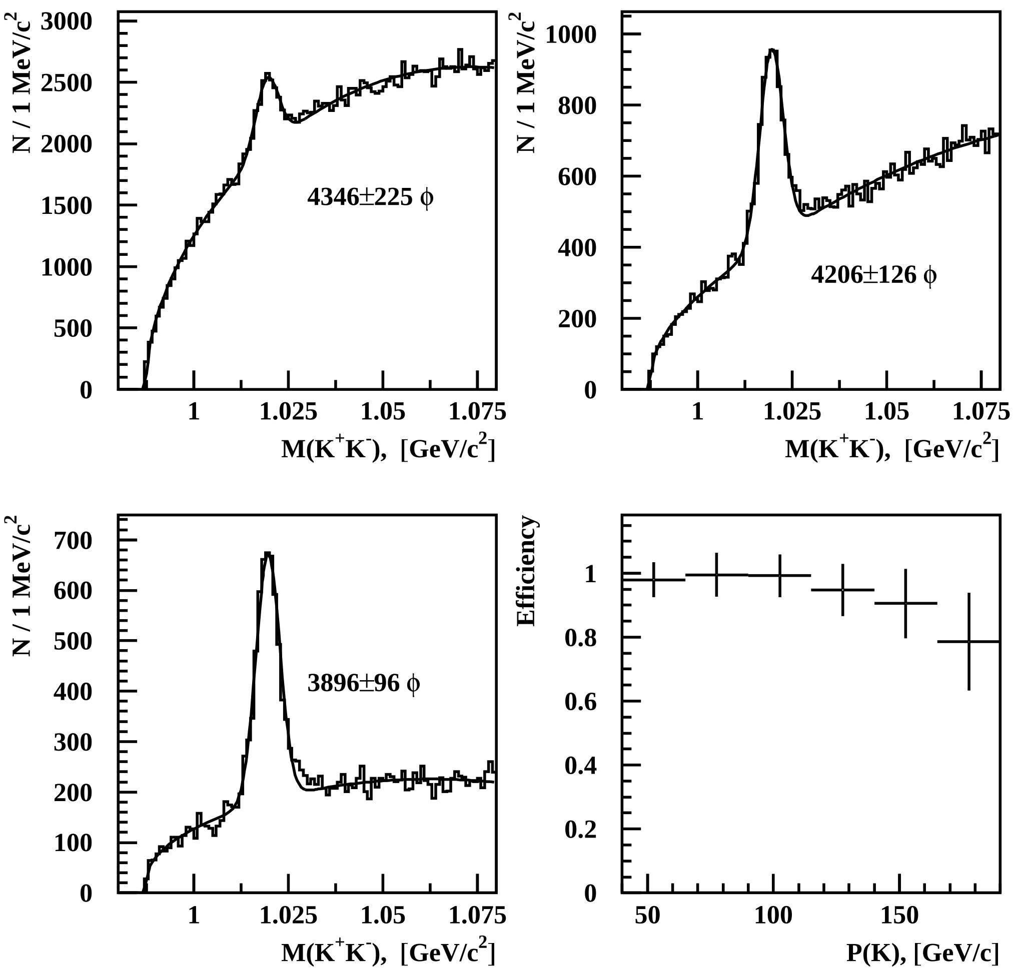
Momentum of particles: $95\,\mathrm{GeV}/c - 105\,\mathrm{GeV}/c$



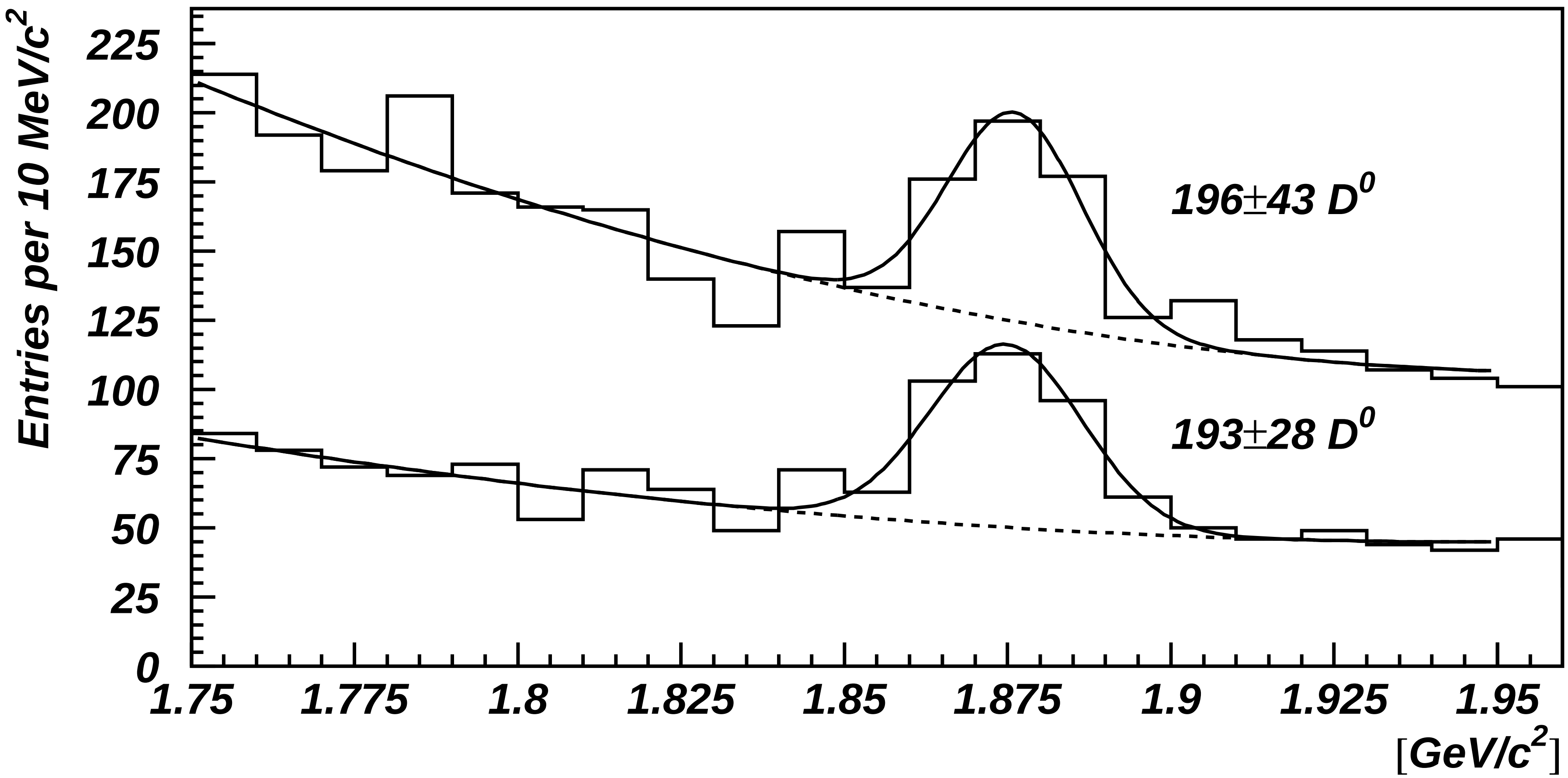
SELEX RICH Efficiency – Protons



SELEX RICH Efficiency – Kaons



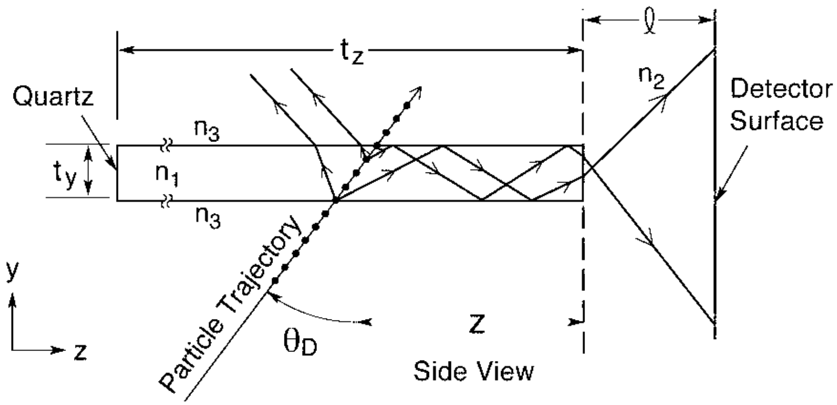
SELEX RICH Efficiency – $D^0 \rightarrow K^{\mp}\pi^{\pm}$

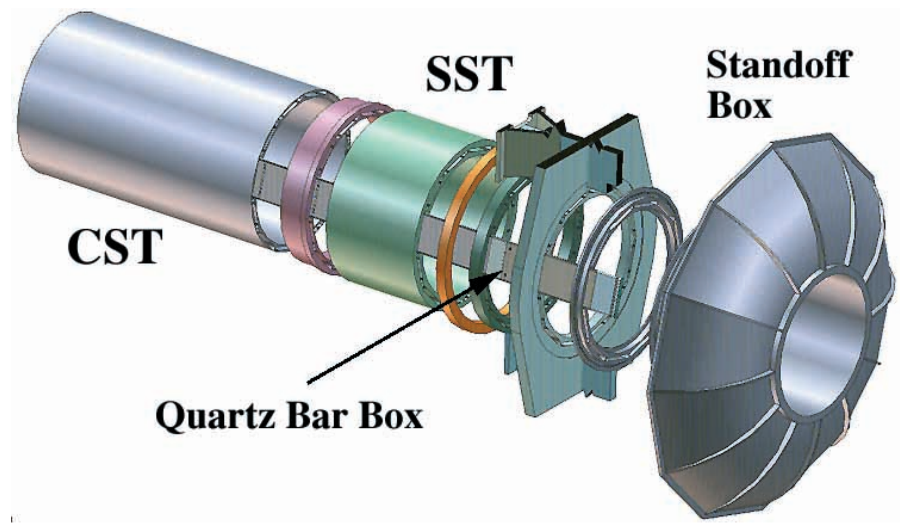


Small statistic: The RICH is too good!!

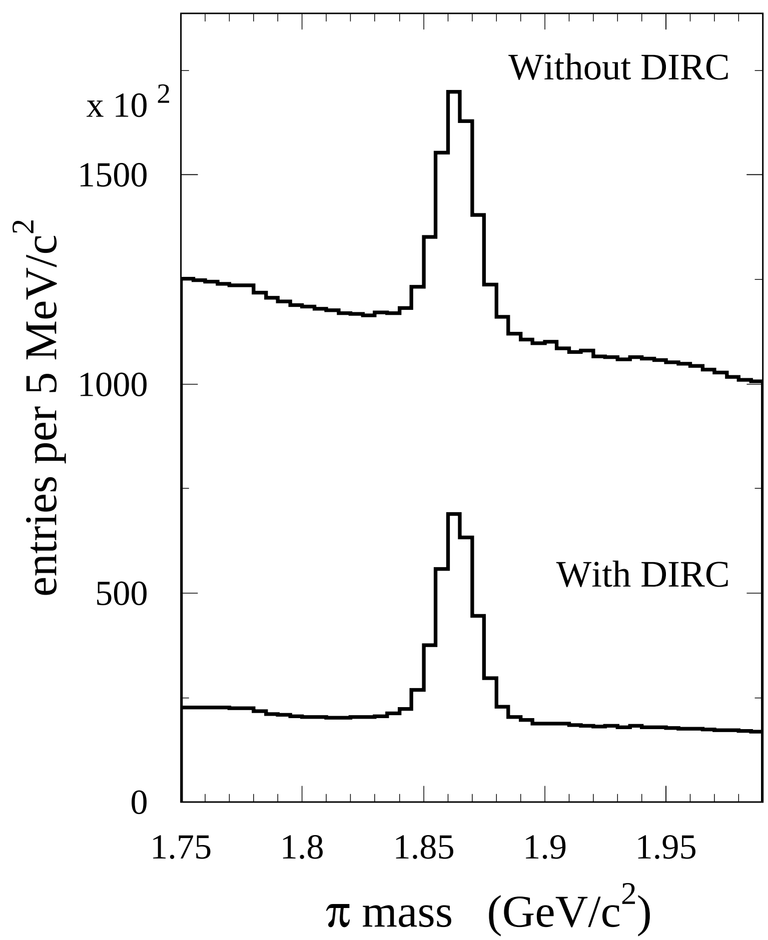
DIRC at BaBar

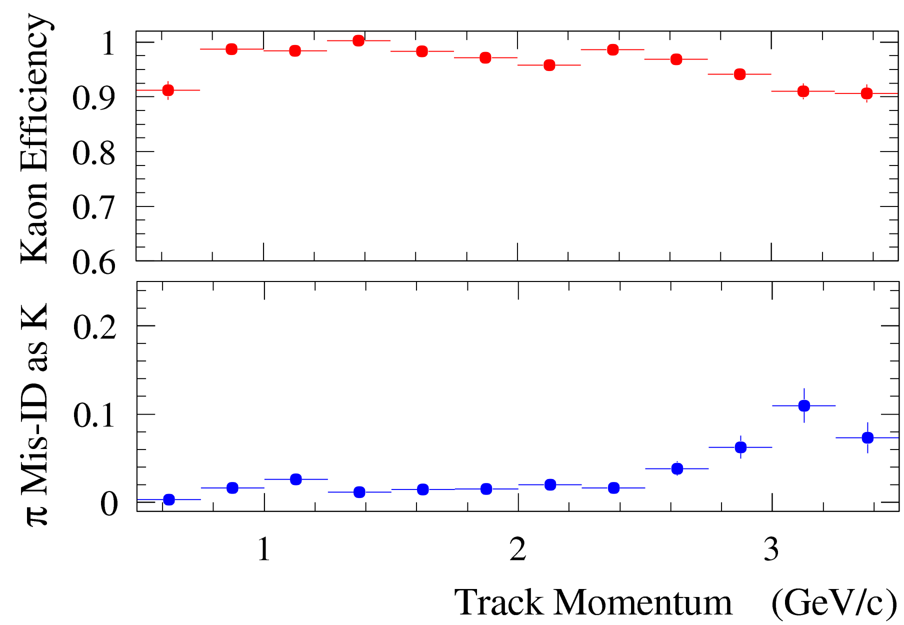
Detection of internally reflected Cherenkov light





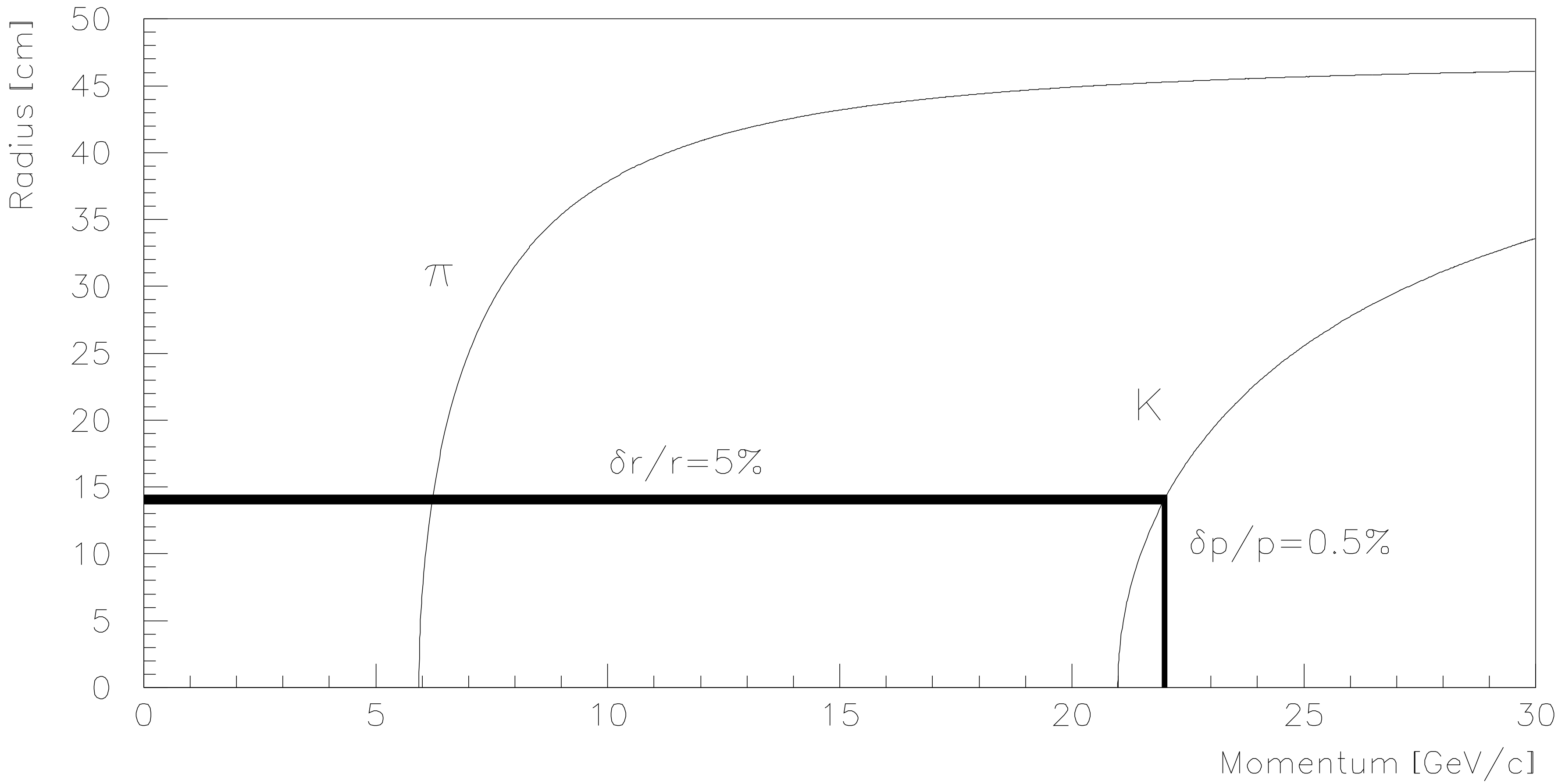
DIRC at BaBar – Performance





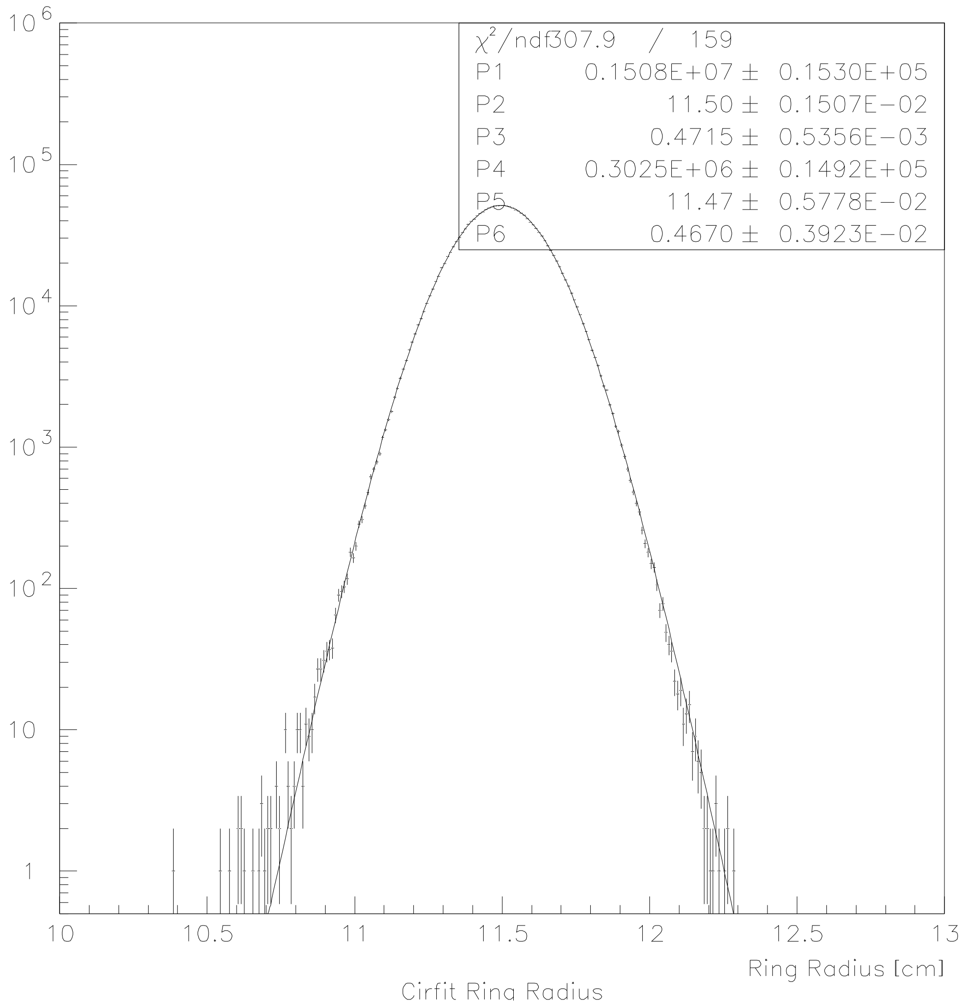
Future Use: CKM

Will use 2 RICHes to really measure velocity. Particle ID comes for free.



How Gaussian is the response?

A Study with SELEX single beam tracks



Gaussian over nearly 5 orders of magnitude!

Summary

- Particle Identification (for charged particles) usually measures the velocity of the particle, identification is combined with the already known momentum.
- Transition Radiation Detectors mostly used in beamlines, but also to measure decay products (mostly electron–pion separation)
- Cherenkov effect is used Threshold Cherenkov Counters
- Cherenkov effect is used in RICH detectors
- RICHes are an established standard detector now.