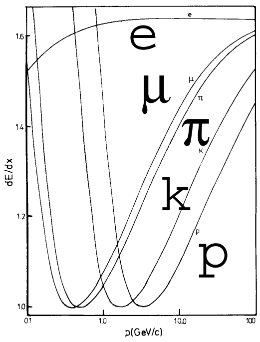
8th Topical Seminar on Innovative Particle and Radiation Detectors
21 - 24 October 2002 Siena, Italy

Progress with Particle Identification

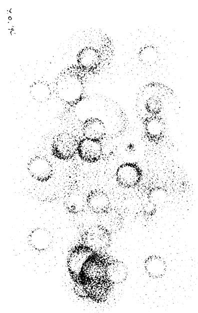
Olav Ullaland / CERN

This talk will partly cover

dE/dX and related techniques

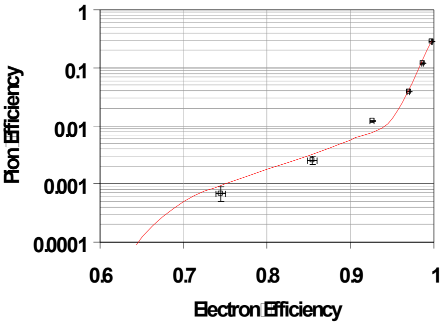


Cherenkov Ring Imaging

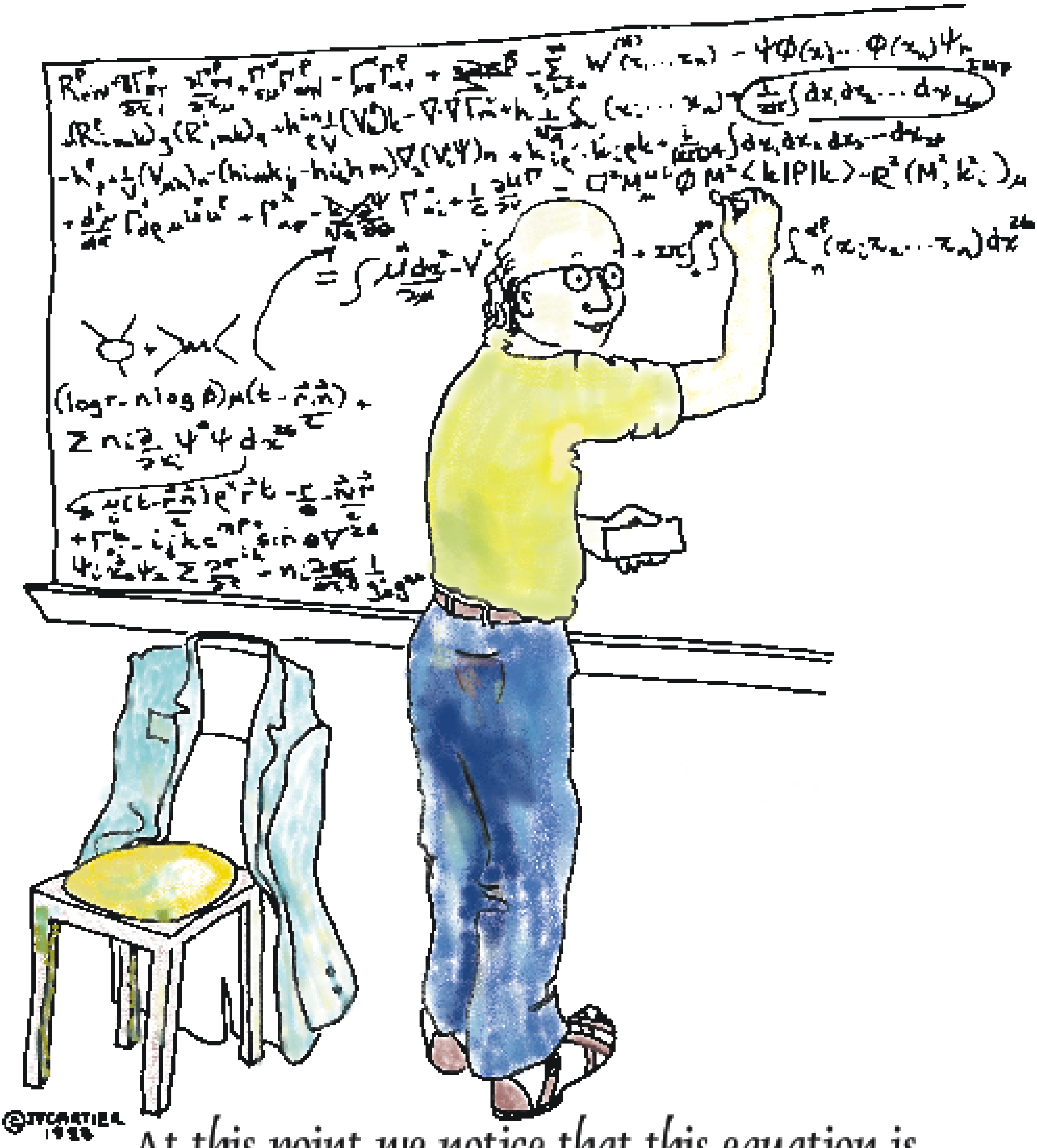


Yoko Ono ®1994

Some aspects of Transition Radiation

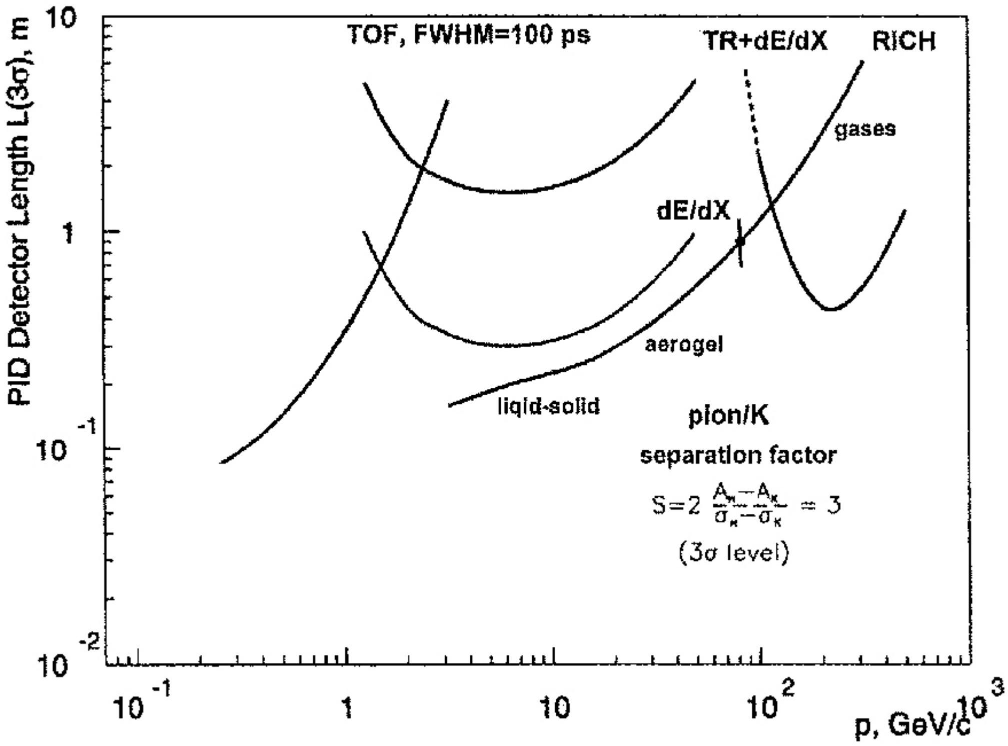


and Time of Flight measurement

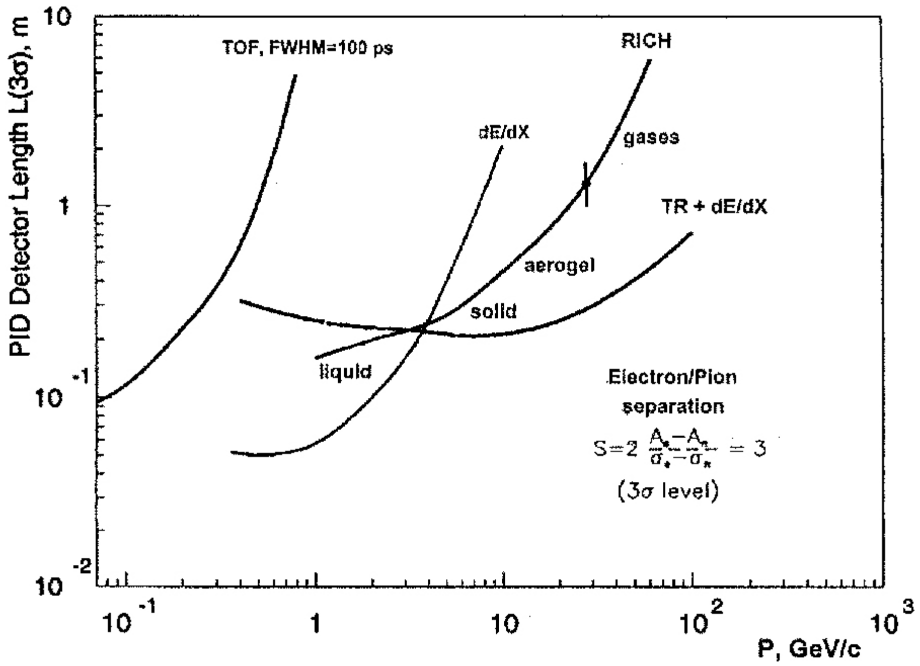


At this point we notice that this equation is beautifully simplified if we assume that particle identification has 92 dimensions.

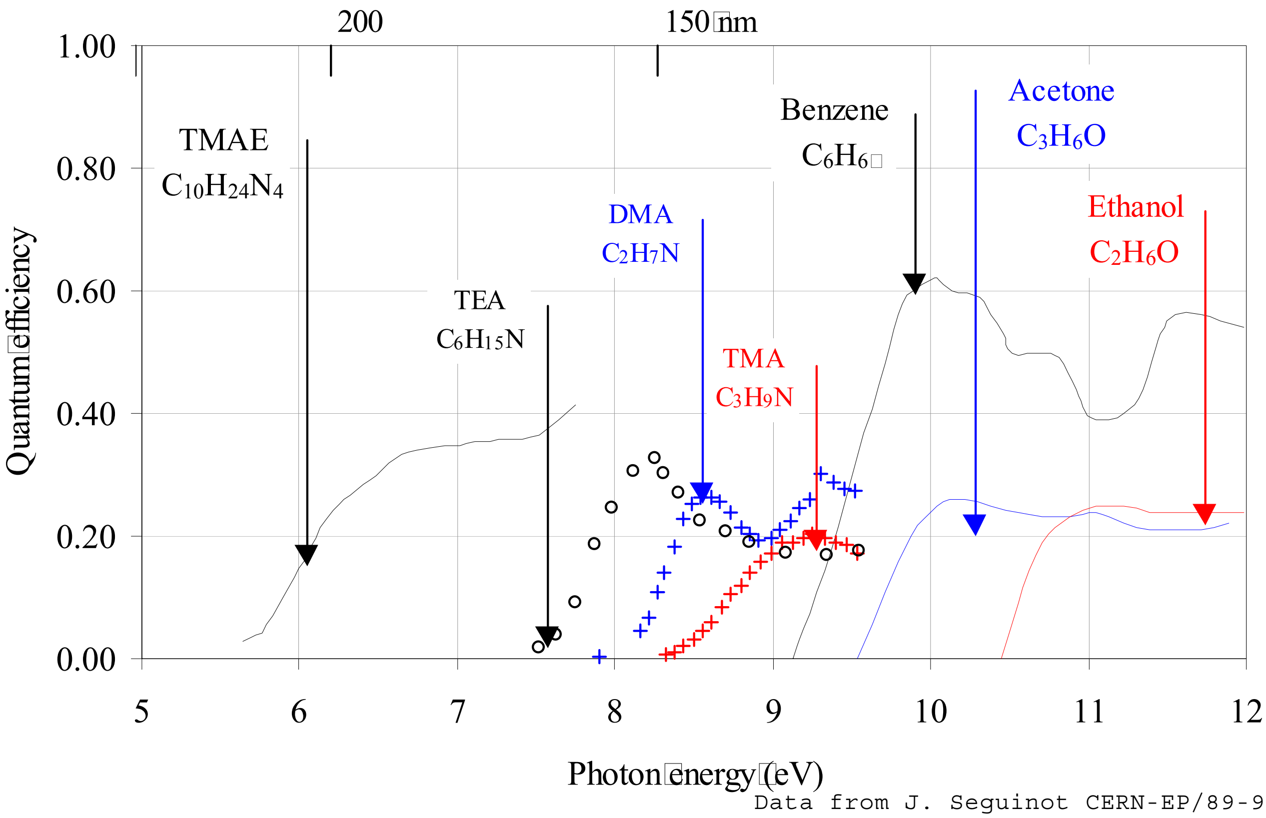
Pion-Kaon separation for different PID methods. The length of the detectors needed for 3σ separation.



The same as above, but for electron-pion separation.



Dolgoshein, NIM A 433 (1999)



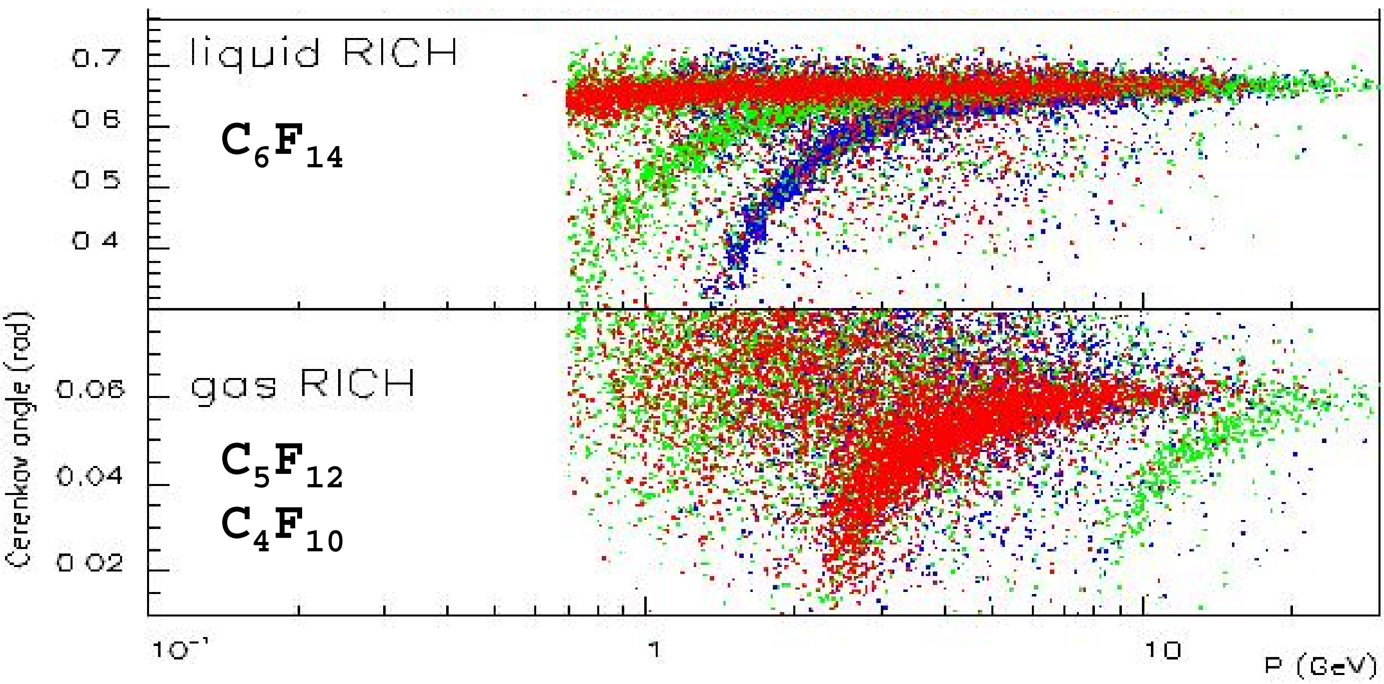
Data from J. Seguinot CERN-EP/89-92

Data from the DELPHI RICHes

p from Λ

K from Φ D*

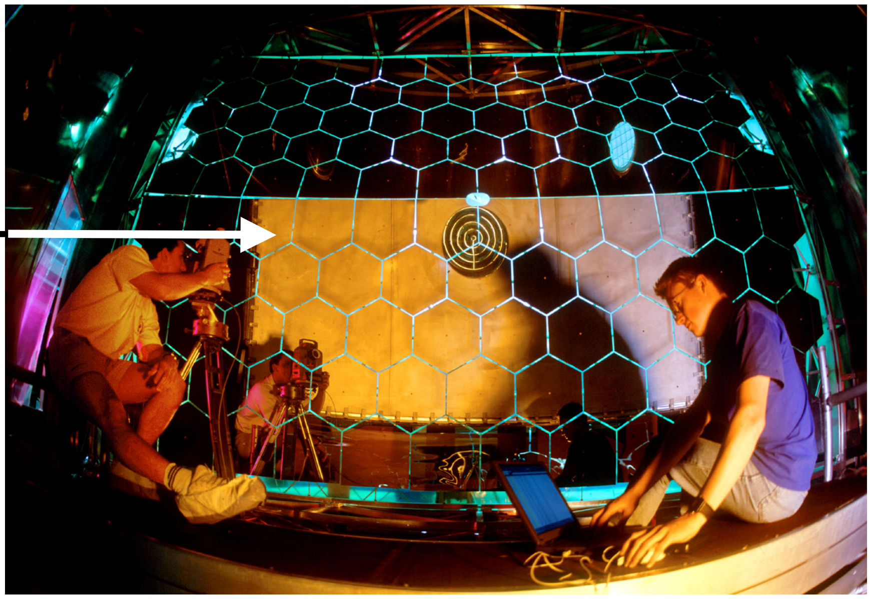
π from K°



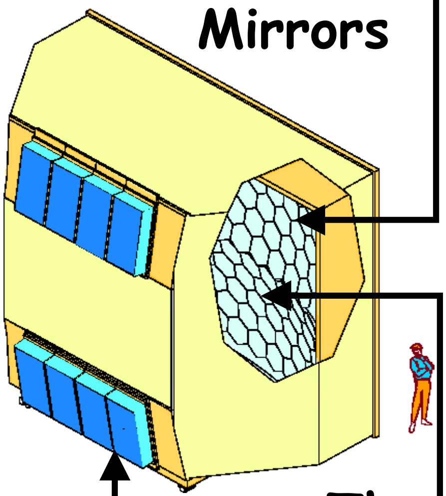
Experiments with CsI photon detectors in RICHes

Experiment	Id. aim (Radiator type)	Momentum range (GeV/c)	# CsI PCs (total m^2)	Status
NA44 TIC CERN	$\pi^\pm/K^\pm$ (gas)	3-8	2 (~0.3)	Terminated
STAR RICH BNL	$\pi^\pm/K^\pm$ $p/\bar{p}$ (liquid)	1-3 2-5	4 (~1)	Terminated
ALICE HMPID CERN	$\pi^\pm/K^\pm$ $p/\bar{p}$ (liquid)	1-3 2-5	42 (~10)	in preparation
HADES RICH GSI	Hadron blind	<1.5	18 (1.5)	Running
COMPASS RICH1 CERN	$\pi^\pm/K^\pm$ $p/\bar{p}$ (gas)	<60	16 (~5.8)	Running
HALL-A RICH JLab	$\pi^\pm/K^\pm$ $p/\bar{p}$ (liquid)	<4	3 (~0.7)	Starting

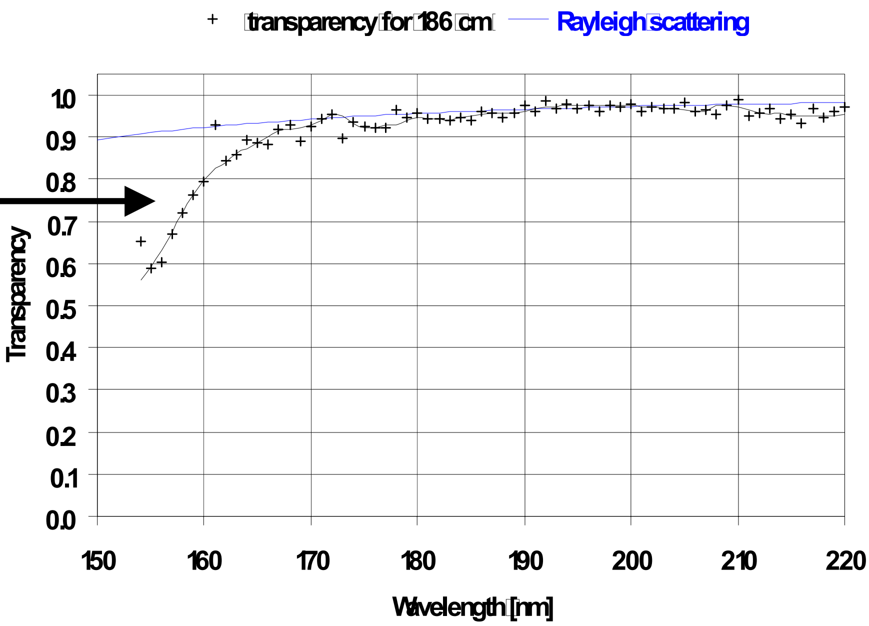
The COMPASS RICH-1 detector



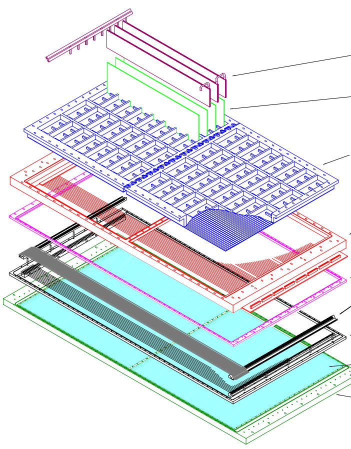
The Mirrors



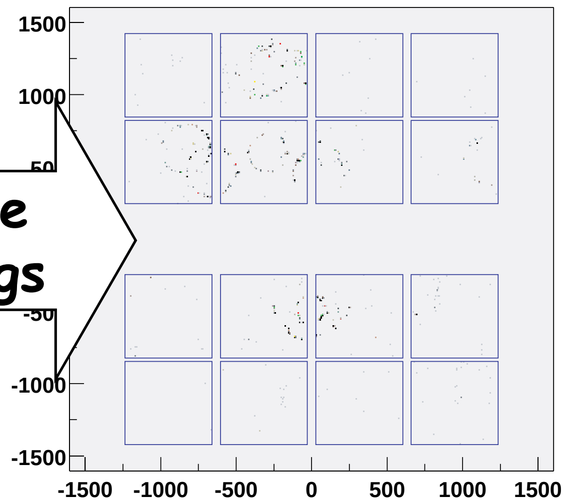
The C_4F_{10} Gas

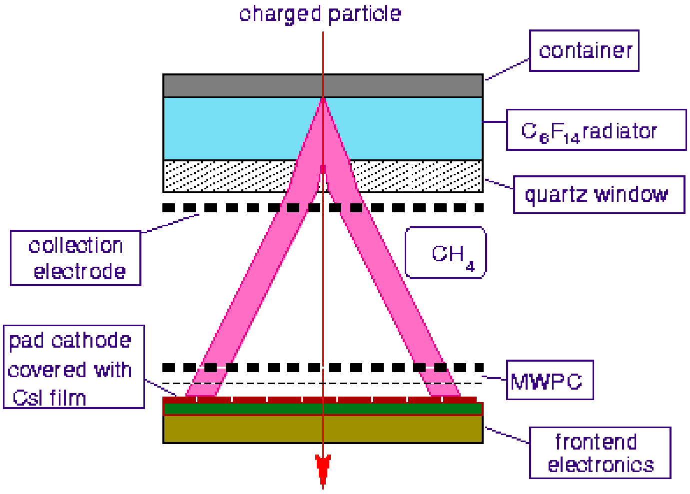


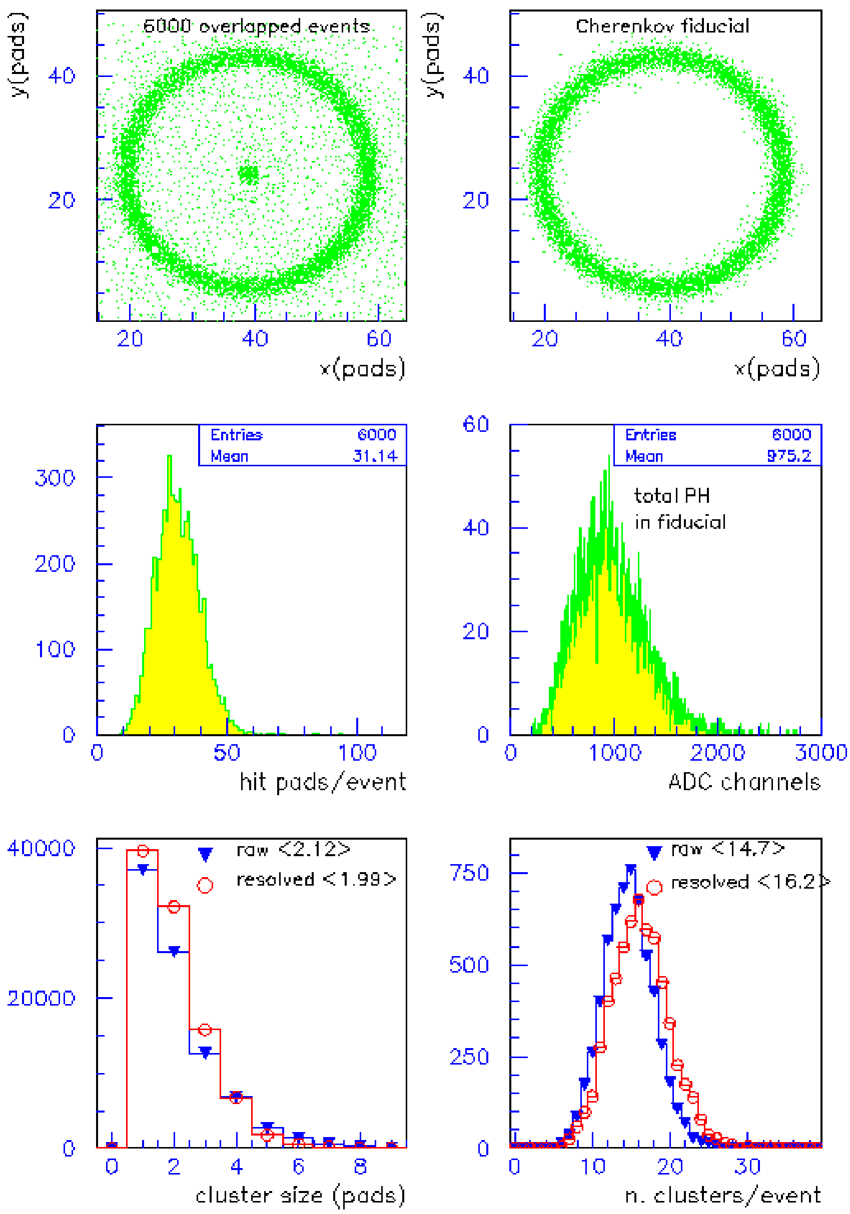
The Photon Detector

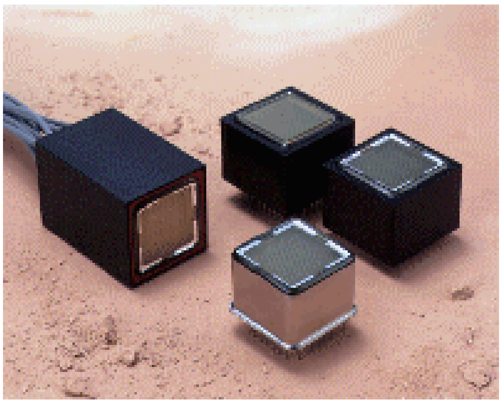


The Rings

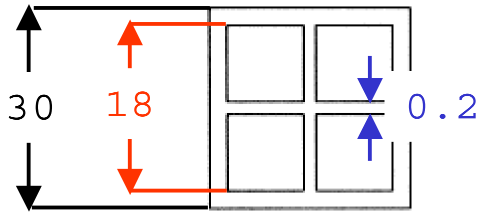


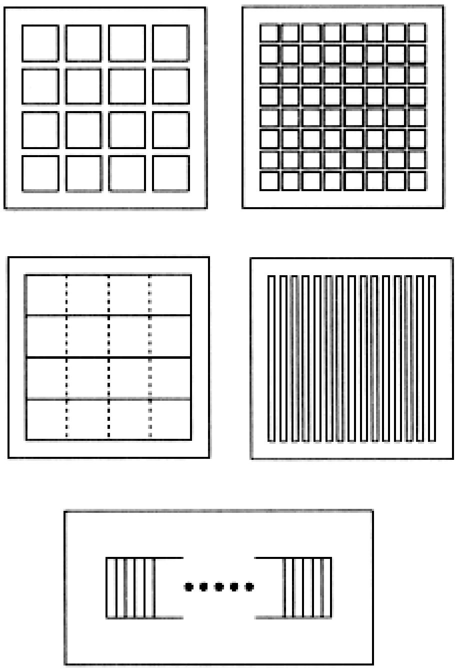

charged particle
container
C_6F_{14} radiator
quartz window
collection electrode
CH_4
pad cathode covered with CsI film
MWPC
frontend electronics

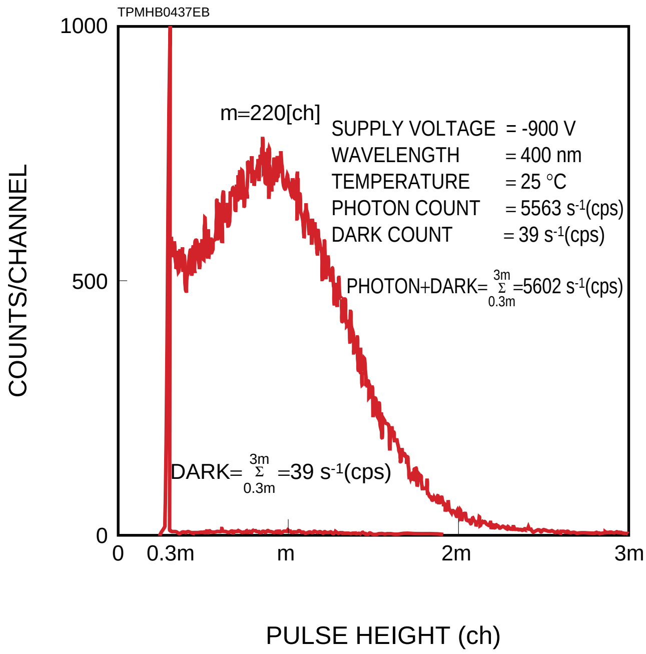

6000 overlapped events
Cherenkov fiducial
y(pads)
x(pads)
Entries 6000
Mean 31.14
hit pads/event
Entries 6000
Mean 975.2
total PH
in fiducial
ADC channels
raw <2.12>
resolved <1.99>
cluster size (pads)
raw <14.7>
resolved <16.2>
n. clusters/event



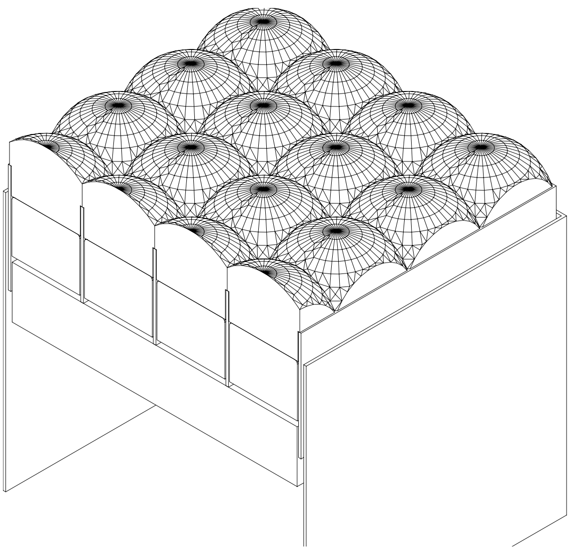
HAMAMATSU Multianode Photomultiplier Tubes

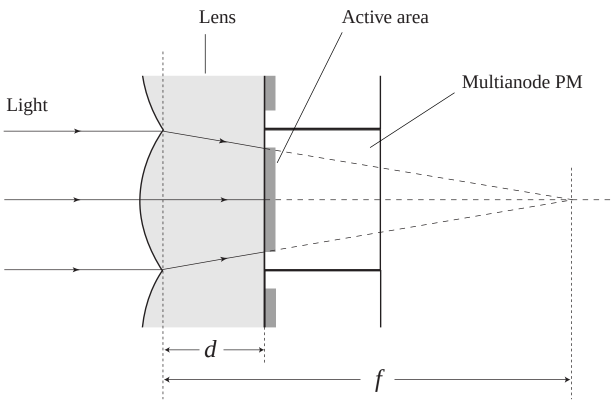






Typical Single Photoelectron PHD per Channel

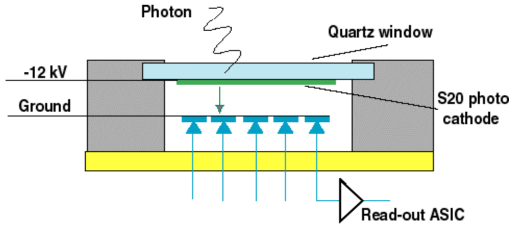




Schematic view of a lens system.

CERN LHCC 2000-037, LHCb TDR 3

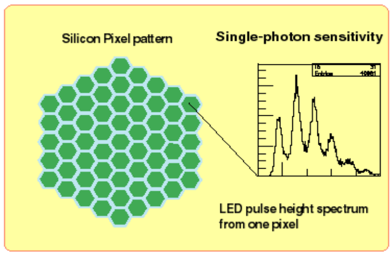
Hybrid Photo Diodes HPD



Hybrid PhotoDiode:

An alternative technique to amplify an electron in a vacuum tube is by bombarding it onto a silicon diode.

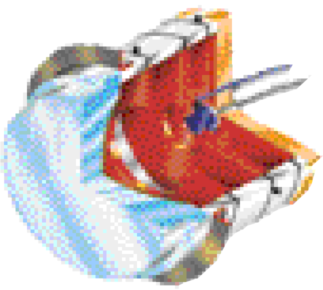
61 pixel Diodes : 2 x 2 mm^2
DEP (NL) + LHCb development

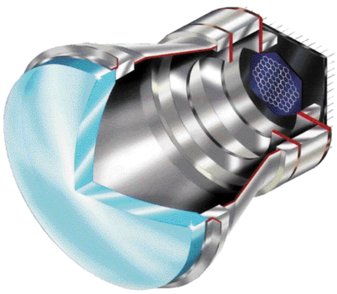


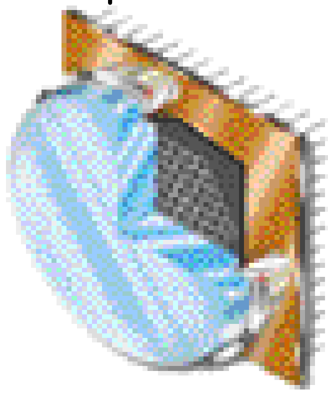
(Some) commercially available HPDs

Photocathode:
Solar Blind
Bialkali
S20
Super S-25

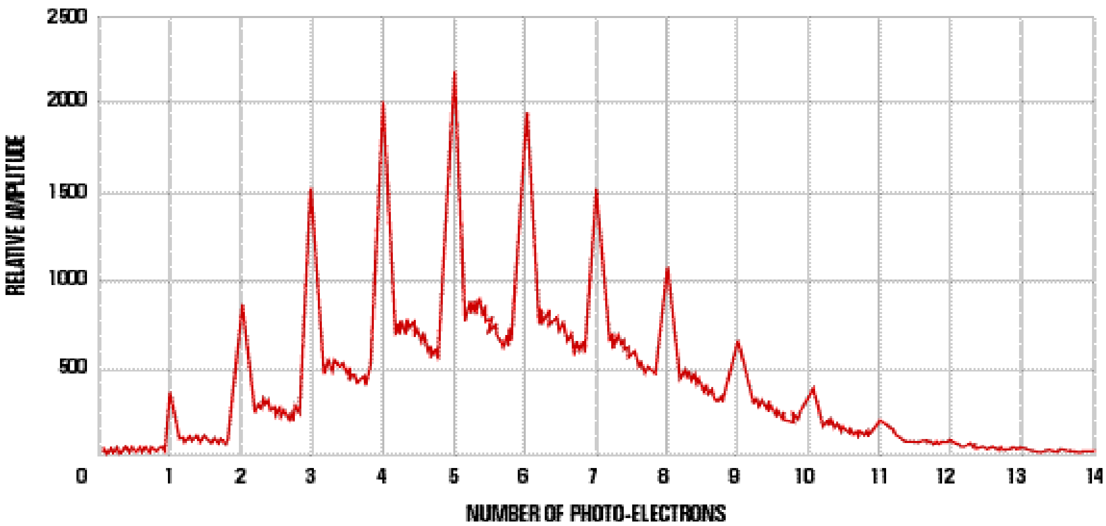
Electrostatic focussing



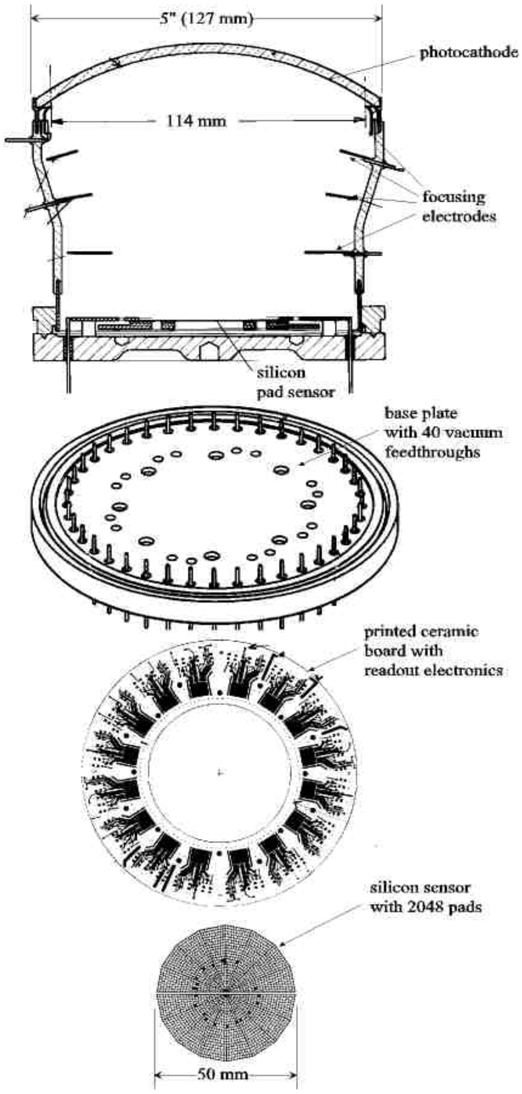


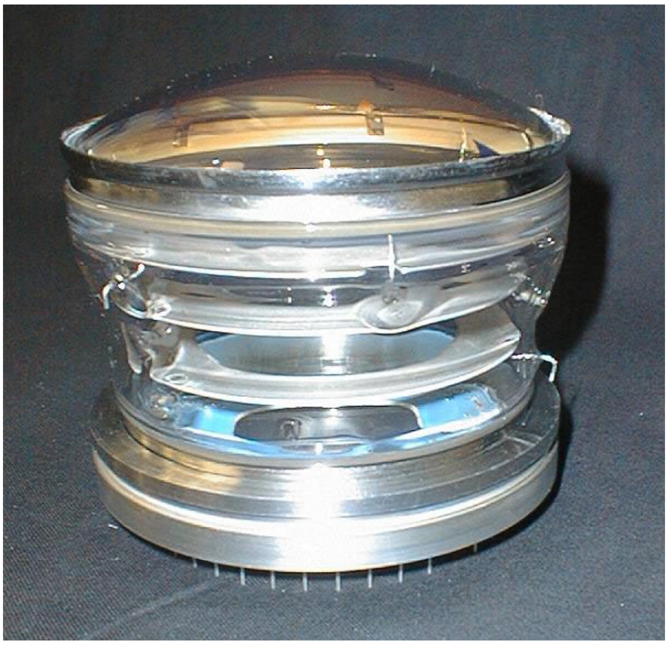


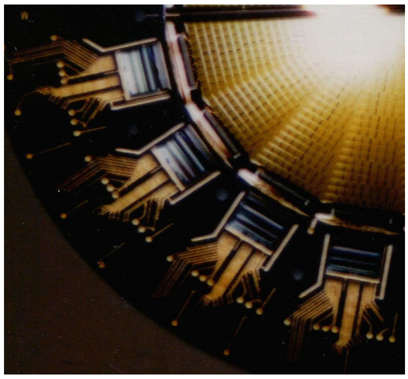
Proximity focussing

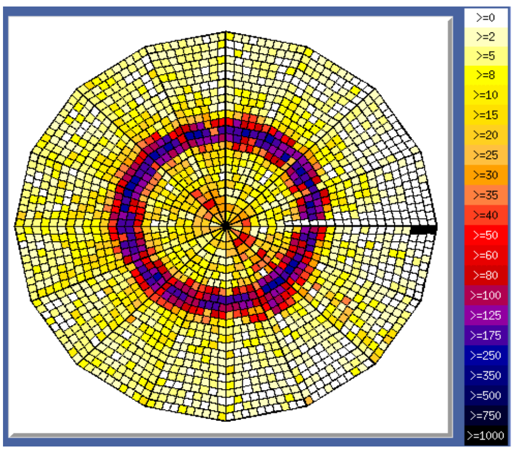


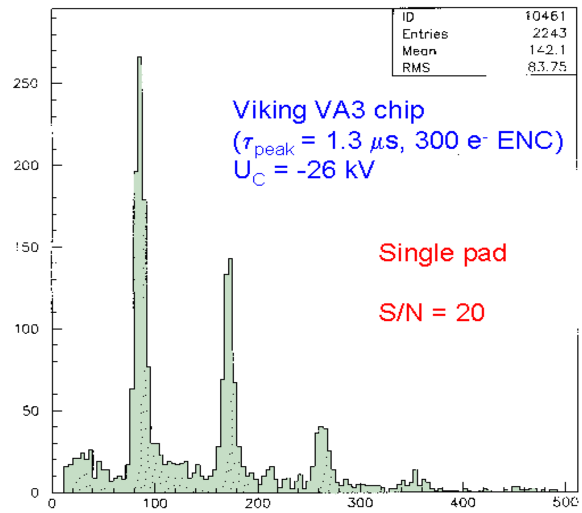
DELFT ELECTRONIC PRODUCTS B.V.



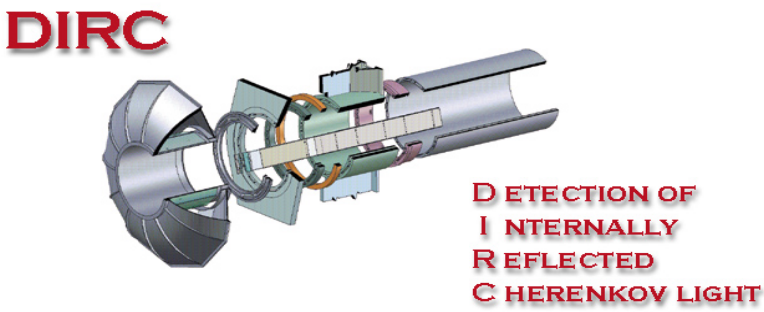


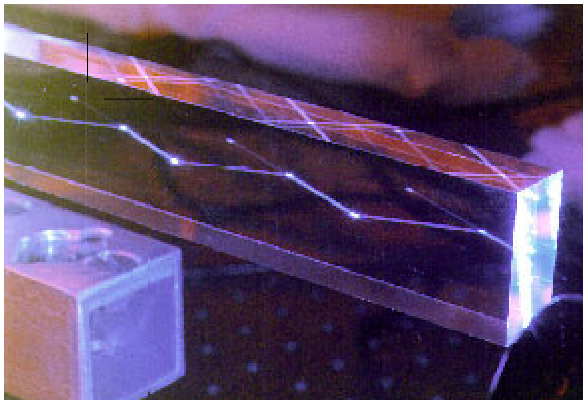


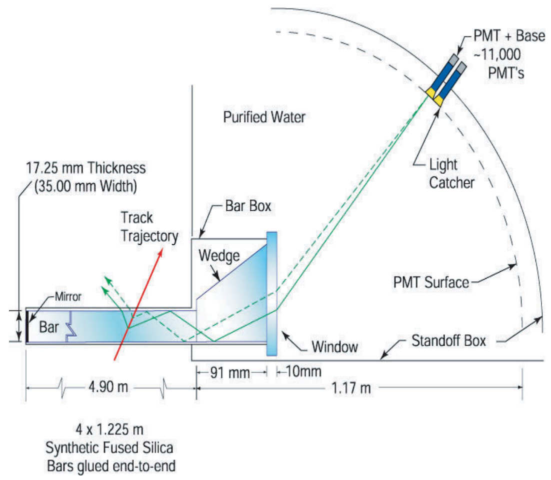


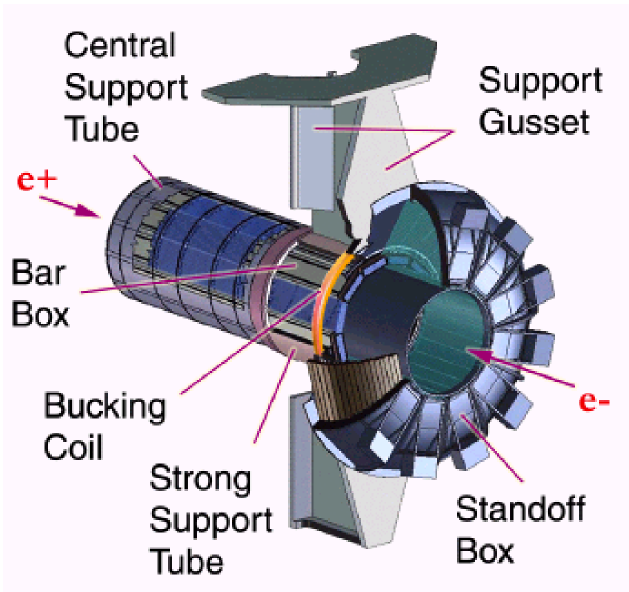


Nucl. Phys. B, Proc. Suppl. : 78 (1999)

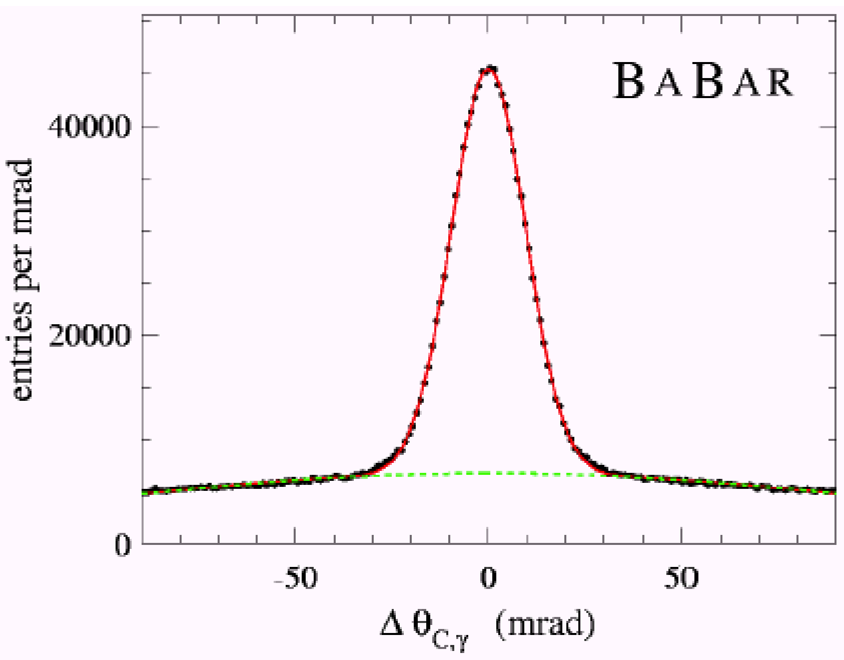








DIRC is a 3- D device, measuring: x, y and time of Cherenkov photons.



Single photon resolution

$\sigma(\Delta\Theta_{c\gamma})$ = **9.6 mrad**

Expectation: ~ 9.5 mrad

dominated by:

7 mrad from PMT/bar size,

5.4 mrad from chromatic term,

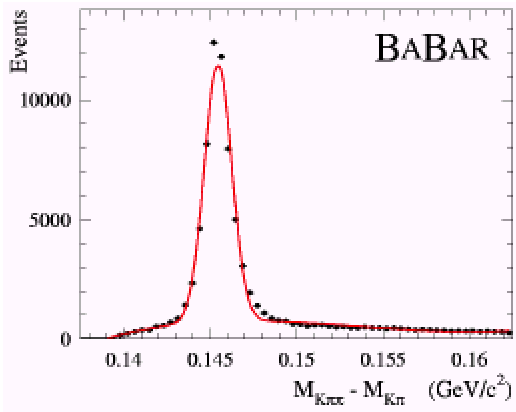
2- 3 mrad from bar imperfections.

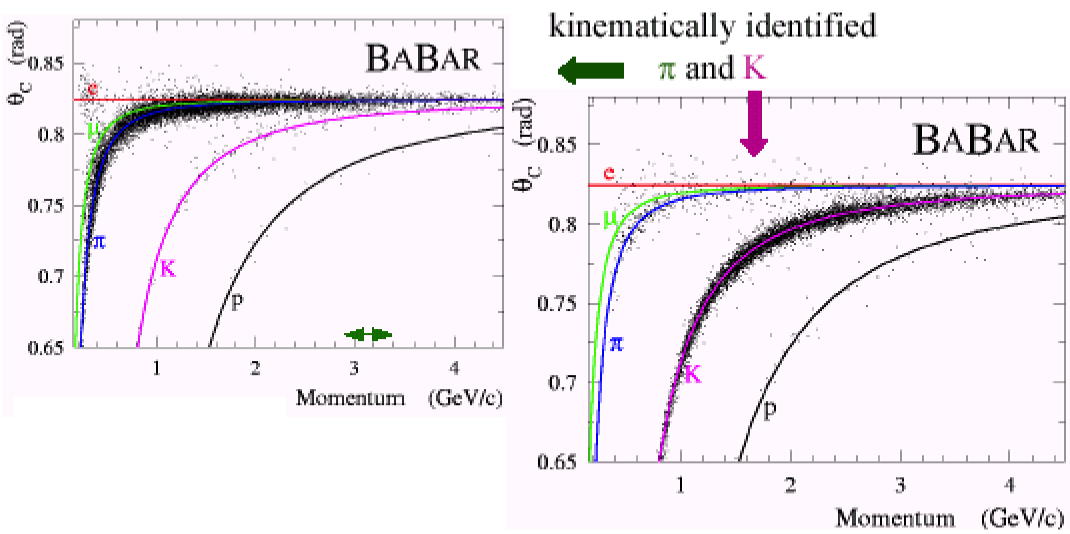
Leith, Novosibirsk 2002

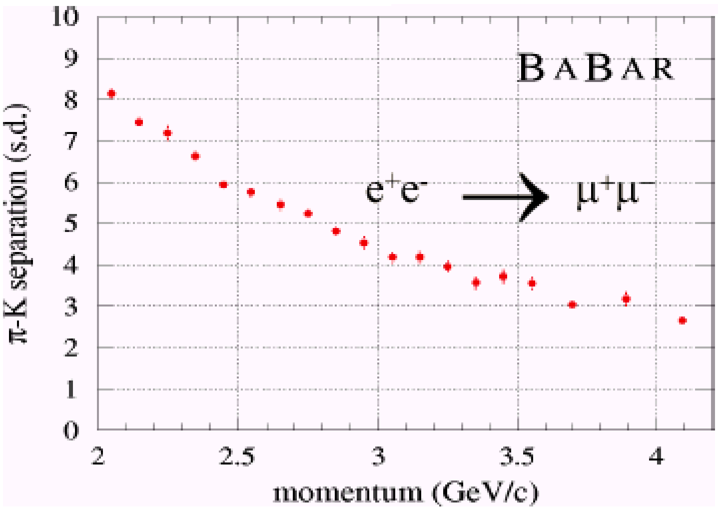
DIRC — Detection of Internally Reflected Cherenkov light

$D^{*-} \rightarrow D^0 \pi^-$

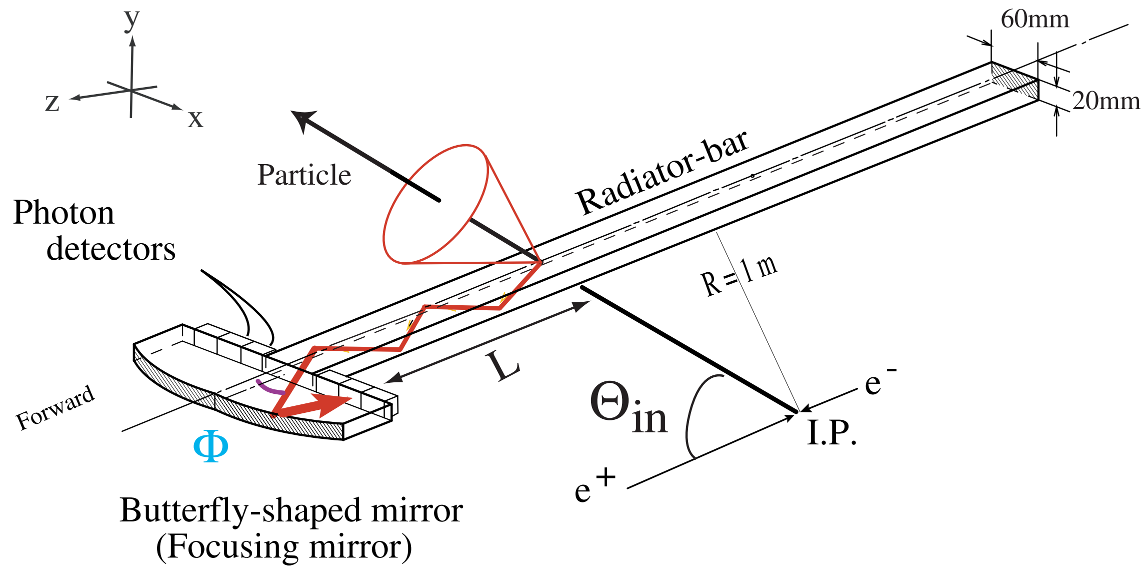
$K^- \pi^+$

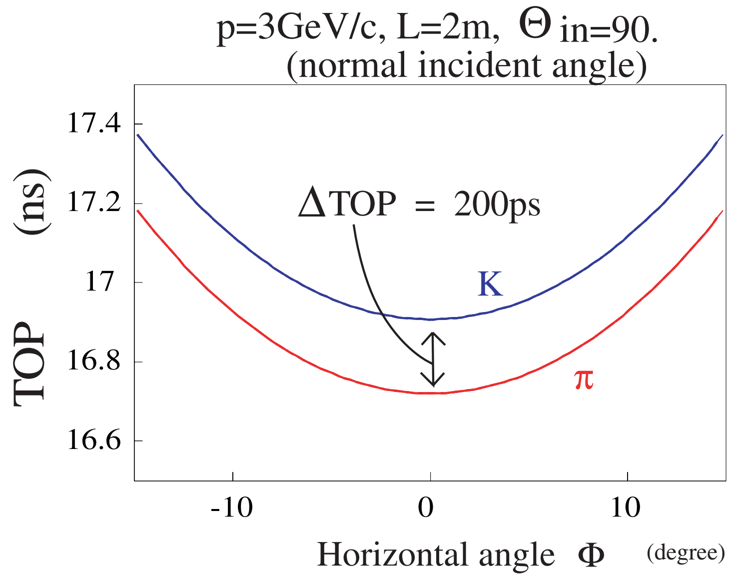


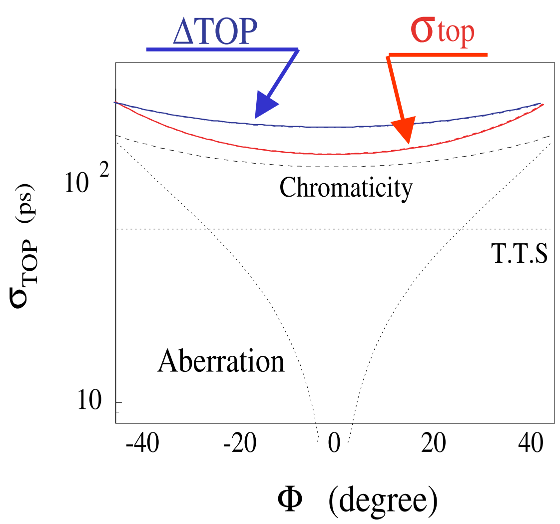




Time Of Propagation counter



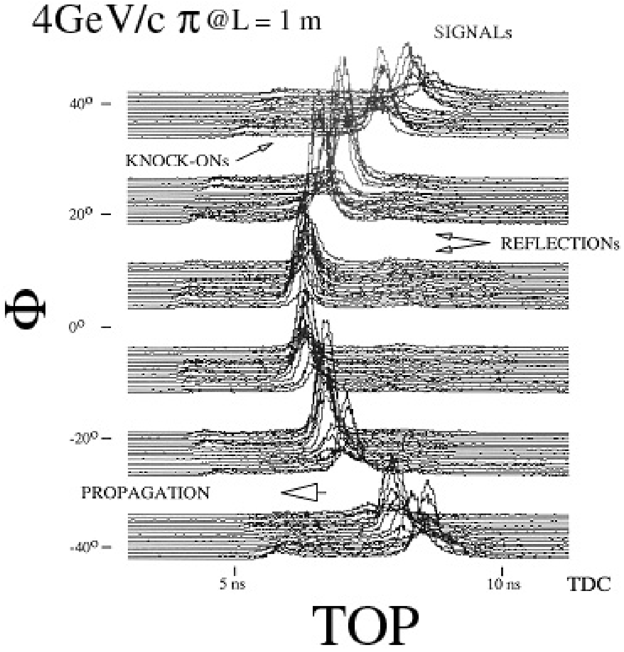




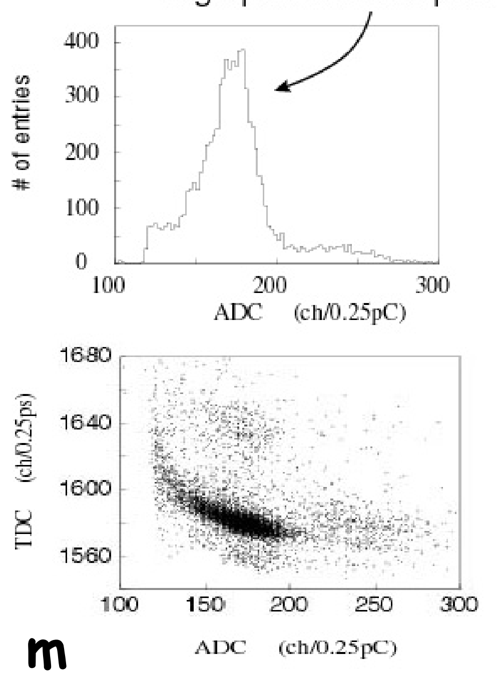
Y. Enari Novosibirsk 2002

Time Of Propagation counter

4GeV/c π @L = 1 m

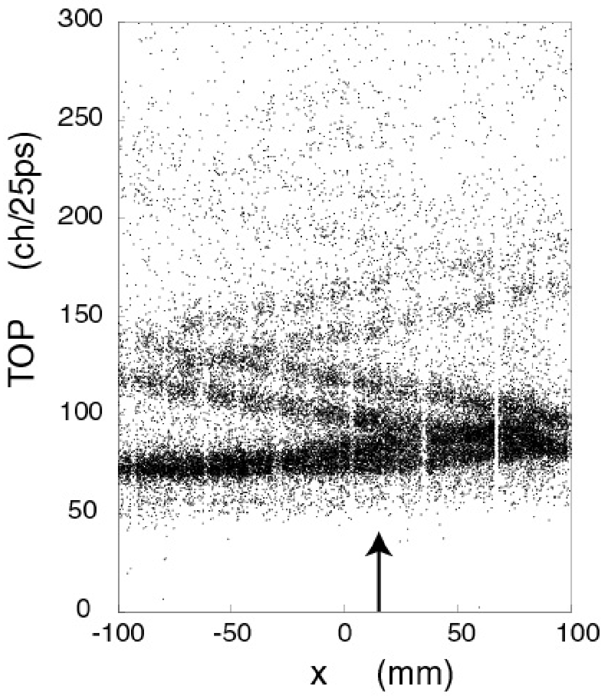


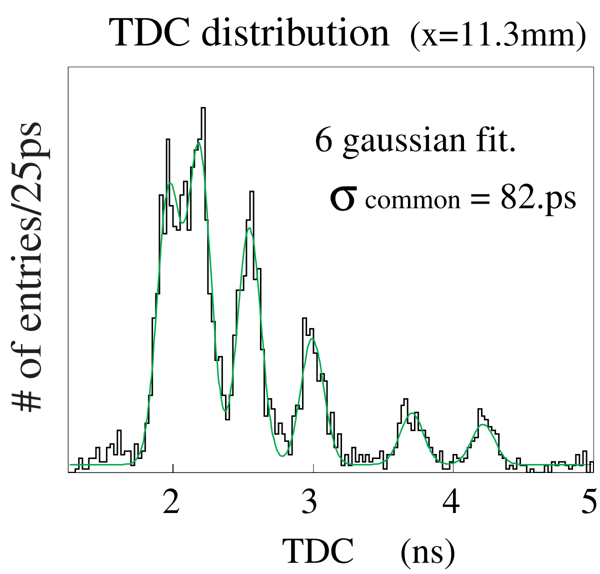
- **ADC & TDC distributions**



Beam test.: 3 GeV/c π^- L=0.3 m

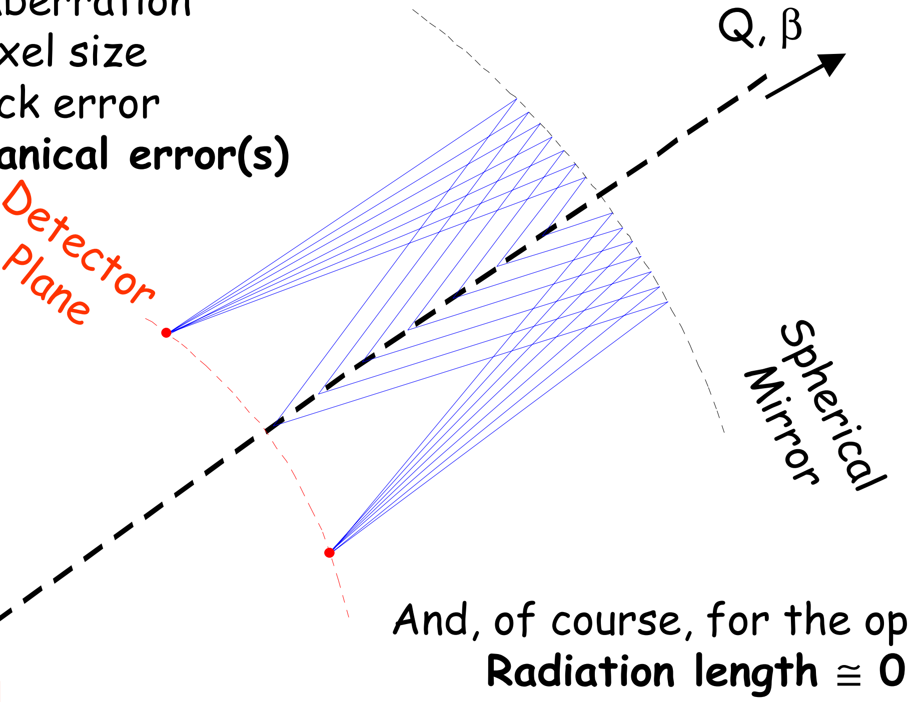
$\Theta_{in}=\Phi_{in}=90°$



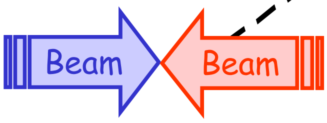


The main uncertainties are
- Emission point error
- Chromatic aberration
- Detector pixel size
- Particle track error
- **Opto-mechanical error(s)**

A little about optics



And reflectivity



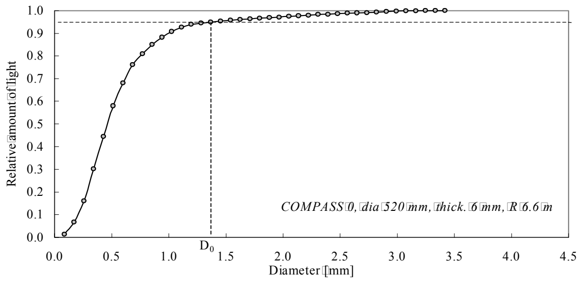
And, of course, for the optics

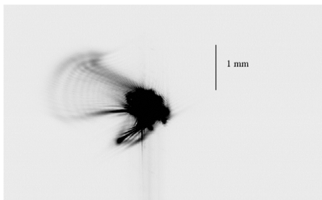
Radiation length ≅ 0

and

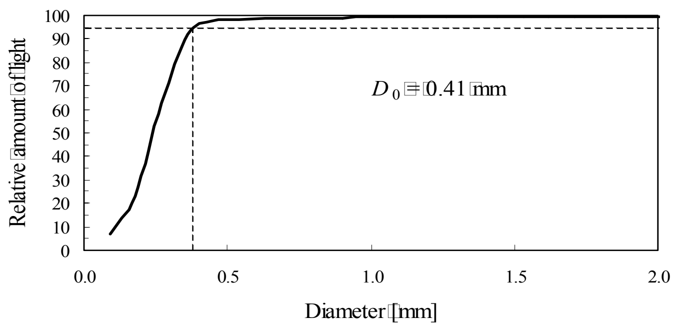
Interaction length ≅ 0

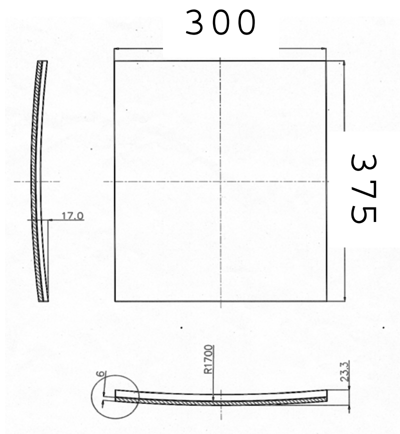
Spot size. R=6.6 m, Ø=50 cm, thickness 6 mm glass or 4.7% X_0

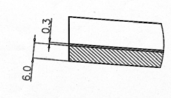




Beryllium-Glass mirror. R=1.7 m, X_0=2%



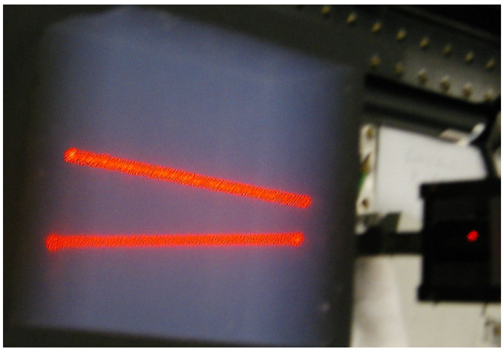


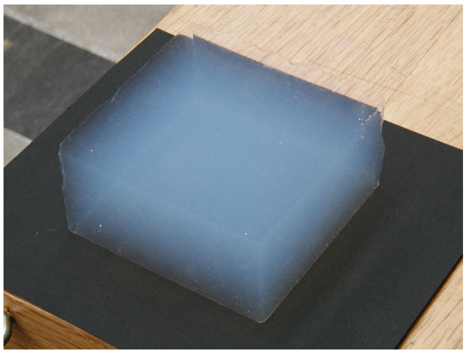


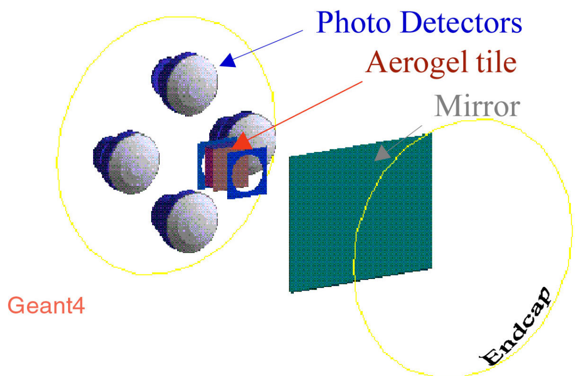
Be	6.0 mm
Glass	0.3 mm

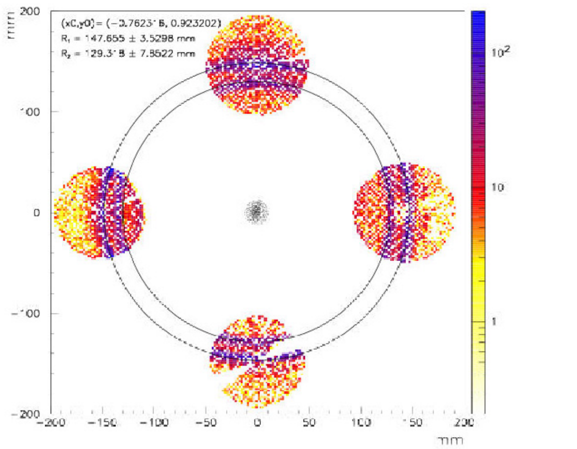
M. Laub, PhD Thesis, Praha, září 2001
IHEP Protvino, Just Optic, Ltd. St. Petersburg and Kompozit Korolev

Progress in Aerogel









	Hygroscopic *Novosibirsk*		Hydrophobic *Matsushita*
Thickness (cm)	4.0	4.0	2.0
Clarity ($10^{-4}\mu m^4/cm$)	72.2	69.5	96.0
n (at 600 nm)	1.0306	1.0298	1.030

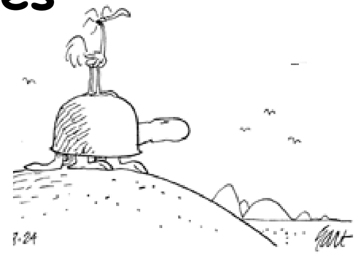
$$T = T_{\lambda \to \infty} \cdot e^{-CL/\lambda^4}$$

Measured and calculated saturated Cherenkov angle and resolution for single photons in mrad.

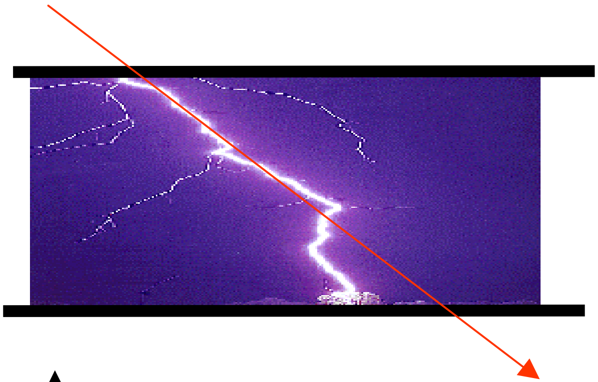
	Producer	Novosibirsk		Matsushita	
	Thickness (cm)	4	8	6	8
Filter					
No filter	$<\Theta_C>$ $<\Theta_C>$MC	250.0 248.7	246.8 245.0	252.2 -	247.3 -
	$\sigma(\Theta_C)$ $\sigma(\Theta_C)$MC	5.4 4.0	5.8 3.9	7.7 -	8.1 -
D263	$<\Theta_C>$ $<\Theta_C>$MC	247.1 246.8	245,4 243.7	248.9 -	248.1 -
	$\sigma(\Theta_C)$ $\sigma(\Theta_C)$MC	5.0 3.1	4.8 3.0	6.2 -	6.8 -
Glass	$<\Theta_C>$ $<\Theta_C>$MC	243.0 243.2	246.0 -	248.5 -	- -
	$\sigma(\Theta_C)$ $\sigma(\Theta_C)$MC	5.4 3.9	5.2 -	6.6 -	- -

Bellunato, Beaune 2002

Time Of Flight techniques

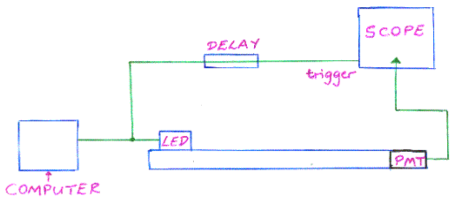


$$\frac{dm}{m} = \frac{dp}{p} + \gamma^2 \left(\frac{dt}{t} + \frac{dL}{L} \right)$$



Something about

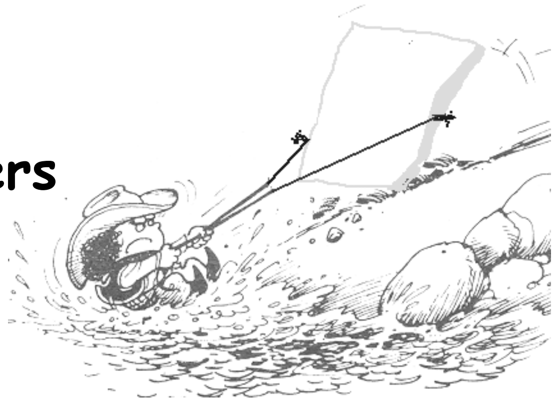
Spark Chambers



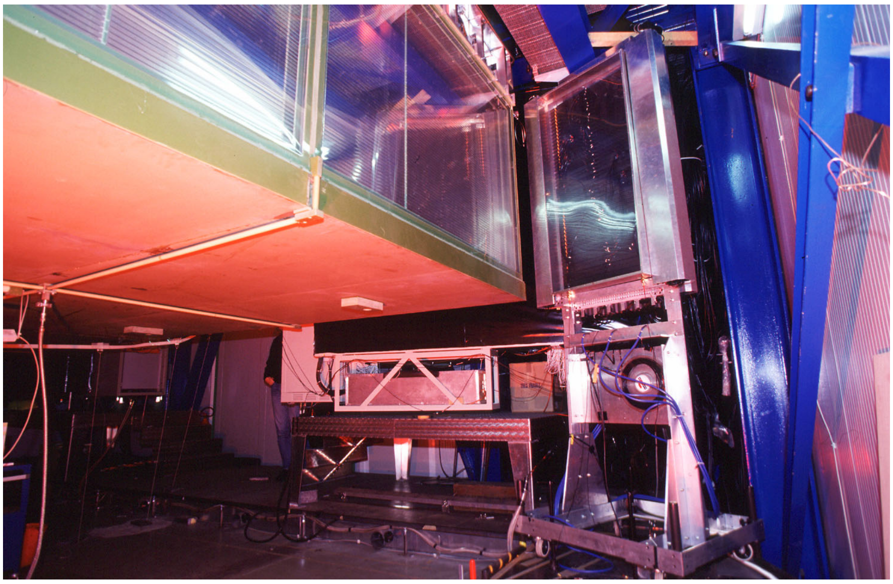
Scintillator hodoscopes

and

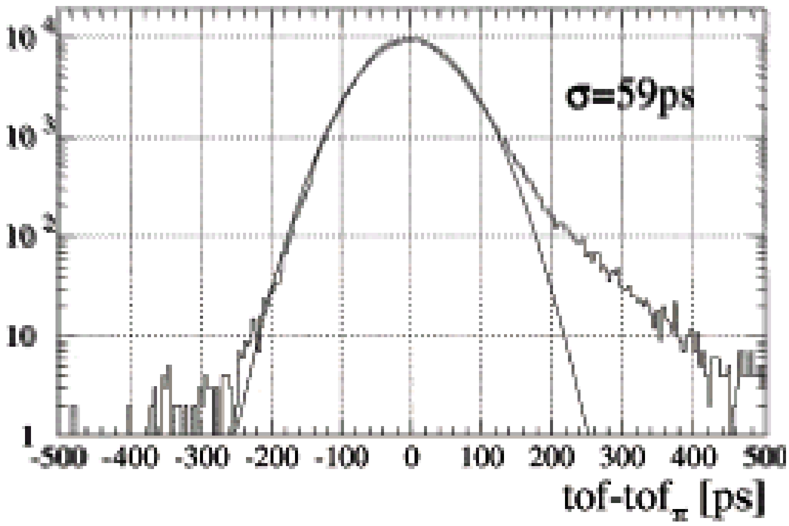
Resistive Plate Chambers



NA49

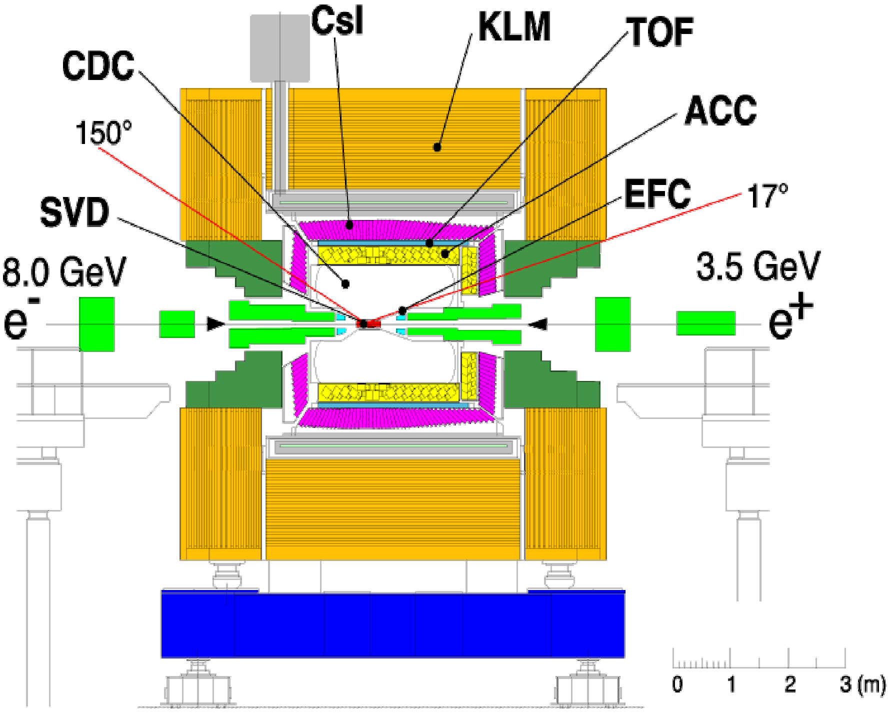


Time-of-Flights detectors at the exit of the NA49 spectrometer.
891 scintillator tiles connected to PM: XP2972
Each tile: 8-10 cm x 3.3 cm x 2.3 cm
TDC and ADC spectra read out.



Klempt, NIM A 433 (1999)

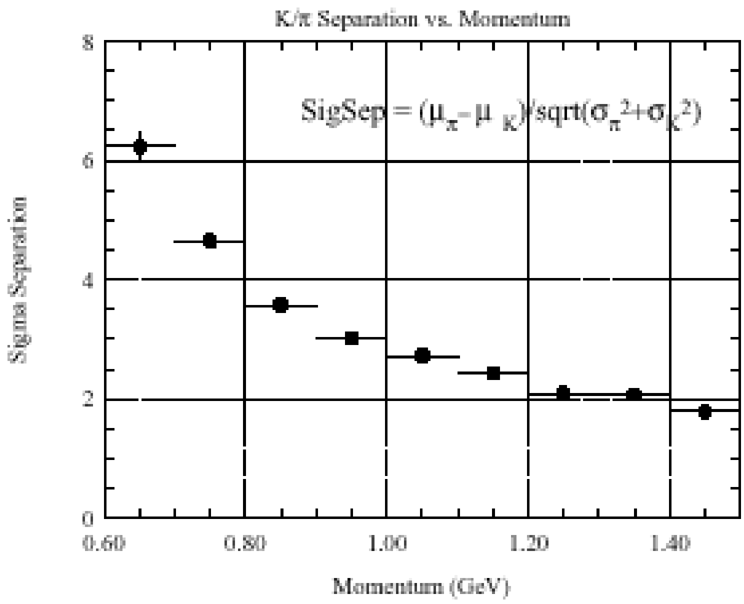
TOF at BELLE

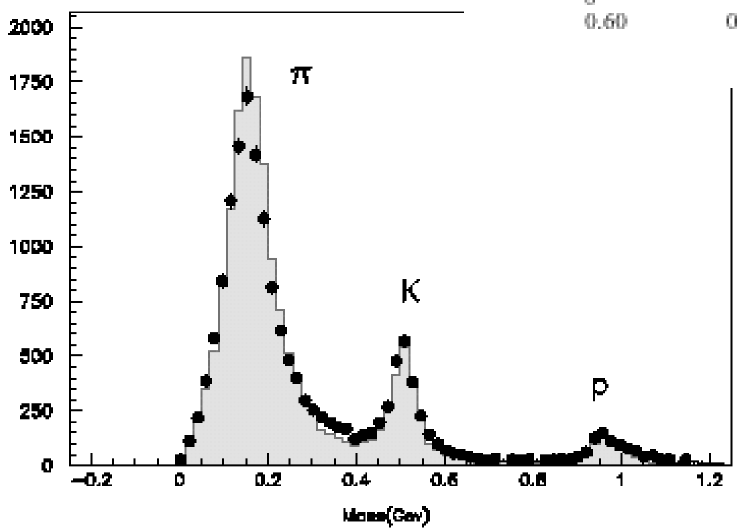


π^{+-} / K^{+-}

separation by TOF.

The resolution for the weighted average time is about 100 ps with a small z dependence.



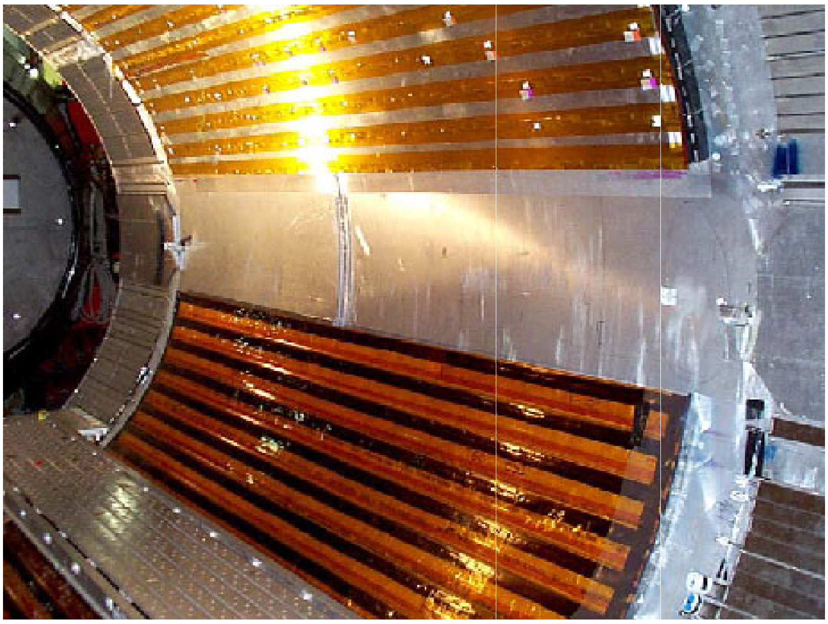


Mass distribution from TOF measurements for particle momenta below 1.2 GeV/c.

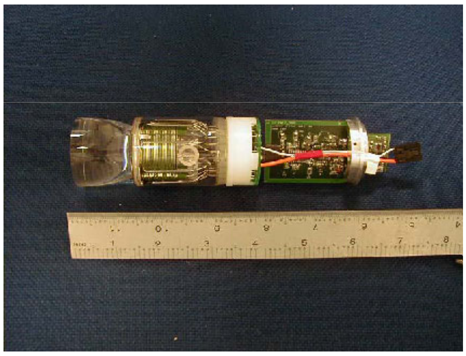
NIM A 479 (2002)

CDF-II Time-of-Flight system

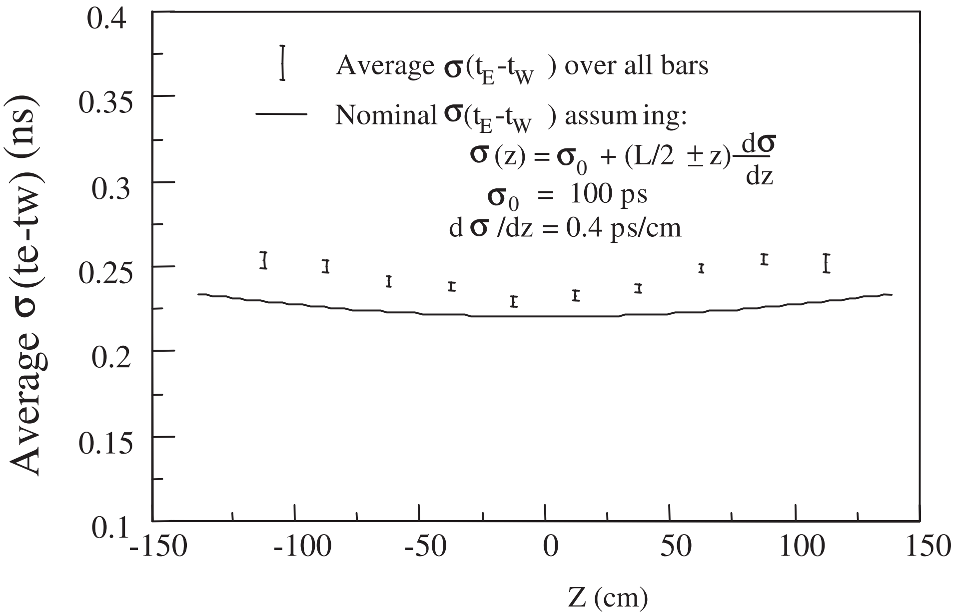
216 Scintillator bars 279 cm x 4 cm x4 cm)
with phototubes attached to both ends (432).



Custom-made Hamamatsu R7766
19 dynode (High gain)
Fine mesh (Increased tolerance to magnetic field)
Small size 1.5 x 2.5 inches
Operated with a positive HV up to 2500V.
Gain reduction factor at B=1.4 T in the range of ~500

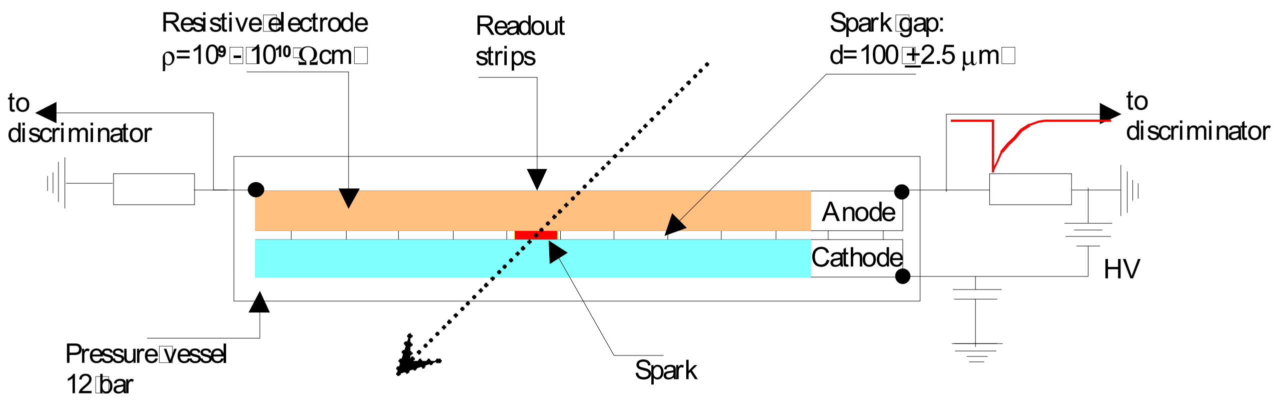


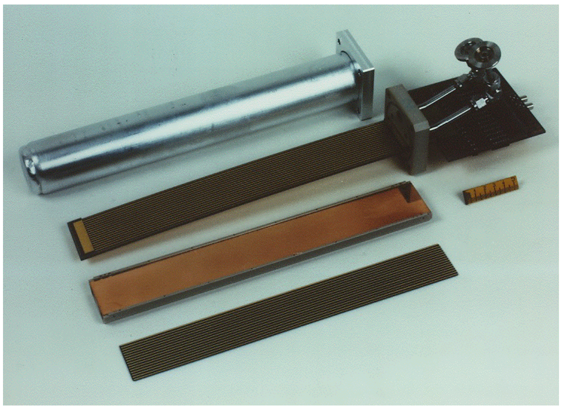
Target performance:
- 100ps resolution over length bar using both PMTS
- Comparison between the time difference for east and west pmt with 100ps resolution Montecarlo ($\sigma_{\Delta t} \approx 2\sigma_{TOF}$)
- From this "systematic-free" time diference resolution
- preliminary $\sigma_{TOF} \approx 125$ps
- Working on the improvement



Vila, Novosibirsk 2002

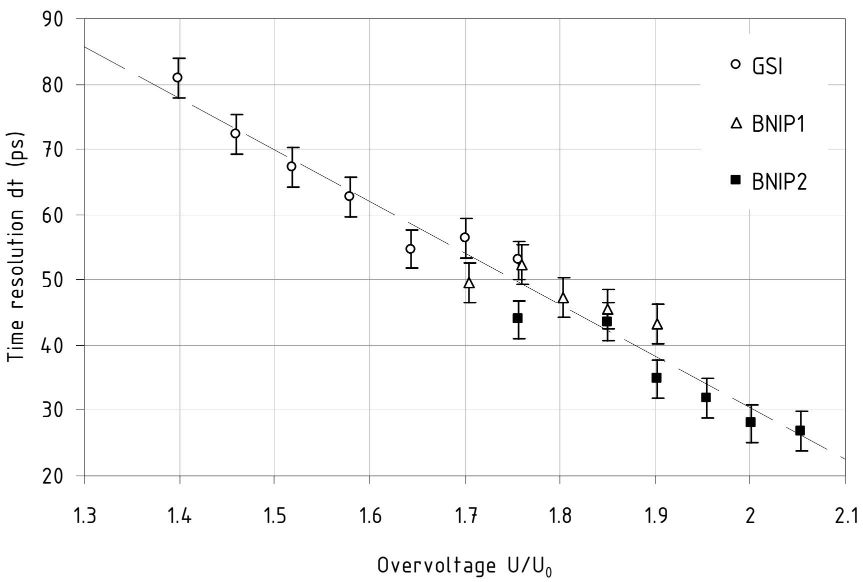
Pestov Spark Counters





The standard gas mixture

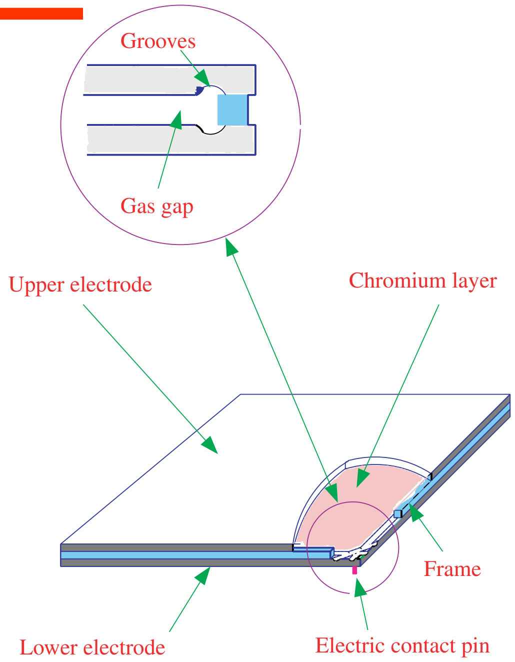
0.6% C_4H_6 1,3-Butadiene
2.5% C_2H_4 Ethylene
20.4% C_4H_{10} i-Butane
76.5% Ar



Schmidt, Nucl. Phys. B 78 (1999)

Time resolution (FWHM/2.35) as function of overvoltage applied to the counter. The graph compares experiments done at GSI and at BNIP. At BNIP gas mixtures with different fractions of butadiene were used. Tails extend beyond the gaussian distribution.

Parallel Plate Chambers



Ceramic Cells

Surface:

2×2 cm^2

5×5 cm^2

10×10 cm^2

Ceramic substrate

1.0 ± 0.01 mm

Chromium layer

0.5-1 μm

Flatness

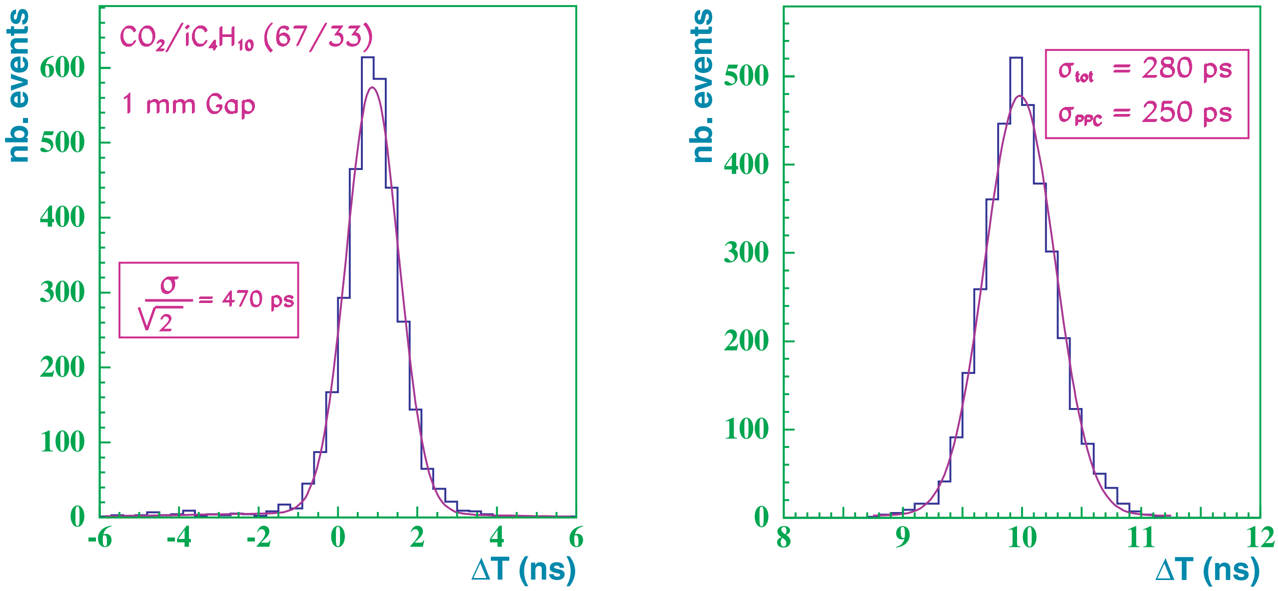
<4 μm

Grooves

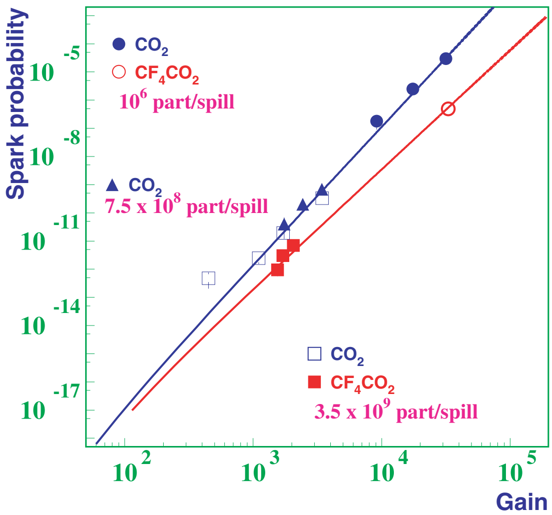
Ø 1 mm

Gas gap

1, 1.5, 2 mm ± 0.05 mm



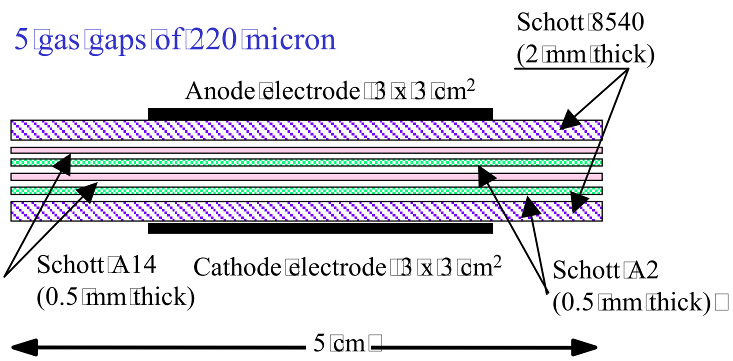
Spark probability as function of gas gain.

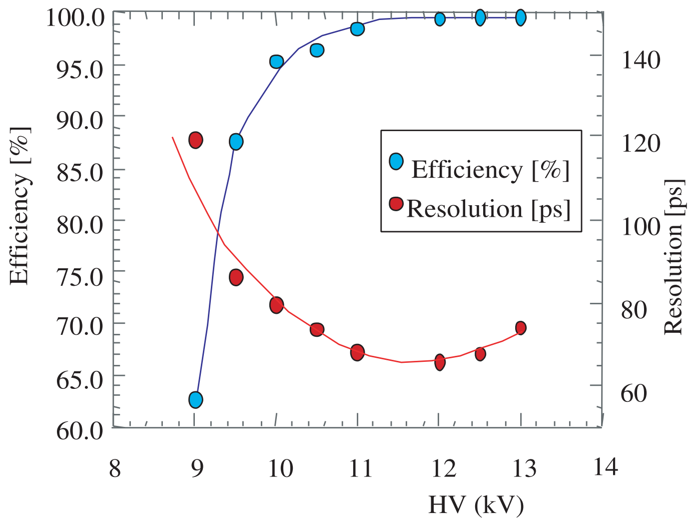


Iglesias, PhD thesis 1997

ALICE TOF with RPC

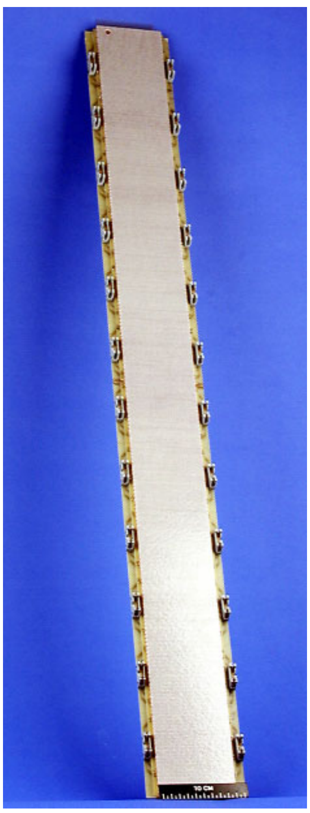
Single cell 3 x 3 cm^2 active area

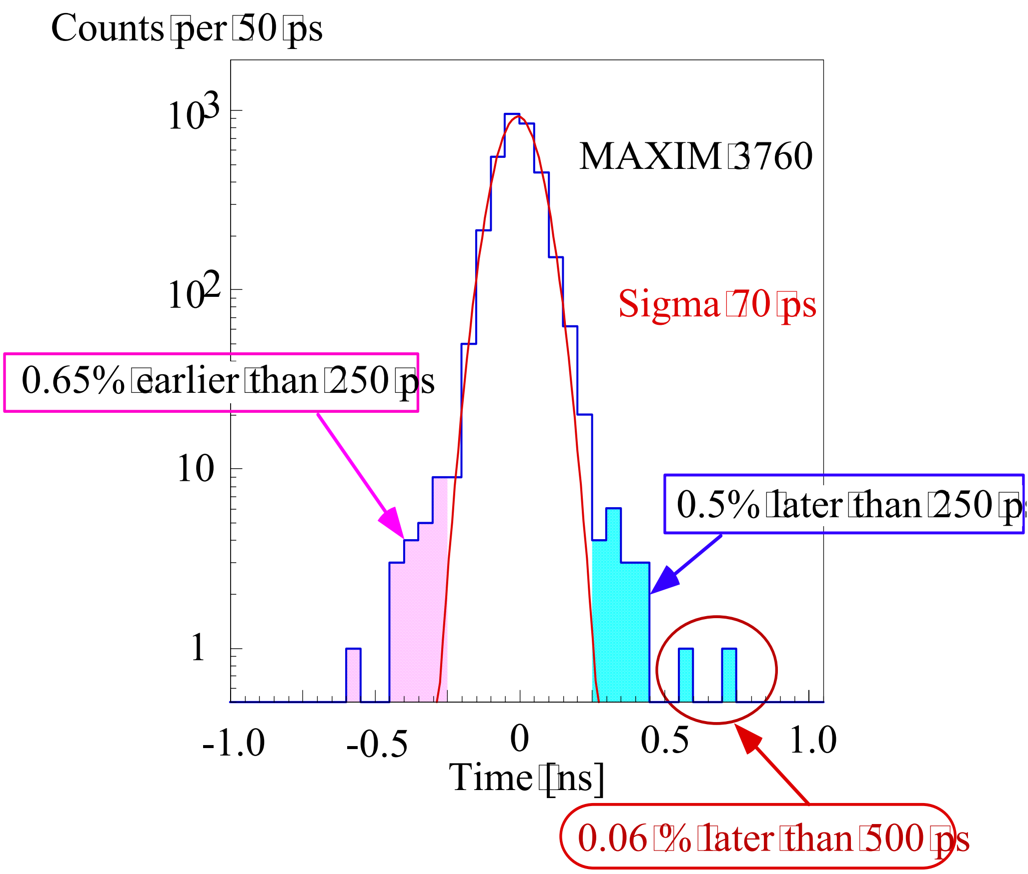




Standard unit detector for ALICE detector (ALICE TOF will be constructed with ~ 1,600 such strips)

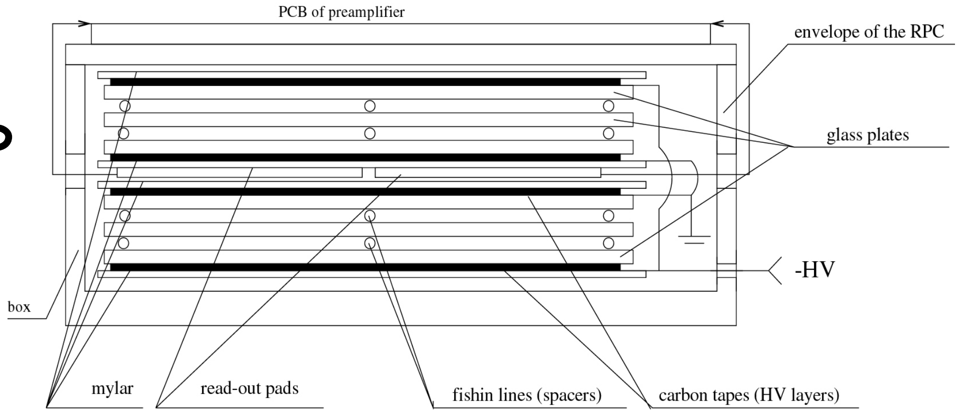
Typical time spectra from readout pad of 1.2 m strip





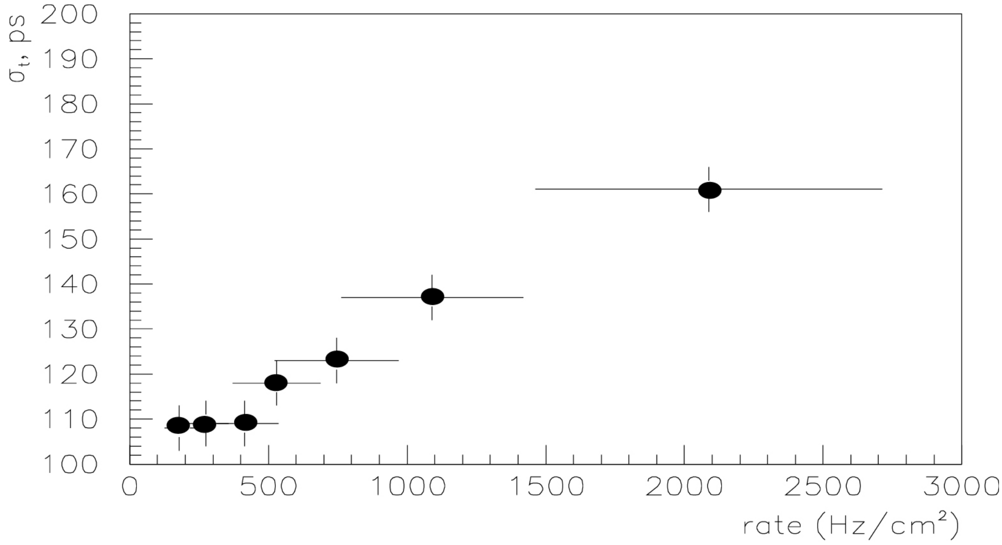
Williams, Vienna 2001

RPC at HARP

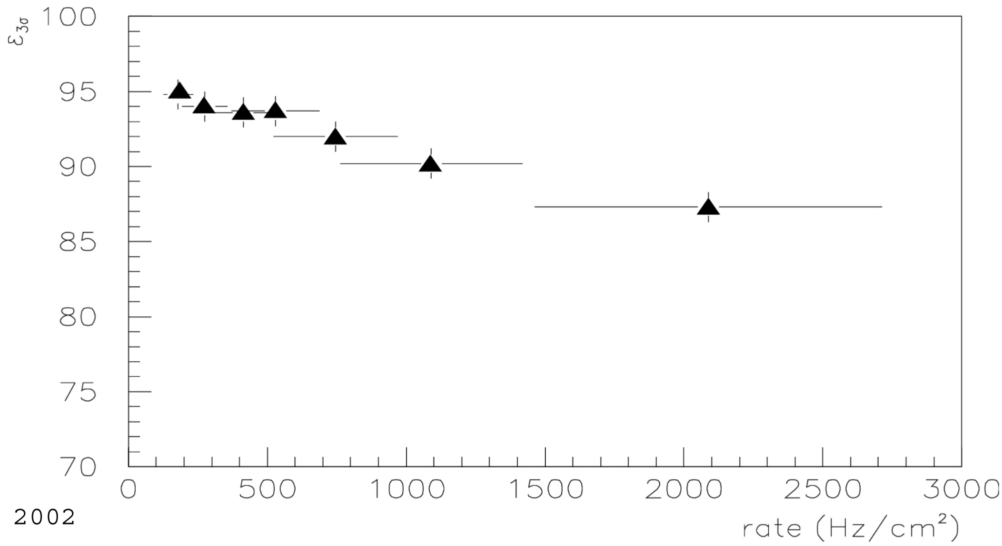


- 0.6 mm glass ~9×10^{12} Ωcm
- Three fishing lines with spacing of 35 mm between them.
- Four fishing line with 40 mm space between them were in chambers made of 130×200 cm^2 plates.
- High voltage was applied to each of double-gap RPCs through electrodes made of high resistive (~1 MΩ/[]) carbon film.
- Two 200 μm mylar sheets one at the top and one at the bottom provide with an isolation between high voltage electrodes and walls of boxes.
- $C_2H_2F_4/C_4H_{10}/SF_6$ 90/5/5%

Time resolution as function of particle rate



Efficiency as function of particle rate



Ammosov, hep-ex/0204022, 2002

$$p = m\beta\gamma$$

$$\frac{dE}{dx} \propto \frac{1}{\beta^2}\ln\left(\beta^2\gamma^2\right)$$

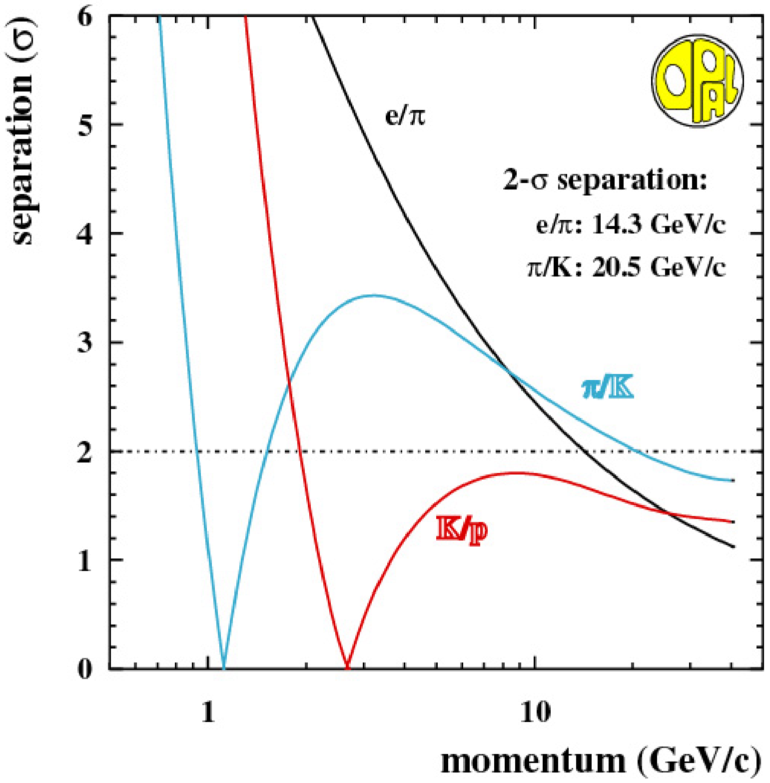
Simultaneous measurement of *p* and *dE/dx* defines *m*.

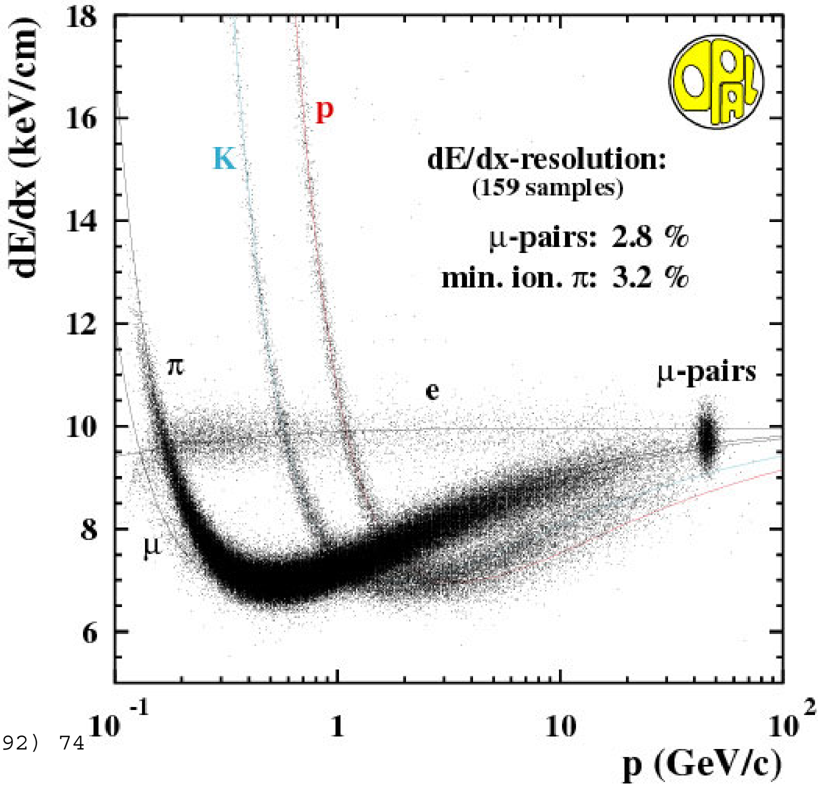
det.	n	x(cm)	P	exp.	meas.	
CLEO2	51	1.4	1 atm	6.4%	5.7%	(μ)
Belle	52	1.5	1 atm	6.6%	5.1%	(μ)
MKII/SLC	72	0.833	1 atm	6.9%	7.0%	(e)
OPAL	159	0.5	4 atm	3.0%	3.1%	(μ)
TPC/PEP	180	0.5	8.5 atm	2.8%	2.5%	
Aleph	344	0.36	1 atm	4.6%	4.5%	(e)

Yamamoto, UH-511-943-99

The OPAL JET Chamber

The chamber is 4 m long with an inner diameter of 0.5 m and an outer diameter of 3.7 m. The sensitive volume is divided into 24 identical sectors, each containing a plane with 159 sense wires.

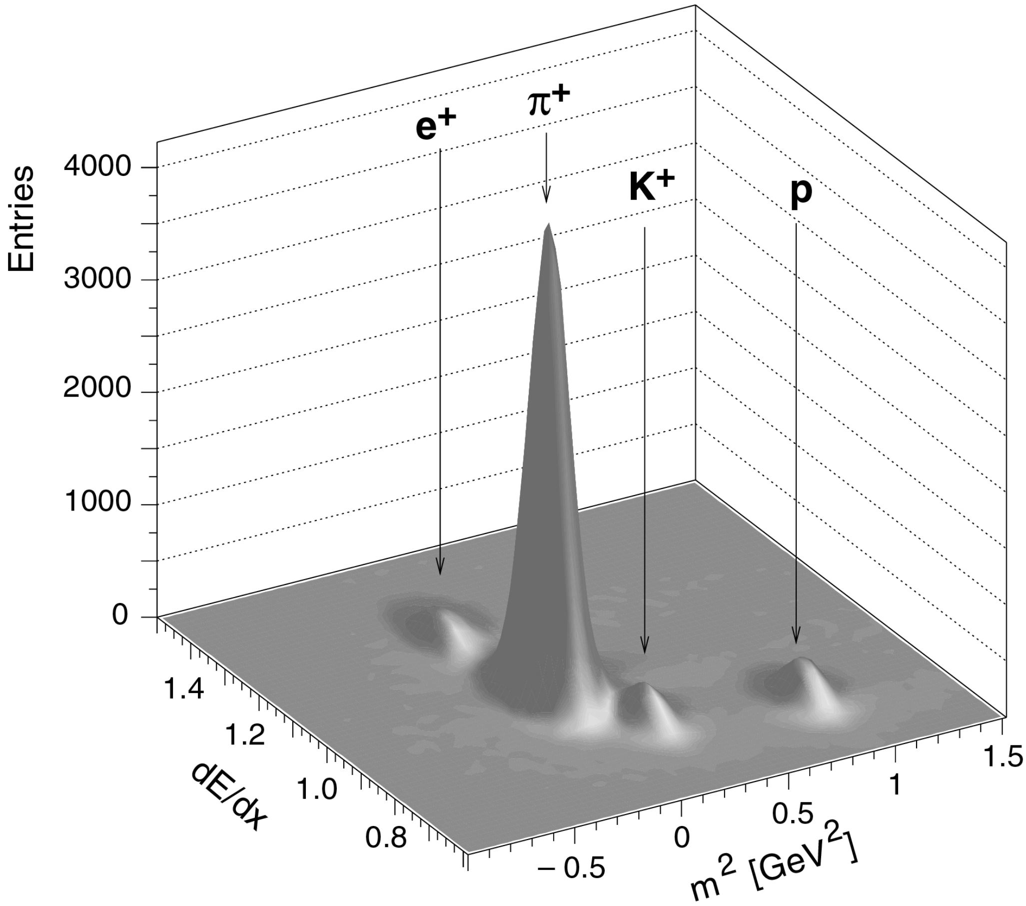




OPAL, NIM A314 (1992) 74

and combined

NA49
Particle identification by simultaneous dE/dX and TOF measurement in the momentum range 5 to 6 GeV/c for central Pb+Pb collision



NA49, CERN-EP/99-001

Particle identification @ CDF

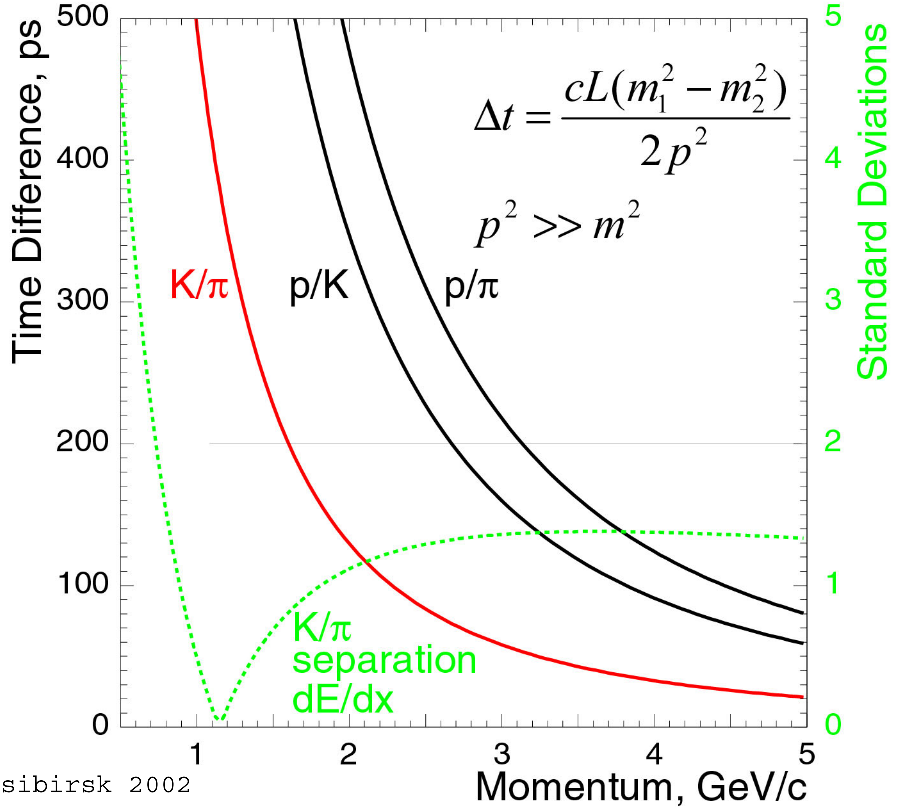
During CDF I particle ID based on dE/dx method using the central drift chamber

For CDF II a TOF complement dE/dx.

- 2σ K/π separation p<1.6 GeV/c
- 2σ K/p separation p<2.7 GeV/c
- 2σ p/π separation p<3.2 GeV/c
- 1.2σ K/p separation over all p

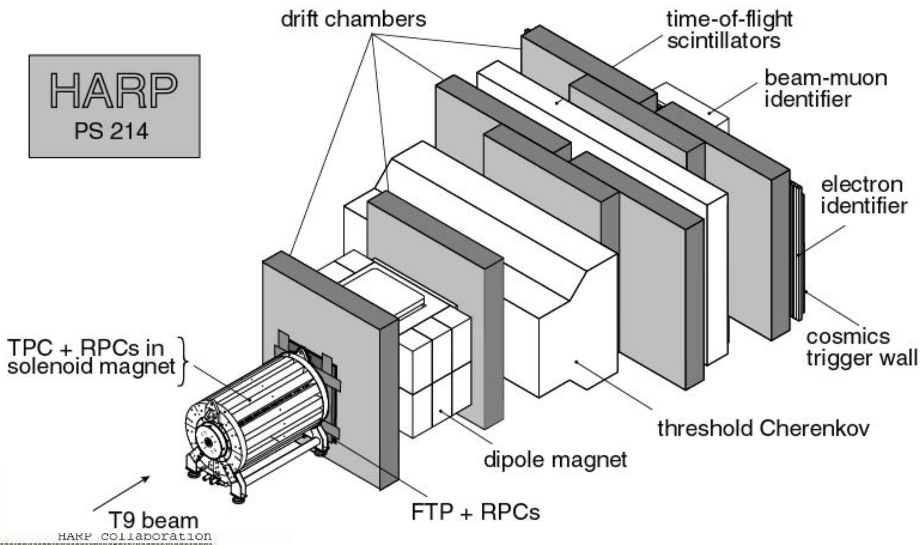
For L= 140 cm ~ R_{tof}

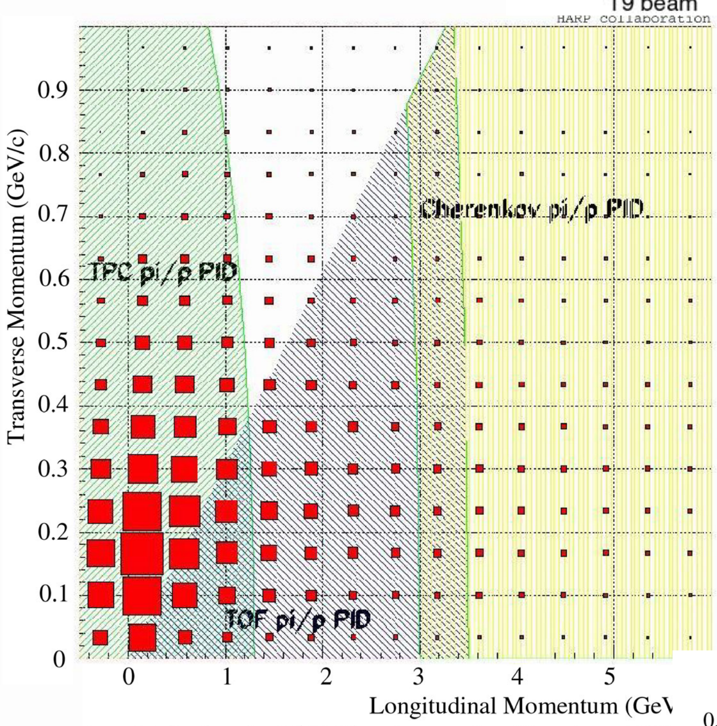
Timing resolution σ_t= 100 ps



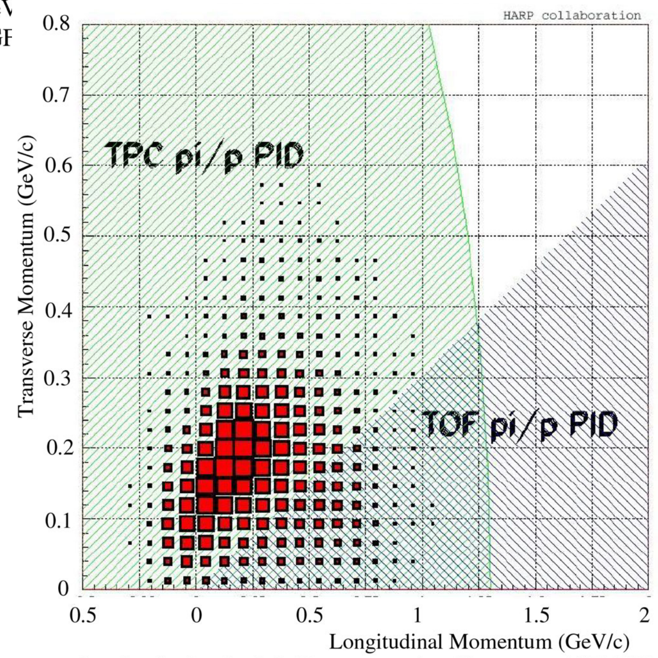
Vila, Novosibirsk 2002

and combined





pion distribution for 15 GeV protons on beryllium target (GF



pion distribution for 2 GeV protons on beryllium target (GFLUKA)

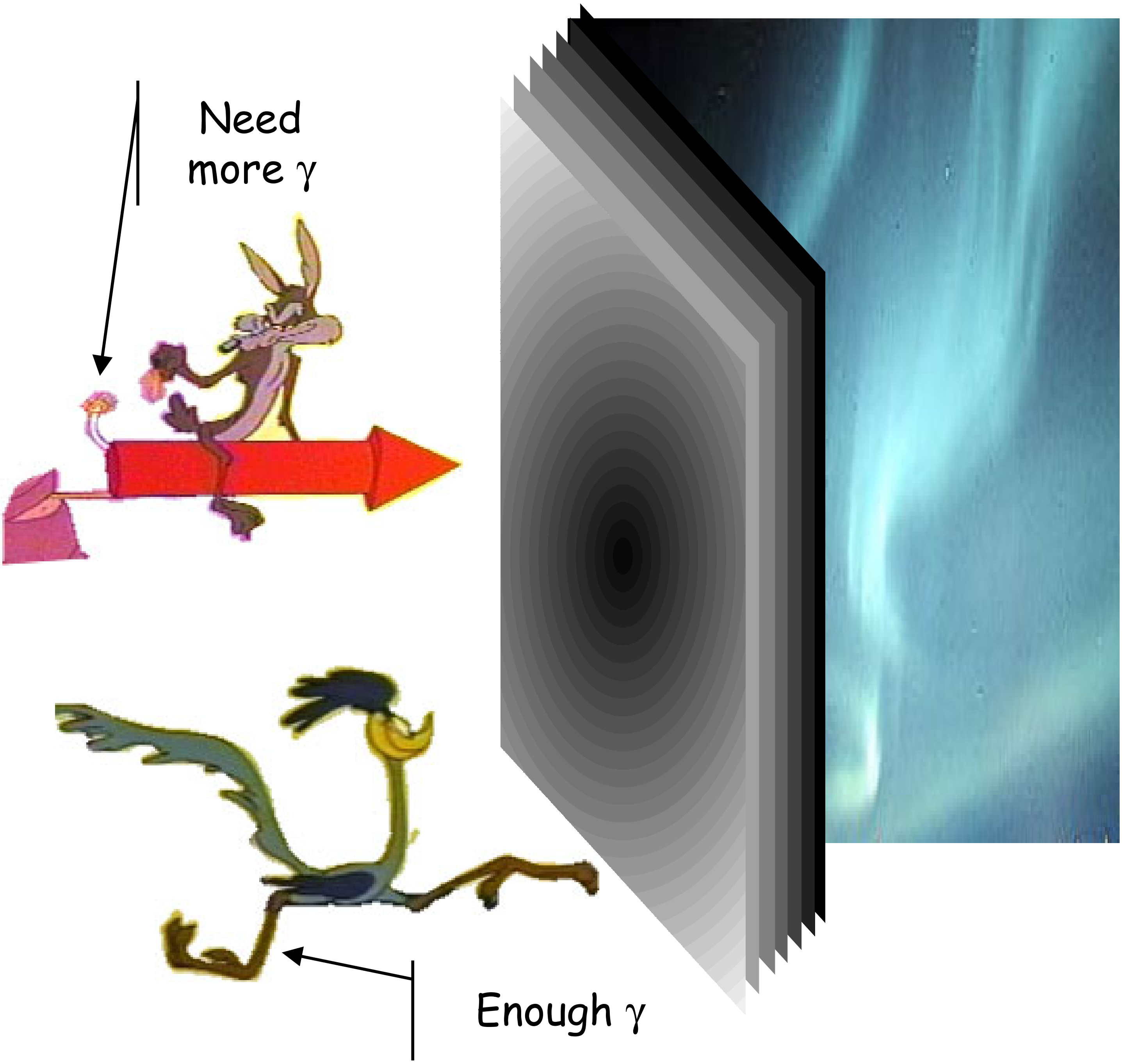
Radicioni, hep-ex/0206028, 2002

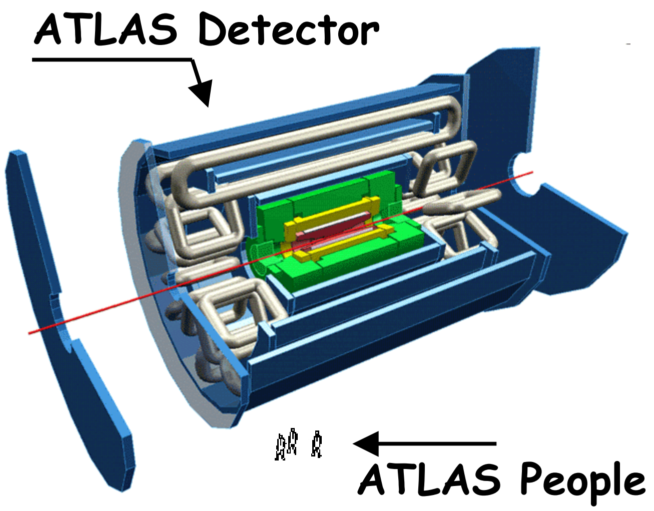
Transition Radiation Detectors

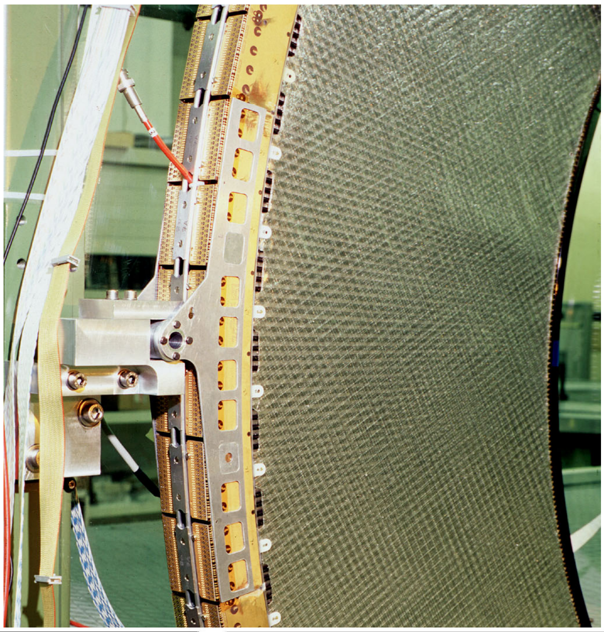
If $\omega >> \omega_0$ =plasma frequency

$$\frac{d^2 S_0}{d\Theta d\omega} = \frac{2\alpha\hbar\Theta^3}{\pi\omega}\left[\frac{1}{a_1} - \frac{1}{a_2}\right]^2$$

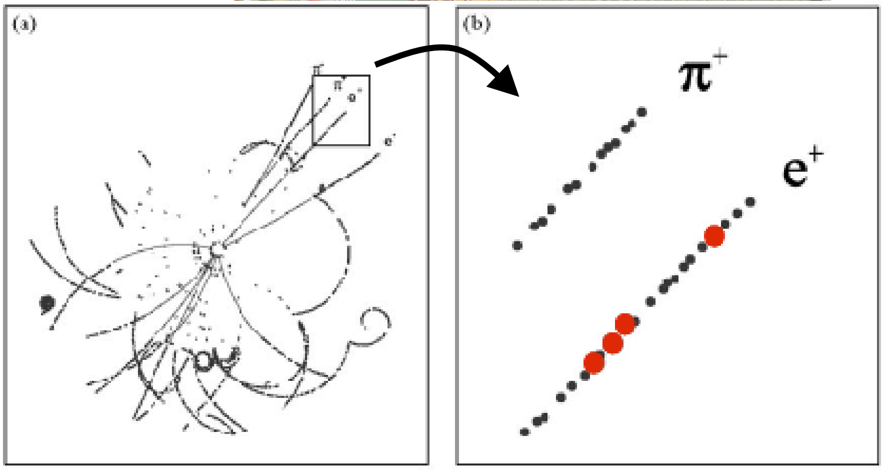
$$a_i = \frac{1}{\gamma^2} + \Theta^2 + \frac{\omega_i^2}{\omega^2}$$

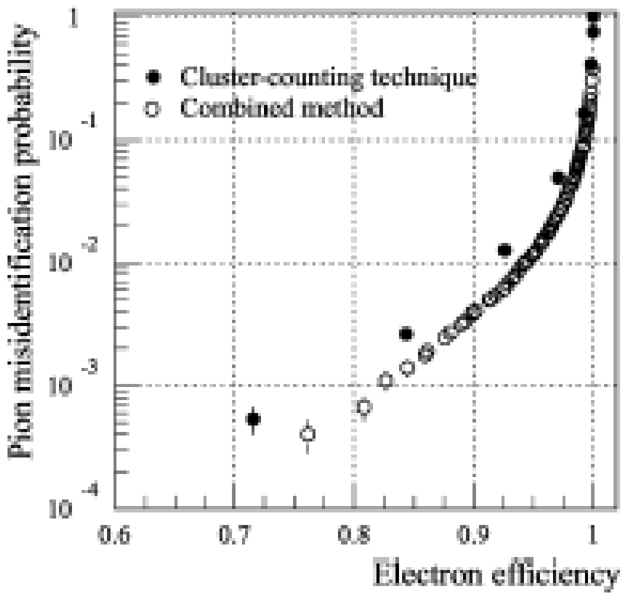






The display of a simulated $B^0_d \rightarrow J/\Psi K^0_s$ event in the ATLAS barrel Inner Detector, at low luminosity (10^{33} $cm^{-2}s^{-1}$) is shown in Fig. 1a. The small box selects a part of a pion track from the K^0_s decay and of an electron track from a J/Ψ decay, shown in an enlarged frame in Fig. 1b.



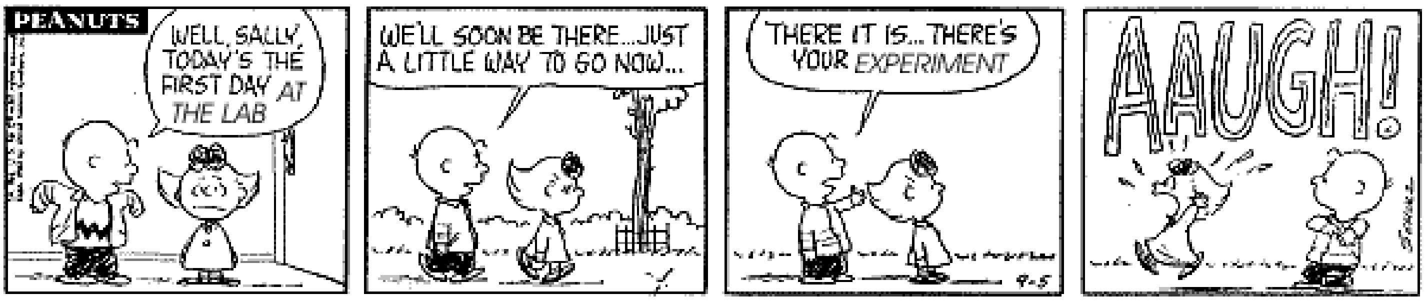


Pion misidentification probability versus electron efficiency at 5 GeV for pseudo-tracks constructed from test beam data. The results are shown for the standard cluster counting technique and for the combined method using also the time-over-threshold information.

NIM A 474 (2001) 172-187

Conclusion

Particle Identification has proven to be a very fertile ground for novel ideas.
In particular the progress in photon detection and in combined systems has evolved very rapidly.



Further information on PID and related techniques at this conference can be found in the following talks:

A. Tonazzo/Milano, The laser calibration system of the Harp tof
G. Prior/Geneve, The HARP Time Projection Chamber
J.-L. Faure/Saclay, Progress with photodectors
R. Pani/Roma, Flat Panel PMT: advances in position sensitive photodetection
P. Antonioli/Bologna, MRPC for the ALICE-tof system
M. Capeans/CERN, ATLAS straw tube TRD
G. Osteria/Napoli, The tof system of the Pamela experiment
R. Pegna/Siena, The HPD: new UV detector for IACT (Imaging Air Cerenkov Telescopes)
D. Casadei/Bologna, Design and test results of the AMS RICH detector
G. Passaleva/Firenze, New results from an extensive aging test on bakelite RPCs