Univerza v Ljubljani

Detectors for Particle Identification

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Ring Imaging CHerenkov counters

New concepts, photon detectors, radiators

Time-of-flight measurement

Summary

Introduction: Why Particle ID?

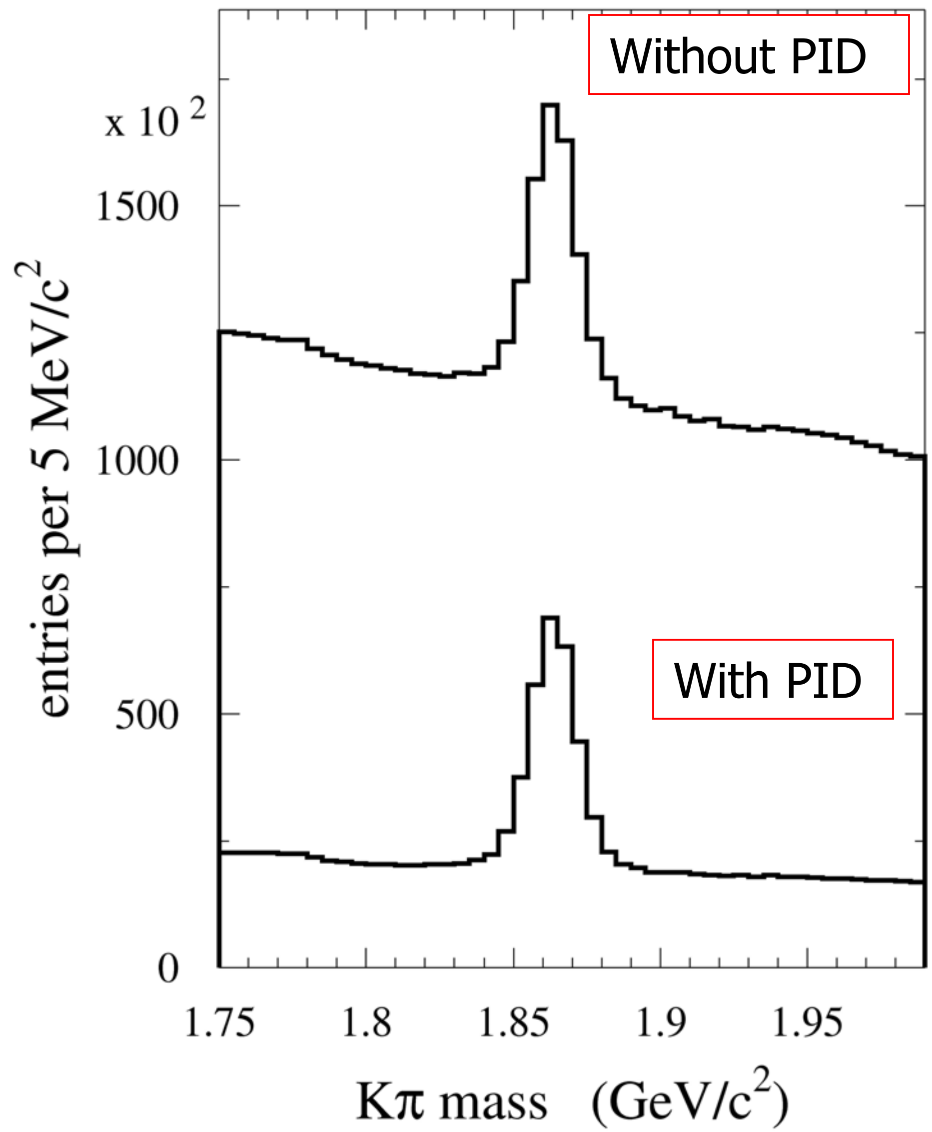
Particle identification is an important aspect of particle, nuclear and astroparticle physics experiments.

Some physical quantities in particle physics are only accessible with sophisticated particle identification (B-physics, CP violation, rare decays, search for exotic hadronic states).

Nuclear physics: final state identification in quark-gluon plasma searches

Astrophysics/astroparticle physics: identification of cosmic rays – separation between nuclei (isotopes), charged particles and high energy photons

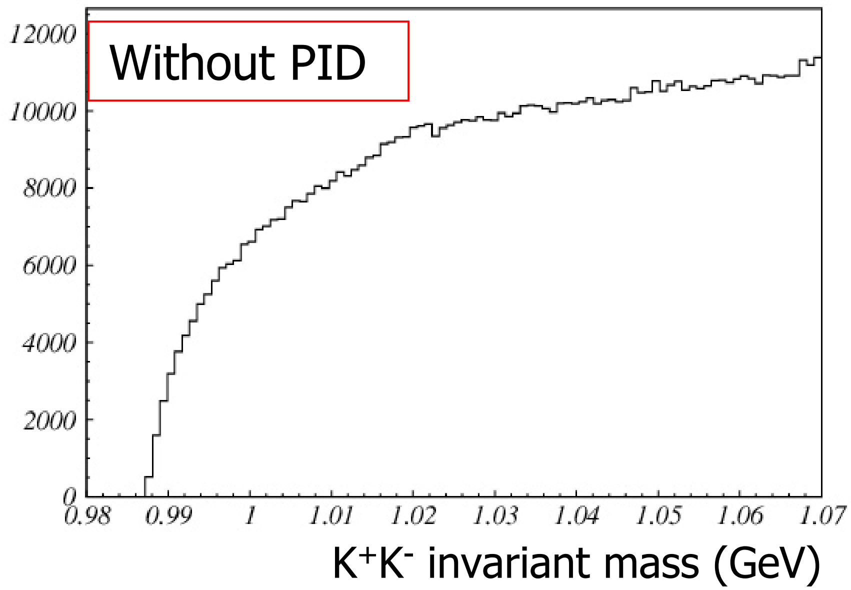
Introduction: Why particle ID?

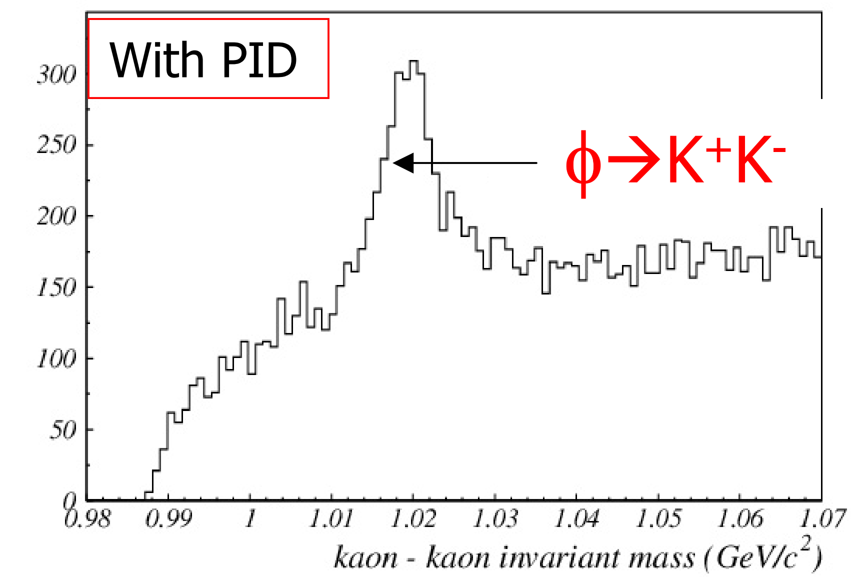


Example 1: B factory

Particle identification reduces the fraction of wrong Kπ combinations (combinatorial background) by ~6x

Introduction: Why particle ID?



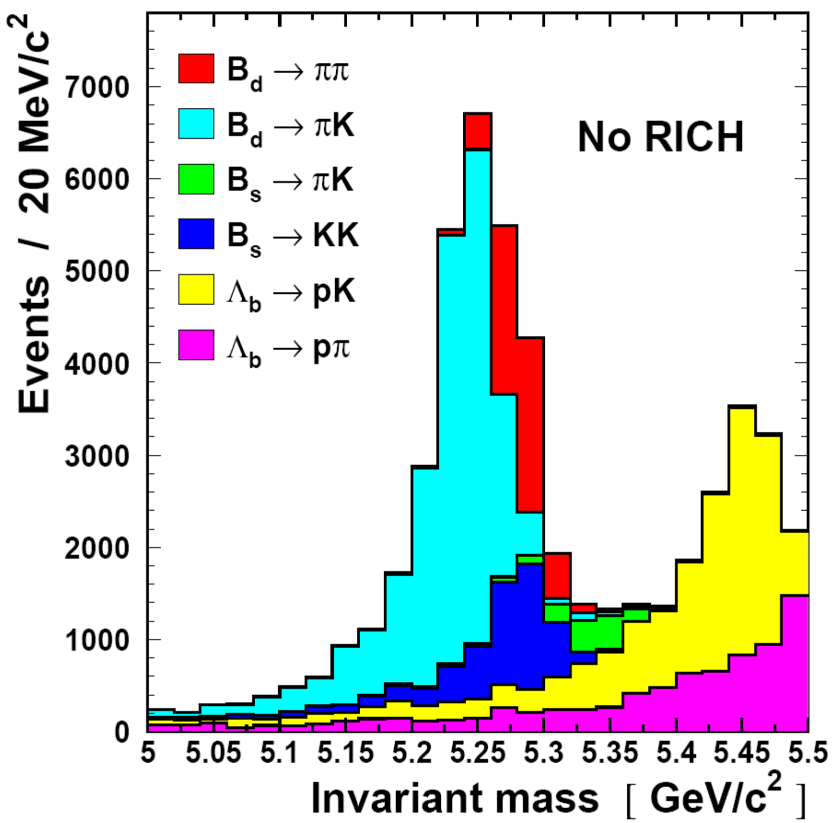


Example 2: HERA-B

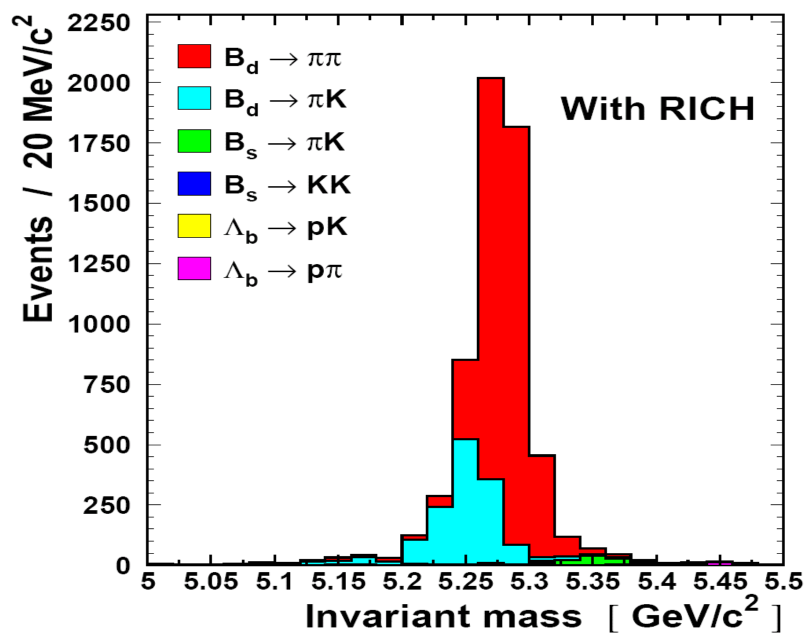
K^+K^- invariant mass.

The inclusive $\phi \rightarrow K^+K^-$ decay only becomes visible after particle identification is taken into account.

Introduction: Why Particle ID?



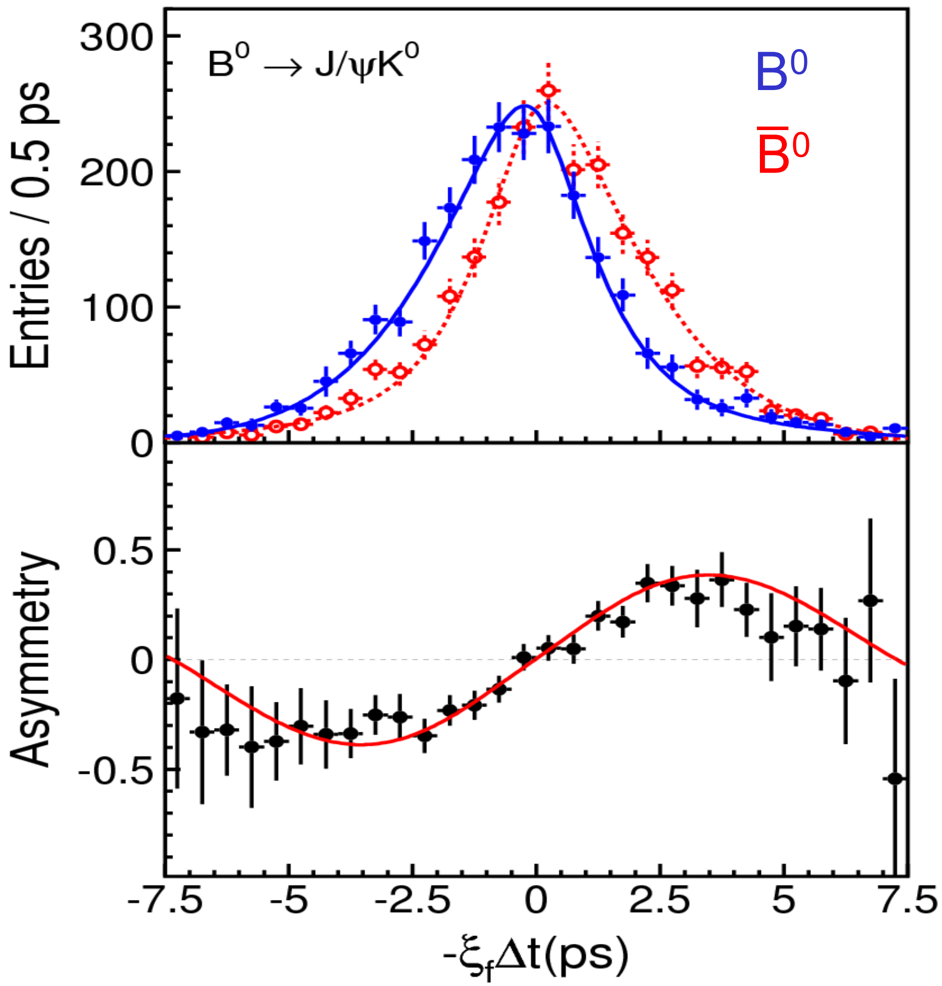
Example: LHCb



Need to distinguish $B_d \to \pi\pi$ from other similar topology 2-body decays and to distinguish B from anti-B using K tag.

Introduction: Why particle ID?

Particle identification at B factories (Belle and BaBar): was essential for the observation of CP violation in the B meson system.



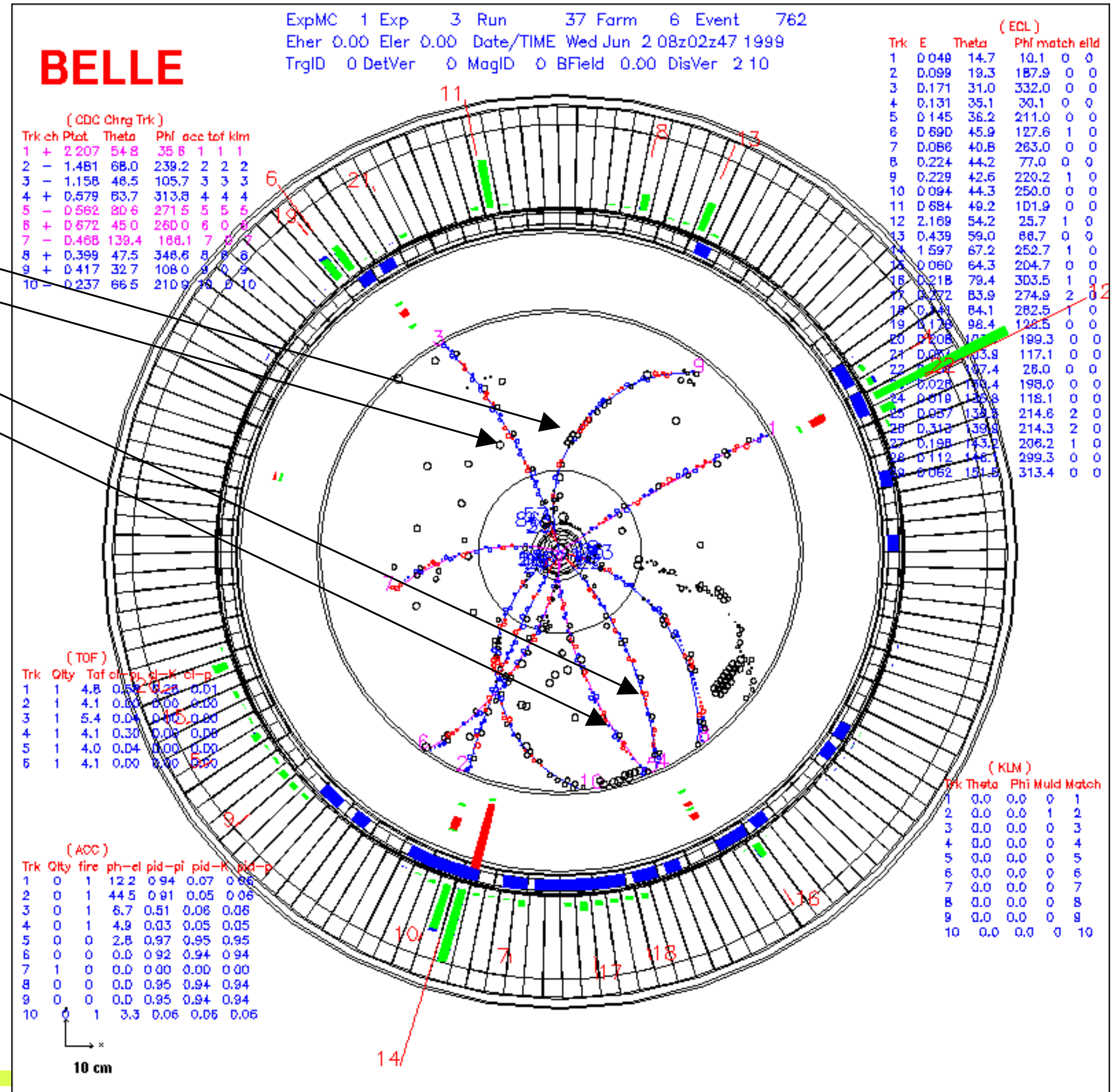
B^0 and its anti-particle decay differently to the same final state $J/\psi\ K^0$

Was it a B or anti-B?

B^0 (or $\overline{B}^0$) → $K^0_S\, J/\psi$

$K^0_S \rightarrow \pi^- \pi^+$

$J/\psi \rightarrow \mu^- \mu^+$

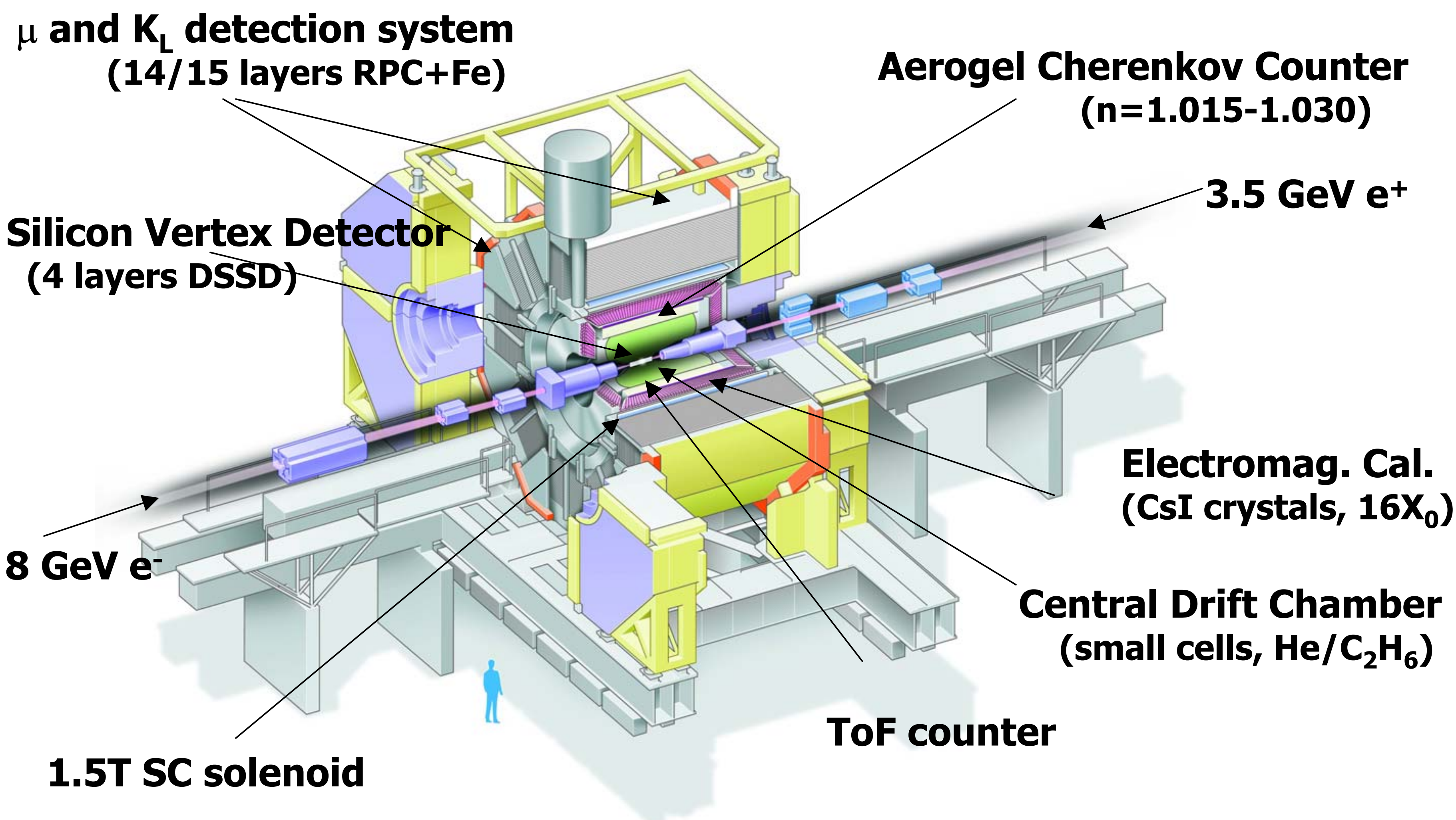


Flavour of the B: from decay products of the other B: charge of the kaon, electron, muon

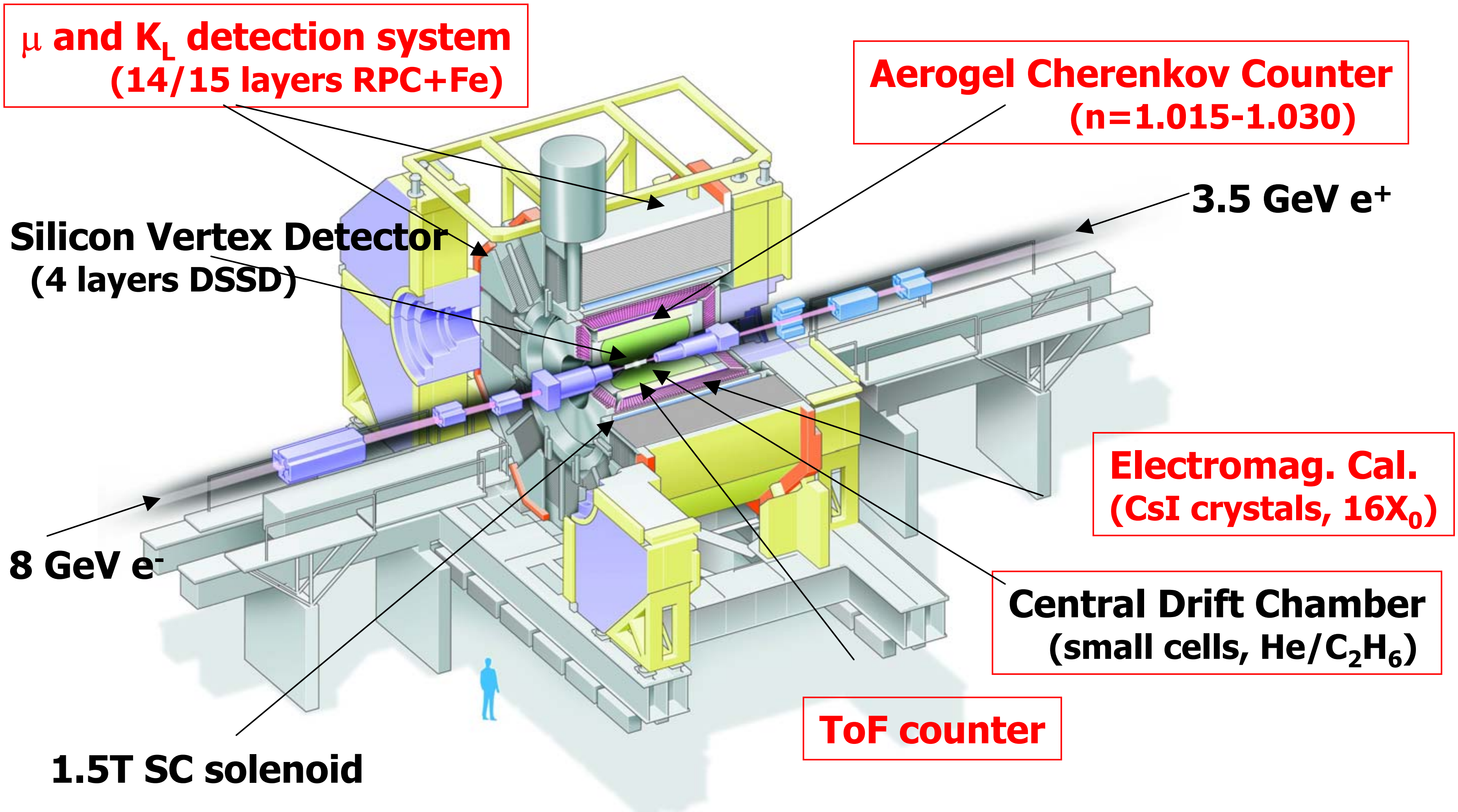
→need particle ID

Belle @ KEK-B in Tsukuba

Belle spectrometer



Particle identification systems in Belle



Identification of charged particles

Particles are identified by their mass or by the way they interact.

Determination of mass: from the relation between momentum and velocity, $p=\gamma mv$. Momentum known (radius of curvature in magnetic field)

→Measure velocity:

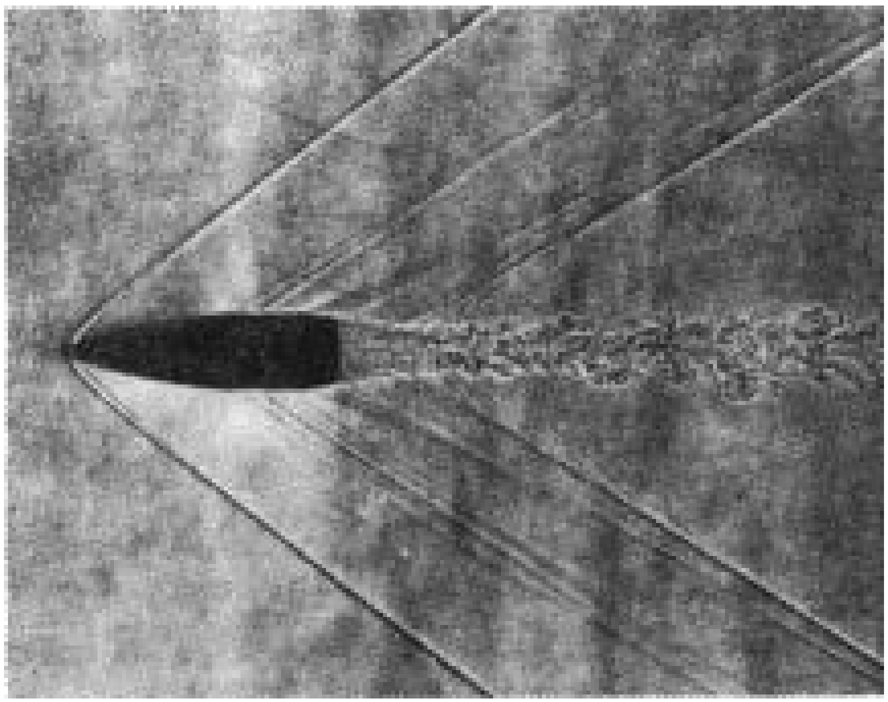
- time of flight
- ionisation losses dE/dx
- Čerenkov angle
- transition radiation

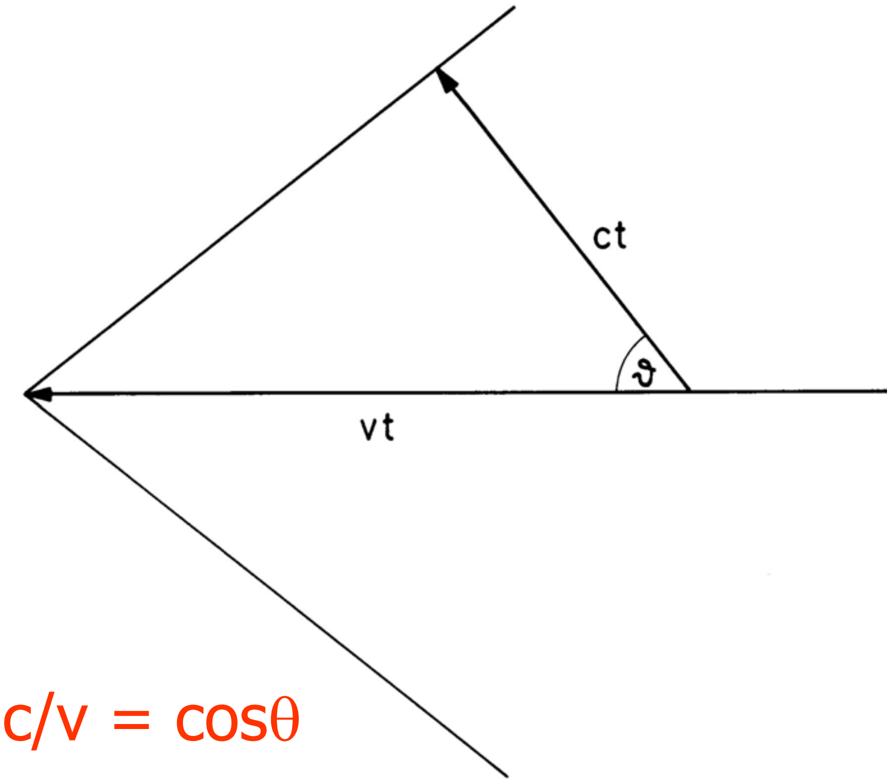
Mainly used for the identification of hadrons.

Identification through interaction: electrons and muons (→ several talks at this conference)

Velocity of a bullet

Determine the velocity of a bullet





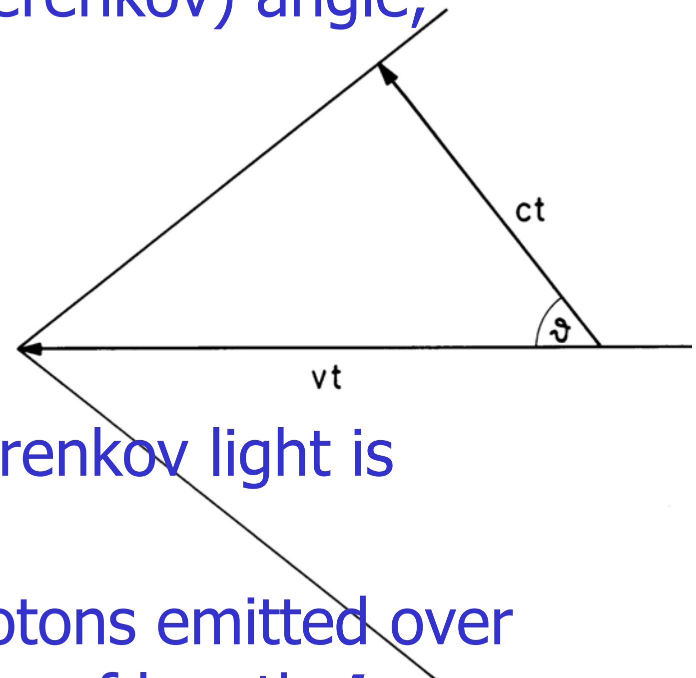
$c/v = \cos\theta$

From the photograph:
angle 52°, $v = c/\cos\theta = 340\text{m/s} / \cos 52° = 552\text{m/s}$

Čerenkov radiation

A charged track with velocity v=βc exceeding the speed of light c/n in a medium with refractive index n emits polarized light at a characteristic (Čerenkov) angle,

$\cos\theta = c/nv = 1/\beta n$



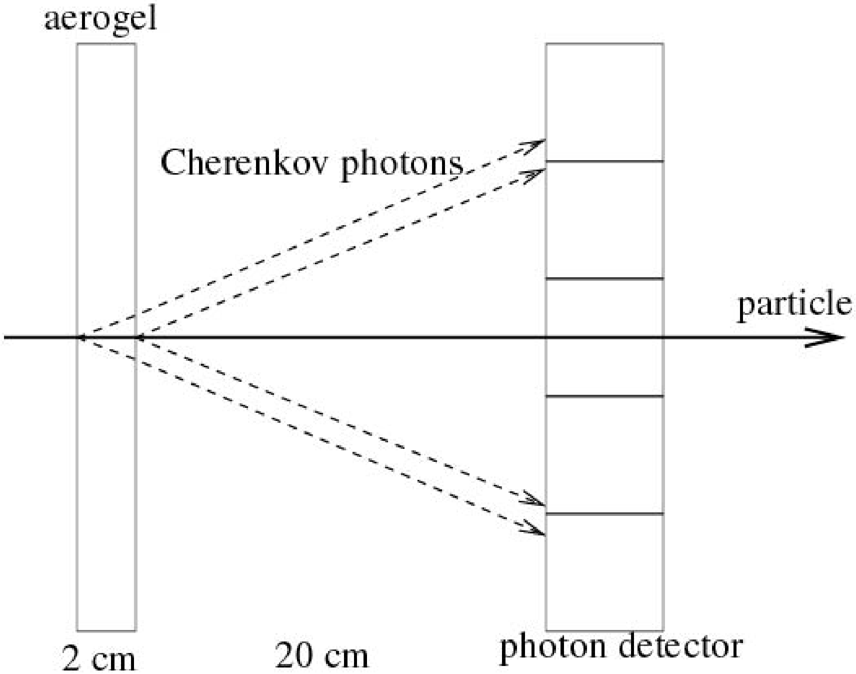
Two cases:

1) $\beta < \beta_t = 1/n$: below threshold no Čerenkov light is emitted.

2) $\beta > \beta_t$: the number of Čerenkov photons emitted over unit photon energy E=hν in a radiator of length ***L***:

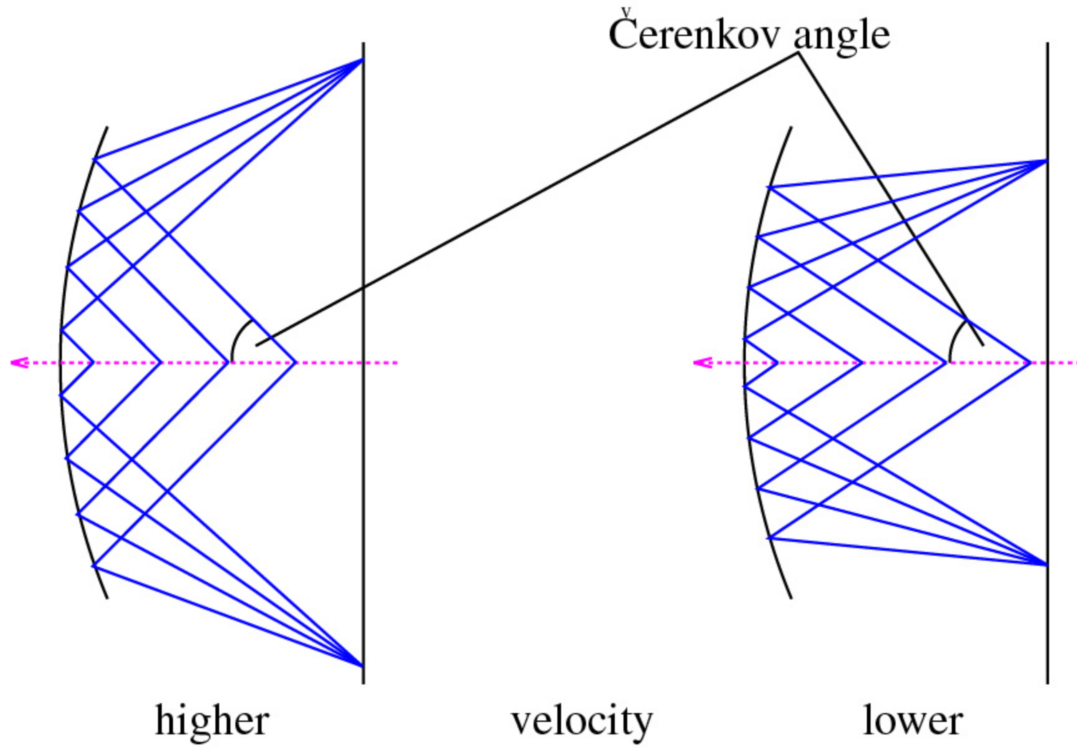
$$\frac{dN}{dE} = \frac{\alpha}{\hbar c} L \sin^2\theta = 370 (cm)^{-1} (eV)^{-1} L \sin^2\theta$$

Measuring Čerenkov angle



Proximity focusing RICH

Idea: transform the direction into a coordinate → ring on the detection plane → Ring Imaging CHerenkov



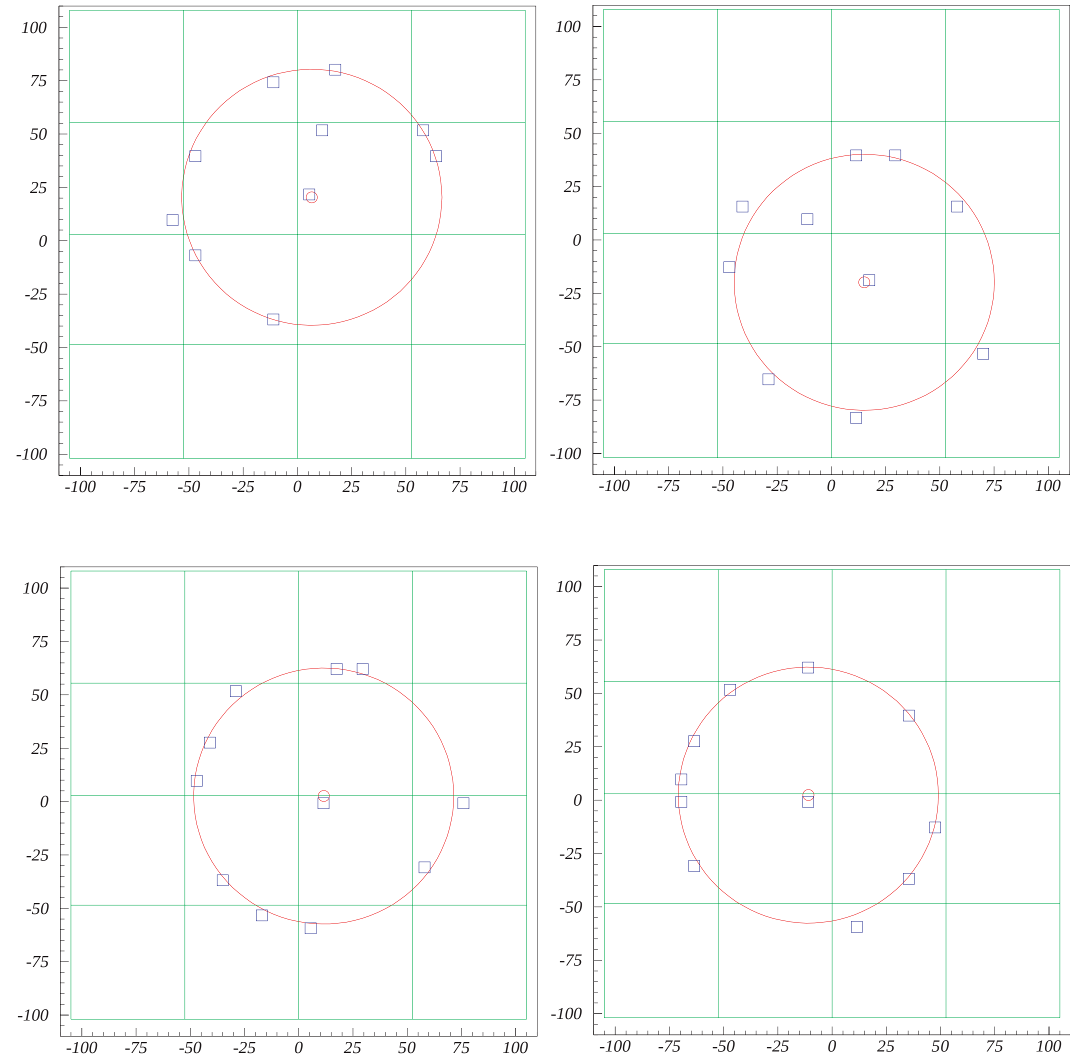
RICH with a focusing mirror

Measuring Čerenkov angle

From hits of individual photons → measure the angle.

Few photons detected

→Important to have a low noise detector



Number of detected photons

Example: in 1m of air (n=1.00027) a track with β=1 emits N=41 photons in the spectral range of visible light (ΔE ~ 2 eV).

If Čerenkov photons were detected with an average detection efficiency of ε=0.1 over this interval, N=4 photons would be measured.

In general: number of detected photons can be parametrized as **$N = N_0 L \sin^2\theta$**

where N_0 is the figure of merit,

$$N_0 = \frac{\alpha}{\hbar c}\int Q(E)T(E)R(E)dE$$

and Q T R is the product of photon detection efficiency, transmission of the radiator and windows and reflectivity of mirrors (as a function of photon energy E).

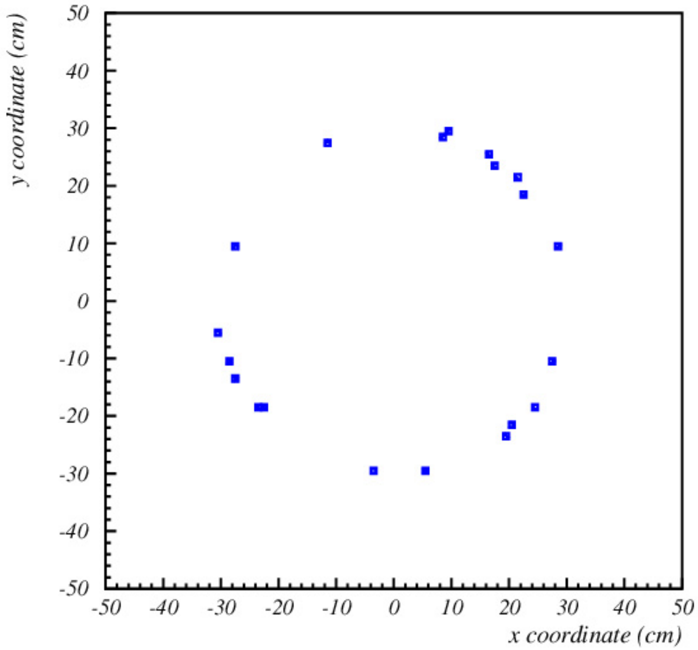
Typically: N_0 = 50 - 100/cm

Photon detection in RICH counters

RICH counter: measure photon impact point on the photon detector surface

→ detection of single photons with

- sufficient spatial resolution
- high efficiency and good signal-to-noise ratio
- over a large area (square meters)



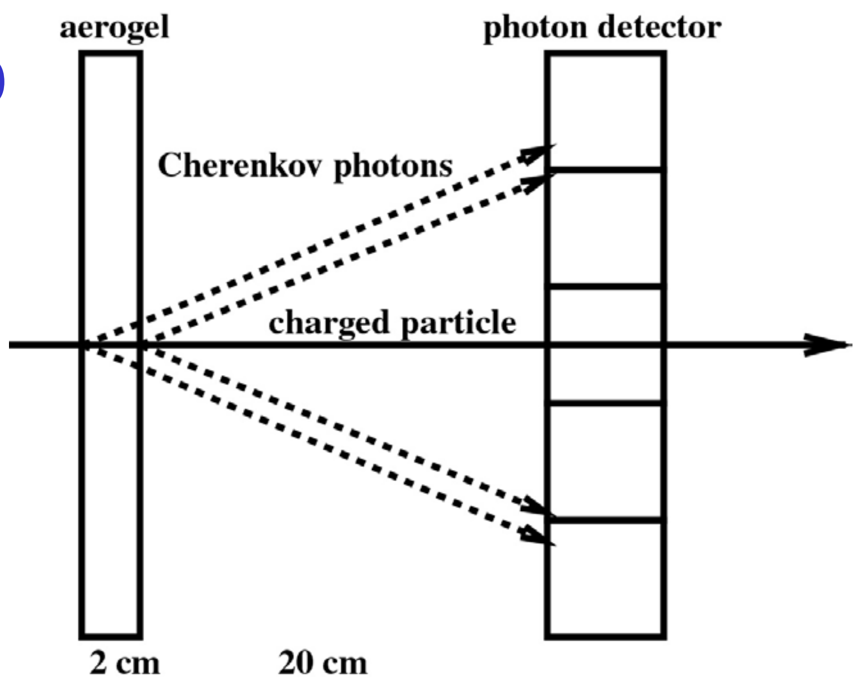
Special requirements:

- Operation in magnetic field
- High rate capability
- Very high spatial resolution
- Excellent timing (time-of-arrival information)

Resolution of a RICH counter

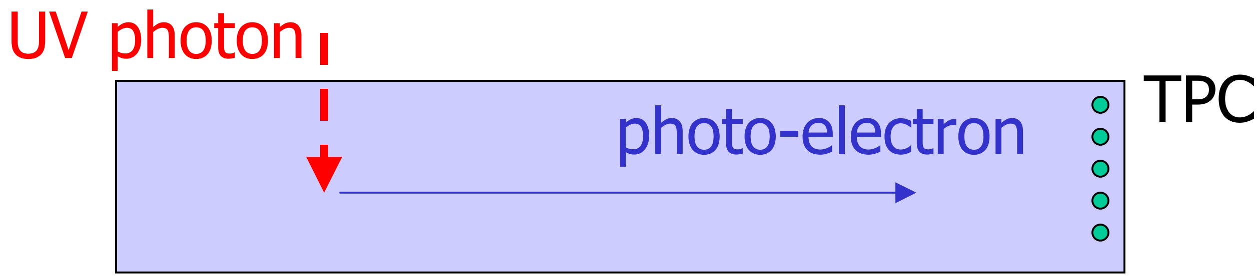
Determined by:

- Photon impact point resolution (~photon detector granularity)
- Emission point uncertainty
- Dispersion: $n=n(\lambda)$ in $1/\beta = n \cos\theta$
- Errors of the optical system
- Uncertainty in track parameters

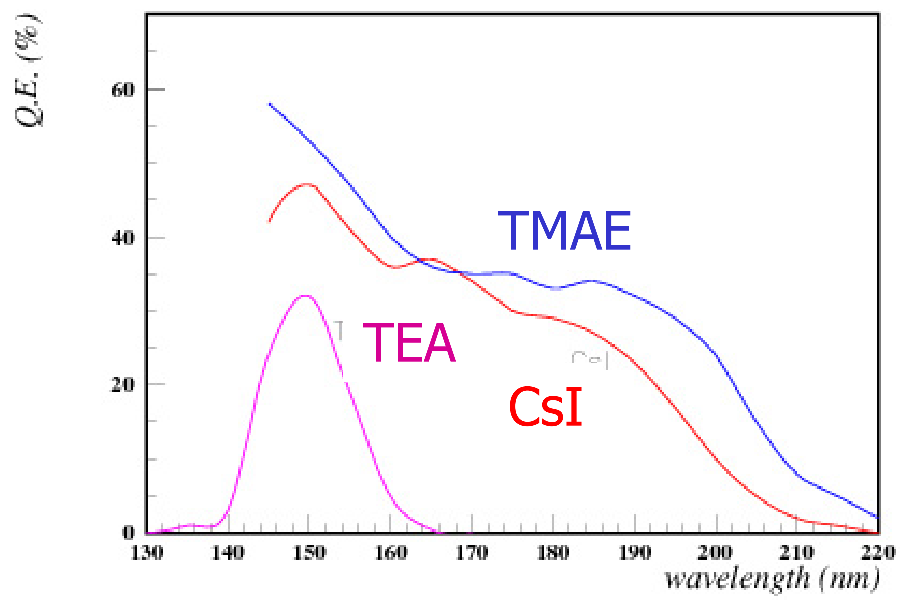


First generation of RICH counters

DELPHI, SLD, OMEGA RICH counters: all employed wire chamber based photon detectors (UV photon → photo-electron → detection of a single electron in a TPC)

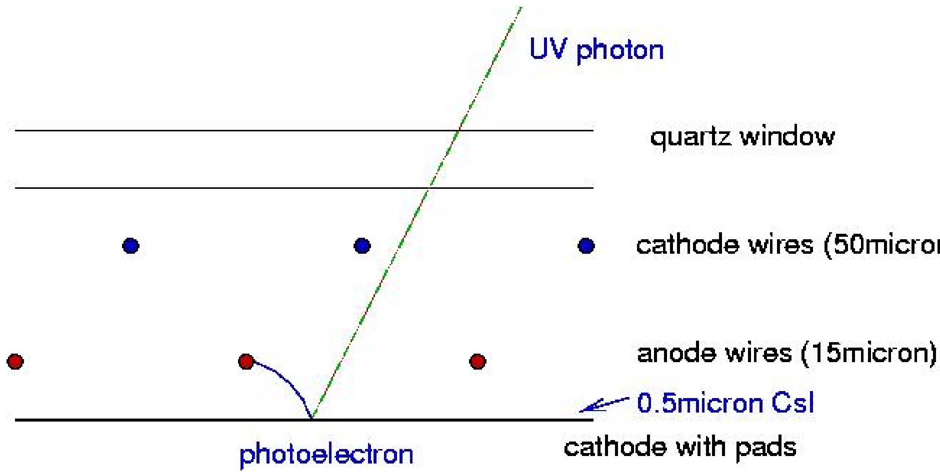


Photosensitive component: TMAE added to the gas mixture



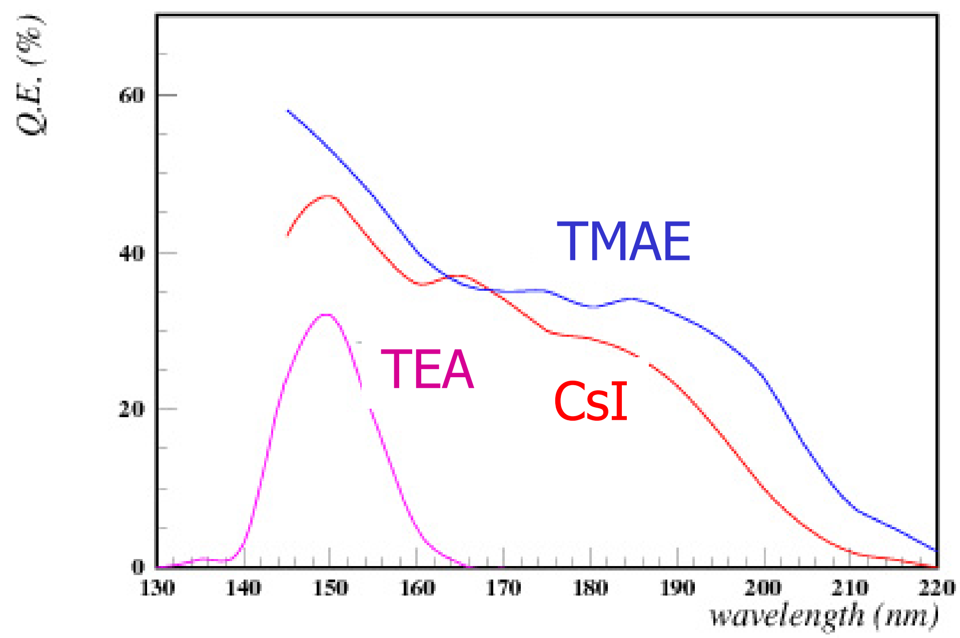
Fast RICH counters with wire chambers

Multiwire chamber with pad read-out: → short drift distances, fast detector



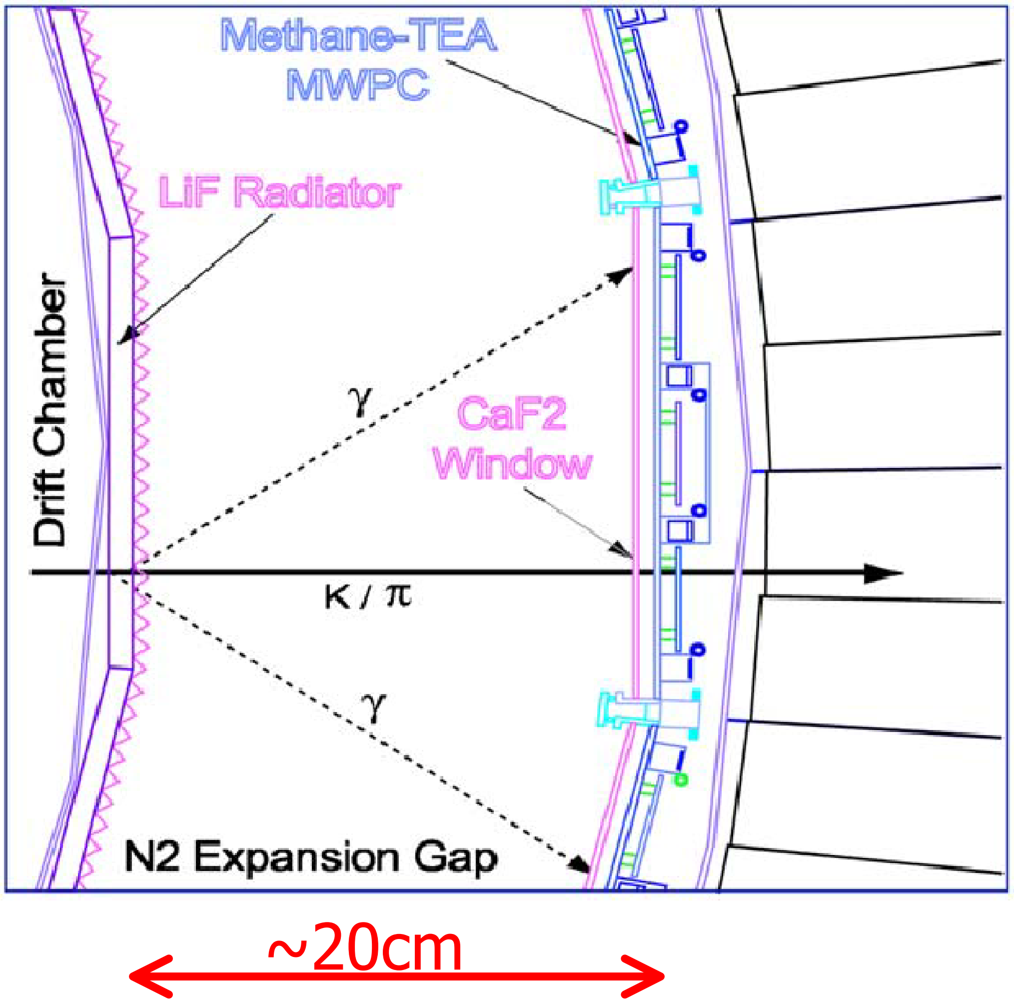
Photosensitive component:

- in the gas mixture (TEA)
- or a layer on one of the cathodes (CsI on the printed circuit pad cathode)



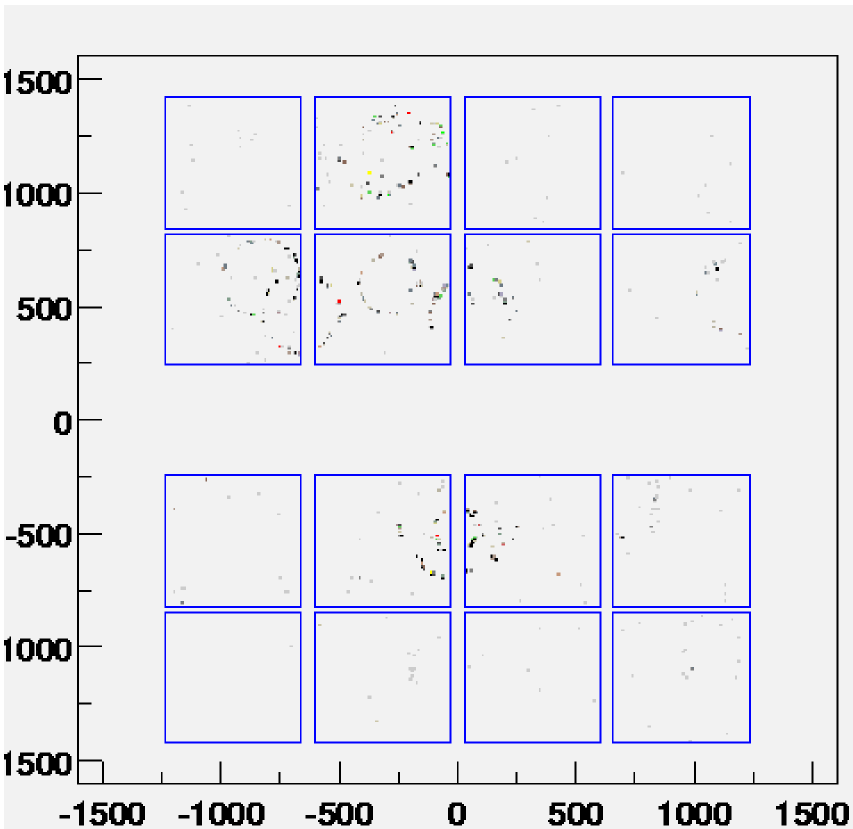
CLEOIII RICH

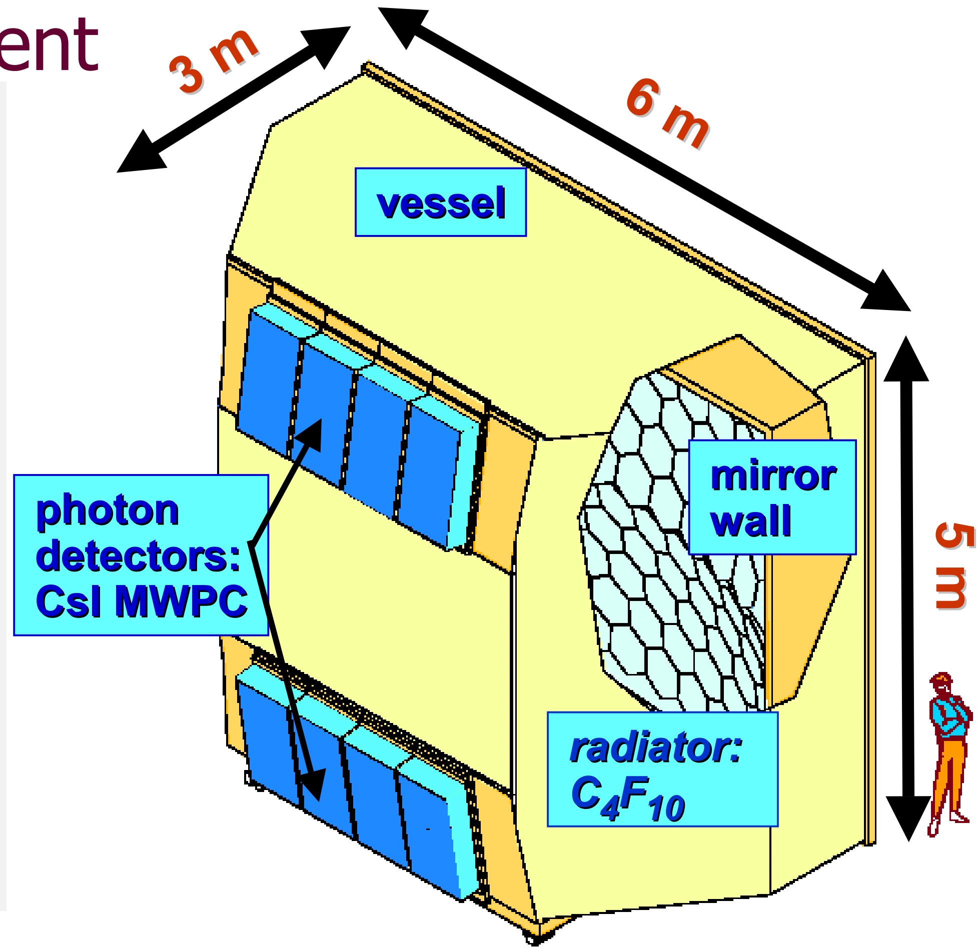
Photon detection in a wire chamber with a methane+TEA.



CsI based RICH counters: HADES, COMPASS, ALICE

COMPASS: calibration event



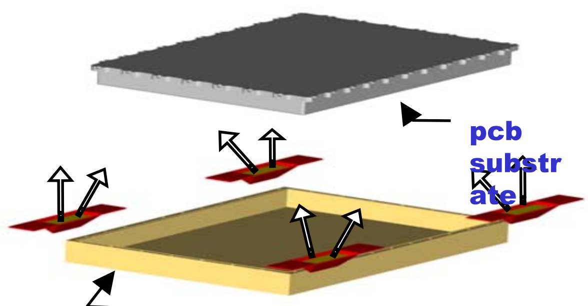


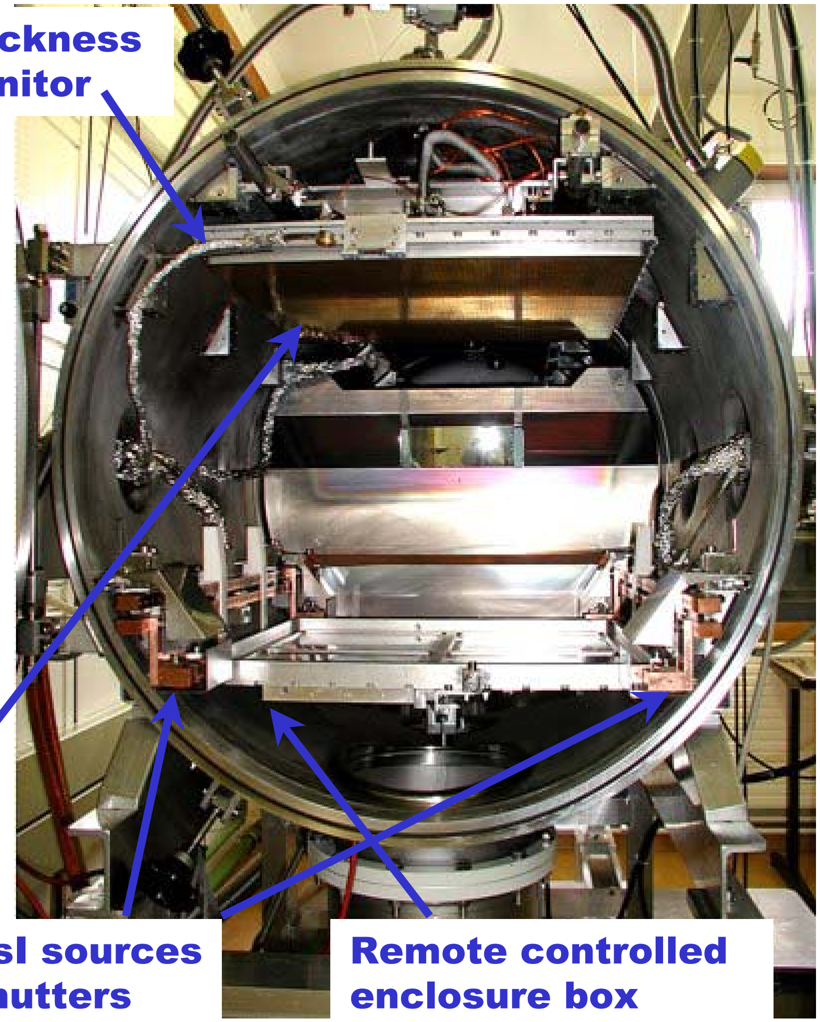
HADES RICH: has been running stably since 1999

CERN CsI deposition plant

Photocathode produced with a well defined, several step procedure, including heat conditioning after CsI deposition

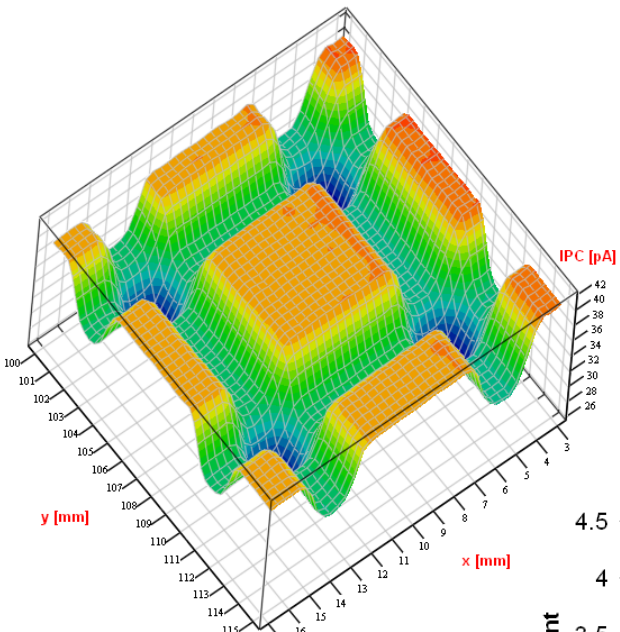
In situ quality control



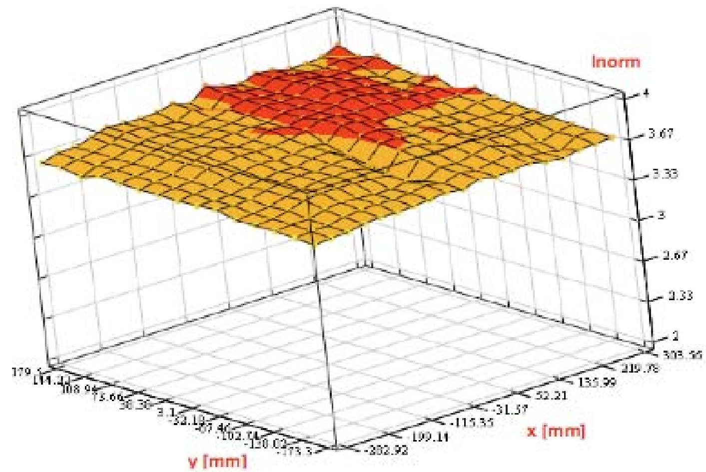


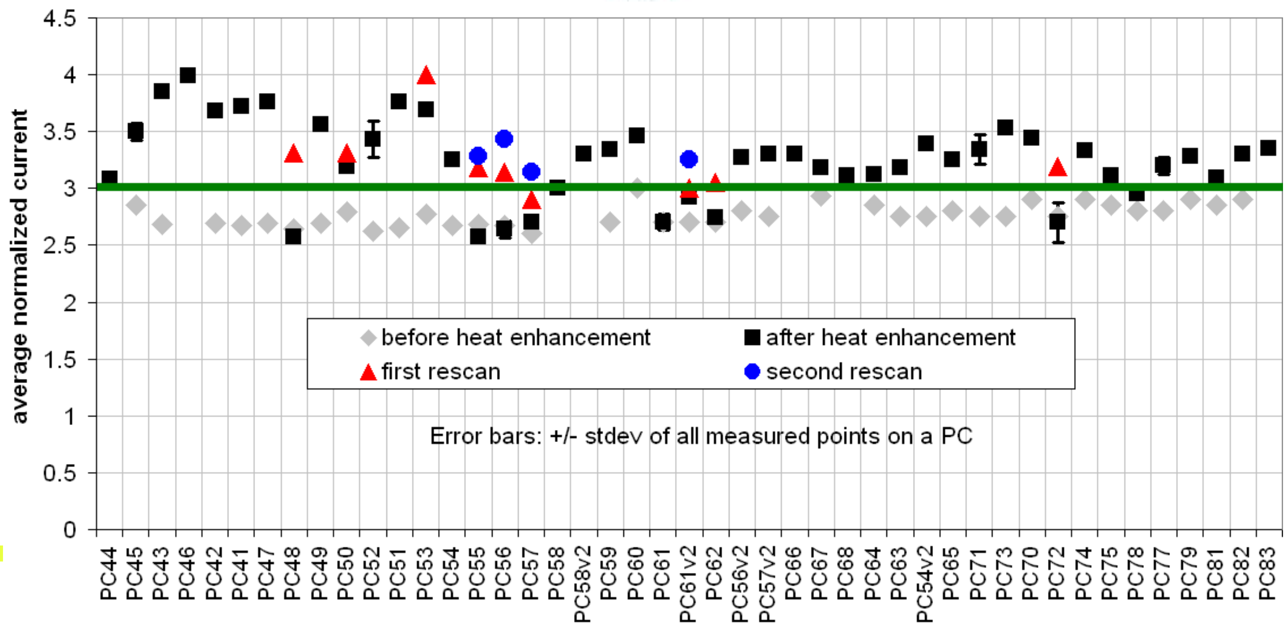
ALICE RICH: Surface sensitivity and production statistics

detailed scan across 2x2 pads



full PC surface (80x48 pads)





details: NIM A 566 (2006) 338

February 23, 2007

ALICE RICH (HMPID) installation

→ Talk by A. Gallas

Early nineties: a new boost

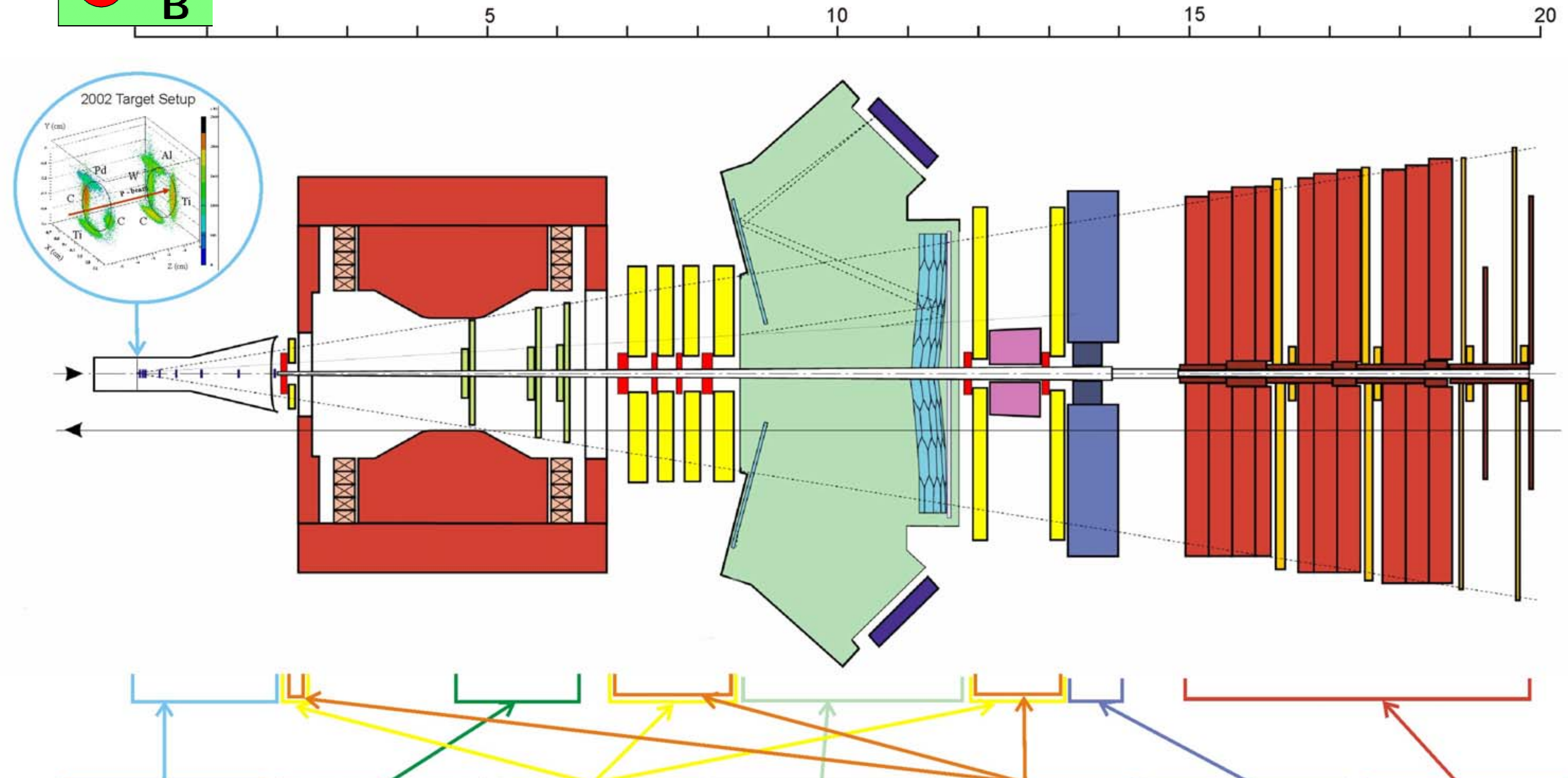
The main motivation came from the planning of experiments to measure CP violation in the B meson system.

Kaon identification: one of the essential features.

Several proposals in Europe, US, Japan → several RICH designs and R+D programs.

Wire chamber based photon detectors were found to be unsuitable (problems in high rate operation, ageing, only UV photons, difficult handling)

HERA-B side view



Target & Vertex
8 layers of double-sided Si-microstrips, movable on Roman-Pots; 8 wire-target (see above)

High p_T
3 superlayers gas, pixel and pad chambers; pre-trigger for high p_T tracks

Outer Tracker
7 superlayers of honeycomb drift chambers, 5 and 10mm cells

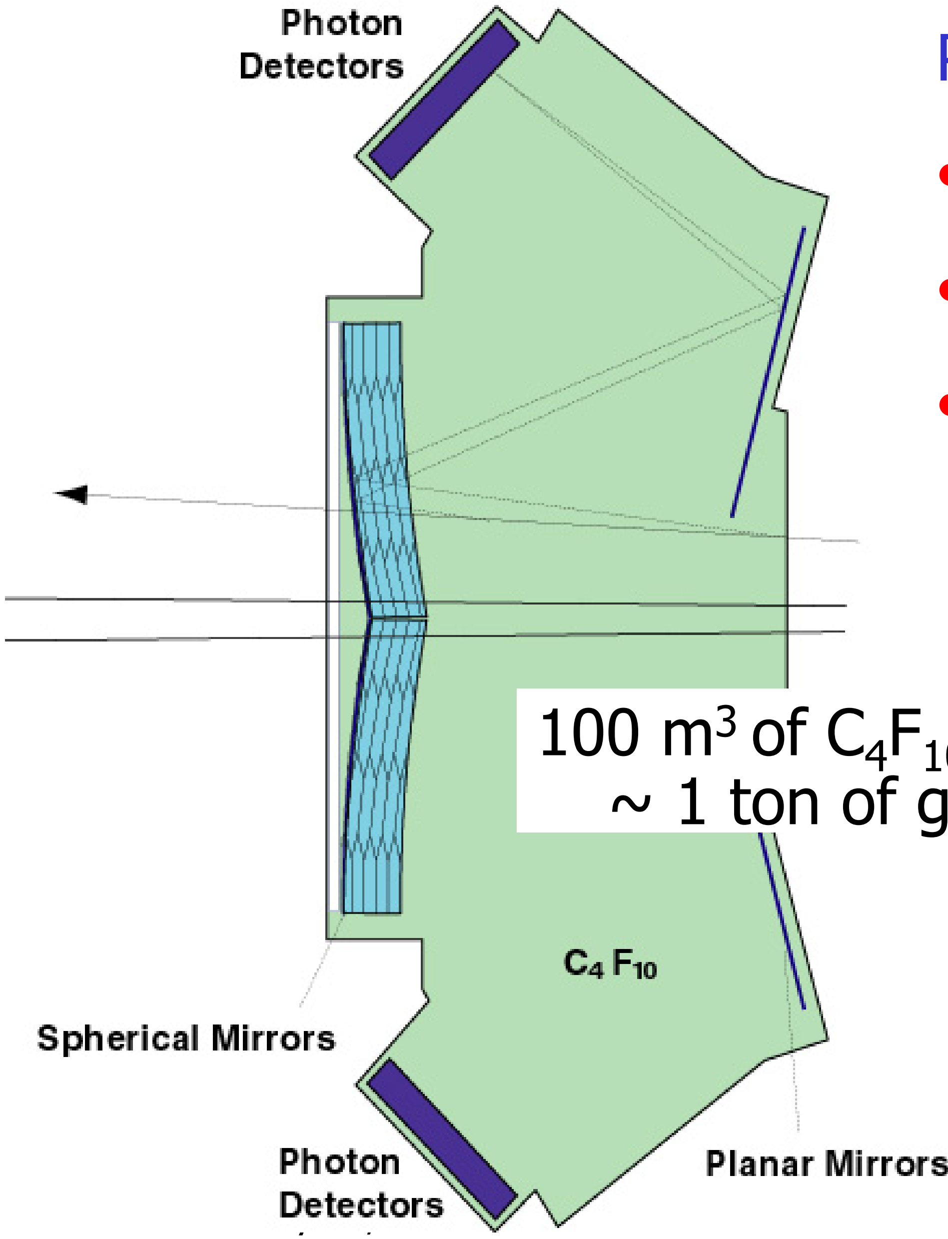
RICH
Spherical mirror inside C_4F_{10} radiator, Lens-enhanced multianode PMT focal plane.

Inner Tracker
7 superlayers of Micro Strip Gas Chambers with GEM-foil

Electromagnetic Calorimeter
W/Pb scintillator sandwich, shashlik WLS readout with PMTs; energy-cluster pre-trigger

Muon System
4 superlayers of gas-pixel, tube & pad chambers; pad-coincidence pre-trigger

HERA-B RICH



$100\ m^3$ of C_4F_{10}
~ 1 ton of gas

Photon detector requirements:

- High QE over ~$3m^2$
- Rates ~1MHz
- Long term stability

HERA-B RICH photon detector

Originaly considered: wire chambers with either TMAE or CsI. Tests: very good performance in test beams, but serious problems in long term operation at very high rates.

Hamamatsu just came out with the metail foil multianode PMTs of the R5900 series: first multianode PMTs with very little cross-talk

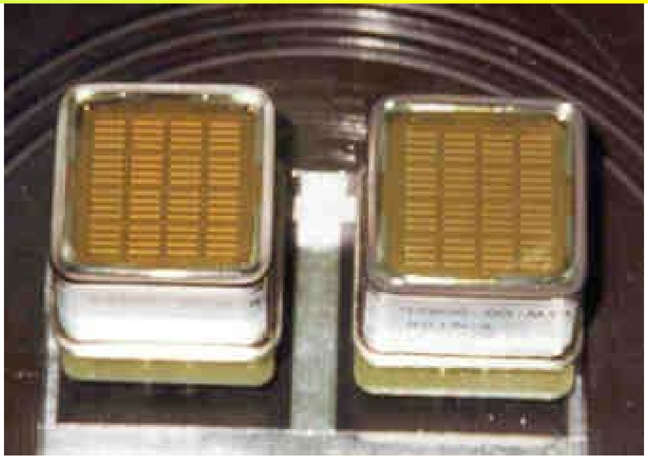
Tested on the bench and in the beam: excellent performance →easy decision

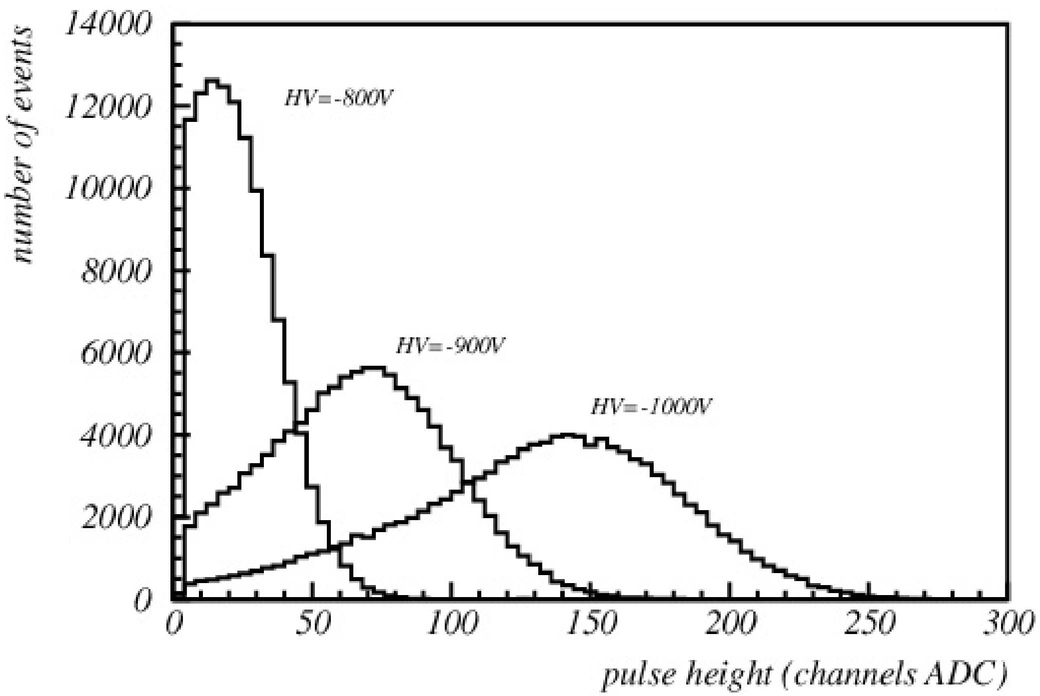
→ NIM A394 (1997) 27

Multianode Hamamatsu R5900-M16 PMT

Multianode PMTs

R5900-M16 (4x4 channels)
R5900-M4 (2x2 channels)





single photon pulse height

Key features:

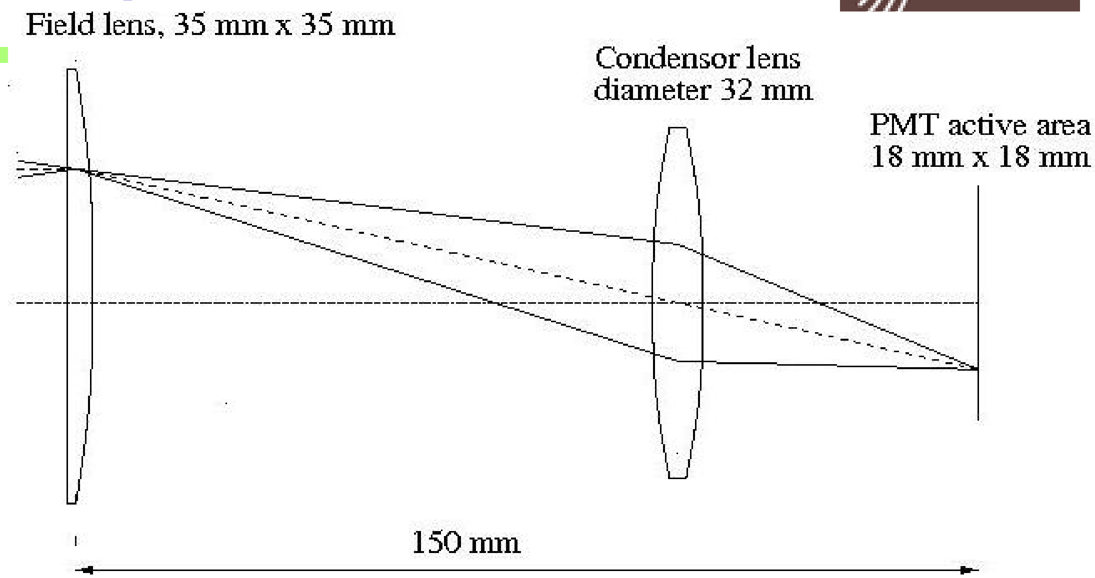
- Excellent single photon pulse height spectrum
- Low noise (few Hz/ch)
- Low cross-talk (<1%)

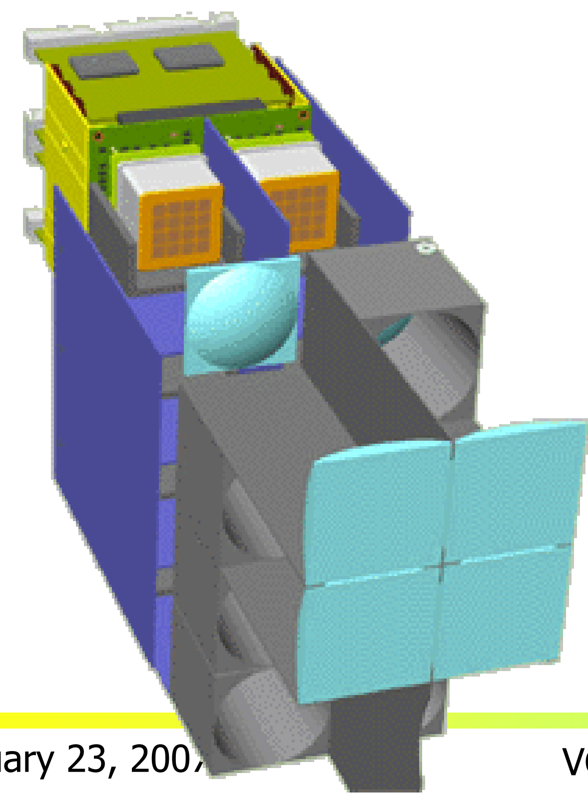
HERA-B RICH photon detector

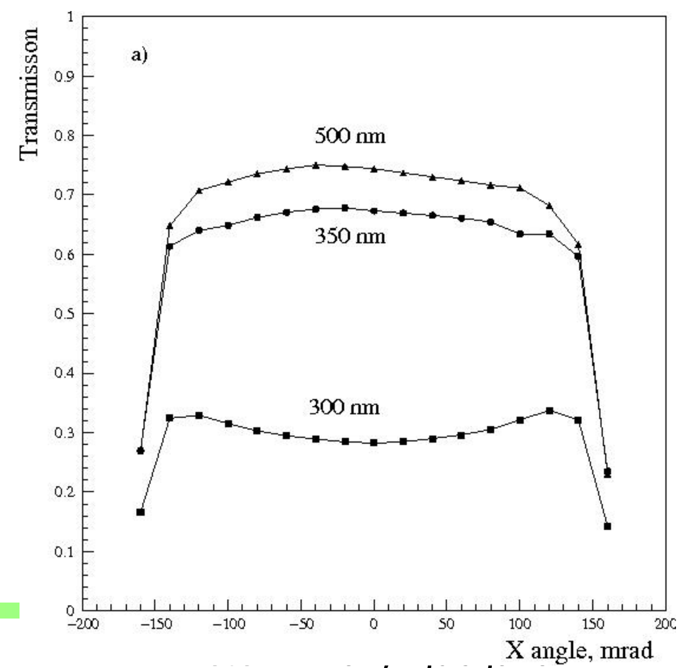
Light collection system (imaging!) to:

-Eliminate dead areas

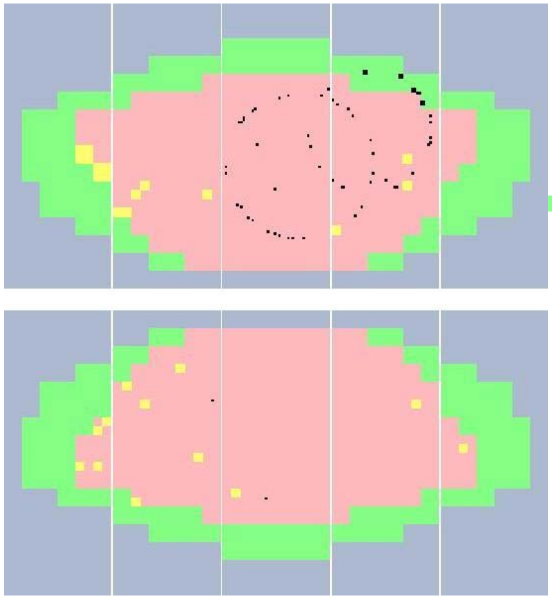
-Adapt the pad size





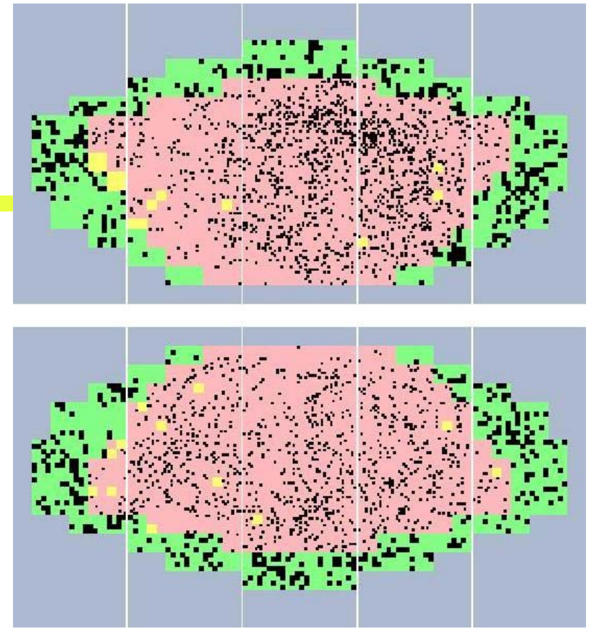


HERA-B RICH



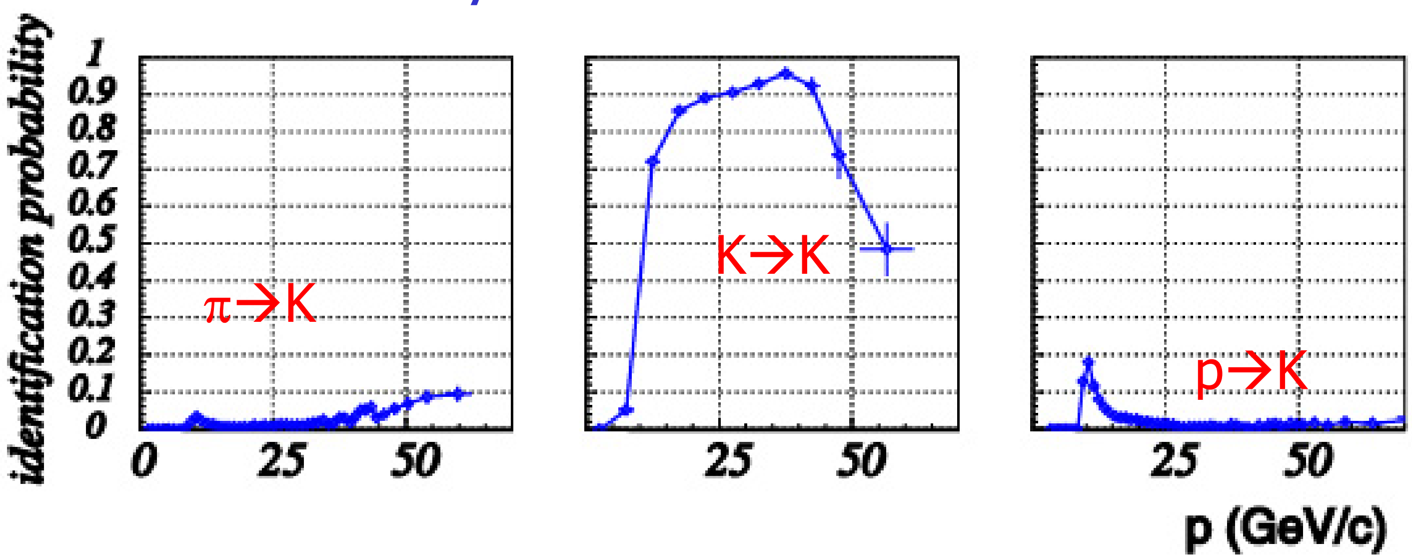
← Little noise, ~30 photons per ring

Typical event →

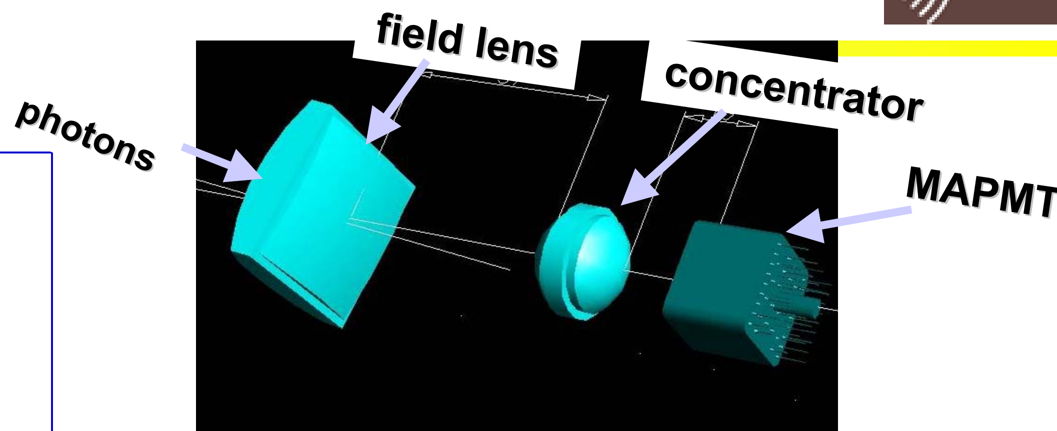


Worked very well!

Kaon efficiency and pion, proton fake probability



Fast photon detector for the COMPASS RICH-1



FAST RICH photon detection:

high beam intensity

high trigger rate

ns time resolution(detector read-out) for backgr. suppression

→ replace wire chambers with CsI photocathode with MAPMTs

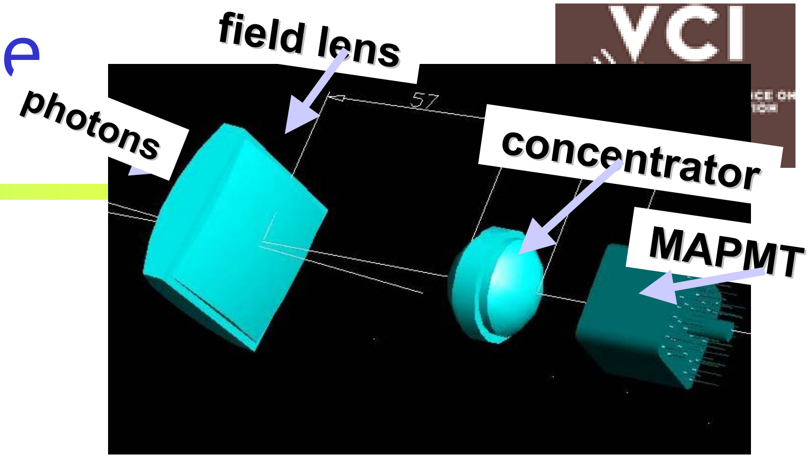
MAPMTs:

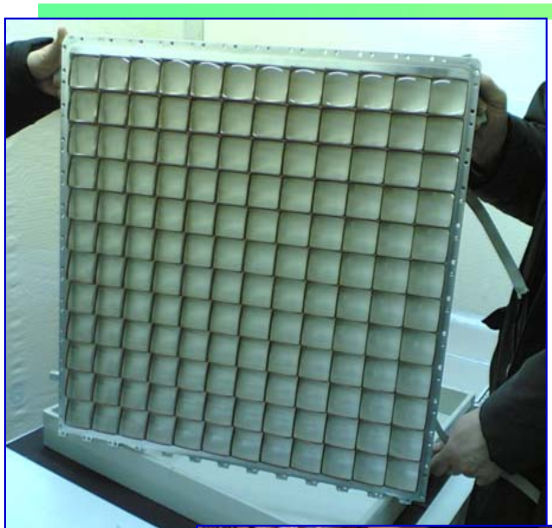
- used in HERA-B RICH

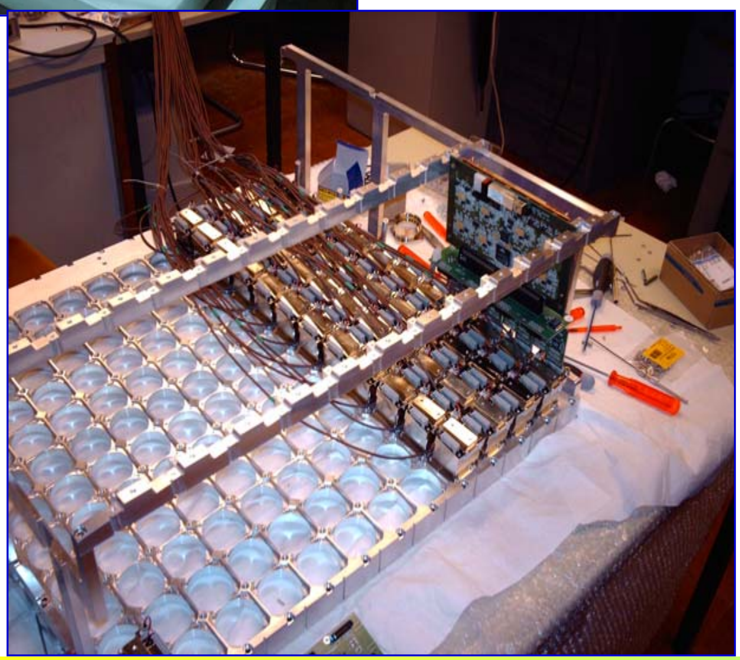
NEW FEATURES OF COMPASS RICH

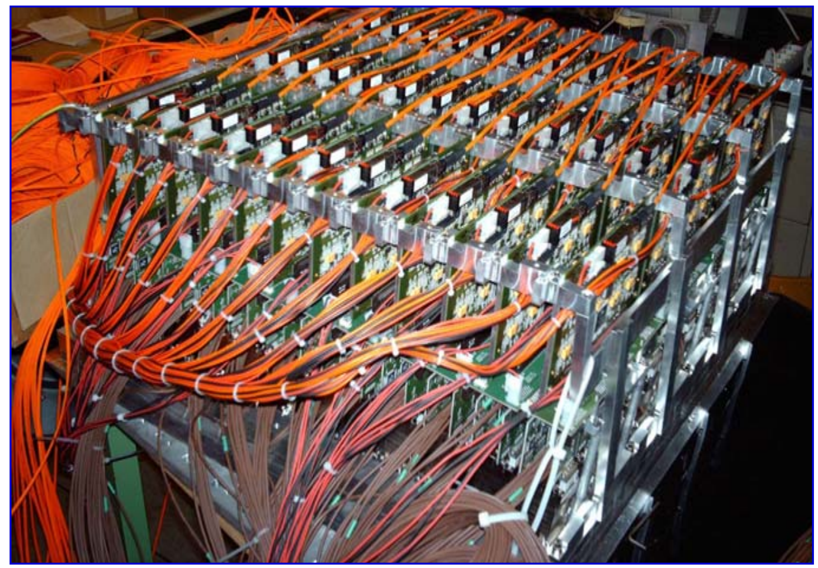
- PMTs & lenses, UV extended (down to 200 nm)
- surface ratio = (telescope entrance surface) / (photocathode surface) = 7
- fast electronics with <120 ps time resolution

Fast photon detector for the COMPASS RICH-1









→ Talk by F. Tessaroto

Fast photon detector for the COMPASS RICH-1

Preliminary results:

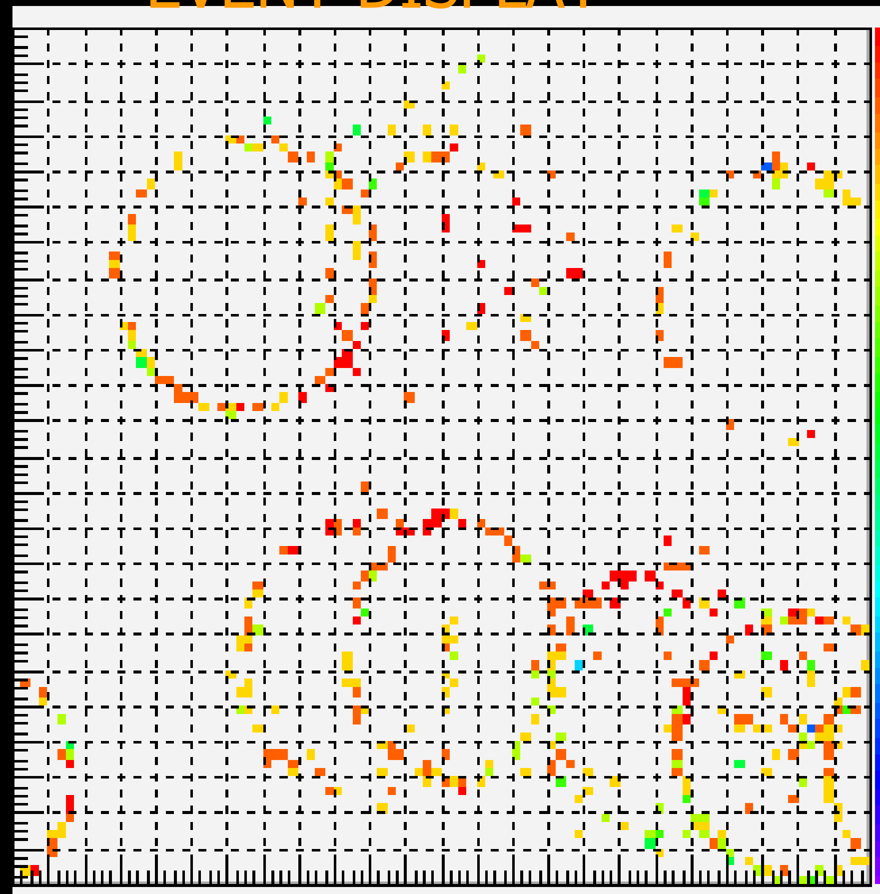
~ 60 detected photons per ring at saturation (β = 1) → N_0 ~66 cm^{-1}

σ_θ ~ 0.3 mrad → 2 σ π-K separation at ~ 60 GeV/c

K-ID efficiency ($K^\pm$ from Φ decay) > 90%

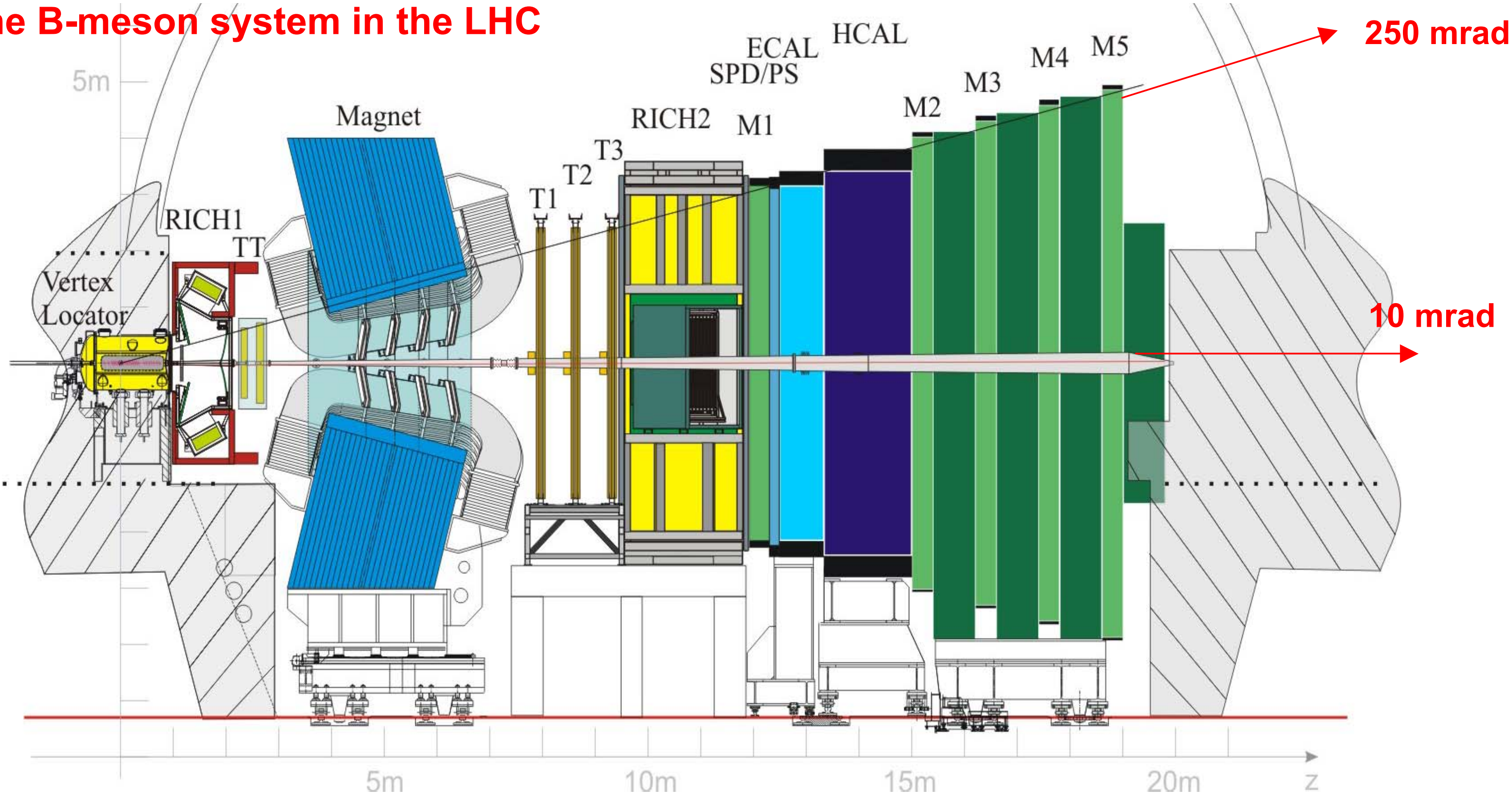
π → K misidentification ($\pi^\pm$ from K_s decay) ~ 1 %

IMAGE FROM THE ON-LINE EVENT DISPLAY



The LHCb detector

Single arm spectrometer for precise CP Violation measurements and rare decays in the B-meson system in the LHC



Vertex reconstruction:
VELO

Trigger:
Muon Chambers
Calorimeters
Tracker

PID:
RICHes
Calorimeters
Muon Chambers

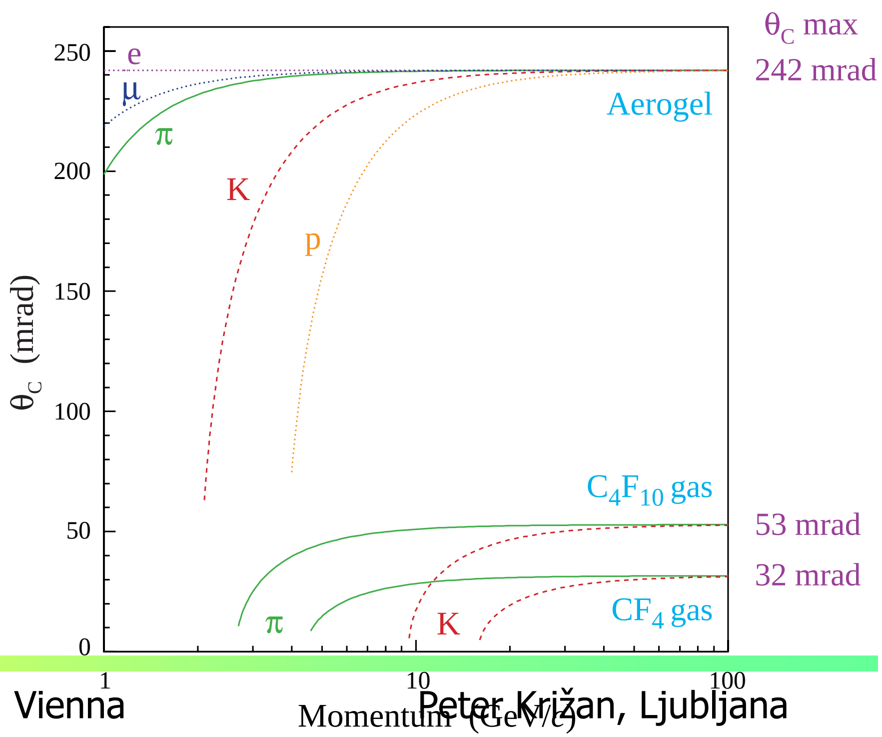
Kinematics:
Magnet
Tracker
Calorimeters

LHCb RICHes

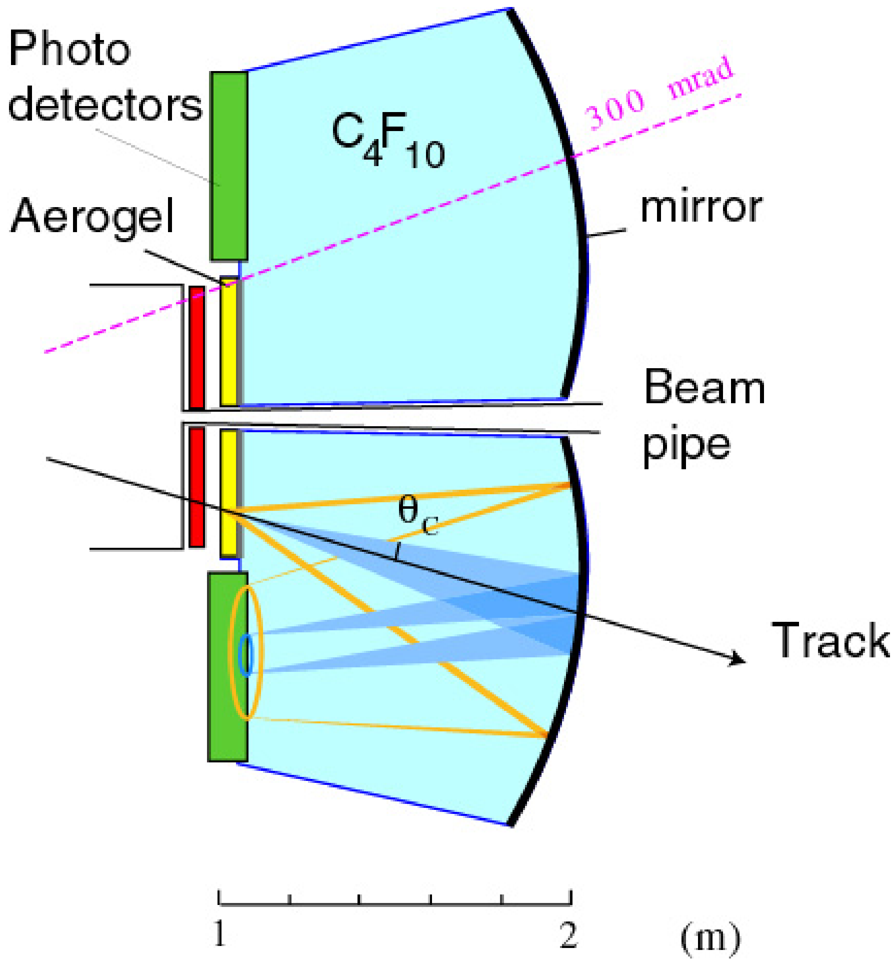
Need:

- Particle identification for momentum range ~2-100 GeV/c
- Granularity 2.5x2.5mm^2
- Large area (2.8m^2) with high active area fraction
- Fast compared to the 25ns bunch crossing time
- Have to operate in a small magnetic field

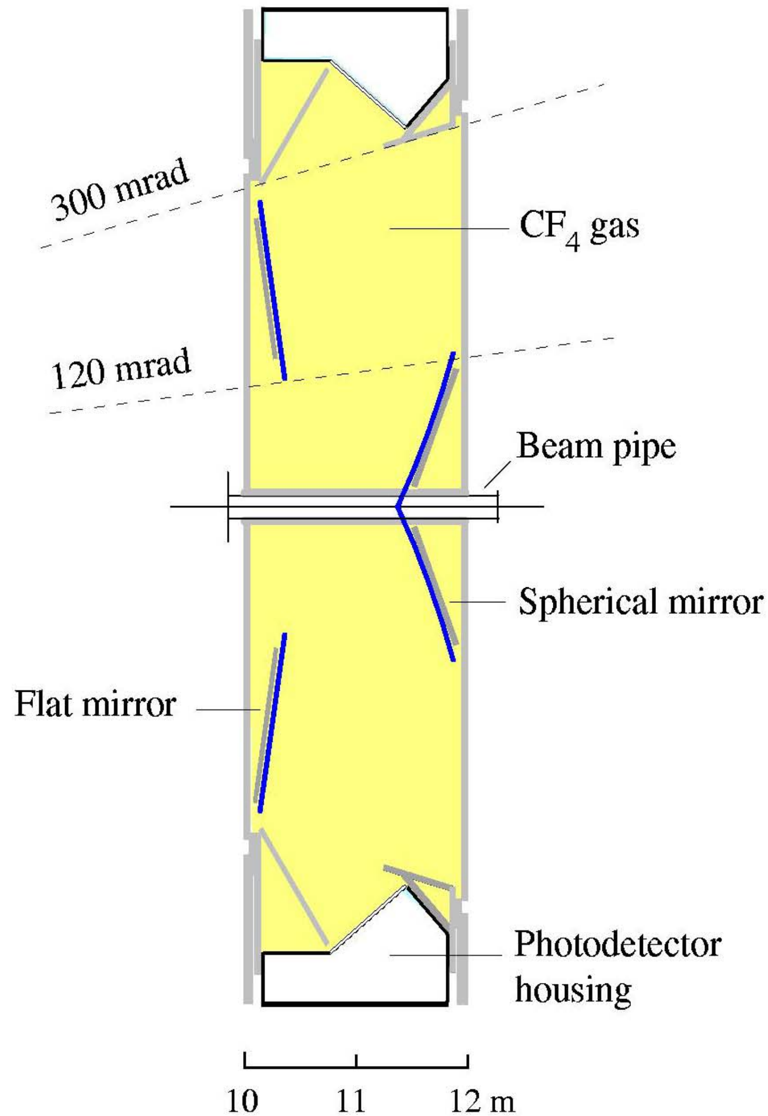
→3 radiators
(aerogel, CF_4, C_4F_{10})



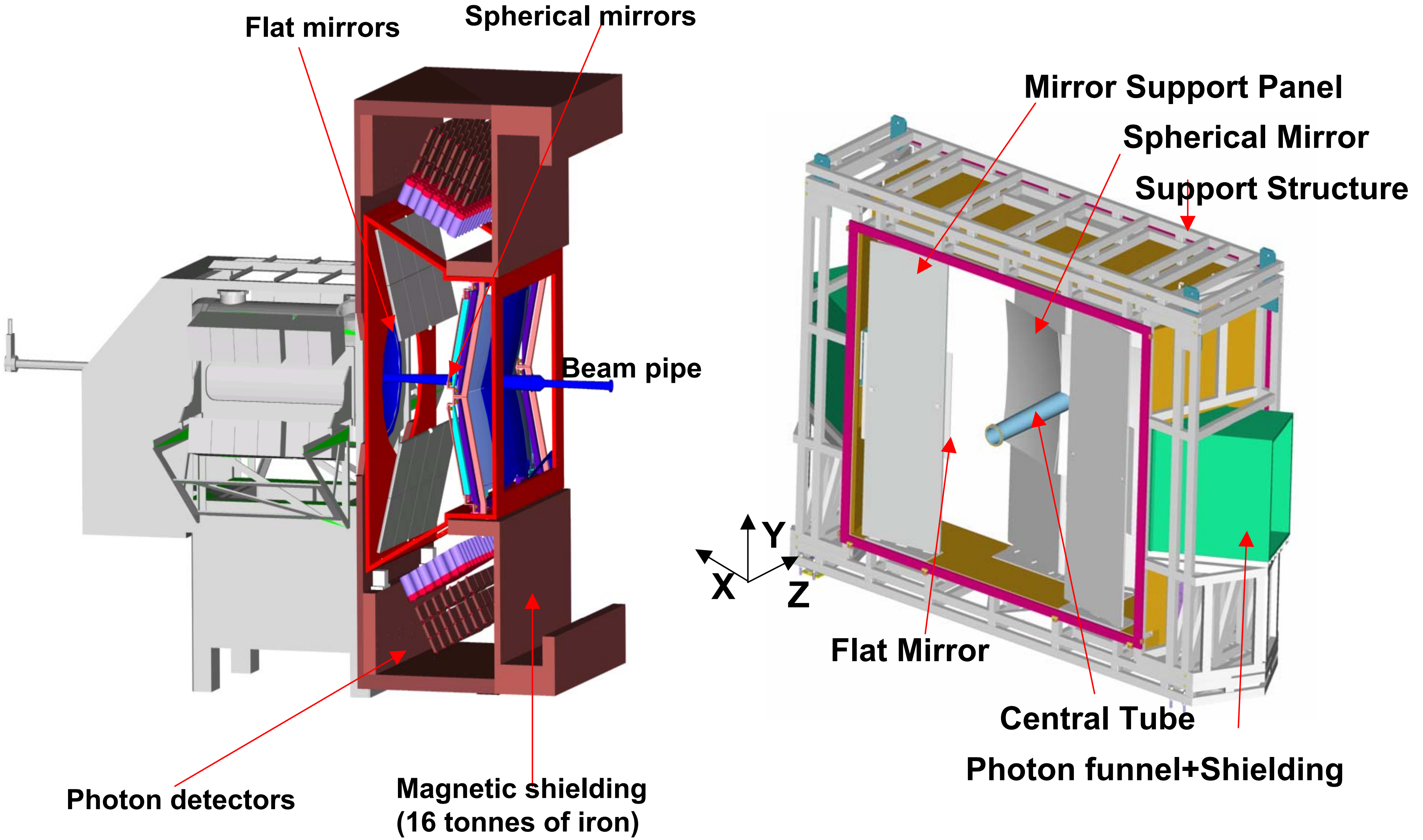
LHCb RICHes



RICH 1 + 2



LHCb RICHes

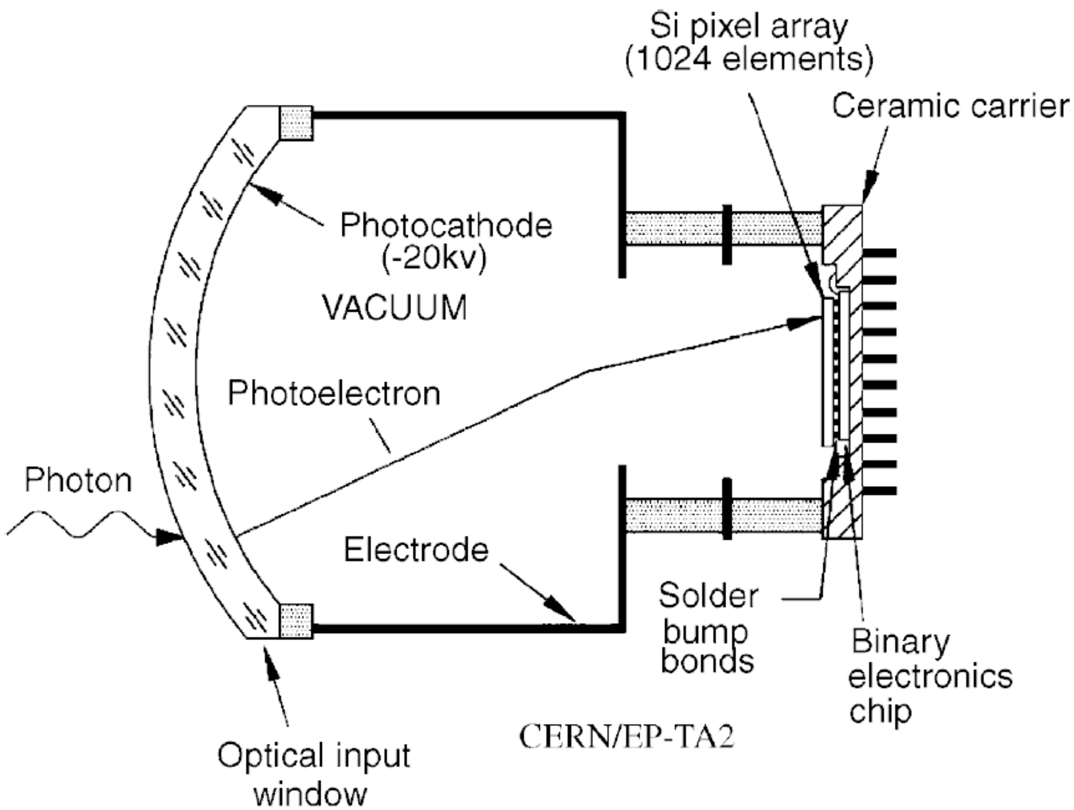

Flat mirrors
Spherical mirrors
Beam pipe
Photon detectors
Magnetic shielding
(16 tonnes of iron)
Mirror Support Panel
Spherical Mirror
Support Structure
Y
X
Z
Flat Mirror
Central Tube
Photon funnel+Shielding

LHCb RICHes

R+D: study two types of hybrid photon detectors and MAPMT with a lens

Final choice: hybrid PMT (R+D with DEP) with 5x demagnification (electrostatic focusing).

Hybrid PMT: accelerate photoelectrons in electric field (~10kV), detect it in a pixelated silicon detector.



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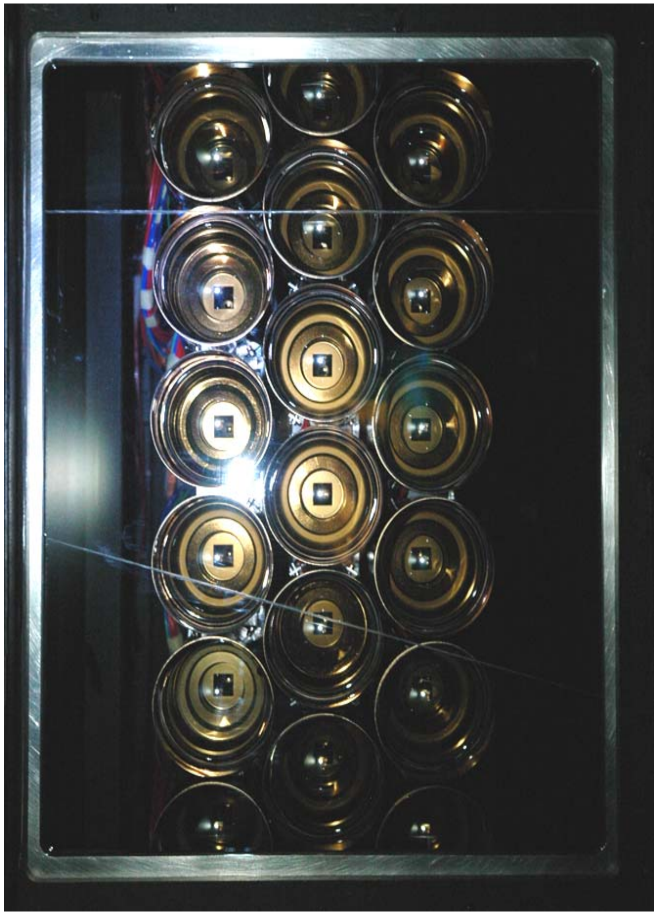
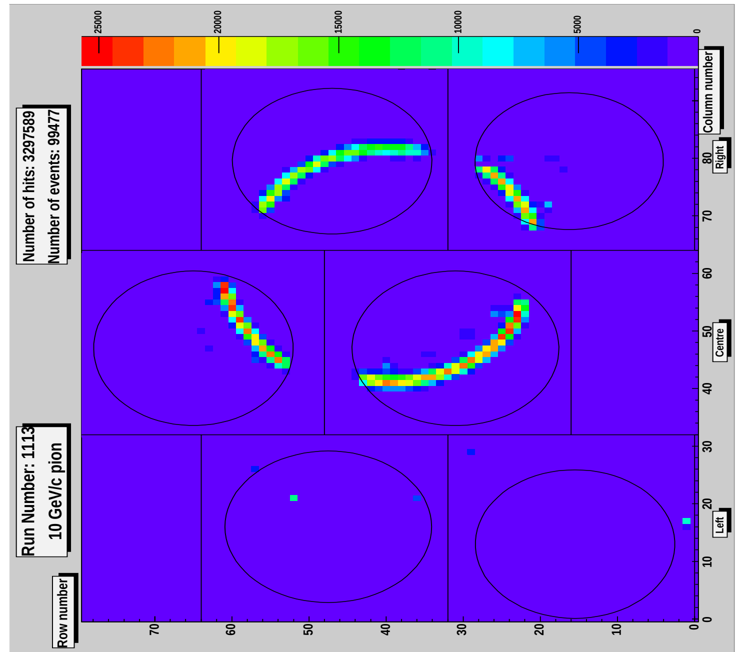
LHCb RICH System test

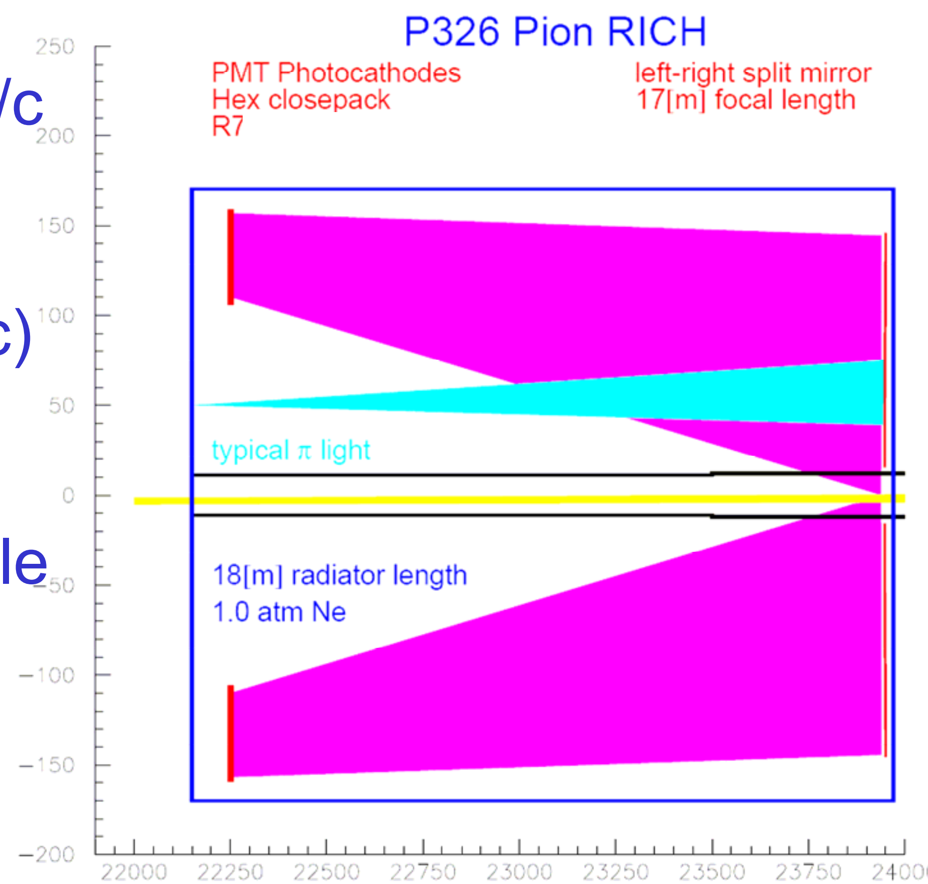




→ Talk by G. Vidal-Sitjes

In preparation: RICH for P236 ($K^+\rightarrow\pi^+\nu\nu$)

π–μ 3σ separation up to 35 GeV/c

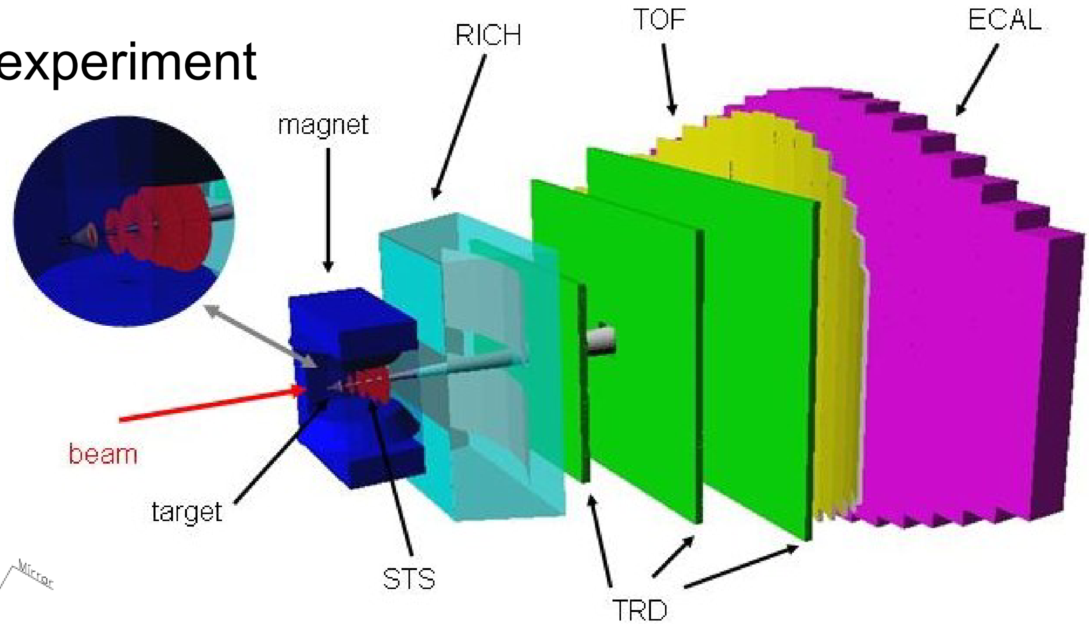


- 18 m long
- Neon at 1 atm (π thr.: 12 GeV/c)
- 2000 PMT
- 18 mm granularity
- 100 ps resolution (to disentangle pileup in the tracker)

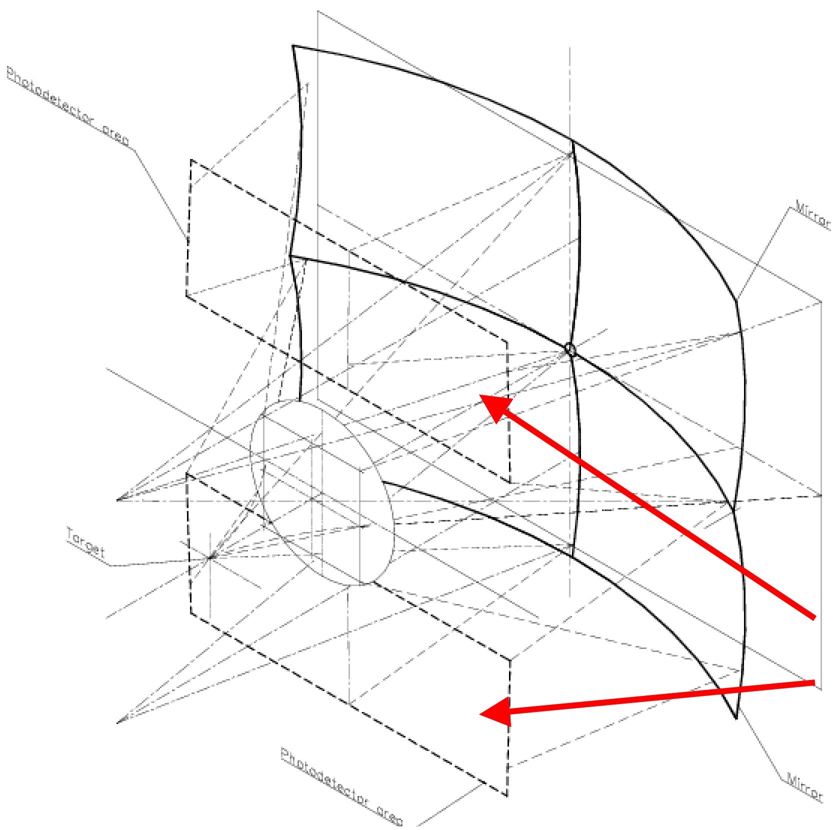
Photon detector: Hamamatsu

Design phase: RICH for CBM at FAIR (GSI)

Compressed Baryonic Matter experiment



RICH: electron ID (= strong π suppression) and hadron ID



• 2.2m long radiator gas (γ_{th} > 40) vessel with beam pipe in the center

•photo-detector: 2 PMT planes shielded by magnet yoke 10MHz rates

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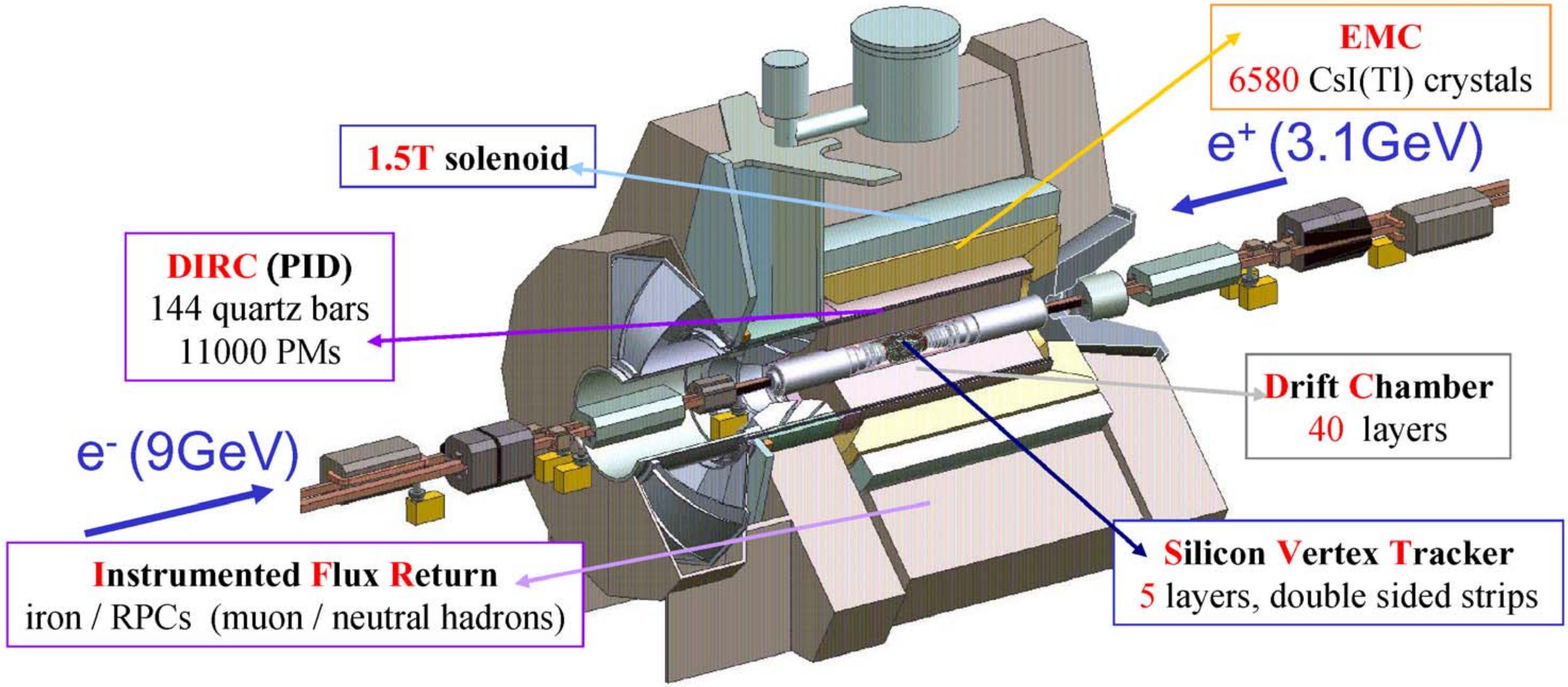
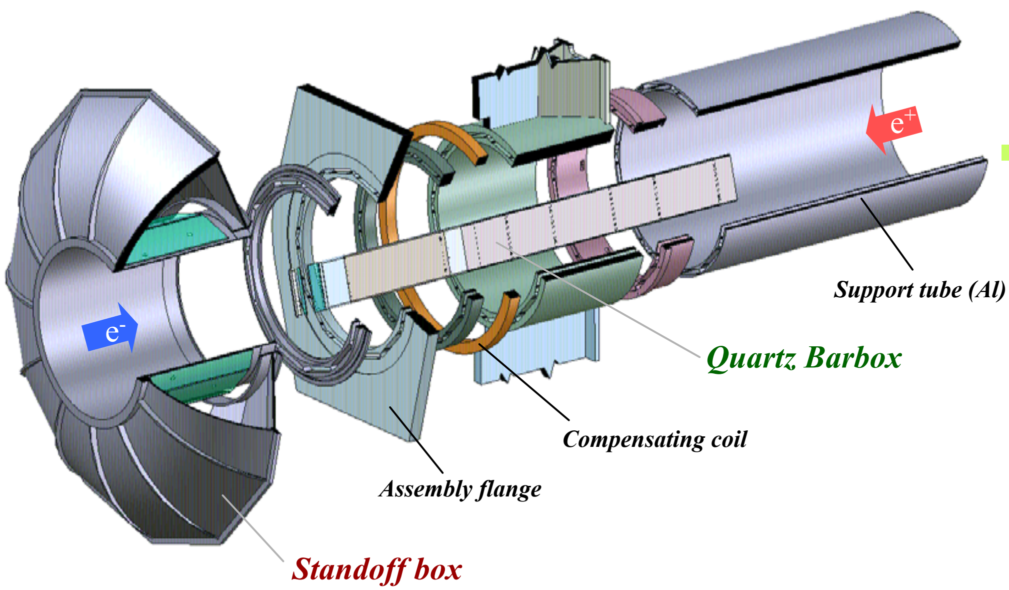
Looks very much like the HERA-B or LHCb RICHes

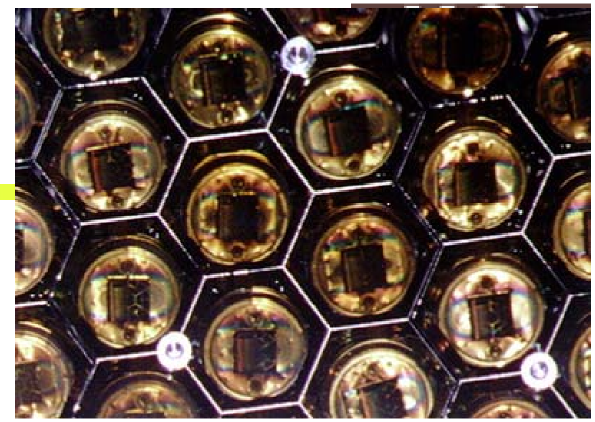
BaBar spectrometer at PEP-II

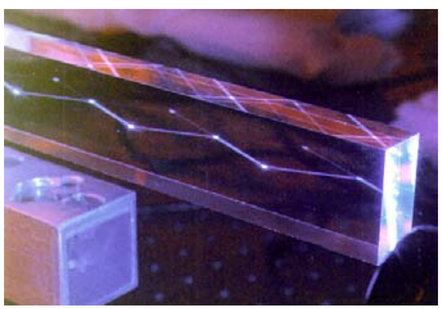


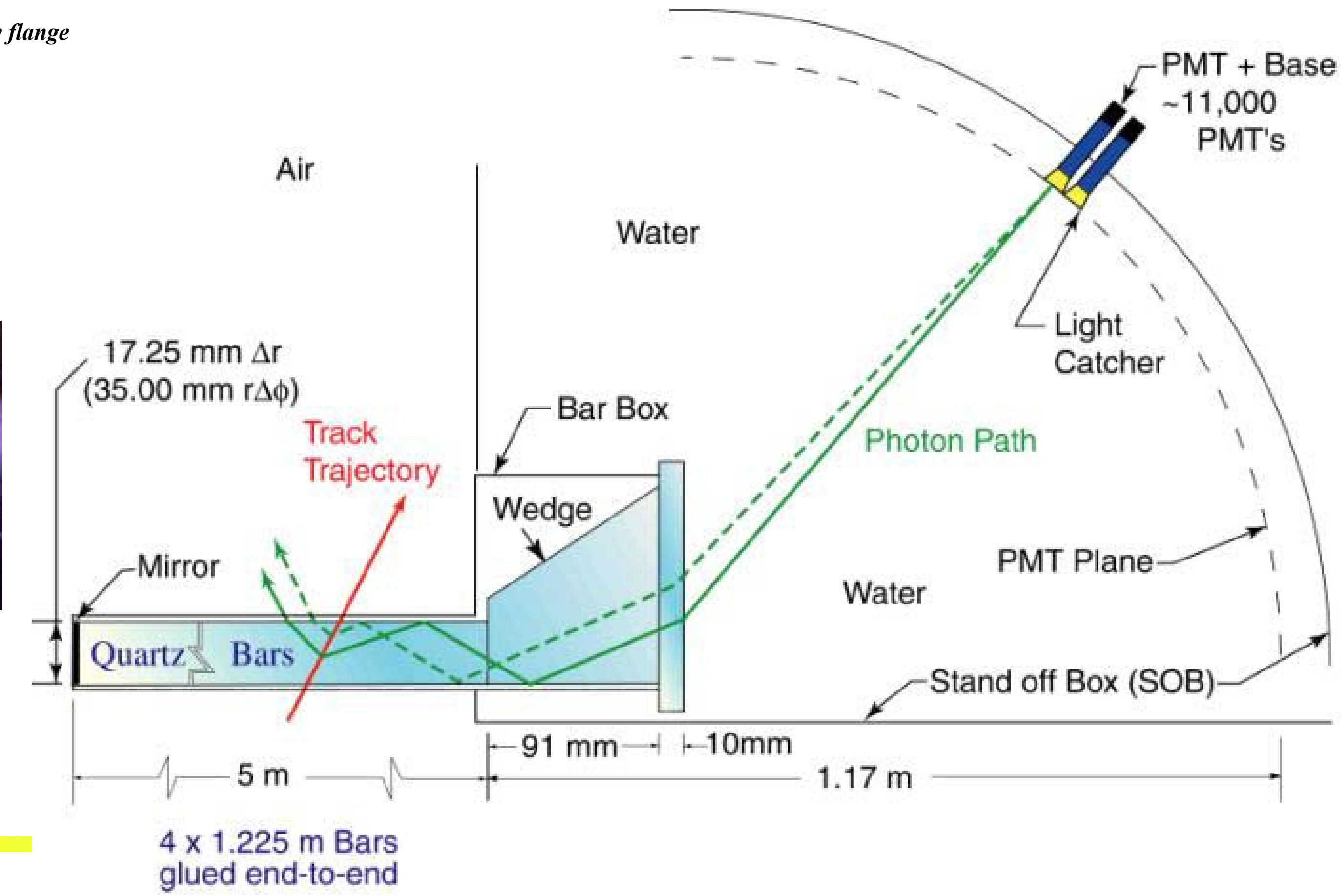
DIRC - detector of internally reflected Cherenkov light

DIRC

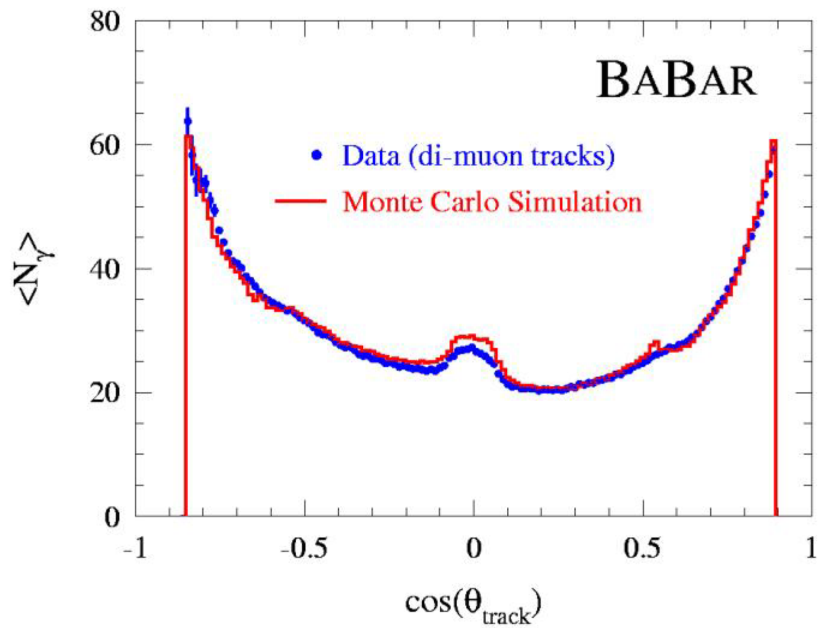

e+
e-
Support tube (Al)
Quartz Barbox
Compensating coil
Assembly flange
Standoff box





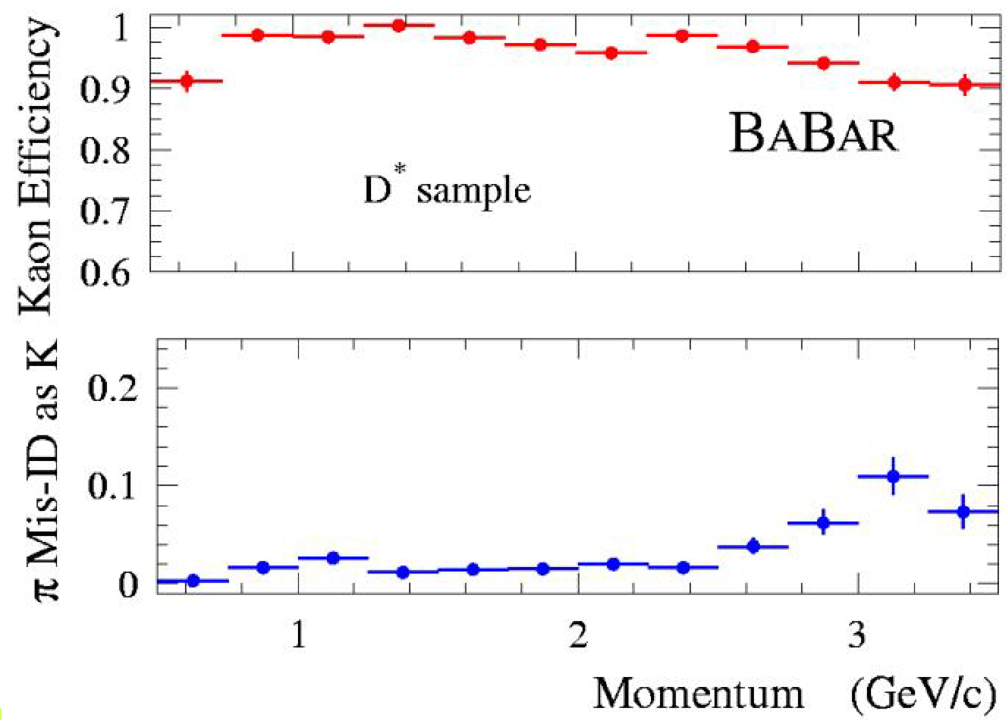

PMT + Base
~11,000
PMT's
Air
Water
Light
Catcher
17.25 mm Δr
(35.00 mm rΔϕ)
Track
Trajectory
Bar Box
Photon Path
Wedge
PMT Plane
Mirror
Water
Quartz
Bars
Stand off Box (SOB)
91 mm
10mm
5 m
1.17 m
4 x 1.225 m Bars
glued end-to-end

DIRC performance



← Lots of photons!

Excellent π/K separation



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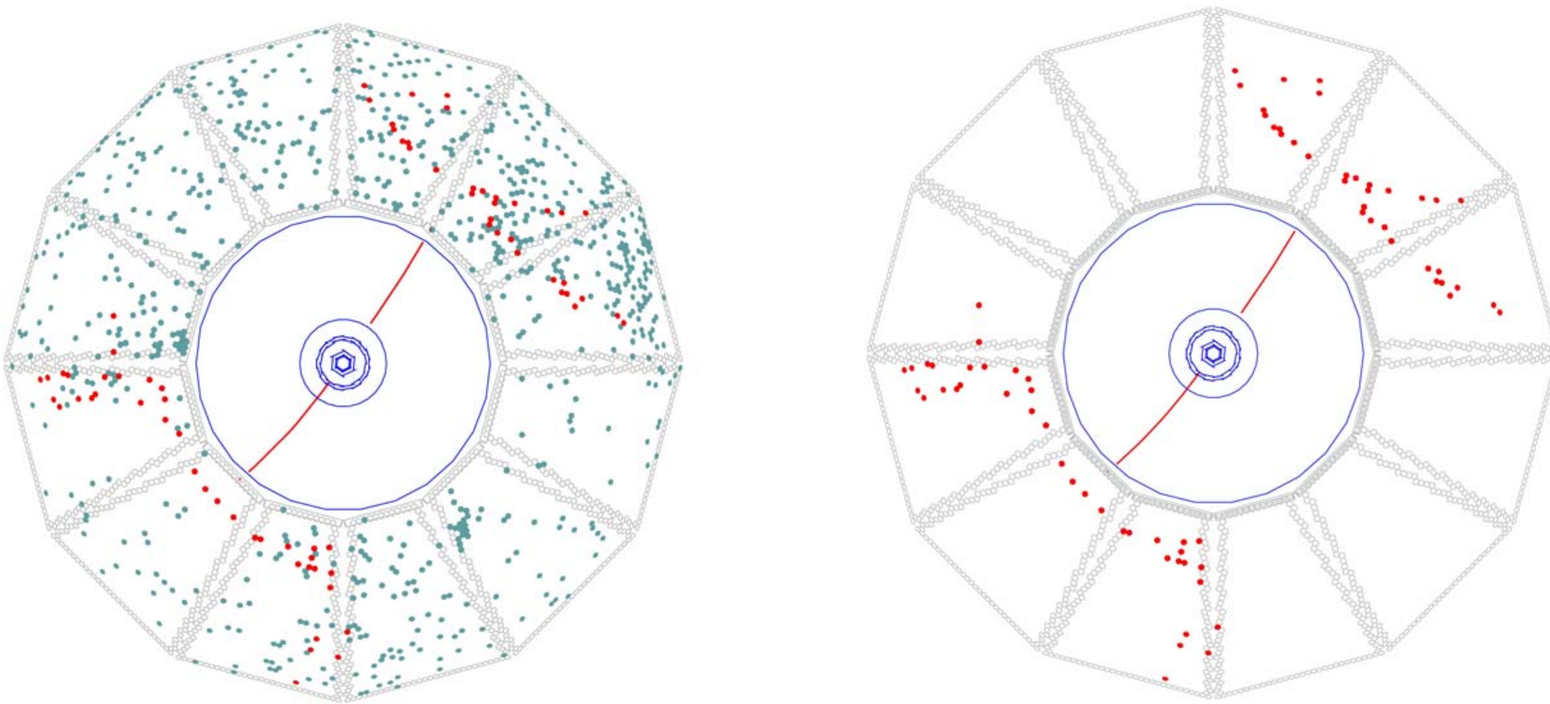
DIRC

BaBar DIRC: a Bhabha event $e^+ e^- \rightarrow e^+ e^-$



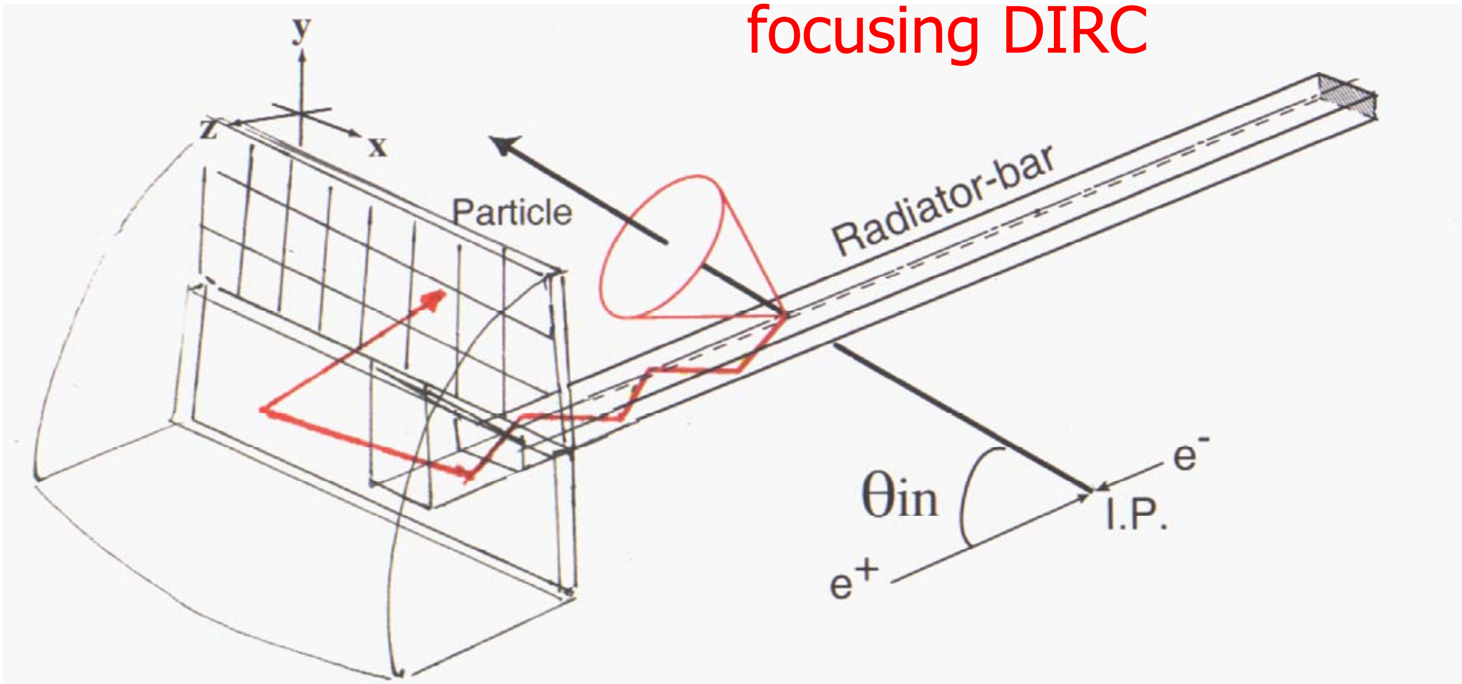
No time cut on the hits

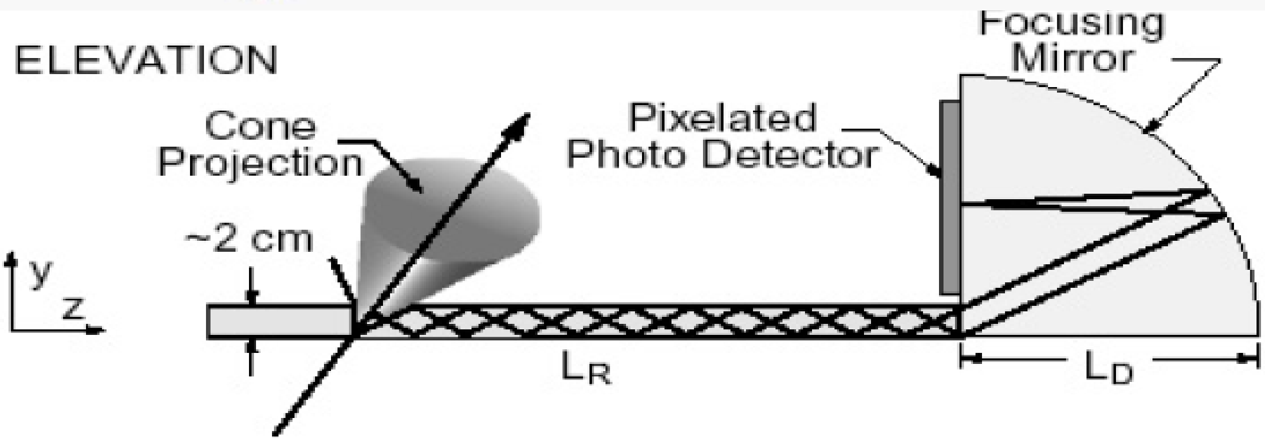
With a +-4ns time cut

Timing information is essential for background reduction

Focusing DIRC

Upgrade: step further, remove the stand-off box → focusing DIRC





Focusing DIRC

Super-B factory: 100x higher luminosity => DIRC needs to be smaller and faster

Focusing and smaller pixels can reduce the expansion volume by a factor of 7-10 !

Timing resolution improvement: σ ~1.7ns (BaBar DIRC)
→ $\sigma \leq$150-200ps (~10x better) which allows a measurement of the photon color to correct the chromatic error of θ_c.

Photon detector requirements:

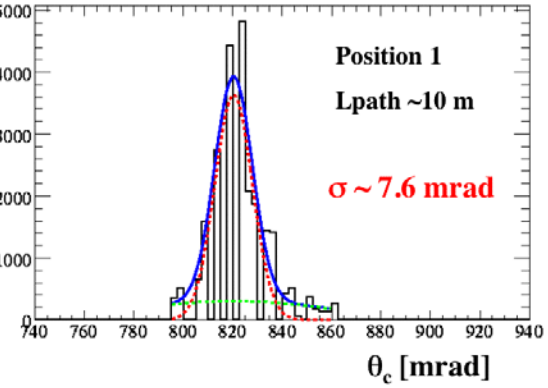
- Pad size <5mm
- Time resolution ~50-100ps

→ Talk by J. Va'vra

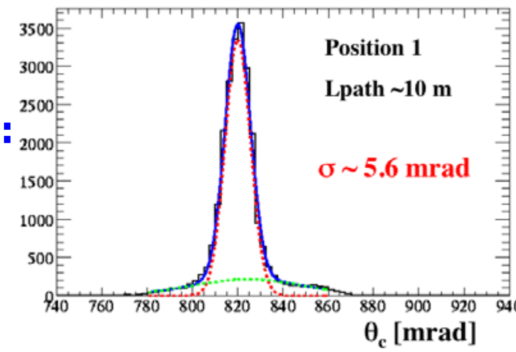
Focusing DIRC- the chromatic correction

θ_C resolution and chromatic correction for 3mm pixels:

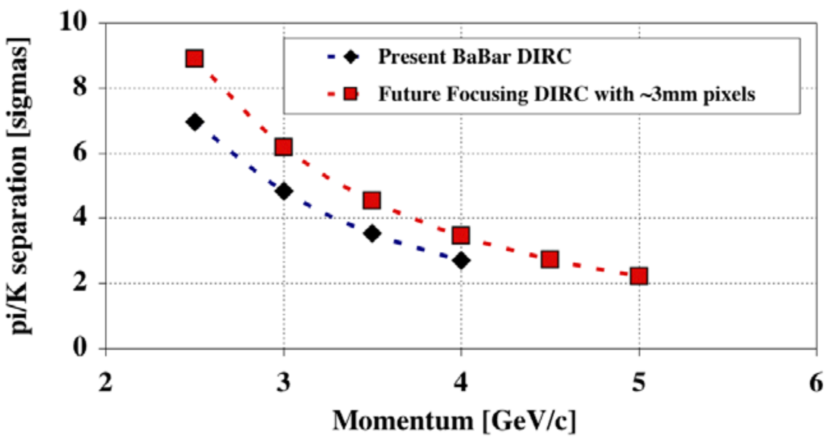
Correction off:

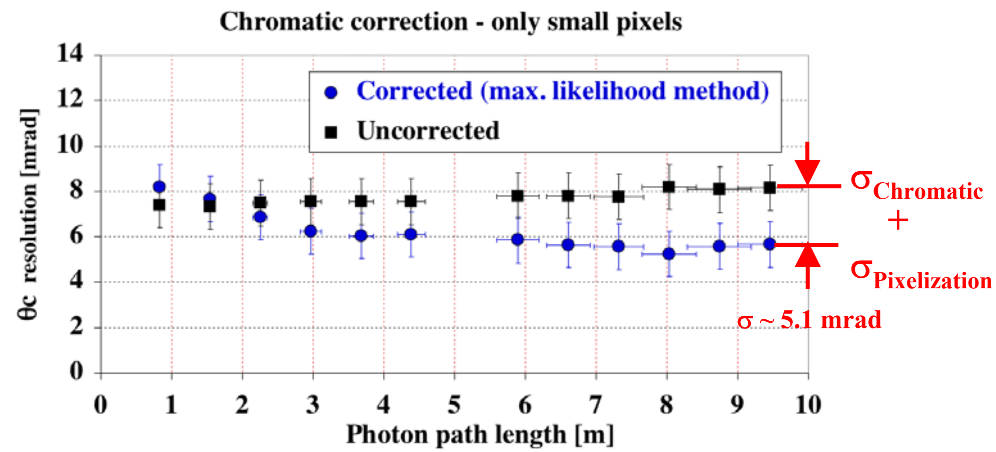


Correction on:



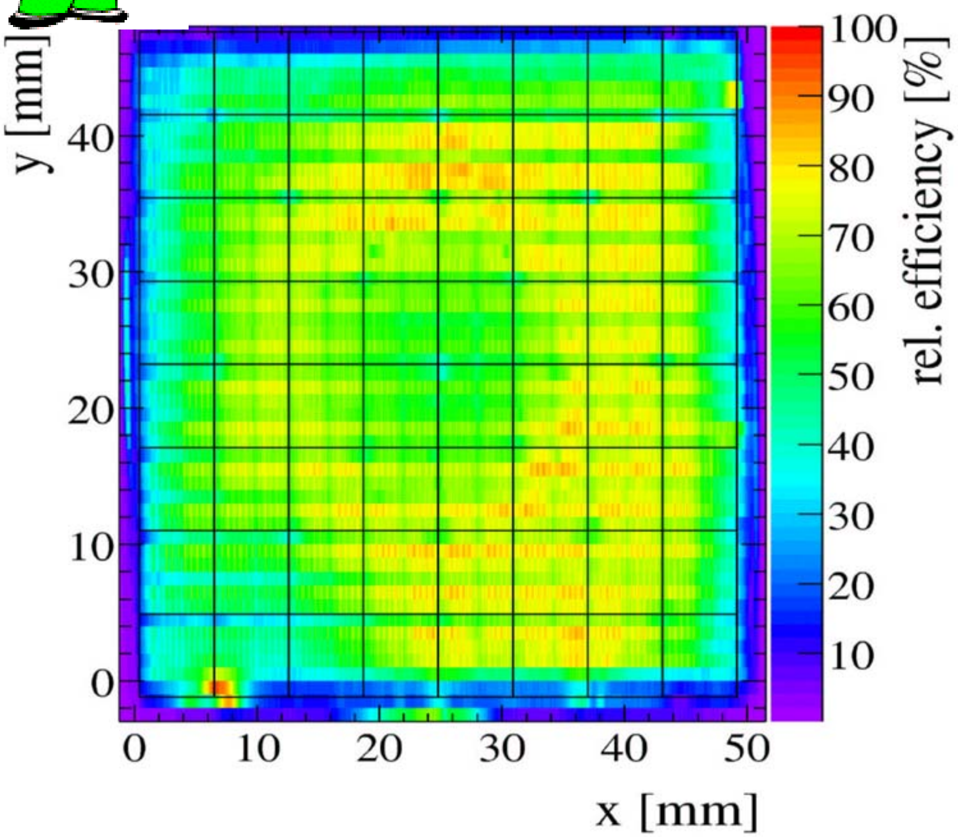
Expected performance:





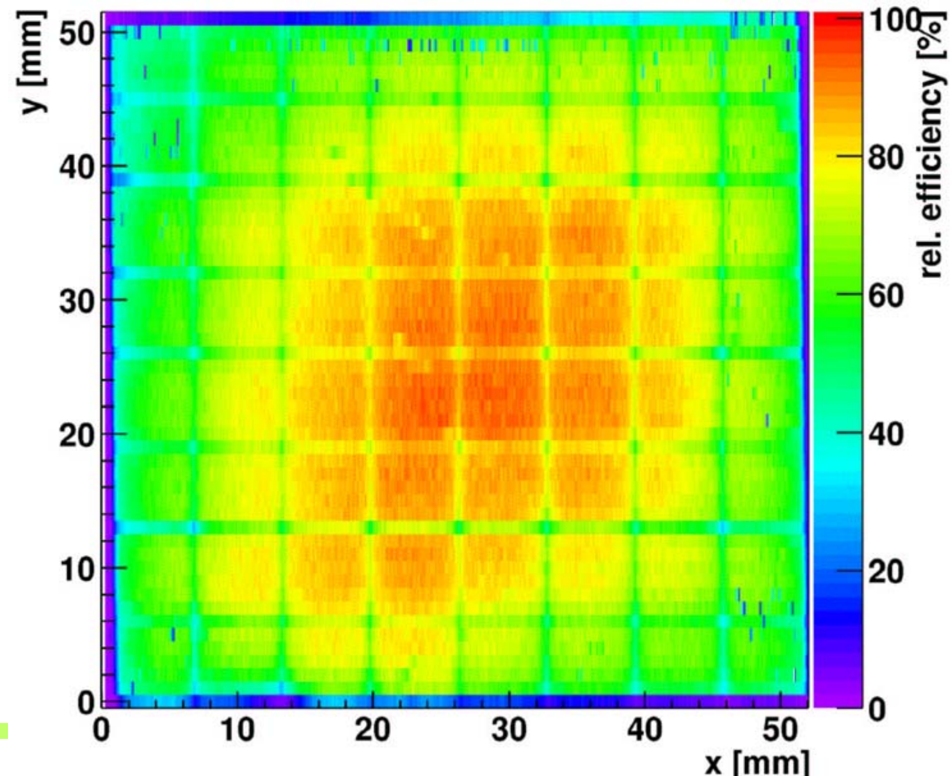
- Expected performance: $N_o = 31\ cm^{-1} \rightarrow N_{pe} \sim 28$ for 1.7 cm fused silica bar thickness
- 3mm pixel size is preferred choice.

Focusing DIRC photon detectors: relative efficiency

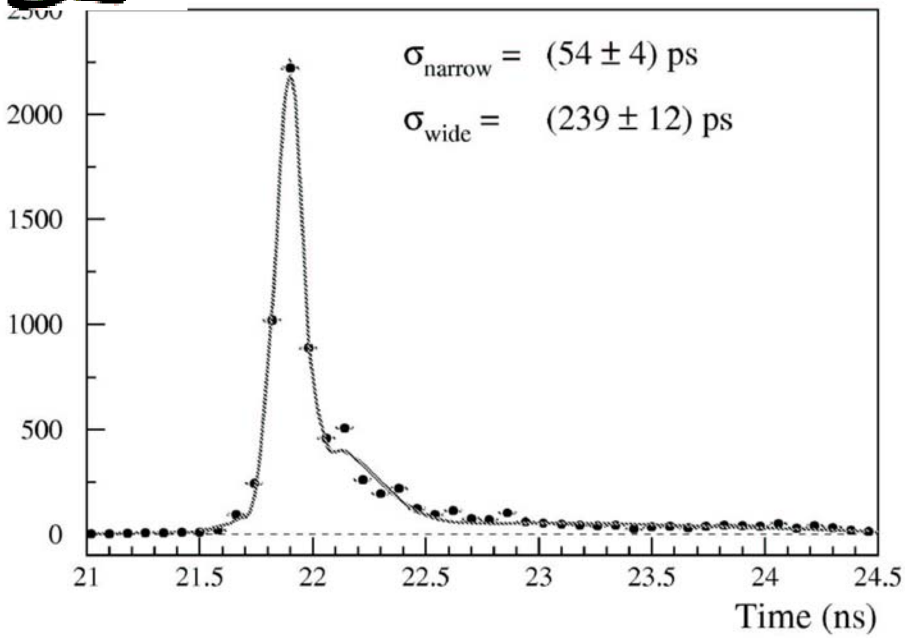


Burle 85011 MCP-PMT

Hamamatsu H8500 (flat pannel)

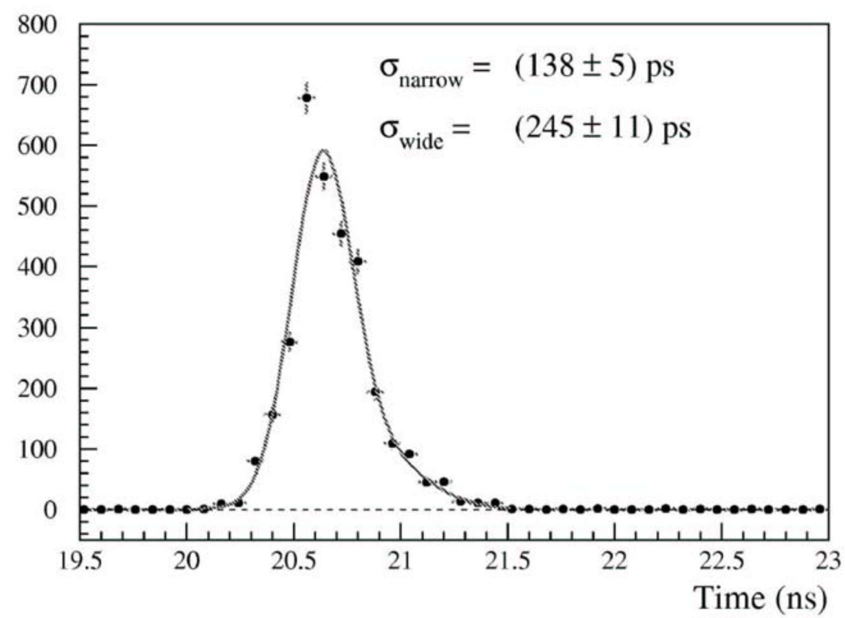


Focusing DIRC photon detectors: time resolution



Hamamatsu H8500 (flat pannel)

Burle 85011 MCP-PMT



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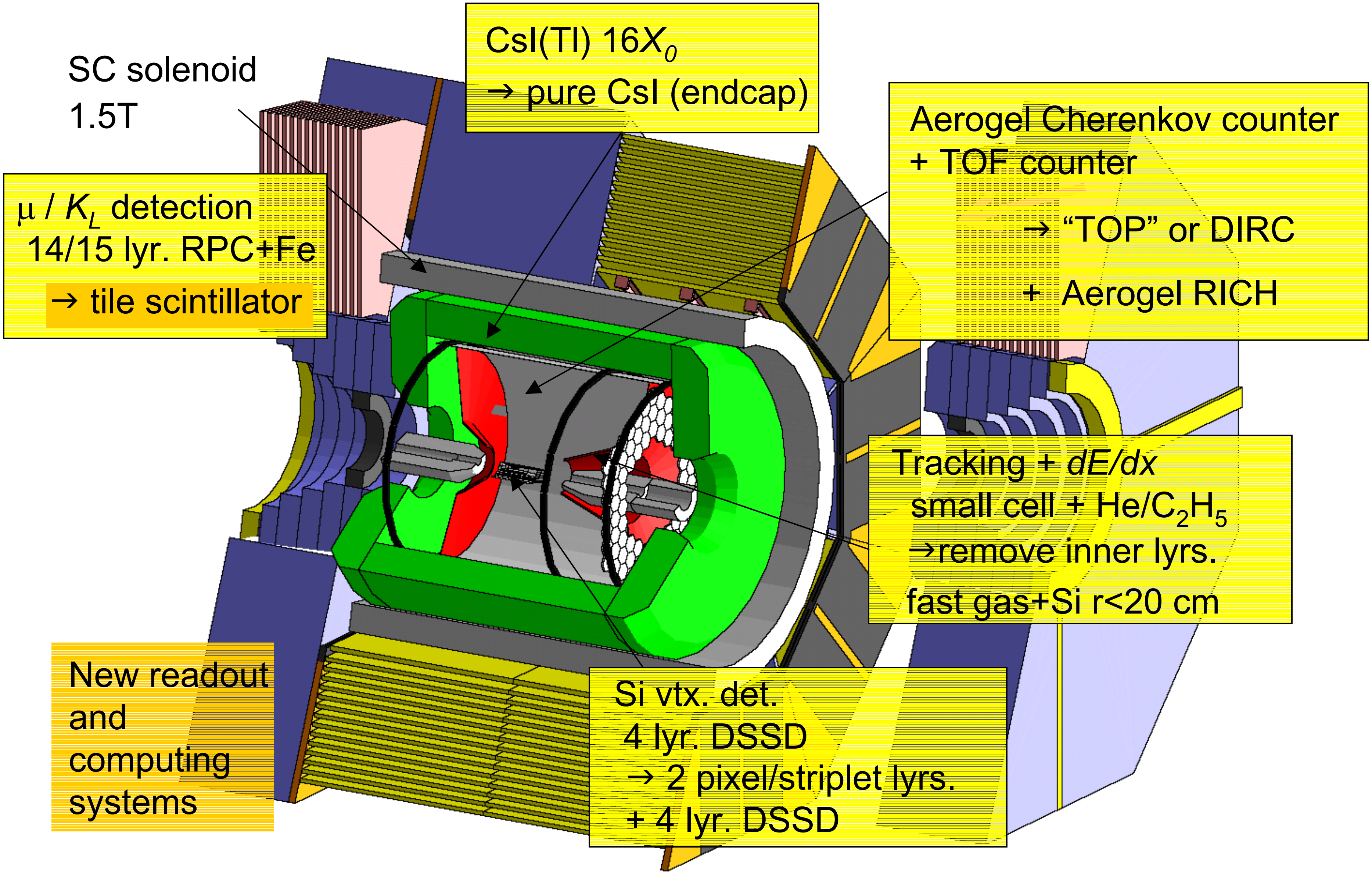
DIRC counters for PANDA (FAIR, GSI)

Two DIRC like counters are considered for the PANDA experiment:

- one very similar to the current DIRC in BaBar,
- the other of focusing type

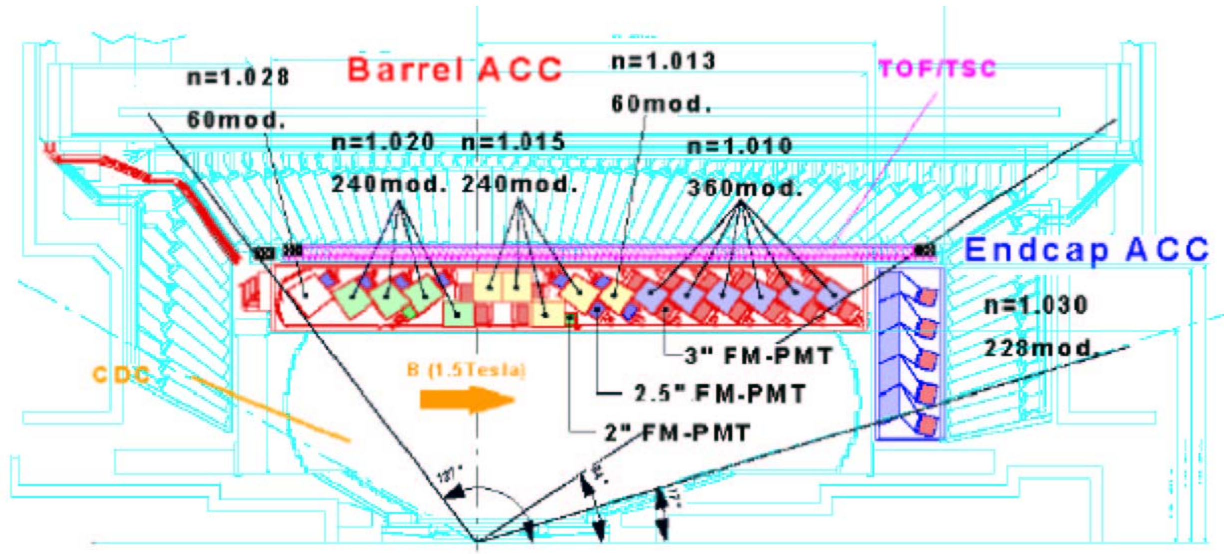
→Talk by L. Schmitt
→Poster B. Seitz B42

Belle Upgrade for Super-B

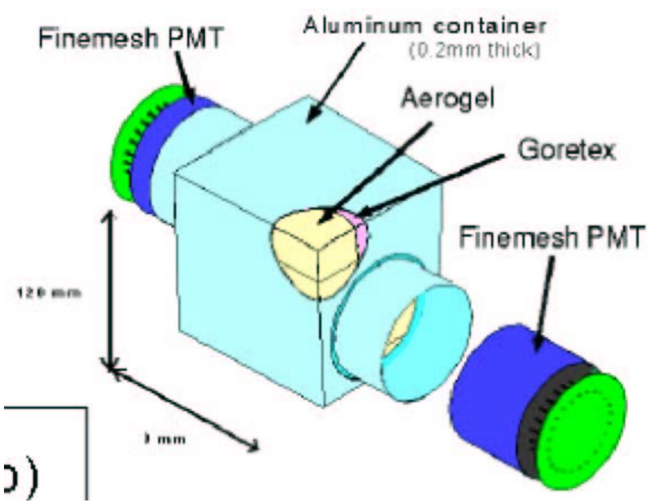


Present Belle: threshold Čerenkov counter ACC (aerogel Cherenkov counter)

K (below threshold) vs. π (above) by properly choosing n for a given kinematic region (more energetic particles fly in the 'forward region')



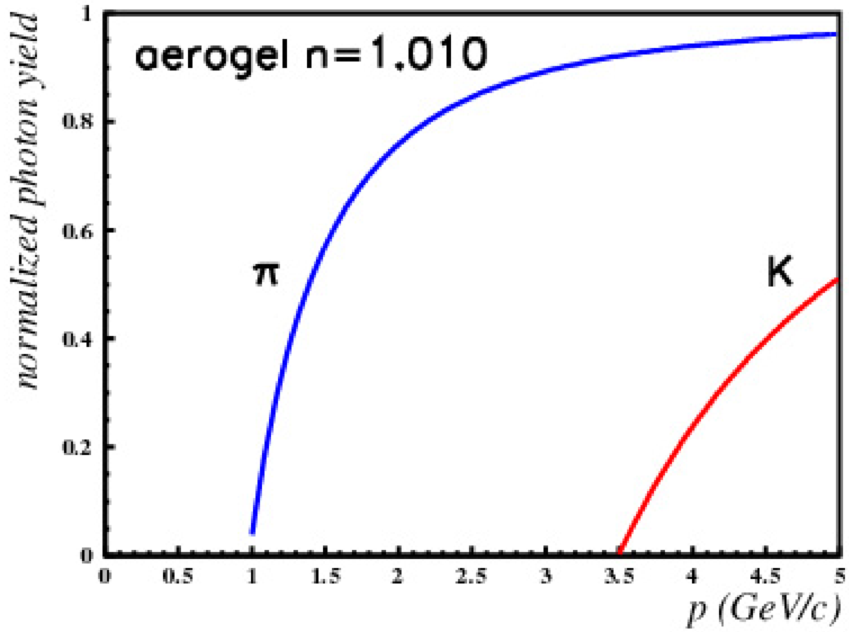
Detector unit: a block of aerogel and two fine-mesh PMTs



Fine-mesh PMT: works in high B fields

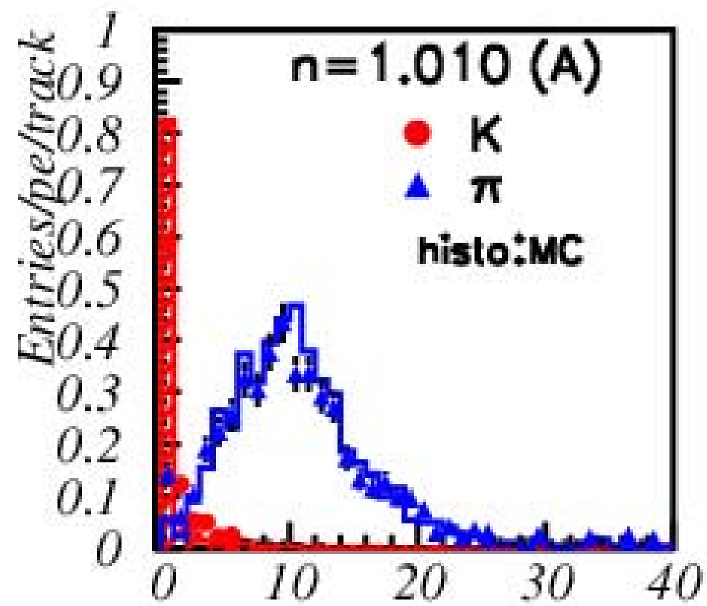
Belle ACC : threshold Čerenkov counter

expected yield vs p

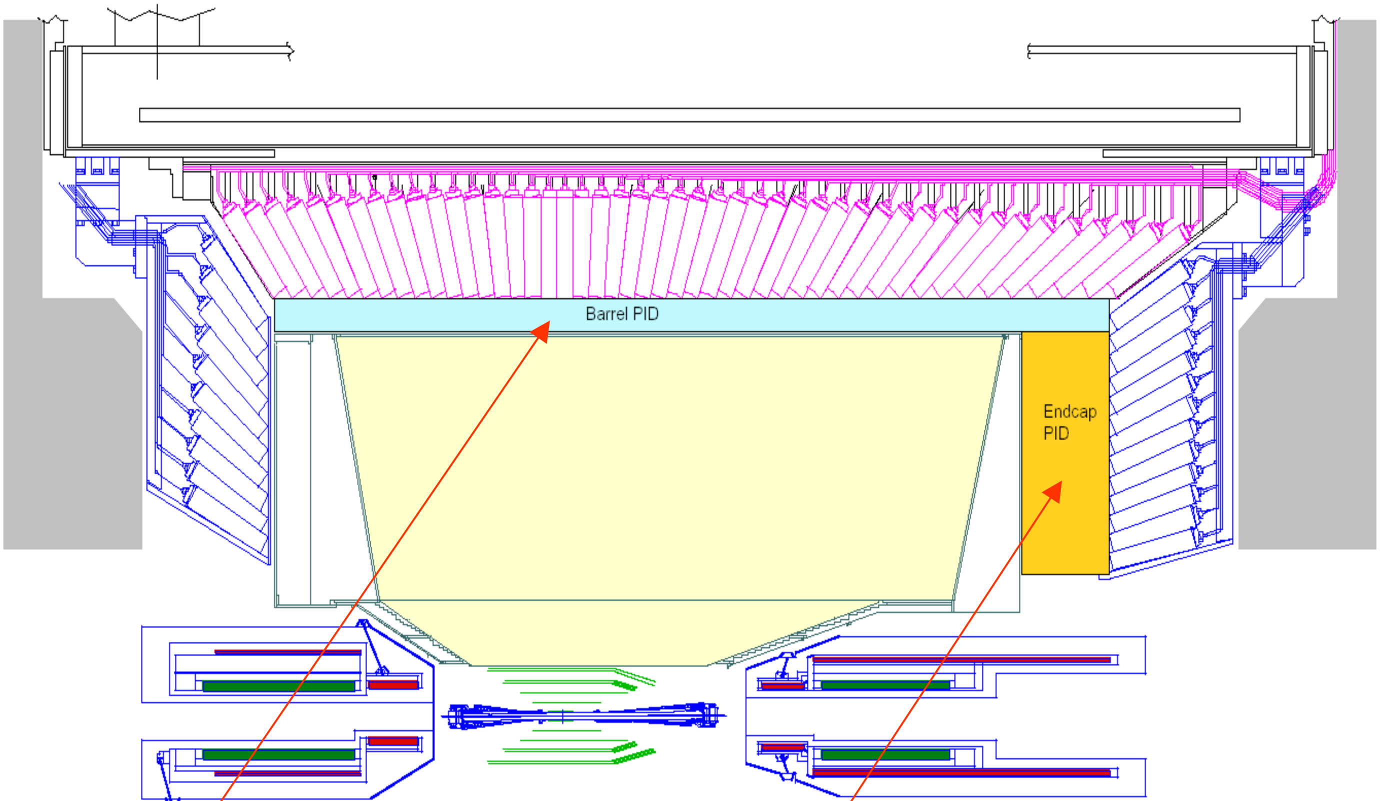


NIM A (200)

yield for 2GeV<p<3.5GeV:
expected and measured number of hits



Belle upgrade – side view

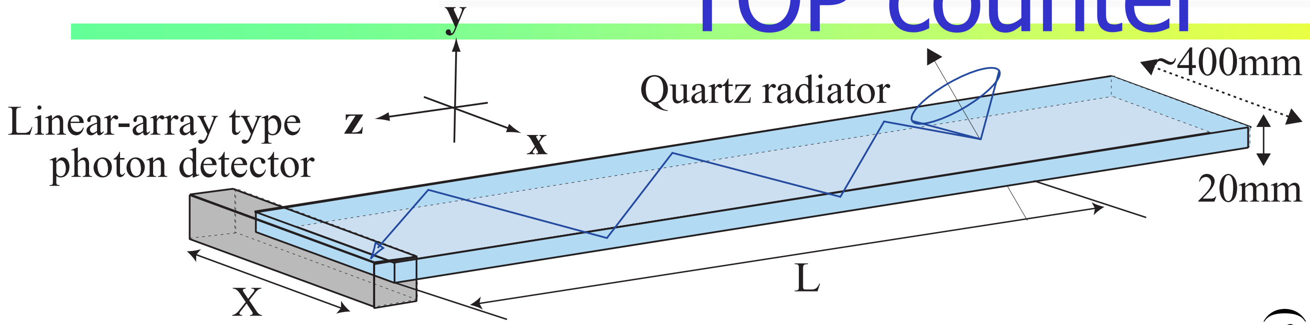


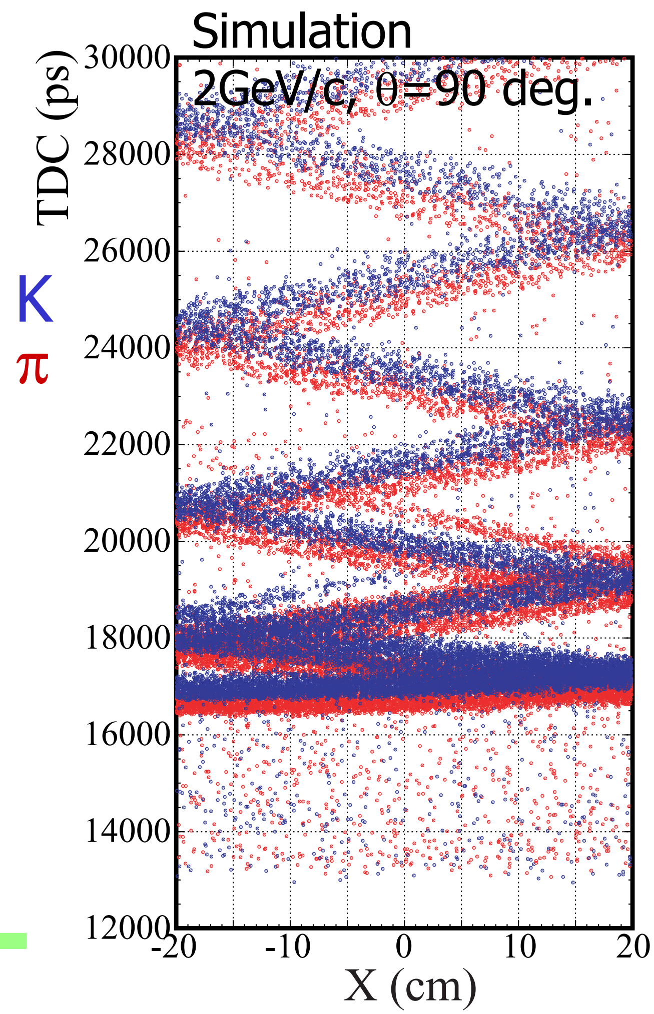
Two new particle ID devices, both RICHes:

Barrel: TOP or focusing DIRC

Endcap: proximity focusing RICH

Belle barrel upgrade: TOP counter





Time-of-Propagation counter:

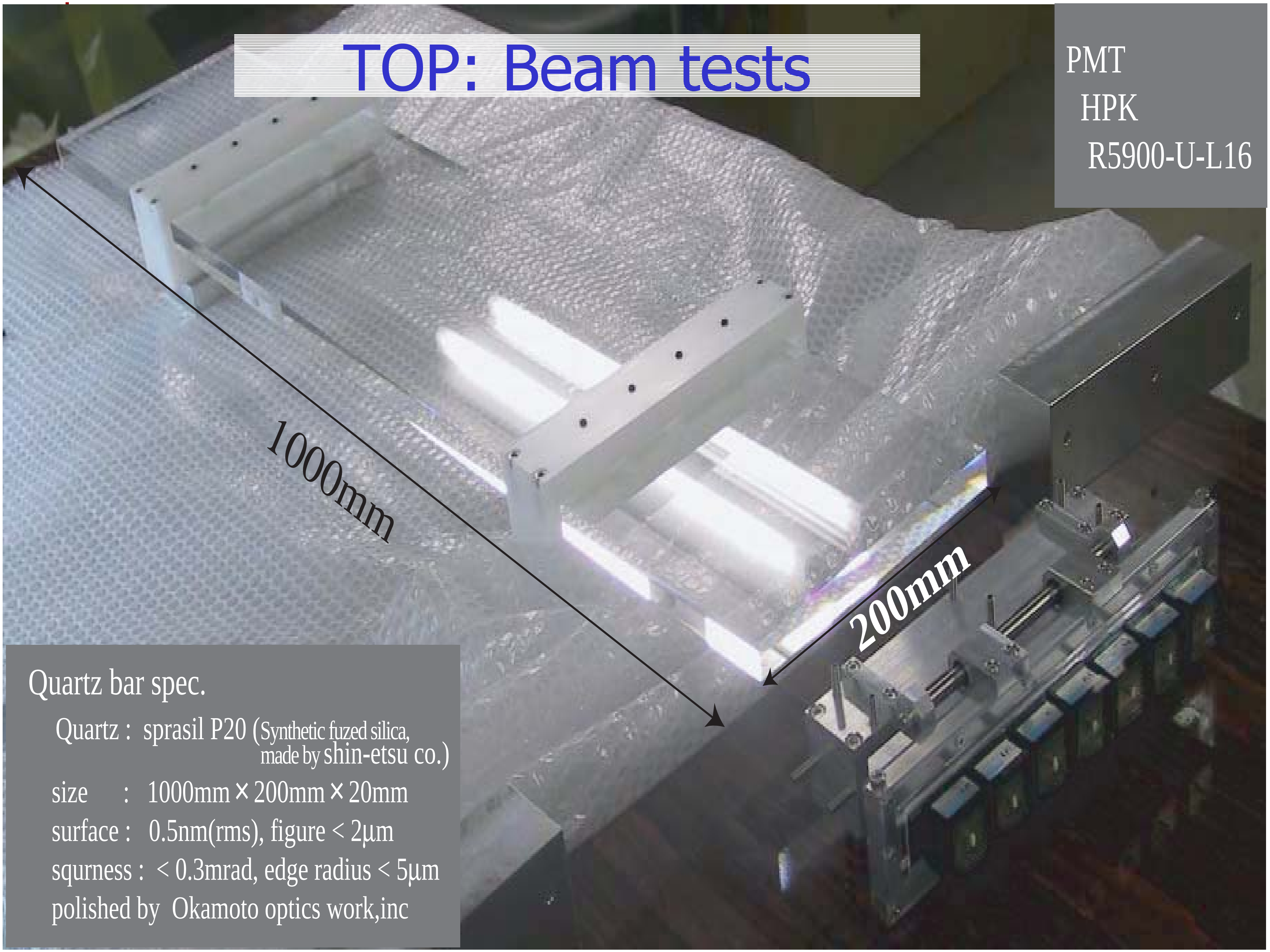
Measurement of

– One (or two coordinates) with a few mm precision

– Time-of-arrival

Excellent time resolution < ~40ps required for single photons at 1.5T

TOP: Beam tests



PMT
HPK
R5900-U-L16

Quartz bar spec.

Quartz : sprasil P20 (Synthetic fuzed silica, made by shin-etsu co.)

size : 1000mm × 200mm × 20mm

surface : 0.5nm(rms), figure < 2μm

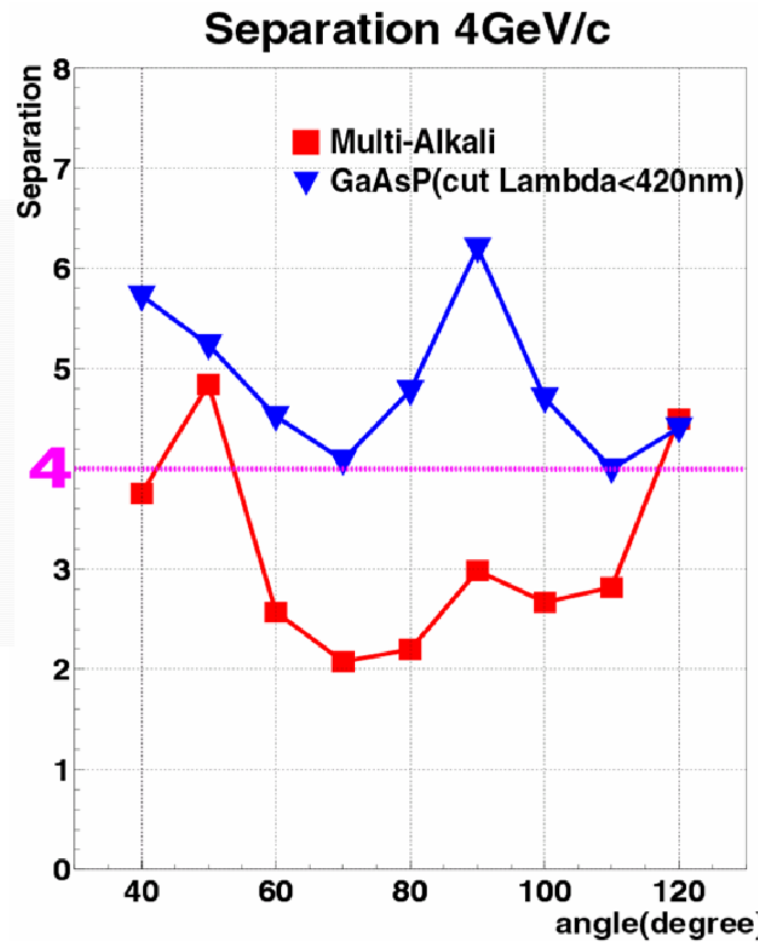
squrness : < 0.3mrad, edge radius < 5μm

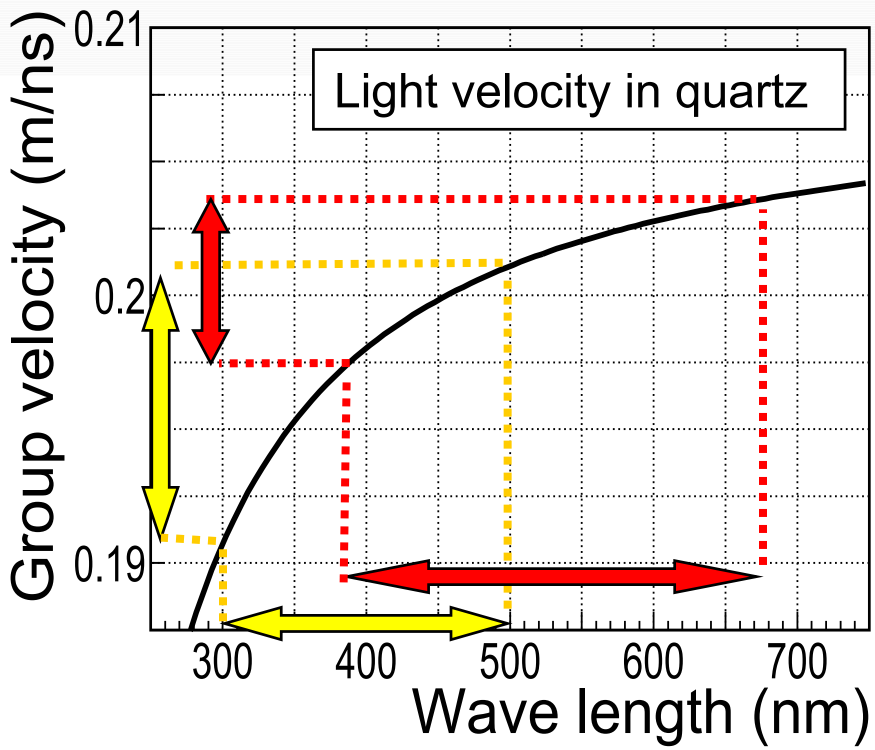
polished by Okamoto optics work,inc

TOP counter MC

Expected performance with:

bi-alkali photocathode: <4σ π/K separation at 4GeV/c (← chromatic dispersion)



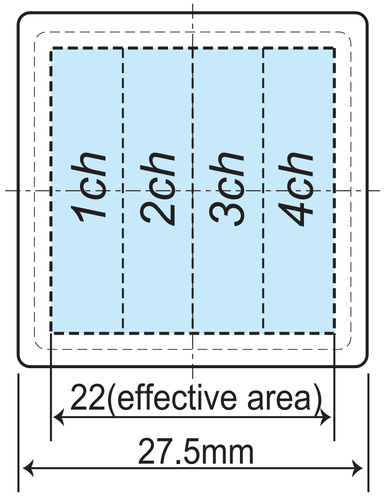


with GaAsP photocathode: >4σ π/K separation at 4GeV/c

GaAsP MCP-PMT with pads

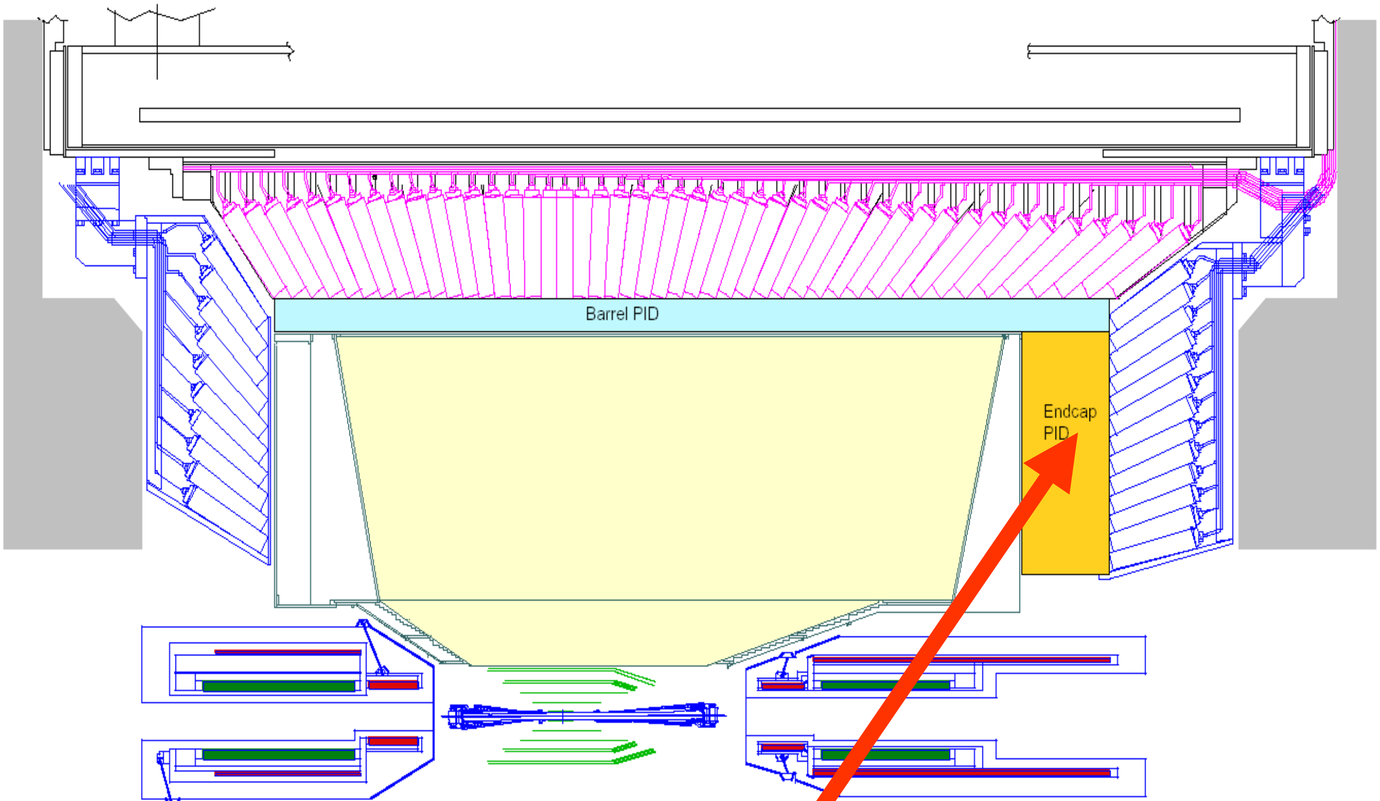
- Square-shape MCP-PMT with GaAsP photo-cathode
- First prototype
  - 2 MCP layers
    - □ ϕ10μm holes
  - 4ch anodes
  - Slightly larger structure
    - Less active area

Target structure



- Enough gain to detect single photo-electron
- Good time resolution (TTS=42ps) for single p.e.
  - Slightly worse than single anode MCP-PMT (TTS=32ps)
- Next: increase active area frac., study ageing

Belle upgrade – side view

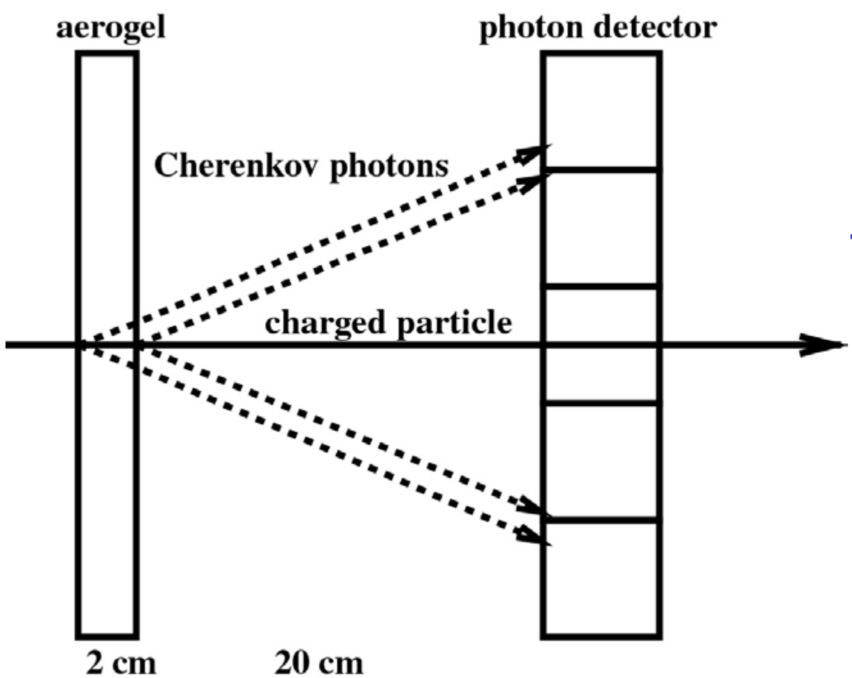


Two new particle ID devices, both RICHes:

Barrel: TOP or focusing DIRC

Endcap: proximity focusing RICH

Endcap: Proximity focusing RICH



K/π separation at 4 GeV/c:
$\theta_c(\pi) \sim 308$ mrad (n = 1.05)
$\theta_c(\pi) - \theta_c(K) \sim 23$ mrad

For single photons: $\delta\theta_c(\text{meas.}) = \sigma_0 \sim 14$ mrad,
typical value for a 20mm thick radiator and 6mm PMT pad size

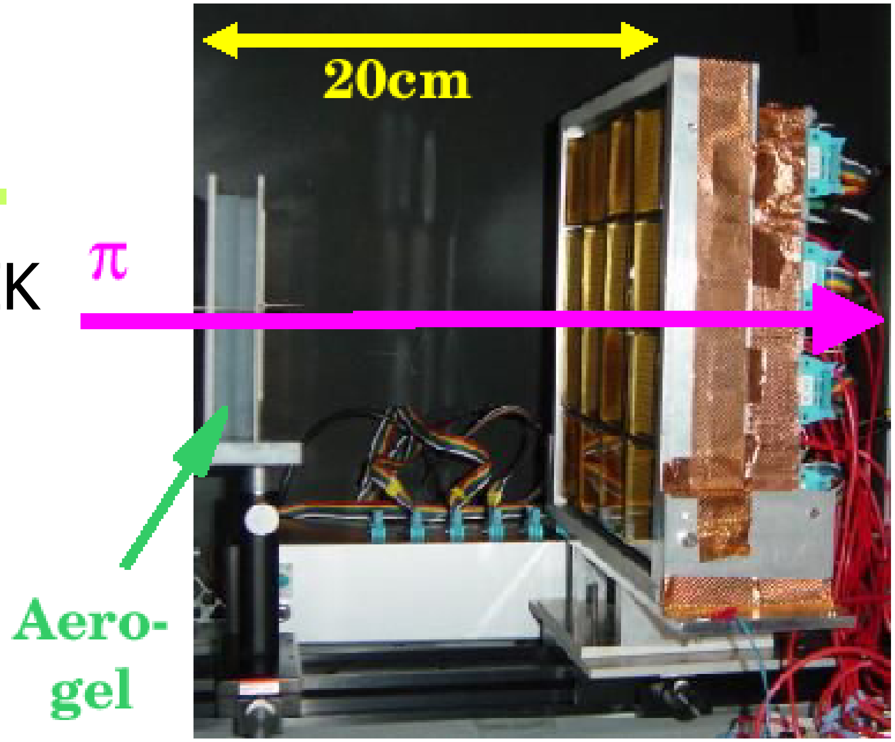
Per track: $$\sigma_{track} = \frac{\sigma_0}{\sqrt{N_{pe}}}$$

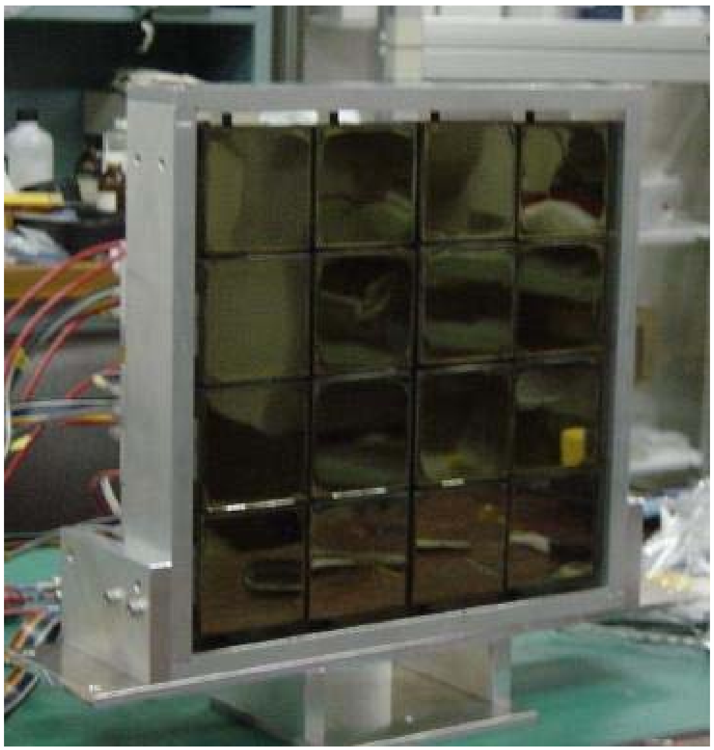
Separation: $[\theta_c(\pi) - \theta_c(K)]/\sigma_{track}$

→ 5σ separation with $N_{pe} \sim 10$

Beam tests

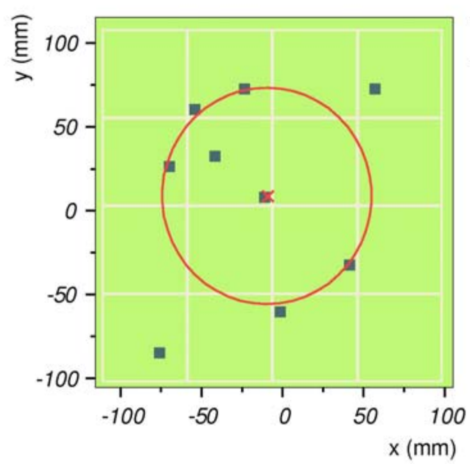
pion beam (π2) at KEK

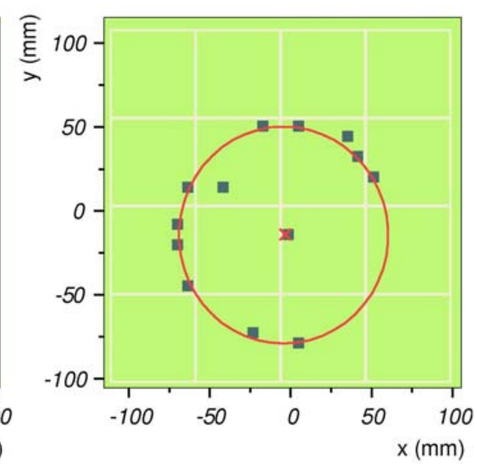




Photon detector: array of 16 H8500 PMTs

Clear rings, little background



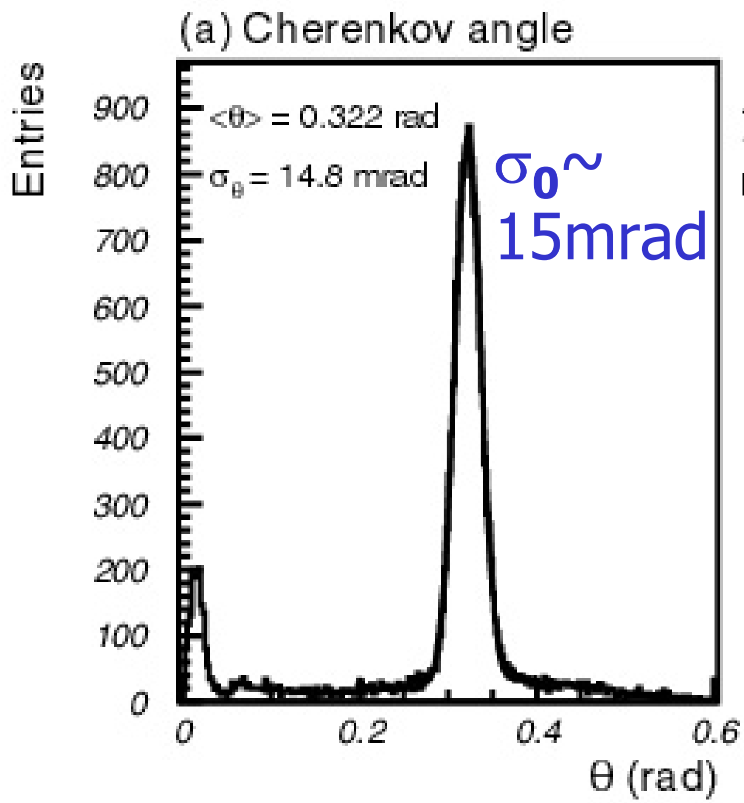


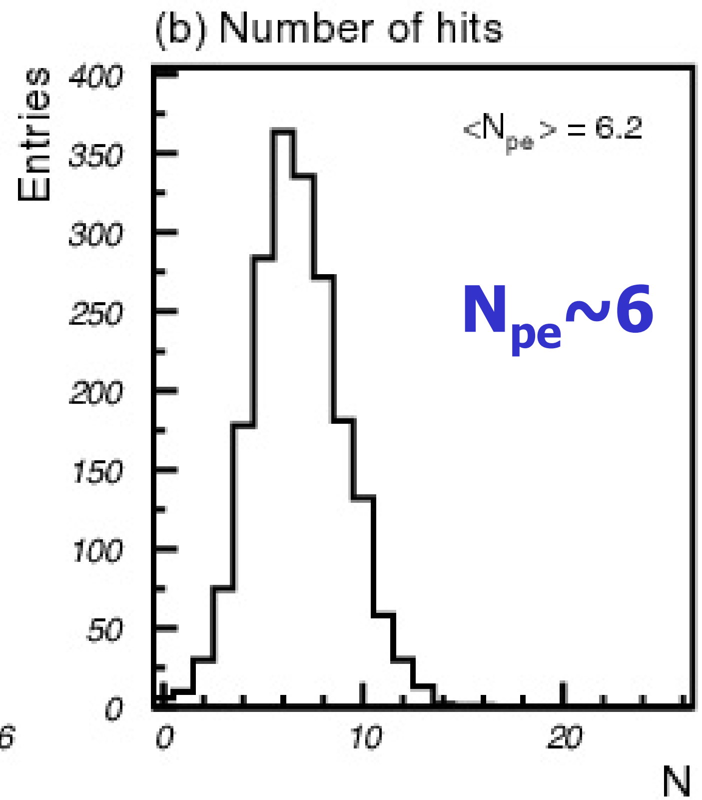
Beam test: Cherenkov angle resolution and number of photons

NIM A521(2004)367; NIM A553(2005)58

Beam test results with 2cm thick aerogel tiles:

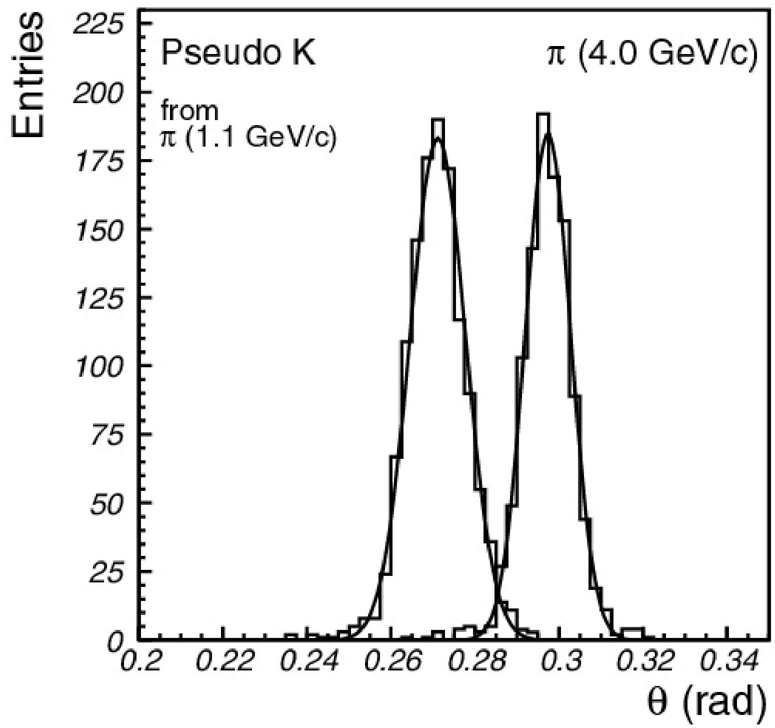
>4σ K/π separation





→ Number of photons has to be increased.

PID capability on test beam data

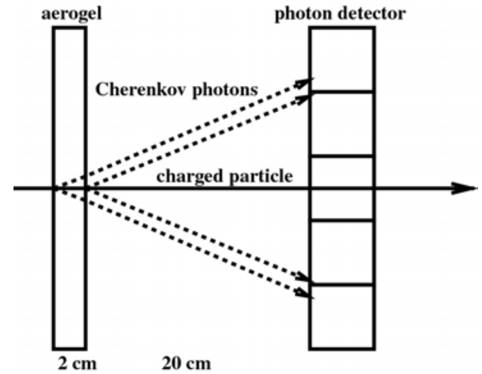


From typical values (single photon resolution 15mrad and 6 detected photons) we can estimate the Cherenkov resolution per track: 5.3mrad;

→ ~4σ π/K separation at 4GeV/c.

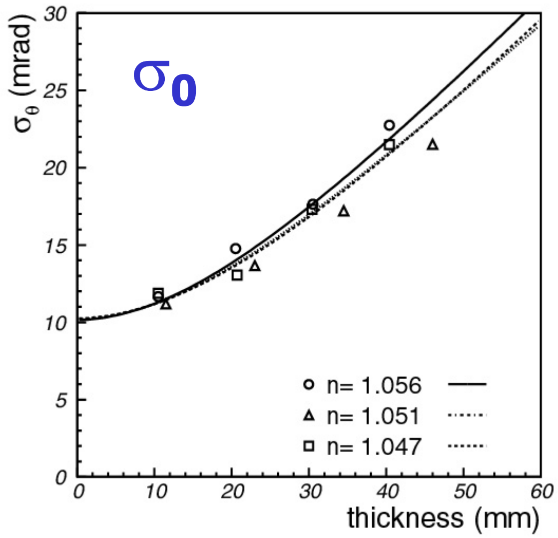
Illustration of PID performance: Cherenkov angle distribution for pions at 4GeV/c and 'kaons' (pions at 1.1GeV/c with the same Cherenkov angle as kaons at 4GeV/c).

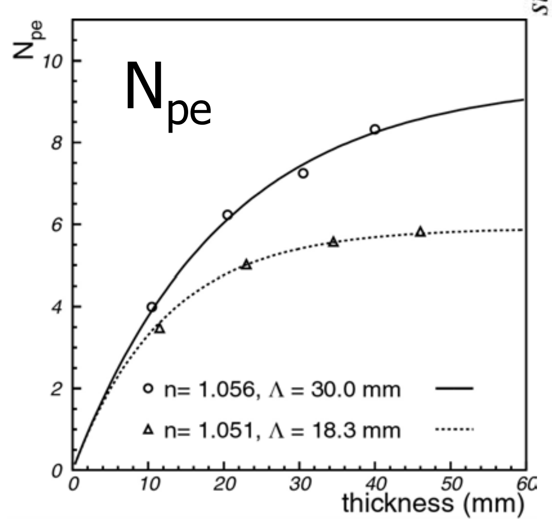
How to increase the number of photons?

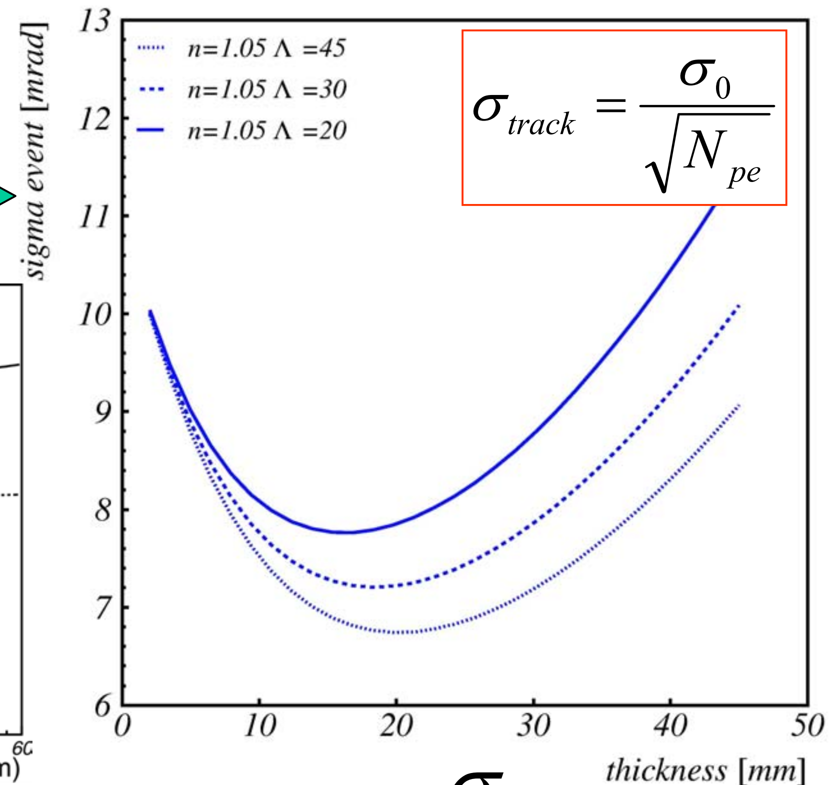


What is the optimal radiator thickness?

Use beam test data on σ_0 and N_{pe}







Minimize the error per track: $\sigma_{track} = \frac{\sigma_0}{\sqrt{N_{pe}}}$

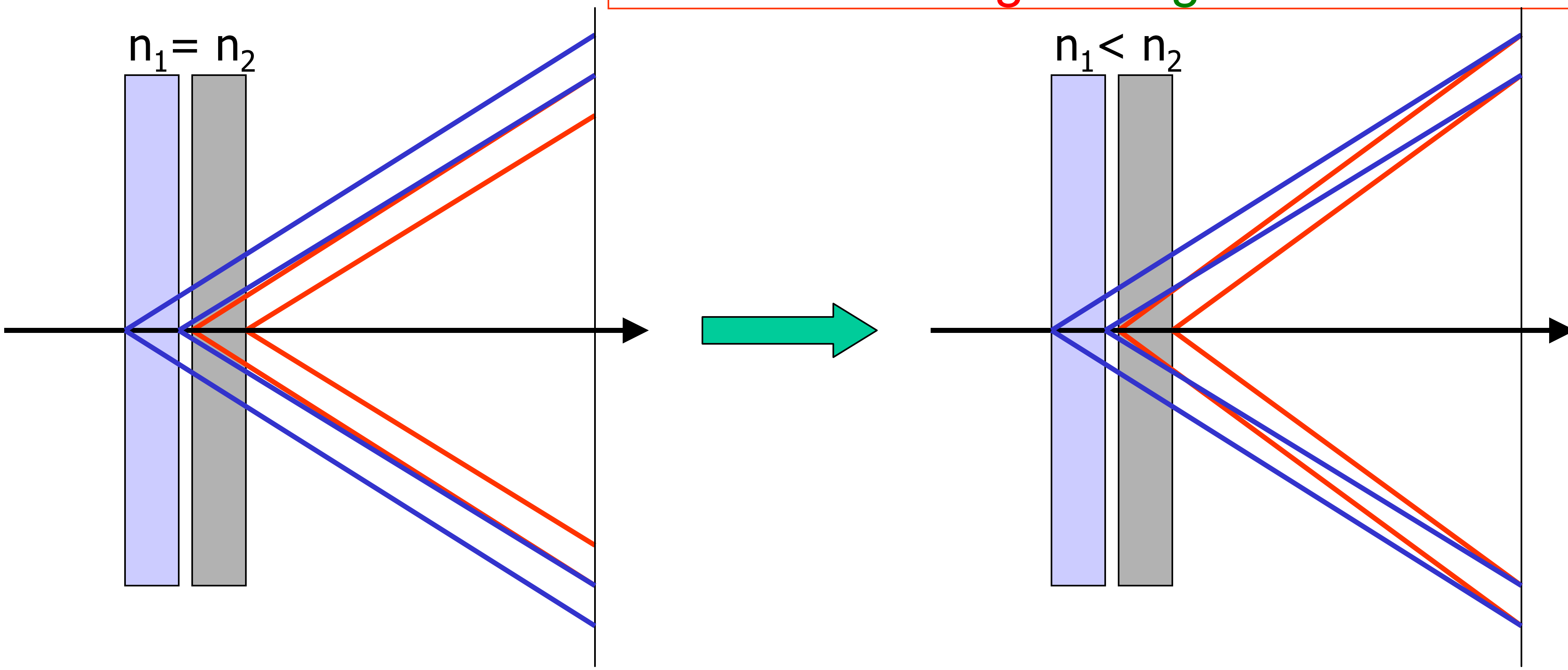
Optimum is close to 2 cm

Radiator with multiple refractive indices

How to increase the number of photons without degrading the resolution?

→ stack two tiles with different refractive indices: “focusing” configuration

normal



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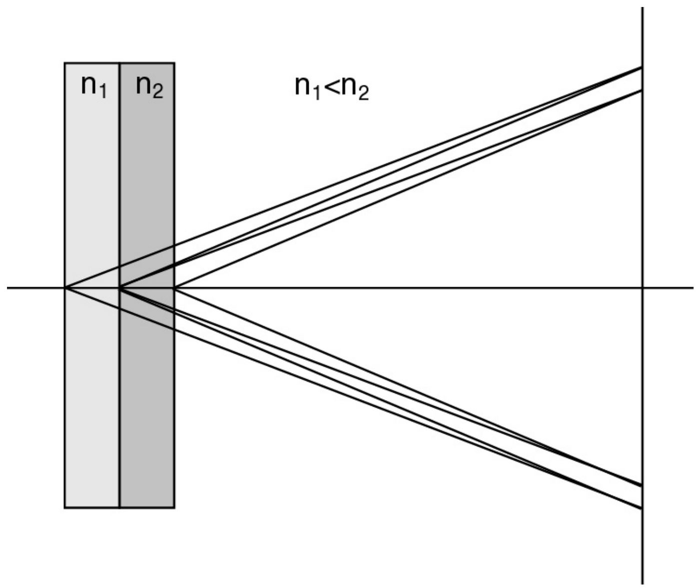
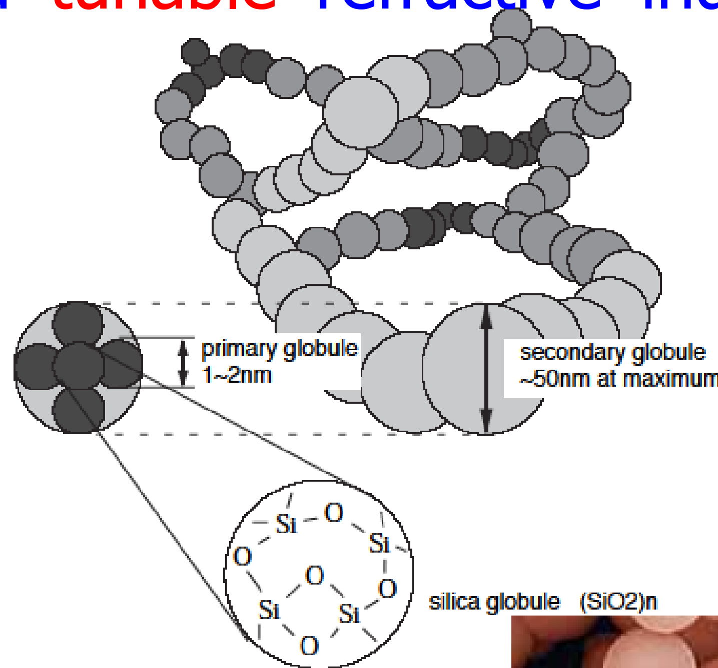
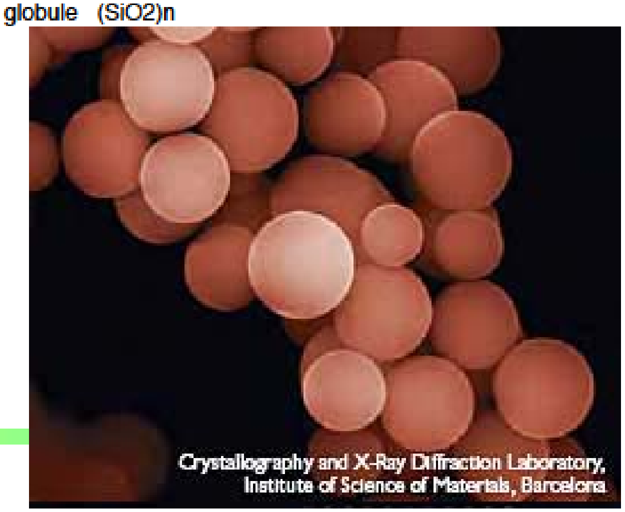
→ focusing radiator

Radiator with multiple refractive indices 2

Such a configuration is only possible with aerogel (a form of Si_xO_y) – material with a tunable refractive index between 1.01 and 1.07.

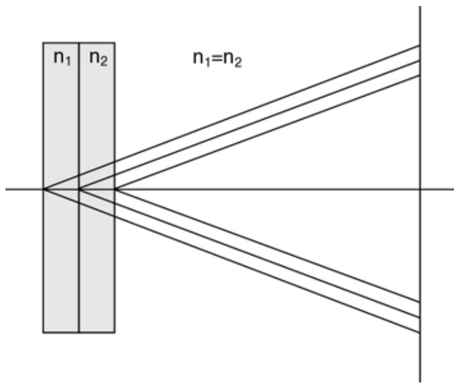


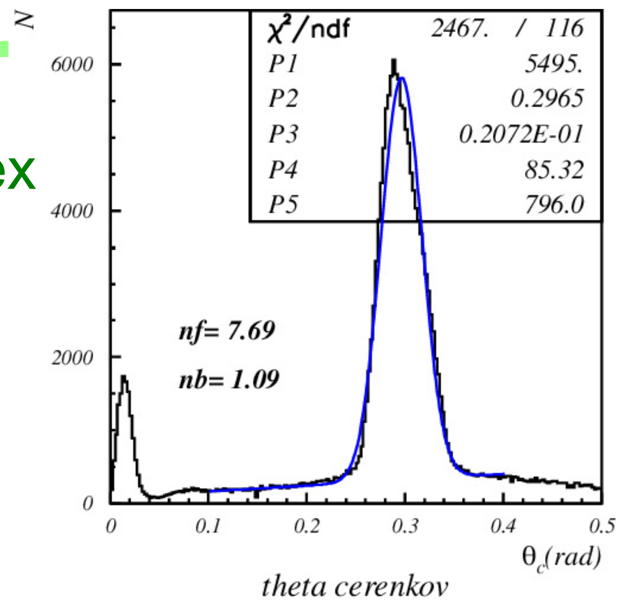


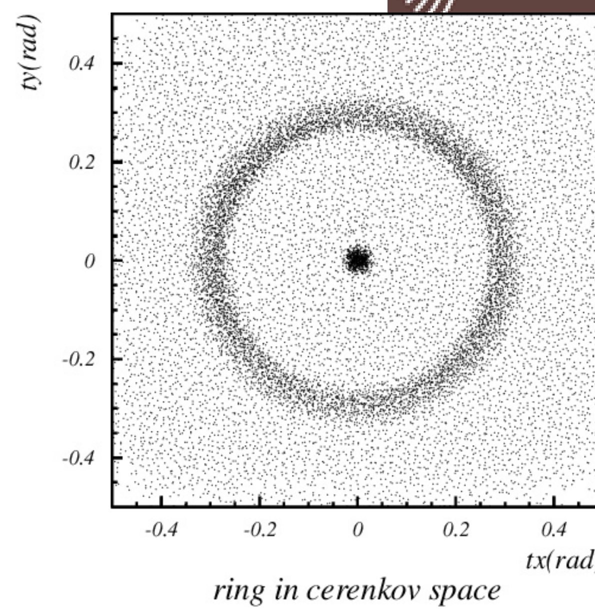


Focusing configuration – data

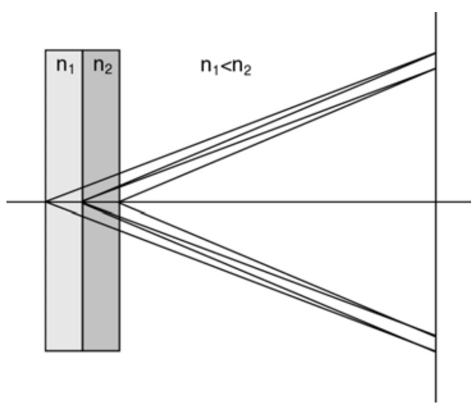
4cm aerogel single index

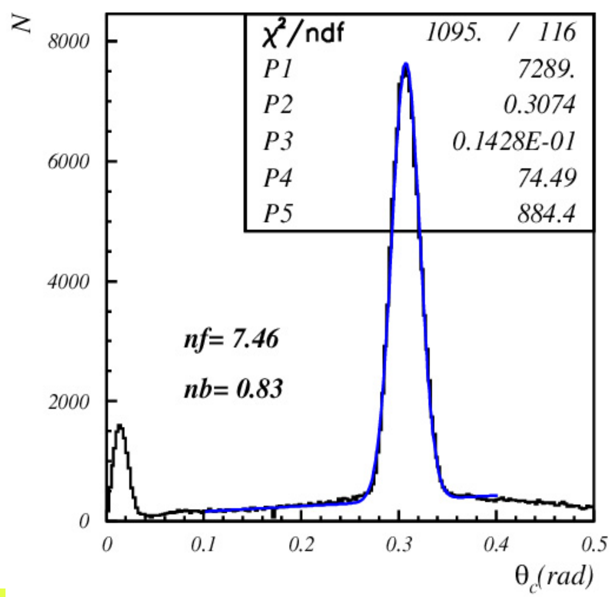


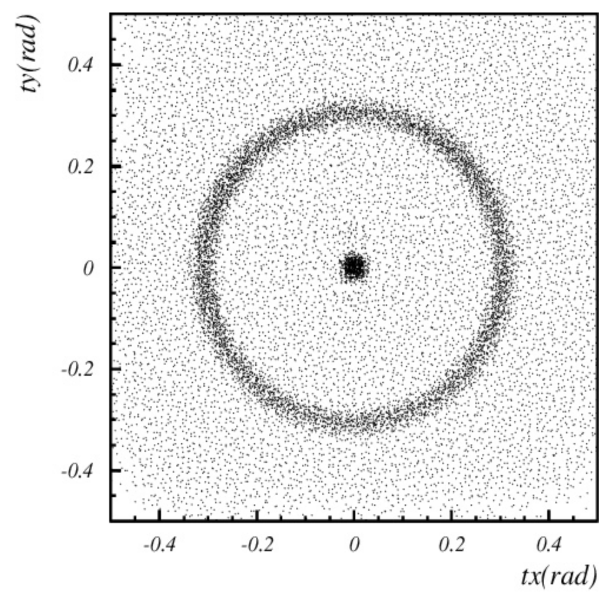




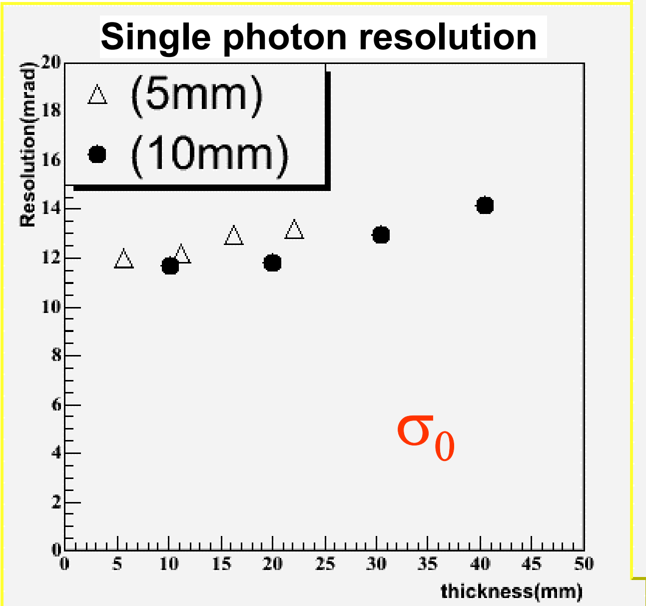
2+2cm aerogel

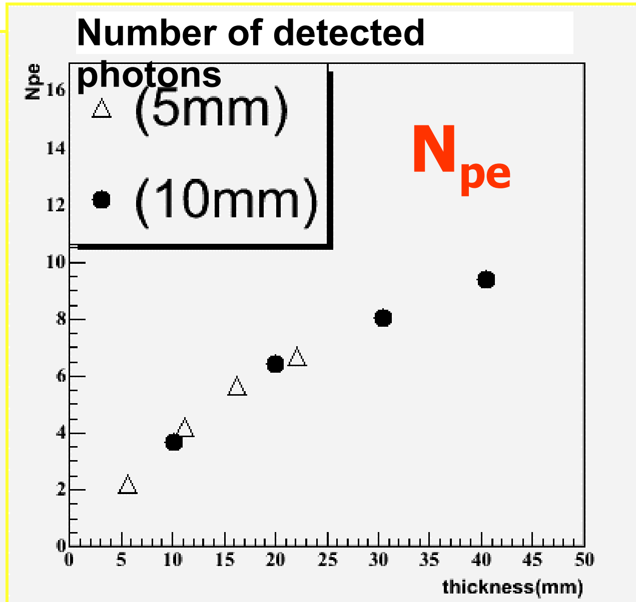


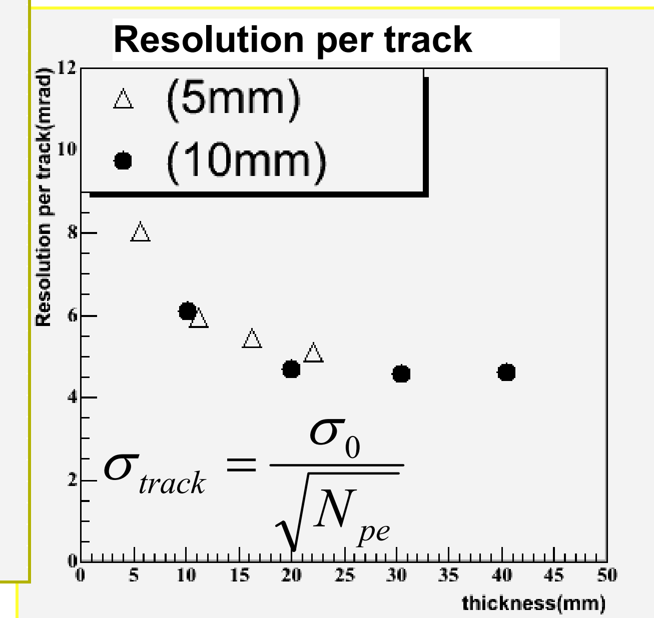


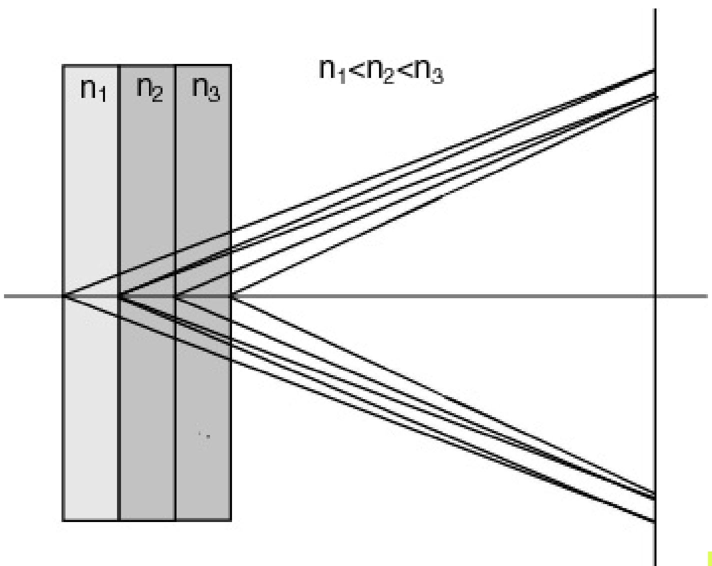


Multilayer extensions









Multiple layer radiators combined from 5mm and 10mm tiles

Cherenkov angle resolution per track: around 4.3 mrad

→ π/K separation at 4 GeV: >5σ

→ Talk by I. Adachi

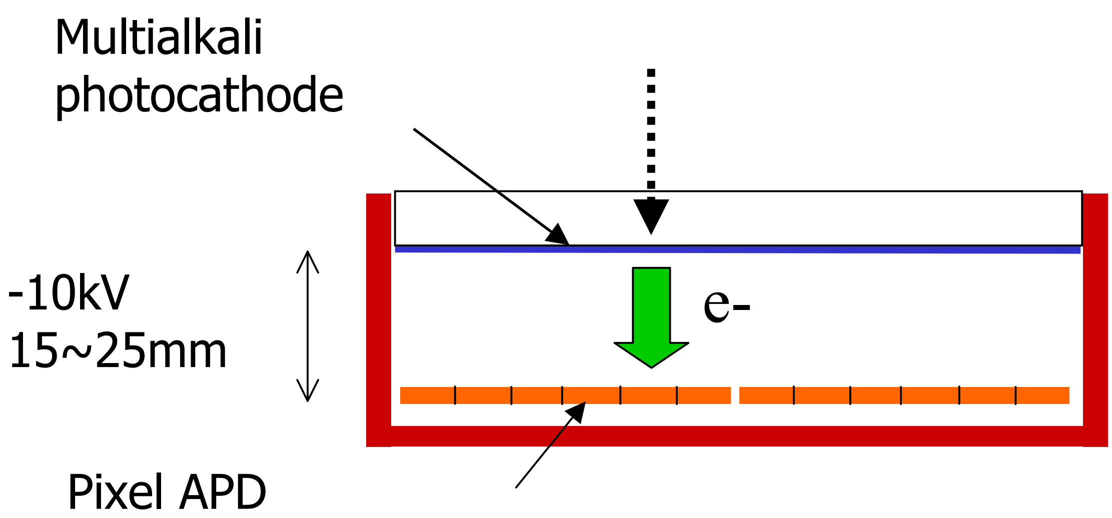
Photon detectors for the aerogel RICH requirements and candidates

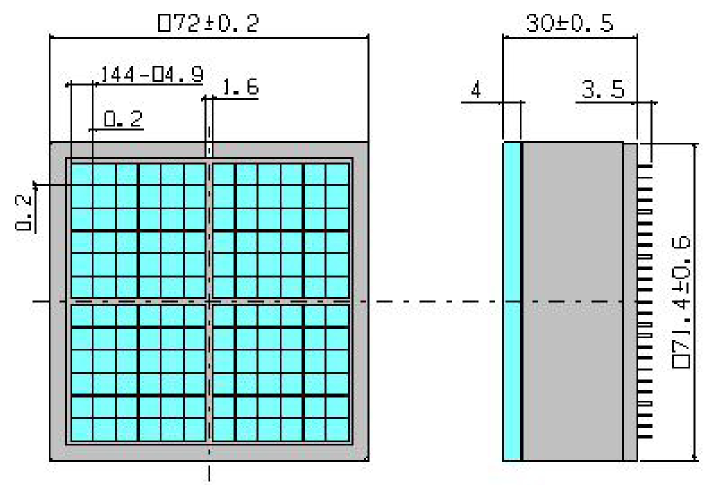
Need: Operation in a high magnetic field (1.5 T)

Pad size ~5-6mm

Candidates:

- MCP PMT (Burle 85011)
- large active area HAPD of the proximity focusing type



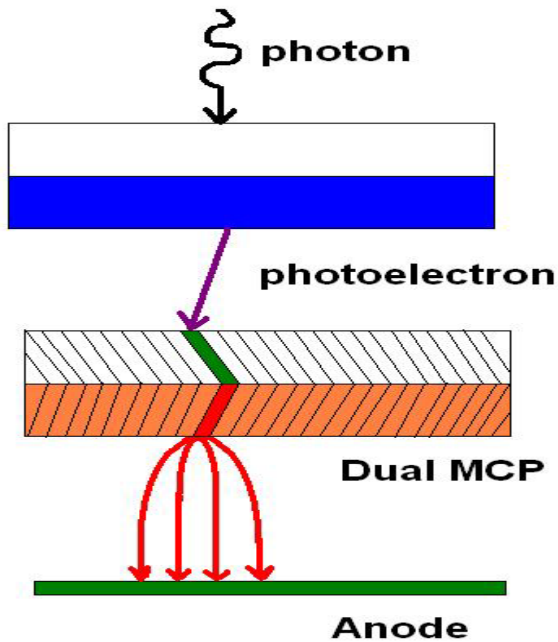


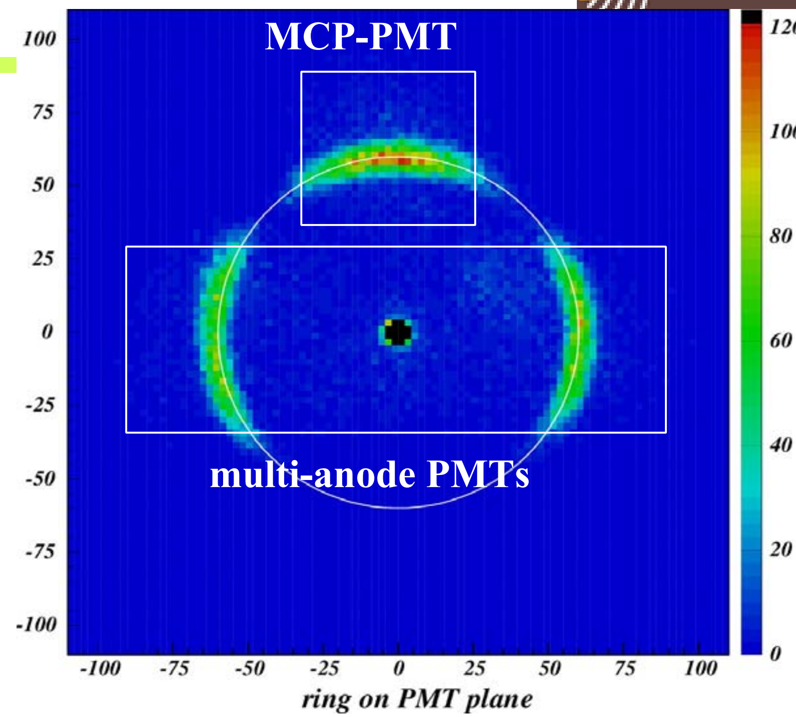
HAPD R&D project in collaboration with HPK.

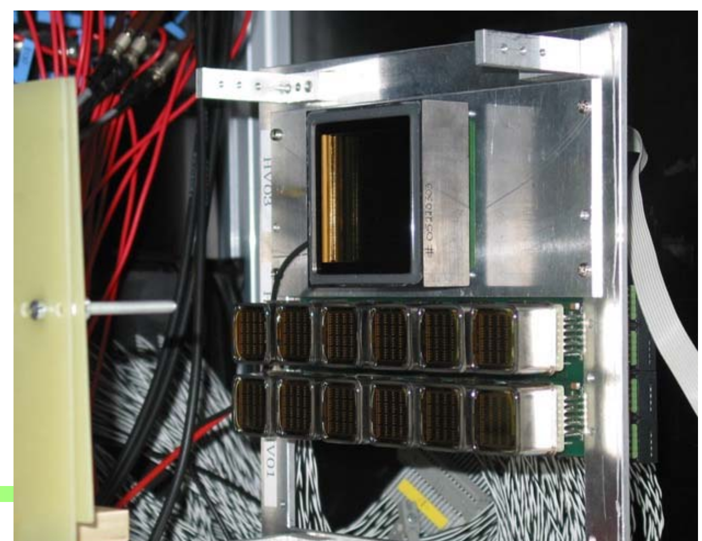
Long development time, now working test samples.

Photon detector candidate: MCP-PMT

BURLE 85011 microchannel plate (MCP) PMT: multi-anode PMT with two MCP steps







→good performance in beam and bench tests
→ very fast
→ R+D: ageing

SiPM as photon detector?

Can we use SiPM (Geiger mode APD) as the photon detector in a RICH counter?

+immune to magnetic field

+high photon detection efficiency, single photon sensitivity

+easy to handle (thin, can be mounted on a PCB)

+potentially cheap (not yet...) silicon technology

+no high voltage

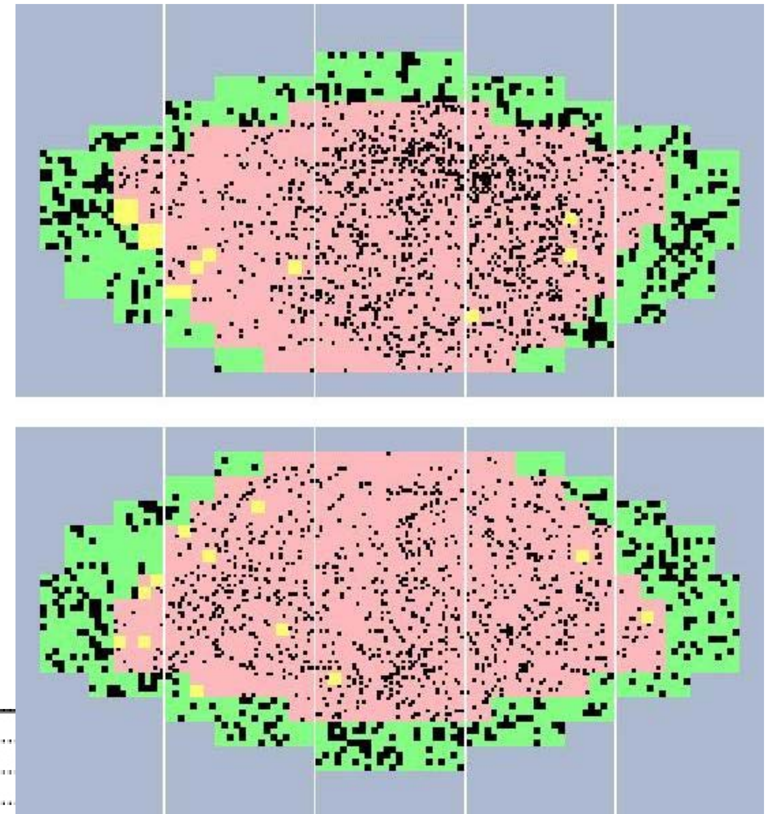
-very high dark count rate (100kHz – 1MHz) with single photon pulse height

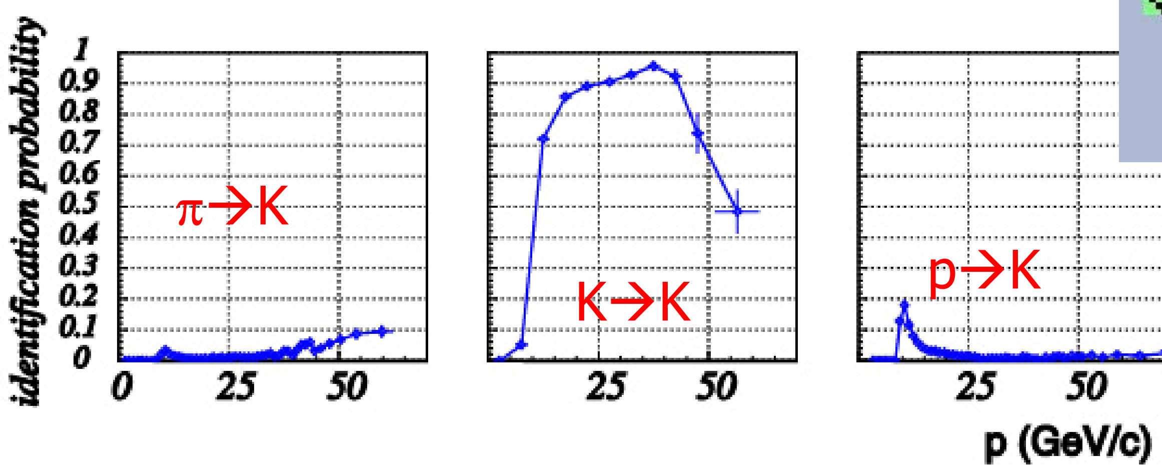
Can such a detector work?

Experience from HERA-B RICH: successfully operated in a high occupancy environment (up to 10%).

Need >20 photons per ring (had ~30) for a reliable PID.

HERA-B RICH event

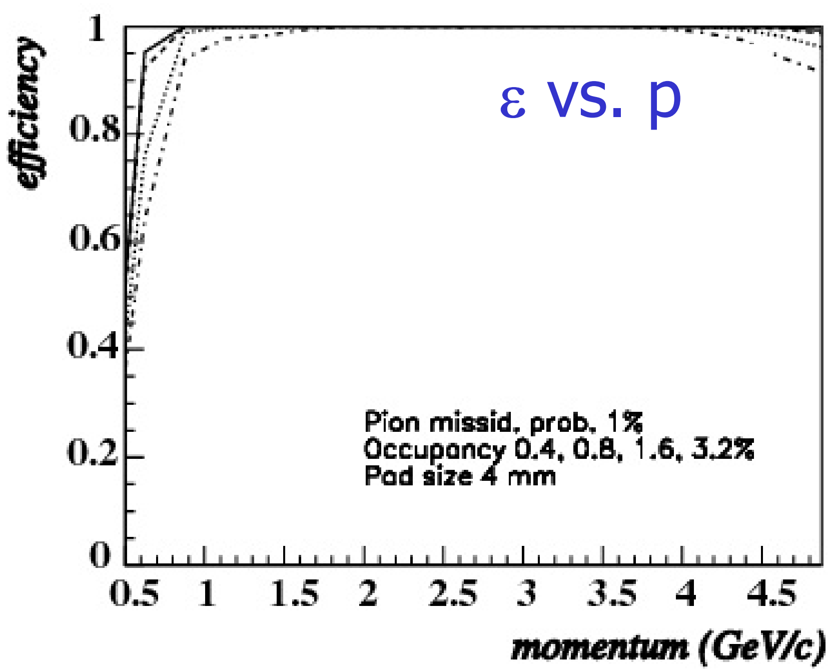


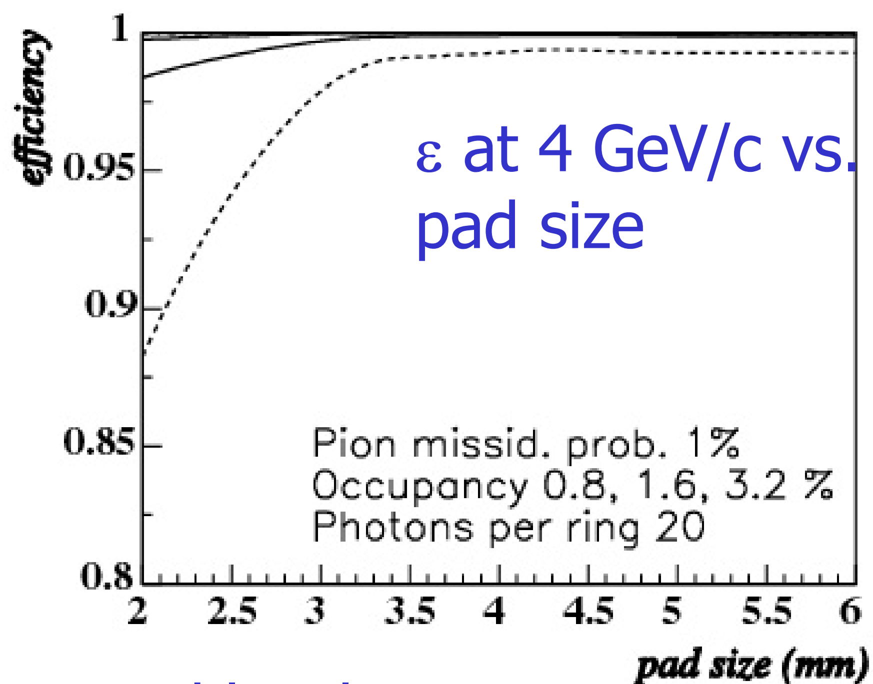


Can such a detector work?

MC simulation of the counter response: assume 1mm^2 active area SiPMs with 0.8 MHz (1.6 MHz, 3.2 MHz) dark count rate, 10ns time window

K identification efficiency at 1% π missid. probability





For different background levels

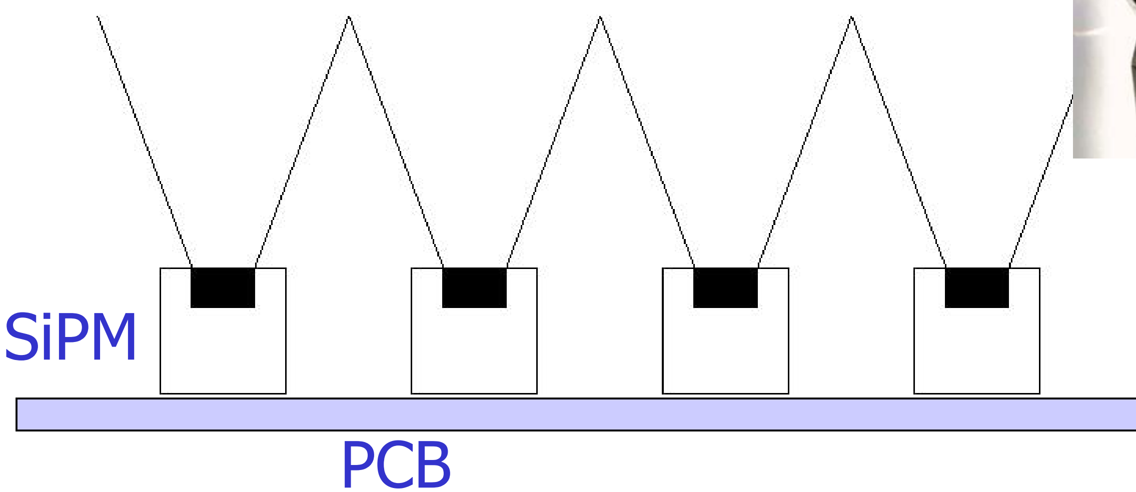
Can such a detector work?

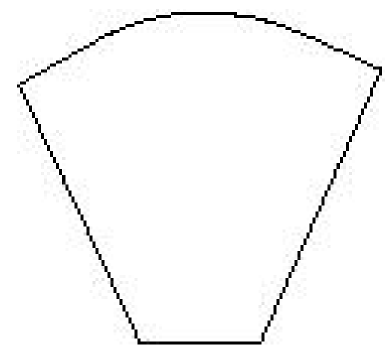
Improve the signal to noise ratio:

•Reduce the noise by a narrow (<10ns) time window

•Increase the number of signal hits per single sensor by using light collectors and by adjusting the pad size to the ring thickness

Light collector with reflective walls





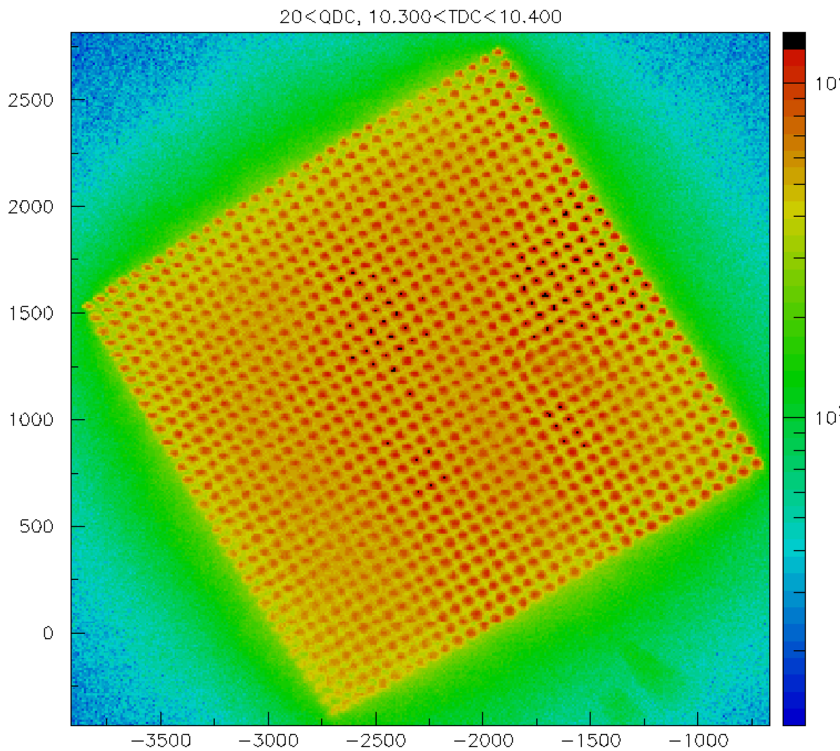
or combine a lens and mirror walls

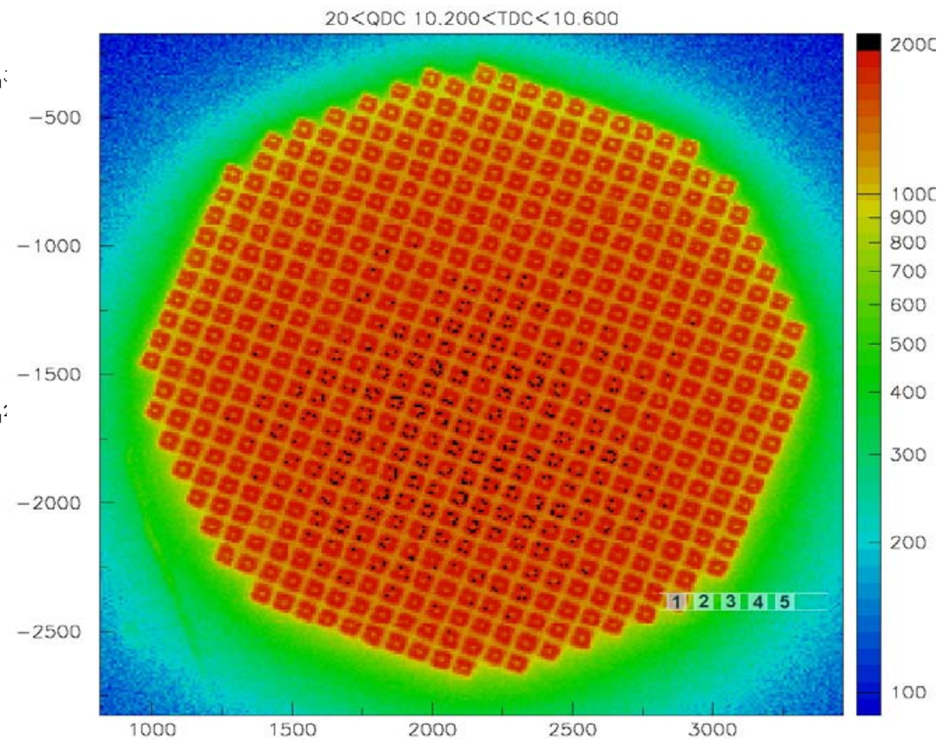
SiPM surface sensitivity

Size: ~1mm

Scanned with laser, resolution ~5 μm

Single photon response

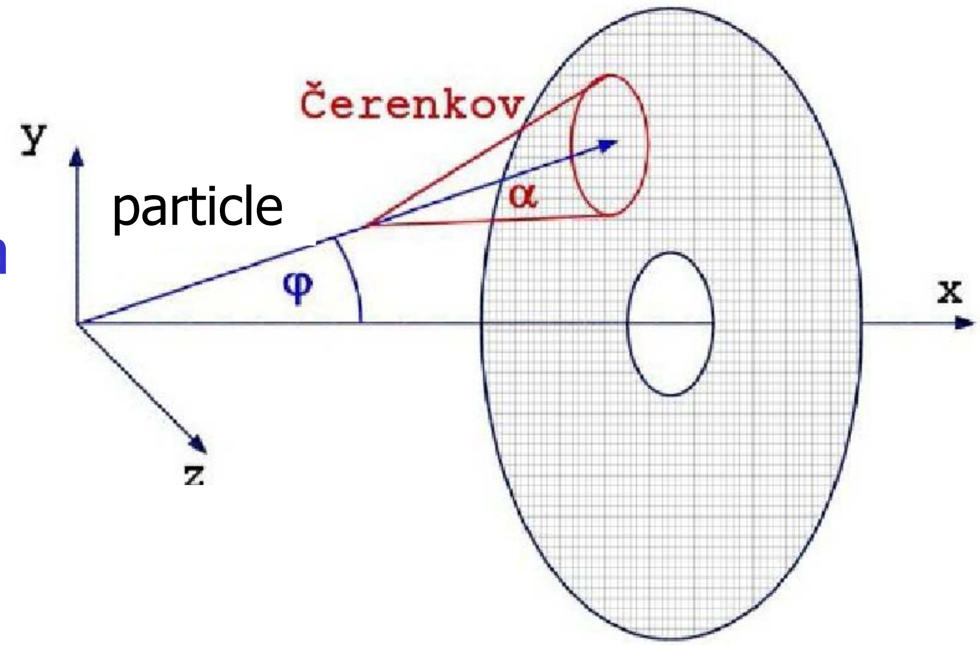


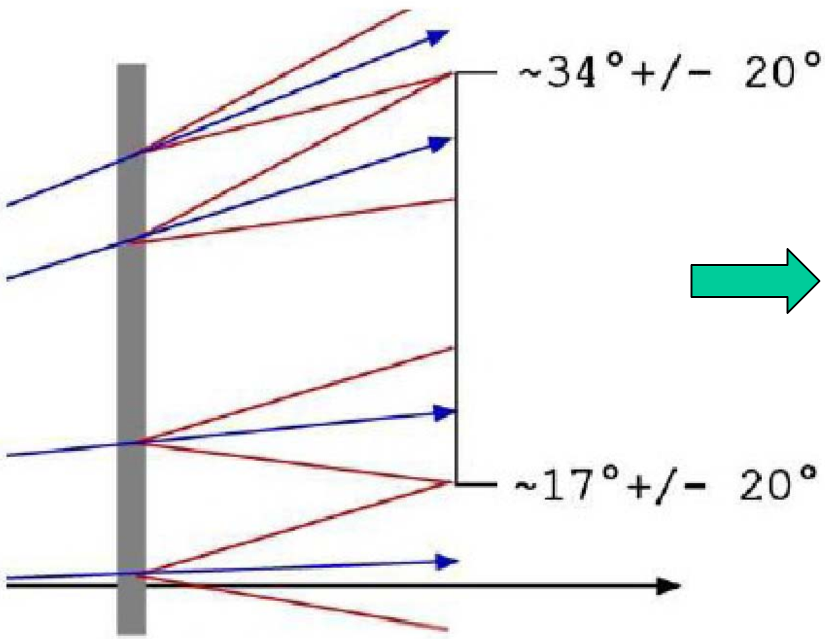


→poster by R. Pestotnik

Light collection: required angular range

For our application only a limited angular range of incident has to be covered at a given position on the detector





~ -3°... 54°

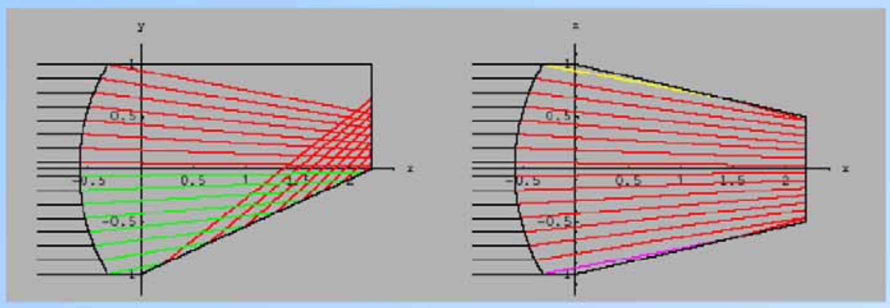
→ Take this asymmetry into account when designing the light collection system.

Peter Križan, Ljubljana

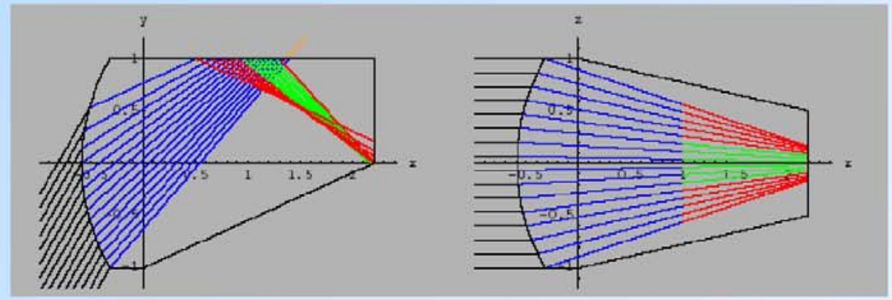
Light collectors: three types

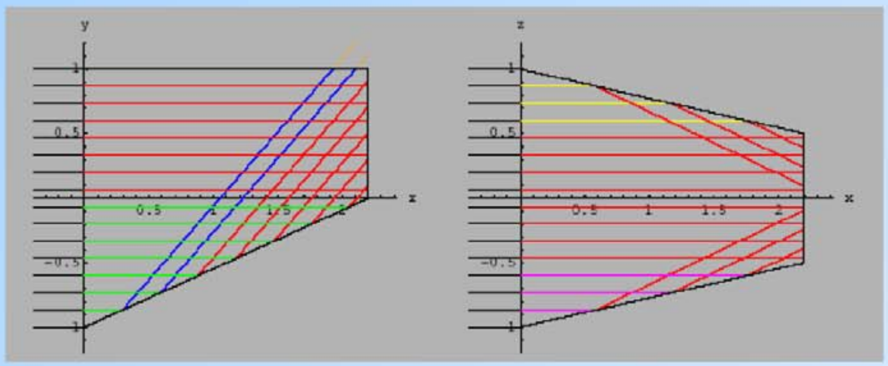
- angle 0^0
  two views

- angle 60^0
  two views



1





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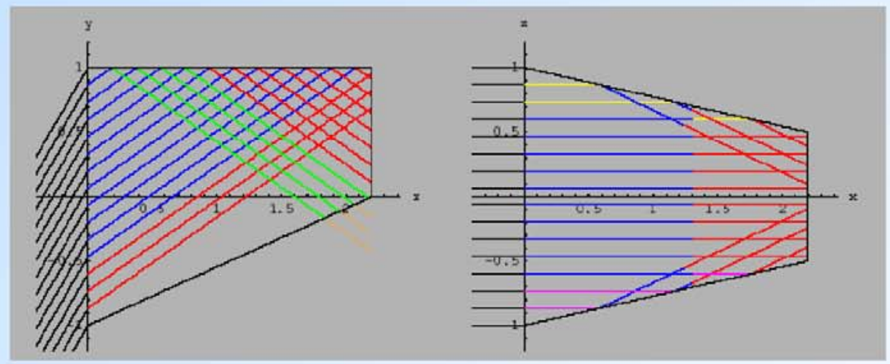

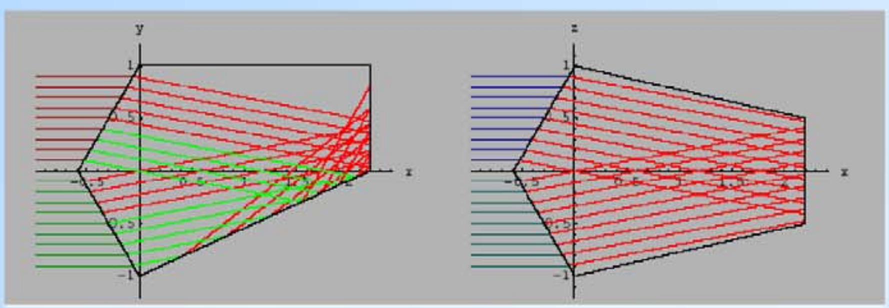

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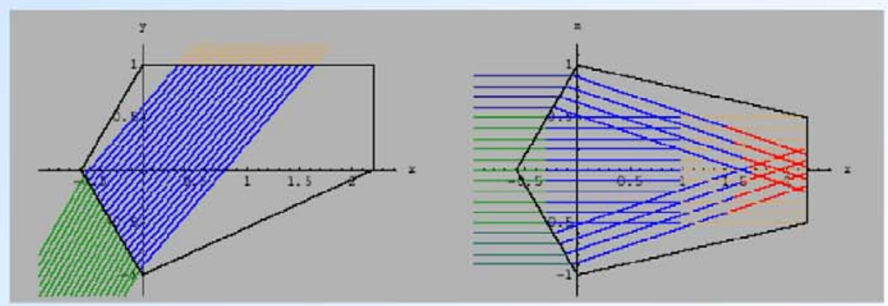
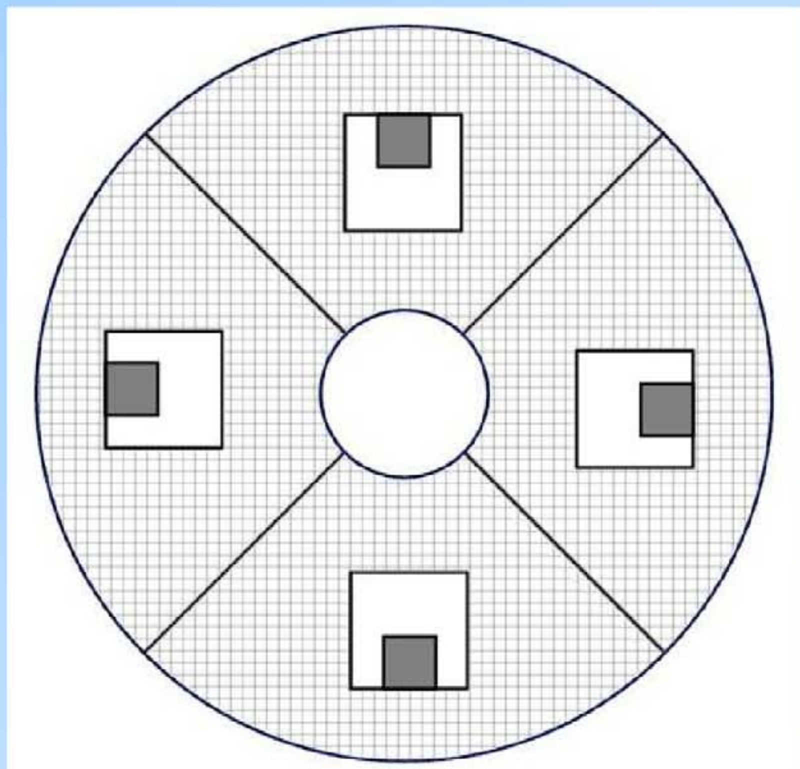
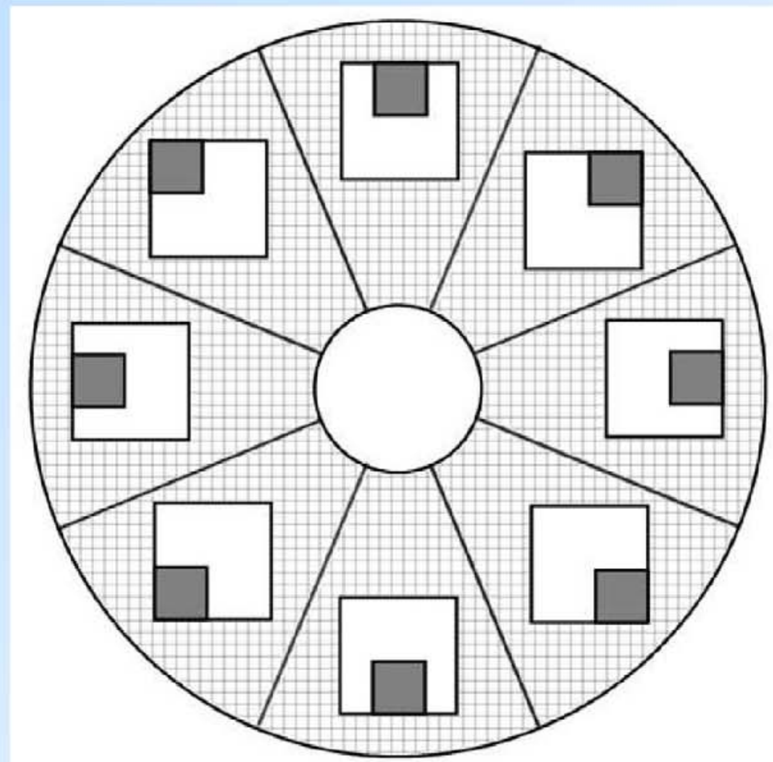


Light collectors: possible arrangement on the detector plane

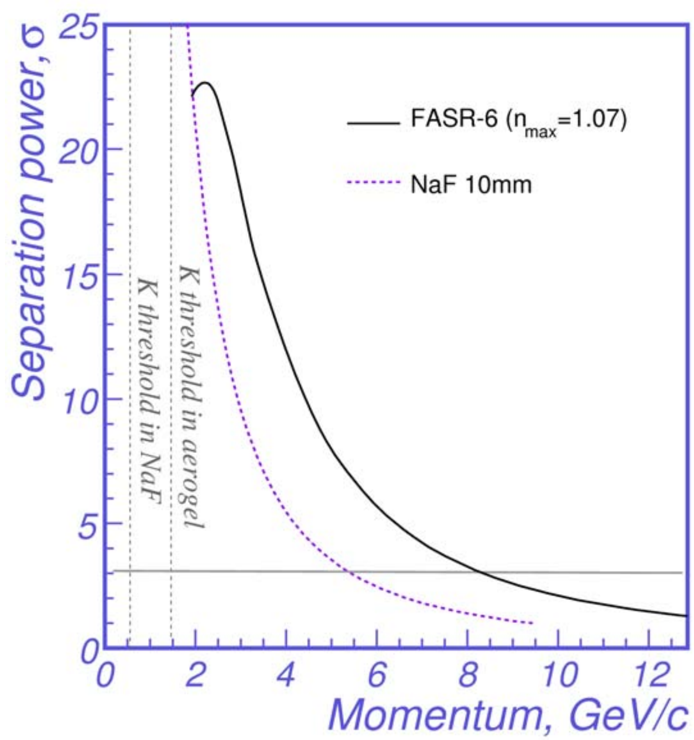
- configurations with one or two different modules





Proximity focusing RICH with NaF as radiator

π/K separation



Instead of aerogel use 1cm of NaF, assume biakali PMTs as photon detector:

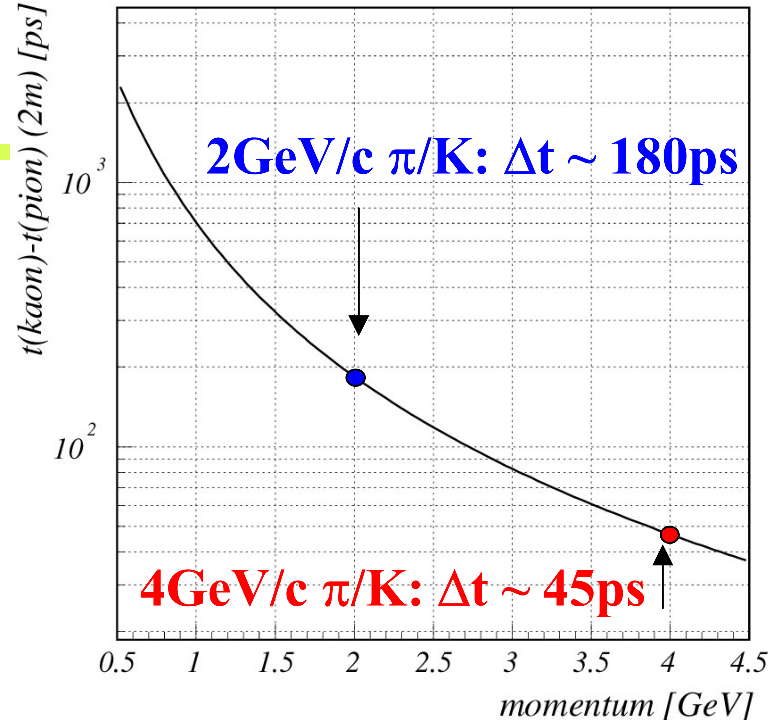
- Higher refractive index → lower Cherenkov threshold
- More photons
- Worse single photon resolution
- Partly compensated, resolution per track somewhat worse than with aerogel
- More material in front of ECAL

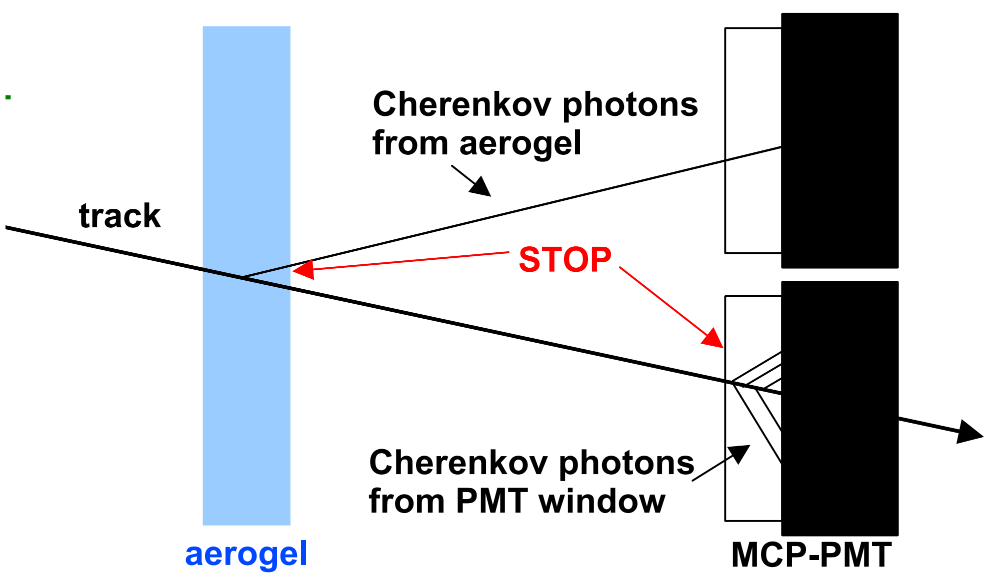
→ talk by S. Kononov

TOF capability

With a fast photon detector (MCP PMT), a proximity focusing RICH counter can be used also as a time-of-flight counter.

Time difference between π and K →





Cherenkov photons from two sources can be used:

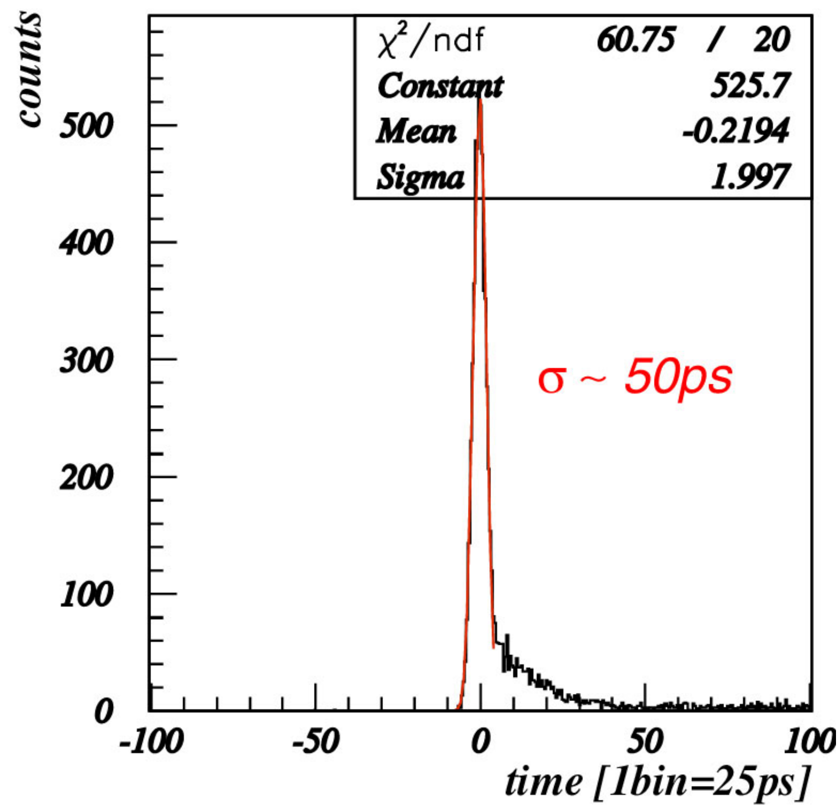
- photons emitted in the aerogel radiator
- photons emitted in the PMT window

TOF capability: photons from the ring

Beam tests: study timing properties of such a counter.

Time resolution for Cherenkov photons from the aerogel radiator: 50ps
→agrees well with the value from the bench tests

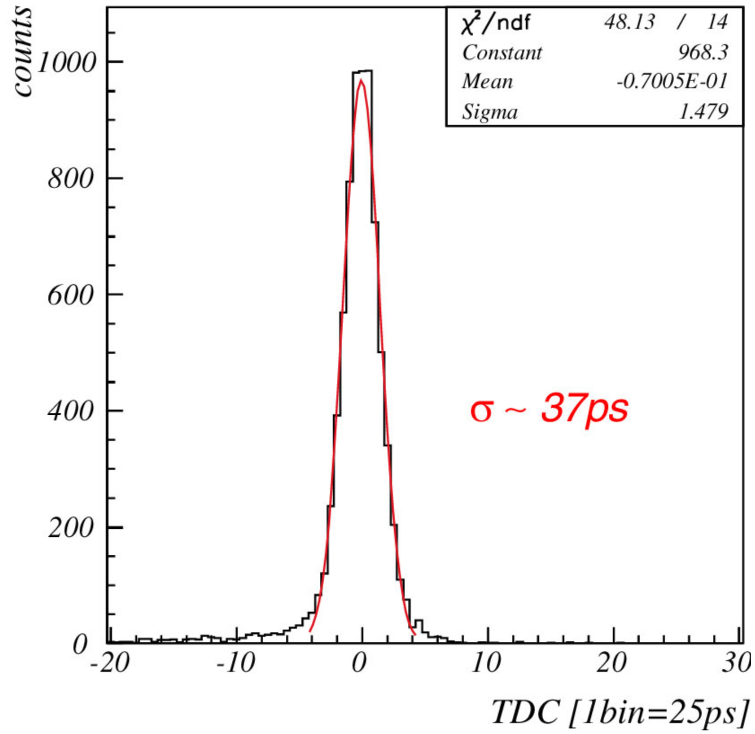
Resolution for full ring (~10 photons) would be around 20ps

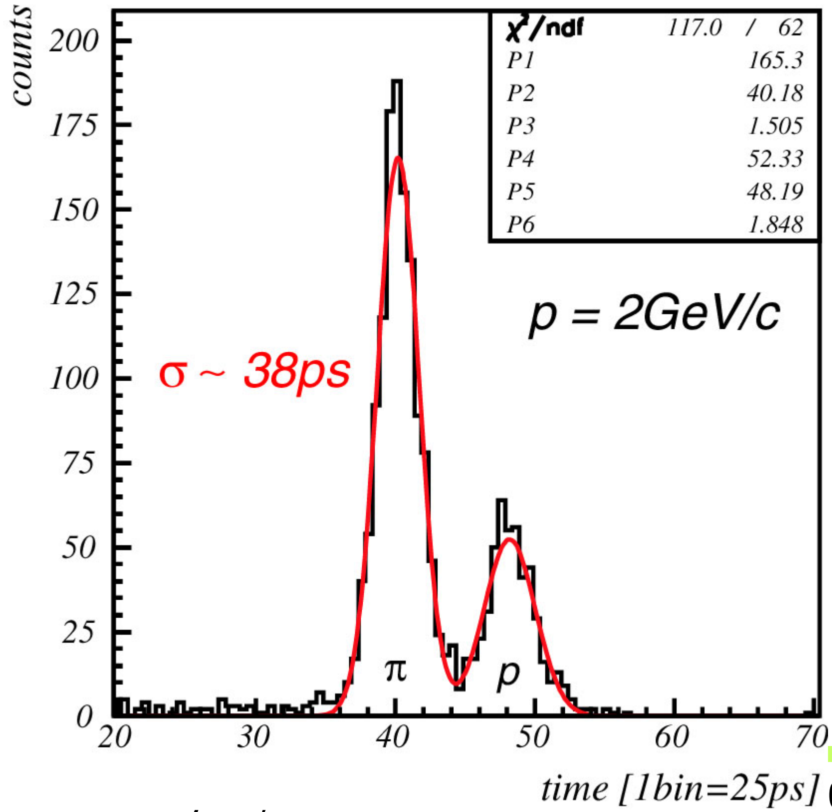


TOF capability: window photons

Expected number of detected Cherenkov photons emitted in the PMT window (2mm) is ~15

Expected resolution ~35 ps →





TOF test with pions and protons at 2 GeV/c.

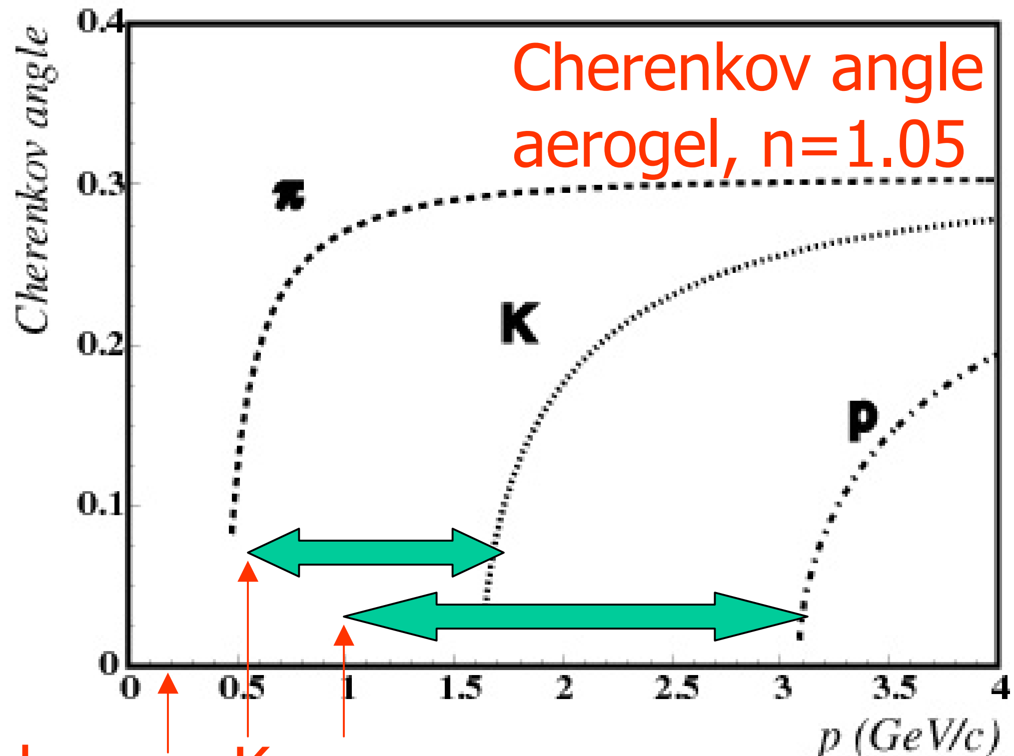
Distance between start counter and MCP-PMT is 65cm

→ Poster by S. Korpar

Time-of-flight with photons from the PMT window

Benefits: Čerenkov threshold in glass (or quartz) is much lower than in aerogel.

Aerogel: kaons (protons) have no signal below 1.6 GeV (3.1 GeV): identification in the veto mode.

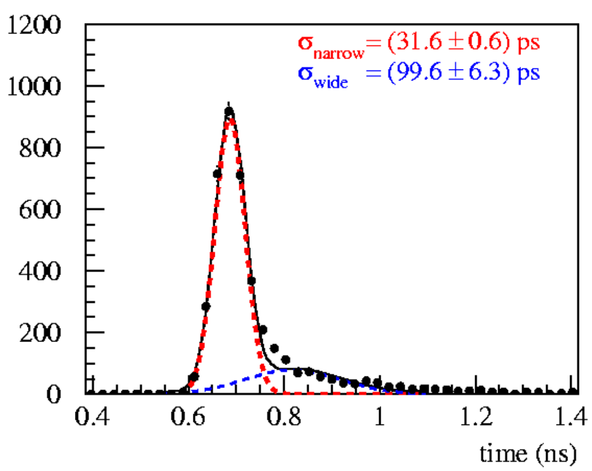


Threshold in the window: π K p

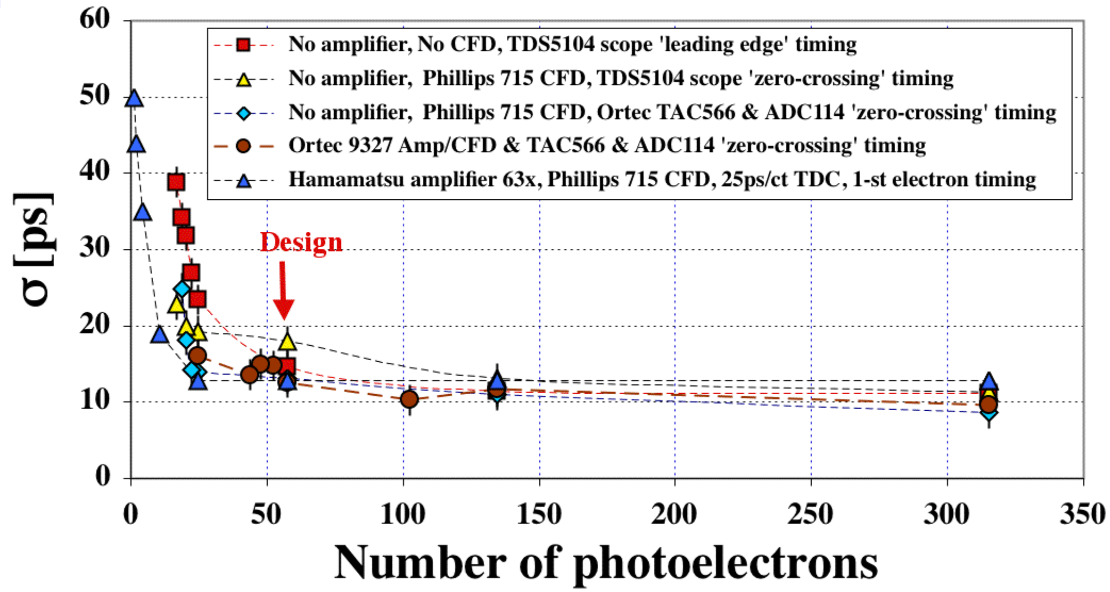
Window: threshold for kaons (protons) is at ~0.5 GeV (~0.9 GeV): → positive identification possible.

TOF counter with Burle/Photonis MCP-PMT

σ $_{TTS}$ - single photo-electrons:



Timing resolution σ = f(Npe):

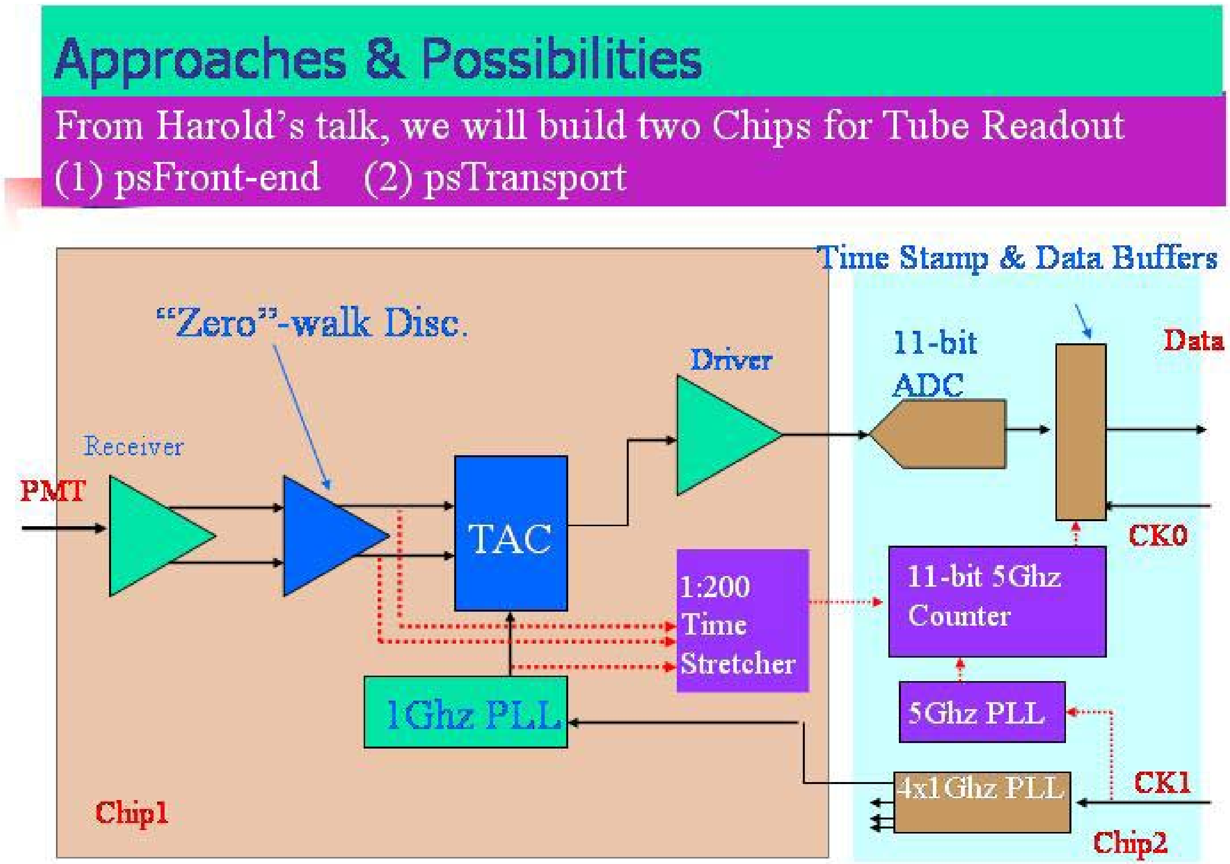


- **TOF counter: Burle/Photonis MCP-PMT with a 1cm thick quartz radiator**
- **Our present best results with the laser diode:**
  - **σ ~ 12 ps for Npe ~ 50-60**, which is expected from 1cm of the radiator.
  - **σ $_{TTS}$ ~ 32 ps for Npe ~ 1**.
  - **Upper limit on the MCP-PMT contribution: σ $_{MCP-PMT}$ < 6.5 ps**.
  - **TAC/ADC contribution to timing: σ $_{TAC\_ADC}$ < 3.2 ps**.
  - **Total electronics contribution: σ $_{Total\_electronics}$ ~ 7.2 ps**.

→ Talk by J. Va'vra

Effort to develop ps TOF counter

H. Frisch & H. Sanders, Univ. of Chicago, K. Byrum, G. Drake, Argonne lab



- ASIC-based technology for a new CFD & TDC

Summary

Particle identification is an essential part of several experiments, and has contributed substantially to our present understanding of elementary particles and their interactions.

RICH counters have evolved to a standard and reliable tool in experimental particle physics.

They will play an essential role in the next generation of B physics experiments at the LHC and SuperB factories.

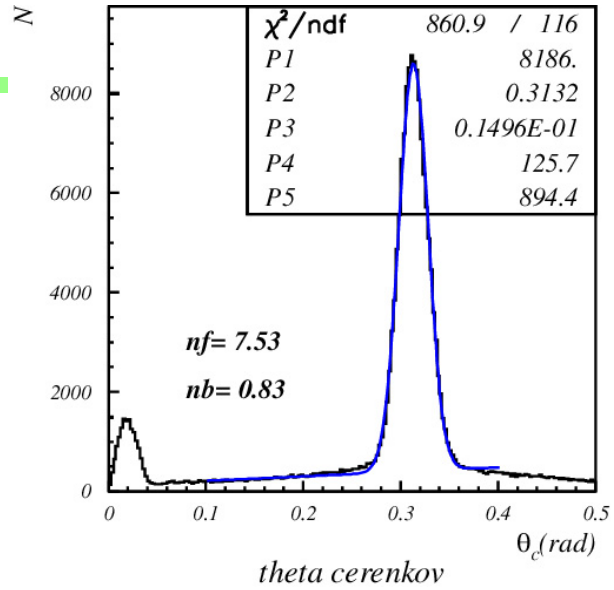
New concepts (focusing radiator, combination with time of flight) are being developed.

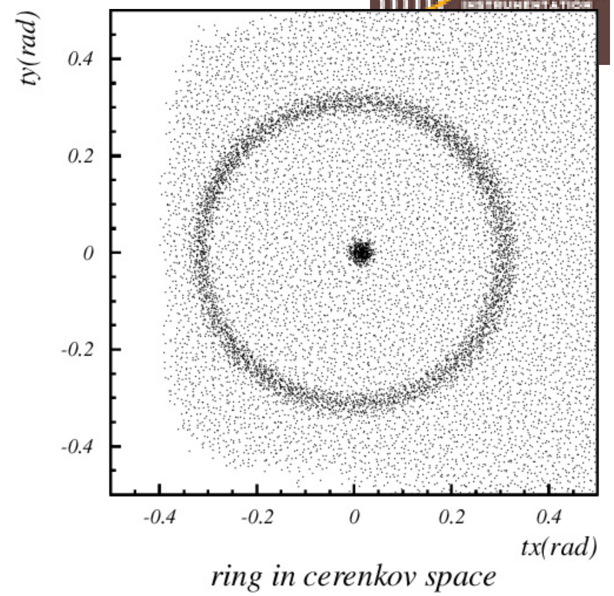
With new fast photon detectors there is a revived interest in the time-of-flight measurements, also in combination with a RICH counter.

Back-up slides

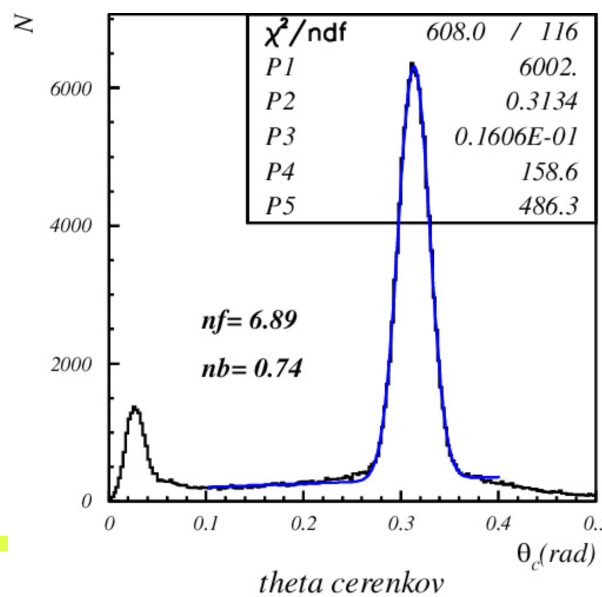
Focusing configuration - inclined tracks

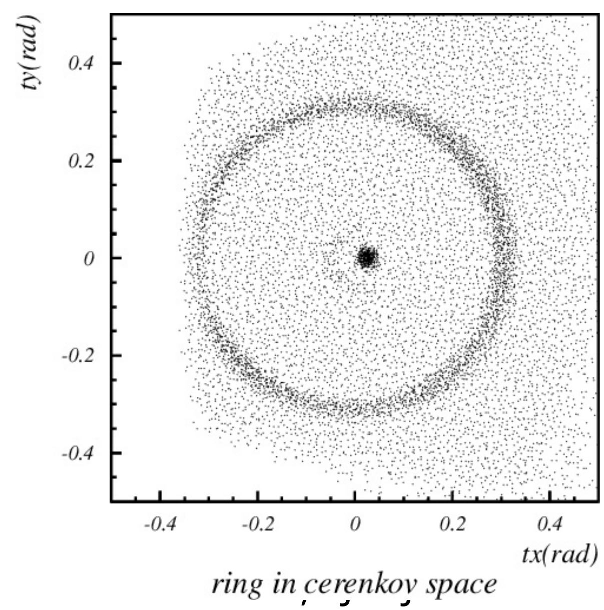
- 2+2cm aerogel
- angle 20°





- 2+2cm aerogel
- angle 30°

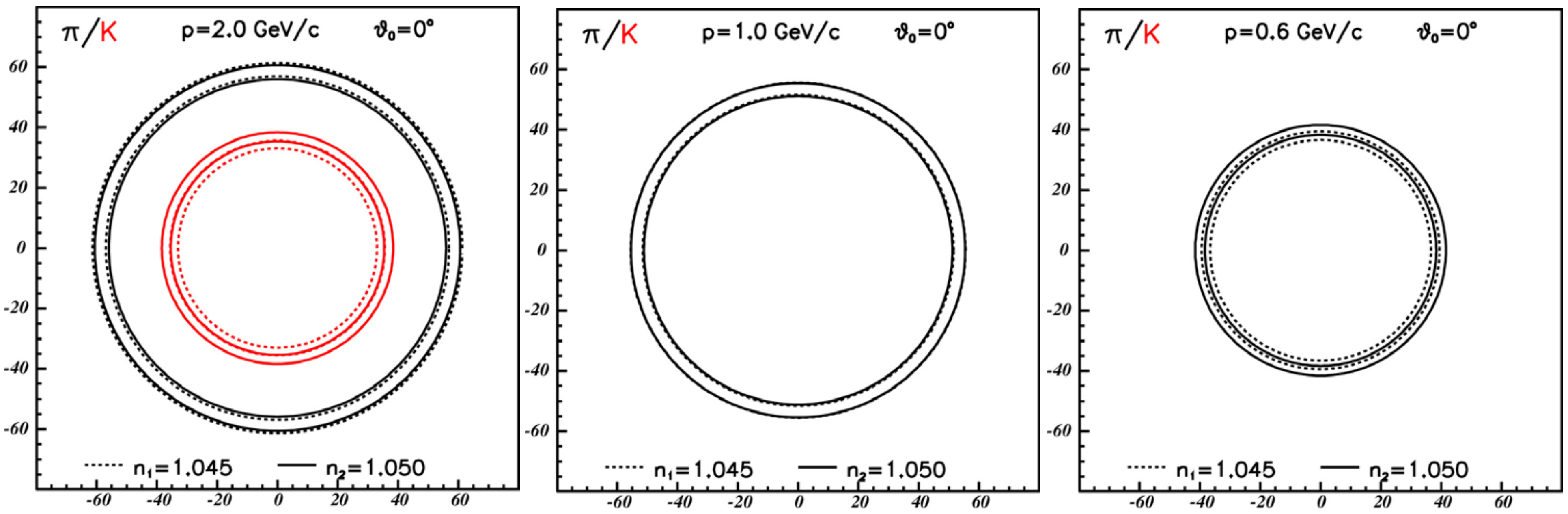




Works as well!

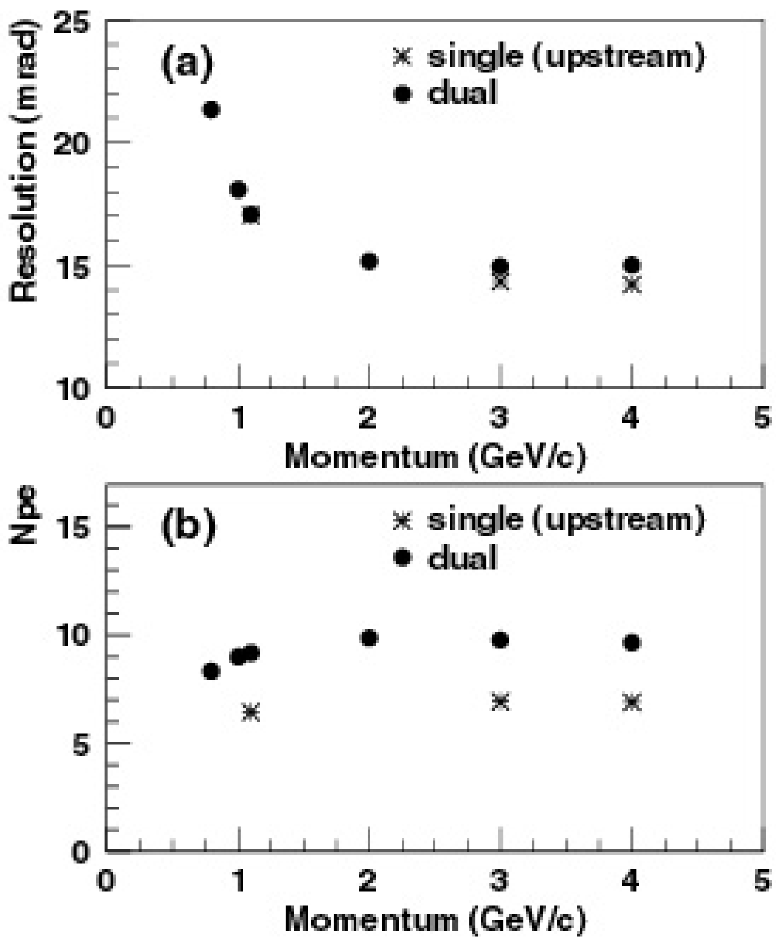
Focusing configuration – low momentum

- Matching of indices: done for high momentum tracks (4GeV/c)
- How is the overlapping of rings at lower momenta?



Good overlapping down to 0.6 GeV/c

Focusing configuration – momentum scan

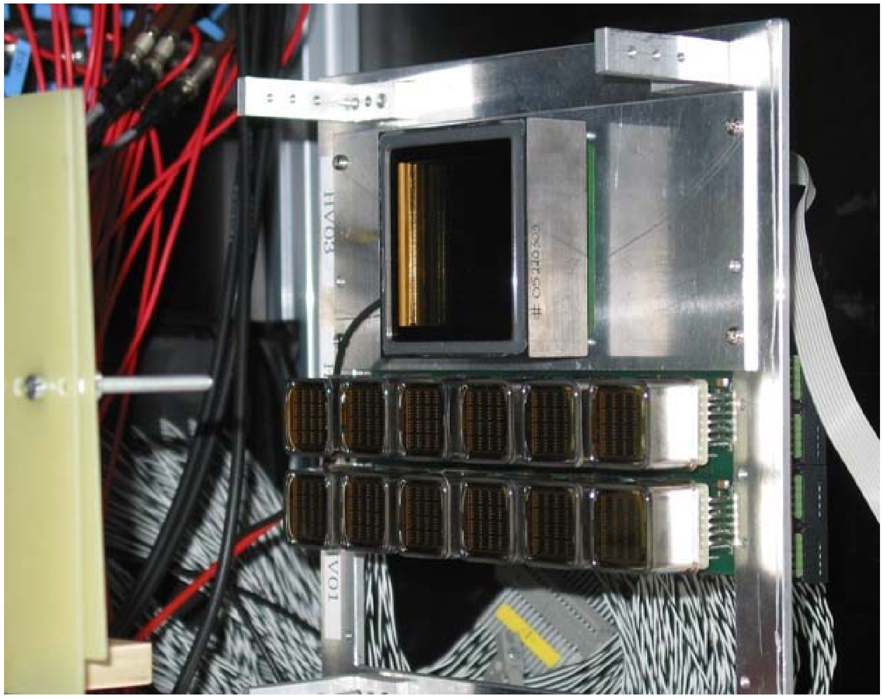


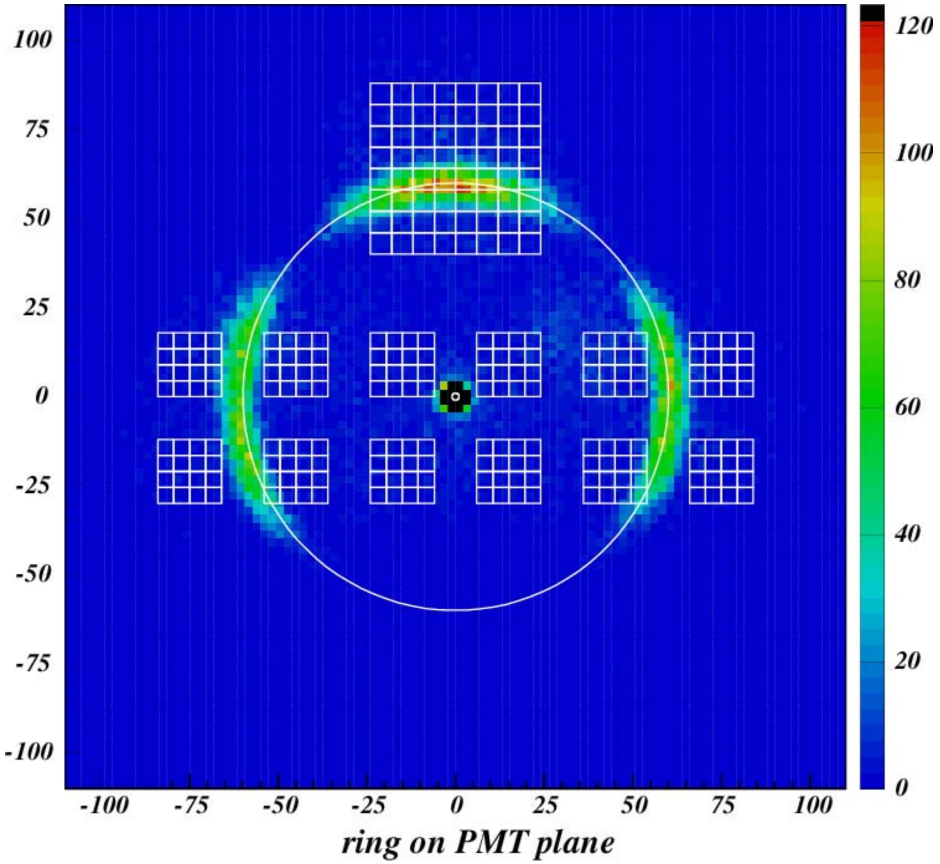
- single photon resolution: dual radiator ~same as single (of half the thickness) for the full momentum range
- number of detected hits: dual radiator has a clear advantage

Overlapp optimized at 4GeV/c→ OK at low momenta as well

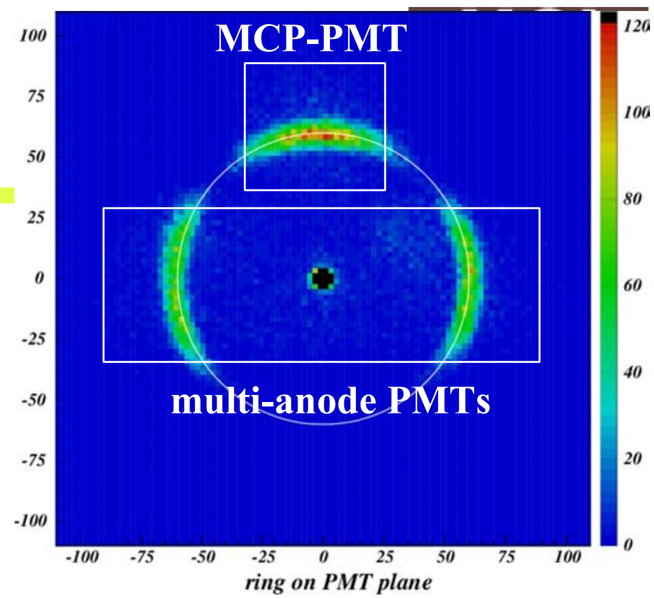
Burle MCP PMT beam test

- **BURLE MCP-PMT** mounted together with an array of 12(6x2) **Hamamatsu R5900-M16 PMTs** at 30mm pitch (reference counter)





Photon detector candidate: MCP-PMT

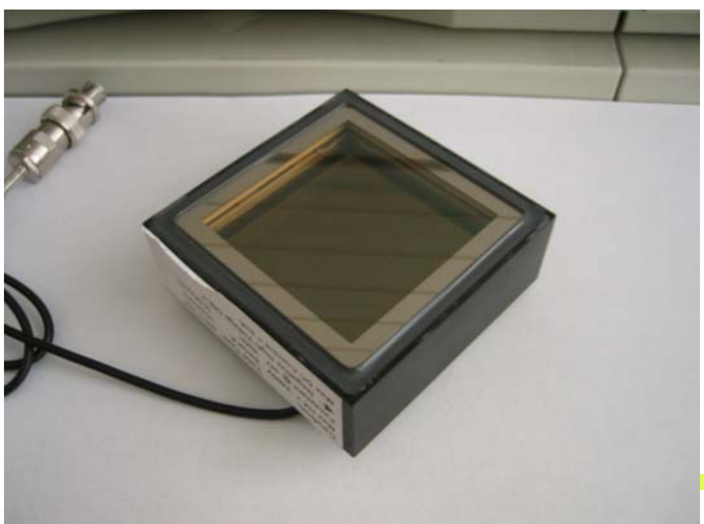


BURLE 85011 MCP-PMT:

- multi-anode PMT with two MCP steps
- 25 μm pores
- bialkali photocathode
- gain ~ 0.6 x 10^6
- collection efficiency ~ 60%
- box dimensions ~ 71mm square
- 64(8x8) anode pads
- pitch ~ 6.45mm, gap ~ 0.5mm
- active area fraction ~ 52%

- Tested in combination with multi-anode PMTs

- σ_ϑ~13 mrad (single cluster)
- number of clusters per track N ~ 4.5
- σ_ϑ~ 6 mrad (per track)
- -> ~ **4 σ π/K separation at 4 GeV/c**



- 10 μm pores required for 1.5T
- collection eff. and active area fraction should be improved
- aging study should be carried out

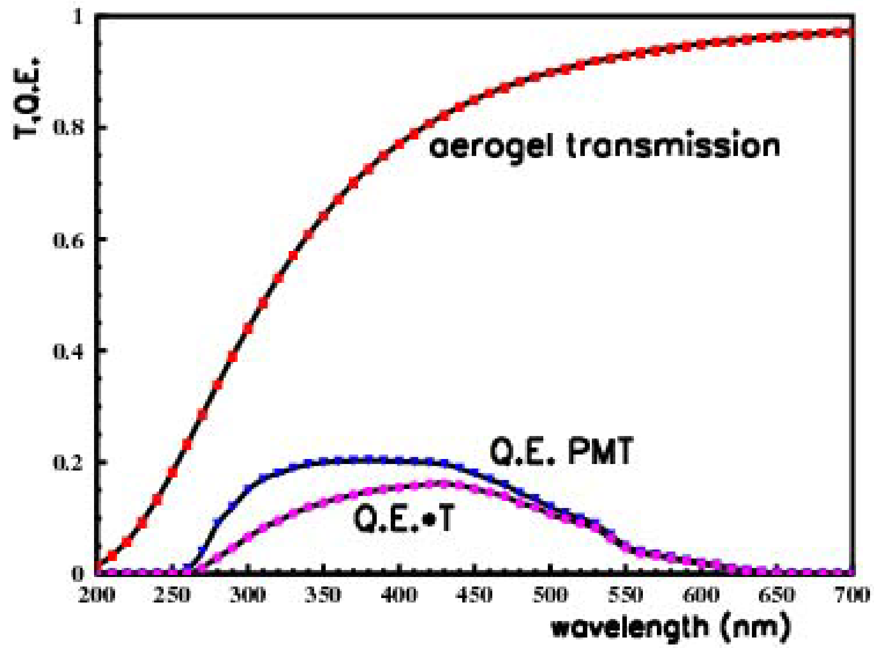
Threshold Čerenkov counters

- Beam veto counters
- Detection of sub-threshold particles in a RICH
- Aerogel Čerenkov counter in Belle: K (below) vs. π (above thr.) by properly choosing n for a given kinematic region

Photon detectors for the aerogel RICH

Needs:

- Operation in high magnetic field (1.5T)
- High efficiency at λ>350nm
- Pad size ~5-6mm

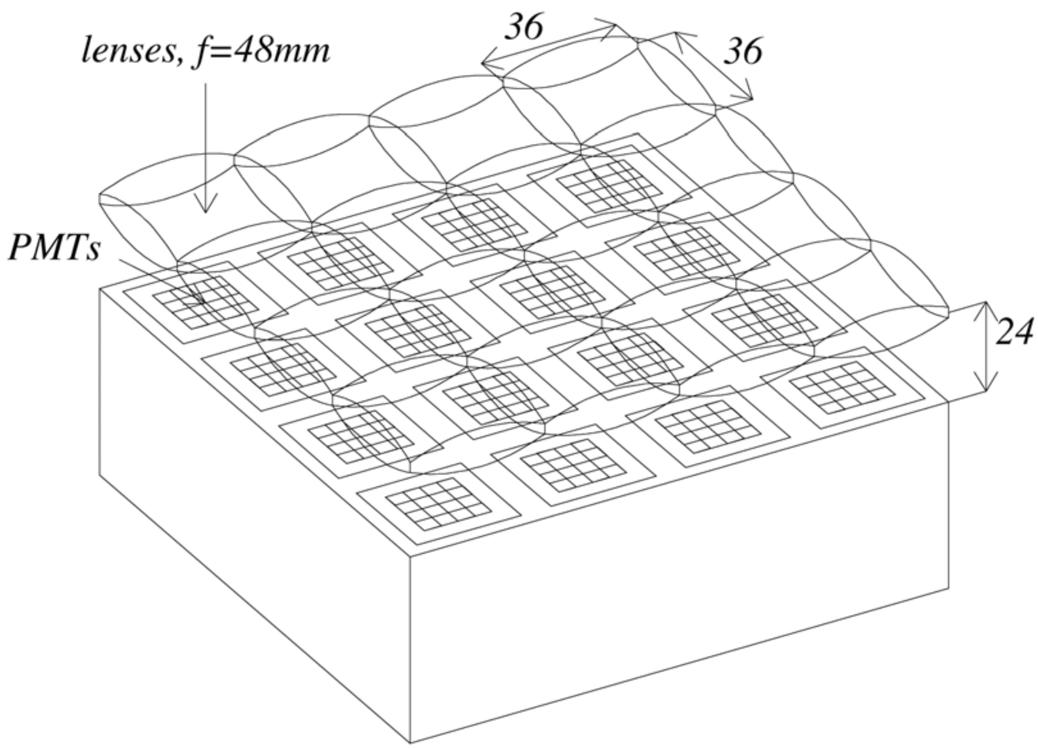


Candidates:

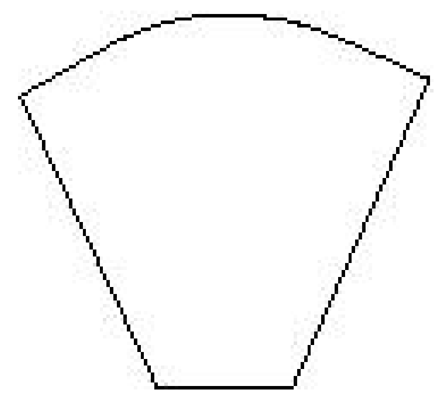
- large area HPD of the proximity focusing type
- MCP PMT (Burle 85011)

Light collection: single vs multi channel

Multichannel device+imaging light collection system: Has a very limited angular acceptance



Single channel: combine a lens and mirror walls



CLEOIII RICH performance

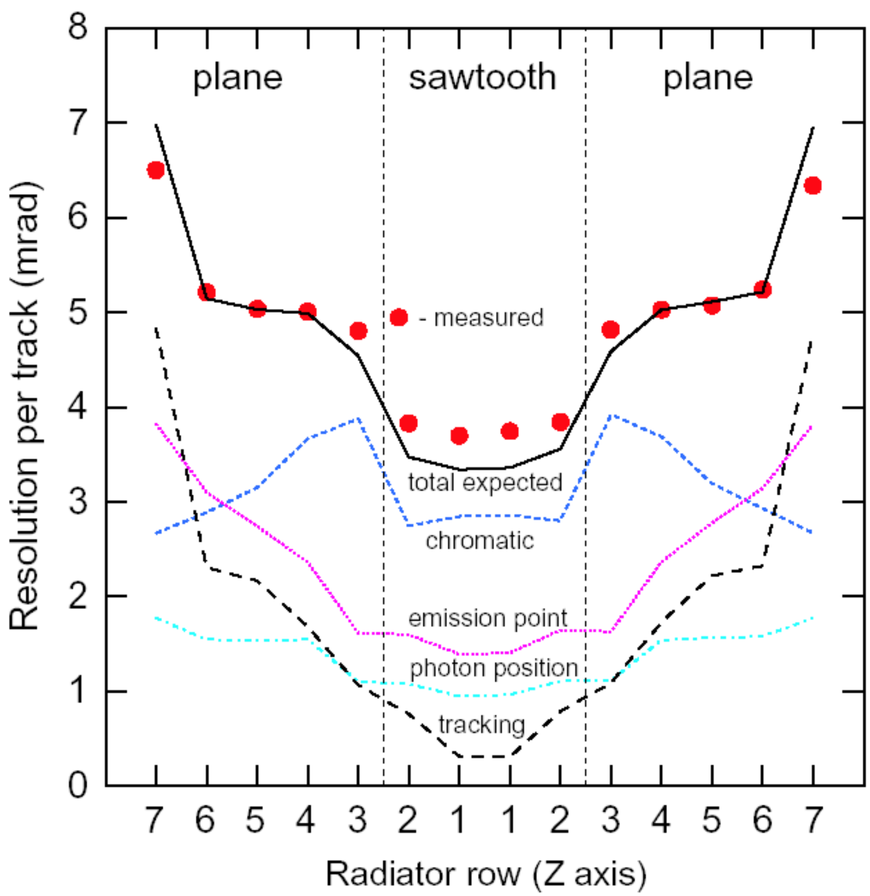


Fig. 2. Cherenkov angle resolution per track versus radiator ring for Bhabha events from data (solid points) and from the sum (solid line) of the different predicted components (as labelled).

The averaged values of the single-photon resolution (σ_θ), the photon yield (N_γ) and the Cherenkov angle resolutions per track (σ_{track}) from Bhabha and hadronic CLEO III events, for flat and sawtooth radiators

Event type	Type of radiators	σ_θ (mrad)	N_γ	σ_{track} (mrad)
Bhabha	Planar	14.7	10.6	4.7
	sawtooth	12.2	11.9	3.6
Hadronic	Planar	15.1	9.6	4.9
	sawtooth	13.2	11.8	3.7

- Excellent performace
- Good agreement with expectations
- Long term stability (4 years)

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Limits of the RICH technique

The choice of RICH radiator medium in case of a specific experiment depends on the particles we would like to identify, and their kinematics:

- the threshold momentum for the lighter of the two particles we want to separate: $\mathbf{p_t = \beta_t \gamma_t m c, \beta_t = 1/n}$ should roughly coincide with the lower limit of momentum spectrum p_{min}. Typically

$$\mathbf{p_{min} \sim 1.5\, p_t}$$

- the resolution in Čerenkov angle should allow for a separation up to the upper limits of kinematically allowed momenta $\mathbf{p_{max}}$

π/K separation example:

Limiting performance at the high momentum side:
irreducible contribution to the resolution – dispersion (n in the Cherenkov relation $\cos\theta = 1/\beta n$ varies with the wavelength)

radiator	LiF solid	C_6F_{14} liquid	C_5F_{12} gas	N_2 gas	He gas
σ_θ (mrad)	7.0	3.9	0.45	0.40	0.13
σ_N (mrad)	2.2	1.2	0.14	0.13	0.04
p_{max} (GeV/c) for 3σ π/K	3.5	6.9	50	100	330
p_{min} (GeV/c)	0.6	0.9	11	28	83

photon detector: TMAE, 10 det. photons assumed

➡ Summary:

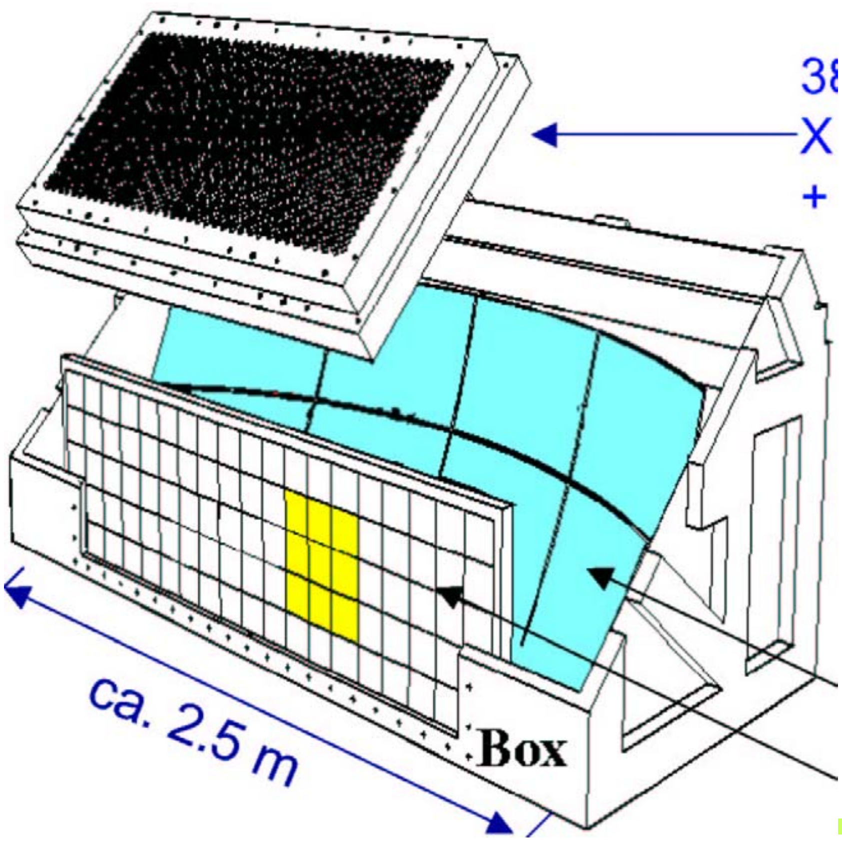
$$\mathbf{p_{max} / p_{min} \sim 4\text{-}7}$$

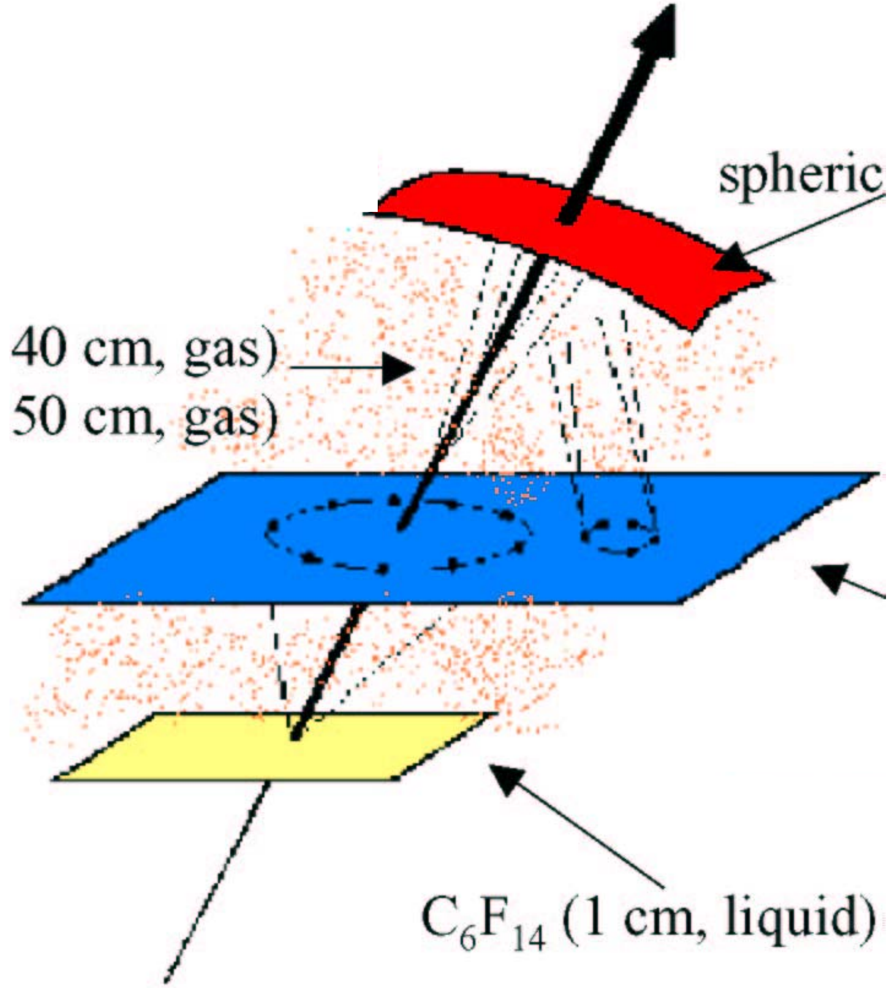
for a 3σ separation between the two particles

For a larger kinematic region **2 radiators are needed!**

RICHes with several radiators

- DELPHI, SLD (liquid+gas)
- HERMES (aerogel+gas)



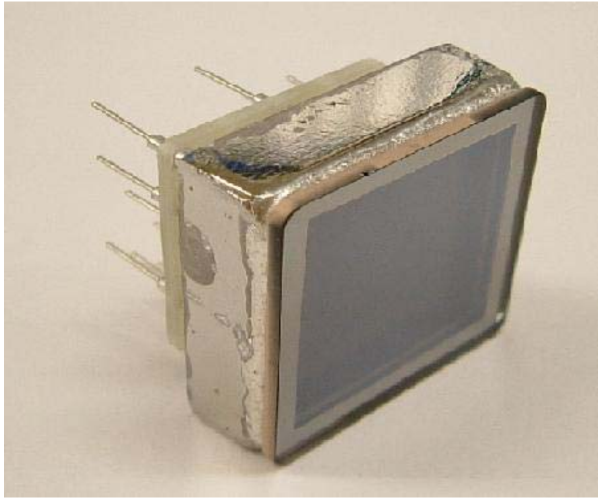


Belle barrel upgrade: TOP counter

Tests on the bench: amplification and time resolution in high magnetic field.

3 MCP-PMTs studied

- Burle (25μm pores)
- Novosibirsk (6μm pores)
- Hamamatsu (6 and 10μm pores)



Hamamatsu SL10

All: good time resolution at B=0

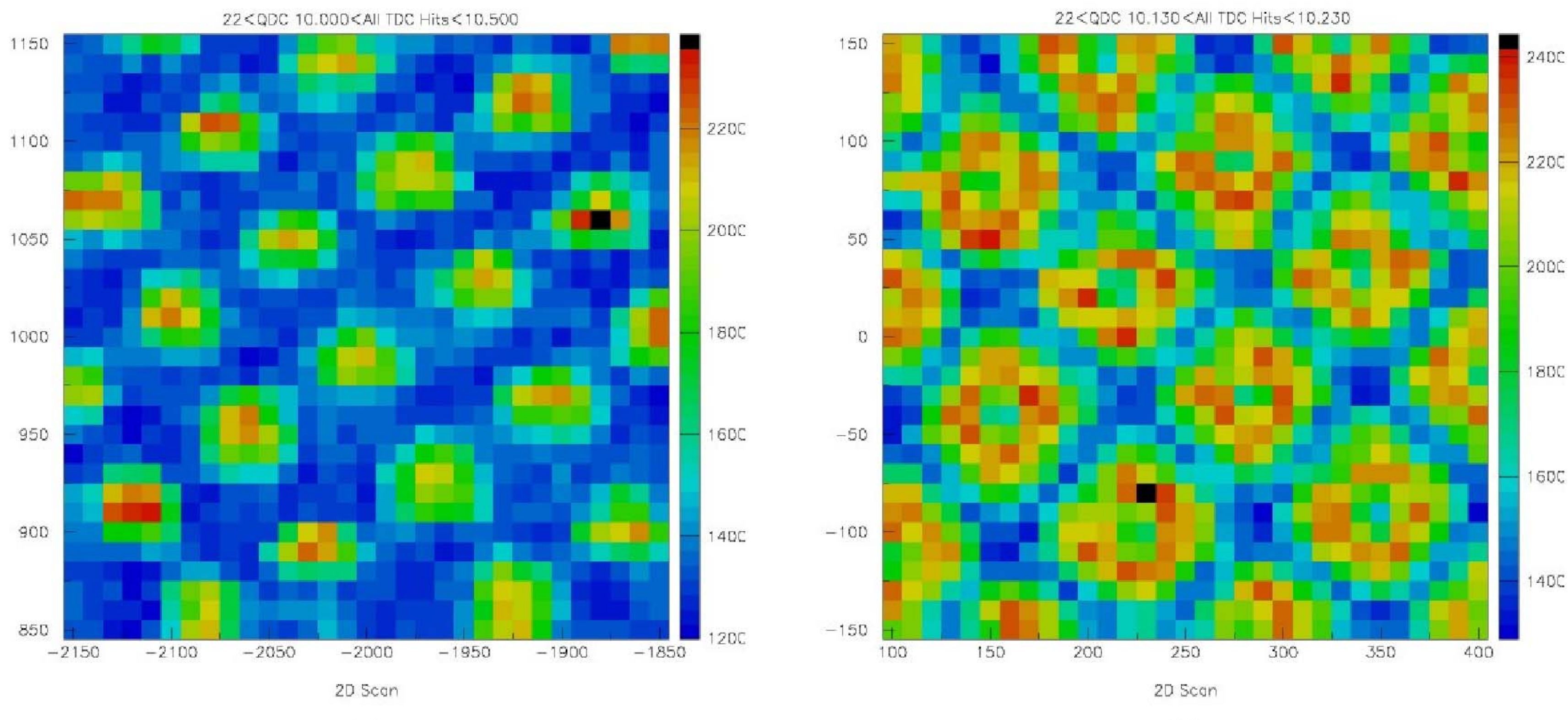
25μm pore tube does not work at 1.5T

NIM A528 (2004) 763

SiPM surface sensitivity

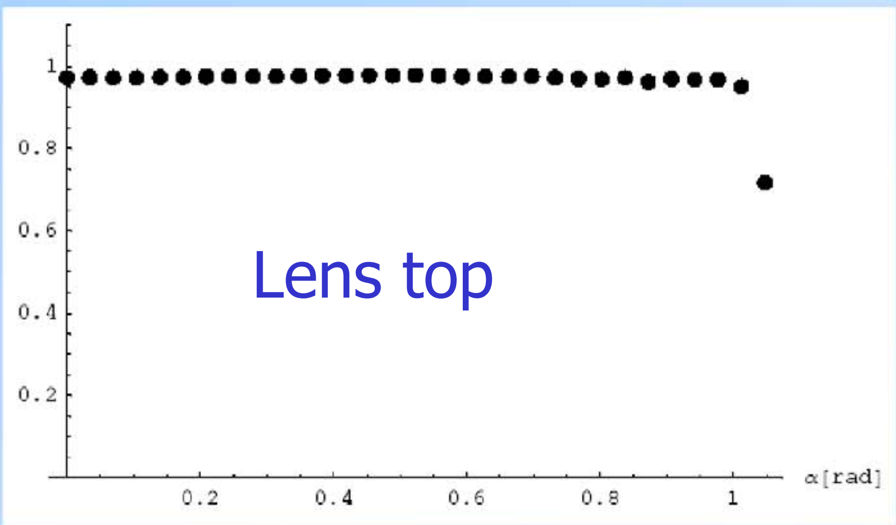
Close-up of the two sensors, 150μm x 150μm, resolution ~5μm

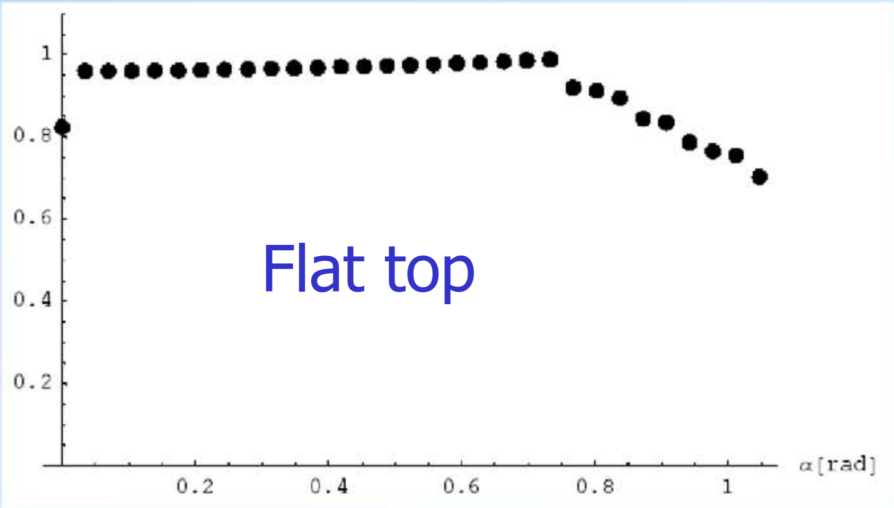
Single photon response

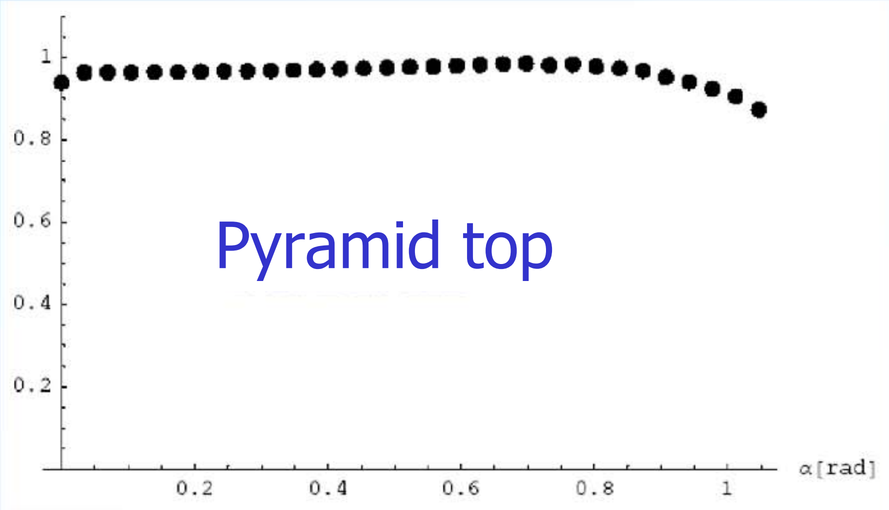


Light collectors: angular acceptance

- efficiency vs. incidence angle for different types





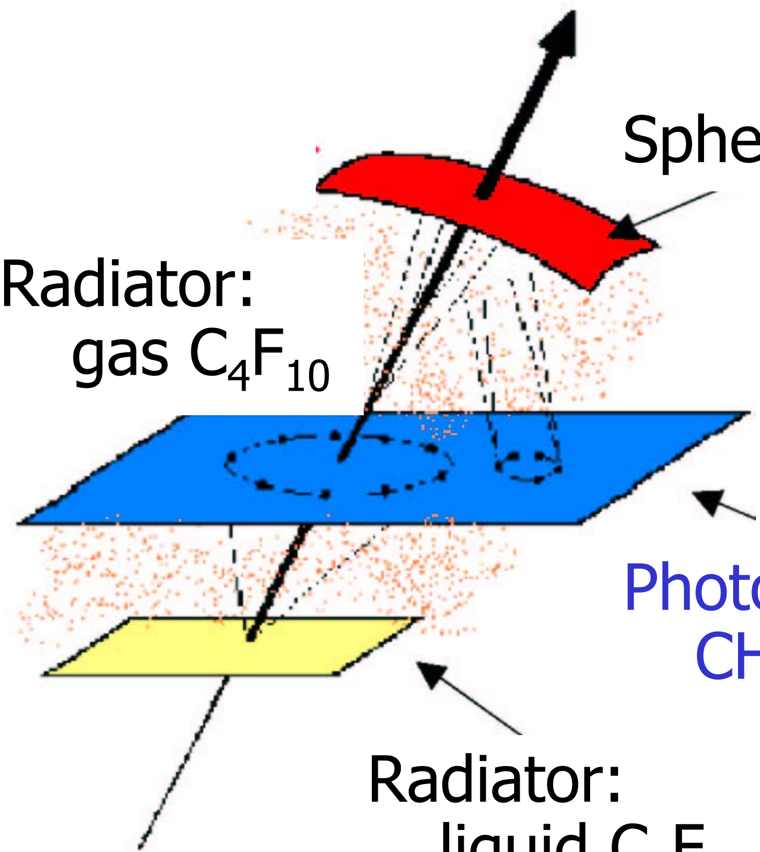


Short historical excursion

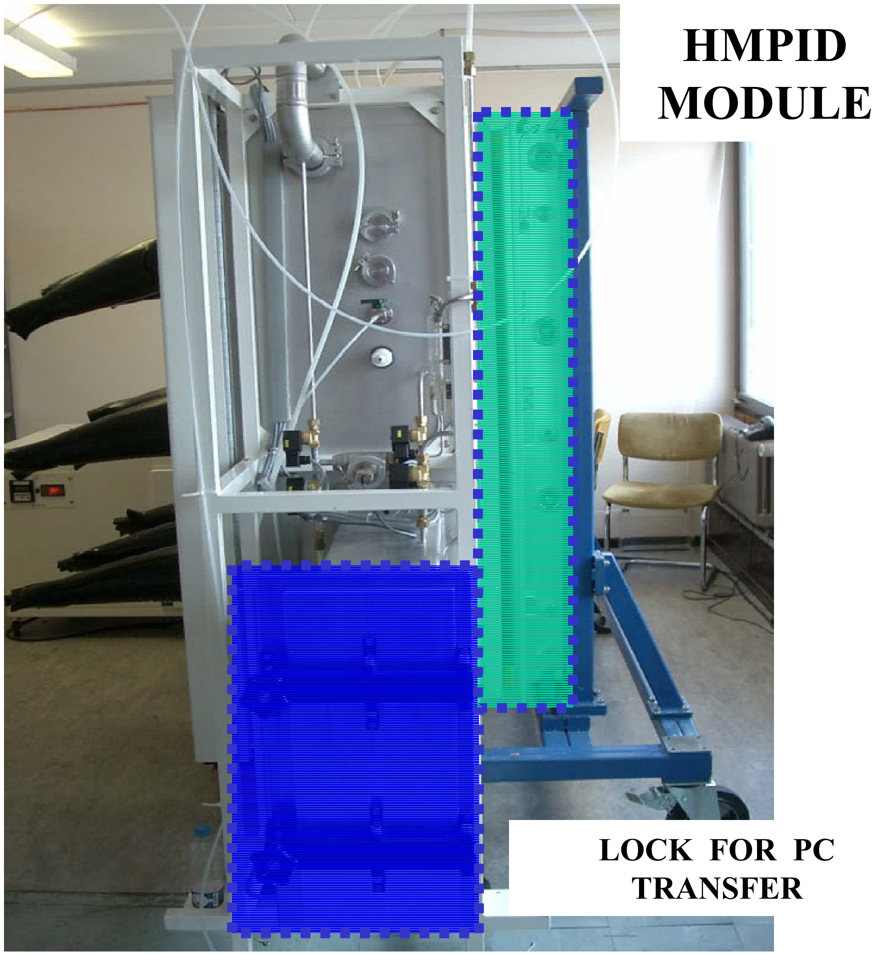
- 1934 Čerenkov characterizes the radiation
- 1938 Frank, Tamm give the theoretical explanation
- 50-ties - 70-ties Čerenkov counters are developed and are being used in nuclear and particle physics experiments, as differential and threshold counters
- 1977 Ypsilantis, Seguinot introduce the idea of a RICH counter with a large area wire chamber based photon detector
- 1981-83 first use of a RICH counter in a particle physics experiment (E605)
- 1992→ first results from the DELPHI RICH, SLD CRID, OMEGA RICH

First generation of RICH counters

Inside the DELPHI RICH:
segmented spherical mirror



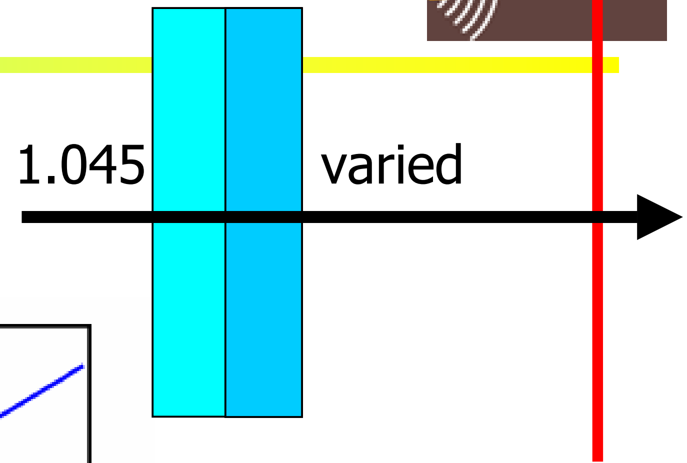
Assembly: Glove box

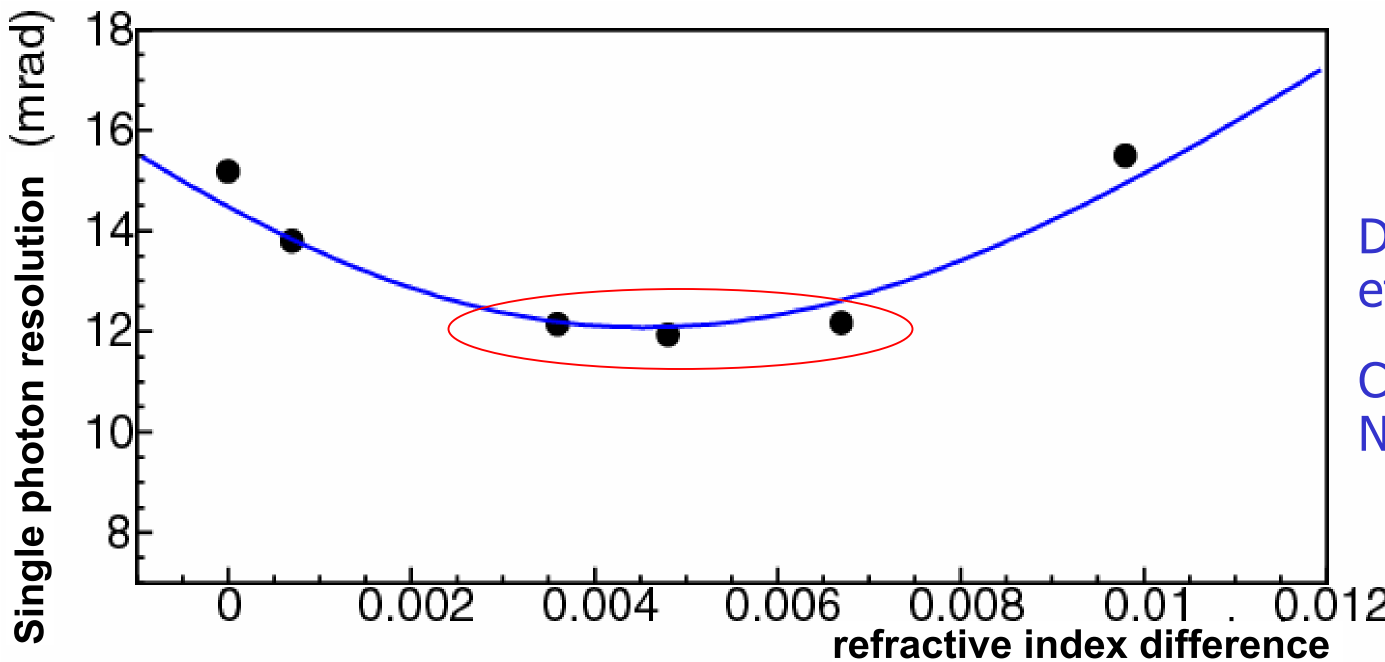


H_2O levels < 10 ppm

Focusing configuration – vary n_2-n_1

- upstream aerogel: d=11mm, n=1.045
- downstream layer: vary refractive index





Data points: S. Korpar et al, Pisa meeting 2006.

Curve: optimisation study NIM A565 (2006) 457

- measured resolution in good agreement with prediction
- a wide minimum allows for some tolerance in aerogel production