Univerza v Ljubljani

Particle identification detectors

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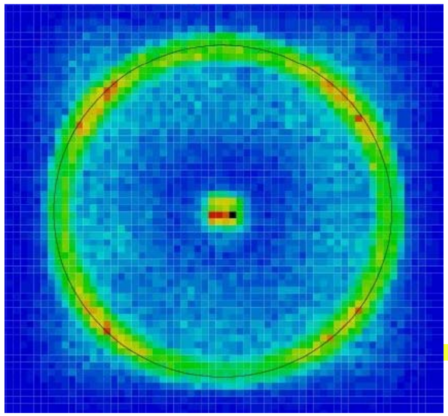


Probing Strangeness in Hard Processes,
Frascati, October 18-21, 2010

Contents

Why particle identification?

Ring Imaging CHerenkov counters

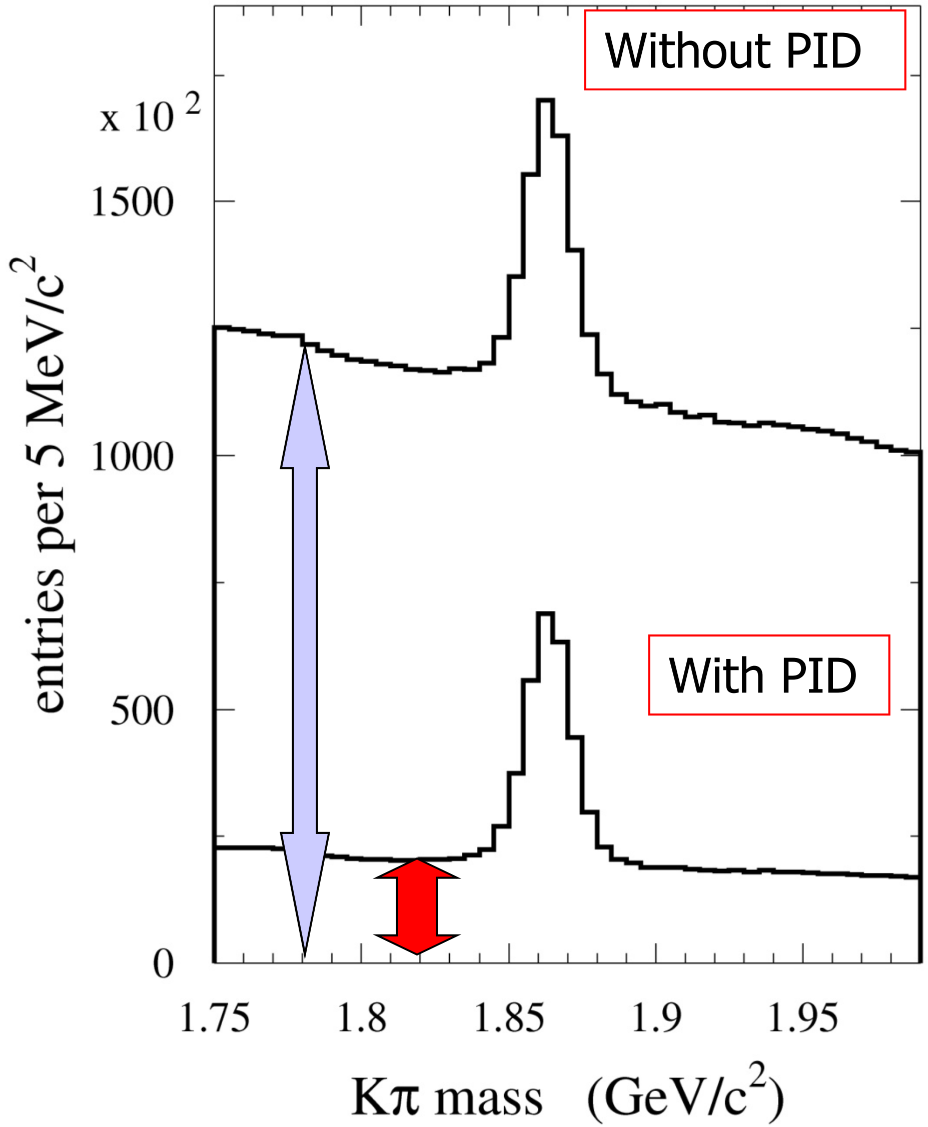
New concepts, photon detectors, radiators

Time-of-flight measurement

Summary

write up in a review paper JINST

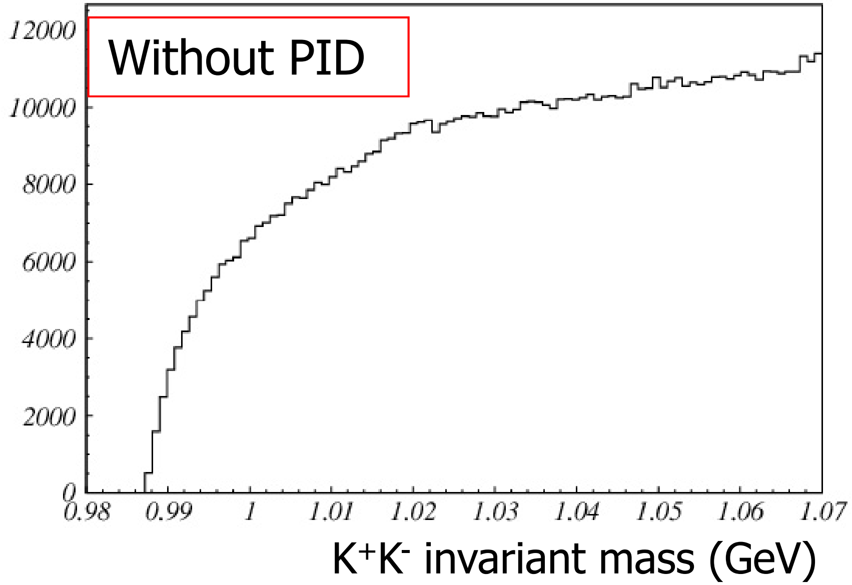
Why particle ID?

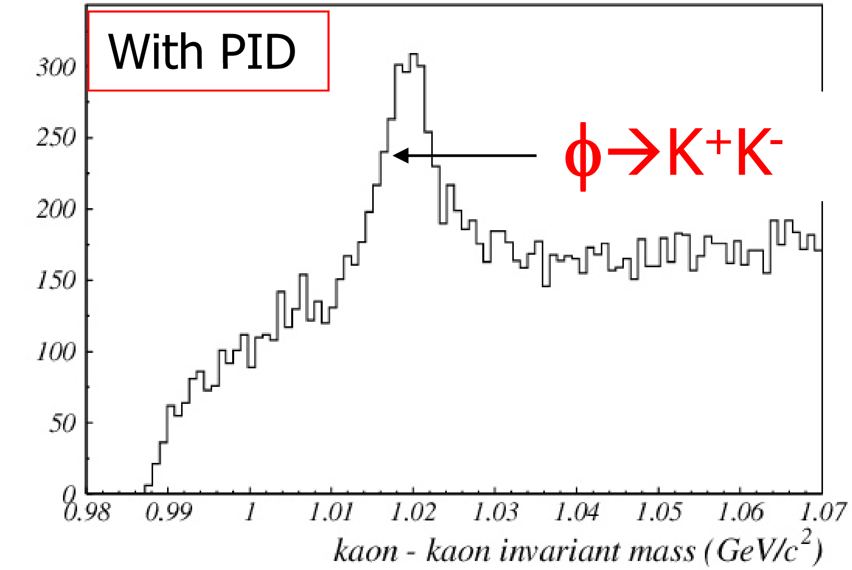


Example 1: B factory

Particle identification reduces the fraction of wrong Kπ combinations (combinatorial background) by ~5x

Why particle ID?





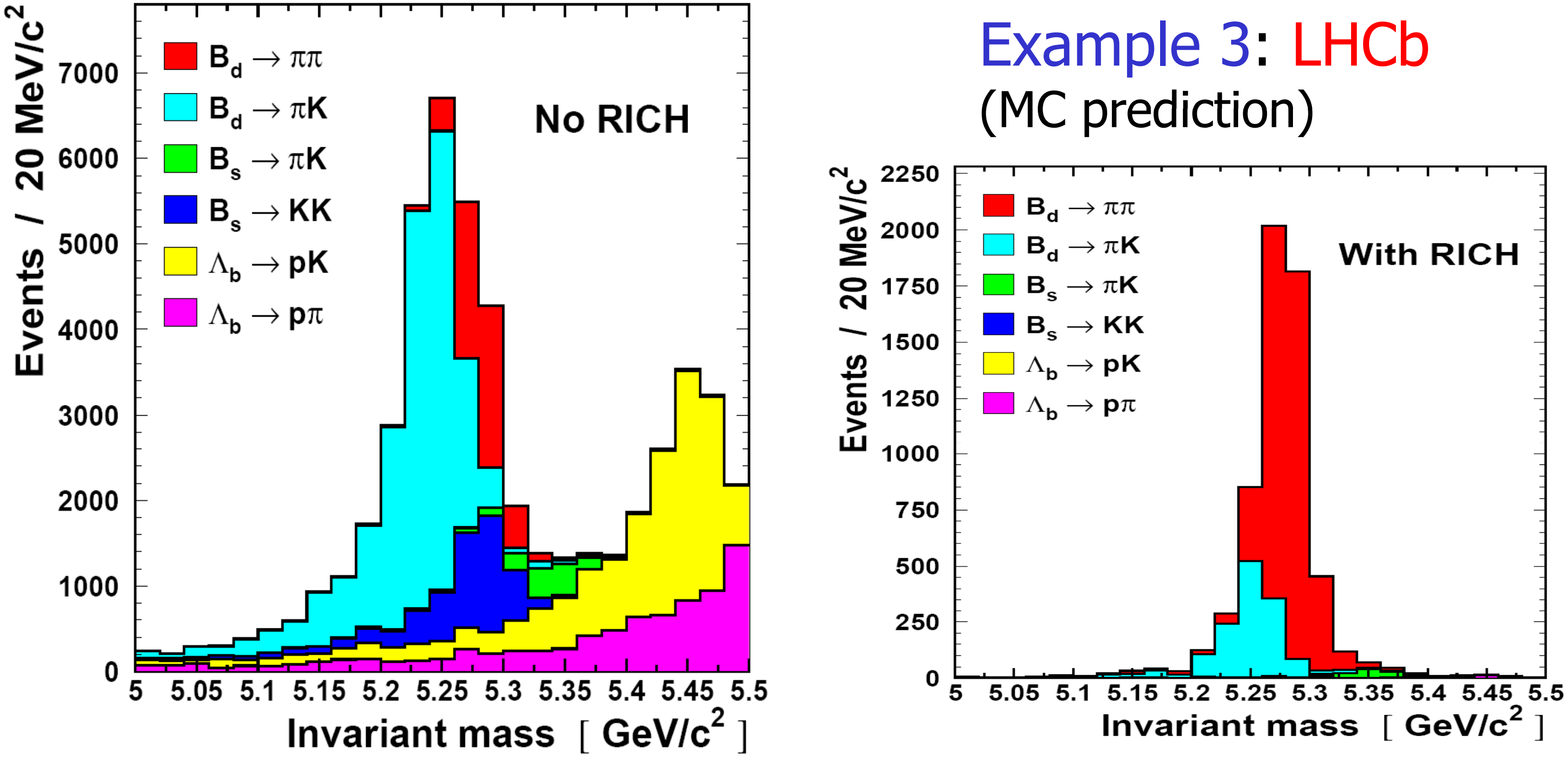
Example 2: HERA-B

K^+K^- invariant mass.

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

Why particle ID?

Example 3: LHCb
(MC prediction)



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

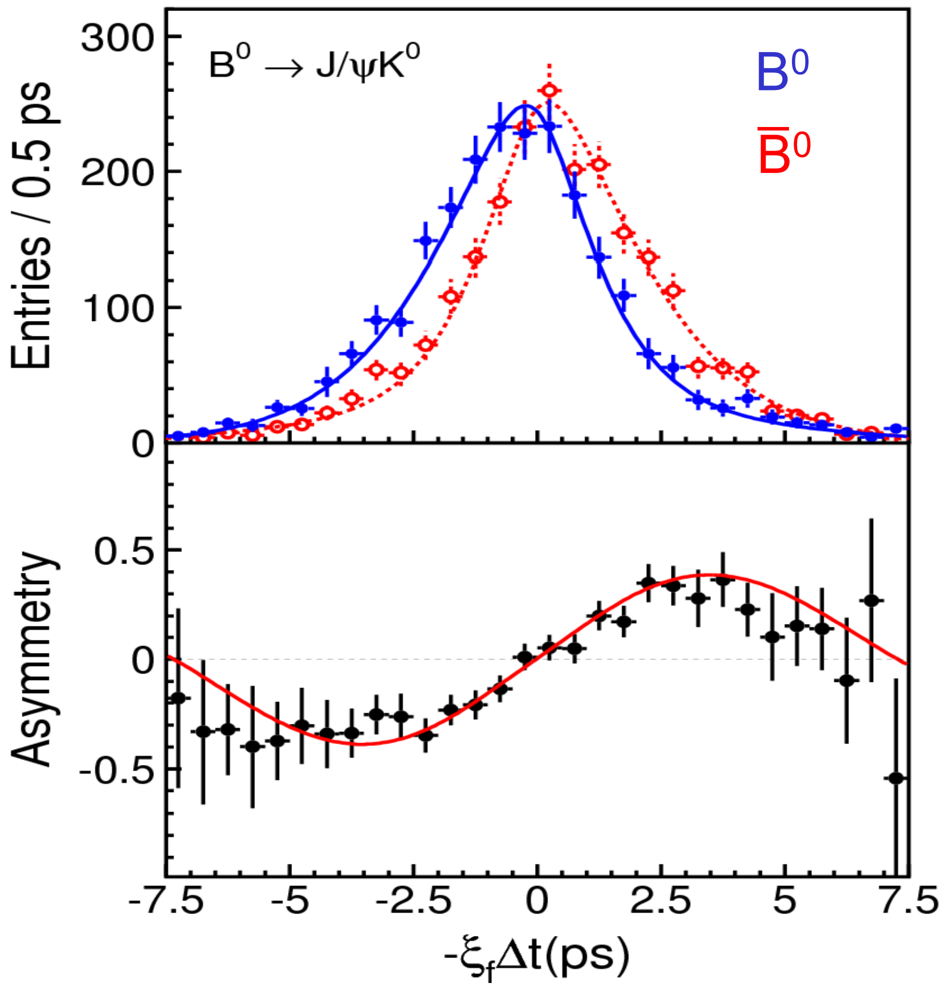
Why particle ID?

PID is also needed in:

- Spectroscopy of charmonium and charmonioum like states
- Spectroscopy of charmed hadrons
- Searches for exotic hadronic states
- Searches for exotic states of matter (quark-gluon plasma)
- Studies of fragmentation functions

Why particle ID?

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

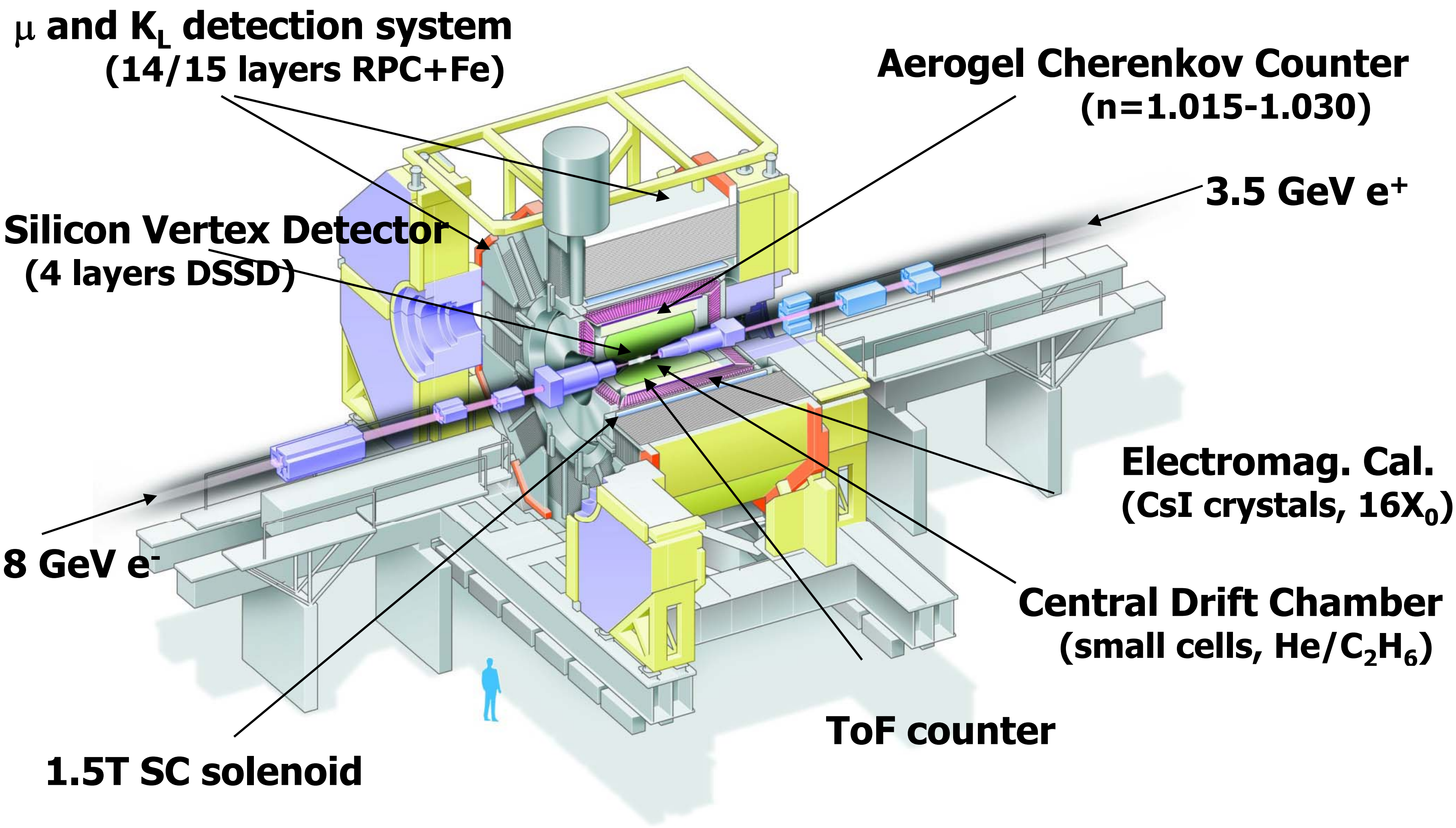


B^0 and its anti-particle decay differently to the same final state $J/\psi\ K^0$

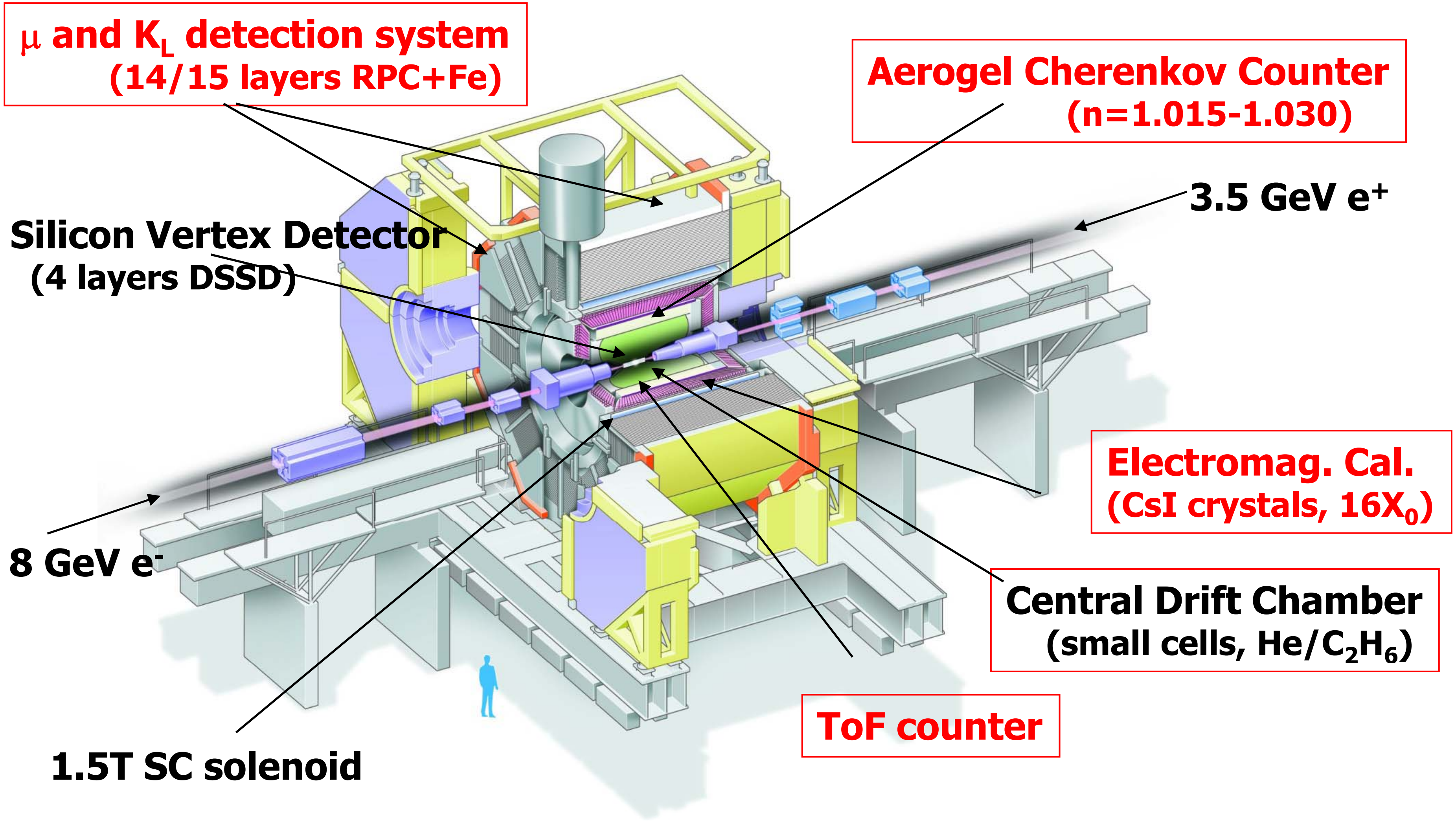
Flavour of the B: from decay products of the other B: charge of the kaon, electron, muon

→particle ID is compulsory

Example: Belle



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
- Cherenkov photon angle (and/or rate)
- transition radiation

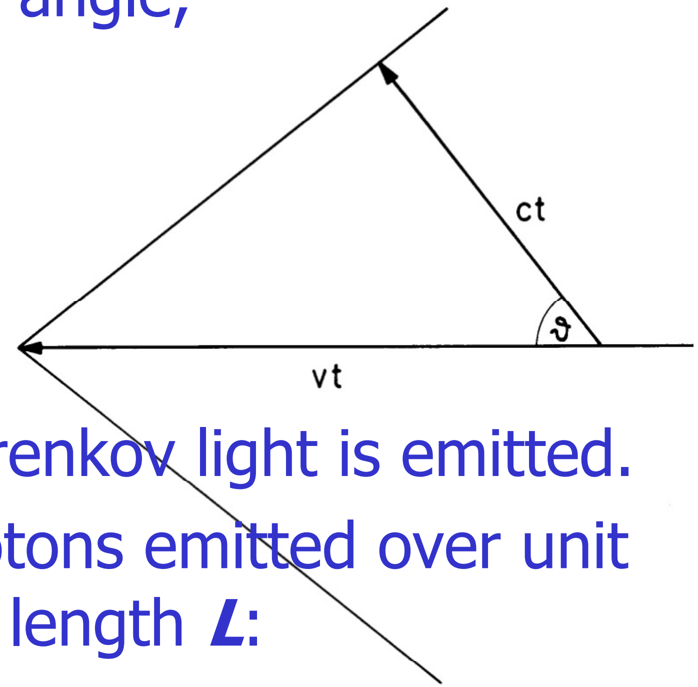
Mainly used for the identification of hadrons.

Identification through interaction: electrons and muons

Cherenkov 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 (Cherenkov) angle,

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



Two cases:

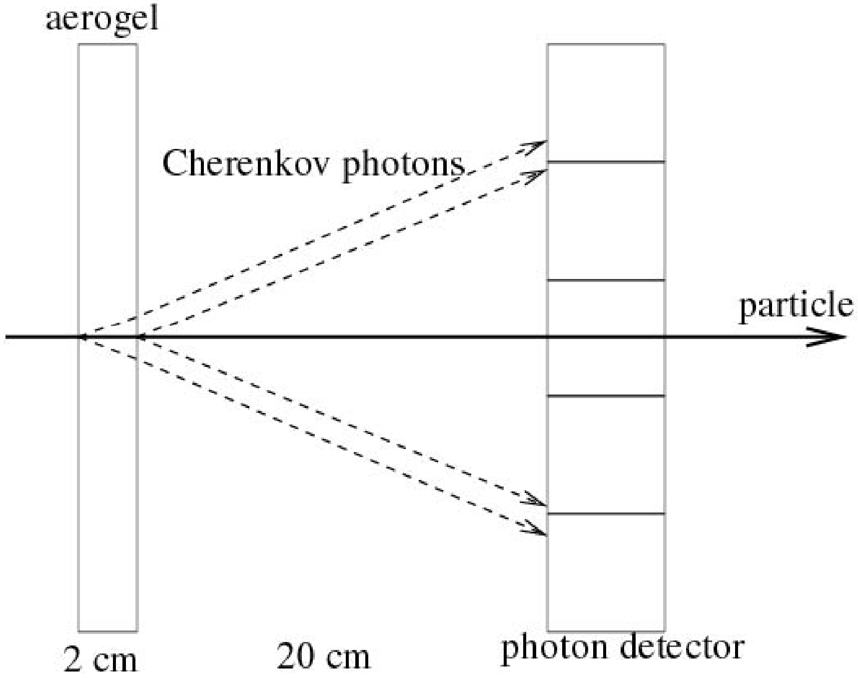
→ $\beta < \beta_t = 1/n$: below threshold no Cherenkov light is emitted.

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

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

→Few detected photons

Measuring Cherenkov angle

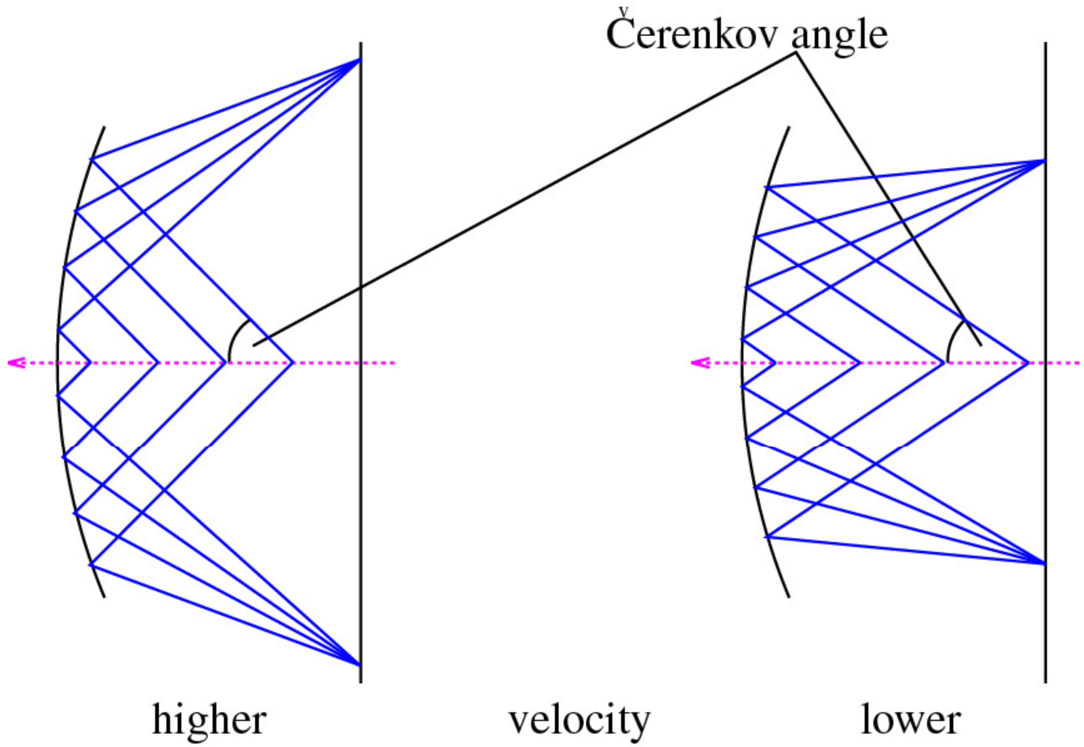


Proximity focusing RICH

Idea: transform the direction into a coordinate →

ring on the detection plane

→ Ring Imaging CHerenkov



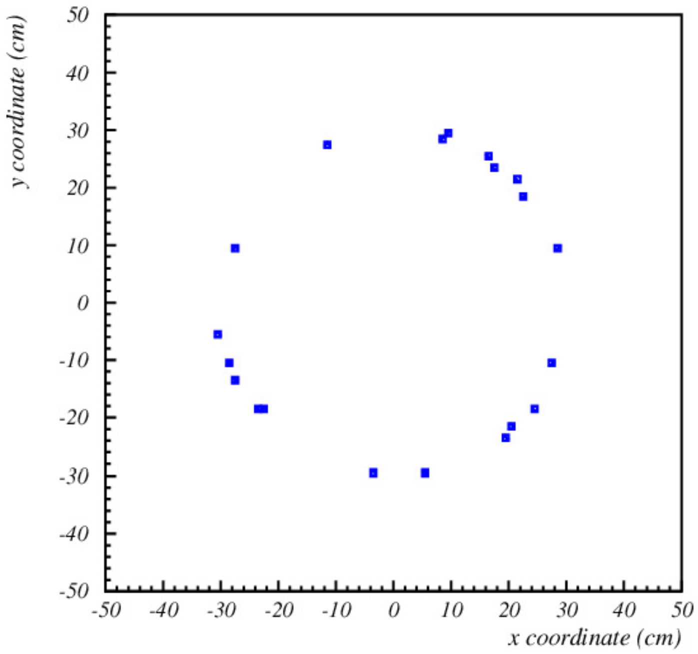
RICH with a focusing mirror

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)



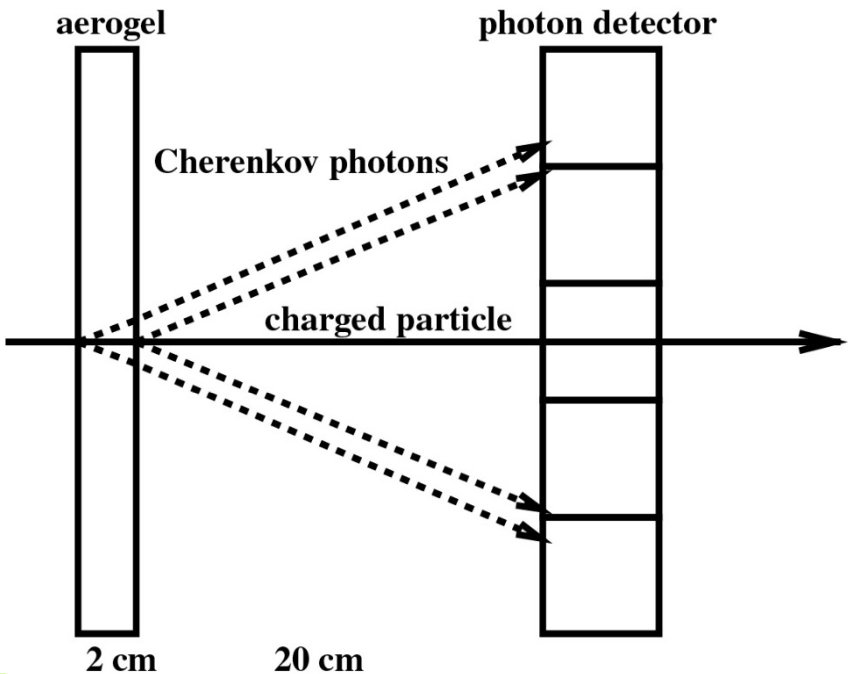
Special requirements:

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

Resolution of a RICH counter

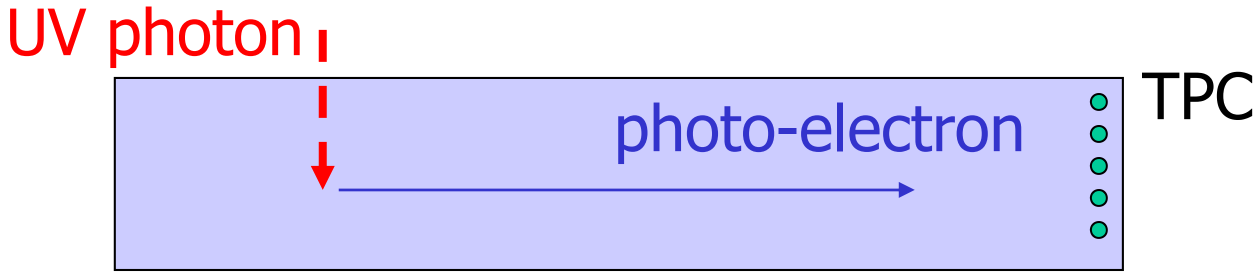
Determined by:

- Photon impact point resolution (~photon detector granularity)
- Emission point uncertainty (not in a focusing RICH)
- Dispersion: $1/\beta = n(\lambda) \cos\theta$
- Errors of the optical system
- Uncertainty in track parameters

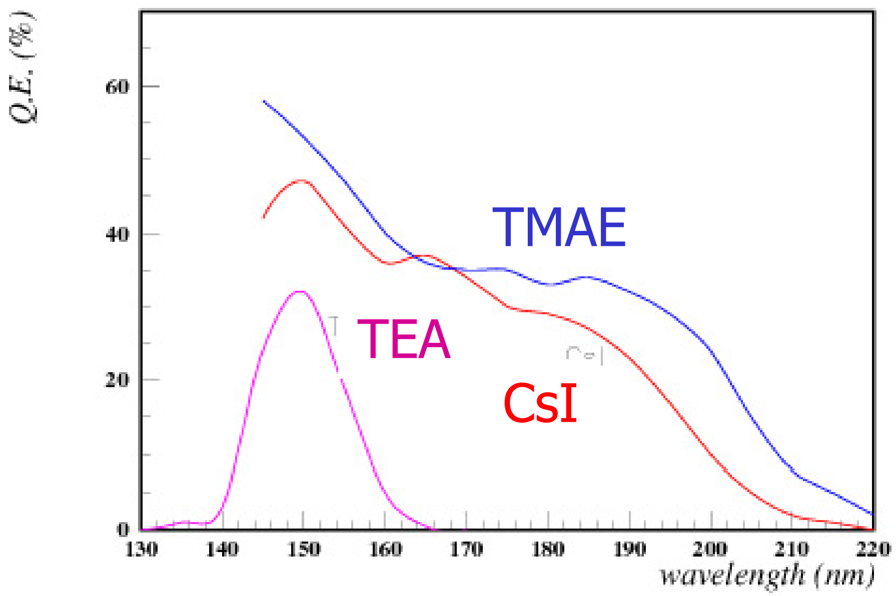


First generation of RICH counters

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

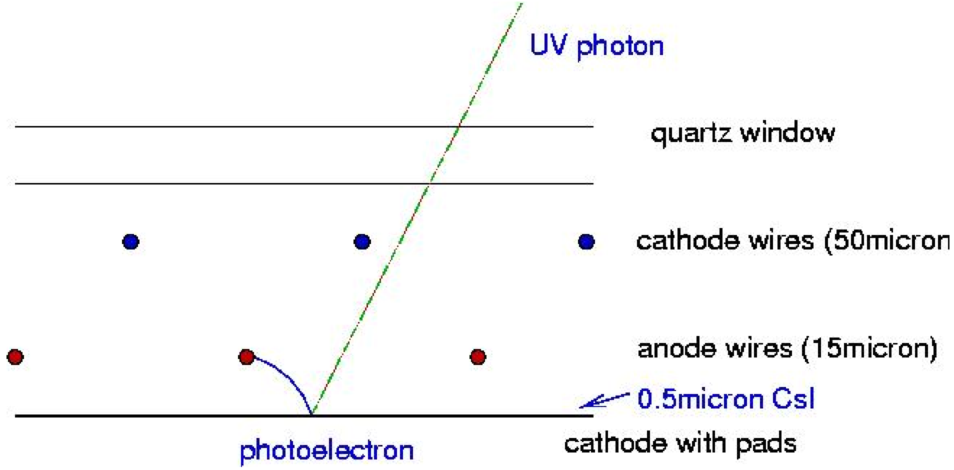


Photosensitive component: TMAE added to the gas mixture



Fast RICH counters with wire chambers

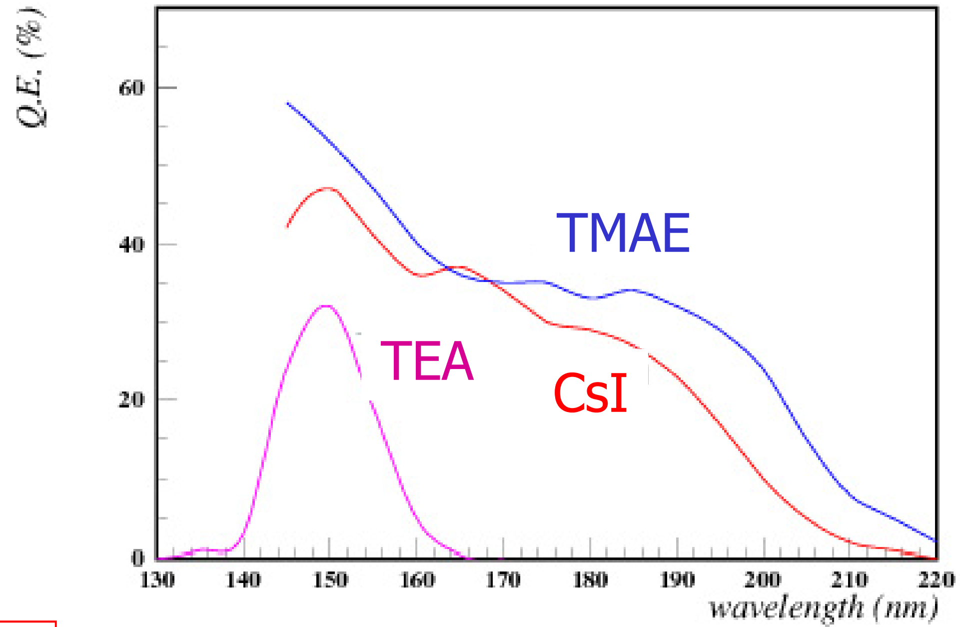
Multiwire chamber with pad read-out: → short drift distances, fast detector



Photosensitive component:

•in the gas mixture (TEA): CLEOIII RICH

•or a layer on one of the cathodes (CsI on the printed circuit pad cathode) →



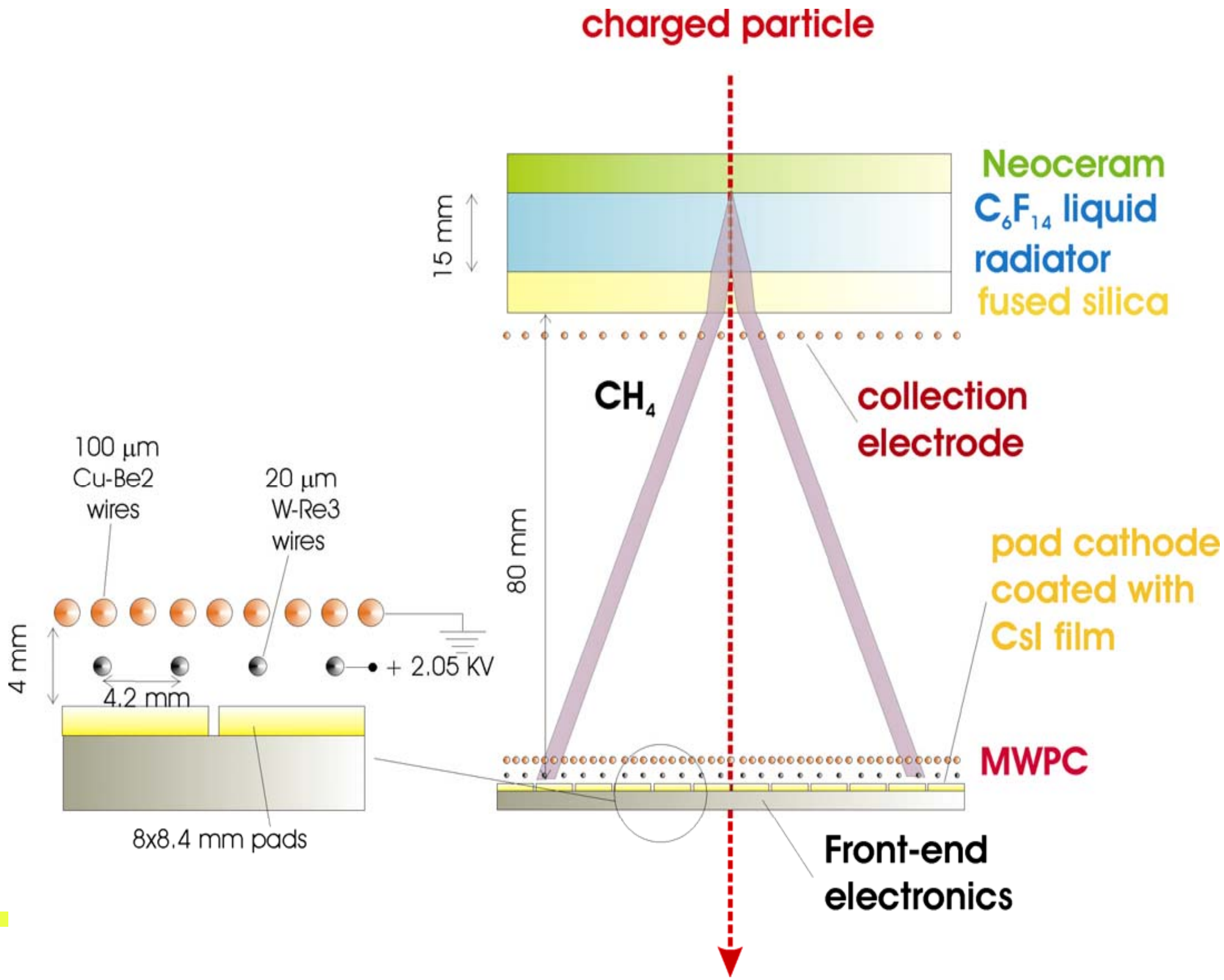
Works in high magnetic field!

CsI based RICH counters: HADES, COMPASS, ALICE

HADES and COMPASS RICH (gas radiator + CsI photocathode): have been running for several years → talk by Fulvio Tessarotto

ALICE:

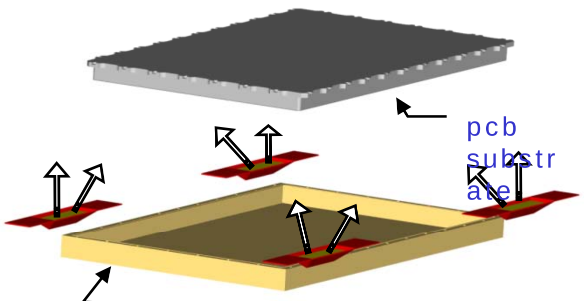
- liquid radiator
- proximity focusing

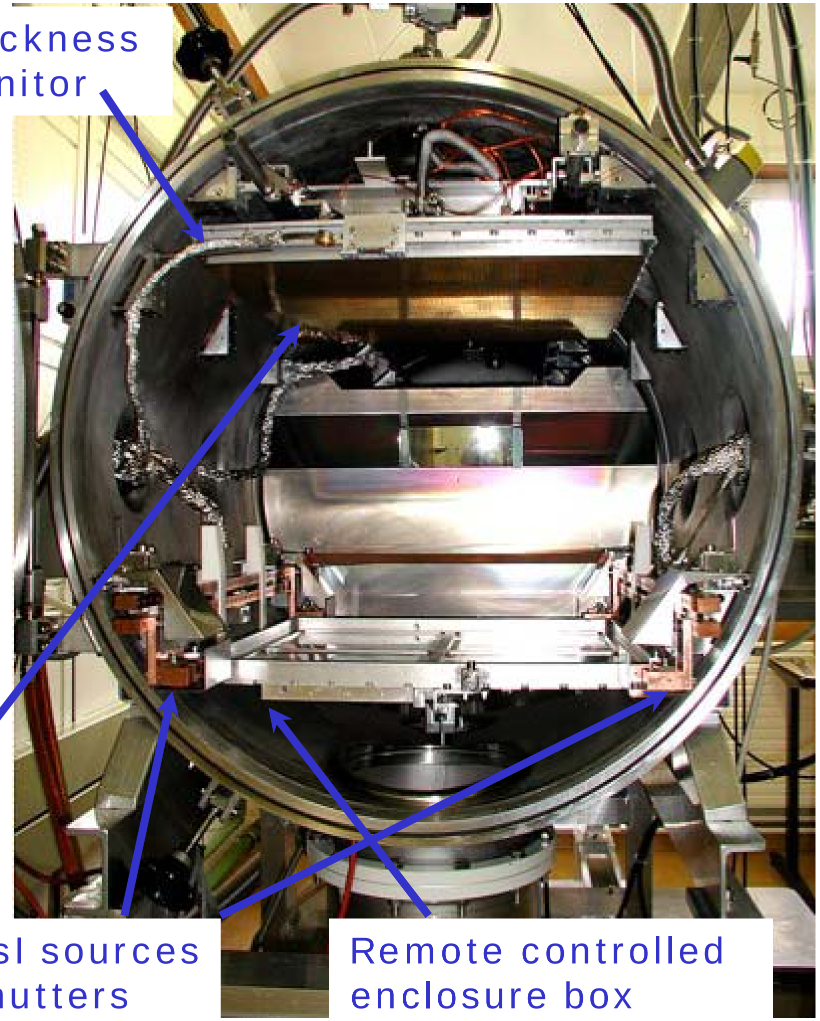


CERN CsI deposition plant

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

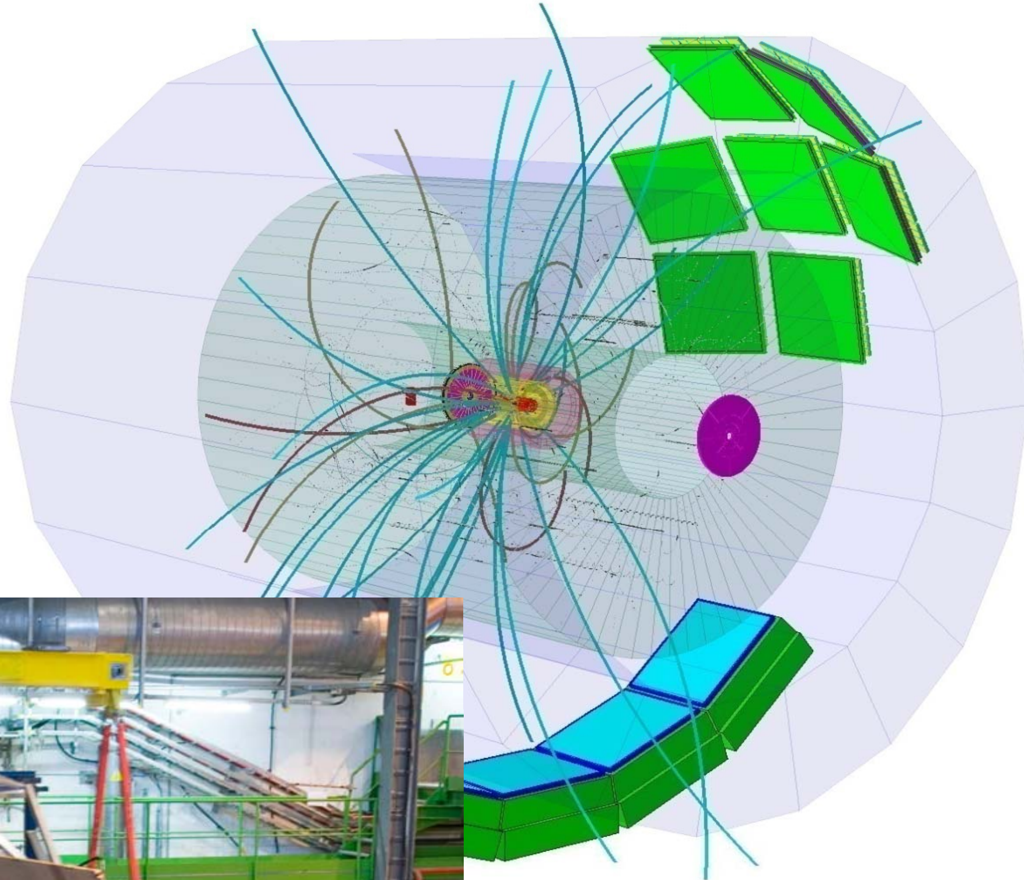
In situ quality control





ALICE RICH

The largest scale (11 m^2) application of CsI photo-cathodes in HEP!

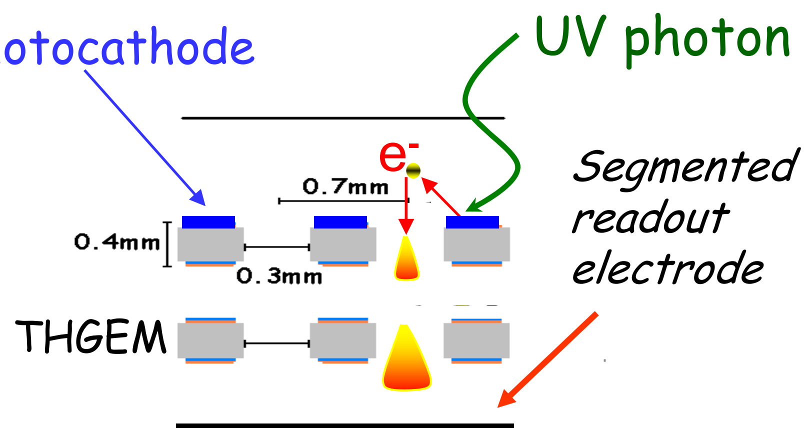


Wire chamber based photon detectors: recent developments

Instead of MWPC:

•Use multiple GEM with semitransparent or reflective photocathode → PHENIX RICH

•Use chambers with multiple thick GEM (THGEM) with transm. or refl. photocathode (considered for the COMPASS RICH)

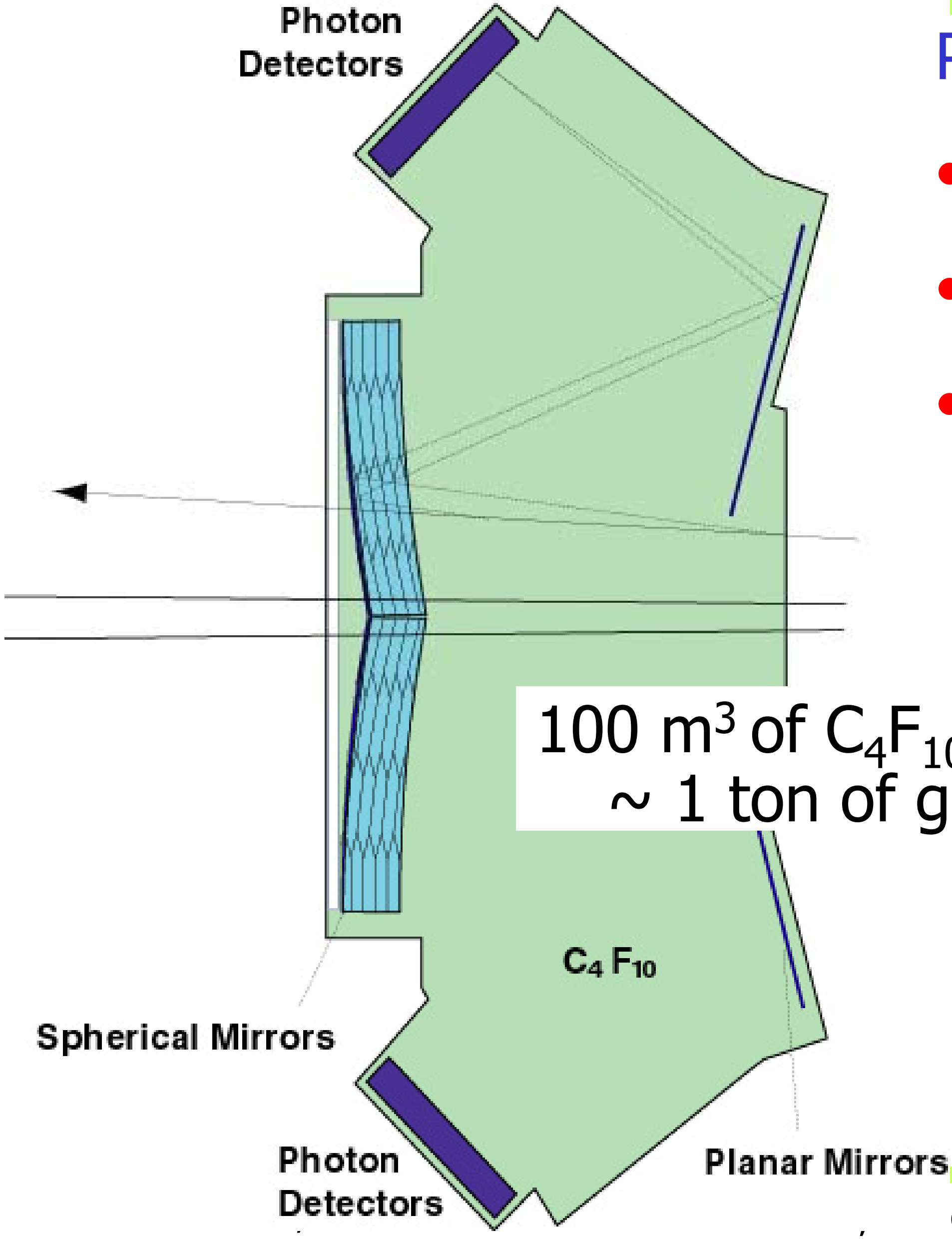


Ion damage of the photocathode: ions can be blocked

Cherenkov counters with vacuum based photodetectors

Some applications: operation at high rates over extended running periods (years) → wire chamber based photon detectors were found to be unsuitable (problems in high rate operation, ageing, only UV photons, difficult handling in 4π spectrometers)

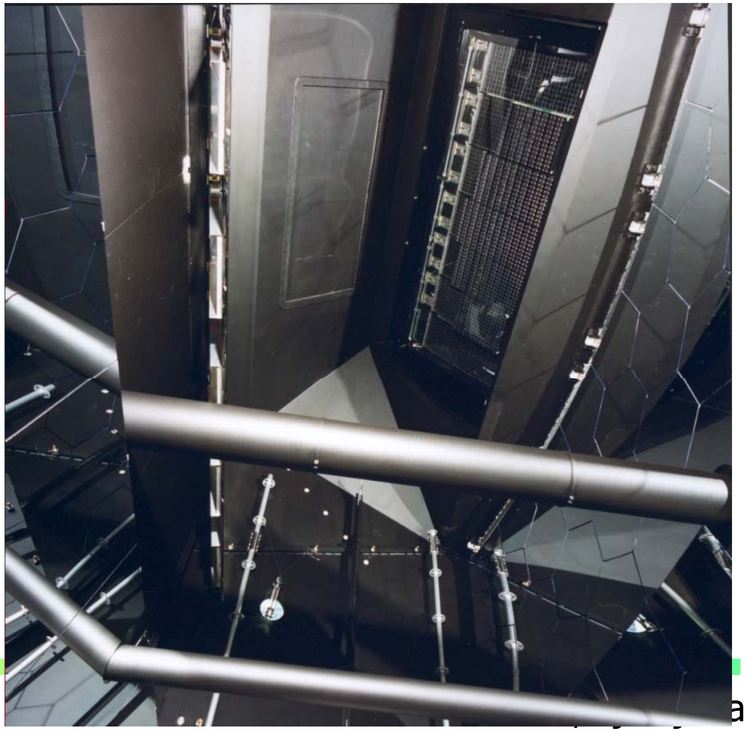
HERA-B RICH



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

Photon detector requirements:

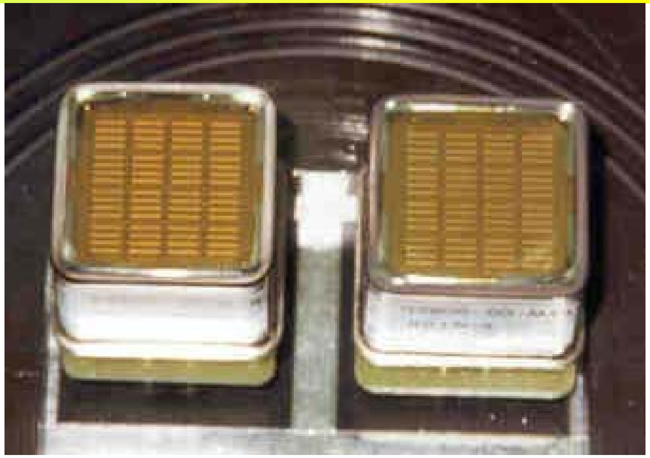
- High QE over ~3m^2
- Rates ~1MHz
- Long term stability

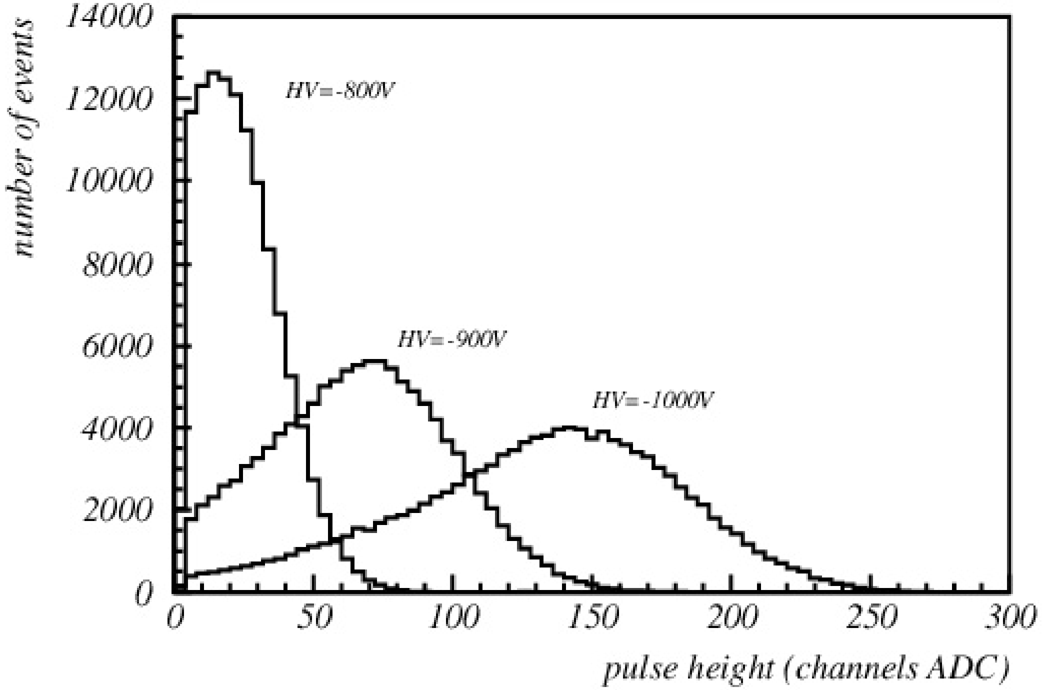


Multianode PMT Hamamatsu R5900-M16

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%)

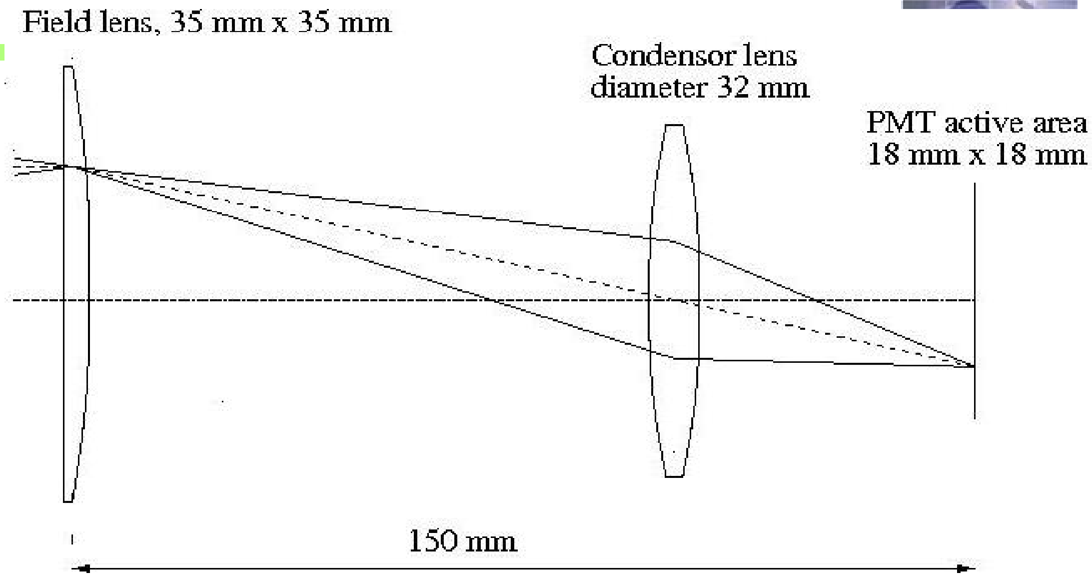
→ NIM A394 (1997) 27

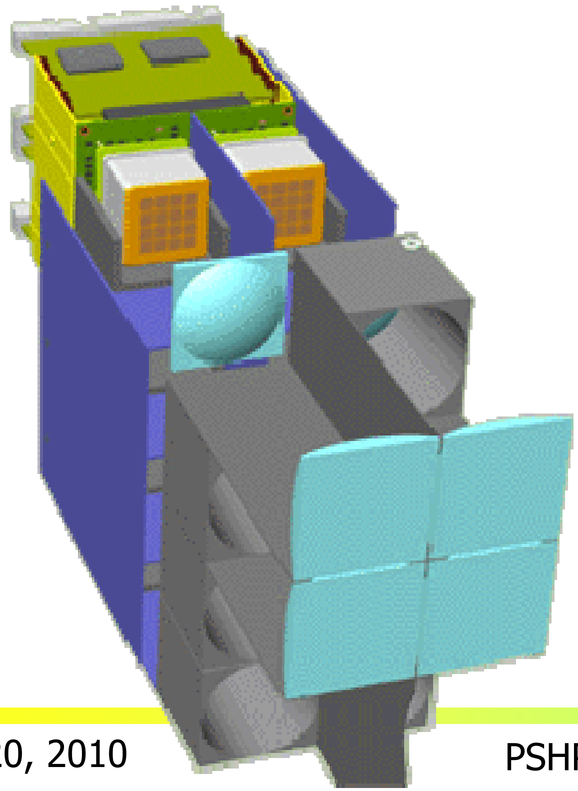
HERA-B RICH photon detector

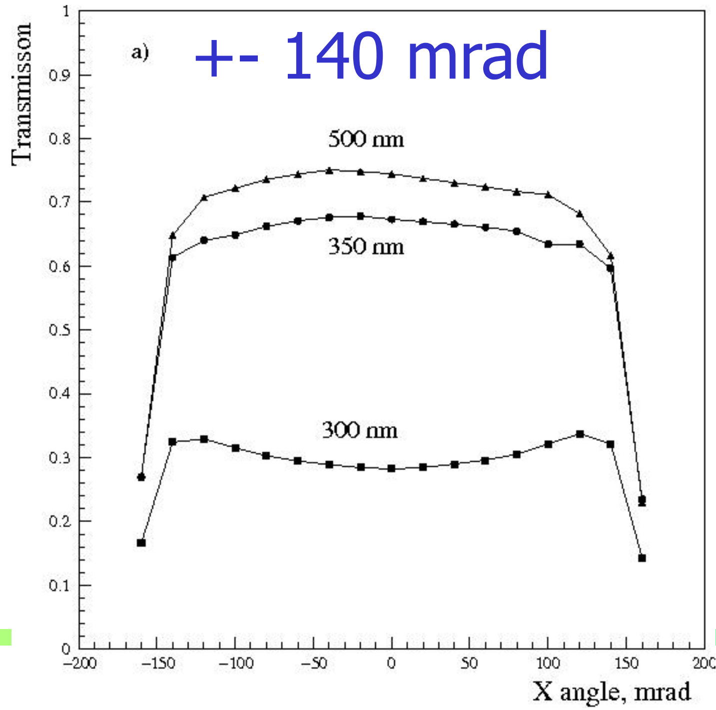
Light collection system (imaging!) to:

-Eliminate dead areas

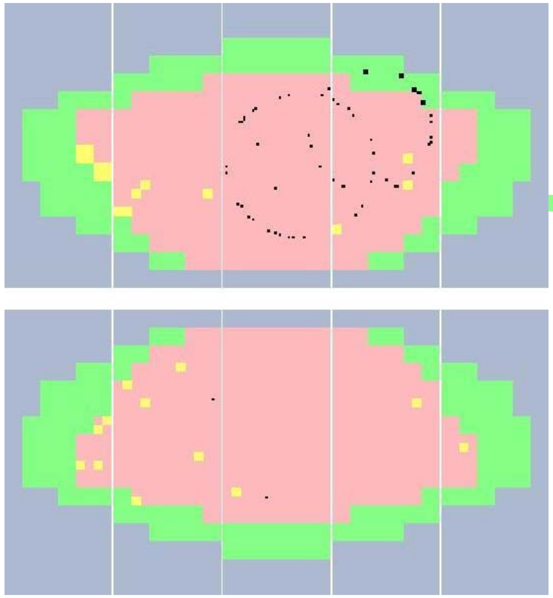
-Adapt the pad size





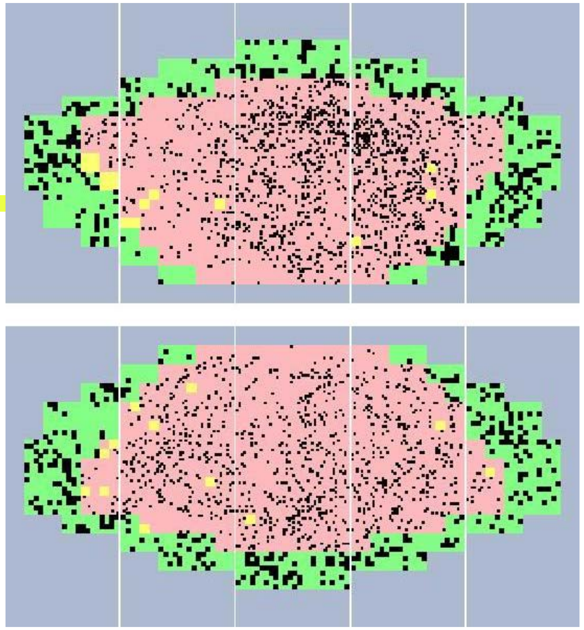


HERA-B RICH

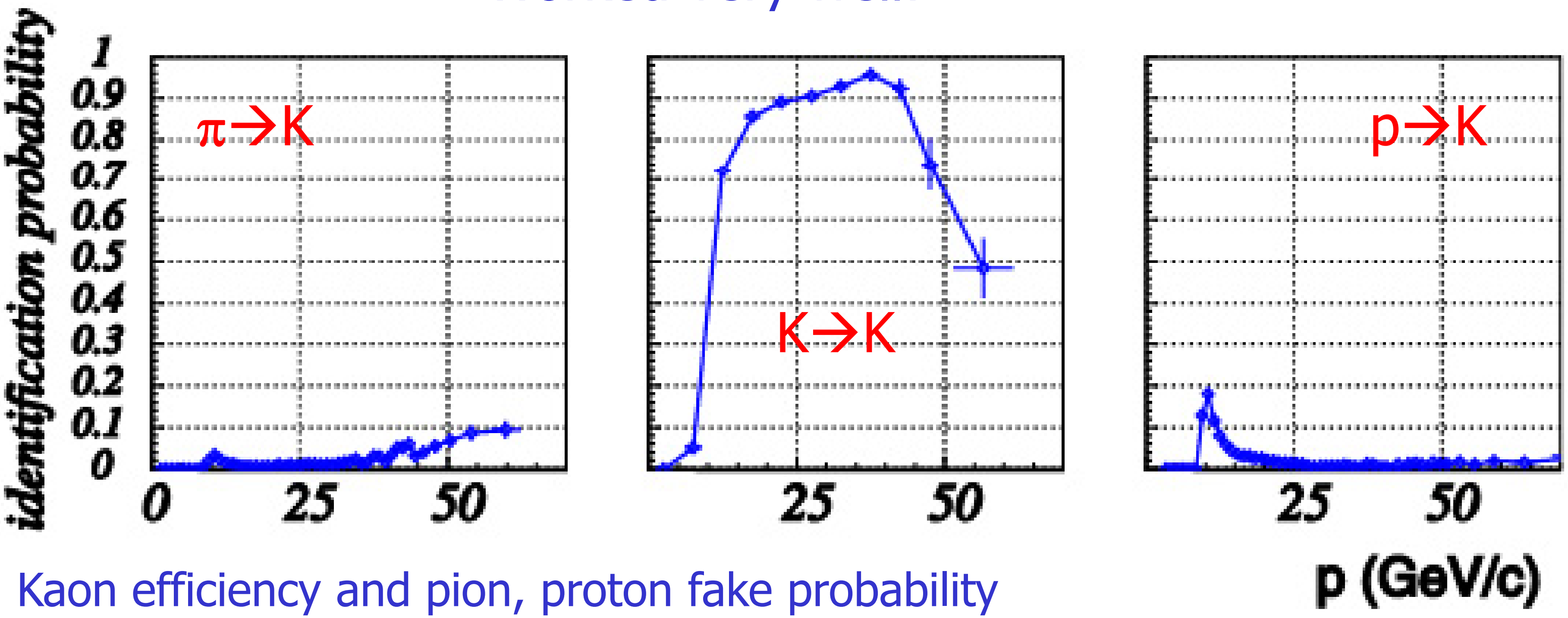


← Little noise, ~30 photons per ring

Typical event →

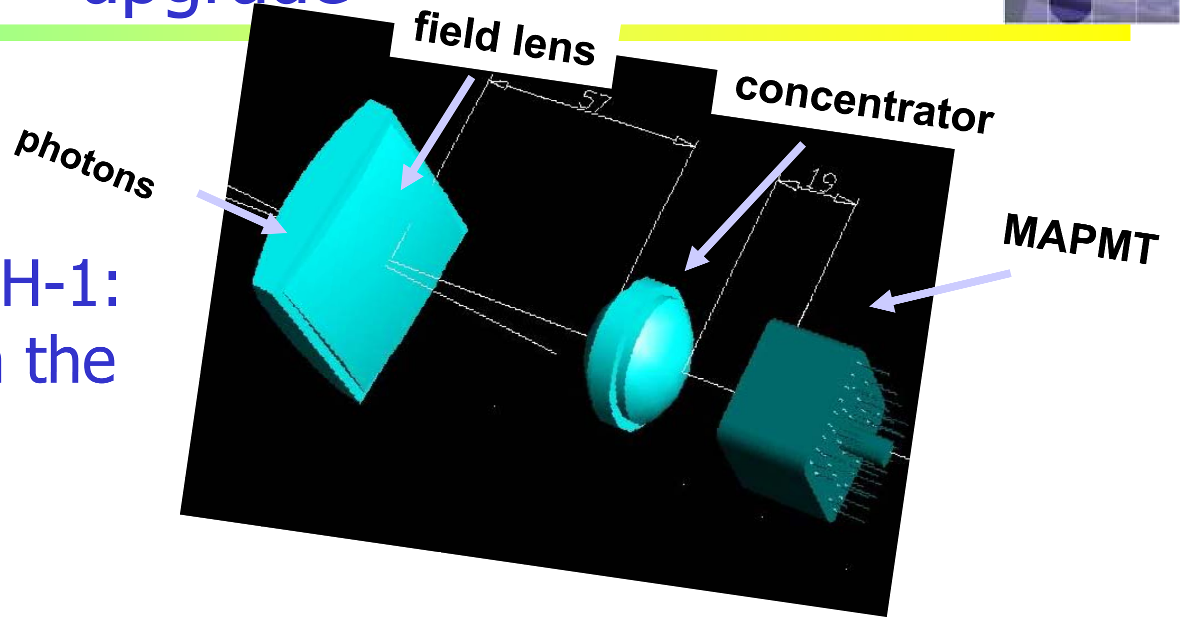


Worked very well!



Kaon efficiency and pion, proton fake probability

Photon detector for the COMPASS RICH-1 upgrade



Upgraded COMPASS RICH-1:
similar concept as in the HERA-B RICH

New features:

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

→ Talk by Fulvio Tessarotto

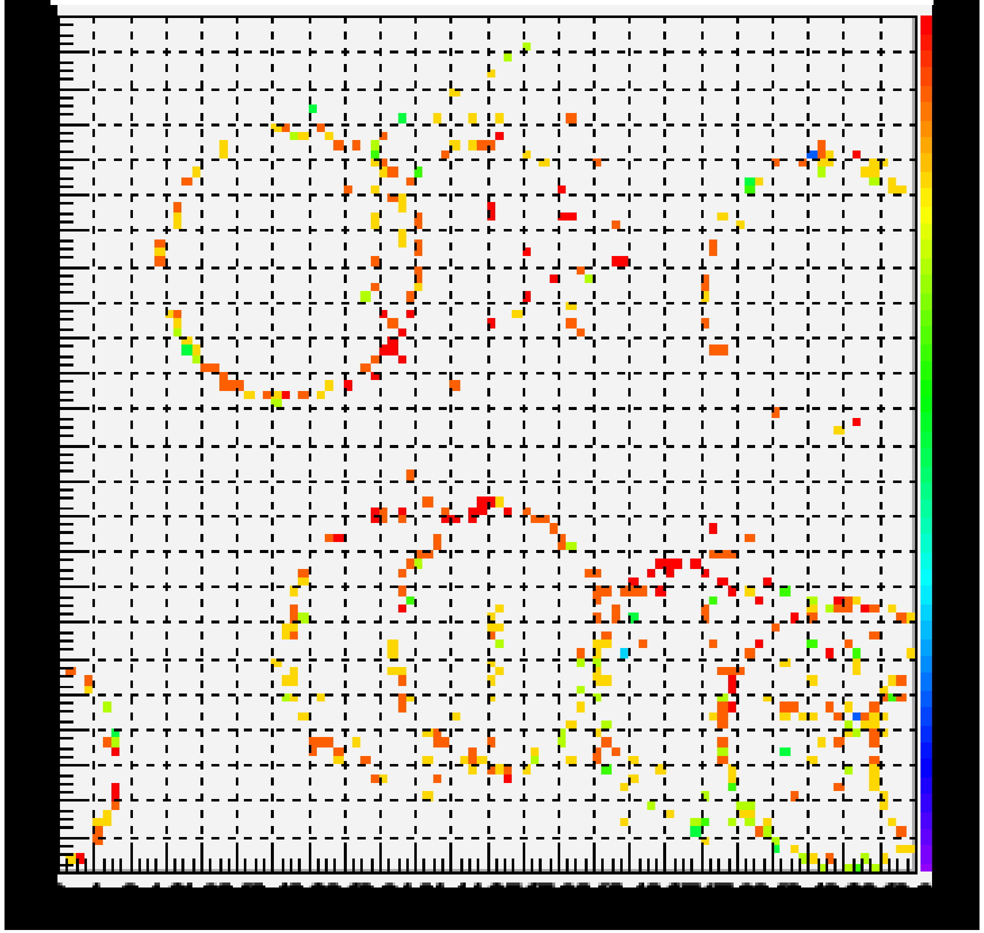
COMPASS RICH-1 upgrade

Performance:

- ~ 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 %

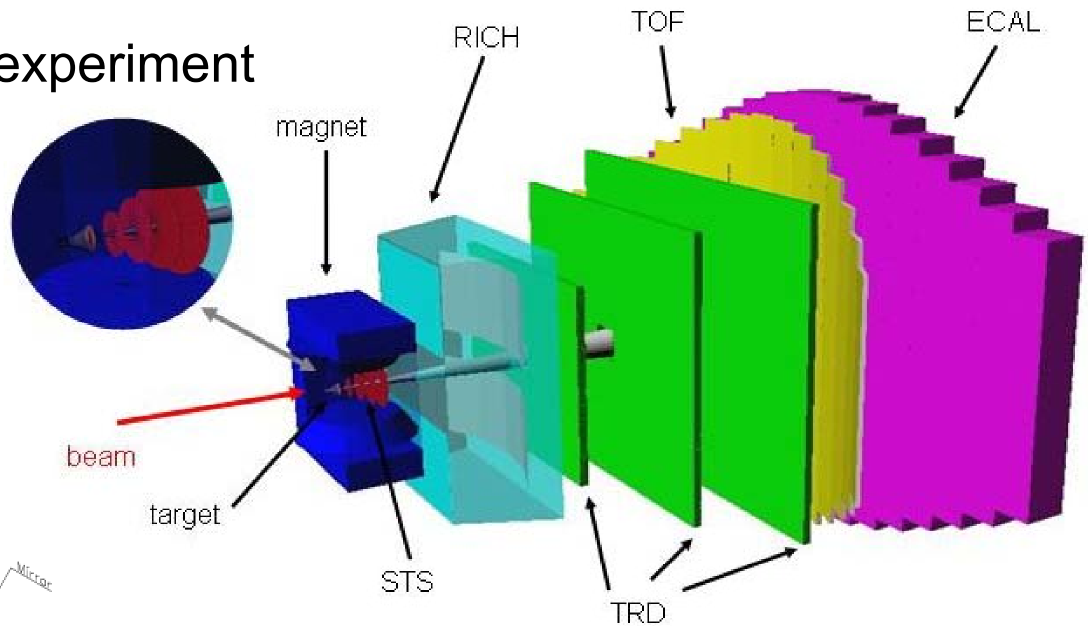
IMAGE FROM THE ON-LINE EVENT DISPLAY

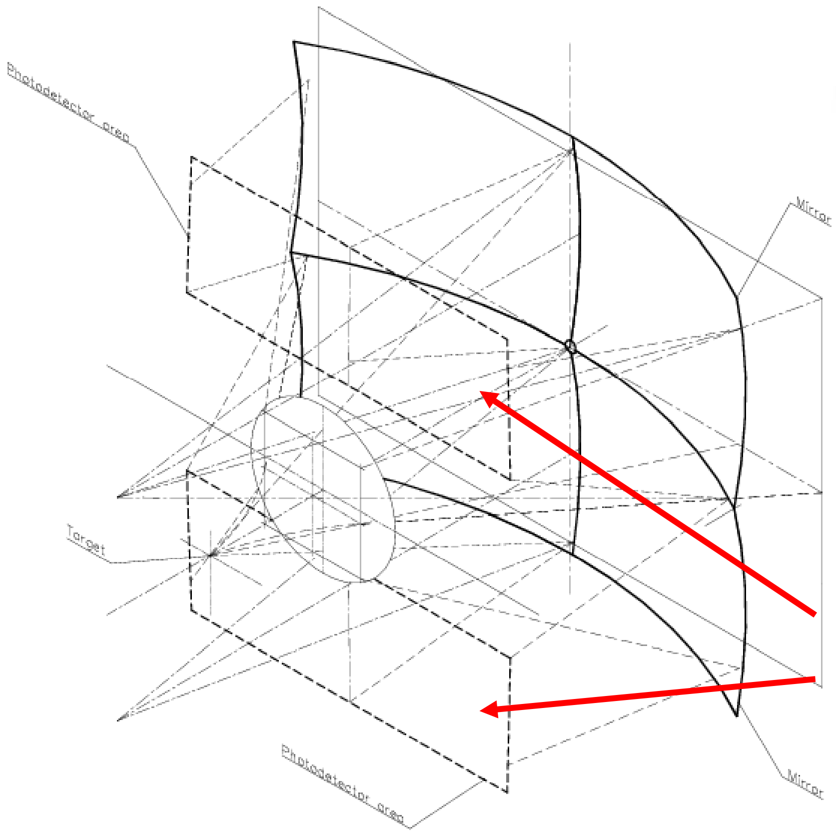


RICH for CBM at FAIR (GSI)

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

NIM A553 (2005) 91

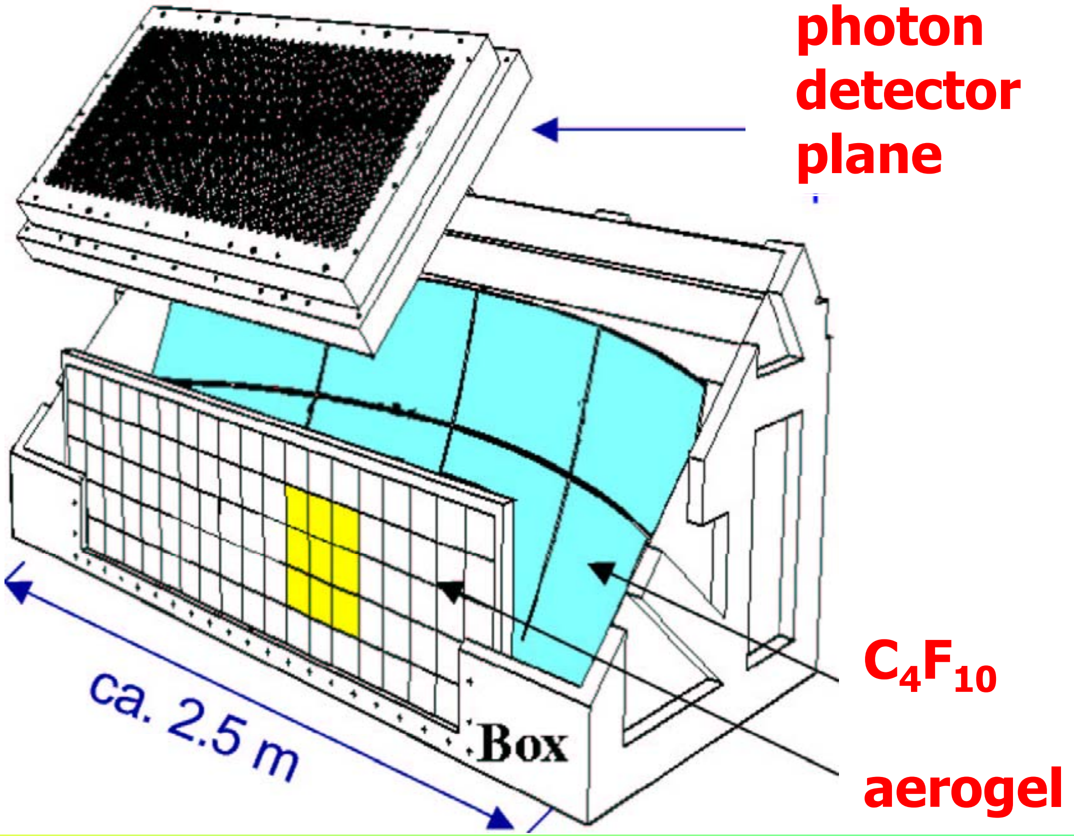
Design similar to HERA-B, COMPASS or LHCb

→ Talk by Christian Pauly

RICHes with several radiators

Extending the kinematic range → need more than one radiator

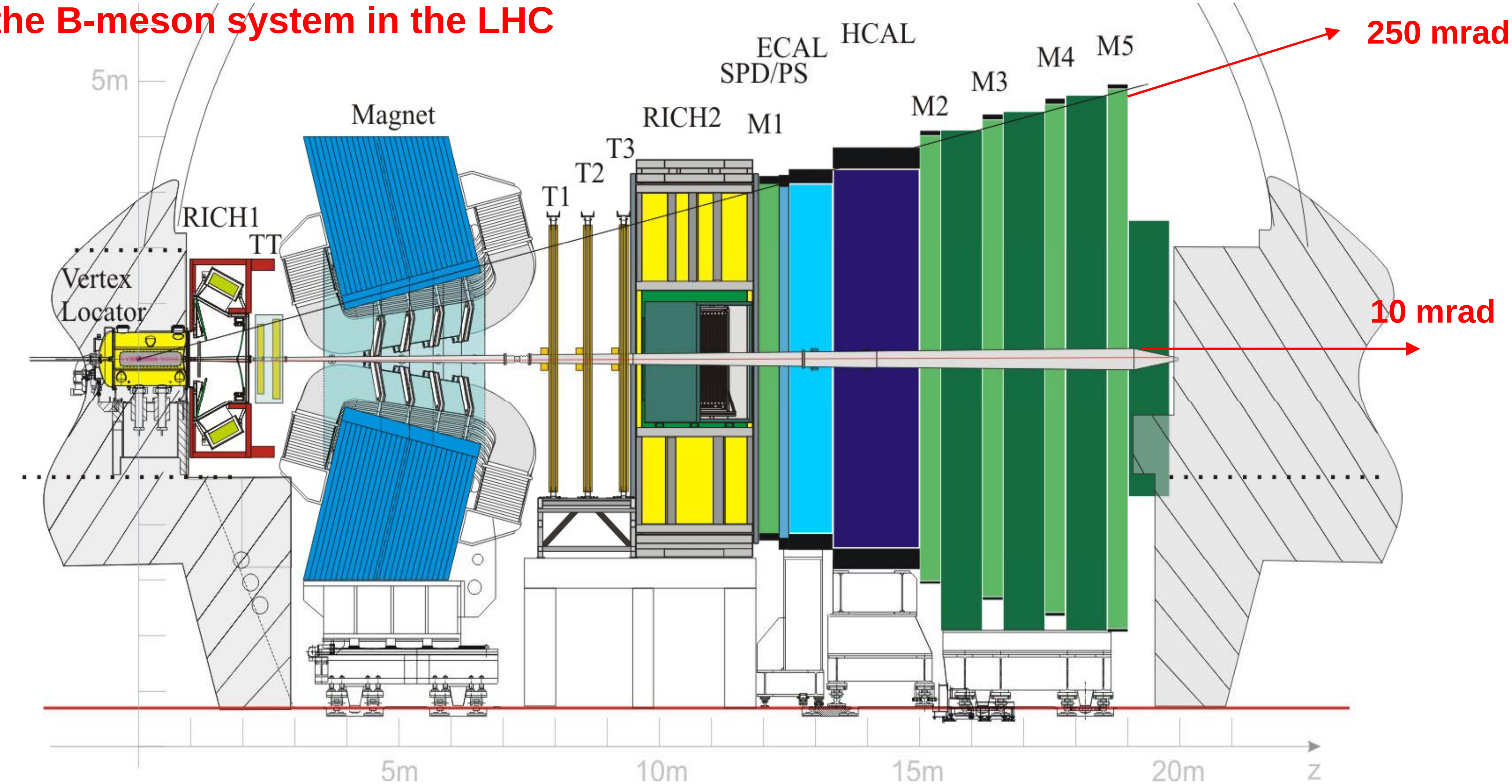
- DELPHI, SLD (liquid+gas)
- HERMES (aerogel+gas)



→ Talk by Raffaele De Leo

The LHCb RICH counters

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



Vertex reconstruction:	Trigger:	PID:	Kinematics:
VELO	Muon Chambers	RICHes	Magnet
	Calorimeters	Calorimeters	Tracker
	Tracker	Muon Chambers	Calorimeters

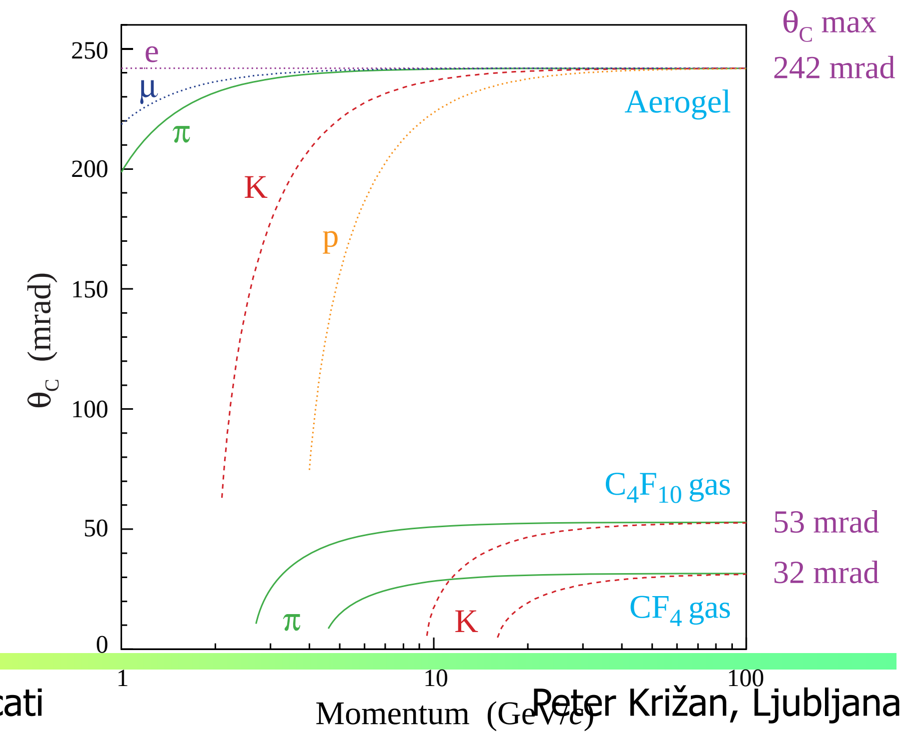
→ Talk by Clara Matteuzzi

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

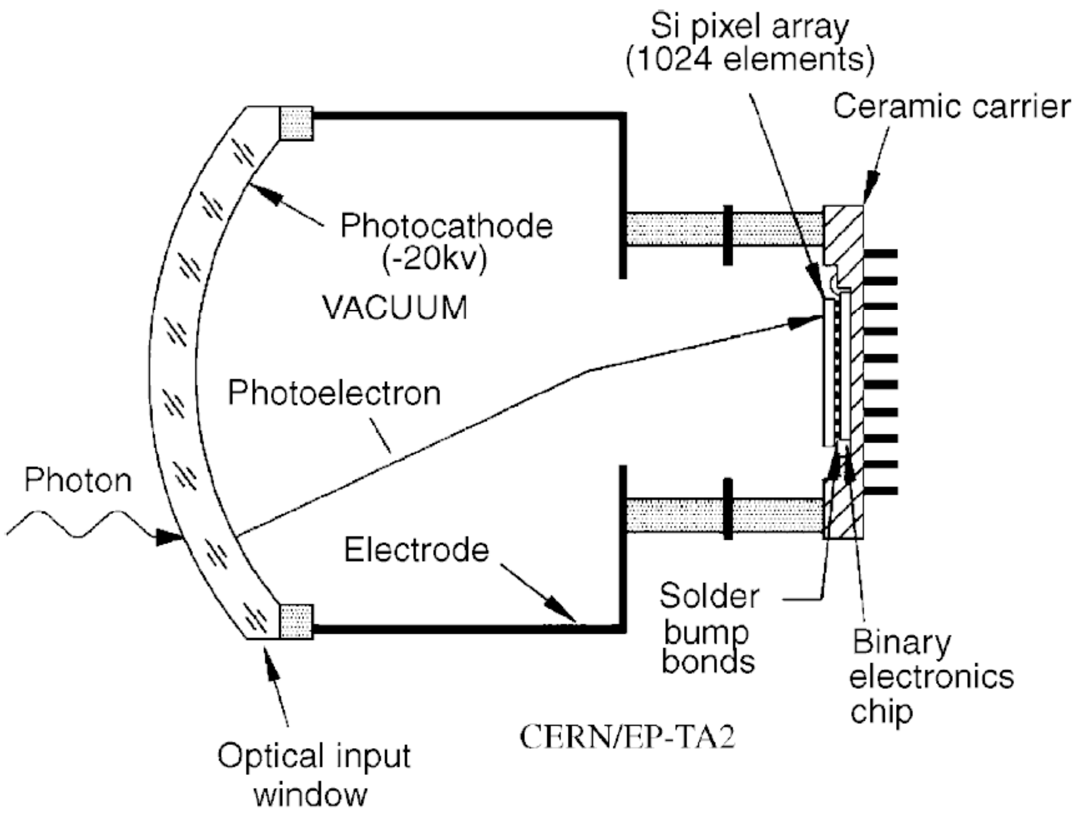
→3 radiators
(aerogel, CF_4, C_4F_{10})



LHCb RICHes

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

Hybrid PMT: accelerate photoelectrons in electric field (~20kV), detect it in a pixelated silicon detector.

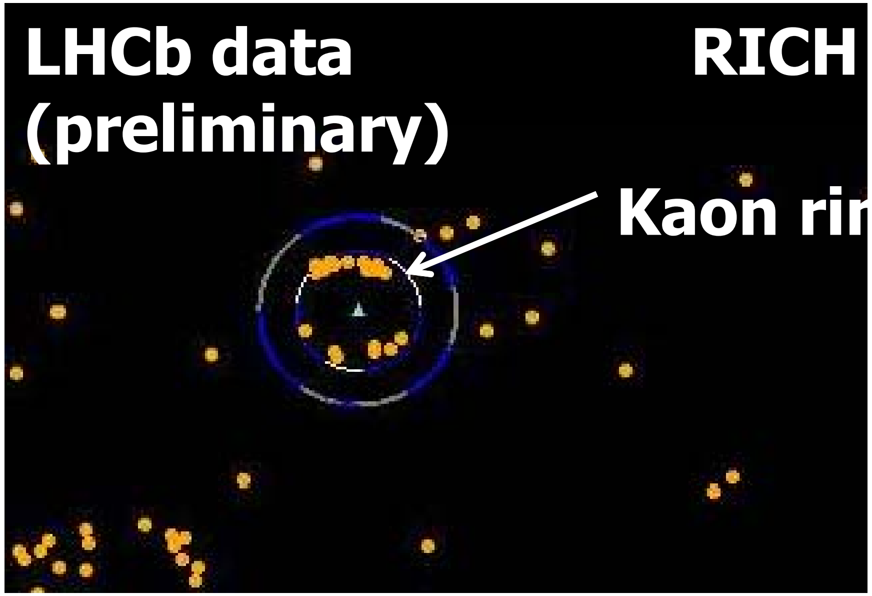


NIM A553 (2005) 333

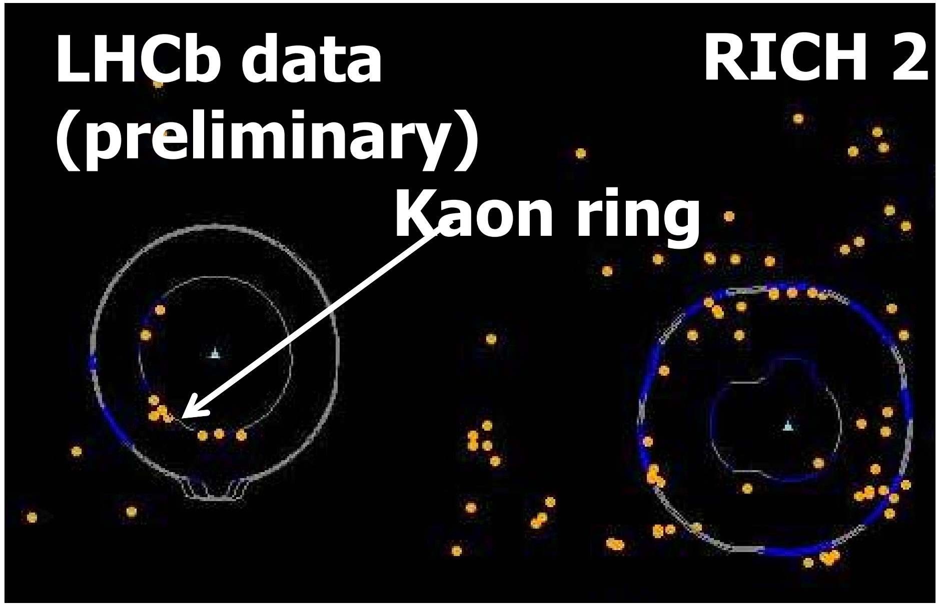
LHCb Event Display

Nov/Dec 2009
LHC beams $\sqrt{s}$ = 900 GeV

RICH1



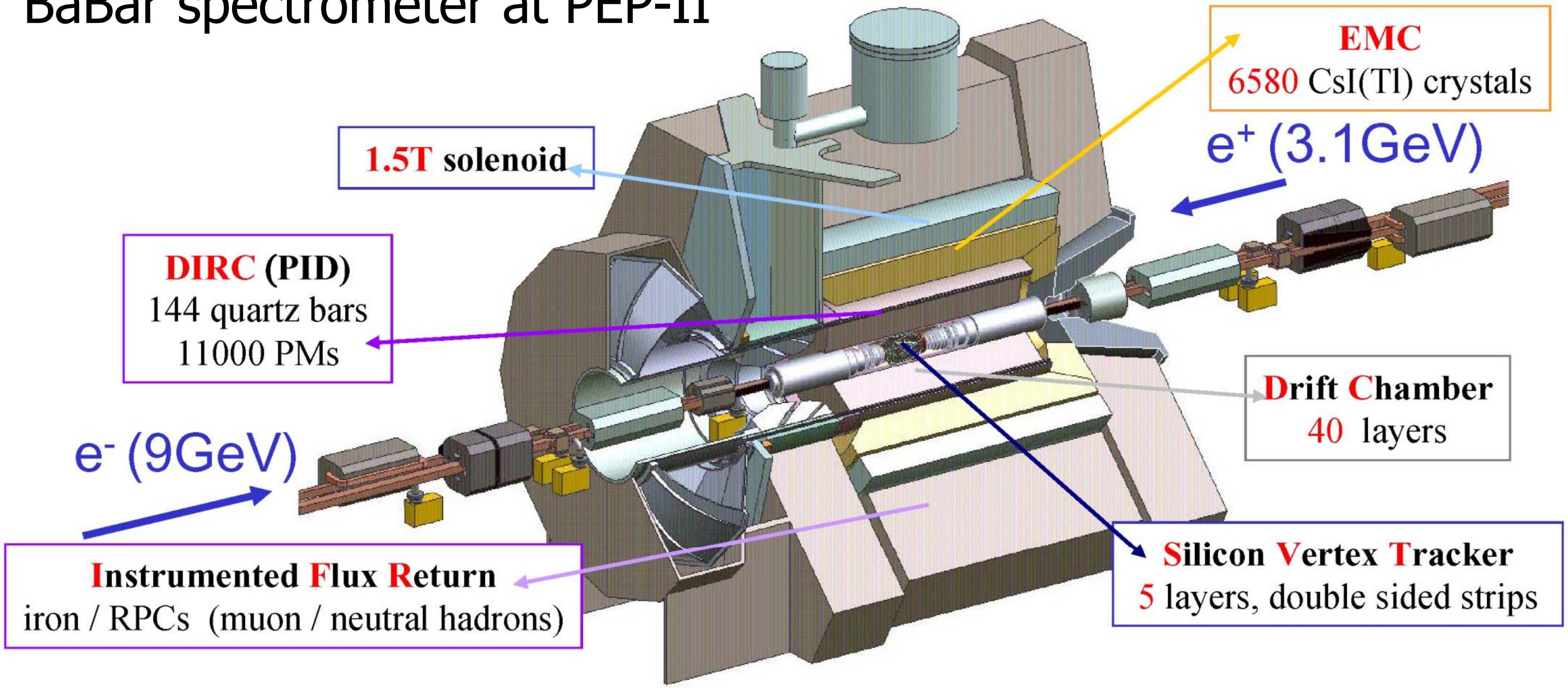
RICH2



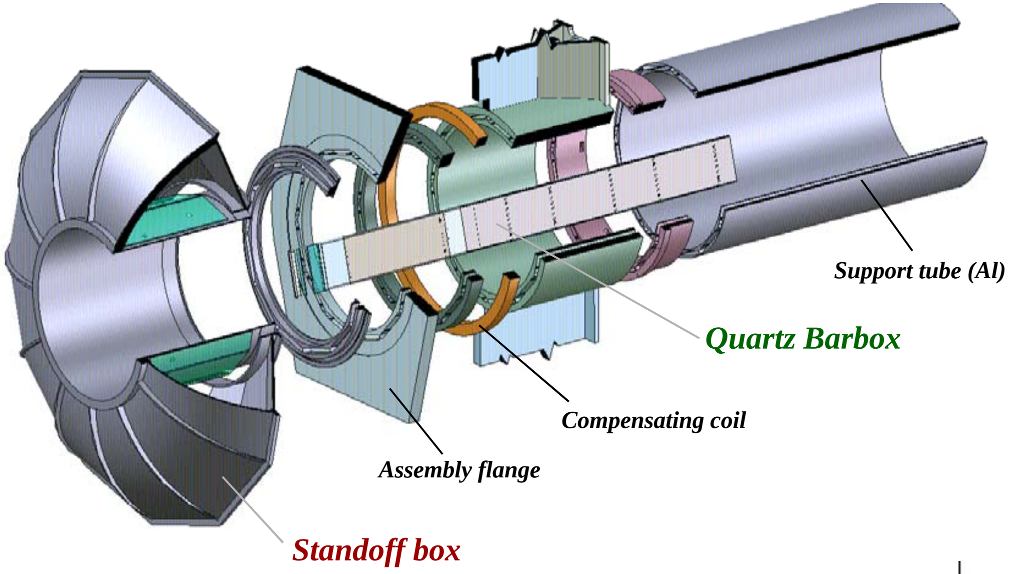
- Orange points → photon hits
- Continuous lines → expected distribution for each particle hypothesis

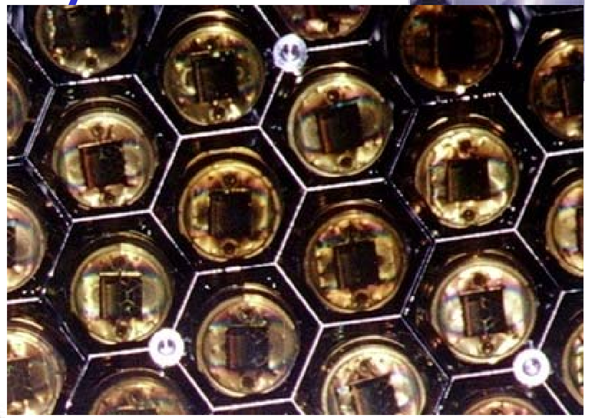
DIRC - detector of internally reflected Cherenkov light

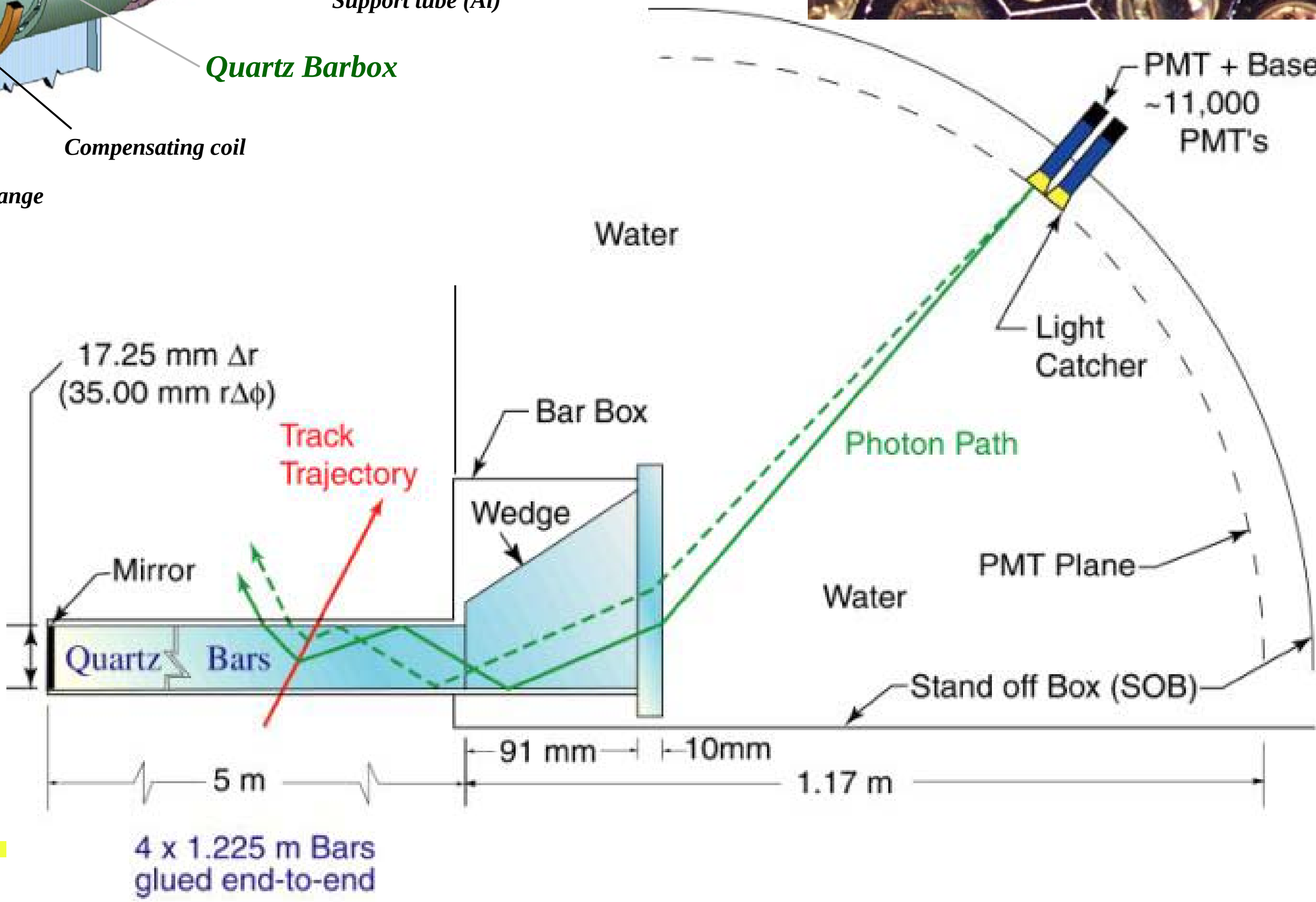
BaBar spectrometer at PEP-II

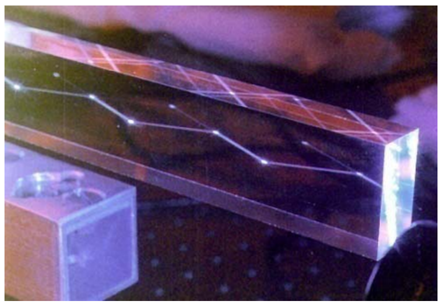


DIRC (@BaBar) - detector of internally reflected Cherenkov light

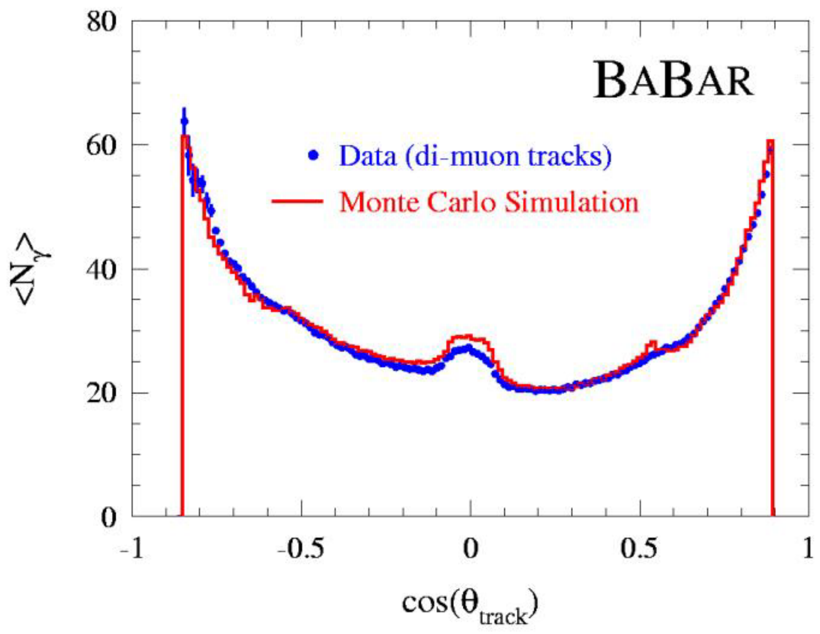






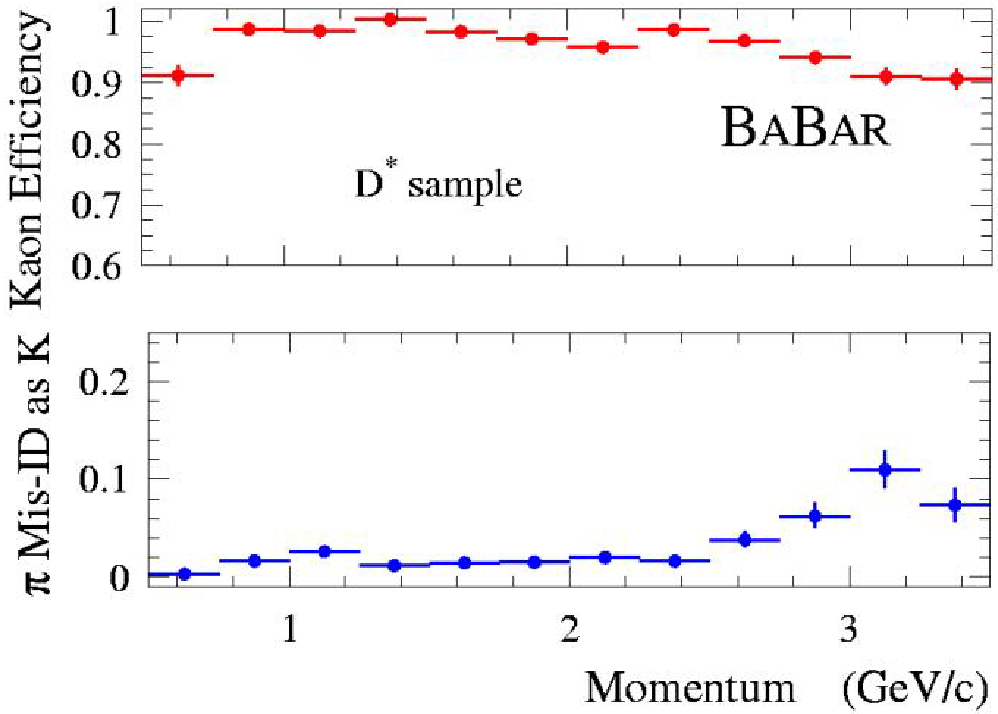


DIRC performance



← Lots of photons!

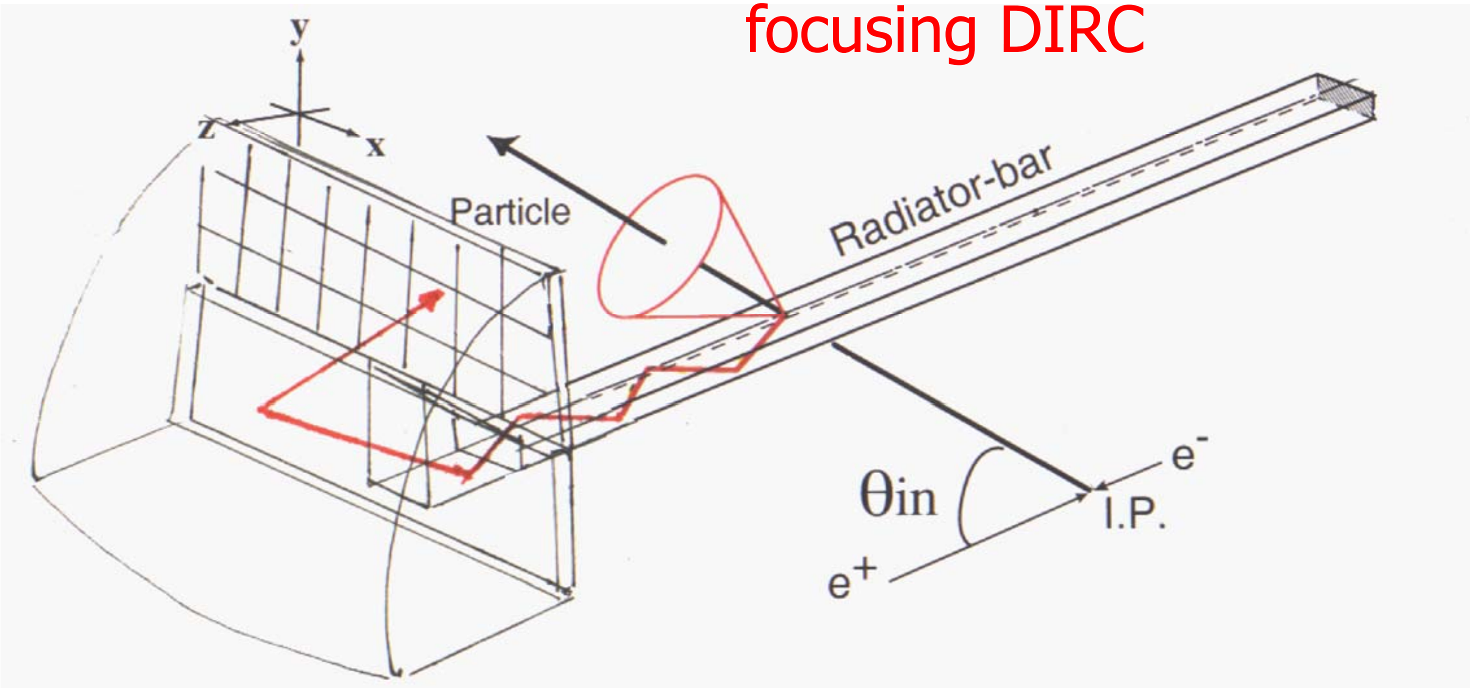
Excellent π/K separation

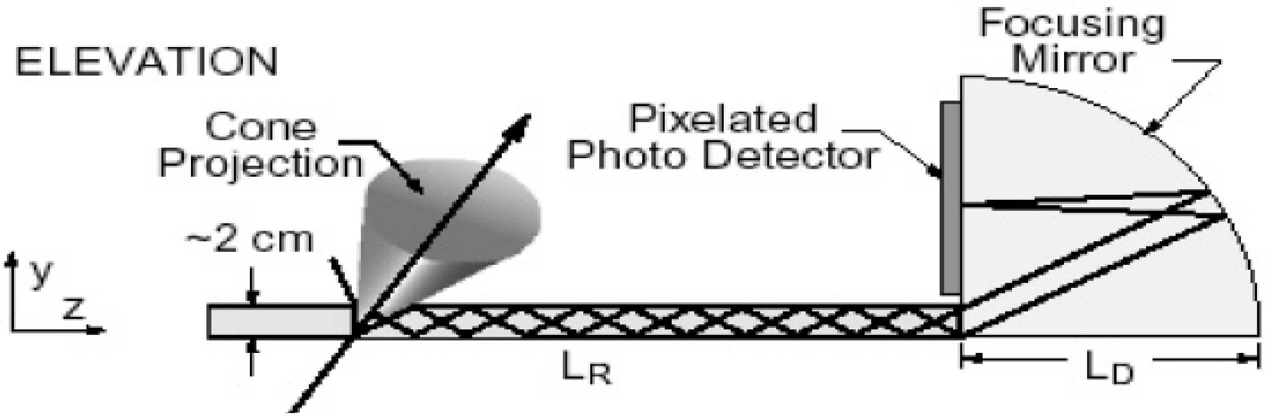


NIM A553 (2005) 317

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) → σ ≤150-200ps (~10x better) allows a measurement of the photon group velocity $c_g(\lambda)$ to correct the chromatic error of θ_c.

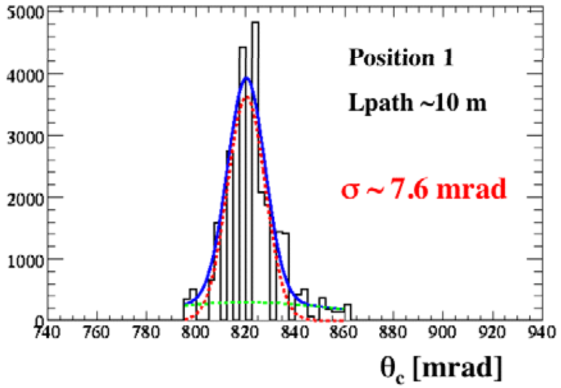
Photon detector requirements:

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

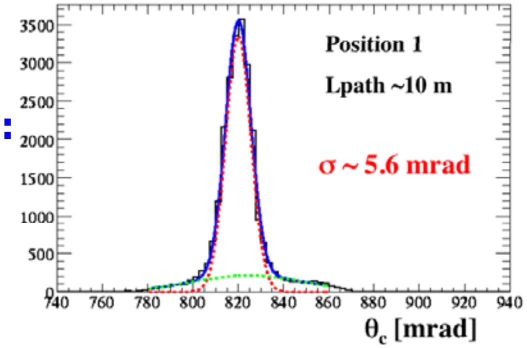
Focusing DIRC- the chromatic correction

Beam test results with BURLE/Photonis MCP PMT

Correction off:

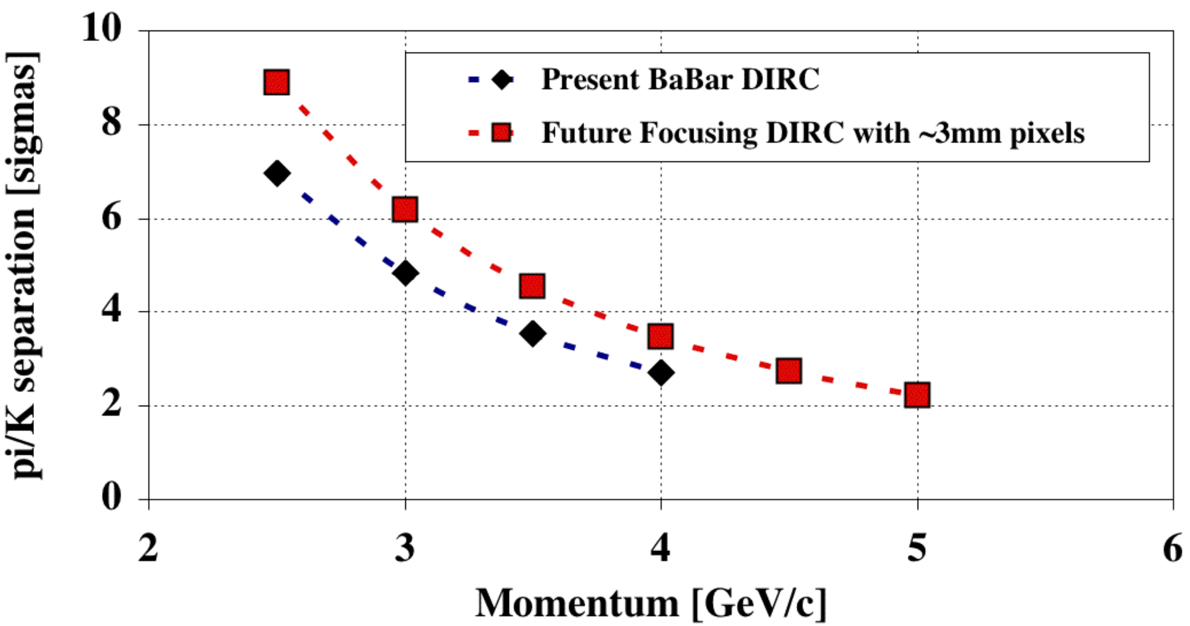


Correction on:

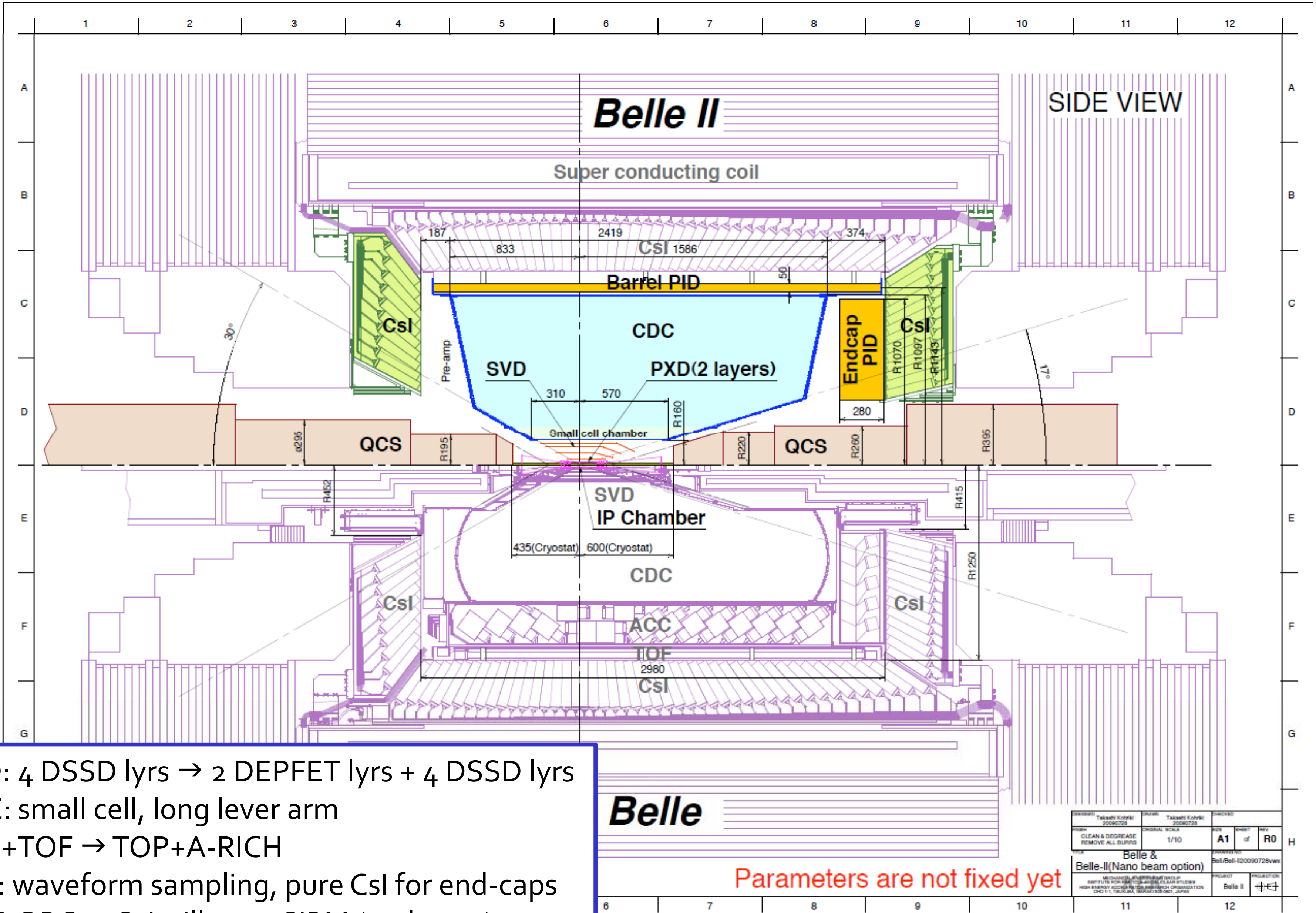


θ_C resolution and chromatic correction for 3mm pixels:

Expected PID performance:



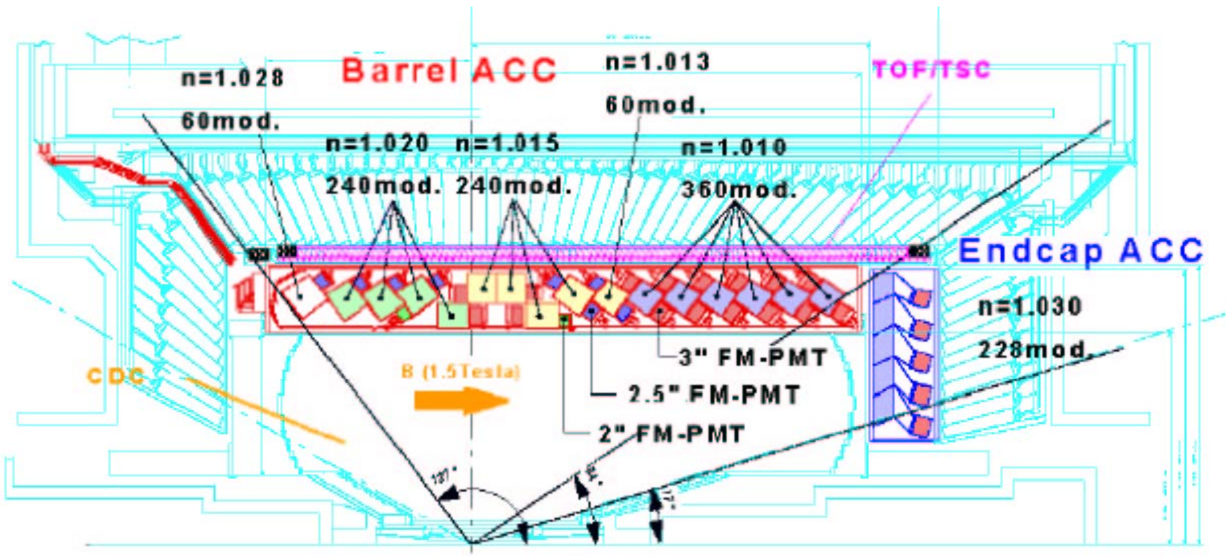
Belle → Belle II



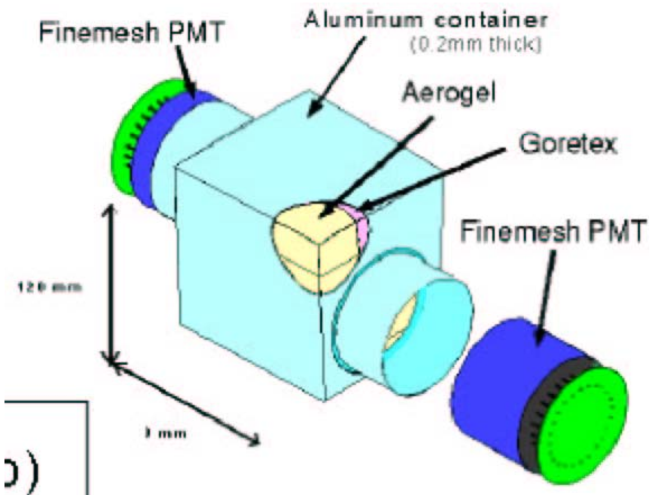
SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC → Scintillator +SiPM (end-caps)

Present Belle: threshold Cherenkov 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

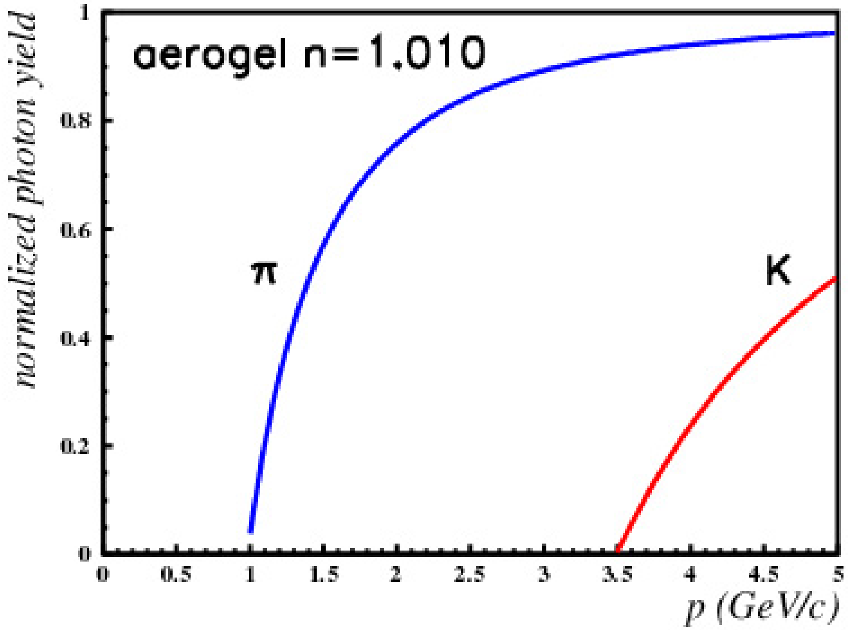


Fine-mesh PMT: works in high B fields

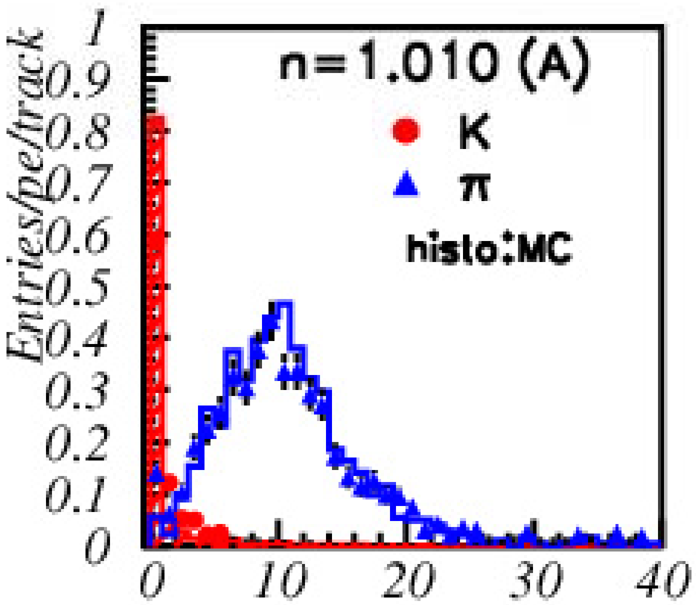
Belle ACC : threshold Cherenkov counter

expected yield vs p

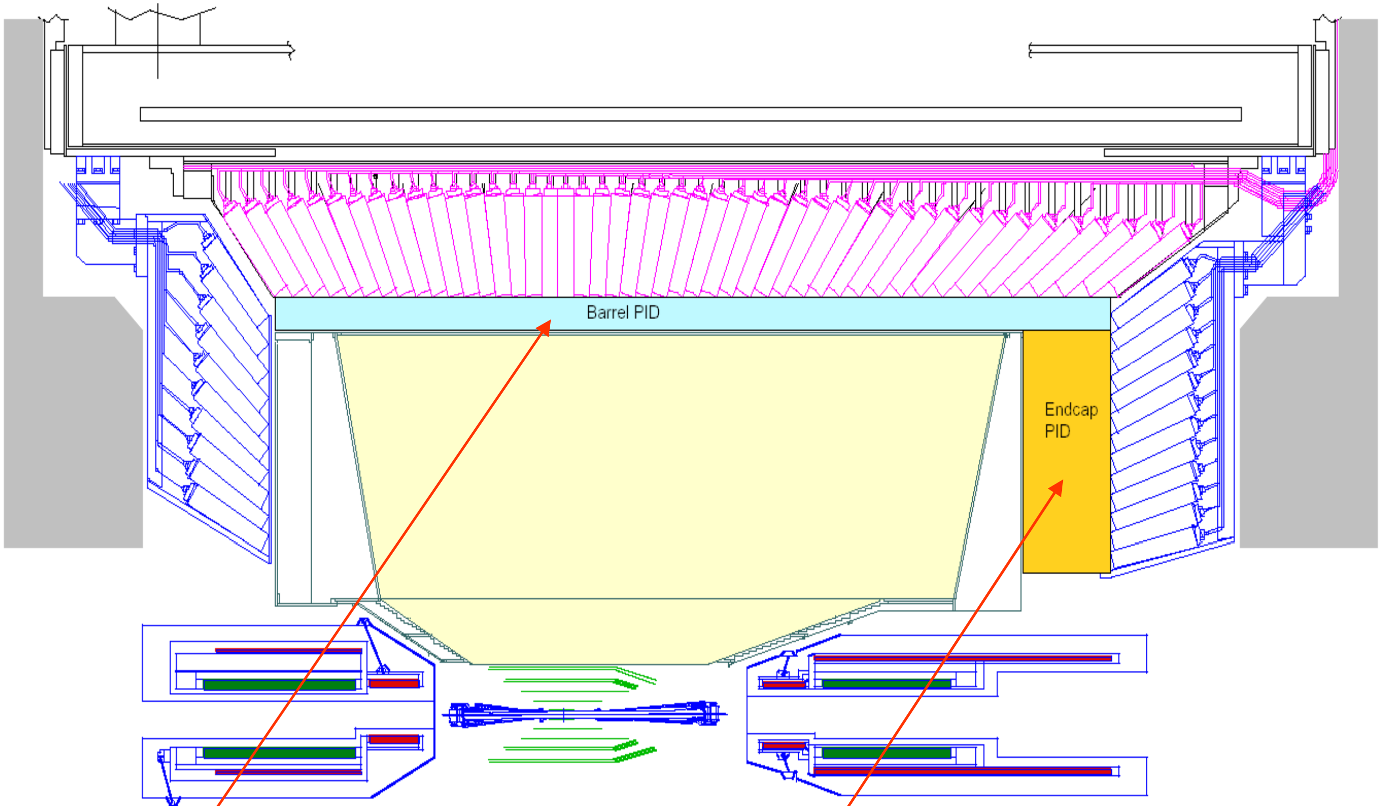
NIM A453 (2000) 321



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



Belle upgrade – side view



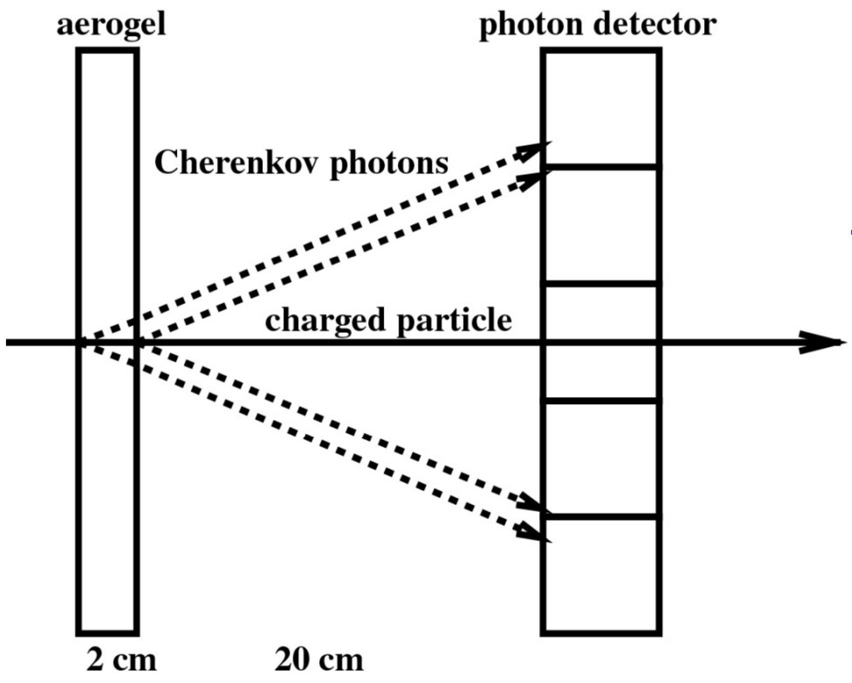
Two new particle ID devices, both RICHes:

Barrel: time-of-propagation (TOP) counter

Endcap: proximity focusing RICH

→Talk by T. Iijima

Endcap: Proximity focusing RICH



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

For single photons: $\delta\theta_c$(meas.)=σ_0 ~ 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: $[\theta_c(\pi) - \theta_c(K)]/\sigma_{track}$

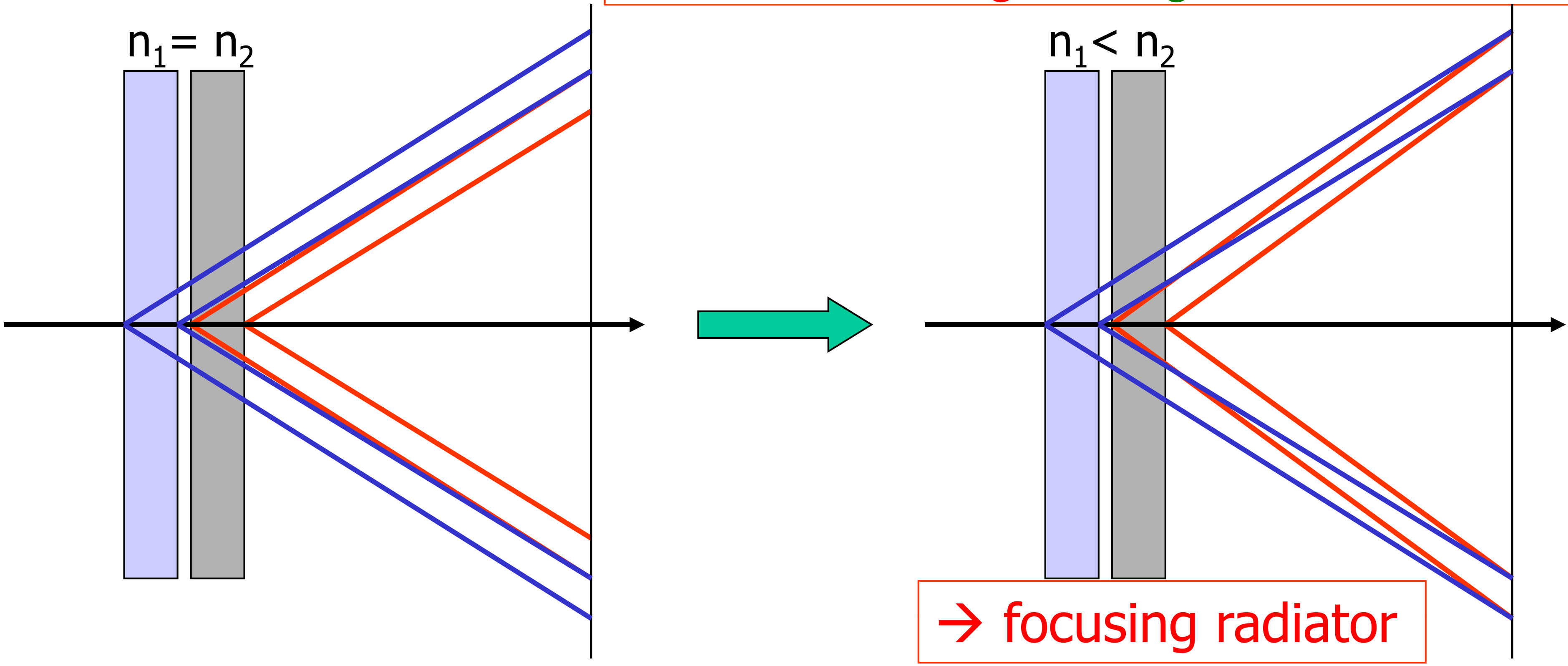
→ 5σ separation with N_{pe}~10

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

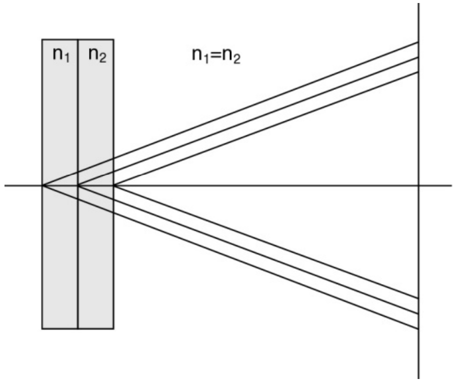


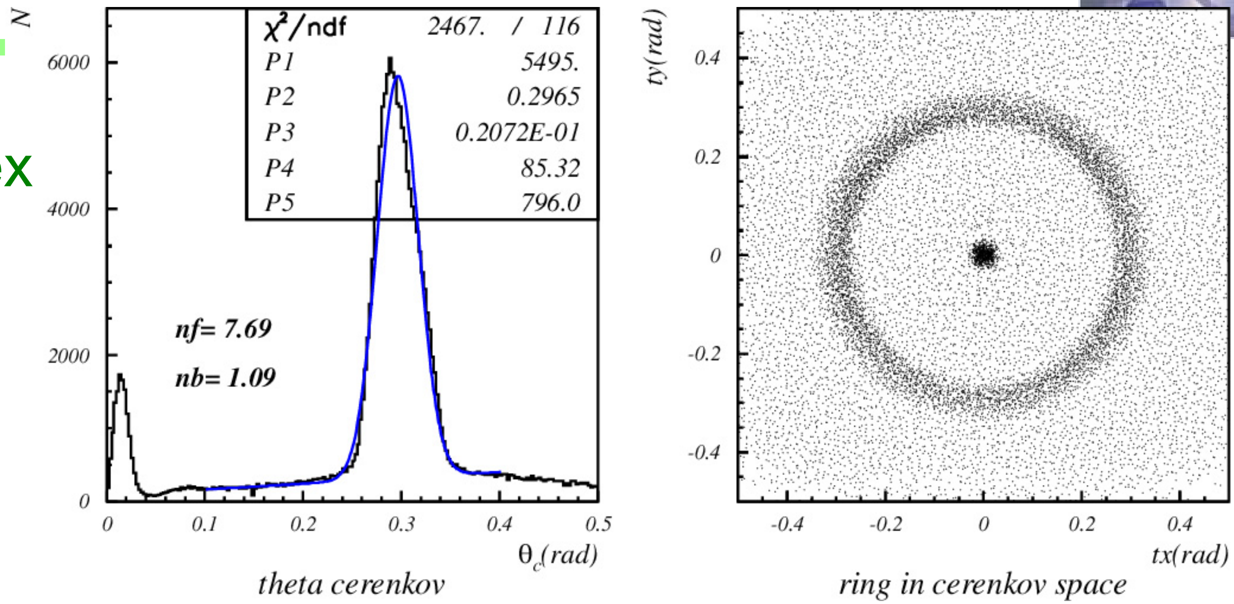
→ focusing radiator

Such a configuration is only possible with aerogel (a form of Si_xO_y) – material with a tunable refractive index between 1.01 and 1.13.

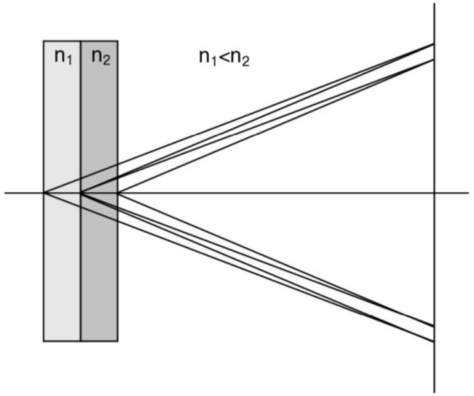
Focusing configuration – data

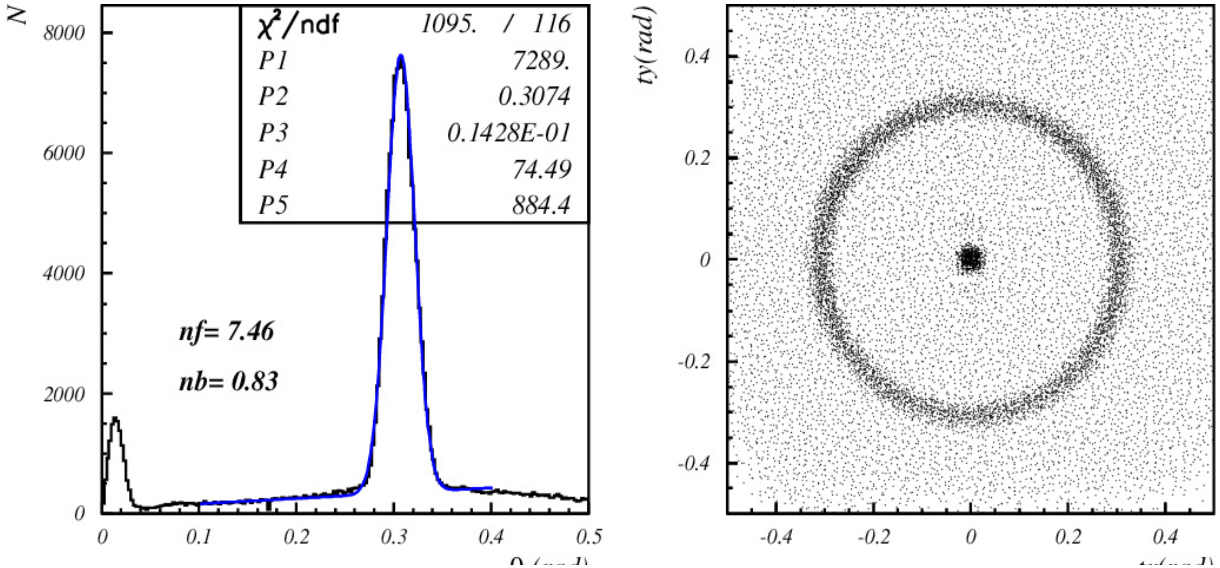
4cm aerogel single index





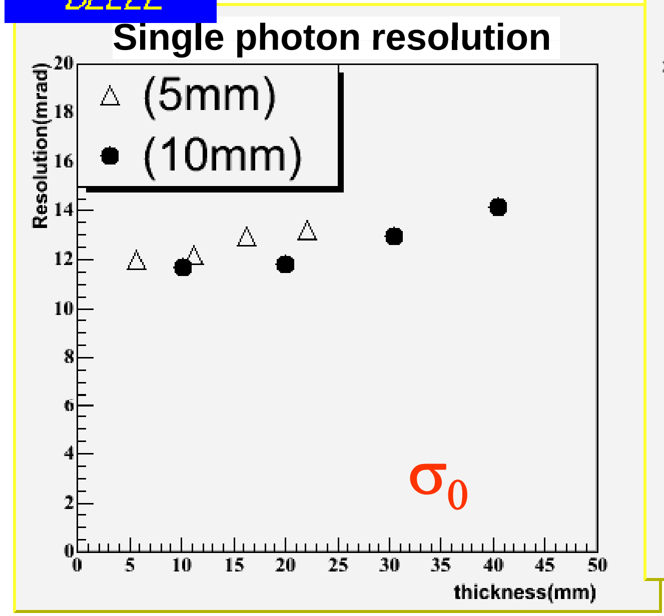
2+2cm aerogel

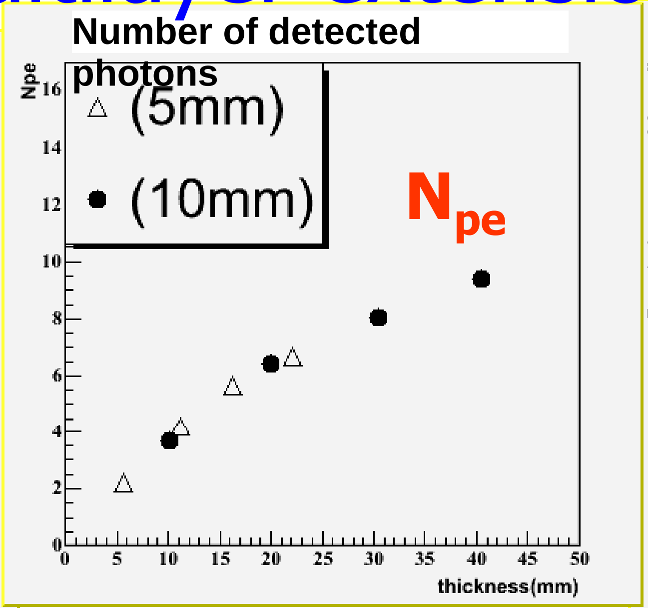


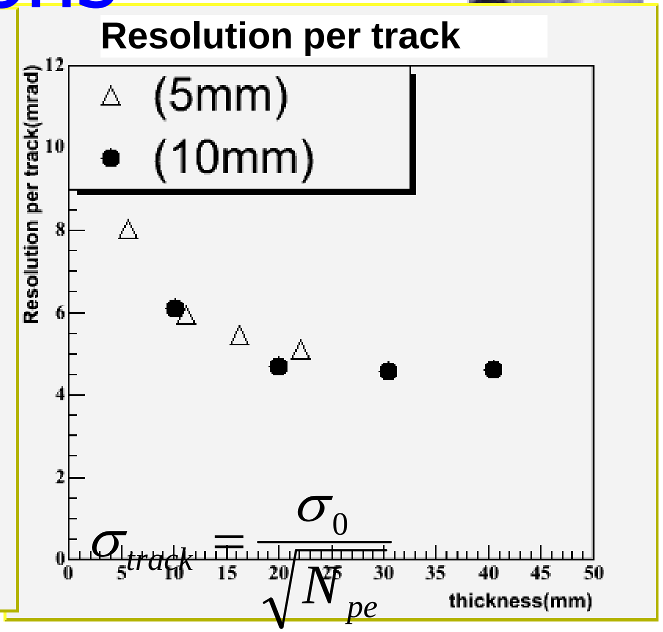


→NIM A548 (2005) 383

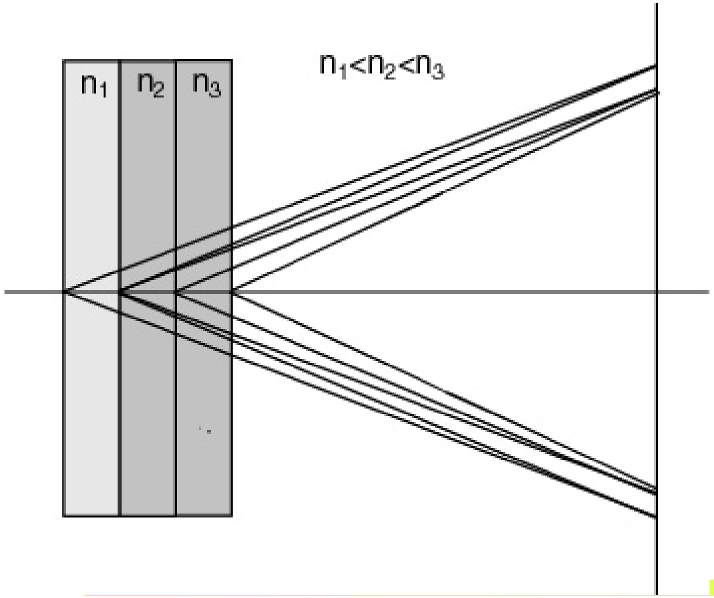
Multilayer extensions







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



Cherenkov angle resolution per track: around 4.3 mrad

→ π/K separation at 4 GeV: >5σ

Several optimisation studies:

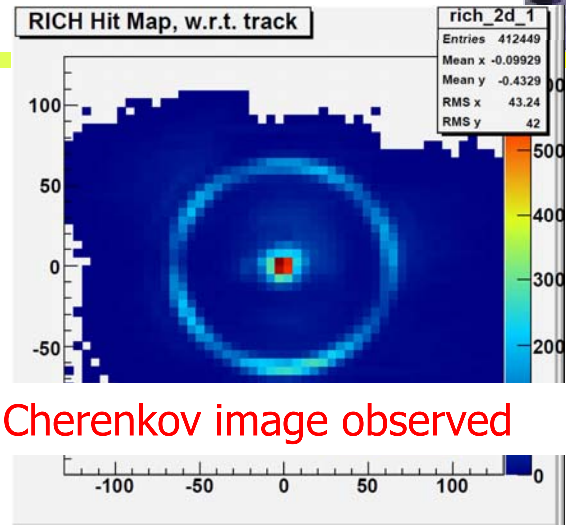
Križan et al NIMA 565 (2006) 457

Barnyakov et al NIMA 553 (2005) 70

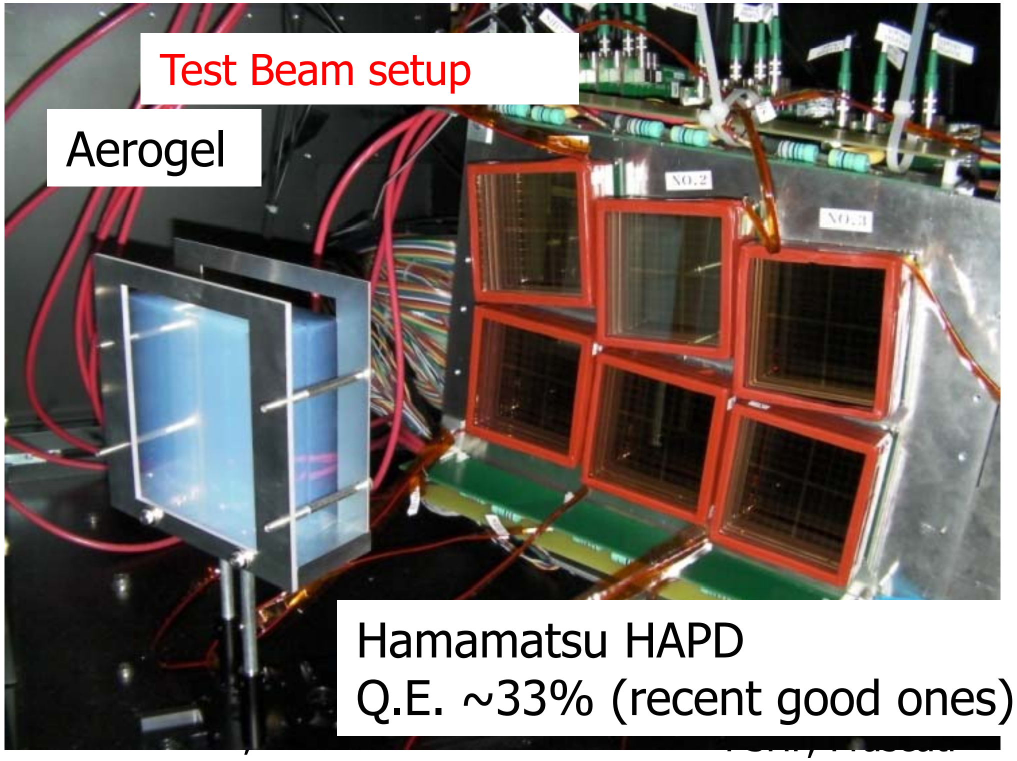
Aerogel RICH photon detectors

Need:
Operation in 1.5 T magnetic field
Pad size ~5-6mm

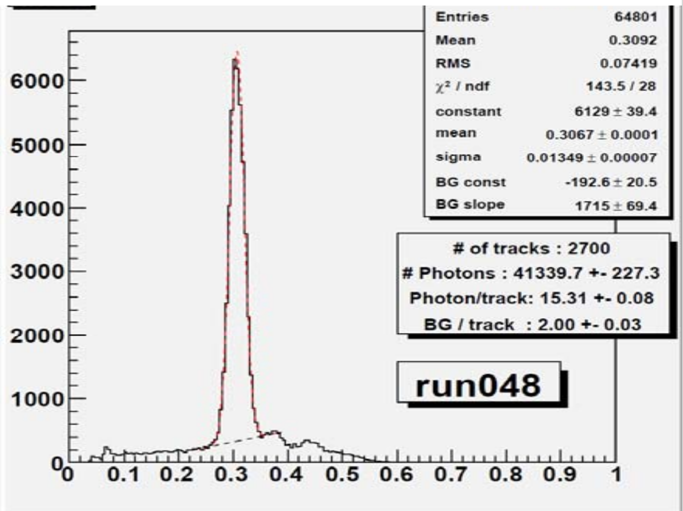
Baseline option: large active area HAPD
of the proximity focusing type



Clear Cherenkov image observed



Cherenkov angle distribution

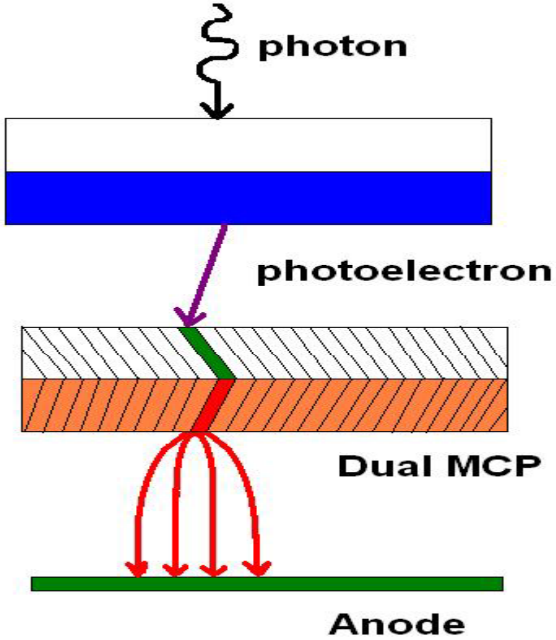


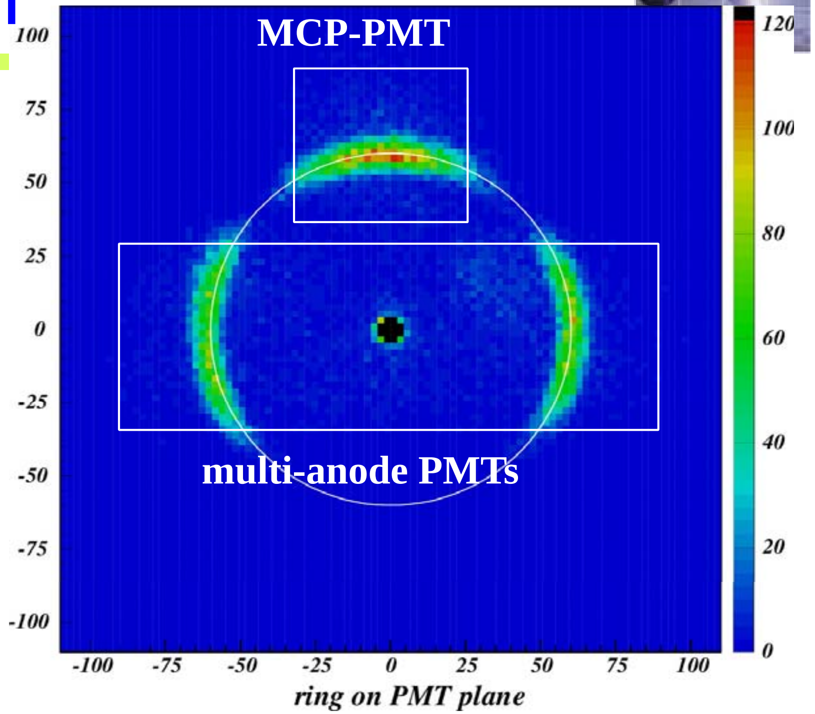
6.6 σ p/K at 4GeV/c !

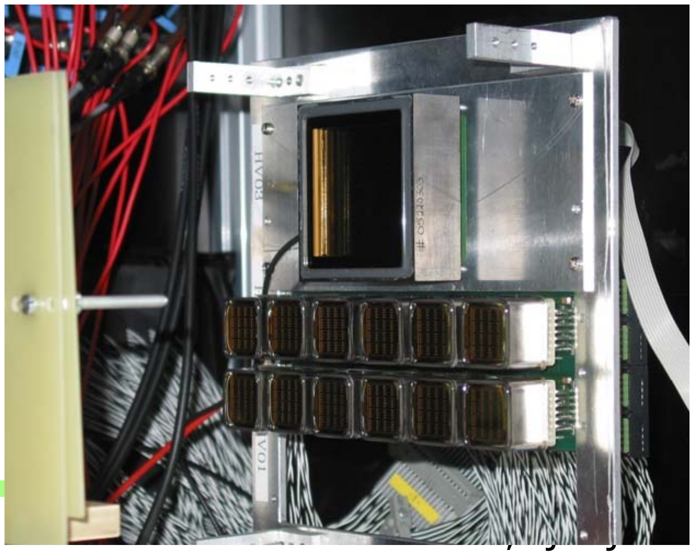
→ NIM A595 (2008) 180

Fallback solution: BURLE/Photonis MCP-PMT

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



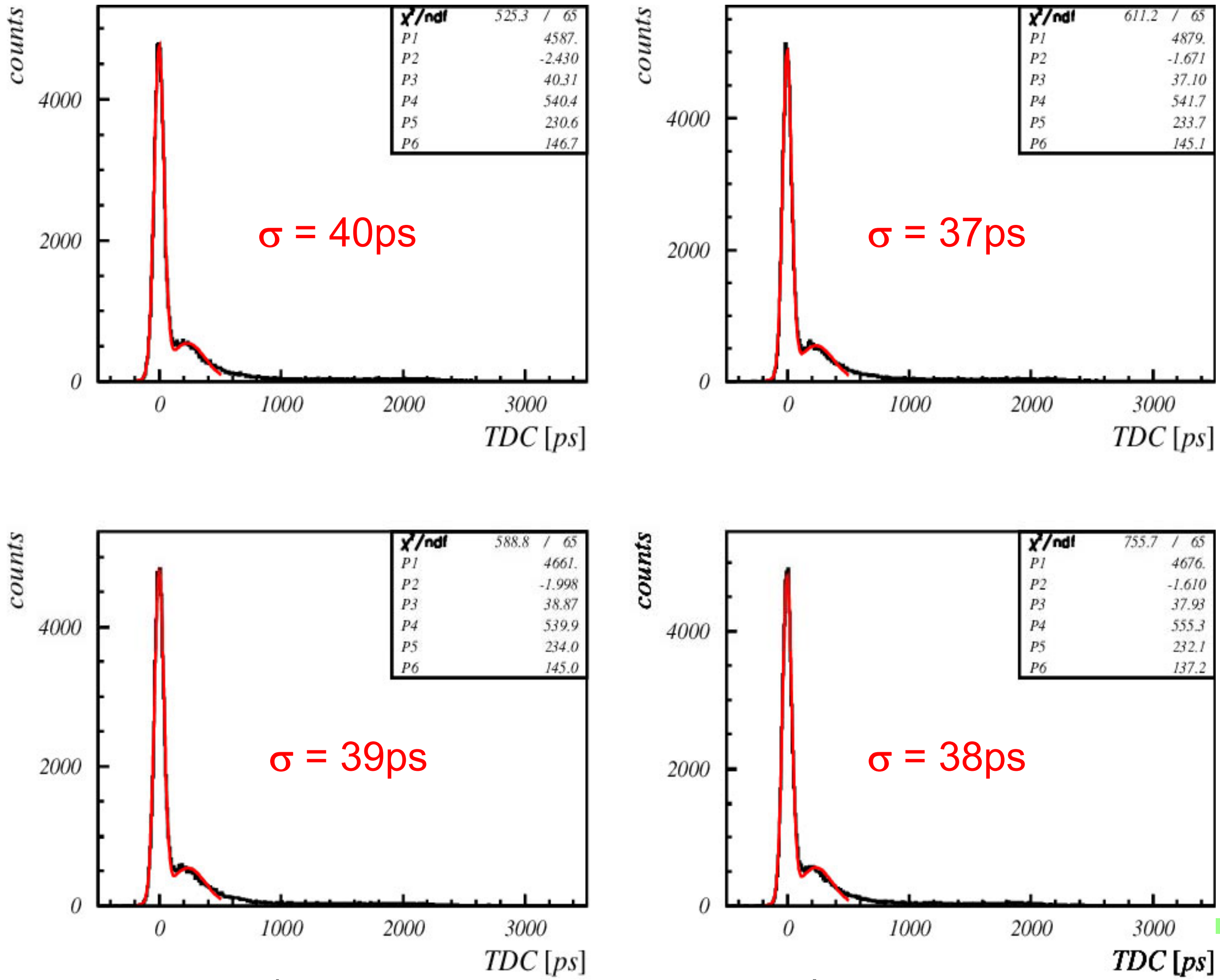




→good performance in beam and bench tests, NIMA567 (2006) 124
→ very fast (<40 ps)
→ ageing?

BURLE/Photonis MCP-PMT

BURLE 85011 microchannel plate (MCP) PMT: time resolution after time walk correction



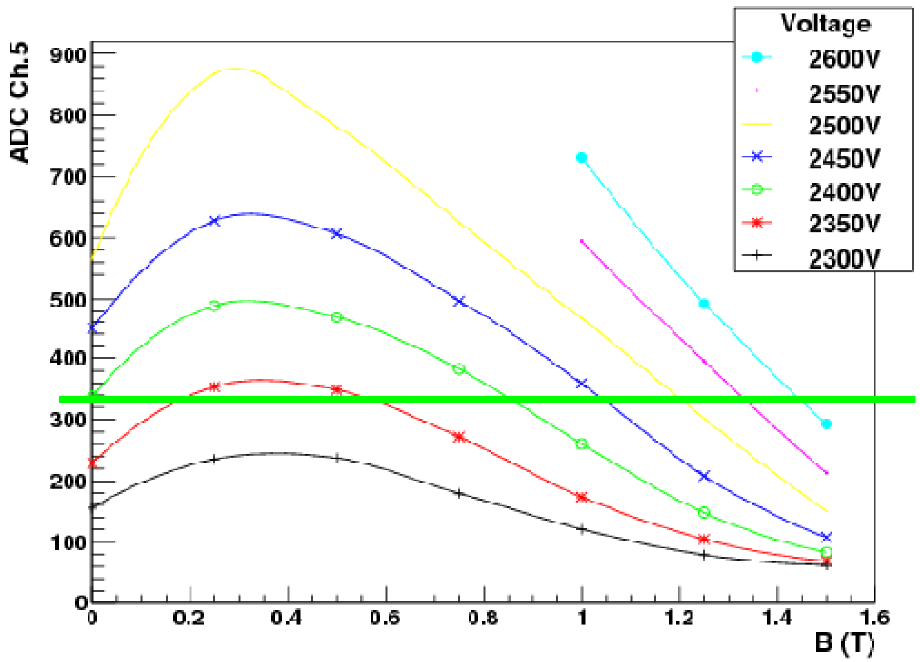
Tails understood, can be significantly reduced by:

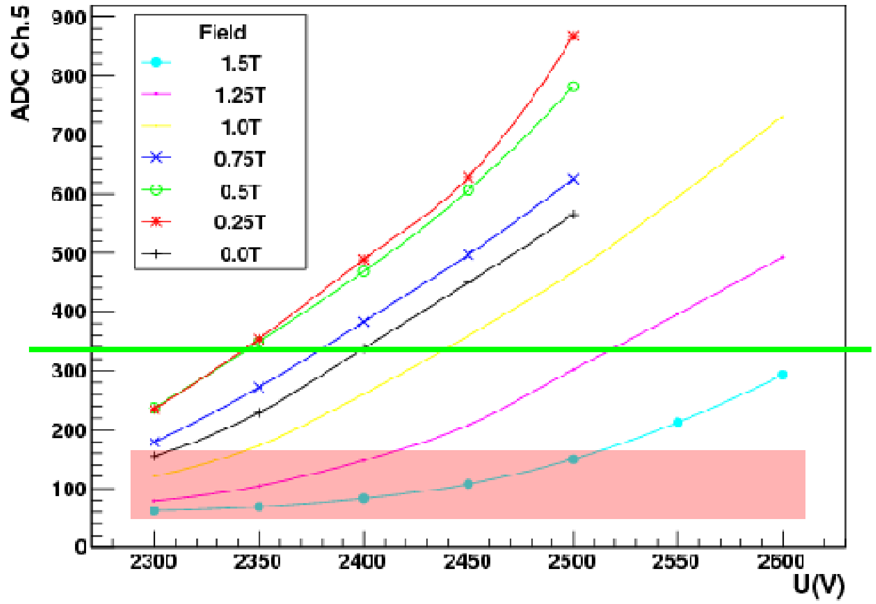
- decreased photocathode-MCP distance and
- increased voltage difference

MCP PMT: Gain in magnetic field

Gain as a function of magnetic field for different operation voltages and as a function of applied voltage for different magnetic fields.

.





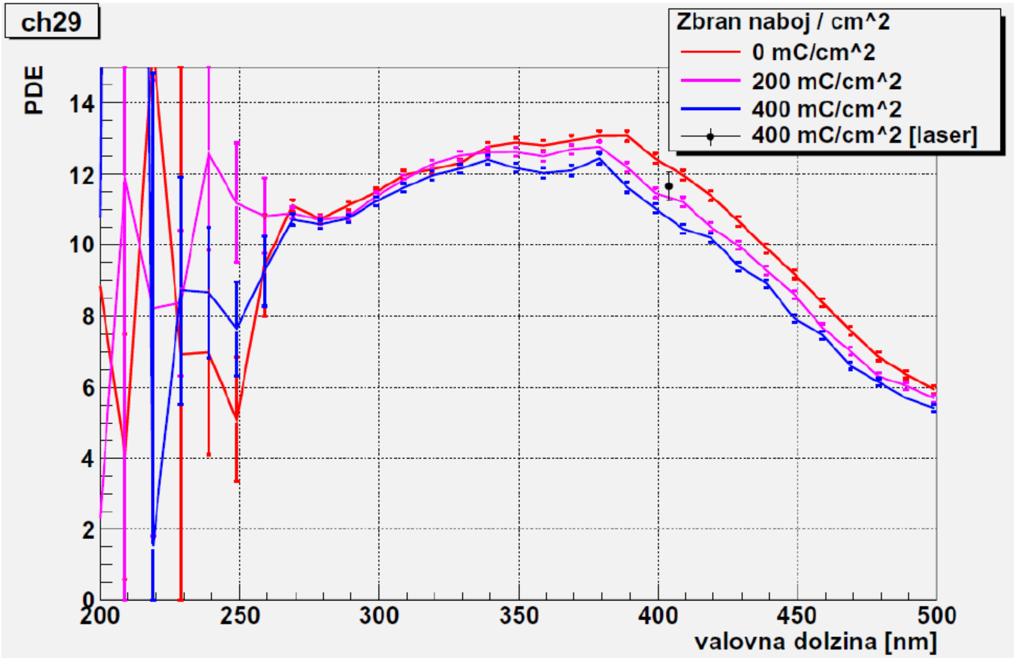
High B field: no problem, to run at the same gain HV → +200V

In the presence of magnetic field, charge sharing and cross talk due to long range photoelectron back-scattering are considerably reduced.

MCP PMT - ageing

Ageing test: high rate illumination of the whole photosensitive surface by LED, pulsed laser monitoring of the amplification. Reference PMT is used for periodic QE measuemnets with a monochromator in the same set-up.

Results:
after 400 mC/cm^2 (= Belle II lifetime) the efficiency drops by about 10% → no problem for operation.



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 <u>single photon pulse height</u>

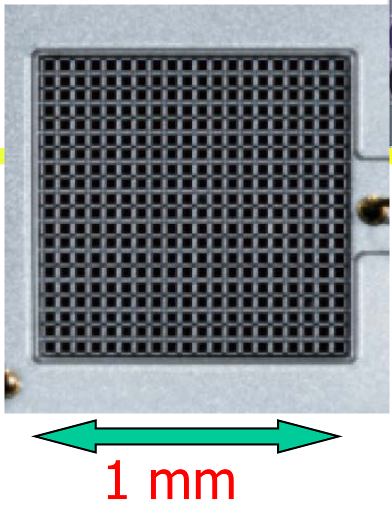
-radiation hardness

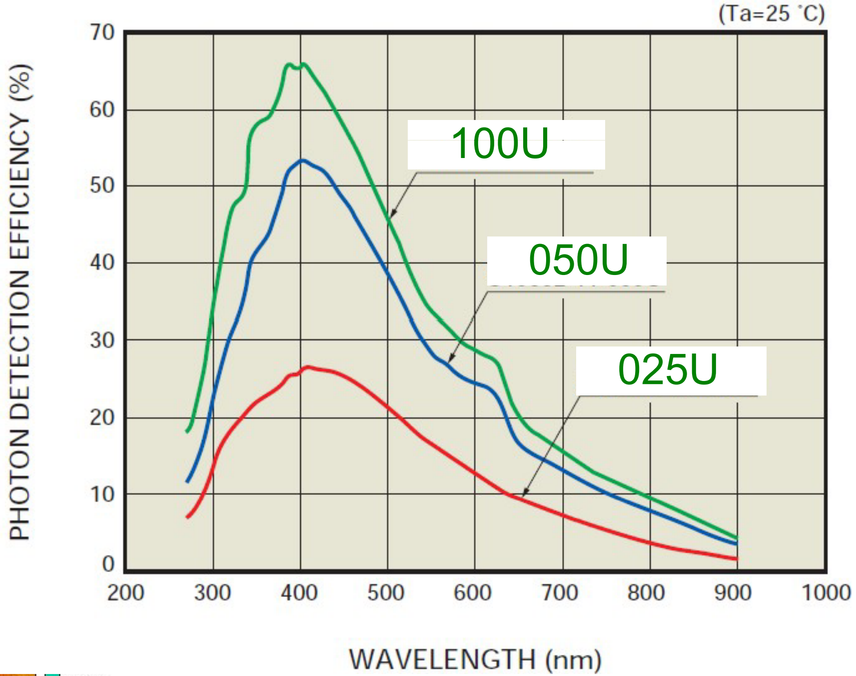
SiPMs as photon detectors?

SiPM is an array of APDs operating in Geiger mode. Characteristics:

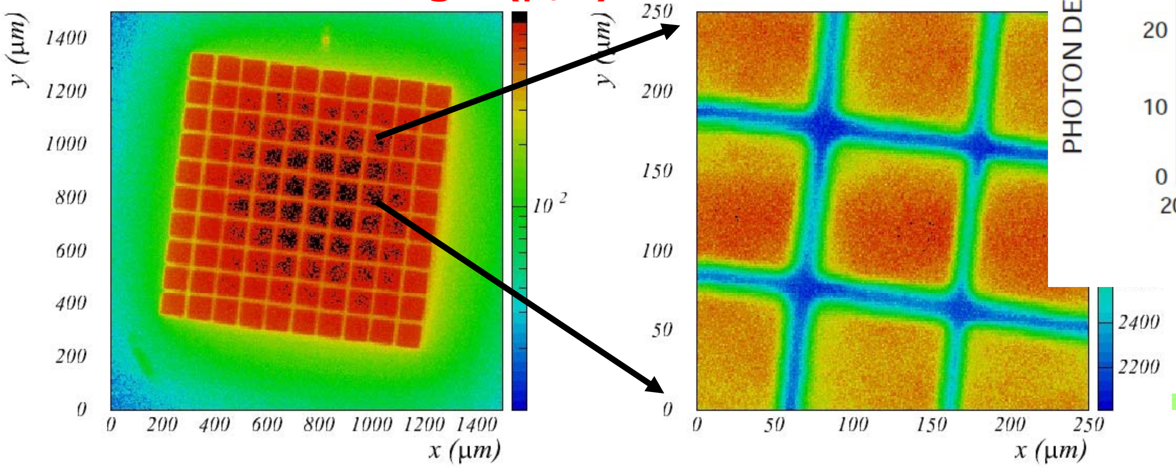
- low operation voltage ~ 10-100 V
- gain ~ 10^6
- peak PDE up to 65%(@400nm)

  $PDE = QE \times \varepsilon_{geiger} \times \varepsilon_{geo}$
- ε_{geo} – dead space between the cells
- time resolution ~ 100 ps
- works in high magnetic field
- dark counts ~ few 100 kHz/mm^2
- radiation damage (p,n)





Hamamatsu MPPC: S10362-11



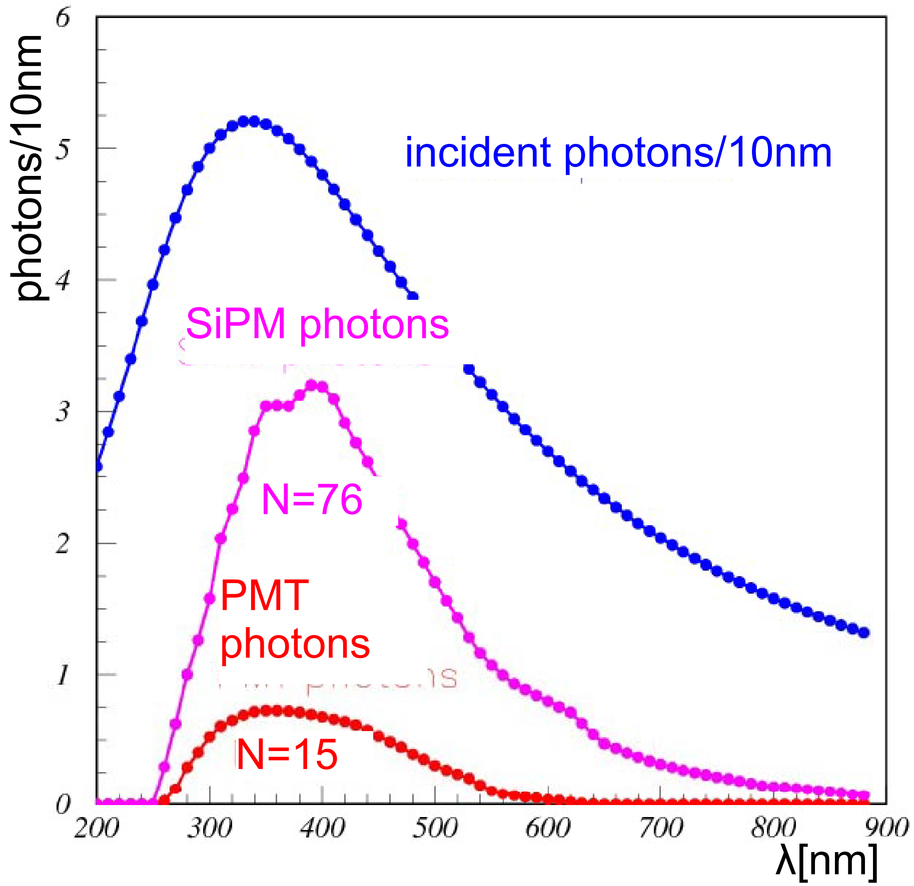
Expected number of photons for aerogel RICH

with multianode PMTs or SiPMs(100U), and
aerogel radiator: thickness 2.5 cm, n = 1.045
and transmission length (@400nm) 4 cm.

N_{SiPM}/N_{PMT}~5

Assuming 100% detector active area

Never before tested in a RICH where we have to detect single photons. ← Dark counts have single photon pulse heights (rate 0.1-1 MHz)

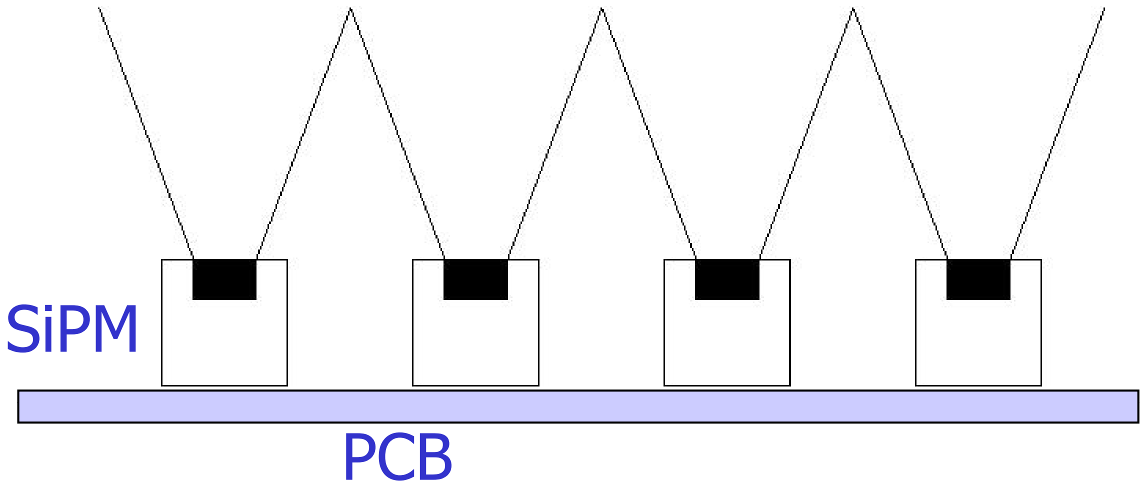


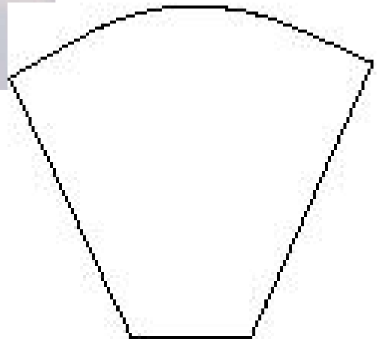
Can such a detector work?

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

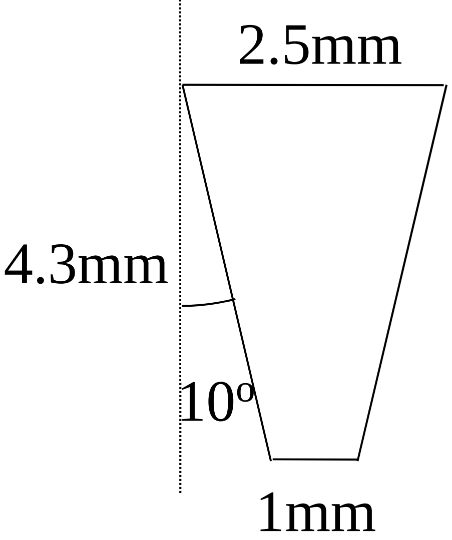
E.g. light collector with reflective walls



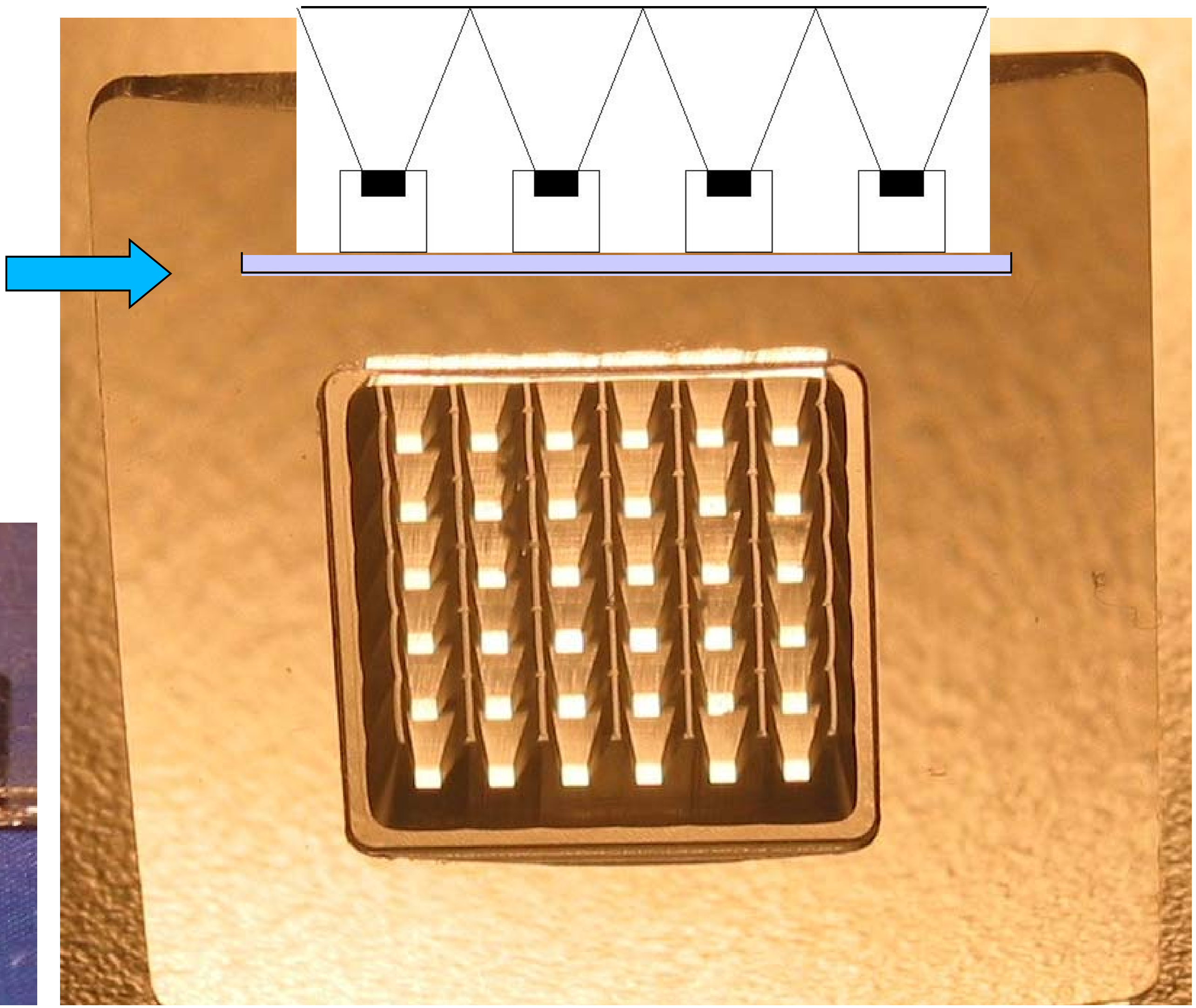


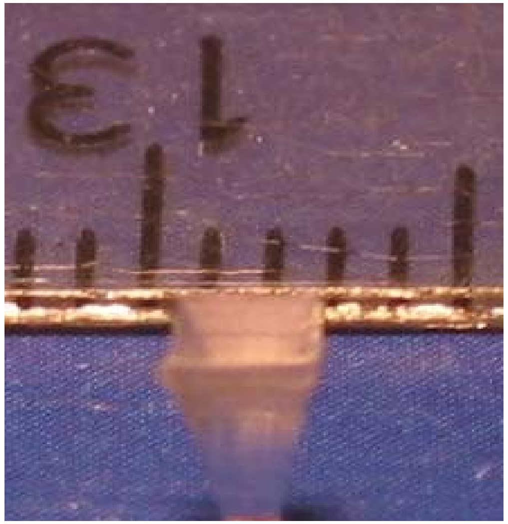
or combine a lens and mirror walls

Detector module design



SiPM array with light guides

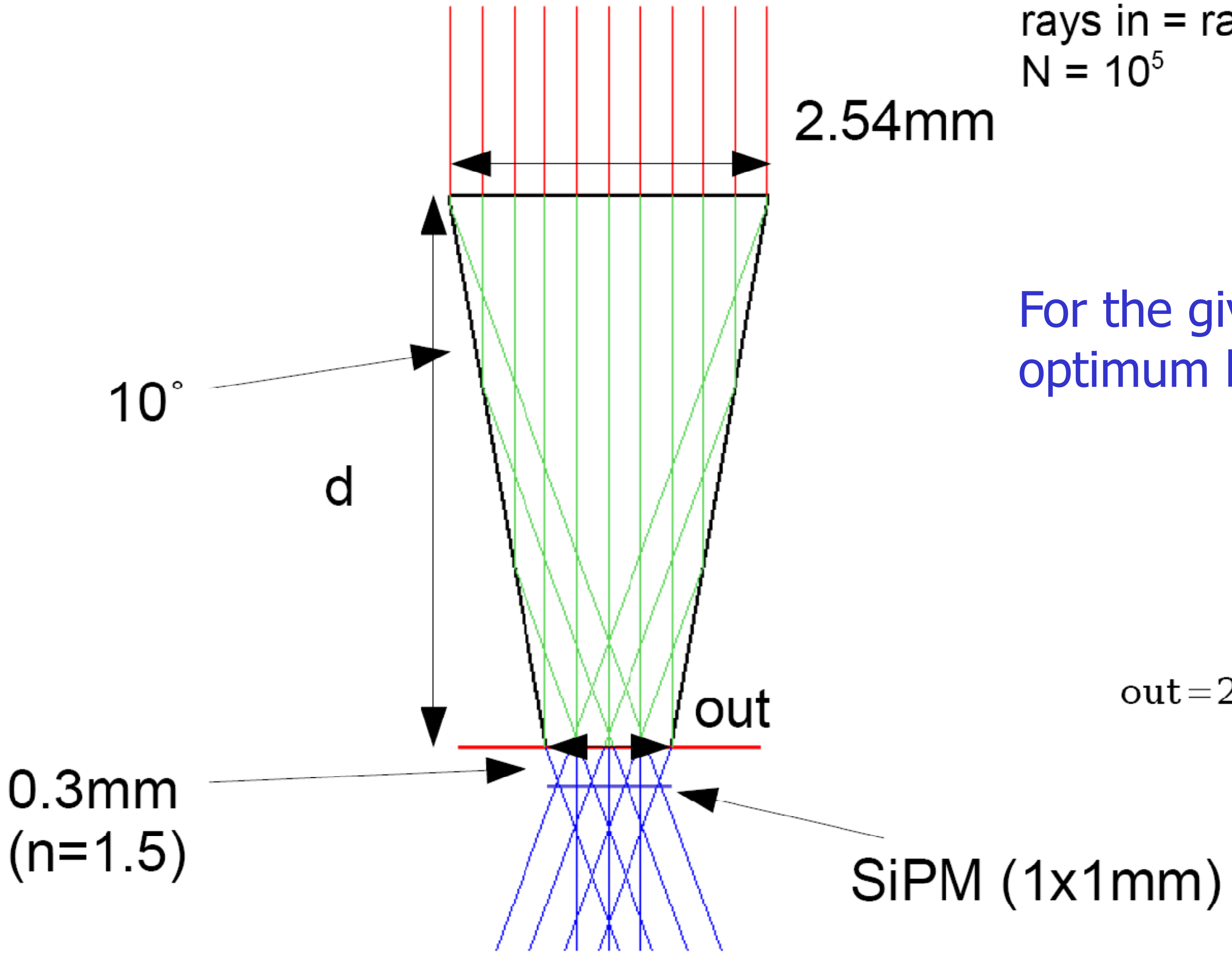




A multi-channel module prepared for a beam test at CERN

Light guide geometry optimisation

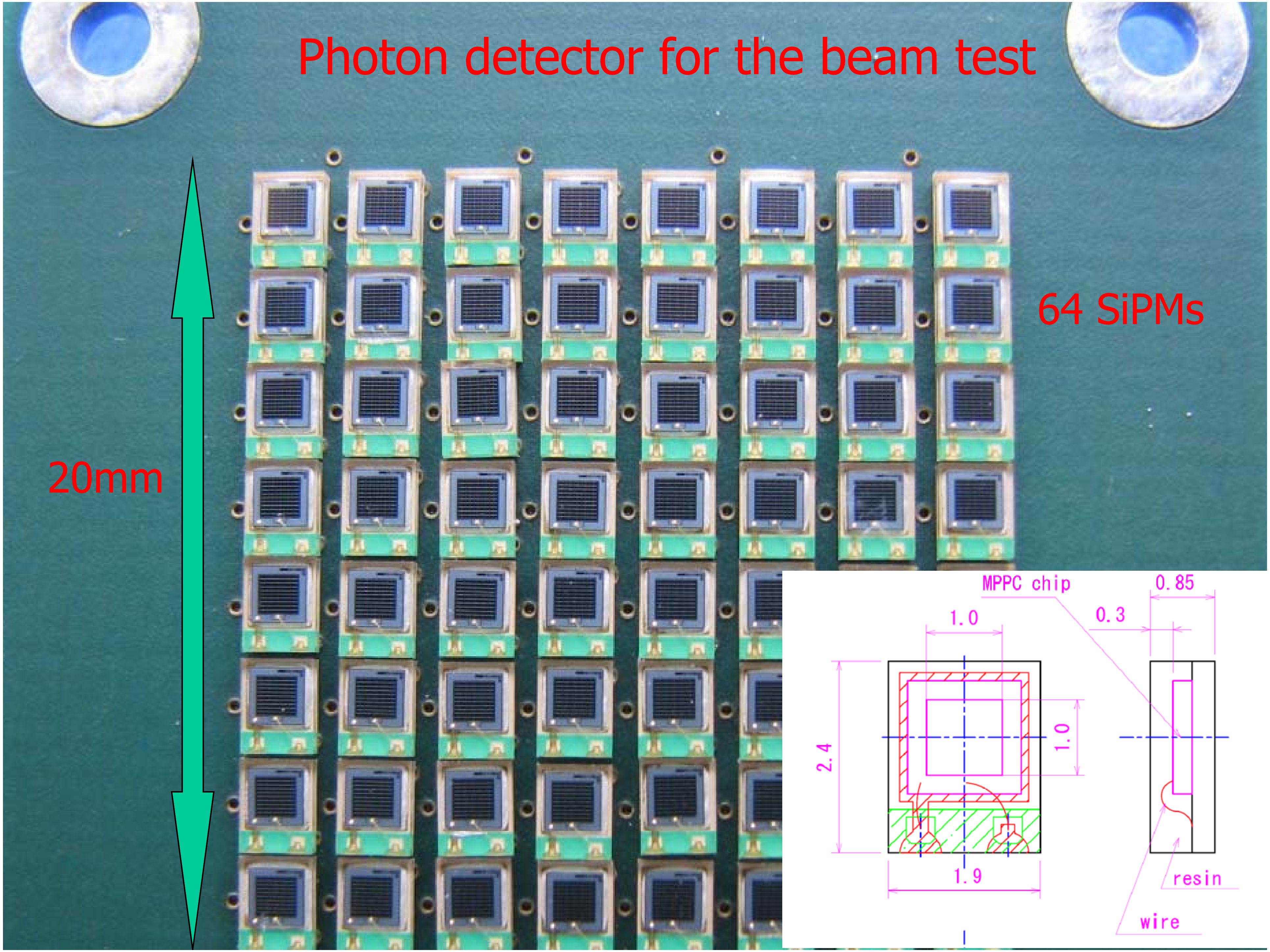
Light Guide Acceptance / (d and out)



rays in = random isotropic 0-30°
$N = 10^5$

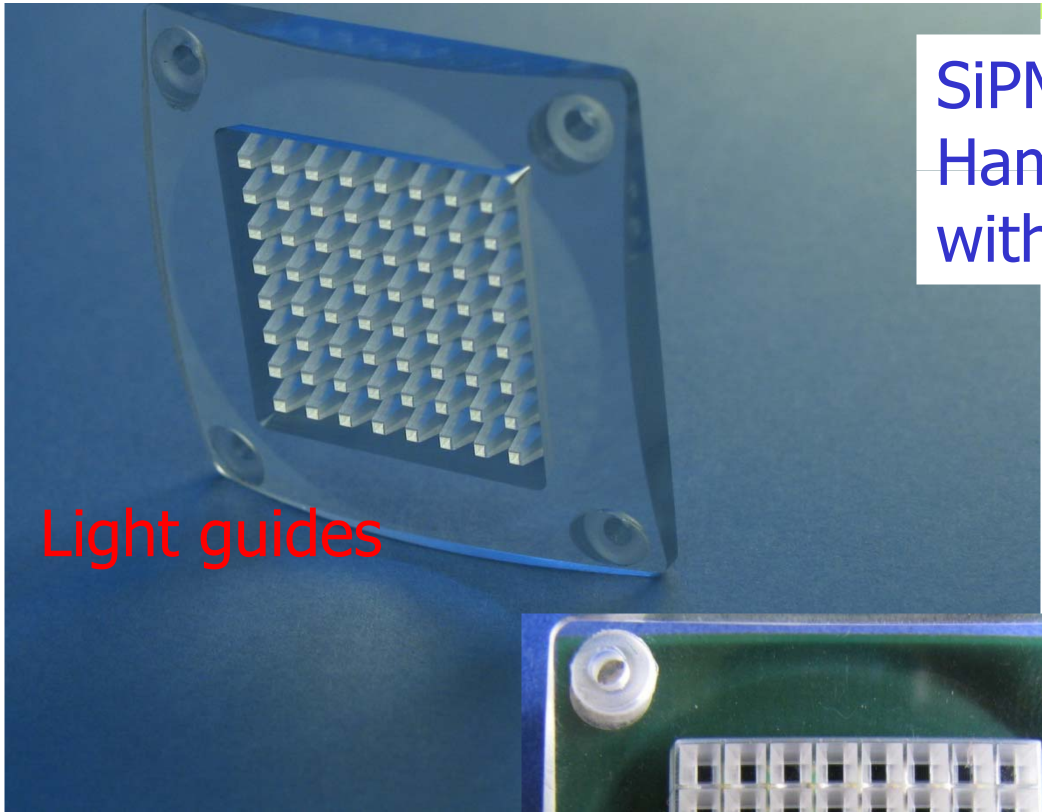
For the given geometry → optimum length 4mm

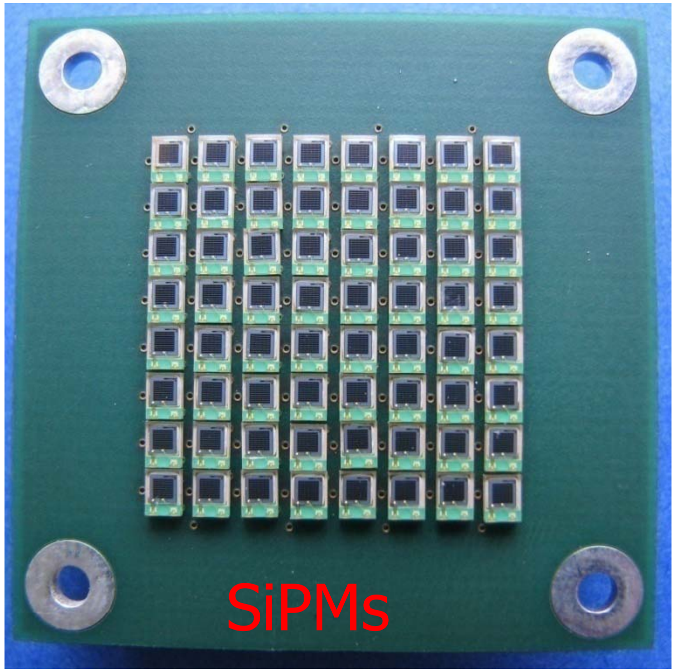
$$out = 2.54mm - 2 * d * \tan(10°)$$


Photon detector for the beam test
64 SiPMs
20mm
MPPC chip
0.85
1.0
0.3
2.4
1.0
1.9
resin
wire

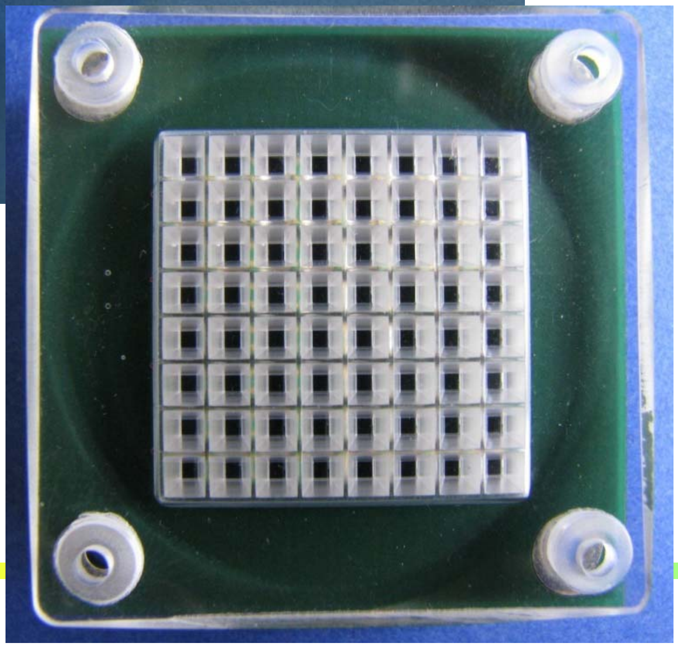
Detector module for beam tests at KEK

SiPMs: array of 8x8 SMD mount Hamamatsu S10362-11-100P with 0.3mm protective layer





2cm

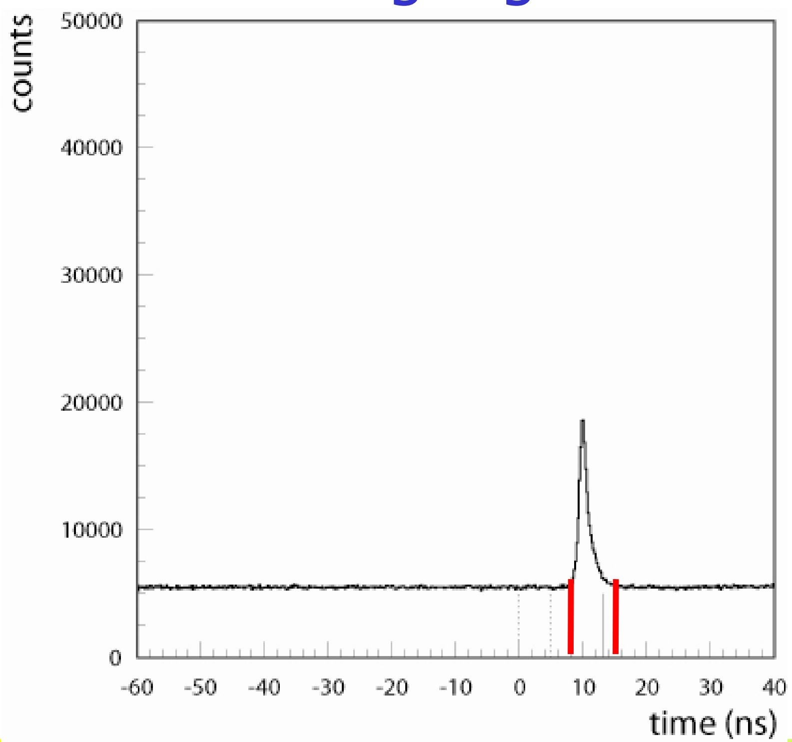


SiPMs + light guides

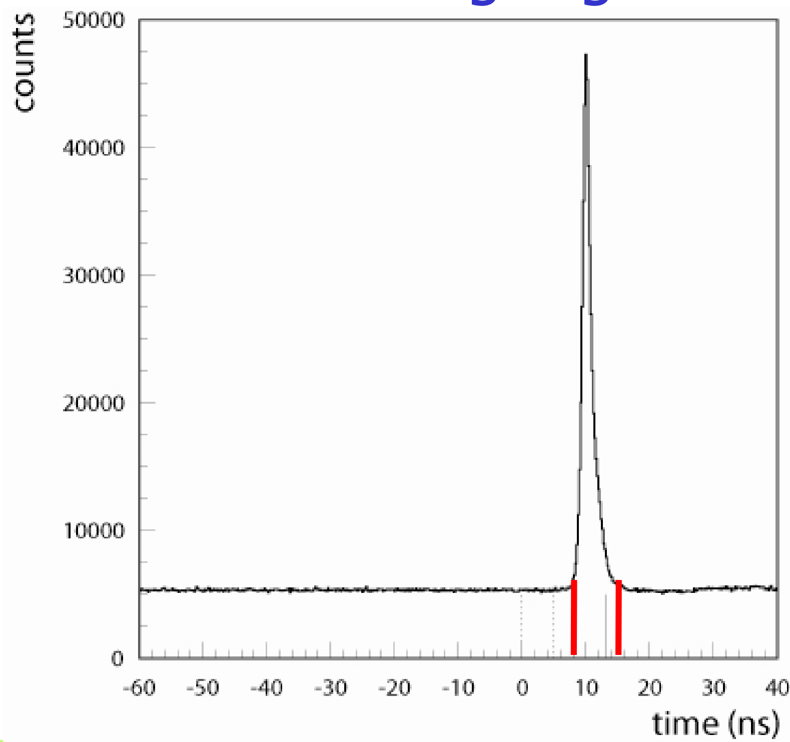
SiPM beam test: TDC distributions

- Total noise rate ~35 MHz (~600 kHz/MPPC)
- Hits in the time window of 5ns around the peak are selected for the Cherenkov angle analysis

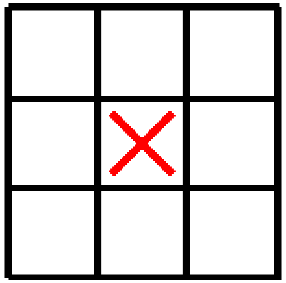
without light guides



with light guides

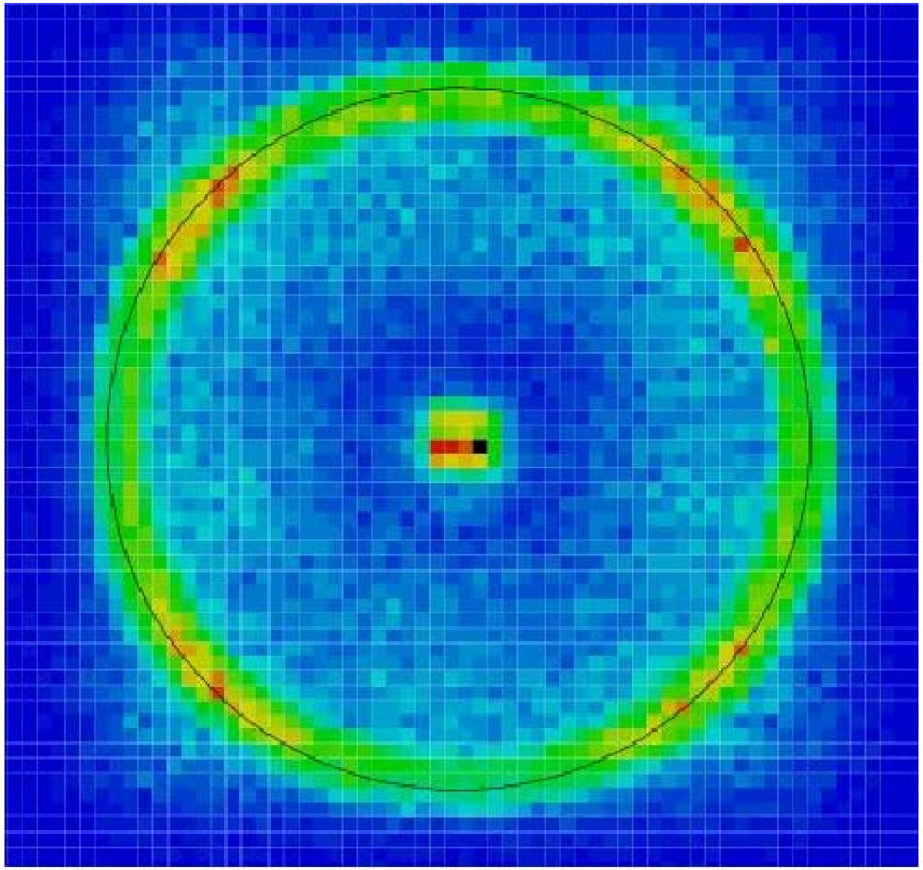


Ring images

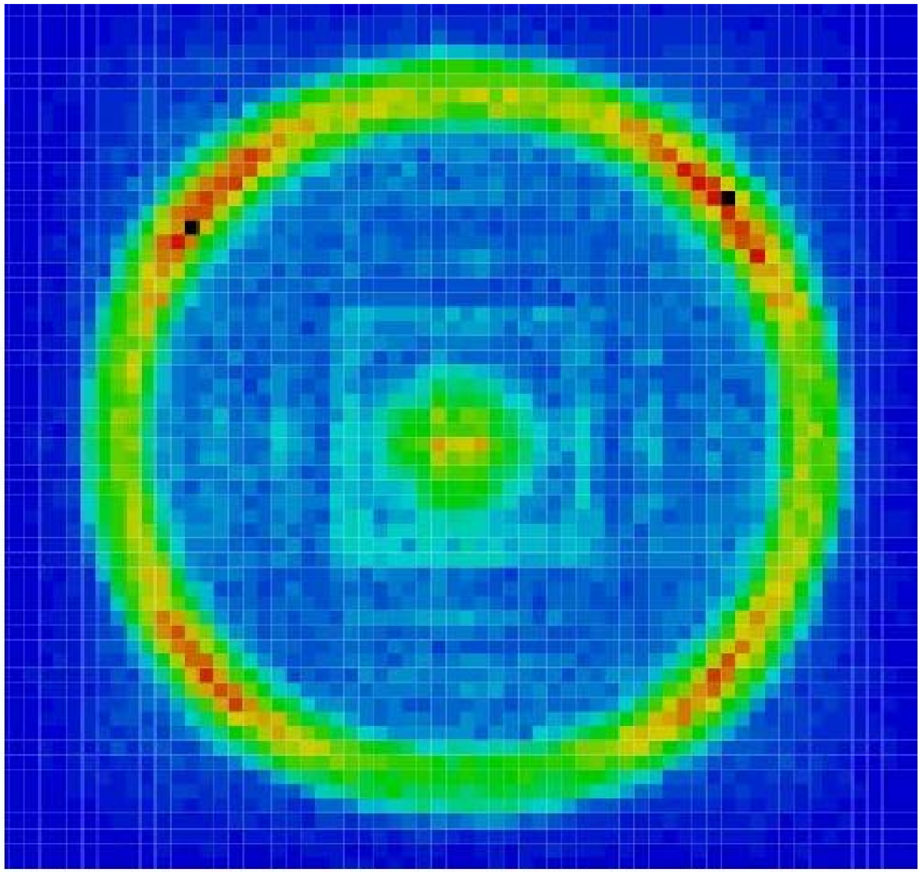


- module was moved to 9 positions to cover the ring area
- these plots show only superposition of 8 positions (central position is not included)

w/o light guides

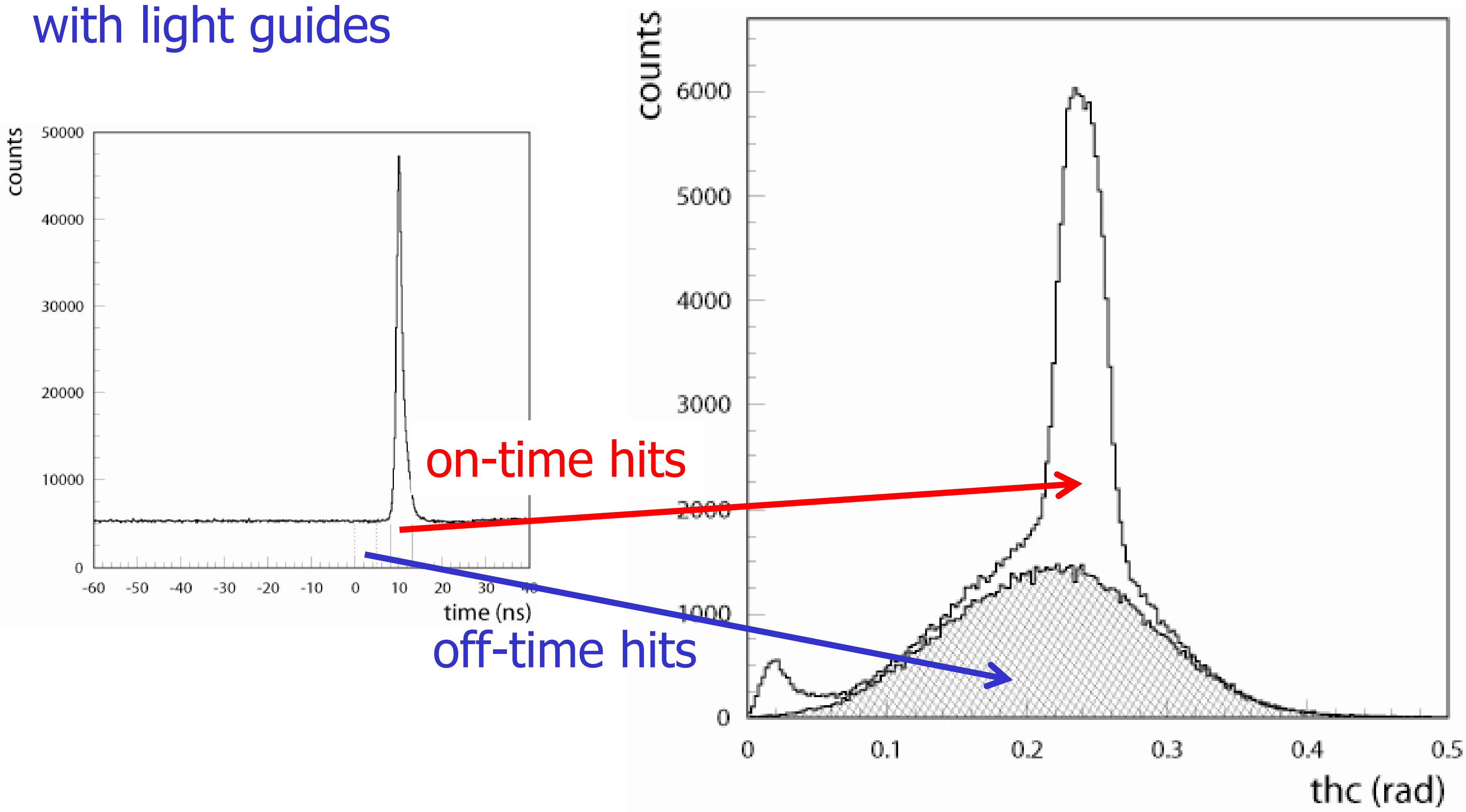


w/ light guides



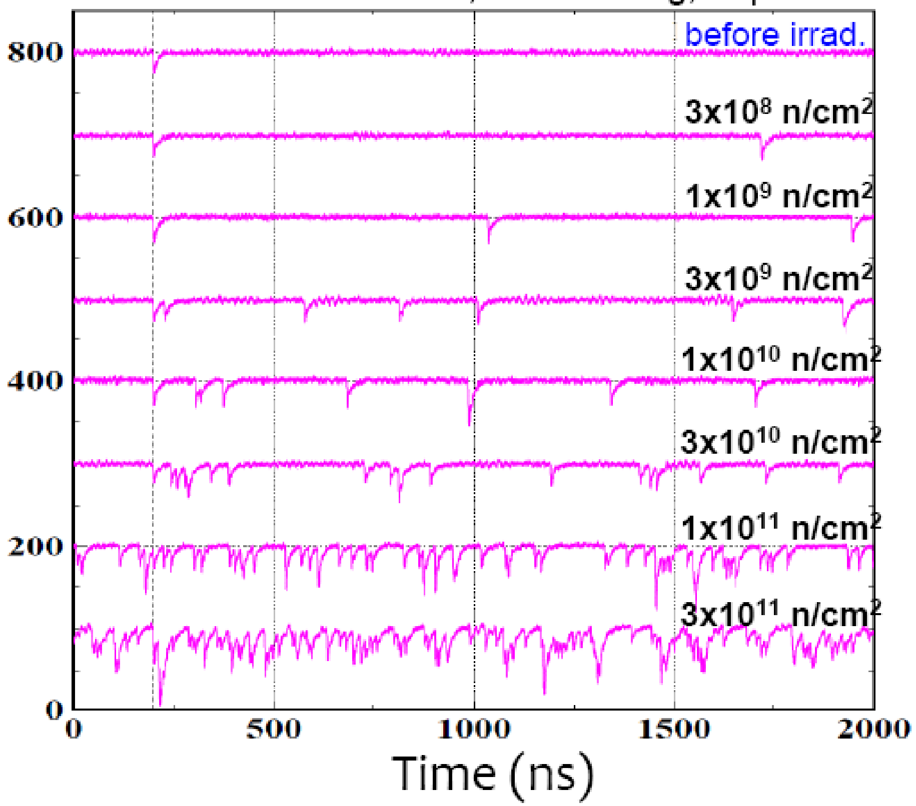
SiPM beam test: Cherenkov angle distributions

with light guides



Radiation damage

I.Nakamura, JPS meeting, Sep. 2008



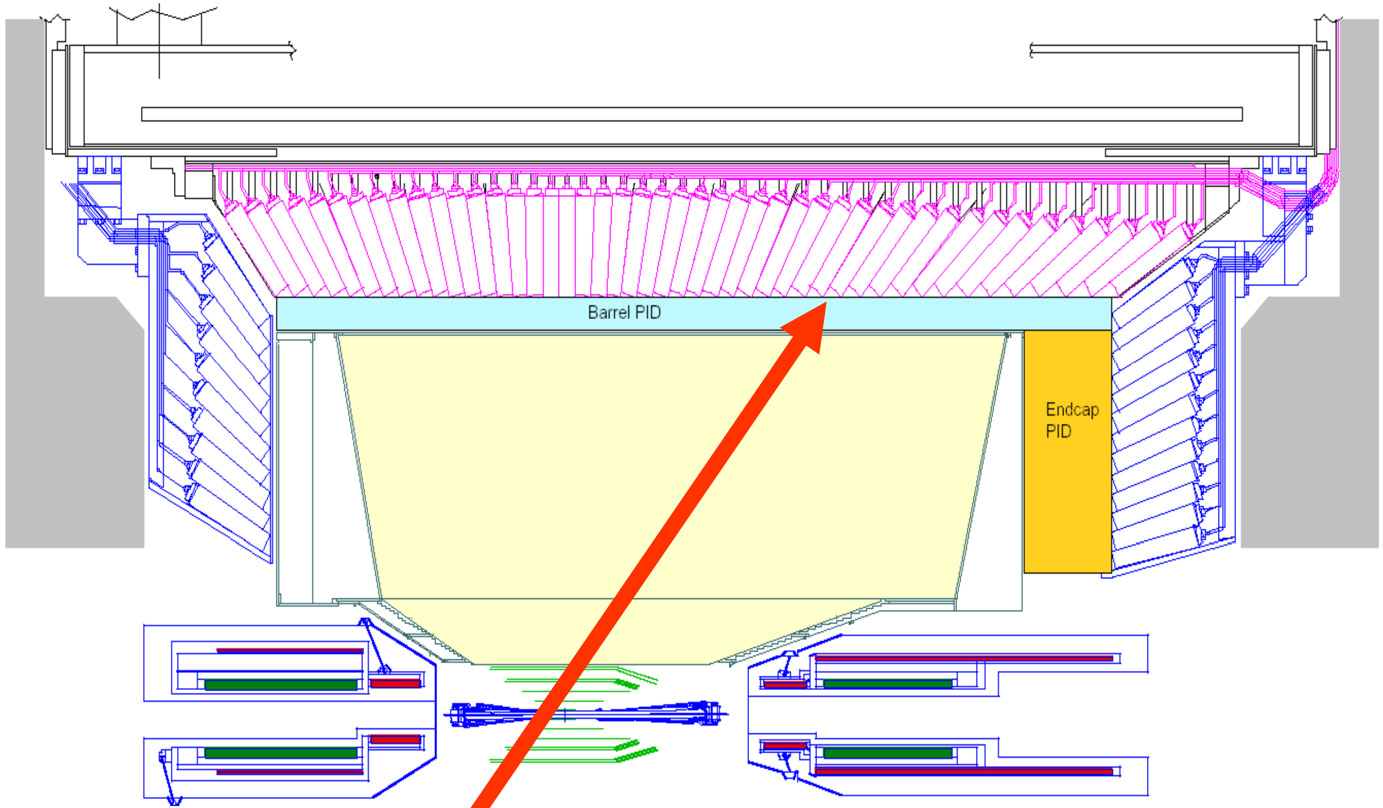
Expected fluence at 50/ab at Belle II: 2-20 10^{11} n cm^{-2}

→ Worst than the lowest line

→Very hard to use present SiPMs as single photon detectors in Belle II because of radiation damage by neutrons

→Also: could only be used with a sofisticated electronics – wave-form sampling

Belle upgrade – side view

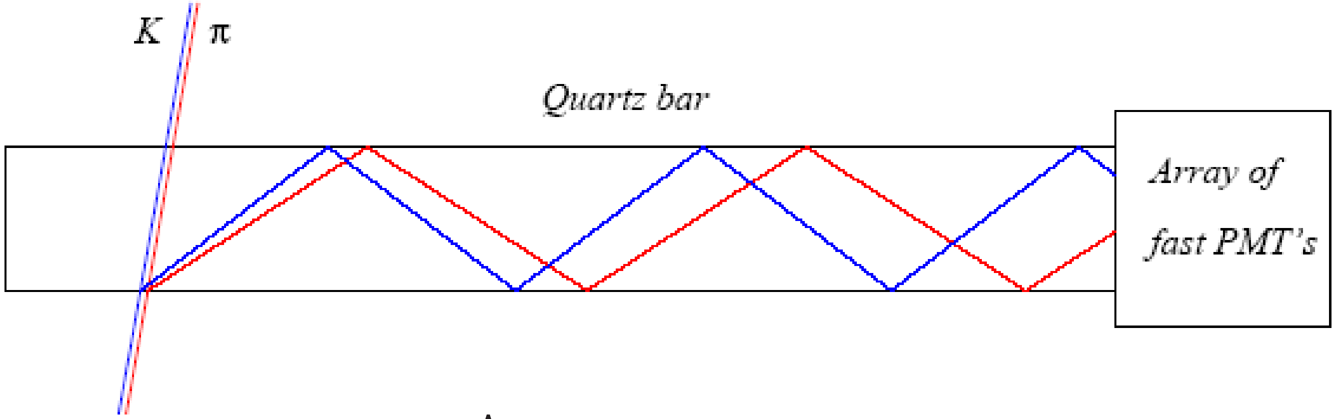


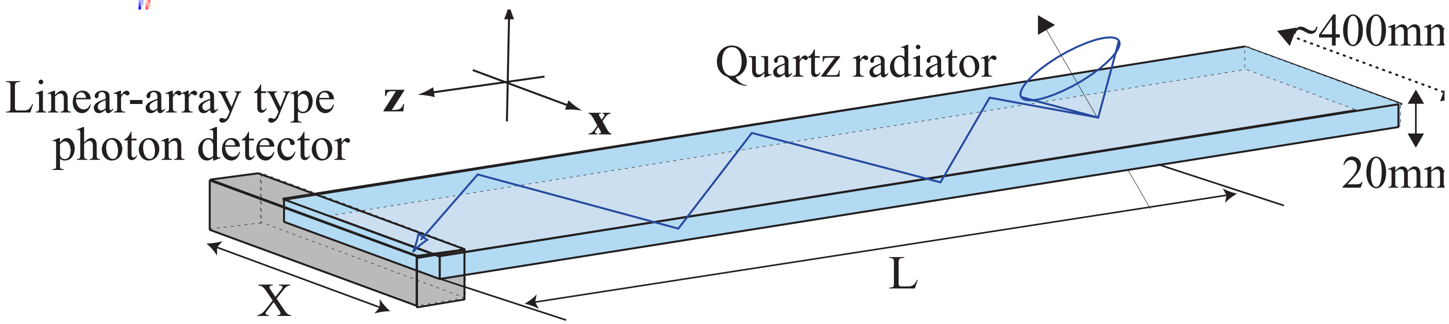
Two new particle ID devices, both RICHes:

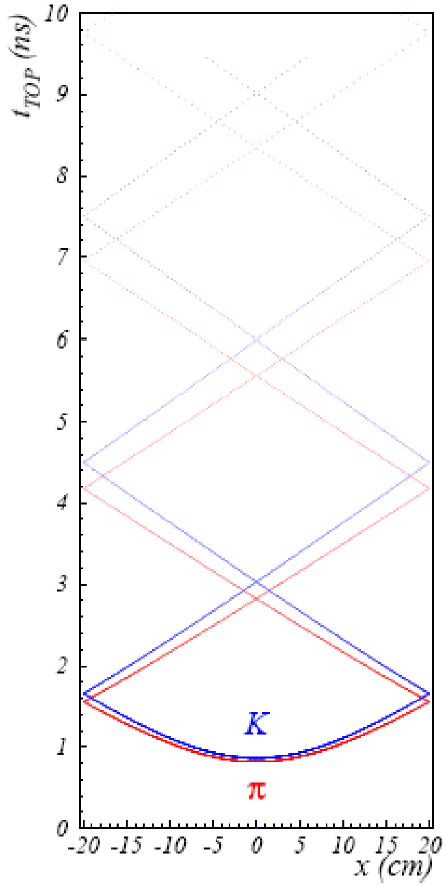
Barrel: Time-of-propagation counter (TOP) counter

Endcap: proximity focusing RICH

Time-Of-Propagation (TOP) counter



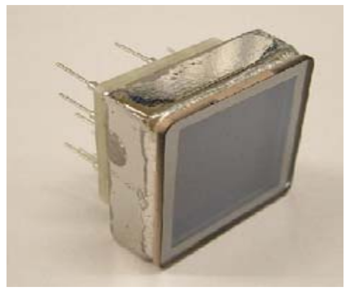




Similar to DIRC, but instead of two coordinates measure:

- One (or two coordinates) with a few mm precision
- Time-of-arrival

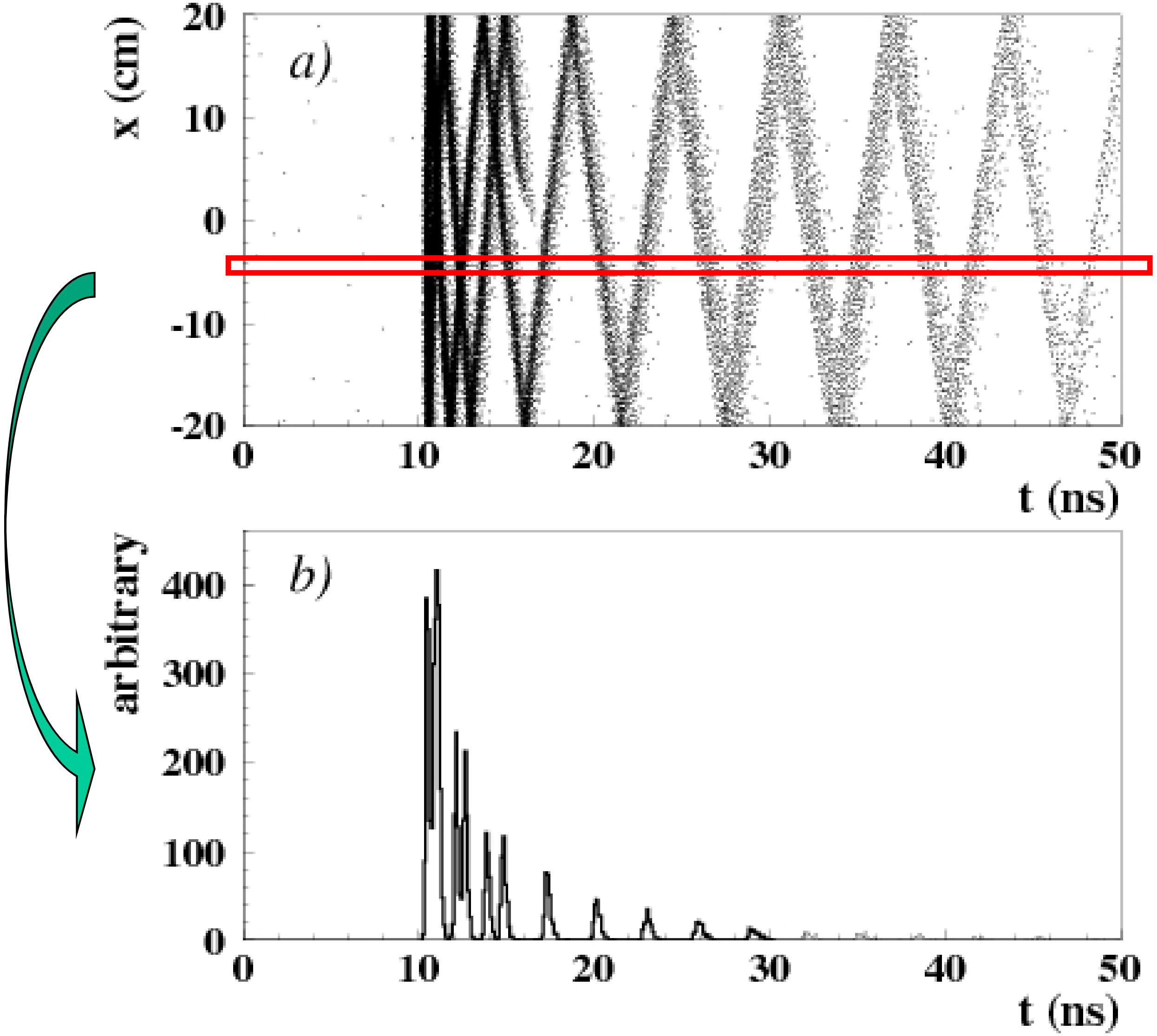
→ Excellent time resolution < ~40ps
required for single photons in 1.5T B field



Hamamatsu
SL10 MCP-PMT

→Talk by T. Iijima

TOP image

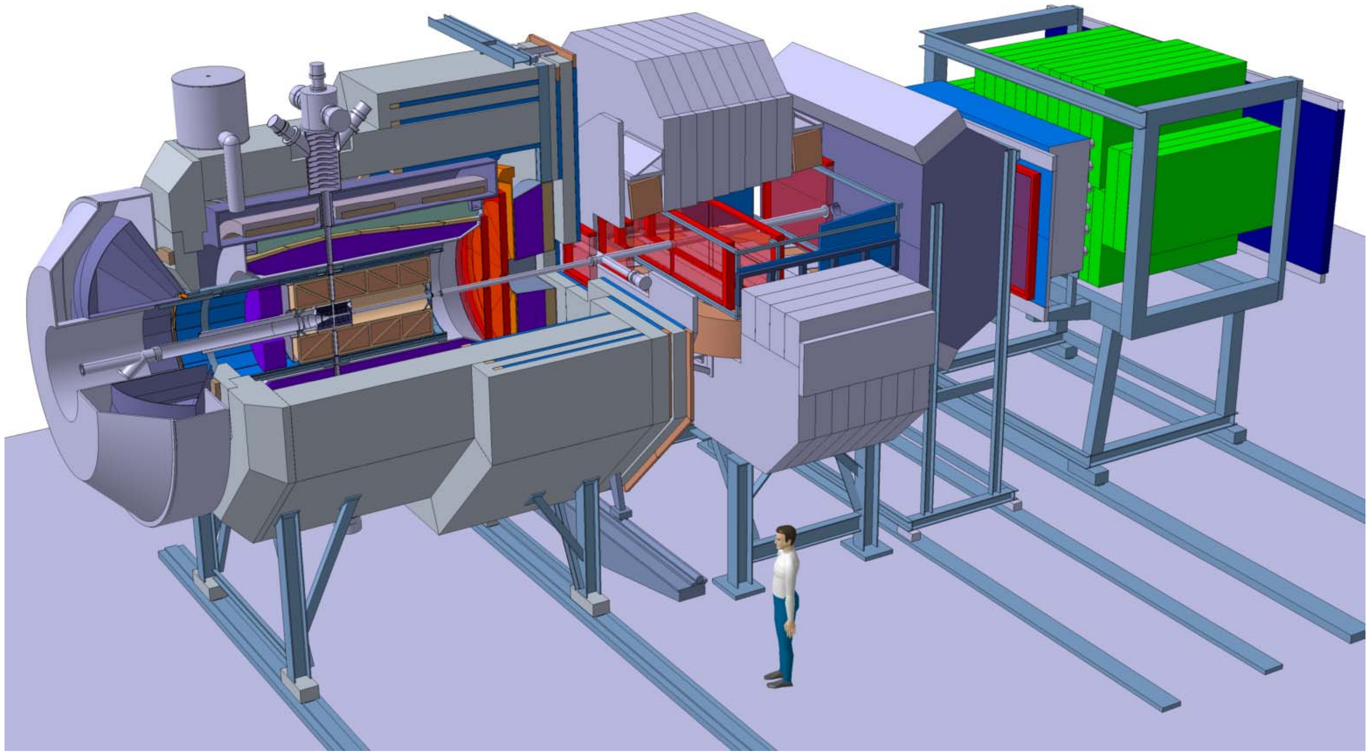


Pattern in the coordinate-time space ('ring') of a pion hitting a quartz bar with ~80 MAPMT channels

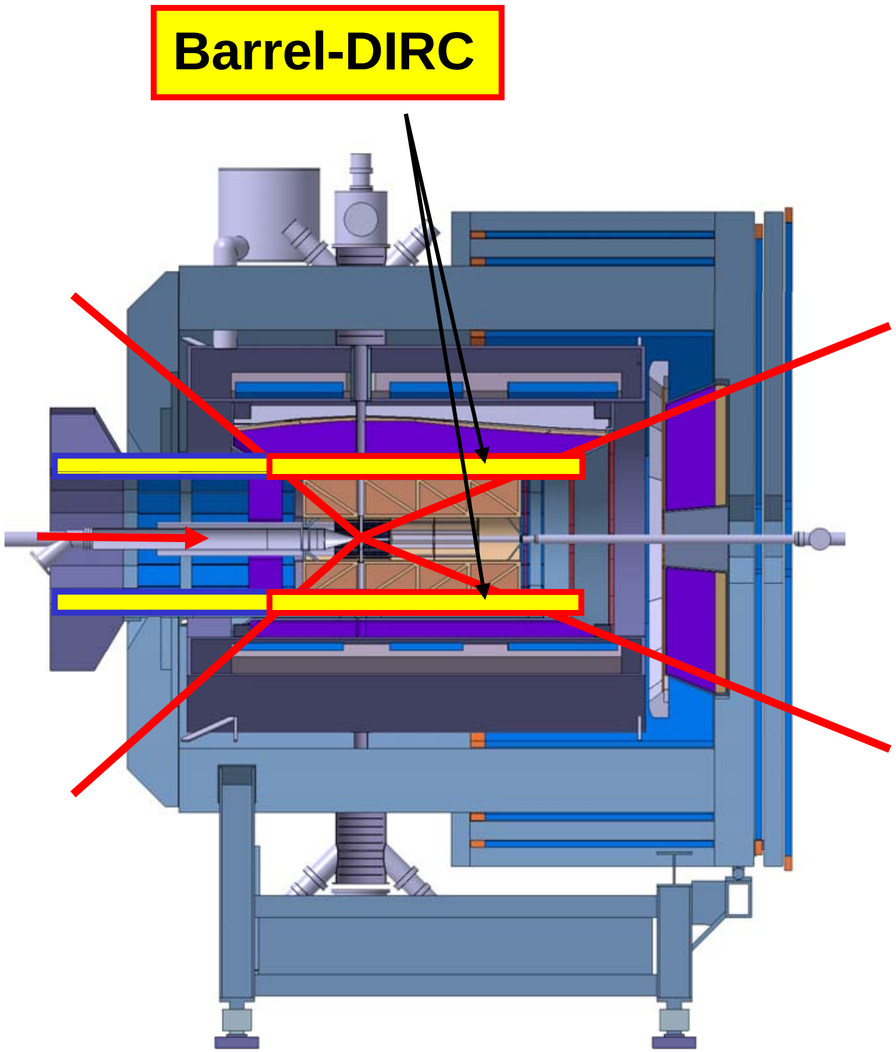
Time distribution of signals recorded by one of the PMT channels: different for π and K

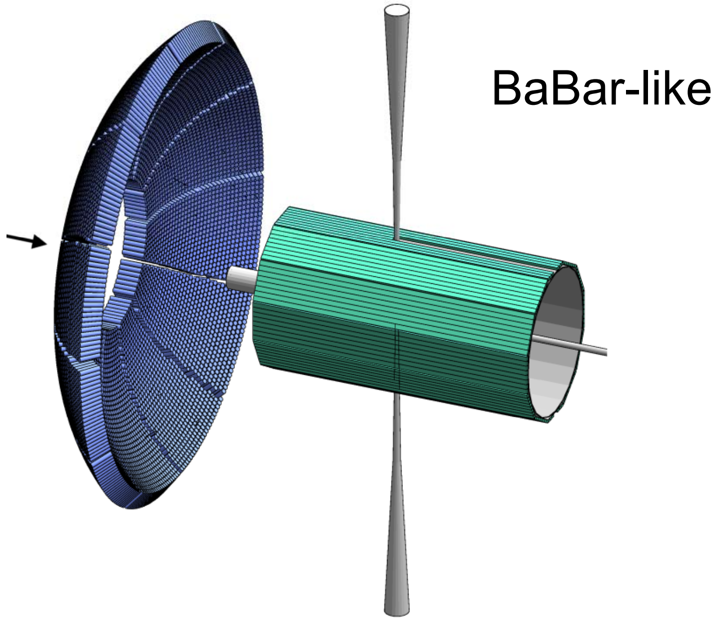
DIRC counters for PANDA (FAIR, GSI)

Two DIRC-like counters are considered for the PANDA experiment



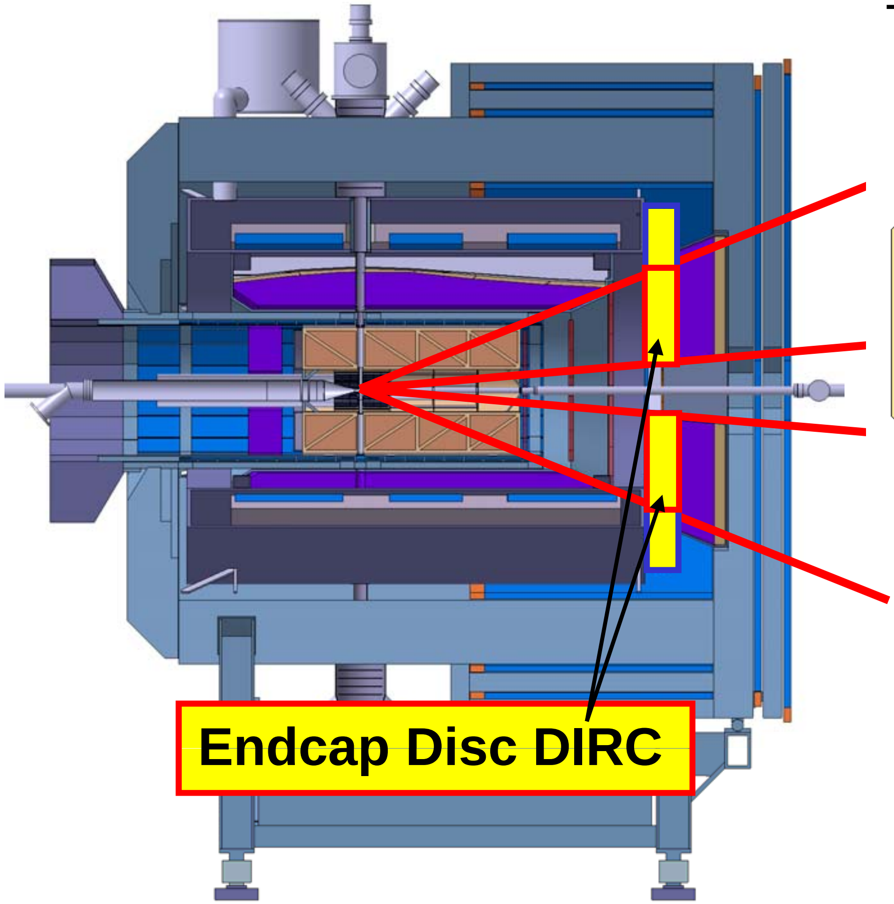
PANDA barrel DIRC





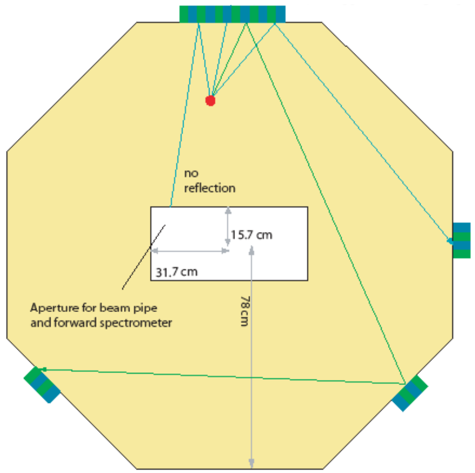
→ Talk by Mathias Hoek

PANDA endcap DIRC

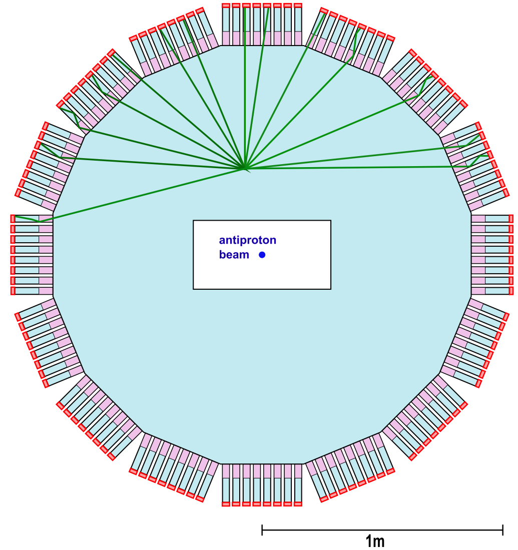


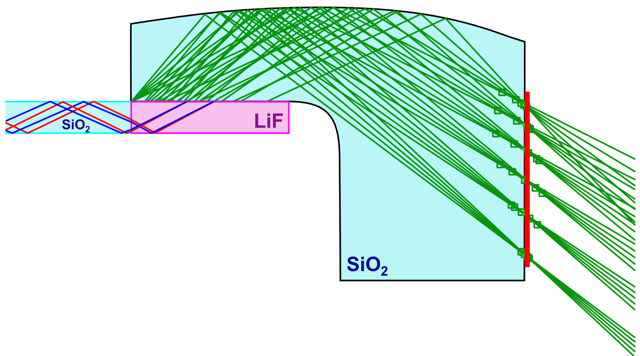
Two different readout designs:

Time-of-Propagation



Focussing light guide

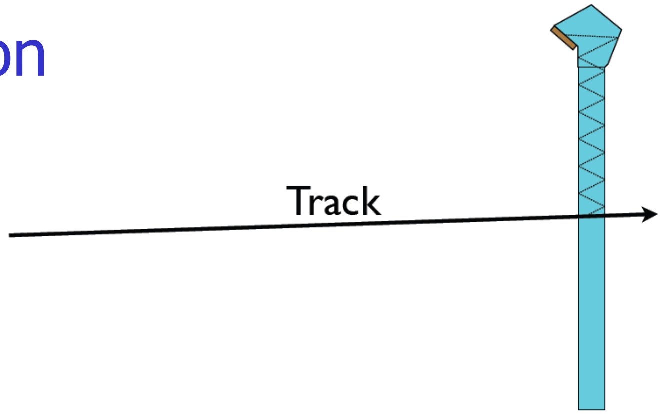


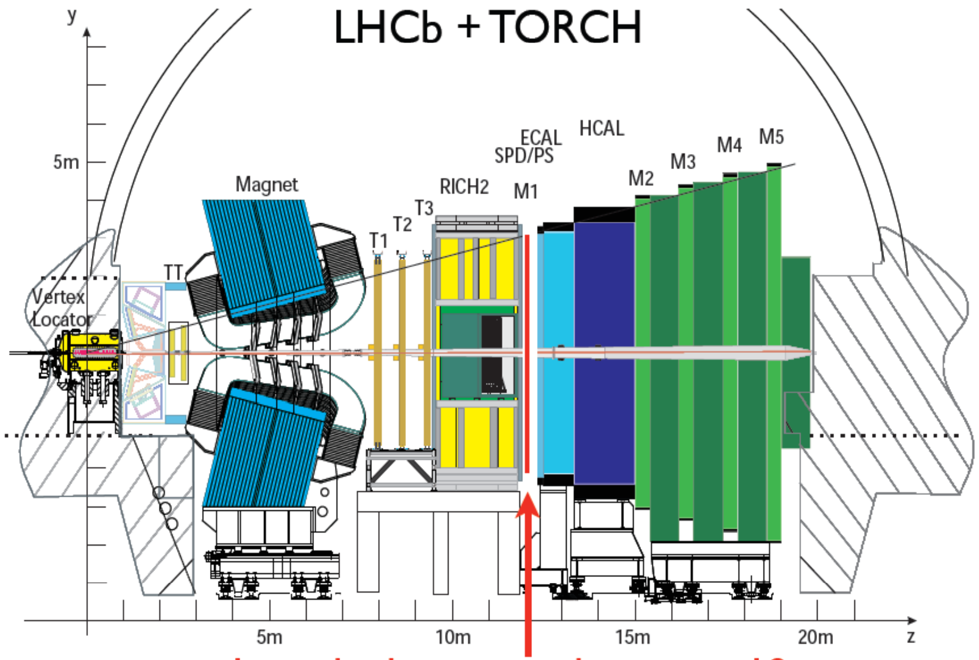


→ Talk by Mathias Hoek

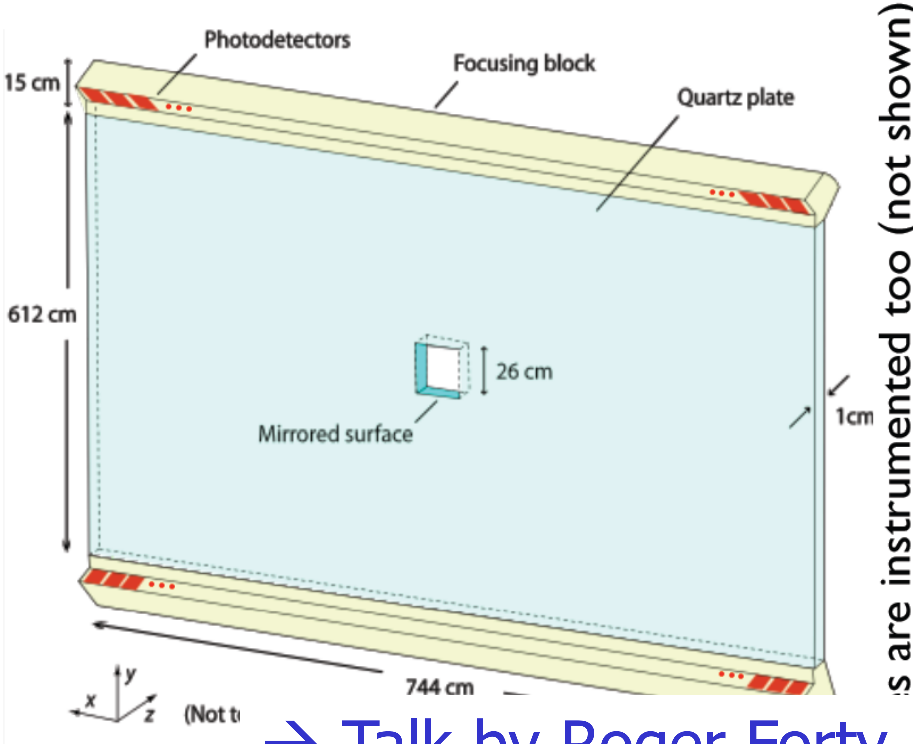
LHCb PID upgrade: TORCH

A special type of Time-of-Propagation counter for the LHCb upgrade





1cm-thick quartz plate at z=12m

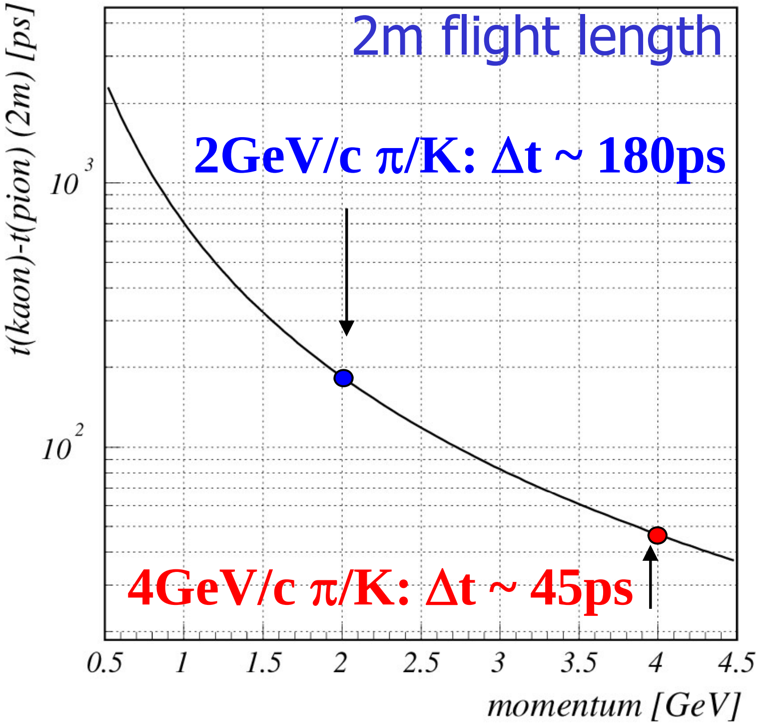


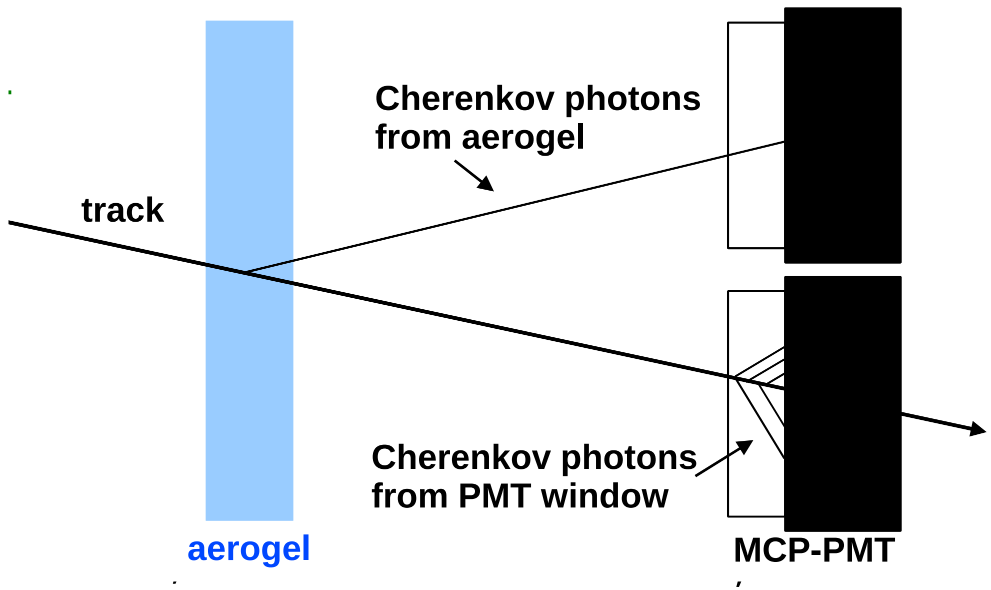
→ Talk by Roger Forty

TOF capability of a RICH

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 →



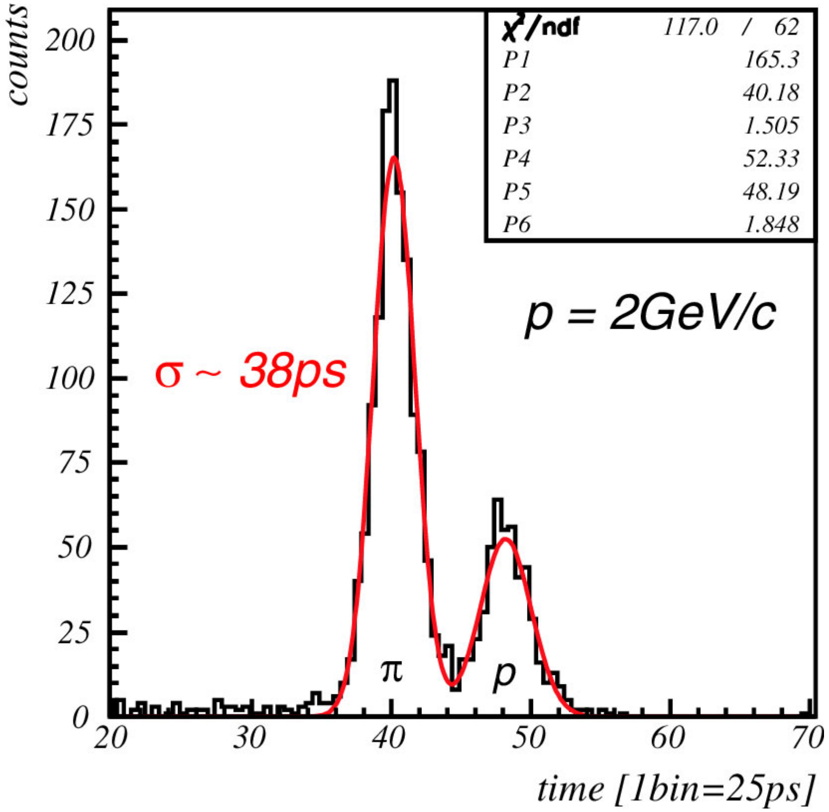


For time of flight: use Cherenkov photons emitted in the PMT window

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

→ In the real detector ~2m

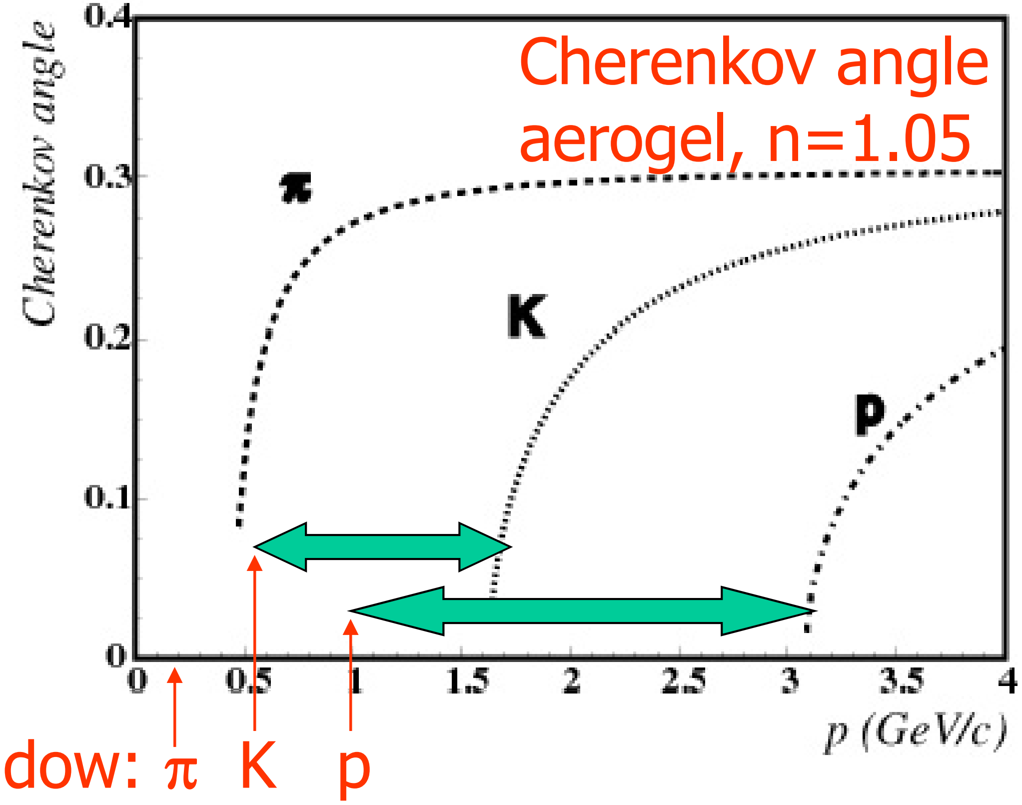
→ 3x better separation

S. Korpar, NIM A572 (2007) 432

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.

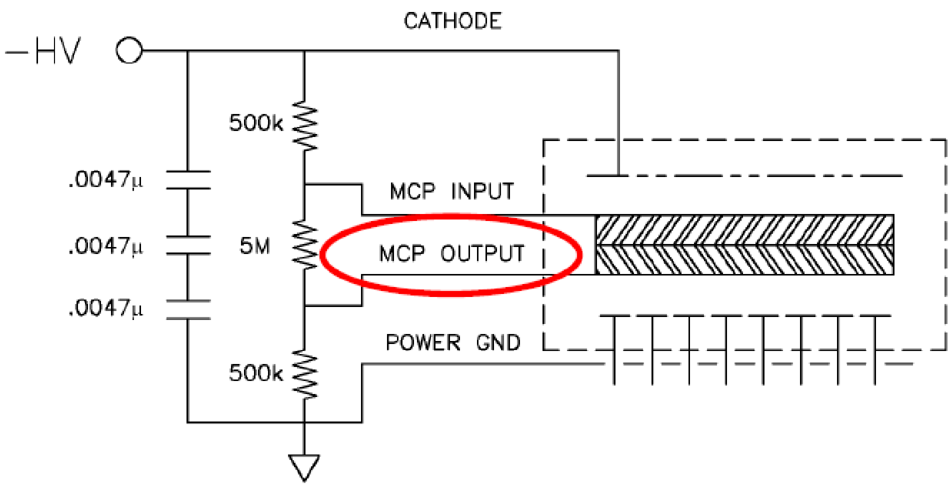


Window: threshold for kaons (protons) is at ~0.5 GeV (~0.9 GeV): → positive identification possible.

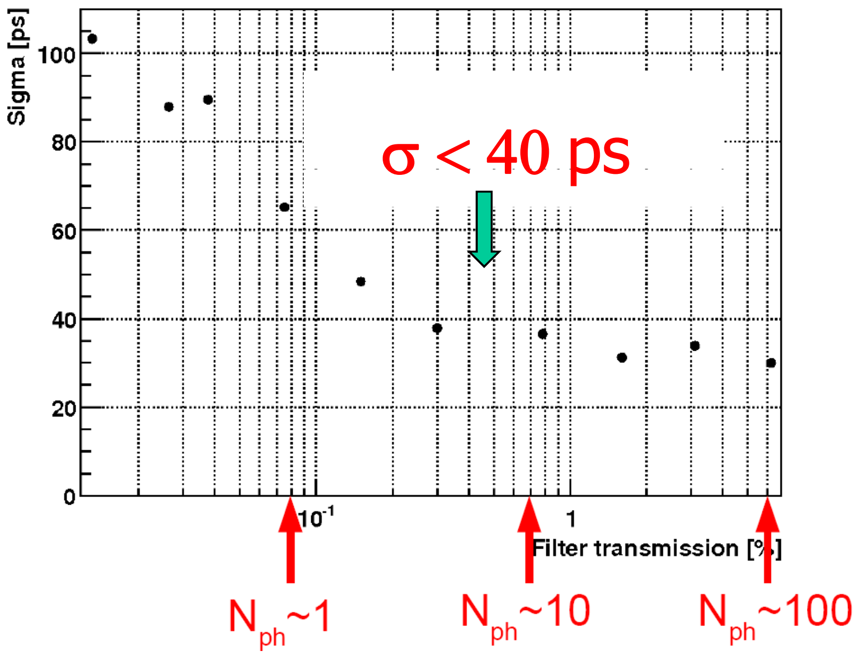
Timing with a signal from the second MCP stage

If a charged particle passes the PMT window, ~10 Cherenkov photons are detected in the MCP PMT; they are distributed over several anode channels.

Idea: read timing for the whole device from a single channel (second MCP stage), while 64 anode channels are used for position measurement



MCP second stage output

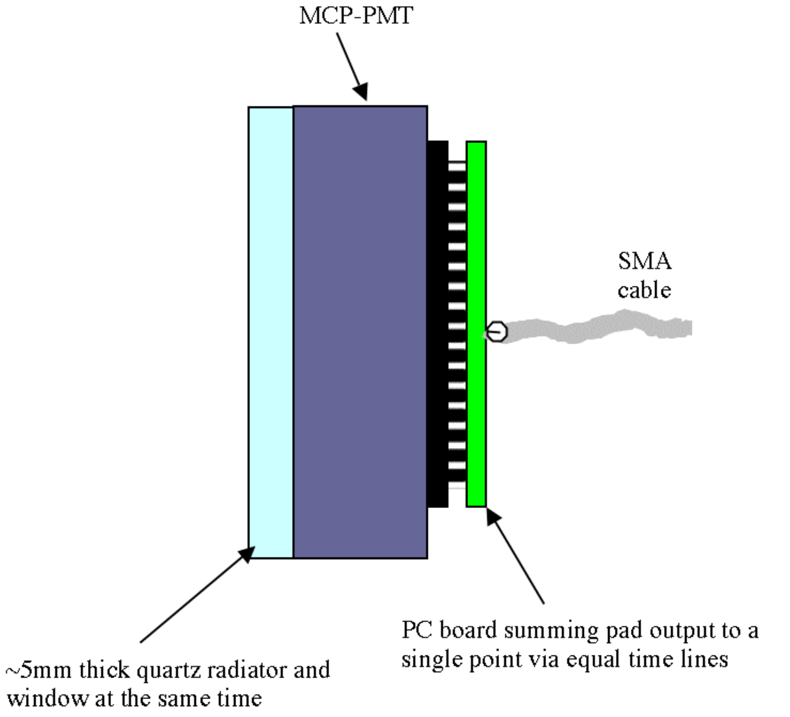


Timing resolution as a function of light intensity

Time-of-flight: stand-alone, revisited

New ingredients:

- Faster photon detectors
- Use of Cherenkov light instead of scintillation photons
- Faster electronics



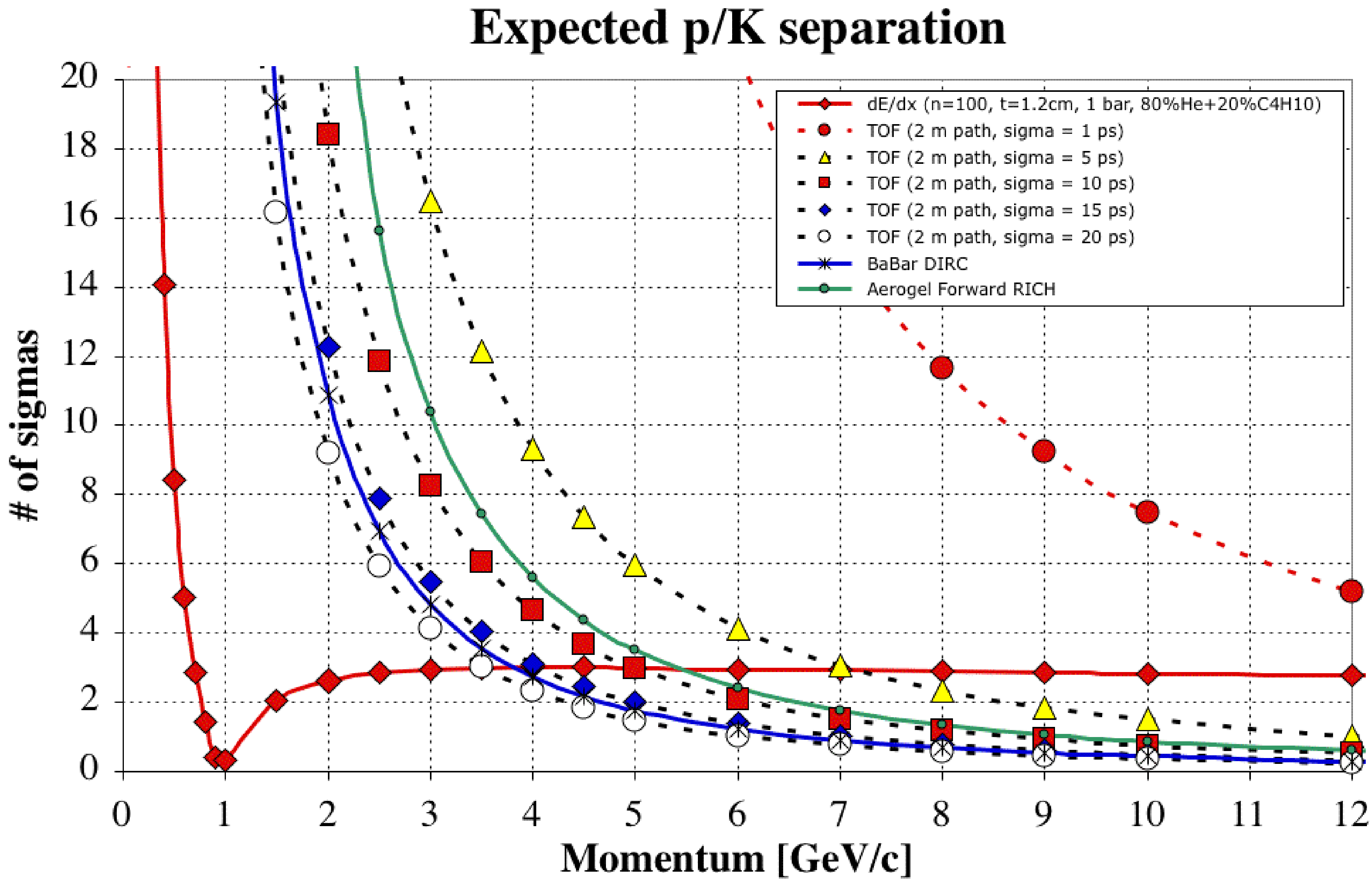
Recent results:

→resolution ~5ps measured

- K. Inami NIMA 560 (2006) 303
- J. Va'vra NIMA 595 (2008) 270

Open issues: read-out, start time

Time-of-flight: stand-alone, revisited

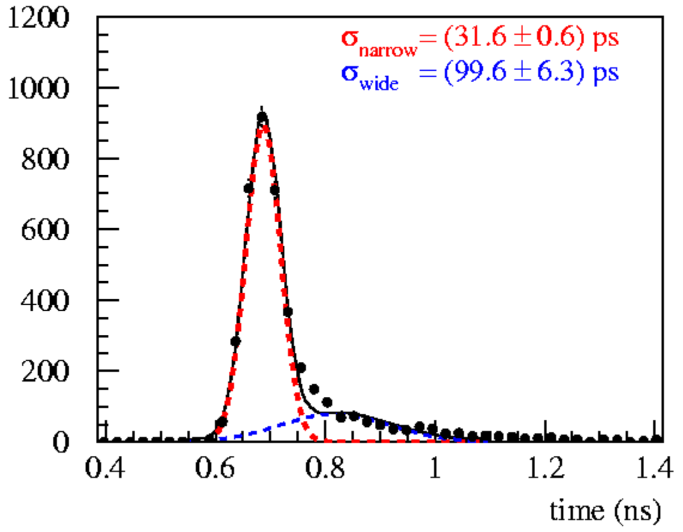


J. Va'vra, slides shown at RICH07

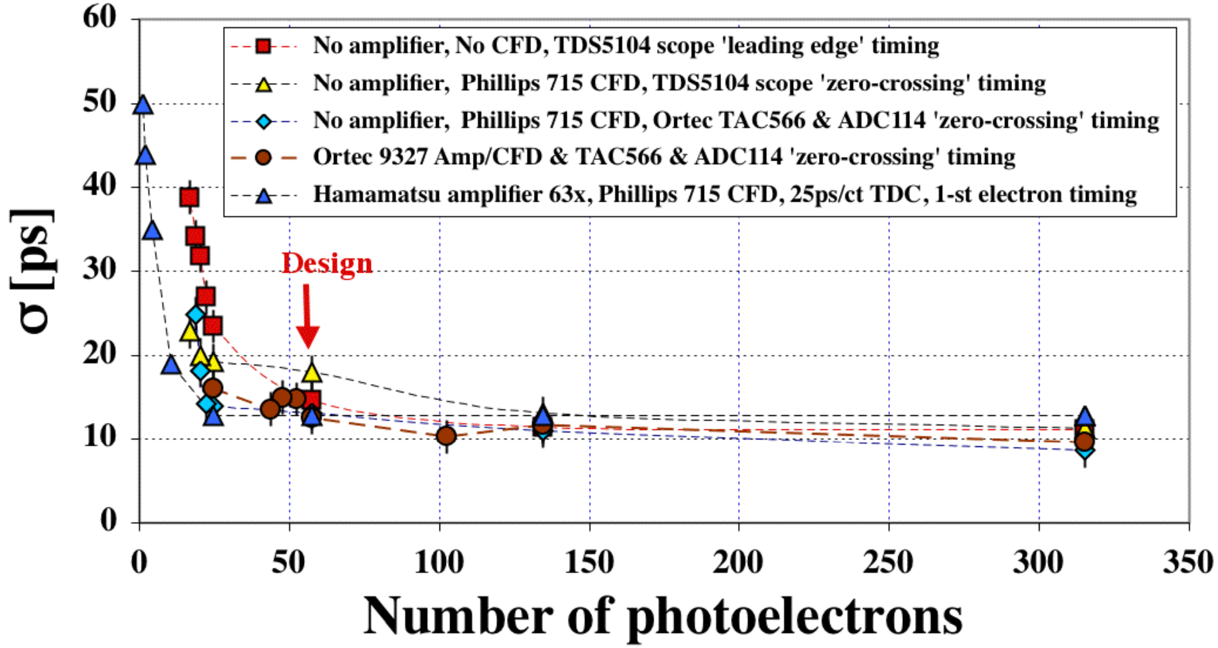
TOF counter with Burle/Photonis MCP-PMT

J. Va'vra, VCI2007

σ_{TTS} - single photo-electrons:

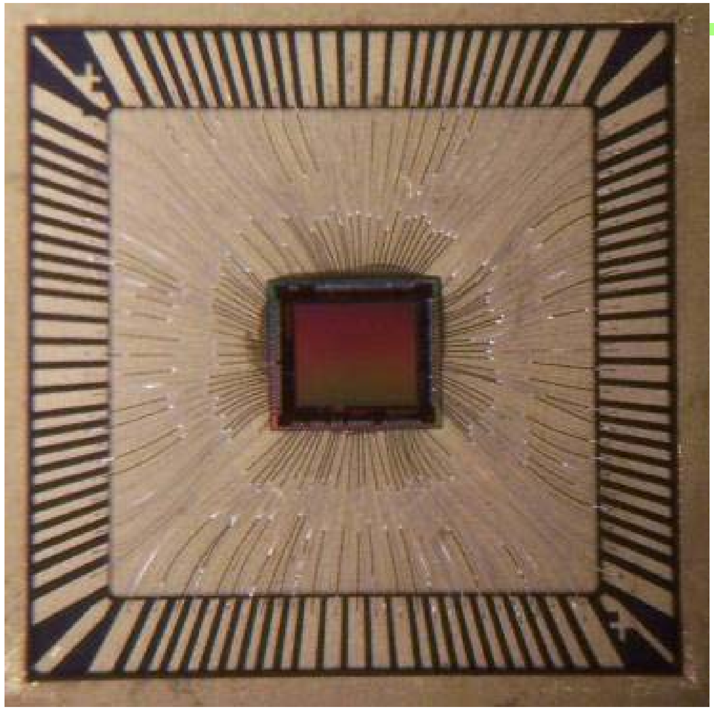


Timing resolution σ = f(Npe):



- **TOF counter: Burle/Photonis MCP-PMT with a 1cm thick quartz radiator**
- **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: $\sigma_{MCP\text{-}PMT}$ < 6.5 ps**.
  - **TAC/ADC contribution to timing: σ_{TAC_ADC} < 3.2 ps**.
  - **Total electronics contribution: $\sigma_{Total\_electronics}$ ~ 7.2 ps**.

Read out: Buffered LABRADOR (BLAB1) ASIC



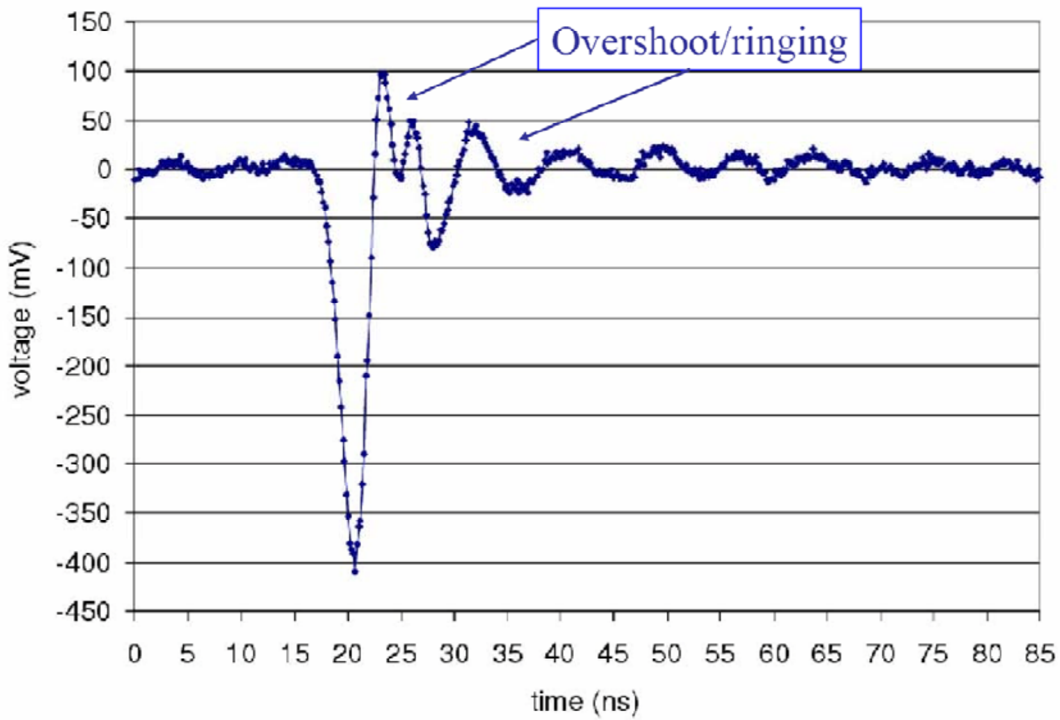
Gary Varner, Larry Ruckman (Hawaii)

Variant of the LABRADOR 3

Successfully flew on ANITA in Dec 06/Jan 07 (<= 50ps timing)

3mm x 2.8mm, TSMC 0.25um

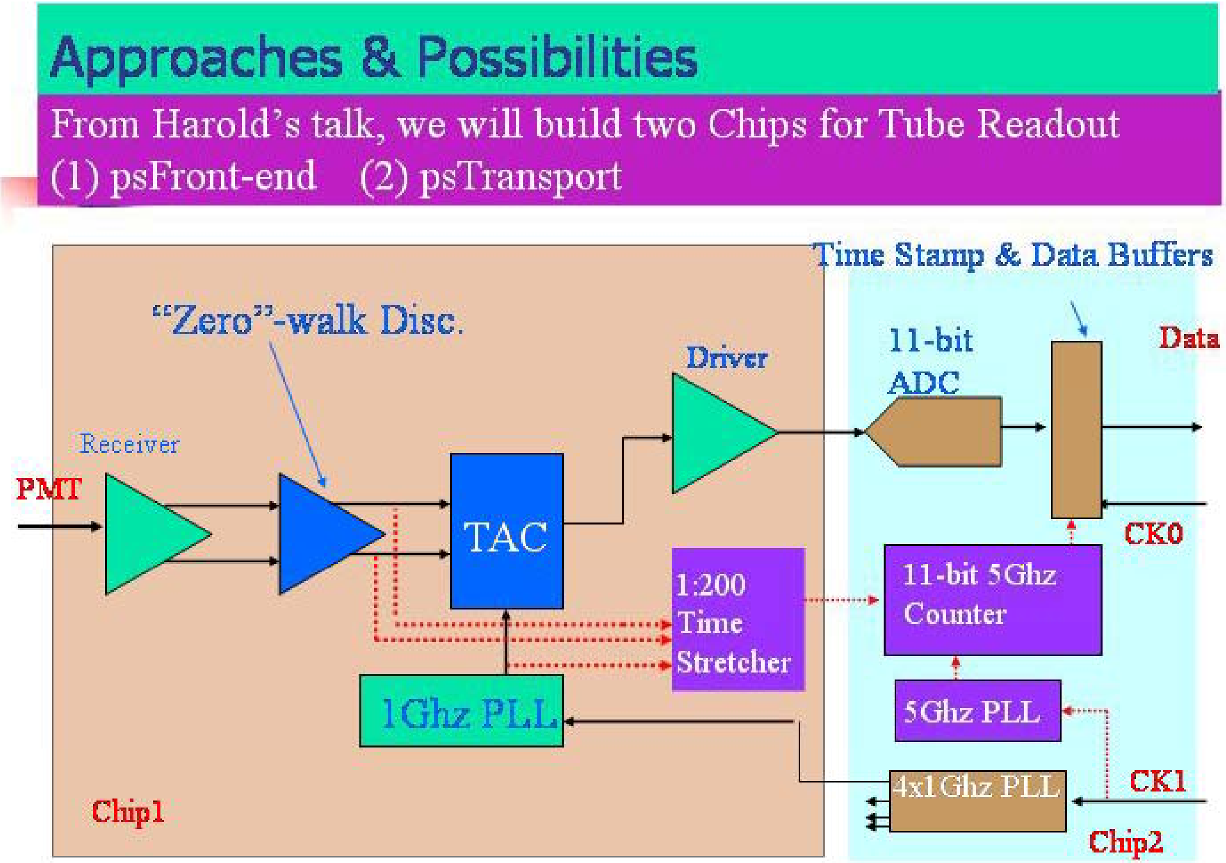
Typical single p.e. signal [Burle]



- 64k samples deep
- Multi-MSa/s to Multi-GSa/s

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

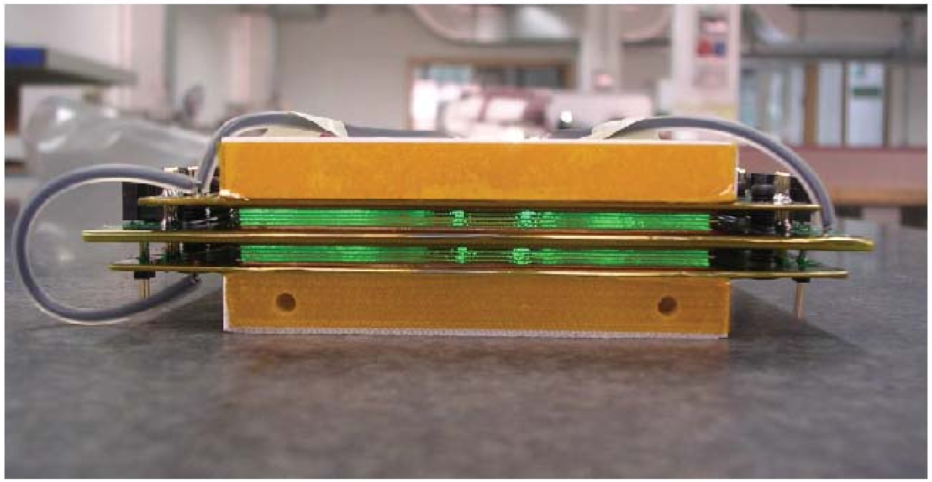
ALICE TOF

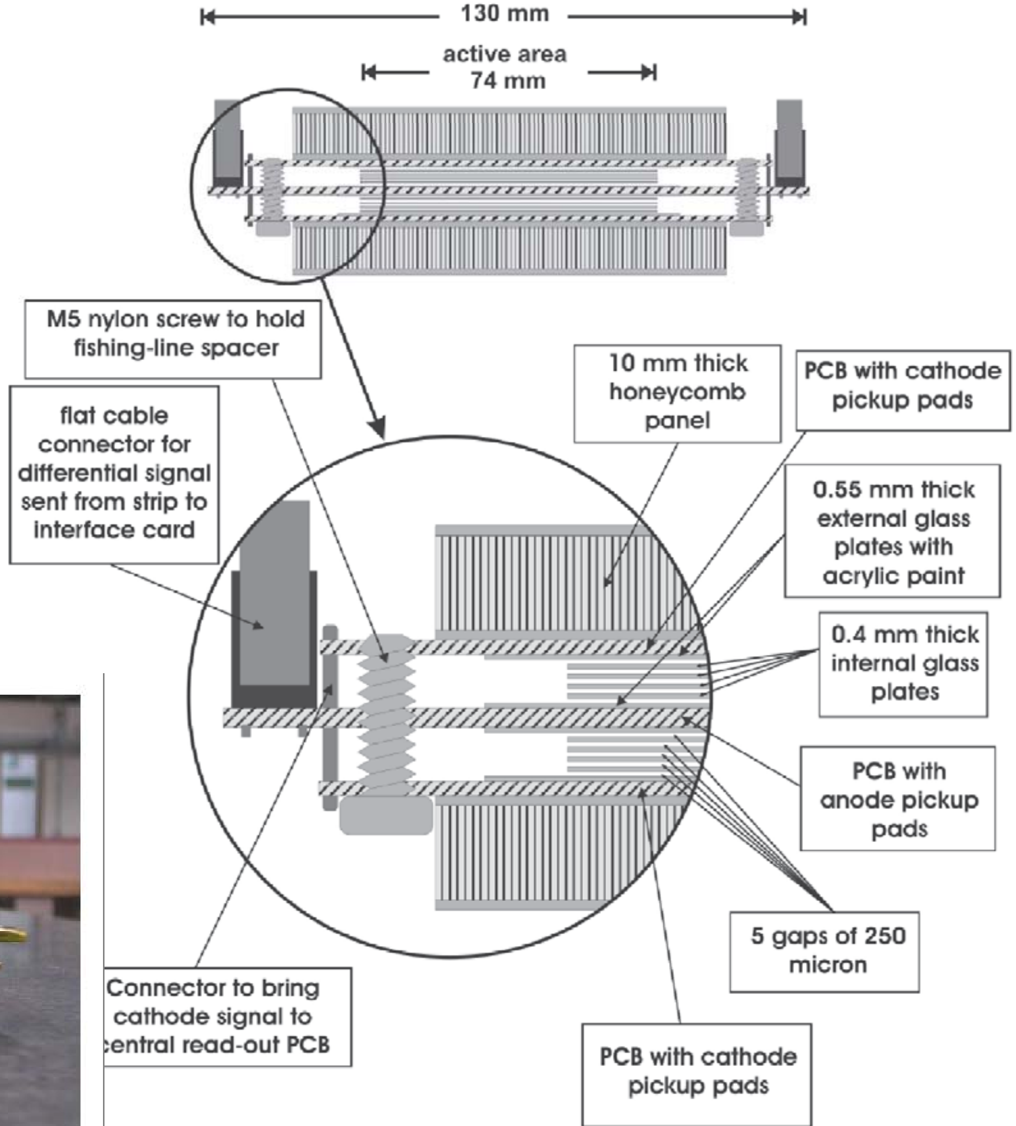
Very fast large area ($140 m^2$) particle detector:

→ MRPC, multi-gap RPC

σ=50ps (incl. read-out)

π/K separation (3σ) up to 2.5 GeV/c at large track densities





Summary

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

Techniques based on Cherenkov radiation have become indispensable for PID

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

New concepts (focusing radiator, combination with time of flight) and new photon detectors 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.

It will be interesting to hear more about the PID upgrade for CLAS12 at this workshop

RICH for CLAS12