Cherenkov Light Imaging in High Energy and Nuclear Physics

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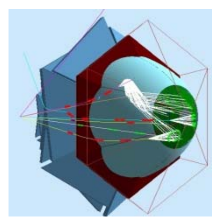
Scope of Review

“Cherenkov Light Imaging in High Energy and Nuclear Physics”

What aspects should/will I try to cover in this review?

- Recent/current and future RICH systems for accelerator experiments…
- …at large facilities – CERN, GSI, KEK, JLab, etc. …
- …in nuclear physics, hadron physics, particle physics…
- …with a glance at the significance of enabling technologies…
- …in 35 minutes or less.


photon detectors


CLAS12

SCOPE OF REVIEW

Many exciting RICH systems are outside the scope of this review:

- Neutrino detectors underground or in natural water/ice;
- Imaging air Cherenkov telescopes.

Will be reviewed by Razmik Mirzoyan Wednesday afternoon

"Cherenkov light imaging in Astroparticle Physics"


SNO


Tunka-133

OUTLINE – FIRST ATTEMPT

BASIC CHERENKOV THEORY

TYPES OF CHERENKOV COUNTERS

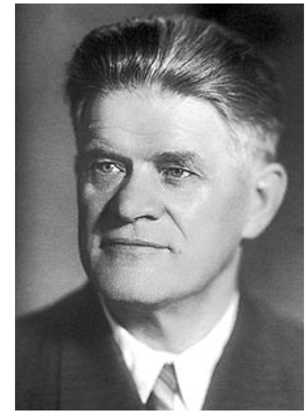
RICH DETECTOR COMPONENTS

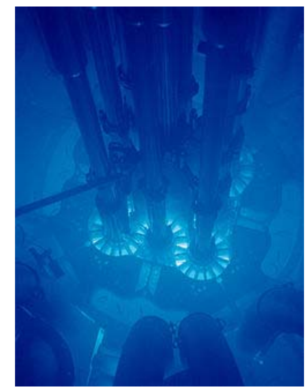
- RADIATORS
- PHOTON DETECTORS

IMAGING PRINCIPLES

EXAMPLES OF RICH COUNTERS

- THE PAST: 80S TO TODAY
- FUTURE RICH SYSTEMS

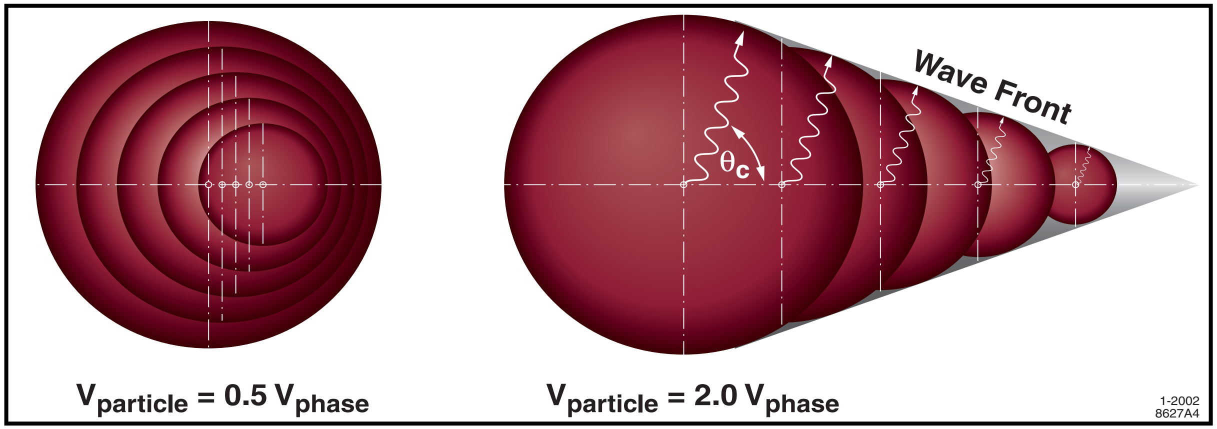




Pretty much following basic structure of our recent review article
"*Cherenkov Counters*", B. Ratcliff & J. Schwiening,

in *"Handbook of Particle Detection and Imaging,"* Claus Grupen, Irene Buvat (eds.), Springer-Verlag Berlin Heidelberg 2011

CHERENKOV RADIATION



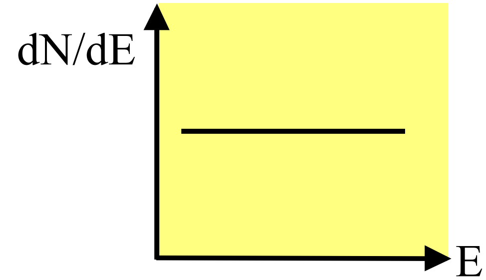
Threshold: $$\beta_{\text{thresh}} = \frac{v_{\text{thresh}}}{c} = \frac{1}{\text{n}(\lambda)}$$

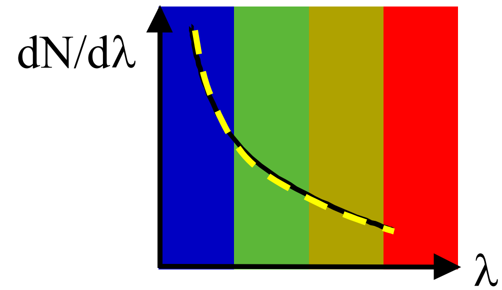
Production angle: $$\cos\theta_c = \frac{1}{\beta\,\text{n}(\lambda)}$$

Number of photons: $$\text{N}_{\text{photons}} = L\,\frac{\alpha^2 z^2}{r_e m_e c^2}\int \sin^2\theta_c(E)\,dE$$

CHERENKOV RADIATION

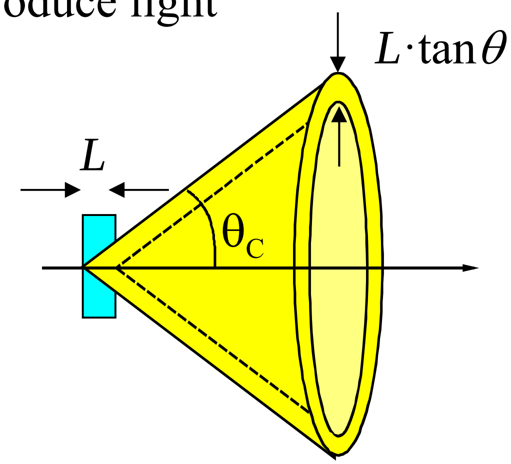
Cherenkov light produced equally distributed
over photon energies, proportional $1/\lambda^2$
→ eery blue light seen in nuclear reactors

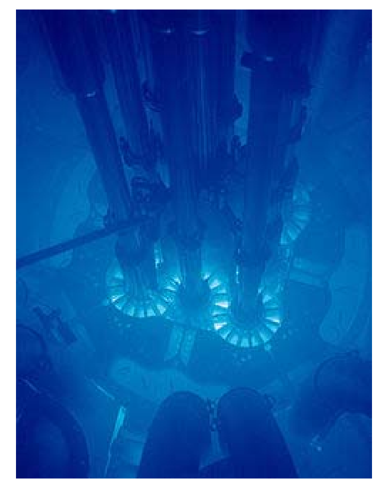




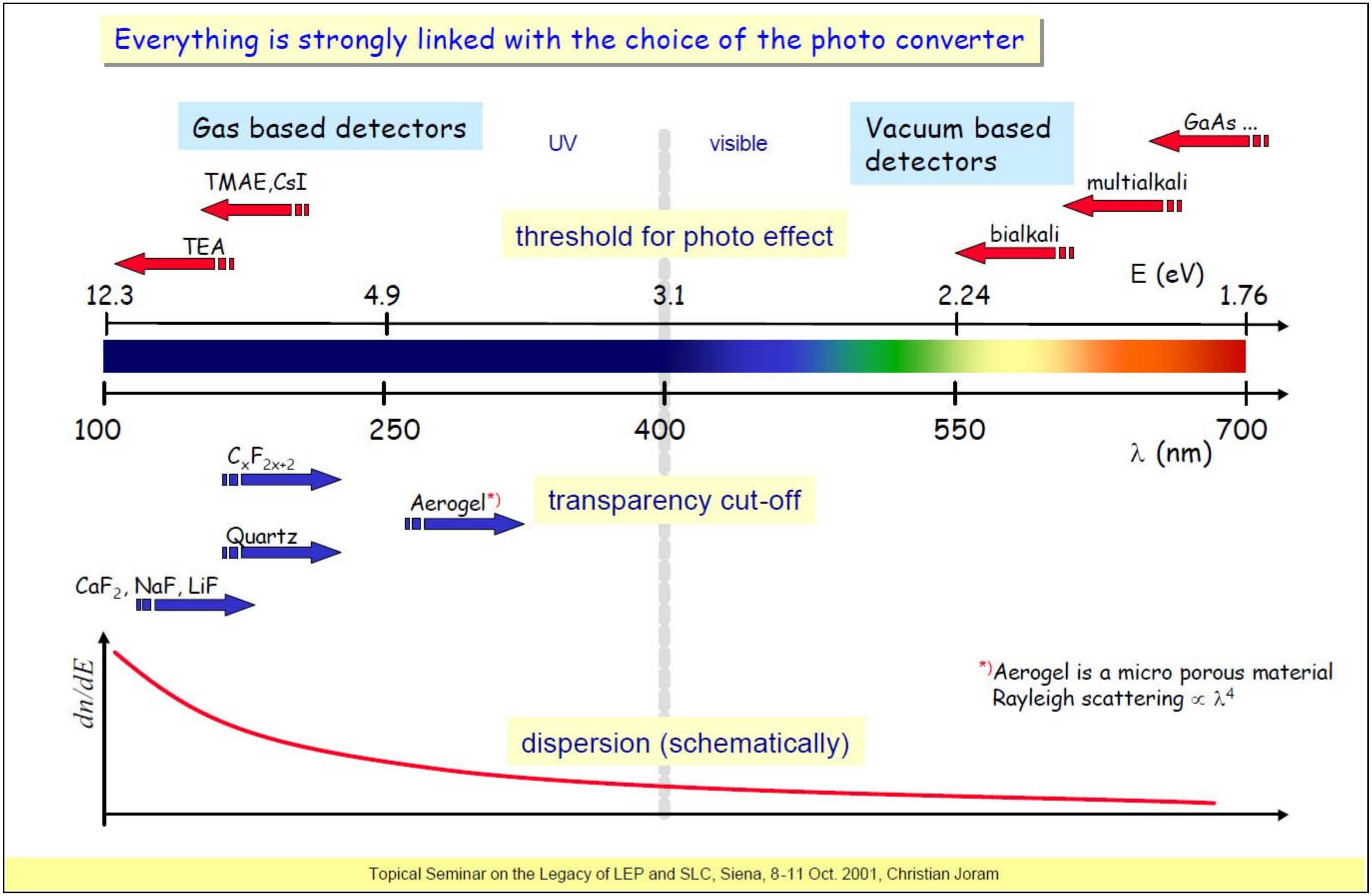
For a given medium, refractive index n,
there is a threshold for light production at $\beta = 1/n$

- Particles with $\beta < 1/n$ produce no light
- Particles with $\beta > 1/n$ produce light



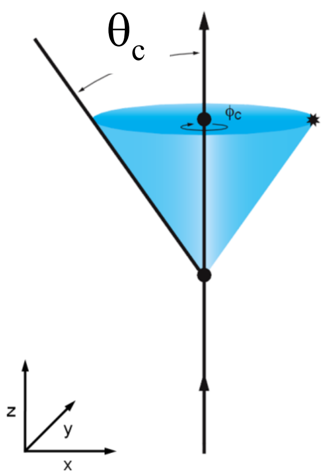


CHERENKOV LIGHT DETECTION



Cherenkov radiation: attractive properties for particle detectors

- Existence of a threshold velocity;
- Number of photons related to particle velocity;
- Emission angle related to particle velocity;
- Angle and photon yield depend on particle charge Z.



Main Cherenkov detector concepts in particle physics:

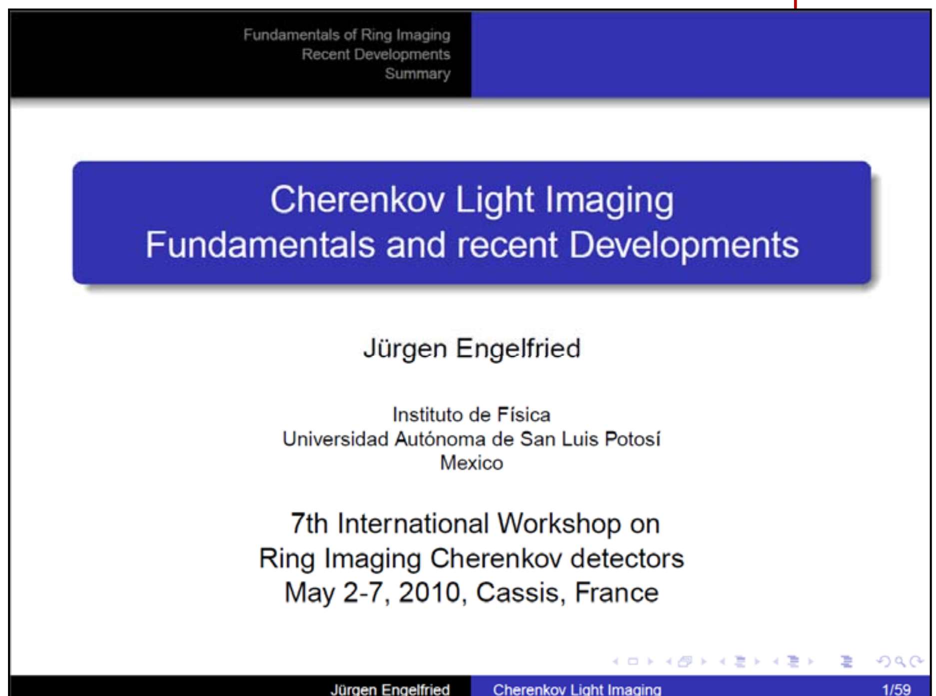
- Select material with refractive index n where particle type A produces Cherenkov light, particle type B does not → threshold counter
- Select material with refractive index n where multiple Cherenkov photons are detected for most particle species, image Cherenkov ring, precisely measure Cherenkov angle → Ring Imaging Cherenkov counter (RICH)
- Compare ring image with expected image for e/μ/π/K/p (likelihood test) or calculate mass from track β using independent momentum measurement (B field, tracking).

OUTLINE – FIRST ATTEMPT

After a few days I realized:

- Jürgen Engelfried gave this talk in a much nicer way at RICH 2010.

- I have nothing original to add.



→ I needed a new outline!

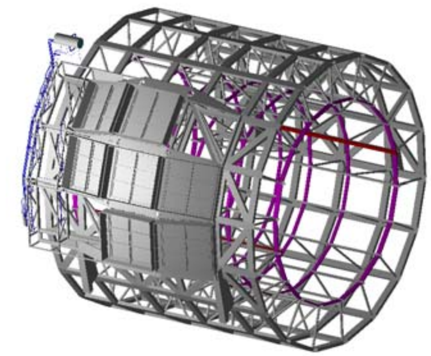
OUTLINE – SECOND ATTEMPT

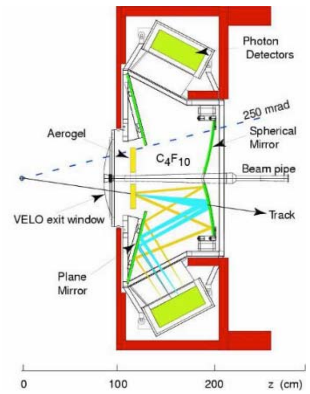
RICH 2013
December 2nd - 6th 2013

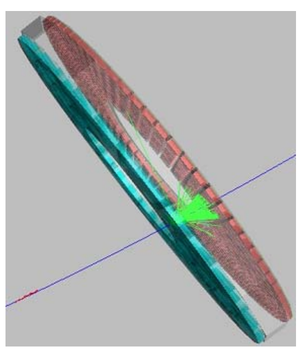
BRIEF INTRODUCTION TO RICH COUNTERS

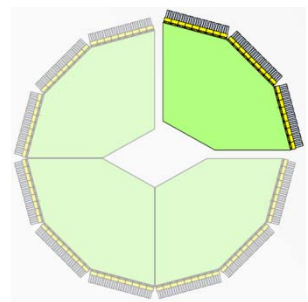
COMPREHENSIVE OVERVIEW OF SUBMITTED PAPERS

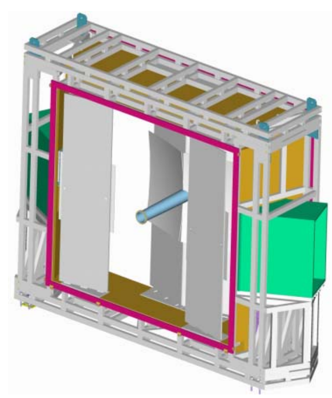
CONCLUSIONS AND OUTLOOK

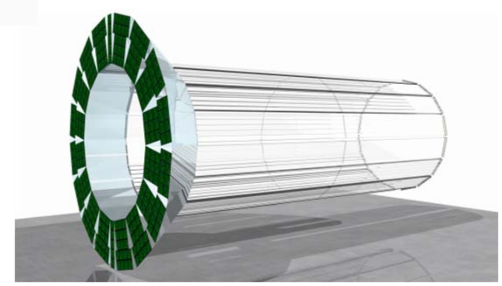


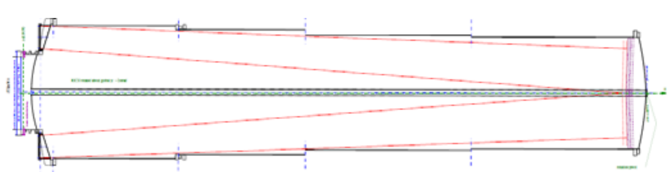












Scope of Review

List of contributions:

- 54 abstracts within scope of this review,
- 28 talks on RICH systems, photon detectors, technical advances, prototyping.

TOP counter
ARICH

Belle II
CBM
CLAS12

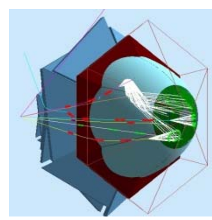
LHCb
PANDA
TORCH

Current RICH
RICH upgrade
TORCH

Barrel DIRC
Endcap Disk DIRC

HMPID
VHMPID


photon detectors


CLAS12

Scope of Review

List of contributions:

- 54 abstracts within scope of this review,
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- Leaderboard: Belle II (13), LHCb (7), PANDA (6), CBM (4), ALICE (3).

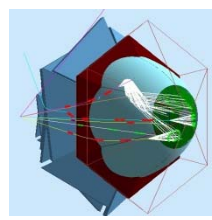
TOP counter
ARICH
sim&reco
mechanical design

prototypes
aerogel
electronics
HAPD
MCP-PMT

Belle II

photon detectors

RICH
sim&reco
system prototypes
MaPMTs



CLAS12

Current RICH
RICH upgrade
TORCH
MCP-PMT
MaPMT
HPD

SuperB

Barrel DIRC
Endcap Disk DIRC
sim&reco
prototypes
electronics
MCP-PMTs

panda

HMPID
VHMPID
reconstruction

ALICE

NA62

CBM RICH

LHCb

COMPASS

hermes

SCOPE OF REVIEW

List of contributions:

- 54 abstracts within scope of this review,
- 28 talks on RICH systems, photon detectors, technical advances, prototyping,

This would leave me with:

- 39 seconds per abstract
- 75 seconds per talk.

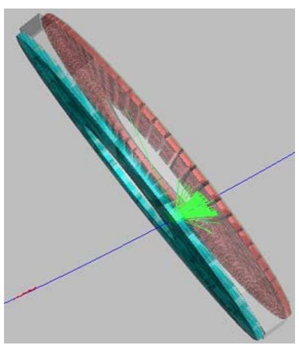
→ I needed a new outline! (again)

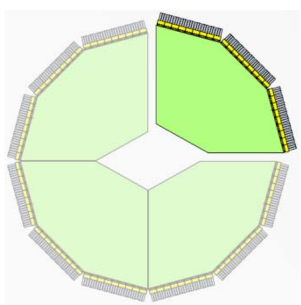
BRIEF INTRODUCTION

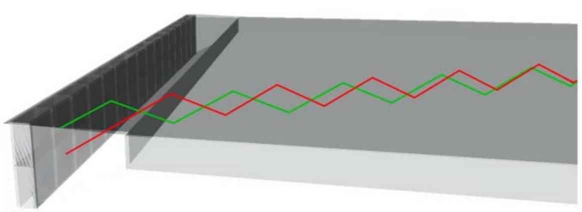
FEW SELECTED RICH SYSTEM EXAMPLES

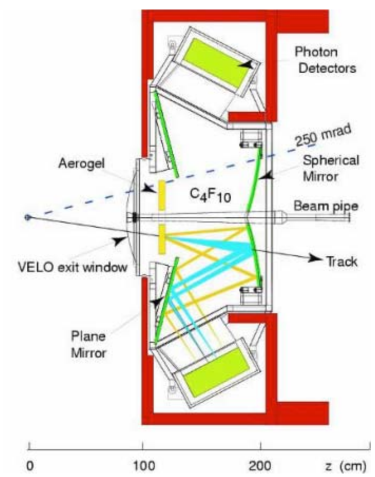
TRENDS AND TECHNOLOGY ADVANCES

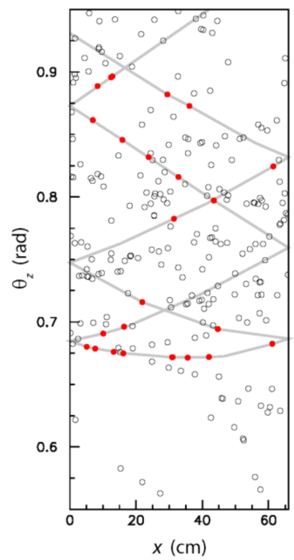
CONCLUSION

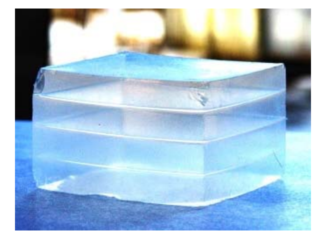


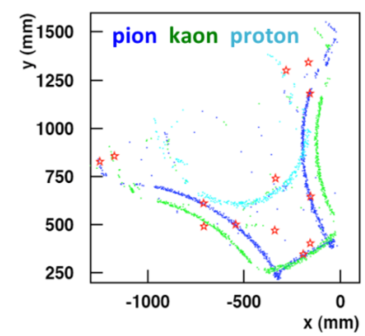












OUTLINE

BRIEF INTRODUCTION

FEW SELECTED RICH SYSTEM EXAMPLES

TRENDS AND TECHNOLOGY ADVANCES

CONCLUSION

I have to pick and choose systems/technologies – the picture will be completed by reviews

- *Status and perspectives of gaseous photon detectors*, A. Di Mauro – Tue 8:30
- *Status and perspectives of solid state photon detectors*, G. Collazuol – Tue 9:10
- ~~*Status and perspectives of vacuum-based photon detectors*, O. Siegmund – Tue 10:20~~
- *Optical components for Cherenkov light imaging devices*, J. Va'vra – Wed 8:30
- *Use of RICH detectors for physics*, S. Stone – Thu 15:50

and the other talks today…

SESSION OVERVIEW

The RICH Detector of the ***NA62*** *Experiment at CERN*, M. Piccini, Mon 10:30

TOP counter for particle identification at ***Belle II*** *experiment*, K. Inami, Mon 10:55

The ***PANDA*** *Barrel DIRC Detector*, M. Hoek, Mon 11:20

The ***LHCb*** *RICH system; detector description and operation*, A. Papanestis , Mon 14:00

ALICE*-HMPID performance during the LHC run period 2010-2013*, G. de Cataldo, Mon 14:25

The large-area hybrid-optics ***CLAS12*** *RICH detector*, M. Contalbrigo, Mon 14:50

Aerogel RICH counter for the ***Belle II*** *forward PID*, S. Nishida, Mon 15:15

Tests of FARICH prototype with fine photon position detection, E.A. Kravchenko, Mon 16:10

R&D on high momentum particle identification with a pressurized Cherenkov radiator, M. Weber, Mon 16:35

Development of an Endcap DIRC for ***PANDA***, O. Merle, Mon 17:00

The ***CBM*** *RICH project*, C. Pauly, Mon 17:25

Upgrade of ***LHCb*** *RICH Detectors*, S. Easo , Mon 18:10

Results from the ***FDIRC*** *prototype*, D. Roberts, Mon 18:35

TORCH *- a Cherenkov based Time-of-Flight detector*, M. van Dijk, Mon 19:00

Future RICH Systems with Aerogel Radiators

- Belle II Forward RICH (focusing, 2 layers)
- CLAS12 (compact hybrid optics)
- FARICH R&D (focusing, multi-layers, possible use in ALICE, Super Tau-Charm, PANDA)

Future RICH Systems using Solid Radiators

- Belle II TOP (barrel, plate geometry, very fast timing)
- PANDA Barrel DIRC (barrel, bar or plate, fast timing)
- PANDA Endcap Disk DIRC (endcap, segmented disk, fast timing, focusing lightguide)
- TORCH (LHCb upgrade) (forward detector, plate, fast timing, focusing lightguide)

GAS RICHES

My apologies to the current and new RICH systems with gaseous radiators.

Four talks will discuss the future systems in the sessions today *(few slides in appendix).*

PID	μ/π	e/π	π/K, K/p
Radiator	Neon	CO_2	C_4F_8O
Momentum	15…35 GeV/c	<10 GeV/c	5…25 GeV/c
Photon detector	HPK R7400U-03	HPK H8500	CsI-MWPC
Timeline	Commissioning 2014	Installation 2017	Proposed (2017/18)

The RICH Detector of the NA62 Experiment at CERN, M. Piccini, Mon 10:30

ALICE-HMPID performance during the LHC run period 2010-2013, G. de Cataldo, Mon 14:25

R&D on high momentum particle identification with a pressurized Cherenkov radiator, M. Weber, Mon 16:35

The CBM RICH project, C. Pauly, Mon 17:25

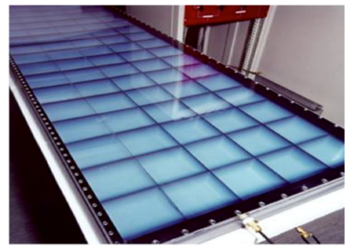
AEROGEL RICHES

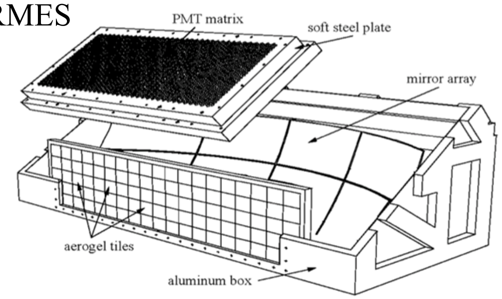
Next generation of aerogel RICHes will profit from past experience (HERMES, Belle, LHCb) and major technological advances in

Aerogel quality

- improved clarity
- fine tuning of refractive index
- large tiles

HERMES



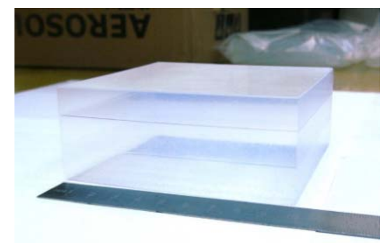


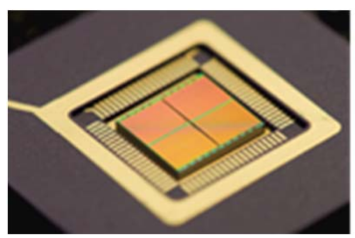
Photon detection

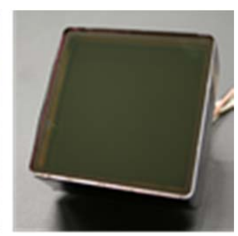
- small pixels
- fast timing

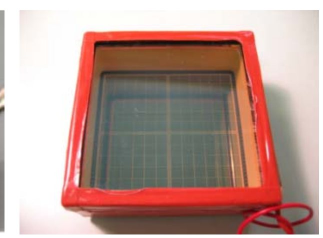
BelleII

FARICH





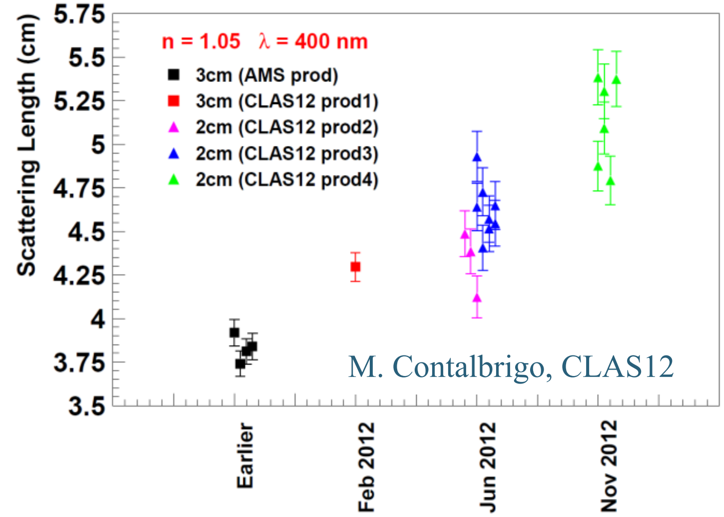




AEROGEL RICHES

Significant improvement in clarity and maximum size of aerogel tiles

(minimize photon loss in bulk and on edges of tile)

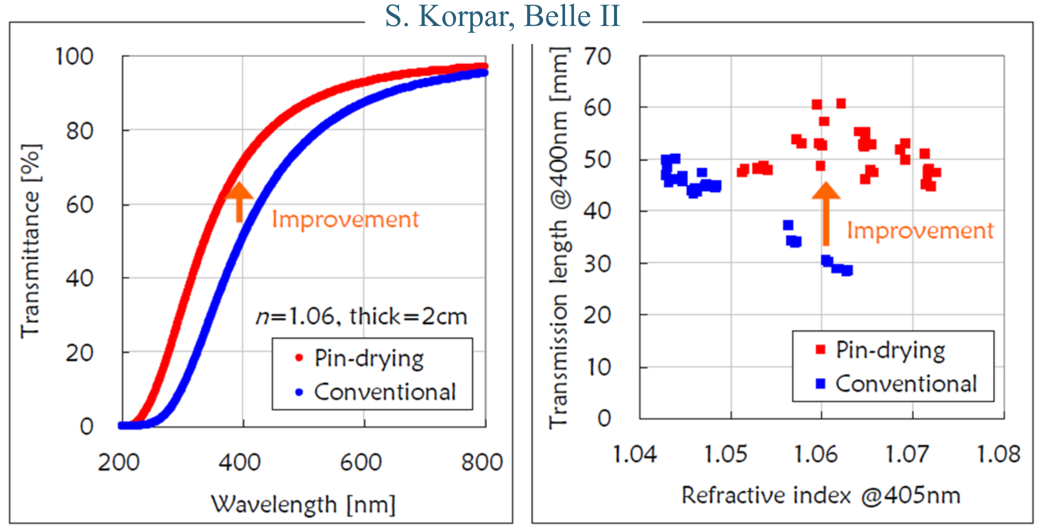


Pinhole drying method further improves transmission

but currently yield of crack-free tiles still low

Hydrophobic aerogels can be precision-cut using water jet.

S. Korpar, Belle II



AEROGEL RICHES – CLAS12

➢ M. Contalbrigo, Mon 14:50

CLAS12 RICH goal: 4σ π/K separation for 3…8GeV/c

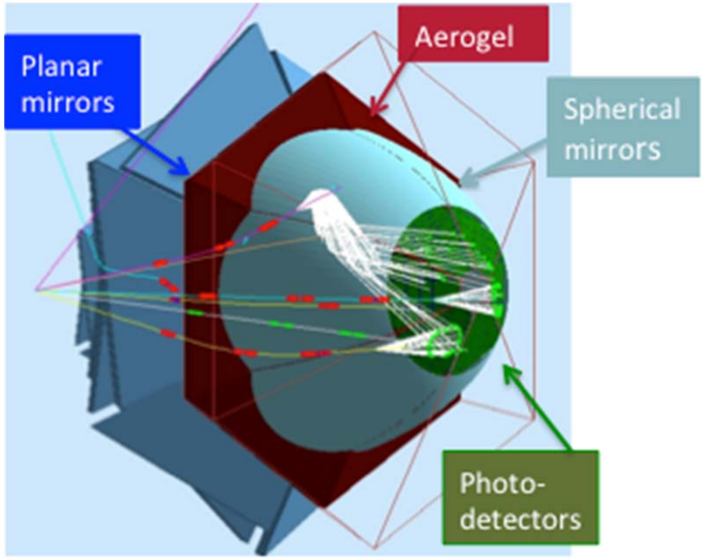
Complex optical paths possible due to improved aerogel transparency.

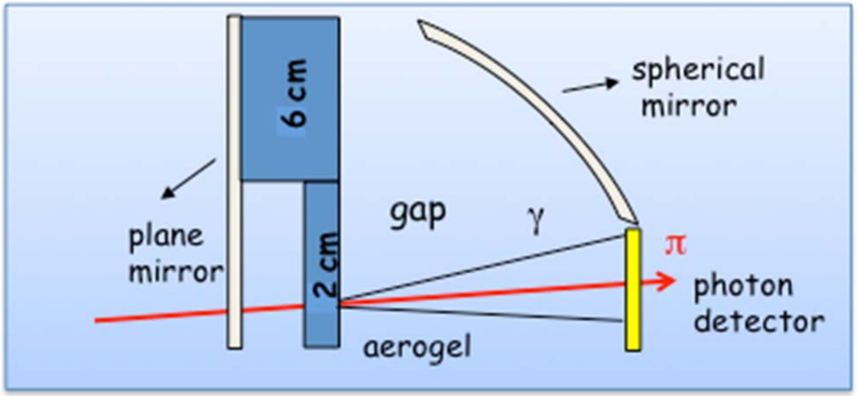
Direct photons from 2cm tile, detected on MaPMT array:

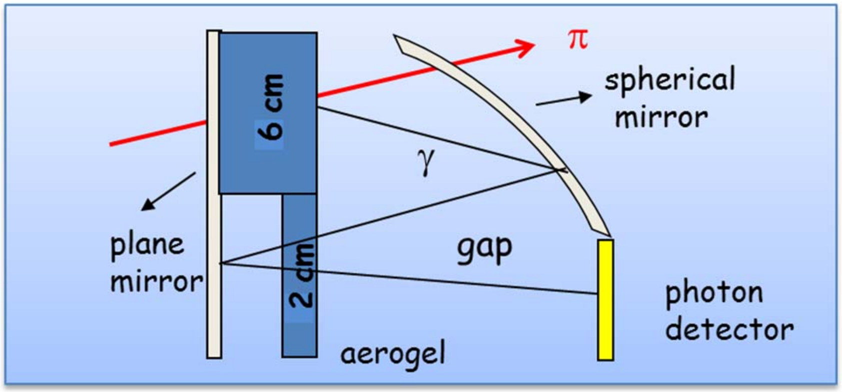
best resolution (smaller angles, high-momentum tracks)

Reflected photons from 6cm tile, reflected from spherical mirror and planar mirror, passing twice through 2cm aerogel before detection on same MaPMT array: still good resolution and photon yield.

→ compact optics, smaller total MaPMT area needed.



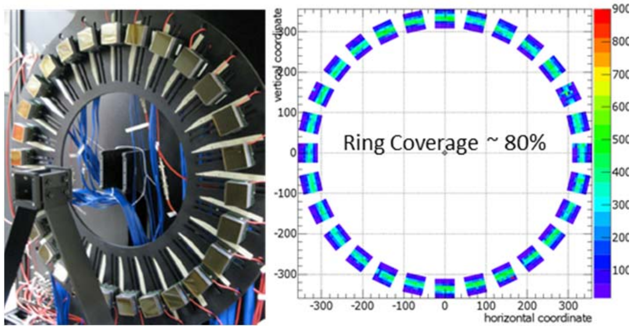




➢ M. Contalbrigo, Mon 14:50

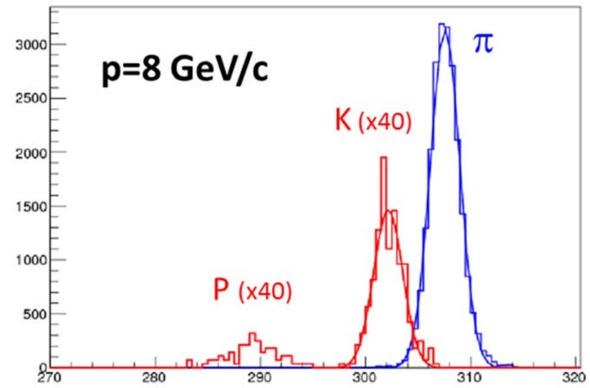
CLAS12 RICH prototype in test beam at CERN,
measure direct paths and focused/reflected paths (incl. 2cm aerogel absorber).

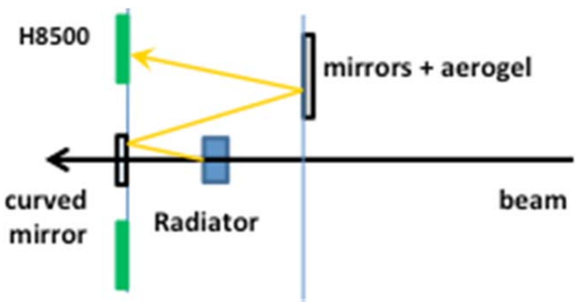
direct photon path configuration

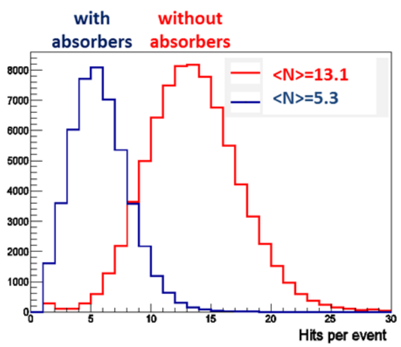


Clean rings for both scenarios.

For direct path: 13 photons per track and good π/K separation up to maximum CLAS12 momenta.







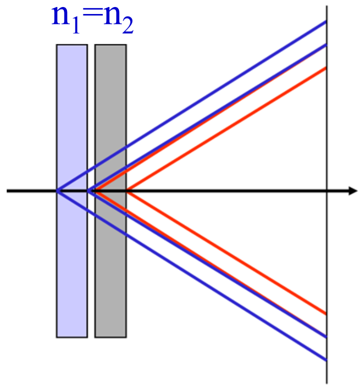
For reflected path: still reasonable photon yield and resolution.

AEROGEL RICHES – BELLE II

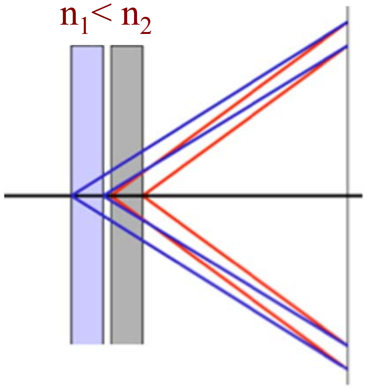
To increase light yield combine two aerogel tiles
with refractive index n_1, n_2

Choice of imaging strategy

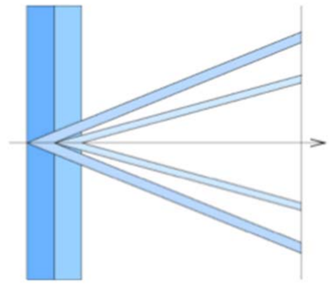
tiles with refractive index $n_1 = n_2$
→ ring twice the thickness as single tile, poor resolution



tiles with refractive index $n_1 < n_2$
→ photons from the two tiles are imaged to same radius
"focusing aerogel"



tiles with refractive index $n_1 > n_2$
→ photons from the two tiles can be cleanly separated



"Focusing aerogel" improves Cherenkov angle resolution
without loss in photon yield. *(NIM A548 (2005) 383, NIMA 565 (2006) 457)*

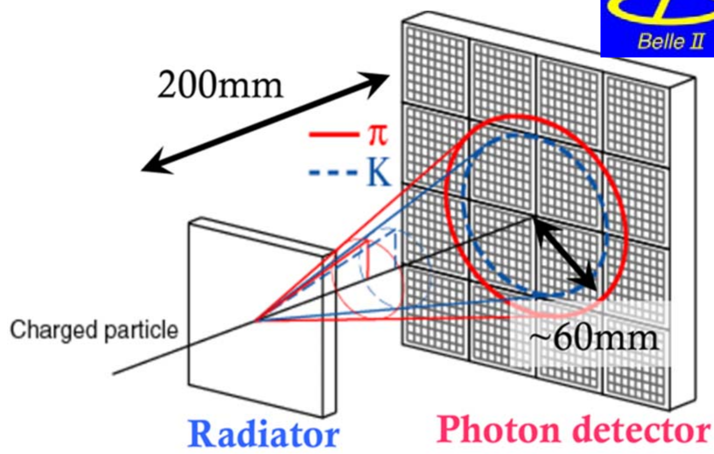
S. Nishida, Mon 15:15

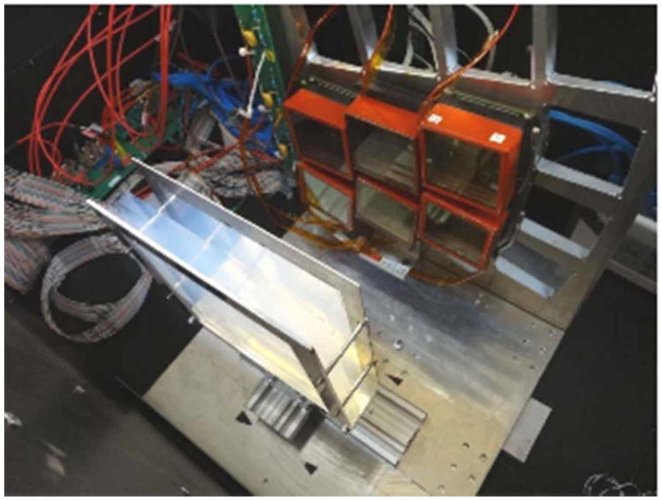
Belle II ARICH goal: 4σ π/K separation for 1…3.5GeV/c

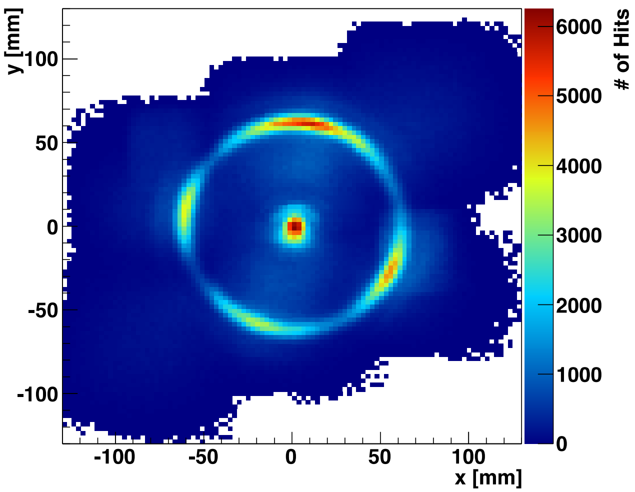
Recent prototype in particle beam at DESY in 2013
(HAPD readout):
8.6 photons per track,
15.4mrad single photon resolution.

Meets Belle II PID requirements.

Full ARICH system installation planned for spring 2015.







$n_1=1.045$
$n_2=1.055$

AEROGEL RICHES – FARICH R&D

➢ E.A. Kravchenko, Mon 16:10

FARICH prototype in CERN test beam

4-layer aerogel (n_{max}=1.046, thickness 37.5mm)

dSiPM matrix readout

20 x 20 cm^2 Philips DPC3200-22-44

3x3 modules = 6x6 tiles = 24x24 dies = 48x48 pixels in total

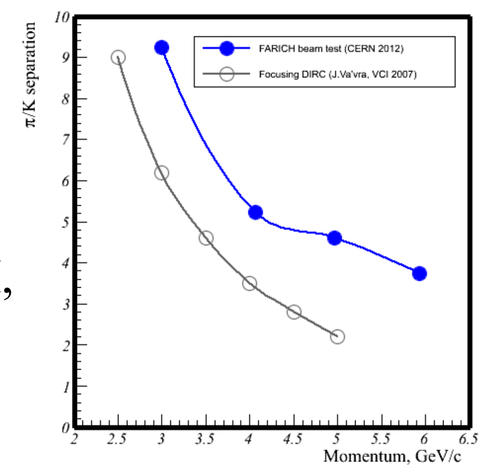
14 photons per track,

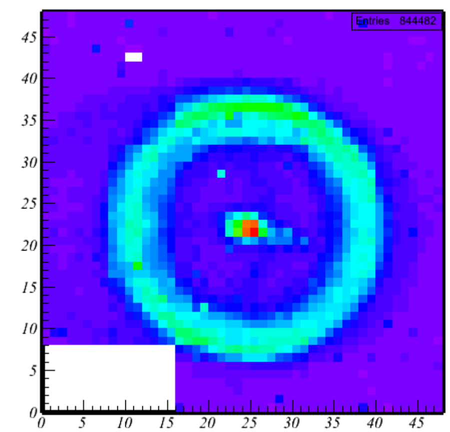
48ps single photon timing,

3.8σ π/K separation at 6 GeV/c.

Technology may have potential for π/K PID up to 10GeV/c

Possible candidate for PANDA Forward RICH, Super Tau-Charm, ALICE VHMPID.





FUSED SILICA RICHES

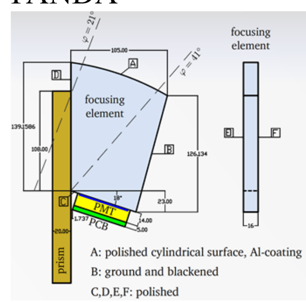
Next generation of RICHes with fused silica radiators will follow in the footsteps of successful BABAR-DIRC, making use of technological advances in

Photon detection

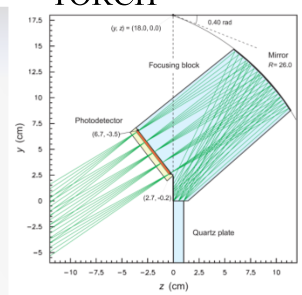
- small pixels
- fast timing
- long lifetime

Focusing optics

PANDA



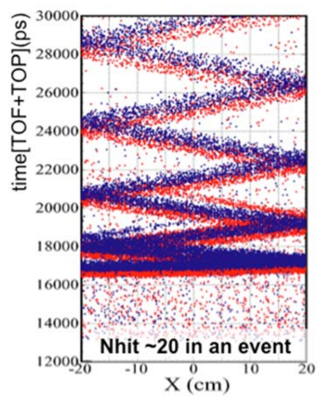
TORCH

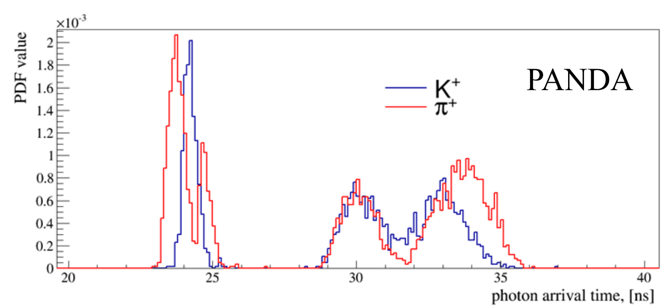


FDIRC

Time imaging

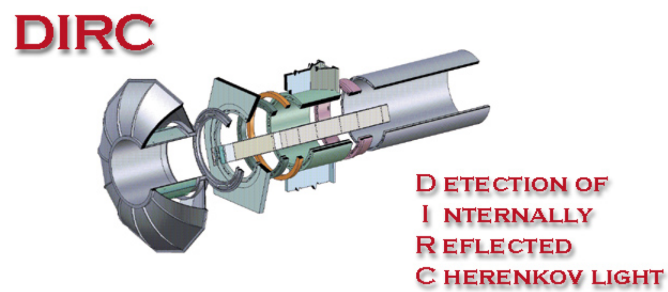
Belle II





Detection of Internally Reflected Cherenkov Light

Used for the first (and, so far, only) time in BABAR as primary hadronic particle ID system, flavor tagging, π/K ID to 4GeV/c.

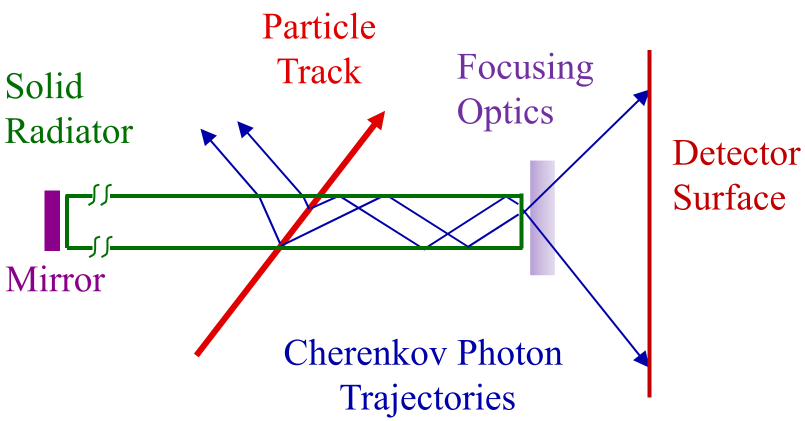


- 1992: first publication of DIRC concept[§].
- 1993-1996: progression of prototypes and DIRC R&D.
- Nov 1994: decision in favor of DIRC for hadronic PID for BABAR.
- Nov 1998: installed part of DIRC; start of cosmic ray run, commissioning run.
- April 1999: BABAR moves into beam line, added 4 more bar boxes.
- Nov 1999: all 12 bar boxes installed, start of first physics run.
- April 2008: last event recorded with BABAR.
- Oct 2013: call for proposals for reuse of BABAR DIRC radiator bars.

[§]*B. Ratcliff, SLAC-PUB-6047 (Jan. 1993)*

DIRC CONCEPT

- Charged particle traversing radiator with refractive index n with $\beta = v/c > 1/n$ emits Cherenkov photons on cone with half opening angle $\cos \theta_c = 1/\beta n(\lambda)$.

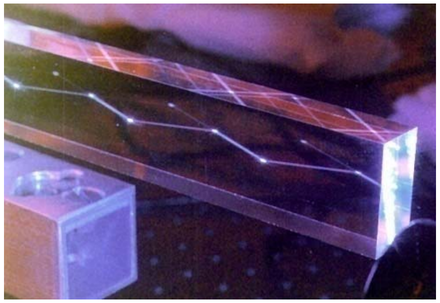


- For $n>\sqrt{2}$ some photons are always totally internally reflected for $\beta \approx 1$ tracks.

- Radiator and light guide: bar, plate, or disk made from Synthetic Fused Silica ("Quartz") or fused quartz or acrylic glass or …

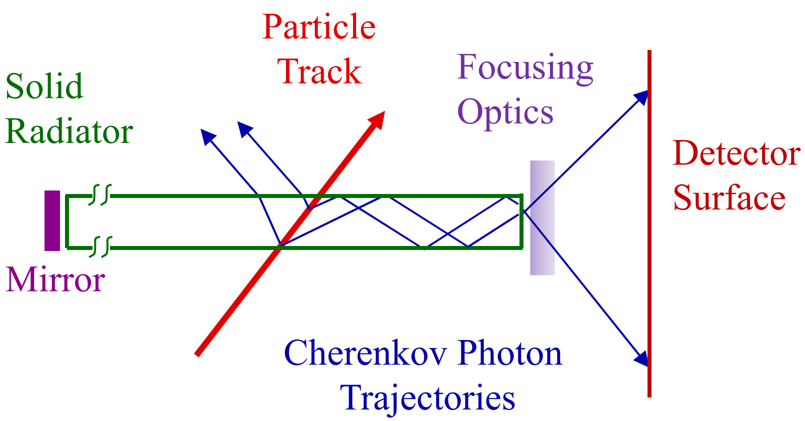
- Magnitude of Cherenkov angle conserved during internal reflections (provided optical surfaces are square, parallel, highly polished)

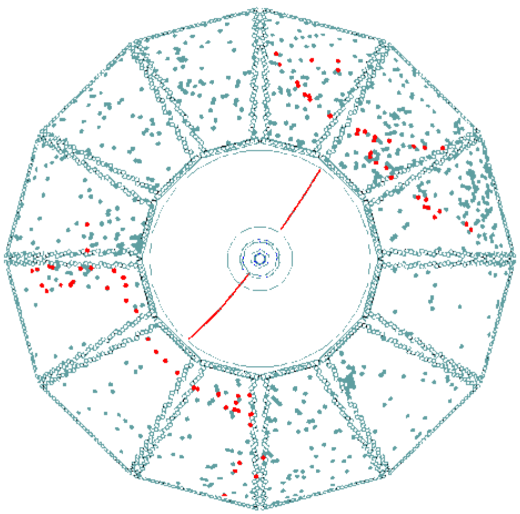
- Mirror attached to one bar end, reflects photon back to readout end.



DIRC CONCEPT

- Photons exit radiator via optional focusing optics into expansion region, detected on photon detector array.
- DIRC is intrinsically a 3-D device, measuring: x, y, and time of Cherenkov photons, defining θ_c, ϕ_c, $t_{propagation}$.
- Ultimate deliverable for DIRC: PID likelihoods.
  Calculate likelihood for observed hit pattern
  (in detector space or in Cherenkov space)
  to be produced by e/μ/π/K/p
  plus event/track background.





BABAR DIRC COMPONENTS

Photon detectors:

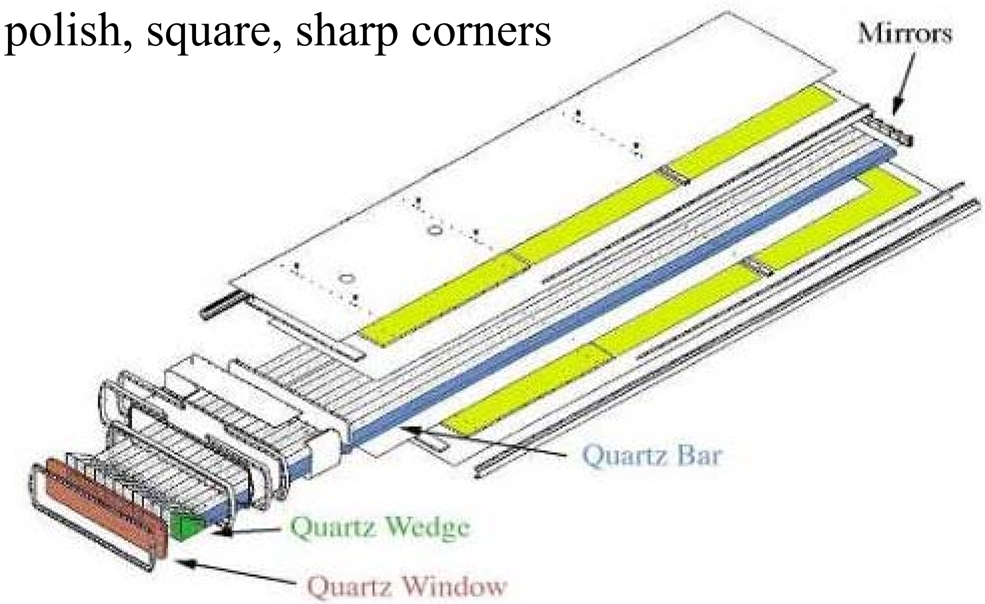
~11,000 standard 1” PMTs
with light concentrators

Expansion volume:

Large tank with ~6,000 liters ultra-pure water

Radiators:

144 long bars, made of 576 short bars
synthetic fused silica
5A rms polish, square, sharp corners

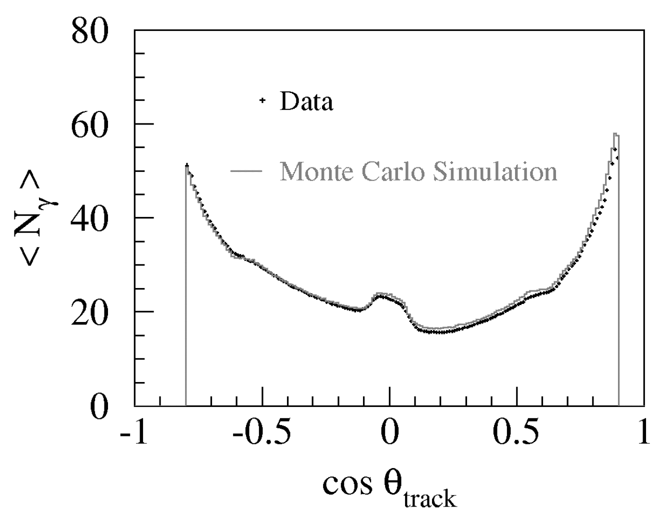


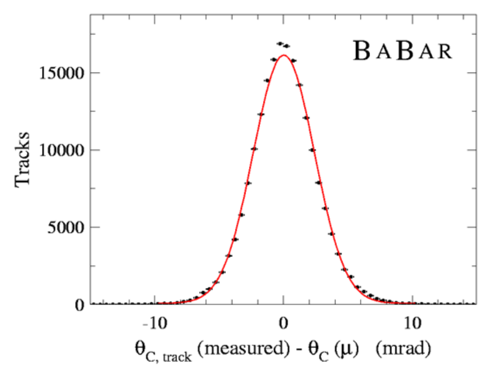
Bar box: 12 bar boxes in BABAR
12 long (4.9m) bars per box
150µm air gap between bars
dry nitrogen flow

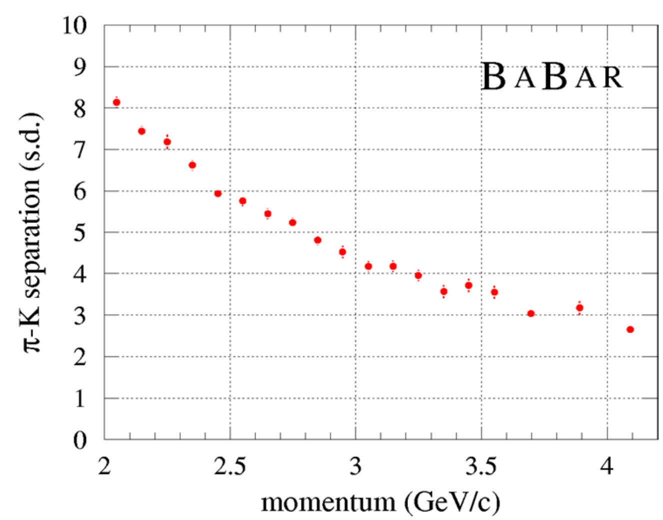
Long bar: 4 short (1.225m) bars
Mirror on forward end
Wedge on readout end

BABAR DIRC PERFORMANCE

Single photon timing resolution	1.7ns
Single photon Cherenkov angle resolution	~10mrad
Photon yield	20-60 photons per track
Track Cherenkov angle resolution	2.4mrad (di-muons)
π/K separation power	4.3σ @ 3GeV/c, ~3σ @ 4GeV/c







Excellent performance: very reliable, robust, easy to operate, significant in almost all BABAR physics results.

IMPROVING ON BABAR DIRC

RICH 2013
December 2nd - 6th 2013

As early as 2000 R&D efforts underway to improve future DIRCs.

- Make DIRC less sensitive to background
  - o decrease size of expansion volume;
  - o use photon detectors with smaller pixels and faster timing;
  - o place photon detector inside magnetic field.
- Investigate alternative radiator shapes (plates, disks)
- Push DIRC π/K separation by improving single-photon θ_C resolution

BABAR-DIRC Cherenkov angle resolution: 9.6 mrad per photon → 2.4 mrad per track

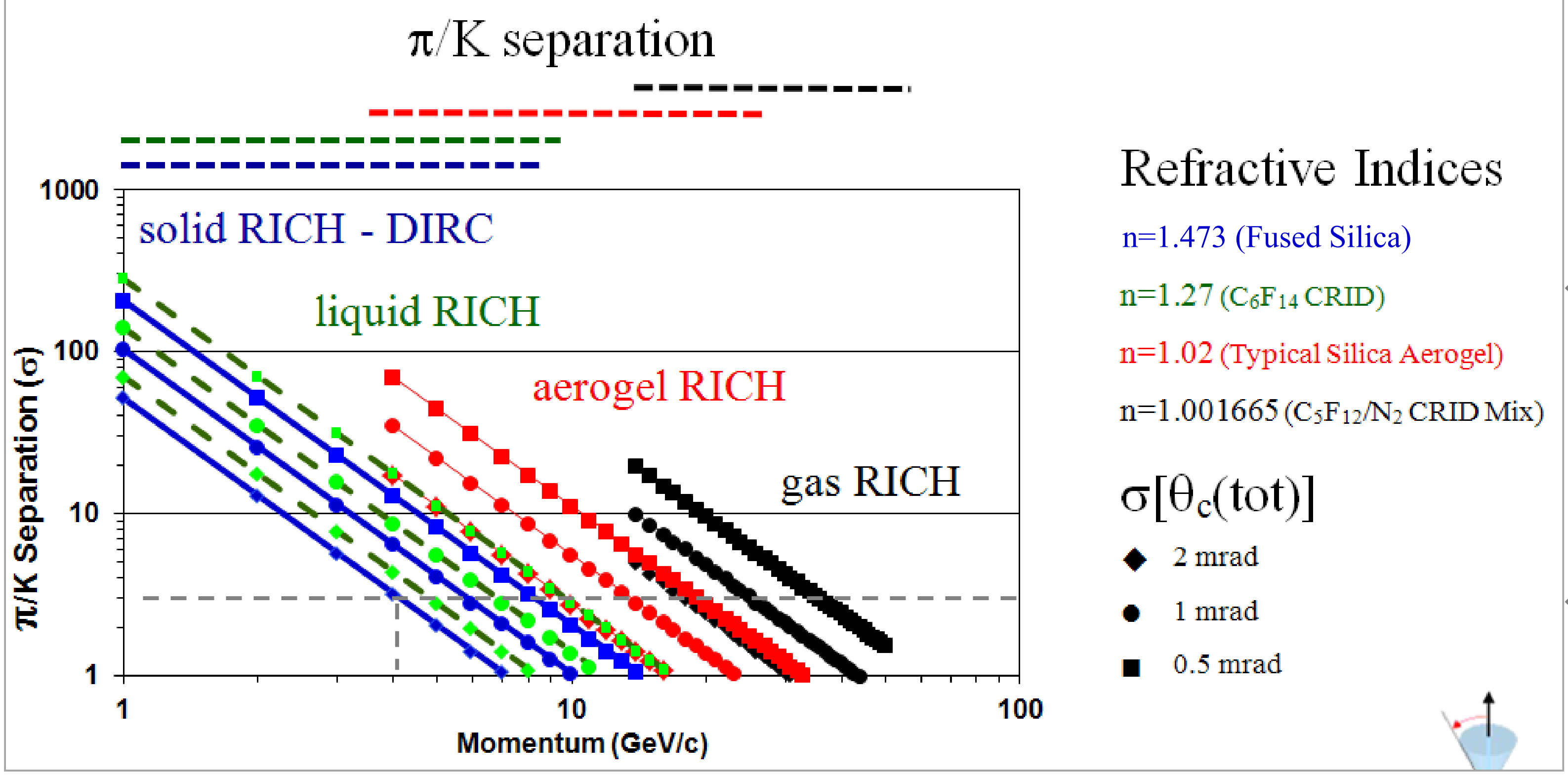
Limited in BABAR by:			Could be improved for future DIRCs via:
▪ size of bar image	~4.1 mrad	→	▪ focusing optics
▪ size of PMT pixel	~5.5 mrad	→	▪ smaller pixel size
▪ chromaticity ($n=n(\lambda)$)	~5.4 mrad	→	▪ better time resolution
	9.6 mrad	→	4-5 mrad per photon → < 1.5–2 mrad per track

SUPERB, BELLE II & PANDA

DIRC LIMITS

$$N_\sigma \approx \frac{(m_1^2 - m_2^2)}{\left(2p^2\sqrt{n^2-1}\,\sigma[\theta_c(tot)]\right)}.$$

(For momenta well above threshold.)



radiator materials

angular error per track

DIRC provides good π/K separation potential significantly beyond 4 GeV/c.

Large refractive index limits effective momentum range to below 10 GeV/c.

based on B. Ratcliff RICH2002

EARLY FDIRC R&D AT SLAC

- Single 3.7m-long BABAR-DIRC bar,
  compact, oil-filled expansion volume,
  focusing mirror (CRID),
  array of H-8500/H-9500 MaPMTs and
  Planacon 85011 MCP-PMTs,
  fast readout electronics
  (both CAMAC and early BLAB).
- Photon yield consistent with BABAR DIRC.
- Demonstrated that the chromatic error of θ_C can be corrected using fast timing.
  (Shown at RICH 2007.)
- Single-photon θ_C resolution 5.5 – 7 mrad after chromatic correction
  for long paths (consistent with G4 simulation).
- Successful proof of principle for Focusing DIRC.
- Basis for SuperB FDIRC design.

J. Benitez, I. Bedajanek, D.W.G.S. Leith, G. Mazaheri, B. Ratcliff, K. Suzuki, J. Schwiening, J. Uher, L.L. Ruckman, G. Varner, and J. Va'vra,

SLAC-PUB 12236 & 12803, NIMA 595 (2008) 104

SUPERB FDIRC

➢ D. Roberts, Mon 18:35

Focusing DIRC (FDIRC):

Intended as barrel PID system for SuperB detector in Italy.

Important constraint:

BABAR DIRC bar boxes to be reused, readout outside magnetic field.

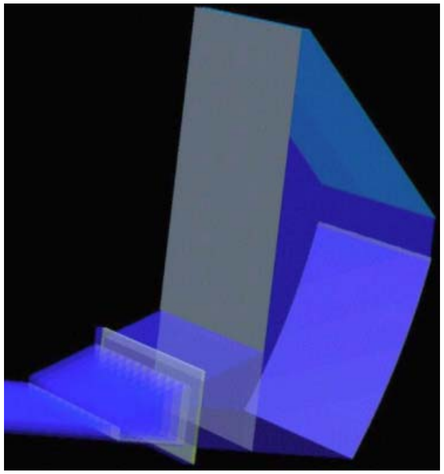
Expected much higher backgrounds at $10^{36}/cm^2{\cdot}s$ (100 times BABAR luminosity)

→ decrease size of expansion volume (main source of background in BABAR DIRC).

Design based on R&D at SLAC; new optics (replace tank with 12 cameras) and electronics

Complete redesign of the photon camera (SLAC-PUB-14282)

- True 3D imaging using:
  - 25× smaller volume of the photon camera
  - 10× better timing resolution to detect single photons
- Optical design based entirely on solid fused silica to avoid water or oil as optical medium
- Array of MaPMTs (H8500) for photon detection.



SUPERB FDIRC

➢ D. Roberts, Mon 18:35

In spite of unfortunate fate of SuperB project,
FDIRC R&D still ongoing.

Prototype in cosmic ray telescope (CRT) at SLAC.

Complete BABAR-DIRC bar box (12 4.9m-long bars)
with new optics attached.

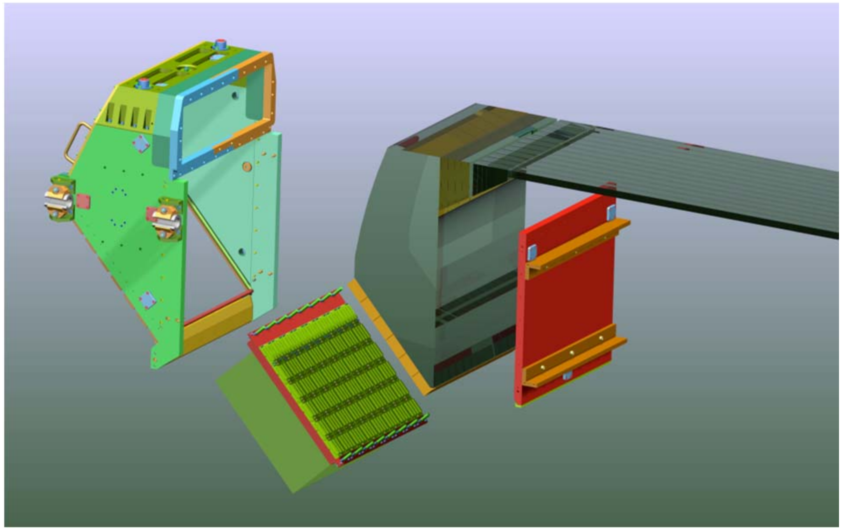
New readout electronics, fast start counter.

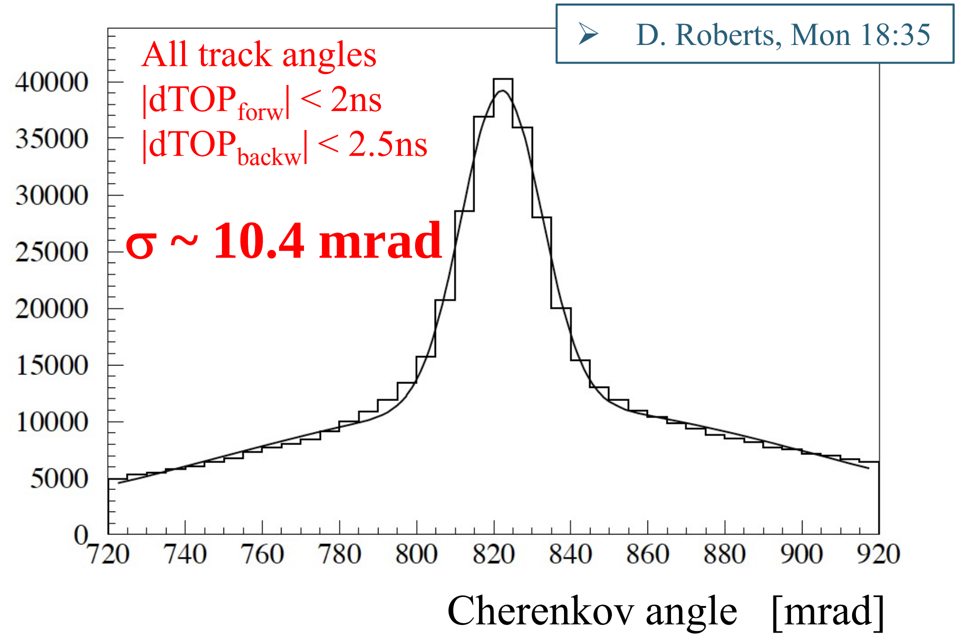
3D tracking of hardened cosmic muons (> 2GeV/c).

Improved simulation and reconstruction to deal with
focusing & planar mirrors and with complex
photon reflection paths in camera block.

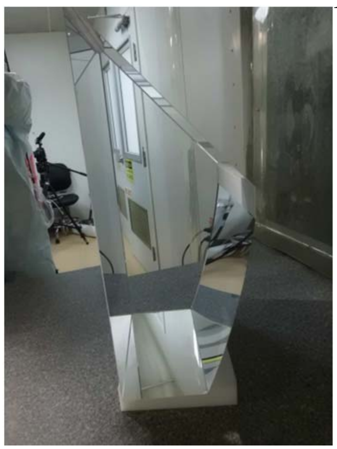
FDIRC

New photon camera is added to BABAR bar box

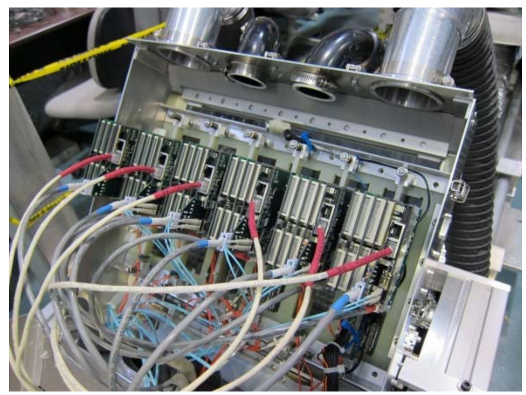




New photon camera



Electronics



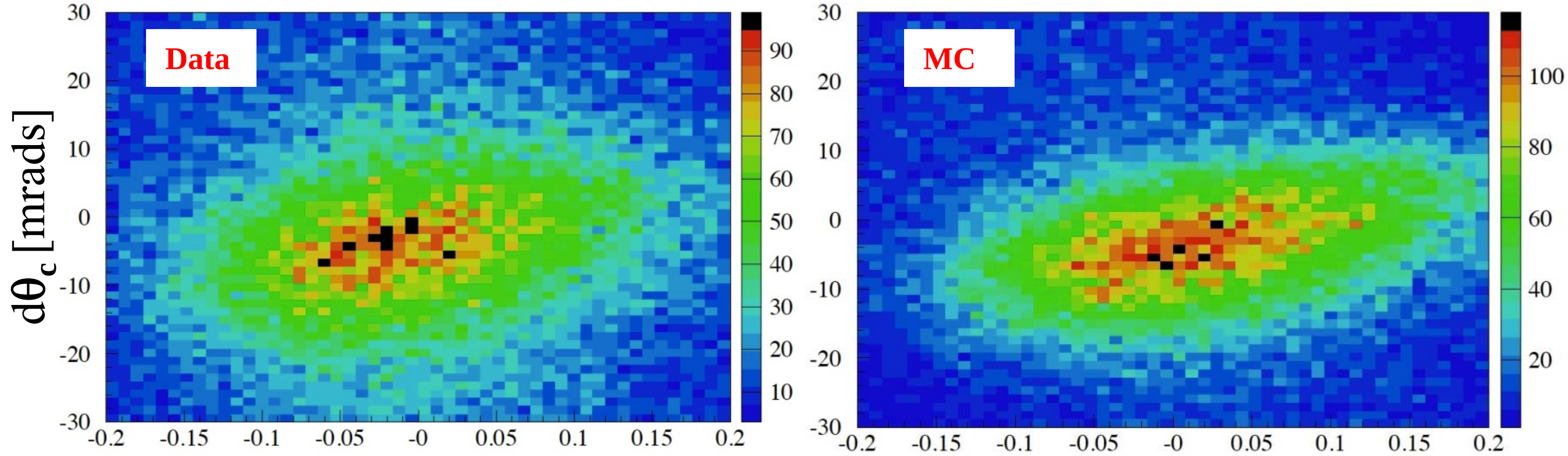
Measured Cherenkov angle resolution (10.4mrad) with hard muons (>2GeV) in cosmic ray telescope with 3D tracks and real DIRC bar box.

Slide: J. Va'vra

FDIRC

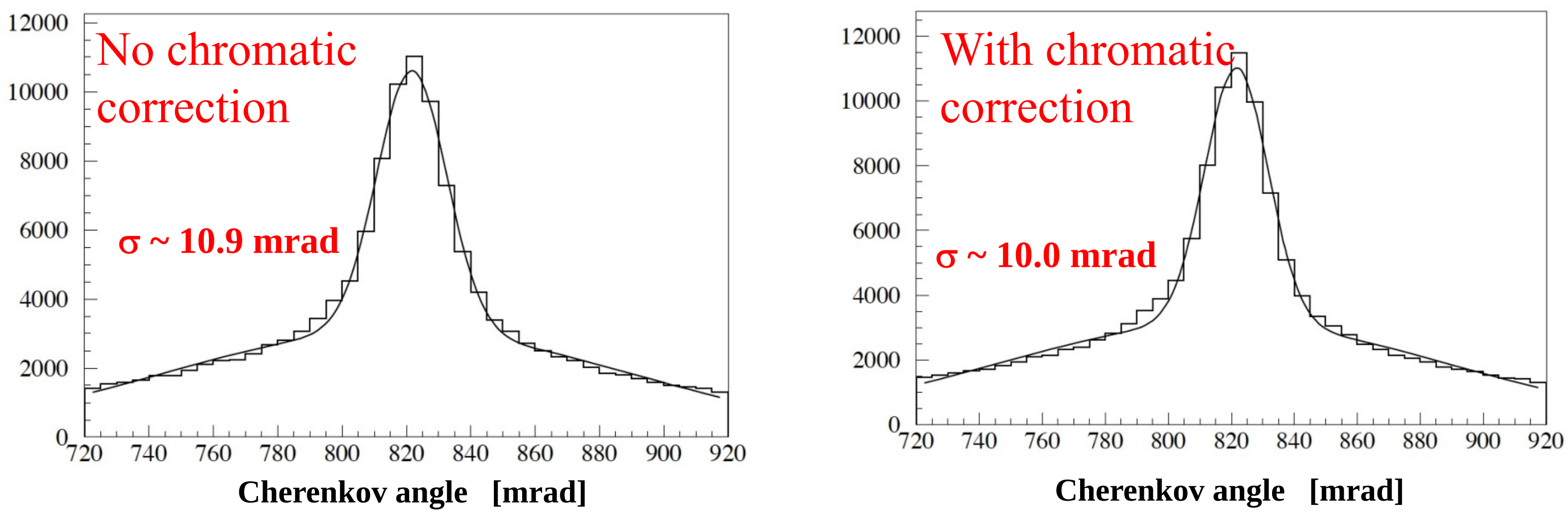
Chromatic correction using 3D tracks and real bar box in CRT.

➢ D. Roberts, Mon 18:35



$dTOP/L_{path} = (TOP_{measured} - TOP_{expected})/L_{path}$

Backward photons, long paths



Use correlation from data to correct θ_c by time. We gain about ~0.8 mrads. MC expects a gain of ~ 1 mrad. We hope to further improve this correction by improving timing resolution.

Slide: J. Va'vra

DIRCs IN PANDA

PANDA: two DIRC detectors

- Barrel DIRC

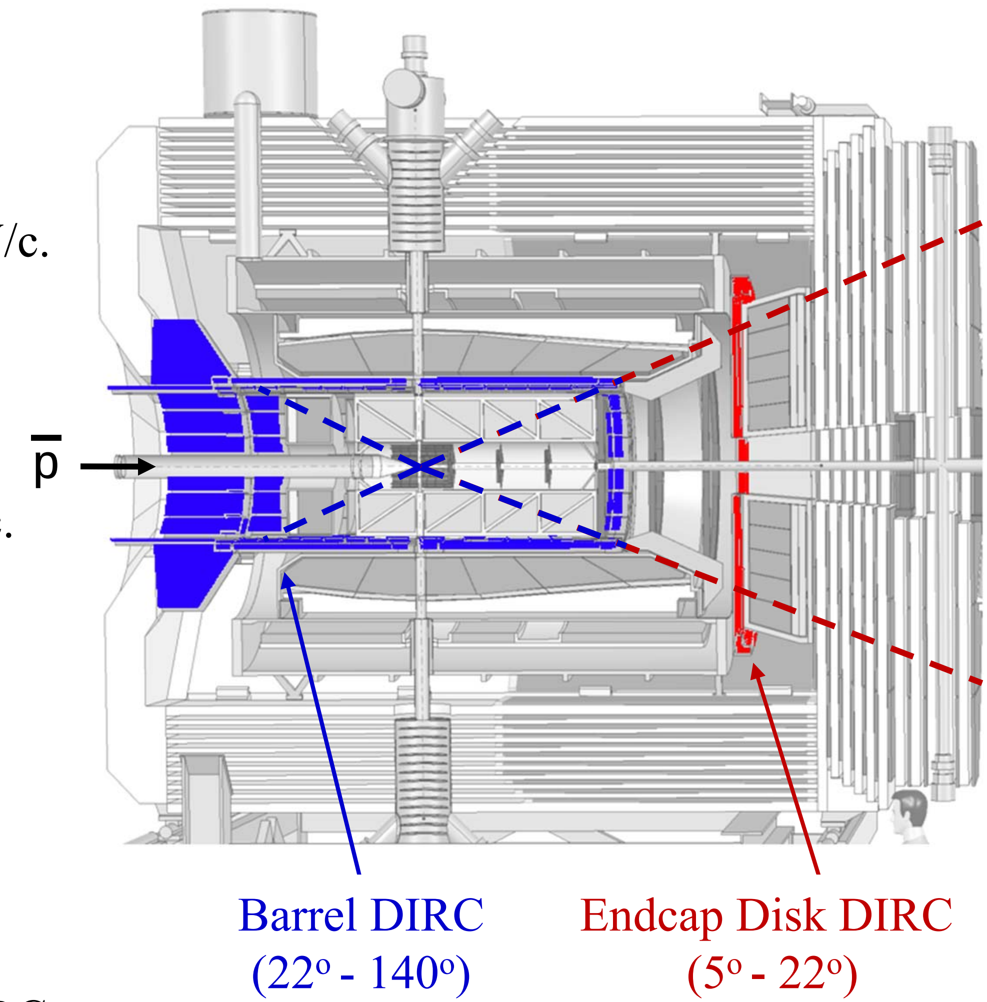
  PID goal: 3σ π/K separation for p<3.5 GeV/c.

  ➢ M. Hoek, Mon 11:20

- Endcap Disk DIRC

  PID goal: 3σ π/K separation for p<4 GeV/c.

  ➢ O. Merle, Mon 17:00



PANDA detector environment:

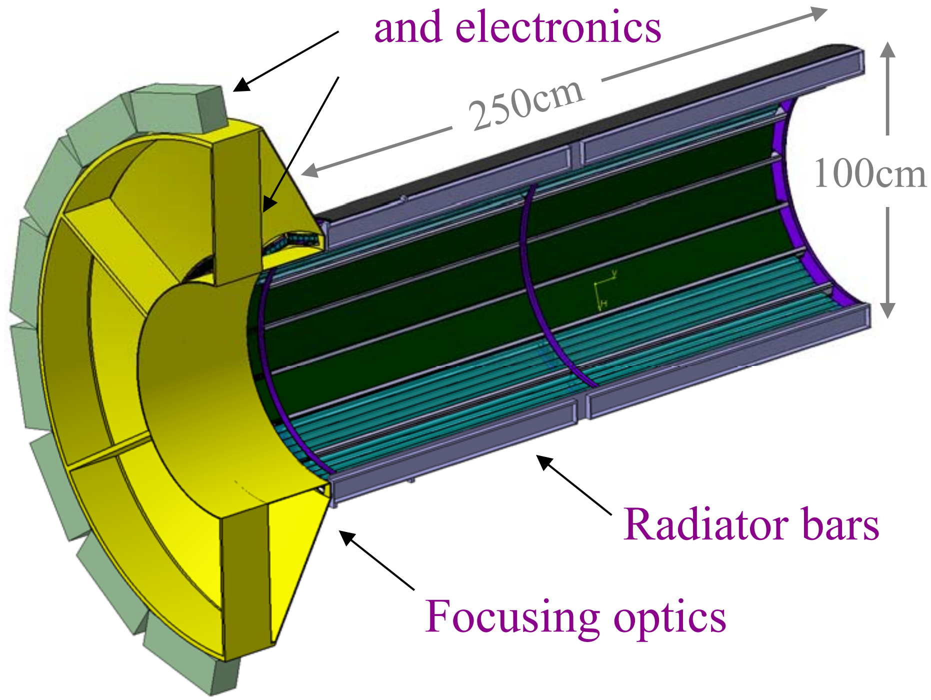
- very limited space in barrel and endcap,

  EM calorimeters just outside both DIRCs.
- trigger-less DAQ with average interaction rate 20MHz.

➢ M. Hoek, Mon 11:20

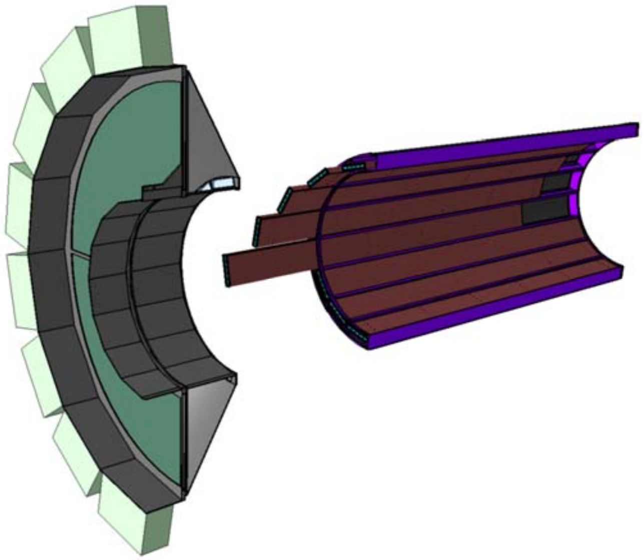
Baseline design: based on BABAR DIRC with key improvements

- Barrel radius ~48 cm; expansion volume depth: 30 cm.
- 80 narrow radiator bars, synthetic fused silica
  17mm (T) × 32mm (W) × 2400mm (L).
- Focusing optics: lens system.
- Compact photon detector:
  30 cm oil-filled expansion volume
  ~15,000 channels of MCP-PMTs
  in 1T B field.
- Fast photon detection:
  fast TDC plus ADC (or ToT) electronics.
- Expected performance:
  Single photon Cherenkov angle resolution: 8-10 mrad.
  Number of photoelectrons for $\beta \approx 1$ track: at least 20.



Finalize design in 2014,
TDR by end-2014
Installation in PANDA 2017.

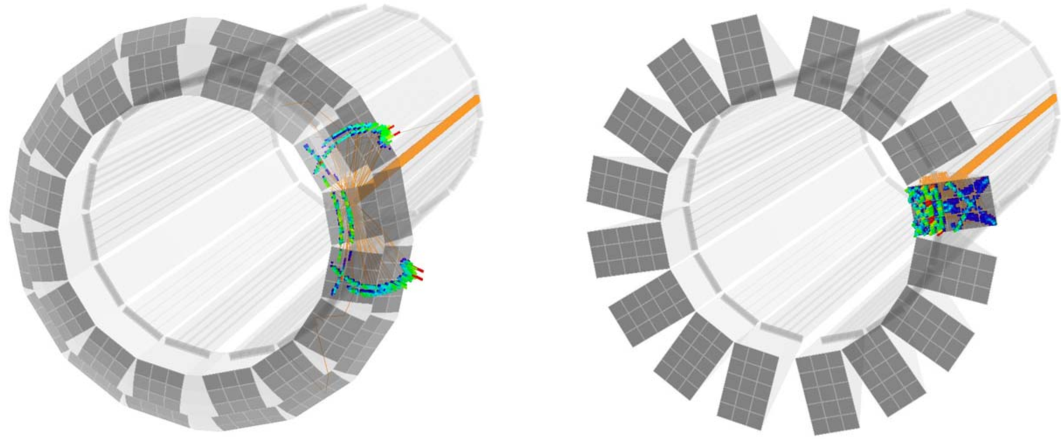
➢ Posters by R. Dzhygadlo and C. Schwarz



Modular mechanical design.

Bar boxes slide into slots, can be installed/removed as required (similar to BABAR DIRC).

Expansion volume detaches for access to bar boxes and tracking detectors.



Still considering several design options

- wide plates (16cm) instead of narrow bars
  → substantial cost saving potential
- solid fused silica prism instead of oil tank
  → improved optical quality, easier maintenance
- possible use of small focusing mirror at bar end instead of lens (similar to Belle II TOP)
- curved or inclined focal plane

PANDA BARREL DIRC

Main technical challenges:

Production of radiator bars/plates

Notoriously difficult and expensive (see BABAR, Belle II)

→ prototype production (30 pieces so far) with optical companies in Europe, US, Japan.

Selection of photon detector

Want <100ps single photon timing with high PDE in 1T field

High PANDA interaction rate: ~200kHz/cm^2 hit rate.

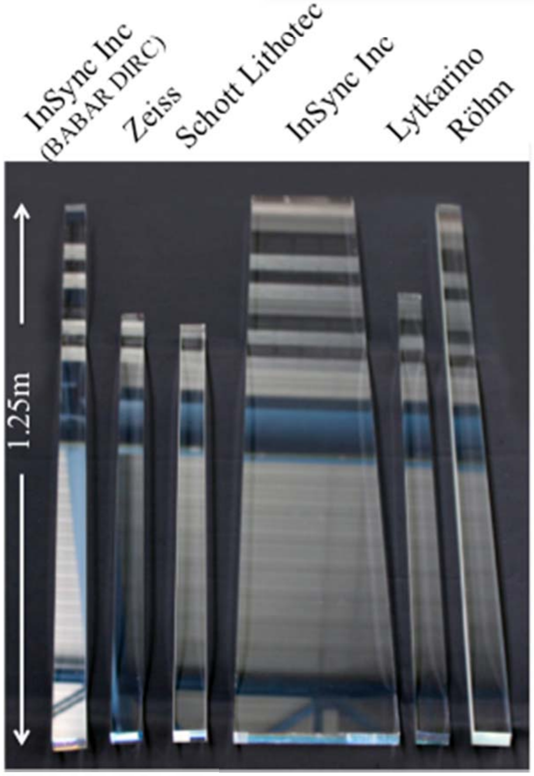
→ MCP-PMTs very attractive option.

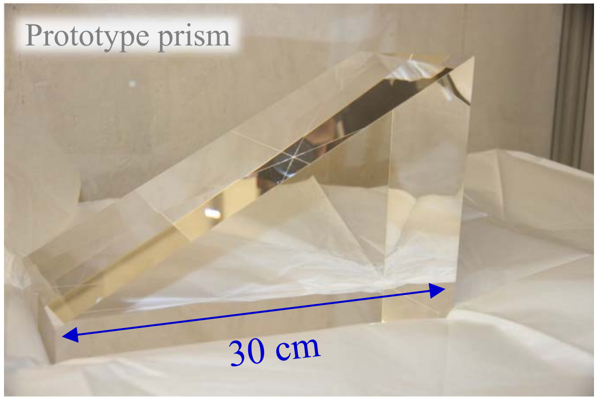
But: 5C/cm^2 total anode charge over 10 year running *(@10^6 gain)*.

Potential show-stopper at time of last RICH conference.

➢ M. Hoek, Mon 11:20

Prototype bars/plate





MCP-PMT AGEING

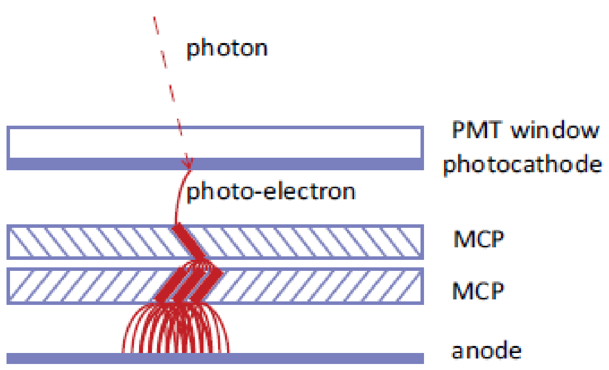
- A. Lehmann, Tue 17:40
- K. Matsuoka, Tue 18:30

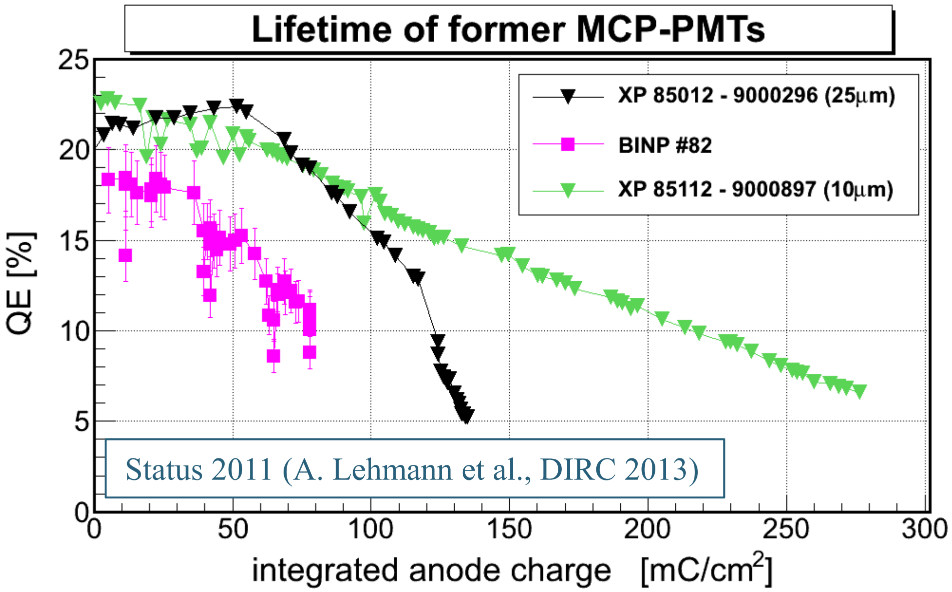
Deterioration of photocathode due to ion backflow.

State of the art in 2011: QE drops by 50% after 0.1-0.3C/cm^2 (2-3 months PANDA)

Numerous approaches tried by manufacturers to extending lifetime

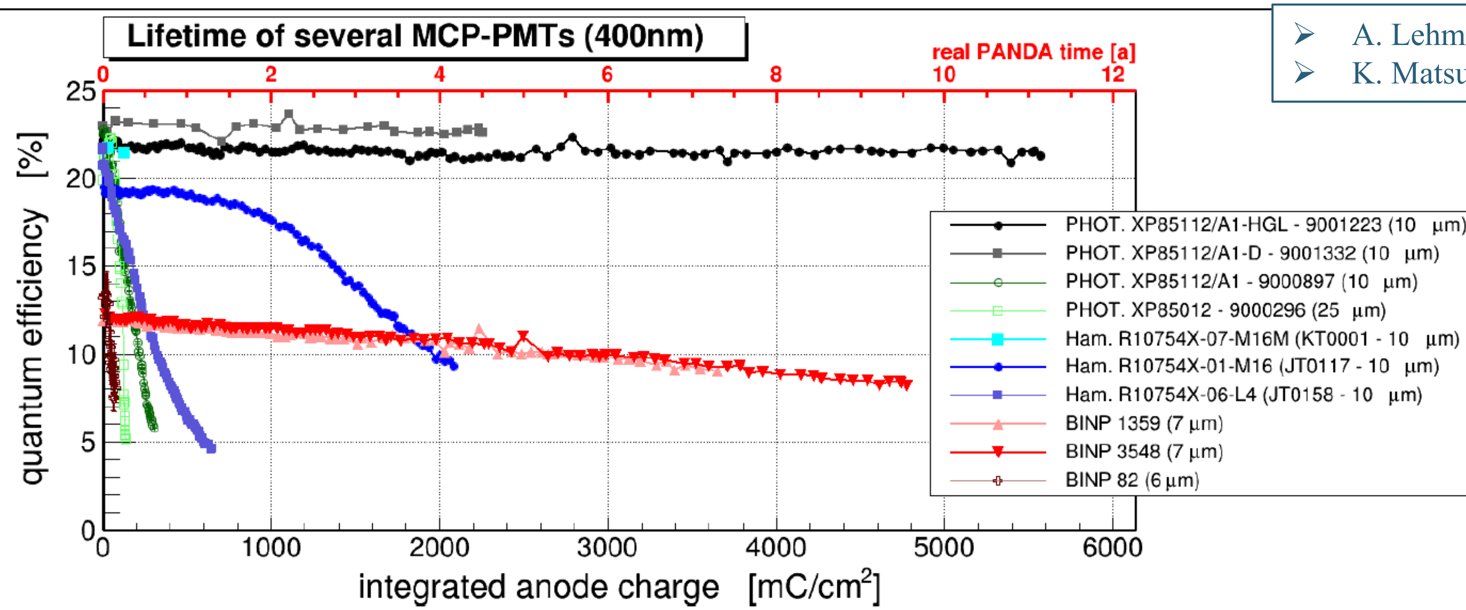
- improved vacuum/electron scrubbing;
- improved ceramic/potting;
- thin aluminum foil between MCPs or between photocathode and first MCP;
- special coating on photocathode;
- Atomic Layer Deposition.





MCP-PMT AGEING

- A. Lehmann, Tue 17:40
- K. Matsuoka, Tue 18:30



- older BINP and PHOTONIS MCP-PMTs: rapid Q.E. degradation
- new PHOTONIS XP85112: **almost no Q.E. drop at 5.6 C/cm^2**
  (with ALD)

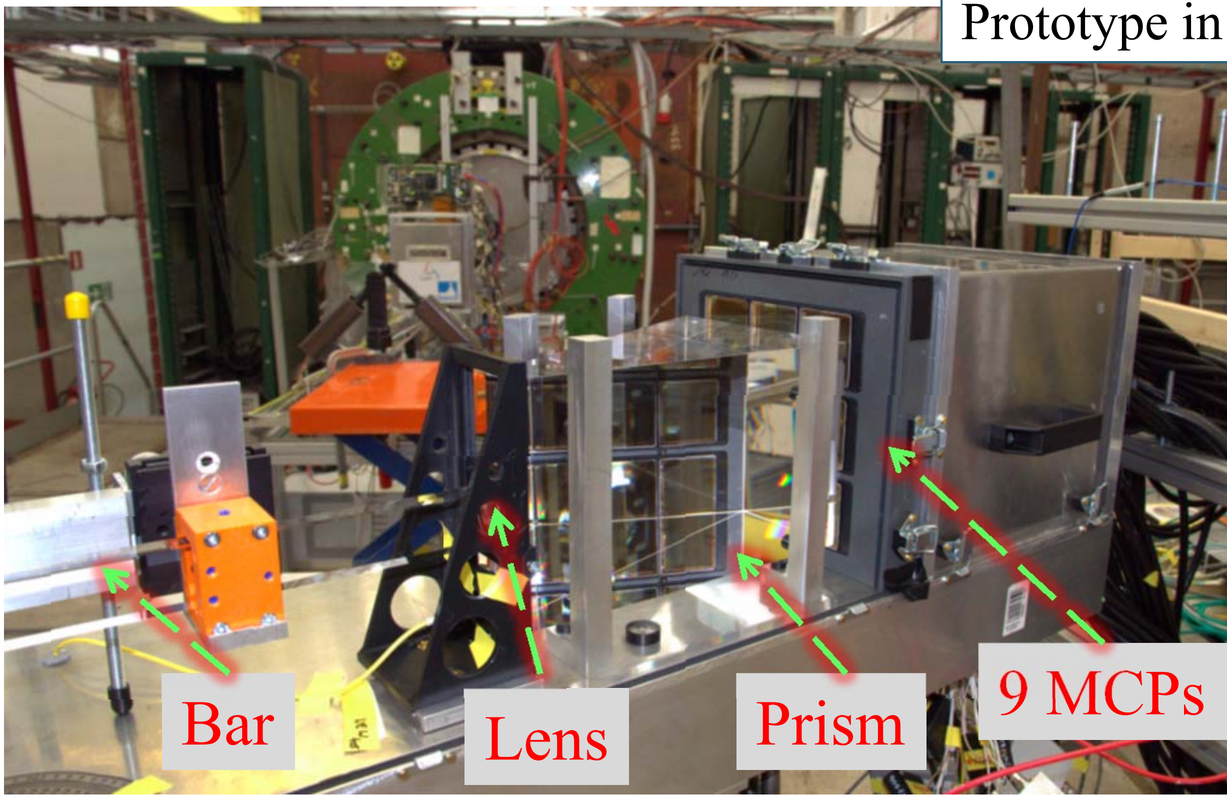
Albert Lehmann DIRC 2013 -- Gießen -- September 4, 2013 27

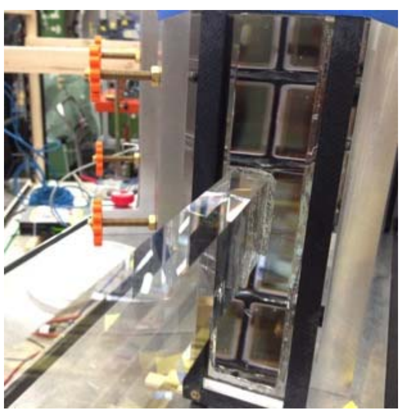
Belle II TOP reporting even longer lifetime for
Hamamatsu SL-10 with ALD, lifetime (much) more than **7 C/cm^2**.

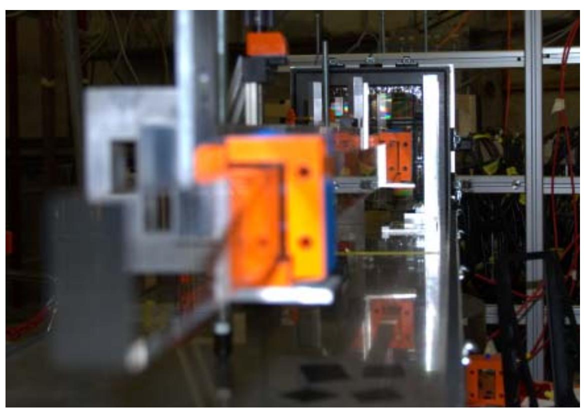
Recent lifetime improvement make MCP-PMTs with ALD an excellent sensor choice for PANDA Barrel DIRC and Belle II TOP.

PANDA BARREL DIRC

Prototype in 2012 CERN testbeam







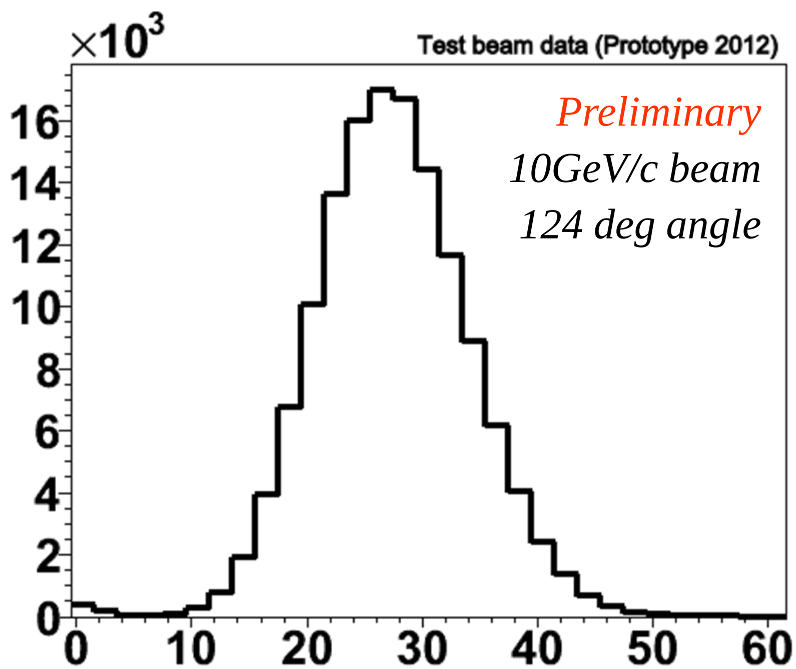
➢ M. Hoek, Mon 11:20

Detailed analysis of 2012 CERN data continuing, still preparing 3D tracking and improved timing/position calibration, plate reconstruction still in preparation.

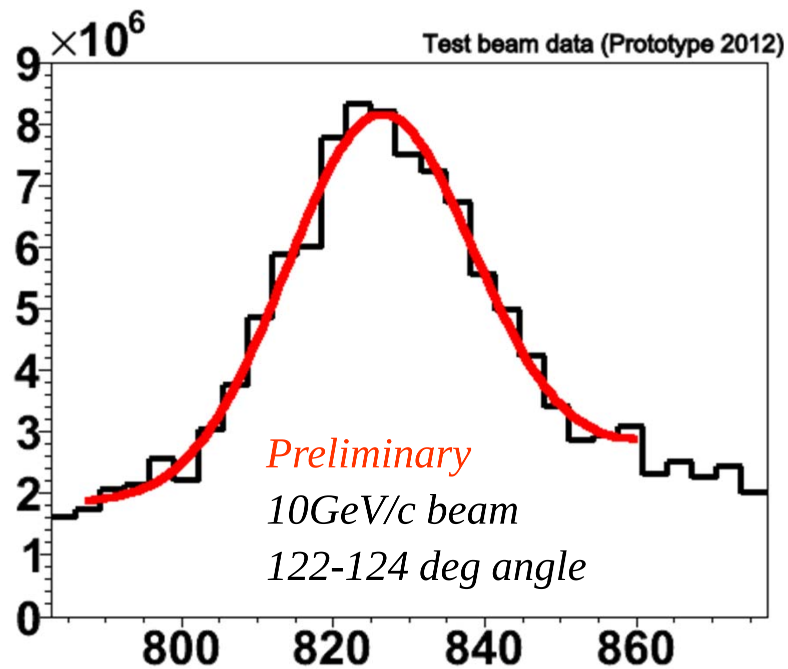
Preliminary performance example:

InSync bar, simple spherical lens with UV A/R coating and 2.2mm air gap.

→ Clear Cherenkov signal with reasonable single photon resolution.



Number of detected photons per trigger



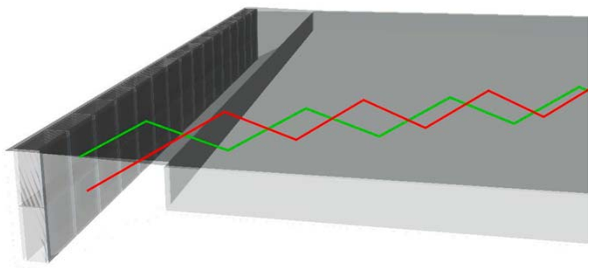
θ_C per photon – average θ_C [mrad]

BELLE II TOP

➢ K. Inami, Mon 10:55

Belle II TOP for barrel PID

PID goal: 3σ π/K separation for p<4 GeV/c



DIRC-type RICH with emphasis on fast timing.

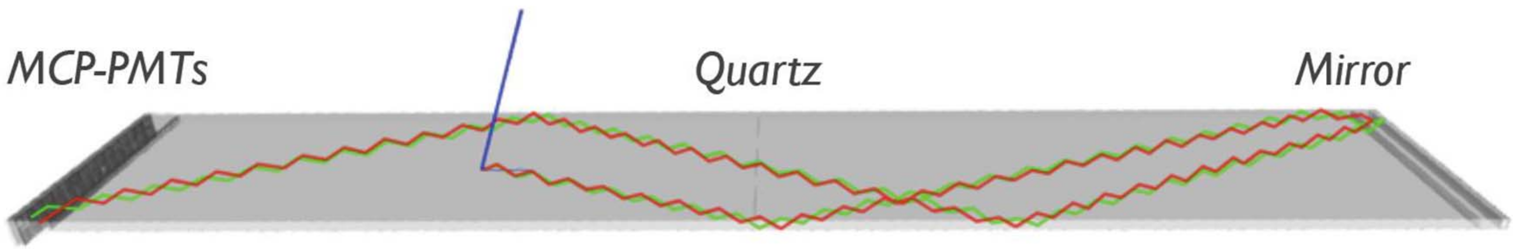
Radiator: fused silica plate 45cm wide, 2cm thick, 250cm long.

TOP barrel formed by 16 plates.

Small expansion volume (10cm depth).

Photon detector: array of 32 Hamamatsu SL-10 MCP-PMTs per sector, 512 in total.

Readout: IRSx waveform sampling ASIC.



Example of Cherenkov-photon paths for 2 GeV/c $\pi^{\pm}$ and $K^{\pm}$.

P. Krizan, DIRC2013 Workshop

BELLE II TOP

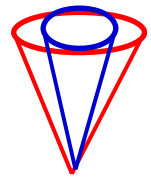
> K. Inami, Mon 10:55

Ring image of TOP counter

Ring image animation

Top view

※A ring image has high sensitivity to incident position and angles of particles.

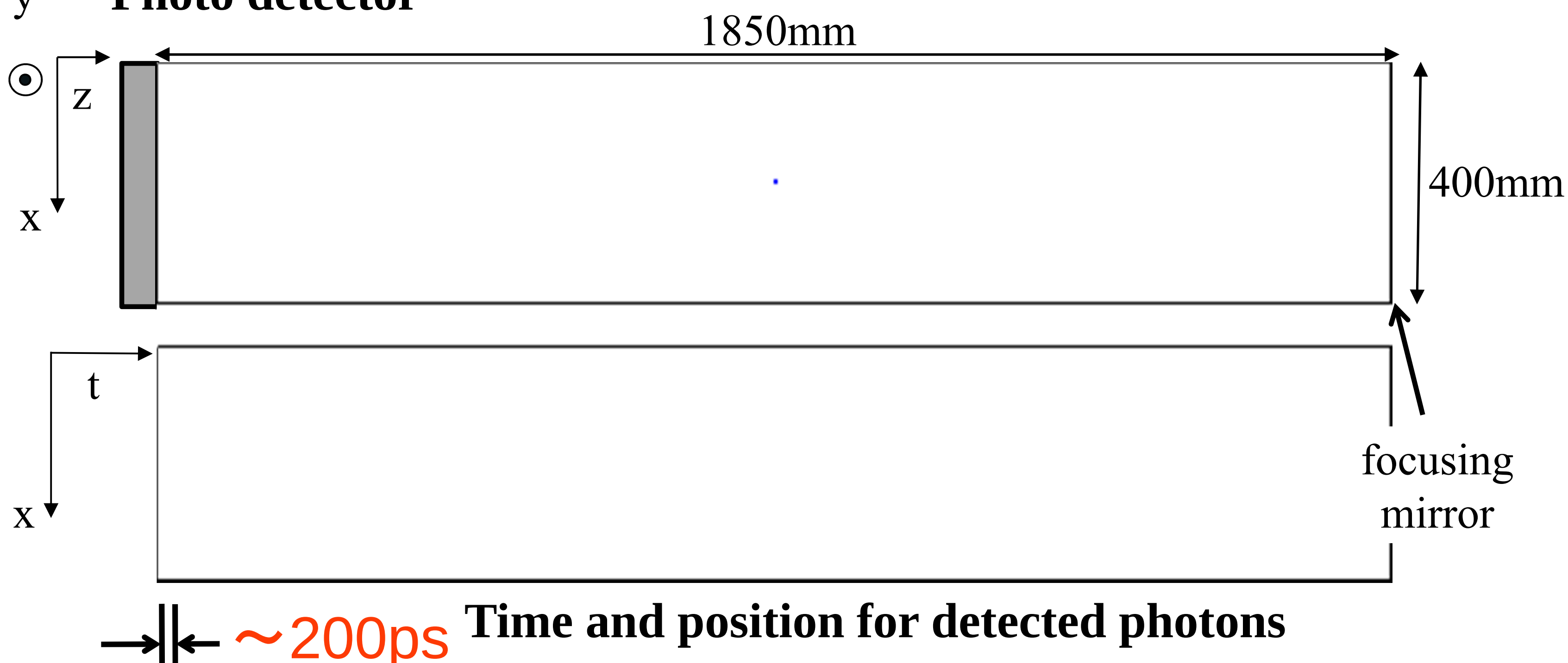


π/K

➡β are different

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

Photo detector



Time and position for detected photons

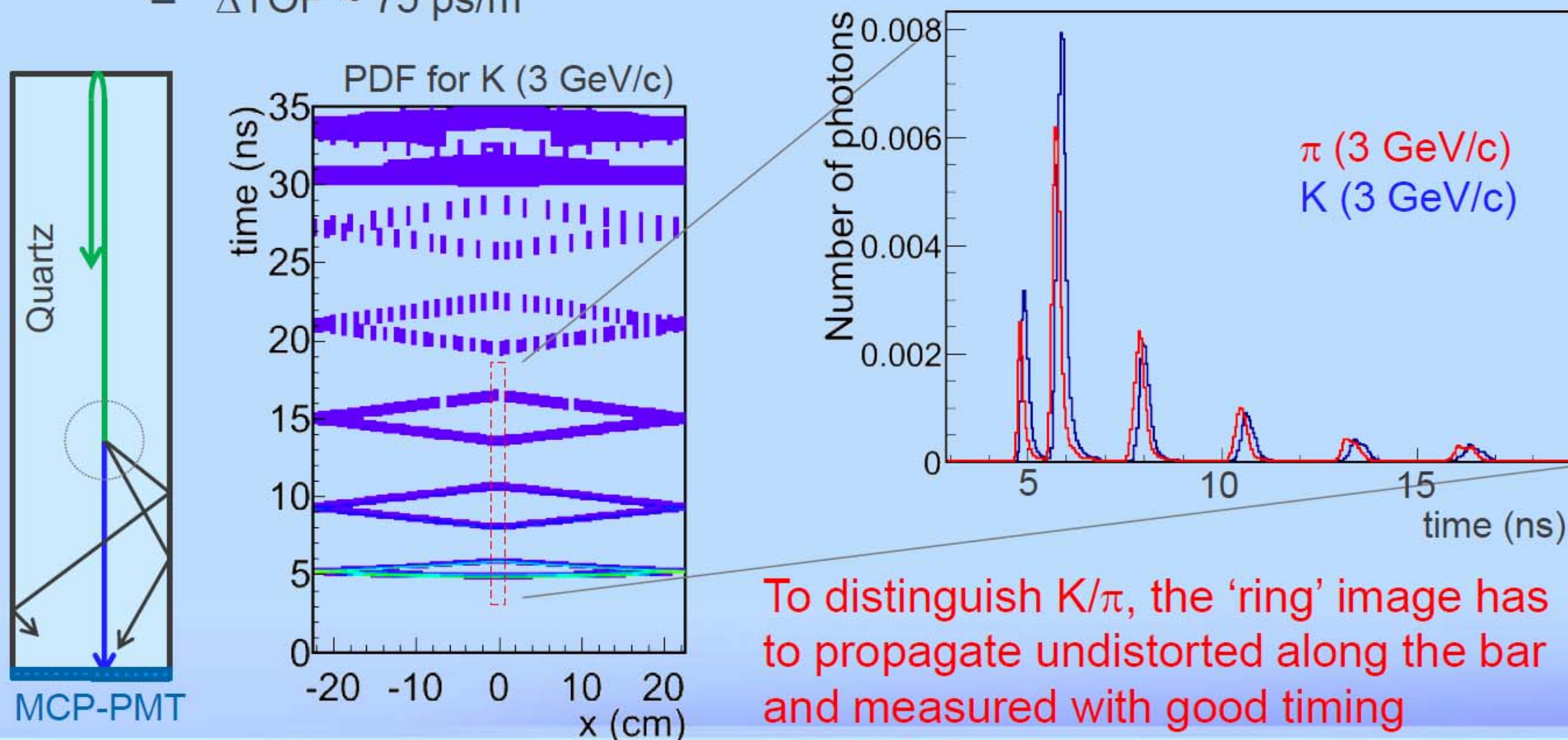
QFPU 2013 Y. Arita, *Belle II TOP counter*

BELLE II TOP

➢ K. Inami, Mon 10:55

TOP counter

- Measure the hit timing of ~20 Cherenkov photons.
- Hit timing difference between 3 GeV/c K and π
  - ΔTOF ~ 50 ps/m
  - ΔTOP ~ 75 ps/m



To distinguish K/π, the 'ring' image has to propagate undistorted along the bar and measured with good timing resolution (~50 ps).

K. Matsuoka, VCI2013

RICH 2013

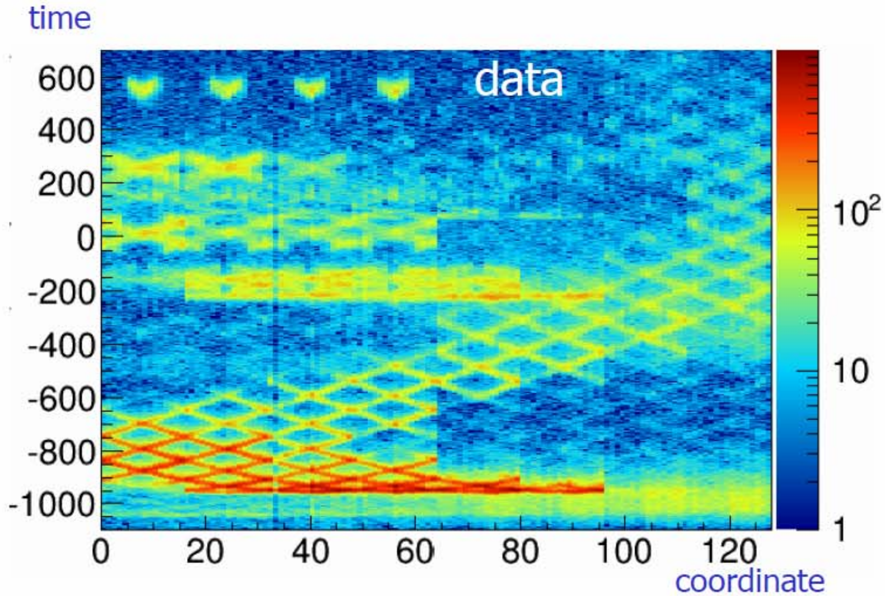
TOP prototype at LEPS SPRING8 in 2013

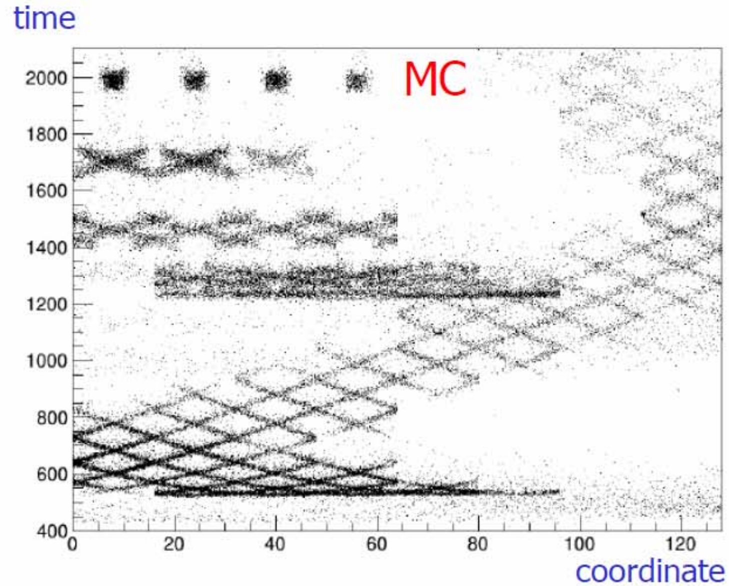
➢ K. Inami, Mon 10:55

TOP image

Pattern in the coordinate-time space ('ring') – different for kaons and pions.

Recorded by the CFD-based read-out.





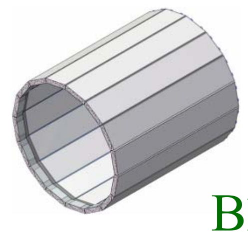
Excellent agreement between beam test data and MC simulated patterns.

P. Krizan, DIRC2013 Workshop

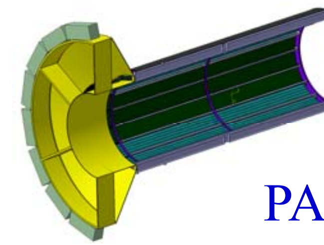
→ Y. Horii, talk at EPS HEP 2013, M. Barret, talk at DPF2013

BARREL DIRC LANDSCAPE

BABAR
DIRC



BELLE II
TOP



PANDA
BARREL DIRC

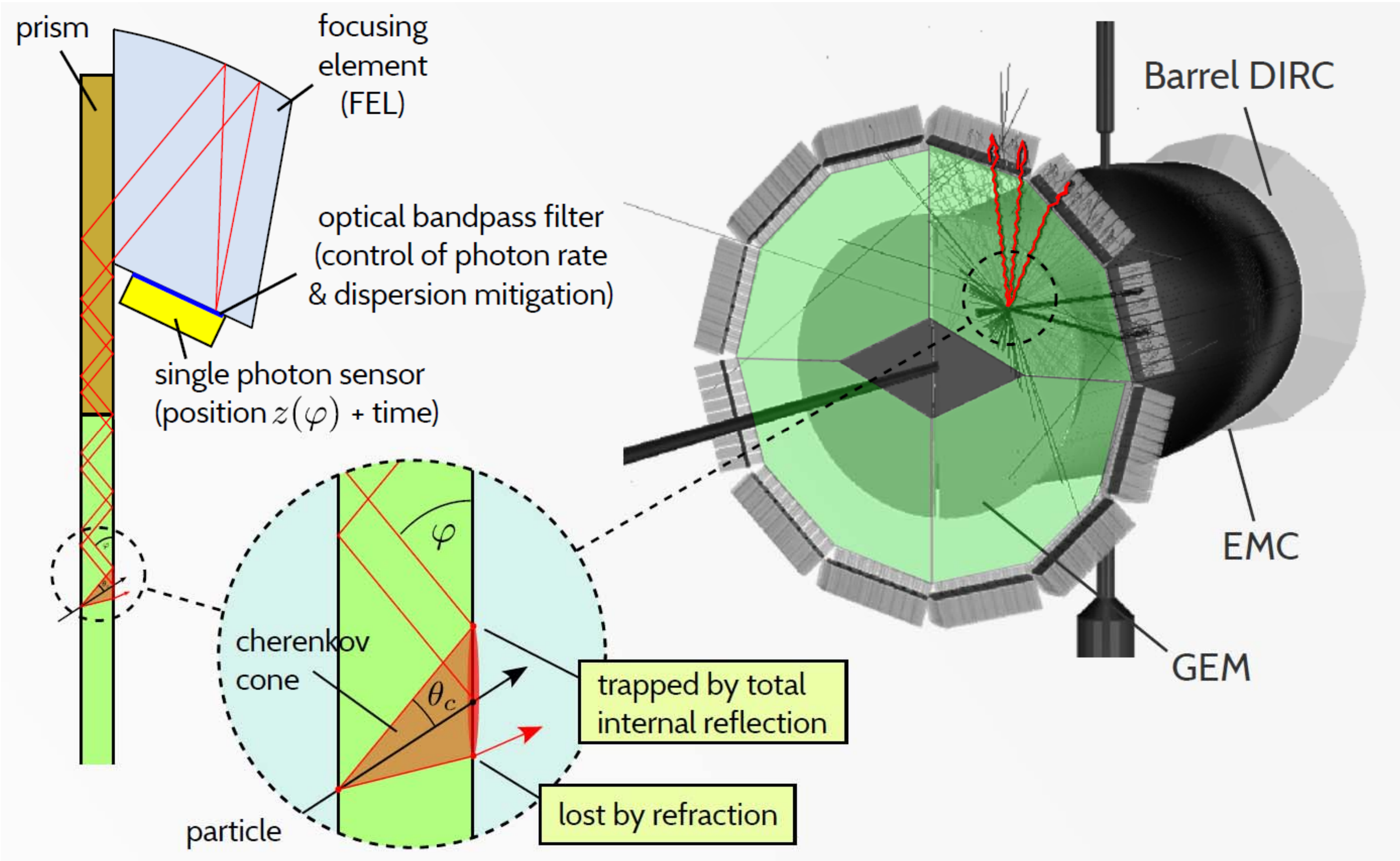
Radiator geometry	Narrow bars *(35mm)*	Wide plates *(450mm)*	Narrow bars *(32mm)*
Barrel radius	85cm	115cm	48cm
Bar length	490cm *(4×122.5cm)*	250cm *(2×125cm)*	240cm *(2×120cm)*
Number of long bars	144 *(12×12 bars)*	16 *(16×1 plates)*	80 *(16×5 bars)*
Expansion volume	110cm, ultrapure water	10cm, fused silica	30cm, mineral oil
Focusing	None (pinhole)	Mirror	Lens system
Photon detector	~11k PMTs	~8k MCP-PMT pixels	~15k MCP-PMT pixels
Timing resolution	~1.7ns	<0.1ns	~0.1ns
Pixel size	25mm diameter	5.5mm×5.5mm	6.5mm×6.5mm
PID goal	3 s.d. π/K to 4 GeV/c	3 s.d. π/K to 4 GeV/c	3 s.d. π/K to 3.5 GeV/c
Timeline	1999 - 2008	Installation 2015	Installation 2017/18

PANDA DISK DIRC

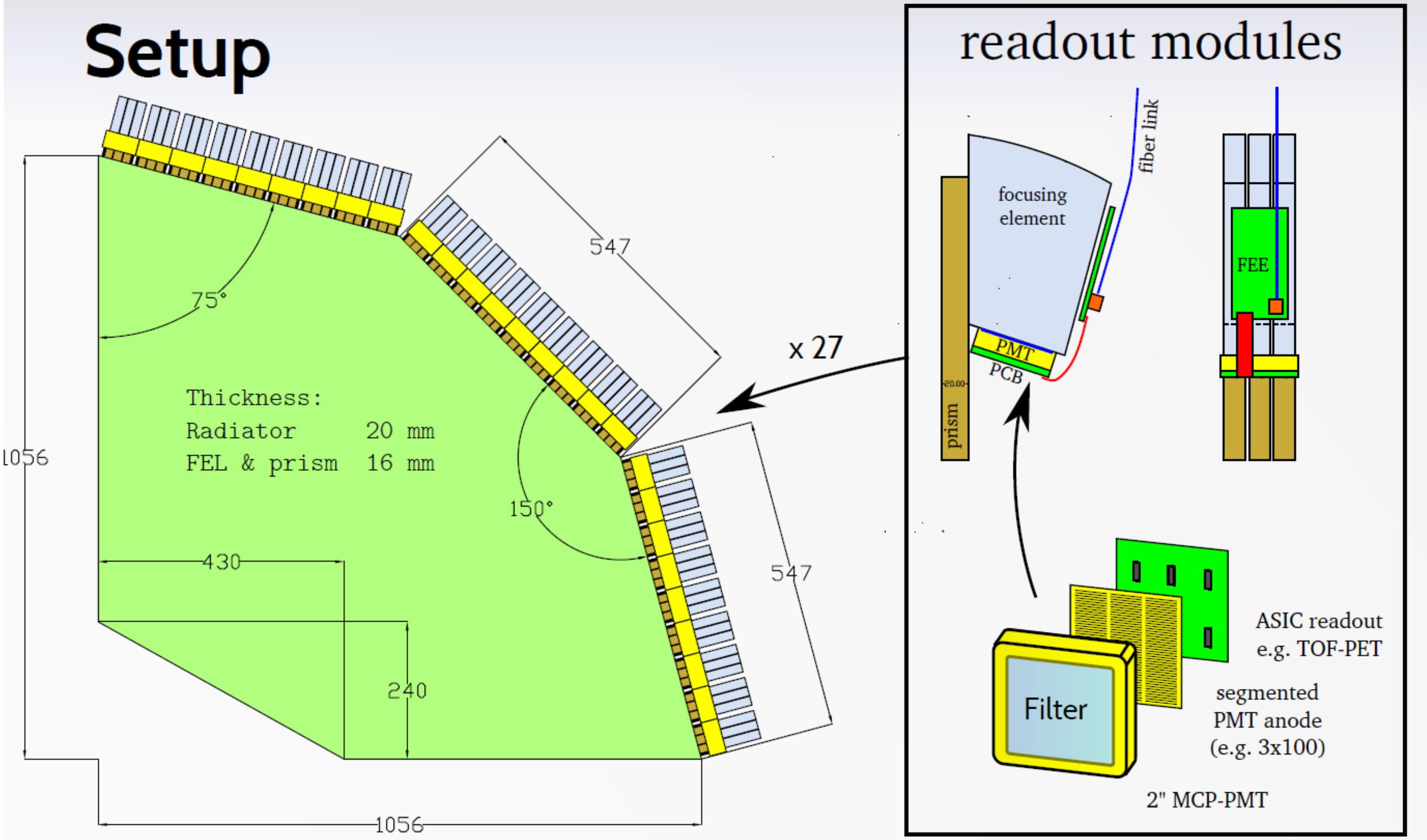
PANDA endcap disk DIRC, PID goal: 3σ π/K separation for p<4 GeV/c

➤ O. Merle, Mon 17:00

First DIRC system for small angle forward PID.



PANDA DISK DIRC



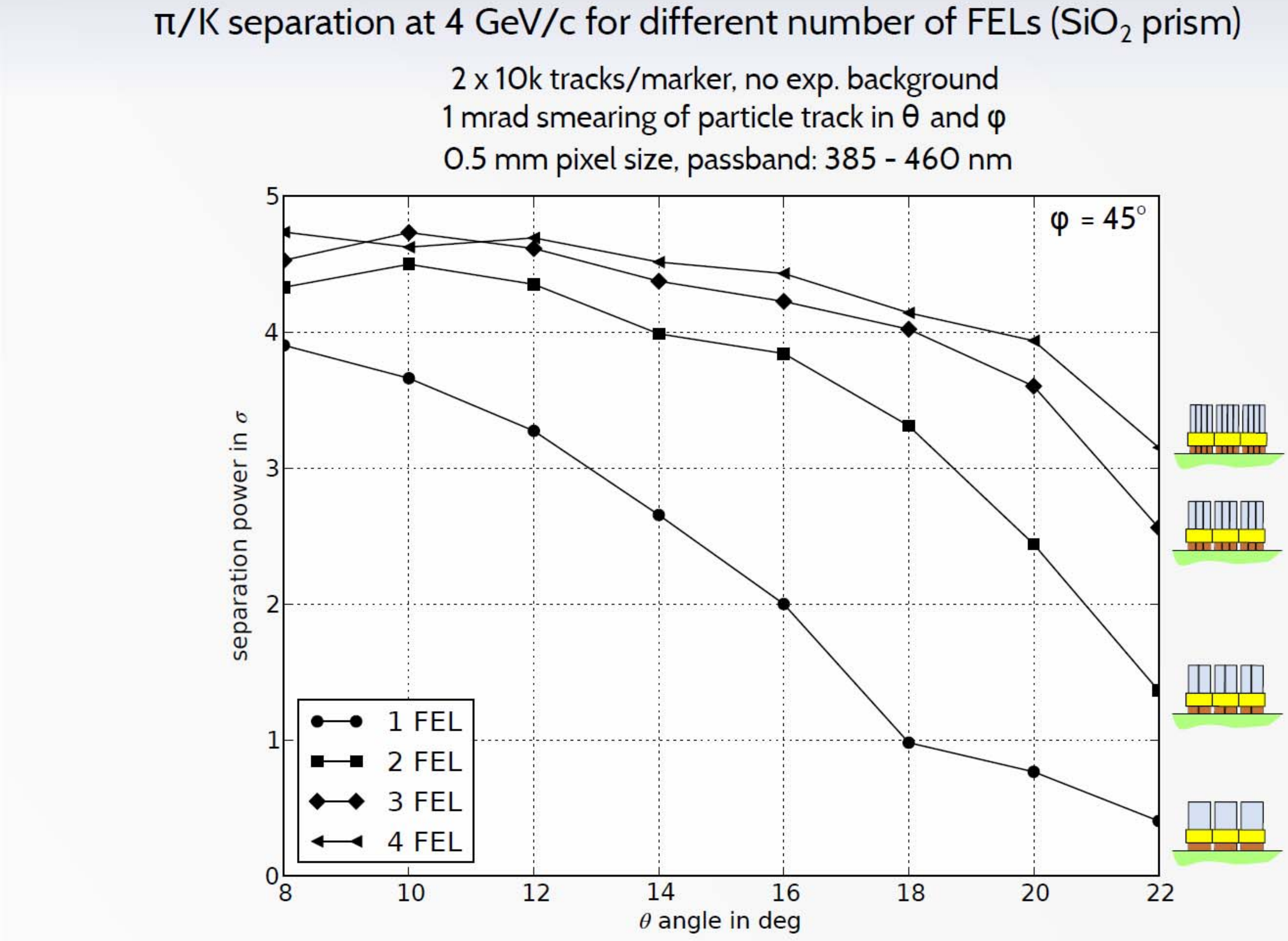
Filter band: 385 nm - 460 nm => $N_{ph} \approx 16$ ⟶

Integrated anode charge: $Q \approx 5.6$ C/cm^2
Avg. rate: 225 kHz/cm^2 (19 kHz/ch)
Peak data rate per module: ~0.6 GBit/s

ASIC candidate: TOF-PET (64 ch/die, 100 kHz/ch, ~6 mW/ch, 50 ps time-bin, 40 ns dead time)

Enhanced-lifetime MCP-PMT would be OK (will use bandwidth filter to restrict rate)
but need fine segmentation (0.5mm pixels, 8 x 128 channel for 2" MCP-PMT)

➤ O. Merle, Mon 17:00



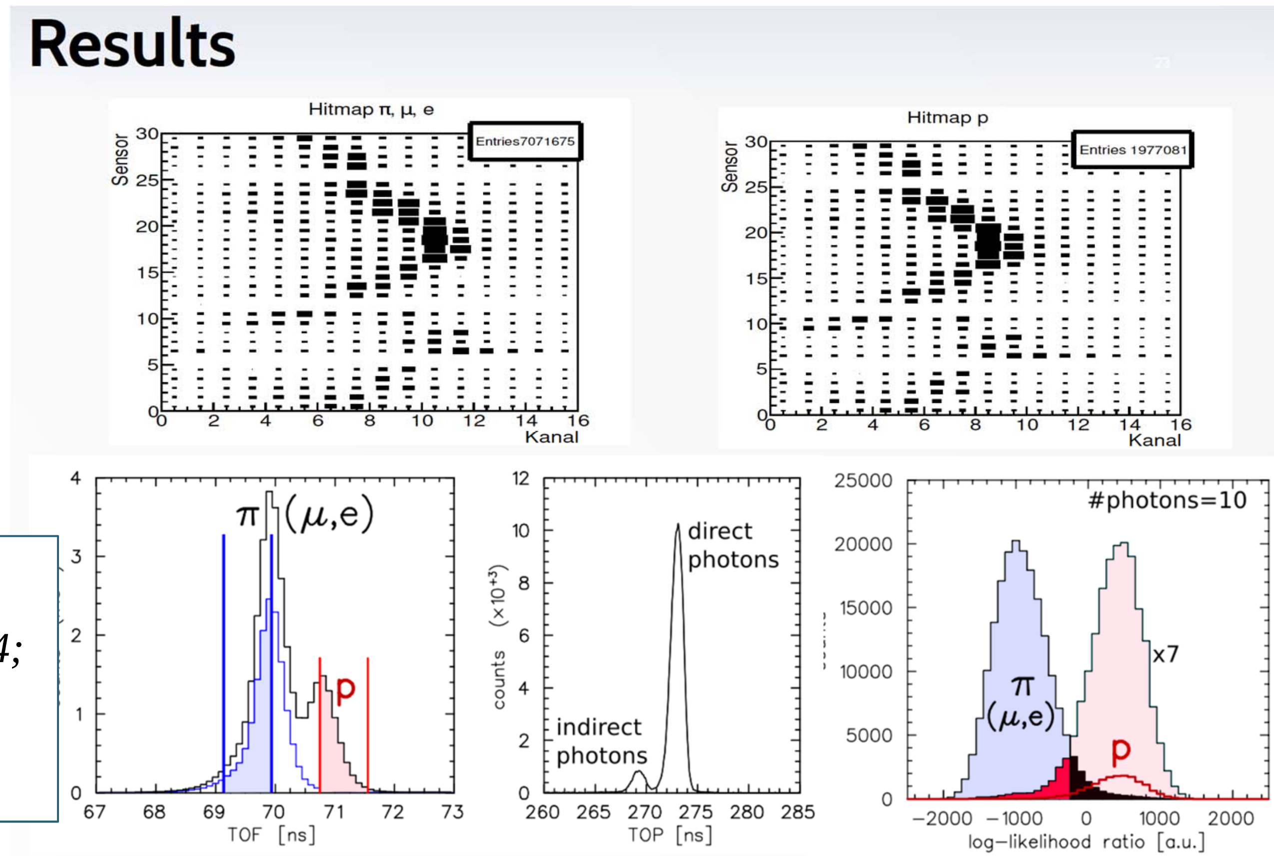
PANDA DISK DIRC

➤ O. Merle, Mon 17:00

Quarter-disk prototype in testbeam at CERN and DESY

Track-by-track PID demonstrated.

Low-cost R&D prototype:
- *borosilicate disk,*
- *PMMA lightguides,*
- *limited number of channels.*



Validate design with
- *high-resolution prototype in 2014;*

TDR by end-2014;

Installation in PANDA 2017.

LHCb TORCH

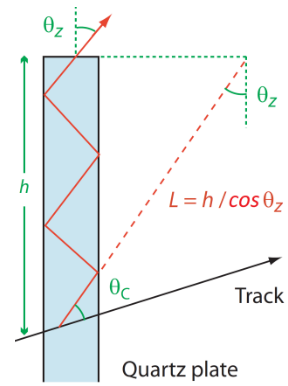
➢ M. van Dijk, Mon 19:00

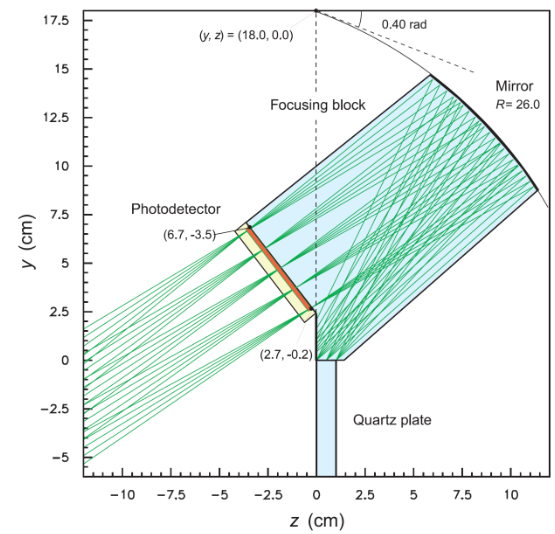
TORCH: R&D project for possible LHCb upgrade:

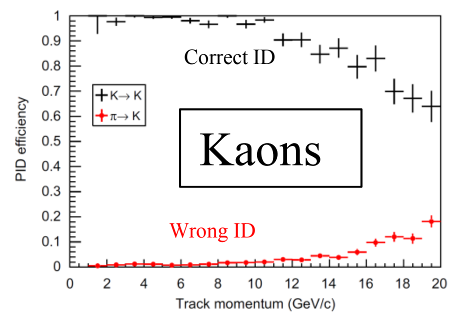
Particle ID for low/intermediate momentum (2-10 GeV/c)

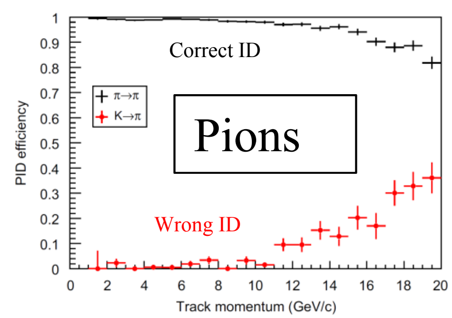
- Large quartz Cherenkov radiator plate (idealised design) with focusing block on top and bottom
- Photons extracted through total internal reflection

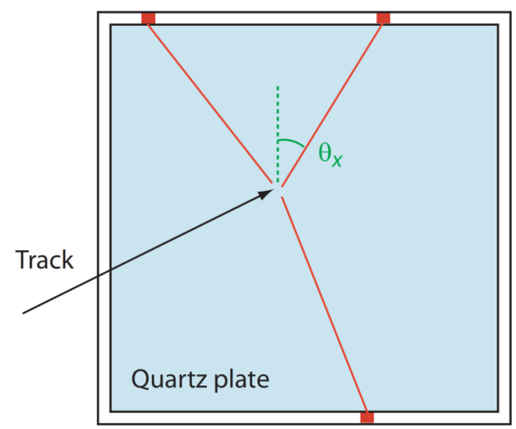
- Pions and kaons are separated in time-of-flight due to slightly different mass
- Precise time-of-flight measurement coupled to momentum information leads to identification
- Goal is to provide 3σ pion-kaon separation (needs <12.5ps per-track resolution)











LHCb TORCH

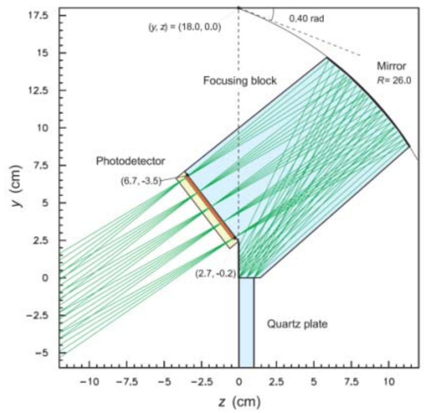
➢ M. van Dijk, Mon 19:00

- Geant simulation of idealised quartz plate and focusing block
- Detector effects to be added in

- Extra (noise) photons detected from secondary tracks (electrons) that also give of Cherenkov radiation
- Width of Cherenkov ring segment due to chromatic dispersion in quartz medium
- Simulation of accumulated photons for a thousand 10 GeV kaons

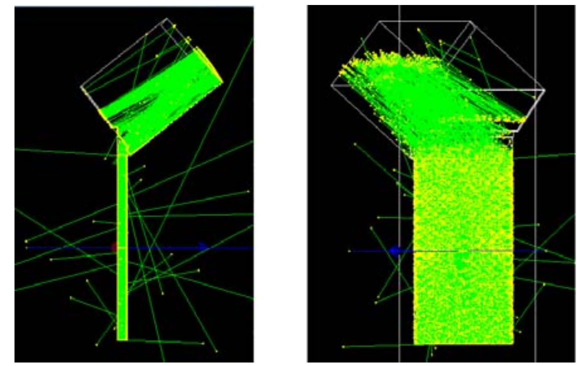
- R&D cooperation with Photek to develop high-granularity, long-lifetime, close-packing MCP-PMT.

MCP-PMT matches requirement for PANDA Disk DIRC.

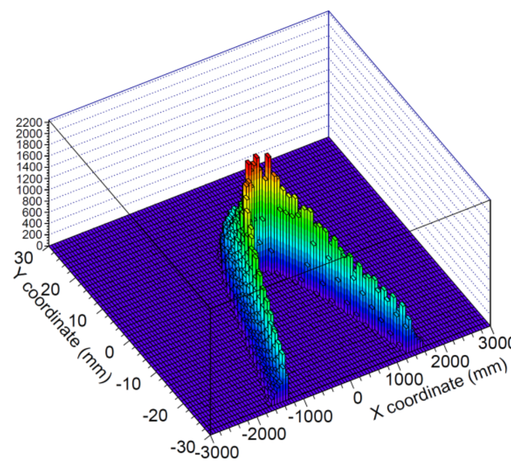


Viewpoint angles: θ=270° φ=0°

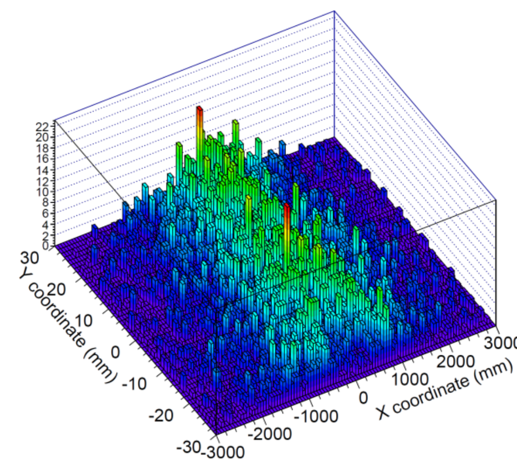
Viewpoint angles: θ=120° φ=0°



Photons from primary track



Photons from secondary tracks



TRENDS AND CONCLUSIONS

Recent technology advances crucial for next generation aerogel / fused silica RICHes.

Aerogel clarity and tile size greatly improve photon yield.

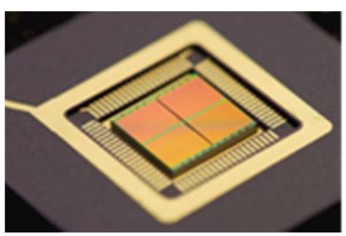
Focusing aerogel configuration due to reliable tuning of aerogel refractive index.

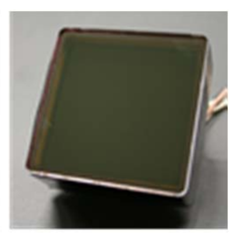
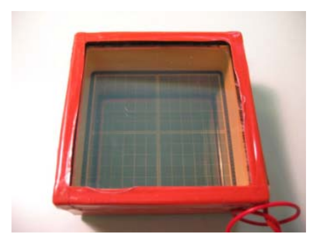
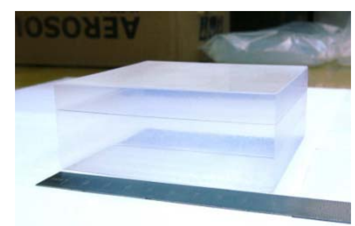
Single photon detectors with fine pixels, fast timing, tolerant of magnetic field
and moderate radiation have become available (HAPDs, MCP-PMTs).

Breakthrough lifetime improvement make MCP-PMT with ALD technology
sensor of choice for high-rate DIRC-type RICHes.

SiPM (G-APD) are making progress by drastically reducing dark count rate
and need for cooling, dSiPM looking promising but not quite there yet.

BABAR-DIRC bars may see second life – TORCH? PANDA? GlueX? …?



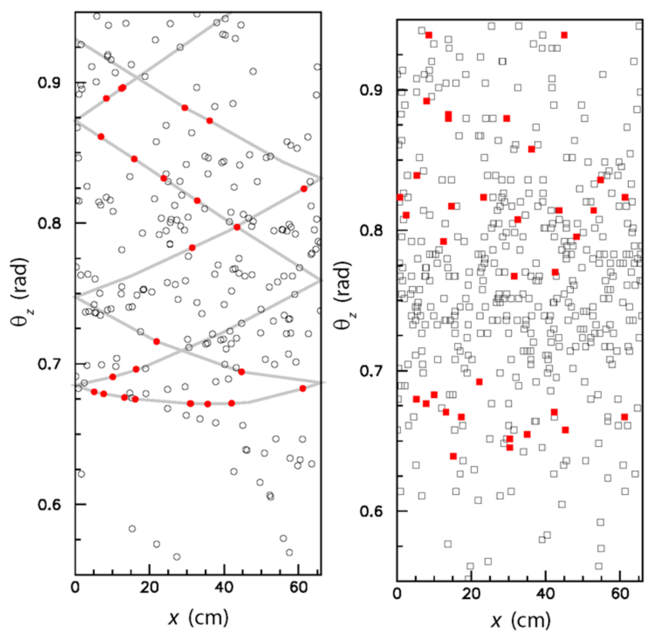
TRENDS AND CONCLUSIONS

Time imaging seemed imminent at RICH in 2010 with Belle II TOP and PANDA Disk DIRC were considering photon detection with only one space coordinate plus very precise timing.

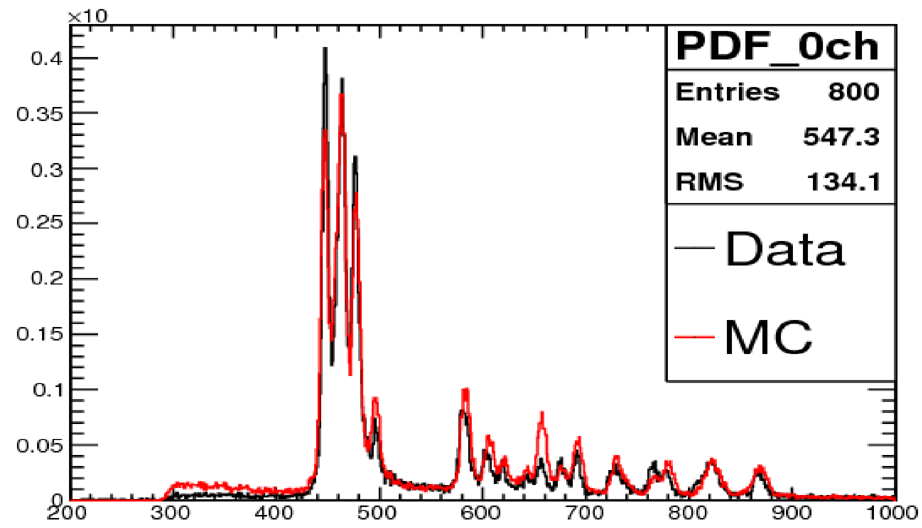
But difficult to control effects of background, alignment, PID less robust – added "Y" pixels.

But technique may be necessary to unfold complicated backgrounds that appear in geometric reconstruction approaches, certainly has potential to further improve performance.

TORCH hit pattern with and without dispersion and reflection off lower edge
R. Forty, DIRC 2013



Belle II TOP time PDF, Y. Arita, QFPU 2013



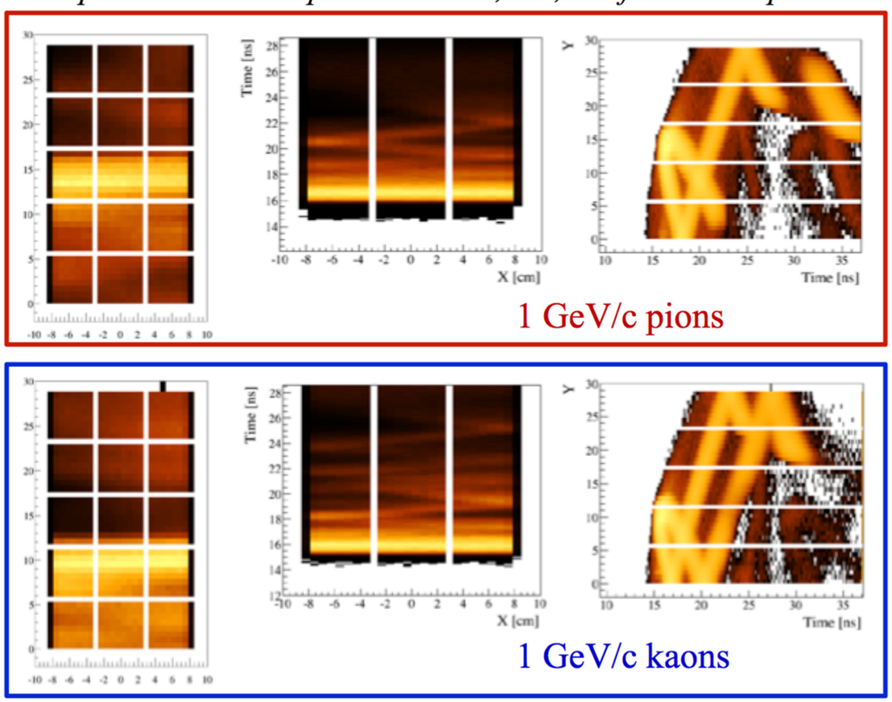
TRENDS AND CONCLUSIONS

Time imaging seemed imminent at RICH in 2010 with Belle II TOP and PANDA Disk DIRC were considering photon detection with only one space coordinate plus very precise timing.

But difficult to control effects of background, alignment, PID less robust – added “Y” pixels.

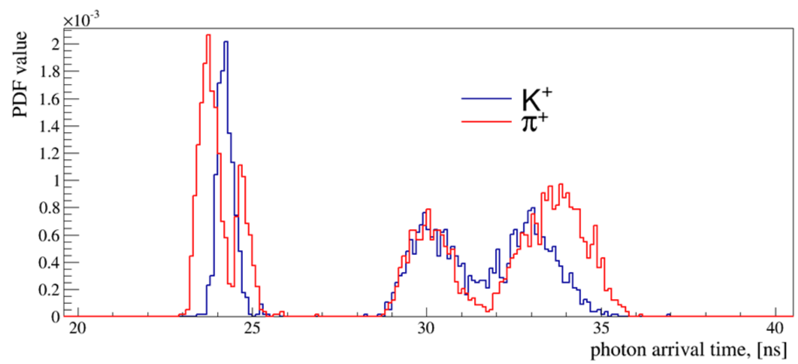
But technique may be necessary to unfold complicated backgrounds that appear in geometric reconstruction approaches, certainly has potential to further improve performance.

Example: simulated hit patterns in X/Y, X/T, T/Y for 1GeV/c particles



Simulation study for PANDA Barrel DIRC with wide plate geometry suggests that time-based PDFs perform significantly better than pure geometric reconstruction.

PANDA Barrel DIRC hit pattern and PDF,
M. Hoek, R. Dzhygadlo, RICH2013



Thank You

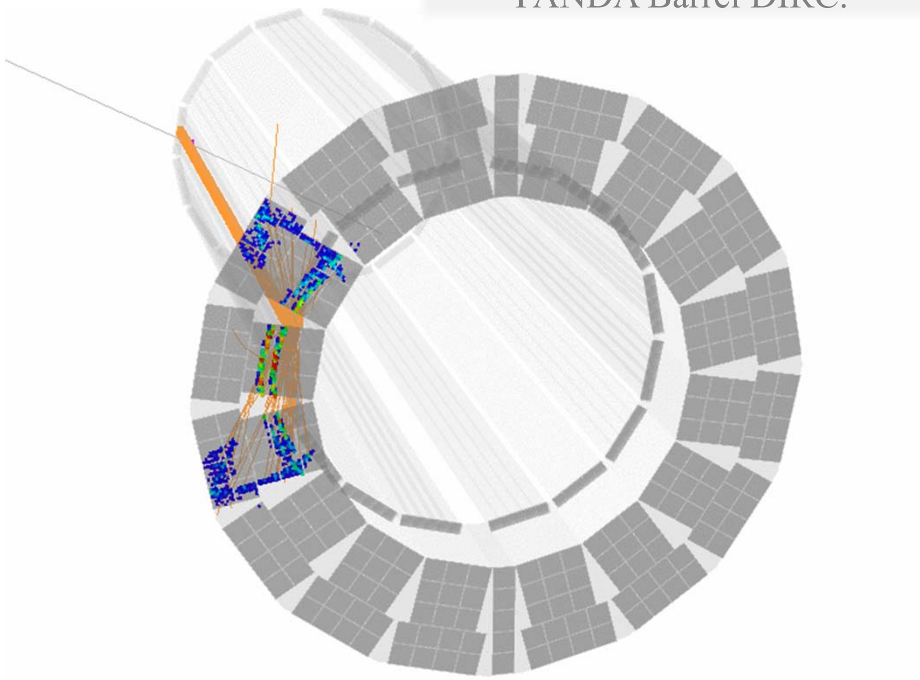
Thank you to the organizers.

Thank you to my RICH colleagues for providing material for this talk

and sorry about skipping so much. *(Additional slides in the appendix.)*

Thank you all for your attention.

Geant simulation of hit pattern in PANDA Barrel DIRC.



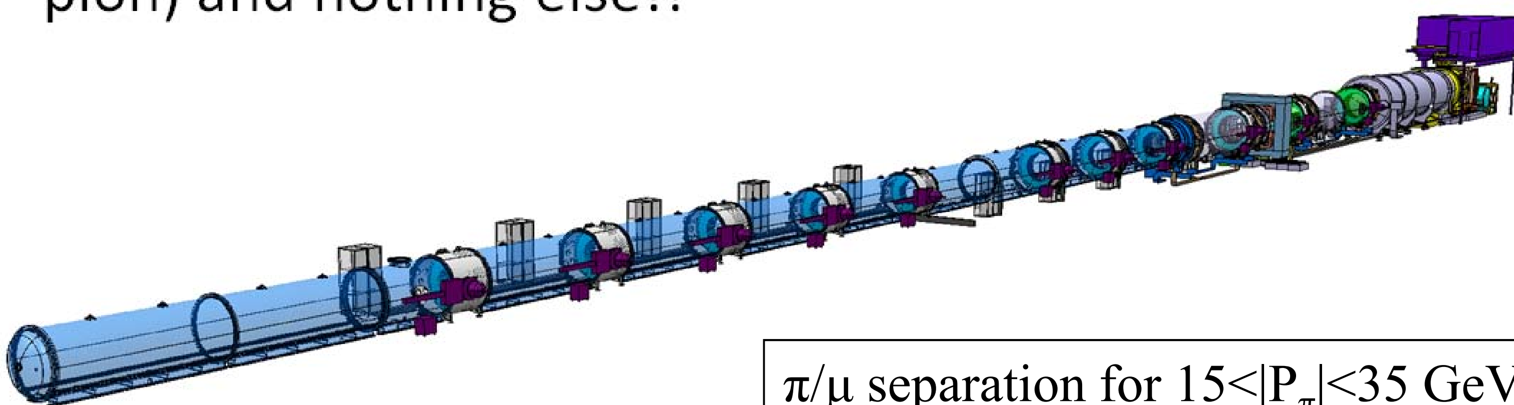
EXTRA MATERIAL

INFN

NA62

The NA62 Experiment at CERN

- NA62 aim at a 10% measurement of the BR($K^+ \rightarrow \pi^+ \nu\nu$)
- Theory: BR = $(0.85 \pm 0.07) \times 10^{-10}$ (very small th.error!!)
- Present result: **$1.73^{+1.15}_{-1.05} \times 10^{-10}$(BNL E787/E949)**
- Very hard from exp.point of view: one charged track (a pion) and nothing else!!

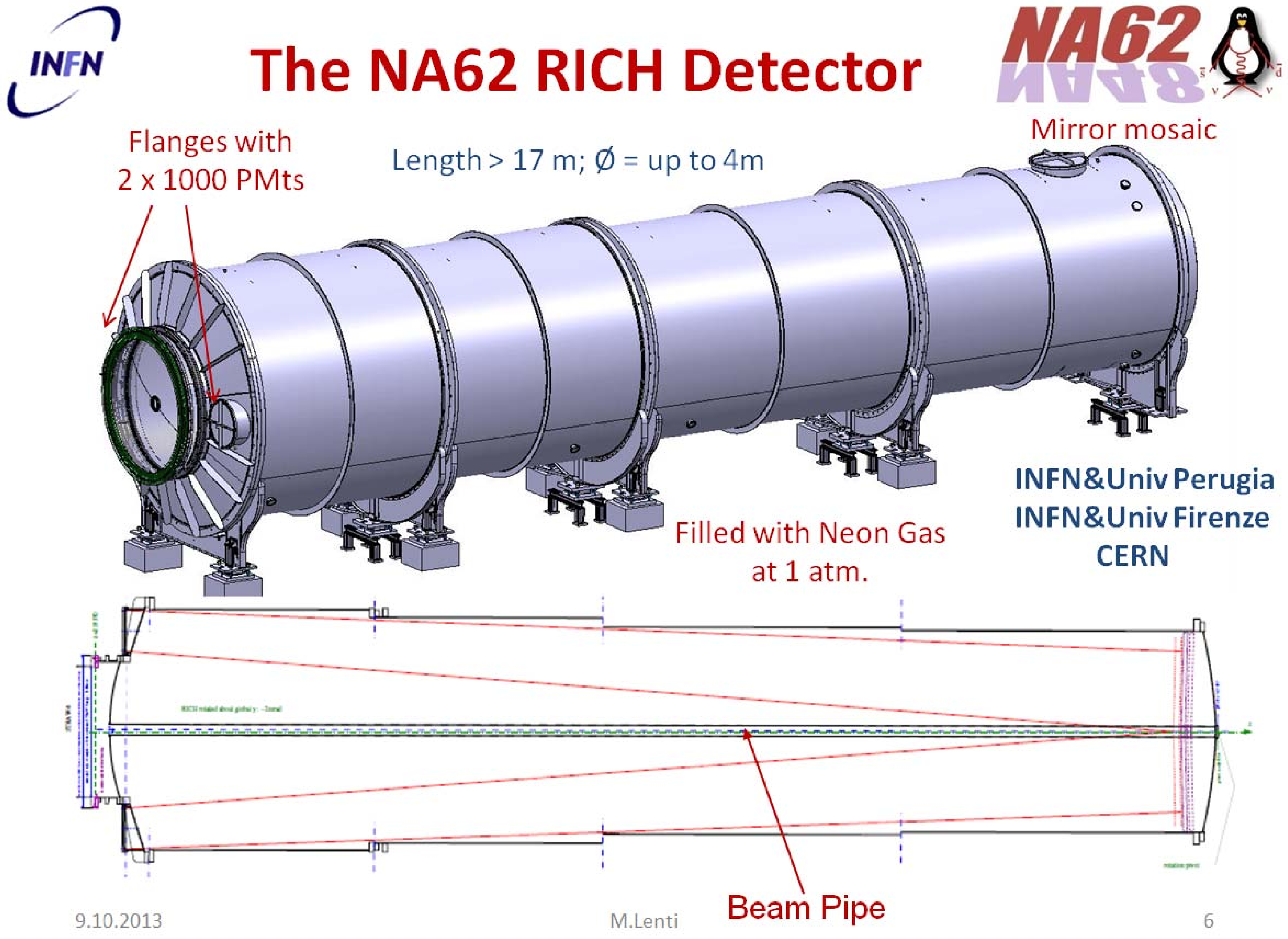


π/μ separation for $15<|P_\pi|<35$ GeV/c

9.10.2013 M.Lenti 3

The RICH Detector of the NA62 Experiment at CERN, M. Piccini, Mon 10:30

NA62 RICH



The RICH Detector of the NA62 Experiment at CERN, M. Piccini, Mon 10:30

NA62 RICH

The Gas System

- Vessel volume: 200 m^3
- Neon at slightly above atmospheric pressure
- Neon density stability < 1%
- Contaminants < 1%

➢ The vessel is first fully evacuated

➢ Then fresh Neon is introduced in the vessel

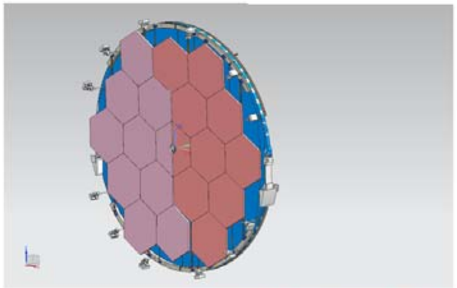
➢ At the end the vessel is valve closed

9.10.2013 M.Lenti 8

The Mirrors

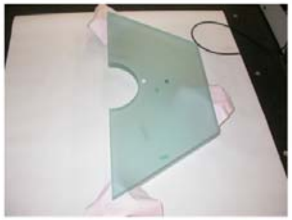
Mirror Assembly

- 18 hexagonal mirrors (700 mm wide, 25 mm thick)
- 2 half mirrors around the beam pipe.



Mirror Parameters + Quality:

- Spherical mirrors f= 17±0.1 m
- Reflectivity > 90% (195 – 650nm)
- $D_o \leq$ 4mm (circle which collects 90% of the reflected light.)



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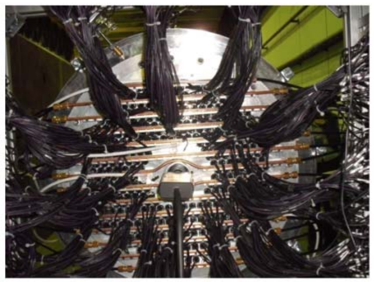
The RICH Detector of the NA62 Experiment at CERN, M. Piccini, Mon 10:30

NA62 RICH

NIM A 593 (2008) 314-318
NIM A 621 (2010) 205-211

Test Beams

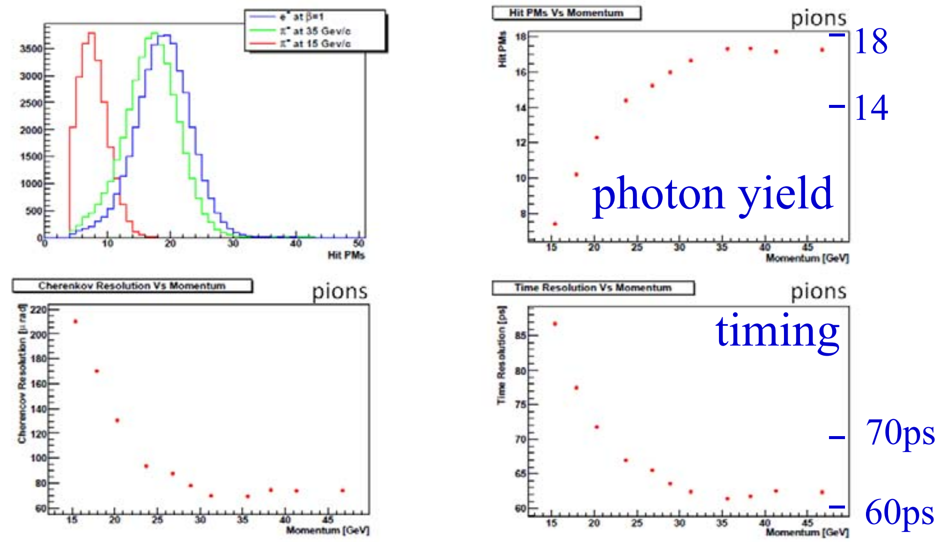
- Strong RD to validate the chosen approach with prototypes
- 2007 Test Beam: RICH proto 96 PMs (time resolution, n.of p.e.)
- 2009 Test Beam: RICH proto 414 PMs (3σ $\pi-\mu$ separation, DAQ,...)



9.10.2013 M.Lenti 19

NIM A 593 (2008) 314-318
NIM A 621 (2010) 205-211

RICH400: performances



9.10.2013 M.Lenti 20

- The NA62 RICH is a far demanding object
- Strong RD validated the project
- Installation schedule:
  - Nov 2013: RICH vessel delivery
  - Jun 2014: Mirrors Installation completed
  - Aug 2014: PM installation completed
  - Sep 2012: Gas filling completed
  - Oct 2014: RICH commissioning and first physics run of NA62

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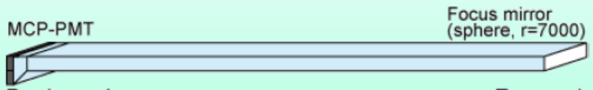
The RICH Detector of the NA62 Experiment at CERN, M. Piccini, Mon 10:30

BELLE II RICH SYSTEMS

Particle Identification Devices

Barrel PID: Time of Propagation Counter (TOP)



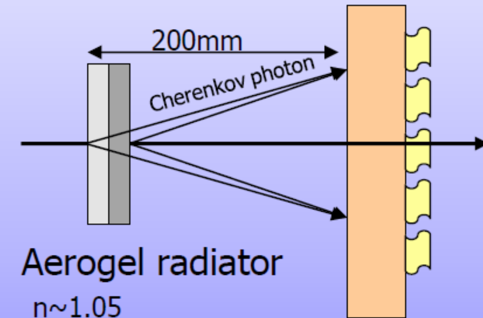
Quartz radiator

Focusing mirror

Small expansion block

Hamamatsu MCP-PMT (measure t, x and y)

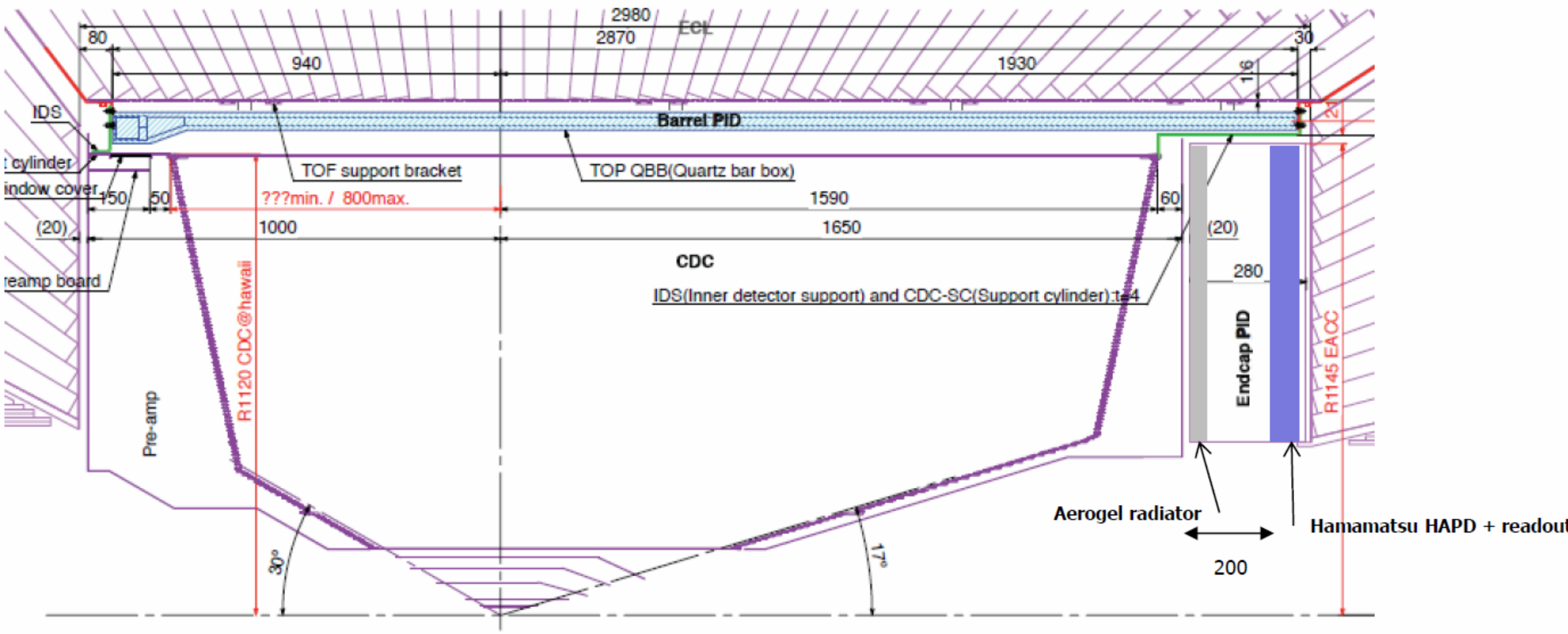
Endcap PID: Aerogel RICH (ARICH)



Aerogel radiator

n~1.05

Hamamatsu HAPD
+ new ASIC



P. Krizan, DIRC2013 Workshop

Peter Križan, Ljubljana

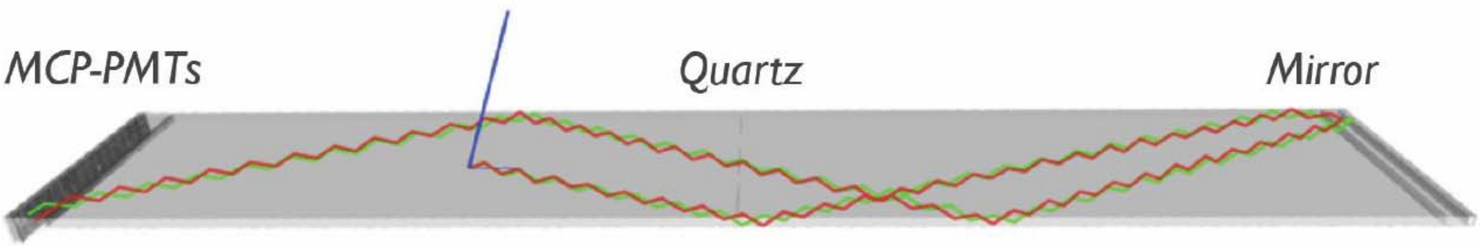
Aerogel RICH counter for the Belle II forward PID, S. Nishida, Mon 15:15

TOP counter for particle identification at Belle II experiment, K. Inami, Mon 10:55

Barrel PID: Time of propagation (TOP) counter

Cherenkov ring imaging with precise time measurement.

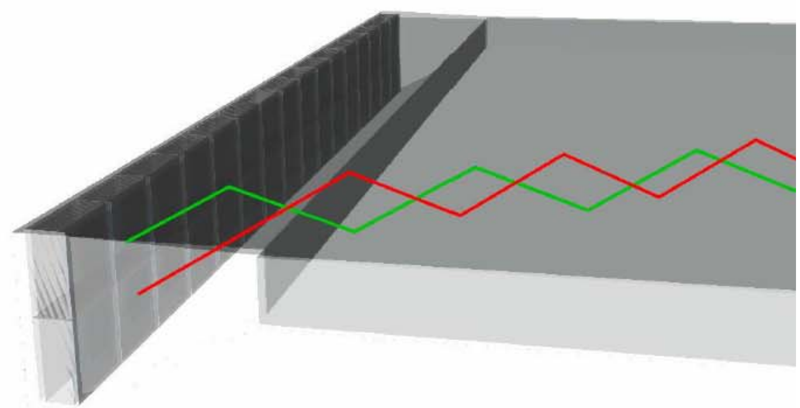
Device uses internal reflection of Cherenkov ring images from quartz like the BaBar DIRC



Example of Cherenkov-photon paths for 2 GeV/c $\pi^{\pm}$ and $K^{\pm}$.

Reconstruct Cherenkov angle from two hit coordinates and the time of propagation of the photon

- Quartz radiator (2cm)
- Photon detector (MCP-PMT)
  - Excellent time resolution ~40 ps
  - Single photon sensitivity in 1.5 T
- Fast read-out electronics



P. Krizan, DIRC2013 Workshop

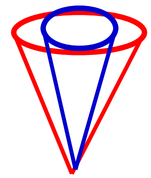
TOP counter for particle identification at Belle II experiment, K. Inami, Mon 10:55

Ring image of TOP counter

Ring image animation

※A ring image has high sensitivity to incident position and angles of particles.

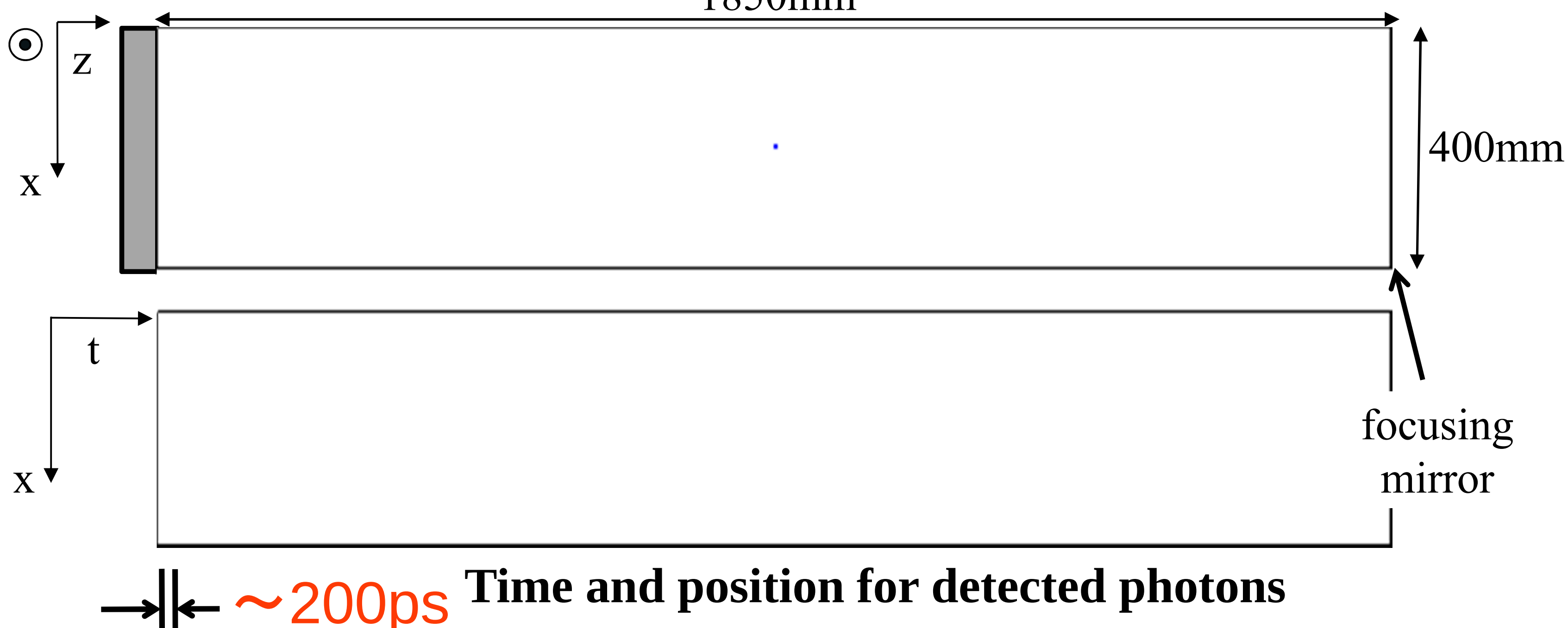
Top view



π/K

➡β are difference

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



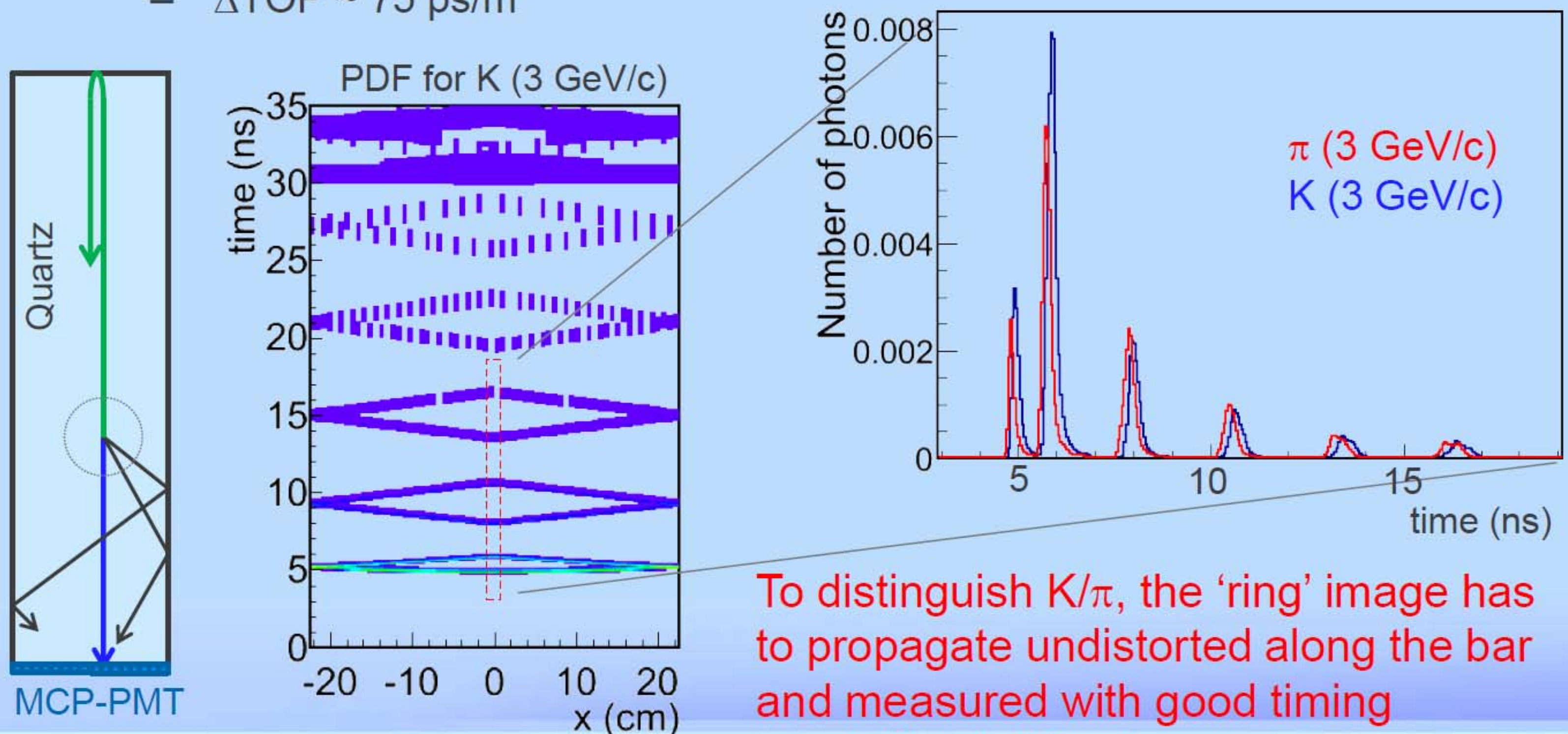
Time and position for detected photons

QFPU 2013 Y. Arita, *Belle II TOP counter*

TOP counter for particle identification at Belle II experiment, K. Inami, Mon 10:55

TOP counter

- Measure the hit timing of ~20 Cherenkov photons.
- Hit timing difference between 3 GeV/c K and π
  - ΔTOF ~ 50 ps/m
  - ΔTOP ~ 75 ps/m



To distinguish K/π, the 'ring' image has to propagate undistorted along the bar and measured with good timing resolution (~50 ps).

K. Matsuoka, VCI2013

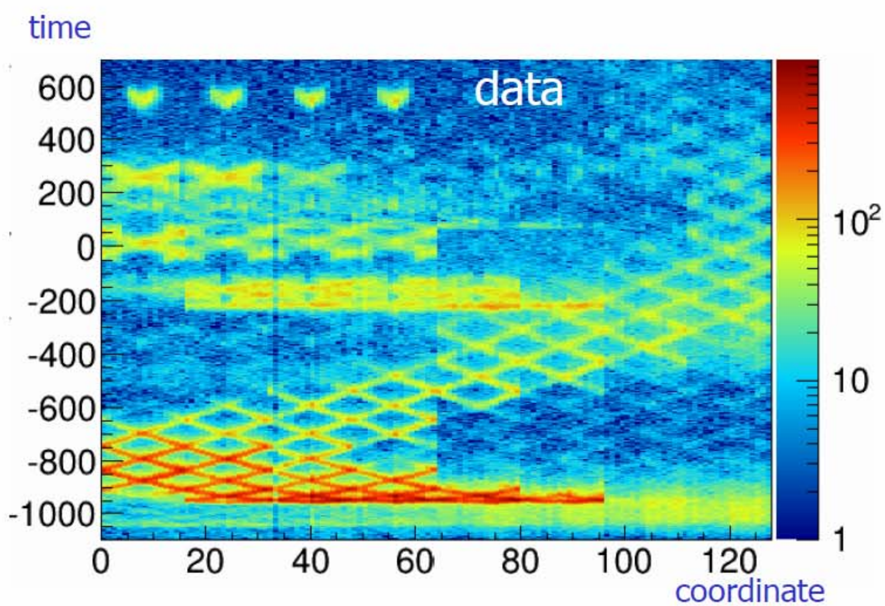
TOP counter for particle identification at Belle II experiment, K. Inami, Mon 10:55

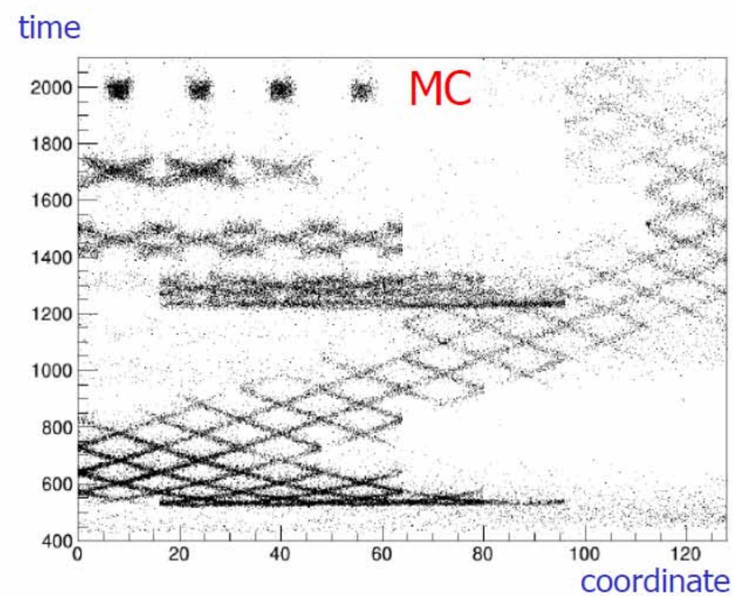
TOP prototype at LEPS SPRING8 in 2013

TOP image

Pattern in the coordinate-time space ('ring') – different for kaons and pions.

Recorded by the CFD-based read-out.





Excellent agreement between beam test data and MC simulated patterns.

P. Krizan, DIRC2013 Workshop

→ Y. Horii, talk at EPS HEP 2013, M. Barret, talk at DPF2013

TOP counter for particle identification at Belle II experiment, K. Inami, Mon 10:55

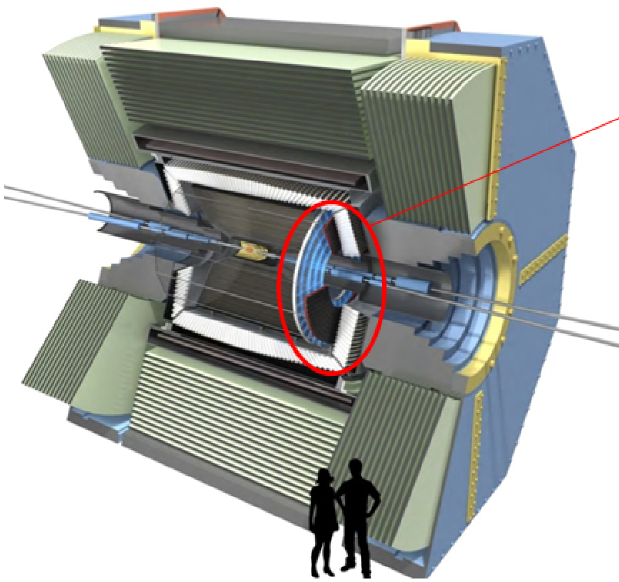
Summary

- A novel ring imaging Cherenkov detector, TOP counter, has been developed for the K/π PID in Belle II.
  - Important to propagate the ring image as it is.
    - Confirmed that the quartz bar can be polished and glued to meet the stringent requirements.
  - Need good timing resolution
    - Detect single photon with ~40 ps resolution by MCP-PMT.
- Prototype TOP counter was tested at LEPS/SPring-8.
  - The QE dependence on the photon incident angle and polarization is specifically important.
  - The ring image was obtained as expected.
- Mass production of the TOP counter is ongoing.
  - To be installed in March 2015.

K. Matsuoka, VCI2013

TOP counter for particle identification at Belle II experiment, K. Inami, Mon 10:55

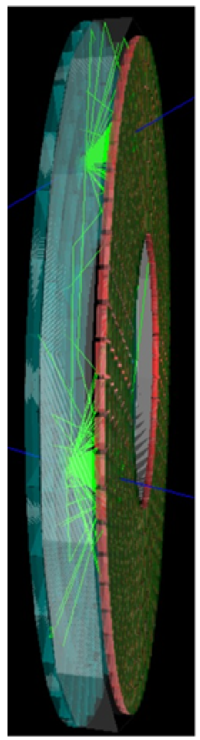
Belle II Aerogel RICH



- Belle II Experiment : Physics run in 2016.
- PID plays an important role.

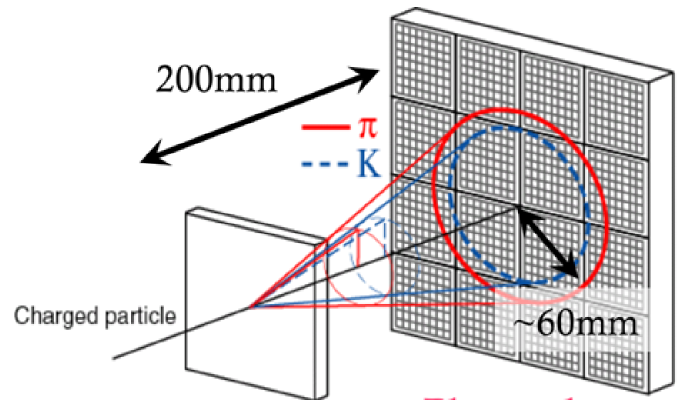
Target: K/π Separation up to 4 GeV.

$$\theta_C(\pi) - \theta_C(K) \simeq 23 \text{ mrad}$$

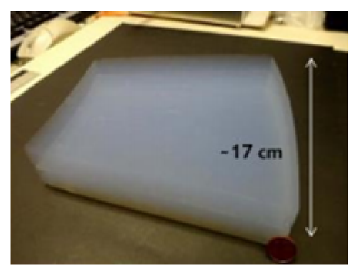


Replace threshold-type Aerogel Cherenkov Counter to Aerogel RICH

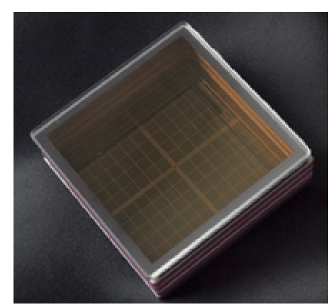
Concept of Aerogel RICH



Aerogel



HAPD



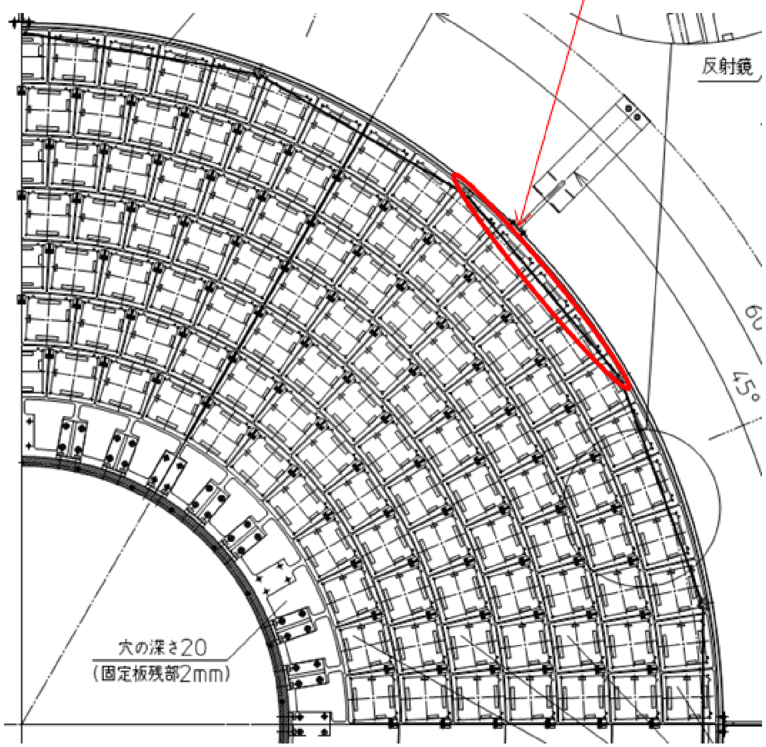
Aerogel RICH counter for the Belle II forward PID, S. Nishida, Mon 15:15

Belle II Aerogel RICH

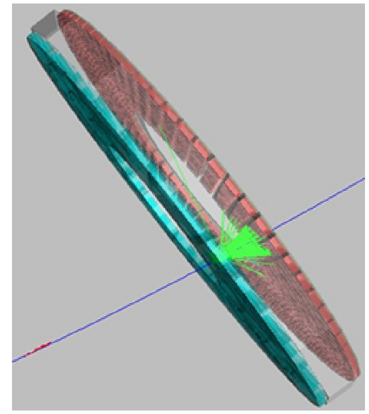
Aerogel RICH detector consists of

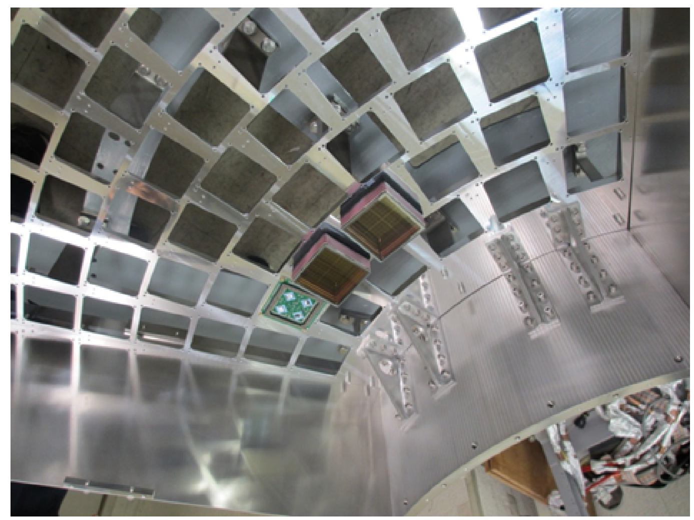
- 420 HAPD
- 248 Aerogel Tiles
  $\langle n \rangle = 1.05$

Mirror



7 rings of HAPD





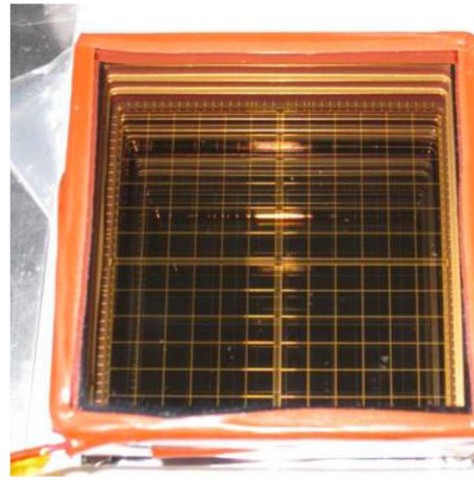
Mock-up

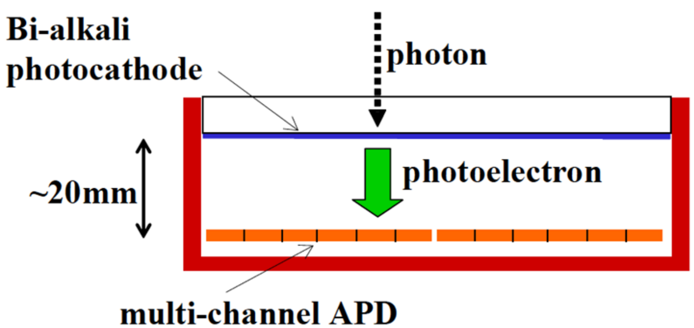
Aerogel RICH counter for the Belle II forward PID, S. Nishida, Mon 15:15

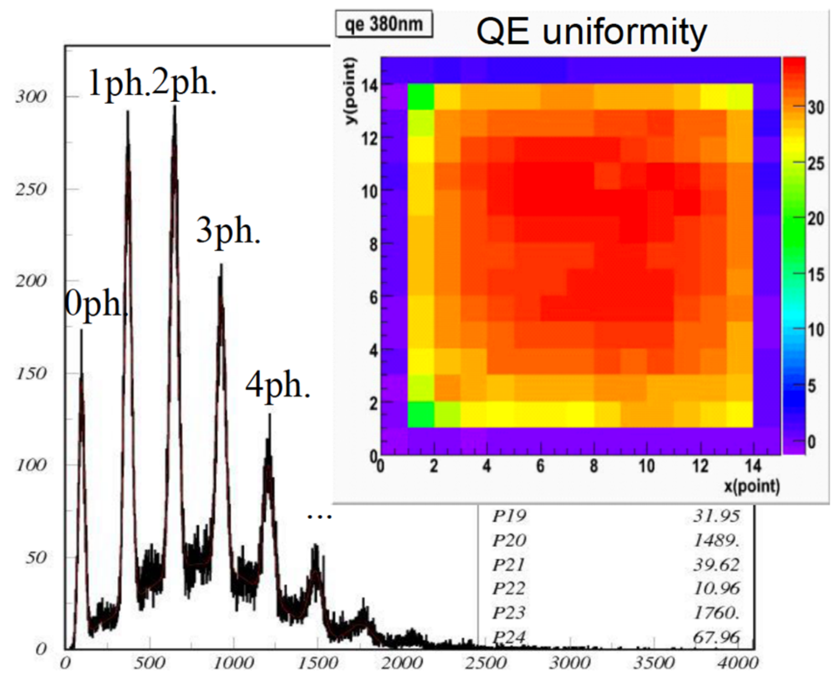
ARICH photon detector: HAPD

Hybrid avalanche photo-detector developed in cooperation with Hamamatsu (proximity focusing configuration):

- 144 (12x12) channels (~5x5 mm^2)
- size ~ 73mm x 73mm (65% active area)
 total gain > 4.5x10^4
(bombardment >1500, avalanche >40)
- typical peak QE ~ 28% (>24%)
- works in magnetic field
(~perpendicular to the entrance window)





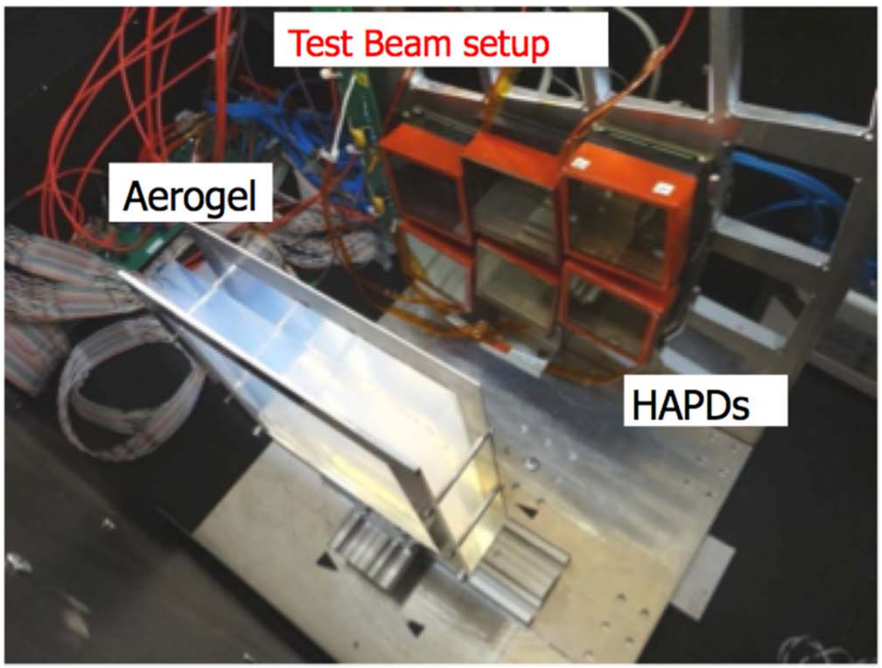


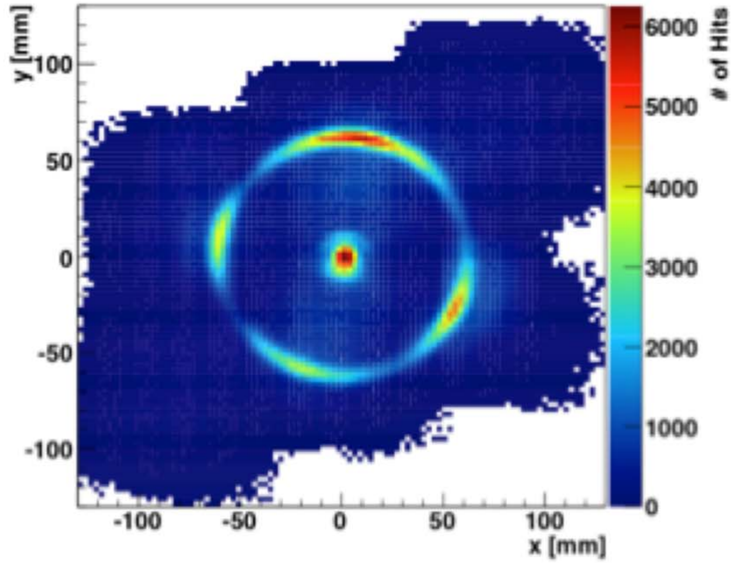
Good photon counting.

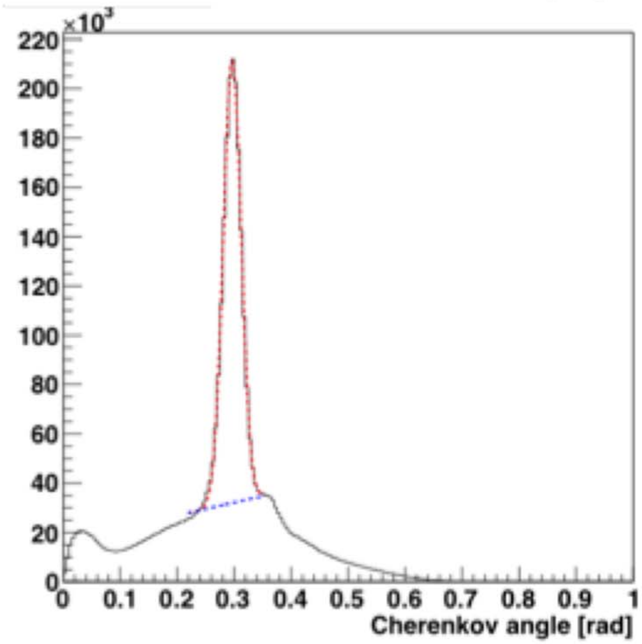
144-channel HAPD for Aerogel RICH at Belle II, S. Korpar, Tue 18:05

Prototype performance

- tests with 120 GeV/c pions @CERN and 5 GeV/c electrons @ DESY
- detected number of photons/ring: ~ 10
- single ph. angle resolution: ~ 15 mrad



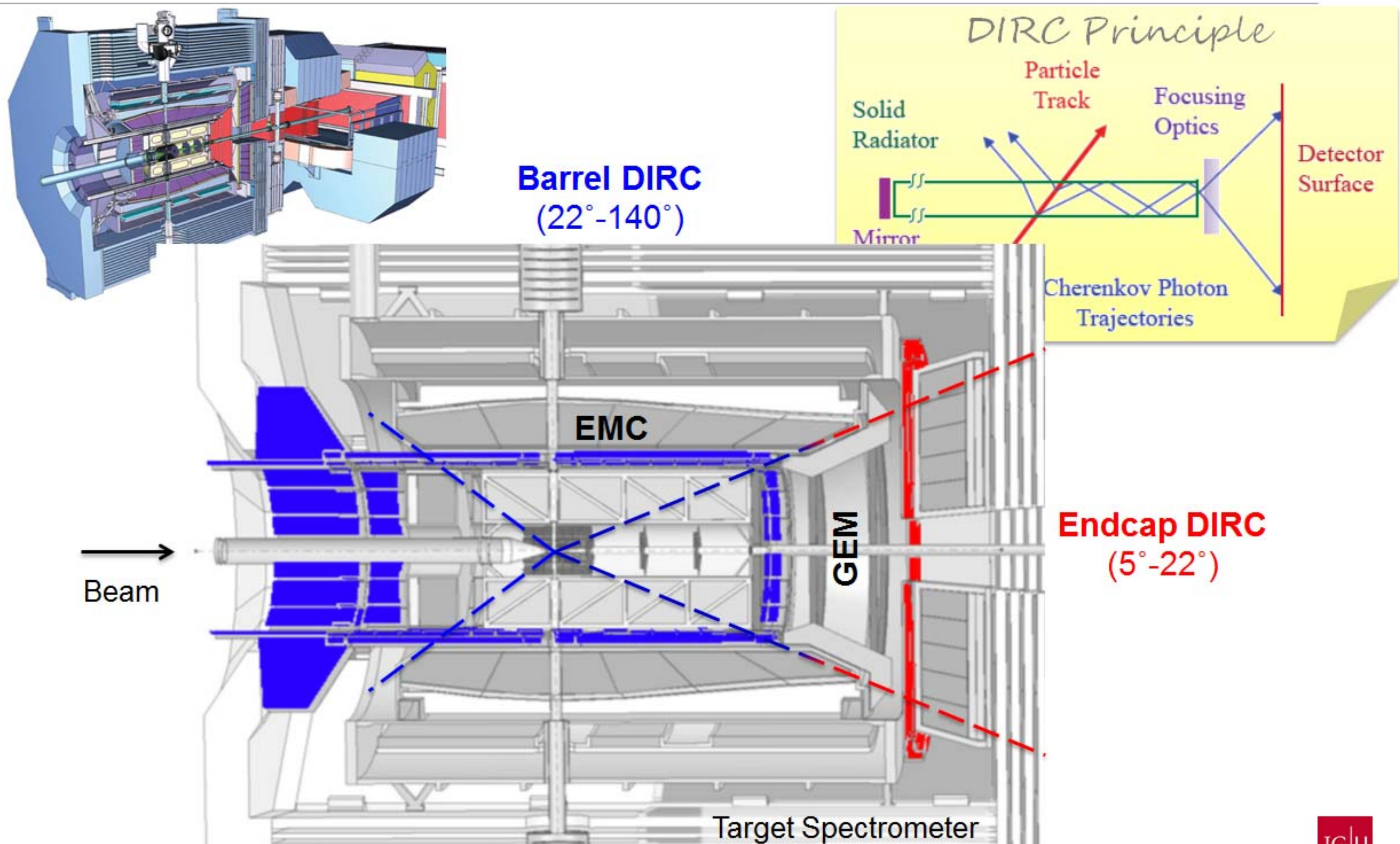




Better than 5 σ π/K separation @ 3.5 GeV/c

Aerogel RICH counter for the Belle II forward PID, S. Nishida, Mon 15:15

PANDA DIRC Detectors



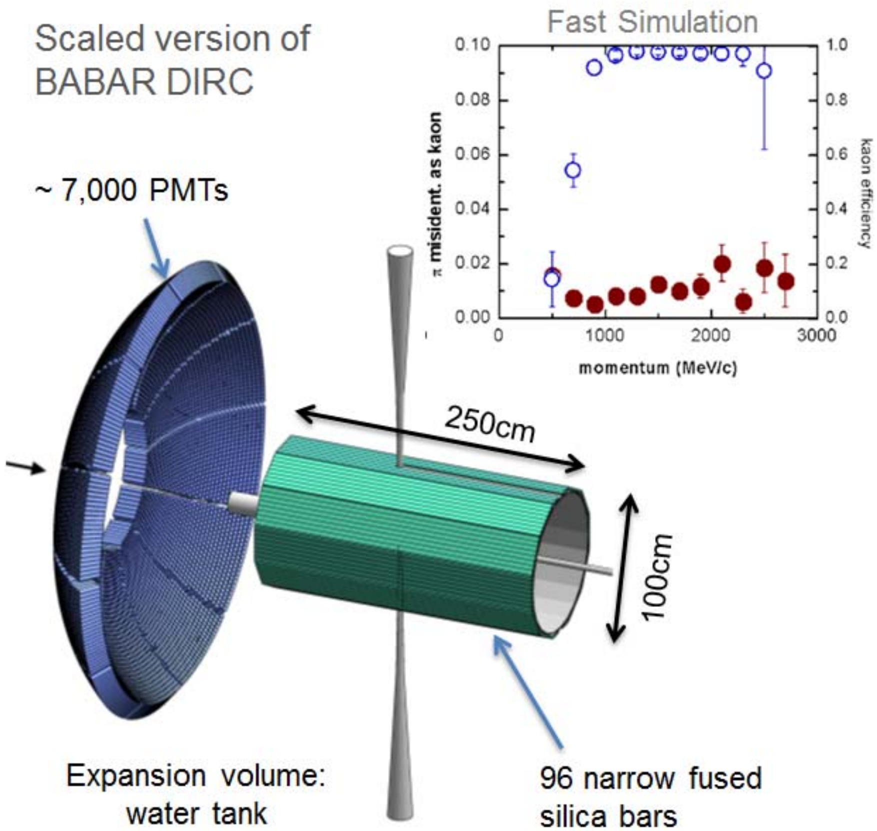
The PANDA Barrel DIRC | M. Hoek | RICH 2013 | 02-06 Dec 2013 | Hayama, Kanagawa, Japan

The PANDA Barrel DIRC Detector, M. Hoek, Mon 11:20

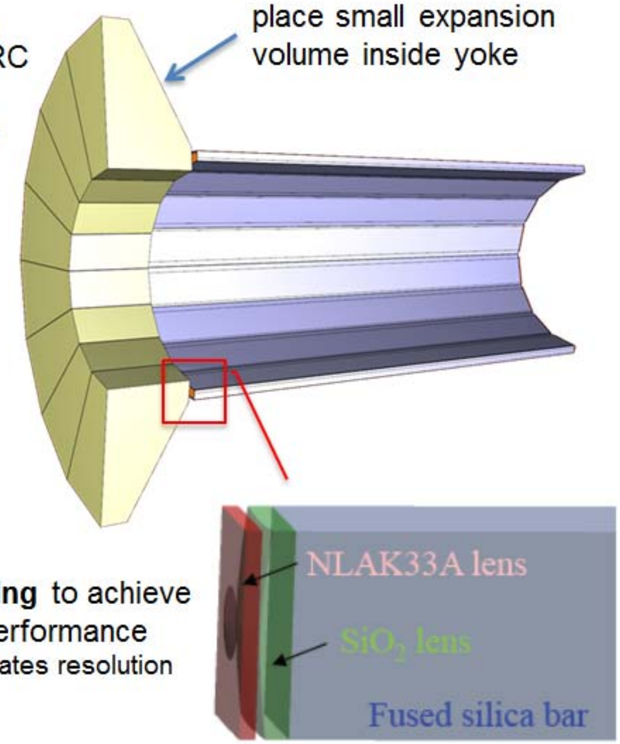
Evolution of Barrel DIRC Design

Initial Design → **Next Iteration**

Scaled version of BABAR DIRC



Benefit from
- SLAC fDIRC R&D
- new MCP-PMT advances



requires **focusing** to achieve required PID performance
- bar size dominates resolution

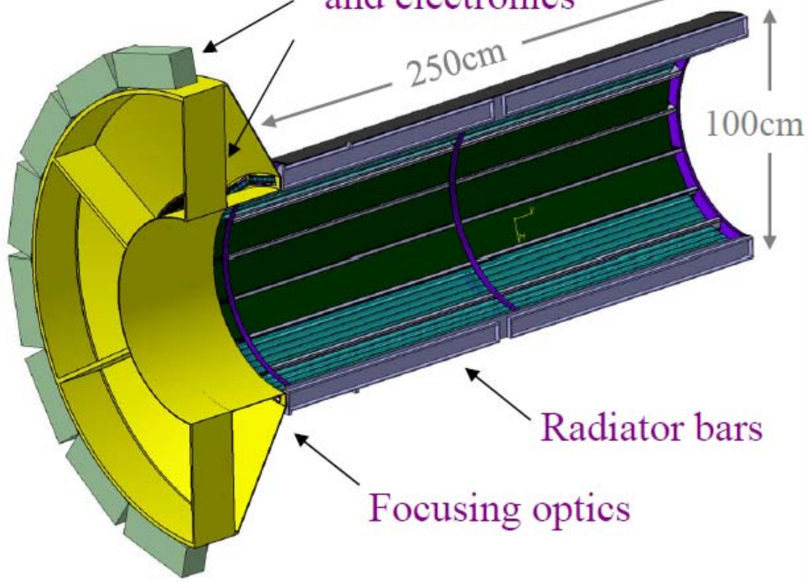
The PANDA Barrel DIRC | M. Hoek | RICH 2013 | 02-06 Dec 2013 | Hayama, Kanagawa, Japan

The PANDA Barrel DIRC Detector, M. Hoek, Mon 11:20

PANDA BARREL DIRC

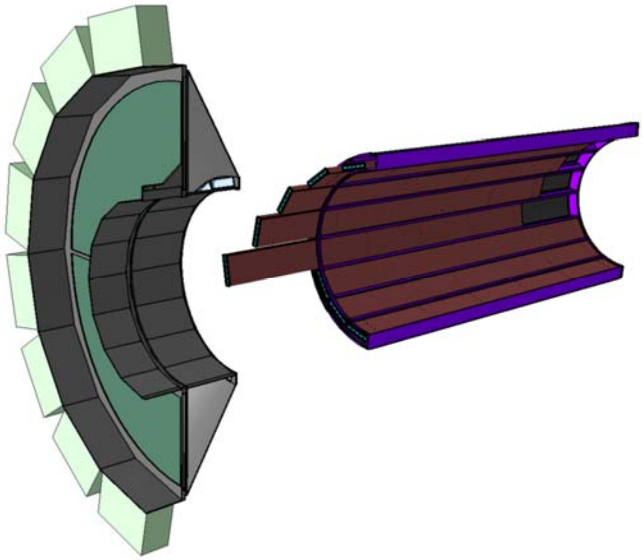
Baseline design: based on BABAR DIRC with key improvements

- Barrel radius ~48 cm; expansion volume depth: 30 cm.
- 80 narrow radiator bars, synthetic fused silica
  17mm (T) × 32mm (W) × 2400mm (L).
- Focusing optics: lens system.
- Compact photon detector:
  30 cm oil-filled expansion volume
  ~15,000 channels of MCP-PMTs.
- Fast photon detection:
  fast TDC plus ADC (or ToT) electronics.
- Expected performance:
  Single photon Cherenkov angle resolution: 8-10 mrad.
  Number of photoelectrons for $\beta \approx 1$ track: at least 20.



The PANDA Barrel DIRC Detector, M. Hoek, Mon 11:20

PANDA BARREL DIRC

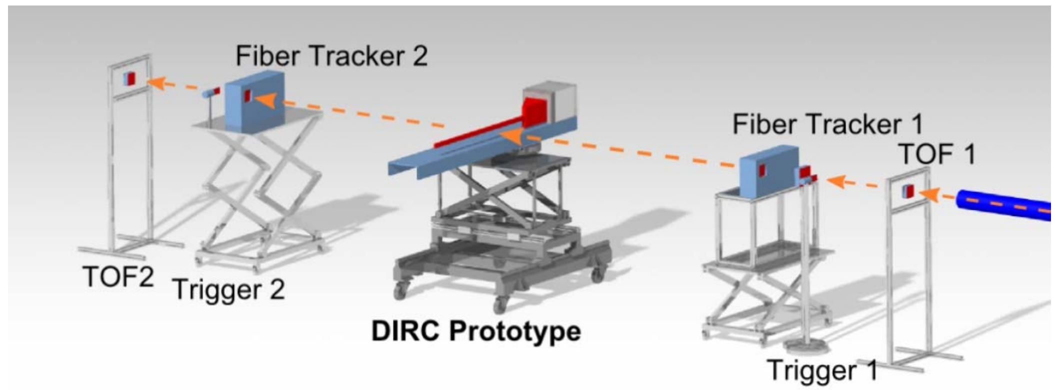


Modular mechanical design.

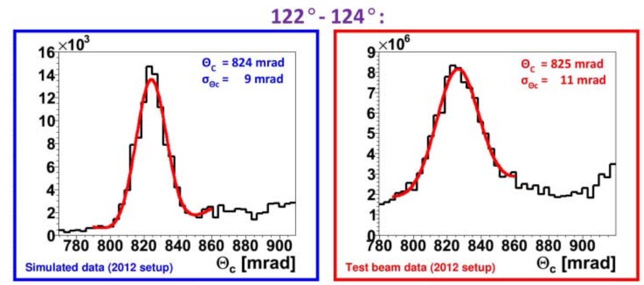
Bar boxes slide into slots, can be installed/removed as required (similar to BABAR DIRC).

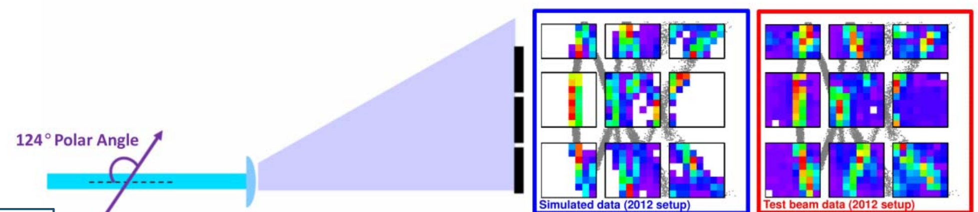
Expansion volume detaches for access to bar boxes and tracking detectors.

Prototype in CERN test beam in 2012.



- **Fine angular scan study**
  2° range with 0.25° steps to avoid pixelization effect.
- **Expected Θ_c = 824 mrad**
  $\sigma_{\Theta c} \approx$ 8 mrad
- Θ_c consistent with expectations.
- Differences in σ comes from beam divergence.





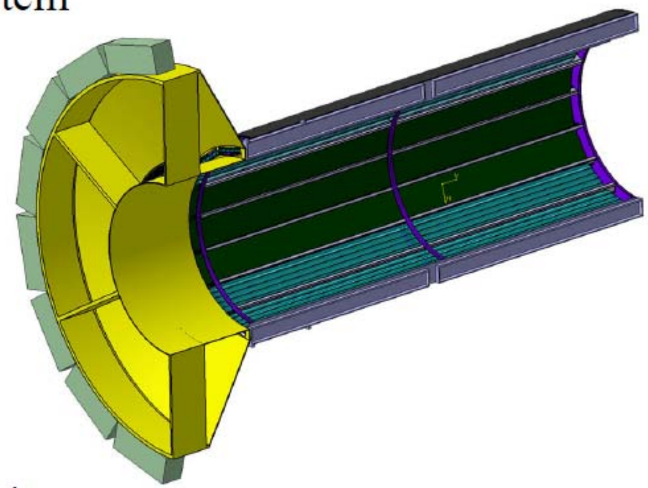
Prototyping the PANDA Barrel DIRC, C. Schwarz, Poster

The PANDA Barrel DIRC Detector, M. Hoek, Mon 11:20

PANDA BARREL DIRC SUMMARY

The PANDA Barrel DIRC design evolved from scaled-down BABAR DIRC to a compact fast focusing DIRC.

Baseline design with narrow bars and high-n lens system appears to meet PANDA PID goals.



Recent lifetime advances make MCP-PMTs an excellent sensor choice.

Ongoing prototype program has identified several potential vendors for radiator fabrication.

Decision on wide radiator plates and solid fused silica prisms as Cherenkov cameras due 2014.

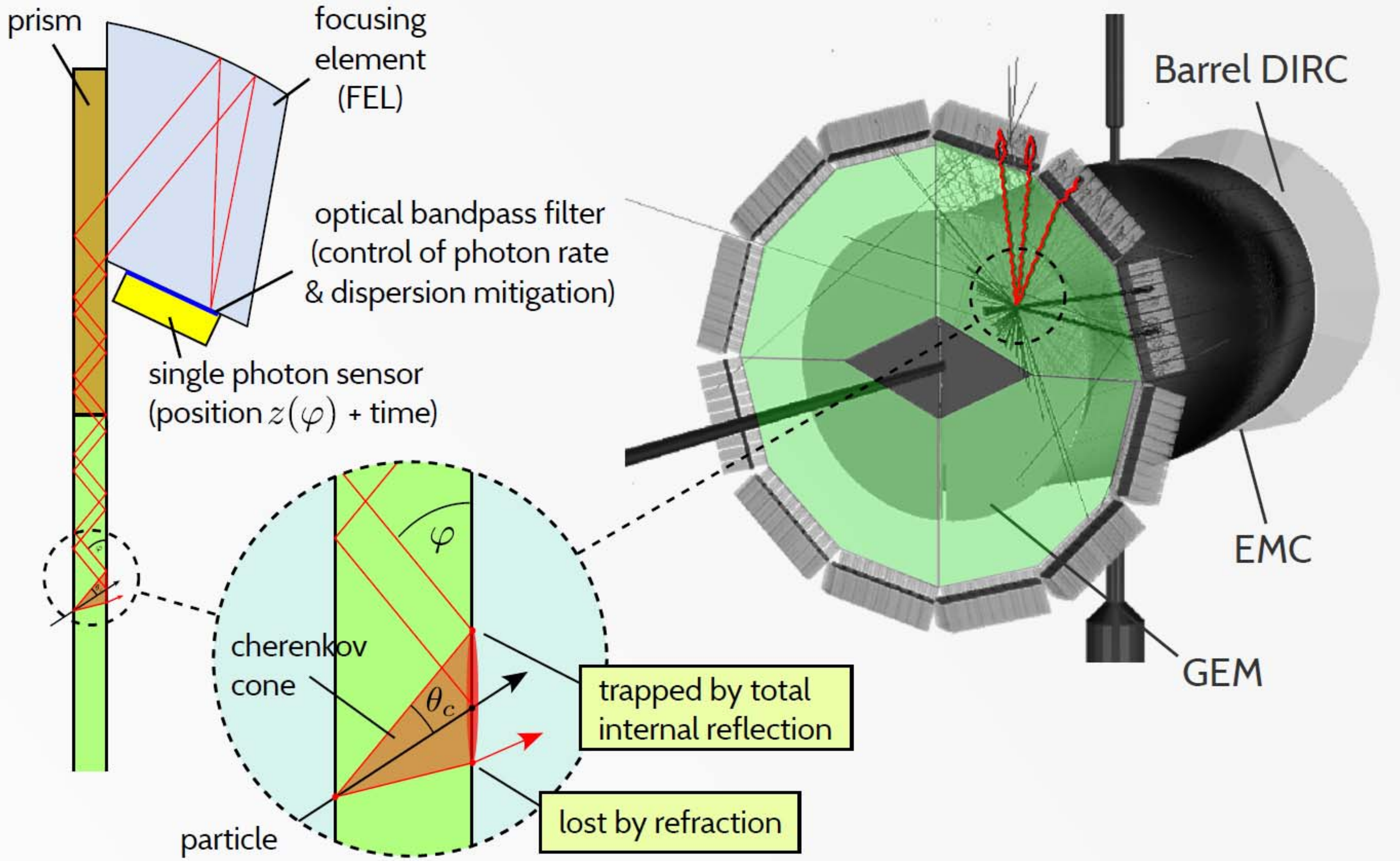
Progression of increasingly complex system prototypes to validate design choices and PID performance using particle beams.

Leading edge technologies, benefit from delayed technology decision
→ system still in R&D phase, Technical Design Report planned for late 2014.

J. Schwiening, DIRC2013, Schloss Rauischholzhausen, September 2013 26

The PANDA Barrel DIRC Detector, M. Hoek, Mon 11:20

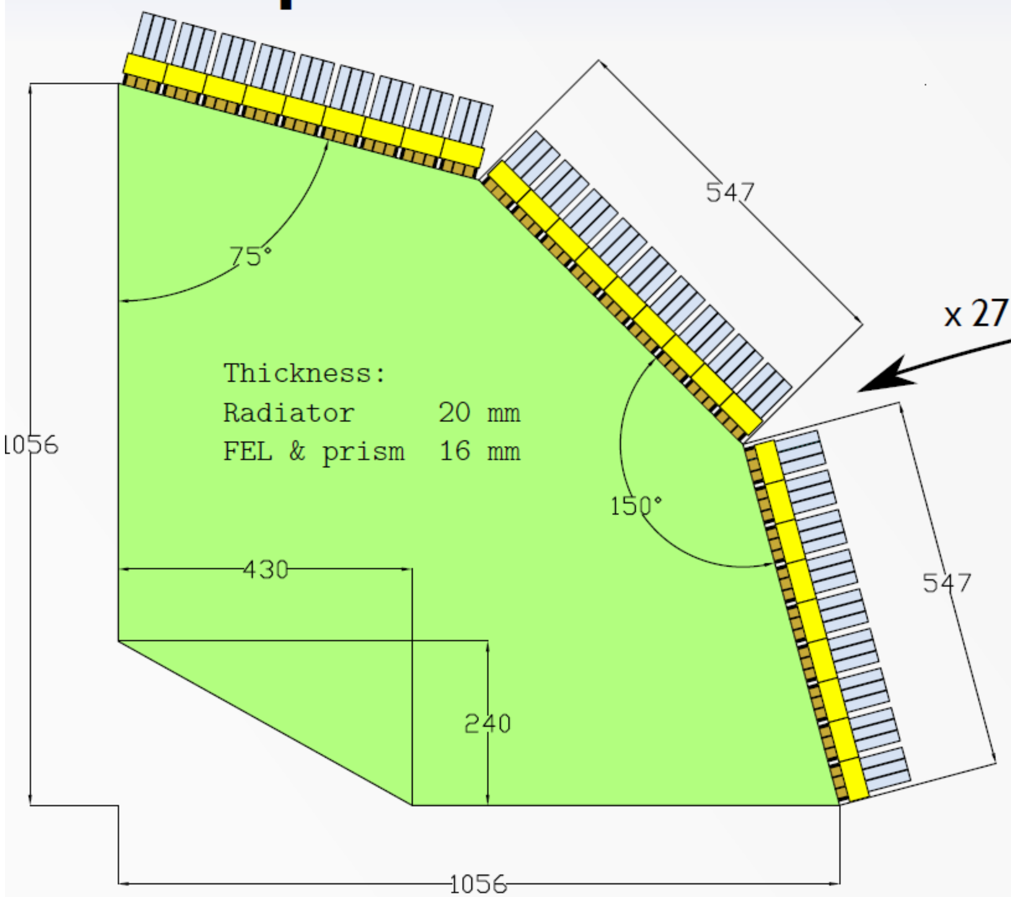
Working principle

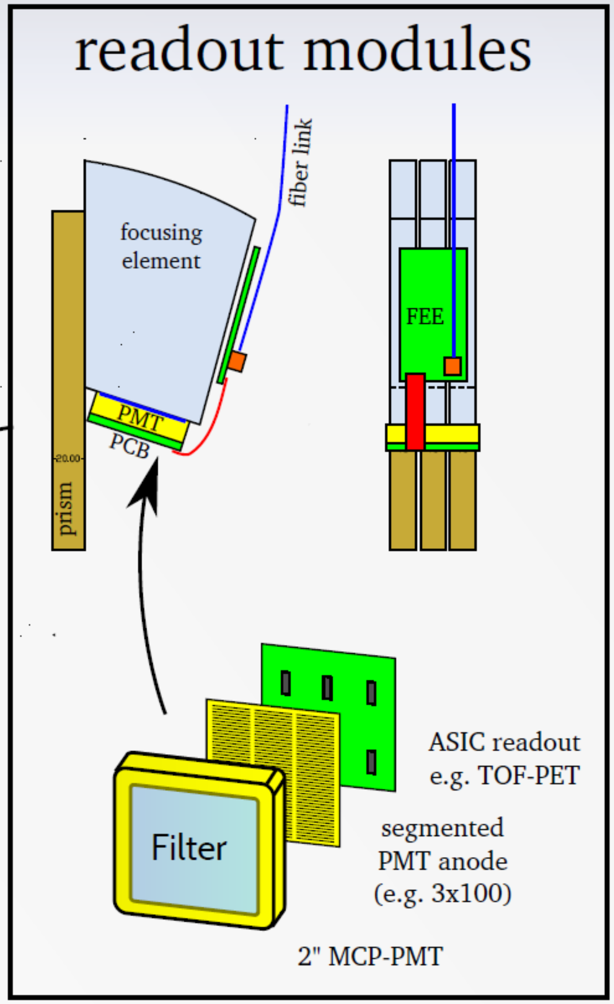


Development of an Endcap DIRC for PANDA, O. Merle, Mon 17:00

RICH 2013
December 2nd - 6th 2013

Setup





Filter band: 385 nm - 460 nm => $N_{ph} \approx 16$ →

Integrated anode charge: Q ≈ 5.6 C/cm^2

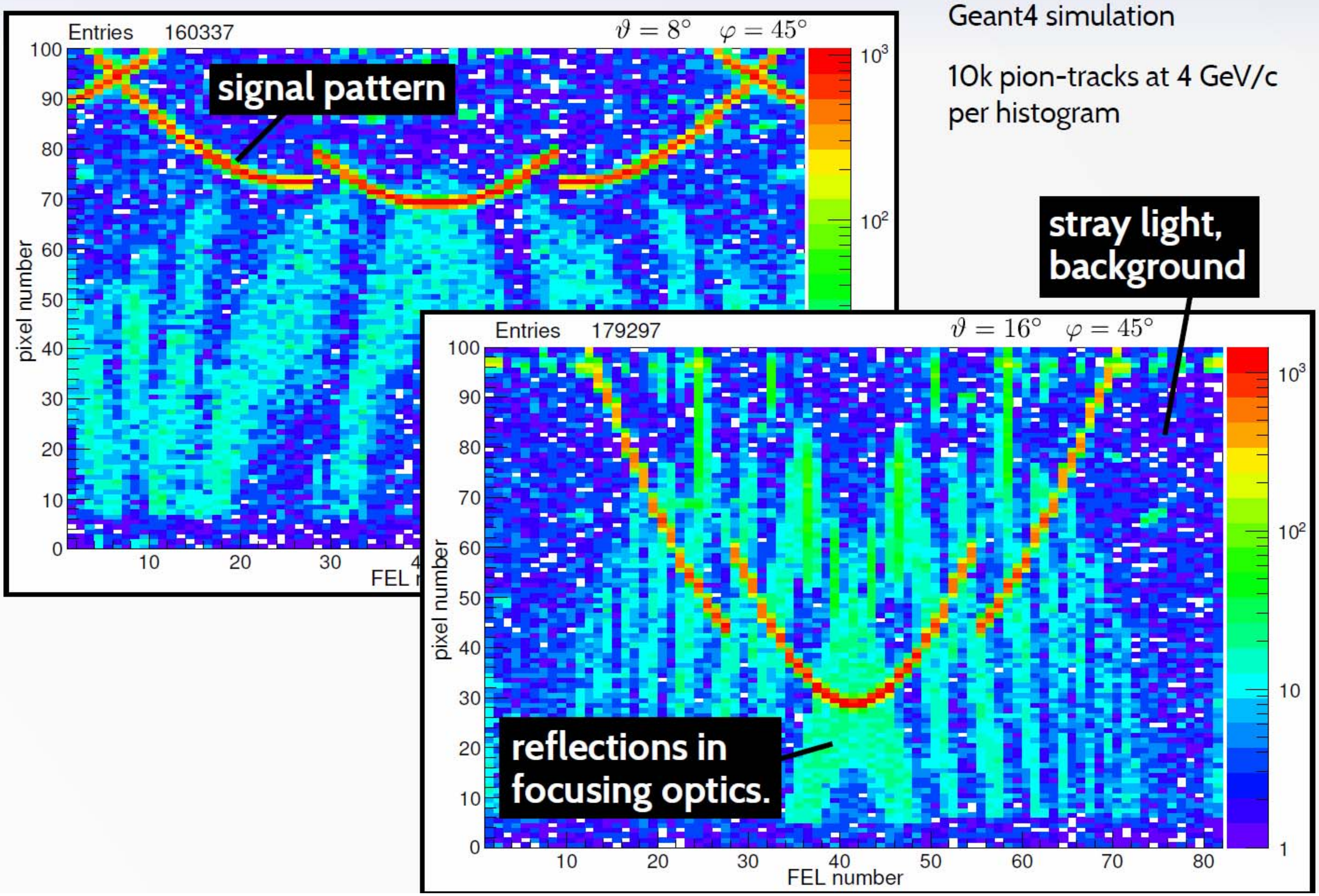
Avg. rate: 225 kHz/cm^2 (19 kHz/ch)

Peak data rate per module: ~0.6 GBit/s

ASIC candidate: TOF-PET (64 ch/die, 100 kHz/ch, ~6 mW/ch, 50 ps time-bin, 40 ns dead time)

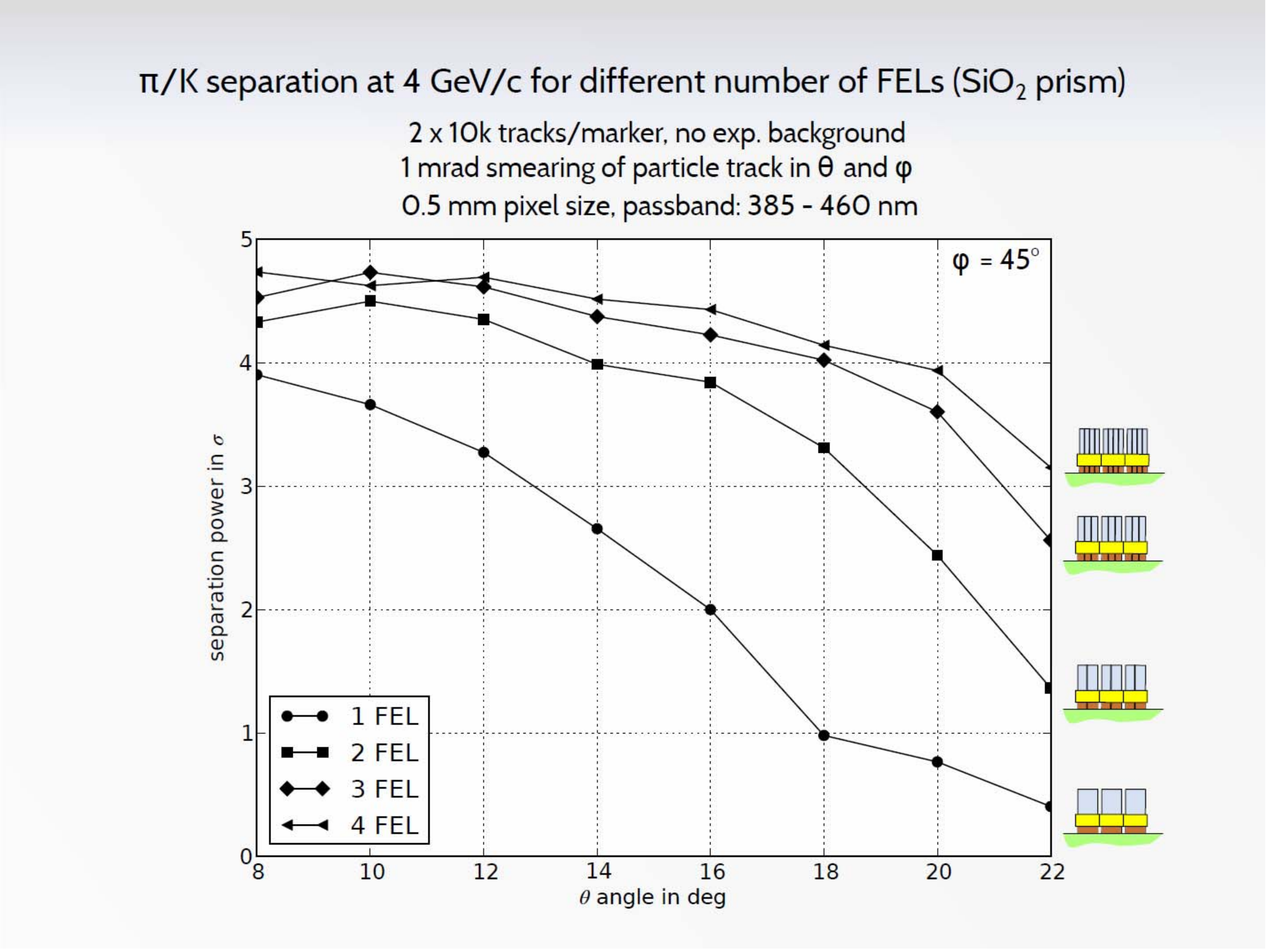
Development of an Endcap DIRC for PANDA, O. Merle, Mon 17:00

Accumulated hit-patterns

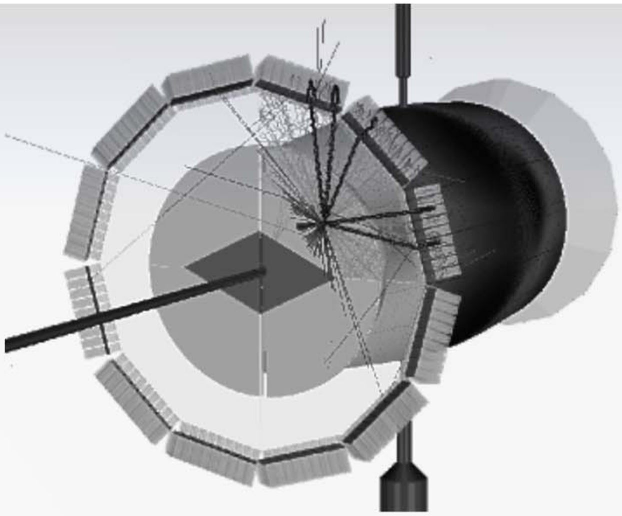


Geant4 simulation

10k pion-tracks at 4 GeV/c per histogram


π/K separation at 4 GeV/c for different number of FELs (SiO2 prism)
2 x 10k tracks/marker, no exp. background
1 mrad smearing of particle track in θ and φ
0.5 mm pixel size, passband: 385 - 460 nm
φ = 45°
separation power in σ
θ angle in deg
1 FEL
2 FEL
3 FEL
4 FEL
0
1
2
3
4
5
8
10
12
14
16
18
20
22

Summary



System design has been revised:

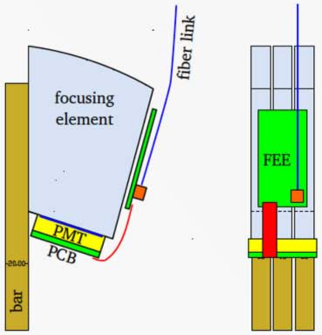
- less demanding optics
- fullfills the PANDA space requirements
- realistic MCP-PMT lifetime and rate requirements
- only minor ASIC modifications needed (analog part)

Basic principle of operation has been demonstrated using a "low-budget" prototype.

Next step: prototype of a high resolution readout module:

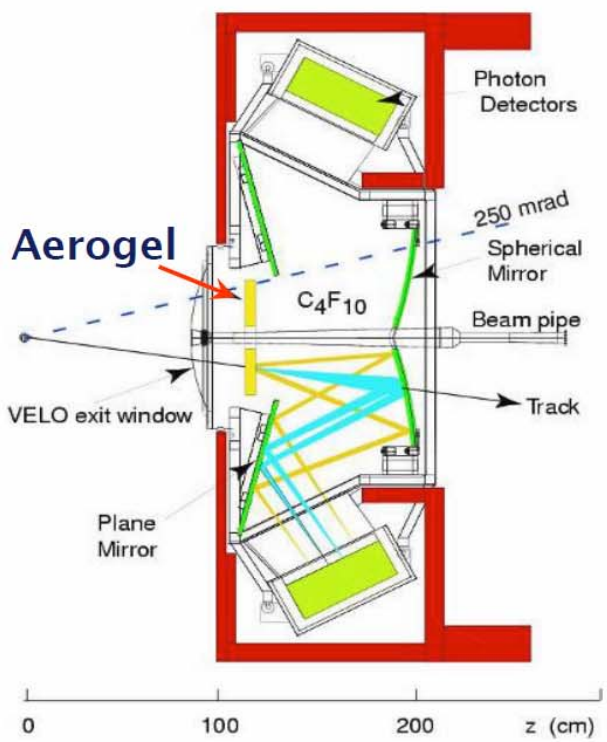
- high precision fused-silica focusing optics
- + MCP-PMT with custom anode + ASIC readout

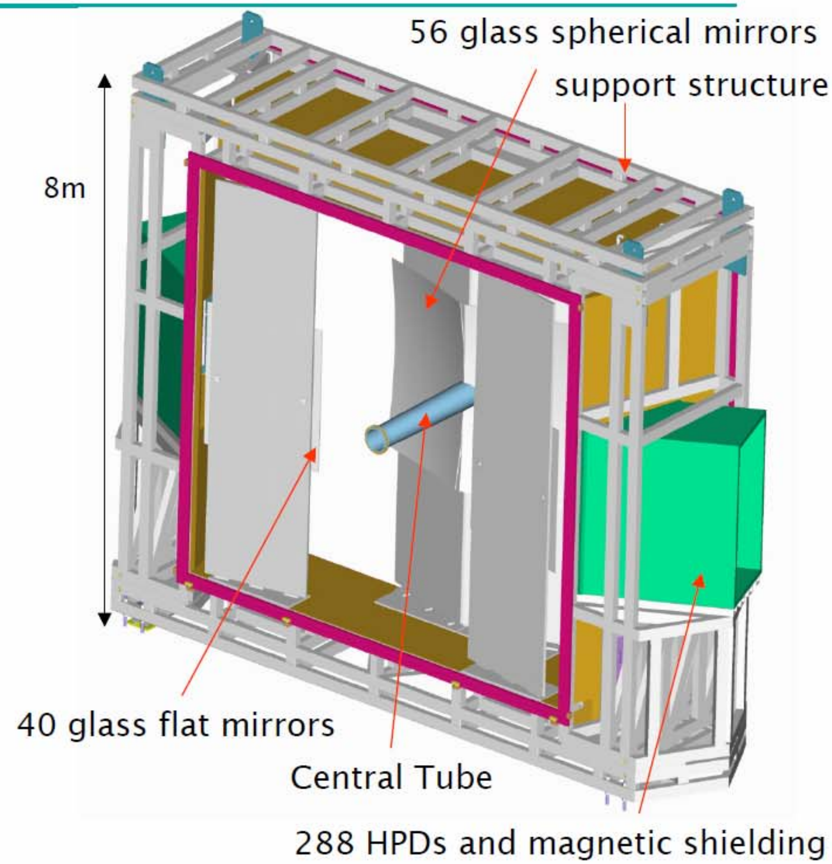
to verify that the desired performance can be reached.



Development of an Endcap DIRC for PANDA, O. Merle, Mon 17:00

RICH Detectors





RICH1:

5 cm aerogel n = 1.03, 1-10 GeV

4 m^3 C_4F_{10} n = 1.0014, up to 60 GeV

RICH2:

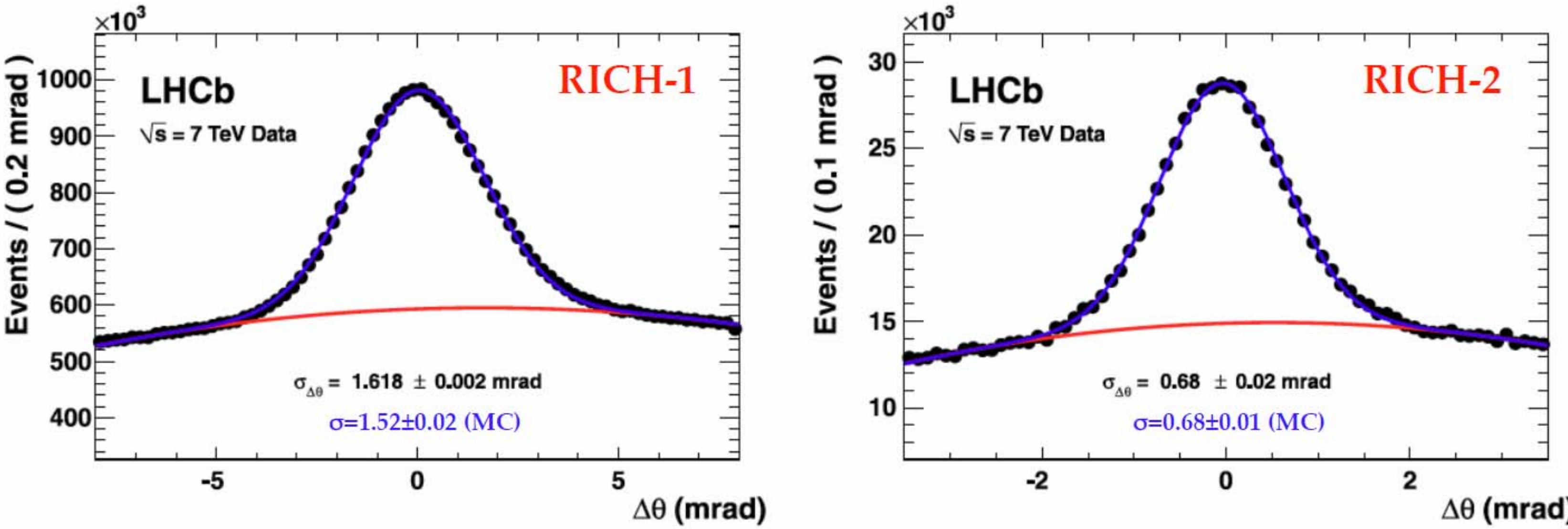
100 m^3 CF_4 n = 1.0005, up to ~100 GeV

2013 IEEE-NSS Massimiliano Fiorini (Ferrara) 4

The LHCb RICH system; detector description and operation, A. Papanestis, Mon 14:00

Cherenkov angle resolution

- Single photon resolution
  - Distributions for saturated (β=1) tracks



- Particle identification is achieved using an overall event log-likelihood algorithm
  - All tracks in both RICH are considered simultaneously

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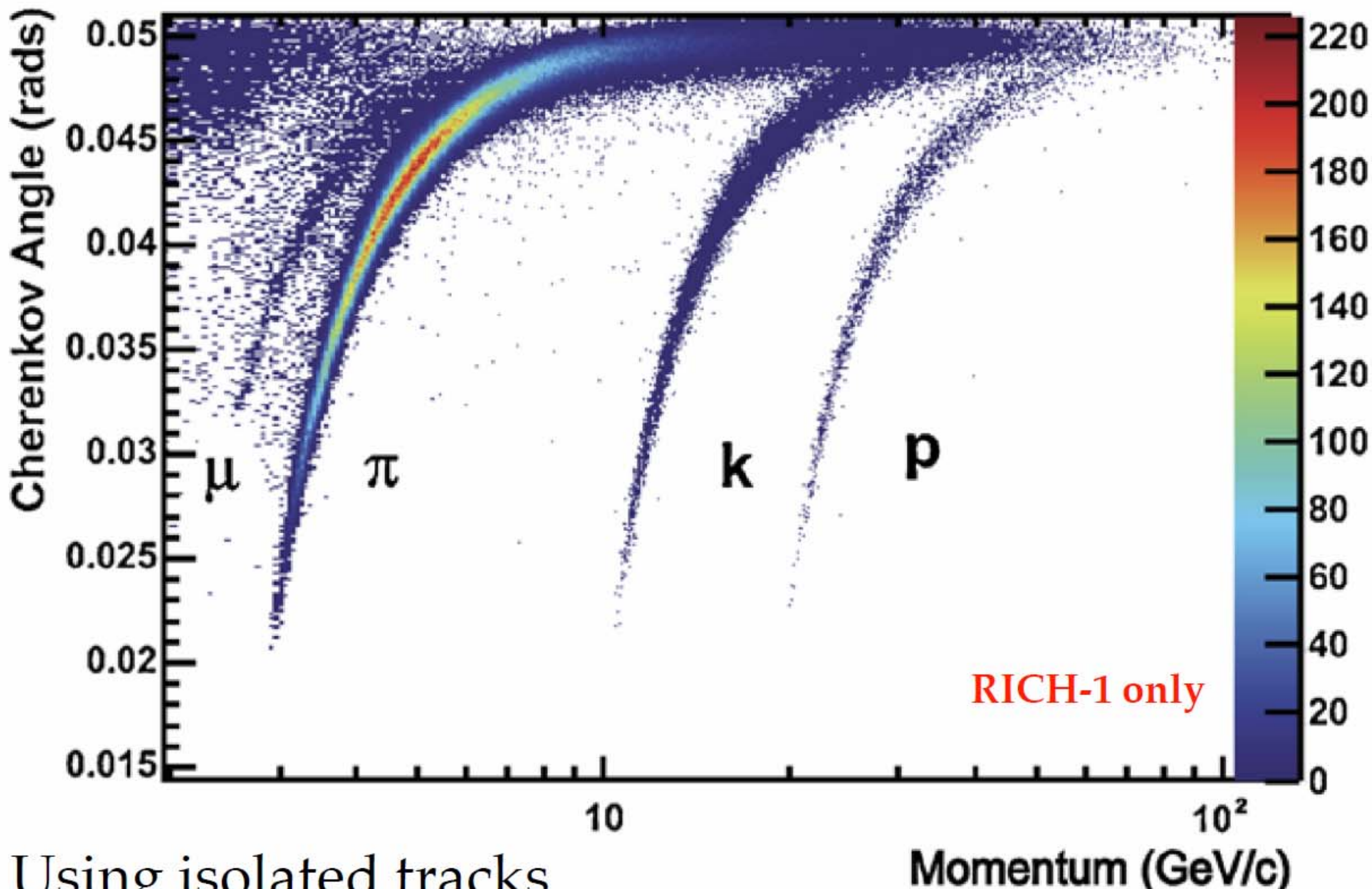
The LHCb RICH system; detector description and operation, A. Papanestis, Mon 14:00

θ_C versus Momentum



- Using isolated tracks

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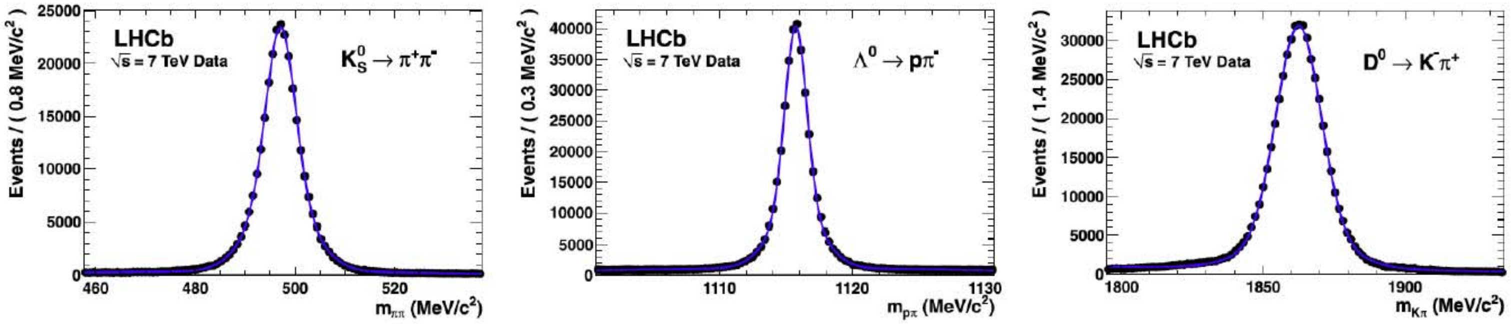
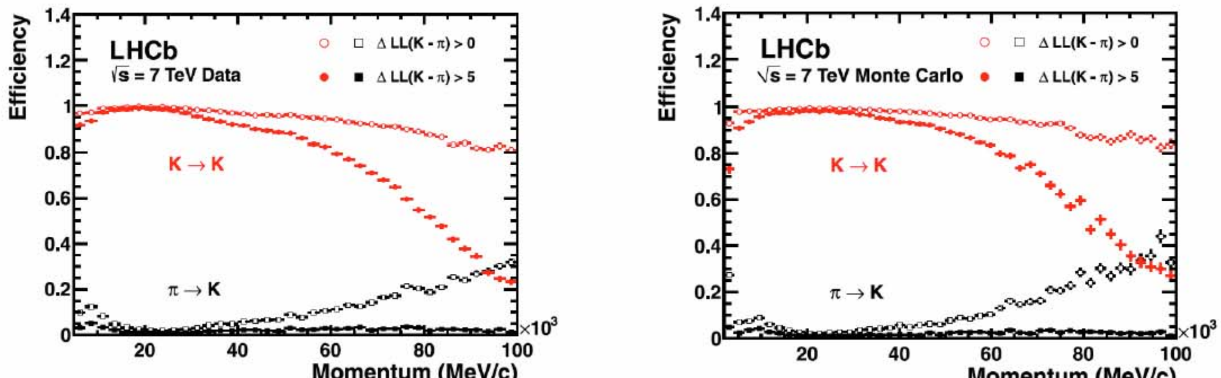
The LHCb RICH system; detector description and operation, A. Papanestis, Mon 14:00

PID Performance (1)



- PID performance evaluated from data
  - Genuine $\pi / K / p$ samples identified from kinematics only



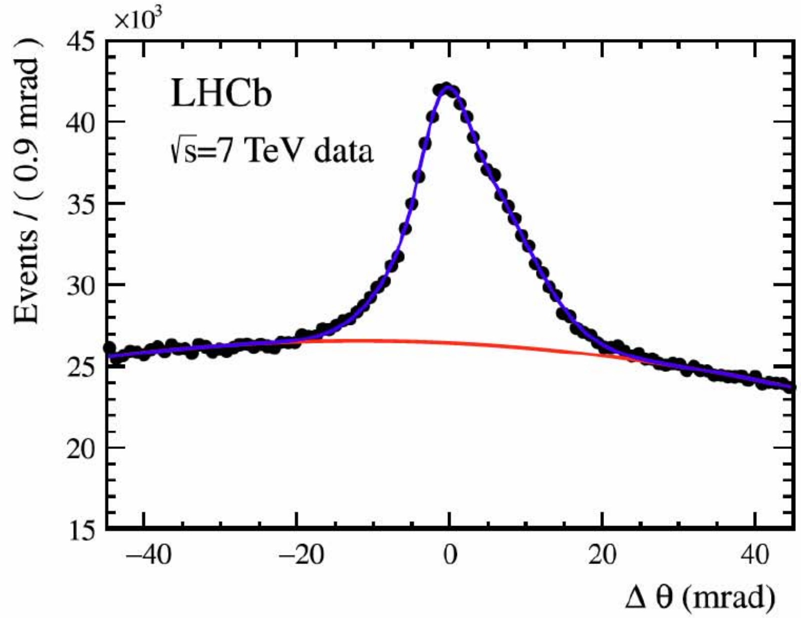
2013 IEEE-NSS Massimiliano Fi

Excellent PID performance, exceeds design specifications

The LHCb RICH system; detector description and operation, A. Papanestis, Mon 14:00

Aerogel resolution

- Single photoelectron resolution for aerogel radiatior
- Measured using good quality tracks with momentum >10 GeV / c
- Peak not symmetric
- σ~5.6 mrad (from the FWHM)
  - 1.8 worse than MC



Light yield (N_{pe}) about 65% of expectation.

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Partly due to aerogel absorbing some C_4F_{10}

The LHCb RICH system; detector description and operation, A. Papanestis, Mon 14:00

Conclusions

- The LHCb RICH detectors have been operated with high efficiency since the end of 2009 in a high track multiplicity environment
- Particle identification performance has been evaluated with data and exceeds design specifications
  - Most LHCb analyses are using RICH PID information, allowing precise measurements of *b* and *c* quark decays
- LHCb proposed an important upgrade (after 2018) to cope with 2×10^{33} $cm^{-2}s^{-1}$ luminosity
  - New photo-detectors and electronics for full detector read-out at 40 MHz
  - Modified RICH-1 optics

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The LHCb RICH system; detector description and operation, A. Papanestis, Mon 14:00

LHCb Upgrade

- Current LHC schedule:

end 2009 – 2012 √s=7 TeV until 2011, then 8 TeV ~3 fb^{-1}	2013 – 2014 LS1	2015 – 2017 √s=13 TeV, 25 ns target ~5 fb^{-1}	2018 – 2019 LS2 18 months

- Luminosity @LHCb reached ~4×10^{32} $cm^{-2}s^{-1}$ ($\mu = 1.6$)
  - ×2 higher than design value ($\mu = 0.4$)
- Plan for an LHCb Upgrade after LS2 → fully exploit LHC flavour physics potential (collect 50 fb^{-1} in 10 years)
  - Increase luminosity up to 2×10^{33} $cm^{-2}s^{-1}$
  - Upgrade the detector
    - Overcome current limitation of ~1 MHz read-out rate → substantial change in LHCb trigger and read-out architecture to read the full detector at 40 MHz

Letter of Intent (2011)
Framework TDR (2012)

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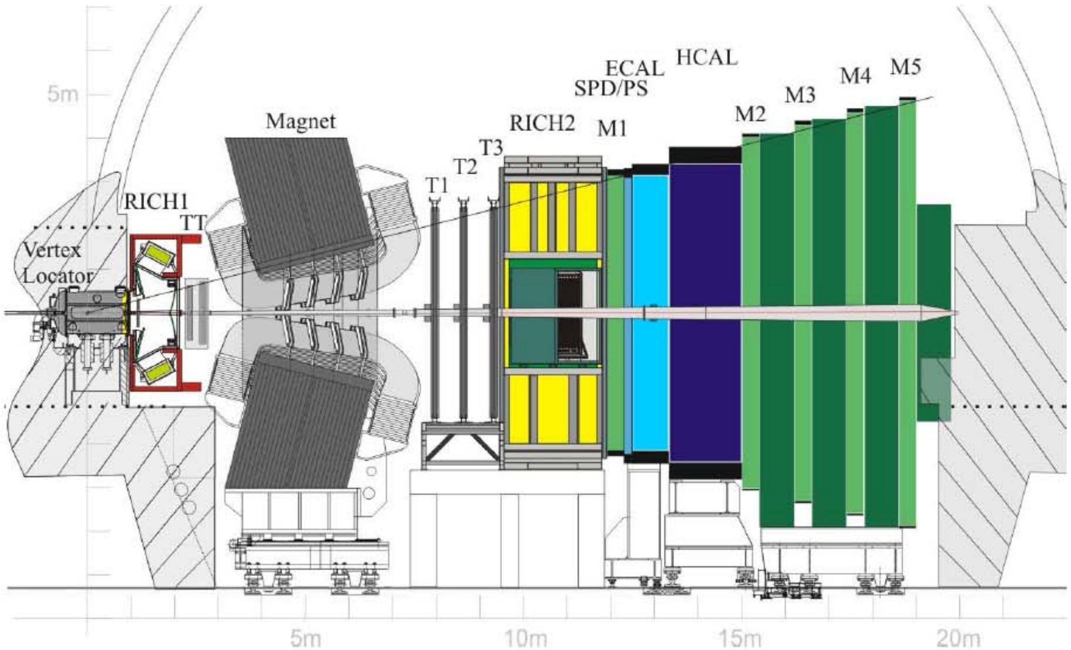
Upgrade of LHCb RICH Detectors, S. Easo , Mon 18:10

Particle Identification

Less is More

- First muon station (M1) as well as preshower (PS) and scintillating pad detector (SPD) will be removed due to reduced role in upgrade trigger scheme.
- Due to occupancy, aerogel radiator in RICH1 will be removed (leaving CF_4 in RICH1 and C_4F_{10} in RICH2).



The LHCb Detector Upgrade, H. Schindler, VCI2013

15 / 20

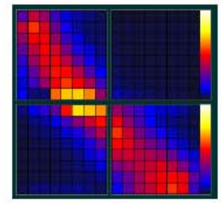
Upgrade of LHCb RICH Detectors, S. Easo , Mon 18:10

LHCb RICH Upgrade

RICH

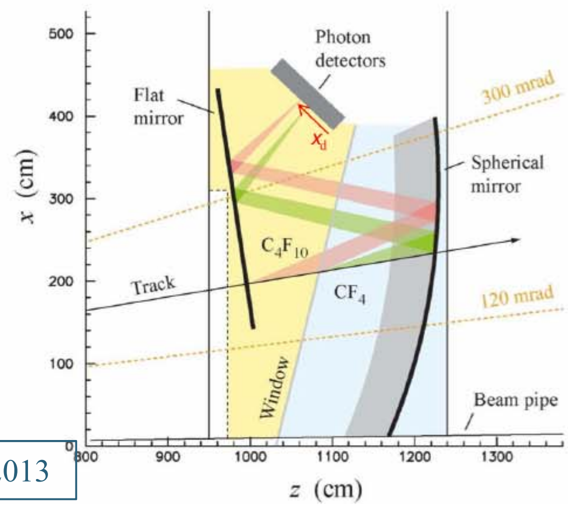
Photon Detectors

- R&D focussed on MaPMTs, potential candidate is Hamamatsu R11265.
- Custom readout ASIC (CLARO) being developed (alternative option: Maroc-3).



Operation at $\mathcal{L} = 2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$

- Preliminary simulation results indicate high occupancy in RICH1 ($\gtrsim 30\%$).
- Several ideas to cope with occupancy problem are being discussed, e. g.
  - new optics to spread out the rings,
  - remove RICH1 and adapt RICH2 to encompass two radiator gases.

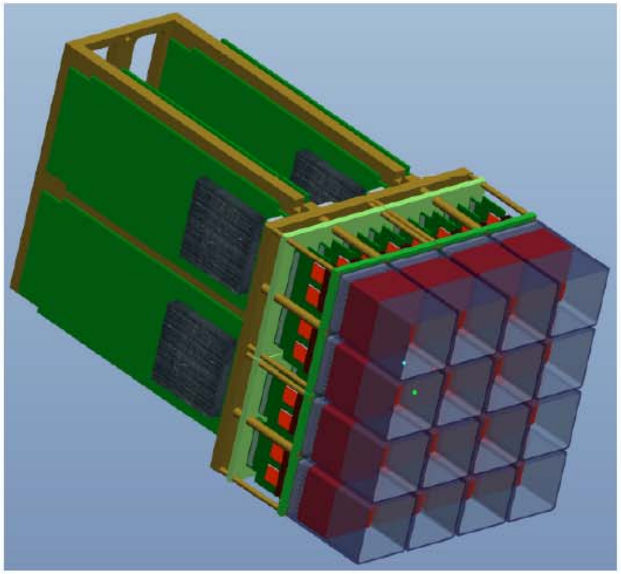


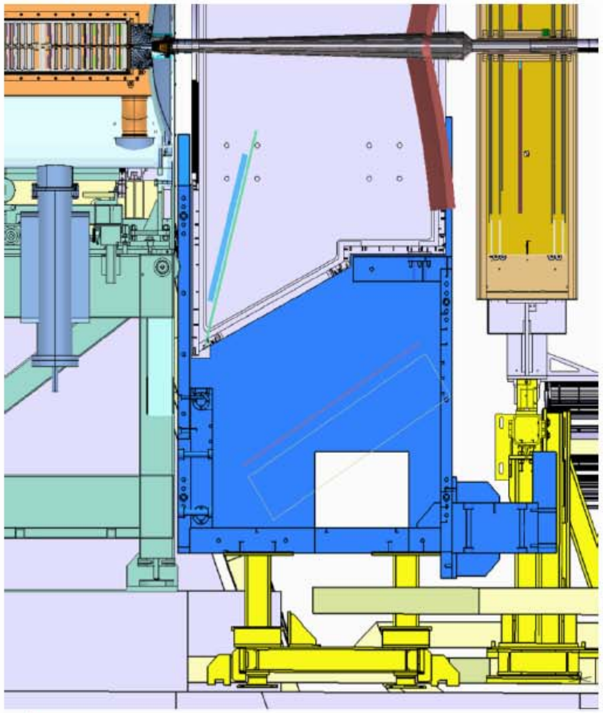
The LHCb Detector Upgrade, H. Schindler, VCI2013

Upgrade of LHCb RICH Detectors, S. Easo , Mon 18:10

Proposed RICH Upgrade (2)

- Increase focal length of RICH-1 spherical mirrors in order to halve the occupancy





- New Ma-PMT totally modular assemblies
  - A few will be installed already next year for characterization

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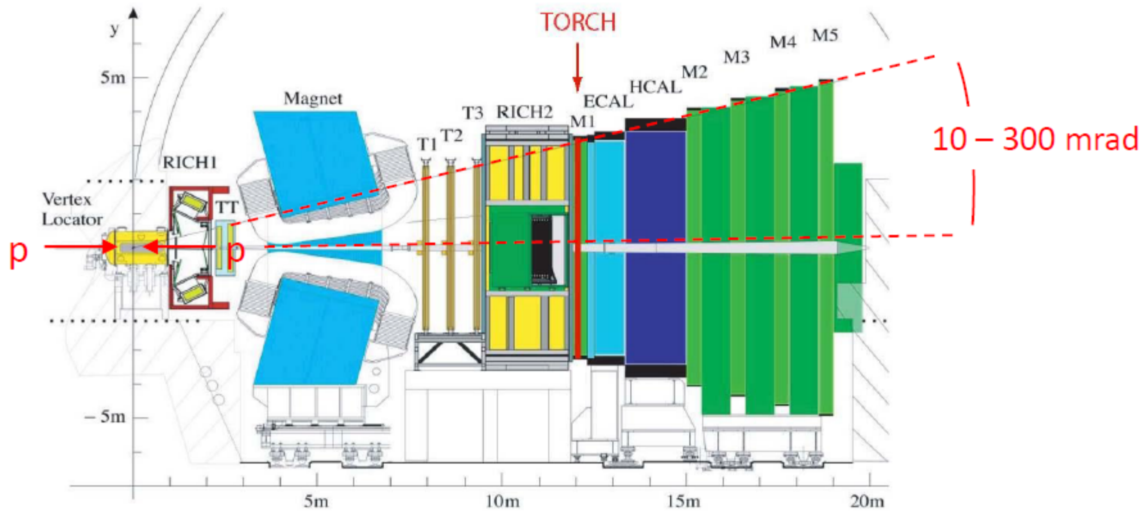
Upgrade of LHCb RICH Detectors, S. Easo , Mon 18:10

LHCb upgrade



- Upgrade of LHCb approved to increase data rate by an order of magnitude to run at luminosity 1–2 × 10^{33} $cm^{-2} s^{-1}$, for installation in 2018
- Current bottleneck is hardware trigger level that reduces the 40 MHz bunch crossing rate to 1 MHz, for readout into the high-level trigger in a CPU farm
  → read out *complete* experiment at 40 MHz, fully software trigger
- RICH system will be kept for particle ID, but one radiator removed (aerogel)
  Space for TORCH in place of M1 (which is part of hardware trigger)

Roger Forty, DIRC2013 Workshop

TORCH 4

TORCH - a Cherenkov based Time-of-Flight detector, M. van Dijk, Mon 19:00

LHCb TORCH

European Research Council

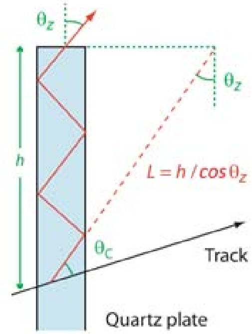
University of BRISTOL

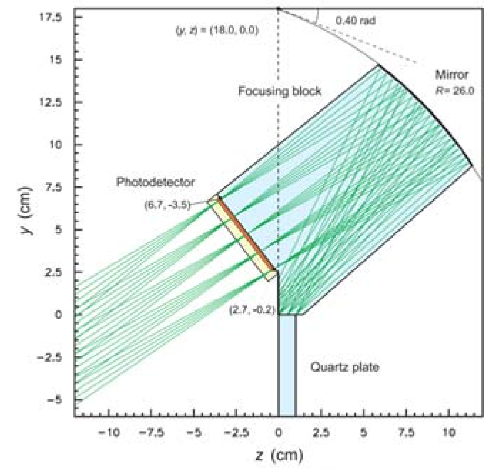
24 November 2013

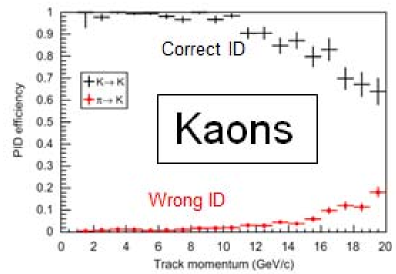
TORCH

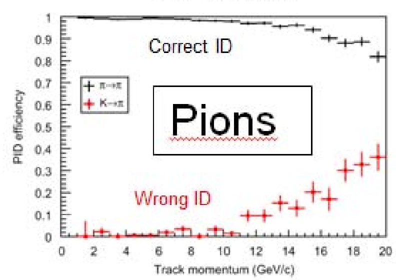
- Particle ID in LHCb for low/intermediate momentum (2-10 GeV/c)
- Large quartz Cherenkov radiator plate (idealised design) with focusing block on top and bottom
- Photons extracted through total internal reflection

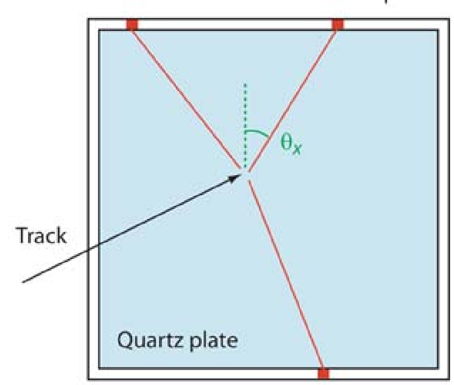
- Pions and kaons are separated in time-of-flight due to slightly different mass
- Precise time-of-flight measurement coupled to momentum information leads to identification
- Goal is to provide 3σ pion-kaon separation (needs <12.5ps per-track resolution)











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TORCH - a Cherenkov based Time-of-Flight detector, M. van Dijk, Mon 19:00

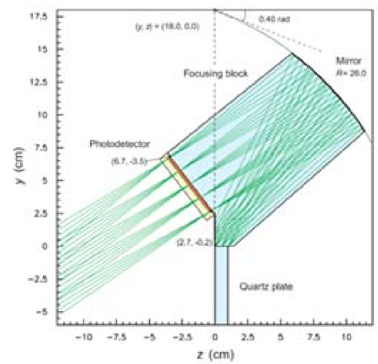
University of BRISTOL

24 November 2013

TORCH

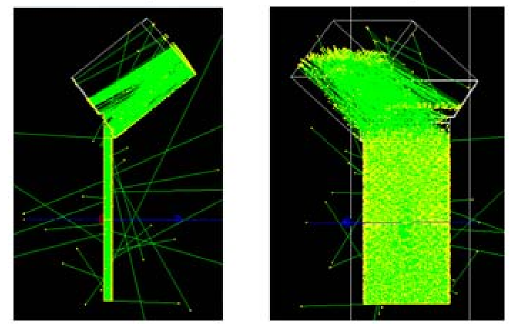
- Geant simulation of idealised quartz plate and focusing block
- Detector effects to be added in

- Extra (noise) photons detected from secondary tracks (electrons) that also give of Cherenkov radiation
- Width of Cherenkov ring segment due to chromatic dispersion in quartz medium
- Simulation of accumulated photons for a thousand 10 GeV kaons
- More information in *"TORCH – a Cherenkov based Time-of-Flight detector"* (19:00-19:25)

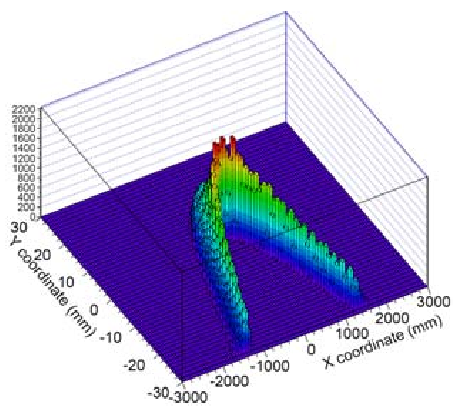


Viewpoint angles: θ=270° φ=0°

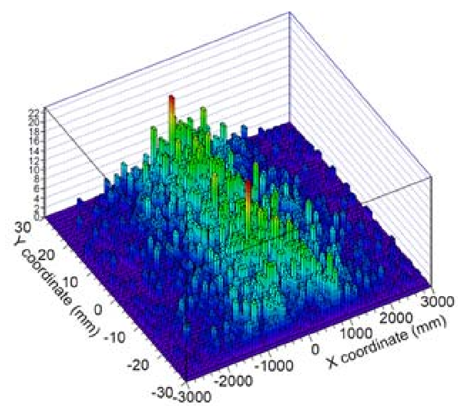
Viewpoint angles: θ=120° φ=0°



Photons from primary track



Photons from secondary tracks



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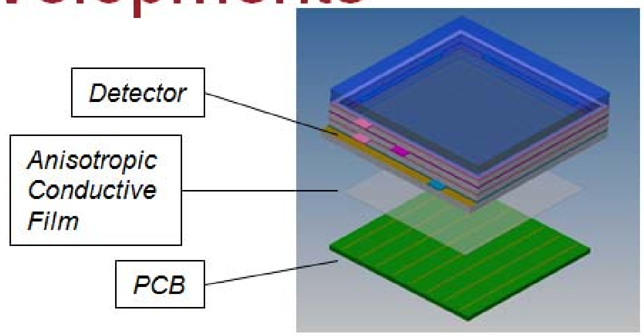
TORCH - a Cherenkov based Time-of-Flight detector, M. van Dijk, Mon 19:00

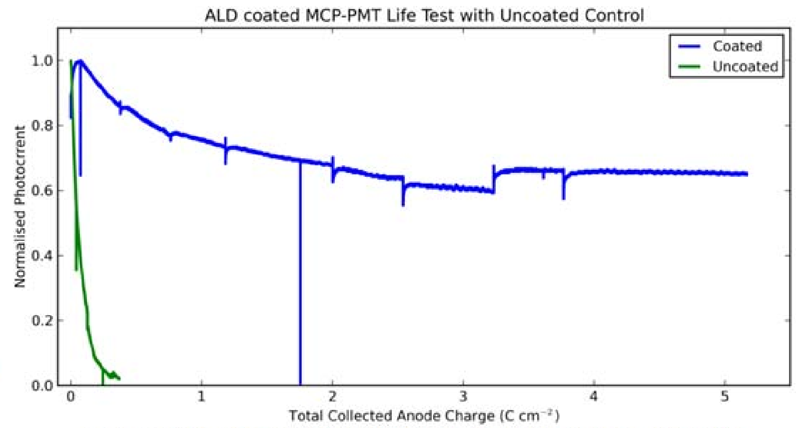
European Research Council
University of BRISTOL
PHOTEK ENVISAGE THE FUTURE

24 November 2013

TORCH – Experimental developments

- MCP-PMT's are the leading detector for time-resolved photon counting
- TORCH MCP-PMT currently in development at Photek (3 year program)
  - Year 1 – Long life demonstrator
  - Year 2 – High granularity multi-anode demonstrator
  - Year 3 – Fully functioning detector
- Technical aims:
  - Lifetime of 5C/cm² accumulated anode charge or better
  - Multi-anode readout of 8x128 pixels
  - Close packing on two opposing sides, fill factor 88% or better (53mm working width within 60 mm envelope)
- Development currently progressing well
  - Delivery of long-life demonstration tubes complete
  - Lifetime and time resolution tests currently underway
- See posters on TORCH MCP-PMT's for more info
  - T. Gys (CERN)
  - J. Milnes & T. Conneely (Photek)





Test of relative efficiency as a function of collected anode charge. Breaks in the plot were created when the detector was taken out of the setup for other testing.

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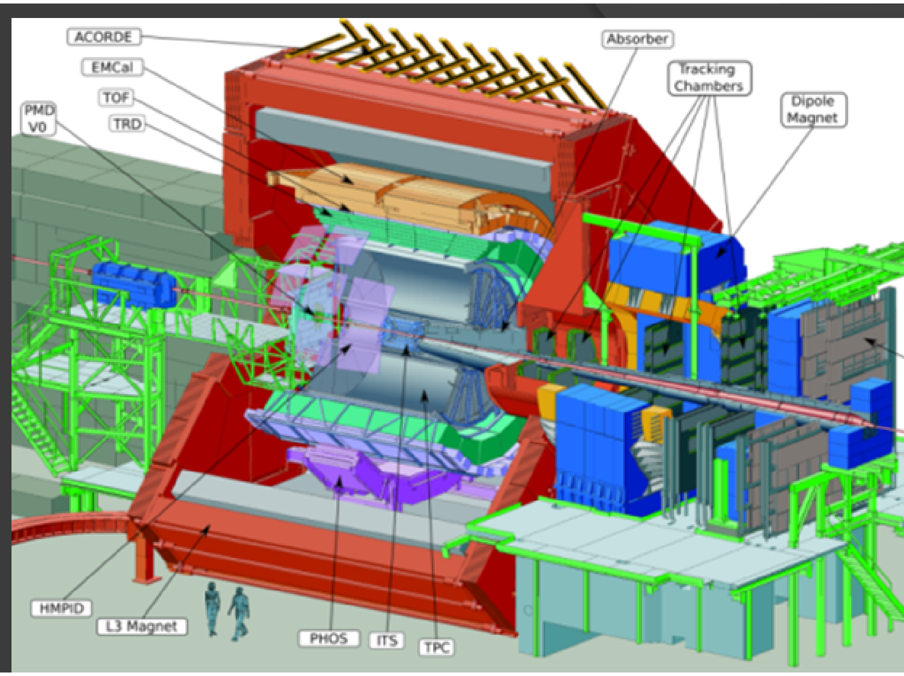
TORCH - a Cherenkov based Time-of-Flight detector, M. van Dijk, Mon 19:00

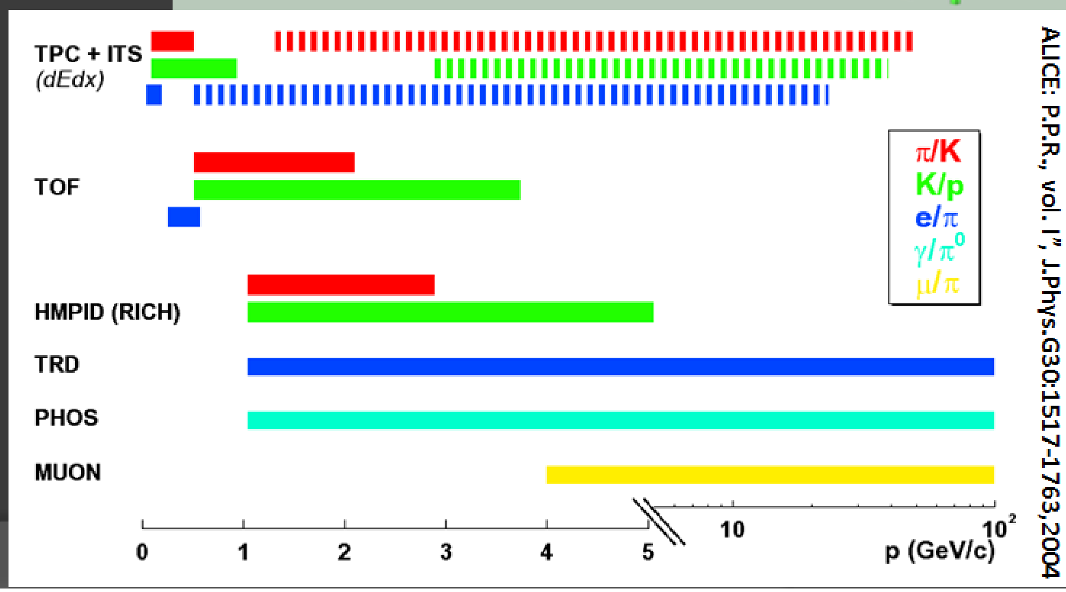
ALICE HMPID/VHMPID

PID in ALICE

- ALICE specifically designed to study Quark-Gluon Plasma in "heavy ion collisions" at LHC, pp studies relevant part of the physics program



- Excellent PID capabilities by combining different techniques over a large momentum range



13/02/2013

R&D on high momentum particle identification with a pressurized Cherenkov radiator,
M. Weber, Mon 16:35

ALICE-HMPID performance during the LHC run period 2010-2013,
G. de Cataldo, Mon 14:25

THE HMPID principle

Proximity focusing, 8 cm gap

RADIATOR

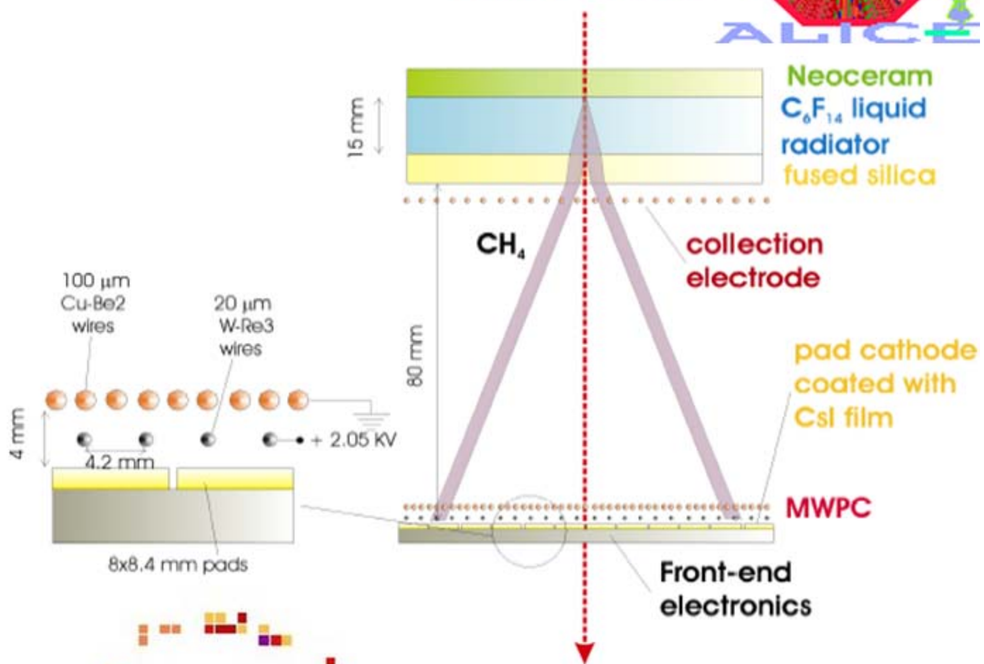
15 mm liquid C_6F_{14},
n ~ 1.2989 @ 175nm, β_{th} = 0.77

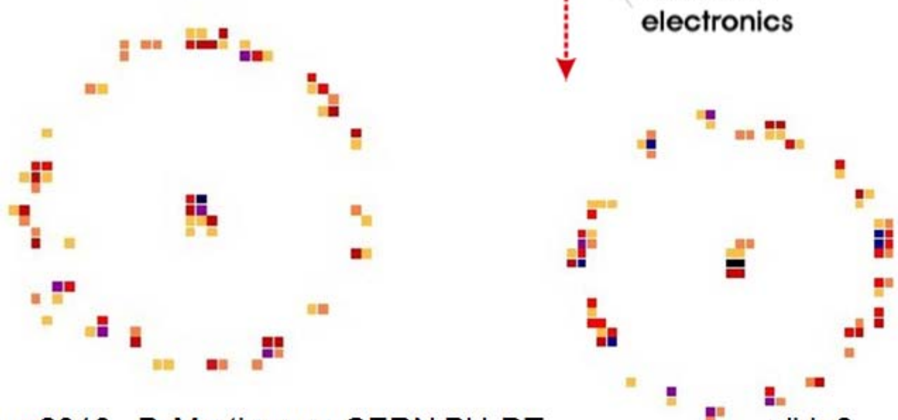
PHOTON CONVERTER

Reflective layer of CsI
QE ~ 25% @ 175 nm.

PHOTOELECTRON DETECTOR

- MWPC with CH_4 at atmospheric pressure (4 mm gap) HV = 2050 V.
- Analogue pad readout



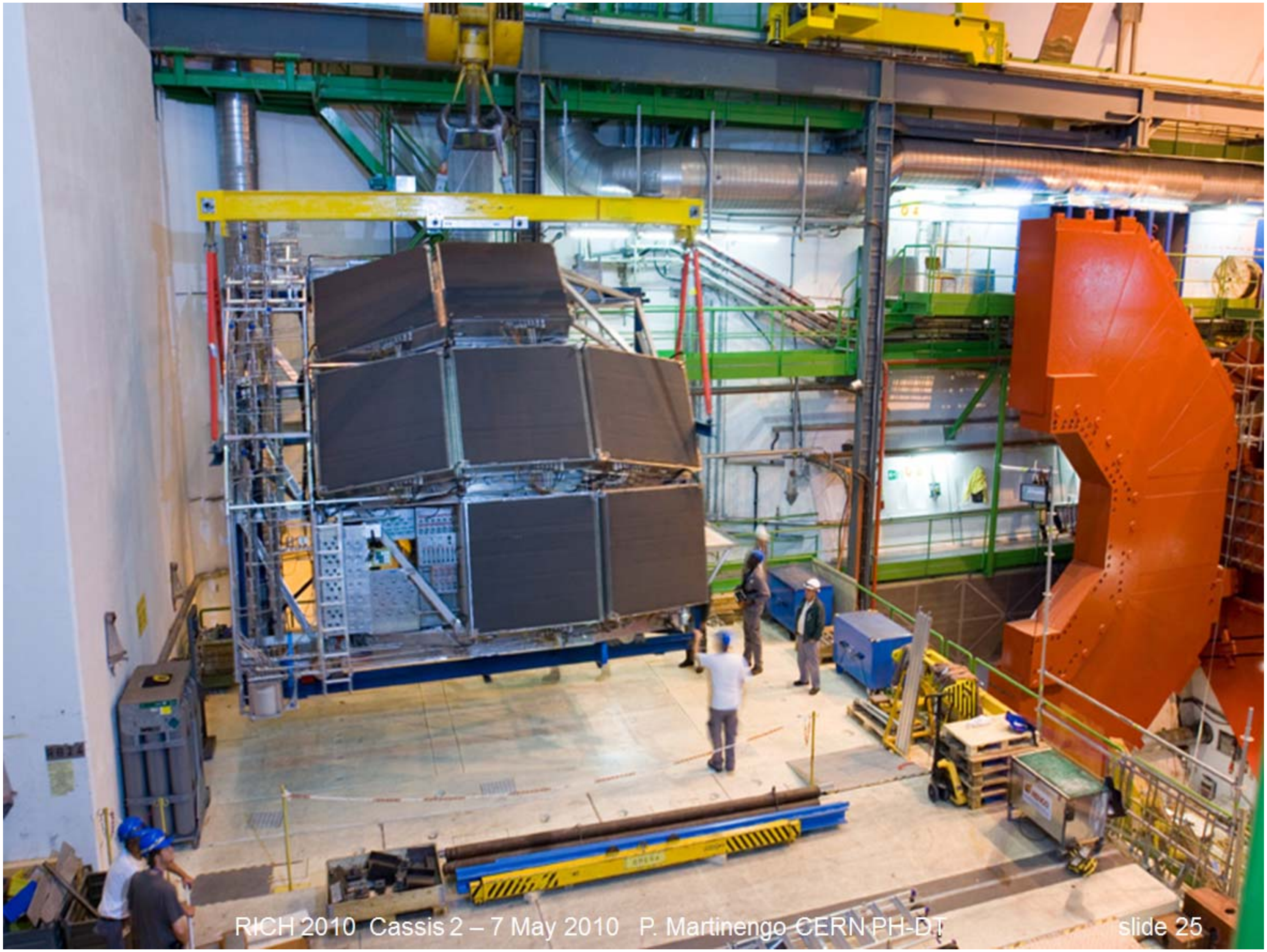


RICH 2010 Cassis 2 – 7 May 2010 P. Martinengo CERN PH-DT slide6

R&D on high momentum particle identification with a pressurized Cherenkov radiator,
M. Weber, Mon 16:35

ALICE-HMPID performance during the LHC run period 2010-2013,
G. de Cataldo, Mon 14:25

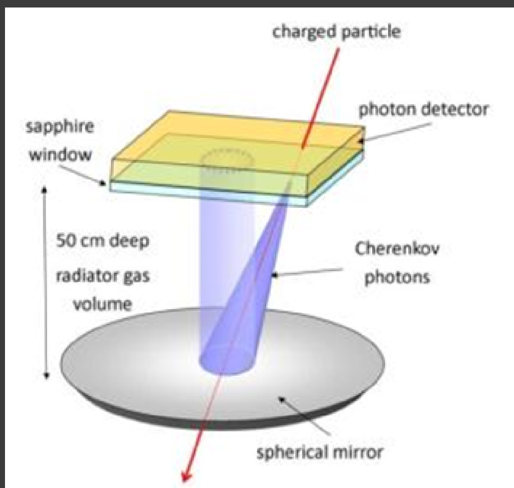
ALICE HMPID/VHMPID

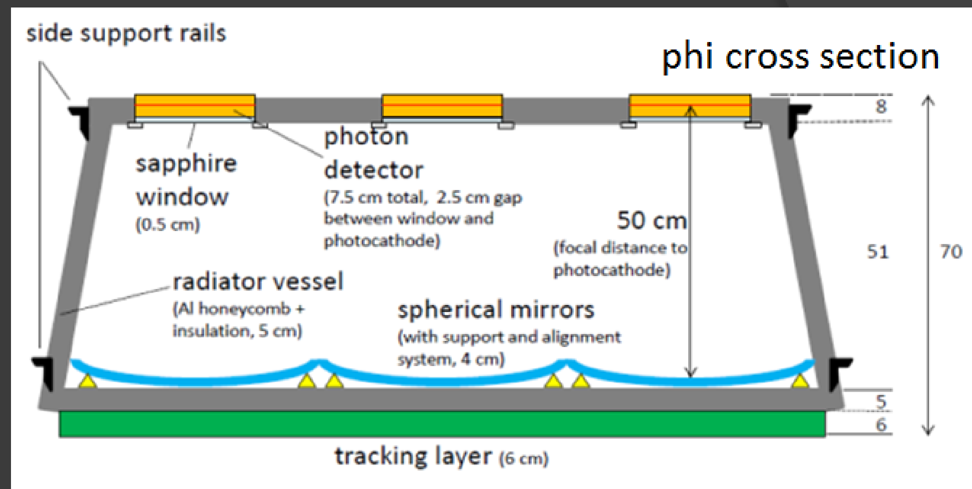


R&D on high momentum particle identification with a pressurized Cherenkov radiator,
M. Weber, Mon 16:35

ALICE-HMPID performance during the LHC run period 2010-2013,
G. de Cataldo, Mon 14:25

Baseline detector principle scheme





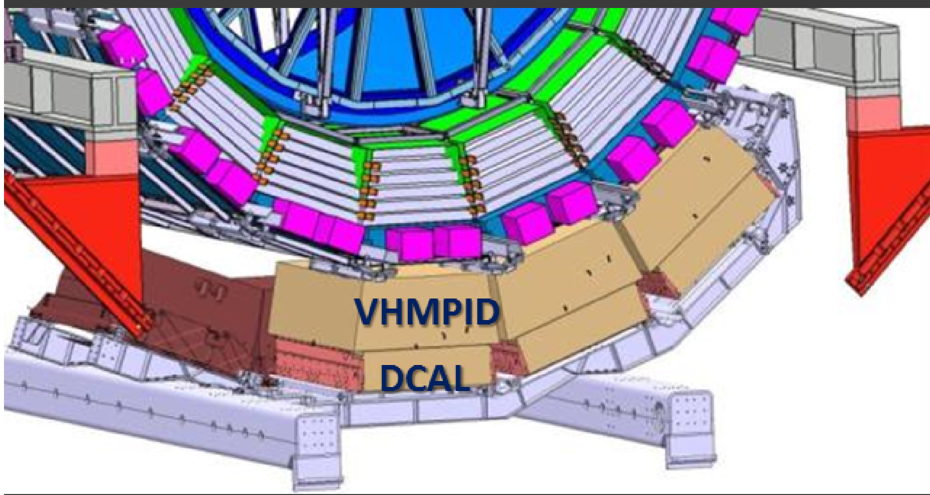
- Focusing RICH, C_4F_8O gaseous radiator L~ 50 cm, operated at 1-3.5 bar
- Al honeycomb radiator vessel, 4 mm sapphire window with A/R coating
- HMPID-like photon detector: MWPC with CsI pad segmented photocathode, operated with CH_4 ; pad size 4x8 mm^2 , 20 µm anode wires, 0.8 mm gap, 4 mm pitch
- 50x50 cm^2 spherical mirror, light C-fiber substrate, Al/MgF_2 coating
- CCC tracking layers with strip chambers
- FEE with analogue readout for centroid measurement, three options:
  - HMPID Gassiplex chip with T/H, modified version from COMPASS RICH (max 500 KHz trigger rate)
  - APV25 with continuous sampling at 40 MHz, as used in COMPASS RICH and HADES RICH upgrades
  - new common FEE developments for ALICE high-lumi upgrade

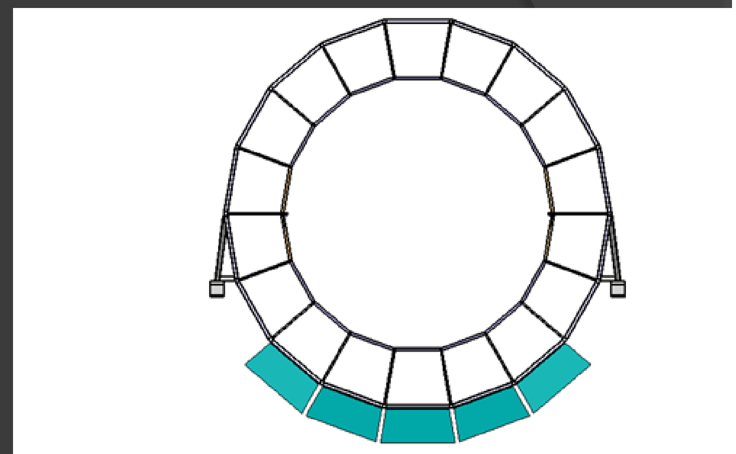
13/02/2013 A. Di Mauro - VCI2013 8/30

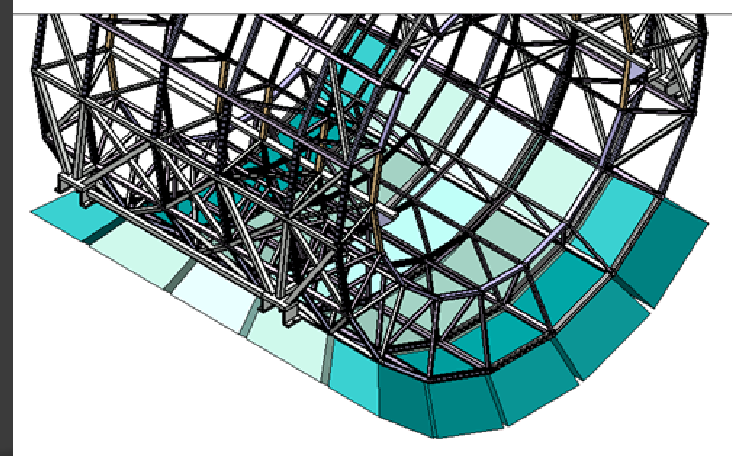
R&D on high momentum particle identification with a pressurized Cherenkov radiator,
M. Weber, Mon 16:35

ALICE-HMPID performance during the LHC run period 2010-2013,
G. de Cataldo, Mon 14:25

Detector layout and integration in ALICE







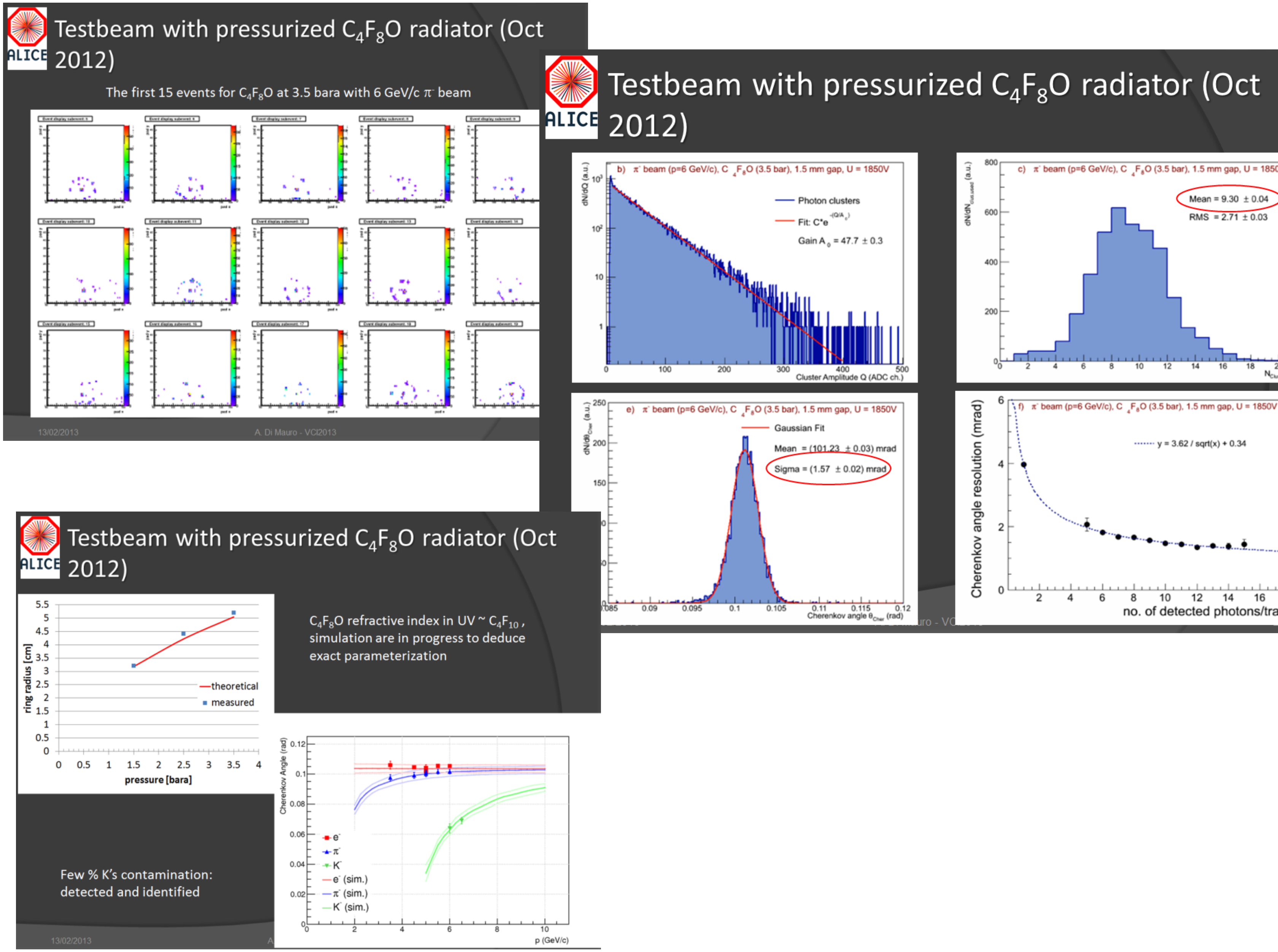
- Module arrangement under study
- 5 Central modules, size ~ $1.4 \times 1.7 \times 0.7\ m^3$
- 10 Side modules, size: ~ $2.7 \times 1.7 \times 0.7\ m^3$

13/02/2013 A. Di Mauro - VCI2013 9/30

R&D on high momentum particle identification with a pressurized Cherenkov radiator,
M. Weber, Mon 16:35

ALICE-HMPID performance during the LHC run period 2010-2013,
G. de Cataldo, Mon 14:25

ALICE HMPID/VHMPID



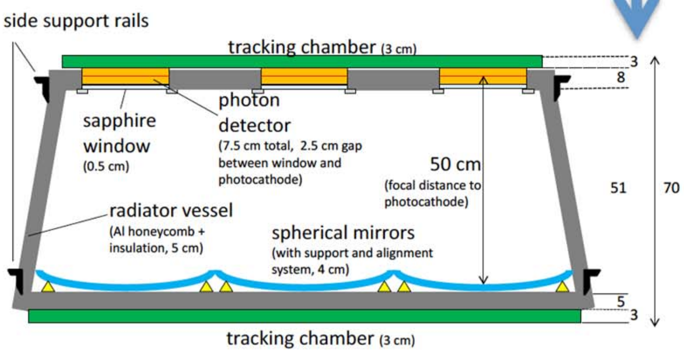
R&D on high momentum particle identification with a pressurized Cherenkov radiator, M. Weber, Mon 16:35

ALICE-HMPID performance during the LHC run period 2010-2013, G. de Cataldo, Mon 14:25

Summary

track-by-track PID in high momentum regime

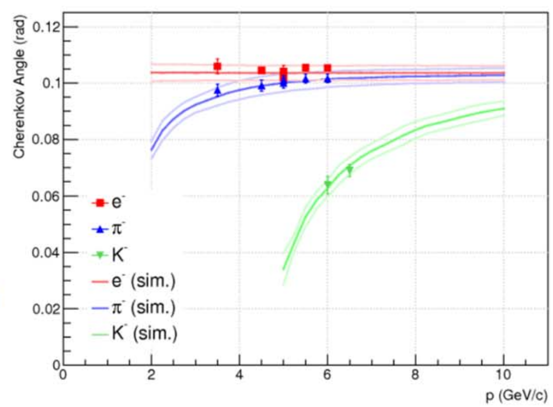
requires



pressurized gaseous RICH:
- Radiator: 3.5 bar C_4F_8O (50 cm)
- Photon detector: CsI-MWPC (CH_4)
- Window: Sapphire
- Mirrors: 3x3

R&D

- smaller anode-cathode gap and pad size
- Excellent chamber performance (Number of photons ~ 10)
- Excellent Cherenkov angle resolution (~ 1.5 mrad)
- Photon detection alternatives (GEM, MCP)



Michael Weber - RICH 2013 - 02.12.2013 29

R&D on high momentum particle identification with a pressurized Cherenkov radiator,
M. Weber, Mon 16:35

ALICE-HMPID performance during the LHC run period 2010-2013,
G. de Cataldo, Mon 14:25

Summary and outlook

- Intense R&D campaign has been performed in 2011/12 to meet new design requirements
- Successful tests of C_4F_8O as Cherenkov radiator in UV, proven preliminary design concepts for pressurization/heating
- Baseline solution for photon-detector: CsI-MWPC with thin gap; new prototype with final layout successfully tested in Dec '12
- Further activities
  - continue tests on CsI-TGEM and Planacon, for "faster" detector option
  - FEE and readout electronics development
  - engineering studies on vessel structure and mirror system
- LoI submitted this week to the ALICE Collaboration, final decision in March

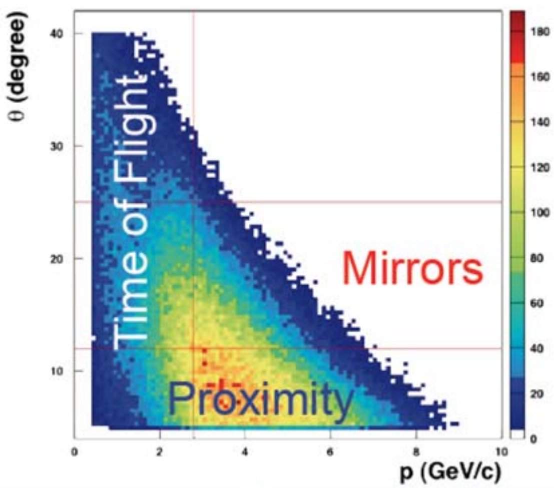
Letter Of Intent: http://arxiv.org/abs/1309.5880
…proposal was not endorsed by the ALICE collaboration…

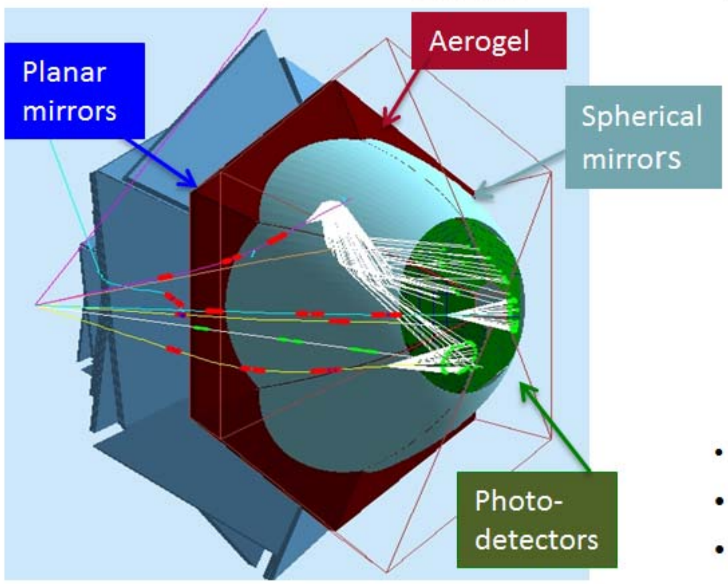
13/02/2013 A. Di Mauro - VCI2013 28/30

R&D on high momentum particle identification with a pressurized Cherenkov radiator,
M. Weber, Mon 16:35

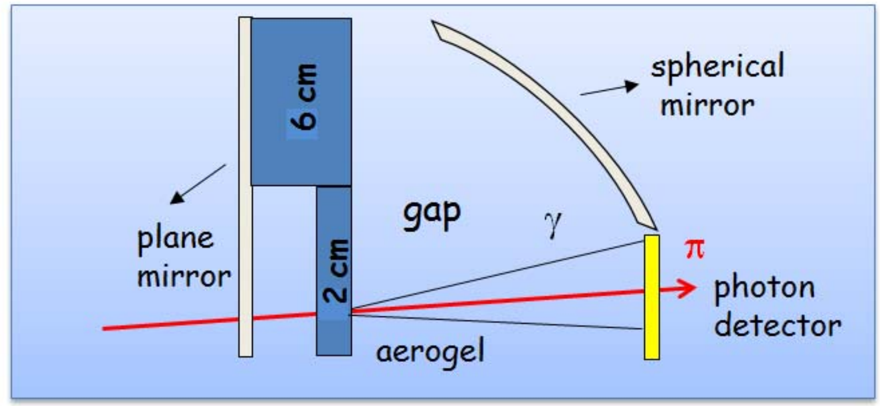
ALICE-HMPID performance during the LHC run period 2010-2013,
G. de Cataldo, Mon 14:25

The Hybrid Optics Design

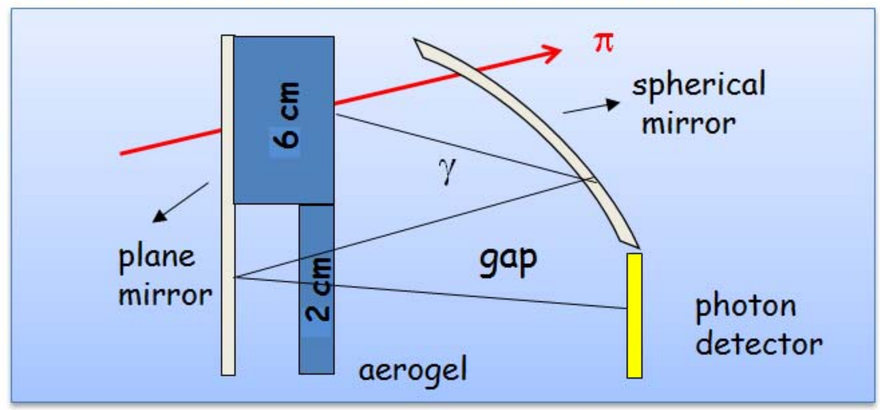




Direct rings/best performance for high momentum particles



Reflected rings for less demanding low momentum particles



- Minimize active area (cost) to about 1 m^2
- Material budget concentrated where TOF is less effective
- Focalizing mirrors allow thick radiator for good light yield

Contalbrigo M. 14th ICATPP, 25th September 2013, Como 11

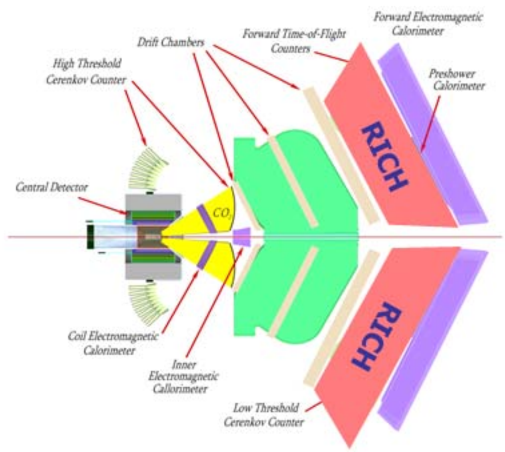
The large-area hybrid-optics CLAS12 RICH detector, M. Contalbrigo, Mon 14:50

The CLAS12 RICH

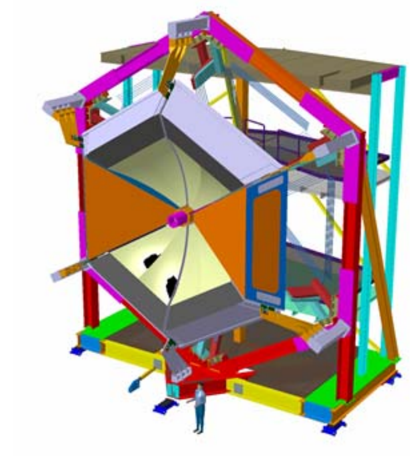
The large-area hybrid-optics CLAS12 RICH detector, M. Contalbrigo, Mon 14:50

CLAS12 Detector at Jefferson Lab

3D structure of the nucleon by polarized deep-inelastic scattering

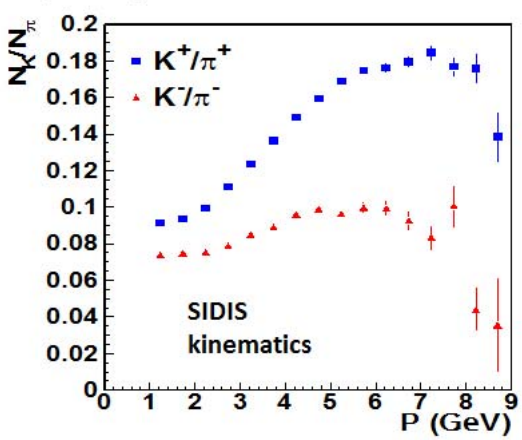


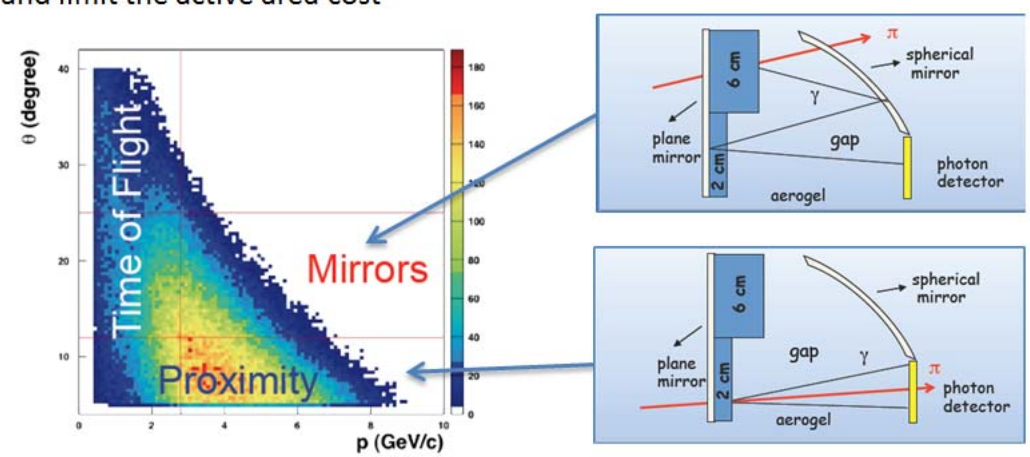
Forward RICH: 2 sectors to accomplish physics program, 1[st] sector by the end of 2016



4σ hadon separation in the 3-8 GeV/c momentum range required to achieve flavor sensitivity

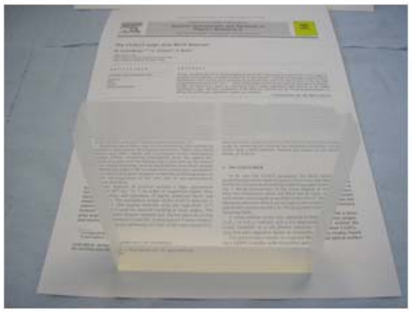
Hybrid optics to fit into CLAS12 clearance and limit the active area cost

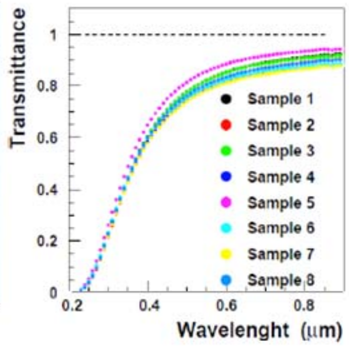


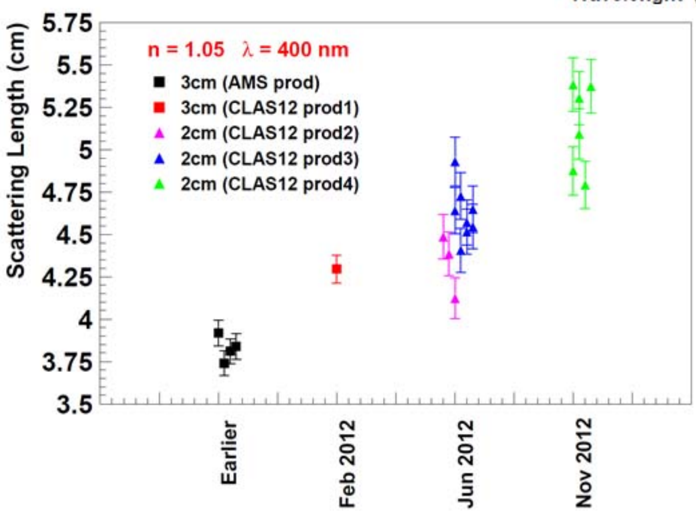


Component Tests

Aerogel Radiator

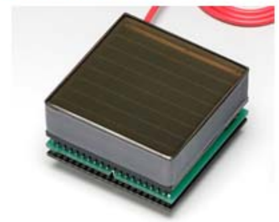


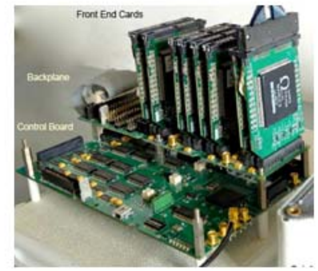


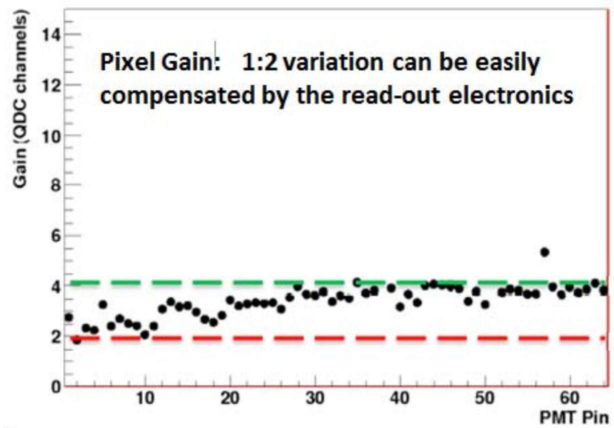


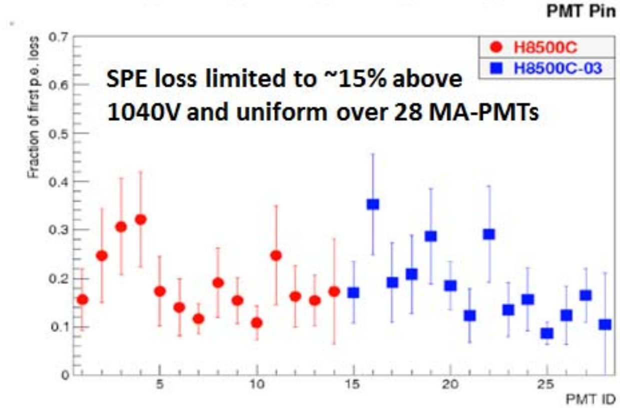
Achieved clarity for large tiles at n=1.05
~ 0.00050 $\mu m^4\ cm^{-1}$
Budker and Boreskov Institute of Novosibirsk

Photon Detection







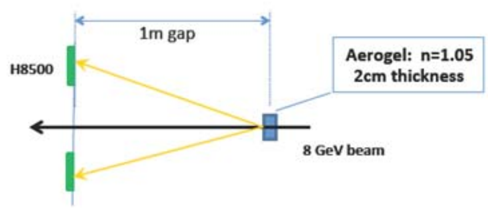


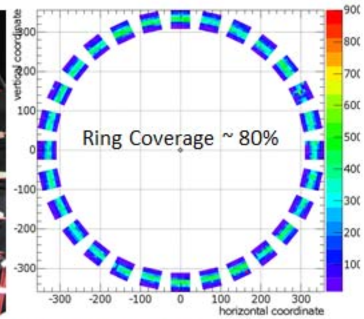
The large-area hybrid-optics CLAS12 RICH detector, M. Contalbrigo, Mon 14:50

Prototype Results

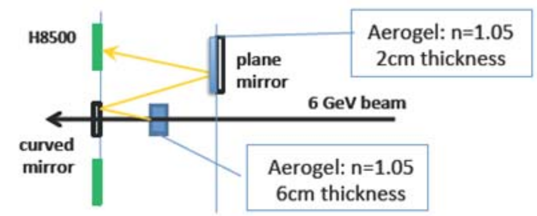
The large-area hybrid-optics CLAS12 RICH detector, M. Contalbrigo, Mon 14:50

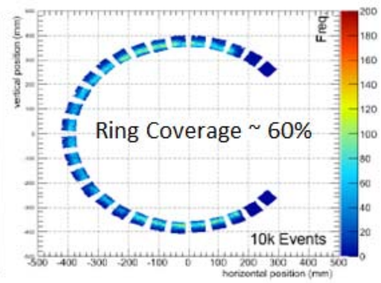
Direct light detection



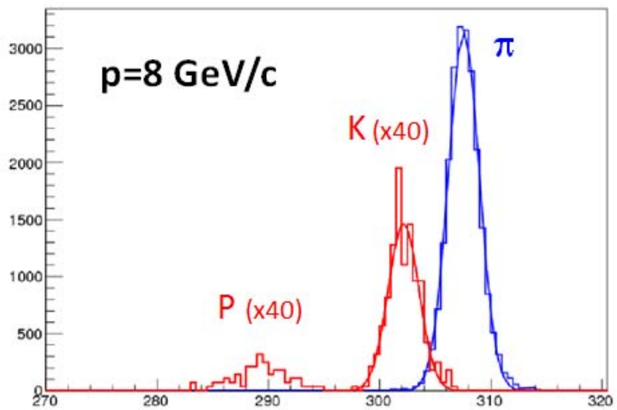


Reflected light detection

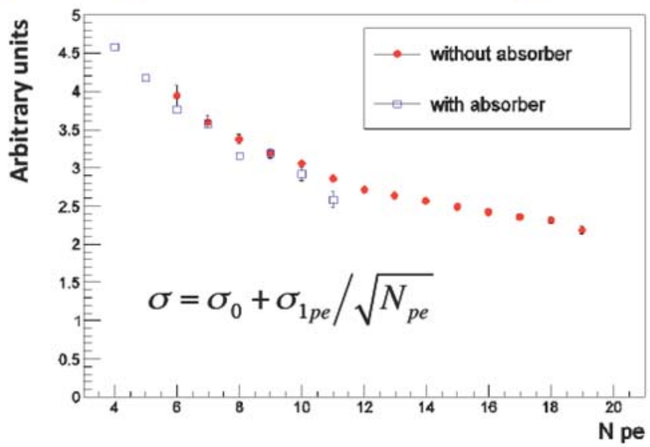




Separation up to the CLAS12 maximum momentum

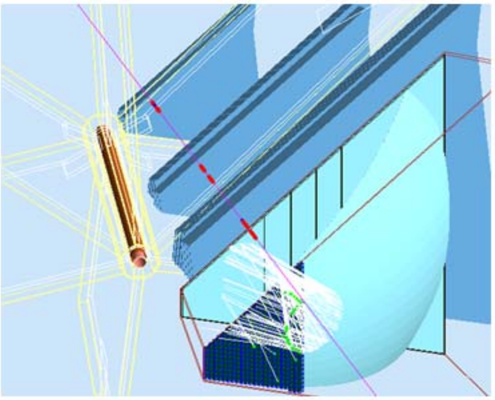


Acceptable light loss without resolution degradation

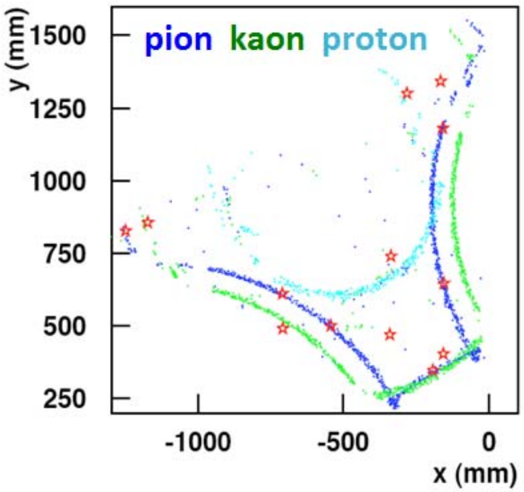


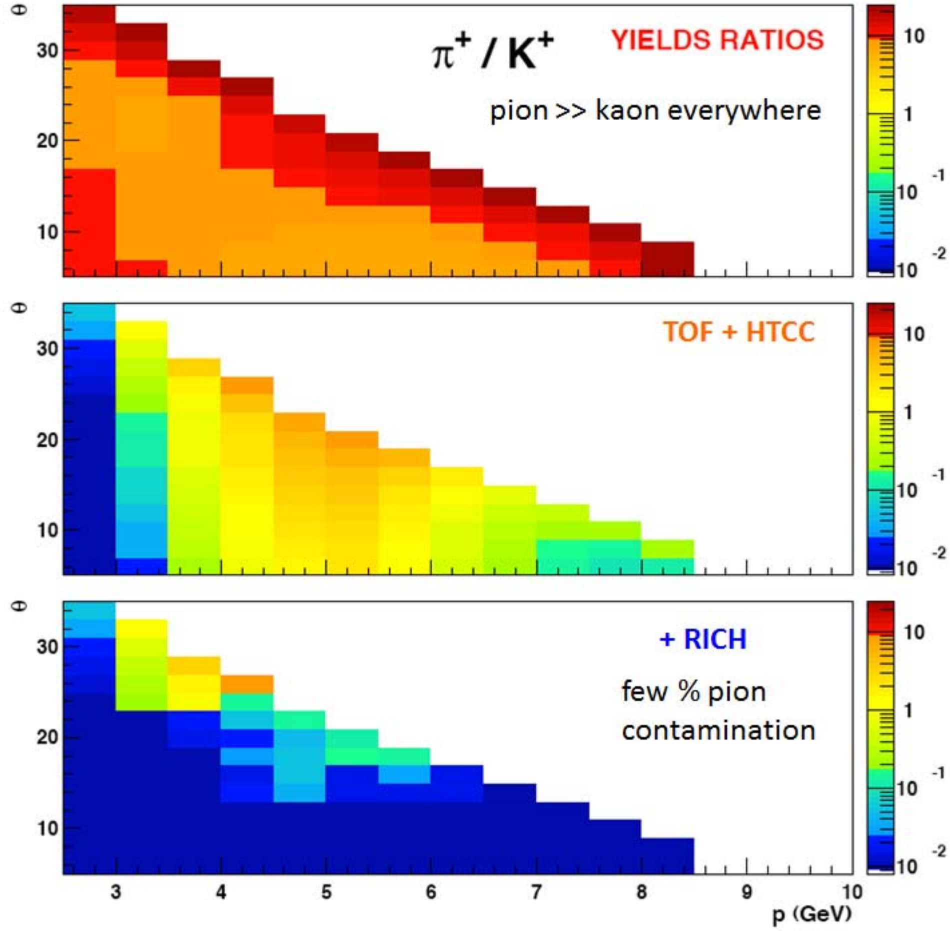
The CLAS12 Hadron ID

One charged particle per sector in average:



Non trivial RICH light patter due to reflections: patter recognition and likelihood ID required





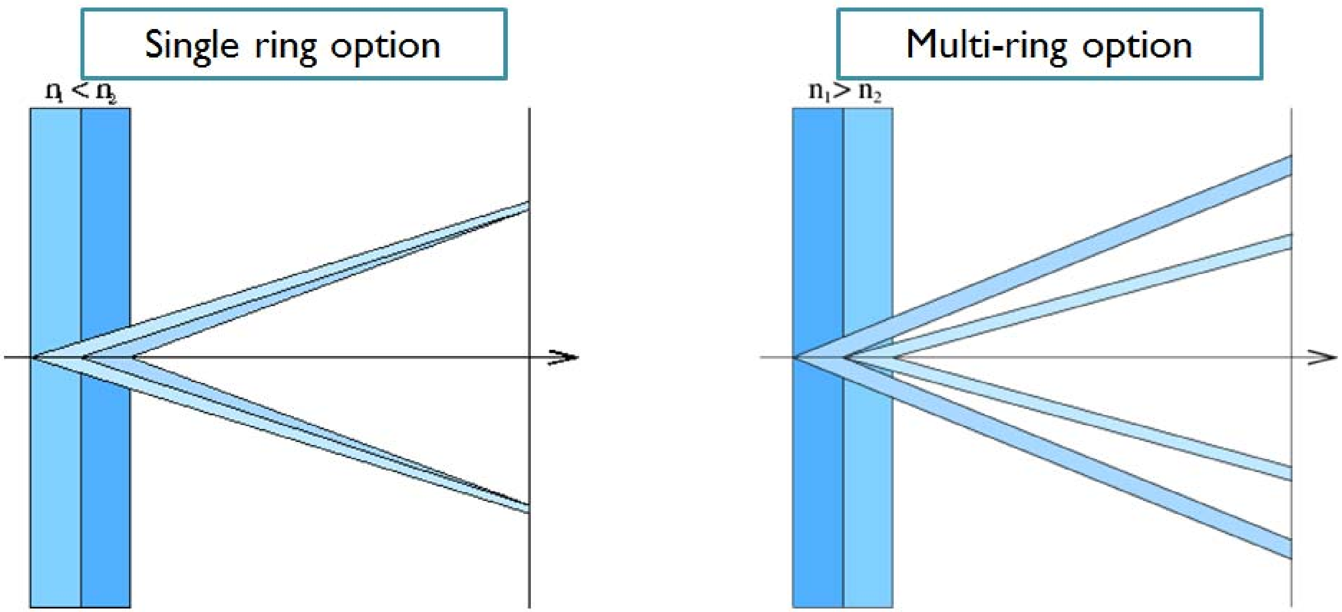
Even with a not yet optimized tuning of pattern recognition and likelihood ID, the π contamination is of the order of 1%

The large-area hybrid-optics CLAS12 RICH detector, M. Contalbrigo, Mon 14:50

FARICH concept

Focusing Aerogel RICH – FARICH

Improves proximity focusing design by reducing radiator thickness contribution into the Cherenkov angle resolution



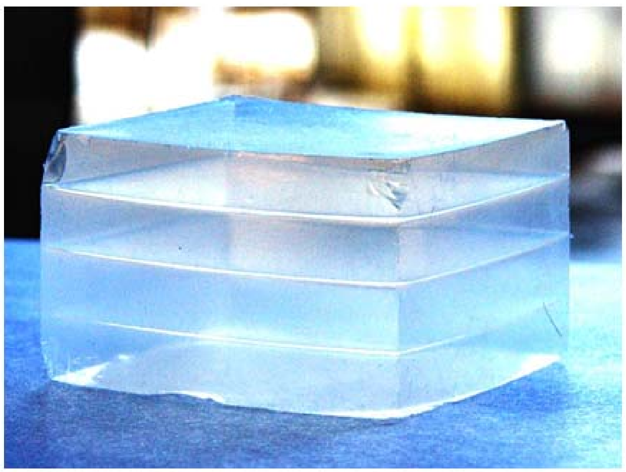
T. Iijima et al., NIM A548 (2005) 383
A.Yu. Barnyakov et al., NIM A553 (2005) 70

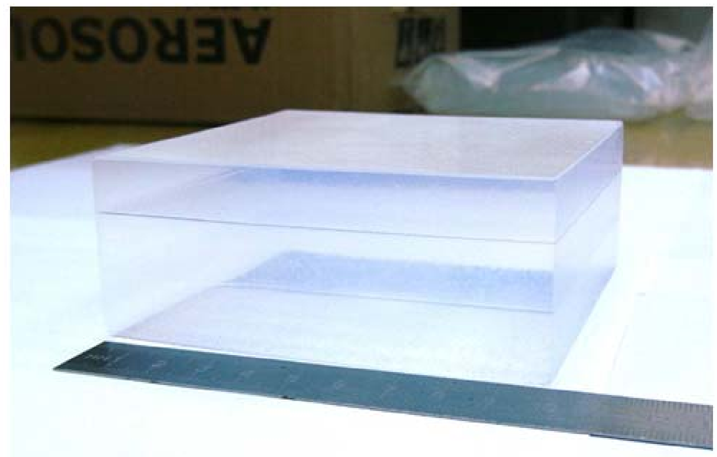
13/02/2013 VCI 2013 2

Tests of FARICH prototype with fine photon position detection,
E.A. Kravchenko, Mon 16:10

Multi-layer 'focusing' aerogels

- Produced by Boreskov Institute of Catalysis (Novosibirsk) in cooperation with Budker Institute since 2004



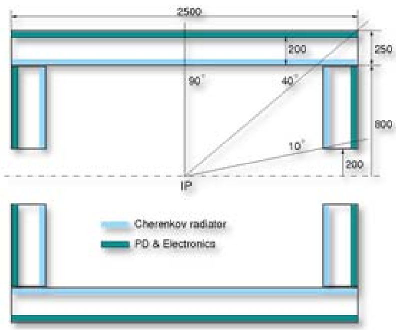


First 4-layer sample produced in 2004
A.Yu.Barnyakov et al., NIM A553 (2005) 70

13/02/2013 VCI 2013 3

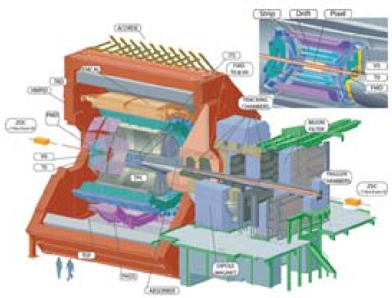
Tests of FARICH prototype with fine photon position detection,
E.A. Kravchenko, Mon 16:10

FARICH projects and proposals



FARICH for Super Charm-Tau Factory (Novosibirsk)

Particle ID: μ/π up to 1.7 GeV/c
$21m^2$ detector area (SiPMs)
~1M channels



FARICH for ALICE HMPID upgrade

Particle ID: π/K up to 10 GeV/c, K/p up to 15 GeV/c
$3m^2$ detector area (SiPMs)

Forward Spectrometer RICH for PANDA

Particle ID: π/K/p up to 10 GeV/c
$3m^2$ detector area (MaPMTs or SiPMs)

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Tests of FARICH prototype with fine photon position detection,
E.A. Kravchenko, Mon 16:10

Sensor array: Philips digital SiPM cooled to -40C

FARICH prototype with DPC…

4-layer aerogel
- n_{max} = 1.046
- Thickness 37.5 mm
- Calculated focal distance 200 mm
- Hermetic container with plexiglass window to avoid moisture condensation on aerogel

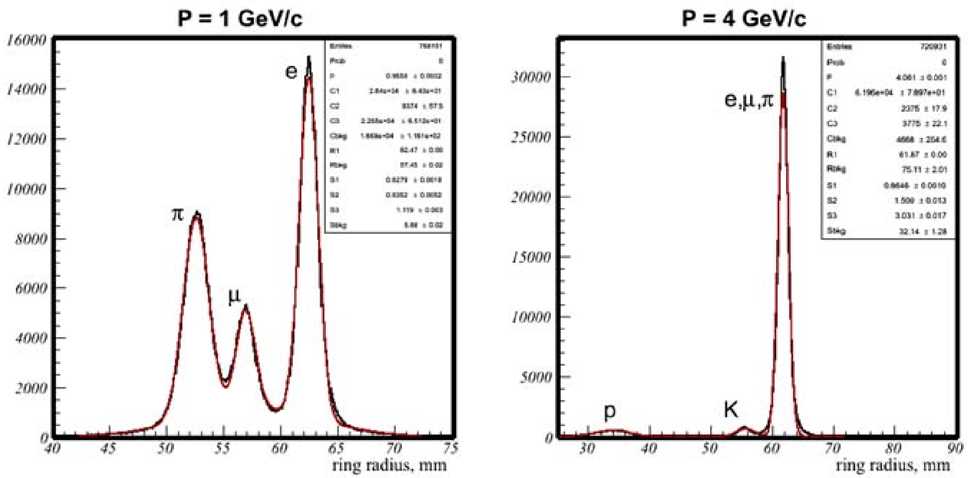
Square matrix 20x20 cm^2
- Sensors: DPC3200-22-44
- 3x3 modules = 6x6 tiles = 24x24 dies = 48x48 pixels in total
- 576 time channels
- 2304 amplitude (position) channels
- 4 levels of FPGA readout: tiles, modules, bus boards, test board

13/02/2013 VCI 2013 10

Tests of FARICH prototype with fine photon position detection,
E.A. Kravchenko, Mon 16:10

FARICH-PDPC: Particle ID

Ring radius distribution

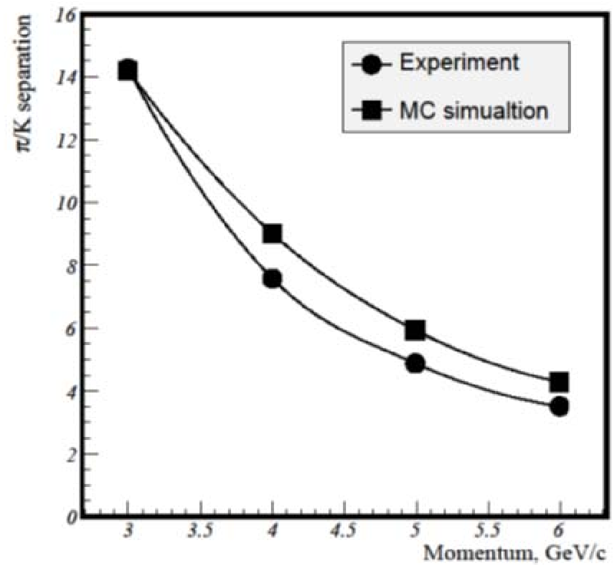


μ/π: **5.3σ** @ 1 ГэВ/*c*

π /K: **7.6σ** @ 4 ГэВ/*c*

2.3 times higher than SuperB FDIRC
(NIM A595 (2008) 104)
1.9 times higher than Belle II ARICH
(NIM A (2013), http://dx.doi.org/10.1016/j.nima.2013.06.080)

$$S(\pi/K)=\frac{R_\pi - R_K}{\sigma_\pi}$$



A.Yu. Barnyakov, et al., NIM A (2013), http://dx.doi.org/10.1016/j.nima.2013.07.068, Article in Press

Tests of FARICH prototype with fine photon position detection,
E.A. Kravchenko, Mon 16:10

Conclusion

- Beam test of FARICH prototype with Philips DPC was prepared and successfully realized in a short time scale.
- Cherenkov rings are detected from focusing aerogel with ~14 photoelectrons for relativistic particles.
- Timing resolution of σ_t=48 ps is achieved for single Cherenkov photons.
- π/K separation obtained for P=6 GeV/c is 3.8σ, μ/π separation is 4.5σ for P=1 GeV/c.
- Signs of radiation damage are observed that partially recovered by annealing at room temperature.
- Very positive experience of 2 weeks operation of the large and complex setup.
- Tests were continued at electron test beam in BINP in January 2013. Results are coming up.

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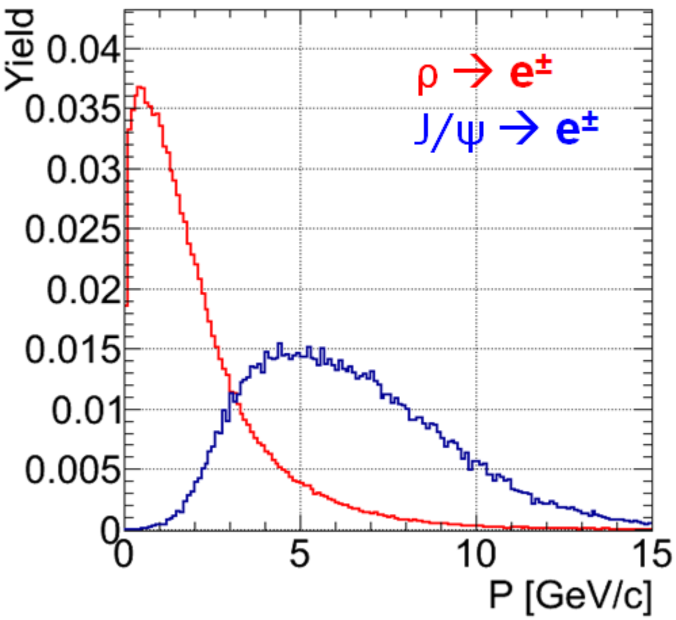
Tests of FARICH prototype with fine photon position detection,
E.A. Kravchenko, Mon 16:10

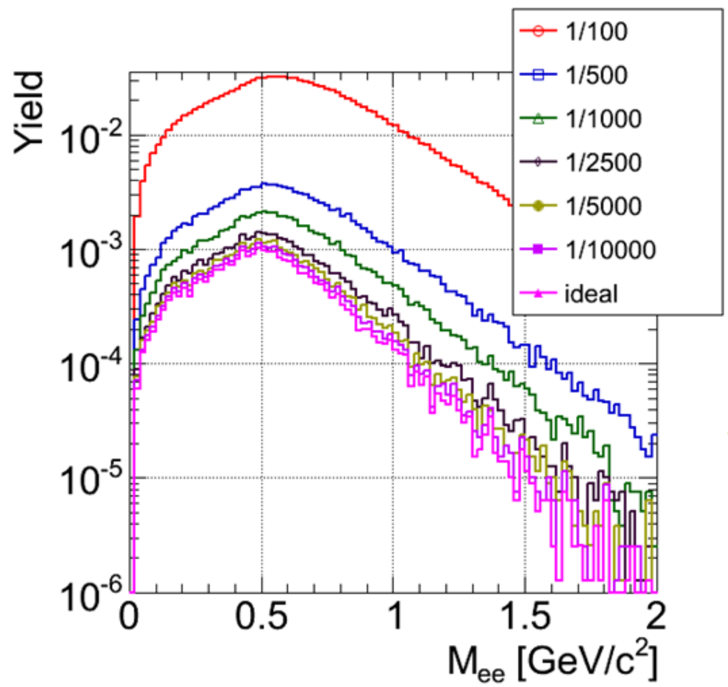
4 **Introduction** Requirements on electron identification

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Rare probes: $\rho, \omega, \phi \rightarrow e^{\pm}$, $J/\psi, \psi' \rightarrow e^{\pm}$



Momentum spectrum of decay-electrons from the ρ and J/ψ mesons



Combinatorial background for low-mass di-electron pairs assuming various pion misidentification levels

- Central Au+Au at 25AGeV:
- 700 pions are produced
- 310 lie in the RICH acceptance.

Identification of e± with p<10GeV

pion rejection factor of $\geq 10^4$

The CBM RICH Detector • Tariq Mahmoud • DIRC2013 • 05.09.2013

The CBM RICH project, C. Pauly, Mon 17:25

7 **The Concept**

Three main components

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

$p_{th} = \frac{m}{\sqrt{2\delta}}$, $\delta_{CO_2} = 4.3 \times 10^{-4}$

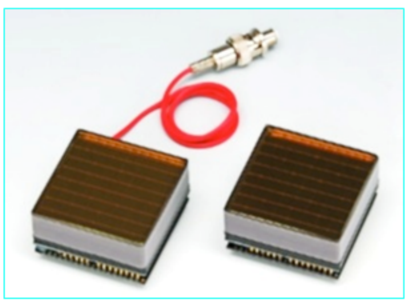
e^- 17.4 MeV $K^\pm$ 17 GeV

$\pi^\pm$ 4.6 GeV p 32 GeV

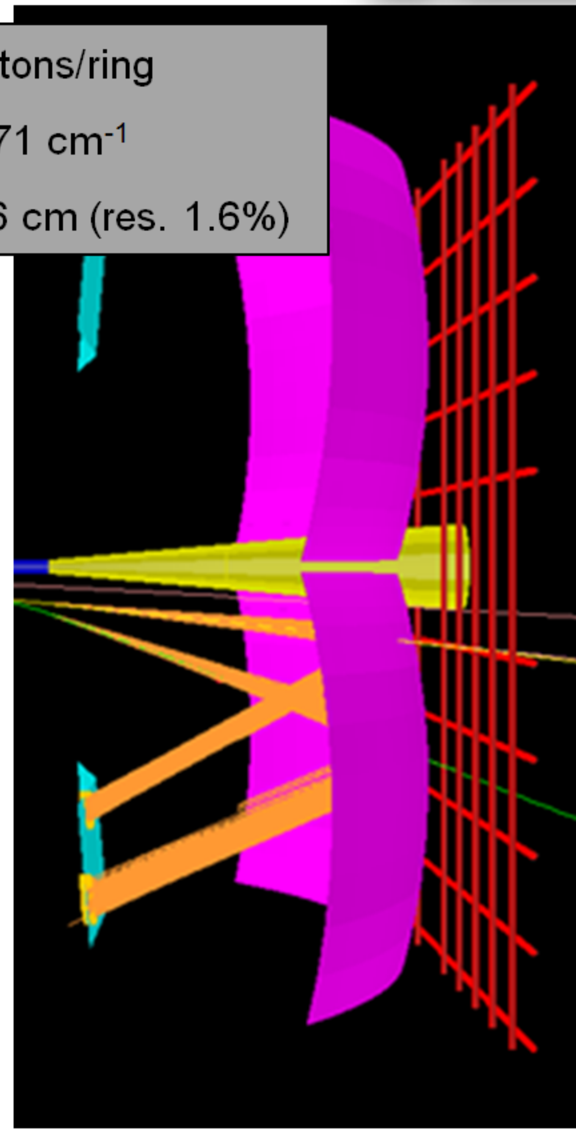
Radiator
- CO_2; $\gamma_{th} = 33$
- $p_{\pi,th} = 4.65$ GeV/c
- V ≈30 m^3
- Length=1.7 m

- 28 photons/ring
- $N_0 \approx 171\ cm^{-1}$
- r_e=4.56 cm (res. 1.6%)

Mirror
- SIMAX-glass, Al+MgF_2
- R = 3m, d ≤ 6mm
- 11.8 m^2
- Tiles of 40×40 cm^2

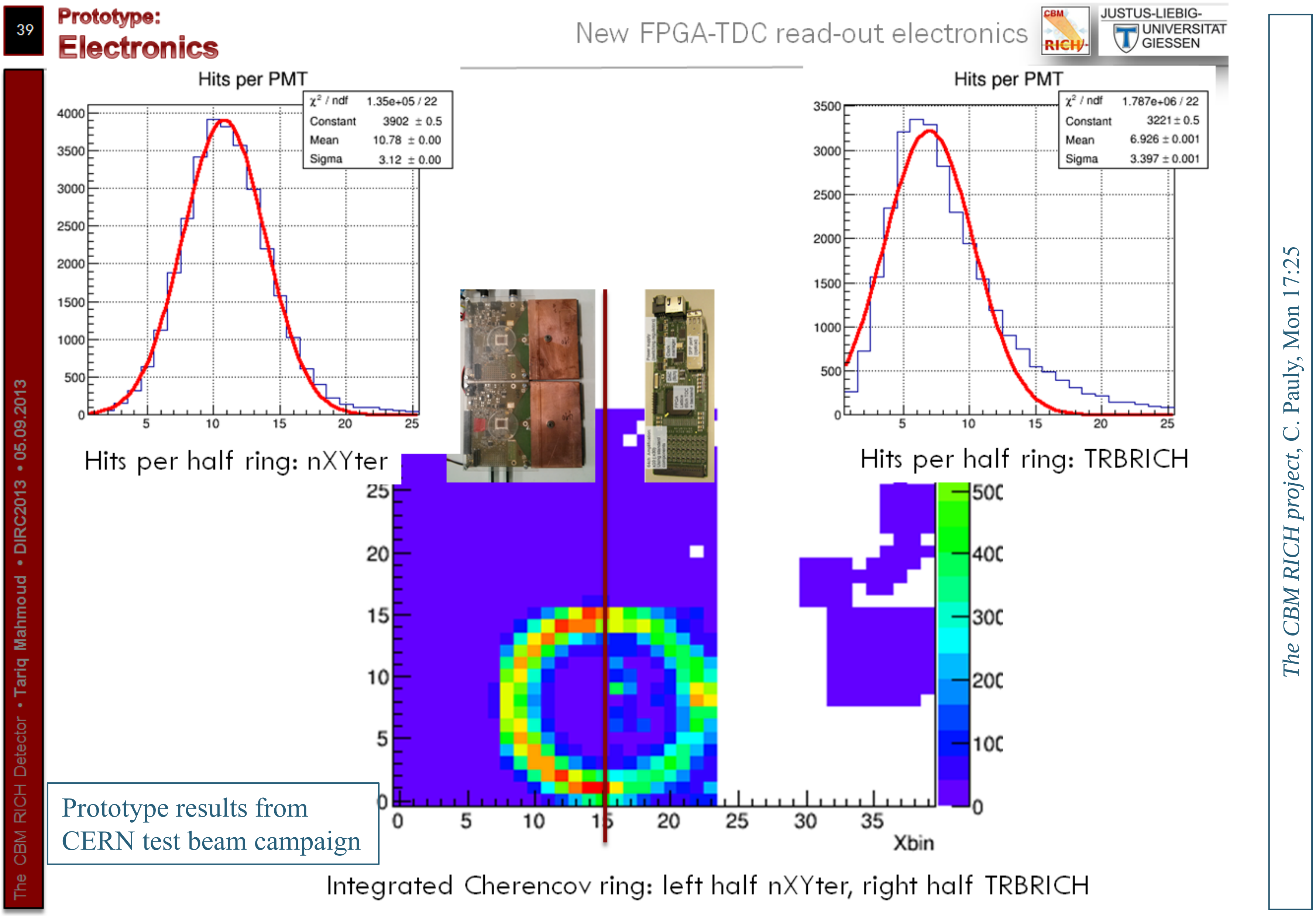


Camera
- 2.4 m^2, 55k Ch.
- MAPMT: H8500 series (Hamamatsu)?



The CBM RICH Detector • Tariq Mahmoud • DIRC2013 • 05.09.2013

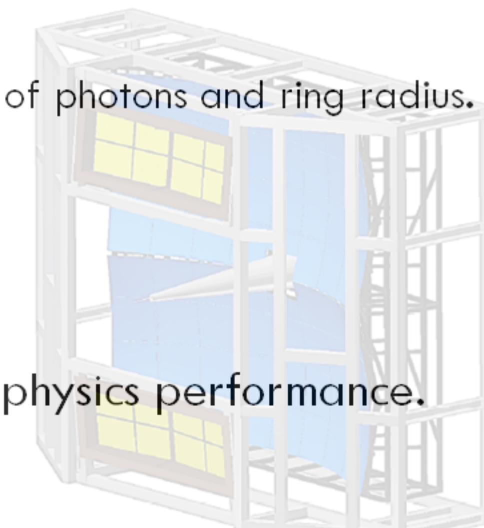
The CBM RICH project, C. Pauly, Mon 17:25


39
Prototype:
Electronics
New FPGA-TDC read-out electronics
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN
Hits per PMT
χ² / ndf 1.35e+05 / 22
Constant 3902 ± 0.5
Mean 10.78 ± 0.00
Sigma 3.12 ± 0.00
Hits per half ring: nXYter
Hits per PMT
χ² / ndf 1.787e+06 / 22
Constant 3221 ± 0.5
Mean 6.926 ± 0.001
Sigma 3.397 ± 0.001
Hits per half ring: TRBRICH
Xbin
Prototype results from CERN test beam campaign
Integrated Cherencov ring: left half nXYter, right half TRBRICH
The CBM RICH Detector • Tariq Mahmoud • DIRC2013 • 05.09.2013
The CBM RICH project, C. Pauly, Mon 17:25

43 **summary** What I have shown you

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

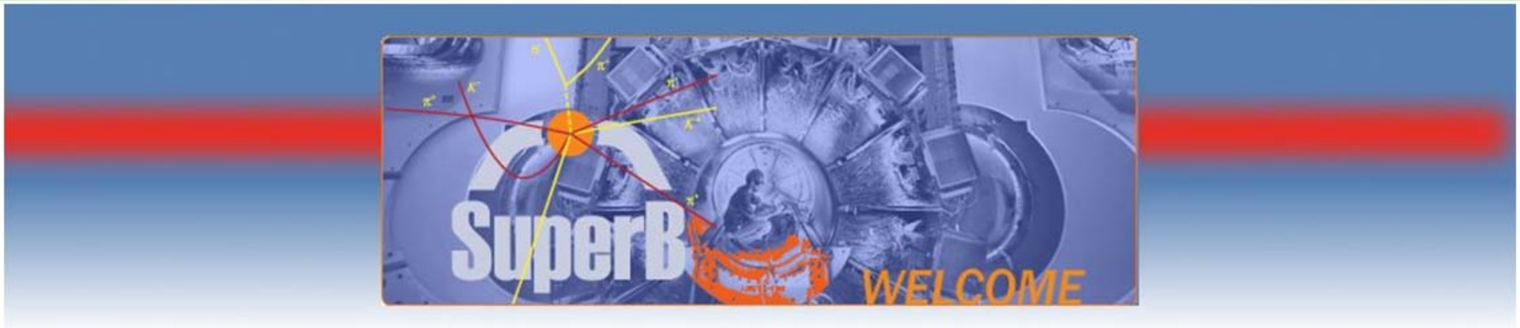
- A RICH concept is established.
- Individual components tested and chosen.
- Real dimension RICH prototype successfully build and tested.
- Test beam:
  - Excellent qualitative and quantitative performance: number of photons and ring radius.
  - WLS test → up to 18% more photons.
  - Comparison of different photon sensors.
  - Up to 1% of O_2 impurity with no effects on number of photons and ring radius.
  - Fixing tolerances of mirror misalignment.
  - Test of new electronics.
- Very good working gas system.
- Simulation under realistic conditions show good physics performance.
- TDR delivered in June 2013.



The CBM RICH Detector • Tariq Mahmoud • DIRC2013 • 05.09.2013

The CBM RICH project, C. Pauly, Mon 17:25

FDIRC FOR ITALIAN SUPERB



Physics Goals

Exploration of CKM parameters at 1% precision.

New physics in search for CP violation in D decays,
in search LFV in tau decays,
in search CP violation in tau decays.

Sensitivity to New Physics phenomena
up to energies ~ 30 TeV
(beyond LHC energies)

Physics white paper
arXiv:1008.1541
Detector CDR
arXiv:0709.0451

Results from the FDIRC prototype, D. Roberts, Mon 18:35

Jochen Schwiening, DIRC Detectors, JLab, Mar 2012 47

FDIRC FOR ITALIAN SUPERB

Focusing DIRC (FDIRC):

barrel PID system for SuperB detector in Italy (Frascati/Tor Vergata).

Important constraint:

BABAR DIRC bar boxes will be reused, readout outside magnetic field.

Expect much higher backgrounds at $10^{36}/cm^2 \cdot s$ (100 times BABAR luminosity)

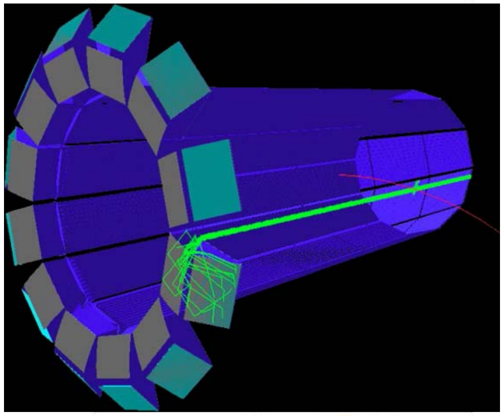
→ decrease size of expansion volume (main source of background in BABAR DIRC).

Design based on FDIRC R&D at SLAC (proof of principle); new optics and electronics

Complete redesign of the photon camera (SLAC-PUB-14282)

- True 3D imaging using:
  - 25× smaller volume of the photon camera
  - 10× better timing resolution to detect single photons
- Optical design is based entirely on Fused Silica glass

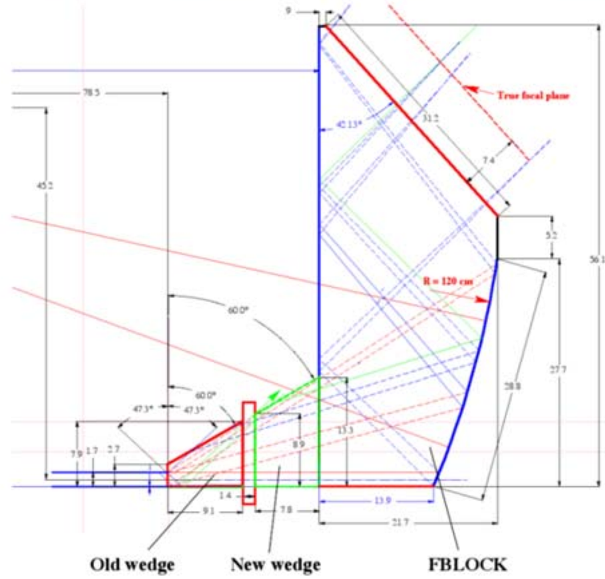
  avoid water or oil as optical medium

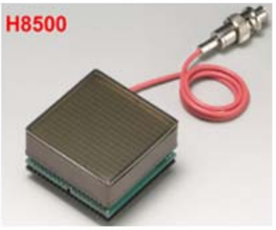


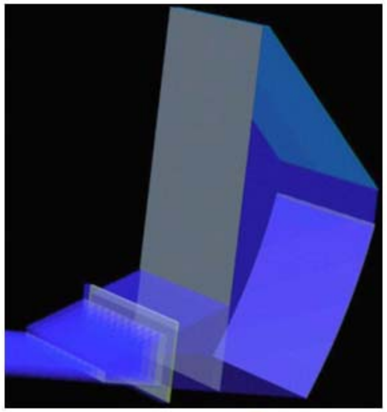
Results from the FDIRC prototype, D. Roberts, Mon 18:35

FDIRC FOR ITALIAN SUPERB

- Photon camera design (FBLOCK):
  - Initial design by ray-tracing (SLAC-PUB-13763)
  - Geant4 model now (SLAC-PUB-14282 – RICH 2010 talk)
  - Focusing block from Corning 7980 sythetic fused silica
- Main optical components
  - New wedge (old bar box wedge was not long enough)
  - Cylindrical mirror to remove bar thickness
  - Double-folded mirror optics to provide access to detectors
- Photon detectors: highly pixilated H-8500 MaPMTs
  - Total number of detectors per FBLOCK: 48
  - Total number of detectors: 576 [12 FBLOCKs]
  - Total number of pixels: $576 \times 32 = 18{,}432$





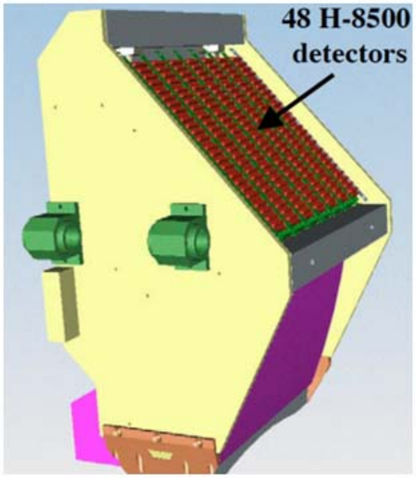


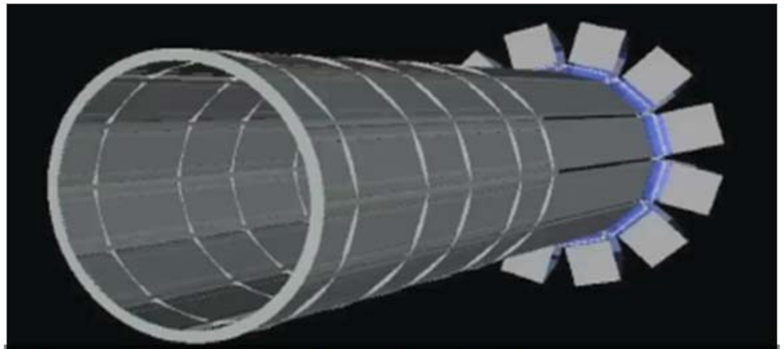
Results from the FDIRC prototype, D. Roberts, Mon 18:35

SUPERB FDIRC

FDIRC FOR ITALIAN SUPERB

- FDIRC design parameters
  - Timing resolution per photon: ~200 ps
  - Cherenkov resolution per photon: 9-10 mrad
  - Cherenkov angle resolution per track: 2.5-3.0 mrad
  - Cherenkov angle determined from 2D spatial coordinates
  - Time primarily used to correct chromatic dispersion
- Members of the SuperB PID system
  - USA: SLAC, Maryland, Cincinnati
  - France: LAL, LPNHE
  - Italy: Bari, Padova
  - Russia: Novosibirsk





Photon cameras at the end of bar boxes in Geant4

New focusing block at SLAC.

Results from the FDIRC prototype, D. Roberts, Mon 18:35

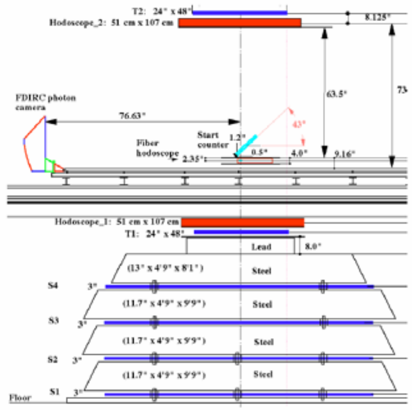
First full-size FDIRC sector at SLAC CRT

A proof-of-principle of the technology

Test facility: SLAC Cosmic Ray Telescope

- Selects muons with $p > 2$ GeV so that $\theta_C = 47.2°$
- Good tracking resolution of ~1.5 mrads
- 3D muon tracks (needed to fully characterize the device)
- Precise timing given by a small Cherenkov start-counter

NIM A701 (2013) 115-126
SLAC-PUB-13873

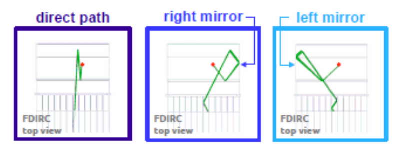


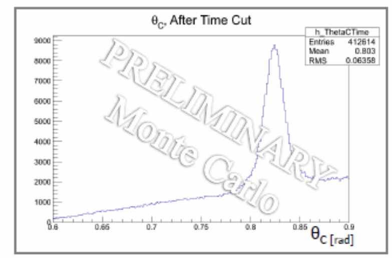
First FDIRC sector built and instrumented

- First fused silica optical block manufactured
- Plating of the surfaces
- Optical coupling
- Mechanical enclosure (Fbox)
- 12 H-8500 MaPMTs (768 channels)
- Fast digitizing electronics (SLAC, Hawaii, LAL)

Data analysis

- Full Geant4 simulation is needed to map pixel hits to photon directions (lookup table)
- Ambiguities due to the multiple possible photon paths:
  - Complex problem (>10 ambiguities per hit)
  - Use hit time to remove some of the ambiguities
  - Various reconstruction algorithms being studied





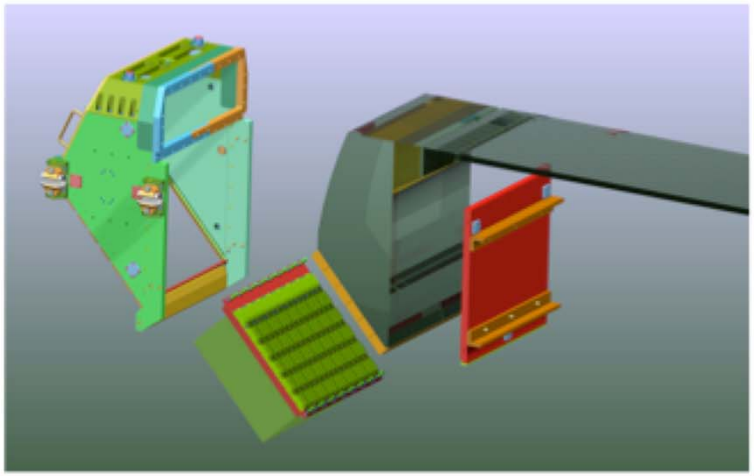
Data are being collected right now
Results are expected soon

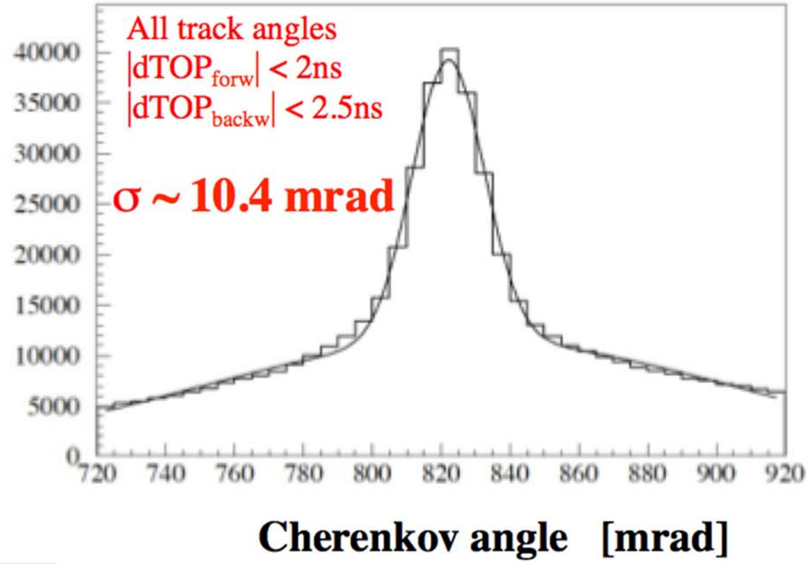
Results from the FDIRC prototype, D. Roberts, Mon 18:35

Martino Borsato, VCI2013

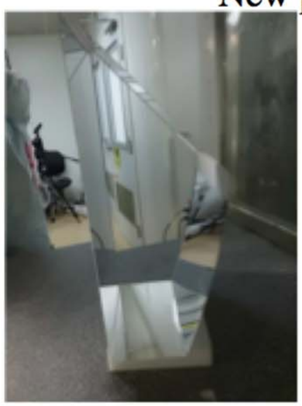
Cherenkov angle resolution in cosmic ray telescope with 3D tracks

New photon camera is added to BaBar bar box

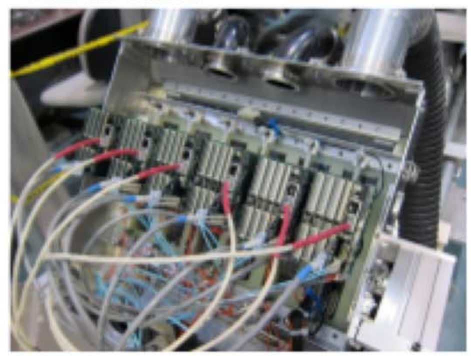




New photon camera



Electronics



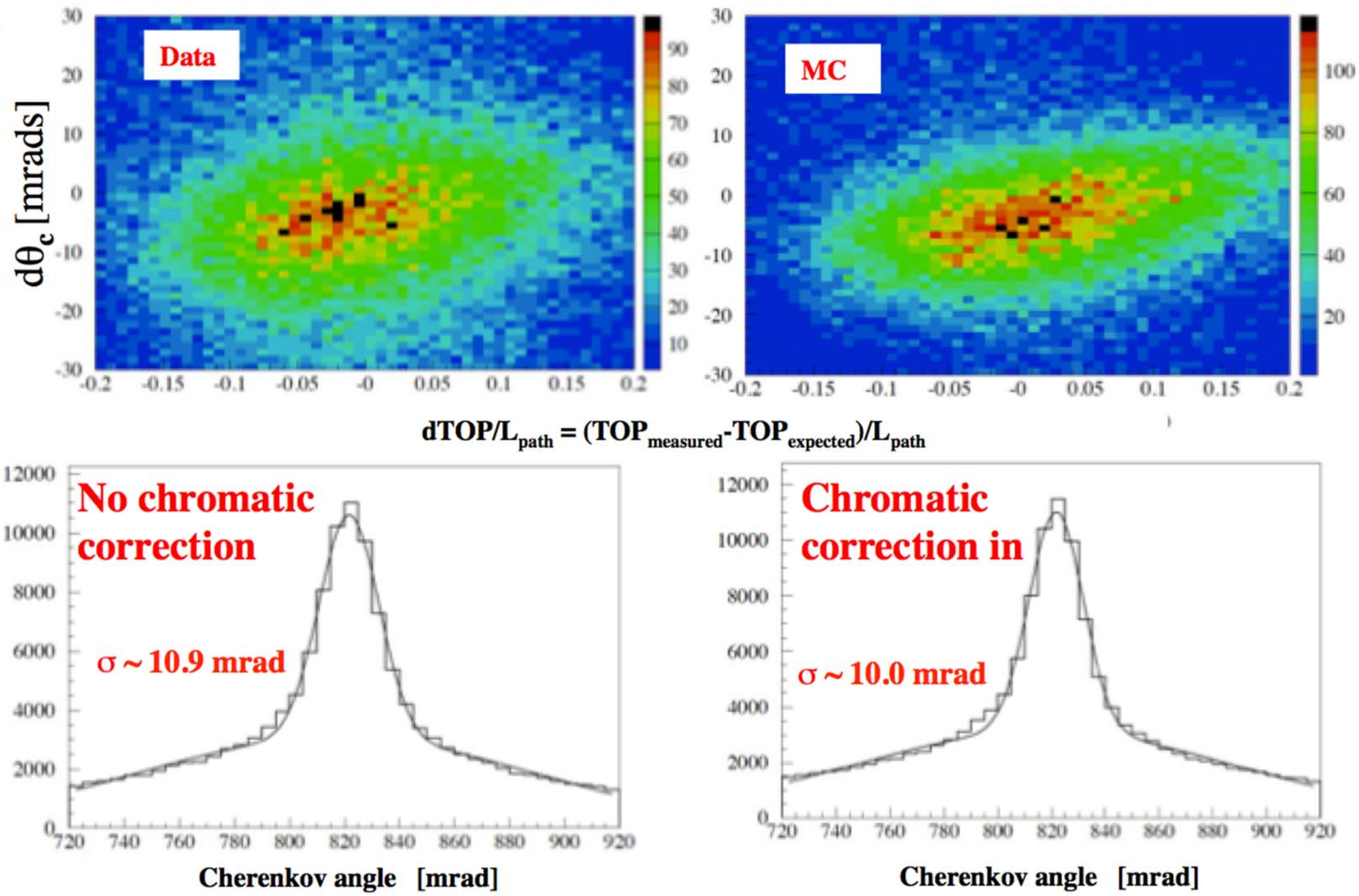
- **Measured Cherenkov angle resolution (10.4 mrads) with hard muons (>2GeV) in cosmicray telescope with 3D tracks and real DIRC bar box.**

J. Va'vra | 11/30/13 | New FDIRC | 1

Results from the FDIRC prototype, D. Roberts, Mon 18:35

Chromatic correction using 3D tracks and real bar box

Backward photons:



- **Use this correlation from data to correct θ_c by time. We gain about ~0.8 mrads. MC expects a gain of ~ 1 mrad. We hope to further improve this correction by improving timing resolution.**

Results from the FDIRC prototype, D. Roberts, Mon 18:35

HERMES RICH

RICH of HERMES -- Dual Radiator RICH: aerogel and C_4F_{10}

Pion, Kaon, Proton and Antiproton Identification at 2-14 GeV/c

HERMES is a deep inelasic scattering experiment.

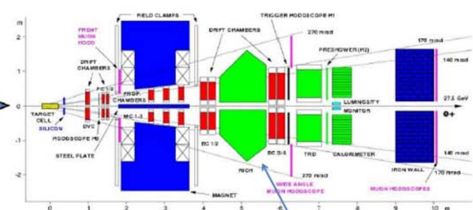
The beam is 27.6 GeV electron or positron of DESY.

The targets are internal gas targets: proton, deuteron, and nuclei -- polarized and unpolarized

The Spin Structure of The Nucleon is studied.

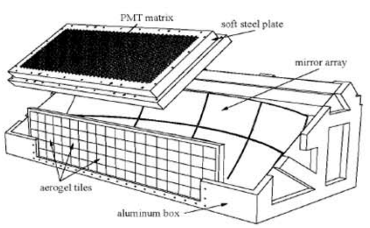
Hadrons are detected in coincidence with scattered electron.

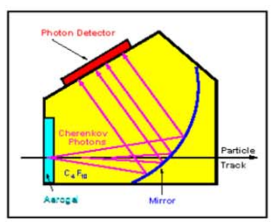
HERMES



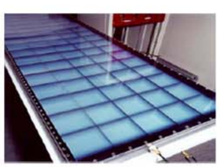
Dual Radiator RICH

Aerogel, n=1.0304, C_4F_{10} gas, n=1.00137





Cherenkov lights are reflected with a common mirror and are detected with 1934 phototubes of ¾ inch diameter.

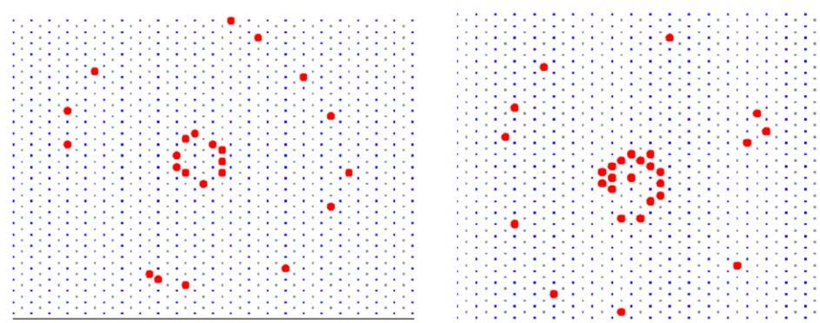


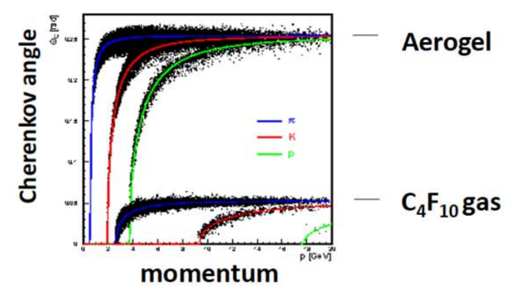
A wall made of aerogel tiles

Examples of dual Cherenkov rings:

Outer ring - aerogel

Inner ring – C_4F_{10} gas





Recent Physics Results from HERMES with RICH

A. Airapetian et al., HERMES, Phys. Rev. D 87 (2013) 012010

Azimuthal asymmetry of pions and Kaons with unpolarized proton and deuteron targets

December, 2013 RICH2013, T.-A. Shibata

HERMES RICH, T.-A. Shibata, Poster