Cherenkov light imaging in particle and nuclear physics experiments

K. Inami (Nagoya univ.)

2016/9/5, RICH2016

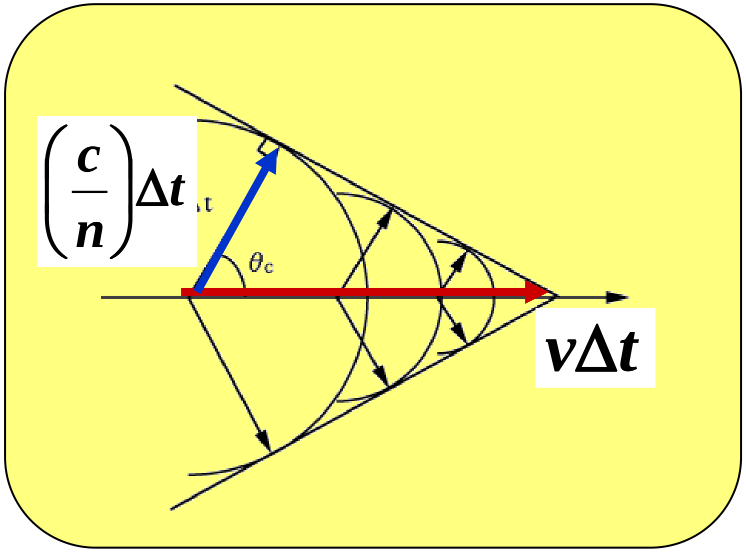
Topics in the session

Performance of the LHCb RICH detectors during the LHC Run II	Antonis Papanestis
ALICE-HMPID performance at 13TeV √s during LHC Run2	Giacinto De Cataldo
Construction and Performance of the NA62 RICH	Massimo Lenti et al
The Belle II imaging Time-of-Propagation (iTOP) Detector	James Fast
Aerogel Ring Imaging Cherenkov at the Belle II spectrometer	Rok Pestotnik et al
The PANDA Barrel DIRC Detector	Jochen Schwiening
The GlueX DIRC Detector	Maria Patsyuk et al
The new large-area hybrid-optics RICH detector for the CLAS12 spectrometer	Marco Mirazita
Overview of LHCb-RICH upgrade	Sajan Easo
The TORCH detector R&D: status and perspectives	Thierry Gys
The RICH detector of the CBM experiment	Tariq Mahmoud et al
The Endcap Disc DIRC of PANDA	Michael Düren et al
The Forward RICH Detector for the PANDA Experiment	Sergey A. Kononov et al
Cherenkov Detector work at Stony Brook University	Thomas Hemmick
A study of the attainable Cherenkov angle resolution in cylindrical mirror-based Focusing DIRC designs using BaBar style radiators	Biplab Dey et al
The Future of RICH Detectors through the Light of the LHCb RICHes	Carmelo D'Ambrosio et al

+ Many presentation in other sessions and also poster session

Cherenkov radiation

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



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

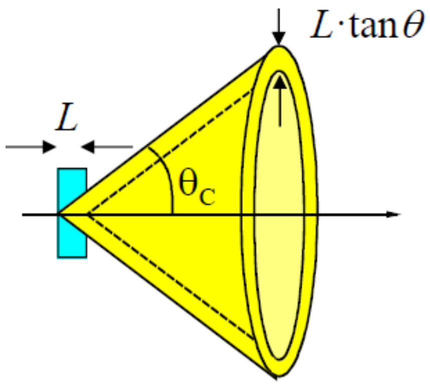
- Angle $$\cos\theta_c = \frac{1}{\beta\, n(\lambda)}$$

We can obtain β information from Cherenkov ring detection.

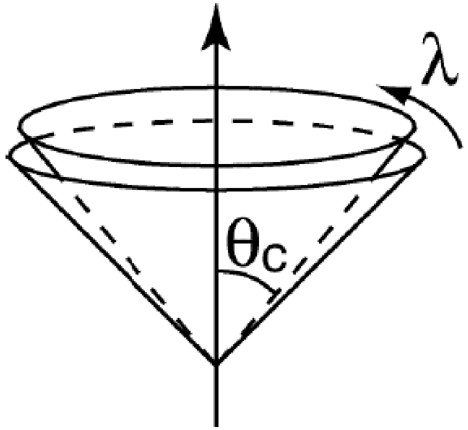
- Photons $$N_{\text{photons}} = L\frac{\alpha^2 z^2}{r_e m_e c^2}\int \sin^2\theta_c(E)\,dE \implies N_{\text{photons}} \propto \frac{1}{\lambda^2}$$

Cherenkov ring imaging

- Radiation in limited region
- Photons collected by photon sensor pixels
  - Radiator length
    - $N_{photons}$ ~ L and image resolution
  - Optics design
    - Proximity/mirror focusing
  - Sensitive wavelength and pixel size of sensors
    - $N_{photons}$ ~ $1/\lambda^2$ and image resolution



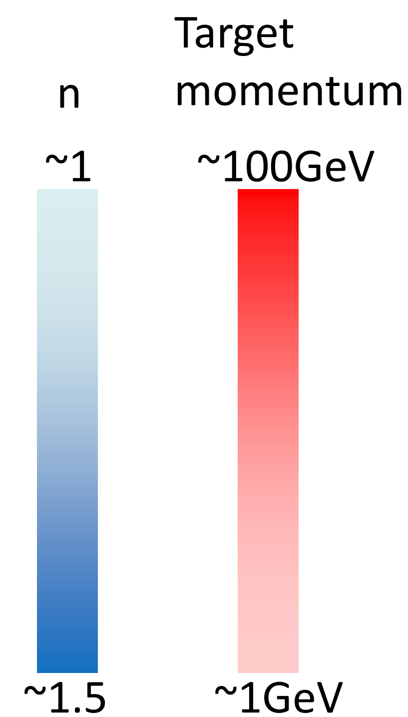
- Notes on reality
  - Chromatic dispersion by refractive index change
  - Detector space, cost, etc.



RICH counters

- Overview of recent counters
  - (From my viewpoint, for selected counters …)
  - Categorized by the radiator type

- Gas
  - LHCb RICH, CBM RICH, NA62 RICH
- Aerogel
  - Belle II ARICH, CLAS12
- Quartz
  - Belle II TOP, PANDA DIRCs, TORCH



RICH using gases

- Ring imaging through focusing mirror (or vessel window)
  - Limit radiation region by mirror (or window)
  - Focus on photon sensor, depending on the Cherenkov angle

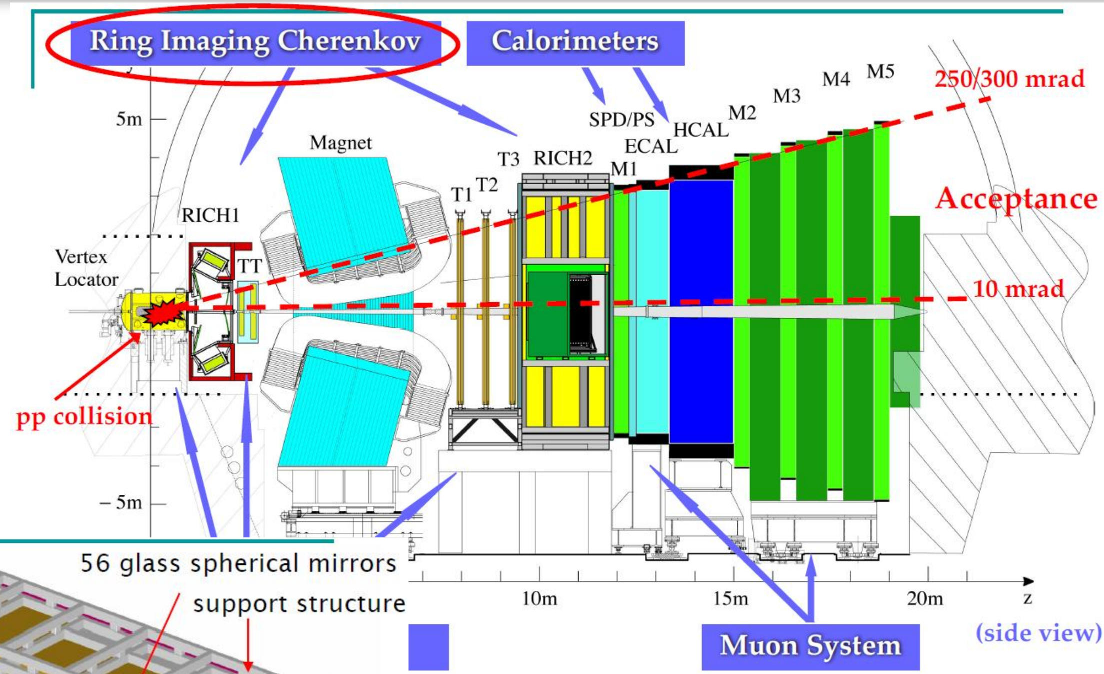
- Low refractive index
  - Higher beta threshold → Target momentum: higher, O(10GeV)
- Narrow Cherenkov angle
  - Larger optics region

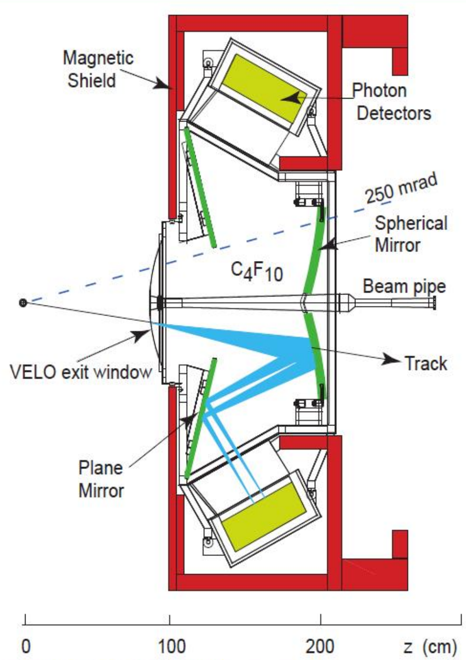
- Advantage to cover large area

LHCb RICH

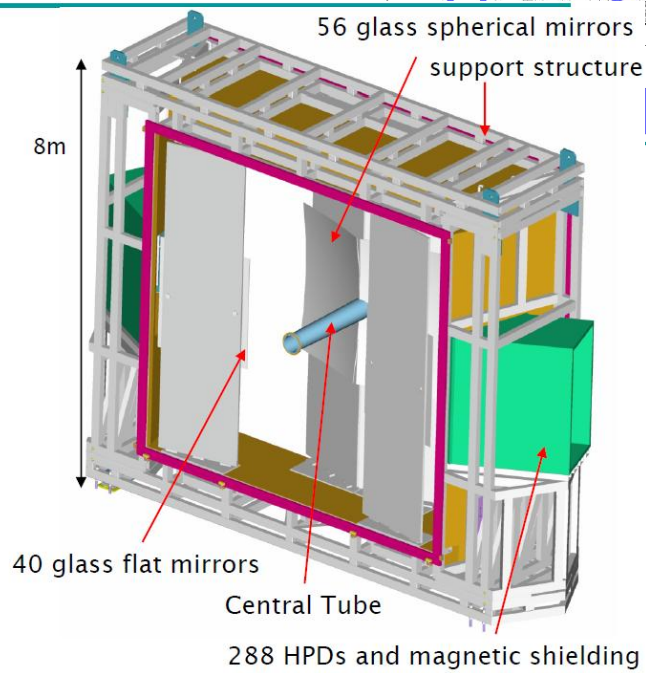
- Separation of π/K/p
- RICH-1; C_4F_{10}, n=1.0014, <60GeV
- RICH-2; CF_4, n=1.0005, <~100GeV
- Focusing mirror optics
- Pixel HPD array

→Will upgrade optics and PMTs in 2019-2020

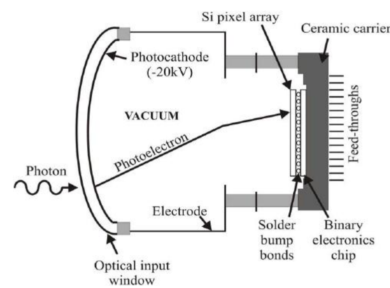




RICH-1 (25-300 mrad)



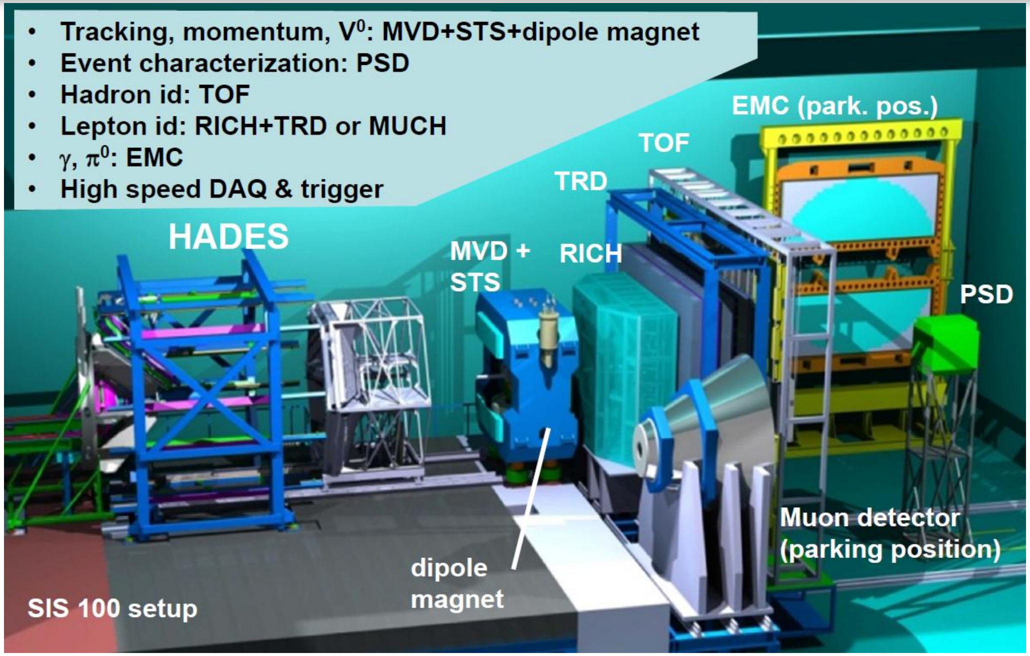
RICH-2 (15-120 mrad)



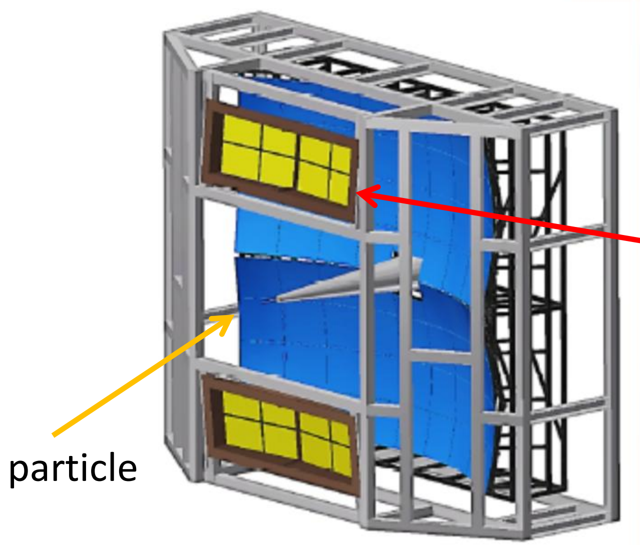
Pixel HPD

CBM RICH

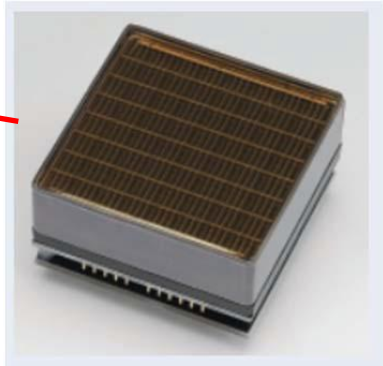
- Separation of e/π/(K) for < 10 GeV
- Radiator; CO_2 gas
- Focusing optics
  - glass mirror: R=3m
- Photodetector (55k Ch.)
  - MA-PMTs
  - Enhanced UV sensitivity using wavelength shifter?



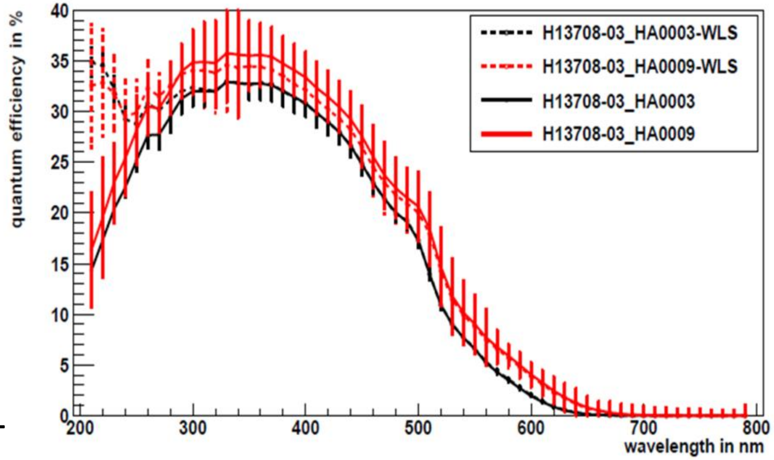
Au+Au



2m x 5.14m x 3.93m (length x height x width)



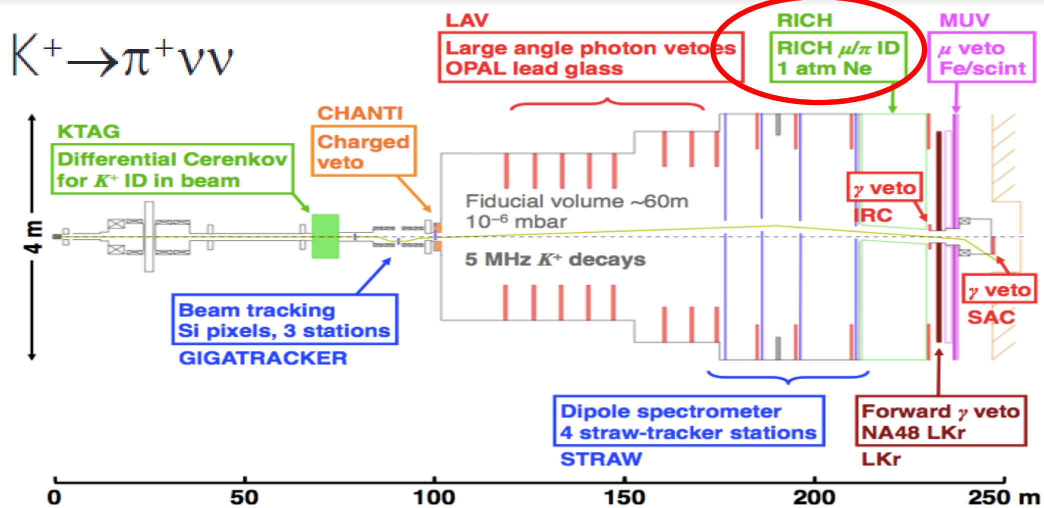
Hamamatsu 2" MA-PMT

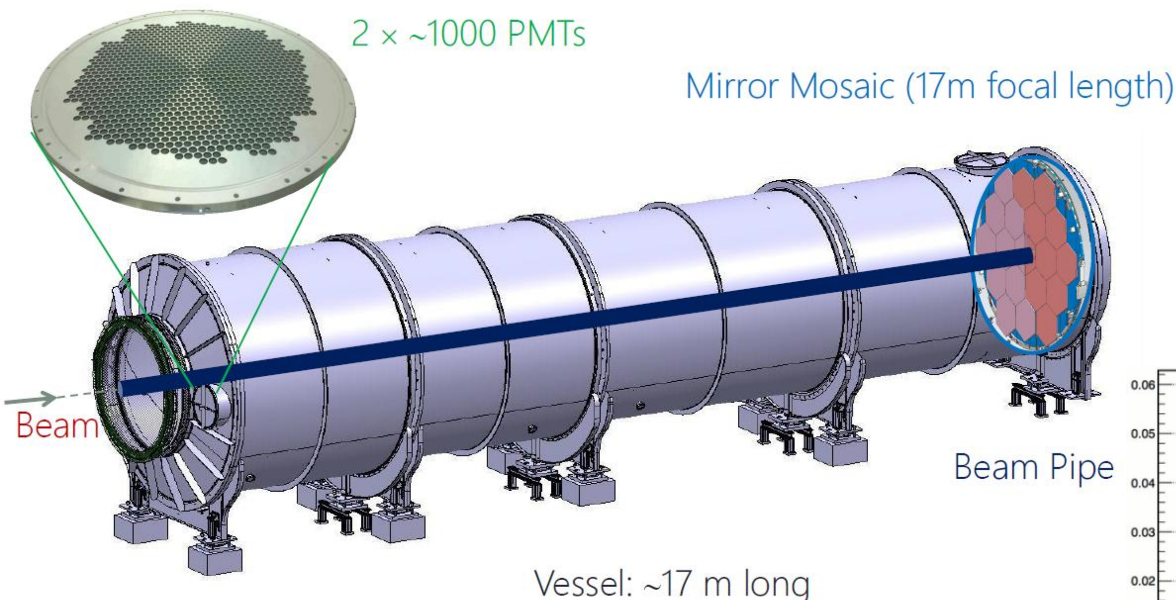


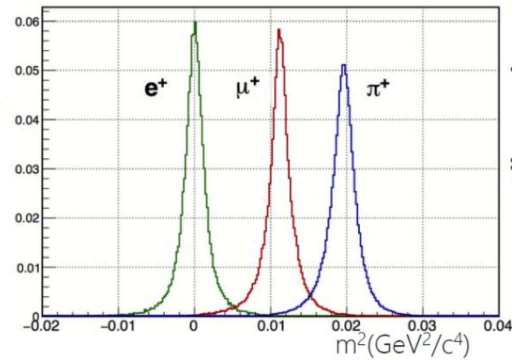
C.Hohne@DIRC2015

NA62 RICH

- Separation of π/μ for 15 - 35GeV
- Neon gas; n=1.000063
- Focusing mirror; 17m focal length
- 2x~1000PMTs
  - Winston cone light guide
- Required performance obtained

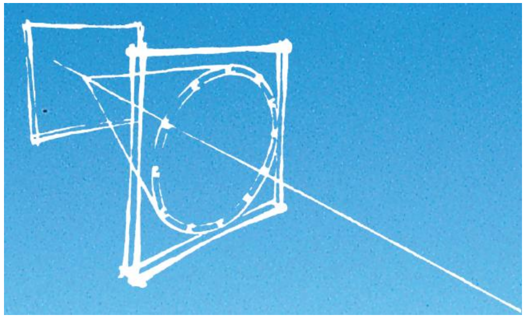






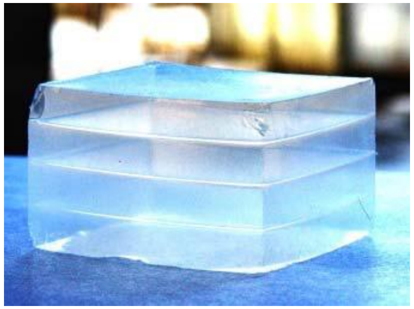
RICH by aerogel

- Ring imaging through proximity focusing or mirrors
  - Cherenkov light comes out directly from radiator of finite region.



- Aerogel improvements
  - Transparency
  - Tunable refractive index
  - Larger tiles

  → Allow more desirable detector design.



- Easy to maintain, once constructed

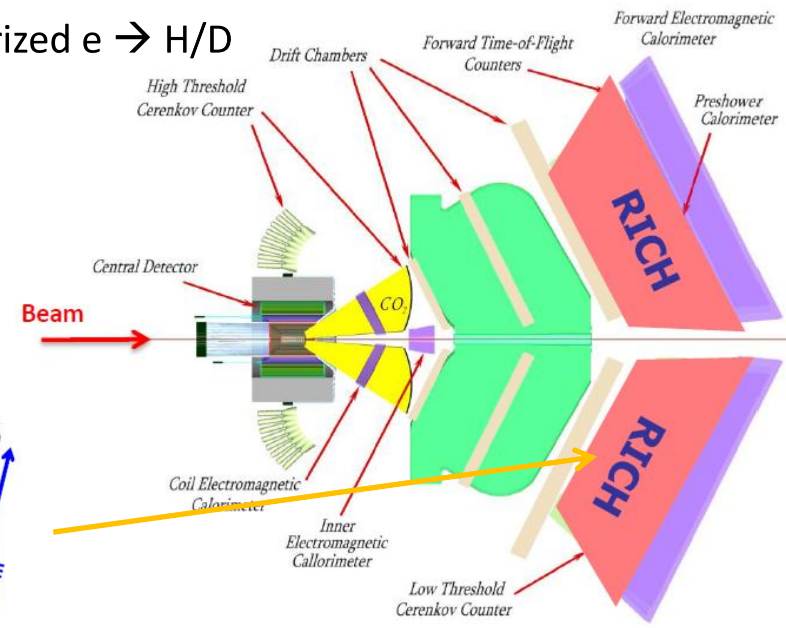
CLAS12 RICH

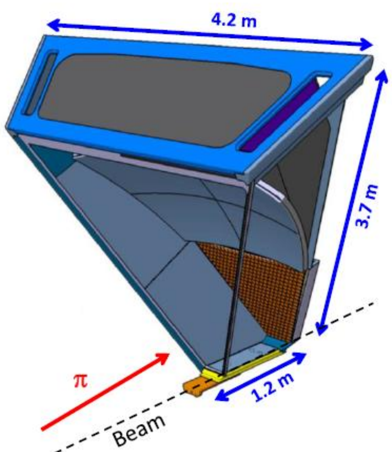
- Selection of π/K/p for 3 – 8 GeV
- Complex optics design
  - Two regions depending on momentum and its required resolution
  - Transparency improvement

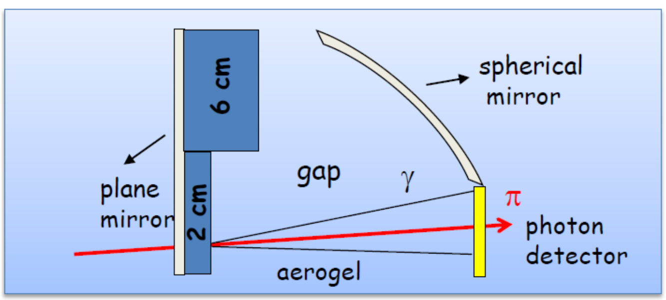
→ Compact optics and smaller sensor area

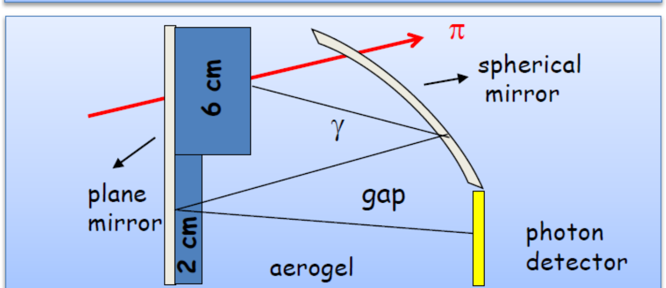
- MA-PMT as photon sensor

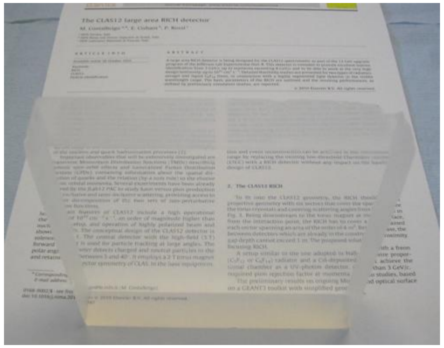
Polarized e → H/D



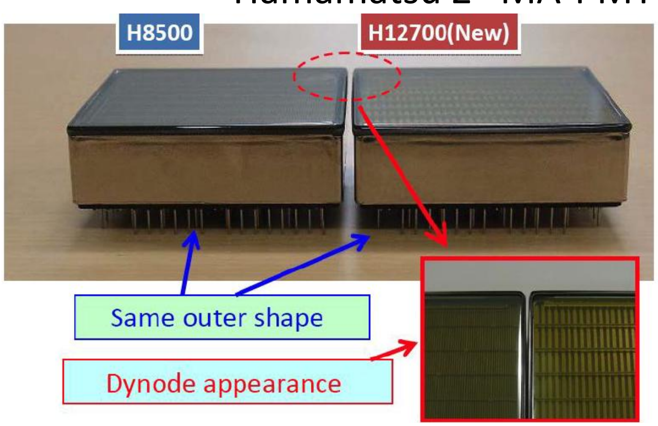






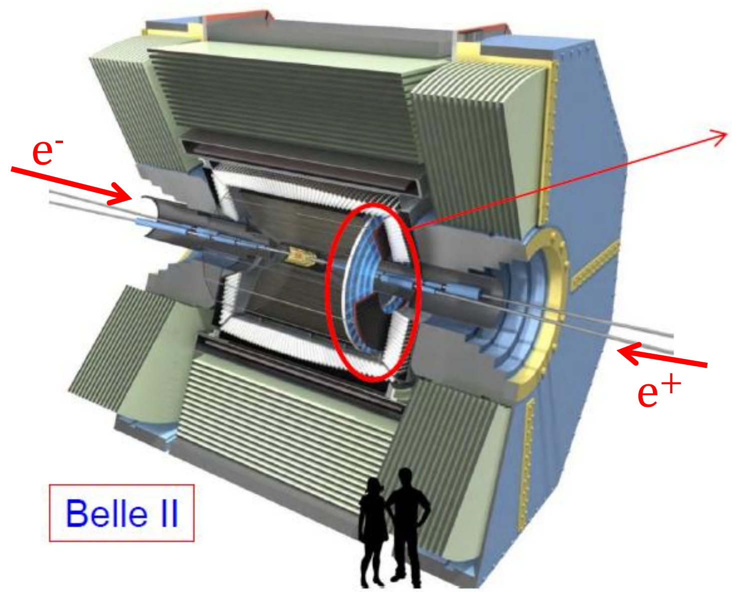


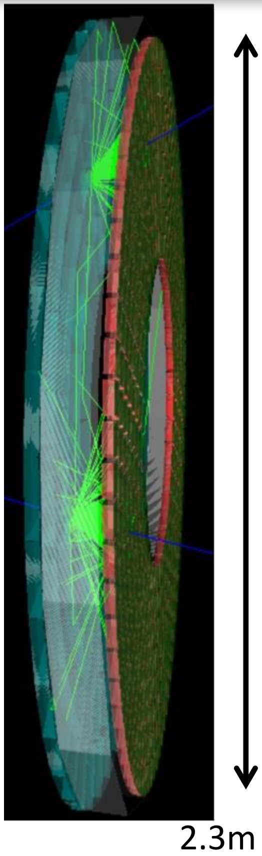
Hamamatsu 2” MA-PMT

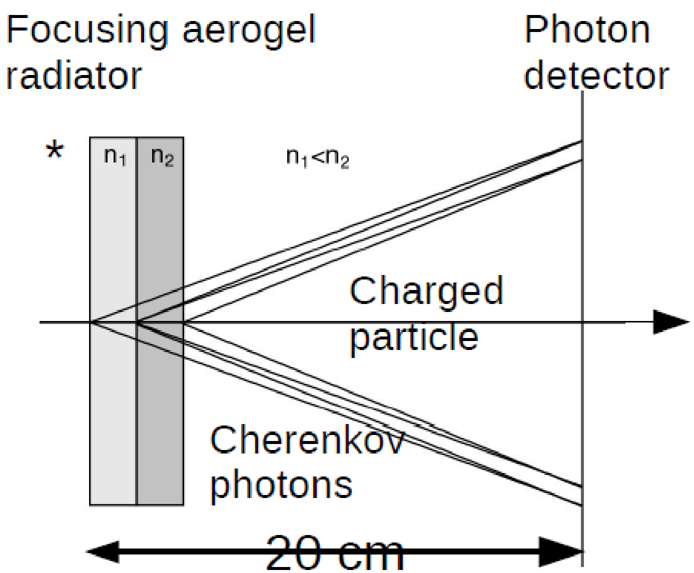


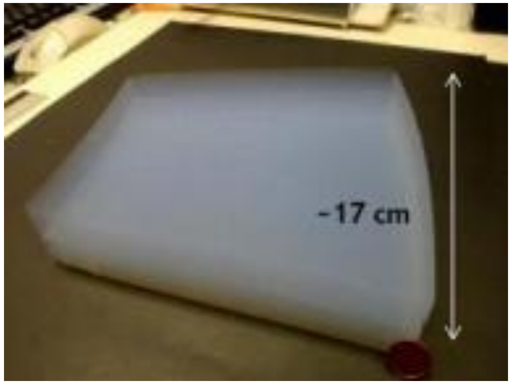
Belle II ARICH

- Separation of π/K/p for 1 – 4 GeV
- Proximity focusing optics
- Two layer aerogel
  - To increase N_{photon}
  - Different index to focus, to improve ring image resolution
    - n_1=1.045, n_2=1.055
- HAPD for readout
  - Work in magnetic field

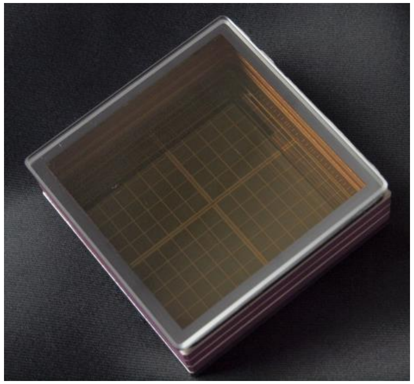




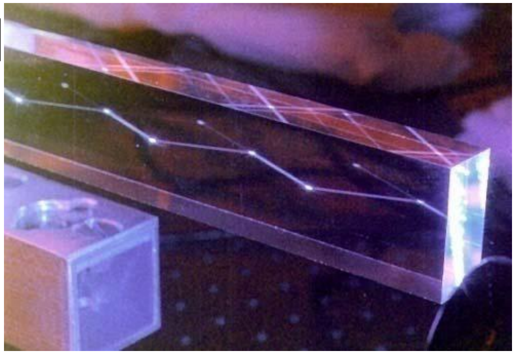




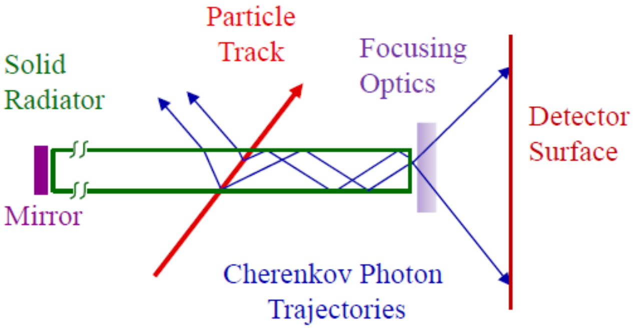
Hamamatsu 2” HAPD



Fused silica (quartz) based RICH



- Ring imaging by DIRC (Detection of Internally Reflected Cherenkov light)
  - Larger (n>1.414) index radiator
- DIRC concept
  - Charged particle emits Cherenkov light.
  - Some Cherenkov photons pass though the radiator because of the totally internally reflection.
  - The Cherenkov angle conserved through the radiator.
  - Photons exit to expansion region with focusing optics.
  - Photon sensors detect the image.

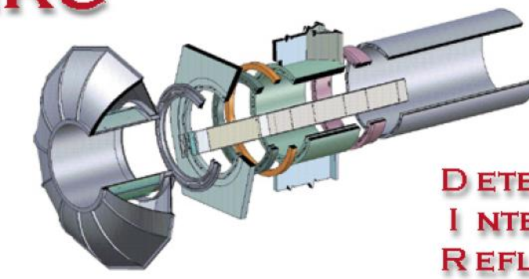


- Thinner space for radiator and optics in the active area

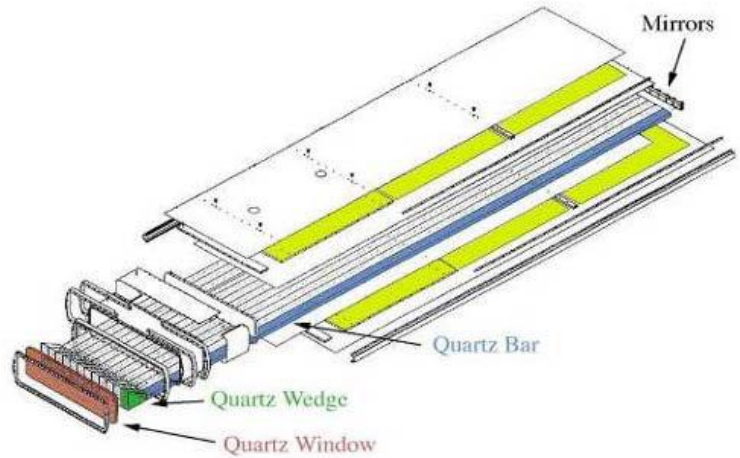
Success of BABAR DIRC

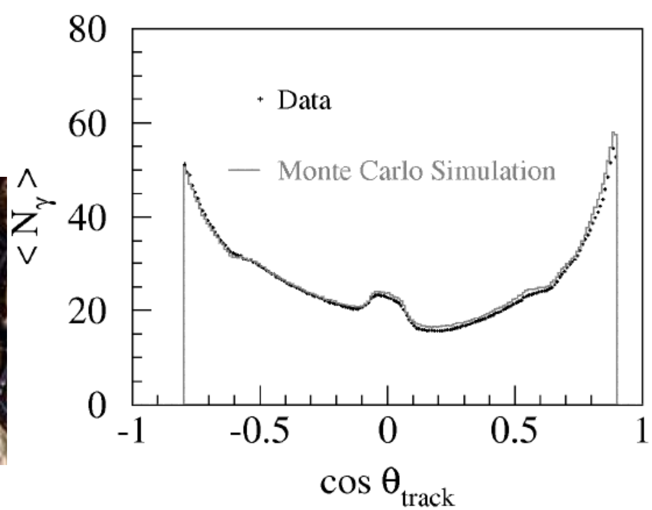
- Separation of π/K for < 4 GeV
- Narrow quartz bars with large expansion volume
  - High quality surface of quartz
  - ~6000L ultra-pure water for expansion
- ~10000 standard 1” PMTs
- Excellent performance, stable operation

DIRC

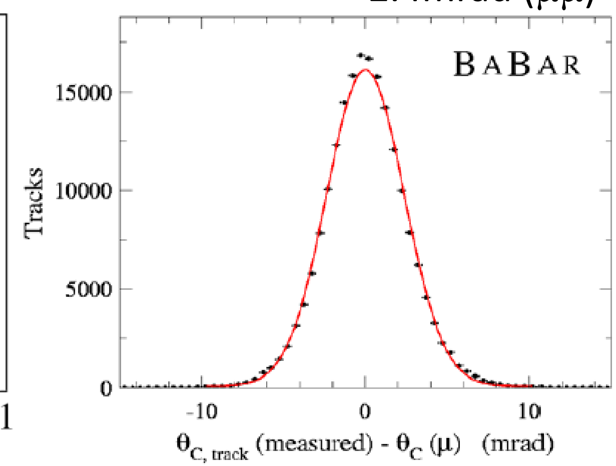


DETECTION OF
INTERNALLY
REFLECTED
CHERENKOV LIGHT





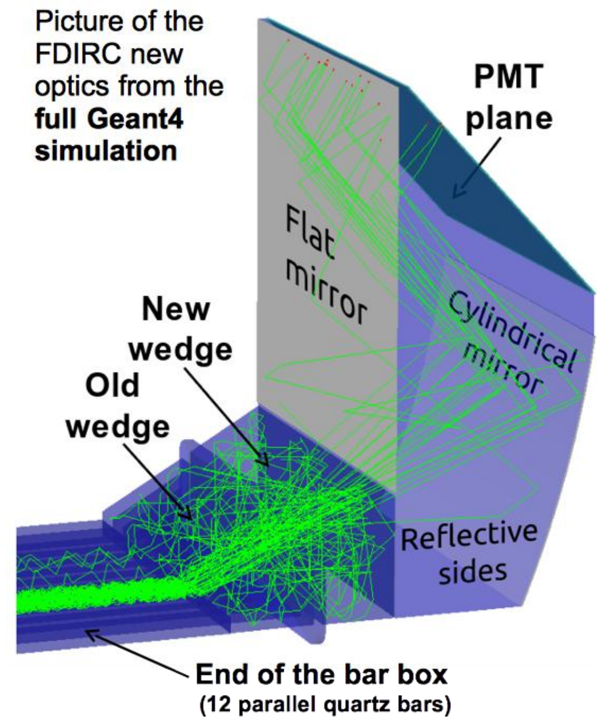
2.4mrad (μμ)

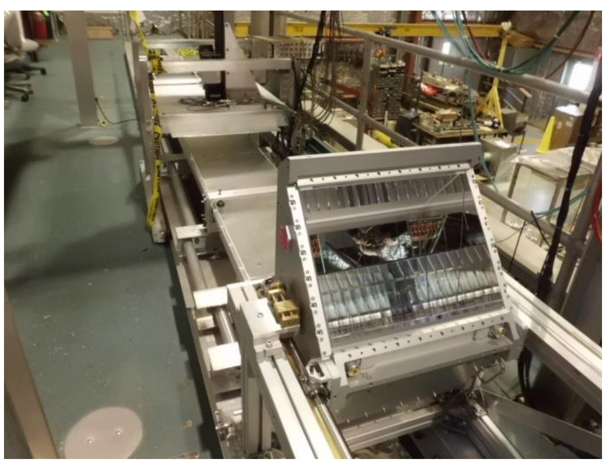


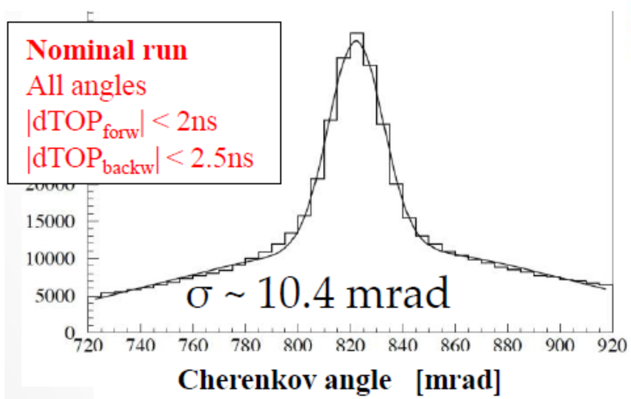
FDIRC R&D

- To improve for future experiment (intended for SuperB)
  - Smaller expansion volume, photon detectors with smaller pixel and fast timing, etc.
  - To be less sensitive to background
  - To improve Cherenkov angle resolution
- Focusing block attached to bar
  - Reduce volume and photon sensor area
- Faster photon detector and electronics
  - For chromatic dispersion correction

→ Prototype works well

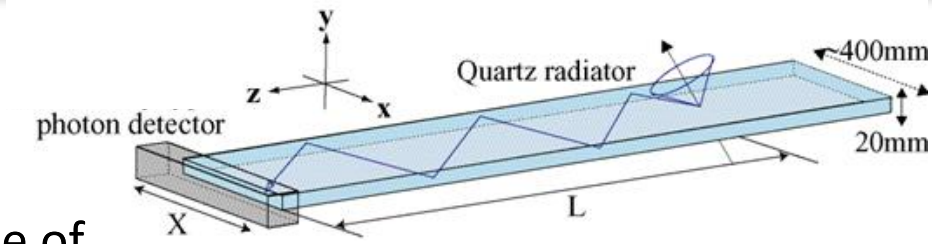




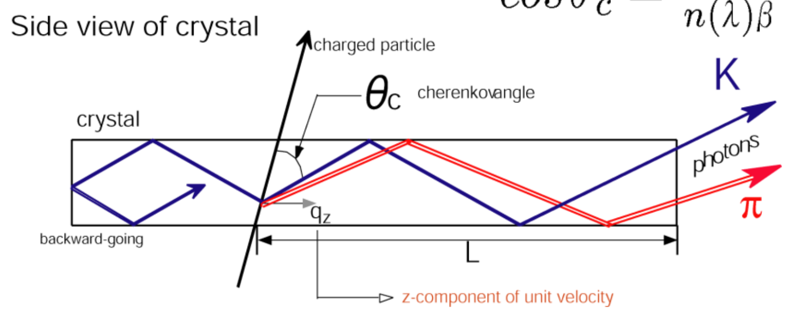


TOP R&D for Belle II

- Cherenkov ring imaging based on the precise timing information
- Difference of path length → Difference of Time of Propagation (TOP)
- Measures TOP + TOF (100-200ps) from IP
- Key technologies:
  - Single photon detection with precise timing (σ<50ps for single photon)
  - Accurately polished large quartz bar

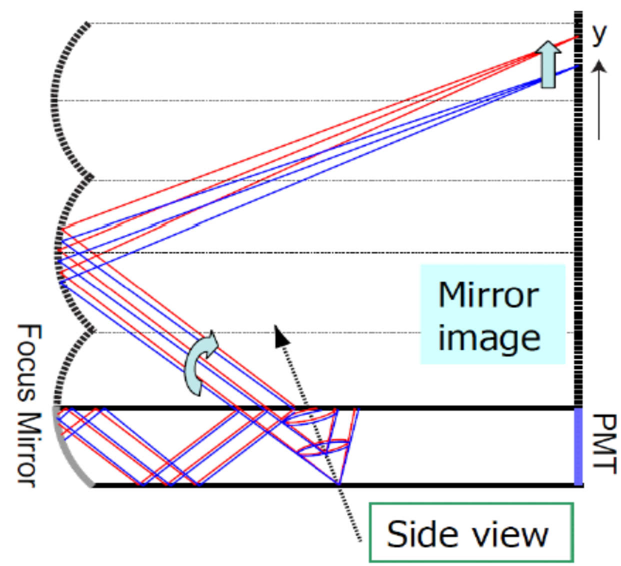


$$\cos\theta_c = \frac{1}{n(\lambda)\beta}$$



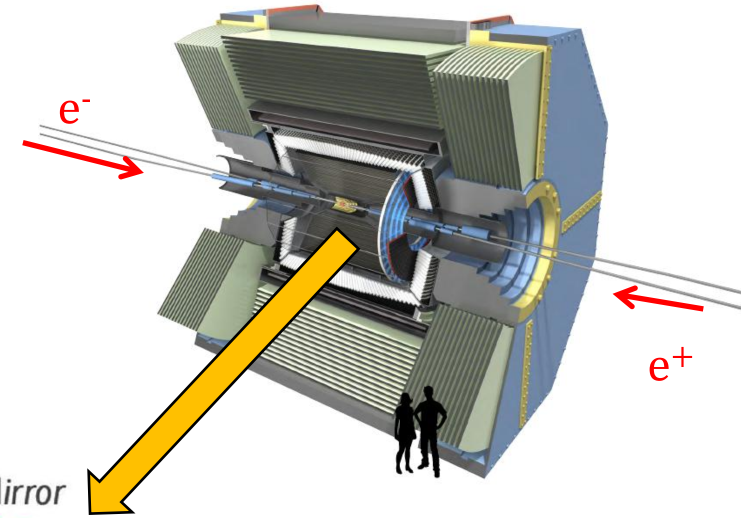
- Chromatic dispersion on light velocity smears the timing resolution by ~100ps.
- Use λ dependence of Cherenkov angle to correct chromaticity

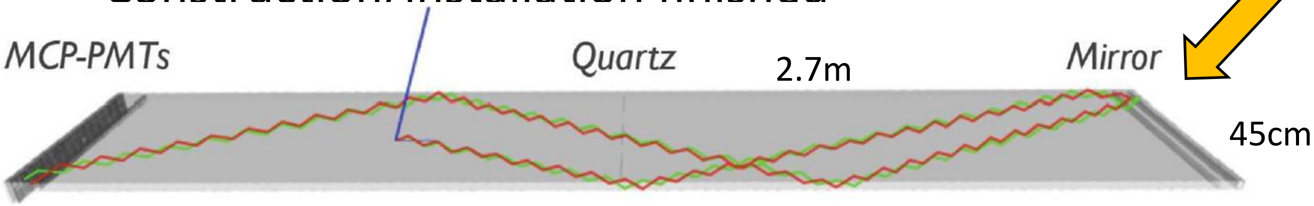
➔ Focusing mirror on bar end, to measure θ_c
  - Long focusing length enlarges y difference.
    - $\Delta\theta_c$~5mrad → Δy~14mm for 2.5m length



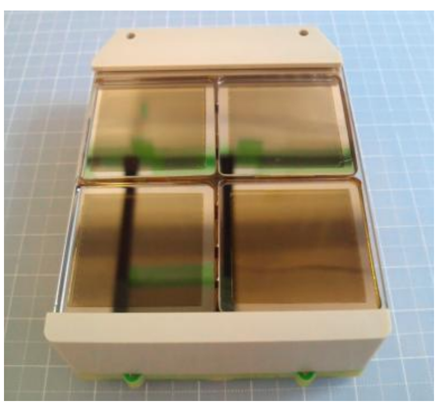
Belle II TOP

- Separation of π/K/p for < 4GeV
- Wide bar with focusing mirror and expansion
  - Focusing mirror: R=6.5m, Expansion:10cm
- 512 MCP-PMTs with 5x5mm^2 pixels
  - With fast readout electronics
- Construction/installation finished

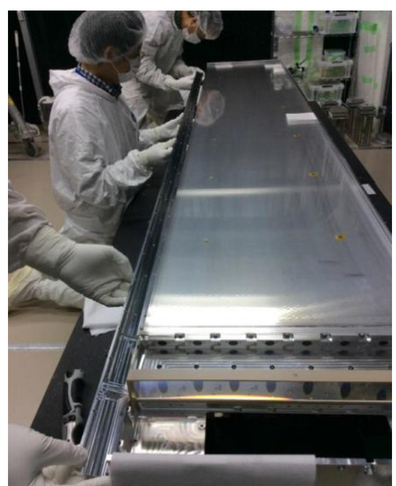


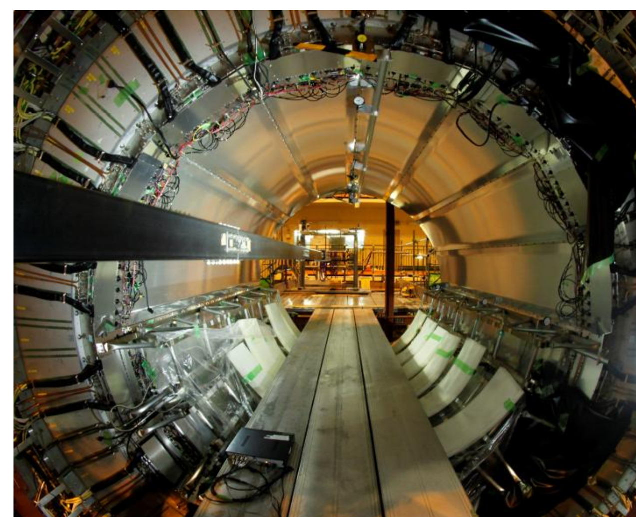


Example of Cherenkov-photon paths for 2 GeV/c $\pi^\pm$ and $K^\pm$.



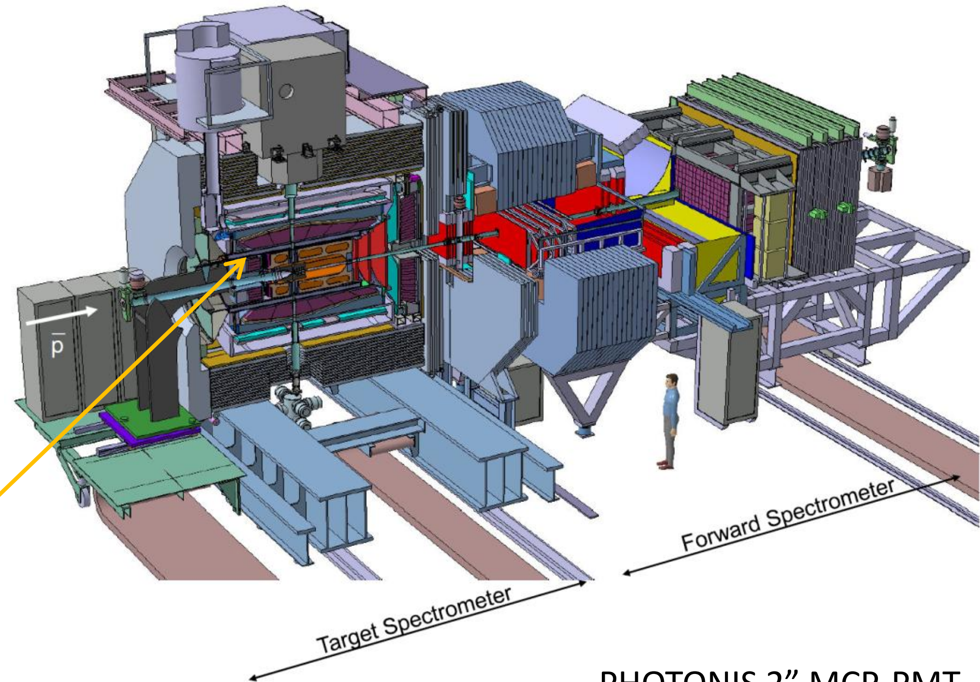
MCP-PMT module with Hamamatsu 1” MCP-PMT

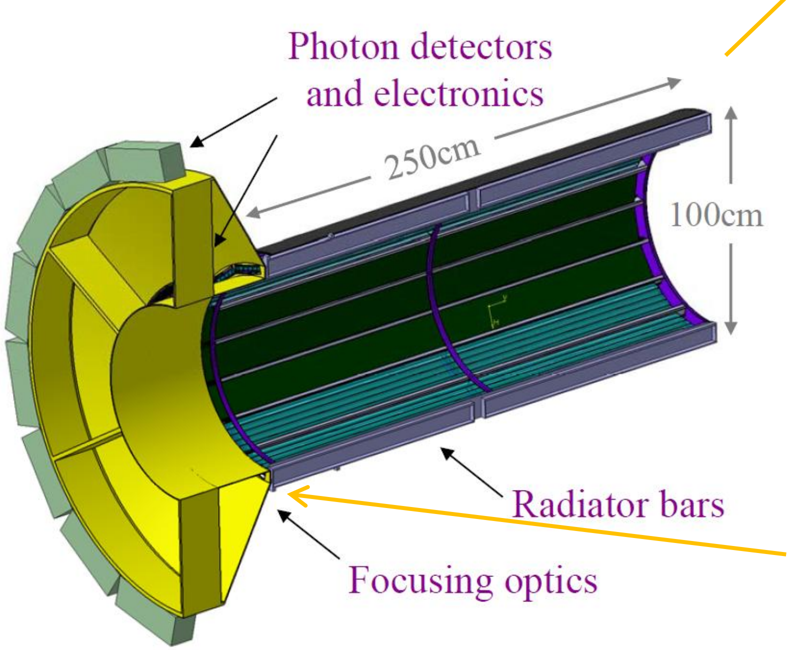


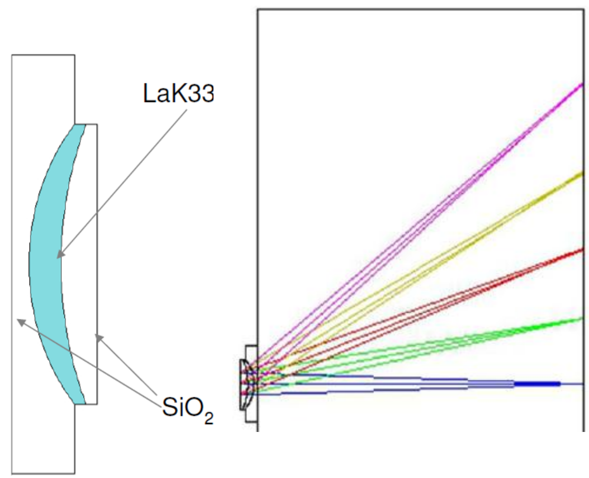


Panda DIRC at barrel

- Separation of π/K for < 3.5GeV
- Based on BABAR DIRC with improvements
  - Lens focusing
  - Compact expansion block
  - Fast photon detection (MCP-PMT)
- Prototype tests and optimization in progress



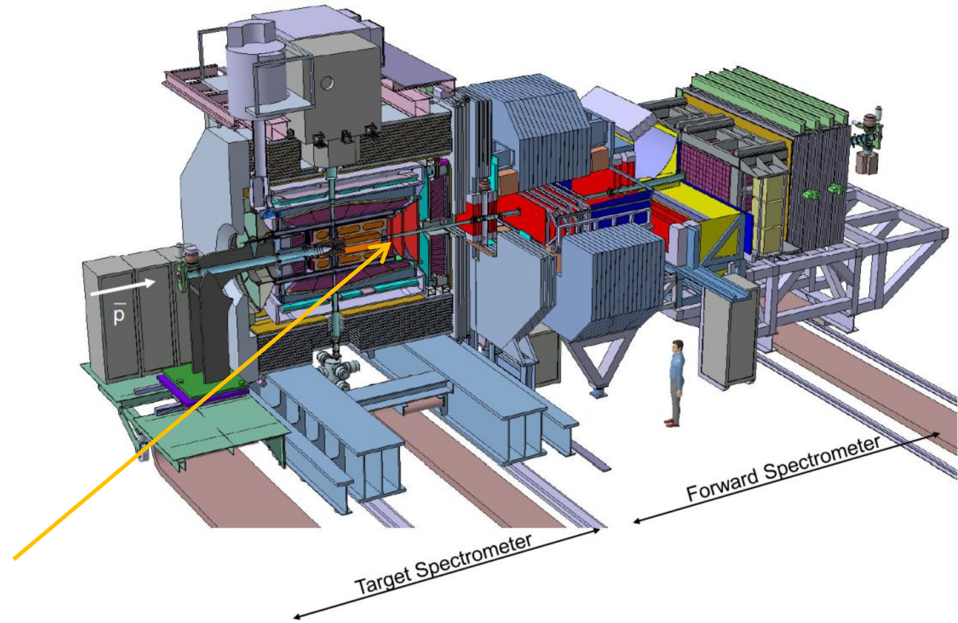




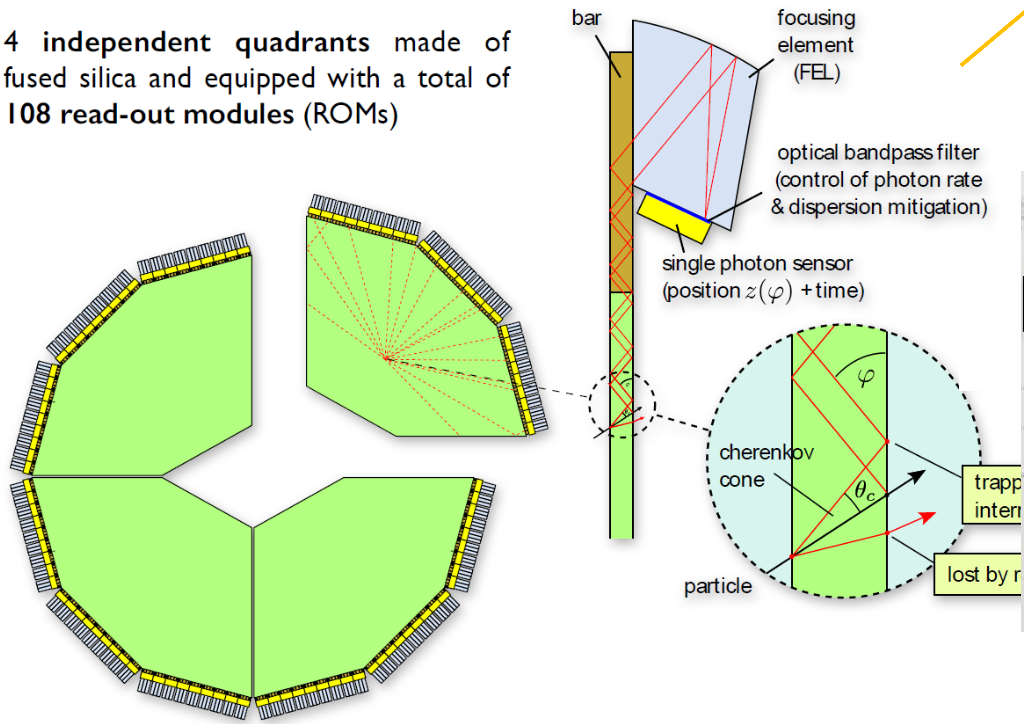
PHOTONIS 2” MCP-PMT

Panda DIRC at endcap

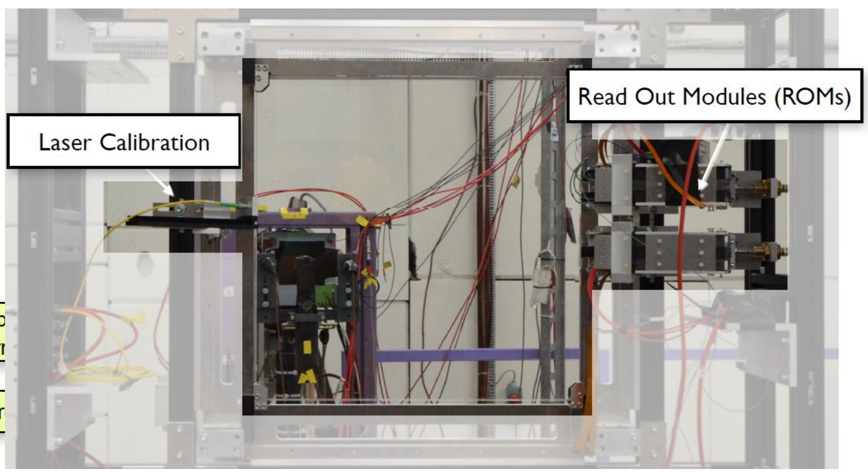
- Separation of π/K for < 4.5 GeV
- Large quartz plate + ROMs
- ROMs (read-out modules) consists
  - Light guide, focusing element
  - 2" MCP-PMT
- Prototype tests in progress



4 **independent quadrants** made of fused silica and equipped with a total of **108 read-out modules** (ROMs)

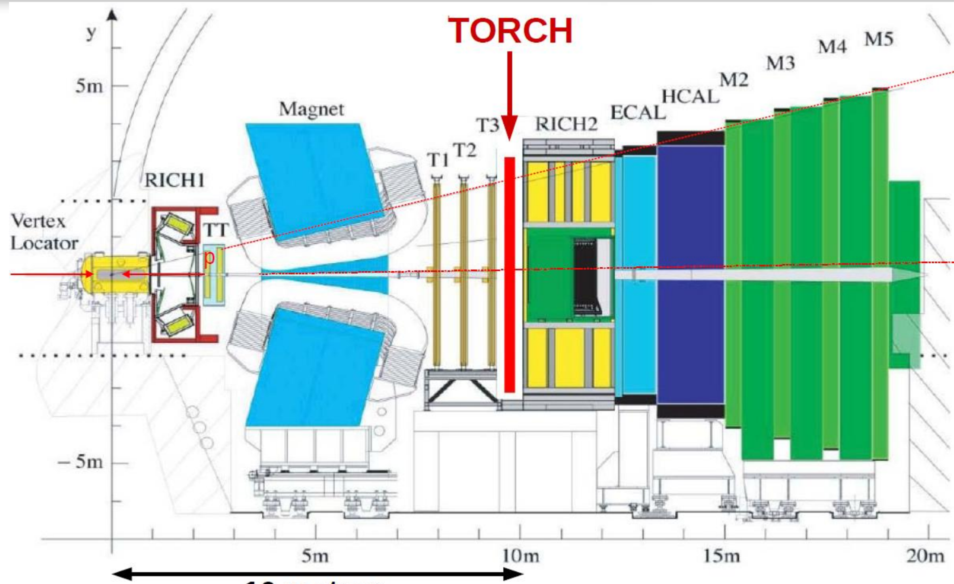


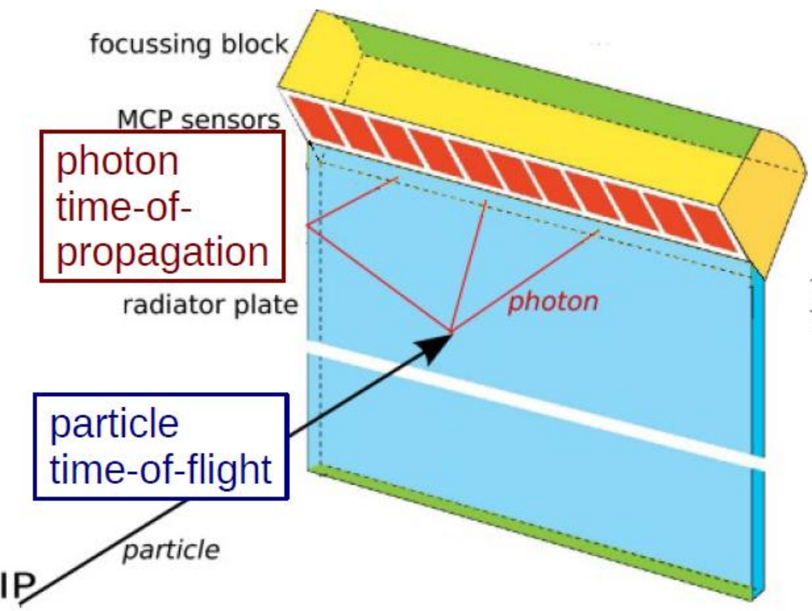
PHOTONIS 2" MCP-PMT

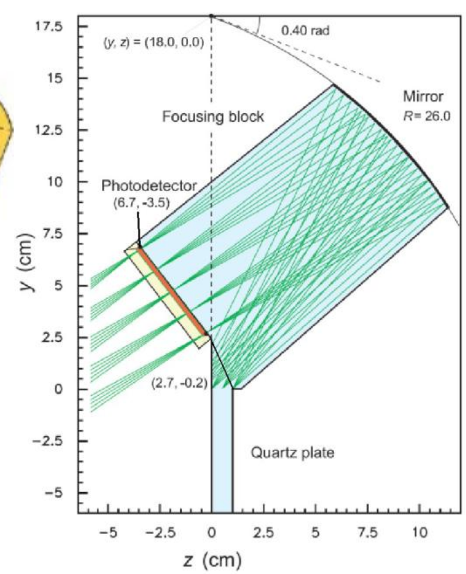


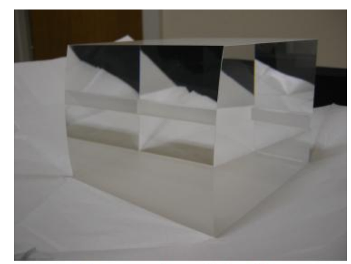
TORCH at LHCb

- TORCH (Time Of internally Reflected Cherenkov)
- Separation of π/K for 1-10GeV
  - Not covered by RICH-1,2
- Large quartz plate + focusing block + MCP-PMTs



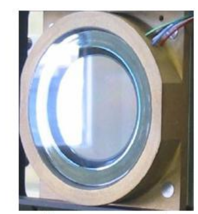


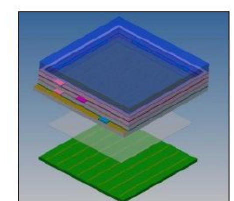



focussing block


radiator

PHOTEK MCP-PMT


phase 2 tube

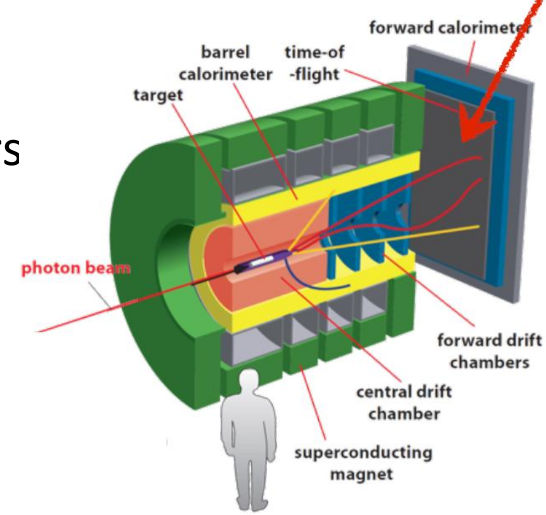

phase 3 tube (visualisation)

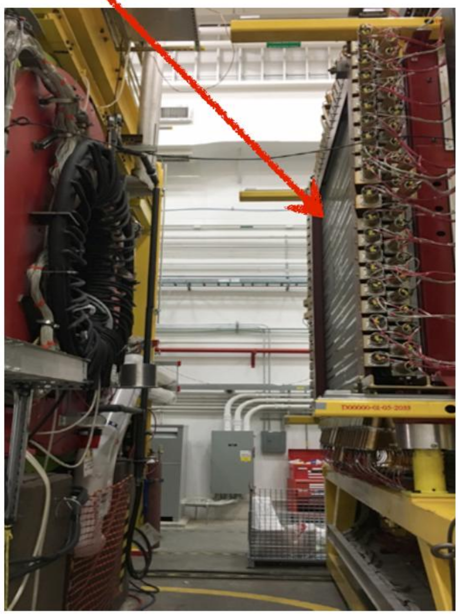
K.Fohl@DIRC2015

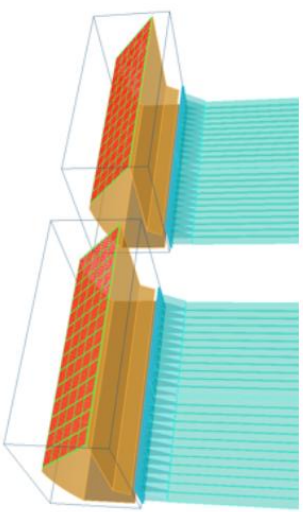
GlueX DIRC

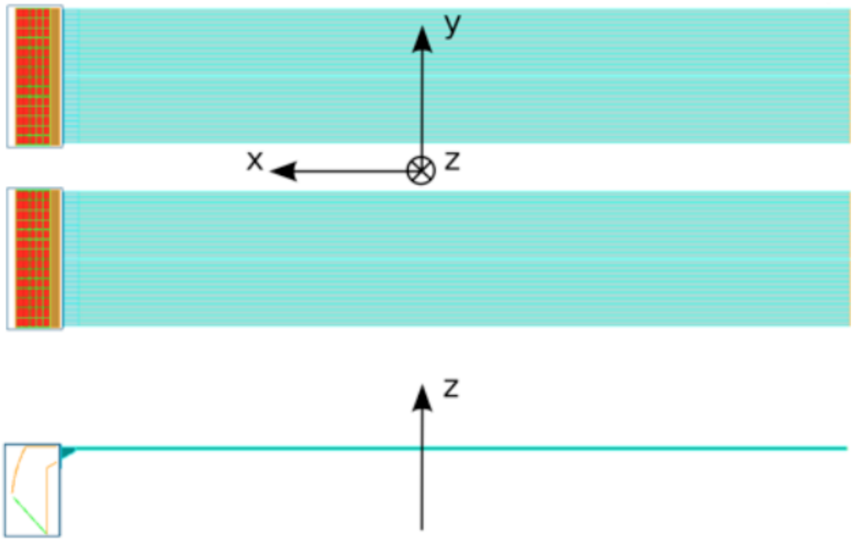
- Separation of π/K for < ~5 GeV
  - Improve momentum range from current detector
- Recycle BABAR DIRC quartz bars
- Focusing block
  - Design based on FDIRC
  - Use water and mirrors
- 2” MA-PMT (Hamamatsu)

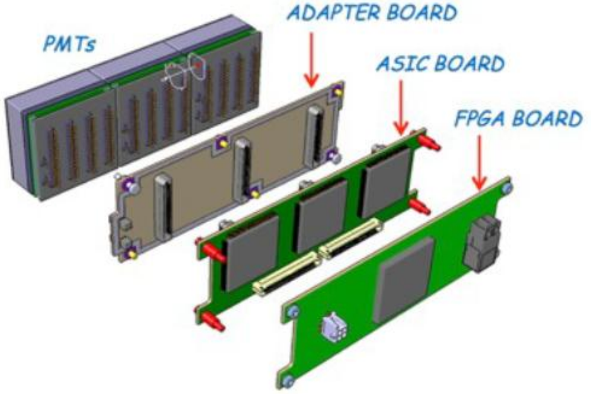
Insert DIRC here!











Summary

- RICH detectors perform excellent particle identification in particle and nuclear physics experiments.

- Gas RICHs work stably in many experiments.
- Aerogel improvement (transparency, index tuning, larger tile) is crucial for new aerogel RICHs
  - Increased number of photon, focusing scheme, large size detector
- Quartz radiator becomes popular. Many ideas coming.
  - Focusing optics + fast MCP-PMT+elec.

- Let's learn news and details from the presentations in this workshop.

Thank you very much.