Particle Identification at Belle II

Saurabh Sandilya
University of Cincinnati
(On behalf of the Belle II Collaboration)

Outline

- Introduction (PID requirement, Belle II)
- Particle Identification in the barrel region
- Particle Identification in the endcap region
- Summary

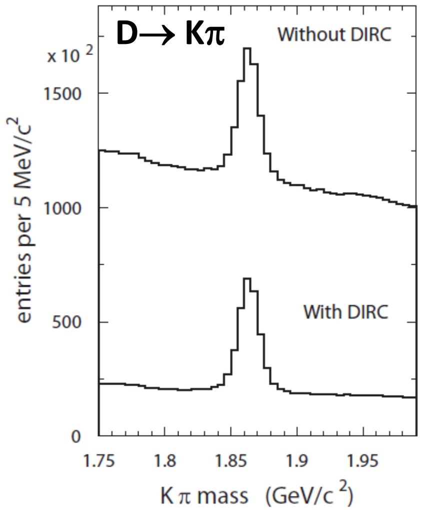
Already discussed
Belle II Physics prospects, status, schedule : Jake Bennett

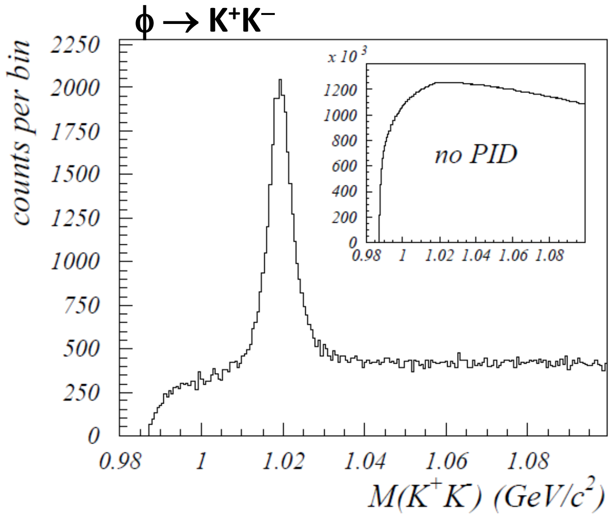
Introduction

- A reliable PID is essential for any high energy physics experiment and crucial for the success of B factories.

BaBar
NIM A 538 (2005) 281

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





HERAB
NIM A 553 (2005) 210

ϕ → K⁺K⁻ decay only becomes visible after particle identification is taken into account.

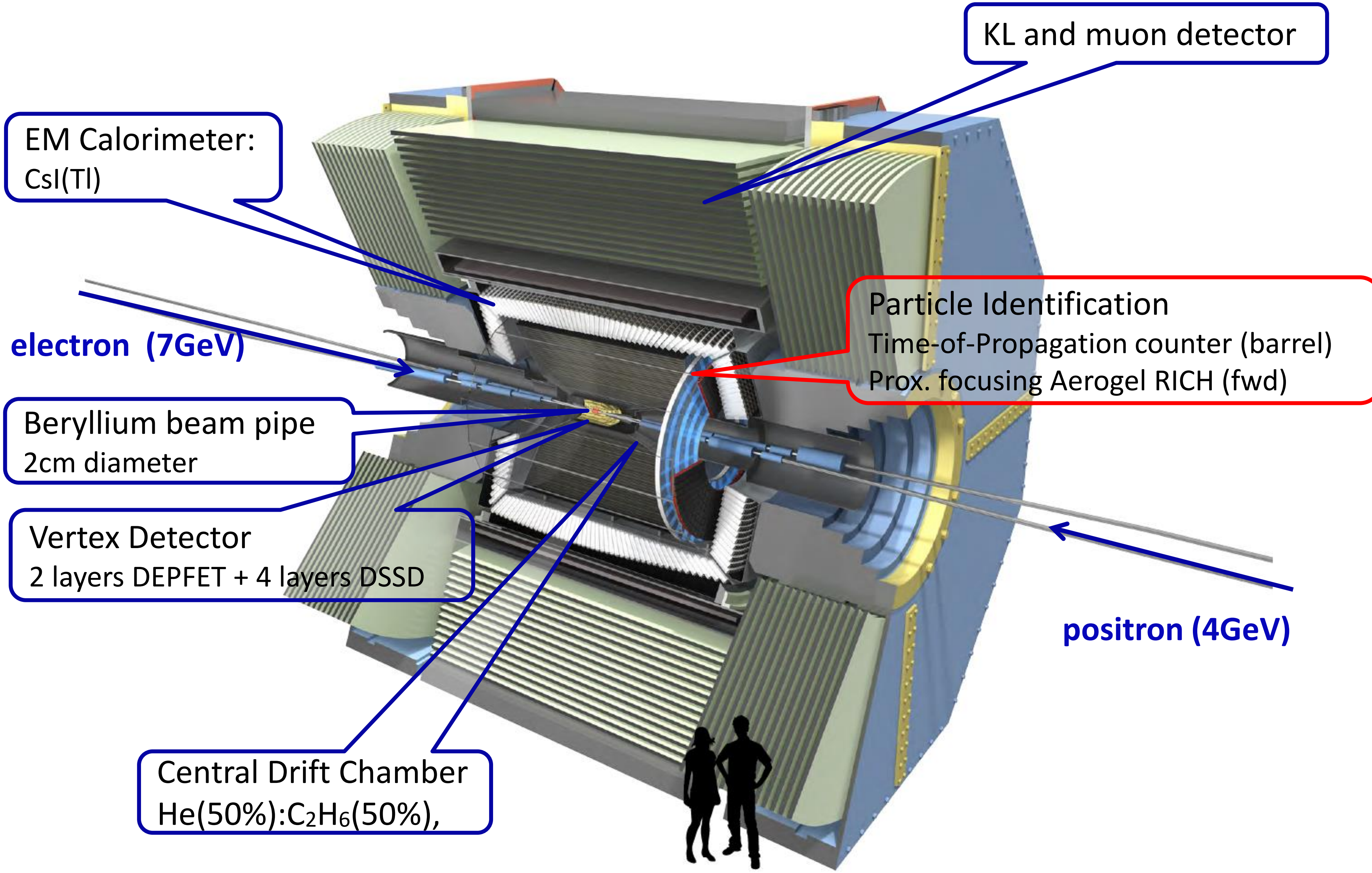
- At B-factories PID is required for tagging B-meson flavor and for precision measurements of rare B/D decays.

- SuperKEKB will deliver 40 times higher event rates than KEKB.

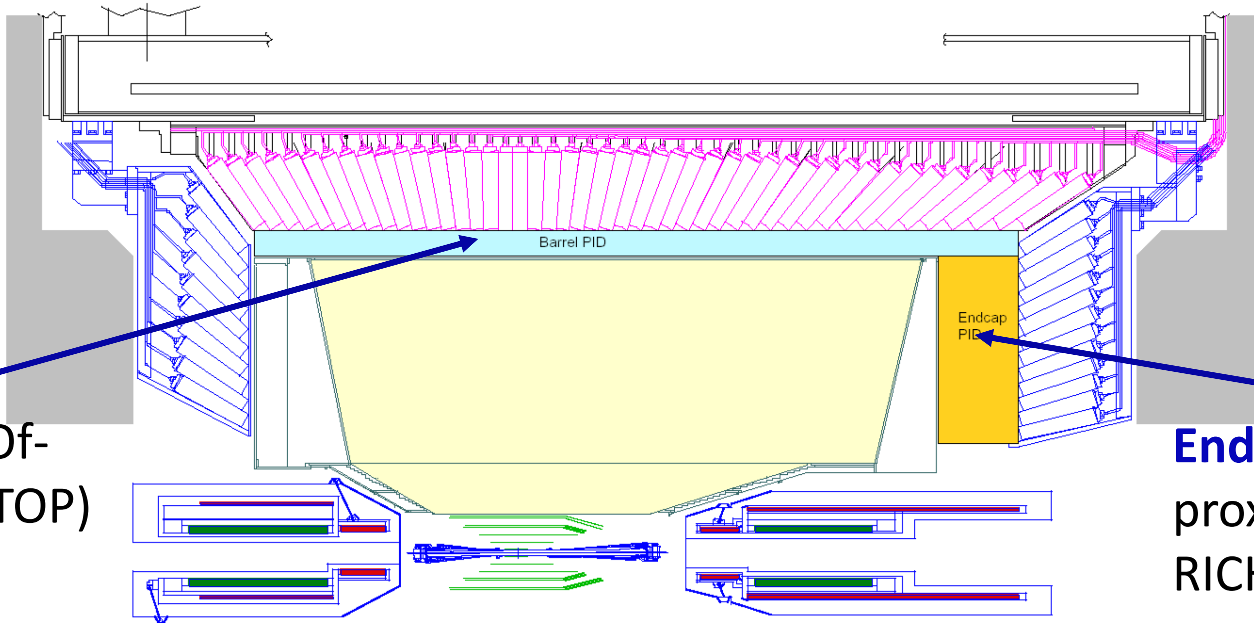
- To cope up with higher rates and stringent requirements for rare decay channels, more efficient PID is needed (for the momentum range up to 4 GeV/c).

- In this talk, I will discuss particle identification systems in barrel (central) and endcap region of the Belle II detector

Belle II Detector



Belle II Detector : PID system



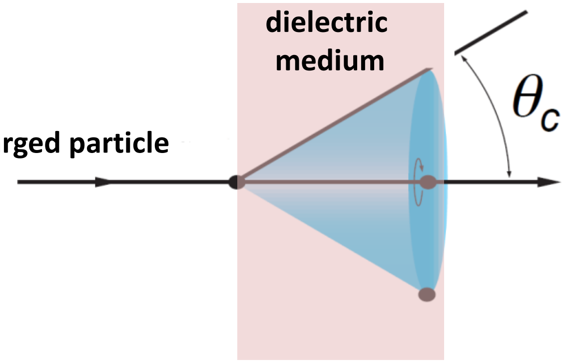
Barrel: Time-Of-Propagation (TOP) counter

Endcap: Aerogel proximity focusing RICH (ARICH)

In both region, PIDs at Belle II are ring imaging Cherenkov devices.

A charged track with velocity ($v = \beta c$) exceeding the speed of light (c/n) in a medium (refractive index n) emits Cherenkov light at a characteristic angle,

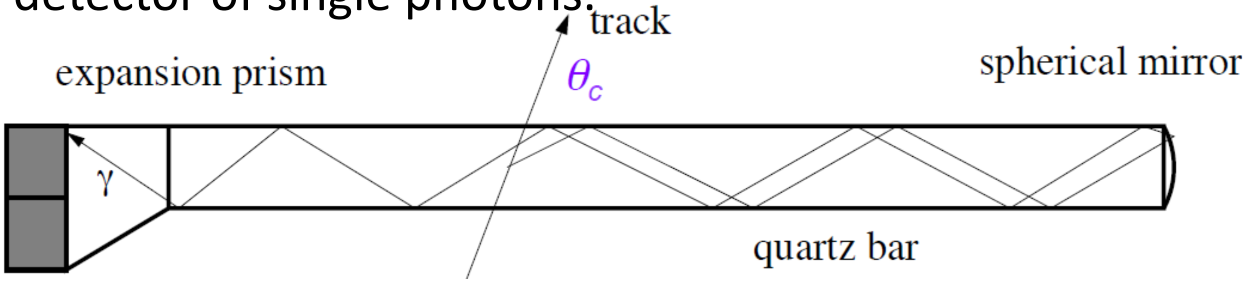
$$\cos\theta_c = 1/n(\lambda)\beta$$



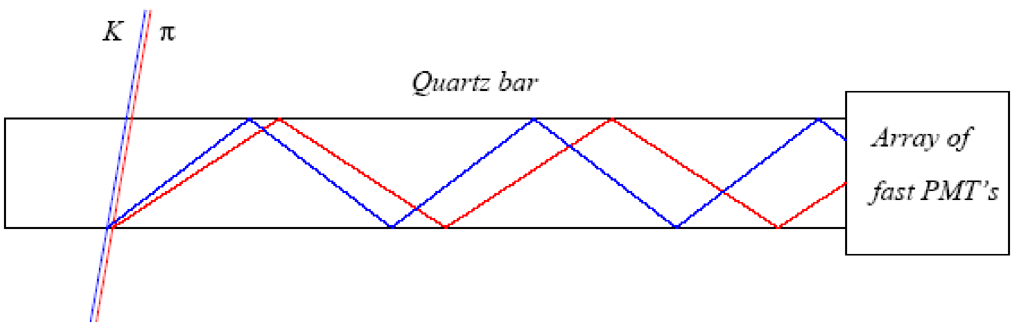
Same momentum pions and kaons will have different velocities (β) and hence the angle of Cherenkov photons.

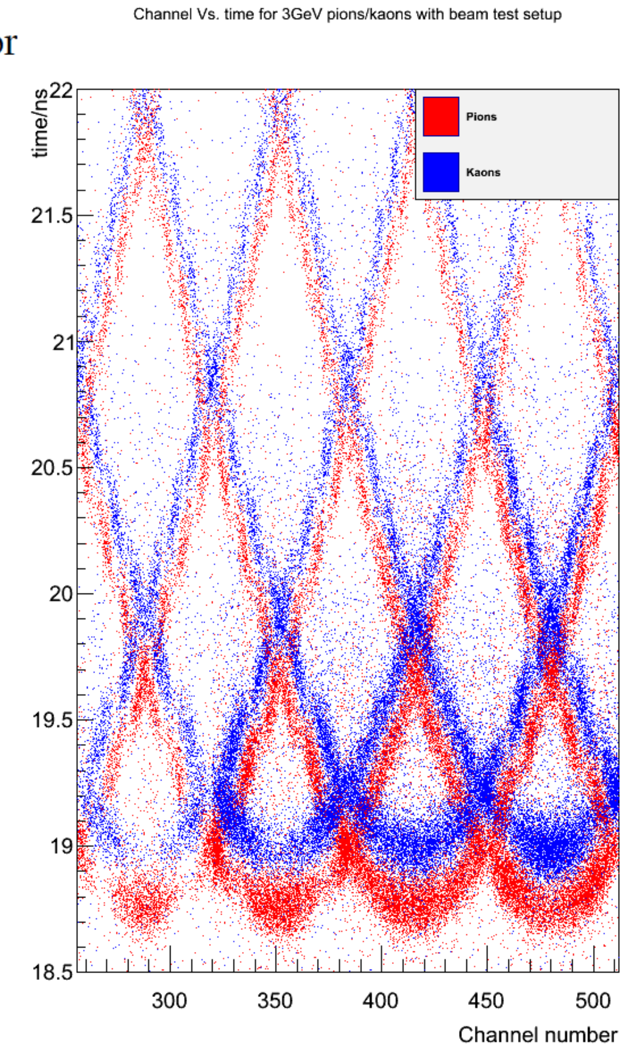
Barrel PID : Working Principle

Cherenkov photons emitted in the quartz radiator from the charged track → total internal reflection → registered at the end of the bar by a fast position sensitive detector of single photons.



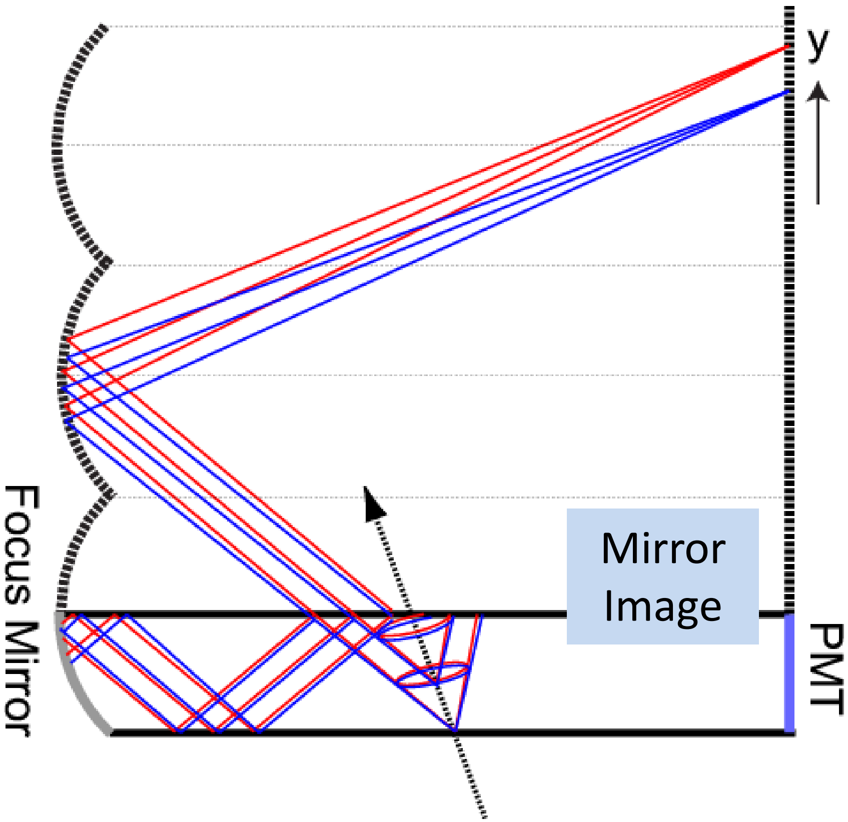
K/π different θ_c → different path length → different time of propagation.



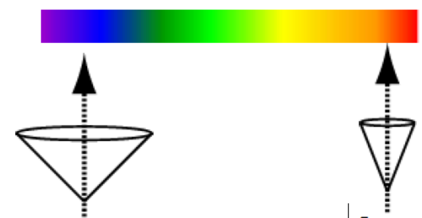


θ_c is reconstructed from: hit position (x,y) in the photo detector plane and time of propagation

Barrel PID : need of Mirror



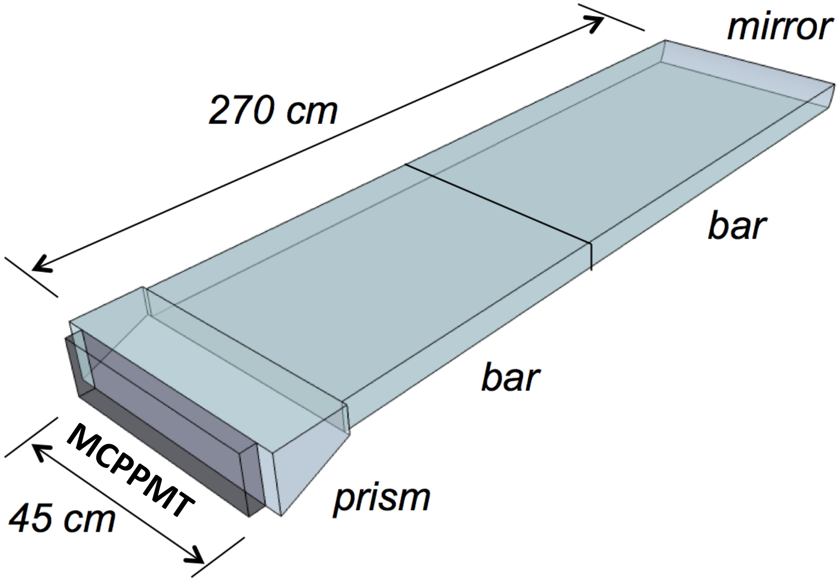
- parallel rays get focused to a single point → removes bar thickness
- non-parallel rays are focused to different points →
  - K/π separation
  -

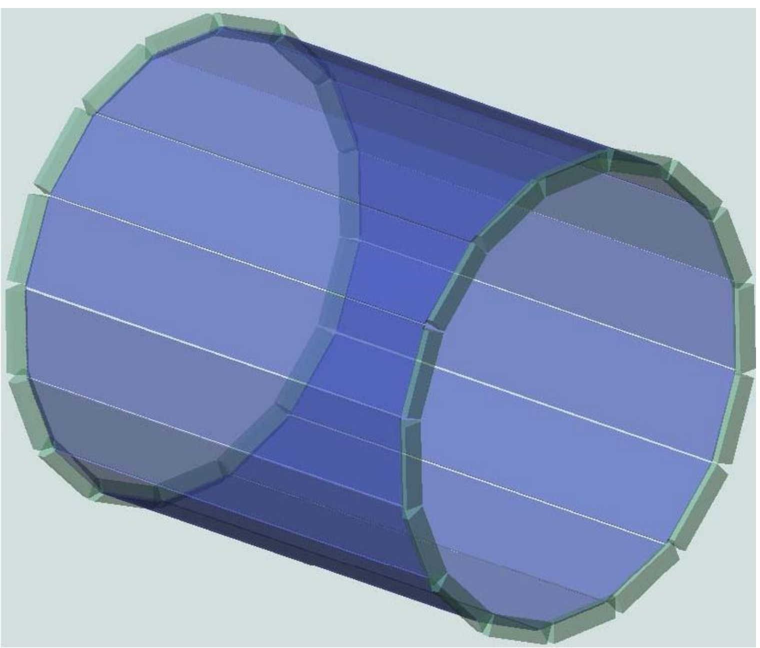


$$\theta_c(\lambda) = \cos^{-1}\left(\frac{1}{n(\lambda)\beta}\right)$$

allows to correct for chromatic dispersion.

Barrel PID : Geometry



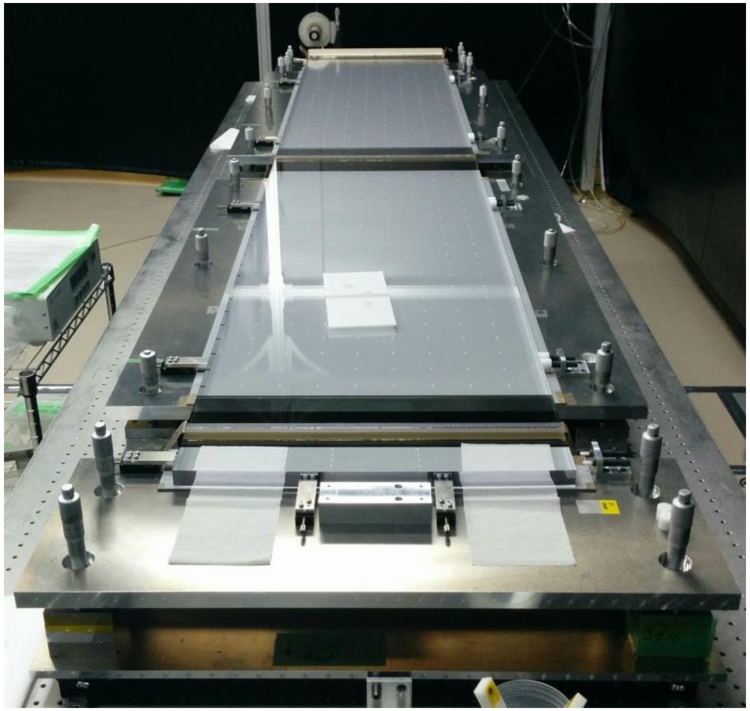


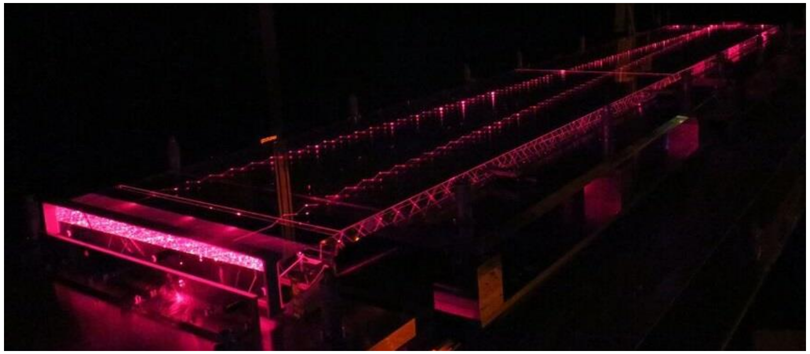
TOP modules consists of:

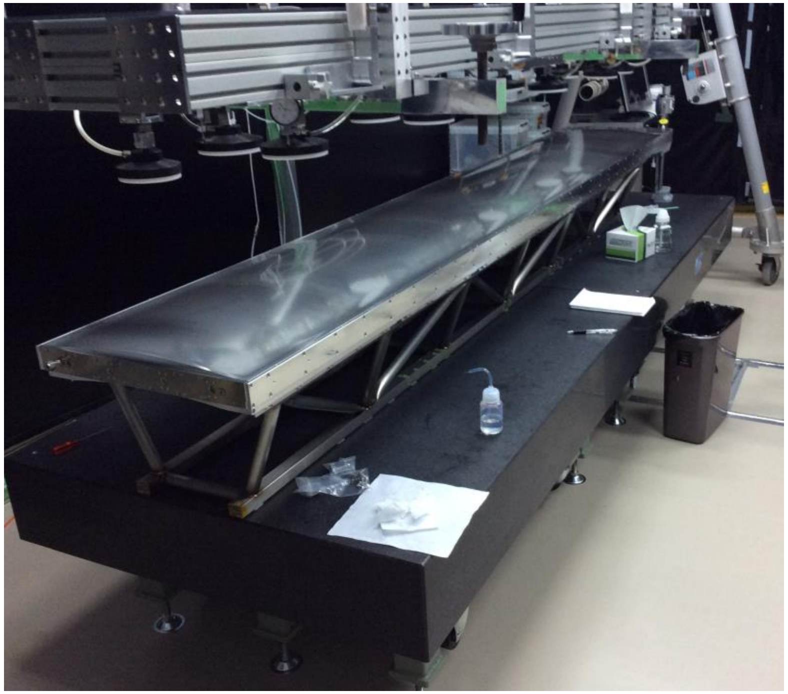
- Two **fused silica bars**, (each $45\times125\times2cm^3$) $\rightarrow$ Radiator to generate Cherenkov photons.
- **Mirror** ($45\times10\times2cm^3$)$\rightarrow$ focus the emitted photons to the sensor plane
- **Prism** ($45.6\times10\times2cm^3 \rightarrow 45.6\times10\times5.1cm^3$) to expand the image and improving resolution.
- **MCPPMT:** At the exit window of the prism, two rows of sixteen fast multi-anode photon detectors (MCPPMT) are mounted.
- In total **16 TOP modules**, are arranged in a barrel shaped array with inner radius ~ 1.2m

Barrel PID : Module preparation

- Optical components, two bars, mirror and prisms, are subjected to acceptance testing (Cincinnati and KEK).
- Assembled and aligned on an optical bench and then epoxied.







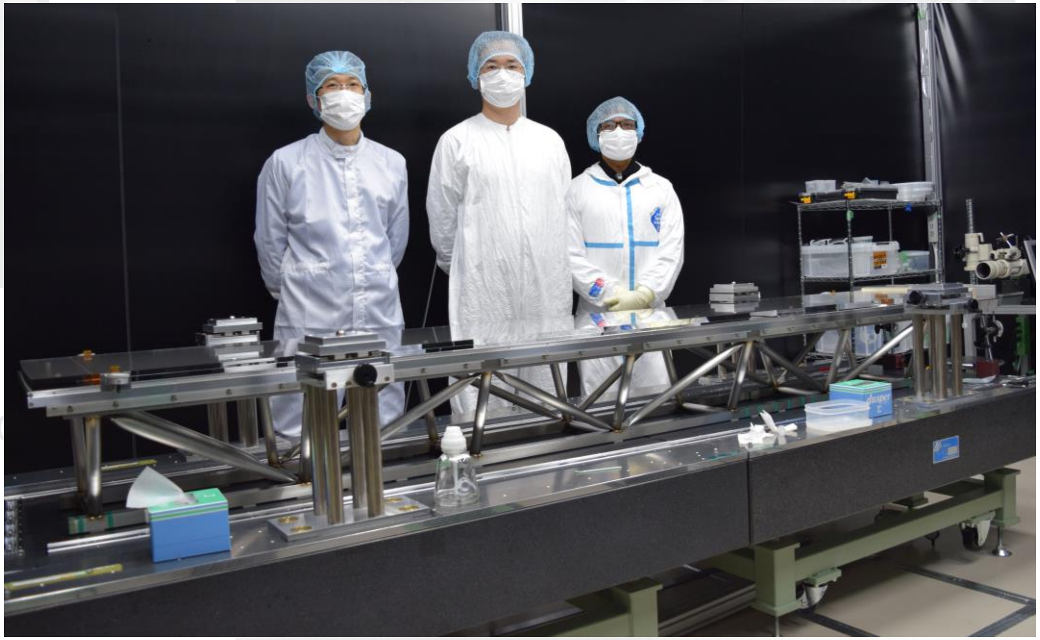
- These components are enclosed in an aluminum frame called the quartz bar box.

Barrel PID : Module preparation

mirror and prisms, are subjected to acceptance

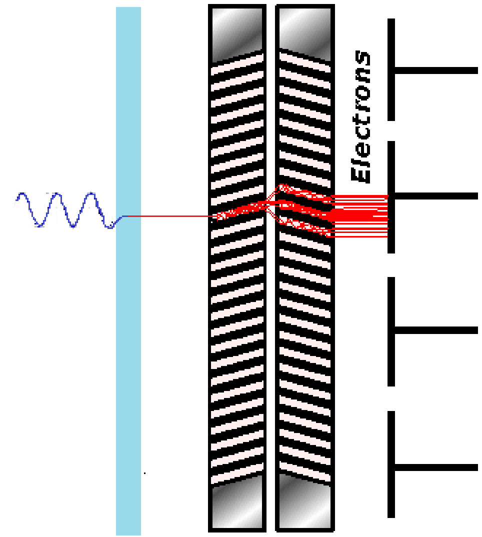
ptical bench and then epoxied.

- These components are enclosed
aluminum frame called the qua
box.



Barrel PID : MCP PMT

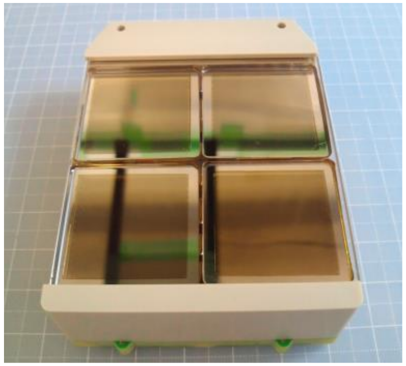
A micro-channel plate (MCP) photomultiplier tube (PMT) provides a good time response.
Transit time spread ~ 30 – 35 ps (required is <50ps)

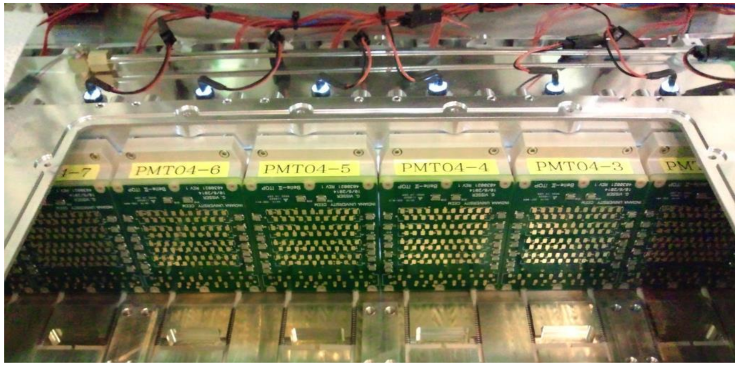


Characterstics

Overall size : 27.5 × 27.5 × 15.6 mm^3
Photo cathode : Multi-alkali (23 × 23 mm^2)
MCP width: 400 μm, pore: 10 μm and bias angle: 13 degrees
Anode 22 x 22 mm^2 (divided into 4 x 4 pads)
Dimensions of each pad: 5.275 x 5.275 mm^2 with gap 0.3mm

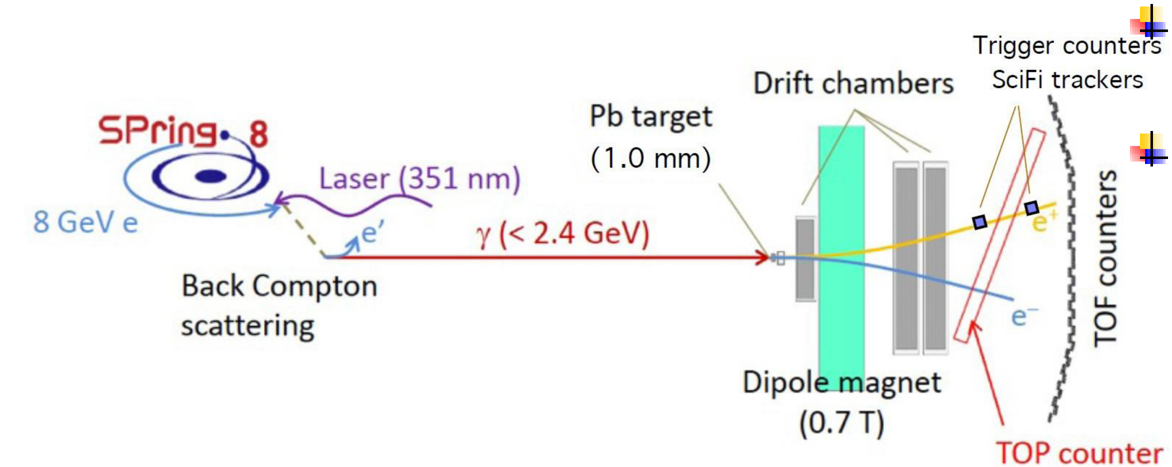
Quantum efficiency : >24% at 350-400nm
Gain : 2 × 10^6 at ~3kV
Dark-rate : 5kHz for 16 anodes





Barrel PID : Beam Test

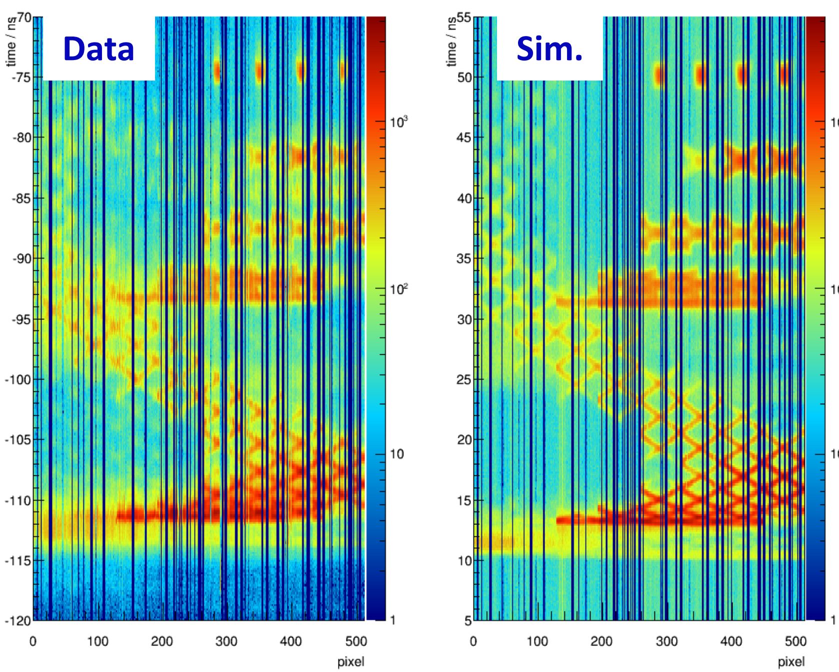
- Beam test in June 2013 at the LEPS beamline at SPring-8 in Japan.



- Secondary positron beam ~2.1 GeV.
- **Prototype** TOP module was placed in LEPS beam – and LEPS subdetectors used to provide tracking and momentum information.

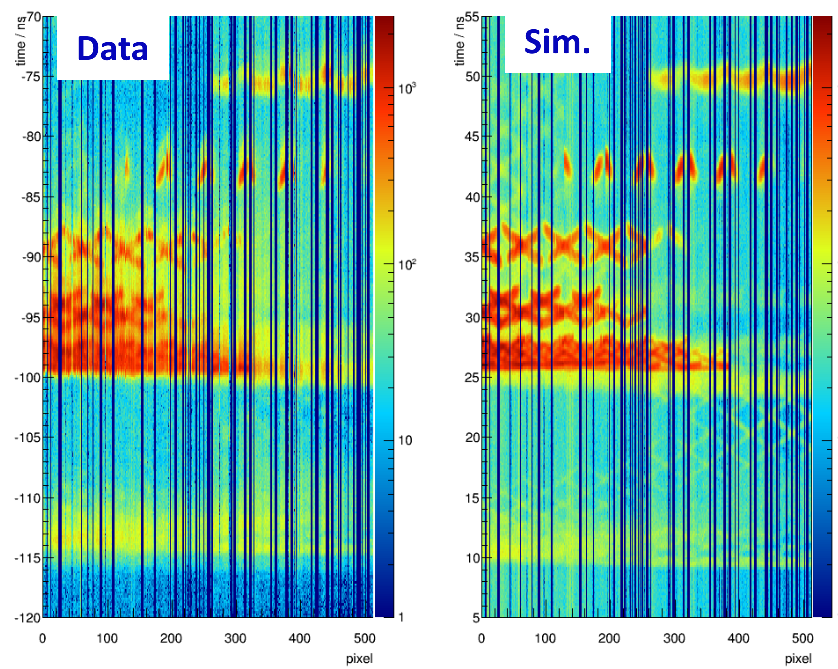
beam hitting the quartz normally.

Data ring image for cosθ = 0.00 | Simulated ring image for cosθ = 0.00



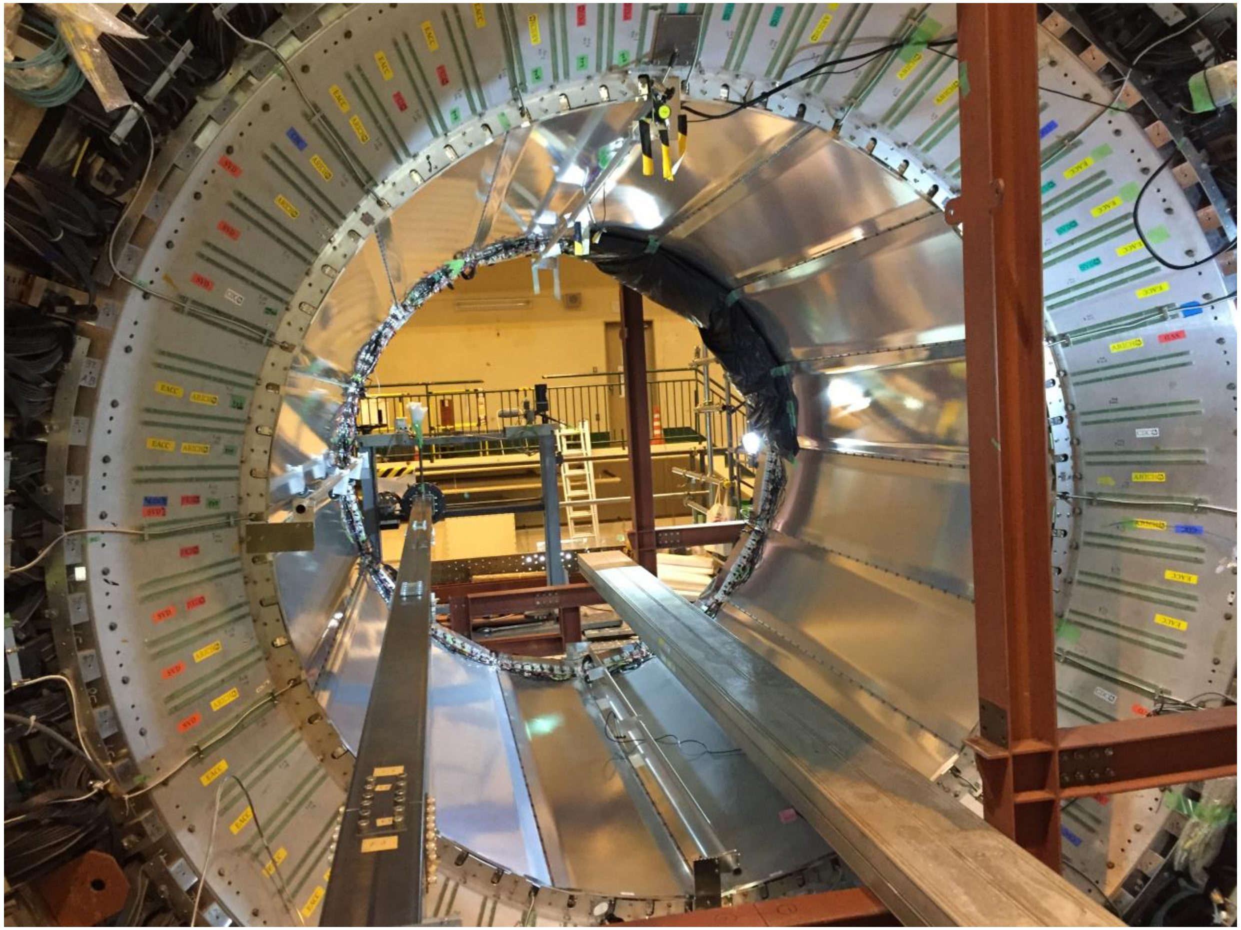
beam hitting the quartz at a forward angle.

Data ring image for cosθ = 0.43 | Simulated ring image for cosθ = 0.43



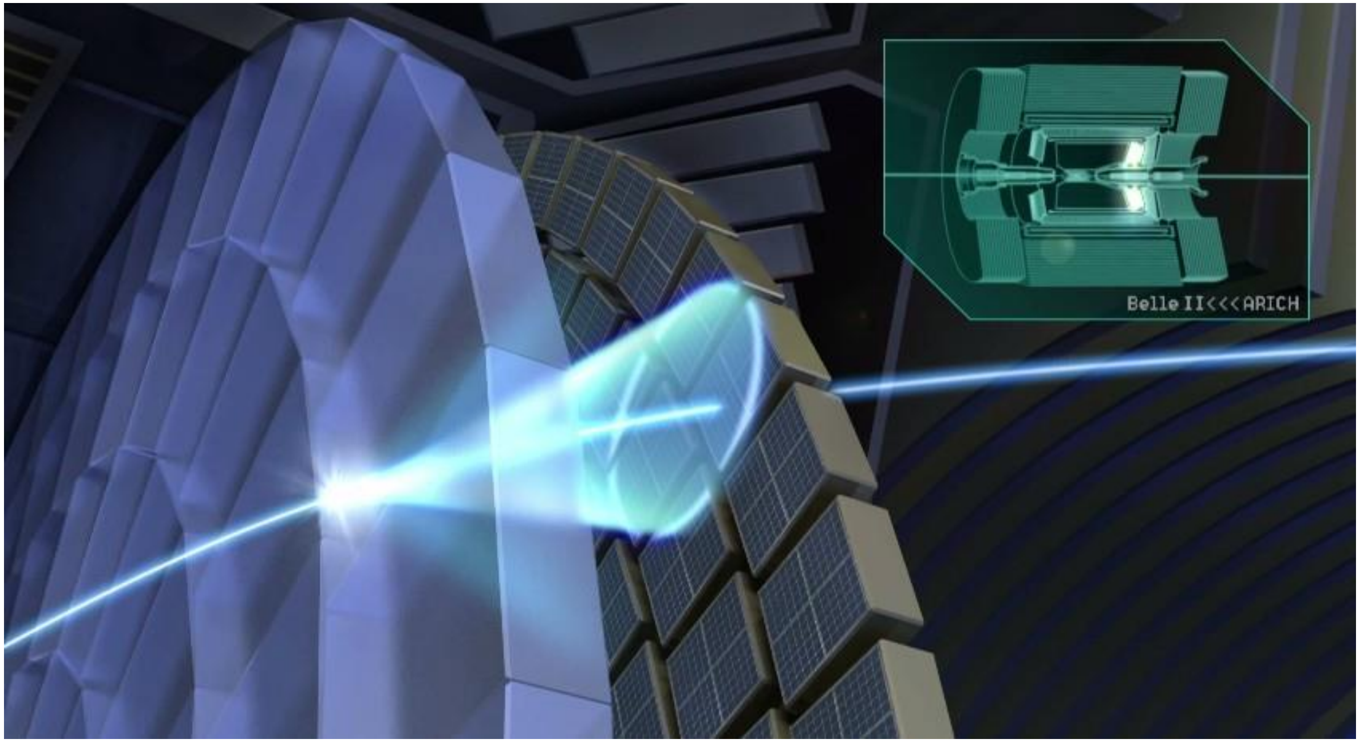
Barrel PID : Current Status

Modules tested (and also being tested) under cosmic ray and laser



Finished installing all the 16 TOP modules on May 20th.

ARICH Detector



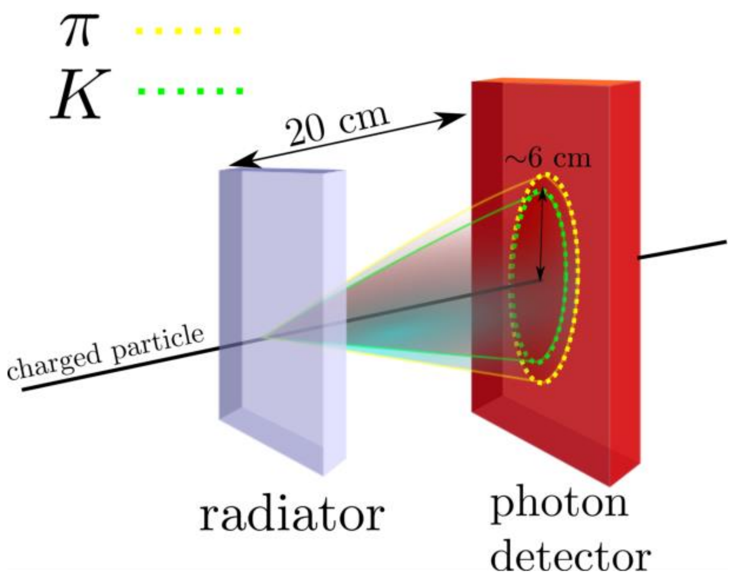
- Provides particle identification system in the front-end endcap region.
- Good separation (> 4σ) between kaons and pions in the full kinematical region of the experiment (~0.5-4.0 GeV/c).
- Great importance not only for the reconstruction of decay modes but also for the efficiency of flavor tagging algorithms.

ARICH: Principle of operation

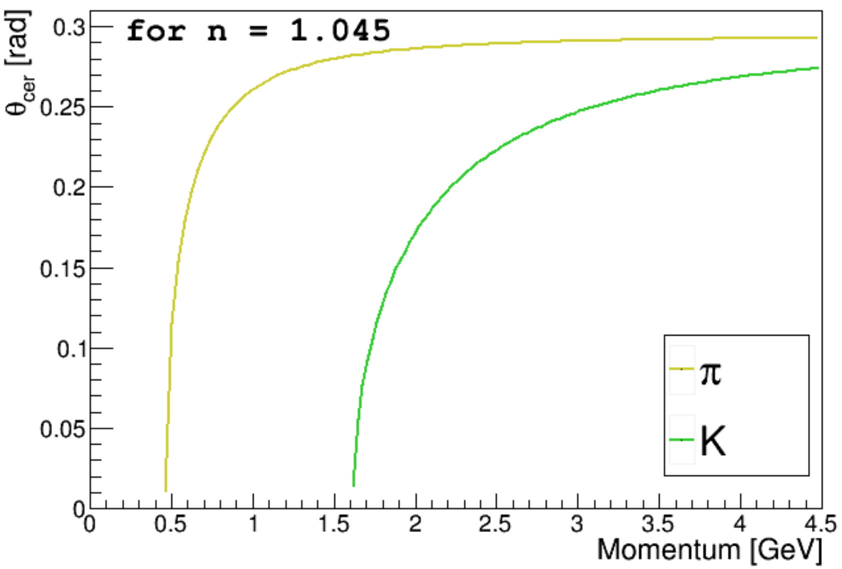
- ARICH also relies on the relation between the emission angle of Cherenkov photons and the charged particle velocity,

  $\cos\theta = 1/n.\beta$ (n = refractive index of the radiator)

- Aerogel tiles are used as a radiator. Photons, emitted in aerogel, then propagate through ~20 cm of an expansion volume and hit the photon detectors (HAPDs).



pions and kaons of equal momenta

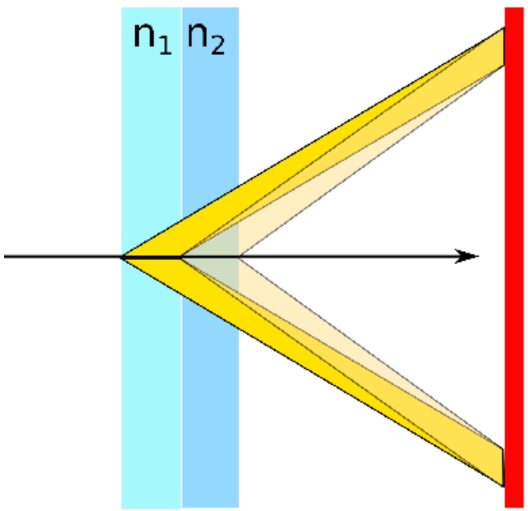


Cherenkov angle vs. particle momentum

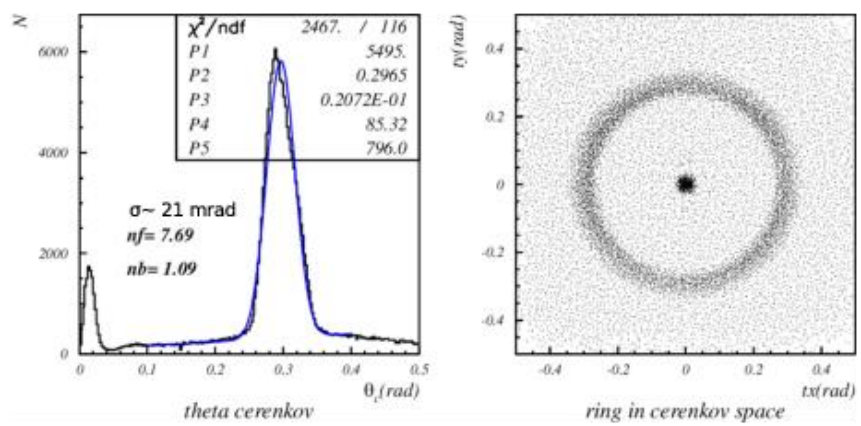
- At 3.5 GeV the difference between the pion and kaon Cherenkov angle is ~30mrad.

ARICH: Principle of operation II

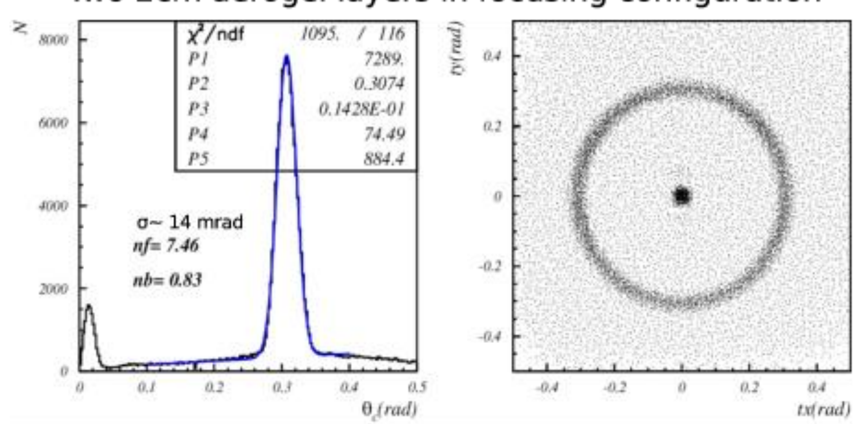
- It is desirable to have as thick aerogel layer as possible, as this increases the number of emitted photons, but thicker aerogel also increases the uncertainty in the photon emission point.
- Two aerogel layers with different refraction indices, are chosen so that the two rings, overlap on the detector plane.



Single 4cm aerogel layer



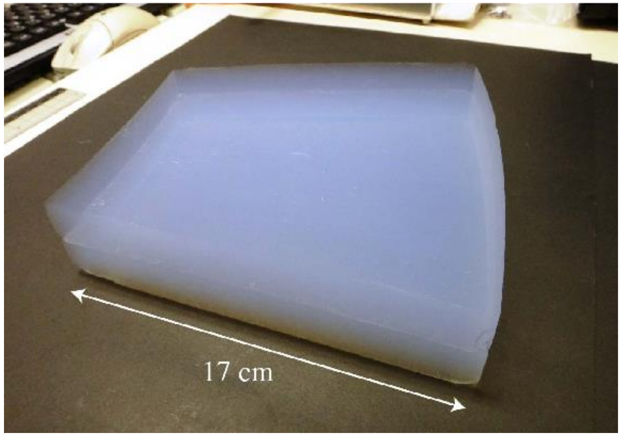
Two 2cm aerogel layers in focusing configuration

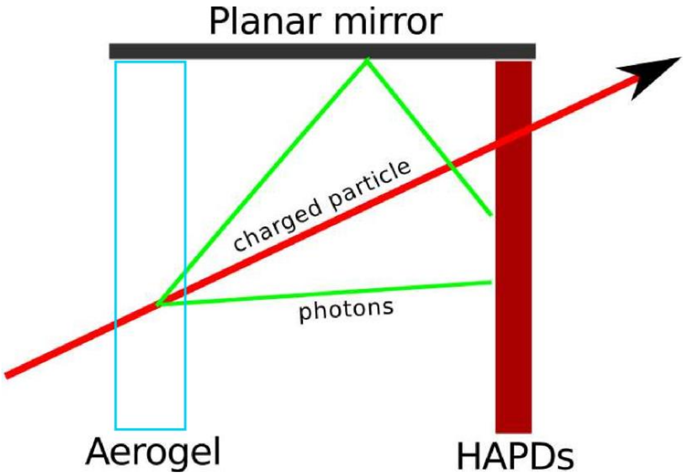


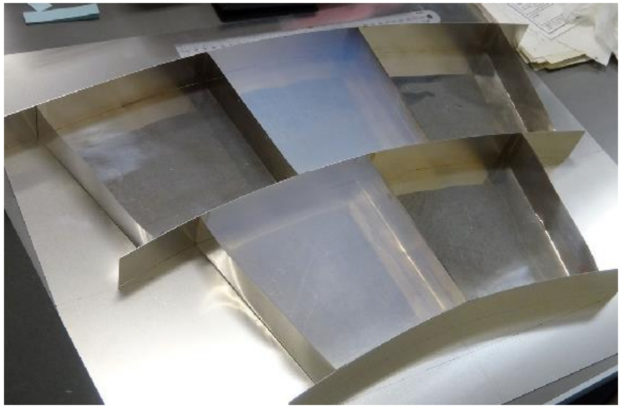
- Refractive index n_1 = 1.045 and n_2 = 1.055

Aerogel (Radiator) in ARICH

- As a radiator a 'silica aerogel' is used, which is an amorphous, highly porous solid of silicon dioxide (SiO_2),
- Tunable (intermediate) refractive index and good optical transparency. Refractive index depends on the silica-air volume ratio (typically 1:9)
- 3.5 m^2 radiator plane is covered by two layers of wedge-shaped aerogel tiles of size $(17 \times 17 \times 2)$ cm^2.





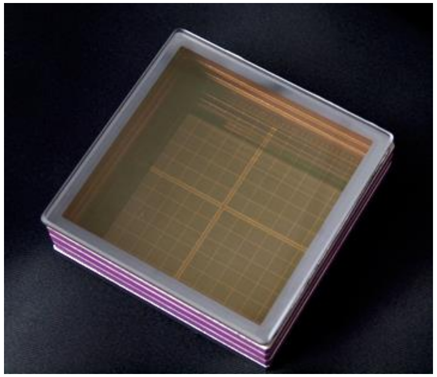


- To maintain good performance on the outer edge of the detector, where Cherenkov photons would miss the photo-sensitive area, 18 planar mirror plates are placed.

HAPD (Photon Detector) in ARICH

Requirements:

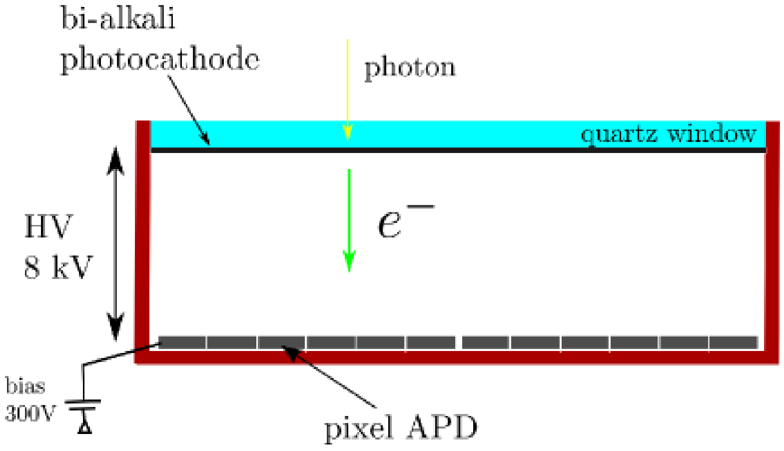
- sensitive to single-photons
- provide two-dimensional position information ~5 mm pixel.
- should be immune to 1.5T Magnetic field
- tolerant to the high radiation environment (1000Gy for γ and 10^{12}cm^2 for neutron in 10yrs)



Hybrid Avalanche Photo-Detector

HAPD Working Principle

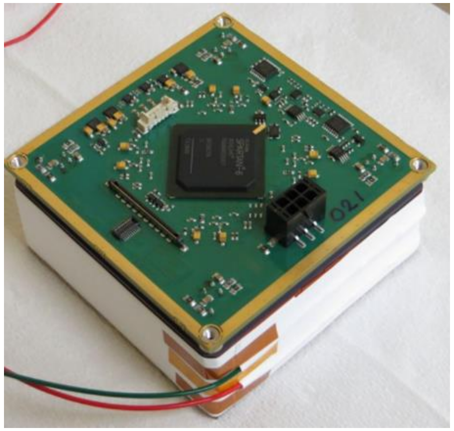
- Incident photon is converted into photo-electron by a bi-alkali photo-cathode (peak quantum efficiency of ~30% at 400 nm.)
- electron accelerates in high electric field towards the segmented avalanche photo-diode (144 pads of size 4.9 × 4.9 mm) ~ 300V reverse bias voltage
- Avalanche gain ~ 40, bombardment gain ~ 1800.
- Detection of a single photon results in an avalanche of about 70,000 electron.



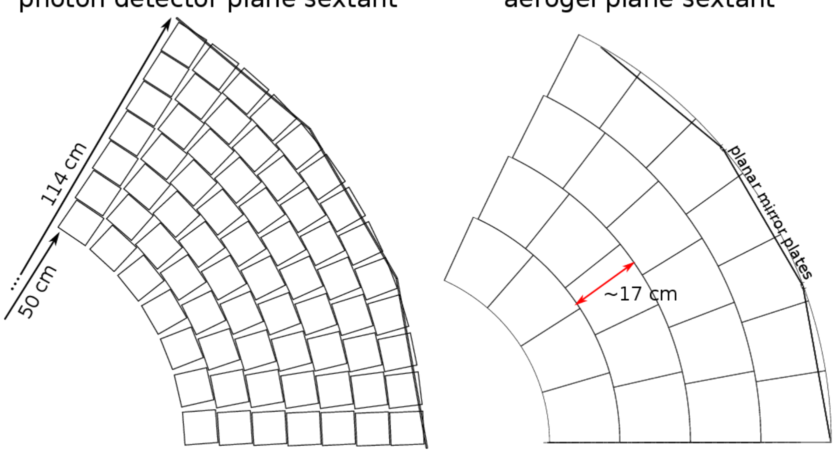
ARICH: Read out and Geometry

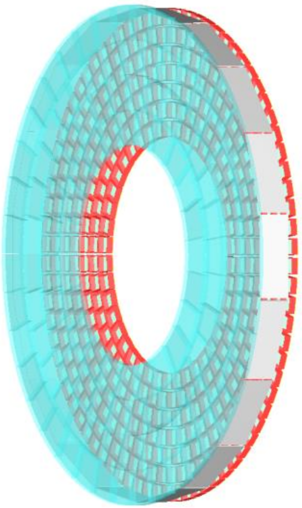
Electronics:

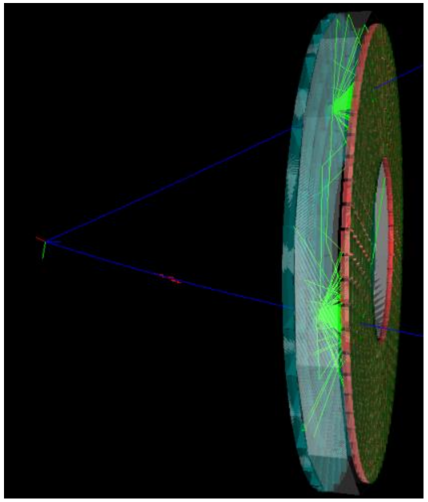
a dedicated high gain and low noise electronics was developed, a digitizer ASIC which consists of a preamplifier, a shaper and a comparator is followed by an FPGA (Xilinx Spartan-6 XC6SLX45), where the hit information is recorded and communicated to further stages of the experiment data acquisition.



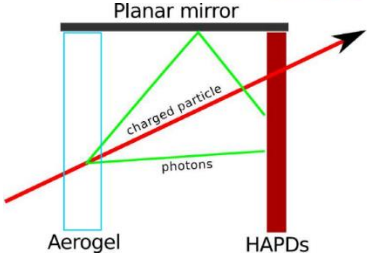
Geometry:







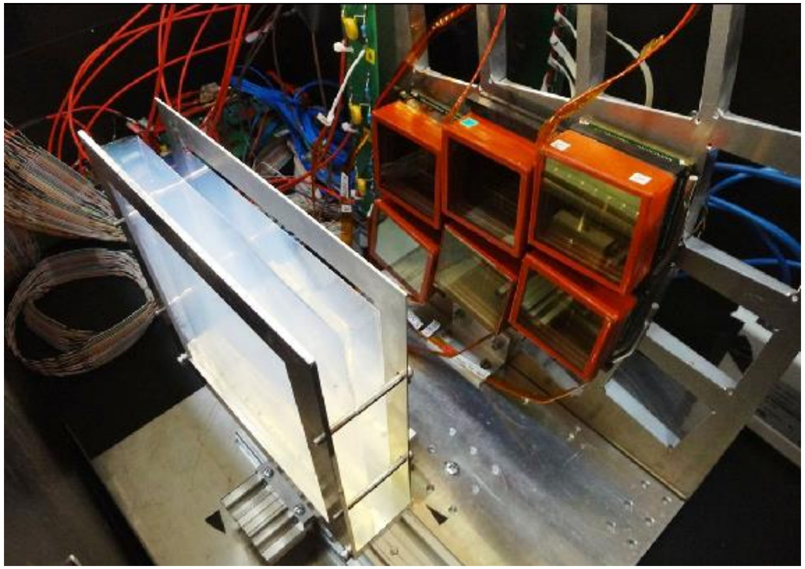
- 420 HAPD modules are arranged in 7 concentric rings.
- 2 × 124 aerogel tiles
- 18 planar mirror plates on the outer edge

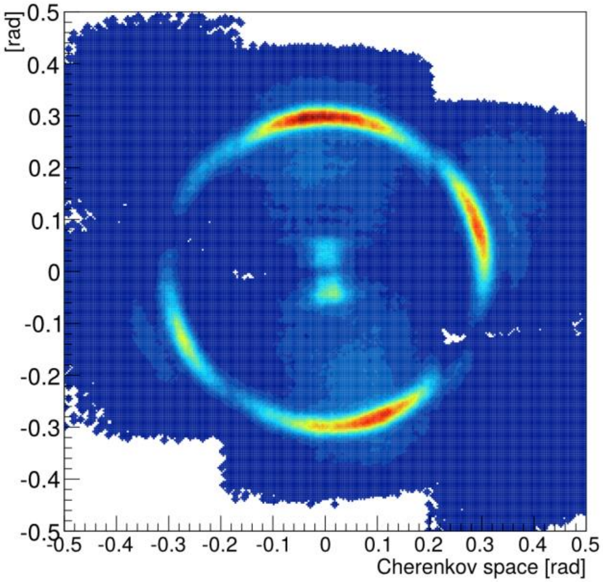


2 pion tracks with 3.5 GeV hitting ARICH

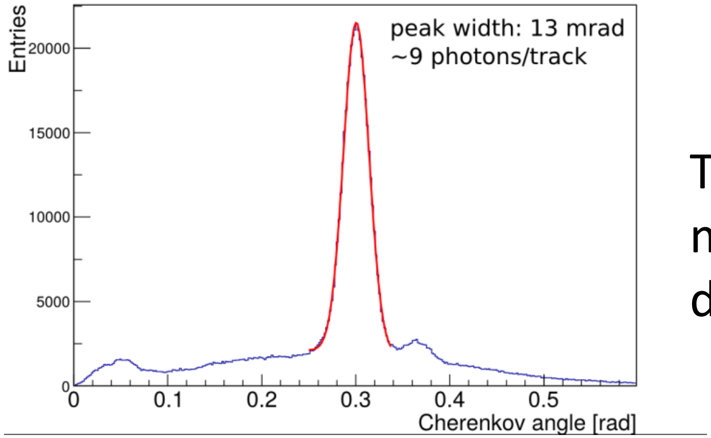
Beam Test

- Prototype of ARICH is constructed, with two consecutive aerogel tiles and six HAPD modules, arranged as in a part of actual detector layout → at DESY 4-5 GeV/c electron beam (2013)





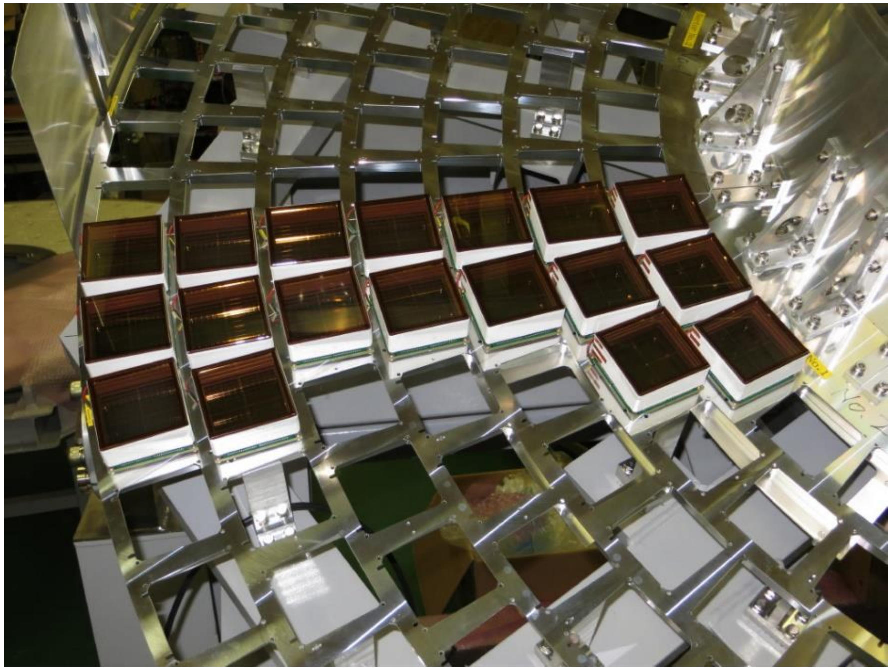
← accumulated distribution of reconstructed Cherenkov angle

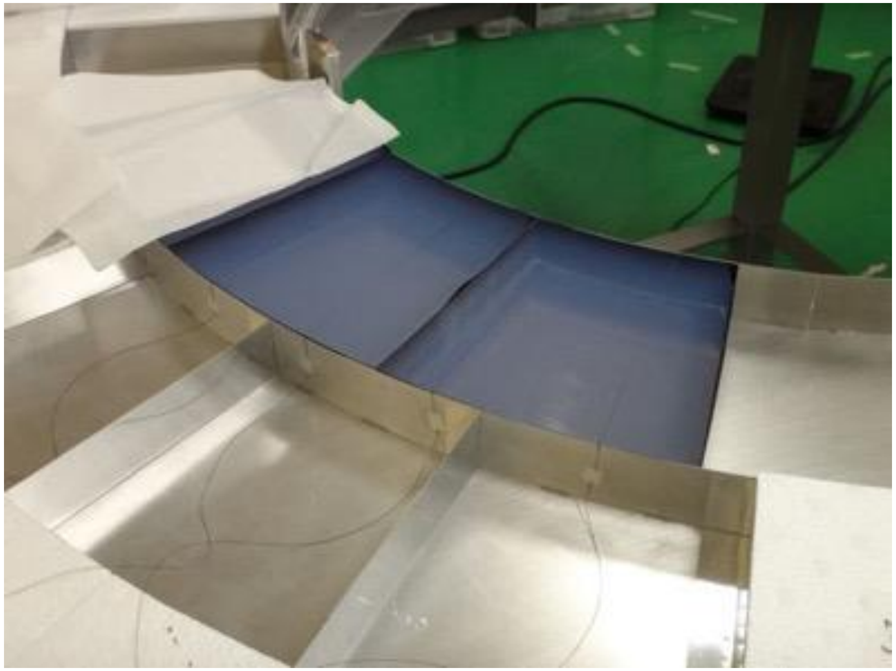


The single photon angle resolution is about 13 mrad and on average 9 photons per track are detected.

Endcap PID : Current Status

- Installation of HAPDs and aerogel tiles has started and will be finished this summer.

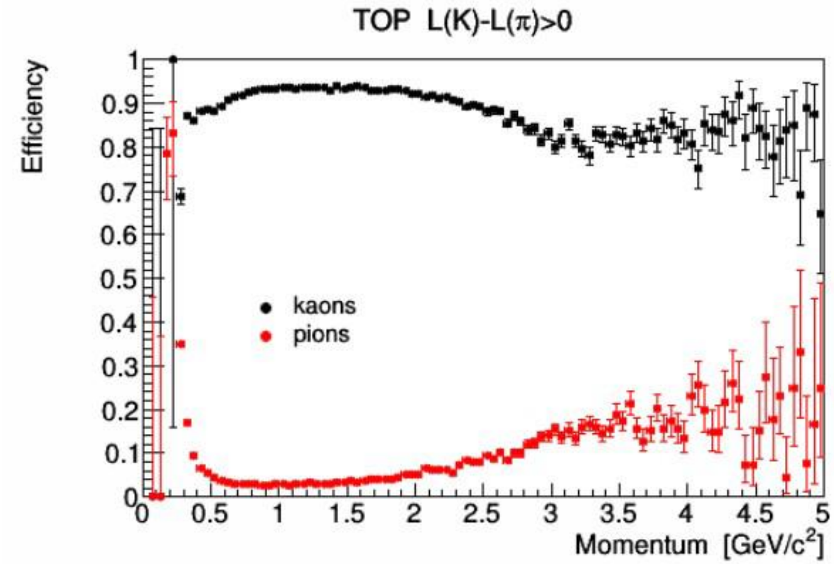


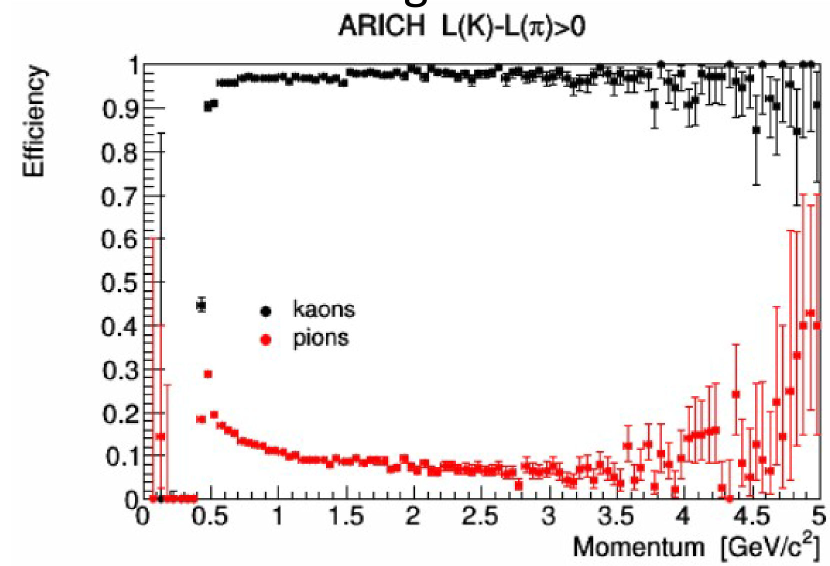


Expected Performance

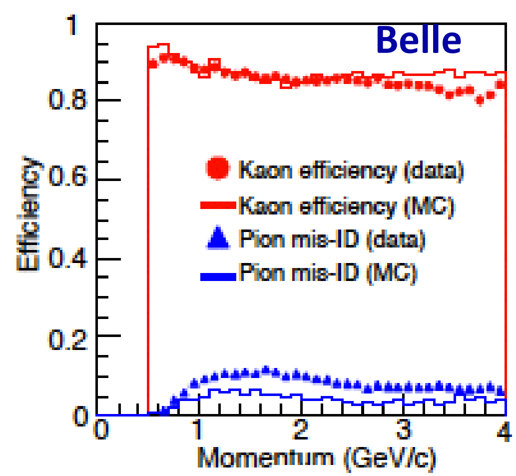
Detailed simulation performed in the Belle II software framework.

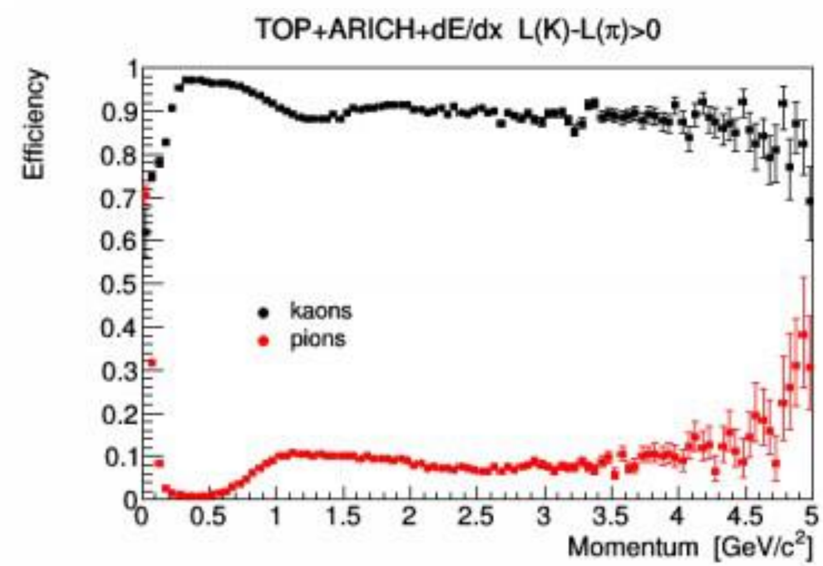
- Results from release-00-05-00 : ccbar events with nominal background





- Excellent K identification efficiency (small π misidentification probability) over wide momentum range.
- Belle II → 93% (4%)
- Belle → 88% (9%)

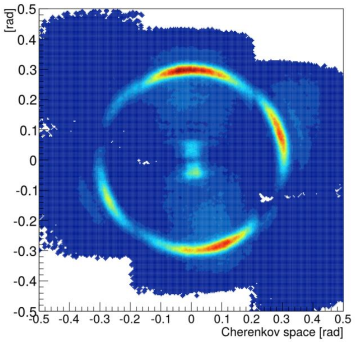


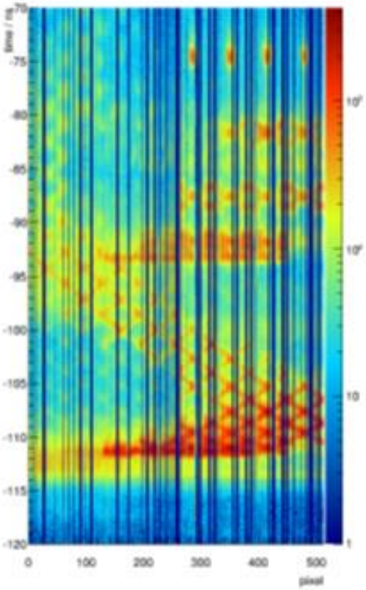


Summary

- In order to achieve physics goals at Belle II, an efficient K/π separation is needed for the momentum range up to 4 Gev/c.
- Two different subdetectors developed for the “barrel” and “endcap” regions, both are Ring Imaging CHerenkov detectors.
- All the 16 TOP modules are installed successfully in the Belle II and cosmic ray/laser testing is ongoing with triggers from Outer Muon detector (KLM).
- Installation of HAPDs and aerogel tiles has started and will be finished this summer.
- Excellent Kaon identification efficiency of 93% at a rather low 4% pion misidentification probability (88%,9% respectively at Belle) over the wide momentum range is expected.

Thank you!





Photons from ice and sea under the sky,
Photons from vast water tanks in halls of stone,
Photons from the atmosphere in an insect's eye,
Photons from aerogels, light, clear, blown,
Photons from liquids, gases, crystals flying by,
Photons from fused silica expanding on a cone.
In RICH detectors where PID truths lie.
One Ring to rule them all, One Ring to find them,
One Ring to bring them all, correlate, and bind them
In RICH detectors where PID truths lie.

Blair N. Ratcliff
NIMA 502 (2003) 211–221