EPS HEP 2015, 22. - 29. 7. 2015, Vienna

Particle Identification Devices at the Belle II experiment

Rok Pestotnik

Jožef Stefan Institute, Ljubljana

on behalf of the Belle II collaboration

Outline

Introduction

Time of Propagation Counter

Aerogel RICH

Summary

Belle II at SuperKEKB B factory

Precision measurements of rare B, D and τ decays

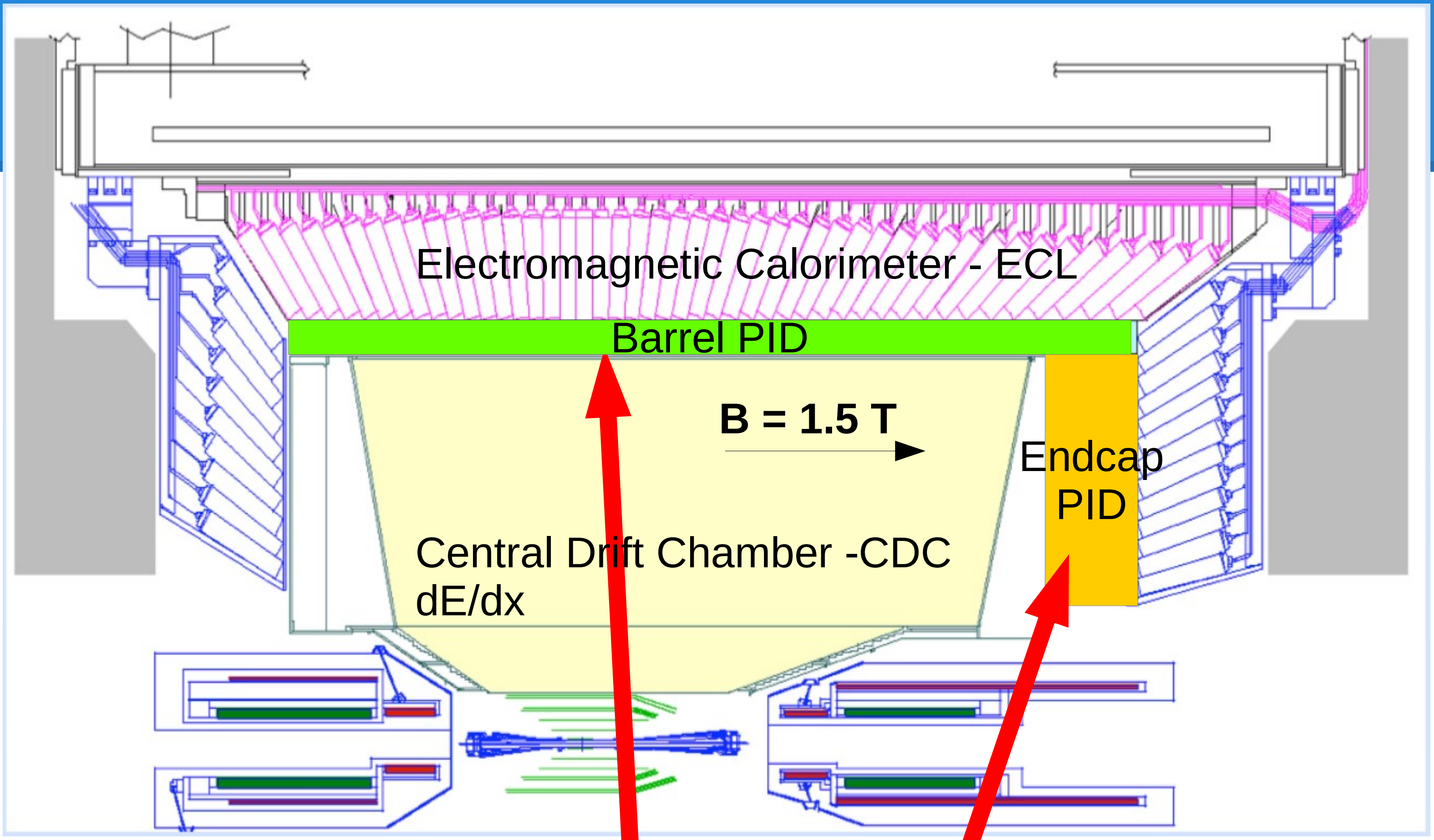
- Other Belle II contributions at the conference:
  - J.Wiechczynski , **The Belle-II Experiment at the Super-KEKB Collider**, 25/7 10:20@ Flavour Physics
  - Chunhua LI, **The data acquisition and trigger system of the Belle II experiment**, 25/7 10:00 @ Detector R&D
  - G.Casarosa, **Inner tracking devices at the Belle II experiment**, 24/7 15:00@ Detector R&D
  - T. Schlüter, **Track Fitting in Belle II: the GENFIT Library and its Performance**, 25/7 10:30, Detector R&D
  - M. Valentan, **The Belle II Pixel Detector: How to deal with high occupancy**, Detector R&D poster

- SuperKEKB will deliver 40 times higher event rates than KEKB.
- Belle II will collect 50ab^{-1} by 2022 → around 10^{10} B mesons
  - Higher rates
  - Much higher backgrounds

→ Significant upgrade of the Belle detector needed.

→ Highly efficient π/K separation for momentum range up to 4GeV/c is needed to identify particles from various decays

Particle identification in Belle II



Two dedicated particle ID devices:

both RICHes → designed to fit into available space

- Barrel: **Time-Of-Propagation (TOP)**
- End-cap: **Proximity focusing Aerogel RICH (ARICH)**

Photo detectors → operation in magnetic field 1.5T

Cherenkov angle:

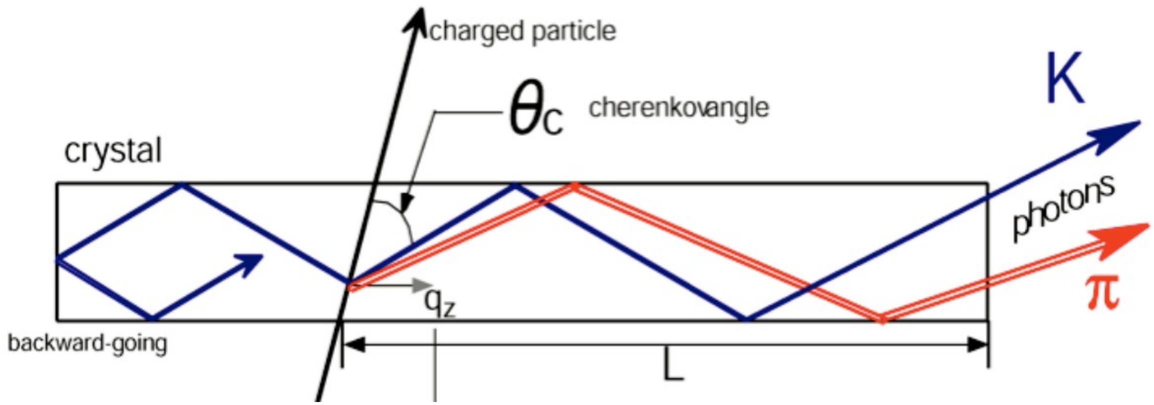
$$\cos\theta_c = \frac{1}{n\beta}$$

Number of emitted photons:

$$\frac{dN}{dE} \propto L \sin^2\theta_c$$

Barrel PID: Time of Propagation counter (TOP)

Cherenkov photons emitted in the quartz radiator → **internally reflected** → registered at the end of the bar by a fast position sensitive detector of single photons.

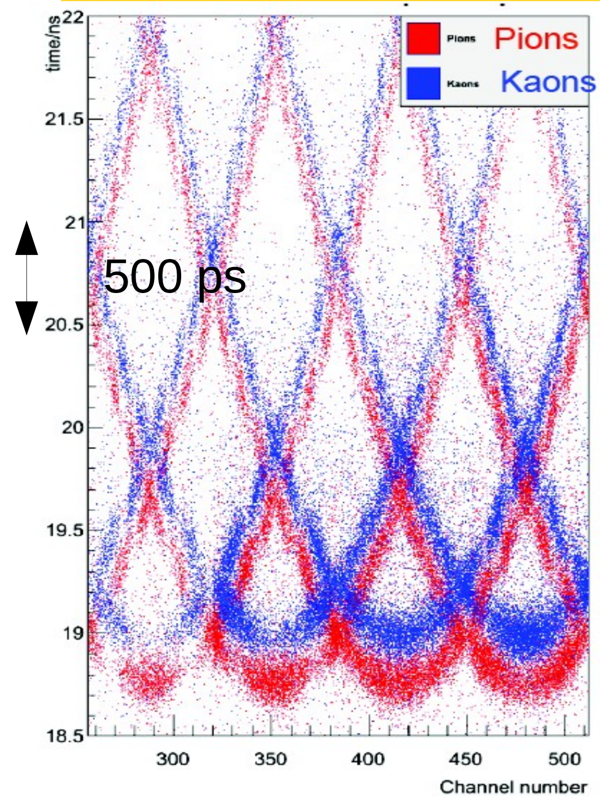


K/π → Different θ_c → Different path length → Different Time Of Propagation

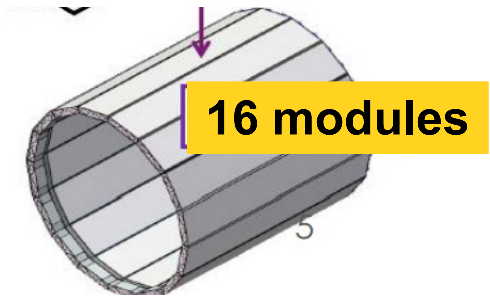
θ_c reconstructed from:

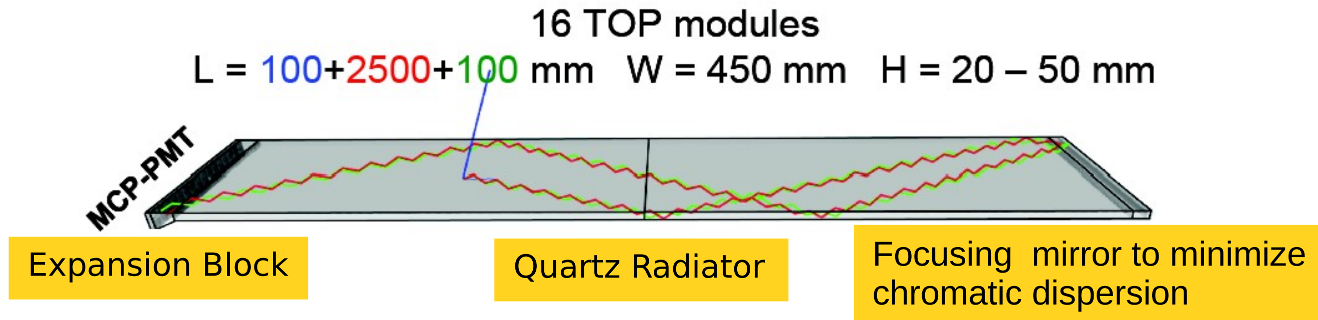
hit position (x,y) and Time Of Propagation of photon.

Arrival time of photons vs position (ch. number)



TOP Design





Radiator: Quartz bar of high quality → Cherenkov photons reflect more than 100x

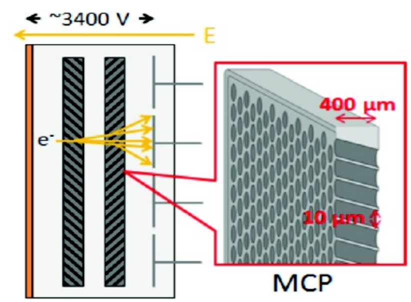
Photodetector → Hamamatsu SL10

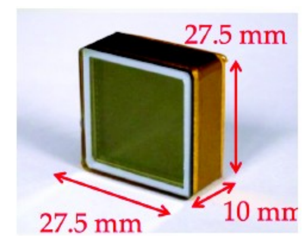
4x4ch 10 μm Micro Channel Plate - PMT

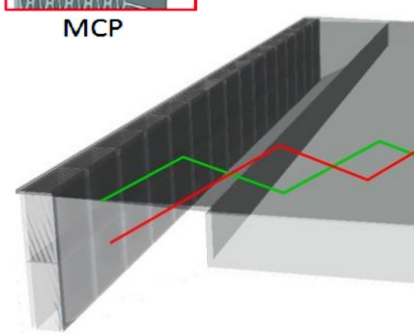
→ works in B=1.5T, gain $2\text{x}10^6$, σ~40ps,

Q.E. min 24% @ 380nm, coll. eff. 50-55%

→ 2x16 sensors /module → 512 total

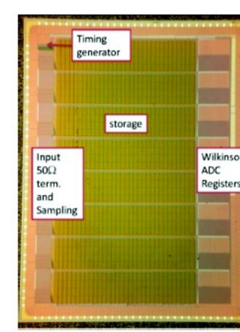






Front End Electronics:

High-speed 4GHz waveform sampling ASICs (“IRSX”) 8 channels/chip σ< 50ps



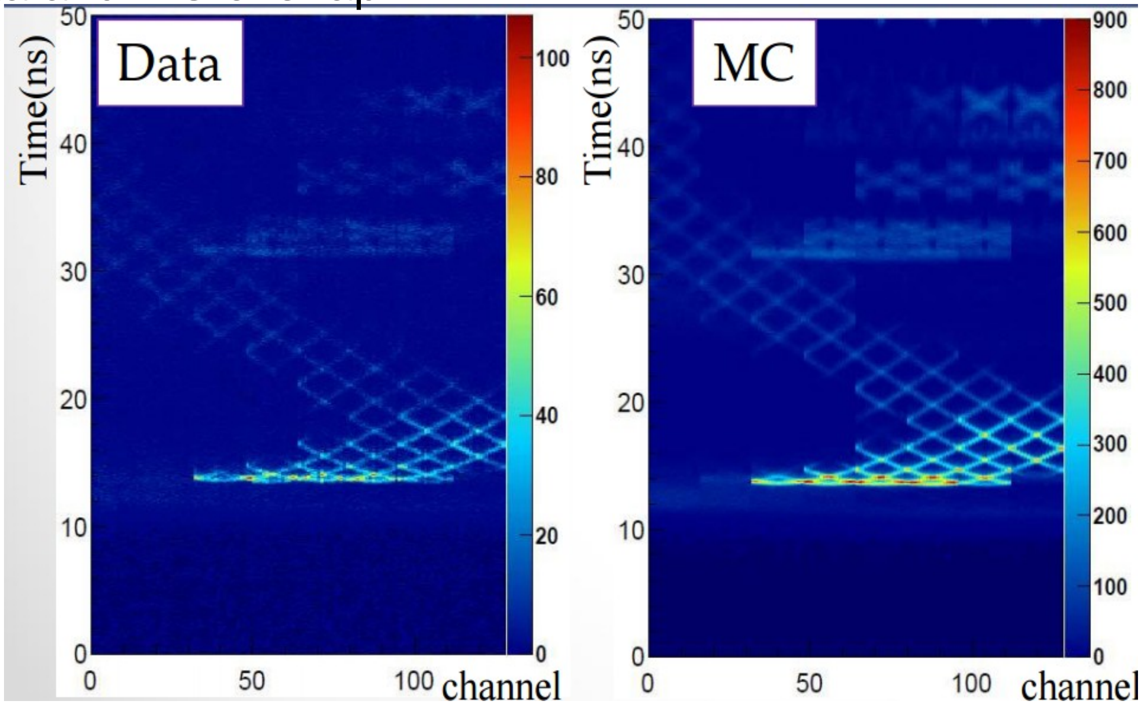
TOP – Beam test @ SPring-8 LEPS 2013

Proof of the principle

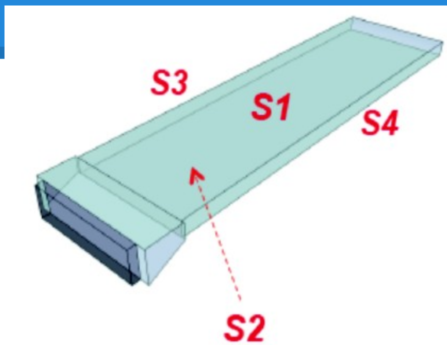
Full scale prototype (with backup electronics)

- 2GeV/c positron beam

Excellent data and MC overlap



TOP Challenges



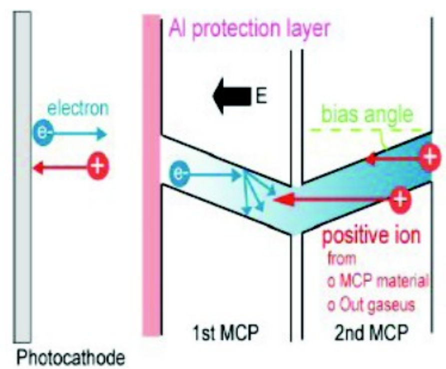
High quality quartz bar:

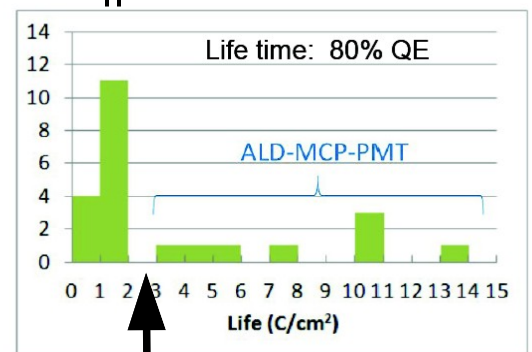
- Flatness < 6.3 μm
- Roughness < 0.5 nm (RMS)
- Perpendicularity < 20 arcsec S1⊥S3,S4
- Parallelism < 4 arcsec S1|| S2

MCP PMT lifetime:

Atomic Layer Deposition to protect the photocathode from the positive ions

→ 284 conventional (will be replaced after degradation) and 284 ALD MCP-PMTs produced





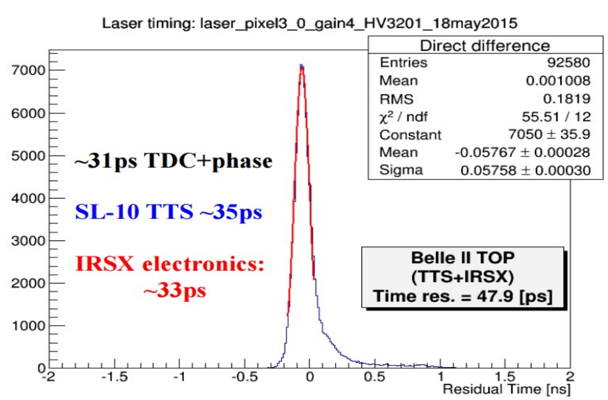
Average lifetime: 1.1 (normal), 8.6 (ALD) C/cm²

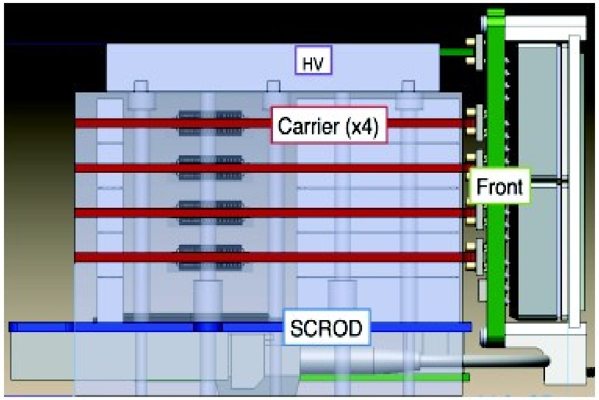
Belle II expectations

Front end electronics:

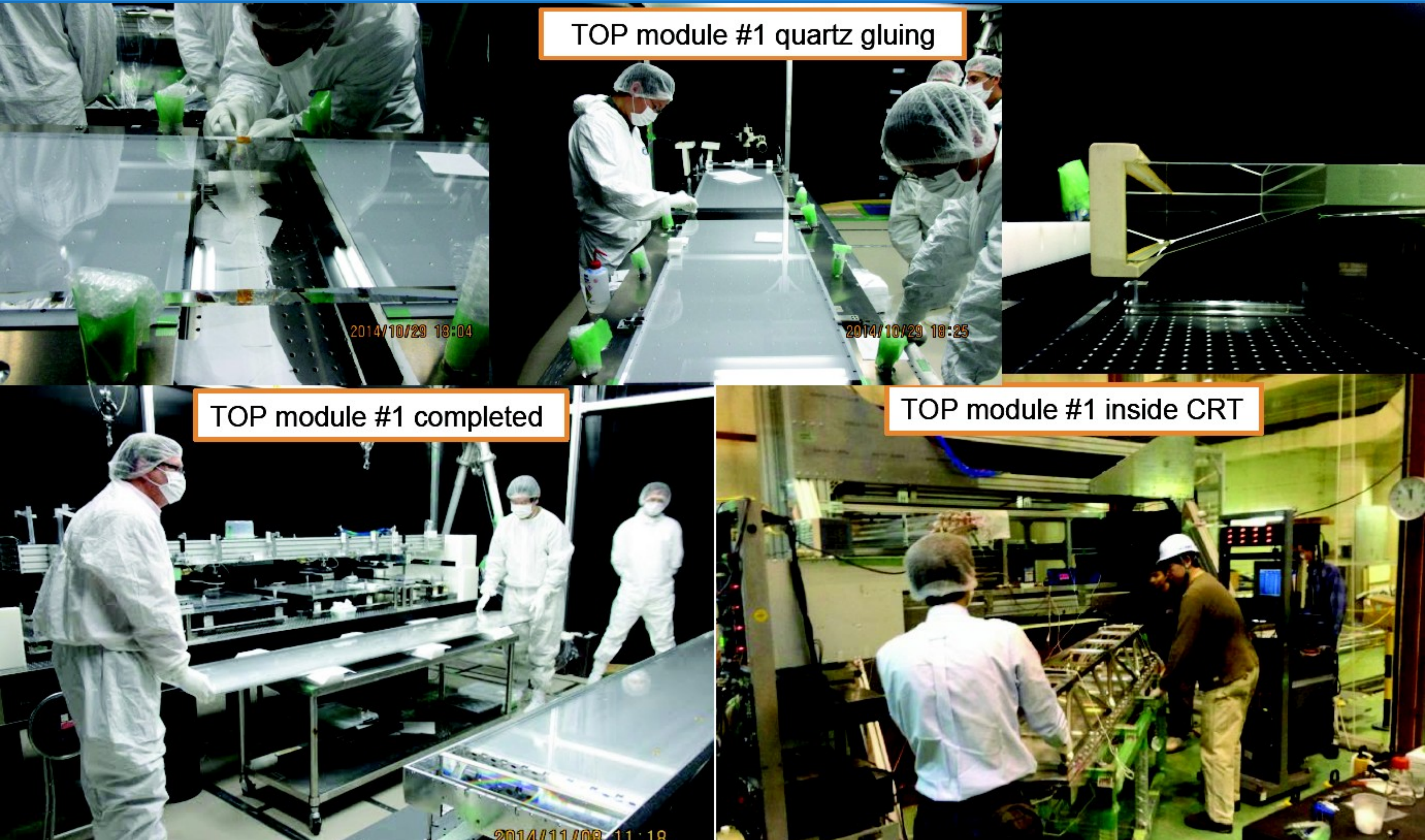
to read 8192 MCP PMT ch.

- 8 channels/ASIC chip,
- 4 ASICs / Carrier board,
- 4 Carrier boards / 8 PMT





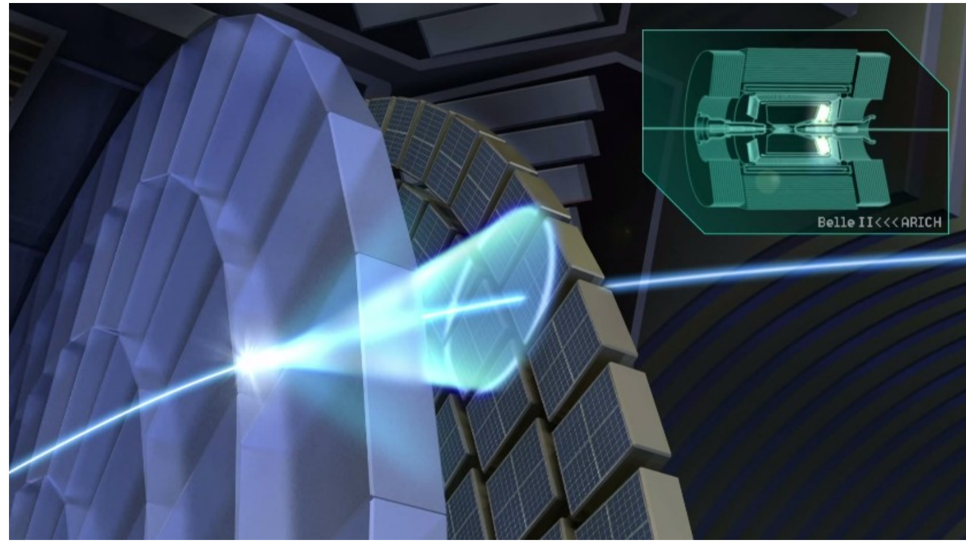
TOP Production – 5 modules finished



Endcap PID:
Proximity focusing Aerogel RICH

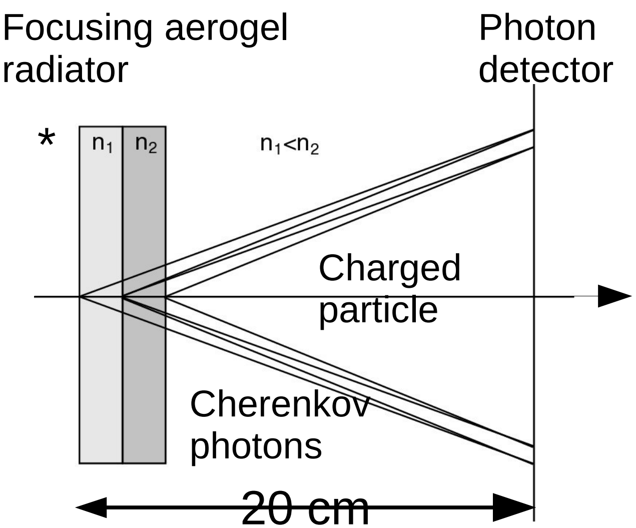
Goals and constraints:

- > 4 σ K/π separation @ 1-3.5 GeV/c
- limited available space ~280 mm
- radiation tolerance (n,γ)



Selected type:

proximity focusing aerogel RICH



- $\langle n \rangle \sim 1.05$
- $\theta_c(\pi) \approx 307$ mrad @ 3.5 GeV/c
- $\theta_c(\pi) - \theta_c(K) = 30$ mrad @ 3.5 GeV/c
  - pion threshold 0.44 GeV/c,
  - kaon threshold 1.54 GeV/c
- neutron fluence: up to ~10^{12} n/cm2
- radiation dose: up to ~1000 Gy

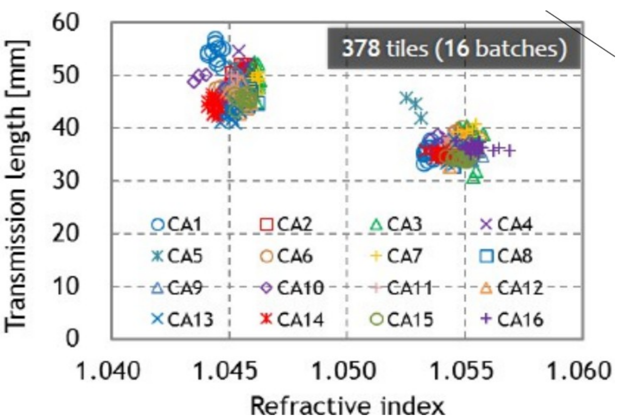
* to increase the number of photons without degrading the resolution

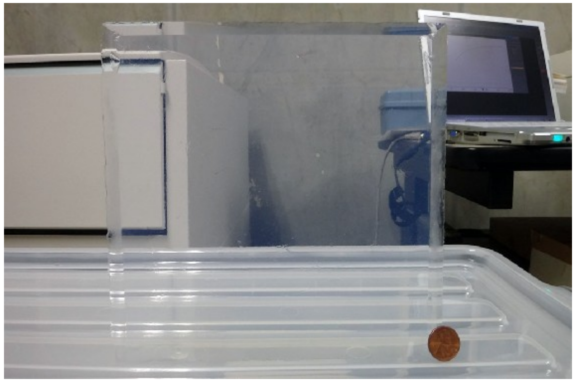
T.Iijima, S.Korpar et al. NIMA548 (2005) 383

ARICH - Aerogel radiator

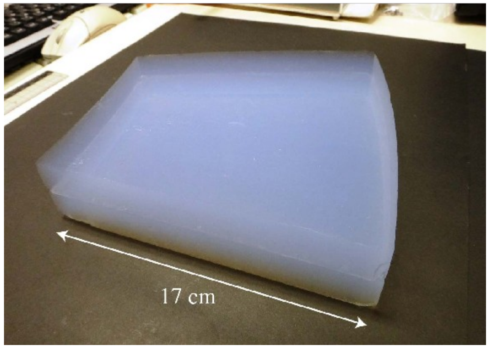
Highly transparent (transmission length @400nm >30mm) hydrophobic silica aerogel

- Two 2cm thick layers n_1= 1.045 n_2= 1.055
- large tiles 18x18x2 cm^3 to minimize photon losses at the edges

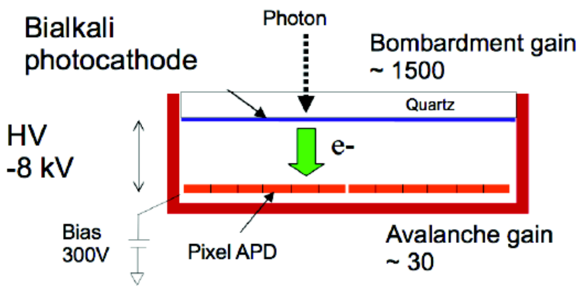


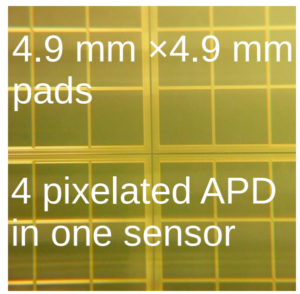


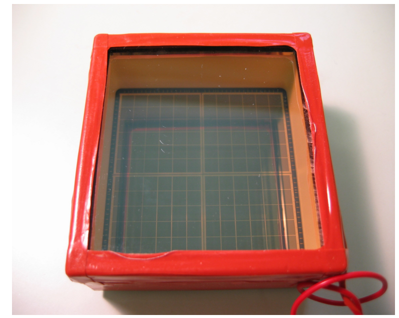
- 449 tiles already produced
- ready for cutting by water jets

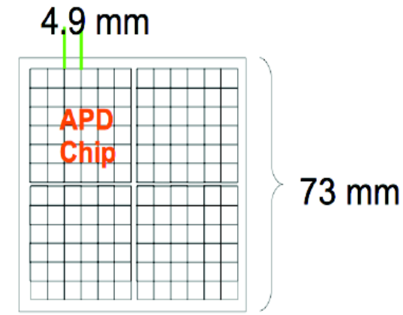


ARICH - 144 ch. Hybrid Avalanche Photo-Detector

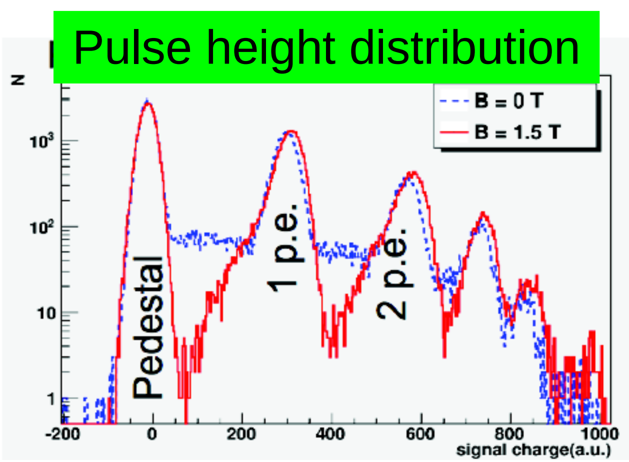


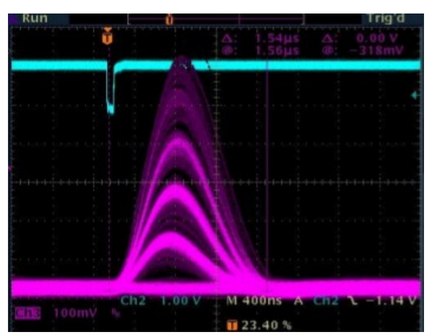


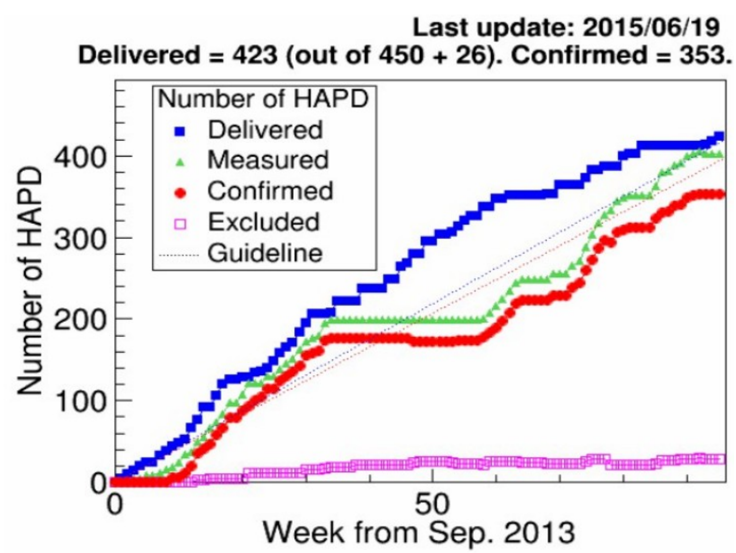




- HAPD developed with the Hamamatsu Photonics
- Works in a magnetic field of 1.5T
- Excellent separation of single photoelectrons



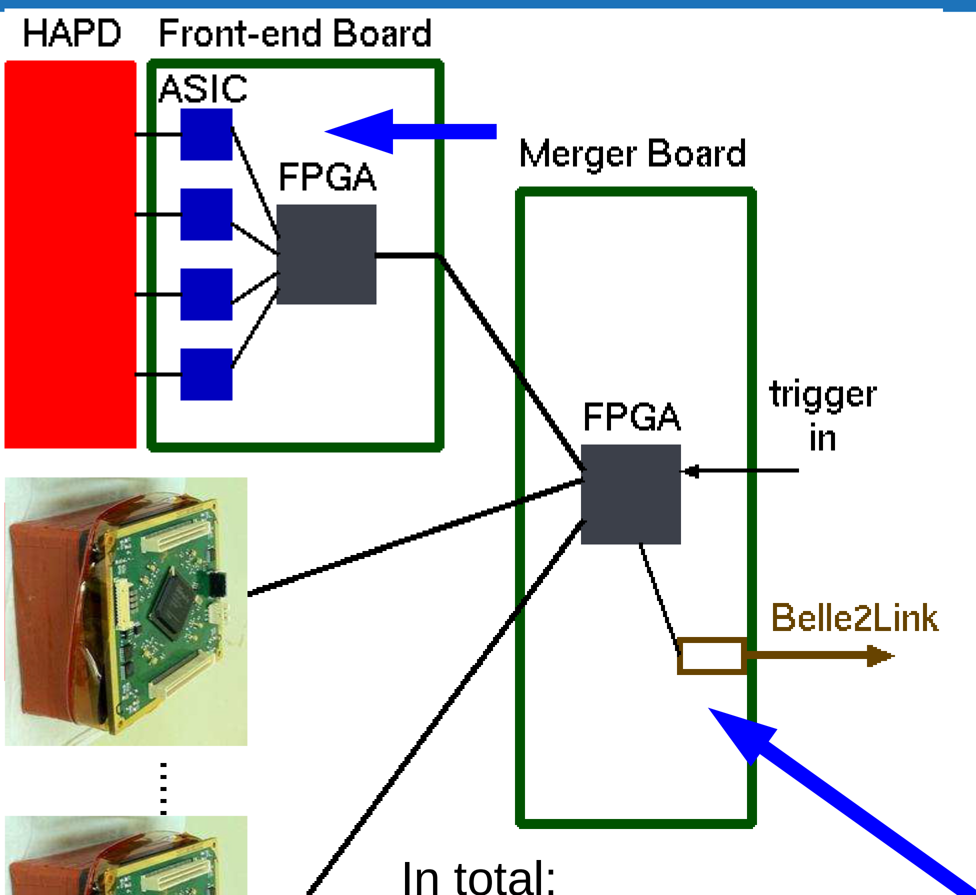




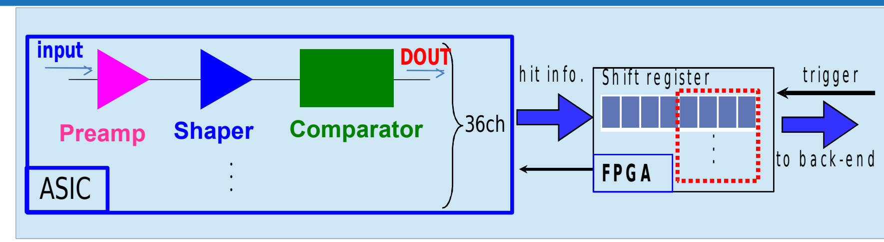
~ 80%(+10%) OK + 10% will be replaced

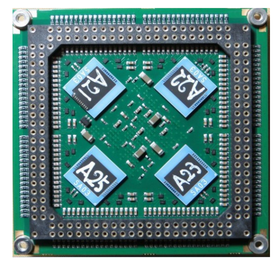
ARICH - Readout electronics

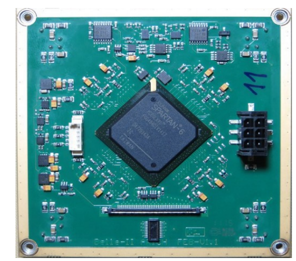
limited space (~5cm) behind the HAPD



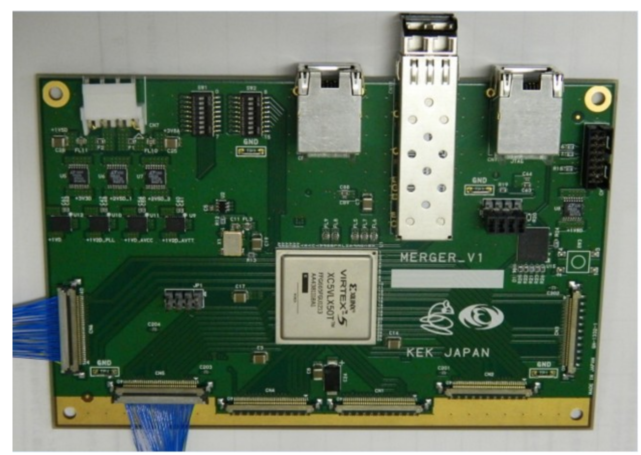
Board with 4 ASICs and Spartan6 FPGA







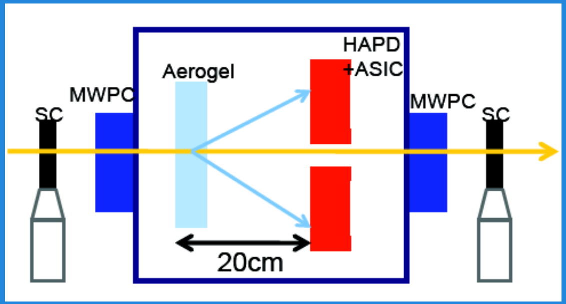
Merger board with Virtex5 FPGA



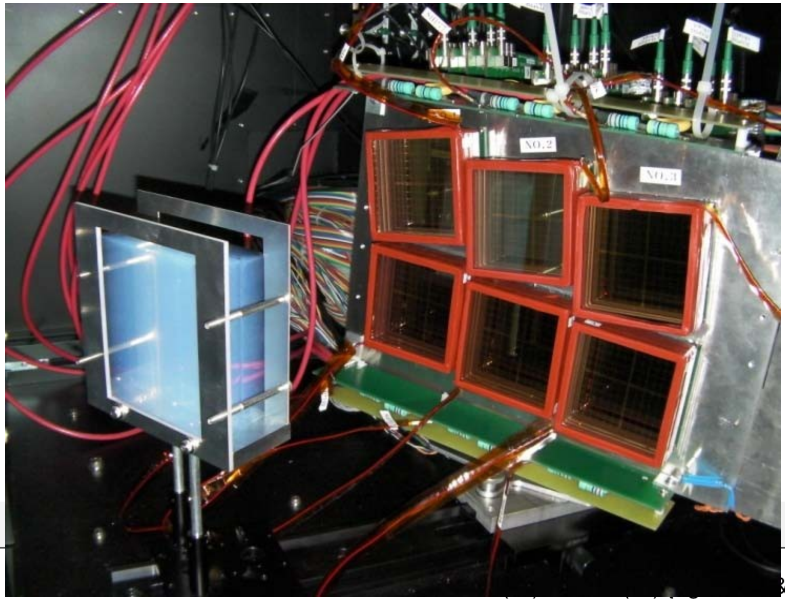
In total:

- 420 FE boards
- 72 merger boards

ARICH
Beamtest @ T4-H6 CERN SPS 2011



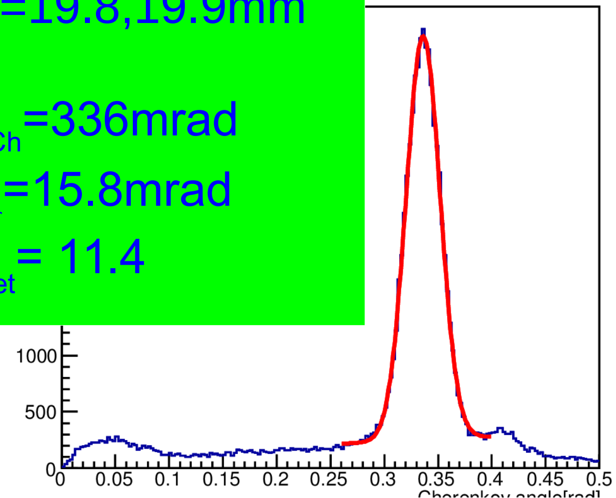
- 6 HAPDs arranged as in the final design
- front-end electronics ~ close to final

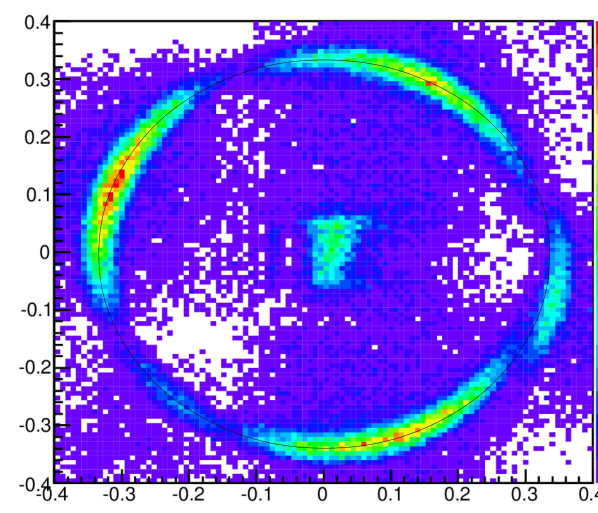


> 5.5 σ K / π separation at 4 GeV/c

double aerogel
- n_0=1.050,1.065
- d =19.8,19.9mm

ϑ_{Ch}=336mrad
σ_ϑ=15.8mrad
N_{det}= 11.4

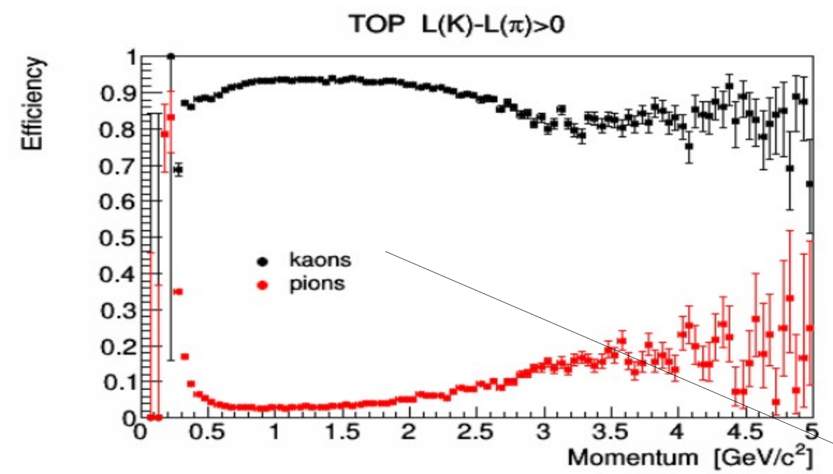


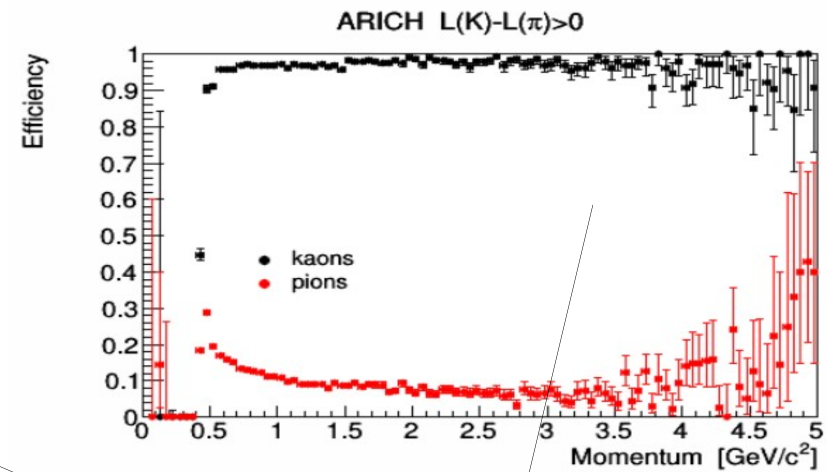


Expected performance

Detailed simulation performed in the Belle II software framework – BASF2

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



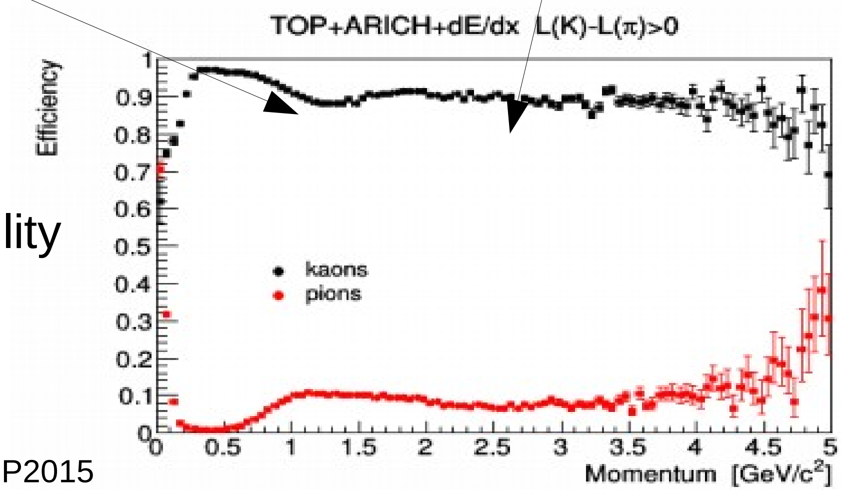


Excellent K identification efficiency over wide momentum range:

→ Belle II: **93%**, 4% π misidentification probability

Compare to:

→ Belle : 88%, 9%



Summary

For efficient particle identification at Belle II two RICH detectors will be installed

- Time of propagation counter → Barrel PID
- Proximity focusing RICH with an aerogel as a radiator → Forward Endcap PID

TOP:

- 1st TOP module is under test in the cosmic ray setup, 4 have optic elements already glued, the rest will be produced by May 2016
- Combined TOP + CDC test is under preparation

ARICH:

- Highly transparent hydrophobic aerogel tiles (n=1.045,1.055) have been produced
- 353 out of 475 Hybrid avalanche photo detectors have been produced and tested
- Mass production of the ARICH readout boards is planned for the next month

All the key components of both detectors have been extensively tested on the bench and in the test beams.

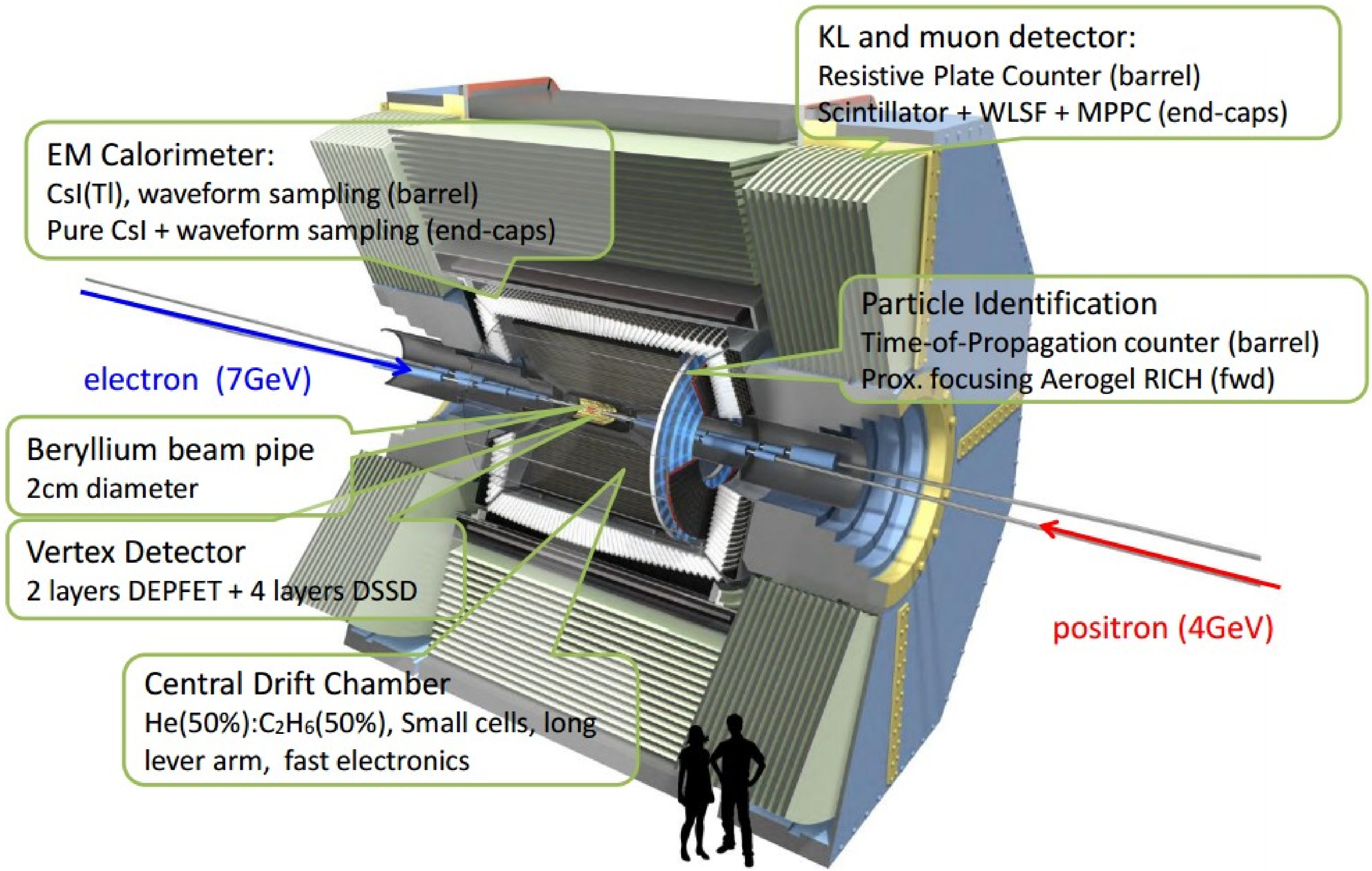
The installation in the Belle II spectrometer → summer 2016

The beam test results and the detector simulations show that the designed detectors will have an excellent kaon identification efficiency at a rather low pion misidentification probability.

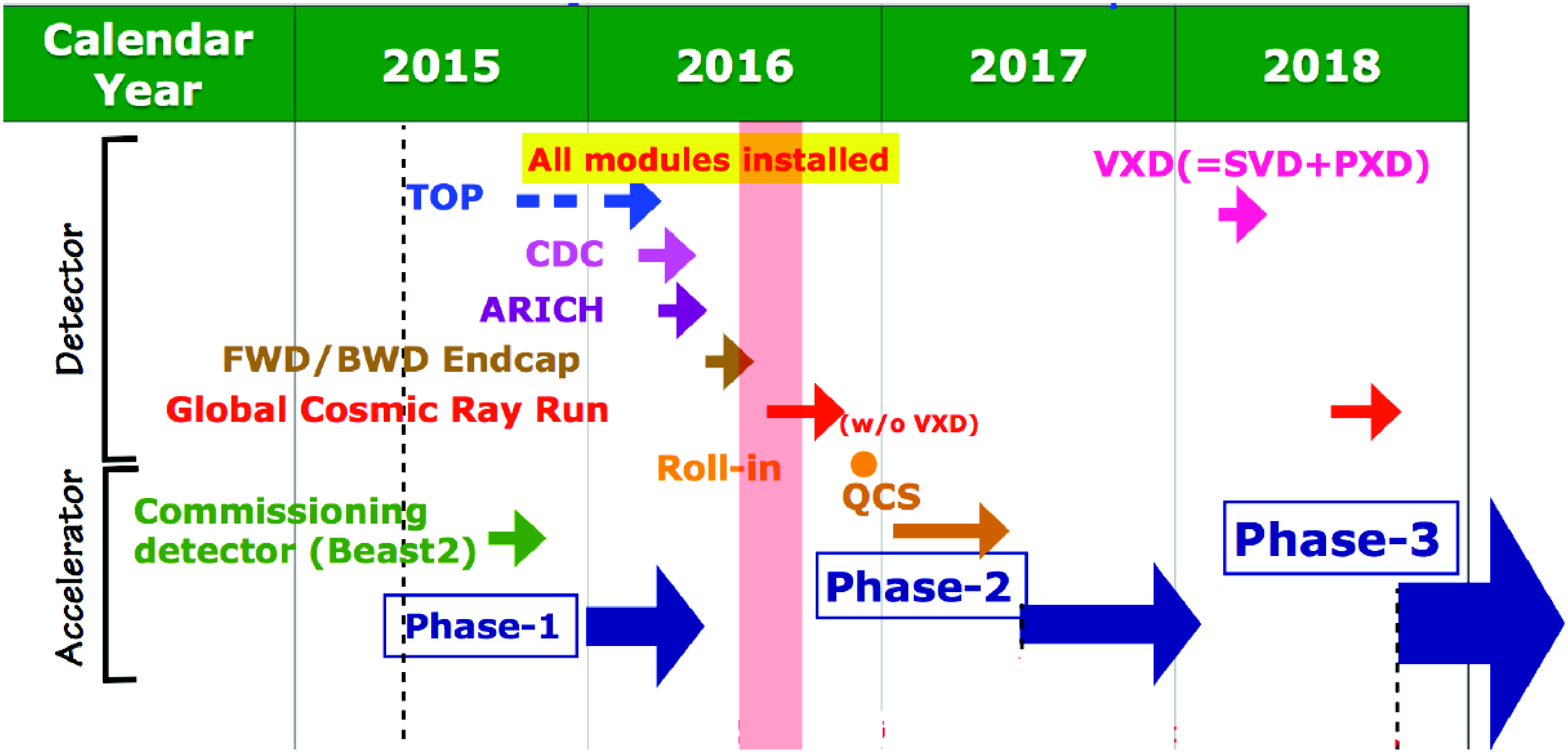
Backup

Belle II spectrometer

Belle II Detector



Schedule



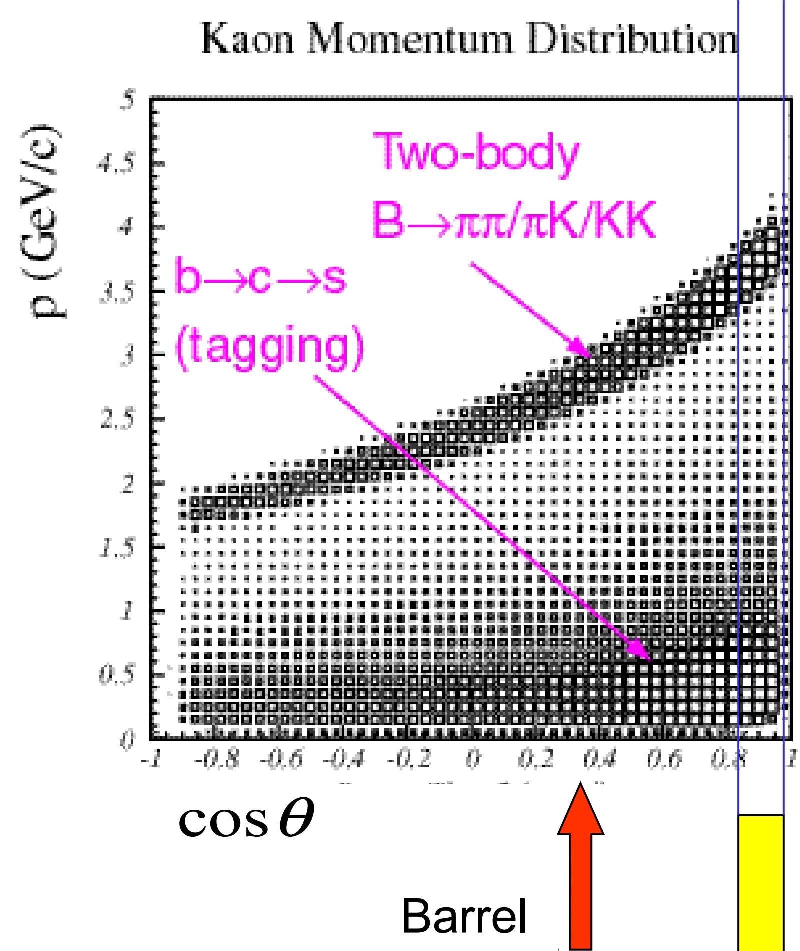
Calendar Year
2015
2016
2017
2018
Detector
Accelerator
All modules installed
VXD(=SVD+PXD)
TOP
CDC
ARICH
FWD/BWD Endcap
Global Cosmic Ray Run
(w/o VXD)
Roll-in
QCS
Commissioning detector (Beast2)
Phase-1
Phase-2
Phase-3

Particle identification requirements

- improve π/K separation for few-body B decays
- good π/K separation for

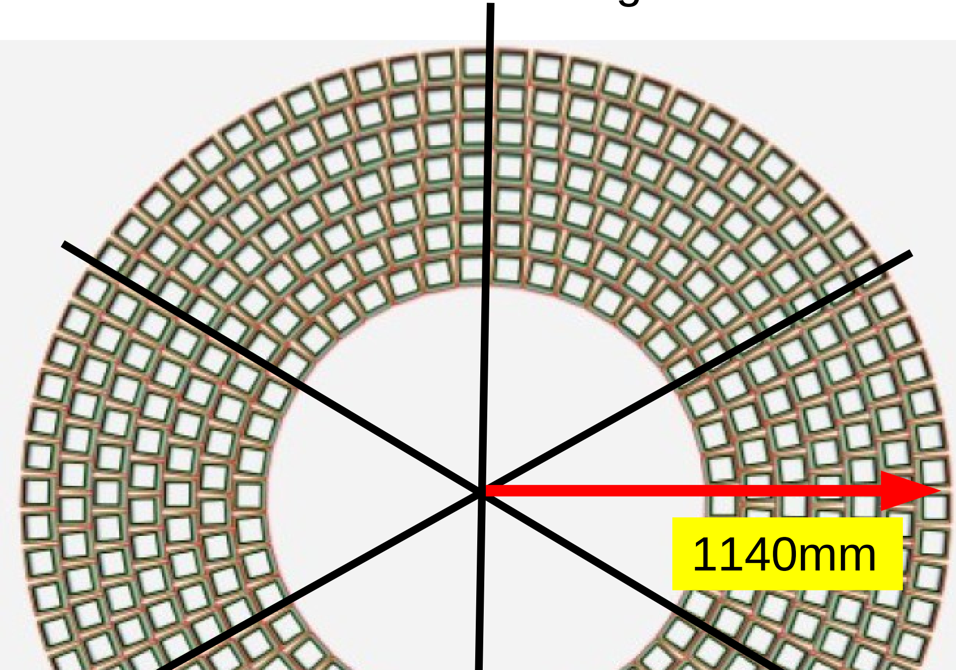
  b → d γ , b → s γ

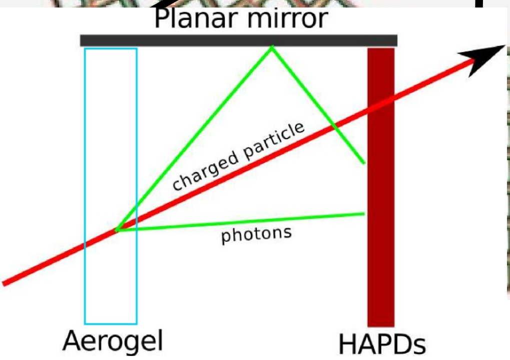
- improve purity in fully reconstructed B decays
- low momentum (<1GeV/c) e/μ/π separation (e.g. for B → Kll)
- keep high the efficiency for tagging kaons



Design of Aerogel RICH

420 HAPD modules in 7 rings

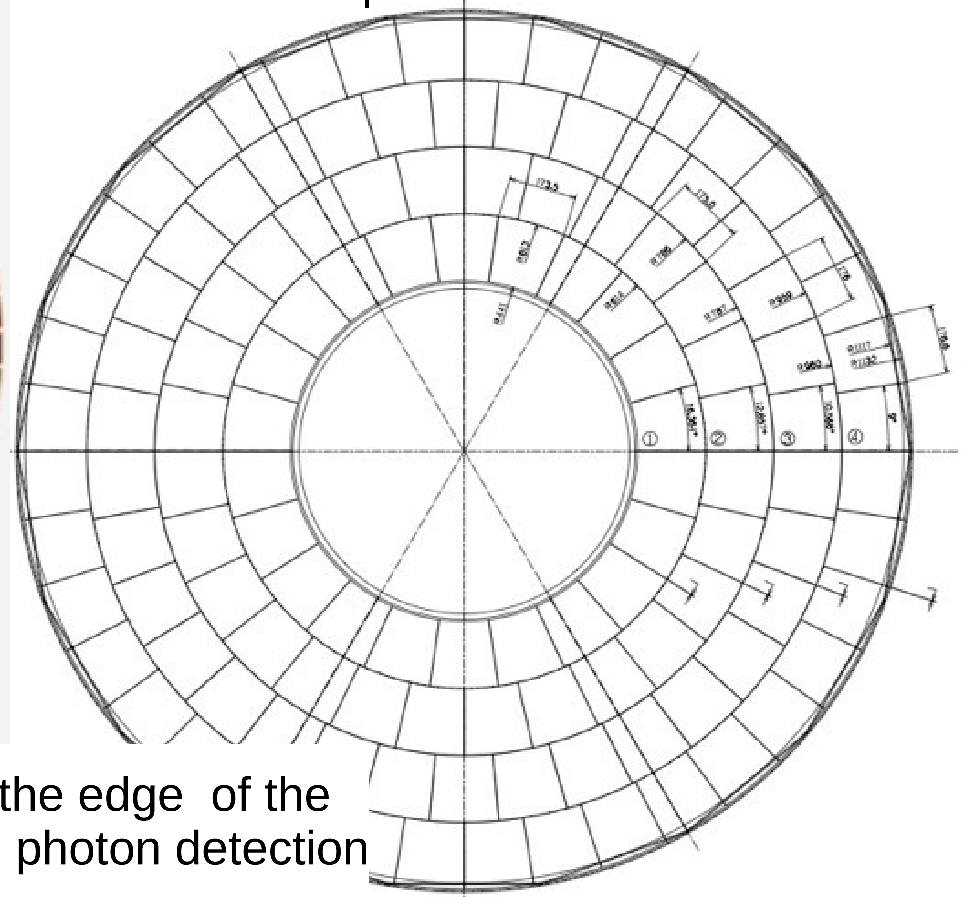




Aerogel : 124x2 pieces

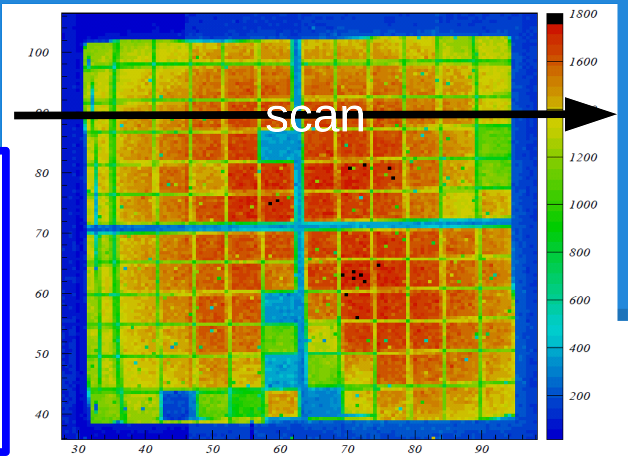
-wedge shape, each layer 20mm thick

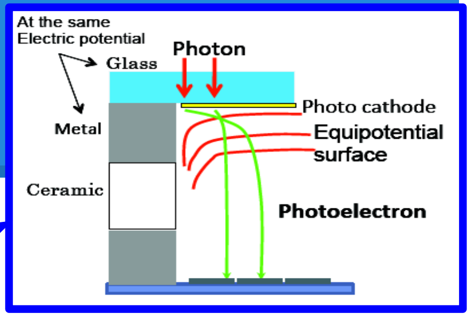
- 4 types depending on radius
- Cut out from square tile ~175 mm in side



Planar mirrors on the edge of the detector to improve photon detection

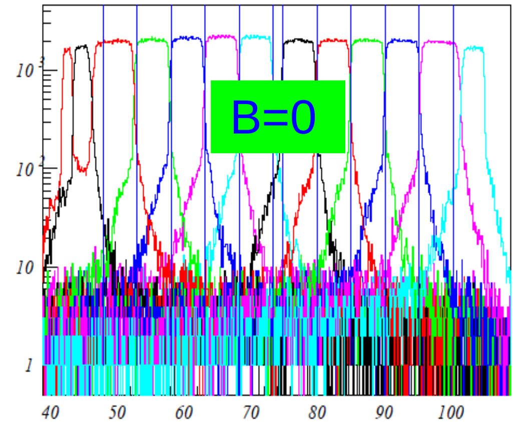
Performance in the magnetic field

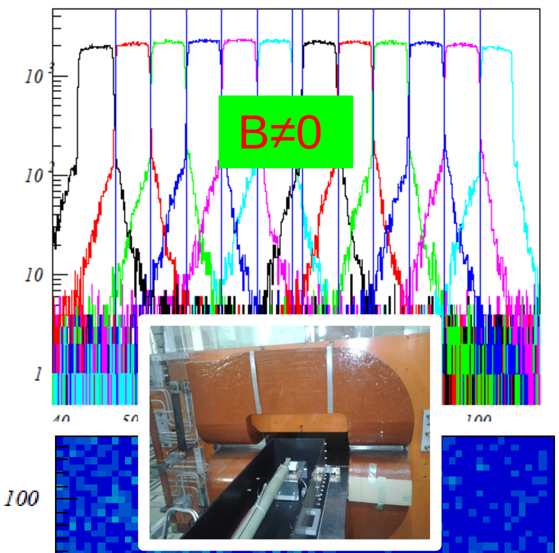


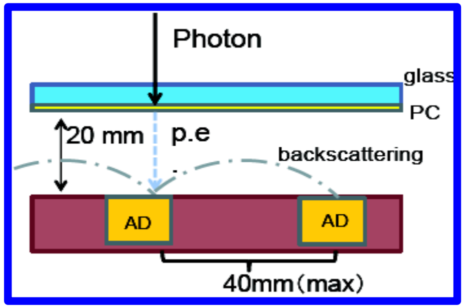


- distortion of electric field lines at HAPD edge produces irregular shapes of areas covered by each channel

- in magnetic field photoelectrons circulate along the magnetic field lines and distortion disappears







- photoelectrons are backscattered from APD and produce long range cross-talk

- in magnetic field photoelectrons follow magnetic field lines and fall back on the same place

(radius of 10 keV electron in 1.5 T is~100μm)

- scattered photons remain