High Energy Accelerator
Research Organization – KEK, Japan

Belle II

Recent developments in software for the Belle II Aerogel RICH

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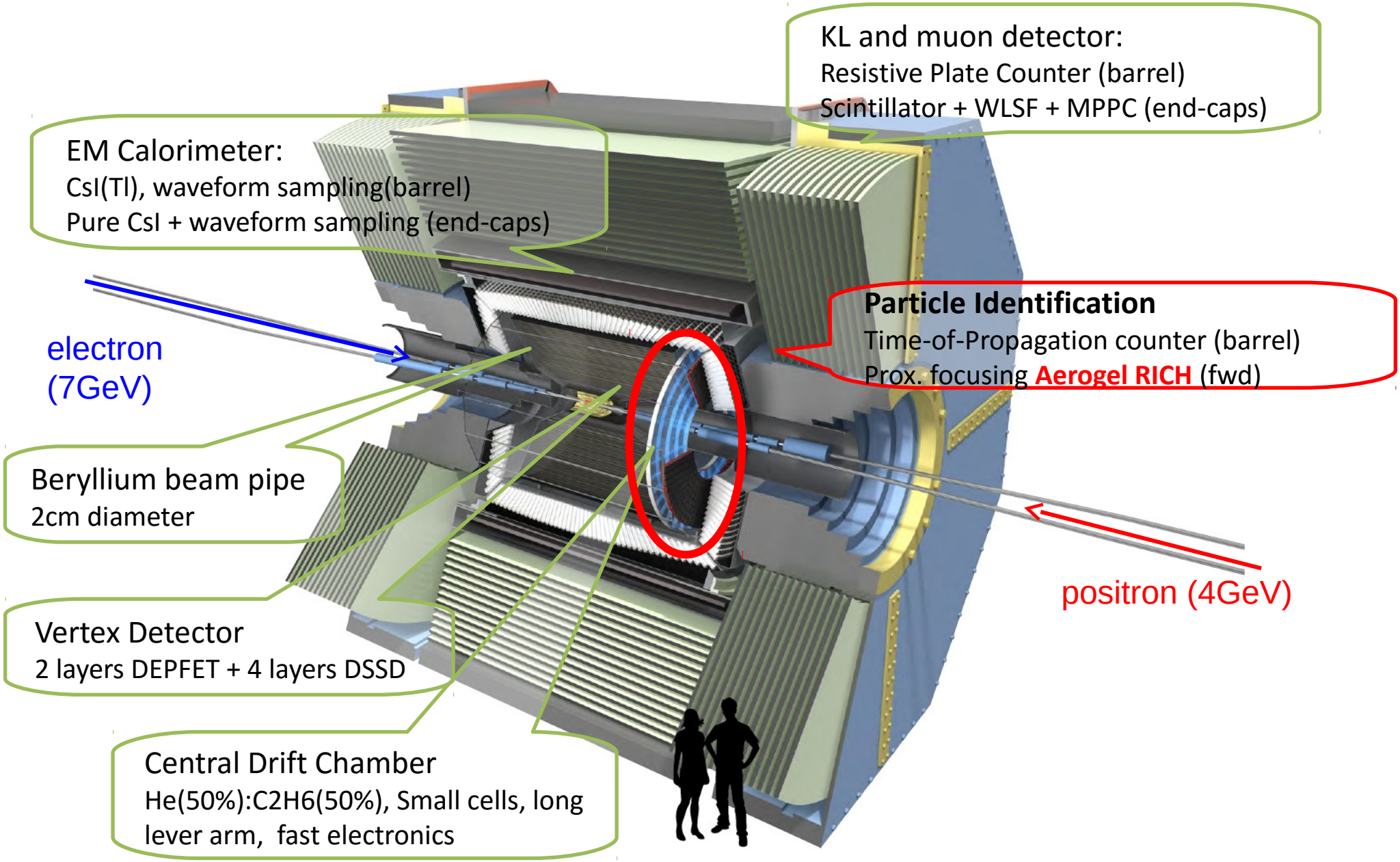
On behalf of the Belle II ARICH group

RICH 2016, Bled, Slovenia, 7.9.2016

The Belle II detector

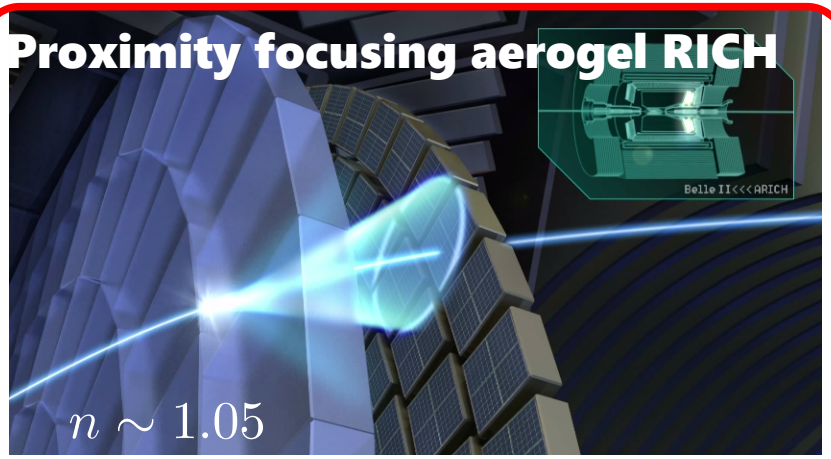


Aerogel RICH

Goal:

4σ π $/K$ separation, at 1.0 - 3.5 GeV
crucial not only for background reduction but also for B flavor tagging

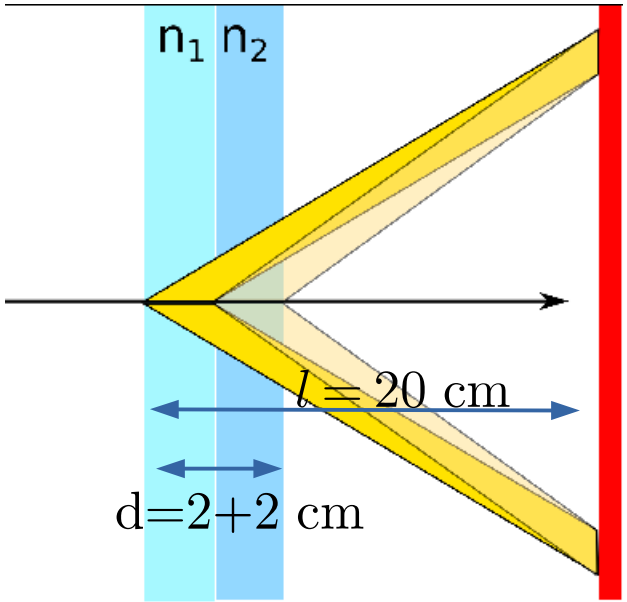
Constraints:
- in 1.5 T magnetic field.
- limited available space ~28 cm.
- radiation hardness (n, γ).



$\theta_C(\pi) = 0.31$ rad @ 3.5 GeV

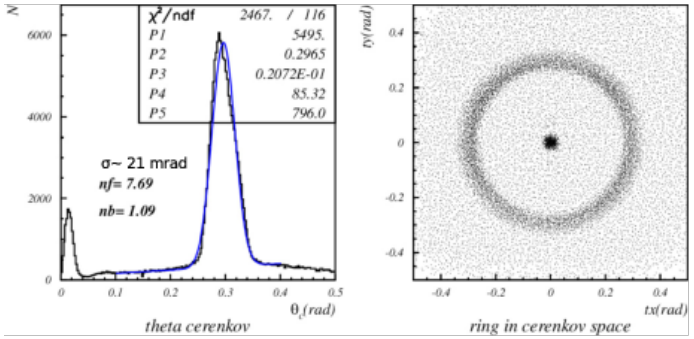
$\theta_C(\pi) - \theta_C(K) = 0.03$ rad @ 3.5 GeV

Novel technique of two aerogel layers in focusing configuration

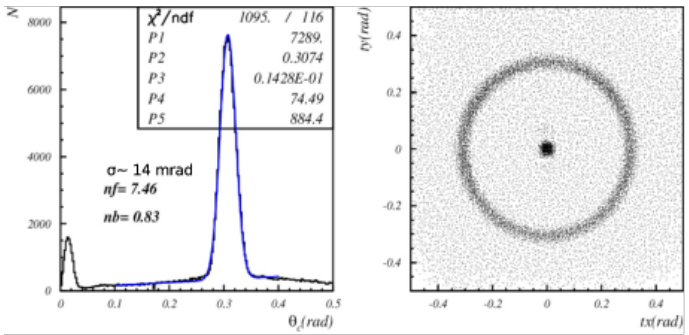


Almost doubling number of Cherenkov photons, without angle resolution degradation!

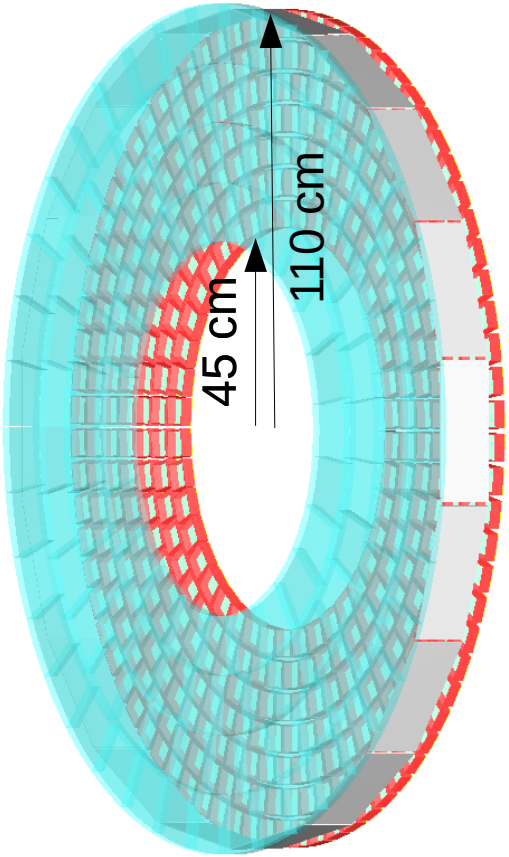
Single 4cm aerogel layer Beamtest data

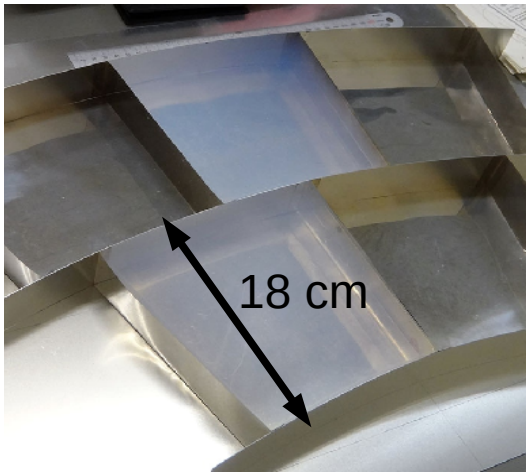


Two 2cm aerogel layers in focusing configuration



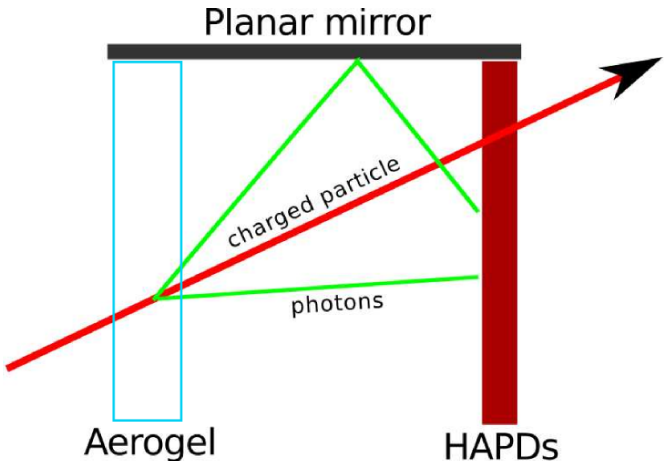
Geometry configuration





420 HAPDs are used to cover the detector plane

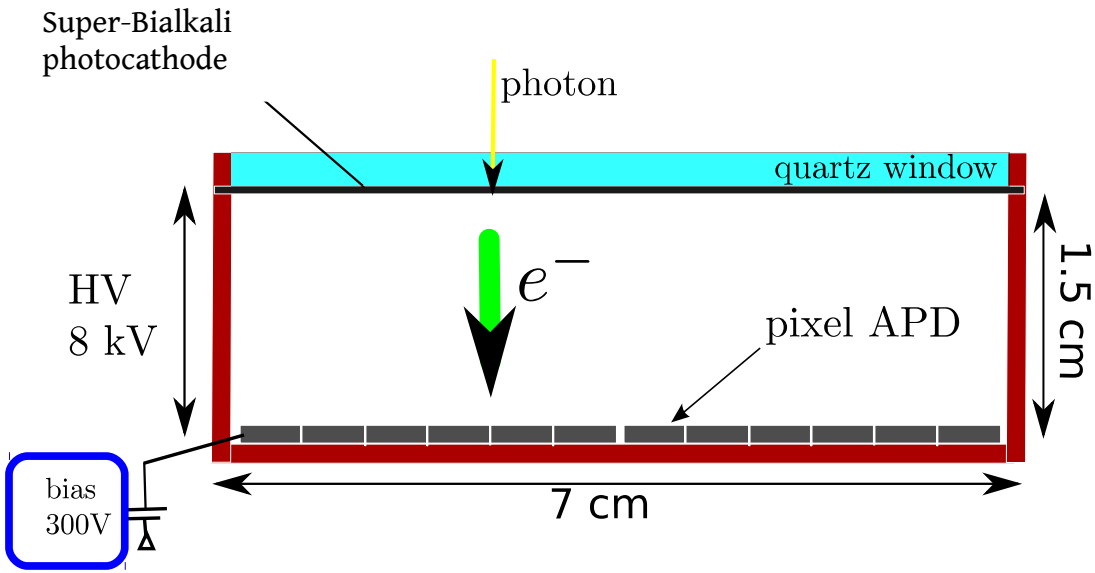
2 x 124 aerogel tiles are used to cover radiator
$n_1 = 1.045 \quad n_2 = 1.055$

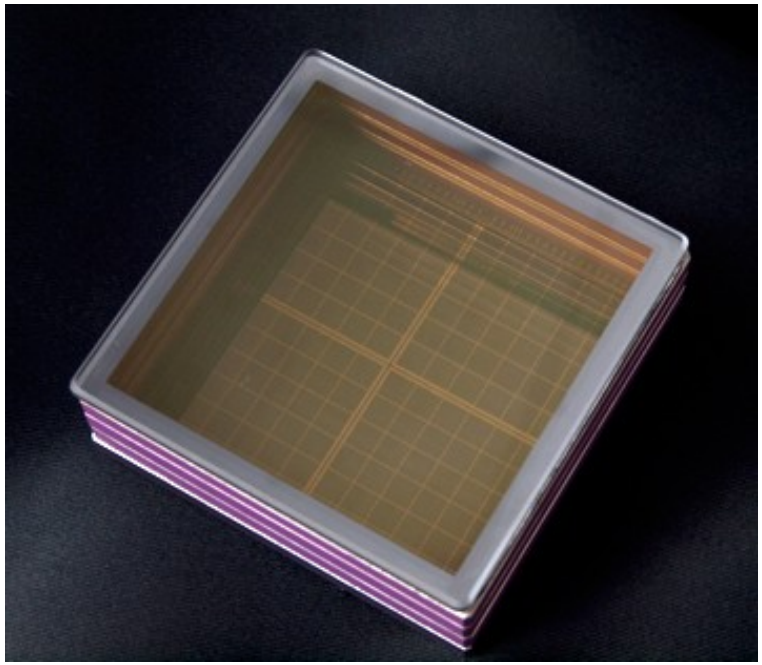


Planar mirrors on the outer edge, to prevent photon loss in that region

HAPD - Hybrid Avalanche Photo-Detector

- Developed in collaboration with Hamamatsu Photonics K.K
- APD: 12 x 12 channels (4 6x6 chips)
- Package size: 72 x 72 mm
- Effective area: ~65%

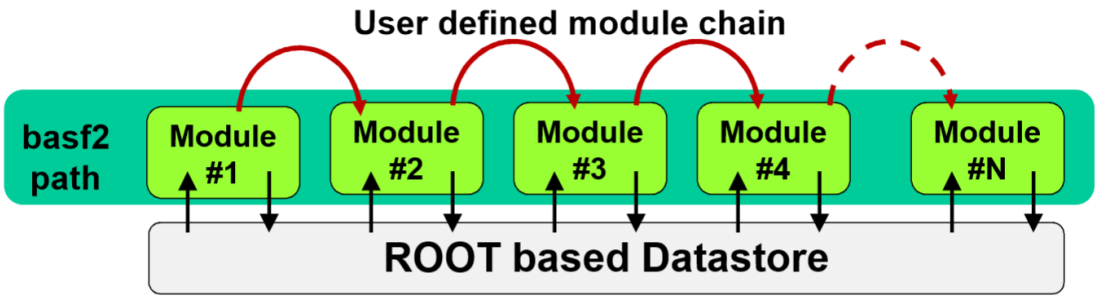




ARICH Software

- Integrated into BASF2 (Belle AnalysiS Framework 2)

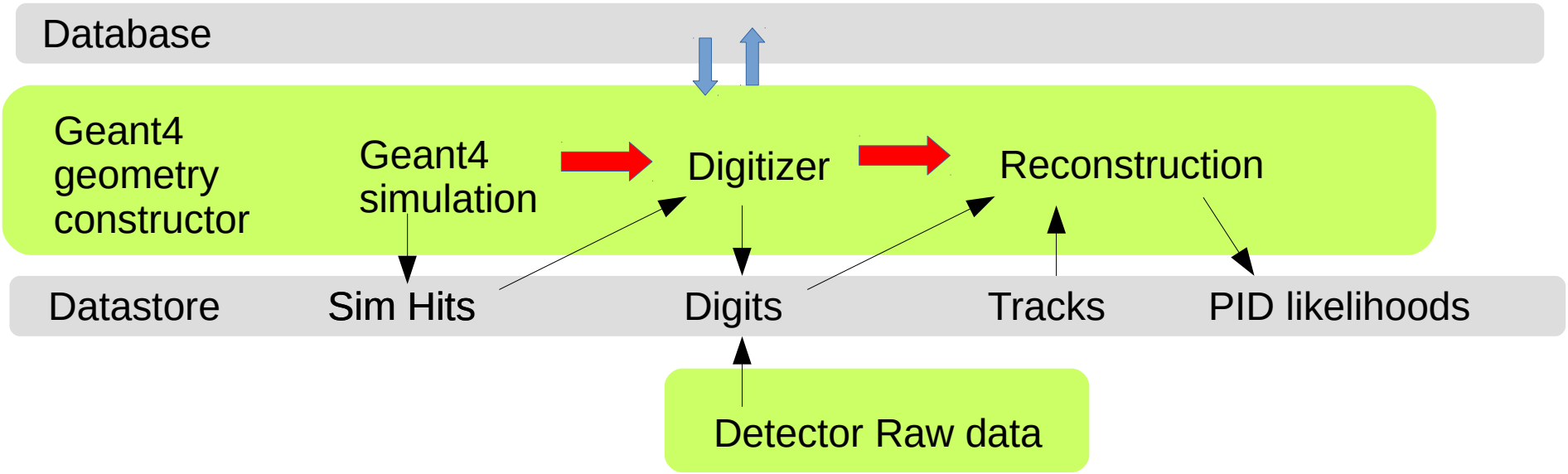
- A “framework” system with dynamic module loading, parallel processing, Python steering, and ROOT I/O



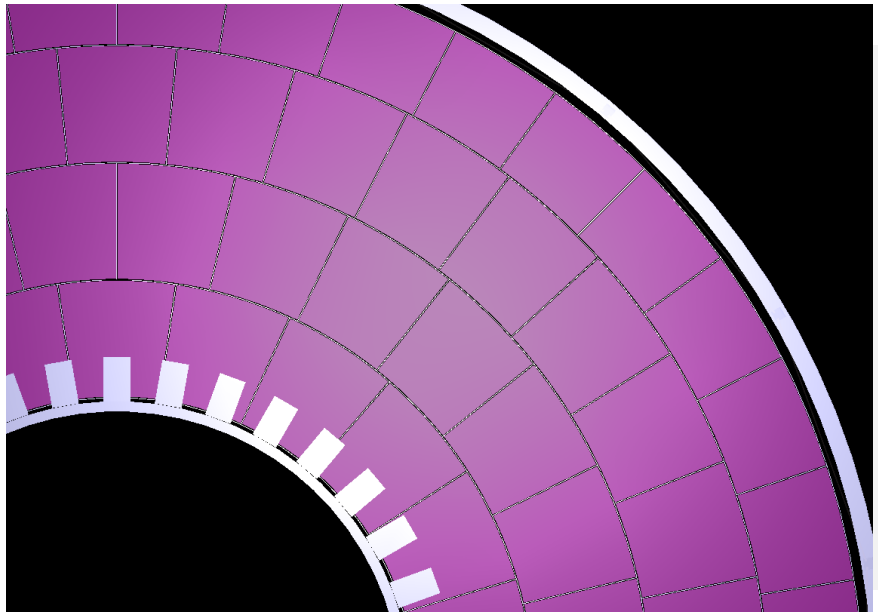
- Full Belle II detector Geant4 simulation

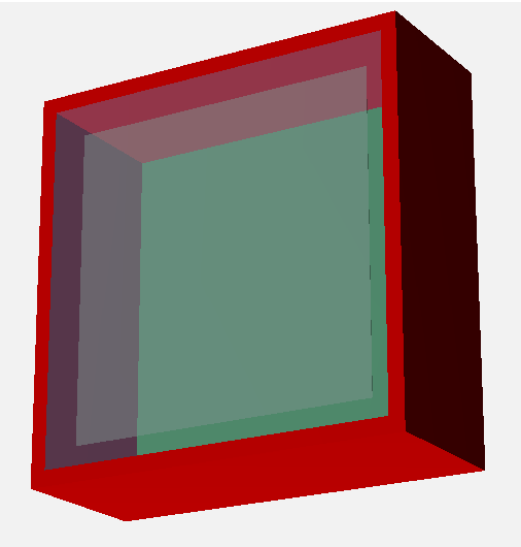
- Reconstruction and data analysis tools (PID, tracking algorithms, etc.)

- Basic event loop

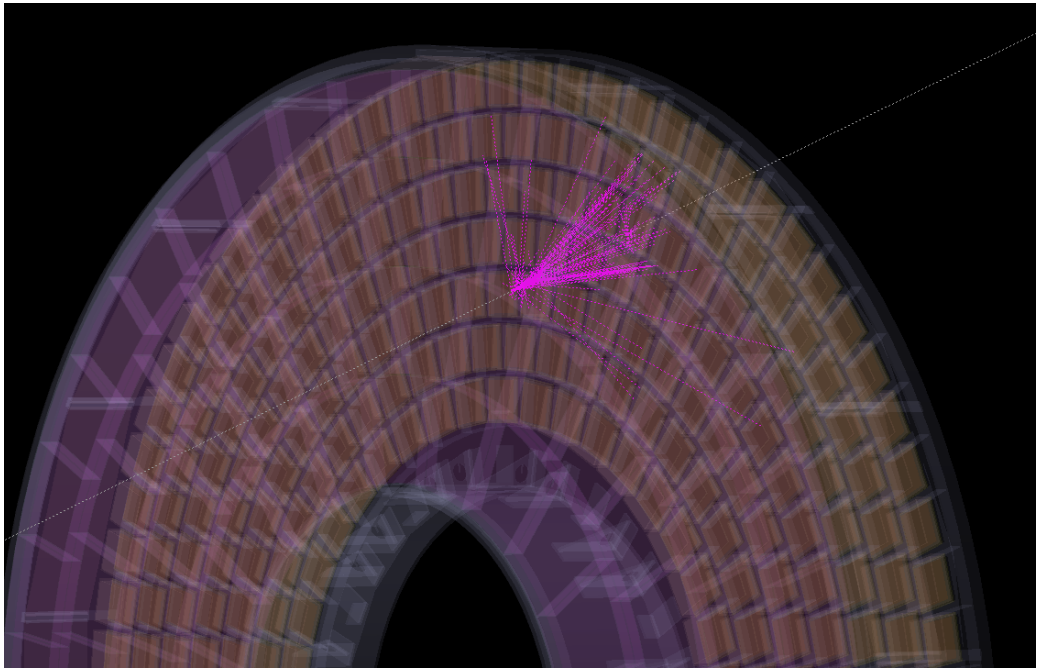


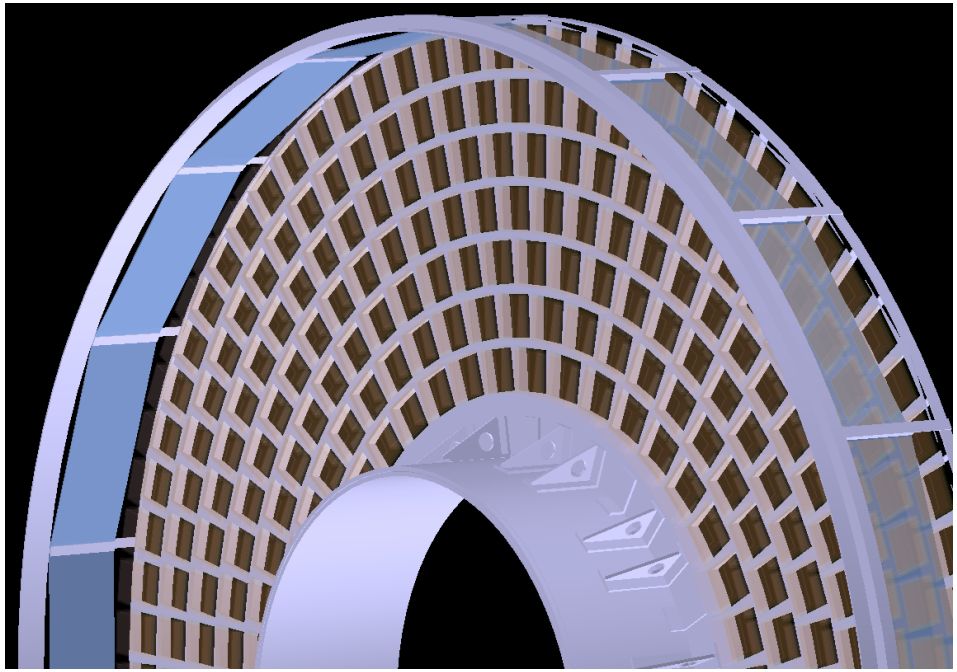
Geant4 geometry description





- Fairy detailed geometry implemented
- all basic components, including aluminum support structure
- cabling and cooling to be added

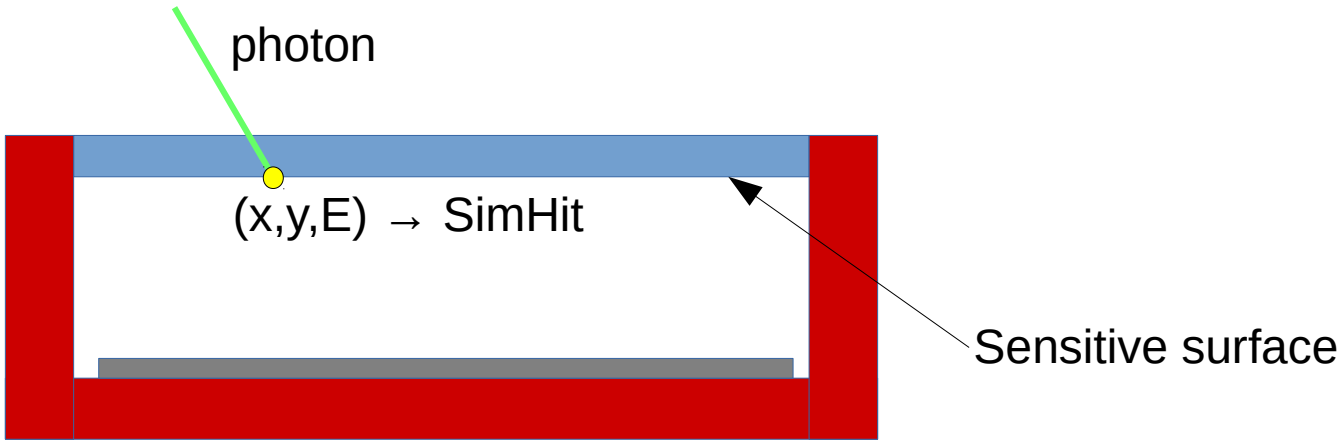




Simulation

- The response of HAPD upon the incident photon is simulated using a simplified scheme.

  Photo-electron emission and propagation are not simulated. Photon position on photocathode is taken as hit position (assuming perpendicular mag. field)



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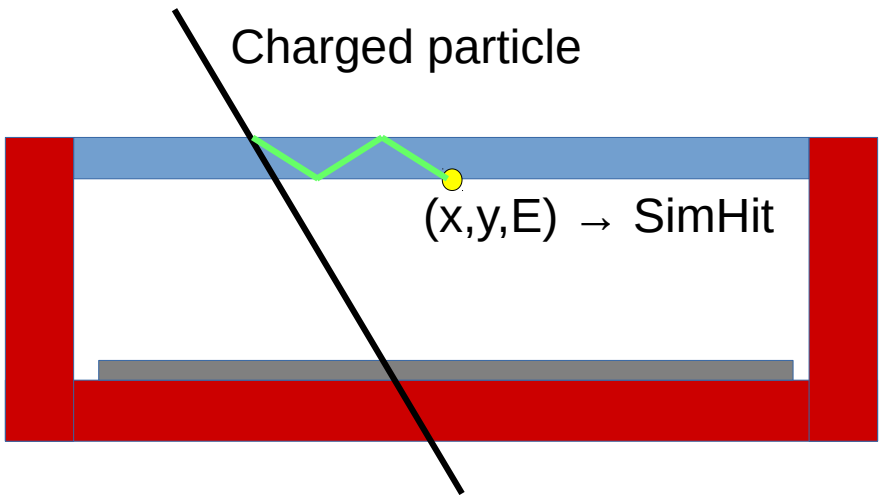
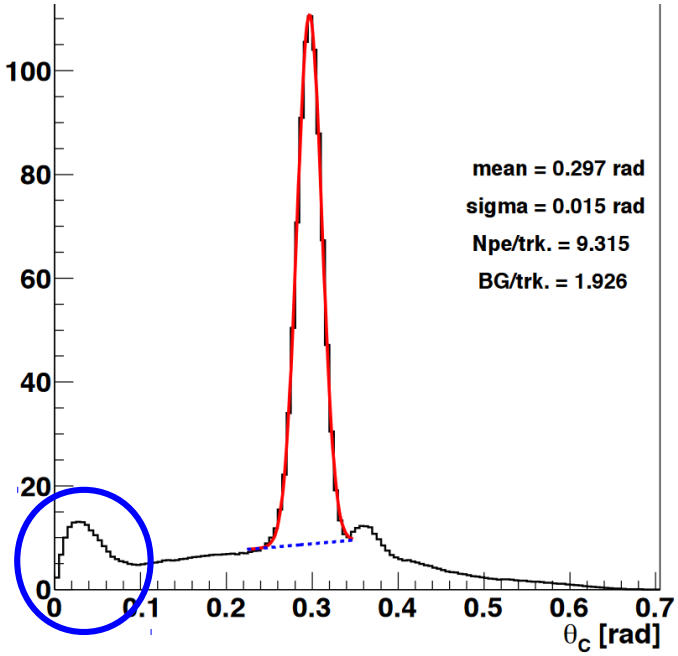
- Several effects observed in beamtests are included in the simulation:

  - production of Cherenkov photons in quartz window and their internal reflection





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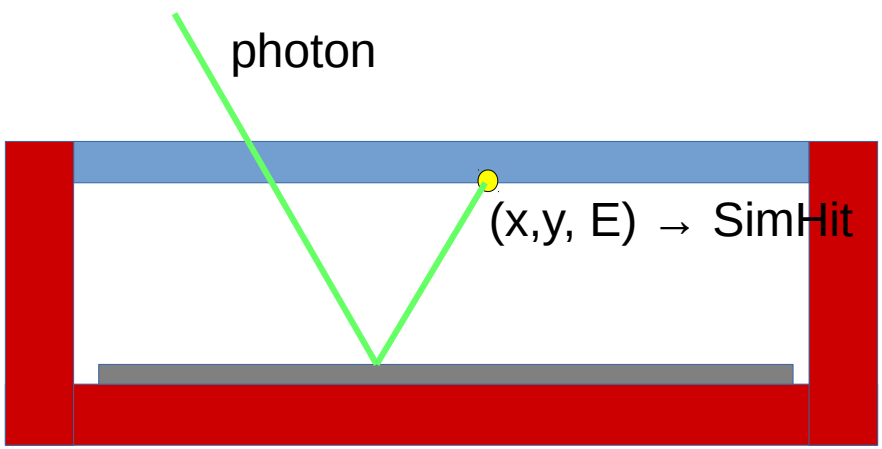
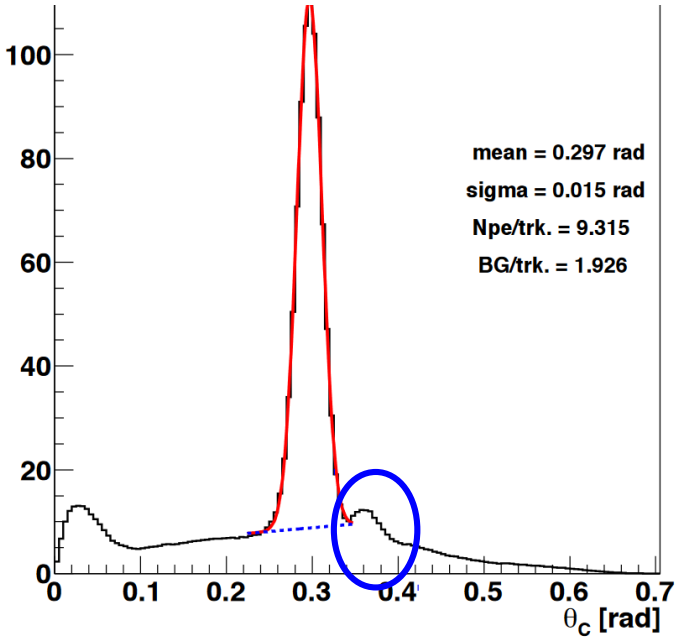
- Several effects observed in beamtests are included in the simulation:

  - production of Cherenkov photons in quartz window and their internal reflection

  - reflection of non-converted photons from APD surface





Digitization

- The digitizer module converts SimHits into Digits, which are used as an input to reconstruction algorithm (Digits ↔ detected photons).

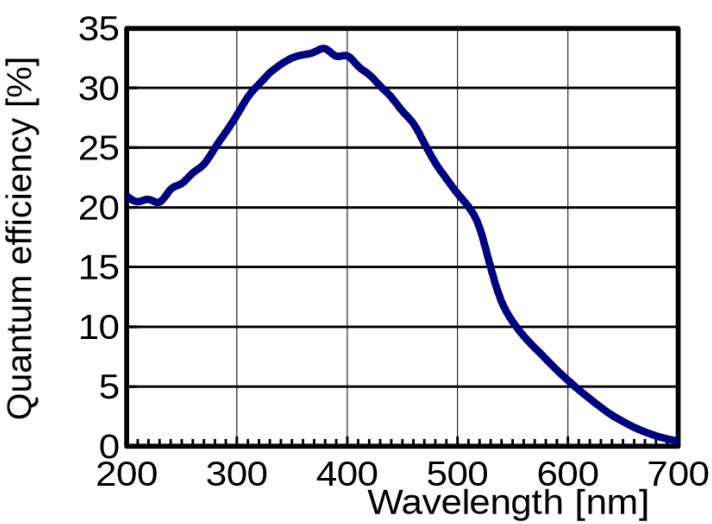
Pixelization SimHit (x,y,E) → APD channel number

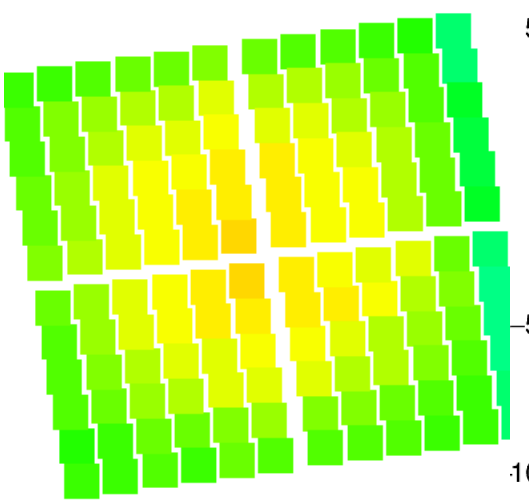
Photocathode QE

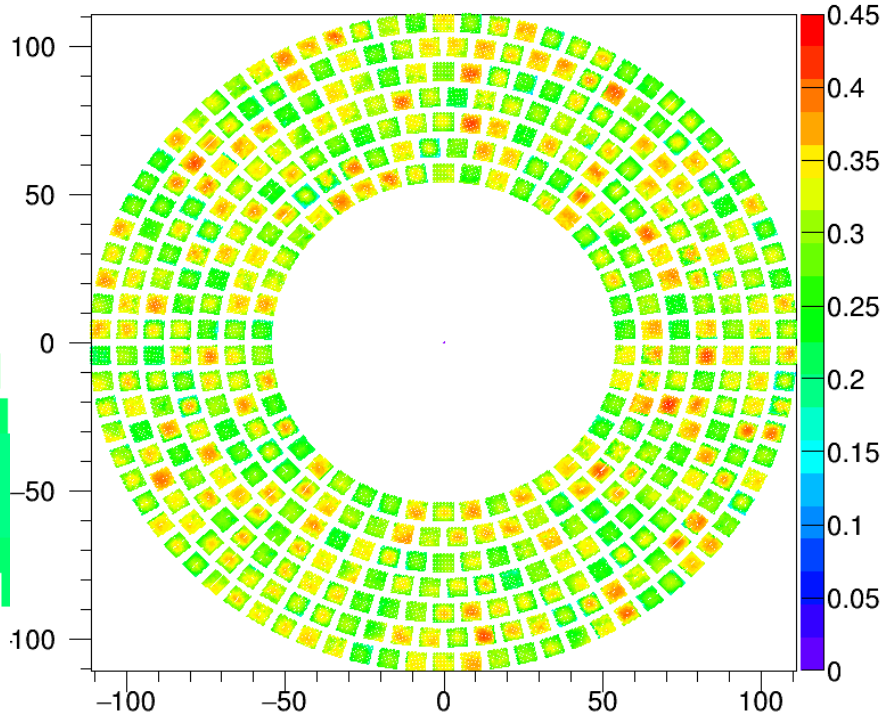
- common $QE(\lambda)$ curve shape is used for all HAPDs

- but scaled according to the QE as measured in HAPD QA tests, channel-by-channel for each HAPD.

Masking of dead channels (from database)







Digitization

Crosstalk of negative polarity

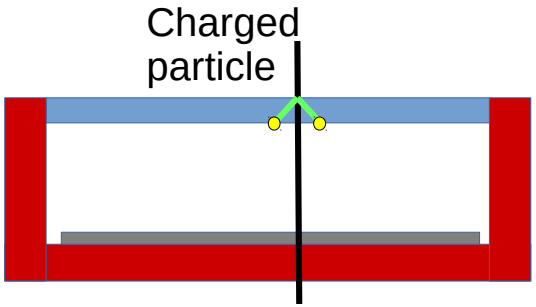
- we observed discrepancy in in angle distribution of Cherenkov photons from HAPD window in simulation and beamtest data.

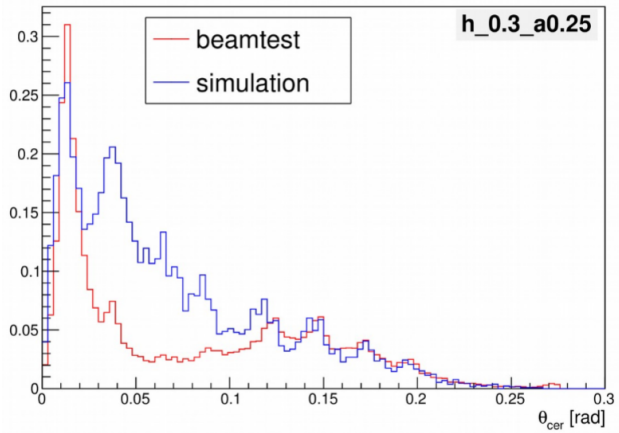
- the origin was negative polarity crosstalk between channels of same APD chip.

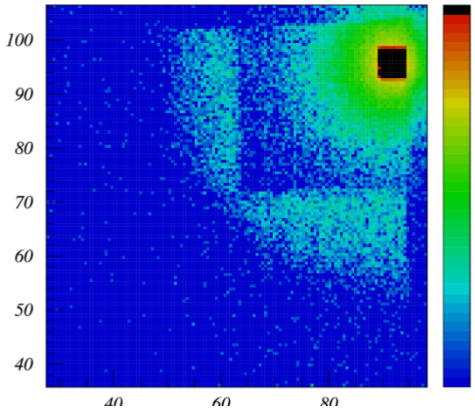
- probability for p.e. detection inversely $\propto$ number of p.e. on chip

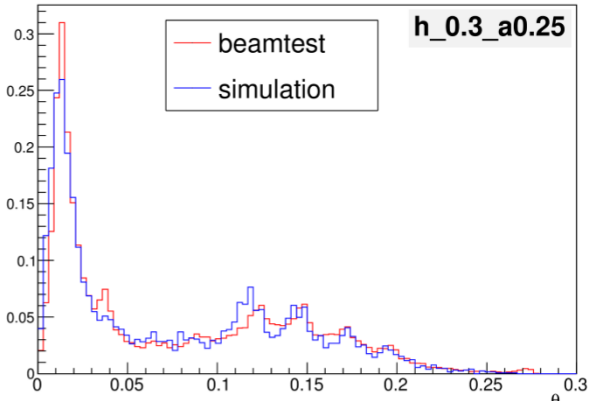
- after inclusion of this effect into digitizer nice agreement between sim/data.

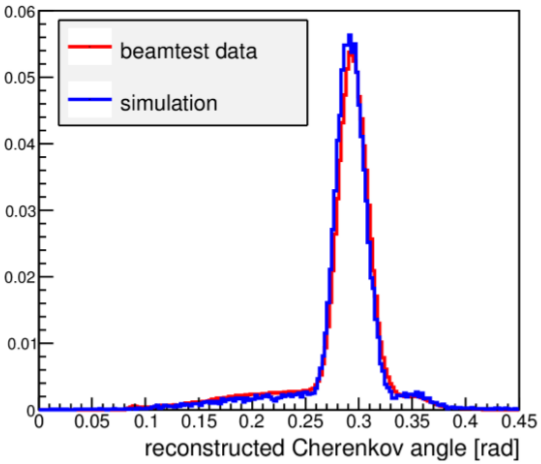
- also for the Ch. photons from the aerogel good agreement is observed.

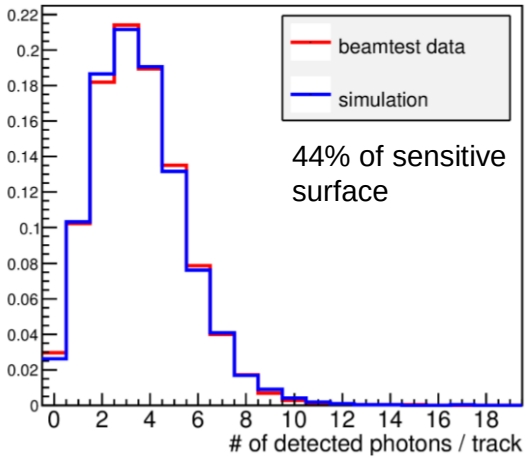










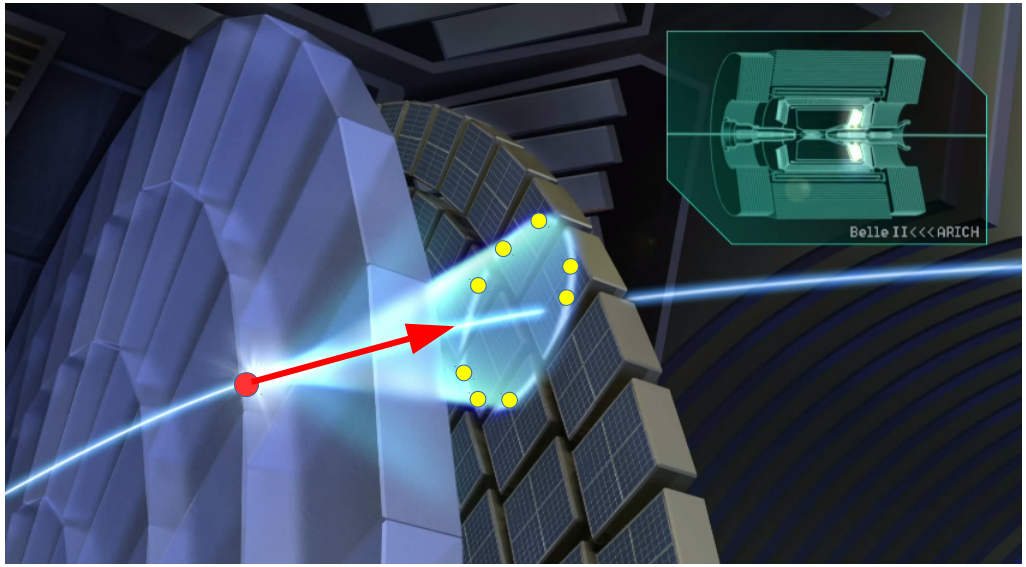


Reconstruction

- reconstructed tracks are extrapolated from the CDC to the ARICH volume.

- we construct likelihood function for 6 particle (e, μ, π, K, p, d) type hypotheses for each track (independently)

- based on comparison of observed pattern of detected photons with the expected one assuming given track parameters and particle type.



Likelihood function

$$\mathcal{L} = \prod_{i}^{pixels} p_i$$

$$p_i = e^{-n_i} n_i^{m_i} / m_i!$$

For each particle hypothesis h

$$\ln \mathcal{L}^h = -\boxed{N^h} + \sum_{\text{hit } i} \left[\boxed{n_i^h} + \ln(1 - e^{-n_i^h}) \right]$$

Expected total number of hits

Expected number of hits on pixel i

Reconstruction

Belle II

Expected number of hits on pixel i

$$n_i = n_i^1 + n_i^2 + n_i^b$$

1st aeogel layer — 2nd — background

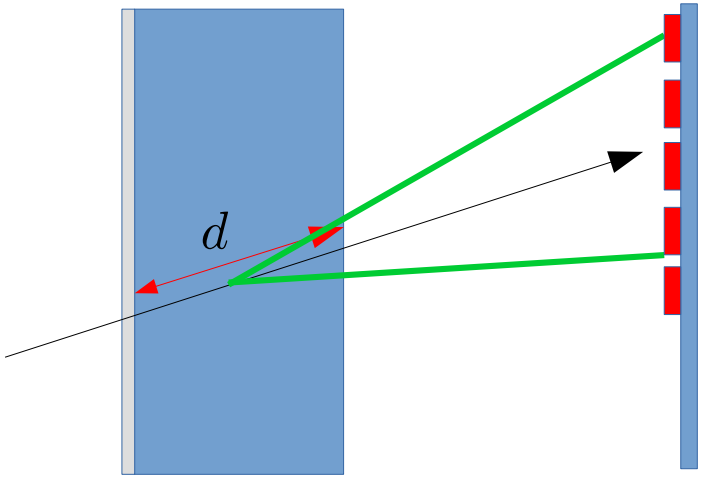
Expected cherenkov peak for given hypothesis h

$$n_i^r = \epsilon_{det} N^r \int_{\Omega_i} \frac{1}{2\pi} G(\theta, \theta_h^r, \sigma_h^r) d\theta d\phi$$

expected number of photons emitted from aerogel layer r (1,2)

Solid angle covered by I-th pixel

$$N^r = \frac{dN_{ch}}{dx} \lambda_{abs} (1 - e^{-d/\lambda_{abs}})$$



Expected total number of hits

$$N = \epsilon_{acc} \epsilon_{det} (N^1 + N^2) + N_b$$

Fraction of ring that falls on photo-sensitive area

a simple toy propagation of 200 “photons” uniformly distributed in ϕ, and with θ_h, from the photon mean emission point in aerogel

Effect of photon loss on aerogel tile edges

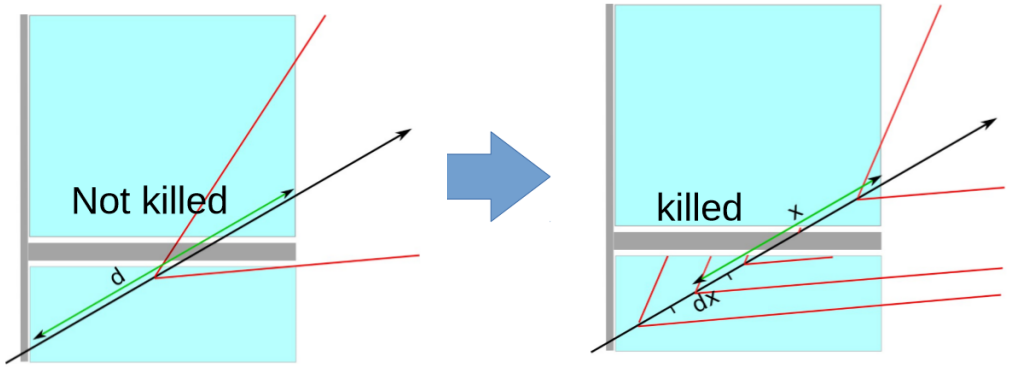
- due to mechanical issues we had to increase the gap between adjacent aerogel tiles from 1 mm → 3 mm.

- effect of photon loss in these gaps not in calculation of N^r → significant decrease in PID performance.
  (most significantly at $p < K_{thr}$)

- update of method to include this effect.

$$N^r \rightarrow N^r(\phi), \quad 20 \text{ bins}$$

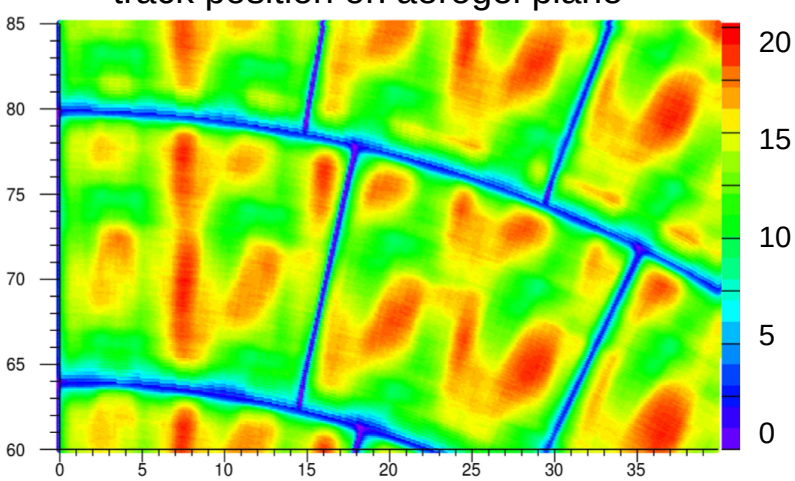
- Performance is largely recovered.
  Only minor effect of larger gaps.

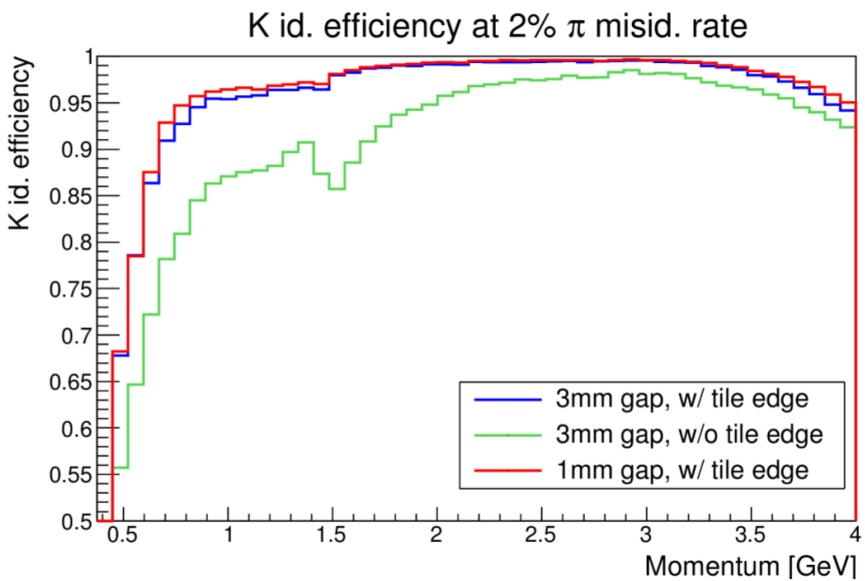


$$N_{ch} = \frac{dN_{ch}}{dx}\lambda_{abs}(1 - e^{-d/\lambda_{abs}})$$

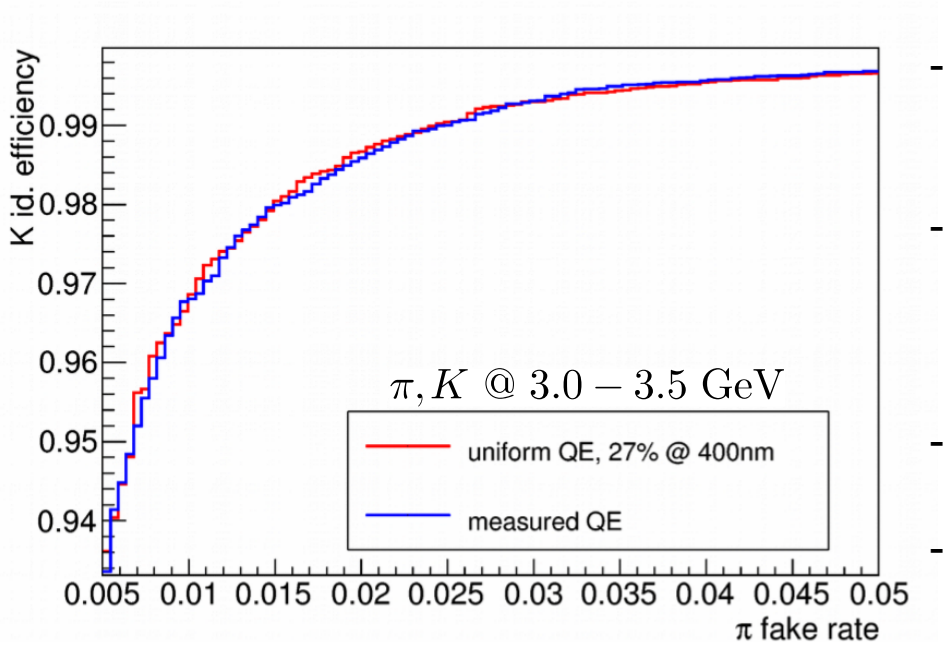
$$\Delta N_{ch} = \frac{dN_{ch}}{dx}\Delta x \; e^{-x/\lambda_{abs}}$$

Number of expected photons vs track position on aerogel plane





Performance

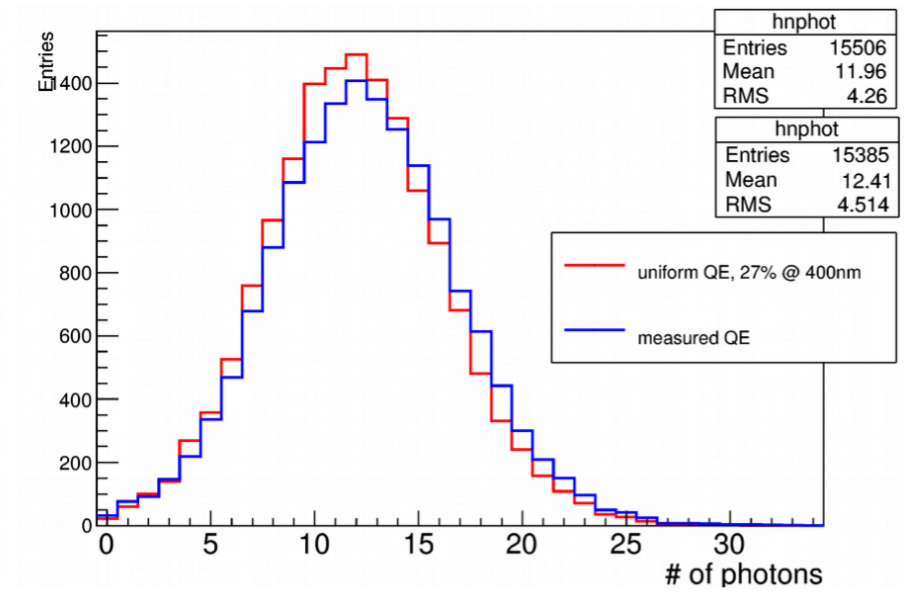


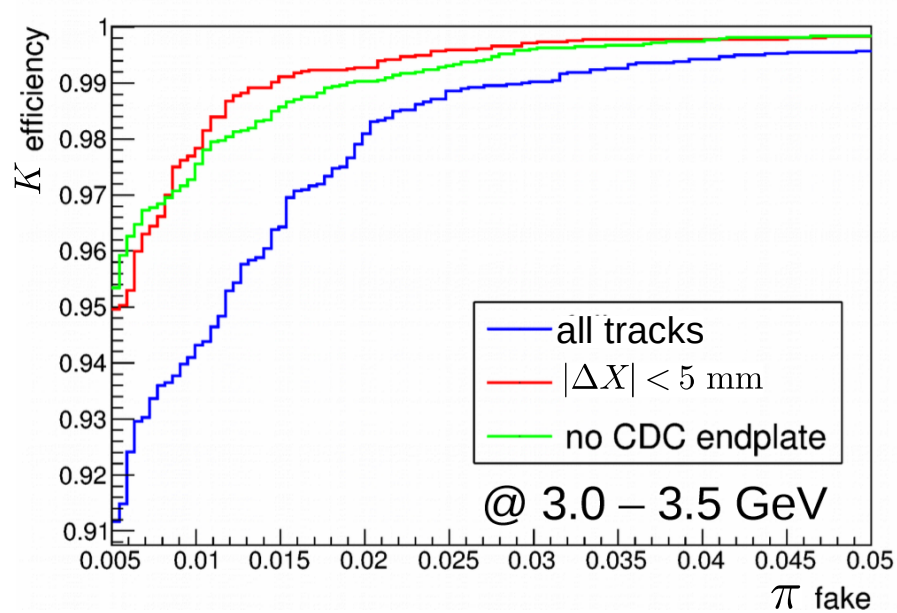
- test of the performance using measured QE maps of HAPDs.

- small increase in number of photons/ring compared to our previous studies with uniform 27% QE (consistent with QE increase)

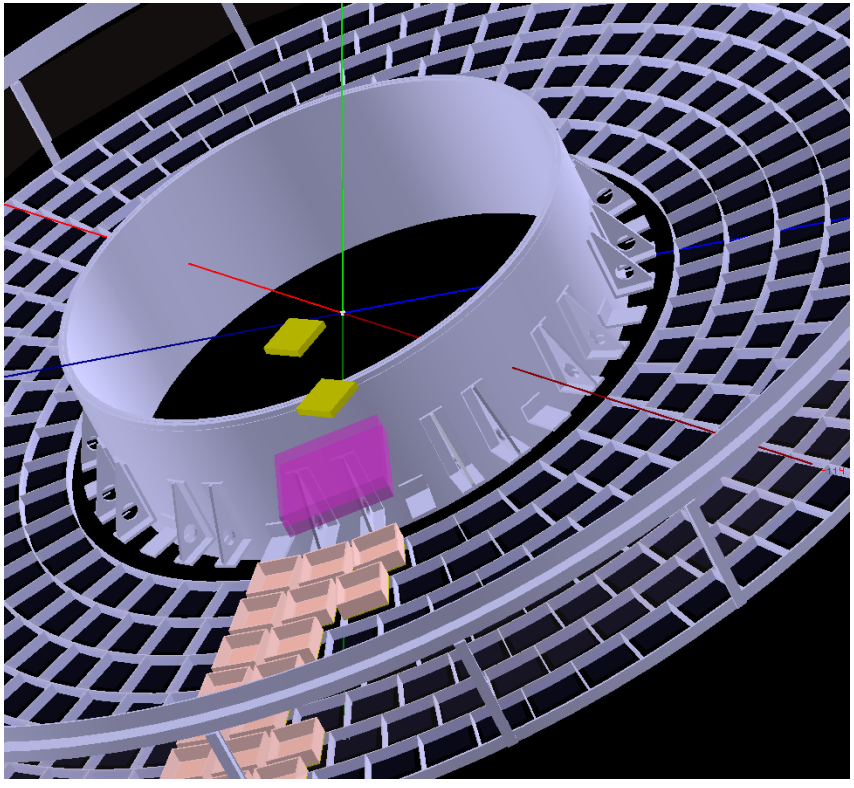
- no effect on performance

- performance mainly degraded by tracks with bad tracking information
  (largely due to scattering in CDC aluminum endplate)

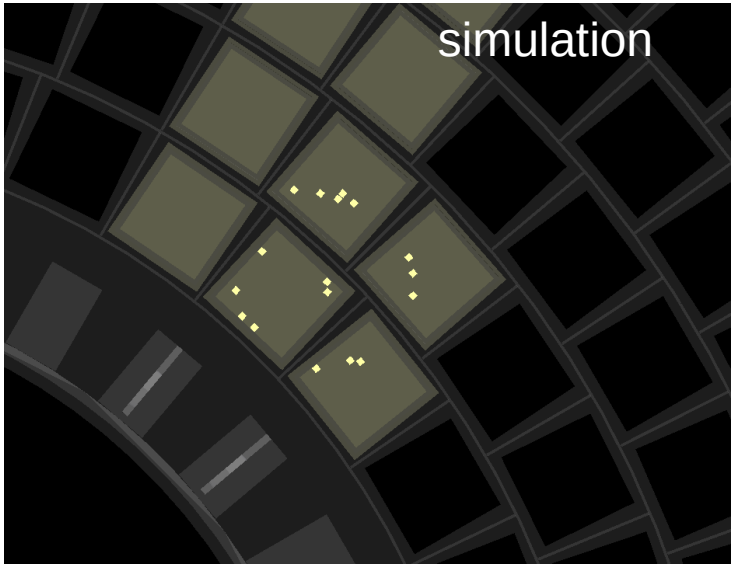


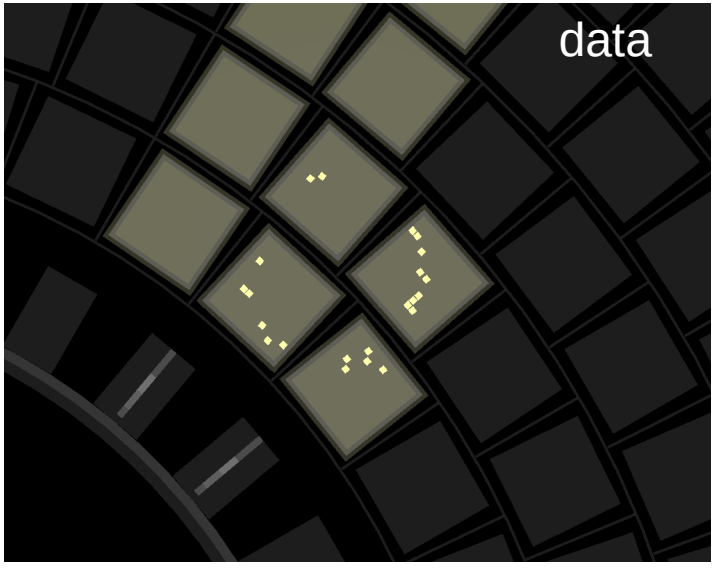


First rings from cosmics



- we recently started a small cosmic test using 6 HAPDs and 1 aerogel tile.
- allows to test first part of data processing chain (reading raw data, channel mappings, etc.)
- Cherenkov rings observed on event display
- at the moment no tracking information, so no Cherenkov angle reconstruction
- comparison of simulated/measured accumulated distributions is underway (hits/event,...).





Summary

- ARICH simulation+reconstruction software is well developed, used for detector performance studies and Belle II MC production campaigns.

- since recently simulation uses detector components properties (QEs, dead channels, etc.) from the database, as measured in QA tests.

- we keep developing and improving the reconstruction algorithm.

- good agreement between beam test and simulated data.

- in recent cosmics test we observed first Cherenkov rings, demonstrating the functionality of many newly developed tools.

- our focus now moves to development of calibration/alignment methods and algorithms.