The ARICH detector

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ARICH community

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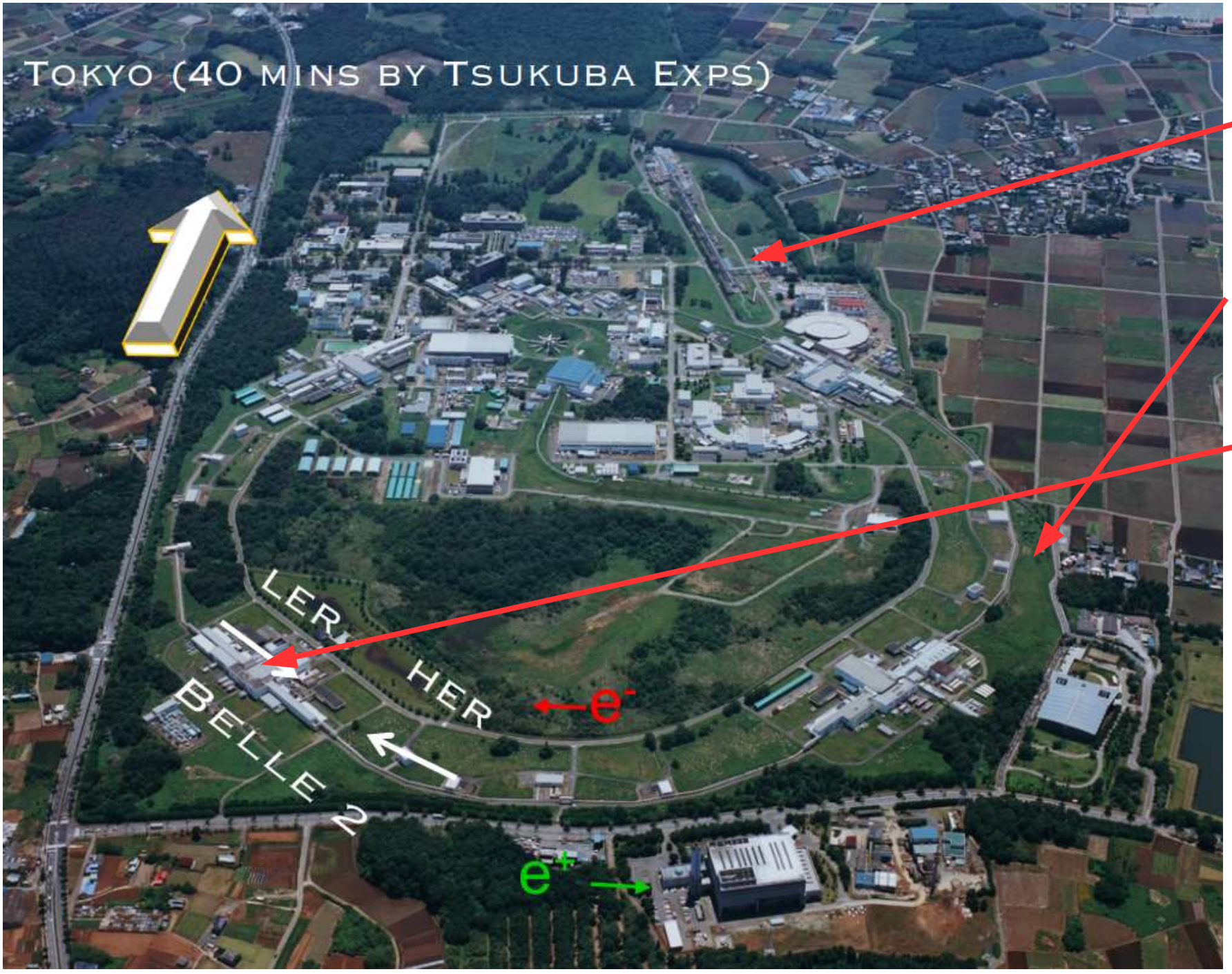
KEK Inter-University Research Institute Corporation
High Energy Accelerator Research Organization



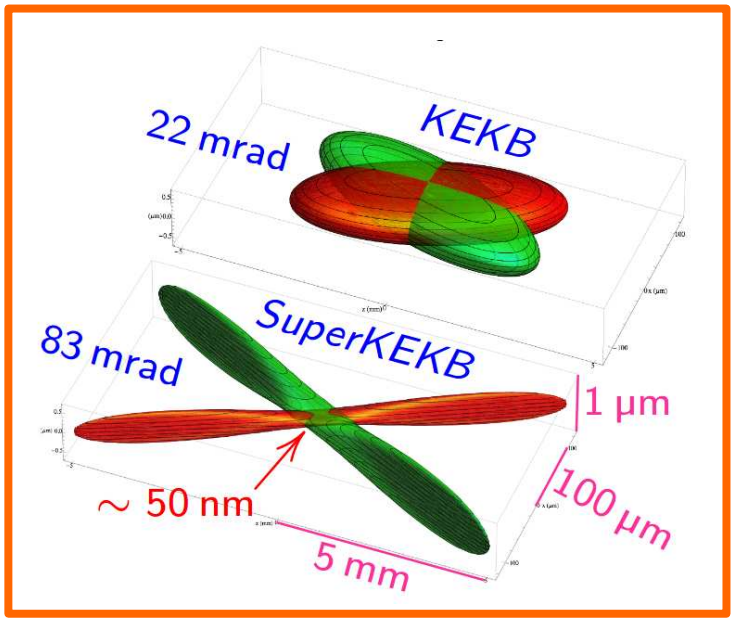
Linear accelerator

Electron and positron storage ring (3 km)

BELLE II detector

SuperKEKB machine

- Located at Japan (Tsukuba)
- Electron positron asymmetric collider.
- Energy in the center of mass is 10.58 GeV, corresponding to the mass of the **Υ(4S)** resonance.
- Upgrade of existing KEKB machine
- The design of SuperKEKB is based on the new concept of the nano-beam scheme.



$$\textbf{Luminosity} = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\zeta_{\pm y}}{\beta_y^*}\frac{R_L}{R_y}$$

Table 8: Machine parameters for HER and LER.

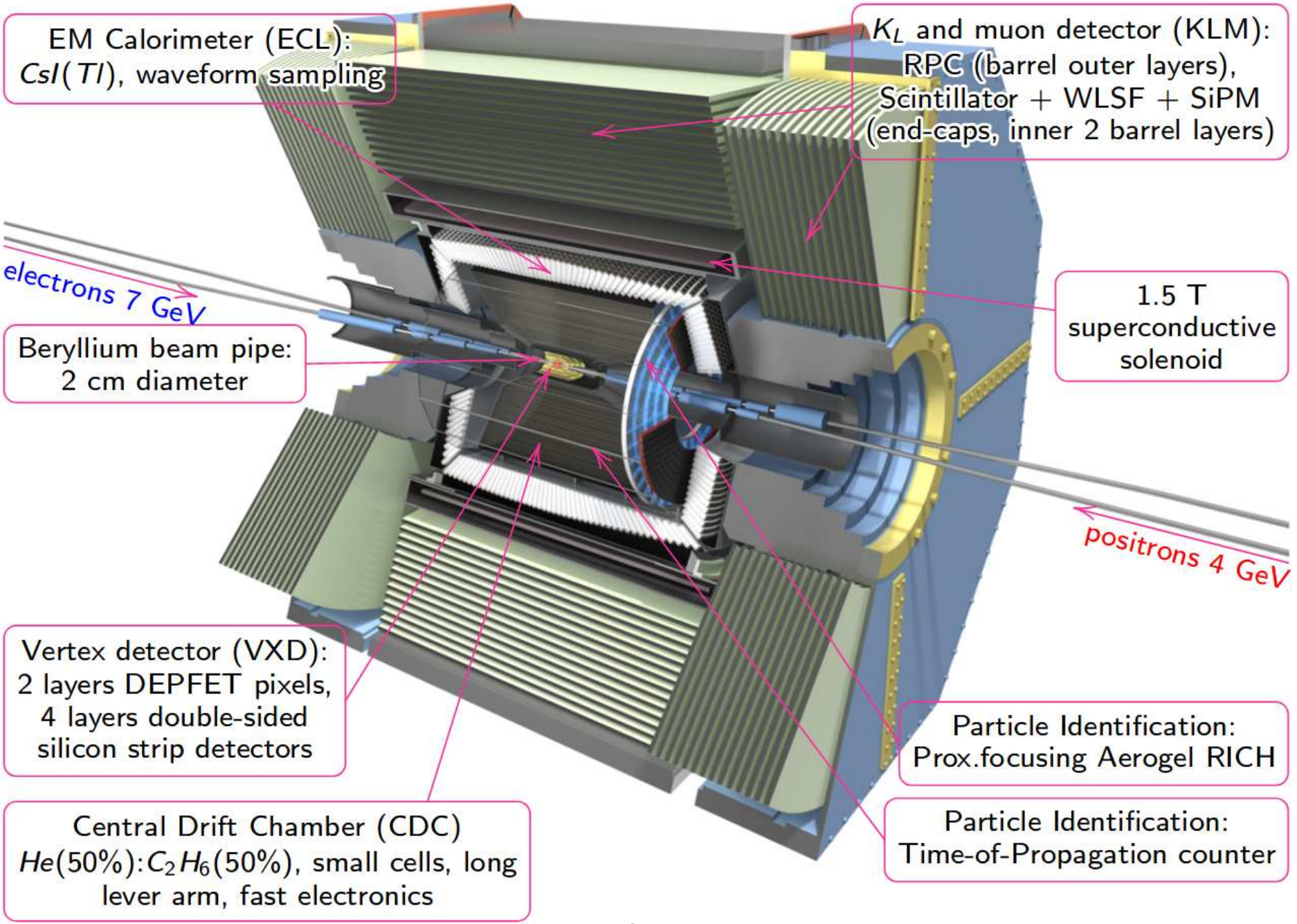
Parameter	LER	HER	Unit
E	4.000	7.007	GeV
I	3.6	2.6	A
β_x^*	32	25	mm
β_y^*	270	300	μm
σ_z	6	5	mm

* indicates values at the IP

Table 9: Machine parameters.

Parameter	Value	Unit
N_b	2500	
C	3016.315	m
$2\phi_x$	83	mrad
L	8×10^{35}	$cm^{-2}s^{-1}$

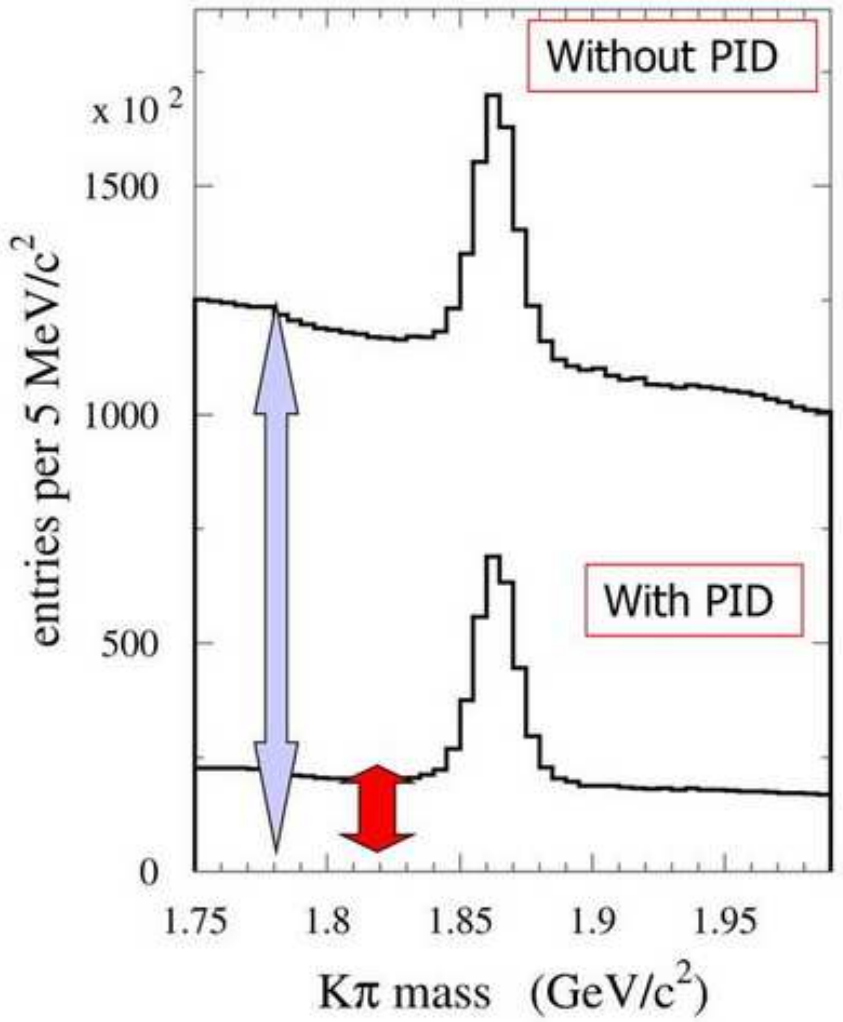
BELLE II detector



ARICH covers [15° -32°] polar angle.

Target performance : K/pi separation at > 4σ C.L. @ 0.5 < p < 4 GeV/c.

Charged particle identification detectors

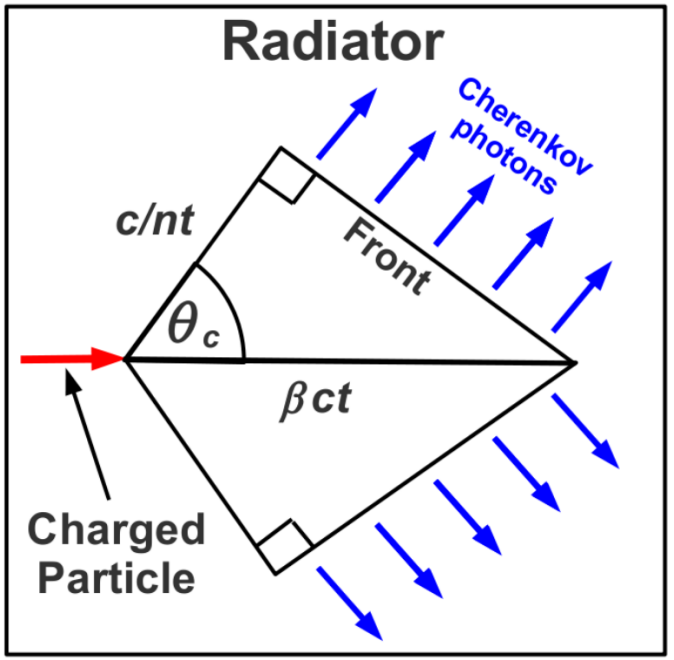


- Tracker system + magnetic field → measurements of the momentum (p) of the track.
- For invariant mass reconstruction we need to know the mass of the products.
- Pions are most probable particles “in a final state” after hadrons decay*.
- Kaons are factor 10 less with respect to pions.
- **Main goal of charged PID is K/pi separation.**

- Cherenkov detectors are widely used for particle identification.

* Among charged hadrons.

Cherenkov effect. How to identify the particle type.



Cherenkov radiation is electromagnetic radiation emitted when a charged particle passes through a dielectric medium of refractive index n with a velocity v greater than the speed of light (c/n) in that medium.

$$\cos\theta_c = \frac{1}{n\beta} \quad \beta = v/c$$

$$\frac{\partial^2 N}{\partial x \partial \lambda} = \frac{2\pi\alpha z^2}{\lambda^2}\left(1 - \frac{1}{(n(\lambda))^2\beta^2}\right) \sim 1/\lambda^2$$

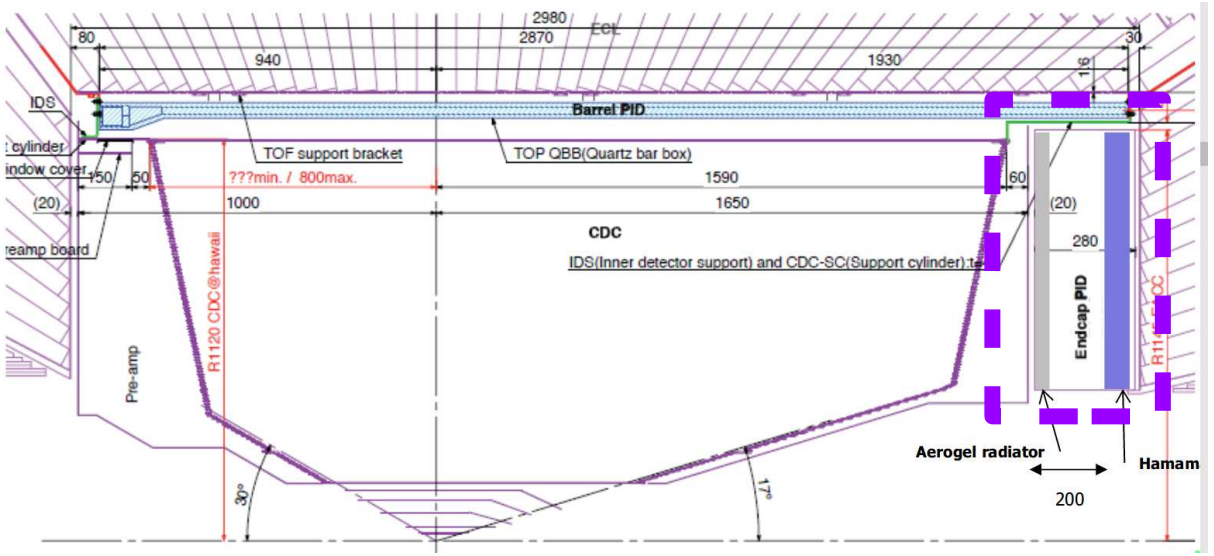
Particle mass $\leftarrow m = \frac{p}{c}\sqrt{n^2\cos^2\theta_c - 1}$

p: Particle momentum

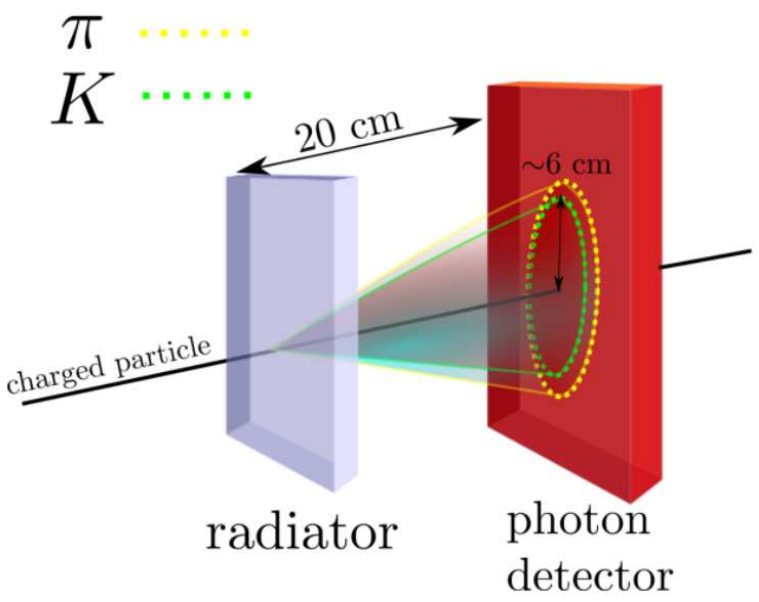
θ_c: Particle Cherenkov angle

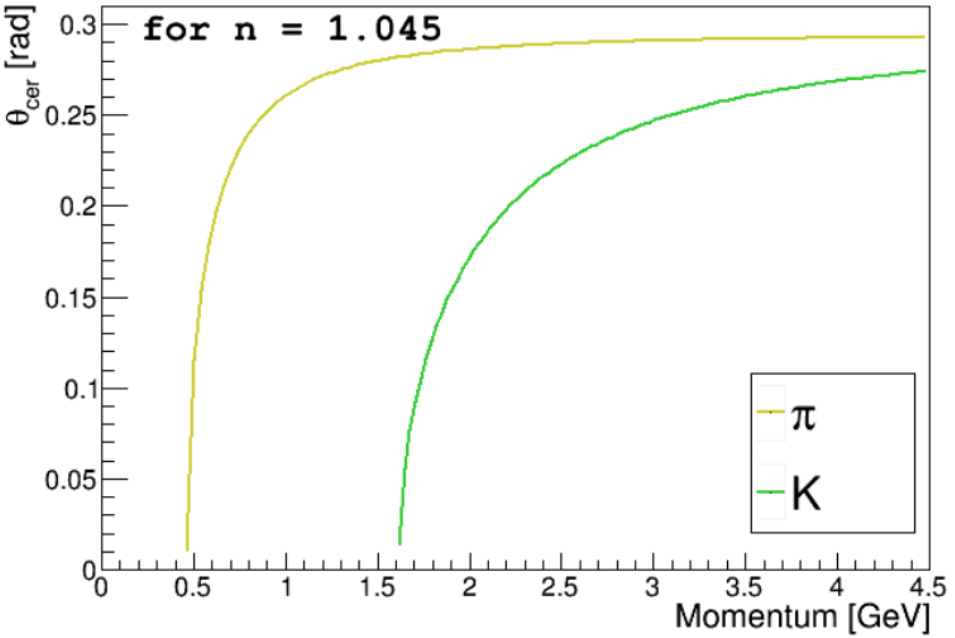
n: Aerogel refractive index

Aerogel Ring Imaging CHerenkov counter (ARICH)



- ARICH detector located in forward endcap (PID) two meters from interaction point.
- Target performance : K/pi separation at > 4σ for 0.5 < p < 4 GeV/c.
- ARICH covers : [15° -32°] polar angle.



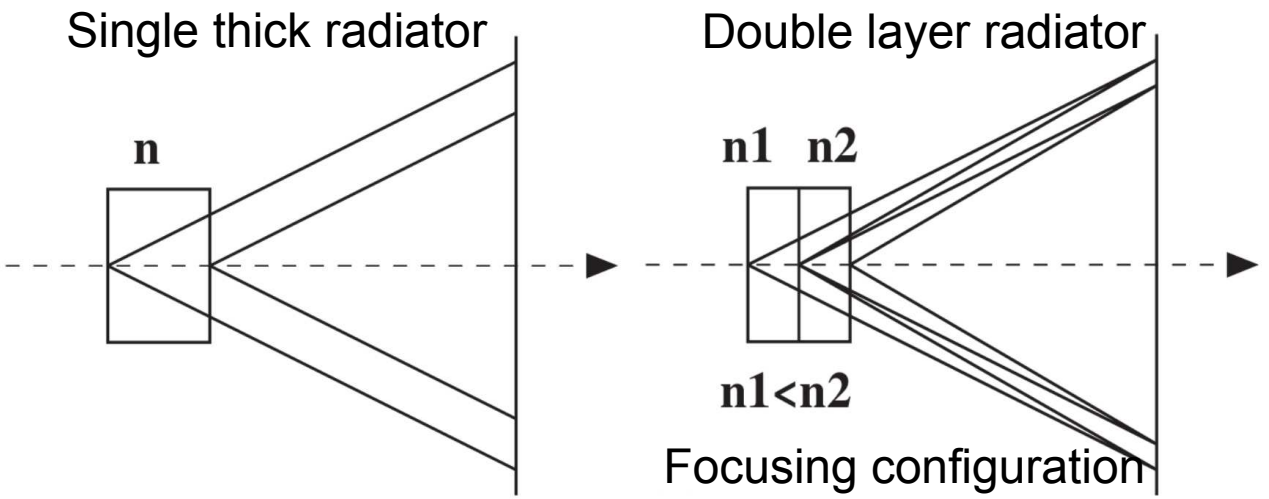


Why we choose aerogel radiator? Why double layer ?

$$\beta = \frac{1}{n\cos(\theta)} \rightarrow \frac{\sigma_\beta}{\beta} = \sigma_\theta \tan(\theta) \rightarrow \frac{\sigma_\beta}{\beta} \rightarrow 0 \quad \theta \rightarrow 0 \quad \boxed{n \rightarrow 1}$$

$$N_{Cherenkov\ light} \sim \left(1 - \frac{1}{n^2\beta^2}\right) L \rightarrow$$ **As a consequence we need to use thicker radiator**

Nuclear Instruments and Methods in Physics Research A 548 (2005) 383–390



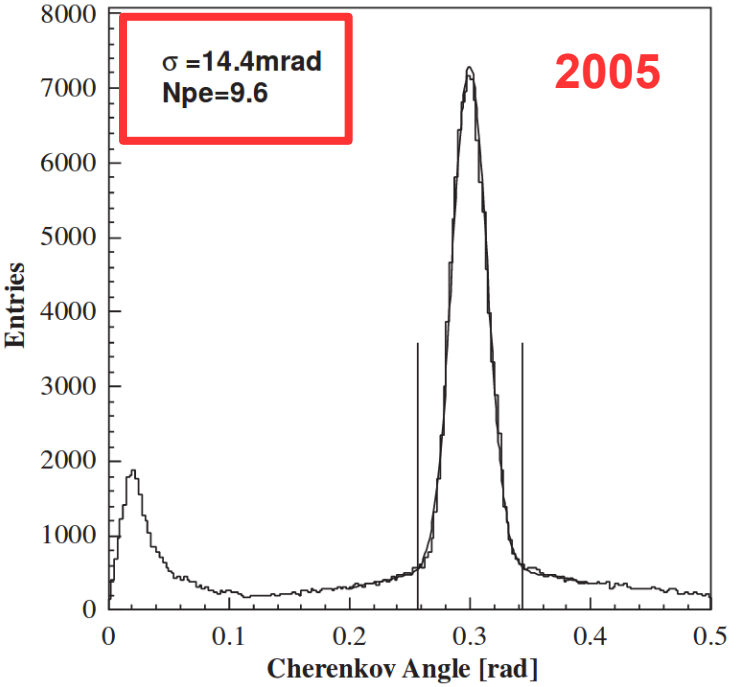


Fig. 7. Distribution of the Cherenkov angle for accumulated single photons from 4 GeV/c pions in the case of a focusing dual radiator combination with 20 mm thick radiators ($n = 1.047$ and $n = 1.057$).

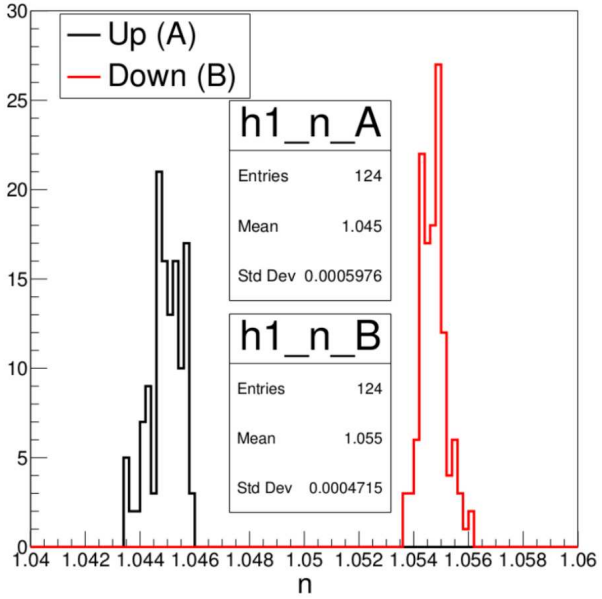
Aerogel - optical properties

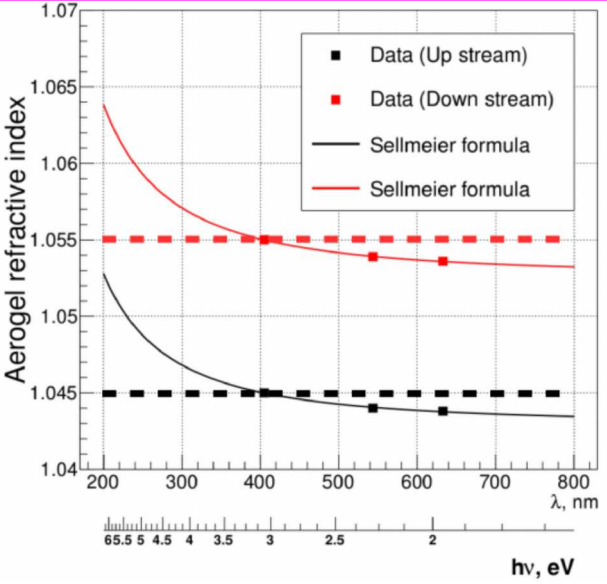
Fine adjustment of n for aerogel :

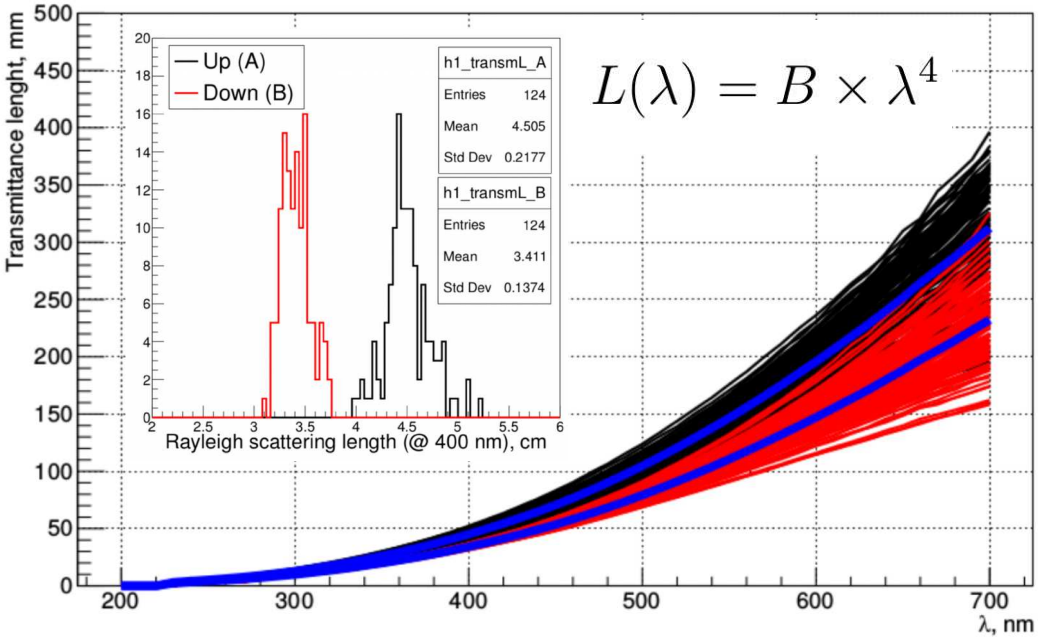
$$n(\lambda) = p_{\text{Intercept}} + k(\lambda)\rho$$

Water-resistant aerogel

Weak dependence RI from λ

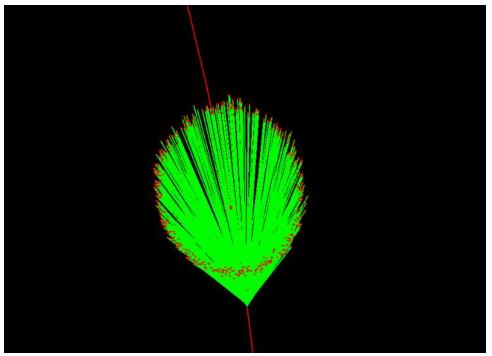


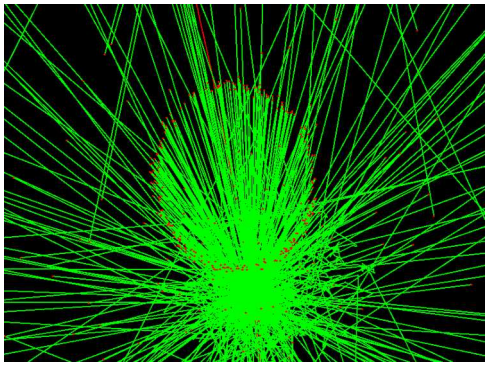


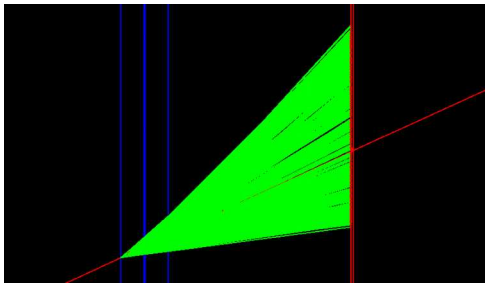


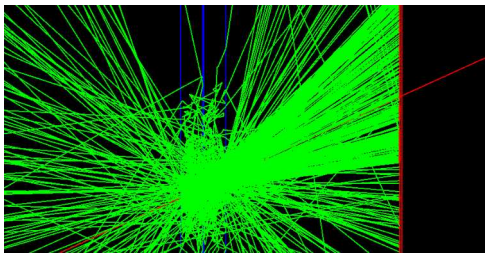
RAYLEIGH OFF

RAYLEIGH ON



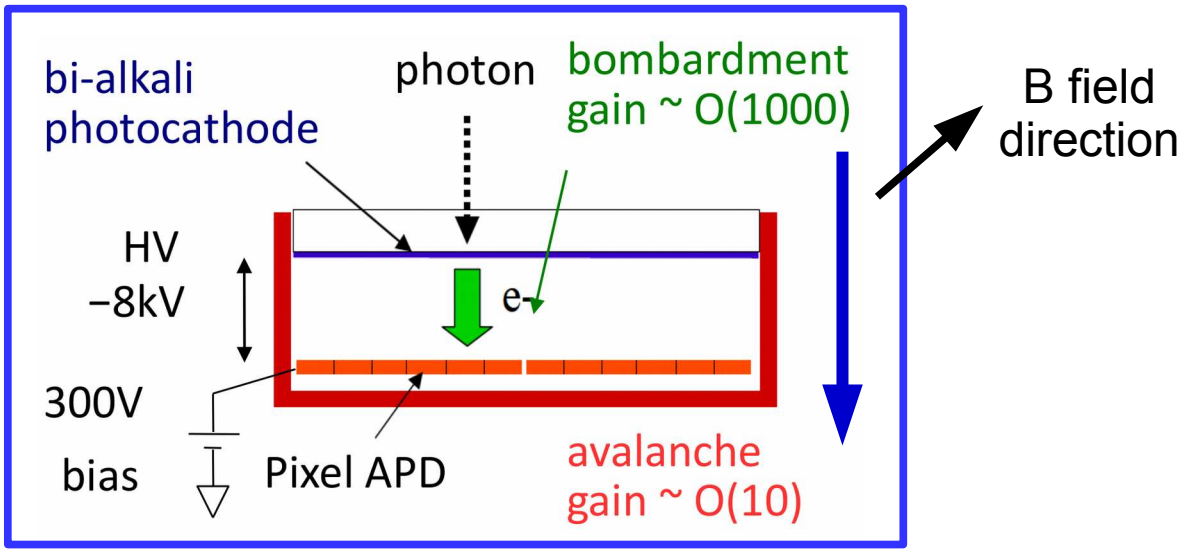


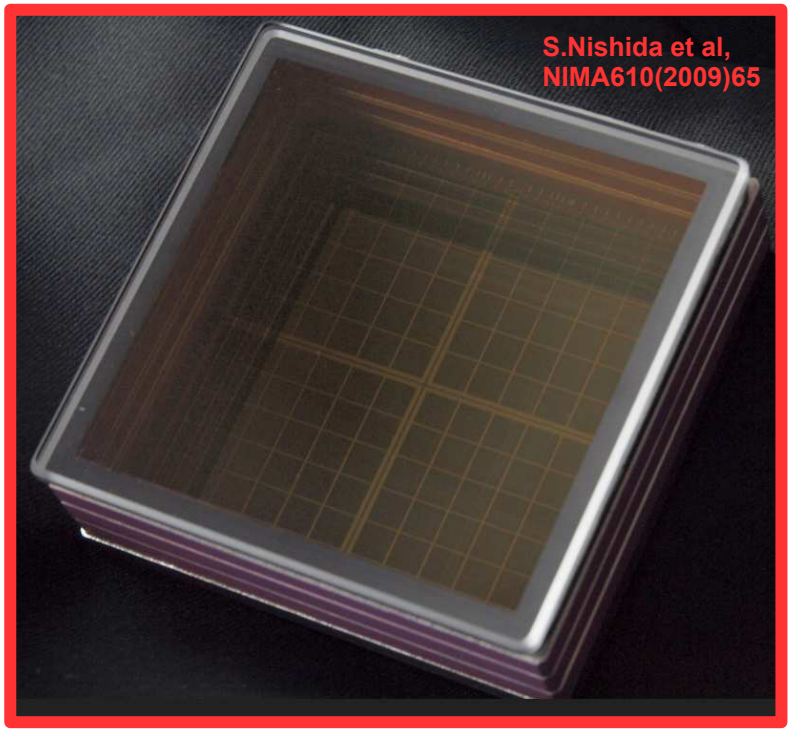




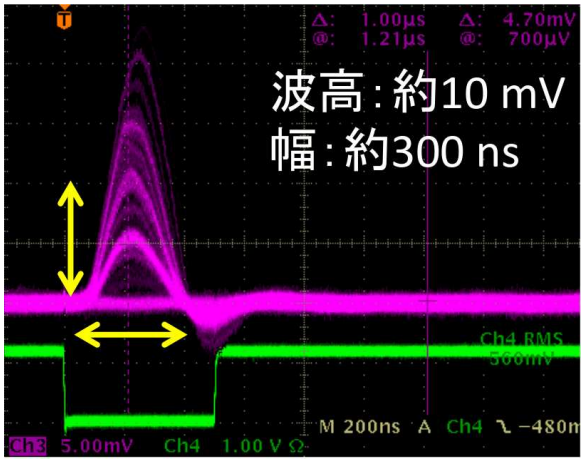
The photon detector : HAPD

- Hybrid Avalanche Photo Detector (HAPD).
- 144 pixelated APDs : 4.9 x 4.9 mm^2 channel size. Effective area : 63 mm×63 mm.
- Signal gain > $4x10^4$ by Hybrid amplification process.
- Operation in 1.5 T magnetic field.

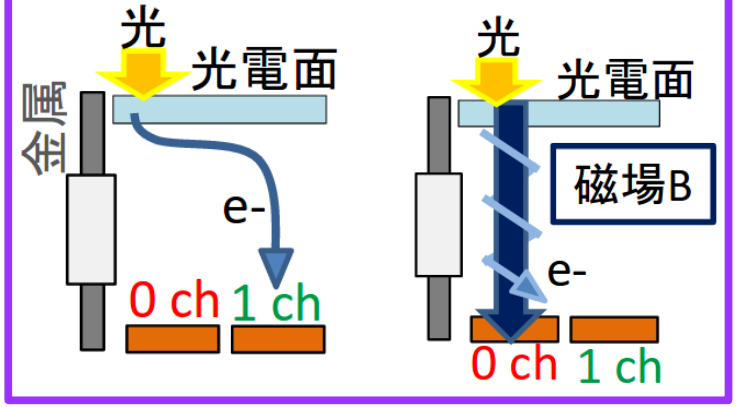


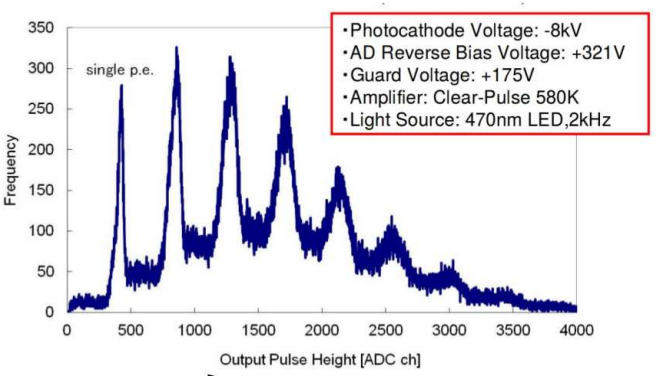


Separate 1 – 2 – 3 p.e.



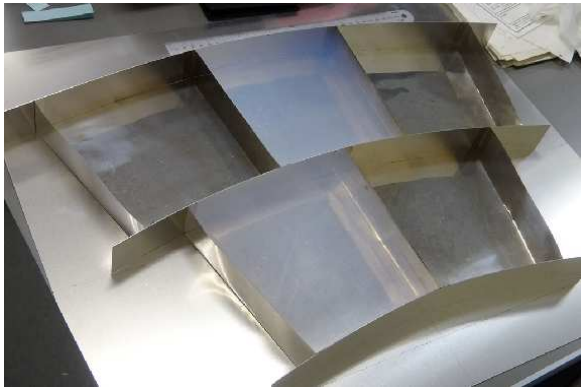
Enhancement in the magnetic field



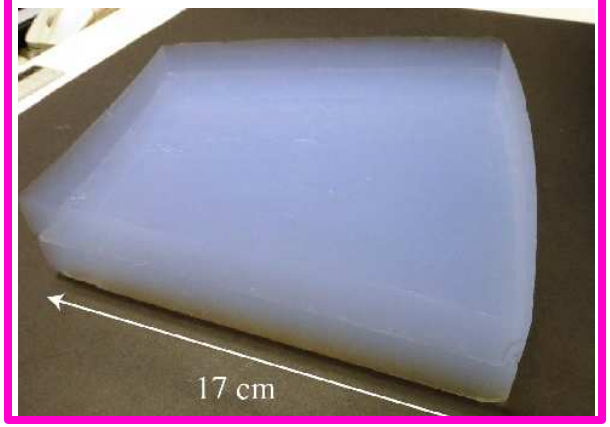


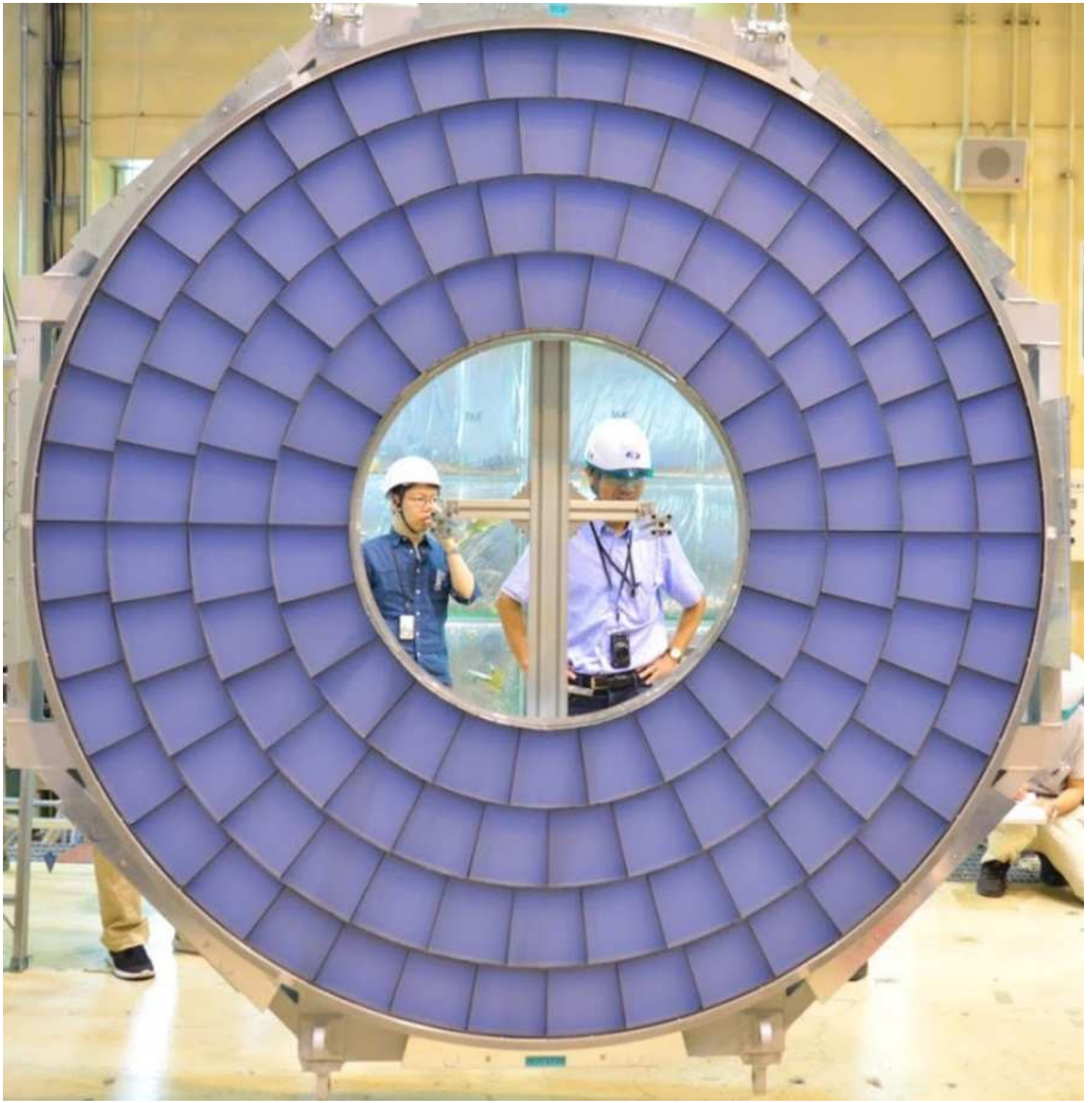
ARICH aerogel plane

- Two aerogel layers
- 124 aerogel tiles per layer
- 248 aerogel tiles in total



Two layers of wedge-shaped aerogel single tiles of size : 17 x 17 x 4 cm^3

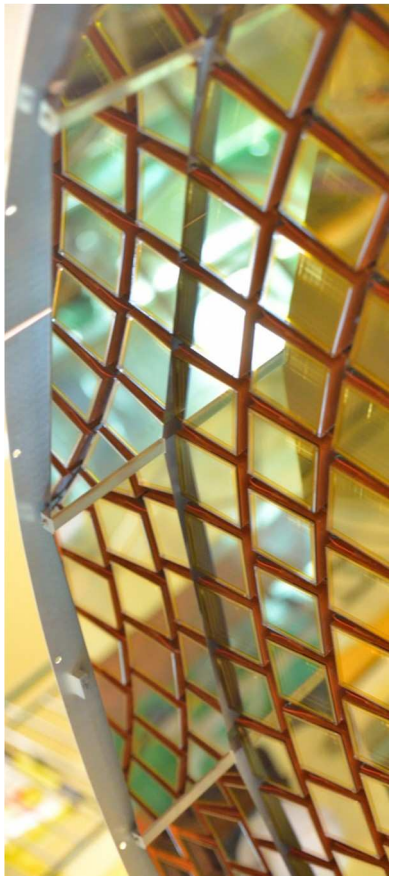


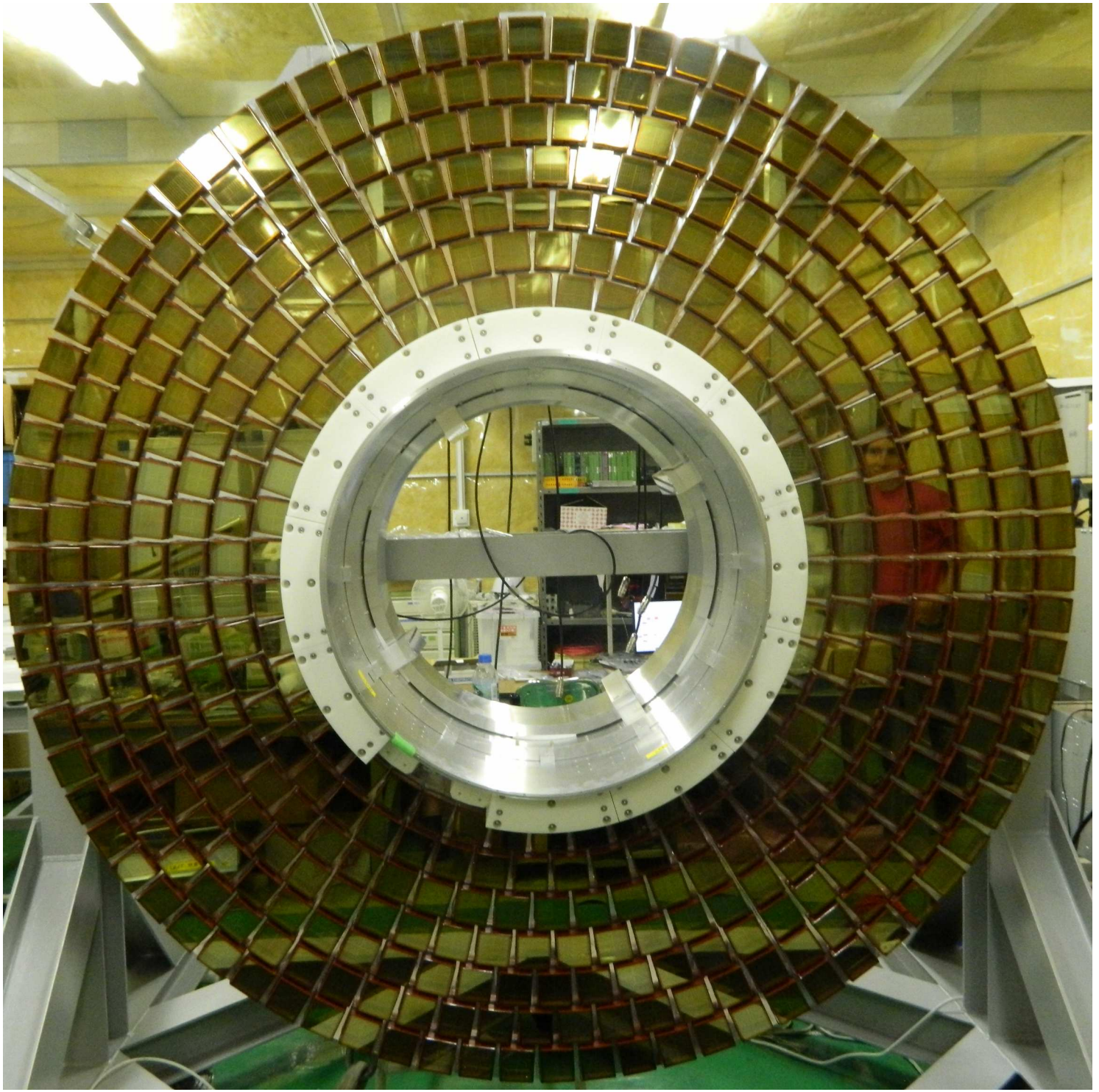


ARICH photon detector

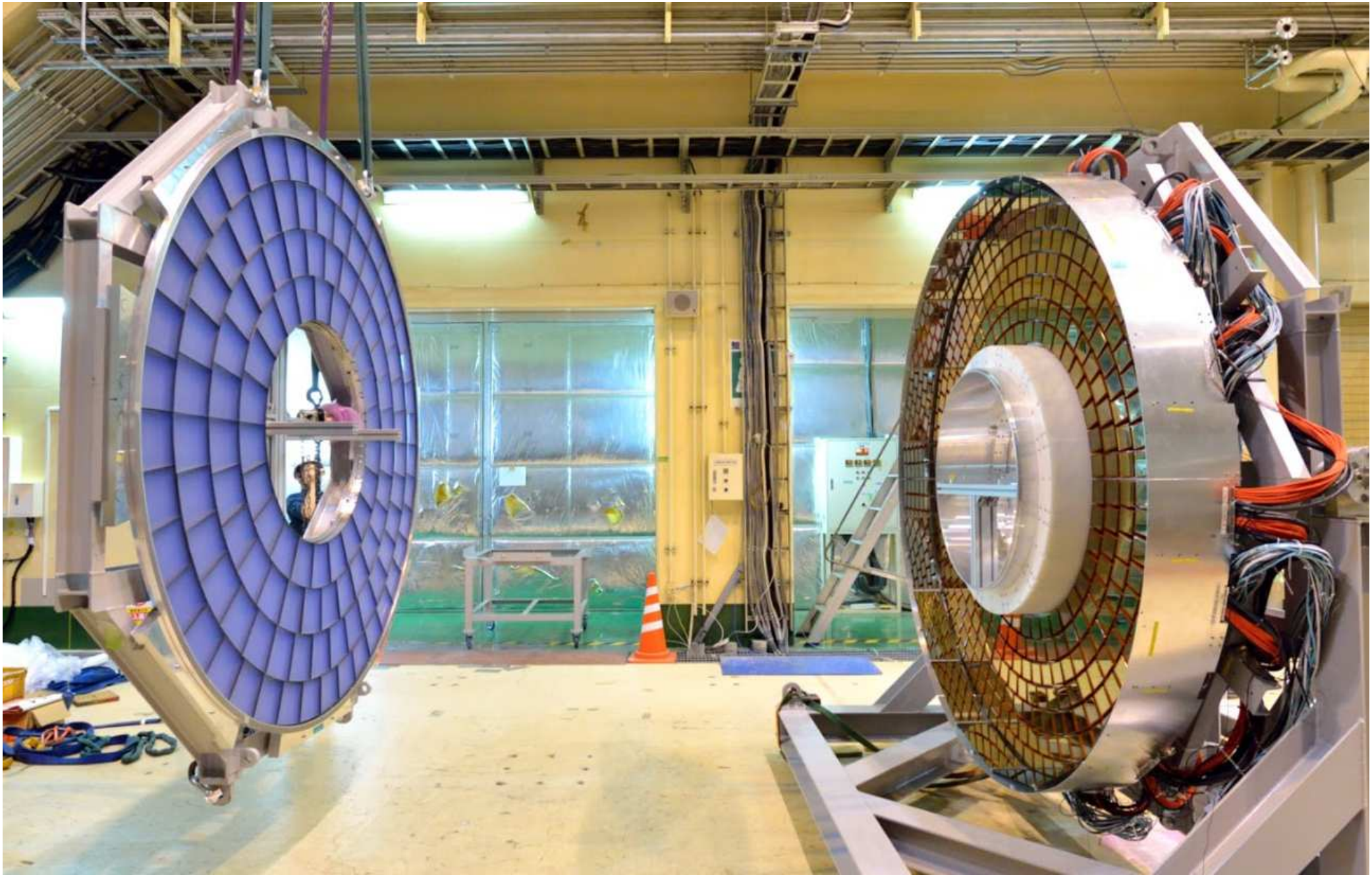
- 420 HAPD modules with
- 60480 redout channels
- 18 planar mirror plates

Mirrors from the edge



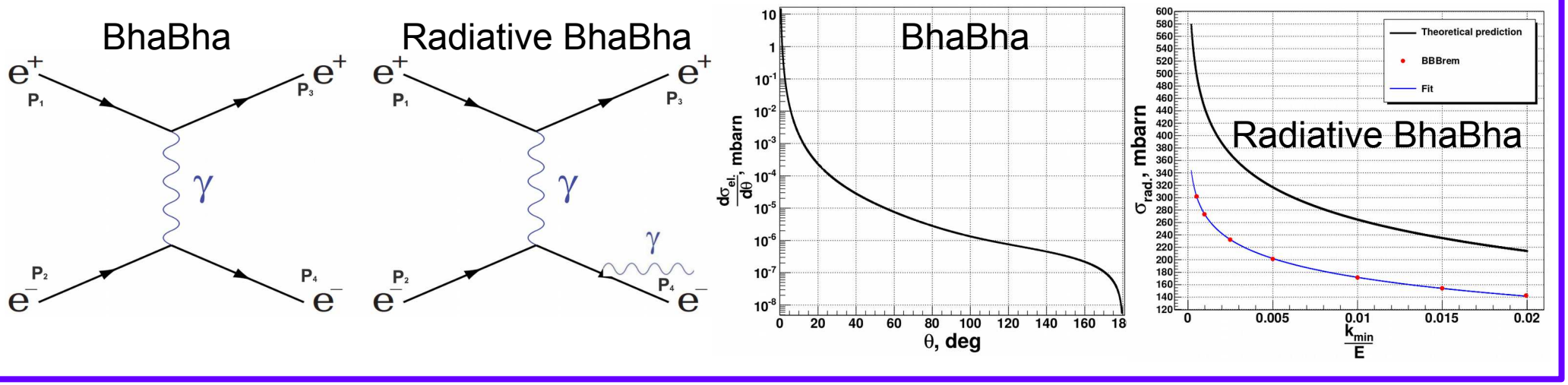


ARICH assembly – October 2017



ARICH performance estimation with BhaBha and radiative BhaBha events.

→ The first collisions at SuperKEKB took place on 26 of April in 2018.



Track selection criterion :

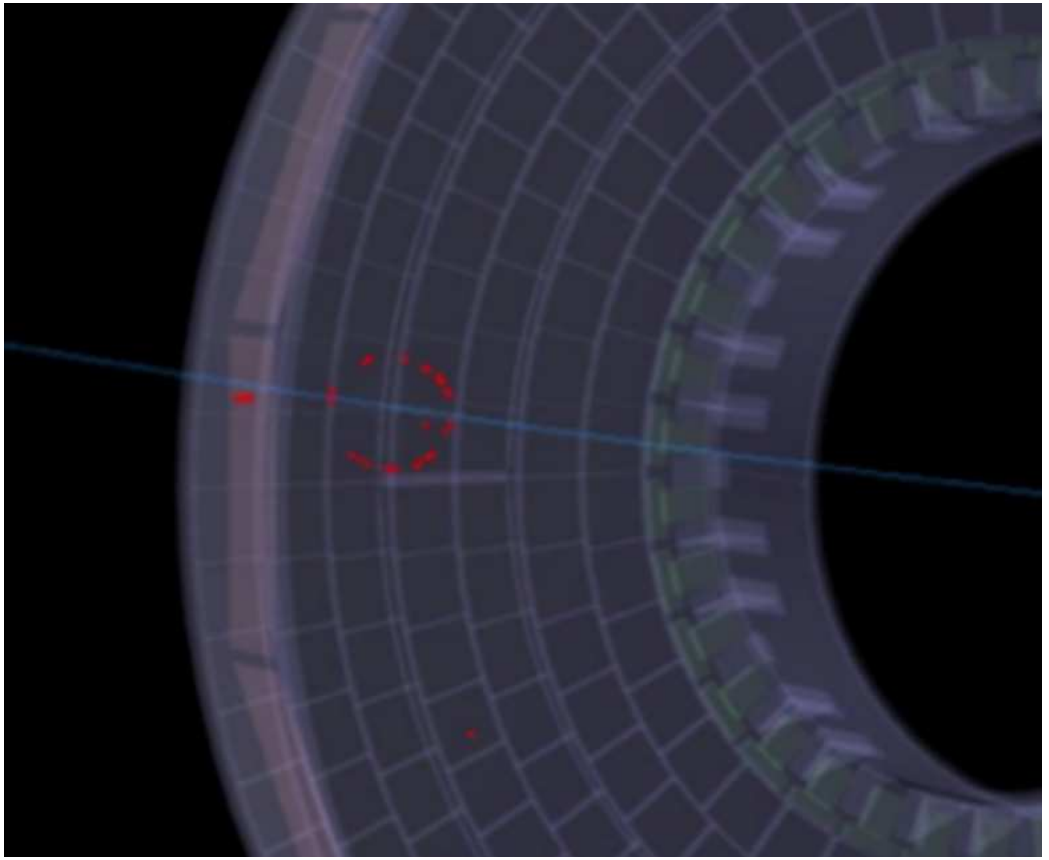
- → Charged track
- → BhaBha triggered events : back to back isolated tracks with ECL energy deposition.
- → Kinematics cuts :
  - → Momentum > 6 GeV/c
  - → z_0 from IP within 1 cm
  - → Impact parameter from IP less then 1 cm

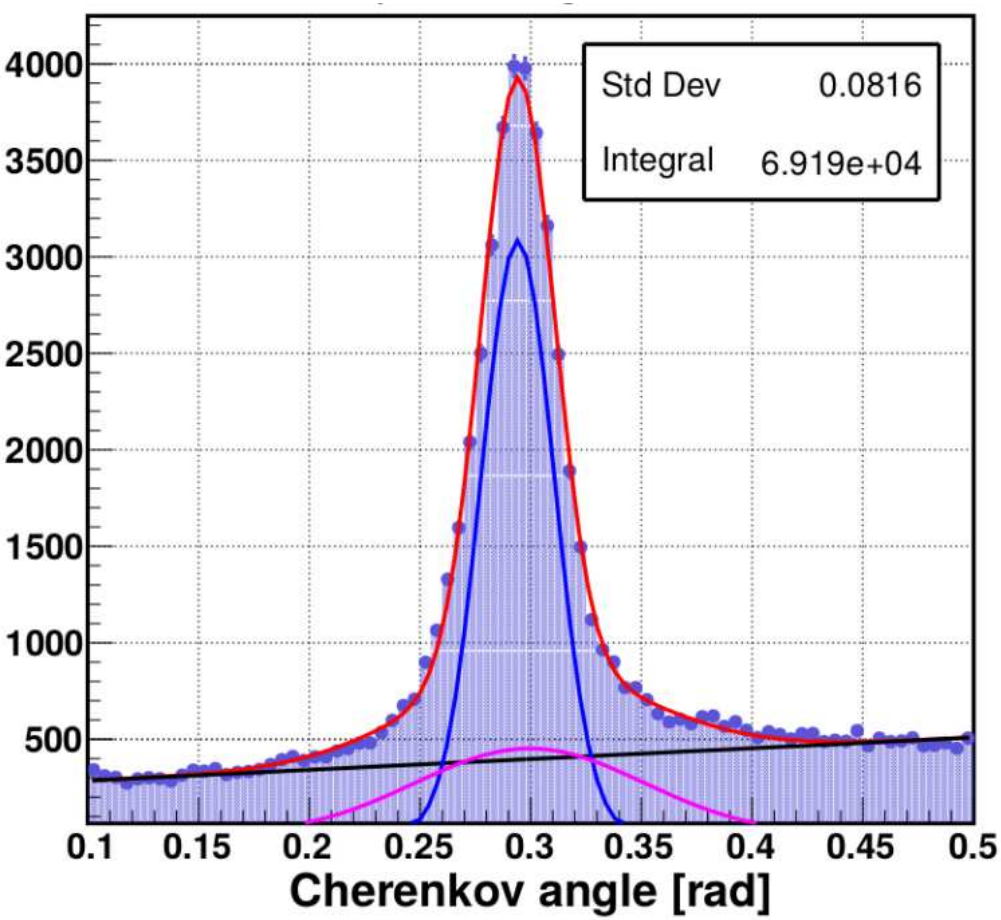
Other considerations :

- → Excluding dead or masked channels/regions
- → Including central drift chamber and ARICH alignment.

Single Cherenkov photon angle resolution.

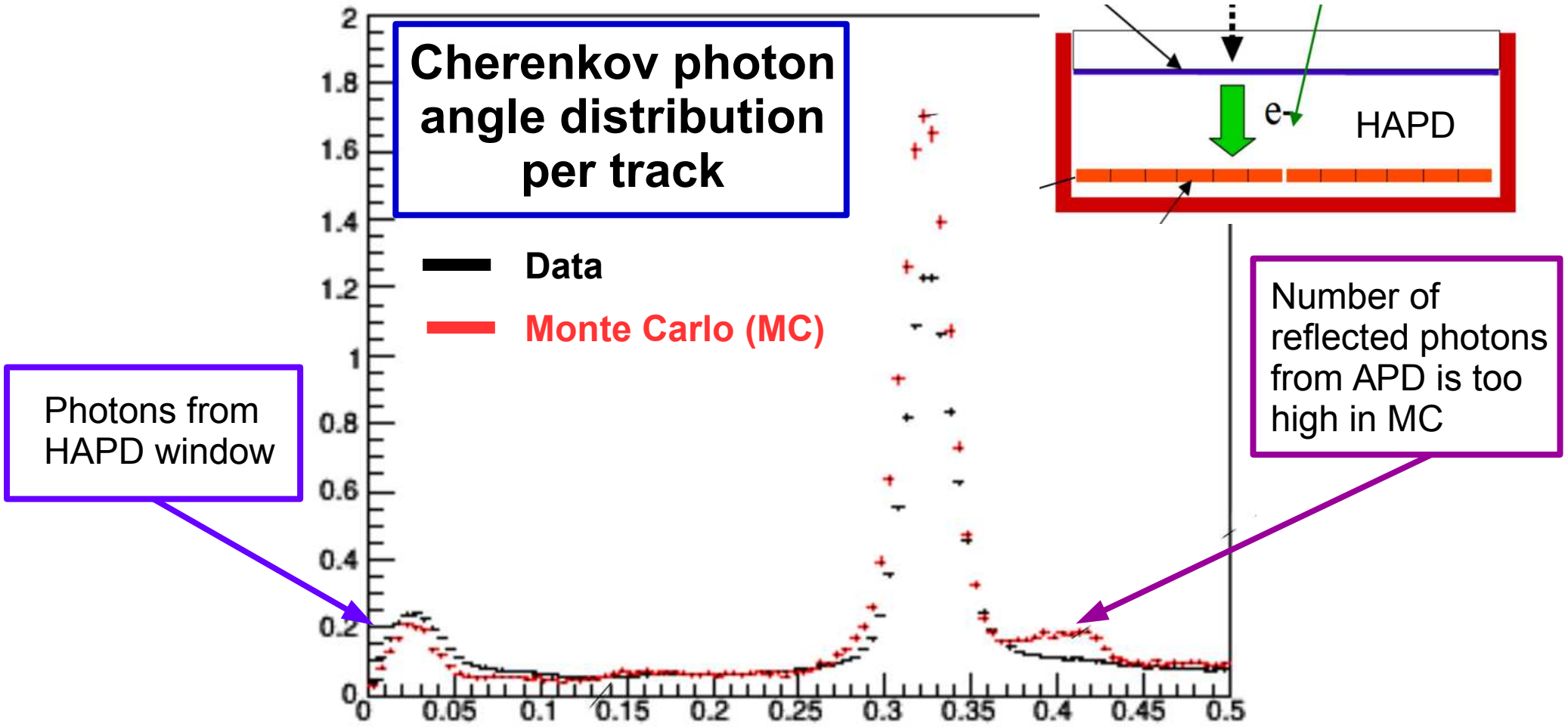
Reconstructed Cherenkov ring visualized with event display.





- Black line - non correlated background (electronics, beam background ...)
- Magenta line - correlated background (Rayleigh scattered photons, reflection from APD ...)
- Blue line – signal photons. Single photon resolution ~14 mrad.

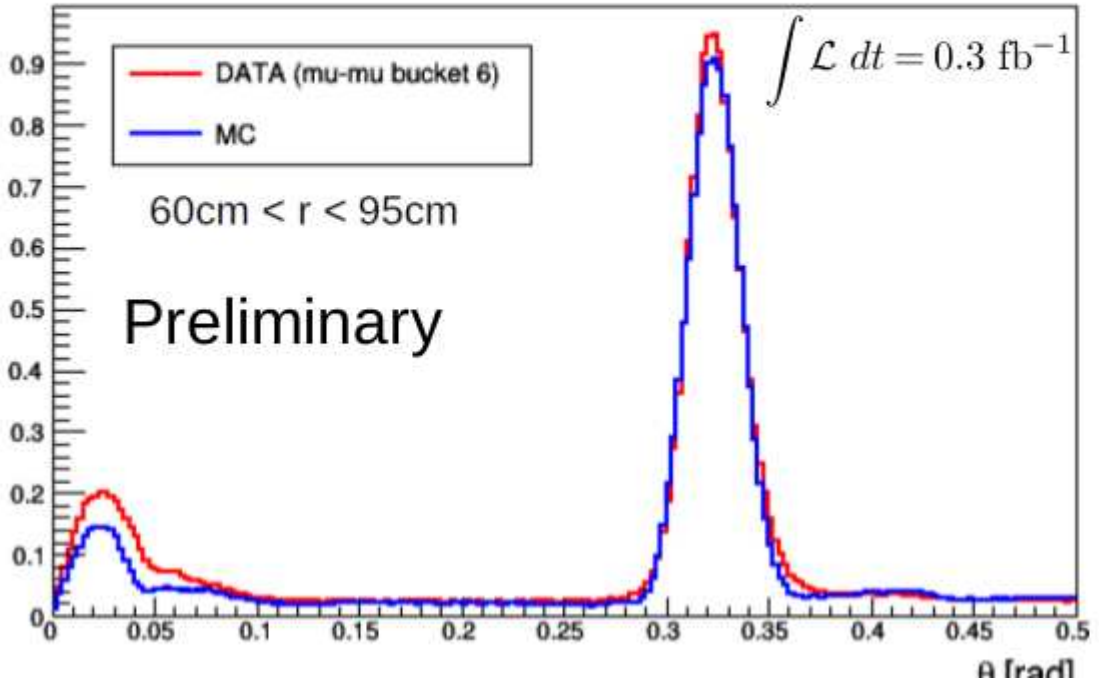
Data vs Monte Carlo (without any tuning) before phase 3



- Number of signal photons is ~20% less with respect to the simulation.
  - The signal threshold is same for all the HAPD's. However the gain and single photon amplitude is different for a given HAPD.
  - The masking of the dead and not working channels is not fully implemented.

Data vs Monte Carlo after light phase 3

Cherenkov angle distribution in $e^+e^- \to \mu^+\mu^-$



DATA

$N_{\mathrm{sig}} = 11.4/\mathrm{track}$

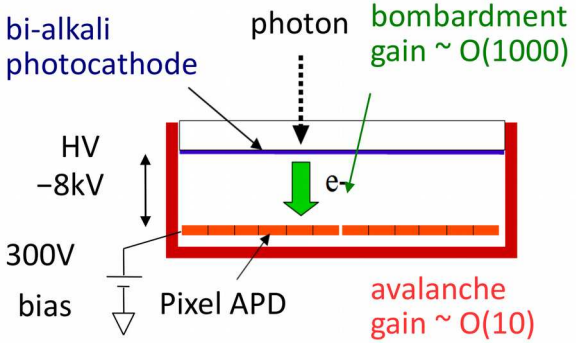
$\sigma_c = 12.7\ \mathrm{mrad}$

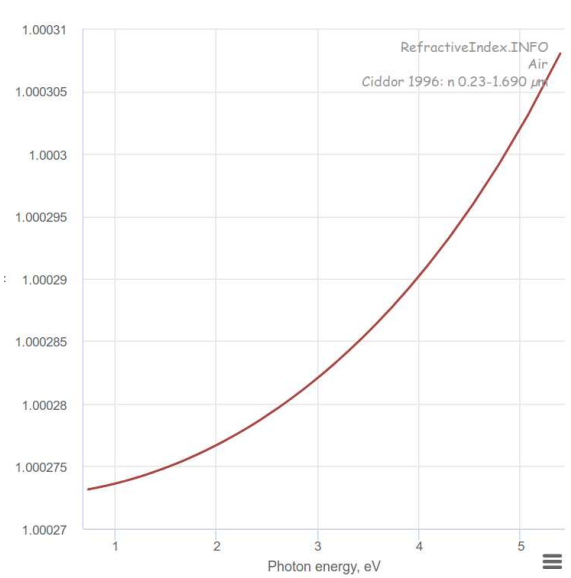
MC

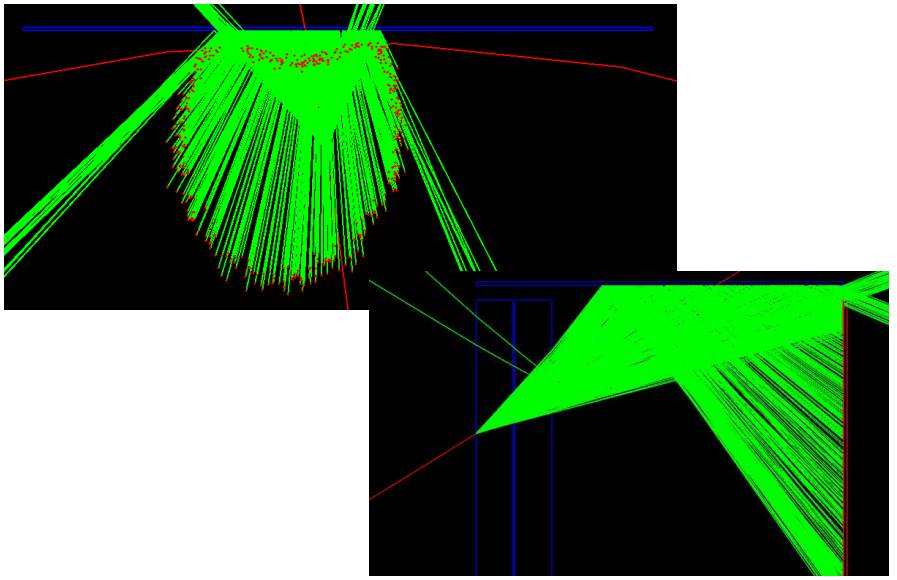
$N_{\mathrm{sig}} = 11.3/\mathrm{track}$

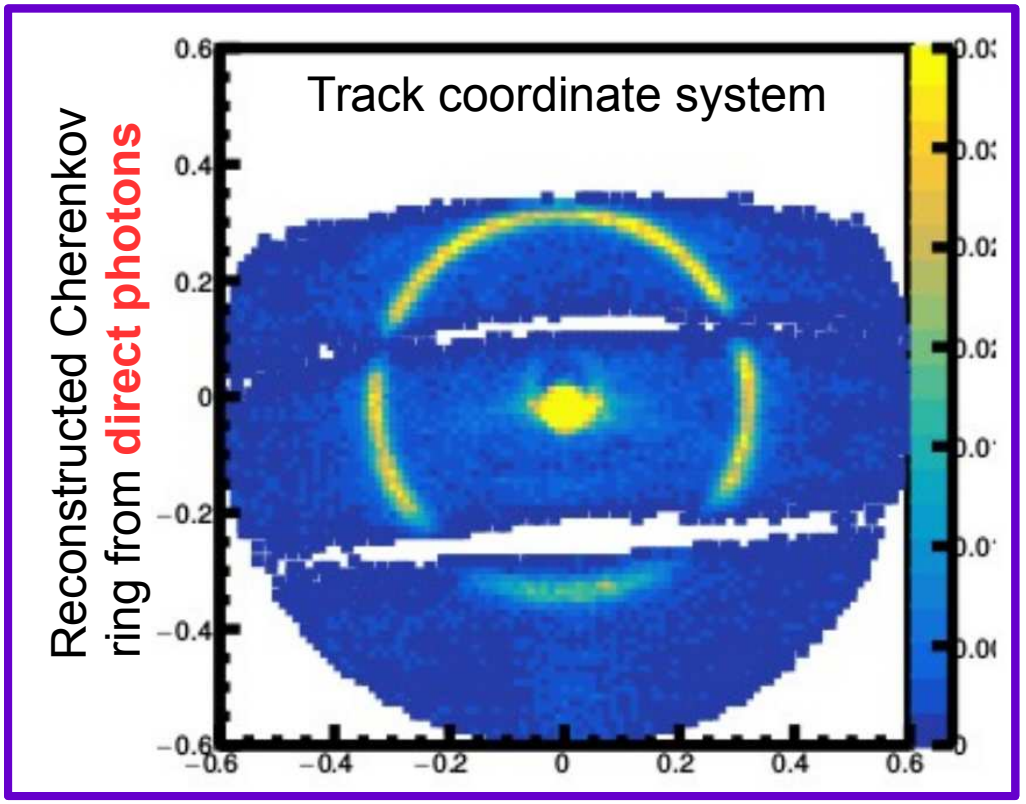
$\sigma_c = 12.8\ \mathrm{mrad}$

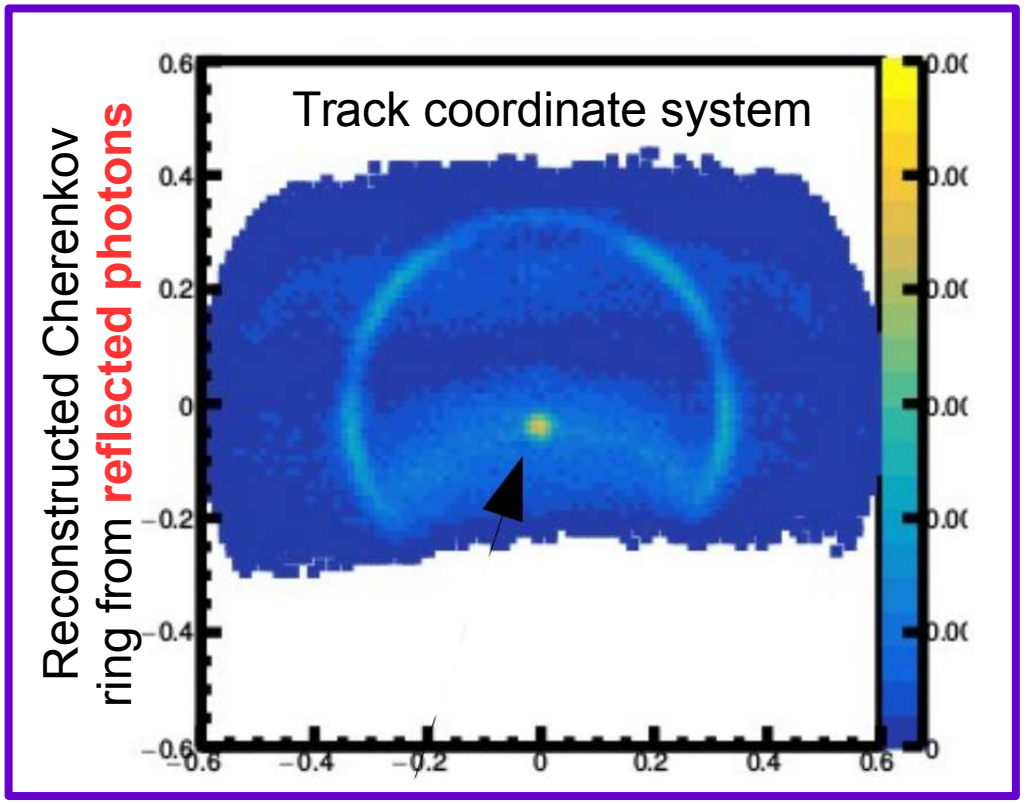
Cherenkov ring in track reference frame



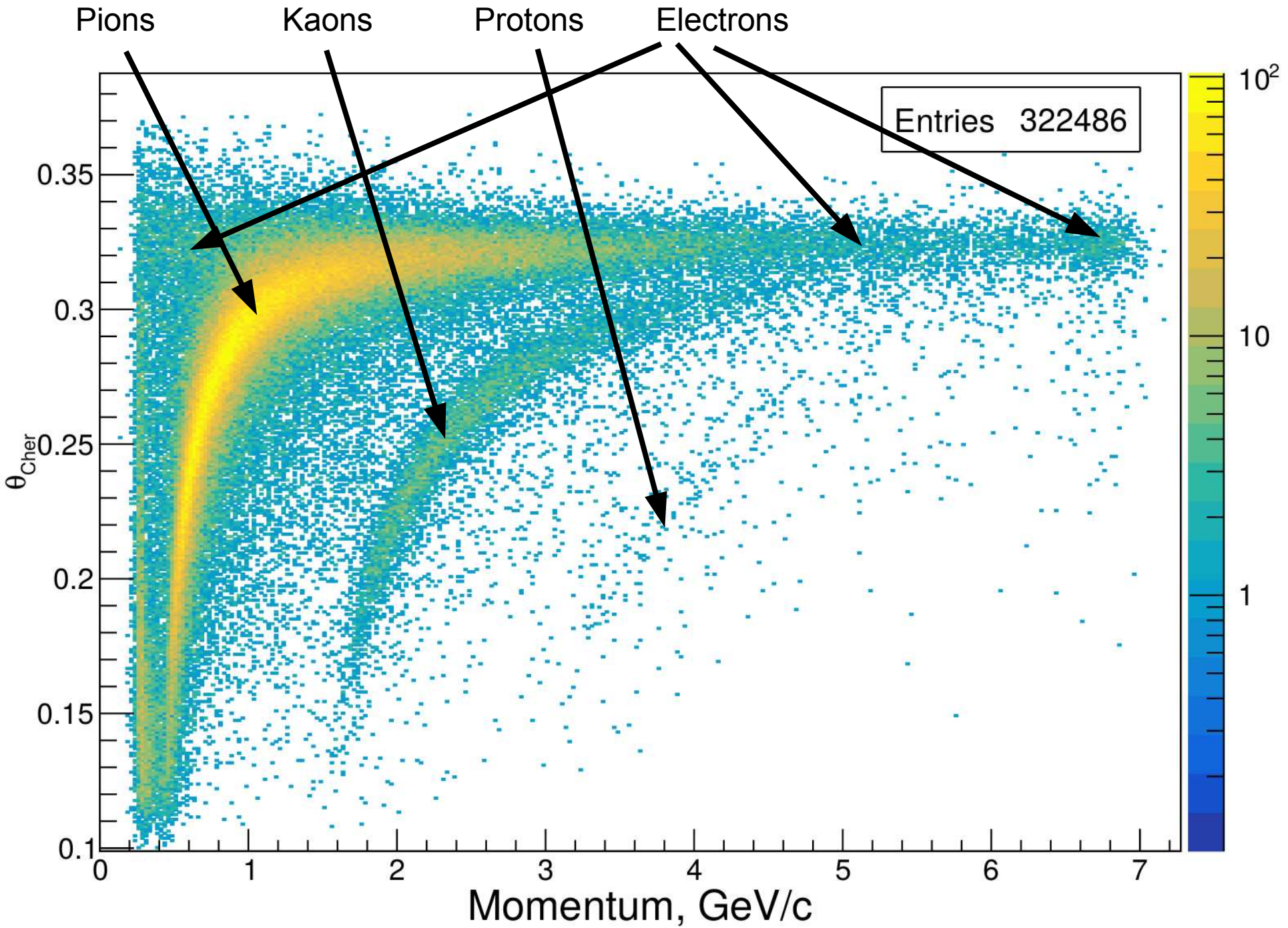




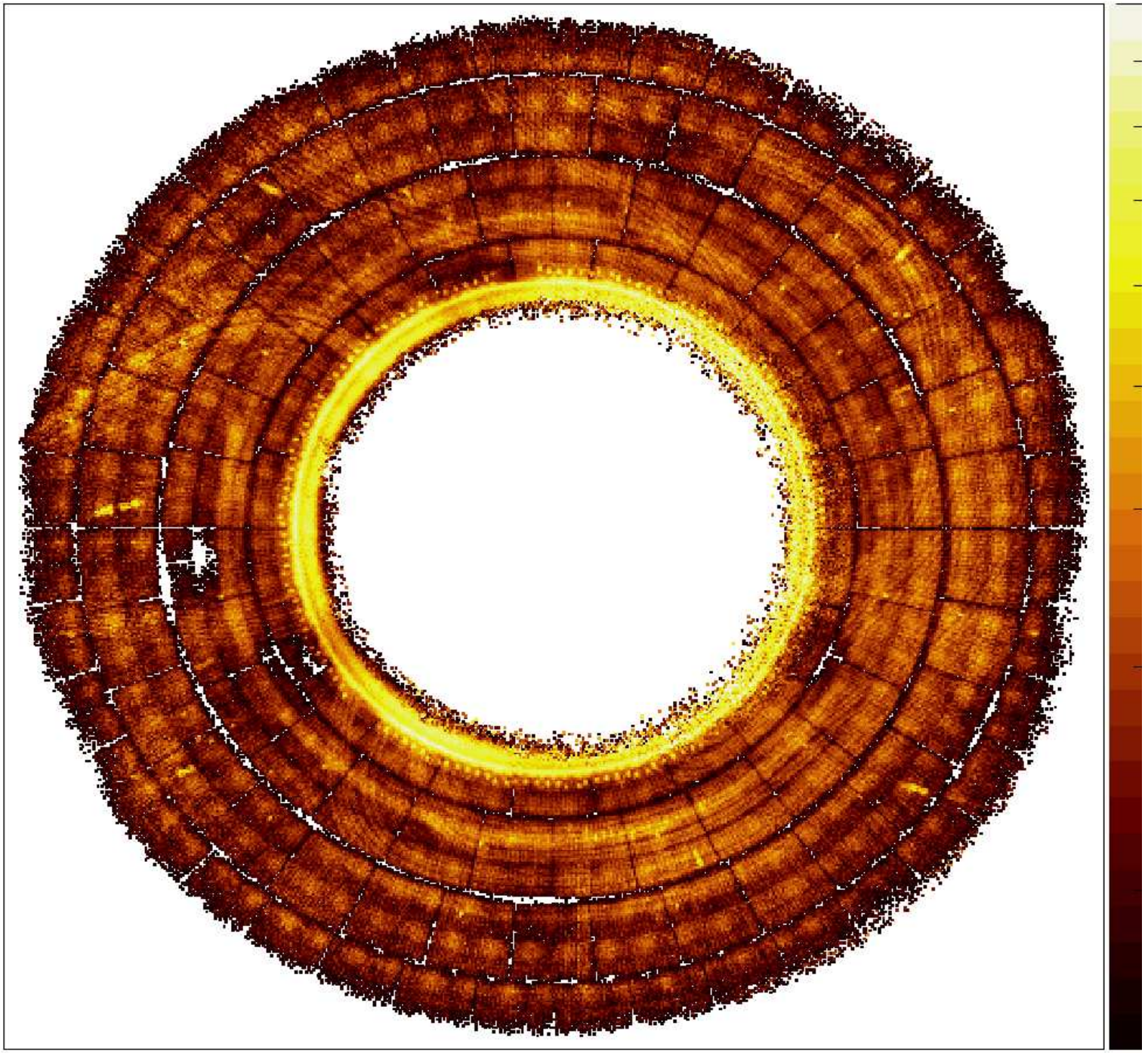




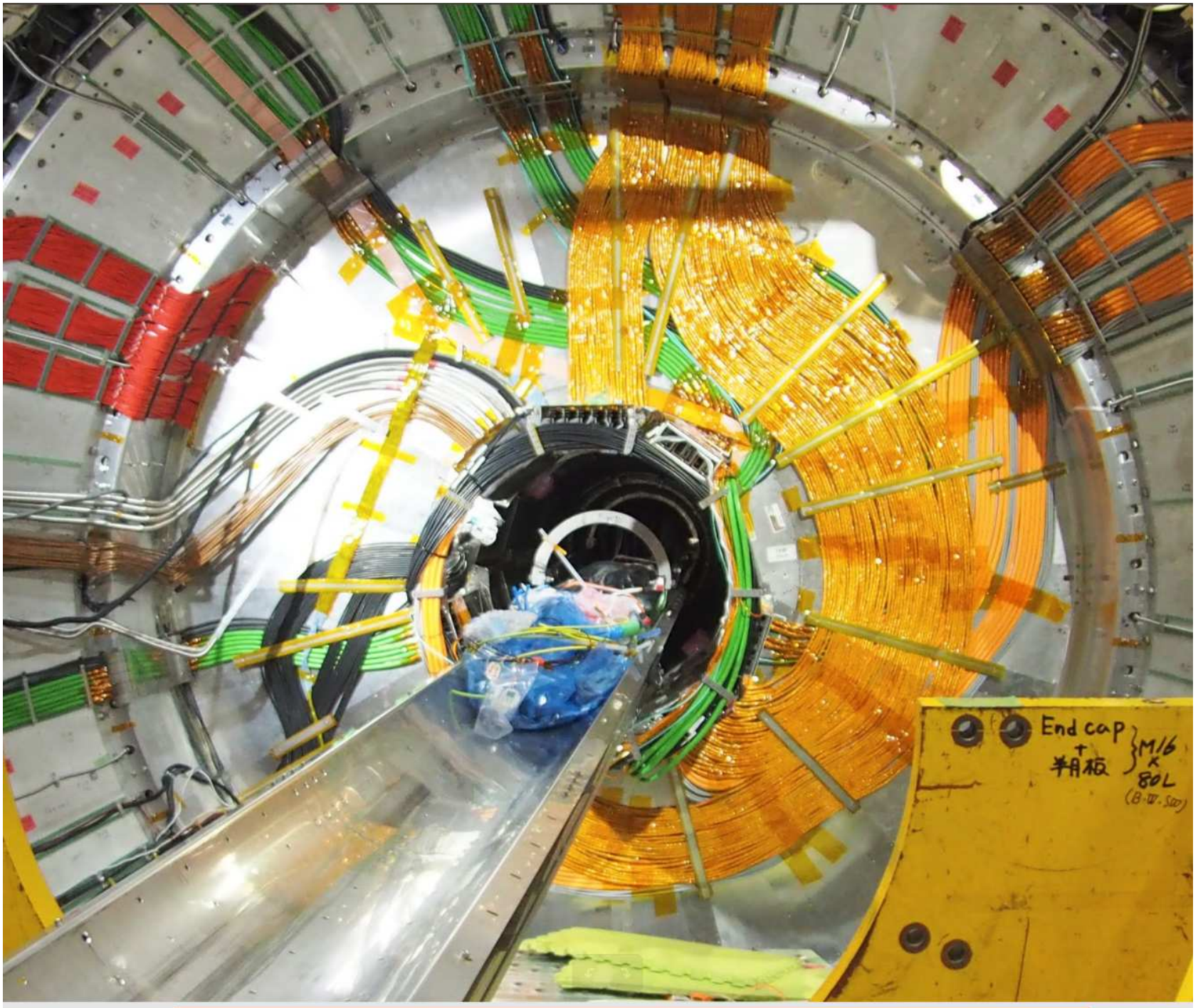
Cherenkov as a function of momentum



Detector tomography with ARICH

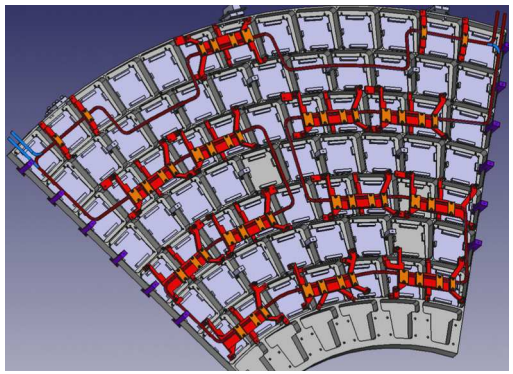


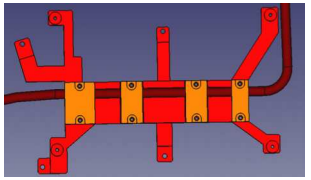
Inner detector cabling

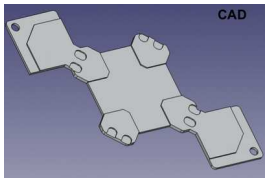


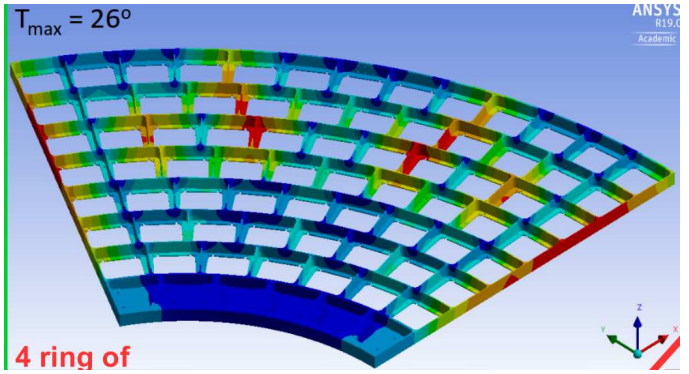
ARICH cooling system upgrade

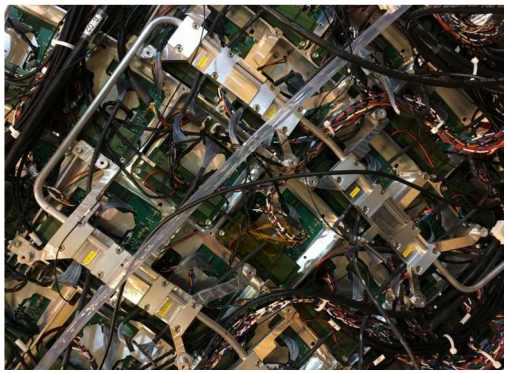
- Baseline cooling system* - was not sufficient to cool down the full detector.
- New cooling system has been designed, simulated, fabricated, installed and tested after phase 2.



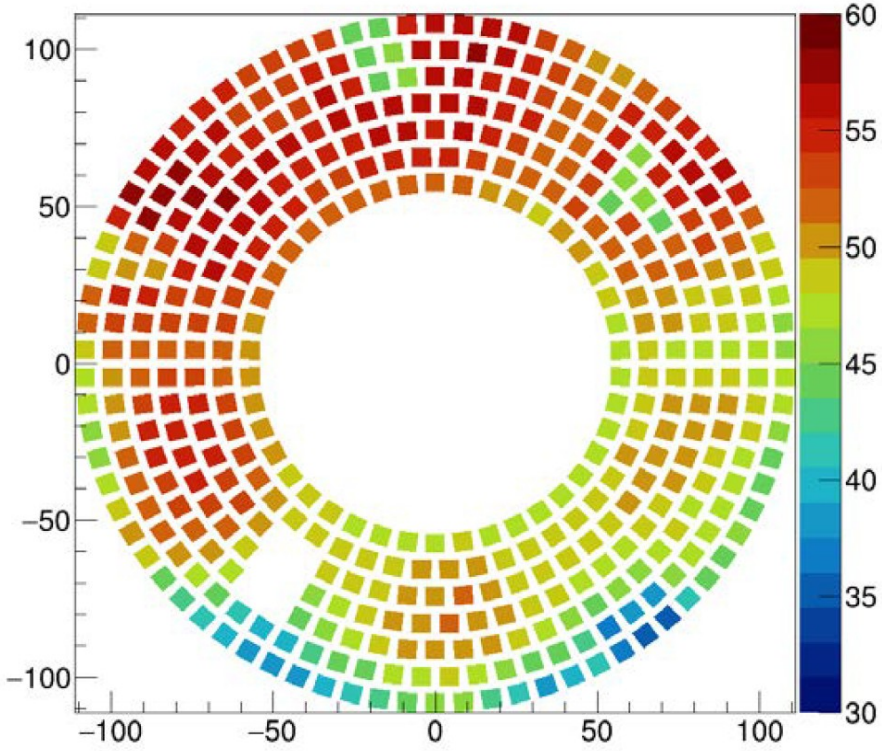




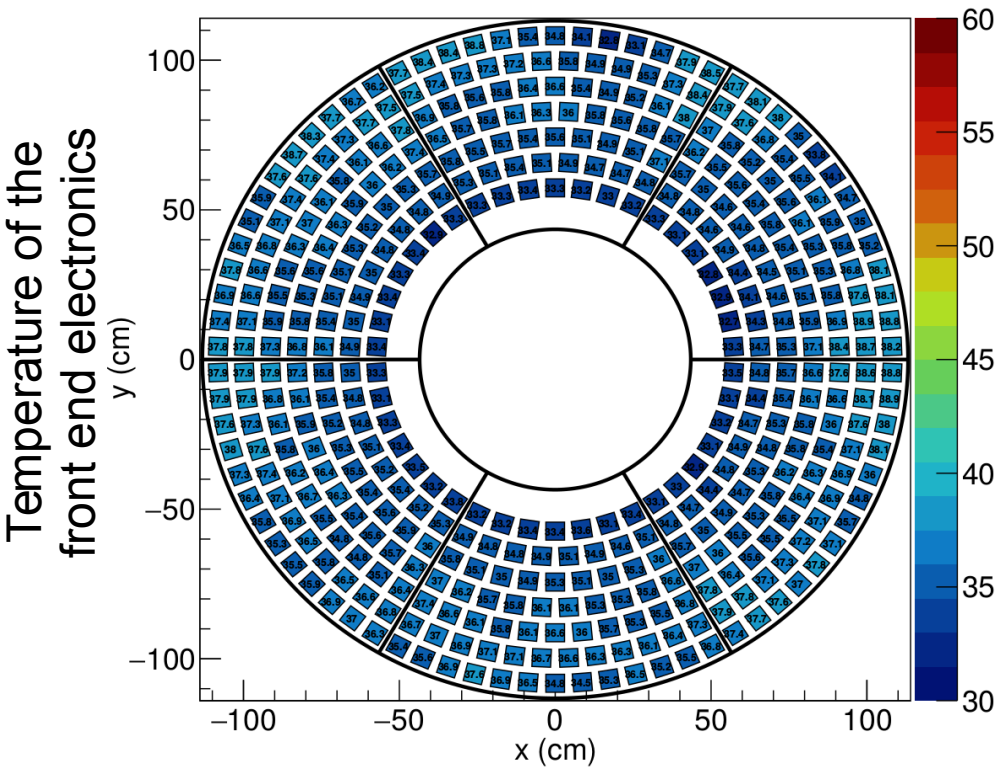




180209-085553 Phase 2



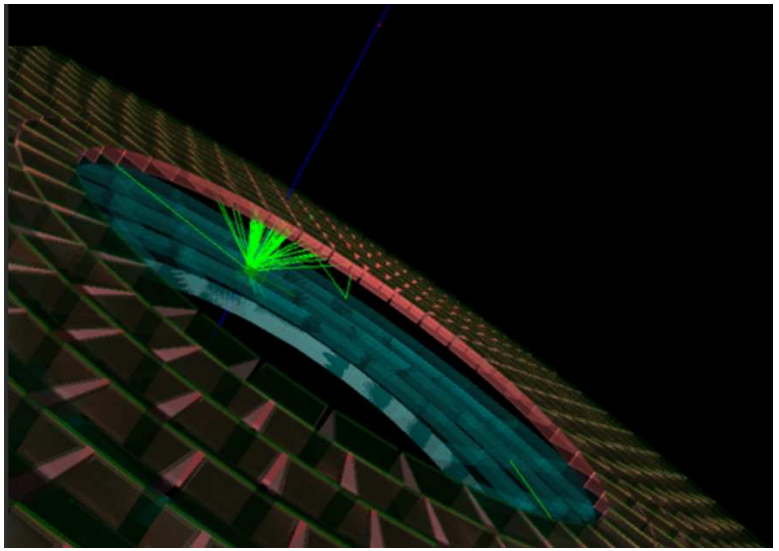
feb_t1 2019.2.14 1:21:1 **After phase 2**

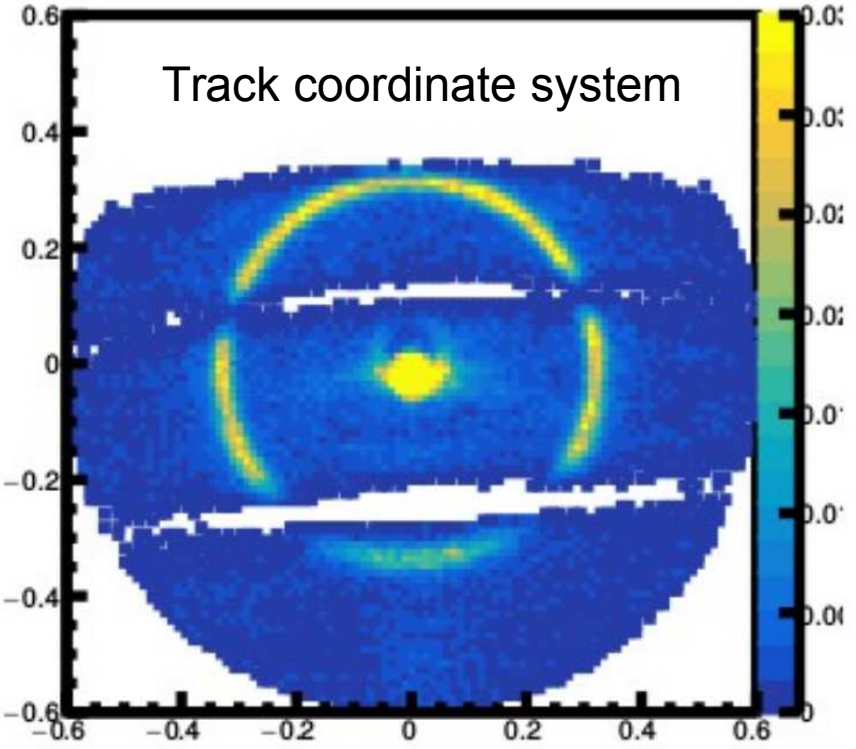


* Designed and installed by the external company.

Conclusions

- BELLE II detector had take first collision data (started 26 of April 2018)
- Estimation of the ARICH detector performance have been done with BhaBha electrons.
- Single photon resolution measured to be ~14 mrad (in agreement with simulation within 10 %).
- Number of signal photons is ~20% less with respect to the simulation.
- It corresponds to ~4 σ K/pi separation for tracks with 4 GeV/c momentum.
- Monte Carlo tuning in ongoing.
- Upgrade of the ARICH cooling system have been done.





Backup slides, appendix, ...