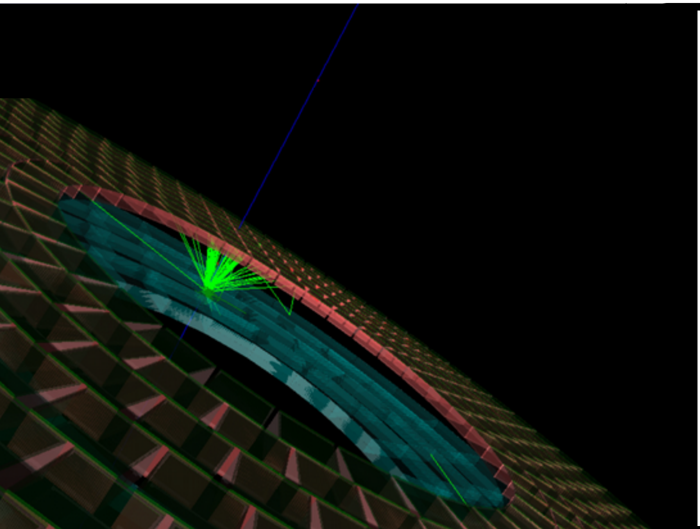
High Energy Accelerator
Research Organization – KEK, Japan

Aerogel RICH counter for the Belle II forward endcap PID

Luka Santelj, KEK

On behalf of the Belle II ARICH group



Content:

- Belle II experiment
- Aerogel RICH
- HAPD
- construction status
- cosmic ray test
- summary

INSTR-2017
Budker INP
Novosibirsk, Russia

Belle II & SuperKEKB

New facility on the **intensity frontier:**

Virtual production of new particles
to probe energies beyond the energy frontier
(prime examples: GIM, M_{c}, 3 gen., M_{t})

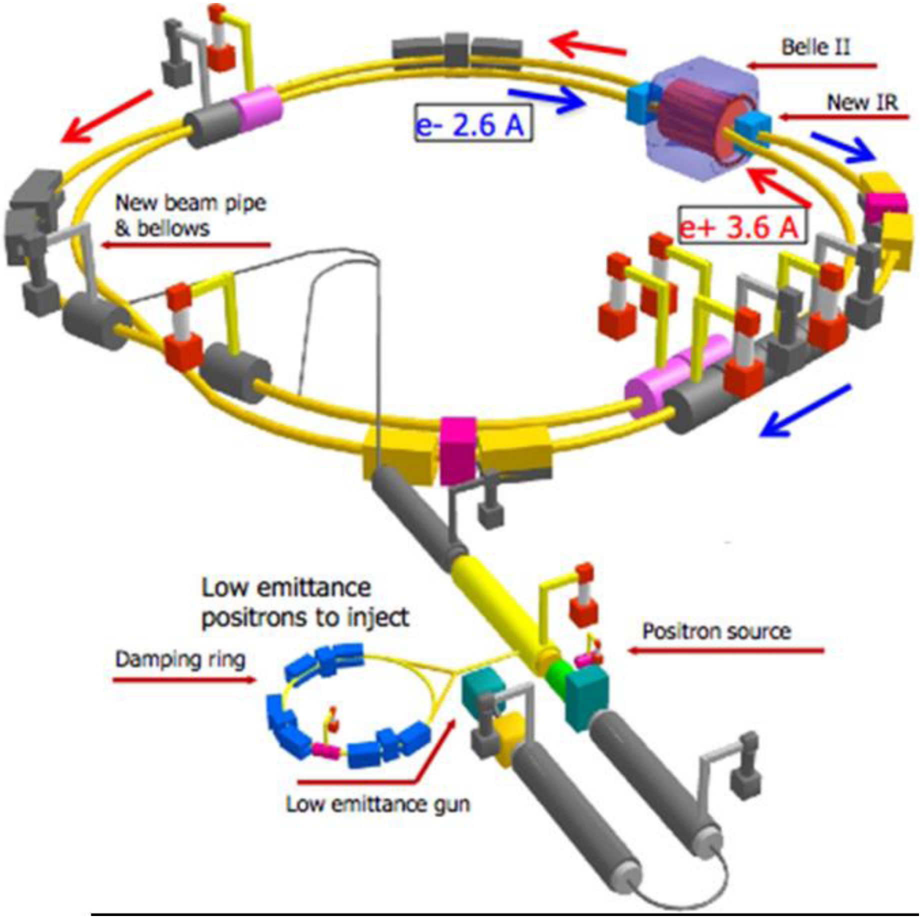
Successor of the very successful KEKB/Belle @ KEK, Tsukuba, Japan.

KEK / Belle
In operation: 1999-2010
Accumulated data: **1 ab^{-1}**
Peak luminosity: **2 x 10^{34} cm^{-2} s^{-1}**

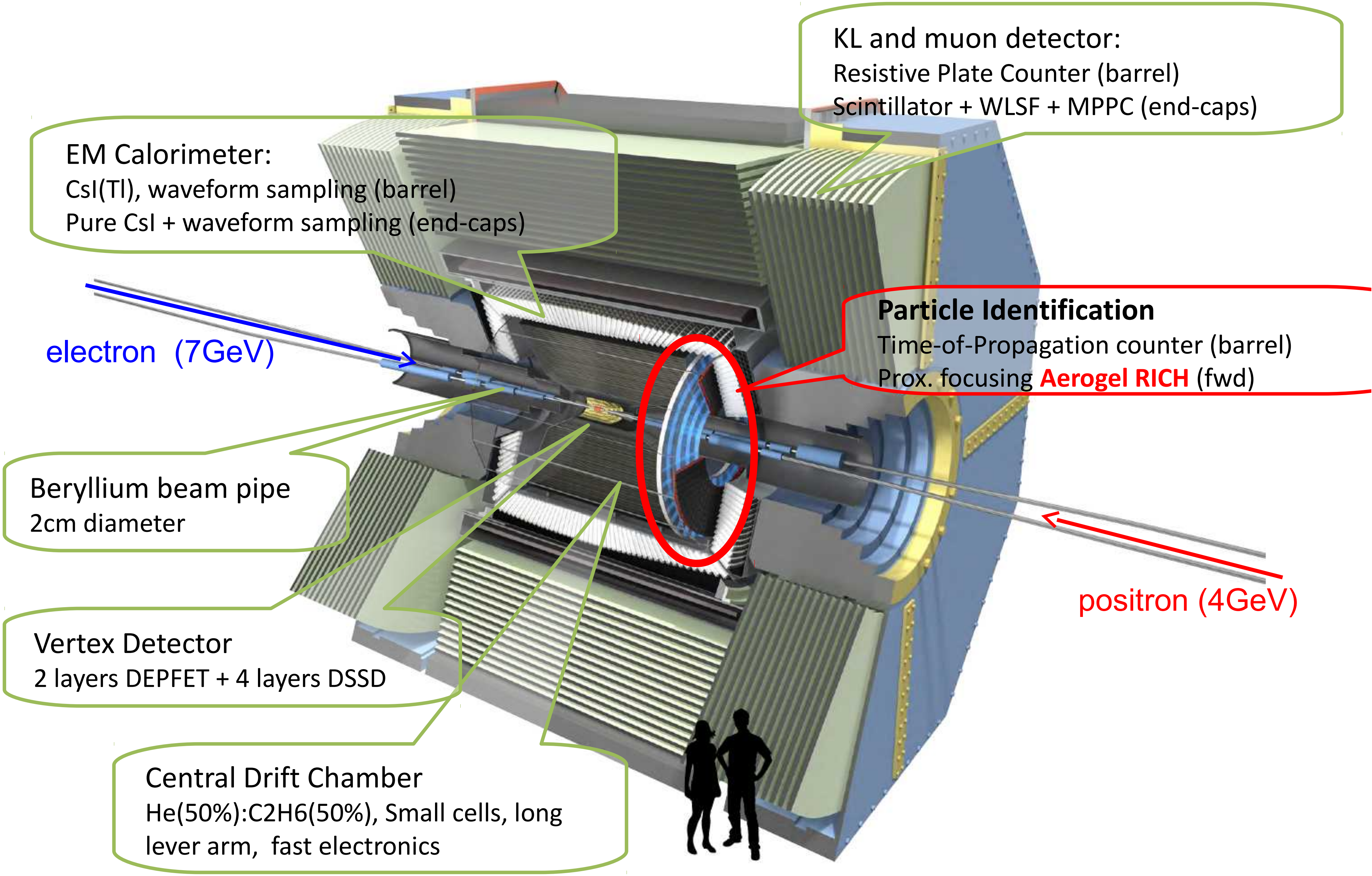
High precision confirmation of the SM flavor structure (KM mechanism is the main source of CPV,...).

KEKSuperB / Belle II
Start: 2018
Accumulated data: **50 ab^{-1}**
Luminosity: **8 x 10^{35} cm^{-2} s^{-1}** **(Belle x 40)**

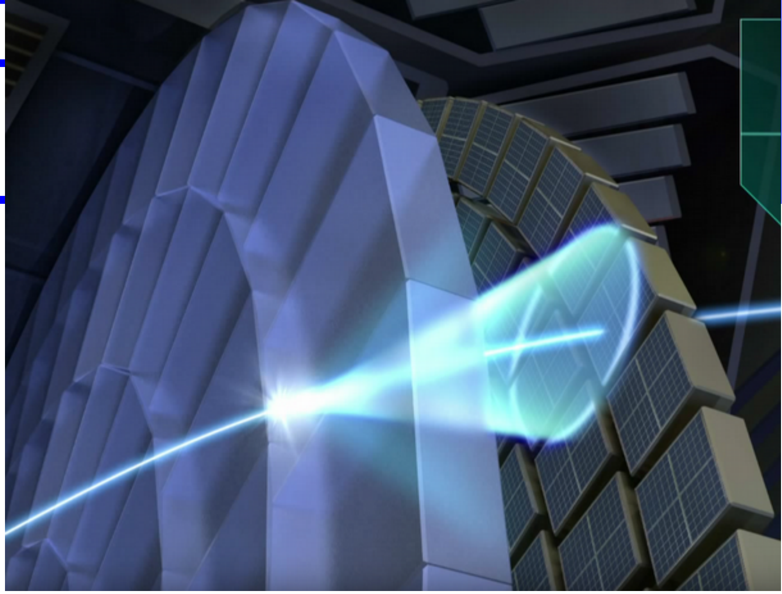
Are there new CPV phases?
Are there right handed currents from NP?
Does nature have multiple Higgs bosons? …



The Belle II detector



Aerogel RICH (ARICH)

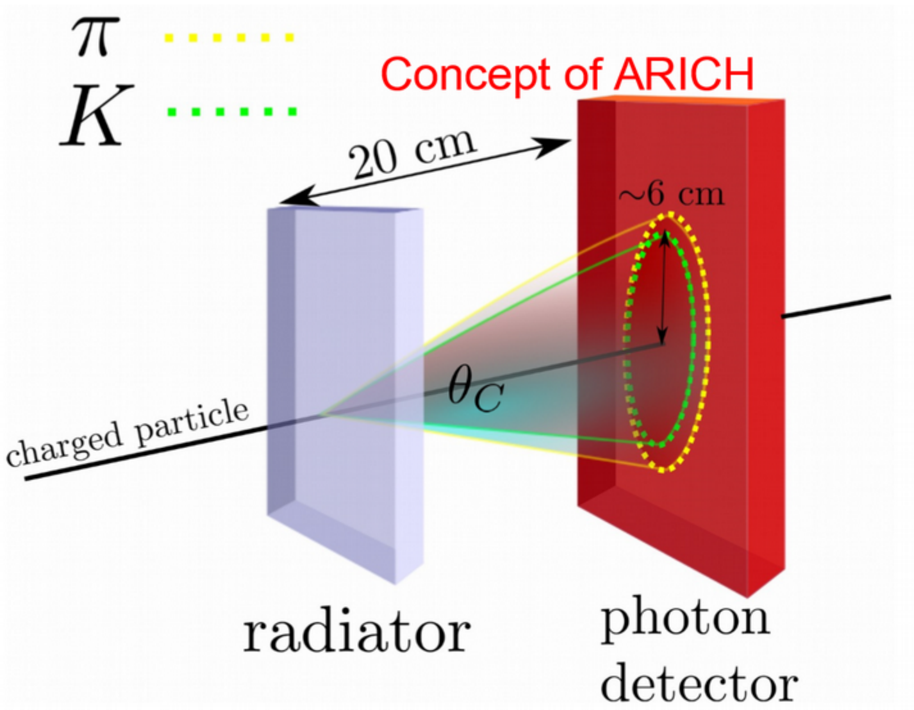


Good particle identification (mainly $\pi\ /K$ separation) is a key issue for Belle II:

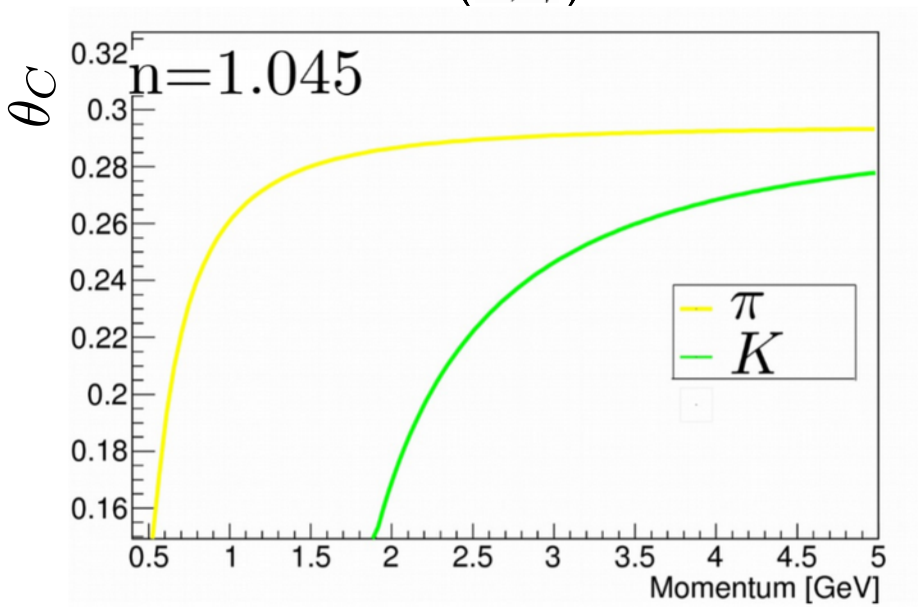
- background reduction (e.g. $B \to \rho\,\gamma$ vs. $B \to K^*\gamma$)
- efficient flavor tagging (determination of B meson flavor)

Goal:
$4\sigma\ \pi\ /K$ separation, at 0.5 - 3.5 GeV

In the forward endcap → **Aerogel RICH.**



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



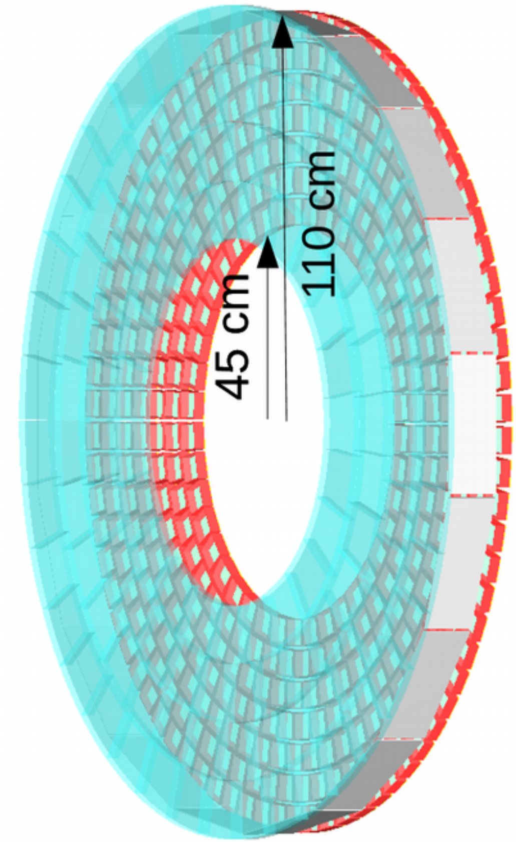
$\theta_C(\pi) - \theta_C(K) \sim 30$ mrad @ 3.5 GeV

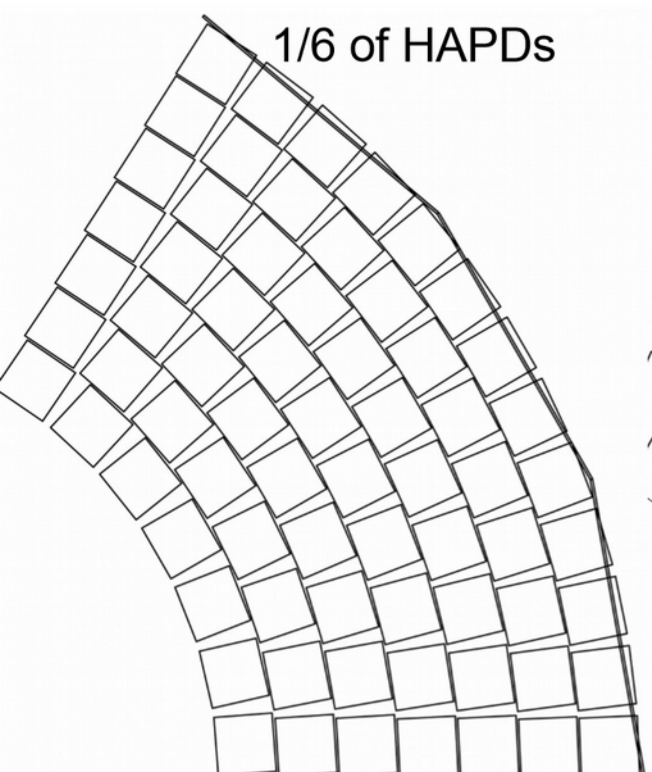
Design of ARICH

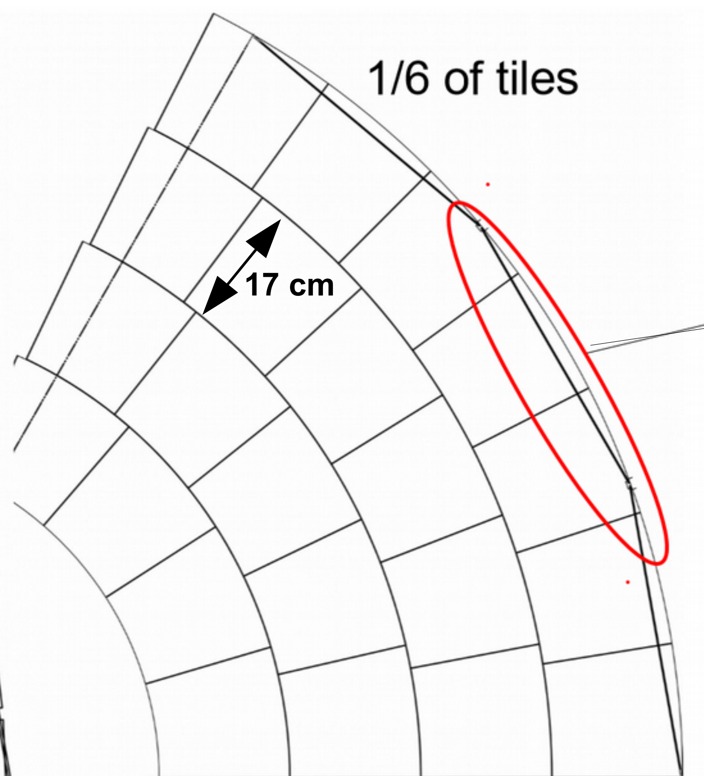
420 HAPD modules arranged in 7 rings.
(inner radius 56 cm, outer radius 114 cm)

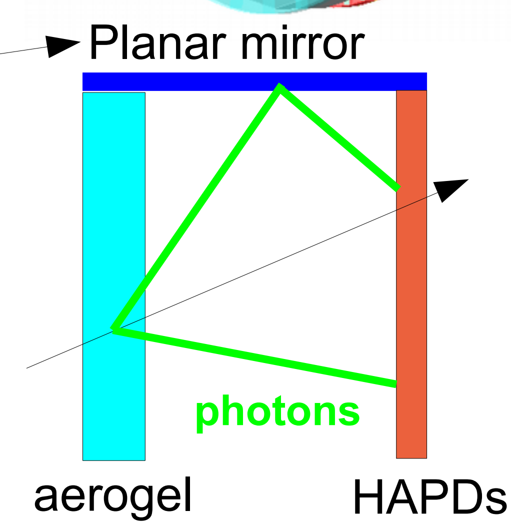
2 x 124 aerogel tiles, wedge shape, 2cm each layer,
4 types (radius dependent, ~17x17 cm)

Planar mirrors on the outer edge, to prevent photon loss.

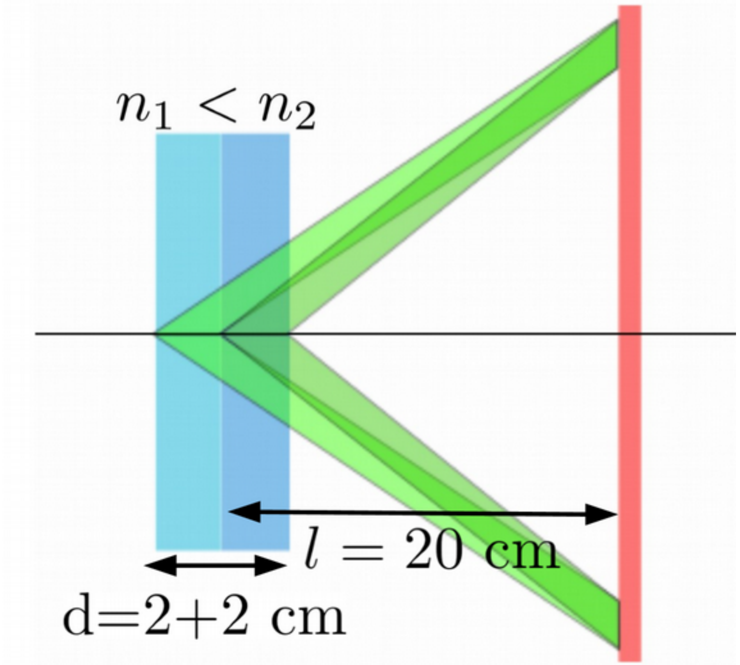








Radiator – Silica Aerogel



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

Two aerogel layers in focusing configuration:

$$\boxed{n_1 = 1.045,\ n_2 = 1.055}$$

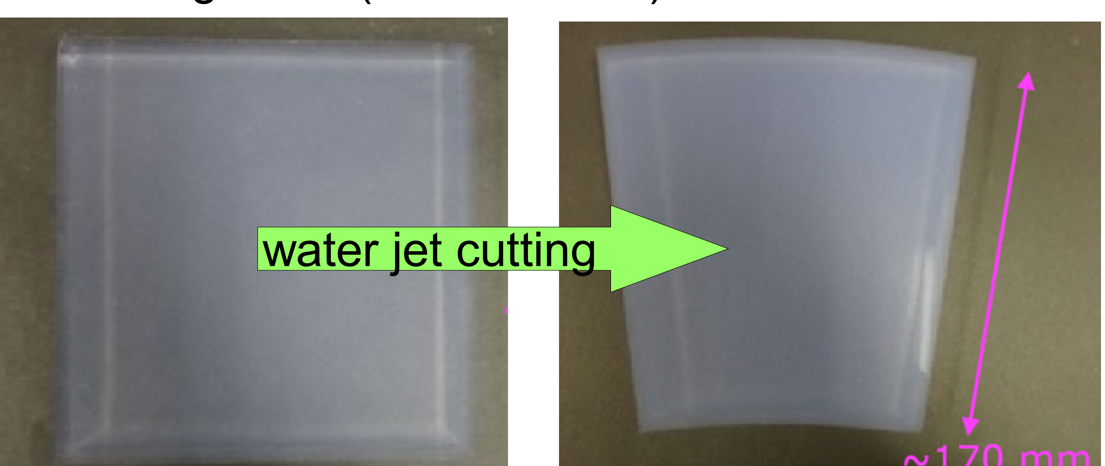
Overlapping rings from 1st and 2nd layer!

Increasing number of photons with no resolution degradation (due to unknown photon emission point).

$$\sigma_{gel} = \frac{d \sin\theta_C \cos\theta_C}{l\sqrt{12}} \frac{1}{\sqrt{N_{p.e.}}} \qquad N_{p.e.} \propto d$$

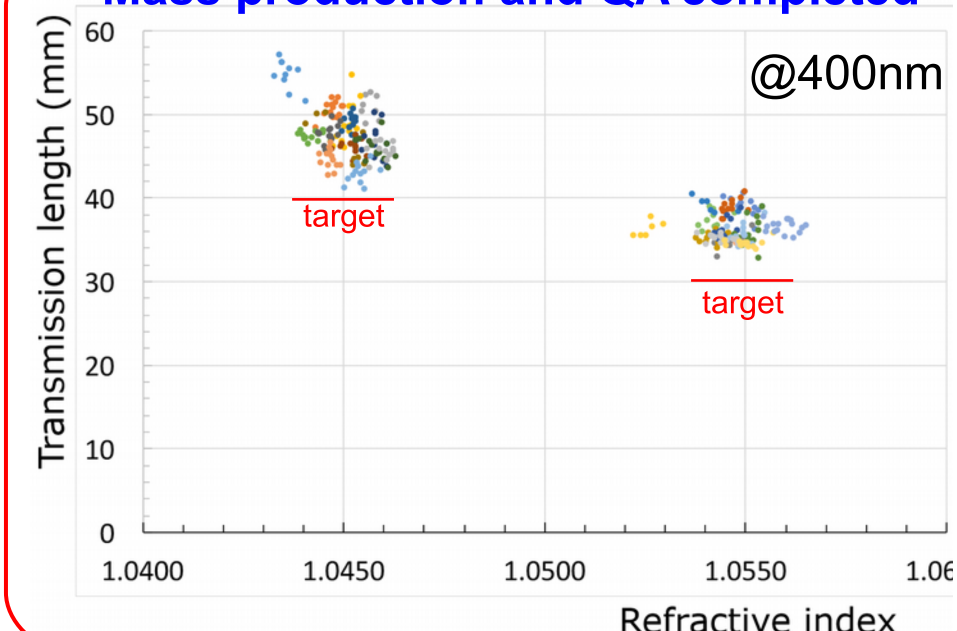
Aerogel with high transparency is required ($\lambda_t > 30$ mm)

Minimize photon loss on tile edges
→ large tiles (~ 17 x 17 cm)



M.Tabata et al.,The Journal of Supercritical Fluids 110 (2016) 183-192

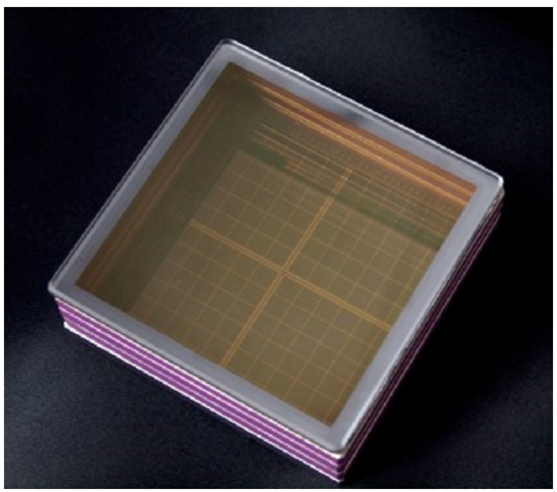
Mass production and QA completed



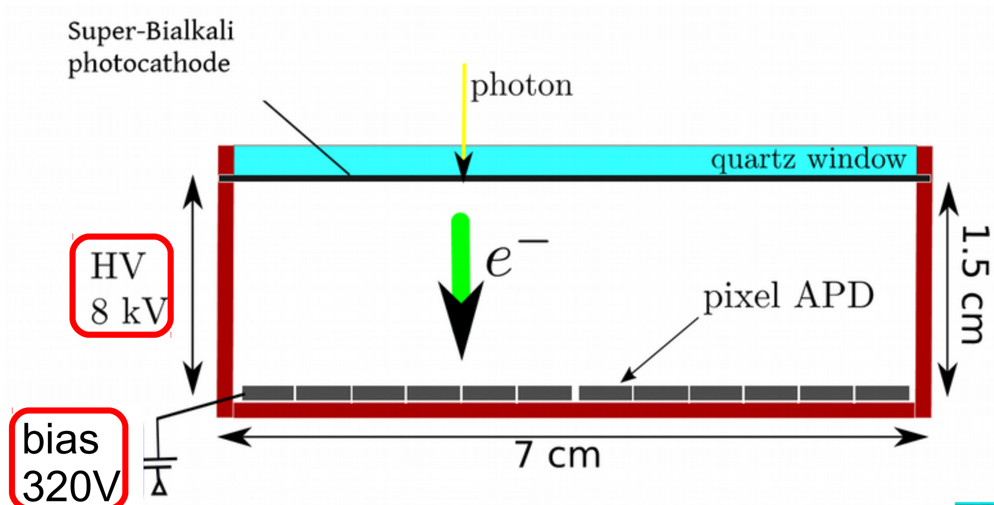
Photon detector – HAPD

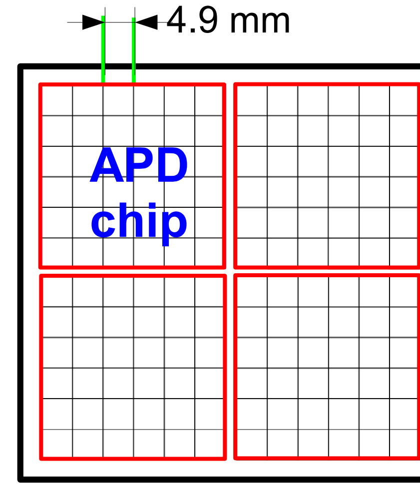
HAPD – Hybrid Avalanche Photo-Detector

- Developed in collaboration with Hamamatsu photonics
- Basic requirements: - 1.5 T - n,γ tolerance ($10^{12}\ n/\mathrm{cm}^2$)
- position resolution
- large coverage (3.5 m^2)

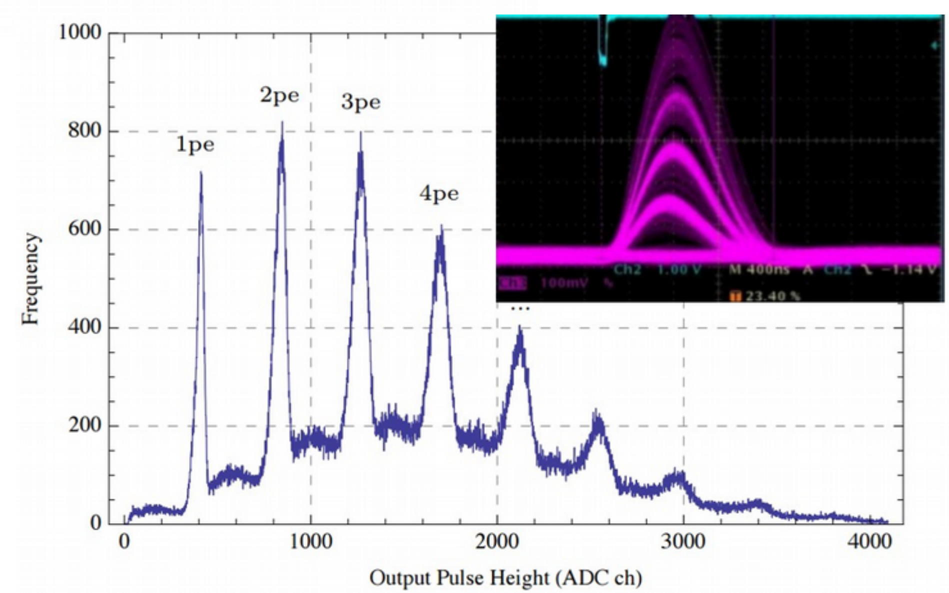


S.Nishida et al, NIMA610(2009)65



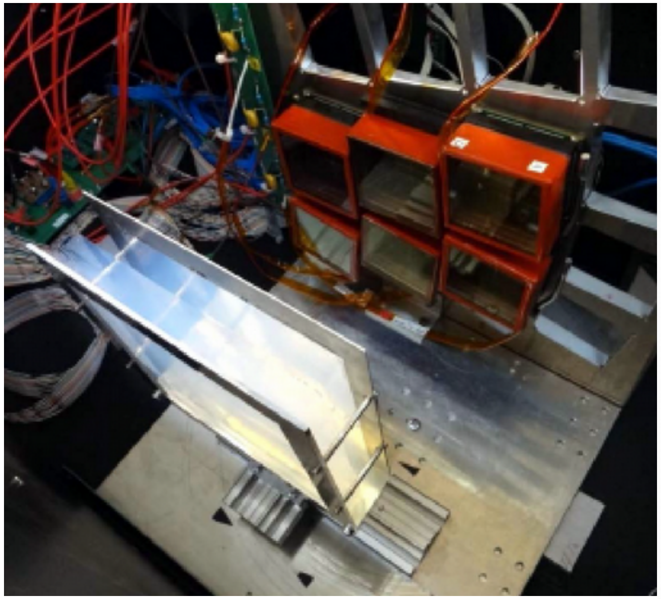


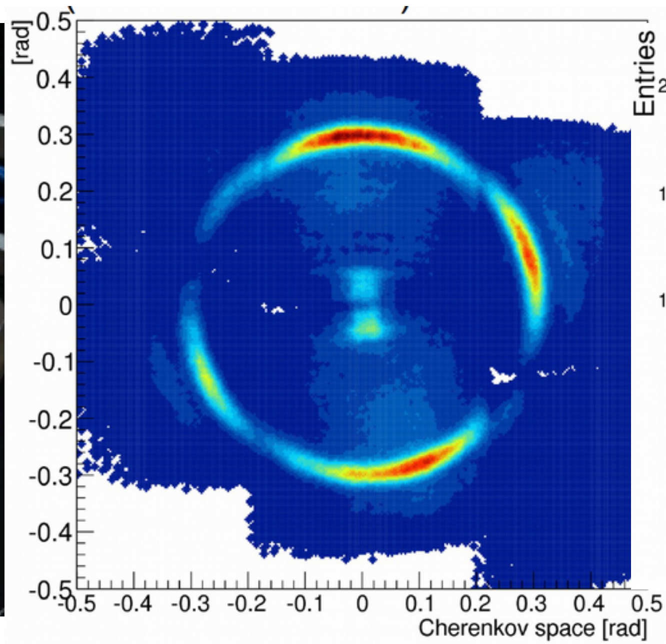
Size	73x73 mm
# of channels	144 (36-ch APDx4)
Total gain	>60000 (1500 x 40)
Peak QE	~30%
Active area	64%
Weight	220g



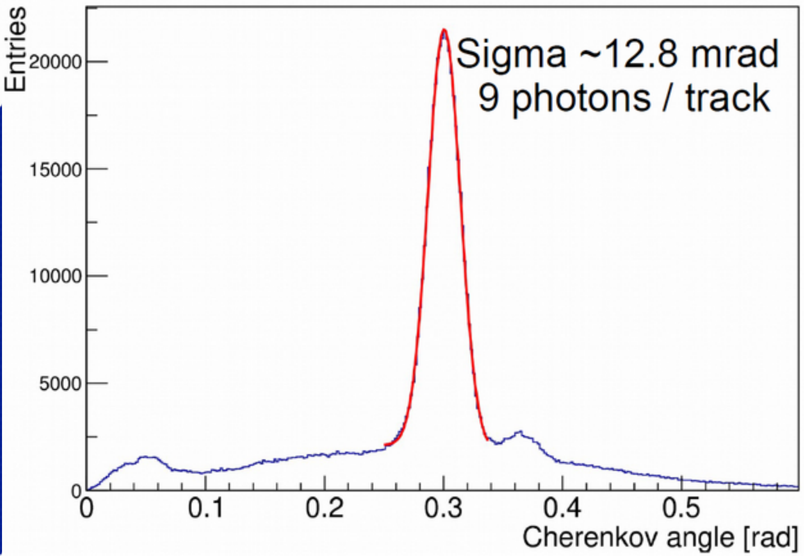
Proof of principle

Beamtests

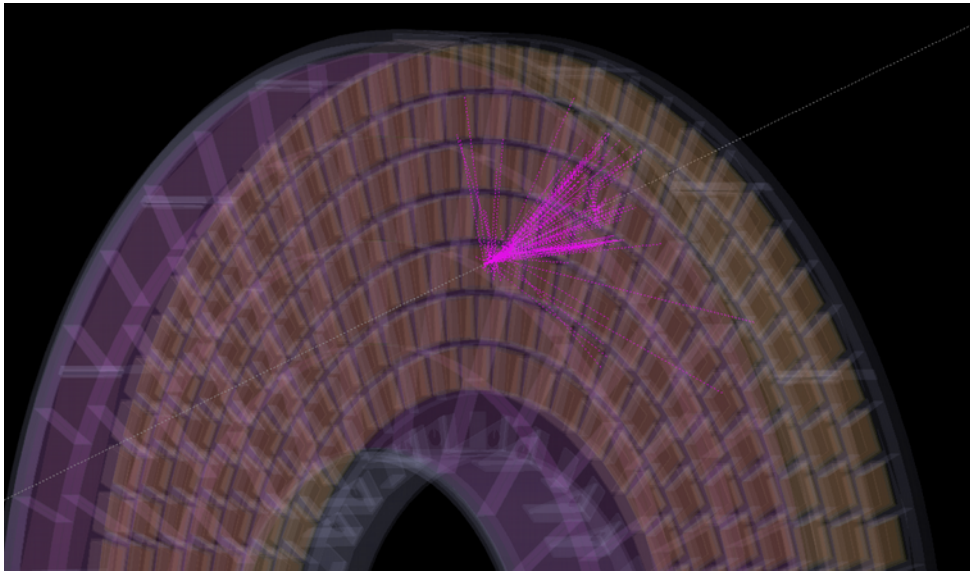


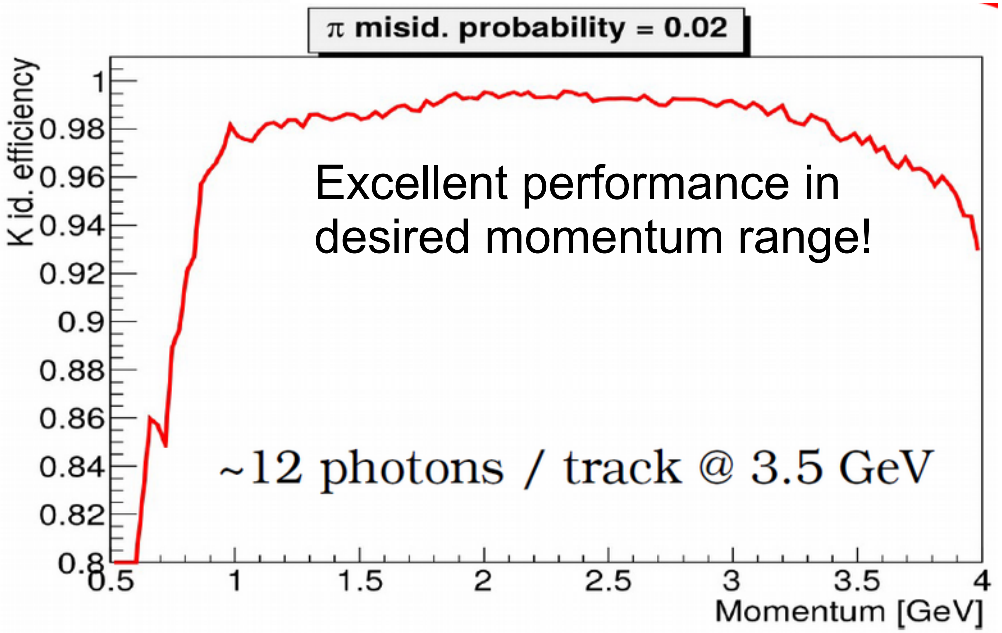


electron beam, 2013 @ DESY



Detailed Geant4 simulation

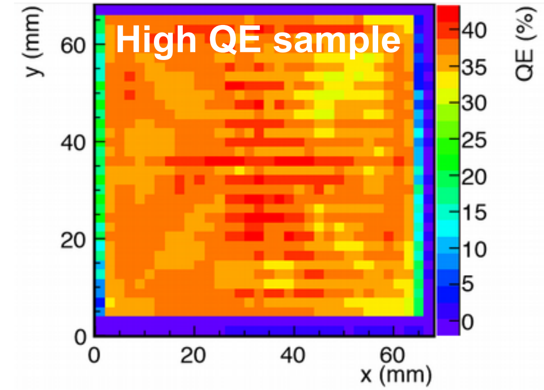


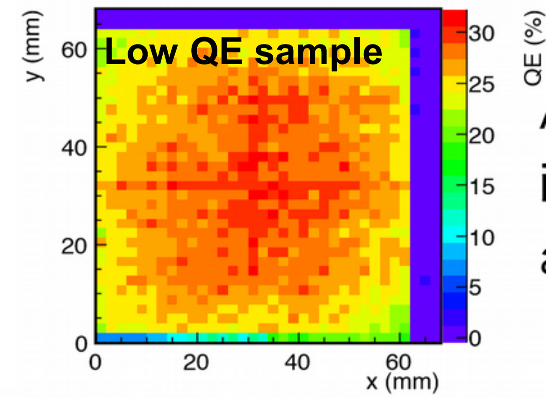


R. Pestotnik et al., Nucl. Instrum. Meth. A766 (2014) 270–273;

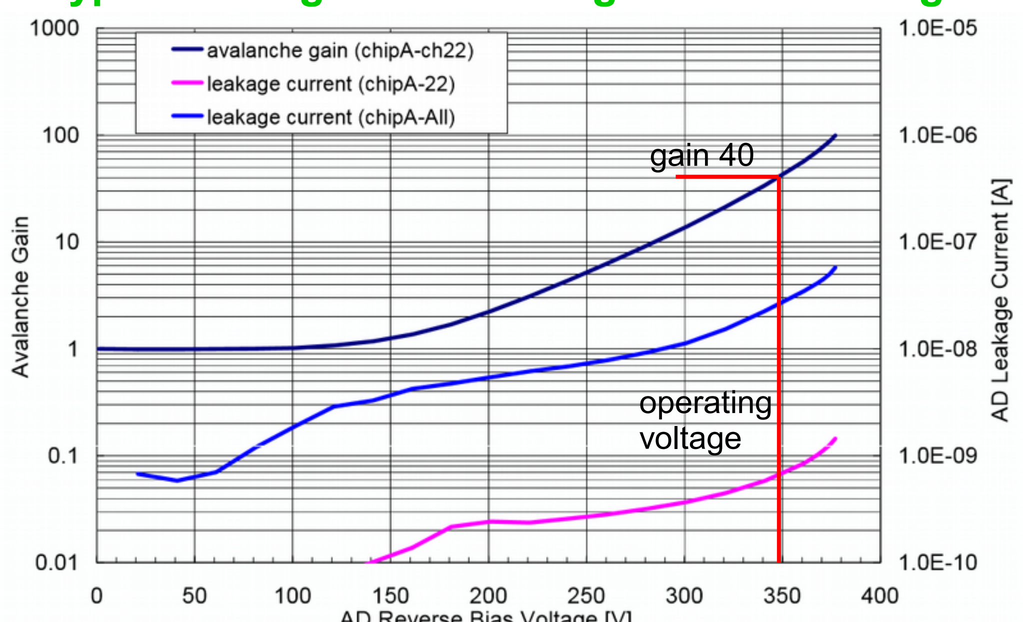
Mass production of HAPDs

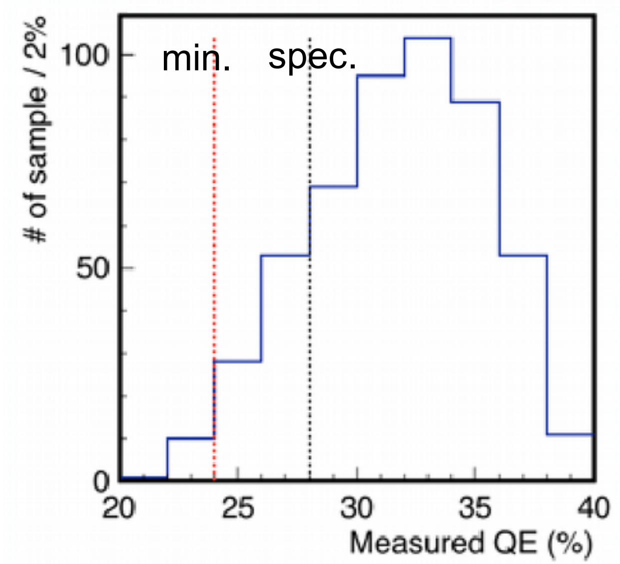
- Mass production finished end of 2016. .
- Extensive QA tests, to measure QE, dead channels, channels gain, APD leakage current
- 90% of delivered HAPDs satisfy required specs. (high APD leakage current, low QE, etc)
- properties in database, available for reconstruction, etc.
- 420+spares HAPD modules (HAPD+FEB) ready for installation.





Typical APD gain and leakage vs. bias voltage

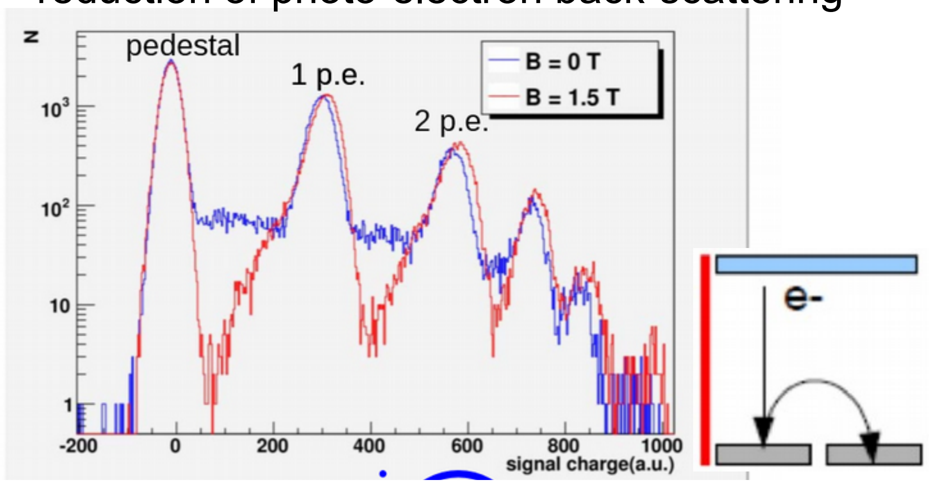




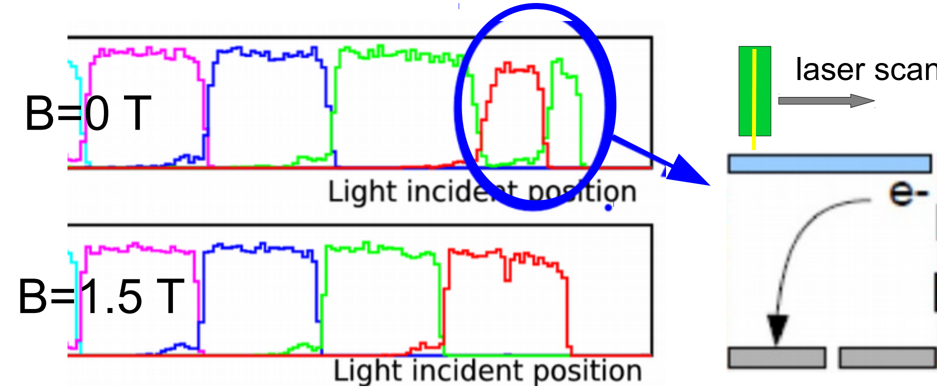
HAPD performance in magnetic field

- In first tests of HAPD prototypes in magnetic field only beneficial effects were observed:

- reduction of photo-electron back-scattering

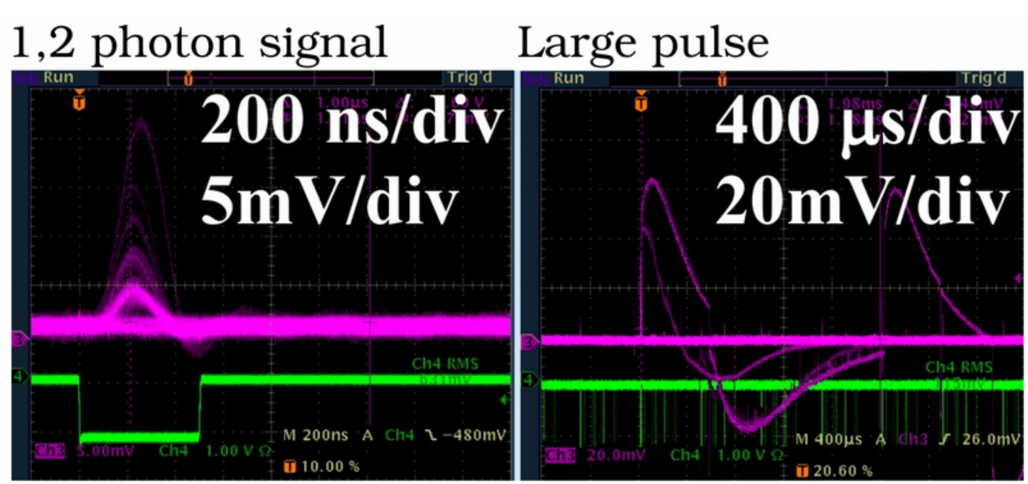


- no image distortion due to electric field non-uniformity on the edges of tube



- In later tests of larger number of HAPDs from mass production it was observed that in some samples **abnormally large signals (pulses)** are generated when operating **in magnetic field**

- all APD channels fired simultaneously
- for most HAPDs only during the HV ramp-up.
- for some samples (~20%) pulses persist
- at rates from 0 to few/s



Effect on HAPD performance

- After each pulse a short dead time period (~0.1s) of readout electronics is induced.
 → for most problematic samples, up to 10% overall dead time.

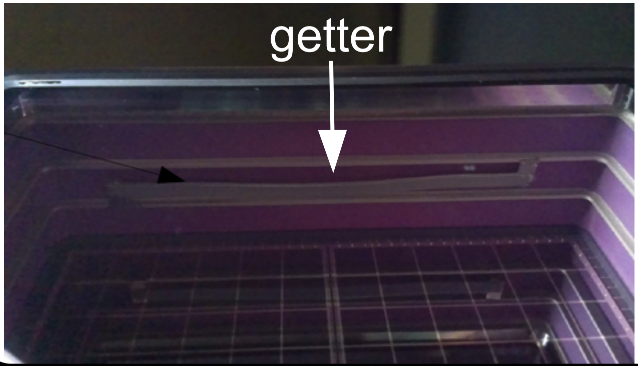
- Occasional damage to readout electronics → largely solved by adding ESD protection diodes to FEB (in front of ASIC inputs)
- So far no effect on HAPD itself is observed.

Getter re-activation

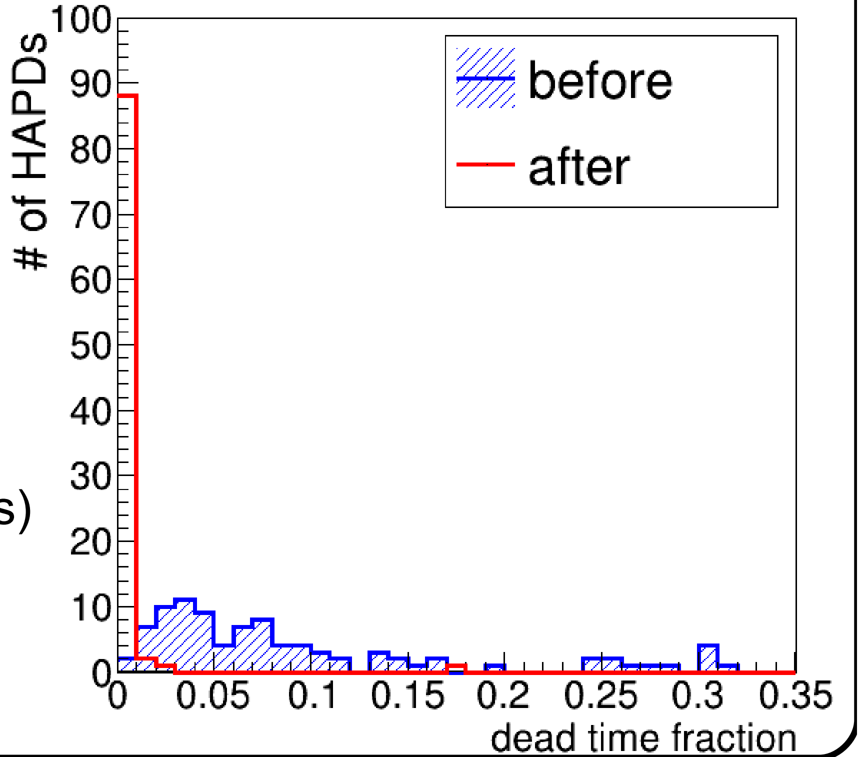
- Getter is a small plate of reactive material in a vacuum tube, activated at the end of HAPD production to improve the vacuum quality.

- Re-doing activation of getter in HAPD tube drastically reduces the rate of large pulses.

- Getter re-activation was done by Hamamatsu for all samples with initially >2% dead time (~20%)

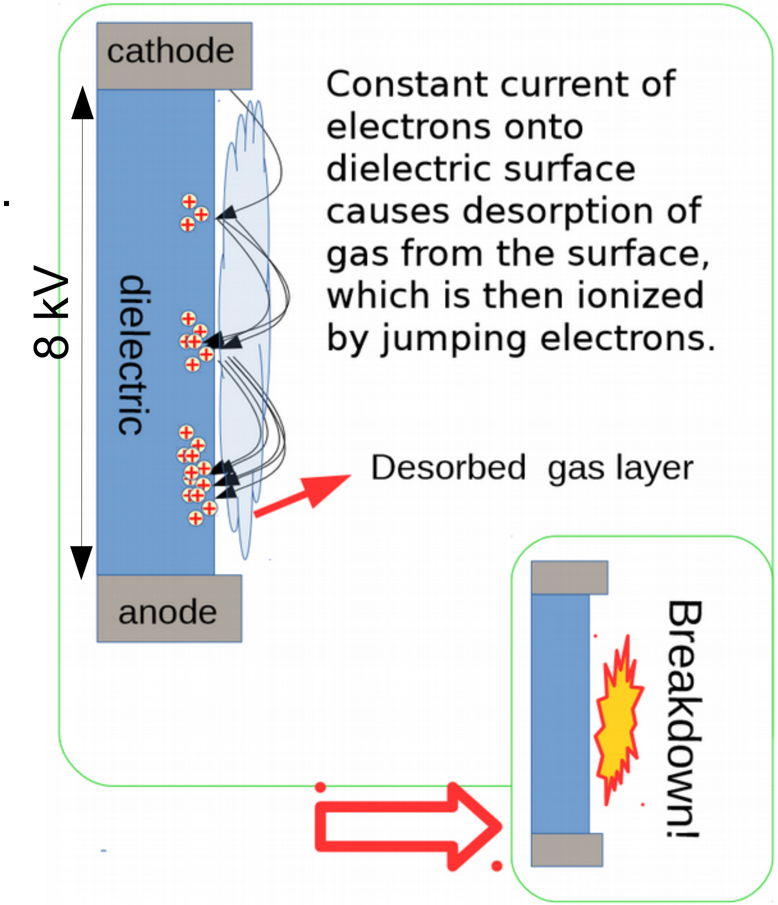


→ all recovered!
(stable for 5 months)

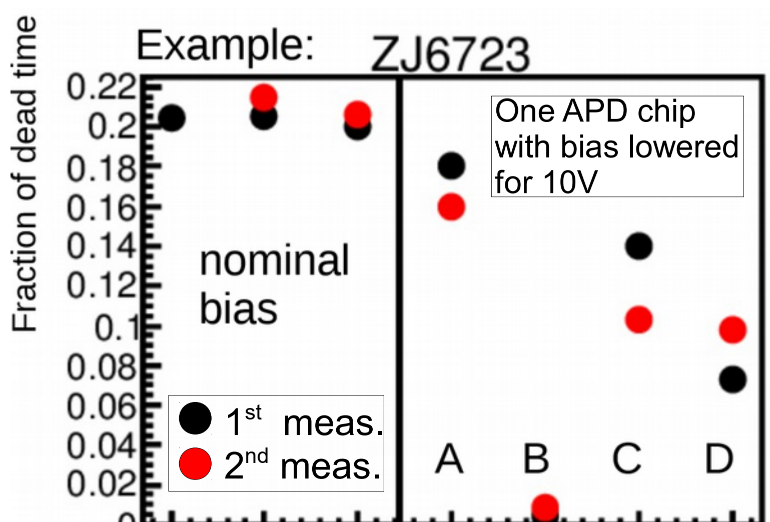


Surface flashover hypothesis

- Initiated by field electrons emitted from cathode under certain conditions an electron avalanche can form, leading to desorption of gas and eventually to breakdown.
- Light emitted in the process spreads over photocathode → large signals over all HAPD
- Breakdown voltage known to depend on magnetic field.
- CMS HCAL uses HPDs, and observe similar anomalously large signals when operating in ~1T.



Puzzling dependency on APD bias voltage



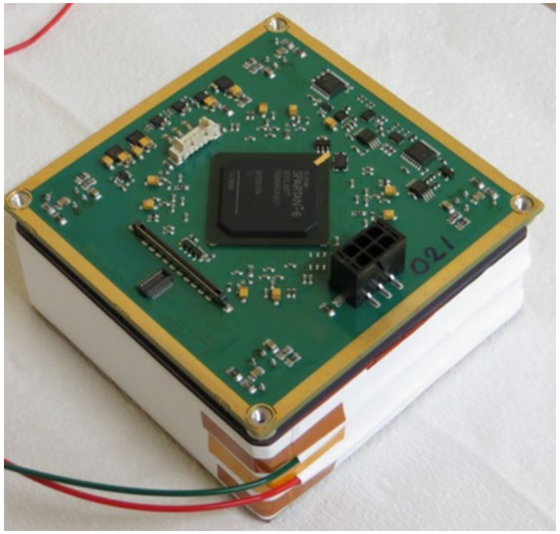
- Some kind of sparking, but origin/mechanism is not understood

If rate of pulses remains stable on long term (confirmed for 5 months) no effect on ARICH performance

L.S. et al., Nucl. Instrum. Meth. A845 (2017) 459 - 462

Readout electronics

- in total 60.000 channels.
- limited space of 5 cm behind array of HAPDs.
- ASIC SA03 (36 ch/chip → 4 ASICS / HAPD).
- Variable gain (3.1-12.5 V/pC) and
  shaping time (100-200 ns)
  → optimization for increasing noise levels (neutron radiation)
- mass production completed.



Front-end Board

4x ASIC (SA03)

Preamp → Shaper → Comparator

FPGA
for hit detect.
DAQ,
monitoring
(Spartan6)

x 6

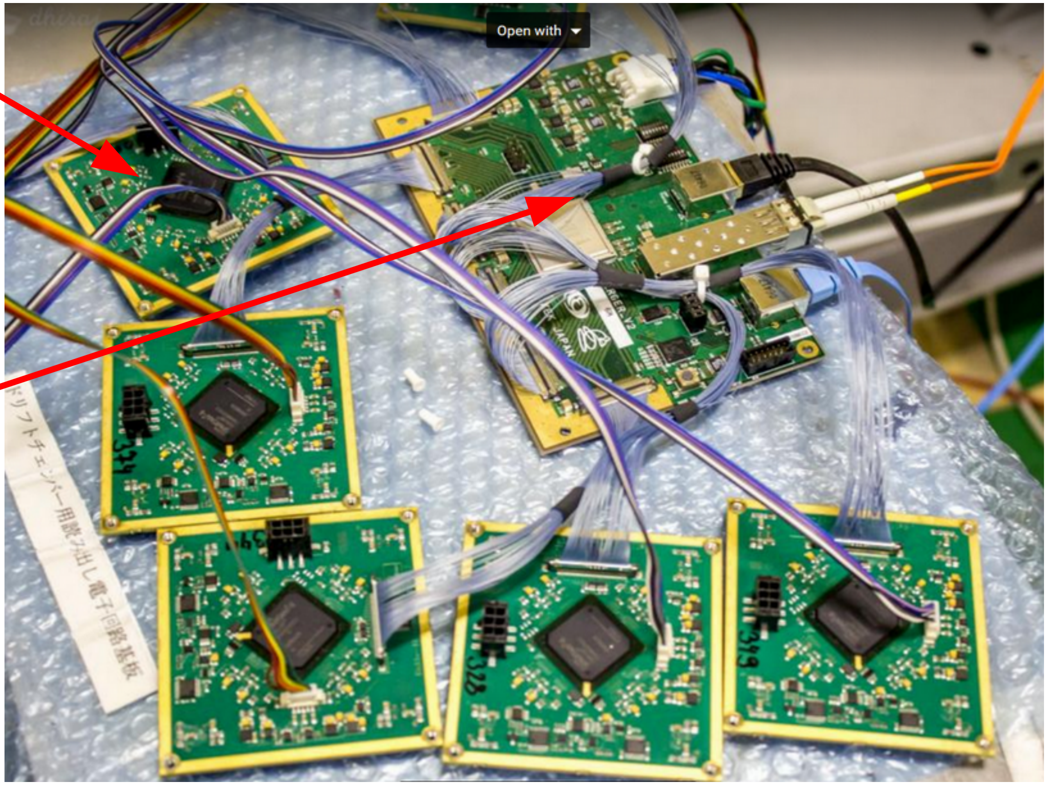
Merger Board

- Collects hit data from 5-6 F.E.B.s
- Send to DAQ system.

FPGA
(Virtex5)

Belle2Link

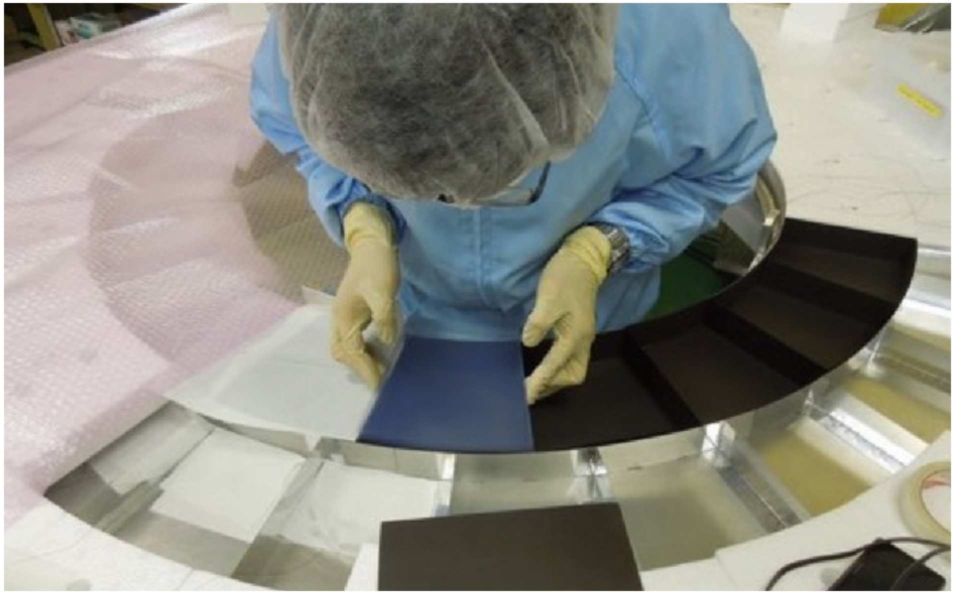
trigger

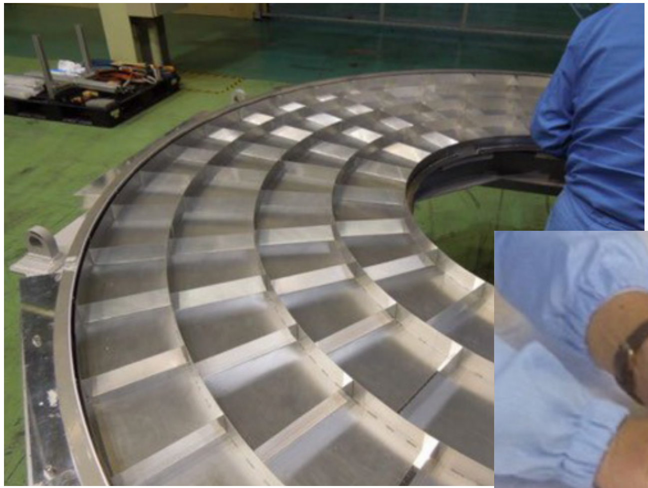


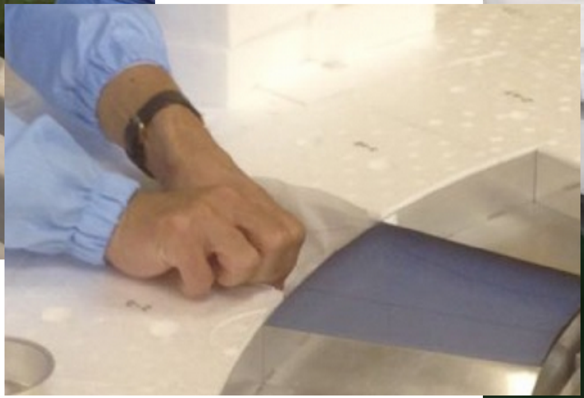
Installation of components

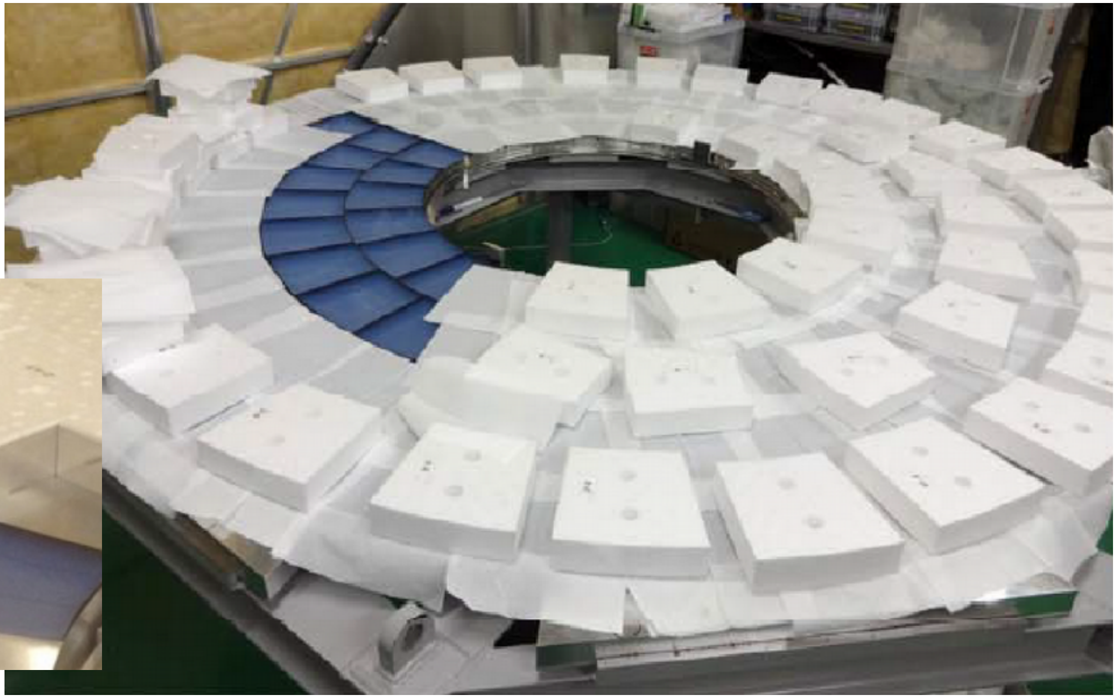
Aerogel tiles

- Tiles separated by 0.5 mm aluminum walls and supported by 1 mm aluminum plate
- Containers wrapped in a black sheet.
- Glass fiber strings to fix tiles to containers
- Installation completed.





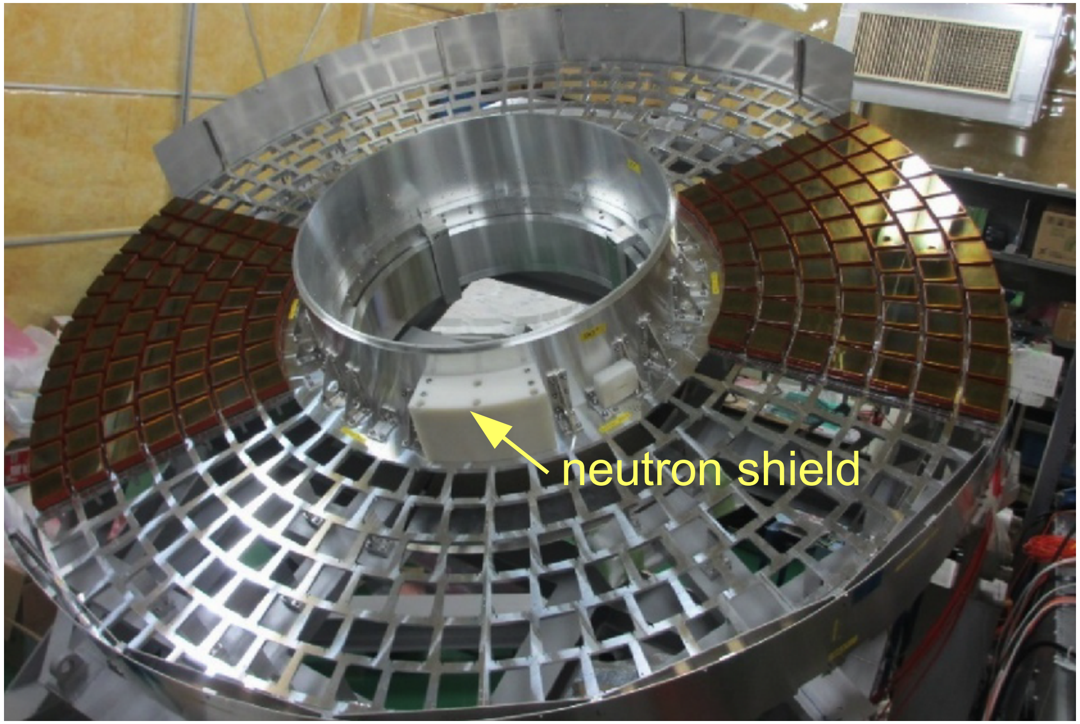


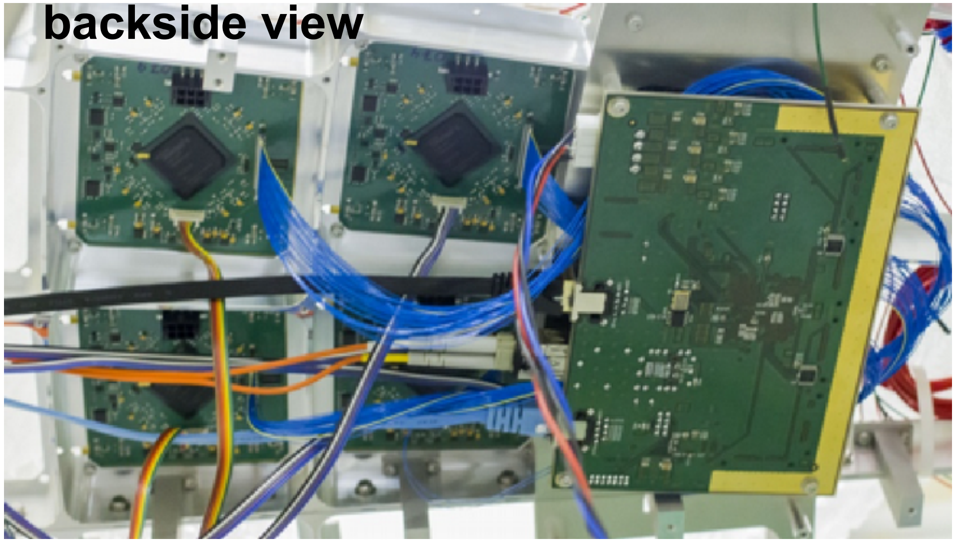


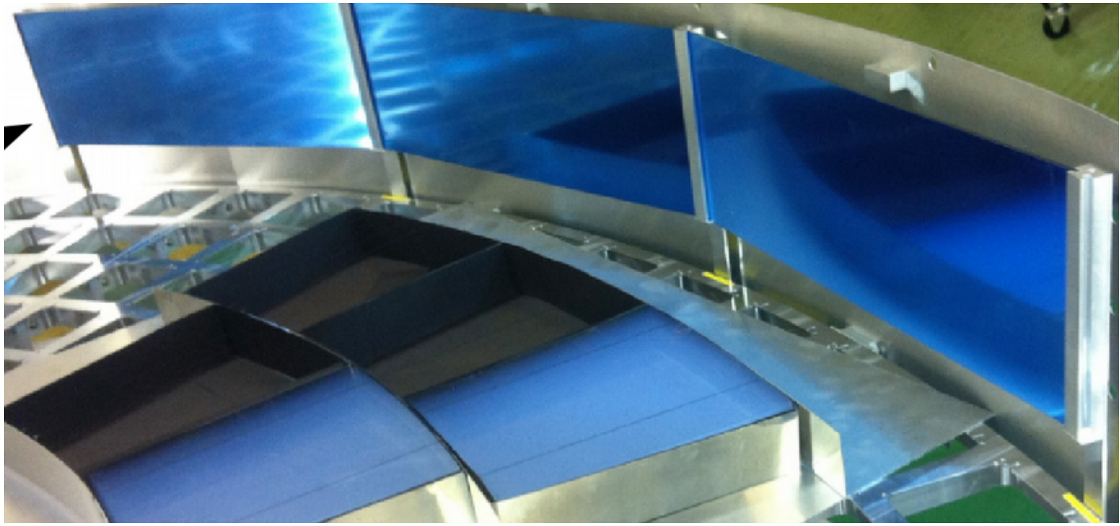
Installation of components

HAPDs & other

- 2 sectors of HAPDs installed (140).
- Test installation of polyethylene neutron shield on the inner side.
- Test installation of mirror plates.
- 40 HAPDs connected to DAQ for tests, 16 fully operational (HV+bias+DAQ) used for cosmic ray test.

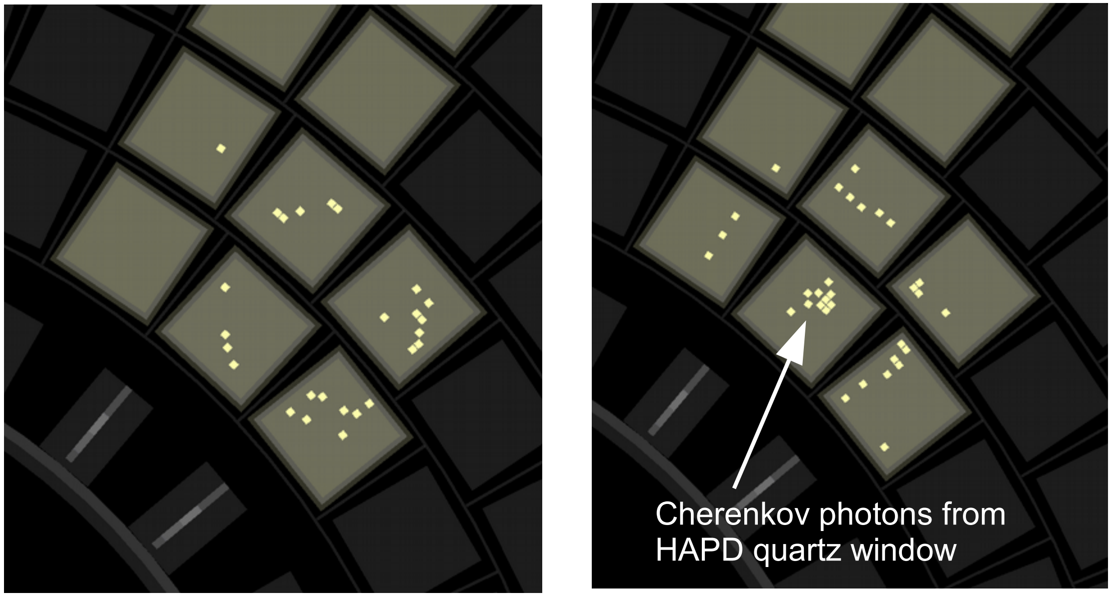


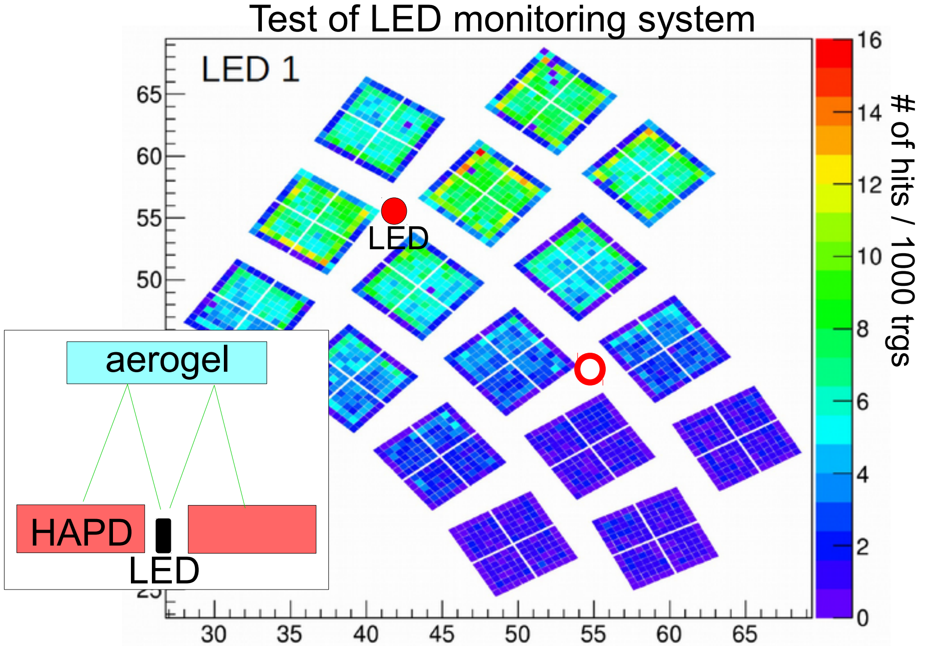




Cosmic ray test

- Using 16 HAPDs and a single aerogel tile (2 layers)
- To confirm HAPD functionality on the structure, with final power supply system and cabling.
- To test DAQ system, data processing software, and develop control software.
- Test of LED monitoring system.
- **First cosmic Cherenkov rings in ARICH were observed in August 2016.**





Summary

- In the Belle2 spectrometer RICH with 2 layer aerogel radiator will be used for PID in the forward endcap.
- As a photon detector HAPD (420) will be used.
- For some HAPDs we observe problematic behavior in magnetic field → successfully mitigated by getter re-activation (improving vacuum quality).
- The mass production of all detector components was completed by the end of 2016 and QA tests were finished.
- Installation of components on structure is ongoing, to be finished in June.
- Cosmic ray test is also ongoing, using part of ARICH and first Cherenkov rings were observed.
- From simulation studies and beamtests we expect excellent performance of ARICH, >95% kaon id. efficiency at low pion fake rates <2%!
- Finally, after full system tests, ARICH is to be installed in Belle2 in September.

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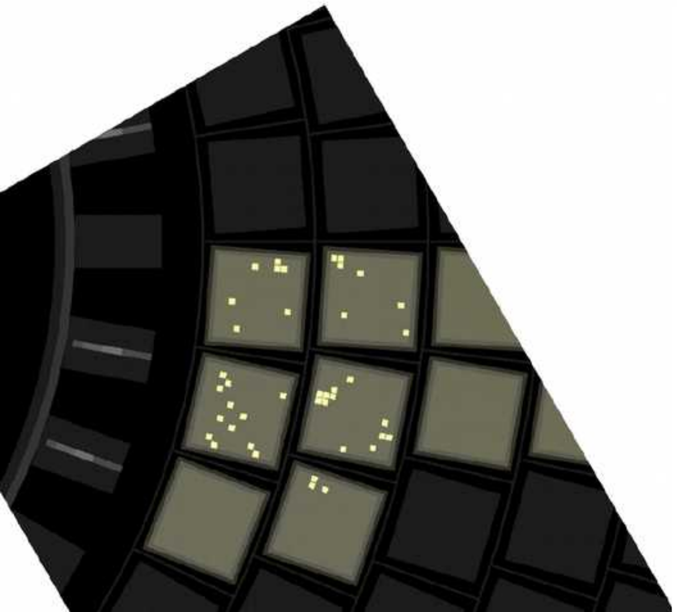
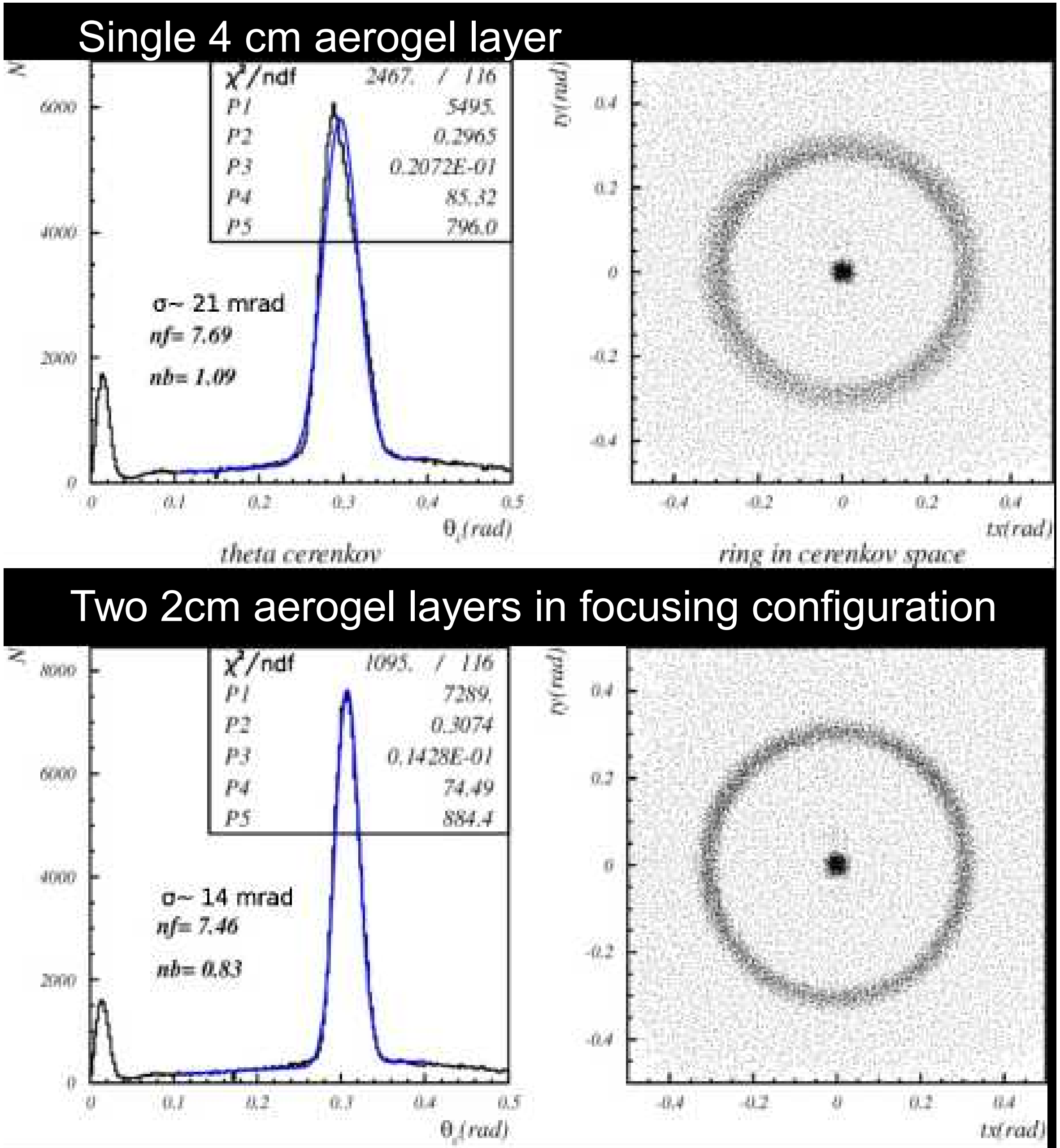


Thank you for your attention!

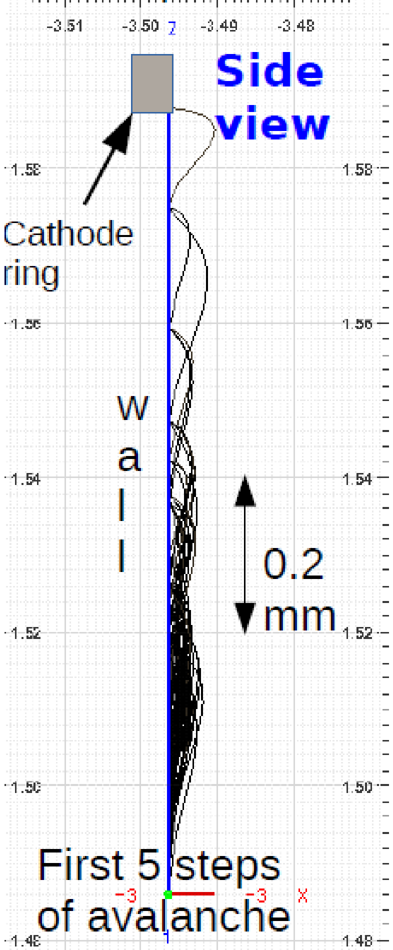
Focusing configuration in beamtest



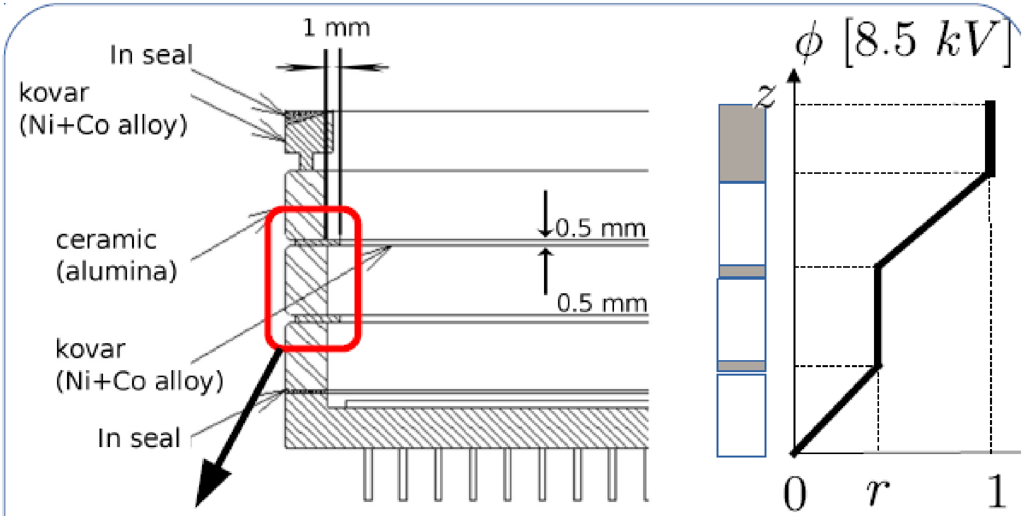
Flashover simulation

- We developed a simple simulation to see if electron avalanche can form on HAPD sidewalls.

Example: $B_z = 0.5\ T,\ HV = 8.5\ kV,\ r = 0.5$

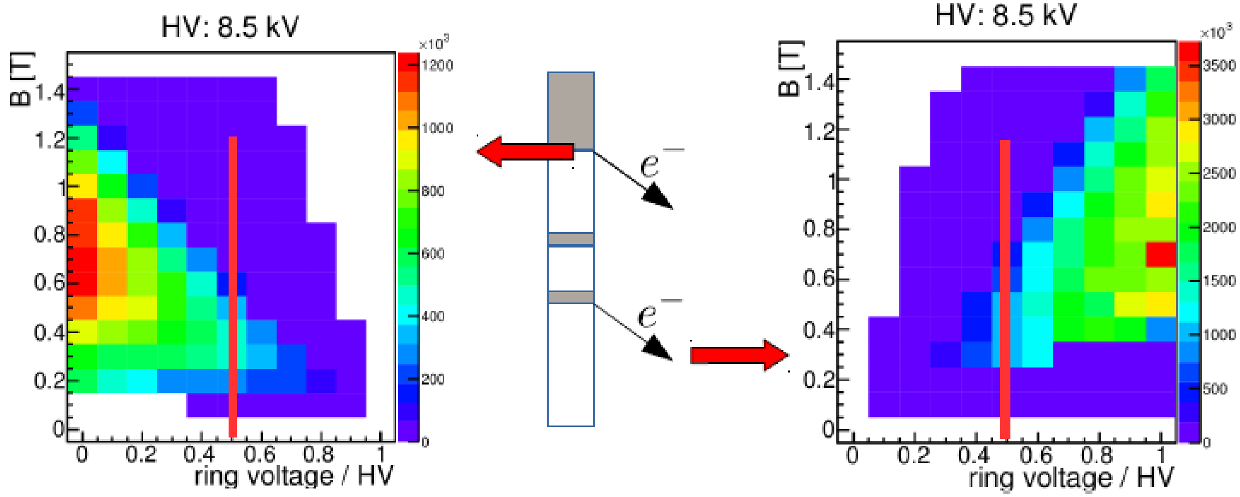


Avalanche can develop!



Metal ring with floating potential

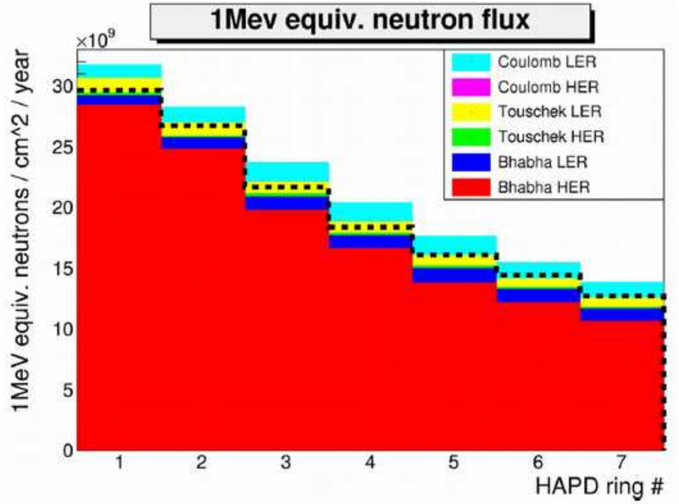
Avalanche development depends on middle ring potential:



Color shows number of electrons in an avalanche

Radiation hardness

- Severe beam-related background is expected in the Belle2 experimental environment.
- Several HAPD irradiation tests performed:
  - In the nuclear reactor → neutrons
  - Irradiation with Co-60 → gamma-rays



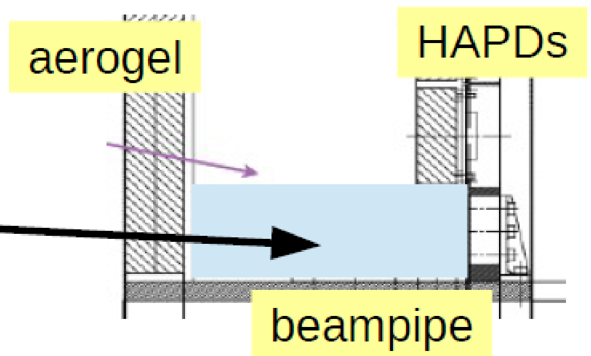
Estimates for 10 years of Belle2 operation :

- neutrons: up to ~ 4×10^{11} n/cm^2 (1MeV eq.) → 4×10^{10} n/cm^2/year
- gammas: up to 1000 Gy (~ 100 Gy for most of HAPDs) → 100 Gy/year

Simulation of the background → shielding of the beam pipe with tungsten

- acceptable gamma radiation dose
- neutrons : Install shielding

  (Polyethylene + 30% Boron) inside the ARICH



R.Pestotnik, Belle2 ARICH@RICH2016