# The Aerogel Ring Image Cherenkov counter for particle identification in the Belle II experiment

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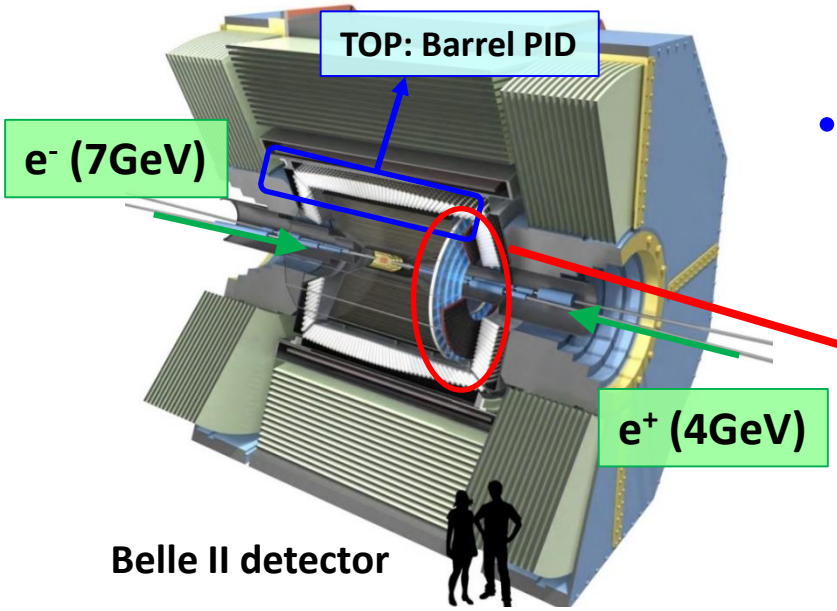
# Introduction

# Belle II ARICH detector

- **Belle II experiment starts in 2018**
  - Search for New Physics in Flavor sector using 50ab$^{-1}$ of B decays
- **Particle identification (PID)** is a major upgrade in the Belle II
  - $K/\pi$ ID is essential for many $B$ decays sensitive to NP models



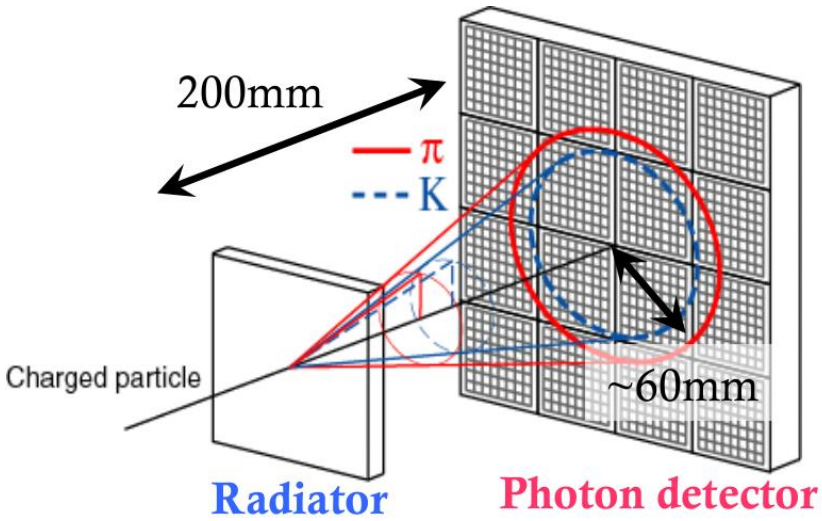

- **Belle :** Aerogel Cherenkov Counter
  - Threshold type PID detector
- **Belle II :** Two new detectors
  - **Ring Imaging Cherenkov detectors**

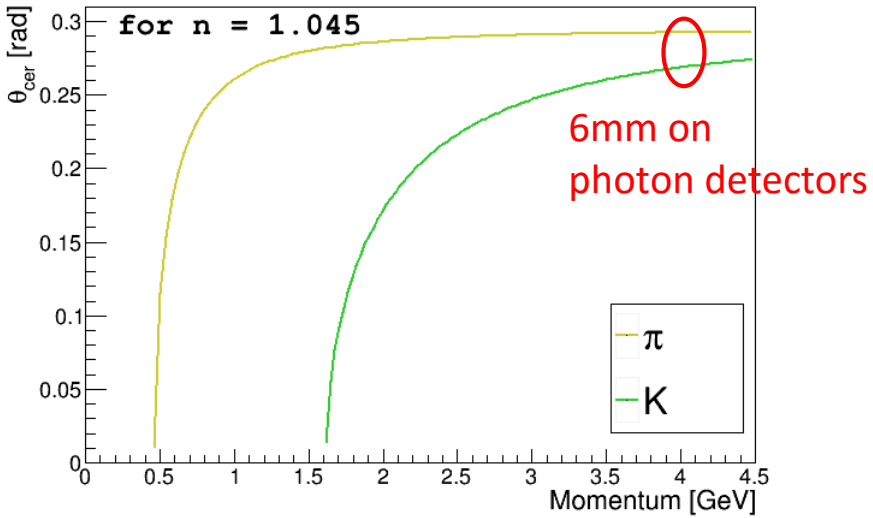
**End-cap PID:**
**Aerogel RICH counter (ARICH)**
- Target range: $0.5 < p < 4$ GeV

# Principle of Aerogel RICH

- Proximity-Focusing Ring Imaging Cherenkov counter using Aerogel
- Particle mass is identified according to emission angle in aerogel radiator
  - $m = \frac{p}{c}\sqrt{n^2\cos^2\theta_c - 1}$ ($n$: refractive index, $p$: particle momentum)
- Cherenkov photons are measured as 2-D ring image
  - **6 mm** difference in $K/\pi$ Cherenkov rings on photo detectors

**Target performance : $K/\pi$ separation at > 4σ C.L. @ $p$ =4 GeV/c**



# Practical requirements

- Several technical challenges for the Belle II operation
  - **Compact detector** in the Belle II end-cap
  - Operation in **high magnetic field of 1.5T**
  - Radiation hardness with **20 times higher γ/n** than Belle I
  - Readout capability for **30 kHz** of maximum trigger rate

⇩ Developed techniques for the ARICH counter

- Aerogel radiator tile with 2 different refractive indexes
- Position sensitive photo detector in magnetic field
- Two level readout electronics to the Belle II DAQ
- Power supply control system with remote access
- LED Light injection system for photon detector monitor

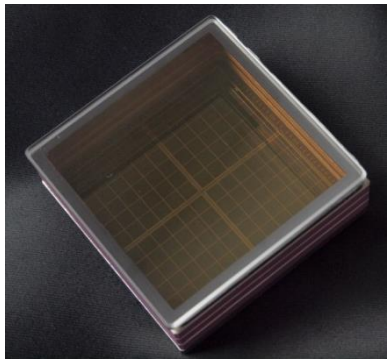
# Detector techniques and construction

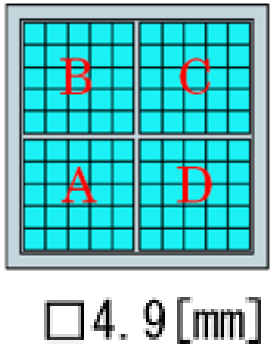
# Photo detector for ARICH

**Hybrid Avalanche Photon Detector (HAPD)**

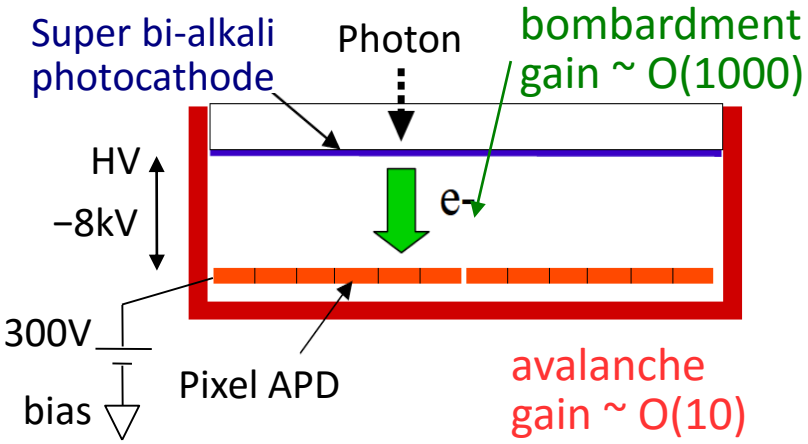
- Developed with Hamamatsu Photonics K.K.
- Good single photoelectron separation

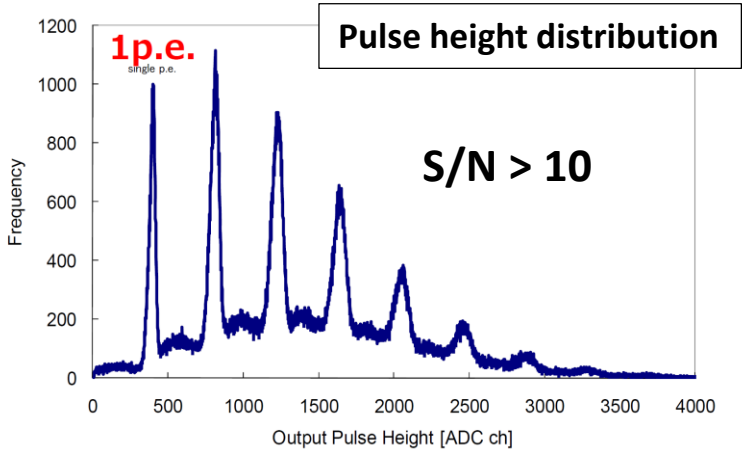
=> 420 HAPDs are ready to be installed






| Parameter | Requirements |
|---|---|
| Size | 72 x 72 mm$^2$ |
| # of pixels | 144 ch (36 x 4 ch) |
| Pixel size | 4.9 x 4.9 mm$^2$ |
| Effective area | 64 % |
| Peak Q.E. | 28 % |
| Dark current | < 1 $\mu$A |
| HV | -8500V |
| Total gain | > 45000 |

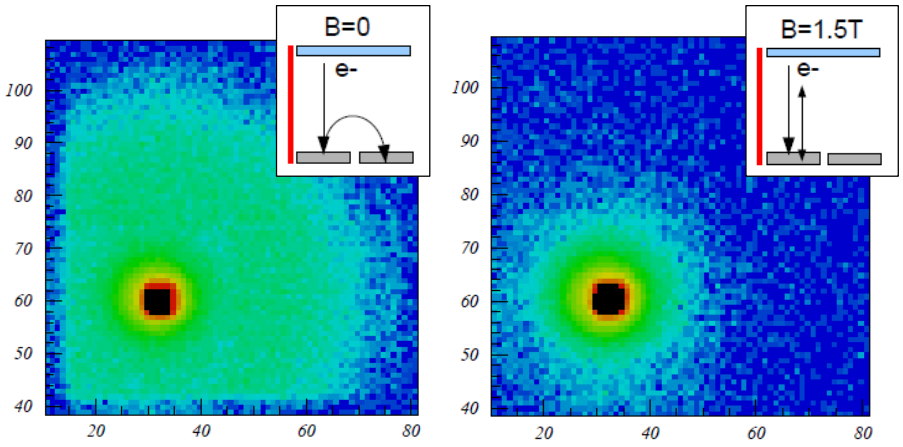


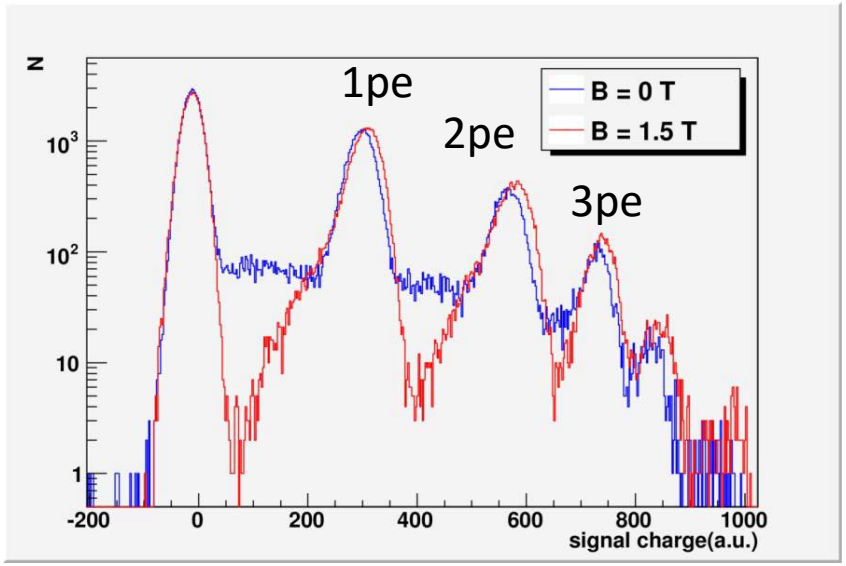



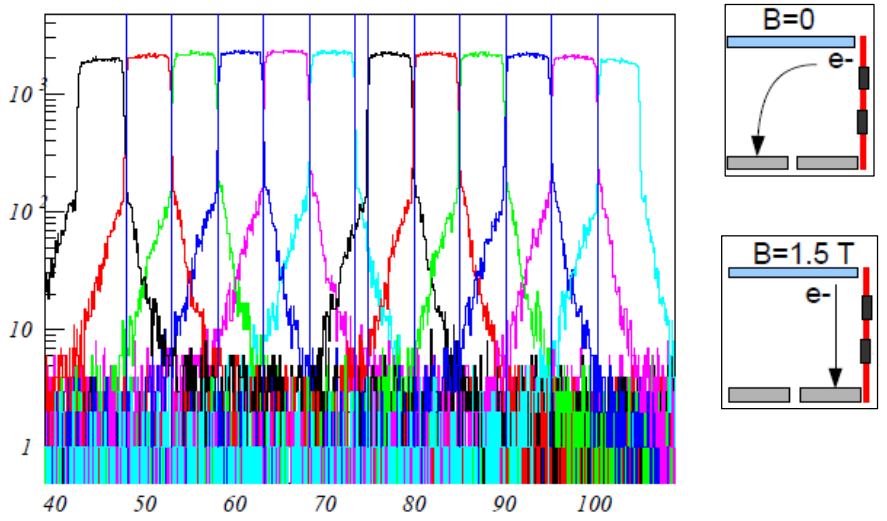
# Performance in 1.5 T magnetic field

**HAPD performance is measured to be totally improved in the magnetic field**

- Reduces p.e. back-scattering cross-talk
- Increases detection efficiency
  - p.e. energy deposited at one place
- Rate non-uniformity due to electric field clearly disappears
- More in poster by K. Ogawa (id:217)



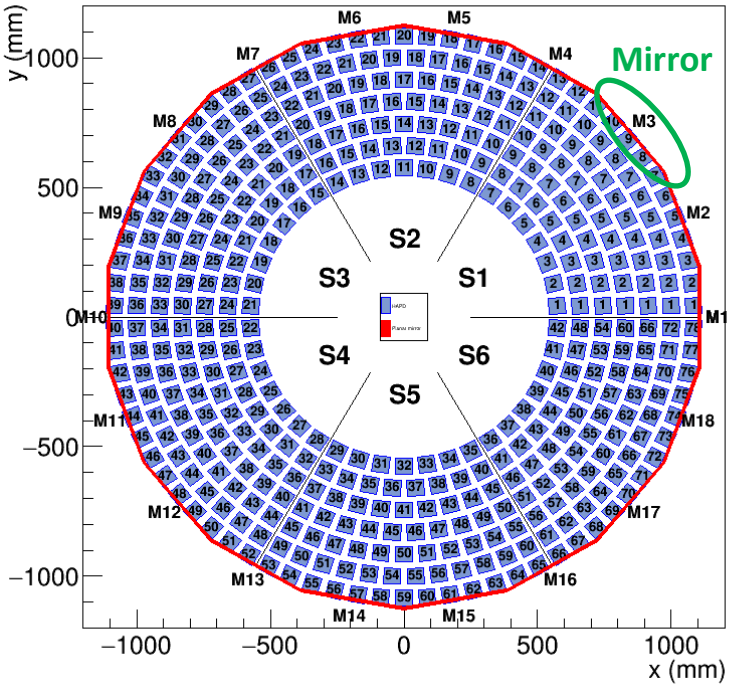



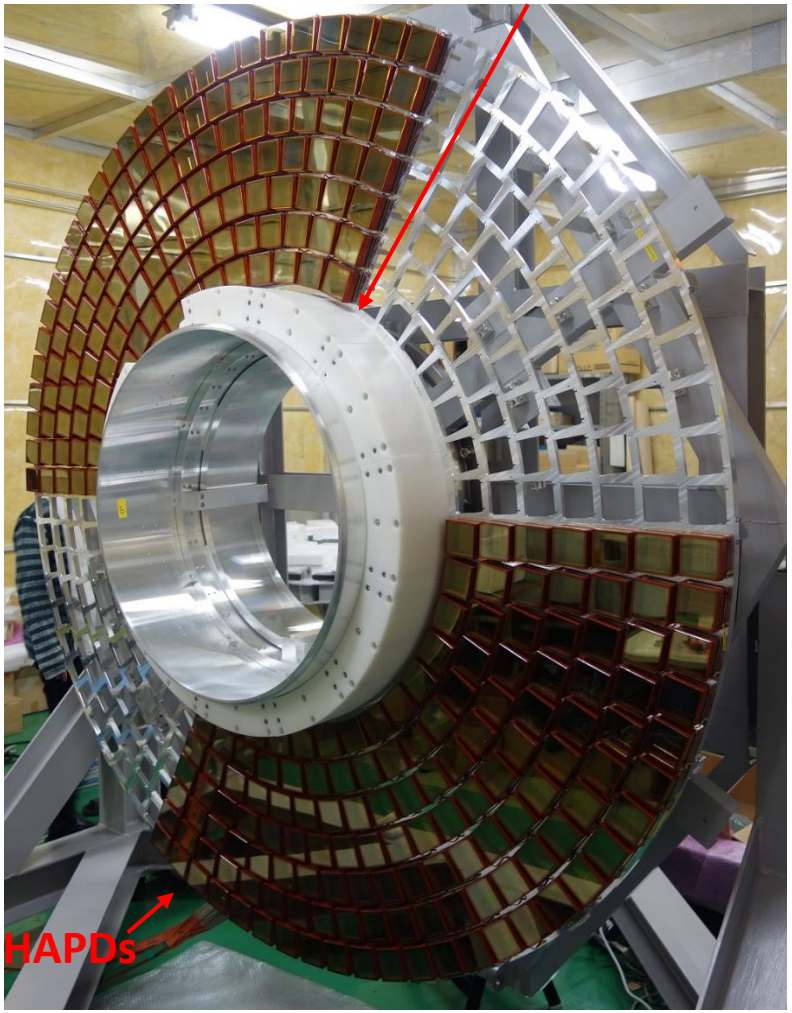



# HAPD support structure

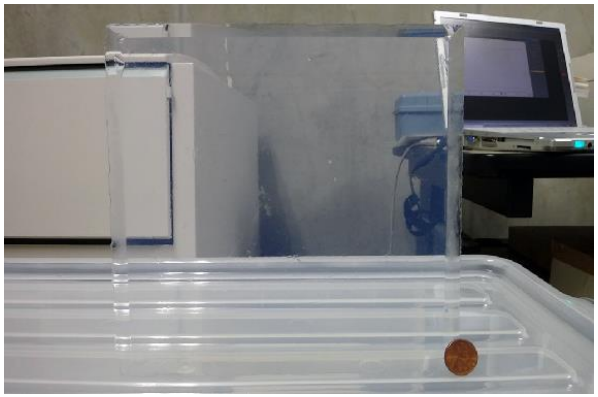
**Aluminum frame for 420 HAPDs**

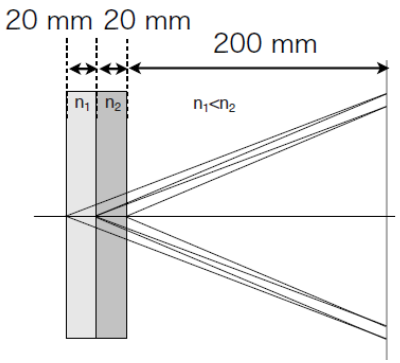
- Mirrors to reflect photons
- Polyethylene shields from neutron
- Installed HAPDs into 4/6 sectors
  - Will be finished in May 2017

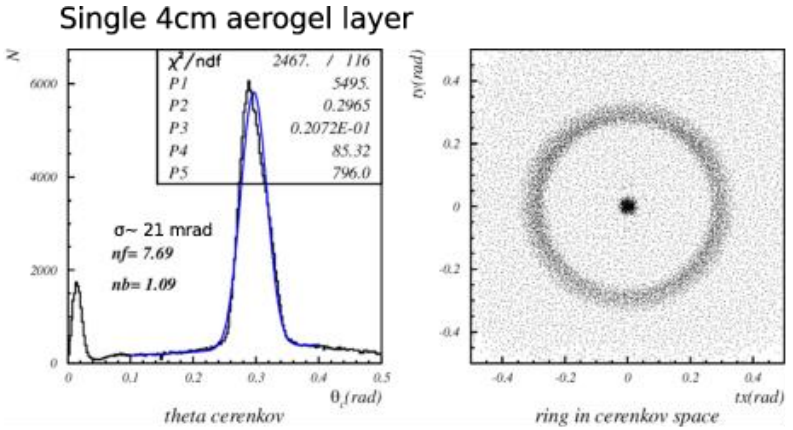


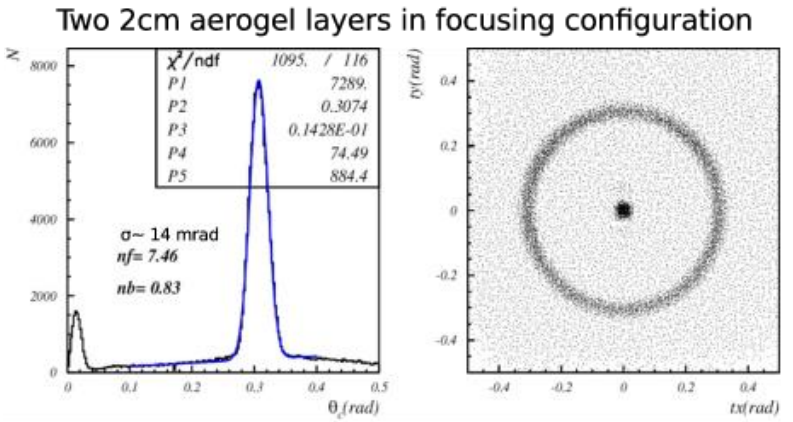



# Silica Aerogel radiator






**New Aerogel with high transparency**

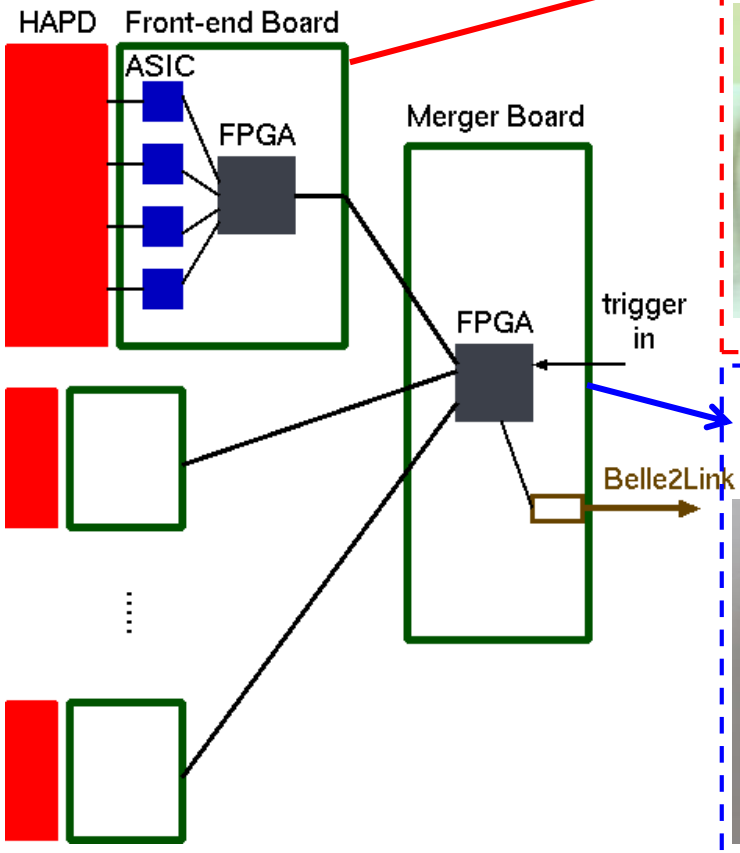
- Transmission length : > 40 mm
- Flexible refractive indexes

- Dual layers to focus ring images
  - Up/down: 1.045/ 1.055 $\pm$ 0.002
- Installation to the ARICH is completed!
  - 248 tiles for 3m$^2$ acceptance
- Details in talk by M. Tabata

# HAPD readout electronics

**Two level of readout electronics located on behind the HAPDs**

- 420 Frontend and 72 merger boards are installed by end of June 2017




**Frontend Board (FEB)**

- 4 custom ASICs on board
  - Comparators to extract photon hits
- Xilinx FPGA (Spartan-6)
  - Converts to bit stream
  - Configuration of ASICs

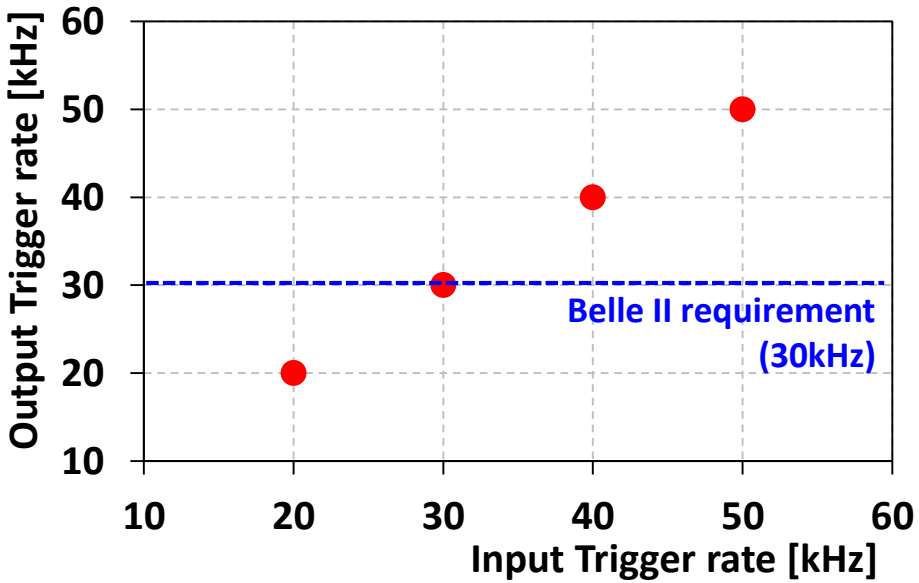
**Merger board (MB)**


- Xilinx FPGA (Vertex-5)
  - Merge 5-6 FEB data
  - Zero suppression
- Interface to Belle II DAQ
  - Belle2Link
  - Trigger Timing system

# Readout performance and slow control

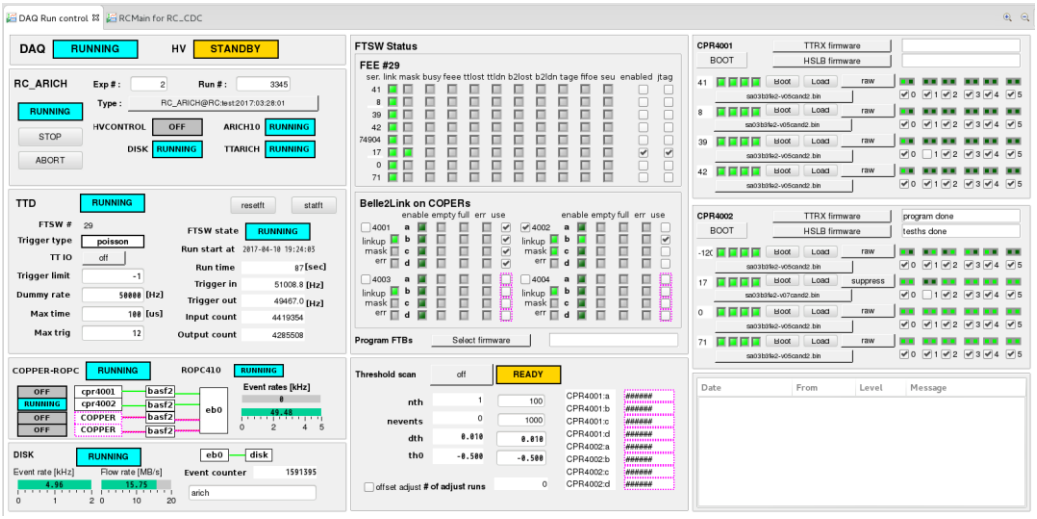
**Readout performance**

- Merger with 6 FEBs to Belle II DAQ
  - With Poisson random triggers
- Achieved Belle II DAQ requirements
  - Running over 30 kHz




**Slow control for the electronics**

- Based on Belle II DAQ software
- Configure parameters on
  - FEB ASICs
  - FEB and MB FPGA
- Monitor temperatures/voltages
- Details in poster by M. Yonenaga (id:58)

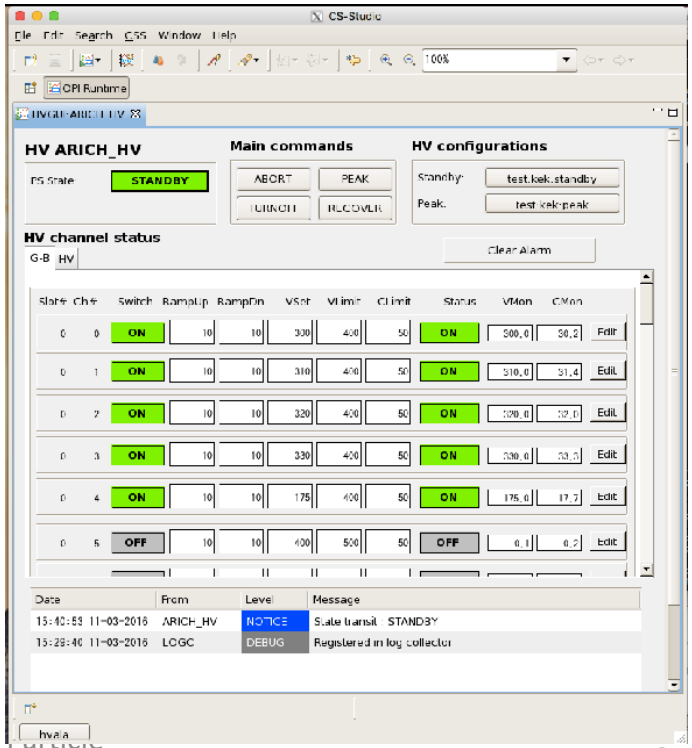


# Power supply

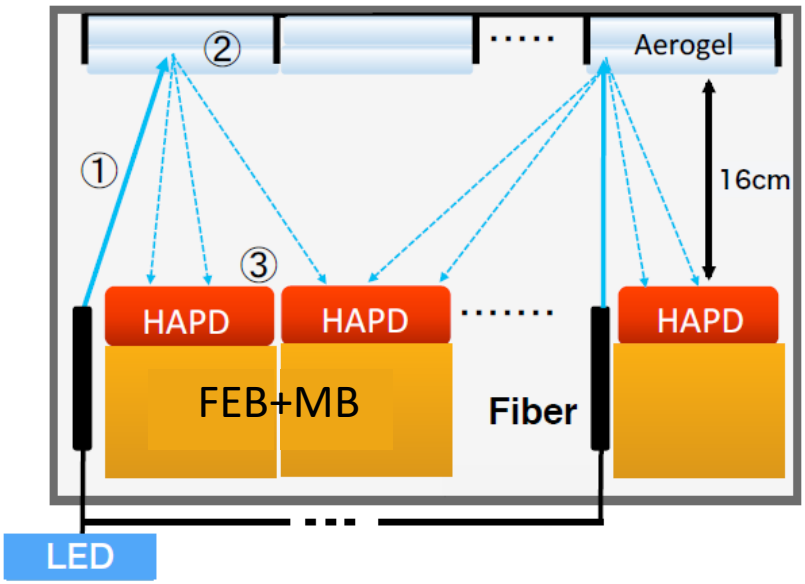
**A power supply system for HAPDs**

- 3 kinds of power inputs for each HAPD
  - HV for bombardment : 8000 V
  - Bias for a APD chip: 350 V
  - Guard for protection: 175 V

  => 6 input channels for a HAPD
- CAEN HV crate and modules
  - HV : A1590N x 27 modules
  - Guard / Bias : A7042P x 45 modules
- Control software based on Belle II DAQ
  - Network based control
  - Software protection of HAPDs
- Details in poster by M. Yonenaga (id:58)



# Light injection monitor system

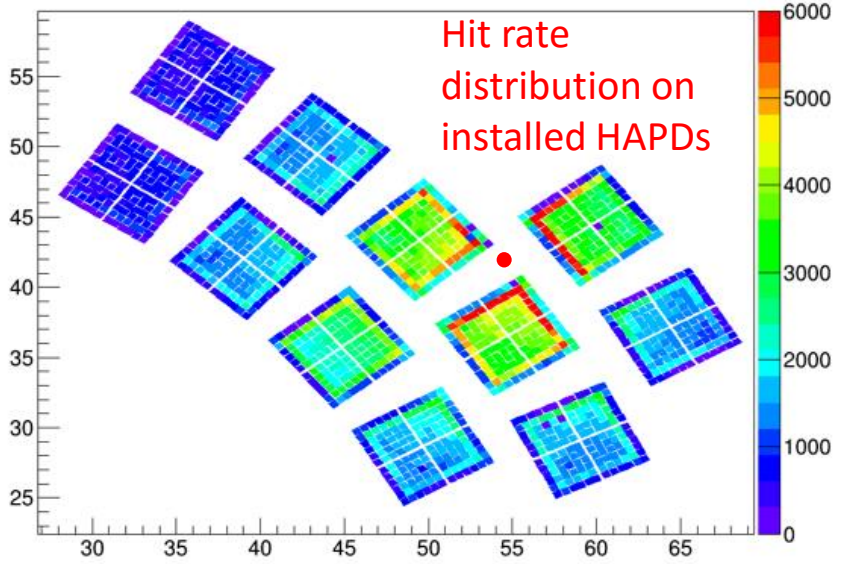



**LED light injection system into ARICH**

- Monitor APD channels
  - 1 p.e. level measurement
- Light diffused from aerogel surfaces
  - Flat intensity on HAPD surfaces
  - 90 injection points with 6 LEDs
- Ready to be installed in coming month

Blue LED

Optical fiber cables
(22 fibers to a LED)

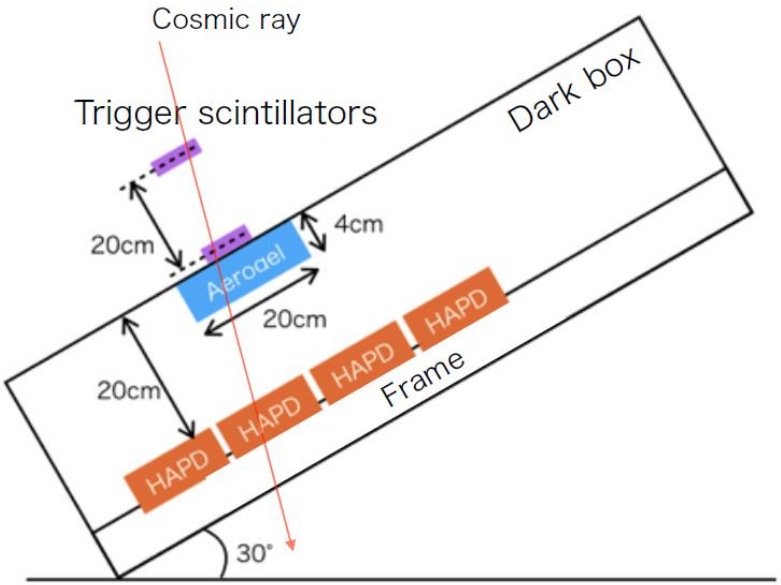


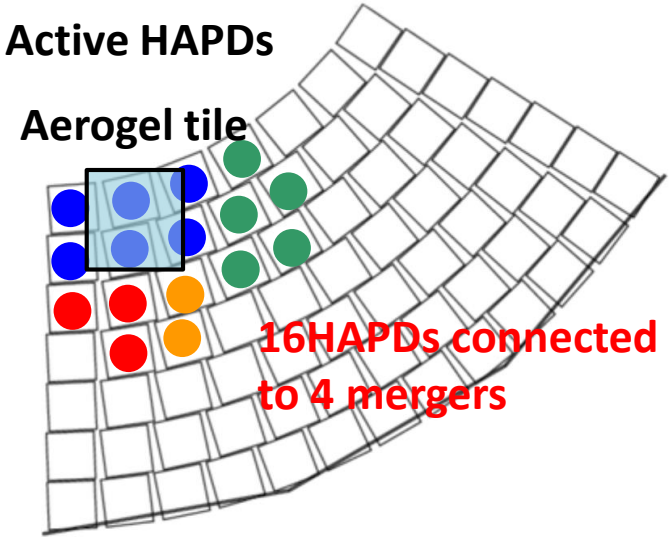
# Cosmic ray test

# Cosmic ray test operation

**Demonstration for ARICH real system**

- Establish full data chain to Belle II DAQ
- Real Cherenkov ring images on HAPDs
- Tentative DAQ with installed modules
  - 16 HAPDs with 4 Mergers
  - Plastic scintillators for trigger

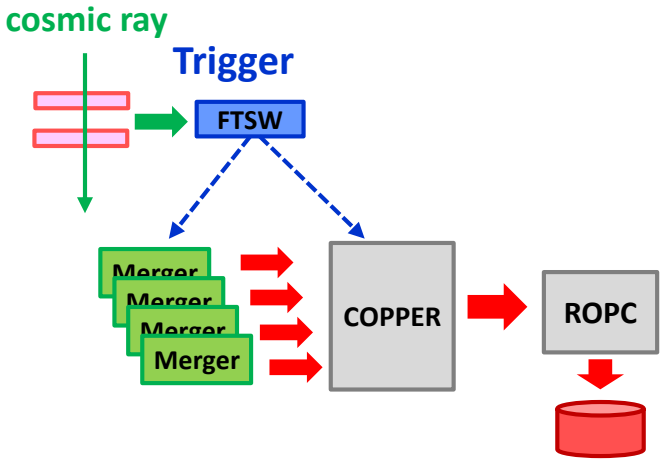


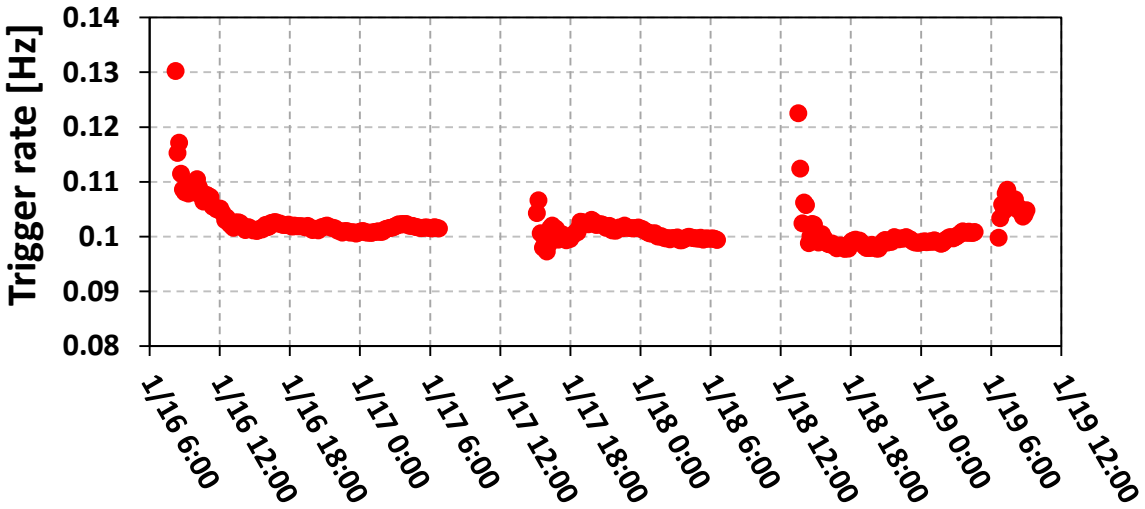
# Cosmic ray DAQ

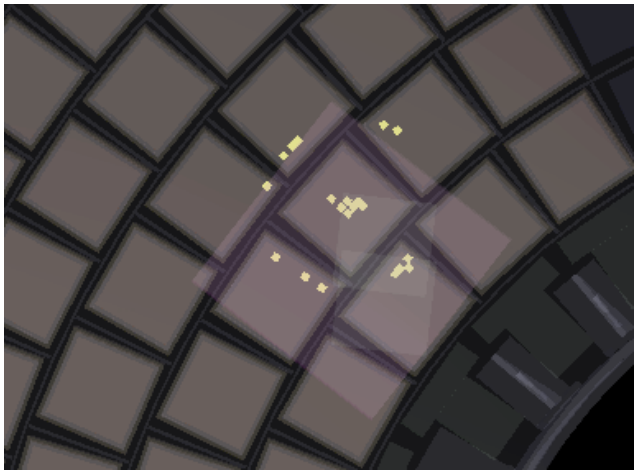
**First combined test with the Belle II DAQ**

- Minimum setup of the Belle II DAQ system
  - 4 Belle2Links on a COPPER board
  - FTSW board for Trigger timing signals
- Stability : Run > 12 hours with 0.1 Hz
- Synchronization : clear signals of ring images
  - The electronics were really synchronized




**ARICH smoothly worked with the Belle II DAQ**



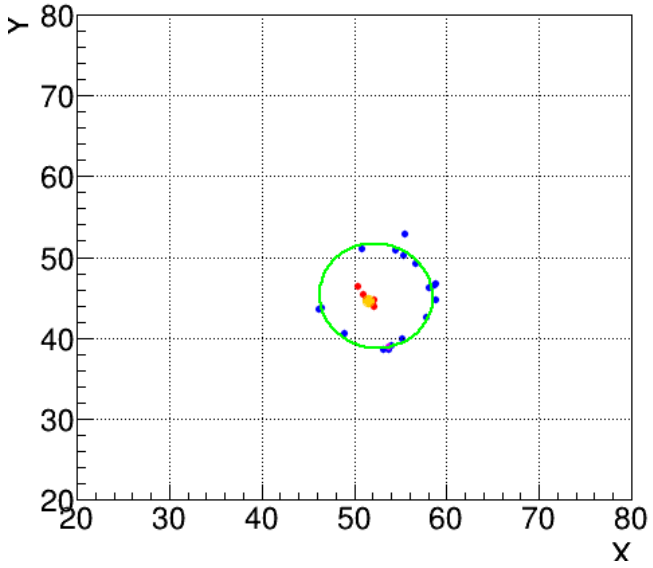
# Cherenkov rings from cosmic rays

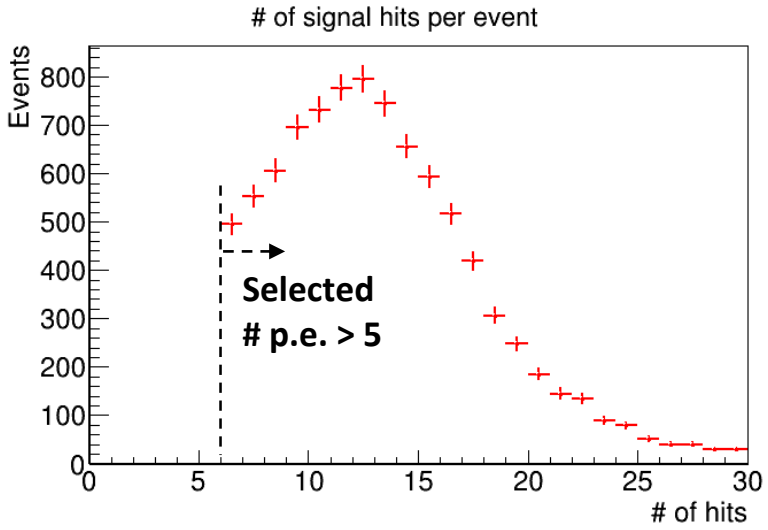
**Extraction of Cherenkov ring images**

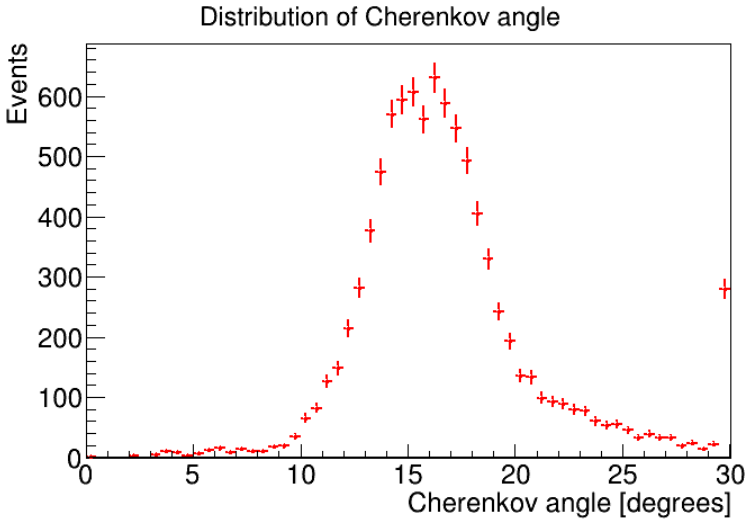
- Fit hit patterns without tracking info.
  - Extract entry points and directions
- Obtained Cherenkov related parameters:
  - # of observed p.e. : **13 p.e.**
  - Cherenkov angle: **17 degrees**

  => **Consistent with $\mu$ @ 0.5 - 4GeV/c**

**Successful operation of ARICH system**



# Summary

- Belle II experiment starts in 2018 to search for New Physics
- The ARICH counter is a major upgrade for the Belle II PID
- Several techniques were developed to observe Cherenkov rings
  - Silica Aerogel radiator and HAPD are key components for ARICH
- Cosmic ray test with partially installed modules was successful
  - Both of the ARICH detector and electronics worked as expected
- Construction of the ARICH will be finished by end of summer 2017

**Related talks and posters:**

- M. Tabata , "Assembly of a Silica Aerogel Radiator Module for the Belle II ARICH System"
- M. Yonenaga, "Development of the slow control system for the Belle II ARICH counter", Poster
- K. Ogawa et al, "Behavior of 144ch HAPDs for the Belle II Aerogel RICH in the magnetic field", Poster