First Experience with the Belle II Aerogel RICH Detector

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Motivation

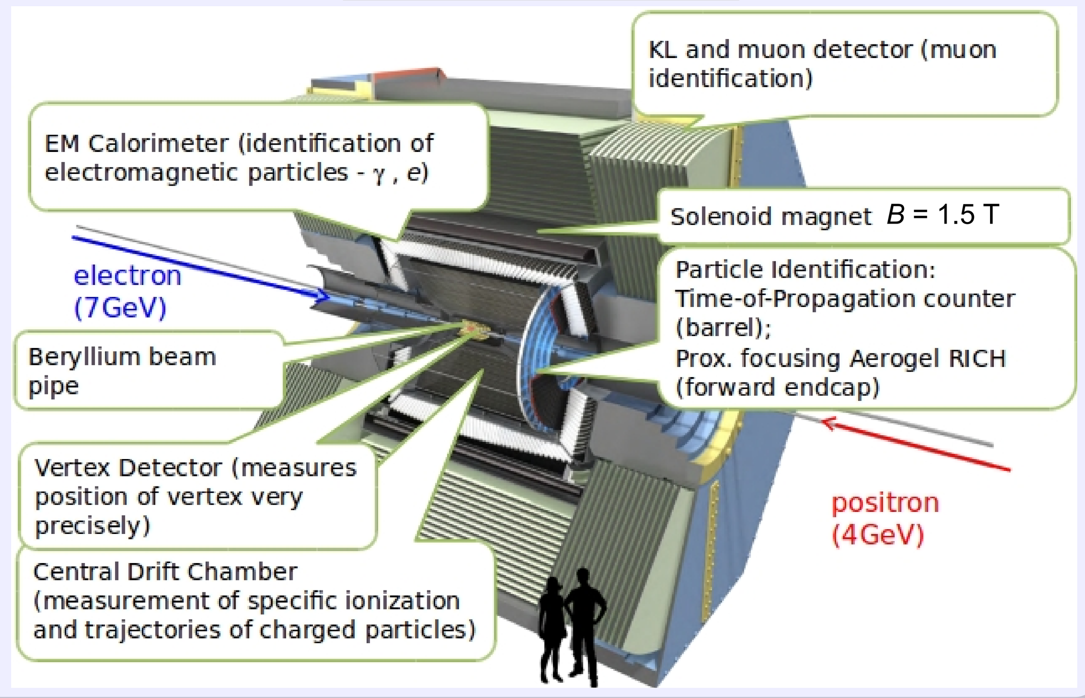
- Belle II experiment is successor of successful Belle experiment
- Looking for physics beyond Standard Model
- Precise measurements of rare B and D meson and τ lepton decays
- The goal is to collect 50-times more data; i.e. 50 ab^{-1}

SuperKEKB Collider

- Asymmetrical cicrcular collider of electrons and positrons at KEK (Tsukuba, Japan), operating at the energy of Υ(4S) resonance:
  $e^+ e^- \rightarrow \Upsilon(4S) \rightarrow B \bar{B}$
- The target electron and positron beam energies are 7.0 GeV and 4.0 GeV, respectively
- The time evolution of decays is calculated from positions of particles' vertices
- **First collisions on 26th April 2018 (at 0:38am, GMT+09:00)**

Belle II Experiment

Belle II Detector



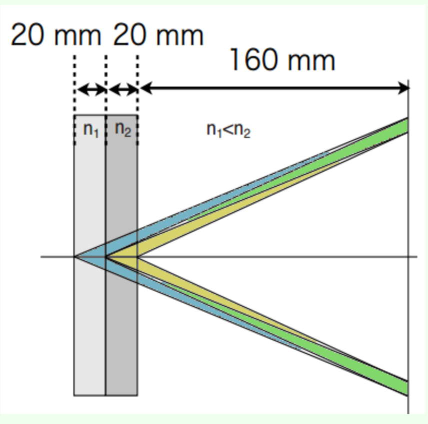
Particle Identification with ARICH Detector

- Aerogel Ring-Imaging Cherenkov Detector (ARICH) provides particle identification in forward endcap of Belle II
- The main purpose is to separate charged kaons from pions for momenta between 0.5 GeV/c and 4.0 GeV/c at the confidence level > 4 σ
- It also discriminates between pions, muons and electrons in region below 1 GeV/c
- Charged particles are detected through Cherenkov radiation
  - Fast charged particle emits photons in aerogel radiator
  - The light cone is propagated in 16 cm of empty space
  - Photons are detected at the sensor plane, where they form a ring shape
  - Particles are identified using maximum likelihood method

Aerogel Ring-Imaging Cherenkov Detector (ARICH)

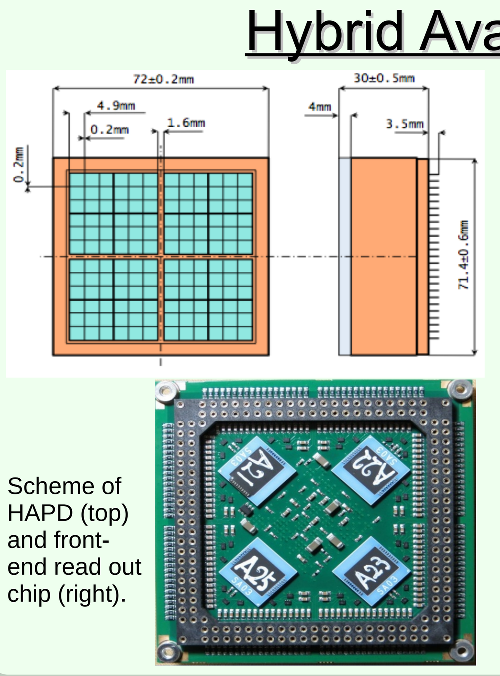
Detector Design

- Main detector parts are: radiator, expansion volume, photodetectors, read-out electronics, reflective mirrors at the edges (to increase the detector geometrical acceptance)



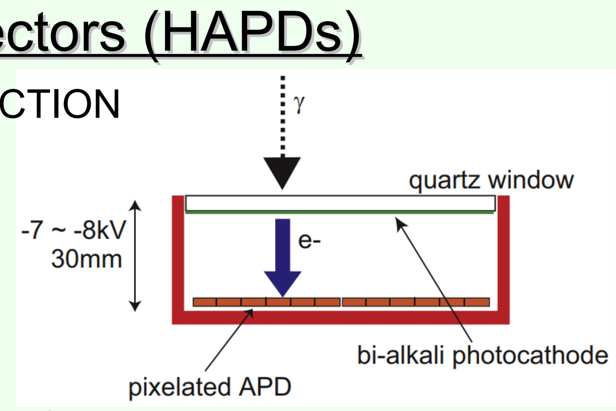
- The double layer aerogel radiator (n_1 = 1.045, n_2 = 1.055) in a focusing configuration allows to collect enough photons without degrading the resolution

Hybrid Avalanche Photo Detectors (HAPDs)



Scheme of HAPD (top) and front-end read out chip (right).

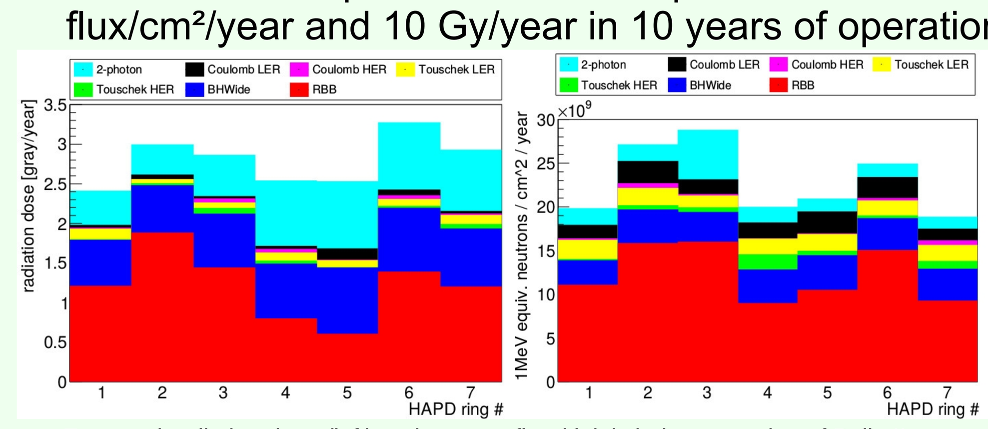
SINGLE PHOTON DETECTION



- Photoelectron is emitted in photocathode
- Electron is accelerated in high electric field
- Electron-hole pairs are generated in APD (signal amplification ~1700)
- Nominal bias voltages multiply charge by factor of 40
- Charge is collected at the back of HAPD
- Analog signal is amplified, shaped and digitized in ASIC
- Digital signal is processed in FPGA, used for communication with data acquisition system

High Irradiation Resistivity

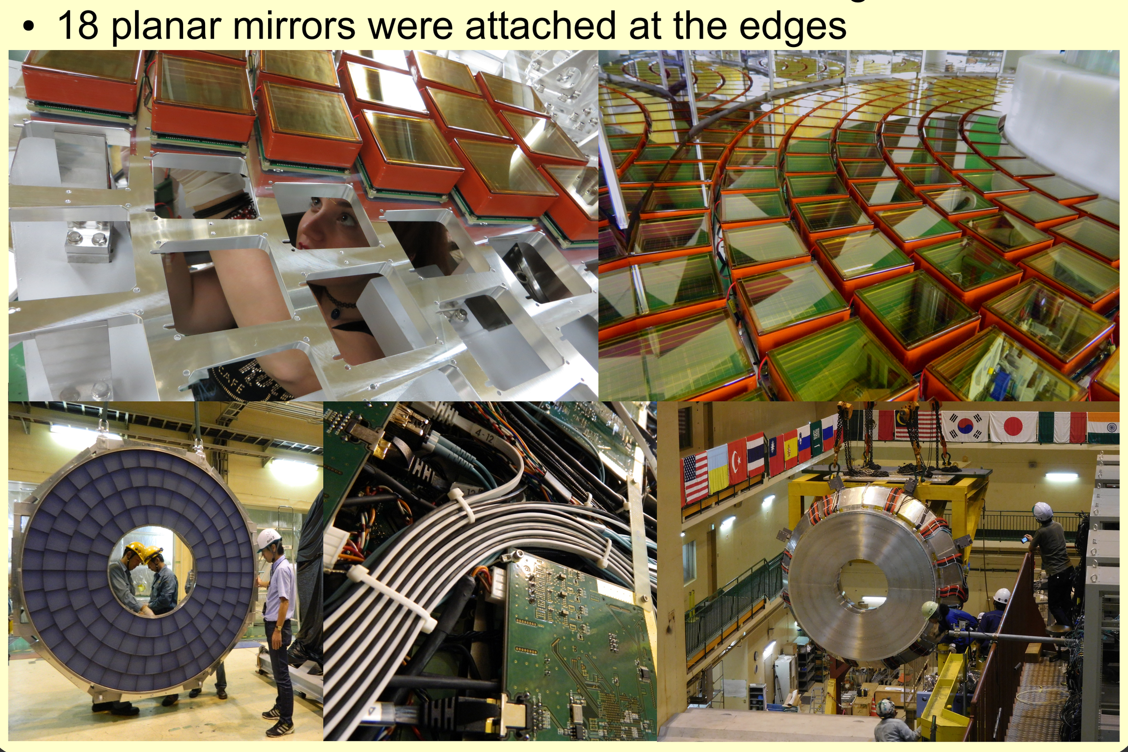
- Requirements for photo sensors:
  - Efficient single photon detection in high magnetic field of 1.5 T
  - Resistant to high neutron and γ irradiation → HAPDs can withstand up to 10^{10} 1 MeV eq. neutron flux/cm²/year and 10 Gy/year in 10 years of operation



Expected radiation dose (left) and neutron flux (right) during operation of Belle II.

ARICH Assemby

- The assembly of ARICH was carried out in 2016 and 2017
- 248 fragile aerogel tiles were installed in 4 concentric rings
- 420 HAPDs were attached in 7 concentric rings
- 18 planar mirrors were attached at the edges

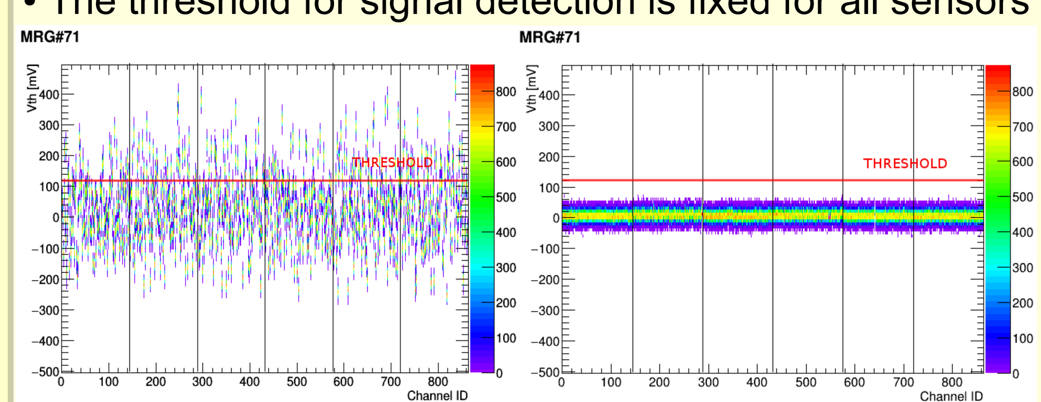


Hardware Calibration

- 3 main measurements:
  - Offset calibration of ASIC channels
  - Signal gain of HAPDs
  - Activity of HAPD/FEB channels

Electronics Channels Offset Calibration

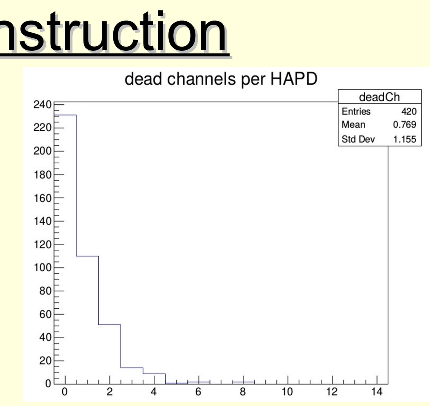
- The electronic noise has different value for each channel
- The main values of noise for all channels are calibrated to the target value, using the offset parameters of read-out electronics
- The threshold for signal detection is fixed for all sensors



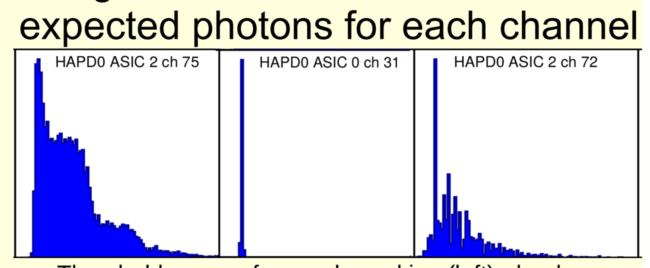
Threshold scans for all channels on 6 sensors before (left) and after (right) offset calibration.

Channels, Used in Reconstruction

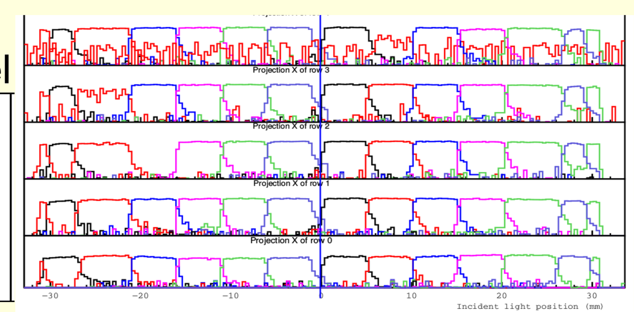
- Permanently or temporarily inactive channels have to excluded from the reconstruction
- The temporarily inactive channels come from the modules that are turned off
- The permanently problematic channels (dead or noisy) were determined from the laser scans of all modules
- During the operation of Belle II, the list of unused channels will be updated, using the ratio of detected and expected photons for each channel



Dead channels are randomly distributed over the sensor plane. The fraction is 0.5 %.



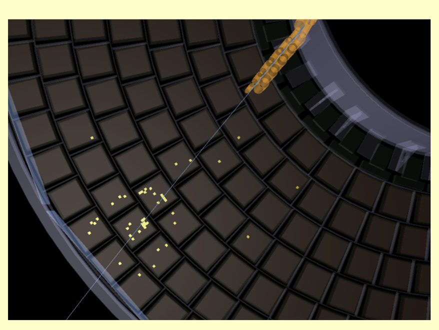
Threshold scans of properly working (left), dead (middle) and noisy (right) channels.



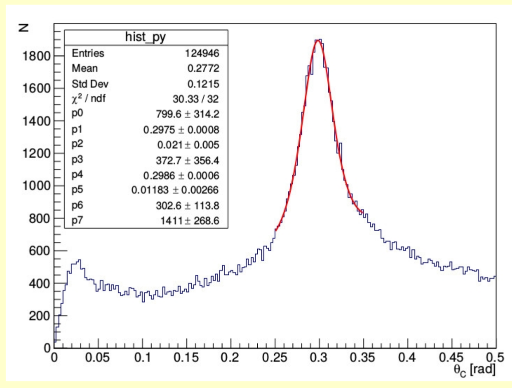
The response of noisy (row 4) and dead (row 2) channels during laser scan.

Commissioning with Cosmic Rays and Beam Collision Data

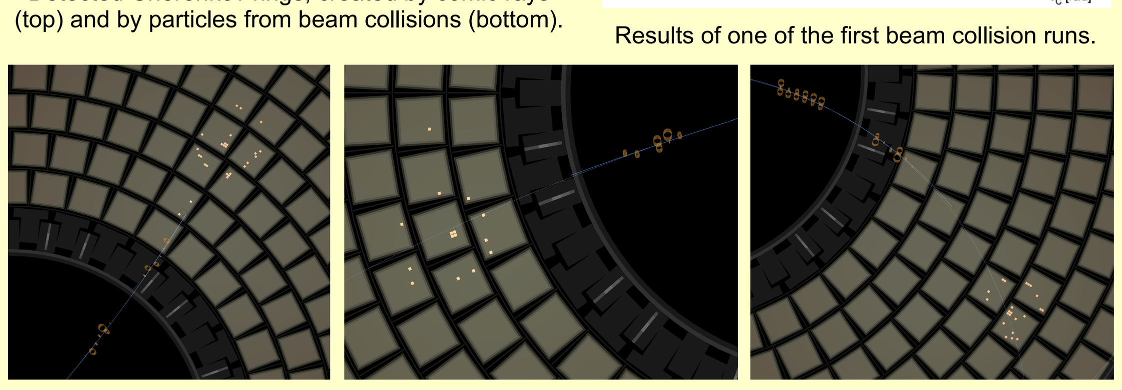
- Two months of commissioning with cosmic rays → Electronics was calibrated, temperature effects were studied
- Cosmics and collisions: Cherenkov rings were observed
- A clear Cherenkov angle peak was seen at ~0.3 rad



Detected Cherenkov rings, created by comic rays (top) and by particles from beam collisions (bottom).



Results of one of the first beam collision runs.



Calibration of Kaon Identification Efficiency

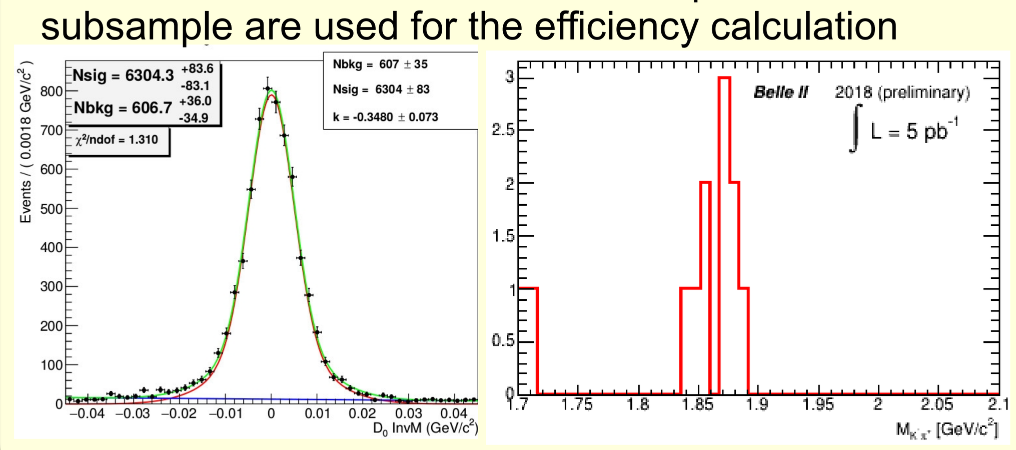
Control Decay Channel

- Control channels, where identity of charged particles can be determined independently from the kinematics
- The decay channel[1]: $D^{+*} \rightarrow D_0(\rightarrow K^- \pi^+)\ \pi^+_s$
- The charge of the slow pion π^+_s is obtained using the information from the tracking system
- The charged particle from the decay of D_0 hits ARICH (PID detector)
- The charged particle is identified as kaon or pion based on the charge

[1] charge conjugated modes are implied

Identification Efficiency Calculation

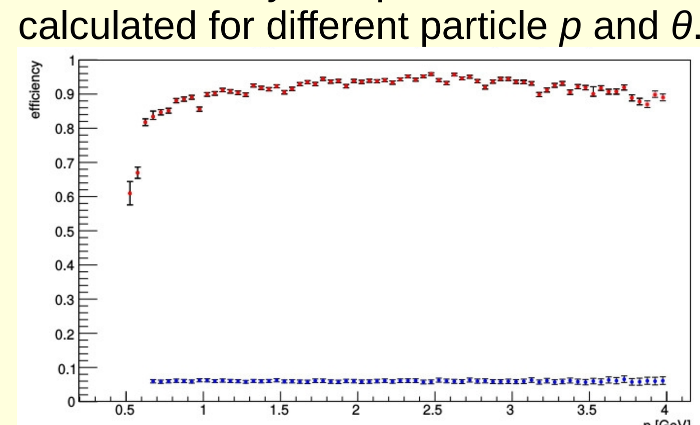
- The source particles are D^{+*} from $c\bar{c}$ continuum
- Efficiency is calculated from number of signal events w/ and w/o PID cut: $\varepsilon_{K/\pi \rightarrow K} = N_{sig,\ pass\ cut} / N_{sig,\ all}$
- Sample: D_0 invariant mass → It is fitted with linear function (for bkg) and 1 (or 2) Gaussians for signal
- The signal shape parameters are fixed used for the fit of subsample of the events that pass PID cut
- The numbers of events in whole sample and subsample are used for the efficiency calculation



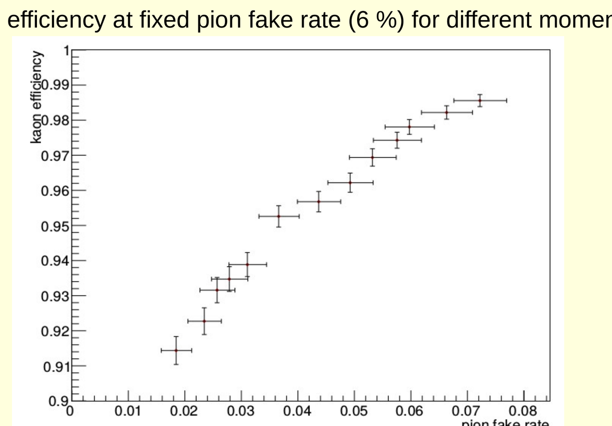
Left: Example of M(D₀)-m(D₀) mass fit with PID cut applied.
Right: The measured D₀ mass from first reconstructed D* decays from beam collisions.

Simulation Results

Kaon efficiency and pion fake rate are calculated for different particle p and θ.



Kaon efficiency at fixed pion fake rate (6 %) for different momenta.



Kaon efficiency with respect to the pion fake rate for p = (3.0, 3.5) GeV and θ =(0.8, 0.96).

Towards Physics Runs

- The commissioning phase of Belle II detector will be finished in July 2018
- The ARICH kaon identification efficiency and alignment studies will be done using the collision data, collected in next couple of months
- The list of dead channels will be prepared with respect to the measurements
- During physics runs the electronics and sensors will be calibrated on daily basis
- The $D^{+*} \rightarrow D_0(\rightarrow K^- \pi^+)\ \pi^+_s$ (and it's charge conjugate) decay channel will be used as one of the control channels for kaon identification efficiency for physics analyses
- The first physics runs are planned for February 2019