First Experience with the Belle II Aerogel RICH Detector

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SuperKEKB Collider

- Asymmetrical circular collider of electrons and positrons at KEK (Takuba, Japan), operating at the energy of \( \gamma (4S) \) resonance: 
  \[ e^+ e^- \rightarrow \gamma (4S) \rightarrow B \bar{B} \]
- The target kaon and positron beam energies are 7.0 GeV and 4.0 GeV, respectively
- The time evolution of decay is calculated from positions of particles’ vertices
- First collisions on 26th April 2018 (at 0:38am, GMT+09:00)

Belle II Experiment

- 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 (\( n_a = 1.045 \), \( n_r = 1.055 \)) in a focusing configuration allows to collect enough photons without degrading the resolution

Aerogel Ring-Imaging Cherenkov Detector (ARICH)

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

Hybrid Avalanche Photo Detectors (HAPDs)

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

Electronics Channels Offset Calibration

- The electronics 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

Hardware Calibration

- Channels, Used in Reconstruction
  - Permanently or temporarily inactive channels have to be 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

Simulation Results

- Kaon efficiency and pion fake rate are calculated for different particle \( p \) and \( \theta \)

Towards Physics Runs

- The commissioning phase of Belle II detector will be finished in July 2018
- The ARICH kaon identification and 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\(^{*+}\) → D\(_0\) (K\(^-\)) \( \pi^+ \) channel is used as one of the control channels for kaon identification efficiency for physics analyses
- The first physics runs are planned for February 2019

Detector Design

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

ARICH Assembly

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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 \( \approx 0.3 \, \text{rad} \)

Control Decay Channel

- Control channels, where identity of charged particles can be determined independently from the kinematics
  - The decay channel: 
    \[ D^{*+} \rightarrow D_0 (K^-) \pi^+ \]
  - The charge of the slow pion \( \pi^- \) 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

Calibration of Kaon Identification Efficiency

- The source particles are D\(^{*+}\) from c\(\bar{c}\) continuum
- Efficiency is calculated from number of signal events \( w \) and w/o PID cut: 
  \[ \text{PID cut: } \theta \text{ or } \phi \text{ or } \theta \wedge \phi \text{ cut} \]
- Sample: \( D_0 \) invariant mass → It is fitted with linear function (for bigk) 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

Identification Efficiency Calculation

- The kaon efficiency for each of the cuts
  - Kaon efficiency and pion fake rate are calculated for different particle \( p \) and \( \theta \)

High Irradiation Resistivity

- Requirements for photo sensors:
  - Efficient single photon detection in high magnetic field of 1.5 T
  - Resistant to high neutron and gamma irradiation → HAPDs can withstand up to \( 1 \times 10^8 \) MeV neutron flux/cm\(^2\)/year and 10 Gy/year in 10 years of operation

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