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Slow control of the Belle II Aerogel Ring Imaging detector

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ABSTRACT

Since 2018, an Proximity Focusing Aerogel Ring Imaging Detector (ARICH) efficiently separates hadrons in the forward end-cap of the Belle II spectrometer. Cherenkov photons emitted in the double-layer aerogel radiator are expanded in 16-cm space and detected on the photon detector, which consists of 420 hybrid avalanche photodiodes and rear readout electronics operating in threshold mode. Each of the sensors requires six different high voltages and a supply of four low voltages for the electronics. Because of the power dissipation, the system also includes a cooling system in which cold water circulates through the Al tubes thermally connected to the readout electronics. Reliable control of supply voltages and monitoring of environmental data and sensor status ensure stable operation of the ARICH detector and early response to sudden changes in current, single event disturbances, overheating, and other faults. In this paper, we introduce the ARICH's slow control system and the data quality monitor used to track performance.

1. Introduction

The Belle II experiment is dedicated to precision measurements of rare decays of B and D mesons and τ leptons [1]. Belle II began data collection in 2019 and has collected 420 fb^{-1} of data to date, mainly at the center-of-mass energy of 10.58 GeV,v which corresponds to the mass of the Υ(4S) resonance. Two particle identification systems are used in the Belle II spectrometer to identify hadron decay products throughout the kinematic range of the experiment, from 0.5 to 4.0 GeV/c. The time-of-propagation detector is installed in the barrel part, while a focusing ring-imaging Cherenkov counter (RICH) Counter with an aerogel radiator is installed in the 28-cm-wide space between the central drift chamber and the electromagnetic calorimeter in the front end cap of the spectrometer. The Cherenkov photons from the aerogel

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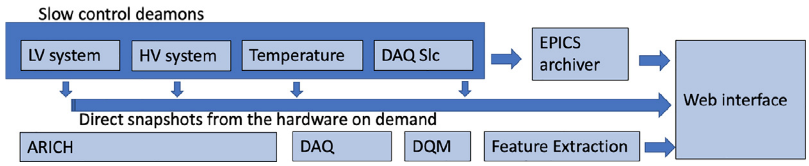

Fig. 1. ARICH slow control and monitoring tools.

radiator are detected by 420 144-channel hybrid avalanche photodetector (HAPD) [2], arranged in seven concentric rings. Each of the sensors is equipped with a front-end electronic readout board and a HV divider board on the back [3]. The operation of the electronics and the sensors is controlled by a special slow control system. Each of the HAPD sensors requires six high voltages for its operation: the cathode high voltage of the order of 6–8 kV, four reverse bias voltages for each of the segmented avalanche photodiodes, and a guard ring voltage of about 300 V. The sensor signals are first amplified and digitized in the ASIC. Chip control and data acquisition are handled by the on-board Xilinx Spartan-6 FPGA. Up to six front-end boards are controlled by a merger board that distributes the experiment clock, controls board settings, single event upsets due to neutron sensitivity [4] and transmits data to the experiment's common data acquisition system. All of these boards require different low voltages for their operation.

2. System description

The Belle II ARICH slow control system consists of four subsystems: The high voltage system is responsible for controlling and monitoring the HAPD high voltages, the low voltage control system is used to control and monitor the voltage supplies to the readout electronics, the environmental monitor is used to monitor the temperature of the detector, and the front-end board control system is responsible for uploading firmware, setting parameters of the readout chip, controlling temperature, and controlling the single event upset mitigation controller [4].

The daemons communicate with other processes using the common Belle II Belle2Link [5] and Networks shared memory 2 protocol [6] and accept requests to turn supply channels on and off and adjust hardware settings. The configuration setting is loaded from a common Belle II database, allowing flexible and controlled change of values (see Fig. 1). The slow system is also responsible for continuous monitoring of voltage and current values as well as other detector parameters – e.g. temperatures and number of hits. The values are regularly stored in the EPICS Archiver database and allow monitoring of each bias channel. Note that only values that change significantly from the previous reading are saved, reducing the need to store large amounts of data due to more than 15,000 of monitoring variables. The slow control graphical user interfaces allows to visualize the current status and history of the slow control variables in an organized way. In Fig. 2 the main mapping window is shown, which allows to visualize the connections between different detector parts. This feature allows to identify locations of malfunctioning parts and was extremely important during the installation and commissioning phase.

2.1. High voltage system

The high voltage system consists of 8 CAEN SY4527 crates, 45 CAEN A7042P 48 channel 500 V common floating return boards supplying four bias voltages and one guard voltage for each of the 420 HAPDs, and 28 CAEN A1590 - AG590 16ch 9 kV boards supplying 420 high voltages. The system is controlled by HV daemons that communicate with the hardware using the CAEN HV wrapper library. To minimize the possibility of discharges, the operation of all 6 HV channels supplying a given HAPD should be synchronous and follow well-defined transitions between different system states. Hardware interlocks ensure the safe operation of the system. In addition, more than 10,000 different parameters are read from the high voltage boards every ten seconds and recorded in the archiver database. For example, the history of bias currents allows to estimate the background irradiation levels on different parts of a detector (Fig. 3).

2.2. Low voltage system

The low-voltage system consists of two Wiener MPOD systems and 12 low-voltage Wiener MPV8008LI modules (0–8 V/5 A; 8 channels; 40W/ch; floating; <2mVp-p ripple). The power supply modules provide +3.8 V, +2V and −2V to the 420 front-end cards and +1.5 V and +3.8 V to the 72 merger cards responsible for data concentration and communication with the usual Belle II acquisition cards.

The system is much simpler than the high voltage one as a common voltage is distributed to several front-end cards and mergers.

2.3. Data quality monitors

Additional processes continuously extract important parameters from the reconstruction running online on a fraction of data, e.g., Cherenkov angle, number of hits per track, number of hot and dead channels, temporal distribution of hits, and allow monitoring of the temporal change of these parameters via various web interfaces (Figs. 4 and 5).

2.4. Environmental monitors

The data acquisition controller implements a process that controls the parameter settings of the readout cards and monitors the basic functionality of the cards — readings of supply voltages, temperatures and single event upsets (SEU) counts (Figs. 6 and 7) . In addition the temperature of inlet and outlet water cooling pipes and the status of the cooling unit are read. There are additional sensors temperature sensors at different parts of the detector are read from a common Belle II environmental monitoring system.

3. Conclusions

The stable operation of ARICH slow control systems ensures the reliable operation of the Belle II ARICH and allows for efficient separation of kaons and pion over the wide kinematic range. The detector performs according to the expectations. Due to a degradation of the signals due to neutron irradiation, the operation will become more and more demanding. Therefore the understanding of ARICH operating parameters is of a crucial importance. With the hardware and the corresponding software tools we make this operation possible.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

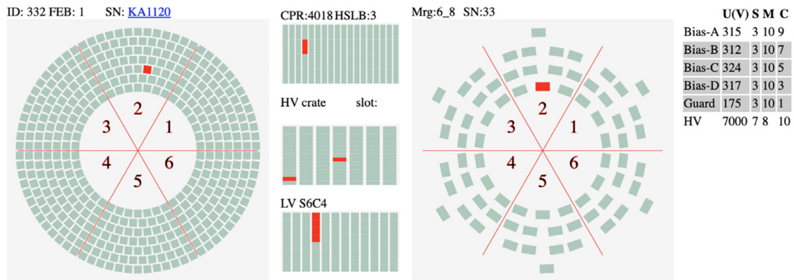

Fig. 2. Debug and mapping window.

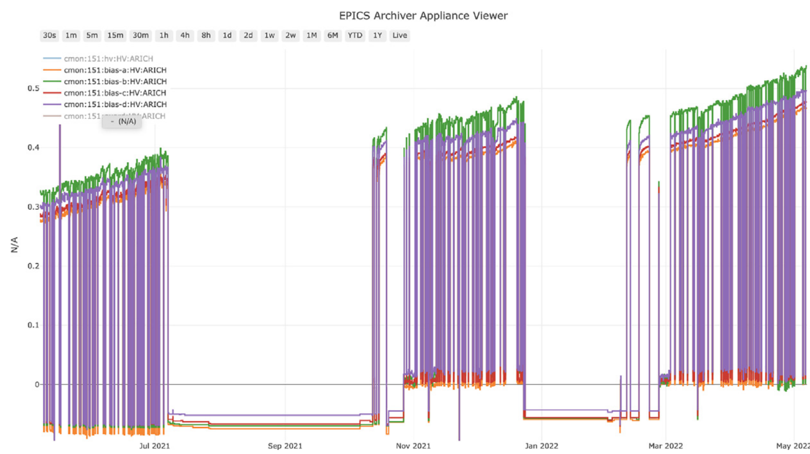

Fig. 3. Monitoring of the bias currents: Due to the irradiation of the sensors, bias currents increase. The time evolution allows to estimate and project the operation usability of the sensors. In this case four bias currents of a particular HAPD are shown as a function of time over a period of about one year. Note that the high voltage is switched off during the detector service. The increase in the current is proportional to the neutron fluence.

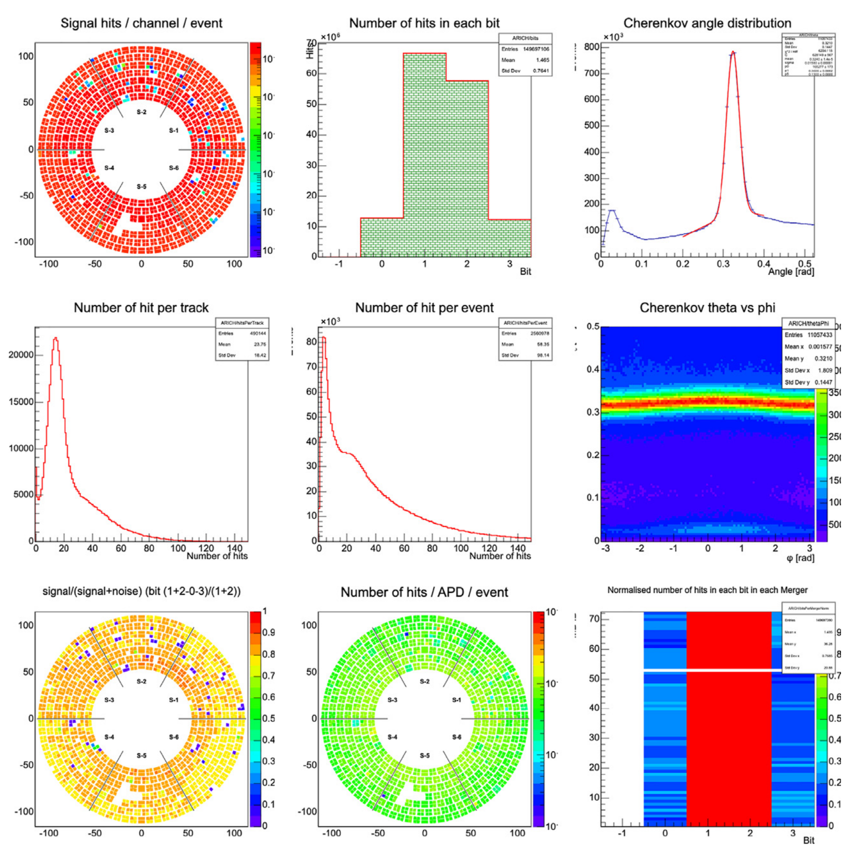

Fig. 4. Data quality histograms: The quality of data is continuously monitored and compared to the reference histograms. It represents the most important feedback to the slow control system. The short reaction time ensures the high quality of the acquired data.

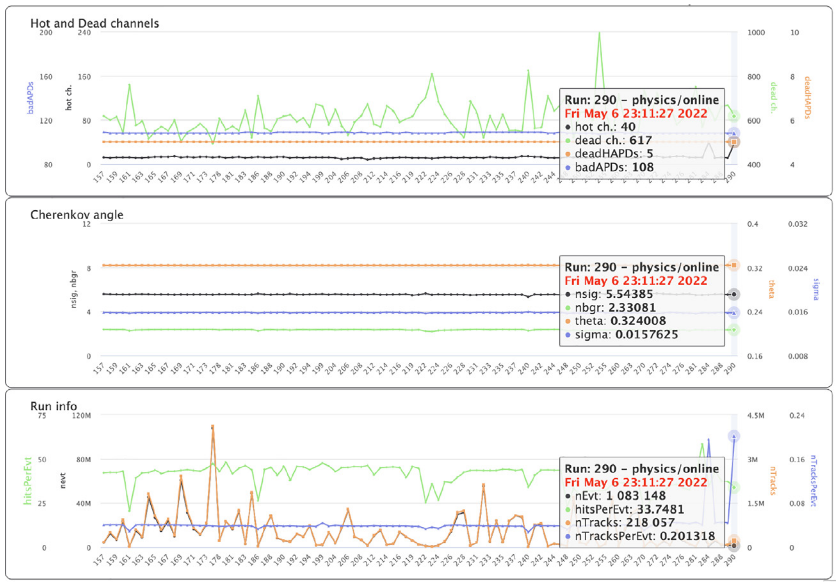

Fig. 5. Time variation of reconstruction parameters: Different figures of merit are plotted as a function of time/ run number. Any discrepancy triggers the intervention of sub detector experts.

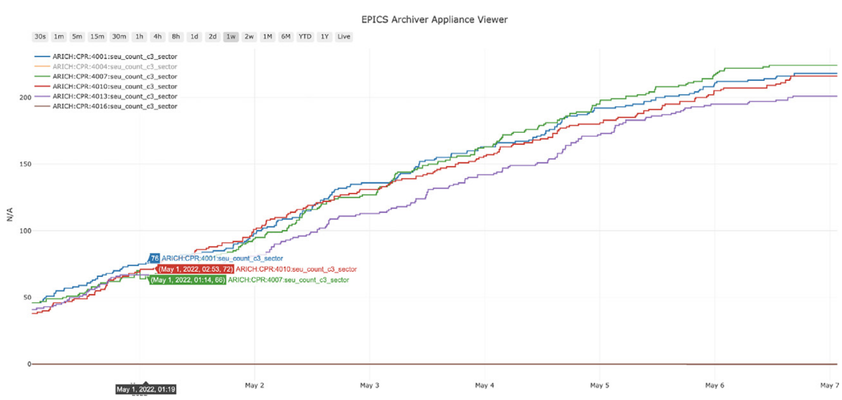

Fig. 6. Cumulative number of single event upsets (SEU) detected in the merger using custom SEU mitigation controller. The SEU data are periodically read from the front end electronics controller boards.

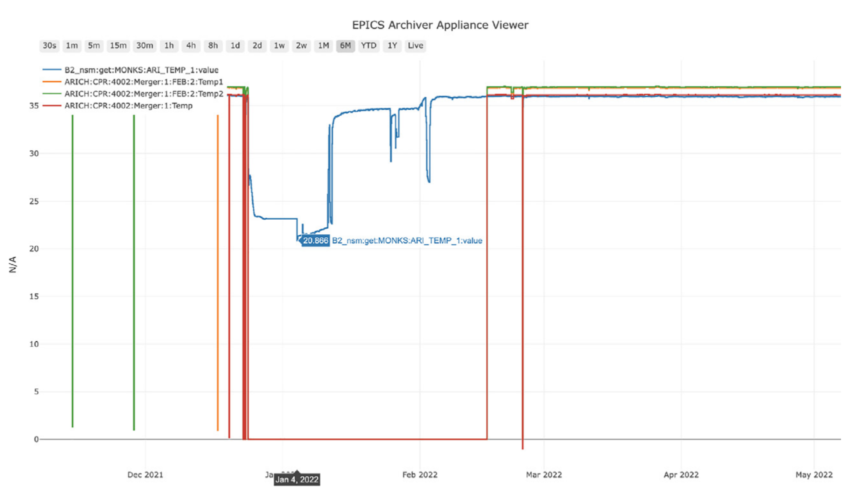

Fig. 7. Temperature of one of the front end boards. During the start of the operation, the temperature of the detector rises. A cooling system consisting of cooling pipes attached to the electronics provide the heat extraction. In case of the temperature rise, the slow control system alerts the subdetector shift crew.

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