ARICH status

Kenta Uno Niigata university

Belle II Trigger/DAQ Workshop 2022 29.Nov.2022



Intro: Radiator

 σ_{θ} : Angle resolution in the detector

 $N_{p.e}$: Number of detected photon

Important to increase $N_{p.e}$ w/o degrading σ_{θ}

• Two aerogel layers with different indices: $n_1 = 1.045, n_2 = 1.055$



Intro: Photon detector

Hybrid Avalanche Photo-Detector(HAPD)

- Radiation tolerance (10¹¹ neutrons/cm²/year)
- Work in 1.5 T magnetic field
- Good single photon detection efficiency



Developed by Hamamatsu Photonics



In total, 420 HAPDs are used (1 HAPD: 4 APDs)

2022/11/29



2022/11/29

Readout: Self-repair on FEB SEU

Effect from neutrons is SEU in the FEB FPGAs

- Frequent SEUs expected in Spartan-6 FPGA: 8 SEUs/(hour, FEB)
- \rightarrow Less data-taking efficiency

Designed firmware: Configuration consistency corrector (C³)

- Detect damaged frame by majority voting redundant frame bits
 - Partial reconfiguration of the firmware \rightarrow No DAQ failure



R.Giordano et. al: arXiv:2010.16194

Picture

Radiator plane



Photon detector plane



Backside plane





2022/11/29

ARICH operation summary Phase 3 run

Summary of Phase 3 operation HAPD operation Exp26 run#914 Signal hits / channel / event

- ~1 % off due to LV cable connection
 - Merger 5_5 with 5 HAPDs
- ~6 % off due to HV, bias problems
 - bias trip, high noise in HV/bias
- → <u>93% channels operational</u>

DAQ operation



- ARICH downtime: Significantly reduced
- Switch the readout to PCIe40 system in 2022ab run
 - Success in migration, no major issue
- → Stable operation in Phase 3



HAPD operation status

Observe sudden increase of leakage current \rightarrow disabled APDs

• Broken APDs due to radiation...?

2020

5.6%

2019

4.8%

Ratio

Signal hits / channel / event



2021

6.0%



Negligible effect of
PID performance
due to masked APDs

The problem of APD is getting stabilized2022/11/29Seems no dependency on beam condition

2022

6.5%

2023

5.4%



LV cable failure

Found contact failure in LV cable

Fixed them by soldering (during LS1)

Confirmed merger 5_5 is recovered

Vlera

No DAQ error \rightarrow Will enable them in next run





DAQ status: PCle40 system

PCIe40 readout system in 2022ab run

• 18 coppers + 6 ropc \rightarrow 2 PCle40 (48ch) + 2 ropc



✓ rari1	RUNNIN	IG NOTREAD	r 🔲 🗖	- H		48096		0	0.00	50		
Belle2link-channel												
0, 1_1 4, 1_5 8, 1_9		92298886 1, 1, 92298886 5, 1 92299147 9, 1			92298886 92298886 92300006	2, 1_3 6, 1_7 10, 1_1		92298886 92298886 92300065	3, 1_4 7, 1_8 11, 1_1;		92298886 92298886 92300127	
12, 2_1 16, 2_5 20, 2_9		92300038 13, 2 92299869 17, 2 92303025 21, 2			92300459 92299782 92303643	14, 2_3 18, 2_7 22, 2_1		92301350 92302242 92303643	15, 2_4 19, 2_8 23, 2_1;		92302214 92302997 92304126	
24, 3_1 28, 3_5 32, 3_9		92304774 25, 3 92304902 29, 3 92304902 33, 3			92304902 92304902 92304902	26, 3_3 30, 3_7 34, 3_1		92304902 92304902 92309510	27, 3_4 31, 3_8 35, 3_1;		92304902 92304902 92261382	
Hostname TTD DMA DMA [kBytes] Size [Bytes] Rate [MB/s]												
rari2	RUNNIN	G NOTREAD				182459		0	0.00			
Belle2link-channel												
0, 4_1 4, 4_5 8, 4_9		92277510 1, 4 92277510 5, 4 92277510 9, 4			92277510 92277510 92277510	2, 4_3 6, 4_7 10, 4_1		92277510 92277510 92277510	3, 4_4 7, 4_8 11, 4_1;		92277510 92277510 92277510	
12, 5_1 16, 5_5 20, 5_9		92277510 13, 5 0 17, 5 92277510 21, 5			92277510 92277510 92277510	14, 5_3 18, 5_7 22, 5_1		92277510 92277510 92277510	15, 5_4 19, 5_8 23, 5_1;		92277510 92277510 92277510	
24, 6_1 28, 6_5 32, 6_9		92277510 25, 6 92277510 29, 6 92277510 33, 6			92277510 92277510 92277510	26, 6_3 30, 6_7 34, 6_1		92277510 92277510 92277510	27, 6_4 31, 6_8 35, 6_1;		92277510 92277510 92277520	
Load	FEE Masking	Save F	EE Mask	ing								

It has been stably operated

Thanks, DAQ upgrade group!

Mask info



Number of disabled channel is 101: Ratio 6.0% JIRA ticket: <u>BIIOPS-313</u>, <u>BIIO</u>

- Unclear alert message for CR :
- → Update alert message and intro
- HV daemon was sometimes unknown (in 2020)
- → Recently, the daemon becomes stable (using restart script etc..)

(the source is not understood yet.. still under investigation)



Recovery script

Introduced recovery script in 2021c

- Most errors fixed by local CR shifters
- → Significantly reduced ARICH downtime



Next Step

- Development of recovery GUI (like CDC) is ongoing
- Implementation of automatic recovery

Question to DAQ team

- (Yu Nakazawa-san already mentioned)
- We'd like to also keep DAQ after detecting an error
- Reconfigure problematic FEEs when DAQ stops for other reason
- \rightarrow If it is possible, we can reduce DAQ crash due to ARICH error

Need to update merger firmware



Your comments are welcome

PID performance of ARICH

Cherenkov angle distribution

$e^+e^- \rightarrow \mu^+\mu^-$ events, 2019 data



DATA

$$N_{sig} = 11.38/\text{track}$$

 $\sigma_c = 12.7 \text{ mrad}$

MC

 $N_{sig} = 11.27/\mathrm{track}$ $\sigma_c = 12.75 \mathrm{mrad}$

Good agreement between data and MC simulation

Particle Identification in ARICH Comparison b.t.w observed hit and the expected PDF

- PDF: Cherenkov angle distribution
- Construct likelihood function for 6 type hypotheses (e, μ, π, K, p, d)

h: particle hypothesis

$$\ln \mathcal{L}_h = -N_h + \sum_{hit \ i} \left[n_i^h + \ln \left(1 - e^{-n_i^h} \right) \right]$$

 N_h : expected total number of hits

 n_i^h : expected number of hits on pixel i% 1 bit (ON/OFF) information in each pixel

Likelihood ratio

$$\begin{split} R_{K/\pi} &= \frac{\mathcal{L}_K}{\mathcal{L}_K + \mathcal{L}_\pi} \\ R_{\pi/K} &= \frac{\mathcal{L}_\pi}{\mathcal{L}_K + \mathcal{L}_\pi} = 1 - R_{K/\pi} \end{split}$$





Stability of PID performance

Calculate K efficiency and π miss-efficiency run-by-run

• $R_{K/\pi} > 0.5$ using D^* sample

Point: beam-induced background increases as higher luminosity



Summary

Stable ARICH operation in Phase 3

- HAPD: 93% channels operational
 - Negligible effect of PID performance due to masked APDs
- <u>Several improvement of firmware and operation system</u>
 - Success in PCIe40 migration → No major downtime in Phase 3
- Good PID performance in Belle II data
- PID performance in data is close to MC expectation!
- <u>Stable PID performance against beam-induced background</u>

Backup



PID performance vs run number in 2022ab

- performance seems stable (also in last period with large backgrounds) \rightarrow
- no clear correlation with bkg. hit rate in the ARICH \rightarrow or CDC background is seen



Planar mirror

- To prevent photon loss for track on the outer edge of the detector
- Possible to photon reflections properly considered in the reconstruction algorithm





Quartz window

Cherenkov photons are also emitted when a particle passes through the quartz window of an HAPD.

 They can be converted to photoelectrons on their first impact on the photocathode or after repeated total internal reflections in the quartz window (refractive index: ~1.5 for quartz)

 \rightarrow Small Cherenkov angle



APD structure

