Belle II operation issues and how they have been addressed

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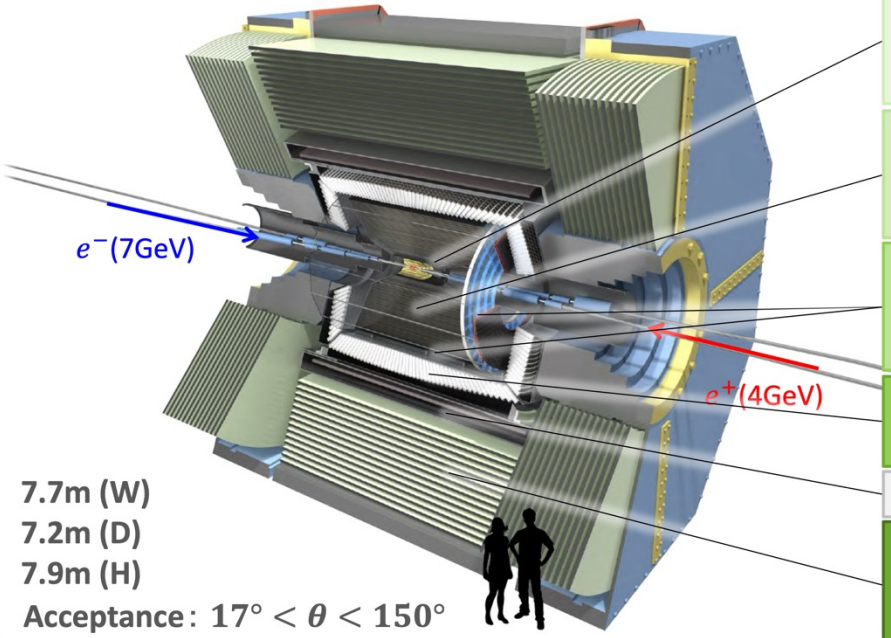
ARC-BPAC joint review

Belle II detector



7.7m (W)
7.2m (D)
7.9m (H)
Acceptance: $17° < \theta < 150°$

Vertex detector
- Inner 2 layers w/ DEPFET (pixel): PXD
- Outer 4 layer w/ DSSD (strip): SVD

Central Drift Chamber (CDC)
- He + C_2H_6 gas (1:1)
- Smaller cell size than Belle

PID detectors (TOP + ARICH)
- Barrel: Time-Of-Propagation counters
- Forward endcap: Aerogel RICH

EM calorimeter
- CsI(Tl) + waveform sampling

Superconducting solenoid: 1.5 T B-field

K_L/μ counter
- Outer barrel: RPC (streamer)
- Endcap/inner barrel: Sci. + MPPC

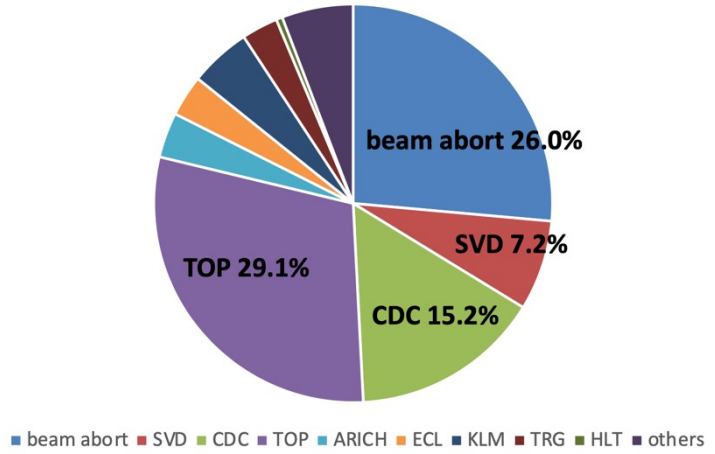
High-rate DAQ
- Maximum Level-1 rate: **30kHz**

Level-1 trigger system
- CDC-tracking + EM-cal + μ
- L1 trigger latency: 4.4 µsec (GDL output)

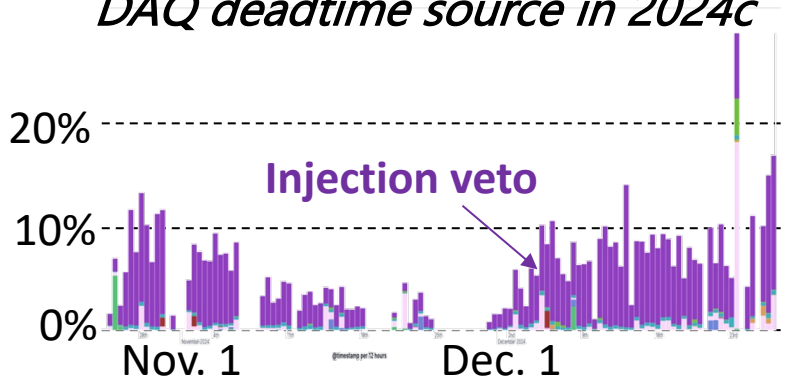
Main issues in 2024c operation

- **Pixel detector (PXD) kept OFF to protect it from sudden beam loss (SBL)**
  - PXD has been damaged due to huge beam loss at IR due to SBLs
- **Central Drift Chamber (CDC) current blow-up**
  - Possible Malter effect, which is an irreversible damage
- **CDC gas gain degradation due to various sources**
  - Beam background, and gas composition and contaminant from avalanches during beam operation
- **Endcap PID counter (ARICH) water flow problem**
  - Resulted in about 13% of dead area in ARICH at end of 2024c
- **Frequent DAQ stops at high beam backgrounds**
  Main causes:
  - Barrel PID (TOP): Frequent b2link errors (b2llost), SEU on Processing System (PS) in front-end
  - CDC: b2tt and b2link errors due to SEU on front-end FPGA
  - Silicon Strip detector (SVD): SEU on front-end ASIC (APV25)
- **Injection trigger-veto deadtime**
  - 5.3% deadtime in overall DAQ running time
  - Larger deadtime under worse injection conditions: injection quality is essential for efficient data taking.
- **Overall data taking efficiency = (DAQ run time – deadtime)/(physics collision time) was 85%, while our target is 90%.**

DAQ stop reason in 2024c



DAQ deadtime source in 2024c

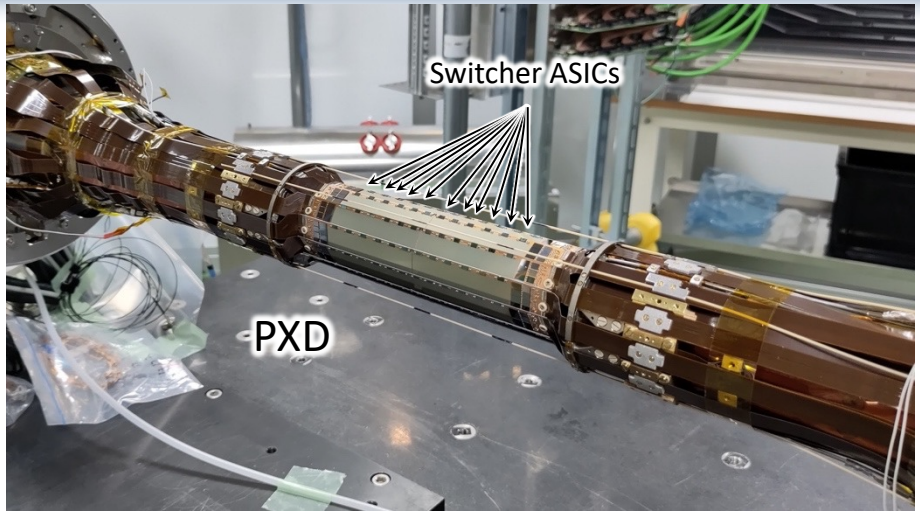


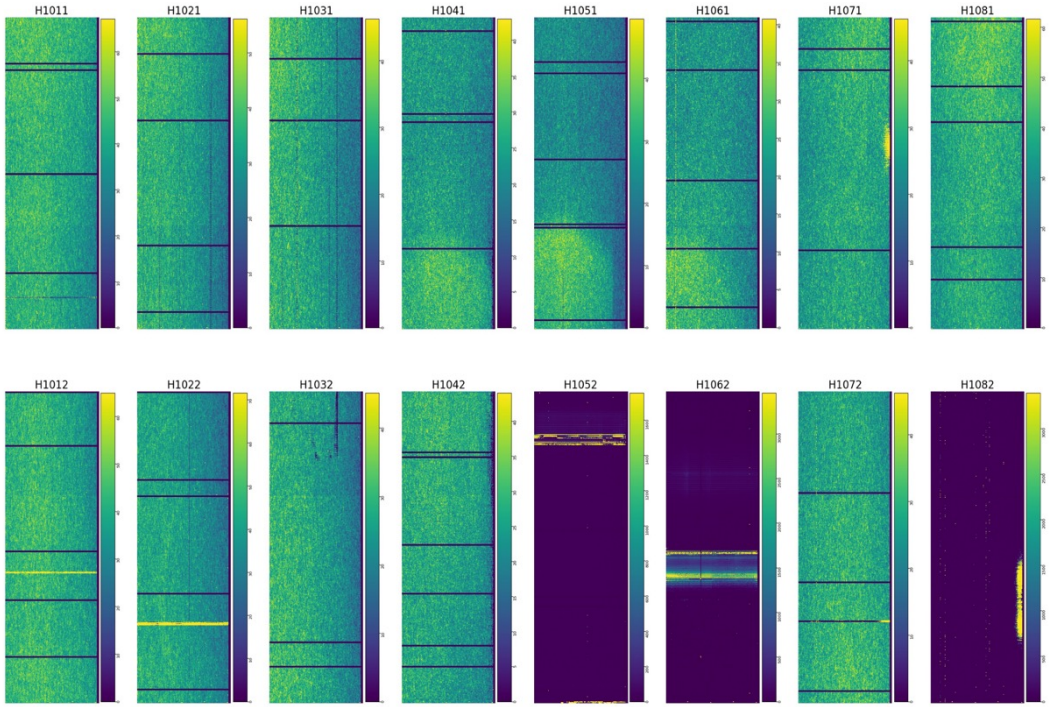
Improving these issues was the top priority mission during the 2025 shutdown period.

Silicon Pixel Detector (PXD)

- **Damages of switcher ASICs due to huge IR beam losses at SBLs (22 Apr, and 5 and 6 May, 2024)**
  - Increase in switcher current that increases the PXD temperature
    - Two ladders had to be additionally turned OFF.
    - → In total, 8 out of 40 modules had to be turned OFF.
  - ~2% dead gates
  - Unstable (noisy) regions appears

- **On 7th May 2024, we decided to temporarily turn off the PXD during beam operation to avoid additional damage until the safe conditions for PXD are realized by sufficient measures and good machine stabilization.**



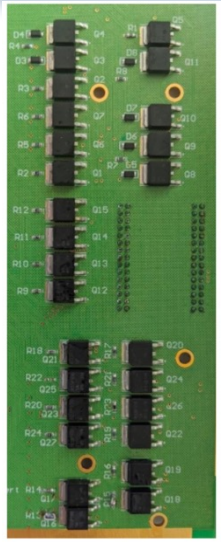


Silicon Pixel Detector (PXD)

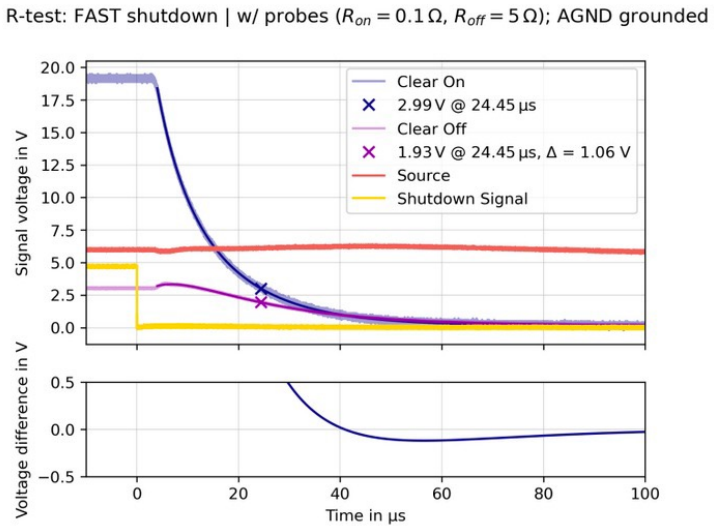
R&D of fast power shutdown

- The feature aims to quickly bring the PXD modules into a safe condition at the SBL event before the IR loss starts damaging the modules.
  - CAVEAT: The fast shutdown scheme is only effective if an early precursor SBL detection signal is available.
  - A candidate is the signal from the clearing electrode, which was observed about 50 us BEFORE the IR beam loss at SBL. In 2025c run, the electrode signal is being monitored to check the reliability of the signals.
  - More details about precursor signal development will be shown by Nakayama-san.
- Developed an active discharge board that rapidly discharges capacitors on power lines through resistors by switching MOSFETs.
  - Requires careful optimization of resistor values to realize both safe and rapid shutdown.
- In high-intensity e-beam test at MAMI, we confirmed that the new shutdown function saves the PXD if it recieves the signals about 30us BEFORE the radiation hit on the PXD.
- Parts procurement is ongoing to start the mass production of the boards, which will be ready in March-April at earliest.

Prototype



Voltages on module at the fast shutdown



Silicon Strip Detector (SVD)

Automatic SEU recovery on front-end ASIC (APV25)

- Firmware-based automatic SEU detection/recovery function has been developed and deployed to recover the SEU without DAQ stop and mitigate the DAQ downtime.
  - Recovery is completed within about 20ms (meanwhile, triggers are stopped by BUSY) with DAQ kept running.
- Reliably running during 2025c
  - Now used as the default in physics data taking
  - Also, tested during machine tuning and high-injection BG: higher SEU frequency. SVD was included in the global run with no sensor bias (= safe conditions for SVD). Still, the frequent SEUs were detected and recovered properly.

Central Drift Chamber (CDC)

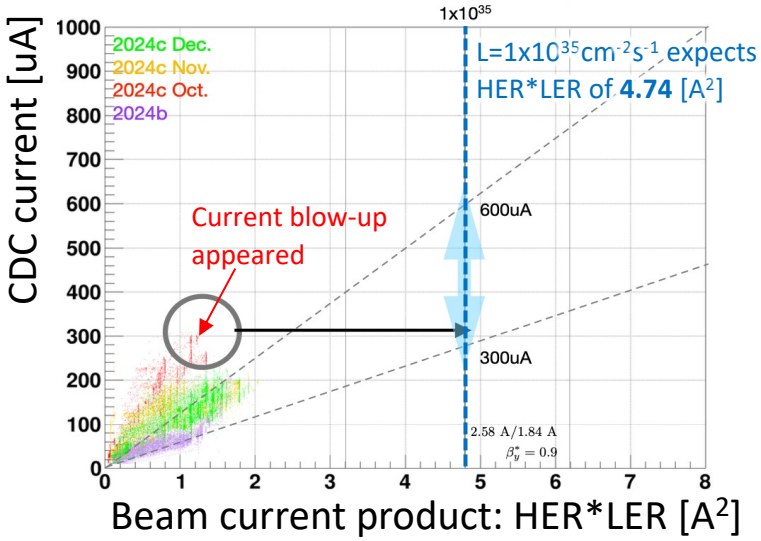
Chamber current blow-up and gain degradation in 2024

- Current blow-up in inner layers of sect.3 (Oct 29) under high beam background (→ resulting in high CDC current) and low water content (~1300ppm): Possibly caused by Malter effect (irreversible aging)
  - Reduced HV of inner layers in sect.3 by 500V (effectively OFF, no hits from there)
  - Increased water content from ~1500ppm to ~3000ppm (known to be beneficial to prevent Malter effect)
  - Limit set on acceptable chamber current to control the beam background levels (so far, up to 260 uA/layer)
- Gain degradation was observed in 2024 as an overall trend; however, isolating the contributions from the aging effect and possible gas pollution due to the avalanche was difficult because of other effects from the gas condition.

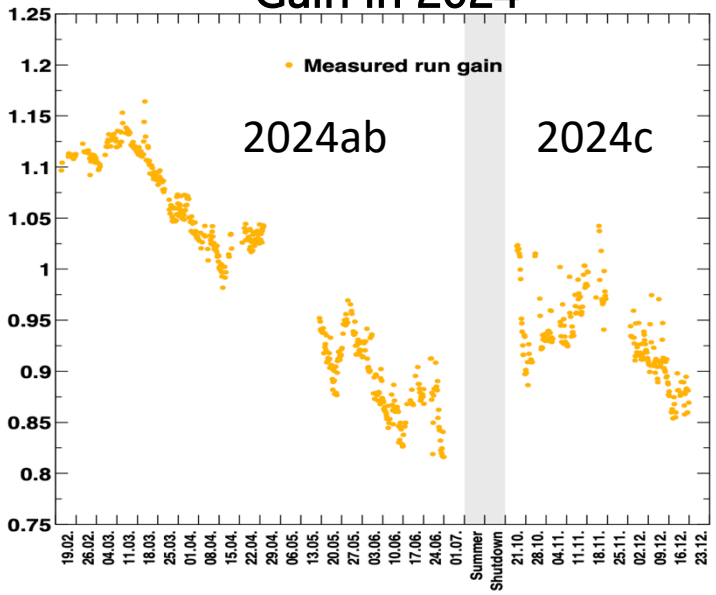
Investigations during shutdown and 2025c

- Cosmic runs with various gas conditions for a better understanding of the gas content (O_2, H_2O, and H_2) contributions to the gain evolution.
  - Help isolate the aging effect component in the gain drop during the physics operation.
- New O_2 supply line added to the gas system: Increasing O_2 possibly helps mitigate the Malter effect as well as H_2O.
- Studies to prepare new operation conditions with lower HV to reduce the CDC currents and aging effects.
  - Operate CDC with low HV, at first in inner layers, and possibly in more outer layers in the future.
  - Special cosmic runs and beam collision runs with lower HV (50% gain in all layers) were taken, and evaluation of impacts on the performance (trigger, tracking, dE/dx …) is ongoing.
- Preparing for a significantly increased fresh gas flow (up to x10): to remove reversible pollution and mitigate the aging effect.
  - The mass flow controller in the exhaust line has to be changed to accept the higher flow rate.

CDC current v.s beam currents in 2024



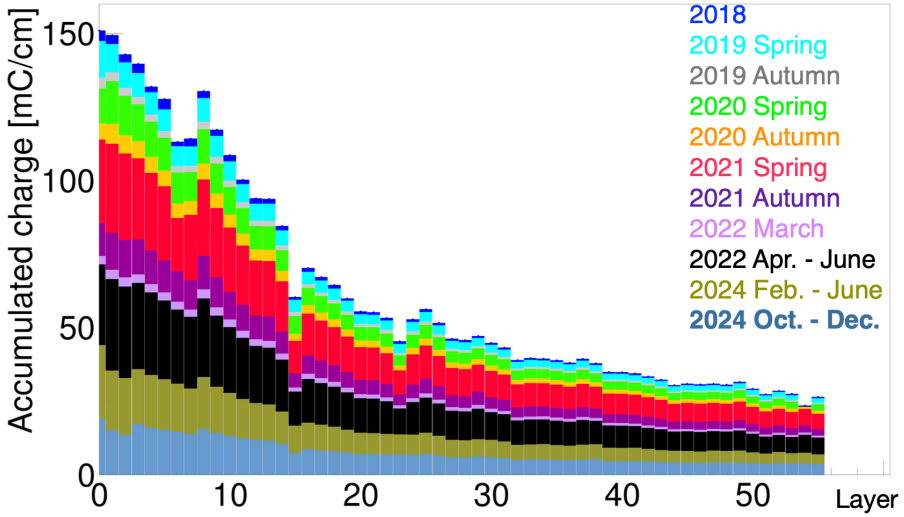
Gain in 2024



Central Drift Chamber (CDC)

Expected aging effect

- Integrated charge in CDC reached 150 mC/cm in 2024c.
- 600uA/layer current (expected at $L=1x10^{35}cm^{-2}s^{-1}$) corresponds to about 700 mC/cm per year at the innermost layer, assuming 6 months of full CDC operation per year.
- Gain degradation speed for the Belle I CDC was estimated to be about 6% per 1C/cm accumulated charge, but we need to estimate that for the Belle II CDC conditions.



Aging effect studies with test chambers

- An initial irradiation at an electron beam in Tohoku University was conducted in November
  - About 350 mC/cm was accumulated. Possible aging effect is now being evaluated.
- New test in spring 2026 to increase accumulated charge.
- Now exploring additional test also at Gif++ at CERN with the DRD1 collaboration for faster charge accumulation.

Barrel PID Counter (TOP)

Improvement in readout system to mitigate frequent DAQ stops

- Feature extraction migration to ROPC in e-hut to avoid DAQ stop due to SEU on Processing System (PS)
  - The new feature extraction has been developed.
  - Final validation is ongoing. Plan to deploy it by 2026a.
- While frequent b2llost errors under high BG seen in 2024c, only a few in 2025c even under very high injection background conditions.
  - Firmware Improvement during shutdown likely helped the mitigation.

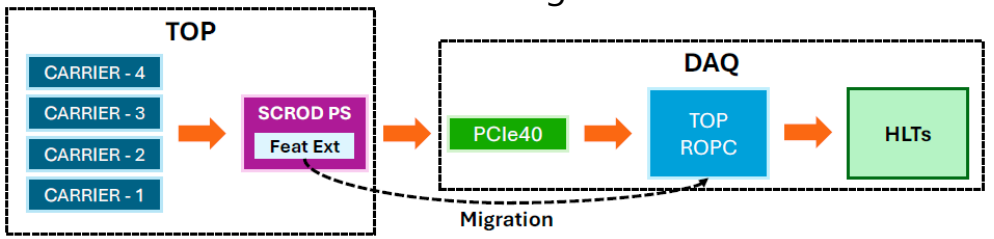
MCP-PMT QE degradation due to beam background

- Accumulated charge on the Photocathode (PMT output charge), which is mainly created by beam background, degrades PMT quantum efficiency (QE).
  - So far, the PMT hit rate due to single-beam background is limitted to 5 MHz.

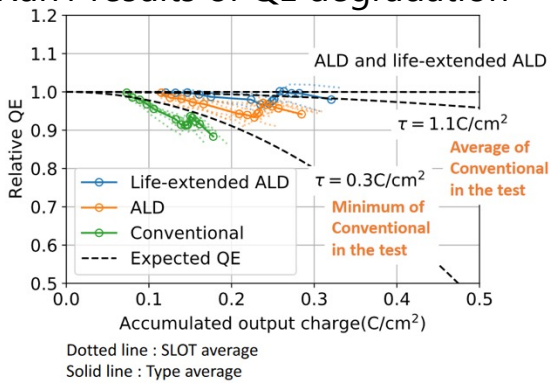
Study for optimization of HV divider values

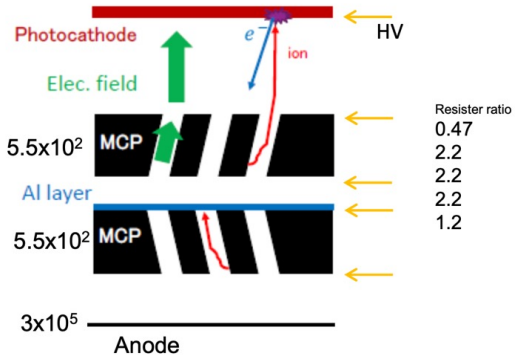
- Adjust the gain in the 1st and 2nd MCP layers and reduce outgas and ions from the 1st layer that go back to Photocathode to mitigate the QE degradation.
- Measuring the gain and after-pulse rate with changed resistors to find optimal resistor values
  - About 30% reduction in after-pulse rate.
- Next steps are to measure QE drop and check the performance in 1.5T in a few months.

Feature extraction migration to ROPC

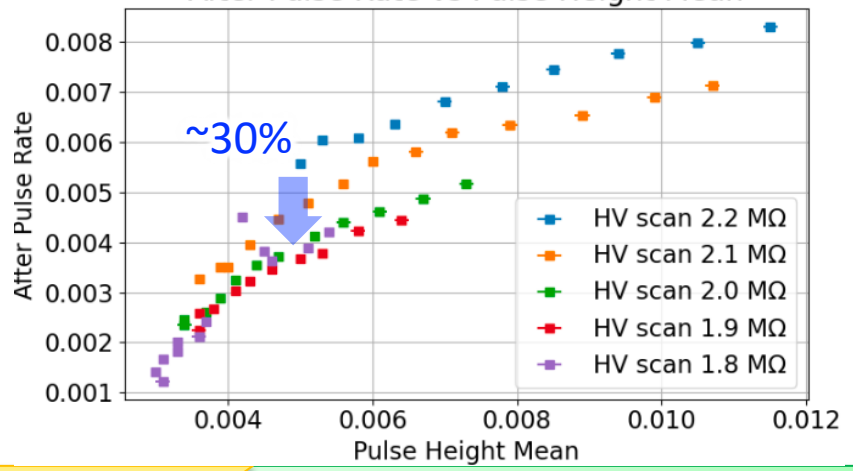


Run1 results of QE degradation





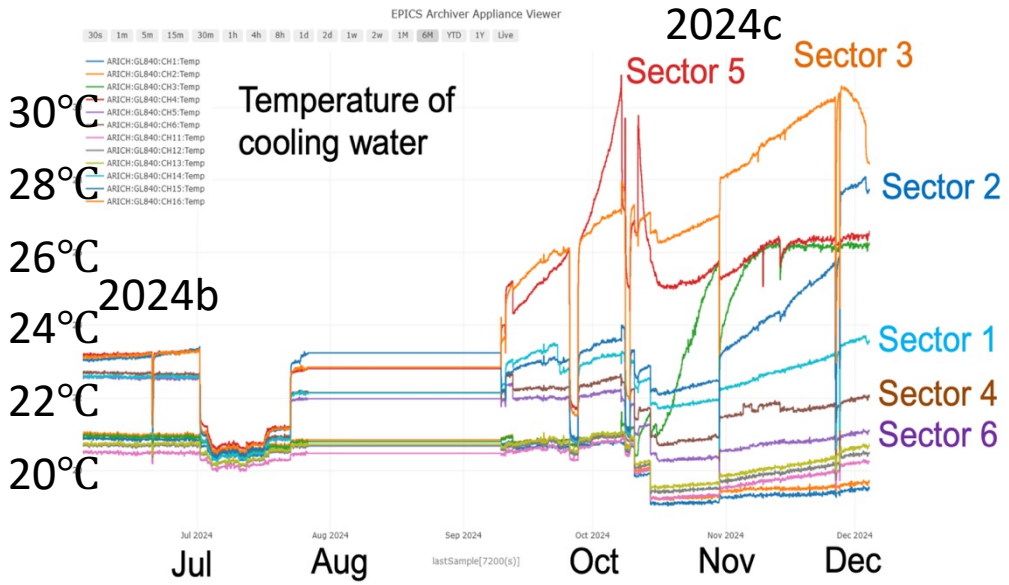
After Pulse Rate vs Pulse Height Mean



Endcap PID Counter (ARICH)

Cooling water flow problem in 2024

- The cooling water flow gradually decreasing after LS1 and stopped in Sectors 3 and 5 during the 2024c run. Resulted in too high temperature in those sectors.
  - About 13% of ARICH had to be turned OFF to keep the HAPD temperature below 50 degC.



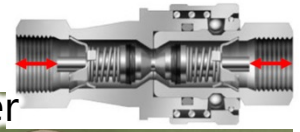
Investigation and repair with FW endyoke open

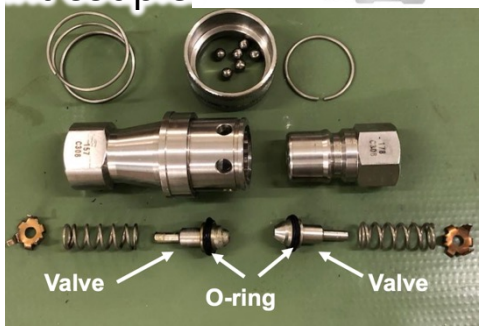
- Quick-joint couplers were identified as the cause of clogging.
  - O-ring inside was swollen and filled the water path. Possibly, due to the anticorrosion agent () injected just after LS1.
- Removed the quick-joint couplers as a countermeasure.

The water sampled from the clogging lines was contaminated

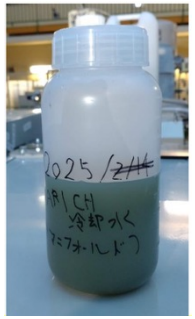
- The material analyses of the sampled water and deposits
  - Cu ions were found in the water.
  - The deposits are composed of copper, fluorine, and organic compounds (possibly benzenoid aromatic compounds).
- Countermeasures
  - Installed a new copper-less chiller,
  - Replaced FEP tubes with Nylon tubes, and
  - Installed a filter

Disassembled quick-joint coupler





Water sampled from manifold

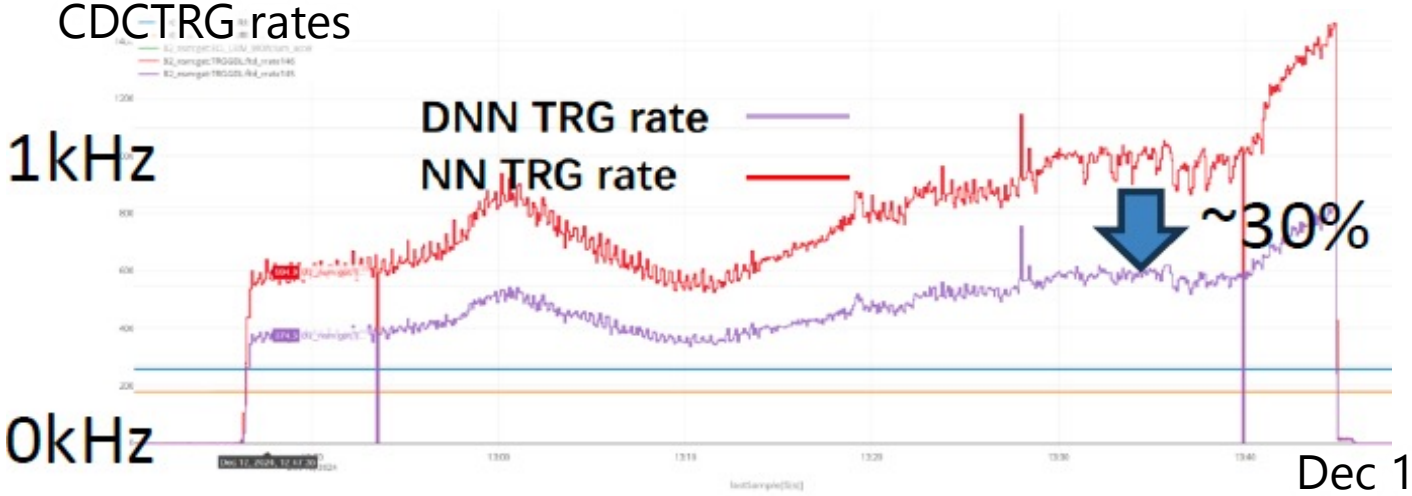


ARICH cooling in 2025c restored and working fine

Level-1 Trigger system

- Strategy to suppress Level-1 trigger rate during the next beam operation (if necessary):
  1. Activate the new DNN-based CDC 3D-track trigger (Liu, Yang)
     - Expected to reduce the CDCTRG rate by about 30%, while also providing improved Z resolution.
  2. Adjust the prescale setting for low-multiplicity triggers, and enable CDC-ECL matching and Bhabha-vetoed triggers
     - Expected to reduce the overall trigger rate by about 30-40%
  3. Modify the prescale setting for calibration data triggers

CDCTRG rates



Dec 17, 2024

NN trigger apply cut as : $abs(z) < 15cm$

DNN trigger apply cut as: $abs(z) < 50cm$ && $q < 0.8$

Data Acquisition System (DAQ)

Automatic restart system w/o DAQ stop (auto subrun restart): has been deployed

- At b2link/b2tt errors, quickly reset the error and continue the data-taking w/o run stop to minimize the DAQ deadtime.
  - Keep the same run while the subrun number increases
- Auto restart sometimes fails: under investigation

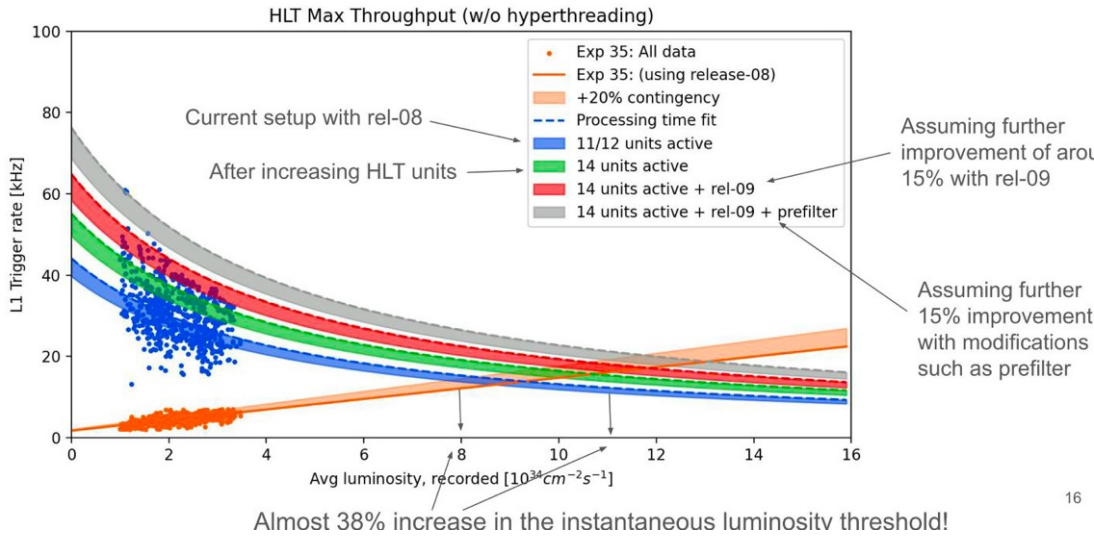
b2link/b2tt = serial links for the DAQ data transmission or trigger/timing distribution.

A new unit of High-Level-Trigger (HLT15) has been installed.

HLT prefilter

- Adding simple cuts, to remove events with high BG close to injection before the HLT reconstruction, can reduce the HLT processing time without significantly compromising efficiency.

- A preliminary prefilter using either CDC and ECL hit or event timing information (event close to injection) has been developed.
- For 2025c, running just in monitoring mode (filter is not activated) with DQM plots showing its performance.



- **TRG/DAQ will cope with luminosity of 10^{35} $cm^{-2}s^{-1}$.**

Summary

- **PXD**
  - Good progress on implementing fast power shutdown to protect against large beam losses at IR.
  - Only effective if an early precursor SBL detection signal about 30us earlier than the IR beam loss is available.

- **SVD**
  - Mitigation for SEU recovery w/o run stops deployed successfully.

- **CDC**
  - Aging effect and possible Malter effect in the future are concerns.
  - Cosmic runs with various gas conditions were performed to understand the the O_2 , H_2O , and H_2 contributions to the gain evolution.
  - Studies to prepare a new operation conditions with lower HV to reduce the CDC currents and aging effects are ongoing.
  - Now preparing for a significantly increased fresh gas flow (up to x10)

- **TOP**
  - Feature extraction migration will be deployed soon to mitigate DAQ stops due to SEU in PS.

- **TRG/DAQ**
  - TRG/DAQ will cope with luminosity of 10^{35} $cm^{-2}s^{-1}$.

backup

ECL, KLM

ECL

Improved readout firmware is under development

- A new waveform fitting algorithm to improve signal amplitude resolution by reducing the injection background effect
- Development is ongoing. Hopefully, it will be done in a couple of months.

KLM

RPC HV sudden turn-off (STO) in 2024ab w/ new-type crate (CAEN SY4527)

- Still, sudden turn off (STO) of HV modules happens with the new type crate, and investigation with the CAEN engineer is ongoing.
  - In 2025c, we switched to the old type crate (SY1527), which has never caused the STO problem.
  - The issue with the old type crate is that it is discontinued and we have only 1 spare.