Data acquisition system of the Belle II experiment

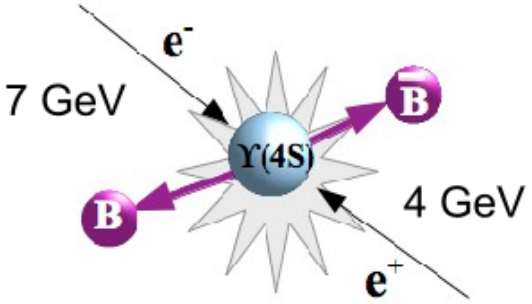
Mikhail Remnev on behalf of the Belle II collaboration

The 2024 International Workshop on Future Tau Charm Facilities

2024.01.17

Belle Experiment

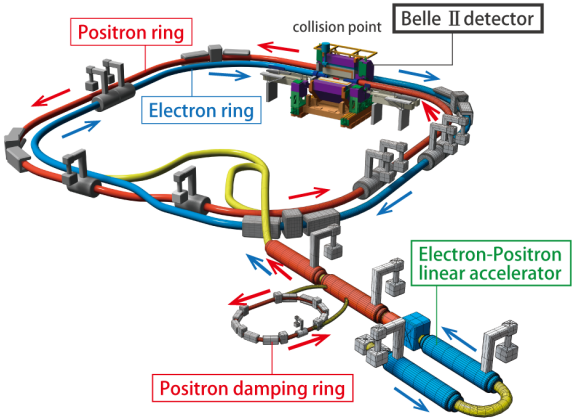
- B-factories — e^+e^- colliders, with the center of mass energy ~10.5 GeV tuned to the $\Upsilon(4S)$ resonance peak.
- Mass production of $B\overline{B}$ pairs for the study of B meson physics.
- Two experiments, BaBar and Belle have been conducted at B-factories, the Belle II experiment is in operation since 2018 and is taking data from SuperKEKB B-factory.

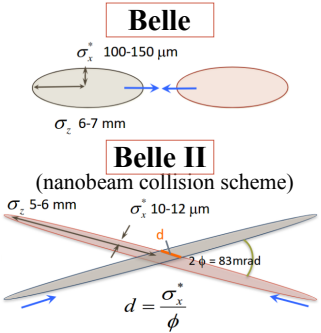


- The Belle experiment on e^+e^- collider KEKB, finished in 2010, with world record luminosity of $2.11 \cdot 10^{34}\text{cm}^{-2}\text{s}^{-1}$.
  - First registration of CP-violation in the decays of B-mesons. The obtained parameters are in accordance with Kobayashi-Maskawa mechanism.
  - Advances in τ-physics, physics of B- and D-mesons.
  - Discoveries of ~20 exotic particle.
  - Belle results are in accordance with the Standard Model.
- To find possible discrepancies with the Standard Model, a higher precision was required.
- Thus, Belle II experiment has started, with the design luminosity being higher than the achieved Belle luminosity by a factor of 30 ($\sim 6 \cdot 10^{35}\text{cm}^{-2}\text{s}^{-1}$).

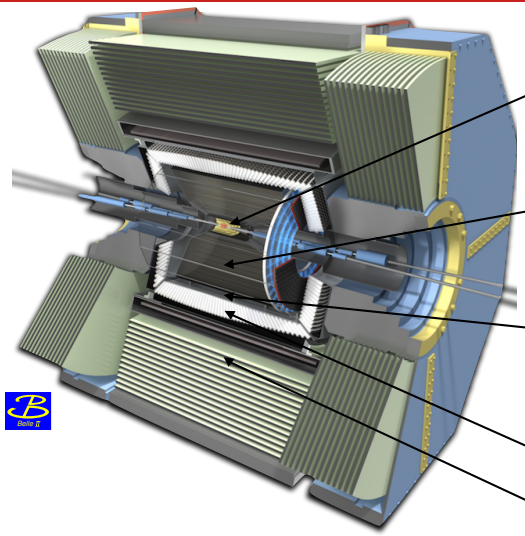
Belle II Experiment

- Goals: physics of B- and D-mesons, τ-physics, search for physics beyond the Standard Model.
- SuperKEKB — asymmetrical e^+e^- collider, $E_{e^-} = 7$ GeV, $E_{e^+} = 4$ GeV.
- Design luminosity $6 \cdot 10^{35}\text{cm}^{-2}\text{s}^{-1}$, ~30 times higher than previous KEKB colldier due to nanobeam collision scheme.
- Background increases by 10-20 times $\Rightarrow$ the upgrade of the detector and DAQ have been necessary.





Belle II Detector



Vertex Detector (VXD)
- 2 inner layers: Pixel Detector (PXD)
- 4 outer layers: Strip Detector (SVD)

Central Drift Chamber (CDC)
- He (50%), C_2H_6 (50%)

Particle identification:
- Barrel: Time Of Propagation detector (TOP)
- Endcaps: Aerogel RICH detector (ARICH)

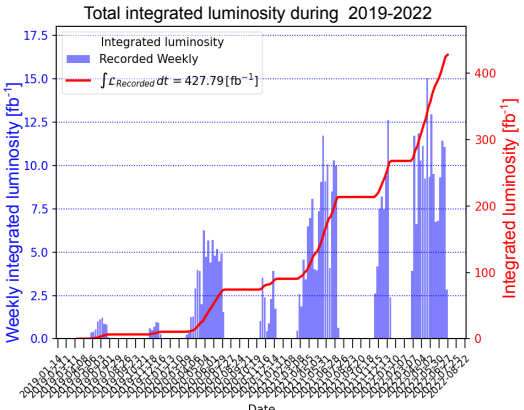
EM calorimeter (ECL)
- CsI(TI) crystals

K_L/μ detector (KLM)

- L1 trigger rate at design luminosity: 30 kHz.
- Data flow from all systems besides PXD: 1.4 GB/s.
- There are also two other important detector components: trigger and data acquisition (DAQ)

Current status

- The first data taking for physics analyses started in 2018.
- In 2019, the experiment has entered its main phase — data collection using all detector subsystems.
- In June 2020, the achieved luminosity exceeded the highest luminosity of Belle experiment.
- As of now, the highest achieved luminosity is $4.7 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Physics data taking will resume in early 2024.



Tasks of the data acquisition system

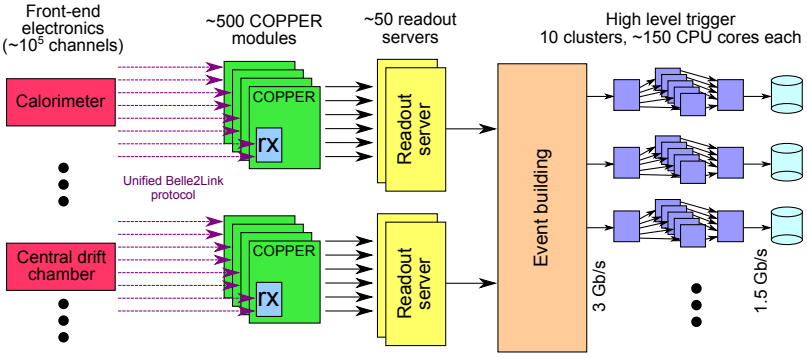
The DAQ system has to read data from $\sim 10^5$ channels, perform event building and data saving.
Tasks of the DAQ system:

1. Data readout.
   - Deadtime has to be less than 1% at the Level 1 trigger rate of 30 kHz.
2. Event building.
3. Run control.

   Run — data taking during $\leq$ 8 hours. During this time period, detector and accelerator parameters are unchanged.
4. Data quality monitoring.

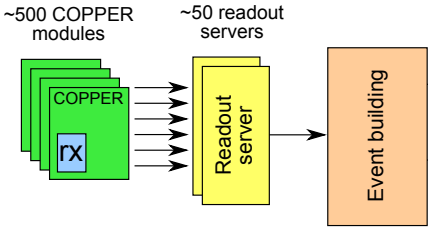
Belle II data acquisition system

- Each subsystem has different front-end electronics (FEE).
- Output from FEEs is sent in digital format over optical links using a unified format.



- Digitized data are read out by COPPER boards (Common Pipelined Platform for Electronics Readout).
- Readout servers perform the initial event building. They also interact with run control system.
- The built events are sent to High Level Trigger (HLT), where the events are reconstructed and filtered.

Slow control

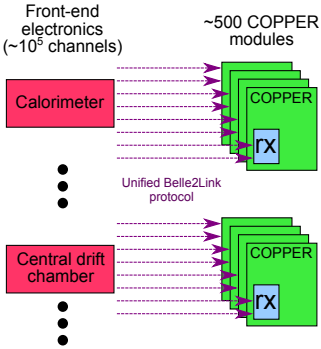


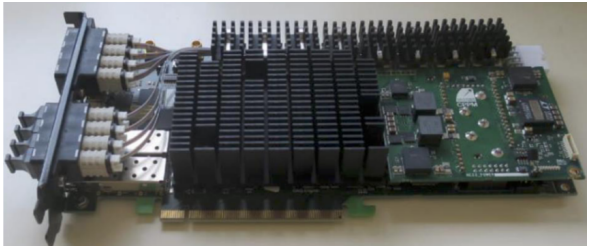
Each DAQ server runs a number of slow control processes that perform the following tasks:

- Monitoring of temperature, humidity, ...
- Initialization of front-end electronics.
- Run control.
- Control of subsystem-specific calibration runs.
- Monitoring of data taking status.

Slow control is implemented with two frameworks: Experimental Physics and Industrial Control System (EPICS) and Network Shared Memory 2 (NSM2).

Upgrade to PCIe40 modules

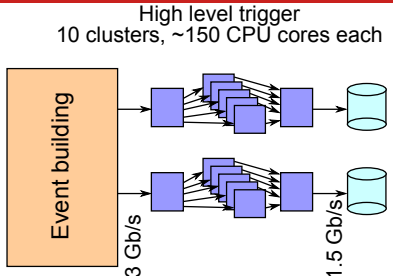




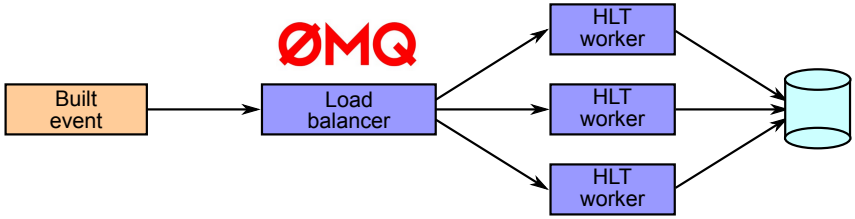
PCI-express based high-speed readout for the Belle II DAQ upgrade

- COPPER modules comprise a possible bottleneck of Belle II DAQ, being the main limit to its throughput at trigger rates higher than 30 kHz.
- Thus, new PCIe40 board with an Altera Arria 10 field-programmable gate array chip has been developed, allowing for 260 kHz trigger rate with 17 Gb/s data throughput without data loss.
- Currently, the entire DAQ system has been upgraded to use PCIe40 boards.

High level trigger (HLT)



- Servers of high level trigger (HLT) perform parallel processing of the built events.
- The events are filtered due to a variety of criteria before being written to disk.
- HLT servers are coordinated using ZeroMQ messaging library.



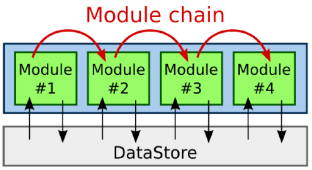
- To filter background events, HLT worker processes perform event reconstruction.

  Event reconstruction — the extraction of physics information (tracks, clusters) from the separate channels information.

High level trigger (HLT)

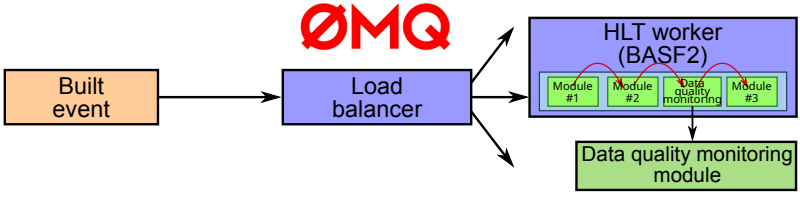
- Event reconstruction software is difficult to develop and requires a lot of computational resources.
- To streamline the development process, the reconstruction modules are structured in BASF2 (Belle Analysis Software Framework 2).

BASF2 is a modular framework. Each reconstruction stage is a separate independent module.
Flexible configuration of module chains allows to use BASF2 in many use cases:



- Event reconstruction in HLT.
- Event simulation.
- Offline data analysis.

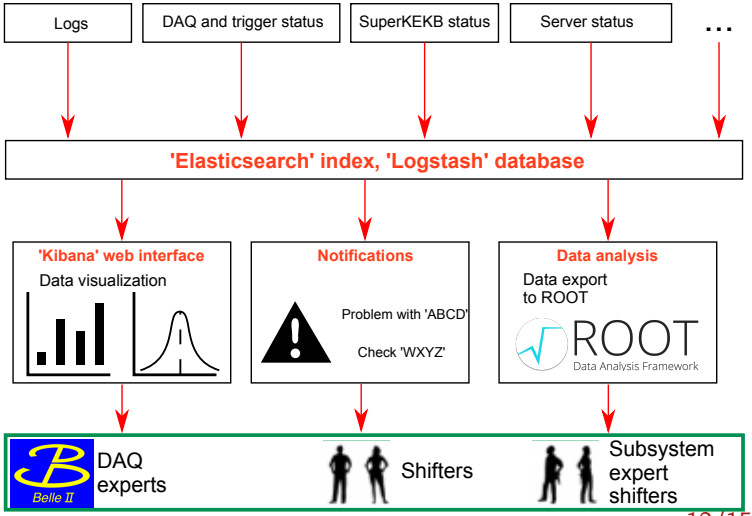
This implementation allows HLT to send event information to data quality monitor between specified steps of the reconstruction.



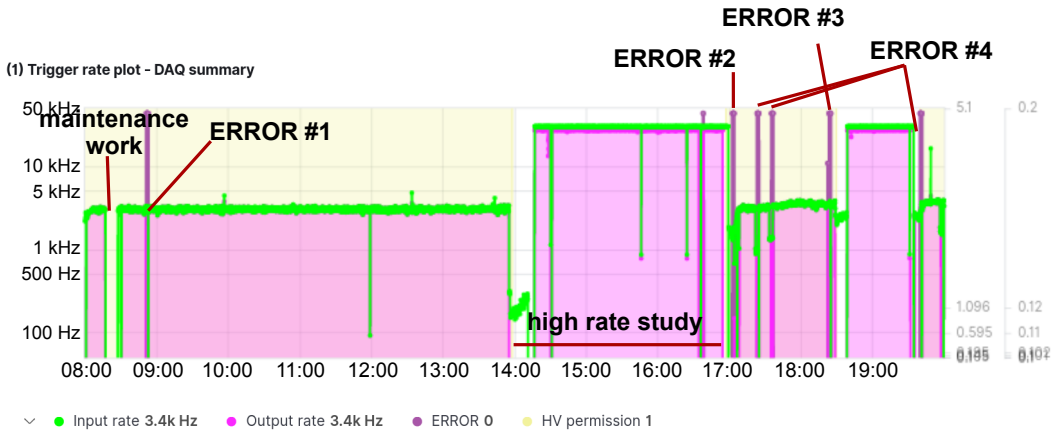
Monitoring

DAQ systems have a lot of components. The stability of these components has to be continuously monitored.

- For DAQ monitoring, we use ELK (Elasticsearch + Logstash + Kibana) software stack.
- ELK is utilized to display slow contorl information. For example, DAQ efficiency.

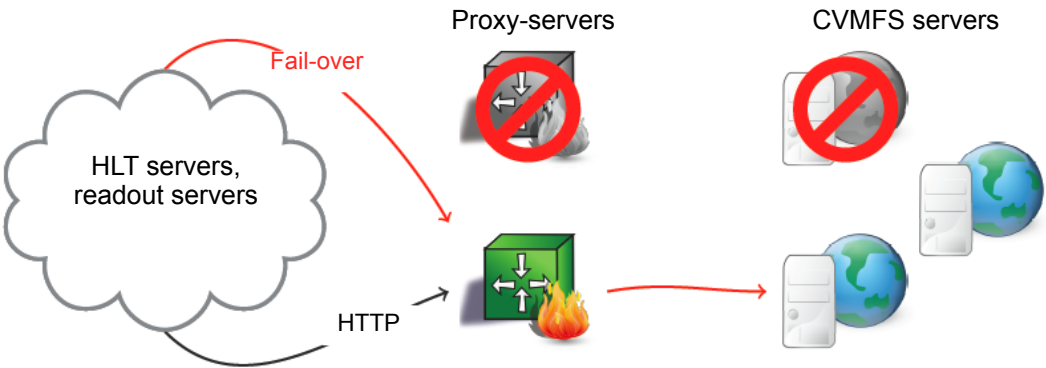


- For example, it is easy to generate a plot to show the efficiency of DAQ by combining the information from multiple sources.



CVMFS

- In the distributed systems (and systems with a large number of users) it is important to have tools to quickly distribute newest versions of the software on all servers.
- In Belle II experiment, we use CVMFS (Cern VM File System).
- New versions of BASF2 and slow control software are uploaded to the CVMFS and become available on all DAQ servers within a few minutes.
- CVMFS supports HTTP proxies, allowing it to work in networks with complicated hierarchy.



Summary

- The data acqusition system of Belle II detector successfully operates at current luminosity
  - Tests show that at 30 kHz the DAQ deadtime will be less than 1%.
- The PCIe40 modules have been developed to read out the data from detector subsystems.
- High level trigger system reduces the size of output data by ∼50% without loss of useful information.
- The software tools being used allow to significantly speed up the discovery of possible issues that can happen during data taking.
- Belle II experiment data acquisition system is being continuosly updated, with the intention of increasing reliability.

Backup slides