The Belle II Online Reconstruction and Software Trigger

CHEP 2018, Sofia, Bulgaria

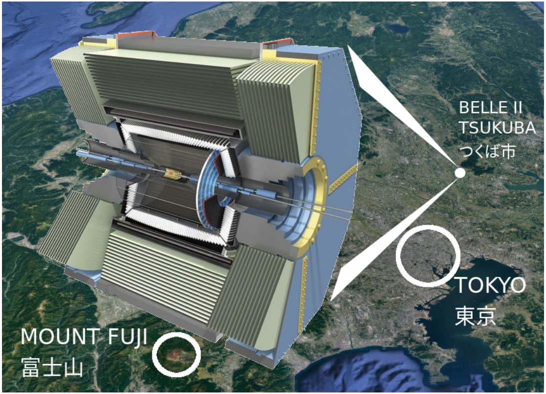
Thomas Hauth for the Belle II Collaboration
Institute of Experimental Particle Physics (ETP), KIT, Germany |

Belle II Experiment

Asymmetric e^+e^- experiment mainly at the $Y(4S)$ resonance (10.58 GeV)

Focus on B, charm and τ physics

Located the KEK Research Center in Tsukuba, Japan



	KEKB/Belle	SuperKEKB/Belle II
operation	1999–2010	2018–
peak luminosity	$2.11 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$	$8 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
int. luminosity	$1023\,\mathrm{fb}^{-1}$ (772 mil. BBar pairs)	$50\,\mathrm{ab}^{-1}$

Functionalities for the basf2 Online Release

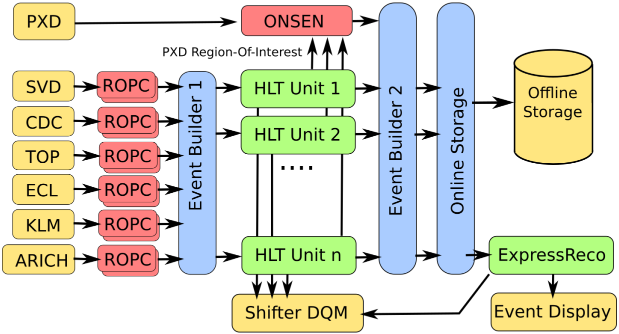
Tasks of the Online Event Reconstruction

- Prescale high-xsection background processes like Bhabha scattering
- Generation of Region-Of-Interest for PXD readout from SVD and CDC tracks
- Select specific events for calibration purposes
- Fast feedback on data quality via DQM plots (ExpressReco)

Supported Run Modes

- Global Cosmic Runs
- SuperKEKB collisions Runs

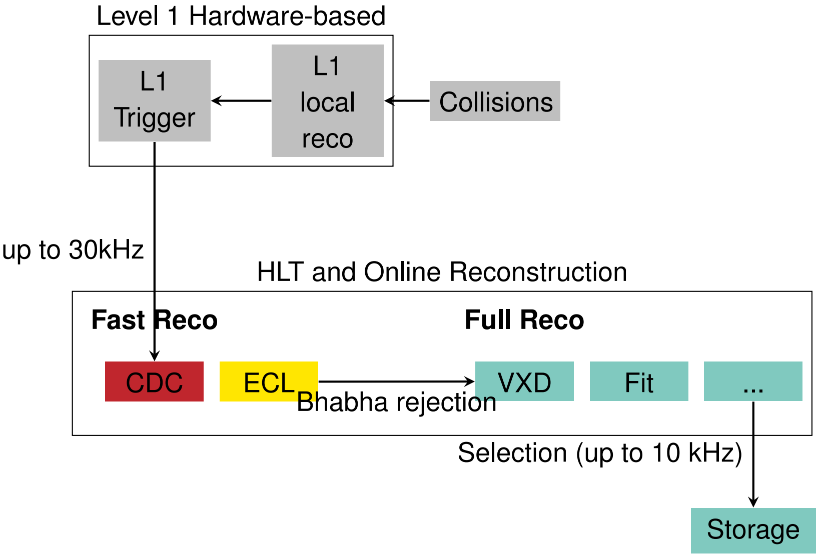
Belle II Data Acquisition System (DAQ)



Read-out PCs (ROPC) collect and forward detector raw data to the first event builder stage.

Pixel Detector (PXD) Region-of-Interest is generated by the HLT event reconstruction and used to select PXD hits combined in the second event builder stage.

Belle II Trigger Processing Chain



Belle II Framework (basf2) in Online Systems

- The software used for online data taking are based on the regular basf2 source code repository and releases
- Most of the framework and reconstruction code developed for offline is re-used also for the online tasks
- Some additional modules and framework functionalities were developed especially for the online data taking
- Some functionalities are not used in the basf2 processing path executed on the HLT nodes to save runtime:
  - No V0 finder running at HLT at the moment
  - One track hypothesis (pion) is fitted while in offline reconstruction the pion, kaon and proton hypothesis are fitted

In the following, some features specific the basf2 online release will be described.

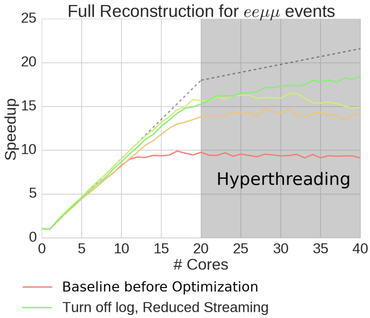
Parallel usage of Belle II Framework (basf2)

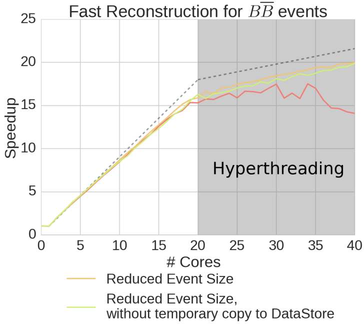
- A good multiprocessing is a crucial feature for the HLT setup, because only when using the capacity of all cores, the events can be reconstructed fast enough.
- The most challenging problem are short-running events, where the streaming and work-distribution is a quite large percentage of the whole execution time.
- As an example, we look into $ee\mu\mu$-events only doing a part or the full reconstruction (which is the setup for HLT, approx. 70 % of the HLT events will be ”small” events).
- One important measure for multiprocessing is the speedup

$$S(n) = \frac{T(n) - T_{\text{init}}(n)}{T(1) - T_{\text{init}}(1)}$$

  where n is the number of started processes.
- Only raw objects are streamed (smaller object size and less complex streaming procedure) than Reconstruction products

Performance parallel basf2





- max 18 speedup (1 input, 1 output process)
- Multiple optimizations were required to come close to the theoretical peak performance
- Possible additional bottlenecks were studied: no obvious culprit, speedup limited by resources shared by all cores: caches, RAM bus

Outcome: sufficient scaling for all event types, working point is 20 processes / node.

Software Trigger Module

- Centralized framework for all cuts and decisions applied for the HLT software stack
- Database up- and download of the cut settings and tag names
- Versioning of all cuts through the condition database
- Easy to extend calculation framework for variables needed in the cuts
- Cuts based on the well-tested `GeneralCut` from the framework
- Easy to use python interface for quick cut development
- Nearly 100% unittest coverage

```
class SoftwareTriggerModule : public Module {
public:
  /// Create a new module instance and set the parameters.
  SoftwareTriggerModule();

  /// Initialize/Require the DB object pointers and any needed store arrays.
  void initialize() override;

  /// Run over all cuts and check them. If one of the cuts yields true, give a positive return value of the module.
  void event() override;

  /// Check if the cut representations in the database have changed and download newer ones if needed.
  void beginRun() override;
```

Experience with First Belle II Collisions

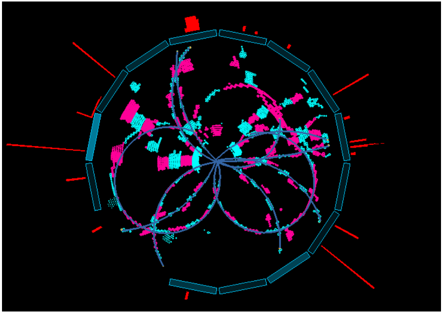
Phase II Start in February 2018 till July 2018

- Complete Belle II detector, except for the innner most silicon-based tracking system
- Primary goals: Quantify accelerator background and commission Belle II detector and associated systems

Phase III Start in February 2019

- Complete Belle II detector
- Continous physics run at peak instantaneous luminosity

First Collisions 26.4.2018!



One of the first hadronic events recorded with the Belle II Detector at 2:27 a.m. JST on the 26th April 2018.
Event data of first collision events properly recorded and processed by the Belle II DAQ and and reconstructed by the online software. Instants after the first collisions occurred, they were shown on the live event display.
Important feedback during the first hours and days of collisions !

Staged Approach for Online Software

All features contained in the release, but the complexity of the executed processing path can be selected by using the appropriate steering file.

- **Stage 1** no online reconstruction, PXD RoI generated for the full sensor, all events stored, minimal DQM on HLT (full on Express Reconstruction)
- **Stage 2** online reconstruction, PXD RoI generated for the full sensor, all events stored, DQM on HLT
- **Stage 3** online reconstruction and HLT decision computed (no filtering), PXD RoI generated from SVD+CDC tracks, DQM on HLT

Depending on the collider, detector and DAQ performance and on the stability of the software we decided when to move to the next stage of testing.

The staged approach ensured that data taking was not interrupted and new features can still be tried out.

Due to the stability of the online reconstruction, we were able to go to stage 3 already a few days after the start of data taking.

Online Software in Phase II

- High-level trigger and Exrpess Reconstruction running stably during cosmics and beam runs
- HLT trigger information is computed but not used to filter any events $\rightarrow$ all events are stored
- However: The HLT trigger information is used to select a set of events for the event display (hadronic, $\mu\mu$ etc.) and for offline skims

Future Developments: ZeroMQ

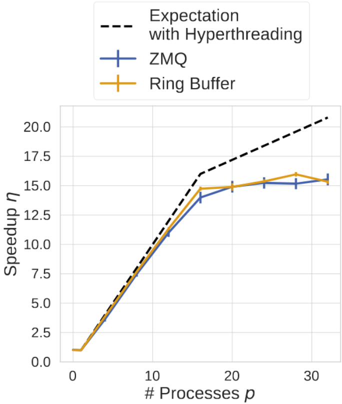
We want to implement more features for the basf2 parallel processing:

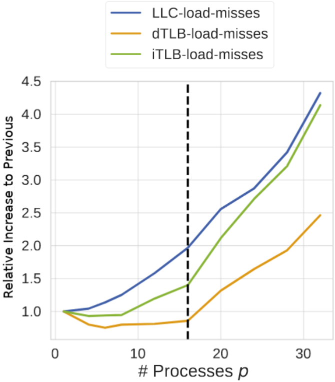
- Transfer of messages of unlimited size between processes
- Better isolation of and monitoring worker processes
- Increase the maintainability of the code base

Reimplementation effort of basf2 message passing

- The current basf2 parallel processing is based on ring buffers in shared memory to exchange event data between processes
- ZeroMQ's basic building blocks *sockets* allow to implement many message passing patterns easily: 1 to 1, publisher subscriber, shared queue etc.
- A new implementation using ZeroMQ library is complete and is currently in the testing and validation phase

Future Developments: ZeroMQ





- Tests on 16-core system confirms the new ZeroMQ implementation achieves the same performance as the ring buffer implementation
- Non-perfect scaling can be explained by the increase of cache-misses when increasing the amount of parallel processes

Summary and Outlook

Belle II Online Software performed excellent in phase II

- Early phase II running provided first chance to test the full software stack and reconstruction together with detector data
- Recorded events during the last 2 month allow us to refine our background simulation and HLT trigger configuration for the upcoming phase III

BACKUP

Relevant Software Trigger Channels

	Cross Section (nb)	Background
BB	1.1000	False
BB charged	0.5643	False
BB mixed	0.5357	False
$B \to J/\psi K_s ee$		False
$B \to \nu\nu$		False
$B \to \pi_0\pi_0$		False
$B \to \rho_0\gamma$		False
Continuum ($s\bar{s}$)	0.3800	False
Continuum ($d\bar{d}$)	0.4000	False
Continuum ($c\bar{c}$)	1.3000	False
Continuum ($u\bar{u}$)	1.6100	False

....

Relevant Software Trigger Channels

	Cross Section (nb)	Background
$ee \to ee$ (Bhabha)	74.4000	(False)
$ee \to eeee$	39.7000	True
$ee \to ee\mu\mu$	18.9000	True
$ee \to \gamma\gamma$	3.3000	False
$ee \to \mu\mu$	1.0730	False
$ee \to \pi\pi$		False
$ee \to \tau\tau$	0.9000	False
$\tau \to$ 1 prong 1 prong		False
$\tau \to e\gamma$		False

The numbers are taken from 'Overview of the Belle II Physics Generators' by P. Urquijo and T. Ferber.

FastReco

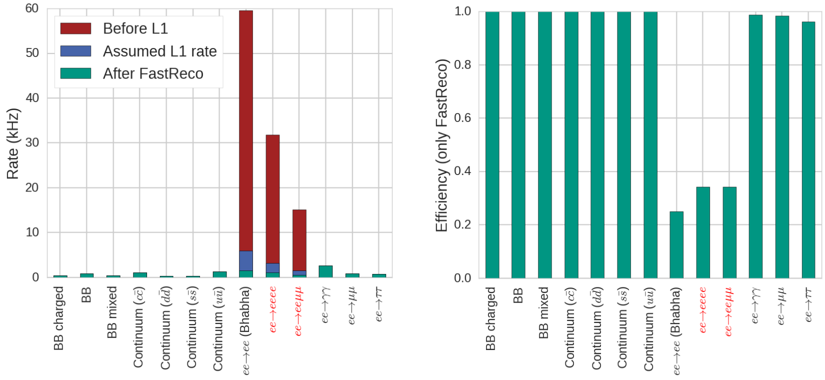
Idea: Run the the ECL reconstruction and the Legendre-based CDC track finding first

- Only around 10% of the runtime of the full reconstruction chain
- Produces ECL clusters and tracks, which can be used to reject the most copious background sources, esp. Bhabha radiation

The following variables are used for cuts after the FastReco

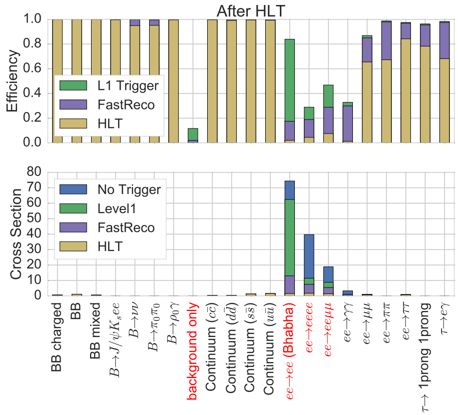
- energy sum of high energetic ECL ($> 0.05 GeV$)
- highest 2 ECL cluster energies summend, highest 3 ECL cluster energy summed
- max p_t in event
- mean(abs(z))
- mean(θ)

FastReco Efficiency



A selection based on FastReco can reduce the rate from 20 kHz up to $\approx$ 12 kHz - without affecting the signal channels.

Efficiency and Rates after HLT

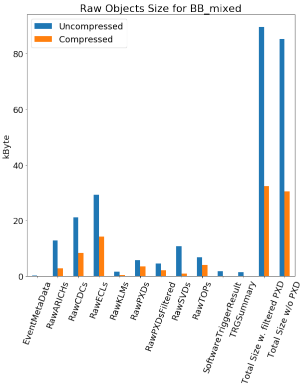


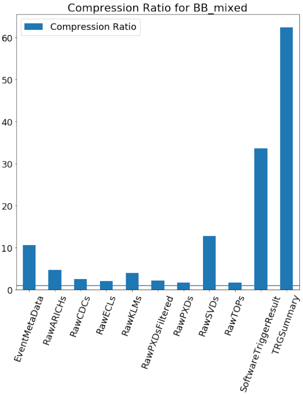
$$\mathrm{R} = \mathcal{L}\sigma = \mathcal{L}\cdot\left(\sum_{i\in\mathrm{Channels}} \varepsilon_i\sigma_i\right) \approx 8.84\,\mathrm{kHz}$$

- The shown efficiency is after Level1, FastReco and HLT.
- The HLT and FastReco can reduce the background channels to a very low rate, reaching the requested 10 kHz.
- Work on the HLT and FastReco menus ongoing
- Phase II will give valuable input to optimizing the menu, esp. with respect to backgound and L1 trigger performance

Event Size and Storage Space

Measurements wit simulated Phase II events





- Compressed Size on disk/event with PXD data = **30 kB**, Uncompressed Size w/o PXD data = **83 kB**
- Compression has very differing impact depending on the Raw object