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*НАСТОЯЩАЯ НАУКА

Data Quality Monitoring on the Silicon Vertex Detector at the Start of the Belle II Experiment

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on behalf of the Belle II PXD, SVD, DAQ, DQM and software collaboration

- Full author list is at the end of the presentation -

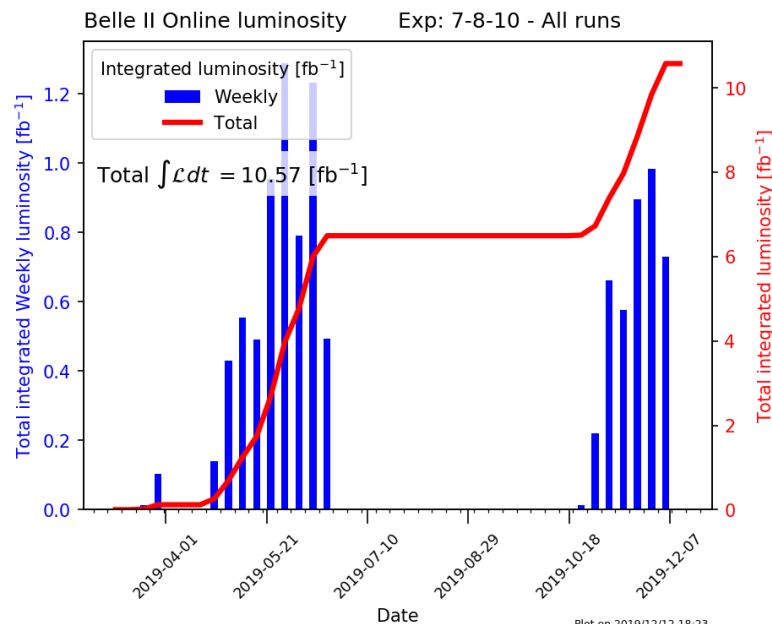
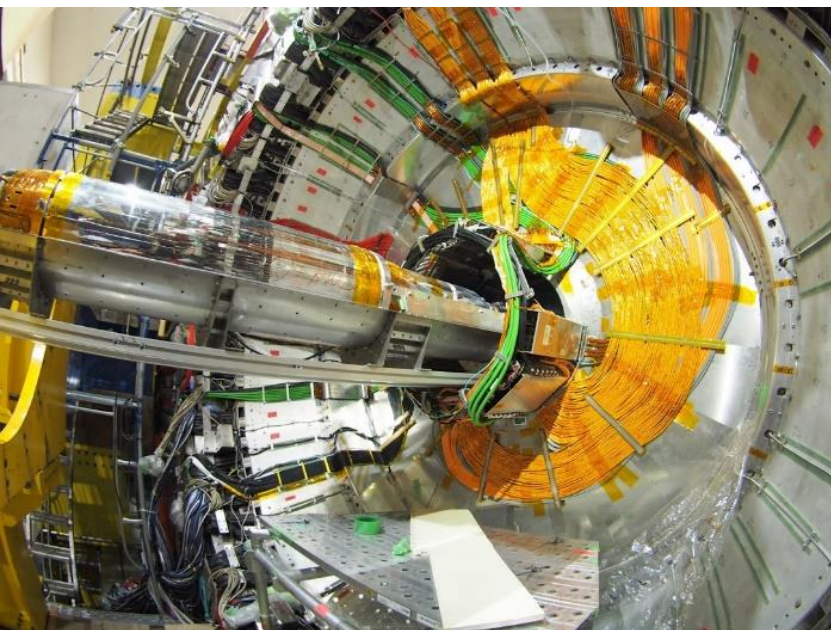
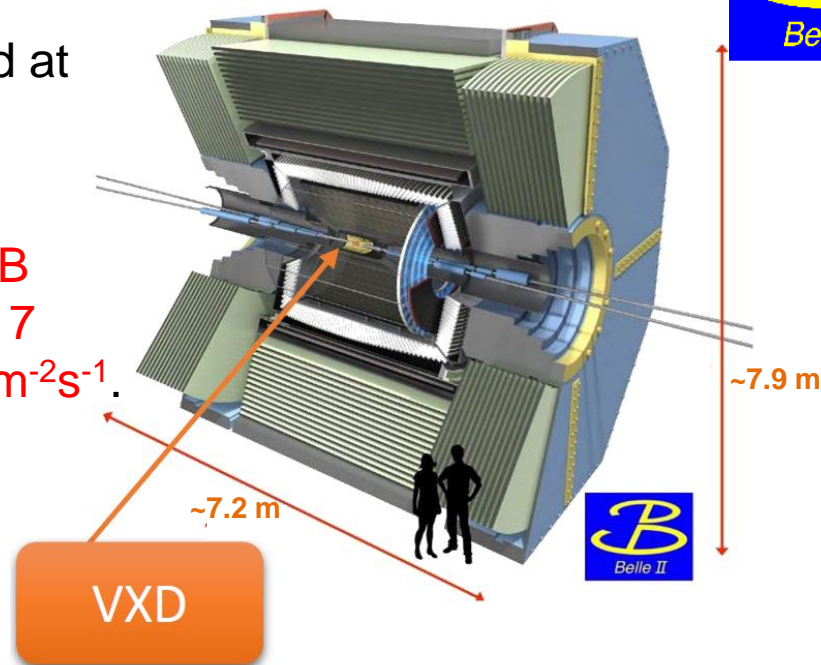
Belle II: General information



Belle II is a particle physics experiment based at the **High Energy Accelerator Research Organization** (KEK) in Tsukuba, Japan.

It is a flavor factory running on the **SuperKEKB** accelerator, an **asymmetric-energy e^+e^-** (4 on 7 GeV) collider with **design luminosity $8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$** .

First physics data with full detector acquired in March 2019.



Belle II: VXD design details



The central vertex and tracking detector of Belle II consists of 2 layers of pixel sensors (PXD), 4 layers of strip detectors (SVD), and a large wire chamber (CDC).



Pixel Detector (PXD)

- Layer 1 of 16 DEPFET sensors
- Layer 2 of 4 DEPFET sensors
- $r = 14 \text{ mm}, 22 \text{ mm}; L = 120 \text{ mm}$
- More technical details on backup slides

Belle II: VXD design details



The central vertex and tracking detector of Belle II consists of 2 layers of pixel sensors (PXD), 4 layers of strip detectors (SVD), and a large wire chamber (CDC).



Silicon vertex detector (SVD)

- 4 layers of double-sided silicon strip sensors, 172 in total
- 768 strips on the p-side, 768 (512) strips on the n-side
- $r = 39, 80, 104, 135$ mm; $L = 600$ mm
- Total sensor area 1.2 m^2
- More technical details on backup slides

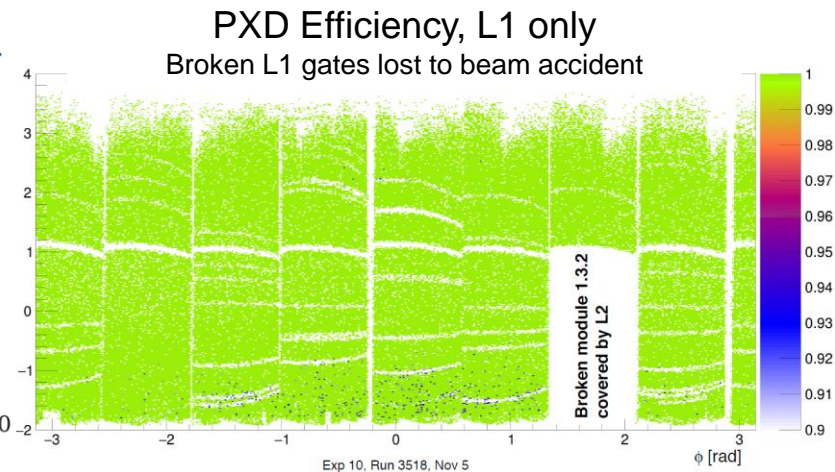
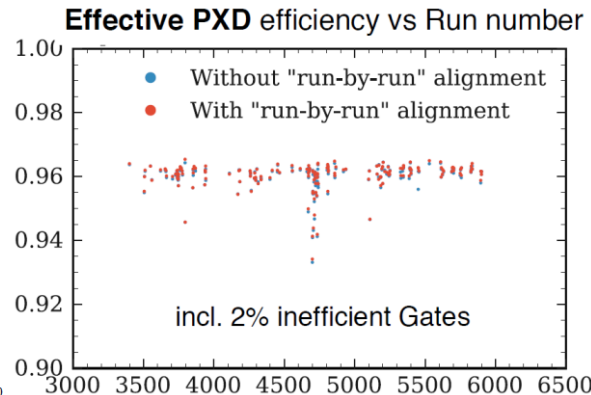
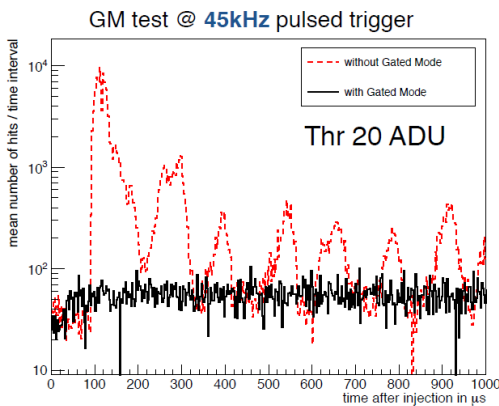
VXD operation: PXD



- The pixel detector currently consist of layer 1 and 4 sensors of layer 2.
- In the Fall 2019 period, PXD performed consistently well with **efficiency over 98%**.
- PXD functionality had to recover from a loss of modules due to operation accidents in spring 2019. Some affected areas of the detector have been dead ever since.
- PXD **ROI selection** successfully verified
- PXD **gated mode operation** has been tested in most modules.

Gated mode operation is a unique feature of DEPFET sensors that allows, during a short time interval, to make DEPFET pixels **insensitive to incoming radiation**. Pixels normally continue integrating charge. Yet, newly acquired charge is cleared and never reaches the internal gate. Thus **pixels keep the charge acquired previously** and the charge generated during the time interval is ignored.

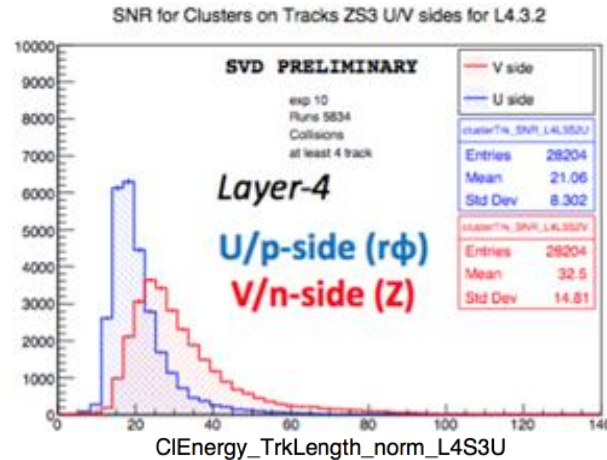
ROIs (Regions of Interest) are areas on the PXD where SVD tracking predicts a high probability of a useful track hit. We use ROI prediction to **decrease PXD event data size by order of magnitude**.



VXD operation: SVD

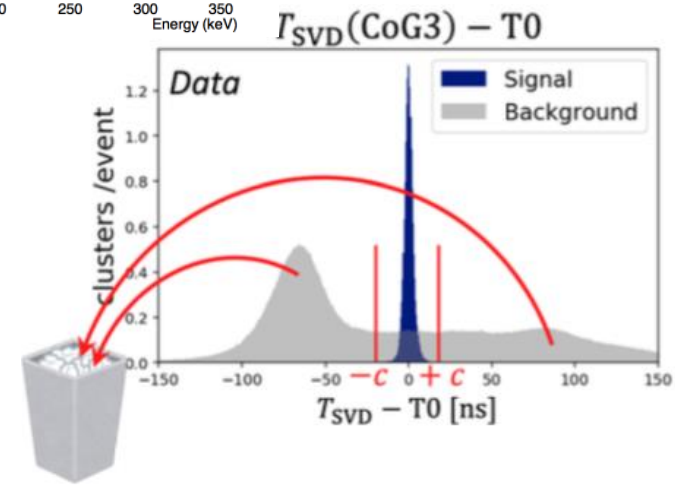
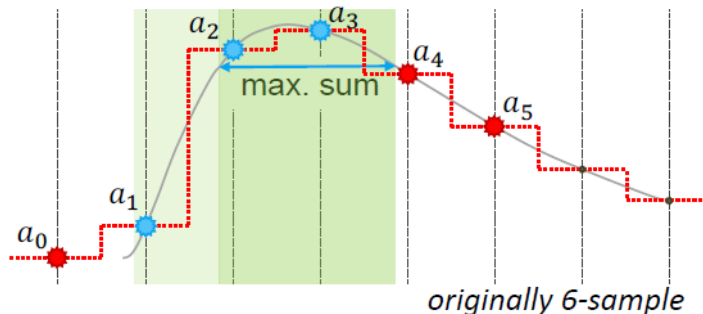
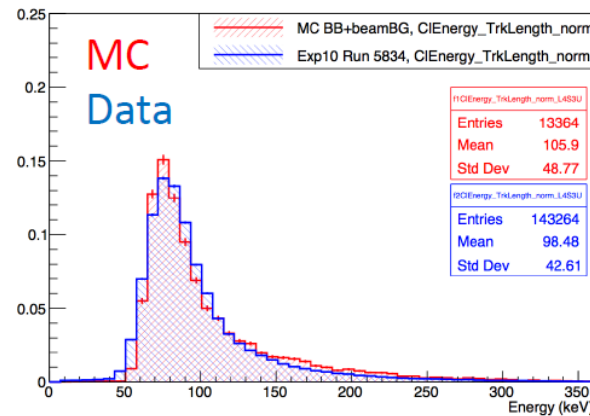


- The **strip detector** (SVD) was **fully installed** as designed.
- SVD was successfully commissioned in the first 2019 runs.**
- Achieved smooth operation and stable performance: hit **efficiency > 99.5%**, **SNR 15-30 in all sensors**
- Detailed studies on hit position resolution and improvement of DATA/MC matching are ongoing
- SVD **occupancy ~0.3%** - **far from the limit** of 2-3%
- To better cope with higher background expected in future years @ higher luminosity:
 - Excellent hit **time resolution achieved ~3 ns** will be exploited for background rejection
 - data reduction** from 6 signal samples / hit to 3 samples / hit



$$SNR = \frac{\sum_i S_i}{\sqrt{\sum_i N_i^2}}$$

S_i (N_i) are the signal (noise) on i_{th} strip



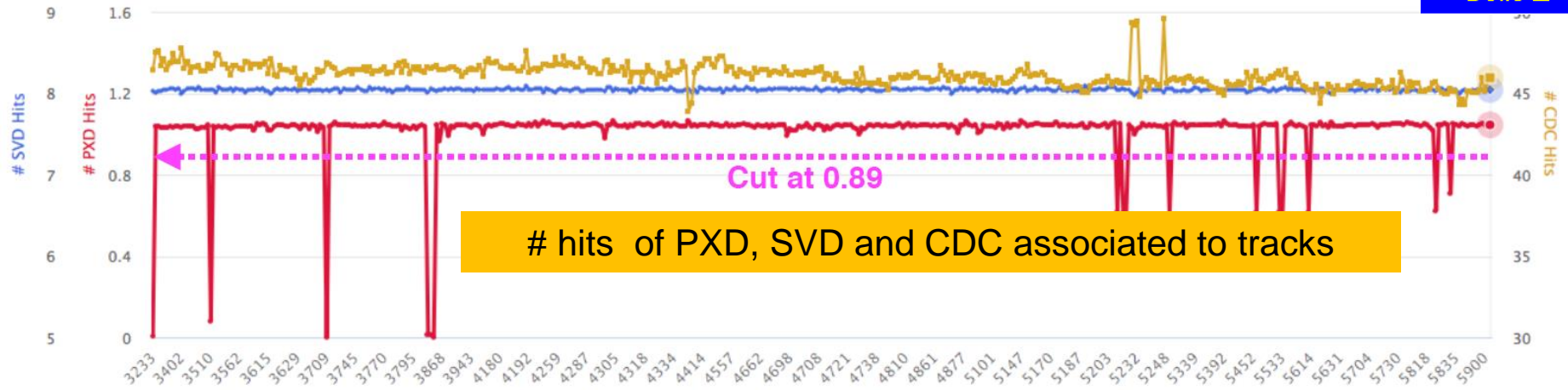
VXD operation: stability



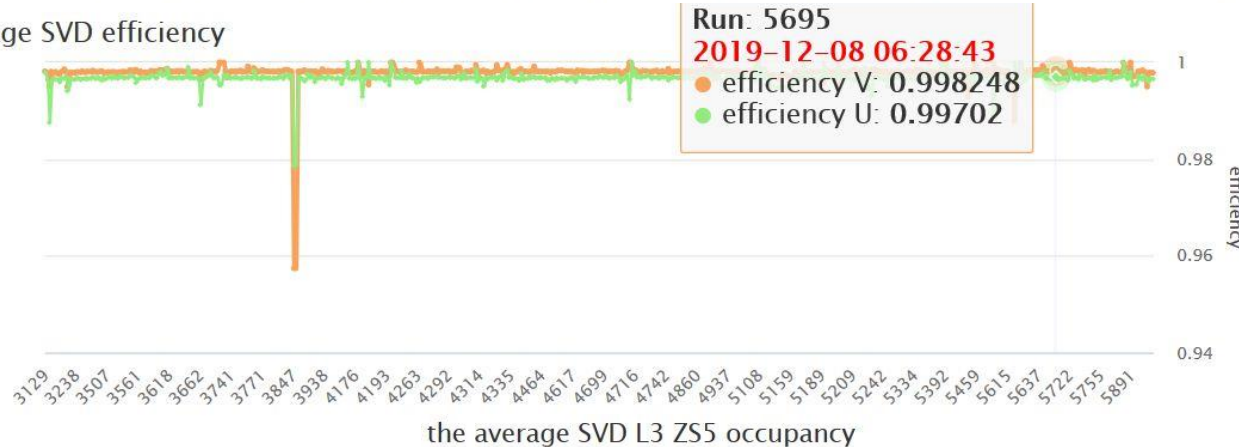
Detector Hits associated (PXD,SVD,CDC)

$N_{\text{event}}(\mu\mu) > 500$

Experiment 10

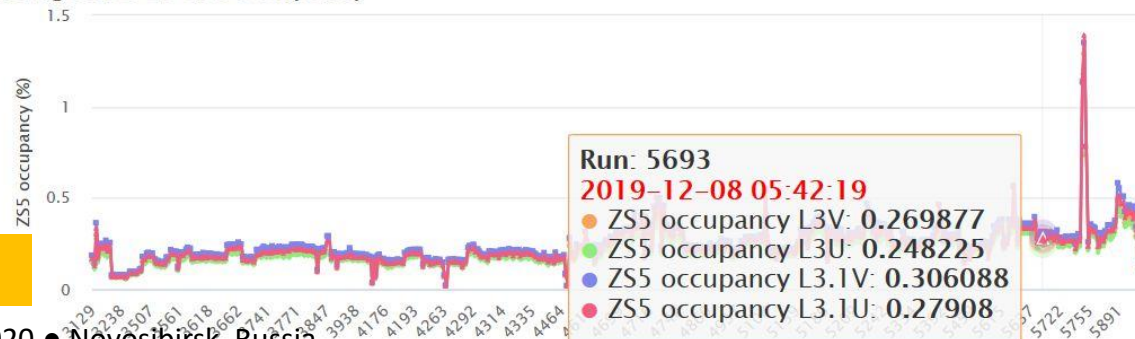


the average SVD efficiency



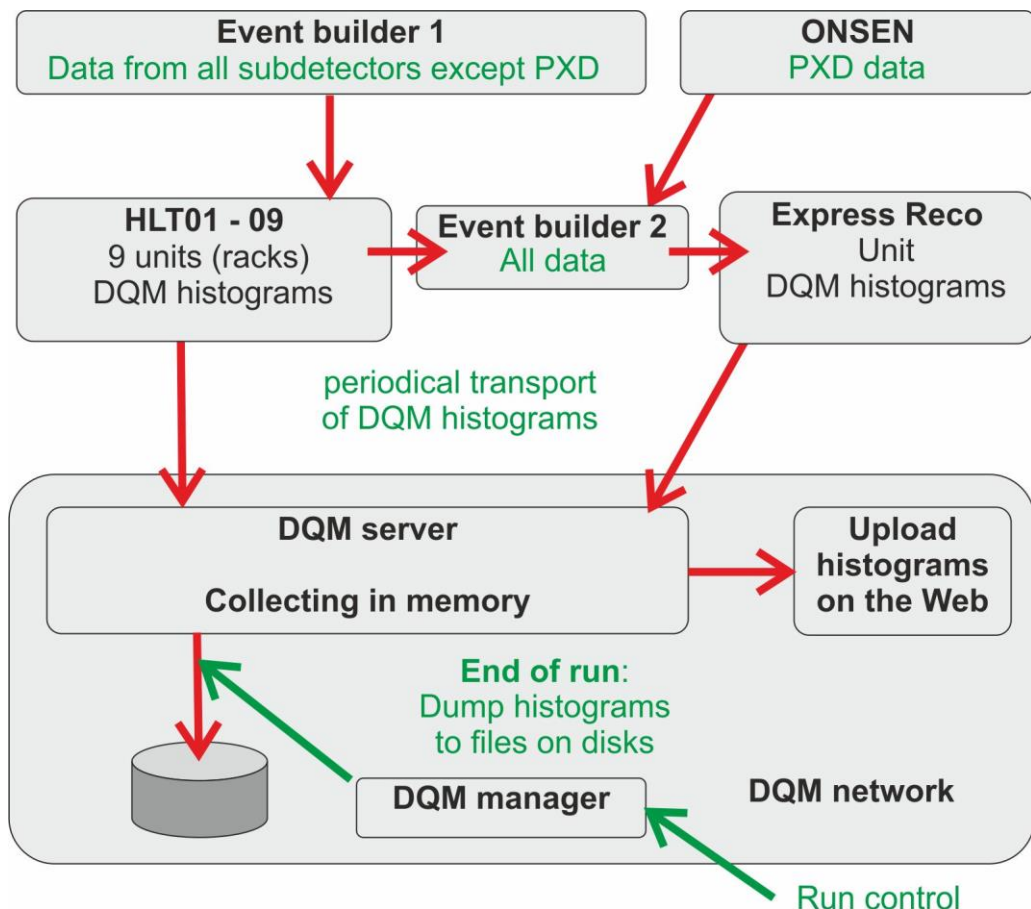
In the Fall 2019 period, PXD & SVD achieved smooth operation and stable performance

the average SVD L3 ZS5 occupancy



SVD occupancy of layer 3

VXD data acquisition workflow



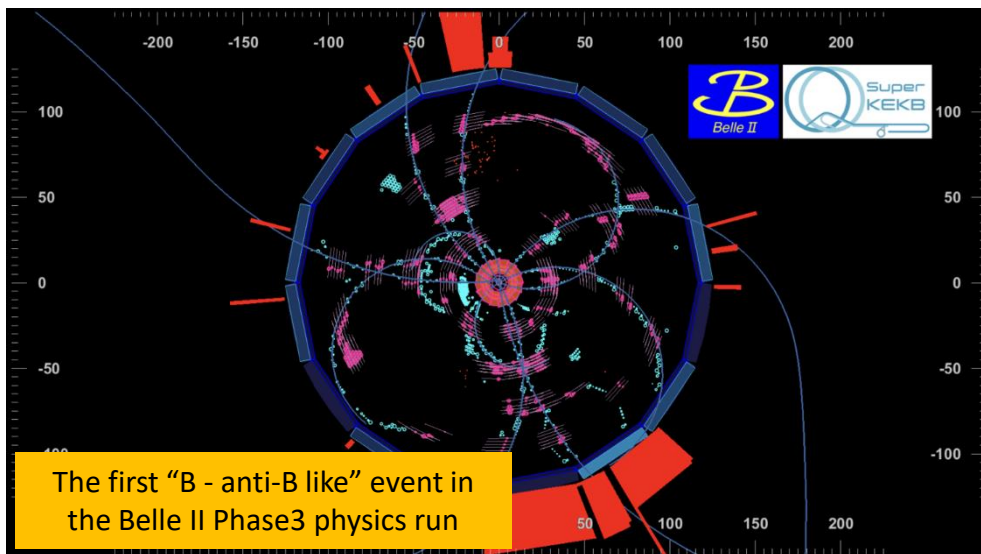
Data workflow for quality monitor of the PXD and SVD subdetectors. Red arrows represent data flows, green markings represent DQM.

- Periodically, more than **7500 histograms** are updated **every ~2 minutes**. **DQM bandwidth** is up to 20-30 MB/s.
- Two sets of DQM histograms are created: from **HLT 01-09** (low-level, timing, triggering etc.) and from **Express Reco** (detector and reconstruction-related).
- Express Reco creates histograms **including PXD** data.
- Only a **subset of data** is processed by Express Reco.
- Dumping of histograms is controlled by the **DQM manager** computer.

Online data monitors are used to **confirm standard performance** of subdetectors and **identify any detector failure**. This helps us to avoid significant data losses and achieve uniformly high data quality.

Also, the monitors confirm proper operation of slow- and run control, and data acquisition chain. They help to **identify acceptable runs** for further processing.

- Data quality monitors use the Belle II **basf2 framework** for data simulation and analysis, running on **a set of isolated computers** with **conservative** update plan to keep **stability** of production.
- Use of **jsroot** for interactive access to the histograms.
- Connection to database and public network is forbidden, **only local services** are used.
- **Data quality monitoring** uses **reconstruction** in the basf2 software framework, up to vertex reconstruction
- Analysis **up to decay reconstruction** is running quasi online on the Express Reco node to check the functionality of full detector.
- Various histograms are accumulated in real time and are monitored by experimental shifters during operation.



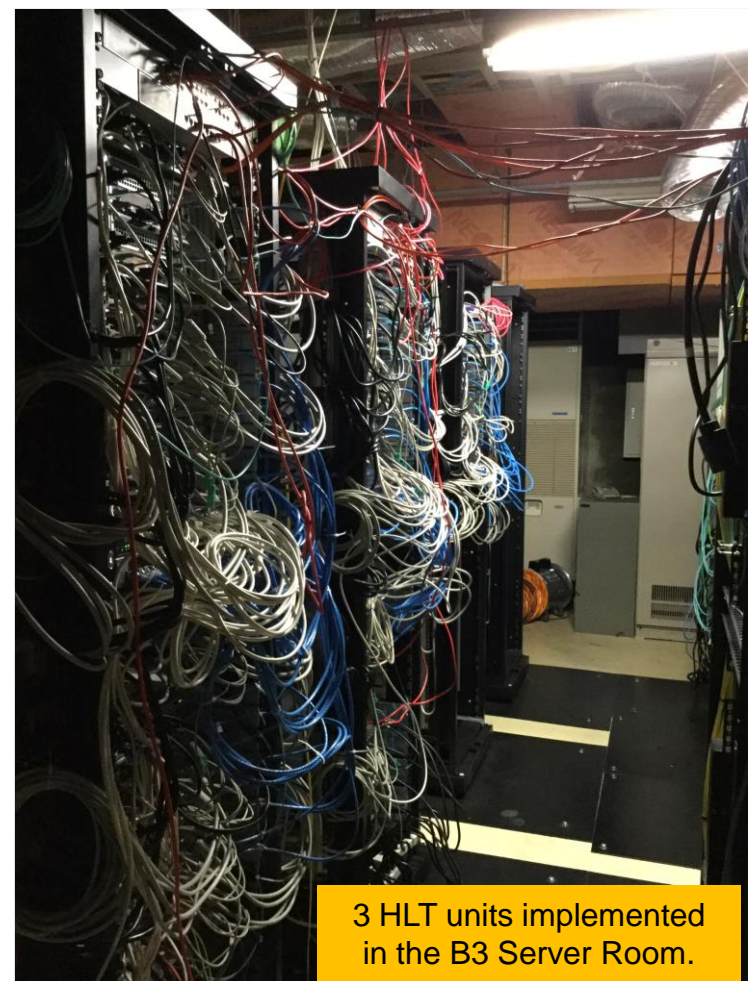
DQM hardware requirements



- At the full luminosity of $8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$, the **physics rate** is **4 kHz** for BBbar and Continuum events and 2 kHz for “low multiplicity” events.
- The expected **average L1 trigger rate** at the full luminosity is **30 kHz** maximum, and it is supposed **to be processed with 6400 cores**. The required **processing rate per core is ~3Hz** resulting in the required average processing time per core and event to be **~0.3 sec**.
- The physics rate estimation shows that at 3 Hz rate, 20% are from BBbar and Continuum, 10% from “low multiplicity” events, and the remaining 70% from other events including beam background radiation.
- The processing time **for “low multiplicity” and “other” events** is expected to be **significantly less** than that for hadronic (BBbar + Continuum) events.



If we assume the processing time per core for a hadronic event (20%) to be 1.0 sec and 0.1 sec for “low multi” and other events (80%), the average processing time per event could be 0.28 sec, which satisfies the 3 events/core/sec processing rate requirement.



3 HLT units implemented in the B3 Server Room.

Data quality online monitoring – HLT vs. Express Reco



- The **HLT cluster** contains **9 units** (racks) for parallel processing events. The Express Reco contains one unit and processes only a sample of events from the data stream.
- **HLT and Express Reco produce histograms** for online monitoring and presentation on the **Web for remote shifters**.
- **PXD data bypass HLT**. PXD histograms are available only from Express Reco.
- HLT and Express Reco reconstruction does not use calibrations from online database.

Belle II DQM Monitoring Pages

This is Belle II DQM monitoring page. Please refer to the following links for DQM monitor.

Live Histograms for Shifters

Histograms are shown interactively.

[HLT histograms for shifters](#)

[ExpressReco histograms for shifters](#)

Live Histograms for Experts

Histograms are shown interactively.

[HLT histograms for experts](#)

[ExpressReco histograms for experts](#)

Online Display for Past Runs

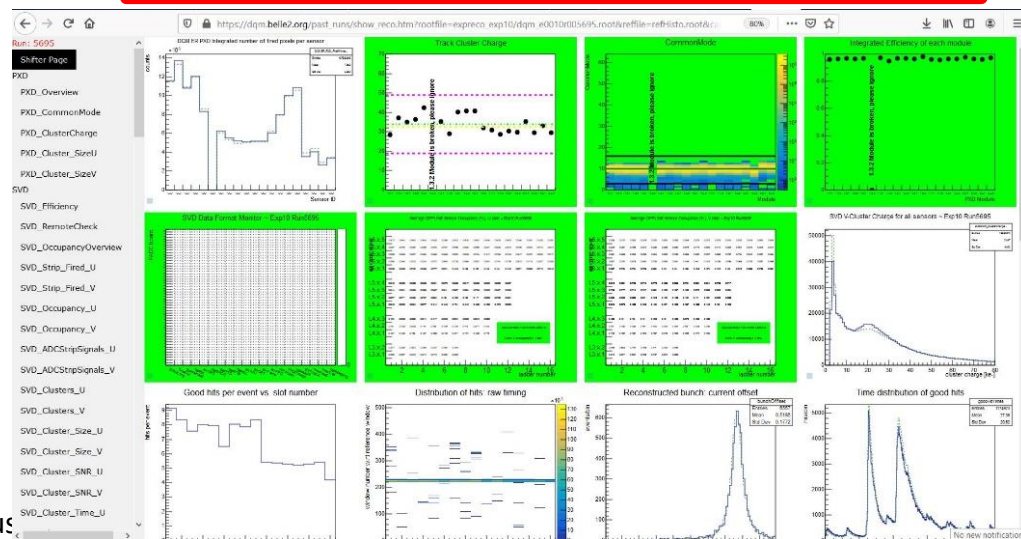
The following pages show the online display for past runs

For Experiment 8:

[HLT Past Runs Display](#)

[ExpressReco Past Runs Display](#)

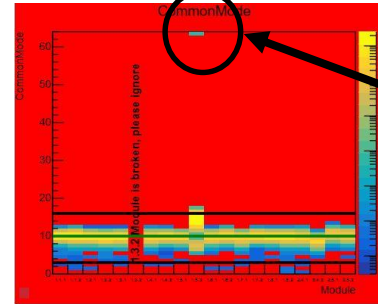
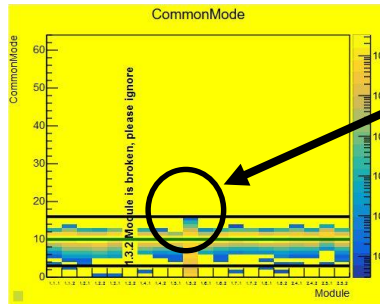
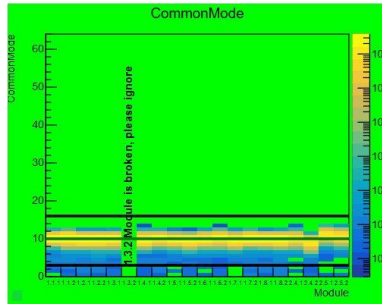
Run 2951	Download	RawFile	OnlineDisplay
Run 2950	Download	RawFile	OnlineDisplay
Run 2949	Download	RawFile	OnlineDisplay
Run 2948	Download	RawFile	OnlineDisplay
Run 2947	Download	RawFile	OnlineDisplay
Run 2946	Download	RawFile	OnlineDisplay
Run 2945	Download	RawFile	OnlineDisplay
Run 2944	Download	RawFile	OnlineDisplay
Run 2943	Download	RawFile	OnlineDisplay
Run 2942	Download	RawFile	OnlineDisplay
Run 2941	Download	RawFile	OnlineDisplay
Run 2940	Download	RawFile	OnlineDisplay
Run 2939	Download	RawFile	OnlineDisplay
Run 2935	Download	RawFile	OnlineDisplay
Run 2934	Download	RawFile	OnlineDisplay



DQM: alerts, reference plots, diagnostics



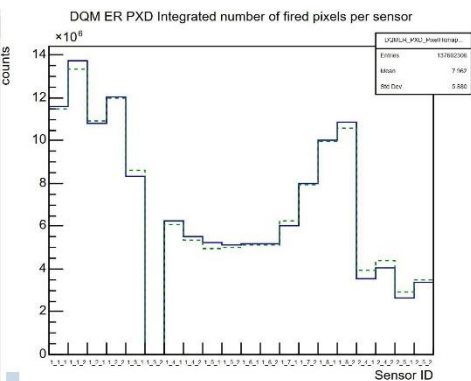
- The DQM system provides **several hundred plots** of various quantities.
- Mostly they are intended **for expert shifters** to diagnose sources of DAQ and detectors problems.
- A more **limited set of plots** is selected for monitoring by **control room shifters** so that they can spot problems quickly, even without expert knowledge about individual subdetectors.
- **Automatic comparisons** with reference data are provided together with **color-coded** plot canvases indicating **serious deviations from reference** (green plot frame meaning no problem) so that problems can be spotted quickly among a large number of plots.
- In case of problems or unclear situations, CR shifter can alert expert detector shifters by a dedicated **chat channel, e-mail, or phone**.
- Any problems are logged, and shifters can subsequently **label runs** as OK or problematic.
- Shifters can also consult **run-by-run comparisons** of selected sets of variables.



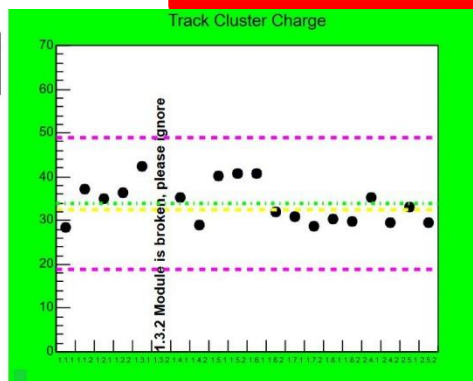
DQM – conditions for alerts, reference plots, diagnostics



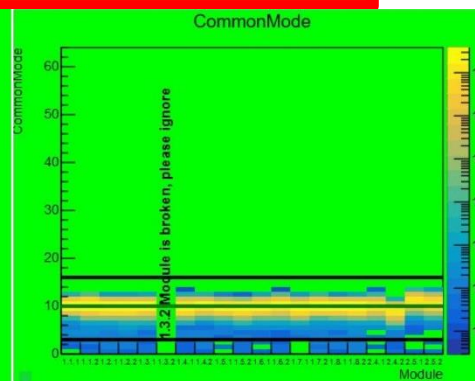
PXD: 4 basic DQM plots



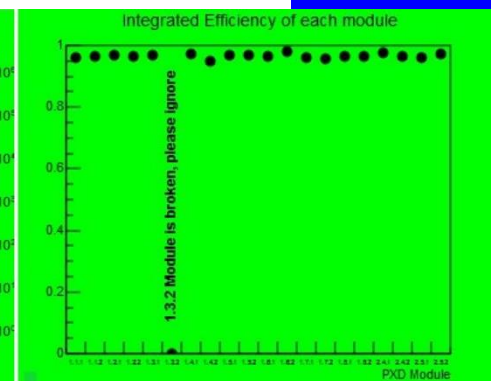
Occupancy – fired pixels



Track cluster charge

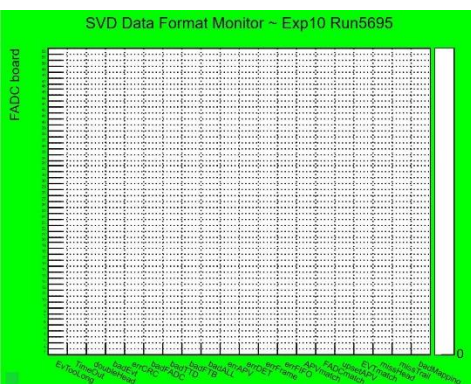


Common mode (signal offset found in all raw data values sampled at the same time)

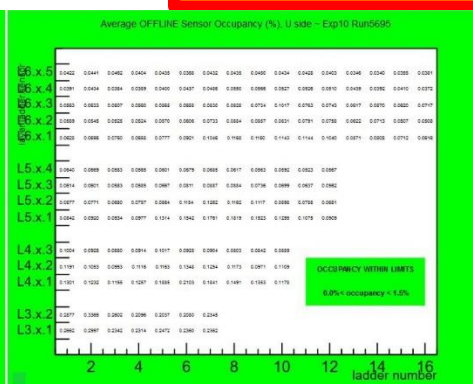


Efficiency

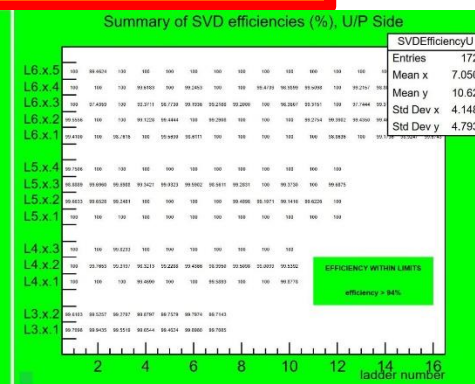
SVD: 4 basic DQM plots



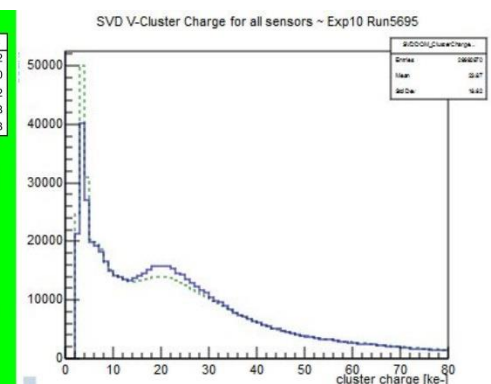
FADC monitor data format check



Occupancy in U strips



Efficiency



Cluster charge in V strips

Highlighted run 5695, 8 December 2019.

VXD DAQ and DQM operation



- Both **Event Builder 1** and **Event Builder 2** are working stably.
- ZMQ-based processing parallelization (ZMQHLT) has been deployed in all HLT units.
 - The data flow is basically working stably
 - System control still undergoing improvements
- **STOP – ABORT – LOAD – START** sequence solves most DAQ-related problems
- **File transfer** to disks from HLT units works stably.
- **Express Reco / Event display**
 - working without serious trouble.
- **DQM units:**
 - Histogram transport working stably.
 - Histogram browser working fine.





Conclusion

The coming spring Belle II run is mostly dedicated to 24/7 physics data taking, the stability of DAQ DQM is a critical issue.

Daily operation of the vertex detectors requires round-a-clock shifts at a considerable cost in terms of work time and management. Automation of DQM tasks can help to reduce this burden while maintaining a high level of data quality.

- PXD and SVD detectors perform well in acquisition of data usable for physics.
- Belle II operated successfully in full detector setup in 2019.
- DQM processing scheme works.
- Online monitors of data quality work and are being optimized for best usability.
- Data quality monitors follow incoming requests and progress in the DAQ system.
- List of monitored values for pixel and strip detectors have been and can be modified on request.
- Updating of DQM software and reference plots is conservative but not frozen.



Thank you for your attention, спасибо за внимание

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Lorenzo Vitale², Sven Vogt³, Marcel Vos¹⁶, Kun Wan⁶, Boqun Wang³, Shun Watanuki⁴¹, James Webb⁴², Norbert Wermes⁵, Christian Wessel⁵, Jarosław Paweł Wiechczyński¹³, Philipp Wieduwilt²², Hendrik Windel⁹, Satoru Yamada²⁶, Hua Ye¹¹, Hao Yin¹⁸, Laura Zani¹³, and Tingyu Zhang⁶ for the Belle II PXD, SVD, DAQ, DQM and software collaborations

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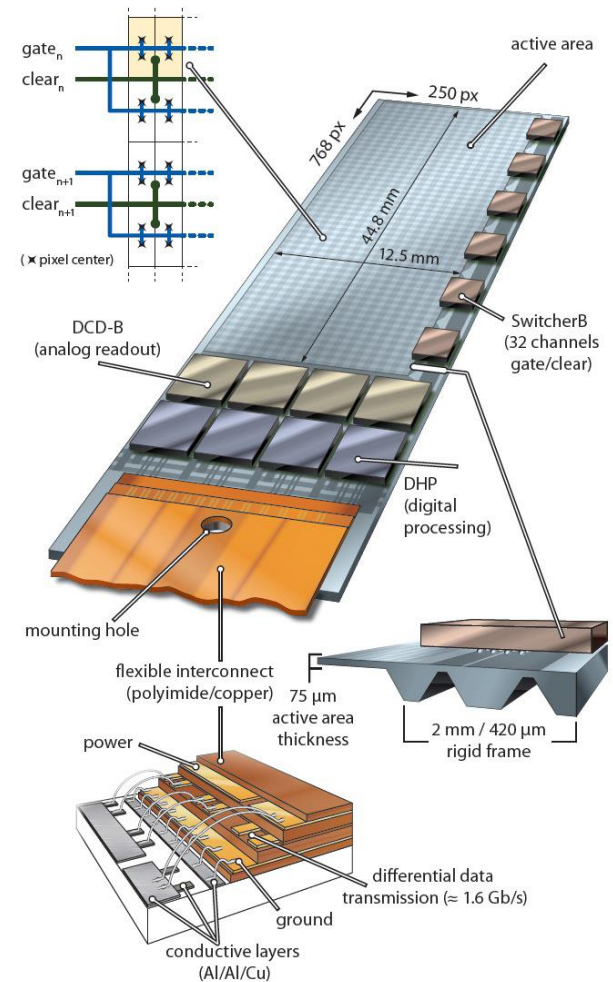
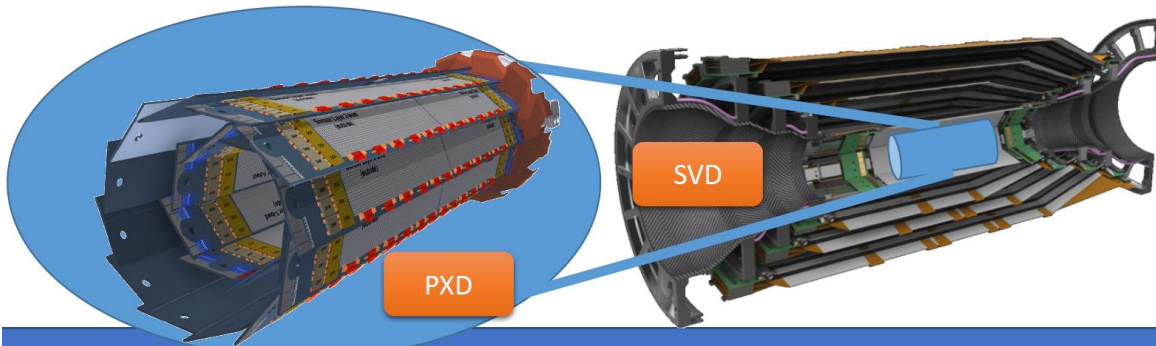
⁴²Univ. of Melbourne, Australia



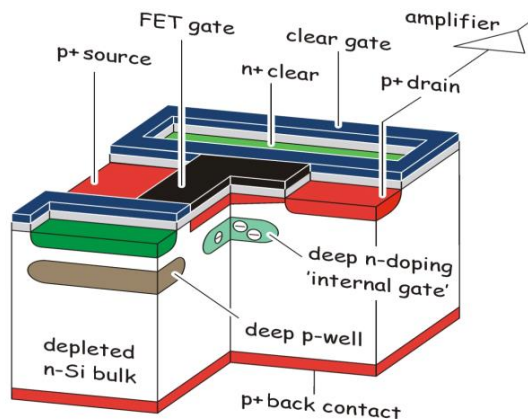


Backup slides

PXD: The DEPFET sensor and readout



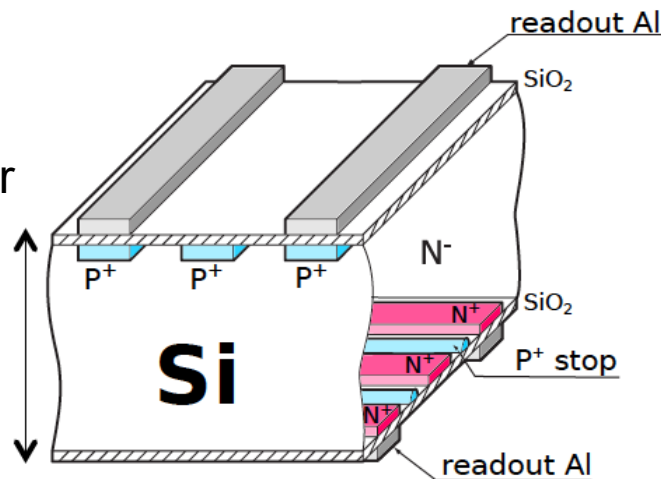
The DEPFET technology of active pixel sensors is among the frontier detector concepts for high energy physics at high luminosities.



Belle II consist of:
 40 PXD half ladders with
 250 × 768 pixels each
 and 7.6×10^6 pixels in
 total, expected occupancy
 up to 3%, at 30 kHz
 trigger rate, PXD
 produces 30 GB raw data
 per second..
 Data volume is further
 reduced by a factor of 10.

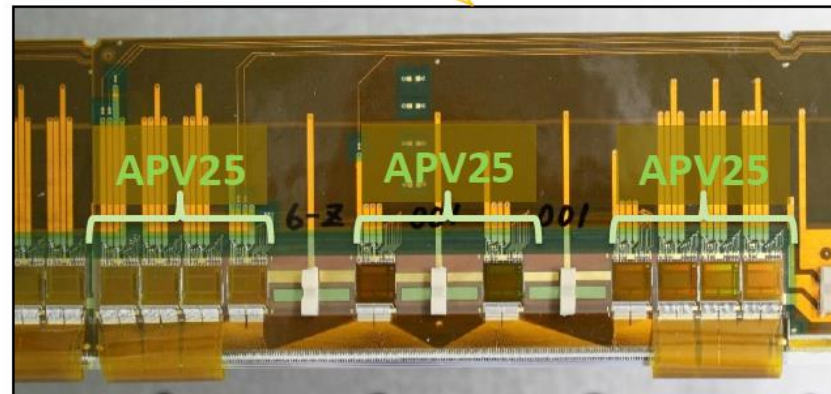
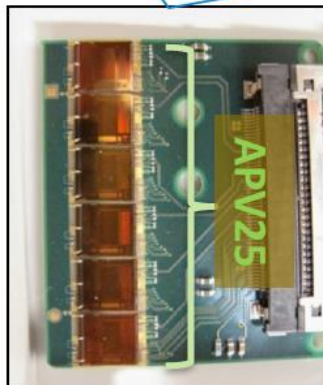
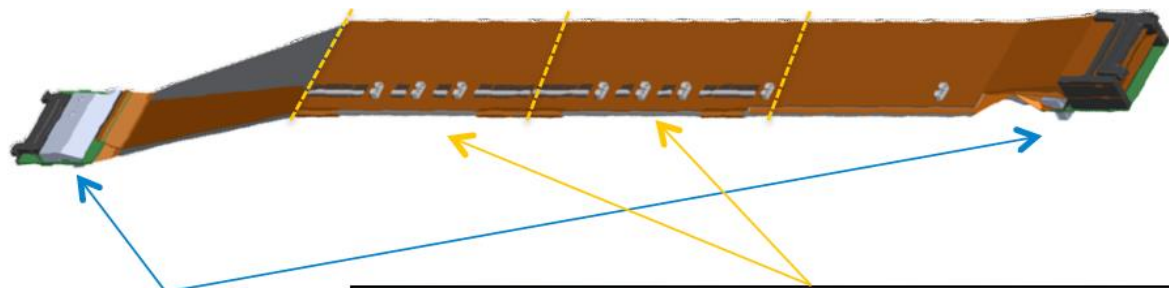
SVD sensor and readout

300-320 microns thick double-sided silicon microstrip detector (DSSD): p-in-n 6" wafer



APV25 chip: originally developed for CMS.

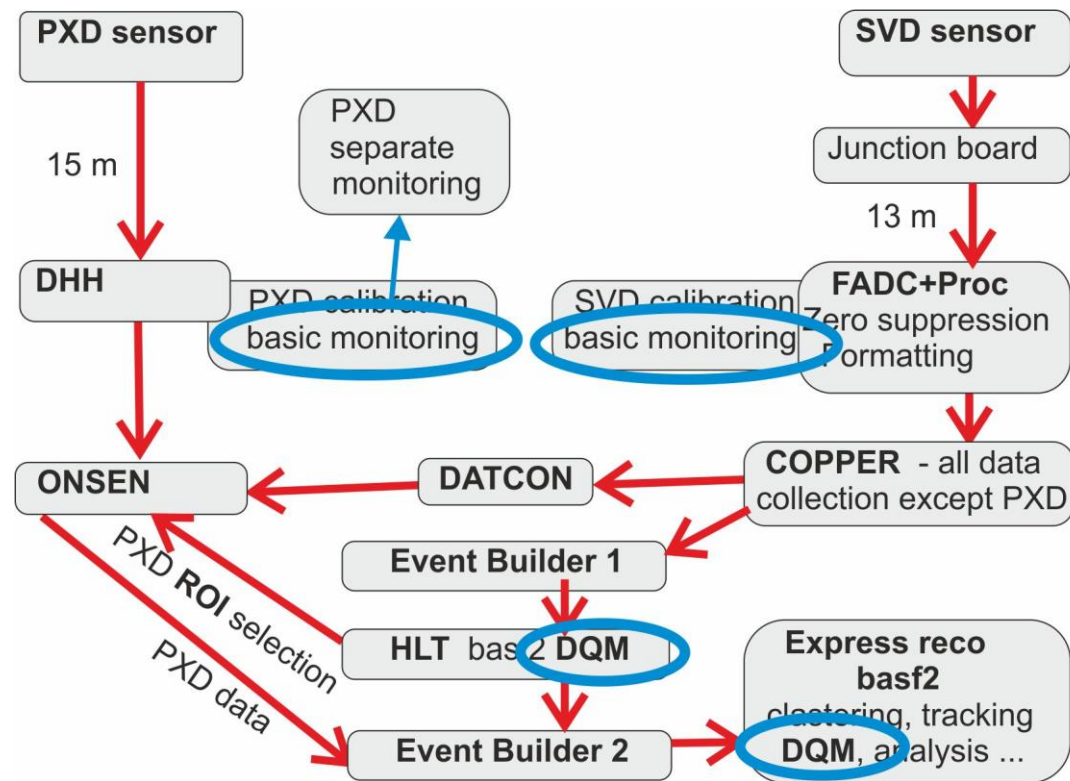
- Shaping time: 50 ns
- # input channels: 128 per chip
- 192 cells deep analog pipeline for dead time reduction
- Thinned down to 100 μ m to minimize material budget
- Central DSSDs \rightarrow 'Origami' chip-on-sensor design to reduce capacitive noise



VXD DAQ and Data Quality Monitoring



Details: DOI: <https://doi.org/10.1016/j.nima.2018.09.003>



Event builder 1 collects data from all subdetectors except PXD and sends it **to the HLT (High Level Trigger) cluster** for processing (histogramming)

PXD data follow a separate path **to Event Builder 2** to **merge** with the rest.

Event Builder 2 sends a sample of its data (so far 100%) to the **Express Reco cluster**, which is the central DQM processing unit.

Data flow (red arrows) for the Belle II vertex subdetectors. The blue markings show data quality monitoring modules.