Data rates from the Vertex detector and managing the beam backgrounds

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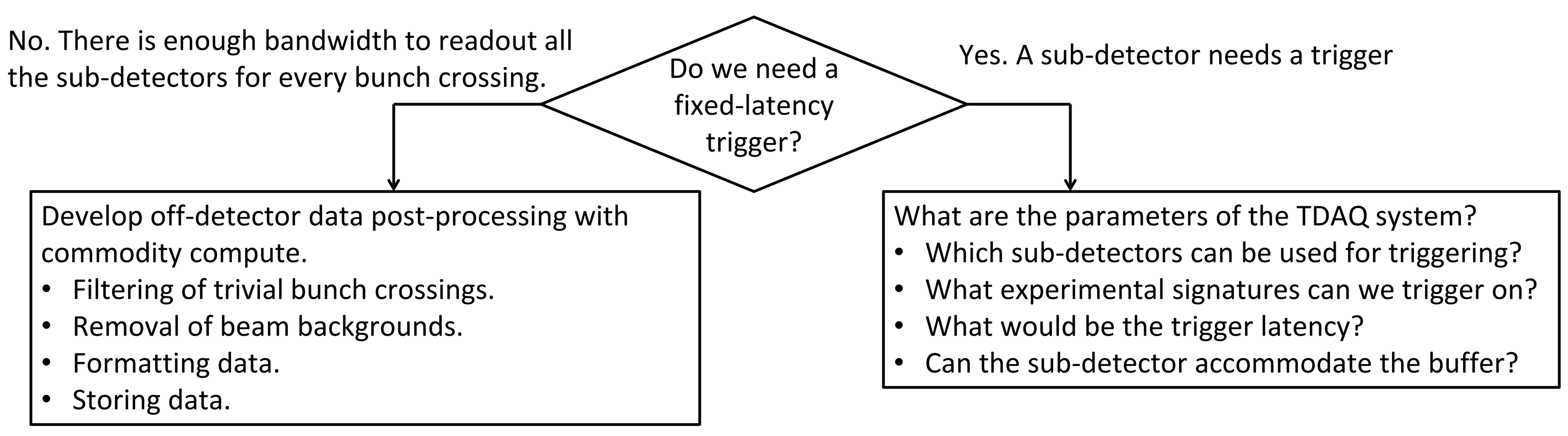
Trigger and Data Acquisition (TDAQ) systems for FCC-ee experiments

The FCC–ee experiments will be producing a lot of data to carry out a variety of searches and measurements. Each detector would need a TDAQ system to transmit its data to commodity computing for further processing. One in about 250 e^+e^- bunch crossings would contain an e^+e^- hard scatter, so real-time collision data filtering (triggering) may be possible.

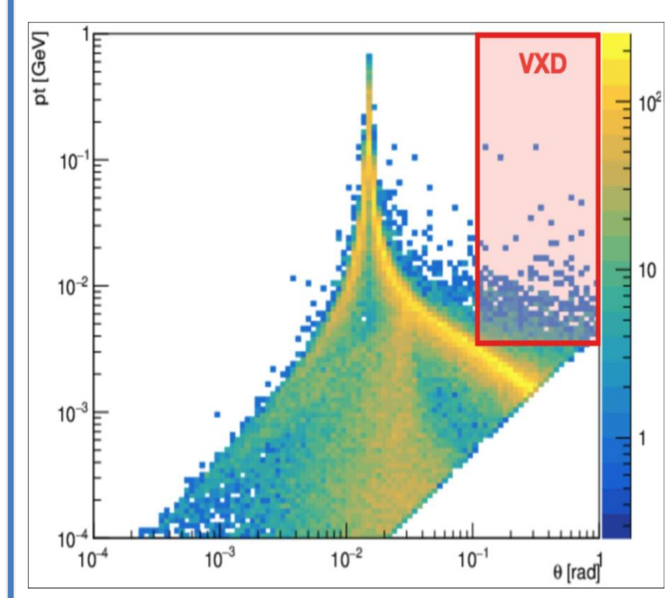
The abundance of data will enable measurements with extreme accuracy; uncertainties on the order of 10^{-5}. Therefore, the TDAQ system should not contribute to the systematic uncertainties more than 10^{-5}. All the data losses from bit errors, hardware failures, buffer overflow in large events should be tiny, and, ideally, all accounted for. If triggers are used, the uncertainty on the trigger efficiency needs to be less than 10^{-5}. The need for a fixed-latency triggering is dictated by a combination of the available data link technologies, detector bandwidth, beam backgrounds, and expected collision rates.

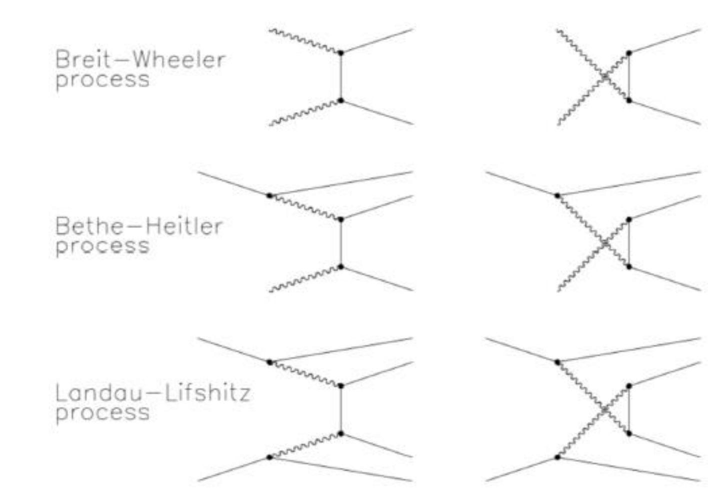
Detailed simulations of data rates are needed to design a TDAQ system.



The trigger-free readout is easier to develop and support that a fixed-latency trigger but it requires more off-detector compute.

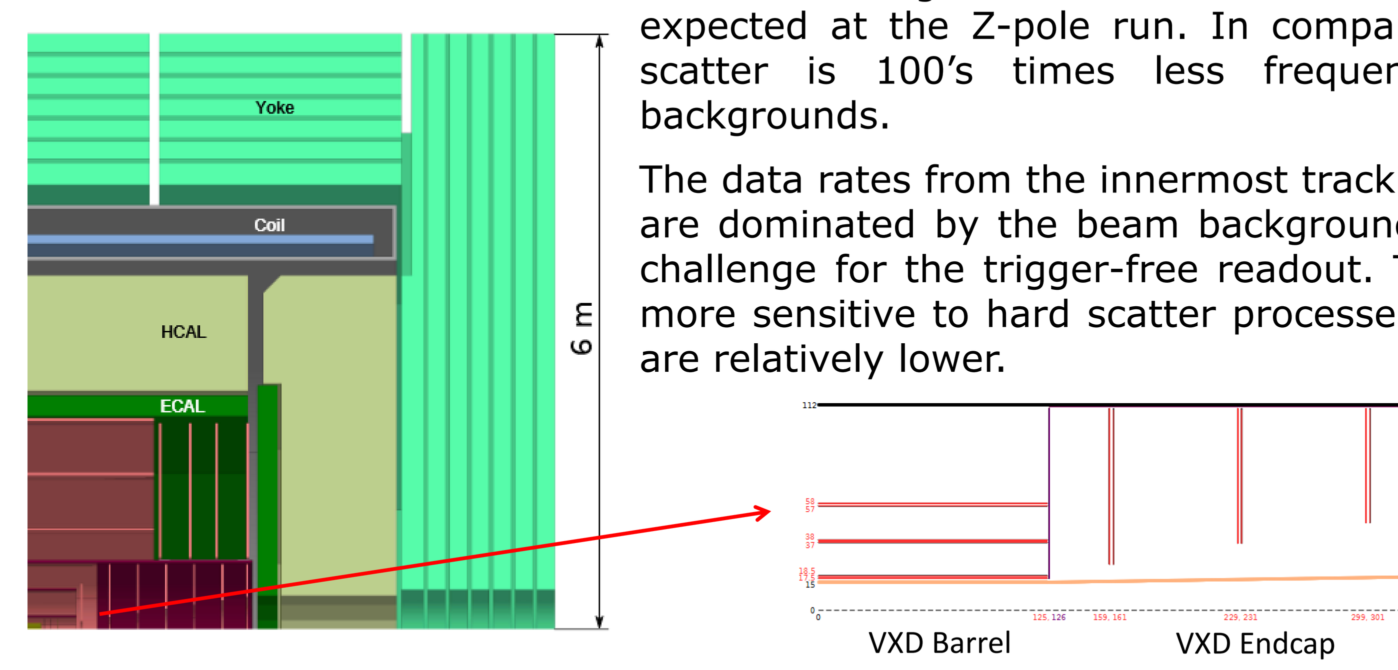
Beam backgrounds





Incoherent e^+e^- pair production is the main source of beam-induced backgrounds. The worst background rate is expected at the Z-pole run. In comparison, the e^+e^- hard scatter is 100's times less frequent than the beam backgrounds.

The data rates from the innermost tracking (vertex) detector are dominated by the beam backgrounds. That's the major challenge for the trigger-free readout. The outer layers are more sensitive to hard scatter processes and the data rates are relatively lower.



Detailed simulations of the vertex detector

We are using GEANT4-based detector simulations via ddsim

Guinea Pig–based beam background samples are kindly provided by the MIT and UniGE teams (thanks to Jan and Stefano).

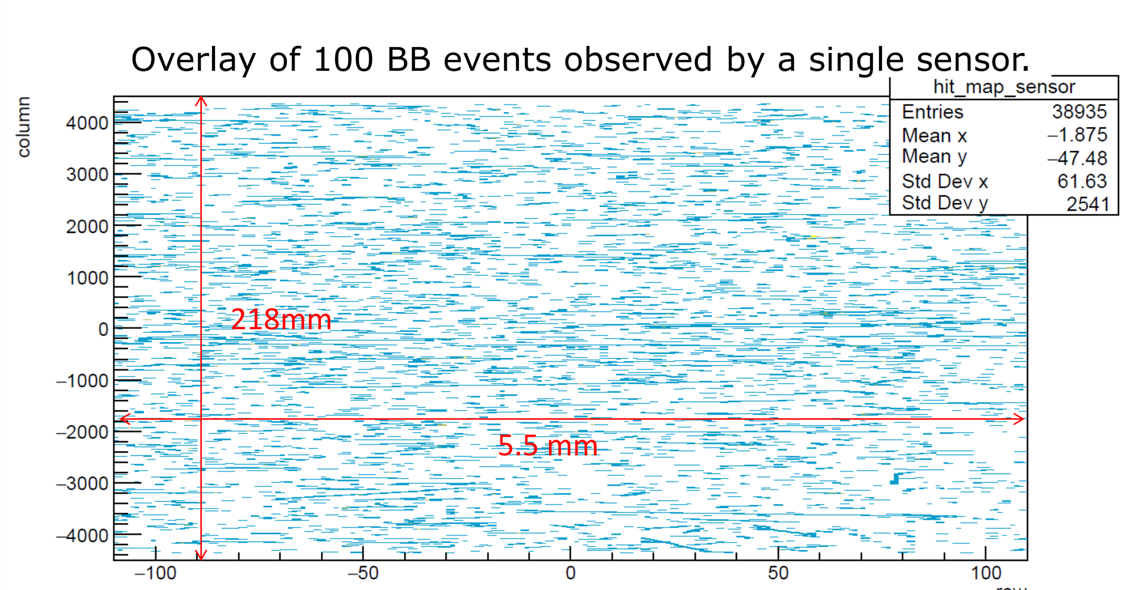
The Vertex Detector digitization is implemented by the Lyon team (thanks to Jessy Daniel, Gaelle Boudoul, and others).

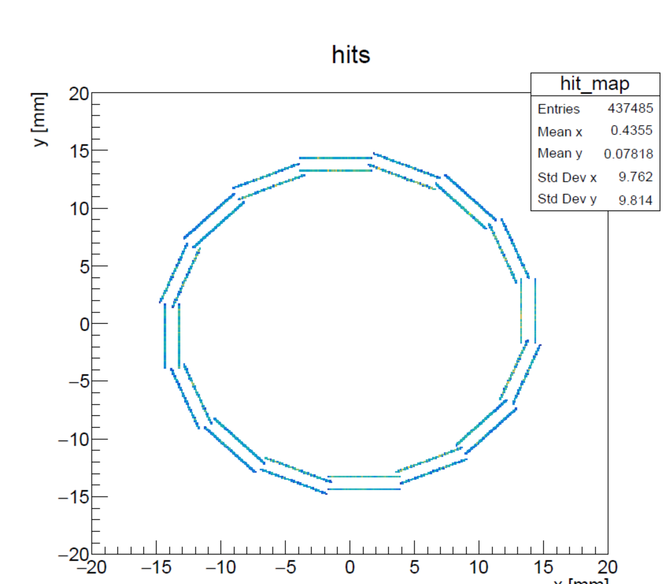
The simulation uses 25x25 um² pixels. The active layer is 50 um thick.

For the hard scatter events we used ZH where Z decays to muons and H decays inclusively.

Our digitization code is using the package from the Lyon group and it outputs individual pixels.

The new digitization code is in GIT: https://gitlab.cern.ch/caoh/k4rectracker
https://gitlab.cern.ch/caoh/cld_config





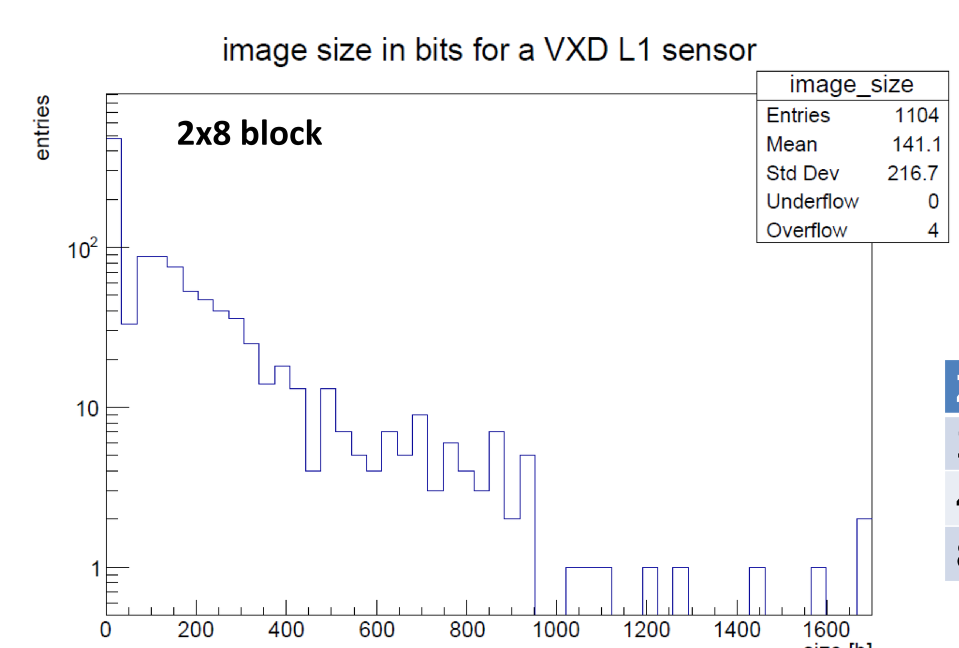
Data rates from the vertex detector

Accurate calculation of the data rate requires some knowledge of the output data format and what kind of data processing happens in the readout chip (e.g. zero suppression).

Currently we assume that the electronic noise is negligible and the rate is dominated by the incoherent pair production.

The pixels are readout in blocks. E.g. a 2x8 block is for 2 pixels along Z-axis and 8 along phi-axis. An block corresponds to 34 bits: 2*8=16 bits of bit map, 5 bits for phi-coordinate of the block, and 13 bits for the z-coordinate of the block. For now we are ignoring ToTs (ionization measurements).

The average image size is ~140 bits per event. We are getting about 7 Gb/s for the sensor assuming 50 MHz collision rate.



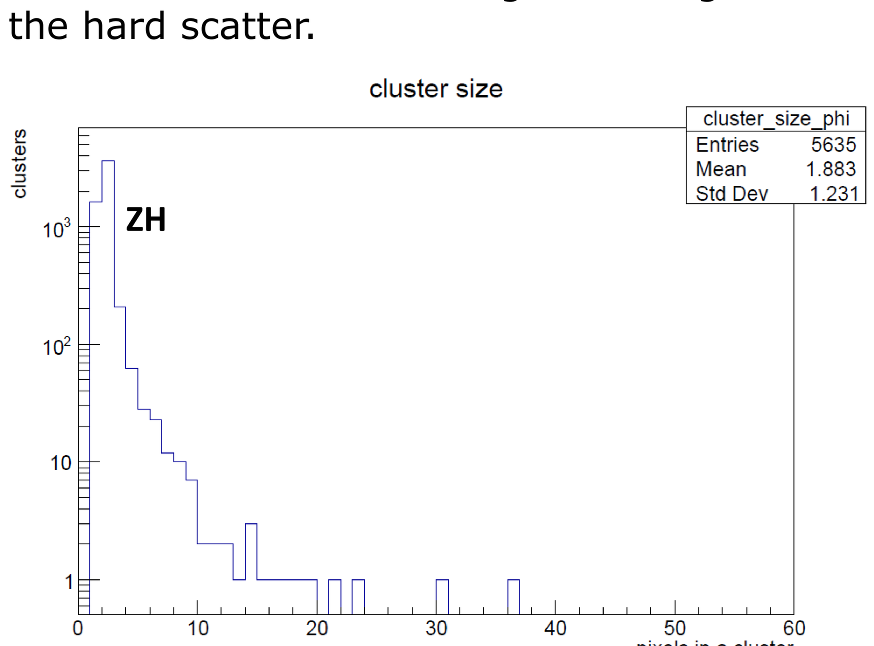
The 4x4 block size gives the smallest data rate.

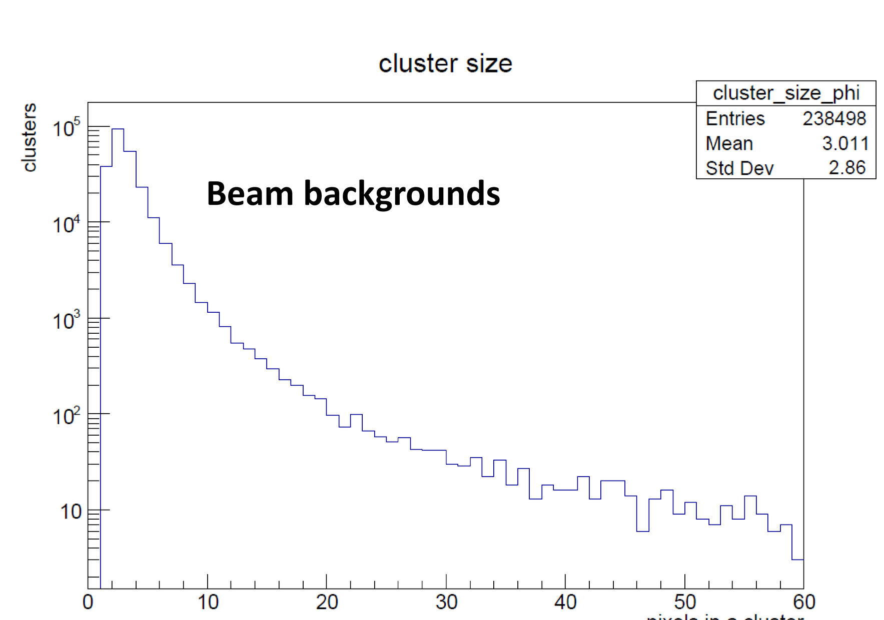
Z\Phi	2	4	8	16
2	130	121	134	176
4	113	**112**	139	200
8	119	131	175	263

Opportunities for on-chip data processing

On-chip (on-edge) data processing in considered to reduce the output rate. Performance of different data processing techniques depends on the experimental signatures observed by the sensors.

Let's consider filtering of groups of pixels (clusters) originating from the background electrons. The beam background originate at the same beam-spot and the same moment as the hard scatter.





The cluster size along the phi-axis is most sensitive to transverse momentum. There is a long tail in the beam background distribution. However, it is unclear if the efficient reduction can lead to a meaningful reduction in the data rate. Other data processing techniques should be studied.

Conclusions and outlook

We are extending the latest simulations of the pixel vertex detector to enable exploration of on-detector processing and optimization of the TDAQ system.

The tentative results are indicating that trigger-free readout of the vertex detector is possible. However, efficient on-chip data reduction requires further studies.

The event reconstruction (e.g. track fitting) need to be able to accept the data after on-detector processing to estimate the impact on detector performance.

Careful optimization of the data format results in notable variations in the output bandwidth.

We are aiming to extend the digitization framework to the other components of the FCC-ee detectors. Close collaboration with the detector experts will be necessary.

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