High Precision Online Luminosity Measurement Using the CMS Phase 2 Upgrade of the Inner Tracker

Alexander Ruede *on behalf of the CMS collaboration ~ ACES 2018*

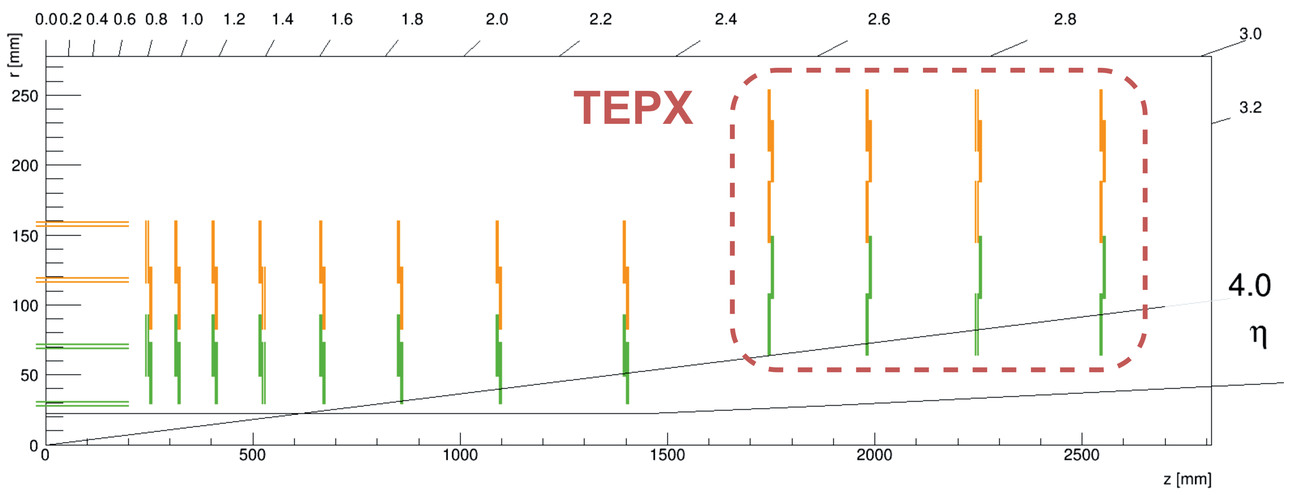


Figure 1: *Position of the four TEPX double-disks within the Inner Tracker.*

Tracker Endcap Pixel Extension

The Inner Tracker Endcap Pixel Extension (TEPX) consists of four double-disks with five rings each (see figure 1). Following properties make it suitable to be exploited for machine induced background and luminosity measurement:

- Position between ~1.75 m and ~2.55 m away from the IP
- Approximatley 2 m^2 of active sensor area
- *Due to position of last disk:* incoming bunch passes ~17 ns before arrival of outgoing collision products
  → Good separation of machine induced background
- Relatively low occupancy suitable for high precision luminosity measurement

Luminosity Trigger

The Phase-II TCDS is planned to incorporate a multi-bit trigger type for each bunch crossing. This allows the implementation of a dedicated luminosity trigger, that is only honored by luminosity subsystems. Figure 2 shows a suggestive implementation for a dedicated luminosity trigger and read out of the TEPX. For a reliable background and luminosity measurement the following requirements must be fulfilled:

- Modules must be configured and able to receive triggers whenever there is beam in the machine
- Independence from central DAQ system
- Maximum trigger rate during stable beams: 75 kHz at a pileup of 200
- Possibility of much higher trigger rate for luminosity-specific fills or beam modes
- Appropriate dimensioning of the DTC to luminosity back end link with enough head room for increased trigger rate

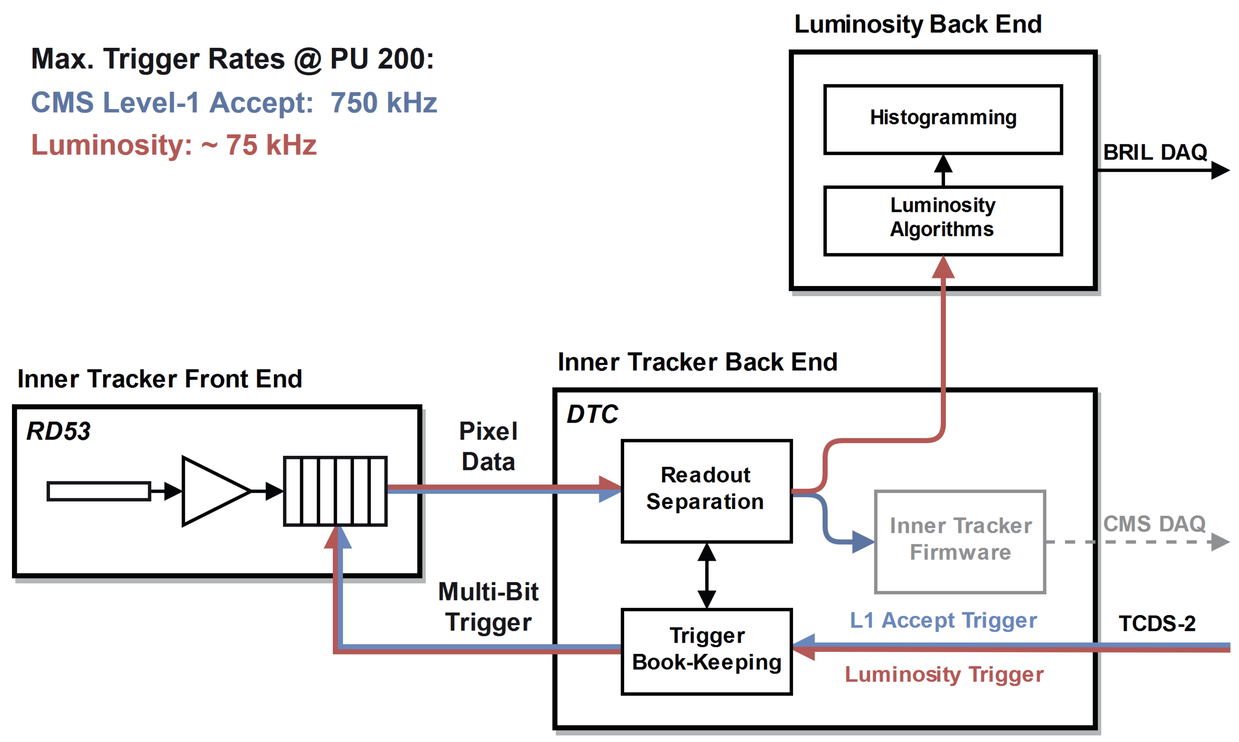


Figure 2: *Block diagram of the multi-bit TCDS-2 trigger including a dedicated luminosity trigger and the separation of the pixel data to the dedicated luminosity back end system.*

Back End

The Inner Tacker Data, Trigger and Control board (DTC) will be used to receive, process, buffer and interface the pixel event data to the cDAQ system. It is foreseen to have a 4x25 Gb/s standard link (TBC) to interface with a dedicated luminosity back end for independent development, data acquisition and processing. The system will be designed for zero backpressure and to meet the latency requirement. Three different architectures will be explored to process an expected maximum data rate of 110 Gbps:

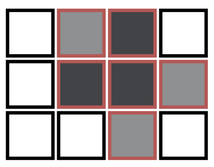
Software (CPU-only)
+ Standard machines and interface links
+ Complex algorithms with standard programming languages
+ Reuse of current offline Pixel Cluster Counting algorithm
- Large amount of machines needed
- High latency, especially for high work loads

Hardware (FPGA-only)
+ Reuse the CMS DAQ and TCDS Hub (DTH) ATCA blade
+ High amount of (all parallel) computing power
+ Low latency
- Complex algorithms difficult to implement
- Time- and expertise-expensive firmware development

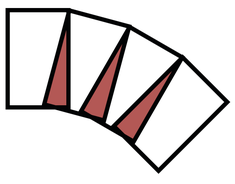
Heterogeneous (FPGA + CPU)
+ Cutting edge technology
+ Fast preprocessing on FPGA and complex algorithms on CPU
+ Entirely programmable in OpenCL
- Expensive
- Not well explored within CMS yet

Luminosity Algorithms

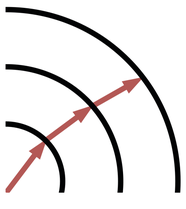
For Phase 2 the target bunch-per-bunch statistical uncertainty is in the order of 1% over a pileup range of four orders of magnitude. The online luminosity will be measured by applying one or several of the following methods. Feasibility and uncertanties still need to be evaluated. Using more than one luminosity measurement algorithm allows cross-checks necessary for the estimation of the systematic error.



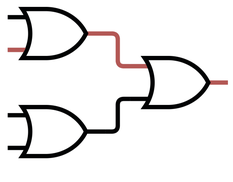
Cluster Counting
- Raw hits are clustered using the standard pixel clustering algorithm or a luminosity specific variant
- The Number of valid clusters is recorded per bunch crossing and accumulated over a configurable period of 2^{12} to 2^{14} orbits



Overlap Stub Counting
- Counting correlated pairs of hits removes systematic uncertainties present in cluster counting
- Due to geometrical overlap of modules: About 26% of the collision-tracks in the TEPX acceptance have a hit in two neighbouring modules of the same disk



Track Counting
- New tracker allows counting of high p_T tracks reconstructed at the trigger level at full collision rate
- This method is potentially more sensitive to variations in tracking performance with pileup, but provides an additional independent measurement of the luminosity.



Hit-Or
- Pixel output feeds two data paths: the triggered DAQ path and a prompt path (called Hit-OR)
- For modules/rings with very low occupancy the fast Hit-Or can be exploited for hit counting or zero counting algorithms.