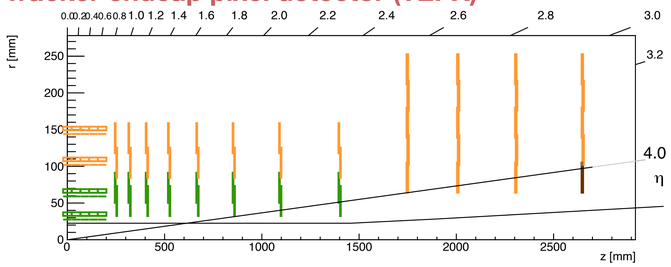
TEPX as a high-precision luminosity detector for CMS at the HL-LHC

Mykyta Haranko on behalf of the CMS collaboration - **TWEPP 2021**

1. Tracker endcap pixel detector (TEPX)



TEPX:

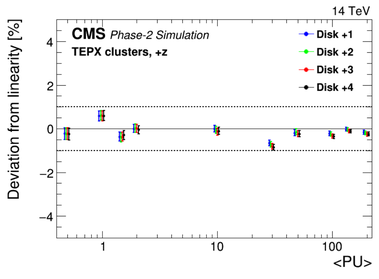
- One z-end consists of 4 double disks 5 rings each
- Is positioned at 175 cm < |z| < 265 cm, 6.3 cm < r < 25.5 cm from the IP
- L1A trigger at 750 kHz is expected (for physics)
- **Additional 75 kHz trigger rate for luminosity**

TEPX D4R1:

- Disk 4 Ring 1 (D4R1) is beyond η = 4 and therefore not useful for tracking
- Gets 17 ns separation between incoming bunch and collision products
- **Full bandwidth (825 kHz or more) for luminosity and beam-induced background measurement**

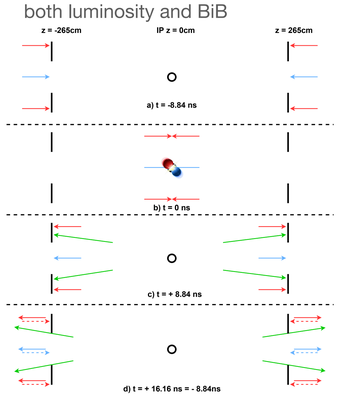
2. Luminosity perspective

- **TEPX incl. D4R1** : (4 quarters x x 5 rings x 4 disks x 2 ends) - **160 luminosity channels**
- **Sampling rate (TEPX excl. D4R1)**
  - 21 samples per BX per second (physics, 75 kHz)
  - 281 samples per BX per second (VdM, 1 MHz)



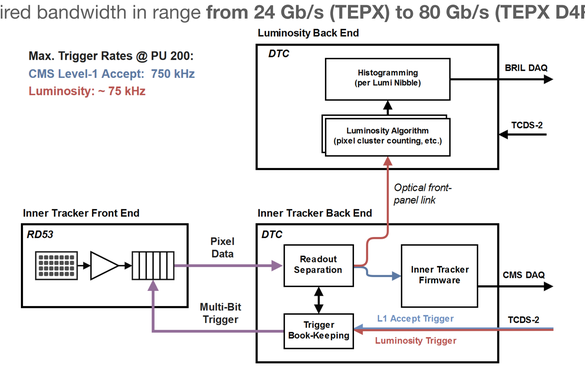
3. Beam-induced background perspective

- Measure before the first colliding bunch in a train (to exclude collision products and albedo)
- Appropriate time tuning to measure both luminosity and BiB



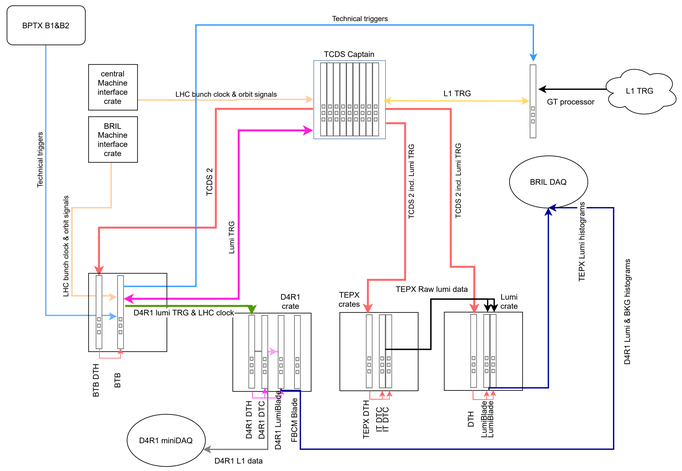
4. Data flow diagram

- **Apollo ATCA platform** will serve as both the data acquisition card and the luminosity processor
- One luminosity processor will receive data from one DAQ card
- Required bandwidth in range **from 24 Gb/s (TEPX) to 80 Gb/s (TEPX D4R1)**



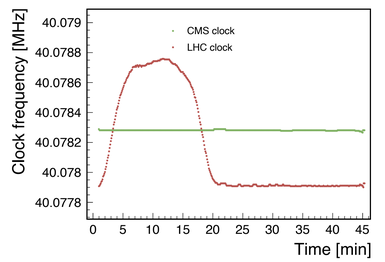
5. Timing and luminosity trigger distribution

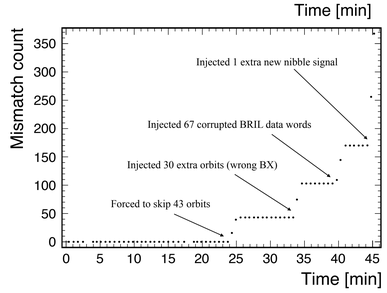
- D4R1 requires dedicated clocking infrastructure to be operated when the CMS clock is not locked to the LHC clock
- In the heart of the structure - **BRIL Trigger Board (BTB)**
- BTB (based on **Serenity ATCA card**) will perform:
  - Generation of independent luminosity triggers
  - Generation of a local TCDS2-like control stream based on the LHC clock
  - Encoding of beam 1&2 signals from BPTX and transferring to the Global Trigger (GT)

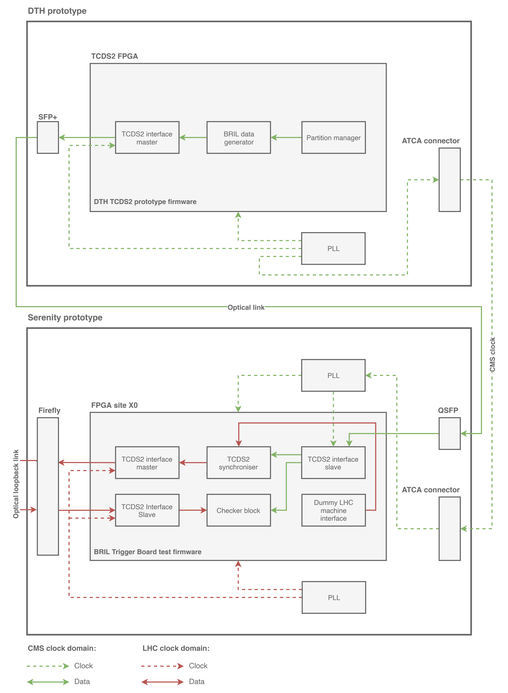


6. BTB proof of concept

- Utilises prototypes of Serenity and DTH boards
- Proven that the TCDS data stream can be transcoded into the LHC clock without issues
- Tests with the LHC ramps replayed by the PLL







7. Real time pixel cluster counting on FPGA - proof of concept

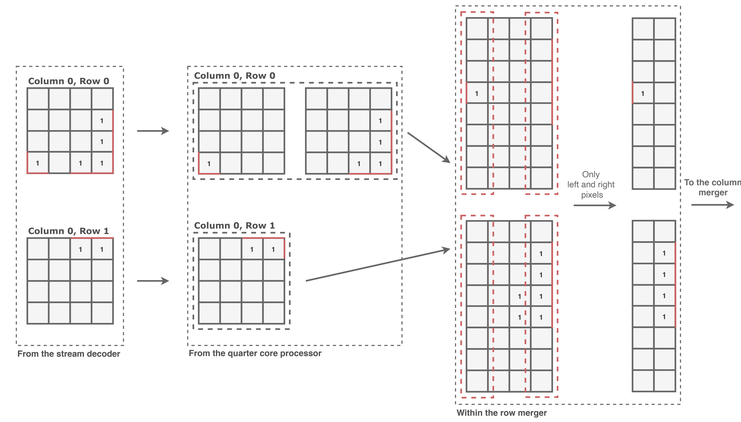
Processor functionality:

- **Stream decoder** recovers 4x4 hit maps (quarter cores) from the encoded data stream
- **Quarter core processor** splits 4x4 hit maps into clusters, analyses boundaries (touch information)
- **Quarter core distributor** filters isolated quarter cores
- **Row merger** performs vertical cluster merging
- **Column merger** performs horizontal cluster merging
- **Count accumulator** combines counts and performs status monitoring (error and warnings flags)

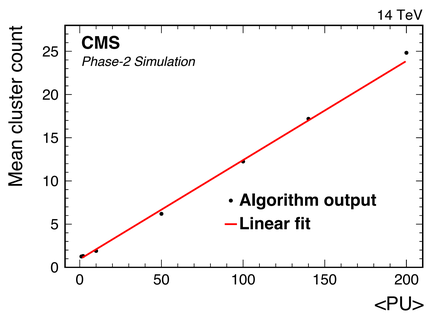
Generic properties:

- Processes raw hits per event per chip
- A set of processors running at 320 MHz
- Multiple buffering stages with configurable buffer sizes and backpressure
- **Resource utilisation on VU13P for TEPX**
  - 352 chips or **176 clustering instances per FPGA**
  - **45% logic resources, 26% BRAM**

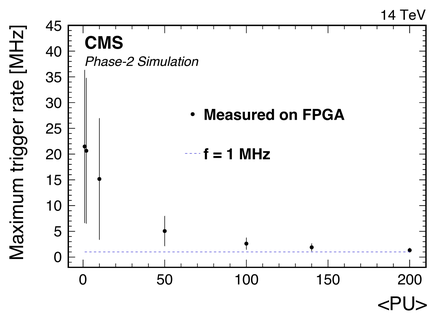
8. Processing example



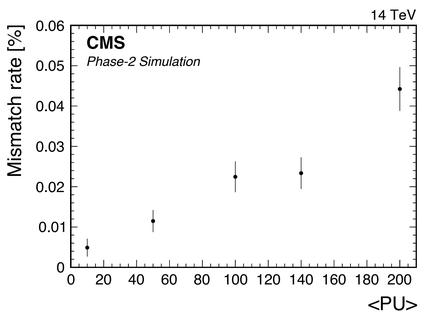
9. Performance of the FPGA clustering algorithm



- Performance tested by injecting CMSSW simulated events and comparing to the offline reconstruction algorithm output



- **Safe margin in processing rate (1.33 MHz at PU200)**



- Most of the mismatches are due to charge filtering in the offline algorithm (not available yet on FPGA)

10. Summary and outlook

- The developed **FPGA real time pixel cluster counting algorithm** performs extremely well and **delivers cluster counts comparable to the sophisticated offline reconstruction algorithm**
- The BTB proof of concept has shown the **feasibility of the timing distribution architecture**
- **The developments are described in the BRIL Phase-2 TDR (CMS-TDR-023)**
- Further steps are planned to study the possibility to perform ToT-based corrections and coincidence counting in overlapping regions as well as to implement the full functionality of the BTB