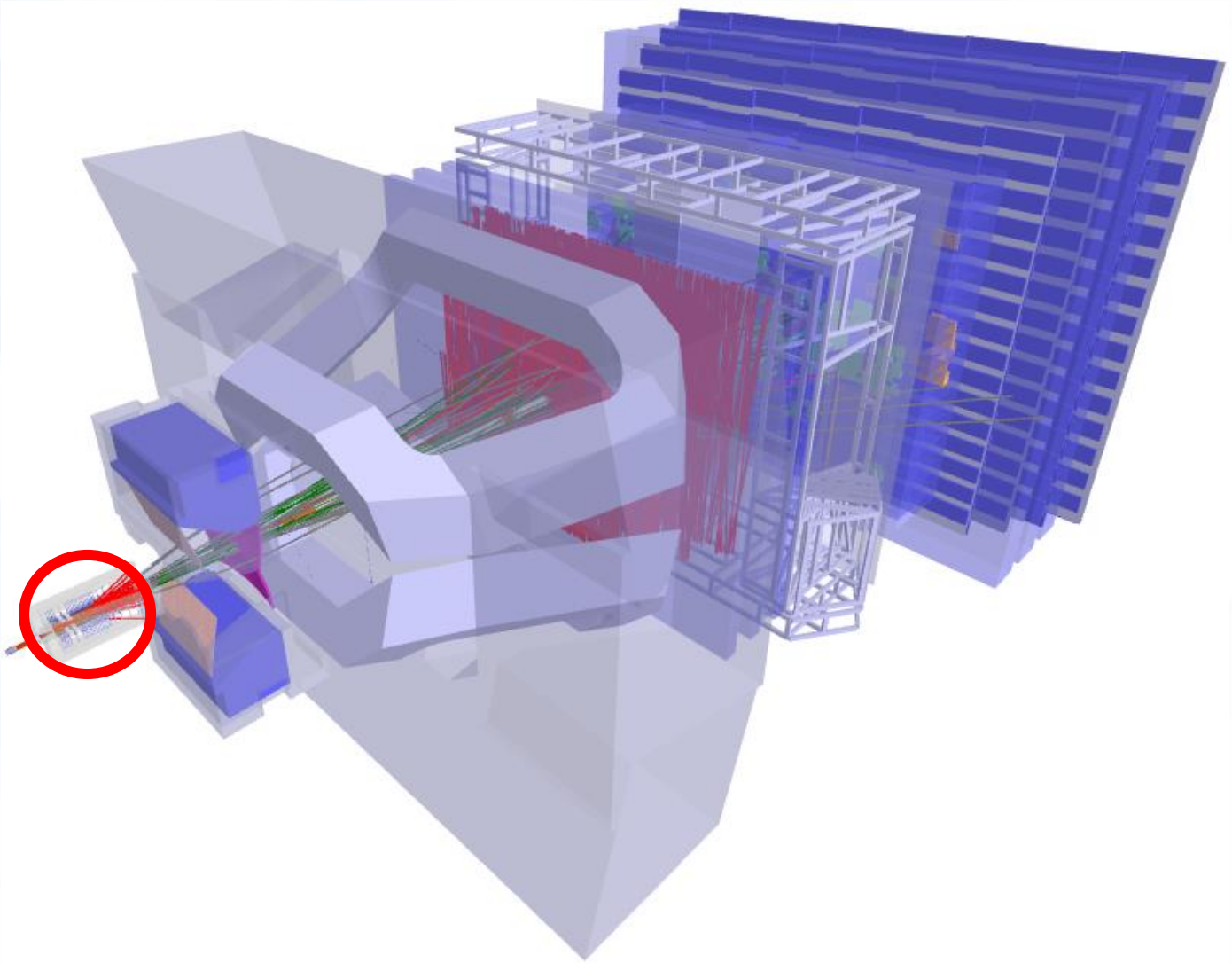
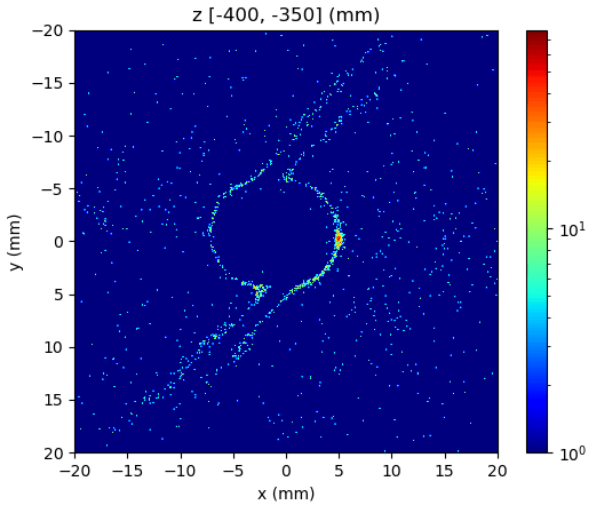
Status of the LHCb Pixel Detector

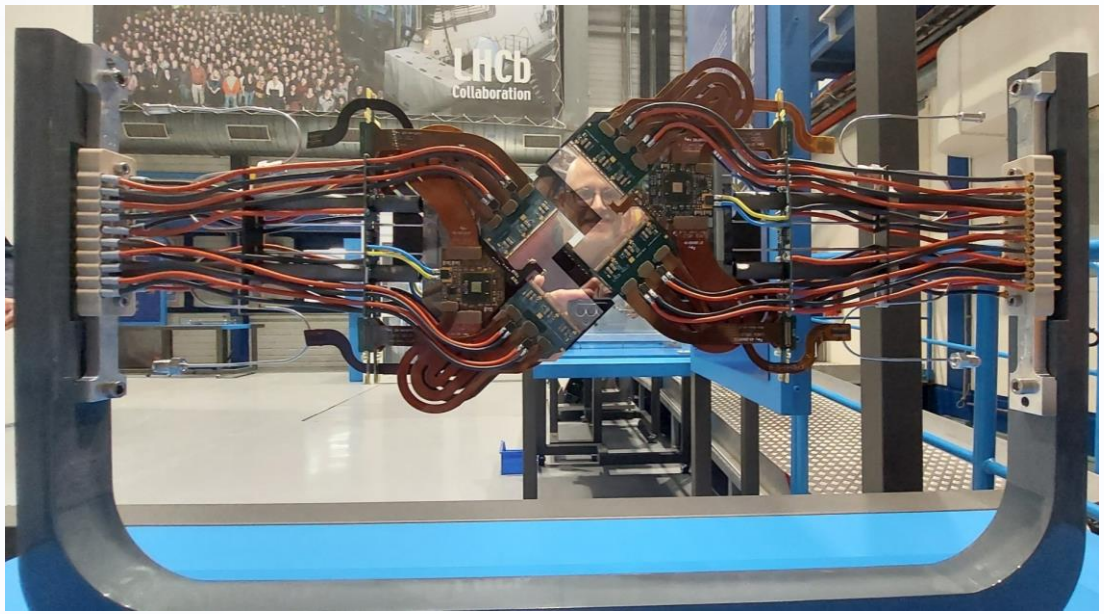


Edgar Lemos Cid, On behalf of the LHCb VELO Group

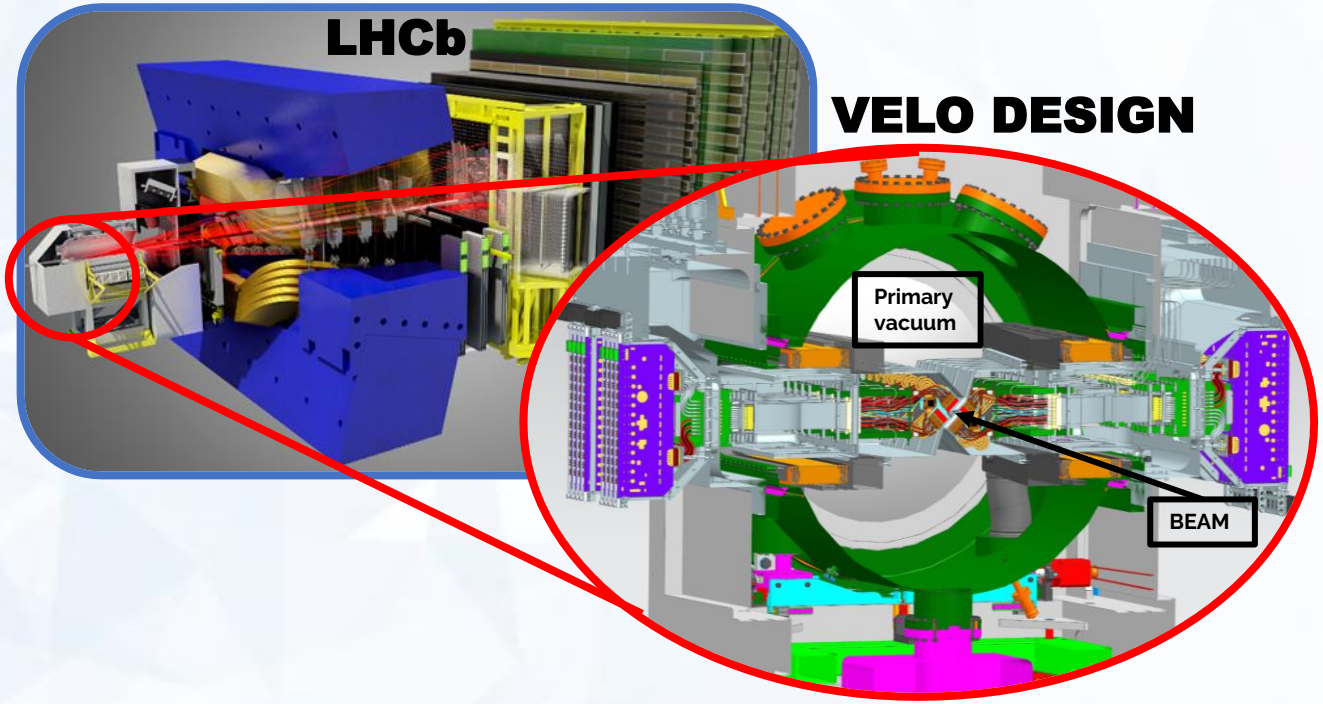
Outline

- LHCb VELO Upgrade.
- Module Assembly.
- Detector Assembly and Installation.
- VELO Safety System (VSS) and Detector Monitoring.
- VeloPix Calibration: Equalization and Bxid Spread.
- Time Alignment.
- VELO Closing.
- Vertex reconstruction.
- DAQ and FPGA clustering.
- HV performance.
- SMOG 2.

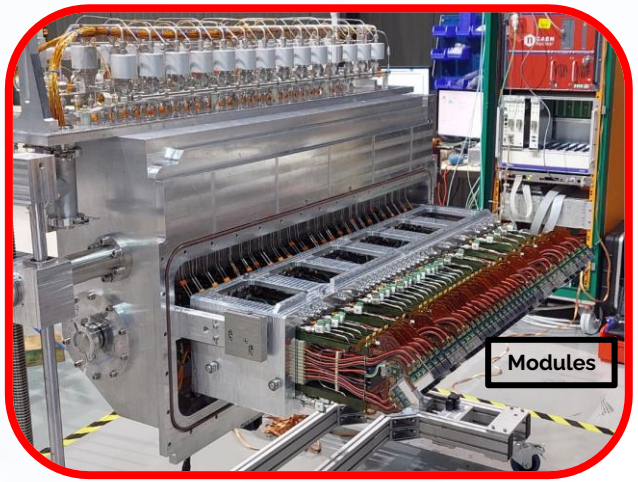


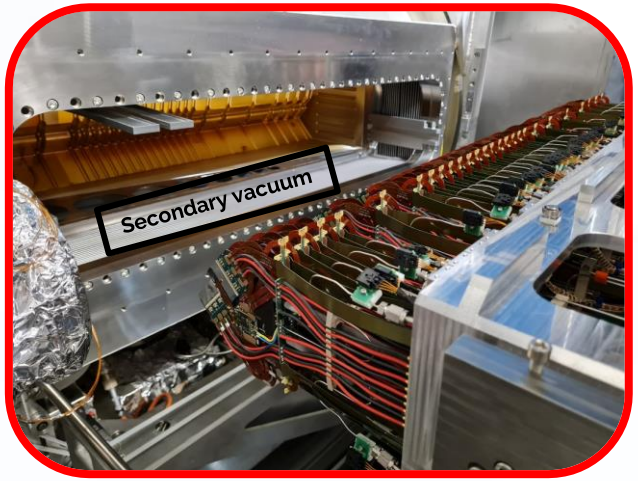


LHCb VELO Upgrade



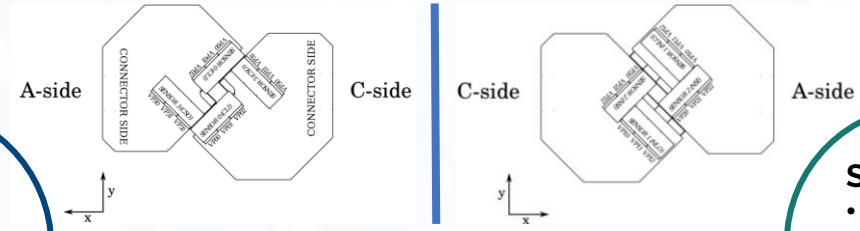
VELO HALF





- LHCb is a forward ($2 < \eta < 5$) arm spectrometer focusing in b-hadron and c- hadron decays. Studies CP violation, rare decay, …
- The Vertex detector (VELO) was successfully updated from silicon strips to pixels in 2022.
  - Closest pixel at 5.1 mm to the LHC beam.
  - Use increased luminosity (5x).
  - Readout all the events at every bunch crossing (40 MHz).
  - 41M pixels across 52 modules in vacuum.
  - Evaporative CO_2 cooling through microchannels.
  - RF foil down to thickness of 150 μm.

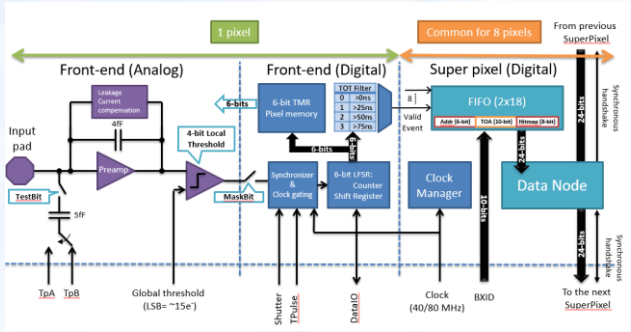
Module Assembly

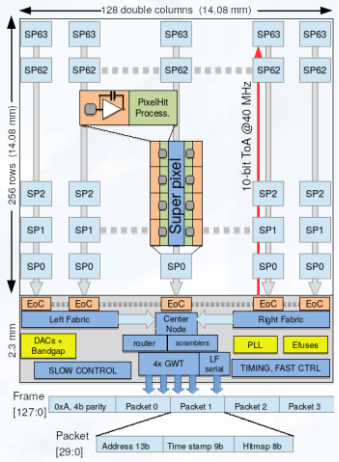


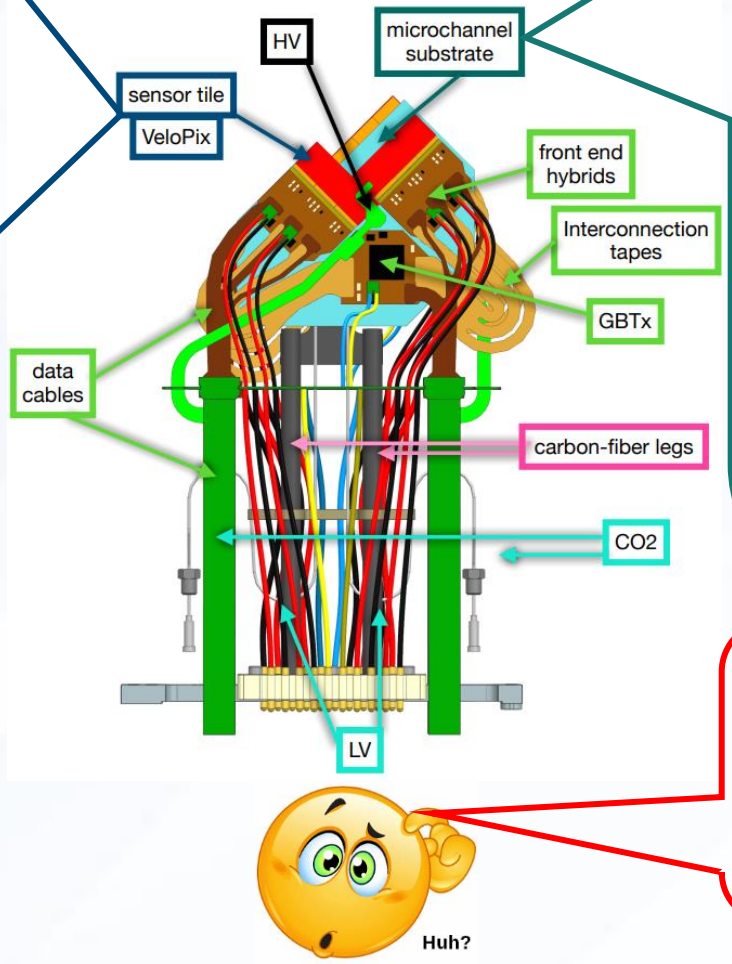
VeloPix:

- 256x256 pixels of 55 x 55 µm.
- 800 Mhits/s/ASIC.
- Continuous, trigger-less and binary readout.
- Radiation hard up to 400 Mrad and SEE tolerant.

*Talk 2018: VeloPix Readout and ASIC.



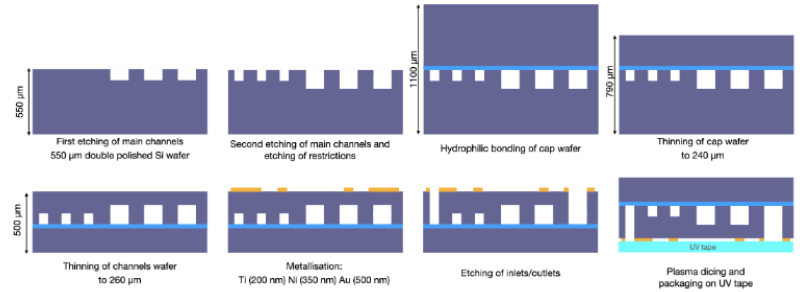


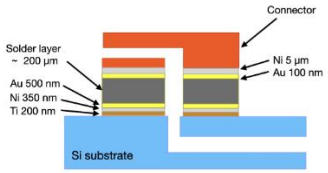


Silicon microchannel substrates:

- Two phase evaporative CO_2 cooling.
- 500 µm wafer with 120 x200 µm² microchannels.
- Cooling power up to 40 W at -30 °C.

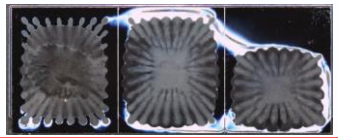
*Microchannel cooling for the LHCb VELO Upgrade I.

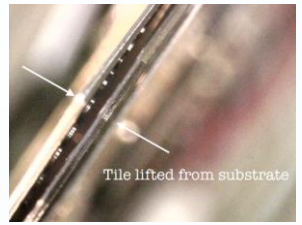




.Challenges in the way.

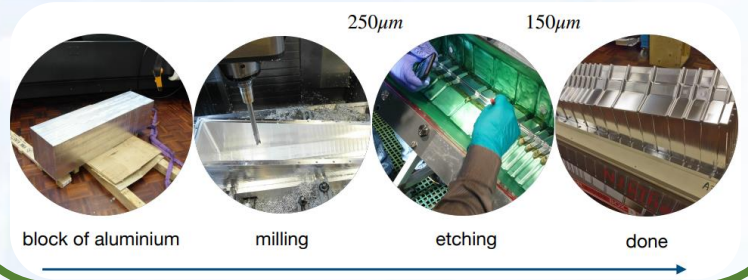
- Glue between ASIC and Substrate.
- GBTx cold operation.
- Connectors metallization.

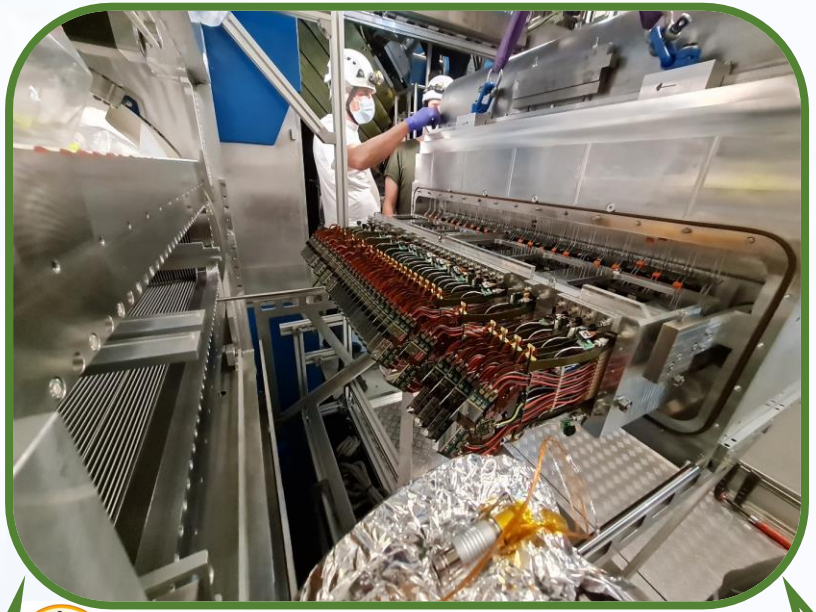




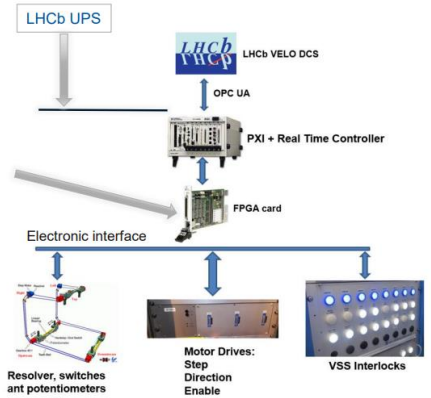
Detector Assembly and Installation

RF Foil:
- 150 μm thick shield that separate VELO vacuum from LHC vacuum.
- 3.5 mm from the beam and 900 μm from the sensors.
- Thermally stable, shield against RF pick-up from the LHC Beam.
- Torlon and Neg coating.

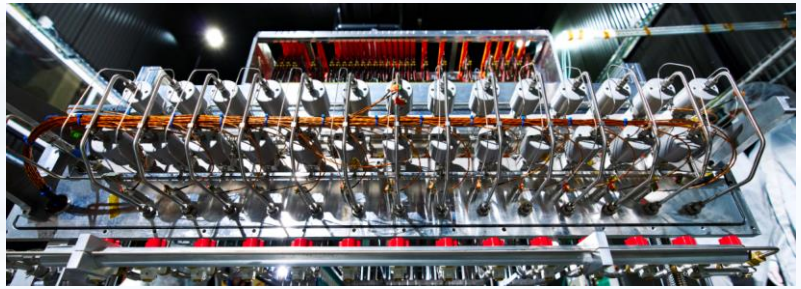


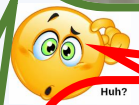


Motion:
- Movement to protect the detector during injection. (Min 3.5 mm).

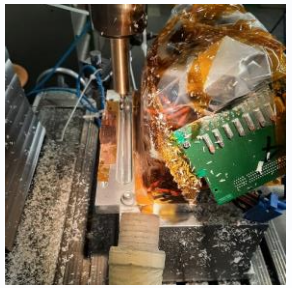


Cooling:
- 52 microchannel cooling plates boiling at the same time.
- Safety system to avoid CO_2 leaks. Max ΔP of 10 mbar between LHC and VELO vacuum.





Challenges in the way:
- Cooling gasket replacement.
- Feedthrough board replacement.

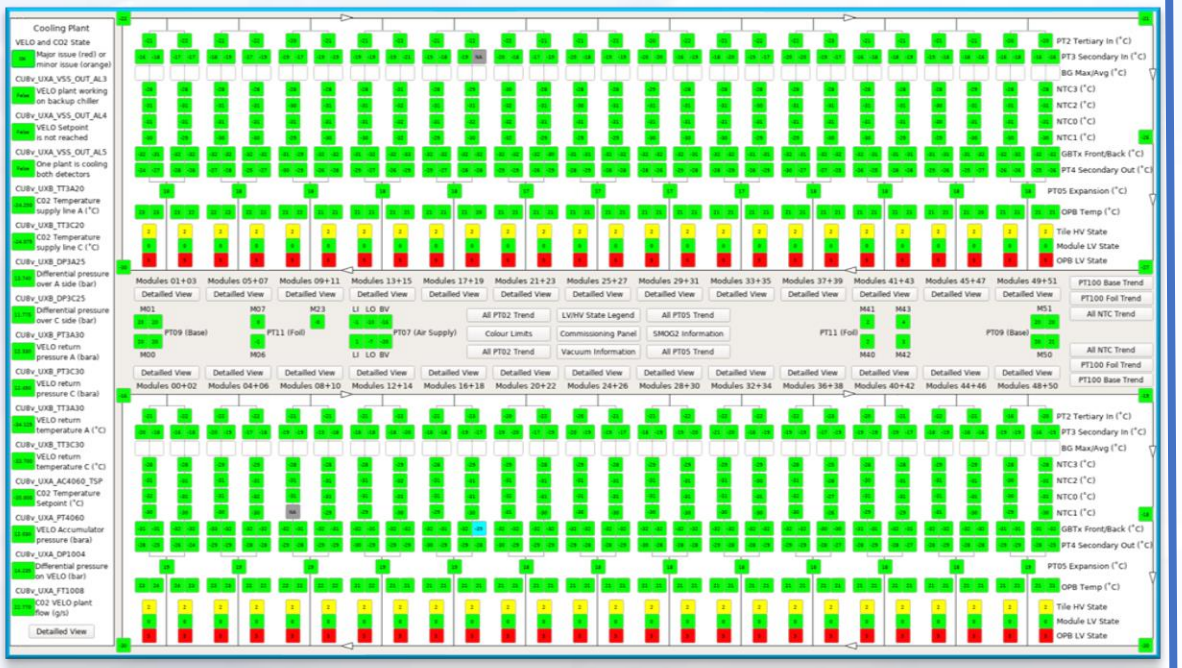


Metrology:
- μm precision measurement needed.
- Measurements performed at the module assembly, detector assembly (cold) and before detector installation (Foil & Modules).

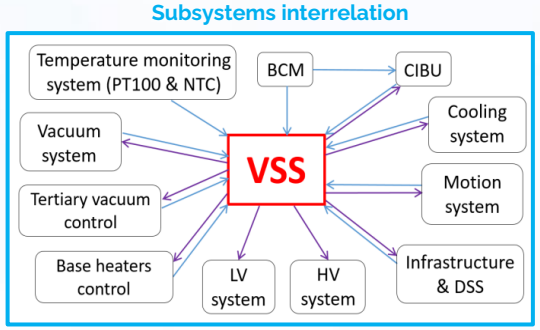
VELO Safety System (VSS) and Detector Monitoring

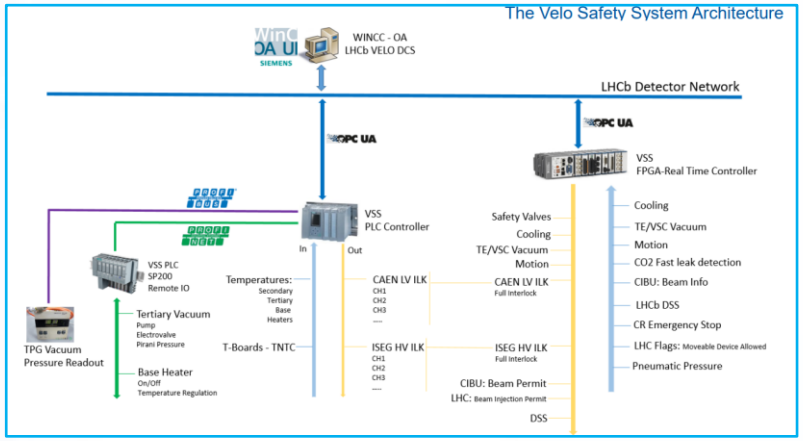
Detector Monitoring:

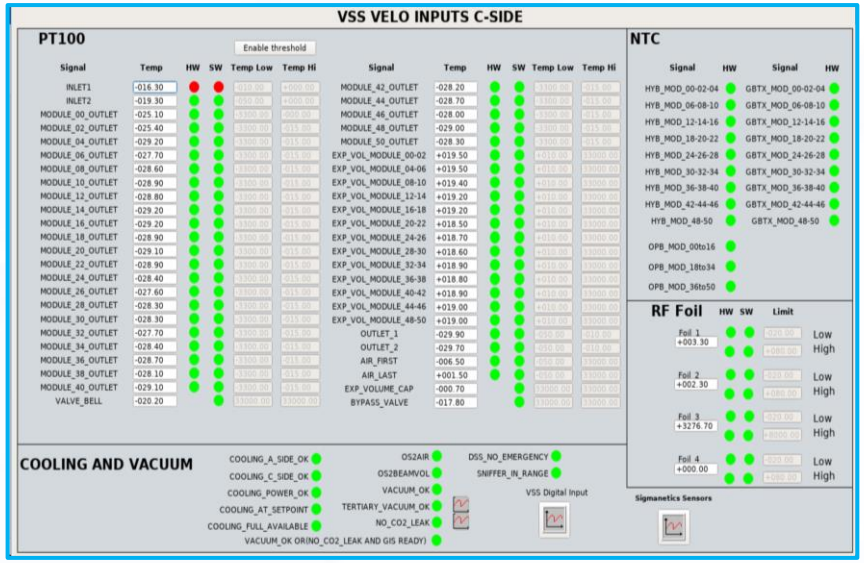
- Monitoring of 1209 temperatures, LV and HV. 624 more to add one per VeloPix bandgap.
- Readings from Vacuum system, SMOG 2 system, cooling plant.

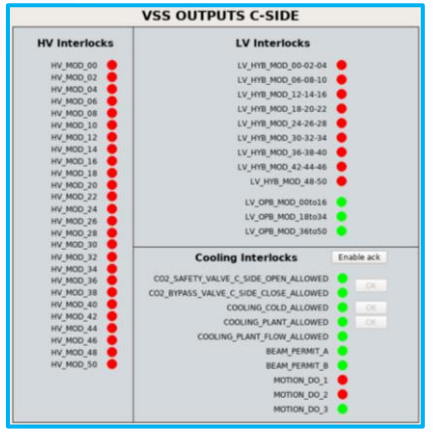


VELO Safety System:









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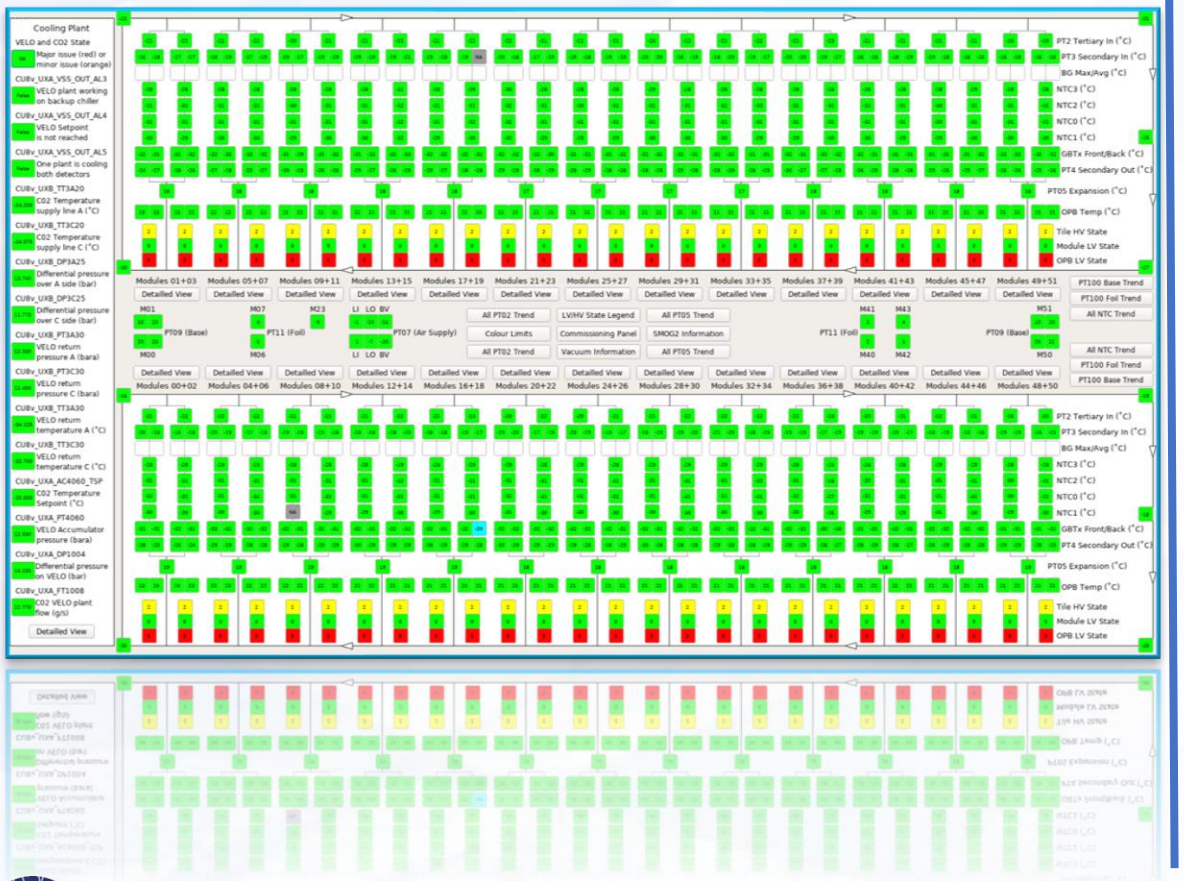
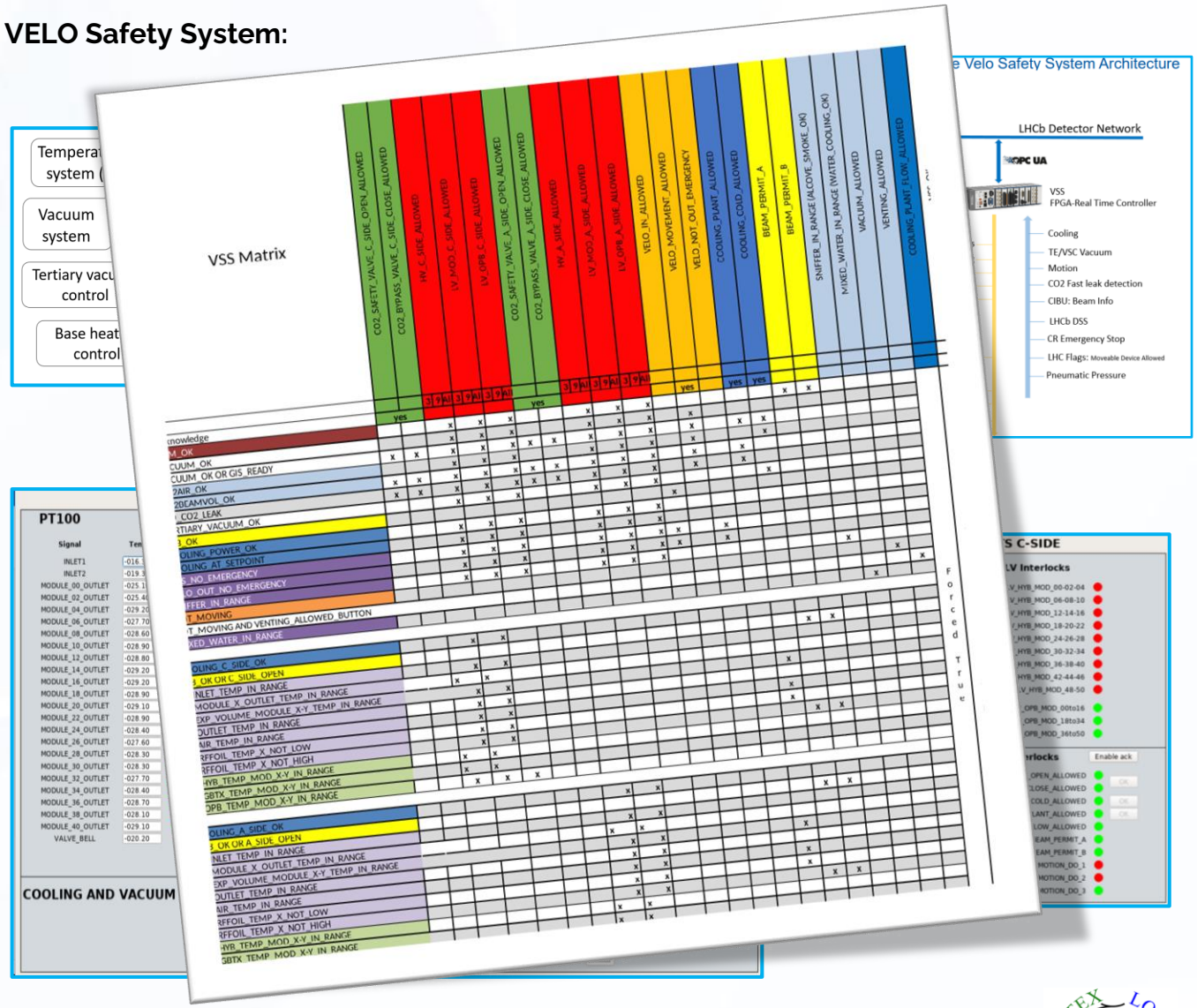


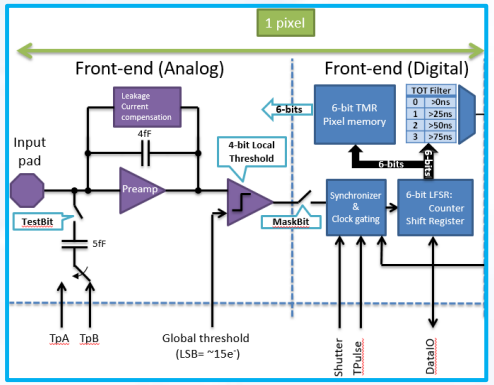
VELO Safety System:



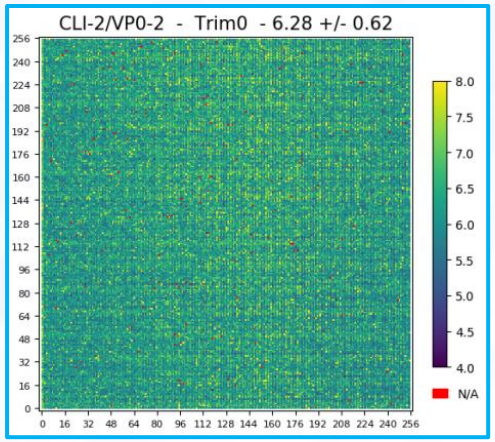
VeloPix Calibration: Equalization & Bxid Spread

Equalization:

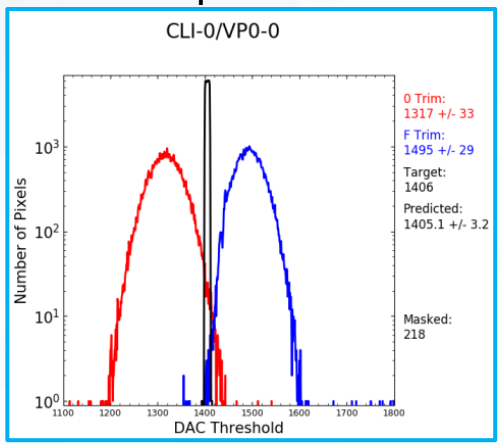
- Estimated using the noise baseline at different threshold values.
- 16 fine tune values per each pixel.
- Use the extreme values (0, 15) for global Threshold scan and calculation of the optimal value.



Noise

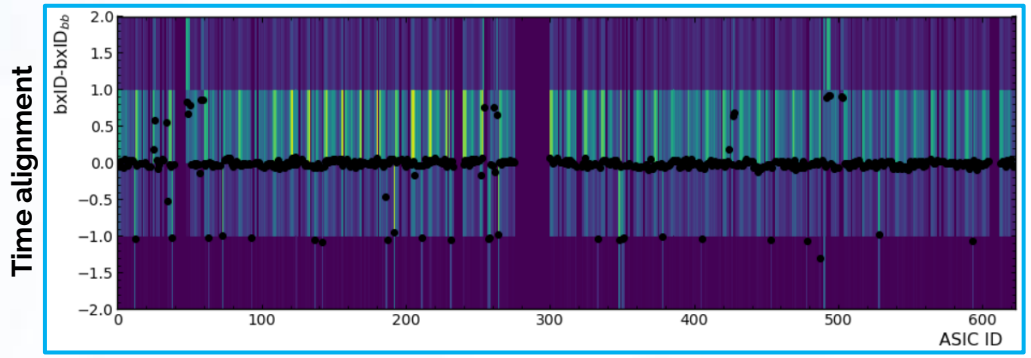


Equalization

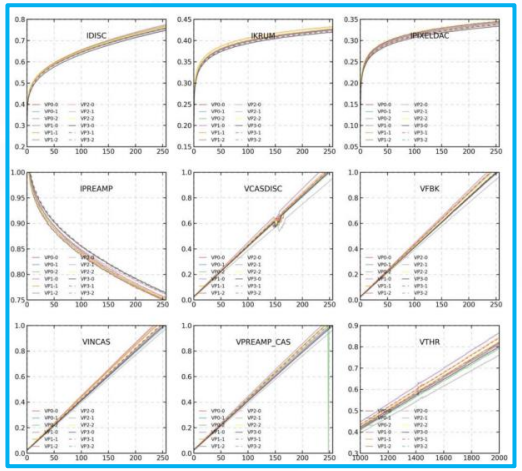


Bxid spread:

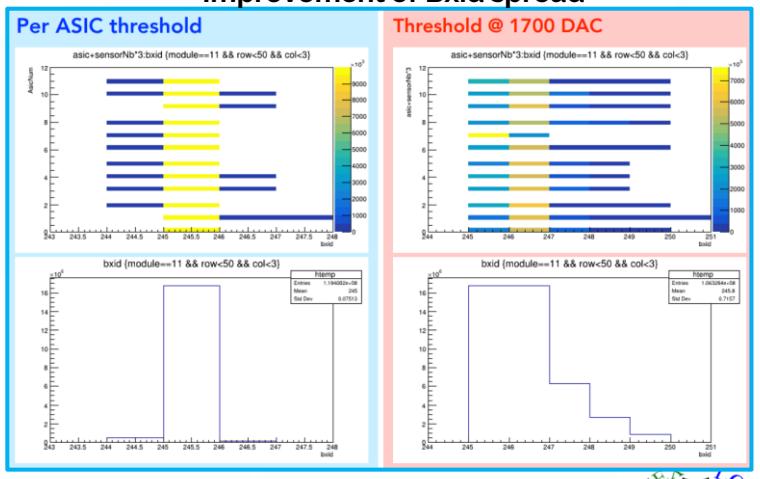
- Equalization not tuned in terms of analog circuit parameters and threshold. First approach to keep the same settings for the full detector.
- During time alignment. ToA Bxid different in pixels of the same ASIC. Analog TP see the same effect.
- DAC scan and Threshold set to eliminate this effect.



DAC Scan

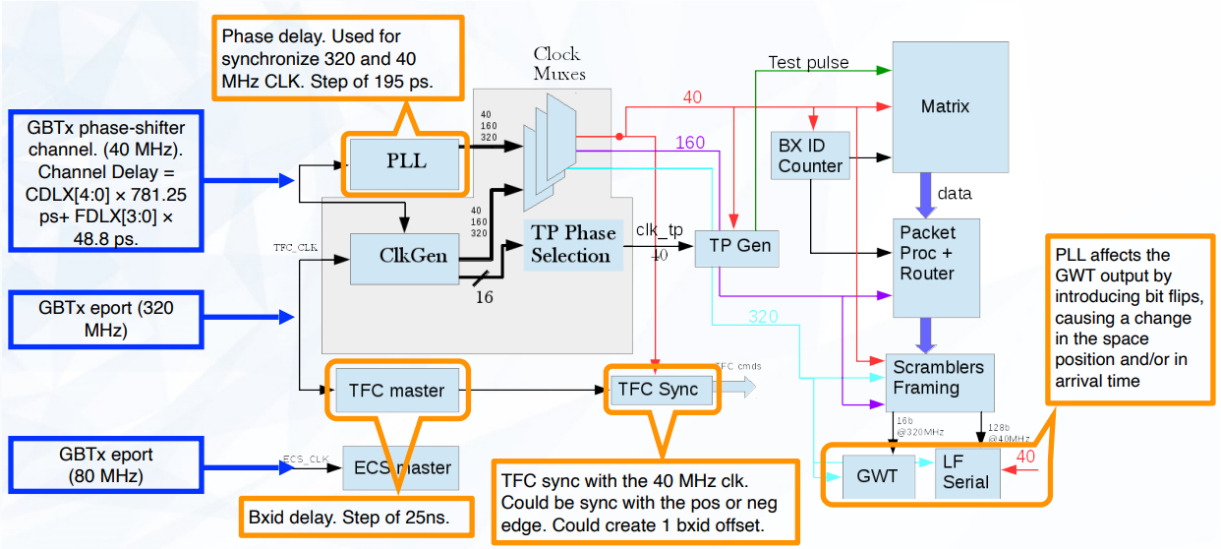


Improvement of Bxid spread

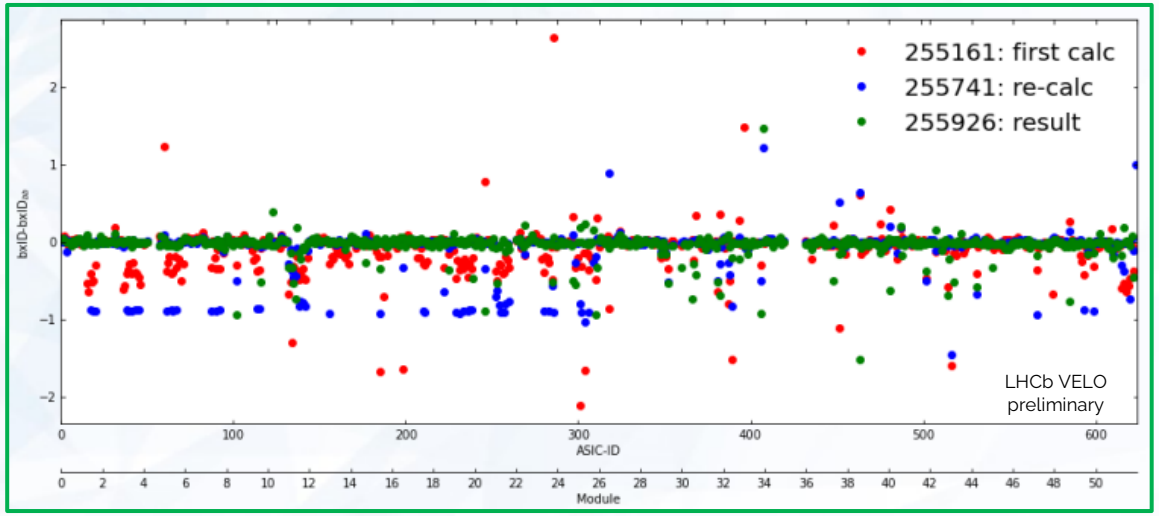


Time Alignment

- Time alignment depends on:
  - Control FPGA placed on surface.
  - GBTx and VeloPix clks
  - Time fast control (TFC) & 40 MHz clk sync.
- Multiple scan done to understand the detector behaviour.
  - PRBS test while scanning the PLL phase.
  - Coarse delay scan on the GBTx.
  - Scan of the sync of TFC with the 40 MHz clk.

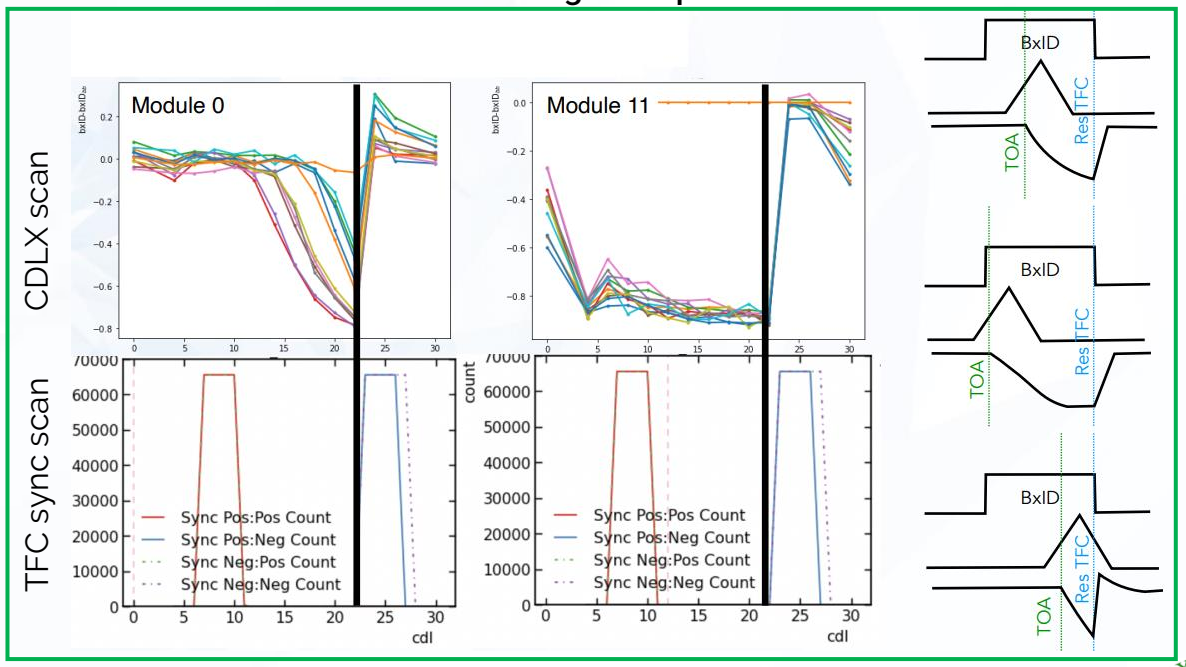


Time alignment performed



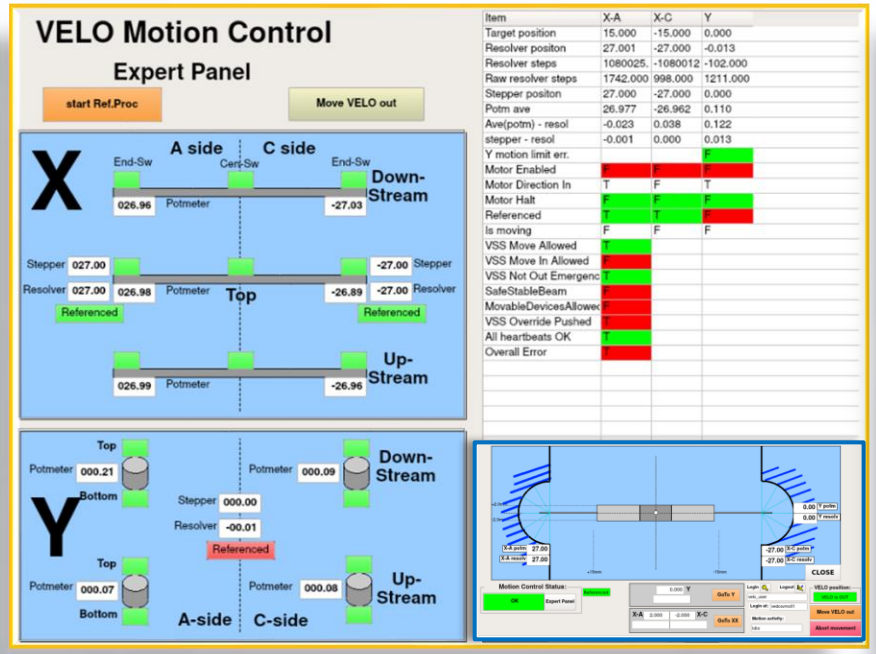
Fraction of bad chips :Total: 5.8%. A side: 8.0%. C side 3.5%
Fraction of out of-time chips: Total: 2.7%. A side: 4.2%. C side 1.3%

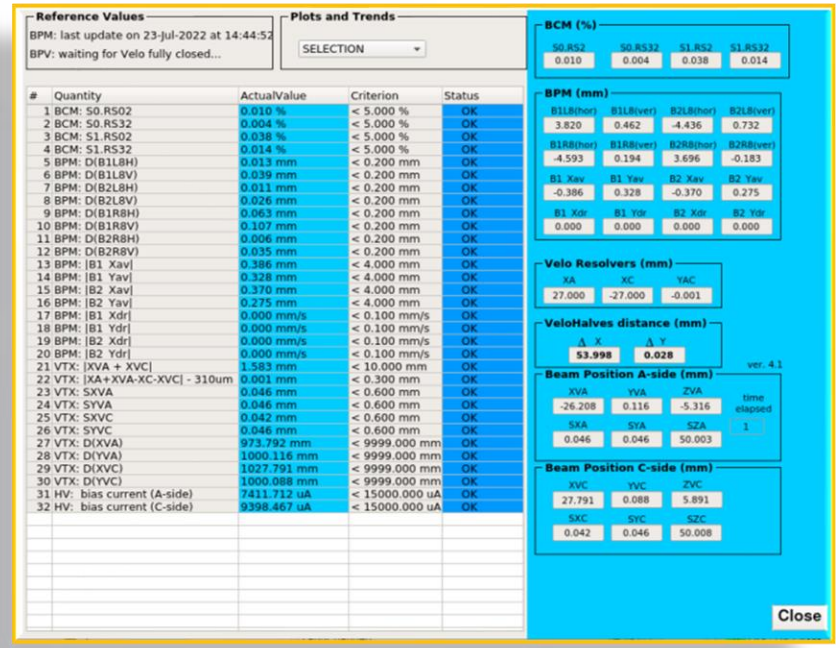
Time alignment procedure



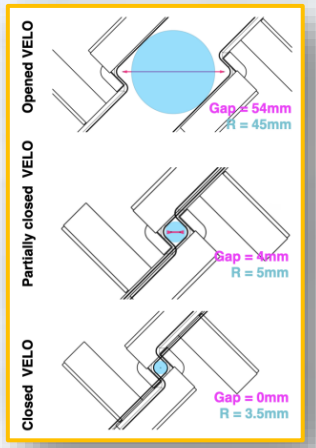
VELO Closing

- Closing is based in the Primary Vertex reconstruction from the detector.
- Multiple criteria need to be satisfied: VSS, stable beam, FPGA communication, Beam Conditions Monitors, Beam Position Monitors, HV current, …
- RF foil reconstructed to proceed to the final closing.
- Increased number of colliding bunches to study the temperature and vacuum variation and validate the closing.

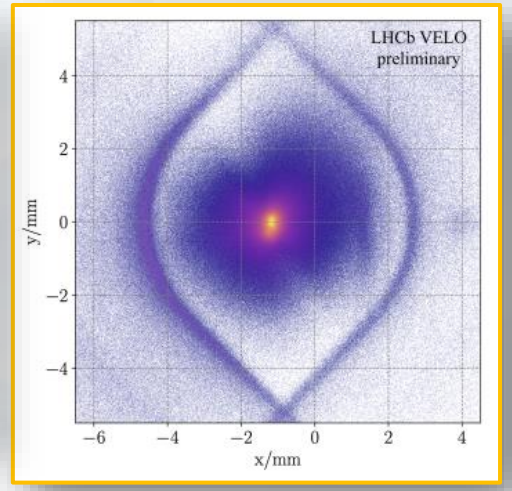




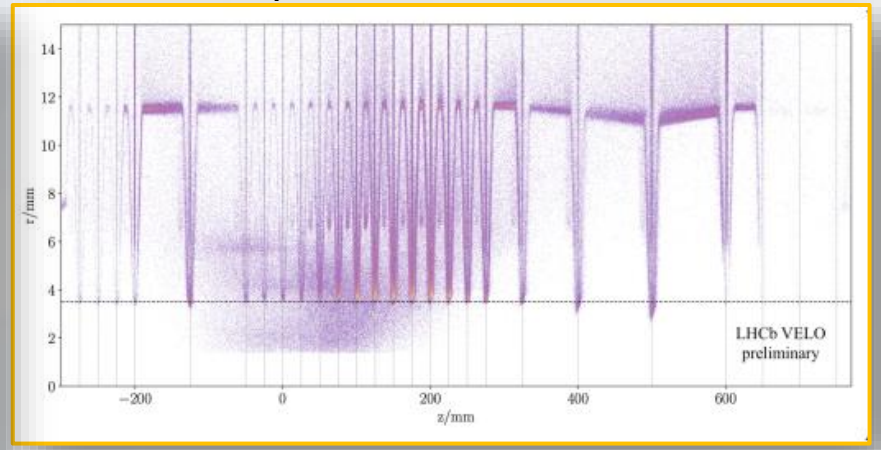
Closing Process



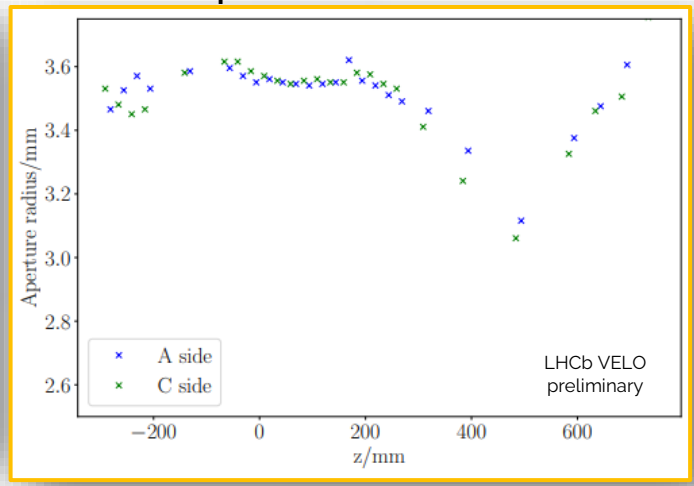
Z projection almost close



Z positions with vertex reconstruction



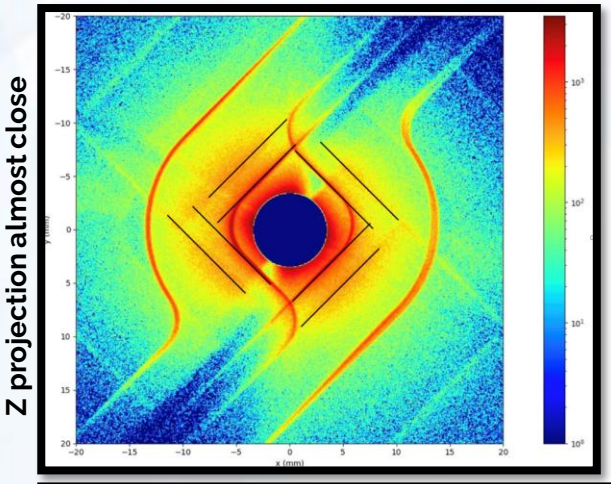
Aperture measurements

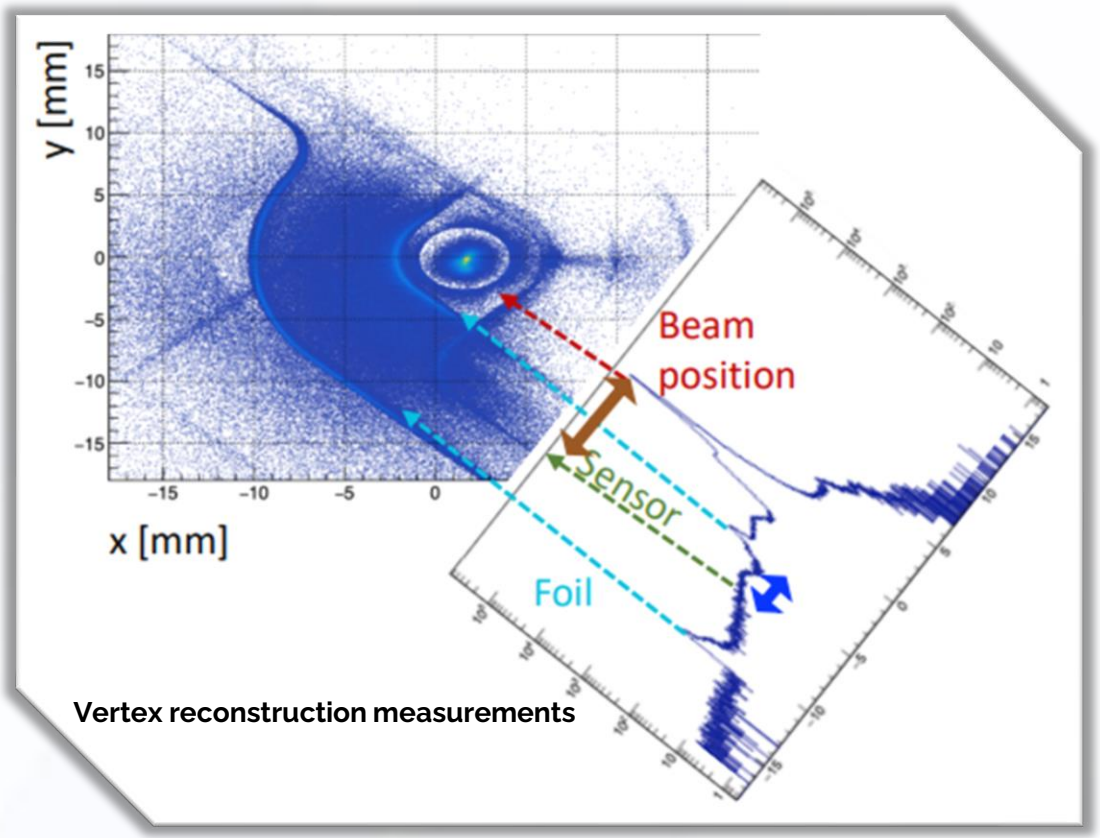


Vertex reconstruction

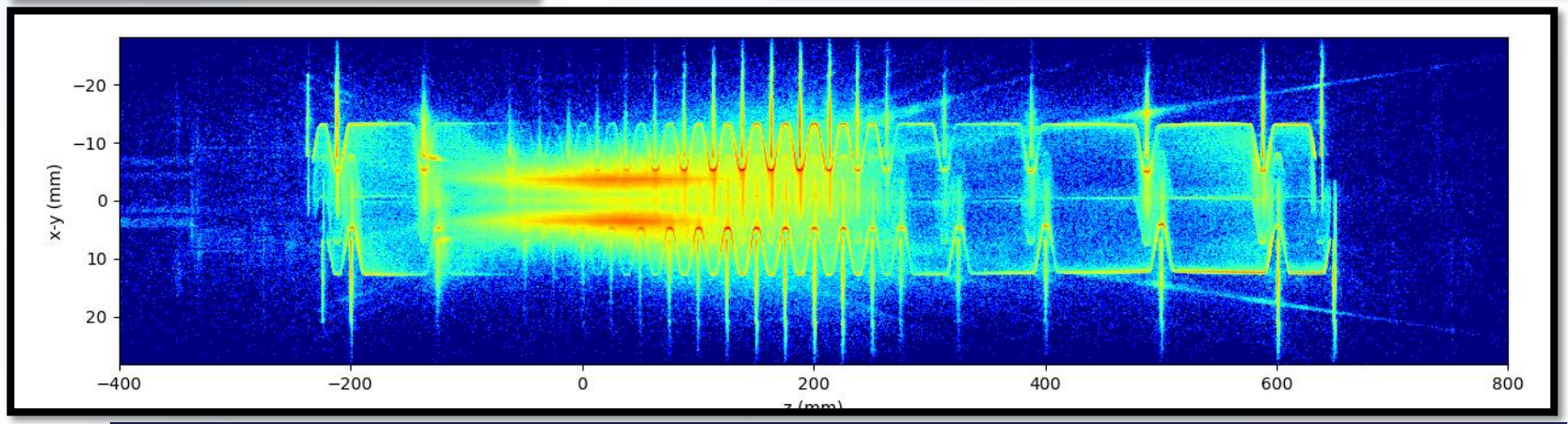
- One spacer was placed in each fixation point (3 per side) of the detector to the motion system to increase the clearance 1 mm.
- Vertex reconstruction measurement of module and RF foil position essential to be confident on removing the spacers.

Spacer





Vertex reconstruction measurements



DAQ and FPGA Clustering

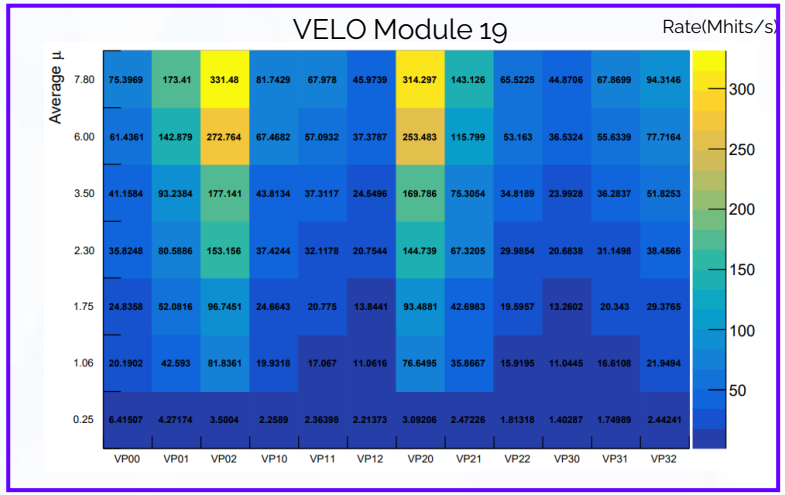
- VELO DAQ: 20 readout links at 5 Gb/s per module.
- Integrating the clustering in the FPGA.
  - 11% reduction of HLT1 reconstruction sequence.
  - O(50) less power consumption in the FPGA compare with the GPU.

*Phase I Upgrade of the Readout System of the Vertex Detector at the LHCb Experiment

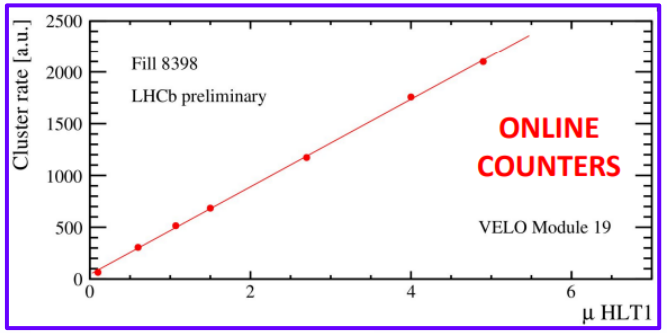
*Readout Firmware of the Vertex Locator for LHCb Run 3 and Beyond

- μ (Number of collisions) scan in terms of VeloPix activity. Clusters and hit rate per VeloPix to measure luminosity.

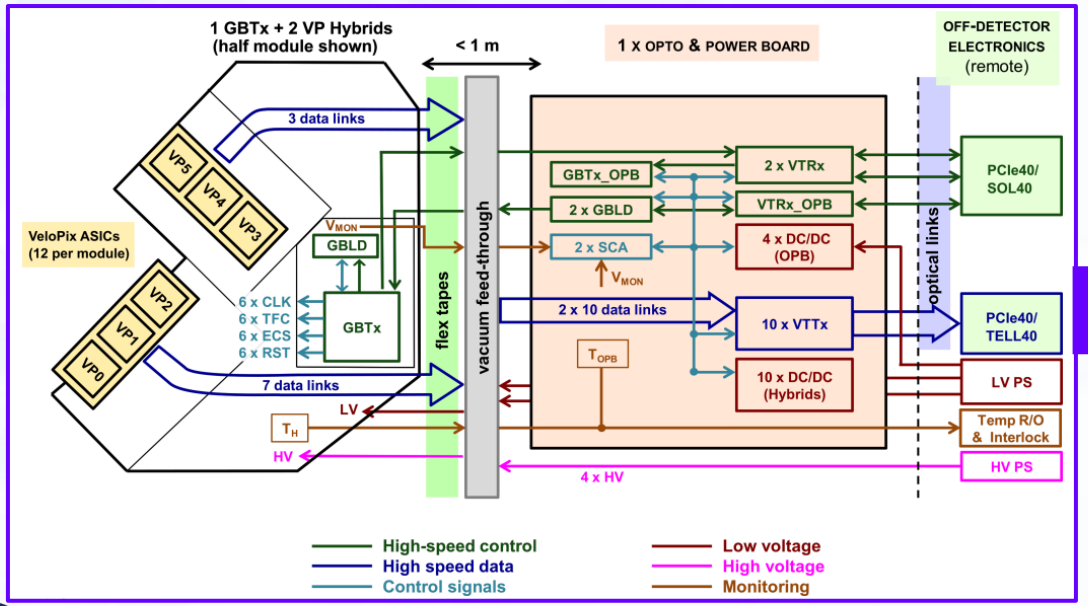
VeloPix Hit Rate



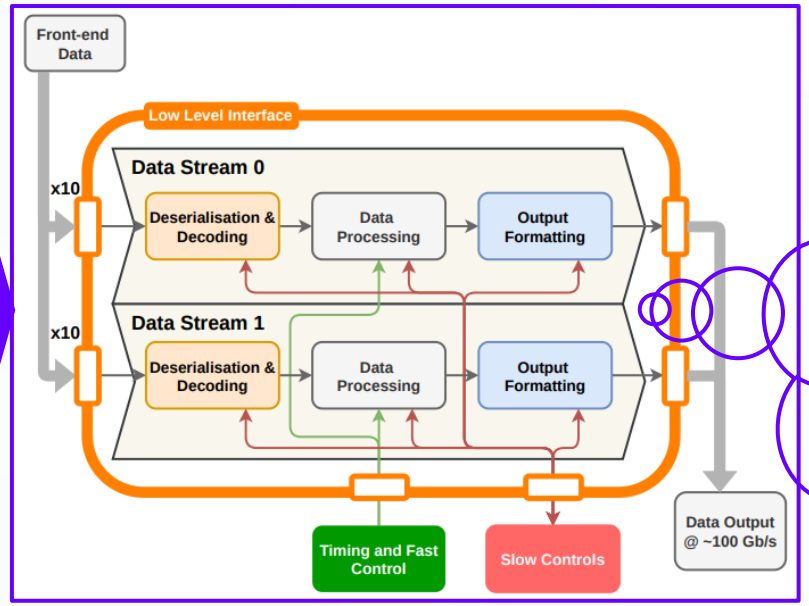
Clusters rate

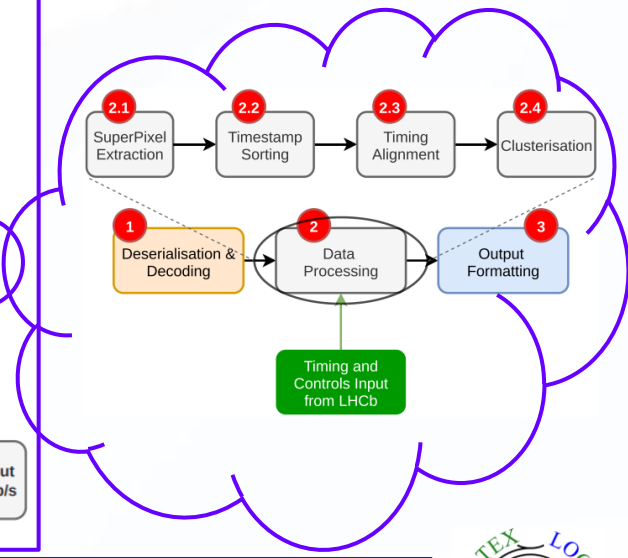


Front end



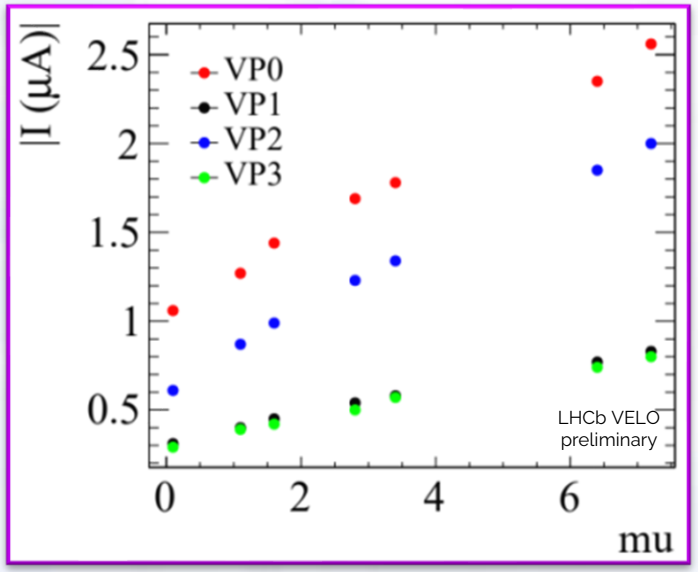
Back end



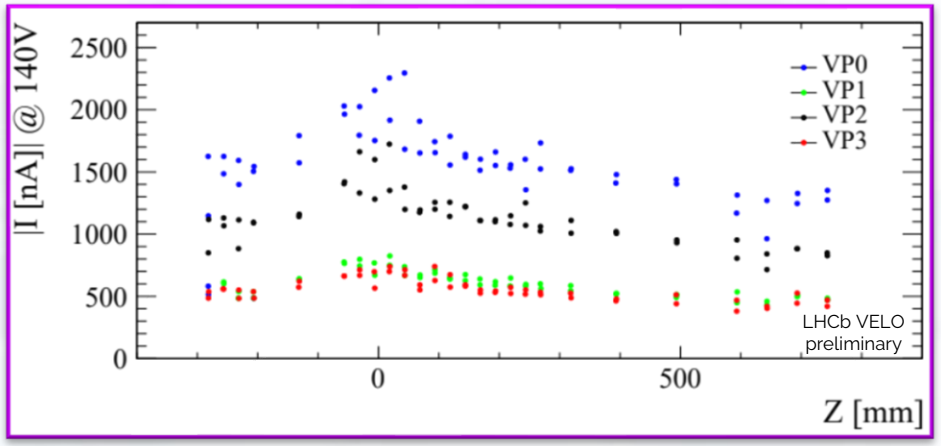


Leakage current evolution

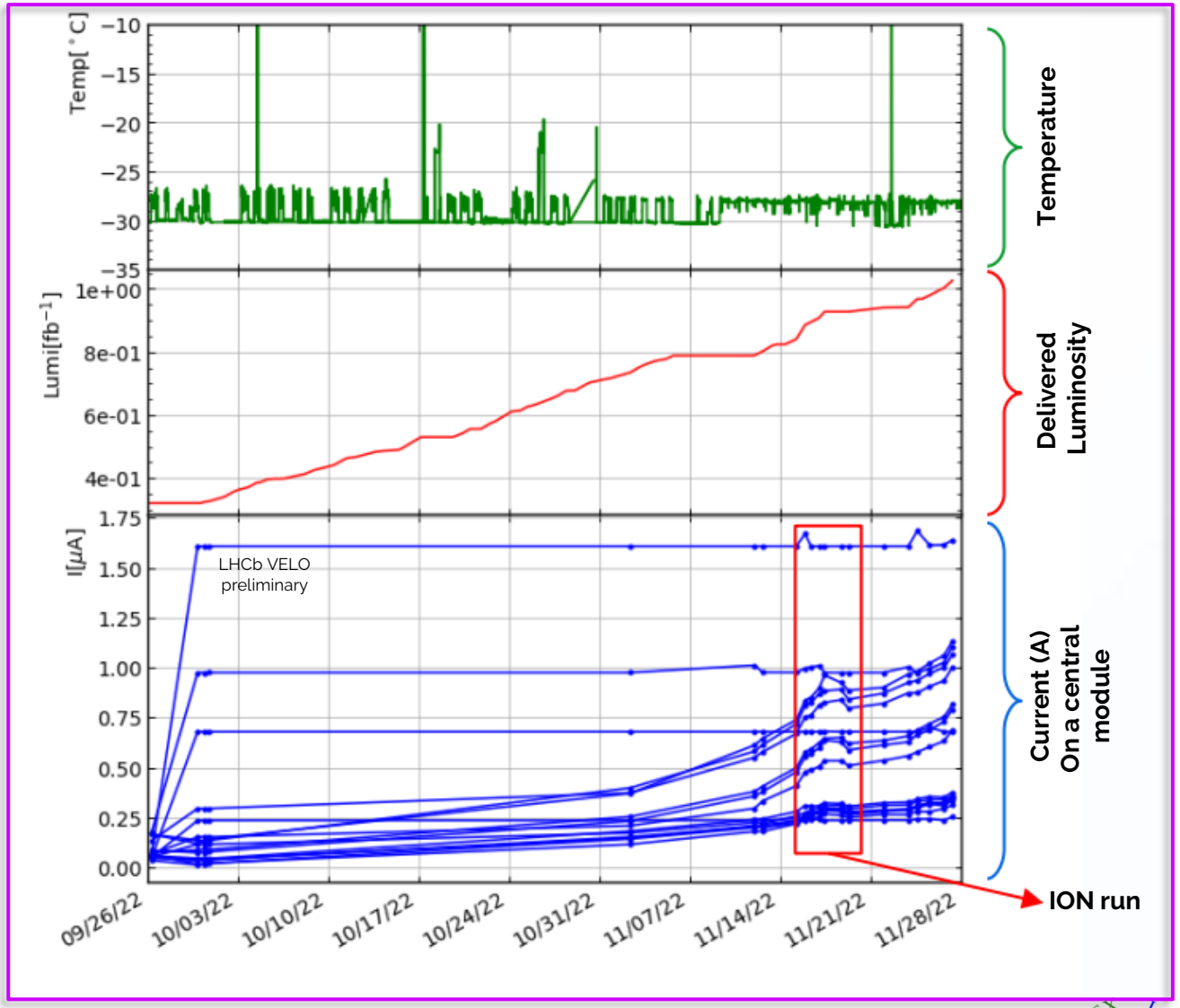
Multiplicity scan. Current increase linear



Leakage current vs Z position

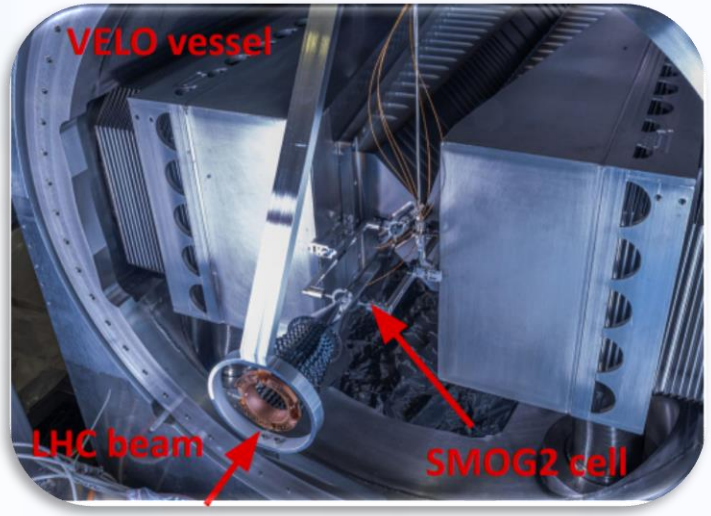


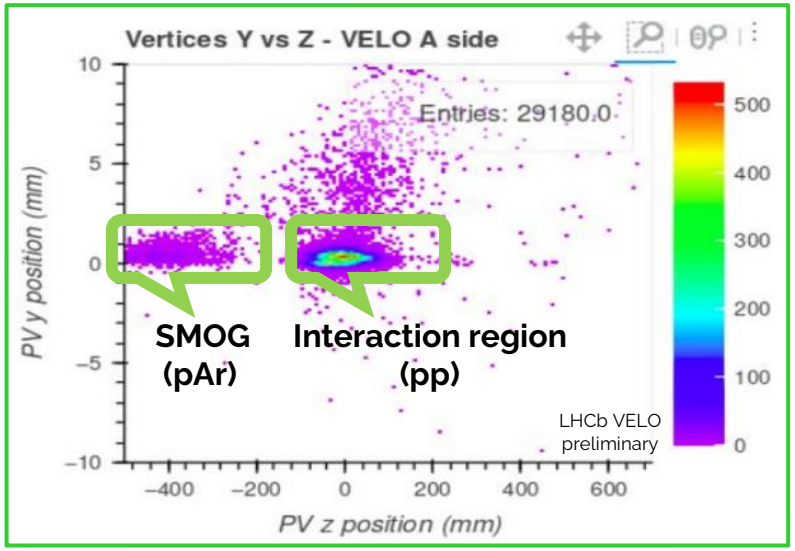
Current evolution in the last 2 months



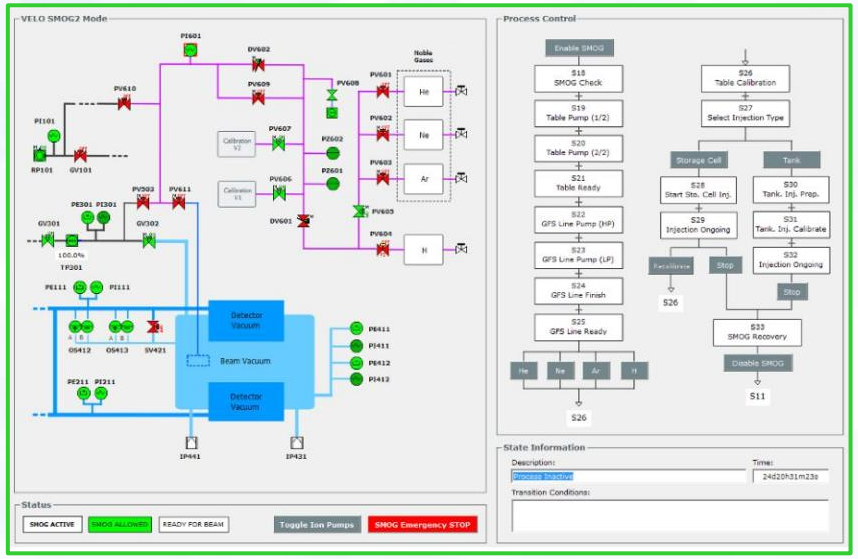
SMOG 2

- SMOG 2 system inject gases (Ar, NE, He and H2) in the LHC beam pipe, acting as the highest-energy fixed-target experiment. (TDR, Physics).
- Gas feed system fully commissioning this year.

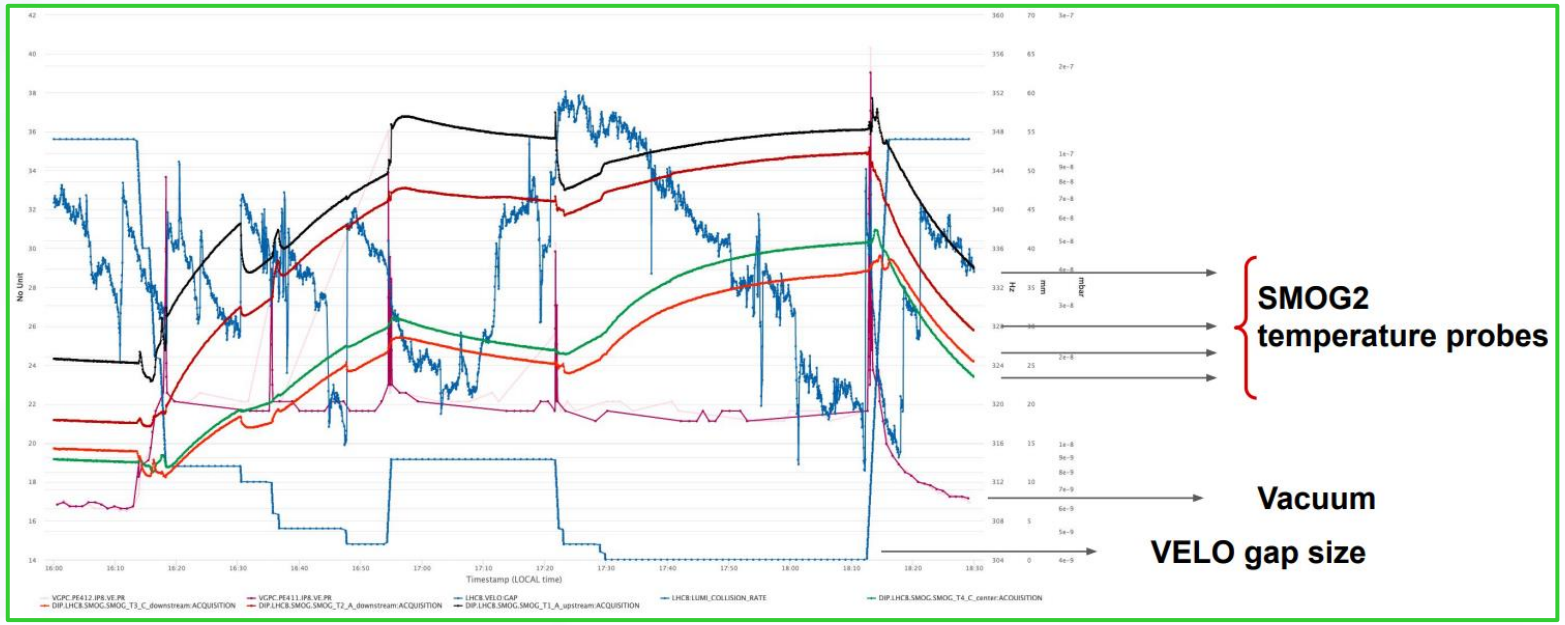




System control

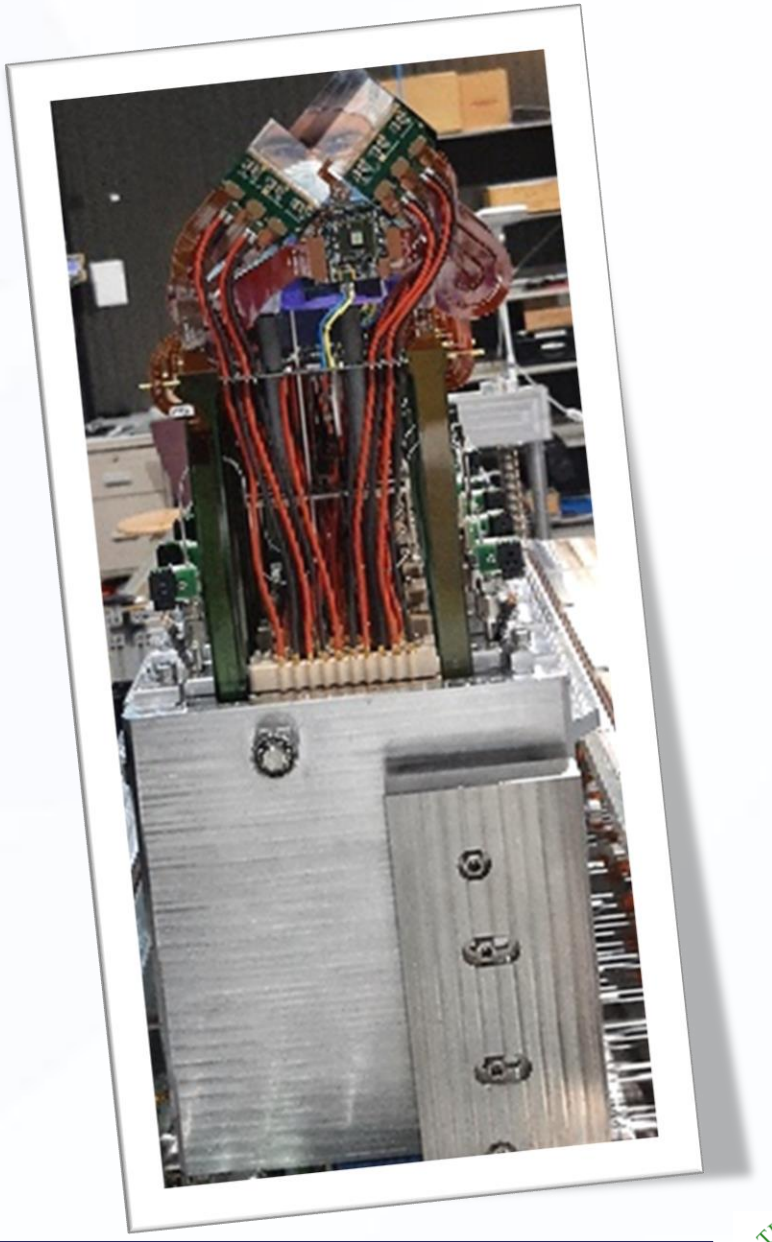


Temperature, vacuum and VELO position



Conclusions

- Successful years of detector assembly and commissioned.
- Infrastructure systems (cooling, vacuum, LV, HV, motion, mechanics) properly working from first day.
- VeloPix tuned to get better performance.
- Time alignment performed with the full LHCb.
- Closing procedure stabilized and daily operational.
- First results on data rate and radiation damage.
- SMOG 2 system commissioning for fix target experiment.



Looking forward for a successful commissioning and data taking year 2023


Thank You!