The LHCb Vertex Locator:
design, operation and results

Pawel Kopciewicz on behalf of the VELO detector group

13th International Conference on Position Sensitive Detectors
September 3-8, 2023, University of Oxford

LHCb spectrometer

The experiment studies CP violation and rare decays of b- and c- hadrons.

JINST 3 (2008) S08005 – The LHCb experiment

CERN-LHCC-2001-0011 – The LHCb VELO TDR

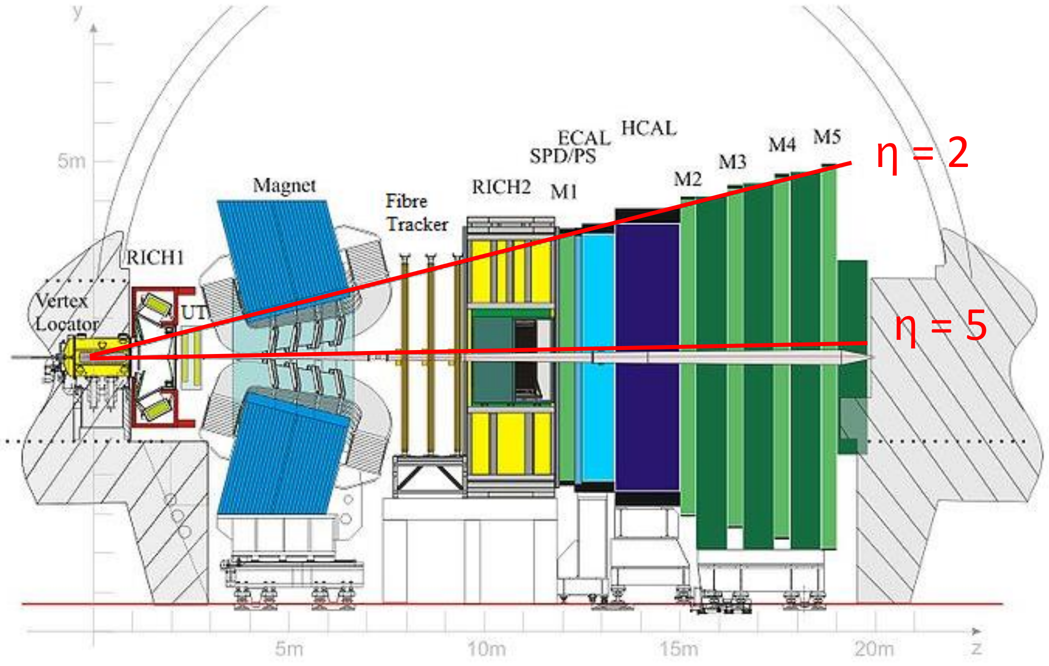
Upgrade I of the spectrometer.

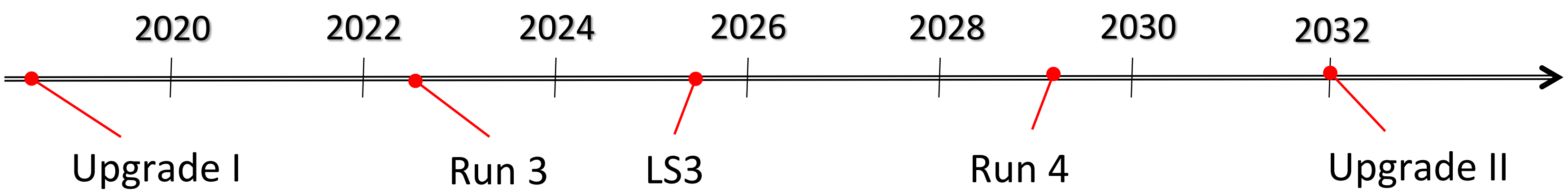
LHCb-DP-2022-02 – The LHCb Upgrade I

- A single-arm forward spectrometer
- Covers $\eta \in (2, 5)$, η – pseudorapidity
- Very precise tracking system
- Upgrade I to triggerless readout at 40MHz
- Upgrade I to increase instantaneous luminosity from $4\times10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ to $20\times10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

LHCb spectrometer

CERN-LHCC-2014-001

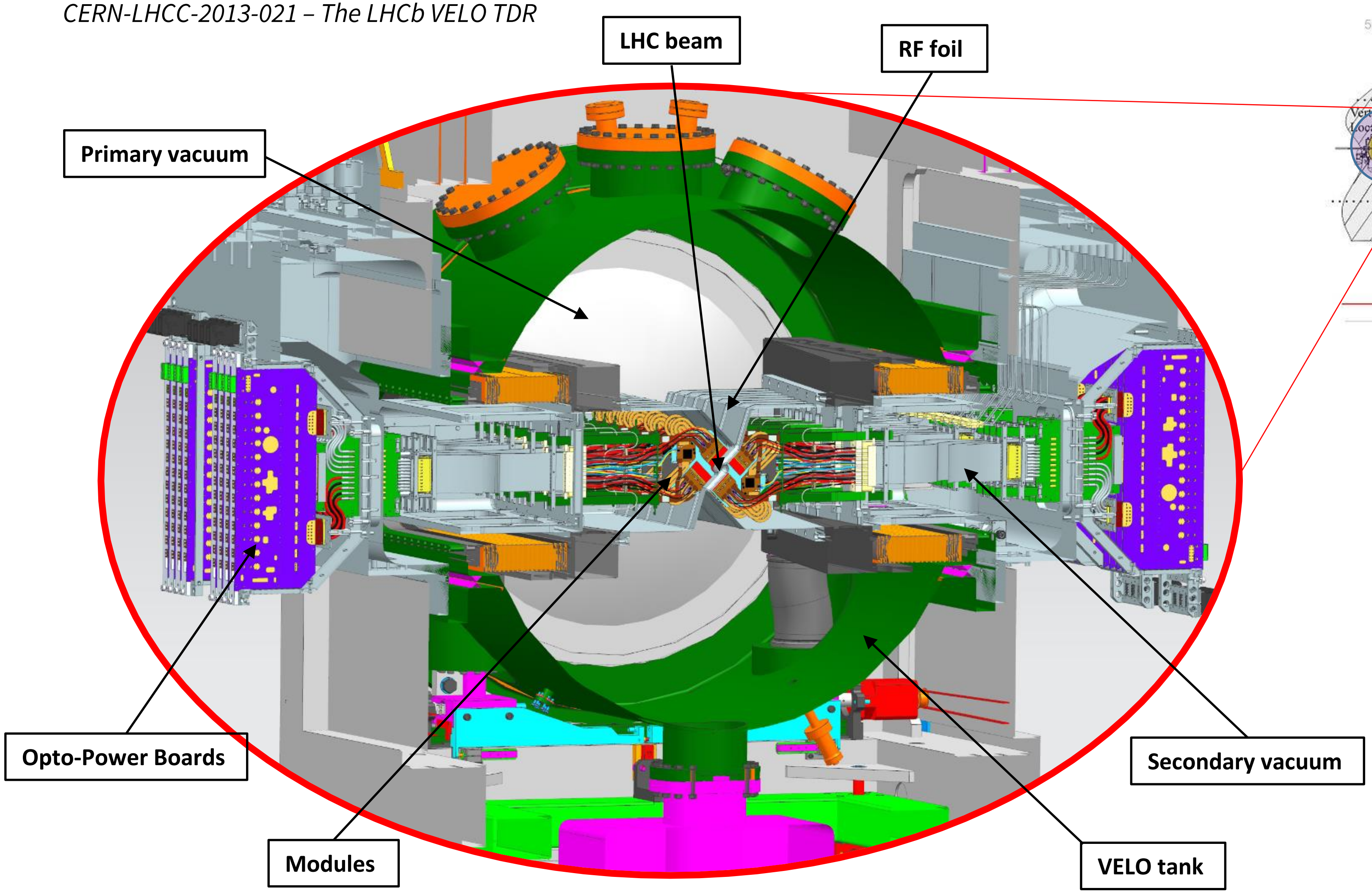


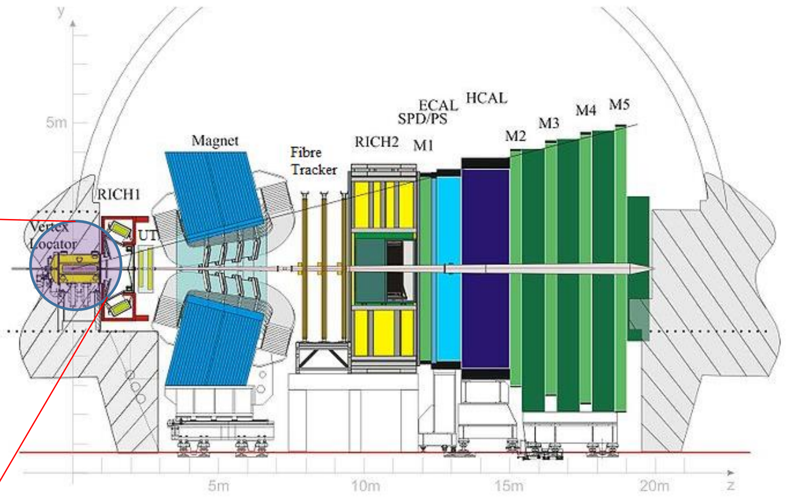


The Vertex Locator

A pixel detector for tracking and vertex reconstruction.

CERN-LHCC-2013-021 – The LHCb VELO TDR





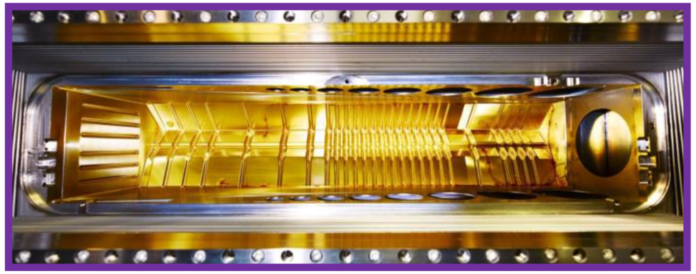
Upgrade I Vertex Locator

- Maintained the basic layout
- Two halves retracted during injection
- Readout at 40 MHz (from 1.1 MHz)
- Silicon microstrips -> silicon pixels
- Innermost edge around 5.1 mm to the beam (from 8.2 mm)
- Two-phase CO_2 cooling
- RF foil with reduced thickness

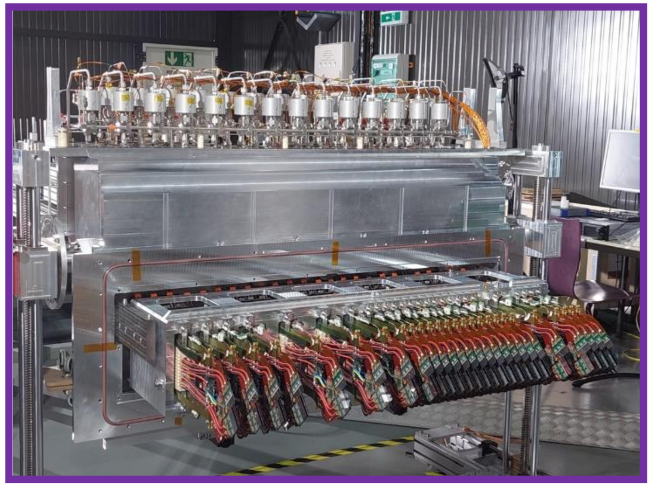
Detector assembly

The RF foil

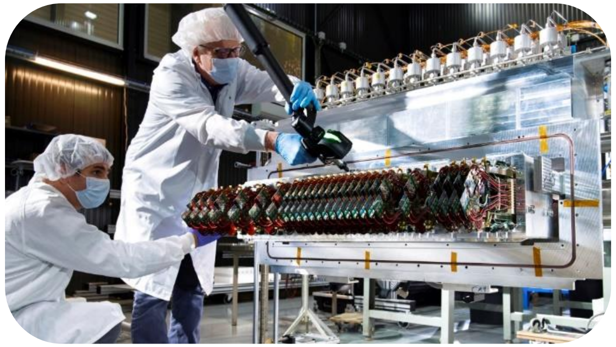
- Milled from solid aluminium block
- 150 µm thick in the inner region
- Shields module assemblies from beam halo and RF pick-up
- Separates LHC and VELO vacuum



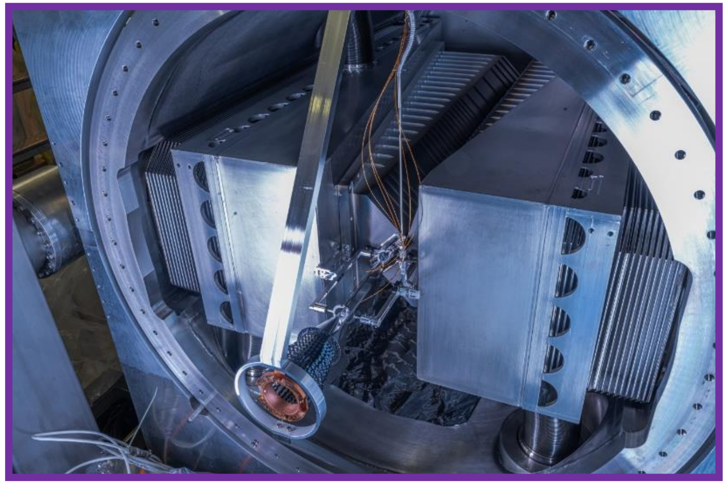
VELO’s one half



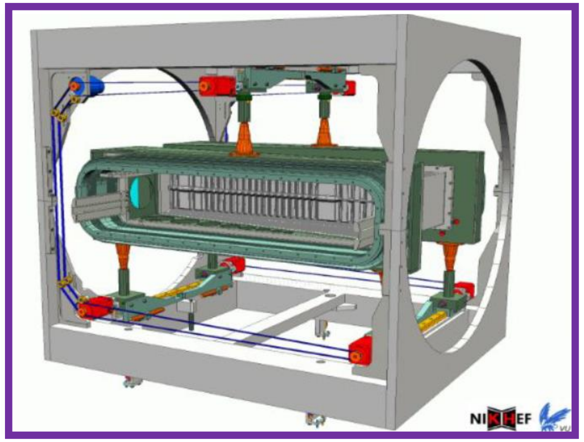
Metrology



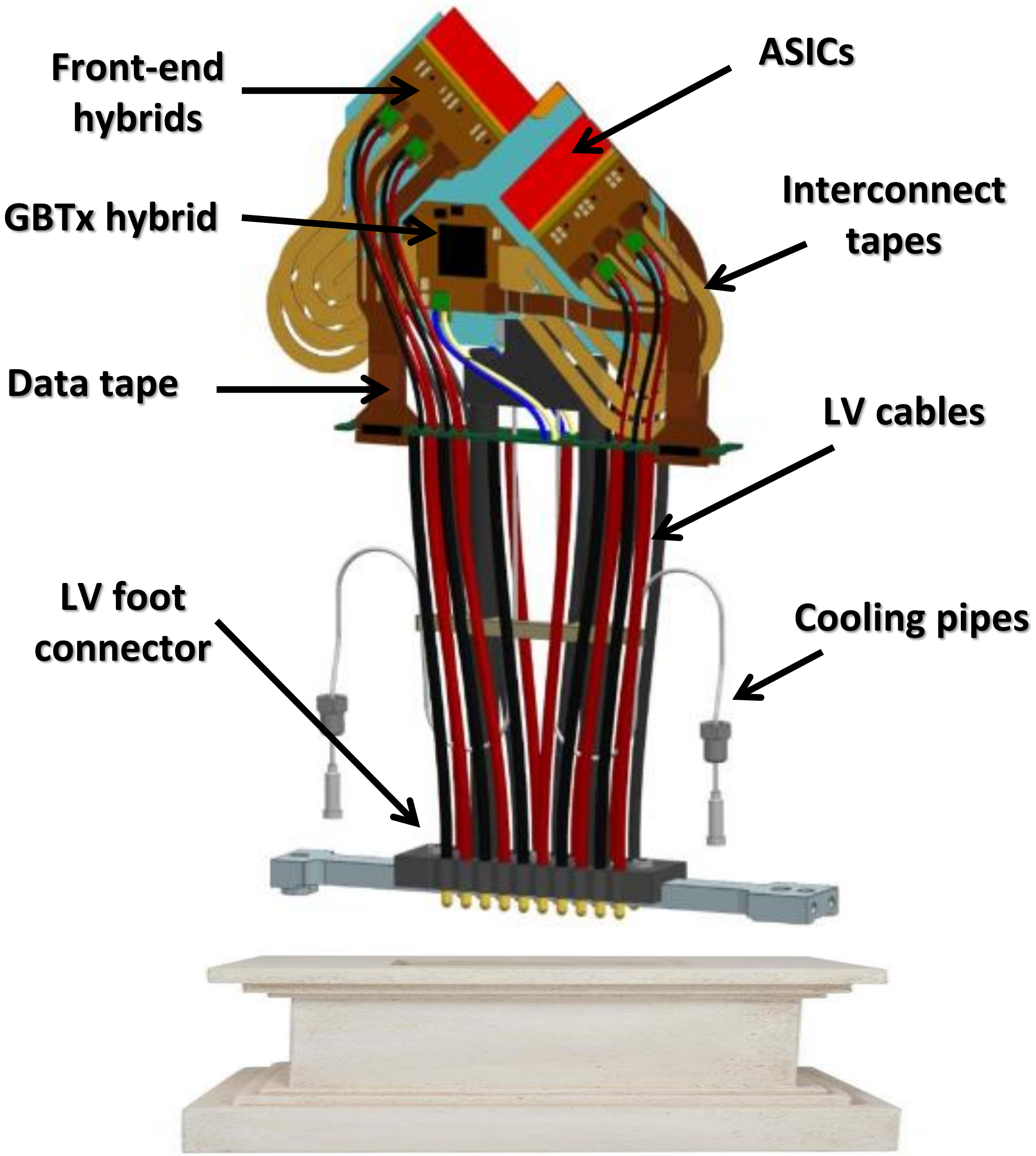
SMOG 2

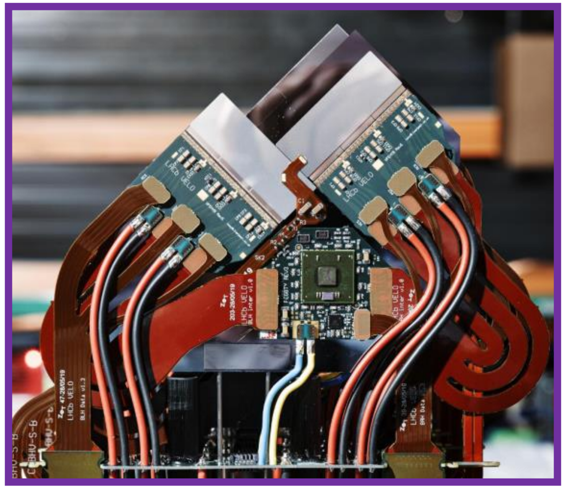


Motion system



The VELO module

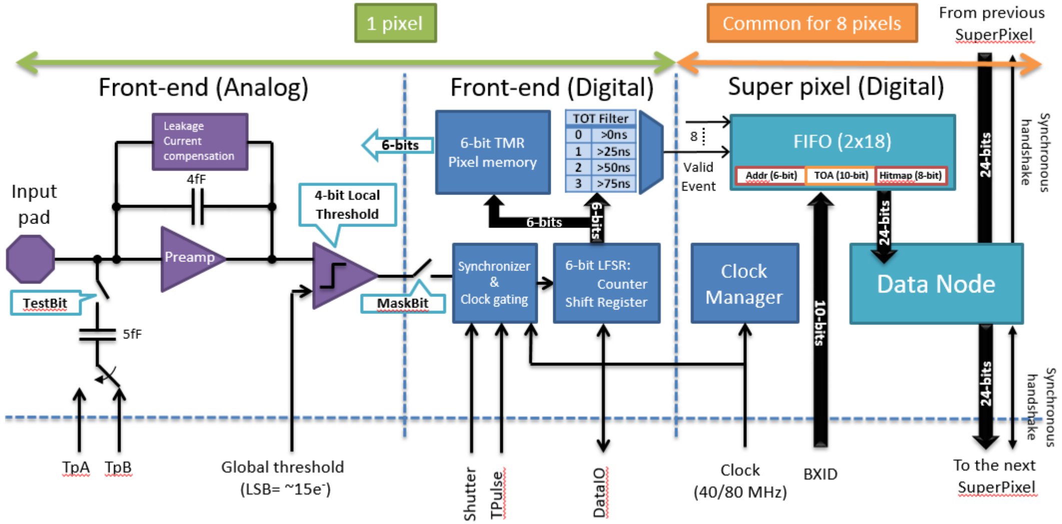




- Pixels of 55 µm pitch
- 256x256 pixels per ASIC
- 3 ASICs per sensor unit
- 12 ASICs per module
- Control via GBTx hybrid
- ASIC rate up to 800 Mhits/s
- Binary triggerless readout
- Radiation hard to 400 Mrad
- 52 modules (26 per A, C side)

The VeloPix ASIC

2015 JINST 10 C01057

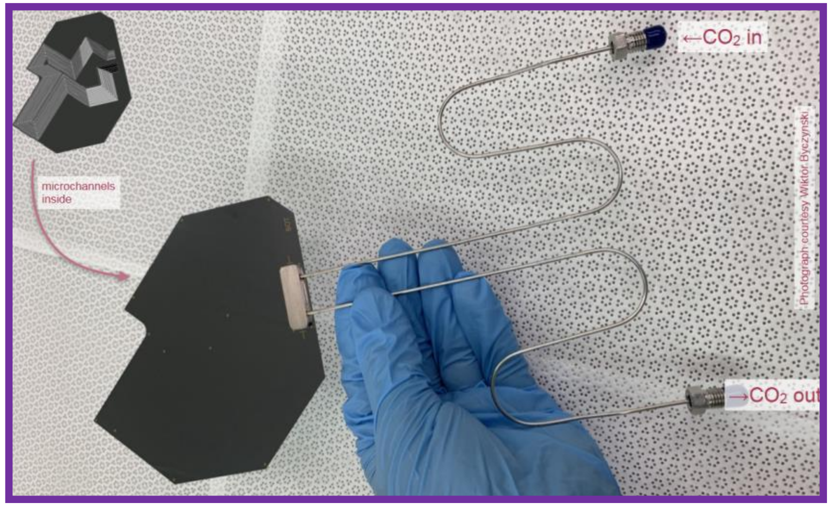


Cooling system

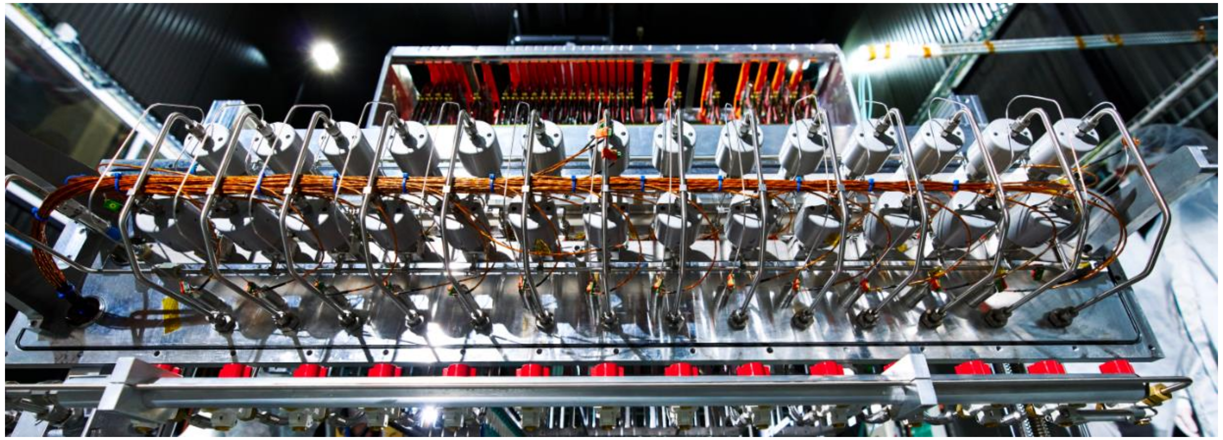
Two-phase CO_2 microchannel cooling.

DOI 10.1016/j.nima.2022.166874

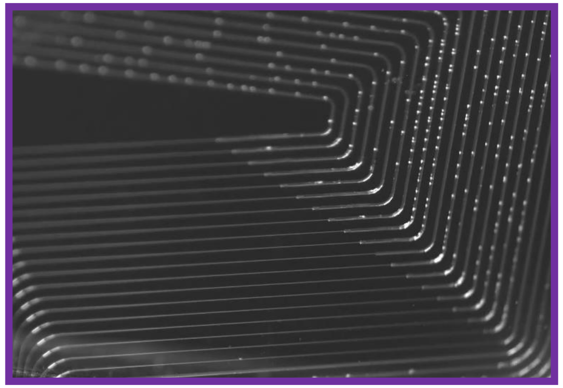
- Cooling system embedded into module substrates
- Two-phase CO_2 circulating in microchannels etched in silicon wafer
- Cooling power of 40 W at -30 ^{o}C (per module)
- Safety system against leaks

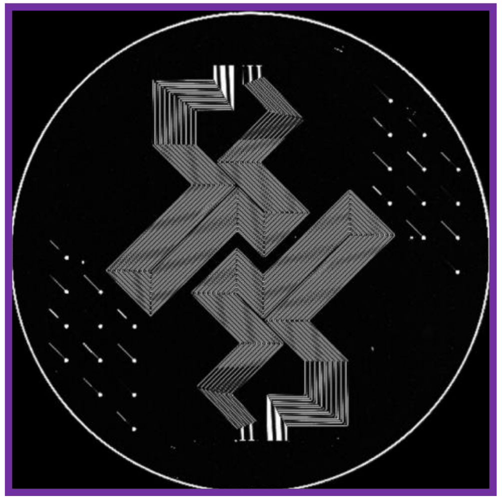


Cooling system for the VELO side



Microchannels





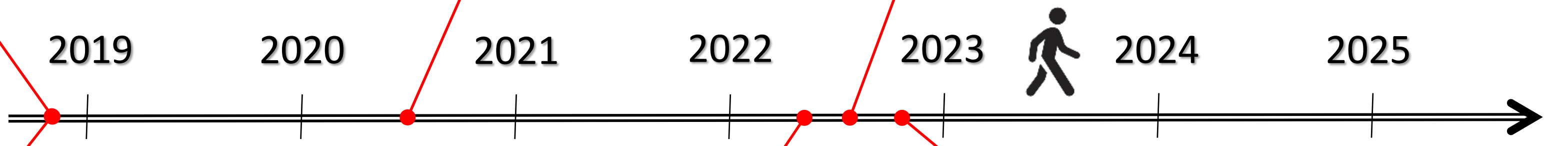
VELO timeline

Covered so far…

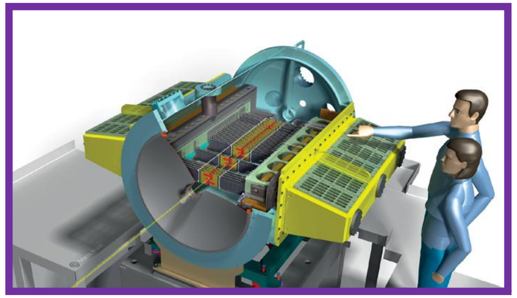
RF foil installation

End of Run 2

Run 3

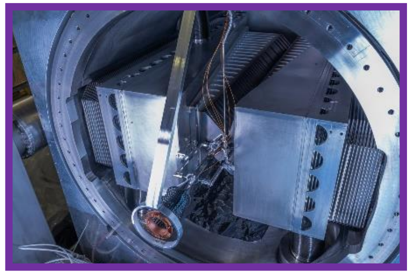


Upgrade I begins!



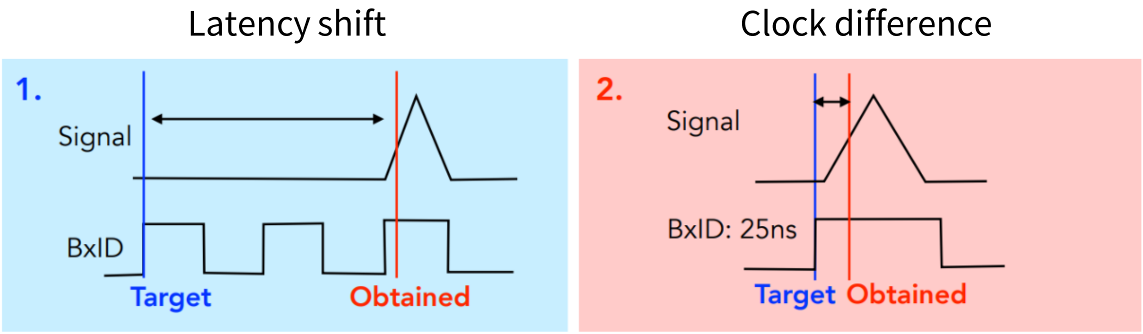
VELO halves assembly

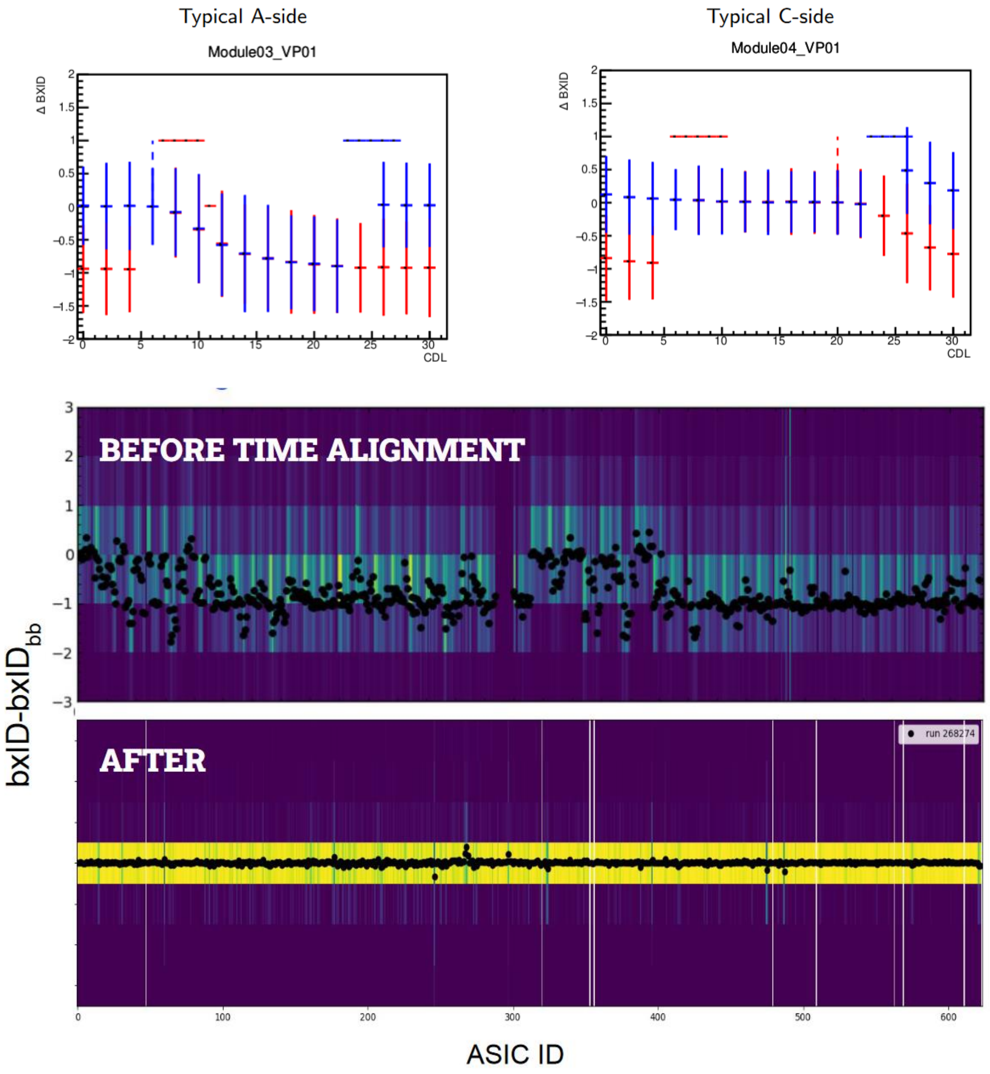
SMOG 2 validation



Time alignment

Alignment in time of the signal response from all ASICs.





Generic strategy:

- Use isolate BXID to find timing of different ASICs

Latency shift:

- SOL40 delay to correct the latency

Clock difference:

- GBTx phase-shifter channel
- Scanning the phase of the ASIC clock to the LHC clock

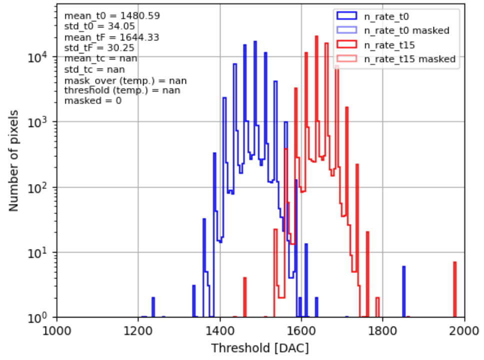
BXID spread for pixels in same ASIC:

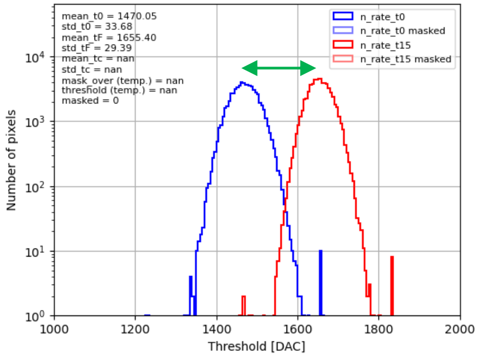
- DAC and signal threshold adjustment

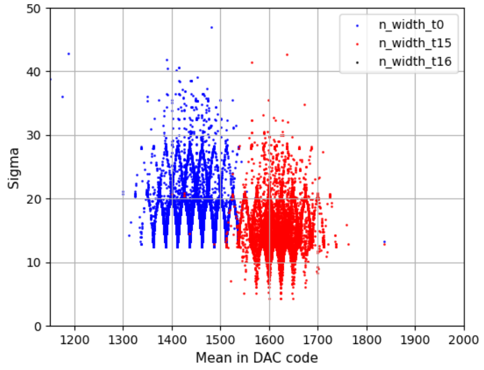
Calibration

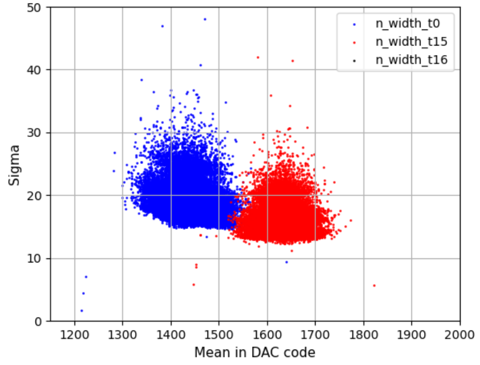
Pixel equalisation

- Threshold scan to estimate the noise
- 16 fine tune trim values
- Extreme trims are applied to find the centre region
- The voltage that drives the range between trims is adjusted
- Different strategies for equalisation, compromised for precision and time

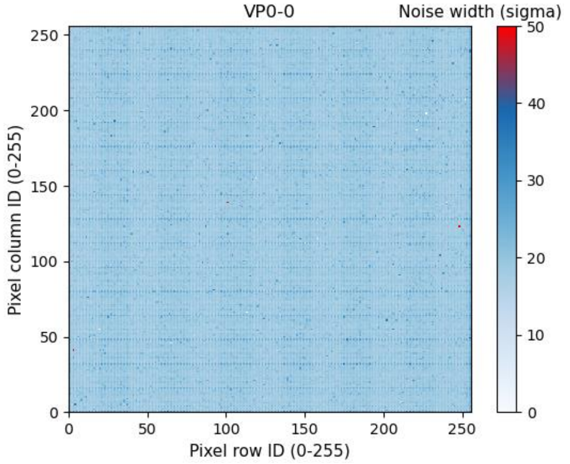




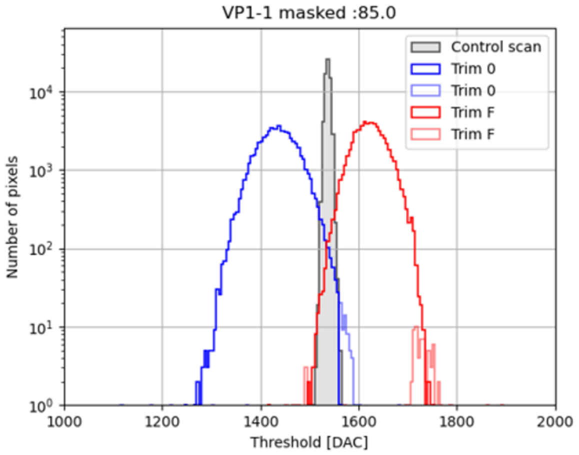


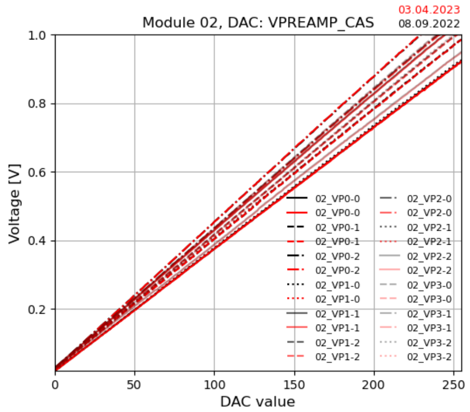


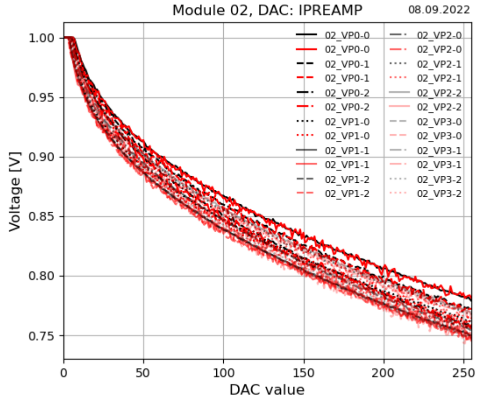
Noise scan



Equalised ASIC





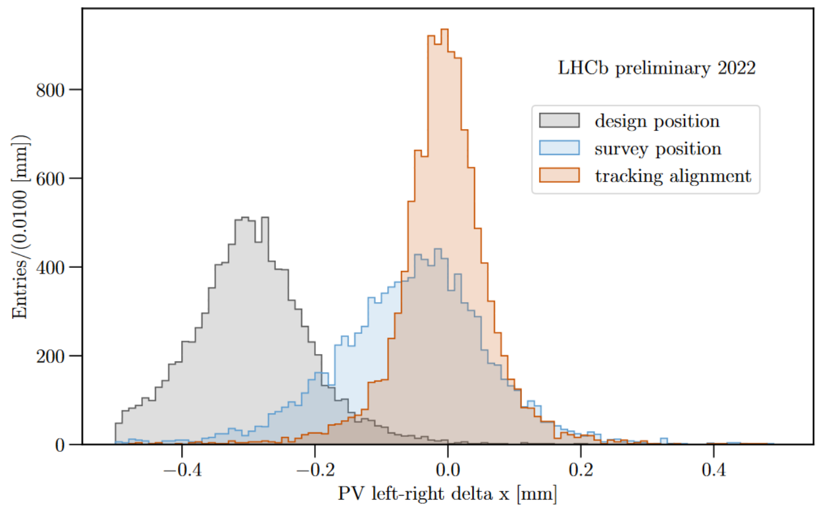


DAC scan

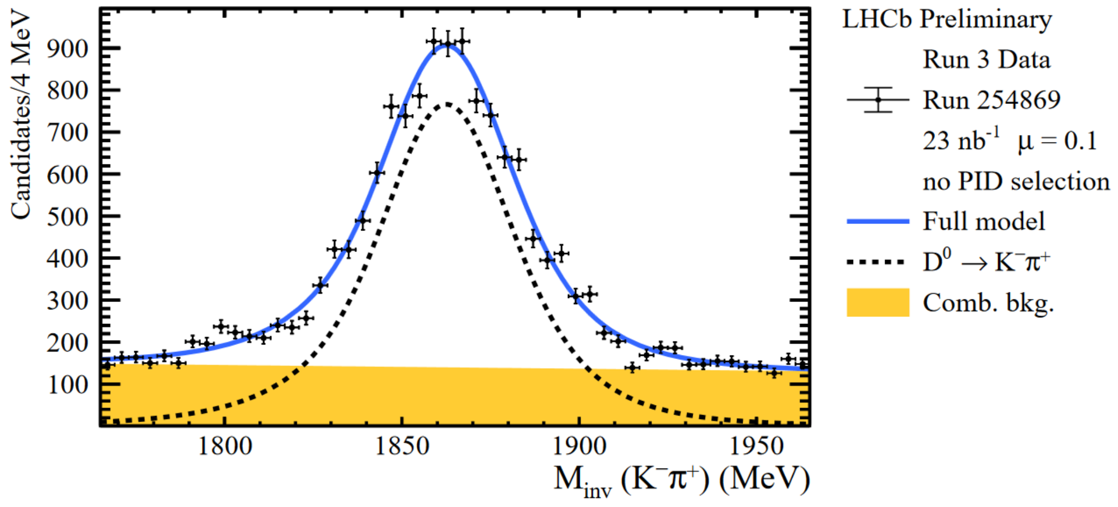
- Variation in operation voltages in different ASICs
- Impact on noise, equalisation, time alignment and power consumption
- Strategy to optimize voltage and current DAC settings

Commissioning

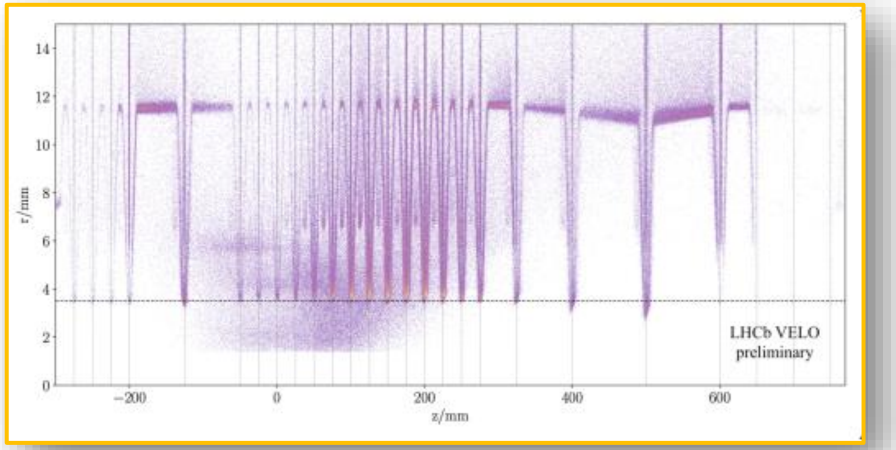
Spatial alignment *LHCb-FIGURE-2022-016*



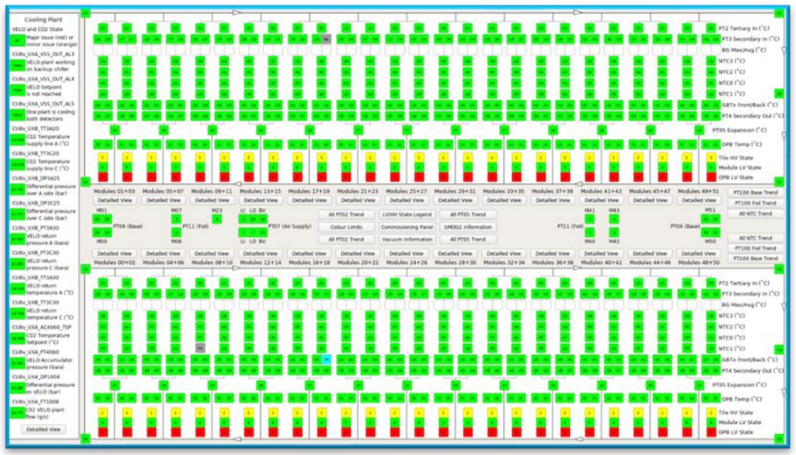
First physics results *LHCb-FIGURE-2023-002*



Vertex reconstruction



Detector monitoring



Vacuum incident

Failure of the LHC vacuum control system.

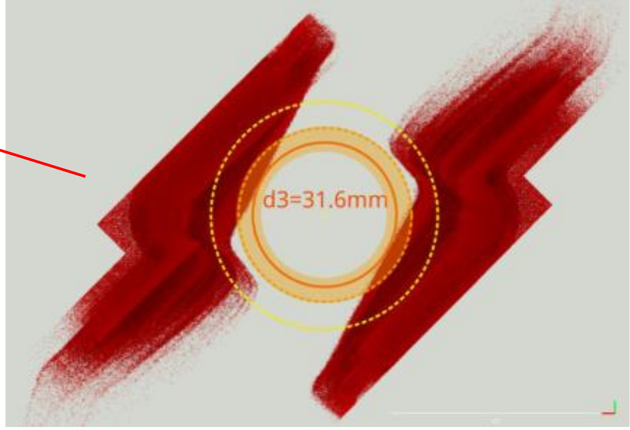
Plastic deformation of the RF foil.

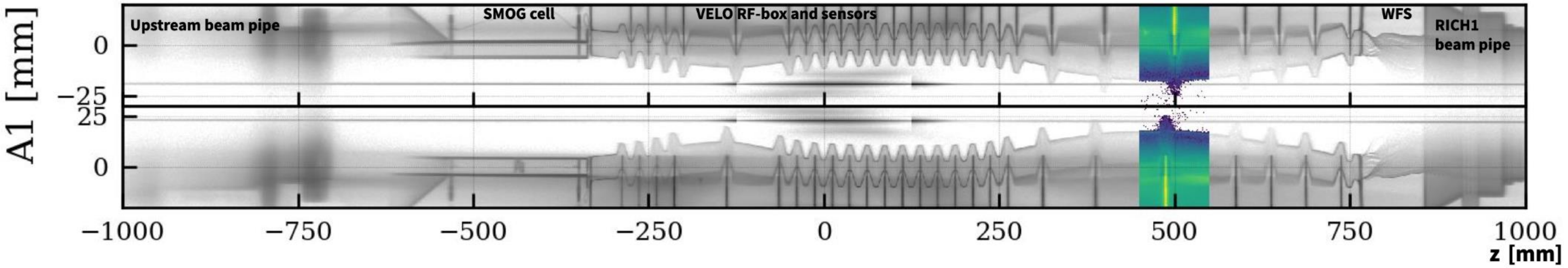
Pumping action into primary vacuum:
- Resulted in 200 mbar pressure on the RF foil
- Designed to withstand 10 mbar

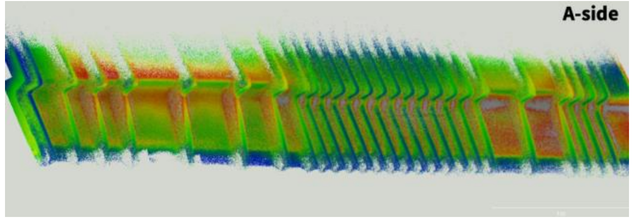
Recovery:
- Simulation and tomography to reconstruct the deformation
- Affects VELO movement
- VELO partially open until RF foil replacement in 2024

The tomography

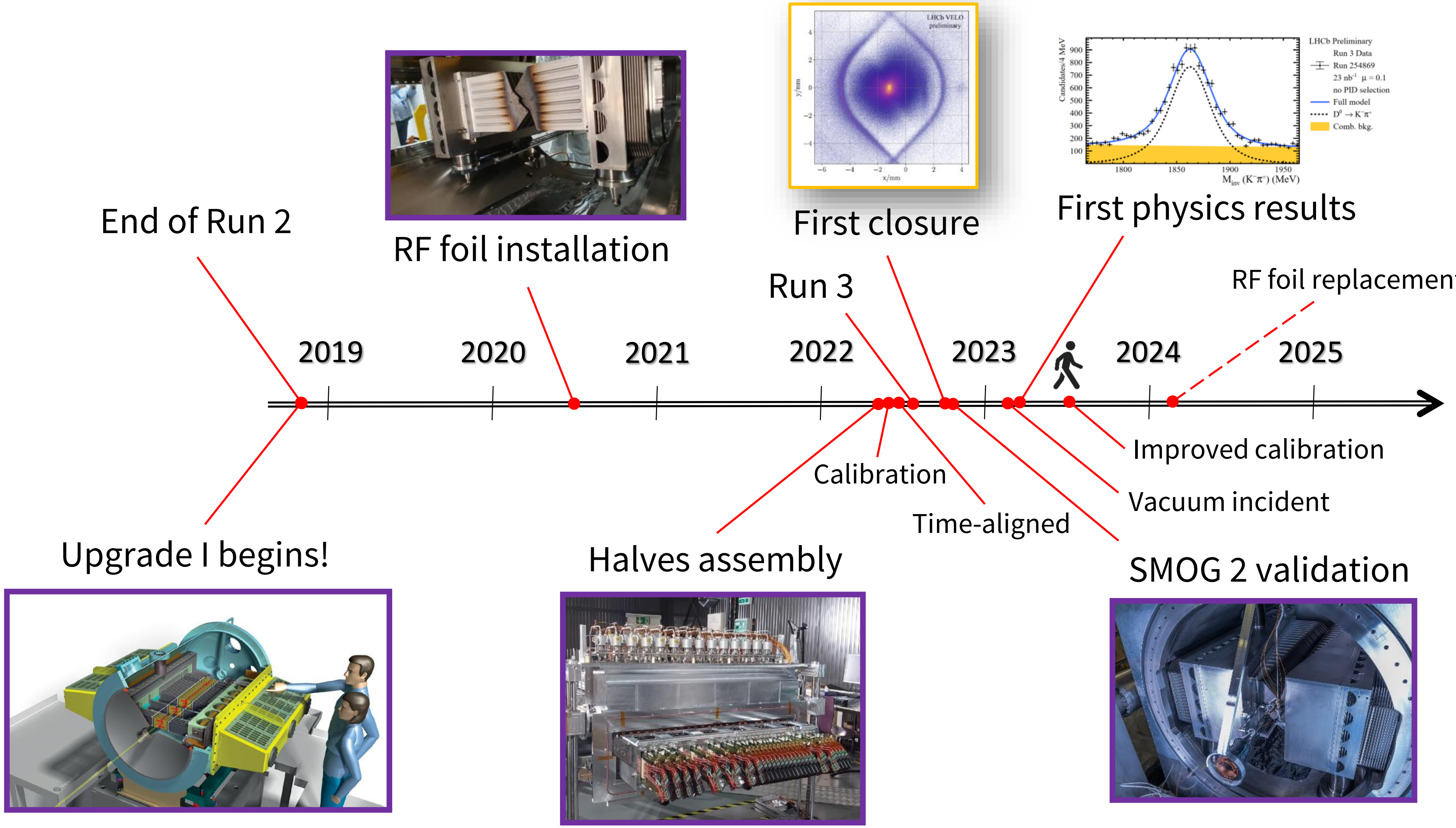
- Radius reduced from 49 to 31.6 mm
- SMOG 2 injection to increase the production of particles outside the interaction region
- Dataset taken on 7.8 TeV
- Events of at least 3 displaced tracks taken into account





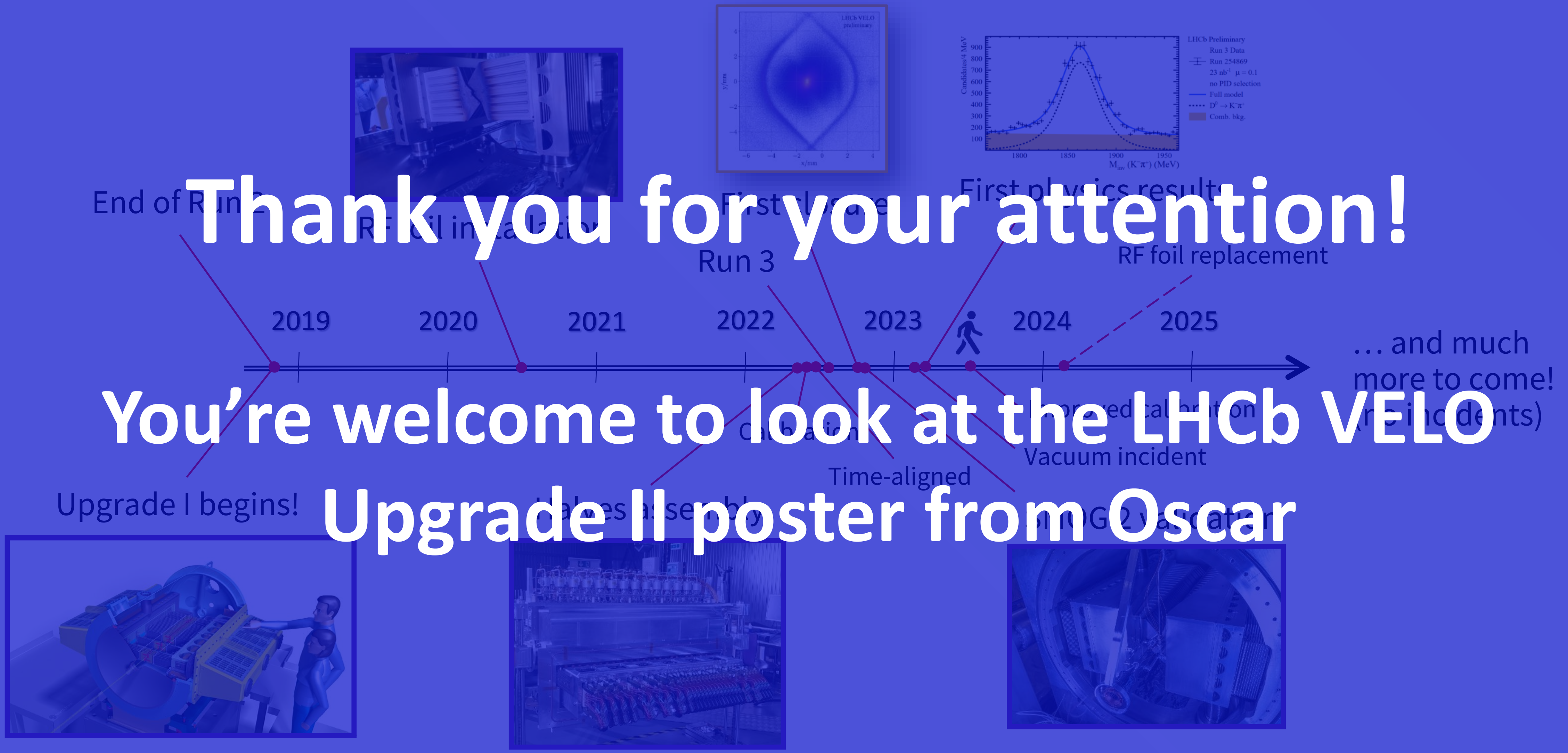


VELO timeline - summary



… and much more to come! (no incidents)

VELO timeline - summary



Thank you for your attention!

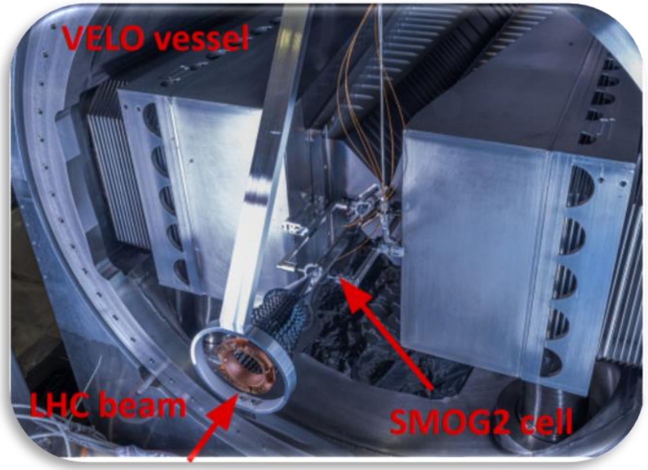
You’re welcome to look at the LHCb VELO Upgrade II poster from Oscar

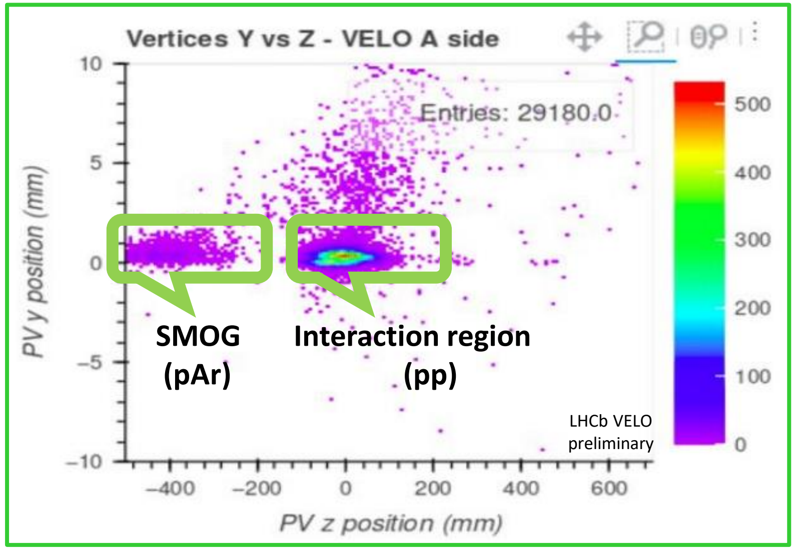
Backup – SMOG 2

SMOG 2 injects noble gases (and hydrogen) into the LHC beam pipe.

The highest-energy fixed target experiment.

CERN-LHCC-2019-005





Temperature, vacuum and VELO position