The LHCb VELO Detector

Design, Operation and First Results

Dr. David Friday on behalf of the LHCb collaboration

MANCHESTER 1824

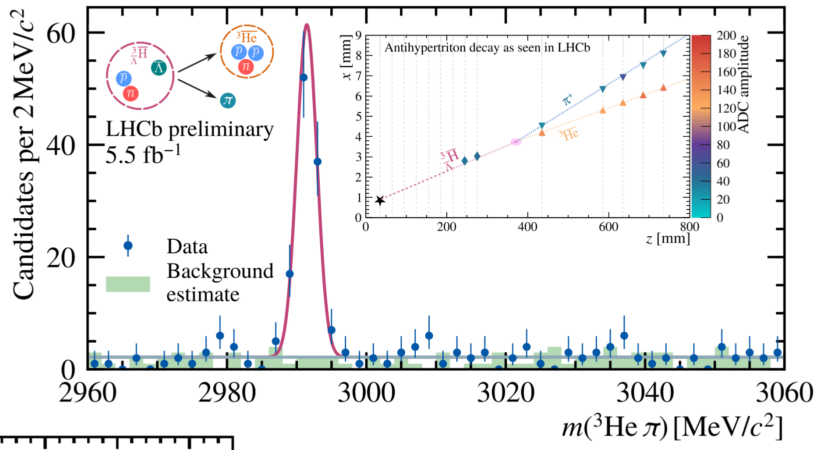
The University of Manchester

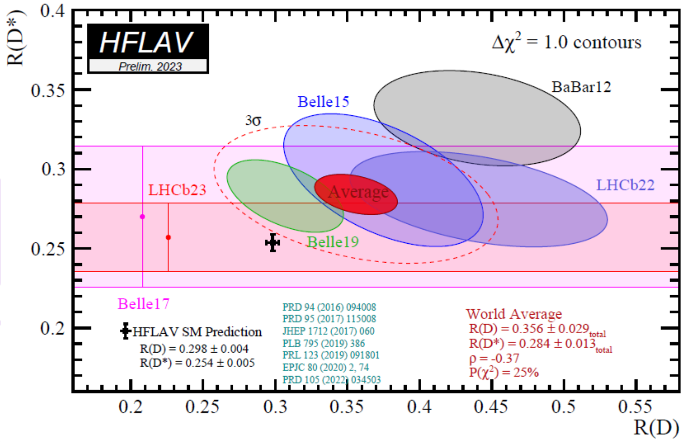
LHCb

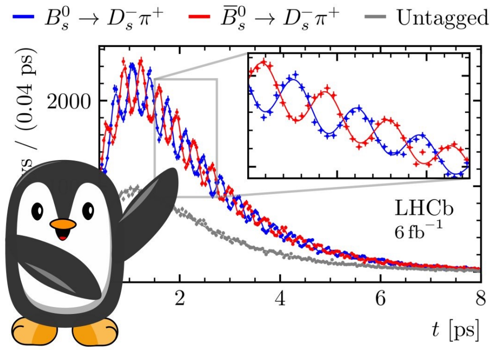
Flavour Physics at LHCb

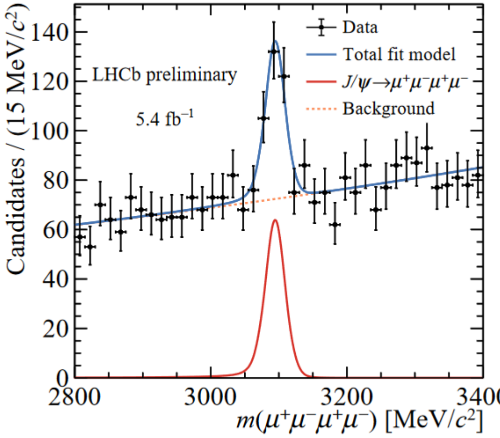
LHCb is a **general-purpose forward detector** at the LHC which is suited to **precision** measurements in the **beauty** and **charm** sectors

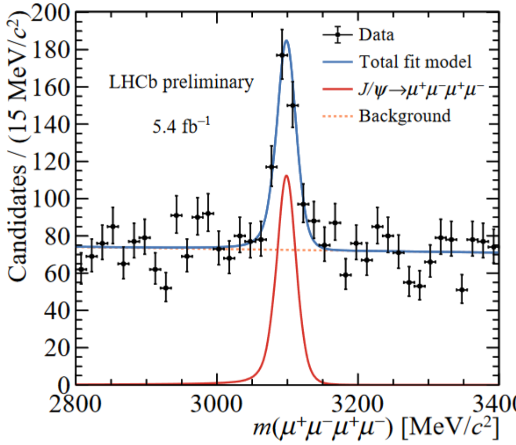
LHCb accumulated 9 fb^{-1} of integrated luminosity during LHC Runs 1 & 2 yielding **precision measurements including…**



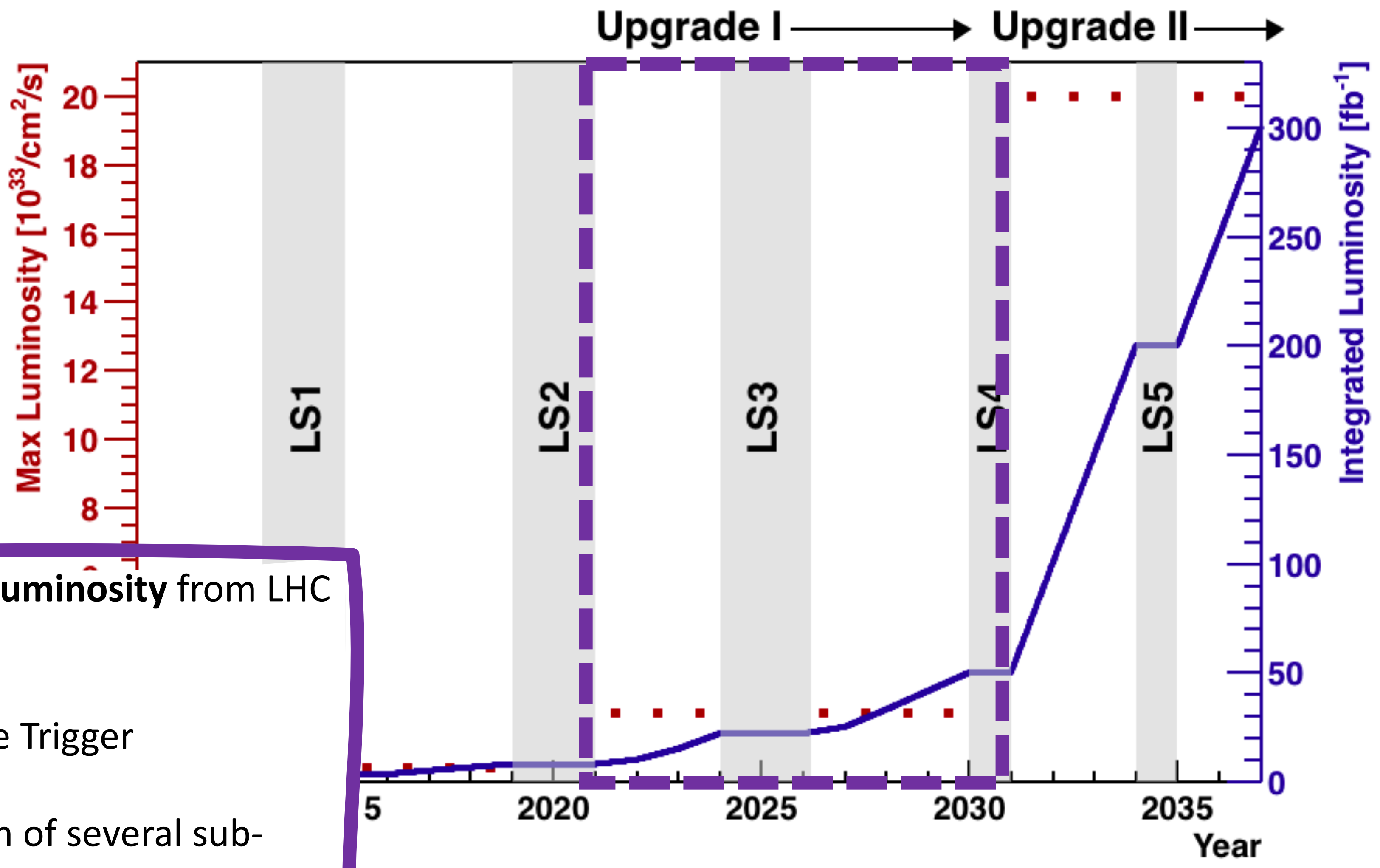








LHCb Upgrade Schedule

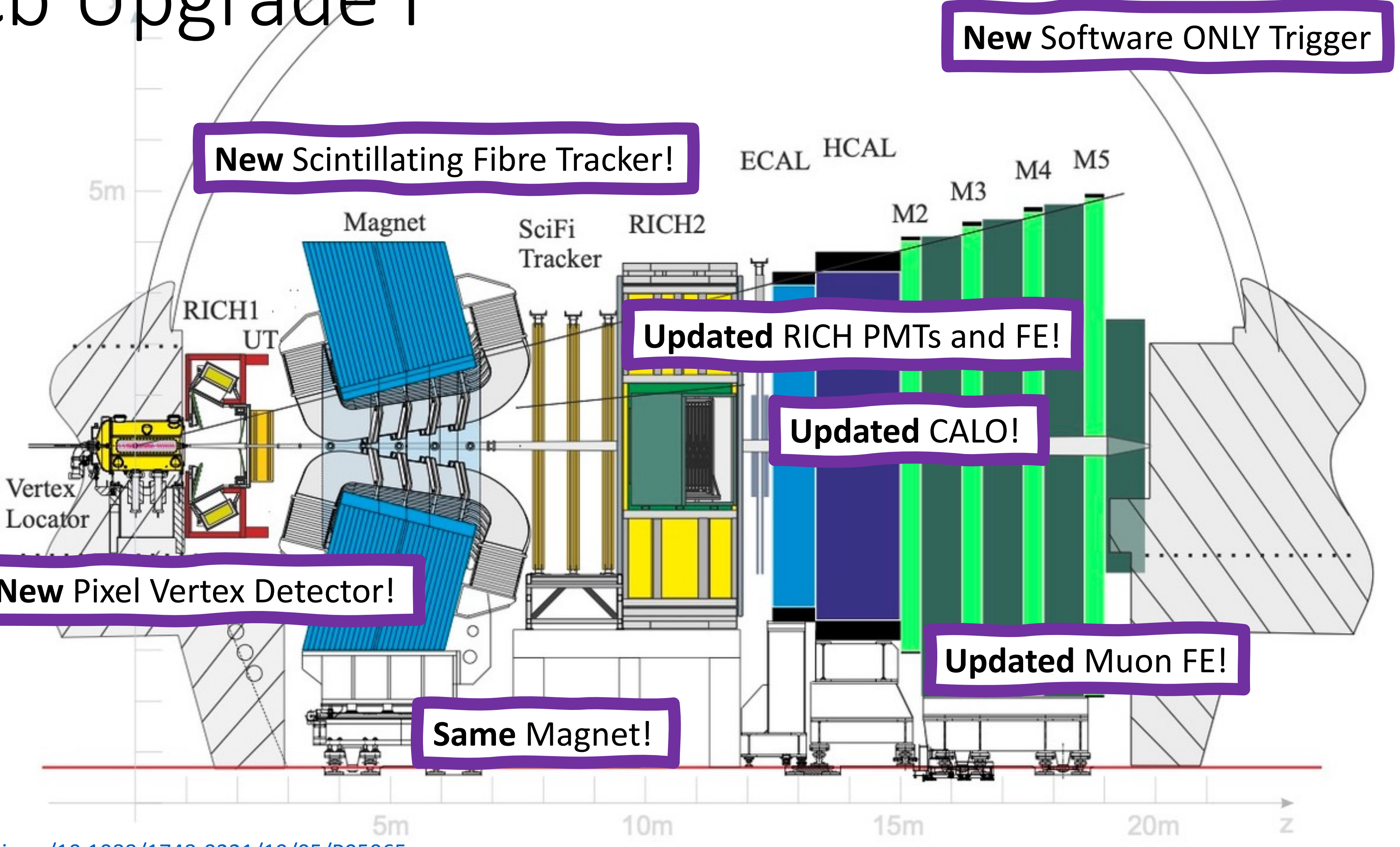


Increase in **Luminosity** from LHC (**x5** Run 2)

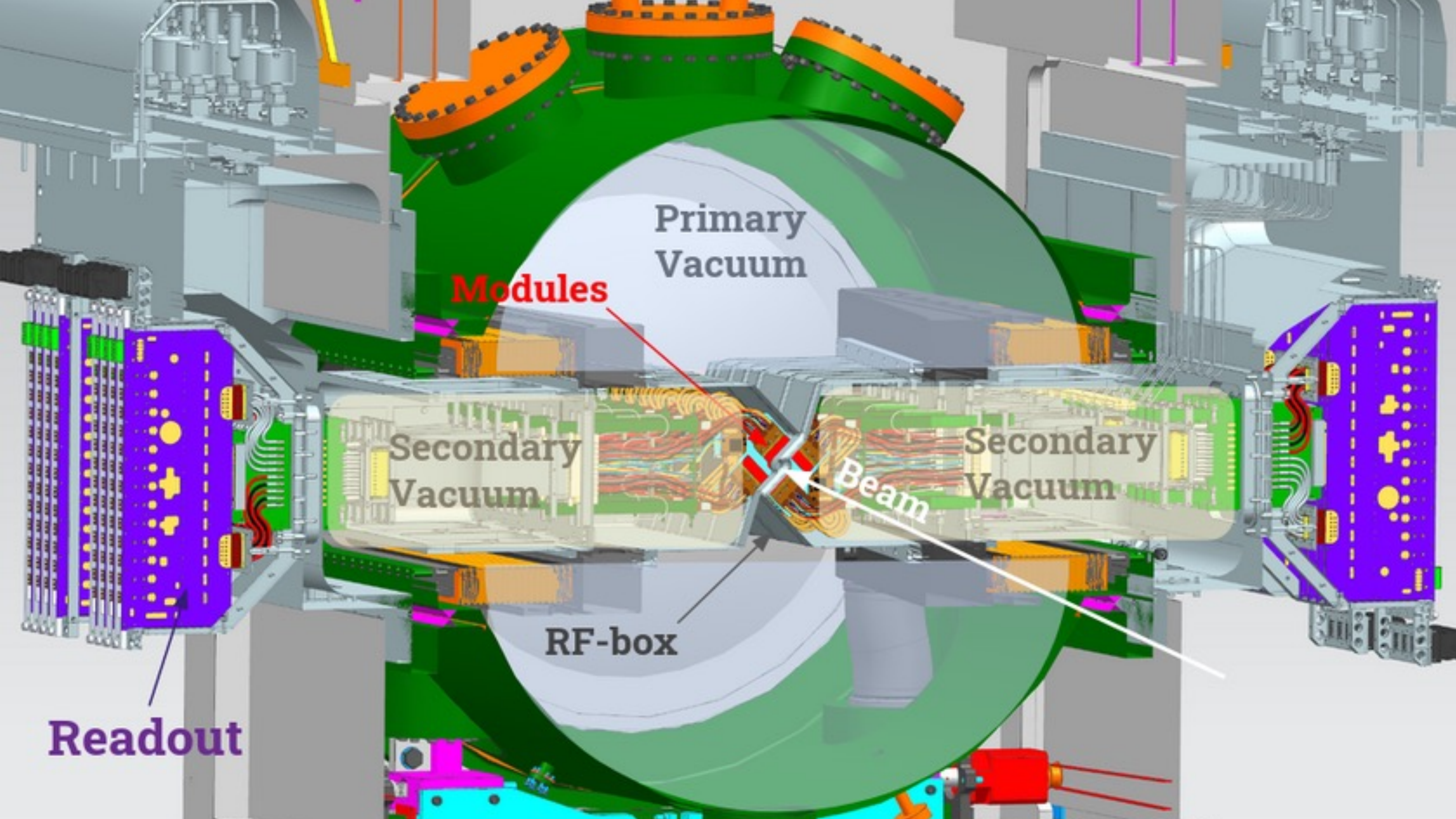
Full Software Trigger

Full re design of several sub-detectors

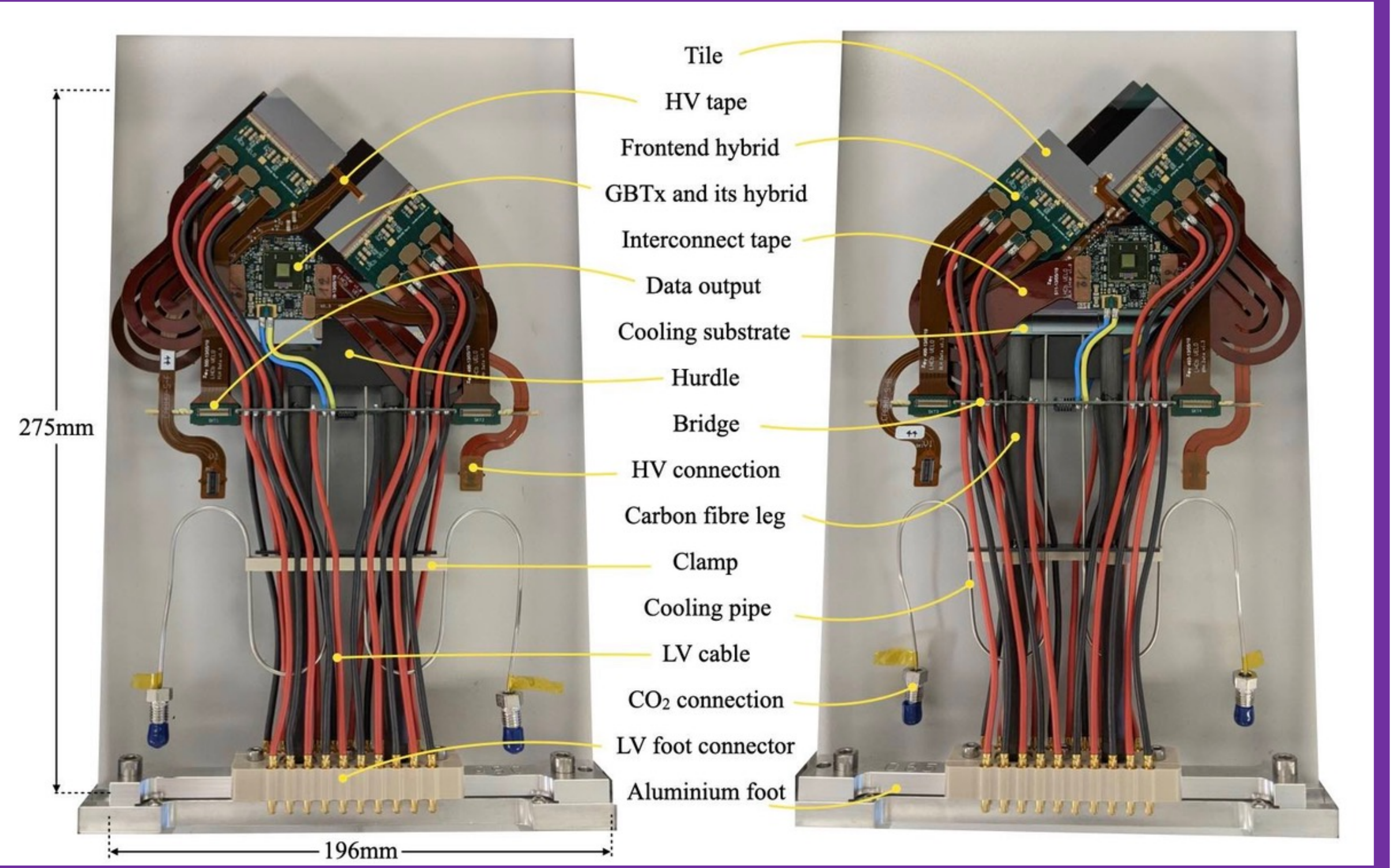
LHCb Upgrade I

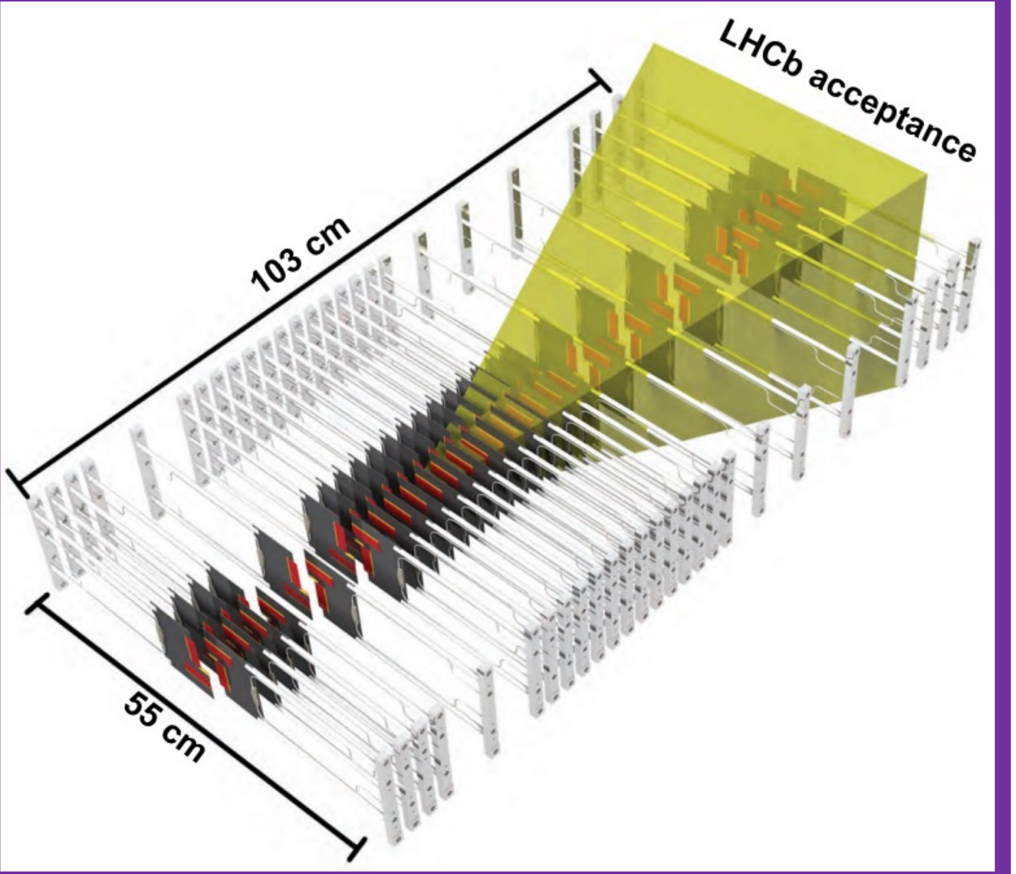


https://doi.org/10.1088/1748-0221/19/05/P05065


Primary Vacuum
Modules
Secondary Vacuum
Secondary Vacuum
Beam
RF-box
Readout

Anatomy of VELO





https://doi.org/10.1016/j.nima.2022.167804

VELO Modules

First element is **5.1 mm** from interaction region

Expected total ionising dose **O(10^{15}) MeV n_{eq}/cm^2**

Immunity against single event effects

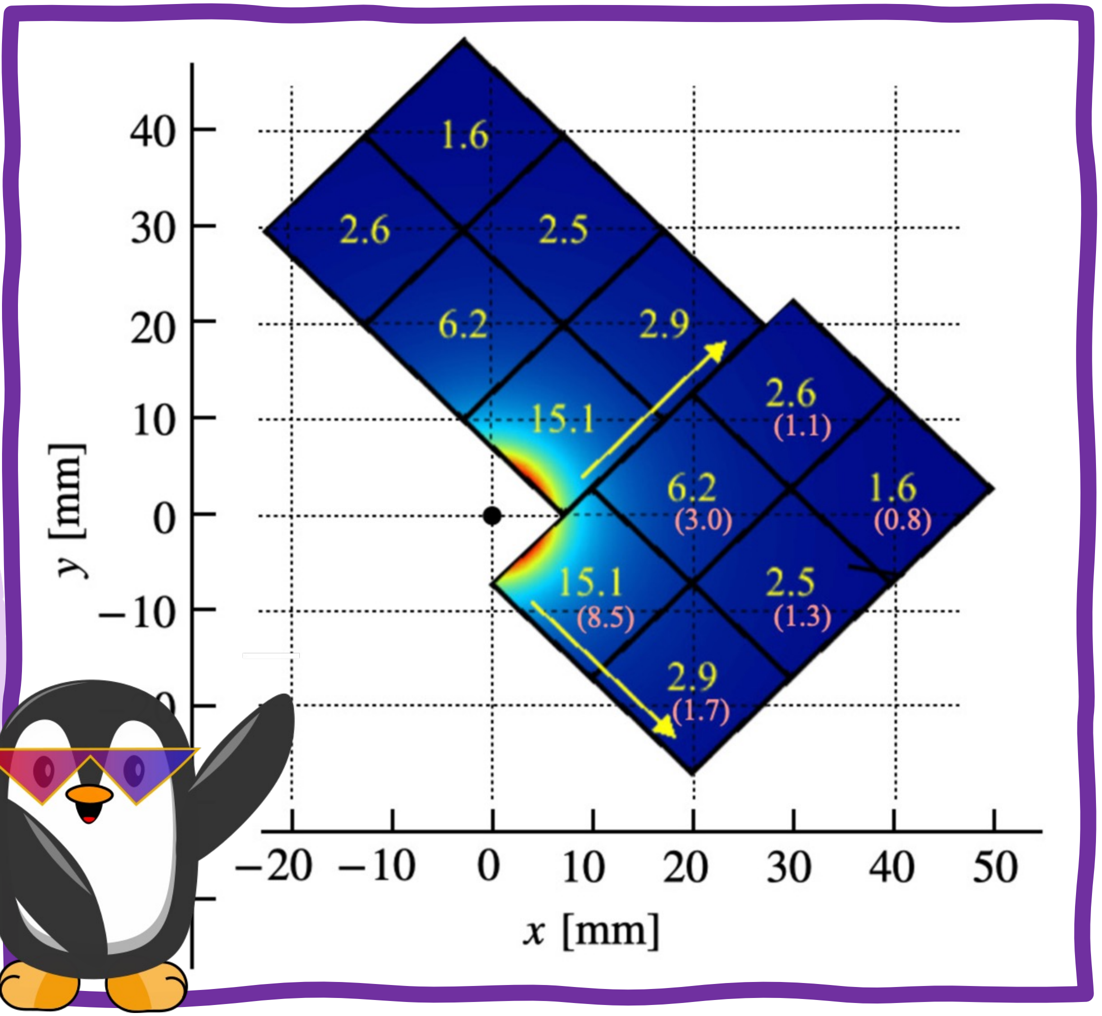
Operate with leakage current of **7nA/pixel** at end of life

High Data Rate Hottest ASIC has rate of **15.1 Gbit/s**

Hit efficiency of > **99%**

Threshold target **1000e**

https://doi.org/10.1016/j.nima.2022.167804



VELO Modules

https://doi.org/10.1016/j.nima.2022.167804

First element is **5.1 mm** from interaction region

Expected total ionising dose **O(10^{15}) MeV n_{eq}/cm^2**

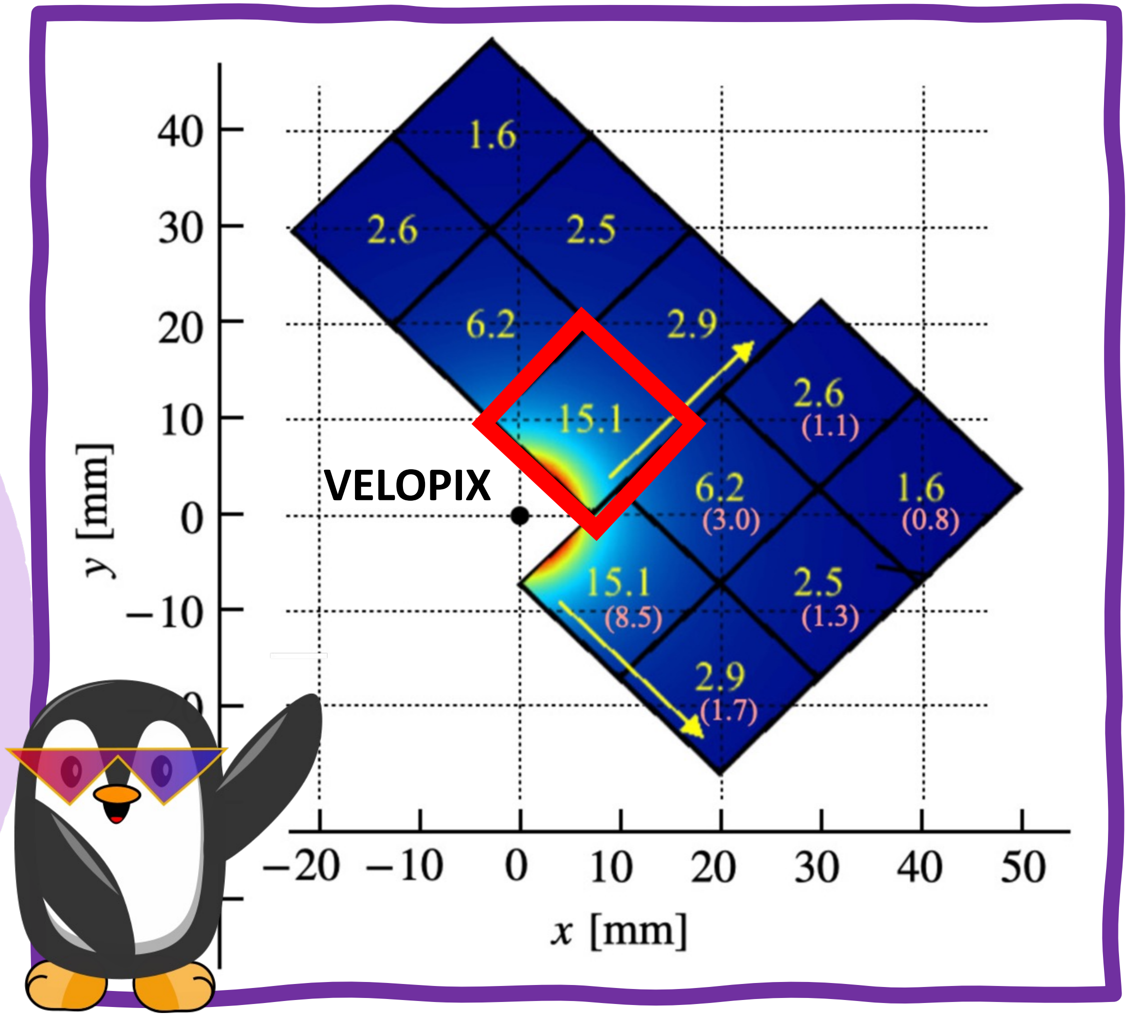
Immunity against single event effects

Operate with leakage current of **7nA/pixel** at end of life

High Data Rate Hottest ASIC has rate of **15.1 Gbit/s**

Hit efficiency of > **99%**

Threshold target **1000e**



VELO Modules

First element is **5.1 mm** from interaction region

Expected total ionising dose **$O(10^{15})$ MeV n_{eq}/cm^2**

Immunity against single event effects

Operate with leakage current of **7nA/pixel** at end of life

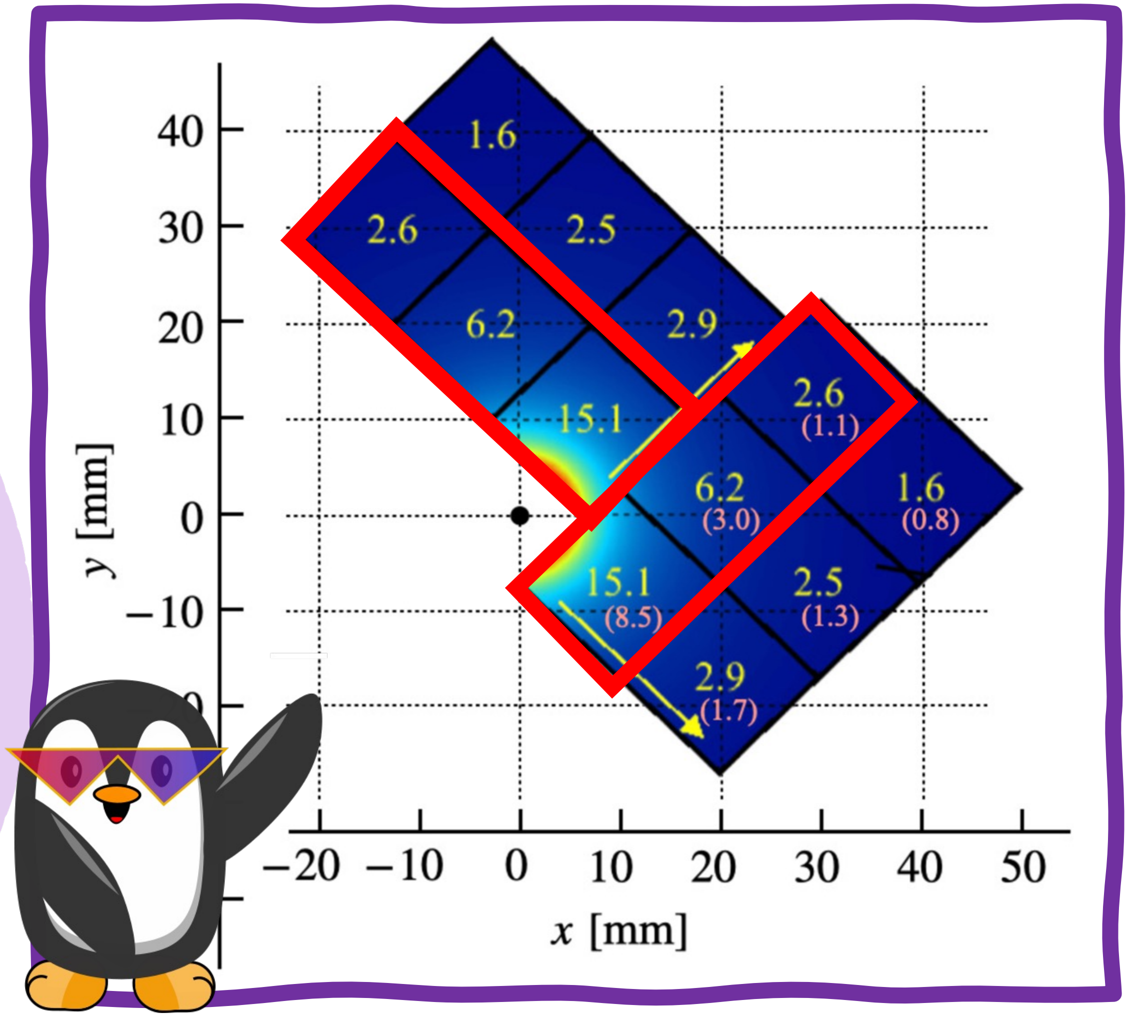
High Data Rate Hottest ASIC has rate of **15.1 Gbit/s**

Hit efficiency of > **99%**

Threshold target **1000e**

Inner Sensors

https://doi.org/10.1016/j.nima.2022.167804



VELO Modules

First element is **5.1 mm** from interaction region

Expected total ionising dose **O(10^{15}) MeV n_{eq}/cm^2**

Immunity against single event effects

Operate with leakage current of **7nA/pixel** at end of life

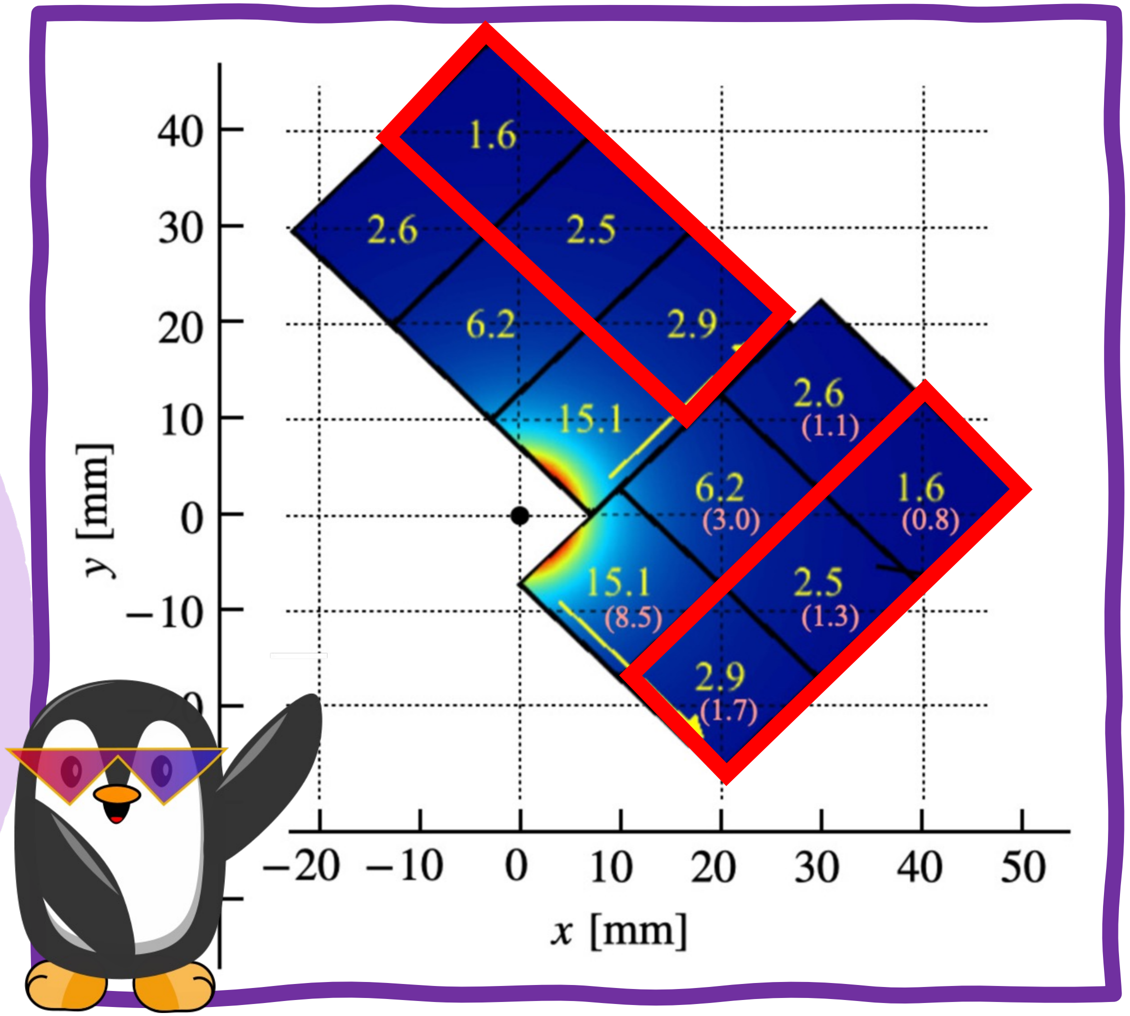
High Data Rate Hottest ASIC has rate of **15.1 Gbit/s**

Hit efficiency of > **99%**

Threshold target **1000e**

Outer Sensors

https://doi.org/10.1016/j.nima.2022.167804



VELOPIX

VELOPIX is closely related to Timepix3.

130 nm CMOS technology.

55 μm x 55 μm pixel size to reach resolution requirements.

A **40 MHz** readout rate.

Trigger-less **binary** output.

Table 1. Specifications of the VeloPix compared to Timepix3.

Feature	VeloPix	Timepix3
Readout type	Trigger-less, binary	Trigger-less, ToT
Timing resolution, range	25 ns, 9 bits	1.5625 ns, 14 bits
Power consumption	$< 1.5\ W/cm^2$	$< 1\ W/cm^2$
Sensor type	Planar silicon, e^- collection	Various, e^- and h^+ collection
Pixels, pixel size	256×256, $55 \times 55\ \mu m^2$	256×256, $55 \times 55\ \mu m^2$
Radiation hardness	400 Mrad, SEU tolerant	No
Peak hit rate (ASIC, pixel)	900 Mhits/s, 50 khits/s	80 Mhits/s, 1.2 khits/s
# links, total bit rate	4× SLVS, 20.48 Gbps	8× SLVS, 5.12 Gbps
Technology	130 nm CMOS	130 nm CMOS

https://cds.cern.ch/record/1624070?ln=en

Superpixel Design

Each **256 x 256** pixel array contains
64 x 128 Superpixels.
This groups pixels in **2 x 4** grids.

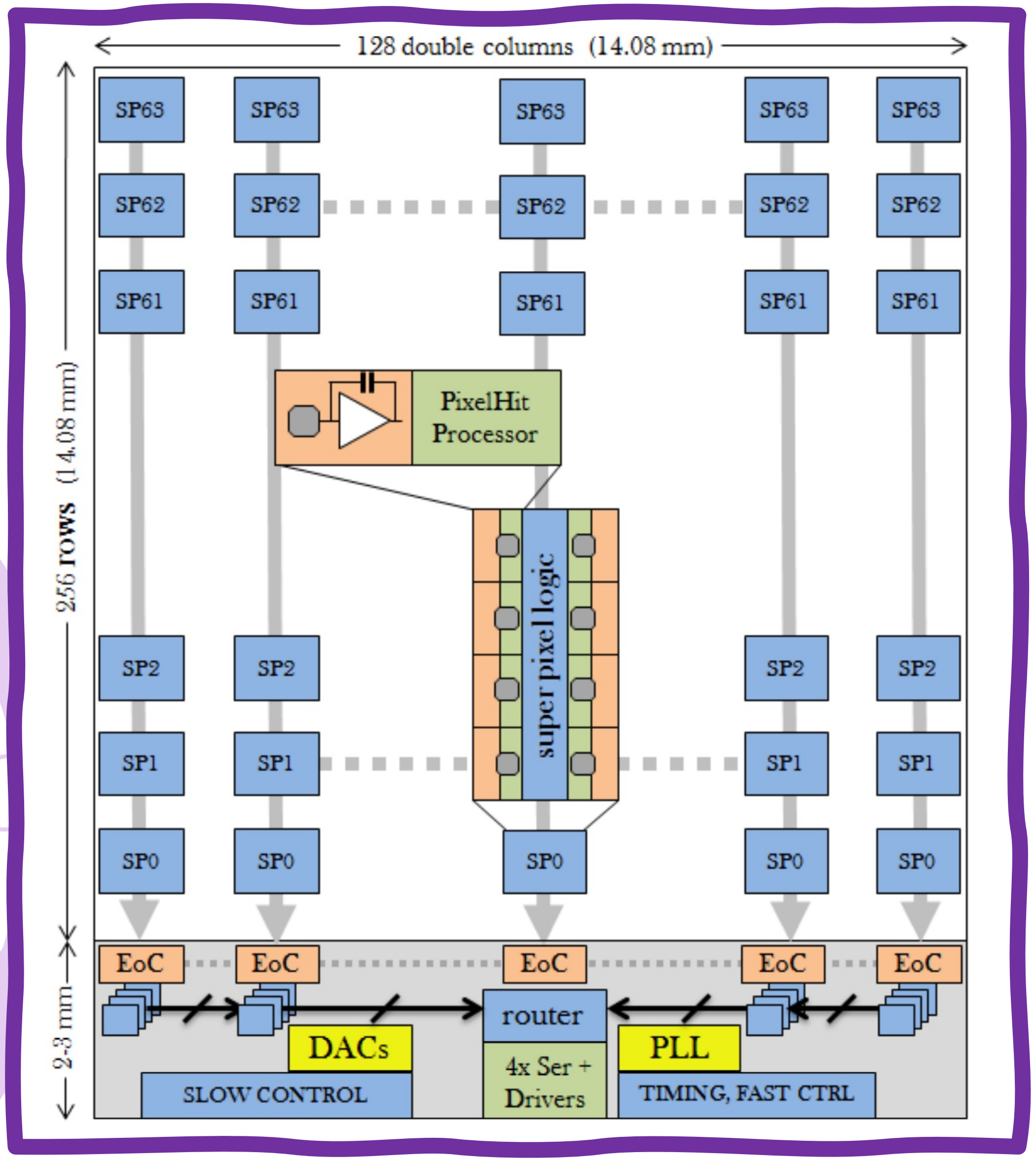
Leverages that **55%** of track clusters have
> 1 pixel

Superpixel packets are only **30 bits**.

29 – 23	22 – 17	16 – 8	7 – 0
SuperPixel column	SuperPixel row	Timestamp	Hitmap

30% reduction in data volume!

http://dx.doi.org/10.1109/TNS.2021.3085018



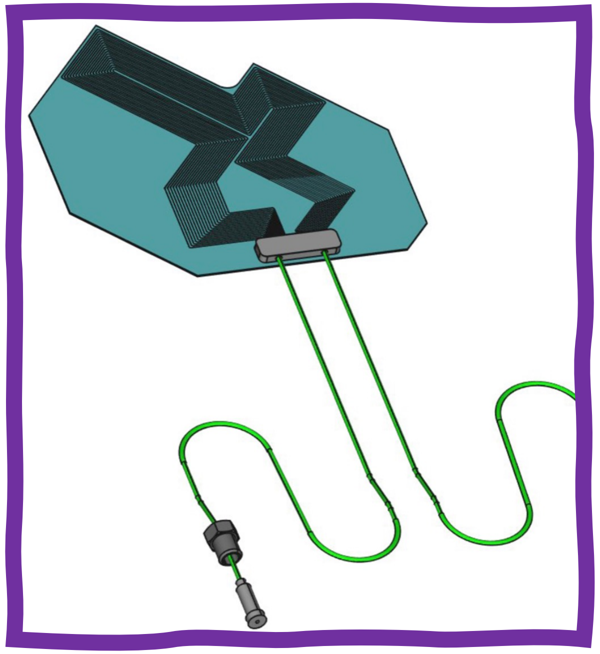
Microchannel cooling

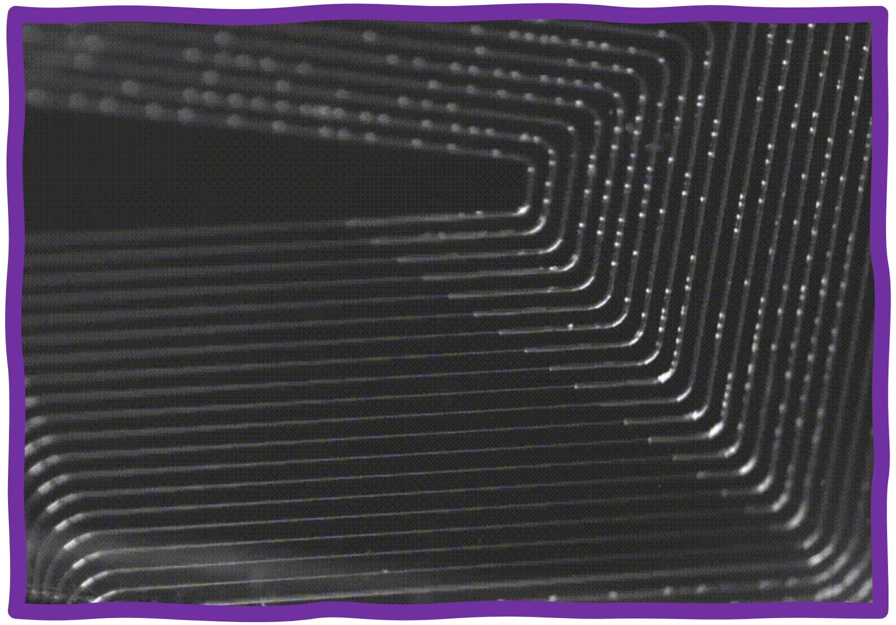
Cooling system designed to extract 40 W per module

CO_2 evaporative cooling system to maintain operational temperature (below -20).

Operated at 14 bar at -36 degrees and **tested** up to 187 bar.

Each module has 19 microchannels with lengths varying from 271mm to 332m.





https://doi.org/10.1016/j.nima.2022.166874

Vacuum Incident

The VELO was originally installed and commissioned in **2022**

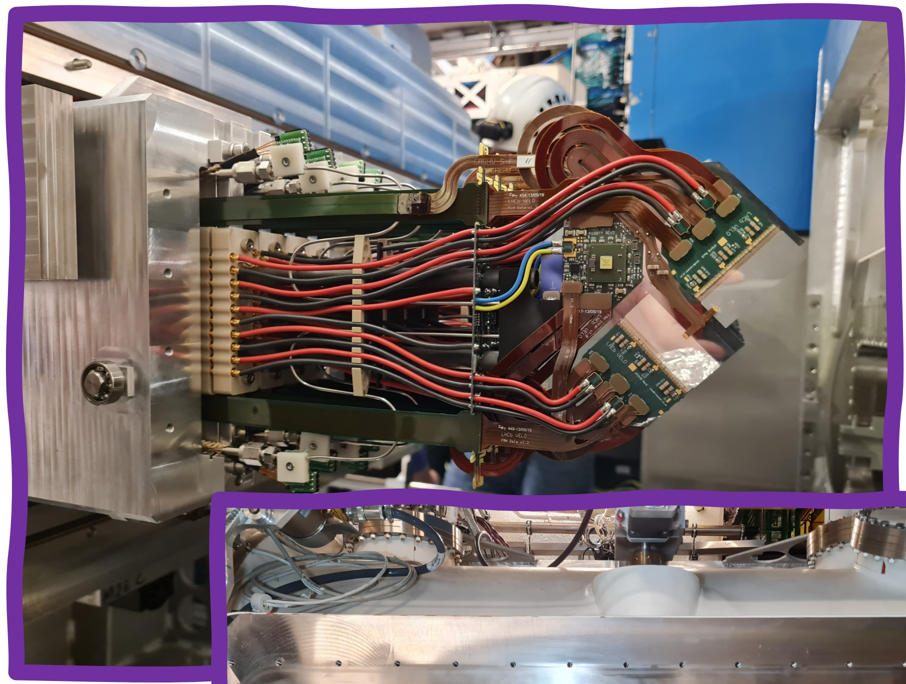
Due to multiple failures in vacuum protection equipment (**January 2023**) a pressure differential above the safety limit formed across the primary and secondary vacuum…

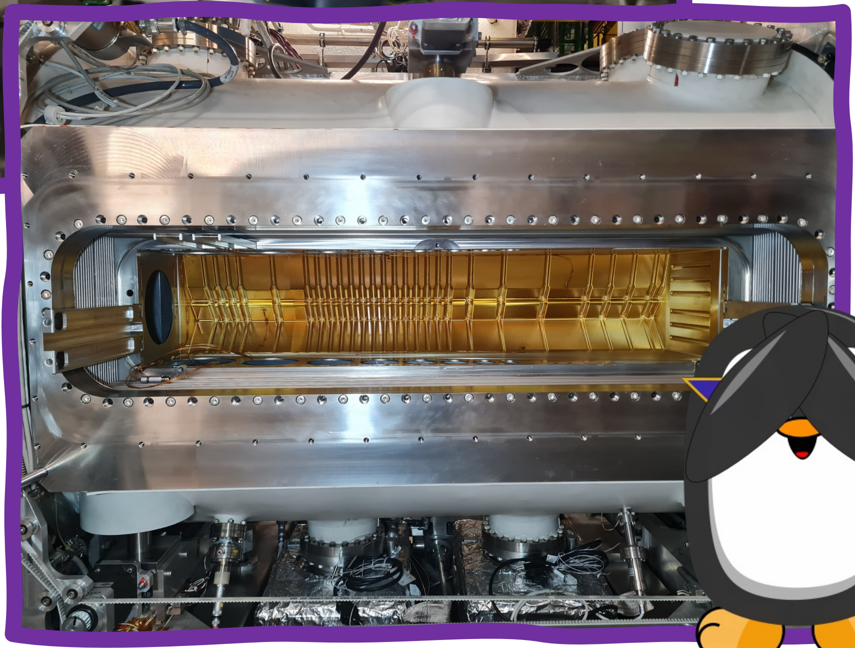
The RF foil was **permanently** deformed

However, the VELO module were **completely** undamaged. As such for 2023 VELO could still run and commission with reduced acceptance

Detailed **tomographic** studies were done to assess the damage!

A **successful** reinstallation campaign to replace the foil was carried out in **early 2024**.



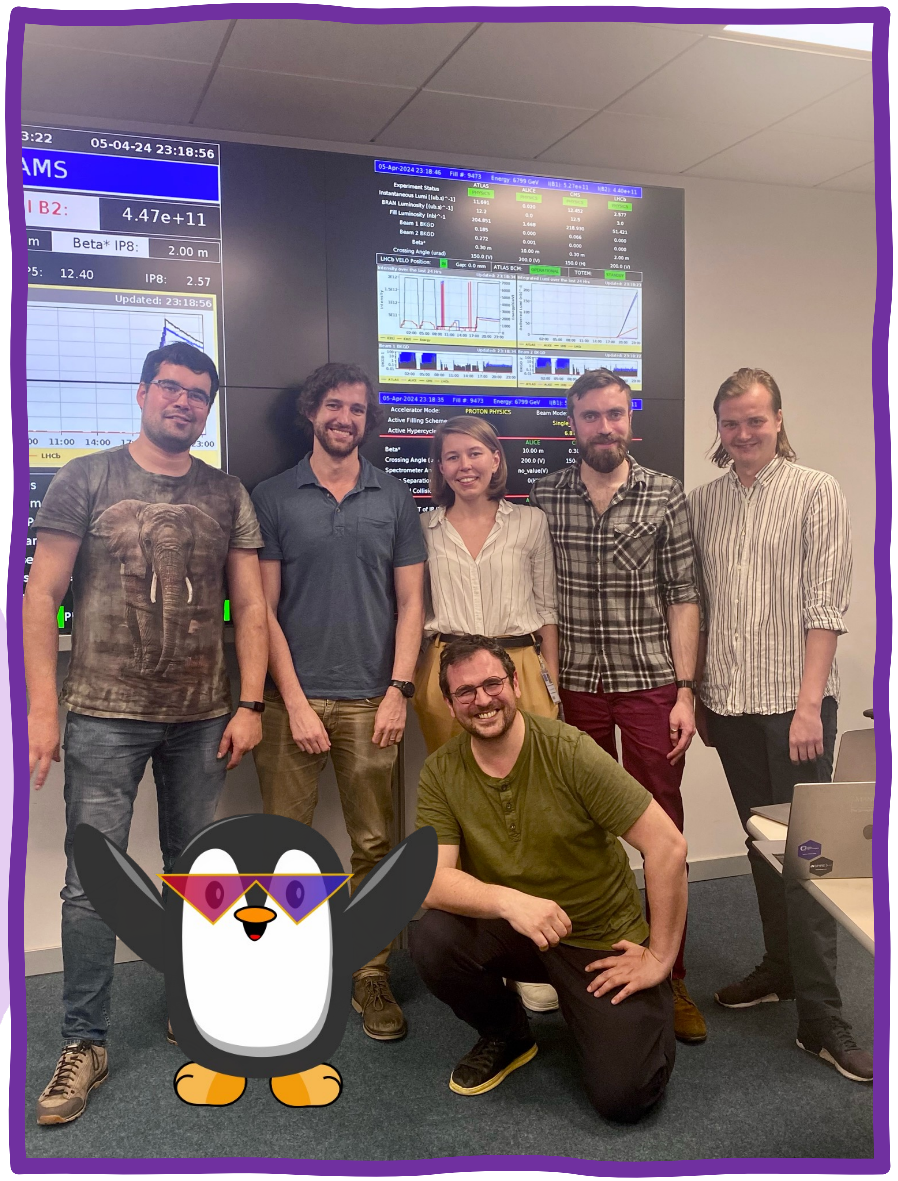


1st Closure of 2024

2024 saw the first closure of the VELO since **January 2023.**

VELO position was validated using **tomography.**

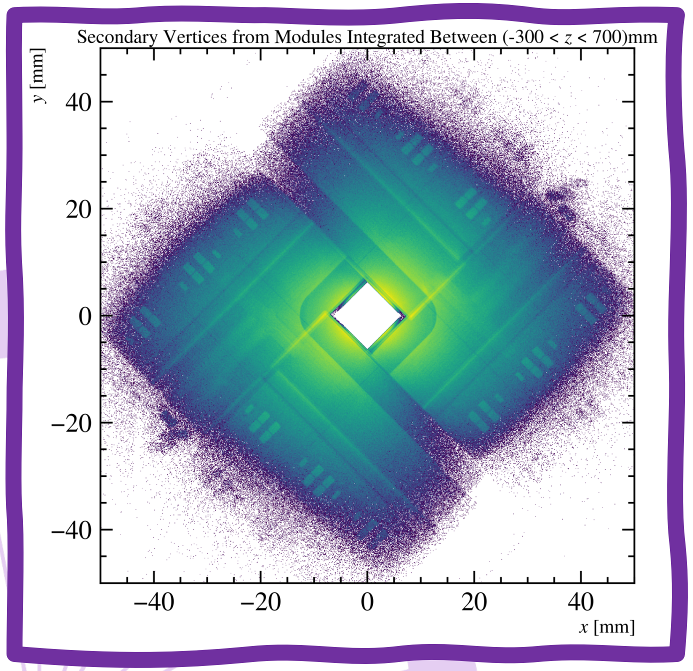
The VELO was closed to its nominal position and has been taking data since April!

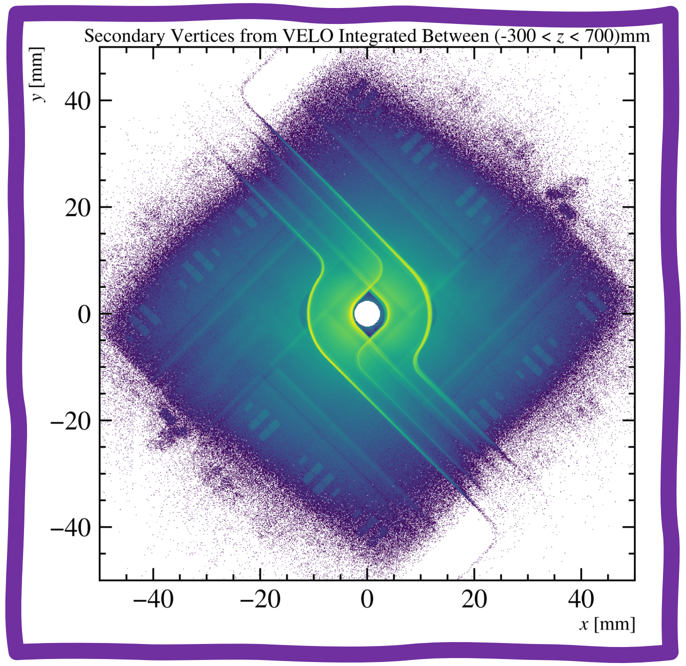


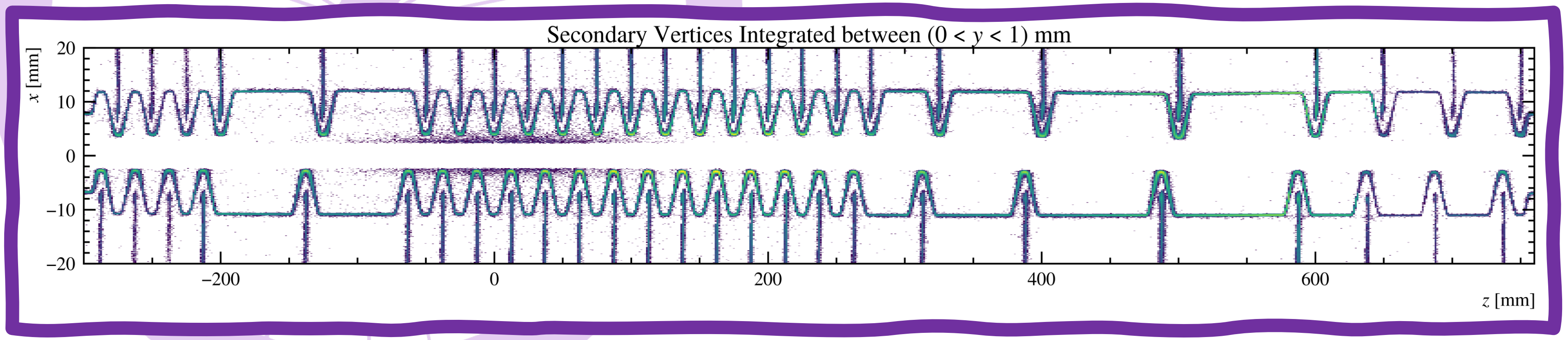
Tomography

Extensive Tomographic studies using **secondary vertices** to validate RF foil reinstallation!

Tomographic and metrology studies ongoing to **fully map** the detector material.







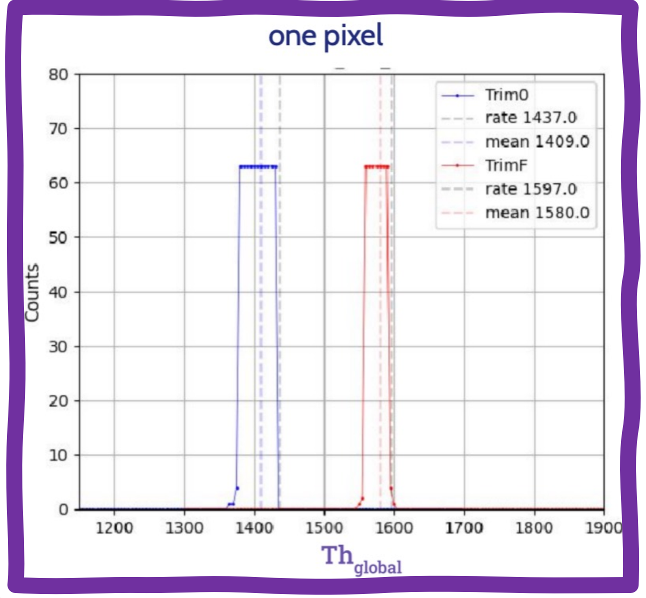
Equalisation

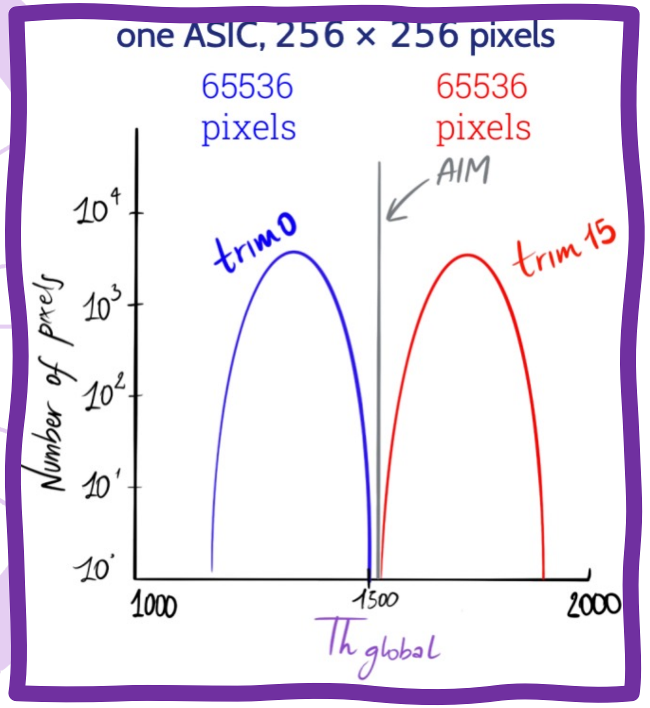
We look to equalise the **noise response** across the VELOPIX for operation by adjusting a Trim value per pixel!

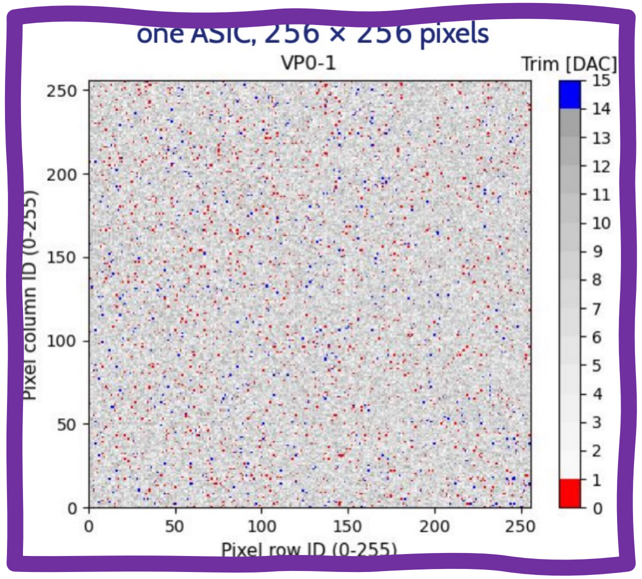
TH_local= Trim + TH_global

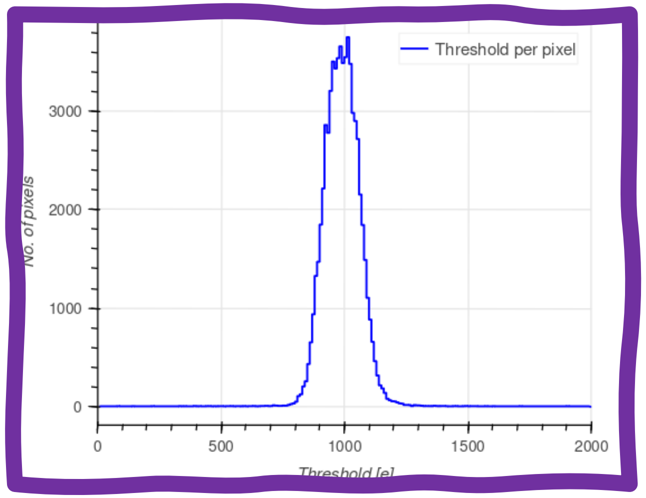
global threshold (Th_global) is defined per ASIC

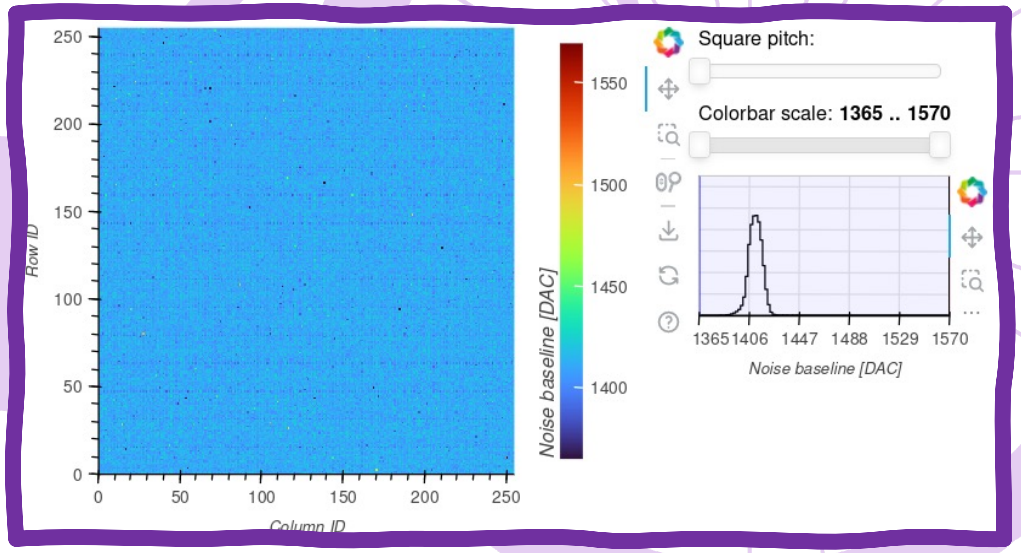
trim defined per pixel (4 bits, 0 - 15)











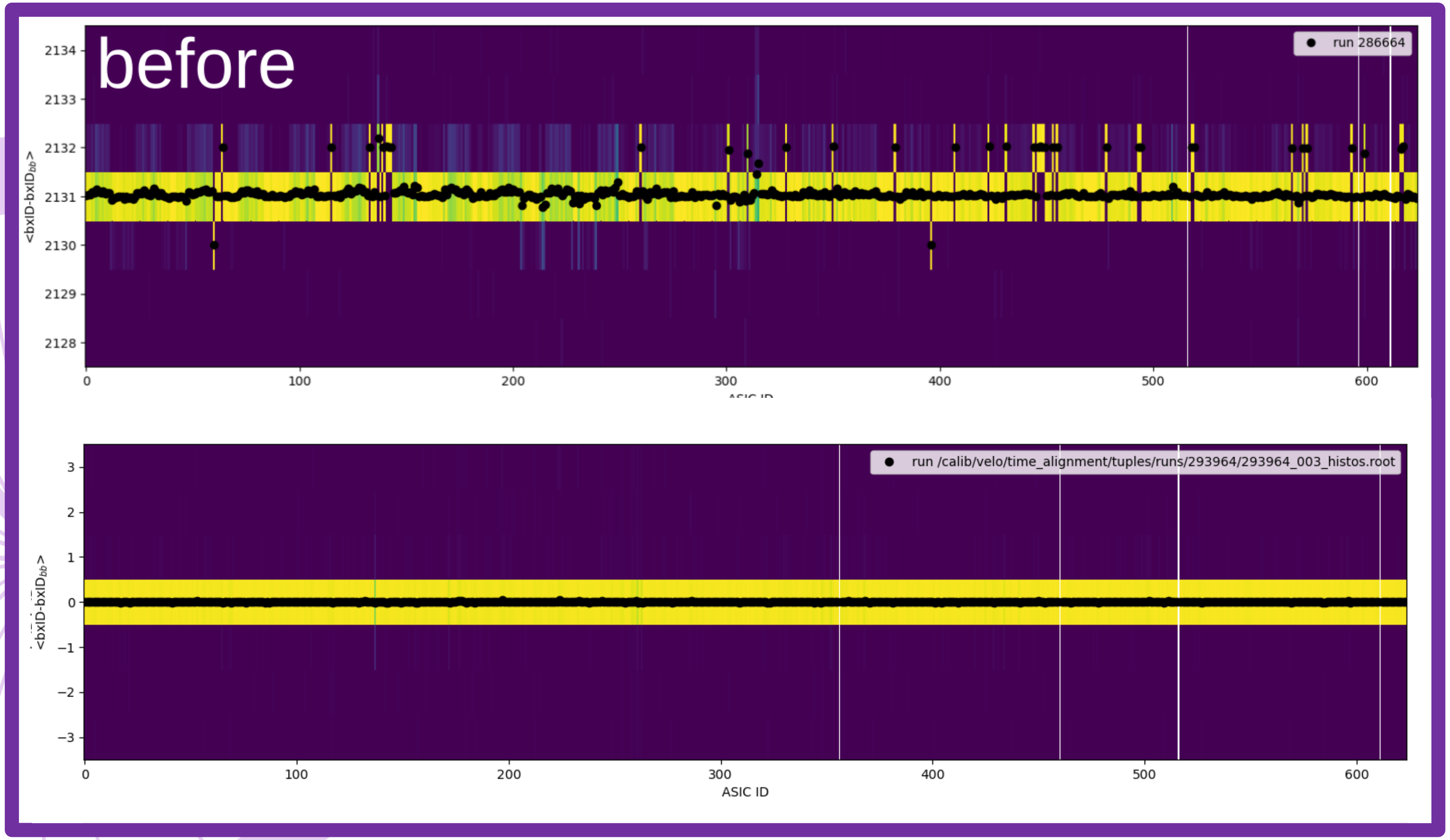
Time Alignment

Two core concepts in time alignment. **Coarse** and **Fine** time alignment.

Coarse time alignment looks to synchronise the signals across the LHC clock

Fine time alignment seek to match low and high amplitude signals to the correct BxID

Mechanism in place to adjust phases and delays in the electronics!



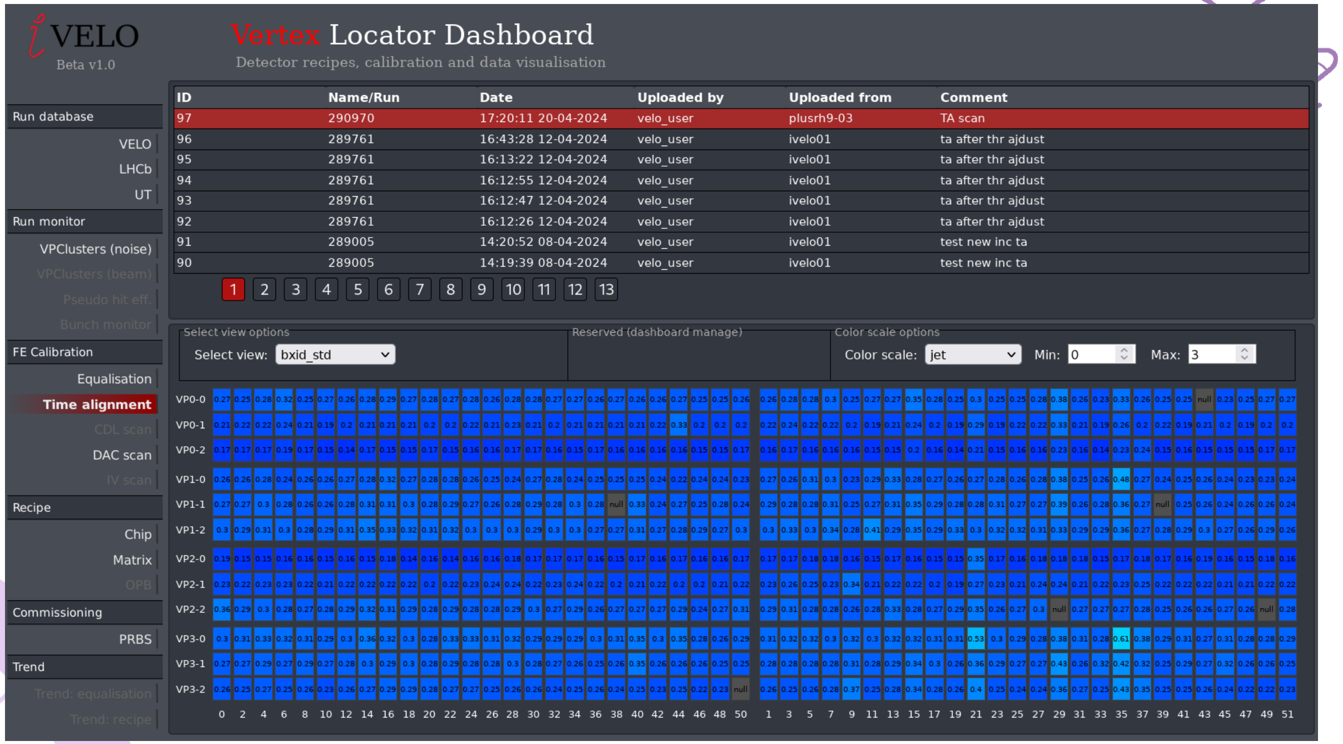
iVELO

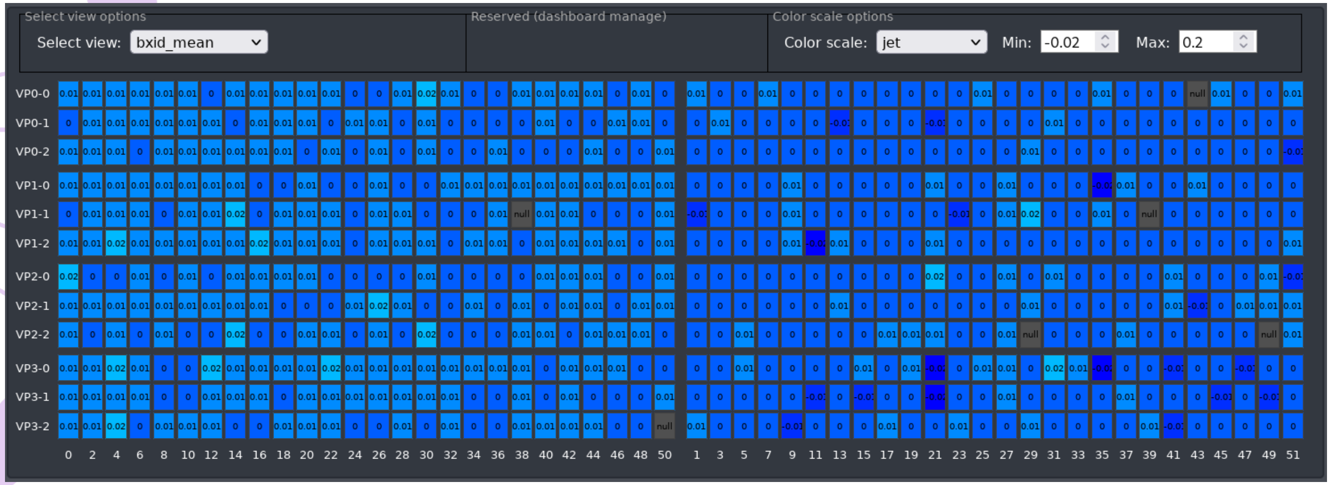
The iVelo with database and web dashboard.

Under development for recipes/calibration.

Relationships between detector activities persisted.

Tracks **41 million** configurations, performance and operational plots.



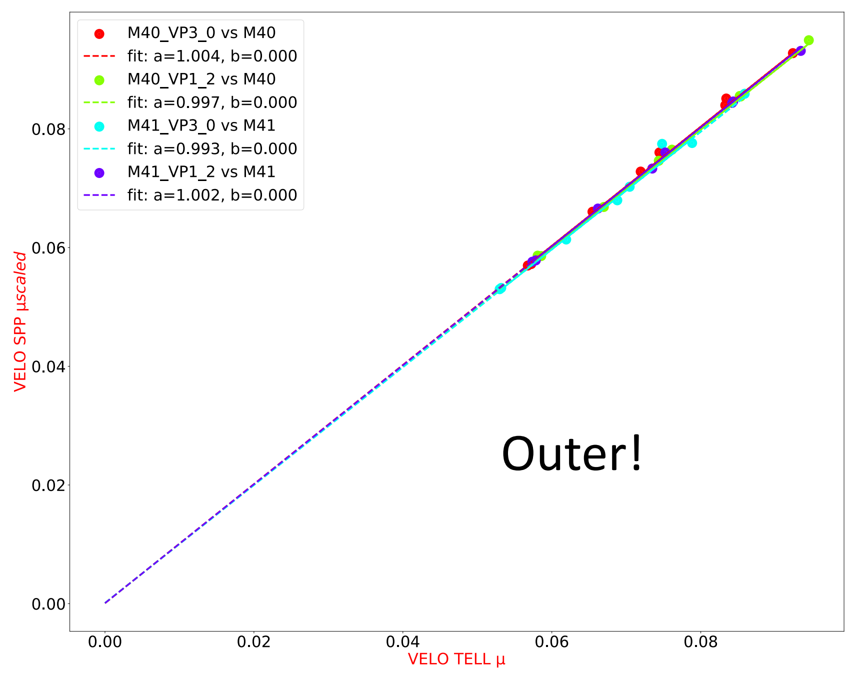


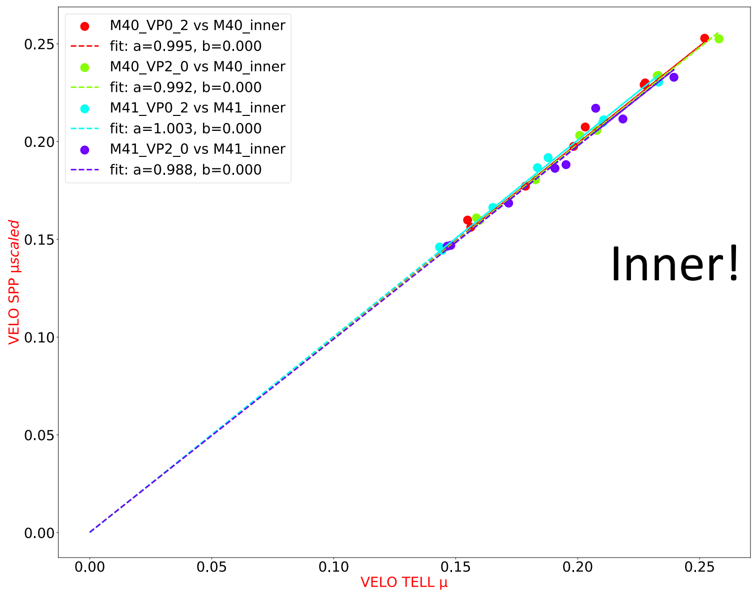
iVELO

High Mu

THE LHC finished its intensity ramp to a full machine for Run III!

LHCb is the **1st** experiment to do clustering in firmware!





Designed to operate at a **mu (visible interactions per crossing)** of **5.3**

Consistent behavior demonstrated across SPP and firmware clustering!

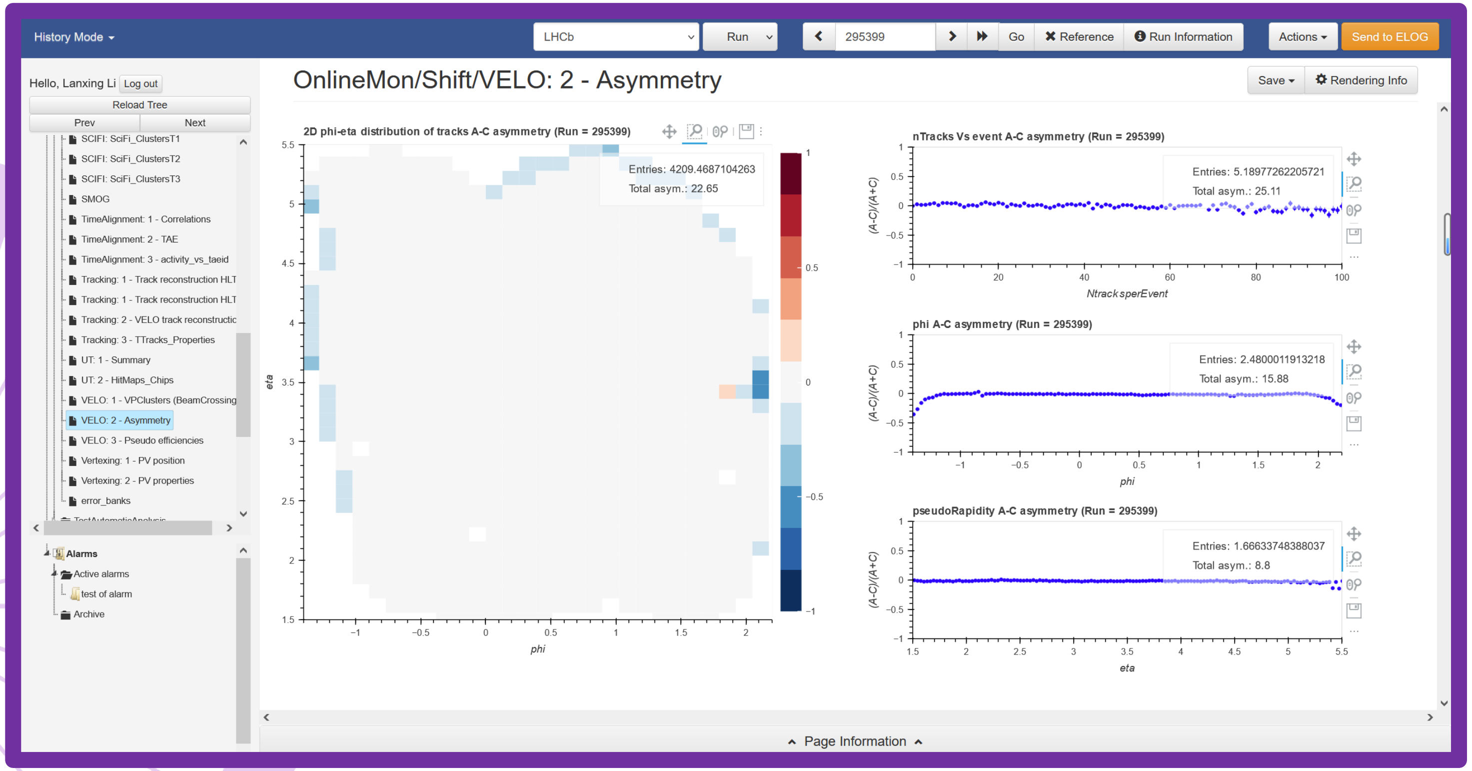
Online Monitoring

Fully Online monitoring platform called MONET available for **all** subdetectors

Can monitor detector quantities in **real time**.

We monitor **occupancy, asymmetry, time alignment** and other quantities during operations.

All monitoring is saved so we can review performance!

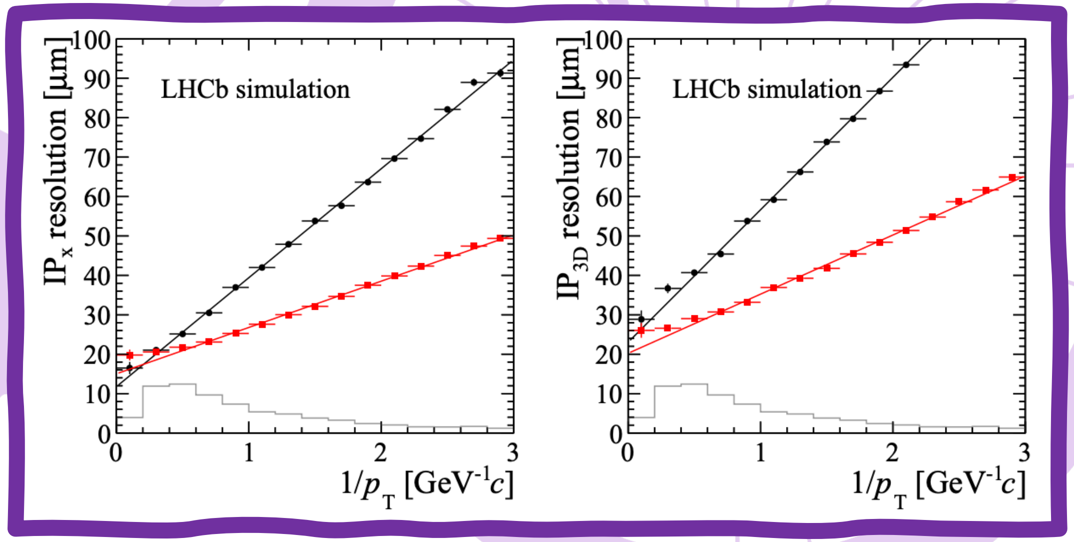


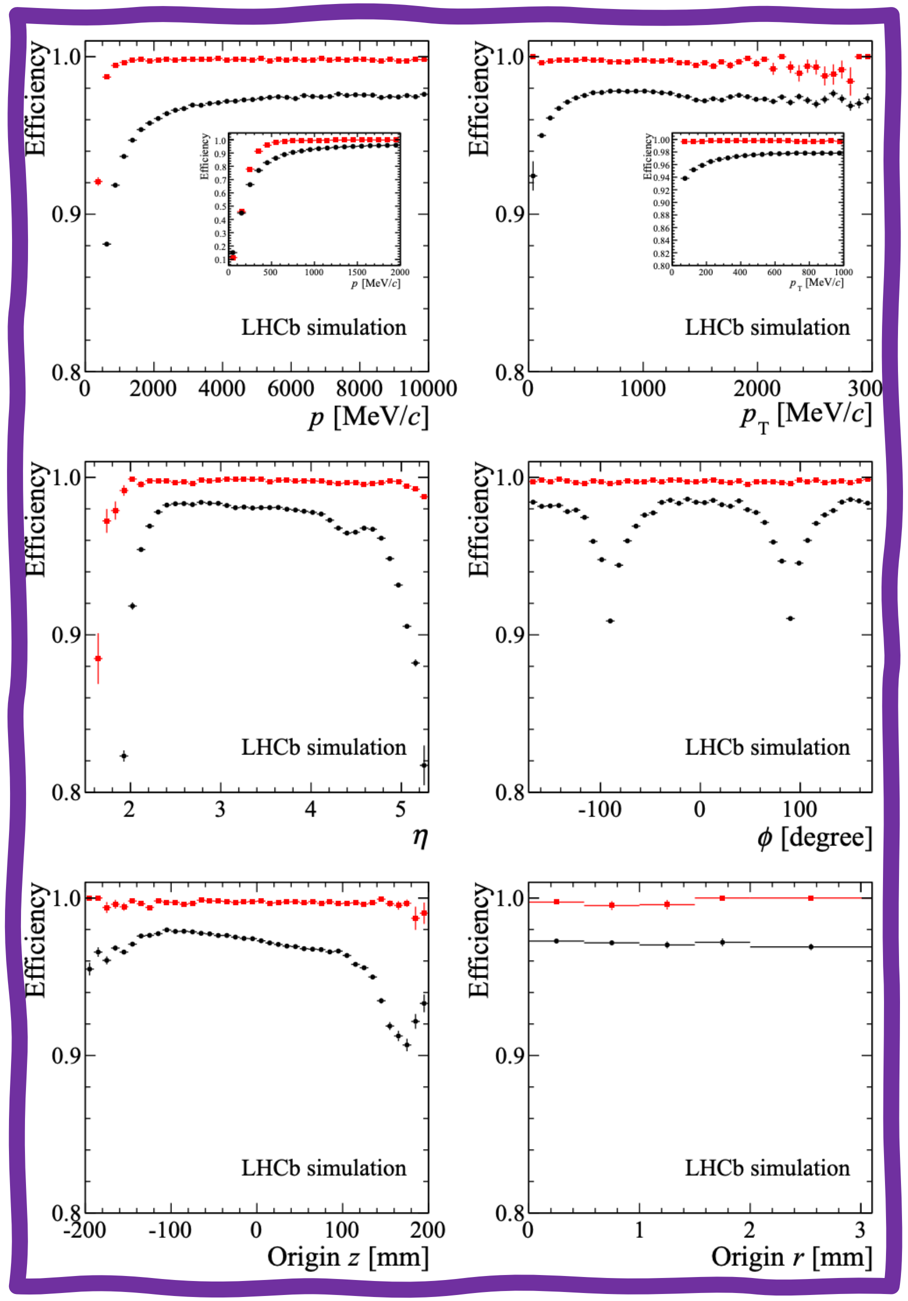
Predicted Performance

Compared to the Run 1(II) VELO (black) the efficiency in almost all areas is predicted to improved.

Module and foil **overlap far improved** seeing an increase in pseudo rapidity and eta.

Key reconstruction quantities such **as IP resolution** also see improvement.





https://cds.cern.ch/record/1624070?ln=en

Summary

Huge and **successful** effort to replace the RF foil!

Great **progress** in commissioning with VELO delivering **high quality** data to the LHCb experiment

Tool development ongoing to **improve** stability!

ANY Questions?