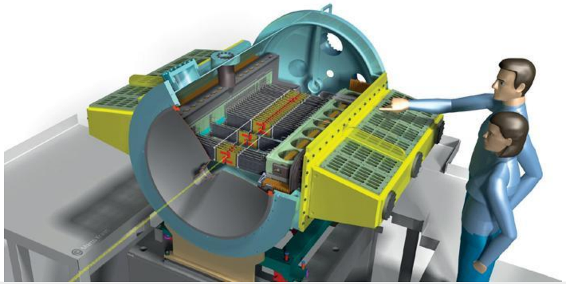
The Vertex Locator

Design, operation and first results



Pawel Kopciewicz, CERN

LHCb experiment

LHCb in a nutshell:

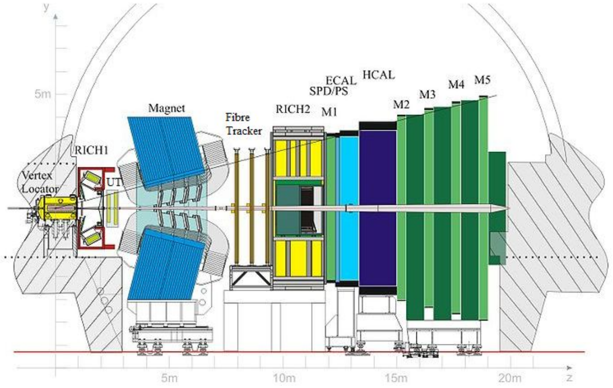
- Study of rare decays of B and D mesons
- Search for New Physics footprints

JINST 3 (2008) S08005 – The LHCb experiment

- Now in the middle of Run 3 (2022 - 2026)

LHCb-DP-2022-02 – The LHCb Upgrade I

- Three tracking detectors (VELO, UT and SciFi)
- SMOG2 experiment integrated
- Upgrade II in the design phase



LHCb spectrometer

CERN-LHCC-2014-001

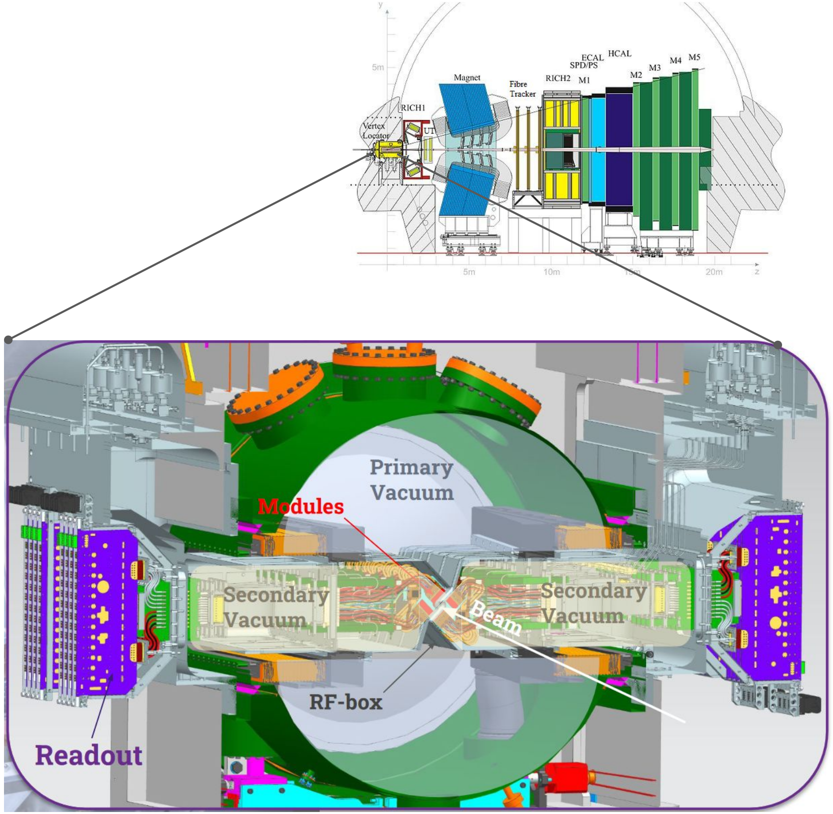
Vertex Locator

VELO (Vertex Locator) in a nutshell:

- VELO is a pixel detector (originally strip detector)

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

- Vital role in tracking and vertex reconstruction
- Surrounds the beam collision region
- VELO stays open during beam injection
- Sensors in secondary vacuum

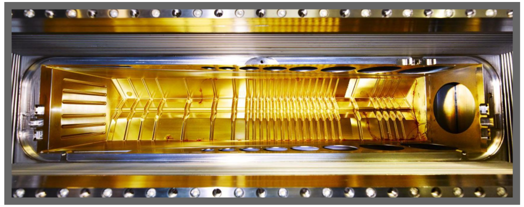


- Closest pixels 5.1 mm to the beams
- Readout at 40 MHz
- 256x256 pixels per ASIC
- 52 modules, 12 ASICs each
- Two-phase CO_2 cooling
- RF foil with 250um thickness

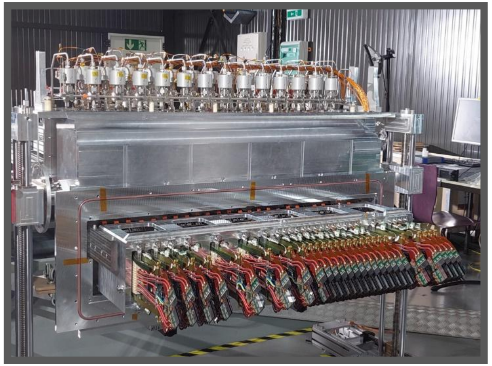
Detector assembly

The RF foil

- Milled from solid aluminium block
- 250 µm thick in the inner region
- Shields module assemblies from beam halo and RF pick-up
- Separates LHC and VELO vacuum
- 3.5 mm from the beam, 0.9 mm from VELO sensors

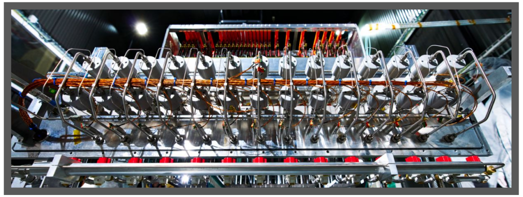


VELO's one half



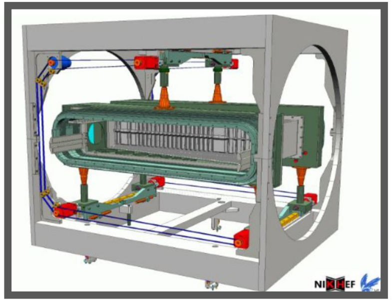
Metrology

Two-phase CO_2 cooling

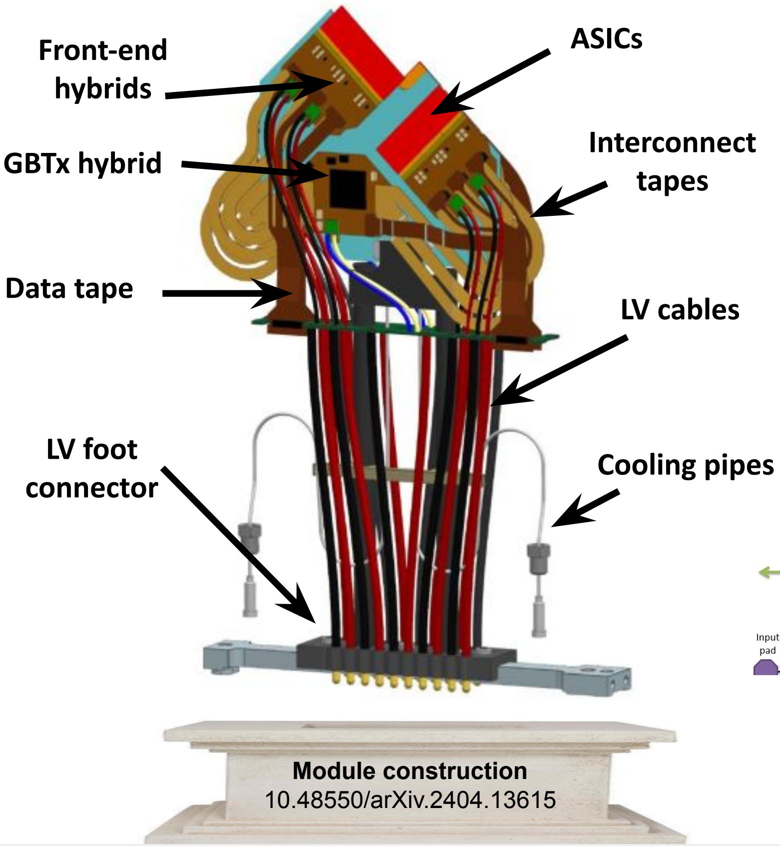


- Cooling system embedded into module substrate
- Two-phase CO_2 in microchannels
- Cooling power of 40 W at -30 ^{0}C
- Safety system against leaks

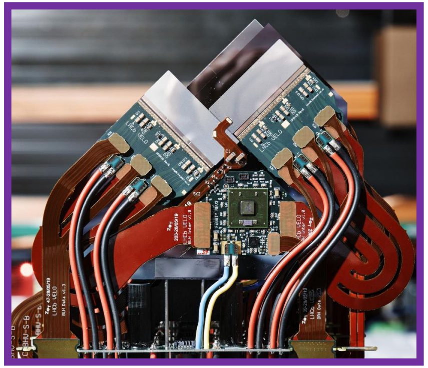
Motion system



VELO module construction

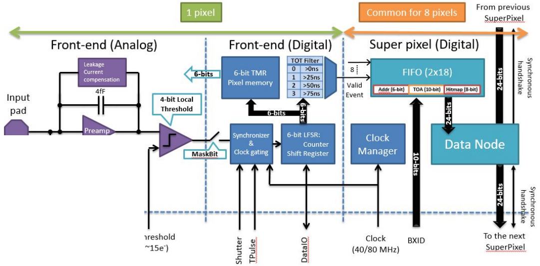


Module construction
10.48550/arXiv.2404.13615

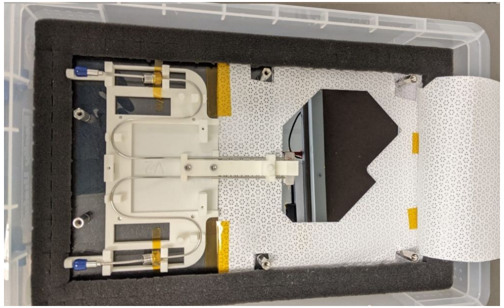


- 256x256 pixels per ASIC
- Pixel pitch of 55 µm (except borders)
- 12 ASICs per module
- Control via GBTx hybrid
- Binary triggerless readout
- Radiation hard up to equivalent of 400 Mrad
- 52 modules (26 for A & C side)

The VeloPix ASIC
10.1088/1748-0221/12/01/C01070



Module substrate cooling panel
10.1016/j.nima.2022.166874.

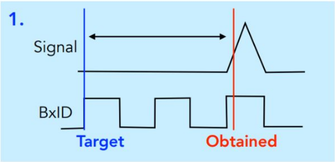


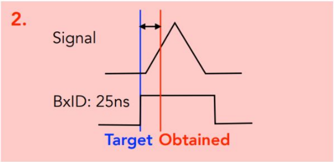
Pawel Kopciewicz, CERN

Time alignment

Assuring each ASIC is aligned in time

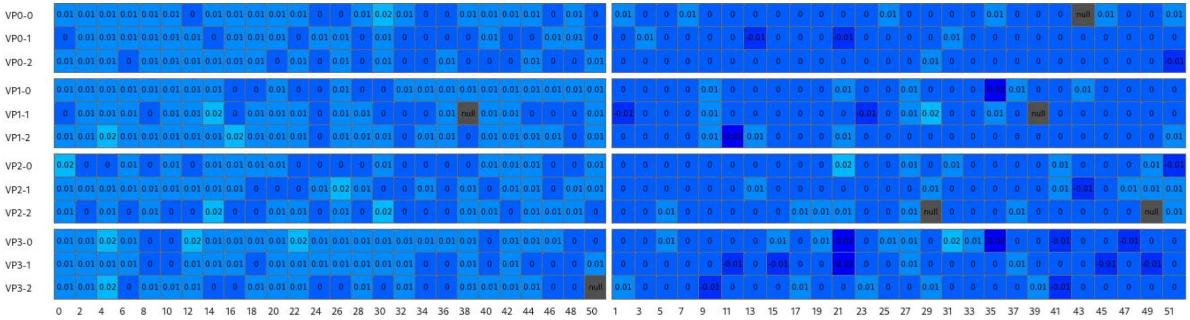
- A necessity of having an individual bunch collision
  - Latency (coarse correction) and GBTx phase shifter (fine)
- Time alignment is threshold dependent
  - Unavoidable local BxID spreads
  - Threshold change needs alignment update

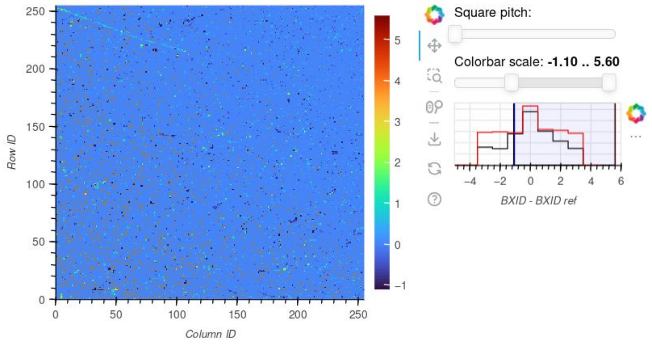




Per pixel time alignment:
Noise, blank pixels and delta electrons can bias the alignment procedure. Pixels with too high or too low thresholds will usually not be properly aligned (and get masked).

VELO after time alignment:
Each square is a mean of how every pixel in the ASIC is aligned (with respect to central value)

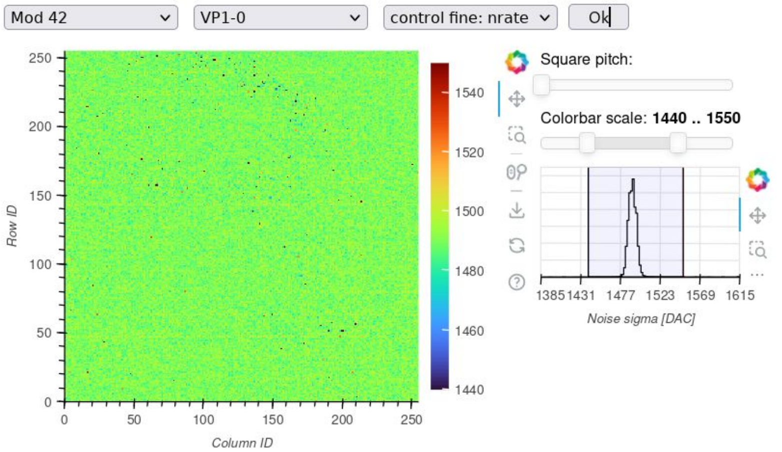




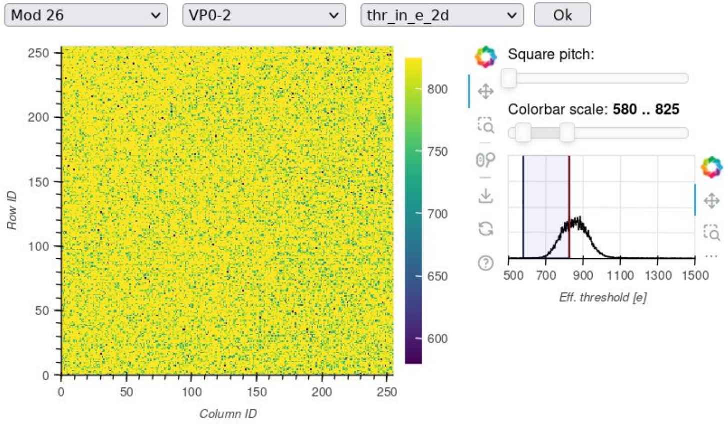
Equalisation

Assuring homogeneous threshold

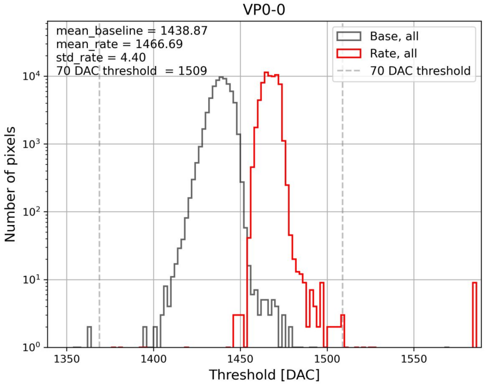
- Equalising rate of the noise
- Threshold set at 1000e above the noise baseline
- Requires time alignment adjustment
- Adjusting currents in pixel’s analog front-end



A map of actual threshold per-pixel: Due to hardware limited resolution the actual threshold is a gaussian distribution.



Control scan of equalised ASIC: Rate based equalisation pushes noisy pixels further from the threshold instead of masking them



Pixel labyrinth

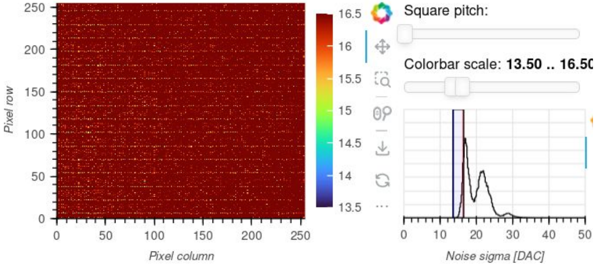
Assuring best performance for daily operation

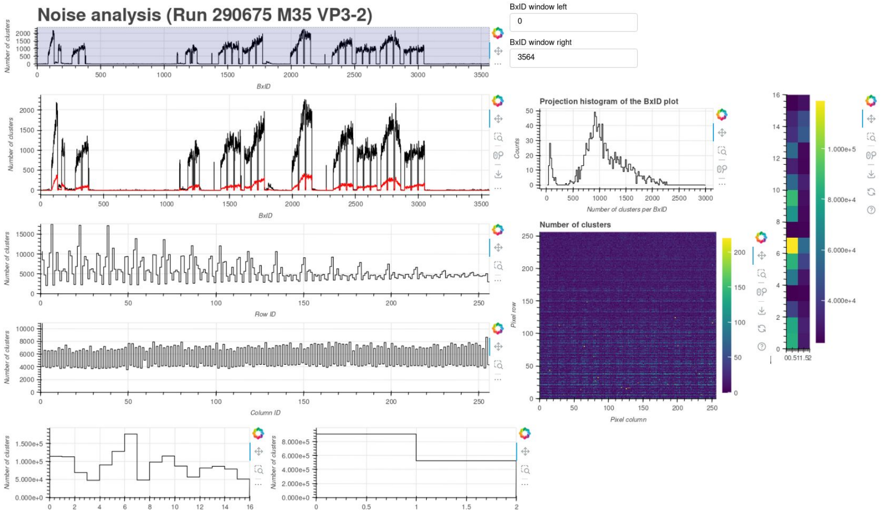
- Each of 41M pixels contribute to success
- Studies on noise and patterns
- Studies on spikes after particles splash
- Improving front-end and TFC stability

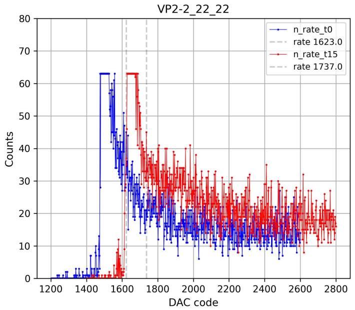
It is not easy to understand every pixel

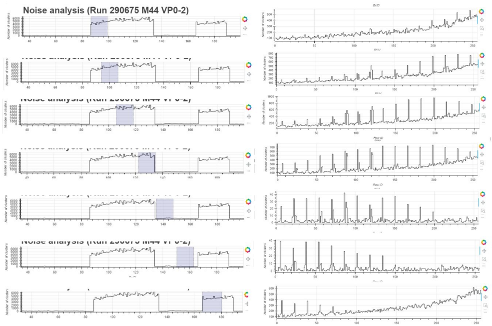
- However we try!
- …

A variety of noise patterns:
Some of them only appearing with LHC beams







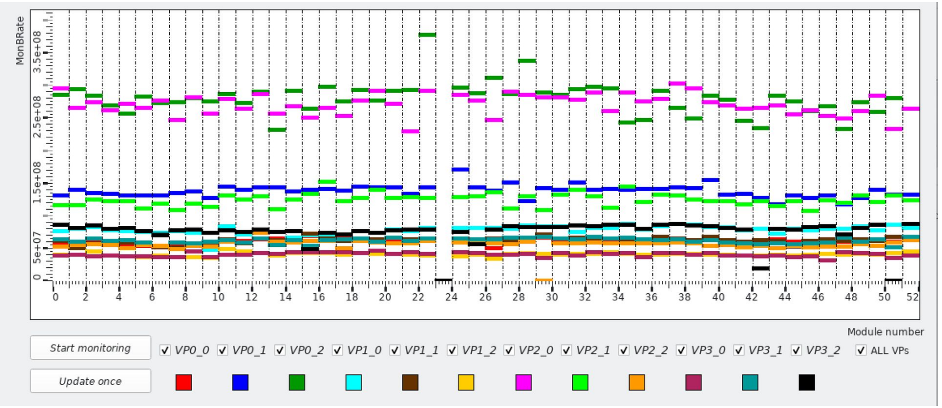


Online monitoring

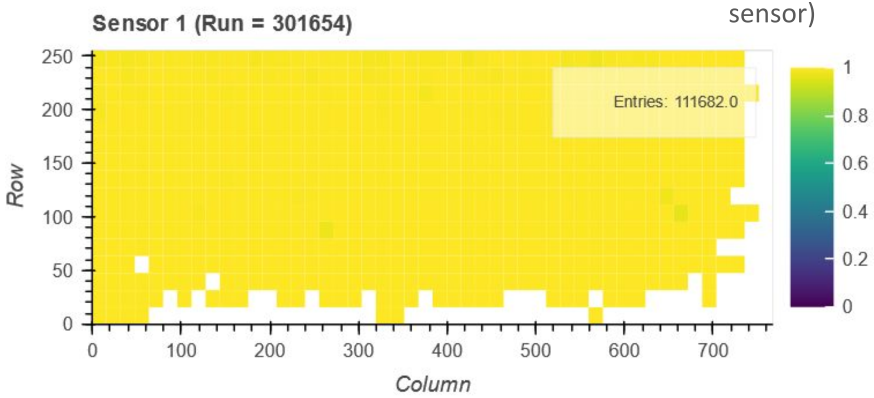
A number of high-level quantities are constantly monitored

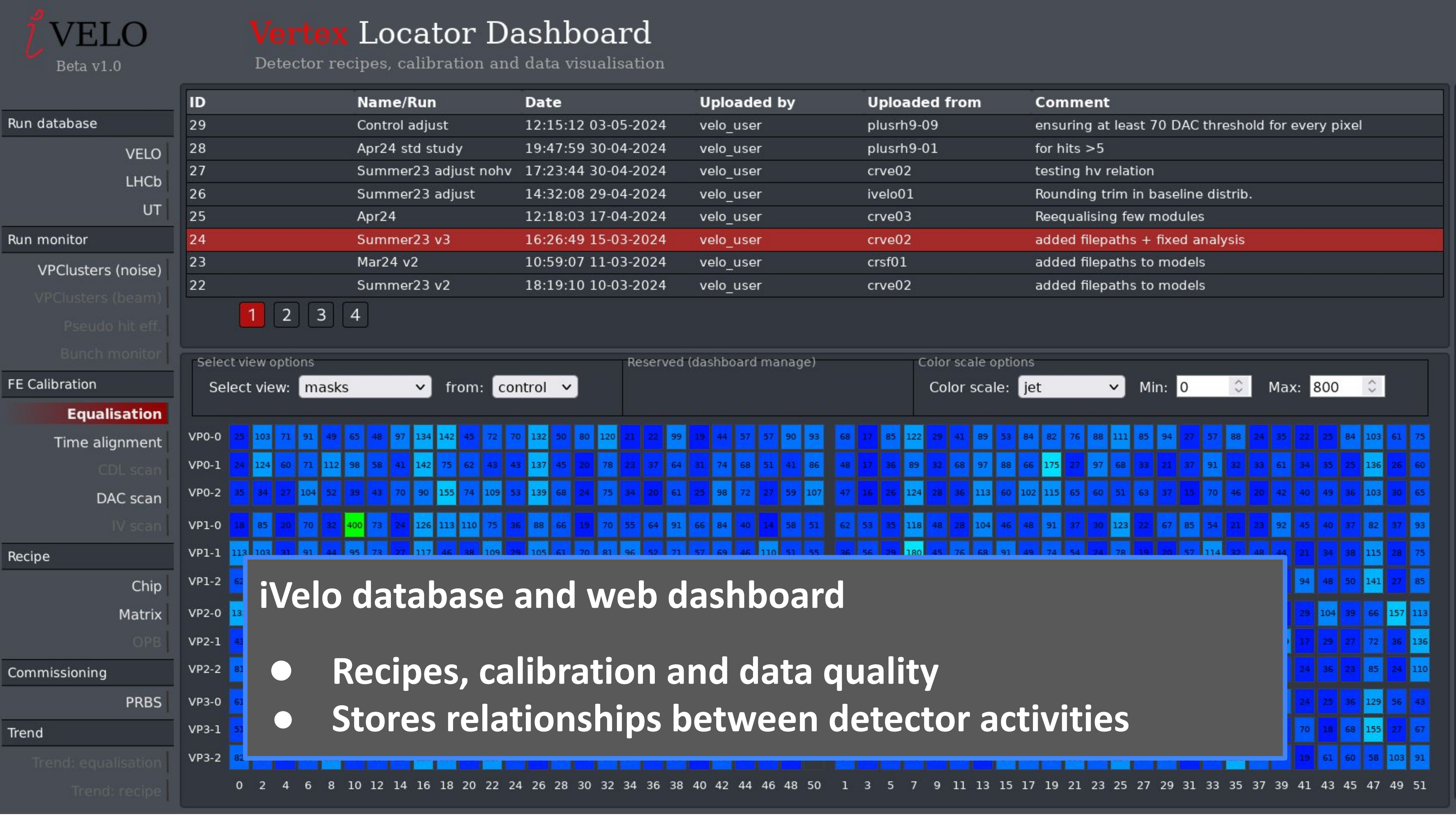
- Tracking (and reconstruction) efficiency 24/7 by Data Managers
- Plenty of expert graphs and trend plots by VELO Piquets
- Common goal is to spot, understand and fix potential issue as soon as possible (pixel SEU, module inefficient, etc.)

Super-Pixel packets per second:
A quantity monitored by VELO piquets (note sensors closer to the beam having much higher rate)



Pseudo hit efficiency:
A quantity monitored by Data Managers (on the plot a view for 1 sensor)





iVelo database and web dashboard

- Recipes, calibration and data quality
- Stores relationships between detector activities

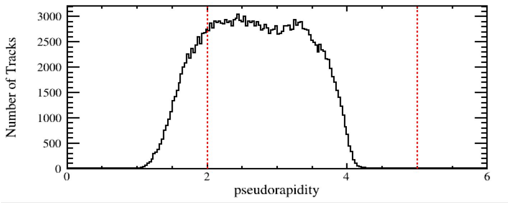
VELO reinstallation in YETS 23/24

VELO operated successfully in 2022

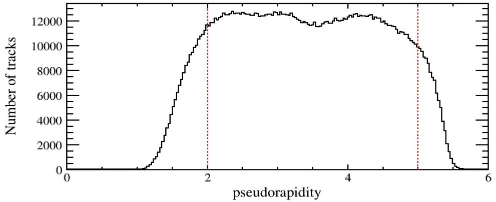
After the vacuum incident in Jan 2023 that left the RF box deformed, used YETS to replace it

- Intense program over 16 weeks
- Extract the detector, replace RF box, bake-out beam pipe
- Reinstallation and recommissioning
- Tomography to image the box in situ
- In 2023 VELO functioned in half closed position
- In 2024 VELO was back to nominal work!

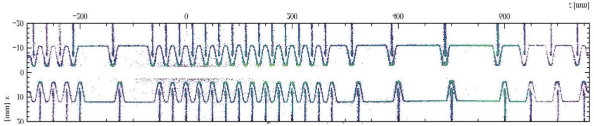
VELO forward acceptance



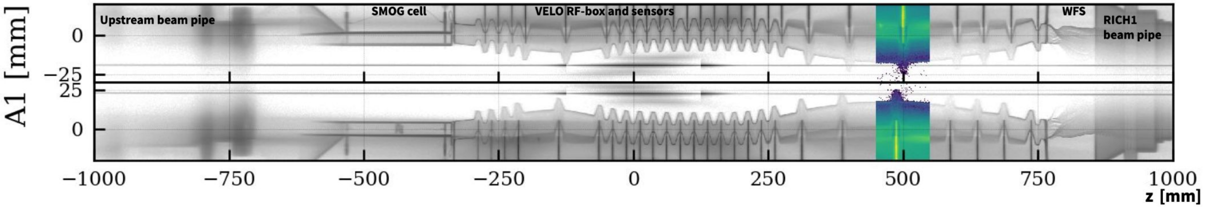
VELO acceptance coverage:
With half open (top) and closed (bottom) position



Tomography with reinstalled RF box:



VELO tomography:
High energy particles interact with VELO material

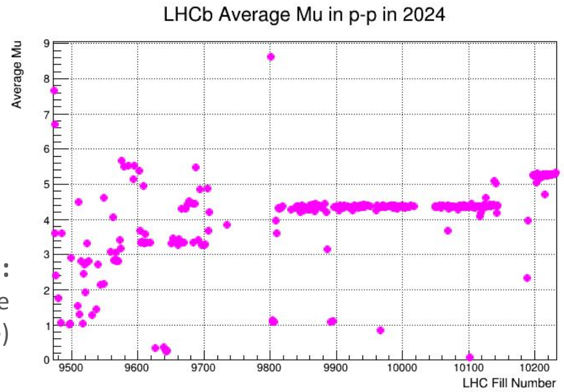


Summary of 2024 operation

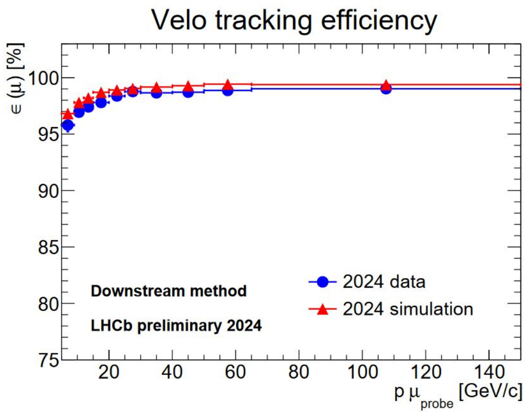
LHCb (and VELO) did great this year!

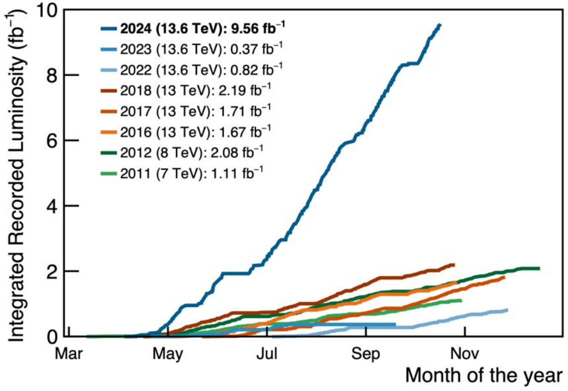
- VELO fully operational for the entire year
- VELO has a DAQ inefficiency below 1%
- VELO has 2.5% ASICs disabled (at least 1.9% recoverable during incoming YETs)
- Expected integrated luminosity for proton-proton recorded by LHCb was achieved!
- Now ongoing LHC PbPb collisions

LHCb average mu:
How LHCb increased mu during the year (LHC's fill 9800 is 19 of June)



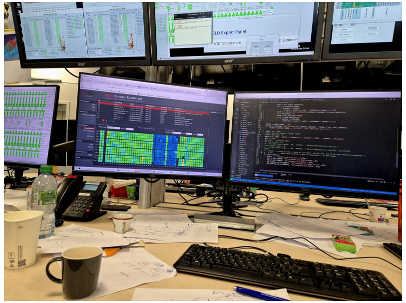
VELO tracking efficiency:
A downstream method using muonic tracks of J/Psi is used to evaluate the efficiency
LHCB-FIGURE-2024-032





Thanks for attention!

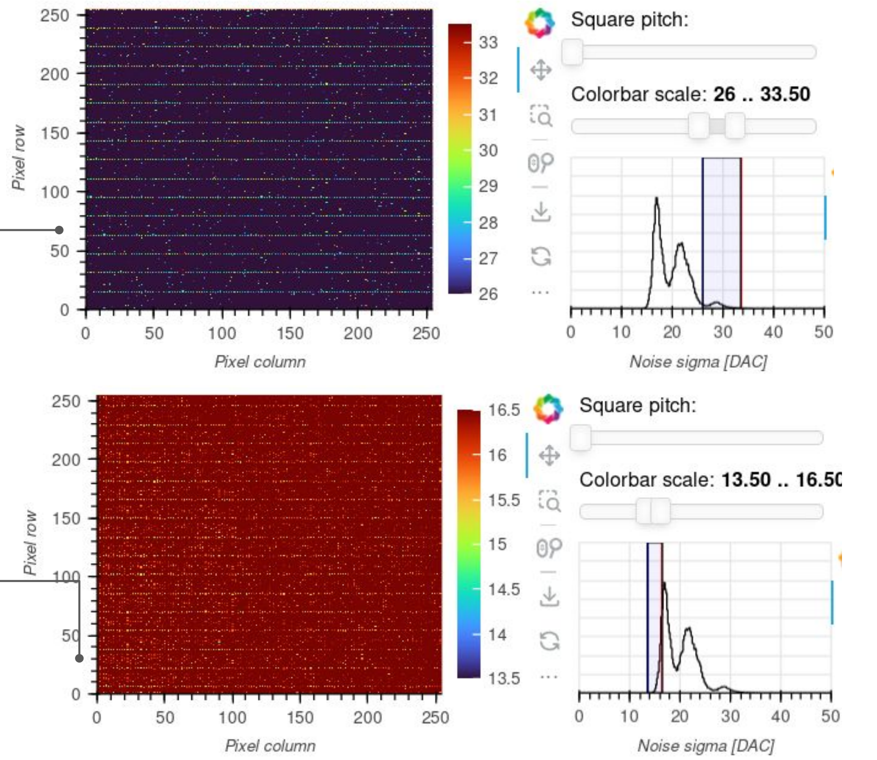
The VELO detector group



Noise in equalisation

When taking 2023 equalisation we noticed some groups of pixels feature different level of the noise. Our equalisation approach is rate-based (it is a descending slope of the noise which is equalised), therefore all the following effects are compensated in the equalisation, i.e. a pixel with extremely high noise can get a lower trim such that its descending slope is possibly the closest to the others.

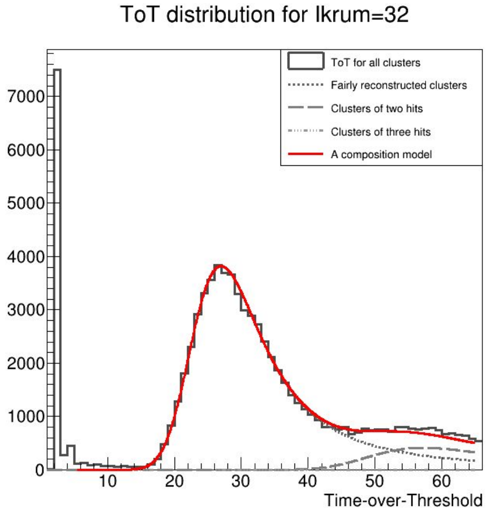
- In some ASICs odd columns get higher noise than even columns
- Despite we equalised taking scans on full matrix (1 per 1x1), we did a study showing that scans with masking give similar results (1 per 4x4 with others masked), validated by a threshold scan of beam (next slide)
- Pattern of rows 15-31-47-... has an increased noise
- **Pattern of rows 6-22-38-... has a bit lower noise** than average but this difference is marginal and is not likely to a difference in the outcoming trim recipe
- The extreme case of even/odd difference was M29 VP2-2, which is now permanently disabled because of issues with its configuring with the HV
- **Odd and even column noise difference forms a very specific block pattern in the detector** (next slide)



Radiation damage

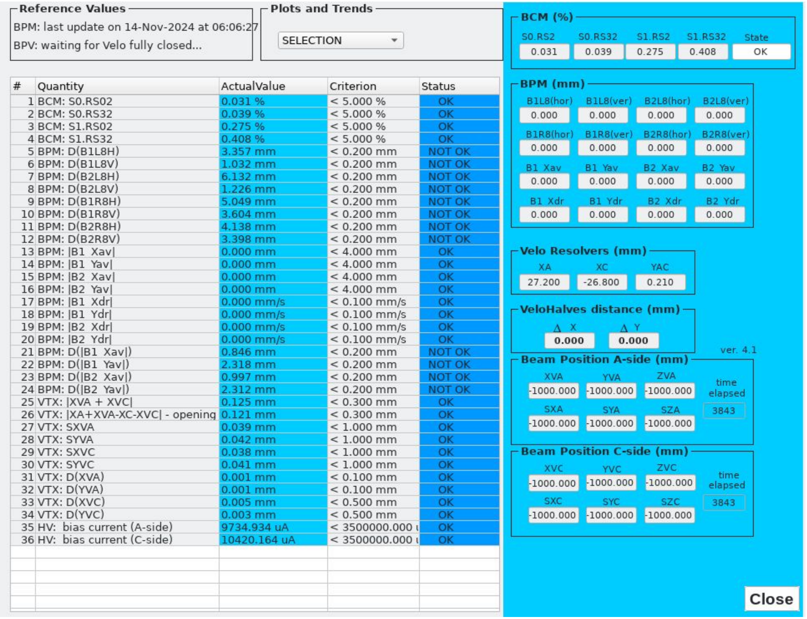
Detector is relatively new and the studies are preliminary

- We have metrics to understand radiation damage
- CCE scans, IV scans, clusters vs HV



Optimizing leakage current compensation: By measuring MPV of Gauss-Landau using Time over Threshold

Backup - VELO Closing



Reference Values

BPM: last update on 14-Nov-2024 at 06:06:27

BPV: waiting for Velo fully closed...

Plots and Trends

SELECTION

#	Quantity	ActualValue	Criterion	Status
1	BCM: S0.RS02	0.031 %	< 5.000 %	OK
2	BCM: S0.RS32	0.039 %	< 5.000 %	OK
3	BCM: S1.RS02	0.275 %	< 5.000 %	OK
4	BCM: S1.RS32	0.408 %	< 5.000 %	OK
5	BPM: D(B1L8H)	3.357 mm	< 0.200 mm	NOT OK
6	BPM: D(B1L8V)	1.032 mm	< 0.200 mm	NOT OK
7	BPM: D(B2L8H)	6.132 mm	< 0.200 mm	NOT OK
8	BPM: D(B2L8V)	1.226 mm	< 0.200 mm	NOT OK
9	BPM: D(B1R8H)	5.049 mm	< 0.200 mm	NOT OK
10	BPM: D(B1R8V)	3.604 mm	< 0.200 mm	NOT OK
11	BPM: D(B2R8H)	4.138 mm	< 0.200 mm	NOT OK
12	BPM: D(B2R8V)	3.398 mm	< 0.200 mm	NOT OK
13	BPM: |B1 Xav|	0.000 mm	< 4.000 mm	OK
14	BPM: |B1 Yav|	0.000 mm	< 4.000 mm	OK
15	BPM: |B2 Xav|	0.000 mm	< 4.000 mm	OK
16	BPM: |B2 Yav|	0.000 mm	< 4.000 mm	OK
17	BPM: |B1 Xdr|	0.000 mm/s	< 0.100 mm/s	OK
18	BPM: |B1 Ydr|	0.000 mm/s	< 0.100 mm/s	OK
19	BPM: |B2 Xdr|	0.000 mm/s	< 0.100 mm/s	OK
20	BPM: |B2 Ydr|	0.000 mm/s	< 0.100 mm/s	OK
21	BPM: D(|B1 Xav|)	0.846 mm	< 0.200 mm	NOT OK
22	BPM: D(|B1 Yav|)	2.318 mm	< 0.200 mm	NOT OK
23	BPM: D(|B2 Xav|)	0.997 mm	< 0.200 mm	NOT OK
24	BPM: D(|B2 Yav|)	2.312 mm	< 0.200 mm	NOT OK
25	VTX: |XVA + XVC|	0.125 mm	< 0.300 mm	OK
26	VTX: |XA+XVA-XC-XVC| - opening	0.121 mm	< 0.300 mm	OK
27	VTX: SXVA	0.039 mm	< 1.000 mm	OK
28	VTX: SYVA	0.042 mm	< 1.000 mm	OK
29	VTX: SXVC	0.038 mm	< 1.000 mm	OK
30	VTX: SYVC	0.041 mm	< 1.000 mm	OK
31	VTX: D(XVA)	0.001 mm	< 0.100 mm	OK
32	VTX: D(YVA)	0.001 mm	< 0.100 mm	OK
33	VTX: D(XVC)	0.005 mm	< 0.500 mm	OK
34	VTX: D(YVC)	0.003 mm	< 0.500 mm	OK
35	HV: bias current (A-side)	9734.934 uA	< 3500000.000 u	OK
36	HV: bias current (C-side)	10420.164 uA	< 3500000.000 u	OK

BCM (%)

S0.RS2	S0.RS32	S1.RS2	S1.RS32	State
0.031	0.039	0.275	0.408	OK

BPM (mm)

B1L8(hor)	B1L8(ver)	B2L8(hor)	B2L8(ver)
0.000	0.000	0.000	0.000
B1R8(hor)	**B1R8(ver)**	**B2R8(hor)**	**B2R8(ver)**
0.000	0.000	0.000	0.000
B1 Xav	**B1 Yav**	**B2 Xav**	**B2 Yav**
0.000	0.000	0.000	0.000
B1 Xdr	**B1 Ydr**	**B2 Xdr**	**B2 Ydr**
0.000	0.000	0.000	0.000

Velo Resolvers (mm)

XA	XC	YAC
27.200	-26.800	0.210

VeloHalves distance (mm)

Δ X	Δ Y
0.000	0.000

ver. 4.1

Beam Position A-side (mm)

XVA	YVA	ZVA	time elapsed
-1000.000	-1000.000	-1000.000	3843
SXA	**SYA**	**SZA**	
-1000.000	-1000.000	-1000.000	

Beam Position C-side (mm)

XVC	YVC	ZVC	time elapsed
-1000.000	-1000.000	-1000.000	3843
SXC	**SYC**	**SZC**	
-1000.000	-1000.000	-1000.000	

Close