# Run 3 performance of new hardware in LHCb

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on behalf of the LHCb collaboration

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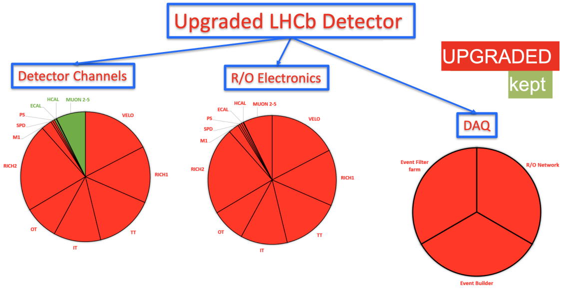
# Introduction

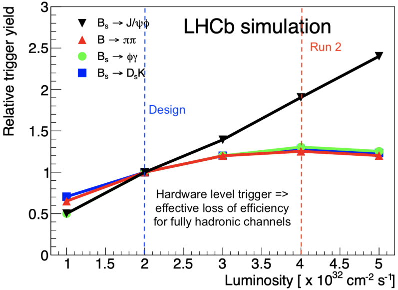
- the LHCb detector has undergone a major upgrade during the Long Shutdown 2
- almost everything is new: from subdetectors technologies to the data acquisition domain, from the timing and fast controls distribution to a full-software trigger architecture
- **2022 has been a commissioning year aiming to achieve the ambitious goal to have a functional new experiment within six months of data-taking with *pp* collisions**

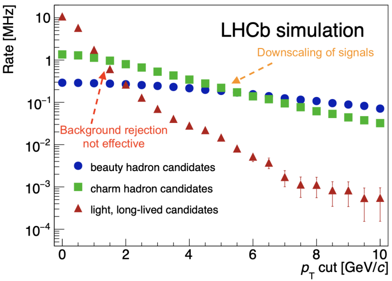


# The LHCb upgrade concept

[arXiv:2305.10515]

- **five-fold increase in the instantaneous luminosity and pile-up** to improve precision in flavour physics observables: see **Carla Gobel's talk** on Monday for the LHCb overview
- effective only with the **removal of the hardware level trigger** ($p_T$ signatures based), the readout of all subsystems at 40 MHz with a complete redesign of the Online system, and an efficient, flexible and full-software trigger architecture (see **Marianna Fontana's talk** later this morning)

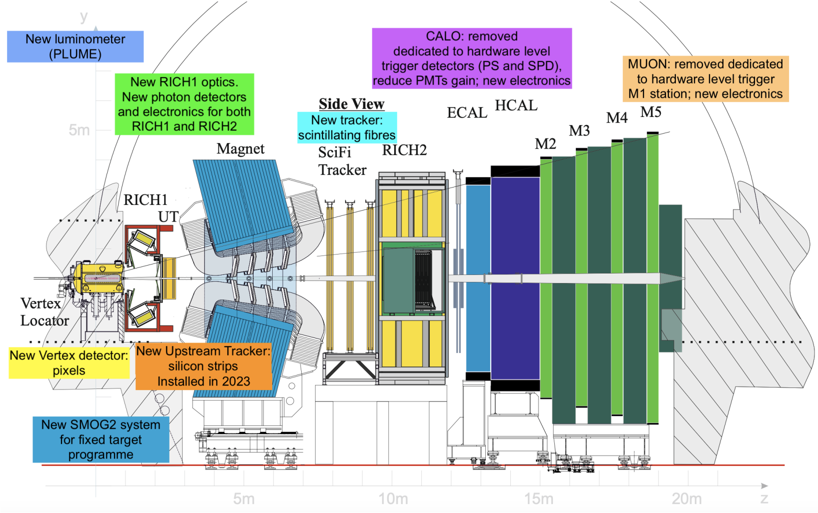



**We expect $\sim$ 300k $b\bar{b}/s$ and $\sim$ 5M $c\bar{c}/s$ in acceptance at the nominal Run 3 luminosity**

# Run 3 LHCb: a new detector overall

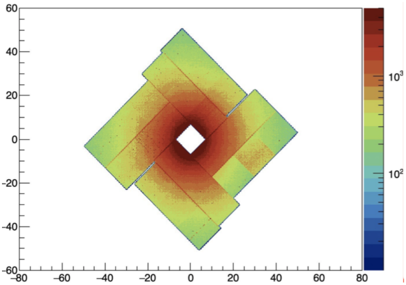
[arXiv:2305.10515]

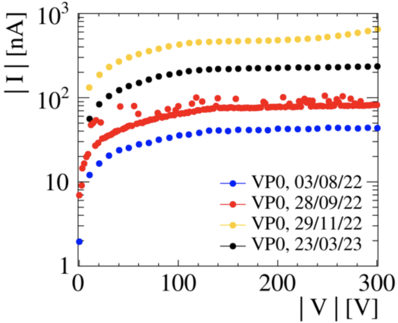



See **Fabio Ferrari's talk** on Thursday for more details

# Vertex Locator (VELO)

- data rate per pixel ASIC up to 15 Gbit/s in the hottest region closer to the beam spot
- clustering in FPGA validated up to 20 MHz (maximum rate achievable in 2022 given the LHC filling scheme)
- I-V curve fully consistent with expectations given the absorbed dose in 2022

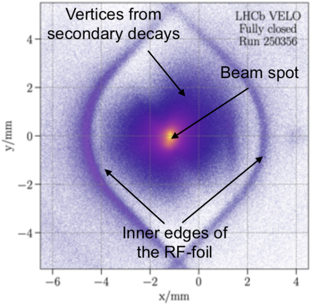


# VELO

- two retractable halves, each at 27 mm from the beam line in open position and at **3 mm** in closed position, has been installed at the beginning of 2022

- use vertices from hadronic interactions to scan the detector material **[JINST 13 (2018) 06, P06008]**

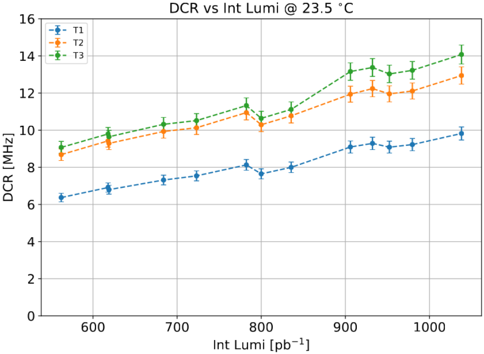



- closing procedure very delicate, requiring the full understanding and control of detector conditions such as **temperatures and pressures for the monitoring of vacuum conditions**, the precise knowledge of the position of the RF foil, and the **reconstruction** of tracks, primary and secondary vertices to be in place: **full closure done on 25/10/22**

# Scintillating fibres tracker (SciFi)

**[LHCB-FIGURE-2023-004]**

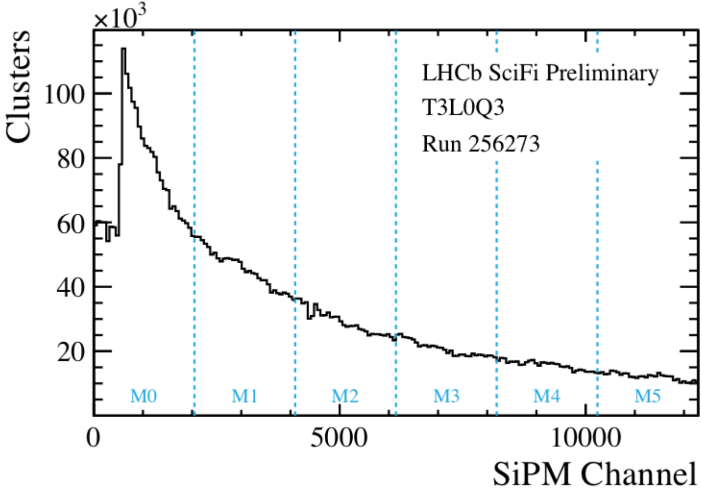
- fibres coupled to SiPM operated at -40 $^{\circ}$C during standard operations, reducing by a factor of 100 the dark counts rate: negligible contribution to track reconstruction since frontend thresholds set at $\geq$ 2.5 photoelectrons equivalent
- behaviour of dark count rate as a function of the absorbed dose when operating at ambient temperature has also been studied during 2022



# SciFi

**[LHCb-FIGURE-2023-013]**

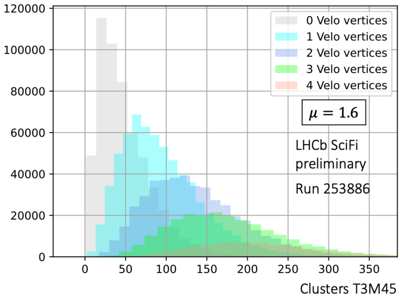
- commissioned in 2022, allowing to reconstruct long tracks by combining with the information from the VELO

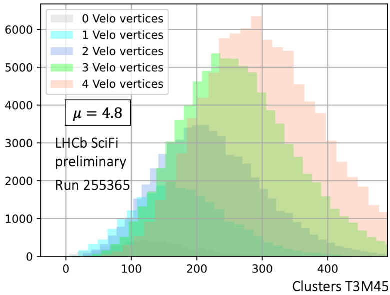


# Matching of VELO - SciFi clusters

**[LHCb-FIGURE-2023-012]**

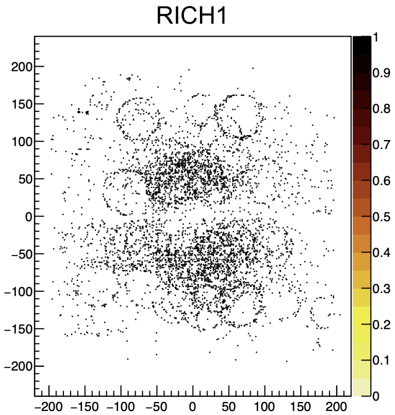
- the matching of VELO tracks and SciFi tracks is structural in building the long tracks objects, used in the large majority of LHCb analyses
- in addition, the mean numbers of VELO vertices and SciFi clusters are ones of the offline counters that are used to measure the **recorded luminosity** by means of a dedicated 30 kHz trigger unbiased data stream

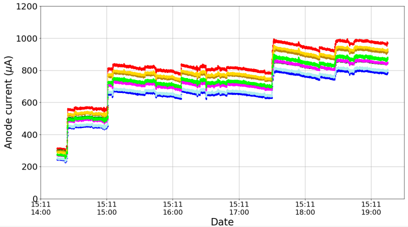


# Ring Imaging Cherenkov (RICH) detectors

- both RICH detectors have been fully functional in 2022: visualisation of rings at nominal luminosity displaying a very good performance also in busy events



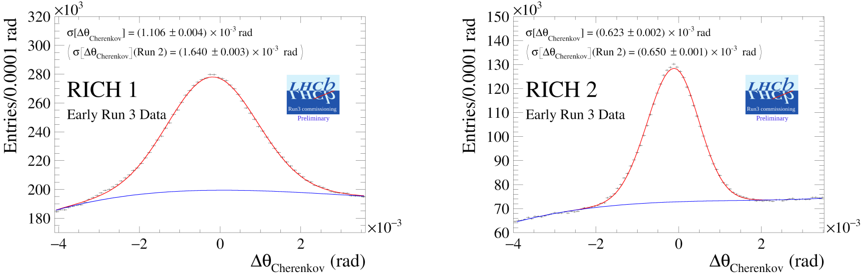




- Multi-anode photomultipliers are operated by powering the last dynode to preserve the gain linearity: high-voltage currents employed as alternative online counters for the **delivered luminosity** (independent from the data taking status)

# RICH detectors performance

**[LHCB-FIGURE-2023-007]**

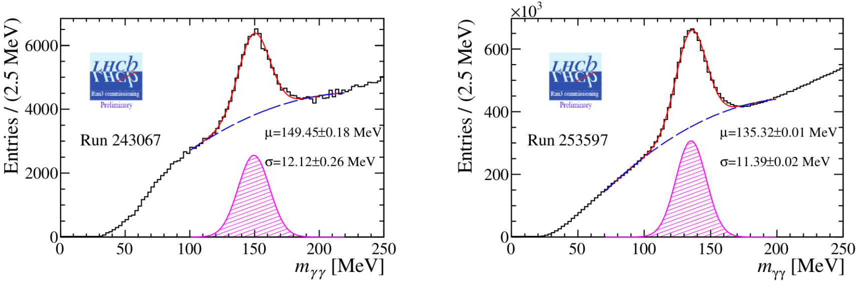
- one of the figures of merit used to determine the performance of the RICH detectors is the single photon Cherenkov angle resolution
- **it is also the first global performance figure of merit that has been determined in 2022, since high momentum tracks are required as input for the recontruction of Cherenkov angles!**
- reconstruction process includes the (software) spatial alignments obtained for RICH photodetectors panels and mirrors, as well as the ones of other subsystems
- **clear performance improvement with respect to the former LHCb**



# Calorimeters

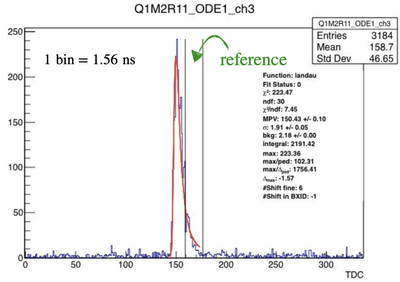
[LHCB-FIGURE-2022-019]

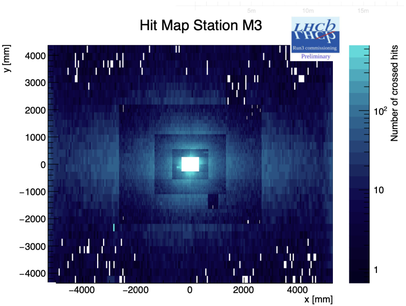
- both ECAL and HCAL fully functional: photons and electrons objects could be used since day one to provide first (software) triggers to the experiment
- inter-cell calibration and time alignment showing an improvement in the di-photon mass peak and in the mass resolution around the $\pi^0$ mass



# Muon system

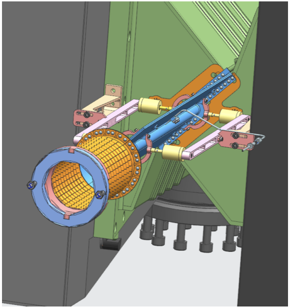
- also the Muon system is now part of the first level of software trigger
- time alignment for all the chambers, including the low populated outer regions, requiring the combination of the information with VELO and SciFi tracks, is being finalised

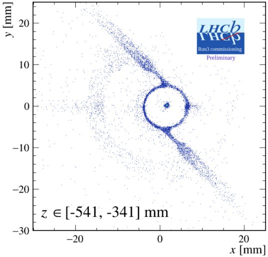


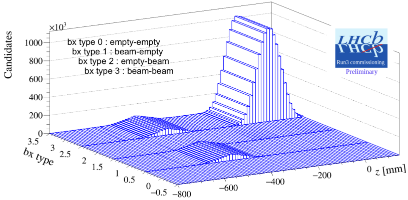



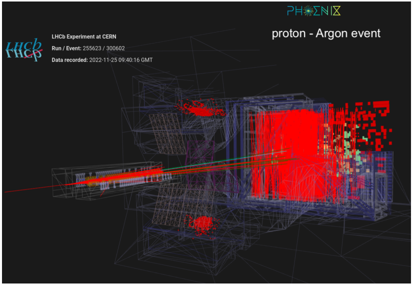
# Fixed-target programme in 2022 on $H_2$, He and Ar

**[LHCB-FIGURE-2023-001]**





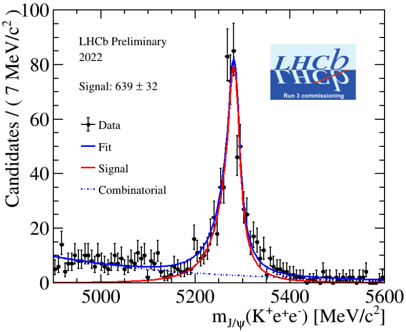



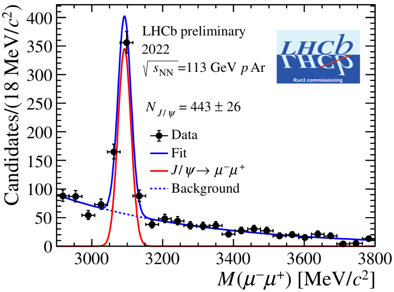

See **Giacomo Graziani's** and **Oscar Boente's talks** for more details

# First mass peaks: $J/\psi \to l^+l^-$

**[LHCB-FIGURE-2023-010], [LHCb-FIGURE-2023-008]**

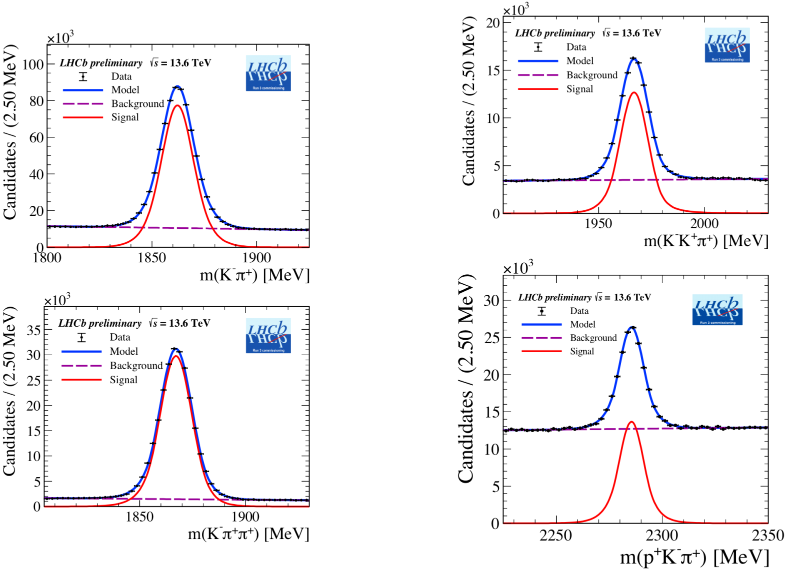
- **huge collaboration-wide efforts in the study of the first data from the new detector!**
- crucial to optimise the performance in view of 2023 and for Run 3 in general
- mass resolutions close to the expectations from Monte Carlo



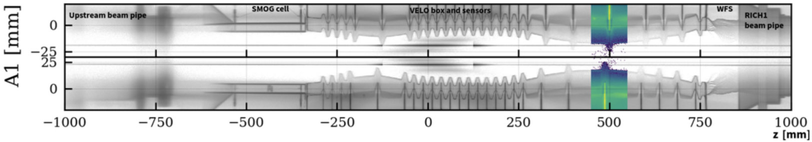
# First mass peaks: charmed mesons

**[LHCB-FIGURE-2023-011]**

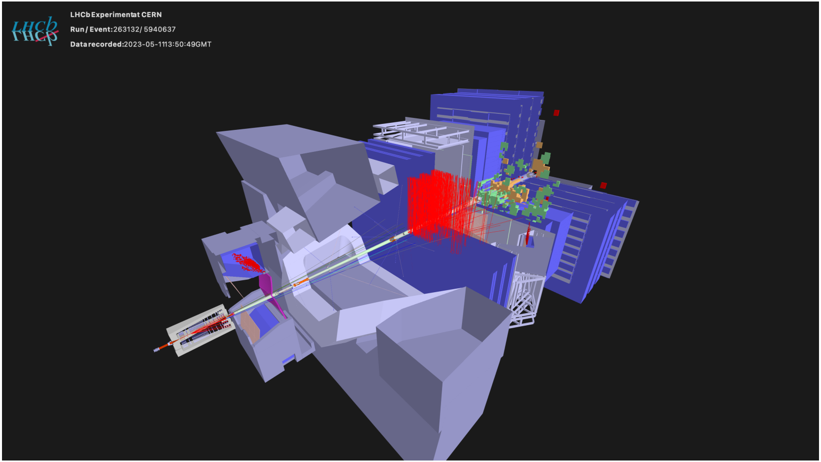


# 2023 restart and LHC vacuum volume incident

- 10/01/23: sequence of failures of the LHC vacuum system induced a 200 mbar pressure differential on the $\sim 150\ \mu$m thin RF foil separating the primary vacuum from the secondary vacuum where the VELO modules are installed ($\Delta$p 20x than designed)
- fortunately **no damage to the detectors modules and cooling**, but a plastic deformation of the RF foil will obstruct the nominal 3 mm aperture with respect to the beam line $\Rightarrow$ **operate in 2023 with a partially opened VELO** (impact on the polar and azimuthal angles acceptance)
- dedicated tomography data taking to determine the minimal distance from the beam line already done and under full assessment
- running configuration will be decided in the June technical stop, but nevertheless the commissioning of the experiment can continue and oppurtunities for physics production remains
- **the damaged RF-foil will be replaced during YETS 23/24**



# Event display with first full machine configuration in 2023



# Conclusions

- 2022 has been a commissioning year for the LHCb experiment as an whole
- at the end of the year we managed to take data at a doubled instantaneous luminosity with respect to Run 2: first figures of merit already indicate a good performance of all subsystems
- LHC vacuum incident will have an impact on the VELO aperture on 2023, but **the LHCb commissioning, including now the Upstream tracker installed at the beginning of the year, can continue**
- in addition, even with a VELO partially open, physics opportunities in 2023 remain
- **the goal is to have the LHCb detector at the best of its performance and running at Run 3 nominal instantaneous luminosity in 2024 and 2025**

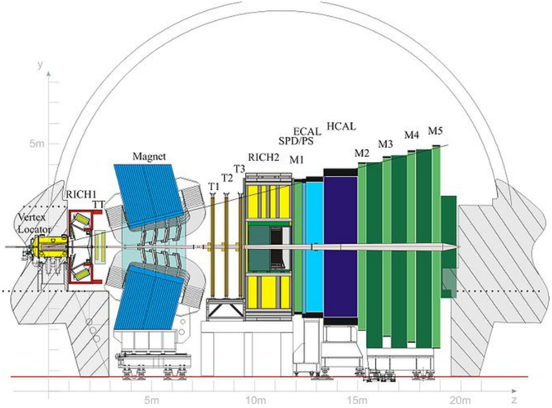
**Thanks!**

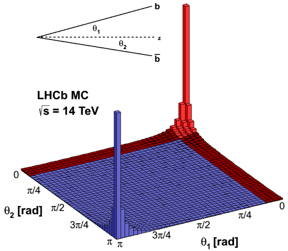
# Extra Slides

# The LHCb detector during Run 1 and 2

**[JINST 3 (2008) S08005]**

- the LHCb detector covers the forward region in the $2 < \eta < 5$ range
- $\sim 25\%$ of the $b\bar{b}$ pairs are produced inside the LHCb acceptance
- LHCb ran with an instantaneuos luminosity of $\mathcal{L} = 4 \times 10^{32}\,\mathrm{cm^{-2}s^{-1}}$, pile-up $\sim 1$
- **CPV, rare *b*-hadron decays, spectroscopy, EW, pQCD, heavy ions**



# The Run 3 LHCb detector: VELO

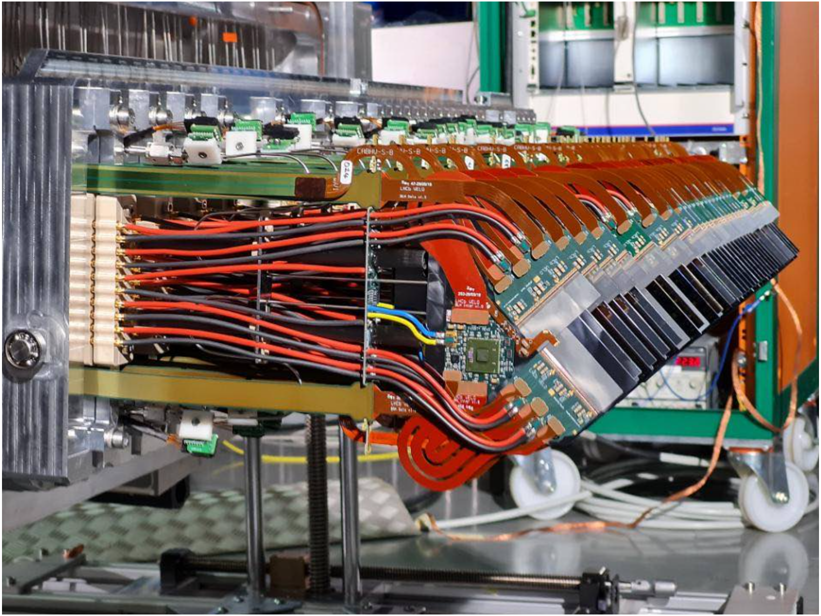
**[arXiv:2305.10515]**

Table 1: Specifications of the upgraded VELO compared to those of the original version.

| | 2009–2018 | 2022 |
|---|---|---|
| RF box inner radius (minimum thickness) | 5.5 mm (300 μm) | 3.5 mm (150 μm) |
| Inner radius of active silicon detector | 8.2 mm | 5.1 mm |
| Total fluence (silicon tip) [$n_{\mathrm{eq}}/\mathrm{cm}^2$] | $4 \times 10^{14}$ | $\sim 8 \times 10^{15}$ |
| Sensor segmentation | $r - \phi$ strips | square pixels |
| Total active area of Si detectors | 0.22 $\mathrm{m}^2$ | 0.12 $\mathrm{m}^2$ |
| Pitch (strip or pixel) | 37–97 μm | 55 μm |
| Technology | n-on-n | n-on-p |
| Number of modules | 42 | 52 |
| Total number of channels | 172 thousand | 41 million |
| Readout rate [ MHz ] | 1, analogue | 40, zero suppressed |
| Whole-VELO data rate | 150 Gbit/s | $\sim$ 2 Tbit/s |
| Total power dissipation (in vacuum) | 800 W | $\sim$ 2 kW |

# The Run 3 LHCb detector: VELO

**[arXiv:2305.10515]**



# The Run 3 LHCb detector: SciFi

[arXiv:2305.10515]

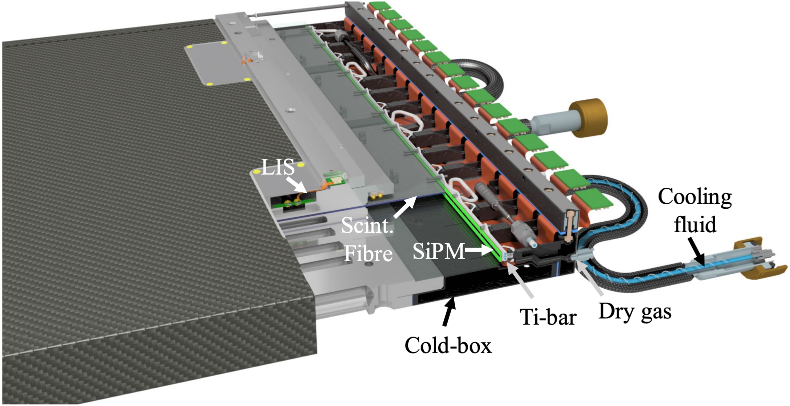
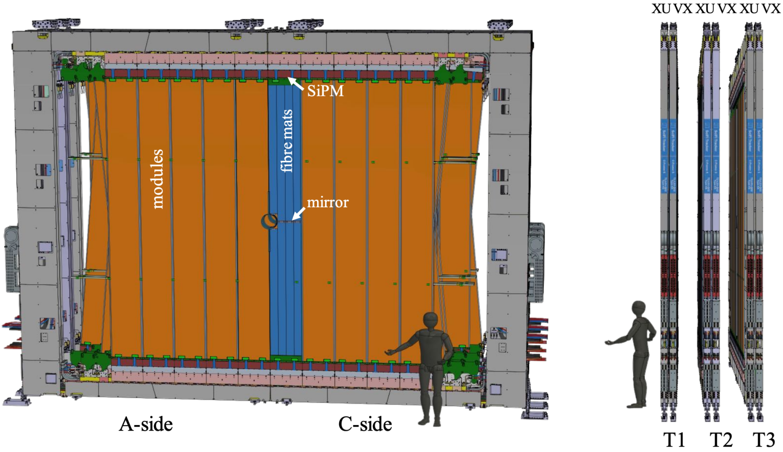



Figure 53: A cutaway view of the cold-box fixed to the fibre module.

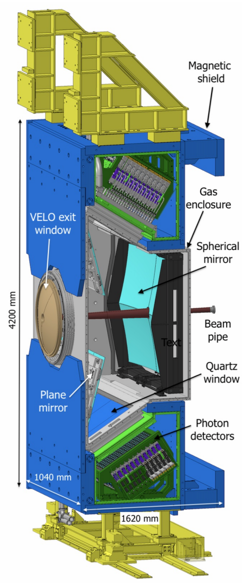
# The Run 3 LHCb detector: SciFi

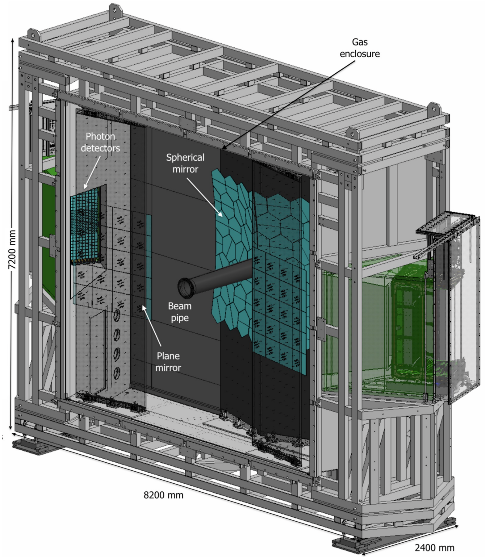
[arXiv:2305.10515]



# The Run 3 LHCb detector: RICH1 and RICH2

[arXiv:2305.10515]



# The Run 3 LHCb detector: CALO

[arXiv:2305.10515]

| Parameter | Requirements |
|---|---|
| Energy range | $0 \leq E_{\mathrm{T}} \leq 10\,\mathrm{GeV}$ (ECAL) |
| Calibration/Resolution | $4\,\mathrm{fC}/5\,\mathrm{MeV}$ $E_{\mathrm{T}}$ per ADC count |
| Dynamic range | 4096-256 = 3840 counts: 12 bits |
| Noise | $\lesssim 1$ ADC counts (ENC $< 4\,\mathrm{fC}$) |
| Termination | $50 \pm 5\,\Omega$ |
| Baseline shift prevention | Dynamic pedestal subtraction |
| Max. peak current | 4–5 mA over $50\,\Omega$ |
| Spill-over residue level | $\pm 1\%$ |
| Integrator peak plateau | $< 1\%$ variation in $\pm 2\,\mathrm{ns}$ |
| Linearity | $< 1\%$ |
| Cross-talk | $< 0.5\%$ |
| Timing | Individual (per channel) |

Table 10: Summary of the requirements for the calorimeter analog FE.

# The Run 3 LHCb detector: MUON

**[arXiv:2305.10515]**

Table 11: Maximum output bandwidth ( Gbit/s) per PCIe interface in the muon system stations at two different luminosity values when zero-suppression is applied; for comparison, also the output rate with no zero-suppression is reported.

| Station | # TELL40 | output rate ( Gbit/s) $\mathcal{L} = 2 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ | output rate ( Gbit/s) $\mathcal{L} = 4 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ | output rate ( Gbit/s) no zero-suppression |
|---|---|---|---|---|
| M2 | 10 | 22 | 27 | 54 |
| M3 | 4 | 24 | 33 | 61 |
| M4 | 4 | 13 | 18 | 35 |
| M5 | 4 | 18 | 25 | 42 |