Performance highlights in LHCb

Elena Dall'Occo

12th Edition of the Large Hadron Collider Physics Conference
03/05/2024

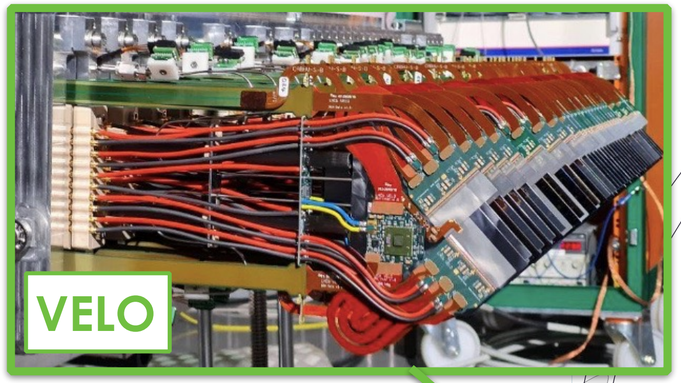
LHCb Upgrade at a glance

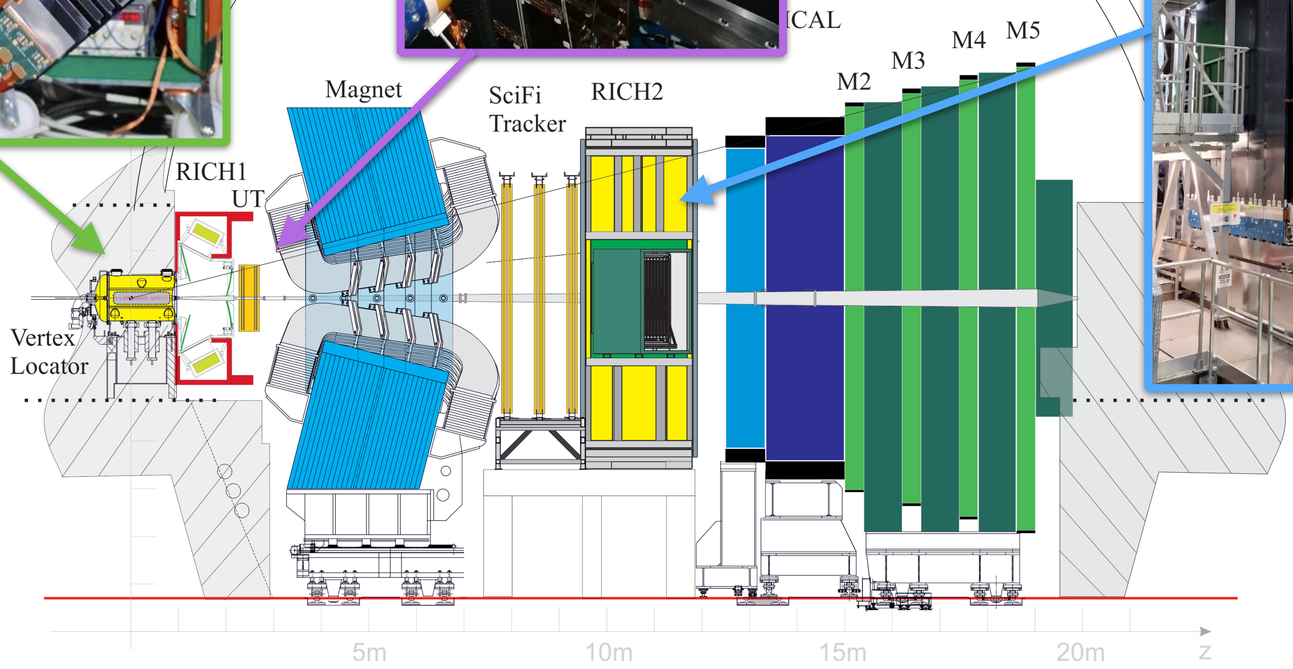
see E. Niel talk for more details!

Brand new detector!

- 5x instantaneous lumi from $4x10^{32}$ cm^{-2} s^{-1} to $2x10^{33}$ cm^{-2} s^{-1}
- average number of visible pp collisions $\mu = 5.5$

tracking system completely replaced





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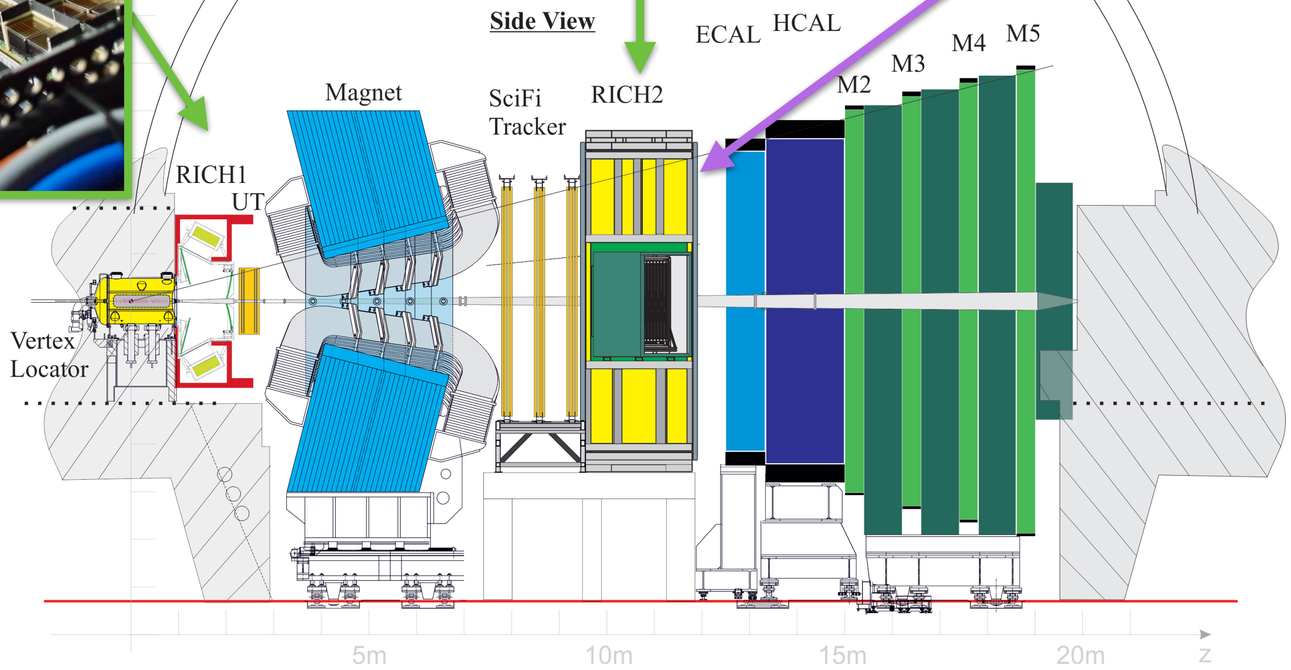
new photo-detectors + new optics

removed first muon station, preshower and scintillating pad detectors + new neutron shielding



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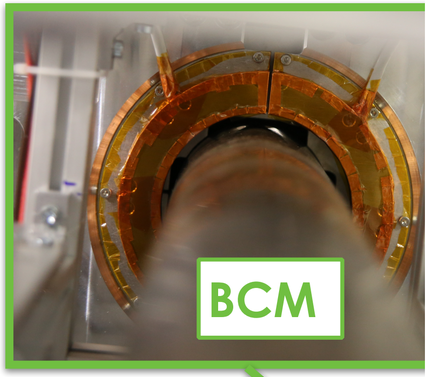
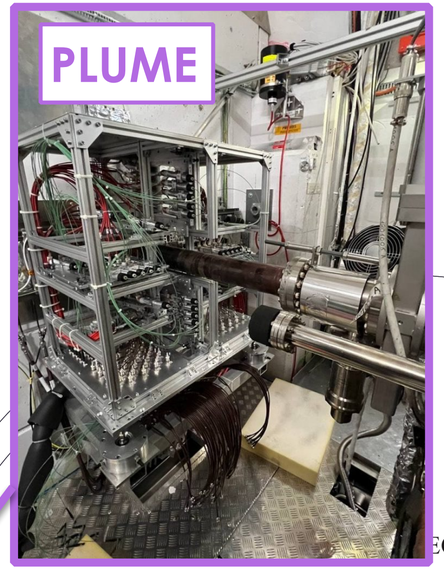
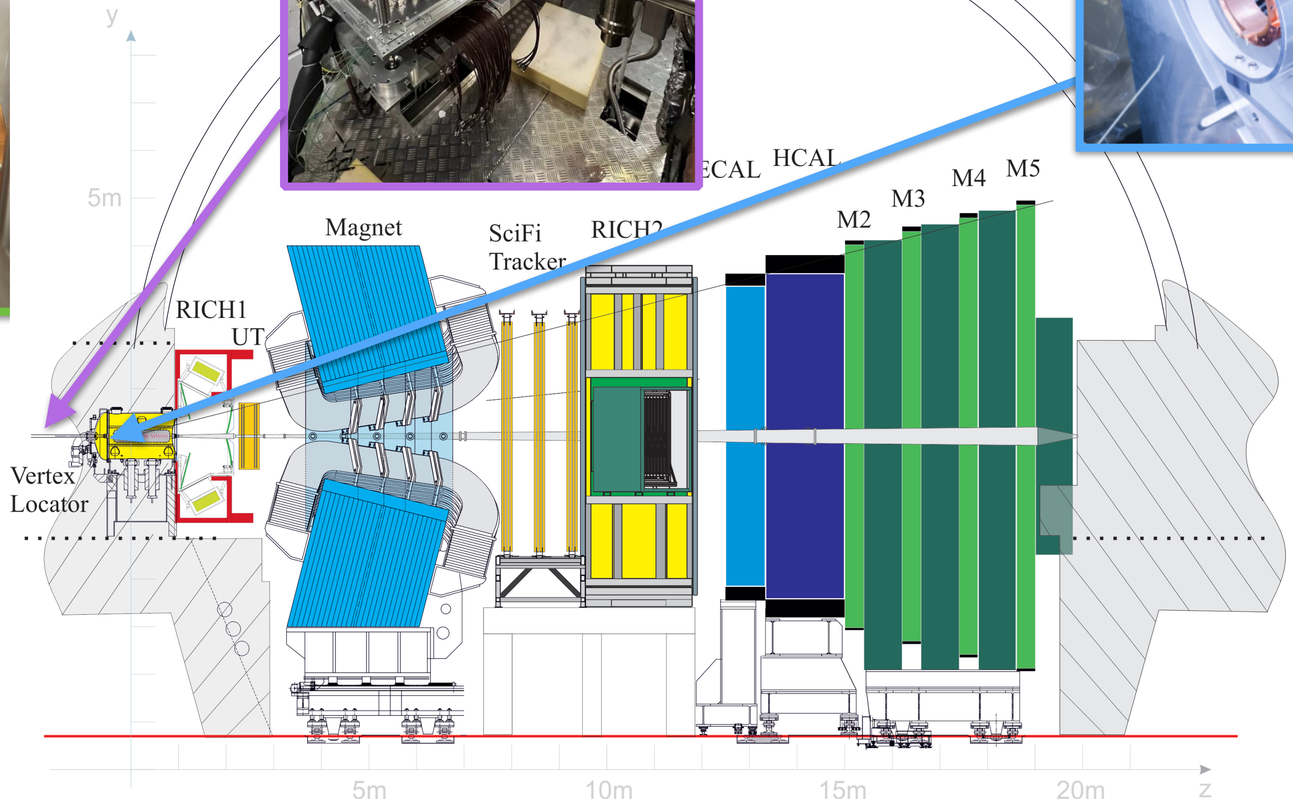


refurbished Beam Conditions Monitor



new luminometer

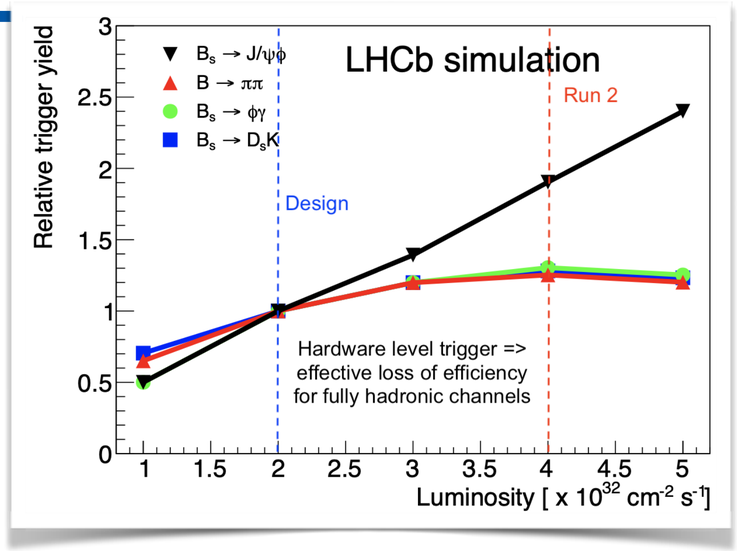
new gas cell



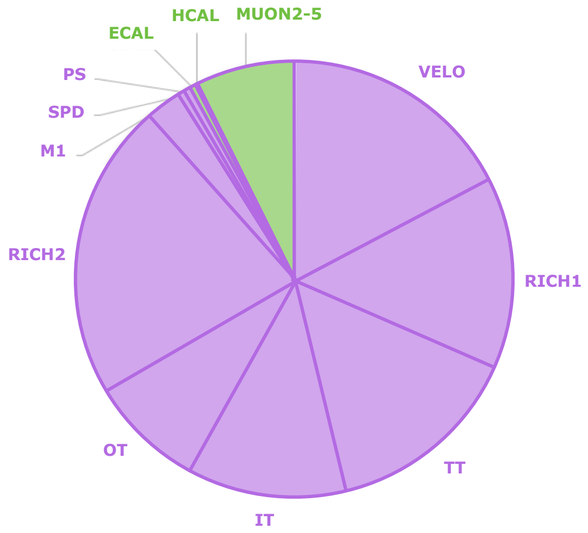
LHCb Upgrade at a glance

readout at 40 MHz

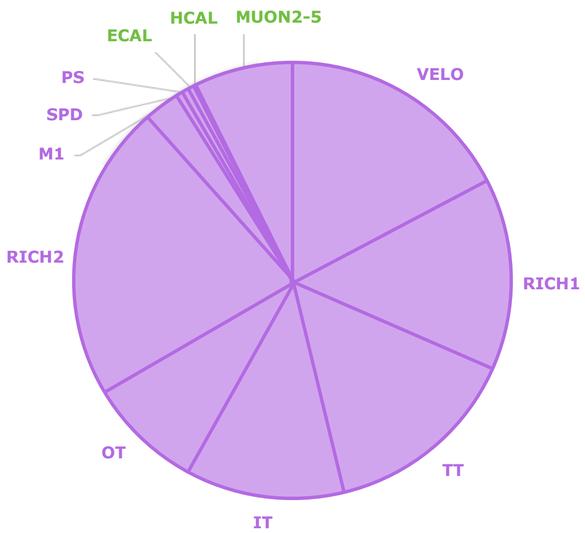
- all electronics and DAQ upgraded
- new timing and fast control distribution
- full software trigger architecture



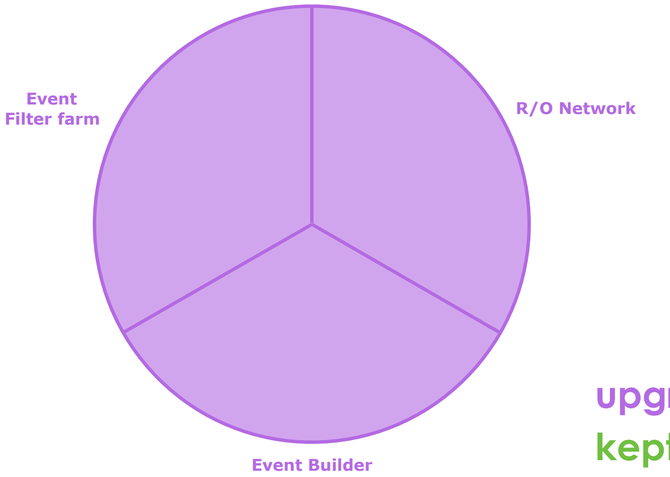
detector channels



R/O electronics



DAQ



upgraded

kept

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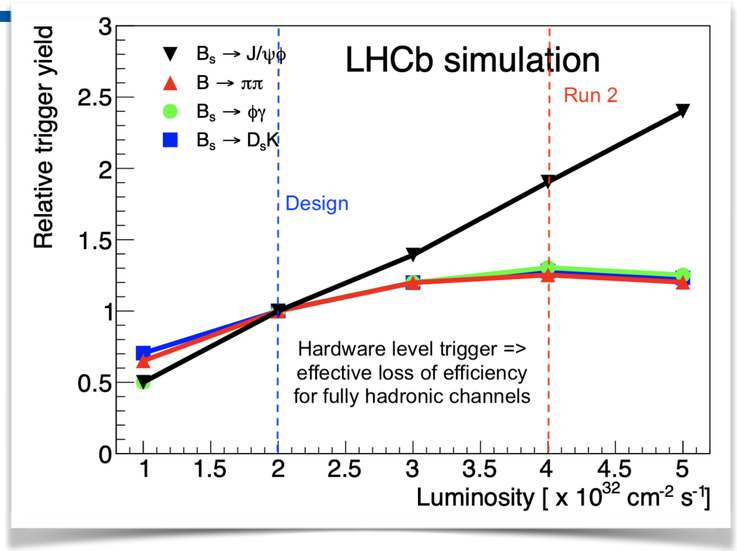

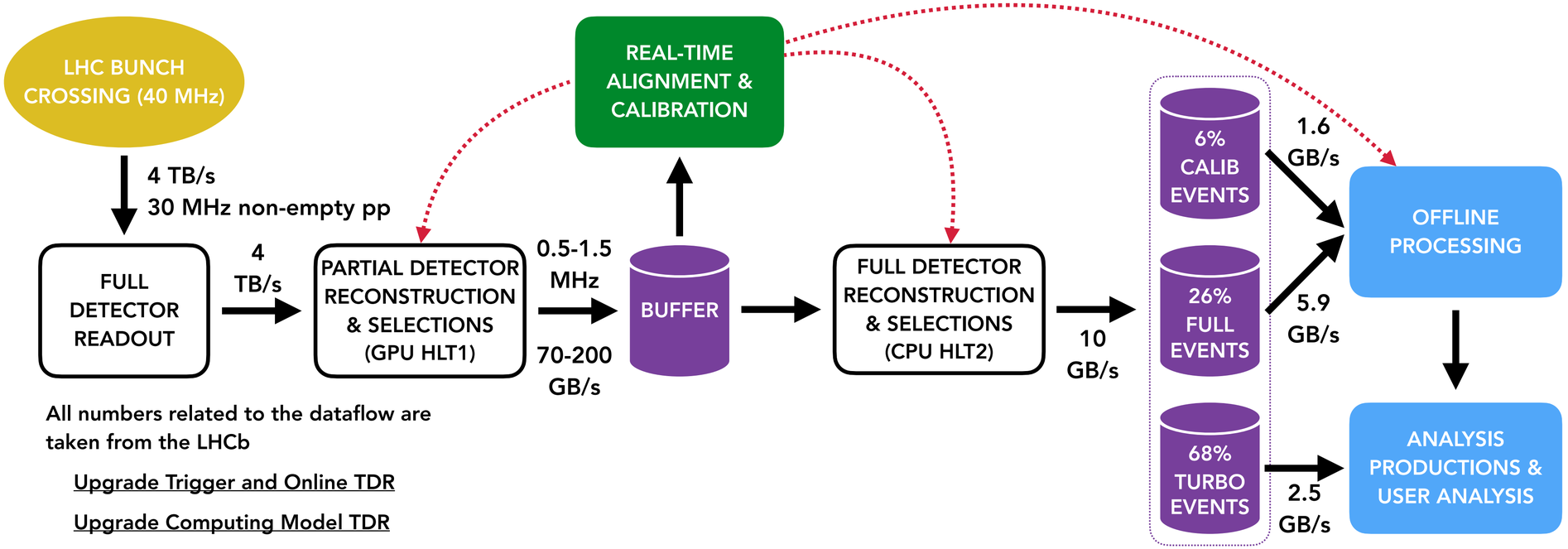

All numbers related to the dataflow are taken from the LHCb

Upgrade Trigger and Online TDR

Upgrade Computing Model TDR

How is it going so far?

2022

- all detectors installed but UT
- local commissioning of subdetectors
- global commissioning of trigger, alignment and calibration
- VELO routinely closed in the last couple of months

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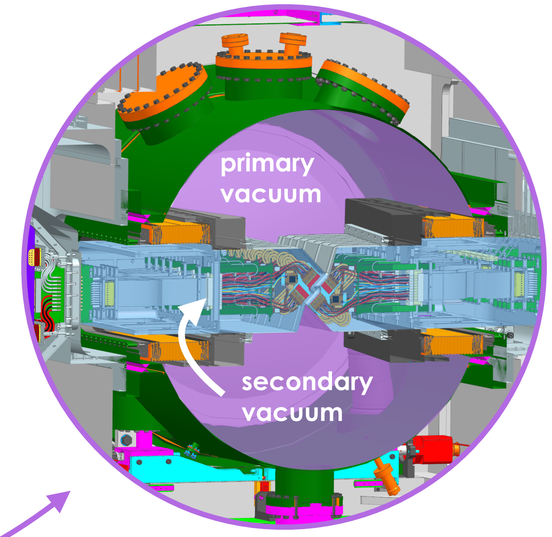
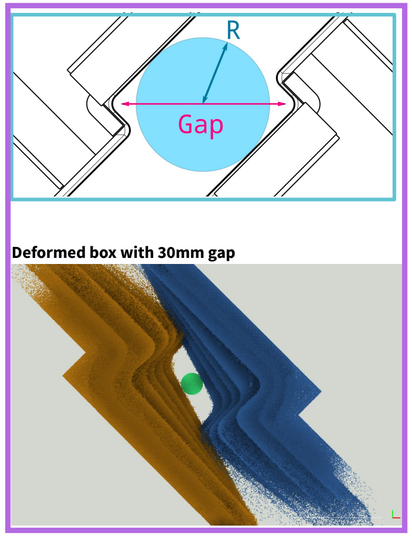
- LHC vacuum incident in the VELO in Jan: operated with VELO gap of 49 mm
- UT completed installation
- commissioning continued
- collected data during ion run





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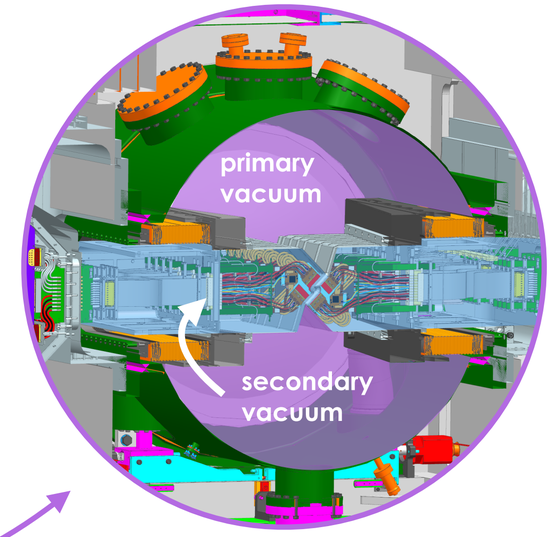
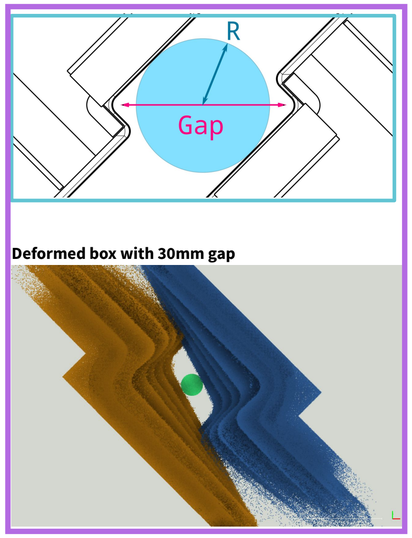
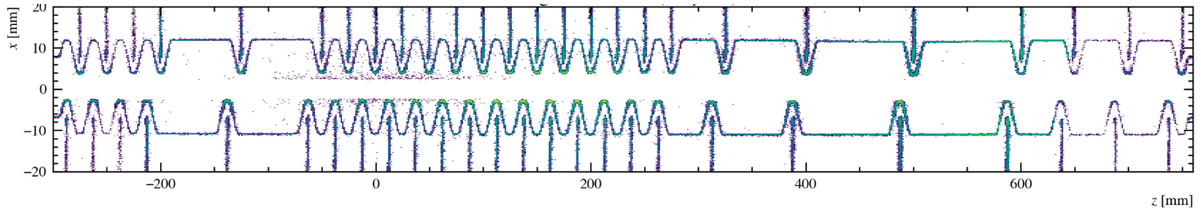




2024

- VELO RF box replaced
- re-commissioned full detector (but UT) during intensity ramp up up to nominal luminosity
- UT commissioning and integration ongoing
- collecting data

new RF-box and VELO modules reconstructed by hadronic interaction vertices

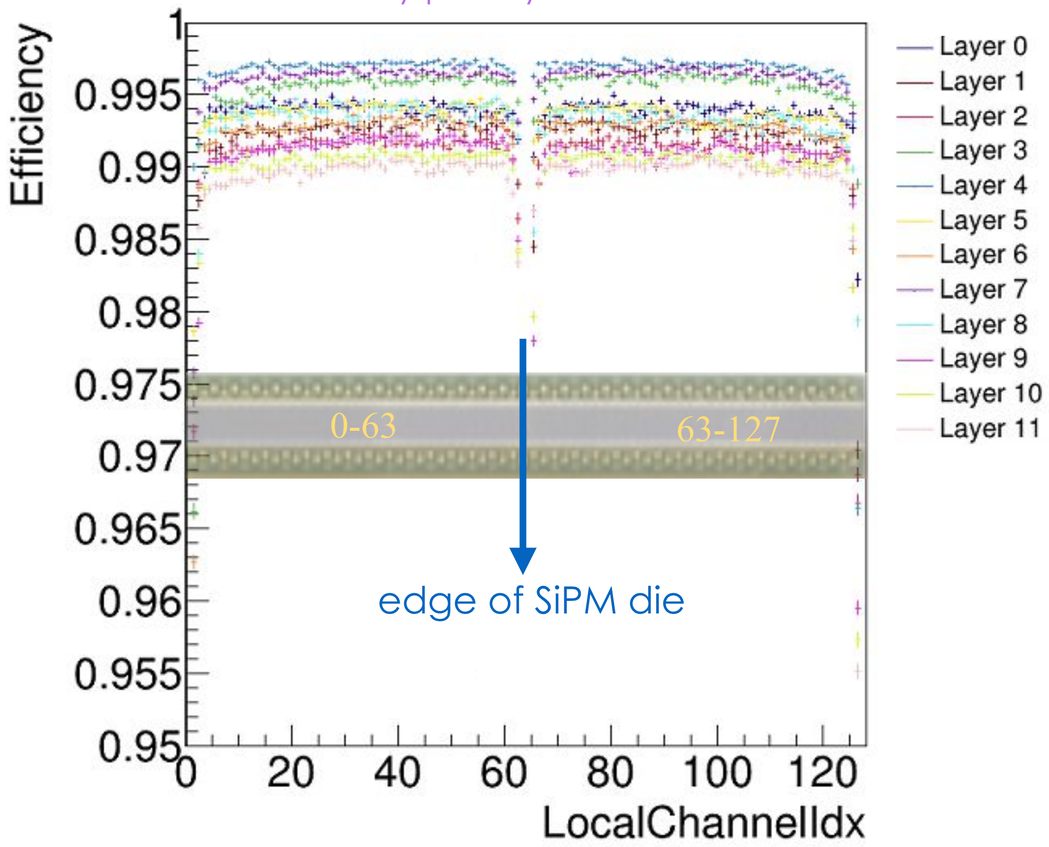


Hit efficiency

hit efficiency for SciFi and VELO approaching design specifications

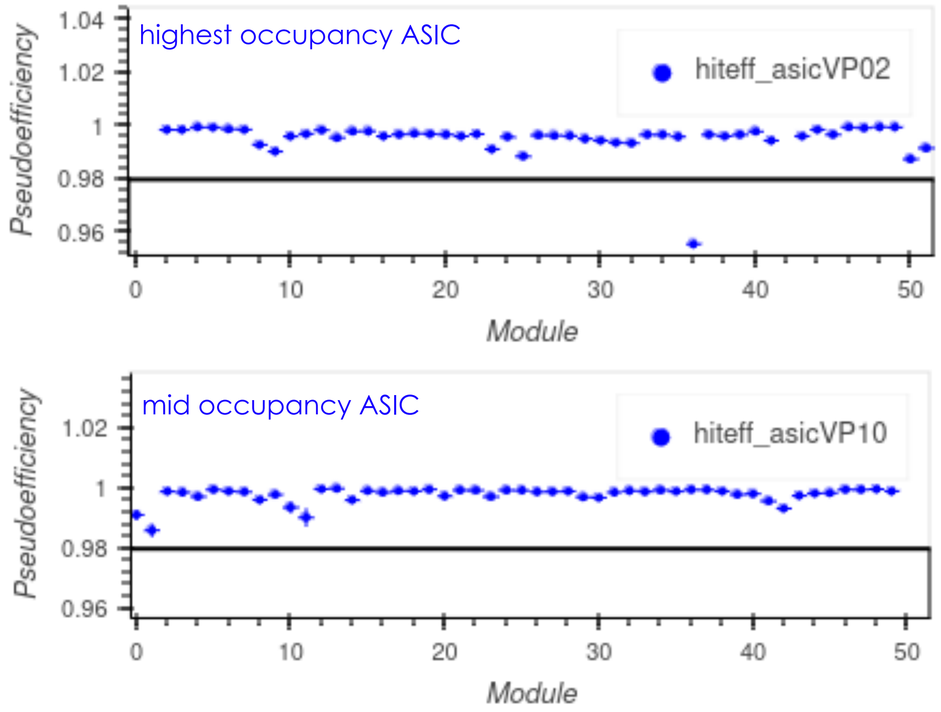
SciFi

hit efficiency per layer



VELO

biased hit efficiency in online monitoring



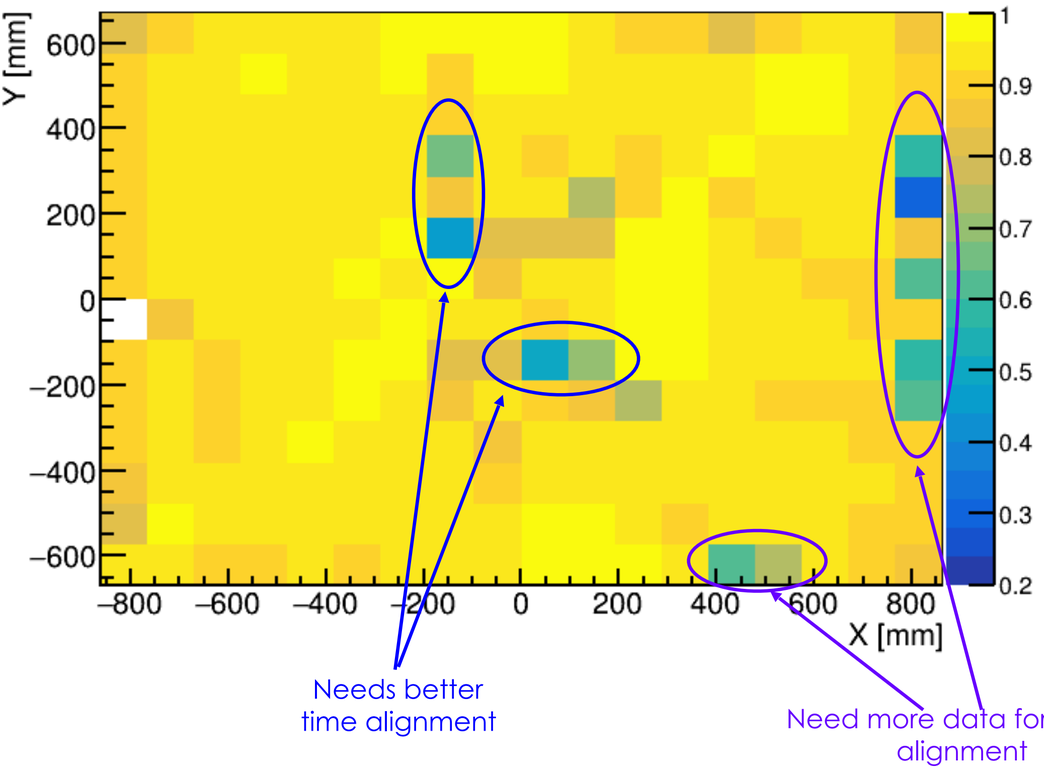
- LHCb Upgrade at a glance
  - tracking system
  - PID system
  - luminosity and beam background
  - DAQ and trigger
- How is it going so far?
- Low-level performance
  - Hit efficiency
  - Cherenkov angle resolution
  - Alignment
  - Calibration
- High-level performance
  - PV resolution
  - PID: muon & electron
  - PID: hadrons
  - Trigger efficiency
- Gas Injection
- Centrality
- Looking ahead…

Hit efficiency

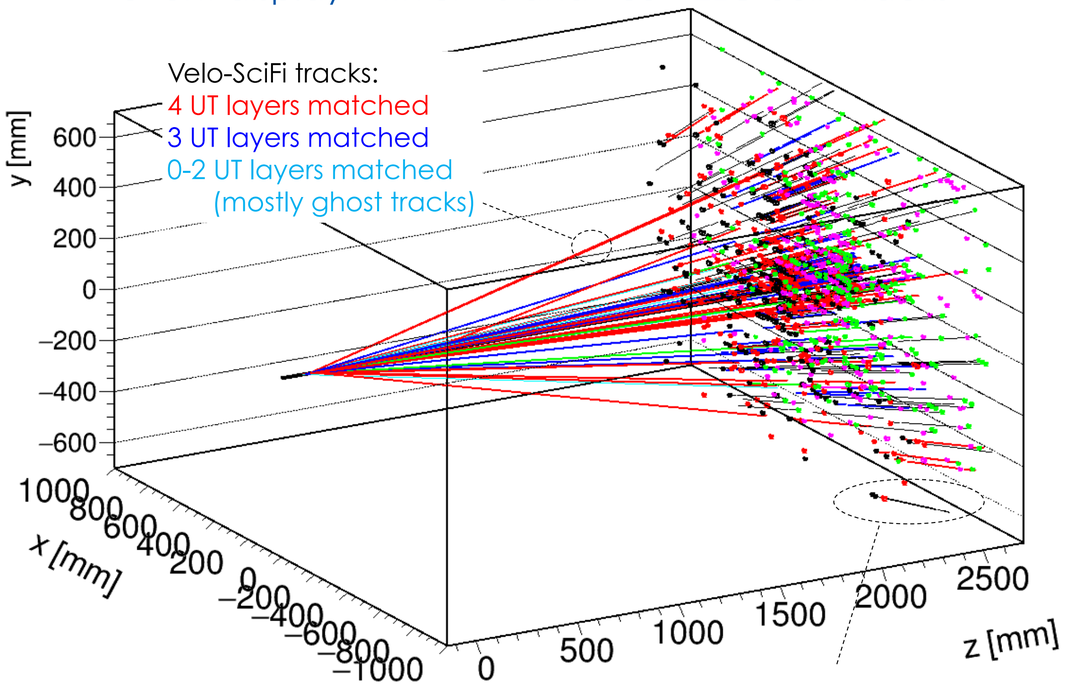
very rapid progress in UT commissioning this year

- coarse time alignment with 450 GeV beam, fine time alignment and space alignment with 6.8 TeV beam
- as of now 96% efficiency as measured on VELO-SciFi tracks matched to 3-4 UT layers
- improvement expected from 2nd round of fine-time and space alignment data and from further tuning of FE thresholds to individual channels

UT efficiency map as measured on Velo-SciFi tracks



event display with 3PVs and ~50 VELO-SciFi tracks



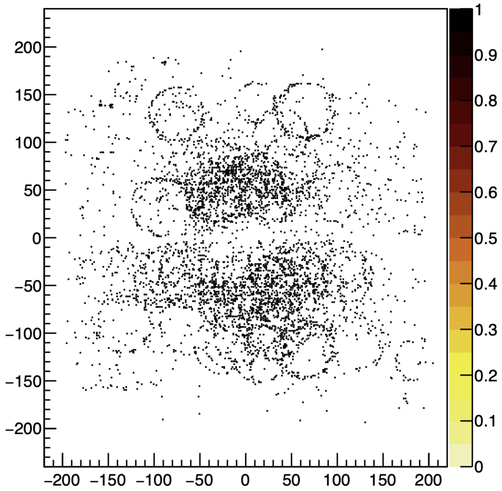
UT layer coincidences among UT clusters (not matched to Velo-SciFi tracks) pointing to PV (low momentum particles not getting through the magnet), coincidence of 4 layers, 3 layers, 2 layers

Cherenkov angle resolution

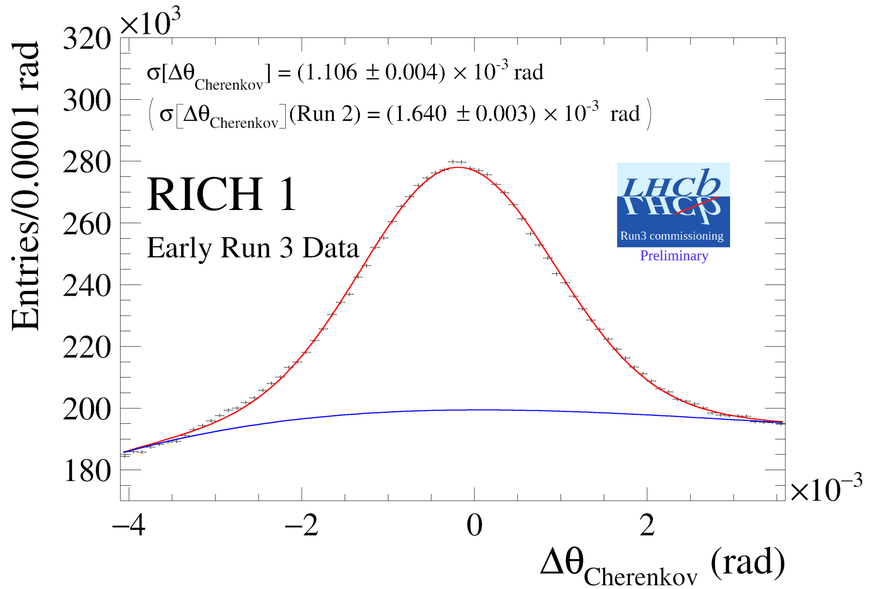
- depends on other subdetectors spatial alignment
- optimisation of operations parameters ongoing, further improvements expected

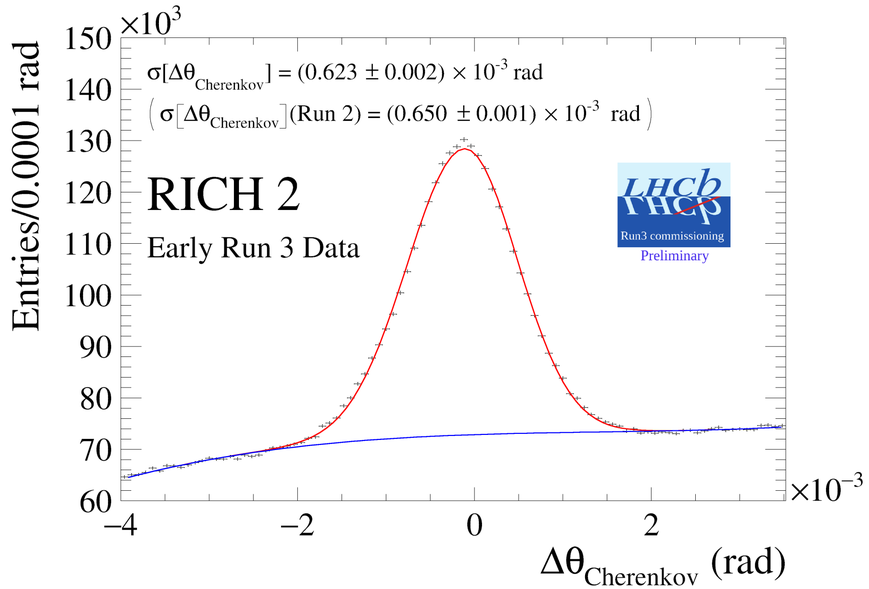
clear improvement from Run 2 to Run 3

RICH 1 at μ=5.5



single photon Cherenkov angle resolution





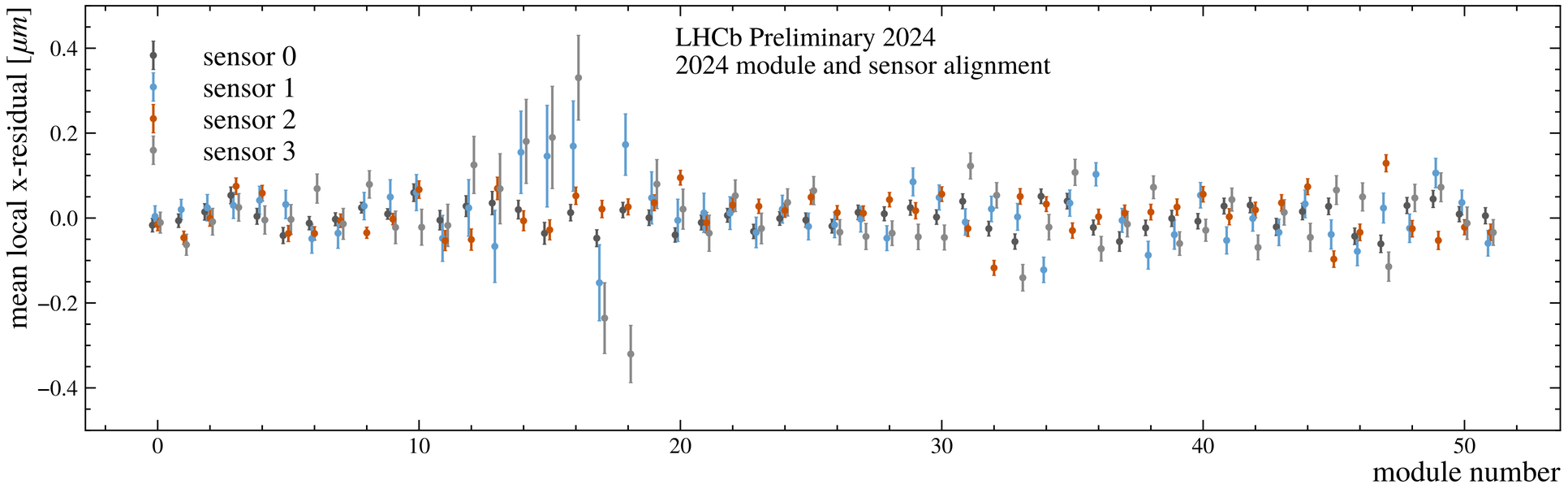
Alignment

LHCb-FIGURE-2024-009

online trackers alignment crucial for a performant track-based trigger

- VELO half alignment automatically evaluated every 10 min, module alignment on demand a few times per year
- SciFi and RICH alignment automatically evaluated and applied on demand
- MUON alignment performed ~once per year

VELO alignment performance



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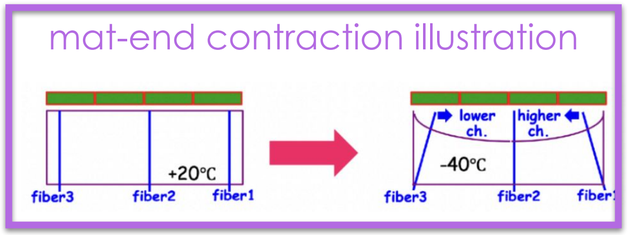
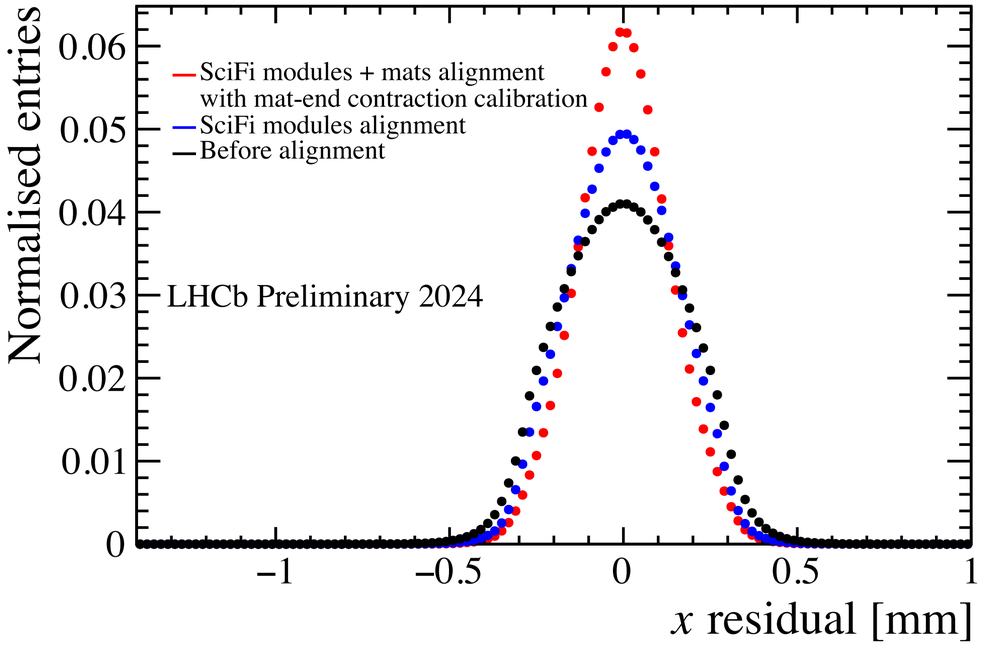
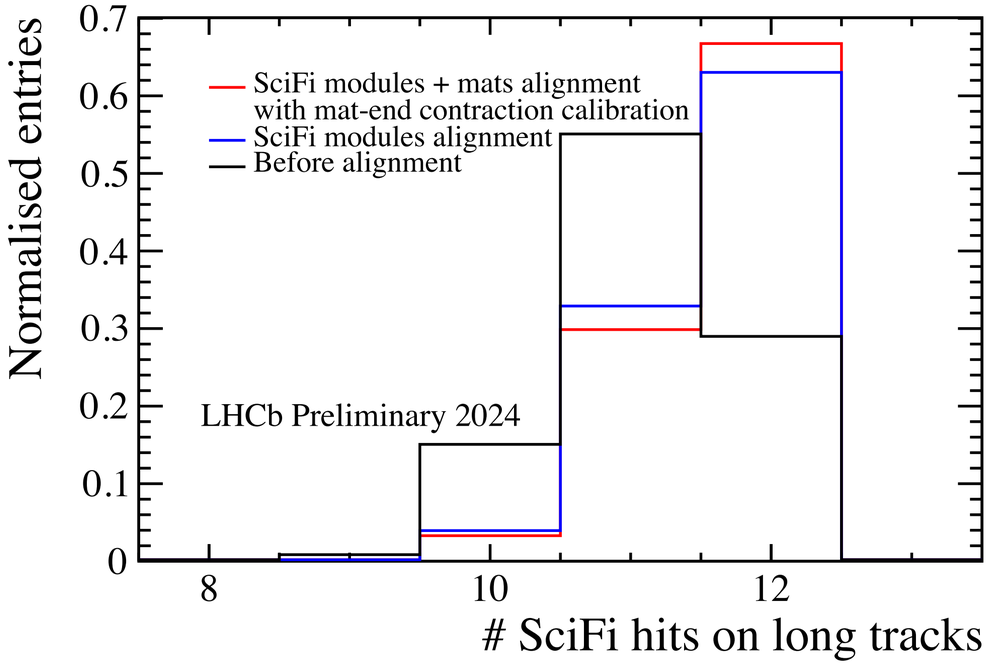


SciFi alignment performance (further improvements ongoing)





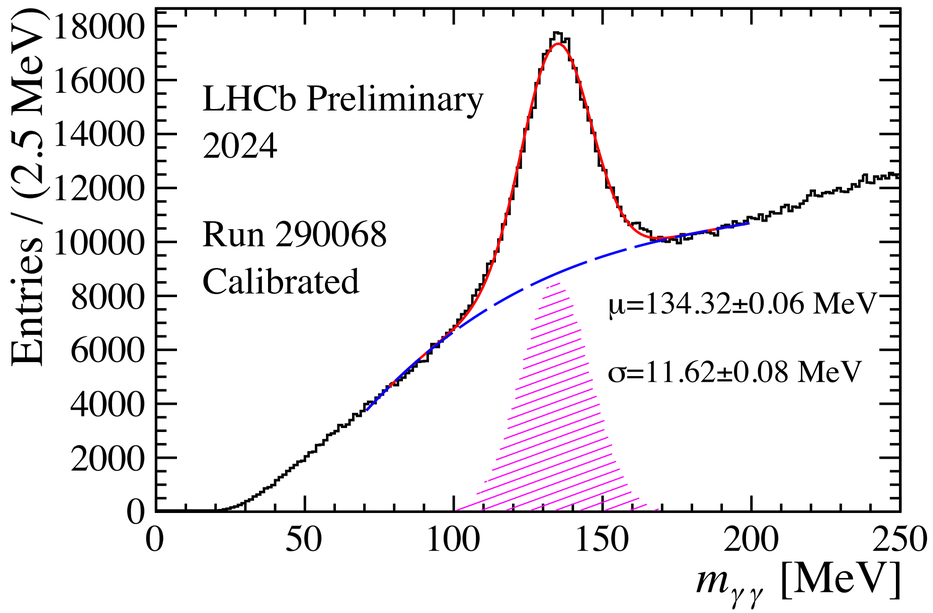
Calibration

LHCb-FIGURE-2024-009

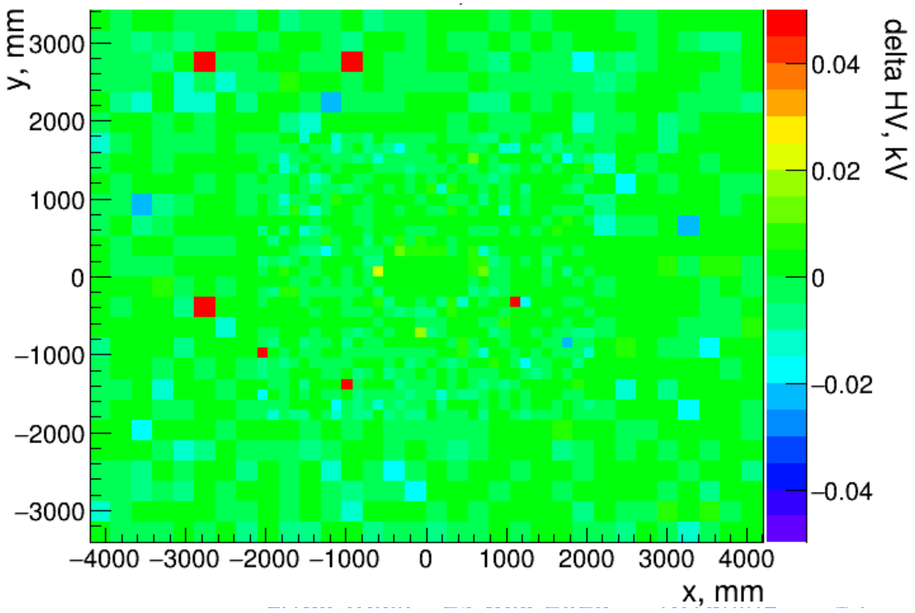
Calibration of calorimeter system crucial to compensate for ageing

- neutral pions based ECAL calibration every month
  - automatic LED calibration for gain adjustment at the end of every fill being implemented
- HCAL calibrated during Technical Stops with a source

ECAL calibration with π^0



HCAL calibration with ^{137}Cs

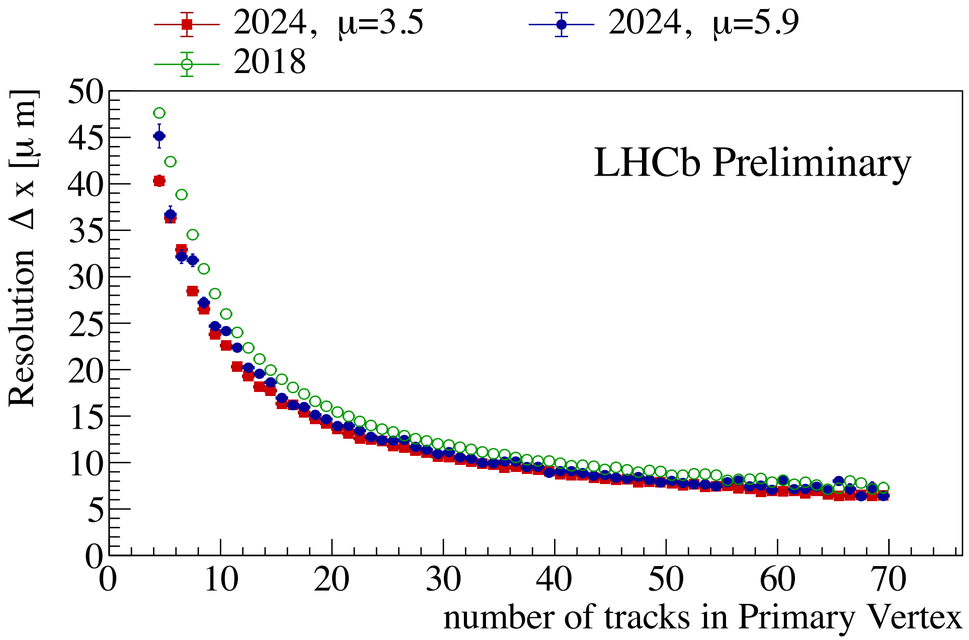


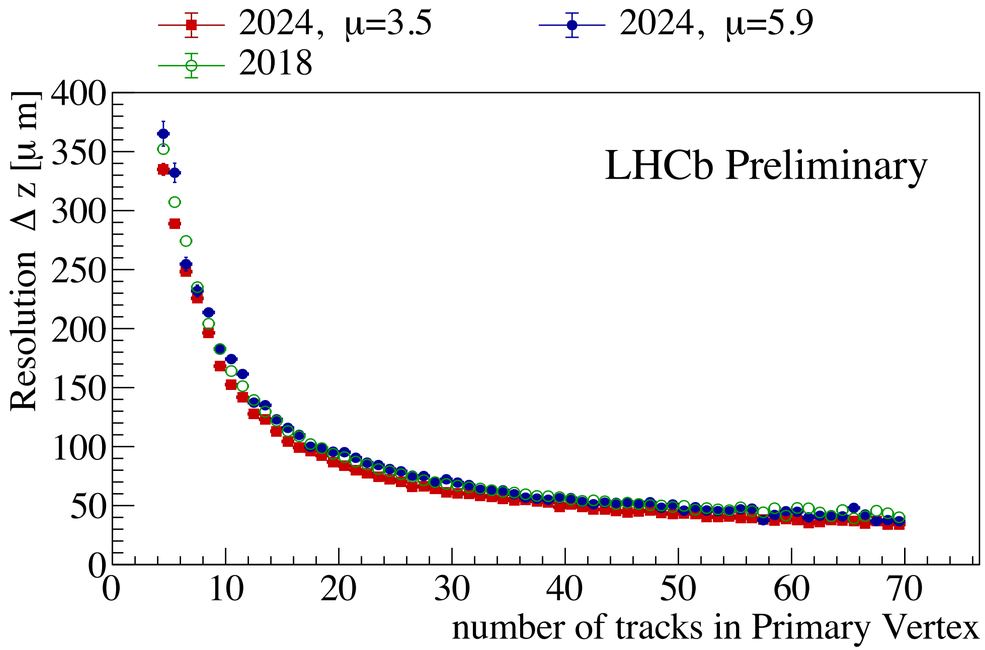
PV resolution

LHCb-FIGURE-2024-010

Comparable performance to Run 2 at higher instantaneous luminosity

- early measurement, further improvements expected





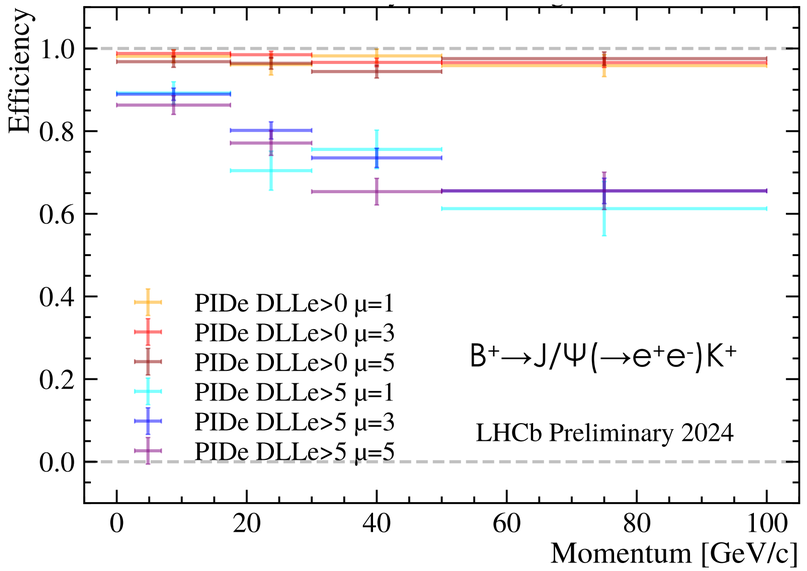
PID: muon & electron

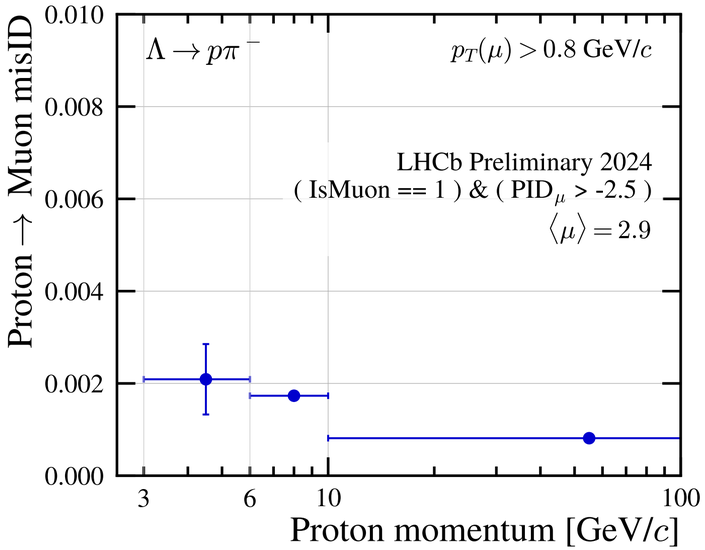
LHCb-FIGURE-2024-010

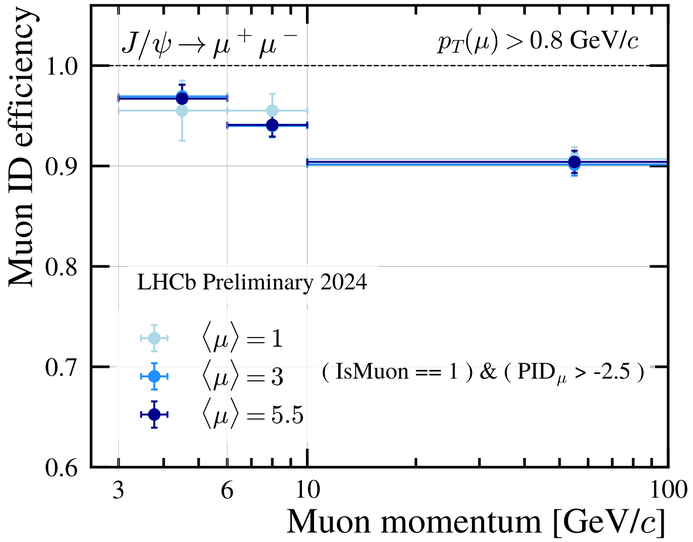
Comparable performance of electron and muon identification wrt Run 2

- no strong dependence observed with instantaneous luminosity

both electrons with brem photon associated





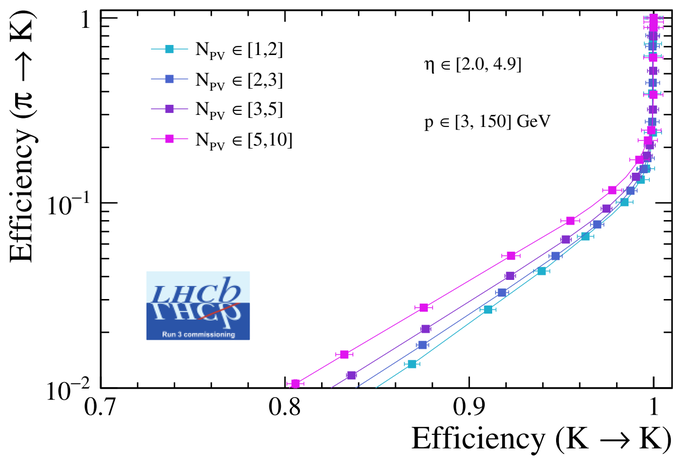


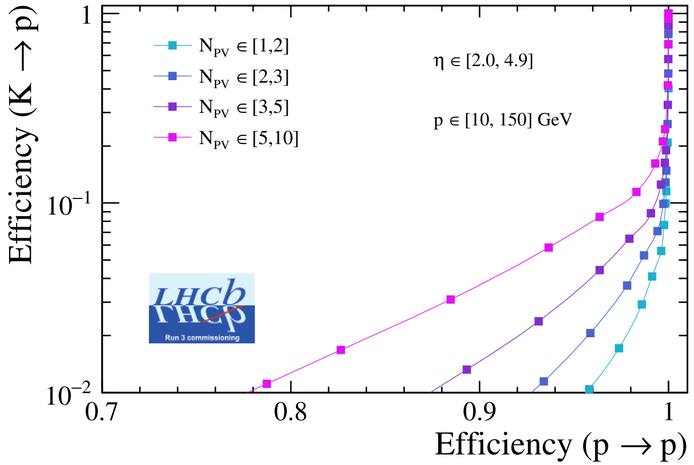
see M. Atzeni talk for more details!

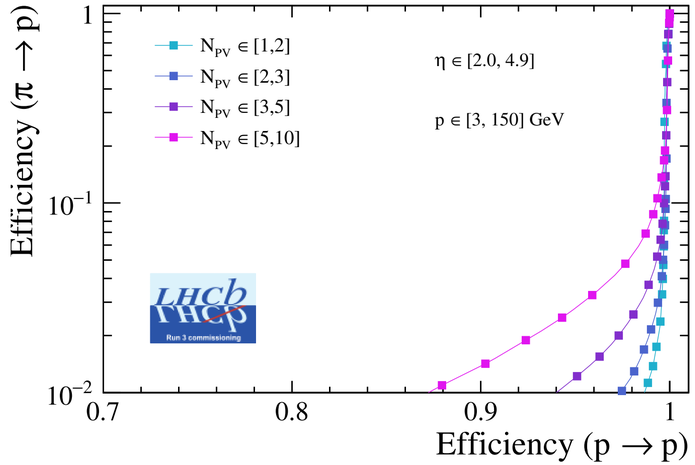
PID: hadrons

LHCb-FIGURE-2023-019

misidentification vs identification efficiency







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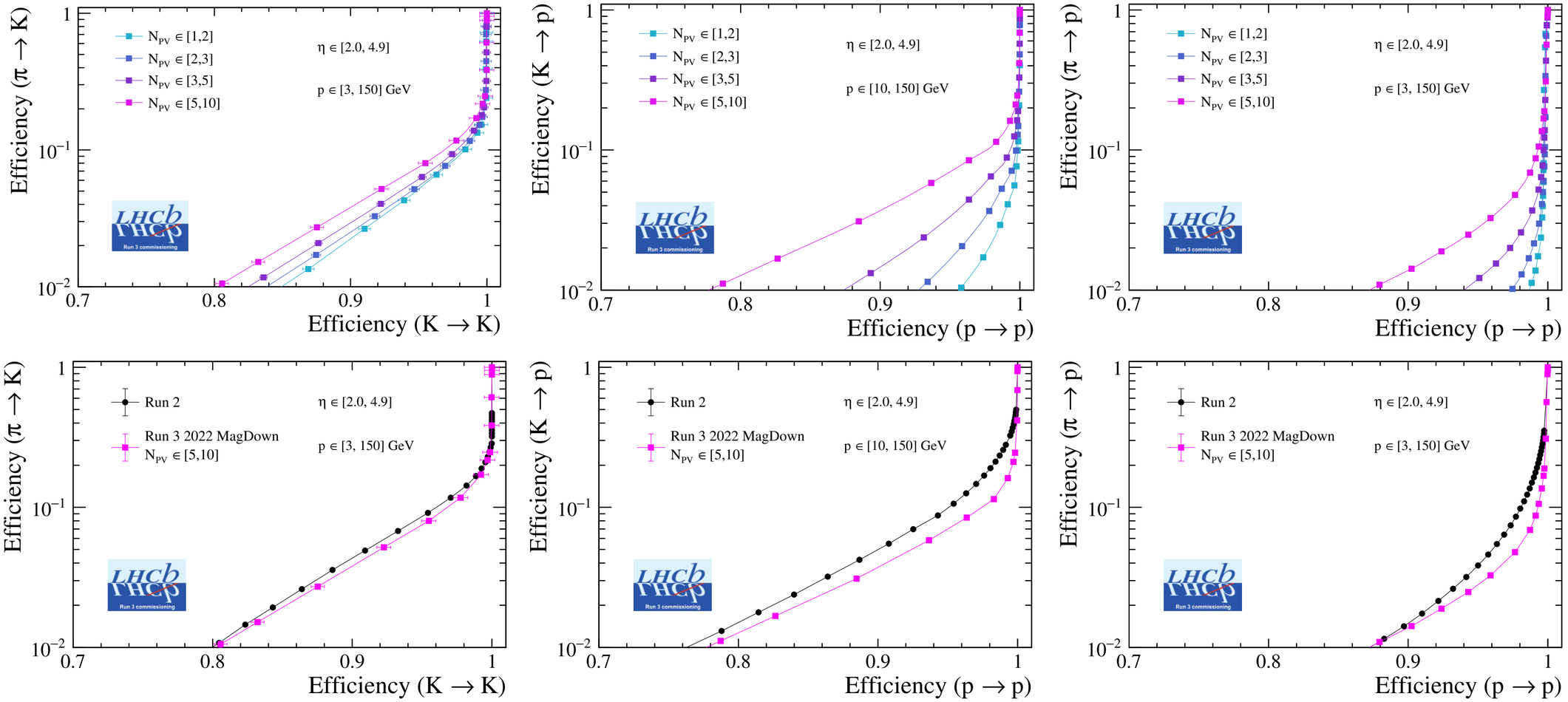


PID as good as Run2 but operating at 5x instantaneous luminosity

Trigger efficiency

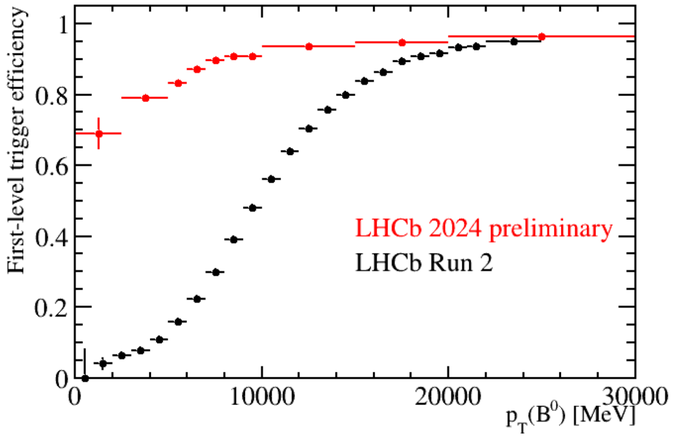
LHCb-FIGURE-2024-006
LHCb-FIGURE-2024-007
LHCb-FIGURE-2024-014

Significant improvements wrt Run 2 in terms of efficiencies at HLT1

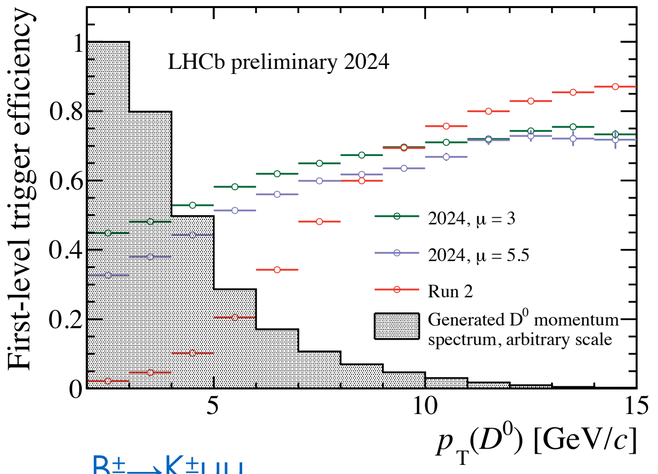
- charm benefits at low Pt where bulk of the signal lies
- significant gain for electron channels
- comparable performance wrt Run 2 for muon channels

see K. Richardson talk for more details!

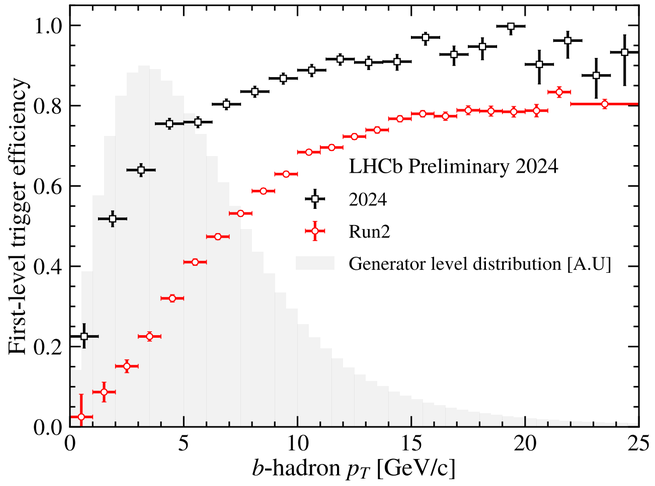
$B^0 \to D^-(\to K^+\pi^-\pi^-)\pi^+$



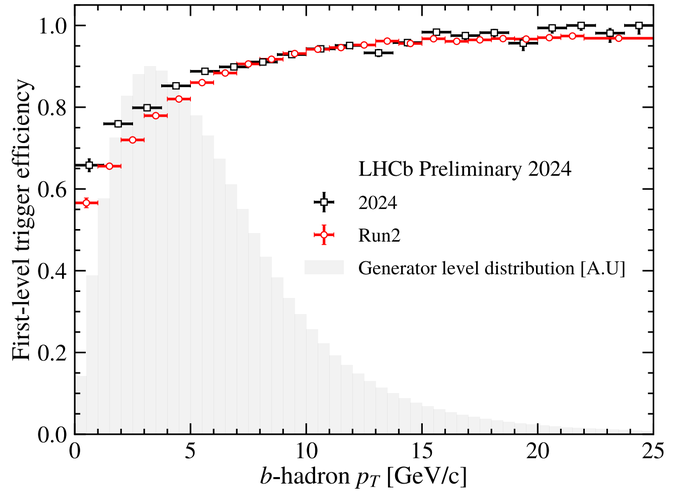
$D^0 \to K^-\pi^+$



$B^\pm \to K^\pm ee$



$B^\pm \to K^\pm \mu\mu$



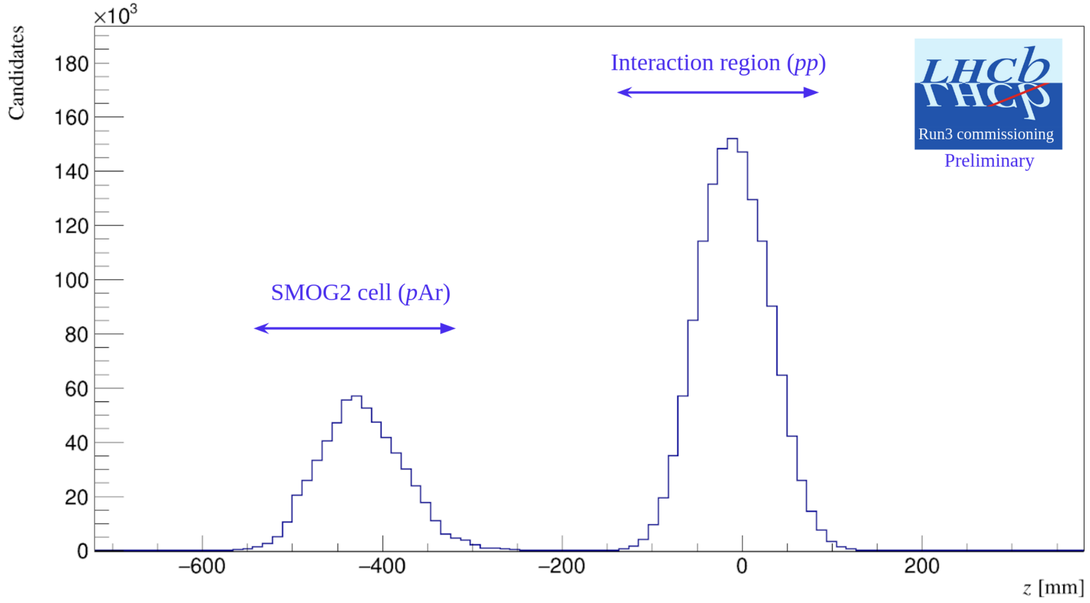
Gas injection

LHCb-FIGURE-2023-001
LHCb-FIGURE-2024-005

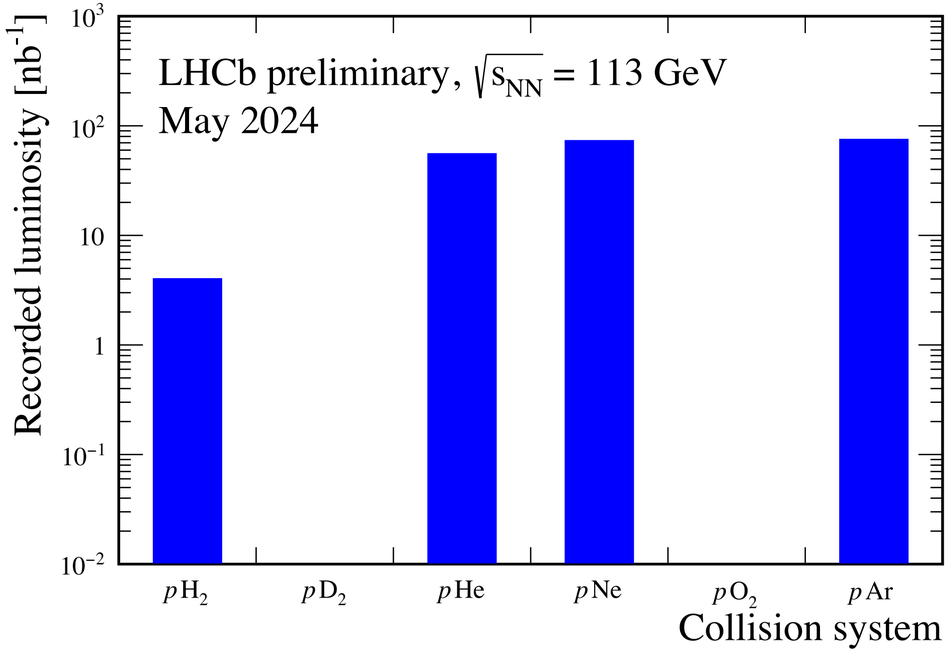
- unique possibility in LHCb to inject gas with SMOG2 and run the experiment in fixed target mode
- already operated with noble gases (He,Ne,Ar) and H_2
- during the EYETS 23/24 upgraded the gas feed system to inject also D_2,O_2

goal is to inject gas in parallel to pp/PbPb data taking throughout 2024

primary vertices distribution



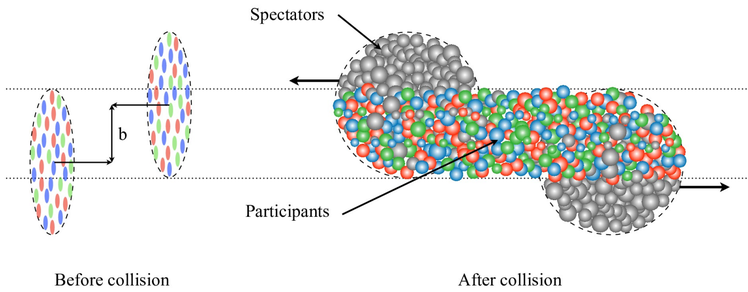
gases injected in 2024 during commissioning

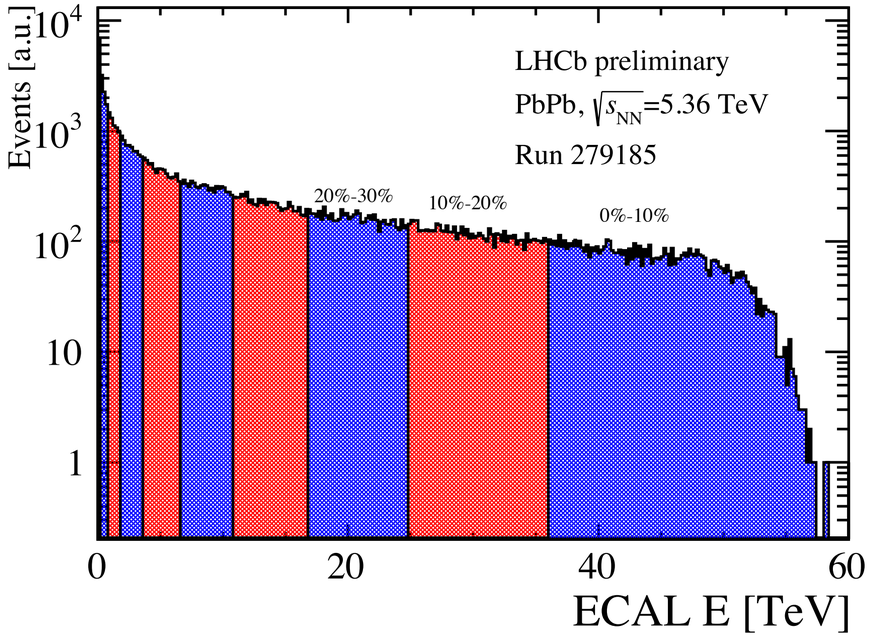


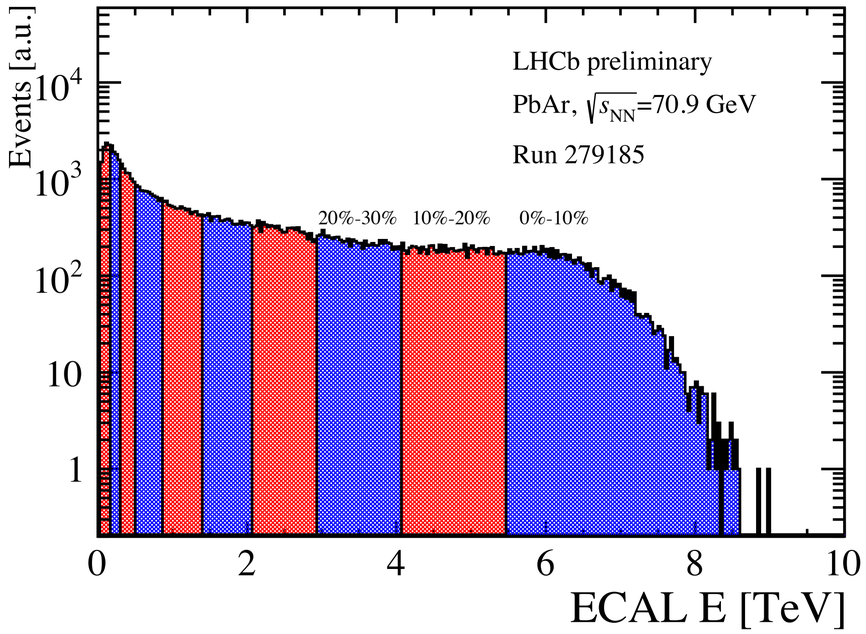
Centrality

- PbPb running conditions in 2022 challenging for data taking:
  - mu~0.002 with beams head on, corresponding to peak luminosity of 1.5e27 cm^{-2} s^{-1}
  - VELO open and UT not operated in global data taking
- additionally Ar injection á-la-SMOG for most of the fills

LHCb-FIGURE-2023-030



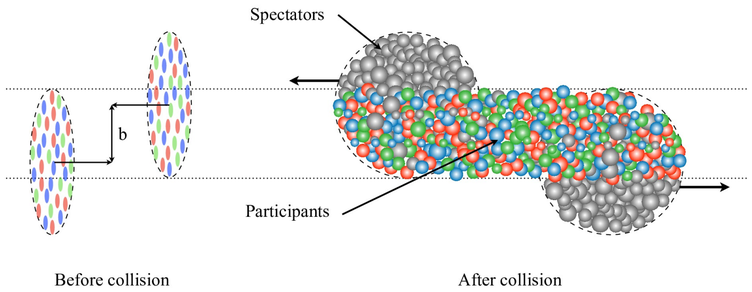


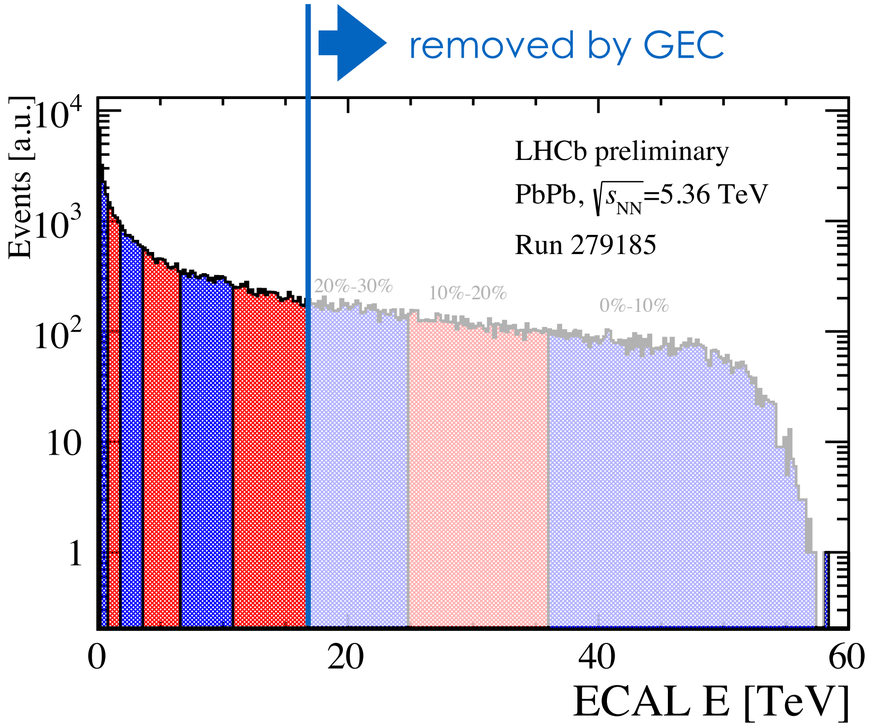


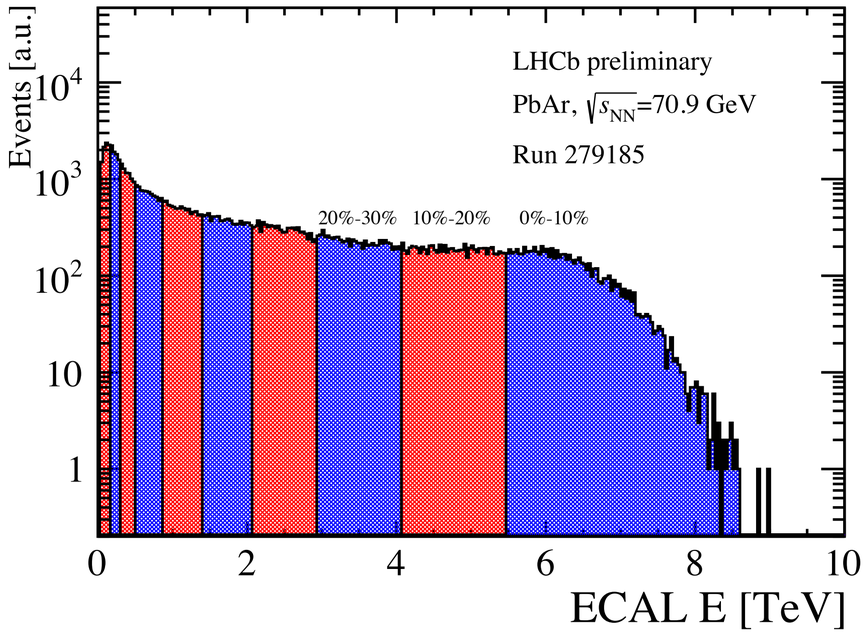
Centrality

- PbPb running conditions in 2022 challenging for data taking:
  - mu~0.002 with beams head on, corresponding to peak luminosity of 1.5e27 cm^{-2} s^{-1}
  - VELO open and UT not operated in global data taking
- additionally Ar injection á-la-SMOG for most of the fills
- trigger mitigation strategy: global event cut (GEC) at 30k SciFi clusters

LHCb-FIGURE-2023-030



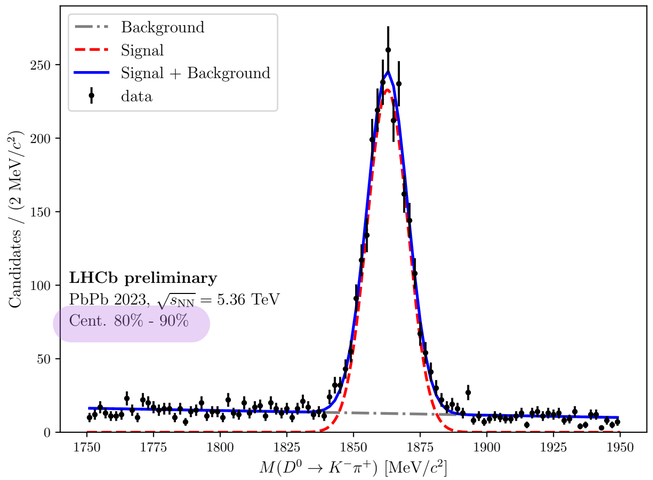


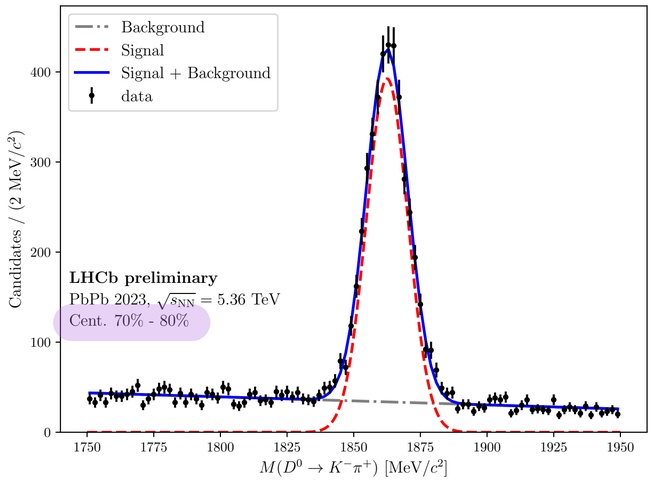


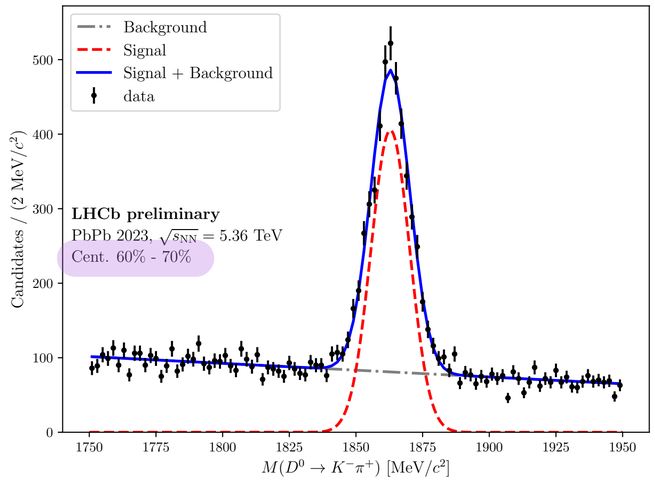
Centrality

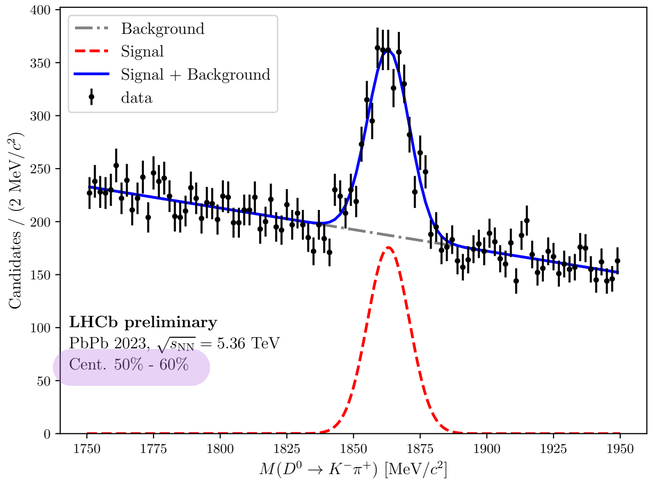
LHCb-FIGURE-2023-030

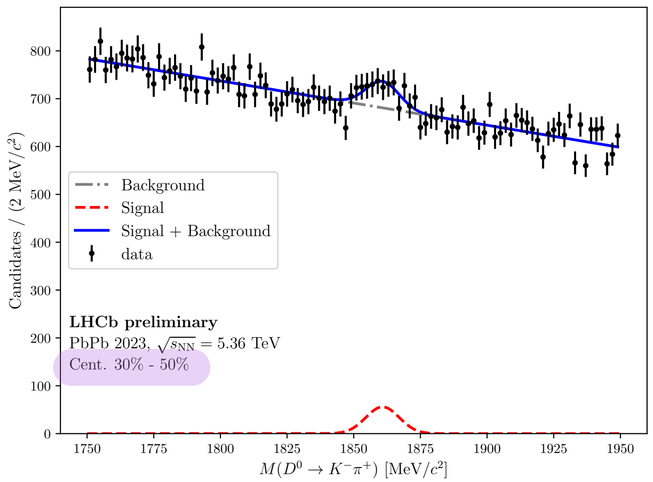
- in Run 2 centrality limited to 70% due to VELO saturation







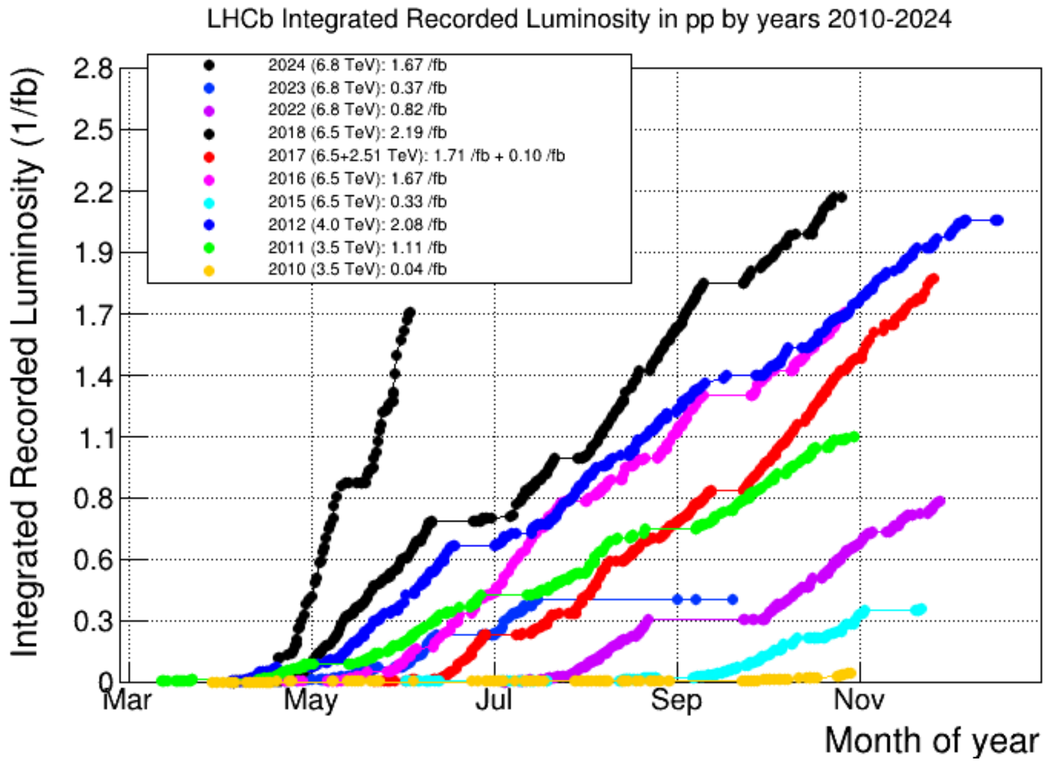




first PbPb 2023 data reconstructed down to 30% centrality

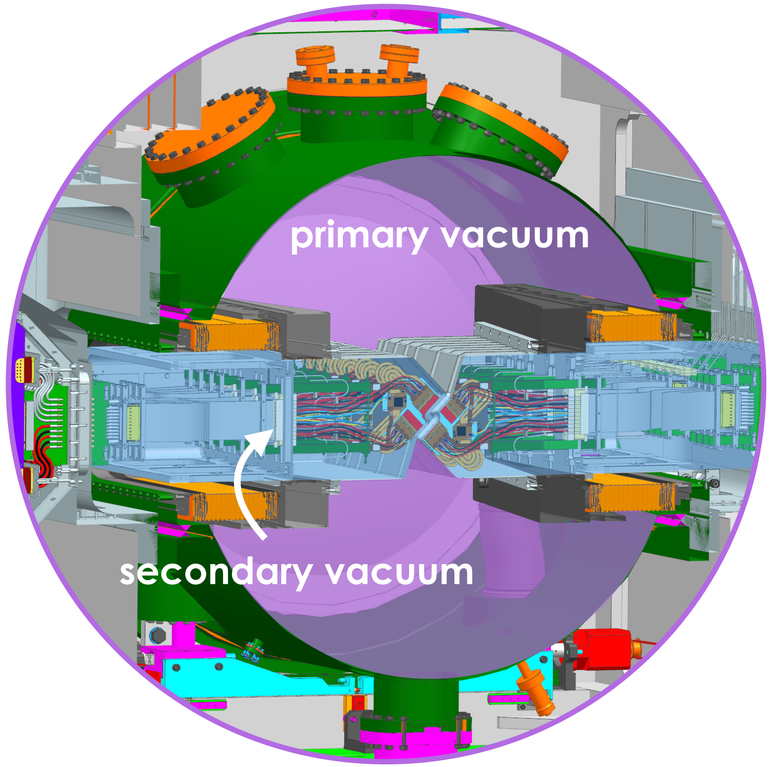
Looking ahead…

- 2024 is the first opportunity to run at nominal conditions: VELO fully closed and design instantaneous luminosity
- intensity ramp-up phase optimally exploited to be ready in time for luminosity production
- now operating stably with data taking efficiency >90% aiming at running continuously at nominal luminosity after the June Technical Stop
- UT quickly catching up, expected to be stably included in global data taking soon



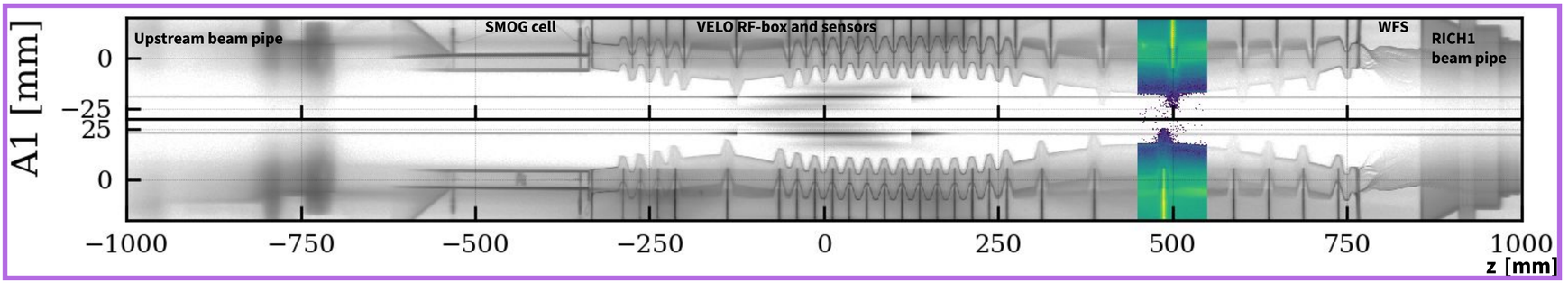
Additional material

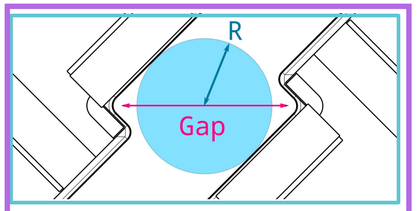
Vacuum incident

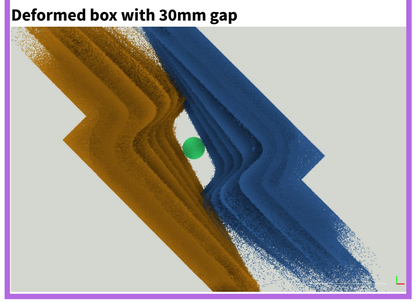


- LHC vacuum incident in the VELO volume led to over pressurisation of the detector volume and deformation of the RF foil
- leading factors to velo position in 2023:
  - deformation of the foil allowing for max 30 mm gap
  - damaged coupling piece in the motion system
- decided not to move the VELO halves at every fill, but keep them fixed to the smallest aperture that allows beam injection
- RF foil replacement in the EYETS23/24

VELO 2023 gap = 49 mm





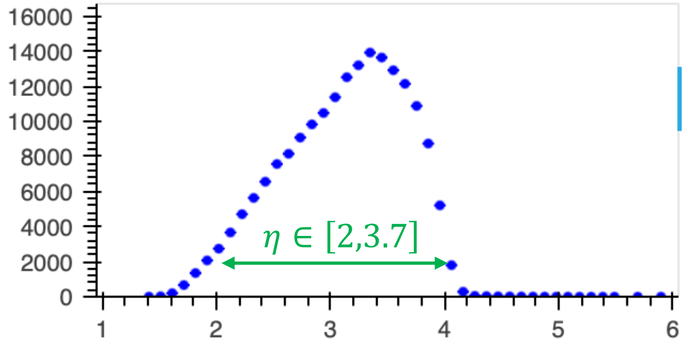


Vacuum incident

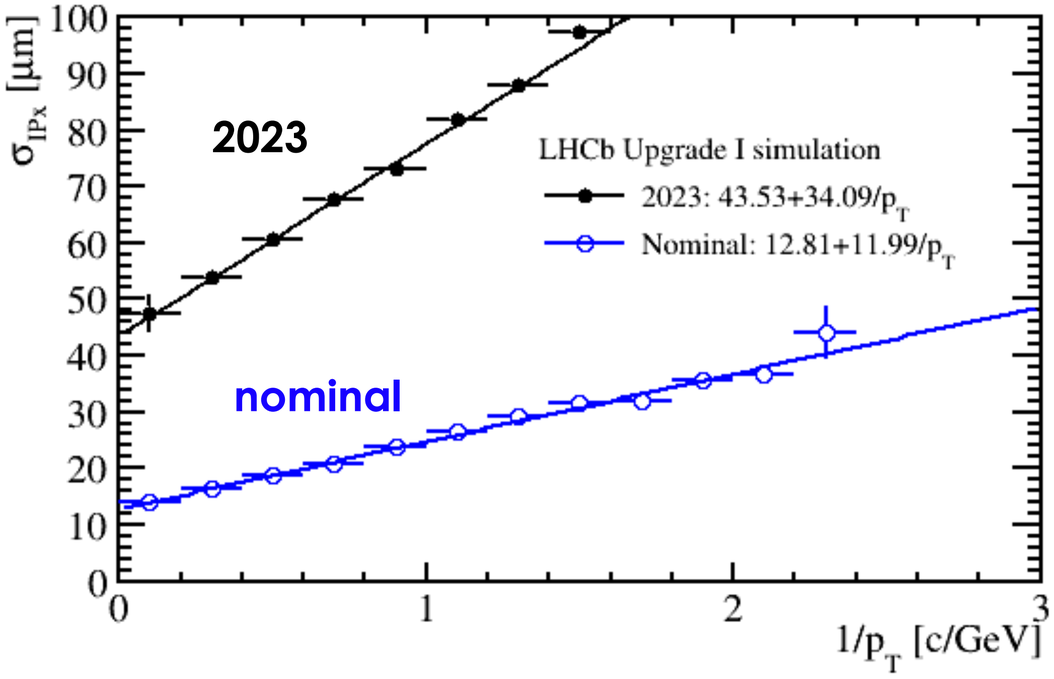
Impact of VELO gap = 49 mm

- acceptance reduced: from η [2,5] to η [2, 3.7]
- impact parameter (IP) resolution degraded

long tracks (up to the last tracking station)



IP resolution from simulation



IP resolution in Run 2