LHCb Status Report

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Overview

- Recent measurements on Run 1 and Run 2 datasets
- 2023 PbPb physics highlights
- Status of 2024 data-taking and current performance

Results using Run 1 and Run 2 datasets

Since the last LHCC

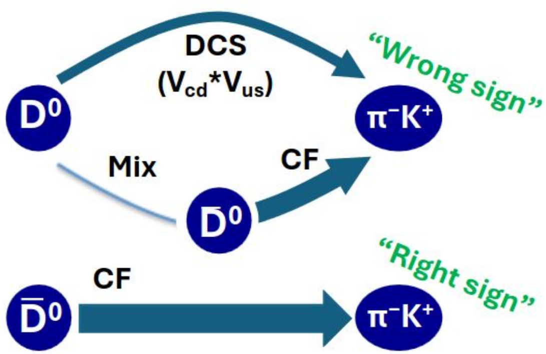
Paper	Title
Submitted since the February 2024 LHCC	
PAPER-2023-018	Search for Prompt Production of Pentaquarks in $\Sigma_c D$ and $\Lambda_c D$ Final states
PAPER-2023-036	Amplitude analysis of the $\Lambda_b \to pK^- \gamma$ decay
PAPER-2023-042	Observation of the $\Lambda_b^0 \to D^+ D^- \Lambda$ decay
PAPER-2023-044	First observation of $\Lambda_b \to \Sigma_c^{(*)++} D^{(*)0} K^-$
PAPER-2023-045	Search for $B_s \to \mu\mu\gamma$
PAPER-2024-001	$B \to D^{*-} D_s^+ \pi^+$ AmAn
PAPER-2024-003	Search for time-dependent CP violation in $D \to \pi\pi\pi^0$
PAPER-2024-006	Search for $B_s \to \phi\mu\tau$
PAPER-2024-009	Λ, $\bar{\Lambda}$ polarisation in pNe
PAPER-2024-011	Comprehensive analysis of local and nonlocal amplitudes in the $B^* \to K^* \mu^+ \mu^-$ decay
DP-2023-004	Tracking of charged particles with nanosecond lifetimes at LHCb
Preliminary results since the February 2024 LHCC	
CONF-2024-001	Observation of the decay $J/\psi \to \mu^+ \mu^- \mu^+ \mu^-$
PAPER-2023-043	First measurement of $J/\psi\phi$ production in pp collisions with no additional activity
PAPER-2024-002	Amplitude analysis of $B_s \to KK\gamma$
PAPER-2024-004	Measurement of the cross-section of $h_c \to p\bar{p}$
PAPER-2024-005	Search for $\Lambda_c \to p\mu\mu$
PAPER-2024-007	Combined measurement of $R(D^+)$ and $R(D^{+*})$ – muonic
PAPER-2024-008	Mixing and CPV with $D^0 \to K\pi$ decays from Run 2 data
PAPER-2024-010	Measurement of the Ξ_b lifetime
PAPER-2024-013	Study of Ω_b and Ξ_b to $\Lambda_c hh$

LHCb has submitted **733 papers to arXiv,** of which **704 are published**.

Mixing and CPV in $D^0 \to K^+\pi^-$ decays

LHCb-PAPER-2024-008

- Full Run 2 dataset. Production flavour tagged via $D^{*+} \to D^0 \pi^+$ decays
- Nuisance asymmetries determined via $D^0 \to K^+K^-$ control mode



Fit time-dependent ratio R(t):

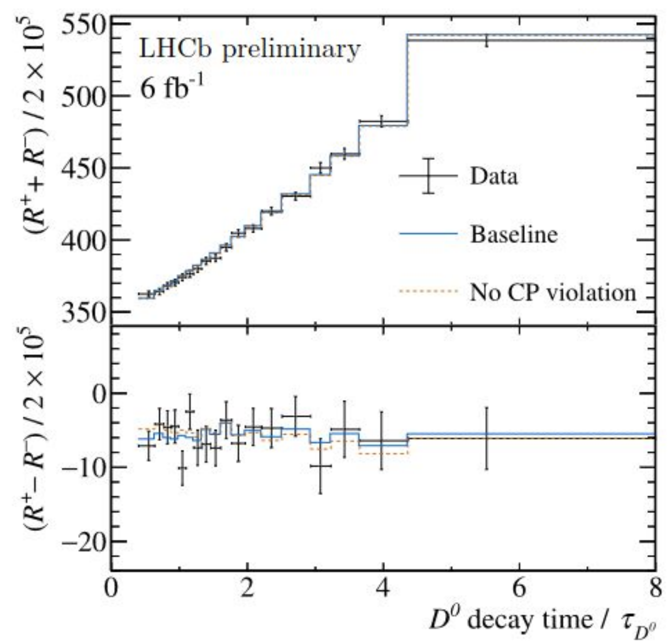
$$R^+_{K\pi}(t) \equiv \frac{\Gamma(D^0(t) \to K^+\pi^-)}{\Gamma(\bar{D}^0(t) \to K^+\pi^-)}$$

$$R^-_{K\pi}(t) \equiv \frac{\Gamma(\bar{D}^0(t) \to K^-\pi^+)}{\Gamma(D^0(t) \to K^-\pi^+)}$$

CPV in decay — CPV in mixing

$$R^{\pm}_{K\pi}(t) \approx R_{K\pi}(1 \pm A_{K\pi}) + \sqrt{R_{K\pi}(1 \pm A_{K\pi})}(c_{K\pi} \pm \Delta c_{K\pi})\frac{t}{\tau_{D^0}} + (c'_{K\pi} \pm \Delta c'_{K\pi})\left(\frac{t}{\tau_{D^0}}\right)^2$$

DCS — Interference — Mixing



Mixing and CPV in $D^0 \to K^+\pi^-$ decays

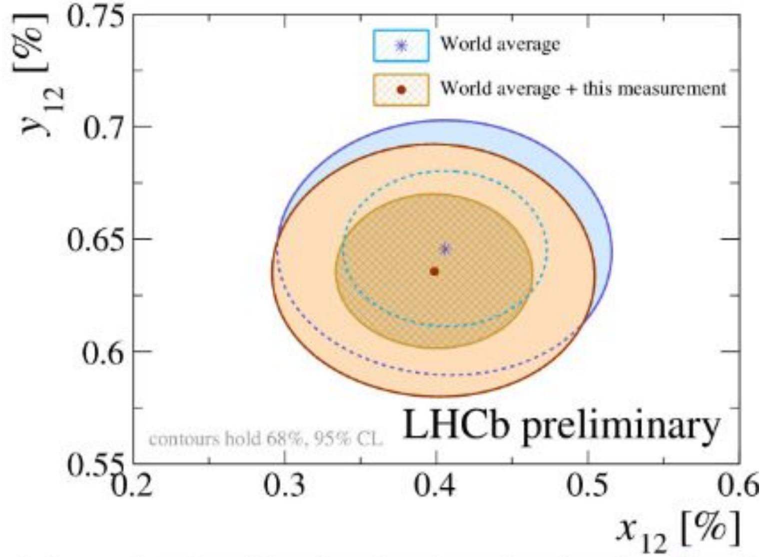
LHCb-PAPER-2024-008

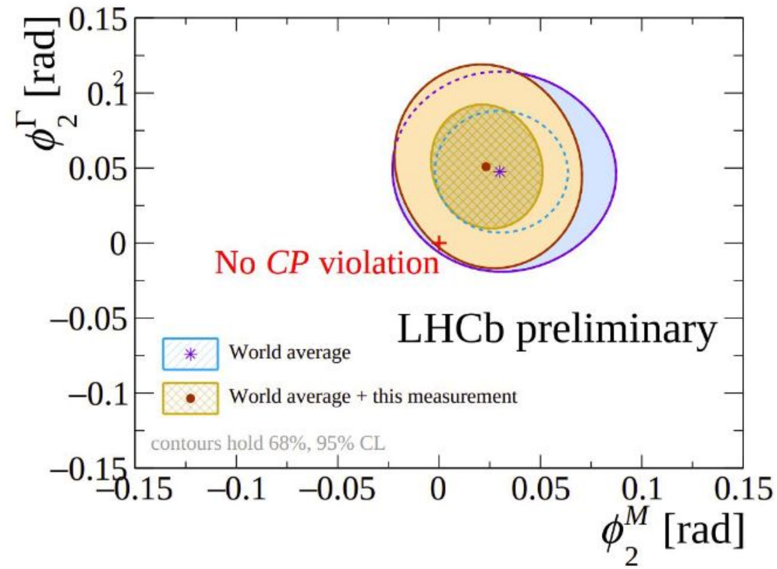
Signal yields: 1.6M WS 412M RS

Parameters	
$R_{K\pi}$	$(343.1 \pm 2.0) \times 10^{-5}$
$c_{K\pi}$	$(51.4 \pm 3.5) \times 10^{-4}$
$c'_{K\pi}$	$(13.1 \pm 3.7) \times 10^{-6}$
$A_{K\pi}$	$(-7.1 \pm 6.0) \times 10^{-3}$
$\Delta c_{K\pi}$	$(3.0 \pm 3.6) \times 10^{-4}$
$\Delta c'_{K\pi}$	$(-1.9 \pm 3.8) \times 10^{-6}$

First evidence of quadratic behaviour ($c'_{K\pi}$)

No evidence of CPV ($A_{K\pi}$, $\Delta c_{K\pi}$, $\Delta c'_{K\pi}$)





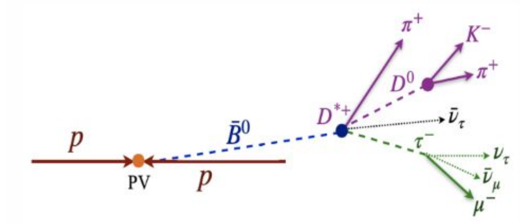
- 60% improvement in precision, still statistically limited

R(D⁺) and R(D*⁺) using muonic τ decays

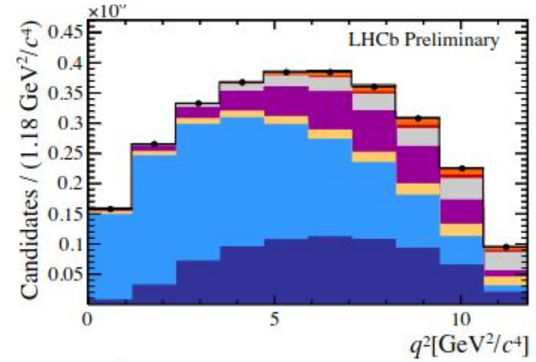
LHCb-PAPER-2024-007

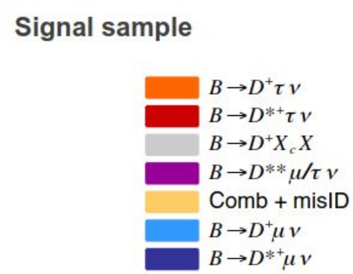
- EW couplings to leptons "universal" (the only difference is the mass) in the SM
  → can be tested in b → clν (Predicted with a ~1% precision in the SM)

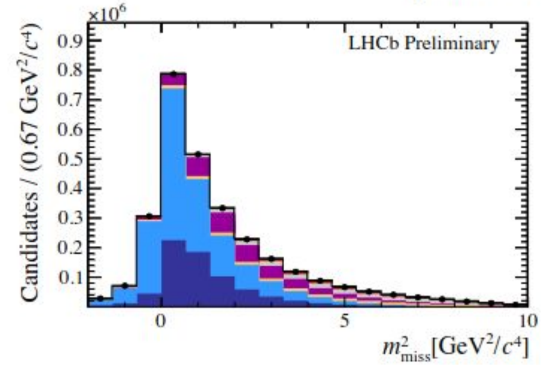
$$R(D^{(*)}) = \frac{\mathscr{B}(B \to D^{(*)}\tau^+\nu_\tau)}{\mathscr{B}(B \to D^{(*)}\mu^+\nu_\mu)}$$



- Experimental challenge: neutrinos → no narrow peak to fit
- Strategy: make 3D template fits to q^2, missing mass and lepton energy distributions





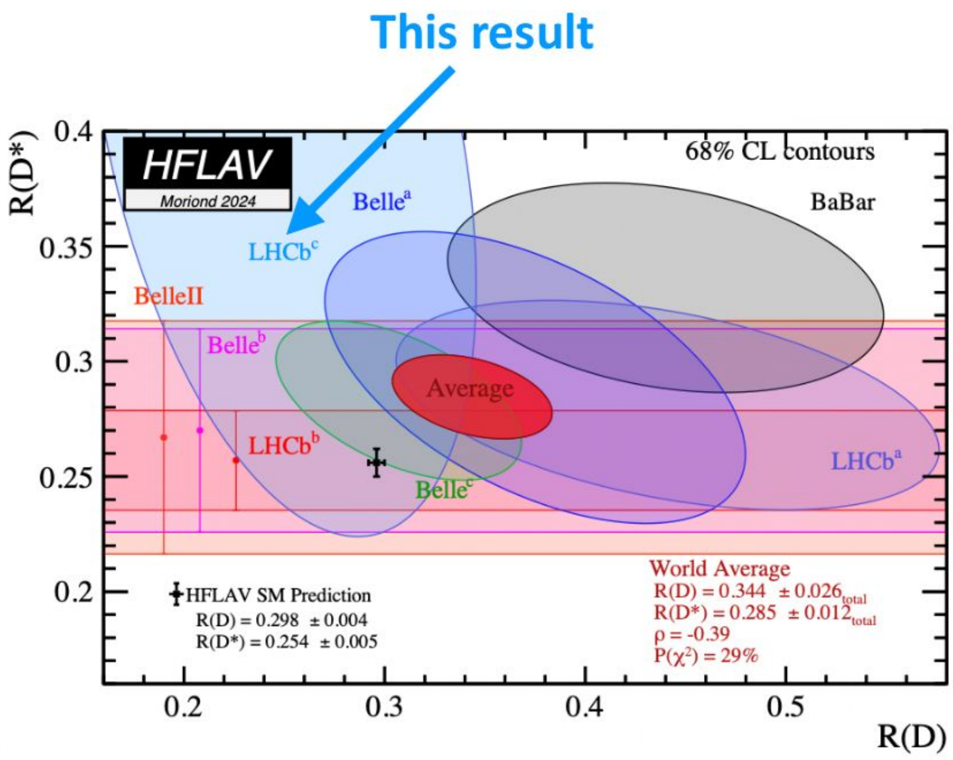


R(D^+) and R(D^{*+}) using muonic τ decays

LHCb-PAPER-2024-007

$$R(D^+) = 0.249 \pm 0.043(stat) \pm 0.047(syst)$$
$$R(D^{*+}) = 0.402 \pm 0.081(stat) \pm 0.085(syst)$$
$$\rho = -0.39$$

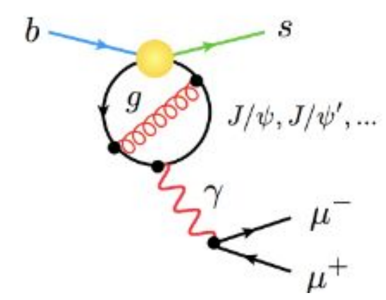
→ Latest LHCb result compatible with SM, but world average still at more than 3σ from the SM



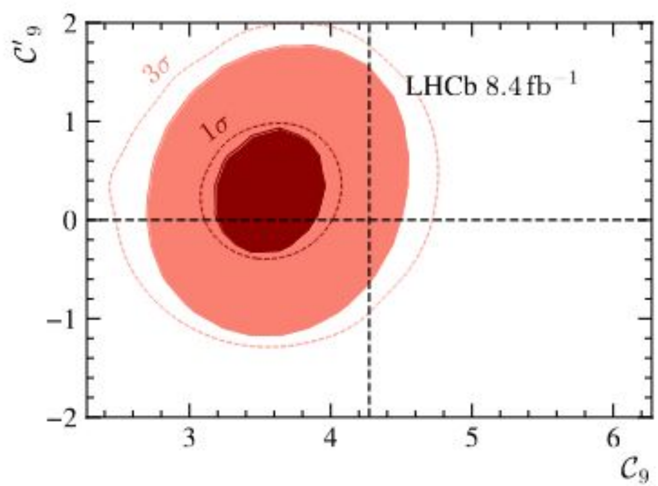
Unbinned analysis of $B \to K^* \mu^+ \mu^-$ decays

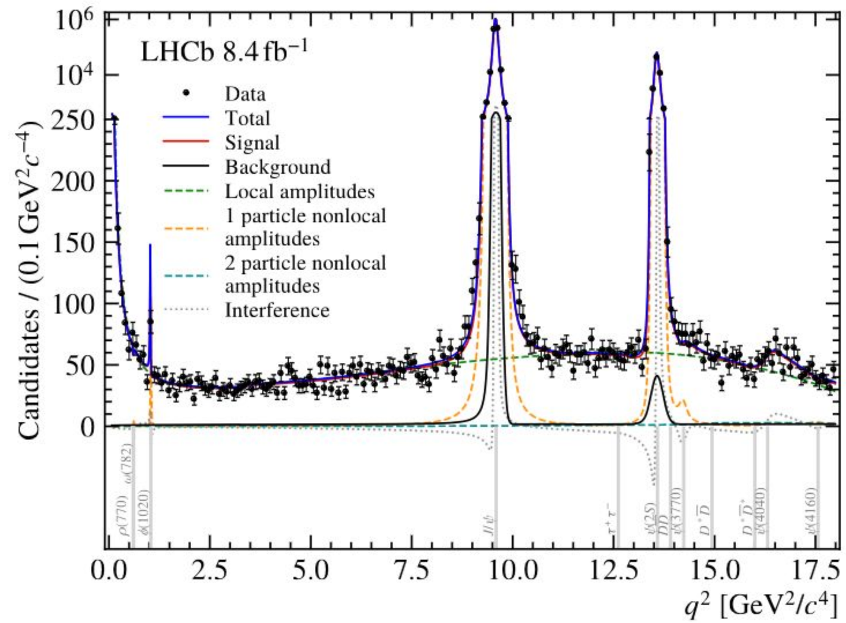
LHCb-PAPER-2024-011

- ❖ Discrepancies in angular observables of $B \to K^* \mu\mu$: NP in C_9 or unaccounted interference with $c\bar{c}$ states?
- ❖ → unbinned angular analysis over the full q^2 range



Wilson Coefficient results	
$\mathcal{C}_9$	$3.56 \pm 0.28 \pm 0.18$
$\mathcal{C}_{10}$	$-4.02 \pm 0.18 \pm 0.16$
$\mathcal{C}_9'$	$0.28 \pm 0.41 \pm 0.12$
$\mathcal{C}_{10}'$	$-0.09 \pm 0.21 \pm 0.06$
$\mathcal{C}_{9\tau}$	$(-1.0 \pm 2.6 \pm 1.0) \times 10^2$





Measurement of the Ξb lifetime

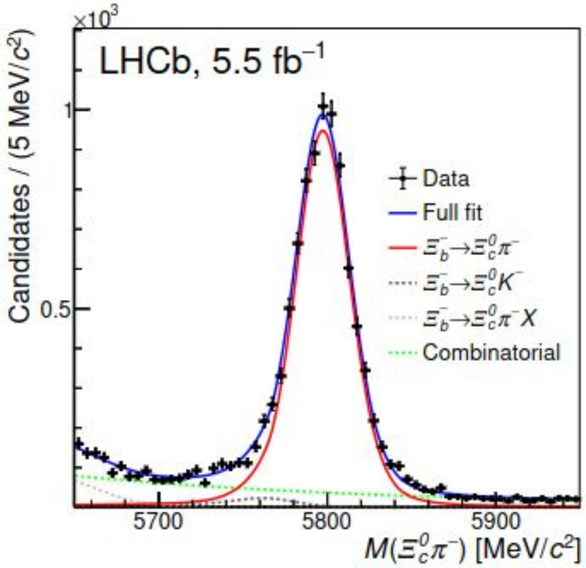
LHCb-PAPER-2024-010

- Precision measurement of beauty hadrons lifetimes → test of heavy quark expansion framework

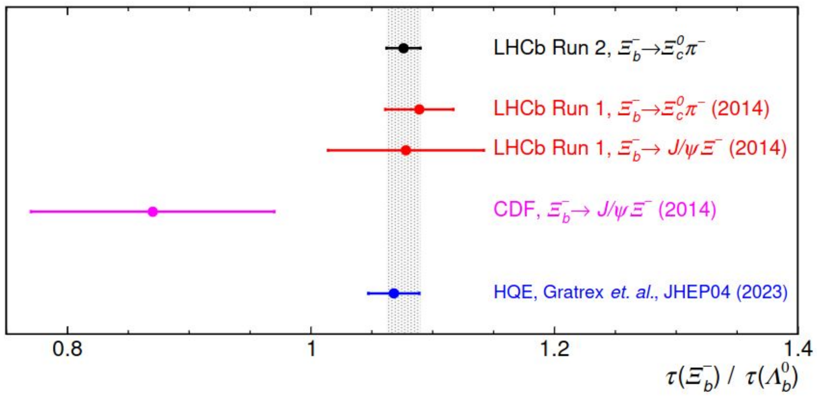
$$R(t) \equiv \frac{N[\Xi_b^- \to \Xi_c^0 \pi^-](t)}{N[\Lambda_b^0 \to \Lambda_c^+ \pi^-](t)} \cdot \frac{\varepsilon[\Lambda_b^0 \to \Lambda_c^+ \pi^-](t)}{\varepsilon[\Xi_b^- \to \Xi_c^0 \pi^-](t)} = R_0 \exp(\lambda t),$$

$$\lambda \equiv \frac{1}{\tau_{\Lambda_b^0}} - \frac{1}{\tau_{\Xi_b^-}}$$

$$\tau(\Xi_b^-)^{\text{Run } 1,2} = 1.578 \pm 0.018 \pm 0.010 \pm 0.011 \text{ ps}$$



- Precision of current world average improved by a factor of 2!
- In agreement with latest theoretical predictions



Λ^0 transverse polarization studies in pNe collisions

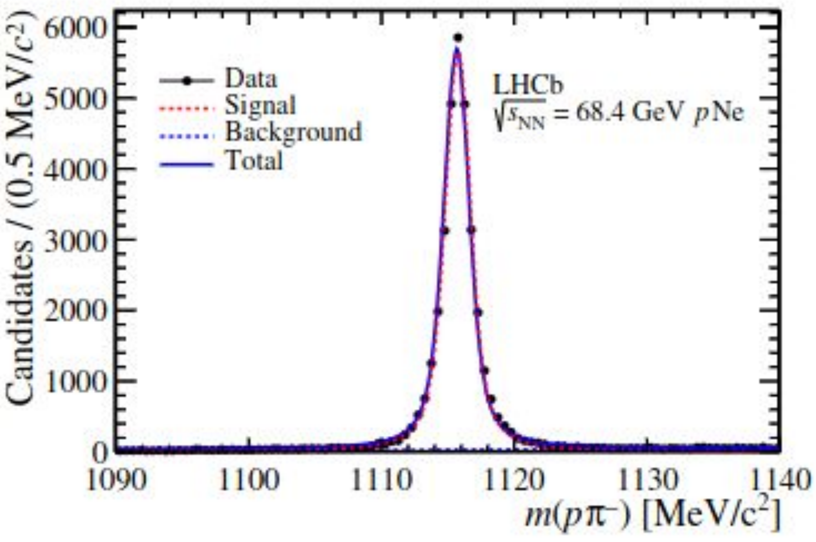
LHCb-PAPER-2024-009

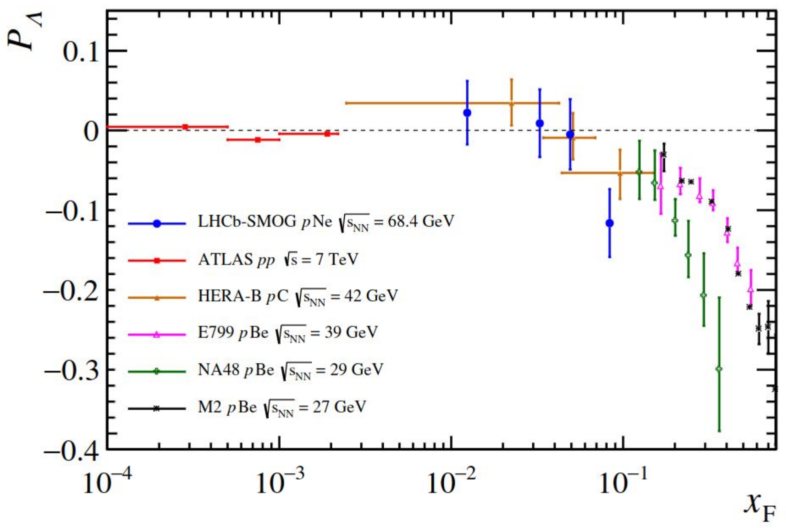
- LHCb can inject gas into the beam pipe to act as a fixed target collision experiment
- Transverse polarization: observed in 1976 in pBe collisions using 300 GeV unpolarised beam → not expected and cause not yet understood PRL 36 (1976) 1113
- Measure it in pNe collisions (2017 data) fitting the angular distribution of the proton

$$\frac{dN}{d\cos\theta} = \frac{dN_0}{d\cos\theta}(1 + \alpha P_\Lambda \cos\theta)$$

$$P_\Lambda = 0.029 \pm 0.019\,(\text{stat}) \pm 0.012\,(\text{syst})$$

$$P_{\bar{\Lambda}} = 0.003 \pm 0.023\,(\text{stat}) \pm 0.014\,(\text{syst})$$





Run 3 data-taking

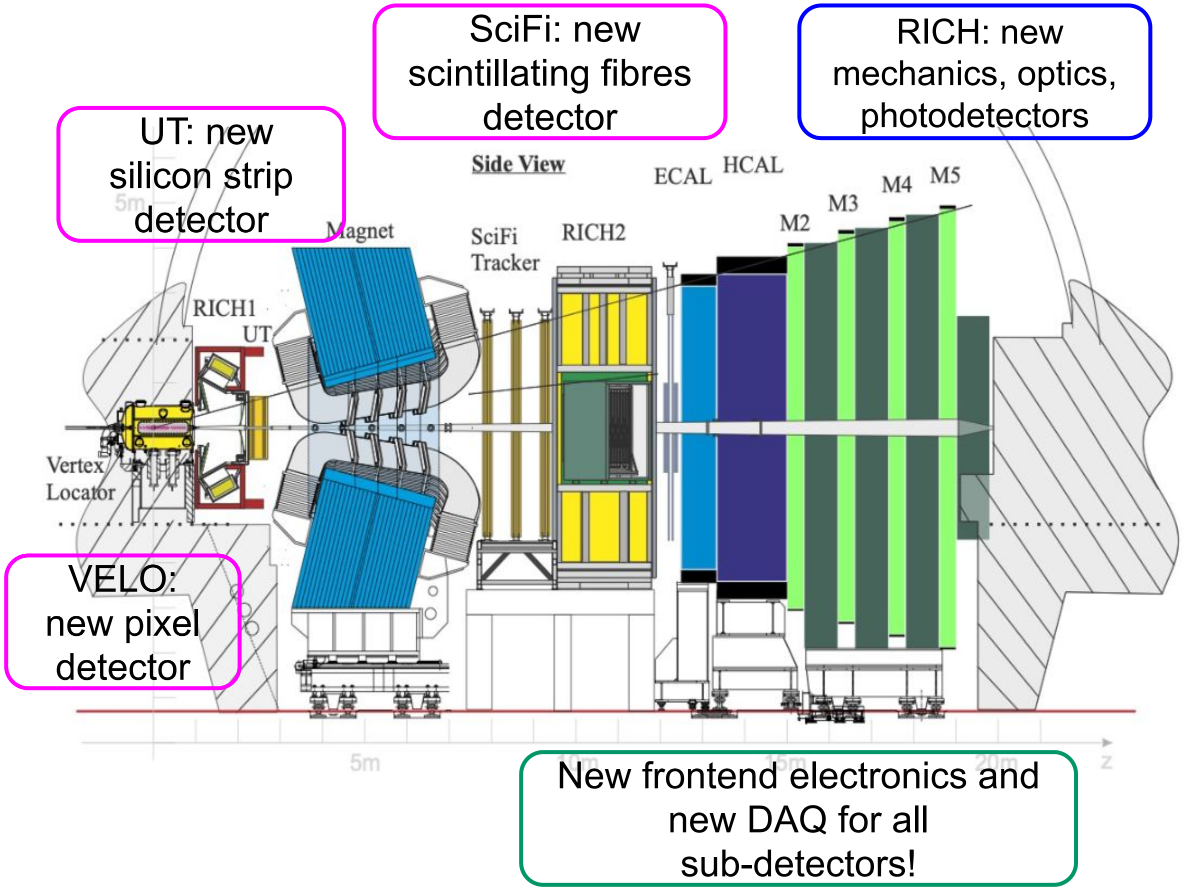
LHCb in Run 3

JINST 19P05065

- The majority of our measurements is statistically limited

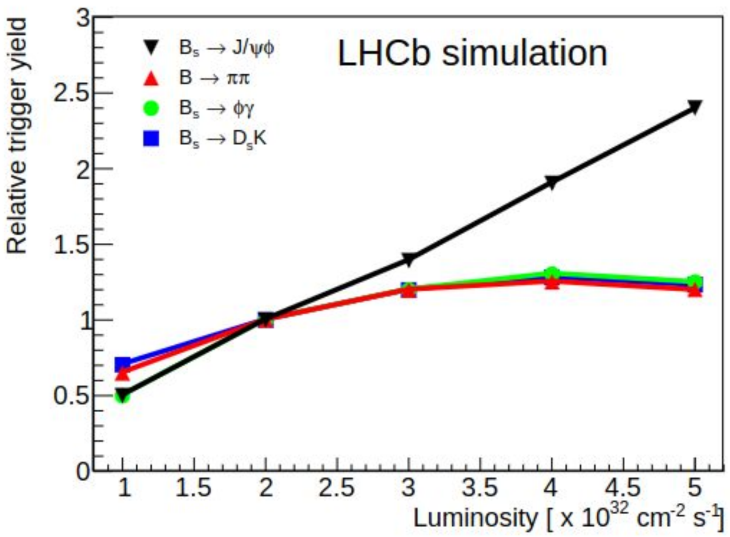
  → **LHCb Upgrade I**: 5x instantaneous luminosity

- Improve physics performance, despite the more challenging environment



Trigger system

- Trigger strategy in Run 1 + Run 2:
  - Hardware trigger (L0), followed by a software trigger
- Higher instantaneous luminosity
  - Tight p_T and E_T cuts saturate hadronic channels → L0 trigger removed
  - Software trigger process events at the full LHC collision rate
  - → room for improving trigger efficiency w.r.t. Run 2

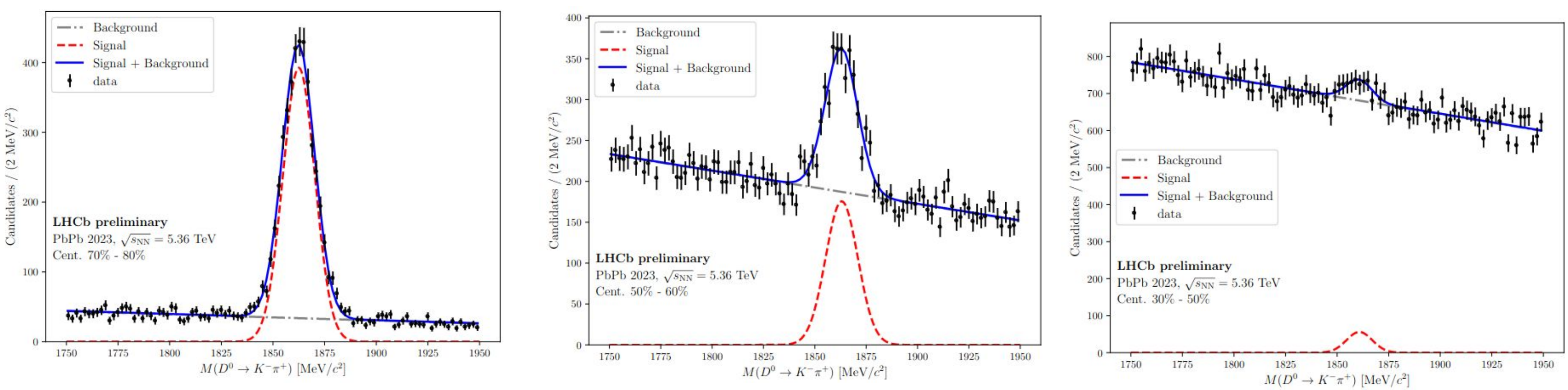


JINST 19P05065

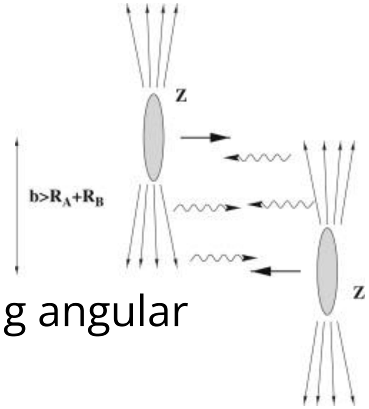
2023 PbPb data

- Goal for Run 3: take advantage of new tracking system (more granular detector) and reach 30% of centrality (VELO was saturating at ~70% in Run 2)
- Despite the challenging 2023 conditions signal events up to mid-central collisions are found
  - VELO in an open position and UT, crucial to reduce ghost rate, not included in the data-taking at the time

LHCb-FIGURE-2024-004

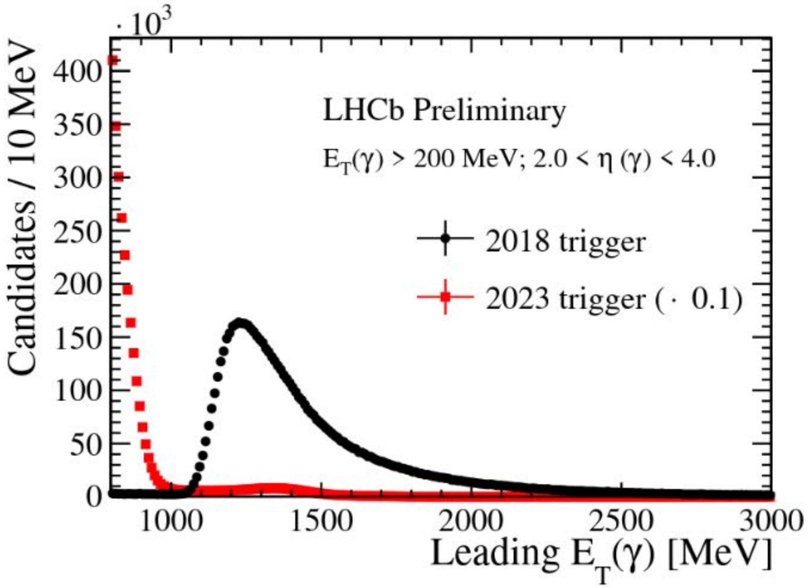


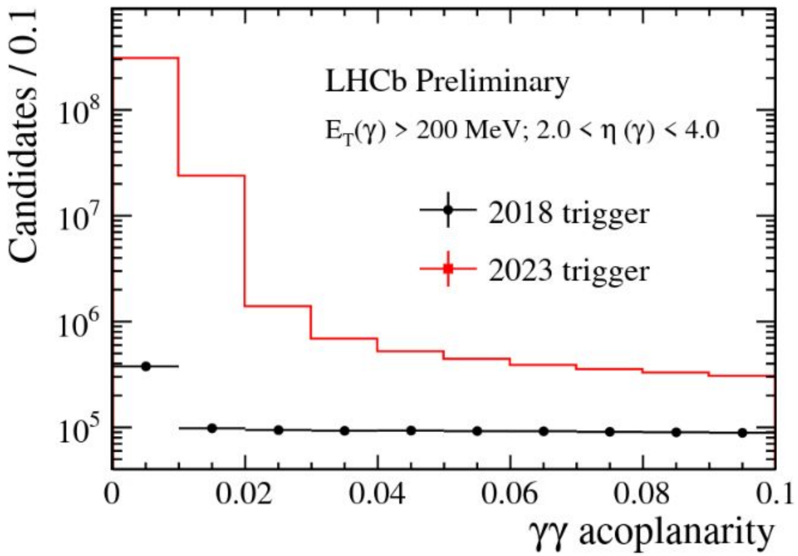
2023 PbPb data



- Ultraperipheral collisions: great laboratory for QCD studies
- How to identify them? Search for photon pair candidates, with strong angular correlation, in low multiplicity PbPb collisions

LHCb-FIGURE-2024-012



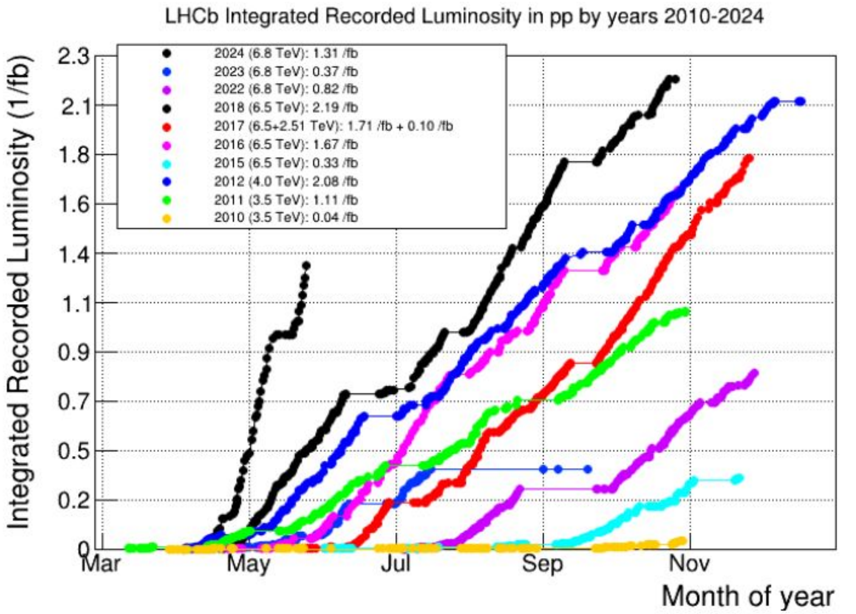


- Big improvement in trigger efficiency thanks to L0 removal!

Status of 2024 data-taking

Progress with data-taking

- 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 >90% data-taking efficiency at $\mathcal{L} = 1.2 \times 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Current running conditions driven by trigger and physics considerations
- Interleaved physics production and optimisation fills aiming to run at $\mathcal{L} = 2.0 \times 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ including the UT and by design trigger and alignment performance after TS1

VELO

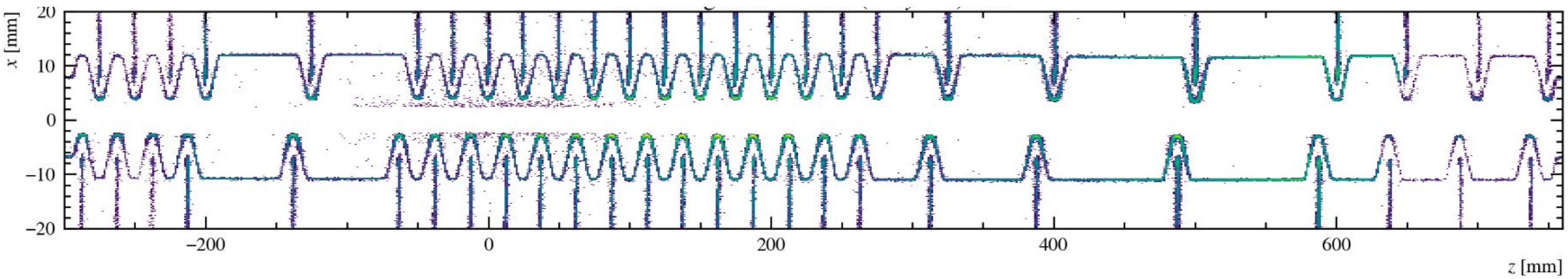
- After RF-foil re-installation, recommissioning without beam
  - infrastructures (cooling, LV, HV), optical links (control and readout)
- Recommissioning with beam during intensity ramp-up
  - time alignment, tuning of FE configuration and DAQ firmware for high occupancy operation
- Closing procedure recommissioned, VELO operated at nominal gap
  - minimal aperture of 3.2mm

Some of the VELO people happy after closing the detector for the first time after last year's incident

VELO

- Performances
  - >99% optical links active
  - hit efficiencies higher than 98%
  - operation at nominal conditions stable

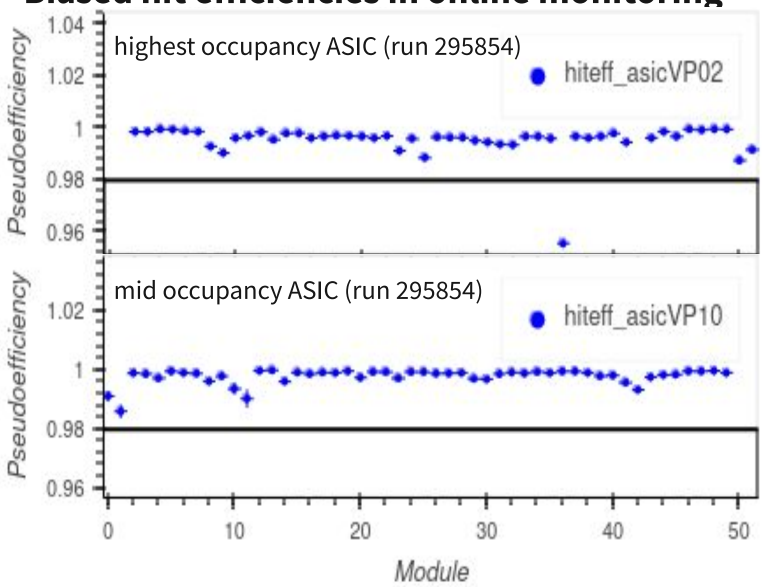
Selfie of the new RF-box and VELO modules with reconstructed hadronic interaction vertices



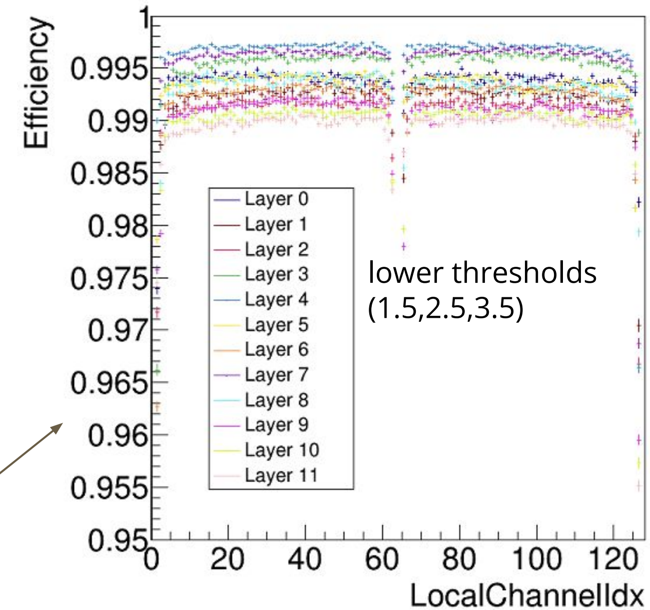
Hit efficiencies

VELO

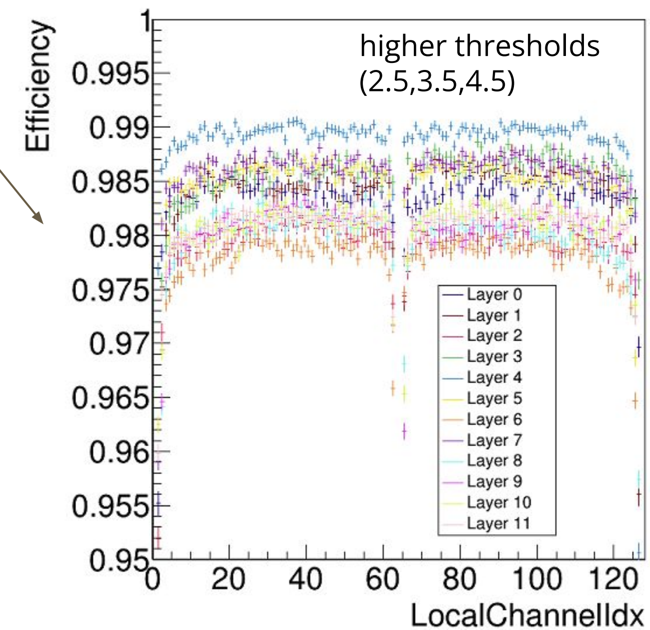
Biased hit efficiencies in online monitoring



SciFi



Different thresholds on numbers of photoelectrons per channel



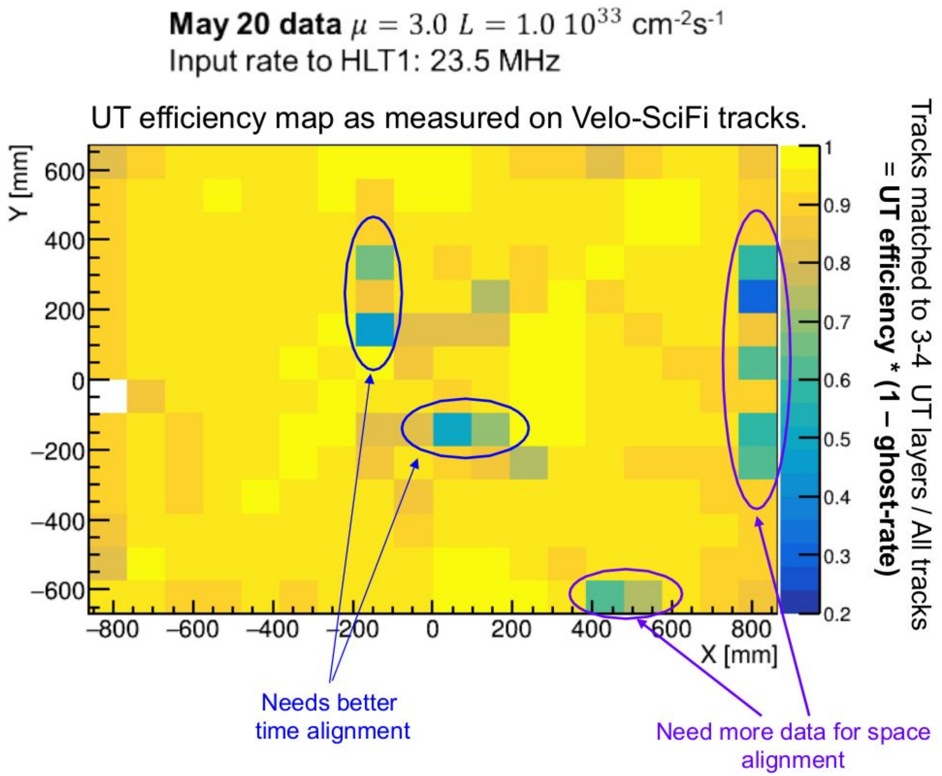
UT

❖ Quick progress in UT commissioning with beams this year!

➢ Coarse time alignment based on 450GeV beam collisions in March

➢ Fine time alignment and spatial alignment based on 6.5 TeV collisions (April 18)

➢ Retuned setting of Front-End ASICs installed on May 17

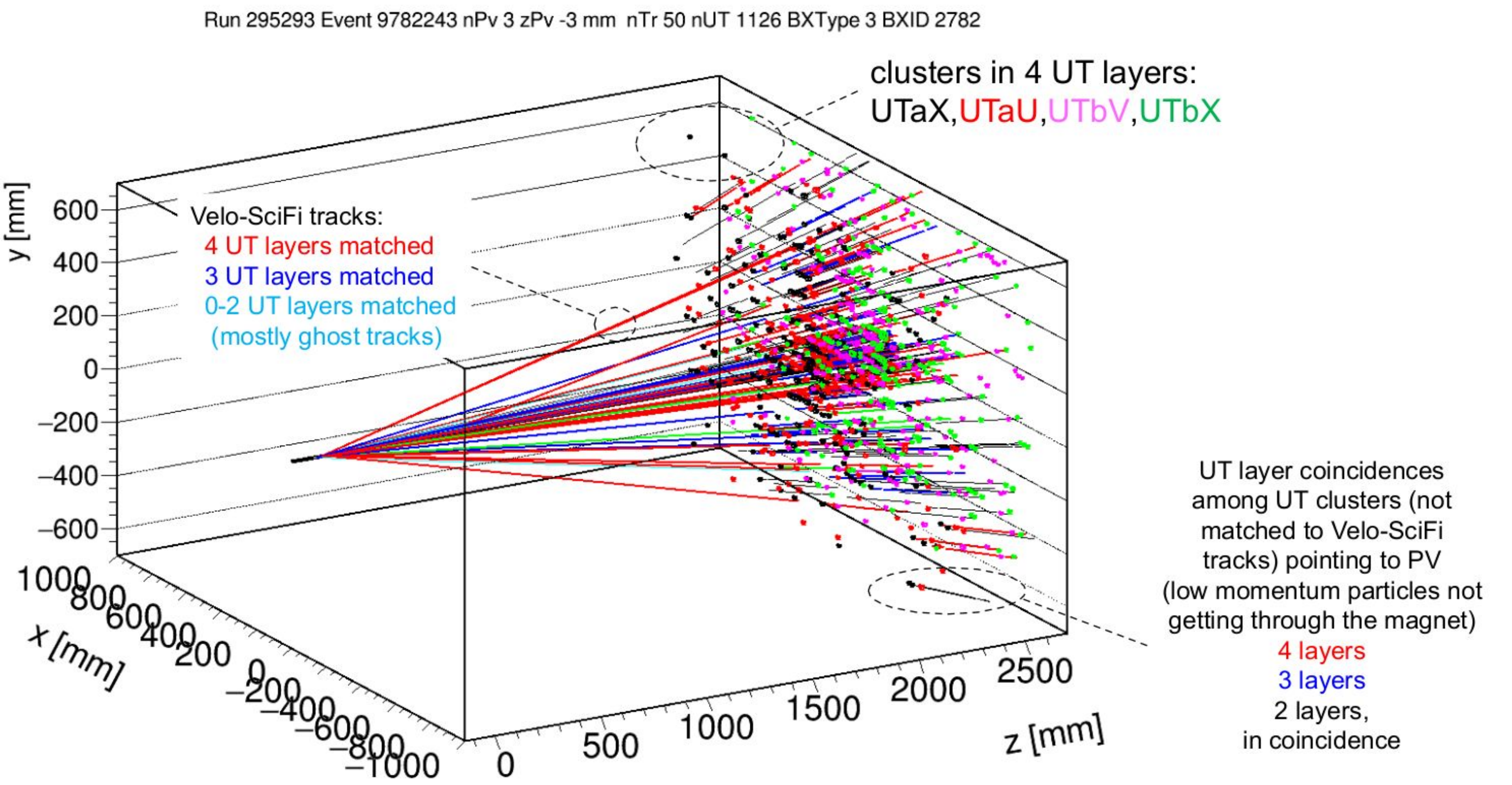


❖ Efficiency on VELO-SciFi tracks is 96%

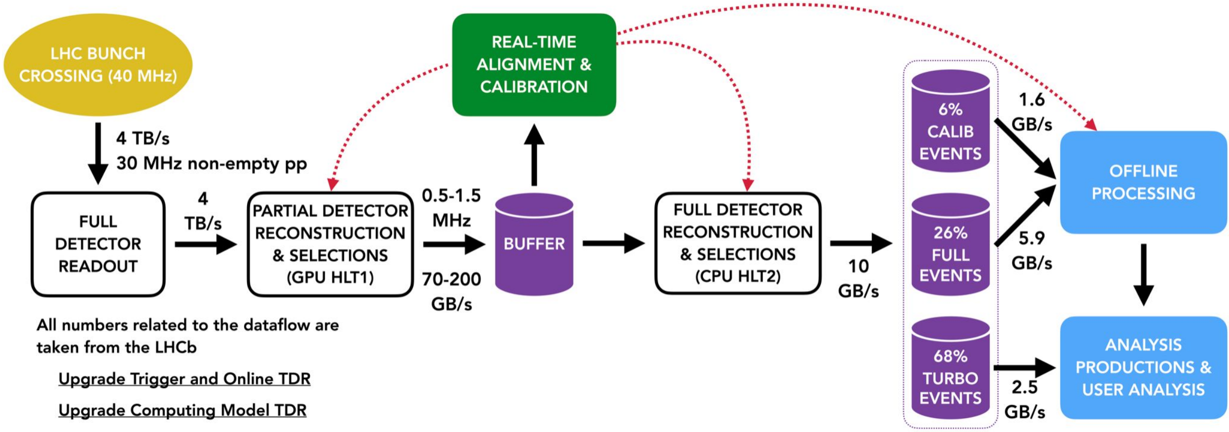
➢ Further improvements from 2nd round of fine-time alignment, spatial alignment and customization of FE thresholds to individual channels

UT

3 PVs, 50 Velo-SciFi tracks (high momentum charged particles getting through the magnet)



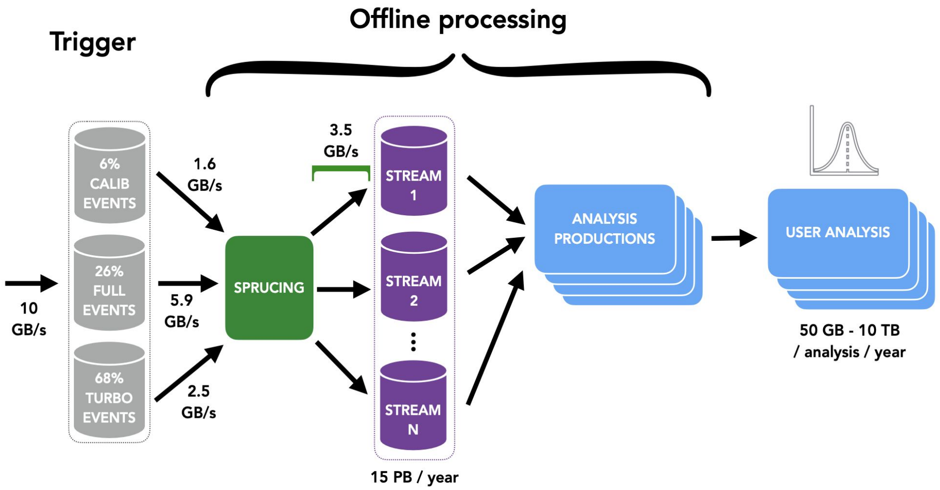
LHCb data-flow



- **HLT1** processing 26MHz of collision data on 330 GPUs
  - Performing online monitoring / calibration / alignment on CPUs
- **HLT2** process data through farm of 3500 CPU nodes
  - Output of HLT2: 10GB/s of physics data as planned in the TDR
- The data is split into 3 Physics streams
  - Turbo: Reduced information ready for analysis by user (2.5GB/s)
  - Full: Further selection performed offline (6 GB/s)
  - TurCal: Data to be analyzed for calibration purposes (1.5GB/s)
- Processed nearly 1 fb^{-1} by the 23rd of May.

LHCb data-flow

❖ All of LHCb's 3 physics streams have been processed offline (the Sprucing processing stage)
❖ Ntuples have been provided to analysts mostly via the centralised Analysis Productions system
❖ Productions "bundled" for WG, minimising reading of the samples and easing operations



All **within 3 days** of data being run through HLT2 at the LHCb pit!

So far we have Spruced 3 PB of data - full data processing chain is in operation.

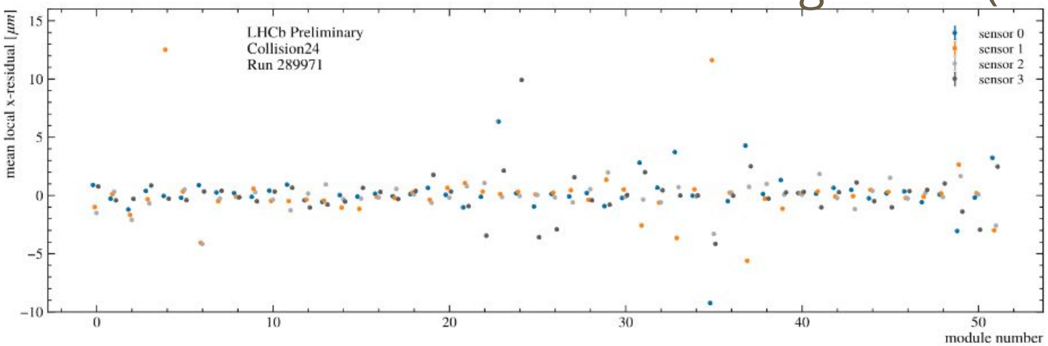
Currently ~**100 Analysis Productions** are "live" and pick up data automatically as it arrives out of the Sprucing

Alignment and calibration

- To achieve best performance: essential to spatially align and calibrate the detector!
  - Detectors have been moved during YETS (and VELO is closed and opened at every fill)

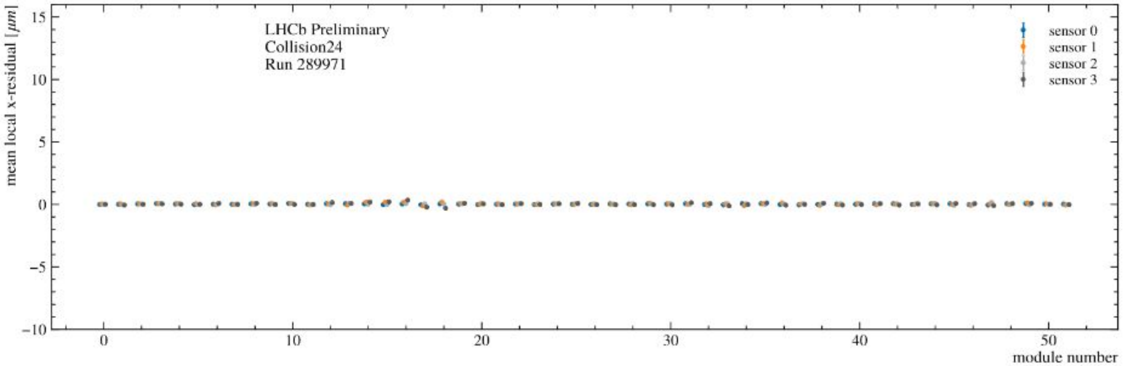
    → evaluate again spatial alignment of detector elements

with 2022 modules and sensors alignment (VELO)



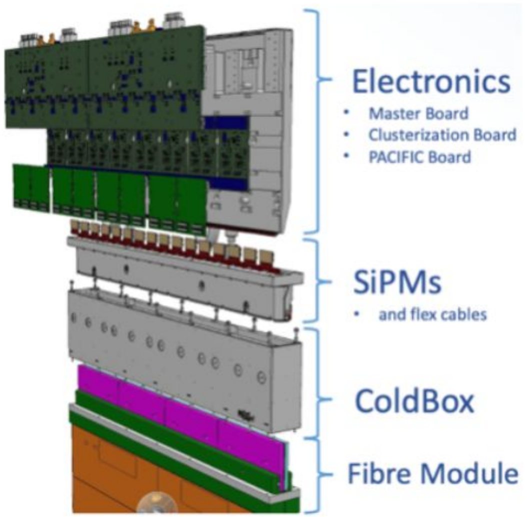
LHCb-FIGURE-2024-009

after new modules and sensors alignment (VELO)

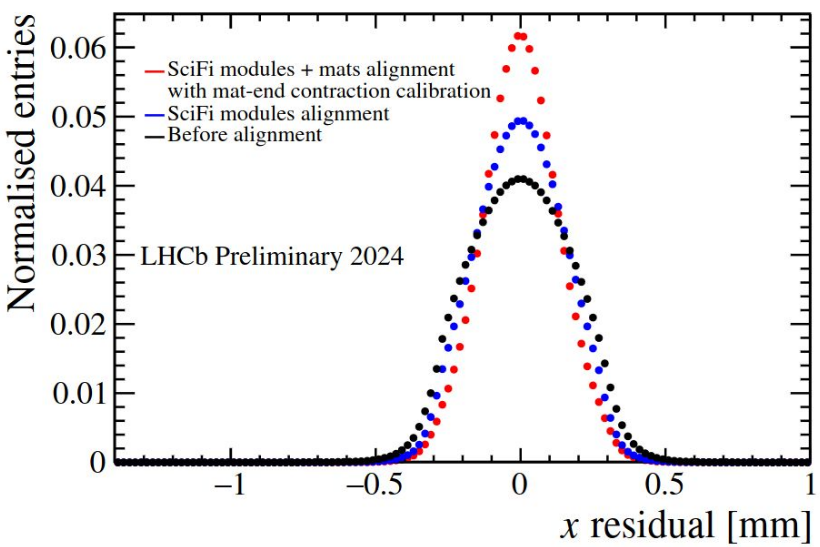


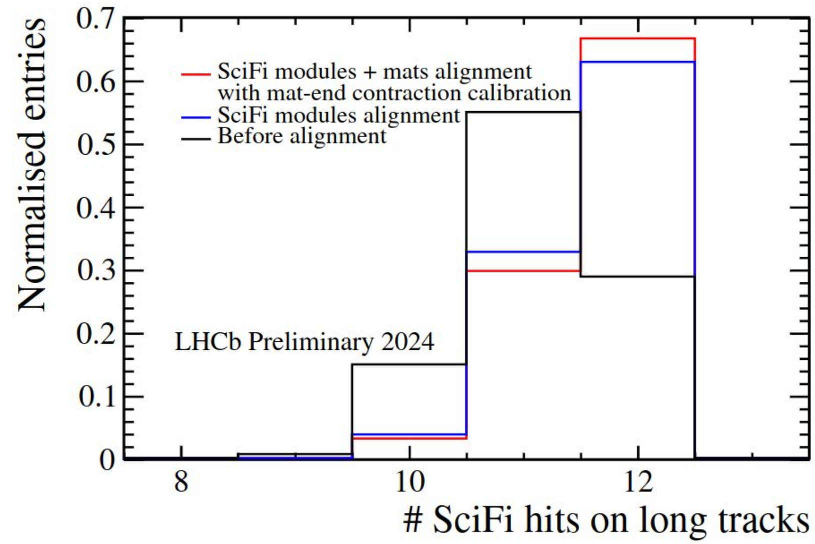
Alignment and calibration (2)

❖ Still room for improving SciFi alignment , but large progress made in the first weeks of data-taking



LHCb-FIGURE-2024-009

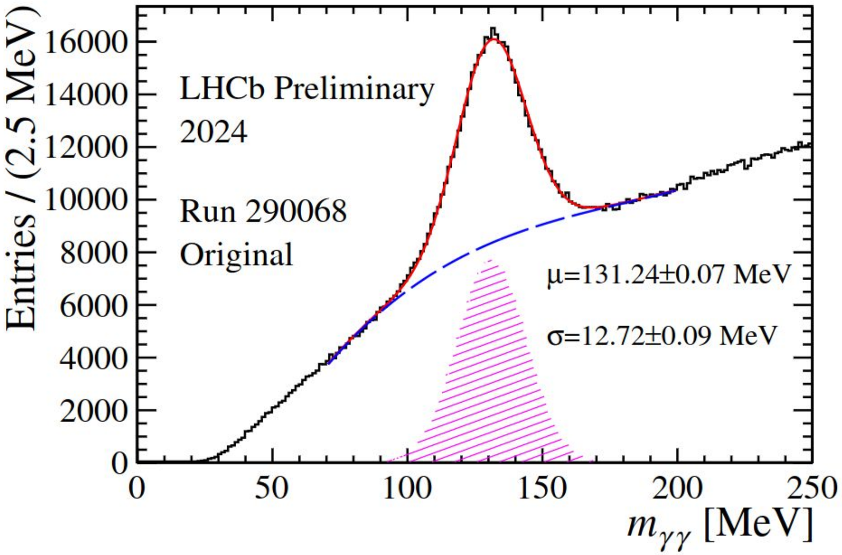


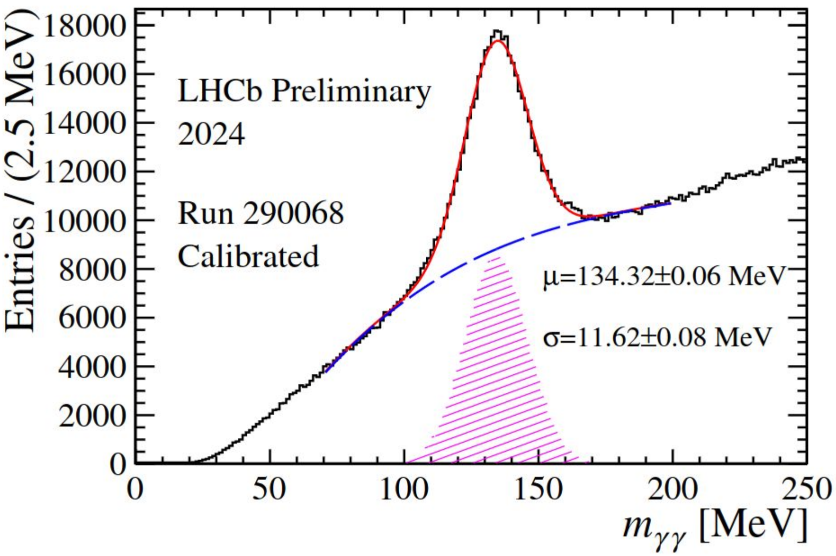


Alignment and calibration (3)

- ❖ Calibrate each of the 6016 cells of the electromagnetic calorimeter via an iterative process
  - ➢ Measure neutral pion invariant mass in all the cells and apply calibration to match PDG value

LHCb-FIGURE-2024-009

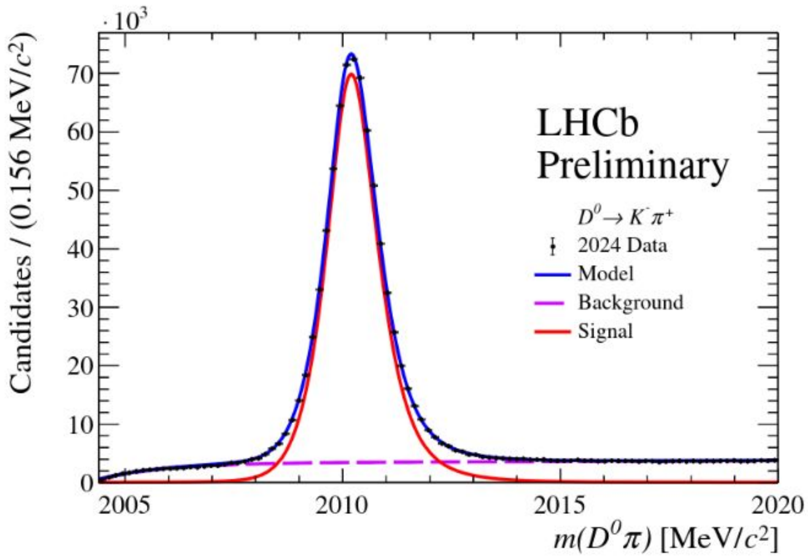


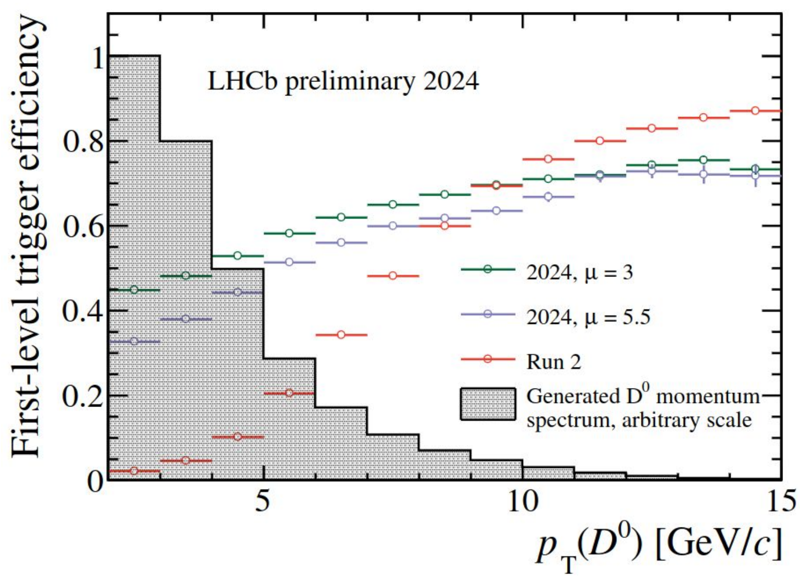


Charm decays in 2024 data

LHCb-FIGURE-2024-006

❖ Removal of hardware trigger improves the efficiency in selecting hadronic charm decays!

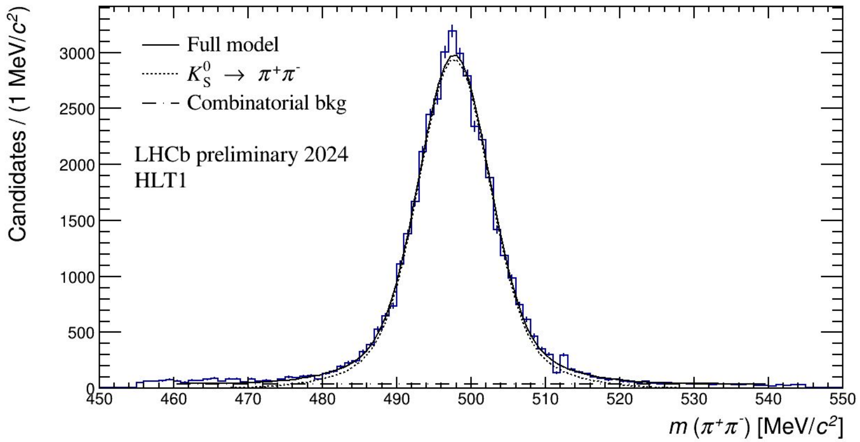


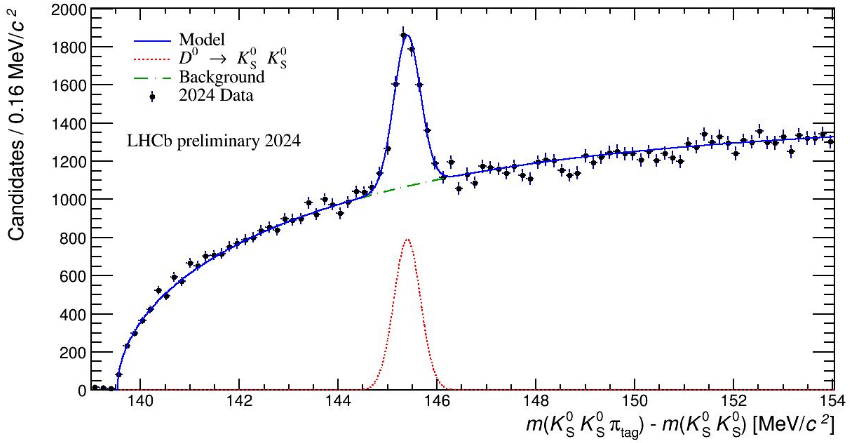


Charm decays in 2024 data

LHCb-FIGURE-2024-008
LHCb-FIGURE-2024-013

- Software trigger → flexibility in design selections
  - K_S^0 candidates reconstructed directly at the first level of the trigger!
  - Dedicated selections to collect single K_S^0 and pairs of K_S^0 → increase efficiency in selecting decays like $D^0 \rightarrow K_S^0 K_S^0$

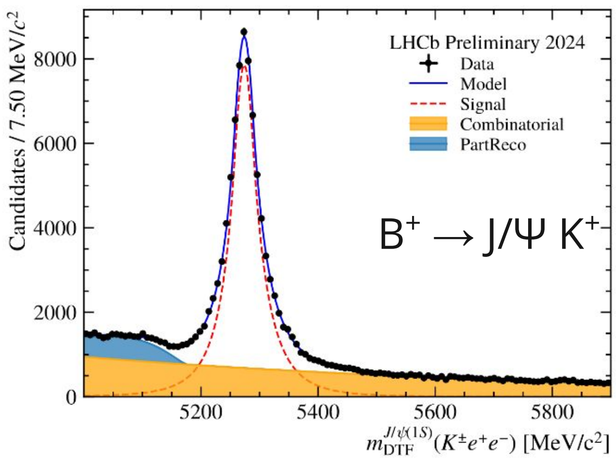


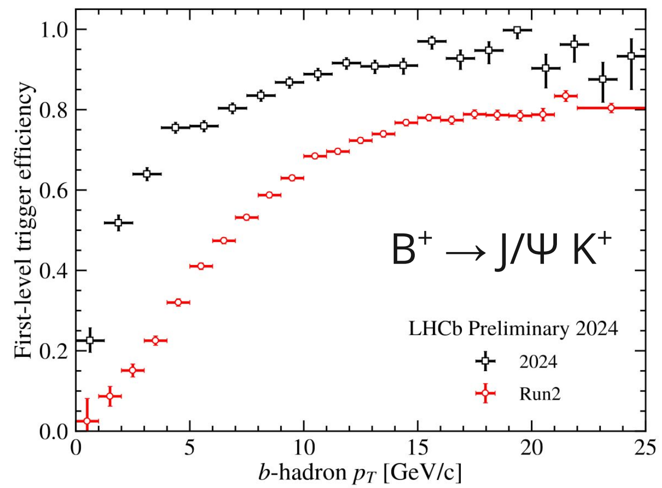


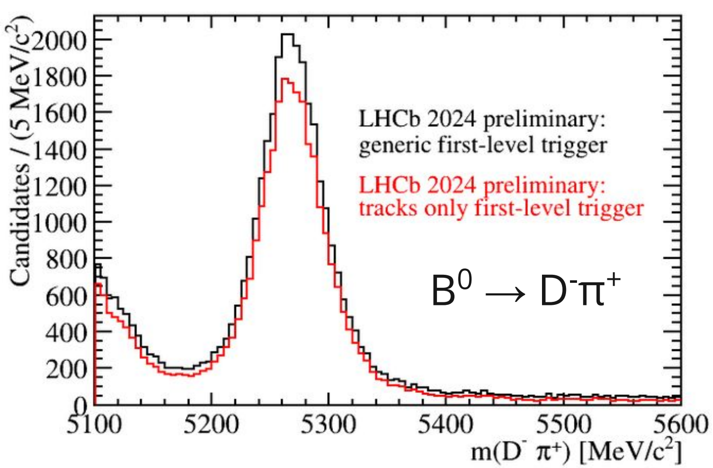
B decays in 2024 data

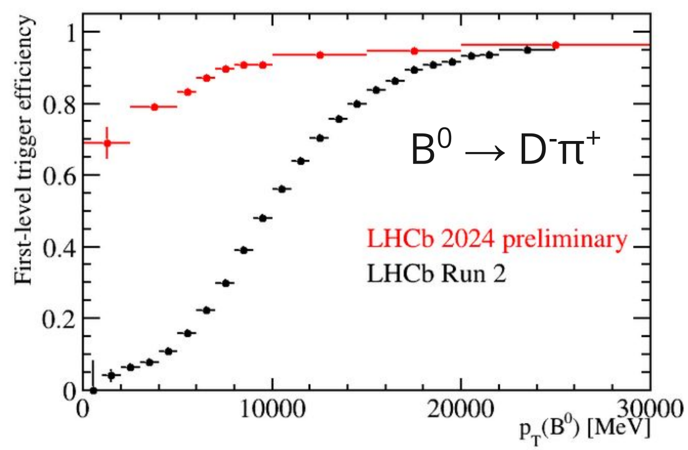
LHCb-FIGURE-2024-007
LHCb-FIGURE-2024-014

❖ Trigger improvements confirmed also in hadronic B decays and when electrons are present in the final state!







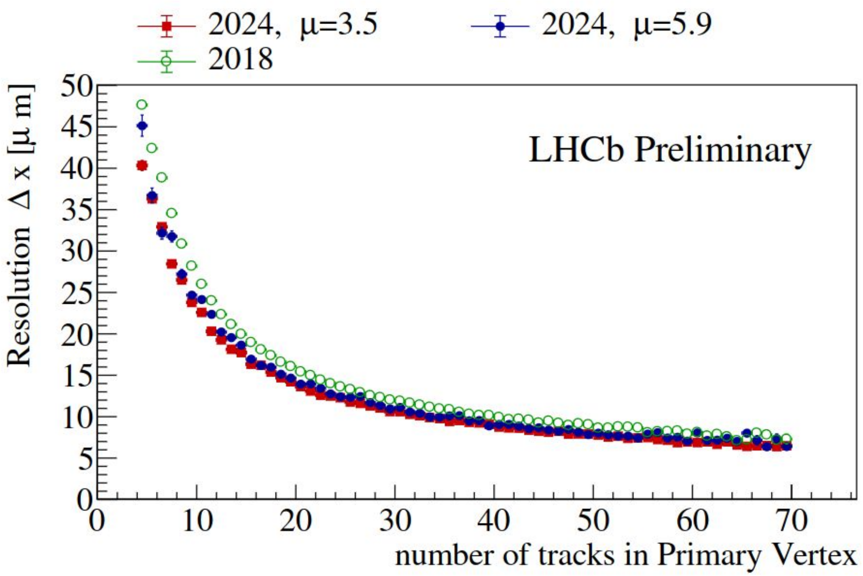


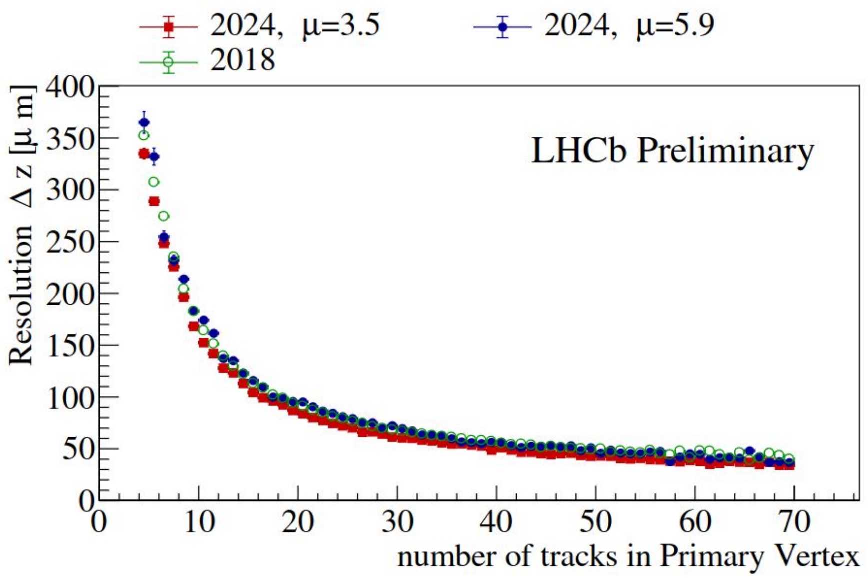
PV resolution

❖ Performance better than Run 2 and stable when varying the average number of visible pp interactions per bunch crossing (μ)

➢ μ=5 → ~ nominal luminosity

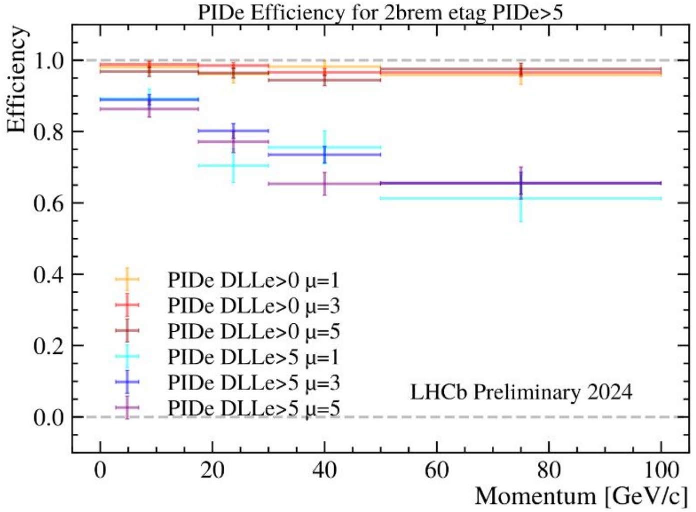
LHCb-FIGURE-2024-011



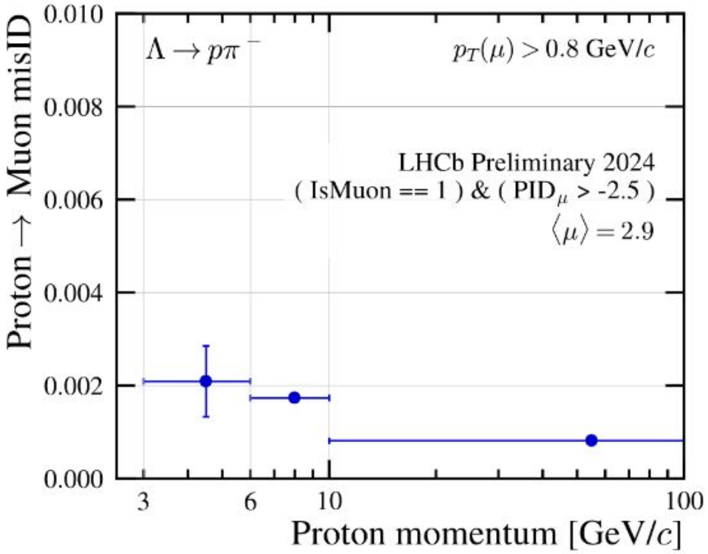


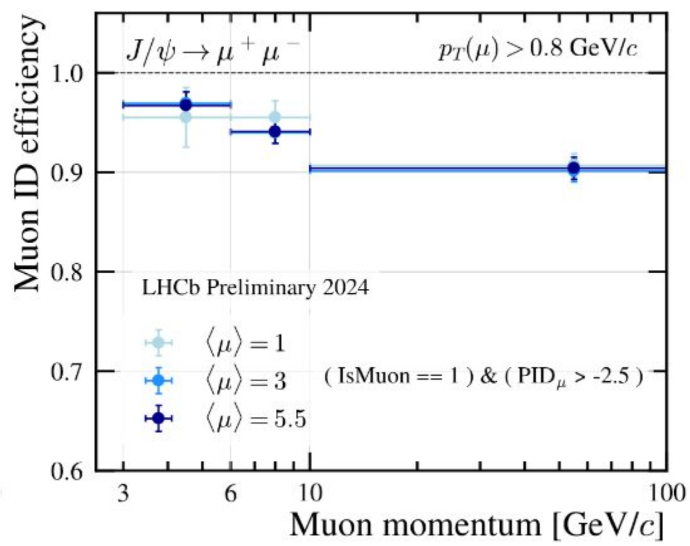
PID performance

- Particle identification by combining information from different subdetectors
  - Difference in log-likelihood between different hypothesis
- Good stability as a function of μ!



LHCb-FIGURE-2024-010

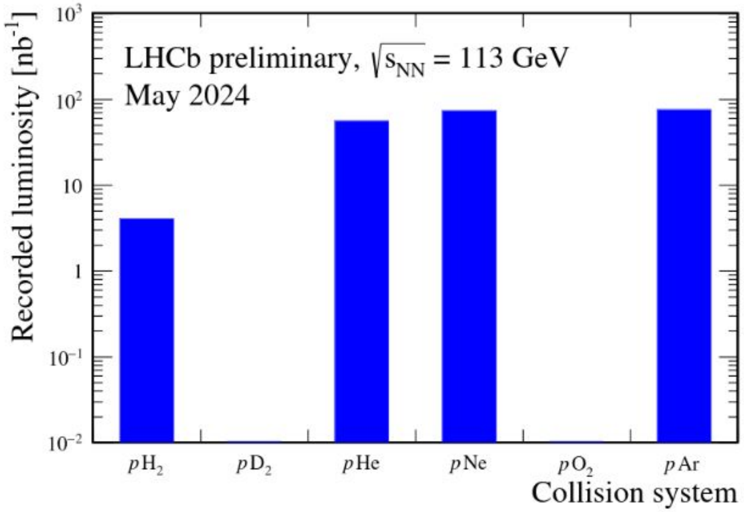


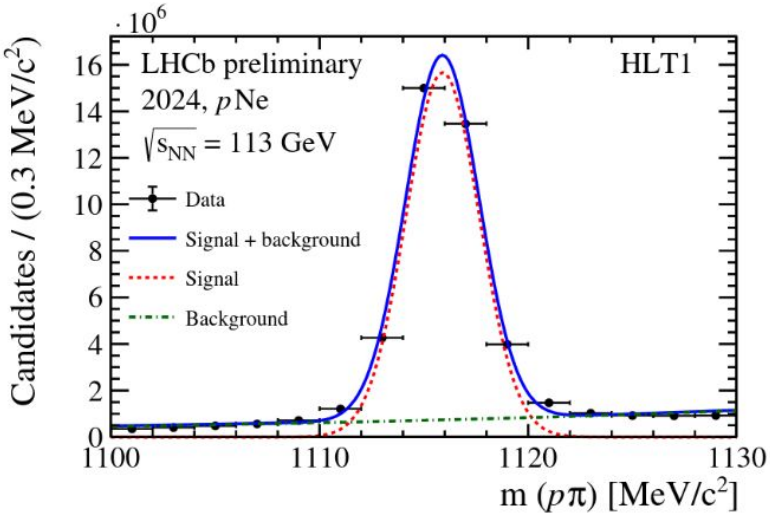


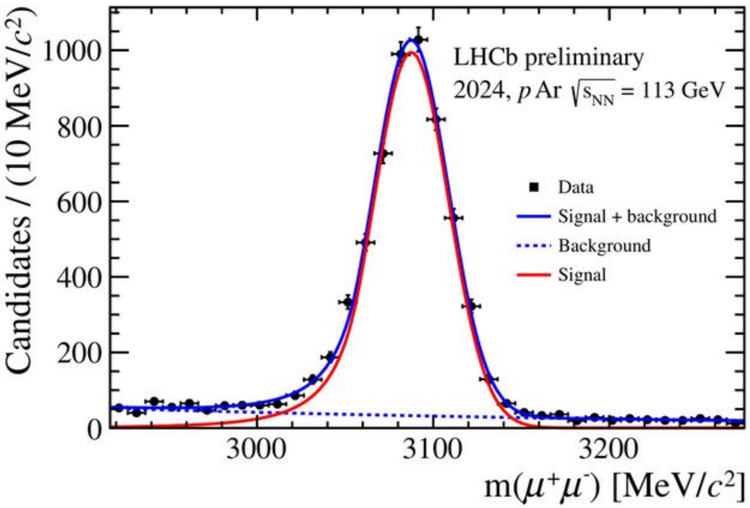
SMOG

LHCb-FIGURE-2024-005

❖ Successfully collected samples in different fixed-target configurations!







Conclusions

- Publishing world leading measurements with Run 1 and Run 2 datasets!
- Currently analyzing 2023 PbPb data
  - Signal events up to mid-central collisions
  - Big improvement in trigger efficiency for UPC
- Exploring the full potential of Upgrade I in 2024
  - Detectors stably operating at nominal conditions
  - Expected improvements of trigger efficiency for hadronic channels confirmed on data
  - Still room for improving final performance, but huge progress made since the beginning of the data-taking

Conclusions (2)

- Not discussed today
  - Online enhancements TDR (for LS3) -- under LHCC review
  - Scoping document for Upgrade 2 (LS4) -- under preparation for submission at next LHCC week
- We warmly thank the LHC for their support and operations!

Backup slides

DAQ LS3 enhancement

- PCIe400: new readout board with 400 Gb/s
  - 48 GBT/lpGBT links compatible with PCIeGen5 or 400 GbE (output bandwidth x4 compared to present generation)
  - Make it available for LS3 LHCb detector upgrades
- Downstream tracking with FPGA (RETINA):
  - Event reconstruction primitives (clusters, tracks) found by FPGA immediately available to event building, freeing resources for other tasks
  - Already implemented in Run 3 for VELO clusters. LS3 proposal: realise a downstream tracking unit using hits from SciFi at 30 MHz (clear benefit for downstream KS and long-lived particle searches)

PCIe400 layout