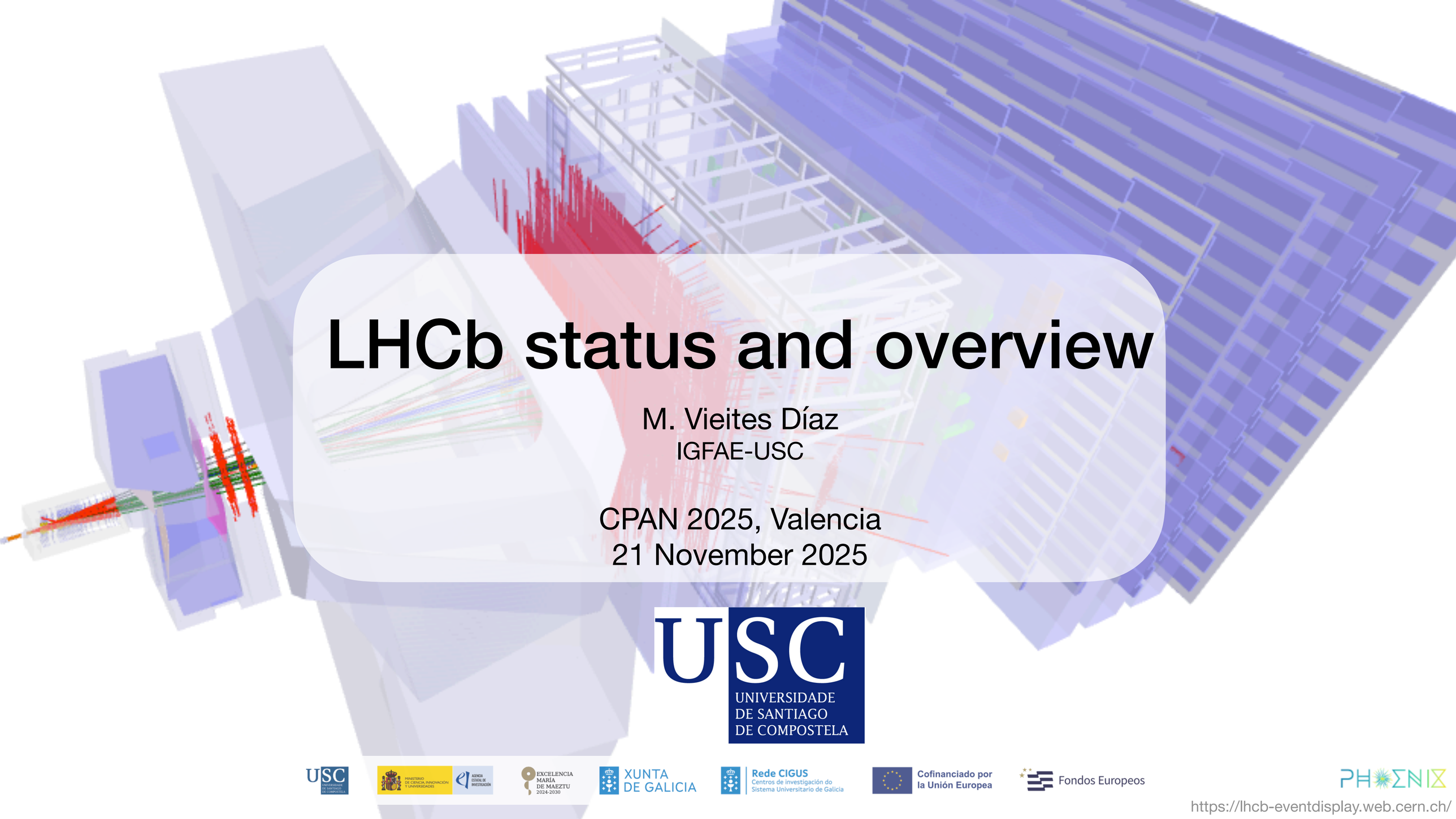

LHCb status and overview

M. Vieites Díaz
IGFAE-USC

CPAN 2025, Valencia
21 November 2025

USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES · AGENCIA ESTATAL DE INVESTIGACIÓN
EXCELENCIA MARÍA DE MAEZTU 2024-2030
XUNTA DE GALICIA
Rede CIGUS Centros de investigación do Sistema Universitario de Galicia
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PHOENIX

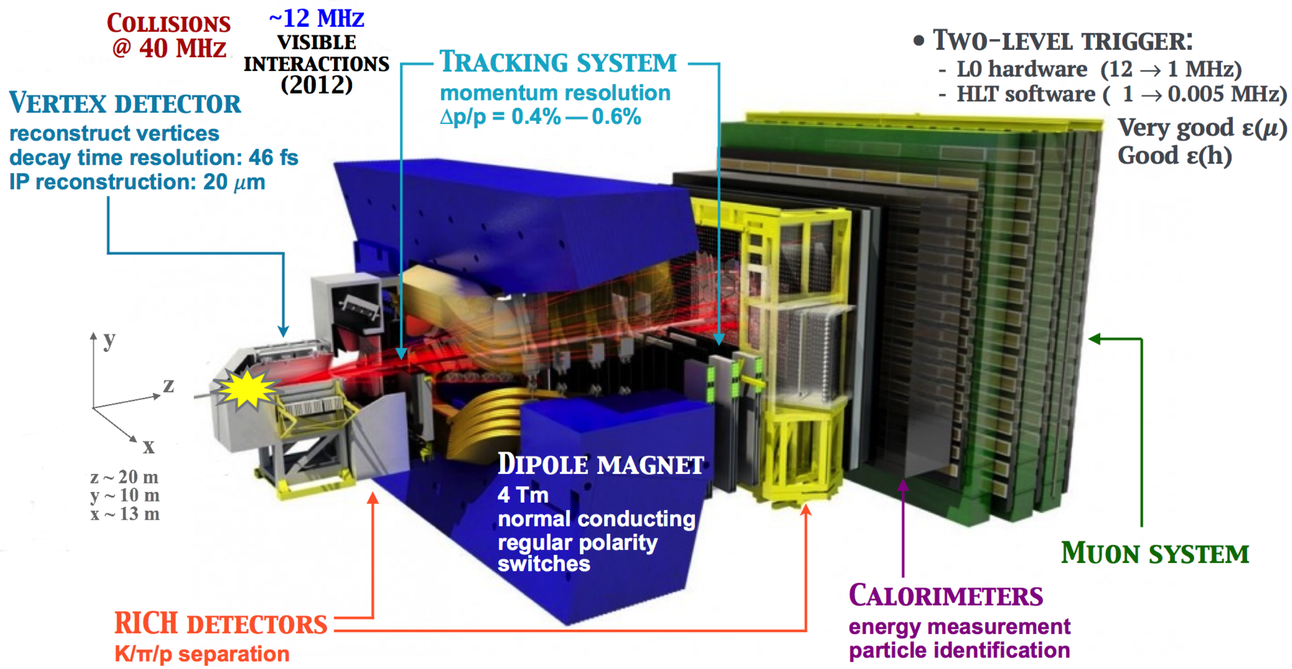
https://lhcb-eventdisplay.web.cern.ch/

The LHCb detector in a nutshell*

*Runs 1&2 Edition

Originally designed to study CP violation and rare decays in beauty and charm decays:

- ✓ Excellent tracking and vertexing
- ✓ Excellent Particle identification
- ✓ Excellent momentum resolution
- ✳ Complicated geometry
- ✳ Not hermetic



$$\Delta E/E_{ECAL} = 1\% + 10\,\%/\sqrt{(E[GeV])}$$

LHCb Detector Performance

International Journal of Modern Physics A
Vol. 30, No. 7 (2015) 1530022
2008 JINST 3 S08005

LHCb Runs 1 and 2 pp data sample: (2011 - 2018) ~ 9 fb^{-1}

LHCb Run 3 pp data sample (2022 - ongoing) ~ 22.5 fb^{-1}

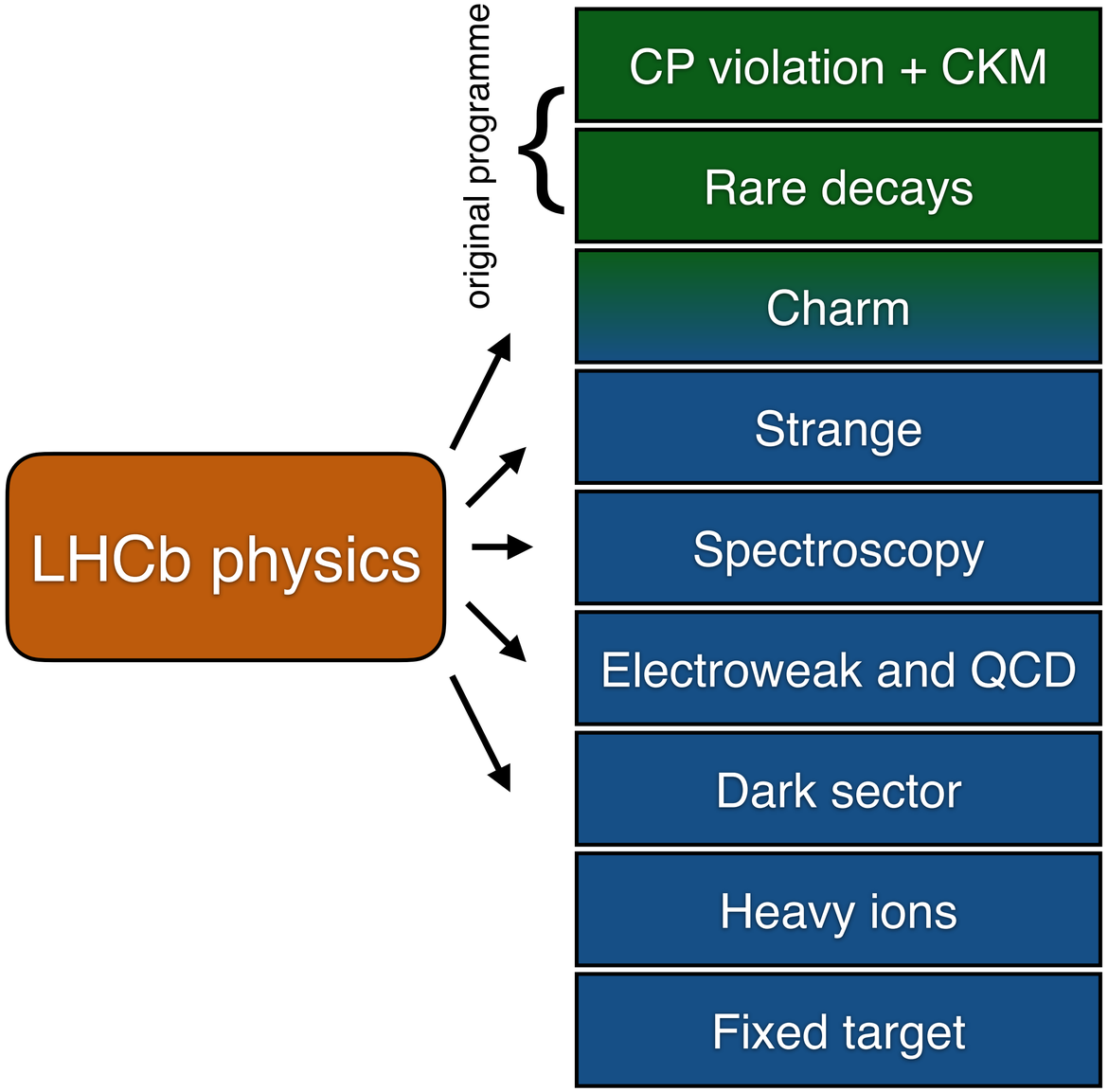
← Upgrade I, currently taking data

The LHCb detector in a nutshell*

Originally designed to study CP violation and rare decays in beauty and charm decays:

- ✓ Excellent tracking and vertexing
- ✓ Excellent Particle identification
- ✓ Excellent momentum resolution
- ✳ Complicated geometry
- ✳ Not hermetic

Physics program has grown very significantly → expanded to a general purpose detector in the forward region



Selected results

- General LHCb highlights
- Recent highlights from the Spanish groups
- Run 3 operations
- A glimpse at Upgrade 2 planning

Matter-antimatter asymmetry

- Until recently, matter-antimatter asymmetry (CP violation) was only observed in processes involving mesons
- This year, LHCb reports the **first observation of CP violation in the decays of baryons**
  - New path in the studies of the Standard Model and its extensions, with several complementary new results in baryons also published this year:

- Measurement of CP asymmetries in $\Lambda_b^0 \to ph^-$ decays

LHCb-PAPER-2024-048
arXiv:2412.13958

- Observation of charge-parity symmetry breaking in baryon decays

LHCb-PAPER-2024-054
arXiv:2503.16954

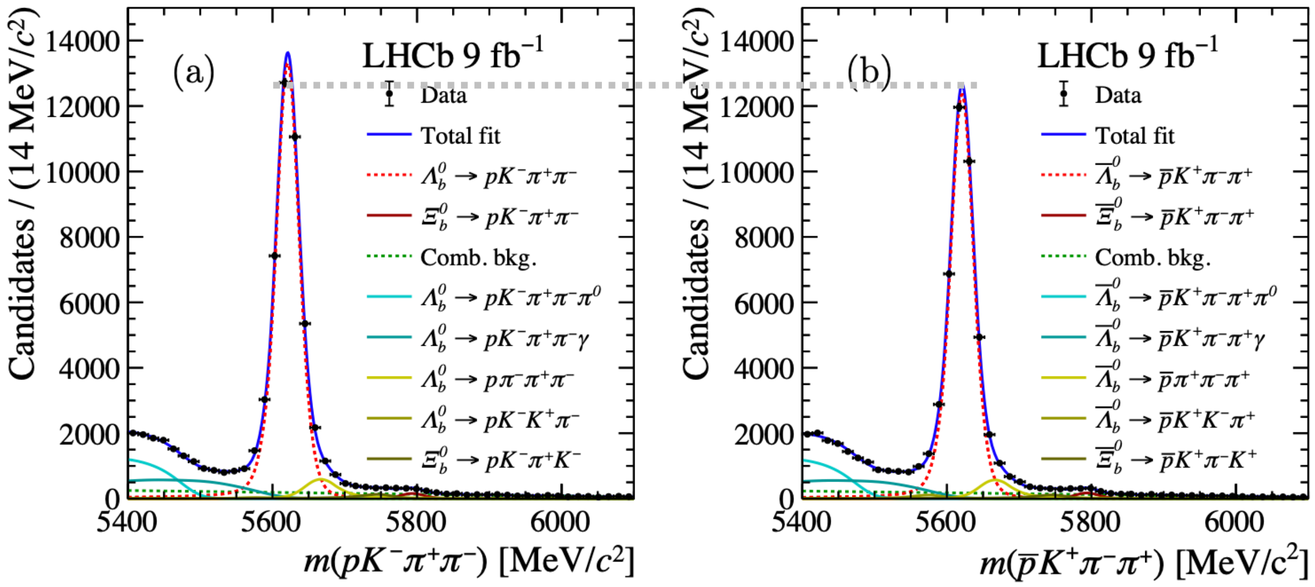
- Study of Λ_b^0 and Ξ_b^0 decays to $\Lambda h^+ h'^-$ and evidence for CP violation in $\Lambda_b^0 \to \Lambda K^+ K^-$

LHCb-PAPER-2024-043
Phys. Rev. Lett. 134 (2025) 101802

Observation of baryonic CP asymmetry

- Using Run1+Run2 dataset, by performing the $\Lambda_b^0 \to pK^-\pi^+\pi^-$ yield asymmetry measurement in regions of phase-space.
- Corrections from differences in production and detection effects (~1%) measured in the $\Lambda_b^0 \to \Lambda_c^+(\to pK^-\pi^+)\pi^-$ control channel.
- Phase-space integrated asymmetry measurement of $(2.45 \pm 0.46 \pm 0.10)\,\%$ (5.2σ)
  - Tested phase-space regions with known resonances, with different decay topologies

LHCb-PAPER-2024-054
arXiv:2503.16954
Nature 643 (2025) 1223

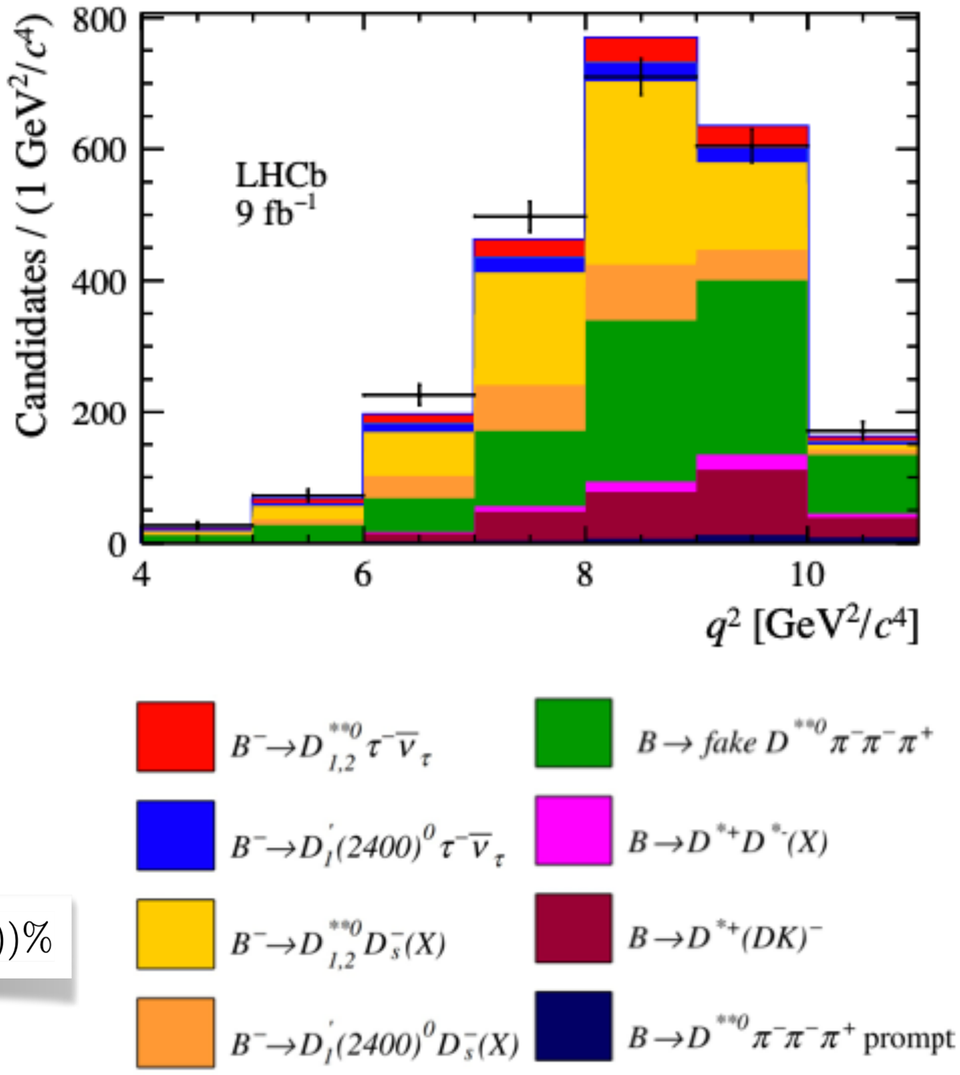


Decay topology	Mass region (GeV/c^2)	$\mathcal{A}_{CP}$
$\Lambda_b^0 \to (pK^-)(\pi^+\pi^-)$	$m_{pK^-} < 2.2$ $m_{\pi^+\pi^-} < 1.1$	$(5.24 \pm 1.29 \pm 0.21)\%$
$\Lambda_b^0 \to (p\pi^-)(K^-\pi^+)$	$m_{p\pi^-} < 1.7$ $m_{\pi^+K^-} \in [0.8, 1.0] \cup [1.1, 1.6]$	$(2.73 \pm 0.82 \pm 0.14)\%$
$\Lambda_b^0 \to (p\pi^-\pi^+)K^-$	$m_{p\pi^-\pi^+} < 2.7$	$(5.39 \pm 0.86 \pm 0.10)\%$
$\Lambda_b^0 \to (K^-\pi^+\pi^-)p$	$m_{K^-\pi^+\pi^-} < 2.0$	$(2.01 \pm 1.16 \pm 0.30)\%$

A new handle on the SL feed-down

LHCb-PAPER-2024-037
[arxiv:2501.14943]

- First evidence for the $B^- \to D^{**0}\tau^-\overline{\nu}_\tau$ decay
  - Hadronic τ decays and fully hadronic decays in the D^{**} decay chain
  - Using LHCb data from Run 1 + Run 2, evidence of the decay mode at the level of 3.5σ
- Analysis statistically limited, however:
  - Validated feed-down assumptions in $\mathscr{R}(D^{(*)})$ analyses (expected shift well within 1σ)
  - Performed BR and LFU measurements, obtaining results within the SM expectations:



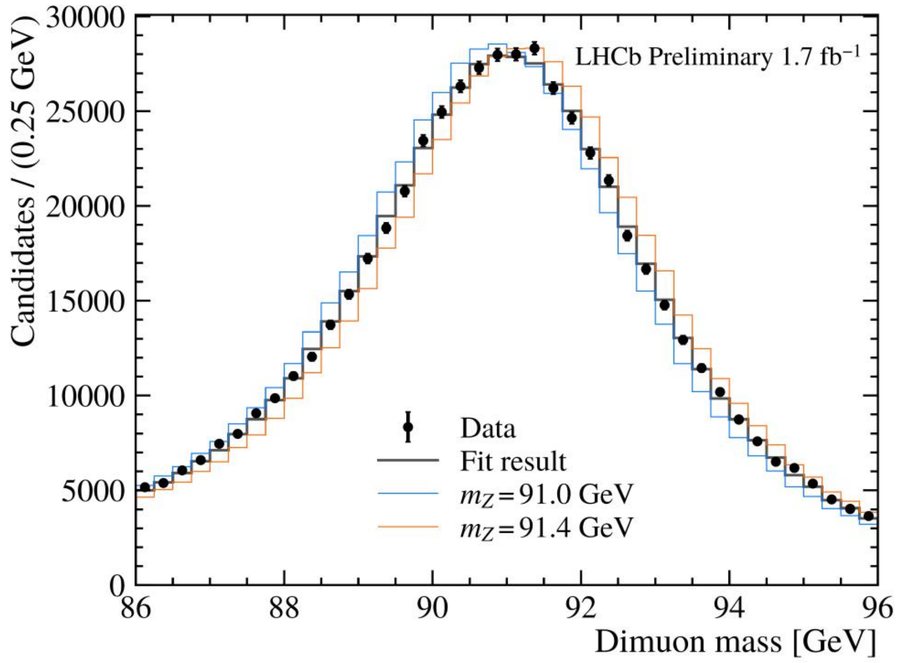
$$\mathcal{B}(B^- \to D^{**0}_{1,2}\tau^-\overline{\nu}_\tau)\times\mathcal{B}(D^{**0}_{1,2} \to D^{*+}\pi^-) = (0.051\pm0.013\,(\text{stat})\pm0.006\,(\text{syst})\pm0.009(\text{ext}))\%$$

$$\mathcal{R}(D^{**0}_{1,2}) = 0.13 \pm 0.03\,(\text{stat}) \pm 0.01\,(\text{syst}) \pm 0.02\,(\text{ext})$$

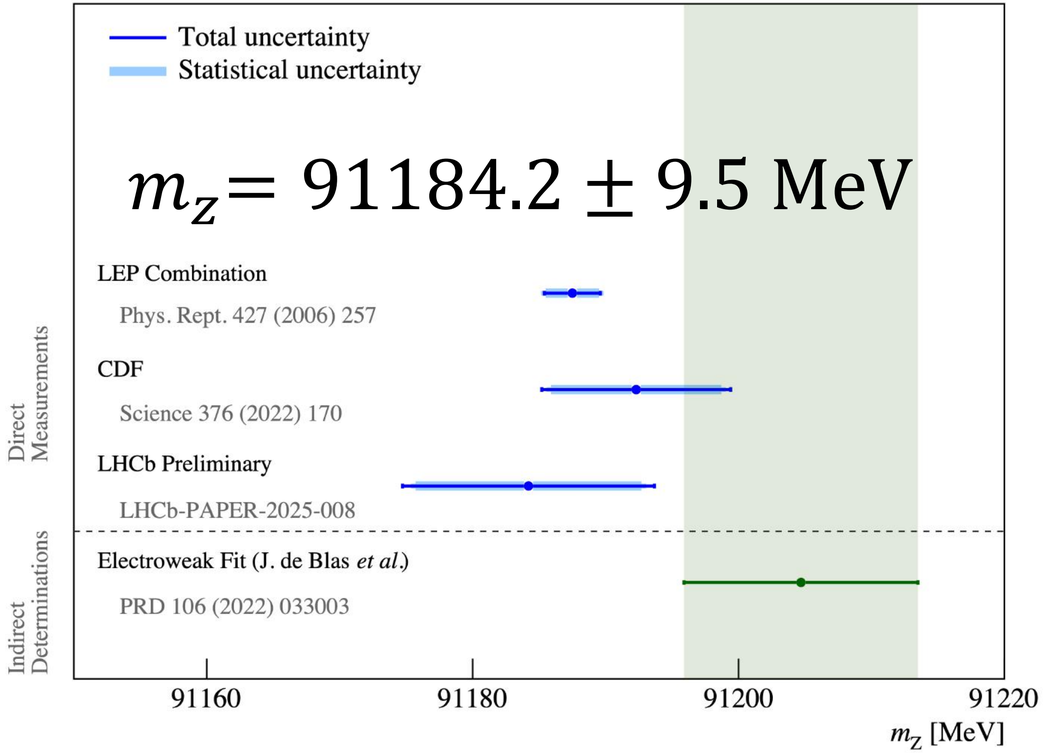
Measurement of the Z boson mass at LHCb

LHCb-PAPER-2025-008
Phys. Rev. Lett. 135 (2025) 161802

- **Most precise Z mass measurement at LEP**, now challenged by hadron collider experiments
- LHCb performed the first dedicated Z boson mass measurement at the LHC in the decay $Z \to \mu^+\mu^-$ in 2016 data
  - using a combination of excellent detector calibration and innovative bias correction technique
  - LHCb is the **first LHC experiment to have measured all three** of m_Z, m_W and $\sin^2\theta^{\ell}_{eff}$!



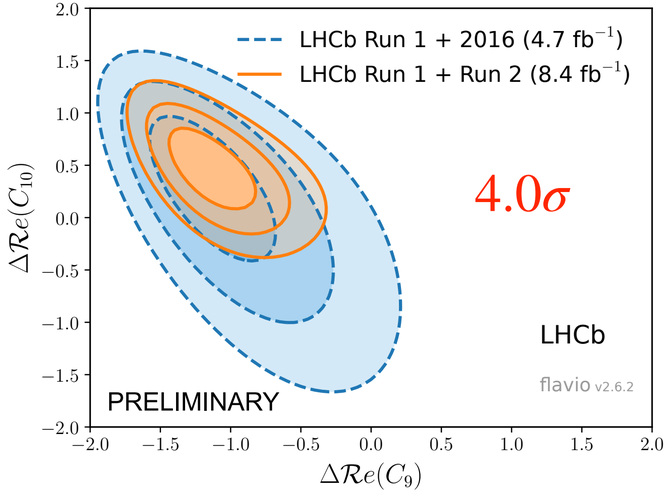
Scan of the dimuon mass distribution with simulation at varying masses to determine the Z boson mass

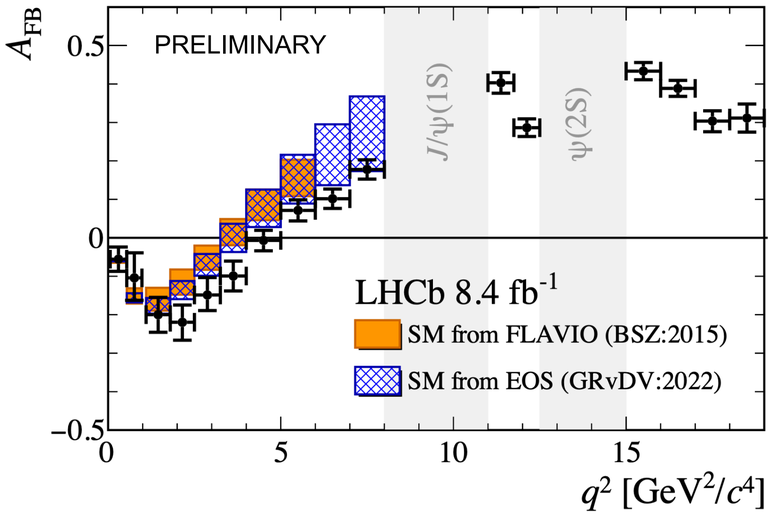


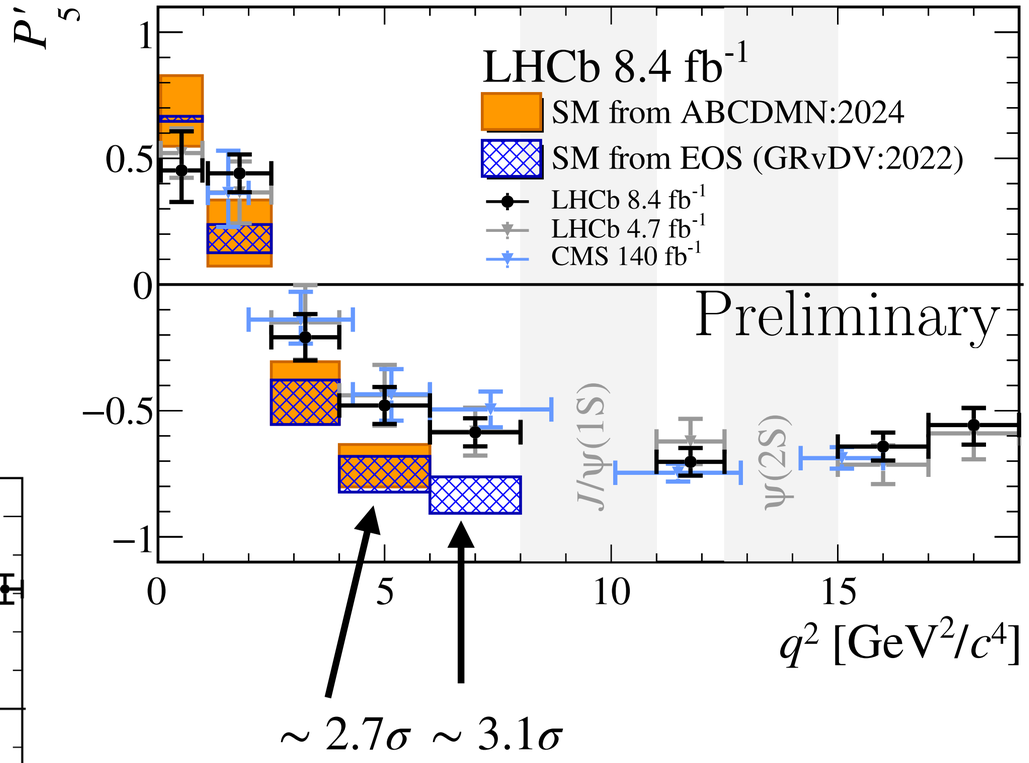
Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$ at LHCb

LHCb-PAPER-2025-041
(In preparation)

- **Binned angular analysis** of $B^0 \to K^{*0}\mu^+\mu^-$ with $8.4\,\text{fb}^{-1}$ from **Run1+2 data**
  - $b \to s\ell\ell$ transition, rare decay, very sensitive to New Physics contributions
  - improved selection, more observables (CPV, …)
  - include finer q^2 binning
  - take into account effects of lepton masses
- **Excellent agreement with previous results**
- Confirms previous long standing tension with SM predictions



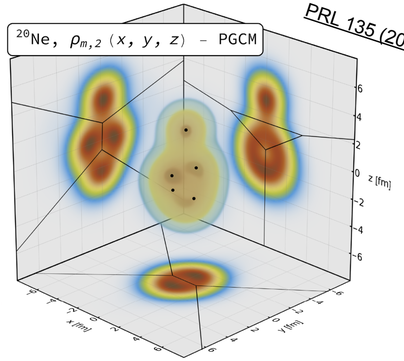




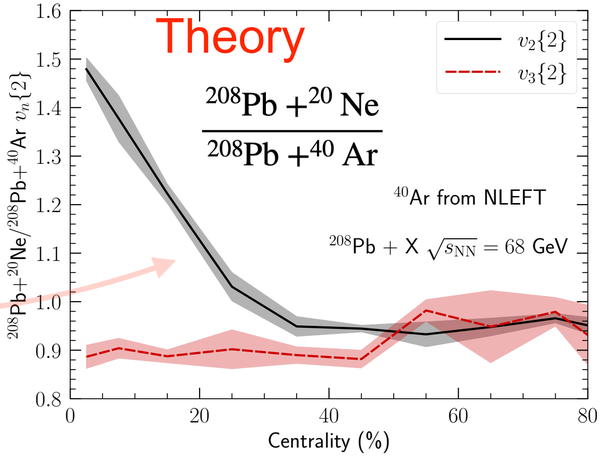
Shedding light on the ^{20}Ne nucleus shape

LHCb-CONF-2025-001
CDS Link

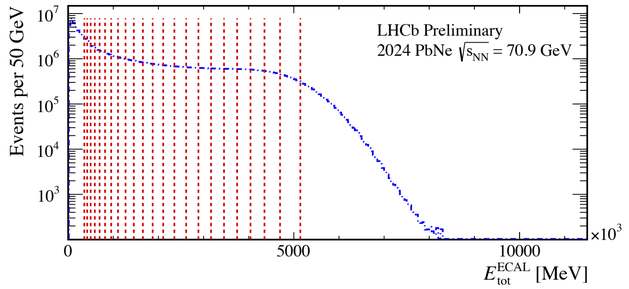
- Measure the anisotropic flow coefficients in PbNe and PbAr coll. at $\sqrt{s_{\mathrm{NN}}} = 70.9$ GeV
- Fixed-target data from the 2024 Heavy ions run
- ECAL energy used as centrality proxy
- Expect the non-spherical ^{20}Ne to show an elliptic flow coefficient v_2 different from that of the nearly spherical ^{40}Ar
- Result in line with theoretical predictions, confirming the ^{20}Ne peculiar shape ⇒ loads of excitement in the Heavy Ion community!

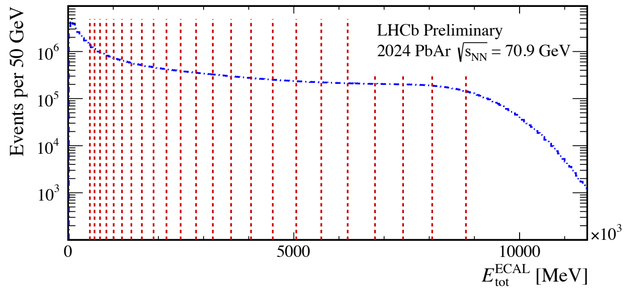


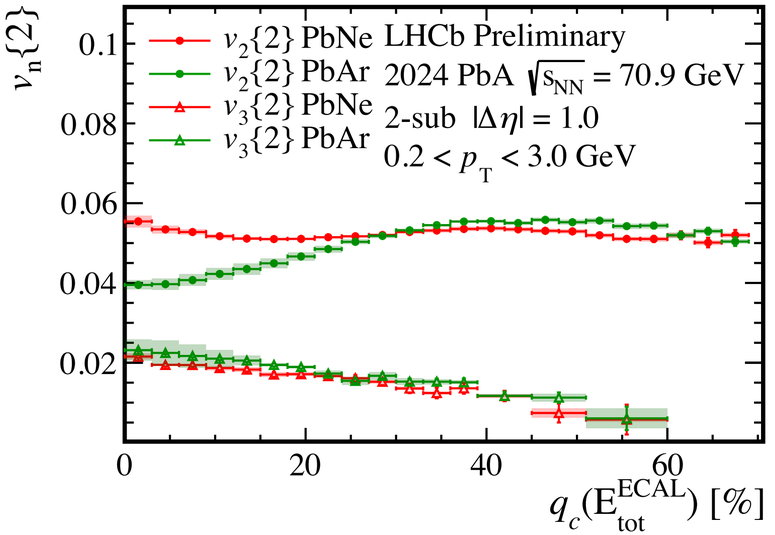
PRL 135 (2025) 012302

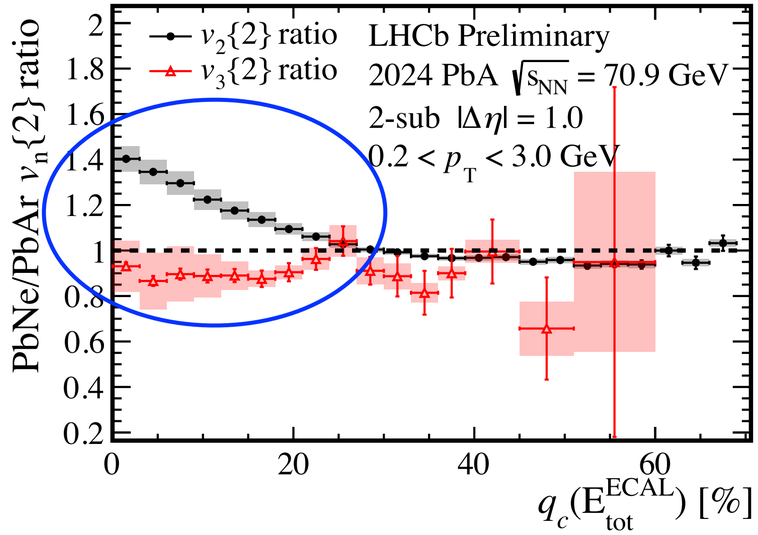


Chun Shen, QM2025









Selected results

- General LHCb highlights
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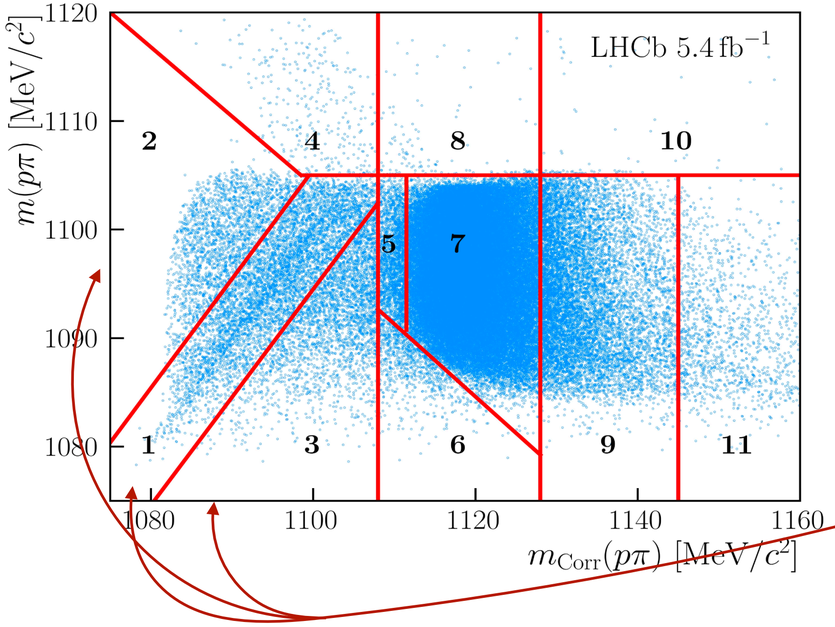
- Run 3 operations
- A glimpse at Upgrade 2 planning

Semileptonic hyperon decays: $\Lambda \to p\mu^-\bar{\nu}_\mu$

LHCb-PAPER-2025-030
arXiv:2511.15681

- New branching fraction measurement with data from 2016-2018 (5.4 fb^{-1})
- $s \to u$ transition, allows for LFU test in new sector and an independent input (to that from kaon decays) on $|V_{us}|$, albeit less precise
- $\Lambda \to p\pi$ as normalisation mode
- Selection heavily based on kinematic constraints
- Signal extraction from binned fit, where regions are defined to enhance signal/background/normalisation contributions.

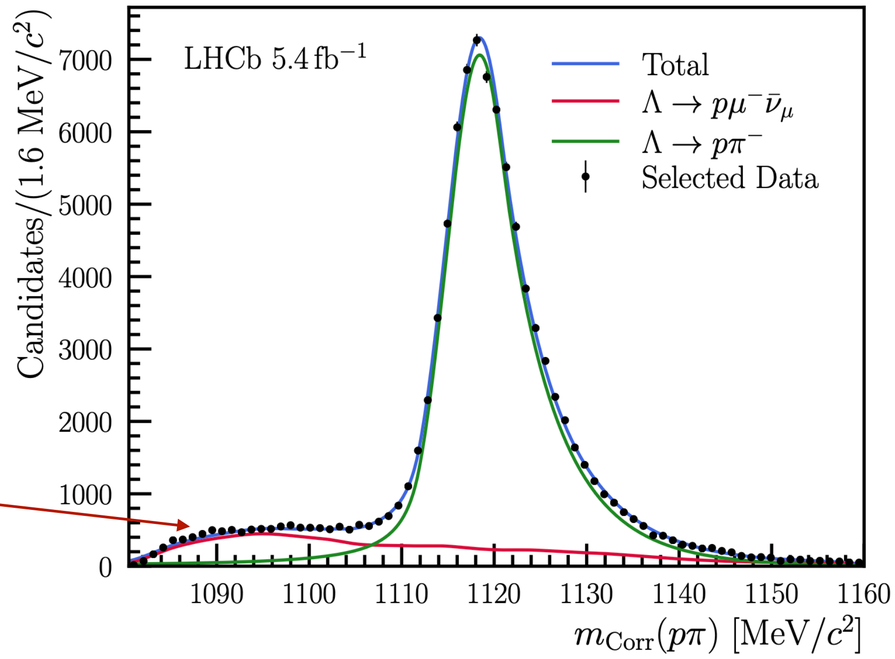
$$\mathcal{B}(\Lambda \to p\mu^-\bar{\nu}_\mu) = (1.462 \pm 0.016 \pm 0.100 \pm 0.011) \times 10^{-4}$$



$$R^{\mu e}_{exp} = 0.175 \pm 0.012$$

QCD Lattice, 0.1735 ± 0.0098
arXiv:2507.09970

Highest signal contribution

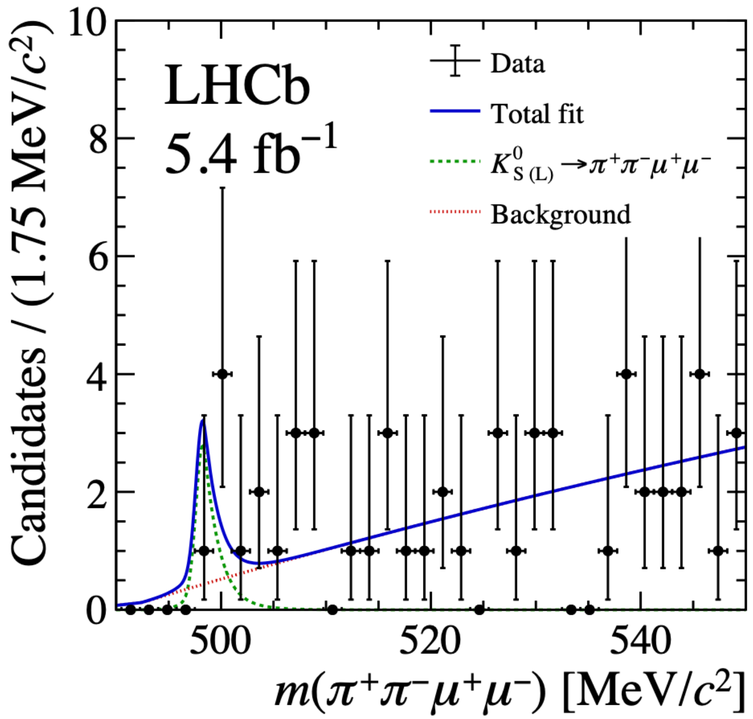


Kaon decays

LHCb-PAPER-2025-045
arXiv:2511.02619

- First search for $K_{S(L)} \to \pi\pi\mu\mu$, probing contributions from $K_{S(L)} \to \pi\pi\gamma^*$, sensitive to chiral perturbation theories
  - Heavily suppressed by kinematics in the SM
- Uses Run 2 data (2016-2018), enabled by new trigger line but still suffering from low trigger efficiency due to very soft final state particles
  - Clear candidate to benefit from the current fully software trigger scheme!
- Search performed using $K_S \to \pi\pi$ as normalisation mode, tight selection leaves only combinatorial background to be dealt with in the fit

$$\mathcal{B}(K^0_S \to \pi^+\pi^-\mu^+\mu^-) < 1.4 \times 10^{-9}$$
$$\mathcal{B}(K^0_L \to \pi^+\pi^-\mu^+\mu^-) < 6.6 \times 10^{-7}$$

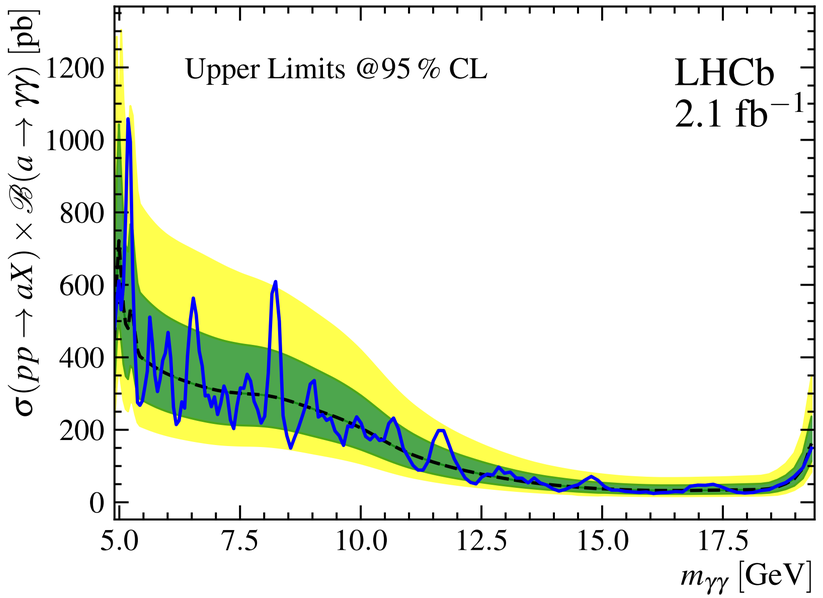


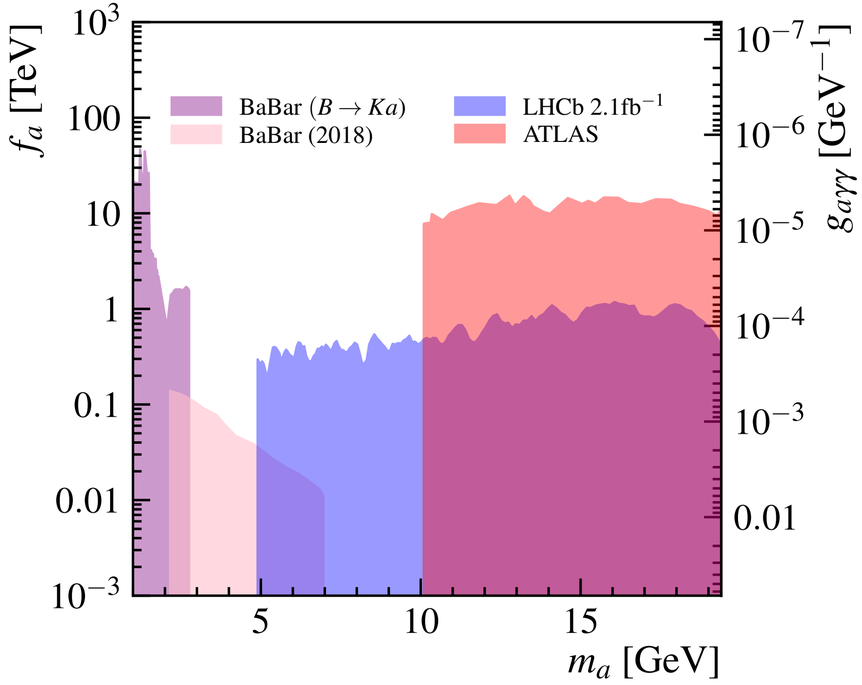
ALP to diphoton searches

LHCb-PAPER-2025-012
arXiv:2507.14390

- Search for Axion-Like particles decaying to a diphoton final state → first analysis with a **fully neutral final state at LHCb**
  - Multiple points of interest: dark matter candidates, couplings to a dark Higgs or composite Higgs models
  - Di-photon final state provides a much cleaner experimental signature than hadrons (or light jets)
  - Same sample allows to search for $B^0_{(s)} \to \gamma\gamma$ and to better study the $b\bar{b}$ bound state η_b
  - Analysis performed on 2018 data sample (trigger), with ~ 2 fb^{-1} and using $\eta \to \mu^+\mu^-\gamma$, $B^0 \to K^*\gamma$ and $B^0_s \to \phi\gamma$ as calibration and control modes

$$\mathcal{B}(B^0_s \to \gamma\gamma) < 2.7\,(2.7) \times 10^{-5},$$
$$\mathcal{B}(B^0 \to \gamma\gamma) < 0.83\,(0.79) \times 10^{-5}$$
$$\sigma(pp \to \eta_b X) \times \mathcal{B}(\eta_b \to \gamma\gamma) < 765\,(710)\ \text{pb}$$

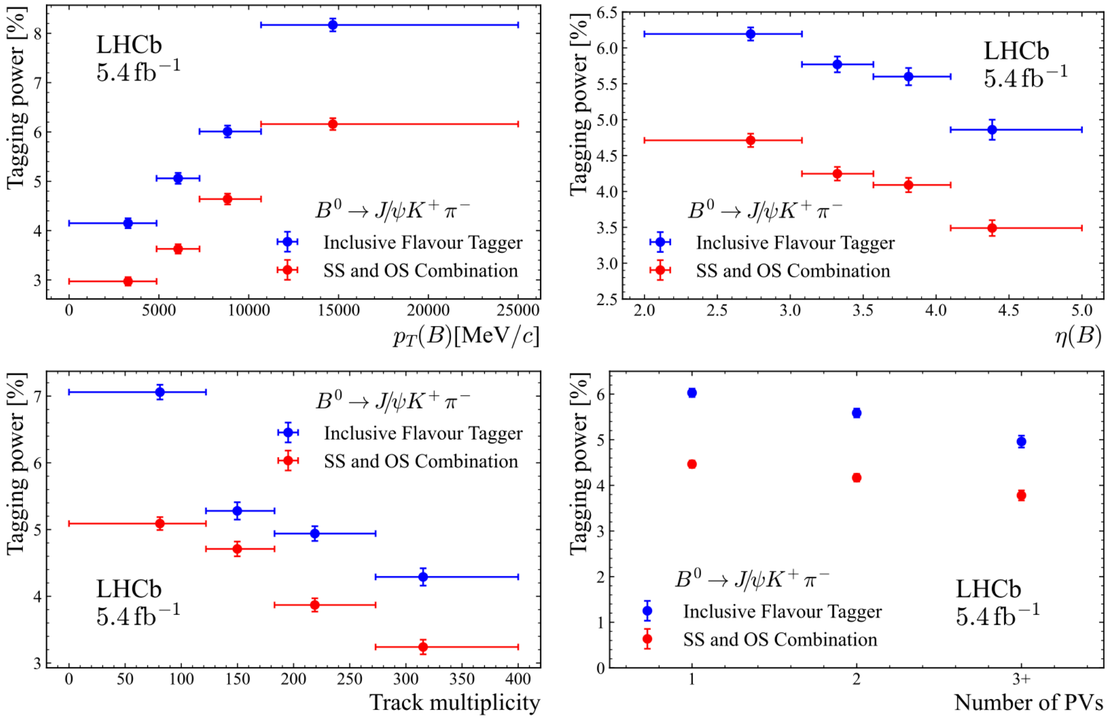




Inclusive Flavour tagging

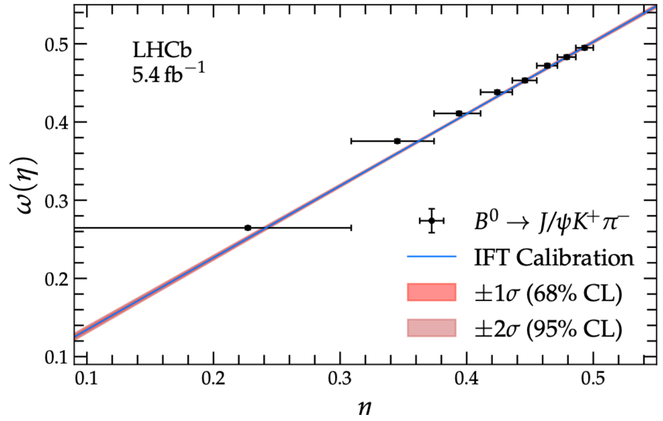
LHCb-PAPER-2025-024
arXiv:2508.20180

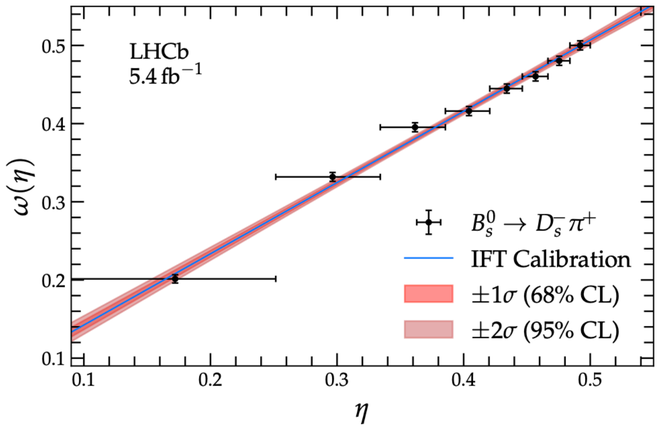
- Profiting from all tracks in the event, unlike classical Same Sign or Opposite Sign taggers
- Mis-tag probability calibrated on $B^0 \to J/\psi K^+\pi^-$ and $B_s^0 \to D_s^-\pi^+$, tagger trained on simulated signal samples
- Improvements channel dependent, but obtaining about 20-35% (in Run 2) improvement when compared to the combination of classical taggers.
- Based on DeepSets [arXiv:1703.06114]



← Performance comparison

Mistag calibration →



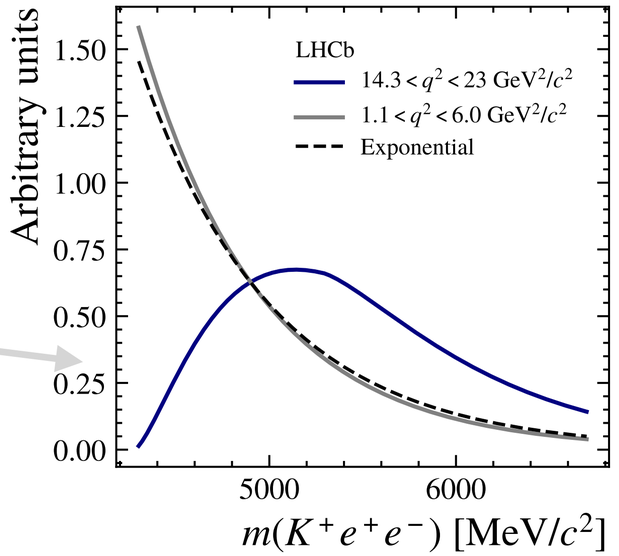


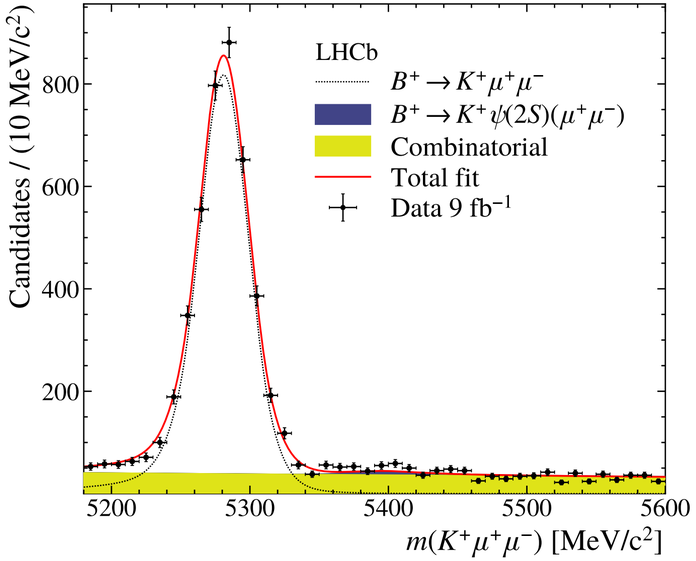
LFU: R_K at high q^2

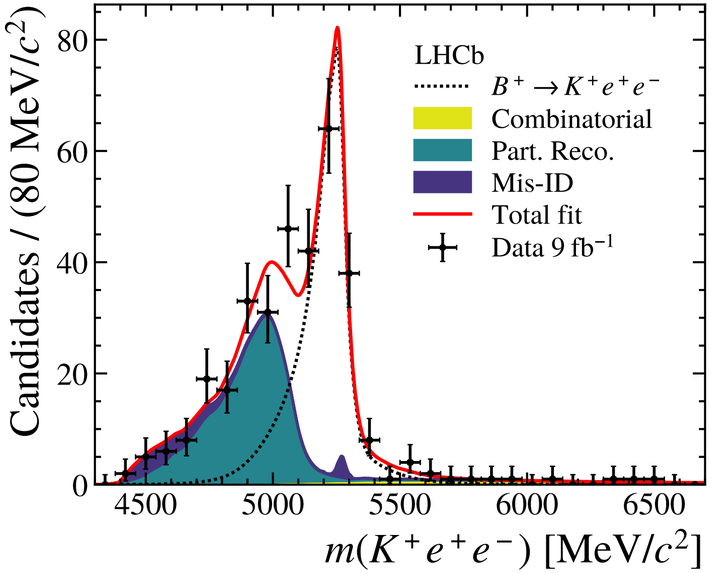
LHCb-PAPER-2024-056
arXiv:2505.03483
JHEP07(2025)198

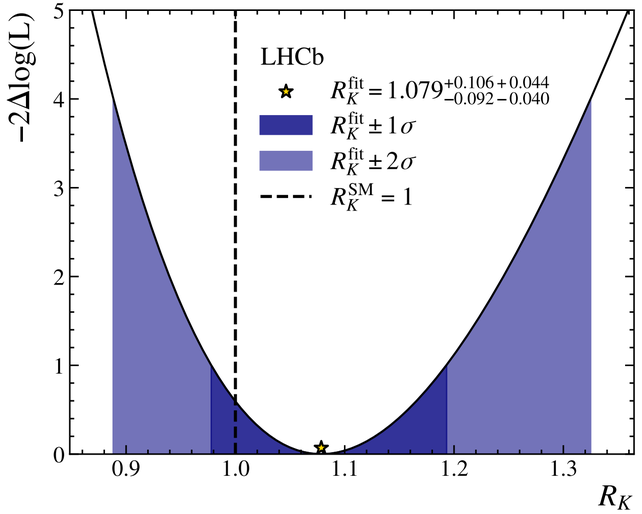
- Test of lepton universality in $B^\pm \to K^\pm \ell^+ \ell^-$ $(\ell = e, \mu)$ decays in region of dilepton mass-squared region $q^2 > 14.3\,\mathrm{GeV}^2/c^4$, using Run1+Run2 dataset ($9\,\mathrm{fb}^{-1}$)
- Challenges from electron bremsstrahlung corrections and distorted phase-space distribution at high q^2
- Ratio of branching fractions R_K compatible with SM prediction

$$R_K(q^2 > 14.3\ \mathrm{GeV}^2/c^4) = 1.079^{+0.106\ +0.044}_{-0.092\ -0.040}$$





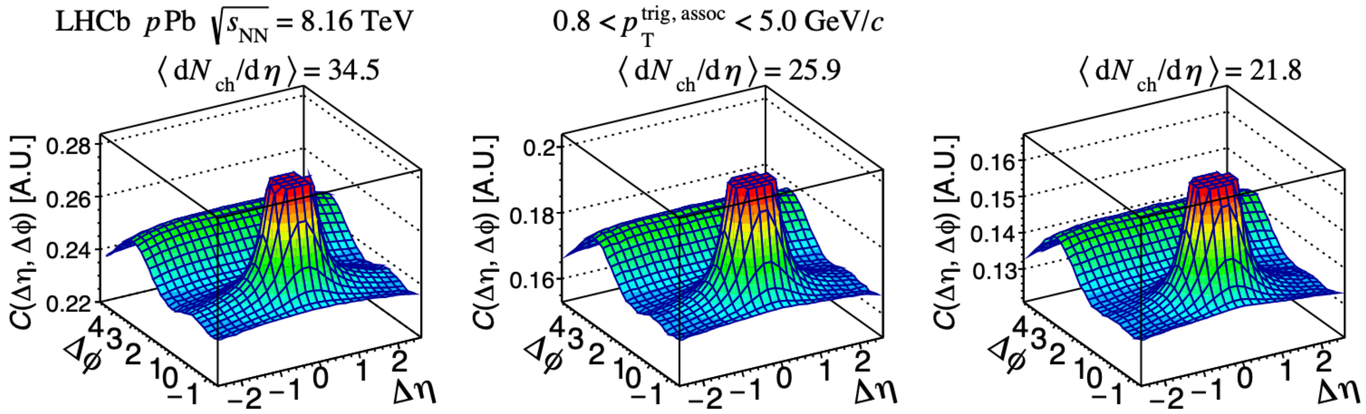


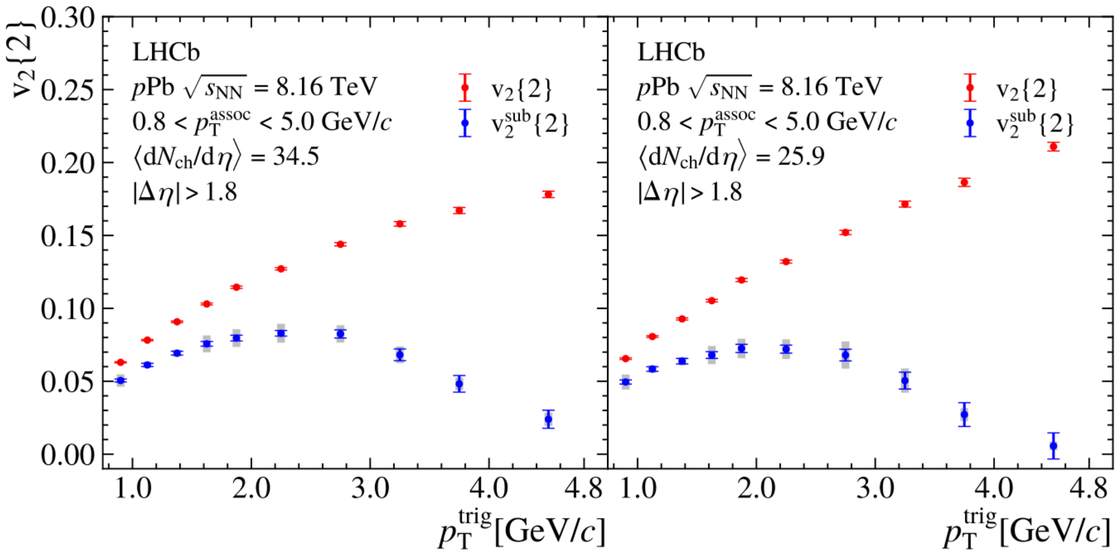


Collective flow in *p*Pb collisions

LHCb-PAPER-2025-003
arXiv:2505.09273

- New strategies to **study the dynamics of Quark-Gluon-Plasma**:
  - QGP behaves as a quasi-ideal fluid → can be described using hydrodynamic equations
  - The geometry of the colliding systems affects the pressure gradients in the QGP, modulating the azimuthal distribution of the produced particles
  - Angular distribution described with a Fourier expansion : second coefficient → elliptic flow, third →triangular flow, …
- First measurement of charged-particle flow harmonic coefficients in *p*Pb collisions (2016 data)
  - the elliptic flow is observed to increase with multiplicity
  - However, for a given multiplicity no significant differences are observed between the forward and backward configurations (*p*Pb-Pb*p*).





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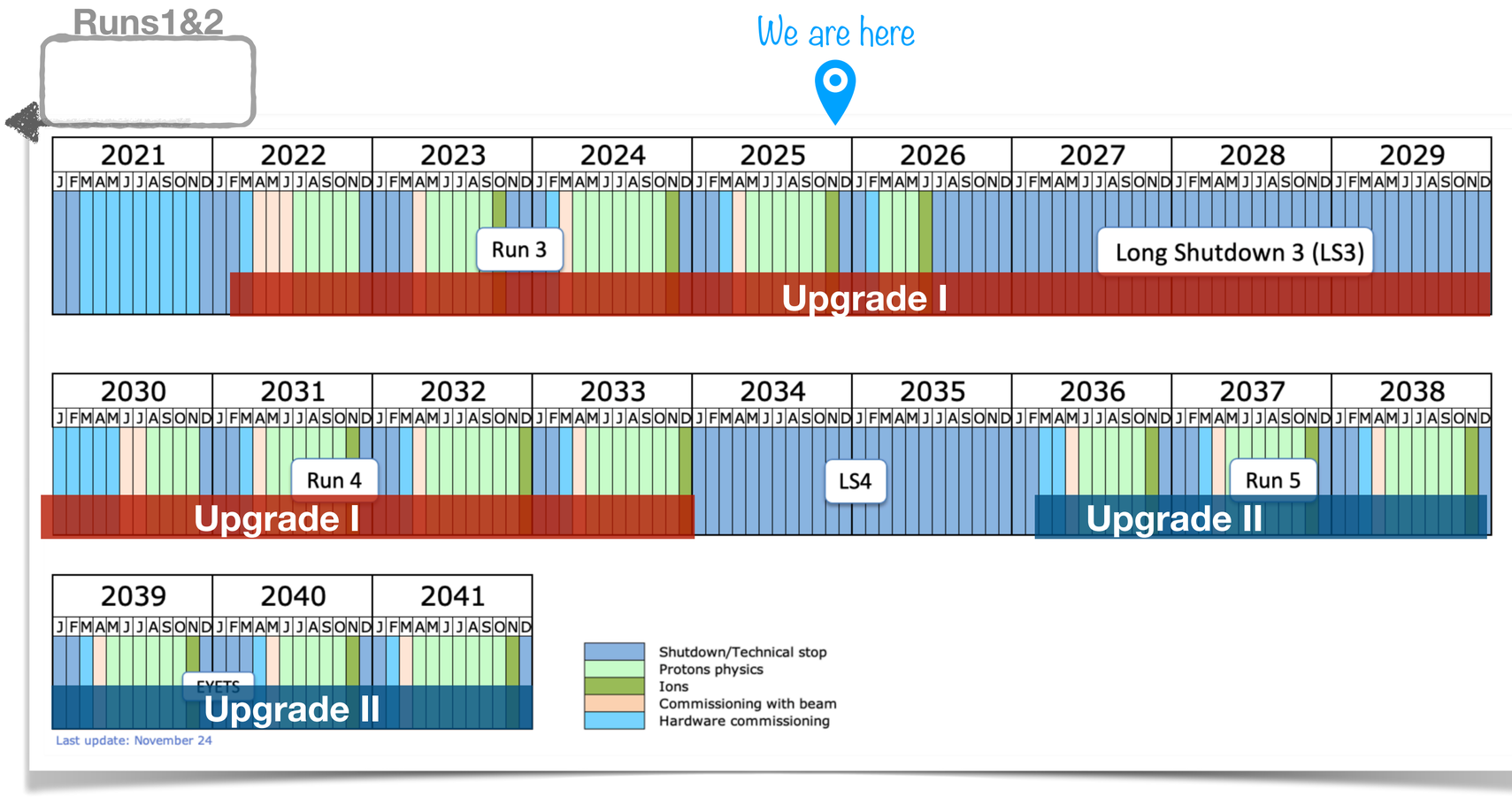
Increasing the data sample

- Main factor in Run 2: higher $\sqrt{s} \rightarrow$ higher $\sigma_{bb} \rightarrow$ more data
- After Run 2: increase the instantaneous luminosity (x5) → more collisions per bunch crossing
  - While keeping the performance!
  - Fully software trigger (x ~2 hadronic modes)
    - total of factor >10 increase relative to Run2

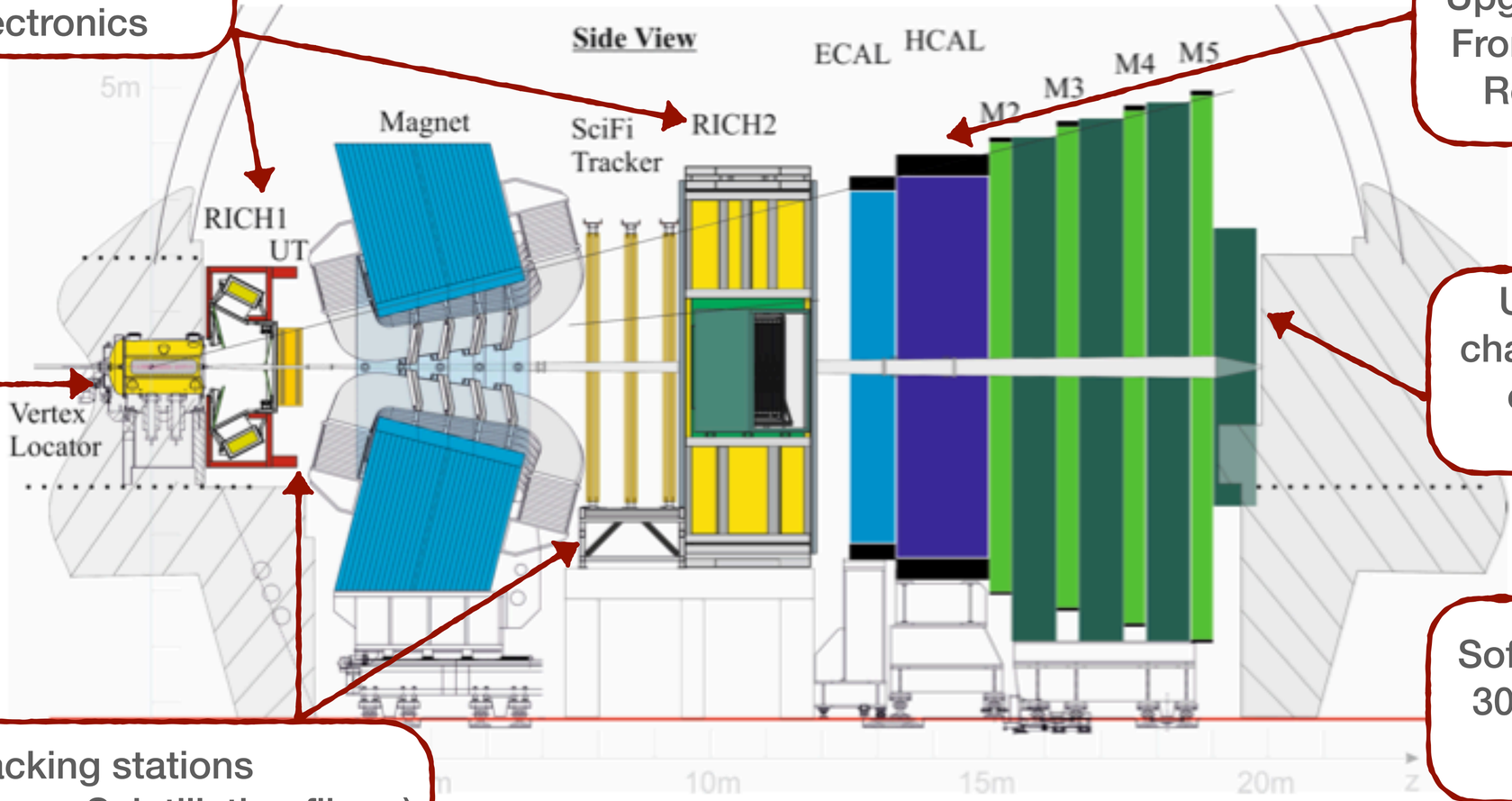


LHC schedule: lhc-commissioning.web.cern.ch

The LHCb detector in Upgrade I (running now)

New RICH PMTs
New electronics

Upgraded Calorimeter
Front-End electronics
Removed SPS/PS



New VELO
Pixels

Upgraded muon
chambers Front-End
electronics, M1
removal

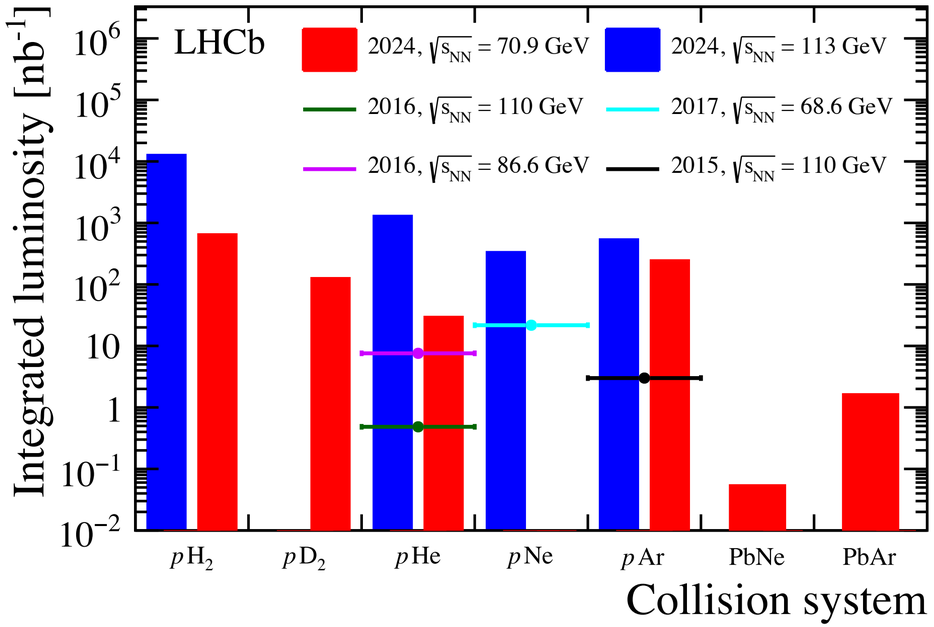
Software only trigger
30 MHz processing

New Tracking stations
(Silicon Microstrips + Scintillating fibres)

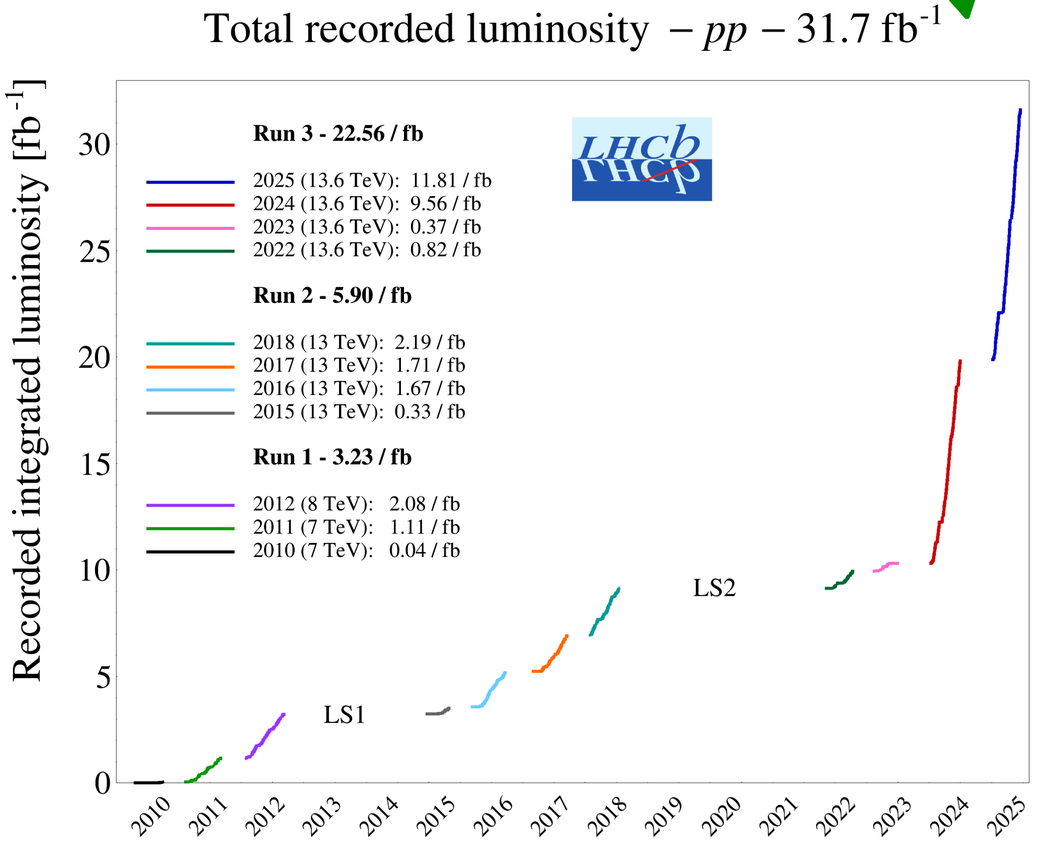
Peak luminosity : $4 \times 10^{32} - 2 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

LHCb Upgrade I
arXiv:2305.10515

Running the new detector



Fixed target, injecting different gasses in the collision region



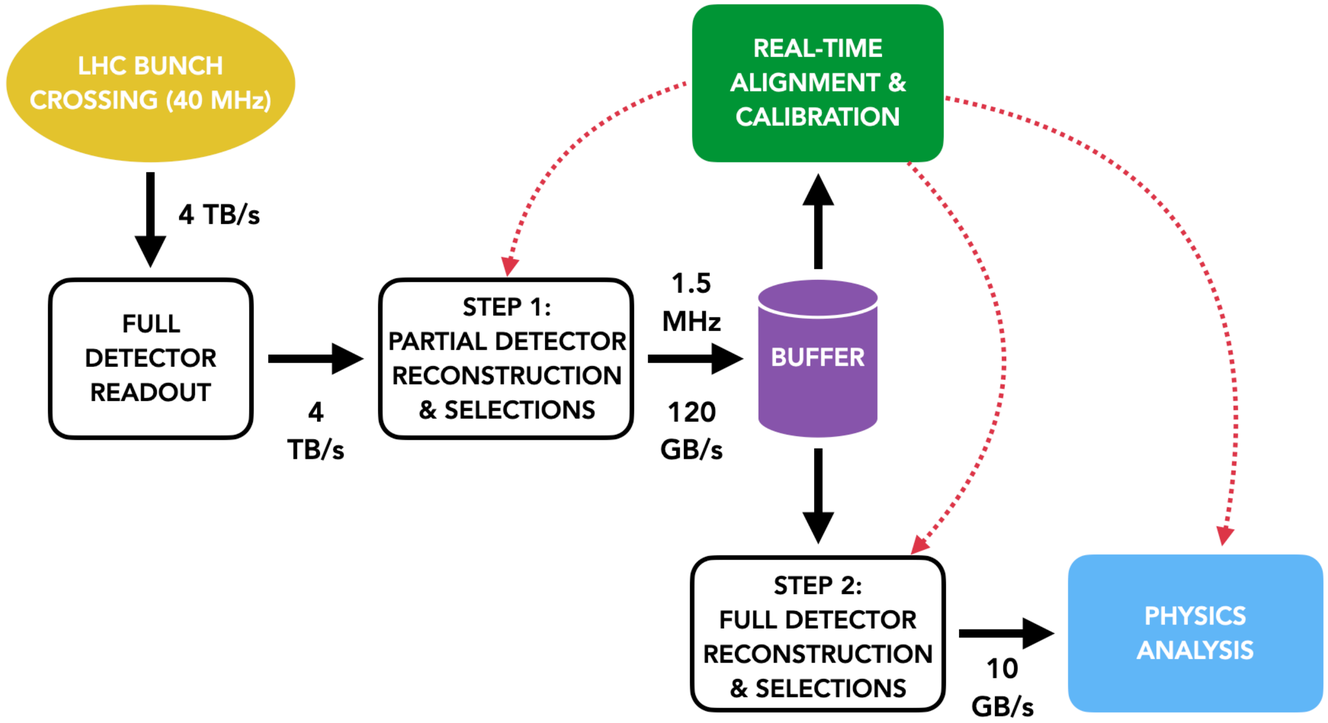
LHCb Runs 1 and 2 pp data sample: (2011 - 2018) ~ 9 fb^{-1}

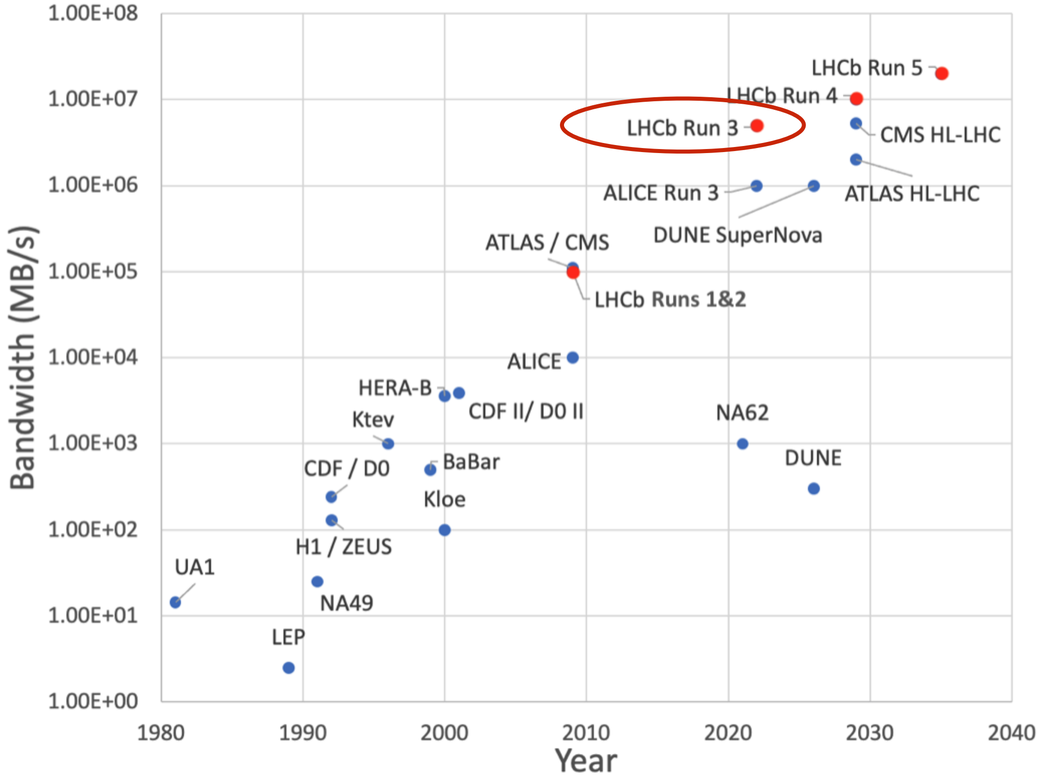
LHCb Run 3 pp data sample (2022 - ongoing) ~ 22.5 fb^{-1}

LHCb Operations: https://lbgroups.cern.ch/online/OperationsPlots/index.htm

LHCb Upgrade: fully software trigger

- All subdetectors read out at 40MHz → full software trigger

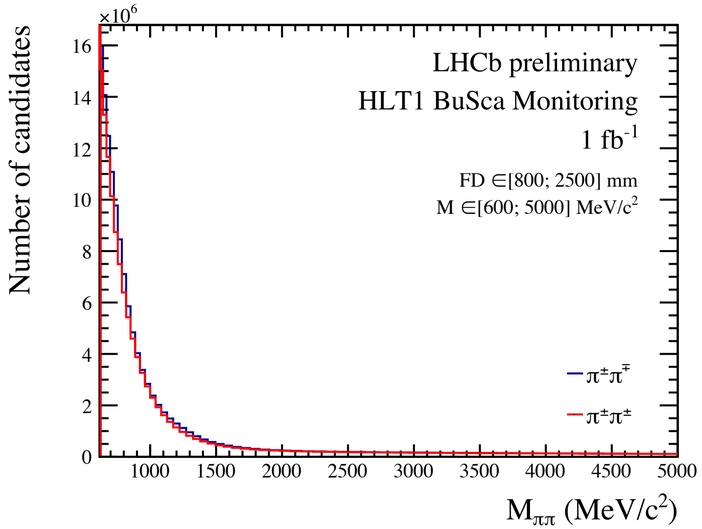


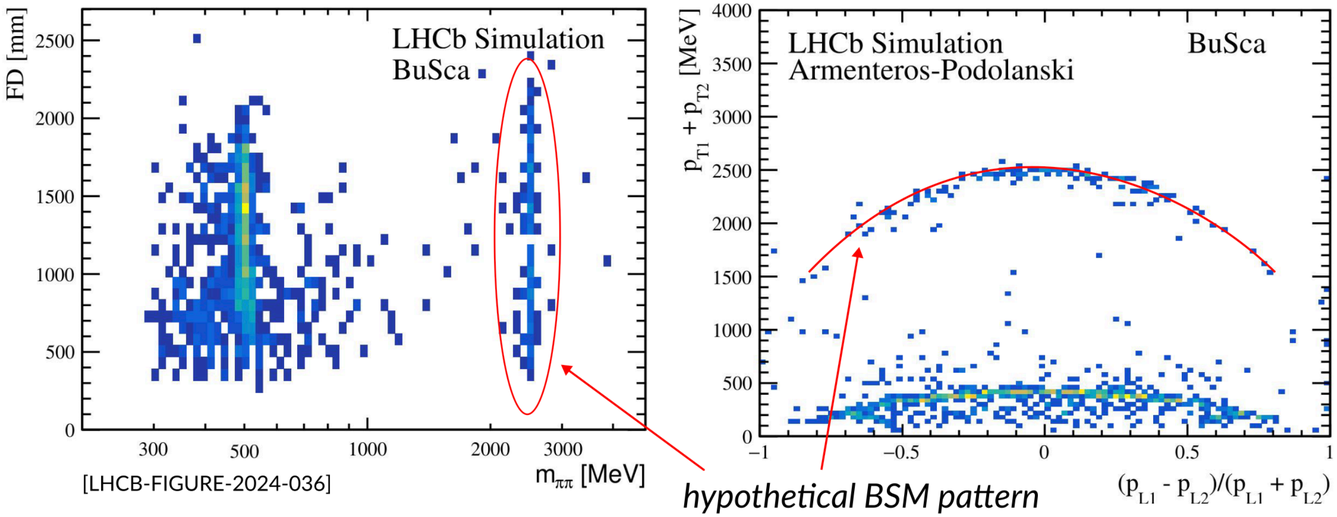


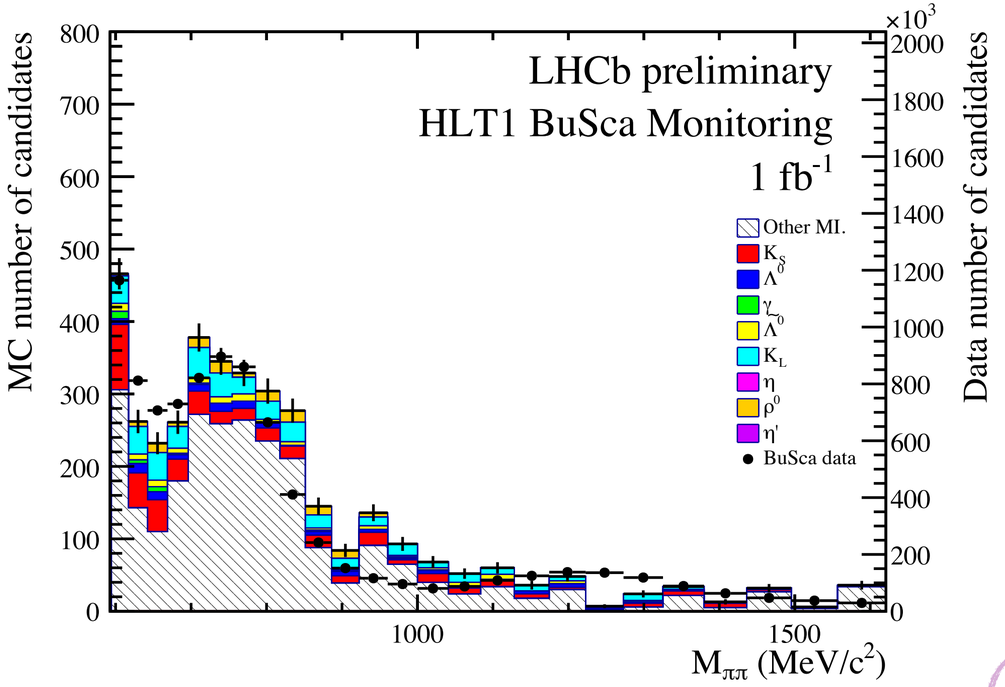
Highest throughput of any HEP experiment

BusCa: going after LLPs

- A Buffer Scanner, designed to search for LLPs using Downstream tracks (no VELO)
- Model independent, running at HLT1 level
- Provides 1D/2D histograms based on flight distance (vertexing) and preliminary kinematic estimations
- Current focus on understanding the data: light resonances, strange decays, known backgrounds…
  - Good agreement with simulation from expected backgrounds
  - Results will guide future development of trigger lines



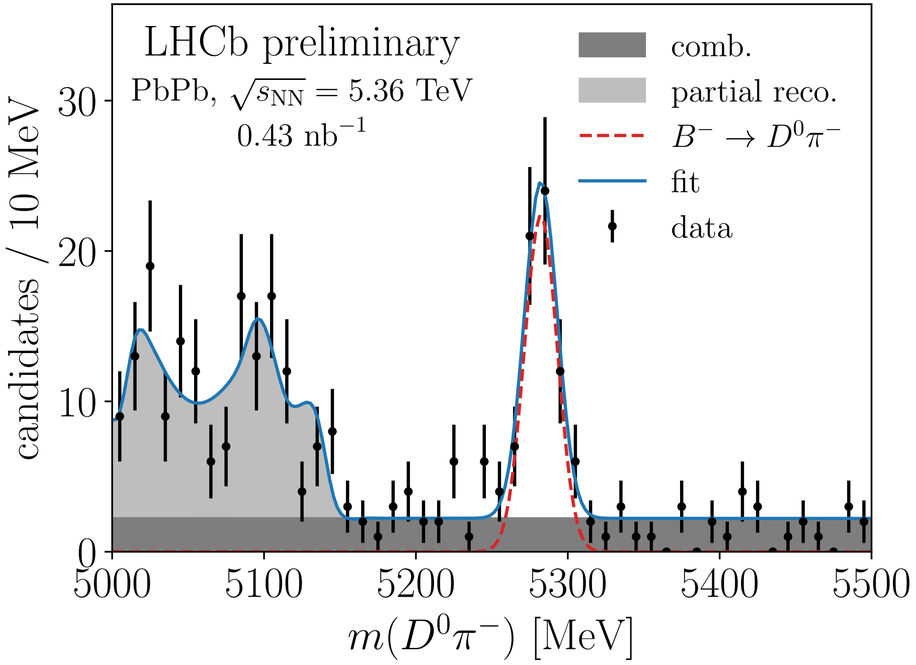




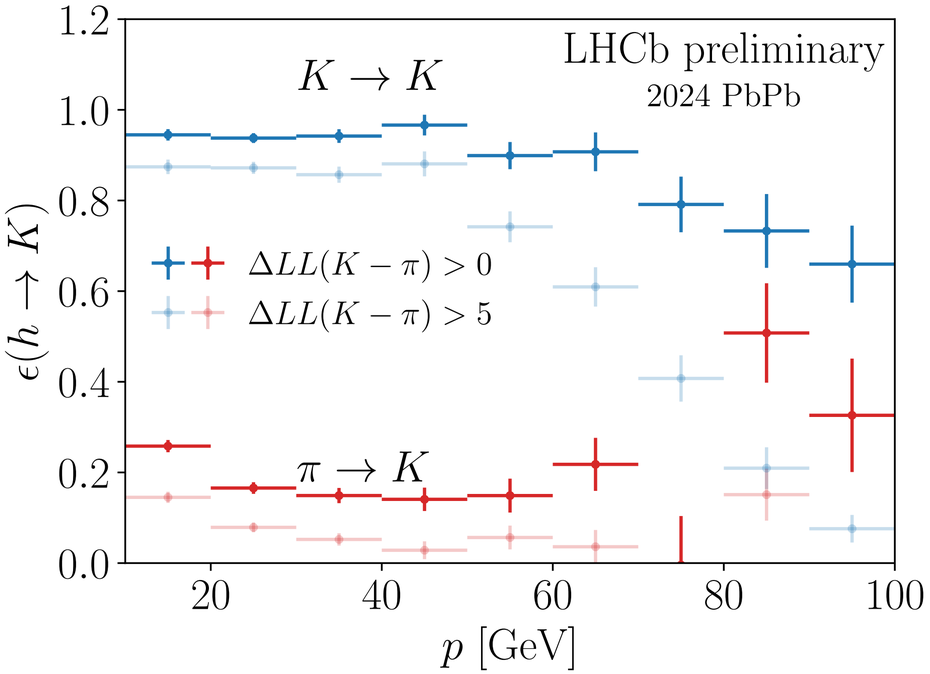
Preliminary studies of *PbPb* 2024 run

- Ongoing analysis of the 2024 PbPb run: $0.43\,\mathrm{nb}^{-1}$ at $\sqrt{s_{\mathrm{NN}}} = 5.36\,\mathrm{TeV}$
- Good charged kaon identification at $30\% - 50\,\%$ centrality
  - (in Run2, only access to 65% centrality)
- Clear signals of open charm ($D^{\pm}$, $D_s^{\pm}$) and beauty ($B^{\pm}$) in *PbPb* collisions

LHCb-FIGURE-2025-004



LHCb-FIGURE-2025-005



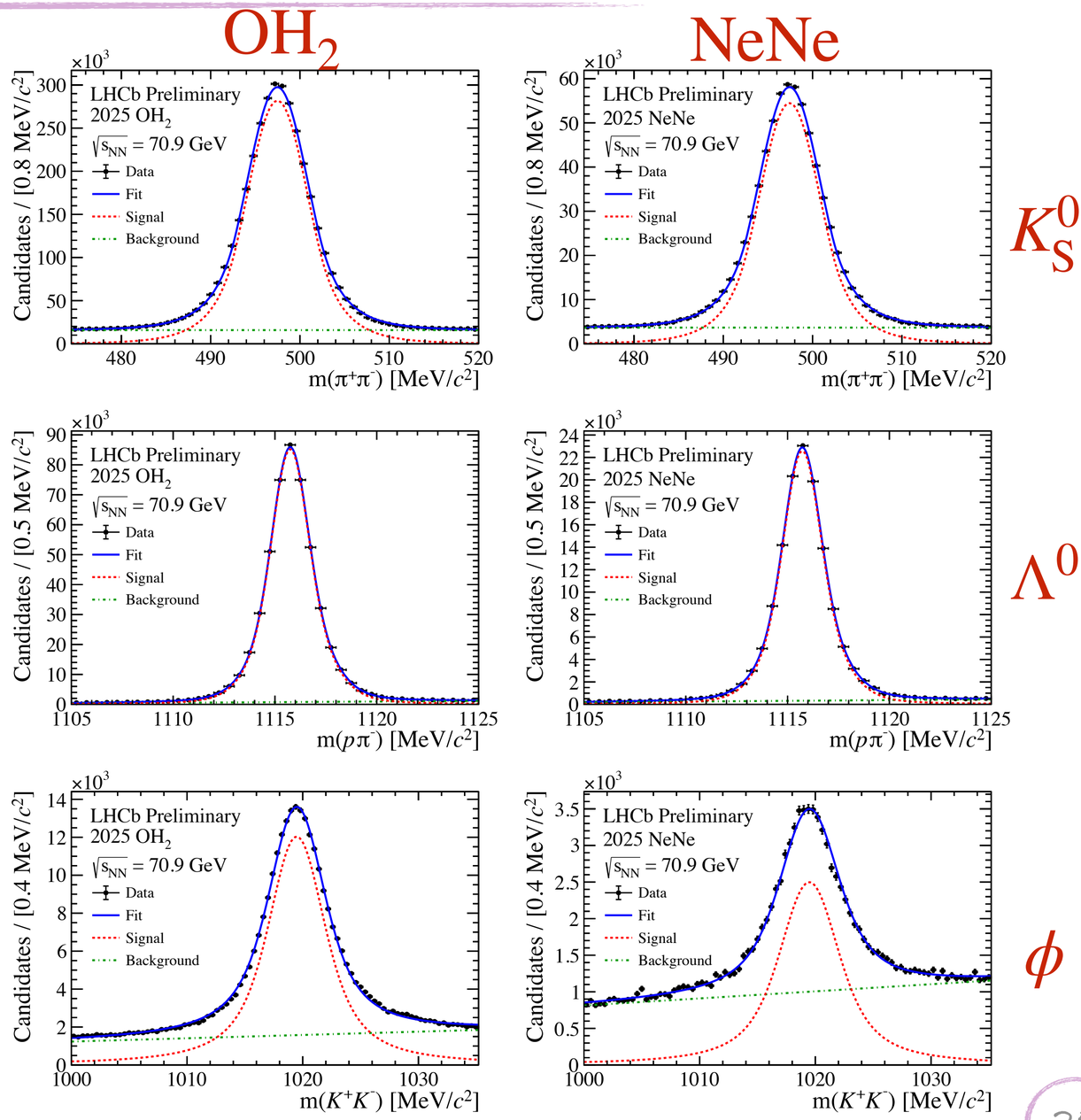
Heavy flavour in fixed-target data

LHCb-FIGURE-2025-019

- Fixed-target data collected with SMOG-2 system
  - gas injection in primary LHC vacuum
  - collect data with various gas targets

- Example of signal from fixed-target data collected during 2025 Oxygen and Neon runs

$$K^0_S \to \pi^+\pi^-$$
$$\Lambda^0 \to p\pi^-$$
$$\phi \to K^+K^-$$



Electrons in Run 3

- x5 visible interactions → x5 tracks: Run 3 has a harsher environment.

Hand-wavy math

✓ **Improved vertexing and tracking**, better efficiency expected in track matching

✓ **Removal of hardware trigger**: large efficiency increase

✓ Extra: better kinematic overlap with the muon samples (better control of the systematics in ratios)

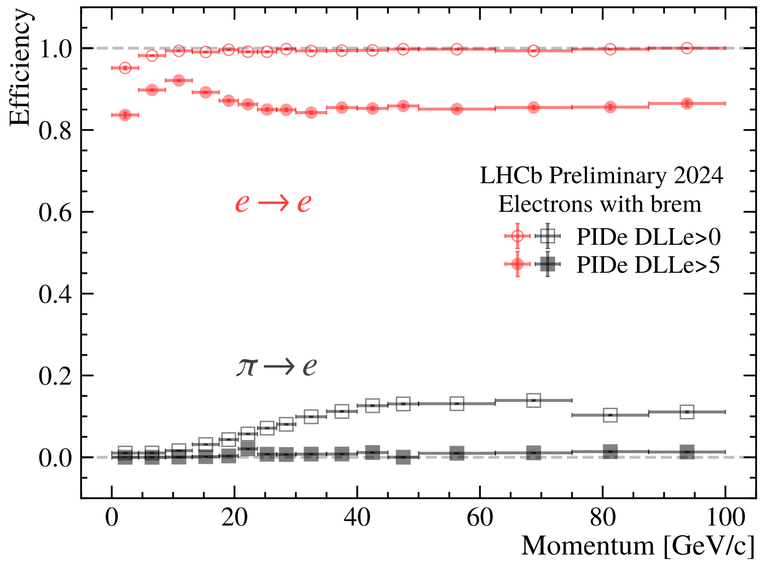
◉ Larger occupancy implies larger backgrounds in a busier calorimeter

◉ Momentum and mass resolution with Bremsstrahlung recovery become more challenging

✓ **Brem. recovery algorithms have been re-written and improved to help coping**

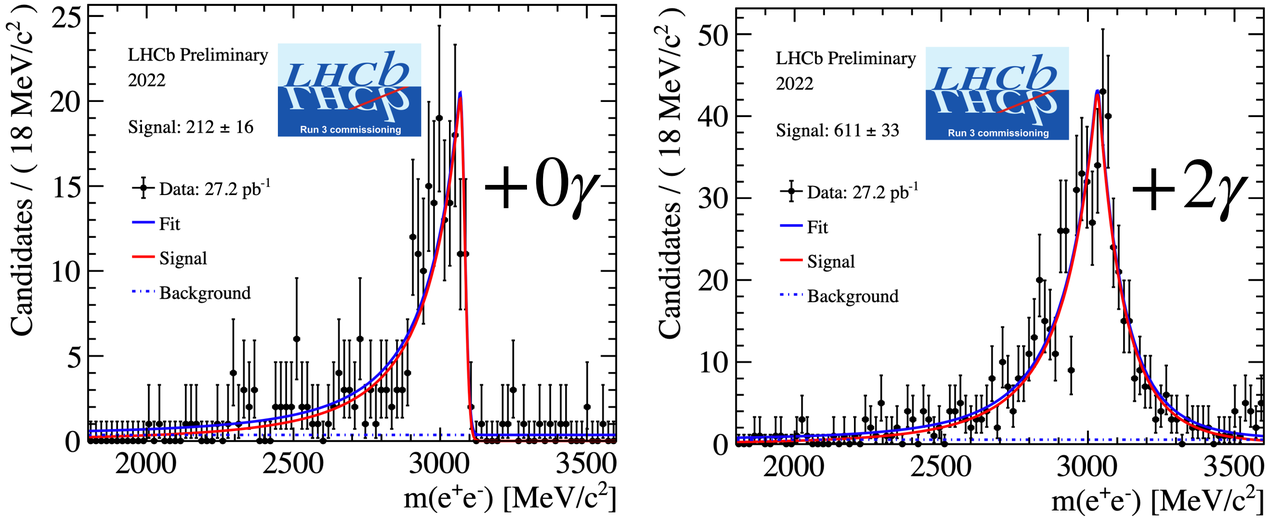
✓ Quicker access to higher level information to make selections more efficient

LHCb-FIGURE-2024-038



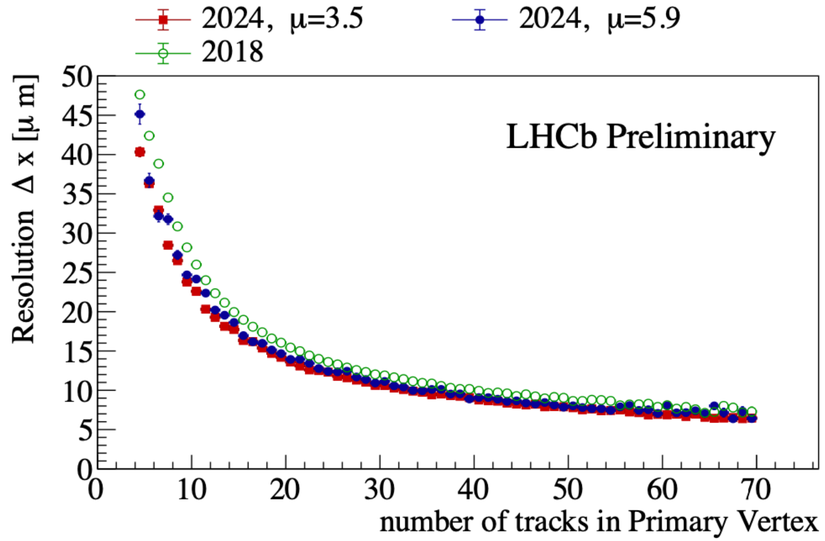
$J/\psi \to ee$

LHCb-FIGURE-2023-010

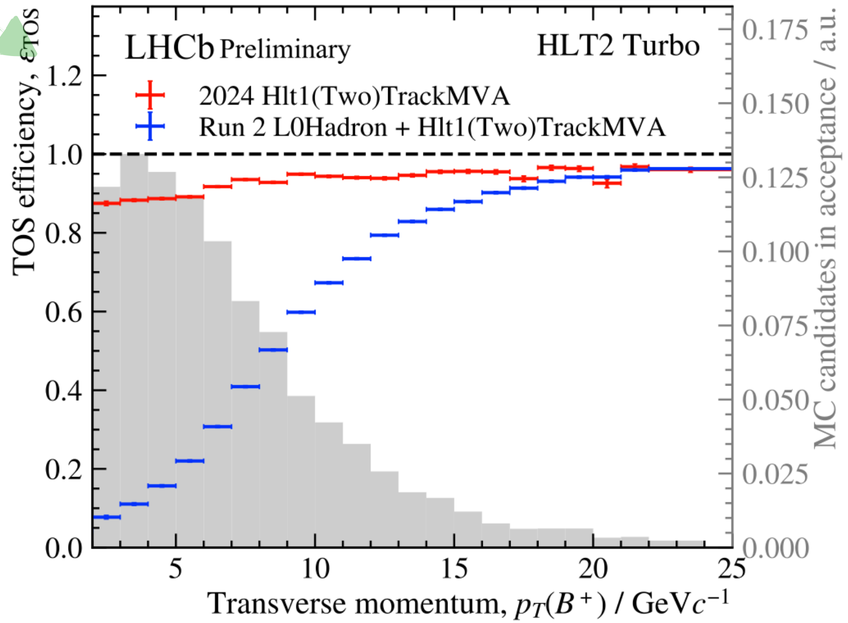


More on LHCb's Run3 performance

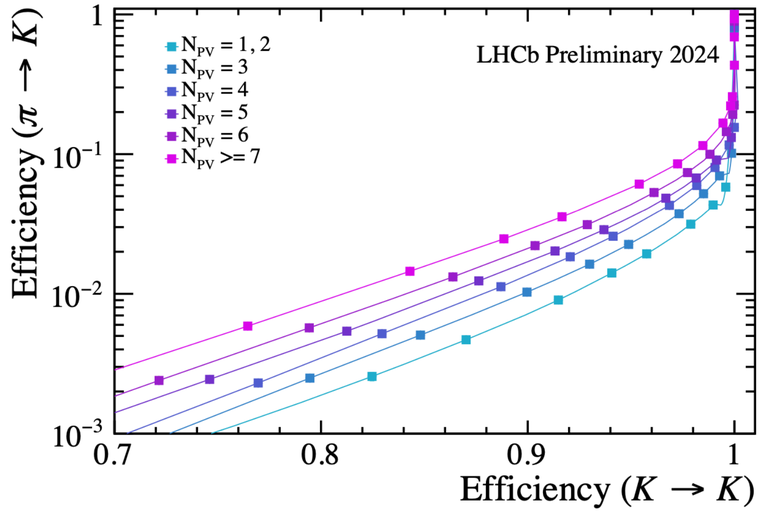
- Good performance of the vertexing
- New software trigger, huge gain in softer tracks
- Particle identification efficiency remains well behaved at high detector occupancy



LHCb-FIGURE-2024-030

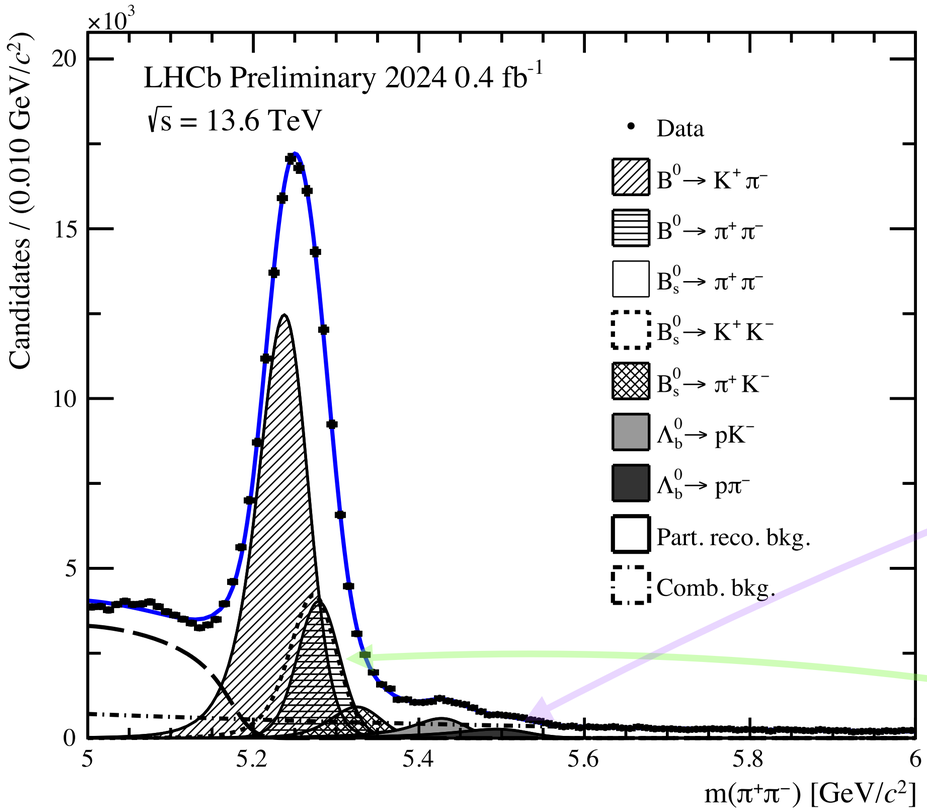


LHCb-FIGURE-2024-031

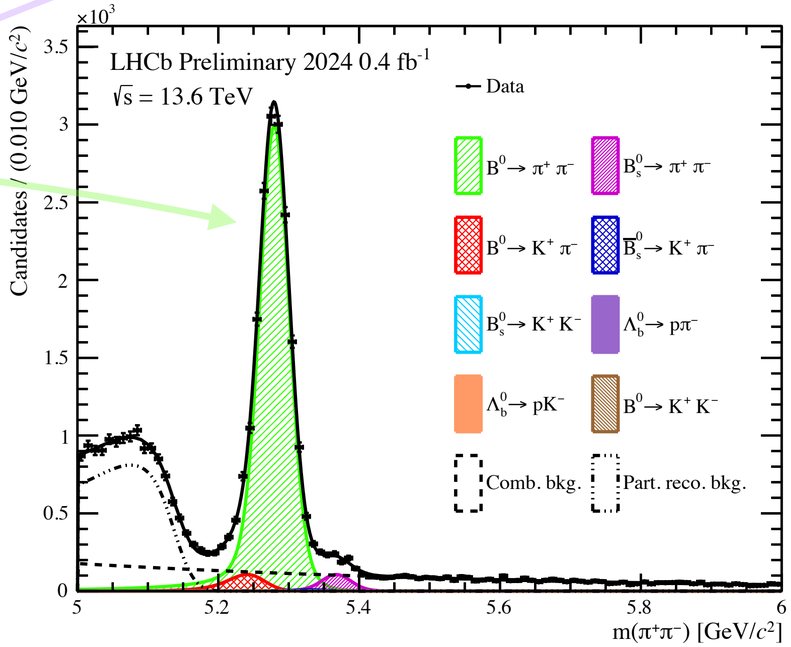


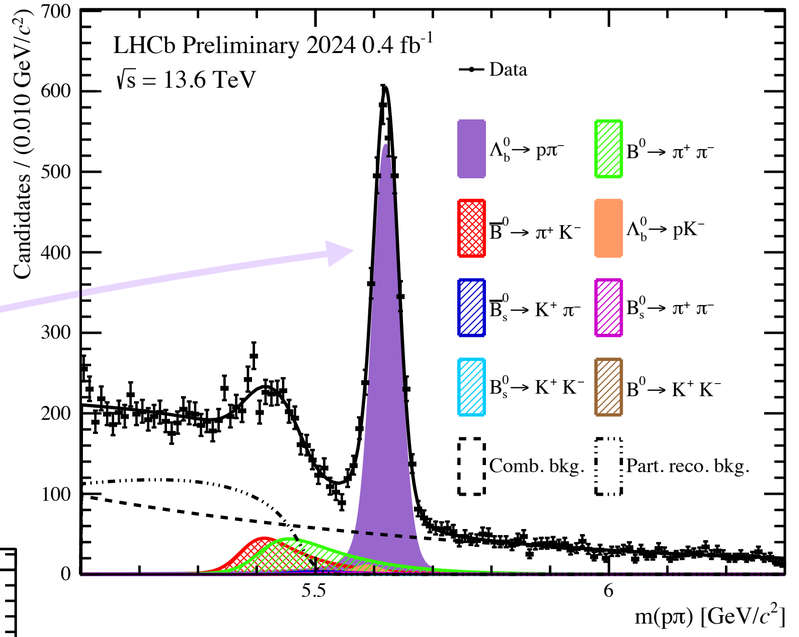
Excellent PID!

LHCb-FIGURE-2025-016



No PID applied



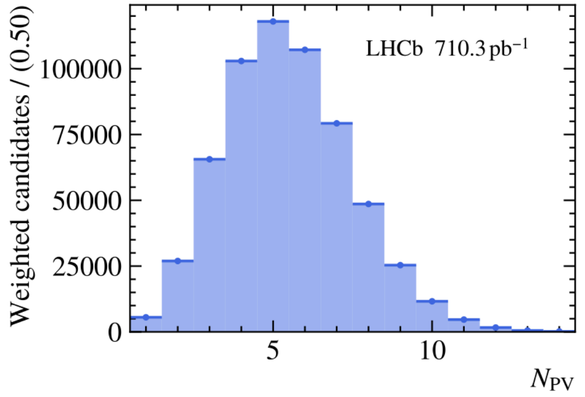


PID selections

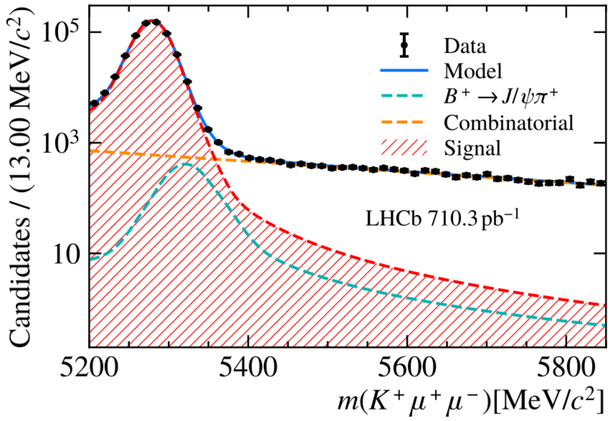
Angular analysis of $B^+ \to K^+ J/\psi(\to \mu^+\mu^-)$

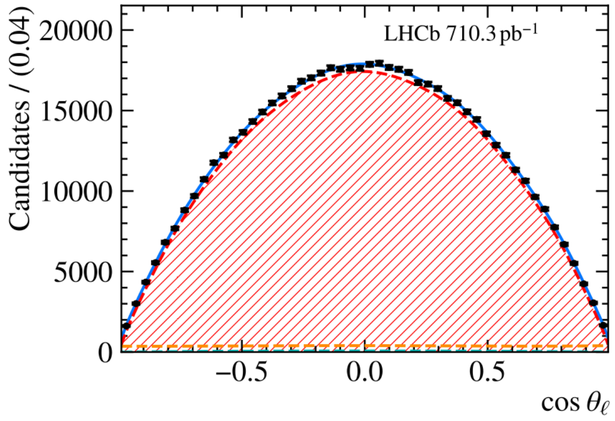
LHCb-PAPER-2025-040
(In preparation)

- Angular distribution parameterised by the forward-backward asymmetry, A_{FB}, and the flatness parameter,F_H, constrained by angular momentum conservation
  - Very well defined measurement to check understanding of new detector
  - Using 1.1 fb^{-1} of data collected in October 2024

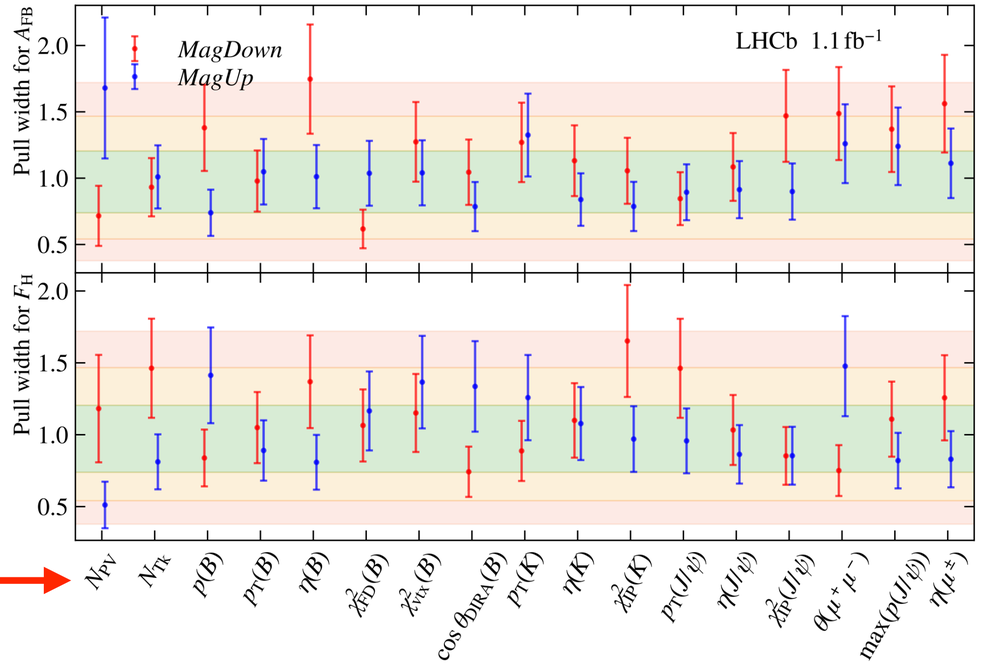


$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta_\ell} = \frac{3}{4}(1-F_{\mathrm{H}})(1-\cos^2\theta_\ell) + \frac{1}{2}F_{\mathrm{H}} + A_{\mathrm{FB}}\cos\theta_\ell$$





Excellent stability!



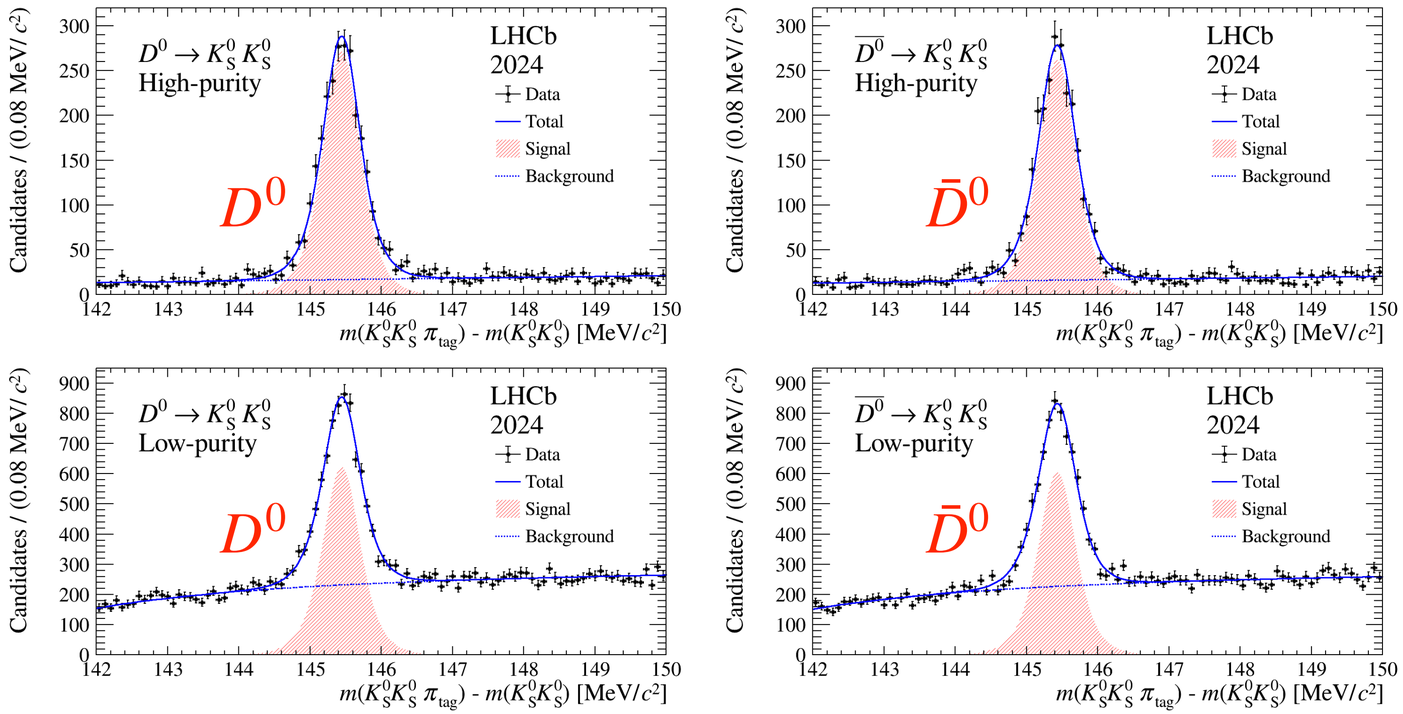
Differential variation of the observables as a function of 17 test variables

CPV in the Charm sector with Run3 data

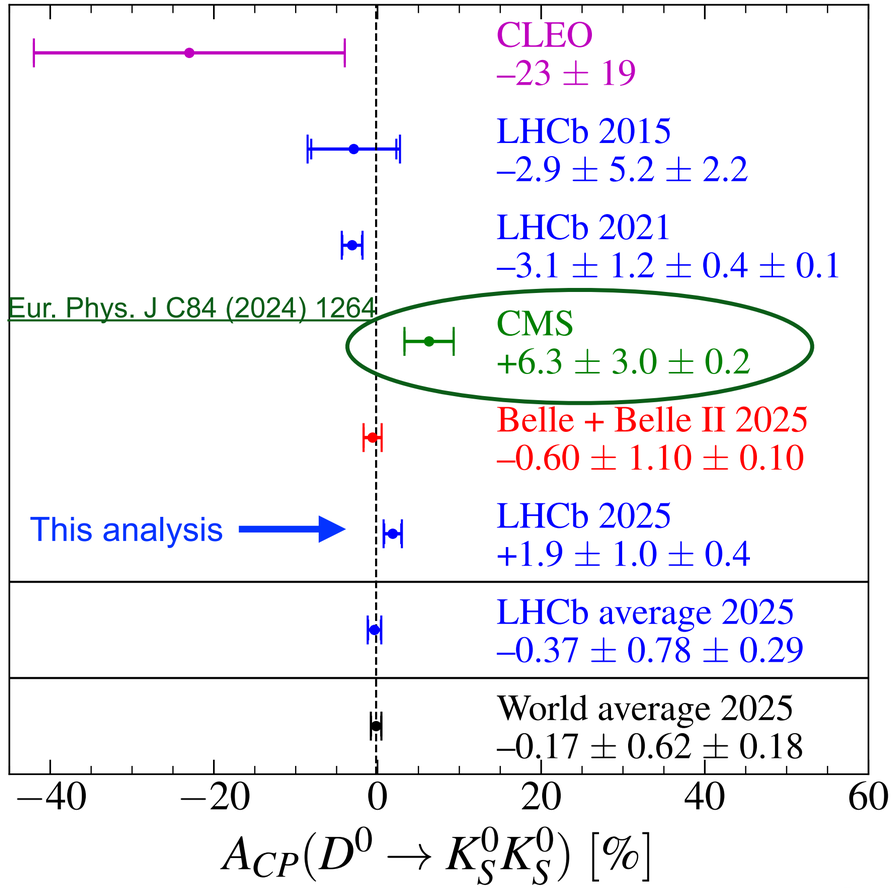
LHCb-PAPER-2025-036
arXiv:2510.14732

- Study of CPV in the up-type quark sector by measuring $A_{CP}(D^0 \to K^0_S K^0_S)$
- $D^0/\overline{D}^0$ tagged by accompanying pion $D^{*+} \to D^0\pi^+$: soft tagging pion π^+ could introduce asymmetries
- $D^0 \to K^0_S\pi^+\pi^-$ used as control mode and tagged with the same method as the signal

Define two categories with different purities according to a MVA classifier



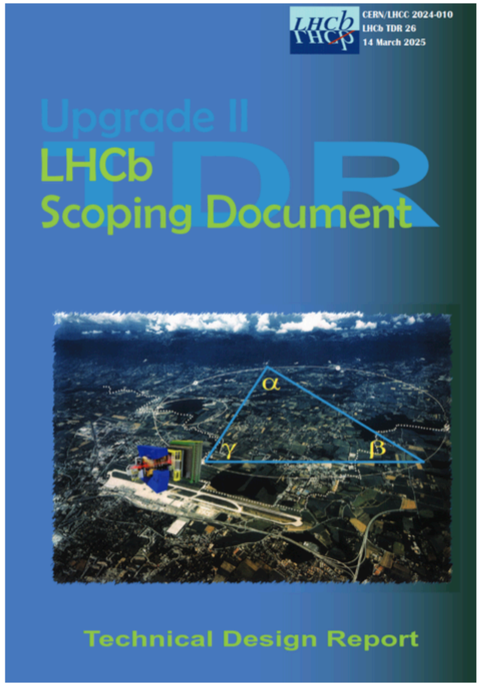
$$A_{CP}(D^0 \to K^0_S K^0_S) = (1.86 \pm 1.04 \pm 0.41)\,\%$$



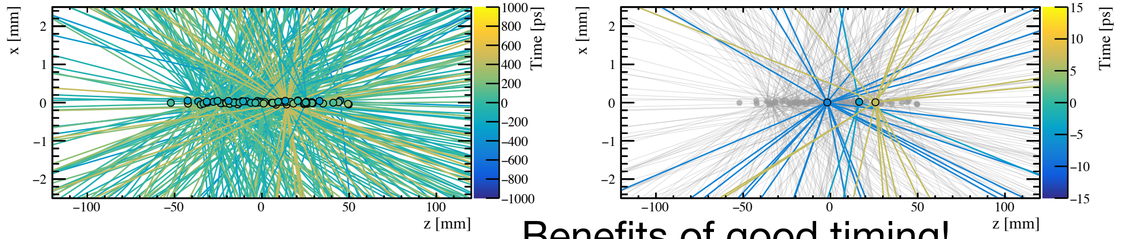
The future: LHCb Upgrade 2

- Additional challenges: much higher occupancy per event and track candidates, as well as radiation!
  - Requirement to include timing information to correctly assign tracks to vertices
  - The scientific review of the LHCb Upgrade II Scoping Document has been concluded by the LHC Committee, and the CERN Research Board has endorsed their conclusions → “middle” scenario recommended
    - Technical Design Reports for the sub-detectors are the next big milestone! To be delivered in 2026.
    - **Target data sample to be collected: 300** fb^{-1}
- **Significant Spanish contributions to the VELO, SciFi, CALO and Trigger&Software (reconstruction and PID) projects !!**

LHCb Scoping Document
CDS:LHCb-TDR-026



LHCb Upgrade II
CDS:LHCb-TDR-023

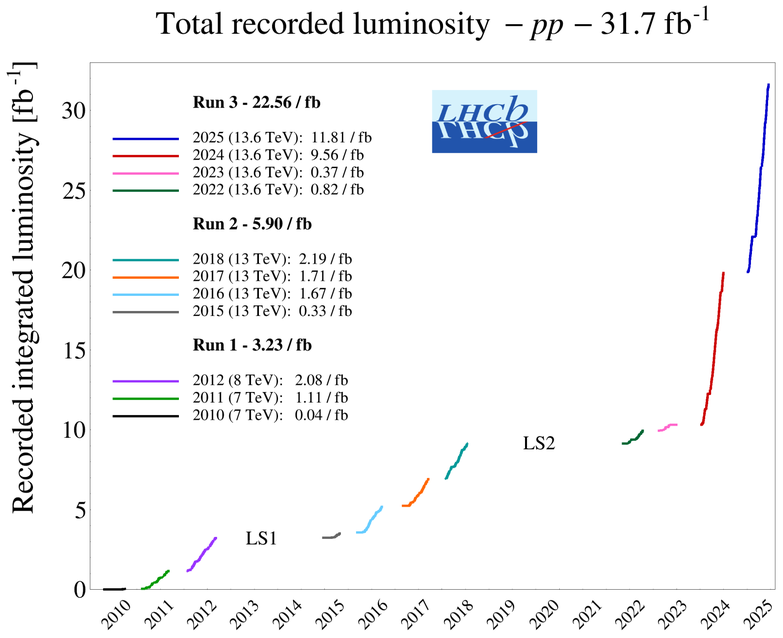


Benefits of good timing!

Upgrade II Peak luminosity : $1 - 1.5 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Summary

- Publishing highly specialised analyses → experience + new developments
- Physics case keeps expanding
- Available sample sizes still constrain many analyses, updates and improvements to be expected with more data
- Data taking with the upgraded detector proceeding very well
- Upgrade 2 project quickly evolving!



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LHCb has ~1800 members, ~1200 authors.

~39 (excluding students) in Spanish institutions!