CERN-RRB-2024-094

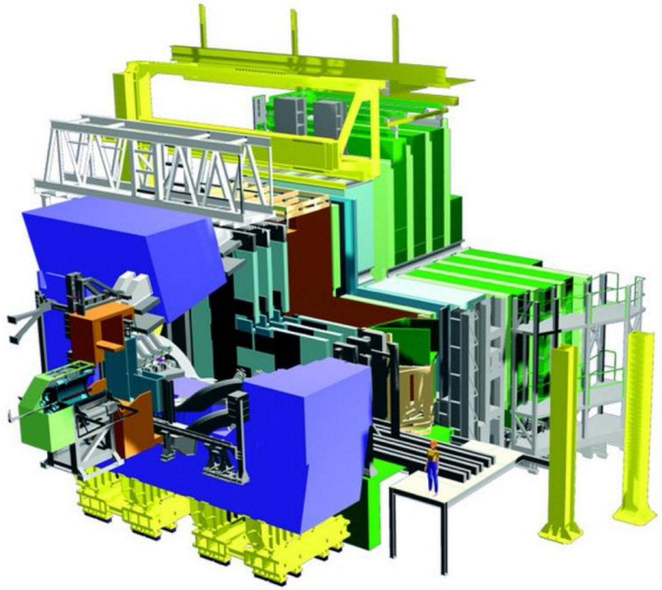
Status of LHCb

Vincenzo Vagnoni (INFN Bologna, CERN)

for the LHCb collaboration

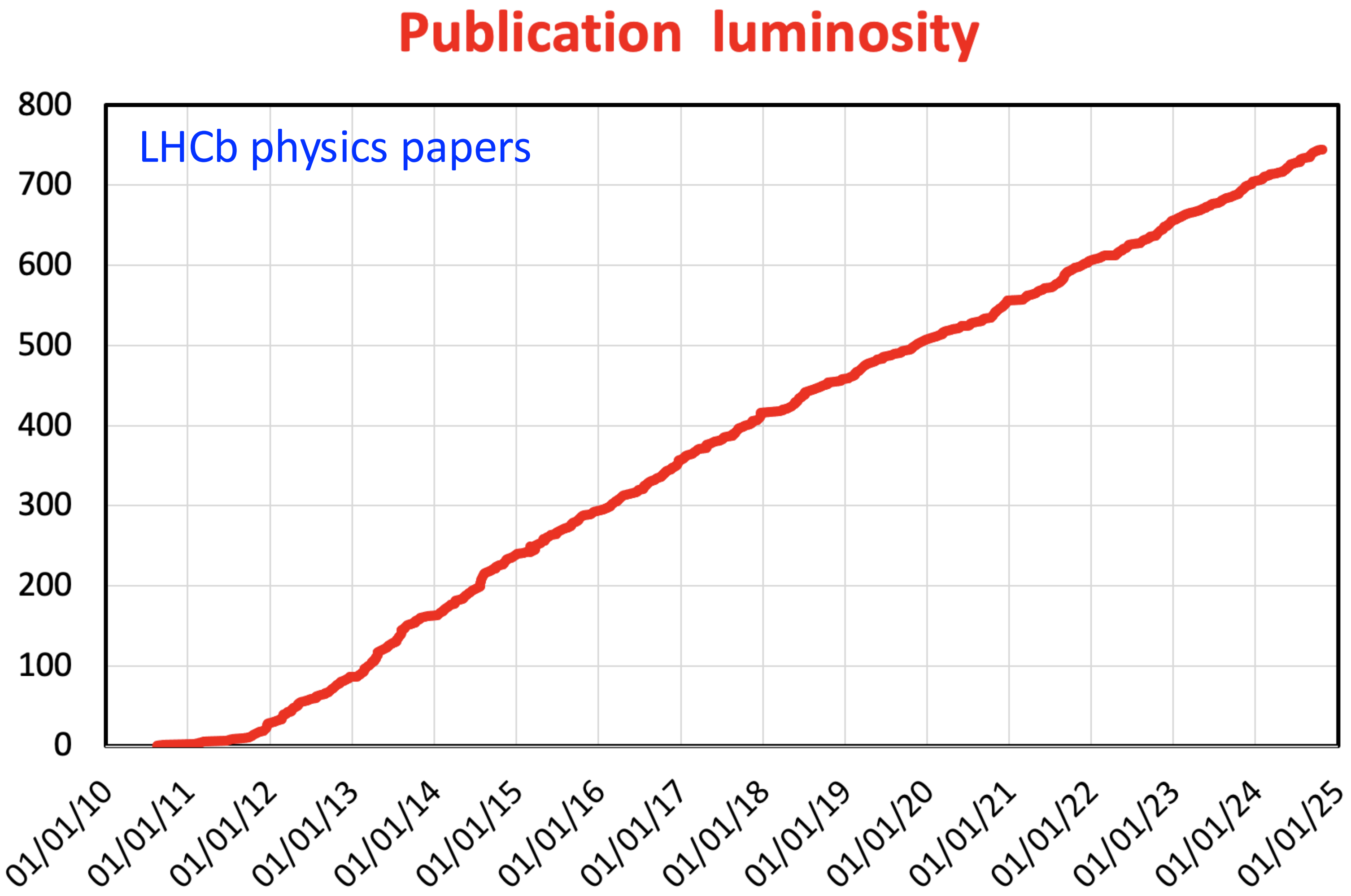
29th October 2024, CERN RRB meeting

LHCb collaboration



- As of today, 1771 members from 108 institutes in 25 countries
  - There were 1710 from 100 institutes in 22 countries when we met last April → the collaboration continues to grow at a steady pace

LHCb publication rate

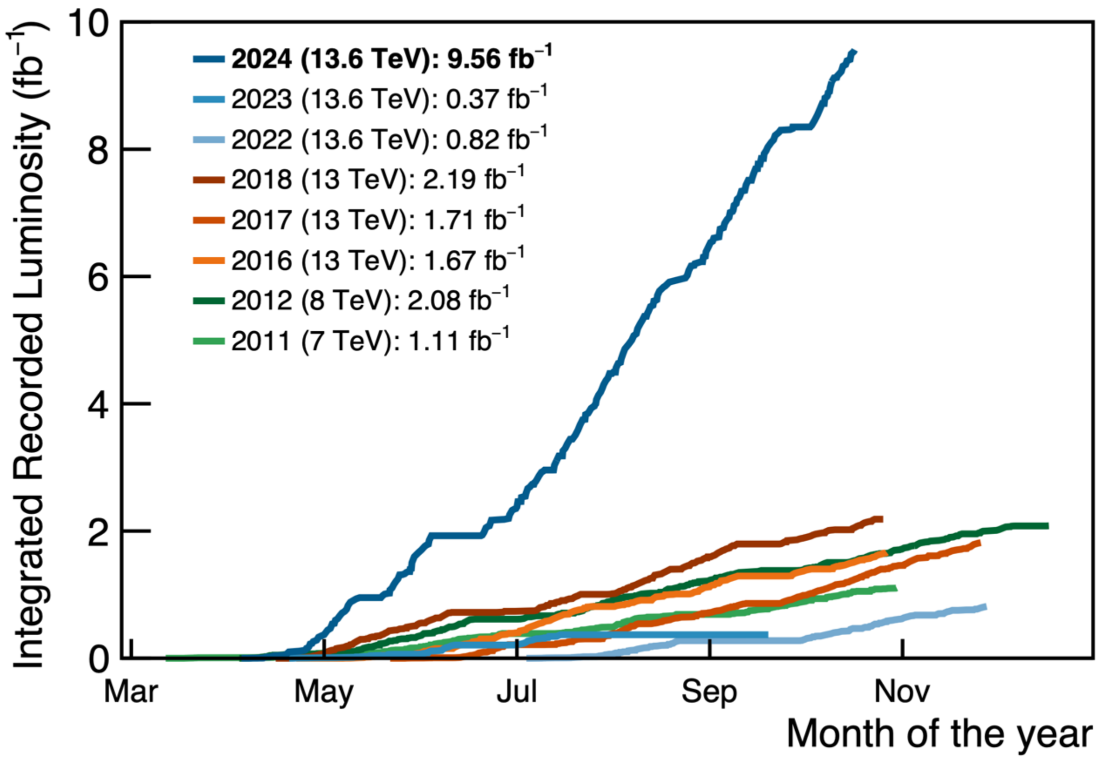


- 745 physics papers produced by LHCb as of today
  - Not including collaboration-wide performance papers
- The number of papers continues to increase in a linear fashion over time, and we haven't yet started to publish with Run-3 data

2024 data taking
(so far)

This year's 13.6 TeV *pp* data taking

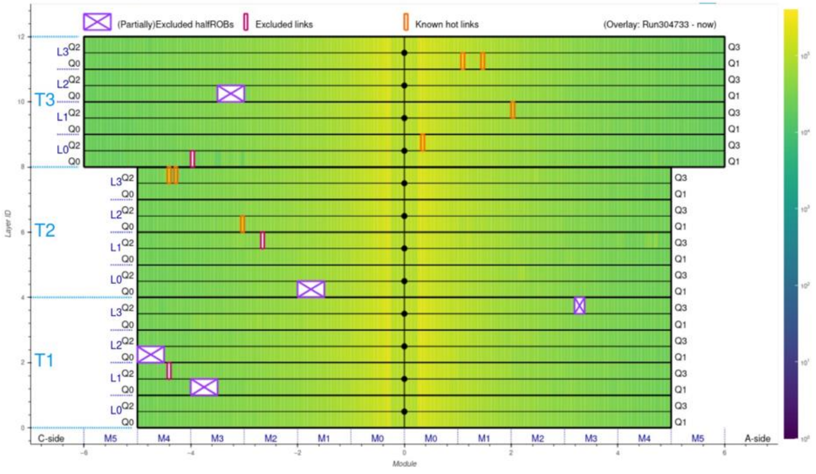
- Extremely successful data taking in 2024!
- All subdetectors have been taking data and participated to the trigger
- Total integrated luminosity: 9.56 fb^{-1}
  - The total integrated luminosity in Run-1 and Run-2 was 9 fb^{-1}



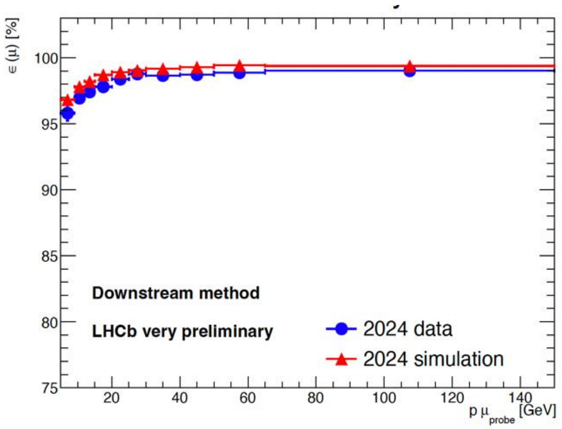
- Not only we surpassed in a single year the integrated luminosity of previous years all together, but with did it with a more efficient trigger, in particular for hadronic charm and beauty decay modes
  - Trigger efficiency x2 or even more, depending on the modes!

Detector performance

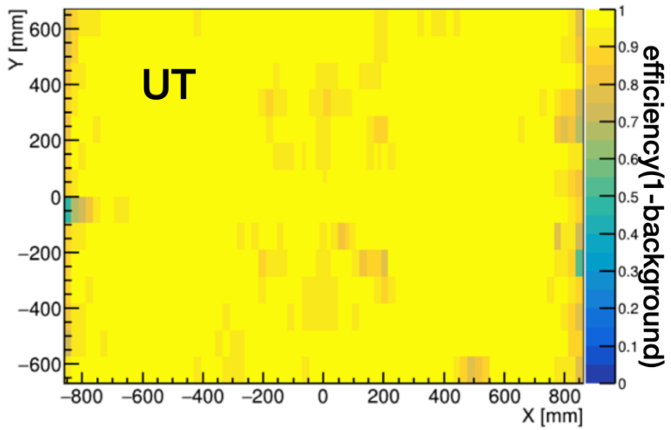
SciFi hitmap



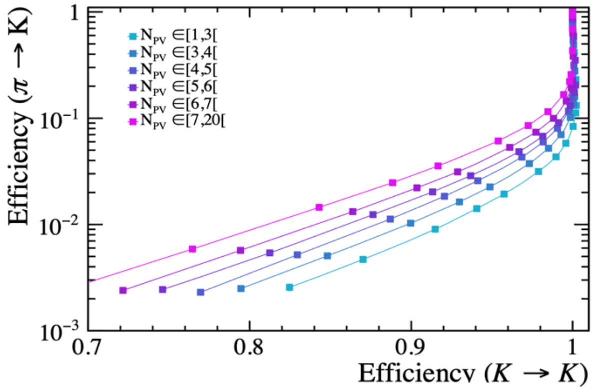
VELO efficiency



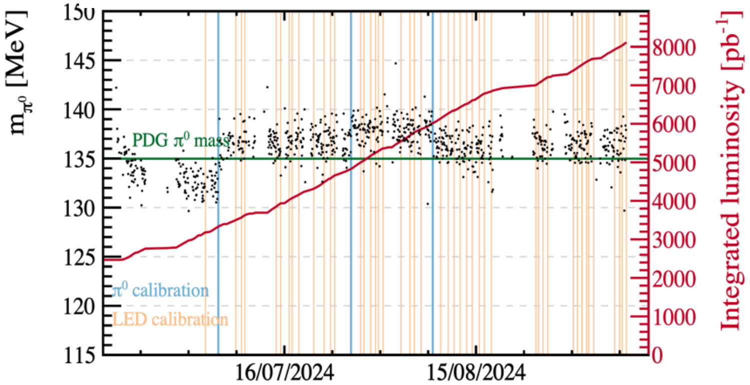
UT efficiency



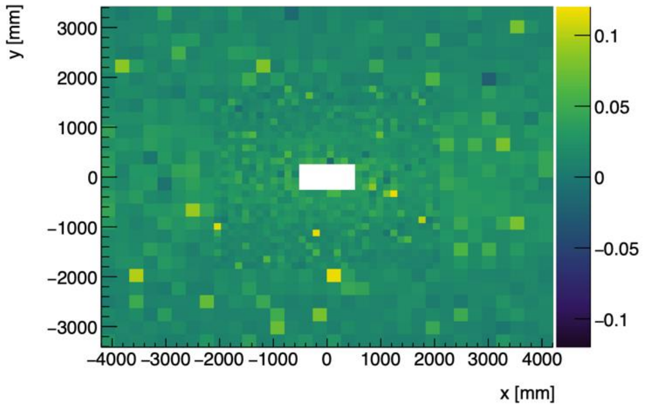
RICH PID



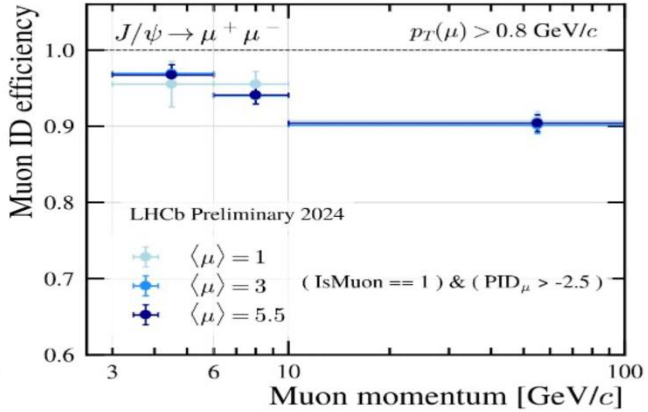
ECAL calibration



HCAL calibration



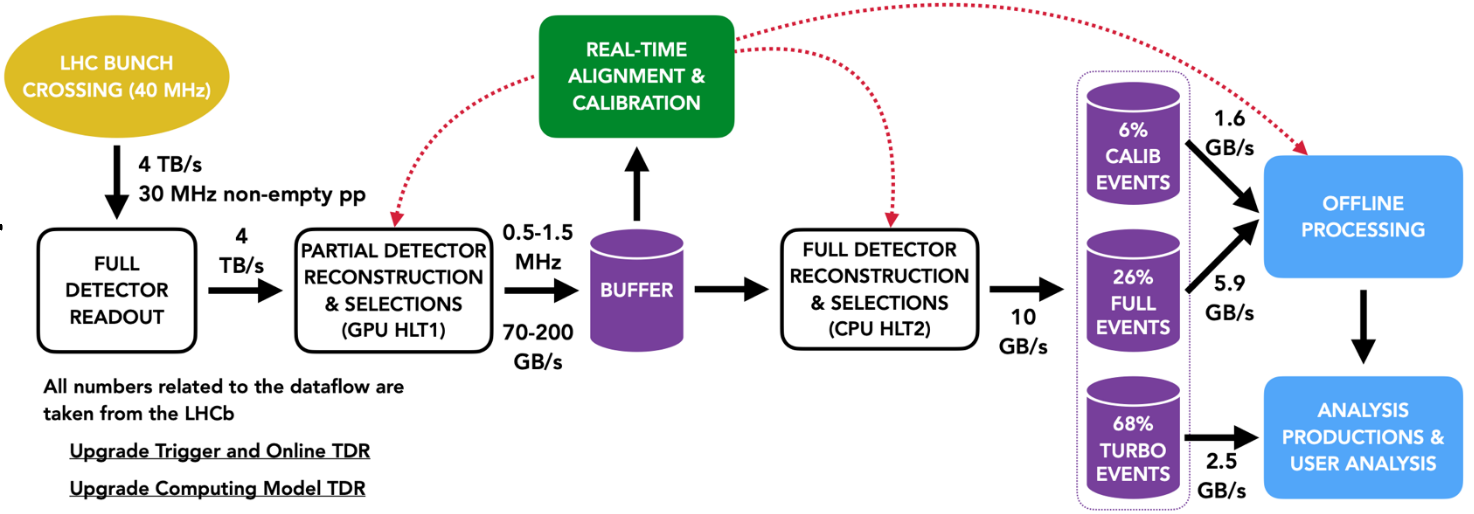
MUON ID

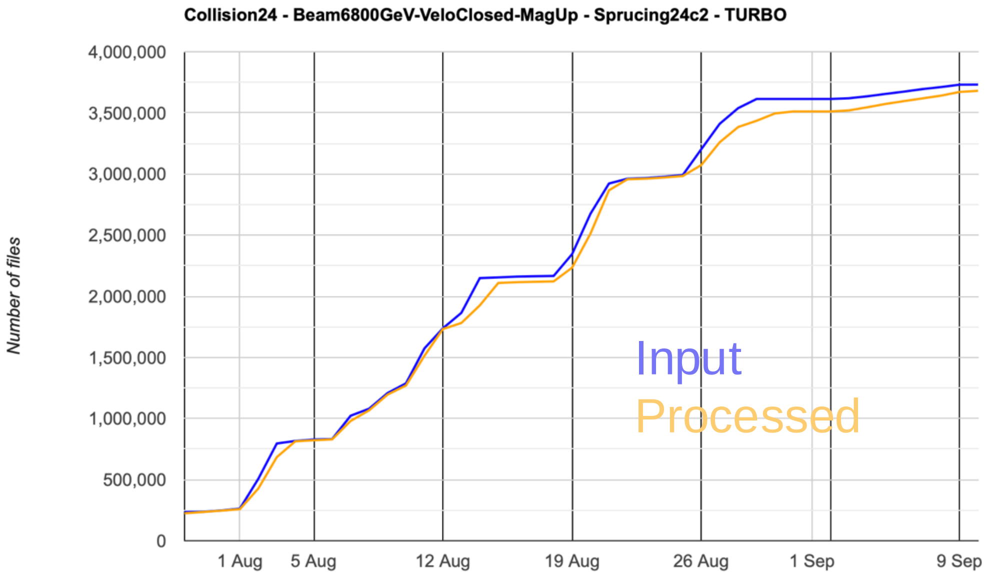


- All subdetectors working as by design!
  - Only major ones mentioned here

Real-time analysis

- Fully software trigger
  - Entire detector read out at full LHC rate with no trigger layer on custom electronics
- First level trigger (HLT1) made with ~500 GPUs
- Second level trigger (HLT2) running on a large CPU-based computing farm
- All data are made available offline for analysts almost in real time → LHCb users can analyse data taken a few days earlier
- First time in HEP!





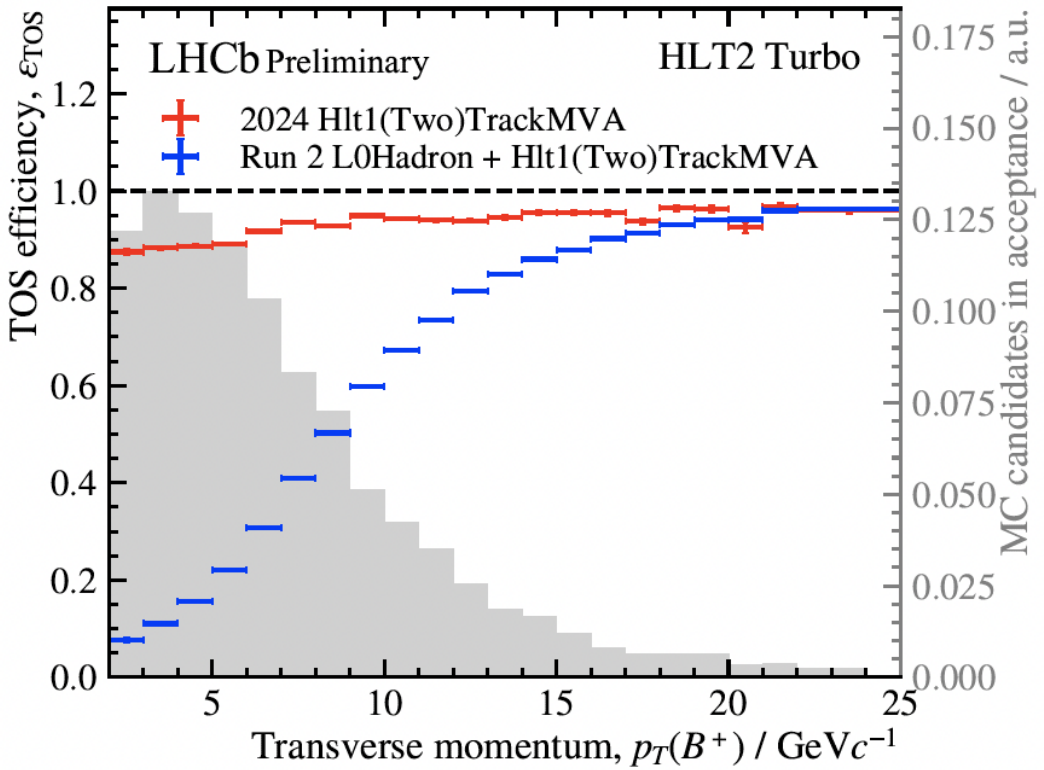
HLT2 resources increased with low-cost investment

- Over the summer we purchased a batch of CPUs for the HLT2 farm, and we replaced ~4400 CPUs on old servers with compatible, more powerful versions
- With a very moderate cost, about 18 CHF/CPU, the CPU power available for HLT2 increased significantly
  - Although at the cost of hard work made by our people from the Online project to perform the replacement at Point 8

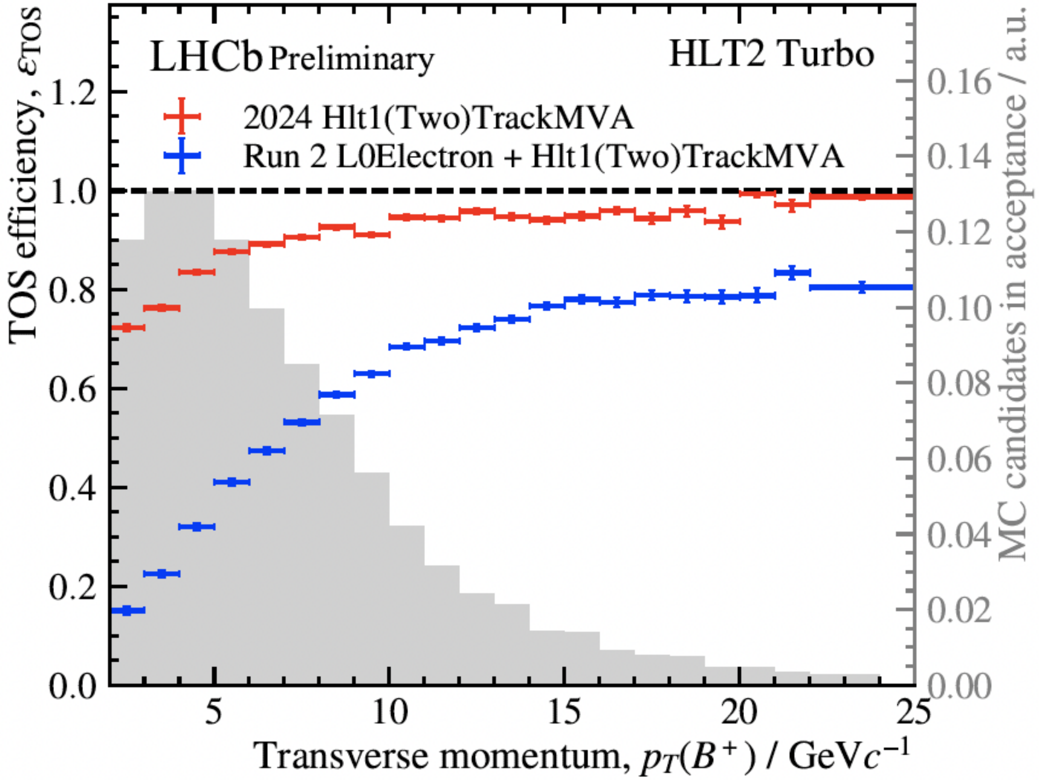
- A similar operation was carried out to add ~160 GPUs to HLT1

2024 trigger (on signal) efficiency

$B^+ \to D^0\pi^+$



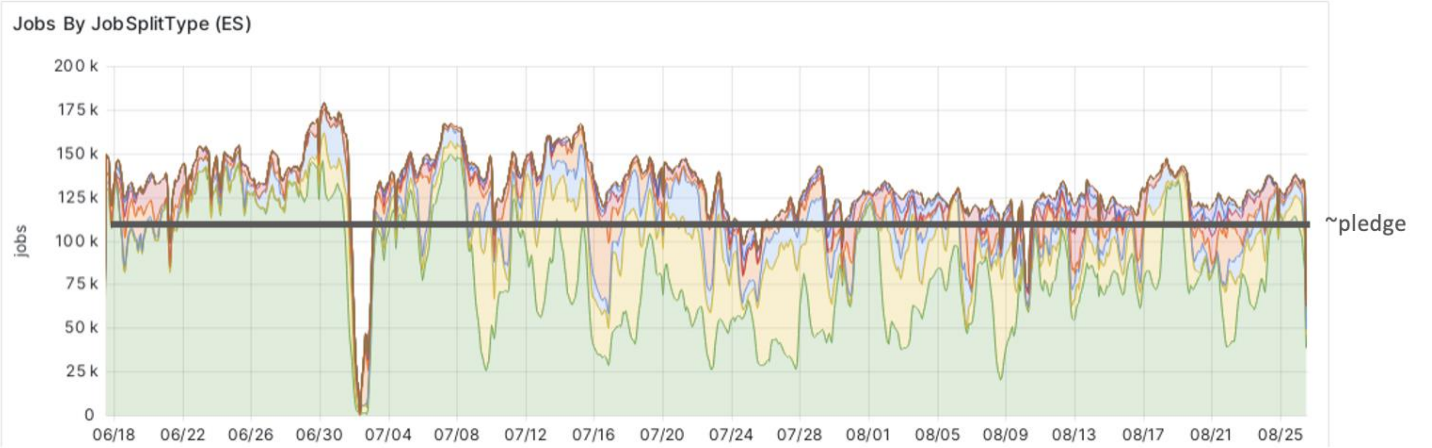
$B^+ \to J/\psi(\to e^+e^-)K^+$

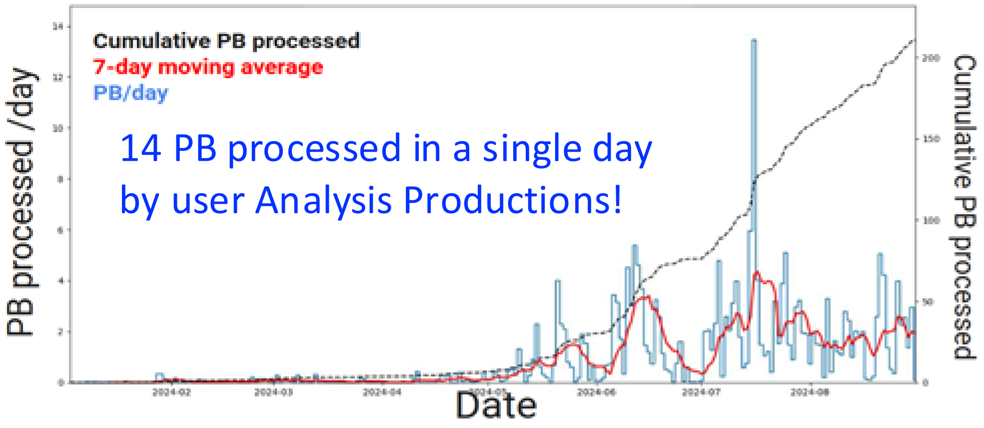


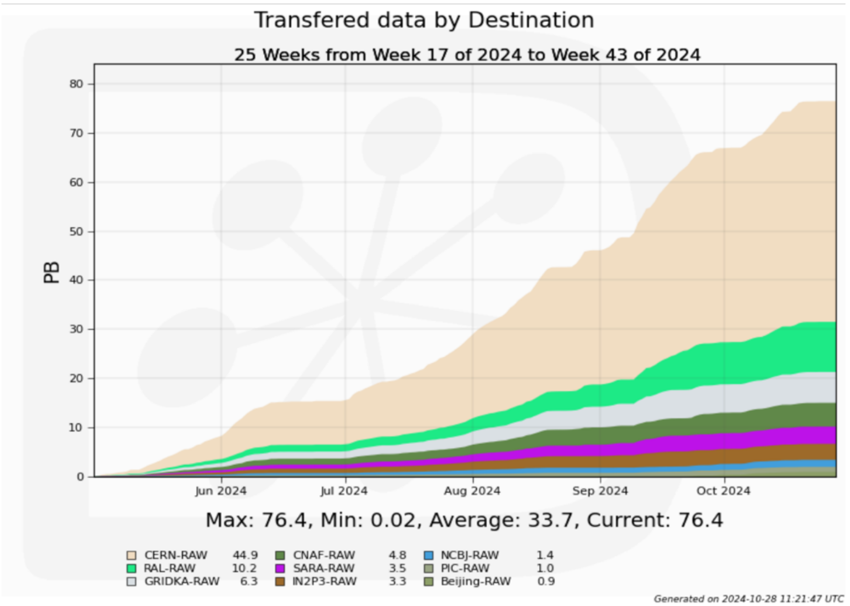
- Run 3 (red) vs Run-2 (blue) → Large gain in efficiency thanks to the removal of the hardware trigger that was cutting low-p_T tracks in Run-2
- One of the central goals of LHCb Upgrade I

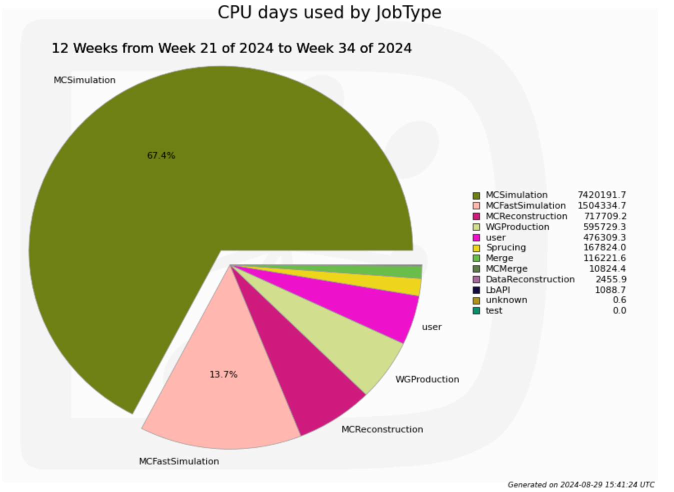
Processing on the WLCG

- Made good use of CPUs on the WLCG Grid
- More than 75 PB transferred from the online farm at Point 8 (including redundant copies)
- More than 40 PB of data processed by data reduction and streaming (a.k.a. "Sprucing")







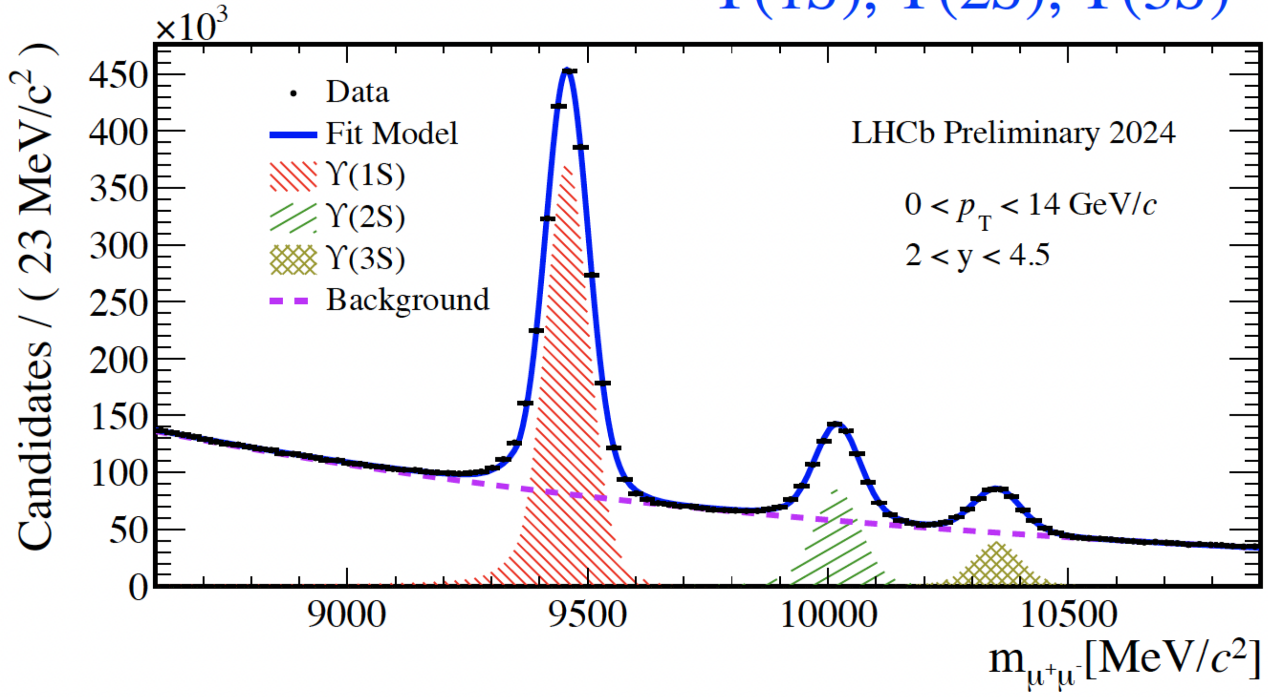


Simulation

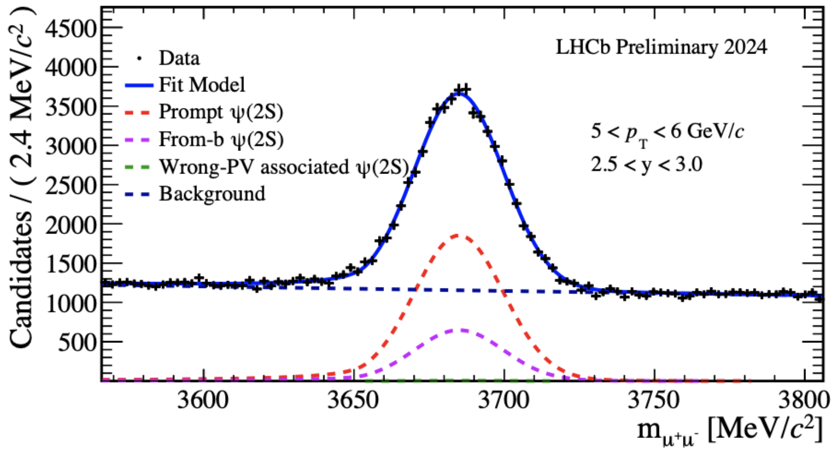
- Intense efforts to support Run-3 data analysis
  - And continue with extensive Run-1 and Run-2 simulations
- Provided Upgrade II samples for the Scoping Document
- Making the simulation faster continues to be a priority
  - Progress on Calorimeter fast simulation with Point libraries and Machine Learning methods
  - AdePT (Accelerated demonstrator of electromagnetic Particle Transport, *i.e.* Geant4 R&D for electromagnetic physics on GPUs) integrated into the simulation framework, now starting tests for ECAL
- ARM architecture
  - Will generate Upgrade II (tracking-only) samples on ARM soon
  - Continuing developments and in-depth physics validation for Run-3 use

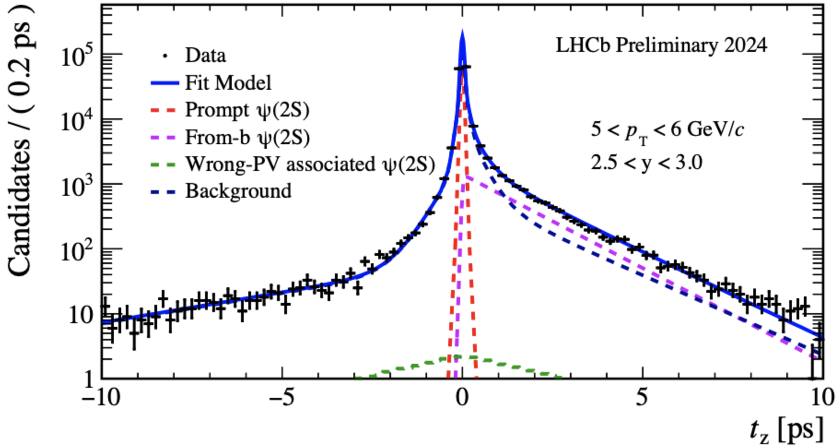
A look at 2024 data: dimuon final states

$\Upsilon(1S), \Upsilon(2S), \Upsilon(3S)$



$\psi(2S)$

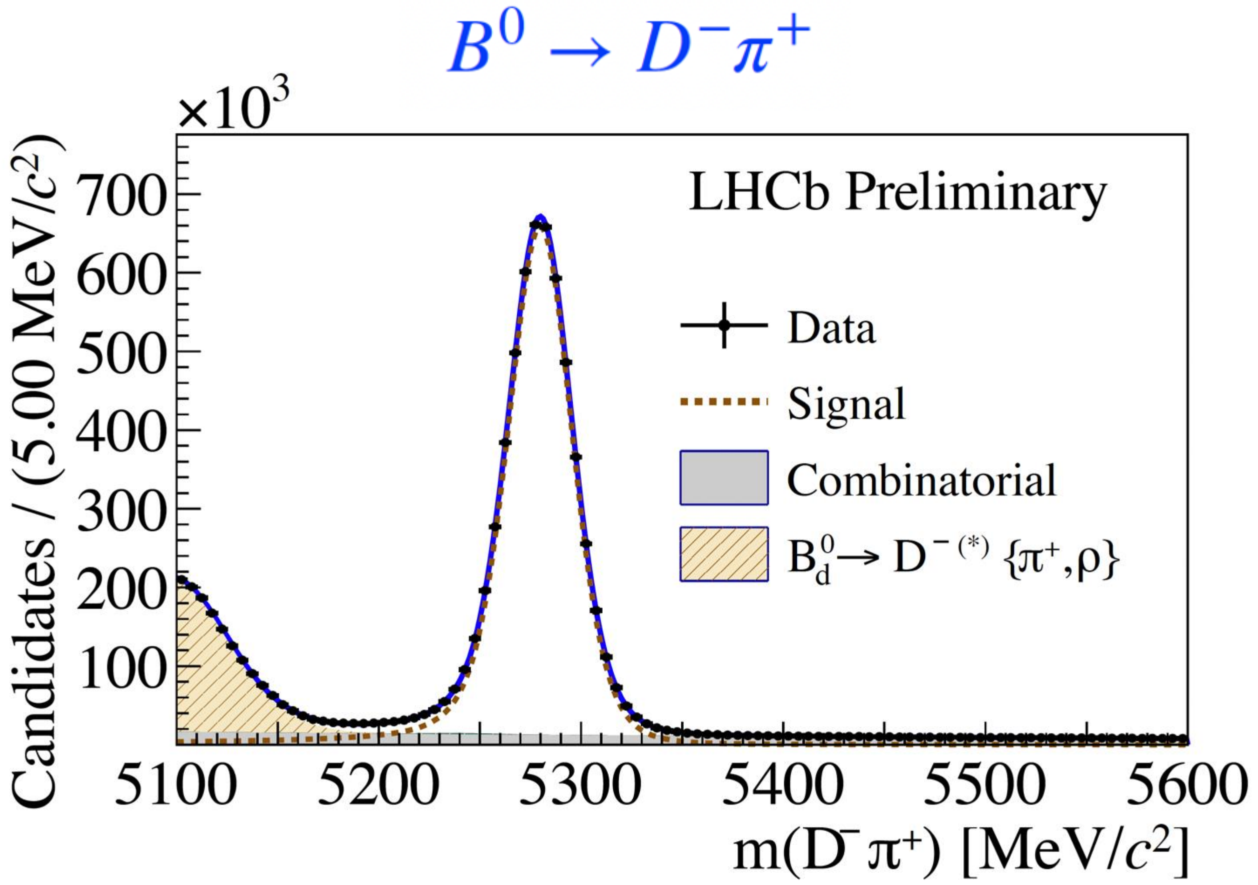




- Alignment quality approached Run-2 level, with excellent mass resolutions

t_z distribution allows to identify contributions from prompt and secondary productions

A look at 2024 data: hadronic *B* decays

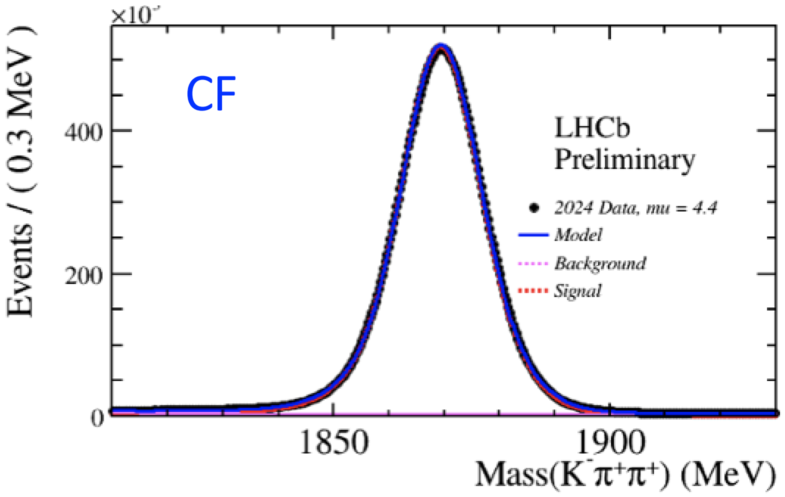


- In this example, 5.8 million reconstructed decays in 5.3 fb^{-1}, corresponding to 1.1 x 10^6 decays per fb^{-1} in 2024
  - To be compared with about 0.36 x 10^6 decays per fb^{-1} in Run-2

A look at 2024 data: 3-body charm decays

- With charm hadronic decays we gain likewise beauty, again thanks to the removal of the hardware trigger

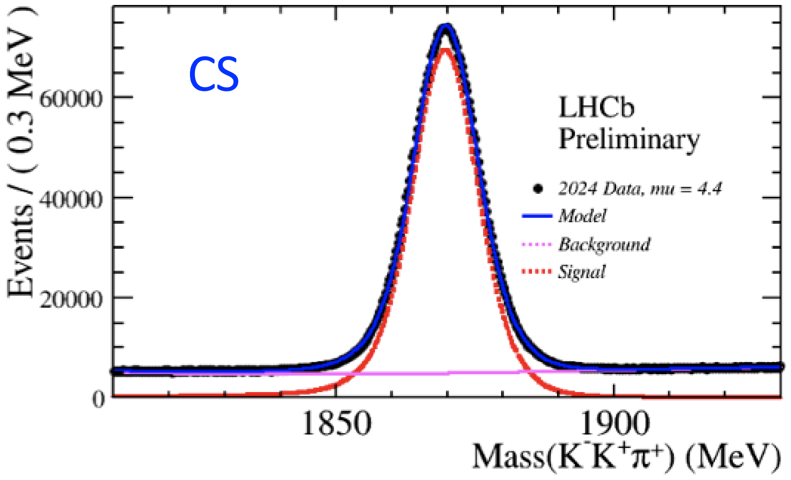
$D^+ \to K^- \pi^+ \pi^+$



$\text{yield}/\text{pb}^{-1} = 1.84 \times 10^6$

($\times$ 2.8 Run2)

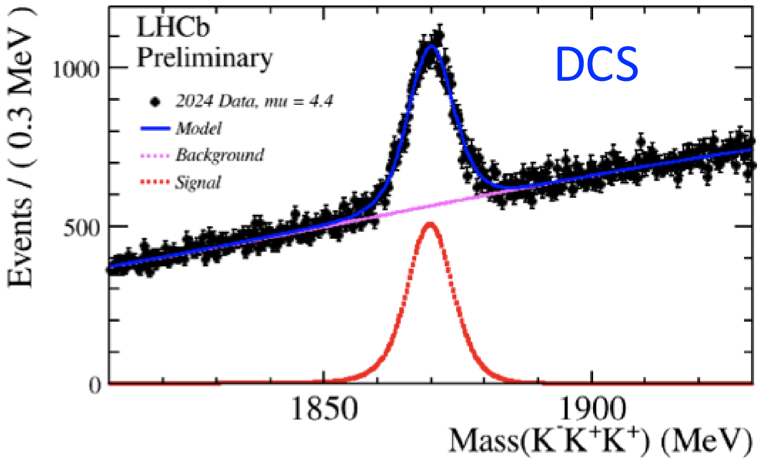
$D^+ \to K^- K^+ \pi^+$



$\text{yield}/\text{pb}^{-1} = 1.97 \times 10^5$

($\times$ 3.2 Run2)

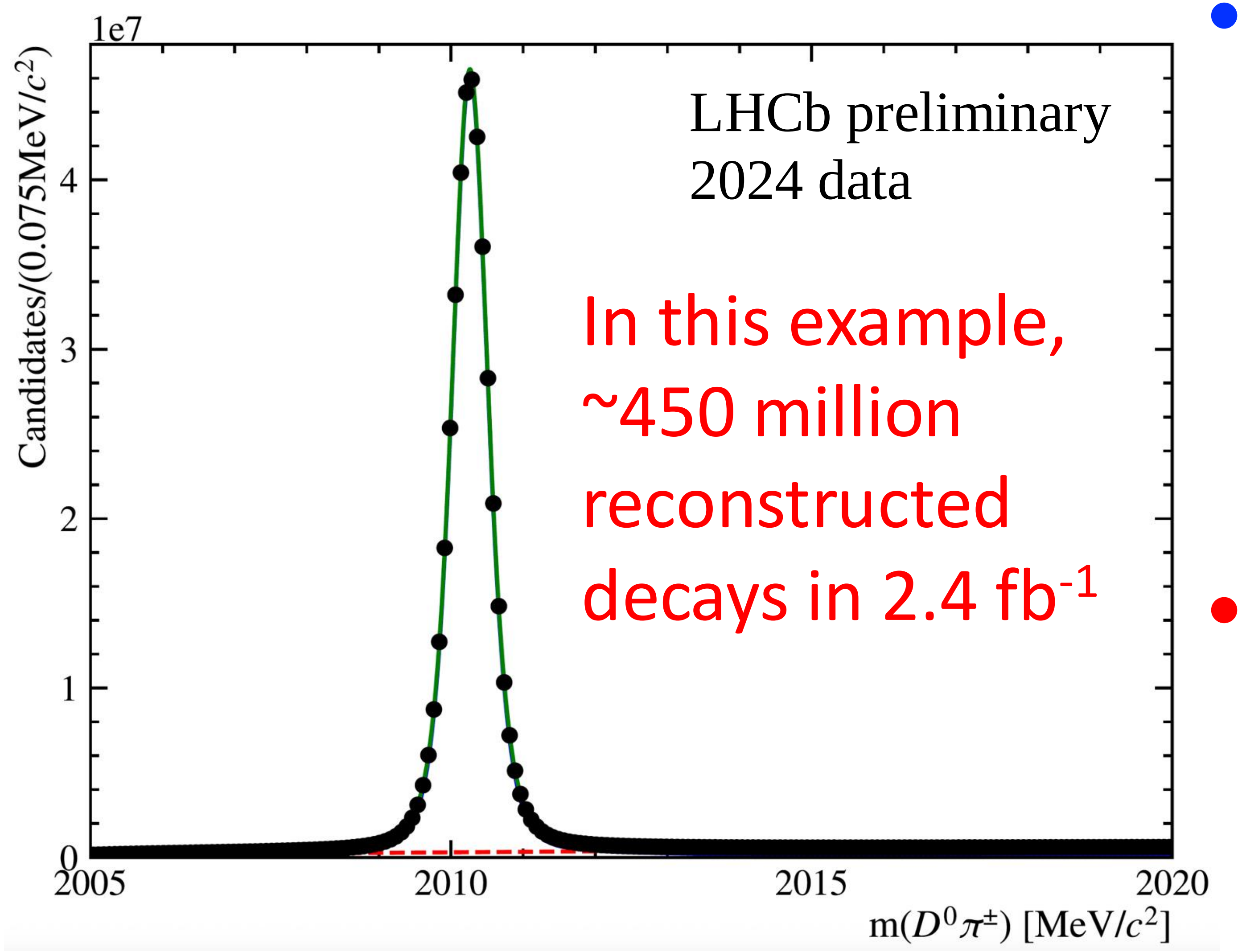
$D^+ \to K^- K^+ K^+$



$\text{yield}/\text{pb}^{-1} = 1.03 \times 10^3$

($\times$ 2.5 Run2)

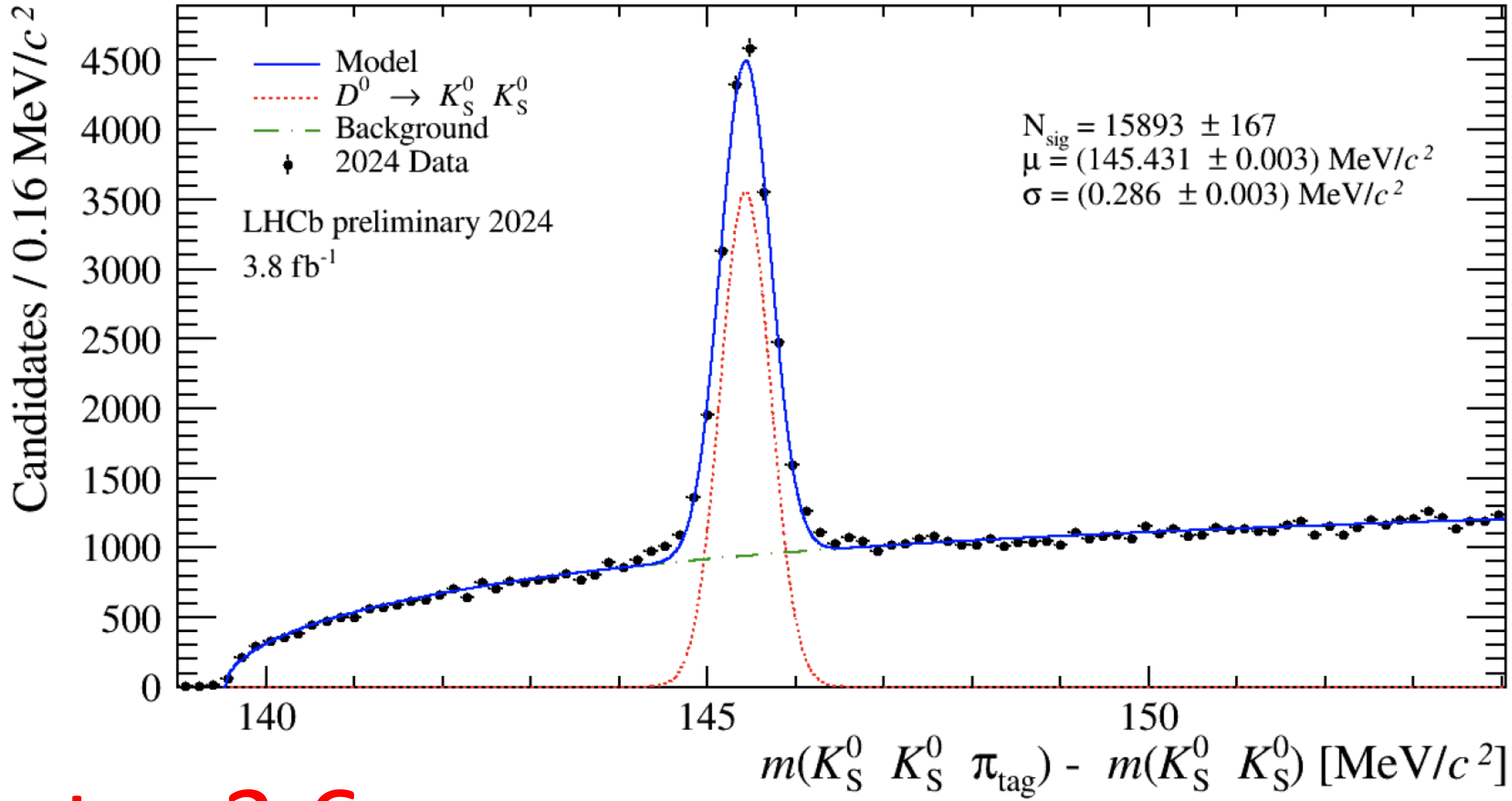
A look at 2024 data: $D^* \to D^0(\to K\pi)\pi$



- About 190 x 10^6 decays per fb^{-1} in 2024
  - To be compared with 85 x 10^6 decays per fb^{-1} in Run-2
- Exciting prospects for charm *CP* violation and mixing measurements in Run-3!

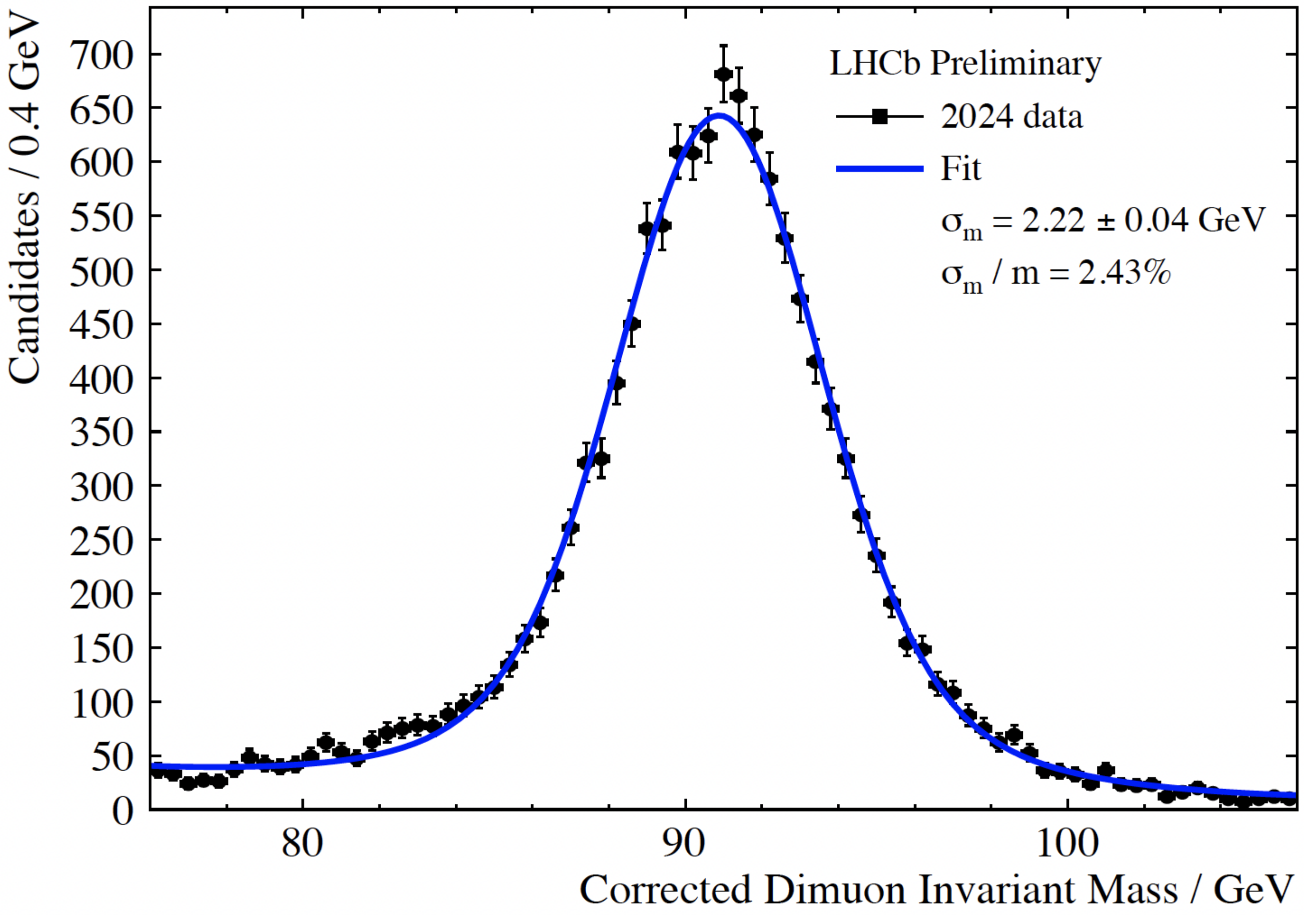
A look at 2024 data: $D^* \to D^0(\to K_S K_S)\pi$

- Also in this case, signal yield per unit luminosity significantly increased when compared with Run-2: about a factor 3.6, thanks to a dedicated K_S track trigger line in HLT1 for the first time



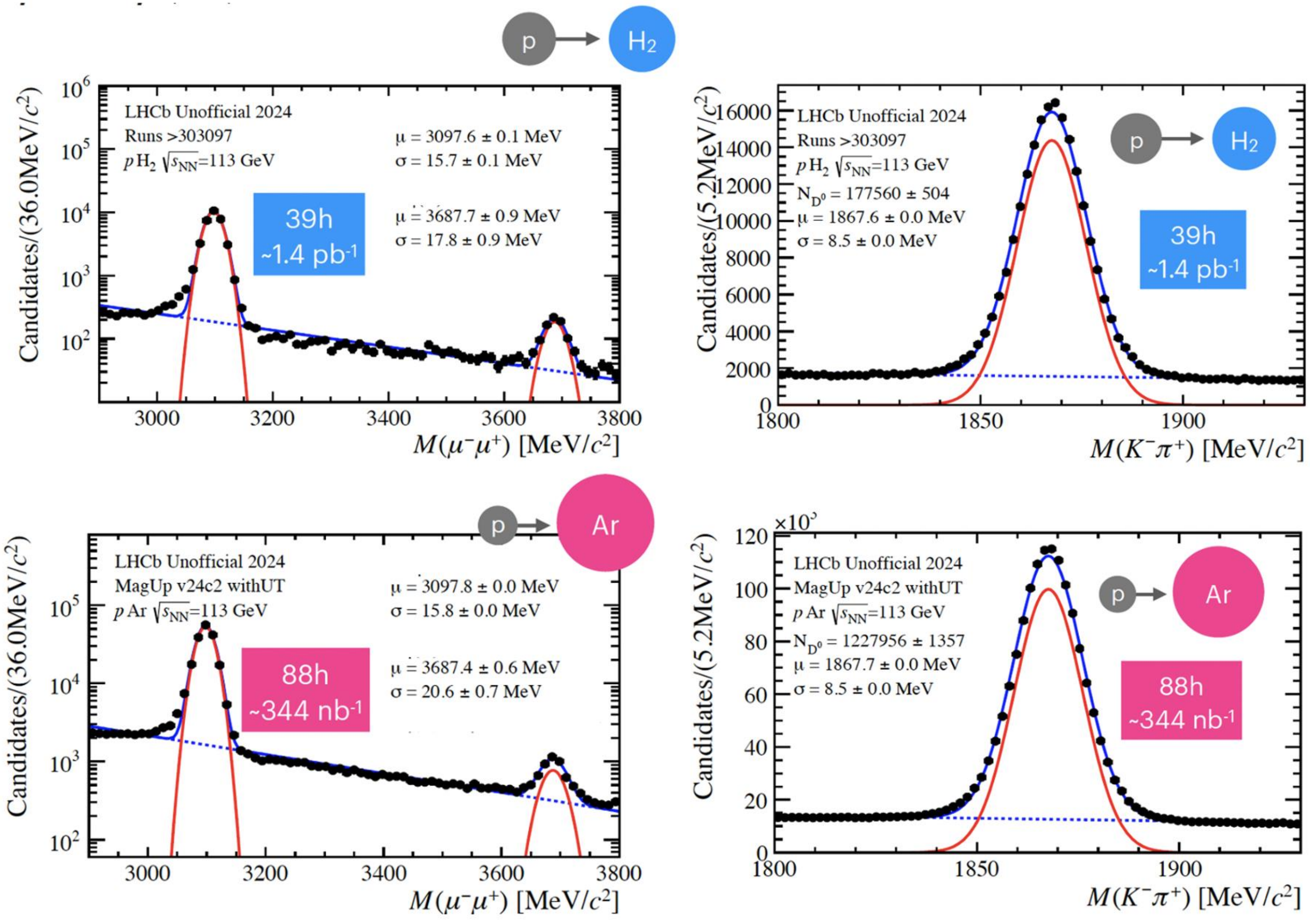
A look at 2024 data: $Z^0 \rightarrow \mu^+\mu^-$

- Very clean peak with high purity and efficiency
- In the high-p_T sector LHCb is also well on track with Run-3 data



A look at 2024 data: fixed-target physics

- Fixed-target programme at the LHC is a unique feature of LHCb
  - *p*-gas collisions now running in parallel with *pp*
- In this example, charmonium and open charm production in pH_2 and pAr collisions



18

Prospects for 2024 Pb-Pb run

- This year for the first time we will take Pb-Pb collision data with the nominal LHCb Upgrade I detector (closed VELO, UT included)
- The Upgrade I detector is much more capable of making measurements with Pb-Pb collisions, due to the higher granularity of its tracking detectors, especially the VELO
  - Can reach much lower centrality than the first LHCb detector, covering the 100%-30% centrality range
- Furthemore, commencing this year we will get a ~70% increase in instantaneous luminosity, mostly thanks to the an increase in the number of colliding bunches at the LHCb interaction point

Physics highlights from publications

Measurement of the CKM angle γ

- Using new improved methods and more channels

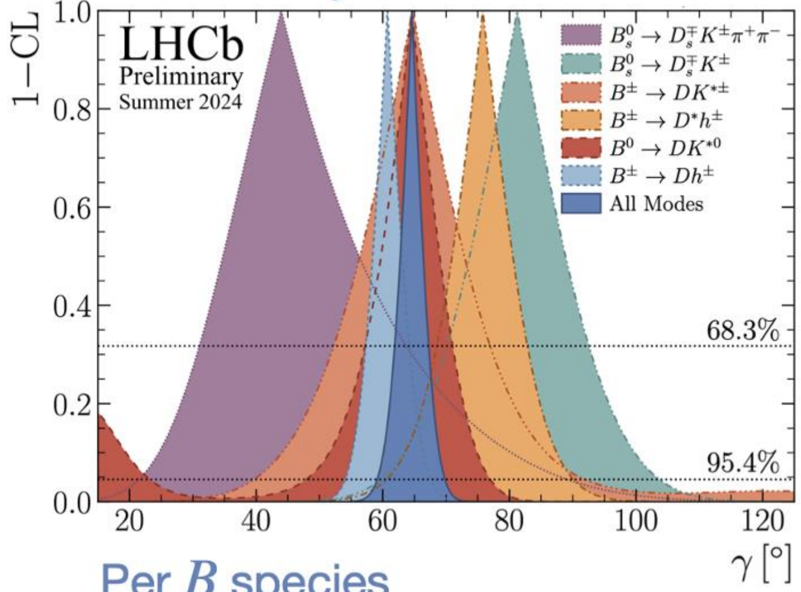
$B^0 \to DK^{*0}$, $D \to h^+h'^+(\pi^+\pi^-)$ with 3 simultaneous D final states.

$B^0 \to DK^{*0}$, $D \to K_s^0 h^+h^+$, binned D decay Dalitz plane analysis.

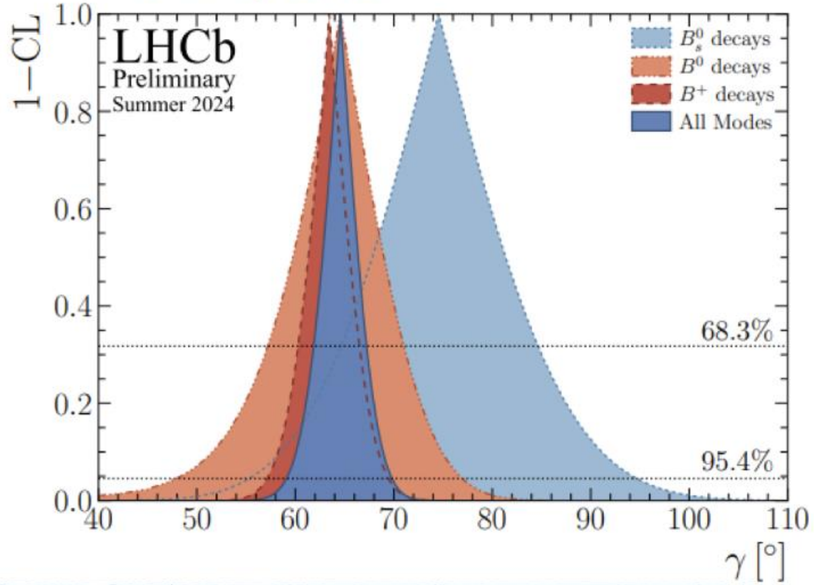
$B^\pm \to DK^{*\pm}$, 4 simultaneous D decays, and first time $D \to K_s^0 h^+h^+$ decay.

$$\gamma = (64.6 \pm 2.8)^\circ$$

Per B decay LHCb-CONF-2024-004



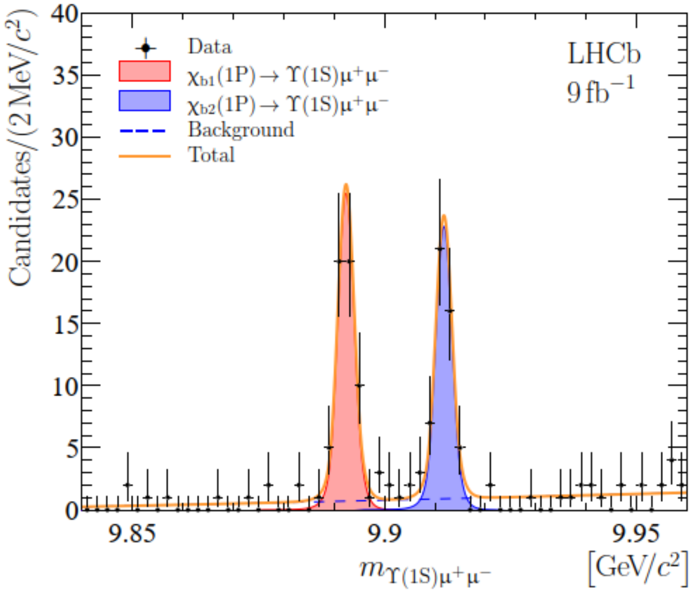
Per B species

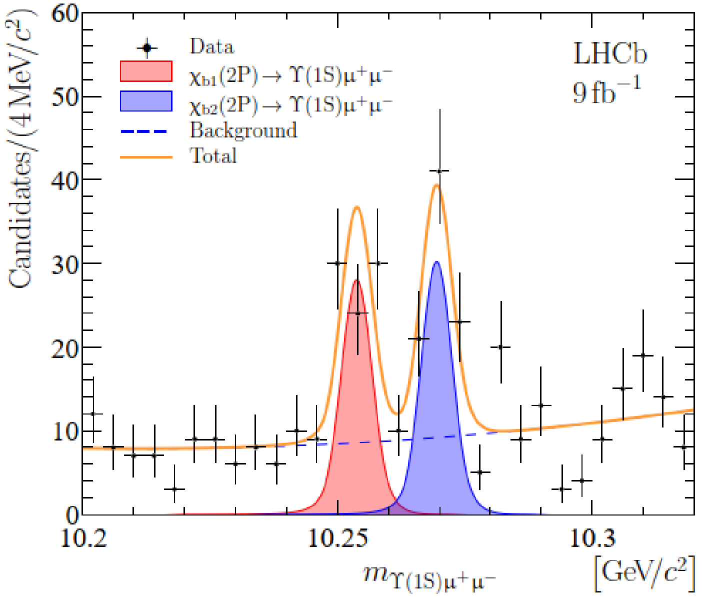


- Run-2 target of 3° precision reached
- The measurement is still largely statistically limited → Run-3 results and beyond will have a huge impact!

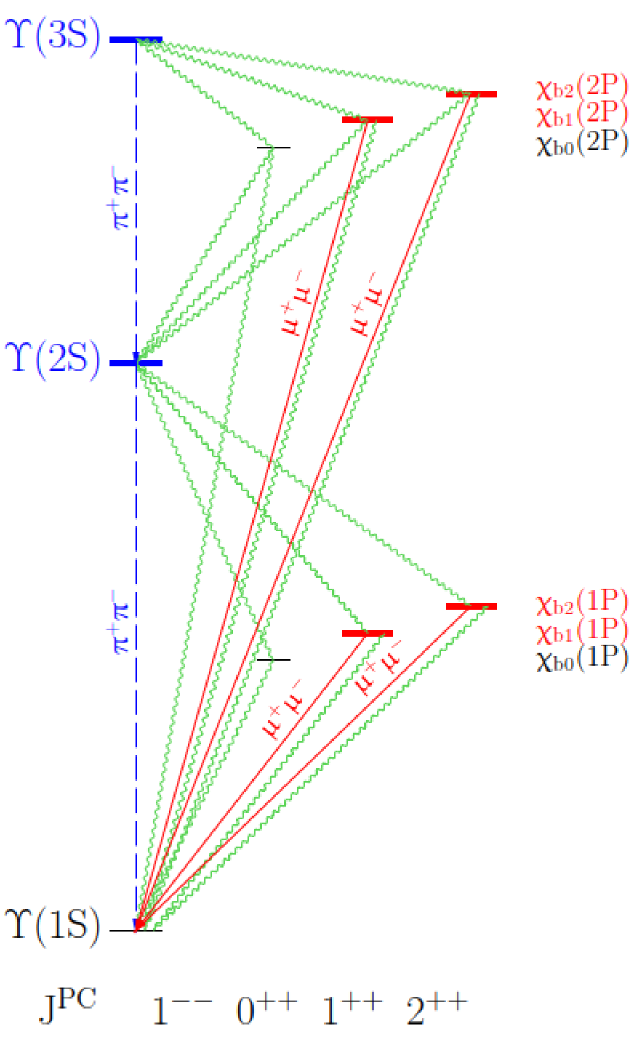
Observation of $\chi_b \to \Upsilon\mu\mu$ decays

- First observation of the muonic "Dalitz" decays of $\chi_{b1}(1P)$, $\chi_{b2}(1P)$, $\chi_{b1}(2P)$ and $\chi_{b2}(2P)$ mesons to $\Upsilon(1S)$
- The newly observed decays together with $\Upsilon(2S)\to\Upsilon(1S)\pi\pi$ and $\Upsilon(3S)\to\Upsilon(2S)\pi\pi$ decays are used for precision mass measurements
- The measurement of the $\chi_{b1}(1P)$ is world's best





LHCb-PAPER-2024-025



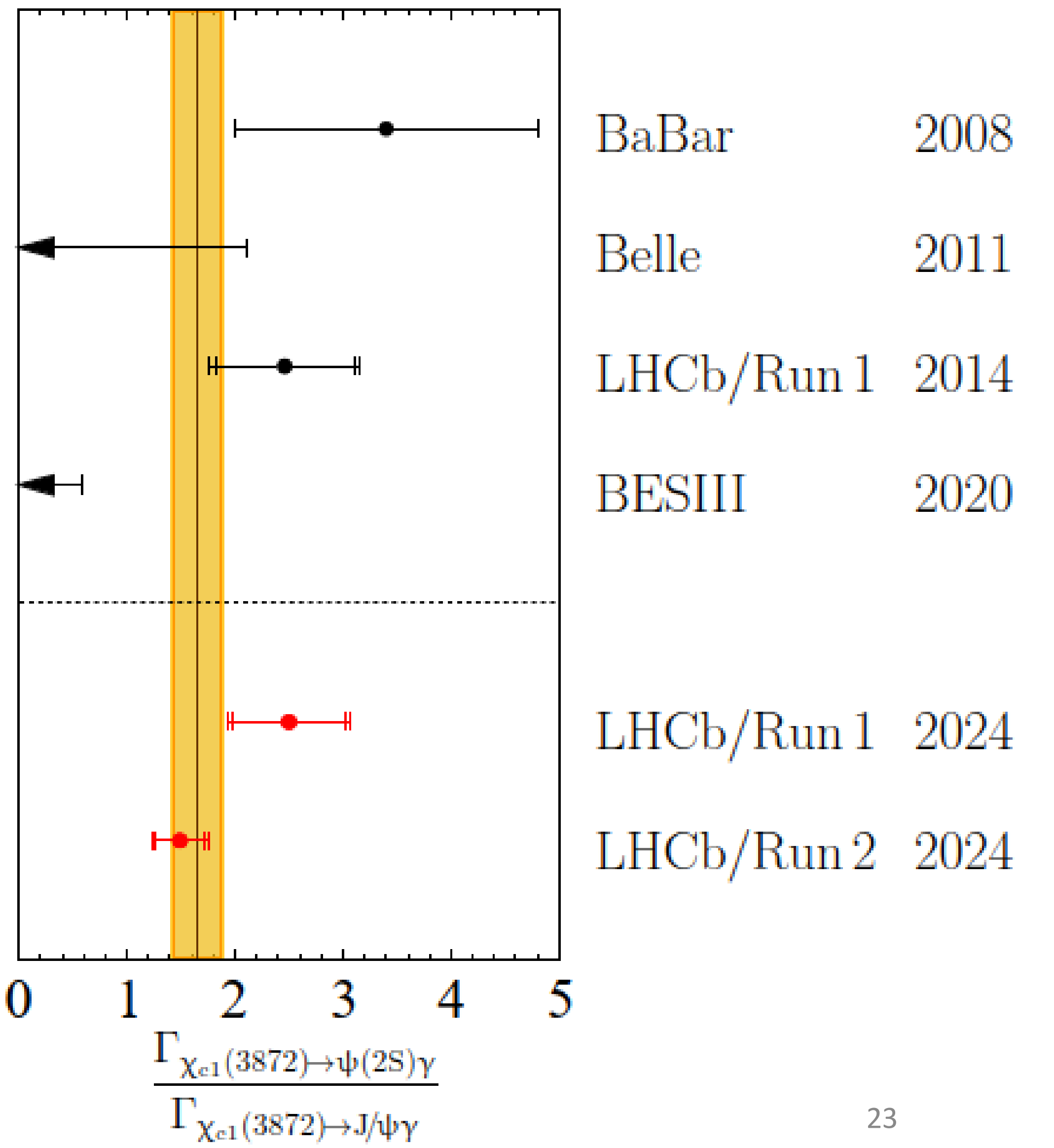
Probing the exotic nature of the $\chi_{c1}(3872)$

LHCb-PAPER-2024-015

- First observation of $\chi_{c1}(3872)\to\psi(2S)\gamma$
- The measurement of the ratio of $\chi_{c1}(3872)\to\psi(2S)\gamma$ to $\chi_{c1}(3872)\to J/\psi\gamma$ branching fractions allows nature of the $\chi_{c1}(3872)$ to be investigated

$$\mathscr{R}_{\psi\gamma} = 1.67 \pm \underset{stat}{0.21} \pm \underset{syst}{0.12} \pm \underset{BR(\psi\to l^+l^-)}{0.04}$$

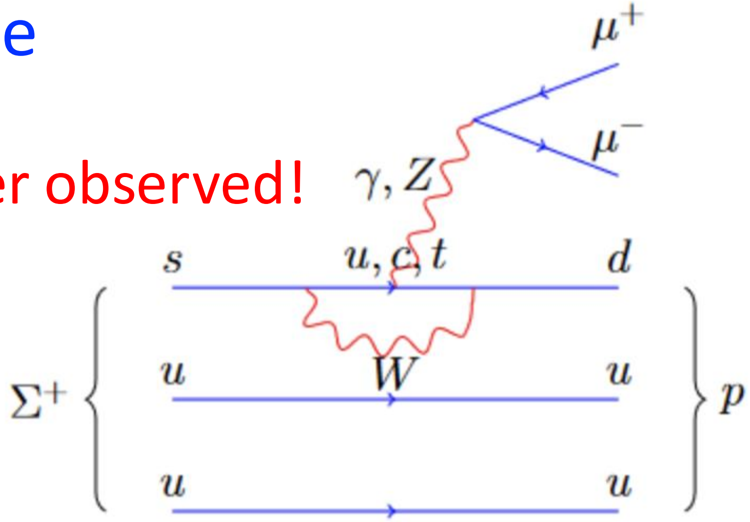
- Such a large value provides evidence for the presence of a compact component (either charmonium or tetraquark) in the $\chi_{c1}(3872)$, disfavouring the pure molecular model



Observation of the rare $\Sigma^+ \to p\mu^+\mu^-$ decay

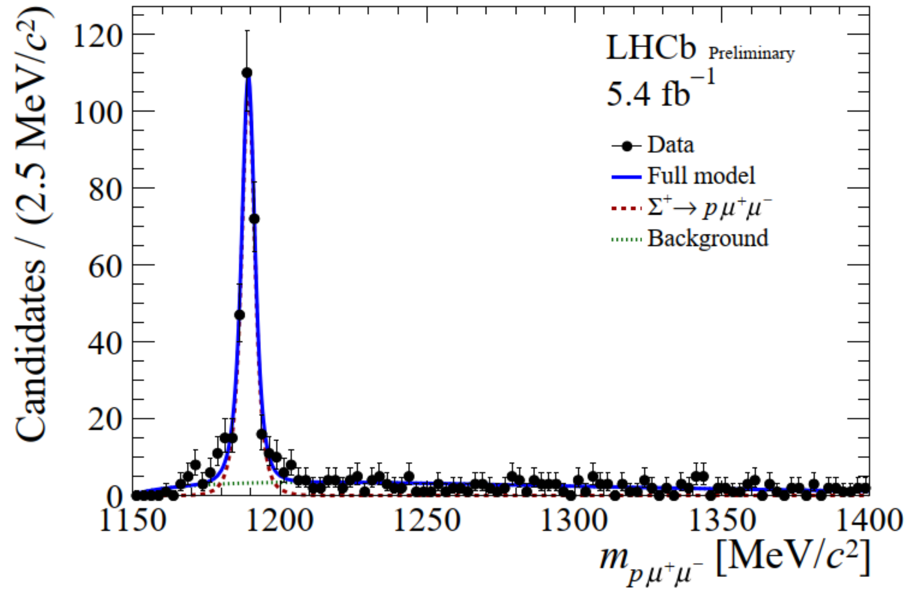
LHCb-CONF-2024-002

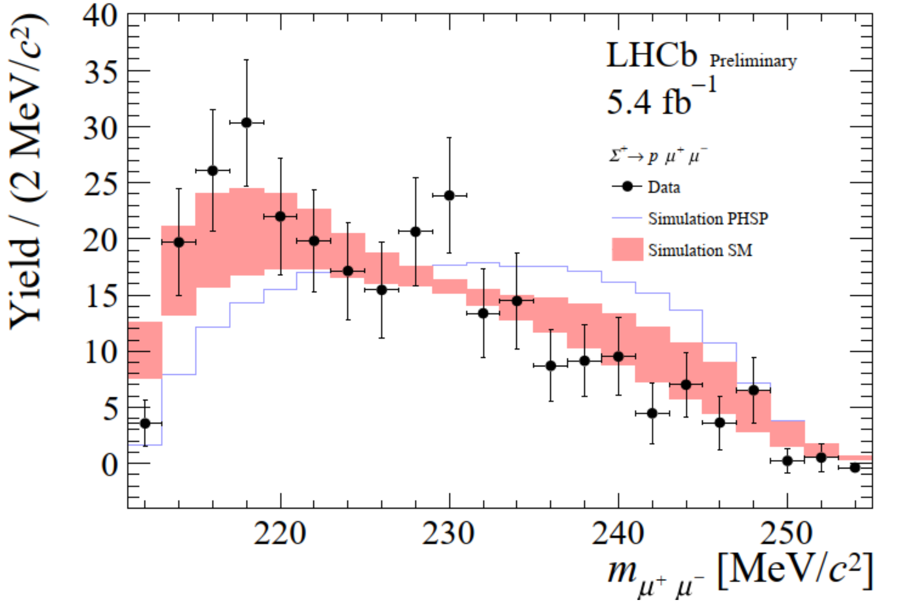
- The $\Sigma^+ \to p\mu^+\mu^-$ rare decay is observed for the first time at more than 5σ
    - Rarest hyperon decay ever observed!



- Interest for the dimuon mass spectrum in the $\Sigma^+ \to p\mu^+\mu^-$ decay due to a 2005 result by the HyperCP (E871) collaboration, which reported a hint of a narrow structure in the dimuon mass distribution with three events only at about 214 MeV/c^2, that would have implied new physics

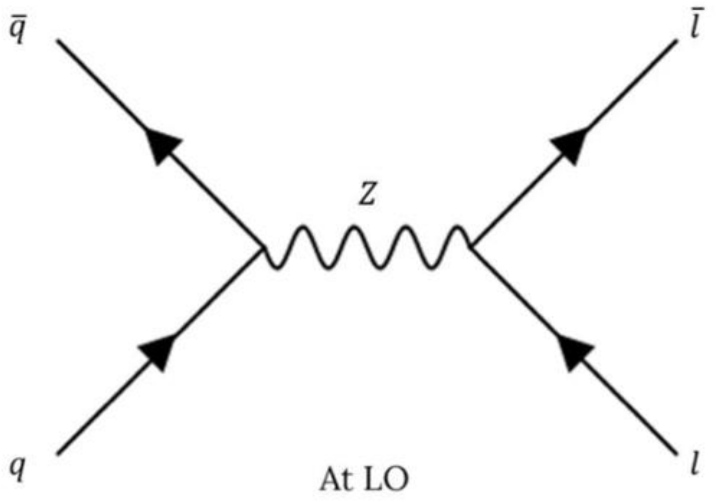
- With much larger statistics, LHCb data do not show any significant peaking structure, hence disconfirming HyperCP's claim



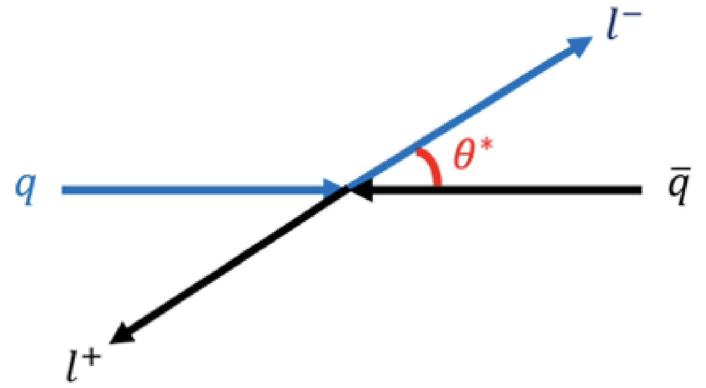


Measurement of the effective leptonic weak mixing angle

- The weak mixing angle is a key parameter of the SM
- The presence of vector and axial-vector couplings that depend on θ_W introduces a forward-backward asymmetry of the angular distribution of the lepton pairs in Drell-Yan events



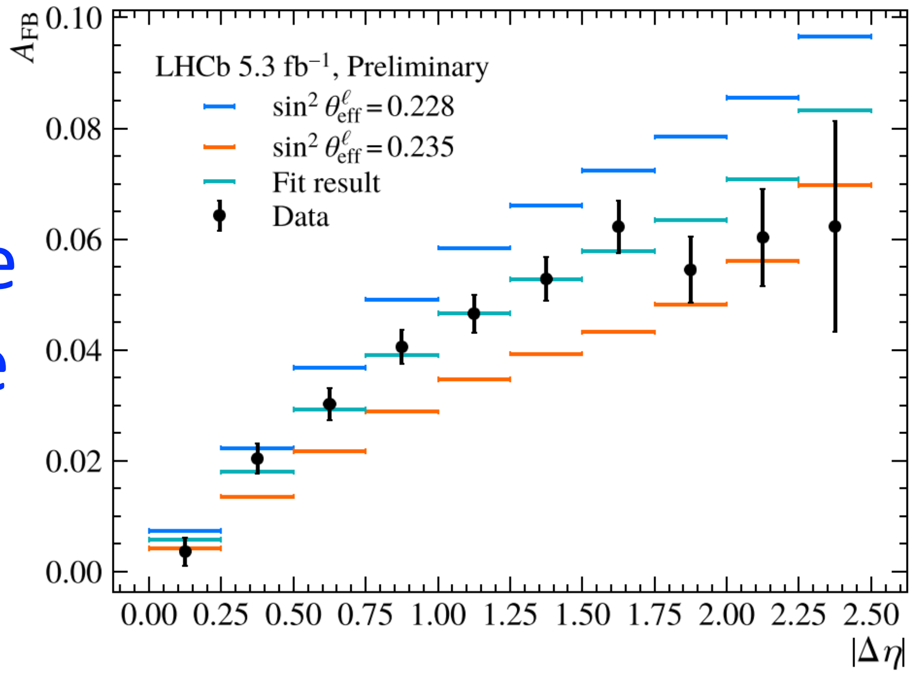
$$\frac{d\sigma}{d\cos\theta^*} \alpha \left(1 + \cos^2\theta^* + \frac{8}{3} A_{FB}^{4\pi} \cos\theta^*\right)$$

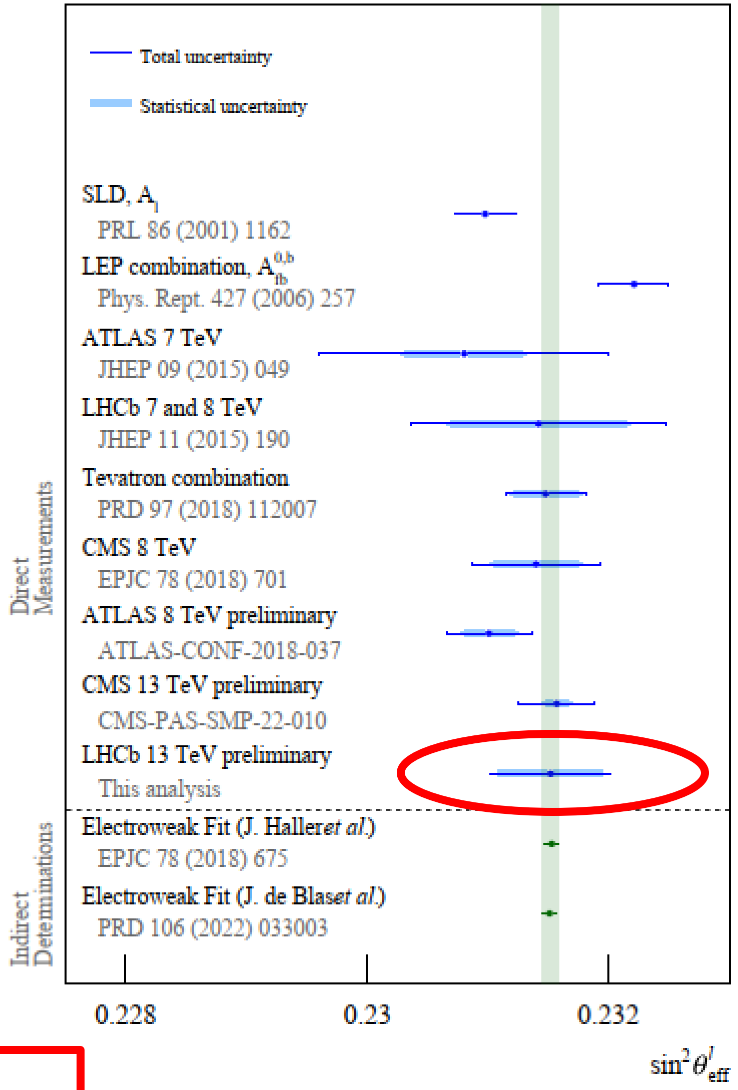


Measurement of the effective leptonic weak mixing angle

LHCb-PAPER-2024-028

- $|\Delta\eta|$ is the absolute difference between the pseudorapidities of the muons produced in the Z boson decay
- A_{FB} is measured in bins of $|\Delta\eta|$, improving the sensitivity, and compared with predictions at NLO in strong and EW couplings this leads to



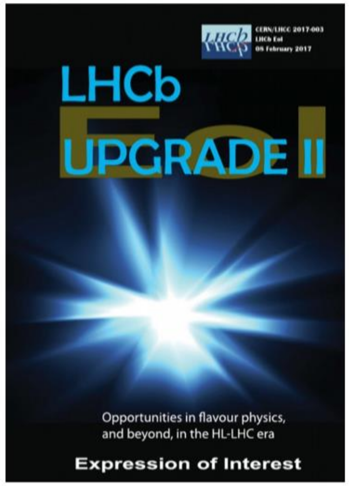


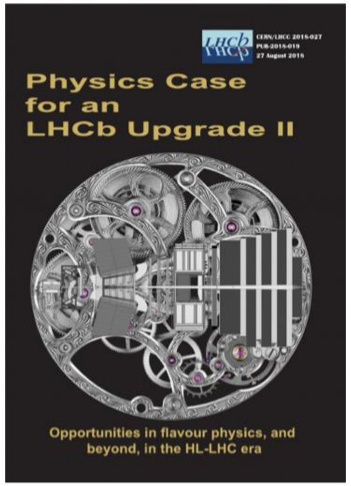
$$\sin^2\theta^\ell_{\rm eff} = 0.23147 \pm 0.00044 \pm 0.00005 \pm 0.00023$$

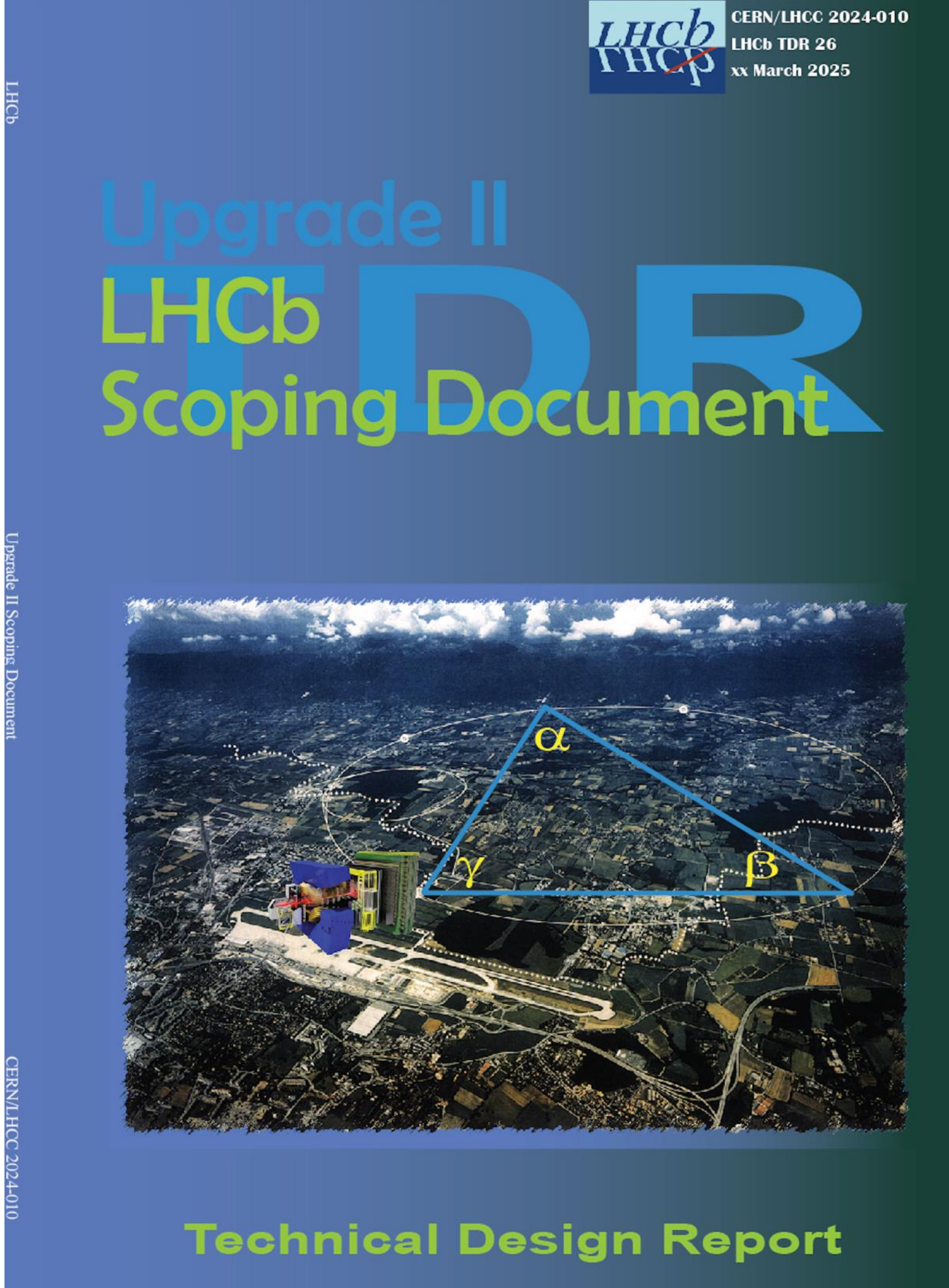
Future upgrades

LHCb Upgrade II Scoping Document

- Following the Expression of Interest (LHCC-2017-003), the Physics Case Document (LHCC-2018-027) and the Framework TDR (LHCC-2021-012), all already reviewed and recommended for approval by the LHCC, LHCb has now submitted for review to the LHCC the Upgrade II Scoping Document







Scoping scenarios

	Baseline	Middle	Low
$\mathcal{L}_{\text{peak}}$ ($10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$)	1.5	1.0	1.0
	(kCHF)	(kCHF)	(kCHF)
VELO	16672	15906	13753
UP	8077	7719	6887
Magnet Stations	2592	2234	0
Mighty-SciFi	21767	21273	17388
Mighty-Pixel	15993	11642	11060
RICH	21450	18415	14794
TORCH	12508	8756	0
PicoCal	27607	27607	21584
Muon	9785	8266	8266
RTA	18800	11700	9500
Online	11800	9467	8993
Infrastructure	14463	13284	12430
Total	181514	156269	124655

- Three scenarios differing in peak luminosity, physics potential, cost and complexity
- TDRs within 2026, construction phase 6 years + 1 contingency, to be ready for installation in LS4

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-LHCC-2024-010
LHCb-TDR-026
September 2, 2024

LHCb Upgrade II Scoping Document

LHCb collaboration

Abstract

A second major upgrade of the LHCb detector is necessary to allow full exploitation of the LHC for flavour physics. The new detector will be installed during long shutdown 4 (LS4), and will operate at a maximum luminosity of $1.5 \times 10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$. By upgrading all subdetectors and adding new detection capability it will be possible to accumulate a sample of $300\,\text{fb}^{-1}$ of high energy pp collision data, giving unprecedented and unique discovery potential in heavy flavour physics and other areas. The baseline LHCb Upgrade II detector has been presented in a Framework Technical Design Report that was approved in 2022. Here, updates are presented alongside scoping options with reduced detection capability and operational luminosity. The costs and physics performance of each scenario are discussed, and an overview of the project management plans is presented.

Scoping scenarios

	Baseline	Middle	Low
$\mathcal{L}_{peak}$ $(10^{34}\,cm^{-2}\,s^{-1})$	1.5	1.0	1.0
	(kCHF)	(kCHF)	(kCHF)
VELO	16672	15906	13753
Online	[illegible]	[illegible]	[illegible]
Infrastructure	14463	13284	12430
Total	181514	156269	124655

To be discussed in the Upgrade II session tomorrow

- Three scenarios differing in peak luminosity, physics potential, cost and complexity
- TDRs within 2026, construction phase 6 years + 1 contingency, to be ready for installation in LS4

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-LHCC-2024-010
LHCb-TDR-026
September 2, 2024

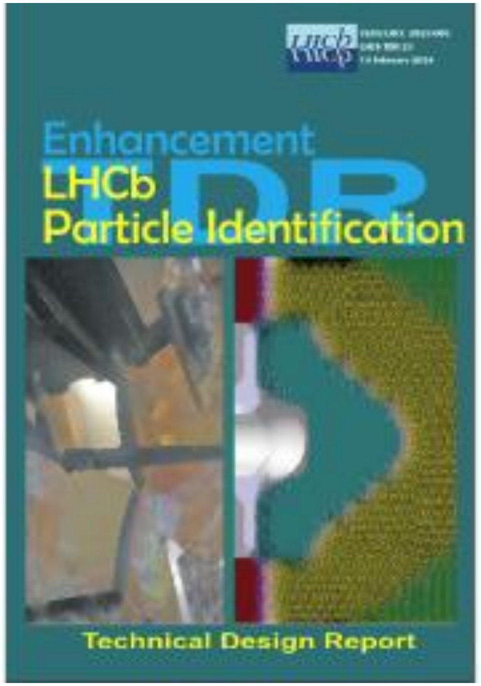
Abstract

A second major upgrade of the LHCb detector is necessary to allow full exploitation of the LHC for flavour physics. The new detector will be installed during long shutdown 4 (LS4), and will operate at a maximum luminosity of $1.5 \times 10^{34}\,cm^{-2}\,s^{-1}$. By upgrading all subdetectors and adding new detection capability it will be possible to accumulate a sample of $300\,fb^{-1}$ of high energy pp collision data, giving unprecedented and unique discovery potential in heavy flavour physics and other areas. The baseline LHCb Upgrade II detector has been presented in a Framework Technical Design Report that was approved in 2022. Here, updates are presented alongside scoping options with reduced detection capability and operational luminosity. The costs and physics performance of each scenario are discussed, and an overview of the project management plans is presented.

Intermediate step: LS3 enhancements

- Both TDRs on LS3 enhancements for ECAL, RICH, the PCIe400 readout board, and the Downstream Tracker on FPGAs have been approved
- These enhancements will enable improved performances for neutral particle reconstruction in the ECAL, for particle identification in the ECAL and RICH, and higher efficiency in long-lived particle reconstruction during Run-4
- Very importantly, we will also test precision timing, to be ready for measuring timestamps with O(10) ps precision in the LHCb Upgrade II

CERN-LHCC-2023-005



CERN-LHCC-2024-001

Conclusion

Closing remarks

- A lot has happened since last RRB meeting → we have achieved three fundamental milestones
  - We have brought the LHCb Upgrade I detector up to its design performance
  - We have demonstrated that the new fully software-based reconstruction and trigger concept is perfectly functional, delivering the promised efficiency improvements for charm and beauty hadronic final states
  - We have completed and submitted for review the Scoping Document of the Upgrade II
- Physics production is as healthy as usual
- Ready to end a wonderful 2024 with the heavy ion run!

The End.