titus.mombacher@cern.ch

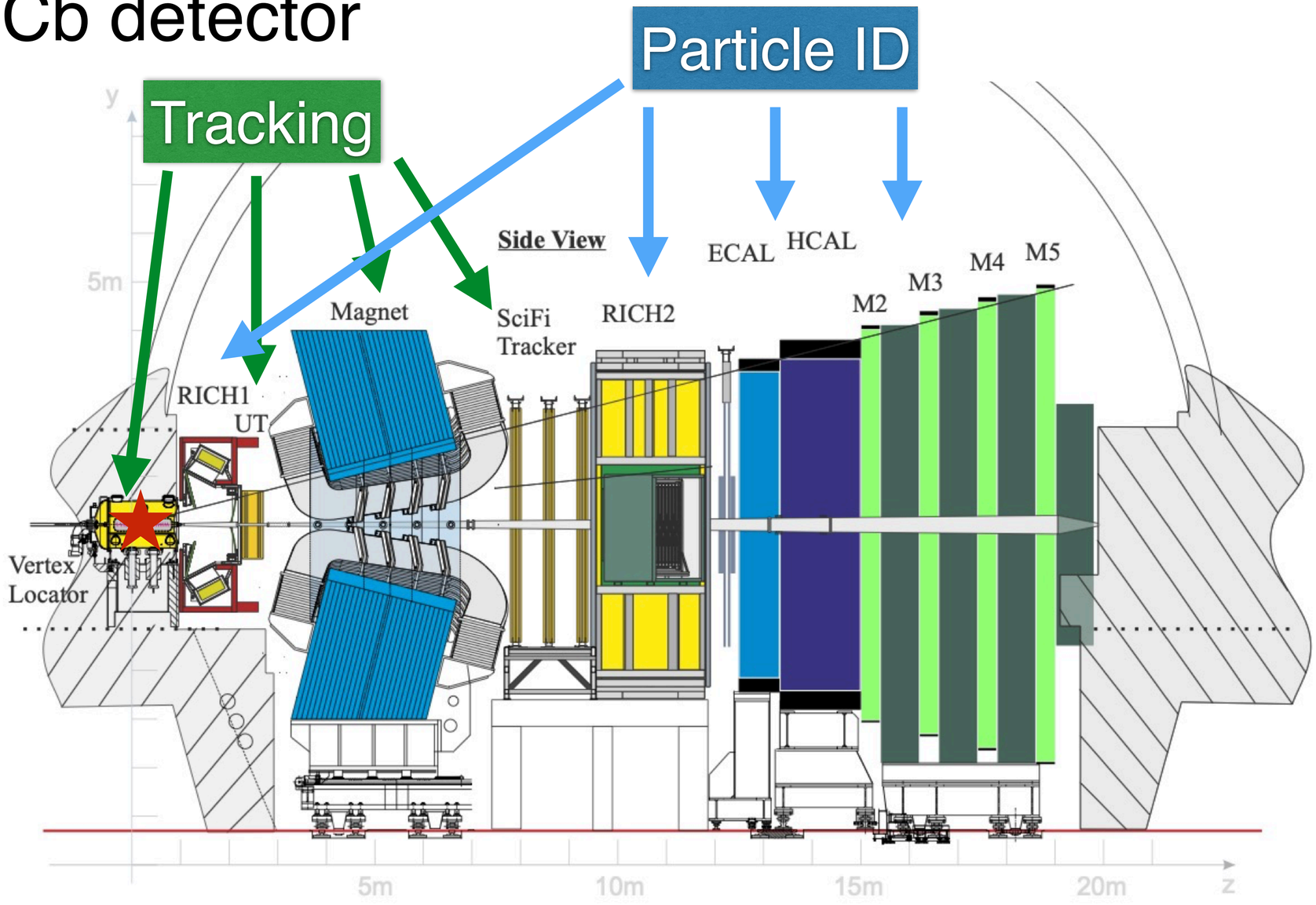
Status of the LHCb experiment

Titus Mombächer (CERN)
On behalf of the LHCb collaboration

LHCC Open Session

18.11.2024

The LHCb detector



New physics results since September LHCC week

Paper	Title	Arxiv Number
Papers submitted since September LHCC week		
LHCb-PAPER-2024-018	First determination of the spin-parity of the $\Xi_c(3055)^{+,0}$ baryons	2409.05440
LHCb-PAPER-2024-021	Measurements of $\psi(2S)$ and $\chi_{c1}(3872)$ production within fully reconstructed jets	2410.18018
LHCb-PAPER-2024-023	Measurement of the CKM angle γ in $B^\pm\to DK^{*}$	2410.21115
LHCb-PAPER-2024-024	Analysis of $\Lambda_b \to pK^-\mu^+\mu^-$ decays	2409.12629
LHCb-PAPER-2024-026	Search for $B_{(s)}^{*0}\to \mu^+\mu^-$ in $B_c^+ \to \pi^+ \mu^+\mu^-$ decays	2409.17209
LHCb-PAPER-2024-028	Measurement of the effective leptonic weak mixing angle	2410.02502
LHCb-PAPER-2024-030	Constraints on the photon polarisation in $b \to s \gamma$ transitions using $B_s^0\to \phi e^+ e^-$ decays	2411.10219
LHCb-PAPER-2024-032	Test of lepton flavour universality with $B_s^0 \rightarrow \phi \ell^+\ell^-$ decays	2410.13748
LHCb-PAPER-2024-033	Study of $D_{s1}(2460)^+ \to D_s^+ \pi^+ \pi^-$ in $B \to \overline{D}^{(*)} D_s^+ \pi^+ \pi^-$ decays	2411.03399
LHCb-PAPER-2024-036	Measurement of ϕ meson production in fixed-target pNe collisions at $\sqrt{s_{NN}} = 68.5$ GeV at LHCb	2411.09343
LHCb-PAPER-2024-041	Measurement of $\psi(2S)$ to J/ψ cross-section ratio as a function of centrality in PbPb collisions at $\sqrt{s_{NN}}$ =5.02 TeV	2411.05669
Preliminary results since September LHCC week		
LHCb-PAPER-2024-031	First evidence for direct CP violation in beauty to charmonium decays	
LHCb-PAPER-2024-034	Amplitude analysis of the $\Xi_c^+ \to pK^-\pi^+$ decay and Ξ_c^+ baryon polarization measurement in semileptonic beauty hadron decays	
LHCb-PAPER-2024-038	Measurement of multiplicity dependence of Υ production ratios in pp collisions at $\sqrt{s}=13$ TeV	
LHCb-PAPER-2024-040	Observation of the open-charm tetraquark state $T^*_{cs0}(2870)^0$ in the $B^- \to D^- D^0 K^0_S$ decay	
LHCb-PAPER-2024-042	A measurement of the differential cross-section for ρ mesons produced in ultra-peripheral PbPb collisions	
LHCb-PAPER-2024-043	Study of Λ^{0}_{b} and Ξ^{0}_{b} decays to $\Lambda h^+ h^{\prime -}$ and evidence for CP violation in $\Lambda^{0}_{b} \to \Lambda K^+ K^-$	
LHCb-PAPER-2024-044	Search for charge-parity violation in semileptonically tagged $D^0 \to K^+\pi^-$ decays	
LHCb-PAPER-2024-045	Study of light meson resonances decaying to $K^0_S K \pi$ in the $B \to (K^0_S K \pi) K$ channels	
LHCb-PAPER-2024-046	Test of lepton flavour universality with $B^+\to K^+\pi^+\pi^-\ell^+\ell^-$ decays	
LHCb-PAPER-2024-047	Search for D^0 meson decays to $\pi^+ \pi^- e^+ e^-$ and $K^+ K^- e^+ e^-$ final states	
LHCb-PAPER-2024-048	Measurement of $C\!P$ asymmetries in $\Lambda_b^0\to ph^-$ decays with the full LHCb Run 1+2 data sample	

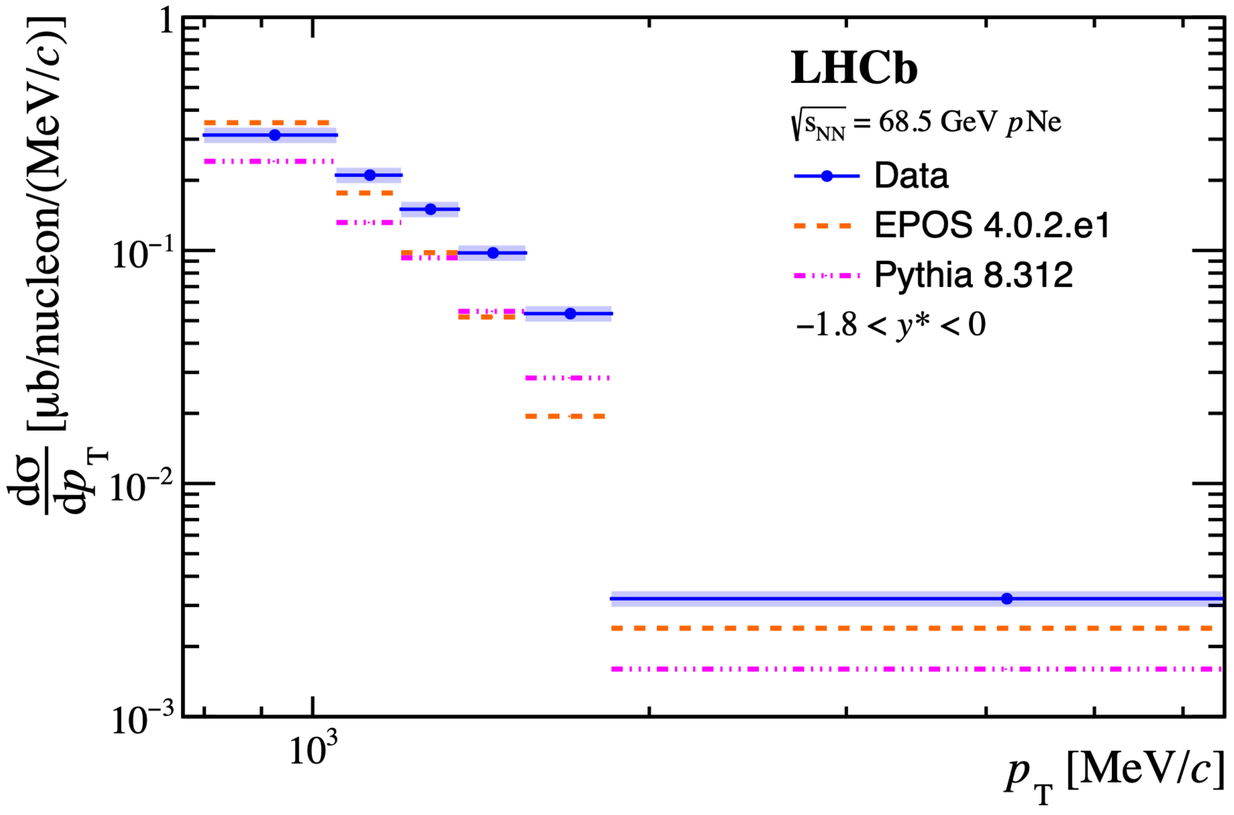
+11

+11

Measurement of ϕ meson production in fixed-target pNe collisions at $\sqrt{s_{NN}} = 68.5$ GeV

- LHCb-unique SMOG setup, collected in 2017
- Study potential Quark-Gluon-Plasma (QGP) formation in small systems
- Strangeness enhancement in QGP, ϕ in ordinary matter OZI suppressed
- Important reference for heavier systems and generator tuning

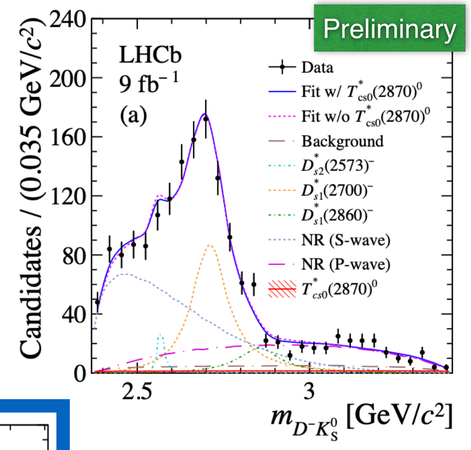
[2411.09343]

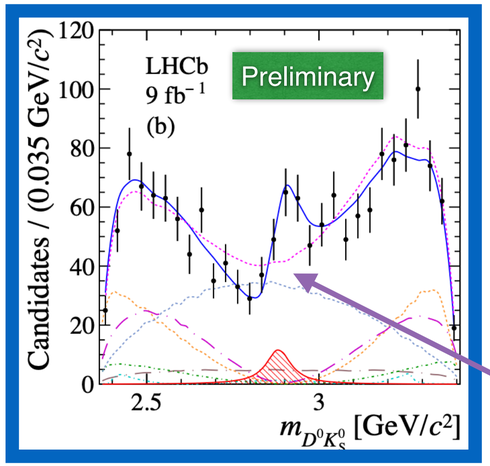


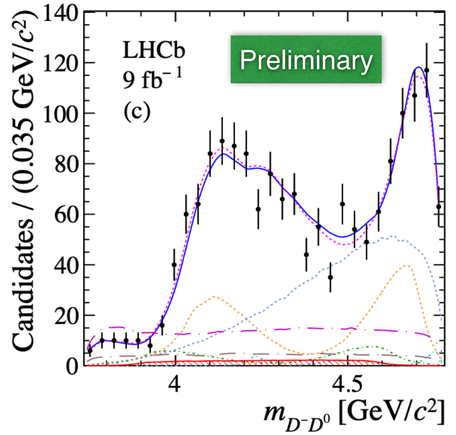
[LHCb-PAPER-2024-040]

Observation of $T^*_{cs0}(2870)^0$ in $B^- \to D^- D^0 K^0_S$

- $cs\bar{u}\bar{d}$, crucial for understanding QCD confinement
- Previous observation of $T^*_{cs0}(2870)^0$ in $B^- \to D^- D^+ K^-$ together with $T^*_{cs1}(2900)^0$ [PRL125(2020)242001]
- New discovery of $T^*_{cs0}(2870)^0 \to D^0 K^0_S$, full Run 1+2 data set
  - $T^*_{cs1}(2900)^0$ not significant
  - Test isospin asymmetries: $T^*_{cs0}(2870)^0$ consistent with isospin conservation



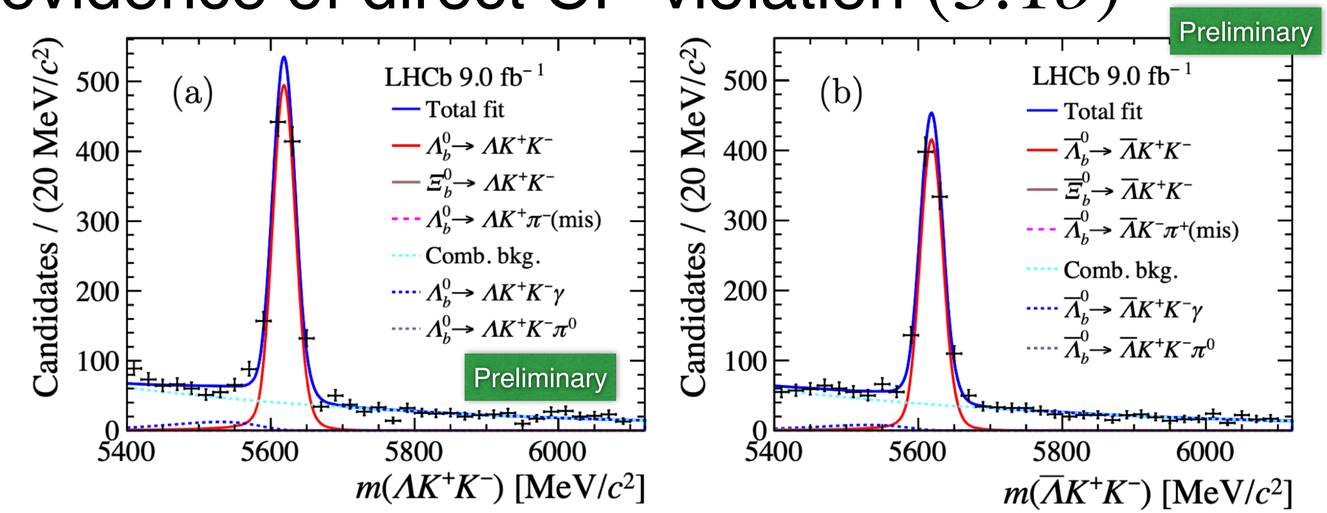




Evidence for direct CP-violation in baryons

- No CP-violation in baryons observed to date
- Study $\Lambda_b^0/\Xi_b^0 \to \Lambda h h^{(\prime)}$ with all 6 final states $(h = \pi, K)$ with full Run 1+2 data
- Search/measurement of branching fractions
- Measurement of CP asymmetries, evidence of direct CP-violation (3.1σ) in $\Lambda_b^0 \to \Lambda K^+ K^-$

$$\Delta\mathcal{A}^{CP}\left(\Lambda_b^0 \to \Lambda\pi^+\pi^-\right) = -0.013 \pm 0.053 \pm 0.018,$$
$$\Delta\mathcal{A}^{CP}\left(\Lambda_b^0 \to \Lambda K^+\pi^-\right) = -0.118 \pm 0.045 \pm 0.021,$$
$$\Delta\mathcal{A}^{CP}\left(\Lambda_b^0 \to \Lambda K^+K^-\right) = 0.083 \pm 0.023 \pm 0.016,$$
$$\Delta\mathcal{A}^{CP}\left(\Xi_b^0 \to \Lambda K^-\pi^+\right) = 0.27 \pm 0.12 \pm 0.05,$$



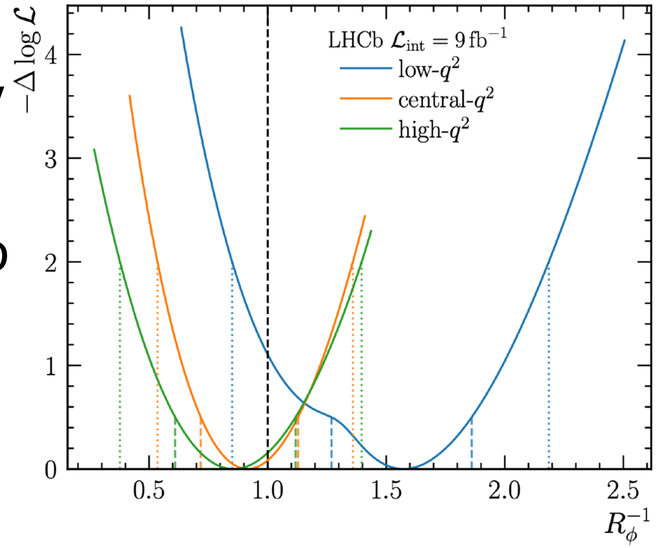
Test Lepton Flavour Universality (LFU) in $B_s^0 \to \phi \ell^+ \ell^-$ and $B^+ \to K^+ \pi^+ \pi^- \ell^+ \ell^-$

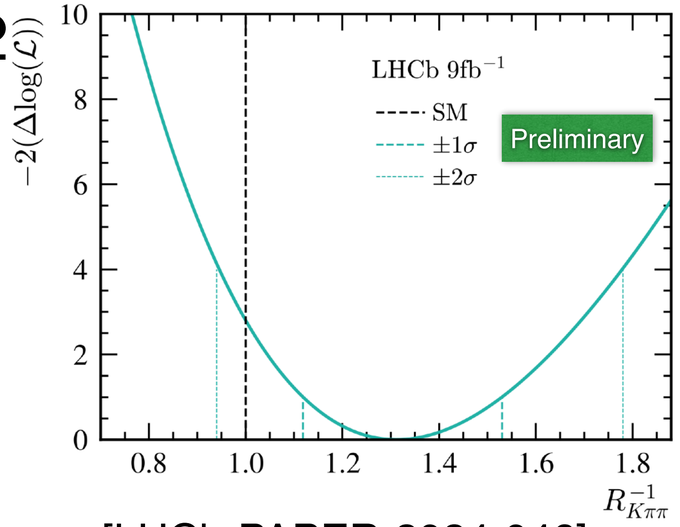
[2410.13748]

- LFU ratios clean probes theoretically and experimentally
  - Hadronic uncertainties cancel
  - Many systematic uncertainties cancel, especially with double ratio

$$R_h = \frac{\mathcal{B}(B \to h e^+ e^-)/\mathcal{B}(B \to h J/\psi(e^+e^-))}{\mathcal{B}(B \to h \mu^+ \mu^-)/\mathcal{B}(B \to h J/\psi(\mu^+\mu^-))}$$

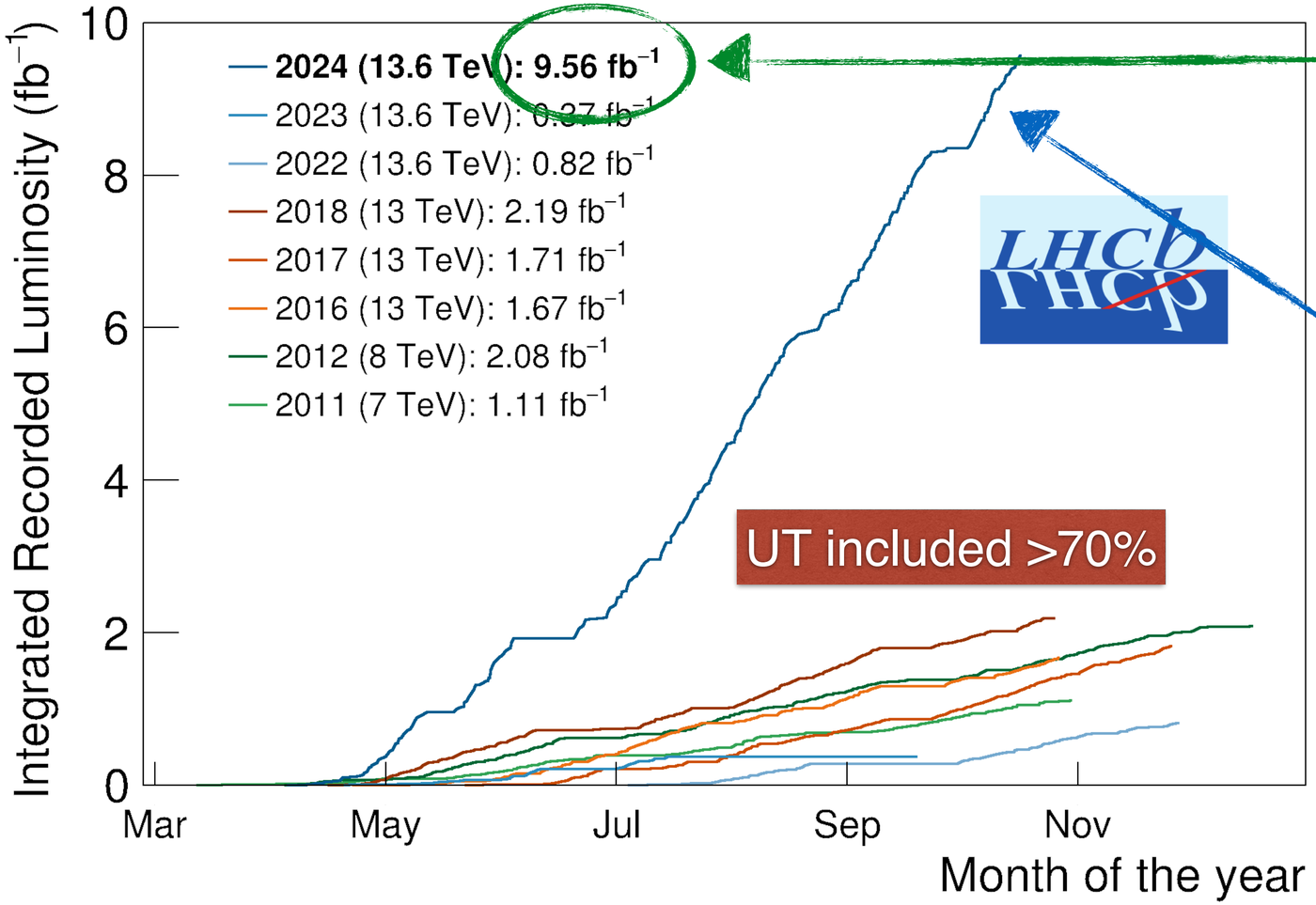
- In the past: $R_K, R_{K^{*0}}, R_{pK}, R_{K_S^0}, R_{K^{*+}}$
- NEW measurements of R_ϕ and $R_{K^+\pi^-\pi^+}$ with Run 1+2
  - First test in B_s^0 and study of complex $K^+\pi^+\pi^-$ system
  - Measurements compatible with the SM
- NEW: the up-sector joins through first observation of $D^0 \to \pi^+\pi^- e^+ e^-$ [LHCb-PAPER-2024-047]





[LHCb-PAPER-2024-046]

Successful 2024 pp data - meeting the goals

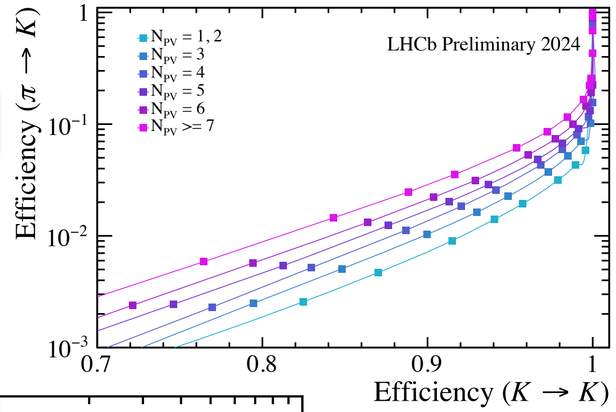


More data than **all previous years together**

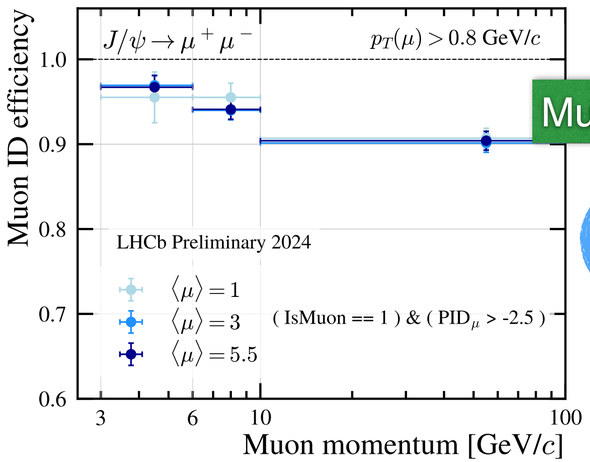
Move to design luminosity:
$\mathscr{L}_{inst} = 2 \times 10^{33} \mathrm{cm}^{-2}/s$

Design performance @design luminosity

RICH PID

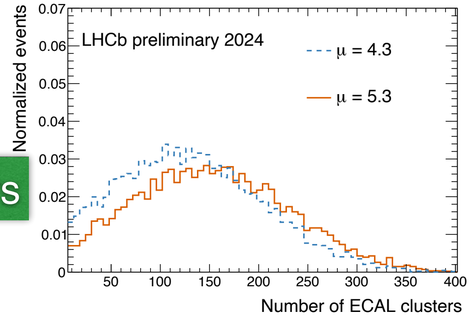


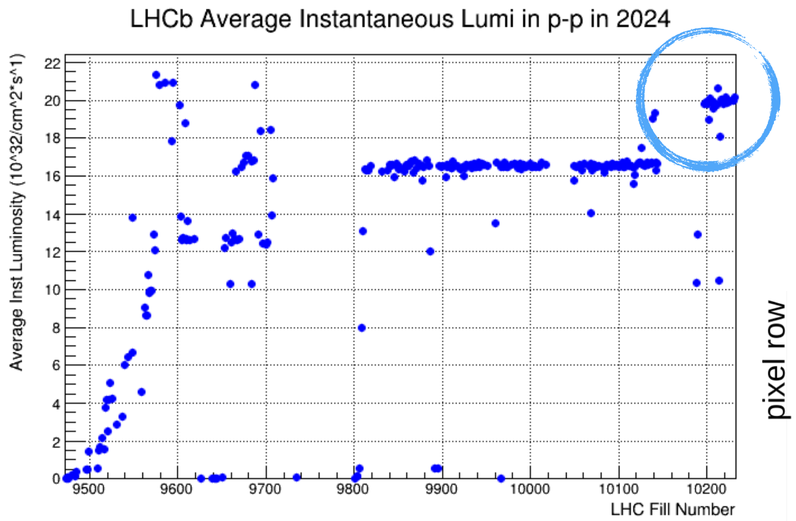
Muon ID

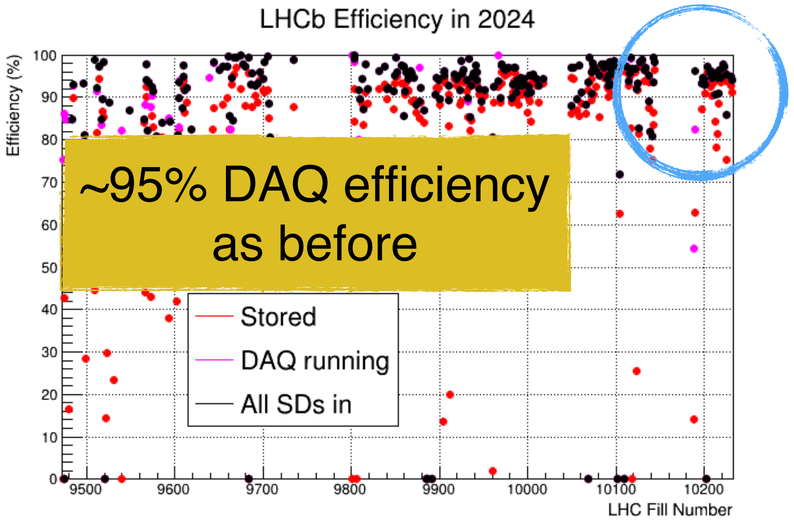


Examples

ECAL clusters

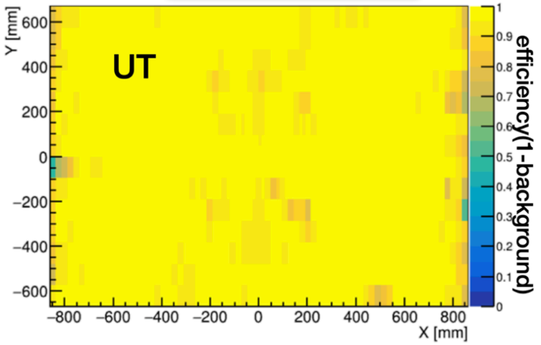




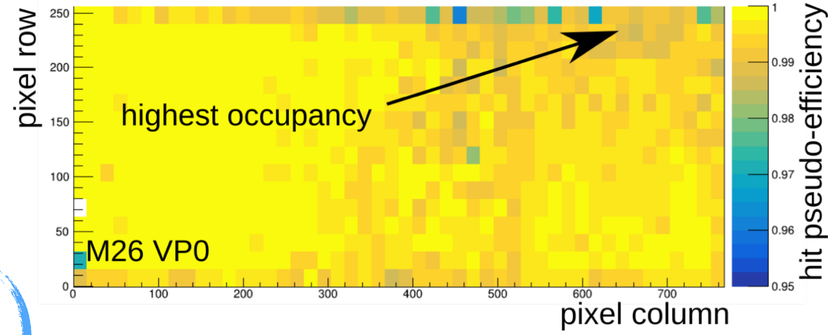


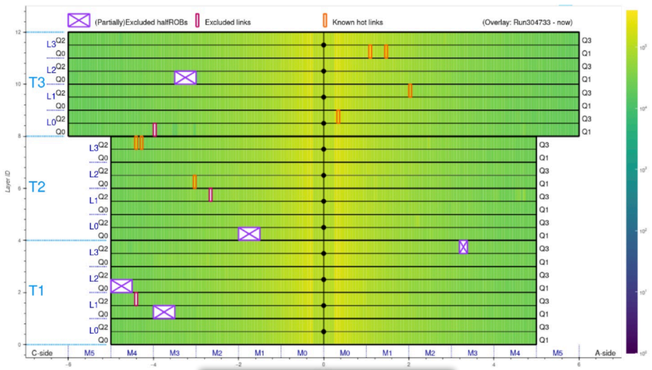
~95% DAQ efficiency as before

UT Efficiency



VELO Efficiency

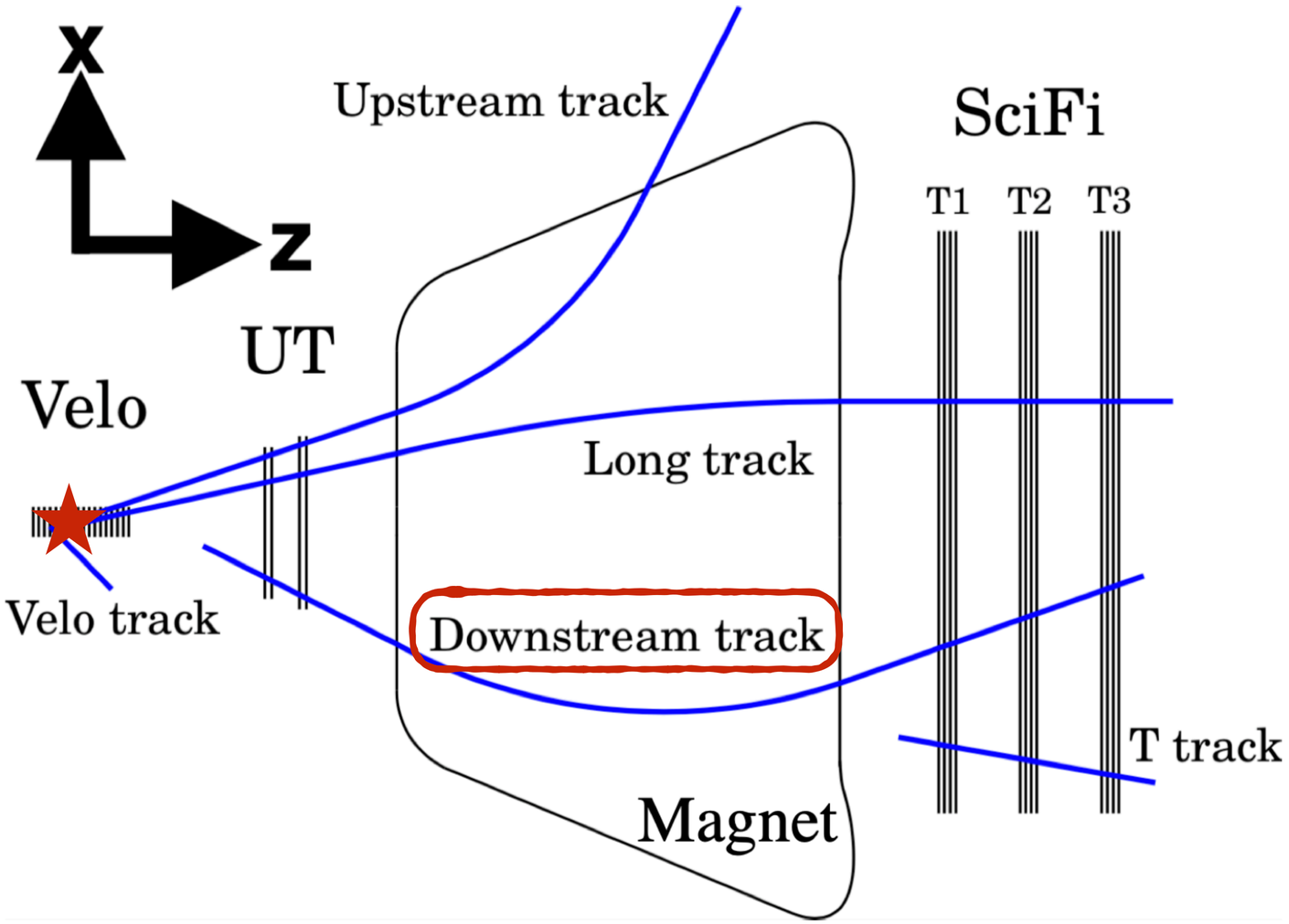




SciFi Hit Map

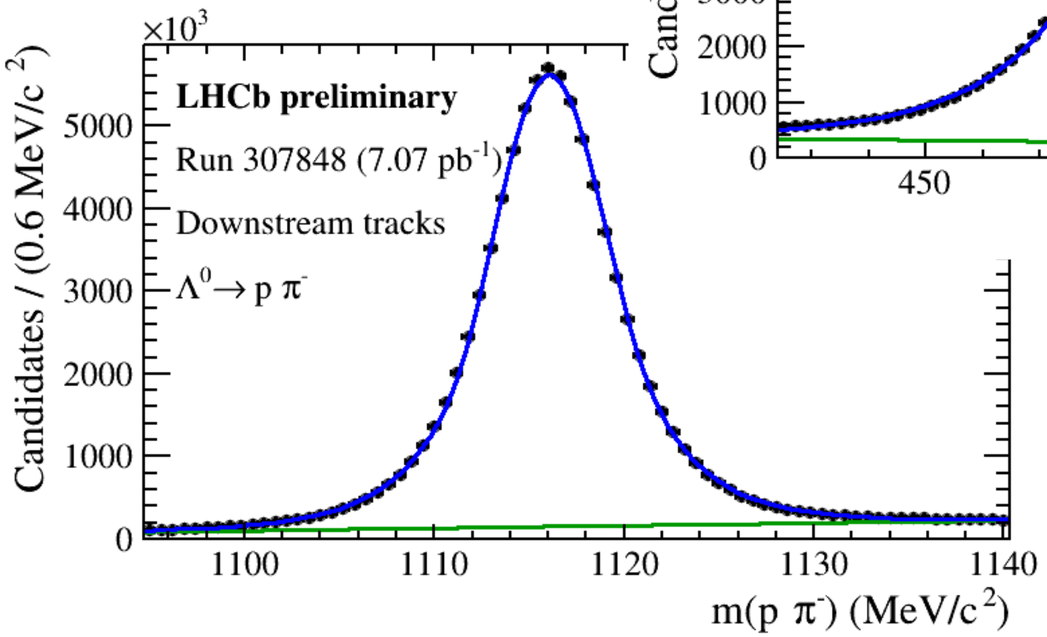
Exploit flexibility of LHCb first level trigger

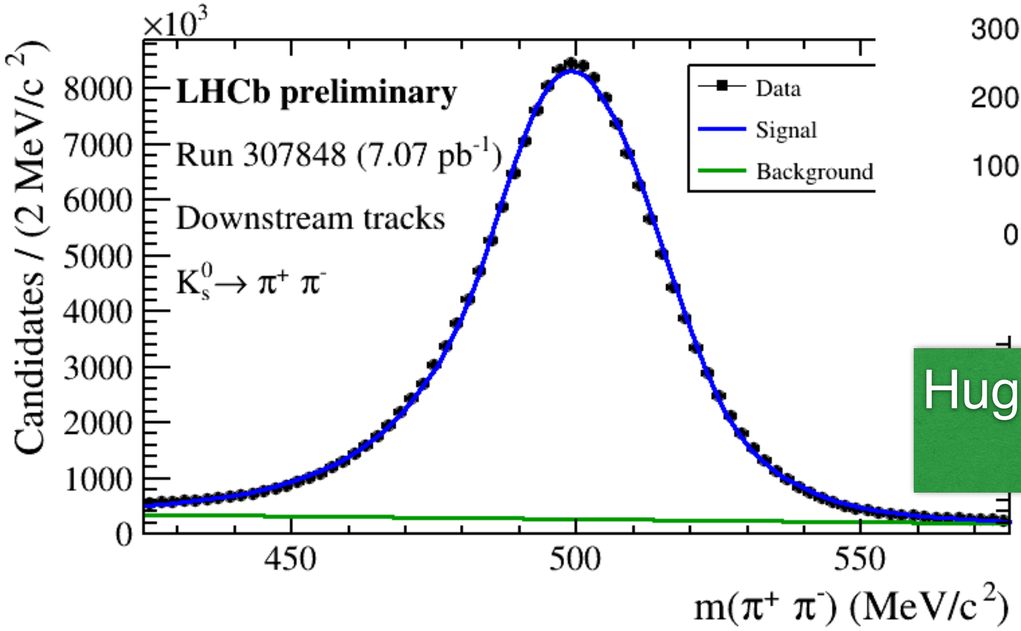
- Include UT in HLT1
  - Better ghost suppression
  - Forward tracking in addition to matching → mitigate saturation at high occupancies
- New trigger selections extending the physics program even more
  - soft displaced dielectron trigger → targeting strange decays to dielectrons
  - **Reconstruct downstream tracks @30MHz** (HLT1) → boost measurements with long-lived particles

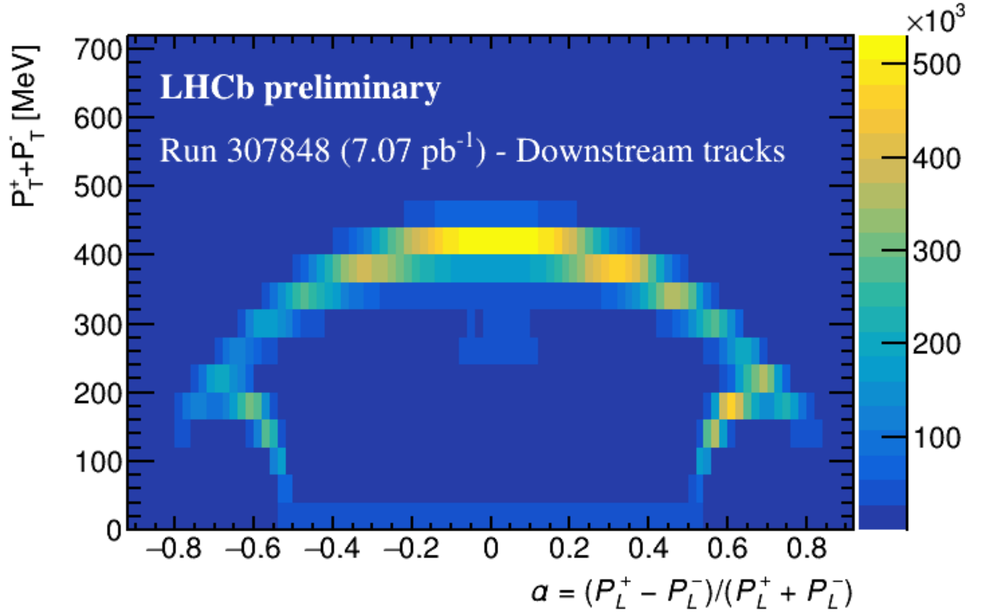


Downstream tracking in HLT1

[LHCb-FIGURE-2024-035]

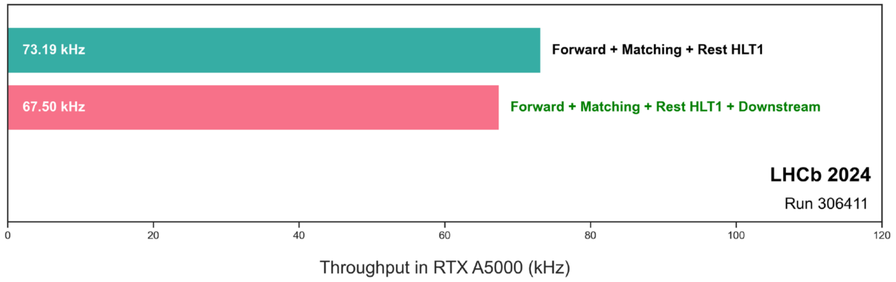






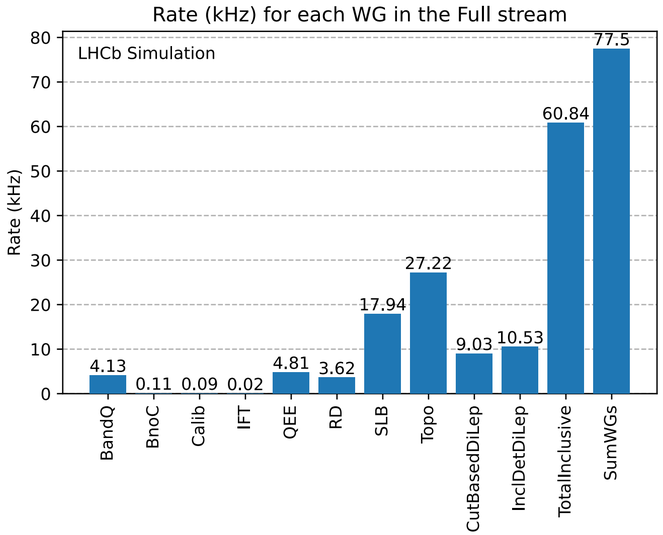
Huge yield of long-lived particles already with 1h data

only moderate throughput reduction

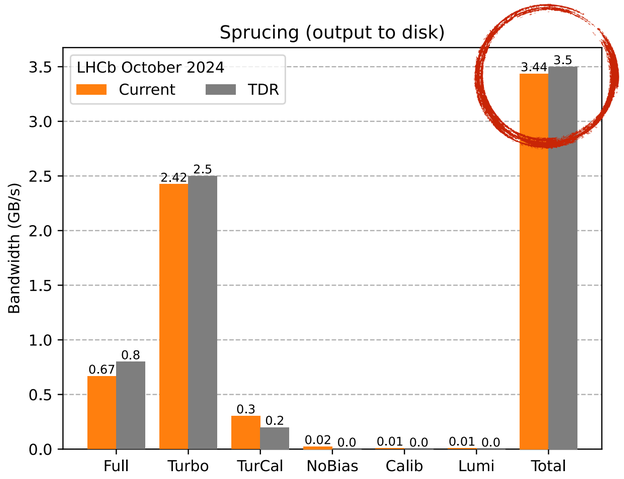


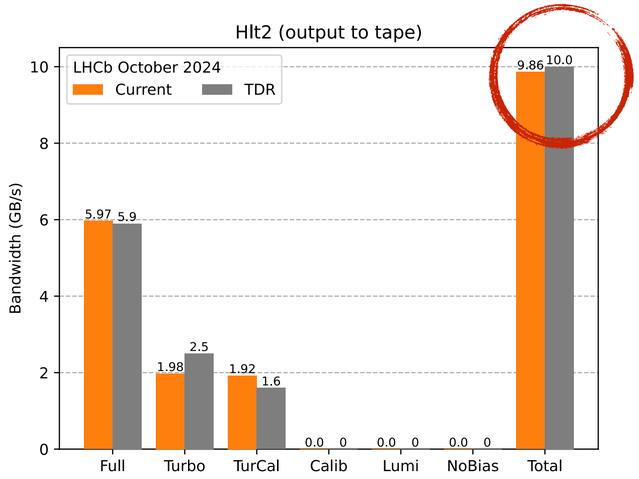
Collaborative efforts to keep bandwidth under control

- Significantly more data due to higher $\mathscr{L}_{inst}$!
- Efforts across all physics working groups, improving HLT2 selections and keeping stored data within limits
- Further refinements during YETS planned in view of extended data taking into 2026



[LHCb-FIGURE-2024-034]

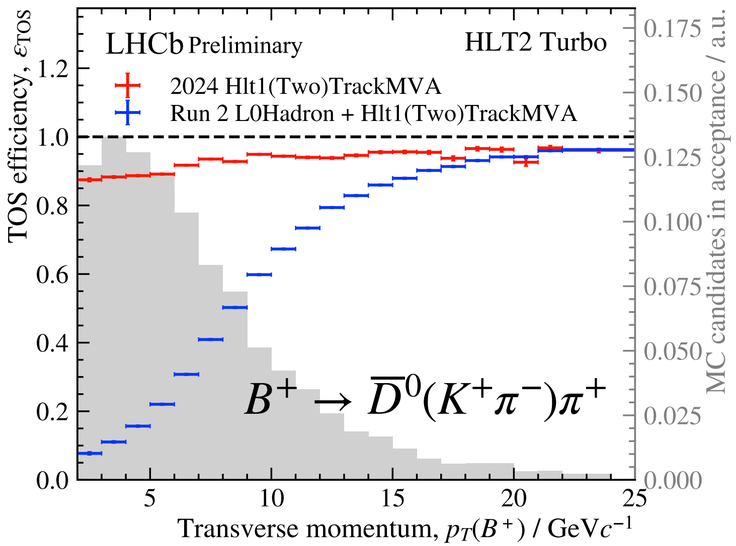


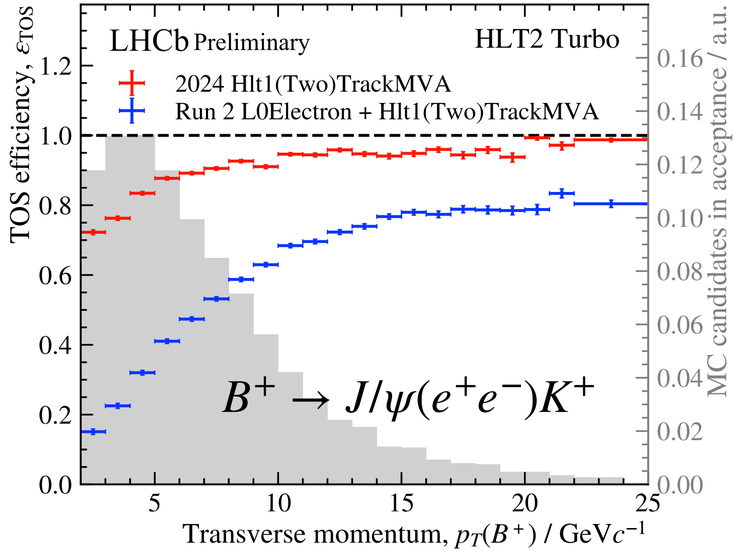


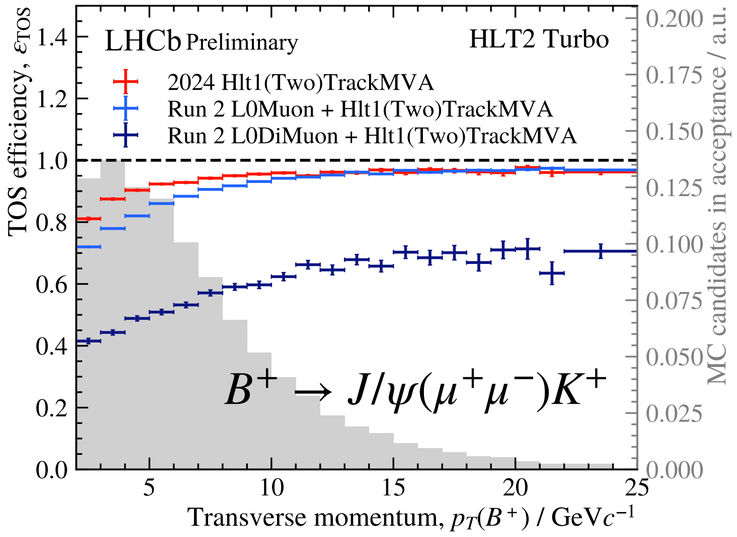
LHCb performance in 2024 - Trigger

- Removal of hardware trigger (L0) improves efficiencies for hadrons (x2) and electrons as expected
- Even improvements on Muon trigger efficiencies!

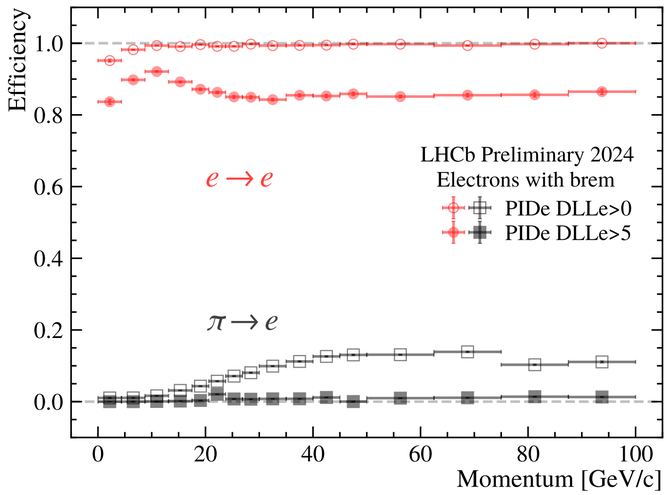
[LHCb-FIGURE-2024-030]

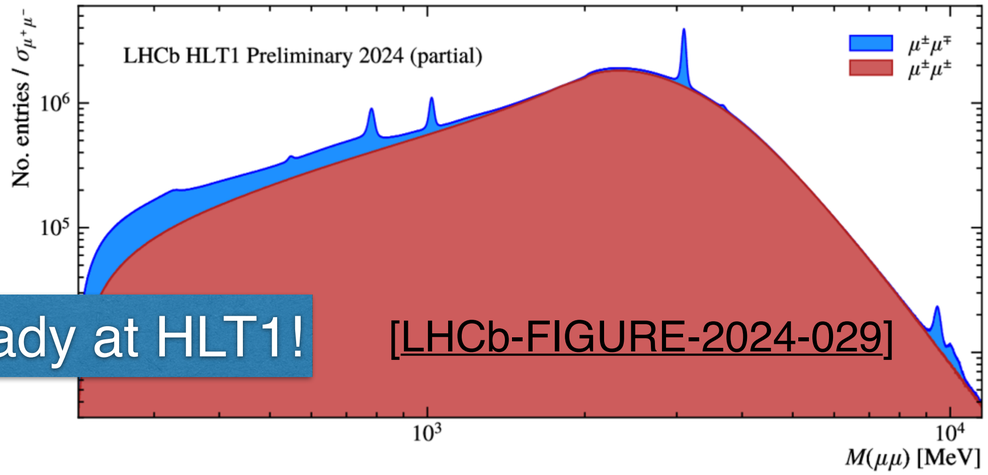






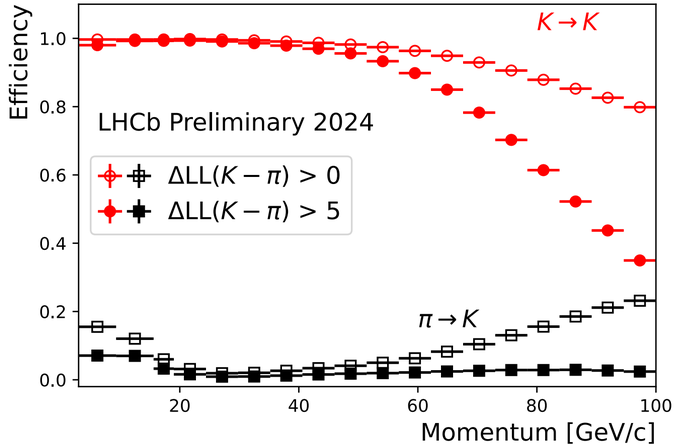
LHCb performance 2024 - Strong particle identification

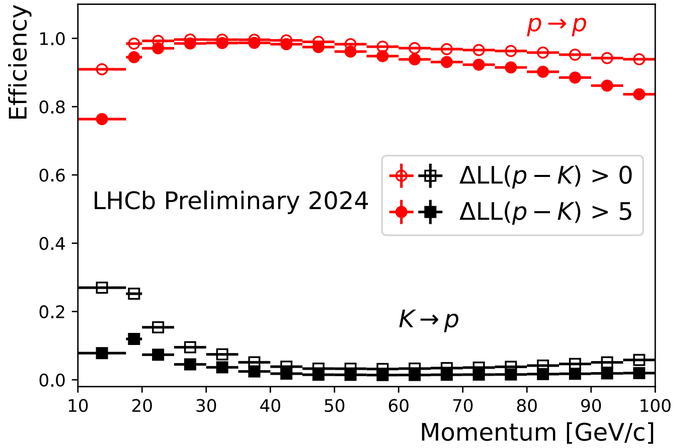


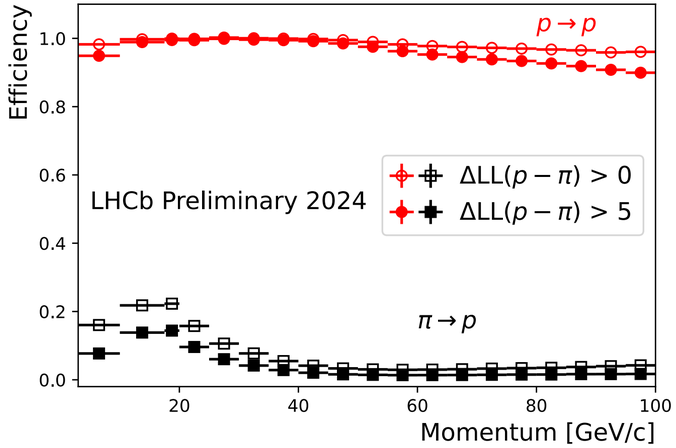


MVA-based muon ID already at HLT1!

[LHCb-FIGURE-2024-029]

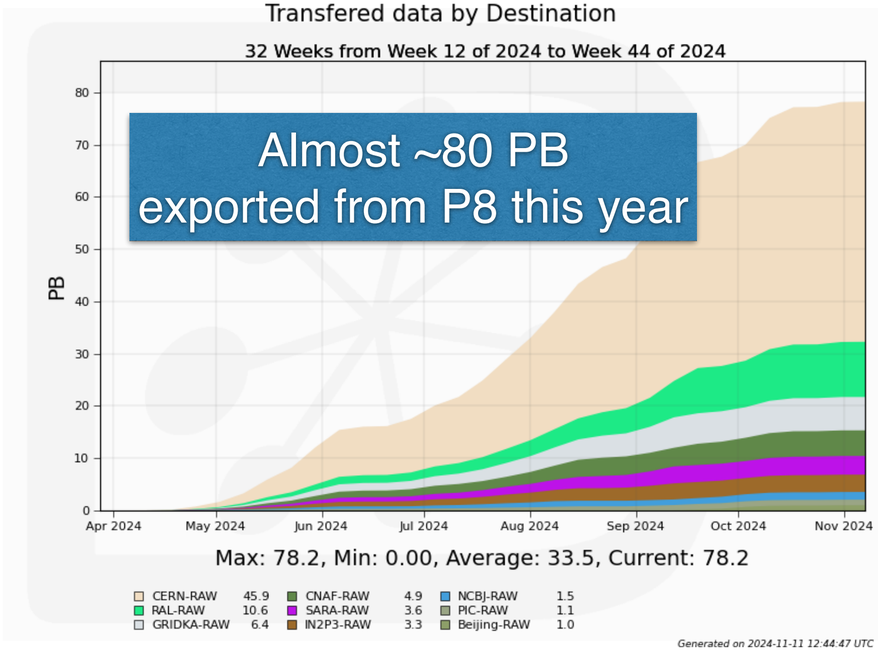


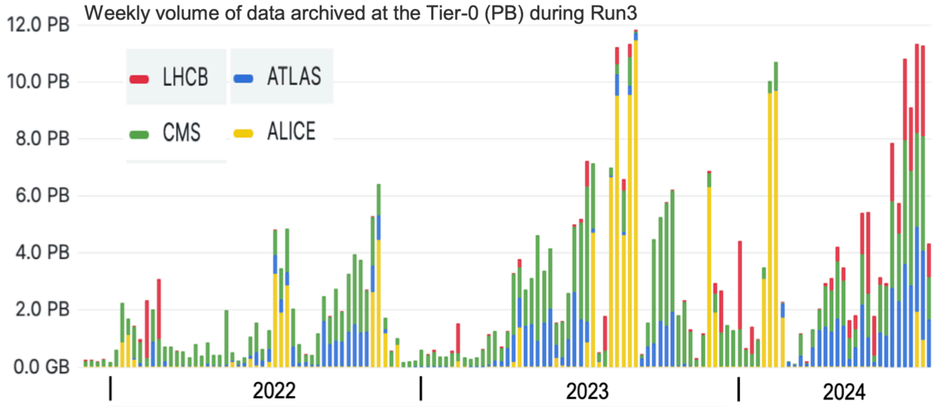




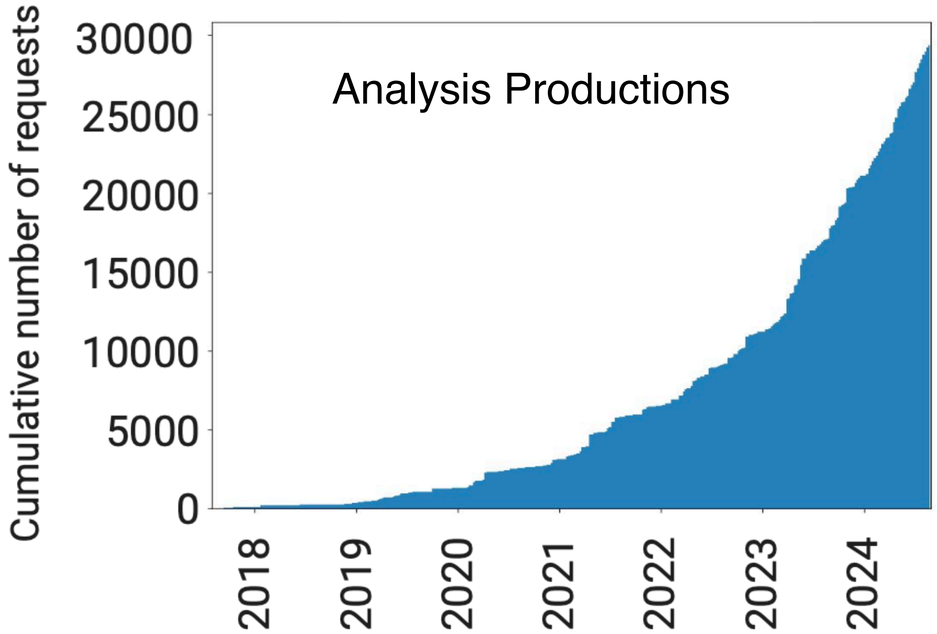
[LHCb-FIGURE-2024-031]

Offline data processing





Data volume similar ATLAS/CMS

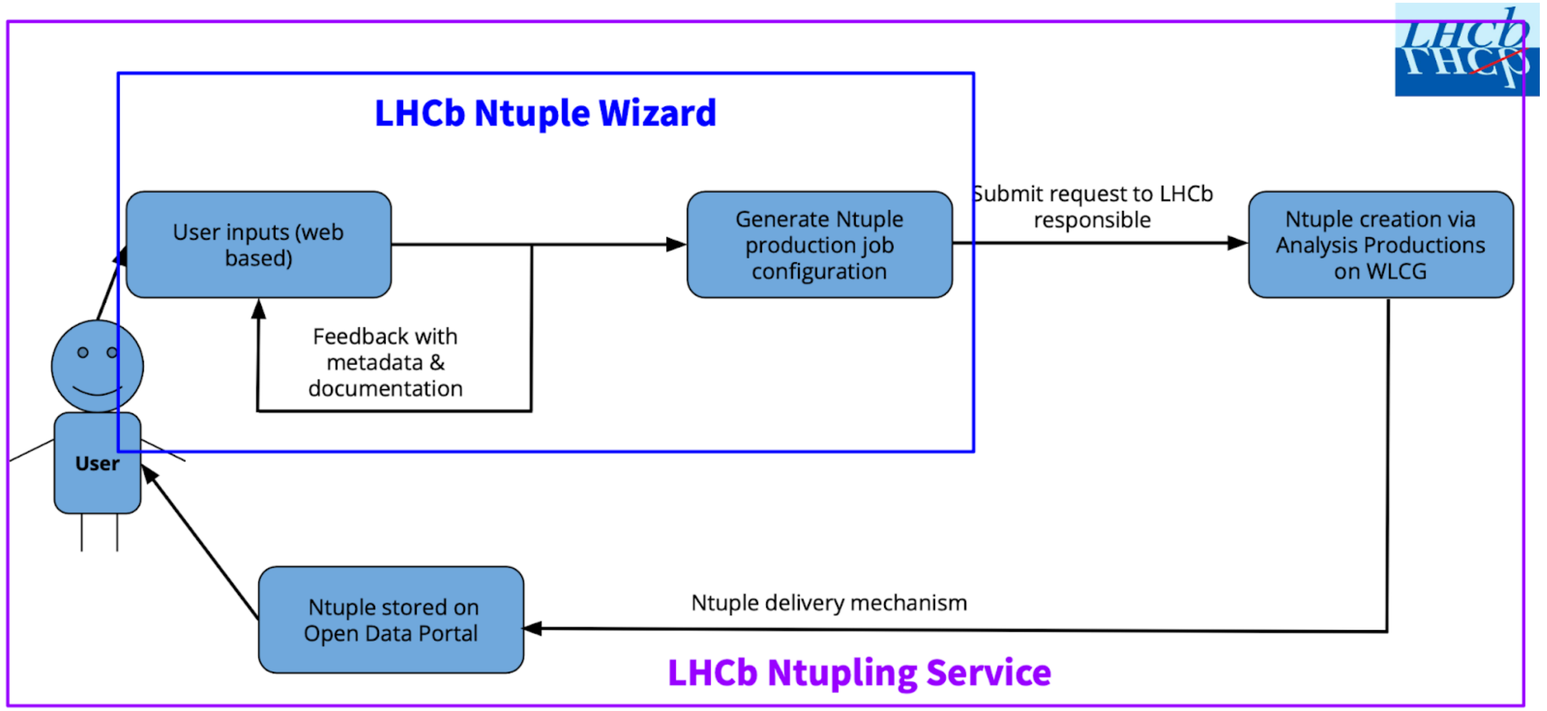


- Analysis Productions to handle huge data load and process tuples:
  - User decides the desired quantities, automated tests with Git CI (small local test productions)
  - Data processing handled centrally
- Large use, 700+ “live” AP pick up data as it was spruced
  - **Analysts looking at data ~days after being recorded**

2024 pp ready for data analysis:
Data Quality of all pp collision data assessed

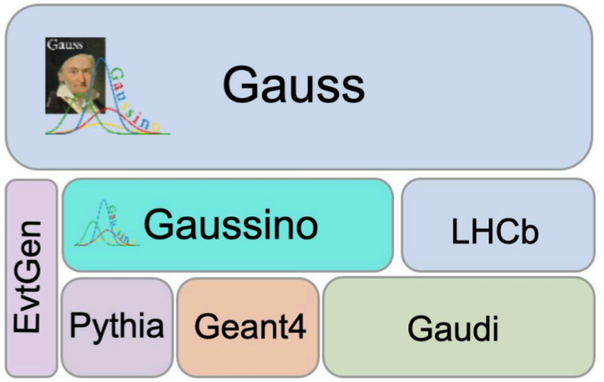
New Tool to explore Open Data: Ntuple Wizard

- Based on Analysis Production as scalable and user-friendly tool to handle huge data
  - Released Run 1 data set end of 2023, 50% of Run 2 to be released 2025
- Publicly introduced in Mini-workshop 22.10. (in context of Implications Workshop)



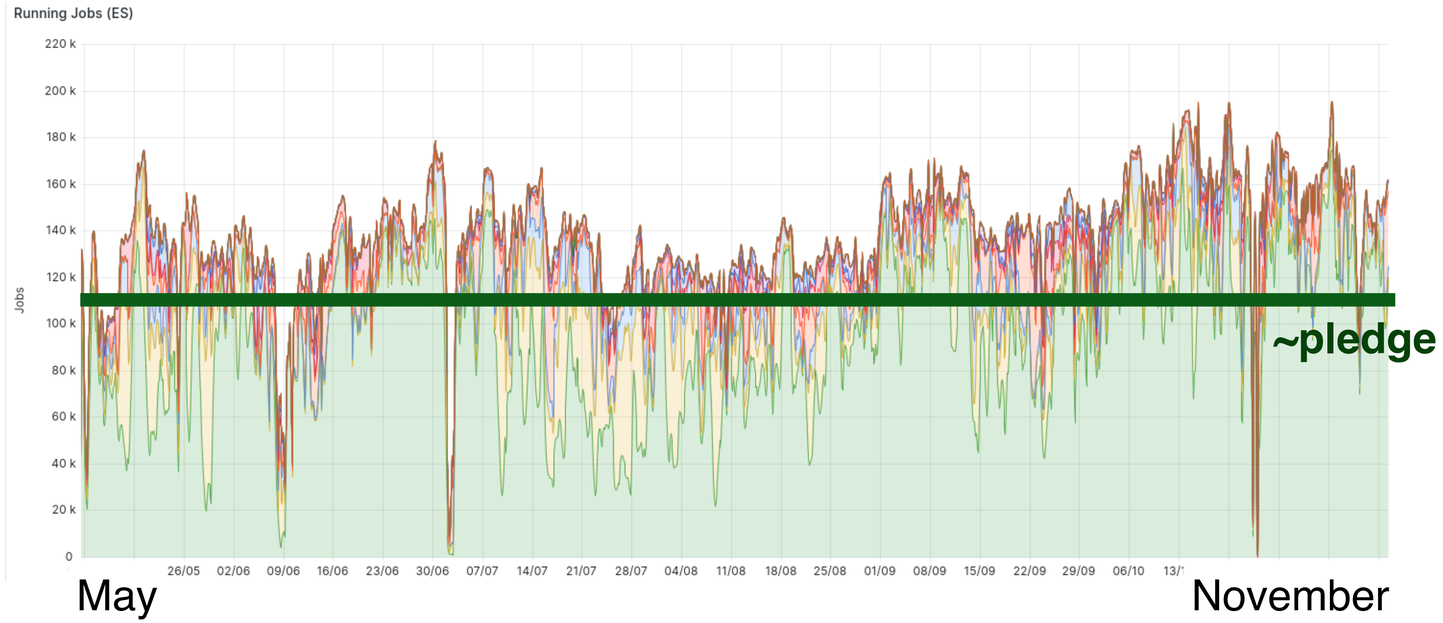
Simulation

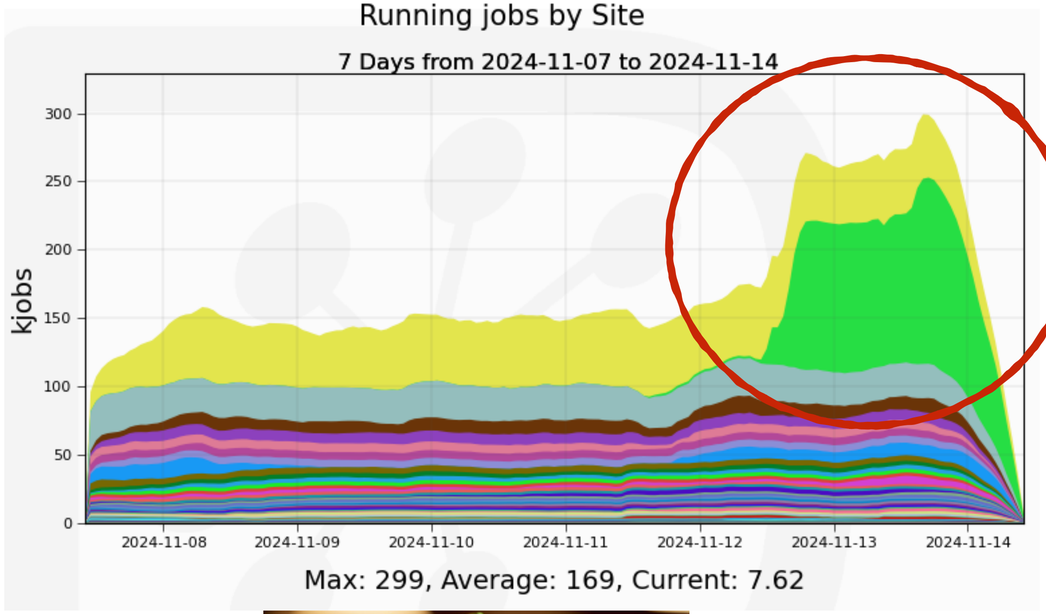
- Many activities ongoing
- 2024 data taking:
  - Different simulation for different periods (beam conditions, luminous region, VELO position, trigger decisions)
  - Simulation ready for some periods
  - Implementation of detector conditions soon (VELO, SciFi, UT)
- Development of Gauss-on-Gaussino
  - New framework for Run 3 and in perspective of Upgrade II
  - Support of DetDesc and DD4HEP
  - Fast (ML-based) simulations interface



Offline Computing

- Efficient use of available WLCG CPU resources (~89% used for simulation)
- Started using 50% of the CPU of the HLT2 Farm (not full farm needed for PbPb)

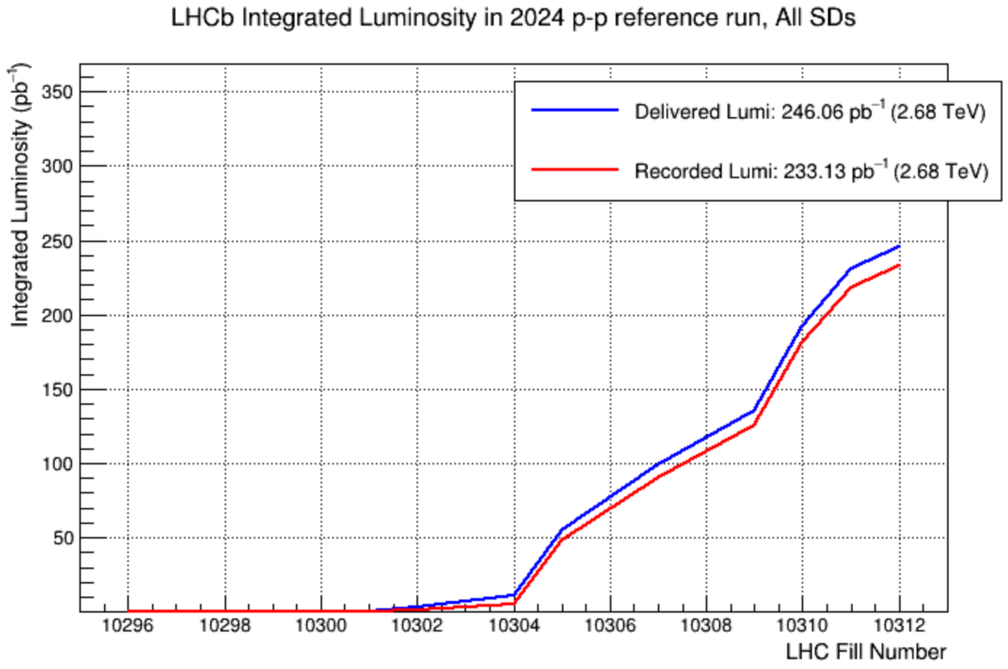


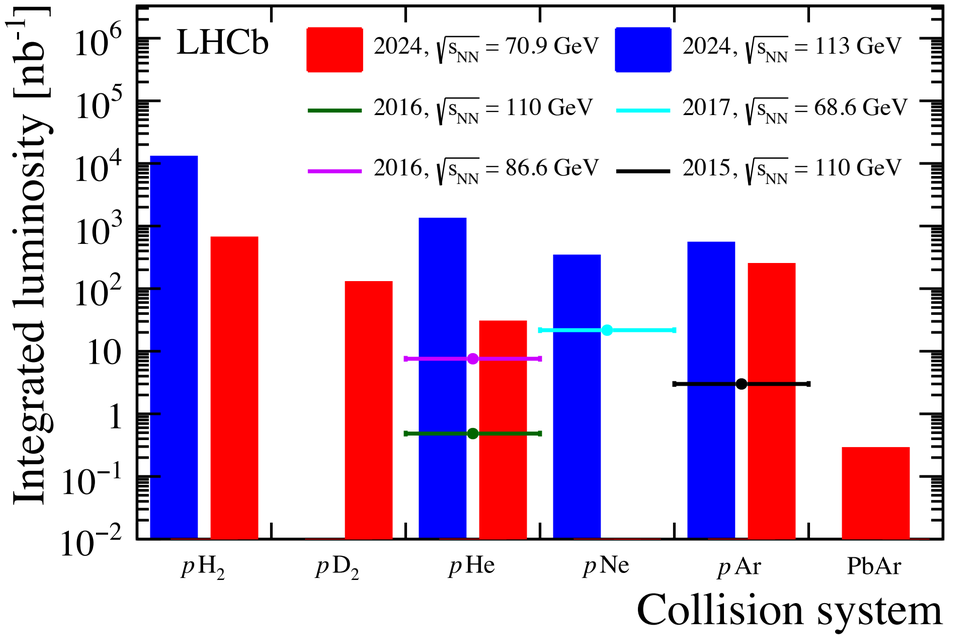


Unprecedented data sample during pp-reference run

- Stored $> 200\,\text{pb}^{-1}$ pp collisions (target: $100\,\text{pb}^{-1}$)
- Large amount of diverse pGas data:
  - collisions with H_2, D_2, He, Ar
  - Increased luminosity by $\mathcal{O}(10-100)$ thanks to innovative SMOG2 cell

Thanks to CERN Vacuum Group for good collaboration!

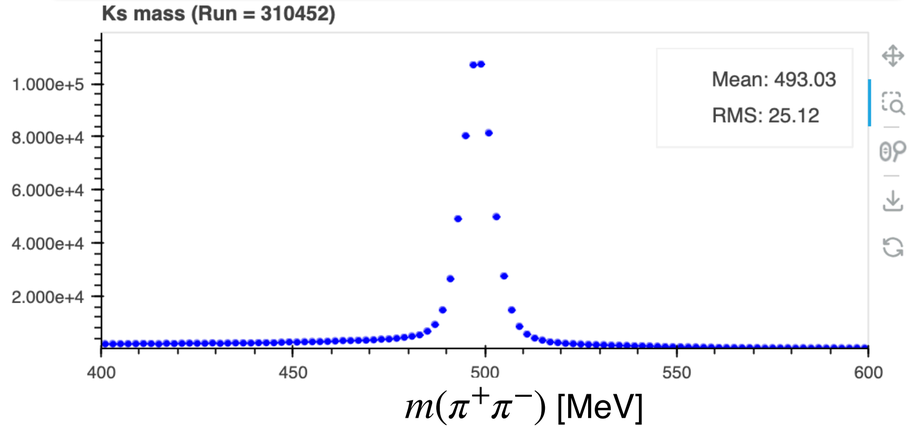


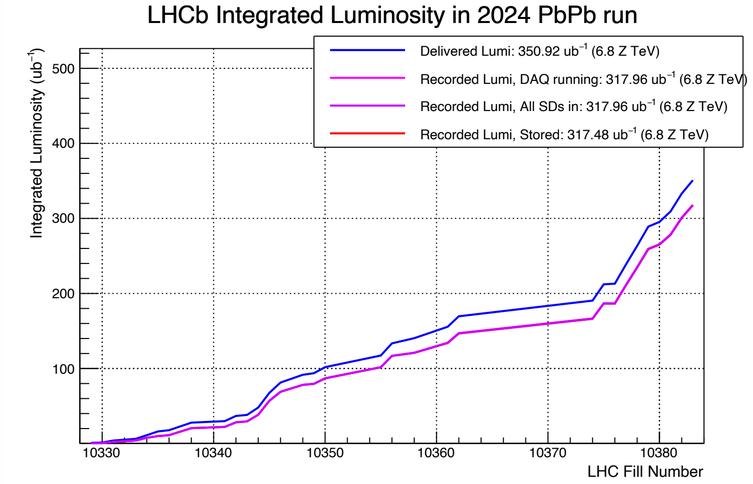


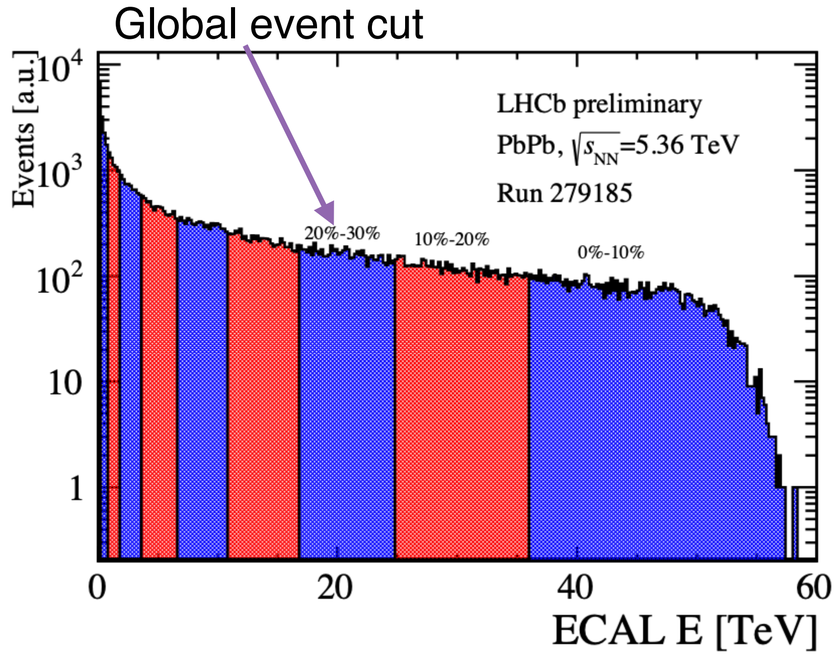
2024 Heavy Ion run

- Ambitious PbPb data taking: PbPb collider and high rate PbGas with SMOG2
- PbPb: Full minimum bias strategy, veto high multiplicity (~30% centrality) → expectation of $300 - 400\,\mu\text{b}^{-1}$ total luminosity already met!
- PbGas: pressure set point finalised
  - PbAr: collected about $1\,\text{nb}^{-1}$
  - Run with PbNe until the end of the Ion run
- Operations running smoothly

Clean $K^0_S \to \pi^+\pi^-$ reco @30MHz in the monitoring







Activities during YETS

- VELO: remove shims (safety: prevented full VELO closing before)
  - ~10% improvement in IP resolution
  - Leaks check and fixing for UT and VELO
- Magnetic Field measurement campaign
  - Especially edge of acceptance → improve alignment
- Consolidate SMOG injection → higher flexibility
- Consolidation Cooling → improve stability
- + general maintenance tasks

No major co-activities

Upgrade II

CP violation
CKM unitarity
FCNC's
beauty, charm, strange
Exotic hadrons
Rare strange decays
Fixed Target (SMOG)
Forward Heavy Ion
Long-lived particles

- **Ultimate flavour factory in coming decades**
  - Improve sensitivity by 3-4 wrt current detector
  - Drive tech developments for future experiments and facilities
- Scoping document under review by LHCC, recommendations expected in 2025/ Q1
- Making sure all lessons are being learned
  - Minimise number of ASIC developments and perform thorough validation
    → Ensure communication with designers in test stage
- DAQ and Firmware establish design early and benefit from LS3 enhancements
  → start commission early with final DAQ system

Conclusions

- 2024 implied a lot of hard work, but is a (still ongoing) success!
  - Run 1&2 still yield large physics output with important impact
  - **Running at design luminosity**
  - **Met the goals: more data this year than all previous together!**
  - Smooth and efficient across nominal pp, pp-reference, Heavy Ion, SMOG2
  - Simulation getting ready for 2024 analyses
  - First Run 3 publications in the pipeline
- Looking forward to a(nother) year of luminosity production in 2025!
- Upgrade II preparations forming steadily

Thank you, LHC!