LHCb status report

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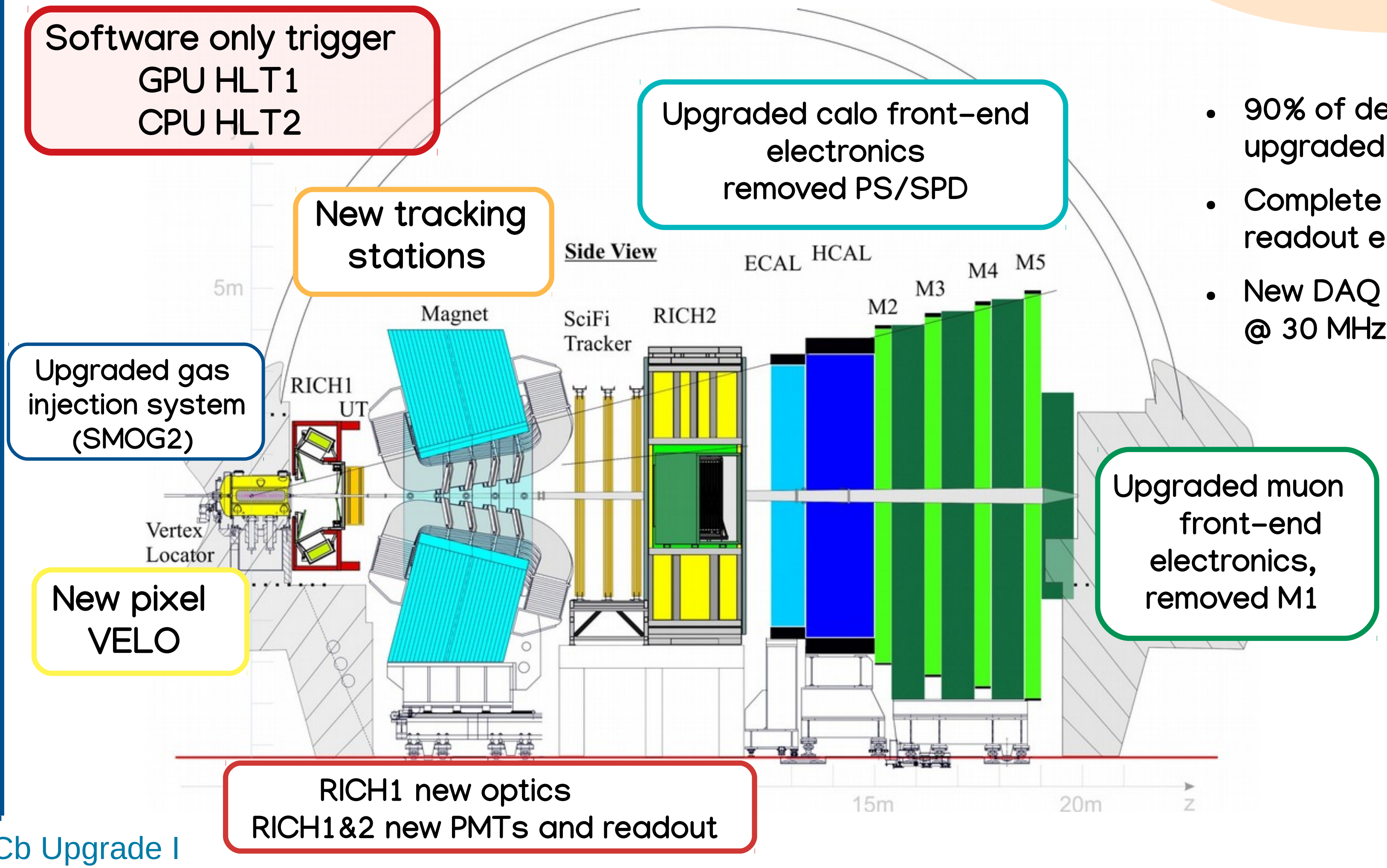
on behalf of the LHCb collaboration

154th LHCC meeting
Open Session

7th June 2023

The LHCb U1 upgrade

$\mathcal{L}_{peak} = 2 \times 10^{33}\ cm^{-2}\ s^{-1}$
(×5 w.r.t Run1)



- 90% of detector channels upgraded
- Complete replacement of readout electronics
- New DAQ & online system @ 30 MHz

Run 3: Where we are now

Completed

Sub-detectors installation

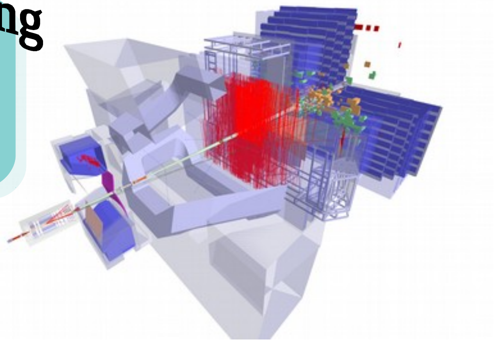
LHCb upgrade I paper published
CERN seminar 16th June

Ongoing

Sub-detectors & data flow commissioning

Commissioning started during 2022
Important milestones achieved

2023 data @ 6.8 TeV

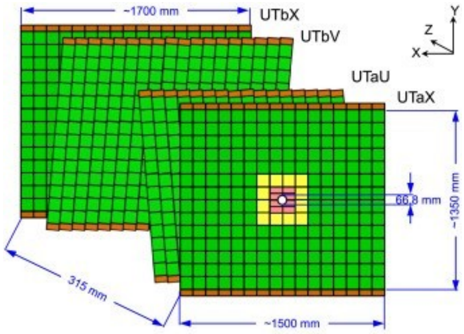


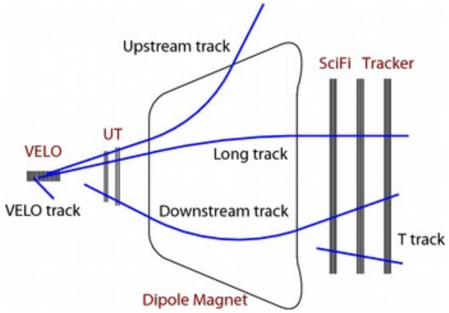
Ongoing

Study of detector performance

First checks on data collected in 2022
Important to address the detector performance

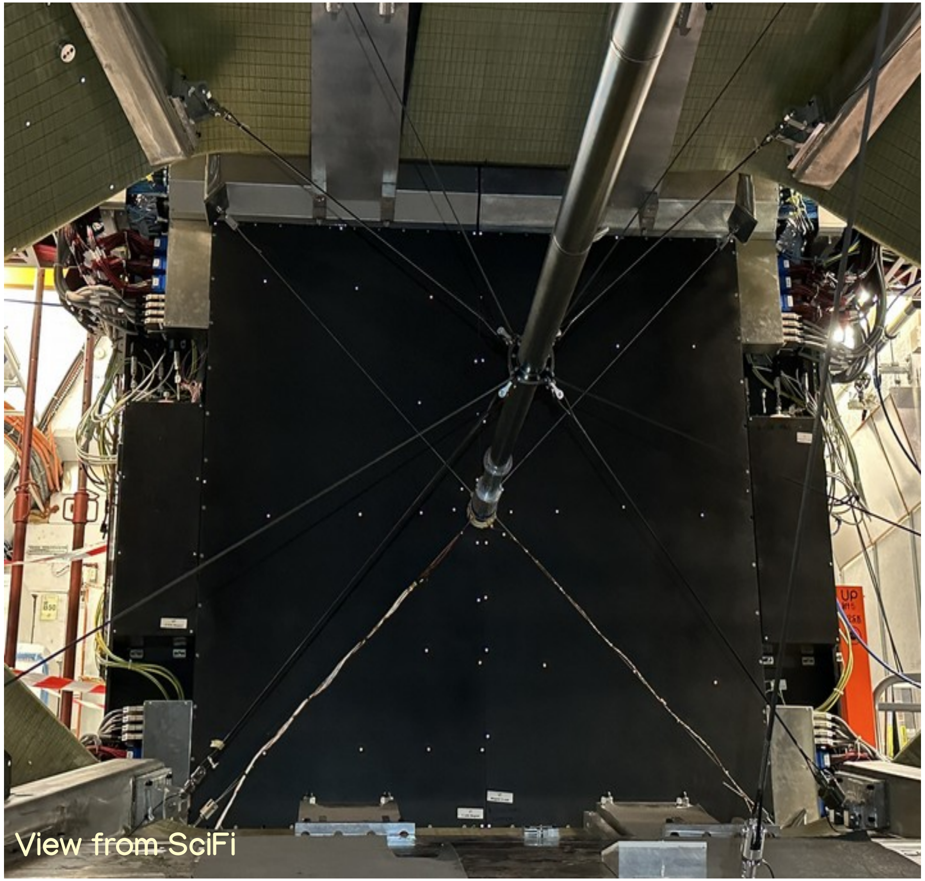
Upstream Tracker





- Part of the software trigger
- Reduce track combinatorics (ghosts)
- Reconstruct long-lived particles

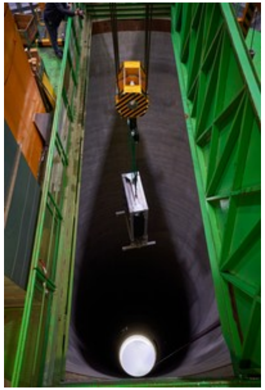
UT successfully closed before the start of 2023 run!



Upstream Tracker

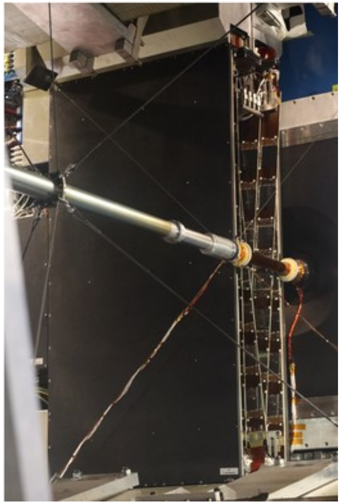
Installation and closure of the UT detector within 22/23 YETS have been a challenging target:

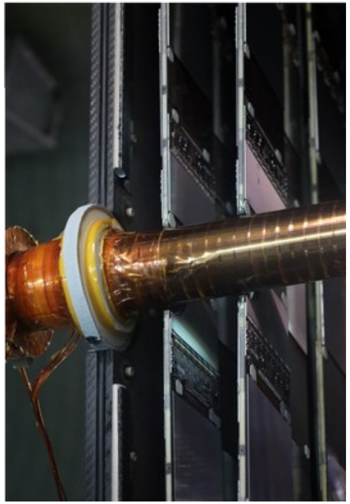
- Mechanical installation in the cavern
- CO_2 cooling commissioning
- Cable chain population and power test
- Test on data-links
- Detector closure

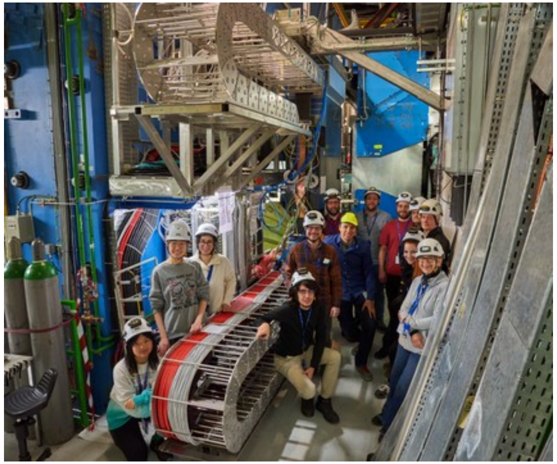


Detector closer to the beam pipe w.r.t previous detector to increase geometrical acceptance and tracking performance

Detector closure, extremely delicate procedure







Upstream Tracker

Commissioning started → a lot of progresses since the beginning of 2023 run

Firmware

4 different flavour
2 flavours currently being deployed on the real hardware, allowing to fix issues and bugs

Control

80% ready → can be used by expert to monitor data taking

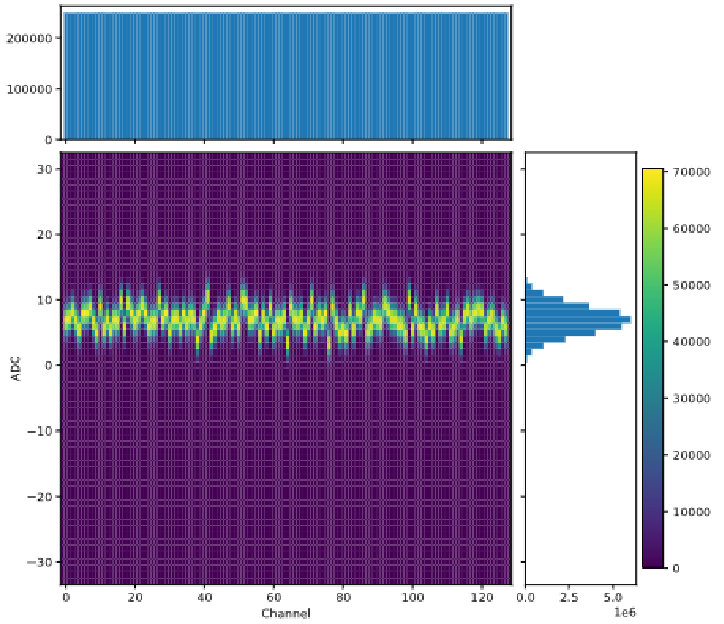
Software

Decoding/reconstruction well advanced
Detector calibrations need to be automated
Integration to general software well advanced

CO_2 cooling running smoothly at 0°C

1st milestone achieved

Run taken on May 12th



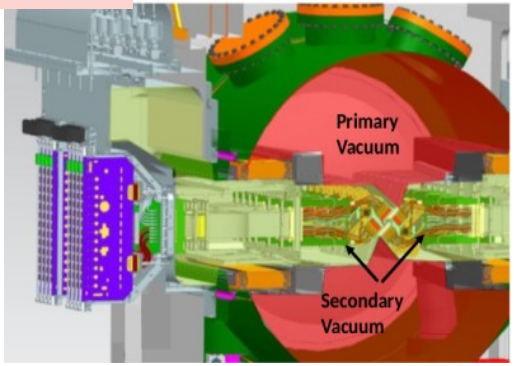
Data collected with 4x3 firmware

LHC vacuum incident in LHCb VELO (10th January 2023)

Primary vacuum (beam) and secondary vacuum (VELO) separated by a thin RF foil

Safety vacuum balance $\Delta P < 10$mbar

Incident



- relay failure lead to loss of control of protection system
  - Safety valve not open
  - Pressure balancing in the wrong direction ($\Delta P \approx 200$mbar)

→ **RF foil deformed** towards the beam vacuum

VELO modules and cooling not damaged and operational

- First estimation of RF deformation using simulations
- Measurement of RF deformation with tomography
- Inspection

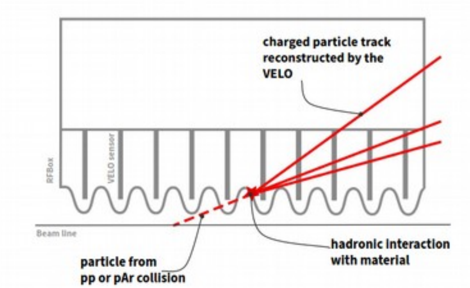
Huge thanks to the LHC vacuum team for their help in recovering from the vacuum incident!

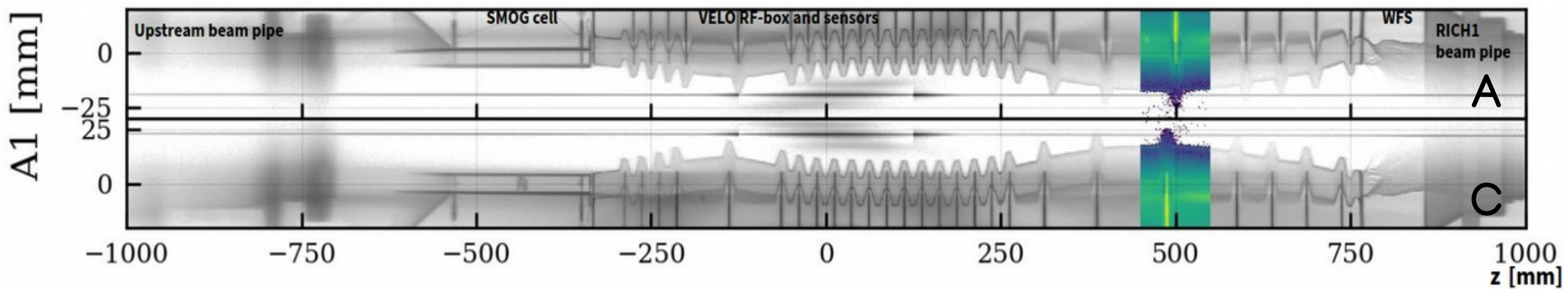
VELO Tomography

Data from 450GeV and 6.8TeV (400b fills)

SMOG2 injection extremely useful to enhance the material interaction coverage (thanks to support of TE-VSC and SMOG team)

Tomography results in agreement with measurement from collimation group





VELO commissioning is progressing

VELO will not be fully closed during the 2023 run → final position has been defined: VELO opened by 16 mm with respect to the nominal fully close position (pending further test to be performed in TS1)

RF foil will be replaced during the 23/24 YETS

Plans for 2023 data taking

First period (Before TS1)

1) Priority to sub-detectors recommissioning
   - Monitoring
   - Firmware performance
   - Timing scans
   - Stability of the systems
   - Debugging
   - Data quality (efficiency, noise, …)
   - Testing

2) Regularly plan time to probe full system (including trigger & data processing)

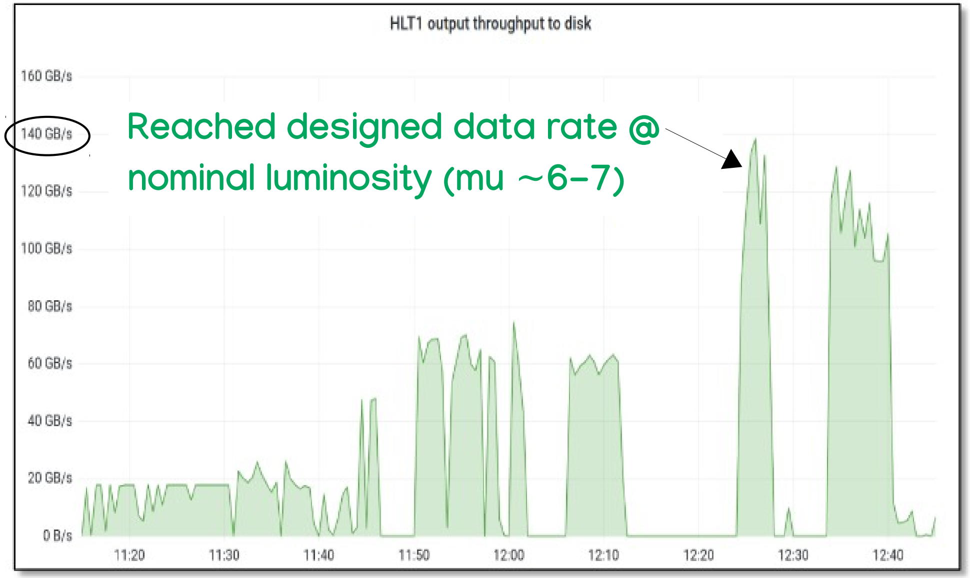
Second period (between TS1 and Pb-Pb run)

- Dedicated to global commissioning
- Physics program (depending on the final position of VELO)

Third period (Pb-Pb run)

- Physics program

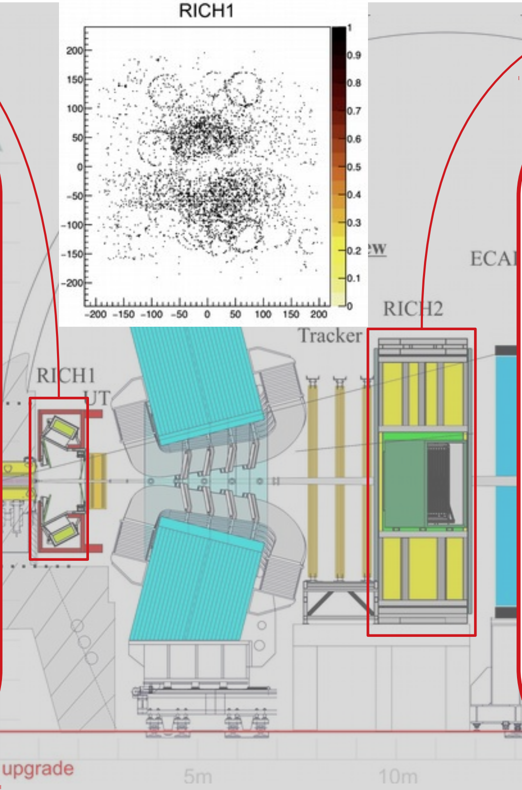
Output of HLT1 on 17 May with increasing luminosity



GPU HLT1 commissioned @ nominal rate and luminosity!

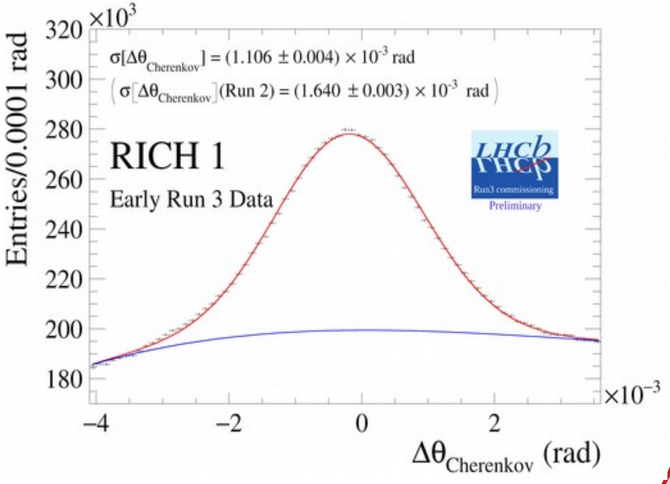
Validating detector performance

RICH



RICH 1

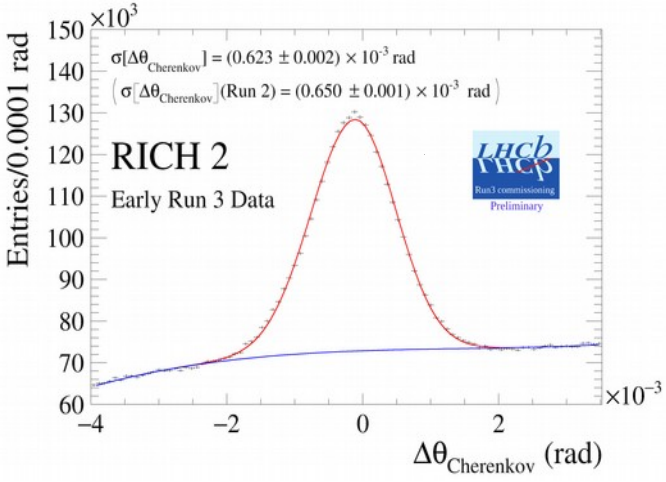
Upstream of the magnet,
2.6 < p < 60 GeV/c



Cherenkov angle resolution

RICH 2

Downstream of the magnet,
15< p < 100 GeV/c



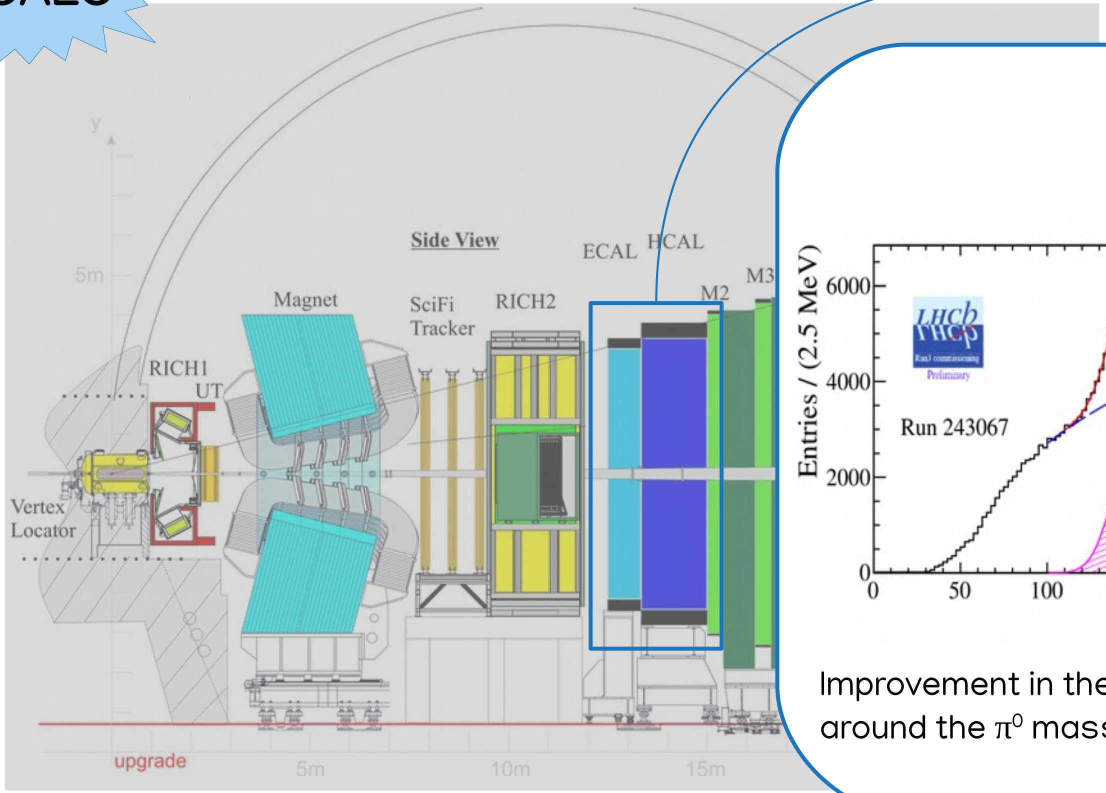
Cherenkov angle resolution

LHCb-FIGURE-2023-007

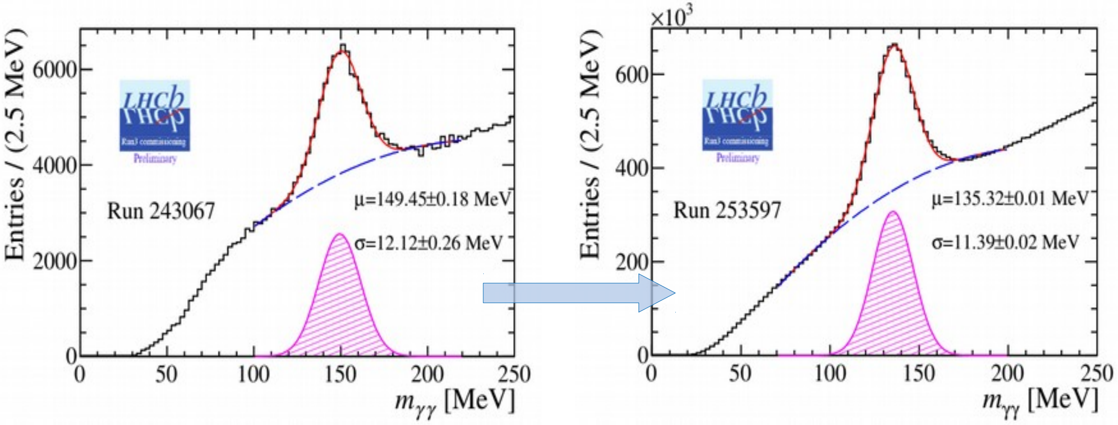
Validating detector performance

2022 data

CALO



$\pi^0 \rightarrow \gamma\gamma$

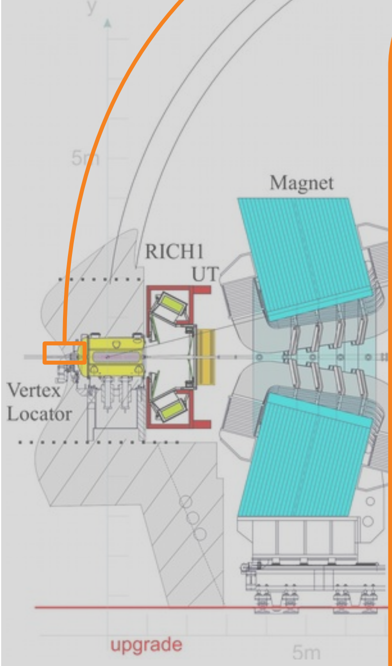


Improvement in the di-photon mass peak and mass resolution around the π^0 mass thanks to inter-cell calibration and time alignment

LHCb-FIGURE-2022-019

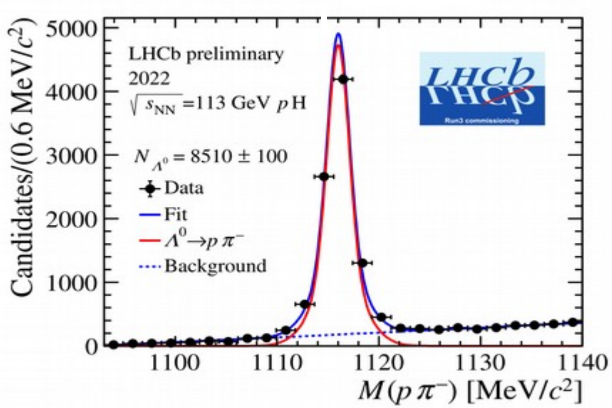
Validating detector performance

SMOG2

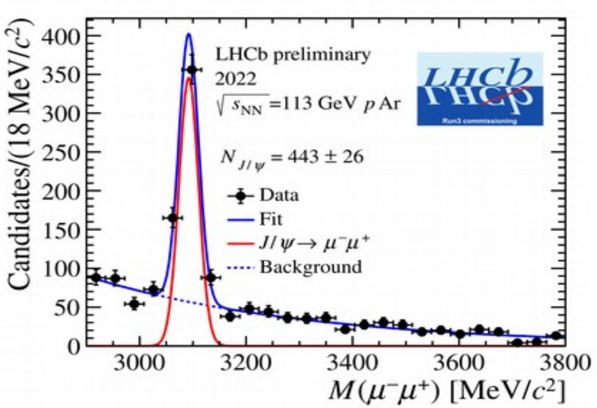


Mass resolutions close to the expectations from Monte Carlo

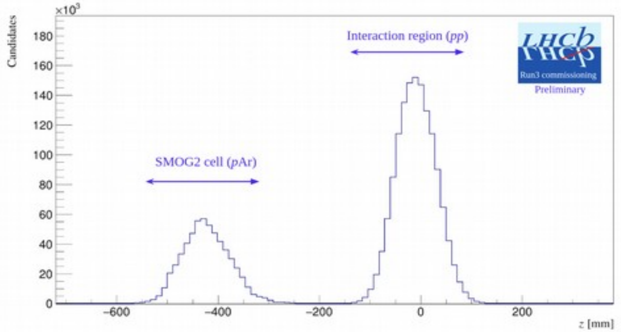
$\Lambda^0 \rightarrow p\pi^-$ in p–H



$J/\psi \rightarrow \mu^+\mu^-$ in p–Ar



Primary vertex longitudinal coordinate for vertices reconstructed by HLT1.



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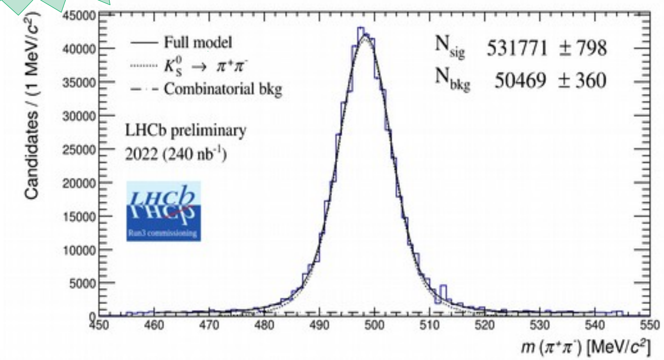
LHCb-FIGURE-2023-008

Validating detector performance

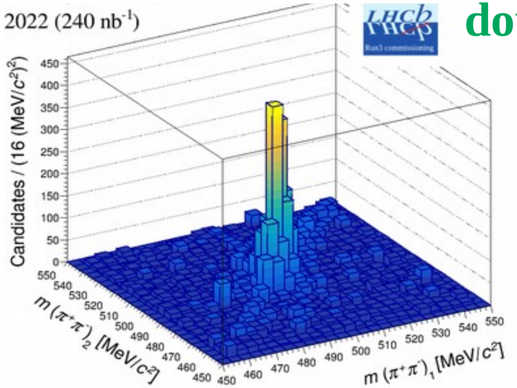
2022 data

HLT1

$K_s \rightarrow \pi^+\pi^-$



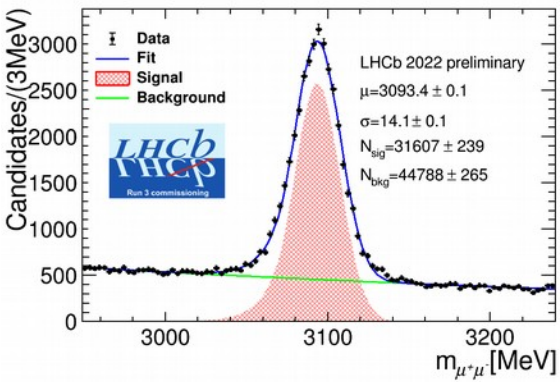
double-K_s



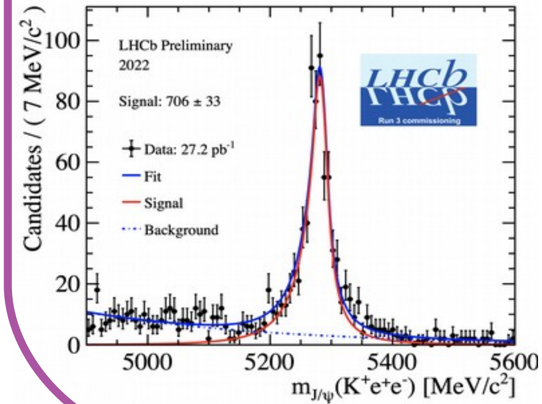
directly from HLT1

HLT2

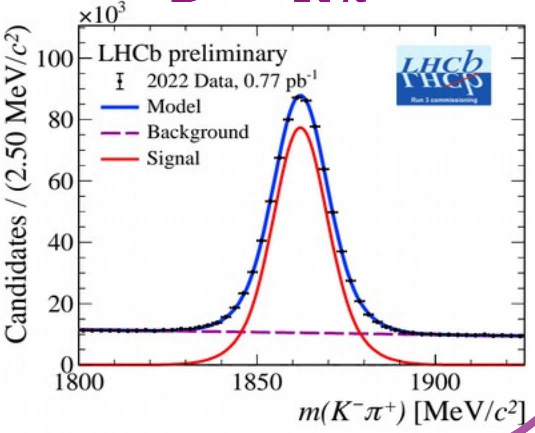
$J/\psi \rightarrow \mu^+\mu^-$



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



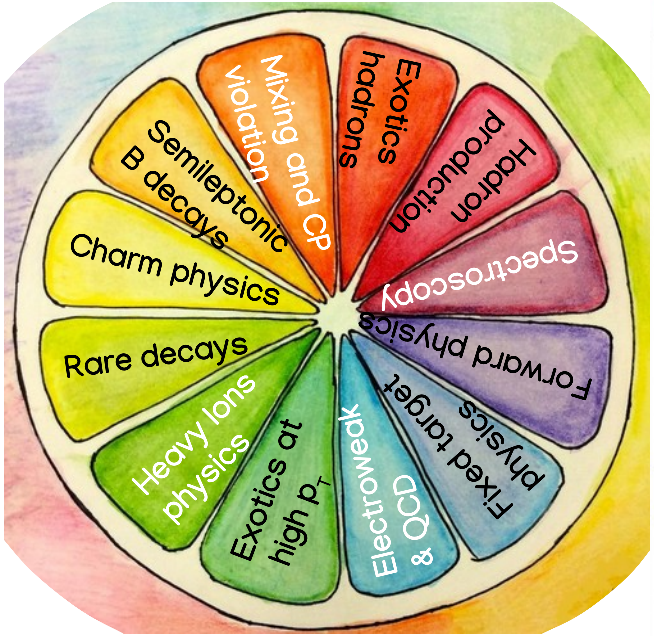
$D^0 \rightarrow K^-\pi^+$



LHCb-FIGURE-2023-005

LHCb-FIGURE-2023-010, LHCb-FIGURE-2023-011, LHCb-FIGURE-2023-017

Physics highlights from Run1+2



Paper	Title
	Submitted since the March 2023 LHCC
PAPER-2022-042	Search for CP violation in the decays $D^+ \to K^+K^-K^+$ and $D_s \to K^+K^-K^+$
PAPER-2022-054	Observation of $B^+ \to J/\psi\eta' K^+$
PAPER-2023-004	Search of $D^* \to \mu^+\mu^-$
PAPER-2023-001	Precision measurement of CPV in penguin-mediated decay $B_s \to \phi\phi$
PAPER-2022-050	Study of charmonium decays to $K_S K\pi$ in $B \to (K_S K\pi)K$
PAPER-2022-052	$R(D^*)$ with τ hadronic decays
PAPER-2022-041	Ξ_c^+ production in pPb at 8.16 TeV
PAPER-2023-003	Measurements of the branching fractions of the decay modes $B_s \to D^{(*)}\phi$
PAPER-2022-053	Ξ_b and Ω_b mass and production
PAPER-2022-047	Associated Production of Prompt J/ψ and Υ at $\sqrt{s} = 13$ TeV
	Preliminary results since the March 2023 LHCC
PAPER-2023-002	Bose Einstein Correlation in pPb
PAPER-2023-005	Search for local CPV in $D^0 \to \pi^-\pi^+\pi^0$ using the energy test with Run 2
PAPER-2023-006	Prompt D^+/D_s^+ meson production in pPb collisions at $\sqrt{s_{NN}}$=5.02 TeV at LHCb
PAPER-2023-007	Measurement of the CP asymmetry in B^- decays to two open charm mesons
PAPER-2023-008	Observation of new baryons in the $\Xi_b^-\pi^+\pi^-$ and $\Xi_b^0\pi^+\pi^-$
PAPER-2023-013	CP violation in $B \to \psi K_S$ decays
PAPER-2023-016	Measurement of the ϕ_s in $B_s \to J/\psi KK$

CP violation in B decays

CP violation observables can be accessed at

e^+e^- colliders

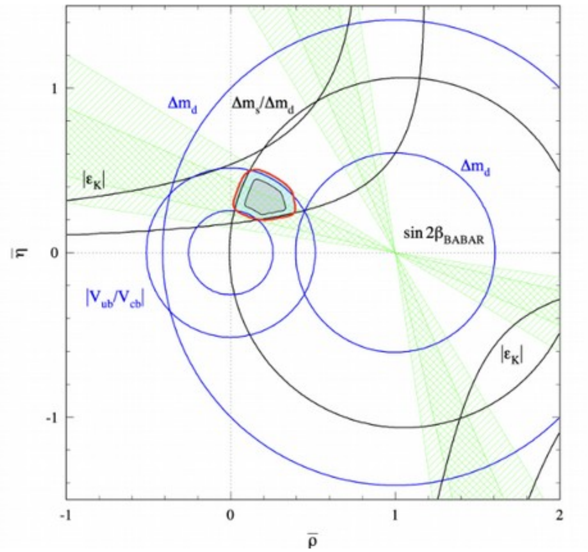
only $B_{u,d}$ are produced

2001 CP violation has been established (and confirmed) by BaBar and Belle measuring $\sin 2\beta \neq 0$ from $B^0 \to J/\psi K_s$
Leading to the the noble prize to Kobayashi and Maskawa

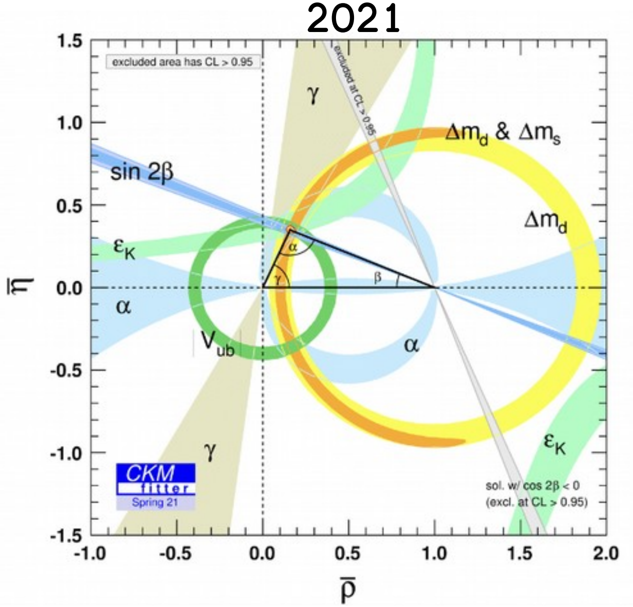
Hadron colliders

Study $B_{u,d}$ system
+
unique opportunity to study B_s system, and thus access different CP violation observables

2001



2021



CP violation in B decays

There are 3 types of CP violation

CP violation in mixing

$$P(B^0 \to \bar{B}^0) \neq P(\bar{B}^0 \to B^0)$$

CP violation in decay

$$P(B^0 \to f_{CP}) \neq P(\bar{B}^0 \to f_{CP})$$

CP violation in interference between decay and mixing

$$P(B^0 \to f_{CP}) \neq P(B^0 \to \bar{B}^0 \to f_{CP})$$

CP violation in B decays

There are 3 types of CP violation

CP violation in mixing
$P(B^0 \to \bar{B}^0) \neq P(\bar{B}^0 \to B^0)$

CP violation in decay
$P(B^0 \to f_{CP}) \neq P(\bar{B}^0 \to f_{CP})$

New results!

CP violation in interference between decay and mixing
$P(B^0 \to f_{CP}) \neq P(B^0 \to \bar{B}^0 \to f_{CP})$

Time-dependent CP asymmetry

$$A^{CP}(t) = \frac{\Gamma(\bar{B}^0(t) \to f) - \Gamma(B^0(t) \to f)}{\Gamma(\bar{B}^0(t) \to f) + \Gamma(B^0(t) \to f)} = \frac{S \sin(\Delta m_d t) - C \cos(\Delta m_d t)}{\cosh(1/2 \Delta \Gamma_d t) + A_{\Delta\Gamma} \sinh(1/2 \Delta \Gamma_d t)}$$

CPV in interference (S) — CPV in decay (C)

$b \to c\bar{c}s$ golden channels ⇒ $S = \sin 2\beta$ from $B^0 \to [c\bar{c}]K^0_s$
$\phi_s^{c\bar{c}s}$ from $B^0_s \to J/\psi K K$

$b \to s\bar{s}s$ pure penguin decay ⇒ $\phi_s^{s\bar{s}s}$ from $B^0_s \to \phi\phi$

Benchmark measurements to search for New Physics

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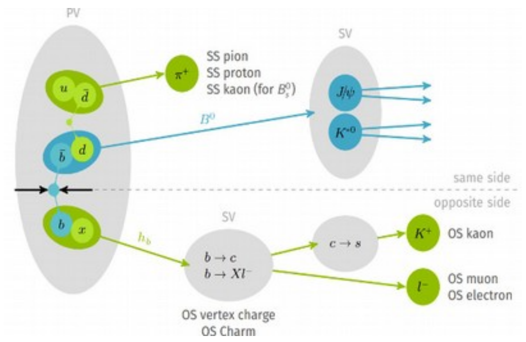
Time dependent CP violation: measurement effects

Flavour tagging

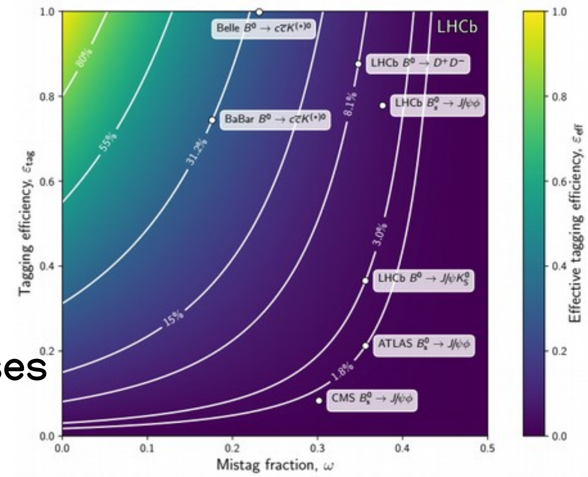
Knowledge of the B meson flavour at production (t=0) is essential



$B^0 \to \psi K_s^0$	ε_{eff} = (4.6–6.5) %
$B_s^0 \to J/\psi K^+K^-$	ε_{eff} =(4.2-4.4)%
$B_s^0 \to \phi\phi$	ε_{eff} = (5.7-6.3)%

B-factory larger effective tagging efficiency ~ 30%

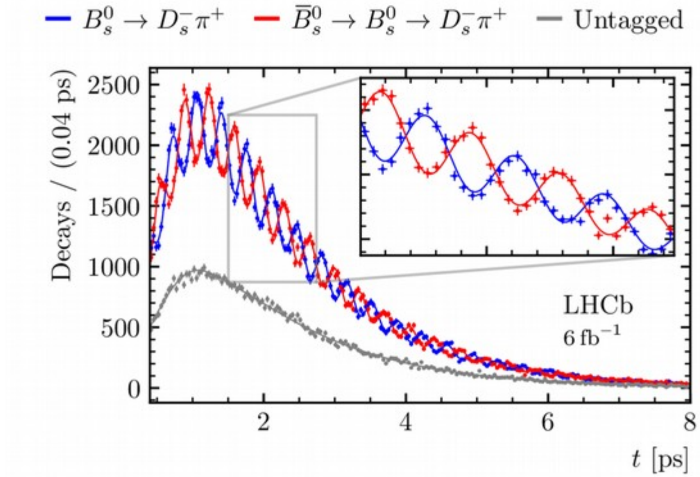
Large improvements for Run2 analyses



Decay-time resolution

Fundamental to resolve $B_s^0 - \bar{B}_s^0$ oscillations

$B^0 \to \psi K_s^0$	σ_t ~ 60 fs
$B_s^0 \to J/\psi K^+K^-$	σ_t ~ 43 fs
$B_s^0 \to \phi\phi$	σ_t ~43 fs



Nature Physics 18, (2022) 1-5

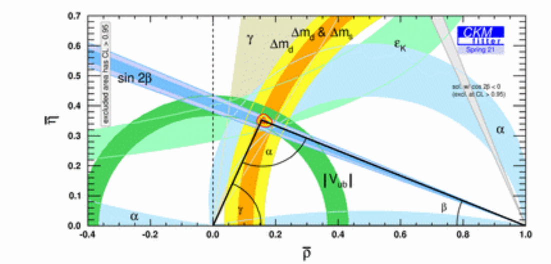
Time dependent CP violation: $\sin 2\beta$

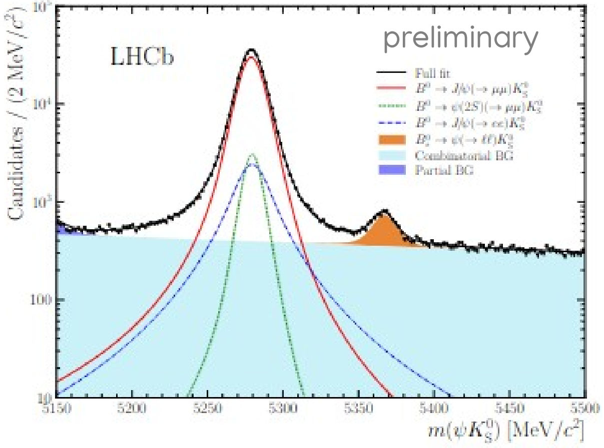
Time dependent CP violation in $b \to c\bar{c}s$ transitions

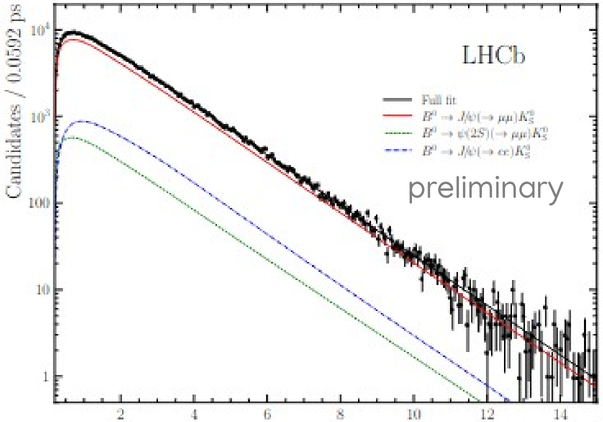
$B^0 \to J/\psi(\mu^+\mu^-)K_S(\pi^+\pi^-)$ ~ 306k	$B^0 \to J/\psi(e^+e^-)K_S(\pi^+\pi^-)$ ~ 43k	$B^0 \to \psi_{2S}(\mu^+\mu^-)K_S(\pi^+\pi^-)$ ~ 24k

$$A^{CP}(t) = \sin(2\beta)\sin(\Delta m_d t)$$

$$\beta \equiv arg[-(V_{td}V^*_{tb})/(V_{cd}V^*_{cb})]$$







Time decay fit for all decays

New result from Run2 data ($6fb^{-1}$ @ 13 TeV)
Fit all channels together and each channel separately

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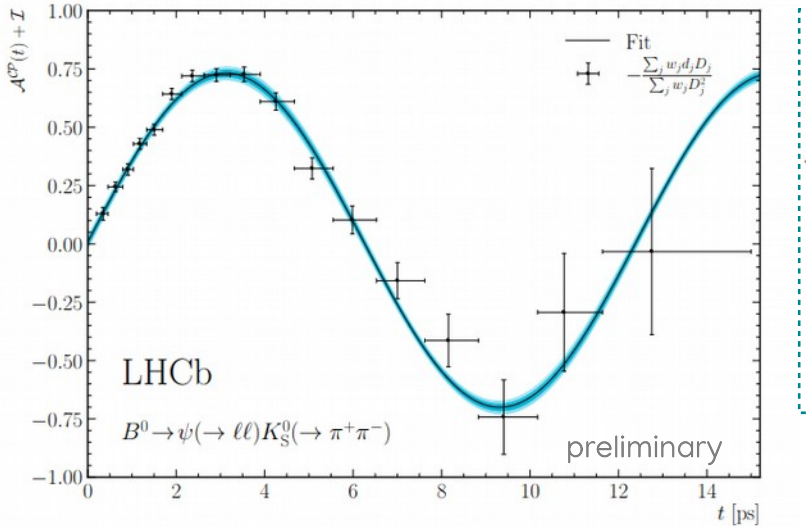
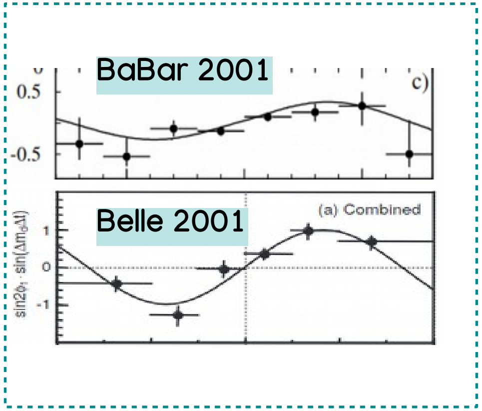
LHCb-PAPER-2023-013 in preparation

Time dependent CP violation: $\sin 2\beta$

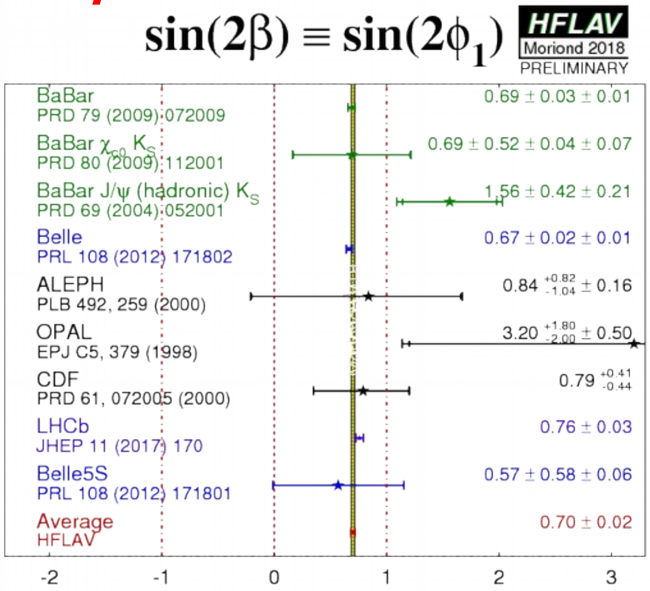
$$A^{CP}(t) = \sin(2\beta)\sin(\Delta m_d t)$$





$$S^{Run2}_{\psi K^0_S} = 0.716 \pm 0.013_{stat} \pm 0.008_{syst}$$

$$C^{Run2}_{\psi K^0_S} = 0.012 \pm 0.012_{stat} \pm 0.003_{syst}$$



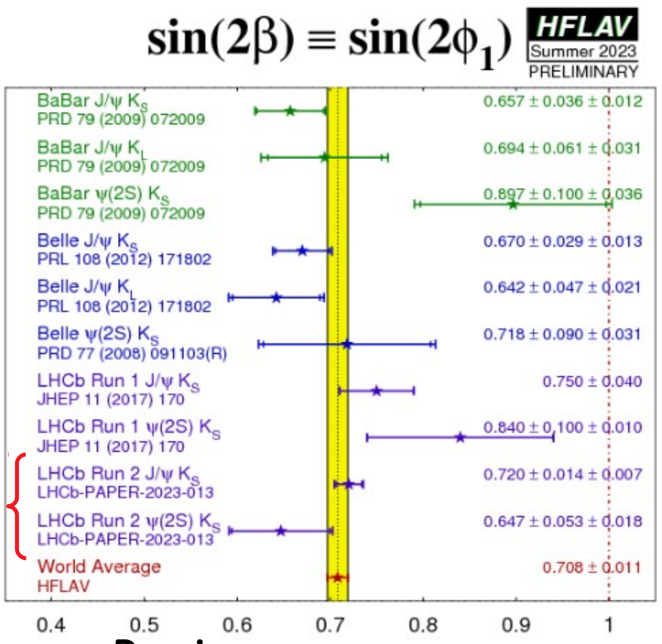
Current average

$$\sin(2\beta)_{HFLAV,2021} = 0.699 \pm 0.017$$

LHCb Run2 is the most precise single measurement to date!

LHCb-PAPER-2023-013 in preparation

Time dependent CP violation: $\sin 2\beta$



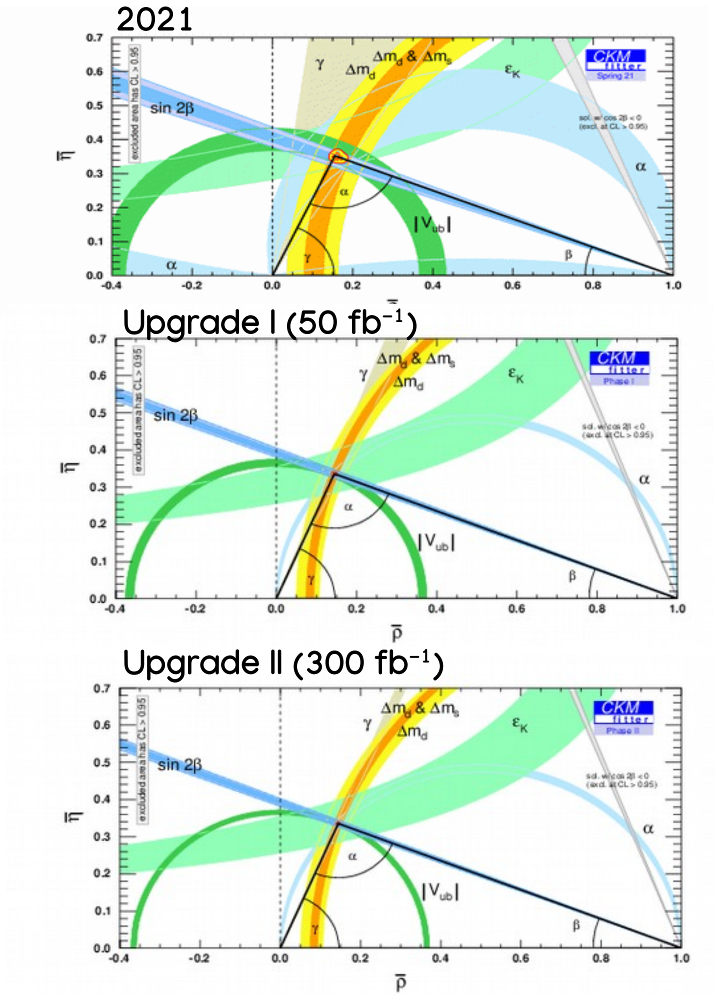
New LHCb

Previous
~~Current~~ average

$$\sin(2\beta)_{HFLAV,2021} = 0.699 \pm 0.017$$

New average

$$\sin(2\beta)_{HFLAV,2023} = 0.708 \pm 0.011$$



CP-violating NP requires precise measurement of SM benchmarks

$\sin 2\beta$

key measurement for NP searches

LHCb-PAPER-2023-013 in preparation

Time dependent CP violation: $\phi_s^{c\bar{c}s}$

Accessible only @ hadron colliders

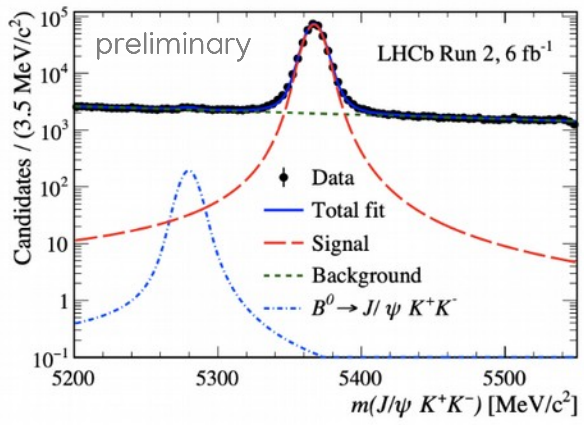
Measurement of CP violation parameter in $B_s^0 \to J/\psi(\mu^+\mu^-)K^+K^-$ (around $\phi(1020)$)

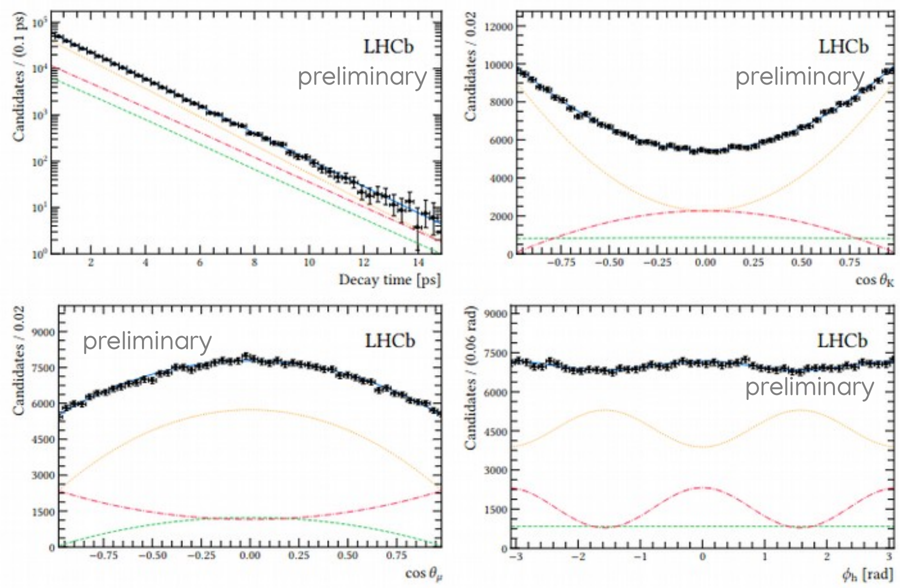
Angular analysis: final state is a mixture of CP-even and CP-odd components

$$A^{CP}(t) = \frac{\Gamma(\bar{B}_s^0(t) \to f) - \Gamma(B_s^0(t) \to f)}{\Gamma(\bar{B}_s^0(t) \to f) + \Gamma(B_s^0(t) \to f)} = \eta_f \sin\phi_s \sin(\Delta m_s t)$$

$$\beta_s \equiv arg[-(V_{ts}V_{tb}^*)/(V_{cs}V_{cb}^*)]$$

$$\phi_s^{c\bar{c}s} = -2\beta_s$$



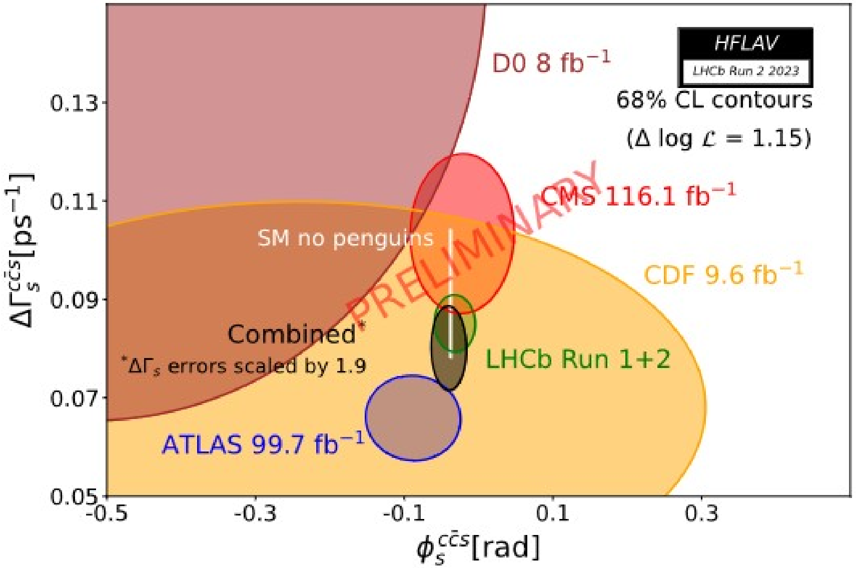


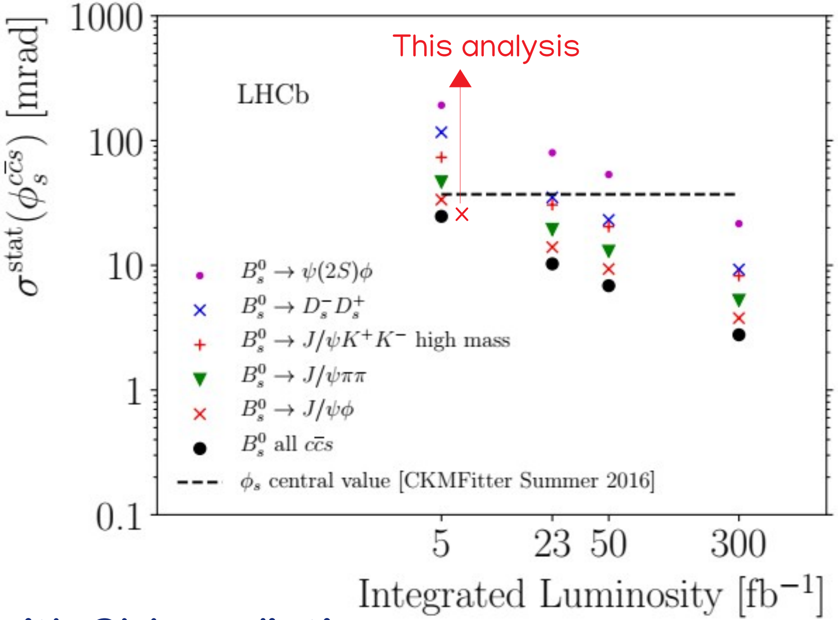
LHCb-PAPER-2023-016 in preparation

Time dependent CP violation: $\phi_s^{c\bar{c}s}$

New LHCb measurement with Run2

$$\phi_s^{c\bar{c}s} = (-0.039 \pm 0.022 \pm 0.006)\, rad$$





Results in agreements with SM prediction but still room for New Physics!

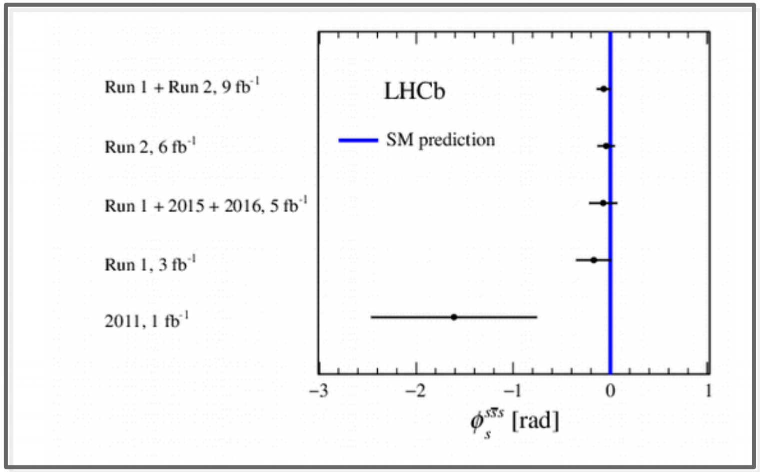
LHCb-PAPER-2023-016 in preparation

Time dependent CP violation: $\phi_s^{s\bar{s}s}$

Accessible only @ hadron colliders

Time dependent CP violation in $B_s^0 \to \phi\phi$ characterized by $\phi_s^{s\bar{s}s}$ and $|\lambda|$ parameters

Final state produced in three linear polarization states → polarization-(in)dependent measurement

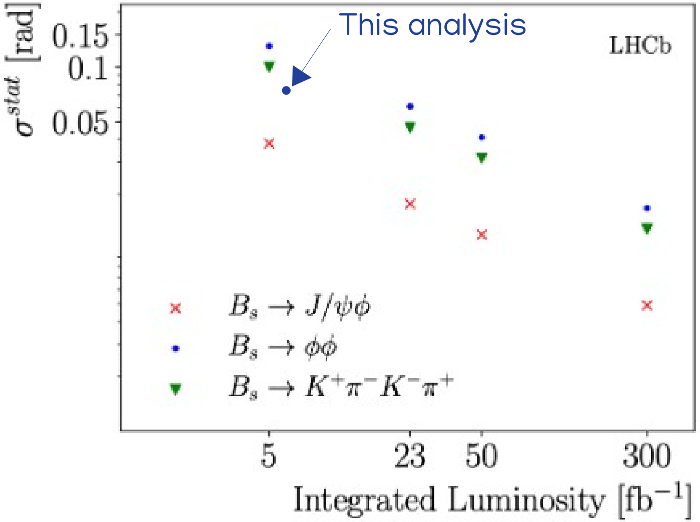


$\phi_{s,0} = -0.18 \pm 0.09\, rad$

$\phi_{s,\parallel} - \phi_{s,0} = 0.12 \pm 0.09\, rad$

$\phi_{s,\perp} - \phi_{s,0} = 0.17 \pm 0.09\, rad$

First polarization-dependent measurement



Run1+2 combination

$\phi_s^{s\bar{s}s} = (-0.074 \pm 0.069)\, rad \qquad |\lambda| = 1.009 \pm 0.030$

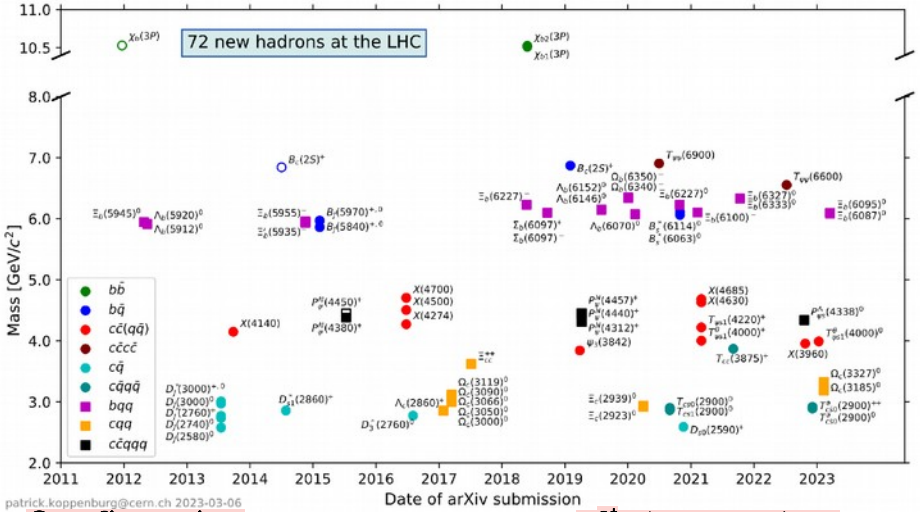
Most precise measurement of time-dependent CP asymmetry in any penguin-dominated B meson decay

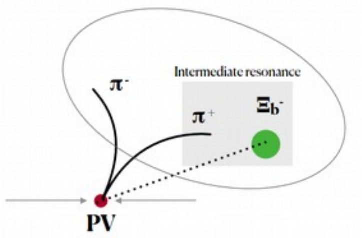
Important for future precision measurements

arXiv:2304.06198

Hadron Spectroscopy: new baryons in $\Xi_b^- \pi^+\pi^-$ and $\Xi_b^0 \pi^+\pi^-$

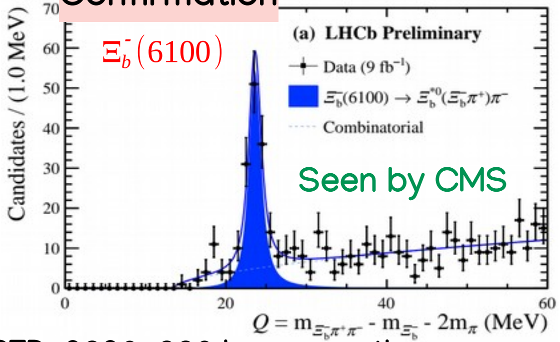
72 hadrons(49 conventional+23 exotic) have been discovered at the LHC, of which 64 by LHCb
Important to develop a deeper understanding of QCD



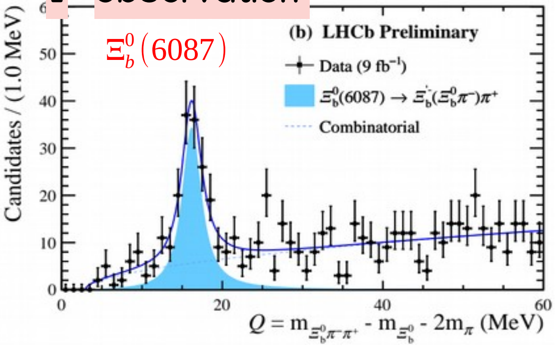


Fully hadronic decay chain →
up to 9 tracks in the final state

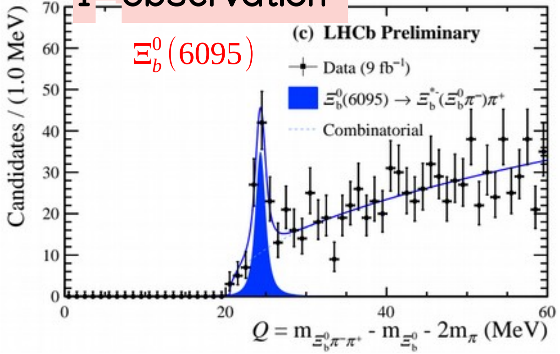
Confirmation



1st observation



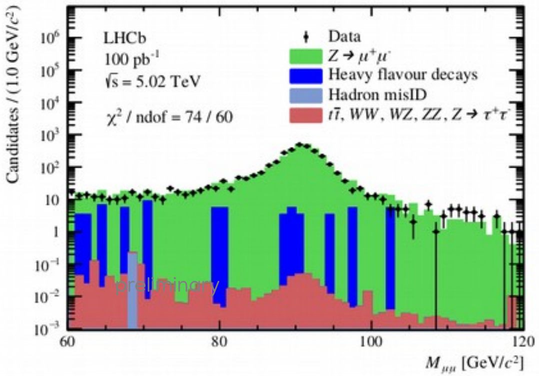
1st observation



LHCb-PAPER-2023-008 in preparation

EW measurements: Z boson production

Z boson production cross section in pp collisions @ $\sqrt{s_{NN}}$ = 5.02 TeV (100 pb^{-1})

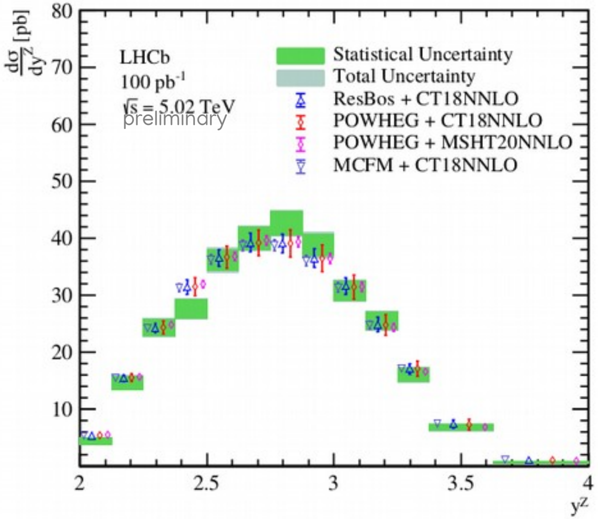


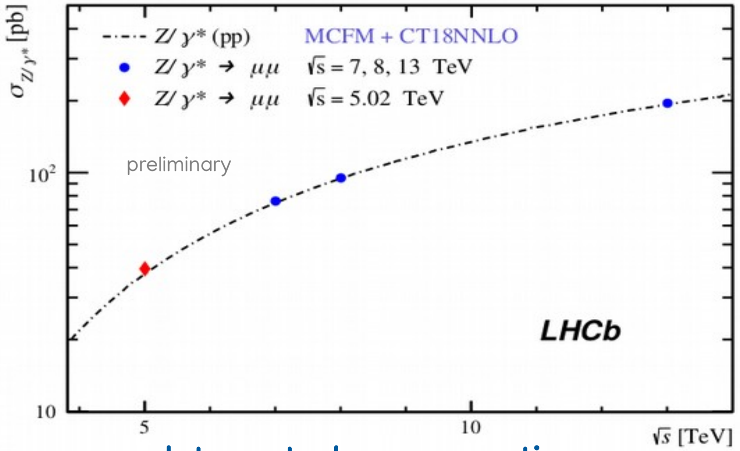
$Z \to \mu^+\mu^-$

$2.0 < \eta_\mu < 4.5 \quad p_T^\mu > 20\, GeV/c$

$60 < M_{\mu\mu} < 120\, GeV/c^2$

LHCb provides EW measurements in forward direction complementary to ATLAS and CMS





Integrated cross sections

$$\sigma_{Z/\gamma* \to \mu\mu} = 39.6 \pm 0.7 \pm 0.6 \pm 0.8\ pb$$

Nuclear modification factors

$$R^F_{pPb} = 1.16^{+0.46}_{-0.34}(stat) \pm 0.11(syst)$$

$$R^B_{pPb} = 3.64^{+1.55}_{-0.94}(stat) \pm 0.20(syst)$$

LHCb-PAPER-2023-010 in preparation

D^+ and D_s^+ production in pPb collisions

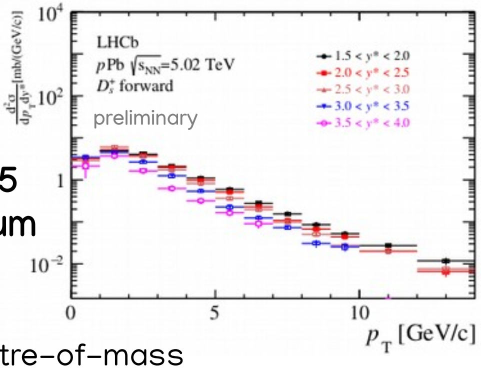
Production of D^+ and D_s^+ mesons in pPb @ $\sqrt{s_{NN}}$ = 5.02 TeV, corresponding to 1.58 ± 0.02 nb^{-1}

Differential production cross section

$$\frac{d^2\sigma}{dp_T dy^*} = \frac{N(p_T, y^*)}{\mathcal{L} \times \varepsilon_{tot} \times \mathcal{B} \times \Delta p_T \times \Delta y^*}$$

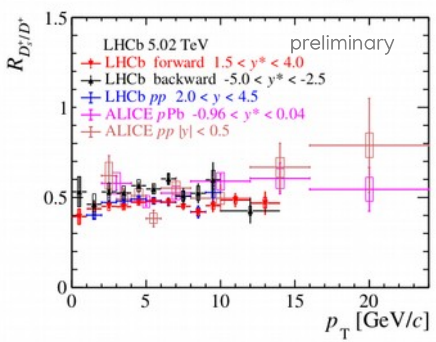
first measurement in

1.5 < y* < 4.0 and −5.0 < y* < −2.5
down to zero transverse momentum



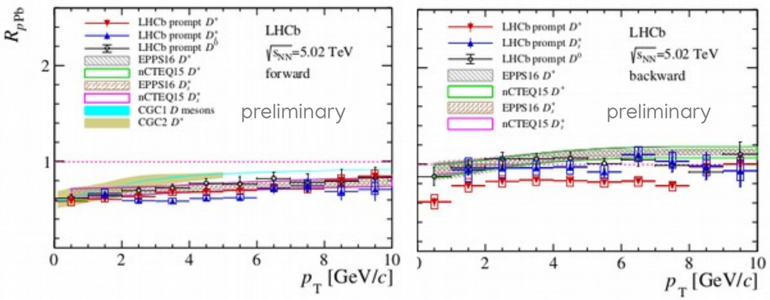
y* = rapidity of candidates in the NN centre-of-mass

Cross section ratios



ratio consistent with pp @ LHCb and ALICE mid-rapidity

Nuclear modification factors



Suppression in the forward region, consistent among different D mesons

LHCb-PAPER-2023-006 in preparation

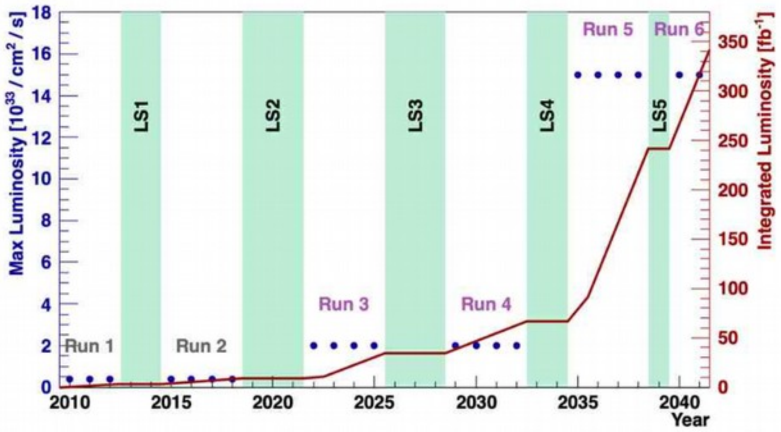
Upgrade II

Fully exploit the HL-LHC for flavour physics

$$\mathcal{L}_{peak} = 1.5 \times 10^{34}\ \text{cm}^{-2}\ \text{s}^{-1}$$

$$\mathcal{L}_{int} \approx 300\ \text{fb}^{-1}$$ during Run 5+6

- Framework TDR approved March 2022 [CERN-LHCC-2021-012]
- Scoping document in preparation for 2024
- Limited-size detector consolidations also proposed for LS3, needed to ensure to keep on the time for Upgrade II
  - Technical Design Report for PID (RICH/ECAL) in preparation



Summary

- ✔ LHCb U1 installation is complete
- ✔ Sub-detectors, trigger and data flow commissioning is advancing
- ✔ A lot of effort to study the early data from Run3:
  - ➢ demostrated the improved detector performance
  - ➢ demostrated performance of the fully software trigger

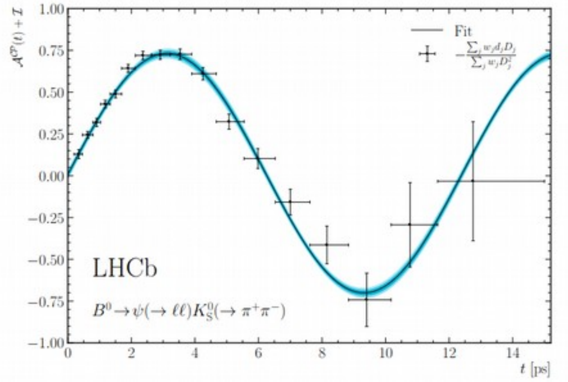
LHCb has a broad physics program and it continues to exploit the Run1+2 data set making important measurements

$$S^{Run2}_{\psi K^0_S} = \sin 2\beta = 0.716 \pm 0.013_{stat} \pm 0.008_{syst}$$

$$\phi_s^{c\bar{c}s} = (-0.039 \pm 0.022 \pm 0.006)\,rad \qquad \phi_s^{s\bar{s}s} = (-0.074 \pm 0.069)\,rad$$

Most precise results in benchmark measurements to search for New Physics!

CERN-LHC Seminar on 13 June



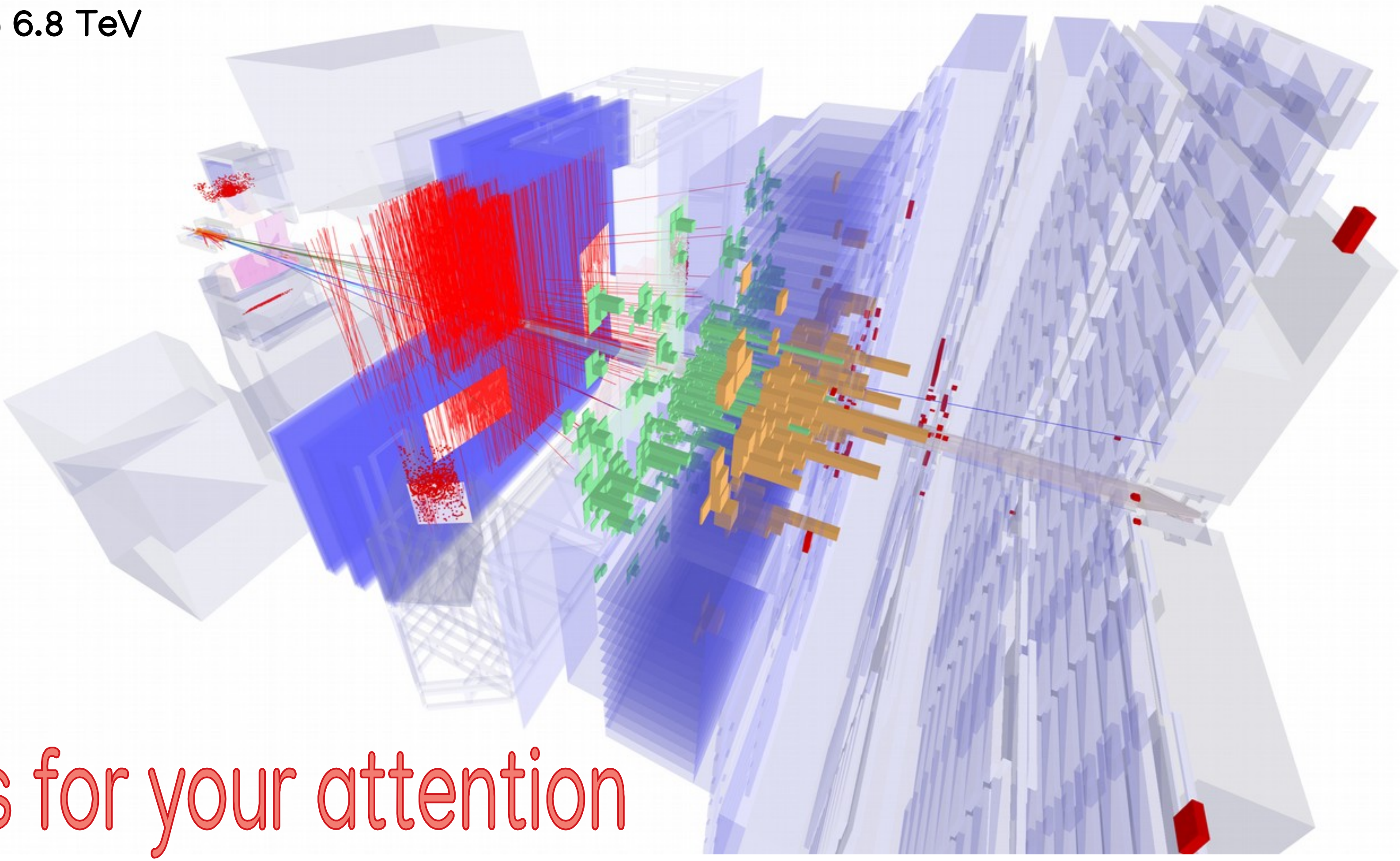
Huge thanks to the LHC for their support!

LHCb Experiment at CERN

Run / Event: 263132 / 5940637

Data recorded: 2023-05-11 13:50:49 GMT

2023 data @ 6.8 TeV



Thanks for your attention