LHCb performance and upgrades

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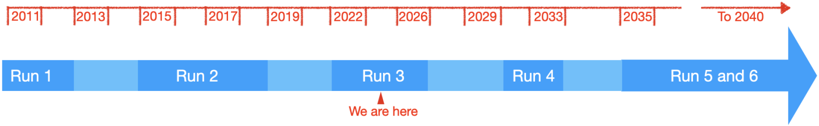
on behalf of the LHCb collaboration

Outline

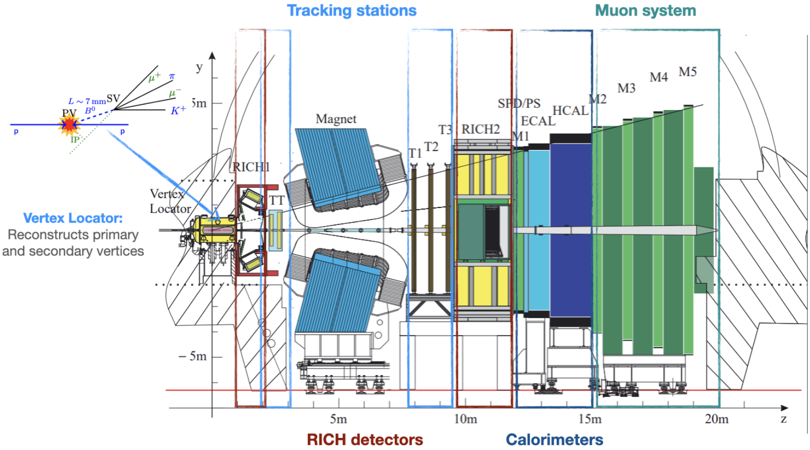
The LHCb experiment

- Designed to perform high precision measurements in flavour physics
- Large cross section of b and c hadrons $\rightarrow$ study all types of B and D decays
- Large physics programme regarding spectroscopy, electro-weak decays, heavy-ions



- Run 1 [2011-2012]: 7-8 TeV and 3 fb^{-1}
- Run 2 [2015-2018]: 13 TeV and 6 fb^{-1}
- Run 3 $\rightarrow$ collecting data at the moment
- Upgrade II $\rightarrow$ performance studies for detector design during the high luminosity LHC

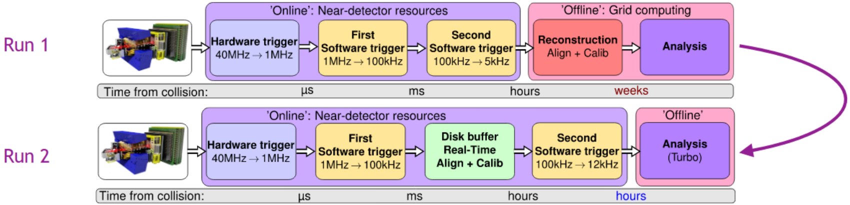
The LHCb experiment in Run 1/2



- Forward detector specialised in measuring properties of b and c hadrons ▸ JINST 3 (2008) S08005

Data taking strategy in Run 1 and Run 2

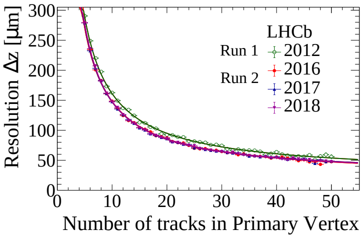
- New trigger model developed in Run 2 → real time analysis model
  ‣ JINST 14 (2019) P040065

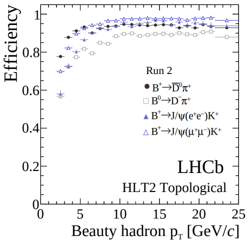


- Events buffered on disk while performing real-time alignment and calibration
- Physics analysis performed directly from the trigger output
- No offline processing in Run 2

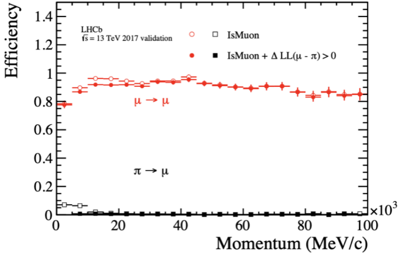
Performance in Run 2: trigger + PID

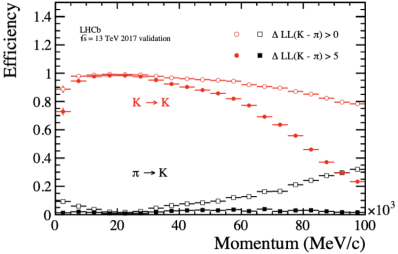
PV resolution and trigger efficiency ▸ JINST 14 (2019) P04013



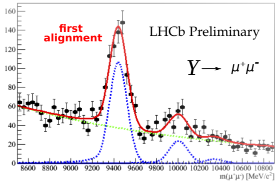


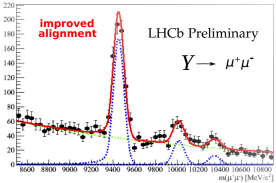
PID ▸ LHCb-FIGURE-2020-012





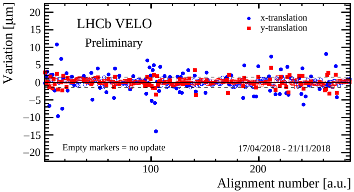
Performance in Run 2: alignment & calibration





Samples selected by HLT1 are used to align and calibrate the detector

- **Alignment procedure with a method based on the Kalman filter**
- **Run automatically at the beginning of each fill (e.g. VELO and tracker alignment take a few min)**
- **Automatic update if the variations are significant**



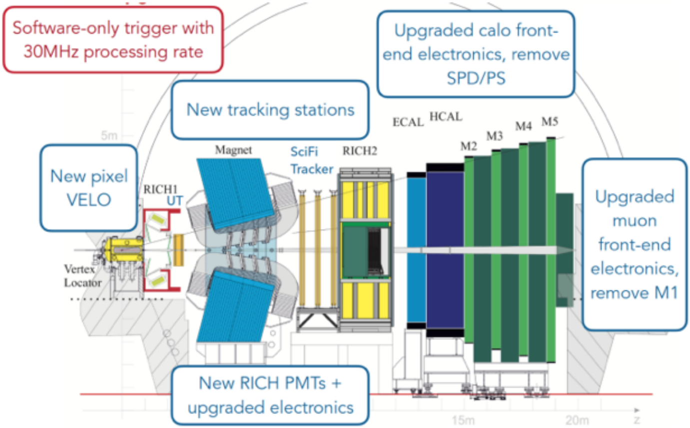
- **Alignment of the full tracker system: VELO, TT, IT, OT, Muon chambers**
- **RICH calibration and alignment of the RICH mirrors**
- **Time calibration of the OT detector**
- **Calibration of the electromagnetic calorimeter using π^0 sample**

LHCb-FIGURE-2019-015

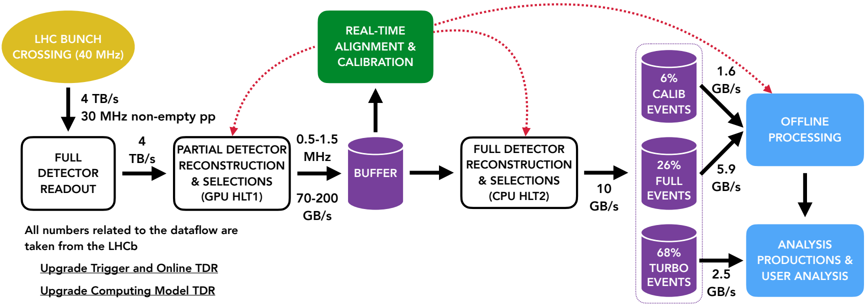
LHCb experiment in Run 3

Brand new detector: Maintain the physics performance at harsher environment (5x higher luminosity)

▸ LHCb Upgrade TDR ▸ JINST 19 (2024) P05065



The LHCb trigger in Run 3



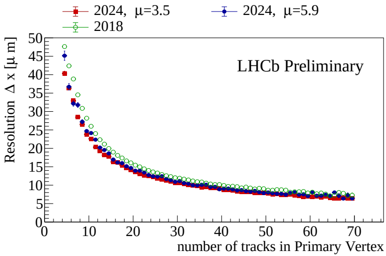
LHCb-FIGURE-2020-016

1. Collision events selected with partial reconstruction (HLT1)
2. Selected events stored in a buffer
3. **Alignment and calibration** are executed
4. Alignment constants are updated if above threshold
5. Second software stage (HLT2) applies the full reconstruction

Performance in Run 3: VELO + SciFi

PV resolution

▸ LHCb-FIGURE-2024-011

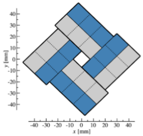


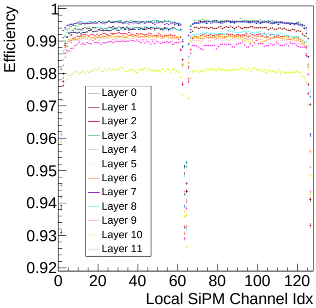
SciFi efficiency

▸ LHCb-FIGURE-2024-016

- Tracker after the magnet completely replaced using Scintillating Fibre (SciFi)
- $>$ 97 % efficiency in each layer of the SciFi Tracker

- Better PV resolution for 2024 data compared to 2018 (Run 2)
- New VELO pixel detector $\rightarrow$ 55 x 55 μm^2 pixels

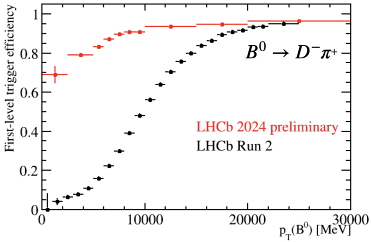




Performance in Run 3: Trigger + PID

Trigger efficiency

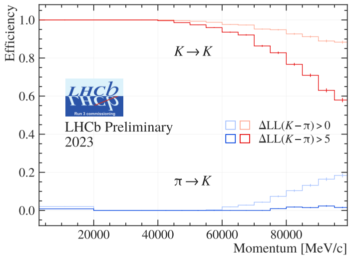
LHCb-FIGURE-2024-014



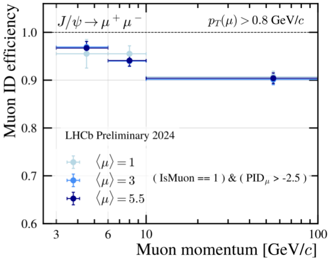
- Trigger efficiency vs B^0 p_T
- Tight p_T and E_T cuts saturate hadronic channels in Run 2
- Removing of hardware trigger gives large efficiency improvements

PID

LHCb-FIGURE-2024-010

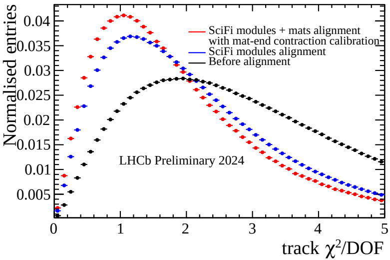


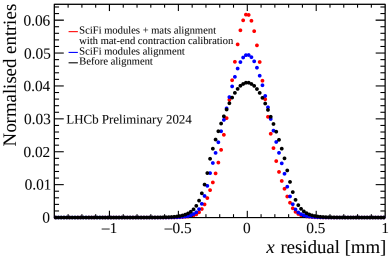
LHCb-FIGURE-2024-010



Alignment and calibration in Run 3

- Completely new detector elements and DOFs for alignment in Run 3
- Aligment reevaluated for all subdetectors keeping track of reinstallation of detectors
- The real-time strategy kept throughout Run 3
- Full tracker alignment performed for the first time in 2024 aligning VELO + UT + SciFi
- Calorimeter calibration in all ECAL cells
- Good quality A & C crucial for best quality data

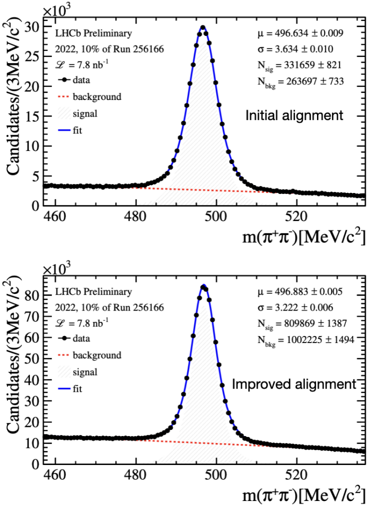




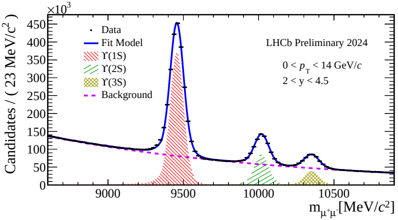
LHCb-FIGURE-2024-009

Alignment and calibration in Run 3: performance

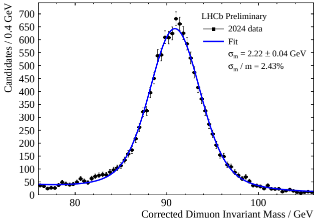
Reaching Run 2 performance in mass resolution



▸ LHCb-FIGURE-2024-028



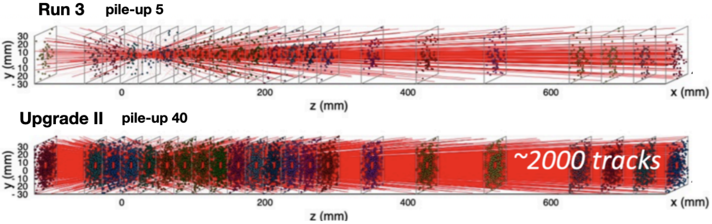
▸ LHCb-FIGURE-2024-020

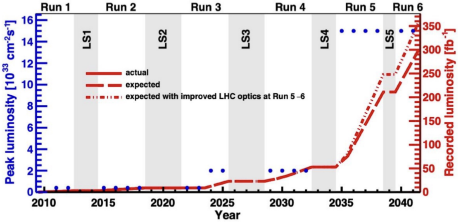


▸ LHCb-FIGURE-2024-025

The LHCb Upgrade II

- Use the high luminosity phase of the LHC to collect large statistics to excel precision in flavour measurements
- Aim to keep the same performance as Run 3 at high pile-up environment

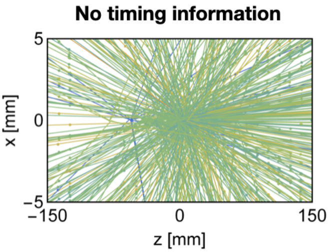




- Improve the detector for Run 5 and 6
- Increase granularity and add timing information
- Innovative data processing to cope with 200 Tb/s

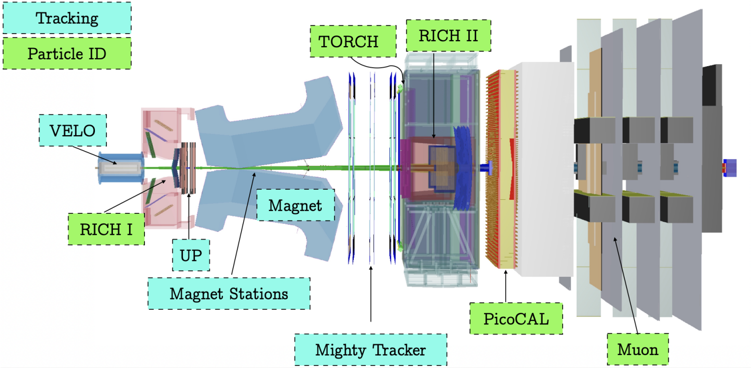
4D tracking

- Vertex reconstruction and association to the correct primary vertex are crucial for the LHCb physics program



- Exploit the spread in time of primary vertices
- Reduced subset of vertices can be selected by applying track timestamps
- Achieved by adding precise timing for every hit $\rightarrow$ 4D tracking
- Mandatory for the VELO but used in other Upgrade II detectors

LHCb Upgrade II detector



LHCb Upgrade II TDR

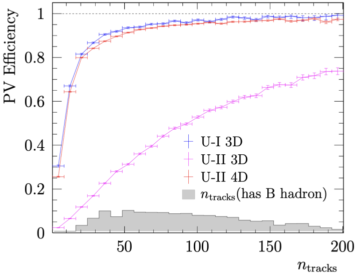
- VELO: hit time resolution 50 ps
- UP: pixel sensors
- Mighty Tracker: pixel inner region, scintillating fibres outer

- RICH 1/2: better optics with reduced pixel size + timing information
- TORCH: Time-of-flight quartz tiles SiPM
- PicoCAL: Timing and segmentation: inner SpaCal, outer Shashlik
- MUON: inner μRWELL, outer MWPC

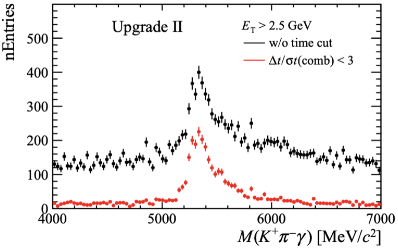
LHCb Upgrade II: expected performance

- Same or better performance than Run 3 in all detectors
- Tracking efficiency similar to Run 3
- Improved time and Cherenkov angle resolution

LHCb Upgrade II TDR



Technology		Cher. angle res. [mrad]
RICH1	MaPMT (Run 3)	0.82
	SiPM	0.51
	SiPM & geometry	0.38
RICH2	MaPMT (Run 3)	0.50
	SiPM	0.42
	SiPM & geometry	0.22



Summary

- The Run 2 LHCb data has paved the path towards precision in flavour physics
- LHCb taking data during the Upgrade I phase (Run 3)
  - Recorded luminosity in 2024 $>$ whole Run 2
  - Good data taking efficiency $>$ 95 %
  - Good data quality for physics
- Upgrade II LHCb presents high technical challenge to maintain the same performance as Run 3
- Upgrade II will will provide excellent prospects for physics and ultimate precision
- We are looking forward to more collisions!

Thank you!

BACKUP

Data taking in Run 3

2022

- Commissioning of all subdetectors (but UT)
- The trigger system, alignment and calibration commissioned and tested

2023

- LHC vaccum incident damaged the VELO RF foil $\rightarrow$ operating with open VELO all year
- UT fully installed

2024

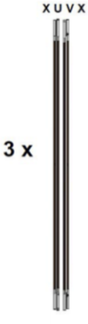
- Replaced VELO RF-foil and re-installed the VELO
- All detectors fully operating and commissioned
- Collecting pp data at the moment

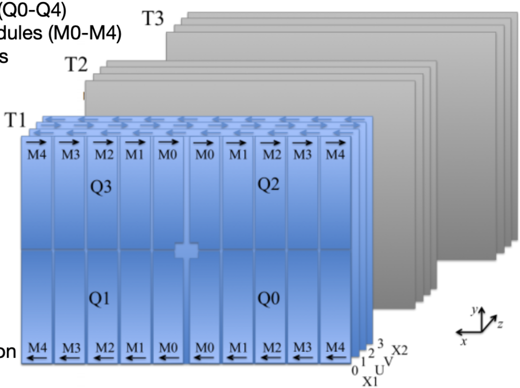
The SciFi detector

Elements:

CFrames

- Stations (T1-T3)
  - HalfLayers (HLO-HL1)
    - Quarters (Q0-Q4)
      - HalfModules (M0-M4)
        - Mats

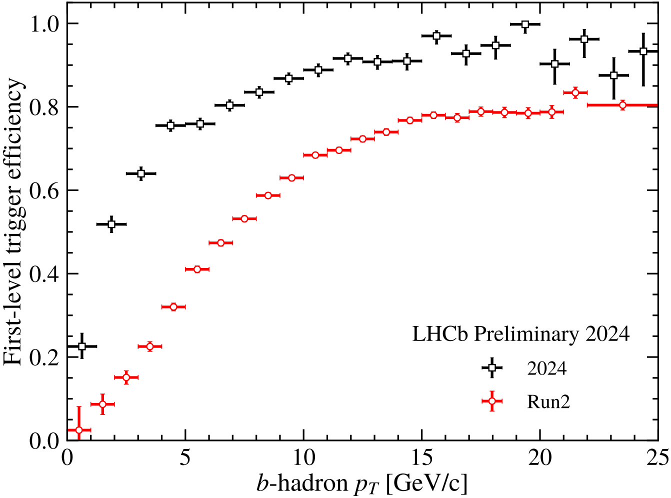




Layers are attached in pairs on each side: CFrames

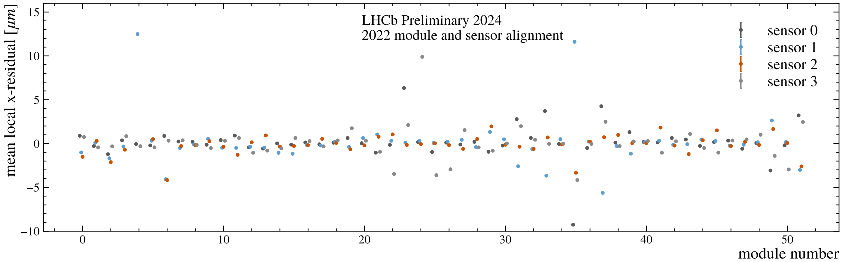
Run 3 performance: Trigger efficiency

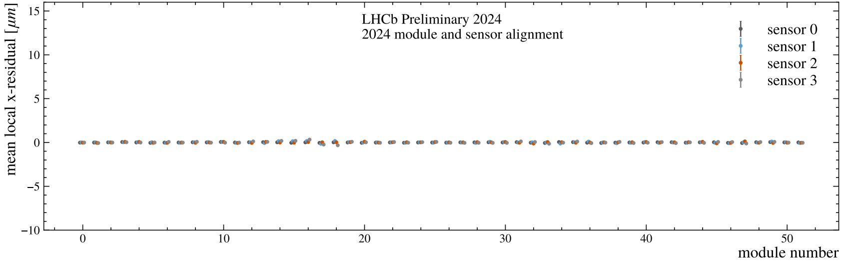
$B^{\pm} \to K^{\pm} e^{+} e^{-}$



▸ LHCb-FIGURE-2024-007

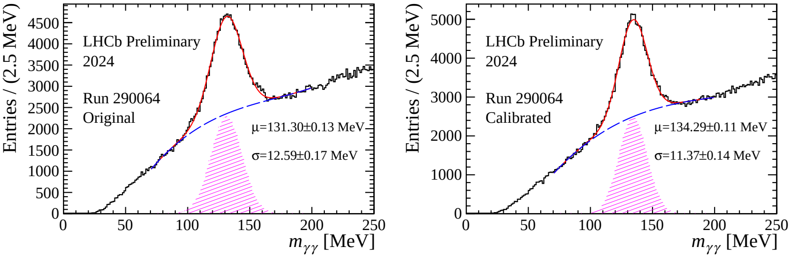
Run 3 performance: VELO alignment





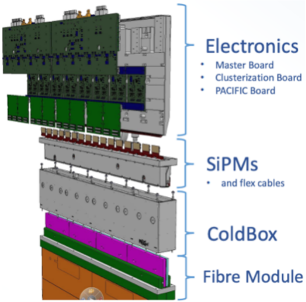
LHCb-FIGURE-2024-009

Run 3 performance: ECAL calibration

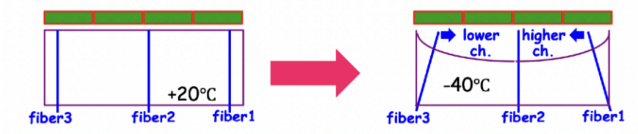


LHCb-FIGURE-2024-009

Run 3 performance: SciFi mat-contraction calibration

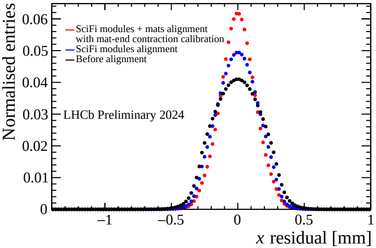


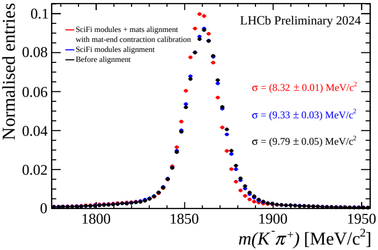
- Each mat contains four SiPMs
- Placed in cold box cooled to -40°C
- Cooling bends the fibre mats $\rightarrow$ modified x mapping of hits
- Overall deformation of 0.2 mm expected



- Calibration conditions to SiPM channels in SciFi to correct for deformations caused by temperature differences

Run 3 performance: SciFi alignment





▸ LHCb-FIGURE-2024-009

Physics prospects

Observable	Current LHCb (up to 9 fb^{-1})		Upgrade I (23 fb^{-1})	Upgrade I (50 fb^{-1})	Upgrade II (300 fb^{-1})
CKM tests					
γ ($B \to DK$, *etc.*)	2.8°	[18, 19]	1.3°	0.8°	0.3°
ϕ_s ($B_s^0 \to J/\psi\phi$)	20 mrad	[22]	12 mrad	8 mrad	3 mrad
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ ($\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu$, *etc.*)	6%	[55, 56]	3%	2%	1%
Charm					
ΔA_{CP} ($D^0 \to K^+K^-, \pi^+\pi^-$)	29×10^{-5}	[25]	13×10^{-5}	8×10^{-5}	3.3×10^{-5}
A_Γ ($D^0 \to K^+K^-, \pi^+\pi^-$)	11×10^{-5}	[29]	5×10^{-5}	3.2×10^{-5}	1.2×10^{-5}
Δx ($D^0 \to K_S^0\pi^+\pi^-$)	18×10^{-5}	[57]	6.3×10^{-5}	4.1×10^{-5}	1.6×10^{-5}
Rare decays					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	69%	[30, 31]	41%	27%	11%
$S_{\mu\mu}$ ($B_s^0 \to \mu^+\mu^-$)	—		—	—	0.2
$A_\text{T}^{(2)}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[58]	0.060	0.043	0.016
$S_{\phi\gamma}(B_s^0 \to \phi\gamma)$	0.32	[59]	0.093	0.062	0.025
$\alpha_\gamma(\Lambda_b^0 \to \Lambda\gamma)$	$^{+0.17}_{-0.29}$	[60]	0.148	0.097	0.038

LHCb Upgrade II TDR