

Status and perspectives of LHCb

Marianna Fontana
on behalf of the LHCb collaboration

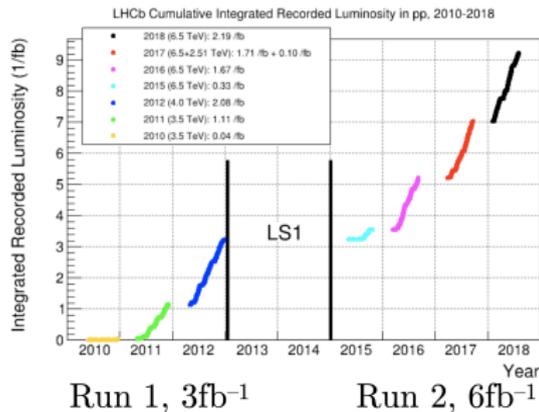
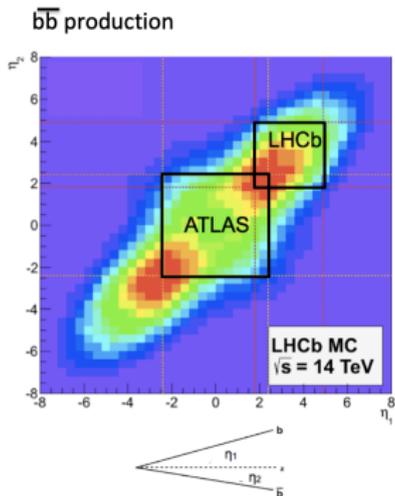
LPNHE (Paris)

Implications Workshop 2022
CERN, 19 - 21 October 2022

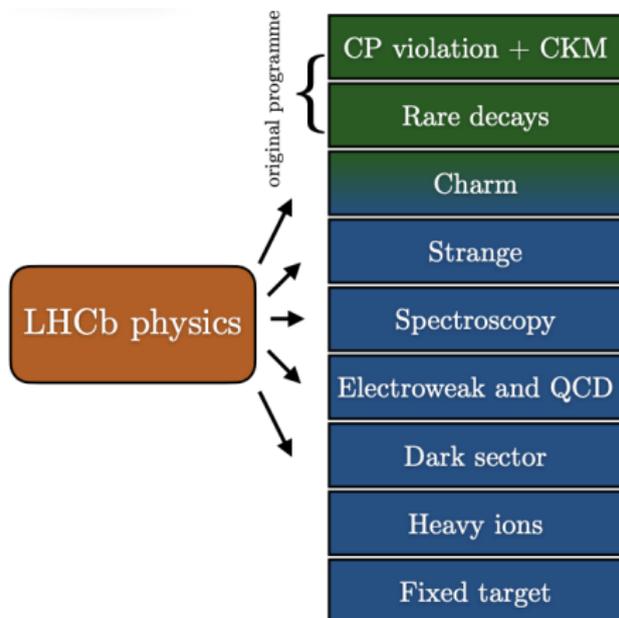


LHCb in a nutshell

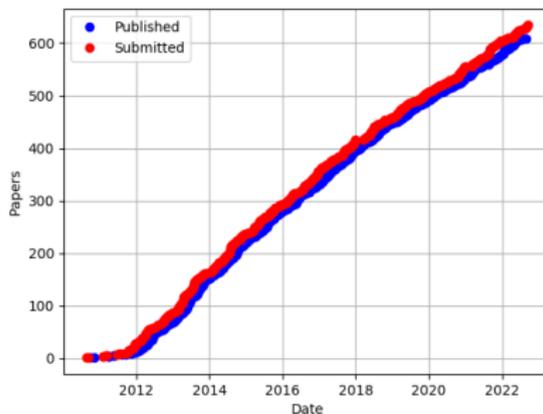
- LHCb originally designed for CP violation and rare decays measurements → nowadays a **general purpose detector**!
- $b\bar{b}$ production in pp collisions mostly in the forward direction
- Run 1+2: 9 fb^{-1} of pp collisions (+ heavy ions, fixed target mode)
- Forward spectrometer ($2 < \eta < 5$) with excellent vertexing, tracking and particle identification
[\[JINST 3 \(2008\) S08005\]](#)



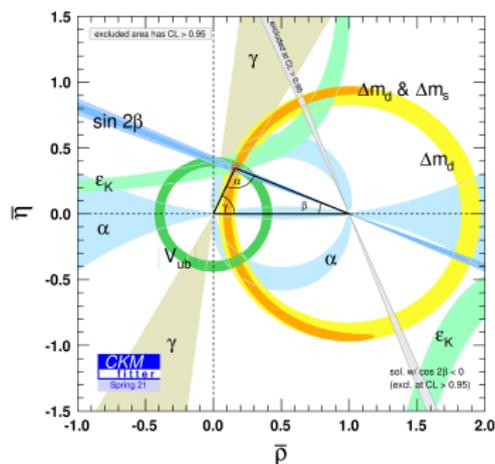
The LHCb physics programme



More than 630 papers submitted!

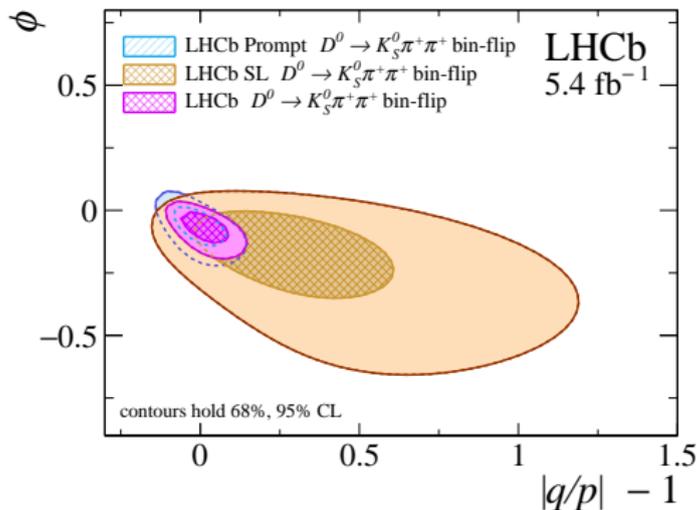


The CKM picture



- Great success of the Standard Model CKM picture
- All measurements agree coherently
- How does that relate to other information which tells us that NP must exist?
- Approaching the 4% uncertainty level on $\gamma \rightarrow$ new combination being shown!

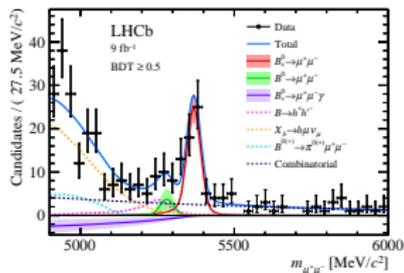
The up sector



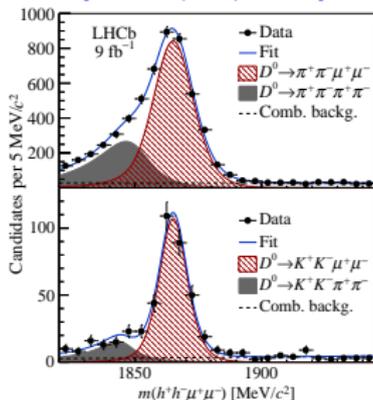
[arXiv:2208.06512]

- CPV in charm observed by LHCb in the difference of CP asymmetries for $D^0 \rightarrow \pi\pi$ and $D^0 \rightarrow KK$
- Now beginning to characterise the individual asymmetries!
- Charm mixing well-established since more than a decade! Keeping improving the precision on the mixing parameters

Rare and semileptonic decays

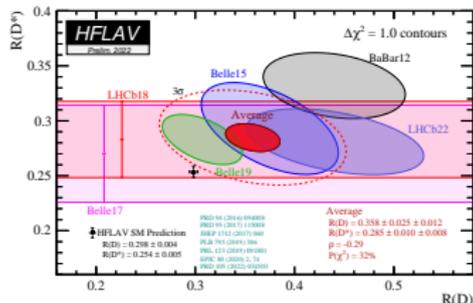


[PRL 128 (2022) 041801]



[PRL 128 (2022) 221801]

- Rich laboratory for SM tests
- Many progress towards the legacy Run 1+2

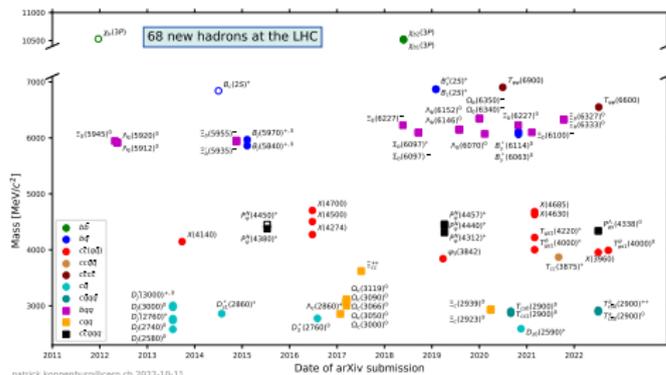
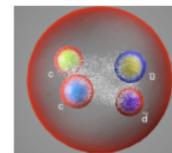
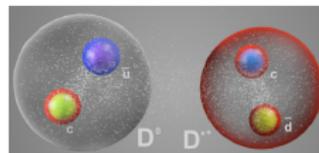


[LHCb-PAPER-2022-039]

Have a look at our latest results presented at the CERN seminar yesterday!!

Search for hadronic states

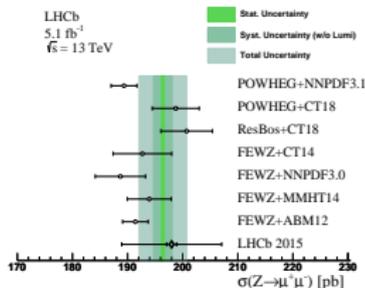
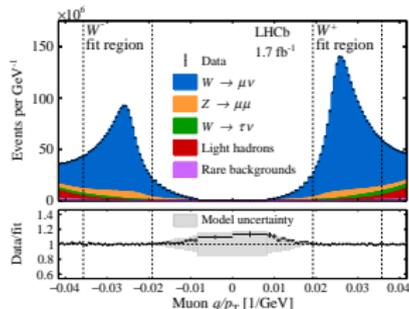
- Conventional and exotic hadronic states are key to study non-perturbative QCD
- Many of them discovered by LHCb
- Nature of exotic states still unclear: hadronic molecule or tightly bound states?



<https://www.nikhef.nl/pkoppenb/particles.html>

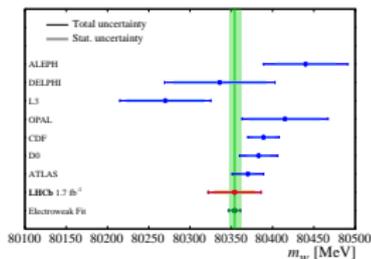
- Workshop on exotic hadrons held yesterday at CERN
- New naming convention proposed by LHCb [[arXiv:2206.15233](https://arxiv.org/abs/2206.15233)]

Electroweak



[JHEP 07 (2022) 026]

$$m_W = 80354 \pm 23_{\text{stat}} \pm 10_{\text{exp}} \pm 17_{\text{theory}} \pm 9_{\text{PDF}} \text{ MeV}$$



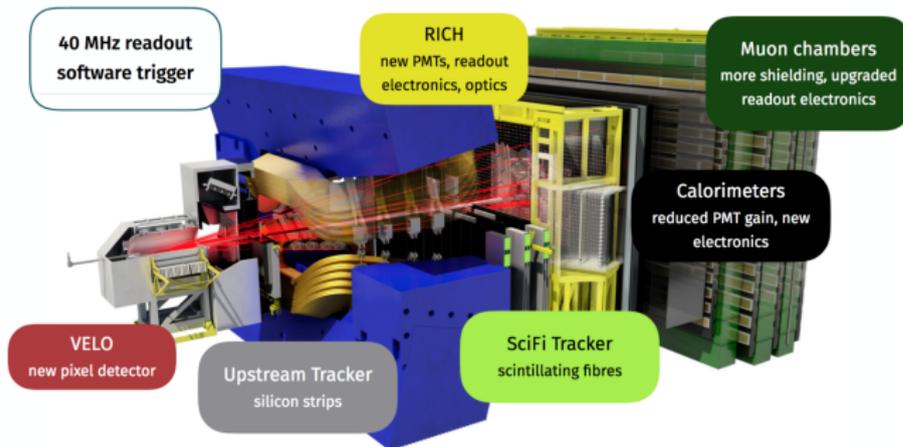
[JHEP 01 (2022) 036]

- LHCb characteristics allow to perform unique observable measurements
- Precision measurement of EW observables allows to search for NP effects
- The W measurement agrees well with the prediction of the global electroweak fit and with previous measurements

The upgraded LHCb

Major upgrade of all sub-detectors

- $\mathcal{L} = 2 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$, pile-up ≈ 5



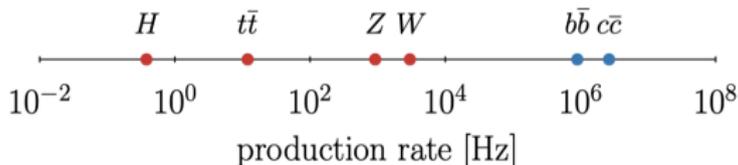
- 100% of the readout electronics replaced
- New data acquisition system and data center
- Very challenging installation and commissioning!

- New pixel-detector **VELO**
- New **RICH** mechanics, optics, photodetector
- New Silicon strip upstream tracker **UT**
- New **SciFi** tracker
- New electronics for **MUON** and **CALO**
- New luminometer **PLUME**

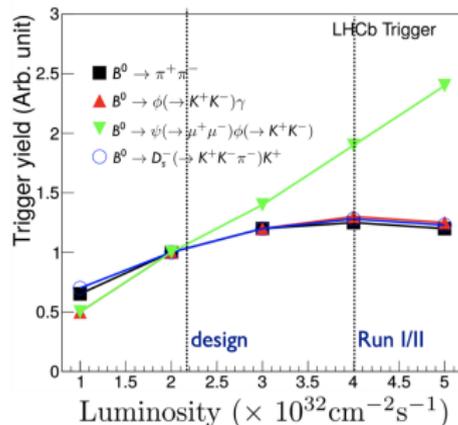
Upgrade the trigger strategy

$$\mathcal{L} = 2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1} \text{ (ATLAS/CMS)} \quad \sqrt{s} = 14 \text{ TeV}$$

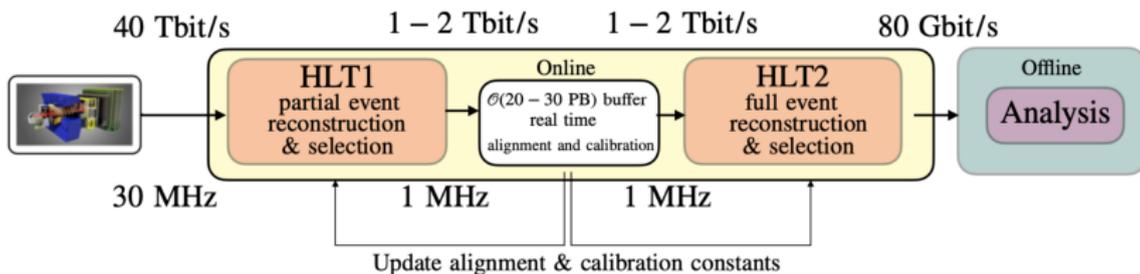
$$\mathcal{L} = 2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \text{ (LHCb)}$$



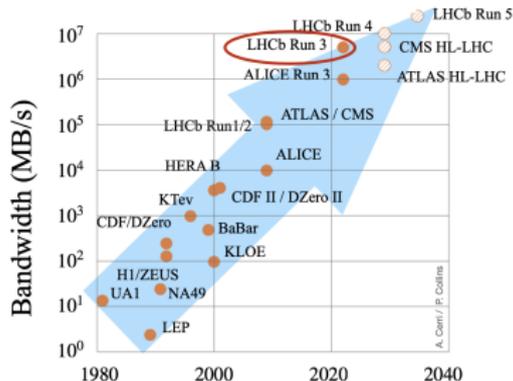
- Heavy flavour hadrons decay to final-state particles with momenta similar to those of particles from the underlying event
- LHCb has to distinguish between signal and signal-like background
- Cannot effectively trigger on heavy flavour using hardware signatures
- Trigger for many hadronic channels saturated already at Run 1–2 luminosity



Upgrade the trigger strategy



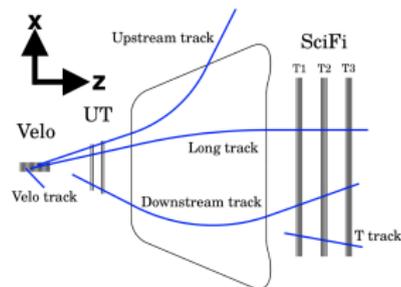
- **Solution:** fully software trigger
- Online reconstruction at 40 MHz
- 30 MHz of inelastic collisions reduced to 1 MHz in Hlt1 (running on GPUs)
- Offline-quality reconstruction in “real-time”
- Increase of hadronic trigger efficiency by 2–4 wrt. Run 2



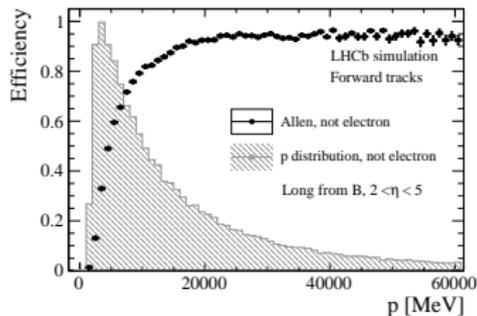
Highest data processing rate of any HEP experiment!

Tracking

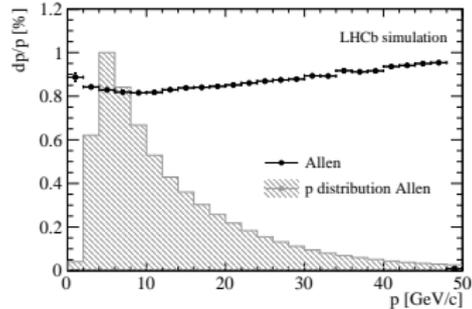
- Various type of tracks in LHCb
- *Long tracks* used for most analyses ($B_s^0 \rightarrow \mu^+ \mu^-$, ...)
- *Downstream tracks* can be used by analyses like for example $D^0 \rightarrow K_S^0 K_S^0$
- Run 2 performance maintained at x5 instantaneous luminosity



[LHCb-FIGURE-2020-014]



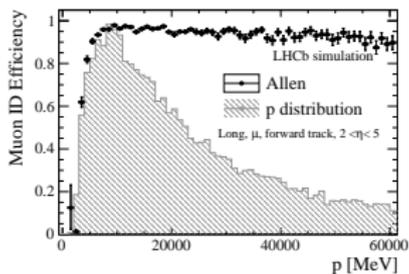
[LHCb-FIGURE-2020-014]



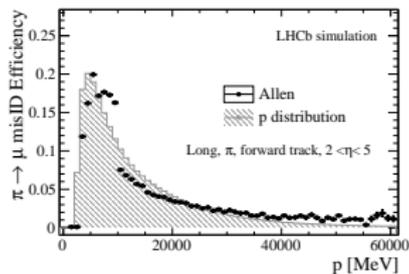
Particle identification

- Fundamental ingredient for LHCb analyses ($B_s^0 \rightarrow \mu^+ \mu^-$, $B^0 \rightarrow h^+ h^-$)
- PID combines information from RICH, calorimeters and muon system
- Used extensively in the trigger
- Expect to keep the same performance in Run 3

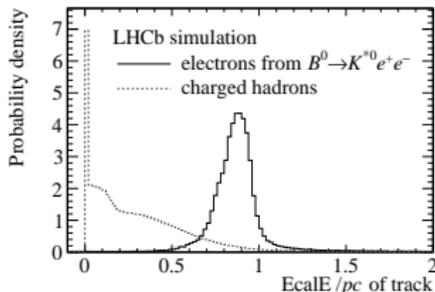
[LHCb-FIGURE-2020-014]



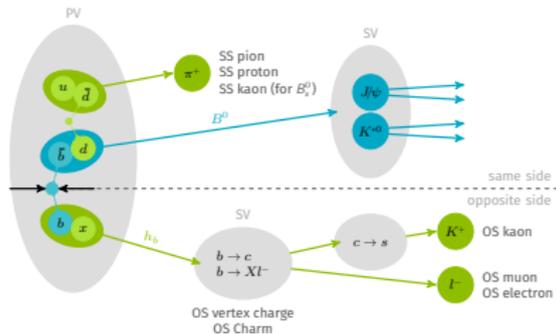
[LHCb-FIGURE-2020-014]



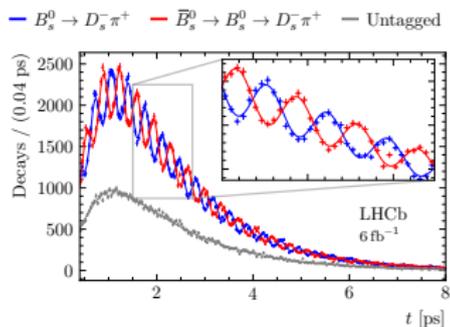
[LHCb-FIGURE-2021-003]



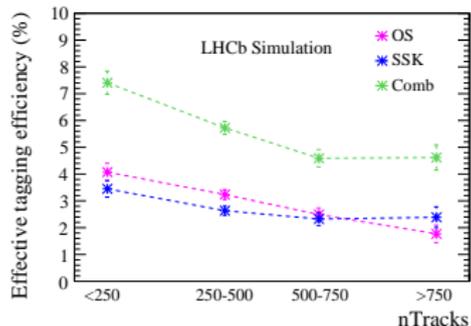
Flavour tagging



- Various algorithms to determine whether a neutral B meson is a particle or anti-particle at production
- Essential for time-dependent analyses like $\phi_s, \sin 2\beta$
- Effective tagging power ε is determined: asymmetry uncertainty $\sim 1/\sqrt{\varepsilon N}$

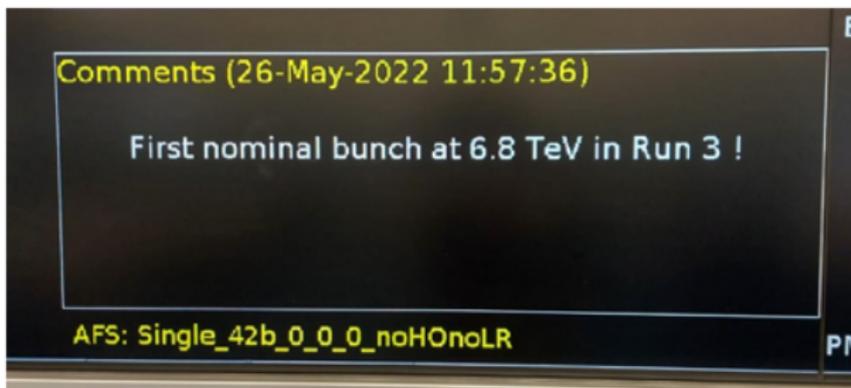


[Nature Physics 18, (2022) 1-5]



[LHCb-PUB-2018-009]

The commissioning trip



5th July 2022: first data at 13.6 TeV



LHCb Experiment at CERN
Run / Event: 236189 / 3032040187
Data recorded: 2022-07-05 14:44:16 GMT



5th July 2022: first data at 13.6 TeV



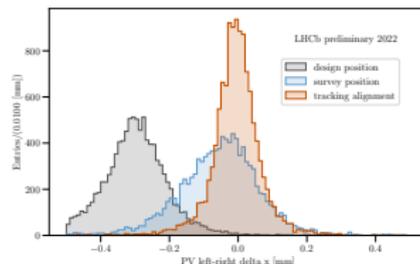
LHCb Experiment at CERN
Run / Event: 236189 / 3032040187
Data recorded: 2022-07-05 14:44:16 GMT



Trackers commissioning

VELO

- Tracks and vertices are reconstructed
- Accurate reconstruction of the beam position achieved
- Closure procedure in progressive steps: partially closed to 2 mm from nominal
- Good alignment reached

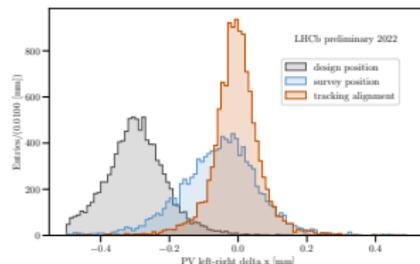


[LHCb-FIGURE-2022-029]

Trackers commissioning

VELO

- Tracks and vertices are reconstructed
- Accurate reconstruction of the beam position achieved
- Closure procedure in progressive steps: partially closed to 2 mm from nominal
- Good alignment reached

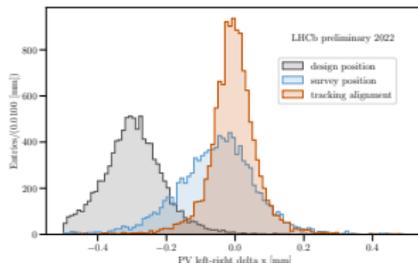


[LHCb-FIGURE-2022-029]

Trackers commissioning

VELO

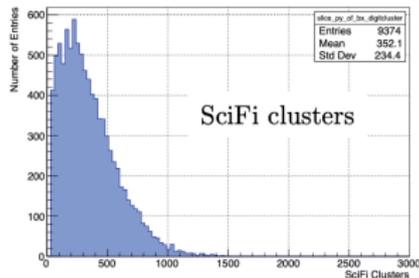
- Tracks and vertices are reconstructed
- Accurate reconstruction of the beam position achieved
- Closure procedure in progressive steps: partially closed to 2 mm from nominal
- Good alignment reached



[LHCb-FIGURE-2022-029]

SciFi

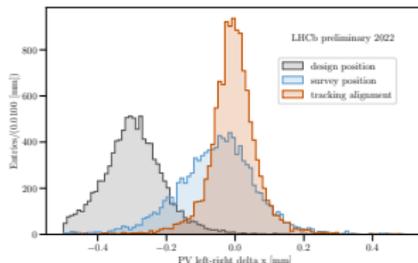
- Time alignment performed to maximise efficiency
- First tracks recorded



Trackers commissioning

VELO

- Tracks and vertices are reconstructed
- Accurate reconstruction of the beam position achieved
- Closure procedure in progressive steps: partially closed to 2 mm from nominal
- Good alignment reached



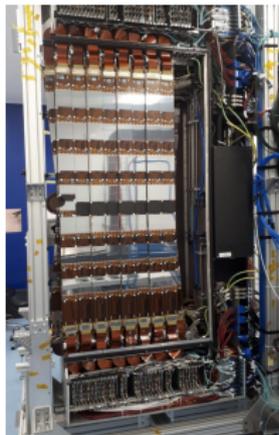
[LHCb-FIGURE-2022-029]

SciFi

- Time alignment performed to maximise efficiency
- First tracks recorded

Upstream tracker

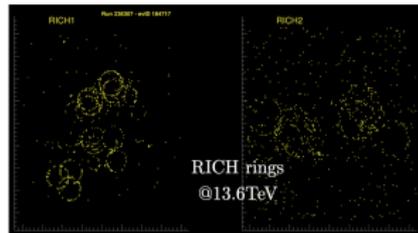
- Good progress towards the full installation at the end of the year



PID detectors commissioning

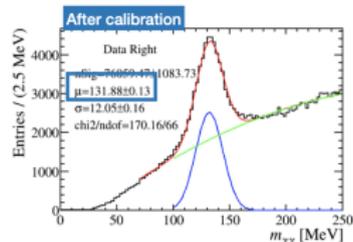
RICH

- RICH took part to stable beams runs since the first injection
- Time alignment performed
- Ready to be included in runs with track reconstruction



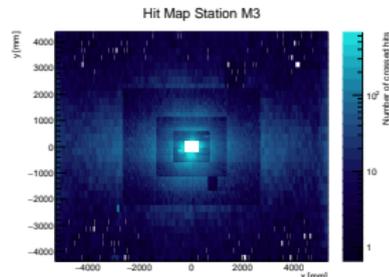
CALO

- The first collisions allowed individual time alignments of the calorimeter channels
- Thanks to the energy calibration, π^0 s have been reconstructed



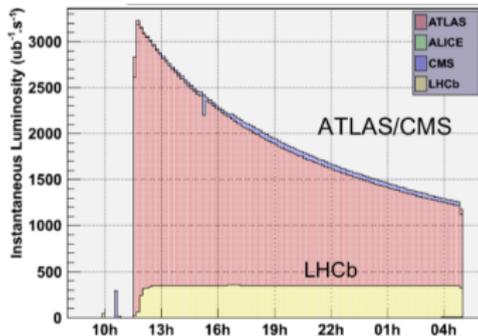
Muon system

- Work ongoing to complete fine time alignment
- Standalone muon reconstruction being tested soon



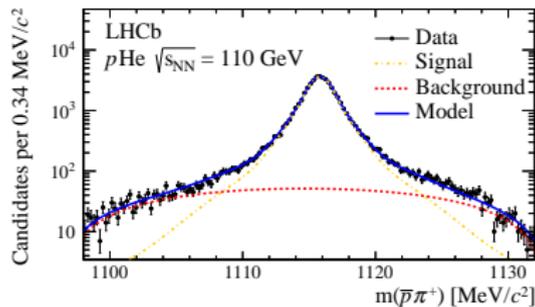
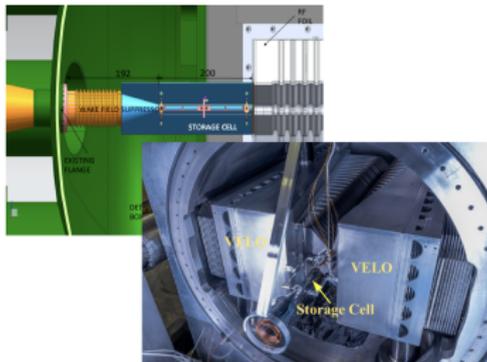
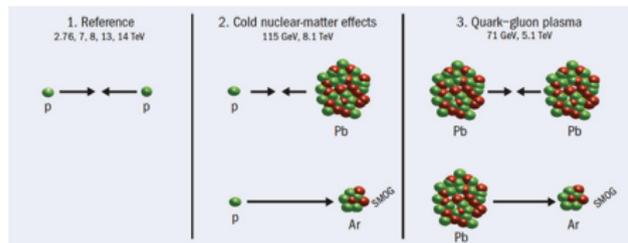
Luminosity

- Time-integrated luminosity necessary to calculate x-secs
- Instantaneous luminosity at LHCb: continuous luminosity levelling
- New dedicated detector PLUME (Probe for LUMinosity MEasurements)
- Preliminary calibration of absolute luminosity at 13.6 TeV performed



Heavy ions and fixed target

- Different kind of environments enrich the LHCb physics programme
- Several results from heavy-ion collisions
- New fixed target device (SMOG2): gas injection system



[arXiv:2205.09009]

1st October 2022: all the pieces together!

The screenshot displays the LHCb TOP control interface. At the top, the system is labeled 'LHCb: TOP' and shows the overall state as 'RUNNING'. The 'Auto Pilot' is currently 'OFF'. The date and time are 'Sat 01-Oct-2022 17:54:32'. The user is 'root'.

Sub-System State:

Sub-System	State
DCS	READY
DAI	READY
DAQ	RUNNING
RunInfo	RUNNING
TFC	RUNNING
EB	RUNNING
Monitoring	RUNNING

Run Info:

- Run Number: 247579
- Run Start Time: 01-Oct-2022 17:53:50
- Run Duration: 00:00:39
- Nr. Events: 738289366
- Step Nr.: To Go: 0 / 0

Trigger Config: `HL1_IP_RS_GEN_RS_04_VEL00` (highlighted with a red box)

Input Rate & Output Rate: (highlighted with a red box)

- Input Rate: 18160.72 kHz
- Output Rate: 838.34 kHz

Sub-Detectors: (highlighted with a red box)

Sub-Detector	State
TDET	NOT_READY
VELOA	RUNNING
VELOC	RUNNING
UTC	NOT_READY
SFA	RUNNING
SFC	RUNNING
RICH1	RUNNING
RICH2	RUNNING
ECAL	RUNNING
HCAL	RUNNING
MUONC	RUNNING
PLUME	RUNNING

Messages:

- 01-Oct-2022 17:53:50 - LHCb executing action GO
- 01-Oct-2022 17:53:51 - LHCb_TFC executing action START_TRIGGER
- 01-Oct-2022 17:53:51 - LHCb in state RUNNING

Full HLT1 tracking sequence

Input rate ~20 MHz (max. with current LHC filling scheme)

All installed sub-detectors included

1st October 2022: all the pieces together!

The screenshot displays the LHCb TOP monitoring interface. At the top, the system status is shown as 'RUNNING' and 'Auto Pilot' is 'OFF'. The date is 'Sat 01-Oct-2022 17:54:32'. Below this, a table lists sub-systems and their states, with 'LHCb' in the 'RUNNING' state. A large 3D model of the LHCb detector is centered, showing the main detector structure and various sub-detectors. The model is rendered in a light blue and white color scheme, with a red vertical bar indicating the beam pipe. The interface also includes a 'Messages' window at the bottom, showing log entries for the system's execution.

System State: LHCb RUNNING Auto Pilot OFF Sat 01-Oct-2022 17:54:32

Sub-System State Run Info

LHCb Experiment at CERN
Main Contact: 2167131 + 465123349
Data recorded: 2022-10-01 17:54:32 GMT

Messages:

- 01-Oct-2022 17:53:50 - LHCb: executing action GO
- 01-Oct-2022 17:53:51 - LHCb: TFC executing action START_TRIGGER
- 01-Oct-2022 17:53:51 - LHCb: in state RUNNING

g sequence

MHz (max.
HC filling
e)

sub-detectors
ded

Towards the ultimate precision: LHCb Upgrade II

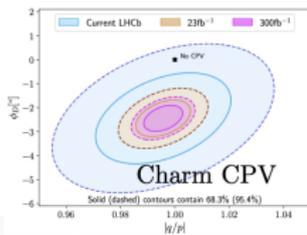
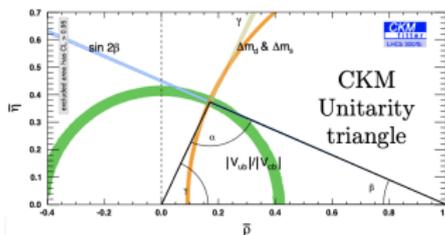
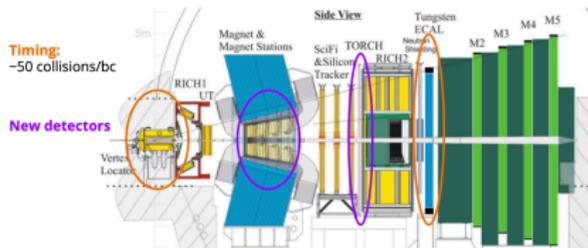


[LHCC-2021-012]

Run 5+6: $\mathcal{L}_{int} = 300 \text{ fb}^{-1}$, Pile-up ~ 40

Starting R&D of new technologies

- precision timing for tracking and PID
- extreme radiation hardness
- Unprecedented sensitivity expected for flavour physics



Conclusion

- Broad physics programme at LHCb
 - Flavour physics, spectroscopy, EW, heavy ions, long lived particles, fixed target
- Upgrade I detector under commissioning
 - The installed detectors are promptly releasing their nominal capabilities
 - First mass peaks appearing
 - Full power of the fully-software trigger being exploited soon
- Already planning for the future
 - FTDR for the Upgrade II detector approved
 - R&D towards new generation subdetectors ongoing



Backup