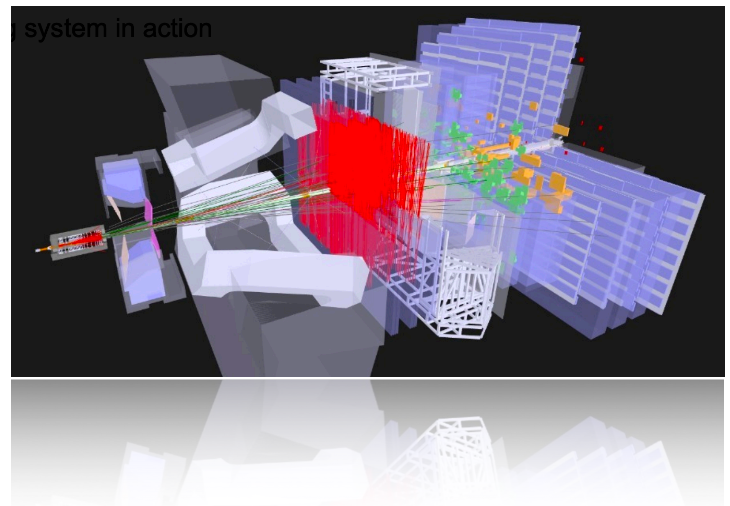


Performance of LHCb Upgrade I in Run 3

Federica Oliva

on behalf of the LHCb collaboration

University of Edinburgh

BEAUTY 2023

Clermont-Ferrand, France, 3th-7th July 2023

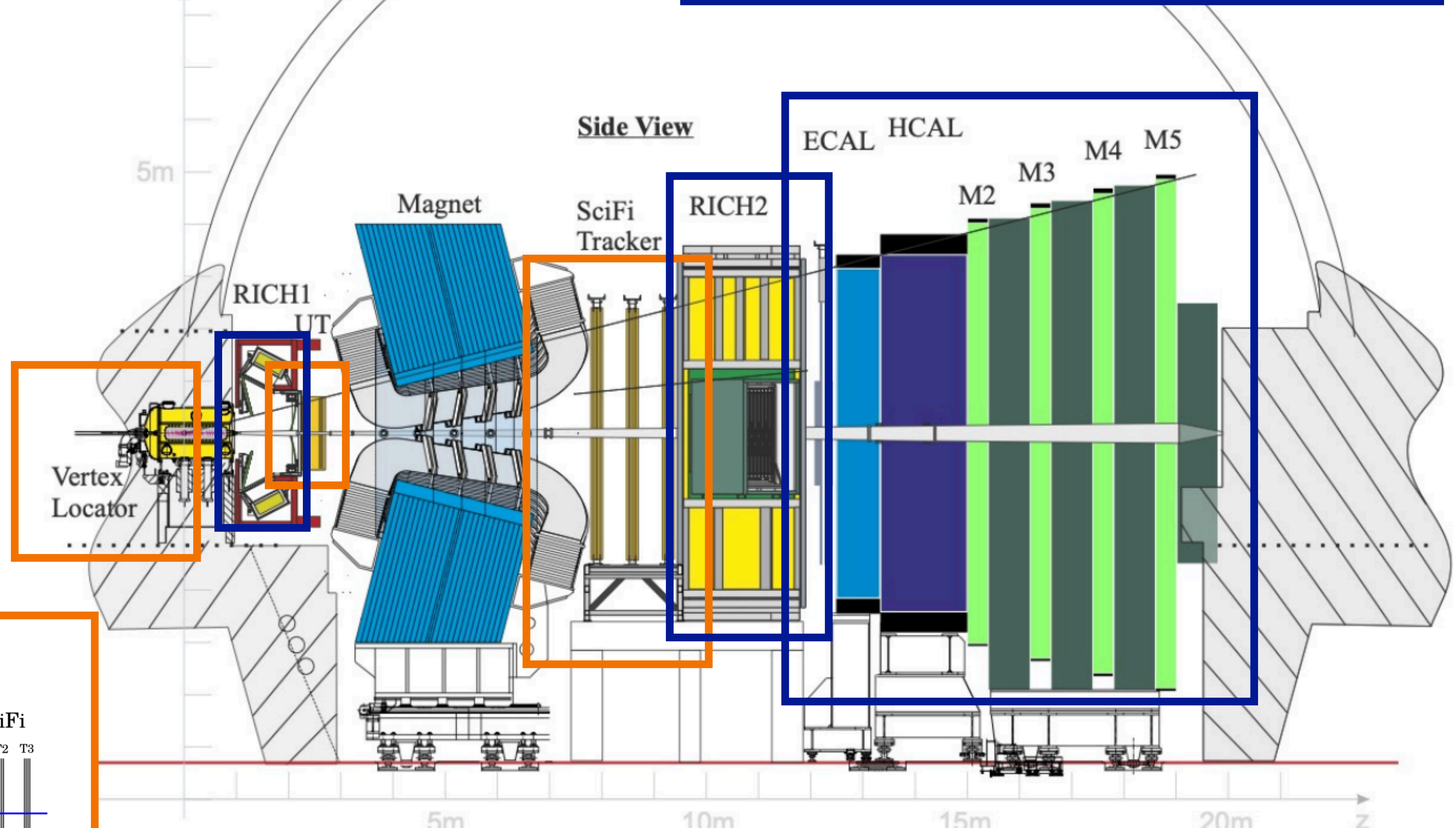
Outline

- LHCb Upgrade I
  - Run3 challenges
  - Trigger (full software)
  - Upgrade of the subdetectors and performance
- First mass plots from the 2022 data taking
- Conclusions and plans

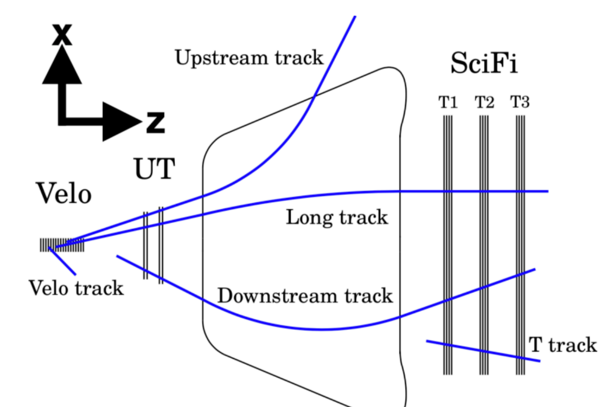
LHCb is a general-purpose forward detector at the LHC which is particularly suited to precision measurements in the beauty and charm sectors

Particle Identification

Charge hadron identification (RICH)
Photon and electron identification (CALO)
Muon identification (Muon chamber)



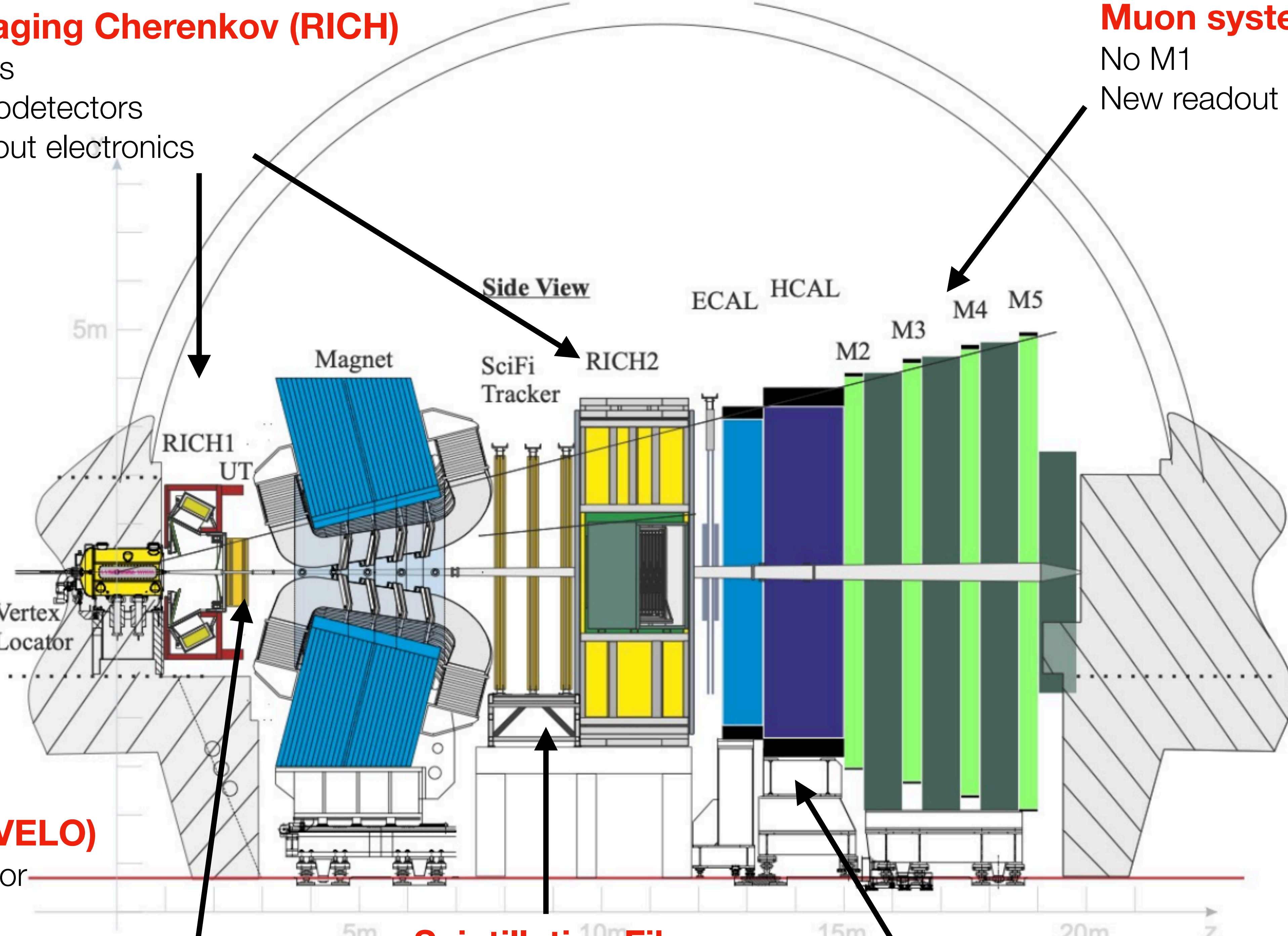
Track reconstruction



The increase of luminosity in Run3 represents a big challenge for LHCb

→ Performance can be preserved only with vast improvements in granularity, readout speed, radiation hardness, and trigger innovations!

LHCb Upgrade I detector layout



Ring Imaging Cherenkov (RICH)
New optics
New photodetectors
New readout electronics

Muon system
No M1
New readout electronics

Vertex Locator (VELO)
New Pixellated sensor

Upstream tracker
Completely new tracker
Installation finished in
March 2023

Scintillating Fiber Tracker (SciFi)
Completely new tracker

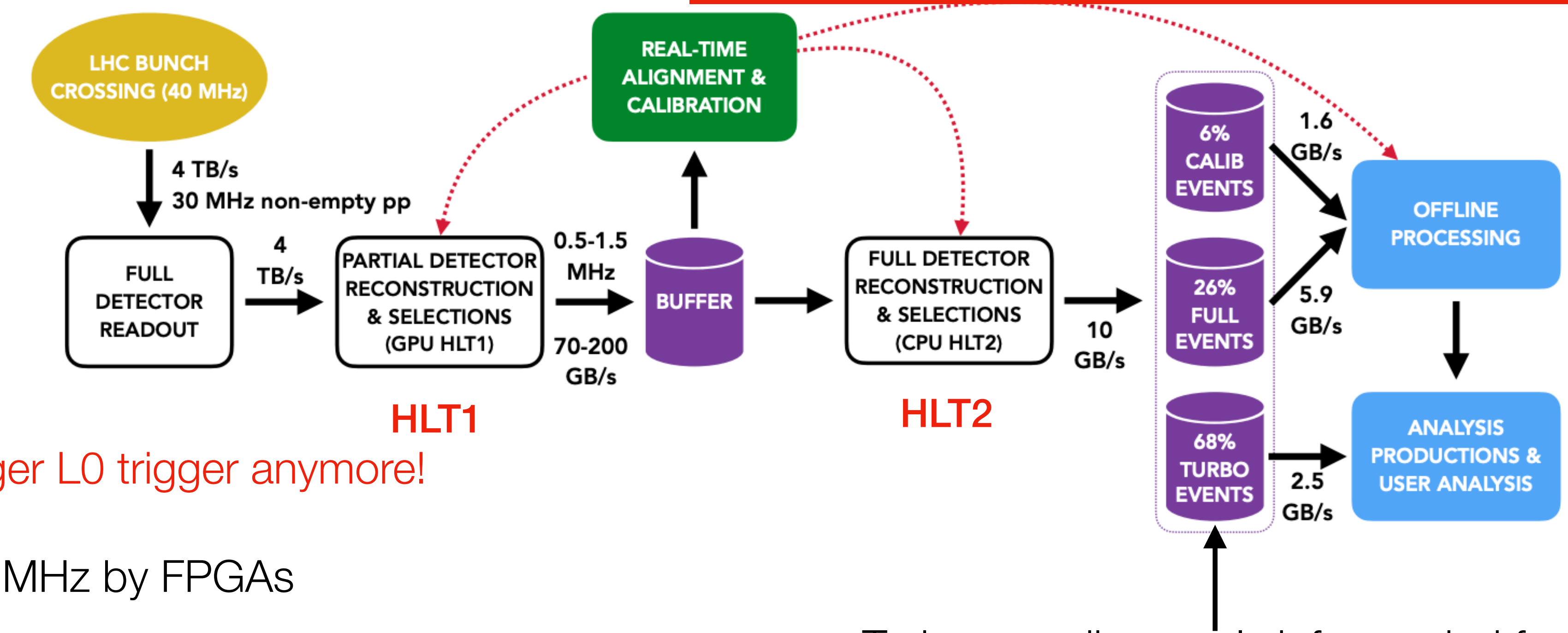
ECal + HCal
New readout electronics

+ FULL software trigger (30 MHz)

LHCb upgrade paper: https://arxiv.org/pdf/2305.10515.pdf

Trigger & Real Time Analysis

First time completely software trigger in a high energy experiment!



➡No Hardware trigger L0 trigger anymore!

Turbo paradigm, only info needed for physics are stored

➡Data stored at 30 MHz by FPGAs

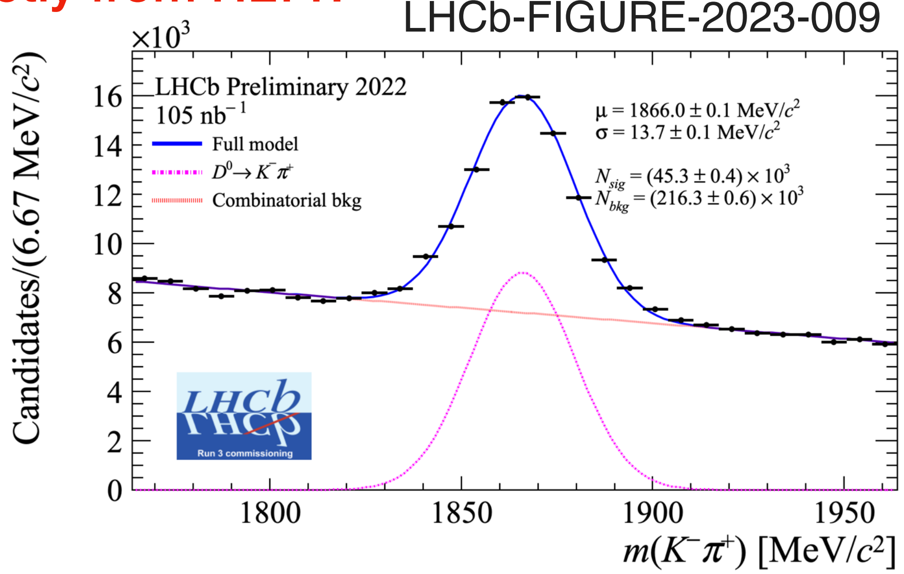
➡HLT 1 running on GPUs - track reconstruction

➡HLT2 runnig on CPUs - reconstruction and selection for each decay

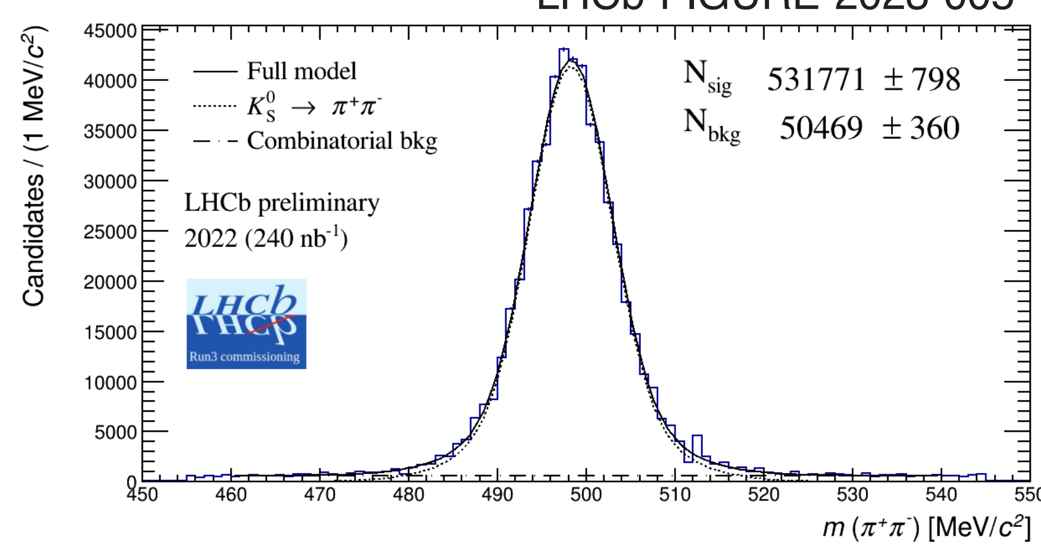
➡Alignment (VELO, RICH mirrors, UT, SciFi, Muon) and calibration (RICH, ECAL, HCAL) of the detectors in real time

➡Plot directly from HLT1!

LHCb-FIGURE-2023-009

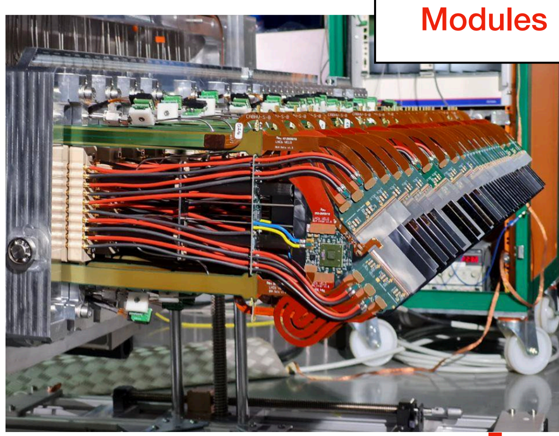


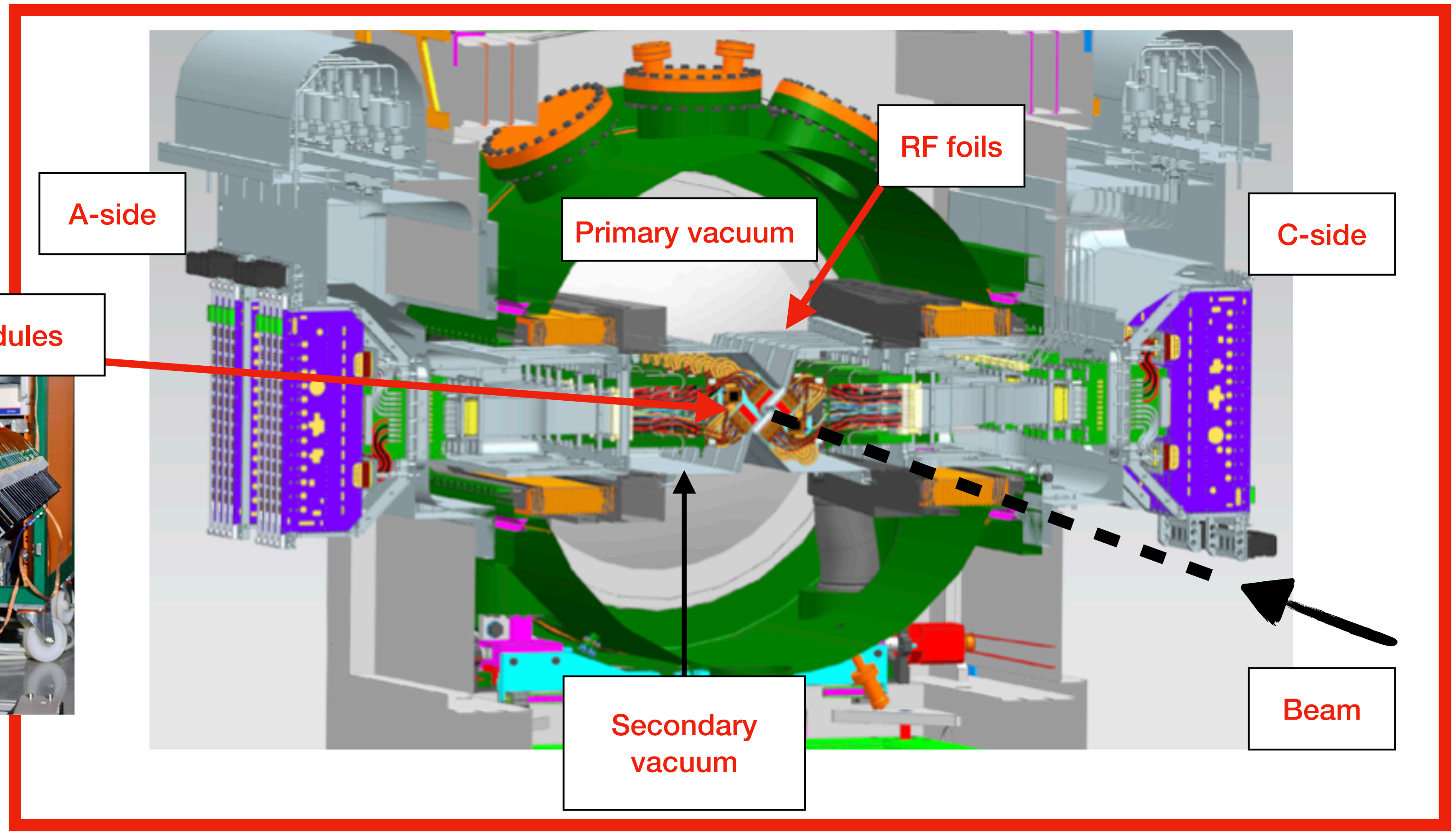
LHCb-FIGURE-2023-005



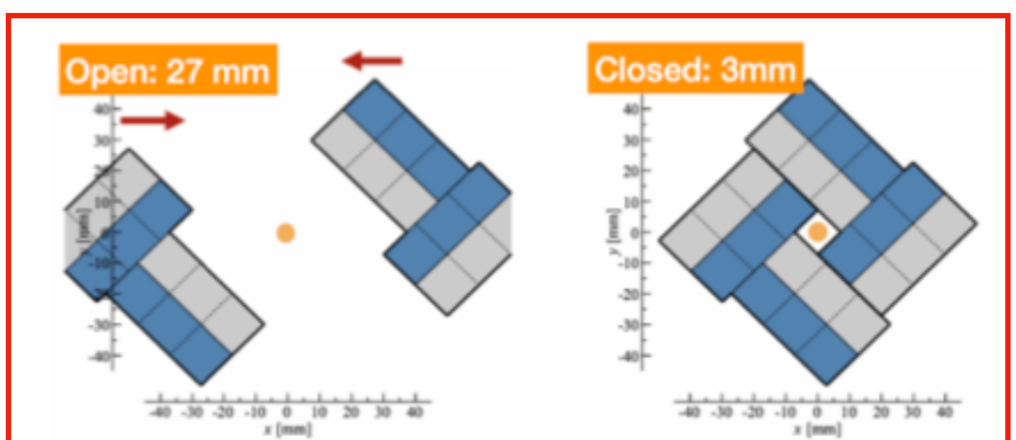
Vertex locator (VELO)

- Redesigned to be compatible with the luminosity increase and the trigger-less readout requirement
- Pixelated hybrid silicon detectors, arranged into 52 modules and cooled by a silicon microchannel cooler
- Movable halves
- RF foils separate the secondary VELO vacuum from the LHC one

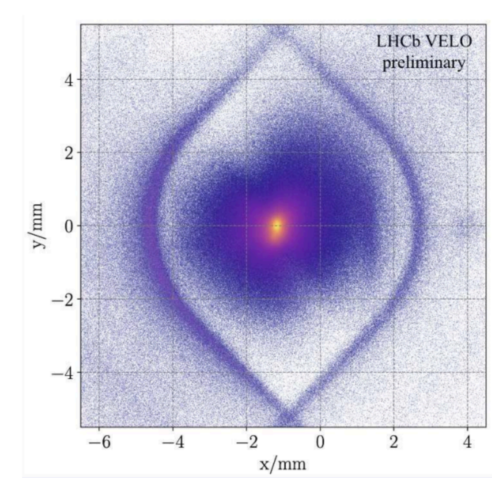




The delicate closing procedure requires precise knowledge of the RF foils, monitoring of vacuum and detector conditions

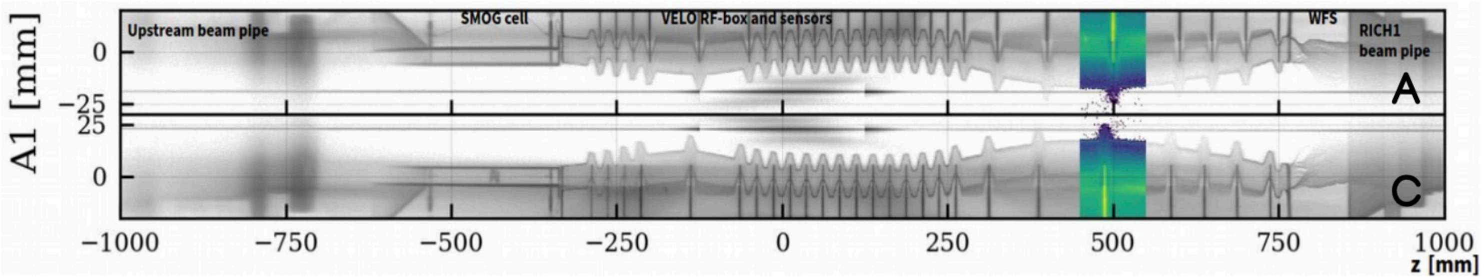


➡full closure on the 25/10/2022

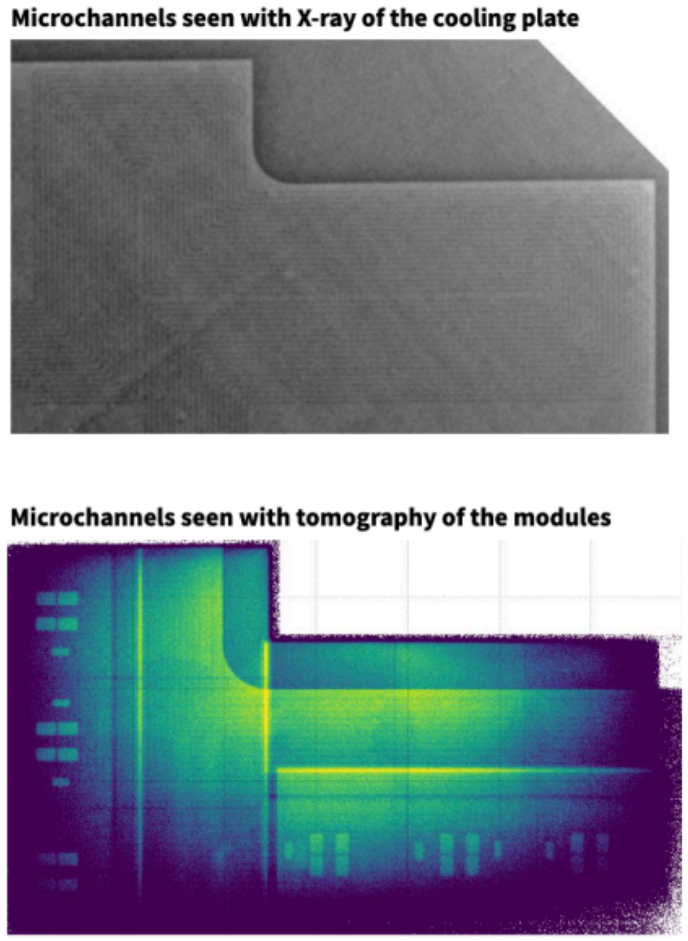


Vacuum incident

10th January 2023 - a loss of the protection system caused a pression differential of 200 mbar between the secondary VELO vacuum and the LHC one (max stand pressure 10 mbar)



Velo Tomography to check the sensor status and to check the shape of the RF foils after the deformation



✔ No damage of the VELO sensors

But…

- VELO cannot be fully closed to the nominal 3 mm position around the beam due to the plastic deformation of the RF foils of about 17 mm
- Intervention is needed to substitute the RF foils during the YETS 2023

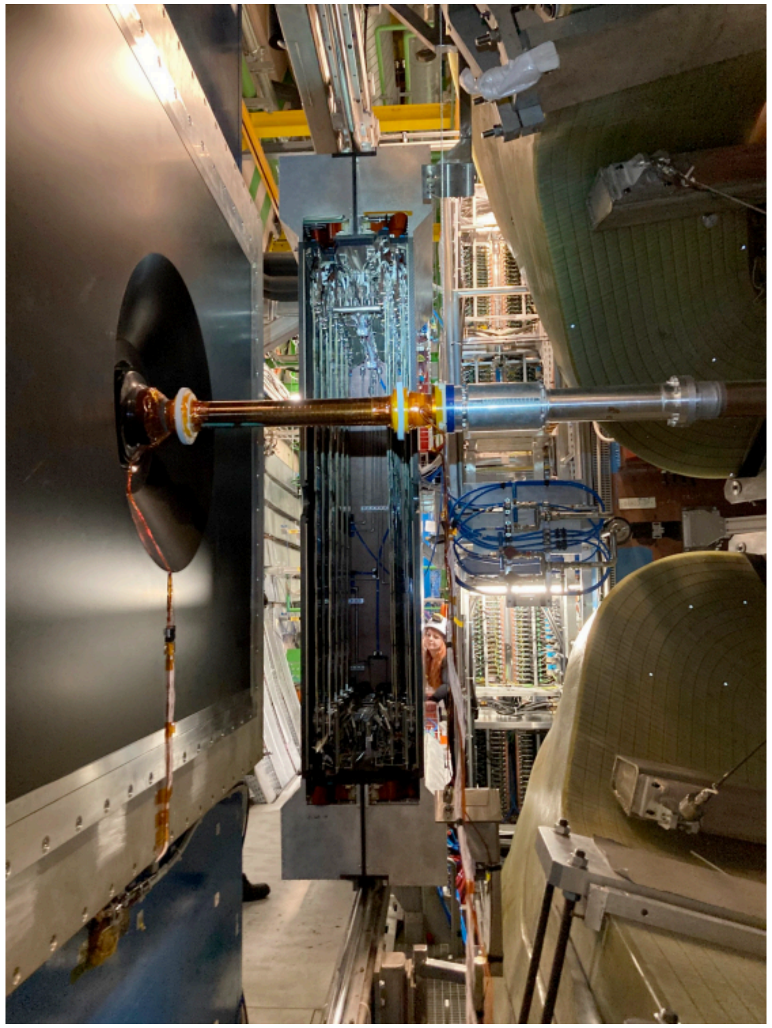
Operation conditions for 2023

VELO partially open during 2023 data taking (24.5 mm per side)

LHCb physics programme affected but still many opportunities for physics

Commissioning of the brand new LHCb will continue this year

Upstream Tracker (UT)



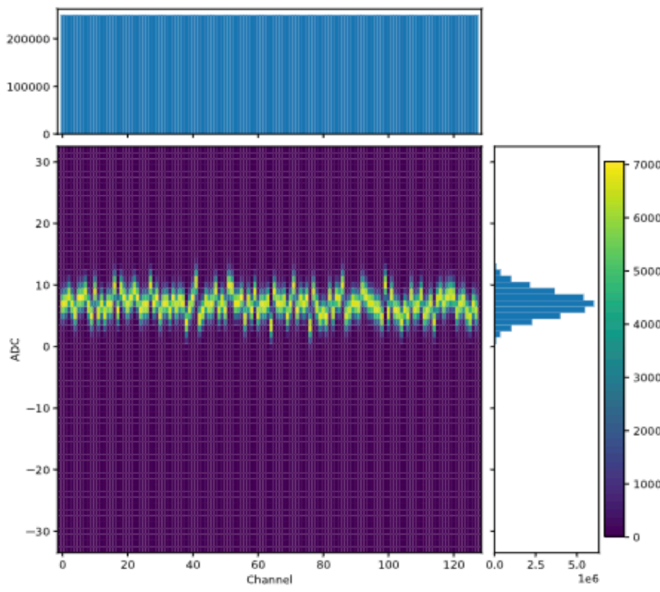
- ➡ Four planes of 1000 total 10x10 cm^2 silicon strip sensors
- ➡ Custom ASIC readout chips (**SALT**)
- ➡ Stave support structures with silicon on both sides
- ➡ increasing segmentation close to beampipe
- ➡ Evaporative CO2 cooling

UT important to reduce ghost track rate for long lived particles

- Start of the installation and first closure in December during the 2022/2023 YETS
- Installation completed in March 2023
- Commissioning ongoing, lots of progress so far

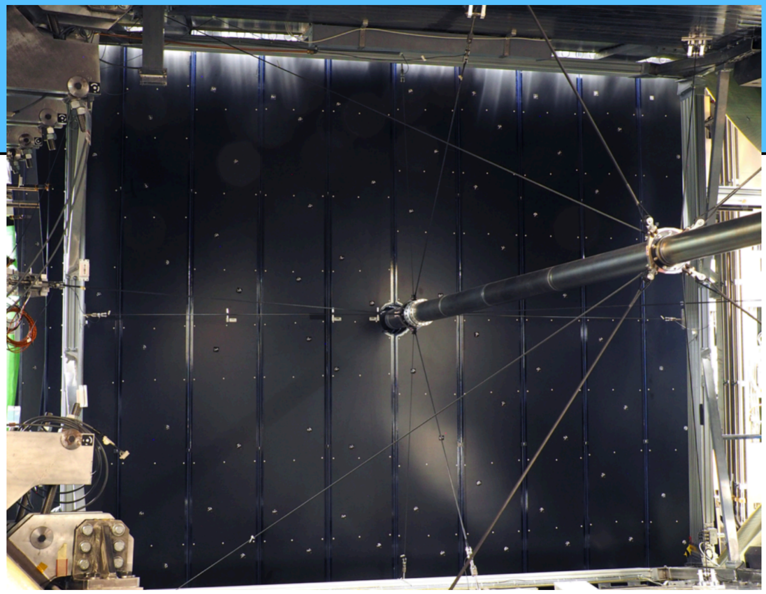
1st milestone achieved

Run taken on May 12th



Data collected with 4x3 firmware

Scintillating Fiber Tracker (SciFi)

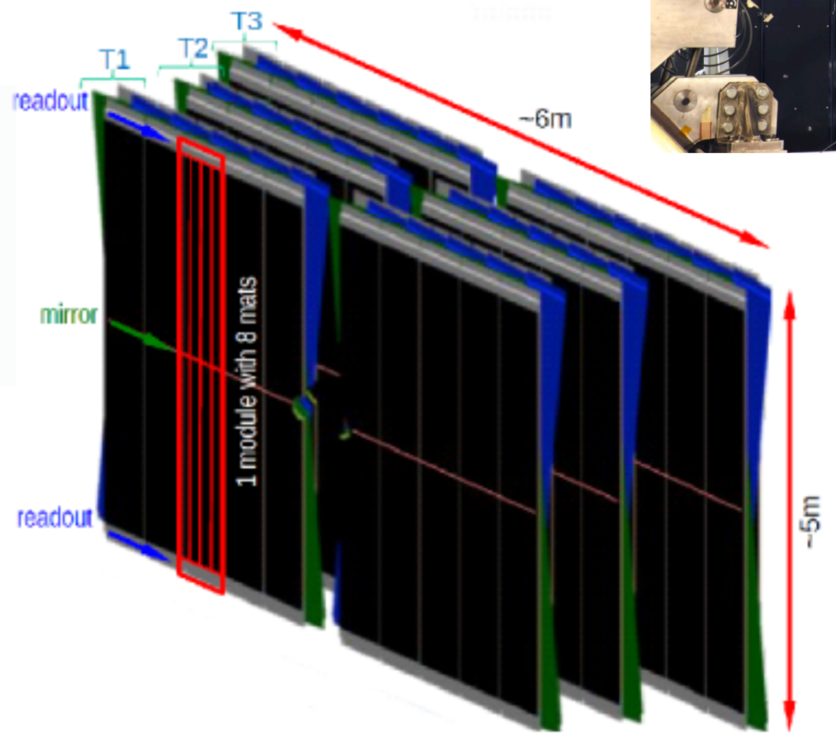


- **Scintillating fibres** 2.5m × 250 µm arranged in fibre mats, for a total of 12 detection planes arranged in 3 stations (**T1, T2, T3**) with 4 layers each (128 modules in total)

- Signal from scintillating fibres are detected by 128-channel arrays of SiPMs, with a channel pitch of 250 µm (N channels)~525k, readout with PACIFIC ASIC

✓ Spatial resolution requirement 100 µm, achieved 80 µm

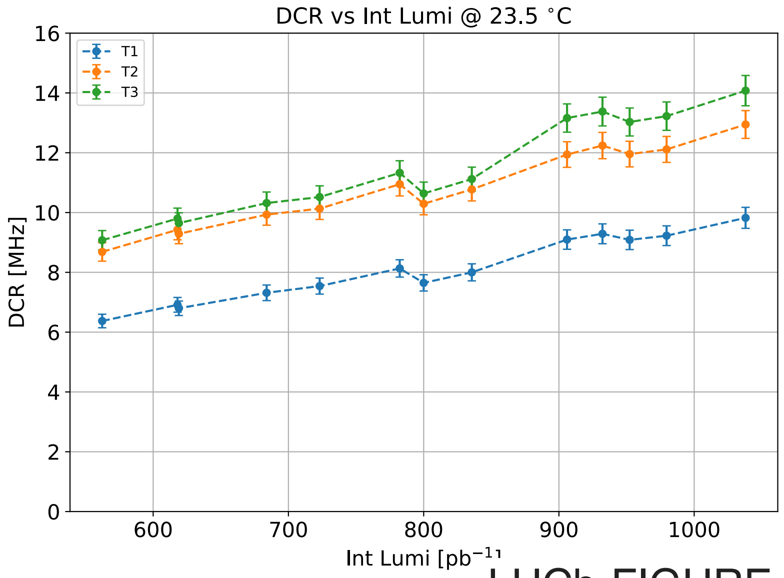
- SiPMs inside a cold box, temperature adjustable between -50 and +30 degrees (@-40 °C during standard operations)



Dark Counts Rate (DCR) studies

Dark count rate studies as a function of the absorbed dose during the commissioning period from October to November 2022

The DCR at 1fb-1 at 23.5 °C ~ DCR at the end of life (50 fb-1) when cooled to -40 °C

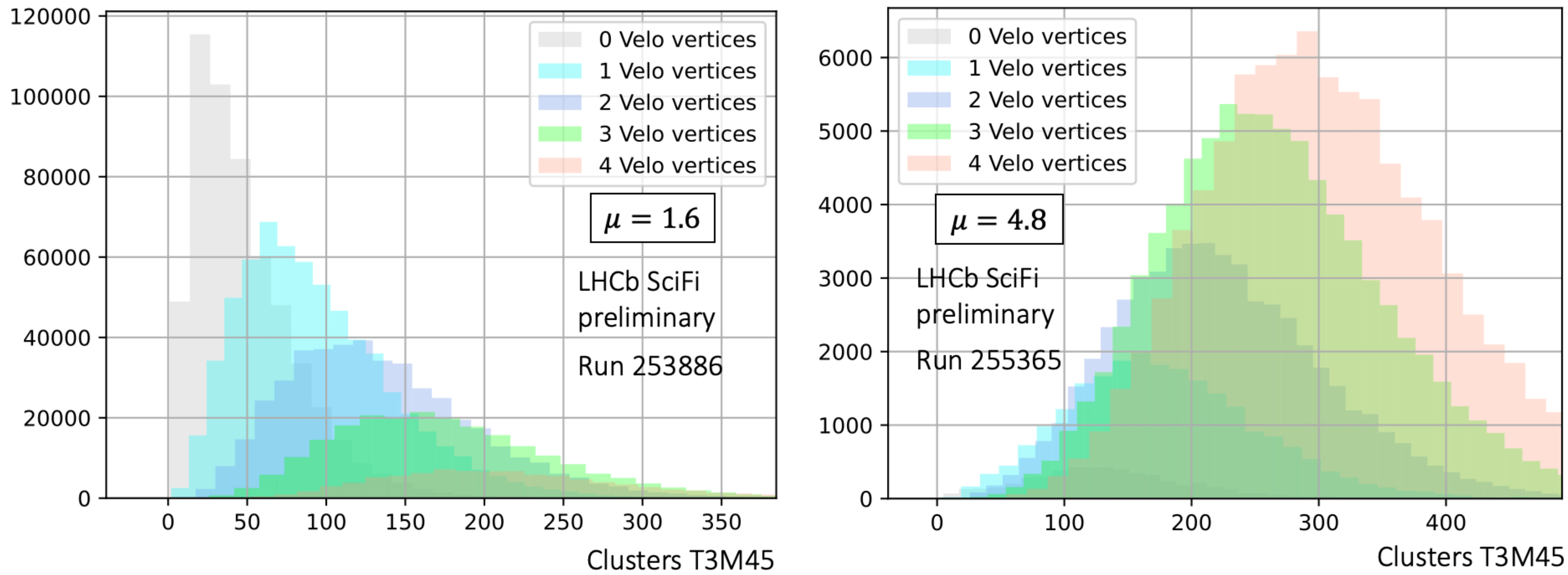


LHCb-FIGURE-2023-004

Long tracks - information from the SciFi clusters are matched with VELO

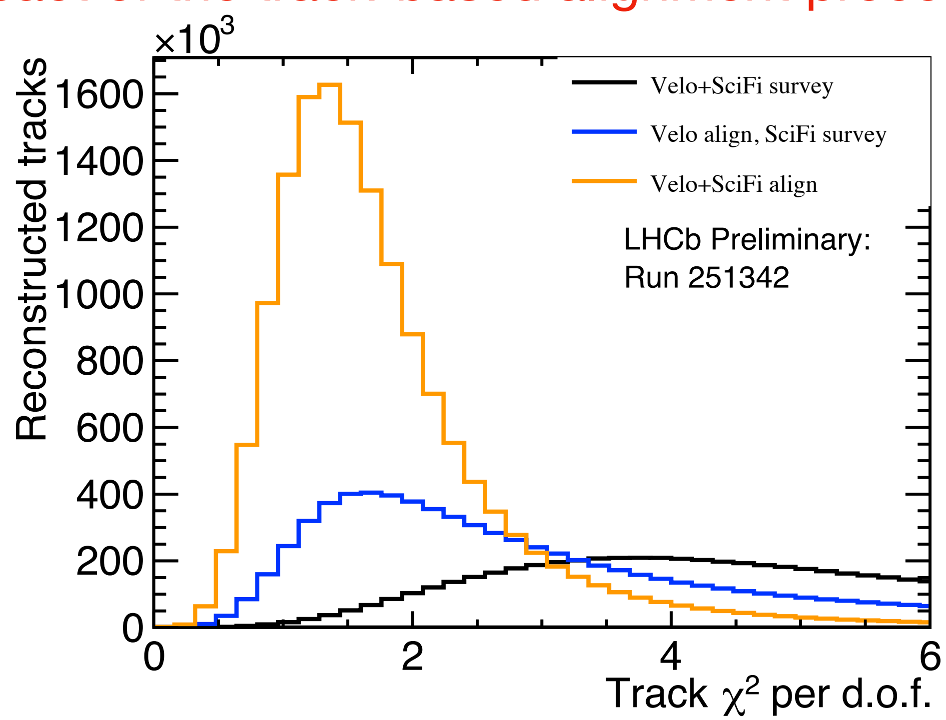
SciFi Clusters and Velo vertices

LHCb-FIGURE-2023-012



Impact of the track-based alignment procedure

LHCb-FIGURE-2022-018

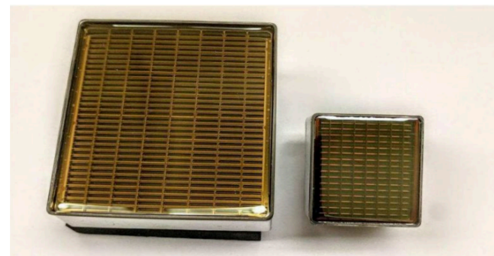


Ring Imaging Cherenkov detector (RICH)

- ✓ New optics
- ✓ New photon detectors (MaPMTs instead of HPDs)

1-inch Hamamatsu R13742,
8x8 pixel matrix, pixel size 2.88 x 2.88 mm^2

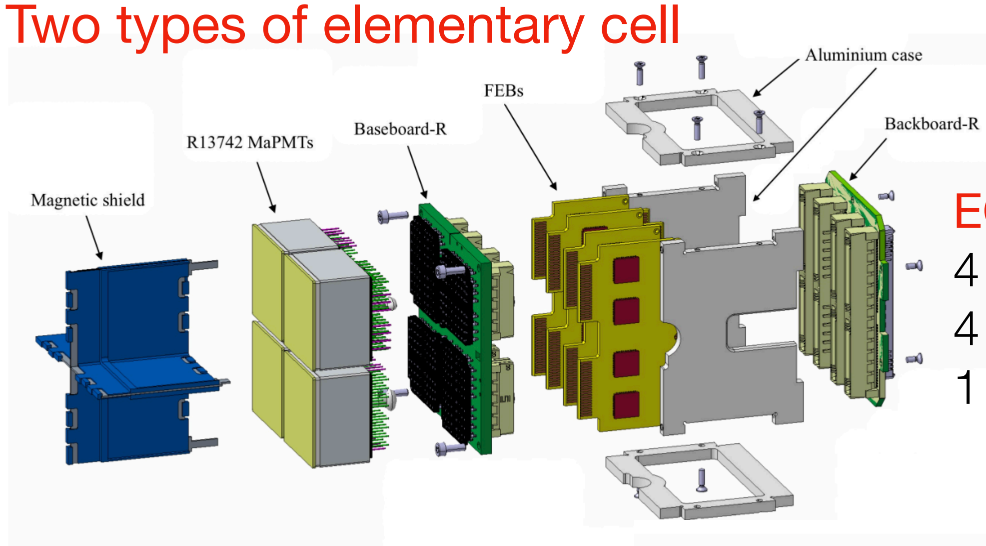
2-inch Hamamatsu R13743,
8x8 pixel matrix, pixel size 6 x 6 mm^2



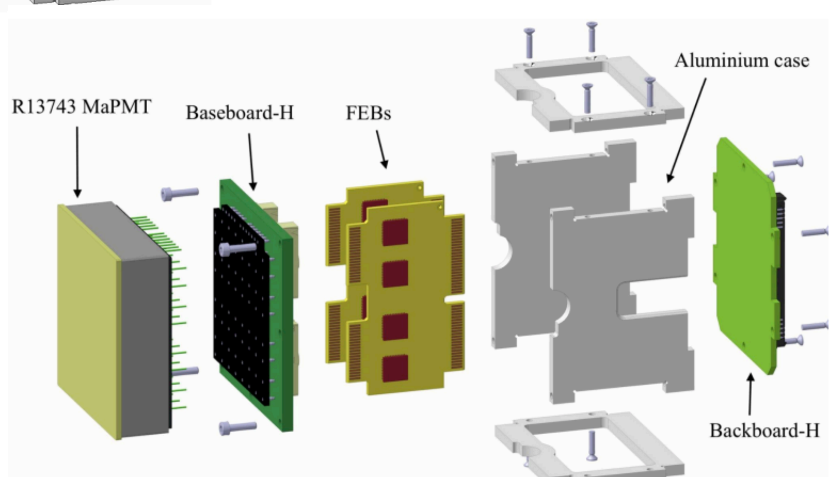
R13743 R13742

- ✓ New readout electronics (Claro ASIC designed to operate at 40 MHz developed by the RICH group)

Two types of elementary cell

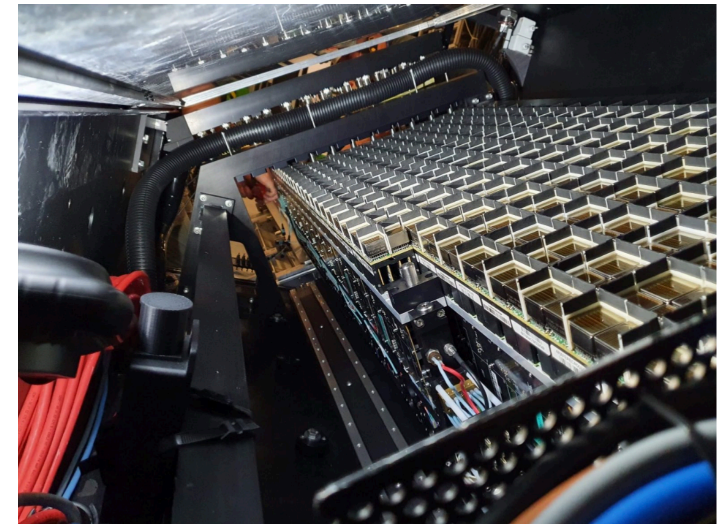


ECR
4 Hamamatsu R13742
4 FEBs with 8 Claro chips,
1 Backboard-R



ECH
1 Hamamatsu R13743
2 FEBs with 8 Claro chips,
1 Backboard-H

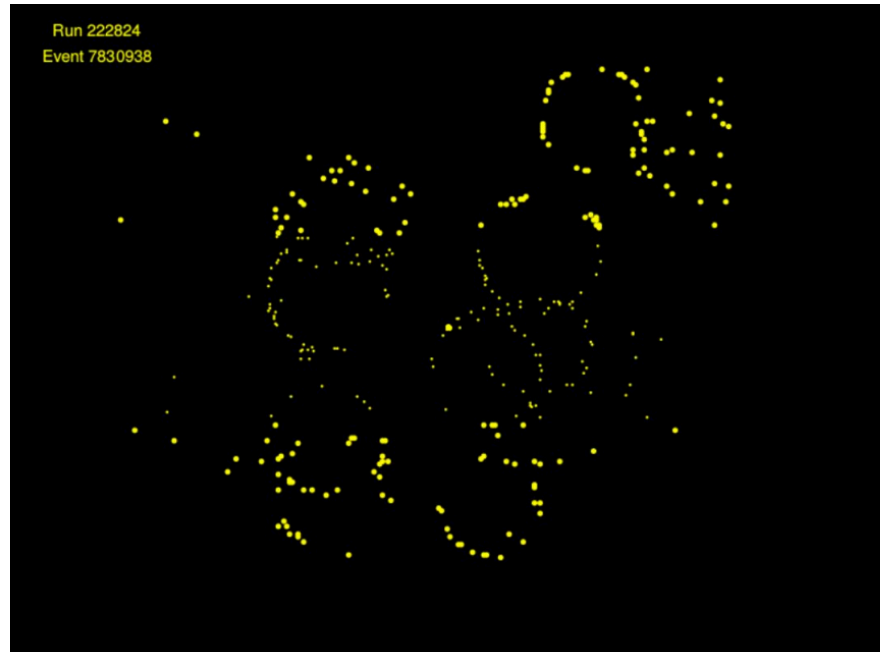
RICH1
1888 1-inch MaPMTs



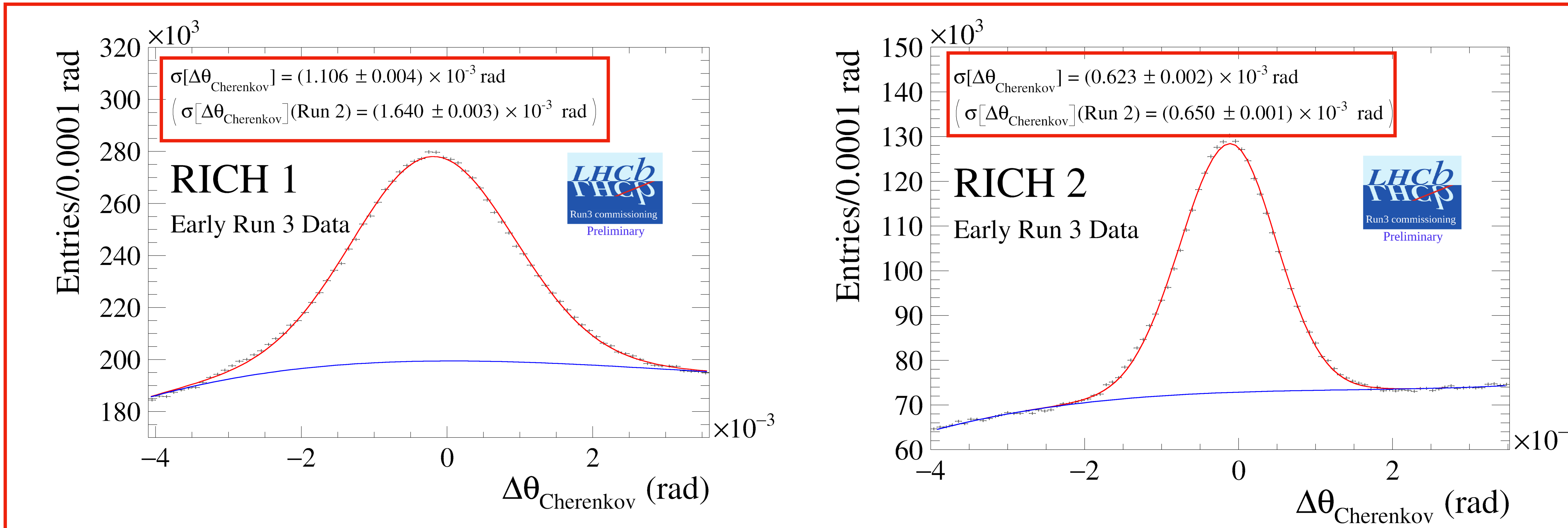
RICH2
768 1inch MaPMTs in the inner region 384 in the outer region

RICH performance

..first rings…

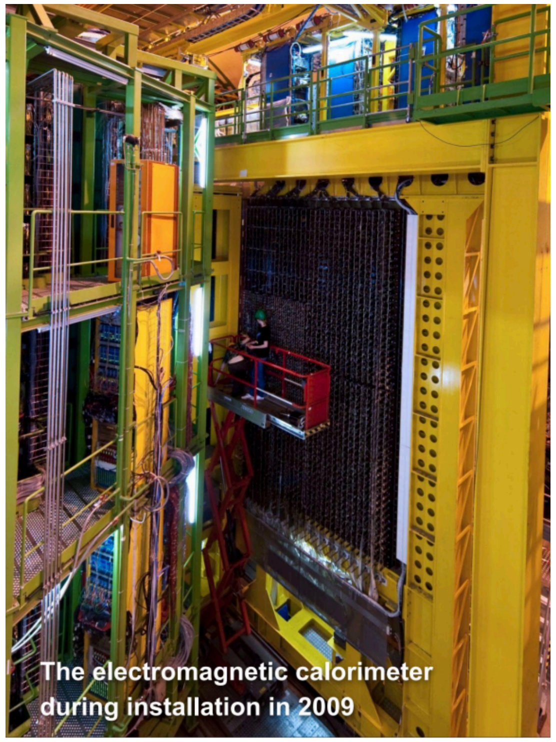


Cherenkov angle resolution LHCb-FIGURE-2023-007

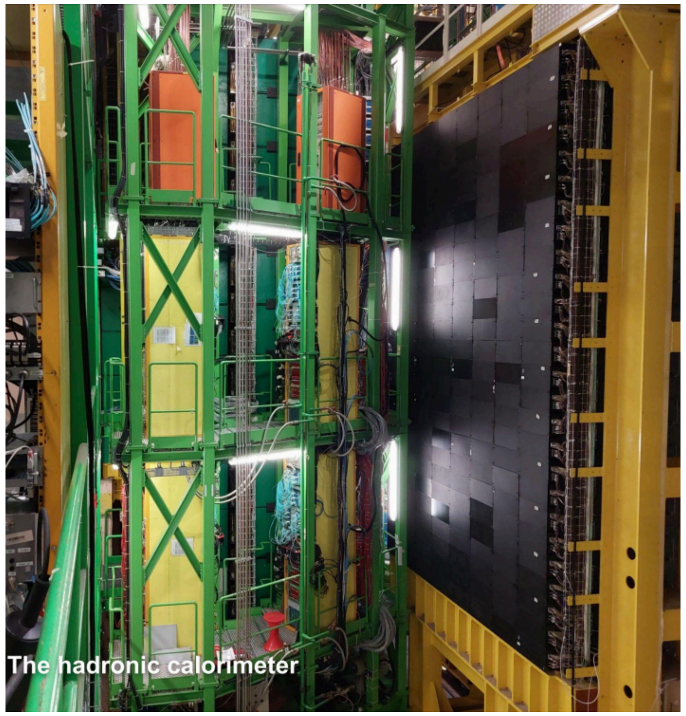


Better than Run2 for RICH 1 and 2!

ECAL



HCAL

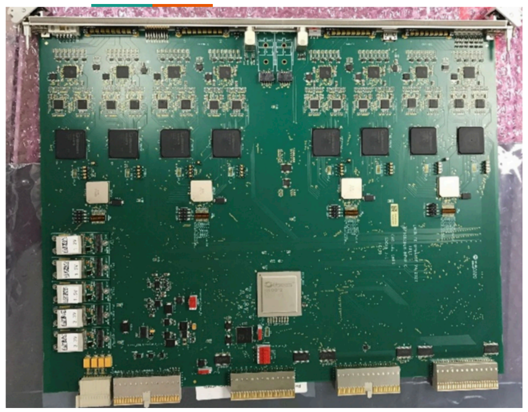


No modification to the active material during LS2: PMT gain lowered by a factor 5 to preserve lifetime of the detector

Calo Readout Upgrade

readout electronics of the electromagnetic and hadronic calorimeters have been entirely redesigned and replaced

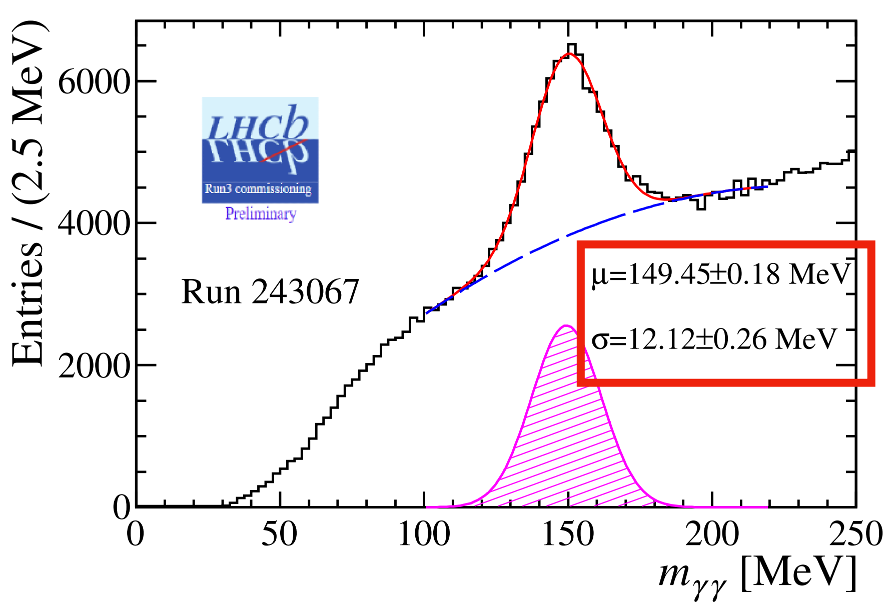
The calorimeter electronics is based on 246 FEBs, 192 for the ECAL and 54 for the HCAL

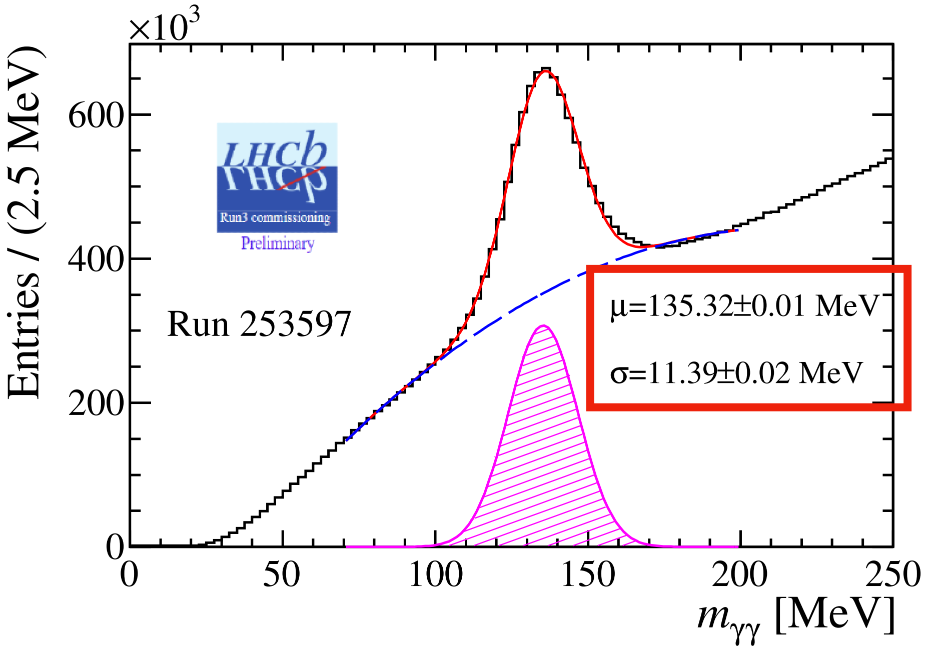


Calo performance

Improvement in the mass resolution around the π^0 mass after inter-cell calibration and alignment

LHCb-FIGURE-2022-019

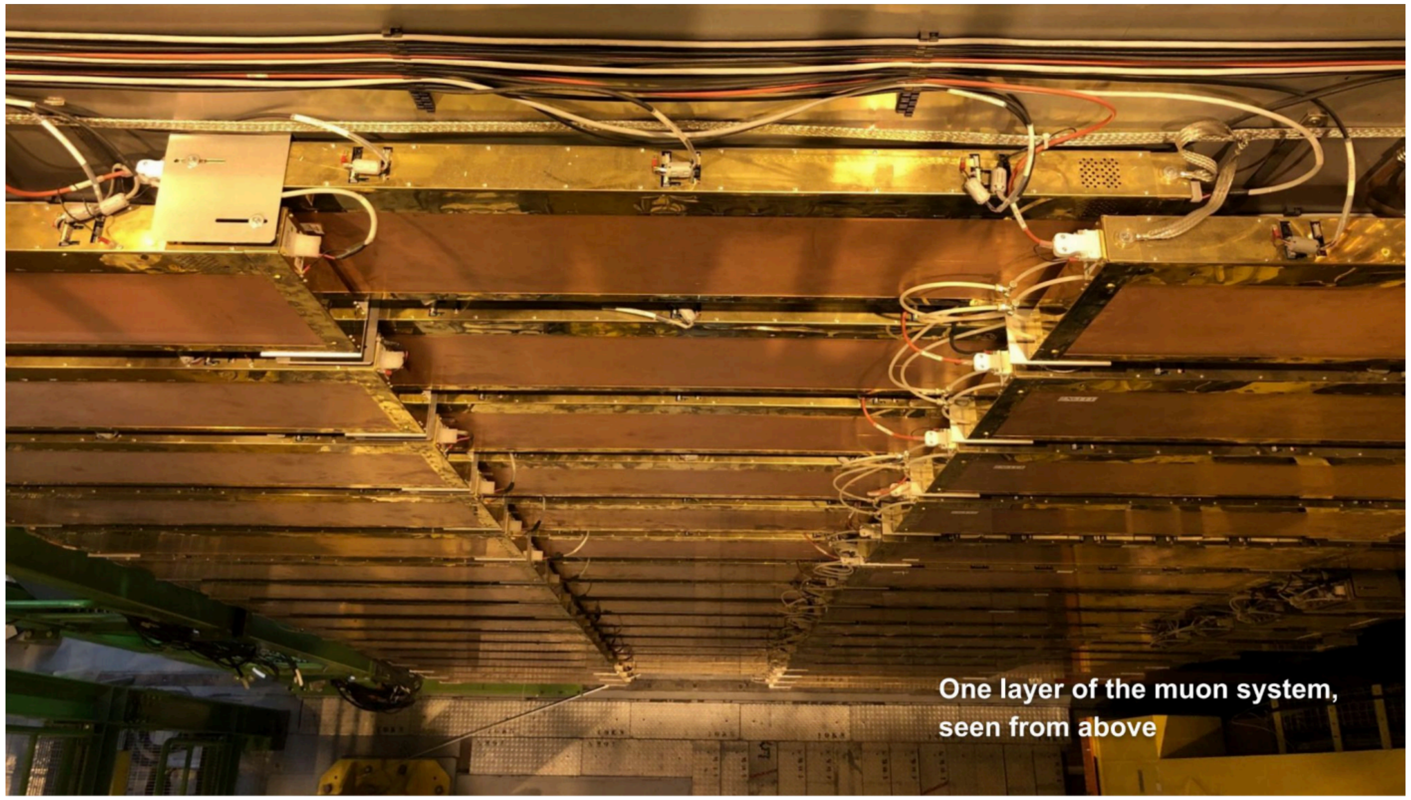




Muon System

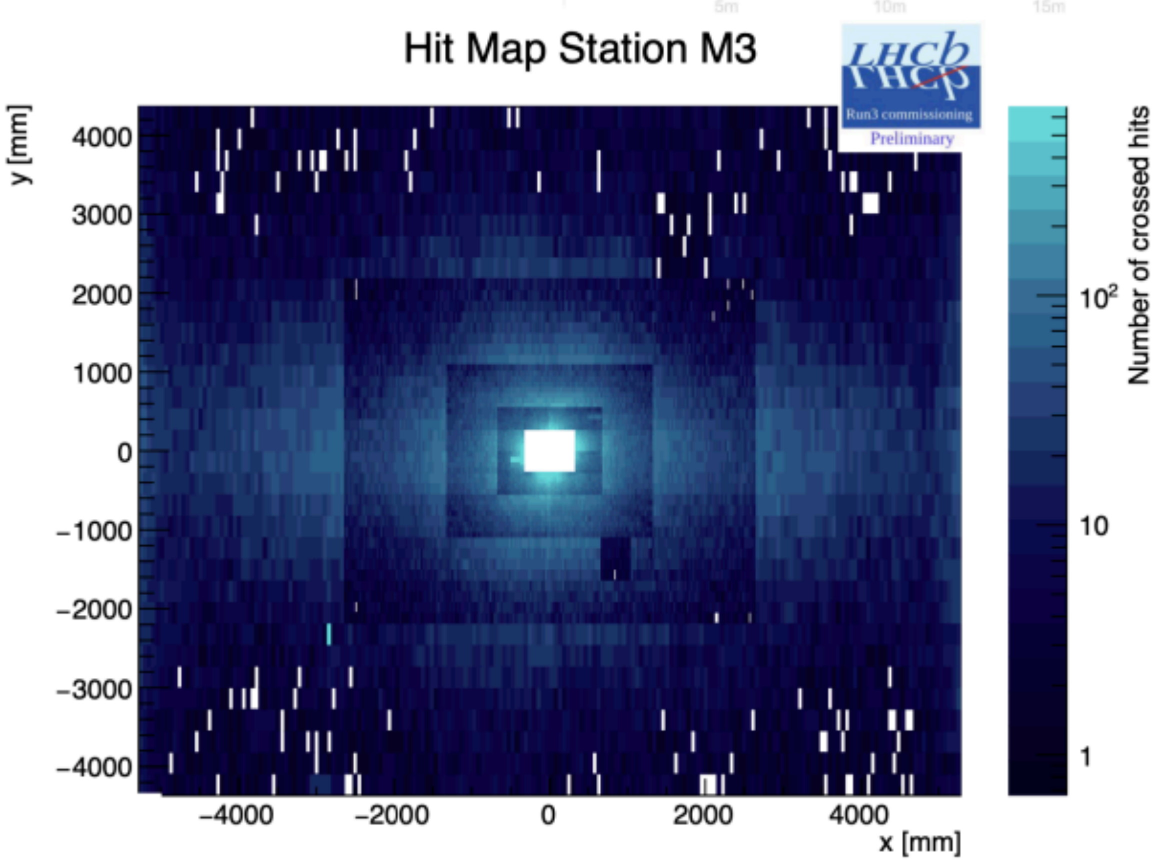
- M1 no longer needed without the L0 hardware trigger

➡Four stations M2 to M5, 1104 multi-wire proportional chambers (MWPC) for a total area of 385 m^2



New readout electronics

Signals are digitised by the front-end CARDIAC boards with:
two CERN and Rio current amplifiers (CARIOCAs) and a diagnostic, time adjustment and logics (DIALOG)

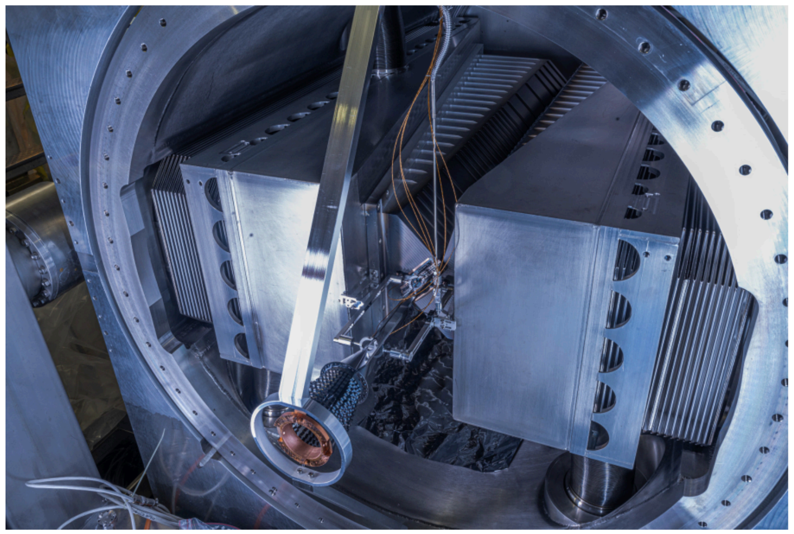


- Muon system part of the first level trigger
- Challenging time alignment that requires to match the information with the VELO and SciFi finalised

Smog2

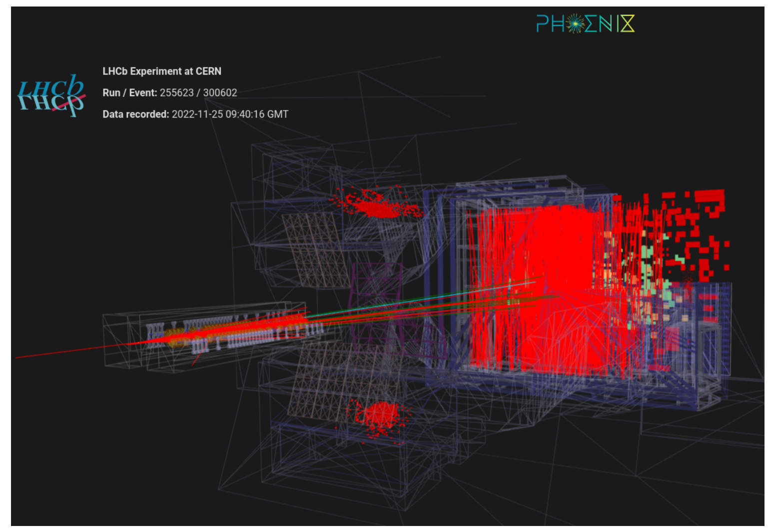
LHCb as a fixed target experiment with an internal gas target (H_2, Ne and Ar)

SMOG2 installed into the VELO vessel

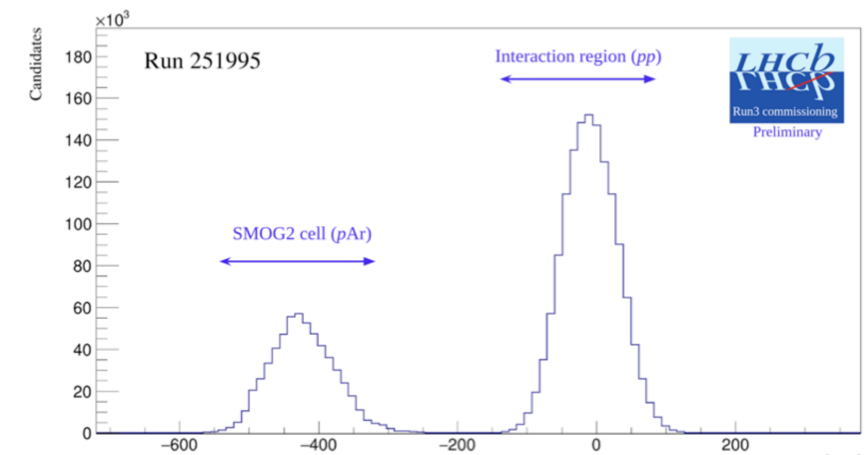


Event display of a p-Ar collision

LHCb-FIGURE-2023-001

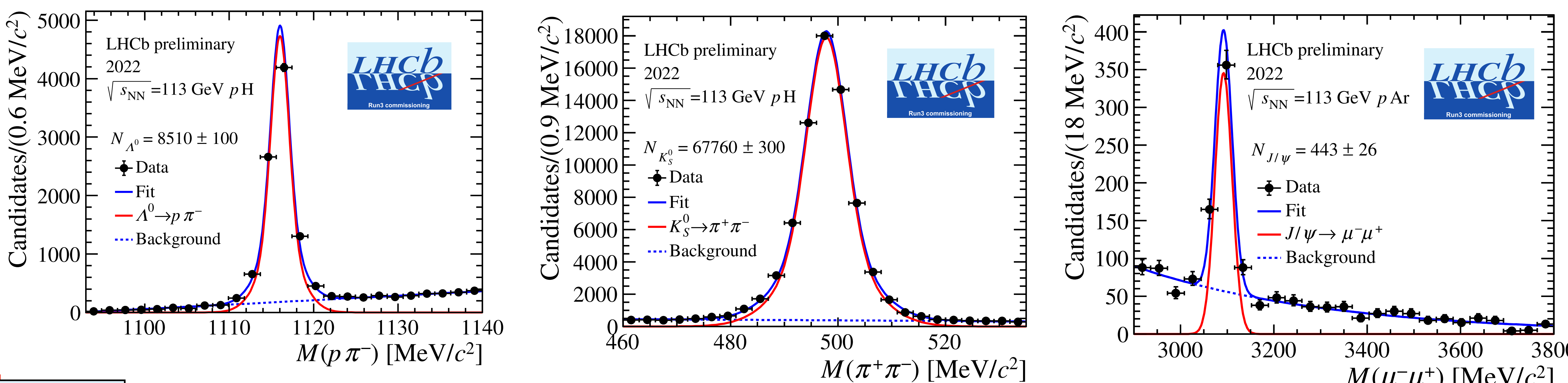


Data taking simultaneously with LHCb one!



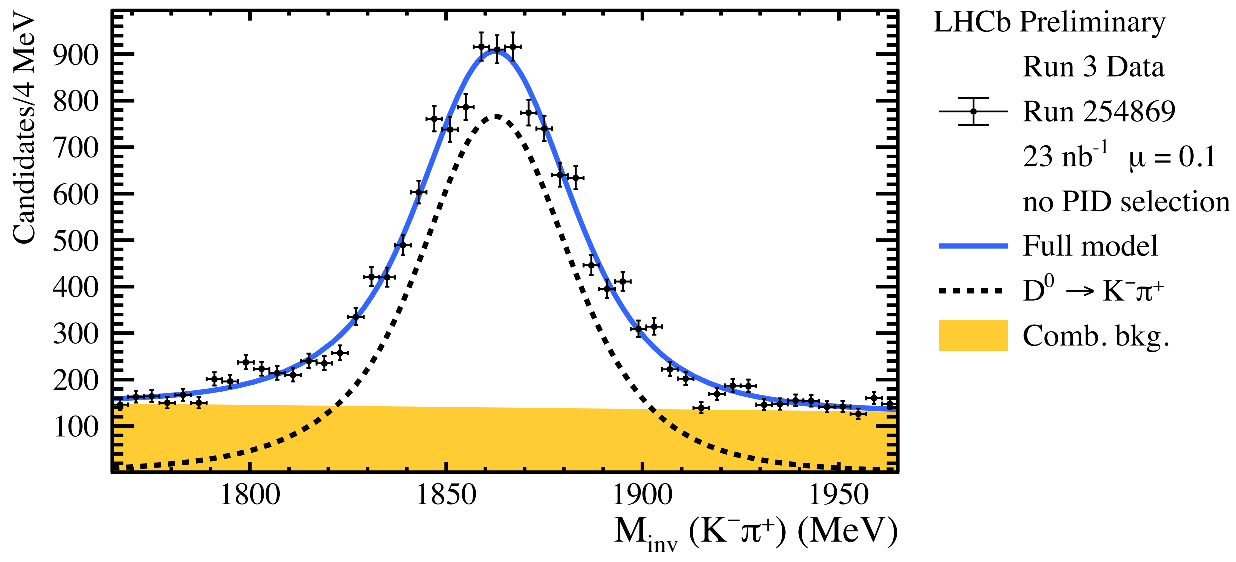
Smog2 performance

LHCb-FIGURE-2023-008

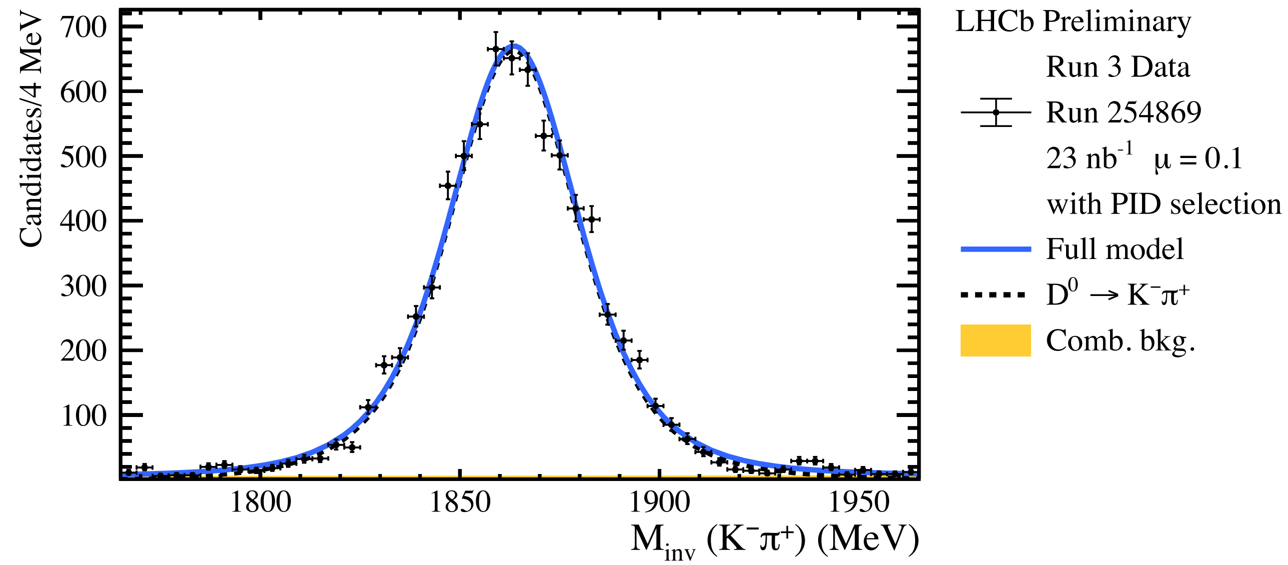


2022 early Data first mass peaks!

D^0 -> K π



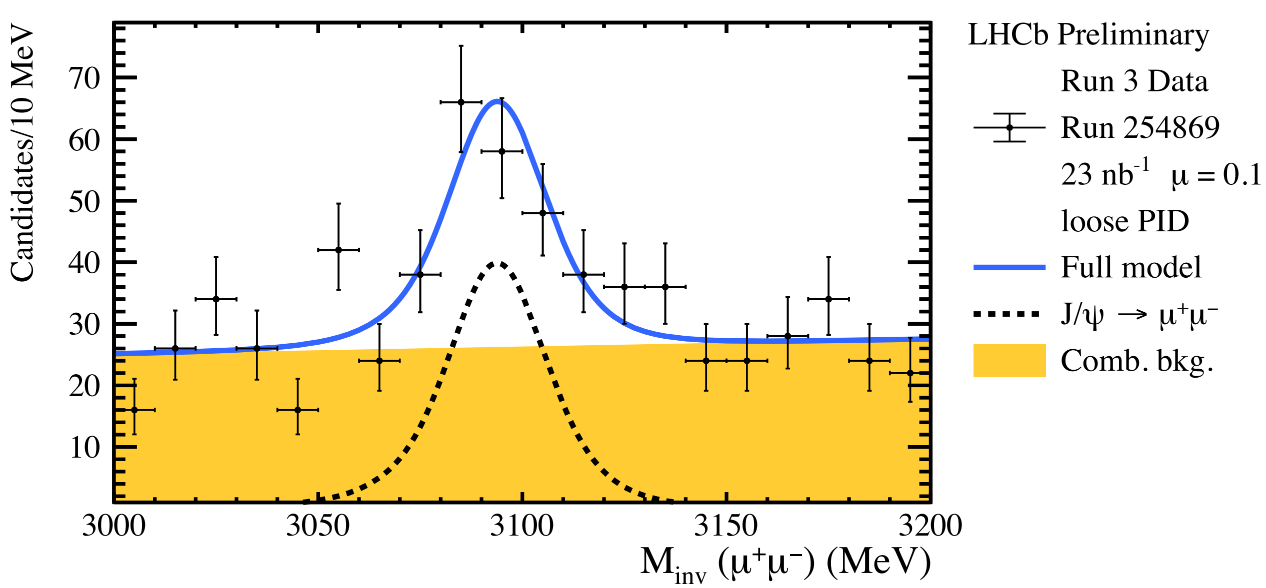
+PID selection



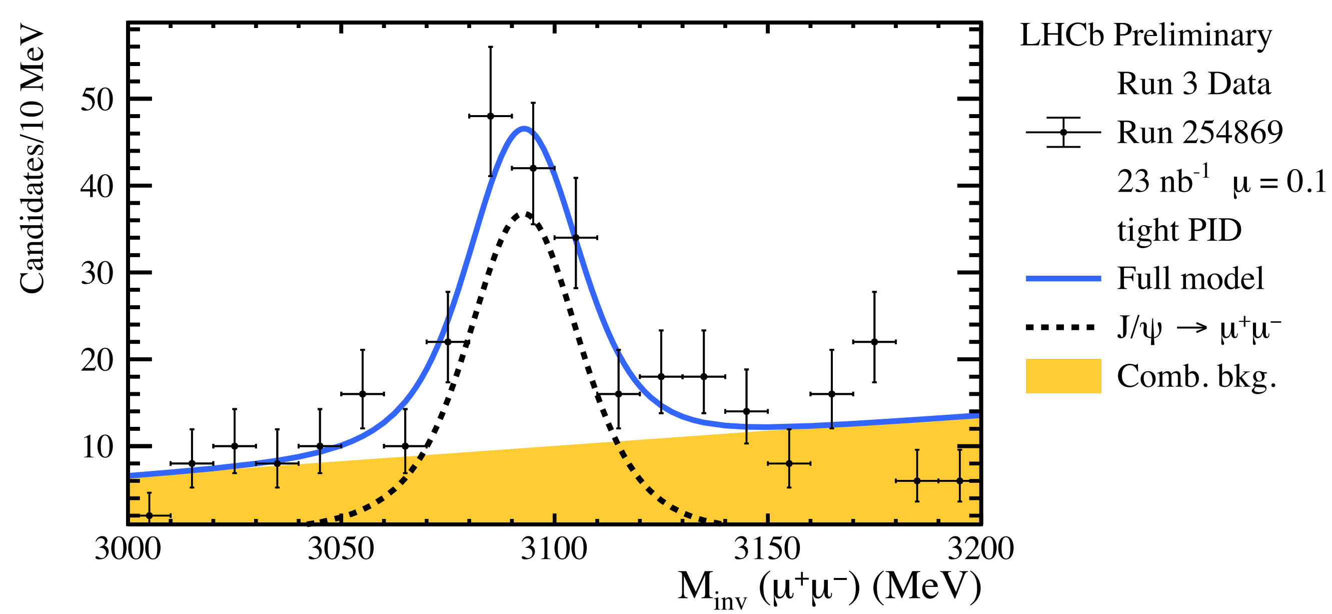
Plots produced with the first alignment, to show the PID early performance

NOT the ultimate Resolution!

J/Ψ -> μμ



+PID selection



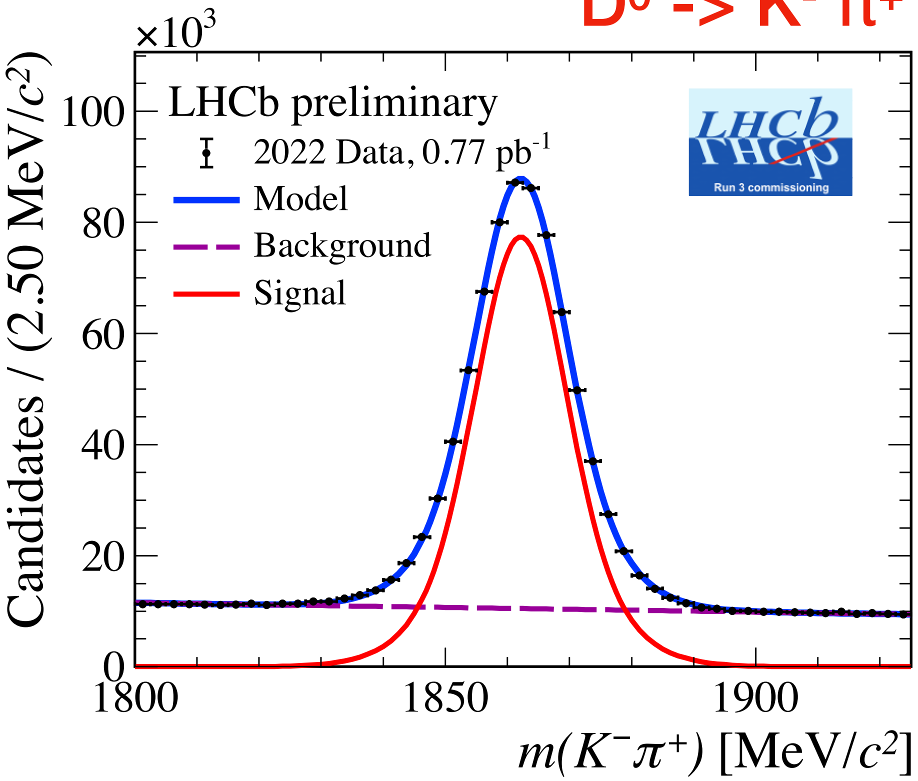
First mass plots

LHCb-FIGURE-2023-011

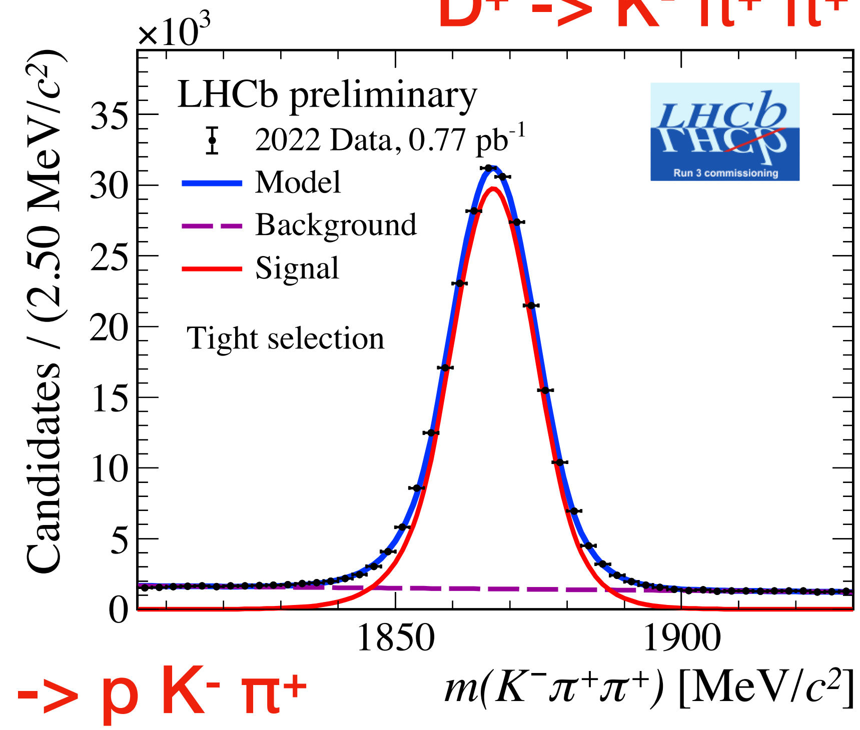
Plots produced using some of the HLT2 lines developed for early charm cross section studies, using the latest alignment

- ➡Mass resolution similar to MC expectations for Run3 (within 1 MeV)
- ➡Validation MC/Data ongoing

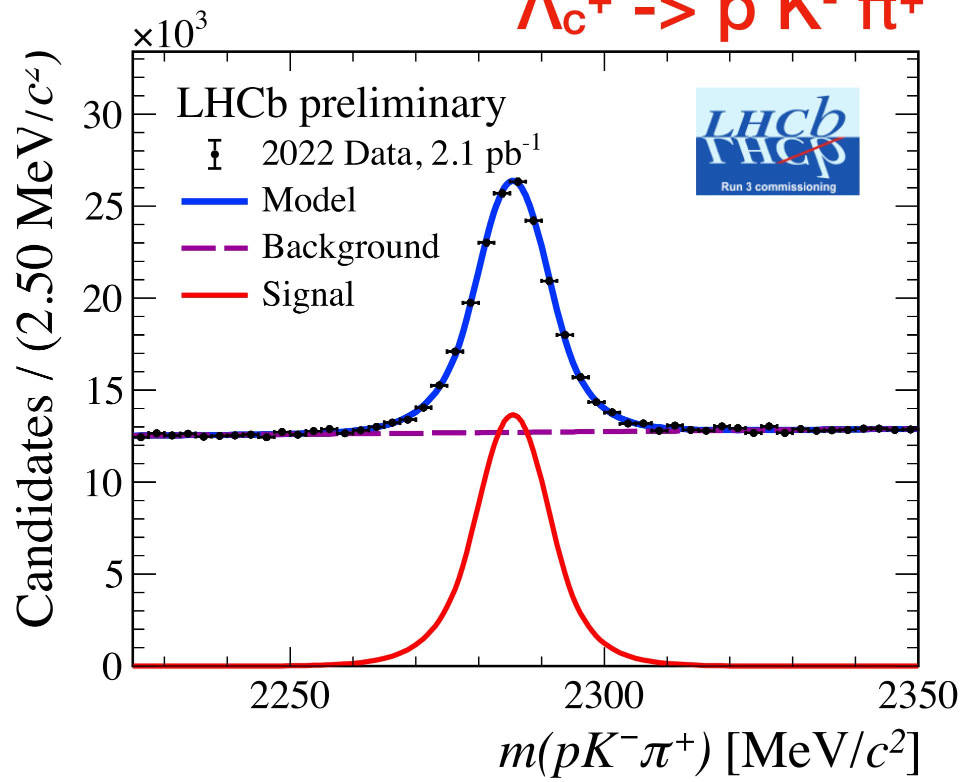
$D^0 \to K^- \pi^+$



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



$\Lambda_c^+ \to p K^- \pi^+$



Conclusions and plans

- Run3 data taken in 2022 helped to better understand the new detector behaviour
- Each subdetector showed good performance at Run3 luminosity, the double with respect to Run2
- An intense phase of commissioning helped to study in detail the alignment and calibration of each subdetector
- Early performance is promising, first mass plots produced!
- Velo will stay open in 2023, still opportunities to study different physics cases
- Commissioning of the full detector ongoing, to run at the best of the performance in 2024 and 2025

For more details on the LHCb upgrade: https://arxiv.org/pdf/2305.10515.pdf