PROCEEDINGS OF SCIENCE

The LHCb Upstream Tracker: operations and performance in Run3

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Abstract. The Upstream Tracker is a critical component of the tracking system in the LHCb Upgrade I detector. It has been commissioned and is now operational, collecting data during Run 3. The tracker enhances the reconstruction of charged particle tracks and long-lived particles, such as Λ and K_s^0, thereby improving the performance of the software trigger. This proceeding will cover experiences with detector operations and data acquisition, along with the performance results based on Run 3 data.

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1. The Upstream Tracker

The Upstream Tracker (UT) [2] is a new silicon strip subdetector in the LHCb experiment, playing a key role in the software trigger. Its main contribution is reducing the ghost rate, the rate of tracks that do not correspond to a real particle passing through the detector, by a factor of two. Its presence in the LHCb reconstruction algorithm enhances the momentum resolution of reconstructed charged particles by combining its hits with tracks reconstructed in the VELO. Moreover, the UT is crucial for the reconstruction of particles that decay outside the VELO, such as long-lived particles.

The UT consists of four layers, each divided into two halves, known as A-side and C-side, which close around the beampipe. Silicon sensors are mounted on carbon fiber structures called staves, each measuring 99.5 mm × 1640 mm. In the first and last layers, the staves (and therefore the strips) are vertically aligned, while in the central layers, they are tilted by ±5° to enhance resolution in the vertical direction. Each stave hosts modules on both sides, alternating between the modules and the readout electronics. The stereo layers contain 16 staves each, whereas the other layers have 18 staves. The staves are enclosed in a box to maintain thermal insulation and protect them from light and air. The box is equipped with a CO_2 cooling system that cools the electronics via an S-shaped titanium pipe integrated into the staves. To avoid condensation while cooling, the UT box is filled with nitrogen.

A UT module is composed of a silicon sensor, supported on a boron nitride ceramic stiffener, itself glued to a hybrid flex circuit which hosts the readout Application-Specific Integrated Circuits (ASICs) [3]. Each hybrid hosts four ASICs. There are four types of silicon microstrip sensors, designed according to their position in the layer to manage different occupancies. Type A sensors, used in the detector's outer region, employ p-in-n technology and have 512 strips with a pitch of 187.5 μm; The other sensor types use n-in-p technology, positioned around the beam pipe, and feature 1024 strips with a pitch of 93.5 μm. Type C and D sensors are half the length of the others, with type D featuring a circular cut-out to fit around the beam pipe.

The front-end ASIC, known as the Silicon ASIC for LHCb Tracking (SALT), is a CMOS 130 nm technology chip with 128 channels per ASIC. SALT integrates an analog processor with a low-power (less than 1 mW/channel), high-speed (40 MSps) 6-bit ADC per channel. It includes a digital signal processor (DSP) for pedestal subtraction, mean common mode subtraction, and zero suppression. Data formatting and serialization are handled by separate blocks. The ASIC is controlled through two interfaces: the Timing and Fast Control (TFC) system, which supplies the 40 MHz clock and other experiment-synchronized commands, and the Experiment Control System (ECS), which configures and monitors the ASIC via an I2C interface.

2. UT data taking and DAQ performances

The UT installation in the LHCb cavern was successfully completed in March 2023, marking the beginning of the data acquisition for the year. Subsequently, the UT underwent a commissioning phase to ensure its readiness for meaningful data collection. At the end of 2023 UT was included in the LHCb Global data taking during the run (Pb-Pb collisions) and in summer 2024 it was included in both stages of the High Level Trigger (HLT1 & HTL2). Stable data taking was achieved, even at the highest collision rates. This was possible thanks to several firmware adjustments and tuning

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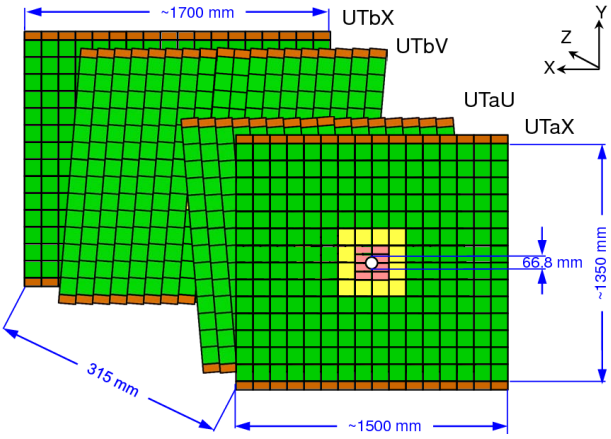

Figure 1: Layout of the LHCb Upstream Tracker for Run 3 [1].

of FE parameters. An even higher overall efficiency ($\sim$ 99%) can be obtained with looser ADC thresholds. Nevertheless, this specific setting represents a challenge for data acquisition at high instantaneous luminosity. The data taking in 2024 was concluded with a very low rate of DAQ errors both during the pp reference run of October 2024 and also during Pb-Pb collisions.

3. UT contribution to the High Level Trigger (HLT)

The Upstream Tracker is part of the LHCb Experiment's tracking system.The entire tracking system was replaced during LS2 and it is composed by the Vertex Locator (VELO), the Upstream Tracker (UT) and the Scintillating Fiber Tracker (SciFi). In the LHCb tracking system, reconstructed tracks are classified based on their hits in tracking detectors:

- Upstream track: tracks with hits in VELO and UT;
- Long track: tracks with hits in VELO and SciFi, optionally UT;
- Downstream track: tracks with hits in the UT and SciFi only.

A new algorithm, called "Downstream", has been developed at LHCb to reconstruct and select Long-lived particles (LLPs) in real time at the first level of the trigger (HLT1). LLPs are present in the SM and in many new physics scenarios beyond it but they are very challenging to reconstruct at LHC due to their very displaced vertices. Downstream tracking will not be possible without the presence of UT in HLT1. The LHCb experiment has been running with this algorithm included in the first level trigger since October 2024. Before this improvement, the main reconstruction sequences in HLT1 were forward tracking (referred to as "Forward") and VELO-SciFi matching with UT (referred to as "Matching"), both of which are used to reconstruct Long tracks, as most of the trigger decisions in HLT1 are based on Long tracks. This algorithm has an impact on the total HLT1 throughput, or the number of events per second that it can process, reducing it by approximately 9% to a value of 67.50 KHz per GPU. This was calculated by demonstrating its effectiveness across distinct sequences on a RTA A5000 card using 22 simulated MinBias sample, unbiased sample of all inelastic proton-proton interactions, with nominal Run3 conditions, Fig.3.

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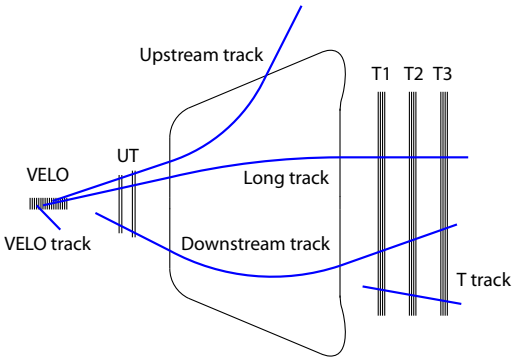

Figure 2: Pictorial view of the track types in the LHCb upgrade tracking system [5].

This algorithm also increase the rejection factor of ghost tracks, that are defined as reconstructed tracks which are fake/random combination of hits. The performance of the algorithm is evaluated by checking the mass distribution of the main decays occurring outside the VELO. The most typical decays in such cases are $\Lambda \rightarrow p\pi^-$ and $K_s^0 \rightarrow \pi^+\pi^-$. Fig.4 shows the mass peak for K_s^0 from one of the data run corresponding to an integrated luminosity of $7.07 pb^{-1}$. The figure shows the mass distribution obtained with HLT1 Downstream tracking.

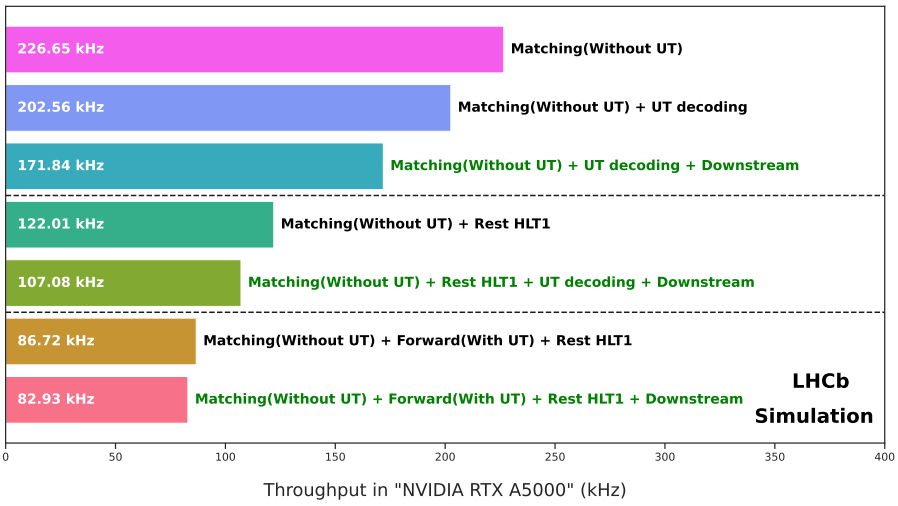

Figure 3: Throughput of the Allen sequence including the Downstream algorithm, executed on a RTA A5000 card using simulated MinBias sample with nominal Run3 conditions.[4].

The reconstruction of long tracks, traversing all tracking subdetectors, is critical for LHCb as many trigger selections rely on them. It exploits the presence of the magnetic field between the UT and the SciFi to provide a percent-level momentum estimate for the reconstructed particles. At HLT1 level, VeloUT tracks are extrapolated upstream of the magnet to the SciFi to form long

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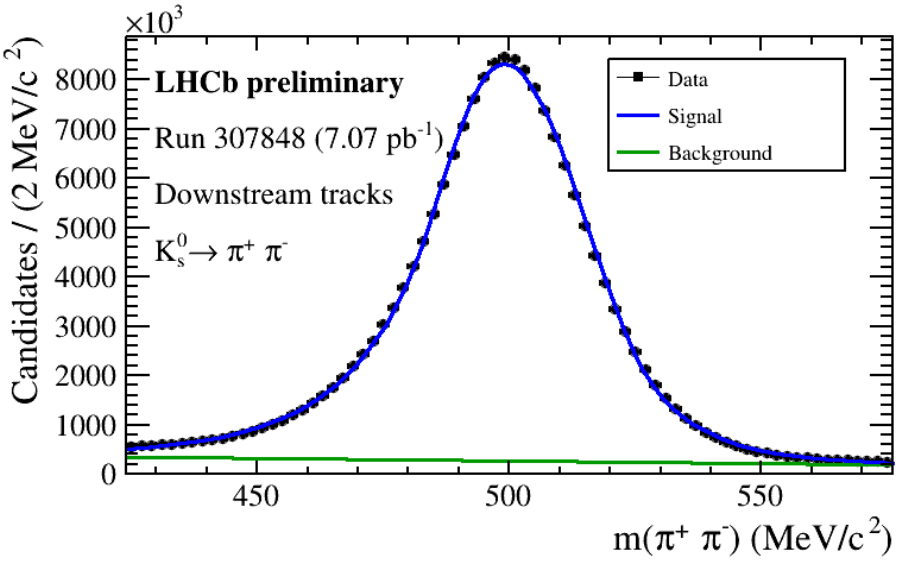

Figure 4: HLT1 Downstream K_s^0 decays from run 307848, corresponding to an integrated luminosity of $7.07 pb^{-1}$, with a mass resolution of approximately 15 MeV/c^2. [5].

tracks. The inclusion of UT in HLT1 and HLT2 has improved the physics performance of the LHCb experiment by improving the momentum resolution of Long tracks. In Fig.5 the mass resolution of the different charm-meson decay is shown for the case of reconstruction using HLT1 + HLT2 with and without UT.

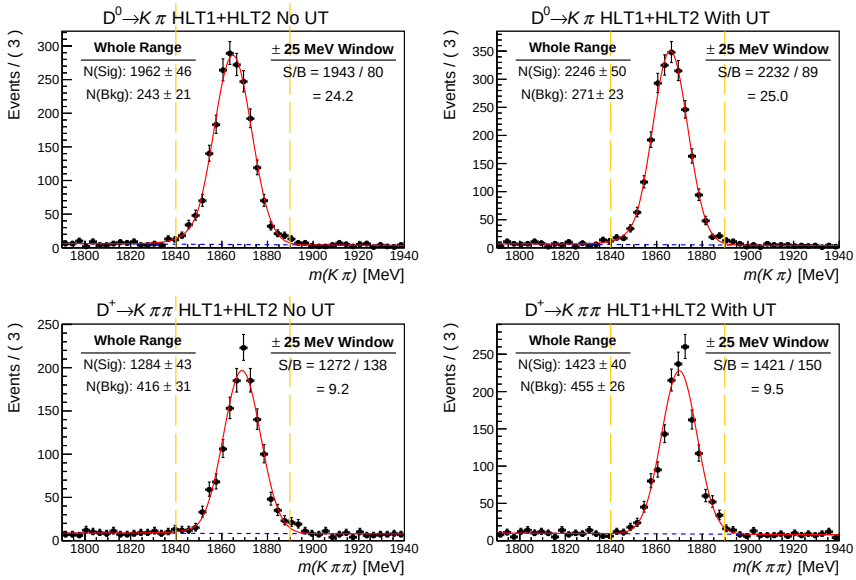

Figure 5: Mass distributions for D^0 and D^+ mesons with HLT1+HLT2 reconstruction with and without UT contribution [5].

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4. Conclusions

The Upstream Tracker forms part of the tracking system of the LHCb Experiment. It has been successfully installed and commissioned. Stability in data acquisition has been achieved through adjustments to the electronics and mechanical interventions. The importance of the UT detector in the LHCb experiment can be summarized in the following contributions: it improves the Ghost rate reduction of a factor 2, that is essential for the software trigger, it contributes to the reconstruction of long lived particles decaying after the velo such as Λ and K_s^0, and it is fundamental to improve the momentum resolution of Long tracks.

Acknowledgments

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