PROCEEDINGS OF SCIENCE

SciFi optimization during commissioning

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The Scintillating Fibre Tracker (SciFi) is a new detector after the magnet at LHCb, which was installed in last year and has been being under commissioning using LHC 2022 and 2023 early collision data. This detector was built from scintillating fibres with a diameter of 250 μm. Scintillation light from fibres is recorded with arrays of state-of-the-art multi-channel silicon photomultipliers (SiPMs). A custom ASIC (PACIFIC) is used to digitize the SiPM signals. Subsequent digital electronics performs clustering and data-compression before the data is sent via optical links to the off-detector DAQ system. The front-end electronics (FEE) internal clock is adjusted in order to achieve low transmission error rates of the data transmission before commissioning with beam. Then SciFi FEE time phase is calibrated with respect to beam interactions to capture detector signals with the correct phase and in the correct bunch cycle. The master clock and control phase are scanned with a granularity around 0.78 ns to obtain the beam scan samples, and the baseline time (t_0) per data link is defined using these samples. A time offset is applied to t_0 for best efficiency, which is determined using SciFi simulation, given that particle arrival times for each data link from proton-proton collisions are different. Moreover, the t_0 has been monitored over a long time scale, which shows a good time stability of SciFi electronics. The detector position is measured and monitored by a camera system, which offers the first measurement of the detector position coming from the survey data. The most precise alignment information is obtained with a software algorithm that uses charged particle trajectories. Positions of each half-layer, module and fibre mat are parametrized by three translations and three rotations and these alignment parameters play an important role in the track reconstruction. In addition, the detector position resolution in track reconstruction is improved significantly due to alignment.

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1. Introduction

The LHCb experiment has undergone a major upgrade between 2019 and 2023, which can improve significantly the experiment sensitivity in the flavour physics sector and will extend the LHCb physics programme [1, 2]. The previous LHCb main tracking system, composed of an inner and outer tracking detector, cannot cope with the increased particle multiplicities and has been replaced by a single homogeneous detector based on scintillating fibres (see Fig. 1).

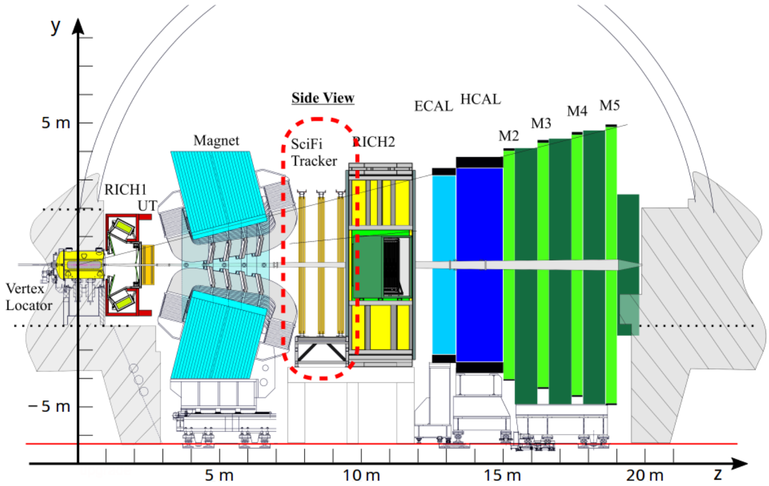

Figure 1: Side view of the LHCb upgrade detector. The Scintillating Fibre Tracker has been installed in the tracking stations located downstream of the LHCb dipole magnet (highlighted in red).

The new Scintillating Fibre (SciFi) tracker consists of three stations each with four detection planes. The detector is built from individual modules (0.5 m × 4.8 m), each comprising 8 fibre mats with a length of 2.4 m as active detector material. The fibre mats consist of 6 layers of densely packed blue-emitting scintillating fibres with a diameter of 250 μm. The scintillation light is recorded with arrays of state-of-the-art multi-channel silicon photomultipliers (SiPMs). A custom ASIC is used to digitize the SiPM signals. Subsequent digital electronics performs clustering and data-compression before the data is sent via optical links to the DAQ system. To reduce the thermal noise of the SiPM, in particular after being exposed to a neutron fluence of up to 10^{12} neq/cm^2, expected for the lifetime of the detector, the SiPM arrays are mounted in so called cold-boxes and cooled down by a cooling liquid running through 3D-printed titanium cold-bars to -40 °C. The detector is designed to provide low material budget (1% per layer), hit efficiency of 99% and a resolution better than 100 μm. The SciFi tracker has been under beam commissioning since July 2022. This proceeding will describe the optimisations during SciFi commissioning.

2. Fine time alignment

The purpose of SciFi fine time alignment during commissioning is to optimize the hit efficiency for LHCb track reconstruction. However, we cannot infer the delay time of best efficiency from cluster number directly because around 23 of the clusters seen in SciFi come from secondary interactions with the material before SciFi. Monte Carlo simulations demonstrate that most of the hits originate from secondary charged particles. Fig. 2 shows the fraction of hits that originate from a particle created at a given z coordinate. The hits from tracks that originate from the genuine pp interaction or a subsequent particle decay are predominantly located close to the interaction region. The remaining hits originate from charged particles created in secondary interactions, mainly in the support of the beam pipe situated in the magnet or in the detectors located upstream of the SciFi detector layer (Vertex Locator, Ring Imaging Detector, Upstream Tracker (UT) and SciFi).

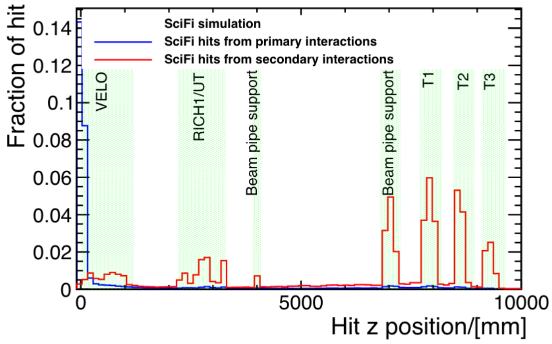

Figure 2: Coordinate of the origin of charged particles that produce a hit in the SciFi detector. The blue histogram peaks at z = 0 and corresponds to hits from particles produced at the pp interaction point and their daughters, while the hits from particles produced in secondary interactions (red) predominantly originate from $z > 0$.

For the synchronisation between the front end signal integration window and the LHC beam collision, adjustable clocks are available at the SciFi front end electronics, which allow us to adjust timing at per datalink level. An essential feature in the LHCb data acquisition system is the possibility to record the signals from consecutive bunch crossings up to several clock cycles around the trigger signal. Such working mode provides the so-called Time Alignment Events (TAE). As an example, the cluster occupancy versus time delay for datalink T1L0Q0M0H0D0 from run 263357 is shown in the top of Fig. 3. The baseline time (t_0) per data link is defined for the time alignment. We can define a figure of merit which we call the asymmetry for two consecutive bunch crossings and for a given datalink, the asymmetry is set to be :

$$Asy = \frac{Occupancy(CurrentWindow) - Occupancy(NextWindow)}{Occupancy(CurrentWindow) + Occupancy(NextWindow)} \tag{1}$$

t_0 is then defined such that beginning the integration at that time gives $Asy(t_0) = 0$. The shape of the asymmetry is presented in the bottom of Fig. 3. The offset times (t_{offset}) are optimized in each HalfRob for a high and stable hit efficiency from simulation. Fig. 4 shows the corresponding hit efficiencies with different delayed times in `T1L0Q0M0H1`. We expect the hit efficiency to be larger than 98% at the working point, the blue horizontal line with efficiency equal to 98% is drawn in these plots. We can see a clear efficiency plateau along scanning times. The median of the plateau, t_M, is defined. t_{offset} is the time difference between t_0 and t_M. Once we know the optimal offset time (t_{off}) for each datalink, we can load the delay time ($t_{delay} = t_0 + t_{offset}$) to the SciFi electronics to achieve the optimal efficiency.

The left plot of Fig.5 shows the variation of t_0 and the LHCb clock as a function of the run number, for the data taking period from around the end of April to around the beginning of June

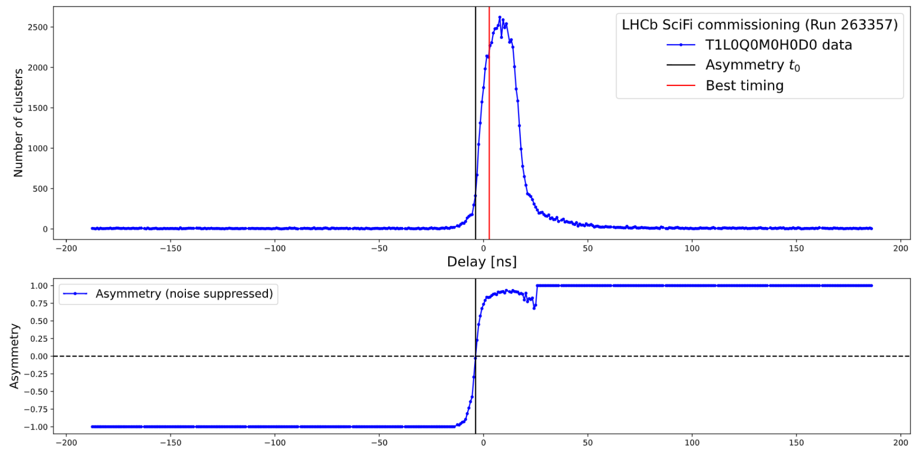

Figure 3: The top plot shows the cluster occupancy over delay time in T1L0Q0M0H0D0 within ±7 TAE windows. Asymmetries for T1L0Q0M0H0D0 as a function of delay time is presented in the plot below. The solid black line represents the baseline time (t_0 at that time gives $Asy(t_0) = 0$.) The red line stands for the best delay time determined.

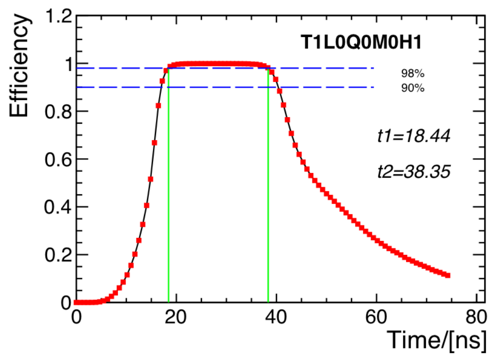

Figure 4: Hit efficiency variation of different delayed times in `T1L0Q0M0H1`, the blue dash lines represent efficiencies and green lines are corresponding to t_1 and t_2.

in 2023. The global LHCb clock is adjusted if it changes by more than 0.5 ns after Run 263357. As a result, the average value of the drift-time residual stays within the range of 0.5 ns. The right plot of Fig. 5 shows the difference of the t_0 values per data link among 4 different calibration runs which were taken within a relatively short time period. These runs were taken in April 2023. The spread of the distributions show the statistical effect. In the dataset shown in this plot, most of the datalinks showed t_0 deviation smaller than 0.25 ns.

3. Position alignment

To reach the best possible physics performance for LHCb in Run 3, alignment and calibration of the tracking detectors are crucial[5]. A preliminary alignment of the VELO detector is performed using VELO tracks reconstructed from this dataset, and a preliminary alignment of the SciFi is then performed using the preliminary VELO alignment and VELO plus SciFi tracks from the sample. In

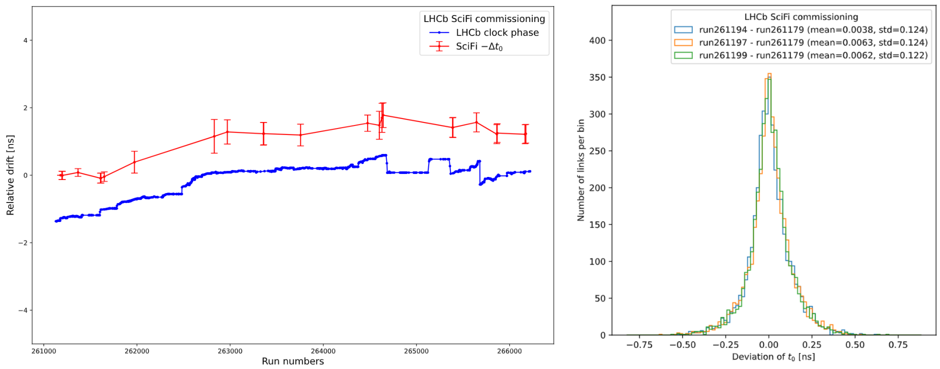

Figure 5: The left plot shows t_0 stability, which is checked versus run number which are taken between around the end of April and around the beginning of June 2023 (red). The corresponding global LHCb clock shifts over time is also shown (blue). The right plot shows the deviations of t_0 across different data links when comparing 4 different calibration runs which were taken within a relatively short time period. The spread of the distribution show the statistical effect.

the first, ‘Velo + SciFi survey’, the description of the detector geometry in simulation is corrected using measurements of the VELO module and sensor positions, and the SciFi module positions. In the second, ‘Velo align + SciFi survey’, the alignment procedure is performed for the VELO detector using VELO seed tacks. Finally, the updated aligned VELO positions are used in the reconstruction of long tracks, and the SciFi is aligned using its survey position as a starting point (‘Velo+SciFi align’). A significant improvement in tracking performance is observed relative to the survey. The track χ^2 per degree of freedom for long tracks in each of these three scenarios is shown in Figure 6. In particular, we can observe that the number and quality of reconstructed long tracks improves when the VELO and SciFi are both aligned.

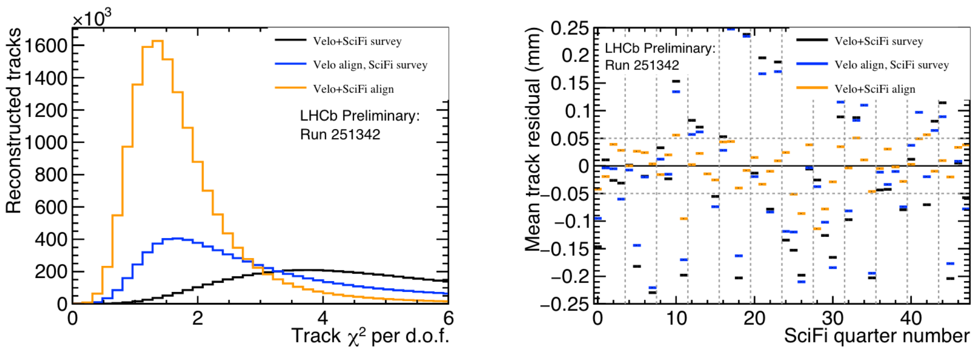

Figure 6: Left: Distribution of χ^2 per degree of freedom for long tracks using survey measurement position for VELO and SciFi (black), using tracking alignment corrections for VELO and survey for SciFi (blue), or using tracking alignment corrections for both VELO and SciFi (orange). Right: Mean tracking residuals in each SciFi quarter.

A new alignment per SciFi mat is proposed this year to further improve the track quality. In this scenario, we consider the translation degrees of freedom (T_x and T_z) for the mats to align them in each SciFi module, given that the track quality cannot be significantly improved by adding the degree of freedom T_z in module alignment. With the additional T_x and T_z per mat alignment, the track χ^2 per degree of freedom for long tracks in each of these two scenarios is shown in Fig. 7, 'SciFi Module + Mat alignment'. In particular, we can observe that the number and quality of reconstructed long tracks improved when SciFi mats are aligned. The observed performance is not final and is expected to continue to improve as the detector and alignment procedure are commissioned.

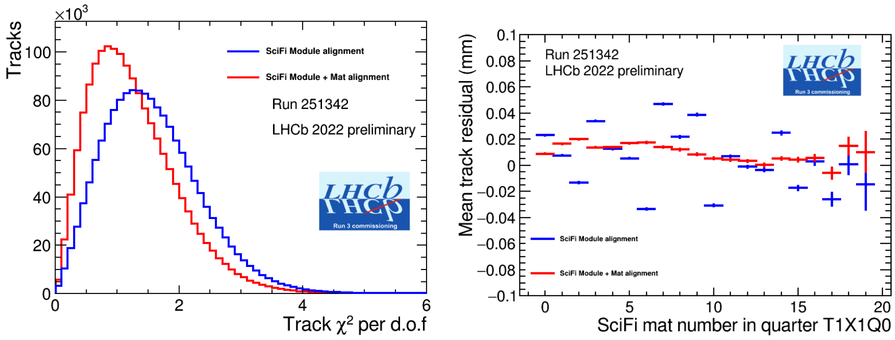

Figure 7: Left: Distribution of χ^2 per degree of freedom for long tracks using tracking alignment per SciFi module (blue), or using tracking alignment corrections for both SciFi module and mat (red). Right: Mean tracking residuals in one SciFi quarter.

4. Conclusions and prospects

The SciFi tracker at LHCb has been under beam commissioning since 2022. Fine time alignment has been performed to optimize the hit detection efficiency for long tracks. Besides, the regular TAE samples during commissioning show good SciFi internal time stability. In addition, SciFi geometrical element position is aligned per module and per mat in reconstruction, which can significantly improve the hit resolution. Further optimization of both hardware and software is underway. We can expect to publish SciFi performance results next year.

References

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