LHCb note 2007-019

Combined Long Tracking Performance

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Abstract

The performance of the track reconstruction for 'Long Tracks' in DC' 06 is presented in detail. An event weighted efficiency of 89.4 % is found for a ghost rate of 16.7 %.

1 Introduction

In this note the performance of the tracking system at the time of DC '06 [1] is described. The layout of the LHCb detector is shown in Fig. 1. The tracking system consists of the Vertex Locator (VELO) [2], the Trigger Tracker (TT) [3] and three stations placed downstream of the magnet (T1-T3). Each of the T stations is further divided into an inner and outer part. The inner part makes use of Silicon micro-strips [4] whilst the outer part is constructed using straw-tubes [5]. The angular coverage of the system is 15 – 300 mrad which corresponds to a range in pseudorapidity, η of 1.9 to 4.9.

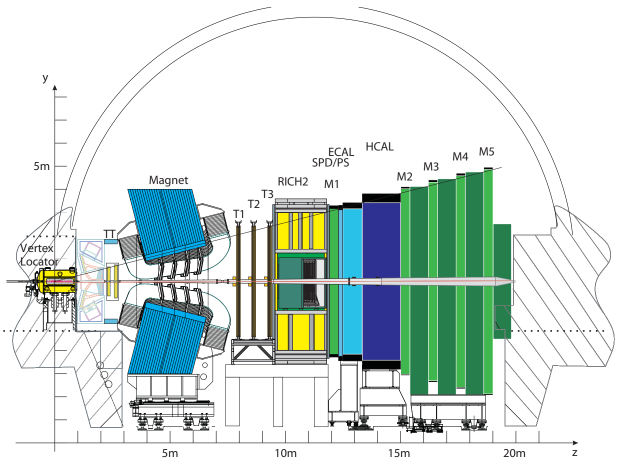

Figure 1: Side-view of the LHCb detector.

The studies presented in this note are focused on the performance for tracks that traverse the entire spectrometer. These so called 'Long Tracks' are measured with the highest precision and are the most important sub-set for the reconstruction of B mesons. The reconstruction of Long Tracks proceeds as follows:

VELO Tracking: A standalone search is made for straight line track segments in the VELO [6].

Forward Tracking: Continuations of the VELO tracks are searched for in the T stations using an optical method [7, 8].

Fit: The forward tracks are fitted using a Kalman filter algorithm which properly takes account of multiple scattering and energy loss within the detector [9].

Seeding: A standalone search is made for track segments in the T stations [10].

Matching: The track segments found in the T stations are extrapolated upstream to the VELO. The predicted track positions are compared to those of the VELO track segments and a χ^2 criterion is used to select good matches [11].

Fit: The matched tracks are fitted using the Kalman filter.

Clone Killing: The tracks found by the forward tracking and matching are combined. As a final step a clone killing algorithm is run to select the best track from among those that share many hits [12]. If two or more tracks are flagged as clones the one with the most hits is selected.

In both the match and forward algorithms information from the TT station is added only at the end of the pattern recognition step. In the case of the forward tracking it is used as one of several criteria to validate a candidate track.

The performance studies were done using data generated for the DC' 06 production. For the reconstruction Brunel v30r14 and XmlDDDB version v30r14 were used. Four data samples were used:

- A sample of 25000 $\mathrm{B}^+ \rightarrow D^0 K^+$ events generated at the default LHCb luminosity of 2×10^{32} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$.
- A sample of 2000 $\mathrm{B_d} \rightarrow J/\psi(\mu^+\mu^-)\mathrm{K_S}(\pi^+\pi^-)$ events generated at the default LHCb luminosity of 2×10^{32} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$.
- A sample of 4000 $\mathrm{B_d} \rightarrow J/\psi(e^+e^-)\mathrm{K_S}(\pi^+\pi^-)$ events generated at the default LHCb luminosity of 2×10^{32} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- A sample of 1000 $\mathrm{B_d} \rightarrow J/\psi(\mu^+\mu^-)\mathrm{K_S}(\pi^+\pi^-)$ events generated at a luminosity of 5×10^{32} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

The majority of results were obtained with the first sample. From the context it should be clear when this is not the case.

2 Definitions

It is first necessary to define performance indicators for Long tracks. A particle is defined to be in the LHCb acceptance if it satisfies the following criteria:

- The particle momentum at its production vertex is more than 1 GeV/c.
- Three reconstructed clusters in the r sensors of the VELO.
- Three reconstructed clusters in the ϕ detectors of the VELO.
- A reconstructed x and u hit in each of the tracking stations T1-T3.
- It does not interact hadronically before the end of the T stations.

The track reconstruction efficiency is then given by:

$$\text{efficiency} = \text{N(accepted } \cap \text{ track reconstructed)/N(accepted)}$$

For the efficiency calculation all particles except electrons satisfying the above acceptance criteria are used regardless of their origin. Electrons are excluded because the majority originate in secondary interactions such as photon conversions. These have little physics interest but are more difficult to reconstruct due to subsequent bremsstrahlung in the detector material. To determine whether a Monte Carlo has been reconstructed an association algorithm is needed. A track is said to be related to a true particle (**MCParticle**) if more than 70 % of the clusters in the VeLo come from that particle and more than 70 % of the hits in the seeding region also come from that particle. The choice of these criteria is somewhat arbitary and will investigated further in Section 3.

The other important indicator of the tracking performance is the ghost rate. The is defined as:

$$\text{ghost rate} = \text{N(rec tracks not related to a } \textbf{MCParticle}\text{)/N(rec tracks)}$$

Both the efficiency and the ghost rate can be calculated in two ways. The first is to calculate these quantities on an event-by-event basis ('event weighted'). If values for the whole event sample are required the averages of the resulting distributions are used. The alternative is simply to calculate the efficiency and ghost rate on the whole sample of tracks ignoring which event the track came from ('track weighted'). Since there are large event-to-event fluctuations in the case of the ghost rate the first method is preferred and will be used for the majority of the results presented in this note.

3 Performance

On average 33.7 tracks are reconstructed per event of which 59 % are of forward type and 41 % are of match type. The matched tracks that are chosen in place of the corresponding forward track by the clone killer are of higher quality. For example the momentum resolution of the best tracks is 4.6 per mille compared to 4.7 per mille for forward tracks alone.

Using the definition given in Section 2 an event weighted efficiency of 0.894 is found [1]. If only the Forward Tracking is run an efficiency of 0.86 is found showing that the track matching contributes noticeably to the overall efficiency. In Fig. 2 the dependence of the efficiency on the pseudorapidity of the track is given. Across the majority of the LHCb acceptance the efficiency is flat. However, there is a dip at a $\eta \sim 4.3$. This is attributed to the material of the 25 mrad section of the beam-pipe which lies within the acceptance of the detector. Fig. 3 shows the efficiency as a function of momentum. It can be seen that:

- Below ~ 10 GeV/c the efficiency falls rapidly. This is because the size's of search windows are typically dominated by the effect of multiple scattering in the detector which increases at lower momenta.
- Above 10 GeV the efficiency reaches a plateau at around 0.95

This performance is similar to what was achieved in the past [13]. Since both the forward and matching algorithms use VeLo seeds as input the maximum performance that can be achieved is limited to the efficiency of the VeLo tracking algorithm which is ~ 0.97 for high momentum tracks

The efficiency for reconstructing tracks that originate from B decays has also been investigated. The results are summarized in Table 1. For the case of muons from $\mathrm{B_d} \rightarrow J/\psi(\mu^+\mu^-)\mathrm{K_S}(\pi^+\pi^-)$ a comparable performance to that obtained with the inclusive track sample is obtained. For the electron case the performance is slightly worse reflecting the fact that bremsstrahlung in the material of the detector makes them harder to reconstruct. The performance for pions from $\mathrm{B_d} \rightarrow J/\psi(\mu^+\mu^-)\mathrm{K_S}(\pi^+\pi^-)$ where the pion's give sufficient hits in the VeLo to be reconstructible as long tracks is poor — there is only a 76% probability to reconstruct such a particle. This is partially attributed to the worse performance of the VeLo track finding for particles that originate far from the interaction point [6].

[1] The corresponding track weighted number would be 0.885.

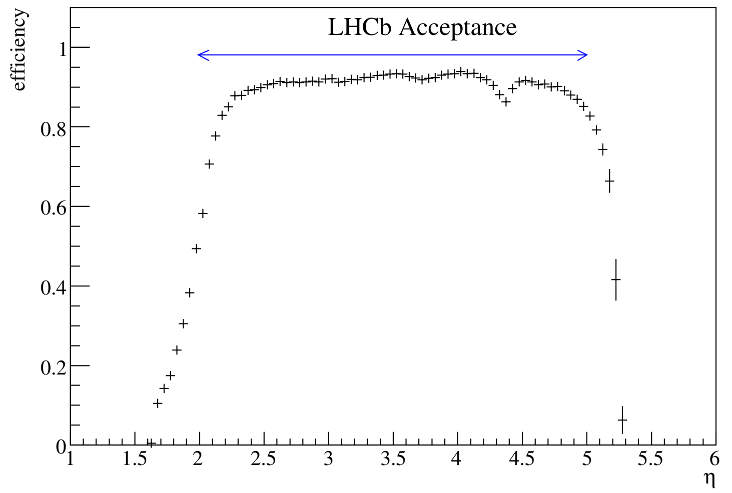

Figure 2: Track finding efficiency as a function of the track pseudorapidity η.

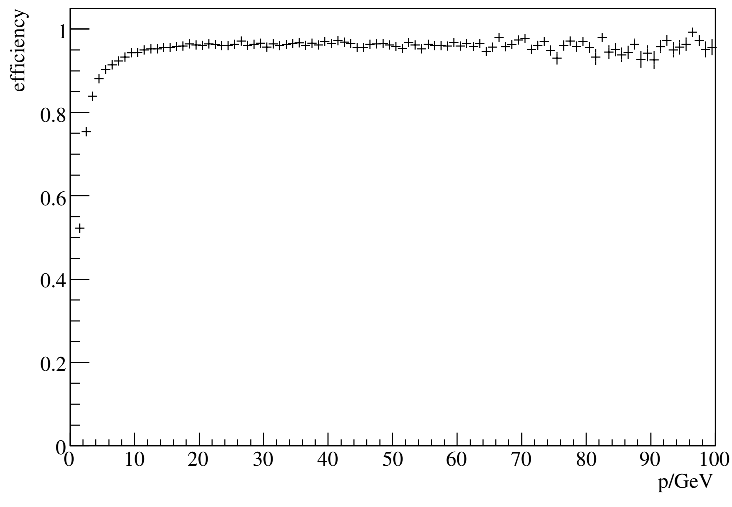

Figure 3: Track finding efficiency as a function of the track momentum.

The event weighted ghost rate is 0.17 [2]. This is worse than the value of 0.10 achieved in the past [13]. The degradation in performance is attributed to

[2]The corresponding track weighted number would be 0.21.

Track type	$\overline{p}$/GeV	Track efficiency (%)
$\mu^{\pm}$ from $\mathrm{B_d} \to J/\psi(\mu^+\mu^-)\mathrm{K_S}(\pi^+\pi^-)$	33	94.2 ± 0.5
$e^{\pm}$ from $\mathrm{B_d} \to J/\psi(e^+e^-)\mathrm{K_S}(\pi^+\pi^-)$	34	90.1 ± 0.4
$\pi^{\pm}$ from $\mathrm{B_d} \to J/\psi(\mu^+\mu^-)\mathrm{K_S}(\pi^+\pi^-)$	12	75.6 ± 2.2

Table 1: Efficiencies for reconstructing tracks from specific B final states. The column labeled final state efficiency refers to the efficiency for reconstructing both tracks.

several factors. First, the occupancy in the T stations has increased by up to 40% as a result of a more realistic beam-pipe design [14, 15] and the decision to increase the size of the Outer Tracker readout gate from 50 ns to 75 ns [16]. In addition, the size of the magnetic field in the region of the TT station is reduced. This makes the use of information from this station less effective in identifying ghost tracks.

In Fig. 4 the properties of ghost and real tracks are compared for four variables: the weighted number of measurements on the track defined as:

$$n_{meas} = n_{velo} + n_{TT} + n_{IT} + 0.5 \times n_{OT}{}^{3},$$

the χ^2/ndof the track pseudorapidity and finally the track's transverse momentum. Compared to real tracks ghost tracks have less measurements and have a worse χ^2/ndof. In addition, they tend to lie at high η and also around $\eta = 4.3$ [4]. Finally, it can be seen that ghost tracks have lower p_t than real tracks. By cutting either on one of these variables or a combination of them the ghost rate can be reduced at the cost of reduced efficiency. In the case of the Match tracks the criteria used to select a good combination of VeLo and T-seeds is stored in the track and can be used to reduce the ghost rate [11].

The simplest and most intuitive variable to use to reduce the ghost rate is the χ^2/ndof of the track fit. Fig. 5 shows the variation of the efficiency versus ghost rate as a function of a cut on this quantity. From this plot it can be seen that by requiring $\chi^2/\mathrm{ndof} < 25$ the ghost rate can be reduced to 0.14 with negligible loss in efficiency. Such a cut also removes the majority of the

[3] The weight of 0.5 takes accounts of the fact that the OT gives twice the number of measurements per track to the IT.

[4] This effect is also attributed to the effect of the 25 mrad cone of the beam-pipe.

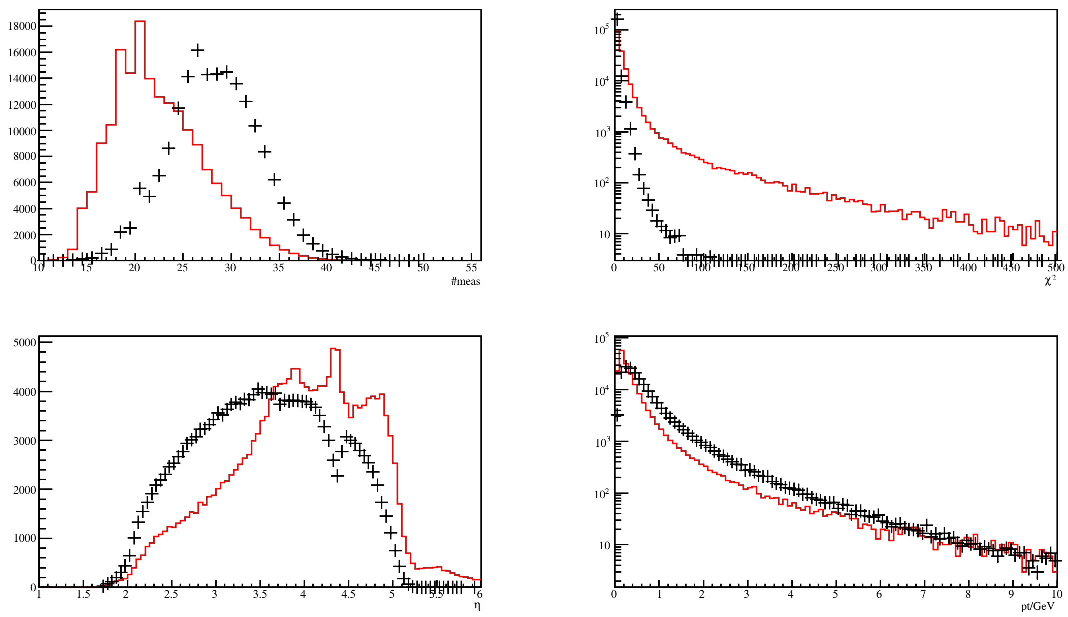

Figure 4: Comparison of the properties real (points) and ghost tracks (solid). The four variables considered are: number of measurements (top left), χ^2/ndof (top right), η (bottom left), p_t (bottom right)

ghosts with $\eta > 5.3$ which are outside the physical acceptance of the detector. This illustrates the fact that many of the variables that can be used to reduce the ghost are corelated. The ghost rate can be further reduced, with some loss in efficiency, by cutting harder on the χ^2/ndof. Since the distribution of the χ^2/ndof is broader at lower momentum this loss is more pronounced at low momentum.

It should also be noted that since in the standard LHCb software no link to the Monte Carlo truth is stored for hits coming from spills other than the event one, if a track from a previous spill were reconstructed it would be classified as ghost. However, in dedicated studies it has been found the rate of such tracks is negligible.

The quality of the reconstructed tracks is good. Fig 6 shows the purity, ie the fraction of correct hits of the reconstructed tracks. The average track purity is 0.985 and very few tracks have purities below 0.9. From this plot it can be infered that similar results will be obtained if the criteria used to define a particle as being reconstructed (Section 2) are varied. This has been tested

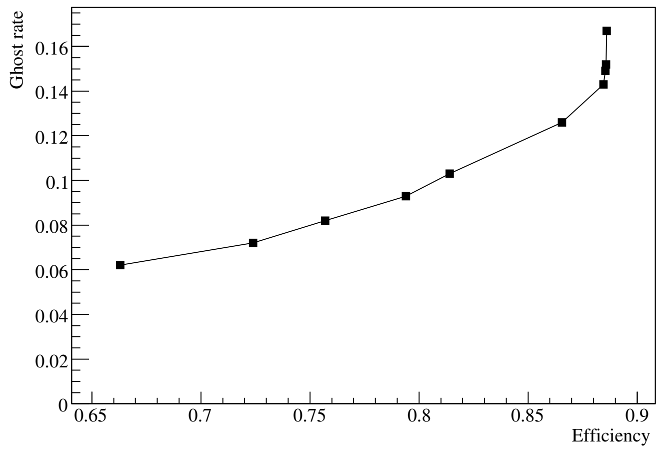

Figure 5: Efficiency versus ghost rate as a function of a cut on the χ^2/ndof. The points from left to right corresponds to cuts at 2, 2.5, 3, 4, 5, 10, 25, 50, 100 and ∞.

directly by studying how the efficiency and ghost rate vary if the association criteria are varied in the range 0.6 to 0.9 (Fig. 7). It can be seen that effect of varying the association requirements is small.

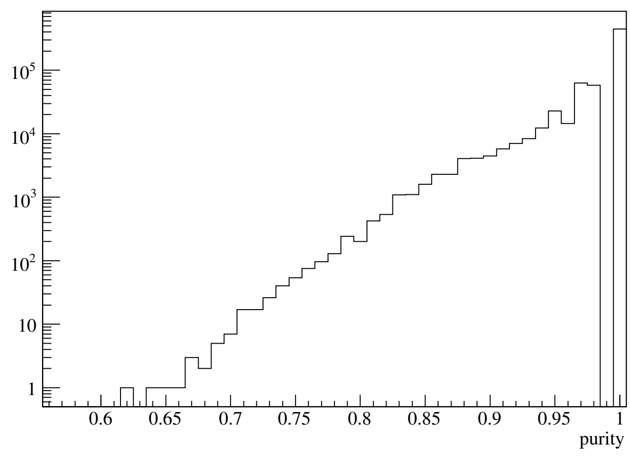

Figure 6: Track Purity.

The performance as a function of the number of visible interactions as defined

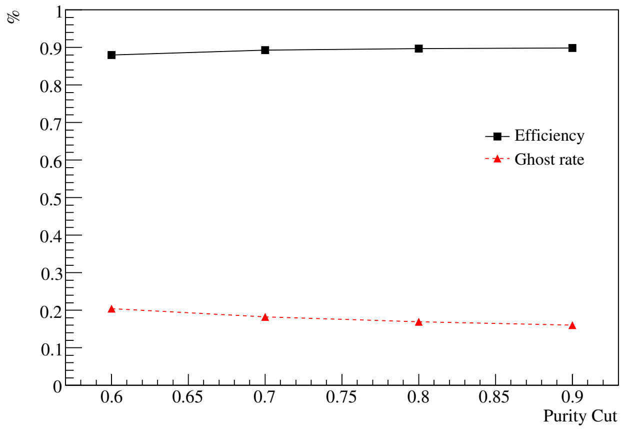

Figure 7: Event-weighted efficiency and ghost-rate as a function of cut on the hit purity required to associate it to a Monte Carlo particle as described in Section 2.

in [3] has also been investigated. Fig. 8 shows the dependence of the efficiency and ghost rate on this quantity. It can be seen that the dependence of the efficiency on the number of visible interactions is quite weak. For each additional visible interaction in the detector the efficiency decreases by $\sim$ 0.01. The ghost rate shows a clear dependence on the number of visible interactions in the detector. For each additional interaction the ghost rate increases by ~ 0.06.

Finally, the performance with data generated at a luminosity of 5×10^{32} cm^{-2}s^{-1} has been studied. In this case an efficiency of 0.88 and a ghost rate of 0.21 is found. If only the number of visible interactions in the event spill effects the performance of the track reconstruction then efficiencies and ghost rates for an arbitrary luminosity can be derived directly from Fig. 8. At a luminosity of 5×10^{32} cm^{-2}s^{-1}, on average there are two visible interactions per B event. From Fig. 8 the efficiency in this case would be expected to be 0.89 and the ghost rate 0.20 — in good agreement with the observed values. At higher luminosities this extrapolation will at some point break down due to increased spillover that further increases occupancies and detector dead-time.

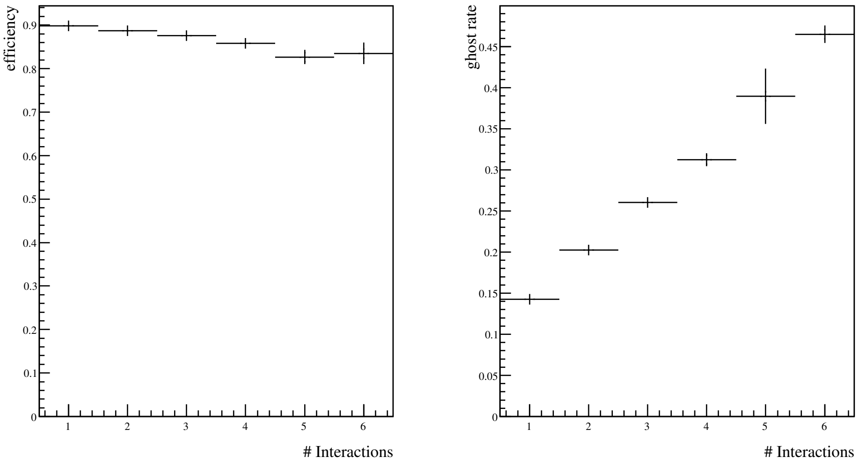

Figure 8: Efficiency (left) and ghost rate (right) versus the number of visible interactions.

4 Summary and Outlook

In this note the performance of the pattern recognition for finding long tracks has been described. An efficiency of ~ 0.95 is achieved for particles above 10 GeV/c. This is similar to that found in previous studies. However, due to the more realistic description of the detector used the ghost rate has increased from around 0.1 to 0.17.

In the future a further reduction in the ghost rate is expected by combining several variables such as the number of measurements and χ^2/ndof of the track fit to give a single powerful discriminating variable. Such an approach is used in the Tsa seeding [10] where the number of hits on a track compared to what is expected, the fit χ^2 and kinematic information are combined into a likelihood. Alternatively, a discriminanting variable could be built from this information. Such an approach would be similar to the information criteria:

$$t = ln\chi^2 - 2 \times ndof$$

proposed as a discriminating variable in [17].

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