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Performance of the combined LHCb track reconstruction algorithms

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Abstract

This note reports on the performance of the complete LHCb track reconstruction, including both the track seeding and track following pattern recognition algorithms. Next to the efficiencies and ghost rates for individual tracks, results on the event reconstruction efficiency for two benchmark physics channels are reported.

1 Track reconstruction

The LHCb track reconstruction algorithms reconstruct the trajectories of charged particles traversing the LHCb spectrometer. Input to the track reconstruction are the measurements in the outer tracker, inner tracker and VELO detector. The track reconstruction task is split into a track fitting task and a pattern recognition task.

The aim of the track fit is to reconstruct the particle trajectory given the measurements in the detectors. The LHCb track reconstruction uses the Kalman filter method[1] to determine the full track state vector and the covariance matrix at several z positions by progressively adding the information of the measurements. This LHCb track fitting is performed by the TRAIL/Gaudi[2] computer program.

Given the set of measurements by the tracking detectors, it is a pattern recognition task to group together those measurements that are caused by the same particle. The pattern recognition task is split into two sub-tasks, *track seeding* and *track following*. The task of track seeding is to find initial track coordinates. The track following extends these track segments by extrapolating them to the other detector planes, where the additional measurements belonging to the track are searched for and added.

Track seeding is best performed in a low magnetic field region. The LHCb spectrometer has two of these regions, the vertex region and the region downstream of the magnet. Track following operates best upstream starting from track segments found in the downstream region extending towards the vertex detector, because these track seeds contain a good estimate of the momentum. Although downstream following is also studied this note only reports on upstream track reconstruction.

Track seeding: Track seeding is performed with the hits of the tracking stations T6-T9. The seeding algorithm[3] combines x-coordinate measurements to form local track vectors ("stubs") in each of the four stations. Linking these stubs with a parabolic fit results in two dimensional trajectories in the $x-z$-plane. Addition of the hits of the stereo planes results in 3-d track segments. A track is defined to be efficiently found if more than 70% of the associated hits are correctly assigned, i.e. a track purity of 70%. Figure 1 shows the seeding efficiency as a function of the momentum for tracks originating from the vertex area and traversing the seeding region, i.e. for "physics quality" tracks. The average seeding efficiency for these tracks is 95 %, with a ghost rate of about 10 %.

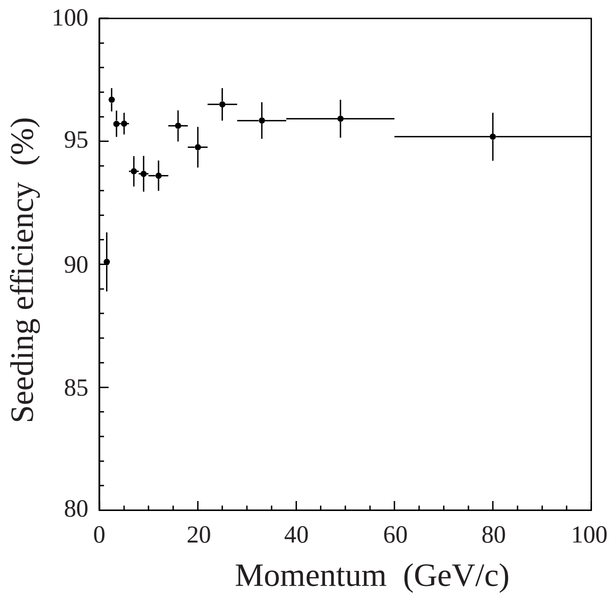

Figure 1: Track seeding pattern recognition efficiency as a function of momentum[3].

Track following: Track following uses the track segments found in the track seeding as initial track states. These seeds are extrapolated from station to station, progressively updating the track state[1] with the measurements. The track following algorithm[4] finds the measurements in a station that form a continuation of the track. The algorithm allows branching in case more than one plausible continuation is found. To test the stand-alone performance of the following algorithm, the track seeding step has been "cheated" by starting with the true track seeds in the seeding region and following them upstream through the magnet. A track is said to be correctly reconstructed if it has a hit purity and hit efficiency of more than 70% and all track parameters within 10 σ of the true value at $z = 2111$ mm (entry point station T2). Figure 2 shows the track following efficiency as a function of momentum for "physics" tracks. The average stand-alone following efficiency is 94.4 %, with a ghost rate of 4.6 %.

Combined seeding and following: The previous paragraphs summarise the results of the stand alone track seeding and track following algorithms already reported in separate notes[3, 4]. By using the track segments found

[1]A track state is a snap shot of the track parameters $(x, y, t_x, t_y, Q/P)$ at a certain z position along the particle trajectory.

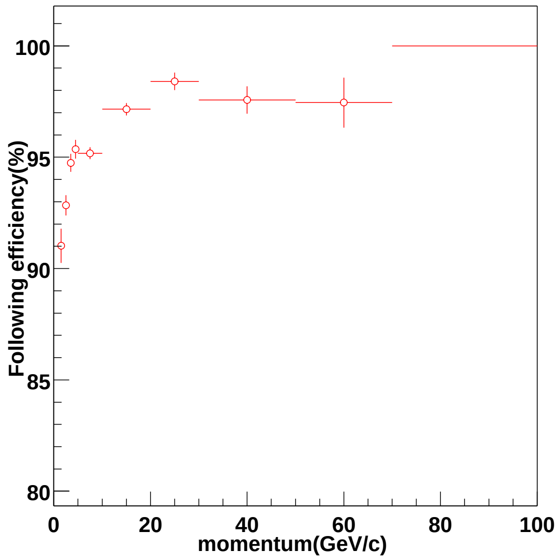

Figure 2: Track following pattern recognition efficiency as a function of momentum[4].

in the track seeding, in the track following algorithm a complete pattern recognition chain can be obtained. As a first implementation ghost track segments found in the track seeding are ignored. Furthermore instead of directly using the track segments the values of the track parameters are taken from the "true track" smeared by a conservative estimate(see [4]) of the expected error in the track seeding. Using the same track selection and track matching criteria as for track following an average track reconstruction efficiency of 89.8 % is found. As the ghost tracks of track seeding were not yet considered a ghost rate for the combined algorithms is not obtained. Figure 3 shows the pattern recognition efficiency for tracking as a function of momentum.

2 Event reconstruction

Individually found tracks are combined to reconstruct the B decays. This section reports on the event reconstruction efficiency for two benchmark physics channels, $B_d \rightarrow \pi^+\pi^-$ and $B_s \rightarrow D_s^{\mp}K^{\pm}$. For both channels data generated with SICBMC v233r4 and dbase version v229r3Matt was used. The events were 'piled up' with minimum bias events corresponding to a luminosity of 5×10^{32} cm^{-2}s^{-1}, i.e. high luminosity mode. The reconstruction of these

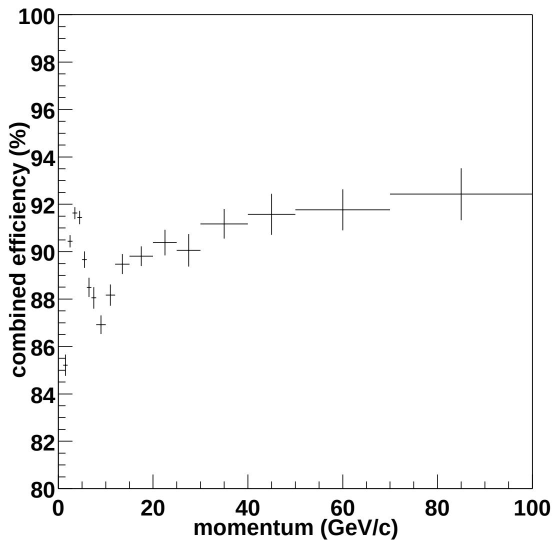

Figure 3: Track seeding followed by track following pattern recognition efficiency as a function of momentum.

B-decays is done using the standard LHCb physics selection algorithms implemented in the AXSELECT analysis package[5].

Pattern recognition from a "tracking point of view". The event reconstruction inefficiency due to pattern recognition is a criterium quantifying the performance of the LHCb tracking system. The event reconstruction efficiency ϵ_{event} is defined as the actual number of reconstructed B events divided by the number that would be obtained if the pattern recognition were fully efficient for all tracks within the LHCb acceptance. This number is obtained from a B signal tape by performing the following steps

- The tracks are reconstructed by the TRAIL/Gaudi program with "cheated" pattern recognition.
- The complete event, i.e. all subdetectors, is reconstructed with the Brunel software[2].
- By means of the AXSELECT routines the physics selection is applied for the B decay under study.

[2]The old RICH ring reconstruction algorithms have been used, i.e. reconstruction mode one.

- In case the event passes the physics selection cuts all tracks are reconstructed with full pattern recognition. If all stable decay products of the B meson are found in the pattern recognition the events is said to be efficiently reconstructed.

	$B_d \to \pi^+\pi^-$	$B_s \to D_s^\mp K^\pm$
$\epsilon_{\text{signal track}}$	$96.8 \pm 0.7\%$	$94.7 \pm 0.9\%$
ϵ_{event}	$93.8 \pm 1.5\%$	$79.3 \pm 3.4\%$

Table 1: Pattern recognition event reconstruction efficiency ϵ_{event} and the individual signal track reconstruction efficiency $\epsilon_{\text{signal track}}$ for $B_d \to \pi^+\pi^-$ and $B_s \to D_s^\mp K^\pm$ signal events.

Table 1 shows this pattern recognition event reconstruction efficiency for the benchmarks B decay modes $B_d \to \pi^+\pi^-$ and $B_s \to D_s^\mp K^\pm$. Clearly the latter decay mode has a lower efficiency because of the four decay particles that have to be reconstructed. Table 1 also shows the individual track reconstruction efficiency $\epsilon_{\text{signal track}}$ for the decay particles of the B meson. These numbers are higher that the average track efficiency of $89.8 \pm 0.1\%$. This can be explained by the fact that the momenta as well as transverse momenta(i.e. a large angle θ) of the B decay particles are significantly higher than that of the underlying events. The track reconstruction efficiency is higher for these type of tracks.

Pattern recognition from a "physics point of view". From a physics point of view the interesting quantity is the total number of fully reconstructed and tagged events we can expect after a year of LHCb operation. An estimate of this number can be obtained by identifying the steps and determining the reduction factors that exist between the number of generated B events in the pp interaction and the final number of fully reconstructed events available for B physics studies. These steps, also schematically depicted in figure 4, are:

- The starting point is the total number of B events with the specific decay mode *generated* in one full year of LHCb operation (10^7 s), i.e. $N_B^{\text{generated}}$.

- Only part of these events have all the B decay products decay inside the LHCb spectrometer *acceptance*. If not all B decay products are in the acceptance the event can not be reconstructed. An events is defined to

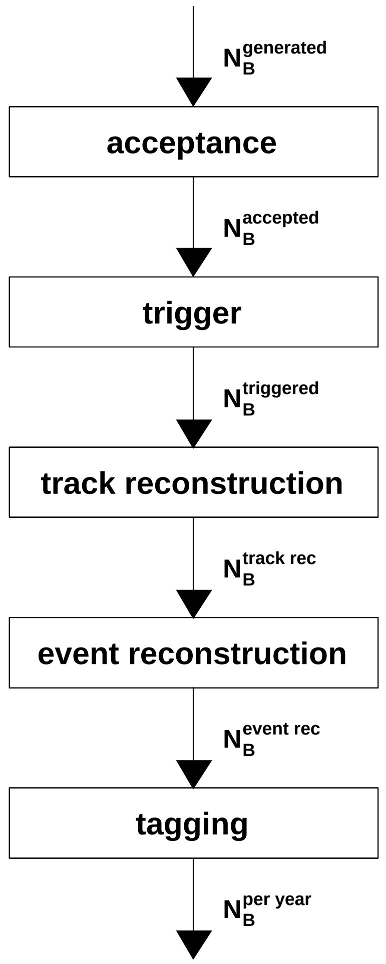

Figure 4: Steps in the event reconstruction that reduce the number of created B events $N_B^{4\pi}$ to the number of events tagged and reconstructed off-line $N_B^{\rm tagged}$ from a physics point of view.

be in the acceptance if it crosses detectors before and after the magnet. The fraction of accepted events is defined as Acceptance $= \frac{N_B^{\text{accepted}}}{N_B^{4\pi}}$ with N_B^{accepted} the number of accepted events.

- Not all B events are *triggered*. This reduces the number of B events to $N_B^{\text{triggered}}$.
- For those events that pass the triggers the *tracks* are *reconstructed* including pattern recognition for tracking. The track reconstruction efficiency is defined as $\epsilon_{\text{track rec}} = \frac{N_B^{\text{track rec}}}{N_B^{\text{triggered}}}$ where $N_B^{\text{track rec}}$ is the number of events with all stable particles found in the track reconstruction.
- The physics event reconstruction is applied for all remaining events. The event reconstruction efficiency is defined as $\epsilon_{\text{event rec}} = \frac{N_B^{\text{event rec}}}{N_B^{\text{track rec}}}$ where $N_B^{\text{event rec}}$ is the number of events that pass the physics selection criteria.
- Finally, for some of the B decays the B mesons need to be *tagged*. This results in the total number of B events for the specific channel per year N_B^{year}.

To make an estimate of the number of expected events for the channels $B_d \rightarrow \pi^+\pi^-$ and $B_s \rightarrow D_s^{\mp}K^{\pm}$ the the program described in the previous section is used to determine several reduction factors. The following procedure is followed:

- For both benchmark channels $B_d \rightarrow \pi^+\pi^-$ and $B_s \rightarrow D_s^{\mp}K^{\pm}$ events have been generated in a 400 mrad solid angle, and stored on tape.
- For the B decay particles it is checked if they are in the acceptance by requiring a first hit in the VELO or station T1 or T2 and a last hit in station T9. This gives a number of physics tracks in the acceptance.
- The track reconstruction algorithms are applied giving the number of events with all physics tracks found in the pattern recognition.
- For the remaining events the physics selection package AXSELECT is called resulting in the number of AXSELECTed events[3].

The resulting number of events are reported in table 2.

[3]Currently the cheated tracks are used by AXSELECT instead of the the pattern recognition tracks because the seeded and followed tracks have not yet been linked to the measurements from the VELO.

	$B_d \to \pi^+\pi^-$	$B_s \to D_s^{\mp}K^{\pm}$
on tape	3387	3606
physics tracks in acceptance	822	348
physics tracks found in pattern rec	723	267
passing AXSELECT	241	111

Table 2: Number of B events for the decay channel $B_d \to \pi^+\pi^-$ and $B_s \to D_s^{\mp}K^{\pm}$ in various steps of the reconstruction process.

These results lead to the reduction factors in table 3. For the trigger and tagging efficiency the numbers from the Technical Proposal[6] are used. For calculating the acceptance an extra factor of 0.342 is used to convert from the number of events generated in a 4π solid angle to 400 mrad[7]. Using a total of 4.5×10^{11}[6] B_d's produced in one year and a branching fraction for $B_d \to \pi^+\pi^-$ of 7.0×10^{-6}[6], 5491 of these events can be expected to be fully reconstructed per year. Using a total of 1.3×10^{11}[6] B_s's produced in one year and a branching fraction for $B_s \to D_s^{\mp}K^{\pm}$ of 9.4×10^{-6}[6], 867 of these events can be expected to be fully reconstructed per year.

Mode	Acceptance	$\epsilon_{\text{trigger}}$	$\epsilon_{\text{track reco}}$	$\epsilon_{\text{event reco}}$	ϵ_{tagged}	N_B^{peryear}
$B_d \to \pi^+\pi^-$	8.7%	17%	88%	33%	40%	5491
$B_s \to D_s^{\mp}K^{\pm}$	3.5%	16%	77%	42%	40%	867

Table 3: Event reduction factors and the final expected LHCb event yield for the channels $B_d \to \pi^+\pi^-$ and $B_s \to D_s^{\mp}K^{\pm}$.

3 Discussion and Outlook

This is the first LHCb note reporting results on

- The combined track seeding and track following algorithms.
  - An average combined track seeding efficiency of $89.8 \pm 0.1\%$ is found.
- The (in)efficiency of pattern recognition on the physics event reconstruction.
  - For $B_d \to \pi^+\pi^-$ events the combined pattern recognition event efficiency is $93.8 \pm 1.5\%$.

- For $B_s \rightarrow D_s^{\mp} K^{\pm}$ events the combined pattern recognition event efficiency is $79.3 \pm 3.4\%$.

The algorithms are not yet finalised. Furthermore combining the algorithms needs some further study. Several improvements can be implemented in the near future:

- Directly use the track parameters found in the track seeding as an input for the track following.
- Follow as well the ghost tracks found in track seeding.
- Match the pattern recognition found tracks in the tracking stations to track segments found in the VELO (see [8] for a first study).

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