Muon ID performance with the reoptimized LHCb detector

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Abstract

The retuning of the muon identification procedure for the reoptimization detector design and performance is presented. The overall efficiency for the muon system only is \((94.3 \pm 0.3)\%\) with a pion mis-identification of \((2.87 \pm 0.05)\%\).

Supporting note for the LHCb TDR 9.


1 Introduction

Muons are very important particles for the LHCb experiment. Final states with muons \((B_d \rightarrow J/\Psi K_s, B_s \rightarrow J/\Psi \Phi, \text{for instance})\) are among the key channels for CP violation measurements. The triggering system also needs to identify muons in a fast and reliable way.

For the LHCb Technical Proposal [1] the first version of the muon ID code was implemented [2, 3, 4]. The system had 94% of efficiency for muons and 1.5% efficiency for pions (misidentified as muons).

The basic idea of the algorithm is to look for hits around the track extrapolation in a window which is called “field of interest” (FOI). As the algorithm depends on the tuning of the FOI as a function of momentum it was expected that after a major redesign of the detector a new tuning had to be done.

The original tuning for the reoptimized detector was producing a lower overall efficiency of 87% for muons above 3 GeV/c with a strong decrease of efficiency for high momenta. Also the efficiency as a function of momentum showed dips, as can be seen in figure 1, that were not observed before the optimization work. Also the muon identification code was completely rewritten in C++ and needed to be checked.

This note presents the final tuning used for the studies included in the LHCb reoptimization TDR.

![Figure 1: Muon efficiency as function of momentum (left side) and pion misidentification (right side). Plot presented on the Particle ID meeting, 22 October of 2002.](image)

2 Identification algorithm

Muons are identified by extrapolating well reconstructed tracks with \(p > 3\) GeV/c into the muon stations. The tracks must be in the M1 and M5 acceptance (the inner station holes are excluded).
Around the extrapolation point in each station, muon hits are searched within FOIs param-
eterized as function of momenta for each station and region.

A track is considered a muon candidate when a minimum number of stations have hits in
their corresponding FOIs as shown in table 1. This number was optimized for high efficien-
cy.

\[
\begin{align*}
M2 + M3 & \quad \text{for } p < 6 \\
M2 + M3 + (M4 \text{ or } M5) & \quad \text{for } 6 < p < 10 \\
M2 + M3 + M4 + M5 & \quad \text{for } p > 10
\end{align*}
\]

Table 1: Stations that must have hits in FOI to select a muon candidate as a function of the track
momentum (in GeV/c).

## 3 Tuning

Using single muons flat in momentum [1,200] GeV and \( \theta \), the FOIs were parameterized from
plots of \((X(Y)_{MC} - X(Y)_{HIT})/pad\_size\) for \( X \) and \( Y \) in each station and region according to
the expression

\[
FOI = \text{par0} + \text{par1} \times e^{-\text{par2} \times p}
\]

where \( p \) is the track momentum in GeV/c.

This is a simpler expression then the one used in the original tuning.

An example of station and region fit is shown in figure 2 for the \( x \) coordinate of M2R3. This
figure shows a scatter plot of the true hit position minus the extrapolated track position in units
of pad size. The three curves shows four, three and two sigmas inclusive regions. We choose
the three sigma curve to be the momentum dependent curve that will define the FOI (one for
each \( x \) and \( y \) view) for each chamber and region.

![Scatter plots of the ratios |Δx|_{MC}/pad\_size and |Δy|_{MC}/pad\_size as a function of momentum in region 3 of station M3. The profile histogram is superimposed. The solid lines are the results of the fits \( \Delta \gamma_{x or y}^2/pad\_size(p) \), for \( n = 2 \) to \( 4 \), with \( n=2 \) for the curve closest to the profile histogram.](image-url)
Figure 3: Muon efficiency (open triangles) as function of track momentum (in GeV/c) in the left axis. In the right axis the pion mis-identification.

4 Discriminating variables and performance

The strategy used to tune the system was based on the maximization of the efficiency while maintaining reasonable levels of pion mis-identification. Those pions could then be eliminated with discriminating variables or analysis cuts. Using a sample of $B_d \rightarrow J/\Psi K_S$ the performance was measured to be $\mu_{\text{eff}} = (94.3 \pm 0.3)\%$ and $\pi_{\text{eff}} = (2.87 \pm 0.05)\%$. This comes from our basic identification algorithm without using any discriminating variables. The efficiency is a flat function of the momentum as shown in figure 3. Some discriminating variables between the muons and the background particles were tested. The average track-hit distance of all hits in FOIs associated to the track was chosen as our main discriminating variable. The probability distribution function of this variable for muons and pions was obtained as shown in figure 4. This likelihood can be combined with the likelihood produced by other detectors to further improve the particle ID performance.

5 Delta likelihood for the muon system

For each track the difference in the logarithm of the likelihood for the muon hypothesis and the logarithm of the likelihood for the pion hypothesis (DLL) is used as a variable to improve the muon sample purity, as shown in figure 5. For instance, with a cut of DLL > −1 the muon efficiency is about 85% and the pion mis-identification is about 1.1%.
Figure 4: Probability distribution function of muons (which has a peak at lower values) and pions as a function of the average track-hit distance in all hits in FOIs.

Figure 5: DLL for a muon (red stars) and a pion sample (black squares).
Figure 6: Muon efficiency (left scale, closed circles for high background and stars for nominal background) and pion mis-identification (right scale, open circles for high background and squares for nominal background). For high background, using a cut DLL $> -0.5$ the muon efficiency goes to about 75% and the pion mis-identification drops to 3.0%.

6 Robustness tests

Using special input files prepared under the hypothesis of a very harsh environment for the muon chambers (with twice more background in M1 and five times more in M2-M5) the robustness of the muon identification system was tested.

Under those conditions, the usual basic algorithm gave a muon efficiency of $(95.33 \pm 0.18)\%$ and the pion mis-identification rose to $(11.71 \pm 0.08)\%$, a clearly unacceptable high rate.

The first strategy to lower the pion mis-identification rate was to combine the track-hit distance (described in the previous section) and the slope variable (difference between the track slope calculated in the muon system and the one given by the tracking). The result can be seen in figure 6 where it is shown that for DLL $> -0.5$ the muon efficiency goes to about 75% and the pion mis-identification drops to 3.0%. Given the high background level in the simulation, the relative reduction of about 16% in the muon efficiency and the relative reduction of 79% of the pion mis-identification puts the system back to a workable condition, albeit with a reduced efficiency for muons.

Another way to fight the high background environment is to reduce the FOIs by a factor of 1.5 for regions R2, R3 and R5 and by a factor of 2.5 for R1 (without using the DLL cut). With those new FOI values the basic algorithm has a muon efficiency of $(87.53 \pm 0.61)\%$ and a pion mis-identification of $(2.72 \pm 0.01)\%$, again a reasonable value. The factors for the FOI were chosen arbitrarily, surely an optimization study using the high background simulation would find better values.

Finally, the third and most effective approach would be to combine the two above strategies with the use of information of other detectors through some multivariated method. Based on our previous work [4] we believe that we can reduce the pion mis-identification to very low levels.

1Files named L0 high background
even with a high background situation.

7 High level trigger muon id code

The high level trigger will use muon identification as part of its selection criteria. The present code was tested using tracks reconstructed with the high level trigger algorithms and no loss in performance was noticed. The code was not fast enough for the trigger system and it was then further optimized\(^2\) showing that it is possible to use the muon identification at the trigger level.

8 Technical details

The muon identification code is implemented as a DaVinci algorithm and the DLL calculation is a tool used in the CombinedParticleMaker algorithm.

9 Acknowledgements

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References


