Hlt1 Muon Alley Description

LHCb Note

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Abstract

This note describes the LHCb Hlt1 muon alley, which is part of the high level trigger. It is intended to confirm the L0 muon trigger and reduce the bandwidth. The performance presented here is done using about 1000 simulated data of some relevant muon channels and 200k of minimum bias events.

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Contents

List of Figures

List of Tables

1 Introduction

This note describes the LHCb Hlt1 muon alley for a $\mathcal{L} = 2 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ scenario.

The LHCb trigger is divided in two levels: Level-0 (L0) and High Level Trigger (Hlt). The L0 selects events with high $\mathrm{P_t}$ muon or calorimeter objects (hadrons, pions, γ and electrons). It reduces the input 40 MHz rate to 1 MHz and it is implemented using custom made electronics. The Hlt reduces the L0 output rate to 2 kHz, the Hlt selected events are saved on permanent storage (see [1] for details). The High Level Trigger is divided in two parts named Hlt1 and Hlt2. The purpose of Hlt1 is to confirm the Level-0 triggering objects reconstructing them in the tracking system and validating their nature using the Particle ID system. The idea follows from the concern to not introduce unnecessary systematic effects in the trigger selection vetoing the possibility that different particles causes the trigger decision at the L0 and Hlt1 levels. The L0 objects confirmation allows to reduce rate to about 30 kHz, so on the remaining events the full pattern recognition, which is very time consuming, can be performed. The final reduction is performed by Hlt2 which selects event by means of inclusive or exclusive B decays trigger algorithms.

The Hlt1 is composed by several trigger algorithms, named "alleys", depending on the nature of object that fired the L0 trigger: muon, hadron, electron γ and π^0. This note is intended to describe the ideas and algorithms used in the Hlt1 Muon Alley, its performance and the plans on how to run at the start up.

The note is organized as follows. In Section 2 a brief overview of the ideas is given, whereas the details of the algorithms will be found in Sections 3 and 4. In Sections 5 and 6 the performance of the alley on the different channels together with the minimum bias retention are presented. The main background passing the final decision is analyzed in Section 7. Section 8 summarizes all the variables needed by the alley algorithms that must be set before starting to run. Section 9 presents a start up scheme for the Hlt1 Muon Alley and Section 10 gives an idea of the size of data to be saved.

2 Muon Alley Overview

Following the strategy adopted by the trigger, the purpose of the Hlt1 Muon Alley is to figure out, on the events triggered by L0 for the high $\mathrm{P_t}$ muons presence, if the L0 decision can be confirmed or not. Hence, as the L0 can give a decision of a Single Muon or a DiMuon we will also have these two distinct trigger lines in the alley. Actually the muon alley implementation is more flexible. In fact in addition to the obvious L0 Single Muon and DiMuon confirmation there are other two selecting algorithms. They improve the efficiency for triggering dimuon events which are crucial for many LHCb measurements. The muon reconstruction in L0 has low efficiency for low $\mathrm{P_t}$ muons, thus often the interesting dimuons events are triggered by L0 as Single Muon failing the L0 DiMuon trigger. To recover them the muon alley searches for dimuons also in L0 Single muon triggered events when the triggering muon is confirmed by either combining it with another confirmed L0 muon candidate[a] or by reconstructing other muon tracks – henceforth called here muon segments – not present among the L0 muon candidates. Therefore there will be 4 muon alley selecting lines: Single Muon, DiMuon from 2 L0 Single muons, DiMuon from 1 L0 Single muon + 1 muon segment and DiMuon from L0 DiMuon. Each of these lines implements two selections at the end giving a total of eight types of selected events. While the reconstruction code of the different sub alleys is almost the same, the cuts applied in the final decision are specific and will be tuned in order to reduce the bandwidth and to keep efficiency as high as possible for various different muon channels.

[a] The L0 muon candidates are the output of the L0 muon searching procedure. Each of them is an aligned sequence of muon hits in muon stations. There is a limitation on the number of candidates that can be stored. It is fixed to two per quadrant and whenever larger number of candidates is reconstructed the sub sample composed by the two highest $\mathrm{P_t}$ candidates from each quadrant is stored and is transmitted by Hlt.

The following algorithm flow summarizes the four lines.

1. Single Muons:
   (a) L0 Entry: L0 SingleMuon Trigger ⇒ Selection of L0 muons that fired L0 ($P_T > L0_{PT}$ Cut Value)[b]
   (b) T Confirmation and VELO Matching: Confirmation with T stations ⇒ Confirmation of momentum ⇒ IsMuon ⇒ T–Velo2d Match ⇒ T–Velo3d Match
   (c) Single Muon Decision: After 1a and 1b
      i. Standard single muon
         - Apply IP and P_t cut ("Hlt1MuonSingleDecision")
      ii. High P_t single muon
         - Apply high P_t cut ("Hlt1MuonSingleNoIPDecision")
2. Dimuons From Two L0Single:
   (a) Proceed as in 1a and 1b for 2 L0 muons
   (b) Combine two tracks with a maximum distance of closest approach
   (c) Dimuons from two L0Single Decision: After item 2b
      i. Dimuons From L0Single with IP and Mass Cut
         - Apply IP and low mass cut ("Hlt1MuonDiMuon2L0WithIPDecision")
      ii. Dimuons From L0Single High Mass Cut
         - Apply high mass cut ("Hlt1MuonDiMuon2L0NoIPDecision")
3. Dimuons From Muon Segment:
   (a) Proceed as in 1a and 1b for one L0 muons
   (b) Reconstruct muon segment (M5-M2) ⇒ proceed as in 1b using the muon segment instead of the L0 muon candidate
   (c) Prepare pairs with one confirmed L0 muon and one confirmed muon segment requiring a maximum distance of closest approach
   (d) Dimuons from Muon Segment Decision: After item 3c
      i. Dimuons From Muon Segment with IP and Mass Cut
         - Apply IP and low mass cut ("Hlt1MuonDiMuonMuonSegWithIPDecision")
      ii. Dimuons From Muon Segment with High Mass Cut
         - Apply high mass cut ("Hlt1MuonDiMuonMuonSegNoIPDecision")
4. Dimuons From L0DiMuons :
   (a) L0Dimuon Trigger ⇒ with two L0muons $\sum P_T > \text{L0 Cut value}$
   (b) Proceed as in 1b for each L0 muon
   (c) Recombine the tracks in pairs with a maximum distance of closest approach ⇒ Check if the pair is from an L0 DiMuon pair
   (d) Dimuons from L0DiMuons Decision. After item 4c
      i. Dimuons From L0DiMuons with IP and Mass Cut
         - Apply IP and low mass cut ("Hlt1MuonDiMuonWithIPDecision")
      ii. Dimuons From L0Dimuons with High Mass Cut
         - Apply high mass cut ("Hlt1MuonDiMuonNoIPDecision")

The lines 1 to 3 are initiated by a L0 Single muon trigger, and the line 4 by a L0 DiMuon trigger. The last name between quotes in the flow above is the name of the selection and by convention it is also the name of container where the tracks or vertices passing the alley cuts are stored.

[b] The cited algorithms will be described in the next sections

3 Confirmation algorithm

3.1 Entry the muon Alley

The algorithm that checks whether the muon alley has to be executed is named L0Entry. It simply checks if the L0 decision was a Single or Dimuon. The L0 Single Muon trigger the requirement is the presence of a L0 muon candidate with a $\mathrm{P_T} > 1.3\ \mathrm{GeV/c}$ and a Global Event Cut (GEC) or a $\mathrm{P_T} > 1.5\ \mathrm{GeV/c}$. The Global Events Cut are based on information from calorimeter and vertex detector with the aim to reject crowded events. The L0 Dimuon trigger the requirement is the presence of a two L0 muon candidates with $\mathrm{P_T^1} + \mathrm{P_T^2} > 1.5\ \mathrm{GeV/c}$. The total L0Muon rate is $\approx$ 220 kHz event rate, while the L0Single is $\approx$ 200 kHz and the L0DiMuon is $\approx$ 50 kHz.

In case of positive result of the L0Entry check the L0 muon candidates are transformed into Muon tracks with position and slopes calculated using the hits from M1 and M2[c]. For the Single muon sub alley only the tracks that satisfy the L0 Single Muon requirements are kept for confirmation. Similarly for the Dimuon sub alley from L0DiMuons only the pairs of tracks that satisfy the L0 Dimuon Muon requirements are kept for confirmation. The other two dimuon sub alleys are entered only after the confirmation of the muon track caused the L0Single decision.

The mean number of Muon Tracks to be confirmed in the T stations is 0.24 for minimum bias events and 1.6 for signal events[d] for L0 Single Muon triggered events and these distributions are shown in Figure 1. Similar numbers for L0DiMuon triggered events are 0.05 and 0.9 pairs.

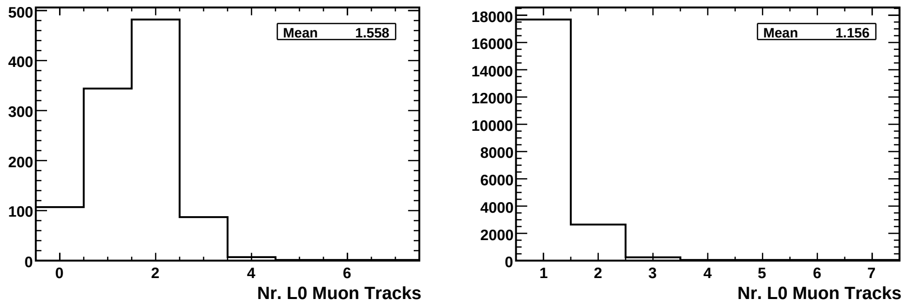

Figure 1 Number of L0 candidates with $\mathrm{P_T} > 1.3\ \mathrm{GeV/c}$ to be confirmed in the T stations. In the left is presented the distribution for $\mathrm{B_s} \rightarrow \mathrm{J}/\psi\phi$ signal events and in the right for minimum bias (without the empty events).

Due to multiple scattering and the muon system granularity, the muon tracks have limited momentum resolution. The $\sigma(1/p)/(1/p)$ is almost momentum independent and the value is about 30% (see Figure 2.)

3.2 Confirmation with T stations

According to the Hlt1 strategy of confirming the L0 objects with the tracking system we try to reconstruct the muon tracks in the T stations[e]. The procedure is schematically the following; the muon tracks are extrapolated to the middle of T3 station, a window is opened around this extrapolation, the T clusters in all T chambers are collected and the T tracks are then reconstructed [3]. The window dimension has been chosen looking at the residual distributions in x or y of the extrapolated muon track and the associated MC hit in the T stations. The windows is equal to 5σ of the residual distribution.

[c]The muon system is composed by 5 stations named M1 to M5 and is decribed in [2].

[d]The performance of the Hlt1 muon alley presented in the note is based on DaVinci v19r14 which uses the HltSys v3r4. The signal events, the one over the performance have been optimized are a sample of 1028 $\mathrm{B_s} \rightarrow \mathrm{J}/\psi(\mu^+\mu^-)\phi$ events accepted by L0 and offline selected. The background rejection has been studied using a sample of 1 million unbiased p-p events usually called minimum bias events.

[e]The tracking system is composed by a vertex detector upstream of the magnet and by 3 stations downstream of the magnet named T1-T3. The T3 is the last tracking station closer to the muon detector so it is the best point for stating the track confirmation.

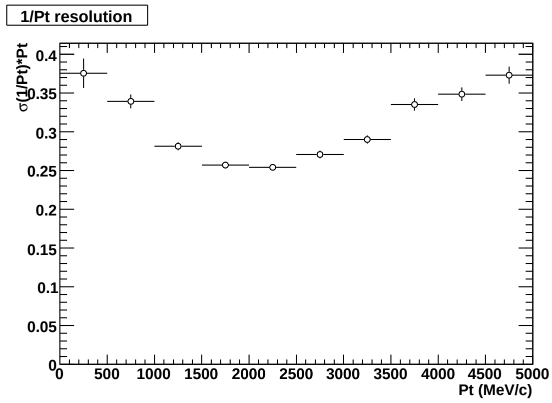

Figure 2 Inverse momentum resolution of the L0 muon candidate as a function of the particle momentum. The increase in the value at low momentum is due to the L0 Single Muon cut.

These residual distributions are dominated by the uncertainty in the extrapolation of the muon track due to the limited muon system granularity. Such granularity decreases moving from inner to outer detector part in 4 concentric regions so we have a set of four search windows according to the position in the muon station of the muon track (see Table 1).

	R1	R2	R3	R4
σ_x [mm]	8	15	29	54
σ_y [mm]	6	10	20	40

Table 1 Position resolution in x and y for each Muon Chambers region obtained in T3.

The efficiency of reconstructing a T track as a function of its momentum[f] is reported in Figure 3. The overall efficiency per track is 96.4% and the momentum resolution is improved with respect to the Muon tracks resolution by a factor 10. In parallel with this high signal efficiency there is a reduction of background: in about one fourth of minimum bias events no T tracks are reconstructed. The L0 muons that do not have a T track associated are completely dominated by muons coming from decayed pions and kaons.

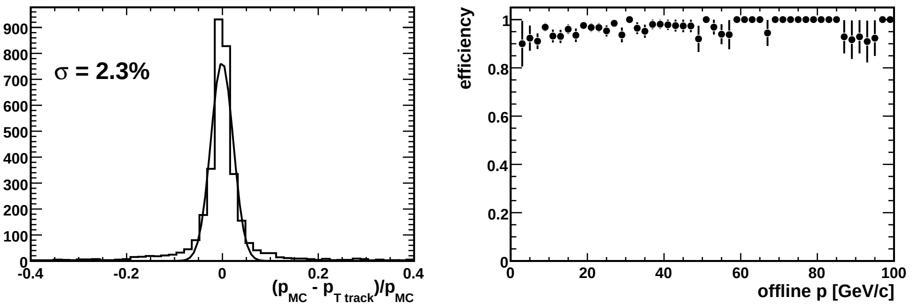

Figure 3 Momentum resolution of the T tracks in the left and efficiency of finding at least one T track associated to a true offline reconstructed muon in the right.

The average number of T tracks per event is 2.4 for signal events and 0.32 in minimum bias. Their distributions are shown in Figure 4. For each signal Muon track there are 1.6 reconstructed T tracks in average as shown in figure 5.

[f]The efficiency is computed for muon tracks associated to an offline reconstructed muon and associated to a true muon coming from a b or a c hadron.

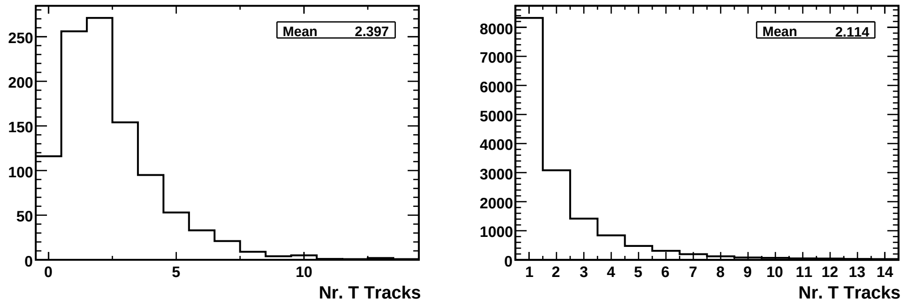

Figure 4 Number of T tracks reconstructed per event . In the left is presented the distribution for $B_s \to J/\psi\phi$ events and in the right for minimum bias. This last one is without the empty events.

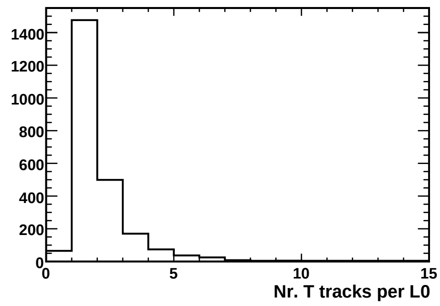

Figure 5 Number of T tracks reconstructed per L0 Muon with $P_T > 1.3$ GeV/c.

3.3 Momentum Confirmation

Since the momentum resolution of the T track is considerably improved with respect to the L0muon, we can clean up the T tracks by applying a $(P_{(Ttrack)} - P_{L0})/P_{(Ttrack)} > -2$ requirement if $P_{(Ttrack)}$ is less than a certain value which depends on the Muon track position (see Table 2).

	R1	R2	R3	R4
p [GeV/c] <	60	30	15	7.5

Table 2 Maximum momentum for which the $(P_{(Ttrack)} - P_{L0})/P_{(Ttrack)} > -2$ is required. The momentum value depends on the muon region where the Muon Tracks is.

These values have been chosen by looking at the two dimensional plot of the momentum as a function of $(P_{(Ttrack)} - P_{L0})/P_{(Ttrack)}$. Figure 6 shows this plot for the muon chamber region 2 for true muons from b or c hadron and for anything else.

This procedure is 99.6% efficient for signal events and reduces the minimum bias events by 14%.

3.4 IsMuon

The muon nature of the particle corresponding to the the T tracks is tested with an procedure almost identical to the off line one [4]. It is called “IsMuon”.

The procedure foresees that the T track is extrapolated back to the muon stations. A window named Field Of Interest (FOI) is opened in each of the muon stations M2-M5 to look for hits. The T track muon nature is confirmed if hits are found in each stations. To take into account the different muon granularity the FOI value used in each region is different. Due to the multiple coulomb scattering in the material traversed by the track the FOI (ΔF) is momentum dependent and a good parametrization has been obtained with the function $\Delta F_{\text{region,direction}} = a_0 + a_1 e^{-(a_2 p)}$. An example of the fitted curve can be given in Figure 7 for region 2 X-direction and the values of the parameters are presented in

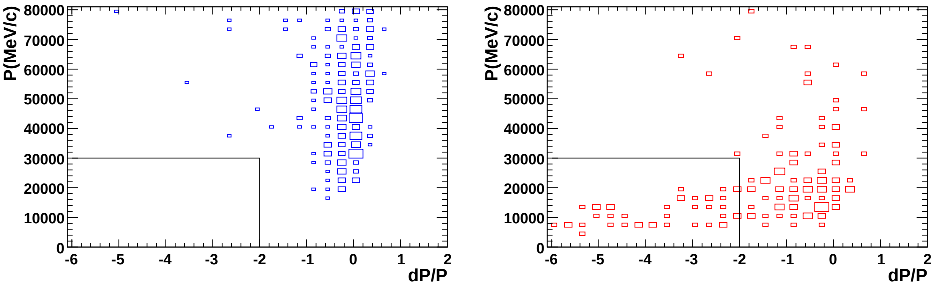

Figure 6 T track momentum as a function of $(P_{(Ttrack)} - P_{L0})/P_{(Ttrack)}$ for true muons from b or c hadron in the left, and for anything else in the right. Both plot are for L0 candidates from R2.

	R1	R2	R3	R4
a_0 x	12.0	17.0	6.0	6.7
a_1 x	13.0	21.0	10.0	15.0
a_2 x	0.11	0.09	0.09	0.10
a_0 y	6.7	9.0	11.0	12.0
a_1 y	3.4	3.4	3.5	3.4
a_2 y	0.02	0.02	0.02	0.02

Table 3 Parameters used in the $\Delta F_{\text{region,direction}} = a_0 + a_1 e^{-(a_2 p)}$. a_0 and a_1 are in half pad unities and a_2 in GeV^{-1}

Table 3. At this point the minimum bias retention is 128 kHz and the efficiency as a function of the offline momentum is also seen in Figure 7. The overall efficiency for signal tracks is 97.6%. The purity, defined as the number of true muons from b or c hadrons over all selected tracks increases from 57.3% from the last step to 80.0%. The average number of tracks in signal events is reduced from 2.4 to 1.8 in signal and from 0.32 to 0.20 in minimum bias events. Their distributions are shown in Figure 8

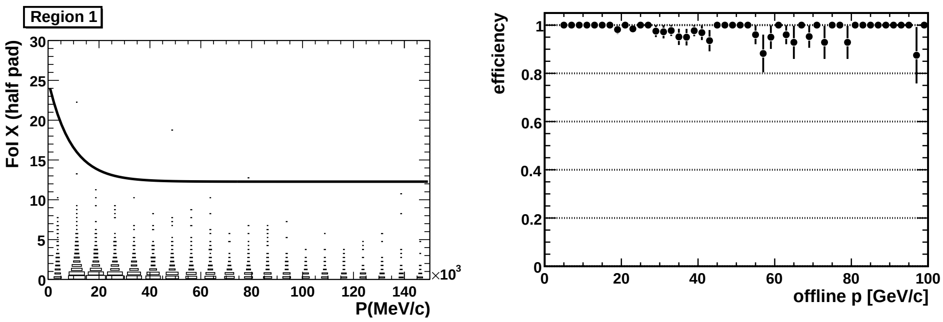

Figure 7 left: X distance, in half pad unities, between the extrapolation of a T track and the closest hit in region 1 of a Muon Station as a function of the off line momentum. The line indicates the FoI used by the "IsMuon" procedure. right: efficiency of the "IsMuon" procedure as a function of offline momentum. Both plots are made for offline reconstructed tracks associated to true muons from b or c hadrons.

3.5 Velo matching

Continuing with the refinement of the track we try to match the T tracks with the tracks reconstructed in Vertex Locator (VELO)[5]. The Velo sensors measures the RZ and ϕZ coordinates of the tracks. Such geometry naturally leads to a two steps track reconstruction. In a first step only the RZ sensors information are used and 2D tracks are reconstructed while in a second step the ϕ sensors measurement are added to get a 3D track. The matching of T tracks with Velo tracks benefits from this two steps reconstruction both in terms of efficiency and in saving CPU time by exploiting a two stages matching

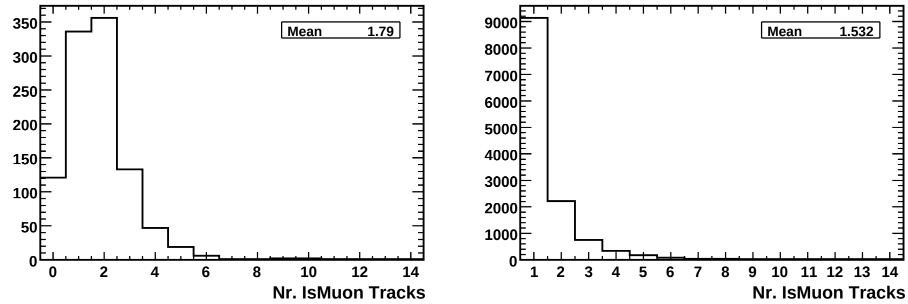

Figure 8 Number of IsMuon tracks reconstructed per event . In the left is presented the distribution for $\mathrm{B_s} \to \mathrm{J}/\psi\phi$ events and in the right for minimum bias. This last one is without the empty events.

procedure. First a match between T tracks and RZ tracks is tried. Only for 2D tracks associated with that T track the 3D Velo reconstruction is performed. Finally the match of the 3D tracks with T tracks is verified.

2D Matching - VeloRZ (or Velo 2D) tracks are created and a matching is tried by extrapolating the T tracks to the Velo detector in the yz plane. If it falls within a tolerance in the same sector as a Velo 2D track the later is tentatively upgraded to a 3D track adding the point in yz plane corresponding to the T track extrapolation. Then both tracks – upgraded Velo and T – are extrapolated to the center of the magnet in x. A cut of 80 mm on the distance between the two extrapolations is applied. On signal events it corresponds to 98% efficiency. In the minimum bias events we have an average number of 52 forward VeloRZ tracks per event, which is reduced to 0.32 after this procedure, their distributions can be seen in Figure 9. In signal, this number is 56.4 and is reduced to 2.8 after the matching. The minimum bias retention at this stage is 116 kHz. This distance between the extrapolations in x that is used for selecting the 2D tracks is shown in Figure 10, both for muons from b or c hadrons, and anything else. As soon as a match is found, the Velo 2D track is selected to be reconstructed as 3D.

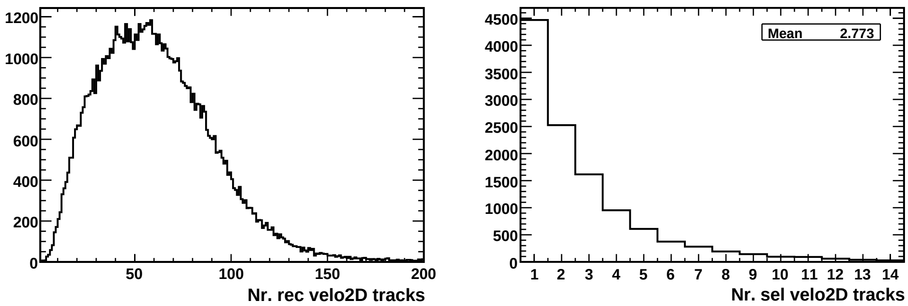

Figure 9 Number of 2D Velo tracks reconstructed in a minimum bias events in the left and the number of selected ones in the right. Only non empty events are shown.

3D Matching - The Velo 2D tracks successfully associated to a T track are reconstructed as a SpaceVelo Track, that is a Velo 3D track. This 3D track will be matched to the T tracks.

The T track and the SpaceVelo are extrapolated to the center of the magnet in xz plane, and to the center of T1 in yz plane. A cut on the χ^2 of the method is applied, where

$$\chi^2 = \frac{dist_x^2}{\sigma_x^2} + \frac{dist_y^2}{\sigma_y^2}$$

The estimation on the errors on the distances are made using:

$$\sigma_x^2 = 8^2 + dSlope^2 \times 80^2\mathrm{mm}^2 \qquad \sigma_y^2 = 8^2 + \theta^2 \times 240^2\mathrm{mm}^2$$

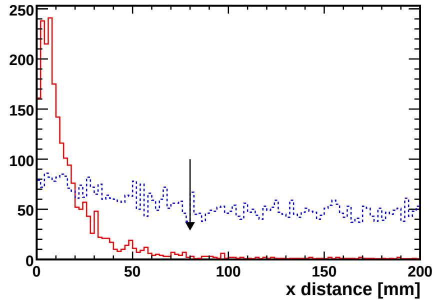

Figure 10 Distance in x between the extrapolations of the 2D Velo and the T tracks to the center of the magnet used to select the tracks. The solid line is for muons from b or c hadrons and the dashed is for other tracks.

where $dSlope$ is the change of x slope due to the magnetic field, and θ is the angle of the track with respect to the beam axis. The values of the parameters are empirically chosen. In Figure 11 the χ^2 distributions for correct and wrong matches are shown, guiding us to choose a value of $\chi^2 < 6$.

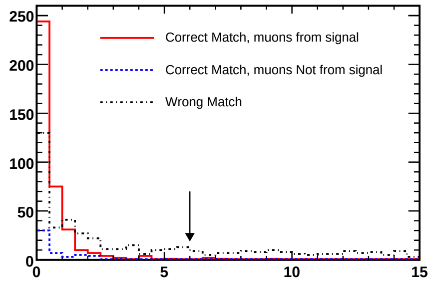

Figure 11 χ^2 of Velo 3D–T match distribution.

With the matched 3D tracks the momentum is recalculated [6] using Velo and T information. A resolution of 1.3% is achieved as shown in Figure 12, which is the final resolution for muons in Hlt1. The efficiency of the matching for offline true muons from signal is 98.0%. The average number of tracks is 1.8 for signal events and 0.20 for minimum bias. Their distributions are shown in Figure 13. At this point we have a retention of 101 kHz minimum bias events.

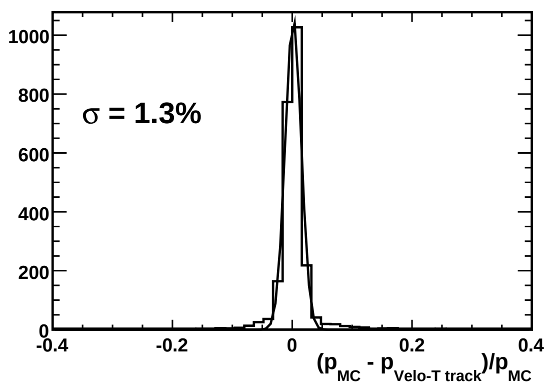

Figure 12 Momentum resolution of the Velo 3D combined with T tracks.

Hlt1 candidates from L0 confirmed tracks As the last step in the reconstruction part of the alley the identification of the candidates which will enter the decision part of the alley is performed.

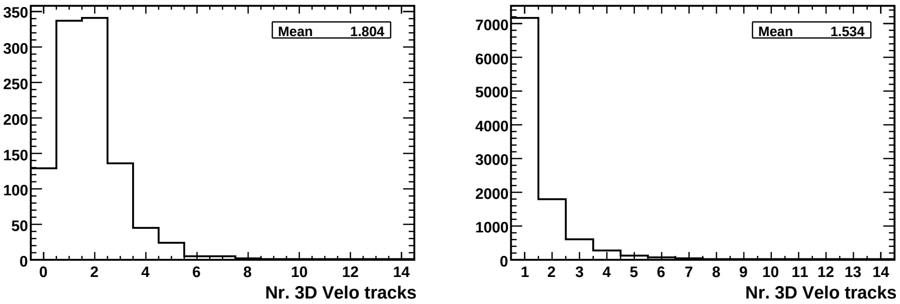

Figure 13 Number of space Velo tracks matched with T tracks. left: for signal events, right: for minimum bias events; the empty events are not shown.

For the L0 Single line this is straightforward: all confirmed Muon Tracks are candidates in input to the decision algorithm. For the Dimuon line originated from L0Dimuon the sample of confirmed Muon Tracks is used to build dimuon pairs on which decision will be applied. Both muons from the L0DiMuon triggers are required to be confirmed.

One of the Dimuon line is originated by L0 Single combining two L0Muon confirmed tracks. The candidates are obtained taking all pairs of confirmed Muon Tracks.

4 Additional algorithms for the DiMuon Line

As explained before to improve the trigger efficiency on dimuon events a dedicated dimuon reconstruction is executed in case of L0Single triggered events. After the positive confirmation of the L0Muon in L0Single Muon triggered events additional muons not reconstructed by L0 are searched. The first step is to reconstruct tracks in the muon stations alone. The next step is to confirm the additional muons with the same strategy already described for the L0Muon.

Creation of Muon Segments The reconstruction of additional muons, called muon segments, is done according to the following procedure [7]. Taking M_5 hits as seeds, this algorithm basically consists in extrapolating a partial segment ($M_5 - M_{i+1}$) to station M_i. When hits are found in all stations from M_5 to M_2, a muon segment is created. To save CPU time the M1 information is not used so the muon segment inverse momentum resolution ($\sigma(1/p)/(1/p)$) is worse than the one for L0 muon candidatess, $\approx 35\%$, as shown in Figure 14.

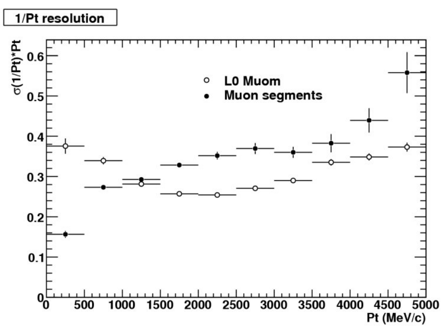

Figure 14 Inverse Momentum resolution of the L0 muon candidates (open circles) and muon segments infunction of the particle momentum.

In order to avoid to reconstruct the same muon segments already reconstructed as a L0 muon, only the ones that do not share M3 and M2 hits with a T confirmed L0muon are selected. After this procedure, the average number of muon segments is reduced to 1.1 and 0.08 in signal and minimum bias respectively. These distributions are shown in Figure 15.

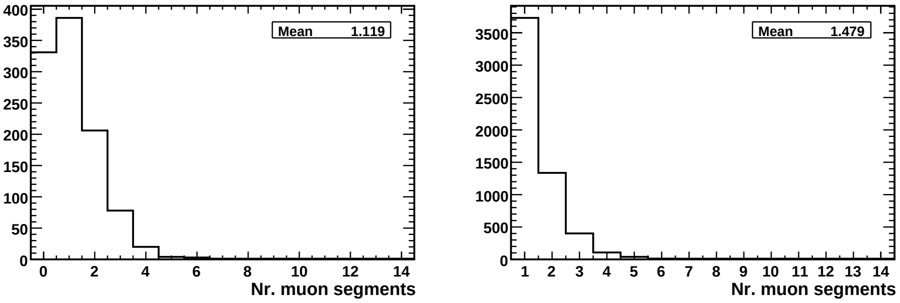

Figure 15 Number of selected muon segments reconstructed in an event. In the left is presented the number for the signal while in the right for minimum bias events for non empty events.

As can be seen in Figure 16, the momentum distribution of the muon segments is more concentrated in lower values than the one for the L0 muons.

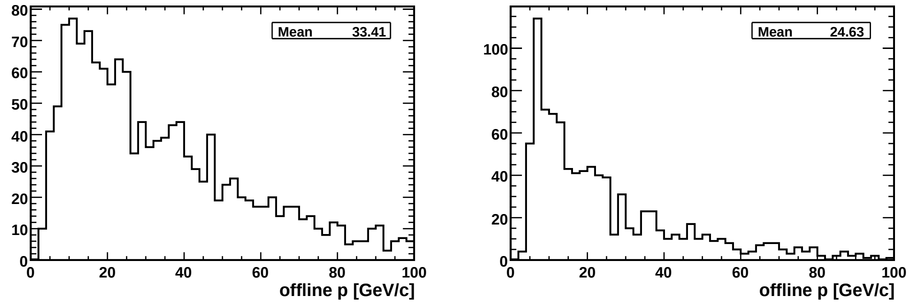

Figure 16 Offline momentum distribution of the L0 muons (left) and muon segments (right).

Muon Segment Matching In the same way as happens with the L0 candidates, a muon segment is extrapolated to the T stations seeking for a confirmation. The lower momentum spectrum of muon segment and the missing of M1 point produces larger extrapolation errors of muons in T stations so the search windows of the T reconstruction algorithm is set to larger values, as shown in Table 4.

	R1	R2	R3	R4
σ_x [mm]	22	43	86	160
σ_y [mm]	9	23	44	47

Table 4 Position resolution of extrapolation to T3 of muon segment in x and y for each Muon Chambers region.

Because of the large window opened, a larger number of T tracks is found for each muon segment. This number in signal is 3.5, to be compared with 1.6 for L0muons. The overall efficiency of finding the T track is 92.2%, lower compared to the ones from L0 muons (96.4%) and it is shown as a function of momentum in Figure 17.

The average number of T tracks per event from muon segments is 2.7 for signal and 0.2 for minimum bias events.

The same momentum confirmation – $(P_{(Ttrack)} - P_{muonsegment})/P_{(Ttrack)}$ cut – and "IsMuon" refinement is used to clean up the T tracks. The overall efficiency of this procedure is 88.0%, shown if Figure 18 as a function of momentum. The number of tracks at this level is 1.3 in signal events and 0.1 for minimum bias, distributed as shown in Figure 19.

The T track originated by a muon segment confirmation has a quality in term of reconstruction accuracy identical to the T tracks originated by L0muon candidates confirmation. As a consequence the

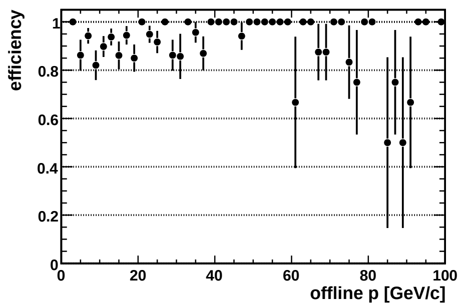

Figure 17 efficiency of finding a T track from muon segments, for offline reconstructed true muons as a function of the momentum of the offline reconstructed track.

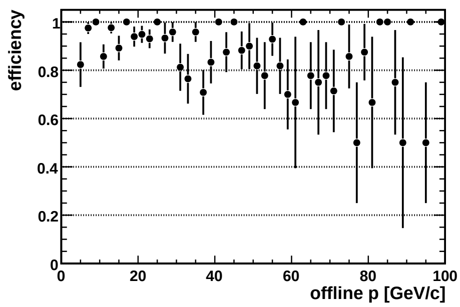

Figure 18 efficiency of IsMuon procedure for offline reconstructed true muons from b or c hadrons

matching of Velo tracks with T tracks originated by muon segment confirmation follows exactly the procedure described in previous paragraph. The overall efficiency of finding a matched 3D track to a T track from a muon segment is 98.0% the same as for matching T tracks from L0 muons. The number of tracks at this point is 1.1 for signal events and 0.09 for minimum bias. Their distributions are shown in Figure 20.

Hlt1 triggering candidates from L0 confirmed tracks and muon segments Dimuon pair are reconstructed from a L0Muon confirmed tracks and a muon segments confirmed tracks. The dimuon pair is the input of the Hlt1DiMuonMuonSeg decision algorithm.

5 Hlt1 Muon Alley reconstruction performance

At this point, we can compute the efficiency of the muon alley reconstruction in selecting the event. This is done by using the Hlt1 benchmark channels with muons:

- 1028 off-line selected $\mathrm{B_s} \to \mathrm{J}/\psi(\mu^+\mu^-)\phi$ events accepted by L0.
- 1164 off-line selected $\mathrm{B_d} \to \mathrm{K}^*\mu^+\mu^-$ events accepted by L0.
- 1075 off-line selected $\mathrm{B_s} \to \mu^+\mu^-$ events accepted by L0.
- 985 off-line selected $\mathrm{B} \to \mathrm{D}^*\mu^+\nu_\mu$[g] events accepted by L0.

To check the ability of trigger in selection interesting events for offline analysis the performance have been evaluated on the events accepted by the selection developed by the analysis group for optimizing the measurements the channels are involved. In Table 5 are shown the efficiencies for each confirmation step described in Section 3 for Single muons and DiMuons originated from 2 L0 candidates, while Table 6 shows the efficiencies for Dimuons from L0 Dimuons line and Table 7 shows the equivalent for Dimuons originated by one muon segment and one L0 candidate (Section 4.)

[g] A combination of $\mathrm{B_s} \to \mathrm{D_s^{*-}}\mu^+\nu_\mu$, $\mathrm{B_d} \to \mathrm{D}^{*-}\mu^+\nu_\mu$ and $\mathrm{B}^+ \to \mathrm{D}^{*0}\mu^+\nu_\mu$.

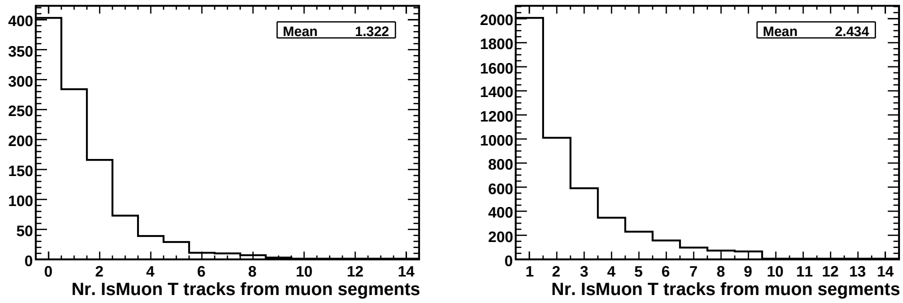

Figure 19 Number of T tracks per event after IsMuon procedure. In the left is presented the number for the signal while in the right for minimum bias events for non empty events.

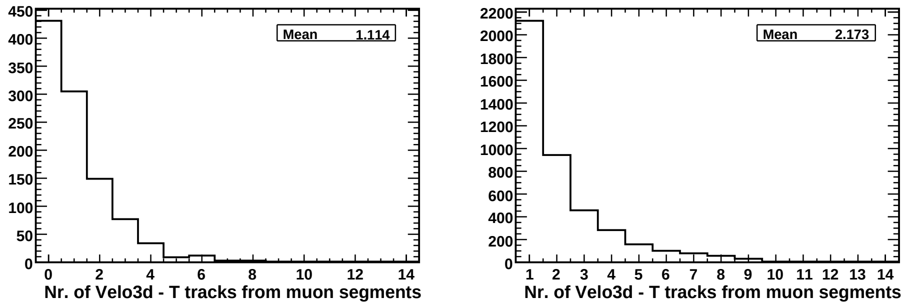

Figure 20 Number of Velo 3d–T tracks per event. In the left is presented the number for the signal while in the right for minimum bias events for non empty events.

6 Trigger Decision

Once we have the tracks reconstructed, the Hlt1 applies cuts in order to keep the minimum bias rate as low as required. In this section we list the variables that needs to be tuned for each one of the eight sub alleys described in Section 2.

A Single Muon Event: To save events with Single muons we select events with Hlt1 muons originated from L0 muon candidates that

- do not point to any primary vertex: minimum of $\mathrm{IP_{PV}} > \mathrm{Hlt1SMuIPCut}$
- has a minimum $\mathrm{P_T}$: $\mathrm{P_T} > \mathrm{Hlt1SMuLowPtCut}$

The efficiency of the cut is shown both for $\mathrm{P_T}$ and $\mathrm{I_P}$ in Figure 21 for $\mathrm{B_s} \to \mathrm{J}/\psi\phi$ events. The value of the cuts can be decided based on the plot of efficiency with respect to the minimum bias retention as shown in Figure 22.

channel	$B_s \to J/\psi\phi$	minimum bias retention (kHz)
Nr. of selected events	100%	226.0
L0 Single Muon with $P_T > 1.3$ GeV/c	90.5%	206
T Confirmation	89.9%	151
Momentum Confirmation and "IsMuon"	89.5%	128
VeloRZ Match	88.9%	116
Velo3D Match	88.9%	101
Pair of Tracks with DOCA < 0.5mm	50.0%	22.9

Table 5 Retention of events in each confirmation step in the Single muon line.

channel	$B_s \to J/\psi\phi$	minimum bias retention (kHz)
Nr. of selected events	100%	226.0
L0 Dimuon Trigger	64.5%	44.3
with Sum $P_t > 1.5$ GeV/c	64.4%	41.8
T Confirmation	64.4%	40.3
Momentum Confirmation and "IsMuon"	64.2%	38.3
VeloRZ Match	64.2%	36.8
Velo3D Match	64.1%	32.9
Pair of Tracks with DOCA < 0.5mm	54.2%	16.7
From L0 pair	53.0%	11.3

Table 6 Retention of events in each confirmation step in the Dimuon from L0 Dimuon line.

A High P_T Single Muon Event To get jet events without any proper time bias we trigger on a Single muon without any I_P cut but with a high P_T threshold. That is an event with a Hlt1 muon candidate from L0 muon that

- has a minimum P_T: $P_T > \mathrm{Hlt1SMuHighPtCut}$

DiMuons As already mentioned, there are 3 DiMuon sub-alleys, one made of 2 L0 confirmed muons originated by L0 Single muon trigger, one made of 2 L0 confirmed muons originated by L0 Dimuon trigger, and another made of 1 confirmed L0 muon and a muon segment. Each one of these are separated into two: Dimuons with IP cut and Dimuons without IP cut. The Dimuons without IP cuts are required by channels with $J/\Psi \to \mu^+\mu^-$ where the lifetime should be unbiased (hence no IP cut) and a high mass cut can be applied. To trigger the $B_d \to K^*\mu^+\mu^-$ events as Dimuons, a high mass cut can not be applied, but in order to keep the minimum bias retention as low as needed, an IP cut is necessary. So, for each one of the 3 DiMuon sub-alleys we will have:

- Dimuons with I_P cut
  - The distance of closest approach between the tracks (DOCA) has a maximum value: $\mathrm{DOCA}(\mu\mu) < \mathrm{Hlt1DiMuMuDOCACut}$.
  - The impact parameter of both muons, with respect to one primary vertex has a minimum value: $\mathrm{Min_{IP}}(\mu) > \mathrm{Hlt1DiMuIPCut}$.
  - The di-muon invariant mass has a minimum value: $\mathrm{Mass}(\mu\mu) > \mathrm{Hlt1DiMuLowMassCut}$.
- DiMuons without I_P cut

channel	$B_s \to J/\psi\phi$	minimum bias retention (kHz)
Any L0 Muon Trigger	100.0%	226.0
L0Muon Confirmed with Velo 3d	97.8%	101.0
At least one muon segment reconstructed	97.8%	101.0
selection of muon segments	75.8%	56.2
T Confirmation	72.4%	52.9
Momentum Confirmation and "IsMuon"	67.5%	47.7
VeloRZ Match	66.8%	46.2
Velo3D Match	64.4%	43.3
Pair of 1L0 + 1 muon seg with DOCA $<$ 0.5mm	60.7%	25.5

Table 7 Retention of events in each confirmation step in the alley with muon segments. The value in the first line of the signal is with respect to the number of events selected and each subsequent line is with respect to the previous one.

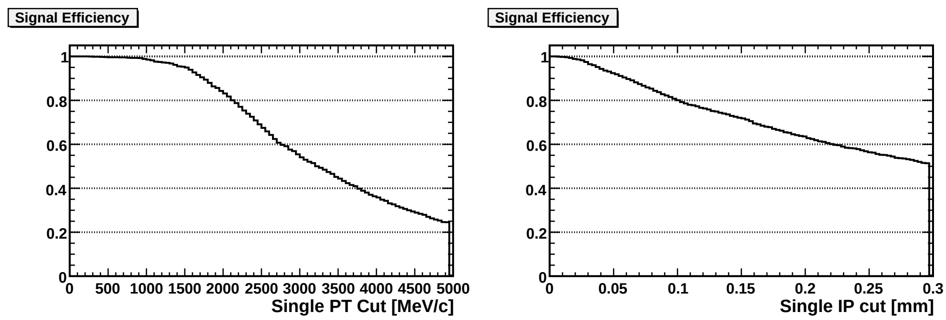

Figure 21 Efficiency of the cut used to take the decision of being a Single Muon Event in $B_s \to J/\psi\phi$ as function of the value of the cut. In the left is presented the P_T cut while in the right is the I_P

– The distance of closest approach between the tracks (DOCA) has a maximum value: $\mathrm{DOCA}(\mu\mu) < \mathrm{Hlt1DiMuMuDOCACut}$.

– The minimum value for its invariant mass: $\mathrm{Mass}(\mu\mu) > \mathrm{Hlt1HighMassWindowCut}$.

It is interesting at this point to look at the Hlt1 reconstruction efficiencies of an "or" of all the three DiMuons before any IP or mass cut. Table 8 shows these numbers for the channels of interest.

The values of the cuts will be chosen as a compromise between the efficiencies for each channel and the bandwidth requirement. Figure 23 shows the efficiency of the IP cut in the DiMuon alley with one muon segment, for $B_d \to K^*\mu\mu$ events as a function of the cut, and in the same Figure, the efficiency as a function of the minimum bias retention is presented.

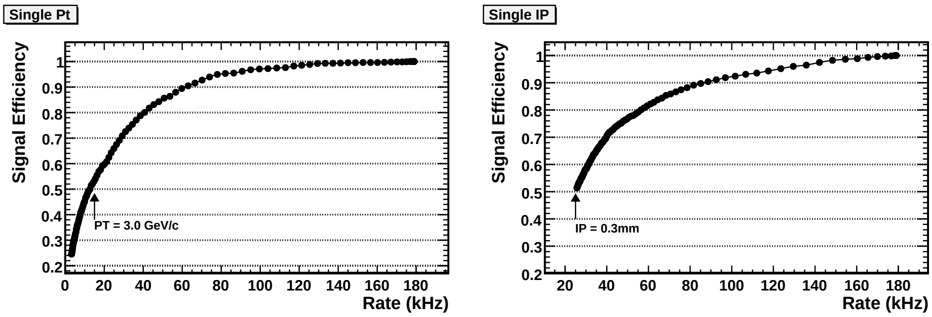

Figure 22 Efficiency of the cut used to take the decision of being a Single Muon Event in $B_s \to J/\psi\phi$ as a function of the minimum bias retention. When the P_T cut is varied the I_P is kept constant and vice versa. The P_T has been varied from 0 to 5 GeV/c in steps of 50 MeV/c. The arrow shows as an example, the value of the cut for a minimum bias retention of 15 kHz (25kHz in the IP plot). The I_P varied from 0 to 0.3mm in steps of 0.003mm

		Single	Any Dimuon	All
Minb retention	[kHz]	101.4	39.5	104.2
$B_s \to J/\Psi\Phi$	ε[%]	97.5	83.8	96.2
$B_s \to \mu\mu$	ε [%]	98.4	89.6	98.1
$B_d \to \mu^+\mu^-K^*$	ε [%]	95.4	80.0	93.4
$B \to D^*\mu^+\nu_\mu$	ε [%]	92.1	28.1	87.9

Table 8 Signal efficiencies for each of the studied channels without applying the final cuts. The efficiencies are calculated with respect to any L0 muon trigger, except for the column labeled “Single” which is with respect to the Single L0 muon trigger.

To illustrate an example of cuts, we have chosen a set that gives about 17 kHz of minimum bias retention, which is:

Hlt1SMuLowPtCut	$>$	1.3 GeV/c
Hlt1SMuIPCut	$>$	0.08 mm
Hlt1SMuHighPtCut	$>$	6.0 GeV/c
Hlt1DiMuMuDOCACut	$<$	0.5 mm
Hlt1DiMuIPCut	$>$	0.15 mm
Hlt1DiMuLowMassCut	$>$	0.5 GeV/c^2
Hlt1HighMassWindowCut	$>$	2.5 GeV/c^2

This gives the efficiencies shown in Table 9.

In order to have an overview of the retention in each step, we present in Figure 24 the efficiency for each one of the four alleys for $B_s \to J/\psi\phi$ events. The efficiency is with respect to events entering the line. In the same Figures are presented two other curves: when the trigger was on at least one of the B daughters, and when both muons were responsible for the trigger. Looking at the dashed curve of the two plots at the left, we can see that very often not both muons were present in the L0 muon trigger, that is the reason for using muon segments.

		Single	Dimuon NoIP	Dimuon IP	All
min bias retention	[kHz]	11.6	4.0	2.7	16.6
$B_s \to J/\Psi\Phi$	ε [%]	78.0	79.4	48.2	91.4
$B_s \to \mu^+\mu^-$	ε [%]	97.3	87.9	85.1	97.8
$B_d \to \mu^+\mu^-K^*$	ε [%]	88.2	29.4	62.3	90.8
$B \to D^*\mu^+\nu_\mu$	ε [%]	76.7	10.3	12.1	76.8

Table 9 Signal efficiency for each of the studied channels. The efficiencies are calculated with respect to any L0 muon trigger, except for the column labeled “Single” which is with respect to the Single L0 muon trigger.

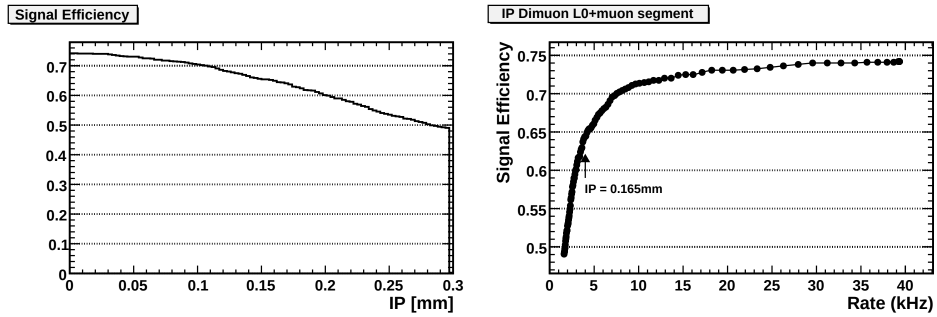

Figure 23 $B_d \rightarrow K^*\mu\mu$ efficiency of the cut used to take the decision of being a DiMuon Event with IP as function of the value of the cut in the left, and as a function of the minimum bias retention in the right. The I_P varied from 0 to 0.3mm in steps of 0.003mm.

Overlap among Dimuons suballeys – In order to quantify the actual contribution of the muon segment alley, one can look at the overlap between this alley and the dimuon from L0 dimuon. In the $B_s \rightarrow J/\Psi\Phi$ for example, 24.0% of the selected events are triggered by the muon segment alley with no IP cut and not by the dimuon from L0 dimuon. For $B_d \rightarrow \mu^+\mu^- K^*$ this number is 15.0% for the IP cut line.

As expected, the dimuons made from 2 confirmed L0 single muons do not contribute to the trigger, all the events triggered by this alley are already in the dimuon from L0 dimuon. This alley is kept anyway, at least at the starting of LHC, in order to be protected against any eventual L0 dimuon problem.

7 What is passing the Single muon alley

In order to understand the background in the Hlt1 muon trigger, the truth origin of the tracks that fires the Single muon alley in minimum bias events has been investigated. An association with a true Monte Carlo particle is considered good if they share more than 70% of the hits in the detector. In case this number of hits is smaller, it is considered as a ghost track. The classification is the following:

- 43.3% Have same MCParticle associated to the T track and to the Velo 3D track
  - 56.9% of these are muons from hadrons cointaing b or c quarks
  - 8.6% are muons from pions or kaons
  - 34.5% are not muons
- 27.8% have different MCParticle associated to the T track and to the Velo 3D track.
- 28.2% are ghosts, either from Velo3d or T track
  - 64.0% of these are ghost only from Velo
  - 25.0% are ghost only from T
  - 11.0% are ghost from both, T and Velo

The high contamination of wrong Velo 3D–T Match is right now being addressed and there is a hope of lowering this background.

8 Hlt1 Muon Alley Variables

In this section we summarize all the variables that needs to be set for a run, with its default value tuned with Monte Carlo data.

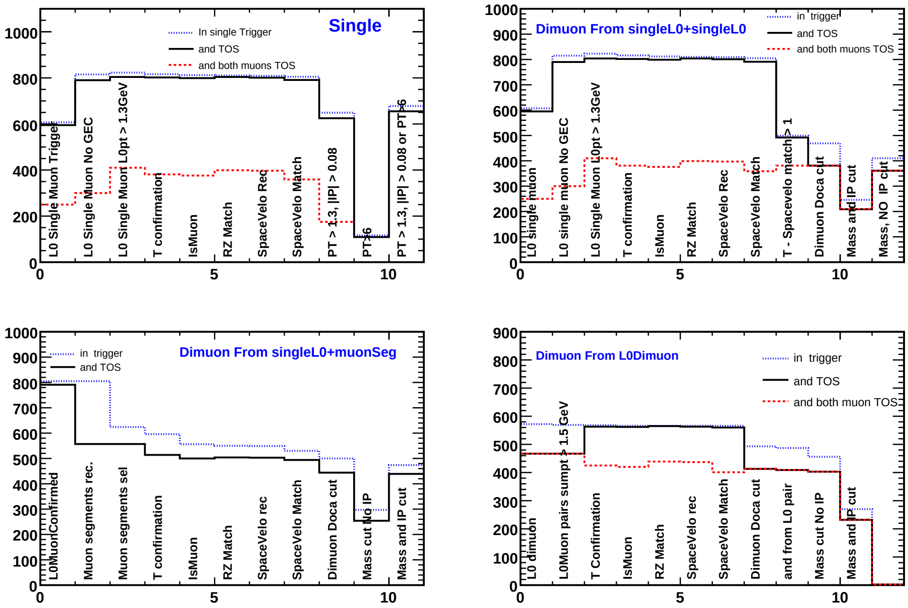

Figure 24 Retention for each step of each sub-alley for $B_s \rightarrow J/\psi\phi$ signal events with respect to events entering the line. The dotted line is for anything present in the trigger, the solid line is for events were at least one of the B daughter was responsible for the trigger, and the dashed is when both muons are present in the trigger. Upper left: Single muon steps; upper right: Dimuons from 2 L0 muon candidates triggered by L0 Single muon; bottom left: Dimuons from 1L0 + 1 muon segment; bottom right: Dimuons from L0 Dimuons.

L0 Confirmation	T Track finding L0μ	σ_x, σ_y – 4 Regions	8
		n σ	1
	T Track cleaning	IsMuon	3×4
		dp/p for 4 p bins	5
	Velo-T 2D	dist_x^{2D}	1
	Velo-T 3D	χ^2	1
	μSegment		R(4)×S(3)×D(2)
	T Track finding	σ_x, σ_y – 4 Regions	8
		n σ	1
	T Track cleaning	IsMuon	3×4
		dp/p for 4 p bins	5
	Velo-T 2D	dist_x^{2D}	1
	Velo-T 3D	χ^2	1
Trigger	Singleμ	Low P_T and IP	2
	Singleμ High P_T	High P_T	1
	Diμ Low mass	Low Mass, IP and DOCA	3×3
	Diμ High mass	High Mass and DOCA	2 ×3
Number of Parameters			98

Actually this 98 can be reduced to 56 for the following reasons:

- σ_x and σ_y will be scaled for each region (2 X 8 becomes 2 X 2) for both L0muons and muon segments.
- The 3 X 4 for the IsMuon will be the same for T tracks from L0muons and from muon segments.
- The 5 parameters for dp/p will be the same for T tracks from L0muons and from muon segments.

- The dist_x^{2D} and χ^2 will be the same for T tracks from L0muons and from muon segments.
- The values of the Mass, IP and DOCA will most likely be the same for the 3 dimuons (3 X 3 + 2 X 3 becomes 4)

9 Start-up Scenario

There are two main points concerning the start-up scenarios that are relevant for the Hlt1 Muon Alley: machine luminosity [8] and LHCb operating conditions.

LHC should start up delivering to LHCb 1 collision per cycle. This number should increase to 19, then to 68 before reaching the nominal value of 2622. This will allow us to turn on the Hlt1 Muon alley gradually, which will be useful for debugging and calibrating it.

There are two important issues related to LHCb operational conditions: low energy beam injection and beam quality. LHC will start colliding 450 GeV protons beams. At this energy the LHCb magnetic field can not be turned on. Only when the machine operates at higher energies (5 Tev or 7 TeV beams) LHCb will be able to perform momentum measurements. Also VELO will only be turned on when the beam conditions are under control. IP and precise $\mathrm{P_t}$ measurements will be available only after some time of operation.

The muon alley will be gradually activated according to the following scheme:

- Low energy collisions and low luminosity. The Hlt1 Muon Alley will not be turned on. LHCb will operate with *Random* or *Interaction* triggers.
- Low energy collisions and moderate luminosity. The Hlt1 Single Muon Alley will be partially turned on. It will consist of the confirmation of the L0 Muon Candidate with T tracks with the IsMuon procedure.
- High energy collisions, moderate luminosity without VELO. With the magnetic field on it will be possible to turn on the momentum confirmation procedure and the Hlt1 Single Muon Alley with High $\mathrm{P_t}$ could be turned on but without VELO Matching. The P_T cut value will be chosen according to the allowed bandwidth.
- High energy collision, moderate luminosity with VELO. It will be possible to turn on the Hlt1 Single Muon Alley with both decisions. After some calibration the Hlt1 DiMuon Alleys could be turned on gradually.
- High energy collisions, high luminosity with VELO. Hlt1 Muon Alley is fully operational.

From an offline analysis of the the first recorded data a B-enriched sample will be produced. Whenever possible, the cut values presented in Section 8 will be determined using the same procedures described in this note using this sample, otherwise Monte Carlo will be used.

10 Summary Box Content

In order to have an idea of the size of the data stored by muon alley in triggered events we list in Table 10 the names of Hlt1 muon containers that will be saved in normal mode with the average number of objects. These numbers have been obtained with the cuts used in this note. At each step of the trigger, the value of the variable used to select each track or vertex is stored with it. In Table 11 we list the number of these information saved in each object. The size of the containers can also be expressed in term of bytes. Each track has 6 states (x, y, z, dx/dz, dy/dz, q/p), 6 values of the applied cuts, about 38 hits in the detector, and a key, which gives 252 bytes. Each vertex has 3 informations (Mass, IP, Doca) and the keys of the tracks that makes the vertex, giving a total of 32 bytes.

	$B_s \to J/\Psi\Phi$
Hlt1MuonSingleDecision	1.1 Tracks
Hlt1MuonDiMuon2L0WithIPDecision	0.4 Vertices
Hlt1MuonDiMuon2L0NoIPDecision	0.7 Vertices
Hlt1MuonDiMuonMuonSegWithIPDecision	0.5 Vertices
Hlt1MuonDiMuonMuonSegNoIPDecision	0.8 Vertices
Hlt1MuonDiMuonWithIPDecision	0.4 Vertices
Hlt1MuonDiMuonNoIPDecision	0.7 Vertices

Table 10 Size of each final summary box.

Infos	
Nr. LHCBId's / Track	**38**
Nr. info / Track	L0 P_T, IsMuon, dist (T-2d), χ^2 (T-3d), Velo-T PT,IP – **6**
Nr. info / Vertex	Mass, IP, Doca – **3**

Table 11 Size of what is saved in each object - track or vertex.

11 References

[1] The LHCb detector at LHC / The LHCb Collaboration / 2008 JINST 3 S08005.

[2] LHCb Muon System Technical Design Report / The LHCb Collaboration / CERN-LHCC-2001-010.

[3] L0 Confirmation with fast, Tsa based tracking in the T-stations / Albrecht, J; Needham, M; Terrier, H / LHCb-2007-118; CERN-LHCb-2007-118, 2007.

[4] The Performance of the LHCb Muon Identification Procedure / Gandelman, M; Polycarpo, E. / LHCb-2007-145; CERN-LHCb-2007-145, 2008.

[5] LHCb Vertex Locator Technical Design Report / The LHCb Collaboration / CERN-LHCC-2001-011.

[6] The Forward Tracking: Algorithm and Performance Studies / Callot, O.; Hansmann-Menzemer, S / CERN-LHCb-2007-015, 2007.

[7] Muon identification in the LHCb High Level Trigger / Satta, A. / CERN-LHCb-2005-071, 2005.

[8] LHC bunch filling schemes for commissioning and initial luminosity optimization / Ferro-Luzzi, M; Herr, W; Pieloni, T. / CERN-LHC-Project-Note-415, 2008.