HLT2 exclusive selections for $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$

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Abstract

We present the HLT2 exclusive selections for the radiative decays $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$, the description of the cuts and their performance. Assuming the nominal LHC conditions (using DC06 simulated data), the selection efficiency for $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$ (on L0 and HLT1 stripped) events was found to be 92% and 77% respectively, for a background rate of 16 and 55 Hz. Assuming a lower than nominal LHC energy and visible interaction rate at LHC*b* (using MC09 simulated data), the selection efficiency was found to be 89% and 77% (on L0 and HLT1 stripped) $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$ events, respectively and the total background retention of both the selections combined is estimated to be 2-3% of the trigger bandwidth.

Contents

1 Introduction

The LHCb trigger comprises of a hardware trigger called L0, and a software or High Level Trigger (HLT) which is further divided into two levels, HLT1 and HLT2. The L0 trigger decision is based on high p_T muons, hadrons, electrons and photons. Events passing the L0 are processed by the HLT1 trigger, which confirms the L0 candidate, and depending on the type of the L0 candidate, uses information from the tracking units and the VELO to perform some high level reconstruction. Finally, HLT2 algorithms are run over all events passing HLT1 and the output is written to tape. The HLT2 consists of inclusive and exclusive lines, where the inclusive lines are for example, the dimuon(electron), single muon (electron), B→DX, $\phi \to KK$ lines etc, and aim to select many channels with a common signature. The exclusive lines aim to select particular decays like B→DK^*, $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$ etc.

The combination of L0 and HLT1 trigger are optimized using benchmark channels of the physics program of LHCb [4] while the HLT2 optimization is done depending on the particular selection.

In the nominal LHC conditions, the L0 and HLT1 are designed to reduce the rate from 40 MHz to 1 MHz and from 1 MHz to about 30 kHz respectively. Events from the LHC*b* trigger can be written to tape at a rate of 2 kHz, so for an HLT1 output rate of 30 kHz, the HLT2 algorithms are needed to provide a reduction in the rate, by a factor of 20.

Following the announcement that the LHC will deliver significant data at lower energies and luminosities different from nominal, a few minimal L0xHLT1 optimization scenarios have been defined, with cuts chosen so as to give more bandwidth to either charm physics, leptonic B decays or hadronic B decays etc and different levels of the trigger can be chosen to run depending on the LHC running conditions

For this note, we have considered two scenarios for the LHC running conditions. One is the nominal LHC energy (and luminosity) scenario, for which we have used the DC06 simulated data. The other scenario assumes an energy of 10 TeV for which we have used the MC09 simulated data. For the optimization of the HLT2 selections, we have used L0 and HLT1 stripped signal and background samples and they are summarized in table 1.

Throughout this note, whenever the results from the HLT2 optimization on DC06 and MC09 data are quoted, their differences are due to the different LHC running conditions assumed in the both the simulations and also the different L0 and HLT1 settings that the data sets from the two simulations are stripped with. Small difference can also be contributed by different detector descriptions in both these simulations, as MC09 has a more up-to-date detector description compared to DC06.

2 Triggering Radiative decays of B mesons at LHCb

Radiative decays are excellent probes of new physics and are among the six key measurements to be made at LHCb. LHC*b* aims to measure interesting physical quantities and search for New Physics in several radiative decays, the most important of which are $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$. Their signal yield for 2 fb^{-1} worth of data has been estimated to be 11,000 and 68,000 events respectively. In fact, even with 100 pb^{-1}, LHCb can be competitive with the current measurements of the direct CP asymmetry in $B_d \to K^*\gamma$ channel.

Radiative decays have a dedicated HLT1 alley, called the Electromagnetic alley, which heavily exploits the unique decay kinematics of the signal. This alley consists of three independent lines, corresponding to L0 photon, electron and π^0 candidates (the π^0 line is not implemented at the moment). Radiative decays are mainly triggered by the photon line (see sec 2.1 and [2] for details) which selects events based on the presence of an isolated high energy photon and two tracks with some minimum requirements on the photon energy, track impact parameter (IP) and transverse momentum (p_T) and their vertex quality.

2.1 The HLT1 Photon line

In the trigger environment, a sizeable fraction of the photons from $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$ offline selected events actually fire the L0 electron trigger [2]. So the HLT1 photon line is executed if the L0 candidate is a photon or an electron. The line begins with photon confirmation by performing fast clusterization in the ECAL region close to the L0 photon candidate, followed by cuts on cluster shape variables to remove merged π^0. This reduces the minimum bias rate by a factor of 3 while retaining 85% of the offline selected signal events. After this step, the 2D VELO reconstruction is used to select tracks with a 2D IP of greater than 0.1 mm, on which the 3D VELO reconstruction is performed. Out of these tracks, the ones with a 3D IP of greater than 0.15 mm are reconstructed in the tracking stations and at least one track is required to have a P_T greater than 650 MeV. The rate reduction at this stage is enough to allow the full 3D VELO reconstruction, after which tracks with a distance of closest approach (DOCA) less than 0.2 mm and a P_T greater than 700 MeV are selected and required to make a two track vertex. The vertex is required to be forward, i.e. $\Delta z > 0$ between the primary and secondary vertices. The photon is then added to this vertex without making any further cuts. The cuts are chosen to keep maximum efficiency on the offline selected events, while keeping the minimum bias rate acceptable. The above mentioned cuts in the HLT1 photon line have been tuned on DC06 simulation, assuming the nominal LHCb luminosity, and are subject to change according to the running conditions this year.

In table 3 the trigger cuts for the two trigger settings used to strip signal and background samples for this study are reported. Note that the photon and electron thresholds have not being changed between the two settings. Any extra efficiency on $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$ when considering the lower energy (MC09 in the table) comes from the loose hadron thresholds.

Table 1 Description of the different trigger thresholds used for the L0 and HLT1 stripping of the samples used in this study.

Threshold	DC06 MeV, mm	MC09 MeV, mm
L0-hadron	3840	860
L0-μ	1200	120
L0-e, γ	2800	2800
HLT1-hadron p_T, IP	1600, 0.09	250, 0.06
HLT1-μ p_T	6200	1000
HLT1-e p_T, IP	2820, 0.13	2820, 0.13
HLT1-γ p_T, IP(track)	2800, 0.15	2800, 0.15

The next stage in selecting radiative decays is the HLT2 and the present study focuses on the HLT2 selection for $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$.

3 HLT2 selections for $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$

3.1 Selection philosophy

The trigger selections have to be optimized to attain maximum efficiency v/s background retention on signal events, but care is needed to avoid biasing physics measurements due to trigger cuts. An example is the lifetime acceptance function which is sensitive to any IP cut made at trigger level [1]. For this purpose, we have chosen not to introduce any more cut variables in the HLT2 selections than those used in the offline selections (described here [3]) for these decays. In the trigger environment, it is likely that the estimates for these quantities are not optimal, and so the cut values for the HLT2 selections were chosen to be less strict than the offline values and at the same time, achieve the highest efficiency for a given background rate.

In table 2, we list the offline cut variables and their cut values, and the corresponding cut values chosen in the HLT2 selections optimized on DC06 and MC09 data samples. Also tabulated are the cuts for the monitoring lines added to the HLT2 selections of both channels. Due to their high background retention rate, the monitoring lines for $B_s \to \phi\gamma$ are prescaled by a factor of 10 while the ones for $B_d \to K^*\gamma$ are prescaled by a factor of 20.

It is important to note that these decays are also triggered on by various hadron triggers with reasonable efficiencies, but such triggers cut on the p_T and IP of the hadron, which is not desirable for the offline analysis of radiative channels, since it complicates the systematic effects [1].

Table 2 Details of the two LHC running scenarios considered in this note and the simulated samples used in each case for this optimization study. The signal events are the events that pass the selection criteria described [3] while for background, minimum bias events are considered. The number of events (both signal and background) quoted here are after the respective L0 and HLT1 stripping.

LHC energy	Visible interaction rate at LHCb	L0 and HLT1 used for sample stripping	Number of signal events $B_s \to \phi\gamma$ ($B_d \to K^*\gamma$)	Number of background events	Simulation	DaVinci version
14 TeV	10 MHz	described in [2], table. 1	2500 (380)	60,000	DC06	v23r1p1
10 TeV	320 kHz	described in table. 1	3100 (1600)	68,000	MC09	v24r2p1

Table 3 Description of the cuts made on $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$ and the cut values used in the offline and HLT2 selections (numbers in brackets are for the cut made for the $B_d \to K^*\gamma$ selection)

Cut Description	Offline value	(DC06)HLT2 value	(MC09)HLT2 value
χ^2significance of the impact parameter (IP) of the charged tracks (K and π) with respect to all primary vertices	>25	>20	>10
χ^2significance of the vertex fit of the ϕ(K*) candidate	<9	<25(16)	<20(16)
maximum (absolute) difference from the PDG mass of ϕ(K*)	<10(55) MeV	<30(120) MeV	<20(80) MeV
monitoring line with a wider (K^*) mass window			<120 MeV
χ^2significance of the IP of the B_s (B_d) candidate with respect to its production vertex (the production vertex of the B candidate is taken to be the vertex with respect to which it has the smallest $IP\ \chi^2$	<9	<25	<20(16)
angle between the B_s (B_d) candidate's momentum and flight direction (also given are the cosine values, see section 3.2)	<10(8) mrad	<63(45) mrad >0.998(0.999)	<63(32) mrad >0.998(0.9995)
monitoring line with a loose cut on the direction angle			>0.99(<141 mrad)
maximum (absolute) difference from the PDG mass of B_s (B_d)	1000 MeV	1000 MeV	1000 MeV
monitoring line with a wide mass window on the B candidate			2000 MeV

Note that the direction angle cut on the B_s or B_d candidate is applied on the cosine of the angle, and not the angle itself, and a < 63 mrad cut on the angle corresponds to a >0.998 cut on the cosine of the angle.

3.2 Signal efficiency and background rates

For the nominal LHC luminosity (DC06 simulation), the cuts mentioned in table 2 result in an efficiency of 92.2 ± 0.5% on $B_s \to \phi\gamma$ signal events and 77.3 ± 2.2% on $B_d \to K^*\gamma$ signal events (the efficiency quoted here is the efficiency with respect to L0 and HLT1 selected events). The minimum bias rates for the two are 16 Hz and 55 Hz (± 2 Hz) respectively. The efficiency v/s rate curves for the two selections are shown in figure 1 where the arrow points to the values achieved by the cuts described in table 2.

The efficiency for finding both signal tracks (in the offline selected and L0 and HLT1 stripped signal samples) in the HLT2 environment is 97% for $B_s \to \phi\gamma$ and 61% for $B_d \to K^*\gamma$. [a]

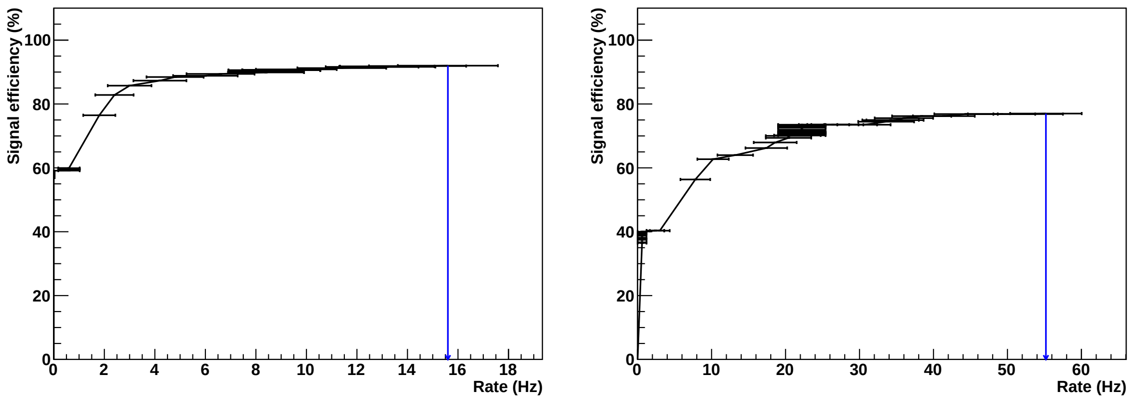

Figure 1 HLT2 rate v/s efficiency for $B_s \to \phi\gamma$ (left) and $B_d \to K^*\gamma$ (right) selections tuned on DC06 data. The arrow indicates the values corresponding to the cut values listed in table 2.

For the 10 TeV and 320 kHz visible interaction scenario (MC09 simulation), the cuts mentioned in table 2 result in an efficiency of 89.4 ± 0.6% on $B_s \to \phi\gamma$ signal events and 76.9 ± 1.7% on $B_d \to K^*\gamma$ signal events (the efficiency quoted here is the efficiency with respect to L0 and HLT1 selected events). From the MC09 stripped minimum bias sample, these selections retain 19 and 58 events respectively. The efficiency v/s min bias retention curves for these selections are shown in figure 2 where the arrow points to the values achieved by the cuts described in table 2. The tracking efficiency for finding all signal tracks is 96% for $B_s \to \phi\gamma$ and 56% for $B_d \to K^*\gamma$.

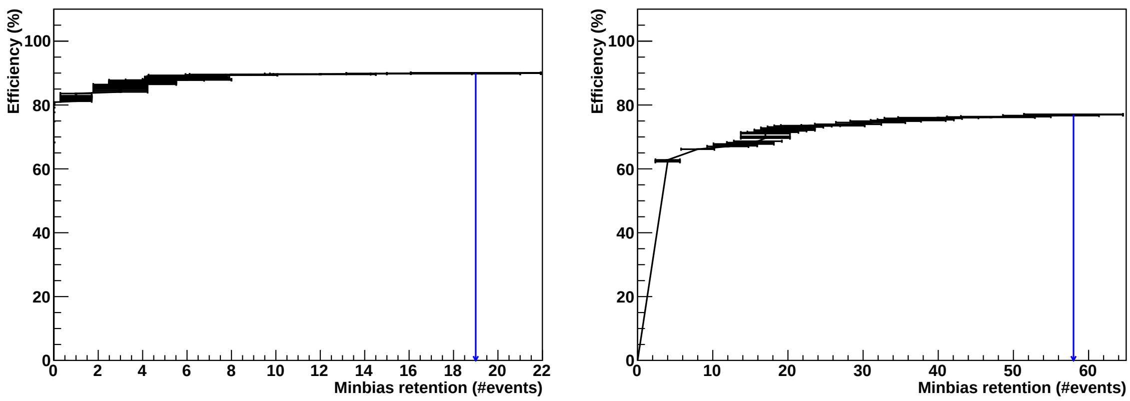

Figure 2 HLT2 background retention v/s efficiency for $B_s \to \phi\gamma$ (left) and $B_d \to K^*\gamma$ (right) selections, tuned on MC09 data. The arrow indicates the values corresponding to the cut values listed in table 2.

It is difficult to quote a trigger rate for these selections for the MC09 study due to different possible running conditions of the LHC, which will require varying rejection factors from the trigger. However,

[a] The efficiency for finding both signal tracks in the HLT2 environment is a measure of how well the HLT2 tracking performs for a certain decay channel. This algorithm looks at all forward tracks made in that event, looks at the monte carlo decay chain (for that certain decay channel) and finds how many tracks were associated to each final state monte carlo particle.

one can calculate the contribution of these selections to the total minbias retention by the entire LHCb trigger. It has been shown that in the strict most trigger scenario, HLT2 has to have a rejection factor of 20 with respect to HLT1 triggered events in order to have an HLT2 output rate under 2 kHz. So for the sample of stripped L0xHLT1 events used in this study, this corresponds to an upper limit of 4300 events that the HLT2 is allowed to trigger on. Neglecting the correlation of the radiative trigger selections with other selections (it is usually very small) the retention of the $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$ trigger lines combined (with monitoring lines) is about 2.5% of the total HLT2 bandwidth.

3.3 Monitoring Lines

The monitoring lines in HLT2, for both $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$ are designed to allow, in the offline analysis, the estimation of any biases produced by different cuts made in the trigger. In the following, we briefly discuss each monitoring line:

- The line with the wider B mass window will potentially allow to see if any structures appear in the background mass distribution
- The line with the wider K^* mass window will allow to see the full K^* line shape, which is a good cross check of various trigger effects in early data. There is no analogous line with a wider ϕ mass window since the mass resolution for ϕ is already quite good in the trigger (4 MeV), and the cut around the mass window is more than three σ
- The line with the very loose cut on the (cosine of) direction angle of the B meson candidate will allow to study effects of this cut on the proper time of the B meson
- There is also a trigger line for $B_s \to \phi\gamma$ and for $B_d \to K^*\gamma$ which uses kaons and pions to which no cut has been applied, so essentially they use every track made in that particular event, to make the ϕ or K* candidate and then combine it with a photon to make a B candidate.

  The other trigger lines use what are known in LHCb as "GoodParticles", which essentially are tracks to which a small momentum (2 GeV), transverse momentum (300 GeV) and IP cut (0.05 mm) has been applied (it is important to remember that the IP cut made on them is smaller than the one made in the Photon alley of HLT1). So the purpose of this monitoring line is to enable one to see the effect of the cuts made on "GoodParticles", if any, on the signal events from the two radiative channels.

3.4 Discussion

One of the requirements for an HLT2 selection is to provide some "knobs" to tune the rate and efficiency of the whole HLT2. The idea will be to optimize all the HLT2 selections globally, and to use these knobs to control the rate if a certain selection retains too much minimum bias. Hence, some of the cuts (as presented in table 2) are chosen to be loose enough for this optimization to not affect the efficiency. This is reflected in the graphs shown in figure 1 and 2, which are almost flat in efficiency over a large range making it possible to gain a factor of 2 or 2.5 in the rate without seriously affecting the efficiency. For these selections, the knobs provided for the global optimazation are the direction angle and IP significance cuts on the B candidate. However, care must be taken in choosing very strict values for these cuts as in the trigger.

4 Summary

We have presented exclusive HLT2 selections for the channels $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$. With DC06 simulation, the minbias rates and are estimated to be 16 and 55 Hz for signal efficiencies (on offline selected, L0xHLT1 stripped events) of 92.2% and 77.3% respectively for the two channels. While with MC09 simulation, their combined minbias retention is roughly 2.5% of the LHCb trigger bandwidth for signal efficiencies (on offline selected, L0xHLT1 stripped events) of 89.4% and 76.9% on $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$ respectively.

5 References

[1] The LHCb Collaboration, B. Adeva et al, *Roadmap for selected key measurements of LHCb*, `LHCb-PUB-2009-029, arXiv:0912.4179v1 [hep-ex]`

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[4] The LHC*b* collaboration, *LHCb Trigger System Technical design report*, CERN-LHCC/2003-031.