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Stripping Selection Studies for $B^0_{(s)} \to \mu^+\mu^-$ Decay Implemented for Stripping 21.

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Abstract

We present the study of the stripping selection requirements for the $B^0_{(s)} \to \mu^+\mu^-$ analysis. This result of this study has been used in Stripping 21 and Stripping 23.

1 Introduction

The stripping selection is a a set of loose cuts applied to reconstructed triggered events. Each analysis has a separate stripping selection in which cuts are tailored for each decay and only events that pass the stripping selection are available for subsequent analysis. The main purpose of the stripping is to avoid running over the full LHCb dataset for each analysis, putting unreasonable demands on processing capacity. A further aim of the stripping selection is to reduce the amount of data to a more manageable size, by removing background events with loose cuts. Stringent selections are then applied offline to the stripped data.

The stripping selection for the $B^0_{(s)} \to \mu^+\mu^-$ analysis has been studied previously [1] but there are several reasons to motivate a new study. The current stripping cuts were chosen based on 3 constraints:

1. the amount of bandwidth allocated to the $B^0_{(s)} \to \mu^+\mu^-$ analysis, originally the order of 10 Hz

2. keeping the selection of normalisation channels as similar as possible to the signal channel selection

3. the highest possible signal efficiencies taking into account point 1 and 2.

These constraints are all still relevant. However new storage methods that use fewer data per event allow a higher retention of events within the allocated bandwidth. Previous $B^0_{(s)} \to \mu^+\mu^-$ analyses have stored events in full DST files, where all tracks in an event selected by the stripping are stored. Alternatively events can be stored on μDST files where only tracks that are used to form the reconstructed decay candidate are saved, leading to less information stored per event. If μDST files are used for $B^0_{(s)} \to \mu^+\mu^-$ analysis then looser stripping cuts could applied allowing more events pass the selection and still be within a reasonable band width.

Furthermore since previous efficiency studies of $B^0_{(s)} \to \mu^+\mu^-$ stripping cuts, new Monte Carlo simulations have been produced making it prudent to check whether the efficiencies of stripping cuts are still accurate.

Finally the motivation for a new study is to see where and if it is possible to increase the efficiency of the signal selection in the stripping lines without retaining too much data.

The current stripping selection for the decay channels relevant to the $B^0_{(s)} \to \mu^+\mu^-$ analyses are outlined in Section 2. Section 3 shows the efficiencies of the current stripping selection by replicating the work done in [1] with the new simulated events.This work focuses on the $B^0_{(s)} \to \mu^+\mu^-$ signal channel and the $B^+ \to J/\psi K^+$ normalisation channel. From these efficiencies, possible areas for improvements are outlined in Section 4, the affect of changes in the stripping selection on the number of events retained by the selection are given in Section 5.

Throughout this study the efficiencies of any stripping cut are calculated for each decay channel using Sim06b-MC2012 simulation, with Pythia 6 and data retention studies in Section 5 used the full 2012 DST files for testing stripping lines.

2 Current Stripping Cuts

The cuts applied to $B^0_{(s)} \to \mu^+\mu^-$ candidate events in the stripping selection are given in Table 1. For $B^0_{(s)} \to \mu^+\mu^-$ decay channels cuts are applied to the B-hadron mass, impact parameter significance (IPS), decay vertex χ^2 and the distance of flight significance (DOFS). The DOFS is defined as the distance between the primary and secondary vertices in the decay. A cut is also applied to muon in then decay which has the smallest impact parameter significance (IPS), the IPS of the muon is required to be greater than 25 in order to exclude muons coming from the primary vertex instead of the secondary vertex. Finally there is an IsMuon requirement, this requires that a muon must have hits near the muon track in three out of the five muon stations.

Further decay channels used for normalisation in $B^0_{(s)} \to \mu^+\mu^-$ analysis are; $B^0_{(s)} \to hh$ where the hadrons are mis-identified as muons, $B^+ \to J/\psi K^+$ and $B^0_d \to J/\psi K^*$ with the J/ψ decaying to two muons, and $B^0_s \to J/\psi\phi$ with the J/ψ decaying to two muons and ϕ to two kaons. In order to make a good normalisation channel a decay must have a well known branching fraction, for all the decays stated above with the exception of $B^0_s \to J/\psi\phi$ where the branching fraction is less well known. Furthermore the reconstruction and trigger efficiencies need to be close to those of the signal channel, the selection is designed to help achieve this; for decay channels with a J/ψ cuts that are applied to two vertex tracks are applied to the J/ψ rather than the B-meson. However additional cuts are necessary for the extra particles present in the normalisation channels which will causes differences to between the signal and normalisation selection. The cut values for the normalisation channels are shown in Tables 1 and 2, where the selection for $B^0_{(s)} \to hh$ is the same as $B^0_{(s)} \to \mu^+\mu^-$ but cuts are applied to hadrons in the decay instead of muons and there is no IsMuon requirement.

$B^0_{(s)} \to \mu^+\mu^-$			$B^+ \to J/\psi(\to \mu^+\mu^-)K^+$		
Particle	Variable	Cut	Particle	Variable	Cut
$\mu^\pm$	IP χ^2 IsMuon	> 25 true	$\mu^\pm$	IP χ^2 IsMuon	> 25 true
			J/ψ	DOFS vertex χ^2 $\mid M_{\mu^+\mu^-} - M_{J/\psi,PDG} \mid$	> 15 < 9 < 60 MeV/c^2
			K^+	IP χ^2	> 25
$B_{(s)}$	$\mid M - M_{B,PDG} \mid$ IP χ^2 DOFS vertex χ^2	< 600 MeV/c^2 < 25 > 15 < 9	B^+	$\mid M - M_{B,PDG} \mid$ IP χ^2	< 600 MeV/c^2 < 25

Table 1: Stripping selection cuts for $B^0_{(s)} \to \mu^+\mu^-$ and $B^+ \to J/\psi K^+$ [1, 2]. DOFS is the Distance of Flight Significance.

$B_d^0 \to J/\psi(\to \mu^+\mu^-)K^*(\to K\pi)$			$B_s^0 \to J/\psi(\to \mu^+\mu^-)\phi(\to K^+K^-)$		
Particle	Variable	Cut	Particle	Variable	Cut
K	IP χ^2	> 4	$K^\pm$	χ^2	> 4
π	IP χ^2	> 4			
K^{*0}	IP χ^2 $\mid M_{\pi,K} - M_{K^{*0},PDG} \mid$	> 25 < 40 MeV/c^2	ϕ	IP χ^2 $\mid M_{\pi,K} - M_{K^{*0},PDG} \mid$	> 25 < 40 MeV/c
$\mu^\pm$	IP χ^2 IsMuon	> 25 true	$\mu^\pm$	IP χ^2 IsMuon	> 25 true
J/ψ	vertex χ^2 DOFS $\mid M_{\mu^+\mu^-} - M_{J/\psi,PDG} \mid$	< 9 > 15 < 60 MeV/c^2	J/ψ	vertex χ^2 DOFS $\mid M_{\mu^+\mu^-} - M_{J/\psi,PDG} \mid$	< 9 > 15 < 60 MeV/c
B_d^0	IP χ^2 $\mid M - M_{B,PDG} \mid$	< 25 < 500 MeV/c^2	B_s^0	IP χ^2 $\mid M - M_{B,PDG} \mid$	< 25 < 500 MeV/

Table 2: Stripping selection cuts for $B_d^0 \to J/\psi K^*$ and $B_s^0 \to J/\psi\phi$ [1,2]. DOFS is the Distance of Flight Significance.

3 Efficiencies of current cuts

Table 3 shows the efficiencies of the stripping selection on $B_{(s)}^0 \to \mu^+\mu^-$ and $B^+ \to J/\psi K^+$ candidate events. The efficiencies highlighted in blue are the efficiencies of each cut with no other cuts applied to the events. The efficiency highlighted in green is the efficiency for the B mass, DOFS, B (or J/ψ) IP χ^2 and B (or J/ψ) vertex χ^2 cuts applied together to the MC events. The efficiency highlighted in yellow is the efficiency of the IP χ^2 cut applied to the muon with the smallest IPS on events which have passed all other cuts in the stripping selection. Finally the total efficiency of all stripping cuts applied together is given at the bottom of the table. The efficiencies have been calculated using events with no stripping selection imposed but with a very loose selection consisting of mass cuts applied. The current stripping selection cuts were then applied to there events and the efficiencies calculated.

The ratio of the efficiencies $B_{(s)}^0 \to \mu^+\mu^-$ and $B^+ \to J/\psi K^+$ are shown in Figure 1 each cut has been applied on the MC events independently of the other cuts. With the exception of the IP χ^2 cuts on the daughter particles, the ratio of efficiencies is well within 2% of 1 for the range of cuts values shown. The ratio of the signal and normalisation channels for the daughter particle IP χ^2 markedly deviates from unity, showing that the IP χ^2 distribution of the muons and kaon are very different as seen previous in [1]. Figure 2 shows the ratio of $B_{(s)}^0 \to \mu^+\mu^-$ and $B^+ \to J/\psi K^+$ efficiencies of the muon and kaon IP χ^2 cuts on events which have already passed a selection of DOFS cuts. The DOFS cut requires events to be greater than a specified value, as the value of the DOFS cut reduces the ratios of the daughter particle IP χ^2 cut efficiencies become flatter and closer to one. The value chosen for the DOFS cut has a large affect on the efficiencies of the daughter particle IP χ^2 cut.

Overall the stripping cut efficiencies are very similar to those calculated on previous MC except that DOFS cut which is 10% higher on the new simulation leading to a 10% increase in the total efficiency.

Stripping cut	$B_s \to \mu^+\mu^-$	$B_d \to \mu^+\mu^-$	$B^+ \to J/\psi K^+$
$\mid M - M_{B,PDG} \mid < 600$ MeV	98.59	98.72	99.86
B, J/ψ vertex $\chi^2 < 9$	97.21	97.18	96.78
B IPS < 5	96.78	96.93	97.52
DOFS(B,J/ψ)> 15	83.74	83.96	82.90
Minimum(μ^+, μ^-) IPS> 5 K^+ IPS > 5	80.16	80.62	86.98
$\mid M(\mu^+\mu^-) - M_{J/\psi,PDG} \mid < 60$ MeV	-	-	96.47
B Mass, DOFS, B IPS, B, J/ψ vertex $\chi^2 < 9$ applied together	78.46	78.88	78.81
Minimum IPS(μ^+, μ^-) > 5 K^+ IPS > 5	90.26	90.53	91.33
$\mid M(\mu^+\mu^-) - M_{J/\psi,PDG} \mid < 60$ MeV	-	-	96.72
Total	$70.82 \pm 0.07\%$	$71.35 \pm 0.07\%$	$69.36 \pm 0.19\%$

Table 3: Stripping selection efficiencies for current stripping selection cuts on $B^0_{(s)} \to \mu^+\mu^-$ and $B^+ \to J/\psi K^+$ simulated signal events. No trigger requirements were applied. The efficiencies highlighted in blue are the efficiencies of each each cut with no other cuts applied. The efficiency highlighted in green is the efficiency for the B mass, DOFS, B (or J/ψ) IP χ^2 and B (or J/ψ) vertex χ^2 cuts applied together to events The efficiency highlighted in yellow is the efficiency of the IP χ^2 cut applied to the muon with the smallest IP χ^2 on events which have passed all other cuts in the stripping selection. Finally the total efficiency of all stripping cuts applied together is given at the bottom of the table.

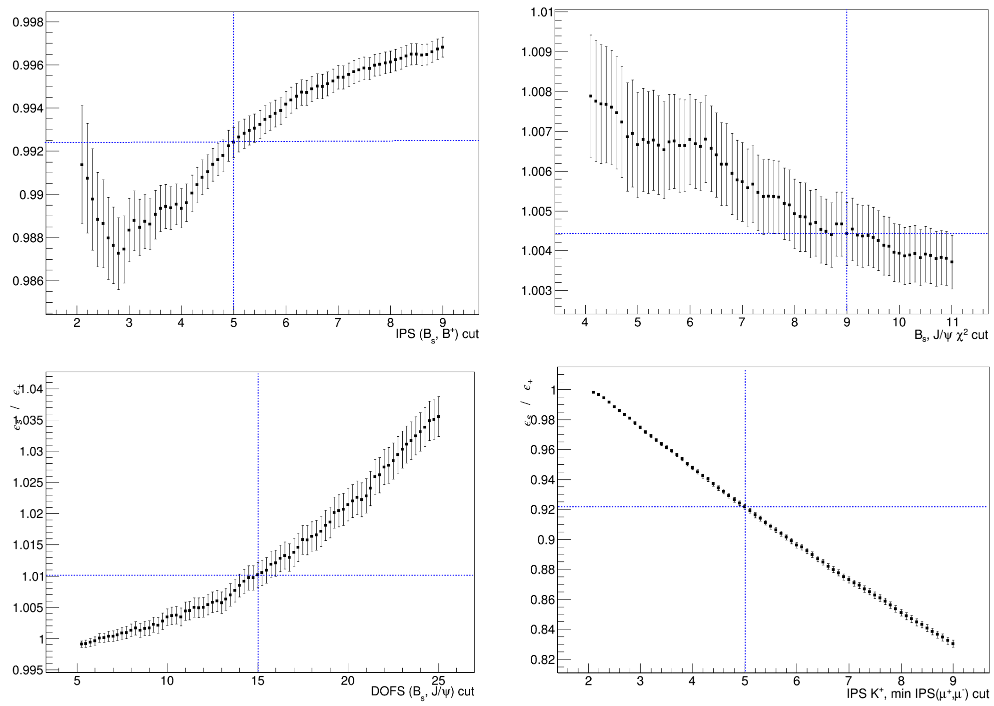

Figure 1: The ratio of $B^0_{(s)} \to \mu^+\mu^-$ to $B^+ \to J/\psi K^+$ stripping efficiencies on MC events when each cut has been applied independently of all other cuts. The current cut values are marked by the blue lines.

4 Improvement studies

Improvements to the stripping selection efficiencies on signal events could be achieved by changing the DOFS cut on the B or J/ψ and the IPS cut applied to the daughter particles. These two cuts have much lower efficiencies, 83% and 80%, respectively, compared with the other selection cuts with efficiencies of $> 90\%$. However, each cut does not remove an independently set of events therefore to find an improvement in the efficiencies of the stripping selection the effect of changing one cut on the whole selection efficiency must be considered rather than each cut efficiency separately. Figure 3 shows the total efficiency on $B^0_{(s)} \to \mu^+\mu^-$ signal events of the stripping selection for a range of DOFS and daughter particles IPS cuts values. The lower the cut, the more efficient the stripping selection is on signal events. In order for any improvement in the stripping selection efficiency to propagate through the rest of the analysis the improvements in the efficiency gained by loosening cuts must not be lost when the trigger is applied. Figure 4 shows the efficiency of the trigger on events which have passed the stripping selection for the range of DOFS and daughter particle IPS cuts used in Figure 3. The trigger efficiency is uniform across the range of cuts therefore any efficiency gained in the stripping selection will not be lost in the trigger.

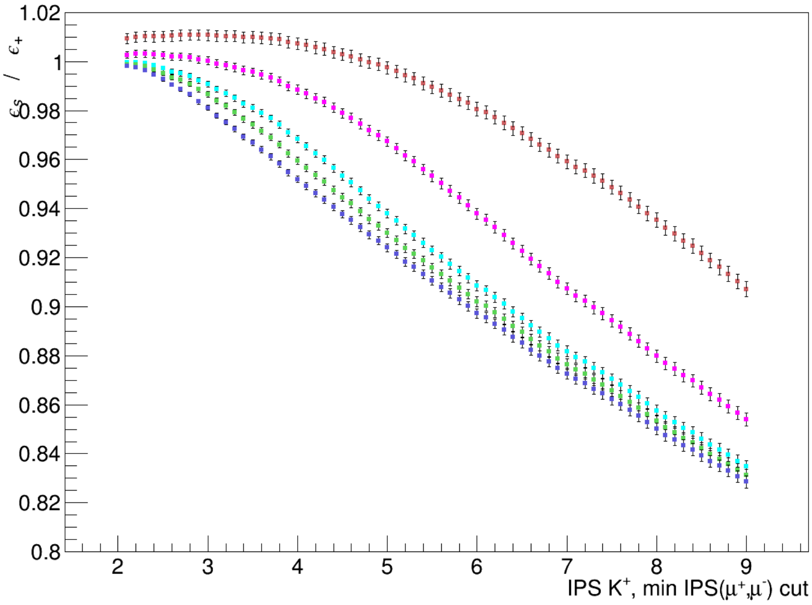

Figure 2: The ratio of $B^0_{(s)} \to \mu^+\mu^-$ muon IP χ^2 cut and $B^+ \to J/\psi K^+$ kaon IP χ^2 cut efficiencies on MC events which have already passed a DOFS requirement. Blue events have DOFS value greater than 5, Green greater than 6, Cyan greater than 7, Magenta greater than 10 and Red greater than 15 which is the current cut value.

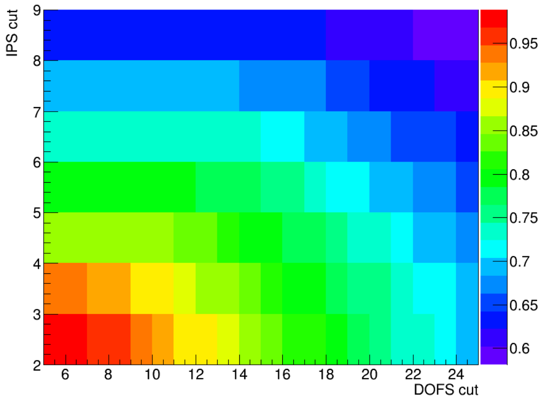

Figure 3: Efficiency of $B^0_{(s)} \to \mu^+\mu^-$ stripping selection cuts for a range of $B^0_{(s)}$ distance of flight and muon impact parameter significance cut values.

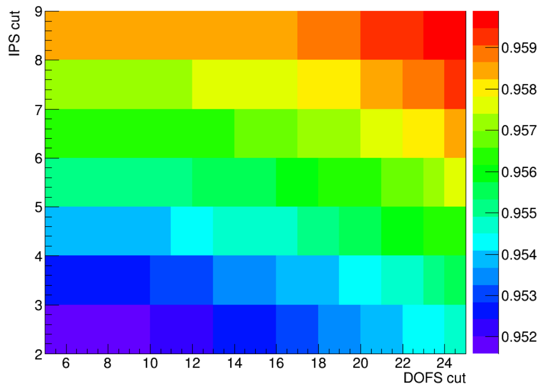

Figure 4: Trigger efficiencies of $B^0_{(s)} \to \mu^+\mu^-$ events that pass the stripping selection cuts for a range of $B^0_{(s)}$ distance of flight and muon impact parameter significance cut values.

To choose combinations of DOFS and daughter particle IP χ^2 cuts the curve shown in Figure 5 was used as a guide. This aims to keep both cuts as tight as possible for a certain efficiency. For each pair of cuts the total efficiency of the stripping selection on $B^0_{(s)} \to \mu^+\mu^-$ and $B^+ \to \mathrm{J}/\psi K^+$ signal is show in Table 4. For the $B^+ \to J/\psi K^+$ channel the DOFS cut is applied to the J/ψ and the daughter IPS cut is applied to the K^+. The efficiencies for the two channels are very similar, within 2% of each other therefore keeping the ratio of their efficiencies close to 1.

An increase of 16% can be gained in the stripping selection efficiencies by using the loosest cuts in Table 4 however looser cuts let through more events therefore before a pair of cuts can be chosen the retention of each set must be investigated.

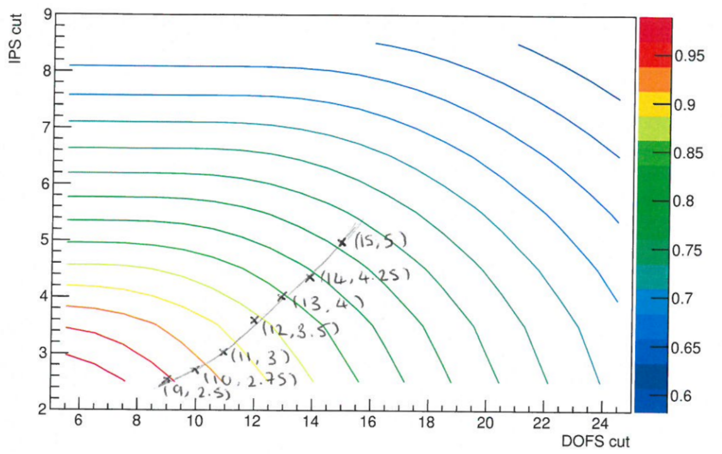

Figure 5: Iso-efficiency curves in the plane of DOFS and B IP χ^2 requirements. Overlaid are proposed pairs of cuts where point(15,5) are the current cut values.

Cuts		$B_s \to \mu^+\mu^-$		$B^+ \to J/\psi K^+$	
DOFS	IPS	Strip.	Strip and Trig.	Strip.	Strip and Trig.
15	5.00	70.8	67.7	69.4	61.6
14	4.25	74.4	71.0	72.6	64.4
13	4.00	76.3	72.8	74.6	66.2
12	3.50	79.2	75.5	77.3	68.5
11	3.00	82.1	78.2	80.1	70.9
10	2.75	84.2	80.2	82.1	72.7
9	2.50	86.3	82.1	84.3	74.5

Table 4: Selection efficiencies on signal and normalisation MC simulated events for optimum combinations of cuts DOFS on the B_s or J/ψ and daughter particle IP χ^2 cuts. The current cut value is the first line, DOFS > 15, IP $\chi^2 < 5$.

5 Retention Studies

One of the purposes of the stripping selection is to reduce the amount of data produced at the LHCb to a manageable size for analysis. Any change in cut values in the stripping selection will alter the data retained by the selection. The normalisation channels used in the $B_s \to \mu^+\mu^-$ analysis are selected using stripping cuts as similar as possible to the cuts on the signal channel in order to keep systematic uncertainties on normalisation calculation as low as possible, therefore any changes to increase the signal selection efficiency must also be included in all lines relevant to the $B_s \to \mu^+\mu^-$ analysis. These channels were outlined, with their selection cuts, in Section 2. The proposed changes in cuts are the DOFS of the B and IP χ^2 of the muons for the $B_s \to \mu^+\mu^-$ channel is equivalent to; $B \to J/\psi\phi$, $B^+ \to J/\psi K^+$ and $B \to J/\psi K^*$, changes are in the DOFS flight cut applied to the J/ψ and the IP χ^2 cut that is applied the ϕ, K^+ or K^* present in the decay.

The relative increase in the number of events retained for each decay has been calculated in the following way. The increases were calculated using 2012 full data files for testing stripping selections. These files had no stripping selection applied but had the same loose mass cuts applied as the MC for determining efficiencies, and then for each decay channel the number of events that pass all the stripping cuts was calculated for all pairs of DOFS and daughter IP χ^2S cuts proposed in Section 4.

In order to determine the relative increase in data retention that changes in DOFS and IP χ^2 causes, the number of events calculated for each set of cuts was divided by the number of events retained for the current set of cuts. This calculation gives 1 for the current selection cuts of DOFS > 25 and daughter IP $\chi^2 > 5$ and values greater than 1 for the other looser cuts studied. Table 5 shows the relative increases for all decay channels used in the analysis.

In the last analysis of the combined 2011 and 2012 data the number of events retained for each decay used in the $B_s \to \mu^+\mu^-$ analysis are shown in Table 6. The number of events varies from channel to channel with $B \to hh$ retaining most events. Table 7 shows the total number of events that we would have expected to retain if different DOFS and daughter particles IPS cuts had been used. These have been calculated by by scaling the number of events for each decays in Table 6 by the fractional increase for each pair of cuts and each decay in Table 5.

In previous analyses the amount of data that can pass the stripping selection has been limited to about 10 Hz, any loosening of the stripping cuts will increase the amount of data retained by the stripping lines. In the past events have been stored in full DST files, however for future stripping selections they will store events in μDST files which produces smaller files therefore it would allow some increase in the retention of data. In moving from storing events on full DST to μDST the change in memory used per event in a micro DST is about a tenth of that used in a full DST [3]. Therefore an increase in retention by a factor any pair of cuts in Table 7 will still be lower than the data used before.

Cuts		Fractional increase in retention				
DOFS	IPS	$B_s^0 \to \mu^+\mu^-$	$B_s^0 \to h^+h^-$	$B^+ \to J/\psi K^+$	$B \to J/\psi K^*$	$B \to J/\psi\phi$
15	5.00	1.00	1.00	1.00	1.00	1.00
14	4.25	1.40	1.31	1.04	1.08	1.27
13	4.00	1.67	1.52	1.09	1.17	1.44
12	3.50	2.40	1.96	1.14	1.30	1.84
11	3.00	3.67	2.70	1.19	1.42	2.48
10	2.75	4.76	3.42	1.25	1.58	3.34
9	2.50	6.75	4.48	1.31	1.80	4.29

Table 5: Fractional increase of the number of events for each decay used in the $B_s \to \mu^+\mu^-$ analysis compared to the current stripping cuts. The row highlighted in blue is the current selection cuts.

Decay	**Events**
$B \to h^+h^-$	14495199
$B_{s,d}^0 \to \mu^+\mu^-$	898663
$B^+ \to J/\psi K^+$	3346863
$B_s^0 \to J/\psi\phi$	456789
$B^0 \to J/\psi K^*$	12582461
Total	31779975

Table 6: Number of events per stripping line for 2011 and 2012 combined data sets [3]. No correlation between lines has been included.

DOFS	IPS	Events / x10^6	Relative Increase	Signal Eff.	Eff. with Trigger
15	5.00	31.7	1.00	70.8	67.7
14	4.25	37.9	1.19	74.4	71.0
13	4.00	42.5	1.34	76.3	72.8
12	3.50	51.4	1.62	79.2	75.5
11	3.00	65.5	2.06	82.1	78.2
10	2.75	79.5	2.40	84.2	80.2
9	2.50	100.0	3.15	86.3	82.1

Table 7: The total retention of each pair for DOFS and daughter particle IP χ^2 cuts, the relative increase compared to the current cuts with the $B_s^0 \to \mu^+\mu^-$ signal efficiency of the stripping cuts and the efficiency of the stripping cuts and stripping cut with the trigger. Blue highlights the current selection used and highlighted in green is the selection cuts proposed in Section 6.

6 Conclusions

This study of the stripping selection used in the $B_s \to \mu^+\mu^-$ analysis has shown the efficiencies of the current stripping selection on $B_s \to \mu^+\mu^-$ signal events to be 71%. An increase to 82% in signal efficiency can be gained if the DOFS cut is loosened to 11 and the daughter IP χ^2 cut is loosened to 3. This change would increase the retention of the $B_s \to \mu^+\mu^-$ stripping selection by a factor of 2. However for future stripping selections the $B_s \to \mu^+\mu^-$ analysis pan to move to using μDST files to store data therefore an increase in the retention by a factor of 2 would overall be much less data compared to the last analysis. The changes of loosening the DOFS cut to 11 and the daughter IPS cut to 3 have been implemented in the stripping selection for Stripping 21.

7 Stripping 23

The changes implemented in stripping 21 have also been included in stripping 23 for Run 2. In addition a cut on the ghost track probability has been implemented on all lines for stripping 23. In stripping 21 and previous stripping versions there was a requirement of the ghost track probability < 0.3 for the $B \to hh$ and $B \to J\phi K^*$ for other lines the cut was applied offline. In order to keep the same selection efficiencies in Run 2 for long tracks from the B the ghost track probability requirement has been changed to < 0.45 as advised in the study [4] for stripping 23.

References

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