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$B_s^0 \to J/\psi\phi$ - ATLAS

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The study of the decay $B_s^0 \to J/\psi\phi$ is of significant interest to particle physics as it allows the measurement of the B_s^0 mixing phase. The $B_d^0 \to J/\psi K^{*0}$ channel provides a valuable testing ground for measurements of $B_s^0 \to J/\psi\phi$ due to its equivalent topology and similar helicity structure of the final states, with the advantage of higher statistics.

An integrated luminosity of $40\ \mathrm{pb}^{-1}$ of ATLAS pp collision data at a center-of-mass energy of 7 TeV are used to reconstruct B_d^0 and B_s^0 mesons. A total of 2340 ± 80 (stat) B_d^0 signal decays are observed after subtracting the background, with a fitted mass of 5279.6 ± 0.9 (stat) MeV. For B_s^0 signal 358 ± 22 (stat) decays are observed, with a fitted mass of 5364.0 ± 1.4 (stat) MeV. Within the statistical uncertainties, the fitted masses of both B mesons are consistent with the world average values.

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1. Introduction

The study of the decay $B_s^0 \to J/\psi\phi$ is of significant interest to particle physics as it allows the measurement of the B_s^0 mixing phase, which is responsible for *CP* violation in this decay channel. The Standard Model prediction for this *CP* violating phase is small, of the order of $\mathscr{O}(10^{-2})$, so any measured excess would be a clear indication of New Physics entering the B_s^0 system. The $B_d^0 \to J/\psi K^{*0}$ channel provides a valuable testing ground for measurements of $B_s^0 \to J/\psi\phi$ due to its equivalent topology and similar helicity structure of the final states, with the advantage of higher statistics. Early fits of the B_d^0 and B_s^0 masses provide a good test of the performance of the ATLAS tracking system.

Data taken between the 24th June and the 24th October 2010, provides a data sample of 40 pb^{-1} of ATLAS pp collision data at a center-of-mass energy of 7 TeV. These are used to reconstruct B_d^0 and B_s^0 mesons. From studies of the signal and background mass distributions, the mean B_d^0 and B_s^0 masses, mass resolutions, and numbers of signal candidates are extracted [1].

2. *B* meson candidate selection

2.1 Common issues in selection of B_d^0 and B_s^0 candidates, J/ψ selection

Events from the muon stream were selected only if both the muon and tracking systems were fully operational. Additionally events must meet the following criteria. The event must contain at least one reconstructed primary vertex with at least 4 associated ID tracks in order to be considered as a collision candidate. Tracks are required to have at least one hit in the pixel detector and at least four hits in the semiconductor tracker. The event must contain at least one pair of oppositely charged muon candidates. The muons are not required to match the object(s) which fired the trigger. No cuts on the p_T of the muons are applied other than the implicit ones in the muon reconstruction, described above.

The tracks of the muon pairs are refitted by the vertexing algorithm [2] to a common vertex and accepted for further considerations if the fit results with χ^2/n.d.o.f. <10. Muon pairs are considered to form a $J/\psi \to \mu^+\mu^-$ candidate if the invariant mass calculated from the refitted track parameters lies within a J/ψ signal region whose lower and upper limits are selected using the results of the J/ψ mass fit. To account for a varying mass resolution the J/ψ candidates are divided into to three classes according to the pseudo-rapidity of the muons: both muons in the barrel region (BB); one muon in the end-cap and one in the barrel (EB), both muons in the end-cap (EE). The muon is labelled a barrel muon when its pseudo-rapidity is $|\eta| < 1.05$ and an end-cap muon when $1.05 < |\eta| < 2.5$. A maximum likelihood fit is used to extract the J/ψ mass and the corresponding resolution for these three subsets, using the method described in [3]. The accepted J/ψ candidates from BB, EB and EE classes are from signal regions selected as $(2959-3229)$ MeV, $(2913-3273)$ MeV and $(2852-3332)$ MeV respectively, retaining 99.8% of J/ψ signal.

2.2 Selection specific to $B_d^0 \to J/\psi K^{*0}$

In the following analysis both charge conjugate states $B_d^0 \to J/\psi K^{*0}$ $(K^+\pi^-)$ and $\overline{B}_d^0 \to J/\psi\overline{K}^{*0}$ $(K^-\pi^+)$ are included. The K^{*0} candidates are reconstructed by selecting all tracks with

$p_T > 0.5$ GeV and $|\eta| < 2.5$ that have not been previously identified as muons, forming them into oppositely charged pairs. Together with the two tracks from $J/\psi \to \mu^+\mu^-$ these are fitted to a common vertex. In the fit the two muon tracks are constrained to the PDG J/ψ mass value 3096.916 ± 0.011 MeV [4]. These quadruplets of tracks are accepted for further selections if the fit has a χ^2/n.d.o.f. <2.5. The new track parameters resulting from the vertex fit are used to calculate the invariant mass of K^{*0} candidates under the assumption that they are $K^+\pi^-$ hadrons. These pairs are assumed to be from K^{*0} decays if the invariant mass falls within the interval $(846-946)$ MeV and the transverse momentum of the K^{*0} candidate is greater than 2.5 GeV. No attempt to use particle identification for the kaon or pion is made in the current study. For each candidate both $K^\pm\pi^\mp$ combinations are tested and in cases when both combinations satisfy the mass criterion the one closest to the K^{*0} mass is chosen. If there is more than one B_d^0 candidate per event is found, only the B_d^0 candidate with the lowest χ^2/n.d.o.f. is retained.

2.3 Selection specific to $B_s^0 \to J/\psi\phi$

The $\phi \to K^+K^-$ candidates are reconstructed from all pairs of oppositely charged tracks with $p_T > 0.5$ GeV and $|\eta| < 2.5$, which are not identified as muons. $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ candidates are sought by fitting the tracks from each combination of $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$ to a common vertex. The two muon tracks are constrained to the PDG J/ψ mass. These quadruplets of tracks are assumed to be from $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ decays if the fit results in a χ^2/n.d.o.f. < 2, the fitted p_T of each track from $\phi \to K^+K^-$ is greater than 1 GeV and the invariant mass of the track pairs (under the assumption that they are kaons) falls within the interval 1009 MeV $<$ m(K$^+$K$^-$) $<$ 1031 MeV. If there is more than one B_s^0 candidate per event then the candidate with the lowest χ^2/n.d.o.f. is chosen.

3. Fit to invariant mass distribution

3.1 Method of fit

An unbinned maximum-likelihood fit is used to extract the B_d^0 and B_s^0 meson masses. The likelihood function is defined by:

$$L = \prod_{i=1}^{N} \left[f_{sig}\mathscr{M}_{\rm sig}(m_i) + (1 - f_{sig})\mathscr{M}_{\rm bkg}(m_i) \right] \tag{3.1}$$

where m_i is the invariant mass of a $J/\psi K^{*0}$ ($J/\psi\phi$) candidate, N is the total number of candidates in the invariant mass range $m_{min} < m_i < m_{max}$ of the fit and f_{sig} represents the signal fraction. The $\mathscr{M}_{\rm sig}$, $\mathscr{M}_{\rm bkg}$ are probability density functions that model the B signal and background mass shapes in this range. For the signal, the mass is modelled with a Gaussian distribution:

$$\mathscr{M}_{\rm sig}(m_i) \equiv \frac{1}{\sqrt{2\pi}\, S\delta m_i} e^{\frac{-(m_i - m_B)^2}{2(S\delta m_i)^2}} \tag{3.2}$$

whose mean value m_B is the hypothesised B meson mass, and its width is a product $S \cdot \delta m_i$. The mass error δm_i is calculated for each $J/\psi K^{*0}$ ($J/\psi\phi$) candidate from the covariance matrix associated with the 4-track vertex fit. The scale factor S accounts for differences between the per-candidate mass errors and the overall mass resolution. For the background, the mass distribution in case of $B_d^0 \to J/\psi K^{*0}$ is modelled with an exponential function:

$$\mathscr{M}_{\rm bkg}(m_i) \equiv \frac{1 + b\, e^{\frac{-(m_i - m_C)}{m_0}}}{\int_{m_{min}}^{m_{max}} \left(1 + b\, e^{\frac{-(m - m_C)}{m_0}}\right) \mathrm{d}m} \tag{3.3}$$

where $m_C \equiv (m_{max} + m_{min})/2$. Parameter b is a factor between the flat and exponential terms and m_0 is an exponential slope. In case of $B_s^0 \to J/\psi\phi$ the background is modelled with a linear function:

$$\mathscr{M}_{\rm bkg}(m_i) \equiv \frac{1}{m_{max} - m_{min}}\,\left[1 + d\,(m_i - m_C)\right] \tag{3.4}$$

where d is the slope of the linear background.

The fit has five free parameters $f_{\rm sig}$, m_B, S, b and m_0 in B_d^0 case and four free parameters $f_{\rm sig}$, m_B, S and d in B_s^0 case. Their values and a covariance matrix returned by the fit are used to calculate the number of B signal decays $N_{\rm sig}$, the mass resolution σ_m and the number of background events $N_{\rm bkg}$ in the mass interval $m_B \pm 3\sigma_m$. The mass resolution σ_m is defined as the half of the width of the B mass distribution for which the integral of M_{sig} retains 68.3% of $N_{\rm sig}$ symmetrically around the fitted mass m_B. The uncertainty on σ_m is calculated using the covariance matrix of the fit. The number of background events $N_{\rm bkg}$ in the mass interval $m_B \pm 3\sigma_m$ and its error are calculated from f_{sig}, b, m_0 (or d), N and the error matrix of the fit.

As the available statistics grows it will be possible to add additional terms to the maximum likelihood fit to include the lifetime and decay angles in order to perform an angular analysis.

3.2 Results of fit

In addition to the selection criteria described previously, cuts are placed on the measured mass and proper decay time uncertainties. This excludes very poorly measured events which would not contribute significantly to the result but could potentially cause problems in the fit. Candidates with a measured mass uncertainty δm_i greater than 160 MeV or with a lifetime uncertainty $\delta\tau_i$ greater than 300 fs are removed. These cuts remove 5% of B_d^0 candidates and 6% of B_s^0 candidates.

Figure 1 shows the invariant mass distribution for B_d^0 candidates in the mass range from $m_{min} = 5050$ MeV to $m_{max} = 5550$ MeV. On the left side of the figure, the candidates passing all selections except the proper decay time cut (hereafter called loose selection) are shown, the right side shows the candidates passing all selection cuts including the proper decay time cut $\tau >$0.35 ps (hereafter called tight selection). In both cases the fit is applied as described in the previous section and the results of the fit are projected onto the distributions. The B_d^0 mass returned by the fits is 5278.6 ± 1.3 MeV and 5279.6 ± 0.9 MeV for the loose and tight selections respectively. These results are consistent with the world average of 5279.5 ± 0.3 MeV [4]. The number of background candidates 10280 ± 110 in the mass range $m_B \pm 3\sigma_m$ is reduced to 1330 ± 60 after applying the proper time cut. With this requirement the number of signal candidates is reduced from 2680 ± 150 to 2340 ± 80 . Table 1 gives a summary of the results of the mass fits, including masses, mass resolutions, number of signal decays and number of background candidates. All given errors are statistical only.

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Figure 2 shows the invariant mass distribution for B_s^0 candidates in the mass range from $m_{min} =$ 5150 MeV to $m_{max} =$ 5600 MeV. As in the case of B_d^0 the left figure shows the loose selection candidates and the figure on right the tight selection candidates, including the proper decay time cut $\tau >$0.40 ps. The B_s^0 masses returned by the fit are 5363.6 ± 1.6 MeV and 5364.0 ± 1.4 MeV for the loose and the tight case, respectively. Both values are consistent with the world average of 5366.3 ± 0.6 MeV [4]. The number of background events with loose selections 764 ± 17 is reduced to 90 ± 7 after the proper decay time cut. With this requirement the number of signal events is reduced from 413 ± 36 to 358 ± 22. All given errors are statistical only.

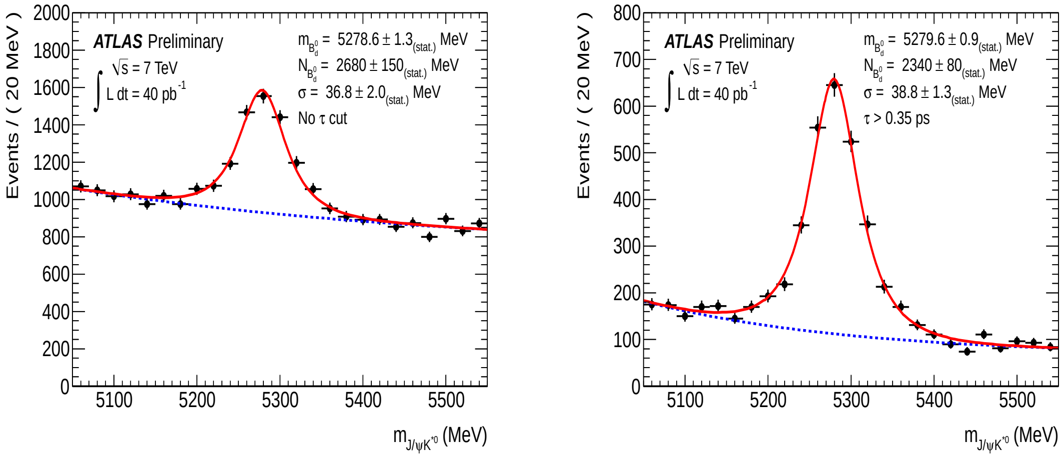

Figure 1: Invariant mass distributions of reconstructed candidates of $B_d^0 \rightarrow J/\psi K^{*0}$ and $\overline{B}_d^0 \rightarrow J/\psi \overline{K}^{*0}$ decays. Left: candidates passing all selections except for the proper decay time cut; right: candidates passing all selections including the proper decay time cut. The points with error bars are data. The solid line is the projection of the result of the unbinned maximum likelihood fit to all candidates in the mass range from 5050 MeV to 5550 MeV. The dashed line is the projection for the background component of the same fit.

Table 1: Summary of fit results to mass distributions of B_d^0 and B_s^0 candidates. The number of background events is given in the range $m_B \pm 3\sigma_m$. Errors indicated are statistical only.

		m_B	σ_m	N_{sig}	N_{bkg}
B_d^0	no τ cut	5278.6 ± 1.3 MeV	36.8 ± 2.0 MeV	2680 ± 150	10280 ± 110
	with τ cut	5279.6 ± 0.9 MeV	38.8 ± 1.3 MeV	2340 ± 80	1330 ± 60
B_s^0	no τ cut	5363.6 ± 1.6 MeV	21.9 ± 1.9 MeV	413 ± 36	764 ± 17
	with τ cut	5364.0 ± 1.4 MeV	26.6 ± 1.5 MeV	358 ± 22	90 ± 7

4. Conclusion

The B_d^0 and B_s^0 mesons are observed by ATLAS in the decays $B_d^0 \rightarrow J/\psi K^{*0}$ and $B_s^0 \rightarrow J/\psi\phi$. Using 40 pb^{-1} of pp collision data at 7 TeV, the total number of observed signal events after

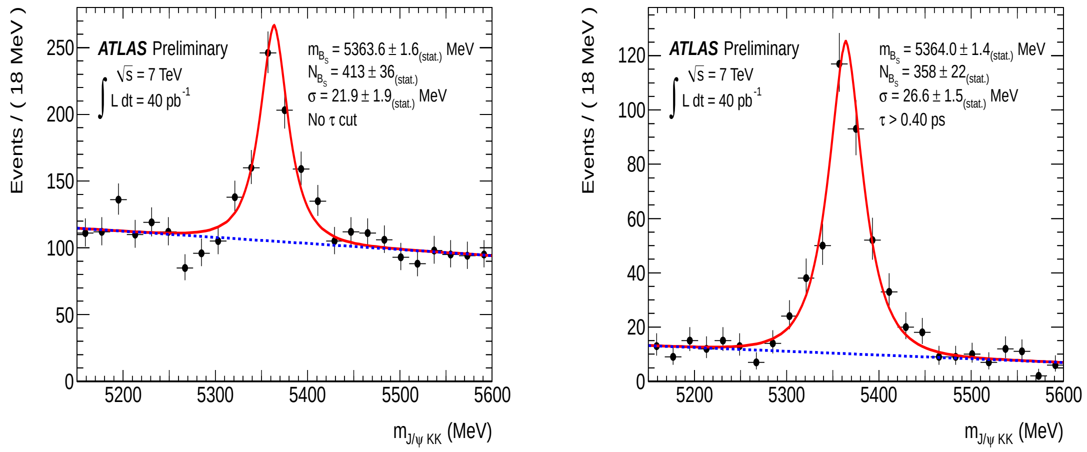

Figure 2: Invariant mass distributions of reconstructed $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ candidates. Left: candidates passing all selections except for the proper decay time cut; right: candidates passing all selections including the proper decay time cut. The points with error bars are data. The solid line is the projection of the result of the unbinned maximum likelihood fit to all $J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ candidates in the mass range from 5150 MeV to 5600 MeV. The dashed line is the projection for the background component of the same fit.

applying all selection cuts is 2340 ± 80 (stat) over a background of 1330 ± 60 (stat) for B_d^0 and 358 ± 22 (stat) over a background of 90 ± 7 (stat) for B_s^0 mesons. Fits to the reconstructed masses yield values of 5279.6 ± 0.9 (stat) MeV and 5364.0 ± 1.4 (stat) MeV for B_d^0 and B_s^0 respectively. Within their statistical uncertainties both numbers are consistent with the world average values 5279.5 ± 0.3 MeV(B_d^0) and 5366.3 ± 0.6 MeV(B_s^0).

References

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