PROCEEDINGS OF SCIENCE

# New suppressed decays of $B_s^0$ mesons at CDF

**Olga Norniella**[*†]
*Illinois University at Urbana-Champaign*
*E-mail:* `norniell@fnal.gov`

The observation of new suppressed $B_s^0$ decays, $B_s^0 \to J/\psi K^*(892)^0$ and $B_s^0 \to J/\psi K_S^0$, and the measurement of their branching ratios is presented. This measurement is based on an integrated luminosity of 5.9 fb$^{-1}$ of CDF data collected by a dedicated di-muon trigger. A cut based optimization is carried out for the observation of $B_s^0 \to J/\psi K^{*0}$, while a neural network is used for the $B_s^0 \to J/\psi K_S^0$. In addition to the observation of the new decay modes, the ratios of branching fractions to the reference $B^0$ decays are measured.

*35th International Conference of High Energy Physics - ICHEP2010,*
*July 22-28, 2010*
*Paris France*

[*] Speaker.
[†] On behalf of the CDF Collaboration

 

PoS(ICHEP 2010)211

While $B^0$ decays have been extensively studied at the B factories experiments, much less is known about $B_s^0$ decays. This contribution presents studies of two specific $B_s^0$ decays [1]: $B_s^0 \to J/\psi K_S^0$ and $B_s^0 \to J/\psi K^*(892)^0$, with $J/\psi \to \mu^+\mu^-$, $K_S^0 \to \pi^+\pi^-$ and $K^*(892)^0 \to K\,\pi$. $B_s^0 \to J/\psi K_S^0$ is a CP eigenstate and has never been observed. Measurement of its lifetime directly probes the lifetime of the heavy mass eigenstate, $\tau_{B_{s,H}}$. Additionally, large samples of $B_s^0 \to J/\psi K_S^0$ can be used to extract the angle $\gamma$ of the unitary triangle [2]. The $B_s^0 \to J/\psi K^{*0}$ decay is yet another unobserved mode which contains an admixture of CP final states. With a larger data sample, an angular analysis of $B_s^0 \to J/\psi K^{*0}$ can be carried out to help disentangle penguin contributions in $B_s^0 \to J/\psi\phi$ [3]. In addition to the first observation of these two decays, the ratios of branching ratios of $B_s^0 \to J/\psi K_S^0$ and $B_s^0 \to J/\psi K^{*0}$ to the reference $B^0$ decays are measured using the relation

$$\mathscr{B}(B_s^0 \to J/\psi K)/\mathscr{B}(B^0 \to J/\psi K) = A_{rel} \times f_d/f_s \times N(B_s^0 \to J/\psi K)/N(B^0 \to J/\psi K),$$

where $K$ represents $K_S^0$ or $K^{*0}$. By measuring the ratio of the number of decays, $N(B_s^0 \to J/\psi K)$ and $N(B^0 \to J/\psi K)$, from data and the relative acceptance, $A_{rel}$, between the $B^0$ and $B_s^0$ from Monte Carlo simulation (MC), the value $\mathscr{B}(B_s^0 \to J/\psi\, K)/\mathscr{B}(B^0 \to J/\psi\, K)$ is extracted by inputting the ratio of fragmentation fractions $f_s/f_d$.

The data used in these analyses are selected from a sample enriched in $J/\psi \to \mu^+\mu^-$ decays, collected by the CDF Run II detector [4]. The integrated luminosity of this sample is 5.9 fb$^{-1}$. The $J/\psi$ dataset contains events with at least one reconstructed $J/\psi$ selected by dedicated di-muon triggers. In addition to the selected $J/\psi$, two tracks are combined with them in a kinematic fit to reconstruct $B^0 \to J/\psi K_S^0$ and $B^0 \to J/\psi\, K^{*0}$ candidates. For the $B^0 \to J/\psi K_S^0$ analysis, the two tracks are reconstructed as pions and combined to define a $K_S^0$ candidate. The $K^{*0}$ candidate for the $B^0 \to J/\psi K^{*0}$ decay is reconstructed from the combination of a $\pi$ and a $K$.

The final event selection in the $B^0 \to J/\psi K^{*0}$ analysis is optimized by maximizing $S/(1.5+\sqrt{B})$. This quantity is well suited for signal discovery as described in [5]. A simultaneous four-dimensional optimization is carried out over 4 quantities: $p_T(\pi)$, $p_T(K)$, transverse decay length $L_{xy}(B_s^0)$ and $B_s^0$ vertex fit probability. For the purpose of extracting the yields of $B^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi K^{*0}$ signals in the invariant mass distribution, an accurate modeling of signals and backgrounds is needed prior to the fit. The signal contributions are modeled with three Gaussians template obtained from a fit to $B^0$ MC. The $B_s^0$ template used in the final fit is identical to $B^0$ template, except for a shift of 86.8 MeV/$c^2$ in the mean value of the three Gaussians. This value corresponds to the known value [6] for the mass difference between $B_s^0$ and $B^0$, $\Delta(m_{B_s^0} - m_{B^0})$. The backgrounds considered in this analysis are combinatorial background, partially reconstructed b hadron decays and $B_s^0 \to J/\psi\phi$ decay. The first one is resulting from different sources, for example a real $J/\psi$ plus two random tracks, where the $J/\psi$ could be a prompt $J/\psi$ or coming from a B decay. Other sources that could contribute to it are fake $J/\psi$ reconstructed with prompt fake muons or fake muons coming from heavy flavor. The combinatorial background is modeled in the final fit with an exponential function. The partially reconstructed background, which is fitted with an ARGUS function [7], is partially reconstructed b hadrons where a five-body decay occurs where a $\pi$, $K$, or $\gamma$ is not reconstructed. Finally, to model the $B_s^0 \to J/\psi\phi$ background, a template consisting of two Gaussians, extracted from simulation, is used. The size of $B_s^0 \to J/\psi\phi$ contribution is constrained using data. A binned log likelihood fit is performed to the invariant mass distributions using the templates for signals and the functions described above. Figure 1 shows the fit, including the different contributions. From the fit, the yields of the $B^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi K^{*0}$ signal are $9530 \pm 110$ and $151 \pm 25$, respectively. The statistical significance of the $B_s^0 \to J/\psi K^{*0}$ signal is $8.0\sigma$. The measured ratio of yields, $N(B_s^0 \to J/\psi K^{*0})/N(B^0 \to J/\psi K^{*0})$, is $0.0159 \pm 0.0022$ (stat.)$\pm 0.0050$ (sys.). The systematic uncertainty is dominated by the combinatorial background contribution uncertainty, with a relative uncertainty for the ratio of 31.4%. The other sources of systematic uncertainty are the signal modeling (4.4%), uncertainty on $\Delta(m_{B_s^0} - m_{B^0})$ (0.1%), combinatorial background modeling (1.3%) and $B_s^0 \to J/\psi\phi$ contribution (1.3%).

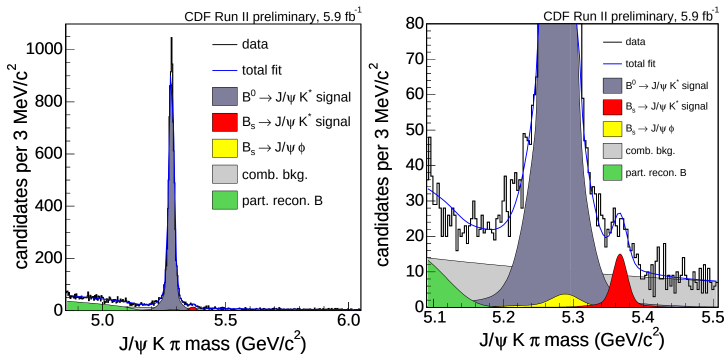


**Figure 1:** Invariant mass distribution for $J/\psi K^{*0}$ and fit including the different contributions (left). The distribution is enlarged in the signal region for more detail (right).

The $B^0 \to J/\psi K_S^0$ decay has two main differences with respect to the $B^0 \to J/\psi K^{*0}$ decay. First, it contains a $K_S^0$, which has a long lifetime. The displacement between the $K_S^0$ candidate vertex and the B candidate vertex is used in the event selection to reduce backgrounds from prompt sources. Moreover, the $K_S^0$ is narrow resonance, so a mass constraint can be applied and improve the mass resolution. Second, the $B_s^0 \to J/\psi K_S^0$ signal contribution is expected to be smaller than the $B_s^0 \to J/\psi K^{*0}$ signal contribution. Therefore it is crucial to effectively suppress combinatorial. A neural network (NN) is used as discriminator. In order to train the NN, simulated $B_s^0$ events are used as signal. Data from the upper side band in the $B^0$ invariant mass distribution, well separated from the signal region, are used as a background data sample. Twenty-two different kinematic and topological variables are chosen as inputs for the NN training. The selection is optimized by maximizing $S/(1.5+\sqrt{B})$ and a likelihood fit is performed to the invariant mass distribution to extract the yields of $B^0 \to J/\psi K_S^0$ and $B_s^0 \to J/\psi K_S^0$ signals. Signals and the two backgrounds are modeled with the same functional form as in the $B^0 \to J/\psi K^{*0}$ analysis. Moreover, in the $B_s^0 \to J/\psi K_S^0$ analysis , $\Lambda_b \to J/\psi\Lambda$, where $\Lambda \to p\pi$, is a background when the $p$ is reconstructed as a $\pi$. This contribution is suppressed using a cut in the angular distribution between $K_S^0$ and the $\pi$ with lower $p_T$. From the fit, shown in Figure 2, the yields of the $B^0 \to J/\psi K_S^0$ and $B_s^0 \to J/\psi K_S^0$ signal are determined to be $5954 \pm 79$ and $64 \pm 14$, respectively. The statistical significance of the $B_s^0 \to J/\psi K_S^0$ signal is $7.2\sigma$. The value of $N(B_s^0 \to J/\psi K_S^0)/N(B^0 \to J/\psi K_S^0)$ is $0.0108 \pm 0.0019$ (stat.) $\pm$ 0.0010 (sys.). The sources of the systematic uncertainty are similar to the other analysis. In this case the relative uncertainties for the ratio are 5.6% from the combinatorial background contribution, 5.6% from the combinatorial background modeling, 4.6% from the signal modeling and 0.1% from the $\Delta(m_{B_s^0} - m_{B^0})$.

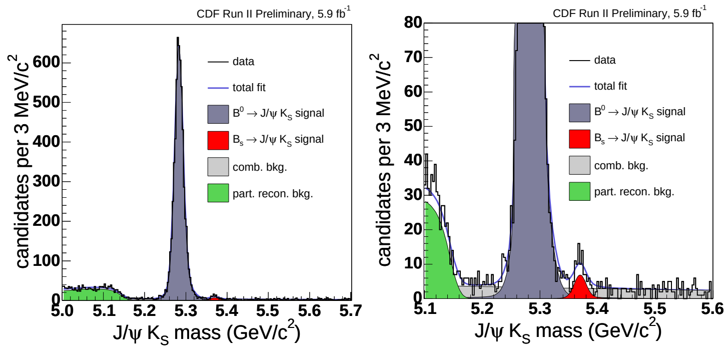


**Figure 2:** Invariant mass distribution for $J/\psi K_S^0$ and fit including the different contributions (left). The distribution is enlarged in the signal region for more detail (right).

To determine the $\mathscr{B}(B_s^0 \to J/\psi K)/\mathscr{B}(B^0 \to J/\psi K)$, where $K$ represents $K_S^0$ or $K^{*0}$, the relative acceptances of $B^0 \to J/\psi K_S^0$ to $B_s^0 \to J/\psi K_S^0$ and $B^0 \to J/\psi K^{*0}$ to $B_s^0 \to J/\psi K^{*0}$ need to be determined from MC. The value for $A_{rel}$ is determined to be $A_{rel}$ = 1.012 ± 0.010 (stat.) ± 0.042 (sys.) for the $K_S^0$ analysis and $A_{rel}$ = 1.057 ± 0.010 (stat.) ± 0.263 (sys.) for the $K^*$ analysis. The $B_s^0$ and $B^0$ lifetimes, B hadron $p_T$ spectrum and polarization, this last one only for the $B_s^0 \to J/\psi K^{*0}$ analysis, induce uncertainties in $A_{rel}$.

To determine $f_s/f_d$ , the most recent CDF measurement [8] of $f_s/(f_u + f_d) \times \mathscr{B}(D_s \to \phi\pi)$ is combined with the actual known value [6] for $\mathscr{B}(D_s \to \phi\pi)$. With the input of $f_s/f_d$ = 0.269 ± 0.033, the ratio of branching fractions to the reference $B^0$ decays are:

$$\mathscr{B}(B_s^0 \to J/\psi K^{*0})/\mathscr{B}(B^0 \to J/\psi K^{*0}) = 0.062 \pm 0.009(stat.) \pm 0.025(sys.) \pm 0.008(frag.),$$
$$\mathscr{B}(B_s^0 \to J/\psi K_S^0)/\mathscr{B}(B^0 \to J/\psi K_S^0) = 0.041 \pm 0.007(stat.) \pm 0.004(sys.) \pm 0.005(frag.).$$

The world-average values for $\mathscr{B}(B^0 \to J/\psi K^{*0})$ and $\mathscr{B}(B^0 \to J/\psi K^0)$ are used for normalization to calculate the absolute branching fractions:

$$\mathscr{B}(B_s^0 \to J/\psi K^{*0}) = (8.3 \pm 1.2(stat.) \pm 3.3(sys.) \pm 1.0(frag.) \pm 0.4(Norm.)) \times 10^{-5},$$
$$\mathscr{B}(B_s^0 \to J/\psi K^0) = (3.5 \pm 0.6(stat.) \pm 0.4(sys.) \pm 0.4(frag.) \pm 0.1(Norm.)) \times 10^{-5}.$$

This measurement is yet another CDF contribution to the exploration of bottom-strange mesons. Further are expected with the 10 fb$^{-1}$ data sample expected in a year from now.

## References

[1] CDF Collaboration, CDF Note 10240 (2010).

[2] R. Fleischer, Eur. Phys. J. C **10**, 299 (1999).

[3] S. Faller, R. Fleischer and T. Mannel, Phys. Rev. D**79**, 014005 (2009).

[4] D. Acosta, et al., Phys. Rev. D**71**, 032001 (2005).

[5] G. Punzi, arXiv:physics/0308063.

[6] K. Nakamura et al., (Particle Data Group), J.Phys. G **37** (2010).

[7] H. Albrecht (ARGUS Collaboration), Phys. Lett. B **241**, 278 (1990).

[8] T. Aaltonen et. al. (CDF Collaboration), Phys. Rev. D**77**, 072003 (2008).