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Suppressed B_s^0 decays at CDF

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We review three recent results of the CDF collaboration on B_s^0 suppressed decays: the first search for CP–violation in the $B_s^0 \to \varphi\varphi$ decay, where two CP–violating asymmetries expected to be zero in the Standard Model are measured, and the observation and the branching ratio measurements of $B_s^0 \to J/\psi f_0(980)$ and $B_s^0 \to J/\psi K^{(\star)}$ decays.

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1. Introduction

In the past decade Tevatron experiments CDF and D0 have pioneered the physics of the B_s^0 meson with a broad program aimed at its exploration. Although significant samples of fully reconstructed B_s^0 decays have been collected allowing decisive progress on B_s^0 mixing, lifetime, decay width difference $\Delta\Gamma_s$ as well as CP–violation measurements, more precise investigations are ongoing. In this report, we review recent results of the CDF collaboration on B_s^0 suppressed decays: the first search for CP–violation in the $B_s^0 \to \varphi\varphi$ decay and the observation of $B_s^0 \to J/\psi f_0(980)$ and $B_s^0 \to J/\psi K^{(\star)}$ decays.

Two features of the CDF II detector [1] are relevant for these measurements: the tracking and the trigger. A high resolution tracking detector provides an excellent resolution on B–meson decay length (30 μm) and mass, typically about 10 MeV/c^2 for $B \to J/\psi X$ modes, that is pivotal for the observation of B_s^0 suppressed modes. This is achieved by double-sided silicon microstrips arranged in five cylindrical layers and an open cell drift chamber with 96 sense wires, all immersed in a 1.4 T solenoidal magnetic field. Signals of $B \to J/\psi X$ modes are efficiently collected by a dimuon trigger [1] with a 1.5 GeV/c transverse momentum threshold, while the trigger on displaced vertex [2] allows the collection of hadronic decay modes like $B_s^0 \to \varphi\varphi$, through online measurement of impact parameters of charged tracks with a resolution (48 μm) comparable with offline measurements.

2. First search for CP–violation in the $B_s^0 \to \varphi\varphi$ decay

The $B_s^0 \to \varphi\varphi$ decay belongs to the class of transitions of pseudoscalar mesons into two vector particles ($P \to VV$), whose rich dynamics involves three different amplitudes corresponding to the polarization states. In the Standard Model (SM) the dominant quark level process is described by the $b \to s$ "penguin" amplitude. Hence, the possibility to access New Physics (NP) through exchange of new virtual massive particles makes the $B_s^0 \to \varphi\varphi$ channel attractive. Indeed, the naïve SM expectation for polarization amplitudes has shown discrepancies with measurements of similar penguin decays [3], raising considerable attention to the so–called "polarization puzzle" [4]. Moreover, having a self–conjugate final state, the $B_s^0 \to \varphi\varphi$ decay is sensitive to the CP–violation in the interference between decay with and without mixing. Actually, the CP–violating weak phase $\phi_s^{B_s^0 \to \varphi\varphi}$ is predicted to be extremely small in the SM and measurement of nonzero CP–violating observables would indicate unambiguously NP.

The first evidence for the $B_s^0 \to \varphi\varphi$ decay has been reported by CDF in 2005 [6]. Using 2.9 fb^{-1} of data, the branching ratio measurement was recently updated [7], $\mathscr{B}(B_s^0 \to \varphi\varphi) = (2.40 \pm 0.21(\text{stat.}) \pm 0.86(\text{syst.})) \times 10^{-5}$, in agreement with the first determination. Signal candidates are reconstructed by detecting $\varphi \to K^+K^-$ decays and are formed by fitting four tracks to a common vertex. Combinatorial background is reduced by exploiting several variables sensitive to the long lifetime and relatively hard p_{T} spectrum of B mesons, while the physics background, given by $B^0 \to \varphi K^\star(892)^0$ decay, is estimated by simulation not to exceed a 3% fraction of the signal. Signals of 295 ± 20 events are obtained by fitting the mass distribution. This data sample has allowed the world's first polarization measurement [7] by analyzing the angular distributions of decay products, expressed as a function of helicity angles, $\vec{\omega} = (\cos\vartheta_1, \cos\vartheta_2, \Phi)$. The total decay

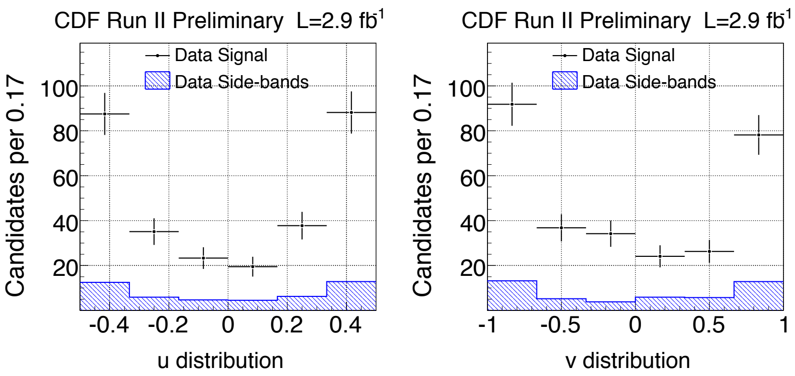

Figure 1: Distribution of u (left) and v (right) for $B_s^0 \to \varphi\varphi$ candidates. Black crosses are background–subtracted data; the blue histogram represents the background.

width is composed of three polarization amplitudes: two CP–even (A_0 and $A_\parallel$) and one CP–odd ($A_\perp$). The measured amplitudes result in a smaller longitudinal fraction with respect to the naïve expectation, $f_{\rm L} = 0.348 \pm 0.041 \pm 0.021$, as found in other similar $b \to s$ penguin decays [3].

Present statistics of the $B_s^0 \to \varphi\varphi$ data sample are not sufficient for a suitable time–dependent analysis of mixing induced CP–violation as the case of the $B_s^0 \to J/\psi\varphi$ decay. However, an investigation of genuine CP–violating observables which could reveal the presence of NP, such as triple products (TP) correlations, is accessible [8]. The TP is expressed as $\vec{p} \cdot (\vec{\varepsilon}_1 \times \vec{\varepsilon}_2)$, where $\vec{p}$ is the momentum of one of the φ meson in the B_s^0 rest frame, and $\vec{\varepsilon}_i$ are the polarization vectors of the vector mesons. There are two triple products in the $B_s^0 \to \varphi\varphi$ decay corresponding to interferences between CP–odd and CP–even amplitudes, one for transverse–longitudinal mixture, $\Im(A_0 A_\perp^\star)$, and the other for the transverse–transverse term, $\Im(A_\parallel A_\perp^\star)$. These products are functions of the helicity angles: the former is defined by $v = \sin\Phi$ for $\cos\vartheta_1 \cos\vartheta_2 \geq 0$ and $v = -\sin\Phi$ for $\cos\vartheta_1 \cos\vartheta_2 < 0$; the latter is defined by $u = \sin 2\Phi$. The u and v distribution for $B_s^0 \to \varphi\varphi$ candidates are shown in fig 1. Without distinction of the flavor of the B_s^0 meson at the production time (*untagged* sample), the following equation defines a CP–violating asymmetry:

$$\mathscr{A}_u = \frac{\Gamma(u>0) + \bar{\Gamma}(u>0) - \Gamma(u<0) - \bar{\Gamma}(u<0)}{\Gamma(u>0) + \bar{\Gamma}(u>0) + \Gamma(u<0) + \bar{\Gamma}(u<0)}, \tag{2.1}$$

where Γ is the decay rate for the given process and $\bar{\Gamma}$ is its CP–conjugate. An equivalent definition holds for v. Being proportional to $\sin\phi_s \cos\delta_i$, where δ_i are relative strong phases between the polarization amplitudes, in $B_s^0 \to \varphi\varphi$ these asymmetries are nonzero only in presence of NP [8].

The CDF collaboration has made the first measurement of $\mathscr{A}_u$ and $\mathscr{A}_v$ asymmetries in $B_s^0 \to \varphi\varphi$ using the data sample described above [9]. The asymmetries are obtained through an unbinned maximum likelihood fit. The sample is split into two subsets according to the sign of u (or v) of $B_s^0 \to \varphi\varphi$ candidates. The invariant mass distribution of each subset is fitted simultaneously in order to extract the signal asymmetry. The small fraction of physics background, such as $B^0 \to \varphi K^\star(892)^0$ as well as non–resonant decay $B_s^0 \to \phi K^+ K^-$ and "S–wave" contamination $B_s^0 \to J/\psi f_0(980)$, is neglected in the fit and its effect is accounted for in the assigned systematic uncertainties. Using a large sample of Monte Carlo (MC) data the detector acceptance and the reconstruction requirements are checked against biases with a 0.2% accuracy. The background asymmetries are consistent with zero, and the final results for signal asymmetries are: $\mathscr{A}_u = (-0.7 \pm 6.4(\text{stat.}) \pm 1.8(\text{syst.}))\%$ and $\mathscr{A}_v = (-12.0 \pm 6.4(\text{stat.}) \pm 1.6(\text{syst.}))\%$. This measurement establishes a method to search for NP through CP–violating observables in $P \to VV$ decays without the need of tagging and time–dependent analysis, which requires high statistics samples.

3. Observation of the $B_s^0 \to J/\psi f_0(980)$ decay

The $B_s^0 \to J/\psi f_0(980)$ decay has attracted significant attention as a potential "S–wave" contamination to the $B_s^0 \to J/\psi\varphi$ signal when the departure from the SM expectation of Tevatron measurement of mixed induced CP-violation was observed at level of about 1.5σ [5]. It was also suggested that enough signal of $B_s^0 \to J/\psi f_0(980)$ decays can be used to measure the CP–violating phase β_s as well, without need of angular analysis [11]. In addition, the CP–odd nature of the $J/\psi f_0(980)$ allows for measuring the lifetime of the B_s^0 CP–odd eigenstate, $1/\Gamma_s^{\text{odd}}$, that is the lifetime of the heavy–mass eigenstate if CP is conserved. This year the Tevatron experiments have quickly confirmed the observations of this mode [12] from LHCb and Belle collaborations [13]. In the following we review the CDF result of the ratio of branching fractions:

$$R = \frac{\mathscr{B}(B_s^0 \to J/\psi f_0(980))\mathscr{B}(f_0(980) \to \pi^+\pi^-)}{\mathscr{B}(B_s^0 \to J/\psi\varphi)\mathscr{B}(\varphi \to K^+K^-)}, \tag{3.1}$$

where $\mathscr{B}(f_0(980) \to \pi^+\pi^-)$ and $\mathscr{B}(\varphi \to K^+K^-)$ are fixed to PDG values [10], while $\mathscr{B}(B_s^0 \to J/\psi f_0(980))/\mathscr{B}(B_s^0 \to J/\psi\varphi)$ is measured using 3.8 fb^{-1}of data collected by the dimuon trigger.

The sample selection is performed by a neural network trained to maximize the separation between signal and background events. A threshold on the output of the neural network is chosen by maximizing $\varepsilon/(2.5+\sqrt{N_b})$ [14], where ε is the signal reconstruction efficiency and N_b is the number of background events estimated from mass distribution sidebands. The background is dominated by a smooth combinatorial component. Physics backgrounds are studied using inclusive simulated decays of b–hadrons into J/ψ final states (fig. 2). The most prominent physics backgrounds in the $J/\psi\pi\pi$ spectrum are $B^0 \to J/\psi K^\star(892)^0$ and $B^0 \to J/\psi\pi^+\pi^-$ decays.

The ratio $\mathscr{B}(B_s^0 \to J/\psi f_0(980))/\mathscr{B}(B_s^0 \to J/\psi\varphi)$ is evaluated as $N(B_s^0 \to J/\psi f_0(980))/N(B_s^0 \to J/\psi\varphi)\varepsilon_{\text{rel}}$, where $N(B_s^0 \to J/\psi f_0(980))$ and $N(B_s^0 \to J/\psi\varphi)$ are the number of signal events of $B_s^0 \to J/\psi f_0(980)$ and $B_s^0 \to J/\psi\varphi$ respectively, extracted by performing an unbinned extended maximum likelihood fit of the candidates mass distribution in [5.26;5.5] GeV/c^2 (fig. 2); ε_{rel} is the relative efficiency for the reconstruction of the two decays. The latter is evaluated by MC simulation, where $B_s^0 \to J/\psi\varphi$ candidates are generated based on CDF preliminary results [15],[1] while $B_s^0 \to J/\psi f_0(980)$ candidates are modeled by a Flatté distribution whose parameters are fixed to the BES experiment results [16]. We found $N(B_s^0 \to J/\psi f_0(980)) = 571 \pm 37(\text{stat.}) \pm 25(\text{syst.})$ with significance much greater than 5σ, and finally $R = 0.292 \pm 0.020(\text{stat.}) \pm 0.017(\text{syst.})$. The measurement is in good agreement with determinations by other experiments and it is the most accurate result to date.

[1] As a strong phase $\delta_\parallel$ is not measured we use the world average value from $B^0 \to J/\psi K^{0\star}$ decays [10].

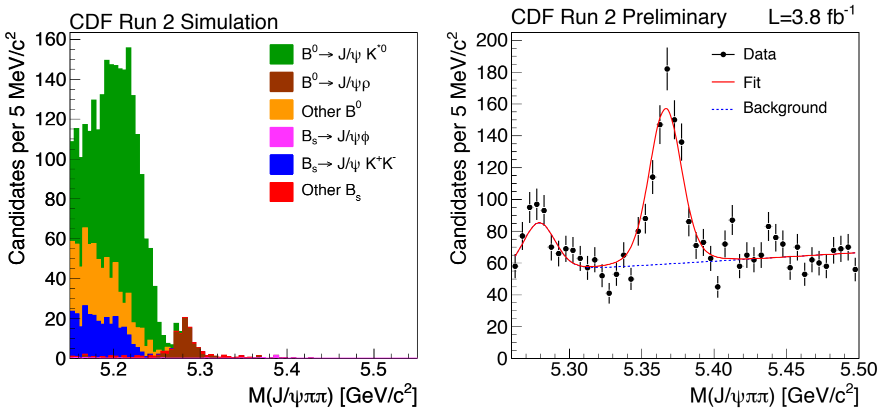

Figure 2: Left: stacked histogram of physics backgrounds in $J/\psi\pi\pi$ mass distribution from simulation. Right: fit to the $J/\psi\pi\pi$ mass distribution.

4. First observation of $B_s^0 \to J/\psi K^{(\star)}$ decays

The two Cabibbo–suppressed decays $B_s^0 \to J/\psi K^\star(892)^0$ and $B_s^0 \to J/\psi K_S$ allow disentanglement of penguin contributions in the decays $B_s^0 \to J/\psi\varphi$ and $B^0 \to J/\psi K_S^0$, respectively. The $B_s^0 \to J/\psi K^\star(892)^0$ decay could be used for the measurement of $\Delta\Gamma_s$ and polarization amplitudes, and $B_s^0 \to J/\psi K_S$ for measurement of $1/\Gamma_s^{\text{odd}}$. The $B_s^0 \to J/\psi K_S$ decay can also yield information on the γ angle of the unitarity triangle [17].

The CDF collaboration has recently reported the first observation of these modes and the measurement of their branching ratios in 5.9 fb^{-1}of data selected by the dimuon trigger [18]. The sample selection was optimized maximizing the sensitivity for either finding evidence of a signal at 3σ, or excluding it at the same confidence level; for the $B_s^0 \to J/\psi K_S$ the selection is based on a neural network, while for $B_s^0 \to J/\psi K^\star(892)^0$ a simpler cut–based analysis is performed, in both cases exploiting vertexing and kinematic discriminating variables. Both analyses have two common background contributions: the combinatorial background and the partially reconstructed background where γ, π or K of multibody decays are not reconstructed. Other physics backgrounds, such as $\Lambda_b \to J/\psi\Lambda$ for $B_s^0 \to J/\psi K_S$ or $B_s^0 \to J/\psi\varphi$ for $B_s^0 \to J/\psi K^\star(892)^0$, give negligible contributions. A binned maximum likelihood fit to the mass distribution of the candidates has been performed to extract the signal yields (fig. 3): 64 ± 14 $B_s^0 \to J/\psi K_S$ and 151 ± 25 $B_s^0 \to J/\psi K^\star(892)^0$ signal events have been observed, both with a significance greater than 5σ. Branching fractions are normalized to rates of the corresponding favored modes, $\mathscr{B}(B^0 \to J/\psi K_S^0)$ and $\mathscr{B}(B^0 \to J/\psi K^{0\star})$, and relative efficiency of reconstruction is evaluated by MC simulation. The branching ratio of the favored decays are fixed to their PDG values [10] and the fragmentation–fraction f_s/f_d is fixed to the most recent CDF measurement of $f_s/(f_u + f_d)\mathscr{B}(D_s \to \phi\pi)$ [19] combined with PDG value of $\mathscr{B}(D_s \to \phi\pi)$. Finally, the measured branching ratios are $\mathscr{B}(B_s^0 \to J/\psi K^\star(892)^0) = (8.3 \pm 1.2(\text{stat.}) \pm 3.5(\text{syst.})) \times 10^{-5}$ and $\mathscr{B}(B_s^0 \to J/\psi K_S) = (3.5 \pm 0.6(\text{stat.}) \pm 0.6(\text{syst.})) \times 10^{-5}$.

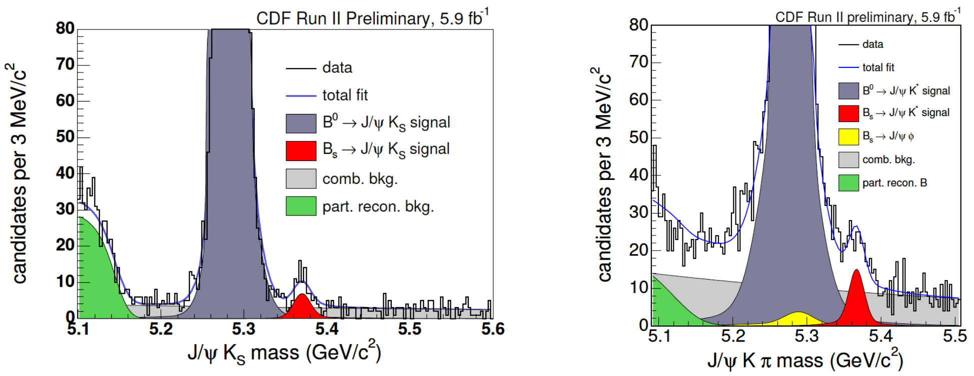

Figure 3: Invariant mass distribution for $J/\psi K^0_S$ (left) and for $J/\psi K\pi$ (right) with fit including the different contributions.

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