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Measurement of ϕ_s and $\Delta\Gamma_s$ at the Tevatron

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We present bounds on the CP violation phase ϕ_s and on the decay width difference $\Delta\Gamma_s$ which characterize the neutral $B_s^0 - \bar{B}_s^0$ meson system. The measurements are performed by the CDF and DØ experiments at the Fermilab Tevatron using $B_s^0 \to J/\psi\phi$ decays with 2.8 fb^{-1} of data per experiment. A data sample of 5 fb^{-1} has already been recorded by each experiment and expect up to doubling this amount by the end of the Tevatron running. Neither of the two Tevatron experiments can provide accurate measurement of the CP violation phase with the current or even expected sample sizes. However they can significantly constrain the allowed parameter space and search for physics beyond the standard model manifested as a large deviation from zero of the CP violation parameter ϕ_s.

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1. Introduction

In the standard model (SM) of particle physics charge and parity (CP) violation occurs due to the presence of complex parameters in the quark and neutrino mixing matrices. In particular, the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1] describes the linear transformation between weak and mass quark eigenstates. Determination of the CKM parameters has been one of the main goals in particle physics in the last decades since CP violation is one of the most important ingredients necessary to explain the asymmetry between matter and anti-matter in the universe [2]. Within the context of the SM, CP violation effects in the quark sector measured in the kaon and neutral B^0 systems lead to the conclusion that CKM induced CP violation is not enough to explain the matter anti-matter asymmetry in the universe. Without invoking new physics (NP), CP violation can also occur through the neutrino mixing matrix which will be studied by future long baseline neutrino experiments. In the meantime, one can search for CP non-conservation beyond the SM. One such possibility is to study $B_s^0 \to J/\psi\,\phi$ decays, where $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$. In these decays CP violation occurs through the interference between the decay amplitudes with and without B_s^0 mixing. In the SM the relative phase between the decay amplitudes with and without mixing, is $\beta_s^{SM} = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$ and is expected to be very small [3, 4]. New physics contributions manifested in the B_s^0 mixing amplitude may alter this mixing phase by a quantity ϕ_s^{NP} leading to an observed mixing phase $2\beta_s^{J/\psi\,\phi} = 2\beta_s^{SM} - \phi_s^{NP}$. Large values of the observed $\beta_s^{J/\psi\,\phi}$ would be an indication of physics beyond the SM [5].

2. Neutral B_s^0 System

A B_s^0 meson is a bound state composed of an anti-bottom quark $\bar{b}$ and a strange quark s. The time evolution of a mixture of the B_s^0 and its antiparticle $\bar{B}_s^0$, $a(t)|B_s^0\rangle + b(t)|\bar{B}_s^0\rangle$, is given by the Schrödinger equation

$$i\frac{d}{dt}\begin{pmatrix} a \\ b \end{pmatrix} = \left(M - i\frac{\Gamma}{2}\right)\begin{pmatrix} a \\ b \end{pmatrix}, \tag{2.1}$$

where M and Γ are 2×2 mass and decay matrices. The mass eigenstates B_L^0 and B_H^0 are linear combinations of the flavor eigenstates B_s^0 and $\bar{B}_s^0$ and are obtained by diagonalizing the Hamiltonian operator. The mass eigenstates have different mass eigenvalues and the mass difference Δm_s is proportional to the B_s^0 mixing frequency recently measured by both CDF [6] and DØ [7] experiments and found to be in good agreement with SM predictions [4]. Moreover, the mass eigenstates have different decay widths Γ_L and Γ_H. The average decay width is defined as $\Gamma_s = (\Gamma_L + \Gamma_H)/2$ and the decay width difference is defined as $\Delta\Gamma_s = \Gamma_L - \Gamma_H$. The mean B_s^0 lifetime $\tau(B_s^0)$ is defined as the inverse of the Γ_s. The decay width difference $\Delta\Gamma_s = 2|\Gamma_{12}|\cos(\phi_s)$ is sensitive to new physics effects [4, 8, 9] that affect the phase $\phi_s = \arg(-M_{12}/\Gamma_{12})$, where Γ_{12} and M_{12} are the off-diagonal elements of the decay and mass matrices. New physics can increase ϕ_s, so $\Delta\Gamma_s$ would be smaller than the SM prediction. Since the SM phase ϕ_s^{SM} is predicted to be very small (≈ 0.004) [4], in a new physics scenario with large contribution to ϕ_s one could approximate $\phi_s = \phi_s^{SM} + \phi_s^{NP} \approx \phi_s^{NP}$. If present, this new physics phase is accessible in $B_s^0 \to J/\psi\,\phi$ decays. In these decays one can measure the CP violation phase $\beta_s^{J/\psi\,\phi}$ which is the relative phase between the direct decay amplitude and mixing followed by decay amplitude. In SM this phase is defined as $\beta_s^{SM} = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$

where V_{ij} are the elements of the CKM quark mixing matrix. Global fits of experimental data tightly constrain the CP violation phase to small values in the context of SM $\beta_s^{SM} \approx 0.02$ [4, 10]. The presence of new physics could modify this phase by the same quantity ϕ_s^{NP} that affects the ϕ_s phase. The recent precise determination of the B_s^0 oscillation frequency [6] indicates that contributions of new physics to the magnitude are unlikely [9]. New physics could contribute significantly to the observed $\beta_s^{J/\psi\phi}$ phase [4, 8, 9] expressed as $2\beta_s^{J/\psi\phi} = 2\beta_s^{SM} - \phi_s^{NP}$. Assuming that new physics effects dominate over the SM phase, we can approximate $2\beta_s^{J/\psi\phi} \approx -\phi_s^{NP} \approx -\phi_s$.

3. Measurement of the CP Violation Phase $\beta_s^{J/\psi\phi}$

The decay of the B_s^0 meson into J/ψ and ϕ is a physics rich decay mode as it can be used to measure the B_s^0 lifetime, decay width difference $\Delta\Gamma_s$ and the CP violation phase $\beta_s^{J/\psi\phi}$. While the B_s^0 meson has spin 0, the final state particles J/ψ and ϕ have spin 1. The total spin in the final $J/\psi\phi$ state is either 0, 1 or 2. To conserver total angular momentum, the orbital angular momentum in the final state must be either 0, 1 or 2. While the J/ψ and ϕ are CP even, the CP of the $J/\psi\phi$ state is given by $(-1)^L$, where L is the orbital angular momentum. Consequently, the states with orbital angular momentum 0 and 2 are CP even while the state with angular momentum 1 is CP odd. Angular distributions of the final muons and kaons from $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$ decays can be used to statistically separate the CP eigenstates. There are three angles that completely define the directions of the four particles in the final state. We use the angles $\vec{\rho} = \{\cos\theta_T, \phi_T, \cos\psi_T\}$ defined in the transversity basis introduced in Ref. [11]. In this basis the decay amplitude is decomposed in three independent components corresponding to linear polarization states of the vector mesons which can be either longitudinal (0), or transverse to their directions of motion and parallel ($\|$) or perpendicular ($\perp$) to each other. The corresponding amplitudes are called A_0, $A_\|$ and $A_\perp$, respectively. The states A_0 and $A_\|$ are CP even while the state $A_\perp$ is CP odd. The three states in the transversity basis are easily expressed as linear combinations of states in either the helicity basis (+1, 0, -1) or the orbital angular momentum basis (S, P, D). In terms of helicity basis, $A_\|$ and $A_\perp$ are linear combinations of the states with helicities +1 and -1, while the A_0 state is the same in both transversity and helicity bases. In terms of the S, P and D waves, the states A_0 and $A_\|$ are linear combinations of S and D, while $A_\perp$ is the same as the P wave state. Separation of the CP even and CP odd final states is crucial to enhance the sensitivity of this analysis to the CP violation phase $\beta_s^{J/\psi\phi}$.

Another important improvement of the sensitivity to the CP violation phase, used by both experiments is the flavor identification of the B_s or $\bar{B}_s$ meson at production by means of flavor tagging. Two independent types of flavor tags are used, each exploiting specific features of the production of b quarks at the Tevatron. The first type of flavor tag infers the production flavor of the B_s or $\bar{B}_s$ meson from the decay products of the b hadron produced by the other b quark in the event. This is known as an opposite-side flavor tag, OST. The OST decisions are based on the charge of muons or electrons from semileptonic B decays or the net charge of the opposite-side jet. The calibration of the OST dilution is determined from $B^\pm \to J/\psi K^\pm$ decays where the tag can be easily compared to the real charge of the b-quark given by the charge of the kaon (a $\bar{b}$ quark inside a B^+ meson leads to a K^+ in the final state while a b quark inside a B^- meson leads to a K^-). The second type of flavor tag identifies the flavor of the reconstructed B_s or $\bar{B}_s$ meson at production by

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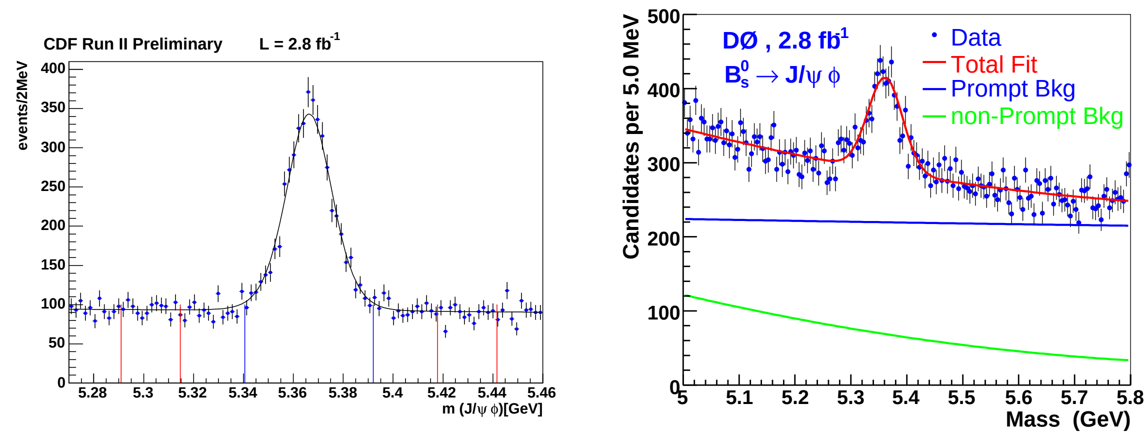

Figure 1: $J/\psi\phi$ invariant mass distributions from CDF (left) and DØ (right). CDF collects ~ 3200 B_s^0 candidates using an artificial neural network selection while DØ accumulates ~ 2000 B_s^0 candidates using a square cut optimization.

correlating it with the charge of an associated kaon arising from fragmentation processes, referred to as a same-side kaon tag, SSKT. At CDF the average dilution $\mathscr{D}$, defined via the correct tag probability $\mathscr{P} = (1+\mathscr{D})/2$, is $(11\pm2)\%$ for the OST and $(27\pm4)\%$ for the SSKT. The efficiencies for a B_s^0 candidate to be tagged are $(96\pm1)\%$ for the OST and $(50\pm1)\%$ for the SSKT. The tagging power measured by the product between the efficiency and the square of the dilution is $\approx 1.2\%$ for OST and $\approx 3.6\%$ for SSKT leading to a total tagging power of $\approx 4.8\%$ [6]. The DØ experiment achieves a total tagging power similar to CDF by employing similar methods [7].

A simultaneous unbinned maximum likelihood fit in the mass, decay time and angular space is performed to extract the parameters of interest, $\beta_s^{J/\psi\phi}$ and $\Delta\Gamma_s$, plus additional parameters referred to as "nuisance parameters" which include the signal fraction f_s, the B_s^0 mass, the mean B_s^0 width $\Gamma_s \equiv (\Gamma_L+\Gamma_H)/2 = 1/\tau(B_s^0)$, the magnitudes of the polarization amplitudes in the transversity basis $|A_0|$, $|A_\parallel|$, and $|A_\perp|$, and the CP conserving strong phases $\delta_\parallel \equiv \arg(A_\parallel A_0^*)$ and $\delta_\perp \equiv \arg(A_\perp A_0^*)$. These phases are either 0 or π in the absence of final state $J/\psi\phi$ interactions. Deviations of these phases from 0 or π indicate breaking of the factorization hypothesis which assumes no interaction between the J/ψ and ϕ in the final state.

The time and angular dependence of the signal probability density function $P_s(t,\vec{\rho},\xi,|\mathscr{D},\sigma_t)$ can be written in terms of two probability density functions, P for B_s and $\bar{P}$ for $\bar{B}_s$, as

$$\begin{aligned} P_s(t,\vec{\rho},\xi|\mathscr{D},\sigma_t) &= \frac{1+\xi\mathscr{D}}{2} P(t,\vec{\rho}|\sigma_t)\varepsilon(\vec{\rho}) \\ &\quad + \frac{1-\xi\mathscr{D}}{2} \bar{P}(t,\vec{\rho}|\sigma_t)\varepsilon(\vec{\rho}), \end{aligned} \tag{3.1}$$

The time and angular probabilities for B_s can be expressed as

$$\begin{aligned} P(t,\vec{\rho}) \propto\ & |A_0|^2 \mathscr{T}_+ f_1(\vec{\rho}) + |A_\parallel|^2 \mathscr{T}_+ f_2(\vec{\rho}) \\ &+ |A_\perp|^2 \mathscr{T}_- f_3(\vec{\rho}) + |A_\parallel||A_\perp| \mathscr{U}_+ f_4(\vec{\rho}) \\ &+ |A_0||A_\parallel| \cos(\delta_\parallel) \mathscr{T}_+ f_5(\vec{\rho}) \\ &+ |A_0||A_\perp| \mathscr{V}_+ f_6(\vec{\rho}), \end{aligned} \tag{3.2}$$

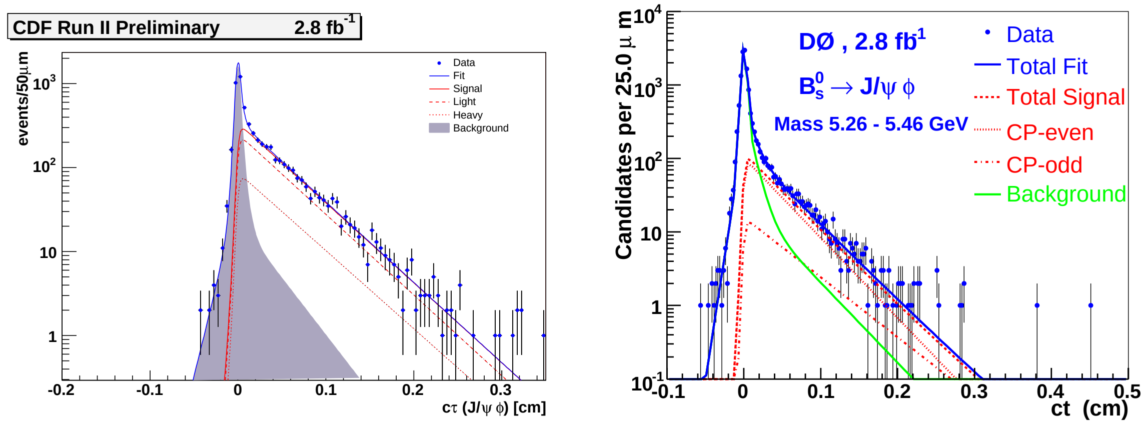

Figure 2: Decay time distributions of B_s with superimposed fit projections from CDF (left) and DØ (right).

where the functions $f_1(\vec{\rho})\ldots f_6(\vec{\rho})$ are defined in Ref. [14]. The probability $\bar{P}$ for $\bar{B}_s$ is obtained by substituting $\mathscr{U}_+ \to \mathscr{U}_-$ and $\mathscr{V}_+ \to \mathscr{V}_-$. The time-dependent term $\mathscr{T}_\pm$ is defined as

$$\mathscr{T}_\pm = e^{-\Gamma t} \times \left[\cosh(\Delta\Gamma t/2) \mp \cos(2\beta_s)\sinh(\Delta\Gamma t/2) \right. \\ \left. \mp\, \eta \sin(2\beta_s)\sin(\Delta m_s t)\right],$$

where $\eta = +1$ for P and -1 for $\bar{P}$. The other time-dependent terms are defined as

$$\begin{aligned}
\mathscr{U}_\pm = \pm e^{-\Gamma t} \times & \left[\sin(\delta_\perp - \delta_\parallel)\cos(\Delta m_s t) \right. \\
& - \cos(\delta_\perp - \delta_\parallel)\cos(2\beta_s)\sin(\Delta m_s t) \\
& \left. \pm \cos(\delta_\perp - \delta_\parallel)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)\right], \\
\mathscr{V}_\pm = \pm e^{-\Gamma t} \times & \left[\sin(\delta_\perp)\cos(\Delta m_s t) \right. \\
& - \cos(\delta_\perp)\cos(2\beta_s)\sin(\Delta m_s t) \\
& \left. \pm \cos(\delta_\perp)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)\right].
\end{aligned}$$

These relations assume that there is no direct *CP* violation in the system. The time-dependent probability density function is convolved with a Gaussian proper decay time resolution function with event-by-event standard deviation σ_t, which is adjusted by an overall calibration factor determined from the fit using promptly decaying background candidates. The lifetime probability density function for the background, $P_b(t|\sigma_t)$, is modeled with a delta function at $t = 0$, one and two exponentials with negative slope for $t < 0$ and $t > 0$, respectively, all of which are convolved with the Gaussian resolution function. The background angular probability density functions are factorized, $P_b(\vec{\rho}) = P_b(\cos\theta_T)P_b(\varphi_T)P_b(\cos\psi_T)$, and are obtained using B_s mass sidebands events.

The fit uses information on the reconstructed B_s^0 candidate mass, the B_s^0 candidate proper decay time and its uncertainty, the transversity angles $\vec{\rho}$ and tag information [6, 7] $\mathscr{P}$ and ξ, where $\mathscr{P}$ is the event-by-event correct tag probability and $\xi = \{-1, 0, +1\}$ is the tag decision, in which $+1$ corresponds to a candidate tagged as B_s^0, -1 to a $\bar{B}_s$, and 0 to an untagged candidate.

The detector acceptance effects on the transversity angle distributions $\varepsilon(\vec{\rho})$ are modeled with $B_s \to J/\psi\,\phi$ simulated data. Three-dimensional joint distributions of the transversity angles are

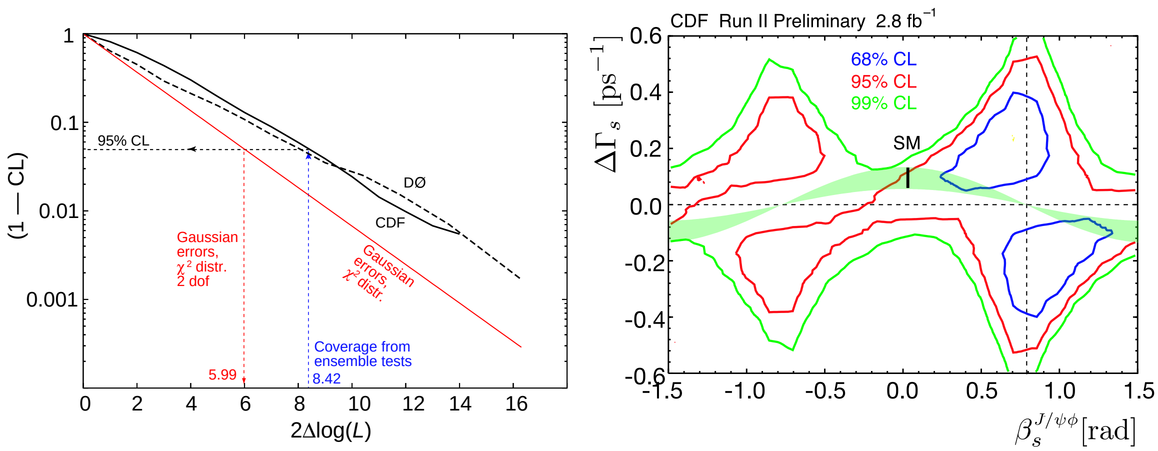

Figure 3: Left: 1 - confidence level as function of 2Δlog(L) for CDF (continuous black line) and DØ (dashed black line) obtained using pseudo-experiments. The red curve is an ideal integrated χ^2 distribution with two degrees of freedom. The relation between 1 - C.L. and 2Δlog(L) would follow this function in an ideal Gaussian case. Deviations of both CDF and DØ curves are due systematic uncertainties and to non-Gaussian behavior of the corresponding likelihood functions. As an example, for the CDF case, the 95% C.L. is obtained by slicing the profiled likelihood at 8.42 units above the minimum instead of the nominal 5.99. Similar non-Gaussian and systematic effects and are observed for both CDF and DØ cases. Right: Confidence regions in $\beta_s^{J/\psi\phi}$ and $\Delta\Gamma_s$ plane for the CDF analysis including non-Gaussian effects and systematic uncertainties. The SM expectation and uncertainty is indicated by the black point. The region allowed in new physics models given by $\Delta\Gamma_s = 2|\Gamma_{12}|\cos\phi_s$ is also shown as light green band.

used to determine $\varepsilon(\vec{\rho})$, in order to correctly account for any dependencies among the angles. The angular analysis is validated by measuring the lifetime, polarization amplitudes and strong phases in $B^0 \to J/\psi K^{*0}$ decays [12]. The results are consistent and competitive with most recent *B*-factory results [13] and support the reliability of the model. Additional confidence is provided by the precise measurement of lifetime and width-difference in untagged $B_s \to J/\psi\phi$ decays [14].

4. Results

The CDF experiment reconstructs a signal sample of $\sim$3200 B_s^0 candidates using a neural network selection while the DØ experiment selects $\sim$2000 events using a square cut optimization method. The $J/\psi\phi$ invariant mass distributions from each experiment are shown in Figure 1. The B_s^0 lifetime and decay width difference measured by CDF in the hypothesis of no CP violation are [15] $\tau(B_s^0) = 1.53 \pm 0.04(\text{stat}) \pm 0.01(\text{syst})$ ps and $\Delta\Gamma_s = 0.02 \pm 0.05(\text{stat}) \pm 0.01(\text{syst})\ \text{ps}^{-1}$. The DØ experiment quotes measurements [16] of the lifetime and decay width difference assuming CP violation $\tau(B_s^0) = 1.52 \pm 0.05(\text{stat}) \pm 0.01(\text{syst})$ ps and $\Delta\Gamma_s = 0.19 \pm 0.07(\text{stat})^{+0.02}_{-0.01}(\text{syst})\ \text{ps}^{-1}$. In the hypothesis of no CP violation DØ measures $\Delta\Gamma_s = 0.14 \pm 0.07(\text{stat})\ \text{ps}^{-1}$. Figure 2 shows the decay time distributions with superimposed fit projections for each experiment. These are the best lifetime and decay width difference measurements in the B_s^0 system to date.

An exact symmetry is present in the signal probability distribution function, which is invariant under the simultaneous transformation ($2\beta_s \to \pi - 2\beta_s$, $\Delta\Gamma_s \to -\Delta\Gamma_s$, $\delta_\parallel \to 2\pi - \delta_\parallel$, and $\delta_\perp \to \pi - \delta_\perp$). This causes the likelihood function to have two minima. Confidence regions in

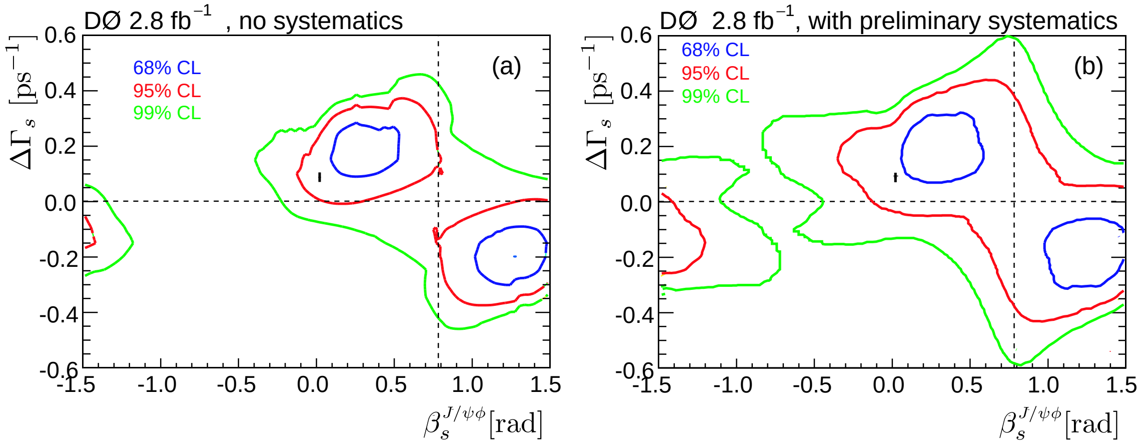

Figure 4: Confidence contours of $\beta_s^{J/\psi\phi}$ and $\Delta\Gamma_s$ including non-Gaussian effects for the DØ case, without systematic uncertainties (left), and with systematic uncertainties (right). The SM expectation and uncertainty is indicated by the black line.

the $\beta_s^{J/\psi\phi} - \Delta\Gamma_s$ plane are constructed by both CDF and DØ . The confidence regions for CDF are presented in Figure 3 while the corresponding confidence regions for DØ are shown in Figure 4. The confidence contours show the expected double minimum structure and they are both shifted in the same direction with respect to the SM expectation. The CDF p-value for the SM point is 7% ($\sim$ 1.8 standard deviations) while the DØ SM p-value is 24% ($\sim$ 1.2 standard deviations). As suggested by the shapes of the profiled likelihoods shown in Figure 3 and Figure 4 the likelihood functions are not Gaussian. To account for non-Gaussian effects each experiment uses a frequentist method which involves generating many pseudo-experiments to determine the actual correspondence between the usual 2Δlog(L) and confidence level. A likelihood ratio ordering principle is used in both analyzes. To account for systematic uncertainties, CDF varies all nuisance parameters flat within $\pm 5\sigma$ with respect to the best fit values and derives different C.L. vs 2Δ log(L) curves. Conservatively, the curve with the largest value of 1-C.L. is chosen for each value of 2Δlog(L). Similarly, DØ includes systematic uncertainties by generating maps of C.L. vs 2Δlog(L) after varying the nuisance parameters corresponding to the dominant systematic uncertainties (B_s^0 oscillation frequency Δm_s and tagging dilution parameterization) within $\pm 1\sigma$ from best fit values.

Possible asymmetries between the tagging rate and dilution of B_s and $\bar{B}_s$ mesons have been studied with control samples and found to be statistically insignificant. Important sources of systematic uncertainty, such as the determination of overall calibration factors associated with the proper decay time resolution and the dilutions are allowed to float in the fit. The mixing frequency $\Delta m_s = 17.77 \pm 0.12$ ps^{-1} is constrained in the fit within the experimental uncertainties [6]. Systematic uncertainties coming from alignment, background angular distributions, decays from other B mesons, the modeling of signal and background are found to have a negligible effect on the determination of both $\Delta\Gamma_s$ and β_s relative to statistical uncertainties.

The ambiguity between the two minima could be resolved if the strong phases $\delta_\parallel$ and $\delta_\perp$ were known. Recent theoretical studies [17] suggest that the strong phases involved in $B_s^0 \to J/\psi\phi$ decays are expected to be close to the corresponding strong phases in $B^0 \to J/\psi K^{*0}$. Using this information the CDF and DØ experiments show that in this hypothesis the preferred solution is the

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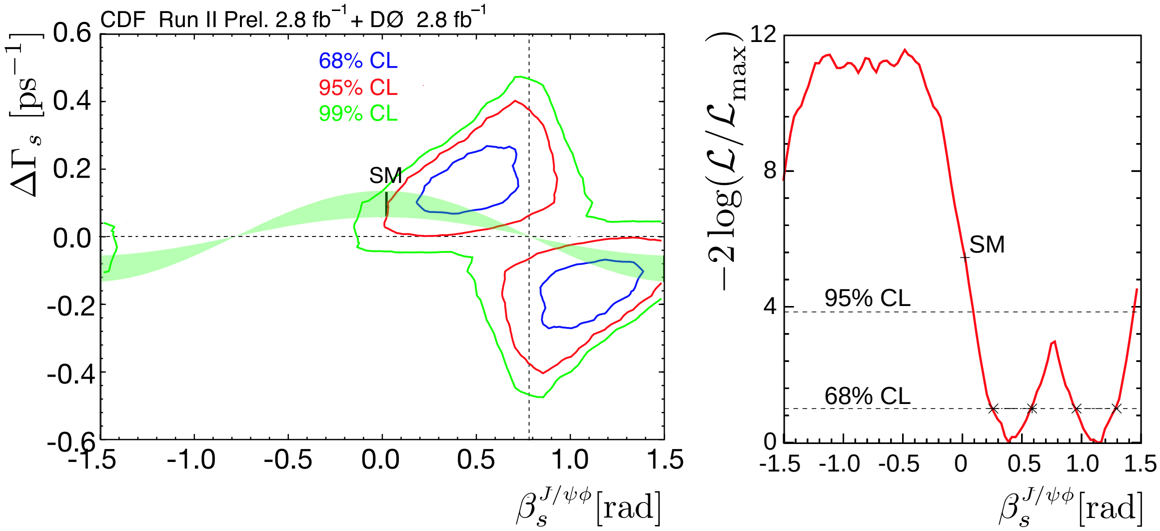

Figure 5: Left: Combined CDF and DØ two-dimensional confidence contours in $\beta_s^{J/\psi\phi}$ - $\Delta\Gamma_s$ plane. The SM point is indicated by the black cross and it has a p-value of 3.4% or 2.1 standard deviations. Right: Combined CDF and DØ one-dimensional likelihood profile for $\beta_s^{J/\psi\phi}$. In this case, the SM p-value is 2.0% or 2.3 standard deviations. Both one-dimensional and two-dimensional profiled likelihoods are scaled so that non-Gaussian effects and systematic uncertainties are included.

one corresponding to positive $\Delta\Gamma_s$.

Combinations of the published CDF analysis with 1.4 fb^{-1} [18] and DØ measurement [16] with 2.8 fb^{-1} have been performed [10, 19] and show departures between two and three standard deviations with respect to the SM prediction. The combination performed in Reference [19] results in a 2.2 σ deviation of $\beta_s^{J/\psi\phi}$ from the SM. The most recent combination performed by CDF and DØ experiments [20] use the latest CDF analysis with 2.8 fb^{-1} [15] and the corresponding DØ analysis with 2.8 fb^{-1} [16]. The results of this combination are shown in Figure 5. The combined SM p-value is 3.4% or to 2.1 standard deviations. This corresponds to the central value of the theoretical SM prediction [4] $\beta_s^{J/\psi\phi} = 0.02$ and $\Delta\Gamma_s = 0.096 \pm 0.039$. The p-value of the point with $\Delta\Gamma_s = 0.096 - 0.039$ is 4.2% or 2.0 standard deviations. The likelihood profile for $\beta_s^{J/\psi\phi}$ alone where $\Delta\Gamma_s$ is allowed to float is also shown in Fig. 5. Irrespective of the value of $\Delta\Gamma_s$, the CP violation phase $\beta_s^{J/\psi\phi}$ is found to be within $\beta_s^{J/\psi\phi}$ is $[0.27, 0.59] \cup [0.97, 1.30]$ at 68% C.L. and within $[0.10, 1.42]$ at 95% C.L. In this projection, the p-value for the SM point is 2.0% or 2.3 standard deviations. It is worth noting that, although a correct estimate of the combined result, this is not the most complete and optimal way to combine CDF and D0 data, being a combination of two-dimensional slices of a much higher dimensional likelihood function. Work is currently ongoing towards implementing a combined fit to the CDF and DØ data sets in all dimensions, effectively providing a combined analysis of both data samples, thus yielding the maximum achievable sensitivity.

Although the combined deviation from the SM expectation is not statistically significant, the independent CDF and DØ fluctuations in the same direction are interesting to follow in the future as the analyzes will be updated using more data. By the end of the Tevatron running, samples of at least 8 fb^{-1} are expected.

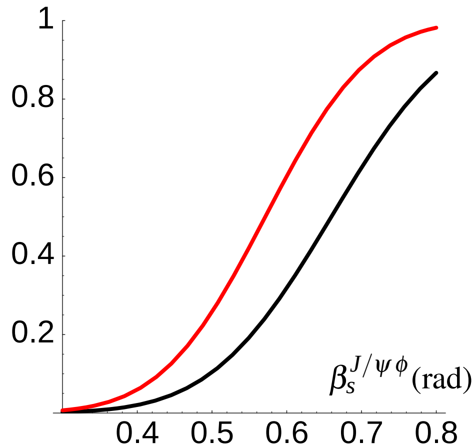

Figure 6: Probability of CDF observing a 5 σ deviation from the SM prediction as a function of $\beta_s^{J/\psi\phi}$ assuming 6 fb^{-1} (black line) and 8 fb^{-1} (red line).

Figure 6 shows the CDF probability of observing a 5σ deviation from the SM as a function of $\beta_s^{J/\psi\phi}$ assuming $\Delta\Gamma_s = 0.1$ ps^{-1}. The extrapolation assumes no further improvements of the analysis. However, improvements in the use of particle identification, tagging power and sample size by using additional triggers are expected from CDF while DØ will optimize the signal selection for better signal to background. According to Ref [21], another significant improvement might come from considering $B_s \to J/\psi f^0(980)$ decays, where $f^0 \to \pi^+\pi^-$.

5. Conclusions

Both CDF and DØ experiments have performed the first measurements of CP violation in $B_s^0 \to J/\psi\phi$ decays. Although the accuracy of these measurements is limited, significant regions in the $\beta_s^{J/\psi\phi} - \Delta\Gamma_s$ plane are excluded. Positive values of $\beta_s^{J/\psi\phi}$ are preferred by both experiments. The combined CDF and DØ measurement shows slightly more than two standard deviation departure from the SM prediction. Although not significant it is interesting to see how the $\beta_s^{J/\psi\phi}$ measurements evolve as more data is accumulated and analyzes improved.

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References

[1] N. Cabibbo, Phys. Rev. Lett. **10**, 531 (1963);
M. Kobayashi and T. Maskawa, Prog. Teor. Phys. **49**, 652 (1973) Phys. Rev. Lett., **51**, 1945 (1983).

[2] A. Sakharov, JTEP Lett. **5**, 24 (1967).

[3] I.I.Y. Bigi and A.I. Sanda, Nucl. Phys. **B193**, 85 (1981).

[4] A. Lenz, U. Nierste, J. High Energy Phys. **06**, 072 (2007).

[5] I. Dunietz, R. Fleischer, and U. Nierste, Phys. Rev. D **63**, 114015 (2001).

[6] A. Abulencia *et al.* (CDF Collaboration), Phys. Rev. Lett. **97**, 242003 (2006).

[7] `http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B54/` .

[8] W.-S. Hou, M. Nagashima, and A. Soddu, Phys. Rev. D, **76**, 016004 (2007);
W.-S. Hou, M. Nagashima, and A. Soddu, Phys. Rev. Lett. **95**, 141601 (2005).

[9] Z. Ligeti, M. Papucci, G.Perez, Phys. Rev. Lett. **97**, 101801 (2006).

[10] CKMfitter Group (J. Charles *et al.*), Eur. Phys. J. C **41**, 1 (2005),
`http://ckmfitter.in2p3.fr`;
M. Bona *et al.* [UTfit Collaboration], J. High Energy Phys. **10**, 81 (2006), `www.utfit.org`.

[11] A. S. Dighe, I. Dunietz and R. Fleischer, Eur. Phys. J. C **6**, 647 (1999).

[12] `http://www-cdf.fnal.gov/physics/new/bottom/070830.blessed-BdPsiKS` ;
V. Abazov *et al.* (DØ Collaboration), arXiv:/0810.0037.

[13] B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. D **76**, 031102(R) (2007);
R. Itoh *et al.* (Belle Collaboration), Phys. Rev. Lett. **95**, 091601 (2005).

[14] T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett. **100**, 121803 (2008).

[15] `http://www-cdf.fnal.gov/physics/new/bottom/`.

[16] V. Abazov *et al.* (DØ Collaboration), Phys. Rev. Lett. **101**, 241801 (2008).

[17] M. Gronau and J.L. Rosner, Phys. Lett. B 669:321-326 (2008).

[18] T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett. **100**, 121802 (2008).

[19] E. Barberio *et al.* Heavy Flavor Averaging Group, 2007,
`http://www.slac.stanford.edu/xorg/hfag/`.

[20] http://tevbwg.fnal.gov/

[21] S. Stone, L. Zhang, arXiv:0812.2832.

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