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Recent results on the Unitarity Triangle from Tevatron

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Summary. — I report on the recent results of Tevatron experiments on the Unitarity Triangle. In particular the measurements of the direct CP asymmetry (A_{CP}) and of the double ratio of CP-even ($D \to K^-K^+$ or $\pi^-\pi^+$) to flavor ($D \to K^-\pi^+$) eigenstate branching fraction (R_{CP}) in the $B \to DK$ decays, that can be used to improve the determination of the CKM angle γ, and the search for new physics in the CP-violating B_s phase β_s using the $B_s^0 \to J/\psi\phi$ decay.

PACS 13.25.Hw – Decays of bottom mesons.
PACS 14.40.Nd – Bottom mesons.
PACS 14.65.Fy – Bottom quarks.

1. – Introduction

At Tevatron the properties of B-mesons can be studied with high precision, thanks to the high-b production cross-section. The use of specialized trigger based on leptons and displaced tracks from primary vertex allow the selection of pure B-meson samples. In this paper we are describing the measurements performed by CDF towards the γ angle measurement using the $B \to DK$ modes (sect. **2**), and the results obtained by D0 and CDF on the mixing phase $\beta_s^{J/\psi\phi}$ (sect. **3**).

2. – γ angle measurements

The measurement of the partial width of $B^- \to DK^-$(1) modes allows a theoretically-clean extraction of the CKM angle γ. This can be obtained in several ways, using different choices of D decay channels [1-4].

We report the first measurement of branching ratios and CP asymmetries of $B^- \to DK^-$ modes performed in hadron collisions, based on an integrated luminosity of $1\,\mathrm{fb}^{-1}$ collected by CDF. Events where the D meson decays to the flavor specific mode $K^-\pi^+$ (D_f^0), or one of the CP-even modes K^-K^+ and $\pi^-\pi^+$ are reconstructed. From

(1) The charge conjugate state is implied throughout the paper.

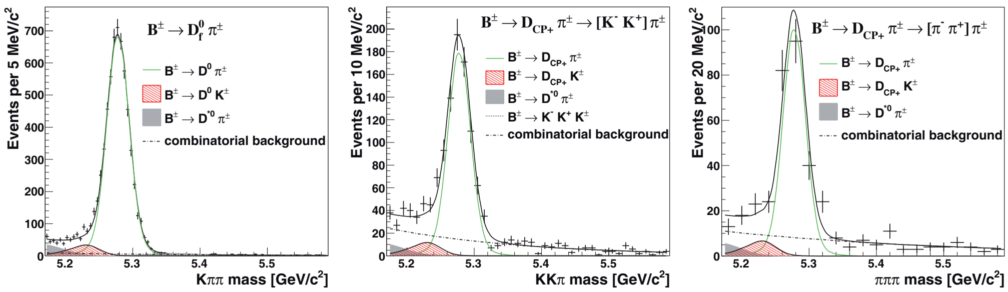

Fig. 1. – Invariant-mass distributions of $B^- \to Dh^-$ candidates for each reconstructed decay mode. The pion mass is assigned to the track from the direct B decay. The projections of the likelihood fit are overlaid for each mode.

these modes, the following observables can be defined [1, 2]:

$$A_{CP+} = \frac{\mathcal{B}(B^- \to D_{CP+}K^-) - \mathcal{B}(B^+ \to D_{CP+}K^+)}{\mathcal{B}(B^- \to D_{CP+}K^-) + \mathcal{B}(B^+ \to D_{CP+}K^+)}, \tag{1}$$

$$R_{CP+} = 2\frac{\mathcal{B}(B^- \to D_{CP+}K^-) + \mathcal{B}(B^+ \to D_{CP+}K^+)}{\mathcal{B}(B^- \to D_f^0 K^-) + \mathcal{B}(B^+ \to \overline{D}_f^0 K^+)}. \tag{2}$$

These quatities are related to the CKM angle γ by the equations [1, 2] $R_{CP+} = 1 + r^2 + 2r\cos\delta\cos\gamma$ and $A_{CP+} = 2r\sin\delta\sin\gamma/R_{CP+}$, where r is the magnitude of the ratio of the amplitudes of the processes $B^- \to \overline{D}^0 K^-$ and $B^- \to D^0 K^-$, and δ is their relative strong phase.

For every $B^- \to Dh^-$ candidate, a nominal invariant mass is evaluated by assigning the charged pion mass to the particle h^- coming from the B decay. The distributions obtained for the three modes of interest (where $D \to K\pi$, KK or $\pi\pi$) are reported in fig. 1; clear $B^- \to D\pi^-$ signal is seen in each. Events from $B^- \to DK^-$ decays are expected to form much smaller and wider peaks in these plots, located about $50\,\mathrm{MeV}/c^2$ below the $B^- \to D\pi^-$ peaks, and as such cannot be resolved. The dominant backgrounds are random track combinations that accidentally meet the selection requirements (combinatorial background), and mis-reconstructed physics background such as $B^- \to D^{*0}\pi^-$ decay, and in the $D^0 \to KK$ final state, the non resonant $B^- \to K^+K^-K^-$ decay, as determined by a study on CDF simulation. An unbinned likelihood fit, exploiting kinematic and particle identification information provided by the $\mathrm{d}E/\mathrm{d}x$, is performed to statistically separate the $B^- \to DK^-$ contributions from the $B^- \to D\pi^-$ signals and from the combinatorial background.

CDF has measured the double ratio of CP-even to flavor eigenstate branching fractions $R_{CP+} = 1.30 \pm 0.24(\mathrm{stat}) \pm 0.12(\mathrm{syst})$ and the direct CP asymmetry $A_{CP+} = 0.39 \pm 0.17(\mathrm{stat}) \pm 0.04(\mathrm{syst})$. These results are in agreement with previous measurements from $\Upsilon(4S)$ decays [5,6], and have comparable uncertainties. They can be combined with other $B^- \to DK^-$ decay parameters to improve the determination of the CKM angle γ.

Another interesting channel that allows a very clean measurement of the γ angle is the $B_s \to D_s K$. Final state of both sign are accessible by both B_s mesons with similar-sized amplitudes: $B_s^0 \to D_s^{\mp} K^{\pm}$, $\bar{B}_s^0 \to D_s^{\pm} K^{\mp}$. The B_s oscillation cause the amplitudes to interfer. In this case we need a time-dependent CP asymmetry measurement.

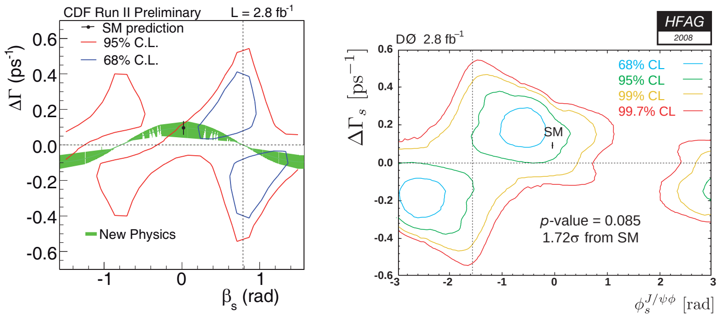

Fig. 2. – Confidence regions in the $\beta_s^{J/\psi\phi}$-$\Delta\Gamma$ plane from CDF (left), in the ϕ_s-$\Delta\Gamma$ plane from D0 (right).

CDF observed 102 ± 18 $\bar{B}_s^0 \to D_s^{\pm} K^{\mp}$ with a statistical significance of 8.1, and measured the ratio of branching ratios $\frac{\mathcal{B}(\bar{B}_s^0 \to D_s^{\pm} K^{\mp})}{\mathcal{B}(\bar{B}_s^0 \to D_s^{+} \pi^{-})} = 0.097 \pm 0.018(\text{stat}) \pm 0.009(\text{syst})$. This analysis is performed using an integrated luminosity of $1.2\,\text{fb}^{-1}$ [7].

3. – Measurements of the CP violation phase $\beta_s^{J/\psi\phi}$

The study of $B_s^0 \to J/\psi\phi$ decays, where $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$ allows the searching for CP non-conservation beyond the Standard Model (SM). In these decays CP violation occurs through the interference between the decay amplitudes with and without mixing. In the SM the relative phase between the decay amplitudes with and without mixing is $\beta_s^{\text{SM}} = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$ and it is expected to be very small [8]. 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 $2\beta_s^{J/\psi\phi} = 2\beta_s^{\text{SM}} - \phi_s^{\text{NP}}$. Large values of the observed $\beta_s^{J/\psi\phi}$ would be an indication of physics beyond the SM [9].

The decay $B_s^0 \to J/\psi\phi$ is a physics rich decay mode as it can be used to measure the B_s^0 lifetime, decay width difference $\Delta\Gamma$ and the CP violation phase $\beta_s^{J/\psi\phi}$. While the B_s^0 meson has spin 0, the final state J/ψ and ϕ have spin 1. Consequently, the total angular momentum in the final state can be either $0, 1$ or 2. States with angular momentum 0 and 2 are CP even while the state with angular momentum 1 is CP odd. Angular distribution of the final muons and kaons from J/ψ and ϕ decays can be used to separete 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. [10].

An unbinned maximum-likelihood fit is performed to extract the parameters of interest, $\beta_s^{J/\psi\phi}$ and $\Delta\Gamma$. The results, obtained using $2.8\,\text{fb}^{-1}$ integrated luminosity, are consistent and competitive with most recent B-factory results [11, 12]. The CDF and D0 experiments reconstruct signal samples of 3200 and 2000 events, respectively. The B_s^0 lifetime and decay width difference measured by CDF are [13] $\tau(B_s^0) = 1.53 \pm 0.04(\text{stat}) \pm 0.01(\text{syst})\,\text{ps}$ and $\Delta\Gamma = 0.02 \pm 0.05(\text{stat}) \pm 0.01(\text{syst})\,\text{ps}^{-1}$, while the corresponding D0 measurements [14] are $\tau(B_s^0) = 1.52 \pm 0.05(\text{stat}) \pm 0.01(\text{syst})\,\text{ps}$ and $\Delta\Gamma = 0.19 \pm 0.07(\text{stat})^{+0.02}_{-0.01}(\text{syst})\,\text{ps}^{-1}$. These are the most precise measurements of the lifetime and decay width difference in the B_s^0 system to date.

Confidence regions in the $\beta_s^{J/\psi\phi}$-$\Delta\Gamma$ plane are constructed by CDF while similar confidence regions are evaluated by D0 in the ϕ_s-$\Delta\Gamma$ plane ($2\beta_s^{J/\psi\phi} \approx \phi_s$). These confidence

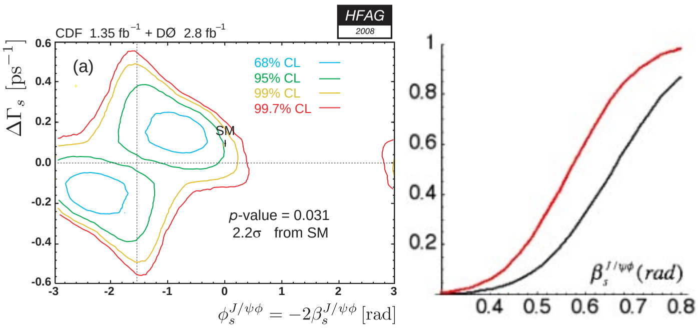

Fig. 3. – (Colour online) Confidence regions in the ϕ_s-$\Delta\Gamma$ plane corresponding to the combined CDF and D0 datasets (left). Probability of CDF observing a 5σ deviation from SM prediction as a function of $\beta_s^{J/\psi\phi}$ assuming $6\,\text{fb}^{-1}$ (black line) and $8\,\text{fb}^{-1}$ (red line).

regions are presented in fig. 2. Both results shifted in the same direction with respect to the SM expectation. The significances of the deviations are 1.8 standard deviations for CDF and 1.7 standard deviations for D0.

Combination of the CDF and D0 results has been performed [15]. The combination includes the D0 analysis with $2.8\,\text{fb}^{-1}$ [14] and a previous CDF result [16] that used only $1.35\,\text{fb}^{-1}$ of data, and results in a 2.2σ deviation of $\beta_s^{J/\psi\phi}$ from the SM and is shown in fig. 3. Although the combined deviation from the SM expectation is not statistically significant, the independent CDF and D0 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 $8\,\text{fb}^{-1}$ are expected. Figure 3 shows the CDF probability of observing a 5σ deviation from the SM as a function of $\beta_s^{J/\psi\phi}$ assuming $\Delta\Gamma = 0.1\,\text{ps}^{-1}$. 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 D0 will optimize the signal selection for better signal to background.

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