HEAVY FLAVOR PHYSICS AT THE TEVATRON

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Recent heavy flavor results at a center of mass energy of 1.96 TeV are presented. The measurements and searches were performed by the D0 and CDF collaborations, using between 1-6 fb^{-1} of data, taken during Run II at the Tevatron.

1 B_s mixing phase from $B_s \to J/\Psi\Phi$ and A_{sl}

The B_s mixing phase is expected to be tiny in the Standard Model (SM):

$$\beta_s^{SM} = arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \approx 0.02, \tag{1}$$

and it is unconstrained by the 2006 measurements of the B_s mixing frequency. Large values, as those induced by New Physics (NP) have not been excluded. The values are accessed experimentally by studying the time evolution of flavor tagged $B_s \to J/\Psi\Phi$ decays or, inclusively, by measuring mixing rate differences between B_s and $\overline{B_s}$. The CDF and D0 collaborations have pursued both paths, and first measurements showed interesting indications of departure from SM predictions, calling for more studies.

1.1 Measurement of the di-muon charge asymmetry at D0

One of the results that has caused much excitement recently has been presented by the D0 collaboration, where the asymmetry of muon pairs produced in semileptonically decaying b hadrons is measured[1]. The asymmetry A_{sl}^b is defined as

$$A_{sl}^b = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}, \tag{2}$$

where N_b^{++} and N_b^{--} are the numbers of events with two b hadrons decaying semileptonically to produce a same sign muon pair. One of the muons is from a $b \to \mu X$ decay, and the other muon from a semileptonic decay after mixing. The quantity A_{sl}^b is expected to be approximately zero within the SM. D0's analysis of 6.1 fb^{-1} of Run II data yields $A_{sl}^b = (-0.957 \pm 0.251(stat.) \pm 0.146(syst.))\%$, which differs from the SM prediction[2] of $A_{sl}^b(SM) = (-0.023^{+0.005}_{-0.006})\%$ at about 3.2σ, indicating an anomalously large B_s mixing phase. Fig.1 shows the asymmetry band in red, the SM prediction, and measurements of a_{sl}^s from D0 and a_{sl}^d from the B factories, for comparison.

The CDF collaboration is also working on an analysis of A_{sl}^b, using a different technique. In it, the muon impact parameter (IP) information is used to fit for the muon sample composition, ensuring that same sign di-muons originate from B decays. This technique has already been used and documented, for example in the CDF measurement of the correlated $B\overline{B}$ cross section[3]. As a first step, CDF has measured the time-integrated mixing probability $\overline{\chi}$, using the IP fit technique.

1.2 Measurement of the time-integrated mixing probability $\overline{\chi}$ at CDF

The time-integrated mixing probability $\overline{\chi}$ is defined as

$$\overline{\chi} = \frac{\Gamma(B^0_{d,s} \to \overline{B}^0_{d,s} \to l^+ X)}{\Gamma(B_{all} \to l^\pm X)} \tag{3}$$

defining an average mixing probability of semileptonically decaying B_d and B_s mesons. At CDF, the number of oppositely charged and same-sign muon pairs is measured and $\overline{\chi}$ is extracted from the ratio $R = [N(\mu^+\mu^+) + N(\mu^-\mu^-)]/N(\mu^+\mu^-)$. A 2004 measurement from CDF[4], showed a discrepancy with an earlier result from LEP. A new CDF result using 1.4 fb^{-1} of data now uses a much tighter muon selection, requiring at least one hit in the first layer of the Silicon Vertex Detector, thus improving the impact parameter measurement significantly. The result is

$$\overline{\chi} = 0.126 \pm 0.008, \tag{4}$$

in very good agreement with the LEP result of $\overline{\chi} = 0.126 \pm 0.004$, and it presents an encouraging first step toward CDF's future A_{sl} measurement.

2 The $B_s \to J/\Psi\Phi$ system

$B_s \to J/\Psi\Phi$ decays are still considered the best probe for new sources of CP violation in B_s decays, however the analysis is complicated by the fact that B_s mesons (spin 0) decay to J/Ψ (spin1) and Φ (spin 0), giving rise to s-wave as well as p-wave contributions. The analysis, documented extensively before, uses a simultaneous fit to mass, decay time, angles and production flavor distributions. Fig.2 documents the current results. The D0 measurement uses 6.1 fb^{-1} and shows a mild disagreement between the SM value and the best fit value, and the CDF result, based on 5.2 fb^{-1}, shows good agreement. It is clear that more information is needed to settle the questions that arise.

An alternative way to access β_s is through the study of $B_s \to J/\Psi f0(980)$ decays. This suppressed decay is a CP=-1 eigenstate and will provide a clean measure of the CP violating parameter β_s, since no complex angular analysis is necessary. Here, the first step toward this goal is reported, which is the reconstruction of this signal and the measurement of the branching ratio in 3.8 fb^{-1} data taken with the CDF detector.

3 Measurement of $BR(B_s \to J/\Psi f0(980))$ at CDF

The search for $B_s \to J/\Psi f0(980)$ decays starts with a loose selection of $\mu\mu\pi\pi$ candidates, which is then improved using a Neural Network based on kinematic variables, track and vertex displacement, and isolation. The identical selection is used for the $B_s \to J/\Psi\Phi$ reference mode. A fit to the signal and normalization channels finally yields 571±37(stat.)±25(syst.) $B_s \to J/\Psi f0(980)$ candidates. For comparison, 2302±49 $B_s \to J/\Psi\Phi$ candidates are observed. Fig.3 shows the invariant mass of the $J/\Psi\pi\pi$ candidate events. The ratio between $BR(B_s \to J/\Psi f0(980), f0(980) \to \pi\pi)$ and $BR(B_s \to J/\Psi\Phi, \Phi \to KK)$ candidates is $0.292 \pm 0.020(stat.) \pm 0.017(syst.)$, resulting in a measurement of the branching ratio

$$BR(B_s \to j/\Psi f0(980), f0(980) \to \pi\pi = 1.85 \pm 0.13(stat.) \pm 0.11(syst.) \pm 0.57(PDG) \times 10^{-4}. \tag{5}$$

The significance of the observation is 17.9σ, and confirms earlier resuts from Belle and LHC-b with higher precision.

4 Search for CP Violation in $D \to \pi\pi$ and $D \to KK$ at CDF

CP violation in the charm sector has been an area of great interest, and recent studies[5] have pointed out that, similarly to D^0 oscillations, NP contributions could play a role in enhancing the size of CP violation in the charm sector. An asymmetry is defined as

$$A_{CP}(h^+h^-) = \frac{\Gamma(D^0 \to h^+h^-) - \Gamma(\overline{D^0} \to h^+h^-)}{\Gamma(D^0 \to h^+h^-) + \Gamma(\overline{D^0} \to h^+h^-)}. \tag{6}$$

At CDF, 5.94 fb^{-1} of data is used to analyze D^* tagged D^0 decays. The asymmetry in $\pi\pi$ and KK samples is measured and corrected for the instrumental asymmetry using $K\pi$ samples, with and without the D^* tag. The resulting limits are the world's most sensitive limits:

$$A_{CP}(D^0 \to \pi^+\pi^-) = [+0.22 \pm 0.24(stat.) \pm 0.11(syst.)]\% \tag{7}$$
$$A_{CP}(D^0 \to K^+K^-) = [-0.24 \pm 0.22(stat.) \pm 0.10(syst.)]\% \tag{8}$$

5 CP Asymmetry in $B^\pm \to D^0 h^\pm$ at CDF

The branching fractions and searches for CP asymmetries in $B^\pm \to D^0 h^\pm$ decays allow for a clean measurement of γ, the least well constrained angle of the CKM matrix. To this end, the ADS method has been proposed[6], making use of doubly Cabibbo suppressed (DCS) D^0 modes. CDF's new measurement of direct CP asymmetry for the DCS modes will be used in the future to extract γ. A DCS fraction and asymmetry is defined as follows:

$$R_{ADS}(K) = \frac{BR(B^- \to [K^+\pi^-]_D K^-) + BR(B^+ \to [K^-\pi^+]_D K^+)}{BR(B^- \to [K^-\pi^+]_D K^-) + BR(B^+ \to [K^+\pi^-]_D K^+)} \tag{9}$$
$$A_{ADS}(K) = \frac{BR(B^- \to [K^+\pi^-]_D K^-) - BR(B^+ \to [K^-\pi^+]_D K^+)}{BR(B^- \to [K^-\pi^+]_D K^-) + BR(B^+ \to [K^+\pi^-]_D K^+)} \tag{10}$$
$$\tag{11}$$

and similar for pions. The experimental challenge is to suppress combinatorial and physics backgrounds when extracting the highly suppressed DCS signal. Using 4 fb^{-1} of data taken with the CDF detector, a combined Likelihood fit is used to distinguish the signal modes from background. As an example, Fig.4 shows the invariant $K^+\pi^+\pi^-$ mass with data and various background and signal distributions. The results for the Kaon mode are shown in Fig.5, demonstrating good agreement with BaBar and Belle. It is the first application of the ADS method at a hadron machine.

6 Conclusion

The Tevatron is producing a steady flow of interesting Heavy Flavor results, and a few of them have been summarized in this article. For the analyses described here, only a fraction of the final Run II data has been used, and we look forward to challenging the SM predictions of Heavy Flavor Physics and constraining parameters of NP models in the months and years to come.

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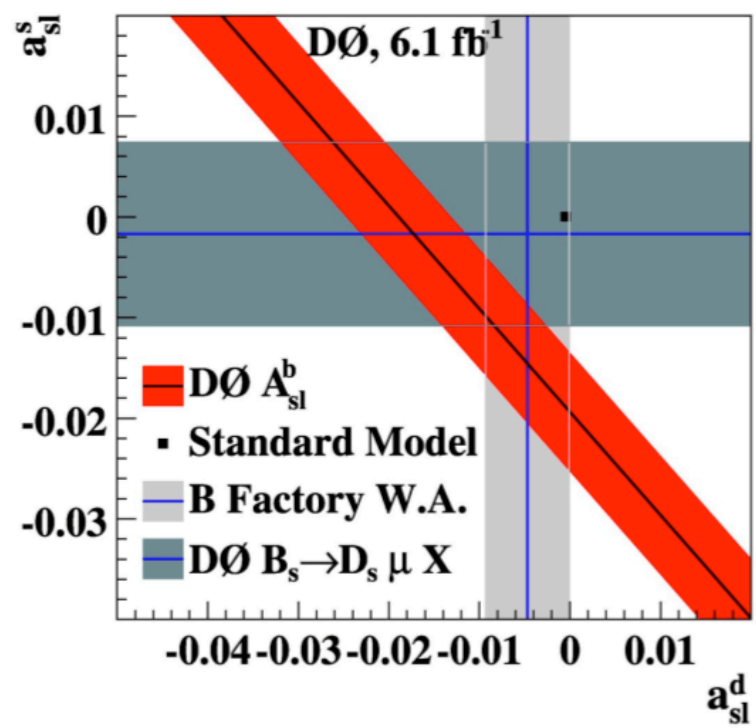
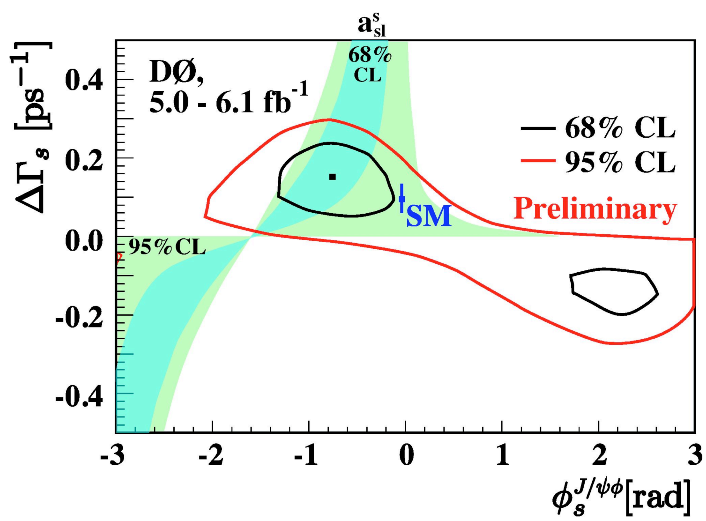


Figure 1: Di-muon charge asymmetry, measured at D0 with 6.1 fb^{-1} of Run II data.



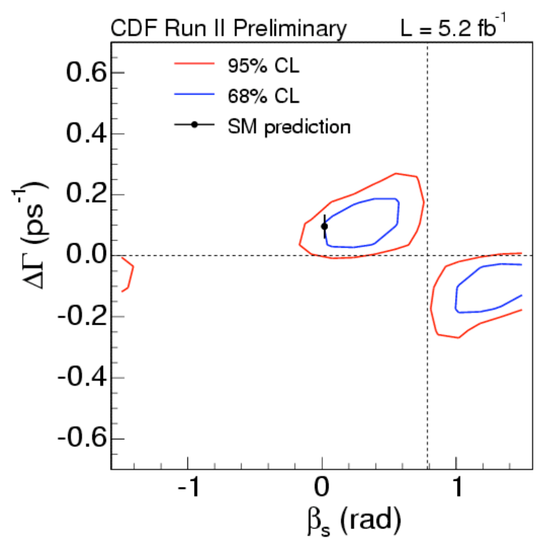


Figure 2: D0 and CDF results of fits to the B_s mixing phase in $B_s \to J/\Psi\Phi$ decays. In the top plot (D0), the information from the measurement of the di-muon charge asymmetry is overlaid in green.

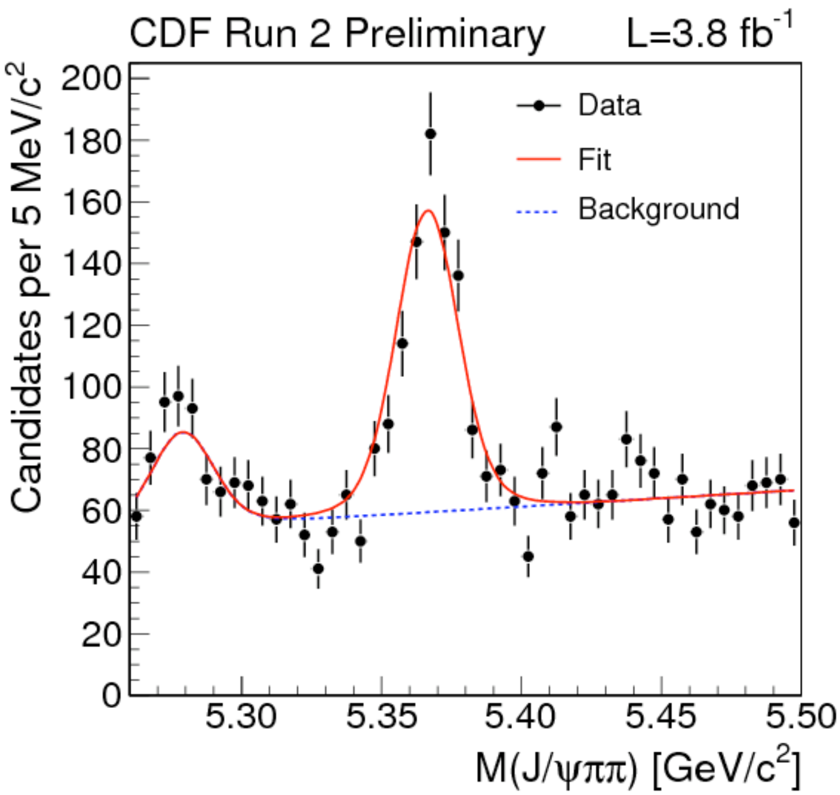


Figure 3: The invariant mass of selected $J\Psi\pi\pi$ candidate events, as measured at CDF with 3.8 fb^{-1} of data.

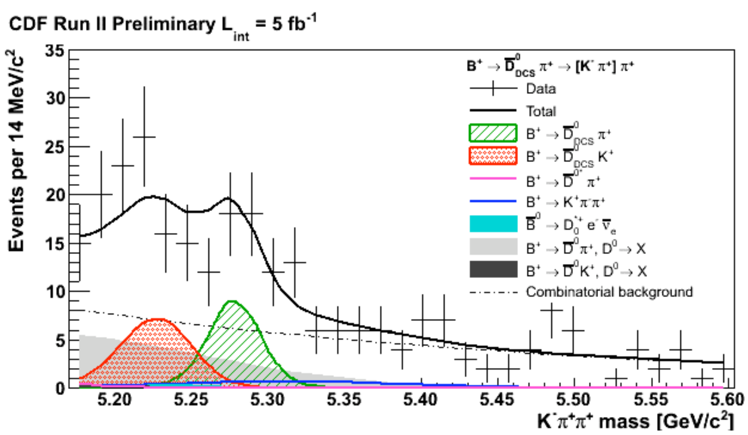


Figure 4: The invariant $K^+\pi^+\pi^-$ mass with data and various background and signal distributions, as measured at CDF with 5 fb^{-1}.

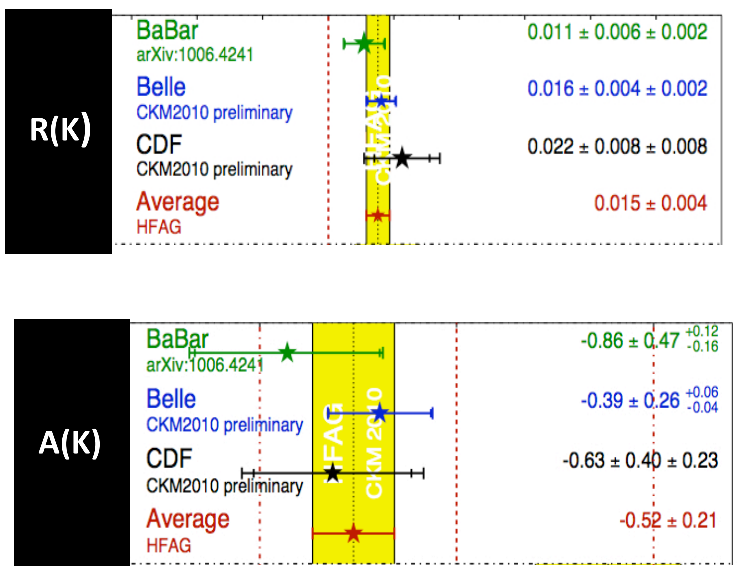


Figure 5: The results of measurements of DCS fractions and asymmetries for the Kaon mode, as measured at CDF with 5 fb^{-1}.