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Results on CP violation from CDF

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Abstract. The CDF experiment at the Tevatron collider is collecting a large sample of fully hadronic decays of Bottom and Charm mesons. First CP Violation measurements have been performed using the initial data, achieving results which clearly state the CDF ability in extracting significant CKM information from $p\bar{p}$ collisions. The first results on direct CP asymmetries on Charm and Bottom decays and future plans from the CDF experiment are discussed in this paper.

PACS. 12.15.Hh Determination of Kobayashi-Maskawa matrix elements – 13.25.-k Hadronic decays of mesons

1 Introduction

The CDF experiment [1] integrated during the 2002–2003 data taking of the Tevatron collider more than 200 pb^{-1} of data at $\sqrt{(s)} = 1.96$ TeV, exceeding the total integrated luminosity collected during the RunI. In the following years, before the turn on of the LHC collider, the data statistics is expected to increase by more than a factor twenty, allowing CDF to perform a broad range of competitive heavy flavor physics measurements related to the study of the CP violation in the bottom and charm sectors. While measurements involving B_s mesons and Λ_b baryons will be unique to the Tevatron experiments until the LHC turn on, thus obviously playing a central role in the physics program of CDF, however also CP measurements in the $B_{d(u)}$ and Charm sectors will be competitive with the B factories. In particular CDF will be competitive in self-tagging modes and direct CP measurements. Just as an example of the CDF capabilities, in Table 1 the event yields for the $B^\circ \to K\pi$ and $D^* \to D^\circ\pi \to [K\pi]\pi$ decays, as observed today, for CDF and for BaBar/Belle experiments are compared. Assuming 300 pb^{-1} per year of data collected by CDF and 150 fb^{-1} by BaBar/Belle, the CDF events yields are comparable or better than the equivalent yields observed at the B factories. In this paper we review the results of the first measurements of CP asymmetries in two body charmless B decays and of D° decays in CP states, performed by CDF using the first 65 pb^{-1} of integrated luminosity, and discuss the future perspectives.

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Table 1. Comparison between event yields for the $B^\circ \to K\pi$ and $D^* \to D^\circ\pi \to [K\pi]\pi$ decays observed today by CDF and the B factories. Last column assumes 300 pb^{-1} per year of data collected by CDF and 150 fb^{-1} collected by the B factories

Mode	CDF Yield	B factories Yield	CDF/B factories Ratio
$B^\circ \to K\pi$	3.4 pb	7.7 fb	0.9
$D^* \to D^\circ\pi$	2300 pb	3000 fb	1.5

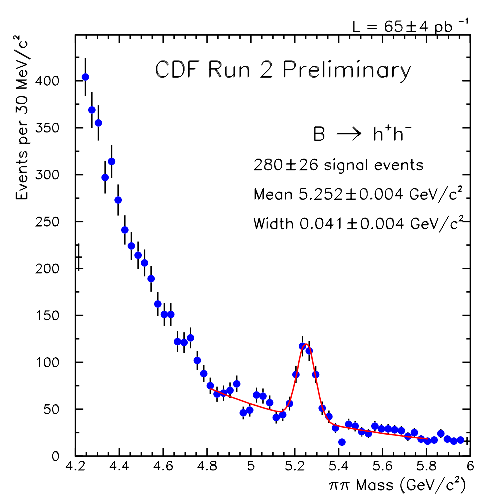

Fig. 1. Invariant mass spectrum for $B \to h^+h^-$ candidates assuming the pion mass hypothesis for both tracks

2 Relative branching fractions and direct CP asymmetries in $B \to h^+h^-$ decays

Using the new trigger on displaced tracks (SVT) [2], CDF has collected several hundred events of charmless B_d and

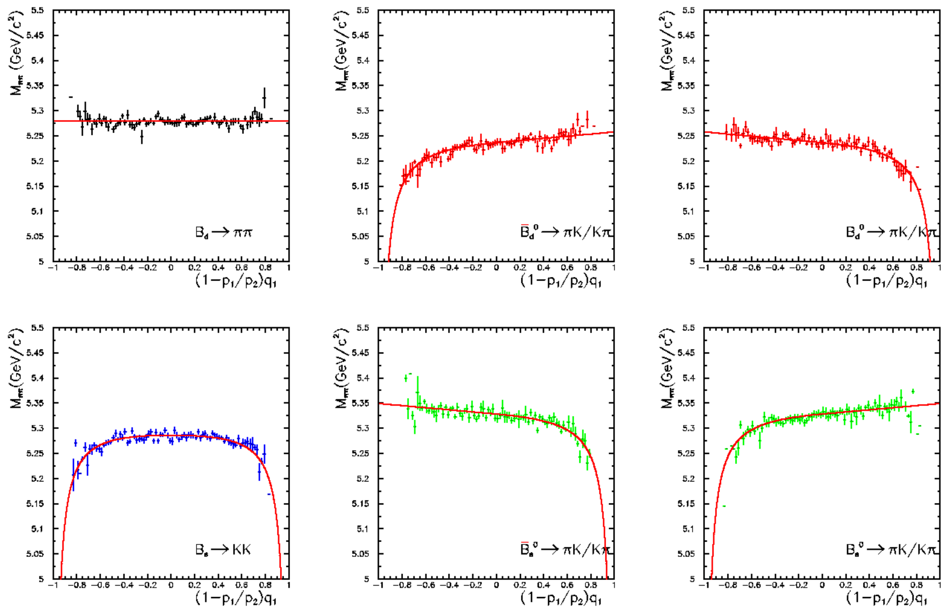

Fig. 2. Correlation between the two kinematic variables (*see text*) used to disentangle the four modes contributing to the $B \to h^+h^-$ signal

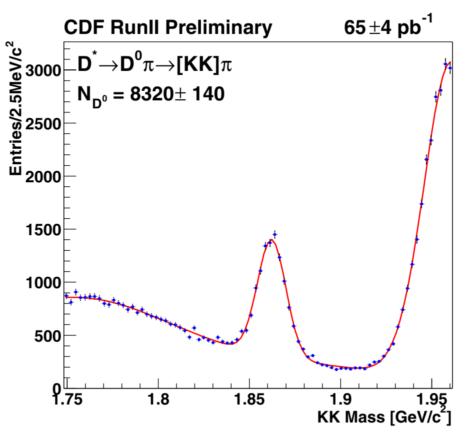

Fig. 3. KK invariant mass spectrum for $D^* \to D^\circ\pi \to [KK]\pi$ candidates, after final selection

B_s decays in two tracks. The invariant mass distribution of the $B \to hh$ candidates from 65 pb^{-1} of integrated luminosity, with the pion mass hypothesis for both tracks is shown in Fig. 1. One of the key physics goals of RunII is to measure time dependent *CP* decay asymmetries in the $B_d^\circ \to \pi^+\pi^-$ and $B_s^\circ \to K^+K^-$ modes, and direct *CP* asymmetries on the self tagging $B^\circ \to \pi^\mp K^\pm$ and $B_s^\circ \to K^\mp\pi^\pm$ modes. In particular the B_s modes will be unique to the Tevatron until the LHC startup. First step in measuring the *CP* asymmetries is disentangling the different components that contribute to the $B \to hh$ signal. This can be achieved in CDF exploiting the $\sim 0.1 \cdot P_T\%$ resolution in measuring charged particle momenta, and using differences in π/K kinematics to separate $K\pi/\pi K$ from $\pi\pi/KK$ exploiting the relationship between the invariant mass and the momentum imbalance between the two tracks. The distribution from a Monte Carlo simulation of the $\pi\pi$ invariant mass ($M(\pi\pi)$) versus the quantity $\alpha = (1 - p_1/p_2) \cdot q_1$, where p_1/p_2 is the ratio of the minimum to the maximum momentum of the two decay hadrons and q_1 is the charge of the lowest momentum hadron, for the differnt decay modes, is shown in Fig. 2. In addition, π/K separation using the specific ionization (dE/dx) measured in the central drift chamber is used, improving separation of the $\pi\pi$ from KK decays. Using the large statistic sample of $D^* \to D^\circ\pi$ decays, we measured a separation power of about 1.2 standard deviations between K and π in the typical momentum range of the decay hadrons in $B \to hh$. The different $B \to hh$ components are separated using an unbinned log-likelihood fit to the kinematic variables $\alpha, M(\pi\pi)$ and π/K dE/dx probabilities. The fractions of $B^\circ \to \pi^\mp K^\pm$, $B^\circ \to \pi^+\pi^-$, $B_s \to K^+K^-$ and $B_s \to \pi^\pm K^\mp$ have been measured to be $53 \pm 6\%$, $14 \pm 5\%$, $32 \pm 6\%$ and $1 \pm 4\%$ respectively. From these results the first measurement of the branching fraction of $B_s \to KK$ is obtained:

$$\frac{Br(B_s^\circ \to K^+K^-)}{Br(B^\circ \to K^\pm\pi^\mp)} = $$
$$= 2.71 \pm 0.73(stat) \pm 0.35(f_s/f_d) \pm 0.81(syst)$$

using the world average measurement of the fragmentation fraction $f_s/f_d = 0.27 \pm 0.04$. From the same fit simultanesously is extracted the direct *CP* asymmetry in the mode $B^\circ \to K\pi$, obtaining:

$$A_{CP} = \frac{\bar{B}^\circ \to K^-\pi^+ - B^\circ \to K^+\pi^-}{\bar{B}^\circ \to K^-\pi^+ + B^\circ \to K^+\pi^-} = $$
$$= 0.02 \pm 0.15(stat) \pm 0.02(syst)$$

Systematic uncertainties in these measurements are currently dominated by observed variations on the measured dE/dx with the data taking period, due to the preliminary calibrations used in this analysis, and from the model

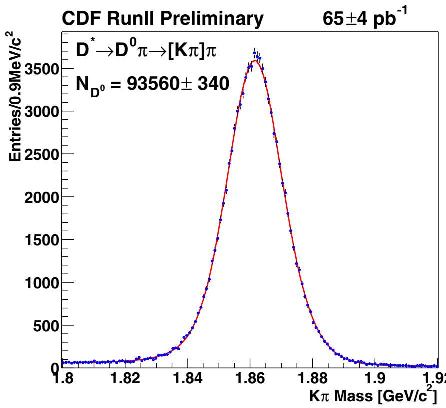

Fig. 4. $K\pi$ invariant mass spectrum for $D^* \to D^\circ\pi \to [K\pi]\pi$ candidates, after final selection

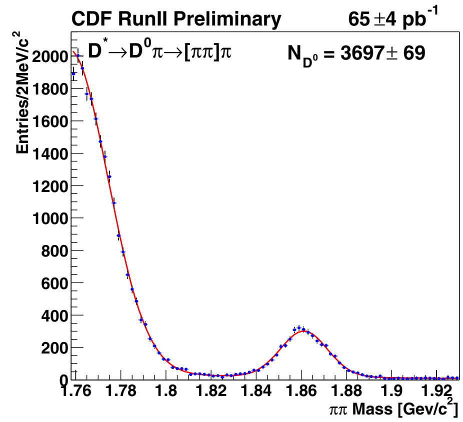

Fig. 5. $\pi\pi$ invariant mass spectrum for $D^* \to D^\circ\pi \to [\pi\pi]\pi$ candidates, after final selection

for the background shape assumed in the fitting function. With 2 fb^{-1} of integrated luminosity CDF expects to collect of the order of 13000 $B \to hh$ decays, reaching a precision of 1% on the direct *CP* asymmetries in the $B^\circ \to \pi^\mp K^\pm$ mode, and measuring the time dependent *CP* asymmetries in the $\pi\pi$ and KK mode at 30% level or better.

3 Partial widths and direct *CP*-violation in D° Meson decays to K^+K^- and $\pi^+\pi^-$

The Standard Model expectations for the rate of *CP* violation in charm decays are generally small, especially for Cabibbo favored modes, with predictions ranging from 0.01 % to 1% for several Cabibbo suppressed decays [3]. The study of direct *CP* asymmetry in the Charm sector becomes then an interesting window to search for non CKM sources of *CP* violation and for studying the effect of non SM couplings in the up–quark sector.

The new trigger on displaced tracks proves to be highly effective in collecting large samples of charm decays, allowing CDF to write on tape so far about 10^6 $D^\circ \to K\pi$ decays. The initial 65 pb^{-1} of data collected during the 2002 data-taking, has been used to measure the relative branching ratios $\Gamma(D^\circ \to K^+K^-)/\Gamma(D^\circ \to K\pi)$ and $\Gamma(D^\circ \to \pi^+\pi^-)/\Gamma(D^\circ \to K\pi)$, and to perform the best measurement of the direct *CP* violating decay rate asymmetries of $D^\circ \to KK$ and $\pi\pi$ available so far.

Invariant mass spectra for the $D^\circ \to K^+K^-$, $D^\circ \to K\pi$, $D^\circ \to \pi^+\pi^-$ candidates reconstructed by CDF are shown in Figs. 3,4, and 5 respectively. Signal purities range from 98% for the $K\pi$ mode, and 95% for the $\pi\pi$ mode to 85% for the KK mode which suffer from larger background contamination arising from partially reconstructed $D^\circ \to K\pi\pi^\circ$ decays. Fitting the invariant mass distribution about 100000 $D^\circ \to K\pi$, 8000 $D^\circ \to K^+K^-$ and 4000 $D^\circ \to \pi^+\pi^-$ candidates have been found. Since the $D^{*\pm}$ decay is a strong interaction process, the charge of the pion from the D^* decay unambiguously tags the D^0 flavor, and allows to measure direct *CP* asymmetries. Moreover since the production of charm mesons in $p\bar{p}$ collisions is *CP* invariant, the only correction we need to apply to the raw asymmetry is due to the tiny intrinsic charge asymmetry of the detectors and of the tracking algorithms ($O(1\%)$ for transverse momenta < 1.5 GeV/c). This tracking asymmetry is relevant only for very low momentum tracks and has been measured using several independent samples where *CP* asymmetry effects are not expected.

With this technique CDF measured the relative branching ratios:

$$\frac{\Gamma(D^\circ \to K^+K^-)}{\Gamma(D^\circ \to K\pi)} = 9.38 \pm 0.18(stat) \pm 0.10(syst)\%,$$
$$\frac{\Gamma(D^\circ \to \pi^+\pi^-)}{\Gamma(D^\circ \to K\pi)} = 3.662 \pm 0.075(stat) \pm 0.034(syst)\%,$$

No significant direct *CP* violation in Cabibbo suppressed D° decays is observed and we measure:

$$A_{CP}(KK) = 2.0 \pm 1.7(stat) \pm 0.6(syst)\%,$$
$$A_{CP}(\pi\pi) = 3.0 \pm 1.9(stat) \pm 0.6(syst)\%$$

The largest source of systematic uncertainty for the relative branching ratios comes from the background model used in the fitting function, while systematics in the direct *CP* asymmetry measurements are currently dominated by the available statistic on the control samples used to measure residual effects on the charge asymmetry corrections. Given the systematic uncertainties currently achieved by these measurements, the addition of more data from CDF RunII should significantly improve the current measurement precision, allowing CDF to test direct *CP* violation in D° decays at 0.1% level in the following years.

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