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Manfred Paulini
Representing the CDF Collaboration
Lawrence Berkeley National Laboratory
Berkeley, California 94720

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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Prospects of Measuring CP Violation in B Decays at CDF

Manfred Paulini
Lawrence Berkeley National Laboratory, MS 50B-5239,
Berkeley, CA 94720, USA

(Representing the CDF Collaboration)

We summarise the prospects of measuring the CP asymmetry in $B^0 \to J/\psi K^0_S$ and $B^0 \to \pi^+\pi^-$ with the CDF detector in Run II starting in 1999. We also explore the feasibility to determine $\sin 2\gamma$ and discuss Run I results relevant to a measurement of CP violation at CDF.

1 CDF in Run I

Good invariant mass resolution and vertex detection capabilities enable the Collider Detector at Fermilab (CDF) to perform a broad B physics program in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV[1]. In this article we briefly review the future of B physics at CDF. We summarize the prospects of measuring CP violation in Run II which is supposed to start in 1999. The B physics goal is to measure the CP asymmetry in $B^0 \to J/\psi K^0_S$ and $B^0 \to \pi^+\pi^-$, and to determine $\sin 2\beta$ and $\sin 2\alpha$, respectively. CDF also plans to look for the CP asymmetry in $B_S \to D_S K$ and $B \to DK$ probing $\sin 2\gamma$.

CDF has the advantage of being an existing experiment that took plenty of data in Run I during 1992-1996. We can use these data to study the ingredients for a future CP violation measurement eg. in $B^0 \to J/\psi K^0_S$. One input is the knowledge of the expected number of $J/\psi K^0_S$ events, which can be extrapolated from the $J/\psi K^0_S$ yield in our current data. The second ingredient is the knowledge of the B flavour at production. For this purpose CDF studies several B flavour tagging methods at a hadron collider environment. The figure of merit to compare flavour tagging algorithms is the effective tagging efficiency εD^2, where ε is the efficiency how often a flavour tag was applicable and D is the dilution $D = (N_R - N_W)/(N_R + N_W) = 1 - 2w$. Here, N_R and N_W are the numbers of right and wrong sign tags, while w is the mistag fraction.

The left hand distribution in Figure 1 shows the invariant $J/\psi K^0_S$ mass distribution from CDF's current data corresponding to about 110 pb^{-1}. About 240 signal events with a signal-to-noise ratio better than 1:1 are observed. This is currently the world's largest sample of $B^0 \to J/\psi K^0_S$ and serves as a nice proof that $B^0 \to J/\psi K^0_S$ decays can be reconstructed in a hadron collider environment in a well understood way.

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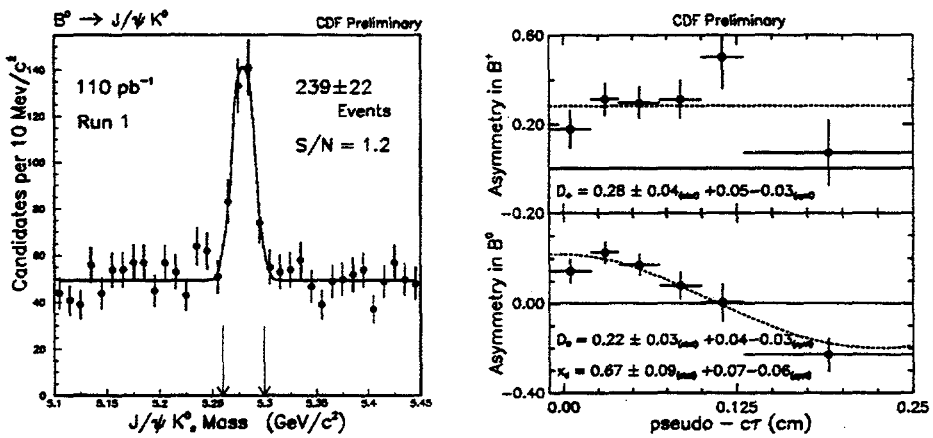

Figure 1: Left: Run I signal of $B^0 \to J/\psi K^0_S$. Right: Asymmetry versus $c\tau$ for B^+ (top) and B^0 (bottom) applying a same side tag to partially reconstructed B mesons.

Several B flavour tagging methods are studied with CDF data. One is referred to as 'same side tagging' (SST). This method exploits charge correlations between B mesons and charged particles produced in the fragmentation of the b quarks. Such correlations are expected to arise from particles produced in the fragmentation chain and from decays of the $L = 1$ B mesons (the B^{**} mesons) [2]. Correlations between B mesons and charged particles have been reported by the LEP experiments [3]. Another way of tagging the flavour of a B meson at production is to exploit the flavour of the other B meson in the event. This can be done through a B semileptonic decay (lepton tagging) or by counting the charge of the other b jet (jet charge tagging). CDF has preliminary results on the effective tagging efficiency of these three methods.

Using a high statistics sample of partially reconstructed B mesons from ℓD^0 (B^+ signature) and $\ell D^+/\ell D^{*+}$ (B^0 signature) combinations, charge correlations between the B candidate and tracks in its vicinity are studied. We select as the tag the track that has the minimum component of momentum p_t^{rel} orthogonal to the momentum sum of that track, the lepton, and the D meson. In the case of charged B mesons we measure $\epsilon D^2 = (5.7 \pm 1.5^{+2.0}_{-1.2})\%$ ($D = (28 \pm 4^{+5}_{-3})\%$) for this same side tagging algorithm. For the B^0 we obtain $\epsilon D^2 = (3.4 \pm 1.0^{+1.2}_{-0.9})\%$ ($D = (22 \pm 3^{+4}_{-3})\%$). The proof that this tagging method actually works is shown in the right hand plot of Fig. 1, where the asymmetry of right minus wrong sign tags normalized to the sum of both is plotted versus the $c\tau$ of the B. The top plot is for B^+ candidates and shows a flat behavior as expected. The bottom plots shows the same distribution for B^0 mesons, and exhibits an oscillatory behaviour as expected from $B\bar{B}$ mixing. This means applying same side tagging to a sample of partially reconstructed B mesons results in a measurement of time dependent B^0 mixing. We obtain $x_d = 0.67 \pm 0.09^{+0.07}_{-0.06}$. We also studied same side tagging with a sample of fully reconstructed $B \to J/\psi K^{(*)}$ decays and obtain somewhat statistics limited results of $\varepsilon D^2 = (4.0 \pm 1.9)\%$ ($D = (33 \pm 8)\%$) and $\varepsilon D^2 = (1.5 \pm 3.0)\%$ ($D = (19 \pm 19)\%$) for B^+ and B^0, respectively.

CDF also studied lepton tagging and obtains $\varepsilon D^2 = (0.71 \pm 0.19)\%$ from soft muons on the opposite side. The preliminary result for the effective tagging efficieny of jet charge tagging is $(1.01 \pm 0.39)\%$, which makes use of information from the silicon vertex detector. Combining the existing measurements on B flavour tagging from Run I results in an effective tagging efficiency of $\approx 3.5\%$.

2 CDF in Run II

At the start of Run II in 1999 the Tevatron together with the Main Injector is supposed to deliver 2 $f\text{b}^{-1}$ in two years. By then the CDF detector will be upgraded with a new silicon vertex detector (SVX II) which doubles the fiducial volume of the current SVX and provides 3-dimensional tracking. A new central tracking system with $\mathrm{d}E/\mathrm{d}x$ capabilities will be in place as well as a new endplug calorimeter. With an upgraded trigger and DAQ system CDF plans to operate a fully hadronic trigger for the first time.

2.1 CP Asymmetry in $B^0 \to J/\psi K^0_S$: $\sin 2\beta$

For the measurement of $\sin 2\beta$ in $B^0 \to J/\psi K^0_S$ CDF expects about 15,000 $J/\psi K^0_S$ events. This event number will be obtained with a lower muon trigger threshold of $p_t > 1.5$ GeV/c, improved muon coverage, and by also triggering on $J/\psi \to e^+e^-$. The effective tagging efficiencies are expected to improve with the upgraded detector. We expect $\varepsilon D^2 \approx 2\%$ for lepton tagging using an electron tag in addition to a μ tag and a better coverage for the lepton identification. For same side tagging we expect $\varepsilon D^2 \approx 2\%$ from a cleaner selection of fragmentation tracks with SVX II. Finally, for jet charge tagging we expect $\varepsilon D^2 \approx 4\%$ from an improved purity of the algorithm with 3-dimensional vertexing and the extented coverage of SVX II. Considering the overlap of all three tags by combining them, we expect a total εD^2 of about 6% resulting in an uncertainty on $\sin 2\beta$ of $\Delta \sin 2\beta = 0.09$.

2.2 CP Asymmetry in $B^0 \to \pi^+\pi^-$*:* $\sin 2\alpha$

The key to measure the CP asymmetry in $B^0 \to \pi^+\pi^-$ is to trigger on this decay in hadronic collisions. CDF plans to do this with a three level trigger system. On Level 1 two oppositely charged tracks with $p_t > 2$ GeV/c found with a fast track processor yield an accept rate of about 16 kHz. This will be reduced to about 20 Hz on Level 2 using impact parameter information ($d > 100\mu$m). On Level 3 the full event information is available further reducing the trigger rate to about 1 Hz. With this trigger we expect about 10,000 $B^0 \to \pi^+\pi^-$ events in 2 fb^{-1}. Assuming the same $\epsilon D^2 = 6\%$ we expect an uncertainty on $\sin 2\alpha$ of $\Delta \sin 2\alpha = 0.10$. Backgrounds from $B \to K\pi$ and $B \to KK$ decays can be extracted from the signal by making use of the invariant mass distribution as well as CDF's dE/dx capability.

2.3 CP Asymmetry in $B_S \to D_S K$*:* $\sin 2\gamma$

The CP asymmetry in $\sin 2\gamma$ completes the test of the unitarity triangle. The angle γ can be probed via the decay $B_S^0 \to D_S^- K^+$ and $D_S^+ K^-$, where both the mixed and the unmixed amplitudes can decay to the same final $D_S^+ K^-$ state. The interference between both amplitudes results in the weak phase γ, but also in a relative QCD phase which is expected to be small but a priori unknown. This measurement requires an all hadronic trigger with similar requirements as for $B^0 \to \pi^+\pi^-$. We expect an overall efficiency times acceptance of $\approx 3 \cdot 10^{-4}$. Because of rapid B_S^0 oscillations a time dependent analysis is required but only a small sample of tagged events is expected at CDF in Run II.

The CP asymmetry in $\sin 2\gamma$ can also be explored via $B \to DK$. In this case the decays are self tagging and a time integated analysis can be performed, but the theoretical uncertainties are large. Thus a measurement of $\sin 2\gamma$ through both modes seems to be challenging at CDF in Run II.

3 Conclusion

In summary we expect to observe CP violation in $B^0 \to J/\psi K_S^0$ and to measure $\sin 2\beta$ with a precision of $\Delta \sin 2\beta = 0.09$ in Run II. We shall also discover CP violation in $B^0 \to \pi^+\pi^-$ measuring $\sin 2\alpha$ with a precision of $\Delta \sin 2\alpha = 0.10$. A measurement of $\sin 2\gamma$ will be challenging in Run II.

1. M. Paulini, ***Highlights of B Physics at CDF***, Fermilab-Conf-95-253-E.
2. M. Gronau, A. Nippe, and J. Rosner, ***Phys. Rev.*** D **47**, 1988 (1993).
3. See eg. I.J. Kroll, ***Masses and Lifetimes of B Hadrons***, Fermilab-Conf-96-032 (1996), and references therein.