Frascati Physics Series Vol. XXXVI (2004), pp.
DAΦNE 2004: Physics at meson factories – Frascati, June 7-11, 2004
Invited Review Talk in Plenary Session

RESULTS ON HEAVY QUARK PHYSICS AT TEV ENERGIES

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Abstract

We review recent result on heavy quark physics at TeV energies focusing on Run II measurements from the CDF and DØ experiments at the Tevatron.

1 Introduction

The CDF and DØ experiments can look back to an already successful heavy flavour physics program during the 1992-1996 Run I data taking period (for a review of B physics results from CDF in Run I see e.g. Ref. [1]). The Fermilab accelerator complex has undergone a major upgrade in preparation for Tevatron Run II. The centre-of-mass energy has been increased from 1.8 TeV to 1.96 TeV

* Representing the CDF and DØ Collaboration.

and the Main Injector, a new 150 GeV proton storage ring, has replaced the Main Ring as injector of protons and anti-protons into the Tevatron.

The initial Tevatron luminosity steadily increased throughout Run II. By the summer of 2004, the peak luminosity reached is $\sim 10 \times 10^{31}$ cm^{-2}s^{-1}. The total integrated luminosity delivered by the Tevatron to CDF and DØ by the time of this conference is ~ 400 pb^{-1}. More than 300 pb^{-1} were recorded to tape by each CDF and DØ. However, most results shown in this review use about 150-250 pb^{-1} of data. The CDF and DØ detectors have also undergone major upgrades for Run II which can be found elsewhere [2].

1.1 Triggering on Heavy Quark Decays

The total inelastic $p\bar{p}$ cross section at the Tevatron is about three orders of magnitude larger than the b production cross section. The CDF and DØ trigger system is therefore the most important tool for finding B decay products. B physics triggers at CDF and DØ are based on leptons including single and dilepton triggers. Identification of dimuon events down to very low momentum is possible, allowing for efficient $J/\psi \to \mu^+\mu^-$ triggers. Both experiments also use inclusive lepton triggers designed to accept semileptonic $B \to \ell\nu_\ell X$ decays. New to the CDF detector is the ability to select events based upon track impact parameter. The Silicon Vertex Trigger (SVT) gives CDF access to purely hadronic B decays and makes CDF's B physics program fully competitive with the one at the e^+e^- B factories.

2 Selected Heavy Quark Physics Results from the Tevatron

With the different B trigger strategies above, the Collider experiments are able to trigger and reconstruct large samples of heavy flavour hadrons. Due to the restricted page limit for these proceedings, we can only very briefly discuss a few selected heavy quark physics results from CDF and DØ in the following.

2.1 B Hadron Masses and Lifetimes

Measurements of B hadron masses and lifetimes are basic calibration measures to demonstrate the understanding of heavy flavour reconstruction. CDF and DØ use exclusive B decay modes into J/ψ mesons for precision measurements of B hadron masses reconstructing the decay modes $B^0 \to J/\psi K^{*0}$, $B^+ \to$

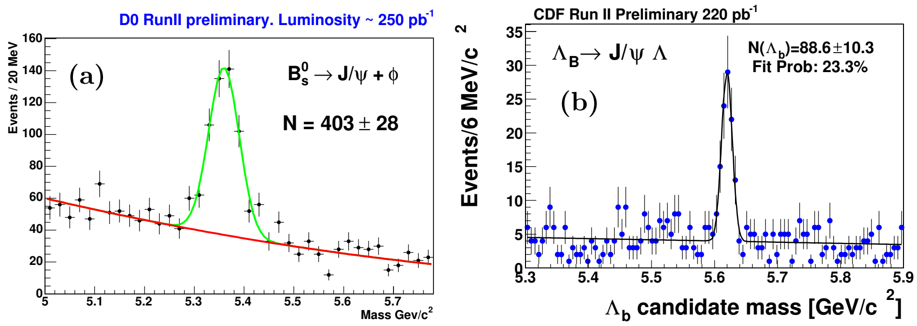

Figure 1: *Invariant mass distribution of (a) $J/\psi\phi$ (DØ) and (b) $J/\psi\Lambda$ (CDF).*

Table 1: *Summary of B hadron mass m_B and lifetime τ_B measurements from CDF and DØ.*

Mode	m_B (CDF) [MeV/c^2]	τ_B (CDF) [ps]	τ_B (DØ) [ps]
$B^0 \to J/\psi K^{*0}$	$5279.6 \pm 0.5 \pm 0.3$	$1.54 \pm 0.05 \pm 0.01$	$1.47 \pm 0.05 \pm 0.02$
$B^+ \to J/\psi K^+$	$5279.1 \pm 0.4 \pm 0.4$	$1.66 \pm 0.03 \pm 0.01$	$1.65 \pm 0.08^{+0.09}_{-0.12}$
$B_S^0 \to J/\psi\phi$	$5366.0 \pm 0.7 \pm 0.3$	$1.37 \pm 0.10 \pm 0.01$	$1.44 \pm 0.10 \pm 0.02$
$\Lambda_b \to J/\psi\Lambda$	$5619.7 \pm 1.2 \pm 1.2$	$1.25 \pm 0.26 \pm 0.10$	$1.22 \pm^{+0.22}_{-0.18} \pm 0.04$

$J/\psi K^+$, $B_S^0 \to J/\psi\phi$ and $\Lambda_b \to J/\psi\Lambda$ (see Fig. 1). These modes combine good signal statistics with little background. The results of the mass and corresponding B hadron lifetime measurements are summarized in Table 1. The B_S^0 and Λ_b masses and lifetimes are currently the world best results.

2.2 Measurement of Lifetime Ratio $\tau(B^+)/\tau(B^0)$

The study of heavy flavour lifetimes is intimately related with the understanding of the decay dynamics of these particles. The DØ experiment measured the lifetime ratio for neutral and charged B mesons using a novel technique. This result exploits the large semileptonic sample of $B \to \mu X$ decays reconstructed in about 250 pb^{-1} of $p\bar{p}$ data. Rather than measuring the individual B^0 and B^+ lifetimes and forming the ratio, this analysis makes use of the fact that $D^{*-}\mu^+$ events mainly originate from B^0 mesons ($\sim$ 86%) while $\bar{D}^0\mu^+$ indicate a B^+ signature ($\sim$ 82%). The construction of the B decay vertex

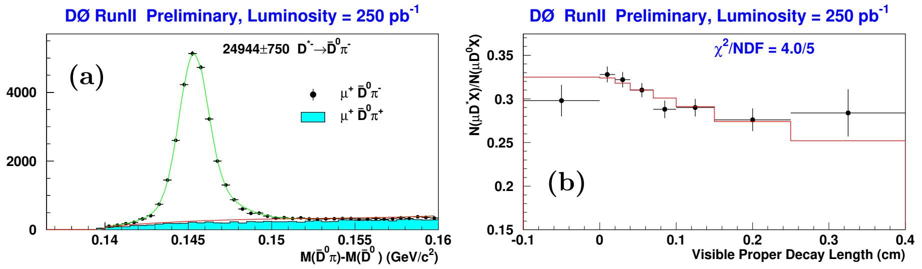

Figure 2: *(a) Mass difference $m(\bar{D}^0\pi) - m(\bar{D}^0)$ for $\bar{D}^0\mu$ events. (b) Ratio of events in D^{*-} (B^0) and $\bar{D}^0$ (B^+) samples as a function of proper decay length.*

uses only $\bar{D}^0\mu^-$ while the slow pion from the decay $D^{*-} \to \bar{D}^0\pi^-$ is only used to distinguish B^0 from B^+ (see Fig. 2(a)) drastically reducing the systematic uncertainty between both decay modes. The events are grouped into bins of proper decay length and the $\bar{D}^0$ event yield is extracted from the $K^+\pi^-$ mass distribution. Feed-down from D^{**} decays is accounted for using Monte Carlo studies. The ratio of events in the D^{*-} (B^0) and $\bar{D}^0$ (B^+) samples as a function of proper decay length, as shown in Fig. 2(b), is used to extract a lifetime ratio of $\tau^+/\tau^0 = 1.093 \pm 0.021 \pm 0.022$. This is one of the most precise measurements of the B^+/B^0 lifetime ratio.

2.3 Charmless B Decays

CDF has shown examples of fully reconstructed hadronic B decays from data using the displaced track trigger (see e.g. Ref. [3]). We report on a new search for charmless B decays mediated by gluonic $b \to s$ penguin decays. These decays are of interest in the light of a possible contribution other than the usual mixing induced phase in the time dependent CP violation asymmetry observed at the B factories. CDF uses 180 pb^{-1} of displaced track trigger data to search for $B^+ \to \phi K^+$ and $B^0_S \to \phi\phi$. Figure 3(a) shows the ϕK^+ invariant mass distribution indicating a signal of (47.0 ± 8.4) B^+ signal events. From this yield, CDF determines the ratio of branching ratios $\mathcal{B}(B^+ \to K^+\phi)/\mathcal{B}(B^+ \to J/\psi K^+) = (7.2 \pm 1.3 \pm 0.7) \cdot 10^{-3}$ and the charge asymmetry $\mathcal{A}_{CP} = -0.07 \pm 0.17^{+0.06}_{-0.05}$. Both results are in good agreement with the B factories.

The search for the never observed mode $B^0_S \to \phi\phi$ was performed in a blind fashion using kinematically similar decays such as $B^0 \to J/\psi K^{*0}$ plus MC

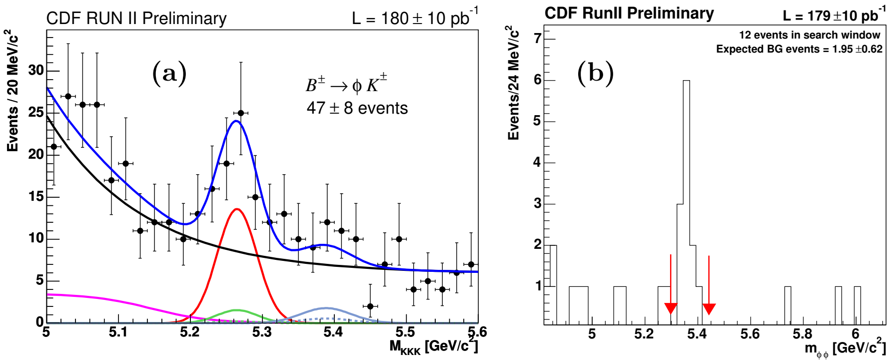

Figure 3: *Invariant mass distribution of (a)* $B^+ \to \phi K^+$ *and (b)* $B^0_S \to \phi\phi$.

for cut optimization. Fig. 3(b) displays a signal of 12 events on an estimated background of about 2 events. CDF determines $\mathcal{B}(B^0_S \to \phi\phi) = (1.4 \pm 0.6 \pm 0.2 \pm 0.5_{BR}) \cdot 10^{-5}$ where the error of $\pm 0.5_{BR}$ results from the uncertainty in $\mathcal{B}(B^0_S \to J/\psi\phi)$ used as normalization mode.

2.4 Measurement of Hadronic Invariant Mass Moments

Using 180 pb^{-1} of data, CDF measured the first two moments of the hadronic invariant mass squared distribution in semileptonic B decays using lepton plus SVT trigger data. Combining a direct measurement of the D^{**} piece – see Fig. 4(a) for the fully corrected inv. mass distribution $m(D^{(*)+}\pi^-_{**})$ – with the D and D^* pieces taken from PDG, CDF finds $M_1 \equiv \langle s_H \rangle - m^2_{\bar{D}} = (0.459 \pm 0.037 \pm 0.019 \pm 0.062_{BR})$ GeV^2 and $M_2 \equiv \langle (s_H - \langle s_H \rangle)^2 \rangle = (1.04 \pm 0.25 \pm 0.07 \pm 0.10_{BR})$ GeV^4 where 0.062_{BR} and 0.10_{BR} refer to the uncertainties coming from the branching ratios needed for the combination of the D, D^* and D^{**} pieces. Fig. 4(b) shows good agreement between the CDF measurement of M_1 and previous determinations.

2.5 Observation of $X(3872)$

Recently, the Belle collaboration reported a new particle $X(3872)$ observed [4] in exclusive decays of B mesons at a mass of 3872 MeV/c^2 decaying into $J/\psi\pi^+\pi^-$. The observation of this narrow resonance has been confirmed by the CDF collaboration and recently also by the DØ experiment as shown in Fig. 5.

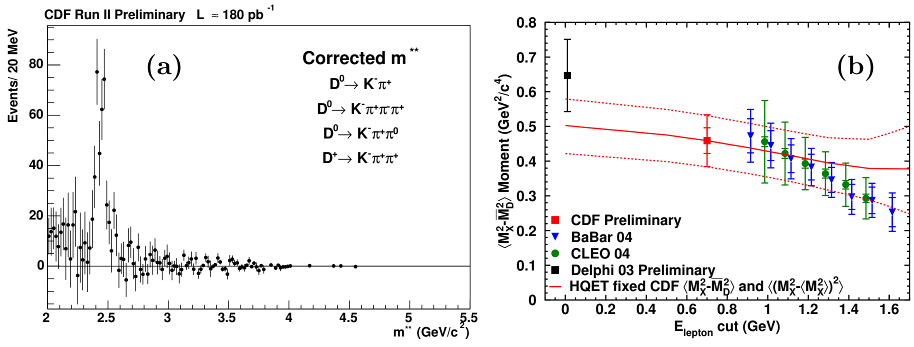

Figure 4: *(a) Fully corrected invariant mass distribution $m(D^{(*)+}\pi^-_{**})$. (b) Comparison between the CDF measurement of M_1 and previous determinations.*

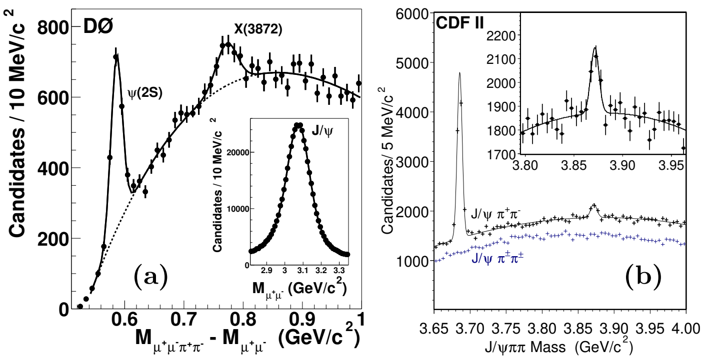

Figure 5: *Mass distribution of $J/\psi\pi^+\pi^-$ candidates from (a) DØ and (b) CDF.*

DØ observes 552 ± 100 $X(3872)$ candidates and measures the mass difference between the $X(3872)$ state and the J/ψ to be $(774.9 \pm 3.1 \pm 3.0)$ MeV$/c^2$. CDF observes 730 ± 90 events at a mass of $(3871 \pm 0.7 \pm 0.4)$ MeV$/c^2$ with a width consistent with the detector resolution.

2.6 Search for Pentaquark States

An exotic baryon, $\Theta^+(1540)$, with the quantum numbers of K^+n has recently been reported by several groups (for an overview, see e.g. Ref. [5]). Such a state has a minimal quark content of $|uudd\bar{s}\rangle$. Evidence for other pentaquark states such as an isospin 3/2 multiplet of Θ's with strangeness $S = -2$ [6] and

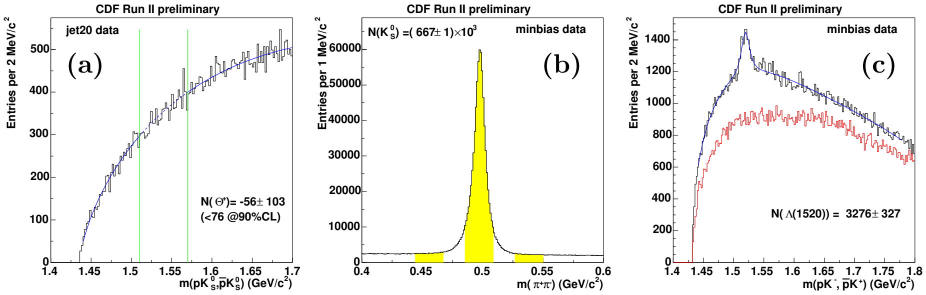

Figure 6: *(a) Search for pentaquark state* $\Theta^+(1540) \to pK^0_S$*. Reference states (b)* $K^0_S \to \pi\pi$ *and (c)* $\Lambda(1520) \to pK^-$*.*

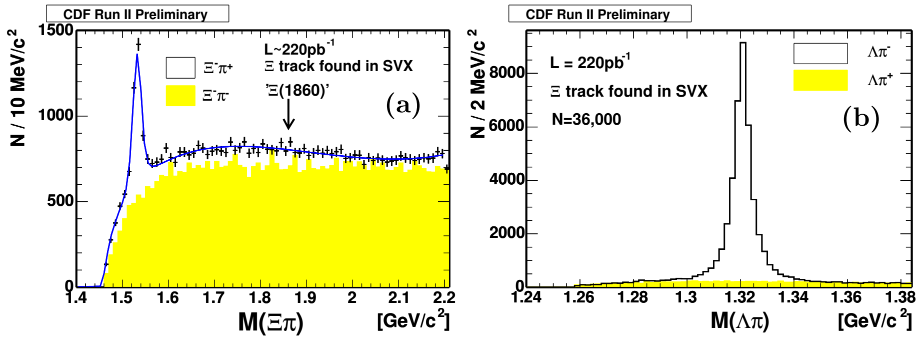

Figure 7: *(a) Search for pentaquark state* $\Xi^{--}_{3/2}/\Xi^0_{3/2} \to \Xi^-\pi^-/\pi^+$*. (b) Reference channel* $\Xi \to \Lambda\pi$*.*

charmed pentaquarks [7] has also been reported. CDF performed a search for the following pentaquark states: $\Theta^+(1540) \to pK^0_S$, $\Xi^{--}_{3/2}/\Xi^0_{3/2} \to \Xi^-\pi^-/\pi^+$ and $\Theta_c \to pD^{*-}$. In each case a reference state has been reconstructed. As shown in Figures 6, 7 and 8, no evidence for a narrow signal has been found.

3 Summary

We review recent result on heavy quark physics at TeV energies focusing on Run II measurements at the Tevatron. A wealth of new B physics measurements from CDF and DØ has been reported. In particular, DØ demonstrates a very competitive B physics program in Run II.

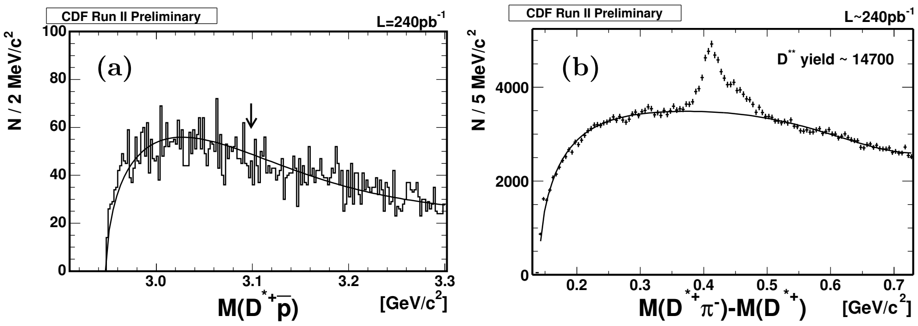

Figure 8: *(a) Search for pentaquark state* $\Theta_c \to pD^{*-}$*. (b) Reference channel* $D^{*-}\pi^+$.

Acknowledgments

I like to thank the organizers for a stimulating meeting. It was a pleasure to attend this great conference. I also would like to thank Ann, Emma and Helen, a constant source of inspiration and support, for their continuous understanding about the life of a physicist.

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