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NEW RESULTS ON B PHYSICS FROM THE DØ EXPERIMENT

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The Tevatron accelerator at Fermilab is now delivering $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV with a peak luminosity of around 10^{32} cm^{-2}s^{-1}. The two main detectors, CDF and DØ, are taking continuously collision data and have recorded approximately 450 pb^{-1} of data. We present selected new results on B physics that were obtained with the DØ detector based on 250 pb^{-1} of Run II data.

1 B physics at Tevatron and the DØ detector

Run II of the Tevatron at Fermi National Accelerator Laboratory started to deliver $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV in April 2002. Compared to the previous Run I (1992-1995), the two experiments CDF and DØ have now already recorded four times more statistics. At Tevatron, the $b\bar{b}$ cross section of $\mathcal{O}(100)$ μb is large, leading to $b\bar{b}$ production rates of a few kHz. However, only approximately every $1/1000^{th}$ event in $p\bar{p}$ collisions contains a b or a $\bar{b}$ quark, making event triggering and online selection for B physics a very delicate and complex task. In contrast to e^+e^- machines at the $\Upsilon(4S)$ state, the Tevatron has the distinct advantage of having access to all b-flavored mesons and baryons such as the $B_{s,c}$ and Λ_b. The high b-production rate on the one hand, and the availability to study several b-flavored species on the other hand, make the Tevatron collider an important laboratory for B physics, that is complementary to the present e^+e^- machines.

The DØ detector was significantly upgraded [1] in order to improve its physics capabilities while being able to cope with the high luminosity of Run II. The detector components that are relevant for B physics are a central-tracking system consisting of a silicon microstrip tracker (SMT) and a central fiber tracker (CFT), both located within a 2 T superconducting solenoidal magnet. The SMT has four detection layers arranged in six barrels with interspersed disks with a total of $\approx 800,000$ individual strips of typical pitch $50-80$ μm, and a design optimized for tracking and vertexing capability at pseudorapidity $|\eta| < 3$. The CFT has eight thin coaxial barrels, each supporting two doublets of overlapping scintillating fibers with axial and stereo information allowing efficient reconstruction of tracks down to $p_T = 180$ MeV$/c$. Track impact parameters d_0, in the plane transverse to the beam axis, are measured with high precision of $\sigma_{d_0} = 50$ μm for tracks with $p_T \sim 1$ GeV$/c$, improving asymptotically to $\sigma_{d_0} = 15$ μm for tracks with $p_T \geq 10$ GeV$/c$. One of the strengths of the DØ experiment is the upgraded muon system with large coverage up to $|\eta| = 2$, allowing the use of single muon and di-muon triggers, particularly suited for detection of semileptonic b-decays and $B \to J/\psi\, X$ decays. As an example, DØ finds in about 250 pb^{-1} a record sample of

400 reconstructed $B_s \to J/\psi(\to \mu^+\mu^-)\,\phi$ events with good signal over background.

2 The Lifetime ratio $\tau(B^+)/\tau(B^0)$

Heavy Quark Expansion (HQE) allows a rigid QCD calculation of the lifetimes of heavy quarks in terms of powers of (m_Q/Λ_{QCD}), leading to several lifetime differences between neutral and charged heavy quark baryons and mesons. In the case of B mesons, the HQE contribution predicts lifetime differences of 3-20% that can be confronted with experimental precision data. DØ has measured the lifetime ratio for charged and neutral B mesons, $\tau(B^+)/\tau(B^0)$, in 250 pb^{-1} of data using a large sample of semileptonic B^+ and B^0 decays. The semileptonic decays were reconstructed in $B \to \mu^+\nu\bar{D}^0(\to K^+\pi^-)X$. The $\bar{D}^0$ candidate was constructed from two particle tracks of opposite charge close to the reconstructed muon fulfilling p_T and track impact significance criteria. The muon track and tracks from the $\bar{D}^0$ had to form a common B-vertex with mass requirement $2.3 < M(\mu^+\bar{D}^0) < 5.2$ GeV$/c^2$. An opening angle in the transverse plane between the reconstructed $\mu^+\bar{D}^0$ momentum and the direction of the primary to the $\mu^+\bar{D}^0$ vertex was required. After these cuts we found about 109,000 events in the $\bar{D}^0 \to K^+\pi^-$ mass peak in $K^+\pi^-\mu^+$ events.

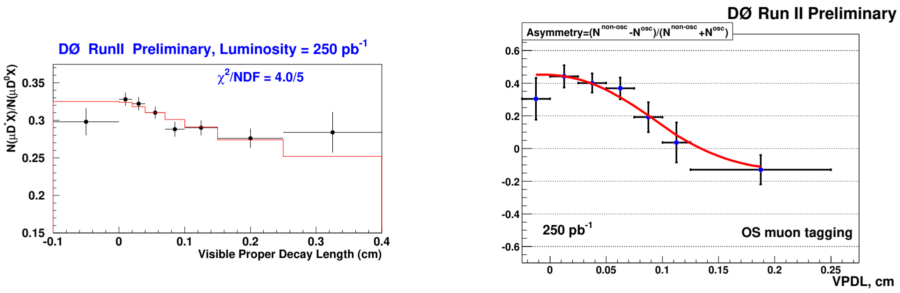

Figure 1. Left: The ratio of events in D^* and D^0 samples as function of the VPDL. The result of the fit is shown as histogram. Right: Asymmetry between the number of mixed (N^{osc}) and the number of unmixed ($N^{non-osc}$) events as function of VPDL. The solid line represents the result of the fit that was used to determine Δm_d.

The reconstructed sample was classified further into two exclusive groups: a "D^* sample" containing all events with $D^{*-} \to \bar{D}^0\pi^-$, i.e., having an additional slow pion, and a "$\bar{D}^0$ sample". For the slow pion reconstruction an additional track with charge opposite to the muon was searched for in all events. The events with correct charge assignment and $0.1425 < \Delta M < 0.149$ GeV$/c^2$ with $\Delta M = M(\bar{D}^0\pi) - M(\bar{D}^0)$ were included in the D^* sample. To ensure a good slow pion reconstruction efficiency, $p_T(\bar{D}^0) > 5$ GeV$/c$ was further applied on the selected events reducing the sample by 35%. Both simulation (MC) and available experimental results from measured branching fractions show that the D^* sample is dominated by $B_d \to \mu^+\nu D^{*-}X$ decays (86%), while the $\bar{D}^0$ sample is enriched in $B^+ \to \mu^+\nu\bar{D}^0X$ decays (82%), so that this separation between the B species gives us access to the lifetime ratio $\tau(B^+)/\tau(B^0)$. Since the semileptonic B decays are only partially reconstructed, the proper decay time of the B can only be approximately determined from the measured decay length, L_T, in the transverse plane. For each event, the *visible proper decay length* (VPDL) was calculated as $x^m = L_T/P_T^{\mu D^0} \cdot M_B$. The events were divided into eight bins of VPDL and the ratio $r_i = N_i(D^{*-}\mu^+)/N_i(\bar{D}^0\mu^+)$ determined separately for each bin i from fits to the $m(K\pi^+)$ mass spectra of the $\bar{D}^0$ and D^* sample. A small combinatorial background in the D^* sample from events containing a true $\bar{D}^0$, counted as signal in the $m(K\pi^+)$ fit, was subtracted using the wrong charge combination $\bar{D}^0\pi^+$ in each VPDL bin. The lifetime ratio is then determined from a simultaneous fit to the measured r_i's in the eight VPDL bins. The following inputs were used in the fit: the relative decomposition of the B's in the $\bar{D}^0$ and D^* samples including reconstruction and slow pion efficiencies, the distribution of the K-factors (from MC) for the different decay chains, in order to correct from $p_T(\mu D^0)$ to $p_T(B)$, and the decay length resolution (from MC). Finally, the lifetime of the B^+ was fixed to the world average value [2]. The left part of Fig. 1 shows the result of the fit to the measured values of the r_i, which yielded the following preliminary result:

$$\tau(B^+)/\tau(B_d) = 1.093 \pm 0.021\,(\mathrm{stat}) \pm 0.022\,(\mathrm{sys}).$$

The systematics are dominated by the uncertainty on a VPDL-dependent slow pion reconstruction efficiency, several uncertainties in the relative reconstruction efficiencies for different decay channels, the experimental errors on the branching fraction of $B^+ \to D^{*-}\pi^+\mu^+\nu X$ used for the determination of the sample decomposition, as well as uncertainties on K-factors and decay length resolution between $\bar{D}^0$ and D^* samples. The preliminary result obtained from DØ is consistent with previous results on $\tau(B^+)/\tau(B^0)$, and is one of the most precise measurements of this lifetime ratio.

3 $B^0/\bar{B}^0$ mixing with opposite-side tagged muons

Flavor oscillations between $B^0 - \bar{B}^0$ mesons are explained by box diagrams in the SM. At the Tevatron, the study of the $B_d^0 - \bar{B}_d^0$ mixing is a crucial benchmark measurement useful for understanding the inital flavor tagging towards a measurement of Δm_s, the flavor oscillation in the B_s system.

Our large sample of semileptonic B decays $B \to \mu^+ D^{*-}\nu X$ allows us to measure the B_d^0 oscillation frequency, Δm_d. To determine the flavor in the inital state, an opposite-side muon tag was employed, relying on the muon charge among the decay products from the "other b-quark" to infer the the original flavor of the reconstructed B_d^0 meson. Muons with $p_T > 2.5$ GeV/c and $\cos(\Delta\phi) < 0.5$ ($\Delta\phi$ being the difference in ϕ between tagged muon and the $\bar{D}^0\mu^+$ system) were considered for tagging. The fraction of tagged muons in the semileptonic sample was determined to be (4.76±0.19)% of all reconstructed $B^0/\bar{B}^0$ mesons. The tagged events were divided in seven bins of the measured VPDL. The number of μ^+D^* events with positive ("oscillated") and negative ("non-oscillated") tags, N_i^{osc} and $N_i^{non-osc}$, were determined in each bin i of VPDL from a fit to the D^* signal peak in the $m(D^0\pi) - m(D^0)$ distribution. This then allowed the construction of the experimental asymmetry observable $A_i = (N_i^{non-osc} - N_i^{osc})/(N_i^{non-osc} + N_i^{osc})$

in each bin, which was fit to extract Δm_d as shown in the right part of Fig. 1. Using 250 pb^{-1} of data we obtain as a preliminary result the VPDL-dependent asymmetry between mixed and unmixed events and find the oscillation frequency:

$$\Delta m_d = 0.506 \pm 0.055\,(\mathrm{stat}) \pm 0.049\,(\mathrm{sys})\ \mathrm{ps}^{-1}.$$

This result is in very good agreement with the world average [2]. The dominating systematic uncertainty in our measurement is the fit procedure used to extract the event yields in each VPDL bin. Currently, this kind of analysis is being repeated for other, complementary, tagging algorithms based on jet charge, same-side tags and opposite-side electrons.

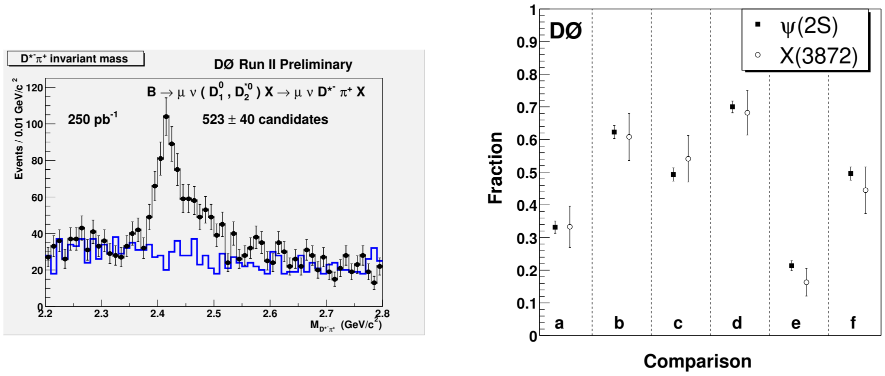

Figure 2. Left: The invariant mass $m(D^{*-}\pi^{+})$ for selected events. The points belong to the $D^{*}\pi$ combinations with opposite charge, while the histogram corresponds to the same charge combinations. Right: Comparison of event-yield fractions for $X(3872)$ and $\psi(2S)$ in the regions: (a) $p_T(J/\psi\,\pi^+\pi^-) > 15$ GeV/c; (b) $|y|$ of $J/\psi\,\pi^+\pi^- < 1$; $\cos(\theta_\pi) < 0.4$, (d) effective proper decay length, $dl < 0.01$ cm; (e) isolation=1; and (f) $\cos(\theta_\mu) < 0.4$.

4 Observation of semileptonic B decays to narrow D^{**} resonances

The orbitally excited states of the D mesons are usually referred to as D^{**} mesons. For an orbital momentum of $L = 1$, one expects one doublet of states with $j = 1/2$, denoted as D_0^{*0} and $D_1^{'0}$, and another doublet with $j = 3/2$, denoted as $D_1^0(2420)$ and $D_2^{*0}(2460)$. In contrast to the $j = 1/2$ states, the D_1^0 and D_2^{*0} decay through D-wave and are thus expected to be narrow (20 to 30 MeV), while the former decay through S-wave and are expected to be wide (several hundreds MeV) [3]. Several experiments have observed the D_1^0 and D_2^{*0} mesons, most recently the Belle and Babar [4] experiments. In DØ we studied the D_1^0 and D_2^{*0} mesons that were produced in semileptonic B decays $B \to (D_1^0, D_2^{*0})\mu^-\nu X \to D^{*+}\pi^-\mu^-\nu X$. The D^{**} invariant mass is shown in the left part of Fig. 2. The points in the plot correspond to the $D^{*}\pi$ combinations with opposite charges while the histograms refer to the same charge combinations. The mass peak in the region between 2.4 and 2.5 GeV/c^2 can be interpreted as the combined effect of the merged D_1^0 and

D_2^{*0} states. According to available experimental results [2], the branching ratio of $B \to \mu^- \nu D^{*+} \pi^- X$ is $(0.48 \pm 0.10)\%$. Our preliminary result now constraints for the first time the component of the $B \to \mu\nu D^{*+}\pi^- X$ process proceeding through the narrow D^{**} states, which is given by:
$\mathcal{B}(B \to D^{**}\mu^-\nu X) \times \mathcal{B}(D^{**} \to D^{*+}\pi^-) = (0.280 \pm 0.021(\text{stat}) \pm 0.088\ (\text{sys}))\ \%$.
The branching ratio above has been determined using normalization to the decay $B \to D^{*-}(\to D^0\pi^+)\mu^-\nu X$, whose uncertainties are well known [2]. The systematic uncertainties are dominated by the uncertainty on the p_T dependence of the soft pion reconstruction efficiency, as well as the effects of possible contributions from wide resonances and the effect of a possible interference between D_1^0 and D_2^{*0} on the tails of the D^{**} mass distribution, which are not yet taken into account.

5 Search for the rare decay $B_s \to \mu^+\mu^-$

The purely leptonic decay $B^0_{d,s} \to \mu^+\mu^-$ is a Flavor Changing Neutral Current (FCNC) process, which is forbidden at the tree level in the SM. Thus, it proceeds through higher order diagrams at a very low rate of $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.42 \pm 0.54) \cdot 10^{-9}$ [5], while the corresponding branching fraction for B_d is suppressed by an additional factor of $|V_{td}/V_{ts}|^2$. The decay amplitudes of $B^0_{d,s} \to \mu^+\mu^-$ can be significantly enhanced in some extensions of the SM, such as type-II two Higgs Doublet Models (2HDM) [6] or minimal supersymmetry, leading to an enhancement of up to three orders of magnitude [7] compared to the SM. In DØ we have searched for this decay using about 240 pb^{-1} of data. The search was based on a blind analysis, hiding the signal "box" around the B_s^0 mass and estimating the background from the sidebands. Reconstructed $B^\pm \to J/\psi K^\pm$ events were used for normalization. The main discriminating variables for selecting $B_s^0 \to \mu^+\mu^-$ events are an isolation criterion for the muon pairs, the transverse decay length of the muon pair and finally, the pointing angle used as consistency between the direction of the primary to the secondary vertex and the $\mu^+\mu^-$ momentum vector. We expected 3.7 ± 1.1 background events and found 4 events after opening the signal region. Our limit for 240 pb^{-1} including statistical and systematic uncertainties is then given by $\mathcal{B}(B_s^0 \to \mu^+\mu^-) \leq 4.6 \cdot 10^{-7}$ at a 95% C.L. This new result is presently the most stringent bound on $B_s^0 \to \mu^+\mu^-$, improving the previously published value [8] significantly.

6 Production and decay characteristics of the $X(3872)$

Recently, the Belle Collaboration [9] discovered a new particle, the $X(3872)$, produced in $B^\pm \to X(3872)(\to J/\psi\,\pi^+\pi^-)\,K^\pm$. The existence of the $X(3872)$ state was later confirmed by CDF [10] and also at Babar [11] in the $J/\psi\,\pi^+\pi^-$ decay channel. At this time it is still unclear, whether this particle is simply a bound $c\bar{c}$ state or perhaps a more exotic meson molecule[a]. DØ has recently performed a detailed study [13] on the $X(3872)$ state in order to examine its production rate and decay characteristics relative to the $\psi(2S)$, which shares the same decay prod-

[a]For a recent discussion on this topic see, e.g., Ref. [12].

ucts. Using 230 pb^{-1} of data, DØ reconstructed 522 ± 100 $X(3872) \to J/\psi\,\pi^+\pi^-$ decays and measured the mass difference Δm of the $X(3872)$ to the $\psi(2S)$ as $\Delta m = 774.9 \pm 3.1\,(\mathrm{stat}) \pm 3.0\ (\mathrm{sys})\ \mathrm{MeV}/c^2$, in good agreement with other results.

The following kinematic variables were examined to allow a direct comparison of the $X(3872)$ event-yield fractions relative to the $\psi(2S)$ event-yields: the transverse momentum $p_T(J/\psi\,\pi^+\pi^-)$, the rapidity of the $J/\psi\,\pi^+\pi^-$, the helicity of the $\pi^+\pi^-$ ($\mu^+\mu^-$) system, the effective proper decay length, and the isolation of the $J/\psi\,\pi^+\pi^-$ system. The relative event-yield fractions for $X(3872)$ and $\psi(2S)$ for the subsamples after the cuts are shown in the right part of Fig. 2. No significant differences between the $X(3872)$ and the $\psi(2S)$ were observed.

7 Conclusions

The upgraded DØ detector builds its strength on a large acceptance in terms of rapidity and transverse momentum of the central tracker and muon system, making it to an excellent tool for studying B physics. We have presented recent preliminary results in B physics, based on the 250 pb^{-1} of Run II data. The preliminary measurement of the lifetime ratio, $\tau(B^+)/\tau(B^0)$, has reached a high level of precision and can be confronted with HQE expectations. The muon reconstruction capabilities allow initial state flavor tagging, which is a key ingredient for the study of flavor oscillations and CP violation. The good tracking efficiency down to very low transverse momentum made the observation of semileptonic B decays to D^{**} mesons possible. Further, we presented a detailed study on the production and decay characteristics of the $X(3872)$ state and the most stringent limit on $B_s^0 \to \mu^+\mu^-$. With more date to analyze, exciting times for a competitive B physics program at DØ has started.

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