DØ Results on Heavy Flavour Production [1]

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Abstract. This review is focused on DØ results on hadron spectroscopy and on production cross sections: the contribution by DØ to the understanding of the $X(3872)$ object, the first observation of separated B^{**} states, measurements of B_c meson properties, and eventually measurements of the inclusive $\Upsilon(1\mathrm{S})$ differential cross section and of the $t\bar{t}$ cross section.

Keywords: D0, Tevatron, heavy flavour, $X(3872)$, B^{**}, B_c, $\Upsilon(1S)$, top quark
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INTRODUCTION

This review is focused on DØ results on hadron spectroscopy and on production cross sections, which represent only a small fraction of the DØ charm-bottom-top activities. After a general presentation of the Tevatron collider and of the DØ detector, the second section will be devoted to the contribution by DØ to the understanding of the $X(3872)$ object, to the first observation of separated B^{**} states and eventually to measurements of B_c meson properties. In the last section we will report on measurements of the inclusive $\Upsilon(1\mathrm{S})$ differential cross section and of the $t\bar{t}$ cross section. All these results are preliminary, unless a reference is quoted.

The Tevatron proton-antiproton collider at Fermilab operates with a center-of-mass energy of 1.96 TeV. Beams are colliding in two points instrumented by the CDF and the DØ multi-purpose detectors. The Tevatron is in its second run since 2001. In 2005 it performed better than expected, and it has already delivered 1 fb^{-1} to each experiment.

Important to heavy flavour production at the Tevatron is the considerable statistical increase over the previous datasets. B physics takes advantage of a substantial cross section, but has also to cope with a huge background, so that the trigger is an important issue. For these analyses, DØ benefits from an efficient trigger based mainly on muon and di-muon selection. All B states are produced at the Tevatron, such that it has a complementary role to B factories. In top physics, analyses are dependent on appropriate triggers as well, as the top quark is produced only once every ten billions events.

The DØ detector consists of three main components: the tracking system includes a high resolution silicon microstrip tracker, surrounded by a central scintillating fiber tracker, both located inside a 2 T superconducting solenoid magnet; the liquid Argon calorimeter is divided into a central part and two end cap calorimeters; eventually the muon system resides beyond the calorimeter and consists of three layers, two of them

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located behind a toroid magnet. All these detector systems are designed with good hermiticity and good coverage in pseudo-rapidity. For a detailed description of the DØ detector, see [1].

SPECTROSCOPY RESULTS

Nature of the $X(3872)$ state

During 2003 Belle announced the observation of a new narrow hadron, temporarily called X, decaying to $J/\psi\pi^+\pi^-$ [2]. CDF [3], DØ [4] and BaBar [5] quickly confirmed this discovery. Up to now it is still unclear whether this $X(3872)$ particle is a $c\bar{c}$-state or a more complex object as a molecule-like $D\bar{D}$ resonance.

DØ has also observed the decays $X(3872) \to J/\psi\pi^+\pi^-$, $J/\psi \to \mu^+\mu^-$, using 230 pb^{-1} of data [4]. The signal has a statistical significance in excess of 5 sigmas and the measured mass is in agreement with those published by the other experiments. The interest in observing the $X(3872)$ at a hadronic collider resides in potentially high statistics and in the suggestion that it is not exclusively produced by weak B decays but also through the strong interaction.

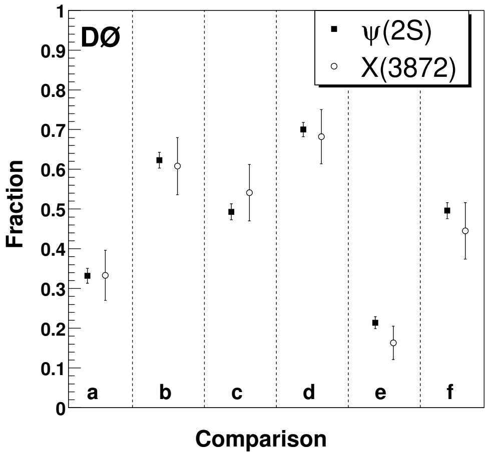

FIGURE 1. Event yield fractions for $X(3872)$ and $\psi(2S)$ in various regions of production and decay variables: (a) $p_T > 15$GeV/c; (b) $|y| < 1$; (c) $\cos(\theta_{\pi\pi}) < 0.4$; (d) effective proper decay length $dl < 0.01$ cm; (e) isolation criteria = 1; (f) $\cos(\theta_{\mu\mu}) < 0.4$.

The charmonium state $\psi(2S)$ with neighbouring mass and with the same decay mode provides a good benchmark for comparisons with the $X(3872)$. DØ has examined the production rate of the $X(3872)$ relative to the $\psi(2S)$ in various regions of production and decay variables: the transverse momentum p_T with respect to the beam axis, the rapidity y, a two dimensional decay-length dl, an isolation criterion with respect to all other reconstructed charged particles within a cone about its direction. Eventually the angular decay distributions of the $\pi^+\pi^-$ and $\mu^+\mu^-$ systems from the $X(3872)$ and the $\psi(2S)$ decays are investigated to check for any differences of helicities. The result of this study is shown in figure 1. There is no evidence for any difference between the $X(3872)$

particle and the $\psi(2S)$. Further studies include looking for other decays which could help to disentangle the different hypotheses for the nature of the $X(3872)$.

Observation of separate orbitally excited B mesons

For each kind of B meson, one expects four orbitally excited B states with L=1, usually called B^{**}. Two of them, labelled B_1 and B_2^*, are narrow and decay to $B^{(*)}\pi$. Their properties are predicted reliably by several theoretical models [6] [7] [8] [9]. B^{**} were however up to now experimentally observed mainly at LEP through inclusive or semi-inclusive decays, preventing their separation in narrow states and precise measurements of their properties [10] [11] [12] [13].

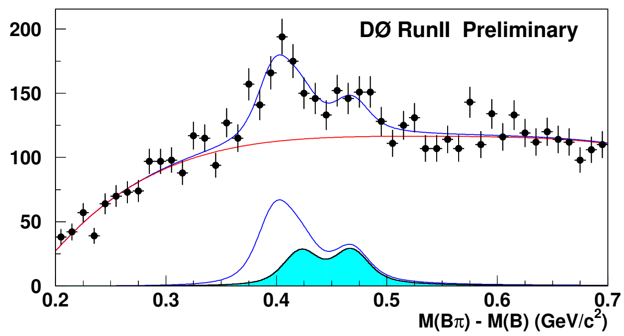

FIGURE 2. Mass difference $M(B\pi) - M(B)$ for exclusively recontructed B mesons. The two upper curves represent the fit to the data and the estimated background. The lower curve shows the signal when the background is subtracted and the filled histogram indicates the contribution of $B_2^* \to B^*\pi$ (left peak) and $B_2 \to B\pi$ (right peak).

The $B^{**} \to B^{(*)}\pi$ decays have been reconstructed in DØ without reconstructing the photon coming from the $B^* \to B\gamma$ decay, using exclusively reconstructed B mesons: B^+ mesons in the $J/\psi K^+$ channel, and B_d^0 from the $J/\psi K^{*0}$ and $J/\psi K_s^0$ final states. Using 350 pb^{-1} of data we obtained more than 10 000 B mesons. This led to the first observation of the two separated narrow states with a statistical significance of 7σ. Actually, due to the missing photon, one expects to find eight mass peaks, but the mass difference between B^{**+} and B_d^{**0} is negligeable relative to the experimental resolution, and the same argument applies to the mass difference between B_2^* and B_1, so that we resolve only two peaks in the invariant mass distribution, as shown in figure 2. The measured B_1 and B_2^* masses and average width are: $M(B_1) = 5724 \pm 4(\text{stat}) \pm 7(\text{syst})$ MeV/c^2, $M(B_2^*) - M(B_1) = 23.6 \pm 7.7(\text{stat}) \pm 3.9(\text{syst})$ MeV/c^2 and $\Gamma = 23 \pm 12(\text{stat}) \pm 9(\text{syst})$ MeV/c^2. Further increase in statistics will allow precision measurements of their production and decay properties.

Properties of the B$_c$ meson decaying to $J/\psi\mu X$

The B_c^+ is the heaviest B meson, ground state of the $b\bar{c}$ system. It has been previously observed by CDF during Run I [15] but with limited statistics. Its study gives a novel experimental insight into heavy quarks dynamics.

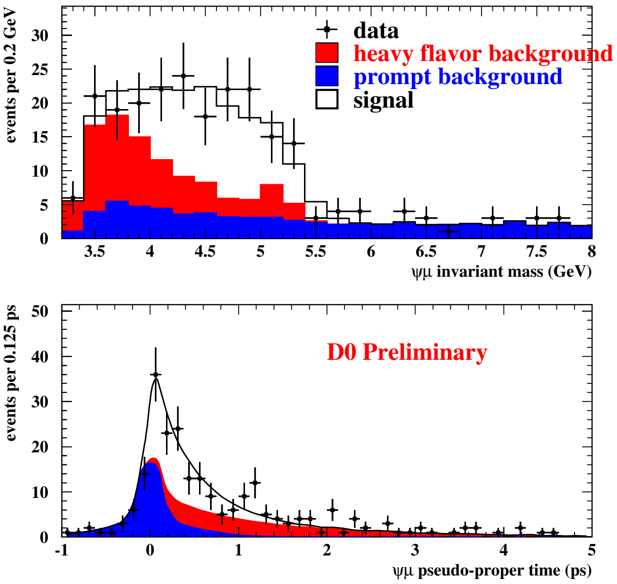

FIGURE 3. $J/\psi\mu$ invariant mass (top) and pseudo-proper time (bottom) distributions for the B$_c \to J/\psi\mu X$ candidates. The points represent the data and the solid curve shows the best combined mass and lifetime likelihood fit to the data. The filled histograms indicate the heavy flavour background (grey) and the prompt background (dark grey).

The $B_c \to J/\psi\mu\nu$ decays has been reconstructed in DØ, taking advantage of the presence of three muons for triggering, and also of a reduced background compared to decay channels with larger branching ratios. Using 210 pb^{-1} of data, 95 B_c with a significance greater than 5σ have been reconstructed. The mass resolution is limited, as it can be seen in figure 3, due to the escaping neutrino. A two-dimensional likelihood fit leads to the following mass and lifetime measurement: $M(B_c) = 5.95^{+0.14}_{-0.13}(\text{stat}) \pm 0.34(\text{syst})\text{GeV/c}^2$ and $\tau(B_c) = 0.448^{+0.123}_{-0.096}(\text{stat}) \pm 0.121(\text{syst})$ ps. As predicted by theory, the B_c lifetime is closer to a charmed meson lifetime than to that of a B meson. In conclusion, the precision of measurements of B_c properties is no longer limited by statistics. Nethertheless, DØ is looking into hadronic decays, to improve the mass and lifetime precision by avoiding the missing neutrino.

CROSS SECTION MEASUREMENTS

Inclusive $\Upsilon(1S)$ differential cross section

DØ measured the inclusive $\Upsilon(1S)$ cross section as a function of the Υ transverse momentum in three rapidity regions [16]. The Υ is reconstructed from the $\mu^+\mu^-$ decay and is assumed to be unpolarized, according to the CDF Run I measurement [17]. The dØ measurement, shown in figure 4, is in agreement with theoretical predictions [18] [19]. It is compatible with the CDF Run I measurement, limited to $|y| < 0.4$ [17].

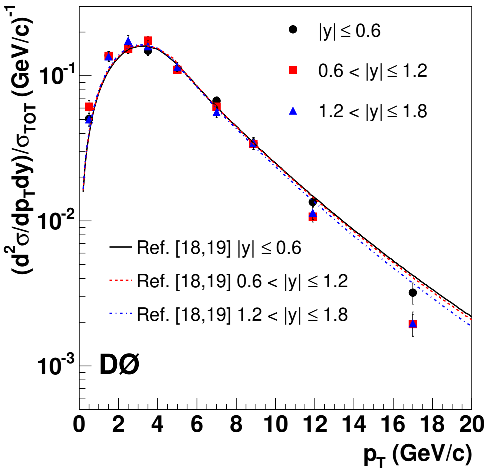

FIGURE 4. Normalized differential cross sections for $\Upsilon(1S)$ production compared to theoretical predictions [18], [19]. The p_T independent systematic uncertainties are not included.

This measurement is based upon 159 pb^{-1} of data and is already limited by systematics. However, increasing statistics would benefit to the high p_T region and would improve the agreement between simulation and data.

$t\bar{t}$ production cross section

The top quark has been discovered at Tevatron in 1995 [20], the only collider able to produce it. Its study is one of the main goals of CDF and DØ. Up to now, the top quark is observed experimentally via $t\bar{t}$ pair production through strong interactions. Electroweak production of a single top is also possible, but with a smaller cross section and a larger background, so that it has not been observed yet. In the Standard Model top quarks decay to a W boson and a b quark and cross section analyses are grouped according to the W decay channel. The possible $t\bar{t}$ final states are therefore dilepton channels, in about 5 % of the cases (excluding the hadronic τ decays), lepton plus jets channels corresponding to $\simeq$ 30 % (also excluding the hadronic τ decays), and fully hadronic final states ($\simeq$ 65 %). The more leptons present in the final state, the smaller the background, but also the lower the statistics. The background can be reduced by requiring one or two jets to be b tagged, using track impact parameters or displaced vertices. The summary of all DØ cross section measurements is shown in figure 5, all results are in agreement with theoretical predictions [21].

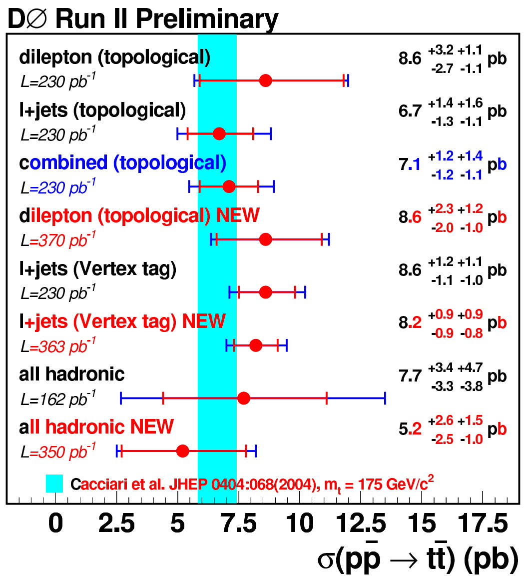

FIGURE 5. Summary of all DØ $t\bar{t}$ cross section measurements at $\sqrt{s} = 1.96$ TeV.

CONCLUSION

The Tevatron is a unique place to study the top quark, but also several B hadrons properties. In 2005 it has already delivered more than 1 fb^{-1} to each experiment. DØ analyses presented here are based on 150 to 370 pb^{-1}. Those limited by statistics will benefit from the expected increase in luminosity during the next years.

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