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DØ Note 2194

B-Physics Results from DØ

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For the DØ Collaboration [1]

The DØ experiment at the Fermilab Tevatron has measured the inclusive single muon and dimuon cross sections for $|\eta^{\mu}| < 0.8$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. The b-quark cross section is extracted using these measurements and found to be in good agreement with next-to-leading order QCD predictions. The inclusive J/ψ cross section in the central region has also been measured and sources of J/ψ production are discussed. Prospects for further B-physics from the DØ experiment are given.

1. Introduction

This paper will review recent B-physics results from the DØ experiment using $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV at the Fermilab Tevatron. The B-physics pursued by DØ centers on production cross sections of inclusive muons, dimuons, and J/ψ's. The b-quark cross section can be subsequently extracted from these measurements and compared to next-to-leading order (NLO) QCD predictions [2]. Published CDF results [3] of the b-quark cross section lie above the central values of these NLO QCD predictions while lower energy data from the UA1 experiment [4] are in good agreement. Measurements of the b-quark cross section by DØ provide an independent test of our theoretical understanding of b-quark production which is important in addition for validating top quark cross section predictions, estimating backgrounds for top quark searches with b-quark tagging, and extrapolating heavy quark cross sections to LHC energies.

The DØ detector is first briefly described. Results on the inclusive muon, dimuon, and b-quark cross sections are presented. Next the inclusive J/ψ cross section is shown and analyses to determine the sources of J/ψ production are described. All results in this paper are preliminary. Other B-physics analyses in progress by DØ are listed and prospects for B-physics using data from the 1994-1995 Tevatron collider run are discussed.

2. DØ Detector

The DØ detector consists of central tracking and transition radiation detectors, a uranium-liquid argon calorimeter, and an extensive muon detection system. Details of the DØ detector and its performance are given in [5]. B mesons are tagged using their semi-leptonic decay into muons thus a few relevant details of the muon system are included here.

The muon system consists of 5 iron toroids plus three layers of 10 *cm* wide proportional drift tubes. A small angle muon system consisting of 3 *cm* wide proportional tubes extends the η coverage of the muon system to $|\eta| < 3.3$. The signed momentum of the muon is measured by its bend in the toroid and the momentum resolution is determined to be $\sigma(p)/p = 0.2(p-3)/p \oplus 0.008p$ (p in GeV/c). The thickness of the calorimeter plus iron is 14-18 λ. This gives a very small punchthrough probability (.005 per prompt muon) and also permits good muon identification within a jet.

Three levels of triggers are used in defining muon triggers. The level 0 trigger is a scintillation counter array which indicates that an inelastic collision has occurred. Each drift cell in the muon system provides a latch bit indicating whether or not it was hit for each beam crossing. The level 1 muon trigger is a hardware trigger which uses these bits to look for muon hits in 60 cm wide roads and requires at least two hits per layer in two or three layers, depending upon the detector geometry. The minimum P_T of a central muon escaping the iron toroid is approximately 3 GeV/c and the level 1 muon trigger is fully efficient at 5 GeV/c. The level 2 muon trigger is a software trigger which uses code similar to that used in offline muon reconstruction. In the results below, inclusive muon triggers require a good level 1 muon trigger and a good quality level 2 muon track with $P_T > 3$ GeV/c. Dimuon and J/ψ triggers require two level 1 and level 2 muon triggers.

3. Inclusive Muon and b-quark Cross Section

Because of the high trigger rate, data for the inclusive muon cross sections were taken in dedicated runs. Good muons were selected offline by requiring each muon to have hits in all three layers of the muon system, to traverse a minimum field integral of 0.6 GeV/c in the toroids, to have at least 1 GeV of associated calorimeter energy, and to possess a matching track in the central tracking chambers. Kinematic requirements on muons were $| \eta^{\mu} | < 0.8$ and $3.5 < P_T^{\mu} < 60$ GeV/c. Cosmic ray contamination was reduced by requiring muons to have a crossing time in the muon chambers (called T0) within 100 ns of the beam crossing time. A total of 17453 events passed all cuts in data runs corresponding to an integrated luminosity of 89 nb^{-1}.

The remaining cosmic ray background after all cuts is estimated by fitting the T0 distribution in the data as the sum of T0 distributions from cosmic ray muons and quality prompt muons (e.g. muons having associated jets). The result of the fit gives the cosmic ray background as 13 $\pm$ 4% independent of P_T.

The combined trigger and offline selection efficiency is found using complete detector and trigger simulation and cross checked using cosmic ray and J/ψ samples collected by the experiment. The differential inclusive muon cross section is shown in Figure 1. It results from dividing the number of muons (corrected for the cosmic ray background) in each measured P_T bin by the product of efficiency, integrated luminosity, and η bite. Also shown in Figure 1 are the known contributions to the inclusive muon spectrum as given by the ISAJET Monte Carlo [6]. The sum of all contributions is in good agreement with the data.

In order to extract the b-quark cross section one must estimate that fraction of the inclusive muon spectrum coming from b-quark decays. The b-quark decay fraction is found using ISAJET results for the known contributions to the inclusive muon spectrum (see Figure 1). For each P_T bin this fraction is cross checked by fitting the P_T^{rel} distribution in the data as the sum of P_T^{rel} distributions from b-quark decay and c-quark plus π/K decay. The quantity P_T^{rel} is the transverse momentum of the muon relative to the associated jet axis where the jet momentum also includes the muon momentum. The P_T^{rel} distributions used in the fit were given by ISAJET. The b-quark fraction of the inclusive muon spectrum found by this fitting procedure is in good agreement with the b-quark fraction determined via Monte Carlo alone.

The integrated inclusive b-quark cross section is determined following the method of UA1 and CDF in order to facilitate comparison [3,4]. First, the b-quark cross section from Monte Carlo is plotted as a function of the b-quark transverse momentum, P_T^b, for those muons satisfying a given P_T^{μ} and η^{μ} range. This cross section is used to define P_T^{min} such that 90% of the muons satisfying the kinematic cuts come from b quarks with $P_T^b > P_T^{min}$. The integrated cross section is also used and we call this value D. Monte Carlo is also used to determine the integrated b-quark cross section for $P_T^b > P_T^{min}$ and the value is called N. The b-quark cross

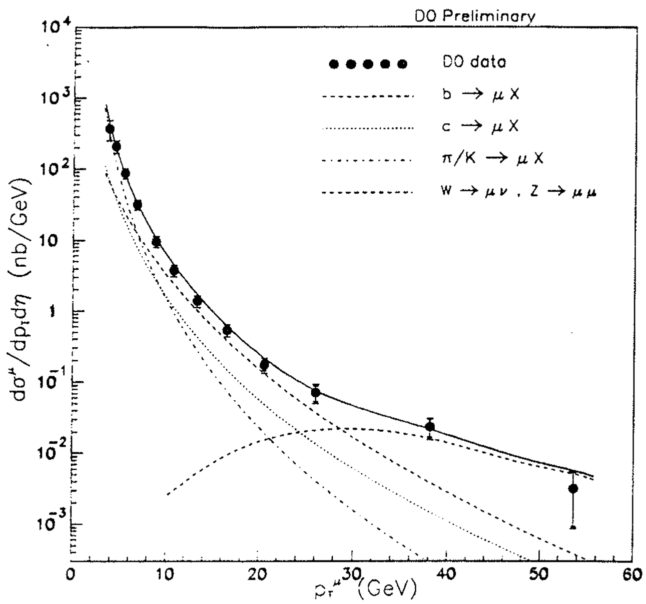

Figure 1: Measured and expected inclusive muon cross section.

section for $P_T^b > P_T^{min}$ is then the product of the integrated inclusive muon cross section from the data times the fraction of the cross section coming from b quark decays times N/D. The value of P_T^{min} can be adjusted by increasing the lower value of the P_T^μ range.

The resulting b-quark cross section is shown in Figure 2 along with the NLO QCD prediction of Nason et al. [1]. Good agreement is observed over the entire P_T range. The total systematic error in the inclusive muon cross section is 17% and arises from uncertainties in the integrated luminosity (12%), muon trigger and offline efficiencies (11%), and cosmic ray subtraction (4%). The total systematic errors on the b-quark cross section are P_T dependent and of magnitude 20-30% from uncertainties in the b-quark fraction (5-10%), P_T^b shape (10-13%), b-quark fragmentation (10-15%), B meson branching ratio (5%), and B meson $\rightarrow \mu$ decay spectrum (5-10%).

Dedicated runs having a total integrated luminosity of 6.7 pb^{-1} were taken to measure the inclusive muon cross section in the region $2.2 < \mid \eta^\mu \mid < 3.3$. Good muon tracks were chosen by selecting high quality three layer tracks with ≥ 18 hits per track. Calorimeter energy confirmation was also required. The resulting inclusive cross section in the small angle region is shown in Figure 3. Also shown are the ISAJET Monte Carlo results for contributing processes to the inclusive cross section. The sum of known contributions describes the data well. Extraction of the b-quark cross section in this η region is in progress.

4. Inclusive Dimuon and b-quark Cross Section

Dimuon selection criteria were similar to those for single muons. Differences for dimuons were that both two and three layer tracks were allowed and no T0 cut was applied. Kinematic cuts required both muons to have $4 < P_T^\mu < 25$ GeV/c and $\mid \eta^\mu \mid < 0.8$. In order to remove sequential decays ($b \rightarrow c\mu, c \rightarrow \mu$) and Z decays the dimuon invariant mass was restricted to 6

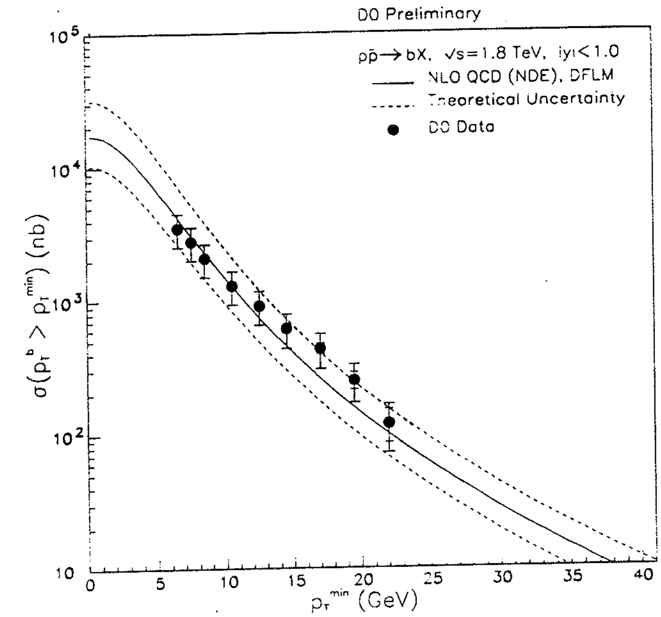

Figure 2: b-quark production cross section and NLO QCD prediction

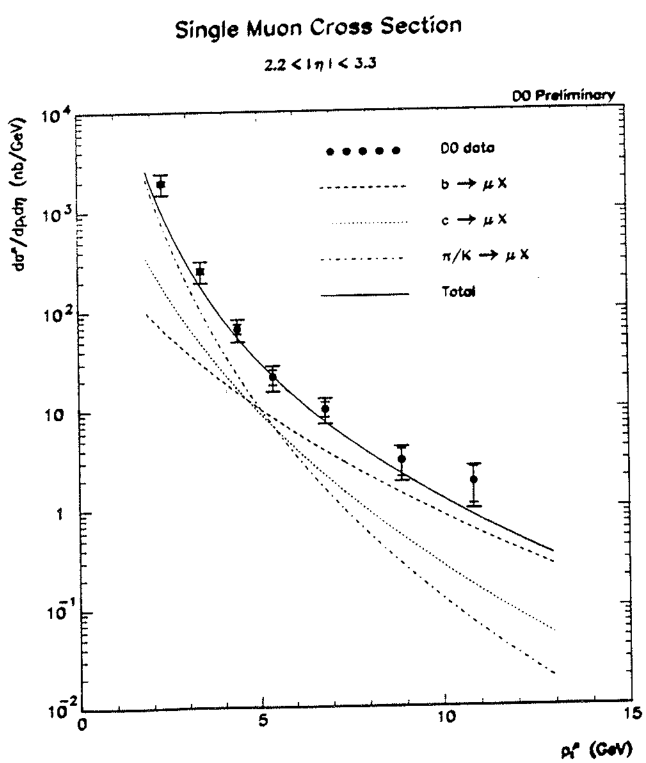

Figure 3: Measured and expected inclusive muon cross section for $2.2 < | \eta^{\mu} | < 3.3$.

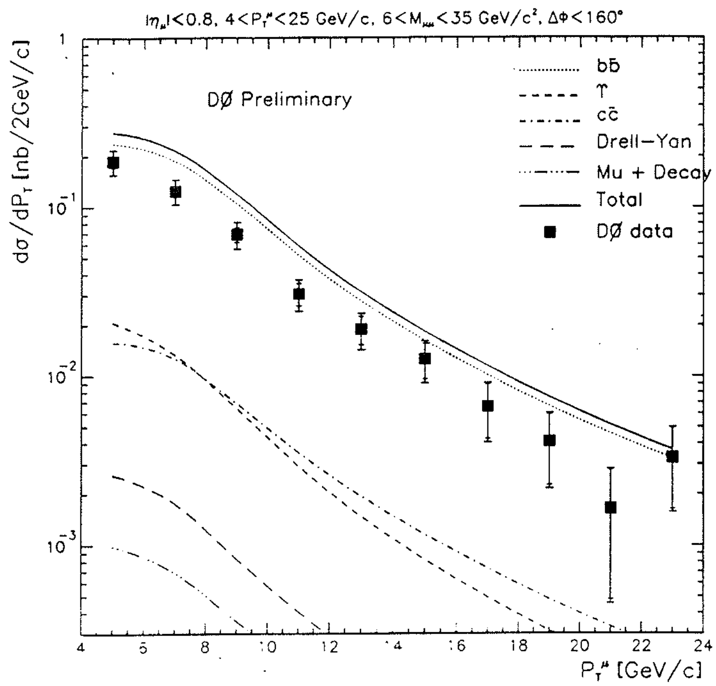

Figure 4: Measured and expected inclusive dimuon cross section.

$< M_{\mu\mu} < 35$ GeV. Cosmic rays were suppressed by the requirement $\Delta\phi < 160°$. A total of 566 events survived all cuts from runs having a total integrated luminosity of 7.2 pb^{-1}.

Cosmic ray background was estimated for each P_T^μ bin by event scanning by two physicists. Trigger and offline selection efficiencies were estimated by taking ISAJET Monte Carlo events through the complete detector and trigger simulators. An exception is the central tracking detector match efficiency which was estimated using appropriate data samples.

Dividing the number of events in each P_T^μ bin by the product of overall efficiency and integrated luminosity results in the inclusive dimuon cross section plotted as a function of the highest P_T^μ shown in Figure 4. The systematic error on each point is 23% coming from uncertainties in luminosity (12%), trigger and offline selection efficiences (15%), central chamber track match efficiency (10%), cosmic ray subtraction (5%), and muon chamber efficiencies (5%). The cross sections for known processes producing dimuon events were estimated using ISAJET and are also shown in Figure 4. The sum of all known dimuon processes from ISAJET is slightly above the data. Unlike the inclusive muon spectrum the dimuon spectrum is dominantly from $b\bar{b}$ production even at low values of P_T^μ. Averaged over all P_T^μ bins the dimuon fraction from $b\bar{b}$ production is $0.87^{+0.13}_{-0.22}$.

The b-quark cross section was extracted from the inclusive dimuon cross section using the same method as from the inclusive muon data as described above. The resulting b-quark cross section is shown in Figure 5 along with the NLO QCD prediction from Nason et al. [1]. For comparison the b-quark cross section extracted from the inclusive muon data is shown and reasonable agreement between the two measurements is observed. The systematic error on each point is approximately 27% from uncertainties in the $b\bar{b}$ fraction of dimuons (20%), b-quark fragmentation uncertainties (15%), b-quark P_T^b shape (10%), and the extrapolation from $| \eta^b | < 0.8$ to $| \eta^b | < 1.0$ (5%).

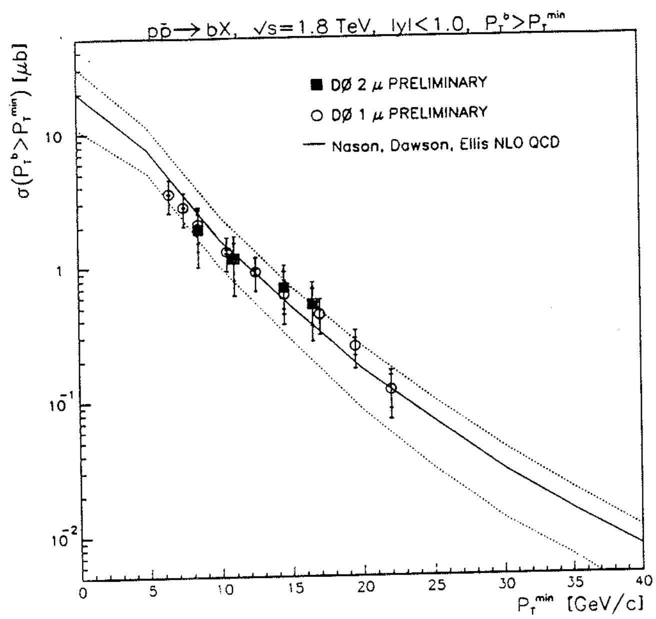

Figure 5: b-quark production cross section from inclusive dimuon and single muon cross sections along with NLO QCD prediction.

5. Inclusive J/ψ Cross Section and Production Mechanisms

To select J/ψ candidates, each muon was required to pass the same track quality criteria as in the dimuon analysis mentioned above. Additionally, the dimuon pair was required to have oppositely signed muons, $2 < M_{\mu\mu} < 4.5$ GeV and $|\eta^{J/\psi}| < 0.6$. The number of J/ψ after all cuts was estimated by fitting the invariant dimuon mass distribution to the sum of a Gaussian centered at the J/ψ mass and a polynomial which described the background (mostly sequential b-quark decays). The total number of J/ψ given by the fit was 450 collected from data runs corresponding to an integrated luminosity of 7.2 pb^{-1}.

Trigger and offline efficiencies were determined as above using complete detector and trigger simulation. The number of J/ψ in each $P_T^{J/\psi}$ bin was determined using the fitting procedure described above. Dividing by the overall J/ψ detection efficiency and the integrated luminosity gives the resulting inclusive cross section times branching ratio shown in Figure 6. The data are in good agreement with the more precise CDF data [7]. Also shown are the theoretical estimates for J/ψ production from b-quark decay and direct charmonium production [1,8,9]. The inclusive J/ψ cross section lies well above the sum of these contributions. Additional diagrams such as gluon fragmentation into J/ψ and χ_c [10] must possibly be included before a complete understanding of J/ψ production is reached.

The fraction of J/ψ's from b-quark decay is estimated using trimuon events. A fit is made to the dimuon invariant mass in the range $1 < M_{\mu\mu} < 5$ GeV as the sum of signal (J/ψ) and background (sequential decays) distributions. Next the dimuon invariant mass is formed using trimuon events (J/ψ plus muon (b-quark) tag). Using the signal and background distributions from the dimuon sample fit, the number of J/ψ in trimuon events can be estimated. No clear J/ψ signal is observed in these trimuon events. ISAJET $b\bar{b}$ Monte Carlo studies are used to

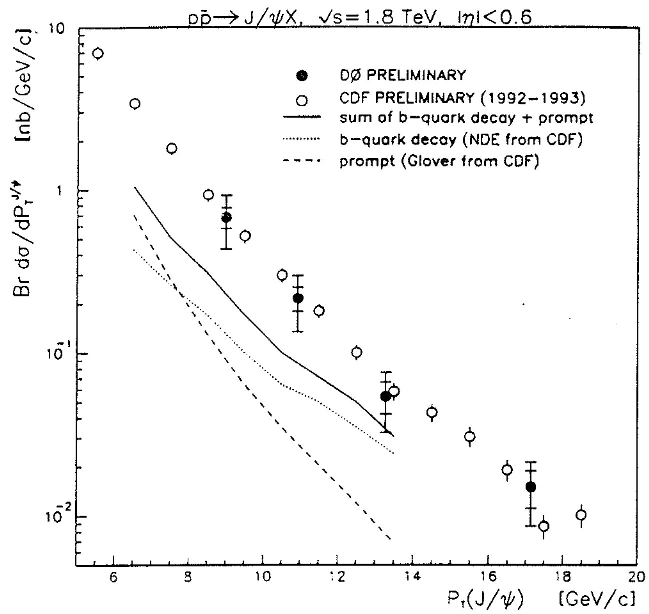

Figure 6: Inclusive J/ψ cross section from DØ and CDF compared with QCD predictions.

determine the fraction of J/ψ plus muon tag events in inclusive J/ψ events. An upper limit for the J/ψ fraction from b-quark decay at the 95% CL is determined to be < 50%.

Also important is the fraction of J/ψ arising from direct charmonium production, primarily through the decay of χ_c. Selection criteria for χ_c include isolated muons and low E_T photons. Isolated J/ψ's were chosen from the J/ψ sample by requiring no jet be found in a $\Delta R = \sqrt{(\Delta\phi^2 + \Delta\eta^2)} < 1.0$ cone about either muon. Photons of energy $E_\gamma > 0.6$ GeV are identified using quality photon selection criteria. Finally the $M_{\mu\mu\gamma}$ - $M_{\mu\mu}$ distribution is made and a peak observed at roughly 0.55 GeV. After background subtraction one finds 19.2 ± 5.5 χ_c produced. Dividing by the photon detection (0.21) and isolation (0.33) efficiencies gives the fraction of J/ψ from χ_c decay as $0.41 \pm 0.14 \pm 0.10$ in good agreement with the CDF result [10].

6. B-Physics Outlook for DØ

DØ is pursuing a number of additional B-physics topics using the 1992-1993 collider data. These include a measurement of the time and flavor averaged $B^\circ - \bar{B}^\circ$ mixing probability, measurements of $b\bar{b}$ correlations which can be used to separate leading order and next-to-leading order contributions to b-quark production, and measurement of the strong coupling constant α_s. In progress as well are determinations of the b-quark cross section using inclusive muon plus jet, small angle muon, and J/ψ cross sections. The fraction of jets containing a b quark as a function of E_T^{jet} is calculable in QCD at NLO using standard algorithms to define jets. DØ is in the process of measuring the heavy flavor content of jets which is also important in understanding the W + b-quark jet background in top quark searches. A measurement of the Υ cross section using dimuons is nearly complete.

Several improvements have been made to improve the B-physics capabilities of DØ for the 1994-1995 collider run. These include the installation of new roof scintillator to improve cosmic ray rejection, use of the muon level 1.5 trigger to improve combinatoric rejection in the small angle regions, and additional muon identification tools in the level 2 trigger such as energy confirmation in the calorimeter. Given the bandwidth allocation limitations imposed on B-physics by DØ, a 50% increase in data acquisition bandwidth allows many B-physics triggers to run unprescaled up to luminosities of $10^{31}/cm^2/s$. Poor cathode pad efficiency in the intermediate angle muon chambers due to particle backgrounds in the collision hall is being addressed with modified electronics and particle shielding.

The B-physics goals for the 1994-1995 collider run include measurements of the inclusive muon, dimuon, and J/ψ cross sections over the full η coverage of DØ. This will subsequently allow measurements of $d\sigma/d\eta$ which are sensitive to the gluon distribution function down to Bjorken x values of 10^{-3}. Detection of muons in the range $|\eta| < 3.3$ will allow improved statistics for $b\bar{b}$ correlation studies using dimuons and J/ψ plus muon tags. Efforts will be made to reconstruct muons using only the innermost layer of the muon system (before the iron toroid) in order to reduce the muon P_T thresholds in dimuon events which will lead to increased statistics.

7. Conclusions

The DØ experiment at the Fermilab Tevatron has measured the single muon and dimuon inclusive cross sections for $|\eta^\mu| < 0.8$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. The b-quark cross section was extracted and is found to be in good agreement with next-to-leading order QCD predictions. The inclusive J/ψ cross section in the central region has been measured and is in good agreement with CDF measurements in the overlapping region of $P_T^{J/\psi} > 8$ GeV/c. An upper limit on the fraction of J/ψ events from b-quark decay is set at 50% and the fraction of J/ψ from χ_c decay is 0.41 ± 0.14 (stat) ± 0.10 (sys) for $P_T^{J/\psi} > 8$ GeV/c. Prospects for further B-physics from DØ are excellent.

References

[1] The DØ collaboration consists of physicists from the following institutions: Universidad de los Andes, University of Arizona, Brookhaven National Laboratory, Brown University, University of California, Davis, University of California, Irvine, University of California, Riverside, LAFEX, Centro Brasileiro de Pesquisas Físicas, CINVESTAV, Columbia University, Delhi University, Fermi National Accelerator Laboratory, Florida State University, University of Hawaii, University of Illinois, Chicago, Indiana University, Iowa State University, Korea University, Kyungsung University, Lawrence Berkeley Laboratory, University of Maryland, University of Michigan, Michigan State University, Moscow State University, University of Nebraska, New York University, Northeastern University, Northern Illinois University, Northwestern University, University of Notre Dame, University of Oklahoma, Panjab University, Institute for High Energy Physics, Protvino, Russia, Purdue University, Rice University, University of Rochester, CEA, DAPNIA/Service de Physique des Particules, CE-SACLAY, Seoul National University, State University of New York, Stony Brook, Superconducting Supercollider Laboratory, Tata Institute of Fundamental Research, University of Texas, Texas A&M University

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