RECENT RESULTS FROM THE DØ EXPERIMENT AT THE TEVATRON

P. DEMINE (for the DØ Collaboration)

CEA-Saclay, DAPNIA/Service de Physique des Particules
(91191 Gif sur Yvette Cedex, France)

UDC 621.1

The DØ experiment at the Tevatron has used $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV to measure the inclusive jet and dijet cross sections. The production cross sections of W and Z bosons were measured using several leptonic final states. Preliminary measurements of B hadrons lifetimes was done. The presence of a top quark signal in the Tevatron data has been reestablished by measuring the top quark pair production cross section in the dilepton channel, $t\bar{t} \to WbW\bar{b} \to \bar{l}\nu_l bl'\bar{\nu}_{l'}\bar{b}$ and in the lepton plus jets channel, $t\bar{t} \to WbW\bar{b} \to q\bar{q}'bl\bar{\nu}_l\bar{b} + \bar{l}\nu_l bq\bar{q}'\bar{b}$

Introduction

The DØ is a multipurpose detector located at the interaction region designated for 2 TeV $p\bar{p}$ collisions at the Tevatron collider at the Fermi National Accelerator Laboratory (USA). Both the detector and accelerator have undergone major upgrades to increase the luminosity and to handle higher interaction rates. The DØ detector has a central tracking spectrometer consisting of a silicon micro-strip tracker and a scintillating fiber detector located within a 2 T solenoidal magnetic field. Both the silicon and fiber trackers provide full coverage in the central region and moderate coverage in the forward region. Particle energies are measured in a large uranium-liquid argon calorimeter. The central muon system consists of several layers of drift tubes and scintillators sandwiching a 1.4 T toroid magnet. The new forward muon system provides coverage up to $|\eta| = 2.0$. The forward proton detector consists of two arms of 18 Roman pots in four quadrupole and two dipole "castles". The scintillating fiber detectors installed in the Roman pots are used to measure scattered protons and antiprotons. The current center of mass energy of the Tevatron accelerator is 1.96 TeV. This is by 9 % larger than for the previous run. The DØ detector has started recording $p\bar{p}$ interactions with its full functionality during 2002. DØ has used the physics quality data collected until January 2003, corresponding to an integrated luminosity of approximately 40, pb^{-1}, to re-establish W, Z, B, and top quark signals. DØ has also measured the inclusive jet and dijet production cross sections and B hadrons proper lifetimes.

1. Jet Cross Section Measurements

Measurements of jet production cross section can be used to test QCD predictions for parton-parton scattering and to constrain the parton density functions (PDF) of the proton, particularly the gluon distribution.

The 9 % relative change of the center-of-mass energy of the Tevatron accelerator is expected to bring a significant increase in the jet cross section at high p_T (by a factor of 2 at $p_T \approx 400$ GeV) according to the NLO QCD prediction.

The data for the jet cross section measurements represent an integrated luminosity of approximately 34 pb^{-1}, and were collected using four inclusive jet triggers. Each trigger requires a localized energy deposited in the calorimeter and a reconstructed jet with p_T above one of the following thresholds: 25, 45, 65, or 95 GeV.

The jets are reconstructed in the DØ calorimeter using an iterative cone algorithm with $\Delta R = \sqrt{\Delta\eta^2 + \Delta\varphi^2} = 0.7$ [1]. The jet energy scale was defined using information from $\gamma +$ jet events, low bias triggers, and Monte Carlo simulations. There are large statistical uncertainties and substantial systematic uncertainties in this energy scale determination that increase with energy due to extrapolation. These are principally caused by the small $\gamma +$ jet statistics above 200 GeV. This is the dominant systematic uncertainty in the jet cross section measurements. The jet measurements are restricted to $|\eta| < 0.5$ to limit the impact of these uncertainties. The jet p_T resolution was measured from the p_T imbalance in dijet events.

We require a primary vertex with at least 5 tracks and $|z_{\rm vtx}| < 50$ cm. The jet selection was based on calorimeter characteristics to reduce the number of misidentified jets. To remove rare instrumental backgrounds to high p_T jet events, we require $\not{E}_T$ to

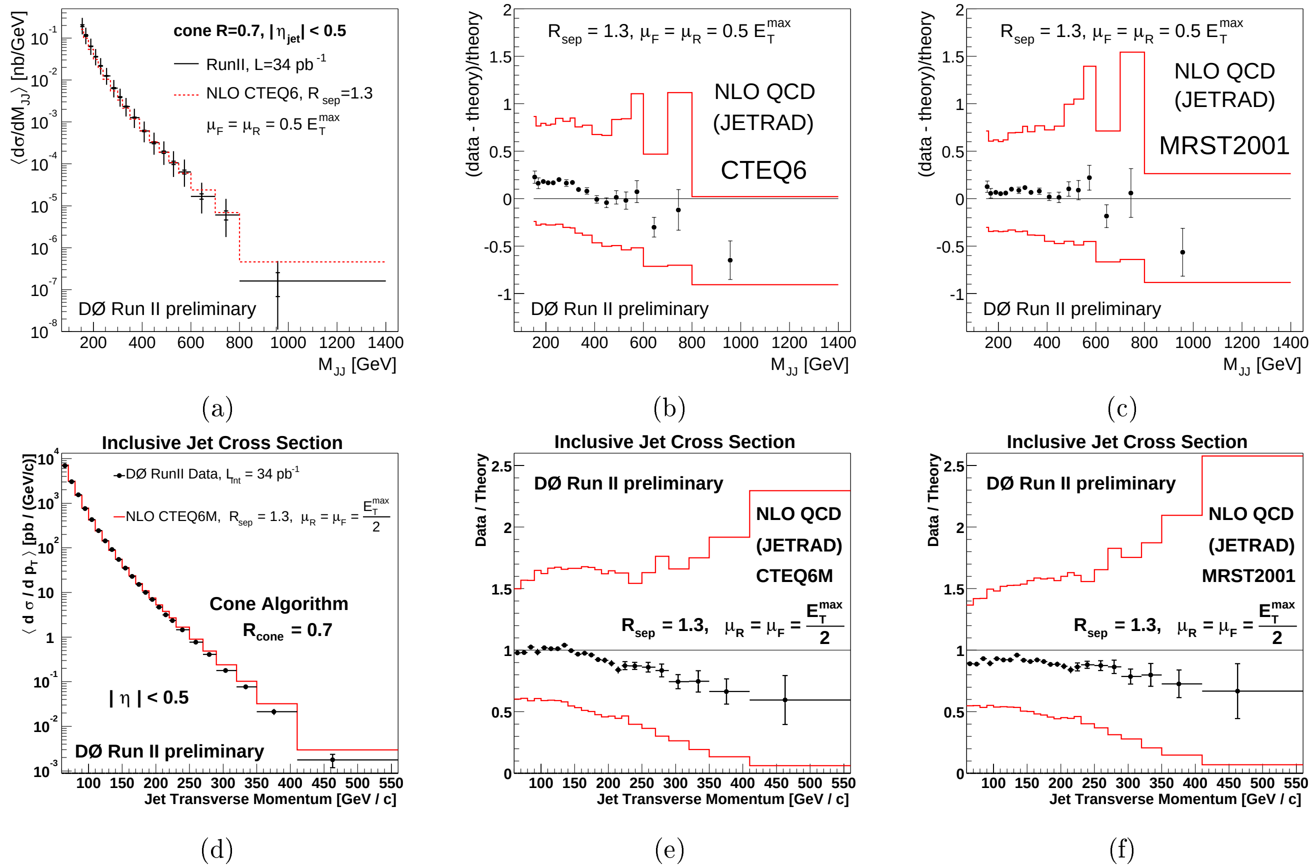


Fig. 1. The dijet cross section as a function of dijet mass (a). The dijet cross section shown as (data − theory)/theory as a function of dijet mass, two PDFs were used in the theory calculation: CTEQ6M (b) and MRST2001 (c). The inclusive jet cross section as a function of jet p_T (d). The inclusive jet cross section shown as data/theory as a function of jet p_T, two PDFs were used in the theory calculation: CTEQ6M (e) and MRST2001 (f)

satisfy the relation $\not{E}_T < 0.7 p_T$ (leading jet)[1]. The cuts efficiencies are estimated from data to be 78 % for the vertex selection and 97 % for the jet selection.

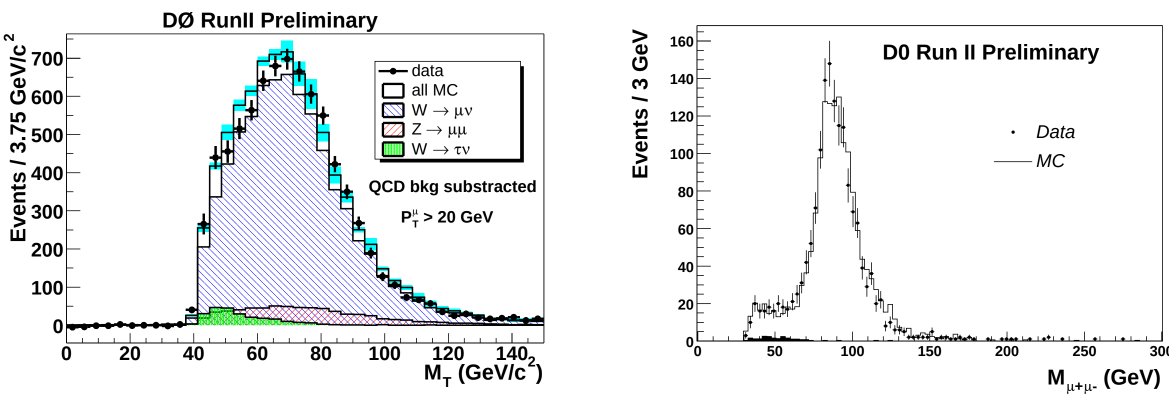
The observed dijet differential cross section as a function of dijet mass is shown in Fig. 1(a). The inclusive jet differential cross section as a function of jet p_T is shown in Fig. 1(d). The 10 % luminosity error, which is correlated bin-to-bin, is not shown.

The observed cross sections were compared with the results of a NLO pQCD calculation made with JETRAD [2] Monte Carlo generator using CTEQ6M [3] and MRST2001 [4] PDF. The factorization and renormalization scales have been set equal to $p_T/2$ of the leading jet in the event and $R_{\rm sep}$ has been set to 1.3. Linear comparisons of the calculation to the data are presented in Fig. 1(b,c,d,e). Within errors, there is an agreement with the theory.

2. *W* and *Z* Cross Sections

One of the key measurements of the DØ electroweak physics program concerns the measurement of the production cross sections of W and Z vector bosons. W and Z bosons are produced at the Tevatron through $q\bar{q}^{(\prime)}$ annihilation. The cleanest signatures involve high p_T electrons or muons: $W \to e\nu_e, \mu\nu_\mu$ and $Z \to e^+e^-, \mu^+\mu^-$ all have small background contamination. Other decays are more difficult to exploit or unobservable. DØ presented their first W and Z cross sections measurements in summer 2002. Many of those

[1] $\not{E}_T$ is the missing energy transverse to the beam direction.



(a) (b)

Fig. 2. Data/MC comparison for the transverse mass distribution of $W \to \mu\nu$ candidates collected by DØ experiment in 17.3 pb^{-1} of Run II data (a). Invariant mass distribution of $\mu^+\mu^-$ pairs collected by DØ experiment in 31.8 pb^{-1} of Run II data (b)

results have been updated using the total integrated luminosity $\mathcal{L} = 31.8 \pm 3.2$ pb^{-1} for the muon channels and $\mathcal{L} = 41.6 \pm 4.2$ pb^{-1} for the electron channels.

2.1. *W* Cross Section Measurements

The $W \to e\nu_e$ candidates are collected with a trigger selecting high p_T central electron candidates; after requiring one tight electron candidate with $E_T > 25$ GeV and missing transverse energy $\not{E}_T > 25$ GeV, 27 370 events remain in the data.

The main background source comes from QCD dijet events, where a jet mimics the electron signal and large $\not{E}_T$ is due to a poorly measured jet. This background is evaluated by assuming that its distribution is flat in the electron isolation plane versus $\not{E}_T$. Additional backgrounds from $W \to \tau\nu_\tau$ decays $(1.5 \pm 0.1\,\%)$ are estimated from Monte Carlo simulations. The total acceptance is 25.8 %. The calculated cross section is $\sigma(W) \cdot \mathrm{Br}(W \to e\nu_e) = 3.054 \pm 0.10$ (stat.) $\pm$ 0.086 (sys.) $\pm$ 0.3 (lumi) nb.

DØ also measures $\sigma(W) \cdot \mathrm{Br}(W \to \mu\nu_\mu)$. $W \to \mu\nu_\mu$ candidates are collected using single muon triggers. After requiring an isolated muon with $p_T > 20$ GeV/c, $\not{E}_T > 20$ GeV and background subtraction, 7 352 W candidates remain. Backgrounds in this channel include misidentified boson decays: $\gamma^*/Z \to \mu^+\mu^-$ $(685 \pm 95$ events), $W \to \tau\nu_\tau$ $(265 \pm 34$ events), and QCD processes $(515 \pm 99$ events). The transverse mass spectrum of the candidate events and the estimated background is shown in Fig. 2. The result is $\sigma(W) \cdot \mathrm{Br}(W \to \mu\nu_\mu) = 3.226 \pm 0.13$ (stat.) $\pm$ 0.10 (sys.) $\pm$ 0.3 (lumi) nb.

2.2. *Z* Cross Section Measurements

For the analysis of $\gamma^*/Z \to \mathrm{e}^+\mathrm{e}^-$ events, a trigger selecting high p_T central electron candidates is used. After requiring two central electrons with $p_T > 25$ GeV, 1 139 candidate events remain in the data. The background for high mass dielectron events comes from Z + Drell-Yan production $(1.7 \pm 0.4\,\%)$ and the QCD $(2.3 \pm 0.1$ (stat.) $\pm$ 1.0 (sys.) %) processes. The QCD instrumental background arises predominantly from dijet events, where one jet fragments to a leading π^0. The background shape is determined from the data. The total acceptance for this analysis is 25.8 %. The measured cross section times branching ratio is $\sigma(Z) \cdot \mathrm{Br}(Z \to \mathrm{e}^+\mathrm{e}^-) = 0.294 \pm 0.011$ (stat.) $\pm$ 0.008 (sys.) $\pm$ 0.03 (lumi) nb.

$\gamma^*/Z \to \mu^+\mu^-$ candidates are selected by requiring two muon candidates with $p_T > 15$ GeV, separated in $\eta - \varphi$ by more than $\Delta R(\mu,\mu) > 2.0$; the estimated background is $1.5 \pm 1.0\,\%$. From 1 585 events containing two muon candidates, DØ measures $\sigma(Z) \cdot \mathrm{Br}(Z \to \mu^+\mu^-) = 0.264 \pm 0.007$ (stat.) $\pm$ 0.017 (sys.) $\pm$ 0.03 (lumi) nb.

Fig. 3 shows the presented results in addition to other measurements of the W and Z cross sections at hadron colliders. The W and Z cross sections rise with the center of mass energy in agreement with NNLO calculations.

3. *B* Physics

Heavy flavor cross sections at hadron colliders are by three orders of magnitude higher than those at $\mathrm{e}^+\mathrm{e}^-$ machines at the $\Upsilon(4S)$ and include the heavier B_s and

B_c mesons and the weakly decaying barions Λ_b and Ξ_b. This opens up a rich field of B physics studies. DØ has made significant improvements of the detector and the trigger to expand their capabilities beyond simply profiting from the higher luminosities of the Tevatron in Run II.

To perform B lifetime measurements in J/ψ exclusive decay modes, an inclusive sample of J/ψ events was collected using di-muon triggers. The data were pre-selected requiring two muons within $|\eta| < 2.4$. The invariant mass distribution of $\mu^+\mu^-$ pairs is shown in Fig. 4(a). Most of the dimuons are coming from the J/ψ decays, but the contribution from ψ' and Υ is also significant.

The inclusive J/ψ events were used to measure an average inclusive B lifetime and an exclusive $B^\pm \to J/\psi K^\pm$ lifetime. A lifetime measurement is essentially a measurement of the distance between the decay vertex and the primary vertex in the plane transverse to the beam direction (L_{xy}) corrected by the Lorentz boost of the decaying B hadron: $c\tau = L_{xy}/(\gamma\beta), \gamma\beta = p_T(B)/m(B)$.

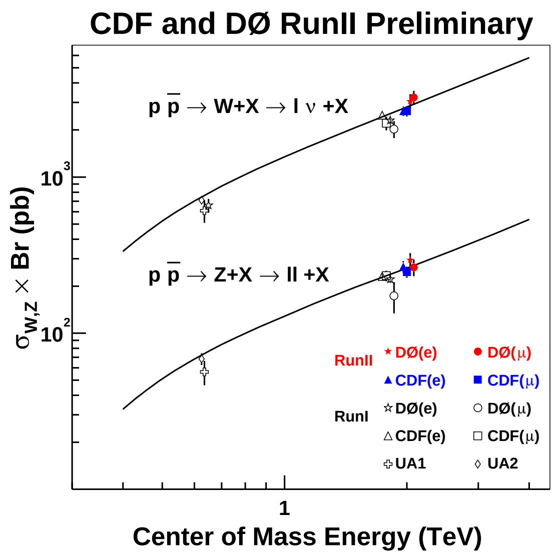


Fig. 3. W and Z cross sections as a function of the center of mass energy

3.1. Inclusive B Lifetime Measurement

In the inclusive measurement, the B hadron is not fully reconstructed so that the quantity $p_T(B)/m(B)$ is not known from event to event. It is therefore obtained as an average correction factor, as a function of the p_T of the J/ψ. The correction factor is computed using the Pythia Monte Carlo generator [5], with the B hadron decays simulated by the QQ program [6]. The proper decay length distribution of the J/ψ background is obtained from the J/ψ sideband windows ($2.6 < m_{\mu\mu} < 2.85$ GeV/c^2 and $3.29 < m_{\mu\mu} < 3.5$ GeV/c^2), and fit to a double Gaussian resolution function and the sum of an exponential plus a constant background. This background is fixed in the J/ψ signal window, and a prompt component and signal exponential convoluted with the resolution function obtained from the sideband windows is added. The signal window decay length distribution, along with its fit, is shown in Fig. 4(b). The systematic uncertainty on the average lifetime is dominated by uncertainties on the correction factor applied (16 μm, mainly from fragmentation uncertainties) and fit biases (13 μm, as determined from Monte Carlo studies). The average lifetime is therefore determined to be

$$\tau_B = 1.56 \pm 0.02 \text{ (stat.)} \pm 0.07 \text{ (sys.) ps}$$

in good agreement with the world average result.

3.2. $B^\pm$ Lifetime Measurement

The use of fully reconstructed B hadrons allows one to estimate the B hadron momentum on an event by event basis and has lower background, and therefore leads to a much reduced systematic lifetime uncertainty. In this analysis, the $B^\pm$ mesons are reconstructed through the decay $B^\pm \to J/\psi K^\pm$, where (in the absence of π/K separation) charged particles compatible with those originating from the J/ψ vertex are assigned the kaon mass.

The background to the lifetime distribution in this case consists of two components: incompletely reconstructed B decays mainly populating the lower $B^\pm$ sideband region, and prompt combinatorial background. The lifetime of the former is determined and fixed in the fit to the signal region, while its fraction is fixed to expectations from Monte Carlo. The $B^\pm$ signal window is fit to this background plus an exponential signal component convoluted with a Gaussian resolution function [8]. The result of the fit is

$$\tau_{B^\pm} = 1.76 \pm 0.24 \text{ (stat.)} \pm 0.07 \text{ (sys.) ps}$$

within its large uncertainty again in agreement with the world average result.

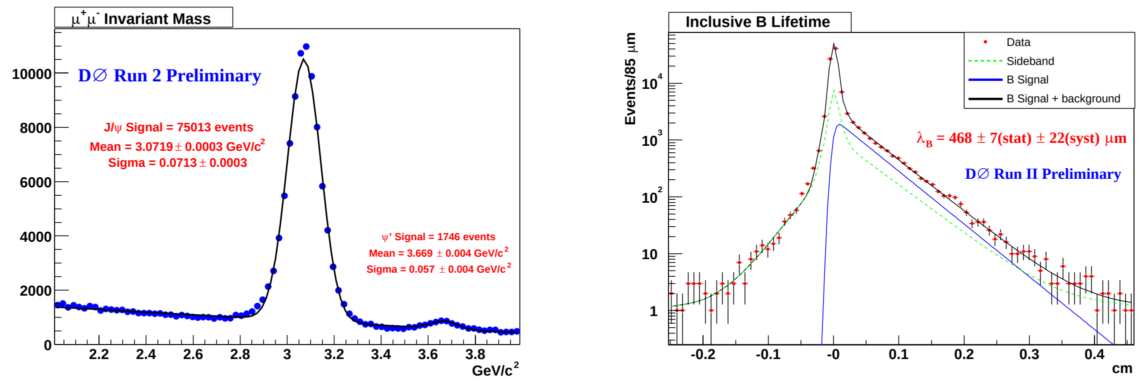


Fig. 4. Invariant mass distribution of $\mu^+\mu^-$ pairs collected by DØ experiment in about 40 pb^{-1} of Run II data (a). Proper decay length distribution of B candidates from the total J/ψ sample (b)

4. Top Quark Production Cross Section

At the Tevatron, top quarks are produced predominatly in pairs through the QCD proceses $\mathrm{q\bar{q}} \to \mathrm{t\bar{t}}$ and $\mathrm{g\bar{g}} \to \mathrm{t\bar{t}}$. Top quarks can also be produced singly via the electroweak vertex Wtb with about half the cross section, but with final states difficult to extract from background. The ratio of top quark production cross sections at $\sqrt{s} = 1.96$ TeV (Run II) and 1.8 TeV (Run I) is 1.295 ± 0.015, with an expected Run II cross-section of $6.7^{+0.7}_{-0.9}$ pb with 85 % (15 %) contribution from $\mathrm{q\bar{q}} \to \mathrm{t\bar{t}}$ ($\mathrm{g\bar{g}} \to \mathrm{t\bar{t}}$) [7].

Within the SM the top quark decays almost exclusively into Wb. The $t\bar{t}$ *dilepton* channel ($\mathrm{t\bar{t}} \to \mathrm{WbW\bar{b}} \to \mathrm{\bar{l}\nu_l b l'\bar{\nu}_{l'}\bar{b}}$) has the smallest branching ratio of approximately 5 %. In the *lepton plus jets* channel ($\mathrm{t\bar{t}} \to \mathrm{WbW\bar{b}} \to \mathrm{q\bar{q}'bl\bar{\nu}_l\bar{b}} + \mathrm{\bar{l}\nu_l bq\bar{q}'\bar{b}}$), the branching is ≈ 30 %.

4.1. $\sigma_{t\bar{t}}$ in the Dilepton Channel

For the analysis of the events in the *dilepton* channel, triggers selecting high p_T central electron candidates are used.

Dilepton selection starts with 2 e or μ with $p_T >$ 15 GeV/c for $\mu\mu$, $e\mu$ channels and $p_T > 20$ GeV/c for ee channel. $\not{E}_T > 25$ GeV is required as a signature of the two W decay neutrinos. The $t\bar{t}$ events are discriminated from $Z \to l^+l^-X$ events by demanding $\not{E}_T > 40$ GeV for events with the dilepton invariant mass, M_{ee} or $M_{\mu\mu}$, in the interval $70 - 110$ GeV/c^2. In addition, the $e\mu$ analysis requires the leptons to be separated in $\eta - \varphi$ by more than $\Delta R(e,\mu) > 0.25$.

Two jets with $p_T > 20$ GeV are demanded as expected by the fragmentation of the top decay b quarks. the backgrounds with softer jets originating from QCD radiation are reduced. Finally, to enhance the signal-to-background ratio, $H_T > 100$ GeV is required[2] (see results in Table 1).

The total acceptance is $\varepsilon_{\mathrm{total}} = 0.077 \pm 0.003$ (stat.)$\pm$ 0.022 (sys.).

The $\sigma_{t\bar{t}}$ production cross-section in $\mathrm{p\bar{p}}$ collisions at $\sqrt{s} = 1.96$ TeV has been determined from the number of observed top candidates in a given channel, the estimated background, the integrated luminosity, and the $\mathrm{t\bar{t}}$ acceptance for a top mass of 175 GeV/c^2.

4.2. $\sigma_{t\bar{t}}$ in the Lepton Plus Jets Channel

The DØ topological analysis does not use b-tagging. First, a data sample enriched with W events is preselected by demanding a loose e or μ with $p_T >$ 20 GeV/c, $\not{E}_T > 20$ GeV, and a Soft Muon Tag veto. Then, the QCD background is evaluated from data for each jet multiplicity. In the e-channel, this background is due to π^0 and γ QCD Compton in jets faking electrons and in the μ-channel is due to real muons from heavy flavour decays. The $W+ \geq 4$ jets background is estimated using the Berends scaling law. Finally, the topological cuts are applied to further reduce the background: at least 4 jets, large H_T and $\mathcal{A}$[3] (see results in Table 2).

[2] H_T is the scalar sum of the transverse energy of the leptons and jets in the event.
[3] The aplanarity $\mathcal{A}$ measures the relative activity perpendicular to the plane of maximum activity.

The analysis of the *lepton plus jets* channels with Soft Muon Tag uses exactly the same preselections as the topological ones, except that the veto on soft muons is removed, the topological requirements on H_T and $\mathcal{A}$ are milder, and at least 3 high p_T jets are required. Soft muon tagging is applied to the selected events. A jet is tagged if a muon with $p_T > 4$ GeV/c is found within $\Delta R(\text{jet}, \mu) < 0.5$ of the jet axis (see results in Table 3).

4.3. Combined $\sigma_{t\bar{t}}$ in Three Dilepton Channels and Four Lepton Plus Jets Channels

The $t\bar{t}$ production cross section at the new Tevtron center-of-mass energy of 1.96 TeV has been determined from the number of observed candidate events in a given channel, the estimated backround, the integrated luminosity, and the $t\bar{t}$ acceptance for $m_t = 175$ GeV/c^2. To estimate the cross section, we take

$$\sigma = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\mathcal{B}r \times \mathcal{L} \times \varepsilon},$$

where N_{obs}, N_{bkg}, $\mathcal{B}r$, $\mathcal{L}$, and ε are respectively the number of events observed, the number of background events, the branching fraction of each specific channel, and the overall signal efficiency.

The combination of the *dilepton* channel channels yields the cross section

$$\sigma_{p\bar{p}\to t\bar{t}} = 29.9^{+21.0}_{-15.7}\ (\text{stat.})\ ^{+14.1}_{-6.1}\ (\text{sys.})\ \pm 3.0\ (\text{lumi})\ \text{pb},$$

the combination of all *lepton plus jets* channels yields the cross section

$$\sigma_{p\bar{p}\to t\bar{t}} = 5.8^{+4.3}_{-3.4}\ (\text{stat.})\ ^{+4.1}_{-2.6}\ (\text{sys.})\ \pm 0.6\ (\text{lumi})\ \text{pb}.$$

T a b l e 1. Run II DØ results in the $t\bar{t}$ dilepton channel

	$\mathcal{L}$, pb^{-1}	All Bkg.	Expected $t\bar{t}$	N_{obs}
ee	48.2	1.0 ± 0.5	0.25 ± 0.02	4
$\mu\mu$	42	0.6 ± 0.3	0.30 ± 0.04	2
eμ	33	0.07 ± 0.01	0.50 ± 0.01	1

T a b l e 2. Run II DØ results in the $t\bar{t}$ lepton plus jets topologic analysis

	$\mathcal{L}$, pb^{-1}	All Bkg.	Exp. $t\bar{t}$	N_{obs}
e+jets	49.5	2.7 ± 0.6	1.8	4
μ + jets	40	2.7 ± 1.1	2.4	4

T a b l e 3. Run II DØ results in the $t\bar{t}$ lepton plus jets Soft Muon Tag analysis

	$\mathcal{L}$, pb^{-1}	All Bkg.	Exp. $t\bar{t}$	N_{obs}
e+jets	49.5	0.2 ± 0.1	0.5	2
μ + jets	40	0.7 ± 0.4	0.8	0

The total combined cross section is

$$\sigma_{p\bar{p}\to t\bar{t}} = 8.5^{+4.5}_{-3.6}\ (\text{stat.})\ ^{+6.3}_{-3.5}\ (\text{sys.})\ \pm 0.8\ (\text{lumi})\ \text{pb}.$$

Summary

Run II at the Tevatron is starting to deliver the physics quality data. Various analyses have been performed using the latest data. Although the DØ detector has not yet been exploited to its fullest potential, the results discussed in this report have already reached accuracy levels similar to Run I ones.

It is a pleasure to thank all participants in the DØ collaboration for the extraordinary amount of effort that they have made to bring to reality the Spring 2003 measurements reported in these proceedings.

1. *Abbott B. et al.* // Fixed Cone Jet Definitions in DØ and R_{sep}. – FERMILAB-Pub-97/242-E.
2. *Giele W.T., Glover E.W., Kosower D.A.* // Nucl. Phys. – 1993. – **B403**. – P. 633.
3. *Pumplin J. et al.* // JHEP. – 2002. – **0207**. – P. 012.
4. *Martin A.D. et al.* // Europ. Phys. J. – 2002. – **C23**. – P. 73.
5. *Sjøstrand T. et al.* // Comput. Phys. Communs. – 2001. – **135**. – P. 238.
6. *CLEO Collaboration*, http: // www.lns.cornell.edu/public/CLEO/soft/QQ.
7. *Cacciari C.M. et al.* // The $t\bar{t}$ Cross-section at 1.8 and 1.96 TeV: a Study of the Systematics due to Parton Densities and Scale Dependence. – CERN-TH-2003-054.
8. *Filthaut F. (for the DØ Collaboration)*, hep-ex/0305062, 2003.

ОСТАННІ РЕЗУЛЬТАТИ DØ-ЕКСПЕРИМЕНТУ
НА ТЕВАТРОНІ

П. Демін (від DØ-колаборації)

Р е з ю м е

В DØ-експерименті на Теватроні використовувалися $p\bar{p}$-зіткнення при $\sqrt{s} = 1,96$ ТеВ для вимірювання інклюзивних поперечних перерізів народження одного чи двох струменів. Перерізи народження W- і Z-бозонів вимірювалися за допомогою різноманітних лептонних кінцевих станів. Було зроблено попередні вимірювання часу життя B-адронів. Присутність сигналу від топ кварка в даних з Теватрона була підтверджена вимірюванням поперечного перерізу народження топ-кваркових пар в *дилептонному* каналі, $t\bar{t} \to WbW\bar{b} \to \bar{l}\nu_l b l'\bar{\nu}_{l'}\bar{b}$ і в каналі, де народжується *лептон і струмені*, $t\bar{t} \to WbW\bar{b} \to q\bar{q}' b l \bar{\nu}_l \bar{b} + \bar{l}\nu_l b q\bar{q}'\bar{b}$.

ПОСЛЕДНИЕ РЕЗУЛЬТАТЫ DØ-ЭКСПЕРИМЕНТА НА ТЭВАТРОНЕ

П. Демин (от DØ-коллаборации)

Р е з ю м е

В DØ-эксперименте на Тэватроне использовались $p\bar{p}$ соударения при $\sqrt{s} = 1,96$ ТэВ для измерения инклюзивных поперечных сечений рождения одной и двух струй. Сечения рождения W- и Z-бозонов были измерены с помощью различных лептонных конечных состояний. Были сделаны предварительные измерения времени жизни B-адронов. Присутствие сигнала от топ кварка в данных с Тэватрона было подтверждено измерением поперечного сечения рождения топ-кварковых пар в *дилептонном* канале, $\mathrm{t\bar{t} \to WbW\bar{b} \to \bar{l}\nu_l b l' \bar{\nu}_{l'} \bar{b}}$ и в канале, где рождается *лептон и струи* , $\mathrm{t\bar{t} \to WbW\bar{b} \to q\bar{q}' b l \bar{\nu}_l \bar{b} + \bar{l}\nu_l b q \bar{q}' \bar{b}}$.