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CDF AND DØ TOP QUARK CROSS SECTION MEASUREMENTS

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Preliminary results of $t\bar{t}$ cross section measurements and single top exclusion limits of the Tevatron experiments CDF and DØ are presented. The different measurements are based on a dataset between 140 and 200 pb^{-1} corresponding to a data taking period from spring 2002 to September 2003. The $t\bar{t}$ cross section measurements are consistent with each other and the Standard Model prediction. Data and Monte-Carlo prediction are in good agreement in the search for single top quark. Its observation is anticipated with roughly 2 fb^{-1} integrated luminosity.

1 Introduction

The top quark is the heaviest elementary particle discovered yet. It completes the third generation of quarks as the weak isospin partner of the bottom quark and has been discovered by the CDF[1] and DØ[2] experiments at the Tevatron $p\bar{p}$ collider during RunI in 1995. Top quarks are primarily produced in quark antiquark pairs at the Tevatron. Within the Standard Model the top quark decays almost exclusively into a W boson and a bottom quark. Conclusively the signature of $t\bar{t}$ production is determined by the decay of the W boson, either leptonically or hadronically. Decay products of τ leptons arising from a W boson are not distinguished from direct W boson decay particles of same flavour at this stage of the measurements.

2 Tevatron Collider

In comparison to RunI, in which proton antiproton collisions have been taken place at the Tevatron collider at a center of mass energy of $\sqrt{s} = 1.8\,\mathrm{TeV}$, in RunII the center of mass energy has been elevated to $\sqrt{s} = 1.96\,\mathrm{TeV}$, giving rise to a 30% increase in the $t\bar{t}$ cross section. The bunch spacing has been reduced from 3500 ns to 396 ns. Major upgrades to the Linac and main injector made it possible to achieve the RunIIa goal of $100 \cdot 10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ instantaneous luminosity. Future improvements are anticipated by a new antiproton recycler and electron cooling.

3 Detector upgrades

The CDF and DØ detectors have been massively upgraded. Driven by physics goals they became very similar. Beside a replaced silicon tracker and central drift chamber the geometric acceptance of the CDF detector has been increased by new forward calorimeters and extended muon coverage. A new silicon tracker, new preshower detectors and a 2 T superconducting solenoid have been added to the DØ detector. Its muon coverage has been extended as well. The data acquisition and trigger systems have been upgraded for both detectors to cope with the shorter bunch spacing compared to RunI.

4 Data samples

The RunII physics data taking started in 2002 (February for CDF and July for DØ). The reported top quark cross section results are based on data taken until September 2003 and vary depending on the analysis channel between 140 and 200 pb^{-1}. This has to be compared to about 110 pb^{-1} accumulated in RunI. Over 400 pb^{-1} of data are already recorded in RunII. Analysis of subsequent data is in progress.

5 Top quark antiquark pair production cross section measurements

The Standard Model prediction for the $t\bar{t}$ production cross section at Tevatron in RunII with a center of mass energy of 1.96 TeV and a given top quark mass of $m_t = 175\,\text{GeV}$ amounts in Next-to-Leading order calculation[3 4] to

$$\sigma_{\text{NLO}}(t\bar{t}) = 6.7^{+0.7}_{-0.9}\,\text{pb}$$

taking into account uncertainties in the proton probability density functions.

5.1 Dilepton channel

The dilepton channel can be characterized by a small branching ratio and relatively few Standard Model backgrounds which are Drell-Yan (in case of like-flavoured leptons) and diboson production, missing transverse energy and isolated lepton fakes. As selection criteria at least two high transverse momentum jets, large missing energy to account for the neutrinos and two oppositely charged leptons are required. CDF requires optionally the second lepton to be very loose, even just an isolated high transverse momentum track. The cross sections derived by CDF with an integrated luminosity of about $200\,\text{pb}^{-1}$ and DØ with $140\,\text{pb}^{-1}$ are

$$\sigma_{\text{CDF}} = 7.0^{+2.4}_{-2.1}(\text{stat})^{+1.6}_{-1.1}(\text{sys}) \pm 0.4(\text{lum})\,\text{pb}$$
$$\sigma_{\text{D}\emptyset} = 14.3^{+5.1}_{-4.3}(\text{stat})^{+2.6}_{-1.9}(\text{sys}) \pm 0.9(\text{lum})\,\text{pb}.$$

CDF pursues also an alternative approach to counting experiments. Merely two leptons are required and significant missing transverse energy in case of like-flavoured leptons. Data are fitted with $t\bar{t}$, WW and $Z \to \tau\tau$ templates in a two dimensional phase space of missing transverse energy and number of jets. The $t\bar{t}$ signal and WW diboson background cross sections are determined with about $200\,\text{pb}^{-1}$ to be

$$\sigma_{\text{CDF}}(t\bar{t}) = 8.6^{+2.5}_{-2.4}(\text{stat}) \pm 1.1(\text{sys})\,\text{pb}$$
$$\sigma_{\text{CDF}}(WW) = 12.6^{+3.2}_{-3.0}(\text{stat}) \pm 1.2(\text{sys})\,\text{pb}$$

(luminosity uncertainties are omitted here and from now on where negligible).

In the $e\mu$-channel of the $t\bar{t}$ production DØ exploits the powerful background rejection of a secondary vertex tagger (SVT) requiring at least one b-tagged jet after preselection cuts. A fit to the jet multiplicity distribution yields

$$\sigma_{\text{D}\emptyset} = 11.1^{+5.8}_{-4.3}(\text{stat}) \pm 1.4(\text{sys}) \pm 0.7(\text{lum})\,\text{pb}$$

with an integrated luminosity of about $160\,\text{pb}^{-1}$.

5.2 Lepton plus jets channel

The lepton plus jets channel can be distinguished by a large branching ratio, W boson plus jets background and multijet background with one jet faking a lepton and missing transverse energy arising from mismeasured jet energies. Preselection cuts are demanding one charged high transverse momentum lepton, multiple high transverse momentum jets and large missing transverse energy.

In the topological analyses, variables with maximal significance and minimal jet energy scale dependence - since dominating systematics - are chosen. Variables like the transverse energy of the event H_T are fitted directly. Alternatively they are combined into a likelihood discriminant either by hand (Discr.) or via a neural network (NN). The measured cross sections for the e and μ lepton plus jet channels combined are

$$\sigma^{H_T}_{\text{CDF}} = 6.7 \pm 1.1(\text{stat}) \pm 1.6(\text{sys})\,\text{pb}$$
$$\sigma^{NN}_{\text{CDF}} = 4.7 \pm 1.6(\text{stat}) \pm 1.8(\text{sys})\,\text{pb}$$
$$\sigma^{\text{Discr.}}_{\text{D}\emptyset} = 7.2^{+2.6}_{-2.4}(\text{stat})^{+1.6}_{-1.7}(\text{sys}) \pm 0.5(\text{lum})\,\text{pb}$$

with an integrated luminosity of about $195\,\text{pb}^{-1}$ and $140\,\text{pb}^{-1}$ for the CDF and DØ experiments respectively.

Several CDF analyses in the lepton plus jets channel require at least one jet to be b-tagged either with a secondary vertex or a soft lepton tagger which exploits low momentum leptons within jets. The cross section is obtained by accumulation of the heavy

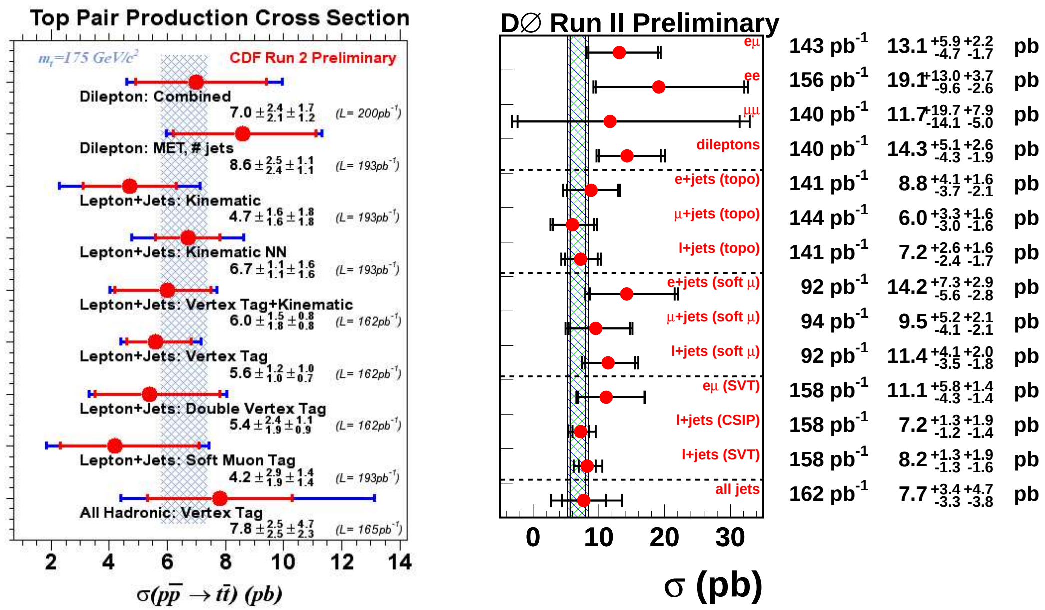

Figure 1. Top quark antiquark pair cross section summary of the CDF and D∅ experiments. For comparison the Standard Model Next-to-Leading order prediction for a top quark mass of $m_t = 175\,\mathrm{GeV}$ including uncertainties on the top quark mass (CDF + D∅) and proton probability density functions (D∅) is superposed.

flavour fraction (HF) and data normalization to the jet multiplicity distribution. Another way to obtain the cross section is to apply a kinematic fit to the shape of the leading jet transverse energy ($E_{\perp\max}^{\mathrm{jet}}$) distribution. Both cross section measurements take advantage of about $160\,\mathrm{pb}^{-1}$ integrated luminosity. In contrast to the first two methods which make use of a secondary vertex tagger a soft lepton tagger (SLT) can be applied. Here the measurement has been accomplished by a counting experiment in the muon plus jets channel with an integrated luminosity of about $195\,\mathrm{pb}^{-1}$. The measured cross sections are given by

$$\sigma_{\mathrm{CDF}}^{SVT,HF} = 5.6^{+1.2}_{-1.0}(\mathrm{stat})^{+1.0}_{-0.7}(\mathrm{sys})\,\mathrm{pb}$$
$$\sigma_{\mathrm{CDF}}^{SVT,E_{\perp\max}^{\mathrm{jet}}} = 6.0^{+1.5}_{-1.8}(\mathrm{stat}) \pm 0.8(\mathrm{sys})\,\mathrm{pb}$$
$$\sigma_{\mathrm{CDF}}^{SLT,\ell=\mu} = 4.2^{+2.9}_{-1.9}(\mathrm{stat}) \pm 1.4(\mathrm{sys})\,\mathrm{pb}.$$

Yet another variation pursued by CDF is to require two jets to be b-tagged with the secondary vertex tagger. This analysis has been subdivided into a standard ($\epsilon_b^{\max} \simeq 0.4$) and a higher efficiency b-tagging version ($\epsilon_b^{\max} \simeq 0.5$) whose primary purpose is not the cross section measurement but to reduce combinatorics in future top quark mass measurements. The cross section of both variants has been determined to be

$$\sigma_{\mathrm{CDF}}^{SVT,\mathrm{Standard}} = 5.4^{+2.4}_{-1.9}(\mathrm{stat})^{+1.1}_{-0.9}(\mathrm{sys})\,\mathrm{pb}$$
$$\sigma_{\mathrm{CDF}}^{SVT,\mathrm{High\ eff.}} = 8.2^{+2.4}_{-2.1}(\mathrm{stat})^{+1.8}_{-1.0}(\mathrm{sys})\,\mathrm{pb}\,.$$

5.3 All hadronic channel

The largest branching fraction accompanied by the largest background is inherent to the all hadronic channel. To reduce the multijet background which exceeds the signal by three orders of magnitude topological cuts and b-tagging has to be applied (here SVT single tagged events have been required). In addition vetos against isolated leptons and poorly reconstructed primary vertices help to enhance the significance. While CDF applies cuts onto topological variables in one or two dimensions to count the excess of sin-

Cross sections	s-channel	t-channel	$s+t$-channel	$\mathcal{L}$
SM prediction (NLO)	$\sigma = 0.88\,\text{pb}$	$\sigma = 1.98\,\text{pb}$	$\sigma = 2.86\,\text{pb}$	—
CDF (@ 95% C.L.)	$\sigma < 13.6\,\text{pb}$	$\sigma < 10.1\,\text{pb}$	$\sigma < 17.8\,\text{pb}$	$160\,\text{pb}^{-1}$
DØ (@ 95% C.L.)	$\sigma < 19\,\text{pb}$	$\sigma < 25\,\text{pb}$	$\sigma < 23\,\text{pb}$	$156 - 169\,\text{pb}^{-1}$

Table 1. Single top quark cross section predictions for a top quark mass of $m_t = 175\,\text{GeV}$ and measurement limits of the CDF and DØ experiments at the 95% confidence limit.

gle tagged events in the $6 < N_{\text{jets}} < 8$ signal region of the jet multiplicity distribution DØ applies a cascade of three neural networks onto topological variables to enhance the significance by cutting on a final discriminant before counting event excess. The cross section measurements yield

$$\sigma_{\text{CDF}} = 7.8^{+2.5}_{-1.0}(\text{stat})^{+4.7}_{-2.3}(\text{sys})\,\text{pb}$$
$$\sigma_{\text{DØ}} = 7.7^{+3.4}_{-3.3}(\text{stat})^{+4.7}_{-3.8}(\text{sys}) \pm 0.5(\text{lum})\,\text{pb}$$

for an integrated luminosity of about $165\,\text{pb}^{-1}$ for CDF and about $160\,\text{pb}^{-1}$ for DØ.

The summary of all CDF and DØ $t\bar{t}$ cross section measurements is given in fig. 1.

6 Single top quark search

The Standard Model prediction for single top quark production at Tevatron in RunII with a center of mass energy of 1.96 TeV and a given top quark mass of $m_t = 175\,\text{GeV}$ amounts in Next-to-Leading order calculation for the t-channel[5] [6] and s-channel[7] respectively to

$$\sigma^t_{\text{NLO}} = 1.98 \pm 0.21\,\text{pb}$$
$$\sigma^s_{\text{NLO}} = 0.88 \pm 0.07\,\text{pb}\ .$$

Single top quarks are produced by electroweak interactions. s-channel cross section measurements can be exploited to obtain limits on the magnitude of the CKM matrix element V_{tb}.

Single top quark events are selected in requiring one isolated high transverse momentum lepton, large missing transverse energy and two high transverse momentum jets of which at least one has to be b-tagged. W-boson plus jets and misidentified $t\bar{t}$ events constitute the dominating background. Data and Monte-Carlo predictions are in good agreement. Cross section limits at the 95% confidence level for the s, t and $s+t$-channels combined are given in table 1. Observation of single top quark production is expected with an integrated luminosity of about $2\,\text{fb}^{-1}$.

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