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Top Quark Physics at the Tevatron

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Introduction

After the successful Run I of the Tevatron (1992-1996),with the *top* quark discovery, both CDF and DØ experiments were extensively upgraded to meet the challenges of the Tevatron Run II collider. The energy of $p\bar{p}$ collisions at the Tevatron was increased from $\sqrt{s} = 1.8$ TeV to $\sqrt{s} = 1.96$ TeV. $t\bar{t}$ production cross section is expected to increase by a factor of $\sim 30\%$. Major upgrades in the Tevatron accelerator chain will increase the Run II instantaneous luminosity: the goal is to achieve $\mathcal{L} = 5 - 20 \times 10^{31}\mathrm{cm}^2\mathrm{s}^{-1}$ while the highest luminosity reached up to now (September 2003) is $5.2 \times 10^{31}\mathrm{cm}^2\mathrm{s}^{-1}$.

In this paper we will present the *top* quark properties measured by both CDF and DØ with the first *physics-quality* data collected during the Run II (March 2002-January 2003). First we will review $t\bar{t}$ cross section measurements in the various decay channels; then top quark mass measurements will be presented.

1 Top Cross Section

At the Tevatron, top quarks are mainly produced in quark-antiquark pairs. 80% of the $t\bar{t}$ production cross section is due to quark-antiquark annihilation ($q\bar{q} \to t\bar{t}$) while the remaining contribution comes from gluon-gluon fusion.

In SM, top quarks decay before hadronization in a real W and a b-quark[1]; subsequently W boson decays in letptonic (charged letpon and a neutrino) or hadronic mode (two quarks). If both W decay in leptonic mode, $t\bar{t}$ are classified as *dilepton*[2] events (BR = 4/81). If one W decays in leptons while the other decays in quarks, $t\bar{t}$ events are classified as *lepton+jets* events (BR=24/81). If both W decay hadronically the final $t\bar{t}$ state is called *all-hadronic* (BR=36/81). In Run I both CDF and DØ experiments have identified $t\bar{t}$ decays in those final states. The combined cross sections for all the channels is $6.5^{+1.7}_{-1.4}$ pb for CDF and 5.9 ± 1.6pb for DØ .

1.1 *Dilepton Channel*

Although the *dilepton* decay mode has the smallest branching ratio it is also the cleanest channel giving a clean signature with small background contamination. The main backgrounds are in decreasing order of magnitude: Drell-Yan ($Z\gamma^\star \to e^+e^-, \mu^+\mu^-$), $Z \to \tau\tau$, diboson production (WW, WZ) and processes with a real lepton and a jet faking the additional letpon. At CDF the event selection is performed requiring two well isolated, oppositely charged high P_T letpons ($P_T > 20$ GeV/c)[1], a large missing transverse energy ($\not{E}_T > 25$ GeV) taking in account the undetected neutrinos, at least two jets with $E_T > 10$ GeV and a large total transverse energy of the event ($H_T > 200$ GeV[3]). Z boson, cosmics and conversions are removed. In 72 pb^{-1} CDF finds 5 candidate events shown in Fig.1(Left) (1 ee, 3 $e\mu$ and 1 $\mu\mu$ candidates) while the expected number of signal events[4] is 2.5 ± 0.3 events. Contamination from background is estimated to be 0.30 ± 0.12 events. The measured cross section for the CDF *dilepton* channel is $\sigma_{t\bar{t}} = 13.2 \pm 5.9(\text{stat.}) \pm 1.5(\text{syst.}) \pm 0.8(\text{lum.})$pb. Also at DØ the *dilepton* final state has been analyzed. The measured cross section is $\sigma_{t\bar{t}} = 29.9^{+21.0}_{-15.7}(\text{stat.})^{+14.1}_{-6.1}(\text{syst.}) \pm 3.0(\text{lum.})$pb.

1.2 Lepton+Jet Channel

The selection starts requiring a W boson decaying leptonically and associated jets. Background in this channel is larger than in the *dilepton* channel,

[1] A $BR \simeq 100\%$ is assumed in this paper for the $t \to W^+b$ decay.

[2] Since τ are more difficult to identify than electrons or muons they will not contribute for the moment to the *dilepton* and *lepton+jet* classes of $t\bar{t}$ decays.

[3] H_T is the scalar sum of transverse energies of jets, leptons and missing transverse energy.

[4] Using the theoretical $t\bar{t}$ production cross section $\sigma_{t\bar{t}}(\sqrt{s} = 1.96\text{TeV}) = 6.70^{+0.71}_{-0.88}$ pb[2]

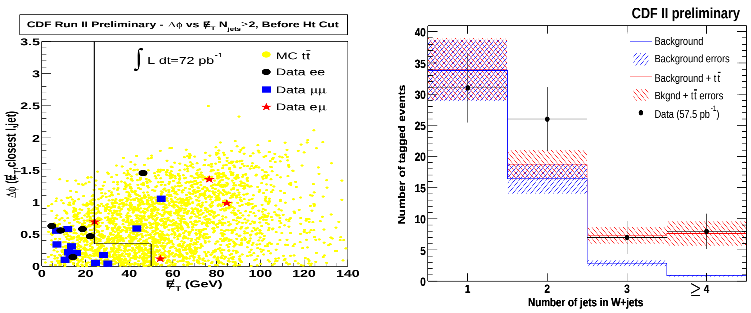

Figure 1: Left: $\Delta\phi_{lep,E_T}$ vs $\not{E}_T$ distribution of the CDF dilepton data events (symbols) overlapped with the distribution from $t\bar{t}$ MC dilepton events (yellow dots). Right: Jet multiplicity in the *lepton+jet* sample measured by CDF. Background and expected signa events and data are shown.

	Backgrounds			Signal	Obs.	$\int \mathcal{L}dt$
	W+jet	Non-W	Total			
e+jets	1.3 ± 0.5	1.4 ± 0.4	2.7 ± 0.6	1.8	4	49.5
μ+jets	2.1 ± 0.9	0.6 ± 0.4	2.7 ± 1.1	2.4	4	40

Table 1: DØ results in the $t\bar{t}$ *lepton+jet* topological analysis.

therefore different strategies have been used to increase the signal to background ratio.

CDF events are selected requiring a high-momentum ($P_T > 20\text{GeV}/c$) central($|\eta| < 1$) and isolated lepton with a large transverse missing energy ($\not{E}_T > 20\text{GeV}$), three or more jets with $E_T > 15GeV$. Z bosons, cosmics and conversions have been removed. Signal to background ratio is increased requiring that at least one jet comes from a b-quark since b-hadrons have a relatively long lifetime. A jet is b-*tagged* if it contains a secondary vertex displaced in the transverse plane from the primary vertex of the interaction. 15 events have been observed in for $\int \mathcal{L}dt = 57.5\text{pb}^{-1}$. Backgrounds from Wbb, Wcc, mistags, Wc and *non-*W are evaluated to be $3.8 \pm 0,5$ events. In Fig.1(Right) the jet multiplicity spectrum is shown. The measured cross section for CDF *lepton+jets* is: $\sigma_{t\bar{t}} = 5.3 \pm 1.9(\text{stat.}) \pm 0.8(\text{syst.}) \pm 0.3(\text{lum.})$ pb.

At DØ , no secondary vertex b-tagging is applied for the moment. Some topological cuts were applied to increase the signal to background ratio. Dominant backgrounds are from *non-*W and *W+jet* processes. Results are shown in Tab.1.2.

Starting from the W enriched sample defined previousely DØ uses an alternative approach to increase the signal to background ratio. The strategy is to require a soft muon in the jet cone indicating a semileptonic b-hadron decay. Two (zero) events were tagged in the $e + jet$ ($\mu + jet$) channel. The total expected background is $0.2 \pm 0.1(0.7 \pm 0.4)$ events. The combined $t\bar{t}$ cross section measured at DØ using both strategies is:

$$\sigma_{t\bar{t}} = 5.8^{+4.3}_{-3.4}(\mathrm{stat.})^{+4.1}_{-2.6}(\mathrm{syst.}) \pm 0.6(\mathrm{lum.})\mathrm{pb}.$$

Combining the dilepton channel with the lepton+jet channel DØ measures a $t\bar{t}$ production cross section of:

$$\sigma_{t\bar{t},DØ} = 8.4^{+4.5}_{-3.7}(\mathrm{stat.})^{+5.3}_{-3.5}(\mathrm{syst.}) \pm 0.8(\mathrm{lum.})\mathrm{pb}.$$

2 Top Mass

The top quark mass is a fundamental parameter in the Standard Model. Through radiative contribution of Higgs boson to W boson and top quark masses it is possibile to give stringent constraints on the Standard Model Higgs boson mass.

The first Run II top quark mass measurement has been performed by the CDF experiment with events selected in the *lepton+jet* channel. The data sample integrated luminosity amounts to $\int \mathcal{L}dt = 72\mathrm{pb}^{-1}$. The differences in selection criteria with respect to the ones described in the *lepton+jet* CDF analysis is that no jet *b-tagging* is required and only events with at least four jets ($E_T > 8GeV$) are considered.

A constraint fitting technique is applied to reconstruct the mass of the top quark. Since no *b-jet* information is used, each event has 12 possibile combinations of assigning jet energies to the quarks in the $t\bar{t}$ lepton+jet final state (Fig.2, Left). The reconstructed mass distribution, shown in Fig.2(Right), is then compared to signal (MC generated with different M_{top}) and background templates. The measured top quark is:

$$M_t = 171.2 \pm 13.4(\mathrm{stat.}) \pm 9.9(\mathrm{syst.})\mathrm{GeV}/c^2.$$

The largest systematic uncertainty[5] for the Run II measurement is due to the uncertainty on the jet energy scales. CDF aims to reduce this latter to $\sim 2\mathrm{GeV}/c^2$.

[5]The second largest systematics comes from uncertainties from Initial and Final State Radiation(2.4 GeV/c^2).

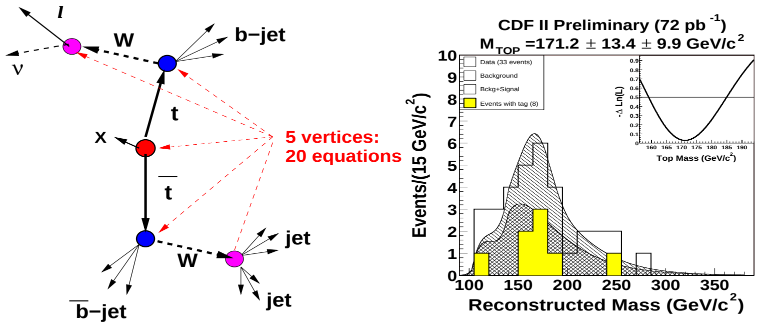

Figure 2: Left: Schematic view of a $t\bar{t}$ decay in the *lepton+jet* channel. Right: Reconstructed top mass using 33 data events. Yellow histogram show events where at least one jet has been b-tagged. Signal ($M_{top} = 175\text{GeV}/c^2$) and background templates for the two component fits are shown. The inset shows $-\Delta \ln L$ of Two-Component fit from where the top quark measurement is extracted.

Predicted uncertainties for W boson mass Run II measurement are $\simeq 25$ MeV/c^2. Combining it with the direct top quark mass measurement it is therefore possibile to give stringent contraints on the Standard Model Higgs boson mass.

Conclusions

Top quarks has been identified in Run II data at Tevatron in the *dilepton* and *lepton+jet* channels by both CDF and DØ experiments. The measured $t\bar{t}$ production cross sections are compatible with theoretical predictions. The measured top quark mass is also compatibile with Run I results. The samples analyzed here are approximately half of the ones collected in the whole Run I of both experiments at the Tevatron. Larger datasets doubling the whole Run I integrated luminosity for each experiment are now at hand and are analyzed. In the near future they will allow physics measurement in the top quark sector well below Run I measurements.

References

[1] MANCA G., *these proceedings.*

[2] CACCIARI M. *et al.*, CERN-TH-2003-054, hep-ph/0303085 Preprint, 2003.