Combined $t\bar{t}$ Production Cross Section in the Lepton+Track and Dilepton Final States using 1 fb^{-1} of data

DØ Collaboration
(Dated: September 24, 2007)

Measurements of the $t\bar{t}$ production cross-section at $\sqrt{s} = 1.96$ TeV in the channels with two fully identified leptons and one identified lepton and one isolated track have recently become available. In this note we present a combination of these measurements. The combined cross section in lepton+track and dilepton channel at the top quark mass of 175 GeV is found to be:

$$\text{combined} \quad : \quad \sigma_{t\bar{t}} = 6.2^{+0.9}_{-0.9} \text{ (stat) } {}^{+0.8}_{-0.7} \text{ (syst) } \pm 0.4 \text{ (lumi) pb.}$$

D0 Result for Conferences 2007

I. INTRODUCTION

The measurements of the $t\bar{t}$ production cross section at $\sqrt{s} = 1.96$ TeV with 1 fb^{-1} of data using events with two identified leptons, ee, $e\mu$ or $\mu\mu$, are described in Ref. [1]. The measurement of the $t\bar{t}$ production cross section utilizing approximately 1 fb^{-1} of collider data and selecting events with one identified lepton and an isolated track ("lepton+track" channel) is summarized in Ref. [2]. In this note we present combinations of the cross sections measured in individual channels.

II. METHOD

A. Dilepton channels

To estimate cross section σ_j in an individual dilepton or lepton+track channel j the following likelihood function is defined:

$$\mathrm{L}(\sigma_j, \{N_j^{obs}, N_j^{bkg}, BR_j, \mathcal{L}_j, \varepsilon_j\}) = \mathcal{P}(N_j^{obs}, \mu_j) = \frac{\mu_j^{N_j^{obs}}}{N_j^{obs}!} e^{-\mu_j}, \tag{1}$$

where $\mathcal{P}(N_j^{obs}, \mu_j)$ is the Poisson probability of expected μ_j signal-plus-background events:

$$\mu_j = \sigma_j \, BR_j \, \mathcal{L}_j \, \varepsilon_j + N_j^{bkg} \tag{2}$$

to be compatible with the number of observed events N_j^{obs} given the luminosity $\mathcal{L}_j$, branching fraction BR_j, efficiency ϵ_j and expected number of background events N_j^{bkg}. The cross section in individual channel is extracted by minimizing the negative log-likelihood function, $-\log \mathrm{L}(\sigma_j, \{\mathrm{N}_j^{obs}, \mathrm{N}_j^{bkg}, \mathrm{BR}_j, \mathcal{L}_j, \varepsilon_j\})$, while the combined cross section from n channels is estimated by minimizing the sum of the negative log-likelihood functions for each individual channel:

$$-\log \mathrm{L}(\sigma, \{N_j^{obs}, N_j^{bkg}, BR_j, \mathcal{L}_j, \epsilon_j\}_{j=1...n}) \approx \sum_{j=1}^{n}(-N_j^{obs} \log \mu_j + \mu_j) \tag{3}$$

where on the right hand side any terms independent of σ have been dropped.

The number of observed events, the estimated background, the $t\bar{t}$ selection efficiency, the decay branching fraction for the $t\bar{t}$ final state where leptons are allowed to originate either directly from a W or from $W \to \tau\nu$ decay, and the integrated luminosity for each of the dilepton channels are summarized in Table 1.

channel	Observed	N^{bkg}	BR	$\mathcal{L}$ (pb^{-1})	ε
ee	16	3.0	0.01584	1036	8.3 %
$e\mu$ nj=1	16	10.2	0.03155	1046	3.1%
$e\mu$ nj$\geq$2	32	6.7	0.03155	1046	12.4%
$\mu\mu$	9	3.6	0.01571	1046	5.1%

TABLE 1: Number of observed events, estimated background, decay branching ratio, integrated luminosity and $t\bar{t}$ selection efficiency, for each dilepton channel.

Similar information for the lepton+track channels is summarized in Table 2.

The preliminary $t\bar{t}$ production cross sections at $\sqrt{s} = 1.96$ TeV in dilepton channels for the top quark mass of 175 GeV are measured to be:

$$ee : \quad \sigma_{t\bar{t}} = 9.6^{+3.2}_{-2.7} \, (\text{stat}) \, ^{+1.9}_{-1.6} \, (\text{syst}) \, \pm 0.6 \, (\text{lumi}) \, \text{pb};$$

$$e\mu : \quad \sigma_{t\bar{t}} = 6.1^{+1.4}_{-1.2} \, (\text{stat}) \, ^{+0.8}_{-0.7} \, (\text{syst}) \, \pm 0.4 \, (\text{lumi}) \, \text{pb};$$

$$\mu\mu : \quad \sigma_{t\bar{t}} = 6.5^{+4.0}_{-3.2} \, (\text{stat}) \, ^{+1.1}_{-0.9} \, (\text{syst}) \, \pm 0.4 \, (\text{lumi}) \, \text{pb};$$

$$\text{dilepton} : \quad \sigma_{t\bar{t}} = 6.8^{+1.2}_{-1.1} \, (\text{stat}) \, ^{+0.9}_{-0.8} \, (\text{syst}) \, \pm 0.4 \, (\text{lumi}) \, \text{pb}.$$

channel	Observed	N^{bkg}	BR	$\mathcal{L}$ (pb^{-1})	ε
e+track, nj=1	4	1.58	0.1066	1035	0.25%
e+track, nj$\geq$2	8	1.83	0.1066	1035	1.31%
μ+track, nj=1	1	1.38	0.1066	994	0.18%
μ+track, nj$\geq$2	8	1.36	0.1066	994	1.08%

TABLE 2: Number of observed events, estimated background, decay branching ratio, integrated luminosity and $t\bar{t}$ selection efficiency for each ℓ+track channel.

The cross sections measurement in lepton+track channels yields:

$$e + \text{track} : \quad \sigma_{t\bar{t}} = 4.7^{+2.2}_{-1.8} \text{ (stat) } ^{+0.9}_{-0.8} \text{ (syst) } \pm 0.3 \text{ (lumi) pb;}$$

$$\mu + \text{track} : \quad \sigma_{t\bar{t}} = 5.3^{+2.5}_{-2.0} \text{ (stat) } ^{+1.2}_{-1.0} \text{ (syst) } \pm 0.3 \text{ (lumi) pb;}$$

$$\ell + \text{track} : \quad \sigma_{t\bar{t}} = 5.0^{+1.6}_{-1.4} \text{ (stat) } ^{+0.9}_{-0.8} \text{ (syst) } \pm 0.3 \text{ (lumi) pb.}$$

B. Dilepton and lepton+track channel combination

The data sample used in the lepton+track analysis is selected to be orthogonal to that of dilepton sample. Since the samples are statistically independent the combined cross section is obtained by minimizing the sum of the negative log-likelihood functions of eight individual channels: ee, $e\mu$ with one and at least two jets, $\mu\mu$, e+track and μ+track with exactly one and two or more jets. The statistical uncertainty on the combined cross section is obtained by the usual procedure of varying the negative log-likelihood by half unit above the minimum.

The systematic uncertainty on the combined cross section is obtained for each independent source of systematic, by varying the source by one standard deviation up and down and propagating the variation into both background estimates and signal efficiencies. A new likelihood function is derived for each such variation to give a new optimal cross section. These variations in the central value of the cross section are then summed quadratically to obtain the total systematic uncertainty. By construction, this method of the cross section computation does not allow the systematic errors to influence the result of the fit. The systematic uncertainties have been classified as uncorrelated (usually of statistical origin in either Monte Carlo or data) and correlated. Variations due to error sources which contribute to the error on the selection efficiency and on the background, are treated as fully correlated.

Combined cross section at $\sqrt{s} = 1.96$ TeV in dilepton and lepton+track channels for the top quark mass of 175 GeV is measured to be:

$$\text{combined} : \quad \sigma_{t\bar{t}} = 6.2^{+0.9}_{-0.9} \text{ (stat) } ^{+0.8}_{-0.7} \text{ (syst) } \pm 0.4 \text{ (lumi) pb,}$$

in a good agreement with the standard model prediction [3].

Figure 1 shows the distributions of basic kinematic variables in the selected signal data sample compared to the predicted backgrounds and $t\bar{t}$ signal normalized to the measured combined cross section. Figure 2 shows H_T distributions for dilepton and lepton+track channels separately normalized to the corresponding measured cross sections.

Table 3 summarizes the contributions from the different sources of systematic uncertainties to the total systematic uncertainty on the cross sections in the dilepton (ee, $e\mu$, $\mu\mu$) and lepton+track channels as well as the breakdown of uncertainties for the combination.

The dependence of the combined cross section in the region of the top quark masses between 165 GeV to 180 GeV can be parameterized as:

$$\sigma_{t\bar{t}}(m_{top}) = \sigma_{t\bar{t}} - 0.05 \frac{\text{pb}}{\text{GeV}} \times (m_{top} - 175 \text{ GeV}). \tag{4}$$

At the current world average top quark mass of 170.9 GeV this yields the cross section of

$$\text{combined (170.9 GeV)} : \quad \sigma_{t\bar{t}} = 6.4^{+0.9}_{-0.9} \text{ (stat) } ^{+0.8}_{-0.7} \text{ (syst) } \pm 0.4 \text{ (lumi) pb.}$$
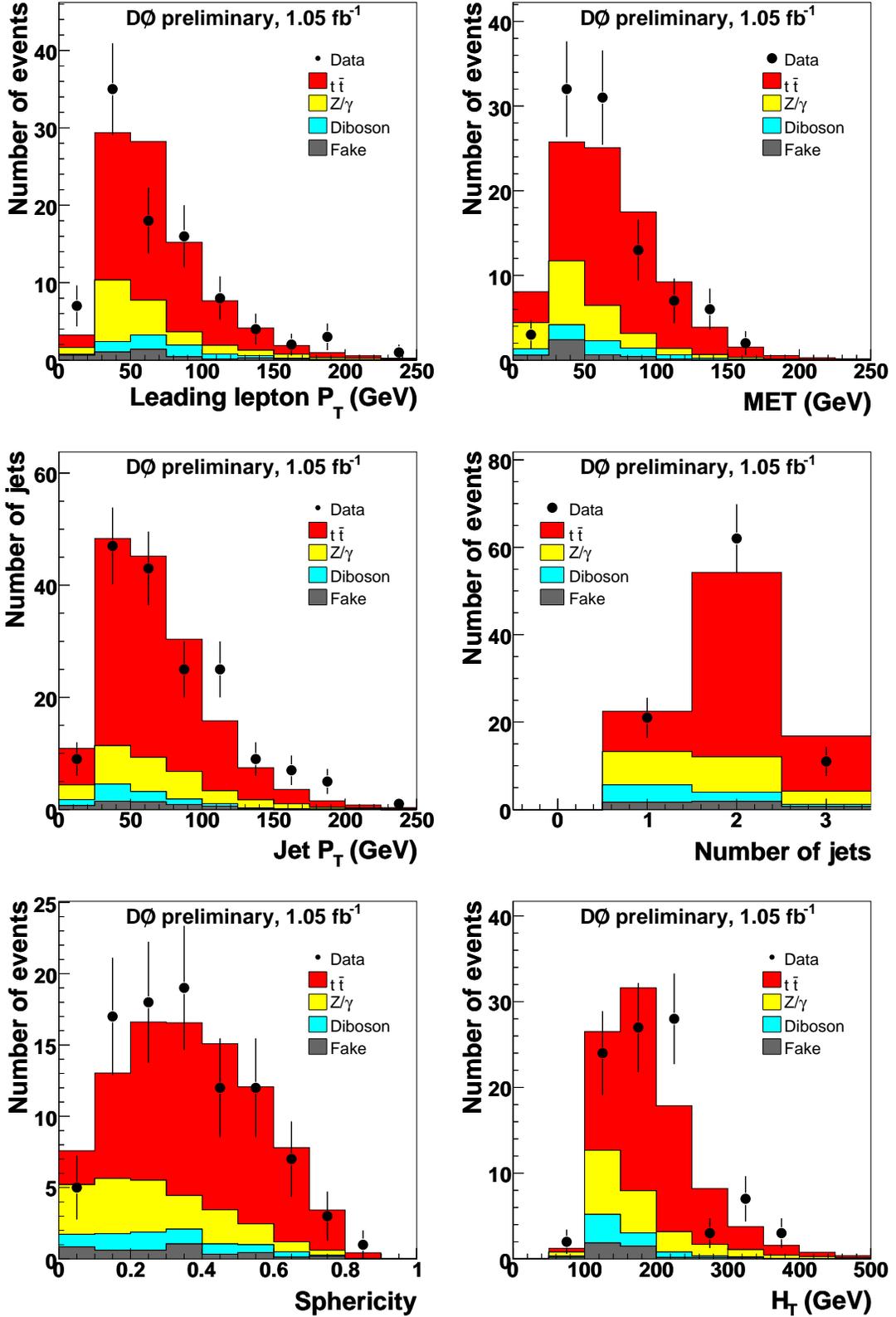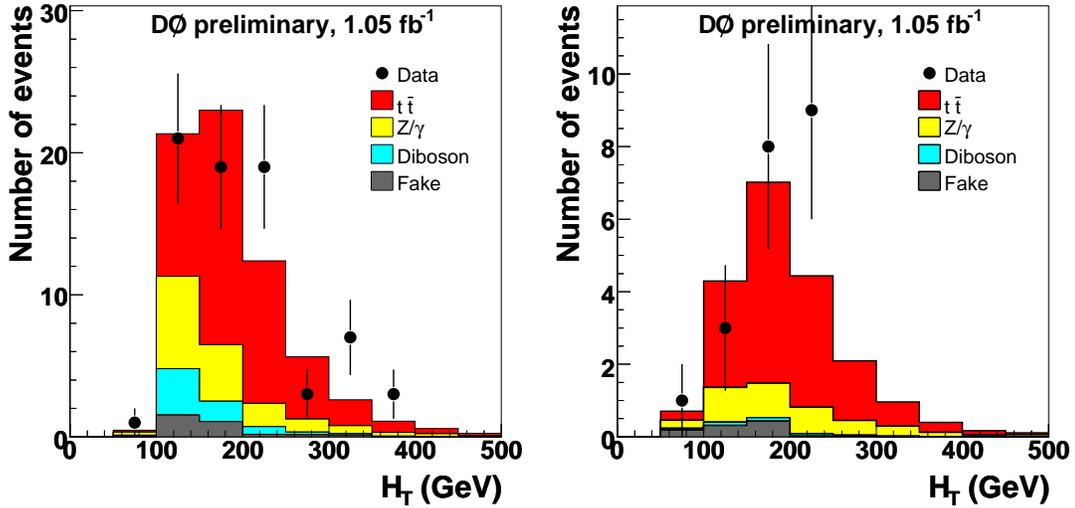
$$\tag{5}$$

FIG. 1: Observed and predicted distributions for various backgrounds and the signal after the final selection cuts for the combination of dilepton and lepton+track channels. From top to bottom and left to right: leading lepton p_T; missing transverse energy (MET or $\not{E}_T$); jet p_T; number of jets (the last bin is inclusive); sphericity; H_T (scalar sum of leading lepton and two jet p_T).

TABLE 3: Summary of systematic uncertainties on $\sigma_{t\bar{t}}$.

Source	$\ell\ell$	ℓ+track	combined
Jet energy calibration	$+\,0.3-0.3$	$+\,0.1-0.1$	$+\,0.3-0.2$
Jet identification	$+\,0.1-0.1$	$+\,0.02-0.03$	$+\,0.04-0.04$
PV identification	$+\,0.3-0.2$	$+\,0.2-0.1$	$+\,0.3-0.2$
Muon identification	$+\,0.2-0.2$	$+\,0.06-0.05$	$+\,0.2-0.1$
Electron identification	$+\,0.6-0.5$	$+\,0.2-0.2$	$+\,0.4-0.4$
Track identification	N/A	$+\,0.7-0.6$	$+\,0.3-0.3$
Trigger	$+\,0.2-0.2$	$+\,0.3-0.2$	$+\,0.2-0.2$
Fakes	$+\,0.2-0.2$	$+\,0.3-0.2$	$+\,0.1-0.1$
b-tagging	N/A	$+\,0.3-0.3$	$+\,0.1-0.1$
MC normalization	$+\,0.3-0.3$	$+\,0.2-0.2$	$+\,0.2-0.2$
Other	$+\,0.2-0.2$	$+\,0.1-0.1$	$+\,0.2-0.2$
Subtotal	$+\,0.9-0.8$	$+\,0.9-0.8$	$+\,0.8-0.7$
Luminosity	±0.4	±0.3	±0.4
Total	$+\,1.0-0.9$	$+\,1.0-0.9$	$+\,0.9-0.8$

FIG. 2: Observed and predicted H_T distributions for various backgrounds and the signal after the final selection cuts in dilepton (left) and lepton+track (right) channels.

[1] D0 Collaboration, *Measurement of the* $t\bar{t}$ *Production Cross-Section at* $\sqrt{s}$ = 1.96 *TeV in Dilepton Final States*, DØ Note 5371-CONF, March 2007.
[2] D0 Collaboration, $t\bar{t}$ *Cross Section in the Lepton+Track Channel with 1* fb^{-1}, DØ Note 5465-CONF, August 2007.
[3] R. Bonciani *et al.*, Nucl. Phys. B **529**, 424 (1998); M. Cacciari *et al.*, JHEP **404**, 68 (2004); N. Kidonakis and R. Vogt, Phys. Rev. D **68**, 114014 (2003); N. Kidonakis, private communication.