



Measurement of $\sigma(p\bar{p} \rightarrow t\bar{t})$ in $\tau + jets$ channel

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This note presents a new measurement of $p\bar{p} \rightarrow t\bar{t}X$ production at $\sqrt{s} = 1.96$ TeV using 350 pb^{-1} of data collected with the DØ detector between 2002 and 2005. We focus on the final state where the W boson from one of the top quarks decays into a τ lepton and its associated neutrino, while the other decays into a quark-antiquark pair. We aim to select those events in which the τ lepton subsequently decays to one or three charged hadrons, zero or more neutral hadrons and a tau neutrino (the charge conjugate processes are implied in all of the above). The observable signature thus consists of a narrow calorimeter shower with associated track(s) characteristic of a hadronic tau decay, four or more jets, of which two are initiated by b quarks accompanying the W 's in the top quark decays, and a large net missing momentum in the transverse plane due to the energetic neutrino-antineutrino pair that leave no trace in the detector media. The preliminary result for the measured cross section is:

$$\sigma(t\bar{t}) = 5.1^{+4.3}_{-3.5} \text{ (stat)} \quad ^{+0.7}_{-0.7} \text{ (syst)} \quad \pm 0.3 \text{ (lumi.) pb}$$

I. INTRODUCTION

The top quark is the heaviest fundamental particle in nature. Precise measurements of its production rate and other properties allow us to perform precision tests of QCD predictions. In addition, any deviations from the Standard Model (SM) may signal the presence of new physics. In this respect, the decays of the top quark into the τ lepton are especially interesting, since the τ is the heaviest lepton. Any non-standard flavor- and mass-dependent couplings could produce a very significant effect in this channel. An interesting example is the charged Higgs boson, which appears in extensions of the SM Higgs sector to 2HDMs (Two-Higgs Doublet Models), and is required in MSSM (Minimal Supersymmetric Standard Model) [1]. Since the Higgs-fermion coupling is proportional to the latter's mass, decays to the heavy τ lepton would be much more frequent than those to the lighter e and μ . This prompts us to search for H^+ decaying to τ leptons. DØ and CDF performed such searches in Run I [2, 3]. The measurement of the SM process presented here is an important ingredient to extending the reach of such searches in addition to performing a crucial test of the Standard Model.

Theoretical computations of $\sigma(p\bar{p} \rightarrow t\bar{t})$ are constantly improving. The latest published NNLO cross section is 6.8 ± 0.4 pb [4]. The decay mode to $\tau + jets$ has a branching fraction of 0.15, the same as the $e + jets$ and $\mu + jets$ channels. However, secondary e 's and μ 's from leptonic decays of a τ lepton are difficult to distinguish from prompt (primary) ones at a hadron collider. Hence, in this analysis we only try to identify the events in which the τ subsequently decays to one or three charged hadrons, zero or more neutral hadrons and a ν_τ (the charge conjugate processes are implied in all of the above). These account for only 0.65 of the τ lepton branching ratio, so we expect the number of events to be lower than in the $e + jets$ and $\mu + jets$ channels.

This note presents the first measurement of the $t\bar{t}$ cross section in this channel, using the data collected during Run II by the DØ detector. The integrated luminosity of our data sample was 349 ± 23 pb $^{-1}$ [5]. After careful optimization of triggers, object identification and using an artificial neural network for the final full-event pattern recognition, we are able to extract the faint signal from the very large background, which is dominated by mismeasured QCD events.

II. THE DØ DETECTOR

The DØ Run II detector [6] is comprised of the following main components: the central tracking system, the liquid-argon/uranium calorimeter and the muon spectrometer.

The central tracking system includes a silicon microstrip tracker (SMT) and a central fiber tracker (CFT), both located inside a 2 T superconducting solenoid magnet. The SMT is designed to provide efficient tracking and vertexing capability at pseudorapidities of $|\eta| < 3$. The system has a six-barrel longitudinal structure, each with a set of four layers arranged axially around the beampipe, and interspersed with 16 radial disks. A typical pitch of 50-80 μm of the SMT strips allows a precision determination of the three-dimensional track impact parameter with respect to the primary vertex, which is the key component of the lifetime based b -jet tagging algorithms. The CFT has eight coaxial barrels, each supporting two doublets of overlapping scintillating fibers of 0.835 mm diameter, one doublet being parallel to the collision axis, and the other alternating by $\pm 3^\circ$ relative to the axis.

The calorimeter is divided into a central section (CC) providing coverage out to $|\eta| \approx 1$ and two end calorimeters (EC) extending coverage to $|\eta| \approx 4$, each housed in separate cryostats. Scintillators placed between the CC and EC provide sampling of showers at $1.1 < |\eta| < 1.4$.

The muon system, covering $|\eta| < 2$, resides beyond the calorimetry and consists of three layers of tracking detectors and scintillating trigger counters. Moving radially outwards, the first layer is placed inside the 1.8 T toroid magnets, and the two following layers are located outside the magnets.

The DØ trigger is a three-level trigger system. Level 1 is a hardware trigger, while levels 2 and 3 are software filters.

III. OBJECT IDENTIFICATION

The most important objects for this analysis are jets and hadronic τ lepton candidates. Jets are reconstructed using an iterative algorithm, which integrates the energy observed in the calorimeter in a cone with radius $\Delta R = \sqrt{\delta y^2 + \delta\phi^2} = 0.5$, where y is detector rapidity and ϕ is the angle in the plane transverse to the beam axis. These jets are required to be in the fiducial region $|\eta| < 2.4$, with $p_T > 20$ GeV/ c . The energy of the jets after reconstruction is corrected to represent the true jet energy [5]. An equivalent correction is derived for Monte Carlo events.

A. τ ID

1. Tau decay modes

The τ lepton has several decay channels, classified by the number of charged particles (tracks) and EM clusters associated with it [7] :

- electron or muon ($\tau \rightarrow e\nu_e\nu_\tau$ or $\tau \rightarrow \mu\nu_\mu\nu_\tau$), BR = 35% .
- single charged hadron ($\tau \rightarrow \pi^-\nu_\tau$), BR = 12% .
- single charged hadron + ≥ 1 neutral particle (i.e., $\tau \rightarrow \rho^-\nu_\tau \rightarrow (n\pi^0 + \pi^-\nu_\tau)$), BR = 38% .
- 3 charged hadrons + ≥ 0 neutral hadrons, BR = 15% (so-called “3-prong” decays).

2. Tau ID variables

At $D\bar{O}$, τ leptons are identified in their hadronic modes as narrow ($\Delta R = 0.3$ cone) jets, isolated and matched to charged tracks. The (most important) discriminating variables are [8]:

- Profile - $\frac{E_T^1 + E_T^0}{\sum_i E_T^i}$, where E_T^i is the E_T of the i^{th} highest E_T tower in the cluster.
- Isolation, defined as $\frac{E(0.5) - E(0.3)}{E(0.3)}$, where $E(R)$ is the energy contained in a $y - \phi$ of radius R around the calorimeter cluster centroid.
- Track isolation, defined as scalar $\sum p_T$ of non- τ tracks in a $y - \phi$ cone of 0.5 around the calorimeter cluster centroid.

Using these and other variables, three Neural Networks (NNs) are trained to identify three types of τ lepton (π -type, ρ -type and 3-prong)

The output of these NNs provides a set of three variables (`nnout` = 1,2,3) to be used to select the τ lepton in the event. The types roughly correspond to the τ lepton decay modes. Type 1 contains only one charged track, type 2 has one charged track and one or more electromagnetic clusters and type 3 has more than one track (multi-prong decays). High values of NN correspond to the physical τ leptons, while low ones should indicate jets misidentified as τ 's (fakes). For more details, see Ref. [8].

B. The Secondary Vertex Tagging Algorithm

The $t\bar{t}$ final state contains two b -jets, while jets in QCD and W +jets events originate most often from light quarks or gluons. Requiring at least one jet in the event to be b -tagged is therefore a very powerful method of background rejection. The b -tagging algorithm used in this measurement is a secondary vertex tagging algorithm (SVT), which explicitly reconstructs vertices that are displaced from the primary vertex. In the fitting procedure, the SVT uses only good quality tracks that have an impact parameter significance > 3 . Also, only secondary vertices which are displaced from the primary vertex in the plane transverse to the beam line by more than 7 standard deviations are considered in this measurement.

a. b-tagging efficiency It is known [9] that the b -tagging, when applied directly to Monte Carlo, gives an efficiency that is higher than data. In order to account for this factor, SVT has been parameterized on $t\bar{t} \rightarrow \mu + jets$ MC and $\mu + jets$ data to compute the correction factor, which scales the MC-derived efficiency. As a result, we obtain the MC tagging probability and the data-corrected one [9]. It can be noted that the data-corrected efficiency is indeed noticeably (30%) lower than what we would expect by applying the SVT directly to MC.

b. c-tagging efficiency An assumption is made that the correction factor obtained by dividing the semi-leptonic b -tagging efficiency in data to the one in MC also is correct for c jets. Hence the MC-obtained inclusive c -tagging efficiency is multiplied by this factor in order to estimate the c -tagging probability.

TABLE I: Background sources, relevant for the $\tau + jets$ analysis. The branching fraction into hadronic τ has been applied

Background	Description	Cross Section
$W + jjjj \rightarrow \tau\nu jjjj$	has identical signature to the signal	~ 18 pb
$Z/\gamma + jjj \rightarrow \tau\tau jjj$	τ lepton is usually found as a jet	~ 2.6 pb
$WZ \rightarrow \tau\nu jj$	needs two extra jets (can be gluon emission)	~ 0.2 pb
$WW \rightarrow \tau\nu jj$	needs two extra jet (can be gluon emission)	~ 0.5 pb
single top	small cross section, but has b jets	~ 0.5 pb
QCD	any 4-jet event that doesn't have a real τ lepton in it	> 100 nb

c. Light jet tagging efficiency The b -tag fake rate from light quarks is computed by measuring the negative tag rate. It is defined by the rate of appearance of secondary vertices with a negative decay length significance. It is assumed that the light quarks have an equal chance to produce a secondary vertex with positive and negative decay length significance (due to finite resolution effects) while the heavy flavor jets can only produce a SV with positive decay length significance. However, this is not quite true and a special scaling factor (SF_{hf}) is introduced to correct for the fraction of heavy flavors among the jets with a negative decay length significance. Another correction is for the presence of long lived particles in light jets (SF_{ll}). Both factors are derived from Monte Carlo.

IV. BACKGROUNDS

Two main distinctive features of the signal determine which backgrounds are important. In order to be relevant, the process must have a high (> 3) number of jets as well as a sizeable (> 15 GeV) \cancel{E}_T . All of the candidate processes are listed in Table IV. The cross sections listed include the branching fractions into τ leptons.

We can conclude that the two dominant background sources are QCD (“fake τ ”) and $W+4$ jets. These two sources were taken into account in this analysis. QCD is derived from the data, while Monte Carlo simulation is used for $W+4$ jets.

This simulation utilizes events generated at $\sqrt{s} = 1.96$ TeV with the ALPGEN 1.2 [10] matrix element generator, assuming a top mass of 175 GeV/ c^2 and the parton distribution function set CTEQ 6.1M [11]. These events are then processed through PYTHIA 6.2 [12]. This package takes into account the gluon radiation and fragmentation effects and also performs the short lived particle decays, except for b hadrons and τ leptons. EvtGen [13] is used to model the decays of b hadrons. τ leptons are decayed using Tauola [14]. The generated events are then processed through a full GEANT [15] simulation of the DØ detector providing tracking hits, calorimeter cell energy and muon hit information. Multiple interactions are added to all events according to a Poisson distribution with a mean that is determined from the average instantaneous luminosity. The same reconstruction and object ID is applied to data and Monte Carlo events. The signal ($t\bar{t}$) Monte Carlo is prepared in the same way.

V. EVENT SELECTION

For this analysis, we used the data collected with a 4-jet trigger, which required 4 jet candidates with $|\eta| < 3.6$ and $E_T > 10$ GeV using a simple cone algorithm. This trigger was designed for the all-hadronic top decay mode and works well for our purposes, since an energetic hadronic τ lepton is always found as a jet candidate. The efficiency of this trigger had been parametrized and cross-checked on data and is applied as a weighting factor to the Monte Carlo events.

The analysis procedure involved several stages:

- Preselection (section V A). At least 4 jets and \cancel{E}_T significance > 3 are required. 653,727 events are selected in the data, with a prediction of 109.9 ± 7.3 $t\bar{t}$ events, for a S:B \approx 1:6,000.
- ID cuts (section V B). At least one good τ lepton candidate and at least one tight SVT tag are required. We also required ≥ 2 jets with $|\eta| < 2.4$ and $p_T > 20$ GeV/ c . 216 events are selected in the data, 9.3 ± 0.6 $t\bar{t}$ among them are expected. S:B \approx 1:58.
- Topological NN (section V D). A sequence of two feed-forward NN's have been trained and applied. The optimal cut on the second NN has been found to be 0.6. With this final cut, we obtained 13 events in data with 4.9 ± 0.3 $t\bar{t}$ among them expected. S:B \approx 1:2.5.

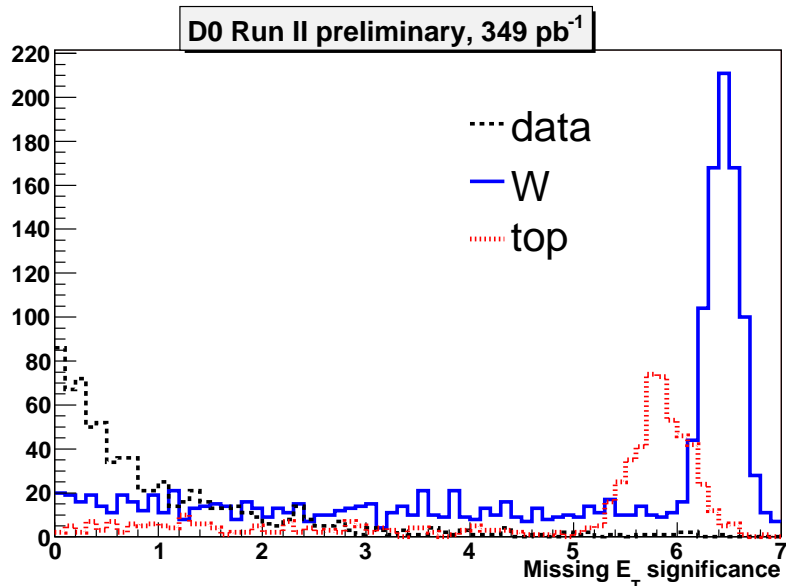


FIG. 1: \cancel{E}_T significance for QCD-dominated data (black), $W + jets$ (blue) and $t\bar{t} \rightarrow \tau + jets$ (red).

The W background has been modeled using ALPGEN Monte Carlo simulation, while QCD background estimates were extracted from the data using the procedure described in section V C. In order to optimize the selection we also used the $t\bar{t}$ Monte Carlo and normalized it to known (either theoretical or computed by ALPGEN) values. In the end we applied this optimal selection to measure the actual $t\bar{t}$ cross section in the data.

A. Preselection

The total number of events recorded by our trigger in this 349 pb^{-1} data set is 17 million. The main goal of preselection was to reduce this dataset, while imposing the most obvious and straightforward requirements that characterize the signal signature. Such characteristic features include the following:

- Moderate \cancel{E}_T arising from both the W vertex and τ decay.
- At least 4 jets must be present.
- At least 1 τ lepton and 2 b jets are present.

\cancel{E}_T significance [17] is defined as measure of the likelihood of \cancel{E}_T arising from physical sources, rather than fluctuations in detector measurements. These fluctuations are predicted from measuring and parametrizing the object resolutions in the data. As can be observed in Fig. 1, a cut on this variable proves to be an effective way to reduce the data set. A cut of 3 was used for preselection.

Now we need to scale the original 10K events of the MC sample to 349 pb^{-1} . The total $t\bar{t}$ cross section is 6.8 pb [4]. Taking into account the branching fraction to the hadronic $\tau + jets$ mode, the effective cross section comes out to be:

$$BR(\tau \rightarrow \text{hadrons}) \cdot BR(t\bar{t} \rightarrow \tau + jets) \cdot \sigma(t\bar{t}) = 0.65 \cdot 0.15 \cdot 6.8 = 0.66 \text{ pb}$$

The relative flavor fractions of the $W + 4jets$ process were taken from ALPGEN simulation as ratios of the simulated cross sections. It was then normalized to the measured total value of $4.5 \pm 2.2 \text{ pb}$ [18]. Table II shows the results of the preselection for both data and the backgrounds.

B. Results of the ID cuts

The next step was to apply the requirement of τ - and b -tagging. Table III shows the selection criteria that we apply to data and MC and Table IV shows the resulting selection efficiencies. Table V shows the breakdown of these events

TABLE II: Preselection results. Shown are the total acceptances (including preselection) and the number of events scaled to $349 \pm 23 \text{ pb}^{-1}$ (no systematic uncertainties except for this luminosity error are included). The ALPGEN samples generation cuts are described in [16]. An estimate of QCD background not included.

	(# passed)/(total #)	σ , pb	# passed scaled
data	653,727/17M		653,727
$t\bar{t} \rightarrow \tau + jets$	6,141/10,878	0.821 ± 0.004	109.93 ± 7.26
$Wbbjj \rightarrow \tau\nu + bbjj$	2,321/11,576	0.222 ± 0.044	9.98 ± 2.08
$Wccjj \rightarrow \tau\nu + ccjj$	2,289/10,995	0.527 ± 0.059	24.77 ± 3.22
$Wcjjj \rightarrow \tau\nu + cjjj$	2,169/10,435	0.920 ± 0.087	42.23 ± 4.87
$Wjjjj \rightarrow \tau\nu + jjjj$	2,683/11,920	14.14 ± 1.3	720.33 ± 81.48

TABLE III: b -tagging and τ ID. In the MC, we use the b -tagging certified parameterization rather than actual b -tagging, that is, we applied the b -tagging weight. We also used the triggering weight as computed by the trigger efficiency parameterization.

data	taggingMC
$\geq 1 \tau$ with $ \eta < 2.4$ and $p_T > 20 \text{ GeV}/c$	$\geq 1 \tau$ with $ \eta < 2.4$ and $p_T > 20 \text{ GeV}/c$
≥ 1 SVT	$TrigWeight \cdot bTagProb$
≥ 2 jets with $ \eta < 2.4$ and $p_T > 20 \text{ GeV}/c$	≥ 2 jets with $ \eta < 2.4$ and $p_T > 20 \text{ GeV}/c$

between type 2 and 3 τ (type 1 is disregarded due to its small contribution to the signal and large background). It can be noted that the S:B at this stage is 1:58, which is too small. In section V D we will describe the topological NN used to enhance the signal content.

At this point, we use these ID algorithms to define 3 subsamples out of the original preselected data sample:

- The “signal” sample - require at least 1 τ lepton with $NN > 0.95$ and at least one SVT tag (as in table III). This is the main sample used for the measurement. It contains 268 events.
- The “ τ veto sample” - Same selection, but instead of $NN_\tau > 0.95$, $0 < NN_\tau < 0.5$ was required for τ lepton candidates and no events with “good” ($NN > 0.8$) τ leptons were allowed. This sample is used for the topological NN training. It contains 21,022 events.
- The “ b veto” sample - at least 1 τ lepton with $NN > 0.95$, but NO SVT tags. This sample is to be used for the QCD prediction. It contains 4,642 events.

C. QCD modeling

The difference between the total number of $t\bar{t}$ and W events and data has to be accounted for by QCD-initiated events, where a τ candidate is a jet, mistakenly identified as a τ lepton. In order to estimate this background contribution, the following strategy was employed.

We started with the “ b veto” sample. This sample is dominated by multijet events in which a jet is misidentified as a hadronic τ . Since the τ candidates here are really jets, we can simply divide η vs p_T distributions of the τ candidates by the same distributions for jets bin by bin to parameterize the τ fake rate. In order to reduce this effect and minimize the statistical uncertainty, we performed a 2D fit to this distribution. This fit was then used for the

TABLE IV: b -tagging and τ ID results. Shown are the total acceptances (including preselection) and the number of events scaled to 349 pb^{-1} . An estimate of QCD background is not included.

	(# passed)/(total #)	Acceptance	# passed scaled
data	216/653,727		216
$t\bar{t} \rightarrow \tau + jets$	524.0/6141	0.0480 ± 0.0020	9.320 ± 0.620
$Wbbjj \rightarrow \tau\nu + bbjj$	54.5/2321	0.0150 ± 0.0024	0.012 ± 0.002
$Wccjj \rightarrow \tau\nu + ccjj$	13.3/2289	0.0039 ± 0.0012	0.034 ± 0.005
$Wcjjj \rightarrow \tau\nu + cjjj$	8.0/2169	0.0025 ± 0.0010	0.160 ± 0.020
$Wjjjj \rightarrow \tau\nu + jjjj$	3.3/2683	0.0009 ± 0.0006	0.860 ± 0.100

TABLE V: b -tagging and τ ID results per type after the η cut (as explained in section VC). Shown are the number of events predicted in signal and observed in the data. An estimate of QCD background is not included.

data	Type 2 91	Type 3 71
$t\bar{t} \rightarrow \tau + jets$	5.61 ± 0.37	2.81 ± 0.18
$W \rightarrow \tau\nu + jets$	0.93 ± 0.04	0.32 ± 0.01

QCD prediction. The distributions in η and p_T have been separately fitted with $A(\eta)$ and $B(p_T)$. The validity of using the normalized product of these two efficiency curves has been checked using closure tests. The result of this procedure can be observed in Fig. 2. For type 3 τ lepton candidates the $0.85 < |\eta| < 1.1$ region was excluded from the fit due to the poor performance of the τ ID Neural Net in this region. The final 2D parameterization of the τ fake rate (normalized product of η and p_T fits) is shown in Fig. 3.

1. Computing the QCD fraction

We assume that probability for a jet to fake a τ lepton is simply $F(\eta, p_T) = A(\eta)B(p_T)$. Then the probability that at least one of the jets in the event will fake a τ can be computed as the following:

$$P_{event} = 1 - \prod_j (1 - F(p_T^j, \eta^j)).$$

By summing up such probabilities over the tagged data, we obtain the QCD background estimate.

Using the results described in the previous section, we get $N_{QCD} = 71.13 \pm 1.56$ for the τ type 2 and $N_{QCD} = 77.46 \pm 0.80$ for the τ type 3, which agrees with the observed data (in Table V) fairly well. One can also observe (see Appendix) that the predicted distributions of the main topological variables (section VD) are in fairly good agreement with what is observed in the data.

D. Topological NN

Similarly to the all-jets analysis [5], we define 2 neural networks (NN) (the Multi Layer Perceptron [19] program was used). The two NNs contain

1. 3 topological (aplanarity, sphericity and centrality) and 2 energy-based (H_T and \sqrt{s}) variables.
2. the output of the first NN, W and t mass likelihoods, p_T and decay length significance of the b jets.

The kinematic and topological variables used are:

- H_T - the scalar sum of all jet's p_T (and τ lepton candidates).
- Sphericity and Aplanarity [5] - these variables are formed from the eigenvalues of the normalized Momentum Tensor of the jets in the event. These are expected to be higher in the top pair events than in a typical QCD event.
- Centrality, defined as $\frac{H_T}{H_E}$, where H_E is sum of energies of the jets.
- Top and W mass likelihood - a χ^2 -like variable. $L \equiv \left(\frac{M_{3j}-m_t}{\sigma_t}\right)^2 + \left(\frac{M_{2j}-M_W}{\sigma_W}\right)^2$, where $m_t, M_W, \sigma_t, \sigma_W$ are top and W masses (175 GeV and 80 GeV respectively) and resolution values (45 GeV and 10 GeV respectively) [5]. M_{3j} and M_{2j} are invariant masses composed of the jet combinations, so as to minimize L .
- p_T and lifetime significance of the leading b -tagged jet.

Many of these variables (for instance the mass likelihood and aplanarity) are only defined for events with 2 or more jets. Thus we require 2 jets with $p_T > 20$ GeV/ c and $|\eta| < 2.5$. Plots of some of these variables, which also serves as an additional check of the agreement between the data and prediction, are included in the appendix.

The result of applying these NN to data is shown in Fig. 4. The maximum signal significance is used to determine the optimal NN cut. The signal significance is defined as $\frac{N_S}{\sqrt{N_S+N_B}}$, where N_S and N_B are the expected numbers of

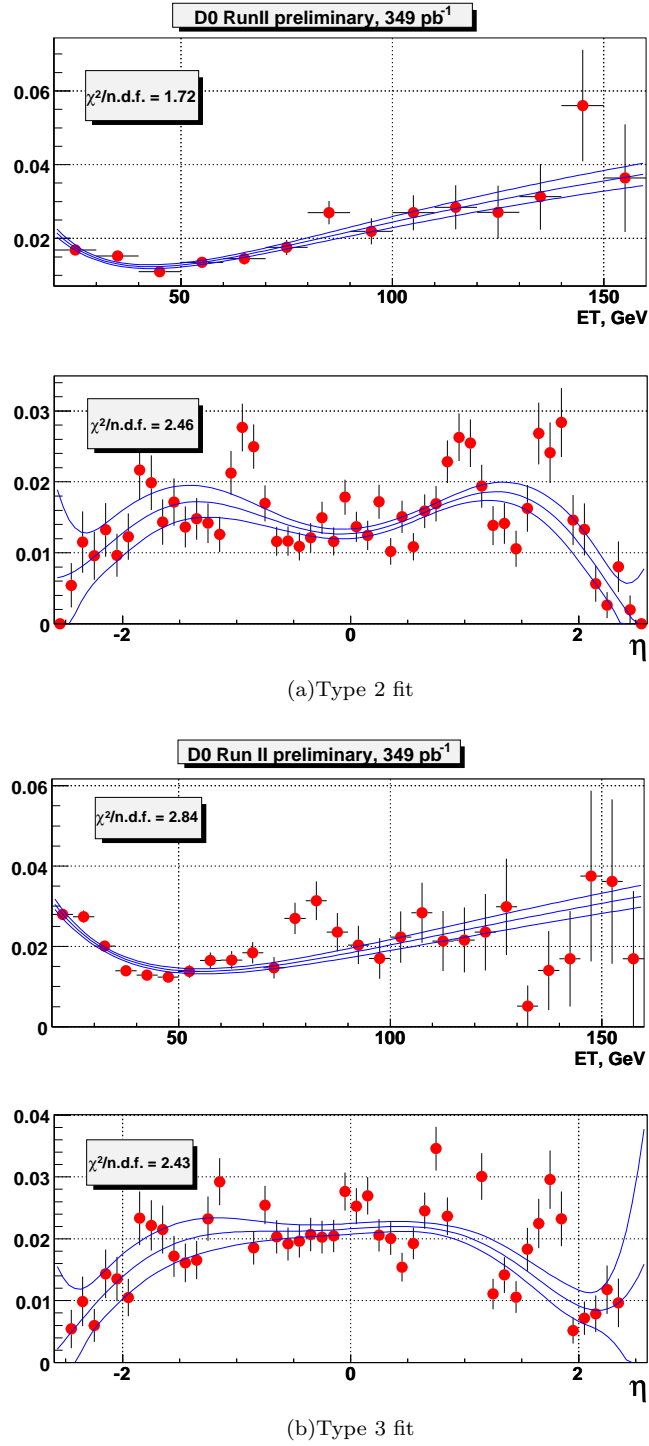


FIG. 2: Fit of the η and p_T distributions of the τ fake rate.

signal and background events respectively and is shown in Fig. 5. This significance reaches its maximum at $NN > 0.9$ for both type 2 and 3. Therefore, this selection is used for the cross section measurement. The results are summarized in Table VI.

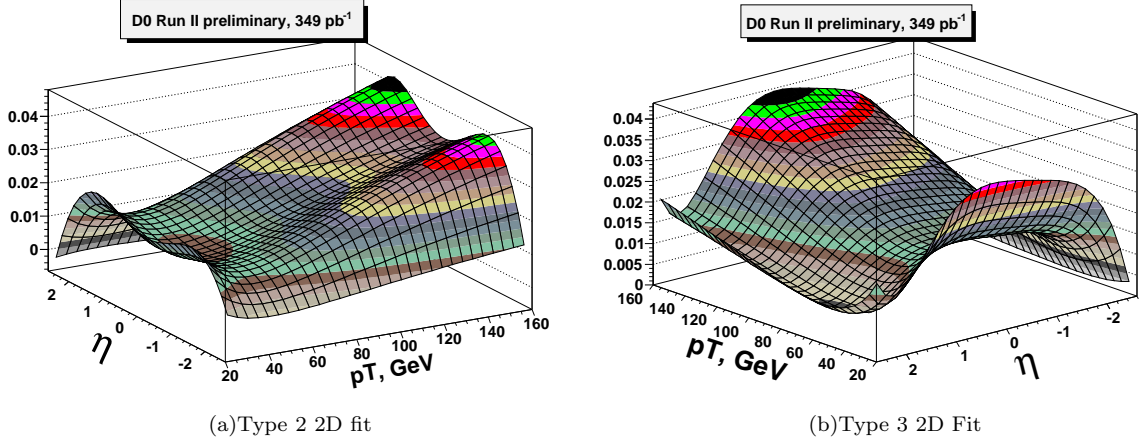


FIG. 3: The 2D combined fit (in η and p_T) of the τ fake rate.

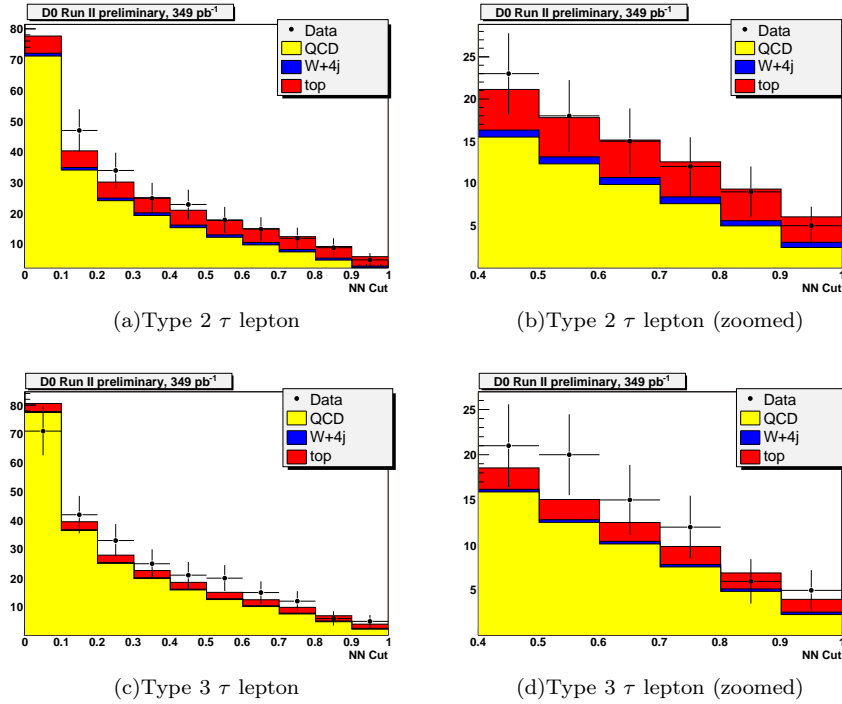
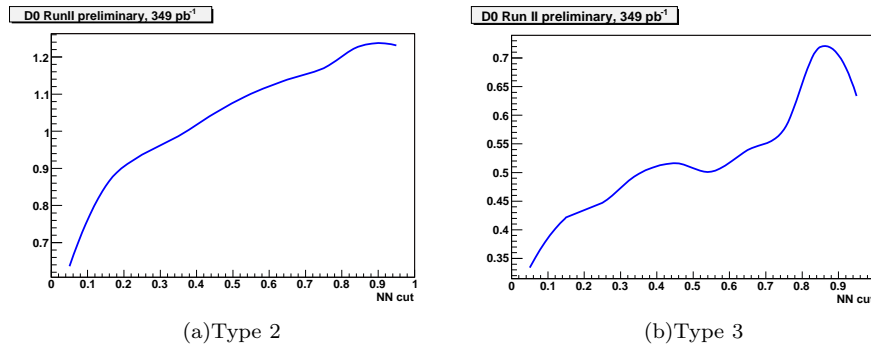


FIG. 4: Result of applying the NN cut. $t\bar{t}$, W and QCD are plotted incrementally in order to compare with the number of events observed in data. Error bars include only statistical uncertainties. $\sigma(t\bar{t}) = 5.54$ pb is assumed. The right plot only shows the entries at high values of NN cut.

TABLE VI: The final result summary after the $NN > 0.9$ cut. $\epsilon(t\bar{t})$ is the total signal acceptance. Uncertainties are statistical only.

Channel	N^{obs}	\mathcal{B}	$\int \mathcal{L} dt, pb^{-1}$	Backgrounds	$\epsilon(t\bar{t})$ (%)	s (7 pb)	$s + b$
τ +jets type 2	5	0.1	349.3	$W \rightarrow \tau\nu$	0.60 ± 0.03	1.57 ± 0.01	$3.83^{+0.46}_{-0.51}$
				fakes	2.41 ± 0.09		
τ +jets type 3	5	0.1	349.3	$W \rightarrow \tau\nu$	0.27 ± 0.01	0.73 ± 0.01	$1.80^{+0.22}_{-0.23}$
				fakes	2.33 ± 0.09		

FIG. 5: $t\bar{t} \rightarrow \tau + jets$ signal significance.TABLE VII: Systematic uncertainties on $\sigma(t\bar{t})$ (in pb).

Channel	τ +jets type 2	τ +jets type 3
Jet Energy Scale	$-0.27, +0.30$	$-0.69, +0.53$
Primary Vertex	$+0.037, -0.036$	$+0.095, -0.093$
MC Stat	$+0.25, -0.22$	$+0.65, -0.58$
Trigger	$-0.020, +0.0025$	$-0.069, +0.0056$
Branching Ratio	$+0.074, -0.071$	$+0.19, -0.18$
QCD fake rate Parameterization	$+0.17, -0.17$	$+0.34, -0.34$
$W \rightarrow \tau\nu$	$+0.19, -0.19$	$+0.19, -0.19$

VI. SYSTEMATIC UNCERTAINTIES

The most important systematic effects (except for the b -tagging, which is treated independently) are summarized in Table VII. Most of them are associated with uncertainties on the corresponding quantities (Jet Energy Scale, Primary Vertex, Branching Ratio and Trigger simulation). The QCD systematics comes mainly from the error of the 2D fit of the τ fake rate. The $W \rightarrow \tau\nu$ uncertainty comes from two sources: the uncertainty of the cross section value and the conservative estimate of the error associated with the method that we used for modeling this background.

A. b -tagging

The effects of uncertainties in tagging b jets are taken into account by varying the systematic and statistical uncertainties on the MC tagging weights. The resulting effect of all of the error sources on the final number is summarized in table VIII, along with the total b ID systematic uncertainty (quoted in table VII).

TABLE VIII: b -tagging systematics sources

Channel	τ +jets type 2	τ +jets type 3
b -tagging	$-0.13, +0.076$	$-0.26, +0.41$
c -tagging	$-0.20, +0.16$	$-0.48, +0.60$
l -tagging	$-0.0051, +0.0051$	$-0.014, +0.014$
SF_{hf}	$-0.00036, +0.00036$	$-0.00094, +0.00094$
SF_{ll}	$-0.00036, +0.00036$	$-0.00094, +0.00094$
μ b -tagging (data)	$-0.091, +0.094$	$-0.24, +0.25$
μ b -tagging (MC)	$+0.11, -0.10$	$+0.28, -0.25$
taggability	$-0.048, +0.049$	$-0.13, +0.13$

VII. CROSS SECTION

The cross section is defined as $\sigma = \frac{\text{Number of signal events}}{\varepsilon(tt) \cdot BR(tt \rightarrow \tau + \text{jets}) \cdot \text{Luminosity}}$. The results are the following:

τ +jets type 2 (single prong) cross section:

$$\sigma(t\bar{t}) = 3.63^{+4.72}_{-3.50} \text{ (stat)}^{+0.49}_{-0.48} \text{ (syst)} \pm 0.24 \text{ (lumi) pb,}$$

τ +jets type 3 (multi-prong) cross section:

$$\sigma(t\bar{t}) = 9.39^{+10.10}_{-7.49} \text{ (stat)}^{+1.25}_{-1.18} \text{ (syst)} \pm 0.61 \text{ (lumi) pb.}$$

The combined cross section was estimated by minimizing the sum of the negative log-likelihood functions (constructed from a Poisson distribution using the number of observed events and “hypothetically” observed events as the Poisson mean) for each channel. The functional form of the likelihood function was the same as has been used for the $e\mu$ channel [20]. The combined cross section yields

$$\sigma(t\bar{t}) = 5.05^{+4.31}_{-3.46} \text{ (stat)}^{+0.68}_{-0.67} \text{ (syst)} \pm 0.33 \text{ (lumi) pb.}$$

VIII. SUMMARY

This note presents the measurement of $\sigma(t\bar{t})$ by the DØ collaboration in the Run 2a of the Fermilab Tevatron. The decay channel studied involves one hadronically decaying τ lepton, 2 b jets, 2 light jets and \cancel{E}_T . The trigger and the corresponding $349 \pm 23 \text{ pb}^{-1}$ dataset were shared with the all-jets channel [5].

The main challenge was to reject the overwhelming QCD background, while at the same time properly handling the physical $W + 4j$ irreducible background. In order to achieve this goal, a NN-based τ ID and SVT b -tagging algorithm was employed. In addition, the relevant topological variables were combined into a NN trained to differentiate the signal from QCD. The single and triple pronged τ lepton channels were treated as independent channels and then combined.

The cross section was measured to be

$$\sigma(t\bar{t}) = 5.05^{+4.31}_{-3.46} \text{ (stat)}^{+0.68}_{-0.67} \text{ (syst)} \pm 0.33 \text{ (lumi) pb.}$$

This result is in agreement with the theoretically predicted value of $6.8 \pm 0.4 \text{ pb}$ [4] as well as other DØ and CDF measurements [5, 16].

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APPENDIX A: KINEMATIC DISTRIBUTIONS

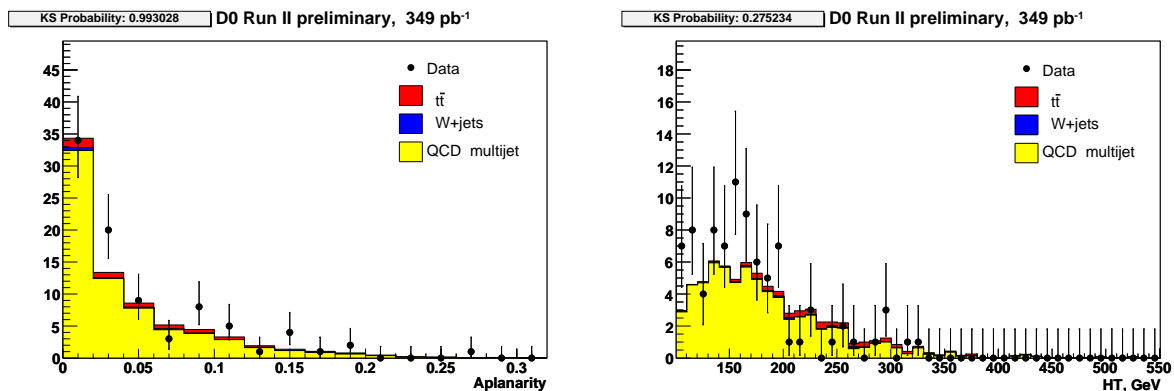


FIG. 6: 2 of the 5 input variables of the first topological NN before the NN cut (τ type 2). The Kolmogorov-Smirnov (KS) probabilities are shown, indicating the quality of the agreement.

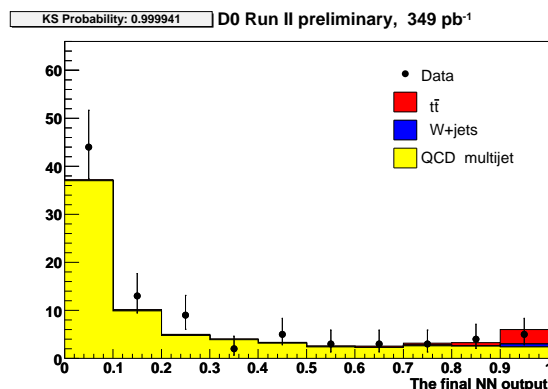


FIG. 7: The resulting output of the second (final) NN (τ type 2).

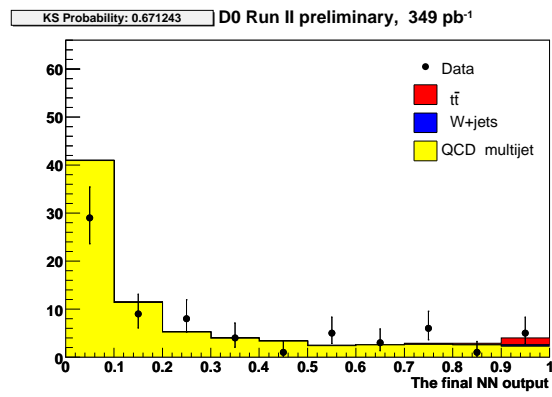


FIG. 8: The resulting output of the second (final) NN (τ type 3).