CDF/ANAL/TOP/CDFR/7057
Version 1.4, August 1, 2004

Event detection efficiency for single top events in CDF

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Abstract

We present event detection efficiencies for the two electroweak single top processes relevant at the Tevatron, i.e. t-channel (Wg-fusion) and s-channel (W^*) production. Our evaluation is based on MadEvent, PYTHIA and TopRex Monte Carlo events. In addition, we include detection efficiencies of backgrounds, whose production cross-sections are well predicted by theory: $t\bar{t}$ and di-boson (WW, WZ and ZZ) production. We use Monte Carlo events simulated and recontructed with software release 4.9.1. The TopFind-Remake was run in release 4.11.1.

1 Introduction

In Run II at the Tevatron, single top quarks are expected to be produced electroweakly via *t-channel* or *s-channel* exchange of an off mass shell W boson. The two production modes are also referred to as $W-$gluon fusion or W^* process. Figure 1 depicts Feynman diagrams for the two production modes. The theoretical cross section at $\sqrt{S} = 1.96$ TeV is [1]: 0.884±0.004 (stat.)±0.050 (NLO scale) pb for s-channel and 1.980±0.004 (stat.)± 0.113 (NLO scale) pb for t-channel, respectively. The uncertainty due to the error in the top quark mass ($\Delta m = \pm 5$) GeV is about 10% [2]. The PDF uncertainty is typically 5%. In total we assume an error of 13% on both cross-sections. We note that the combined single-top cross section of about 2.9 pb is roughly twice smaller than the $t\bar{t}$ cross section [3, 4, 5, 6].

In Run I at the Tevatron, both CDF and DØ have searched for single top production [7, 8, 9]. The published 95% C.L. upper limits set by CDF are 13 pb on t-channel and 18 pb on s-channel, and 14 pb for the combined channels [9]. The limits reported by the

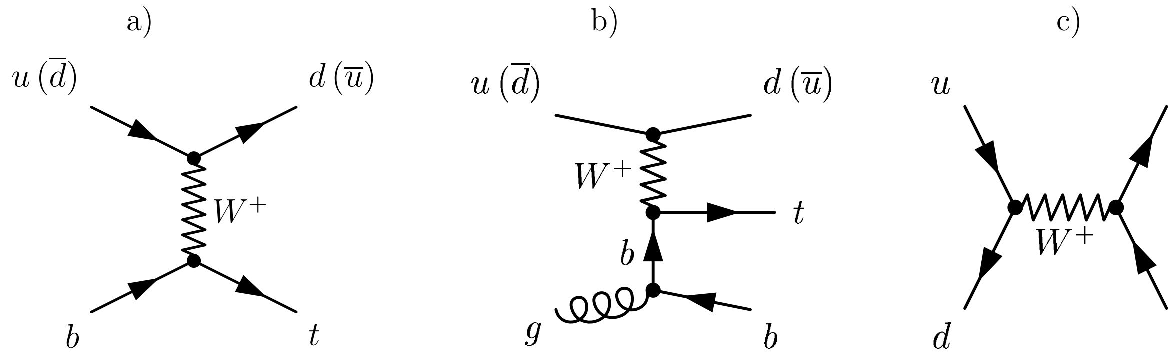

Figure 1: Feynman diagrams for single top production: a) t-channel $2 \rightarrow 2$ after introduction of a b-quark PDF, b) t-channel W-gluon-fusion diagram, is a NLO contribution if a b-quark PDF is used, c) s-channel (W^*).

DØ Collaboration are comparable: 22 pb on t-channel and 17 pb on s-channel production [7, 8]. For Run 2, preliminary studies show that a 3 σ excess could be observed with roughly 1.2 fb^{-1} of data. This calculation used Run I Monte Carlo samples, with a simple scaling for increases in luminosity, detector acceptance, and signal and background cross sections [10, 11]. The aim of this document is to present the single top event detection efficiency $\epsilon_{\rm evt}$ based on Run 2 Monte Carlo samples.

2 Monte Carlo Samples and Selection Requirements

The Monte Carlo samples used for this analysis are generated with MadEvent [14], PYTHIA v6.203 [12], Herwig [13] or TopRex [15]. Simulation and production were performed in the 4.9.1 release of the CDF offline software. We used the *runMC* executable, 4.9.1 version 11. The reconstructed events were passed through TopFind, linked against CDF software release 4.11.1, to produce TopNtuples [16]. Table 1 gives an overview on the samples we use. In our previous analyses we used Pythia for the single top signal [17, 18]. Pythia has two weaknesses: (1) Pythia does produce polarized top-quarks, while from electro-weak theory we know that the top-quark must be 100% polarized along the d-quark direction in the top-quark rest frame [19, 20, 21]. (2) Comparison of Pythia with NLO calculations of differential cross-sections show that in the t-channel the kinematic distributions of the second b-quark from gluon splitting (the one which is not promoted to a top-quark) are not modelled well. In particular, the p_T distribution of the second b is too soft, and the η distribution to much forward (shifted to high values of $|\eta|$). We address both issues mentioned above by using the matrix element generator MadEvent, which include the correct polarization of the top-quark its matrix element (issue 1). Secondly, we generate two t-channel samples with MadEvent, one $2 \rightarrow 2$ ($qb \rightarrow q't$) and one $2 \rightarrow 3$ ($qg \rightarrow q'tb$ sample. Both are mixed to better reproduce the theoretically predicted distributions of the second b-quark. The exact mixing prescription is documented in Ref. [22].

Sample	Process	Description	N gen.	N ntup.
MadGraph Samples, all with $W \to e, \mu, \tau$				
mtop0s	t-ch.	LO $2 \to 2$		156606
mtop1s	t-ch.	NLO $2 \to 3$		198903
mtop2s	s-ch.	LO		199953
TopRex Samples, all with $W \to e, \mu, \tau$				
rtop0s	t-ch.	TopRex L0; $W \to e, \mu, \tau$		199803
rtop1s	t-ch.	TopRex NLO; $W \to e, \mu, \tau$	199459	199459
rtop2s	s-ch.	TopRex LO; $W \to e, \mu, \tau$	200107	200107
Pythia Samples, all W decay modes				
ttop0s	t-ch.	standard, no filter	512000	499189
ttop1s	s-ch.	standard, no filter	512000	440000
ttopei	$t\bar{t}$	Pythia, standard, no filter	740000	398037
Herwig Samples, $t\bar{t}$, all W decay modes				
ttopli	$t\bar{t}$	standard, no filter	382000	378471
ttoppk	$t\bar{t}$	m_{top}=170 GeV	208000	
ttopsk	$t\bar{t}$	m_{top}=180 GeV	208000	
Di-boson samples, Alpgen				
atop4x	WW0p	$W_1 \to e,\ \mu,\ \tau$	967329	944969
atop0y	WZ0p			
atop0z	ZZ0p			

Table 1: Monte Carlo samples used in the single top analysis.

Selection Cut	TopNtuple Implementation
CEM electron	`TN->electron_Region[ne]==0`
Fiducial	`TN->electron_Fiducial[ne]==1`
$E_T \geq 20.0$ GeV	`TN->electron_Et[ne]>=20.0`
$p_T \geq 10.0$ GeV	`TN->electron_TrkPt[ne]>=10.0`
$E_{had}/E_{em} \leq 0.055 + 0.00045E$	`TN->electron_Hadem[ne]<=(0.055+0.00045* TN->electron_En[ne])`
$L_{shr} \leq 0.2$	`TN->electron_LshrTrk[ne]<=0.2`
$E/P \leq 2.0$ .OR. $p_T > 50$ GeV	`TN->electron_EP[ne]<=2.0 || TN->electron_TrkPt[ne]>50.0`
$\|z_0\| \leq 60.0$ cm	`fabs(TN->electron_TrkZ0[ne])<=60.0`
$\Delta z\| \leq 3.0$ cm	`fabs(TN->electron_DeltaZ[ne])<=3.0`
$-3.0 \leq Q \cdot \Delta x \leq 1.5$ (cm)	`qd=((float)TN->electron_Charge[ne])* TN->electron_DeltaX[ne]; qd >= -3.0 && qd <= 1.5`
$\chi^2_{strip} \leq 10.0$	`TN->electron_StripChi2[ne]<=10.0`
Good COT Axial Segments≥ 3	`TN->electron_TrkAxSeg[ne]>=3`
Good COT Stereo Segments≥ 3	`TN->electron_TrkStSeg[ne]>=3`
Isolation ≤ 0.1	`TN->electron_Isol[ne]<=0.1`
Conversion Veto	`TN->electron_Conversion[ne]!=1`

Table 2: The baseline cuts for CEM electrons for Run 2 analyses (adapted from Ref. [23]).

2.1 Baseline Cuts

The selection requirements used are the standard cuts of the lepton+jets working group. We first require the events to have the OBSV vertex in the fiducial volume of the detector: $|z_0| < 60$ cm (`fabs(TN->obsp_Vz[0])<60.0`). The tight lepton selections along with the corresponding TopNtuple implementation are given in Tables 2 and 3. For further information about these selections, we point the reader to Ref. [23]. For CEM electrons, the fiducial and E_T selections are referred to as *geometric* cuts. The next group of cuts in Table 2 are the *lepton ID* cuts, which together with the isolation cut define the tight electrons. Similar definitions apply to CMUP and CMX muons.

Jet Counting: We count jets using the corrected transverse energy E_T. Corrections are applied to all jets reclustered with *TopEventModule* (jet collection 3; JetClu algorithm, cone size 0.4) with E_T(raw) ≥ 8 GeV and $|\eta_{\text{Detector}}| < 2.8$. We use corrections for relative energy, time-dependence, energy scale and multiple-interactions, i.e. level 4 corrections [24]. We count jets with E_T(raw) ≥ 8 GeV, $\mathsf{E}_\mathsf{T}^{\mathsf{corr}} \geq 15$ GeV and $|\eta_{\text{Detector}}| < 2.8$. We extended the standard tight jet definition by enlarging the η range from $|\eta_{\text{Detector}}| < 2.0$ to $|\eta_{\text{Detector}}| < 2.8$. The reason for that is that we can significantly improve our signal-to-background ratio. We expect our acceptance for t-channel single top events to increase by about 30%. The background and the s-channel acceptances on the other hand do not increase significantly: s-channel $\approx +2\%$, $Wb\bar{b}$ +4%, $Wc\bar{c}$ +7%, Wc +15%. Overall we gain in S/B. Fig. 2 shows the jet multiplicity distribution for t- and s-channel single top events. The bulk of the events is concentrated in the 2-jet bin.

Selection Cut	TopNtuple Implementation
CMUP muon	(TN->muon_muontype[nm]&3)==3
CMX muon	(TN->muon_muontype[nm]&4)==4
$p_T \geq 20.0$ GeV/c	TN->muon_Pt[nm]>=20.0
$E_{had} \leq max(6, 6 + 0.0280(p - 100))$	TN->muon_HadEnergy[nm]<=6.0 || (TN->muon_HadEnergy[nm]<=6.0+0.028 *(TN->muon_P[nm]-100.0))
$E_{em} \leq max(2, 2 + 0.0115(p - 100))$	TN->muon_EmEnergy[nm]<=2.0 || (TN->muon_EmEnergy[nm]<=2.0+0.0115 *(TN->muon_P[nm]-100.0))
$\|z_0 \leq 60.0$ cm	fabs(TN->muon_Z0[nm])<=60.0
CMU$\|\Delta x\| \leq 3.0$ cm (for CMUP muons only)	fabs(TN->muon_CmuDx[nm])<=3.0
CMP$\|\Delta x\| \leq 5.0$ cm (for CMUP muons only)	fabs(TN->muon_CmpDx[nm])<=5.0
CMX$\|\Delta x\| \leq 6.0$ cm (for CMX muons only)	fabs(TN->muon_CmxDx[nm])<=6.0
Good COT Axial Segments≥ 3	TN->muon_TrkAxSeg[nm]>=3
Good COT Stereo Segments≥ 3	TN->muon_TrkStSeg[nm]>=3
$\|d_0\| \leq 0.2$ cm if no Si hits	TN->muon_TrkSiHits[nm]==0 && fabs(TN->muon_D0[nm])<=0.2
$\|d_0\| \leq 0.02$ cm if Si hits	TN->muon_TrkSiHits[nm]!=0 && fabs(TN->muon_D0[nm])<=0.02
Isolation ≤ 0.1	TN->muon_Isol[nm]<=0.1
Cosmic Veto (for data only)	(TN->summary_fTopEventClass[0]&0x20)==0

Table 3: The baseline cuts for CMUP and CMX muons for Run 2 analyses (adapted from Ref. [23]). The cosmic veto is only applied to data, not Monte Carlo events.

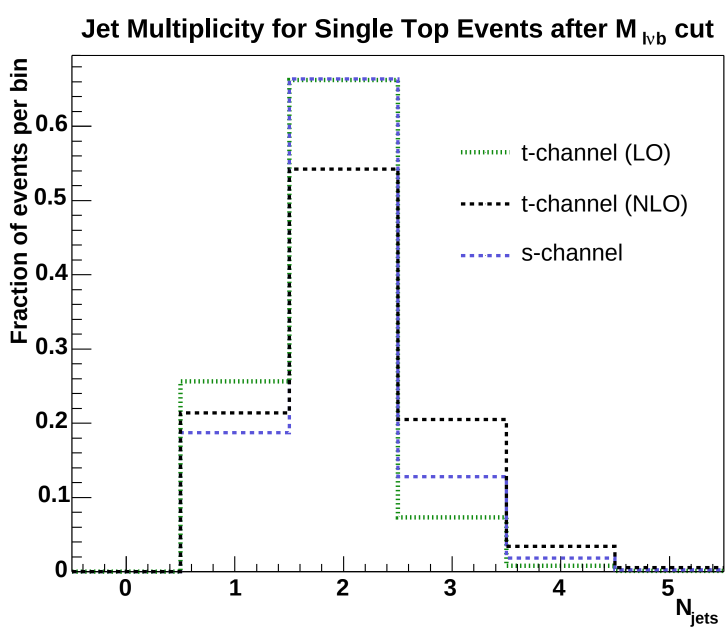

Figure 2: Jet multiplicity distribution after b-tag for MadGraph LO, NLO and s-channel.

Cut on $\not\!\!E_T$: To select leptonic W boson events we require a missing transverse energy of $\not\!\!E_T \geq 20$ GeV. Since we use corrected jet energies, we also need to use corrected $\not\!\!E_T$ to be consistent. The following corrections are performed: Since muons pass the calorimeter without showering we have to correct for that. For muons identified as *tight muons* this is already done by *TopEventModule* and the corrected quantitiy is available in the *TopNtuples* we use for our analysis, variable `TN->summary_fmuoMet[0]`. For data only, we apply curvature corrections to tight muons on ntuple level. The difference $\Delta P_T = P_T(\mu;\ \text{raw}) - P_T(\mu;\ \text{corr.})$ is added vectorially to $\not\!\!E_T$. The third correction arises from jet energy corrections. We calculate the difference between the corrected and raw jet energy: $\Delta E_T = E_T(\text{raw}) - E_T(\text{corr.})$. Jet energy corrections are applied as described above. The $\not\!\!E_T$ is corrected by adding to it the energy differences ΔE_T vectorially. We then demand $\not\!\!E_T$ (corr.) ≥ 20 GeV.

Cosmic rejection: On muon data only we use the cosmic tagger flag to reject cosmic ray events. Certain quantities used for cosmic rejection are not well modelled by the Monte Carlo detector simulation. Therefore, we do not include the cosmic rejection in the Monte Carlo acceptance calculation. The signal loss for W+2 jet events was estimated from data and is 1.23%. [25]. This has to be included as an additional factor in the event detection efficiency.

Further cuts:

- Dilepton rejection: We require one and only one tight lepton (`TN->summary_fnTightLepton[0]==1`). We also veto events where an additional electron candidate is found in the forward (plug) calorimeters, (PHX electrons).

- Z boson rejection: In addition, we veto events, if we find a second, loosely identified lepton candidate, that forms an invariant mass with the primary lepton between $76 < M_{\ell\ell} < 106$ GeV/c^2. In TopNtuple this is implemented as `(TN->summary_fTopEventClass[0]&0x8)==0`.

- B-tag requirement: At least one jet must be identified as likely to contain a b-quark (`TN->jet_secvTag[nj]==1`). The b-tagging relies on the reconstruction of displaced secondary vertices with the silicon microstrip detector. Secondary vertices with a transverse decay length significance ($\Delta L_{xy}/\sigma_{xy}$) above 3 are accepted as a b-tag for jets. For consistency we require that the charged lepton z_0 is within a window of 5 cm around the primary vertex used for b-tagging.

2.2 Top Mass Reconstruction

One important requirement to establish the production of a certain elementary particle is to reconstruct one of its most distinct features, its invariant mass. In the standard model top quark decay is dominated by the mode $t \to b + W$, which has a branching ratio close to 100%. In our analysis we reconstruct leptonic W boson decays. We therefore reconstruct $M_{\ell\nu b}$ as an estimator for m_{top}.

b-jet assignment: The first step to calculate the top quark mass is to reconstruct the b-quark 4-momentum vector. Our event selection criteria require at least one b-tagged jet be present. If there is one and only one b-tagged jet in the event, this jet is used for top mass reconstruction. If there are more b-tagged jets, we pick the b-jet which has maximum $Q\,\eta$. Q is the lepton charge (in units of the elementary charge e) and is used to tag top and anti-top events. η is the pseudo-rapidity of the b-jet. The b-jet 3-momentum vector $\vec{p}$ is corrected by a scale factor obtained from the jet corrections. We use jet corrections level 7, which includes all available corrections. We set the b-jet mass to $m_{\mathrm{b-jet}} = 5$ GeV, and calculate the energy: $E_b^2 = m_{\mathrm{b-jet}}^2 + \vec{p}^2$.

The second step is to reconstruct the W boson 4-momentum. Our event selection is such that we allow one and only one tight charged lepton (e or μ) in our events. The neutrino remains undetected. In reasonably good approximation the transverse momentum, p_t, of the neutrino is given by the missing transverse energy $\not{E}_T$, as obtained from calorimeter information. To improve the precision on the $\not{E}_T$ measurement three corrections are applied. The first two are the same as described in section 2.1. The jet energy correction, however, has to be consistent with the fact that we use level 7 corrections for the b-jet. In contrast to the $\not{E}_T$ corrections described in section 2.1 we therefore use correction level 6 for the jets. We do not use level 7 corrections because they include out-of-cone corrections. Using them in the $\not{E}_T$ calculation would mean double-counting out-of-cone energies.

Calculating the neutrino $\mathbf{p_z}$ component: The z-component of the neutrino momentum is unknown. However, under the assupmtion that we are dealing with a real leptonic W boson event the neutrino p_z can be calculated up to a two-fold uncertainty using the following kinematic constraints:

$$p_\mu(W) = p_\mu(\ell) + p_\mu(\nu) \qquad\qquad p_\mu(\nu)\,p^\mu(\nu) = 0 \tag{1}$$

Solving for $p_z(\nu)$ gives:

$$\begin{aligned} p_z(\nu) &= \frac{\kappa\, p_z(\ell)}{E^2(\ell) - p_z^2(\ell)} \pm \frac{1}{2\left(E^2(\ell) - p_z^2(\ell)\right)} \qquad (2)\\ &\quad \cdot\sqrt{\left(2\kappa p_z(\ell)\right)^2 - 4\left(E^2(\ell)p_T^2(\nu) - \kappa^2\right)\cdot\left(E^2(\ell) - p_z^2(\ell)\right)} \\ \text{with } \kappa &= 0.5\left(M_W^2 - m_\ell^2\right) + \cos\left(\phi_\ell - \phi_\nu\right)\cdot p_T(\ell)\,p_T(\nu) \qquad (3) \end{aligned}$$

For the calculation we use $p_T(\nu) = \not{E}_T$. Out of the two solutions we choose the one which has the smallest absolute value. If the p_z turns out to be complex with non-zero imaginary part (the expression beneath the square root is negative) we use only the real part of p_z. That happens in about 30% of the cases (for single top production; number obtained from Monte Carlo) due to detector mismeasurements (fully compatible with the detector resolution). We use $M_W = 80.448$ GeV, $m_\mu = 0.105658$ GeV and $m_e = 0.000511$ GeV. We calculate the neutrino energy using:

$$E(\nu) = \sqrt{\not{E}_T{}^2 + p_z^2} \tag{4}$$

We calculate the invariant mass of the charged lepton, the neutrino and the b-jet $M_{\ell\nu b}$ which for signal events estimates the top quark mass.

3 Single Top Signal Acceptances

3.1 Cut Flow

Following is a brief discussion of the sequence of cuts used in this study. The cut flow is shown in Tables 4. The number of Monte Carlo generated events is given in the line named `Total`. We first select events which have the OBSV vertex in the fiducial volume of the detector: $|z_0| < 60$ cm. We then select events which have at least one tight electron according to the TopEventModule classification. Next we impose the additional lepton identification requirements. For the $\not\!\!E_T$ selection we apply jet corrections as described in section 2.1. We require one and only one tight lepton per event, which we call `Tight Di-Lepton Veto`. After the di-lepton veto we subdivide the events in three categories according to the subsystem where the tight lepton was detected: `CEM`, `CMUP` and `CMX`. We also veto events which have an additional Phoenix electron in the plug, `PHX Veto`. For CEM events there is an additional conversion veto. In addition, we apply a Z^0 veto which is described in Ref. [23]. The number of events passing the requirement $\not\!\!E_T \geq 20$ GeV is given in the line `Missing Et`. The number of events that have a positive tag for at least one taggable jet is given in the line denoted `b tag` $\geq$ `1`. The final requirement concerns the reconstructed top quark mass $M_{l\nu b}$, and retains only events in which $140 < M_{l\nu b} < 210$ (GeV/c^2). For the t-channel search only we apply an additional cut: We require at least one jet to have $E_T > 30$ GeV.

Cut	0 jet	1 jet	2 jet	3 jet	4 jet	≥ 5 jets	all
Total	3013	37733	82673	33931	5072	815	163237
OBSV < 60.0	2925	36682	80173	32425	4853	774	157832
≥ 1 Tight Std. lepton	1156	13997	27062	3798	568	78	46659
≥ 1 with add. ID cuts	852	10358	20377	2862	428	58	34935
CEM electrons							
Tight Di-Lepton Veto	457	5879	11583	1580	235	35	19769
PHX Veto	455	5876	11580	1579	235	35	19760
Z Vertex Cut	455	5876	11579	1579	235	35	19759
Conversion veto	452	5863	11545	1574	235	35	19704
Z veto	449	5801	11349	1545	230	35	19409
Missing Et	421	5202	10259	1402	201	30	17515
b tag ≥ 1	0	1663	4251	692	119	13	6738
b-tag=1 or 2	0	1663	4251	691	119	13	6737
$140 \leq M_{b\ell\nu} \leq 210$	0	1385	3563	487	70	10	5515
$\mathsf{E_T(Jet1)} \geq 30$ GeV	0	1283	3442	478	69	10	5282
CMUP muons							
Tight Di-Lepton Veto	269	3209	6426	941	133	17	10995
PHX Veto	269	3206	6425	941	133	17	10991
Z Vertex Cut	269	3206	6425	941	133	17	10991
Z veto	266	3192	6375	933	131	17	10914
Missing Et	246	2839	5708	836	115	17	9761
b tag ≥ 1	0	893	2394	395	67	8	3757
b-tag=1 or 2	0	893	2394	395	67	8	3757
$140 \leq M_{b\ell\nu} \leq 210$	0	755	1999	280	34	6	3074
$\mathsf{E_T(Jet1)} \geq 30$ GeV	0	703	1954	274	32	6	2969
CMX muons							
Tight Di-Lepton Veto	124	1266	2368	341	60	6	4165
PHX Veto	124	1262	2368	341	60	6	4161
Z Vertex Cut	124	1262	2368	341	60	6	4161
Z veto	124	1253	2351	340	58	6	4132
Missing Et	114	1109	2055	296	50	6	3630
b tag ≥ 1	0	351	859	146	27	6	1389
b-tag=1 or 2	0	351	859	145	27	6	1388
$140 \leq M_{b\ell\nu} \leq 210$	0	280	723	94	17	4	1118
$\mathsf{E_T(Jet1)} \geq 30$ GeV	0	255	696	91	17	4	1063
All							
Tight Di-Lepton Veto	850	10354	20377	2862	428	58	34929
PHX Veto	848	10344	20373	2861	428	58	34912
Z Vertex Cut	848	10344	20372	2861	428	58	34911
Conversion veto	845	10331	20338	2856	428	58	34856
Z veto	839	10246	20075	2818	419	58	34455
Missing Et	781	9150	18022	2534	366	53	30906
b tag ≥ 1	0	2907	7504	1233	213	27	11884
b-tag=1 or 2	0	2907	7504	1231	213	27	11882
$140 \leq M_{b\ell\nu} \leq 210$	0	2420	6285	861	121	20	9707
$\mathsf{E_T(Jet1)} \geq 30$ GeV	0	2241	6092	843	118	20	9314

Table 4: Cut flow table of single top event selection for t-channel single top-quark Monte Carlo events.

CEM electrons

Cut	0 jet	1 jet	2 jet	3 jet	4 jet	≥ 5 jets	All
b tag = 1	0	1385	3526	431	58	8	5408
Jet 1 $E_t \geq 30$ GeV	0	1283	3407	423	57	8	5178
b tag = 2	0	0	37	56	12	2	107

CMUP muons

Cut	0 jet	1 jet	2 jet	3 jet	4 jet	≥ 5 jets	All
b tag = 1	0	755	1981	252	27	5	3020
Jet 1 $E_t \geq 30$ GeV	0	703	1938	247	26	5	2919
b tag = 2	0	0	18	28	7	1	54

CMX muons

Cut	0 jet	1 jet	2 jet	3 jet	4 jet	≥ 5 jets	All
b tag = 1	0	280	714	81	12	4	1091
Jet 1 $E_t \geq 30$ GeV	0	255	687	78	12	4	1036
b tag = 2	0	0	9	13	5	0	27

All

Cut	0 jet	1 jet	2 jet	3 jet	4 jet	≥ 5 jets	All
b tag = 1	0	2420	6221	764	97	17	9519
Jet 1 $E_t \geq 30$ GeV	0	2241	6032	748	95	17	9133
b tag = 2	0	0	64	97	24	3	188

Table 5: Cut flow table of single top separate search. We show the cut flow for the additional cuts applied after the $M_{\ell\nu b}$ cut. The lines with "`b-tag = 1`" give the number of events in the 1-b-tag bin. The lines with "`Jet 1` E_t $\geq$ `30 GeV`" give the number of events in the 1-b-tag bin after the extra cut on the leading jet E_T. The lines named "`b tag = 2`" give the number of events in the double-tag-bin.

4 Event Detection Efficiency

The final aim of our analysis is to calculate the single top quark production cross section σ_{st}. The calculation is based on the following formula:

$$\sigma_{st} = \frac{N_{\text{signal}}}{\epsilon_{\text{evt}} \cdot \int \mathcal{L}\, dt} \tag{5}$$

Here N_{signal} is the number of observed signal events, which we obtain for example from a maximum likelohood fit. ϵ_{evt} is the event detection efficiency which is the average probability of a single top event to be detected, i.e. to be found in our selected candidate sample. $\int \mathcal{L}\, dt$ is the integrated luminosity, which we will abbreviate as $\mathcal{L}_{\mathsf{int}}$ in the paragraphs below.

At the current stage the integrated luminosity of CDF is not high enough to make a measurement of σ_{st} which is significantly different from 0. Therefore, we will set an upper limit on the cross-section. For this (5) is not directly used. However, we will use (5) to calculate the number of expected signal events. For this purpose it takes the form:

$$\mathsf{N}_{\mathsf{signal}}^{\mathsf{predict}} = \sigma_{st}^{\mathsf{theo}} \cdot \epsilon_{\text{evt}} \cdot \mathcal{L}_{\mathsf{int}} \tag{6}$$

The purpose of this note is to document the calculation of ϵ_{evt}, the event detection efficiency. This is done using the Monte Carlo samples listed in Tab. 1. ϵ_{evt} can be decomposed into 4 factors:

$$\epsilon_{\mathsf{evt}} = \epsilon_{\mathsf{evt}}^{\mathsf{MC}} \cdot \epsilon_{\mathsf{BR}} \cdot \epsilon_{\mathsf{corr}} \cdot \epsilon_{\mathsf{trig}} \tag{7}$$

Here ϵ_{evt}^{MC} is the event detection efficiency as we obtain it from our samples of simulated events. In some of these samples the W boson was only allowed to decay into leptons: $W \rightarrow e/\mu/\tau + \nu$. This has to be taken into account by applying the factor $\epsilon_{\mathsf{BR}} = 0.3204$ [29]. ϵ_{corr} is a correction factor which takes into account the difference between simulated and data events. ϵ_{corr} gives a measure how well the Monte Carlo simulation models the detector. ϵ_{trig} is the trigger efficiency. The correction factor is again composed out of several parts:

$$\epsilon_{\mathsf{corr}} = \frac{\epsilon_{\mathsf{z0}}^{\mathsf{data}}}{\epsilon_{\mathsf{z0}}^{\mathsf{MC}}} \cdot \frac{\epsilon_{\mathsf{leptonid}}^{\mathsf{data}}}{\epsilon_{\mathsf{leptonid}}^{\mathsf{MC}}} \cdot \frac{\epsilon_{\mathsf{reco}}^{\mathsf{data}}}{\epsilon_{\mathsf{reco}}^{\mathsf{MC}}} \cdot \frac{\epsilon_{\mathsf{tag}}^{\mathsf{data}}}{\epsilon_{\mathsf{tag}}^{\mathsf{MC}}} \tag{8}$$

Since trigger and id efficiencies vary for different subdetectors (we use CEM, CMU/CMP and CMX), we have different ϵ_{evt} in the three cases: $\epsilon_{\mathsf{evt}}^{\mathsf{CEM}}$, $\epsilon_{\mathsf{evt}}^{\mathsf{CMUP}}$ and $\epsilon_{\mathsf{evt}}^{\mathsf{CMX}}$. The determination of $\epsilon_{\mathsf{evt}}^{\mathsf{MC}}$ from Monte Carlo simulations will be discussed in the next section. We use the following values for the trigger efficienies and reconstruction and identification scale factors which were derived from data [30, 31, 32]:

- $\epsilon_{z0}^{data} = 0.951 \pm 0.001 \pm 0.005$ is the z vertex cut efficiency in data [28]. In Monte Carlo we obtain $\epsilon_{z0}^{MC} = 0.965 \pm 0.003(stat.)$ for the MadEvent and TopRex samples and $\epsilon_{z0}^{MC} = 0.967 \pm 0.003(stat.)$ for the Pythia samples ttop0s and ttop1s. The correction factors therefore are: $\epsilon_{z0}^{data}/\epsilon_{z0}^{MC} = 0.986 \pm 0.006$ and $\epsilon_{z0}^{data}/\epsilon_{z0}^{MC} = 0.983 \pm 0.006$.

- The b-tagging efficiency differs between data and Monte Carlo. Therefore, we need to correct our acceptance calculation which is based on Monte Carlo events.

Efficiencies	CEM	CMUP	CMX
Trigger	$\epsilon_{trig}^{\rm CEM} = 0.9656 \pm 0.0006$	$\epsilon_{trig}^{\rm CMUP} = 0.887 \pm 0.007$	$\epsilon_{trig}^{\rm CMX} = 0.954 \pm 0.006$
ID s. f.	$\epsilon_{ID}^{\rm CEM} = 0.965 \pm 0.006$	$\epsilon_{ID}^{\rm CMUP} = 0.939 \pm 0.007$	$\epsilon_{ID}^{\rm CMX} = 1.014 \pm 0.007$
Reco s. f.	$\epsilon_{reco}^{\rm CEM} = 1.0$ per def.	$\epsilon_{reco}^{\rm CMUP} = 0.945 \pm 0.006$	$\epsilon_{reco}^{\rm CMX} = 0.992 \pm 0.003$

Table 6: Electron and muon trigger efficiencies and ID efficiency scale (correction) factors for 200 pb^{-1}.

$\epsilon_{tag-jet}^{data}/\epsilon_{tag-jet}^{MC} = 0.82 \pm 0.06$ is the corrections factor for b-tagging efficiency [36]. This correction factor is valid per tagged b-jet. If a Monte Carlo sample contained only events with one and only one b-jet per event, the factor would be applicable globally. However, since there are also double-tag events the global correction factor has to be determined. One method is the counting method as described in Ref. [37]. We applied this method to our Monte Carlo samples. Each b-tagged jet is considered individually. Randomly we discard $1 - \epsilon_{\sf tag}^{\sf data}/\epsilon_{\sf tag}^{\sf MC} = 18\%$ of the jets and count the remaining events with at least one b-jet. The results on the global correction factor $K = \epsilon_{tag,global}^{data}/\epsilon_{tag,global}^{MC}$ are given in Table 7 for 3 cases: (1) 1 or 2 b-tags (K_{12}), (2) exactly 1 b-tag (K_1), (3) exactly 2 b-tags (K_2).

B-tag Efficiencies				
Process	Sample	K_{12}	K_1	K_2
t-chan.	mtop0s/1s	0.8255	0.8304	0.6396
s-chan.	mtop2s	0.8489	0.891	0.6808
t-chan.	rtop0s/1s	0.8259	0.8319	0.6625
s-chan.	rtop2s	0.8503	0.894	0.6741
t-chan.	ttop1s	0.8215	0.8229	0.7229
s-chan.	ttop0s	0.8543	0.9021	0.6628

Table 7: Correction factor for b-tagging efficiency of the various single top samples.

For the t-channel K_{12} and K_1 are only little higher than 81%, since there is only one central high-p_T b-jet in the event. For the s-channel the correction factor is about 88% because there are two b-jets in the event.

4.1 Determination of $\epsilon_{\sf evt}^{\sf MC}$

We determine the event detection efficiency based on Monte Carlo events. We apply all selection and identification cuts to our simulated data. Tab. 8 summarizes the number of remaining events in the 2-Jet bin, after b-tagging (N_{btag}), after the $M_{\ell\nu b}$ cut, after the additional cut on the first jet E_T (N_{jet1}), after $M_{\ell\nu b}$ cut in the 1-b-tag bin (N_{1tag}), after the $M_{\ell\nu b}$ and E_T(jet1) cut in the 1-b-tag bin ($N_{1tag,ET}$) and after $M_{\ell\nu b}$ cut in the 2-b-tag bin (N_{2tag}).

	MadEvent		TopRex		Pythia	
Process	t-chan.	s-chan.	t-chan.	s-chan.	t-chan.	s-chan.
ID	mtop0s/1s	mtop2s	rtop0s/1s	rtop2s	ttop1s	ttop0s
N_{tot}	163237	199953	213586	200107	499189	440000
N_{obsv}	157832	192931	206333	193052	482770	425541
CEM Electrons						
N_{btag}	4251	7706	3827	7354	3914	4622
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	3563	5068	3053	4896	3300	3067
N_{jet1}	3442	4904	2966	4749	3212	2974
N_{1tag}	3526	3686	3017	3626	3288	2280
$N_{\mathsf{1tag,ET}}$	3407	3555	2931	3498	3200	2201
N_{2tag}	37	1382	36	1270	12	787
CMUP Muons						
N_{btag}	2394	4253	2135	4302	2437	2787
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	1999	2748	1669	2887	2012	1846
N_{jet1}	1954	2661	1617	2809	1953	1795
N_{1tag}	1981	2022	1639	2171	2002	1385
$N_{\mathsf{1tag,ET}}$	1938	1952	1588	2104	1943	1344
N_{2tag}	18	726	30	716	10	461
CMX Muons						
N_{btag}	859	1579	947	1653	861	1135
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	723	1050	753	1087	747	770
N_{jet1}	696	1011	733	1049	727	747
N_{1tag}	714	779	734	853	744	564
$N_{\mathsf{1tag,ET}}$	687	747	714	822	724	545
N_{2tag}	9	271	19	234	3	206
ALL						
N_{btag}	7504	13538	6909	13309	7212	8544
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	6285	8866	5475	8870	6059	5683
N_{jet1}	6092	8576	5316	8607	5892	5516
N_{1tag}	6221	6487	5390	6650	6034	4229
$N_{\mathsf{1tag,ET}}$	6032	6254	5233	6424	5867	4090
N_{2tag}	64	2379	85	2220	25	1454

Table 8: Number of Monte Carlo events after event selection in the 2-jets bin.

We give all these different numbers because we plan to reoptimize the final cuts within the given choices. Using the numbers in Tab. 8 we calculate the Monte Carlo event detection efficiency $\epsilon_{\mathsf{evt}}^{\mathsf{MC}}$ which is given in Tab. 9.

Monte Carlo Event Detection Efficiency in %						
	MadEvent		TopRex		Pythia	
Sample	t-chan.	s-chan.	t-chan.	s-chan.	t-chan.	s-chan.
CEM Electrons						
ϵ_{btag}	0.83	1.23	0.57	1.18	0.78	1.05
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.70	0.81	0.46	0.78	0.66	0.70
ϵ_{jet1}	0.68	0.79	0.44	0.76	0.64	0.68
ϵ_{1tag}	0.69	0.59	0.45	0.58	0.66	0.52
$\epsilon_{\mathsf{1tag,ET}}$	0.67	0.57	0.44	0.56	0.64	0.50
ϵ_{2tag}	0.01	0.22	0.01	0.20	0.00	0.18
CMUP Muons						
ϵ_{btag}	0.47	0.68	0.32	0.69	0.49	0.63
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.39	0.44	0.25	0.46	0.40	0.42
ϵ_{jet1}	0.38	0.43	0.24	0.45	0.39	0.41
ϵ_{1tag}	0.39	0.32	0.25	0.35	0.40	0.31
$\epsilon_{\mathsf{1tag,ET}}$	0.38	0.31	0.24	0.34	0.39	0.31
ϵ_{2tag}	0.00	0.12	0.00	0.11	0.00	0.10
CMX Muons						
ϵ_{btag}	0.17	0.25	0.14	0.26	0.17	0.26
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.14	0.17	0.11	0.17	0.15	0.18
ϵ_{jet1}	0.14	0.16	0.11	0.17	0.15	0.17
ϵ_{1tag}	0.14	0.12	0.11	0.14	0.15	0.13
$\epsilon_{\mathsf{1tag,ET}}$	0.13	0.12	0.11	0.13	0.15	0.12
ϵ_{2tag}	0.00	0.04	0.00	0.04	0.00	0.05
ALL						
ϵ_{btag}	1.47	2.17	1.04	2.13	1.44	1.94
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	1.23	1.42	0.82	1.42	1.21	1.29
ϵ_{jet1}	1.20	1.37	0.80	1.38	1.18	1.25
ϵ_{1tag}	1.22	1.04	0.81	1.06	1.21	0.96
$\epsilon_{\mathsf{1tag,ET}}$	1.18	1.00	0.79	1.03	1.18	0.93
ϵ_{2tag}	0.01	0.38	0.01	0.36	0.01	0.33

Table 9: $\epsilon_{\mathsf{evt}}^{\mathsf{MC}} \cdot \epsilon_{\mathsf{BR}}$ for single top Monte Carlo samples. The statistical error on the efficiencies is 0.01% or less.

4.2 Determination of ϵ_{evt}

To convert $\epsilon_{\mathsf{evt}}^{\mathsf{MC}} \cdot \epsilon_{\mathsf{BR}}$ into ϵ_{evt} we need to calculate ϵ_{corr} first. We have to do that for each sample separately, since the b-tagging efficiency per event depends on the sample. To cover the different cut scenarios we also have to give the numbers for (1) more than 1 b-tag, (2) exactly 1 b-tag and (2) exactly two b-tags. We calculate the errors on ϵ_{corr} by adding the relative errors on $\epsilon^{\mathsf{data}}_{\mathsf{z0}}/\epsilon^{\mathsf{MC}}_{\mathsf{z0}}$, $\epsilon^{\mathsf{data}}_{\mathsf{leptonid}}/\epsilon^{\mathsf{MC}}_{\mathsf{leptonid}}$, $\epsilon^{\mathsf{data}}_{\mathsf{reco}}/\epsilon^{\mathsf{MC}}_{\mathsf{reco}}$ and $\epsilon^{\mathsf{data}}_{\mathsf{tag}}/\epsilon^{\mathsf{MC}}_{\mathsf{tag}}$. We present the results on ϵ_{corr} including the errors in Tab. 10.

Correction Factor Monte Carlo to Data						
	MadEvent		TopRex		Pythia	
Sample	t-chan.	s-chan.	t-chan.	s-chan.	t-chan.	s-chan.
Sample	mtop0s/1s	mtop2s	rtop0s/1s	rtop2s	ttop1s	ttop0s
CEM Electrons						
btag ≥ 1	0.784±0.058	0.807±0.059	0.785±0.058	0.809±0.060	0.780±0.057	0.811±0.060
btag $== 1$	0.788±0.058	0.847±0.062	0.790±0.058	0.850±0.063	0.781±0.058	0.856±0.063
btag $== 2$	0.607±0.045	0.648±0.048	0.629±0.046	0.641±0.047	0.686±0.051	0.629±0.046
CMUP Muons						
btag ≥ 1	0.720±0.053	0.742±0.055	0.721±0.053	0.744±0.055	0.717±0.053	0.745±0.055
btag $== 1$	0.725±0.054	0.779±0.058	0.727±0.054	0.782±0.058	0.718±0.053	0.787±0.058
btag $== 2$	0.558±0.041	0.595±0.044	0.579±0.043	0.590±0.044	0.631±0.047	0.578±0.043
CMX Muons						
btag ≥ 1	0.817±0.060	0.842±0.062	0.818±0.060	0.843±0.062	0.813±0.060	0.845±0.062
btag $== 1$	0.822±0.061	0.883±0.065	0.824±0.061	0.886±0.065	0.814±0.060	0.892±0.066
btag $== 2$	0.633±0.047	0.675±0.050	0.656±0.048	0.668±0.049	0.715±0.053	0.656±0.048

Table 10: ϵ_{corr} for single top Monte Carlo samples.

Having calculated ϵ_{corr} we can now compute ϵ_{evt} based on (7). The result is presented in Tab. 11. Using the values for ϵ_{evt} we calculate the number of expected events according to (6), these results are shown in Tab. 12.

Event Detection Efficiency in %						
	MadEvent		TopRex		Pythia	
Process	t-chan.	s-chan.	t-chan.	s-chan.	t-chan.	s-chan.
Sample	mtop0s/1s	mtop2s	rtop0s/1s	rtop2s	ttop1s	ttop0s
CEM Electrons						
ϵ_{btag}	0.631±0.048	0.963±0.073	0.435±0.033	0.920±0.069	0.590±0.045	0.822±0.062
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.529±0.040	0.633±0.048	0.347±0.027	0.612±0.046	0.498±0.038	0.546±0.041
ϵ_{jet1}	0.511±0.039	0.613±0.046	0.337±0.026	0.594±0.045	0.484±0.037	0.529±0.040
ϵ_{1tag}	0.527±0.040	0.483±0.037	0.345±0.027	0.477±0.036	0.497±0.038	0.428±0.033
$\epsilon_{\mathsf{1tag,ET}}$	0.509±0.039	0.466±0.036	0.336±0.026	0.460±0.035	0.483±0.037	0.413±0.032
ϵ_{2tag}	0.004±0.001	0.138±0.011	0.003±0.001	0.126±0.010	0.002±0.000	0.109±0.009
CMUP Muons						
ϵ_{btag}	0.300±0.023	0.449±0.035	0.205±0.016	0.454±0.035	0.310±0.024	0.419±0.032
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.251±0.020	0.290±0.023	0.160±0.013	0.305±0.024	0.256±0.020	0.277±0.022
ϵ_{jet1}	0.245±0.019	0.281±0.022	0.155±0.012	0.297±0.023	0.249±0.019	0.270±0.021
ϵ_{1tag}	0.250±0.020	0.224±0.018	0.158±0.013	0.241±0.019	0.255±0.020	0.220±0.017
$\epsilon_{\mathsf{1tag,ET}}$	0.245±0.019	0.216±0.017	0.154±0.012	0.234±0.018	0.248±0.019	0.213±0.017
ϵ_{2tag}	0.002±0.000	0.061±0.005	0.002±0.000	0.060±0.005	0.001±0.000	0.054±0.005
CMX Muons						
ϵ_{btag}	0.131±0.011	0.203±0.016	0.111±0.009	0.213±0.017	0.134±0.011	0.208±0.017
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.111±0.009	0.135±0.011	0.088±0.007	0.140±0.011	0.116±0.010	0.141±0.012
ϵ_{jet1}	0.106±0.009	0.130±0.011	0.086±0.007	0.135±0.011	0.113±0.009	0.137±0.011
ϵ_{1tag}	0.110±0.009	0.105±0.009	0.087±0.007	0.116±0.010	0.116±0.010	0.109±0.009
$\epsilon_{\mathsf{1tag,ET}}$	0.106±0.009	0.101±0.008	0.084±0.007	0.111±0.009	0.113±0.009	0.105±0.009
ϵ_{2tag}	0.001±0.000	0.028±0.003	0.002±0.000	0.024±0.002	0.000±0.000	0.029±0.003
ALL						
ϵ_{btag}	1.063±0.082	1.615±0.123	0.751±0.058	1.587±0.121	1.034±0.079	1.449±0.111
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.890±0.069	1.058±0.082	0.595±0.047	1.057±0.081	0.870±0.067	0.964±0.075
ϵ_{jet1}	0.863±0.067	1.024±0.079	0.578±0.045	1.026±0.079	0.846±0.065	0.936±0.073
ϵ_{1tag}	0.887±0.069	0.812±0.063	0.590±0.046	0.833±0.065	0.868±0.067	0.757±0.060
$\epsilon_{\mathsf{1tag,ET}}$	0.859±0.067	0.783±0.061	0.573±0.045	0.805±0.063	0.844±0.065	0.732±0.058
ϵ_{2tag}	0.007±0.002	0.228±0.019	0.007±0.001	0.210±0.017	0.003±0.001	0.192±0.017

Table 11: $\epsilon_{\mathsf{BR}} \cdot \epsilon_{\mathsf{evt}}^{\mathsf{MC}} \cdot \epsilon_{\mathsf{corr}} \cdot \epsilon_{\mathsf{trig}}$ for single top Monte Carlo samples.

	MadEvent		TopRex		Pythia	
Process	t-chan.	s-chan.	t-chan.	s-chan.	t-chan.	s-chan.
Sample	mtop0s/1s	mtop2s	rtop0s/1s	rtop2s	ttop1s	ttop0s
N_{btag}	3.37±0.55	2.29±0.37	2.38±0.39	2.24±0.36	3.28±0.53	2.05±0.33
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	2.82±0.46	1.50±0.24	1.88±0.31	1.50±0.24	2.76±0.45	1.36±0.22
N_{jet1}	2.74±0.45	1.45±0.24	1.83±0.30	1.45±0.24	2.68±0.44	1.32±0.22
N_{1tag}	2.81±0.46	1.15±0.19	1.87±0.31	1.18±0.19	2.75±0.45	1.07±0.17
$N_{\mathsf{1tag,ET}}$	2.72±0.44	1.11±0.18	1.81±0.30	1.14±0.19	2.67±0.44	1.03±0.17
N_{2tag}	0.02±0.01	0.32±0.05	0.02±0.01	0.30±0.05	0.01±0.00	0.27±0.05

Table 12: Number of expected events for single top Monte Carlo samples.

5 $t\bar{t}$ background

5.1 $t\bar{t}$ cross-section

In $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV top quark production is dominated by $t\bar{t}$-pair production via the strong interaction. Quark-antiquark annihilation is the dominating sub-process, contributing about 85% of the cross-section. NLO corrections to the cross section are available since the late 1980's [26, 27]. More recent calculations try to improve the predictions by resumming leading and next-to-leading logarithmic terms in the cross-section which mainly originate from soft initial-state gluon bremsstrahlung. Table 13 shows the predictions of three different groups for $m_{\mathrm{top}} = 175$ GeV. The results of Berger and Con-

	m_{top}	$\sigma_{t\bar{t}}$	Ref.
Berger and Conto.	175 GeV	$7.15^{+0.09}_{-0.55}$ pb	[3]
Bonciani et al.	175 GeV	$6.70^{+0.71}_{-0.88}$ pb	[4, 5]
Kidonakis	175 GeV	6.77 ± 0.42 pb	[6]
Bonciani et al.	170 GeV	$7.83^{+0.86}_{-1.04}$ pb	[4, 5]
Bonciani et al.	180 GeV	$5.75^{+0.59}_{-0.75}$ pb	[4, 5]

Table 13: Cross-section predictions by three different groups of theorists for $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

topanagos (BECO) were scaled down from their predictions for $\sqrt{s} = 2.00$ TeV. In our analysis we use the prediction by Bonciani et al. (BCMN) [4, 5] to calculate the number of expected $t\bar{t}$ events. Two reasons motivate that decision:

1. BCMN work with the most recent set of PDFs.
2. The error assigned by BCMN includes systematic uncertainties due to the choice of the PDF.

To take into account different predictions by BECO and Kidonakis we assign half the difference between BCMN and BECO as additional systematic uncertainty $\Delta_2 = 0.23$ pb and add it quadrature to the error assigned by BCMN. Since we use a Gaussian constraint on the background in our analysis we also need to symmetrize the errors. We do that by taking the average between the negative and positive errors. Additionally, we need to add the uncertainty in $\sigma_{t\bar{t}}$ due to the top mass uncertainty $\Delta m_{\mathrm{top}} = 5$ GeV. We take the average difference between the cross section for 170/175 GeV and 180/175 GeV, which is $\Delta_3 = 1.04$ GeV. Adding all three uncertainties in quadrature we get:

$$\Delta\sigma_{t\bar{t}} = \sqrt{0.795^2 + 0.23^2 + 1.04^2}\ \mathrm{pb} = 1.32\ \mathrm{pb} \tag{9}$$

Thus, we use $\sigma_{t\bar{t}} = (6.70 \pm 1.32)$ pb. Including the scaled uncertainty due to the other theoretical predictions (also for $m_{\mathrm{top}} = 170, 180$ GeV) we get the numbers given in Table 14.

170 GeV	(7.83 ± 1.54) pb
175 GeV	(6.70 ± 1.32) pb
180 GeV	(5.75 ± 1.13) pb

Table 14: Cross-section predictions used in our analysis to predict the number of $t\bar{t}$ background events.

ϵ_{evt}: We calculate ϵ_{evt} for $t\bar{t}$ events using the Pythia Carlo program. We use the 398037 events of the *ttopei* sample. The number of Monte Carlo events for our six cut scenarios are listed in Tab. 15. The Monte Carlo event detection efficiency is give in Tab. 16. The b-tagging scale factors are given in Tab. 17. The correction factors ϵ_{corr} are listed in in Tab. 18. The event detection efficiency ϵ_{evt} can be found in Tab. 19. The number of expected events are given in Tab. 20. For the Gauss constraint we include the systematic uncertainties due to the event generator and the top mass uncertainty. The final numbers used in the Gauss contraint are given in Tab. 21.

	$t\bar{t}$ samples			
Process	ttbar Pythia	Herwig	Herwig, 170	Herwig, 180
ID	ttopei	ttopli	ttoppk	ttopsk
N_{tot}	398037	378471	206958	208000
N_{obsv}	384875	365743	199998	200976
CEM Electrons				
N_{btag}	2197	2074	1151	1150
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	1020	996	591	513
N_{jet1}	994	969	572	501
N_{1tag}	825	801	478	403
$N_{\mathsf{1tag,ET}}$	801	777	460	393
N_{2tag}	195	195	113	110
CMUP Muons				
N_{btag}	1292	1263	695	706
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	644	613	356	320
N_{jet1}	627	593	344	314
N_{1tag}	509	496	288	259
$N_{\mathsf{1tag,ET}}$	494	479	277	253
N_{2tag}	135	117	68	61
CMX Muons				
N_{btag}	497	497	252	262
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	237	262	126	121
N_{jet1}	233	258	121	118
N_{1tag}	187	207	99	99
$N_{\mathsf{1tag,ET}}$	184	203	94	96
N_{2tag}	50	55	27	22
ALL				
N_{btag}	3986	3834	2098	2118
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	1901	1871	1073	954
N_{jet1}	1854	1820	1037	933
N_{1tag}	1521	1504	865	761
$N_{\mathsf{1tag,ET}}$	1479	1459	831	742
N_{2tag}	380	367	208	193

Table 15: Number of Monte Carlo events after event selection in the 2-jets bin.

Monte Carlo Event Detection Efficiency in %				
	$t\bar{t}$ samples			
Sample	ttbar Pythia	Herwig	Herwig, 170	Herwig, 180
CEM Electrons				
ϵ_{btag}	0.55	0.55	0.56	0.55
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.26	0.26	0.29	0.25
ϵ_{jet1}	0.25	0.26	0.28	0.24
ϵ_{1tag}	0.21	0.21	0.23	0.19
$\epsilon_{\mathsf{1tag,ET}}$	0.20	0.21	0.22	0.19
ϵ_{2tag}	0.05	0.05	0.05	0.05
CMUP Muons				
ϵ_{btag}	0.32	0.33	0.34	0.34
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.16	0.16	0.17	0.15
ϵ_{jet1}	0.16	0.16	0.17	0.15
ϵ_{1tag}	0.13	0.13	0.14	0.12
$\epsilon_{\mathsf{1tag,ET}}$	0.12	0.13	0.13	0.12
ϵ_{2tag}	0.03	0.03	0.03	0.03
CMX Muons				
ϵ_{btag}	0.12	0.13	0.12	0.13
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.06	0.07	0.06	0.06
ϵ_{jet1}	0.06	0.07	0.06	0.06
ϵ_{1tag}	0.05	0.05	0.05	0.05
$\epsilon_{\mathsf{1tag,ET}}$	0.05	0.05	0.05	0.05
ϵ_{2tag}	0.01	0.01	0.01	0.01
ALL				
ϵ_{btag}	1.00	1.01	1.01	1.02
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.48	0.49	0.52	0.46
ϵ_{jet1}	0.47	0.48	0.50	0.45
ϵ_{1tag}	0.38	0.40	0.42	0.37
$\epsilon_{\mathsf{1tag,ET}}$	0.37	0.39	0.40	0.36
ϵ_{2tag}	0.10	0.10	0.10	0.09

Table 16: $\epsilon_{\mathsf{evt}}^{\mathsf{MC}} \cdot \epsilon_{\mathsf{BR}}$ for $t\bar{t}$ Monte Carlo samples. The statistical error on the efficiencies is 0.01% or less.

B-tag Efficiencies				
Process	Sample	K_{12}	K_1	K_2
ttbar Pythia	ttopei	0.8566	0.9155	0.6729
Herwig	ttopli	0.8584	0.9211	0.6636
Herwig, 170	ttoppk	0.8562	0.9117	0.6815
Herwig, 180	ttopsk	0.8565	0.9128	0.6811

Table 17: Correction factor for b-tagging efficiency of the various $t\bar{t}$ samples.

Correction Factor Monte Carlo to Data				
	$t\bar{t}$ samples			
Sample	ttbar Pythia	Herwig	Herwig, 170	Herwig, 180
Sample	ttopei	ttopli	ttoppk	ttopsk
CEM Electrons				
btag ≥ 1	0.813±0.060	0.815±0.060	0.813±0.060	0.813±0.060
btag == 1	0.869±0.064	0.875±0.064	0.866±0.064	0.867±0.064
btag == 2	0.639±0.047	0.630±0.046	0.647±0.048	0.647±0.048
CMUP Muons				
btag ≥ 1	0.748±0.055	0.750±0.056	0.748±0.055	0.748±0.055
btag == 1	0.799±0.059	0.804±0.060	0.796±0.059	0.797±0.059
btag == 2	0.587±0.044	0.579±0.043	0.595±0.044	0.595±0.044
CMX Muons				
btag ≥ 1	0.847±0.063	0.850±0.063	0.848±0.063	0.848±0.063
btag == 1	0.906±0.067	0.912±0.067	0.902±0.067	0.904±0.067
btag == 2	0.666±0.049	0.657±0.048	0.675±0.050	0.674±0.050

Table 18: ϵ_{corr} for $t\bar{t}$ Monte Carlo samples.

Event Detection Efficiency in %				
	$t\bar{t}$ samples			
Process	ttbar Pythia	Herwig	Herwig, 170	Herwig, 180
Sample	ttopei	ttopli	ttoppk	ttopsk
CEM Electrons				
ϵ_{btag}	0.433±0.033	0.431±0.033	0.437±0.035	0.434±0.035
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.201±0.016	0.207±0.017	0.224±0.019	0.194±0.017
ϵ_{jet1}	0.196±0.016	0.202±0.016	0.217±0.018	0.189±0.016
ϵ_{1tag}	0.174±0.014	0.179±0.015	0.193±0.017	0.162±0.014
$\epsilon_{\mathsf{1tag,ET}}$	0.169±0.014	0.173±0.014	0.186±0.016	0.158±0.014
ϵ_{2tag}	0.030±0.003	0.031±0.003	0.034±0.004	0.033±0.004
CMUP Muons				
ϵ_{btag}	0.215±0.017	0.222±0.018	0.223±0.019	0.225±0.019
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.107±0.009	0.108±0.009	0.114±0.010	0.102±0.010
ϵ_{jet1}	0.104±0.009	0.104±0.009	0.110±0.010	0.100±0.009
ϵ_{1tag}	0.091±0.008	0.094±0.008	0.098±0.009	0.088±0.009
$\epsilon_{\mathsf{1tag,ET}}$	0.088±0.008	0.090±0.008	0.095±0.009	0.086±0.008
ϵ_{2tag}	0.018±0.002	0.016±0.002	0.017±0.002	0.015±0.002
CMX Muons				
ϵ_{btag}	0.101±0.009	0.106±0.009	0.098±0.010	0.102±0.010
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.048±0.005	0.056±0.005	0.049±0.006	0.047±0.006
ϵ_{jet1}	0.047±0.005	0.055±0.005	0.047±0.006	0.046±0.005
ϵ_{1tag}	0.041±0.004	0.048±0.005	0.041±0.005	0.041±0.005
$\epsilon_{\mathsf{1tag,ET}}$	0.040±0.004	0.047±0.005	0.039±0.005	0.040±0.005
ϵ_{2tag}	0.008±0.001	0.009±0.001	0.008±0.002	0.007±0.002
ALL				
ϵ_{btag}	0.749±0.059	0.760±0.060	0.758±0.063	0.761±0.063
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.357±0.030	0.371±0.031	0.388±0.035	0.343±0.032
ϵ_{jet1}	0.348±0.029	0.361±0.030	0.375±0.034	0.335±0.031
ϵ_{1tag}	0.305±0.026	0.320±0.028	0.333±0.031	0.291±0.028
$\epsilon_{\mathsf{1tag,ET}}$	0.297±0.026	0.310±0.027	0.319±0.030	0.284±0.028
ϵ_{2tag}	0.056±0.006	0.056±0.007	0.060±0.008	0.055±0.008

Table 19: $\epsilon_{\mathsf{BR}} \cdot \epsilon_{\mathsf{evt}}^{\mathsf{MC}} \cdot \epsilon_{\mathsf{corr}} \cdot \epsilon_{\mathsf{trig}}$ for $t\bar{t}$ Monte Carlo samples.

	$t\bar{t}$ samples			
Process	ttbar Pythia	Herwig	Herwig, 170	Herwig, 180
Sample	ttopei	ttopli	ttoppk	ttopsk
N_{btag}	8.03±1.79	8.14±1.82	8.13±1.83	8.16±1.83
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	3.82±0.86	3.97±0.89	4.16±0.95	3.67±0.84
N_{jet1}	3.73±0.84	3.86±0.87	4.02±0.92	3.59±0.82
N_{1tag}	3.27±0.74	3.43±0.77	3.57±0.82	3.12±0.72
$N_{\mathsf{1tag,ET}}$	3.18±0.72	3.32±0.75	3.43±0.79	3.04±0.70
N_{2tag}	0.60±0.14	0.60±0.14	0.64±0.16	0.59±0.15

Table 20: Number of expected events for $t\bar{t}$ Monte Carlo samples.

$t\bar{t}$ final prediction		
Cut	ϵ_{evt}	N events
btag	0.749±0.060	8.03±1.80
M$\ell\nu$b	0.357±0.034	3.82±0.88
jet1	0.348±0.033	3.73±0.85
1tag	0.305±0.031	3.27±0.76
1tag, ET	0.297±0.030	3.18±0.74
2tag	0.056±0.007	0.60±0.14

Table 21: Summary of event detection efficiency and number of expected events for $t\bar{t}$ Monte Carlo samples.

6 Di-Boson Acceptance

To predict the number of di-boson events in our selected data sample we use the theoretical cross-sections predicted by Campbell and Ellis [38]:

$\sqrt{s}$	WW	WZ	ZZ
2.00 TeV	13.5 pb	4.02 pb	1.60 pb
1.96 TeV	13.30 pb	3.96 pb	1.57 pb

Campbell and Ellis give a relative error on the cross-sections of 3%. Their numbers are given for $\sqrt{s} = 2.00$ TeV. We rescale those numbers to 1.96 TeV. We take the mean of a linear and a quadratic interpolation. We calculate the number of expected di-boson events in the same way as for single to and $t\bar{t}$. The results are shown in the following tables: The number of Monte Carlo events for our six cut scenarios are listed in Tab. 22. The Monte Carlo event detection efficiency is give in Tab. 23. The b-tagging scale factors are given in Tab. 24. The correction factors ϵ_{corr} are listed in in Tab. 25. The event detection efficiency ϵ_{evt} can be found in Tab. 26. The number of expected events are given in Tab. 27 and Tab. 28.

Process	WW0p	WZ0p	ZZ0p
ID	atop4x	atop0y	atop0z
N_{tot}	944969	191011	223606
N_{obsv}	913775	184934	216547
CEM Electrons			
N_{btag}	1170	230	29
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	496	118	12
N_{jet1}	447	107	12
N_{1tag}	494	96	11
$N_{\mathsf{1tag,ET}}$	445	86	11
N_{2tag}	2	22	1
CMUP Muons			
N_{btag}	663	143	53
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	273	63	24
N_{jet1}	256	58	21
N_{1tag}	273	57	17
$N_{\mathsf{1tag,ET}}$	256	52	14
N_{2tag}	1	6	7
CMX Muons			
N_{btag}	307	69	17
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	134	32	8
N_{jet1}	120	28	8
N_{1tag}	132	28	7
$N_{\mathsf{1tag,ET}}$	119	24	7
N_{2tag}	2	4	1
ALL			
N_{btag}	2140	442	99
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	903	213	44
N_{jet1}	823	193	41
N_{1tag}	899	181	35
$N_{\mathsf{1tag,ET}}$	2	162	32
N_{2tag}	5	32	9

Table 22: Number of Monte Carlo events after event selection in the 2-jets bin.

Monte Carlo Event Detection Efficiency in %			
Sample	WW0p	WZ0p	ZZ0p
CEM Electrons			
ϵ_{btag}	0.04	0.12	0.01
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.02	0.06	0.01
ϵ_{jet1}	0.02	0.06	0.01
ϵ_{1tag}	0.02	0.05	0.00
$\epsilon_{\mathsf{1tag,ET}}$	0.02	0.05	0.00
ϵ_{2tag}	0.00	0.01	0.00
CMUP Muons			
ϵ_{btag}	0.02	0.07	0.02
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.01	0.03	0.01
ϵ_{jet1}	0.01	0.03	0.01
ϵ_{1tag}	0.01	0.03	0.01
$\epsilon_{\mathsf{1tag,ET}}$	0.01	0.03	0.01
ϵ_{2tag}	0.00	0.00	0.00
CMX Muons			
ϵ_{btag}	0.01	0.04	0.01
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.00	0.02	0.00
ϵ_{jet1}	0.00	0.01	0.00
ϵ_{1tag}	0.00	0.01	0.00
$\epsilon_{\mathsf{1tag,ET}}$	0.00	0.01	0.00
ϵ_{2tag}	0.00	0.00	0.00
ALL			
ϵ_{btag}	0.07	0.23	0.04
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.03	0.11	0.02
ϵ_{jet1}	0.03	0.10	0.02
ϵ_{1tag}	0.03	0.09	0.02
$\epsilon_{\mathsf{1tag,ET}}$	0.00	0.08	0.01
ϵ_{2tag}	0.00	0.02	0.00

Table 23: $\epsilon_{\mathsf{evt}}^{\mathsf{MC}} \cdot \epsilon_{\mathsf{BR}}$ for di-boson Monte Carlo samples. The statistical error on the efficiencies is 0.01% or less.

B-tag Efficiencies				
Process	Sample	K_{12}	K_1	K_2
WW0p	atop4x	0.8233	0.8242	0.6316
WZ0p	atop0y	0.8361	0.8551	0.6889
ZZ0p	atop0z	0.772	0.7714	0.7778

Table 24: Correction factor for b-tagging efficiency of the various di-boson samples.

Correction Factor Monte Carlo to Data			
Sample	WW0p	WZ0p	ZZ0p
Sample	atop4x	atop0y	atop0z
CEM Electrons			
btag $\geq$ 1	0.781±0.058	0.793±0.058	0.732±0.054
btag == 1	0.782±0.058	0.811±0.060	0.731±0.054
btag == 2	0.599±0.044	0.653±0.048	0.737±0.054
CMUP Muons			
btag $\geq$ 1	0.718±0.053	0.729±0.054	0.673±0.050
btag == 1	0.719±0.053	0.745±0.055	0.672±0.050
btag == 2	0.551±0.041	0.600±0.044	0.678±0.050
CMX Muons			
btag $\geq$ 1	0.814±0.060	0.826±0.061	0.763±0.056
btag == 1	0.815±0.060	0.845±0.062	0.762±0.056
btag == 2	0.625±0.046	0.681±0.050	0.768±0.057

Table 25: ϵ_{corr} for di-boson Monte Carlo samples.

Event Detection Efficiency in %			
Process	WW0p	WZ0p	ZZ0p
Sample	atop4x	atop0y	atop0z
CEM Electrons			
ϵ_{btag}	0.030±0.002	0.092±0.009	0.009±0.002
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.013±0.001	0.047±0.006	0.004±0.001
ϵ_{jet1}	0.011±0.001	0.043±0.005	0.004±0.001
ϵ_{1tag}	0.013±0.001	0.039±0.005	0.003±0.001
$\epsilon_{\mathsf{1tag,ET}}$	0.011±0.001	0.035±0.005	0.003±0.001
ϵ_{2tag}	0.000±0.000	0.007±0.002	0.000±0.000
CMUP Muons			
ϵ_{btag}	0.014±0.001	0.048±0.005	0.014±0.002
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.006±0.001	0.021±0.003	0.006±0.001
ϵ_{jet1}	0.006±0.001	0.020±0.003	0.006±0.001
ϵ_{1tag}	0.006±0.001	0.020±0.003	0.005±0.001
$\epsilon_{\mathsf{1tag,ET}}$	0.006±0.001	0.018±0.003	0.004±0.001
ϵ_{2tag}	0.000±0.000	0.002±0.001	0.002±0.001
CMX Muons			
ϵ_{btag}	0.008±0.001	0.028±0.004	0.006±0.001
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.004±0.000	0.013±0.003	0.003±0.001
ϵ_{jet1}	0.003±0.000	0.012±0.002	0.003±0.001
ϵ_{1tag}	0.003±0.000	0.012±0.002	0.002±0.001
$\epsilon_{\mathsf{1tag,ET}}$	0.003±0.000	0.010±0.002	0.002±0.001
ϵ_{2tag}	0.000±0.000	0.001±0.001	0.000±0.000
ALL			
ϵ_{btag}	0.052±0.004	0.169±0.019	0.029±0.005
$\epsilon_{\mathsf{M}\ell\nu\mathsf{b}}$	0.022±0.002	0.082±0.011	0.013±0.003
ϵ_{jet1}	0.020±0.002	0.074±0.011	0.012±0.003
ϵ_{1tag}	0.022±0.002	0.071±0.010	0.010±0.003
$\epsilon_{\mathsf{1tag,ET}}$	0.020±0.002	0.063±0.010	0.009±0.003
ϵ_{2tag}	0.000±0.000	0.010±0.003	0.003±0.001

Table 26: $\epsilon_{\mathsf{BR}} \cdot \epsilon^{\mathsf{MC}}_{\mathsf{evt}} \cdot \epsilon_{\mathsf{corr}} \cdot \epsilon_{\mathsf{trig}}$ for diboson Monte Carlo samples.

Process	WW0p	WZ0p	ZZ0p
Sample	atop4x	atop0y	atop0z
N_{btag}	1.11±0.12	1.07±0.14	0.07±0.01
$N_{\mathsf{M}\ell\nu\mathsf{b}}$	0.47±0.05	0.52±0.08	0.03±0.01
N_{jet1}	0.43±0.05	0.47±0.07	0.03±0.01
N_{1tag}	0.47±0.05	0.45±0.07	0.03±0.01
$N_{\mathsf{1tag,ET}}$	0.43±0.05	0.40±0.07	0.02±0.01
N_{2tag}	0.00±0.00	0.07±0.02	0.01±0.00

Table 27: Number of expected events for diboson Monte Carlo samples.

Cut	N events
btag	2.25±0.27
M$\ell\nu$b	1.02±0.14
jet1	0.93±0.13
1tag	0.94±0.13
1tag, ET	0.85±0.12
2tag	0.07±0.02

Table 28: Summary of event detection efficiency and number of expected events for diboson events.

7 Conclusions

We present the event detection efficiency for single top, $t\bar{t}$ and di-boson events in the CDF II detector. We calculate the number of expected events for 162 pb^{-1} of data. Table 29 summarizes our results for the 2-jet bin with $M_{\ell\nu b}$ cut. The single top signal

t-channel	s-channel	$t\bar{t}$	Di-Boson
2.82 ± 0.46	1.50 ± 0.24	3.82 ± 0.86	1.02 ± 0.14

Table 29: Summary of number of expected events for t- and s-channel single top, $t\bar{t}$ and di-boson production.

estimate is based on simulated events generated with MadEvent, $t\bar{t}$ Monte Carlo events were generated with Pythia and di-boson events with Alpgen.

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