$t\bar{t}$ cross section measurements at Tevatron

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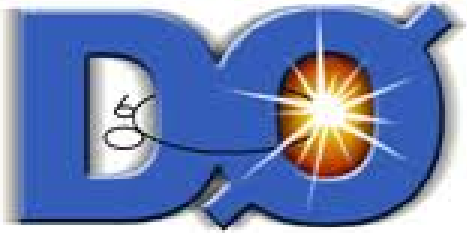
on behalf of CDF and D0 Collaborations



Top 2011 International workshop

Sant Feliu de Guixols, Spain

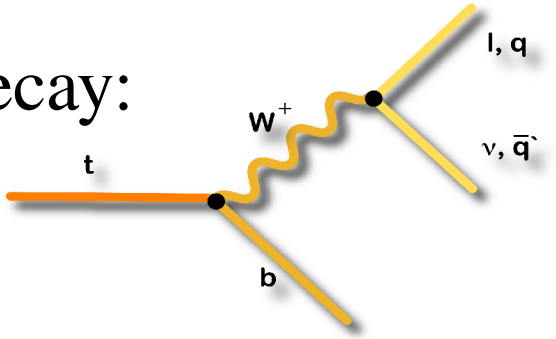
26 Sept. 2011

Motivation

$t\bar{t}$ production at Tevatron:

~ 85% ~ 15%

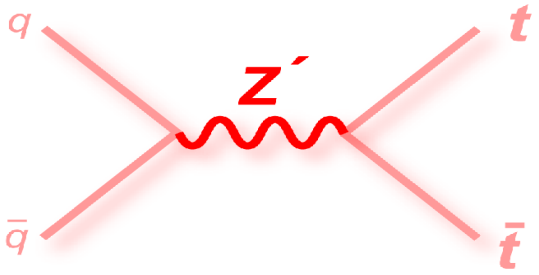
top decay:

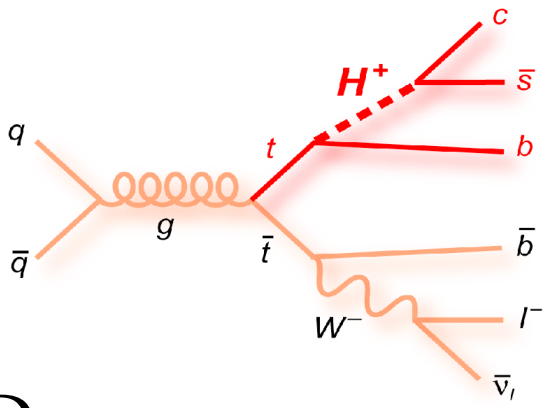


B(t → Wb) ~ 100%

New physics – beyond SM → can affect the prod. cross section

examples:





Why we measure cross section:

→ top – produced with small α_s test pQCD

→ looking for new physics

→ background for Higgs searches

Methodology

$$\sigma_{t\bar{t}} = \frac{N_{data} - N_{bckg}}{A \cdot L}$$

N_{data} → selected candidate events

N_{bckg} → estimated from MC

→ data fit of discriminant variable

L → integrated luminosity

A → acceptance (inc. trig. , select., b-tagging* eff.)

NNLO QCD predictions: (M_t = 172.5 GeV/c^2)

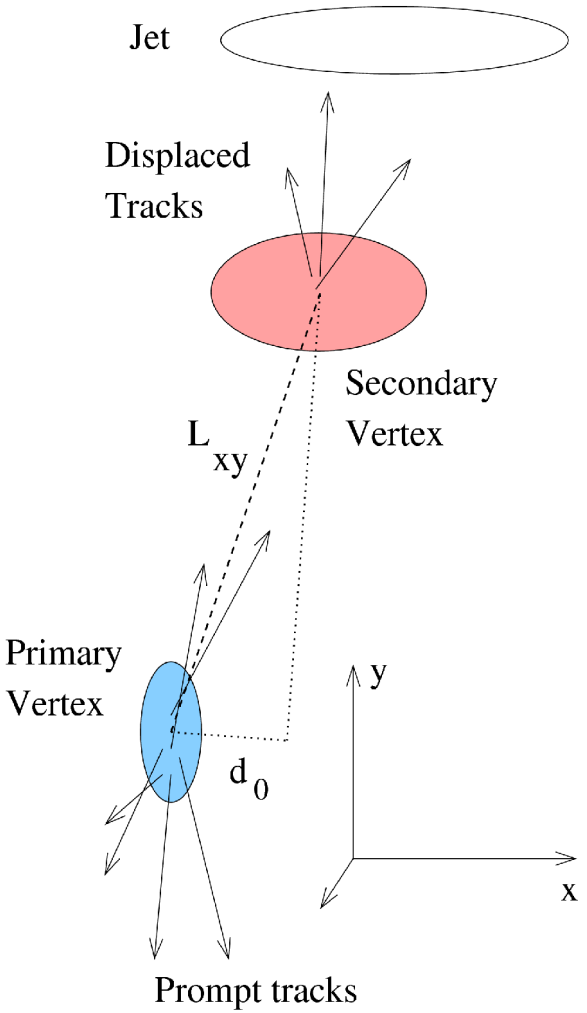
Moch and Uwer	Phys. Rev. D**78** 034003 (2008)	$\sigma_{t\bar{t}} = 7.46^{+0.48}_{-0.67}\ pb$
Cacciari *et al.*	JHEP **09** 127 (2008)	$\sigma_{t\bar{t}} = 7.14^{+0.76}_{-0.87}\ pb$
Kidonakis *et al.*	Phys. Rev. D**78** 074005 (2008)	$\sigma_{t\bar{t}} = 7.27^{+0.76}_{-0.85}\ pb$
Ahrens, Neubert *et al.**	arXiv:1003.5827v3 [hep-ph]	$\sigma_{t\bar{t}} = 6.30 \pm 0.19^{+0.31}_{-0.23}\ pb$

* NLO+NNLL

~ 5 – 10 % uncer.

Measurements: topological (kinematic info) or using b-tagging

b-tagging



3 different approaches:

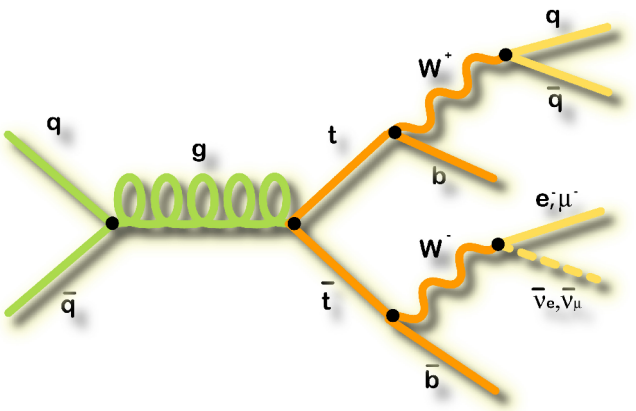
- based on impact parameter d_0
- secondary vertex
- soft lepton tagger

Neural network:

→ combine information of vertices and impact parameter

→ CDF: include also information about soft lepton inside jet

Lepton + jet channel



Signature

high p_T isolated lepton

large missing E_T (MET)

4 jets (2 b-jets)

S/B (4 jets)

topo	1 b-tag
2:3	4:1

Main background

1) W+jets (W+hf, W+light)
   → fit the Data by shapes from MC (Alpgen)
2) multijet (QCD)
   → data driven method
3) elektroweak (using MC, normalized to NLO cross section)
   → diboson, Z+jets – Alpgen, Pythia
   → single top – MadGraph or CompHep

Lepton + jet channel topological

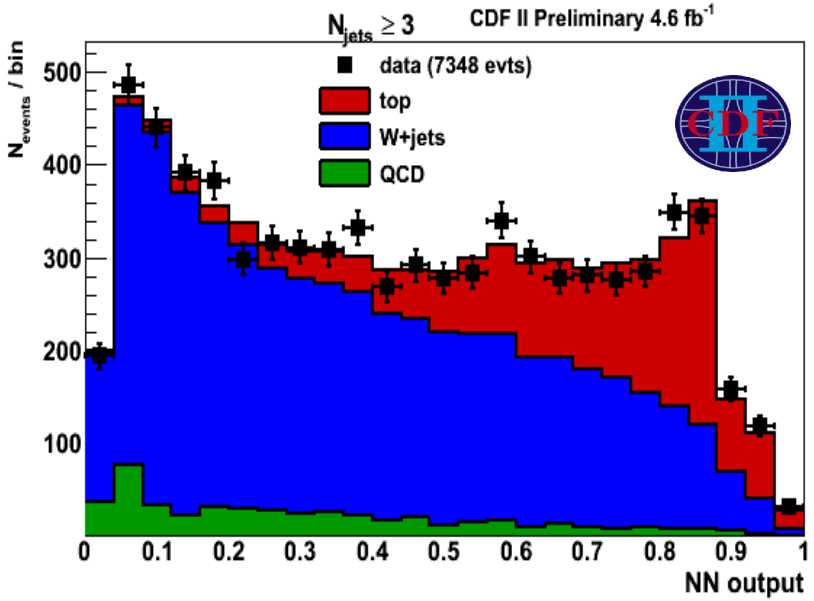
Signal – background discrimination:

→ differences in kinematic properties

→ NN (CDF), BDT (D0) … inputs: H_T, aplanarity, sphericity, …

Cross section

→ fit the discriminant output by the signal & background templates

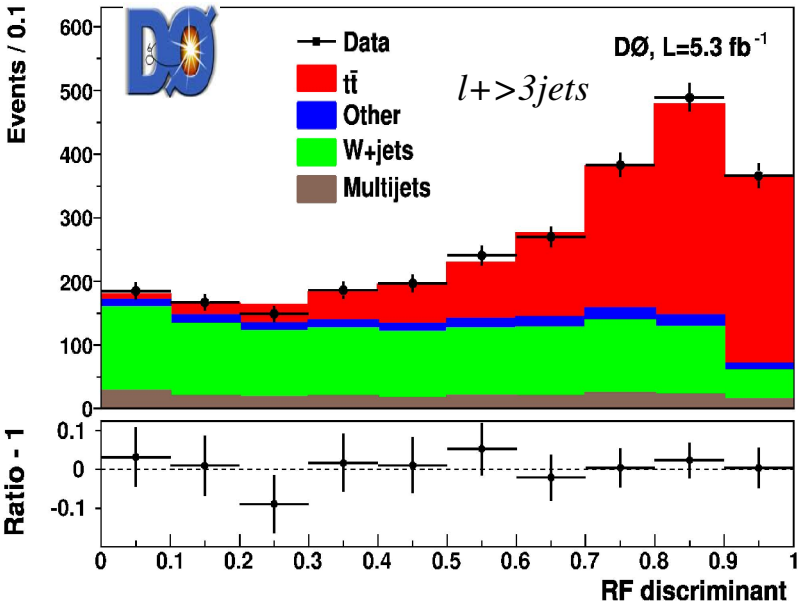


$(M_t = 172.5\ \mathrm{GeV/c^2})$

rel. uncer. ~9%

$$\sigma_{t\bar{t}}[pb] = 7.71 \pm 0.37(stat) \pm 0.36(syst) \pm 0.45(lumi)$$

$$\sigma_{t\bar{t}}[pb] = 7.68 \pm 0.31(stat)^{+0.64}_{-0.56}(syst)$$



Lepton + jet channel using b-tag

b-tagging efficiency

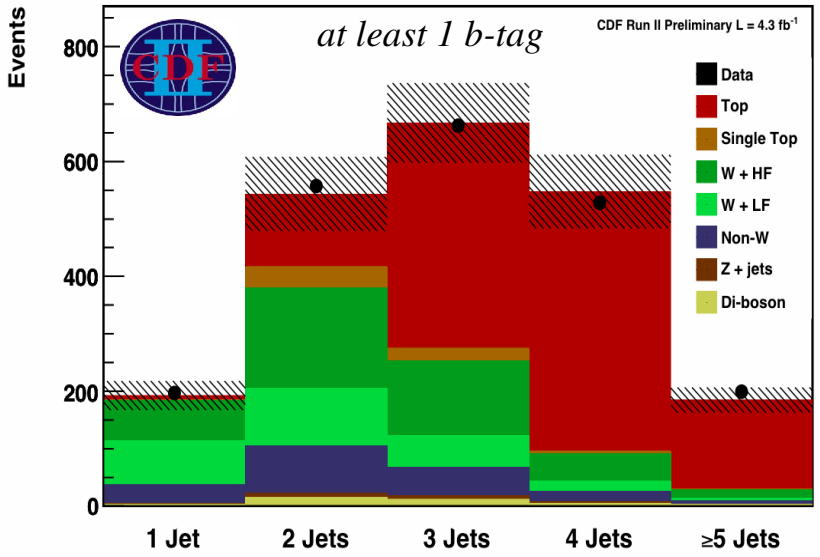
→ need to include to signal prediction

→ correct W+jets estimations

Cross section

→ binned likelihood fit using N_{jets}, $N_{\text{b-jets}}$

Channel	Sample	0 b-tags	1 b-tag	>1 b-tags
e+3 jets	W+jets	3358 ± 151	316 ± 26	29 ± 4
	Multijet	675 ± 70	75 ± 8	7 ± 1
	Z+jets	271 ± 40	26 ± 6	2 ± 1
	Other	172 ± 18	41 ± 6	9 ± 1
	$t\bar{t}$	289 ± 27	381 ± 30	147 ± 14
	Total	4765 ± 124	839 ± 37	194 ± 16
	Observed	4754	846	199
e+> 3jets	W+jets	440 ± 73	55 ± 10	6 ± 1
	Multijet	141 ± 15	23 ± 3	2 ± 0
	Z+jets	43 ± 7	6 ± 2	1 ± 0
	Other	30 ± 4	8 ± 1	2 ± 0
	$t\bar{t}$	202 ± 24	322 ± 31	180 ± 19
	Total	857 ± 51	413 ± 25	190 ± 18
	Observed	899	401	160

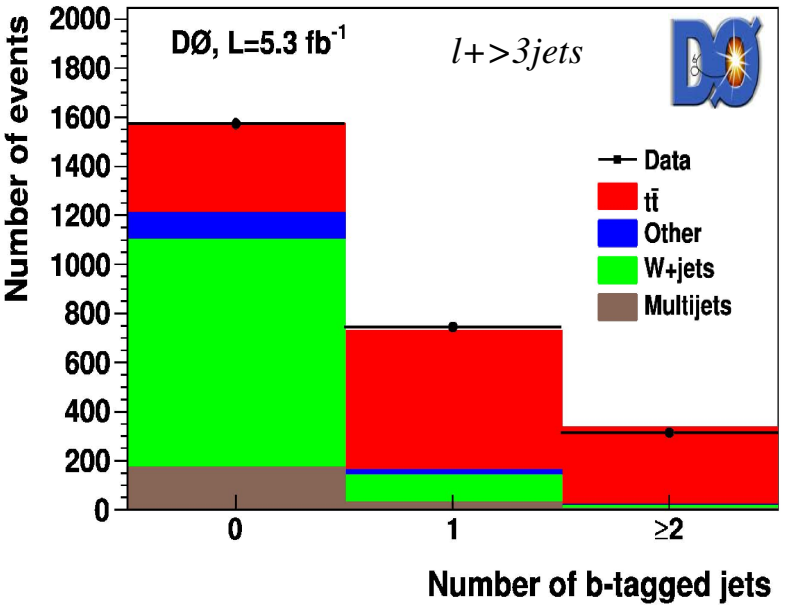


rel. uncer. ~11%

(M_t = 172.5 GeV/c^2)

$$\sigma_{t\bar{t}}[pb] = 7.22 \pm 0.35(stat) \pm 0.56(syst) \pm 0.44(lumi)$$

$$\sigma_{t\bar{t}}[pb] = 8.13 \pm 0.25(stat)^{+0.99}_{-0.86}(syst)$$



Lepton + jet channel

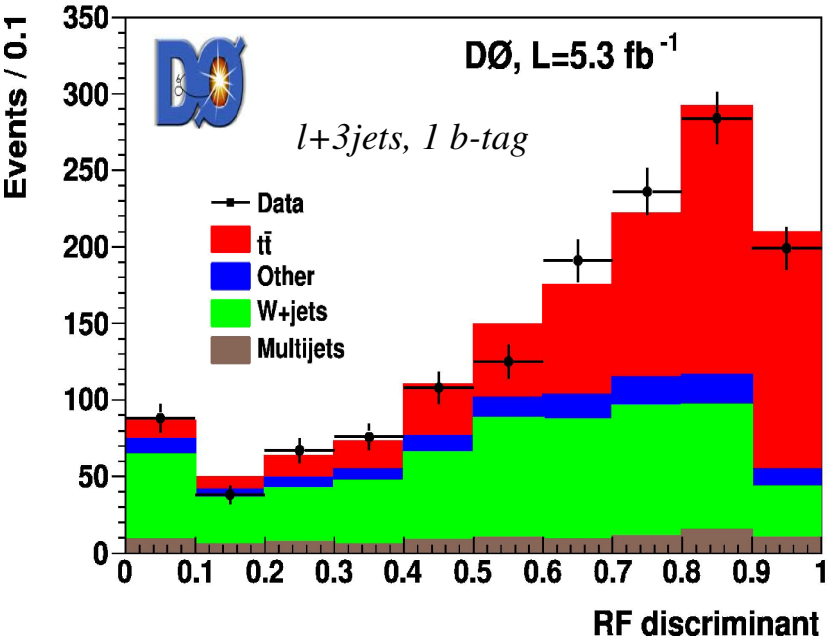
D0 combination:

topological + b-tagging

$$\sigma_{t\bar{t}}[pb] = 7.78^{+0.77}_{-0.64}(stat+syst+lumi)$$

(M_t = 172.5 GeV/c^2)

rel. uncer. ~ 9%



CDF – $t\bar{t}$ / Z cross section:

$$\sigma_{t\bar{t}} = \left(\frac{\sigma_{t\bar{t}}}{\sigma_Z}\right)_{\text{exp}} (\sigma_Z)_{th} \qquad (\sigma_Z)_{th} = 251.3 \pm 5.0\ pb$$

Eur. Phys. J. **C35**, 325 (2004)

→ *reduces luminosity uncertainty*

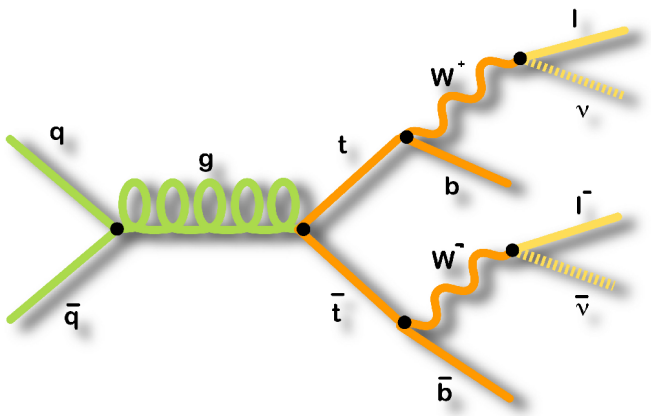
topo: $\sigma_{t\bar{t}}[pb] = 7.82 \pm 0.38(stat) \pm 0.37(syst) \pm 0.15(Z\,theory)$

b-tag $\sigma_{t\bar{t}}[pb] = 7.32 \pm 0.35(stat) \pm 0.59(syst) \pm 0.14(Z\,theory)$

→ *combination:* $\sigma_{t\bar{t}}[pb] = 7.70 \pm 0.52$

rel. uncer. ~6.8%

Dilepton channel



Signature

2 high p_T isolated leptons

large missing E_T (MET)

2 b-jets

Main background

1) Drell-Yan, diboson

→ using MC (Alpgen or Pythia)

→ normalized to NLO cross section

→ CDF – contamination of $Z/\gamma^* \to ee/\mu\mu$ – estimation from high MET events in the Z mass window

2) multijets (fake lepton)

→ estimated from data

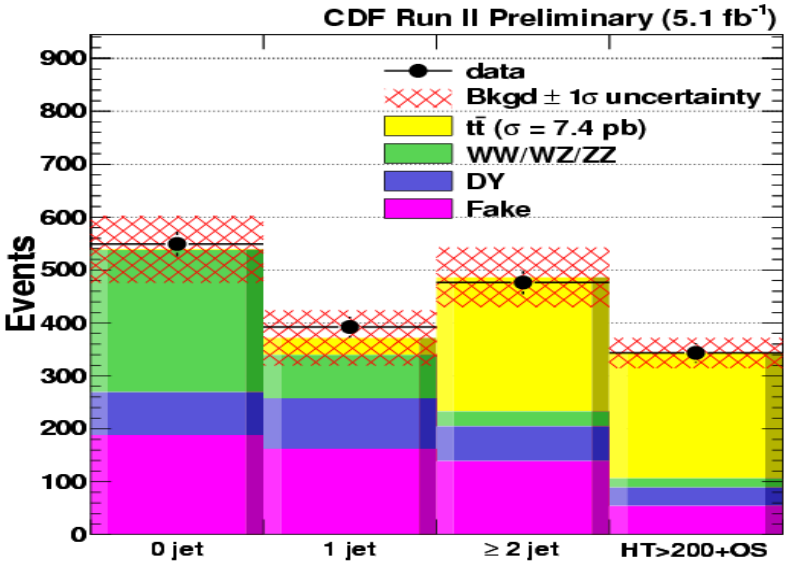
S/B

topo	1 b-tag
3:1	15:1

Dilepton channel

Signal – background discrimination:

→ CDF: MET and H_T cuts



CDF II preliminary (5.1 fb^{-1})

$t\bar{t}$ Signal Events per Dilepton Flavor Category before b-tagging				
Source	ee	$\mu\mu$	eμ	$\ell\ell$
WW	3.08±0.64	2.68±0.56	5.96±1.21	11.72±2.36
WZ	1.56±0.25	0.98±0.16	0.93±0.16	3.48±0.55
ZZ	1.02±0.79	0.82±0.64	0.42±0.33	2.25±1.75
Wγ	0.42±0.44	0.00±0.00	0.00±0.00	0.42±0.44
DY→ $\tau\tau$	2.88±0.55	2.97±0.56	6.42±1.16	12.26±2.18
DY→ $ee + \mu\mu$	11.54±2.22	8.40±1.62	2.45±1.09	22.40±3.24
Fakes	7.23±2.29	12.85±4.22	33.20±10.25	53.27±14.70
Total background	27.73±4.28	28.69±5.04	49.38±10.85	105.80±17.24
$t\bar{t}$ (σ = 7.4 pb)	54.65±2.65	54.92±2.65	127.55±6.10	237.13±11.30
Total SM expectation	82.38±6.63	83.61±7.46	176.93±16.80	342.92±28.30
Observed	74	96	173	343

(M_t = 172.5 GeV/c^2)

topo: $\sigma_{t\bar{t}}[pb] = 7.40 \pm 0.58(stat) \pm 0.63(syst) \pm 0.45(lumi)$

b-tag $\sigma_{t\bar{t}}[pb] = 7.25 \pm 0.66(stat) \pm 0.47(syst) \pm 0.44(lumi)$

rel. uncer.
~ 13%

Dilepton channel

Signal – background discrimination:

→ H_T cut and NN b-tagging

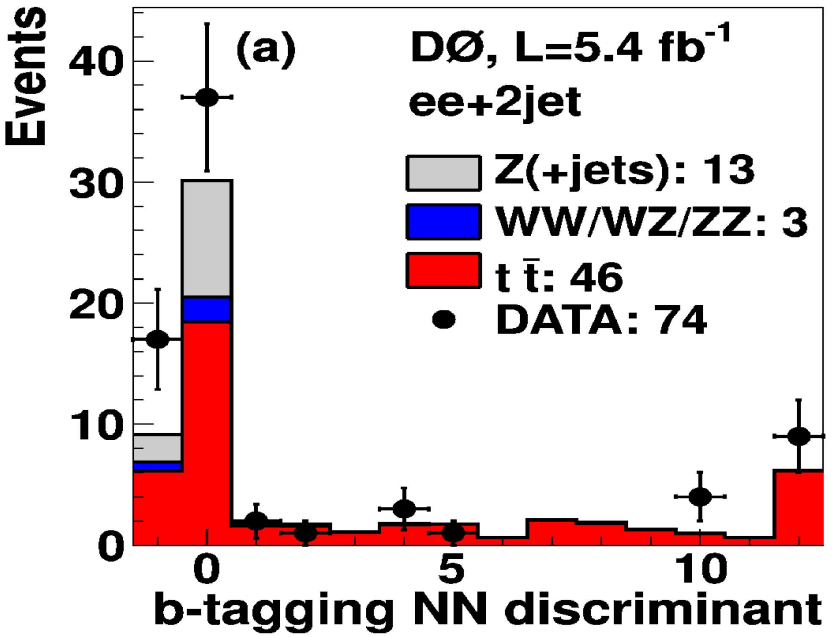
Cross-section

→ simultaneously fitting NN distribution and maximizing the likelihood func.

$$\sigma_{t\bar{t}}[pb] = 7.36^{+0.90}_{-0.79}(stat+syst+lumi)$$

rel. uncer. ~ 11%

(M_t = 172.5 GeV/c^2)



output of 2 leading jets

Channel	$Z \to \ell\ell$	Diboson	Instrumental background	$t\bar{t} \to \ell\bar{\ell}b\bar{b}\nu\bar{\nu}$	N_{exp}	N_{obs}	$\frac{\text{Observed}}{\text{Expected}}$
ee+2jet	12.6 ± 2.0	3.0 ± 0.4	-	45.6 ± 5.3	61.1 ± 7.1	74	1.21 ± 0.20
$\mu\mu$+2jet	67.3 ± 9.7	5.1 ± 0.7	7.6 ± 1.2	59.8 ± 6.6	139.8 ± 15.7	144	1.03 ± 0.14
$e\mu$+2jet	30.3 ± 4.2	8.6 ± 1.2	22.7 ± 8.6	191.5 ± 18.8	253.1 ± 24.3	281	1.11 ± 0.13
$e\mu$+1jet	40.9 ± 4.8	20.7 ± 2.4	25.3 ± 10.5	52.1 ± 9.4	139.0 ± 16.5	150	1.08 ± 0.16

L+J and DIL combination: $\sigma_{t\bar{t}}[pb] = 7.56^{+0.63}_{-0.56}(stat+syst+lumi)$

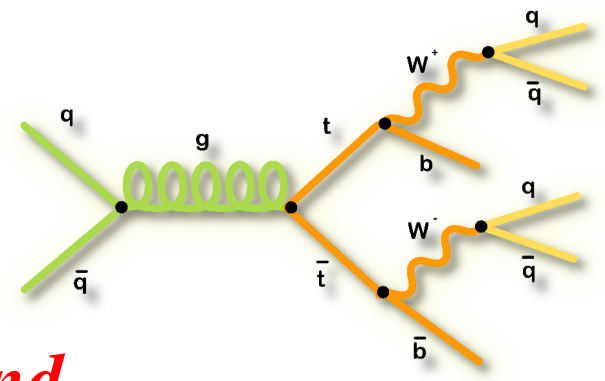
rel. uncer. ~ 8%

All hadronic channel

Signature

6 jets (2 b-jets)

S/B … 1:2

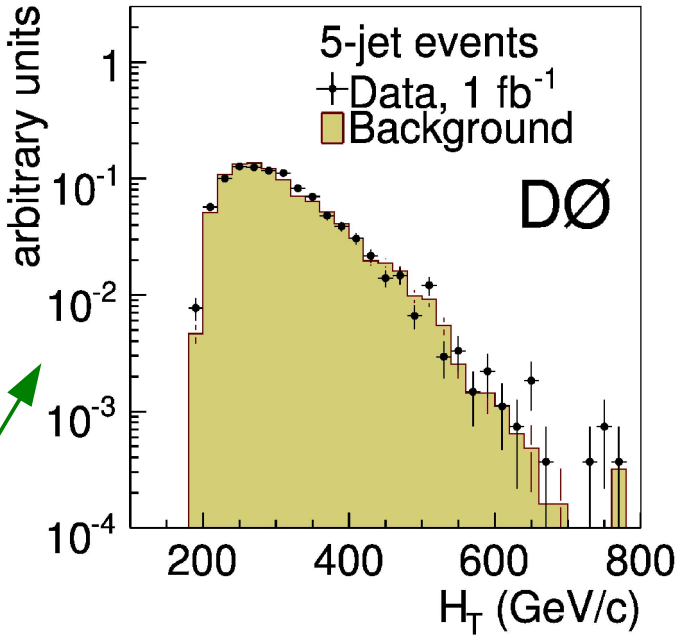


Main background

Multijets

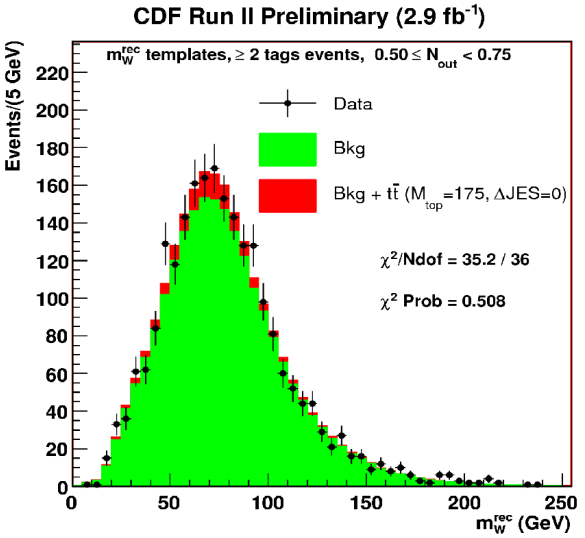
→ estimated from data:

D0: attaching low pT jets from >6 jets events to 4 and 5 jet events



CDF: → jet's tag rate evaluated using 4 jet events

→ kinematic and normalization estimated by applying the rate to signal region

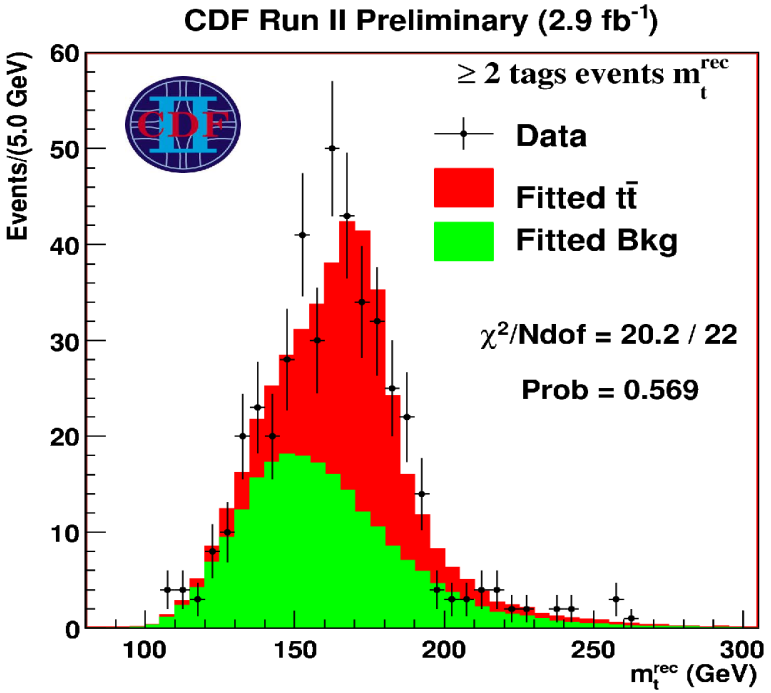


All hadronic channel

Signal – background discrimination

→ CDF: NN, D0: maximum likelihood

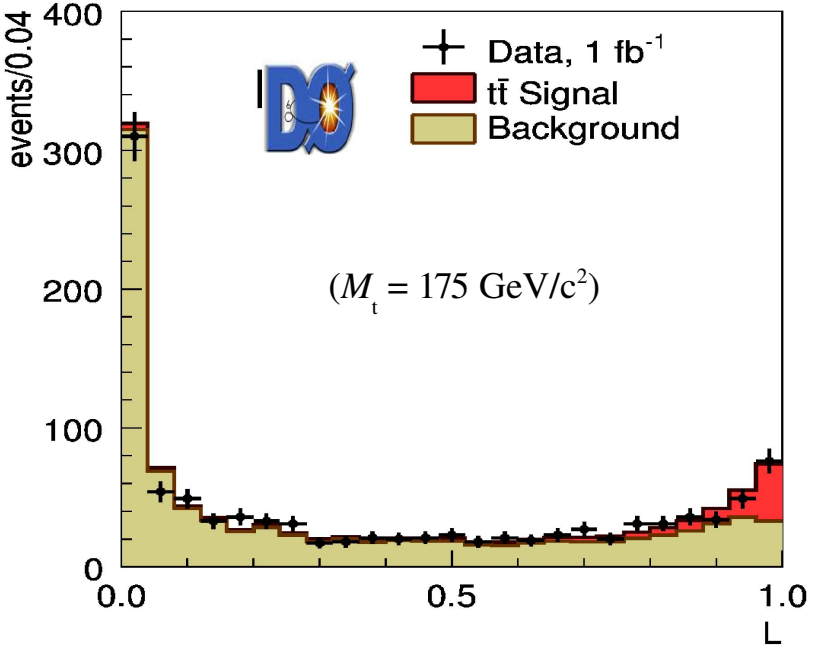
→ inputs: H_T, invariant mass, centrality, ...



$$\sigma_{t\bar{t}}[pb] = 7.2 \pm 0.5(stat) \pm 1.1(syst) \pm 0.4(lumi)$$

(M_t = 172.5 GeV/c^2)

rel. uncer. ~ 18%



$$\sigma_{t\bar{t}}[pb] = 6.9 \pm 1.3(stat) \pm 1.4(syst) \pm 0.4(lumi)$$

(M_t = 175 GeV/c^2)

rel. uncer. ~ 29%

Hadronic τ + jets channel

semi-hadronic τ candidate

→ narrow jet, odd num. of charge tracks, π^0's low multiplicity

CDF: further isolation and energy cuts, visible mass < 1.8 GeV

D0: τ jets candidates (NN), sub-cluster + track in the EM calor. cluster

3 τ lepton types: → 1 trk, no EM cluster $(\tau^{\pm} \rightarrow \pi^{\pm} \nu_{\tau})$

→ 1 trk, ≥ 1 EM cluster $(\tau^{\pm} \rightarrow \pi^{\pm} \pi^{0} \nu_{\tau})$

→ ≥ 2 trks, ≥ 0 EM cluster $(\tau^{\pm} \rightarrow \pi^{\pm} \pi^{\pm} \pi^{\pm} (\pi^{0}) \nu_{\tau})$

Background

Diboson, single top, Z+jet – theory cross section + MC acceptance

QCD – data driven method

W+jets

fit of data NN output by templates
allow floating contribution of this two

Hadronic τ + jets channel

Signal – background discrimination:

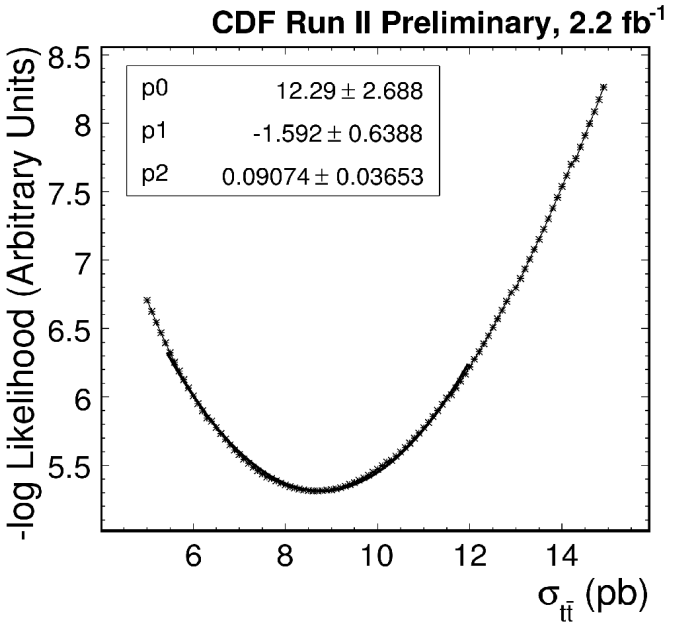
→ NN, inputs: MET, lead jet E_T, H_T, ...

Cross-section

→ CDF: Poisson likelihood - funct. of cross section, -2ln(L) minimum

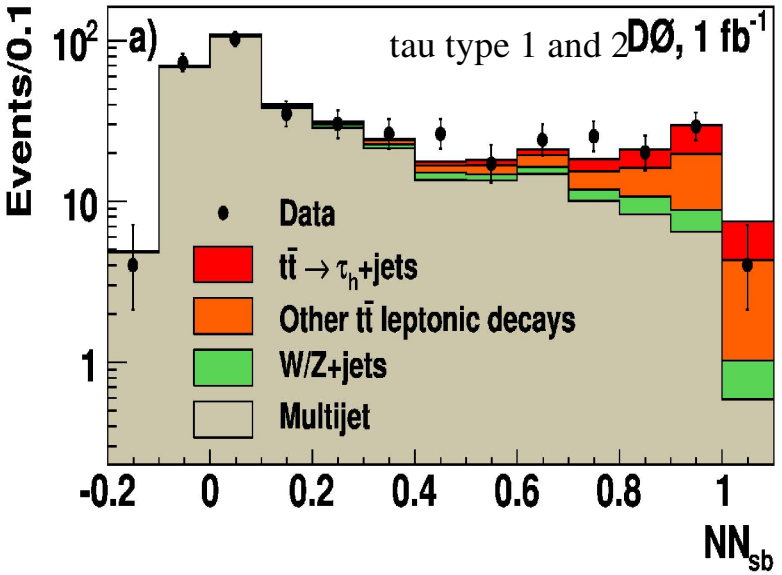
→ D0: fit NN output by neg log-likelihood, use predicted branch. ratio

rel. uncer.
~ 48%



$\sigma_{t\bar{t}}[pb] = 8.8 \pm 3.3(stat) \pm 2.7(syst)$

(M_t = 172.5 GeV/c^2)



rel. uncer.
~ 22%

$\sigma_{t\bar{t}}[pb] = 6.3^{+1.2}_{-1.1}(stat) \pm 0.7(syst) \pm 0.4(lumi)$

(M_t = 175 GeV/c^2)

MET + jets channel

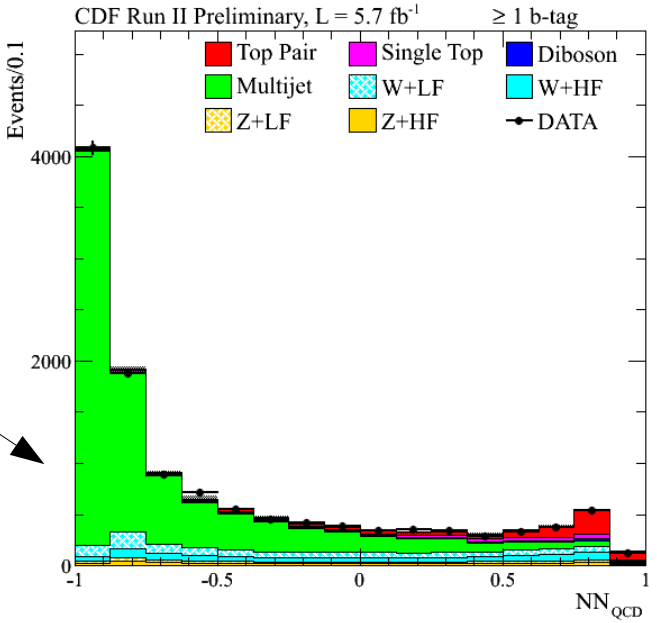
→ comprise events with W → $\tau\nu$ events with hadronical τ decays

Events selection:

→ Large MET

→ 2 or 3 high p_T jets (≥ 1 b-tag)

→ NN_{QCD} > -0.5 (reduce multijets bckg)

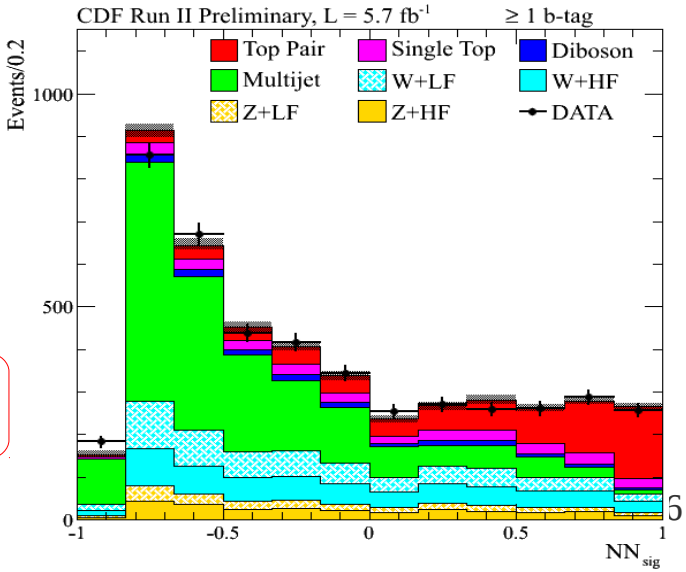


Background

QCD → data driven method

→ b-tag rate extracted from data sample with 2 or 3 jets

MET {50-70}, $\Delta\Phi$(MET, j_2)<0.4



Other → MC estimations

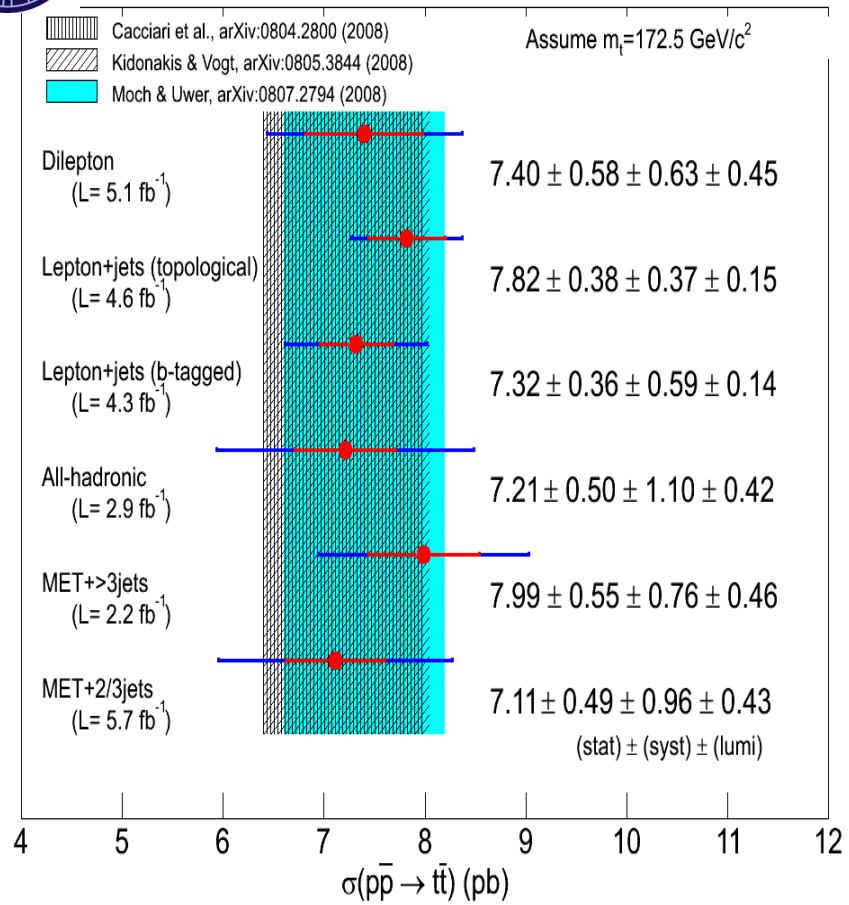
Cross section – binned likelihood method

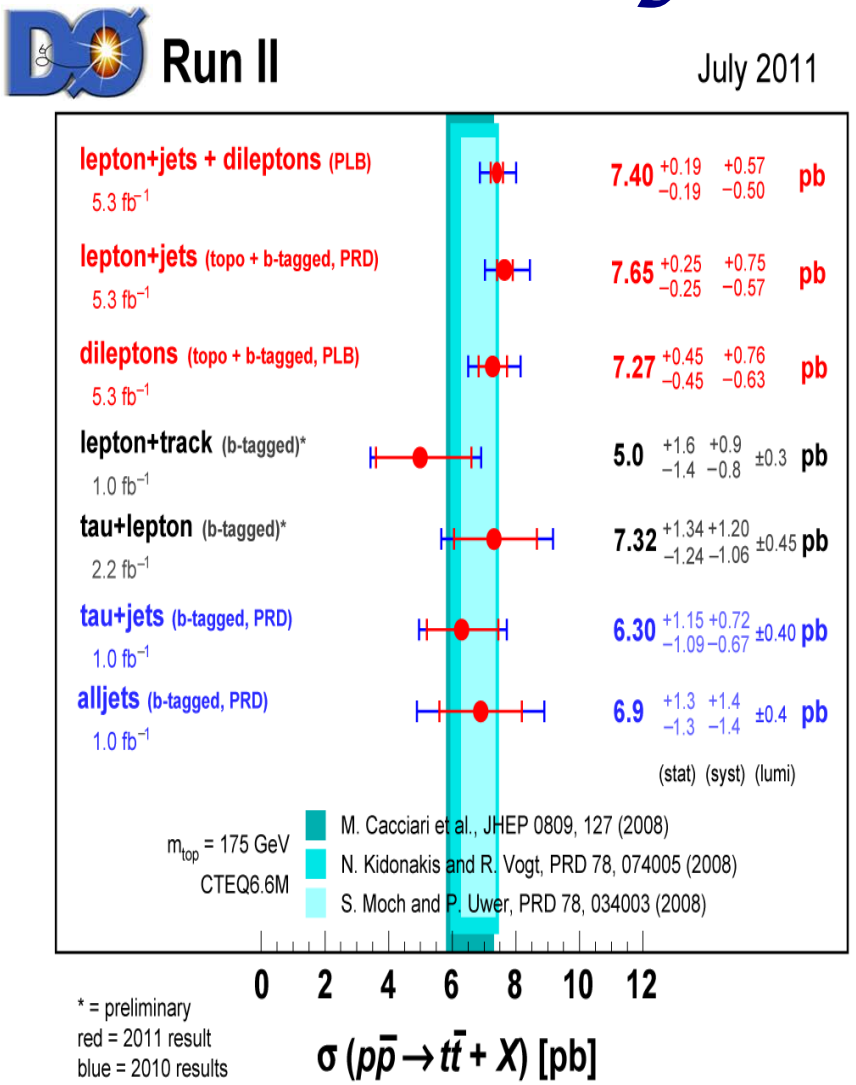
$$\sigma_{t\bar{t}}[pb] = 7.12^{+1.20}_{-1.12}(stat+syst)$$

(M_t = 172.5 GeV/c^2)

rel. uncer. ~ 16%

Tevatron measurements summary





→ Good compatibility between CDF and D0 results

→ consistency between the different channels and with SM predict.

Conclusions

Tevatron measure the cross section in all possible top decay channels:

- many measurements are systematics limited
- the best measurement – $t\bar{t}$ / Z
  → relative uncertainty (~6.8%) less then in th. Predictions
- well understood $t\bar{t}$ sample

CDF + D0 combination under preparation

Plan: study the final dataset ~10 fb^{-1} (per experiment)