Measurement of Top Pair Production Cross-Section in Lepton+Hadronic Tau Channel

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on behalf of DØ Collaboration

PHENO 2008 SYMPOSIUM

LHC Turn On

University of Wisconsin-Madison

Motivation

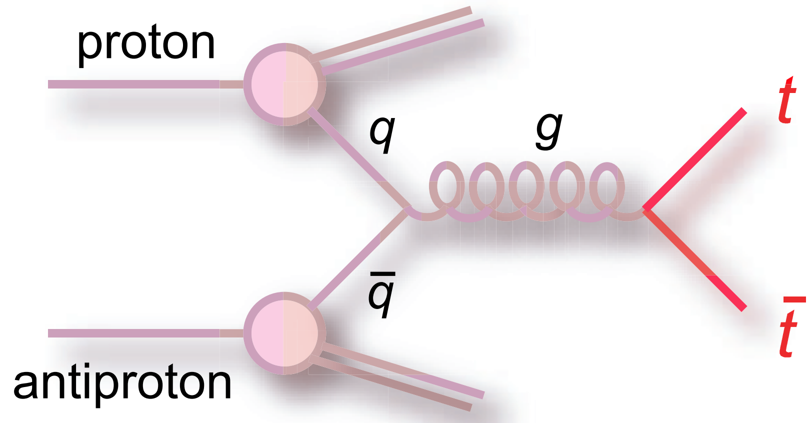
- A pure third generation decay which has not been observed with 3σ significance.

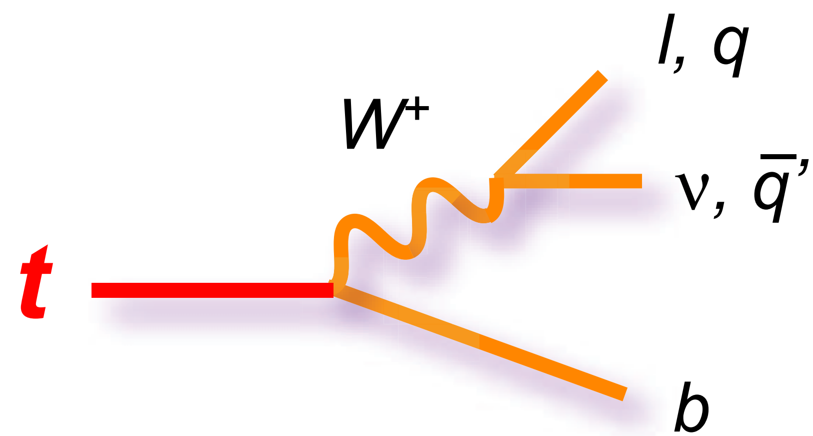
$$t \rightarrow \tau \nu_\tau b$$

- Search for new physics in top quark **decay** mechanisms.

- In many top quark analyses, it is assumed that top quark decays predominantly via weak interaction into a W boson and a b quark.

$$t \rightarrow Wb$$





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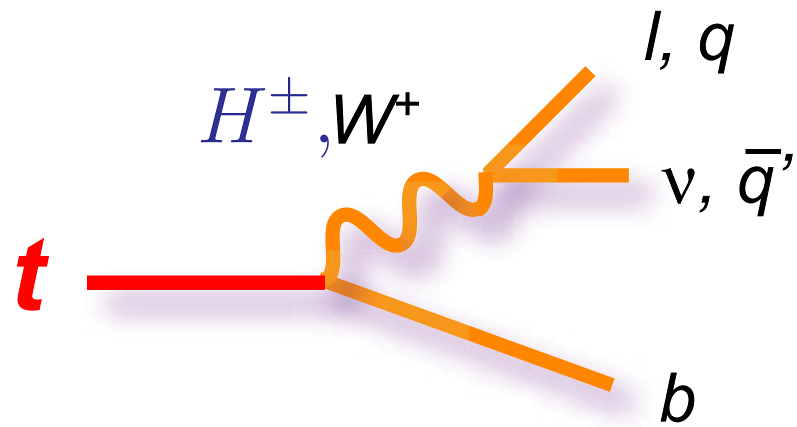
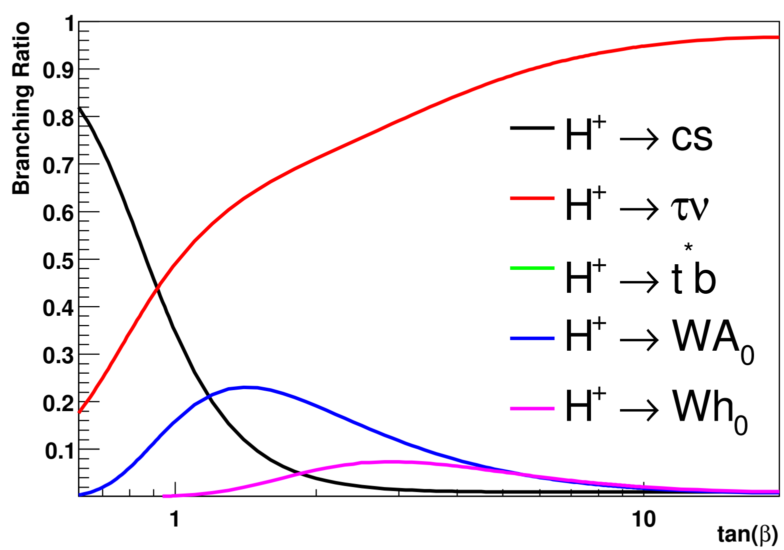
New physics in top quark decay mechanism

Charged Higgs exist in non-minimal Higgs model (e.g. 2HDM) or beyond standard model physics (e.g. MSSM). Top quark can decay to charged Higgs.

$$t \rightarrow H^{\pm} b \rightarrow \tau \nu_{\tau} b$$

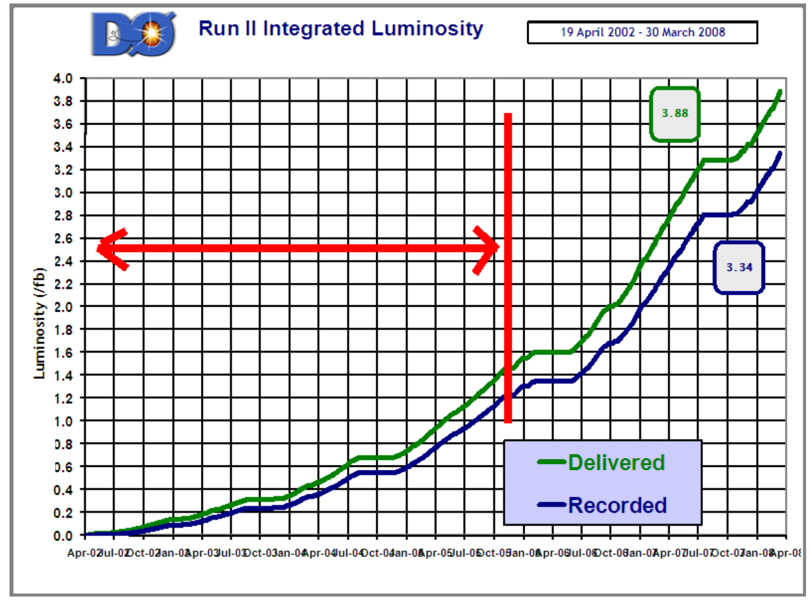




At large $\tan\beta$, the charged Higgs decay predominantly into taus. Figure made with CPsuperH, CPC 156 (2004), 283.

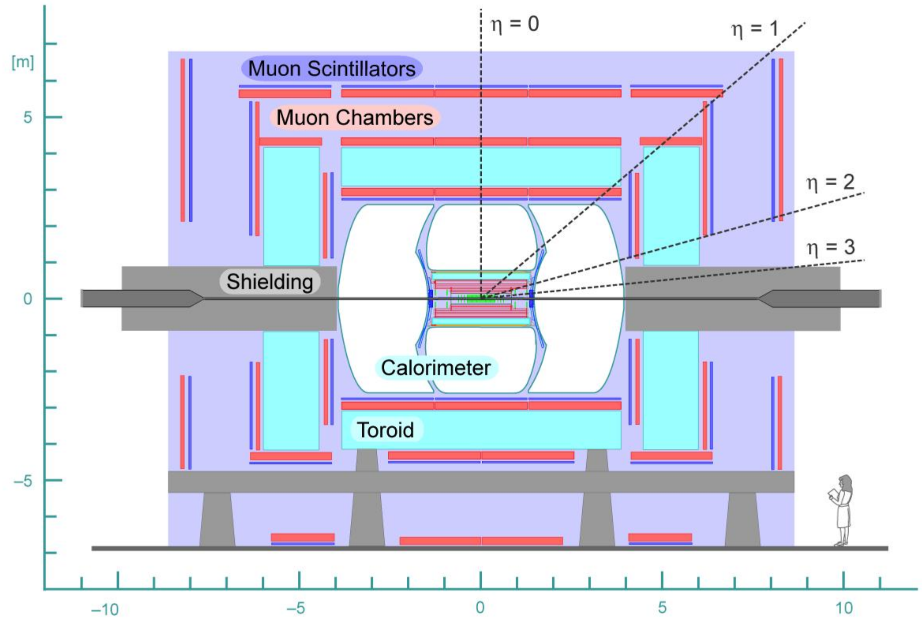
Experimental Apparatus: Fermilab Tevatron Accelerator

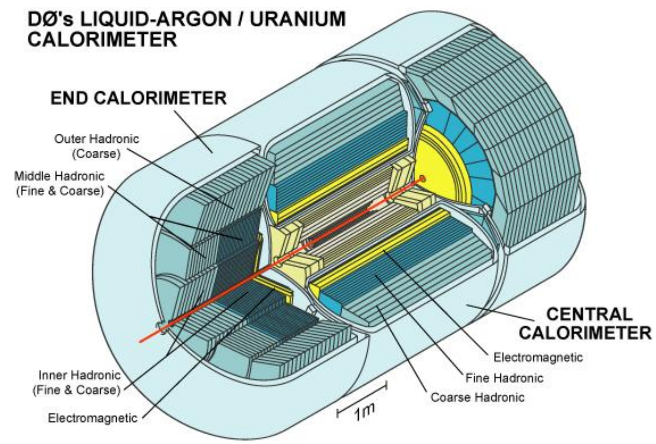
Proton-antiproton collider with center-of-mass energy 1.96 TeV.

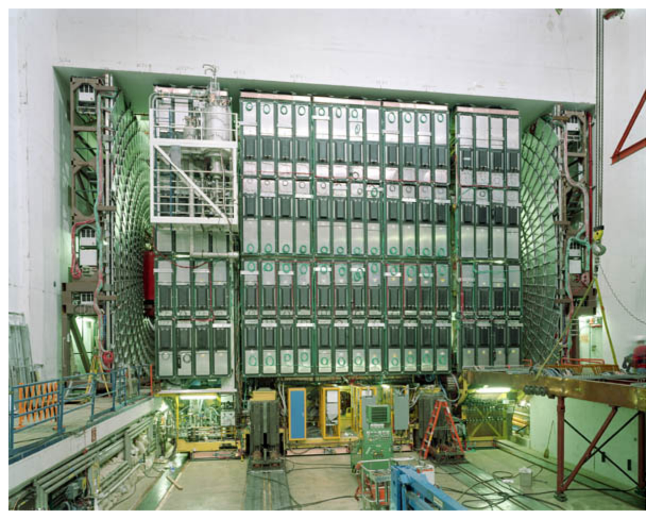


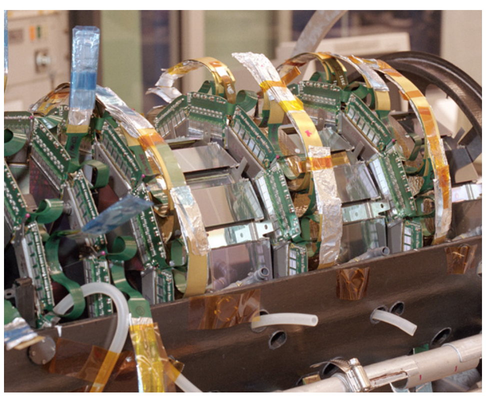
Analysis uses 1.0 fb^{-1} of recorded data from April 2002 to February 2006.

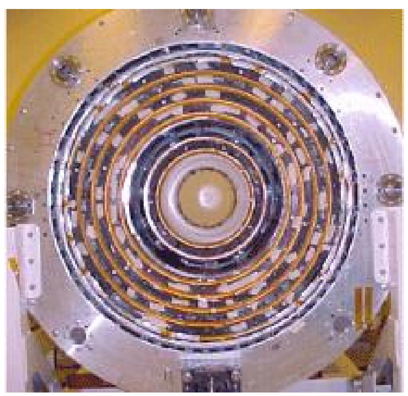
Experimental Apparatus: DØ Detector



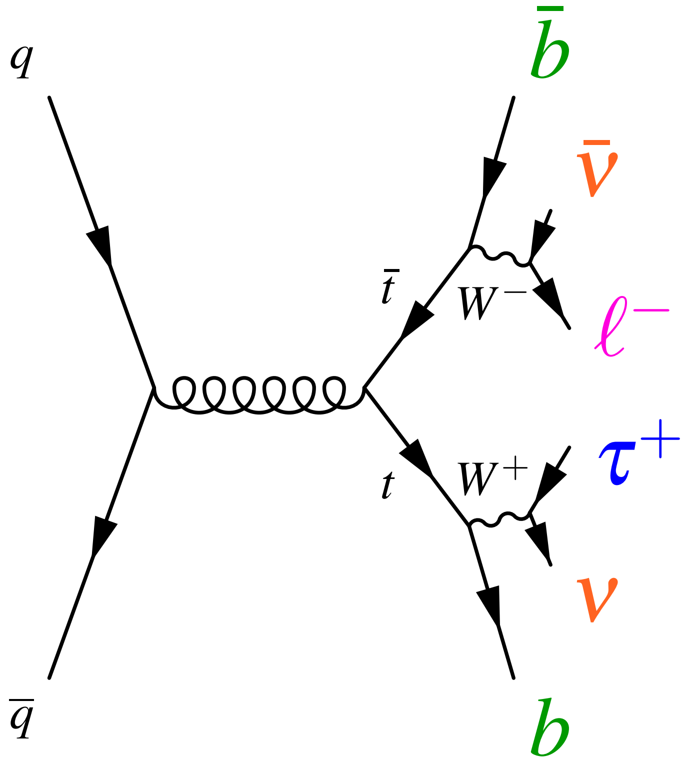








Event Preselection

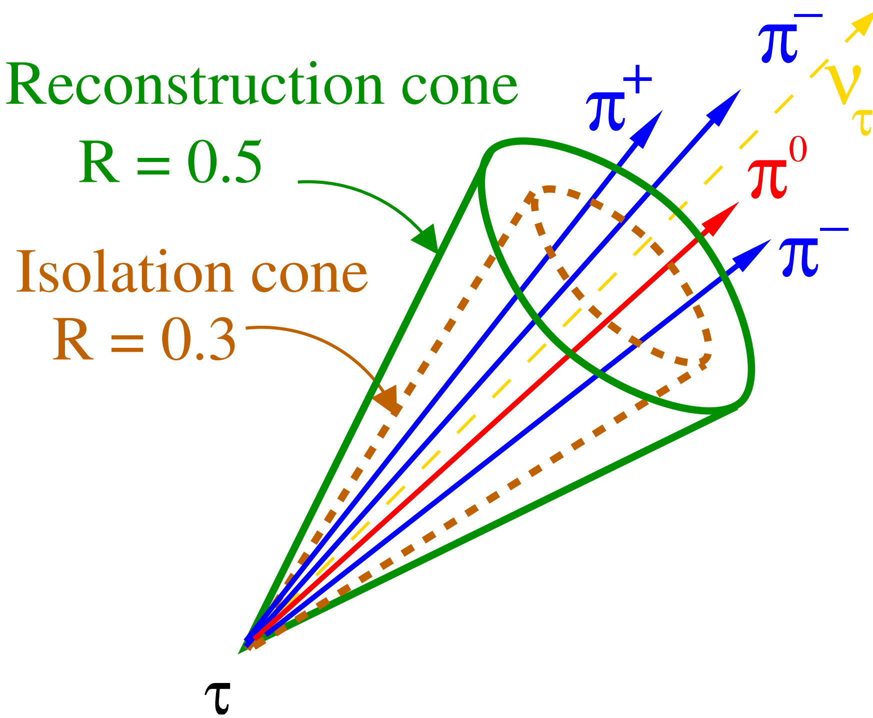


- **One isolated electron (muon),** $p_T > 15(20)$ **GeV,** $|\eta| < 1.1(2.0)$**.** Veto second isolated lepton.
- **One isolated tau with** $E_T > 10$ **GeV, appears as narrow jet**.
- **At least two jets,** $p_T > 20$ **GeV,** $|\eta| < 2.5$**, leading jet** $p_T > 30$ **GeV.**
- $\not{E}_T > 15$ **GeV, from the presence of three neutrinos.**
- **Lepton** and **tau** are expected to have opposite charge sign.
- **Identify** $b-$**quark jet to increase signal to background ratio.**

It is a lepton + three jets event !

Tau reconstruction and identification: Basics

Tau lifetime ~ 0.29 ps, $ct = 87\mu$m. Decay products of a highly-boosted tau are **almost collinear** with the tau.



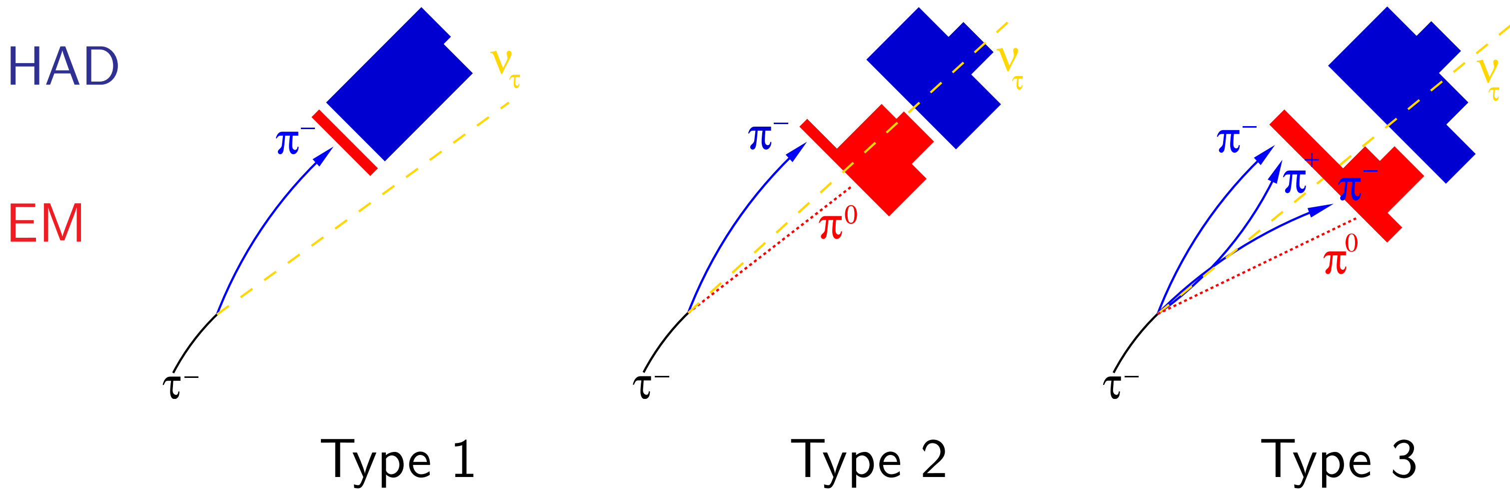
$$\mathrm{BR} \approx 35\% : \tau^- \rightarrow e^-\bar{\nu}_e\nu_\tau, \mu^-\bar{\nu}_\mu\nu_\tau$$
$$\mathrm{BR} \approx 10\% : \tau^- \rightarrow \pi^-\nu_\tau$$
$$\mathrm{BR} \approx 35\% : \tau^- \rightarrow \pi^- N\pi^0\nu_\tau$$
$$\mathrm{BR} \approx 15\% : \tau^- \rightarrow \pi^-\pi^+\pi^- N\pi^0\nu_\tau$$

Leptons from tau decays will be swamped by leptons from W/Z decays.

Hadronic decay products will appears as **narrow, isolated jets**, with **charged tracks and hadronic energy deposition**.

Neutral pions will appear as **electromagnetic energy deposition**.

Tau reconstruction and identification: DØ Algorithm

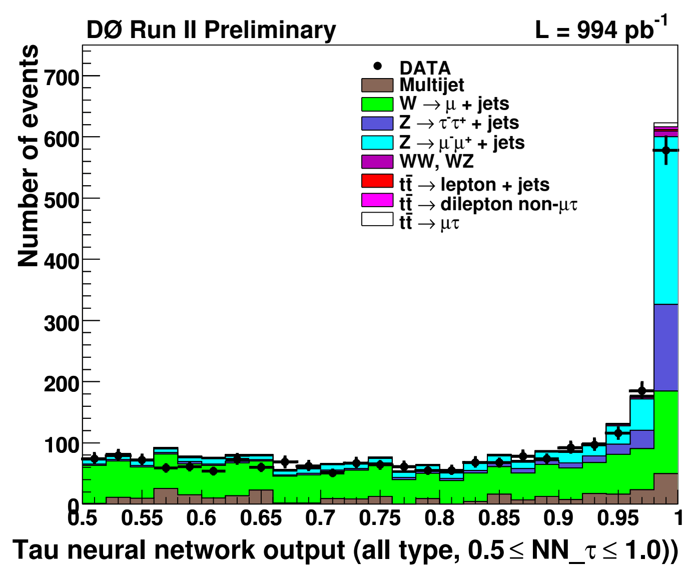


Type 1: one track, w/o EM cluster.

Type 2: one track, w/ EM clusters.

Type 3: two or more tracks.

Neural networks algorithm is used to identify taus.



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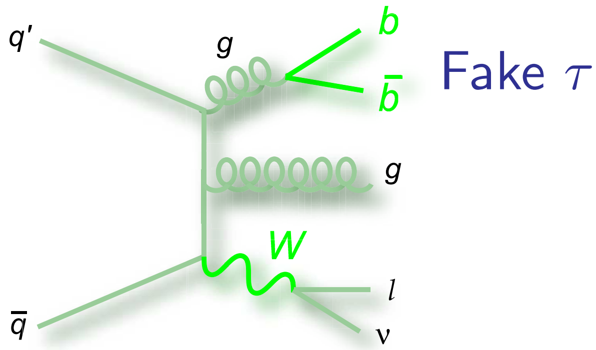
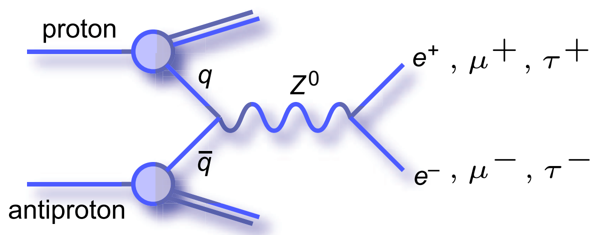
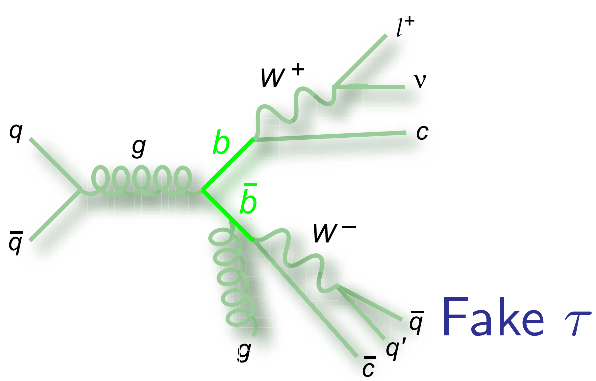
Background Processes and Their Estimation



W+jets, use shapes from MC and normalized to data.



Z+jets, estimated from MC.

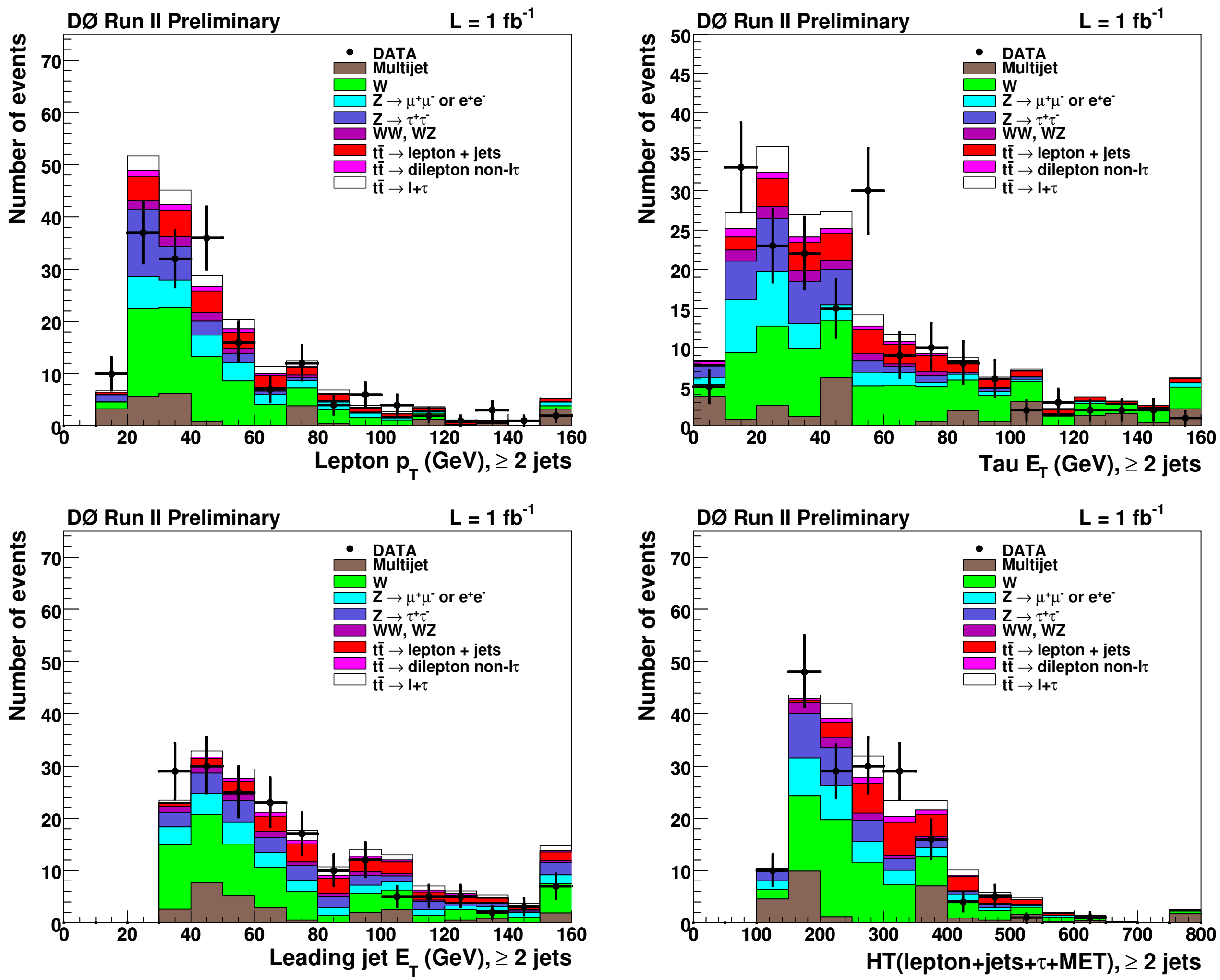


Multijet, estimated using MC and data events with same charge sign (SS).

$$N_{\text{Multijet}} = N^{SS}_{\text{data}} - N^{SS}_{\text{W+jets like}}$$

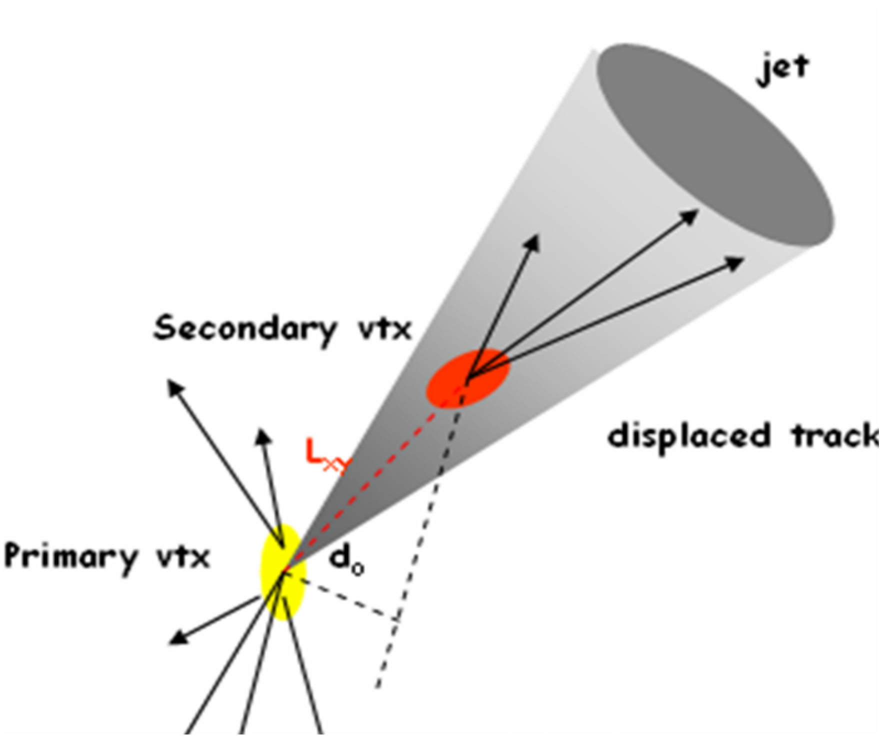
Other small backgrounds (e.g. diboson) are estimated using MC.

Preselected sample

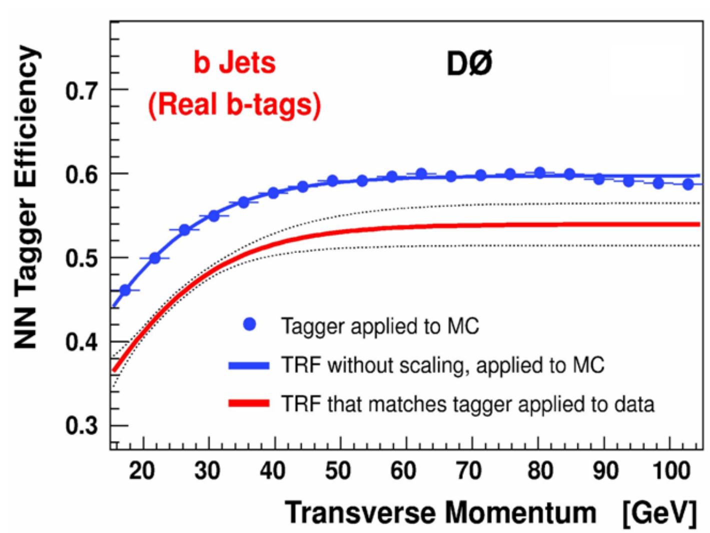


Hint of tops in the sample (S:B $1:8$), now add $b-$tagging.

Neural network b−tagging



Combine information from displaced tracks and secondary vertices into one neural network output.



Average efficiency to tag b-quark in this analysis is 54 %, with fake rate of 1 %.

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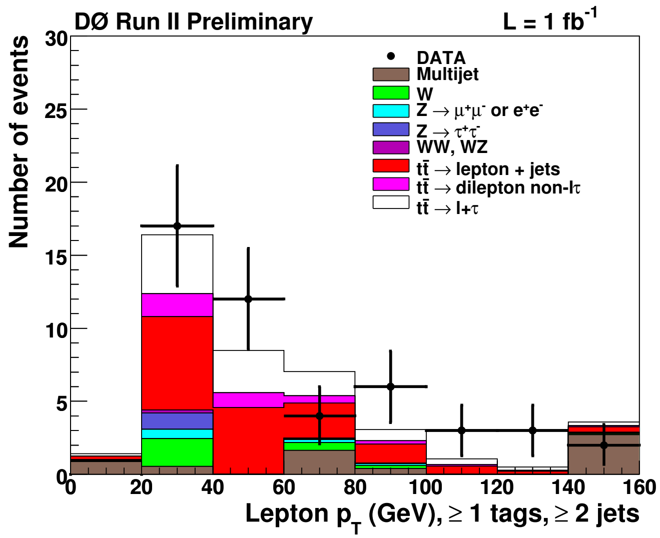
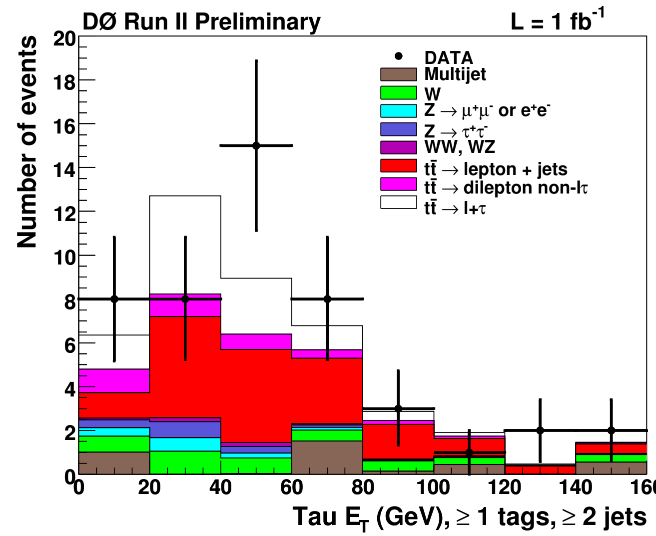
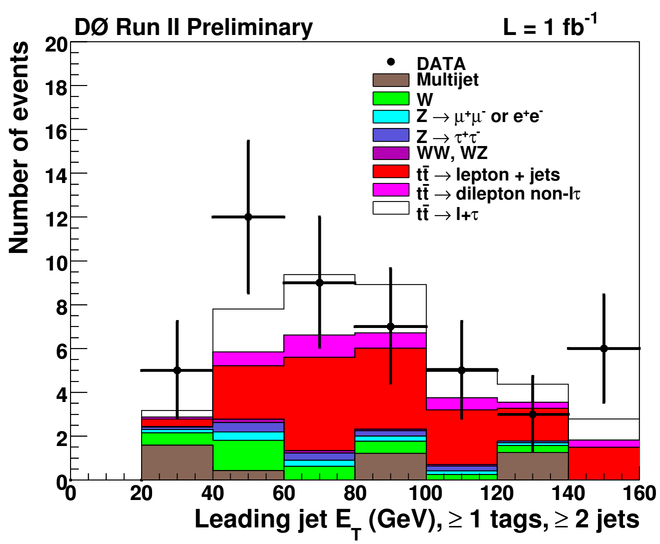
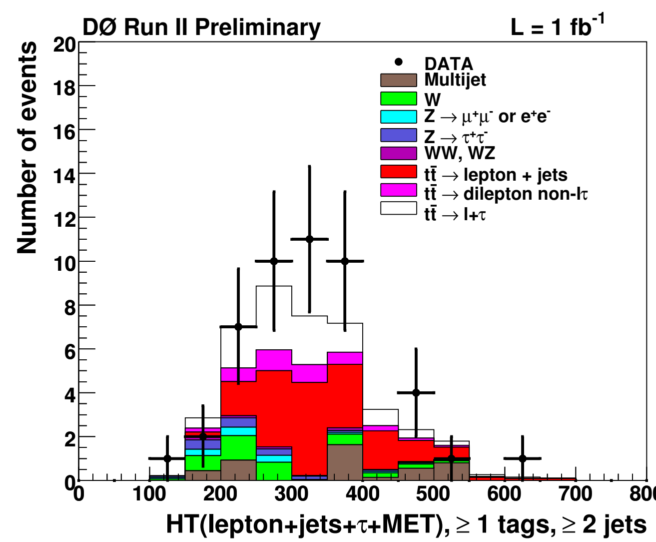
$b-$tagged sample









Elimination of multijet background

Assume that multijet events contribute equally to opposite-charge sign (OS) and same-charge sign (SS) sample.

$$
\begin{aligned}
N^{OS}_{\text{data}} &= N^{OS}_{t\bar{t},W,Z,\text{diboson}} + N^{OS}_{\text{Multijet}} \\
N^{SS}_{\text{data}} &= N^{SS}_{t\bar{t},W,Z,\text{diboson}} + N^{SS}_{\text{Multijet}}
\end{aligned}
$$

Then

$$
N^{OS}_{\text{data}} - N^{SS}_{\text{data}} = N^{OS}_{t\bar{t},W,Z,\text{diboson}} - N^{SS}_{t\bar{t},W,Z,\text{diboson}}
$$

Cross-section extraction

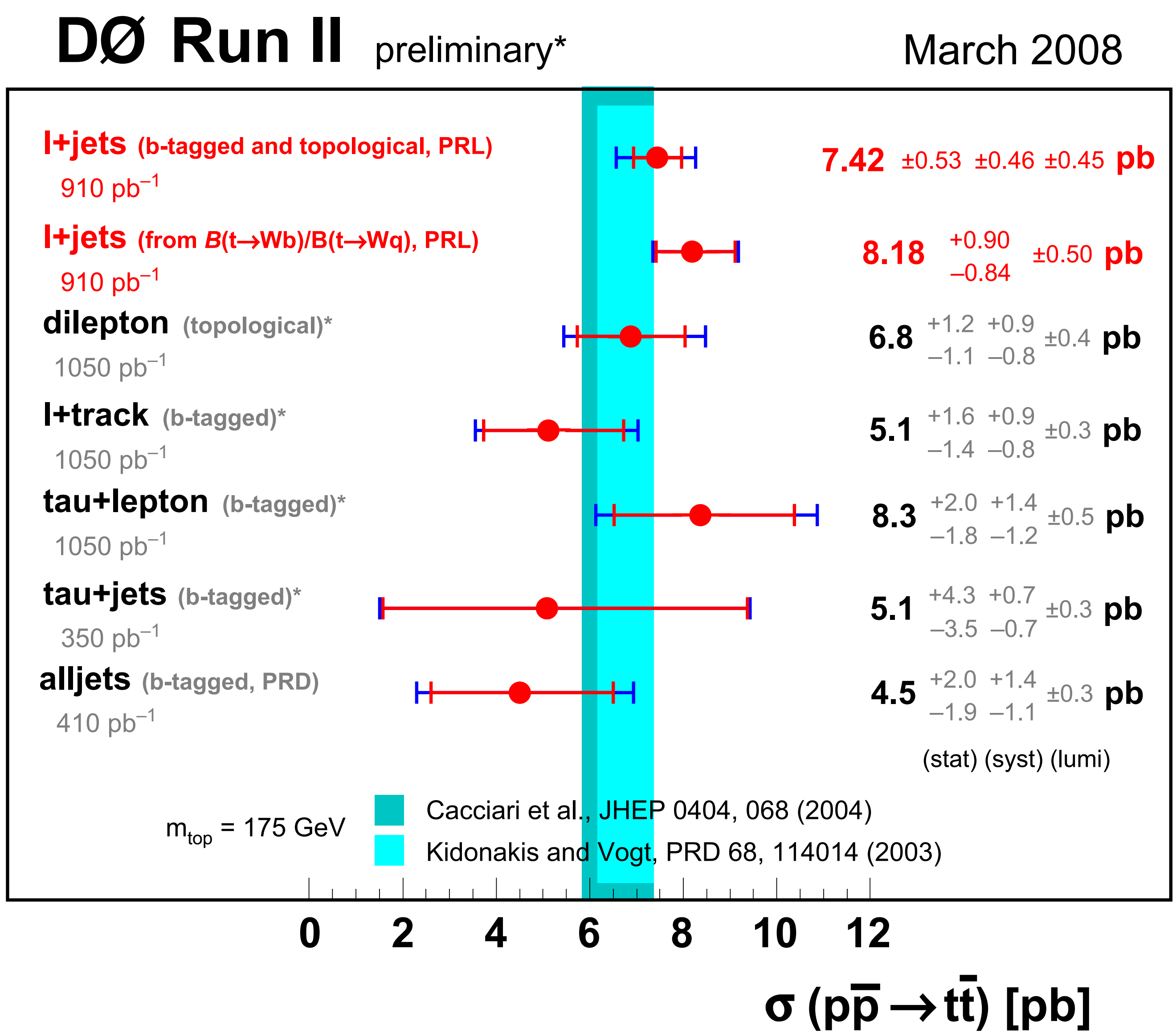
In the individual $e\tau$ and $\mu\tau$ channel, the cross-section is extracted using:

$$\sigma_{t\bar{t}} = \frac{N_{\rm data}^{OS} - N_{\rm data}^{SS} - \left(N_W^{OS} - N_W^{SS}\right) - N_Z^{OS} - N_{\rm diboson}^{OS}}{\left(\epsilon_{t\bar{t}}^{OS} - \epsilon_{t\bar{t}}^{SS}\right) \times \mathcal{L}}$$

In the combined measurement over more than one channels, we minimize a negative log-likelihood function based on the Poisson probability to observe a number of events (N_j^{obs}) in each individual channel j.

We measure:

$$\sigma_{t\bar{t}} = 8.3^{+2.0}_{-1.8}\,(\mathrm{stat})^{+1.4}_{-1.2}\,(\mathrm{syst}) \pm 0.5\,(\mathrm{lumi})\ \mathrm{pb}$$


DØ Run II preliminary*
March 2008
l+jets (b-tagged and topological, PRL)
910 pb⁻¹
7.42 ±0.53 ±0.46 ±0.45 pb
l+jets (from B(t→Wb)/B(t→Wq), PRL)
910 pb⁻¹
8.18 +0.90 −0.84 ±0.50 pb
dilepton (topological)*
1050 pb⁻¹
6.8 +1.2 −1.1 +0.9 −0.8 ±0.4 pb
l+track (b-tagged)*
1050 pb⁻¹
5.1 +1.6 −1.4 +0.9 −0.8 ±0.3 pb
tau+lepton (b-tagged)*
1050 pb⁻¹
8.3 +2.0 −1.8 +1.4 −1.2 ±0.5 pb
tau+jets (b-tagged)*
350 pb⁻¹
5.1 +4.3 −3.5 +0.7 −0.7 ±0.3 pb
alljets (b-tagged, PRD)
410 pb⁻¹
4.5 +2.0 −1.9 +1.4 −1.1 ±0.3 pb
(stat) (syst) (lumi)
m_top = 175 GeV
Cacciari et al., JHEP 0404, 068 (2004)
Kidonakis and Vogt, PRD 68, 114014 (2003)
0 2 4 6 8 10 12
σ (pp̄→tt̄) [pb]

Measurement of $\sigma \times \mathbf{BR}(t\bar{t} \to \ell + \tau + b\bar{b})$

A simple measure of top quark decay rate to tau lepton.

Assume standard model cross-section for expected top events which are coming from lepton+jets and non-tau dilepton decay modes.

$$\sigma_{t\bar{t}} \times \mathbf{BR}(t\bar{t} \to \ell + \tau + b\bar{b}) = \frac{N^{OS}_{\mathrm{data}} - N^{OS}_{\mathrm{non-tau}\ t\bar{t},W,Z,\mathrm{diboson}} - N_{\mathrm{Multijet}}}{\epsilon^{OS}_{t\bar{t}\to\ell+\tau+b\bar{b}}}$$

At $m_{top} =$ 175 GeV / $\sigma_{t\bar{t}} = 6.8$ pb, we measure:

$$\sigma_{t\bar{t}} \times \mathbf{BR}(t\bar{t} \to \ell + \tau + b\bar{b}) \quad = \quad 0.19^{+0.08}_{-0.08}\,(\mathrm{stat})^{+0.07}_{-0.07}\,(\mathrm{syst}) \pm 0.01\,(\mathrm{lumi})\ \mathrm{pb}.$$

The standard model expectation is 0.126.

Less statistically significant than the cross-section: **low purity of real taus in the selected sample**.

The cross-section extraction uses additional acceptance from **l+jets and non-tau dilepton**.

Conclusions from Tevatron analysis

- We measured both the top quark pair production cross-section using lepton+hadronic tau events, and the $\sigma \times \mathbf{BF}(t\bar{t} \to \ell\tau\nu\nu b\bar{b})$

$$\begin{aligned} \sigma_{t\bar{t}} &= 8.3^{+2.0}_{-1.8}\,(\mathrm{stat})^{+1.4}_{-1.2}\,(\mathrm{syst}) \pm 0.5\,(\mathrm{lumi})\ \mathrm{pb} \\ \sigma_{t\bar{t}} \times \mathbf{BR}(t\bar{t} \to \ell\tau\nu\nu b\bar{b}) &= 0.19^{+0.08}_{-0.08}\,(\mathrm{stat})^{+0.07}_{-0.07}\,(\mathrm{syst}) \pm 0.01\,(\mathrm{lumi})\ \mathrm{pb}. \end{aligned}$$

- Very **exciting** and **challenging** analysis which uses **all** object identification: electron, muon, tau, tracks, jets, $b-$tagging, MET.
- Will be used in a global search for charged Higgs boson in combination with dilepton and lepton+jets channels: **Add sensitivity to tauonic charged Higgs model**. **Require orthogonality between pure dilepton, lepton+tau, and lepton+jets channels**.
- Will be published as part of cross-section measurement in the dilepton channel.

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Outlook for LHC

- Current efficiency at the Tevatron is about 5 % for pure lepton+tau events, equivalent to about 10 lepton+tau events per 1 fb^{-1}.
- With 80 million top quark pairs produced per year at the LHC, even at reconstruction efficiency of **1000 times smaller** than at the Tevatron, we can expect to have about 15 lepton+tau events per year.
- The **real challenge** is the task to develop the algorithm for, and suppress the background to tau reconstruction at the LHC !
- Tevatron has the advantage of being a well-understood environment, and can expect to have at least four times as much data used in this analysis. **On the path to evidence/discovery**.

The race is on: Who will see the pure third generation decay first ?

We hope that we will hear the answer at Pheno 2009

Thank you !

Back-up Slides

Table 1: Input variabls to the neural-network $b-$tagging algorithm.

Variable	Description
SVT_{SL} DLS	Decay length significance of the secondary vertex
CSIP Comb	Weighted combination of the tracks' impact parameter significance
JLIP Prob	Probability that the jet originates from the primary vertex
$SVT_{SL}\ \chi^2_{d.o.f.}$	Chi square per degree of freedom of the secondary vertex
$SVT_L\ N_{\rm tracks}$	Number of tracks used to reconstruct the secondary vertex
SVT_{SL} Mass	Mass of the secondary vertex
SVT_{SL} Num	Number of secondary vertices found in the jet

Table 2: Branching ratios (in unit of %) for dominant leptonic and hadronic decay modes of tau, sorted by expected tau type, as stated in Particle Data Book 2006 edition.

Decay modes	Branching ratio (%)
Leptonic decay	
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$	17.84 ± 0.05
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$	17.36 ± 0.05
Type 1 Hadronic single-prong decay without π^0	
$\tau^- \to \pi^- \nu_\tau$	10.90 ± 0.07
Type 2 Hadronic single-prong decay with π^0	
$\tau^- \to \pi^- \pi^0 \nu_\tau$	25.50 ± 0.10
$\tau^- \to \pi^- 2\pi^0 \nu_\tau$	9.47 ± 0.12
$\tau^- \to \pi^- 3\pi^0 \nu_\tau$	1.04 ± 0.08
Type 3 Hadronic three-prong decays	
$\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau$	9.33 ± 0.08
$\tau^- \to \pi^- \pi^+ \pi^- \pi^0 \nu_\tau$	4.59 ± 0.07

Table 3: Data and predicted numbers of events before and after b-tagging is applied. Standard model cross section and branching ratios are assumed for $t\bar{t}$ production. Uncertainties are statistical only.

	before b-tagging		after b-tagging	
	$\mu\tau$	$e\tau$	$\mu\tau$	$e\tau$
W	38.0 $\pm$ 1.7	34.1 $\pm$ 3.5	2.31 $\pm$ 0.22	2.13 $\pm$ 0.27
$Z/\gamma^* \to ee$ or $\mu\mu$	20.7 $\pm$ 1.1	5.8 $\pm$ 0.6	1.09 $\pm$ 0.11	0.38 $\pm$ 0.05
$Z/\gamma^* \to \tau\tau$	19.6 $\pm$ 1.2	7.5 $\pm$ 0.6	1.02 $\pm$ 0.10	0.54 $\pm$ 0.06
Diboson	2.8 $\pm$ 0.1	5.1 $\pm$ 0.6	0.21 $\pm$ 0.01	0.34 $\pm$ 0.07
Multijet	10.6 $\pm$ 6.3	12.7 $\pm$ 6.6	4.52 $\pm$ 3.01	-1.27 $\pm$ 1.77
$t\bar{t} \to \ell + \tau + 2b + 2\nu$	7.8 $\pm$ 0.1	6.67 $\pm$ 0.1	5.64 $\pm$ 0.04	4.70 $\pm$ 0.05
$t\bar{t} \to$ other dileptons	4.3 $\pm$ 0.1	0.73 $\pm$ 0.1	3.14 $\pm$ 0.03	0.47 $\pm$ 0.07
$t\bar{t} \to \ell +$ jets	12.7 $\pm$ 0.1	12.41 $\pm$ 0.2	8.40 $\pm$ 0.11	7.88 $\pm$ 0.12
Total Expected	116.6 $\pm$ 6.8	85.0 $\pm$ 7.7	26.33 $\pm$ 3.02	15.17 $\pm$ 1.97
Data	104	69	29	18

Table 4: Systematics for the measurement of $\sigma_{t\bar{t}}$.

	$\mu\tau$ $\Delta\sigma$	$e\tau$ $\Delta\sigma$	combined $\Delta\sigma$
Jet energy calibration	$+0.30$ -0.50	$+0.33$ -0.36	$+0.43$ -0.35
PV identification	$+0.36$ -0.34	$+0.23$ -0.37	$+0.38$ -0.21
Muon identification	$+0.21$ -0.20	–	$+0.12$ -0.12
Electron identification	–	$+0.59$ -0.53	$+0.25$ -0.24
Tau identification	$+0.16$ -0.15	$+0.15$ -0.15	$+0.16$ -0.16
Trigger	$+0.00$ -0.00	$+0.12$ -0.07	$+0.14$ -0.13
Fakes	$+0.45$ -0.42	$+0.59$ -0.53	$+0.50$ -0.49
b-tagging	$+0.31$ -0.34	$+0.44$ -0.41	$+0.45$ -0.37
MC normalization	$+0.18$ -0.18	$+0.15$ -0.15	$+0.13$ -0.13
Background/MC statistics	$+1.46$ -1.46	$+1.19$ -1.19	$+1.00$ -0.91
Other	$+0.08$ -0.08	$+0.09$ -0.10	$+0.19$ -0.18
Subtotal	$+1.76$ -1.67	$+1.64$ -1.59	$+1.40$ -1.24
Luminosity	±0.49	±0.52	±0.51
Total	$+1.83$ -1.95	$+1.72$ -1.67	$+1.49$ -1.34

Table 5: Systematics for the measurement of $\sigma_{t\bar{t}} \times \mathbf{BR}$.

	$\mu\tau$ $\Delta\sigma \times \mathrm{BR}$	$e\tau$ $\Delta\sigma \times \mathrm{BR}$	combined $\Delta\sigma \times \mathrm{BR}$
Jet energy calibration	$+0.030$ -0.023	$+0.017$ -0.019	$+0.022$ -0.020
PV identification	$+0.020$ -0.011	$+0.019$ -0.010	$+0.019$ -0.011
Muon identification	$+0.004$ -0.004	–	$+0.005$ -0.005
Electron identification	–	$+0.027$ -0.025	$+0.015$ -0.014
Tau identification	$+0.006$ -0.006	$+0.006$ -0.006	$+0.007$ -0.006
Trigger	$+0.014$ -0.013	$+0.005$ -0.003	$+0.006$ -0.006
Fakes	$+0.034$ -0.036	$+0.030$ -0.030	$+0.032$ -0.033
b-tagging	$+0.025$ -0.019	$+0.022$ -0.020	$+0.023$ -0.020
NLO $t\bar{t}$ cross-section	$+0.027$ -0.026	$+0.023$ -0.022	$+0.025$ -0.024
MC normalization	$+0.009$ -0.009	$+0.006$ -0.005	$+0.007$ -0.007
Background/MC statistics	$+0.066$ -0.066	$+0.045$ -0.045	$+0.041$ -0.037
Other	$+0.004$ -0.004	$+0.007$ -0.007	$+0.010$ -0.008
Subtotal	$+0.093$ -0.089	$+0.074$ -0.071	$+0.072$ -0.066
Luminosity	±0.011	±0.012	±0.011
Total	$+0.094$ -0.090	$+0.075$ -0.072	$+0.073$ -0.067