Measurement of the top pair production cross section at DØ using dilepton and lepton + track events

Outline

- Experiment
- Top Quark
- Dilepton Selection
- Lepton+Track Selection
- Conclusions & Updates

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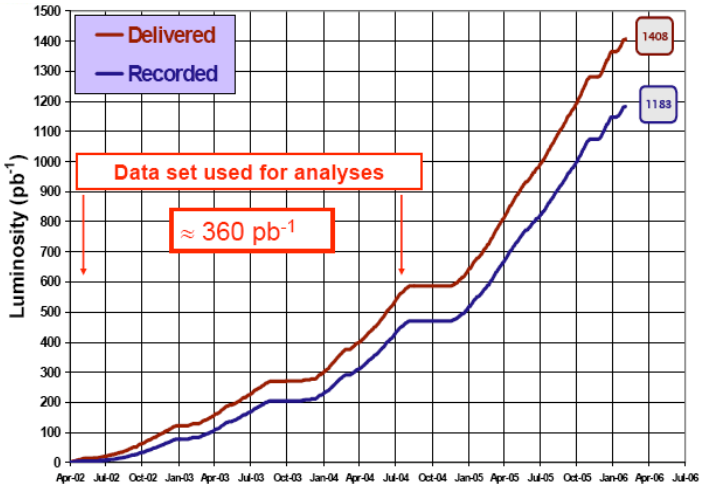
Fermilab Tevatron

$p\bar{p}$ collider at $\sqrt{s}$ =1.96TeV

Upgraded from Run I (1.8TeV):

- 36 bunches (396 ns spacing)
- Improved Linac
- Main injector (150 GeV proton storage ring)
- Antiproton "recycler" (began June 2004)
- Peak luminosity >10x higher than Run I

Currently the world's only source for top quarks!



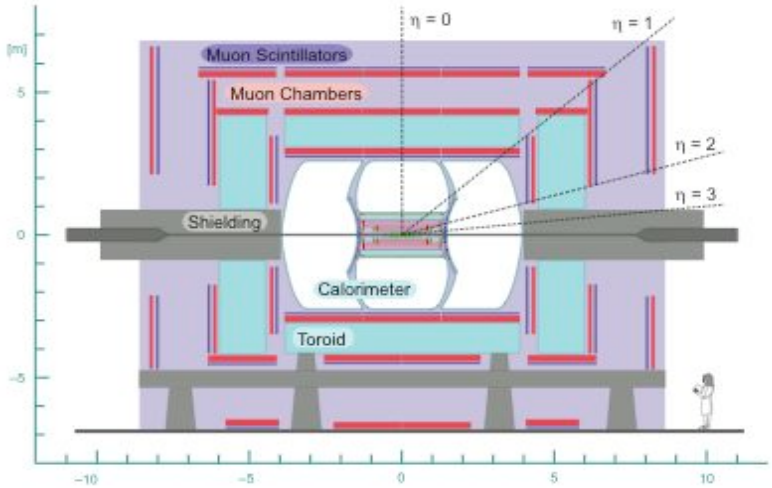
Run II Integrated Luminosity

Integrated Luminosity

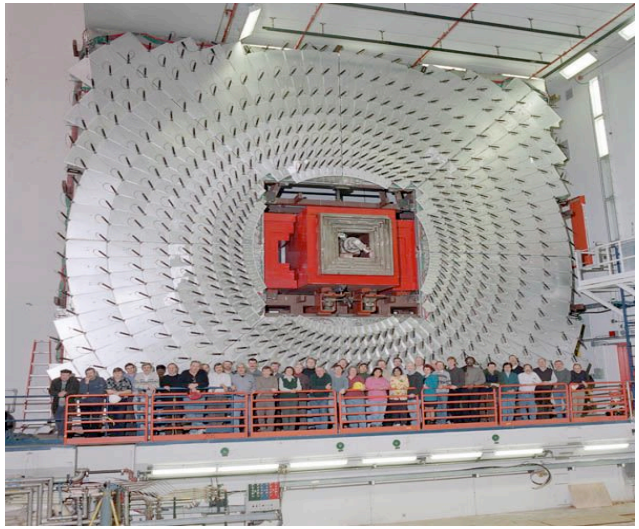
- Run I: $\int Ldt \sim 125\ pb^{-1}$
- Run II so far > 1 fb^{-1}
- Run II expected: 4 - 8 fb^{-1}
- This analysis: 360-370 pb^{-1} corresponding to April 2002-August 2004

DØ Detector

DØ detector is comprised of:



- Central Tracking Detectors
  - Silicon Microstrip Tracker
    - Allows b-tagging of jets!
  - Scintillating Fiber Tracker
  - Surrounded by 2T solenoid magnet



- Liquid Argon Calorimeter
  - Uranium/Copper/stainless steel absorber plates
  - Surrounded by liquid Argon
- Muon Spectrometer
  - 3 Layers of wire chambers
  - 3 Layers of scintillation counters
  - 1.8T toroid magnet outside innermost layer

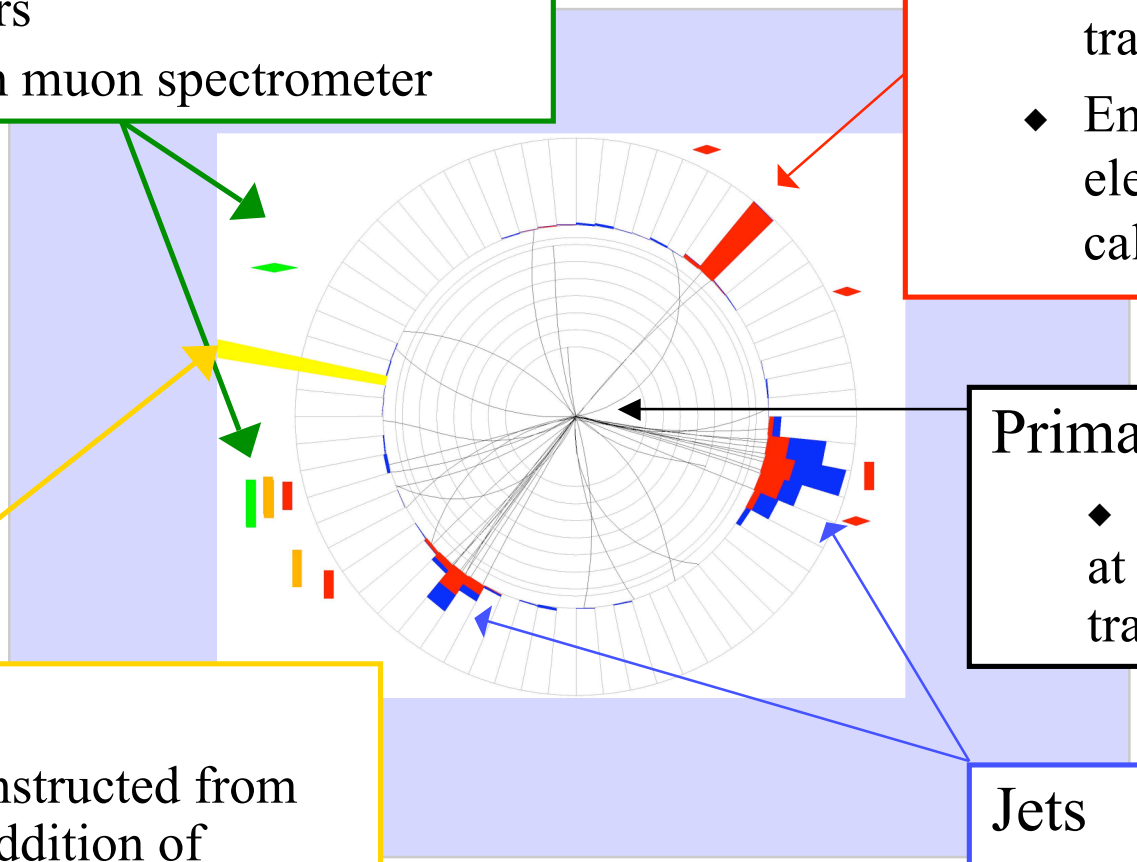
Object Identification

Muons

- Tracks in central tracking detectors
- Hits in muon spectrometer

Electrons

- Tracks in central tracking detectors
- Energy clusters in electromagnetic calorimeter



Primary Vertex

- Reconstructed from at least 3 quality tracks

ME_T

- Reconstructed from vector addition of calorimeter E_T, corrected for muon and track P_T

Jets

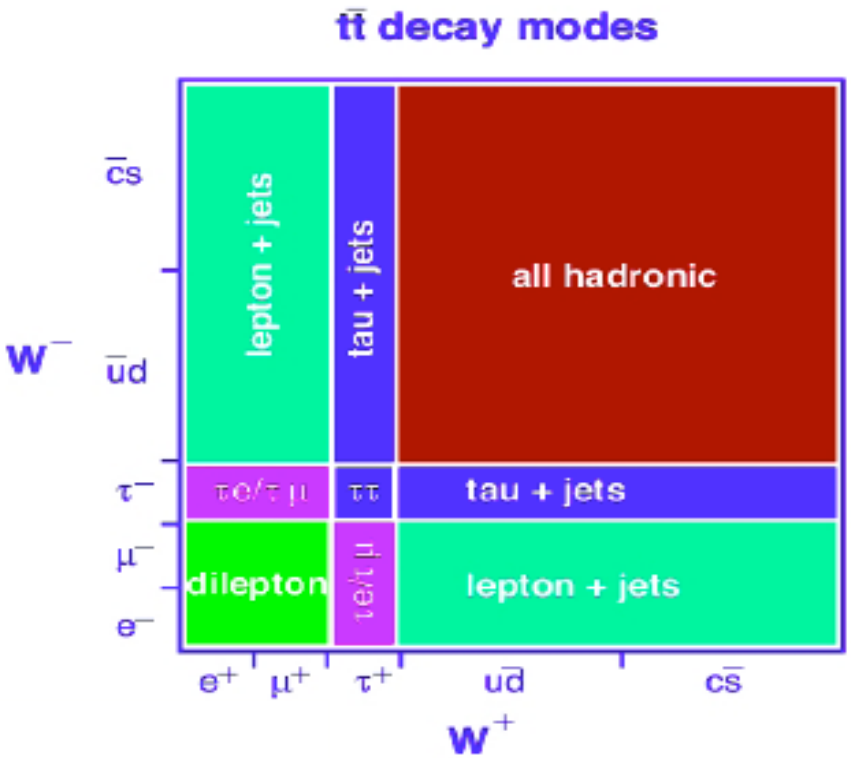
- Energy clusters in calorimeter

Top Quark Decay

Top quark decays to W + b quark (~100%) in Standard Model

Final decay states determined by W decay mode:

- 2 b-quark jets
- up to 2 leptons + neutrino pairs
- up to 4 additional jets



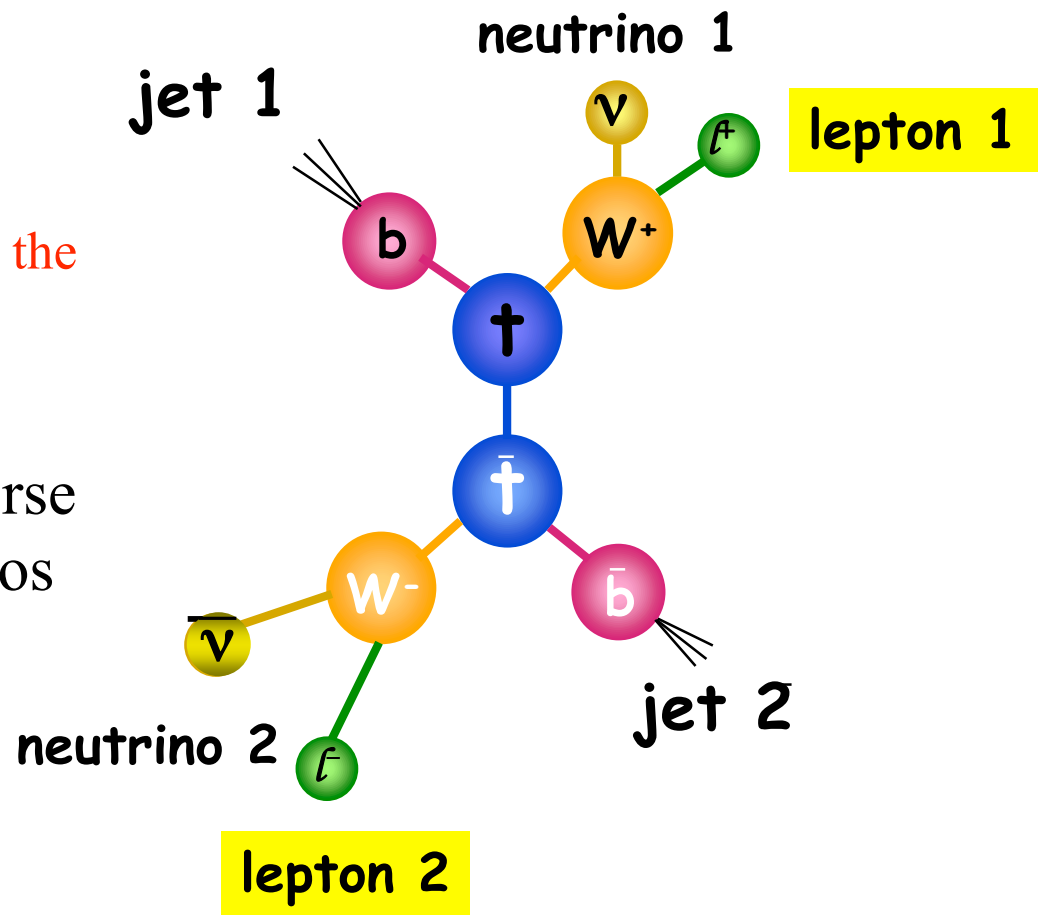
All hadronic ~ 44 %
Lepton + Jets ~ 46%
Dilepton ~ 10%

ee+eμ+μμ ~ 6%, including e's and μ's originating from τ's (W→ τν decay)

Branching Ratios (%):

$t\bar{t} \rightarrow \ell\ell$ Signature

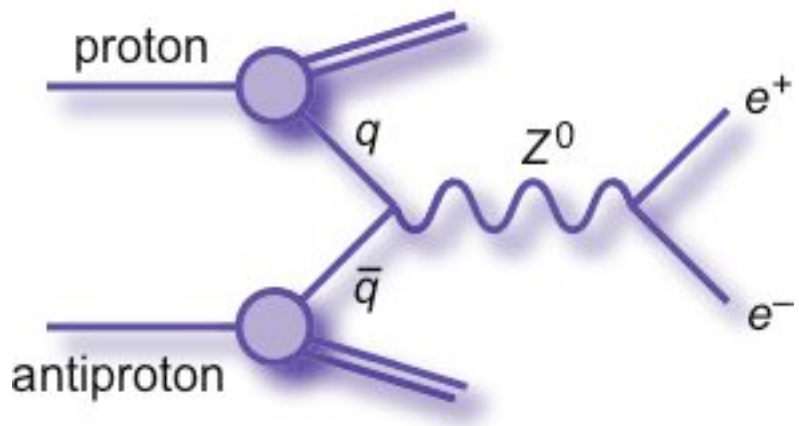
- 2 high-P_T (transverse momentum) leptons
  - Isolated from each other and the jets
- 2 high-P_T jets
- Significant missing transverse energy (ME_T) from neutrinos



Few background processes share this signature!

Type of Backgrounds

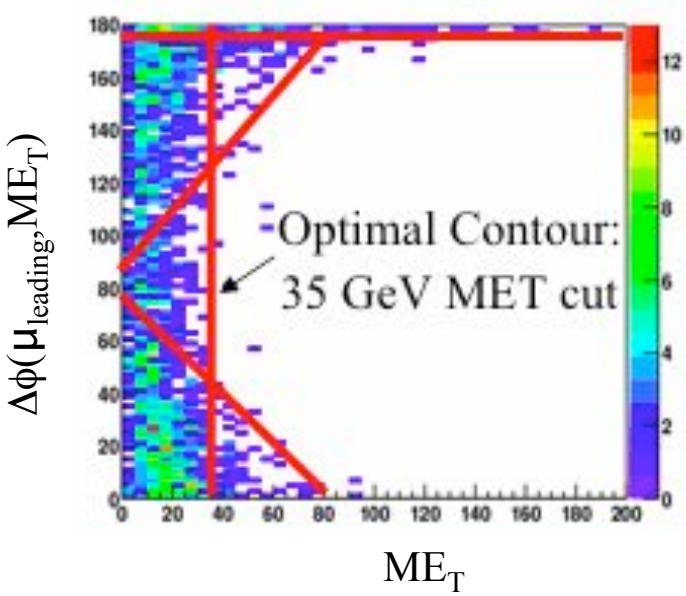
- Physics Backgrounds
  - With intrinsic ME_T
  - $Z/\gamma^* \rightarrow \tau\tau \rightarrow \ell\ell$, $WW/WZ \rightarrow \ell\ell$
  - Small backgrounds
  - Estimated from Monte Carlo (MC)



- Instrumental Backgrounds
  - $Z/\gamma^* \rightarrow ee\ (\mu\mu)$
    - No intrinsic ME_T, fake ME_T due to calorimeter energy resolution and noise
    - Estimated from data (MC, normalized to data)
    - Dominant background in ee & uu
  - Instrumental leptons : multijet production & W + jets
    - ee: at least one fake electron, relatively small background
    - $\mu\mu$: at least one muon fakes isolation from jets, relatively small background
    - $e\mu$: at least one fake electron or one fake isolated muon, dominant background
    - Estimated from data for all 3 channels

Event Selection

- Leptons
  - ≥2 isolated, opposite charged leptons from primary vertex
  - Trigger
  - P_T › 15 GeV
- Jets
  - ≥2 jets, P_T › 20 GeV
- Orthogonality vetoes
- Background rejection cuts:



ee

- ME_T > 35 GeV (tightened at low M_{ee})
- Remove events with $80 \leq M_{ee} \leq 100$
- Cut on event shape variable

eμ

- H_T > 122 GeV ($H_T = p_T^{lepton1} + p_T^{jet1} + p_T^{jet2}$)

μμ

- ME_T > 35 GeV (tightened at high & low values of $\Delta\phi(\mu_{leading}, ME_T)$)
- $\chi^2 > 2$ (χ^2 is an event variable which tests consistency with Z hypothesis)

Signal & Background Estimates

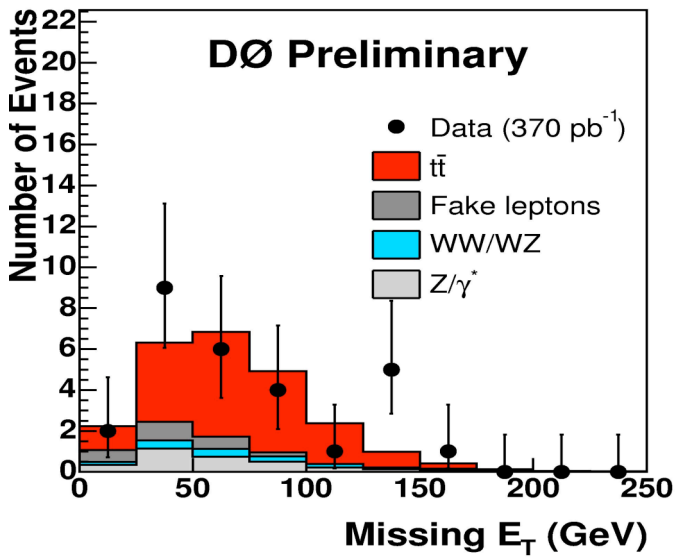
Estimated yields in all channels after full selection:

Category	ee	$\mu\mu$	$e\mu$	$\ell\ell$
Integrated luminosity (pb^{-1})	384	363	368	–
Z/γ^*	$0.75^{+0.18}_{-0.21}$	$1.01^{+0.22}_{-0.34}$	$1.22^{+0.33}_{-0.39}$	$2.98^{+0.43}_{-0.55}$
WW/WZ	$0.20^{+0.10}_{-0.14}$	$0.20^{+0.08}_{-0.07}$	$1.13^{+0.45}_{-0.48}$	$1.53^{+0.47}_{-0.50}$
Instrumental leptons	0.09 ± 0.03	0.13 ± 0.04	$2.13^{+2.50}_{-1.66}$	$2.35^{+2.50}_{-1.67}$
Total background	$1.0^{+0.2}_{-0.3}$	$1.3^{+0.3}_{-0.4}$	$4.5^{+2.6}_{-1.8}$	$6.8^{+2.6}_{-1.8}$
Signal efficiency	0.082	0.064	0.139	–
Expected signal	3.5 ± 0.4	2.5 ± 0.3	$11.3^{+1.2}_{-1.4}$	$17.3^{+1.3}_{-1.5}$
SM expectation	$4.5^{+0.4}_{-0.5}$	$3.8^{+0.4}_{-0.5}$	$15.8^{+2.8}_{-2.3}$	$24.1^{+2.9}_{-2.4}$
Selected events	5	2	21	28

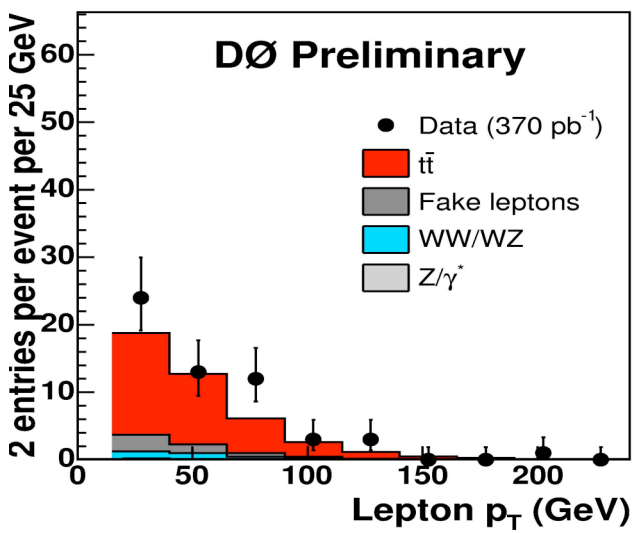
Yields scaled to integrated luminosity used for each channel. Expected signal yields assume $t\bar{t}$ cross section of 7 pb.

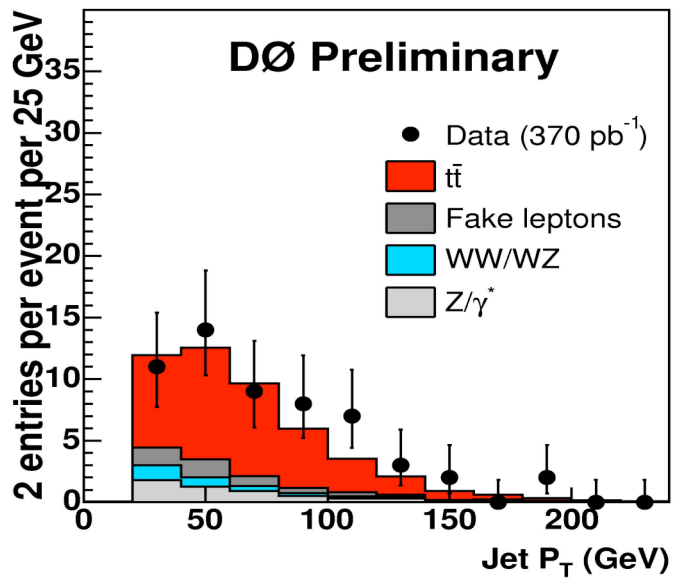
The errors on yields represent statistical and systematic errors added in quadrature.

Kinematic Distributions



- After full selection
- All channels combined
- Signal estimated with $t\bar{t}$ Monte Carlo





Cross Section Measurement

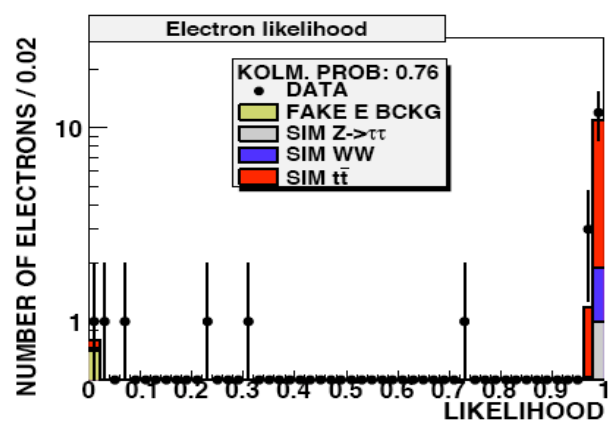
Data from April 2002-August 2004

Channel	# observed events: N_{obs}	Background: N_{bckg}	Signal Efficiency	Branching Ratio	$\mathcal{L}$ (pb^{-1})
ee	5	1.0	0.082	0.01584	384
eμ	21	4.5	0.139	0.03155	368
μμ	2	1.3	0.064	0.01571	363

Cross section = (N_{obs} - N_{bckg}) / (Signal Efficiency x Branching Ratio x Integrated Luminosity)

$$\begin{aligned} ee &: \quad \sigma_{t\bar{t}} = 7.9^{+5.2}_{-3.8}\,(\text{stat})\,^{+1.3}_{-1.0}\,(\text{syst})\ \pm 0.5\,(\text{lumi})\ \text{pb} \\ e\mu &: \quad \sigma_{t\bar{t}} = 10.2^{+3.1}_{-2.6}\,(\text{stat})\,^{+1.6}_{-1.3}\,(\text{syst})\ \pm 0.7\,(\text{lumi})\ \text{pb} \\ \mu\mu &: \quad \sigma_{t\bar{t}} = 1.8^{+4.8}_{-3.0}\,(\text{stat})\,^{+1.0}_{-1.2}\,(\text{syst})\ \pm 0.1\,(\text{lumi})\ \text{pb} \end{aligned}$$

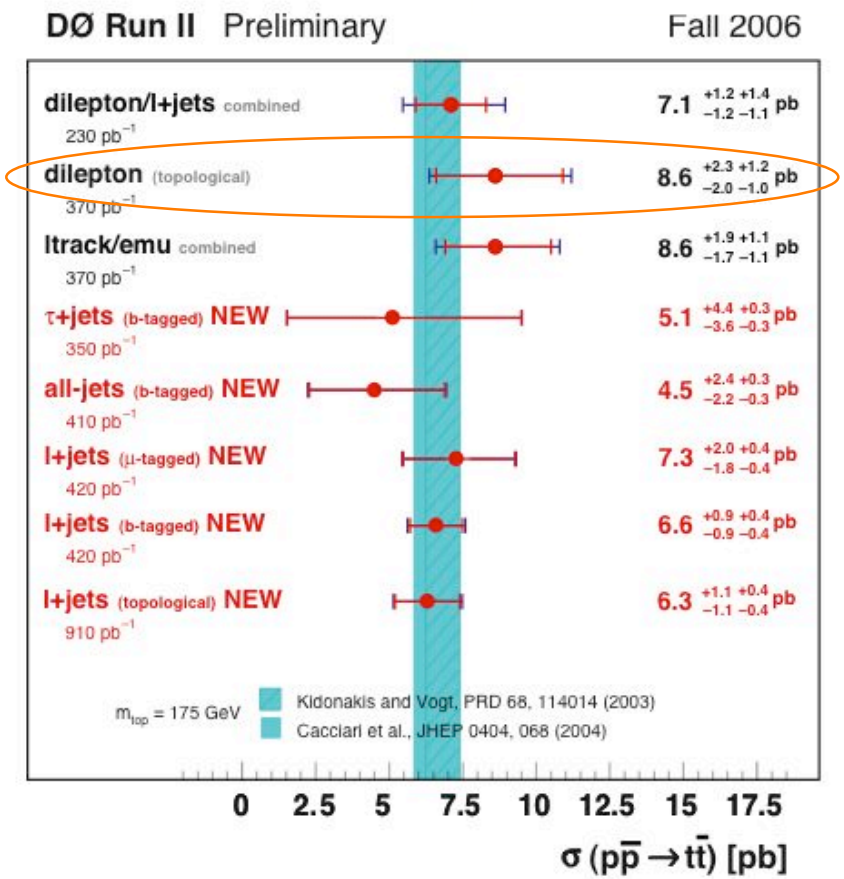
Note: The instrumental background yield in the eμ channel is actually extracted from fitting an electron likelihood distribution, rather than by the simple counting method defined above.



Cross Section Measurement

The combined top production cross section in the dielectron, dimuon, and electron muon final states:

$$\sigma_{t\bar{t}} = 8.6^{+2.3}_{-2.0}\,(\text{stat})\,^{+1.2}_{-1.0}\,(\text{syst})\ \pm 0.6\,(\text{lumi})\ \text{pb}.$$



Our result is consistent with the Standard Model prediction!

Primary sources of systematic error are jet energy scale calibration and lepton reconstruction.

Lepton + Track Analysis

Dilepton Channels

- Benefit from few backgrounds
- Suffer from low branching ratio (~6%)
- Suffer from low signal efficiency
  - largest hit in signal efficiency is from requiring 2 fully reconstructed leptons!

Signal Efficiency

ee	8.2%
eμ	13.9%
μμ	6.4%

Lepton + Track Selection

- 1 isolated lepton, P_T >15 GeV

  Electron or Muon
- 1 isolated track, P_T > 15 GeV
- ≥1 jet, P_T > 20 GeV
- ME_T :
  - For e +track >15-20 GeV
  - For μ+ track > 25-35 GeV

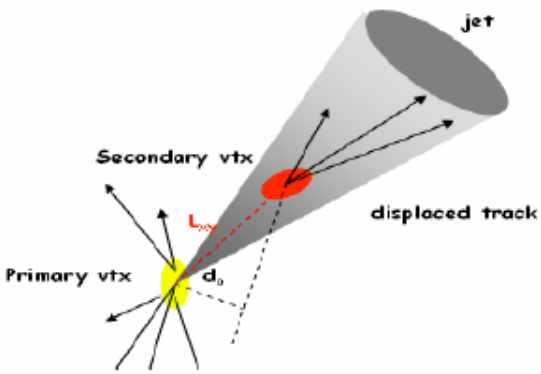
  (Tighter cuts are for events in Z mass window)
- Veto on eμ events to ensure channel orthogonality for combination

Still a lot of background in sample!

b-Tagging

Signal: 2 high P_T jets are from b-quark

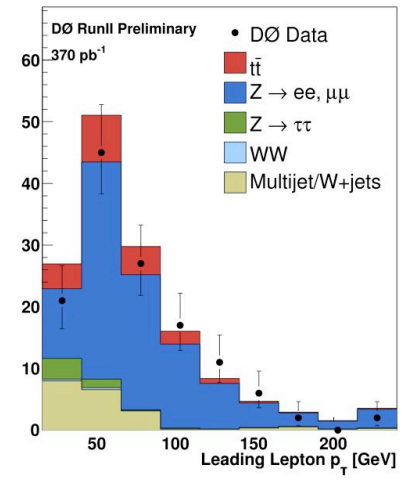
- Require at least one jet to be b-tagged!



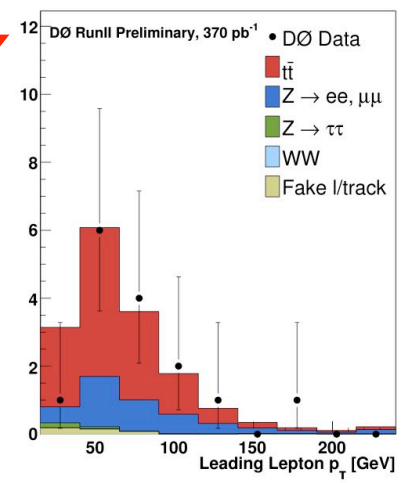
b quark hadronizes into B-meson which travels a few mm before decaying

- Secondary vertex algorithm uses tracks with high impact parameter significance
- Decay length significance of secondary vertex $L_{xy} / \sigma_{Lxy} > 7$
- Any jet with reconstructed secondary vertex is b-tagged!

Backgrounds (Z + jets): most jets are from light quarks or gluons



b-Tagging



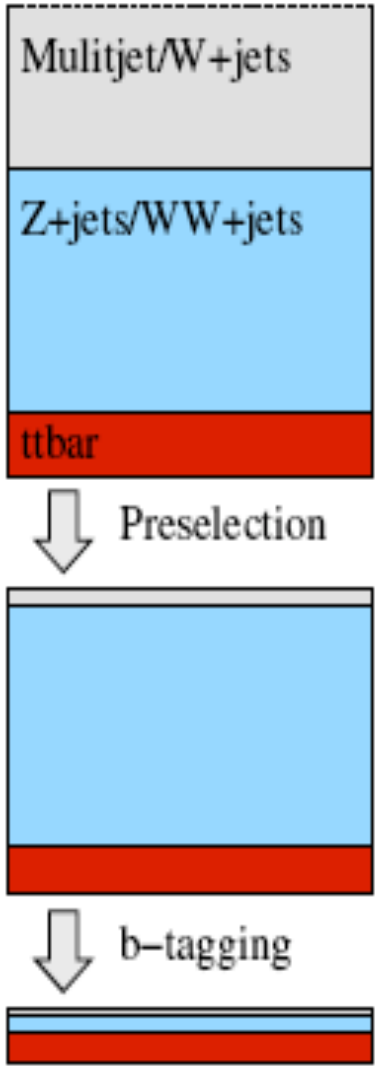
Signal & Background Estimation

Signal Estimation

- $t\bar{t}$ Monte Carlo
  - Jet b-tagging efficiency estimated using semi-leptonic b decays in data
  - Probability to tag a light quark jet (mistag rate) is measured in multijet events in data

Background Estimation

- Physics Backgrounds: $Z/\gamma^* \rightarrow \tau\tau$, $WW \rightarrow \ell\ell$
  - Estimated with MC
  - b-tagging efficiency from $Z/\gamma^* \rightarrow ee\ (\mu\mu)$, W+ jets
- Instrumental Backgrounds
  - $Z/\gamma^* \rightarrow ee\ (\mu\mu)$
    - Estimated from MC, normalized to data
    - b-tagging efficiency from $Z/\gamma^* \rightarrow ee\ (\mu\mu)$ data with low ME_T
  - Instrumental leptons : multijet production & W + jets
    - Fake electrons, fake isolated tracks, or fake isolated muons
    - Estimated in Data
    - Tagging probability for multijet (W+jets) is estimated in data sample with isolated lepton and low (high) ME_T



Results

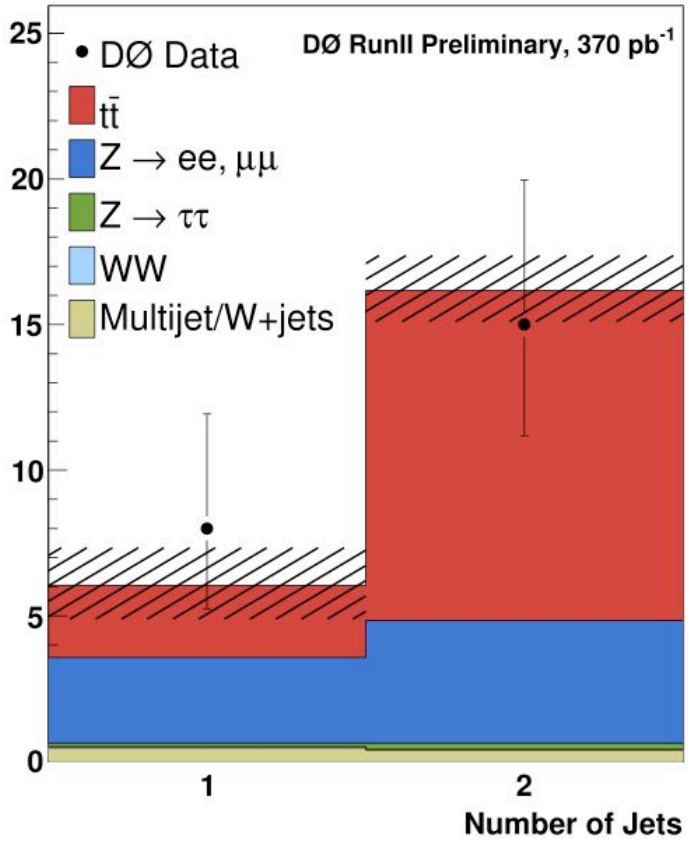
Estimated yields in both channels after full selection:

	e + track		μ + track	
	Njets = 1	Njets $\geq$ 2	Njets = 1	Njets $\geq$ 2
	Expected number of tagged events			
WW	0.037 ± 0.002	0.010 ± 0.002	0.016 ± 0.001	0.009 ± 0.002
$Z/\gamma^* \to \tau\tau$	0.09 ± 0.02	0.13 ± 0.02	0.03 ± 0.01	0.09 ± 0.02
$Z/\gamma^* \to ee, \mu\mu$	1.49 ± 0.04	2.35 ± 0.06	1.44 ± 0.04	1.86 ± 0.06
Multijet/W+jets	0.36 ± 0.06	0.35 ± 0.07	0.08 ± 0.02	0.05 ± 0.03
Total background	1.97 ± 0.08	2.83 ± 0.09	1.57 ± 0.05	2.00 ± 0.07
Tot. uncertainty (stat+syst) on bkg	$+0.91\ -0.85$	$+0.87\ -0.64$	$+0.77\ -0.77$	$+0.51\ -0.49$
$t\bar{t}$	1.55 ± 0.03	6.59 ± 0.07	0.92 ± 0.02	4.74 ± 0.06
Total	3.53 ± 0.08	9.4 ± 0.1	2.49 ± 0.05	6.74 ± 0.09
Tot. uncertainty (stat+syst) on $t\bar{t}$ + bkg	$+0.99\ -0.86$	$+0.99\ -0.85$	$+0.83\ -0.77$	$+0.67\ -0.64$
	Observed number of tagged events			
Data	7	9	1	6

Yields scaled to integrated luminosity used for each channel. Expected signal yields assume $t\bar{t}$ cross section of 7 pb.

The errors on yields represent statistical uncertainties unless explicitly stated otherwise.

Cross Section Measurement



Primary sources of systematic error:

- jet energy scale calibration
- Z background
- track and lepton reconstruction
- tagging rate for signal

$$\text{lepton+track}: \ \sigma_{t\bar{t}} = 7.1\ ^{+2.6}_{-2.2}\ (\text{stat})\ ^{+1.3}_{-1.3}\ (\text{syst})\ \pm 0.4\ (\text{lumi})\ \text{pb}.$$

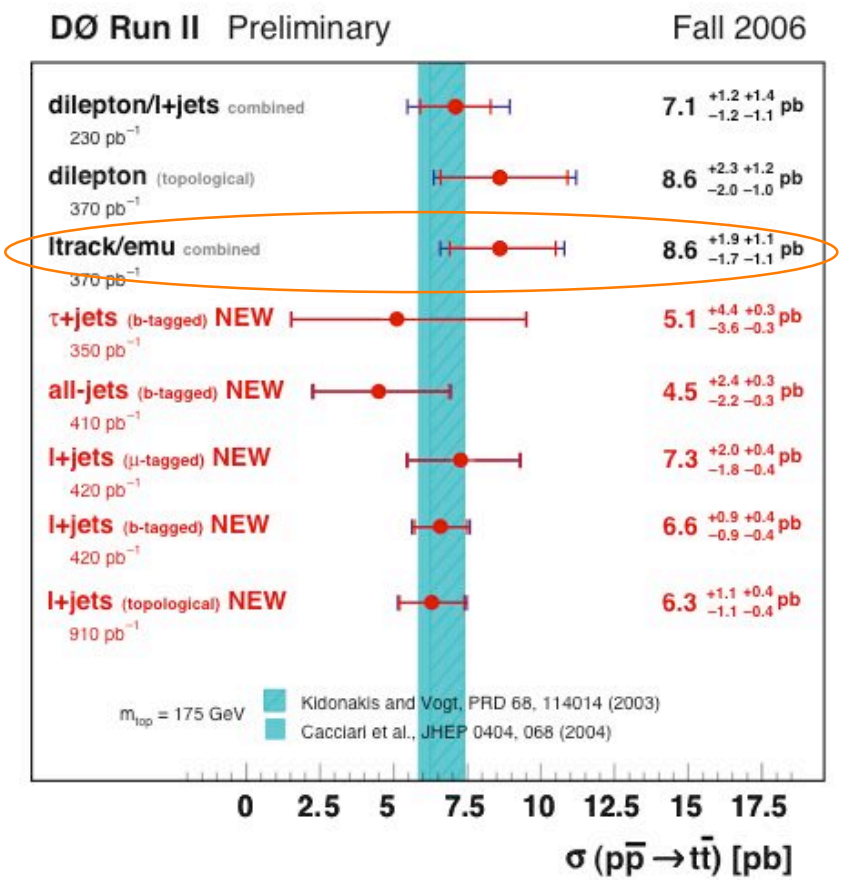
$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{Bkg}}{\epsilon \int L dt}$$

N_{obs} = # of observed events
N_{Bkg} = estimated background yield
ε = efficiency
L = luminosity

Cross Section Measurement

The combined top production cross section using the lepton + track and electron muon final states:

$$\sigma_{t\bar{t}} = 8.6^{+1.9}_{-1.7}\,(\text{stat})\,^{+1.1}_{-1.1}\,(\text{syst}) \pm 0.6\,(\text{lumi})\ \text{pb}.$$



Our result is consistent with the Standard Model prediction!

Conclusion and Updates

We have measured the top pair production cross section in dilepton and lepton + track events using ~370pb^{-1}

- The combined result for dielectron, dimuon, and electron muon final states, using a total of 28 events, is:

$$\sigma_{t\bar{t}} = 8.6^{+2.3}_{-2.0}\,(\text{stat})\,^{+1.2}_{-1.0}\,(\text{syst})\ \pm 0.6\,(\text{lumi})\ \text{pb}.$$

- The combined result for e+track, μ+ track, and electron muon final states, using a total of 44 events, is:

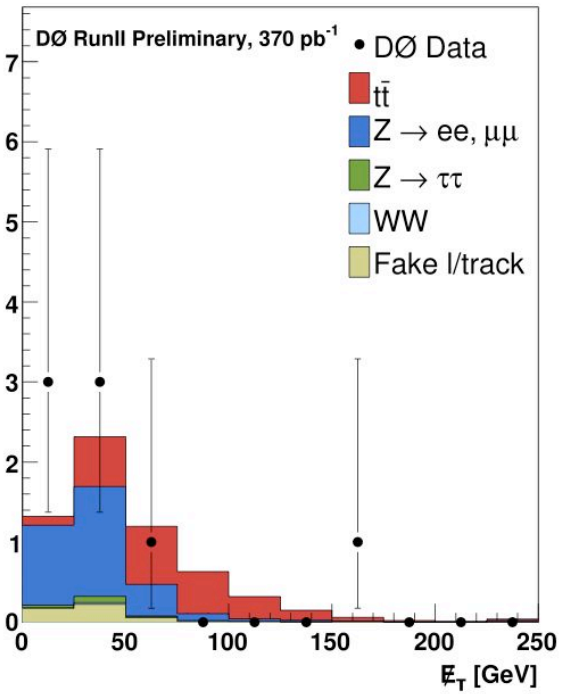
$$\sigma_{t\bar{t}} = 8.6^{+1.9}_{-1.7}\,(\text{stat})\,^{+1.1}_{-1.1}\,(\text{syst})\ \pm 0.6\,(\text{lumi})\ \text{pb}.$$

- We are working on a combination with all five selections, which accounts for correlations between the channels →Combination includes new selection criteria for the μμ channel!

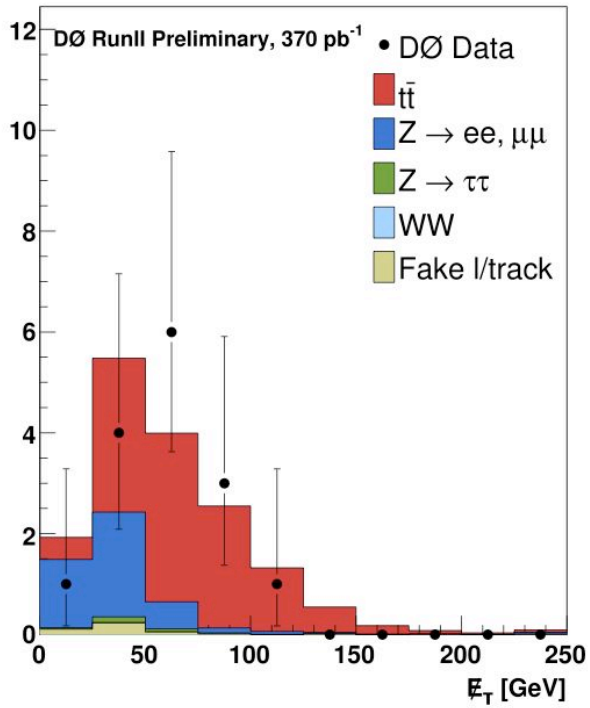
- Results are still statistically limited! All channels are currently being analyzed with a higher data set: ~1fb^{-1}

Kinematic Distributions

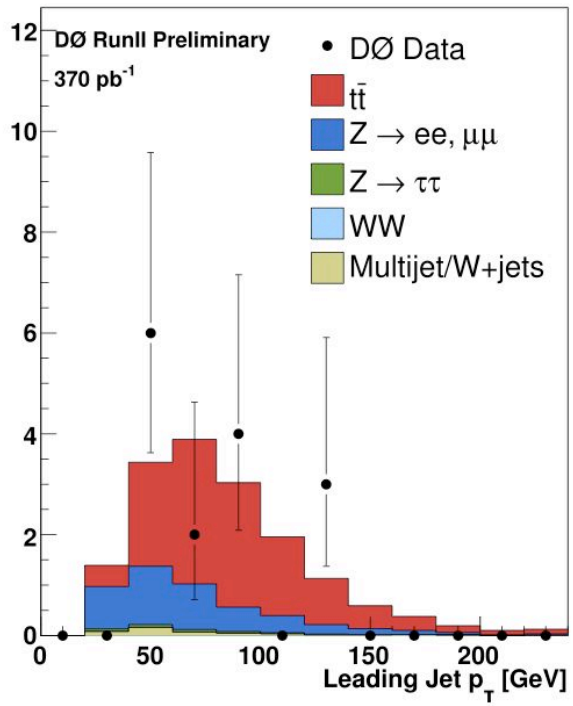
- After full selection
- e + track and μ + track channels combined



= 1 jet



≥2 jets



≥2 jets