Measurement of Top Pair Production Cross Section at DØ Using Di-lepton Events

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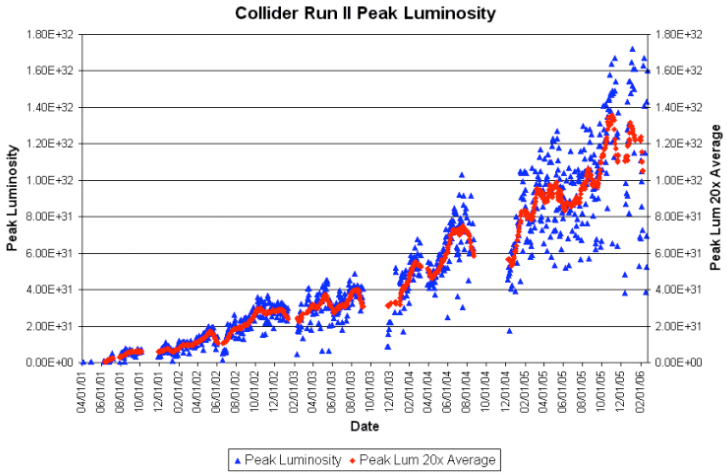
Fermilab Tevatron

$p\bar{p}$ 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)

Currently the world's only source for top quarks!

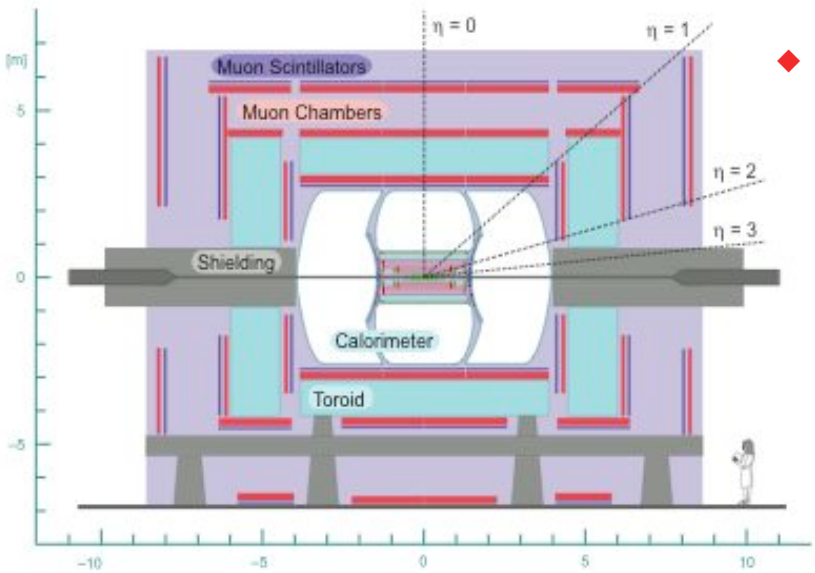


Peak Luminosity 8x higher than Run 1

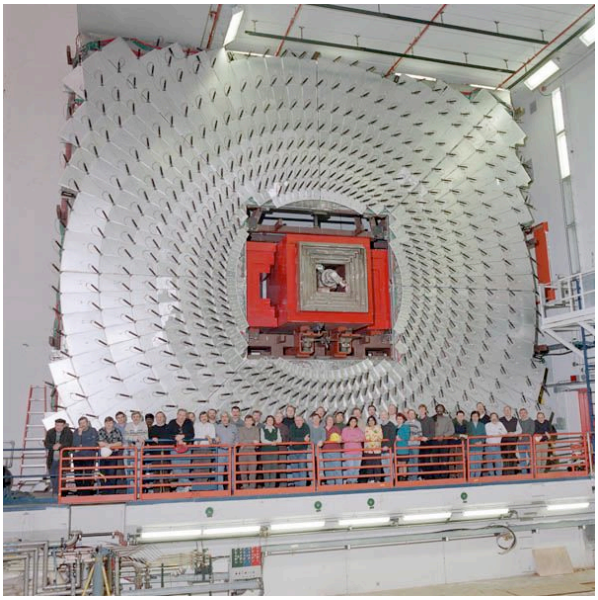
- Run I: $\int Ldt \sim 125\ pb^{-1}$
- Run II so far ~ 1 fb^{-1}
- Run II expected: 4 - 8 fb^{-1}

DØ Detector

DØ detector is comprised of:

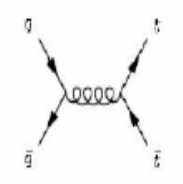


- Central Tracking Detectors
  - Silicon Microstrip Tracker
  - Scintillating Fiber Tracker
  - Surrounded by 2T Solenoid Magnet
- Liquid Argon Calorimeter
  - Uranium/Copper/Stainless Steel Absorber Plates
  - Surrounded by Liquid Argon
- Muon Spectrometer
  - 3 layers of Wire Chambers
  - 3 layers of Scintillation Counters
  - 1.8T Toroid Magnet outside innermost layer

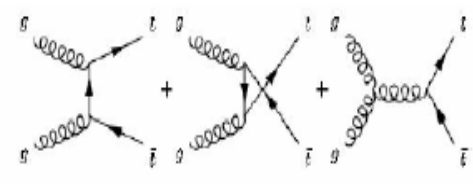


Top Quark Production

Top Quark Pair Production in $p\bar{p}$ collisions at Tevatron (1.96 TeV):

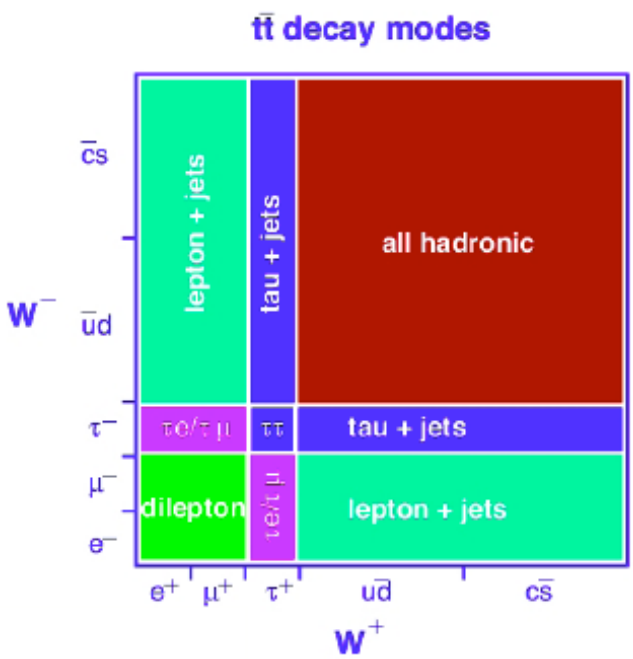


85% $q\bar{q}$ annihilation,



15% gg fusion

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



Final decay states determined by W decay mode:

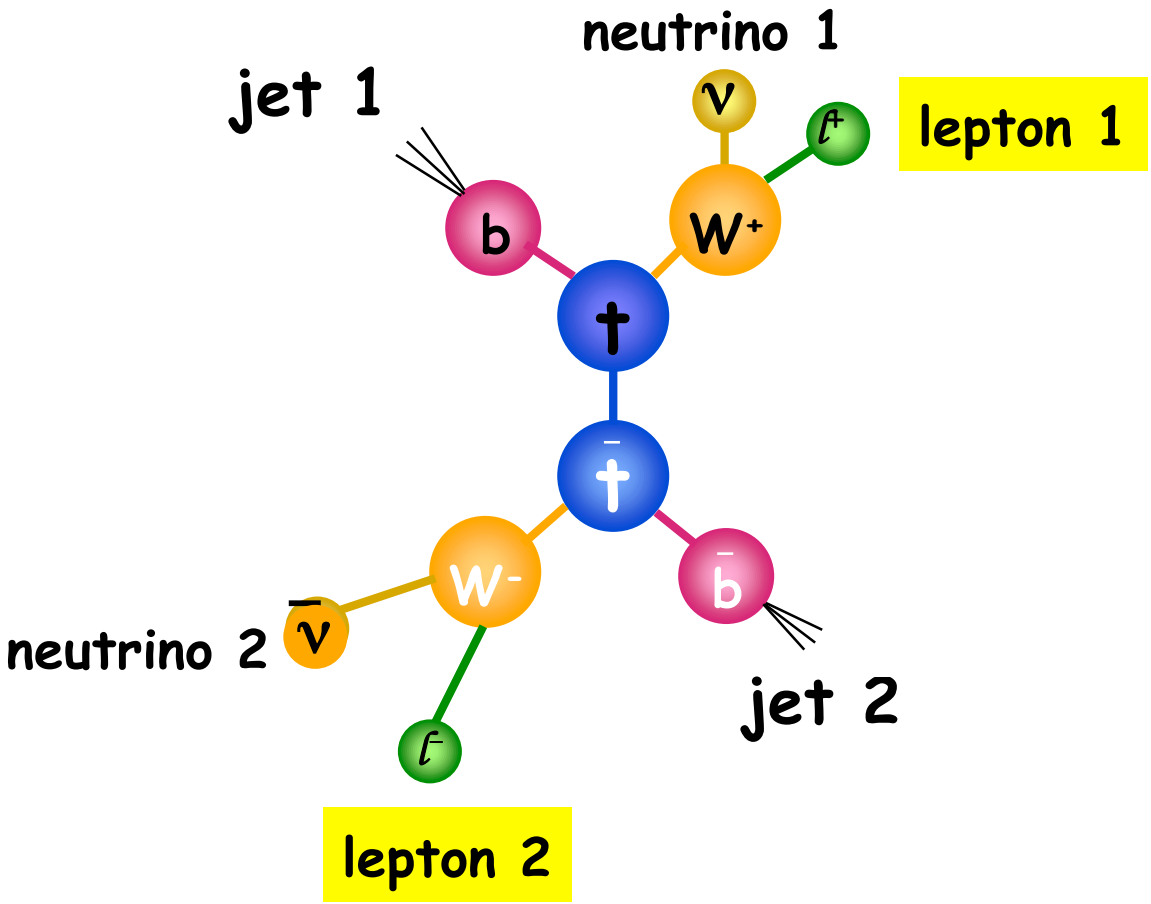
- 2 b-quark "jets"
- up to 2 leptons + neutrino pairs
- up to 4 additional jets

Branching Ratios (%):

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

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

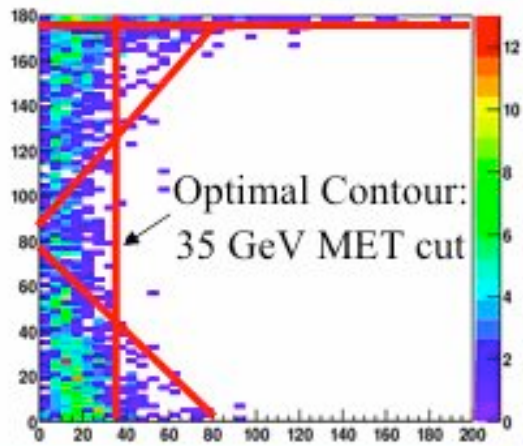


Type of Backgrounds

- 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)
    - Dominant background in ee & eu
  - Instrumental leptons : QCD multijets & 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 and one fake isolated muon, dominant background
    - Estimated from data for all 3 channels

Event Selection

- Leptons
  - ≥2 isolated, oppositely charged leptons from primary vertex
  - Trigger
  - P_T > 15 GeV



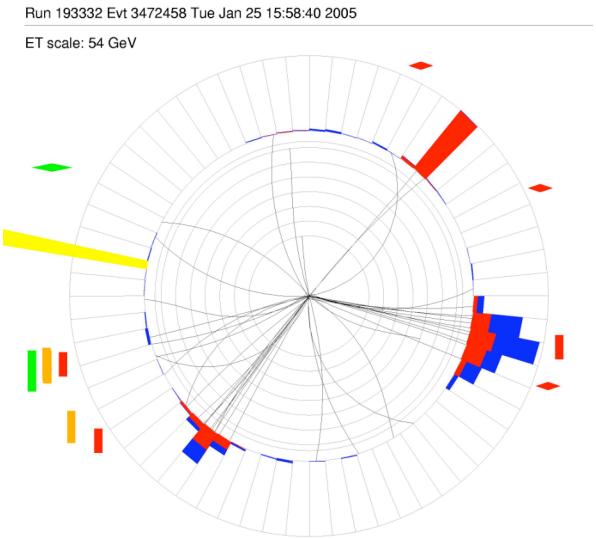
Contour Cut for 240pb^{-1}

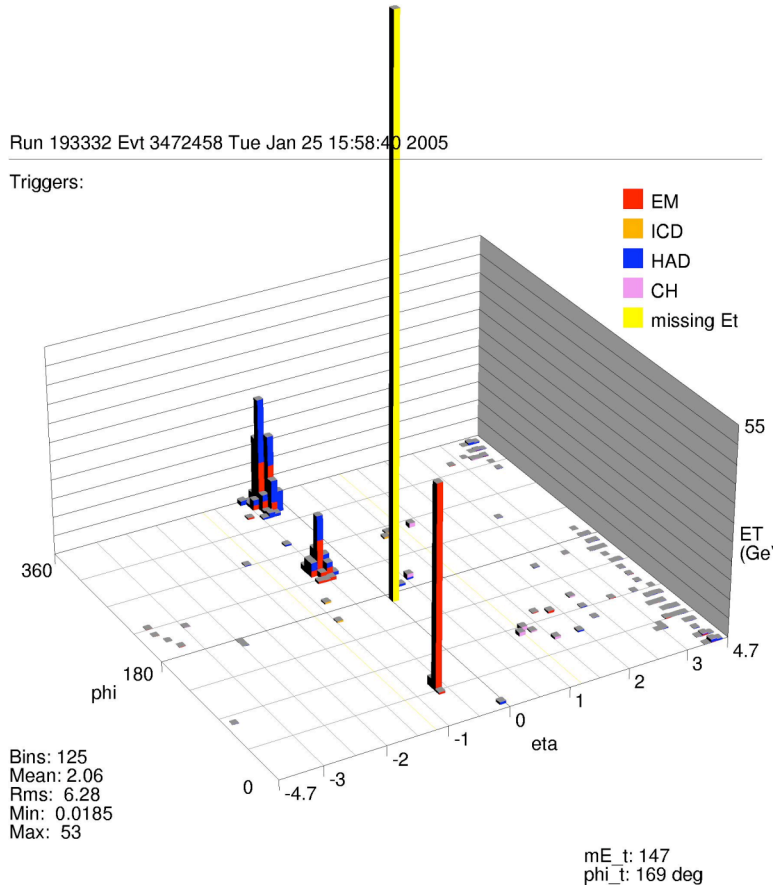
- Jets
  - ≥2 jets, P_T > 20 GeV

- 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
  - μμ: ME_T > 35 GeV (tightened at high & low values of $\Delta\phi(\mu_{leading}, ME_T)$)
    χ^2 > 2 (χ^2 is a p_T-based event variable which tests consistency with Z hypothesis)
  - eμ: H_T > 122 GeV (H_T is the scalar sum of leading lepton p_T and p_T of the 2 leading jets)

eμ Candidate Event

	p_T	η	φ
e	65.1	-0.54	0.85
μ	48.1	0.57	3.40
jet 1	192.3	-0.18	6.03
jet 2	80.9	-0.43	4.08
ME_T	156.0		2.63





Background Estimates

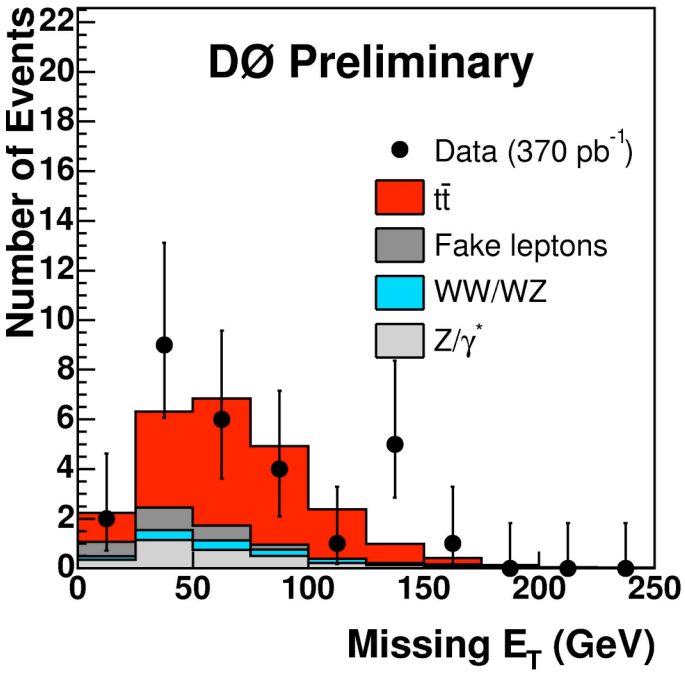
Estimated yields in all channels after full selection

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	$11.3^{+1.2}_{-1.4}$	$17.3^{+1.3}_{-1.5}$
Selected events	5	2	21	28

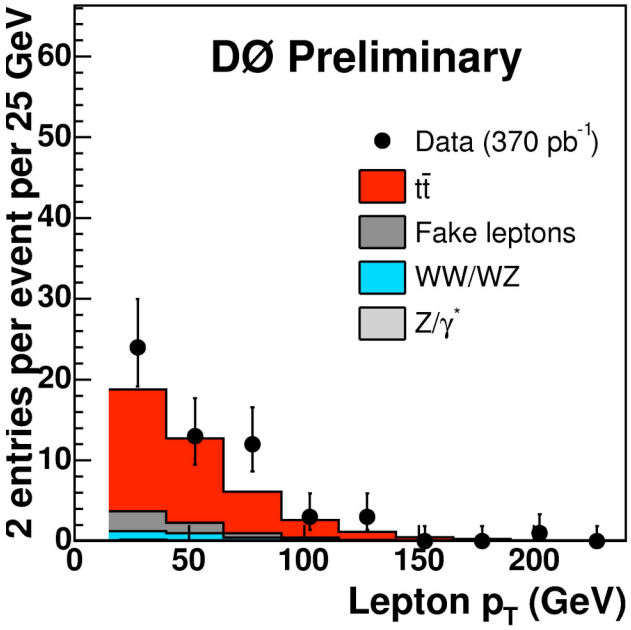
Yields scaled to integrated luminosity used for each channel. Expected signal yields assume $t\bar{t}$ cross section of 7 pb and full selection.

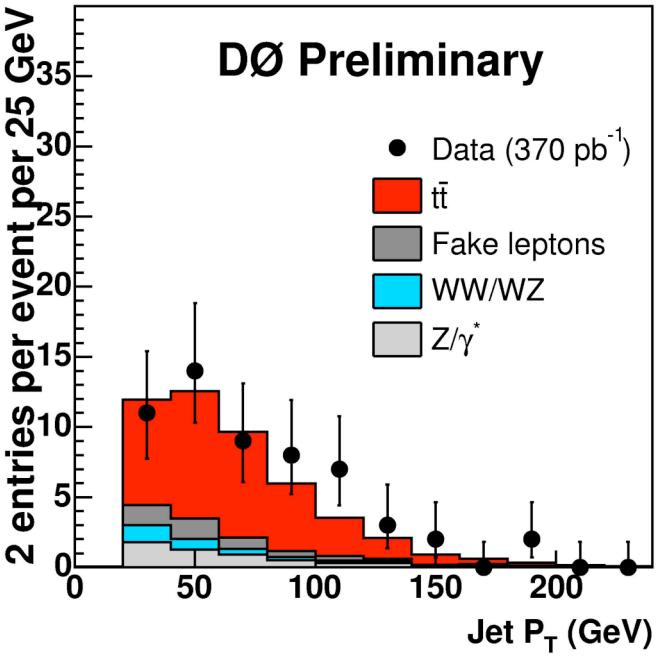
The errors on yields represent statistical and systematic errors added in quadrature.

Kinematic Distributions



- After full selection
- All channels combined





Cross Section Measurement

Data from April 2002-August 2004

Channel	# obs. events	Background	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

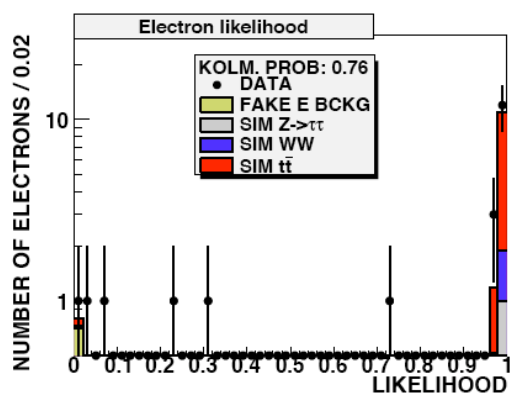
Cross section = (N_{obs} - N_{bckg}) / (Branching Ratio x Efficiency x Integrated Luminosity)

$$\mathrm{ee} \;:\quad \sigma_{t\bar{t}} = 7.9^{+5.2}_{-3.8}\,(\mathrm{stat})\,^{+1.3}_{-1.0}\,(\mathrm{syst})\;\pm 0.5\,(\mathrm{lumi})\;\mathrm{pb}$$

$$\mathrm{e}\mu \;:\quad \sigma_{t\bar{t}} = 10.2^{+3.1}_{-2.6}\,(\mathrm{stat})\,^{+1.6}_{-1.3}\,(\mathrm{syst})\;\pm 0.7\,(\mathrm{lumi})\;\mathrm{pb}$$

$$\mu\mu \;:\quad \sigma_{t\bar{t}} = 1.8^{+4.8}_{-3.0}\,(\mathrm{stat})\,^{+1.0}_{-1.2}\,(\mathrm{syst})\;\pm 0.1\,(\mathrm{lumi})\;\mathrm{pb}$$

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

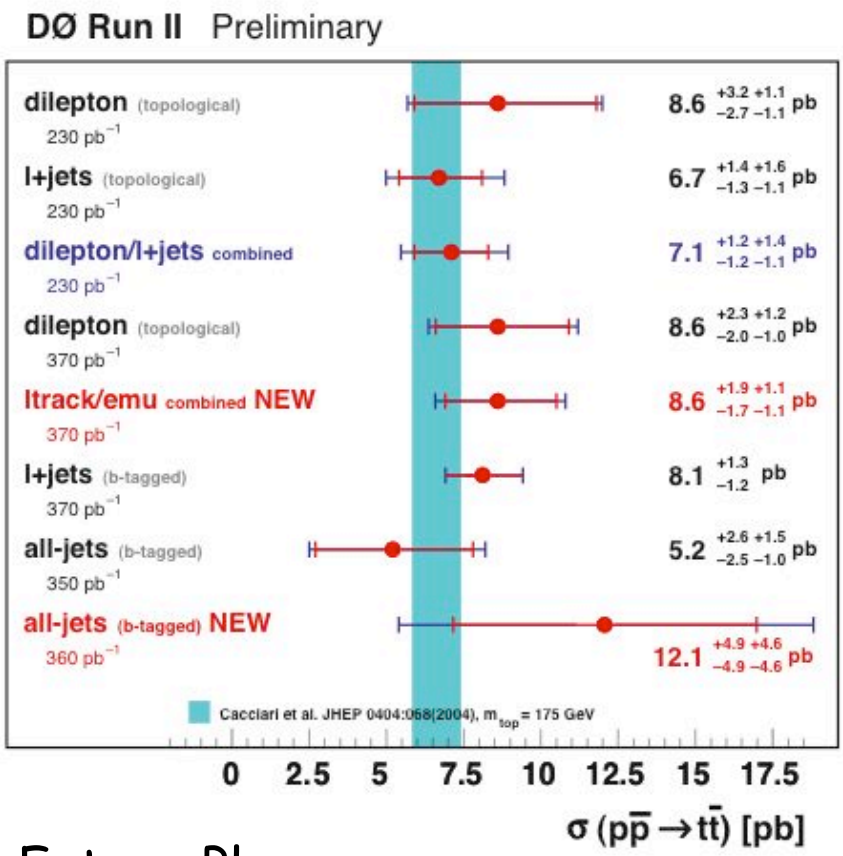


Primary sources of systematic error: jet energy calibration and electron and muon reconstruction

Conclusions

We have measured the top production cross section using the dielectron, dimuon, and electron muon final states. The combined result is:

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



Our result is consistent with the Standard Model prediction!

Future Plans

- Studies are ongoing to improve di-lepton selection and efficiency
- Measurements utilizing larger data sets are already underway: ~800pb^{-1}