

Top Quark Production and Decay Properties in Proton-Antiproton Collisions

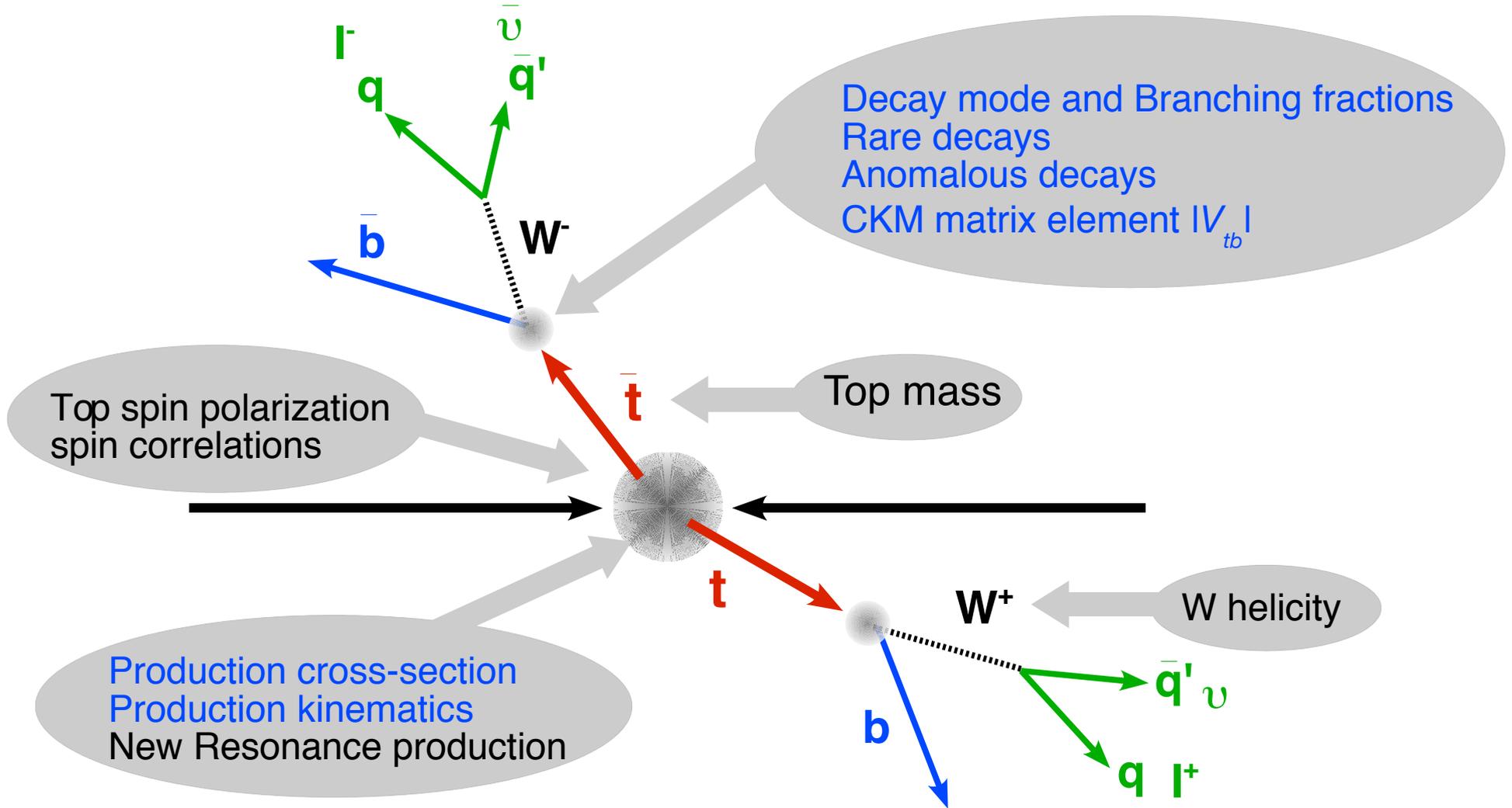


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On behalf of the CDF and DØ Collaborations

APS Meeting
Tampa, Florida,
16-19 April 2005

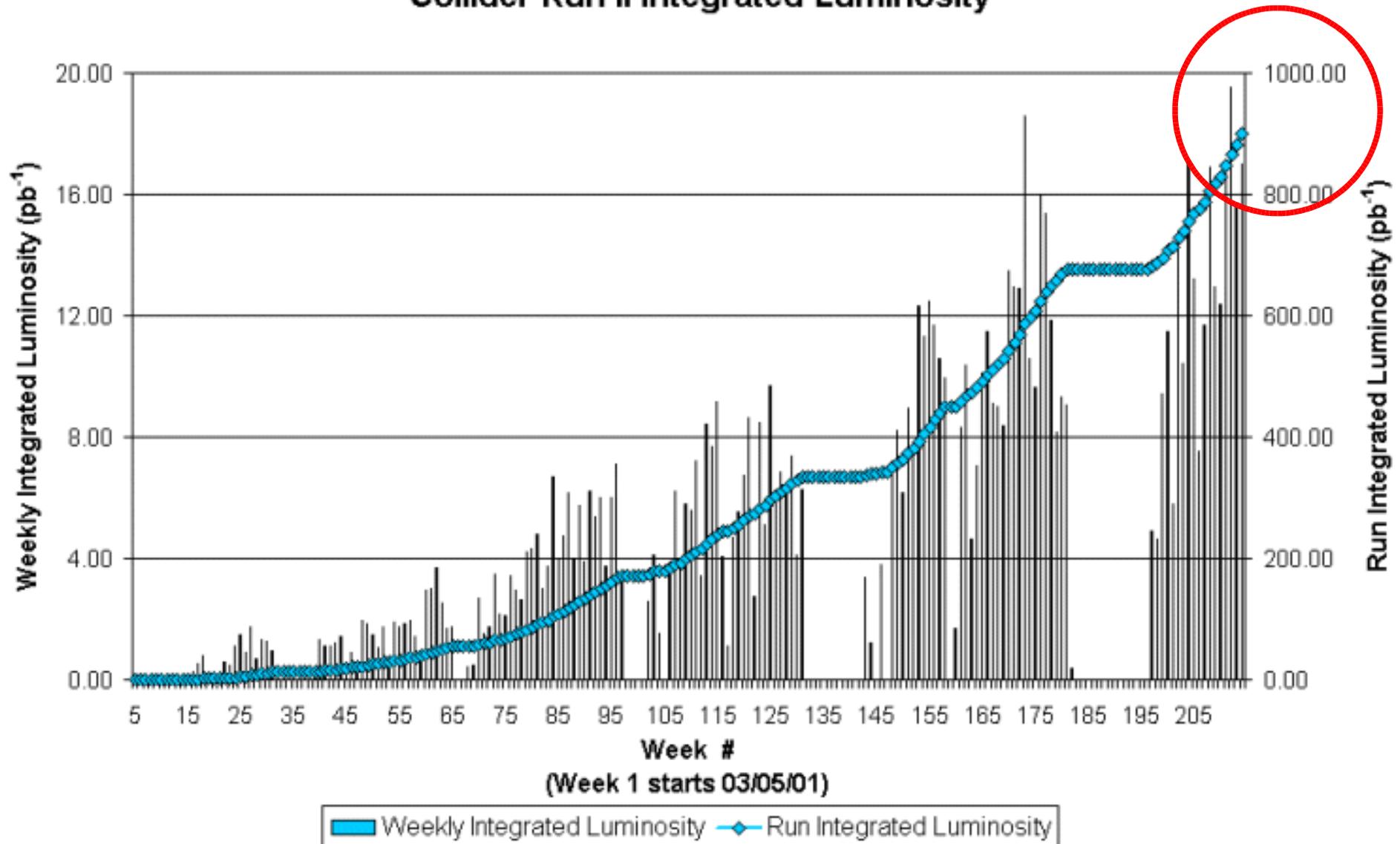
Top Quark Physics



Tevatron Performance

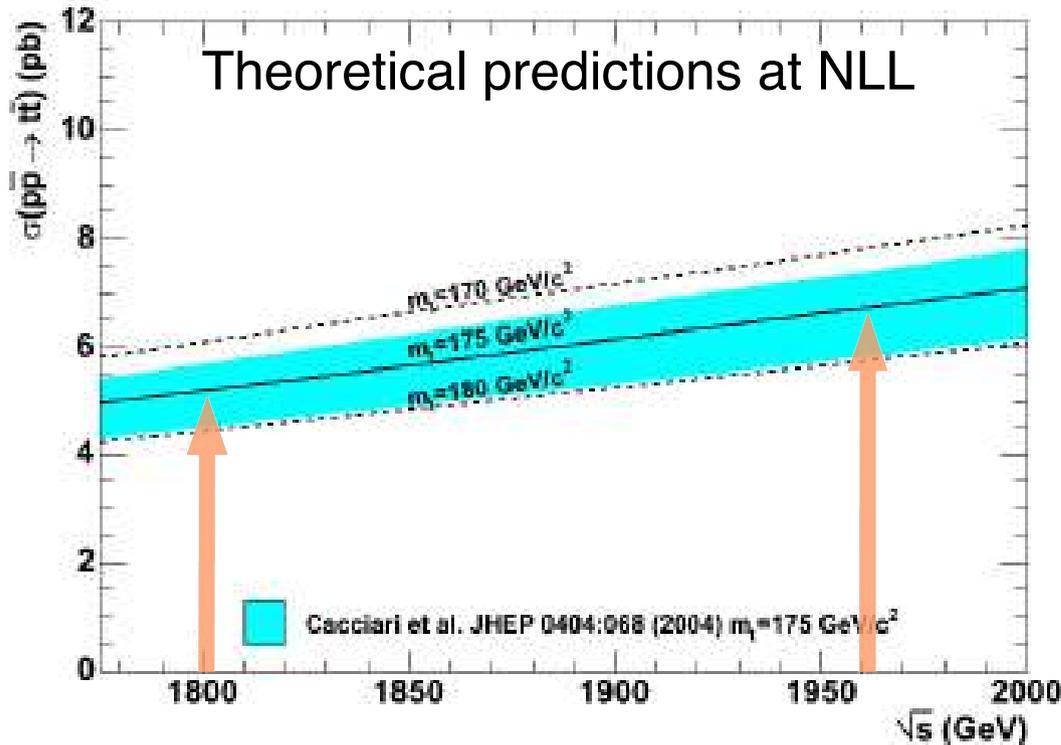
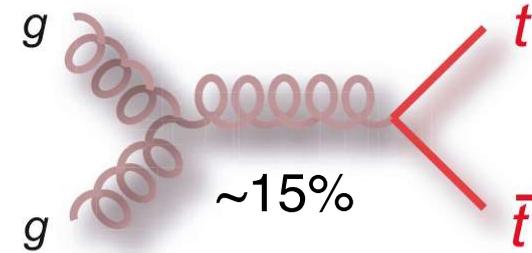
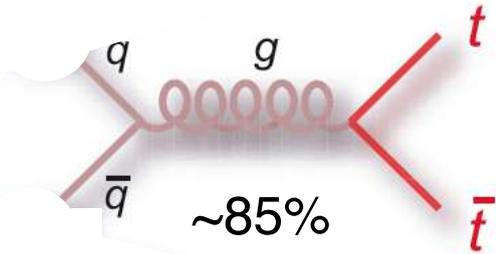
Peak luminosity $> 1 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

Collider Run II Integrated Luminosity



Top Quark Pair Production

In $p\bar{p}$ collisions at the Tevatron, top quarks are predominantly pair produced



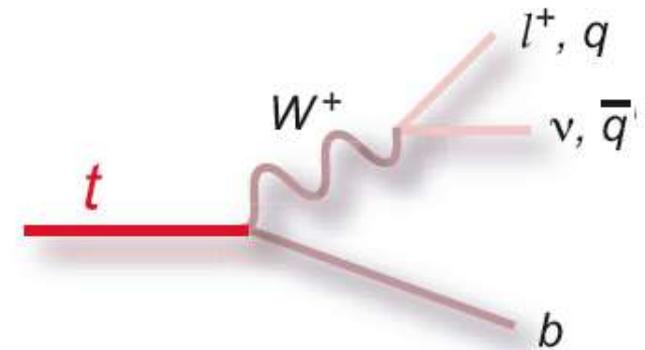
30% increase in cross-section
from $\sqrt{s} = 1.8 \rightarrow 1.96 \text{ TeV}$

Dominant theoretical uncertainties:

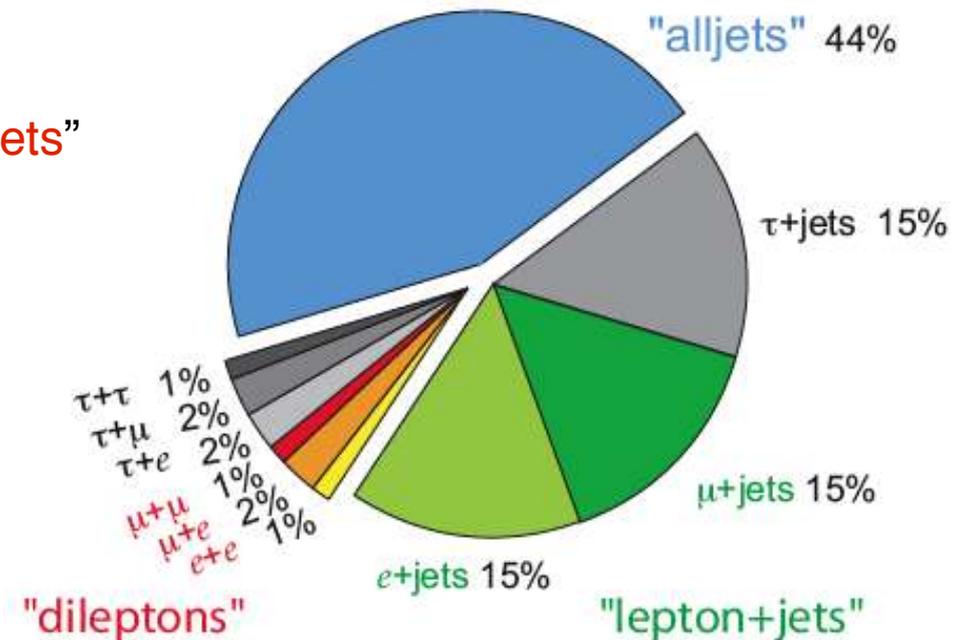
- renormalization/factorization scale (5%)
- PDF (7%)

Top Quark Decay

- Electroweak decay
- In SM, top decays 99.9% of the time to Wb
- Top decays before it hadronises
top lifetime (10^{-24} s) \ll hadronization (10^{-23} s)



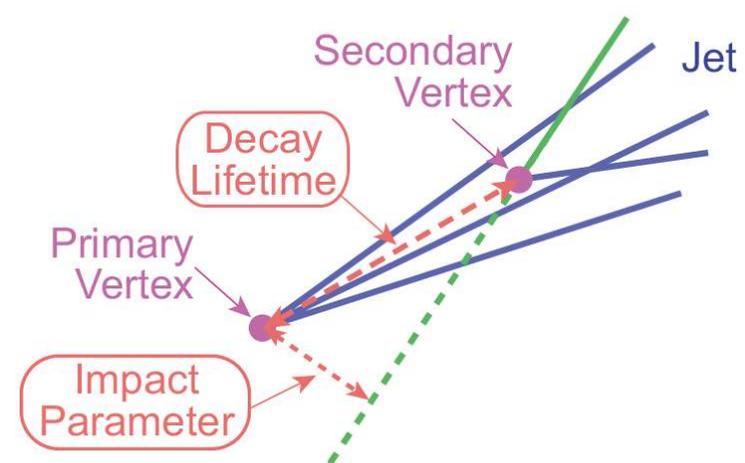
- Event classification
 - done on the basis of W 's decay products
 - 3 categories: “dileptons”, “lepton+jets”, “alljets”
- Event identification
 - Need to reconstruct
 - electrons
 - muons
 - jets from b quarks
 - jets from light quarks
 - missing transverse energy



b-jet identification

B hadrons...

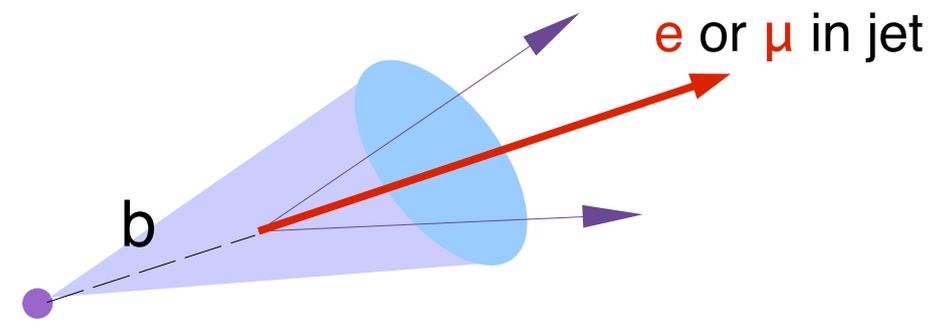
...are long-lived and massive



The diagram shows a primary vertex (red dot) where several tracks (blue lines) originate. A secondary vertex (red dot) is located further along one of the tracks, representing the decay of a B hadron. A dashed red line indicates the decay path from the primary to the secondary vertex, labeled 'Decay Lifetime'. A dashed red line perpendicular to the track at the primary vertex is labeled 'Impact Parameter'. A green line represents the 'Jet' direction.

- Vertex of displaced tracks
- Impact parameter probability

...may decay semileptonically



The diagram shows a B hadron (purple dot) decaying into a lepton (red arrow) and a neutrino (grey arrow). The lepton is labeled 'e or μ in jet'. A blue cone represents the jet's angular distribution.

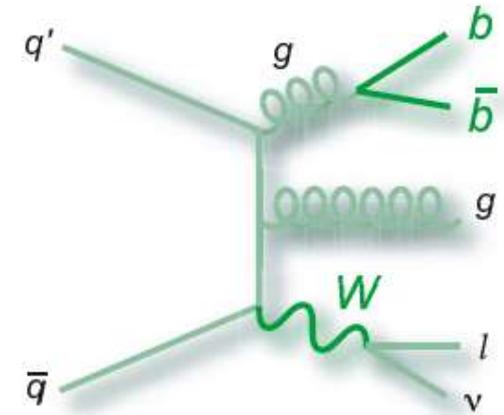
- Identify low-pt muon inside jet

60% ← Top event tagging efficiency → 15%
0.5% ← False tag rate (per jet) → 4%

Backgrounds

Events with real W or Z bosons

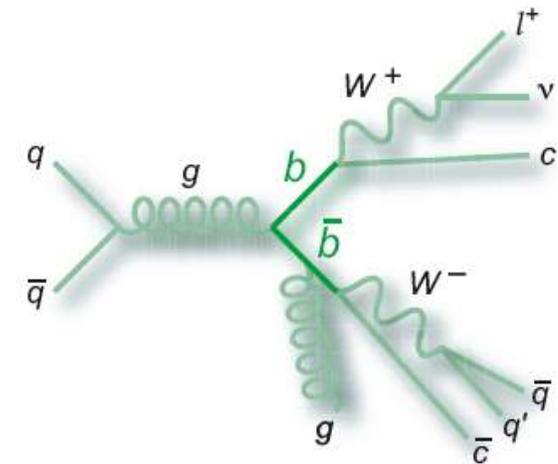
- W +jets
- Z +jets
- WW , WZ , ZZ



Events with misidentified isolated leptons

Multijet events

- with a jet mis-identified as an electron
- heavy flavour production with a mis-identified isolated electron or muon from a b decay



Other minor sources

- cosmic rays, multiple interactions, etc.

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

- Test Standard Model prediction
 - New measurements at a different \sqrt{s}
 - Increased statistics
- First step toward any top property analysis
- Process potentially sensitive to New Physics
 - new heavy resonance
 - non-SM contamination from production or decay
(measuring in different channels also cross-check to make sure it is SM cross-section)
- These events are an important background source for other types of analyses
 - single top production search
 - Higgs search
- Help improve QCD understanding in preparation for LHC
 - test perturbative QCD

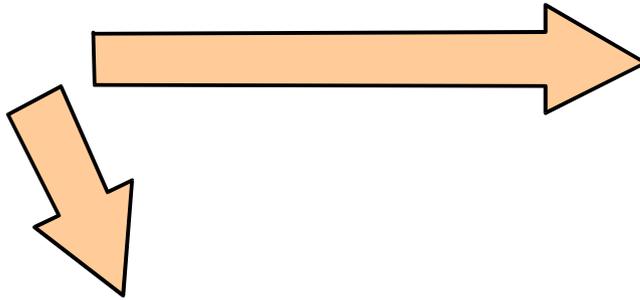
Since April 2002, CDF and DØ collaborations have collected $> 0.6 \text{ fb}^{-1}$ each
Results presented here use $150\text{-}350 \text{ pb}^{-1}$

$t\bar{t}$ cross-section: “dileptons”



Event characteristics:

- 2 leptons
- 2 b -jets
- missing E_T

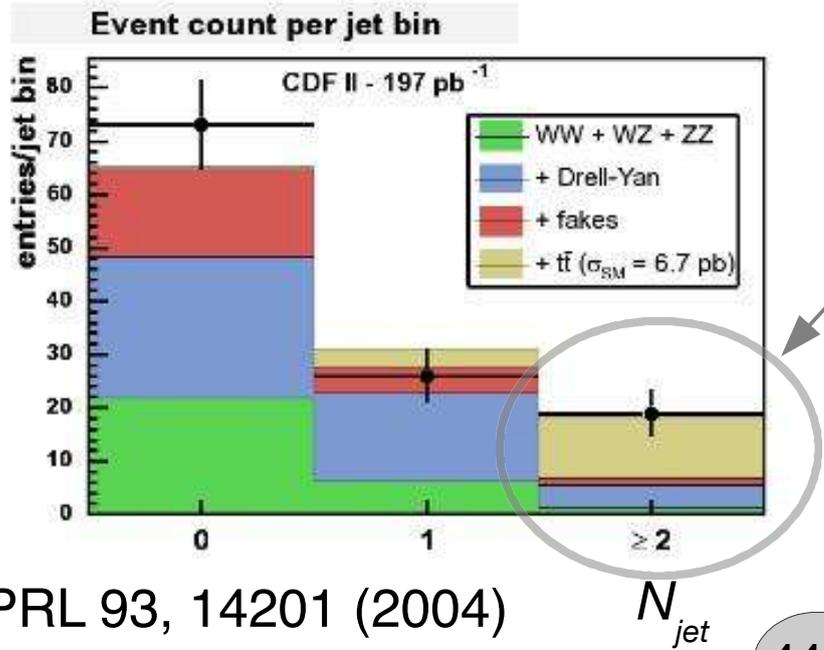


Inclusive measurement

Fit E_T vs N_{jet} distribution to different templates of SM processes.

One lepton and one opposite-charged track

$S/B \sim 2$

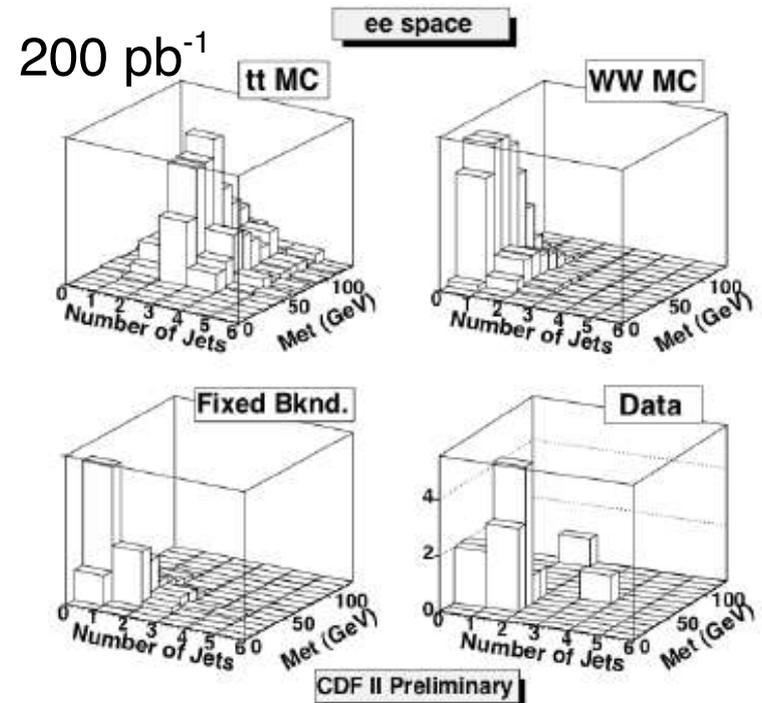


PRL 93, 14201 (2004)

N_{jet}

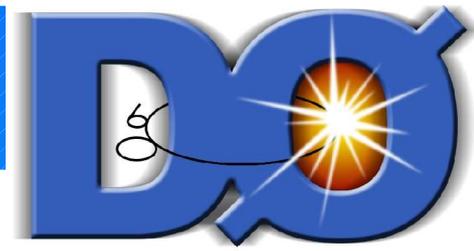
44%

9 $7.0^{+2.7}_{-2.3}(\text{stat})^{+1.5}_{-1.3}(\text{sys}) \pm 0.4(\text{lumi}) \text{ pb}$



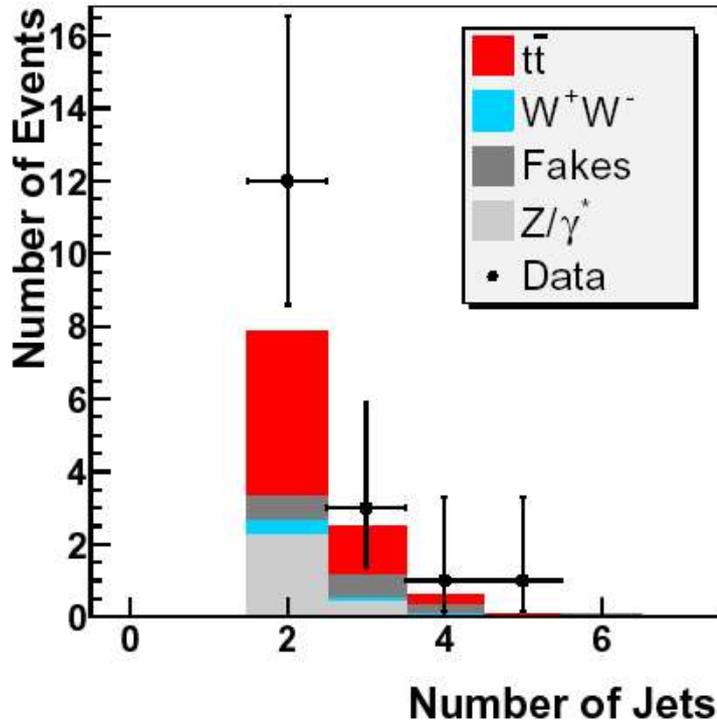
$8.6^{+2.5}_{-2.4}(\text{stat}) \pm 1.1(\text{sys}) \text{ pb}$ 31%

$t\bar{t}$ cross-section: “dileptons”



Two opposite-charged leptons

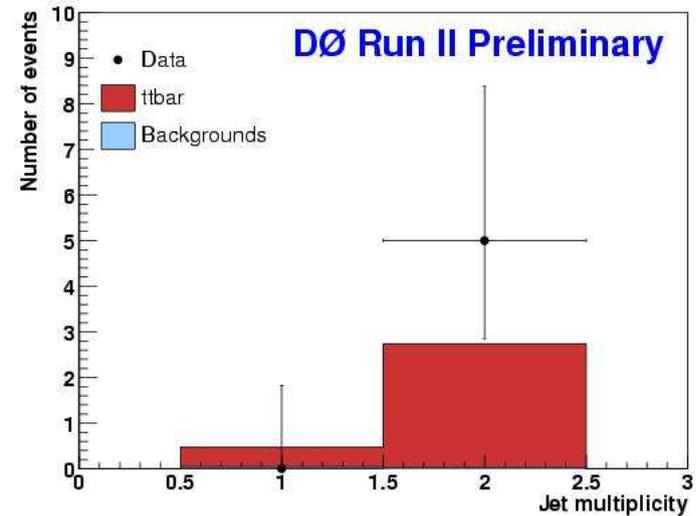
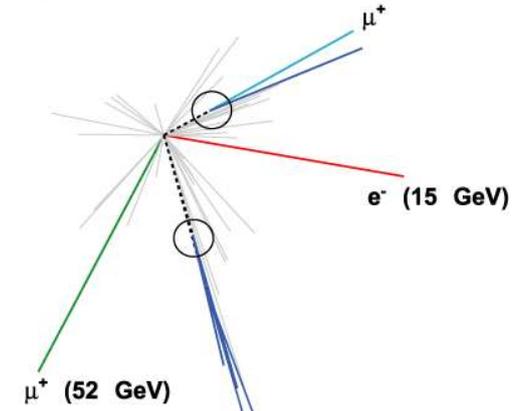
(R7.00001, R7.00003, R7.00004) S/B~3



$14.3^{+5.1}_{-4.3}(\text{stat})^{+2.6}_{-1.9}(\text{sys}) \pm 0.9(\text{lumi}) \text{ pb}$

54%

Electron-muon with SVT b-tag



$11.1^{+5.8}_{-4.3}(\text{stat}) \pm 1.4(\text{sys}) \pm 0.7(\text{lumi}) \text{ pb}$

41%

$t\bar{t}$ cross-section: “lepton+jets”

Event characteristics:

- 1 lepton
- 4 jets (including 2 b -jets)
- missing E_T

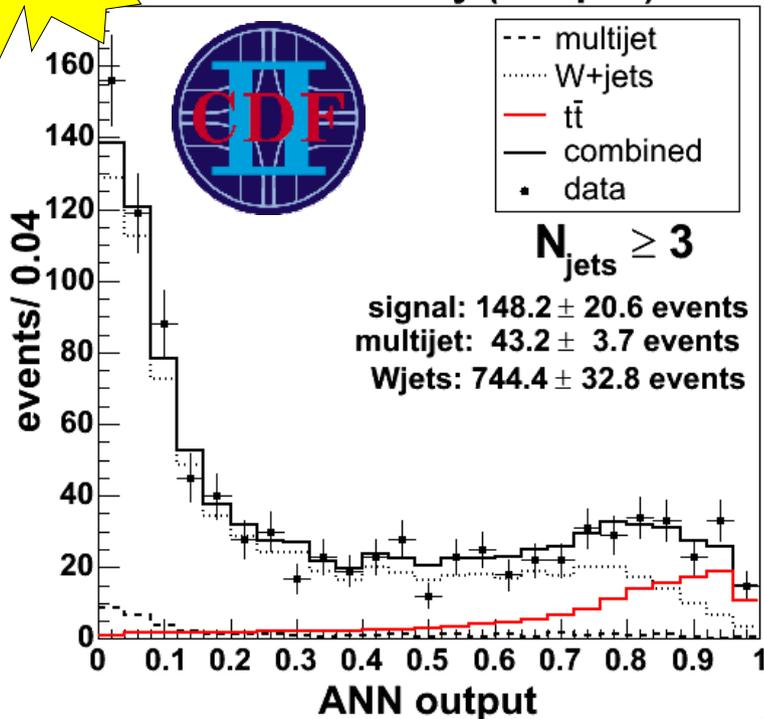
Extract $t\bar{t}$ content of samples based on kinematic characteristics of the events. (no b -tagging)

Neural Net

Topological discriminant

NEW

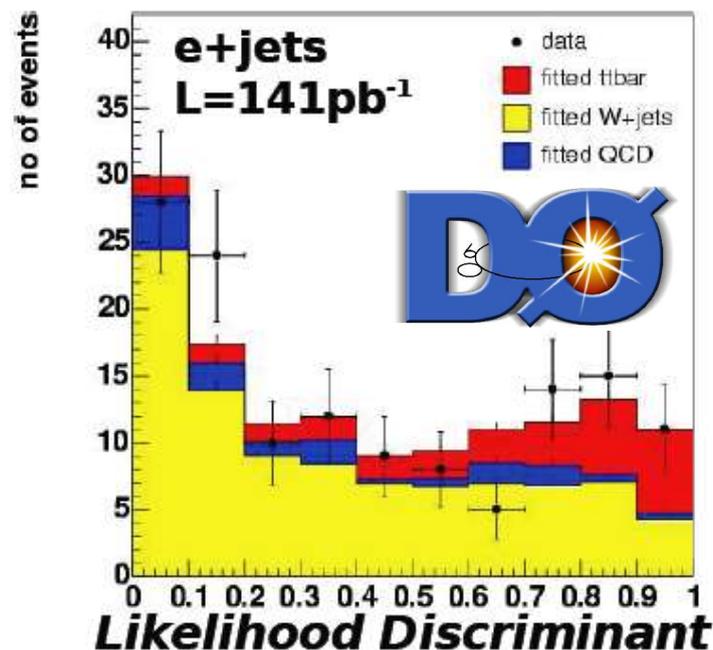
CDF Preliminary (347 pb^{-1})



21%

6.0 ± 0.8 (stat) ± 1.0 (sys) pb

(R7.00005, R7.00006)



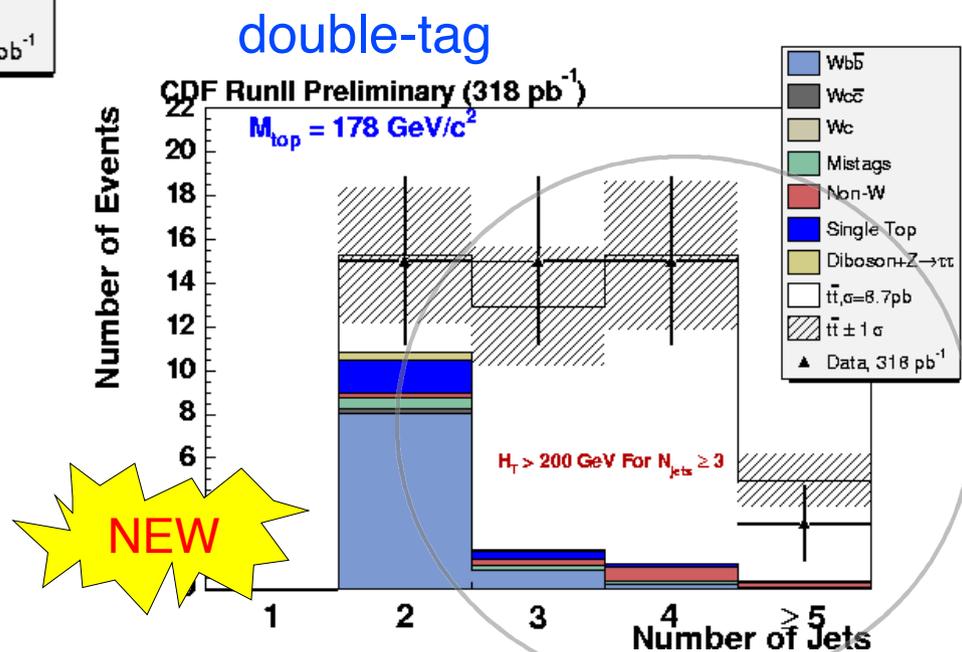
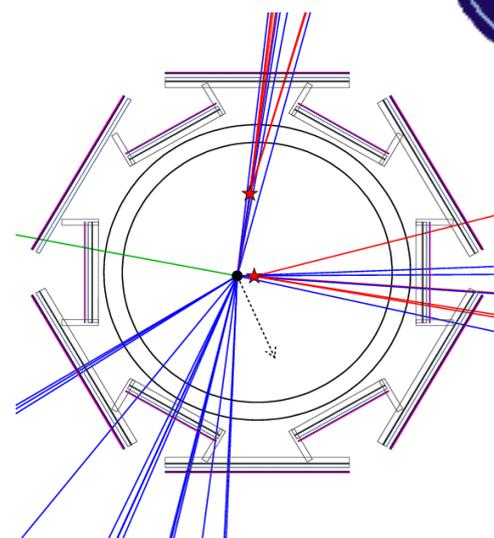
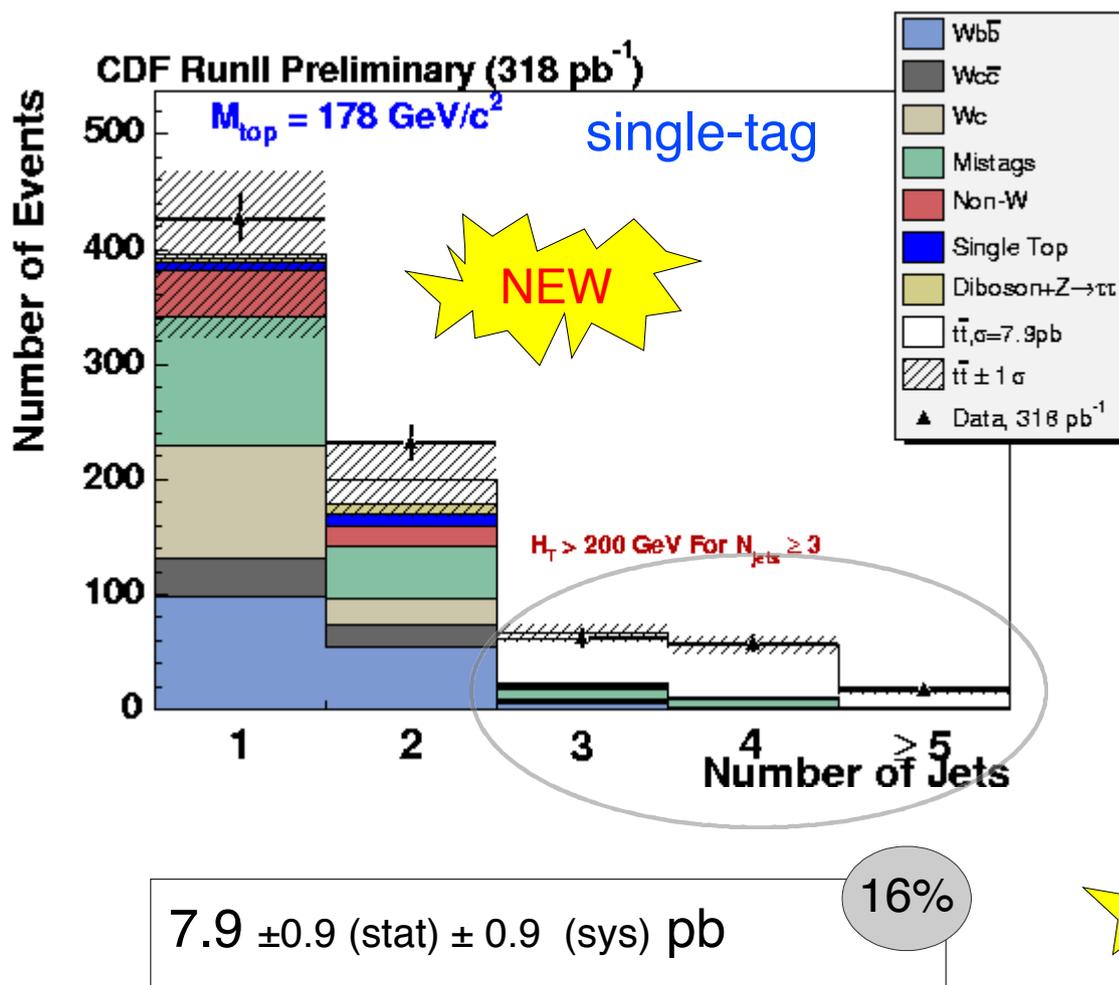
32%

$7.2^{+2.6}_{-2.4}$ (stat) $^{+1.6}_{-1.7}$ (sys) ± 0.5 (lumi) pb

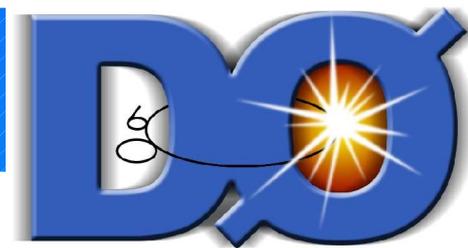
$t\bar{t}$ cross-section: “lepton+jets”



Require secondary vertex tagging
Count number of events with ≥ 3 jets

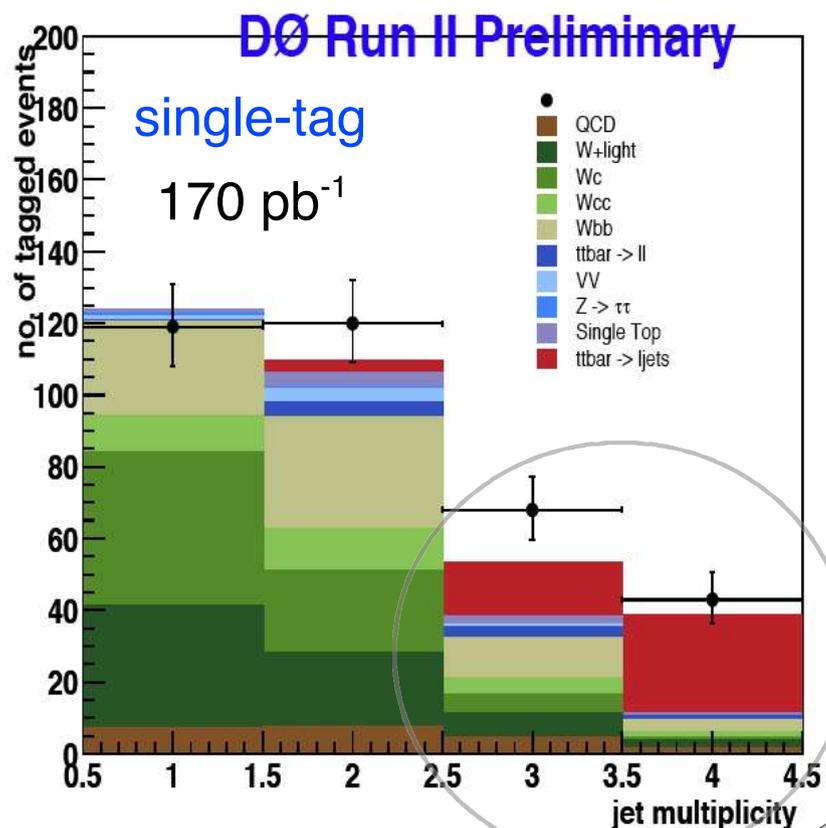


$t\bar{t}$ cross-section: “lepton+jets”



Use two different b -tagging algorithms
Count number of events with ≥ 3 jets

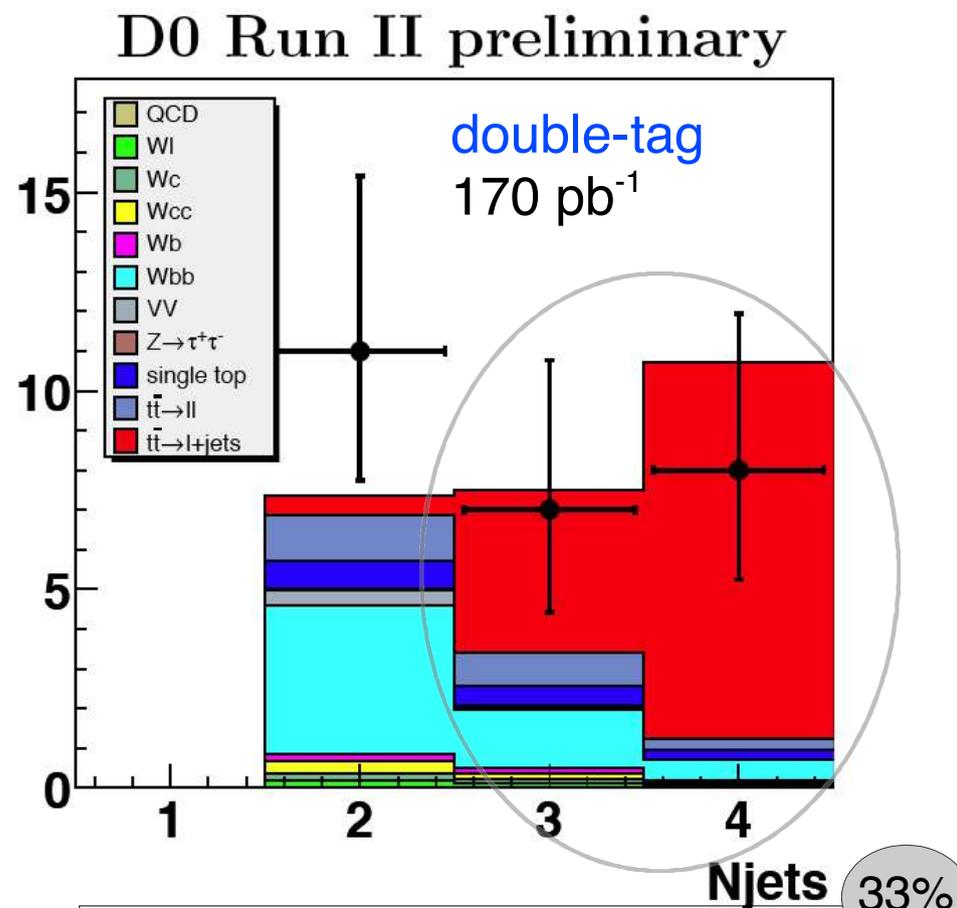
Secondary Vertex Tag



29%

$8.2 \pm 1.3 \text{ (stat)} \pm 1.9 \text{ (sys)} \pm 0.5 \text{ (lumi) pb}$

Counting Signed Impact Parameter



33%

$7.2 \pm 1.3 \text{ (stat)} \pm 1.9 \text{ (sys)} \pm 0.5 \text{ (lumi) pb}$

$t\bar{t}$ cross-section: “alljets”

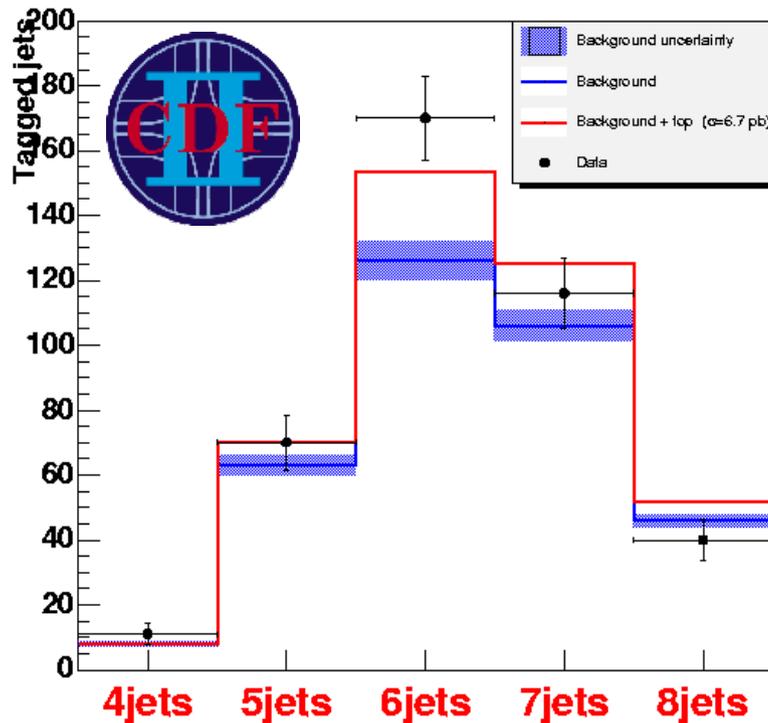
Event characteristics:

- 6 jets (including 2 b -jets)

SVX tag + fit to N_{jets}

(T7.00004)

CDF Run II preliminary, $L=165 \text{ pb}^{-1}$



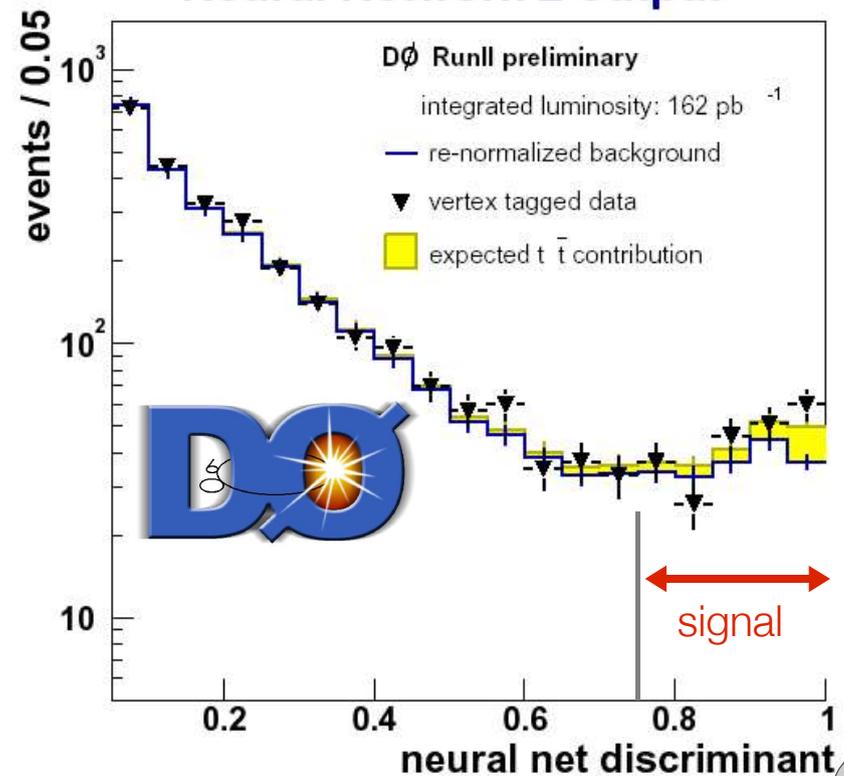
68%

$7.8 \pm 2.5(\text{stat}) \pm 4.7 \pm 2.3(\text{sys}) \text{ pb}$

SVT tag + Neural Network

(R7.00002)

Neural Network 2 output

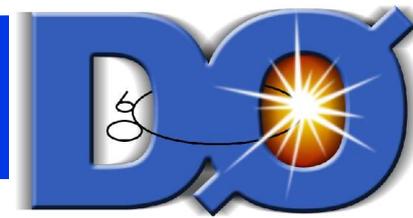


76%

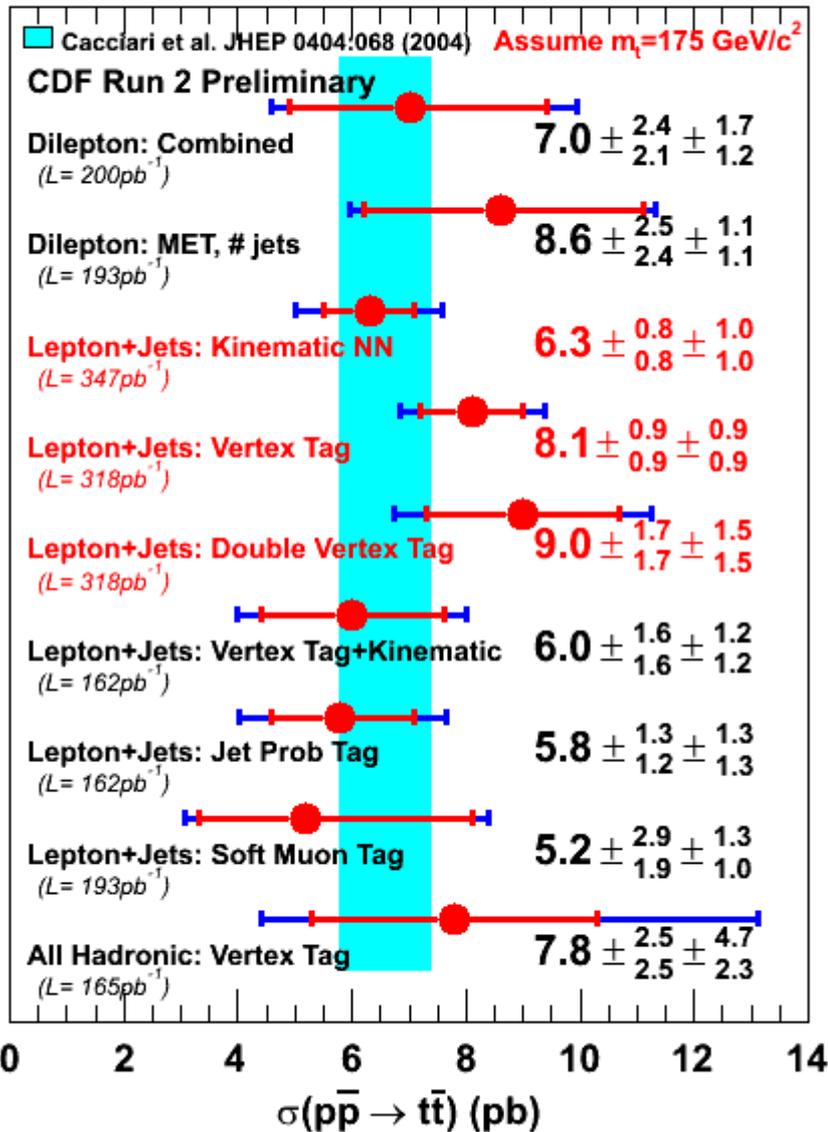
$7.7 \pm 3.4 \pm 3.3(\text{stat}) \pm 4.7 \pm 3.8(\text{sys}) \pm 0.5(\text{lumi}) \text{ pb}$



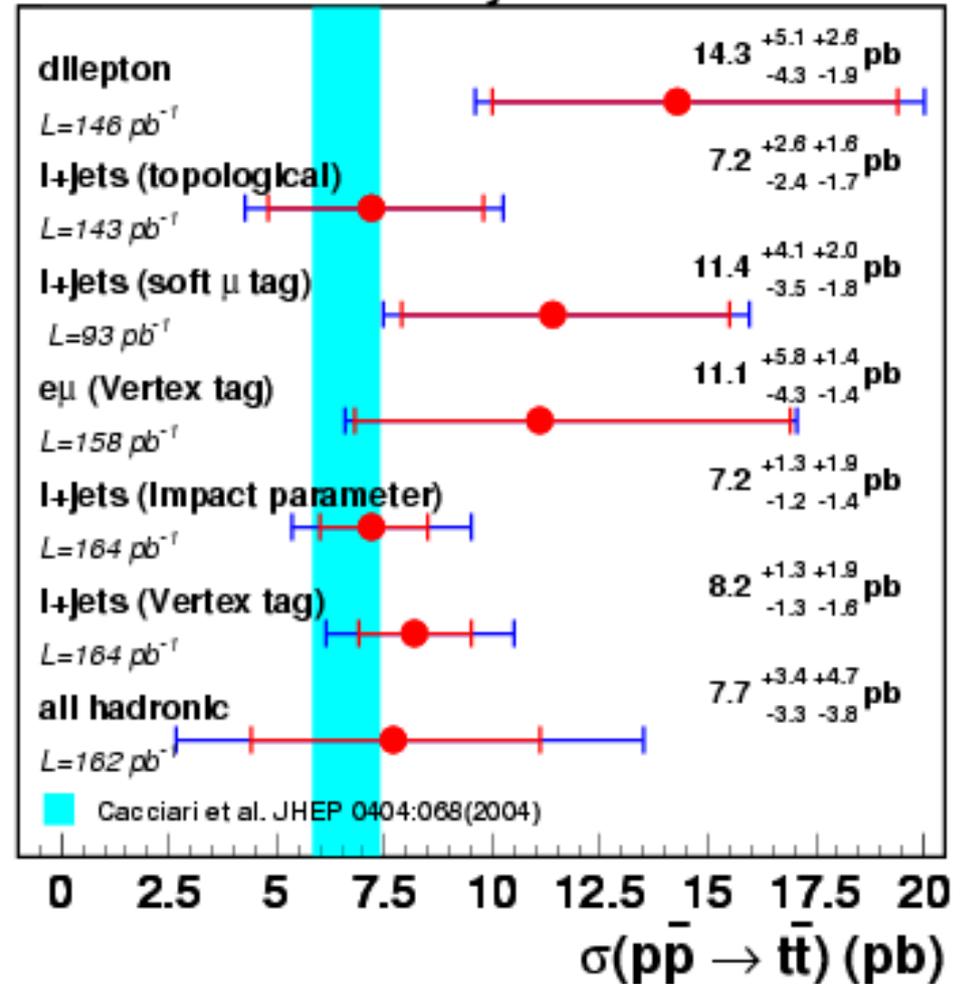
$t\bar{t}$ cross-section summary



(T7.00008)

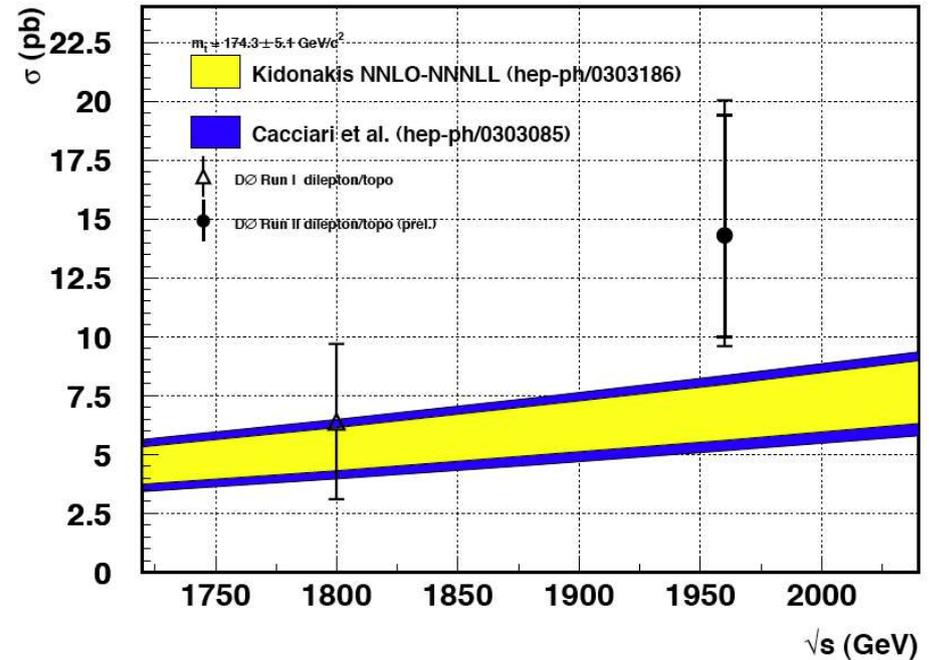
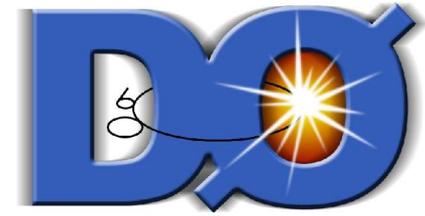
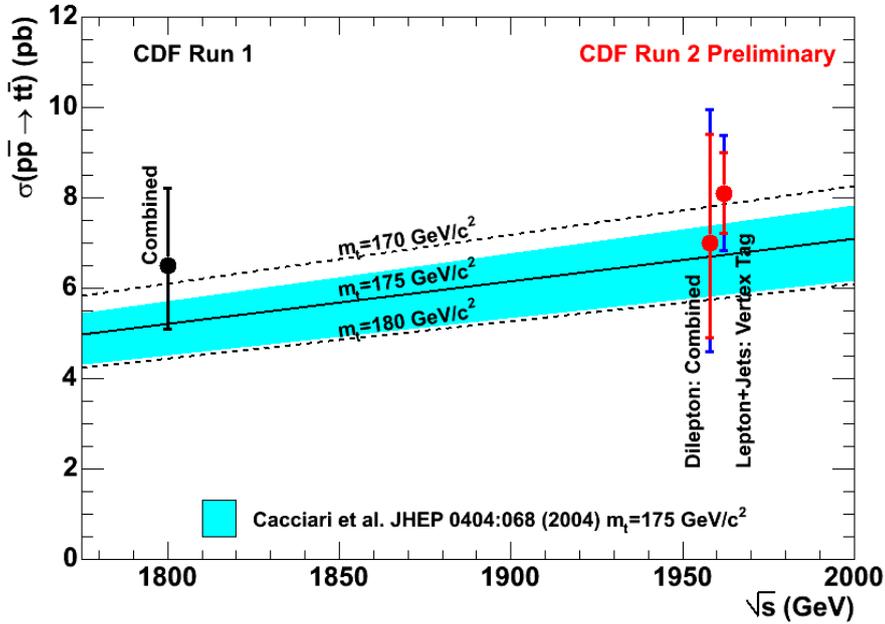


DØ Run II Preliminary





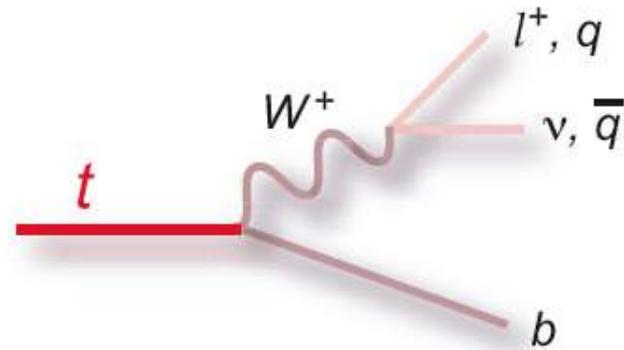
$t\bar{t}$ cross-section summary



Top Decay Measurements

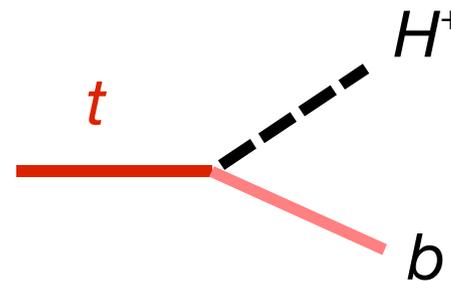
■ Test SM predictions

- $\text{Br}(t \rightarrow Wb) \sim 100\%$



■ Look for New Physics

- Anomalous kinematic distributions of particular final states
Ex. SUSY cascade decays
- Anomalous decay modes
Ex. $t \rightarrow H^+ b$



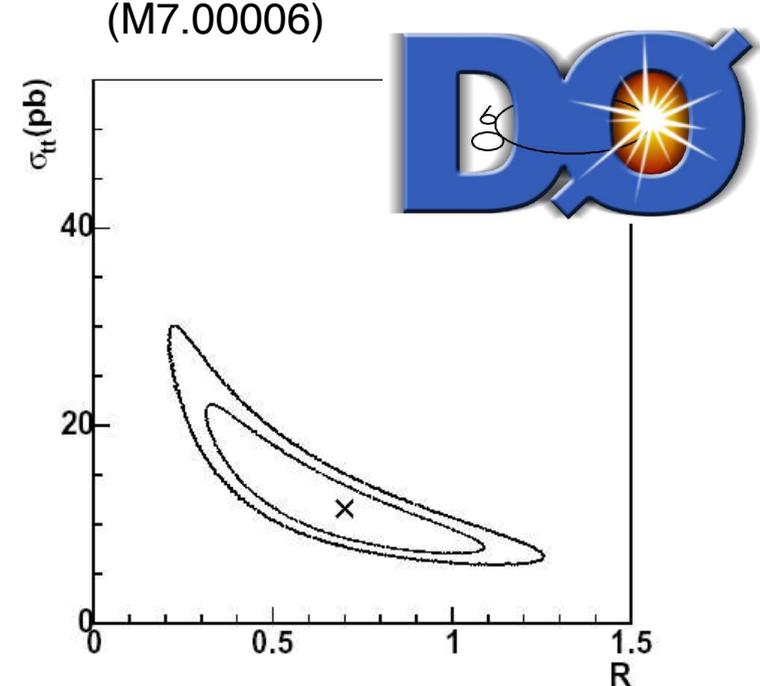
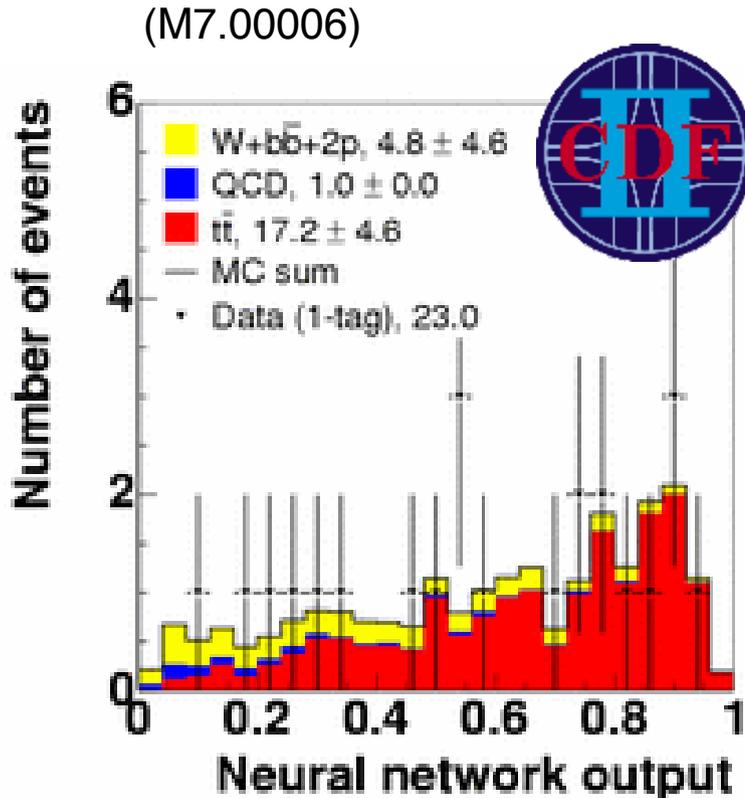
Top Decay: branching fraction ratio

$$R = B(t \rightarrow Wb) / B(t \rightarrow Wq) = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$

Compare number of events with 1 and 2 *b*-tags.

SVX + NN fit (l+jets and dilepton)

SVT/CSIP (l+jets)

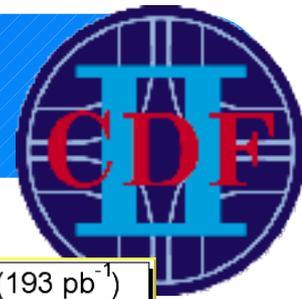


$$R = 1.11^{+0.21}_{-0.19} \text{ (stat+syst)}$$

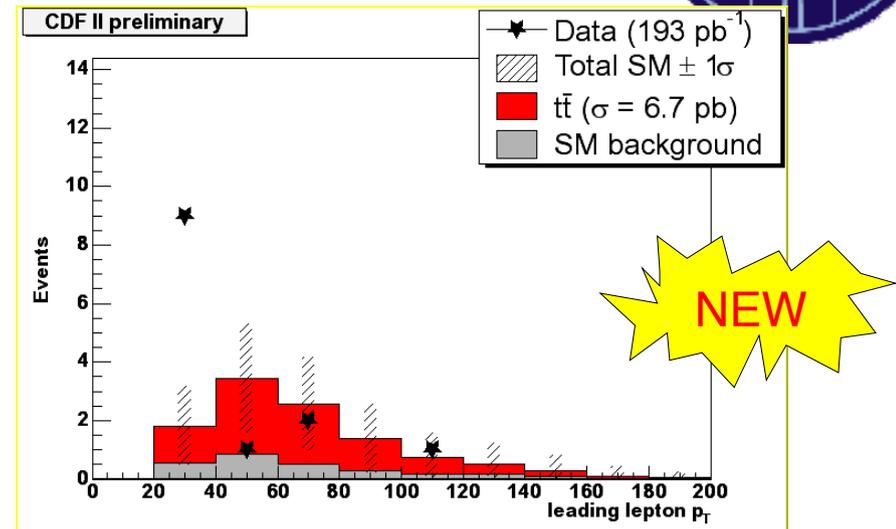
$$R_{\text{CSIP}} = 0.65^{+0.34}_{-0.30} \text{ (stat)} \quad ^{+0.17}_{-0.12} \text{ (syst)}$$

$$R_{\text{SVX}} = 0.70^{+0.27}_{-0.24} \text{ (stat)} \quad ^{+0.11}_{-0.10} \text{ (syst)}$$

Top Decay: anomalous kinematic



- E_{ν_T}, P_t leading lepton, angle between E_{ν_T} and P_t , T variable
- Use KS-test on sub-samples
- The probability of obtaining a data sample less consistent with the SM than what is observed is 1.0-4.5%

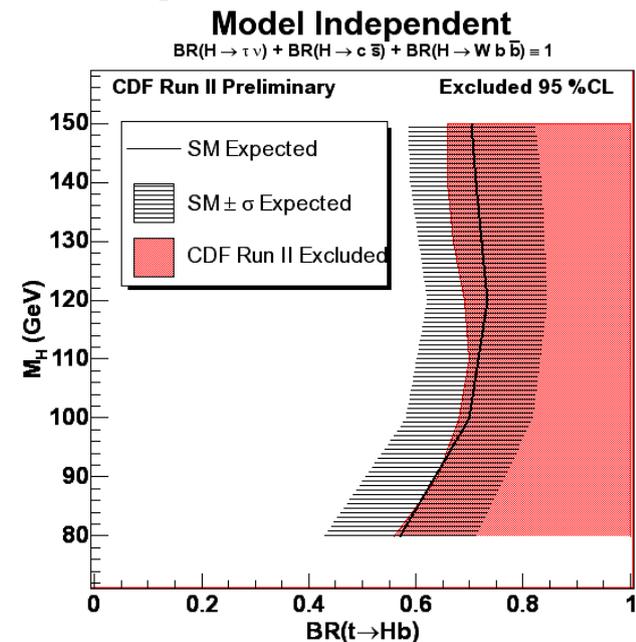


Top Decay: anomalous decay modes

- Fix cross-section to SM value and assume $B(t \rightarrow Hb)$
- dileptons, lepton+jets, lepton+hadronic tau
- Results: calculate constraints on

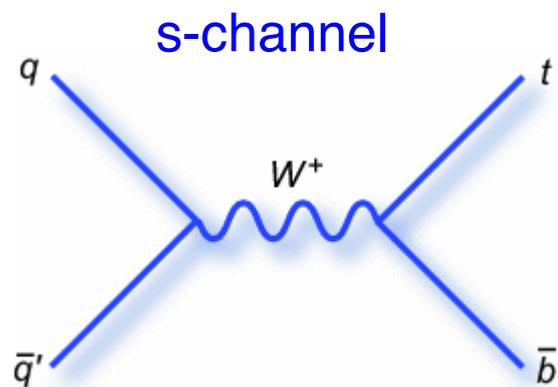
$$M_H \text{ vs } \tan \beta$$

$$M_H \text{ vs } B(t \rightarrow Hb)$$

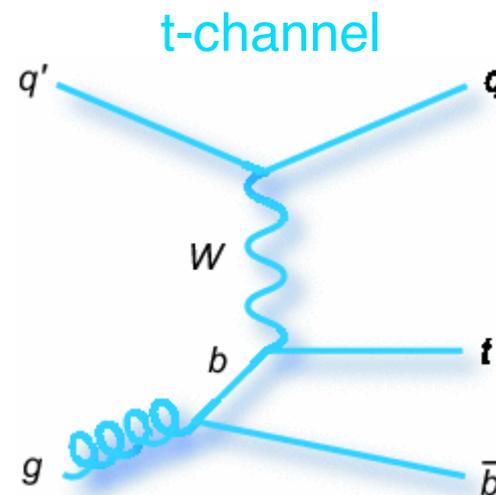


Single top production

- Electroweak process
- Has never been observed before!
- Two main production modes at the Tevatron



$0.88 \pm 0.11 \text{ pb}$



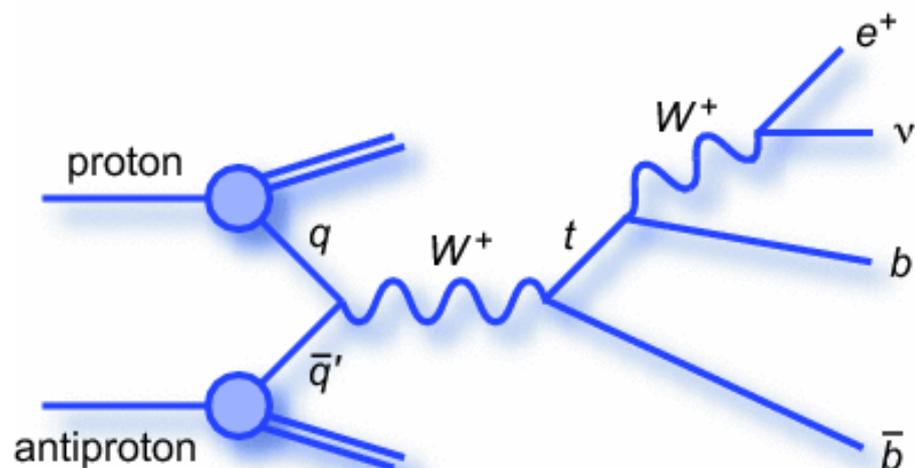
$1.98 \pm 0.25 \text{ pb}$

- Cross-section about half that of $t\bar{t}$ production, but much higher irreducible background
- Search for New Physics (s/t-channel have different sensitivity)
- Single top events can be used to directly measure $|V_{tb}|$ without any assumptions on the number of quark generations

Single top production

Event characteristics:

- 1 lepton
- ≥ 2 jets (≥ 1 b -jet)
- missing E_T



Analysis Outline:

1. Event Selection

- select W-like events
- maximize acceptance
- model backgrounds

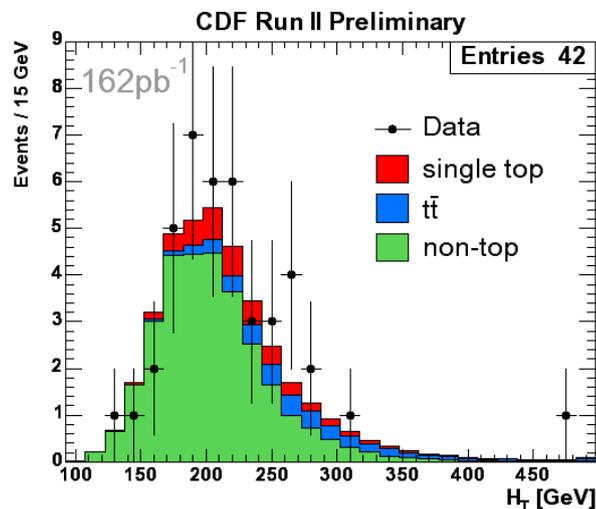
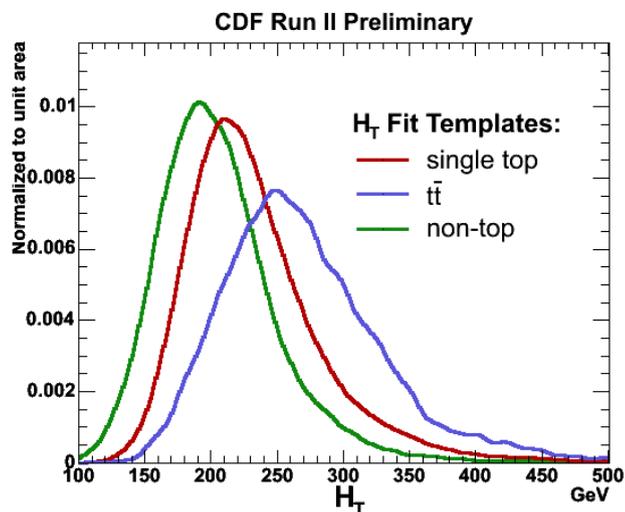
2. Separate signal from backgrounds

3. Determine (limits on the) cross-section

Single top production

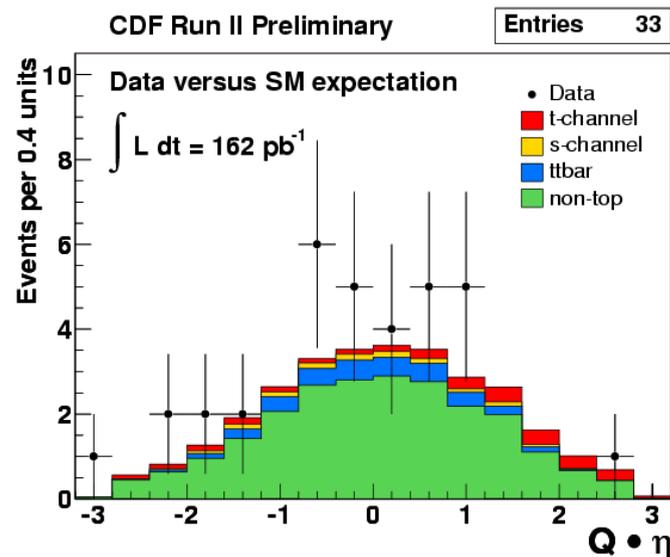
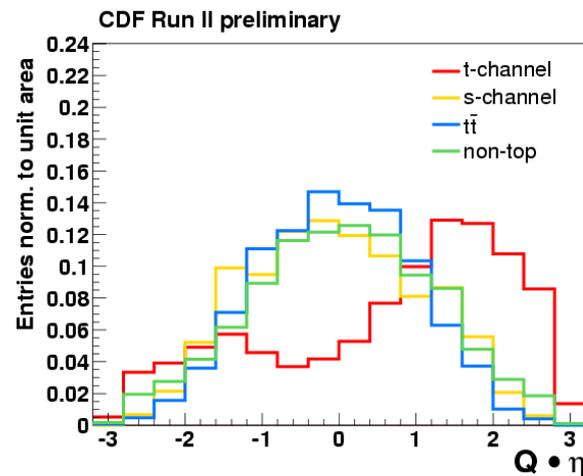


Combined search



σ (s+t channel) < 17.8 pb @ 95% CL

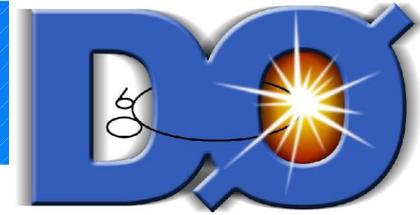
Channel-specific search



σ (s-channel) < 13.6 pb @ 95% CL
 σ (t-channel) < 10.1 pb

Phys. Rev. D71, 012005 (2005)

Single top production

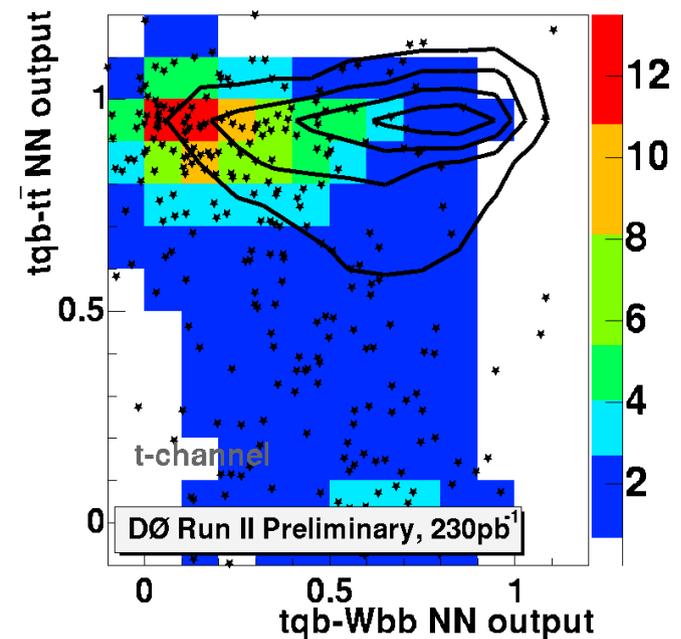
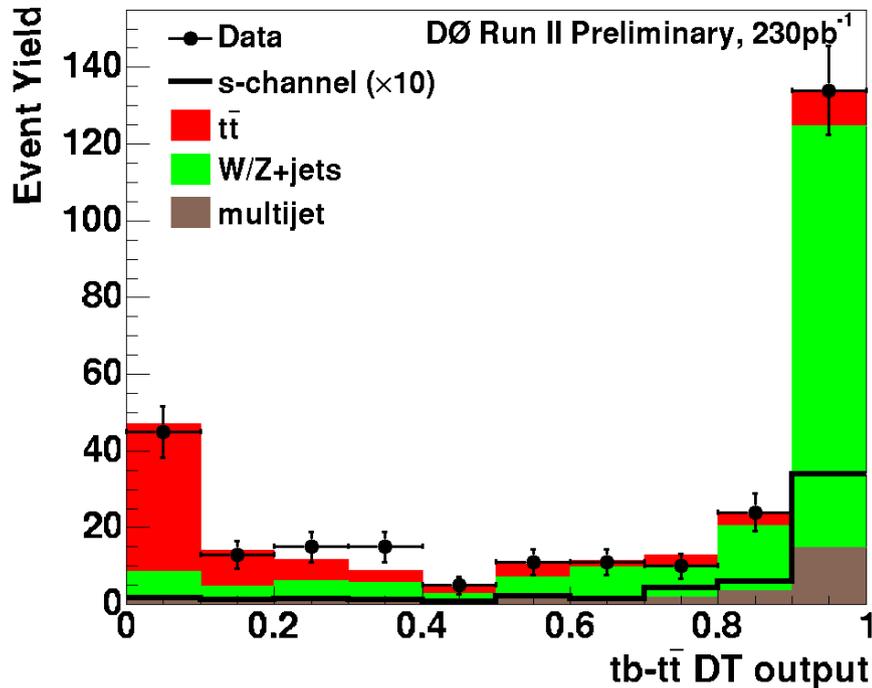
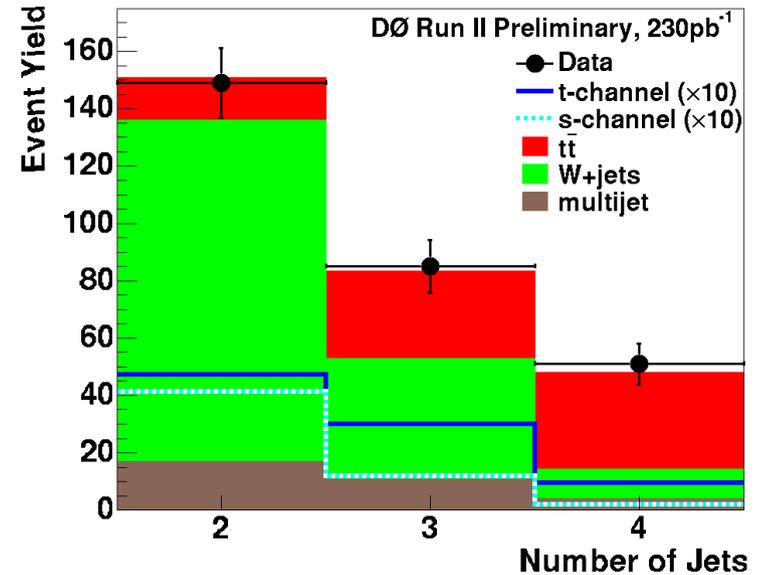


Separate signal from backgrounds

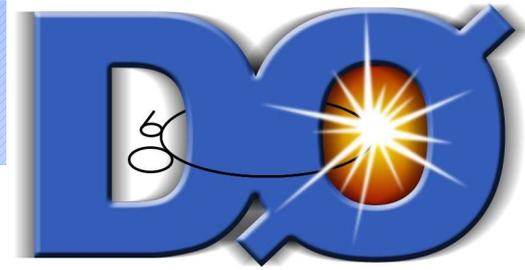
- cut-based
- decision tree
- neural network

Determine cross-section

- 2-D likelihood fit (DT and NN)
- event counting (cut-based)



Single top production



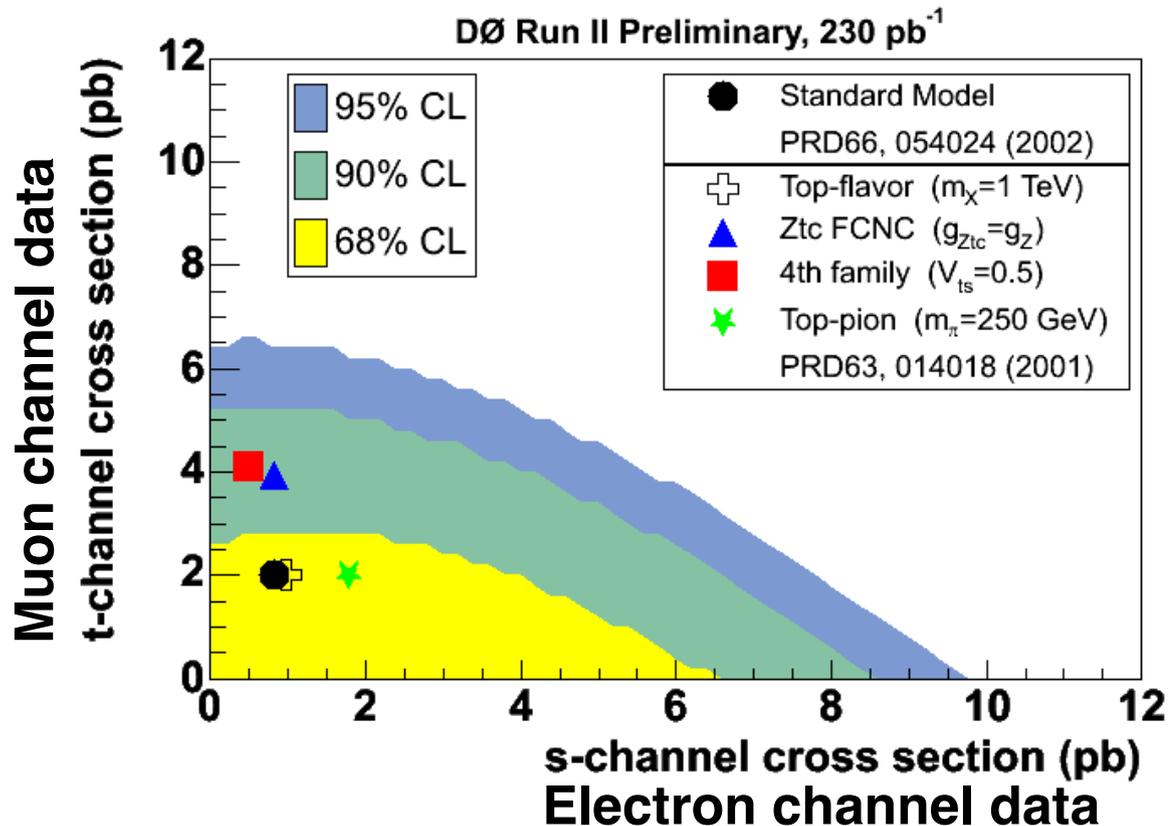
Upper limits on production cross-section (pb) at 95% CL

	s-channel	t-channel
Cut-based	10.6 (9.8)	11.3 (12.4)
Decision Tree	8.3 (4.5)	8.1 (6.4)
Neural Network	6.4 (4.5)	5.0 (5.8)

Cut-based

Decision Tree

Neural Network



Summary

■ Top pair production cross-section

- currently measured to 20%
- goal is to reach $\sim 10\%$ with $\sim 2 \text{ fb}^{-1}$

$$\sigma_{tt} = 6.3 \pm 0.8 \text{ (stat)} \pm 1.0 \text{ (syst)}$$

(lepton+jets, Neural Network, 347 pb^{-1})



■ Top decays

- currently measured to 20%

■ Single top production

$$\sigma(\text{s-channel}) < 6.4 \text{ pb}$$
$$\sigma(\text{t-channel}) < 5.0 \text{ pb}$$

(lepton+jets, Neural Network, 230 pb^{-1})



- Road to Discovery

- Need more statistics
- Improve sensitivity of analyses
- Observation is hoped for with $1\text{-}2 \text{ fb}^{-1}$ of data

■ Just seeing the tip of iceberg - still a lot more data to be analysed

And if you want more....

B8.	Saturday	10:45am-12:30pm
M7.	Sunday	3:15pm – 5pm
R7.	Monday	10:45am-12:30pm
T7.	Monday	1:30pm-3:20pm
V7.	Monday	3:30pm-5:20pm

40 parallel sessions talks