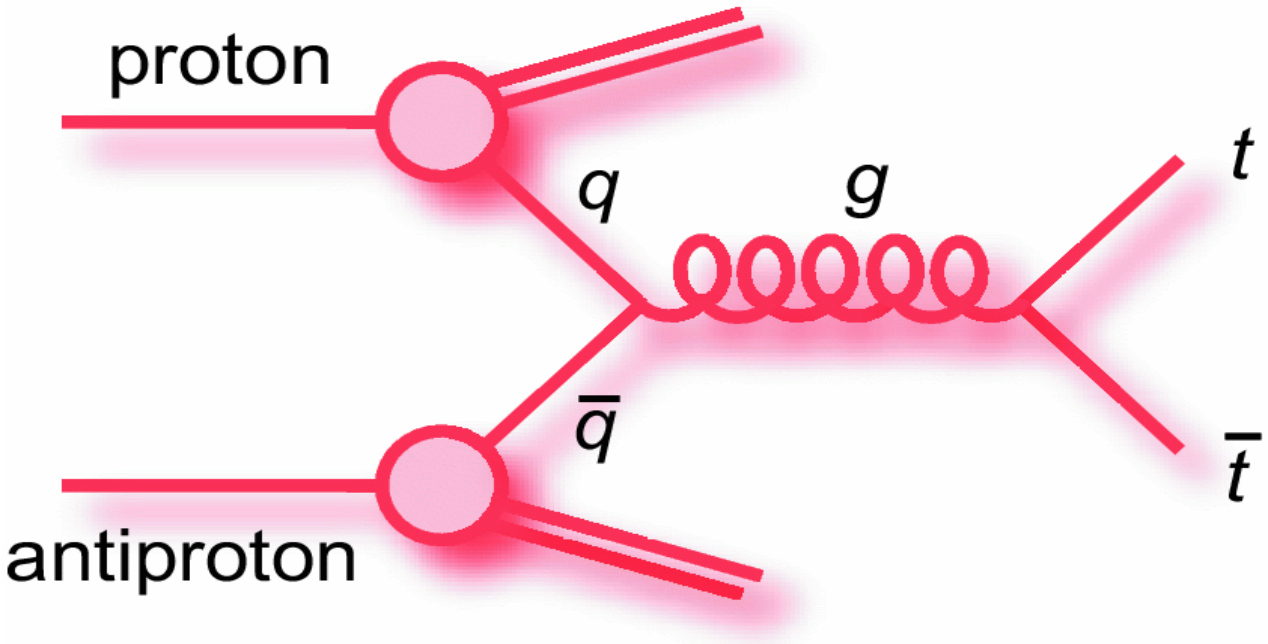
# Top Quark Production Cross Section at $E^{cm}$=1.96 TeV




Reinhard Schwienhorst

MICHIGAN STATE UNIVERSITY

on behalf of the DØ and CDF Collaborations

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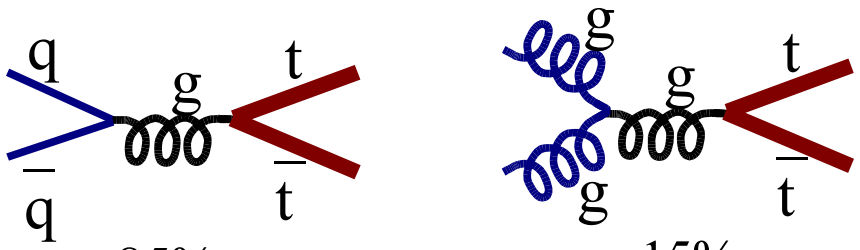
# Outline



- **Introduction**
  - **Top Quark Production and Detection at the Tevatron**
- **Top Production Cross Section at CDF**
  - **Dilepton**
  - **Lepton+jets**
  - **All-jets**
- **Top Production Cross Section at DØ**
  - **Dilepton**
  - **Lepton+jets**
  - **All-jets**
- **Cross Section Summary**

# Top Quark Production at the Tevatron

## Production Modes

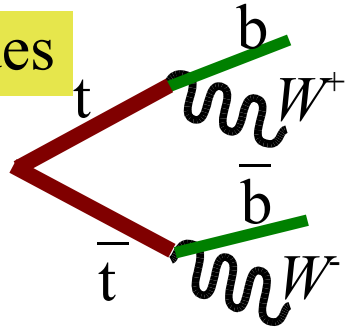


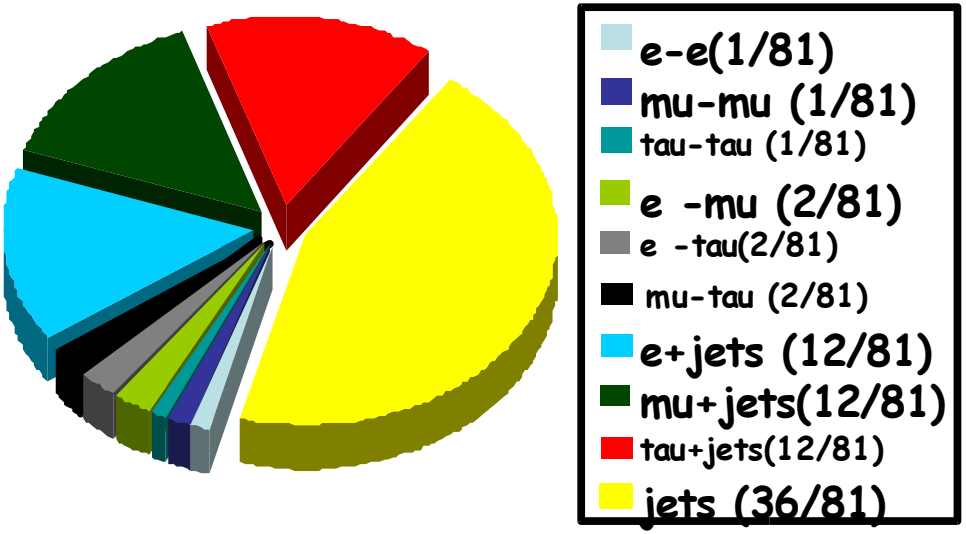

~85% ~15%

- $\sigma(p\text{-}p \rightarrow t\bar{t} + X) = 6.77 \pm 0.47$pb
  - (N)NLO, at $m_t$=175GeV
    - PDF uncertainty ~10%
- Experimental Signatures:
  - 1 or 2 leptons, ≥2 jets or ≥6 jets (2 b-jets)
- Backgrounds:
  - W/Z/DY+jets, mis-reconstruction
- Test SM production and decay
  - Establish top quark dataset for subsequent measurements

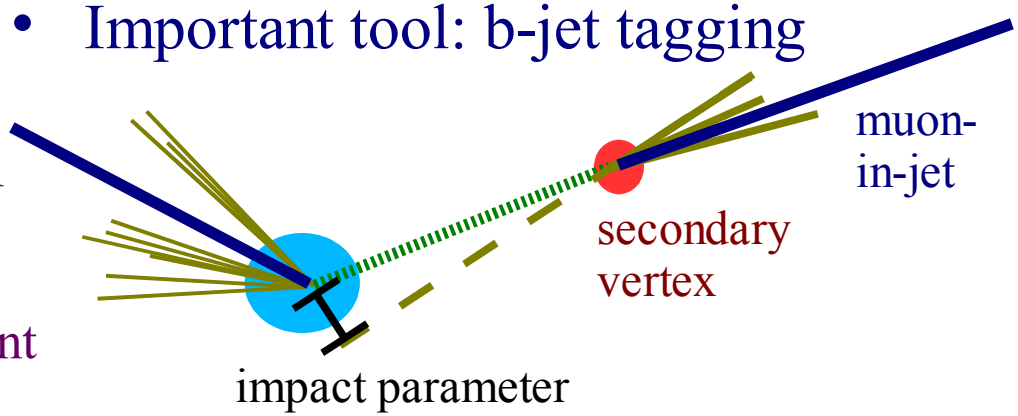
## Decay Modes

- Classify analysis channels by decay of the *W*s

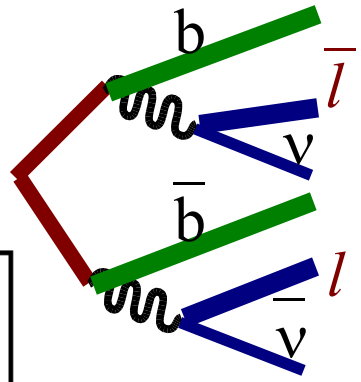



- Important tool: b-jet tagging



# Lepton+Track




**200pb$^{-1}$ Run II data**

**2 Leptons**

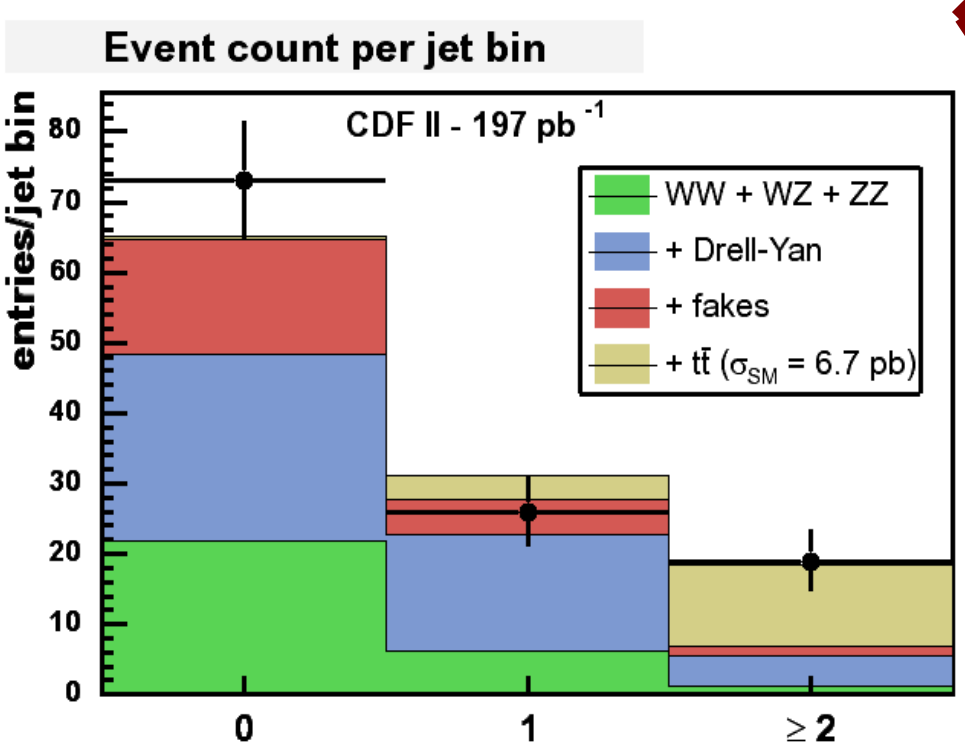
- **1 electron or muon**
- **1 isolated track**
- **$p_T$>20 GeV**
- **$|\eta| < 1$ (muons),**
- **$|\eta| < 2$ (electrons)**

**+ Missing Et**

- **Missing $E_T$ > 25GeV**

**+ ≥ 2 jets**

- **$E_T$>20GeV, $|\eta| < 2$**




**Systematic Uncertainties**

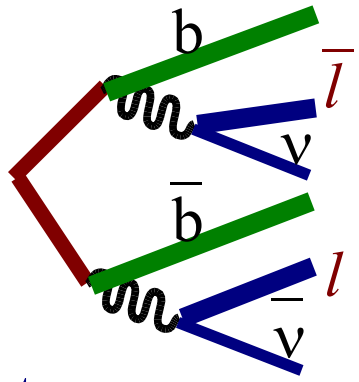
**Signal: particle ID ~5%, JES 6%,**
**FSR 7%, PDF 6%**
**Backgrounds: also sample normalization**
**(30% for DY)**

$$\sigma(t\bar{t}) = 7.0^{+2.7}_{-2.3}(stat)^{+1.5}_{-1.3}(syst) \pm 0.4(lumi)\,pb$$

At $m_t$ = 175 GeV

# Di-Lepton

2 well-identified leptons ($ee$, $e\mu$, $\mu\mu$), $E_T$>20GeV



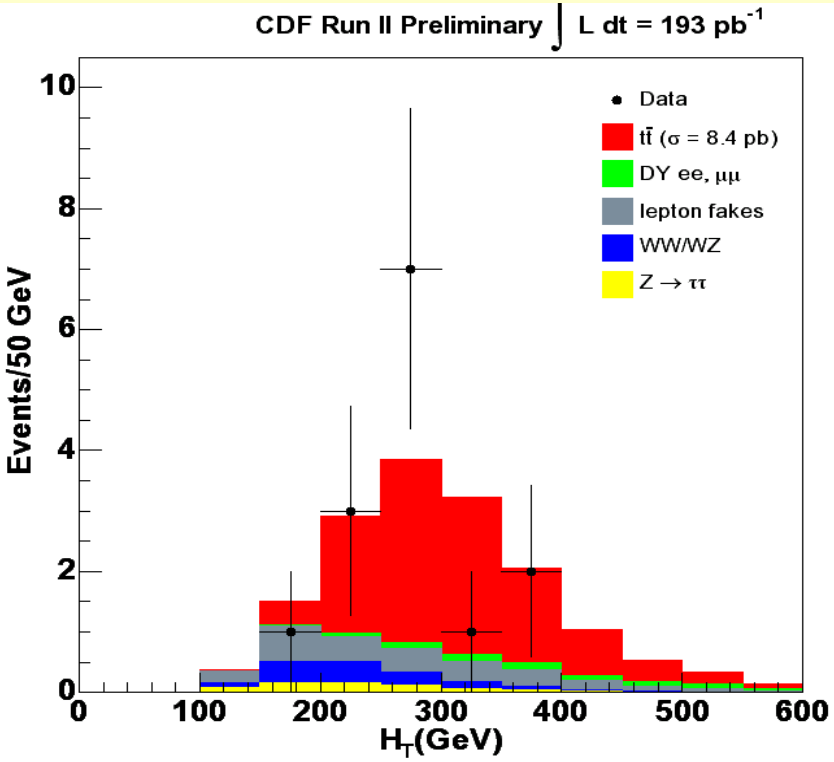

## Cut-based

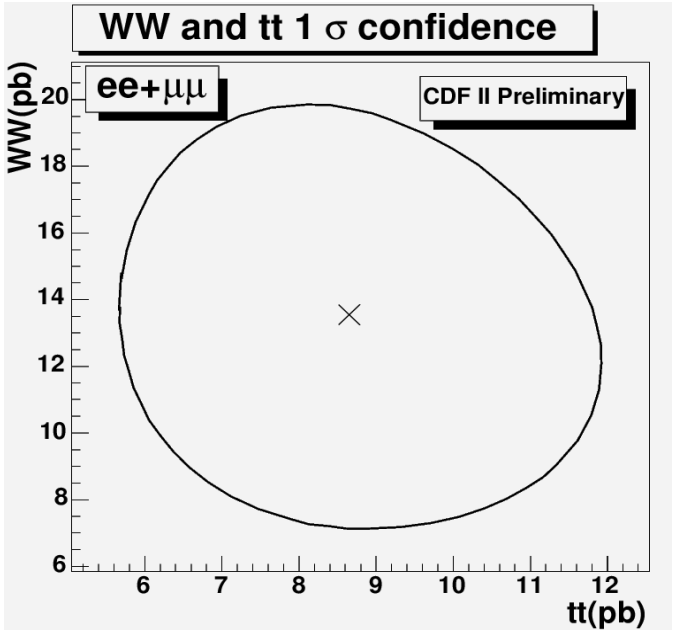
- Require 2 jets
- Require oppositely charged leptons
- Require total transverse energy >200GeV

## Inclusive

- Fit jet-inclusive data to WW+tt+background contributions

$\sigma(t\bar{t}) = 8.4\ ^{+3.2}_{-2.7}\ (stat)\ ^{+1.5}_{-1.1}\ (syst) \pm 0.5\ (lum)$ pb

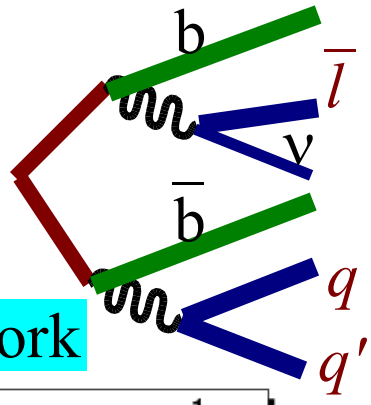


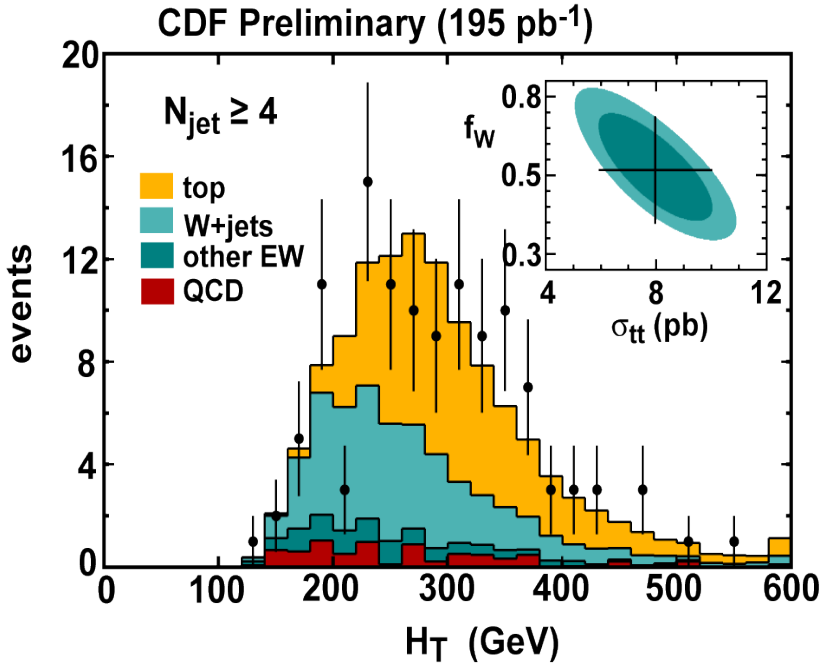

| CDF II preliminary | $e\mu$ only | $ee + \mu\mu + e\mu$ | Theory |
|---|---|---|---|
| $\sigma(t\bar{t})$ (pb) | $8.6^{+3.4}_{-3.2} \pm 0.9$ | $8.6^{+2.5}_{-2.4} \pm 1.1$ | $6.7 \pm 0.3$ |
| $\sigma(WW)$ (pb) | $11.5^{+3.6}_{-3.6} \pm 0.6$ | $12.6^{+3.2}_{-3.0} \pm 1.2$ | $12.5 \pm 0.8$ |
| $\sigma(Z \to \tau\tau)$ (pb) | $233^{+45}_{-42} \pm 17$ | – | $253.1 \pm 0.5$ |

# Lepton+Jets Topological

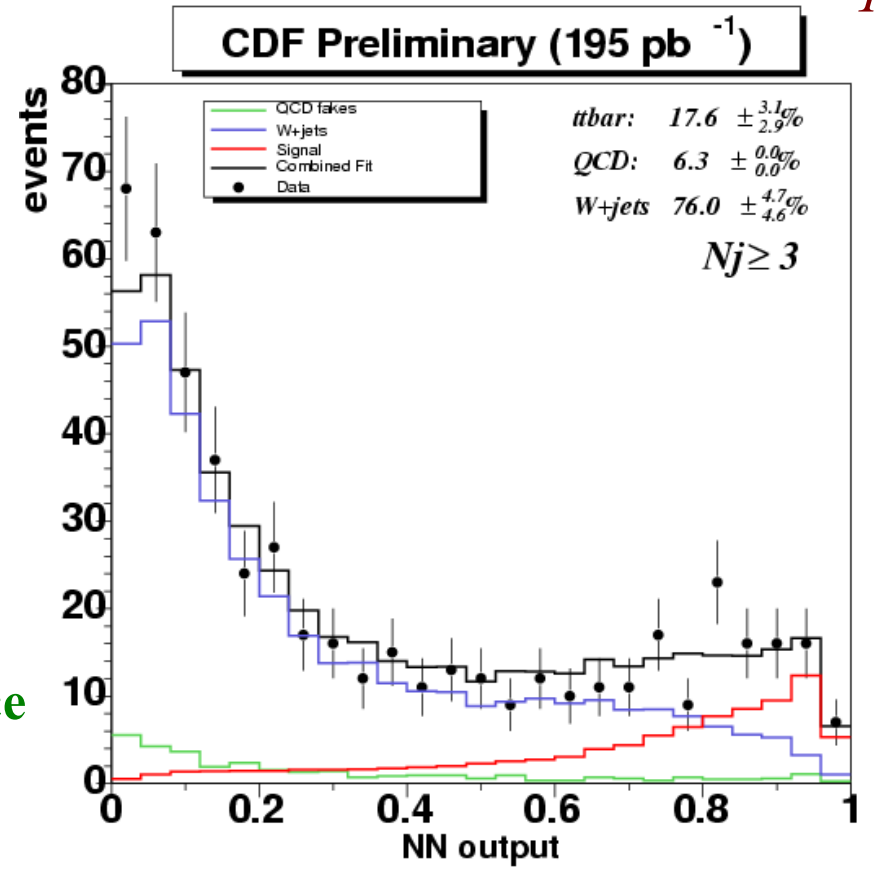
1 lepton ($E_T$>20GeV), Missing $E_T$>20GeV, ≥ 3 jets ($E_T$>15GeV)




## Fit to total transverse energy




## 7-input Neural Network




**Systematic Uncertainties for shape and acceptance**

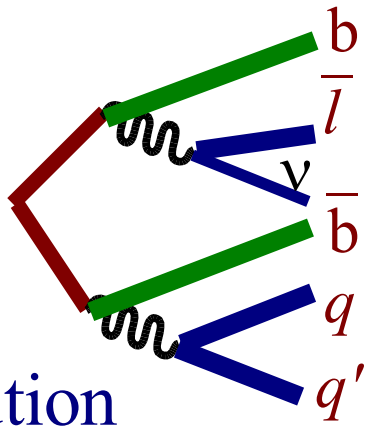
**Shape: ~30% (JES), acc: ~7% (JES, PDF)**

| Sample | Data Observed | Fraction | Cross Section |
|---|---|---|---|
| W+≥3 Jets | 519 | $0.126 \pm 0.042$ | $4.7 \pm 1.6 \pm 1.8$ pb |
| W+≥4 Jets | 118 | $0.503 \pm 0.130$ | $8.0 \pm 2.0 \pm 3.0$ pb |

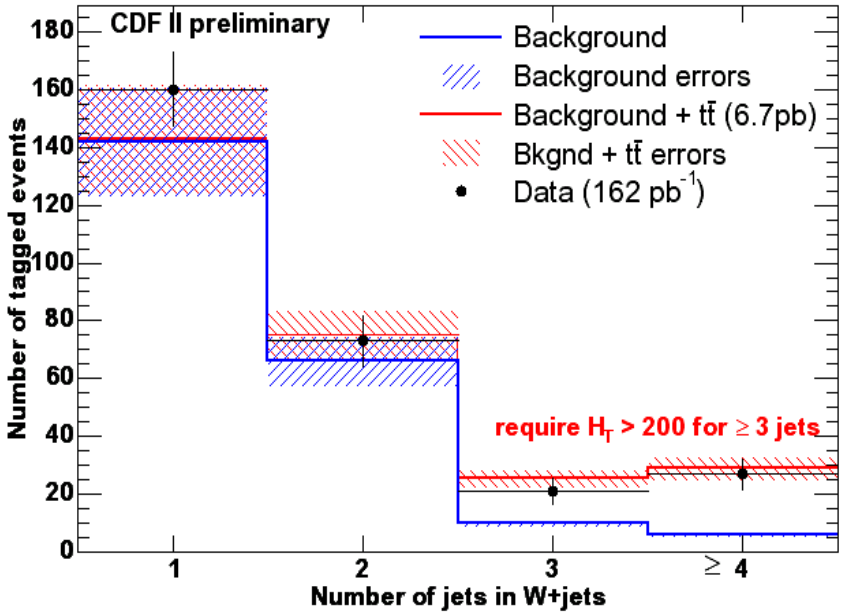
| Sample | Events | $t\bar{t}$ fraction | $\sigma(t\bar{t})$ |
|---|---|---|---|
| W+≥3 Jets | 519 | $0.176 \pm 0.030$ | $6.7 \pm 1.1 \pm 1.5$ pb |
| W+≥4 Jets | 118 | $0.473 \pm 0.100$ | $7.5 \pm 1.6 \pm 2.0$ pb |

# Lepton+Jets with SVX b-tag

1 lepton ($E_T$>20GeV), Missing $E_T$>20GeV, ≥ 3 jets ($E_T$>15GeV)




- Systematic uncertainty
  - 5-10% for tagging
- ≥1 tags and HT>200GeV

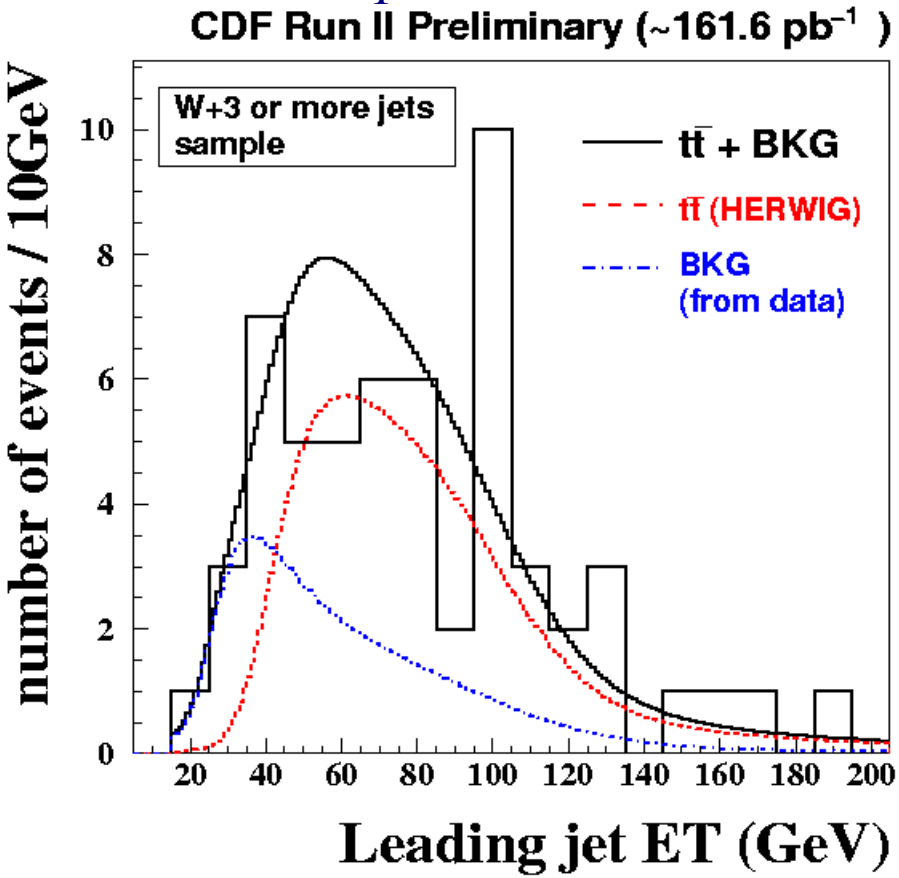



$$\sigma_{t\bar{t}} = 5.6^{+1.2}_{-1.1}(\text{stat.})^{+0.9}_{-0.6}(\text{syst.})\,\text{pb}$$

- ≥2 tags

$$\sigma_{t\bar{t}} = 5.0^{+2.4}_{-1.9}(\text{stat})^{+1.1}_{-0.8}(\text{syst})\text{pb}$$

- ≥1 tags and fit to leading jet $E_T$ distribution




$\sigma(t\bar{t}) = 6.0$ +1.5-1.8 (fit) ± 0.8 (sys) pb

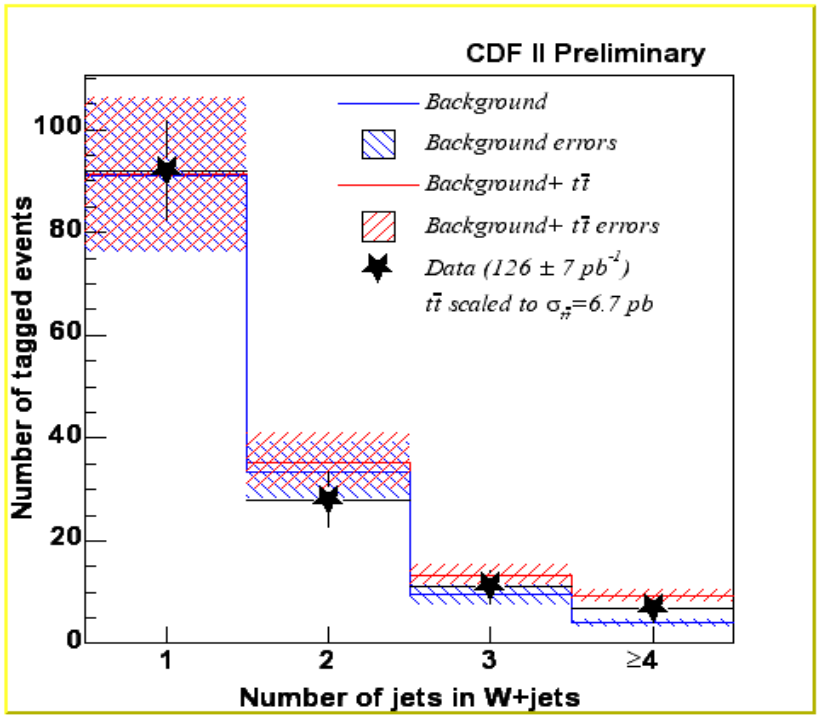
# Lepton+Jets with b-tag

1 lepton ($E_T$>20GeV),

Missing $E_T$>20GeV,

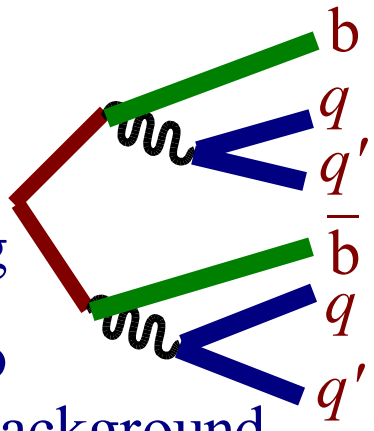
≥ 3 jets ($E_T$>15GeV)

- Soft-Muon b-tag
  - Muon in jet from B meson decay

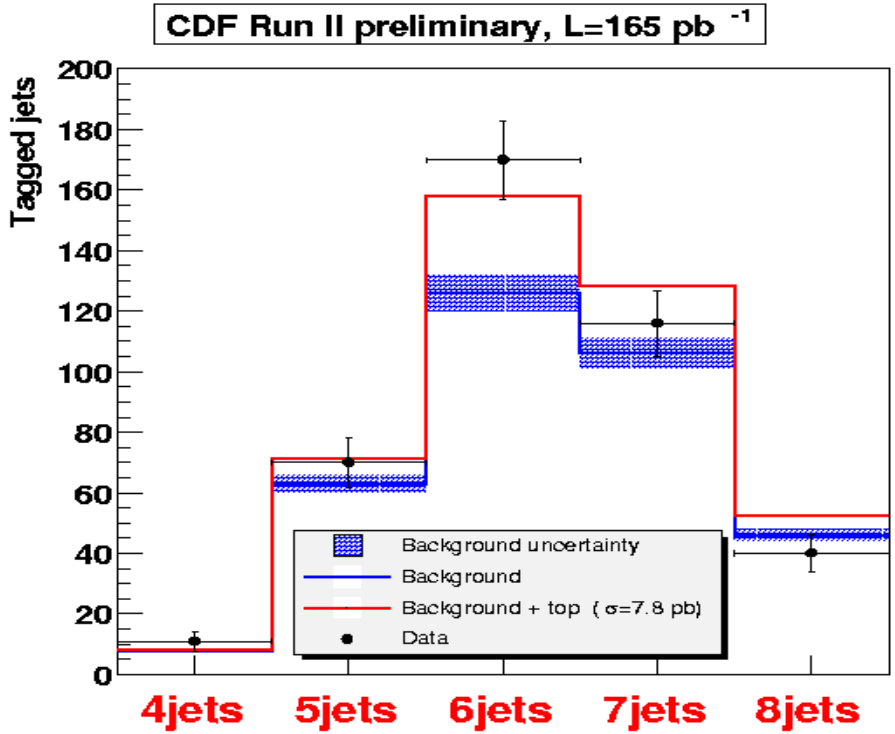



$$\sigma_{t\bar{t}} = 4.1^{+4.0}_{-2.8}\,(\text{stat.}) \pm 1.9\,(\text{sys.})\text{pb}$$

# All-Jets



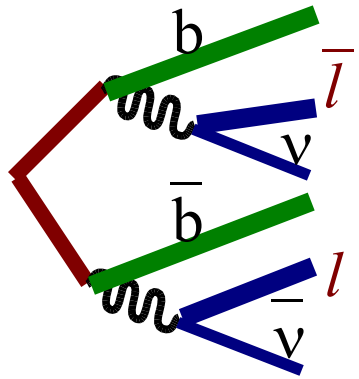

- $6 \le N_{jets} \le 8$, ≥1 tag
- Kinematical cuts to reject large QCD background
  - Aplanarity
  - $H_T$, $H_T - E_T^{\text{jet1}} - E_T^{\text{jet2}}$




$$\sigma_{t\bar{t}} = 7.8 \pm 2.5(stat)\ ^{+4.7}_{-2.3}(syst) = 7.8^{+5.3}_{-3.4}\ pb$$

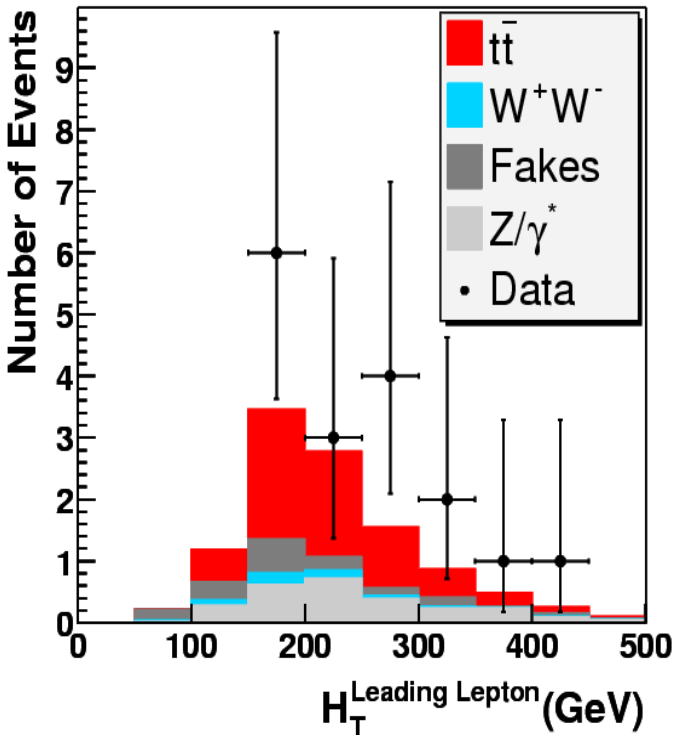
# Di-Lepton

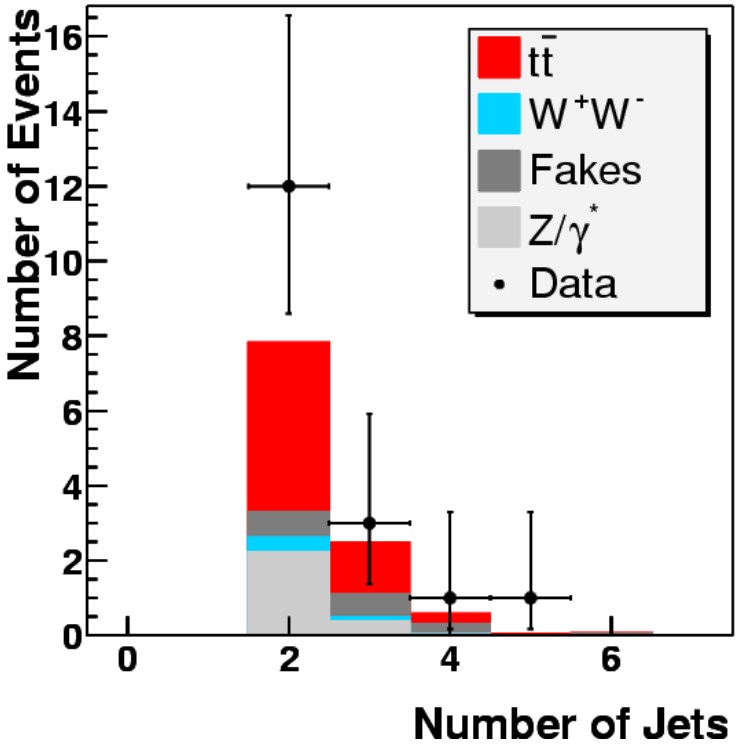
2 well identified leptons (*ee*, *e*μ, μμ)




- 140pb$^{-1}$ Run II data
- Analyze *ee*, *e*μ, μμ separately then combine results
  - Di-Lepton trigger
  - Lepton $E_T$>15GeV
    - $E_T$(e)>20GeV (*ee*)
    - $|\eta^e_{det}|<1.1$, $|\eta^\mu_{det}|<2$
  - Missing $E_T$>25GeV
    - >35GeV for *ee*,μμ
  - ≥2 jets, $E_T$>20GeV
  - *Z* mass window cut
  - HT = $E_T^{l1} + \Sigma_i E_T^{jet\ i}$ >120GeV (μμ), >140GeV (*e*μ)

- Systematic Uncertainty
  - Acceptance: Jet Energy Scale ~7%
  - Backgrounds: MC normalization ~40%

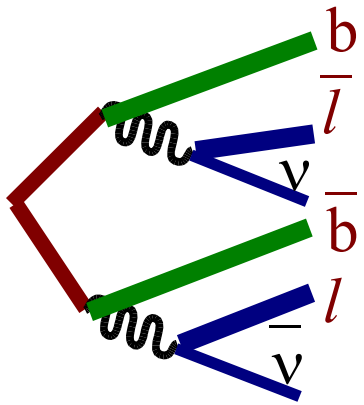


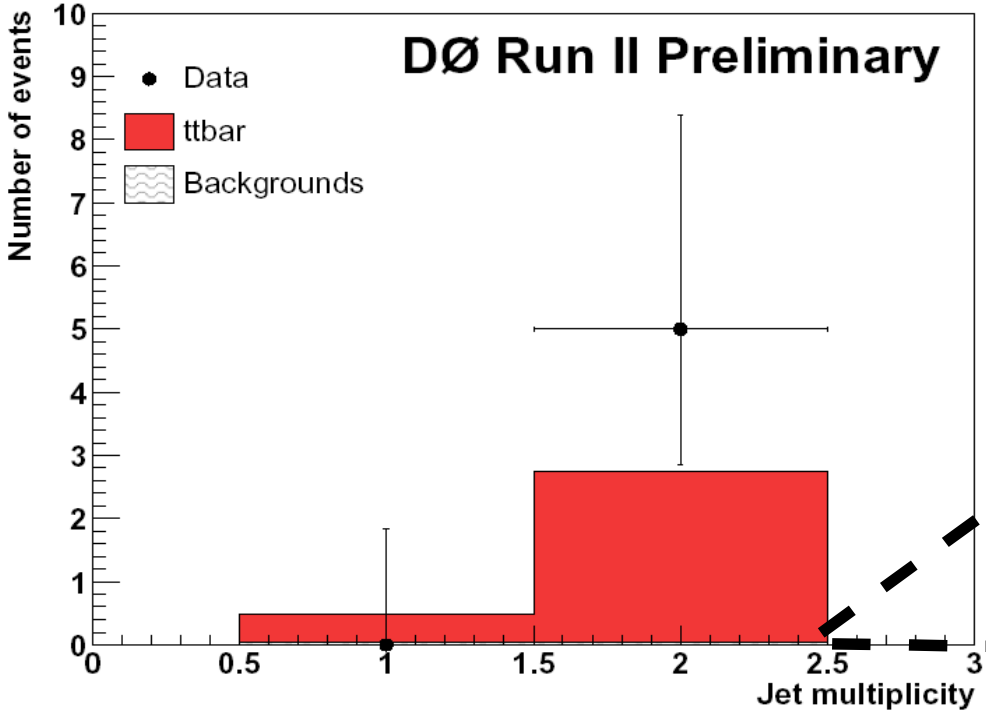

$$\sigma_{t\bar{t}} = 14.3^{+5.1}_{-4.3}\ (\text{stat})\ ^{+2.6}_{-1.9}\ (\text{syst}) \pm 0.9\ (\text{lumi})\ \text{pb}$$

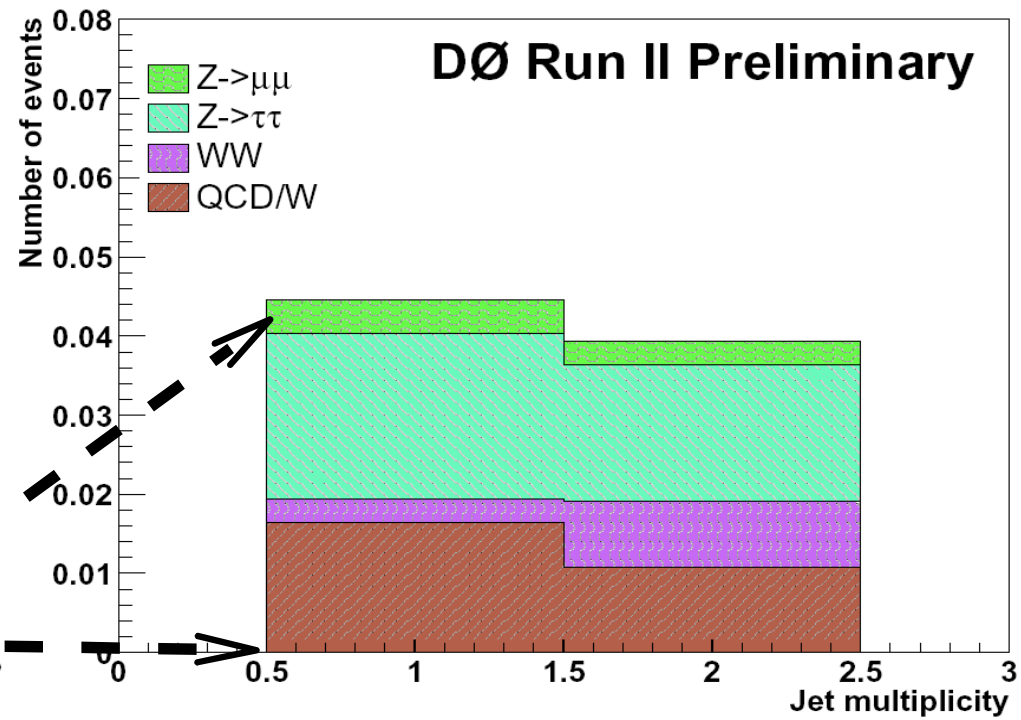
# Di-Lepton ($e\mu$) with b-tag

$e,\mu$ ($E_T$>15GeV), missing $E_T$>25GeV, ≥ 1 jets ($E_T$>20GeV)




- Require secondary vertex b-tag
- Analyze $N_{jets}$=1 and $N_{jets}$≥2 separately
  - Then take product of likelihoods
- Systematic Uncertainty
  - b-tagging: ~10%
  - Jet energy scale: ~6%
  - Object ID: ~3%

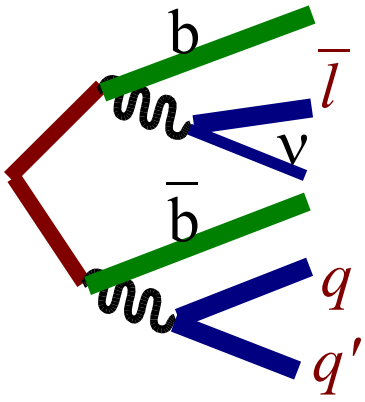


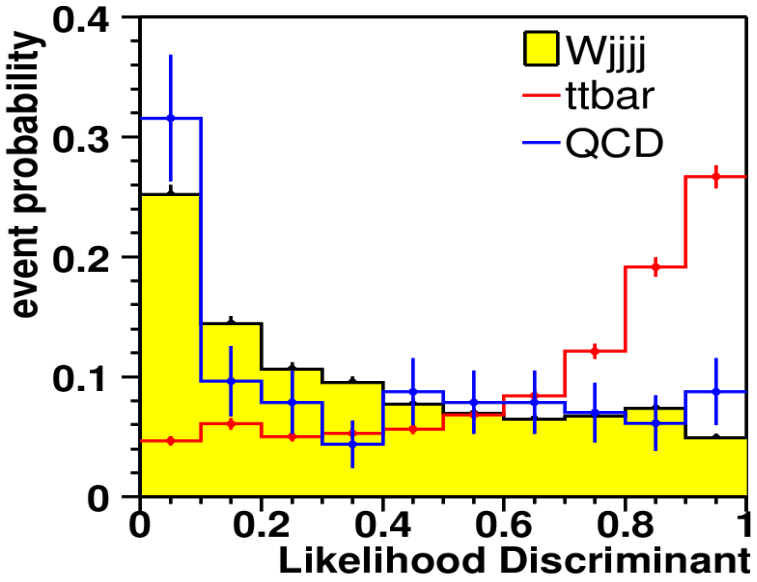



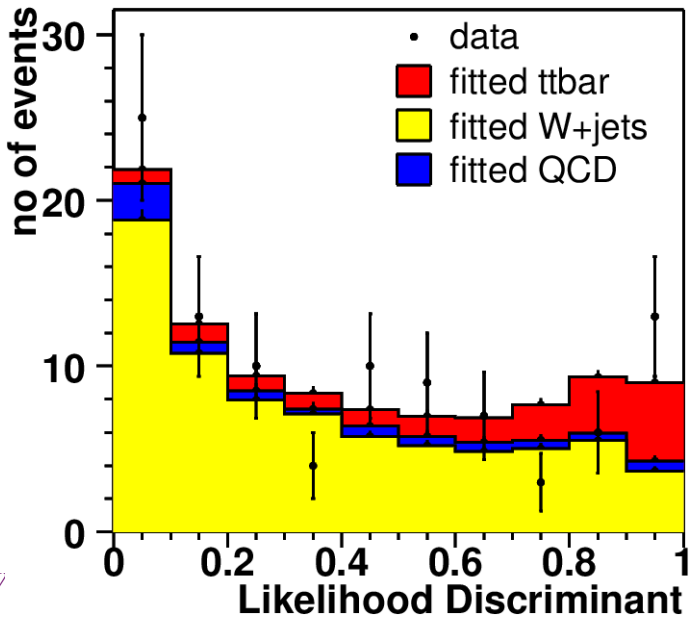

$$\sigma_{t\bar{t}} = 11.1^{+5.8}_{-4.3}(\text{stat}) \pm 1.4(\text{syst}) \pm 0.6(\text{lumi})\ \text{pb}$$

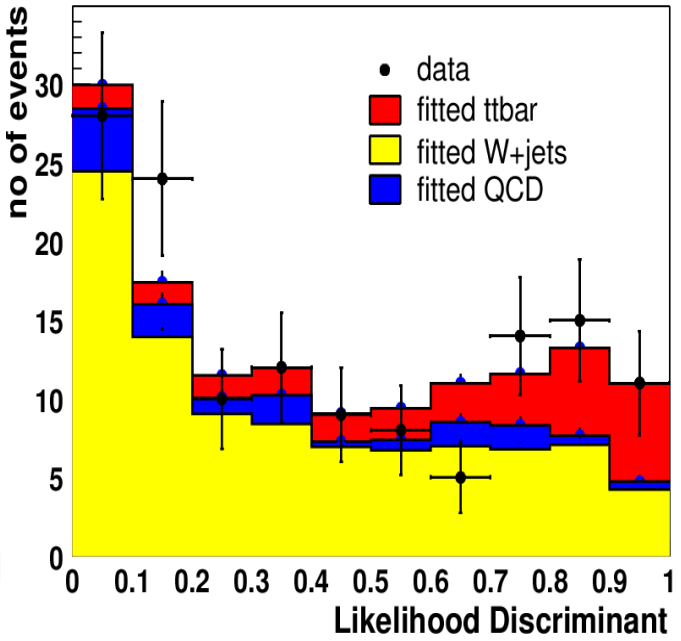
# Lepton+Jets Topological

- 140pb$^{-1}$ Run II data
- Analyze *e*+jets and μ+jets separately
  - Lepton+jets trigger
  - Lepton $E_T$>20GeV
  - ≥4 jets, $E_T$>15GeV, |η|<2.5
  - Missing $E_T$>20GeV (*e*)
  - Missing $E_T$>17GeV (μ)
- Build likelihood from topological variables
  - Sphericity
  - Aplanarity
  - $H'_{T2} = (H_T - E_T^{jet\,1})/H_Z$
  - $K'_{Tmin} = \Delta R^{ij}_{min} E_{Tmin}/E_T^W$



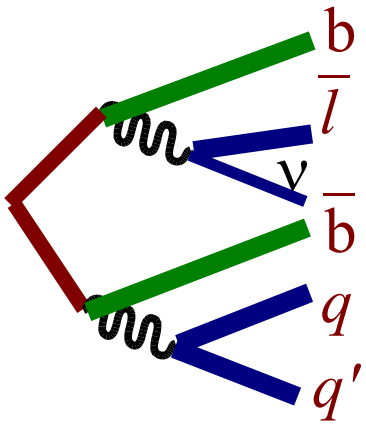




$$\sigma_{p\bar{p}\to t\bar{t}+X} = 7.20^{+2.58}_{-2.39}\,(\text{stat})\,^{+1.57}_{-1.68}\,(\text{syst}) \pm 0.47\,(\text{lumi})\,\text{pb}$$

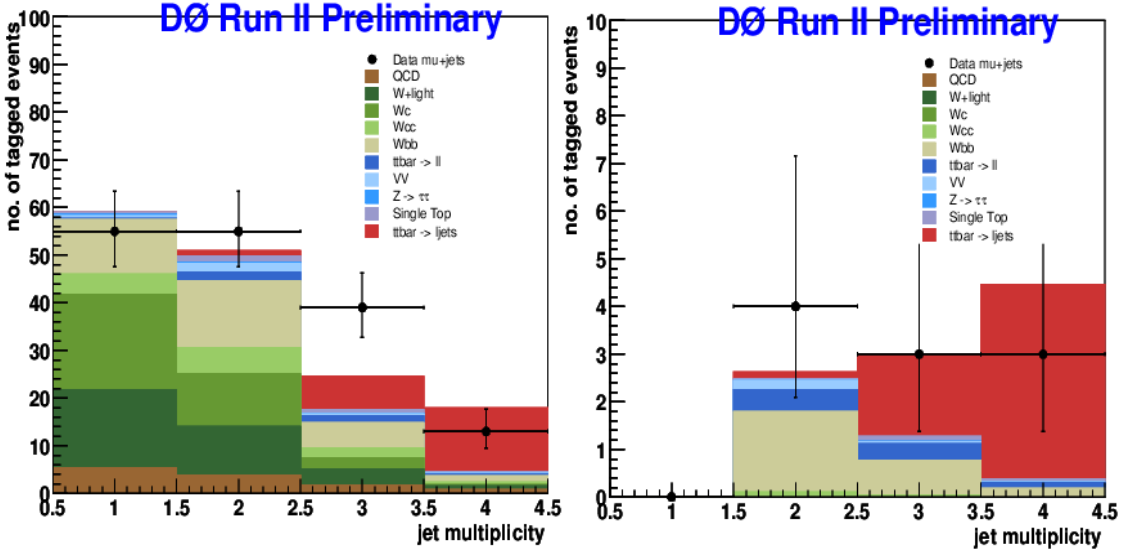
# Lepton (μ)+jets with b-tag

1 lepton ($E_T$>15GeV), missing $E_T$>17GeV, ≥ 3 jets ($E_T$>20GeV)

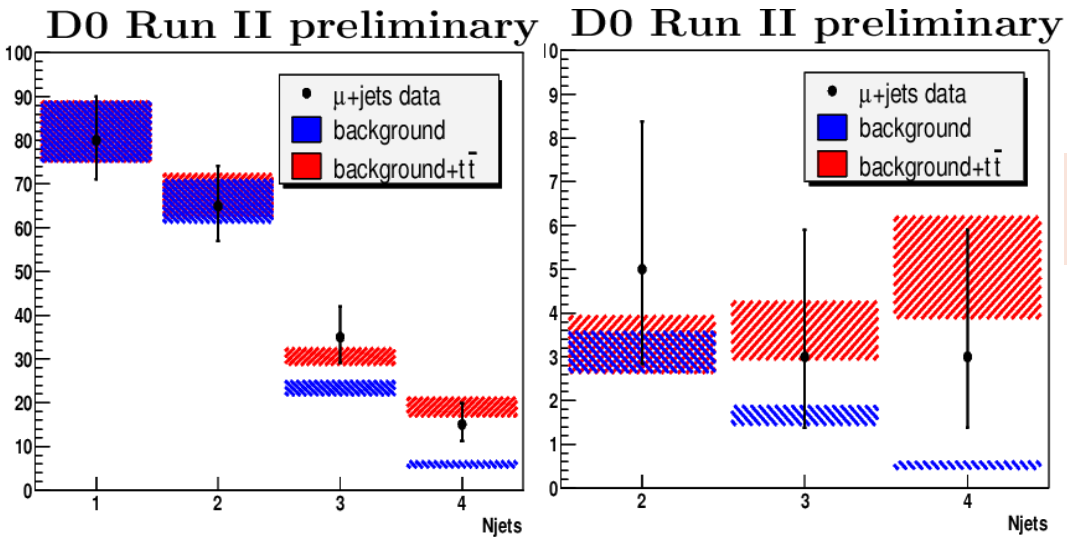



- 158pb$^{-1}$ Run II data
- Systematic Uncertainties
  - Jet Energy Scale: ~10%
  - Background normalization: ~10%
  - B-tagging efficiency: ~10%

## Secondary Vertex Tagger:




## Impact Parameter Tagger:



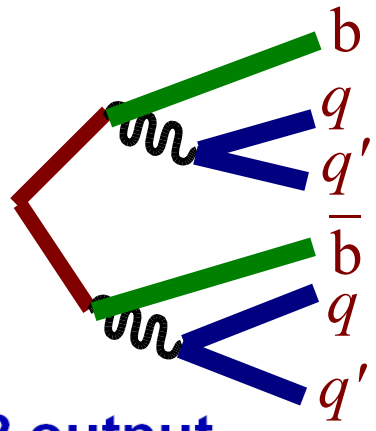

## Impact Parameter Tagger:

$$\sigma_{t\bar{t}} = 5.23^{+1.72}_{-1.52}\,(stat)\,^{+1.73}_{-1.18}\,(syst)\,\pm 0.34\,(lumi)\,\mathrm{pb}$$

## Secondary Vertex Tagger:

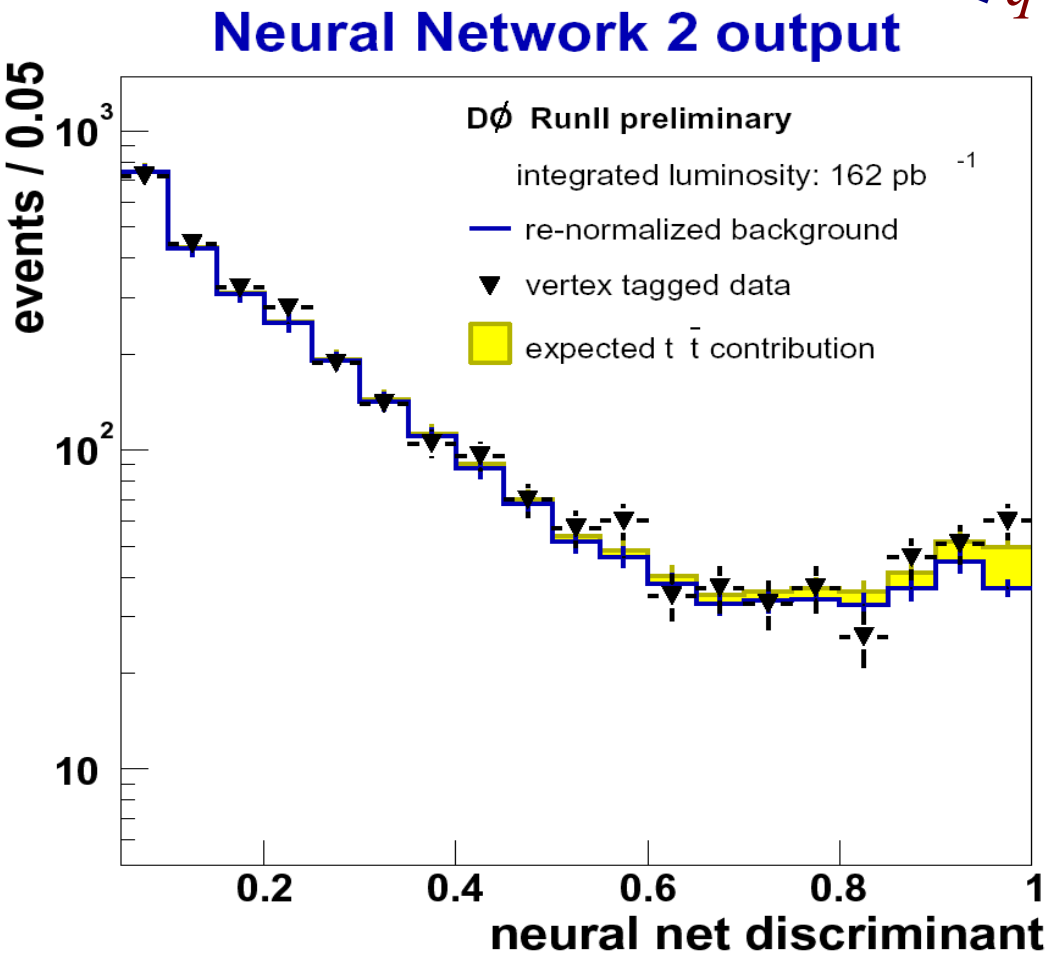
$$\sigma_{t\bar{t}} = 6.86^{+1.90}_{-1.70}\,(stat)\,^{+1.93}_{-1.68}\,(syst)\,\pm 0.44\,(lumi)\,\mathrm{pb}$$

# All-Jets



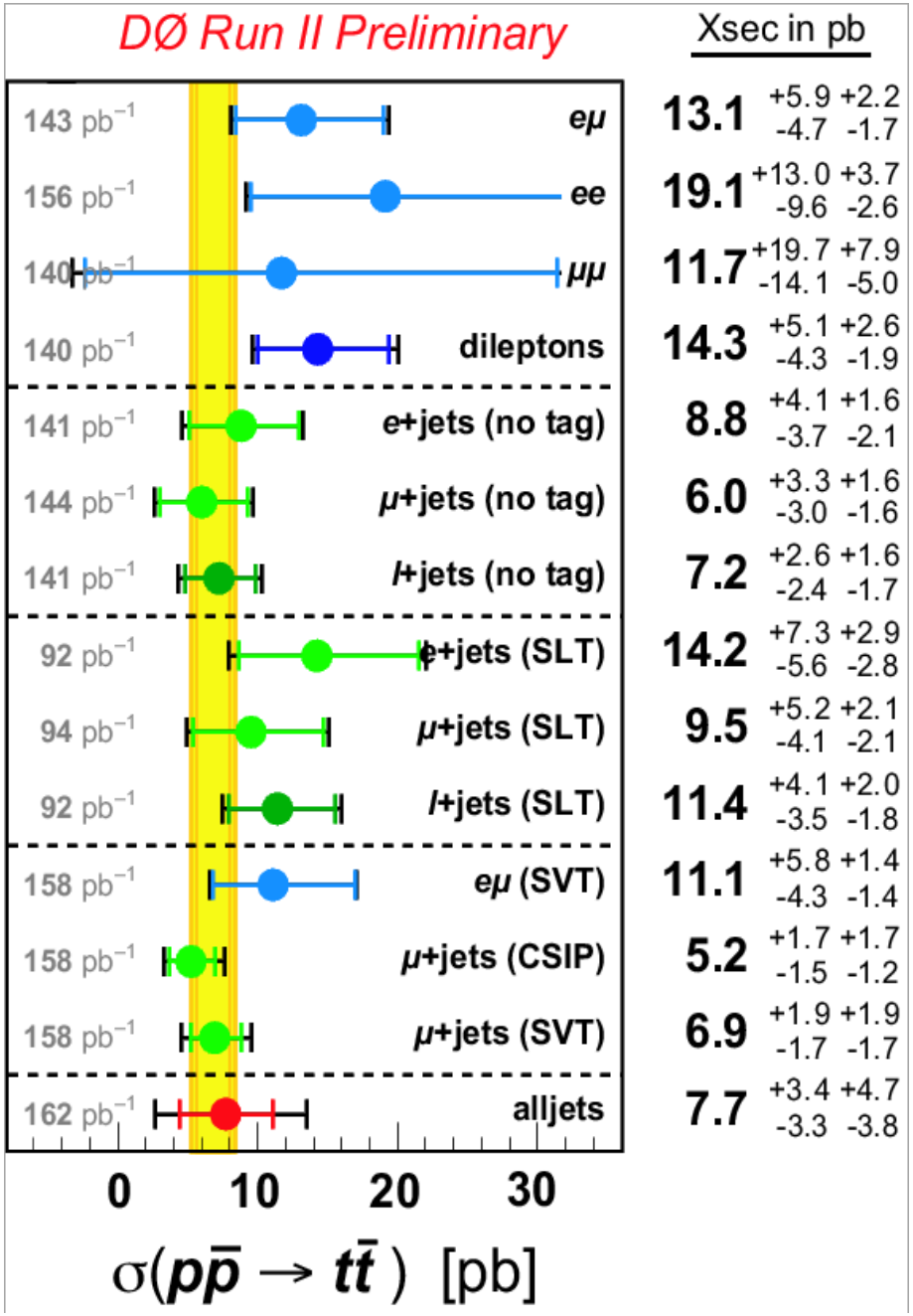

- Require ≥6 jets
  - $E_T$>15GeV, |η|<2.5
  - Background: QCD multi-jet
    - Estimated using data
- Require ≥1 b-tag (SVT)
- Chain of 3 Neural Networks to separate signal from background
  - Variables used:
    - Event Energy
    - Event Shape
    - Rapidity distributions
    - Top decay products: top mass, W mass

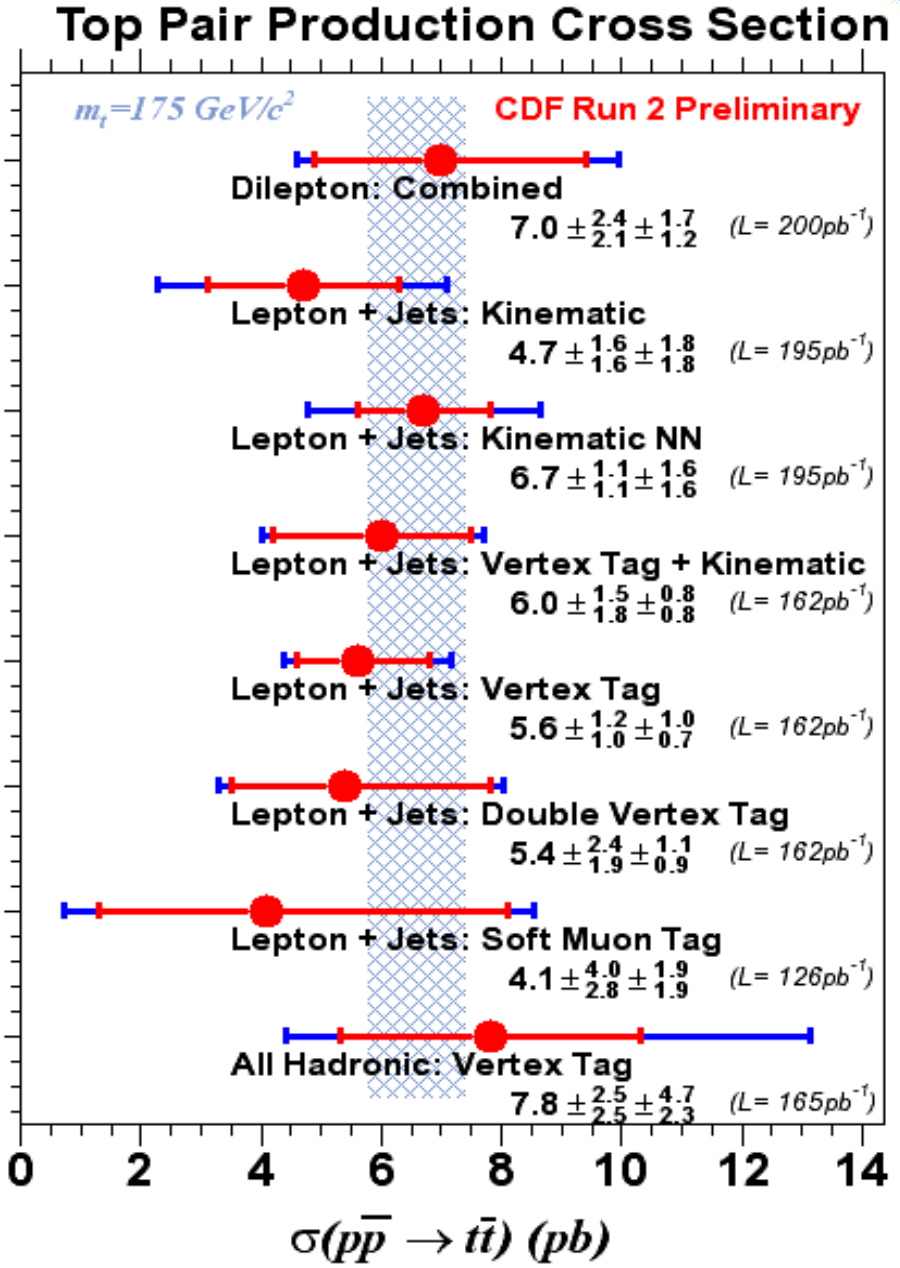
- Systematic Uncertainties
  - dominated by JES: ~28%




$$\sigma(t\bar{t}) = 7.7^{+3.4}_{-3.3}(\text{stat})^{+4.7}_{-3.7}(\text{syst}) \pm 0.5(\text{lumi})\ \text{pb}$$

# Cross Section Summary

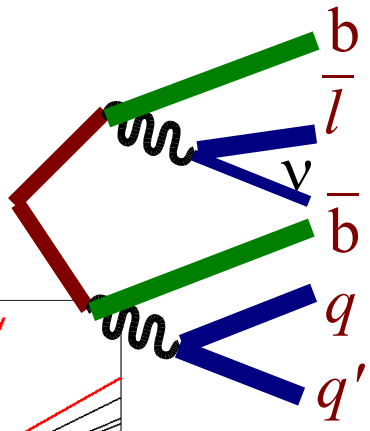


# Backup Slides

# Lepton+Jets with b-tag

1 lepton ($E_T$>20GeV), Missing $E_T$>20GeV, ≥ 3 jets ($E_T$>15GeV)




- Reconstruct secondary vertex from decay of B meson
  - Require 1 b-tagged jet