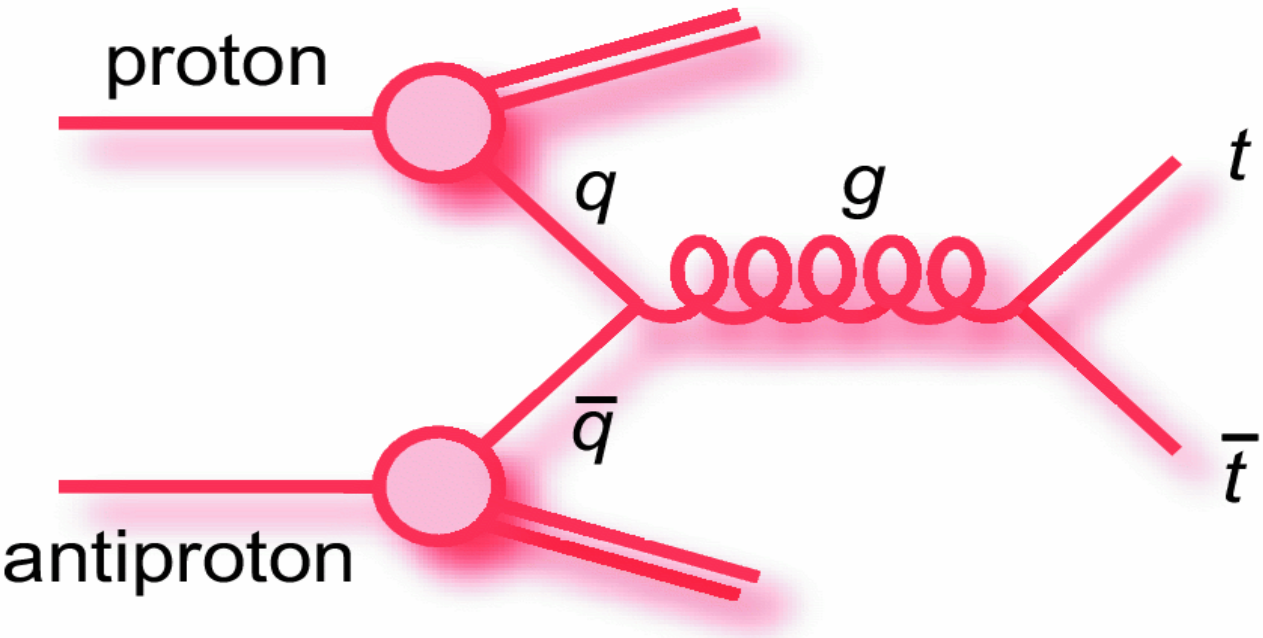
Top Quark Production Cross Section at E^{cm}=1.96 TeV



Reinhard Schwienhorst

MICHIGAN STATE UNIVERSITY

on behalf of the DØ and CDF Collaborations

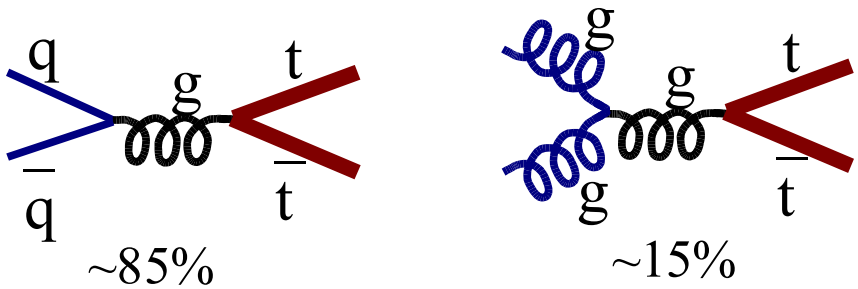
5èmes Rencontres du Vietnam, August 5 – 11, 2004, Hanoi, Vietnam

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

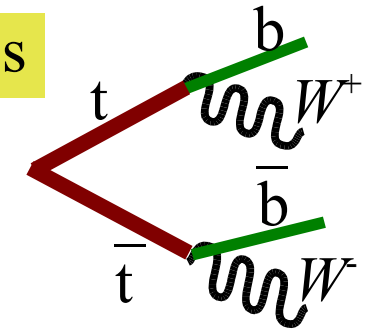
Production Modes

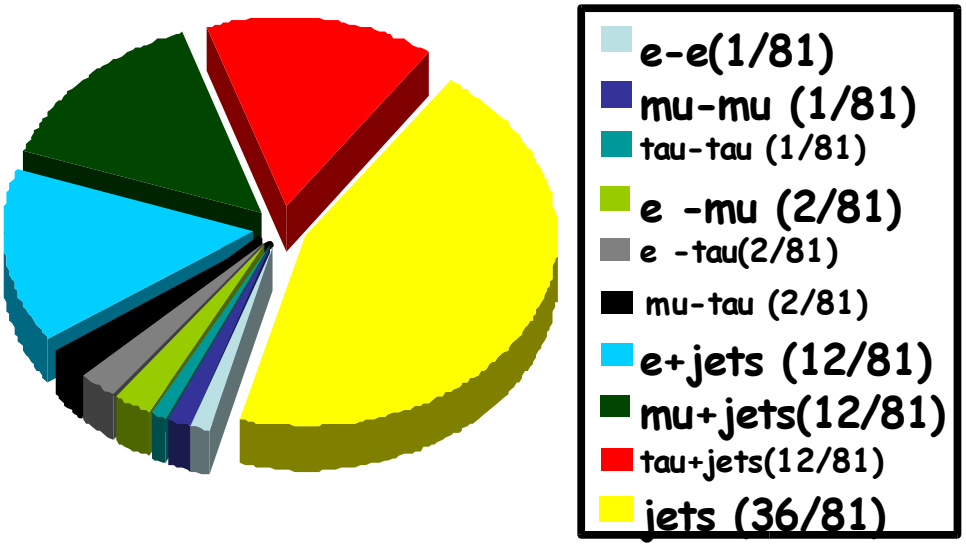


- $\sigma(p\text{-}\bar{p} \rightarrow t\bar{t} + X) = 6.77 \pm 0.47$pb
  - (N)NLO, at m_t=175GeV
    - PDF uncertainty ~10%
- Experimental Signatures:
  - 1 or 2 leptons, ≥2 jets or ≥6 jets (2 b-jets)
- Backgrounds:
  - W/Z/DY+jets, mis-reconstruction
- Test SM production and decay
  - Establish top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

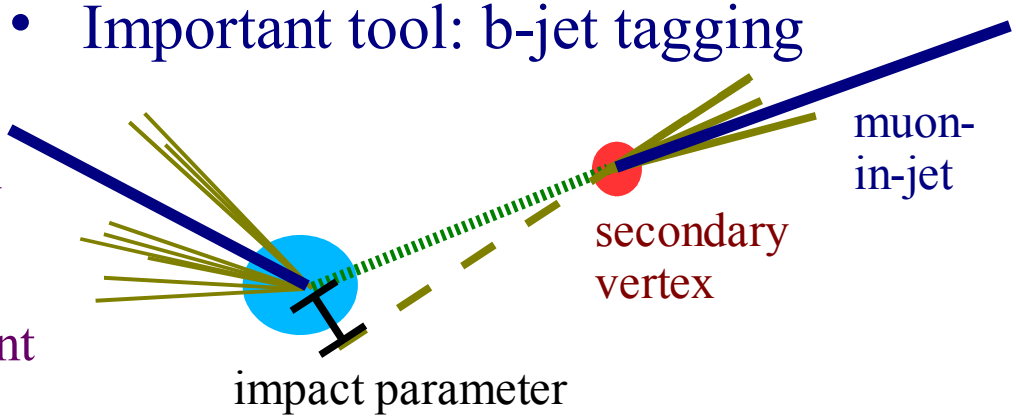
Decay Modes

- Classify by decay of the *W*s

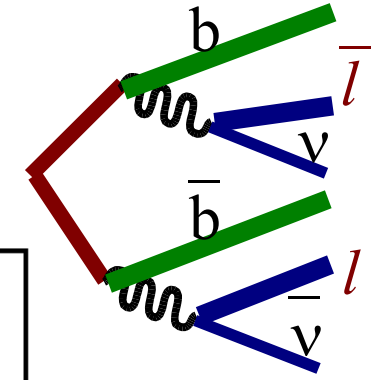




- Important tool: b-jet tagging



Lepton+Track



200pb^{-1} Run II data

2 Leptons

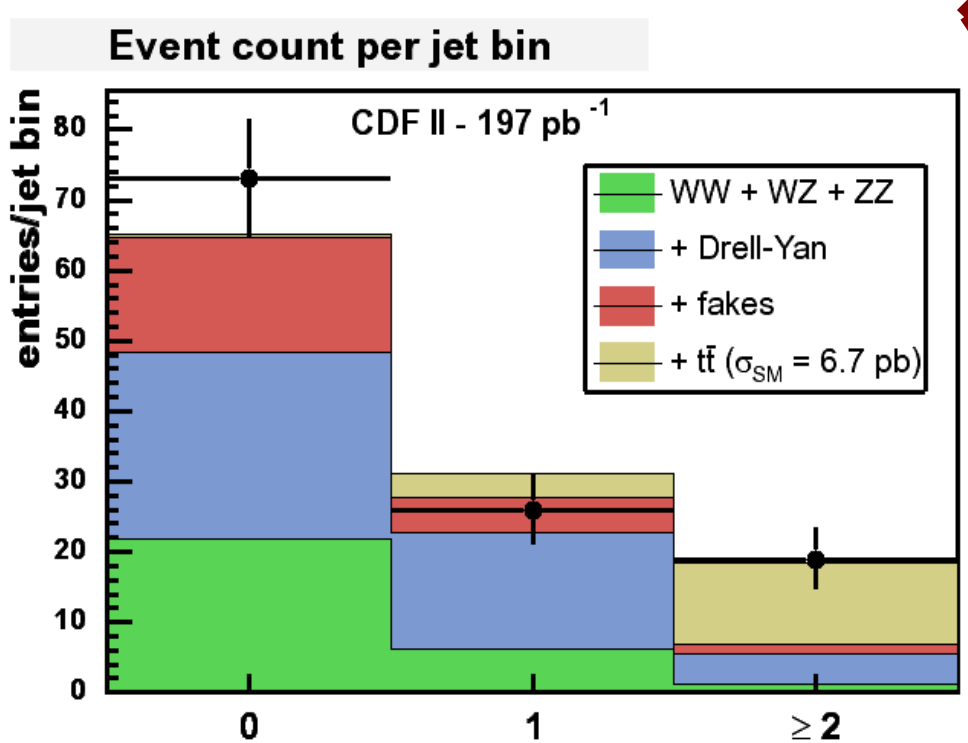
- **1 electron or muon**
- **1 isolated track**
- **p_T>20 GeV**
- **|η| < 1 (muons),**
- **|η| < 2 (electrons)**

+ Missing Et

- **Missing E_T > 25GeV**

+ ≥ 2 jets

- **E_T>20GeV, |η| < 2**



Systematic Uncertainties

Signal: particle ID ~5%, JES 6%, FSR 7%, PDF 6%

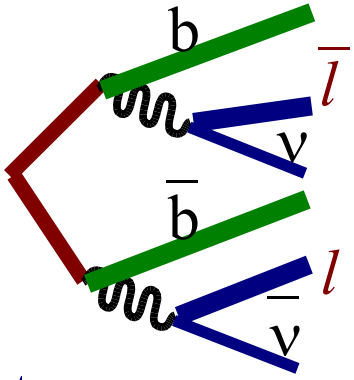
Backgrounds: also sample normalization (30% for DY)

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

At m_t = 175 GeV

Di-Lepton

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



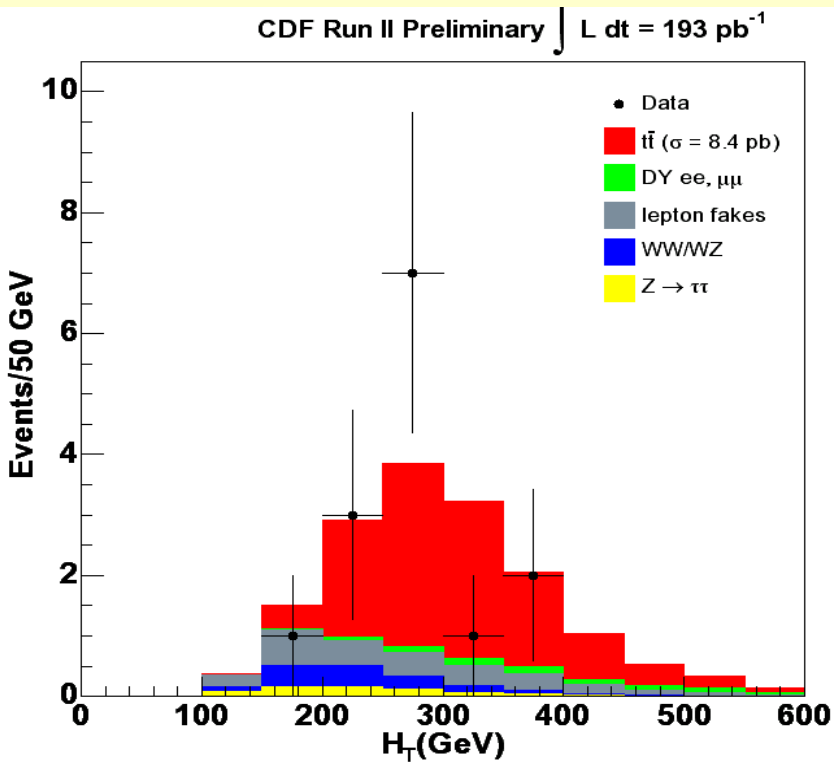
Cut-based

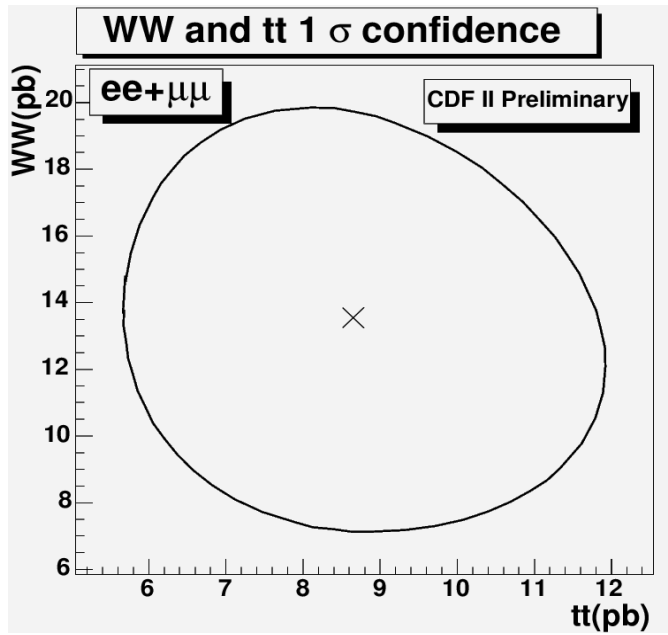
- Require 2 jets
- Require oppositely charged leptons
- Require total transverse energy >200GeV

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*) +/- 0.5 (*lum*) pb

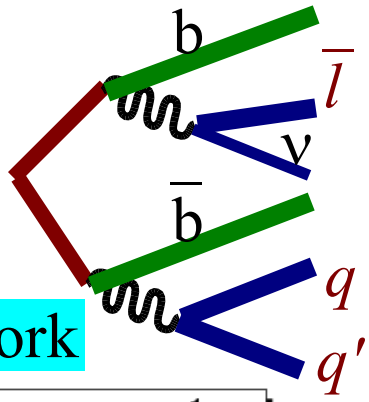




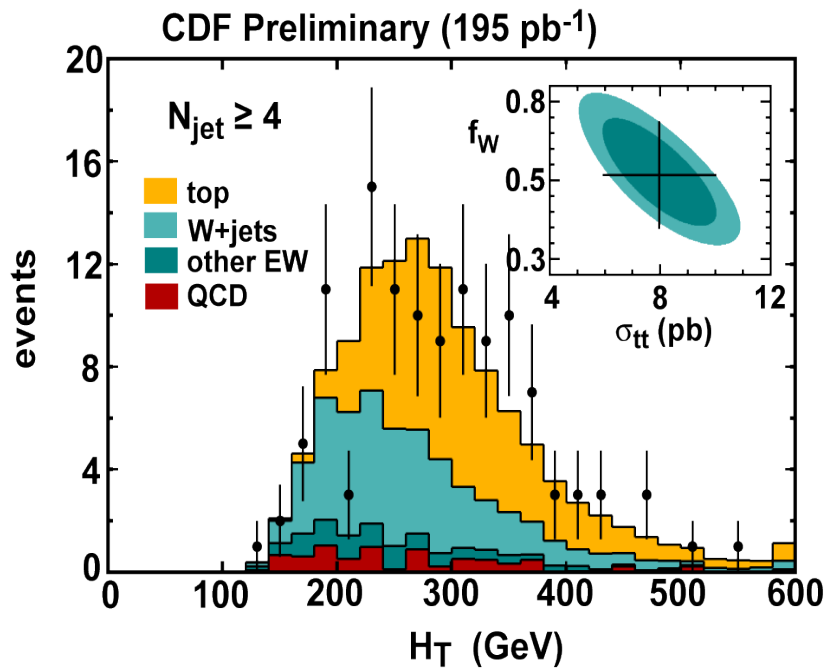
CDF II preliminary	$e\mu$ only	$ee + \mu\mu + e\mu$	Theory
$\sigma(t\bar{t})$ (pb)	$8.6^{+3.4}_{-3.2} \pm 0.9$	$8.6^{+2.5}_{-2.4} \pm 1.1$	6.7 ± 0.3
$\sigma(WW)$ (pb)	$11.5^{+3.6}_{-3.6} \pm 0.6$	$12.6^{+3.2}_{-3.0} \pm 1.2$	12.5 ± 0.8
$\sigma(Z \to \tau\tau)$ (pb)	$233^{+45}_{-42} \pm 17$	–	253.1 ±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

Lepton+Jets Topological

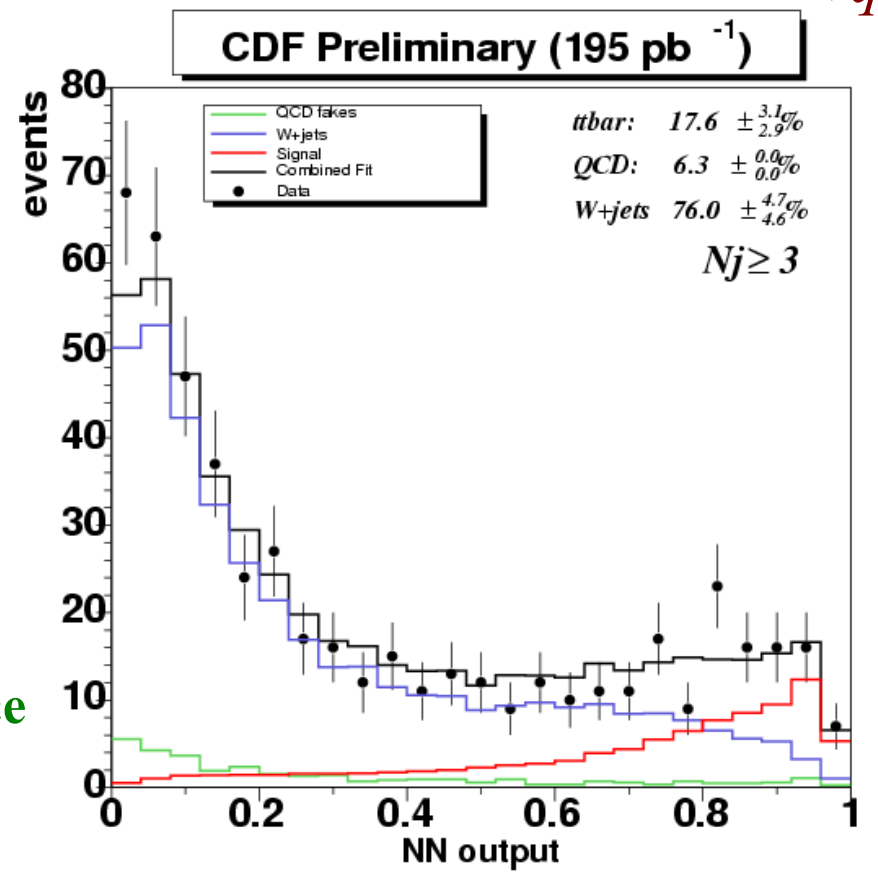
1 lepton (E_T>20GeV), Missing E_T>20GeV, ≥ 3 jets (E_T>15GeV)



Fit to total transverse energy



7-input Neural Network



Systematic Uncertainties for shape and acceptance

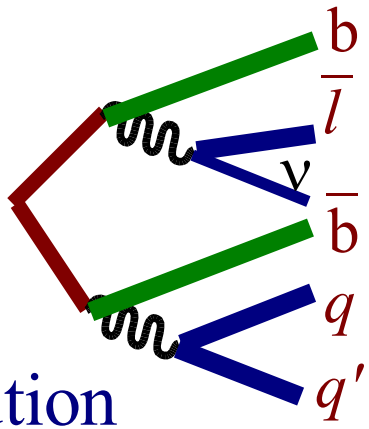
Shape: ~30% (JES), acc: ~7% (JES, PDF)

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

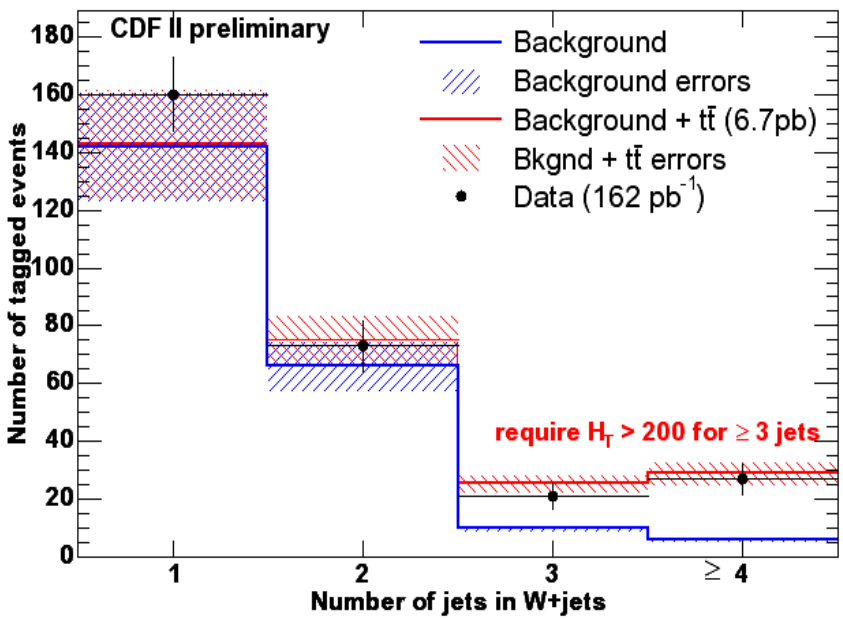
Sample	Events	$t\bar{t}$ fraction	$\sigma(t\bar{t})$
W+≥3 Jets	519	0.176 ± 0.030	6.7 ± 1.1 ± 1.5 pb
W+≥4 Jets	118	0.473 ± 0.100	7.5 ± 1.6 ± 2.0 pb

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

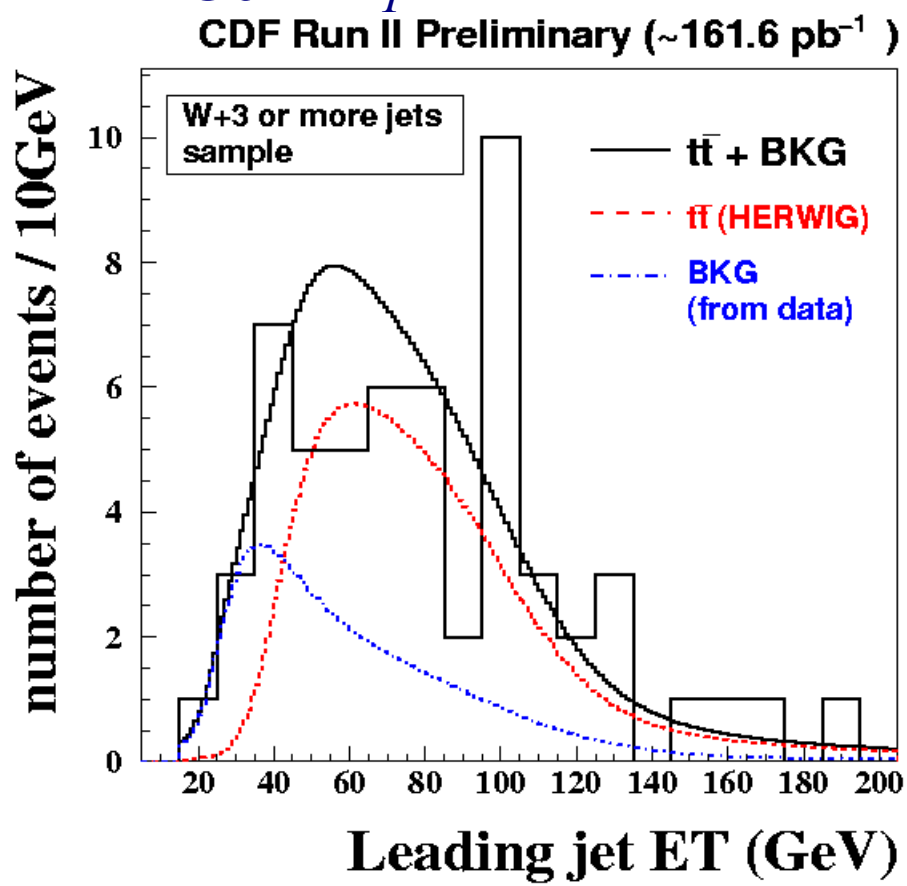


$$\sigma_{t\bar{t}} = 5.6^{+1.2}_{-1.1}(\text{stat.})^{+0.9}_{-0.6}(\text{syst.})\ \text{pb}$$

- ≥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



$$\sigma(t\bar{t}) = 6.0\ {}^{+1.5}_{-1.8}\ (\text{fit}) \pm 0.8\ (\text{sys})\ \text{pb}$$

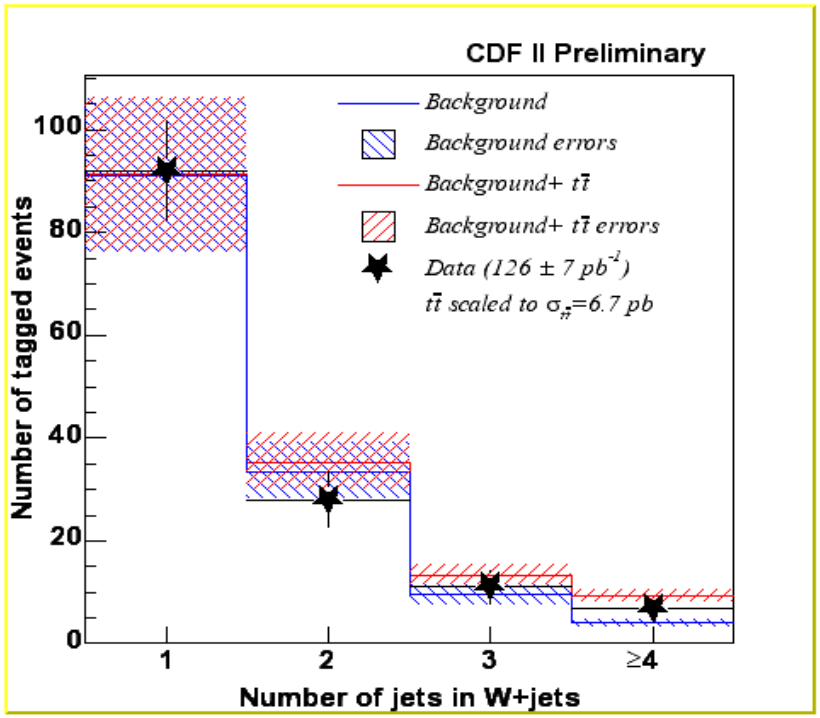
Lepton+Jets with b-tag

1 lepton (E_T>20GeV),

Missing E_T>20GeV,

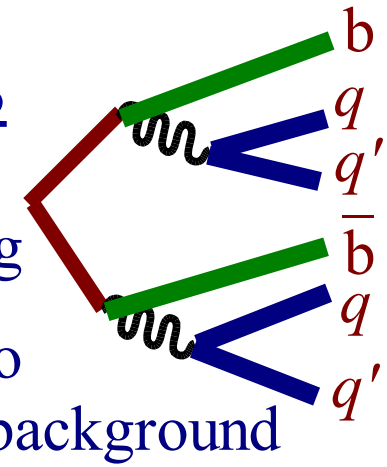
≥ 3 jets (E_T>15GeV)

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

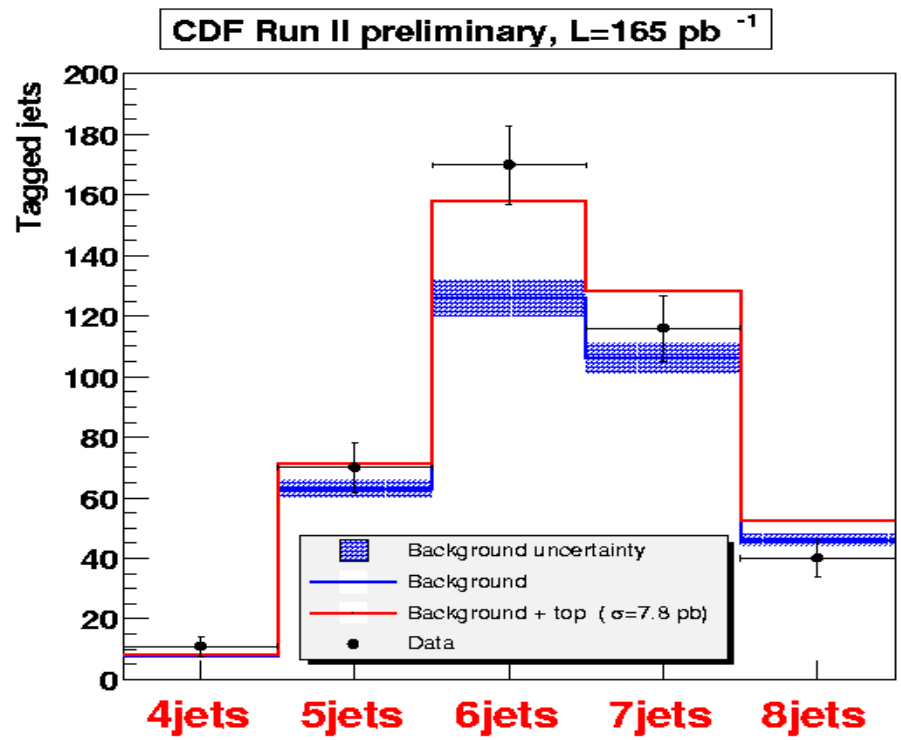


$$\sigma_{t\bar{t}} = 4.1^{+4.0}_{-2.8}\,(\text{stat.}) \pm 1.9\,(\text{sys.})\text{pb}$$

All-Jets



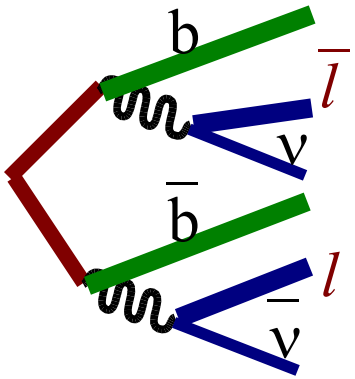
- $6 \le N_{jets} \le 8$, ≥1 tag
- Kinematical cuts to reject large QCD background
  - Aplanarity
  - H_T, $H_T - E_T^{\text{jet1}} - E_T^{\text{jet2}}$



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

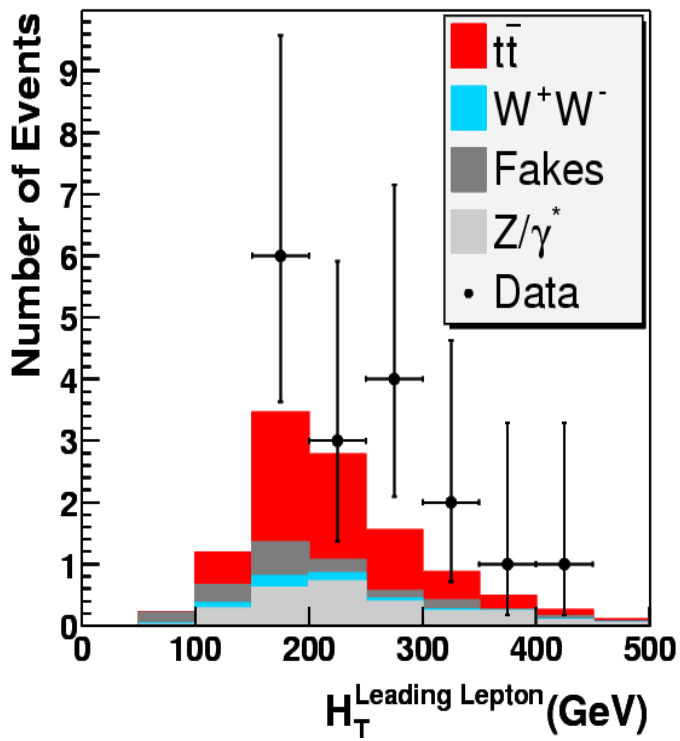
Di-Lepton

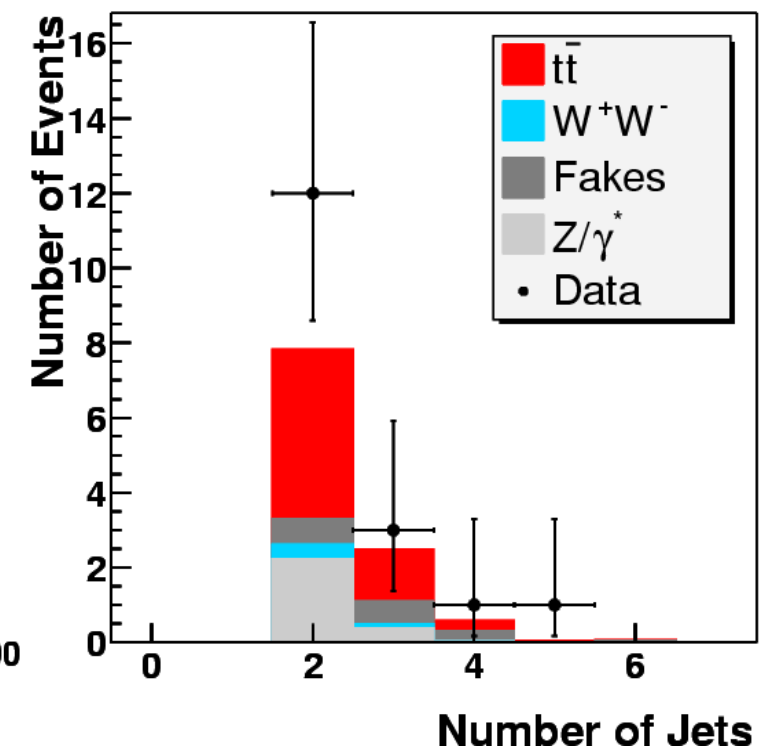
2 well identified leptons (ee, $e\mu$, $\mu\mu$)



- $140pb^{-1}$ Run II data
- Analyze ee, $e\mu$, $\mu\mu$ 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,$\mu\mu$
  - ≥2 jets, E_T>20GeV
  - Z mass window cut
  - $HT = E_T^{l1} + \Sigma_i E_T^{jet\ i}$ >120GeV ($\mu\mu$), >140GeV ($e\mu$)

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

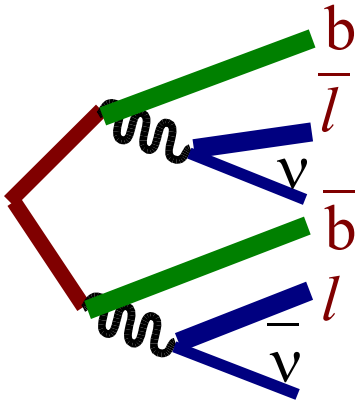




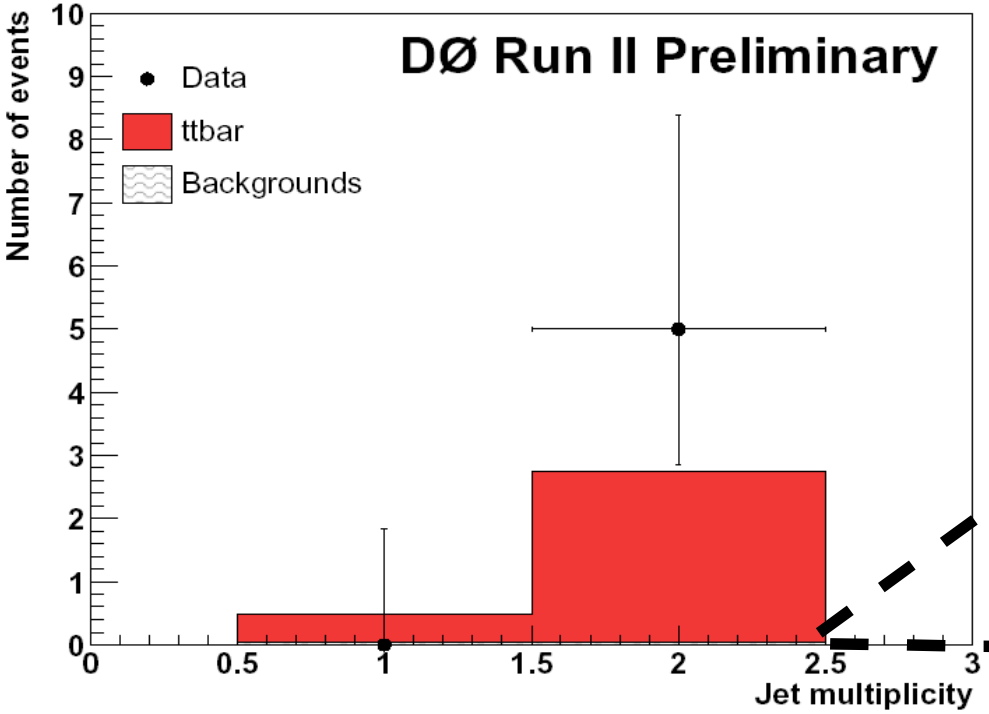
$$\sigma_{t\bar{t}} = 14.3^{+5.1}_{-4.3}\ (\text{stat})\ ^{+2.6}_{-1.9}\ (\text{syst})\ \pm 0.9\ (\text{lumi})\ \text{pb}$$

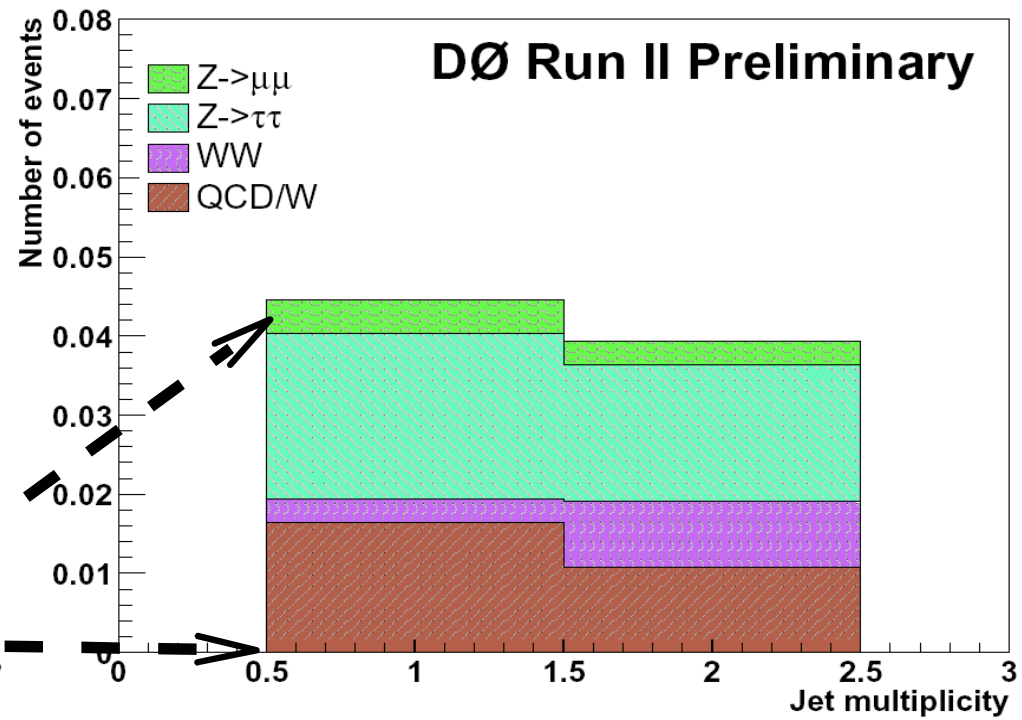
Di-Lepton ($e\mu$) with b-tag

e,μ (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%

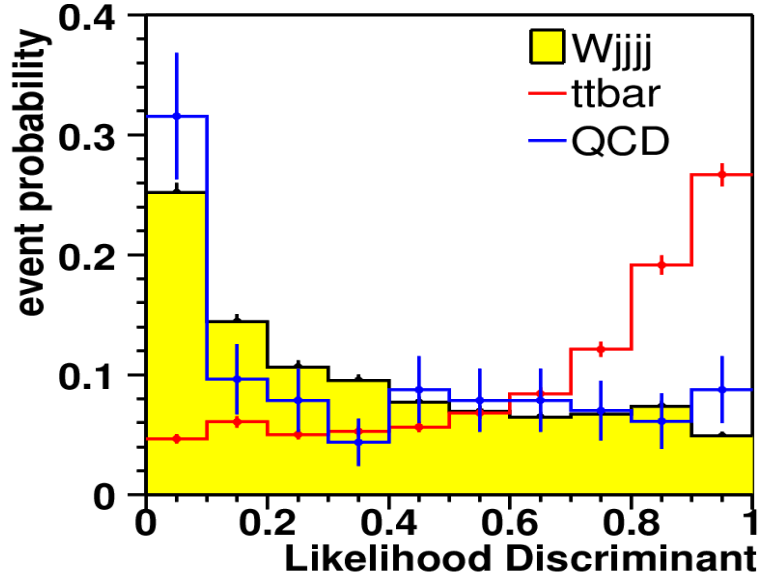


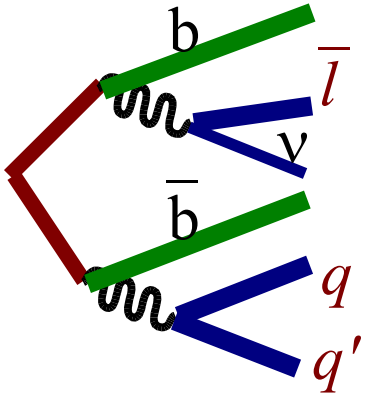


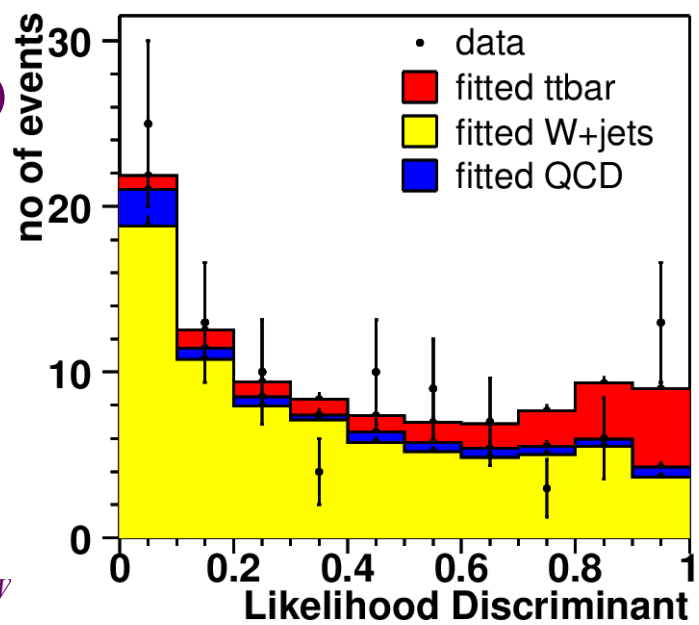
$$\sigma_{t\bar{t}} = 11.1^{+5.8}_{-4.3}(\text{stat}) \pm 1.4(\text{syst}) \pm 0.6(\text{lumi})\ \text{pb}$$

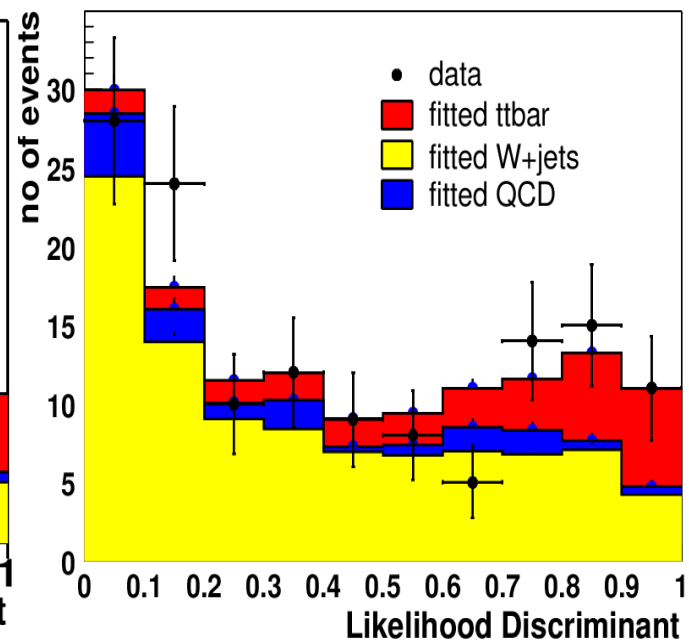
Lepton+Jets Topological

- 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
  - $H'_{T2} = (H_T - E_T^{jet\,1})/H_Z$
  - $K'_{Tmin} = \Delta R^{ij}_{min} E_{Tmin}/E_T^W$





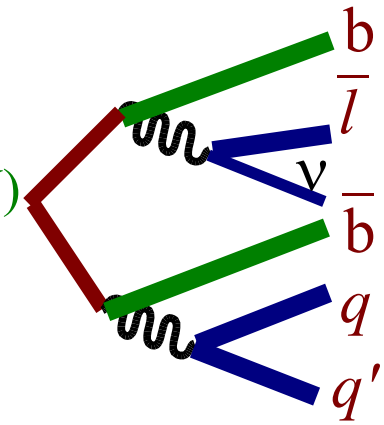




$$\sigma_{p\bar{p}\to t\bar{t}+X} = 7.20^{+2.58}_{-2.39}\,(\text{stat})\,^{+1.57}_{-1.68}\,(\text{syst})\ \pm 0.47\,(\text{lumi})\ \text{pb}$$

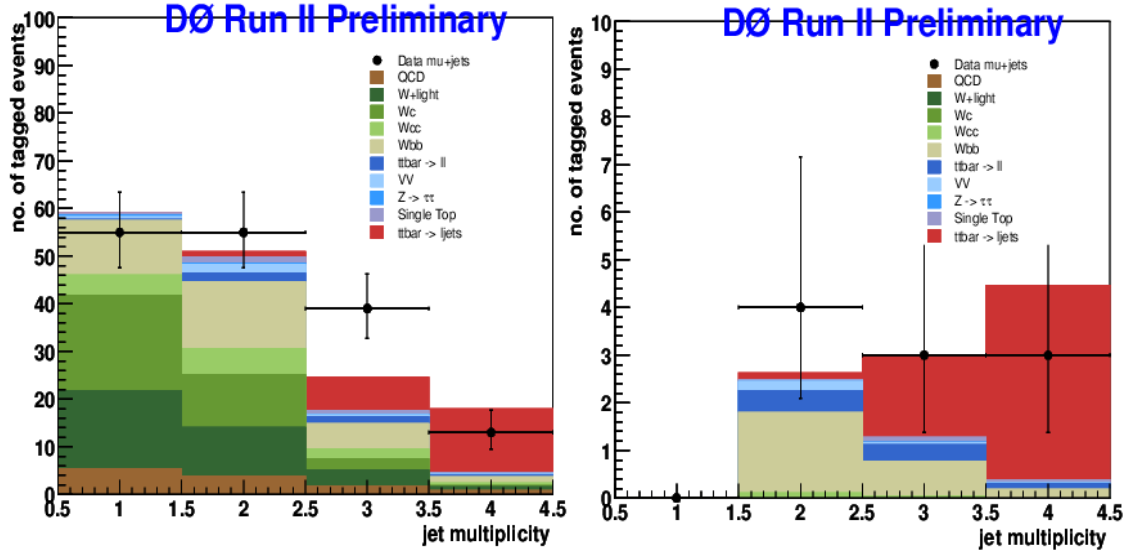
Lepton (μ)+jets with b-tag

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

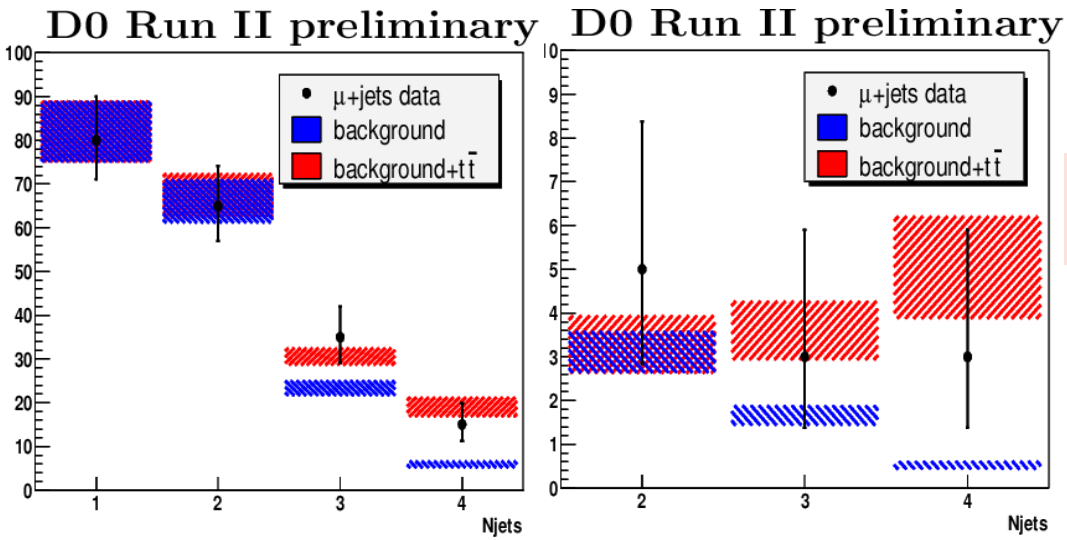


- 158pb^{-1} Run II data
- Systematic Uncertainties
  - Jet Energy Scale: ~10%
  - Background normalization: ~10%
  - B-tagging efficiency: ~10%

Secondary Vertex Tagger:



Impact Parameter Tagger:



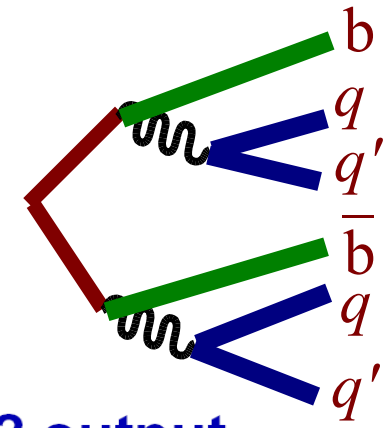
Impact Parameter Tagger:

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

Secondary Vertex Tagger:

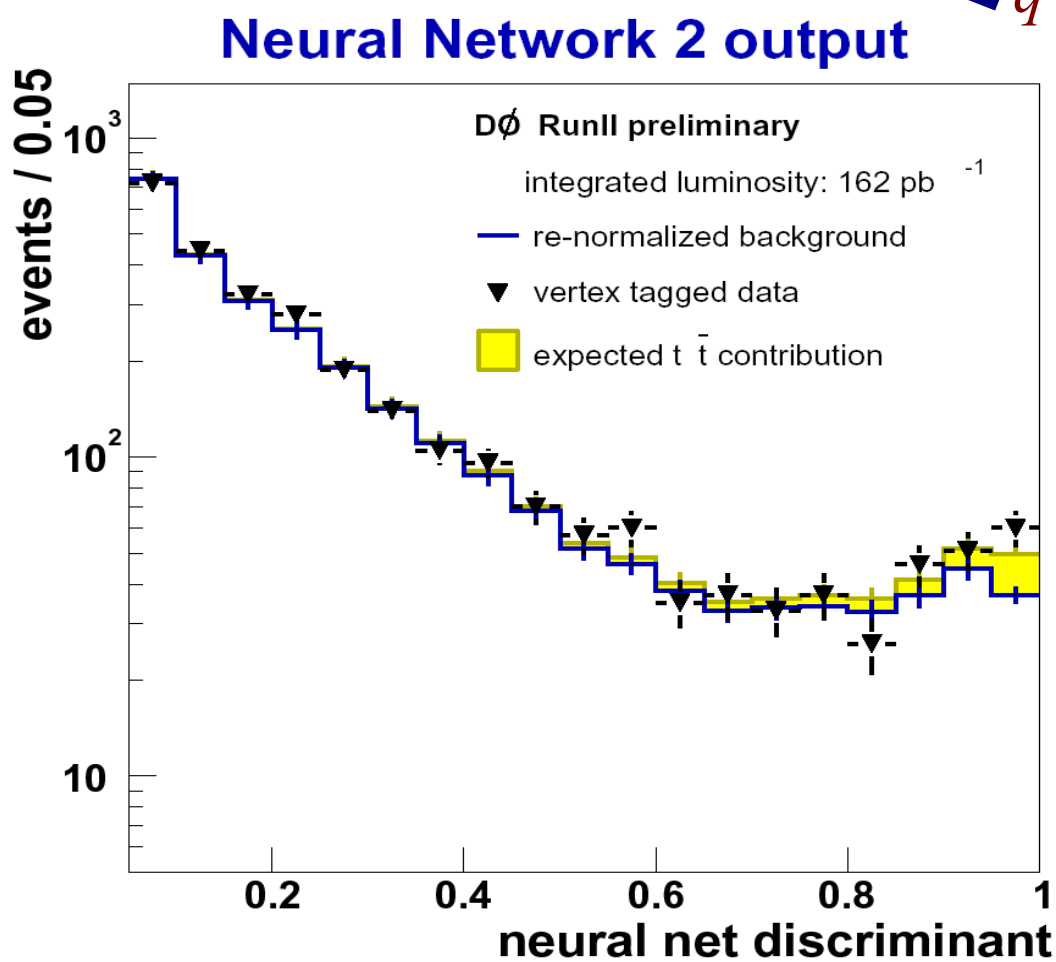
$$\sigma_{t\bar{t}} = 6.86^{+1.90}_{-1.70}\,(stat)\,^{+1.93}_{-1.68}\,(syst)\,\pm 0.44\,(lumi)\,\mathrm{pb}$$

All-Jets



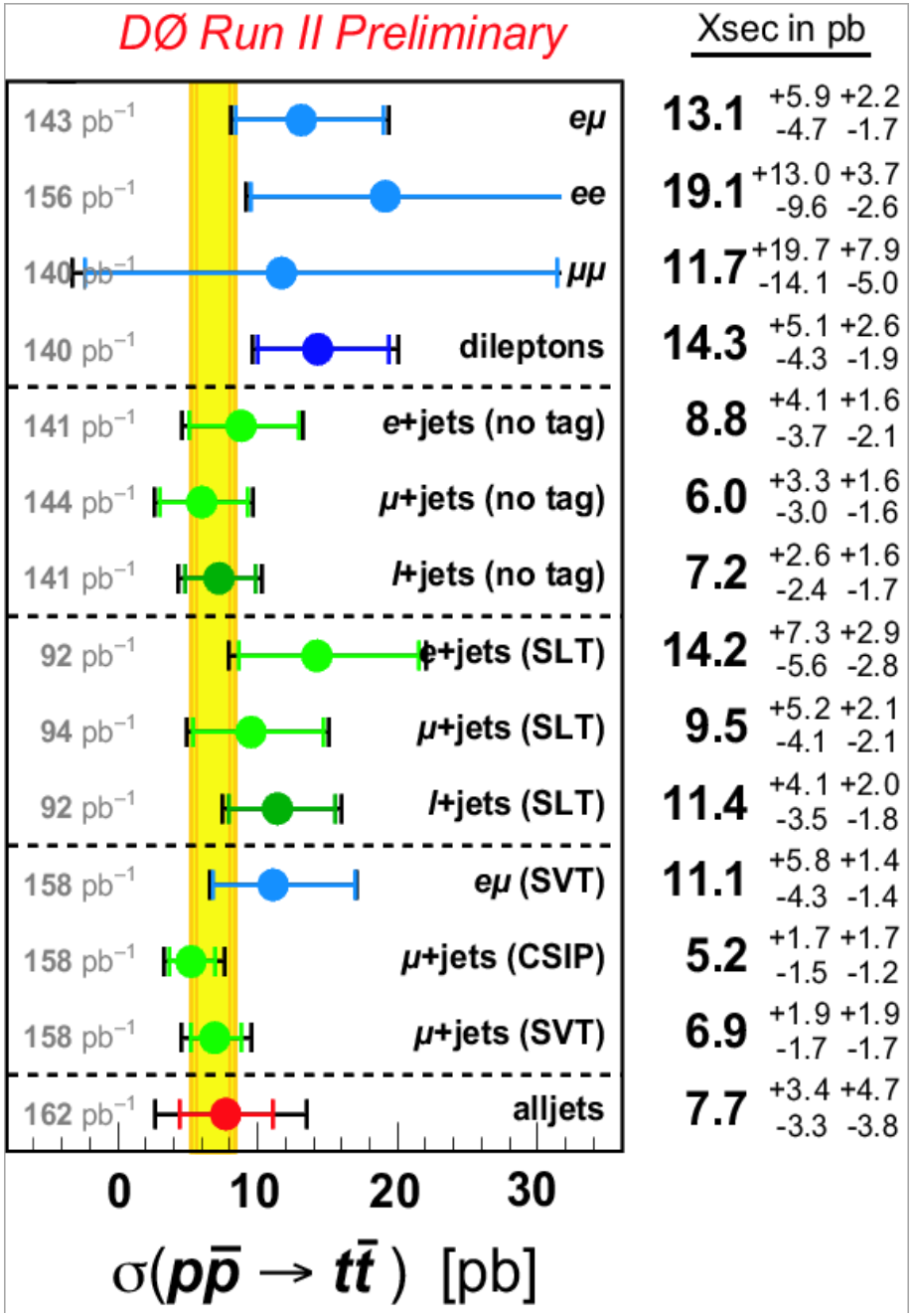
- Require ≥6 jets
  - E_T>15GeV, |η|<2.5
  - Background: QCD multi-jet
    - Estimated using data
- Require ≥1 b-tag (SVT)
- Chain of 3 Neural Networks to separate signal from background
  - Variables used:
    - Event Energy
    - Event Shape
    - Rapidity distributions
    - Top decay products: top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

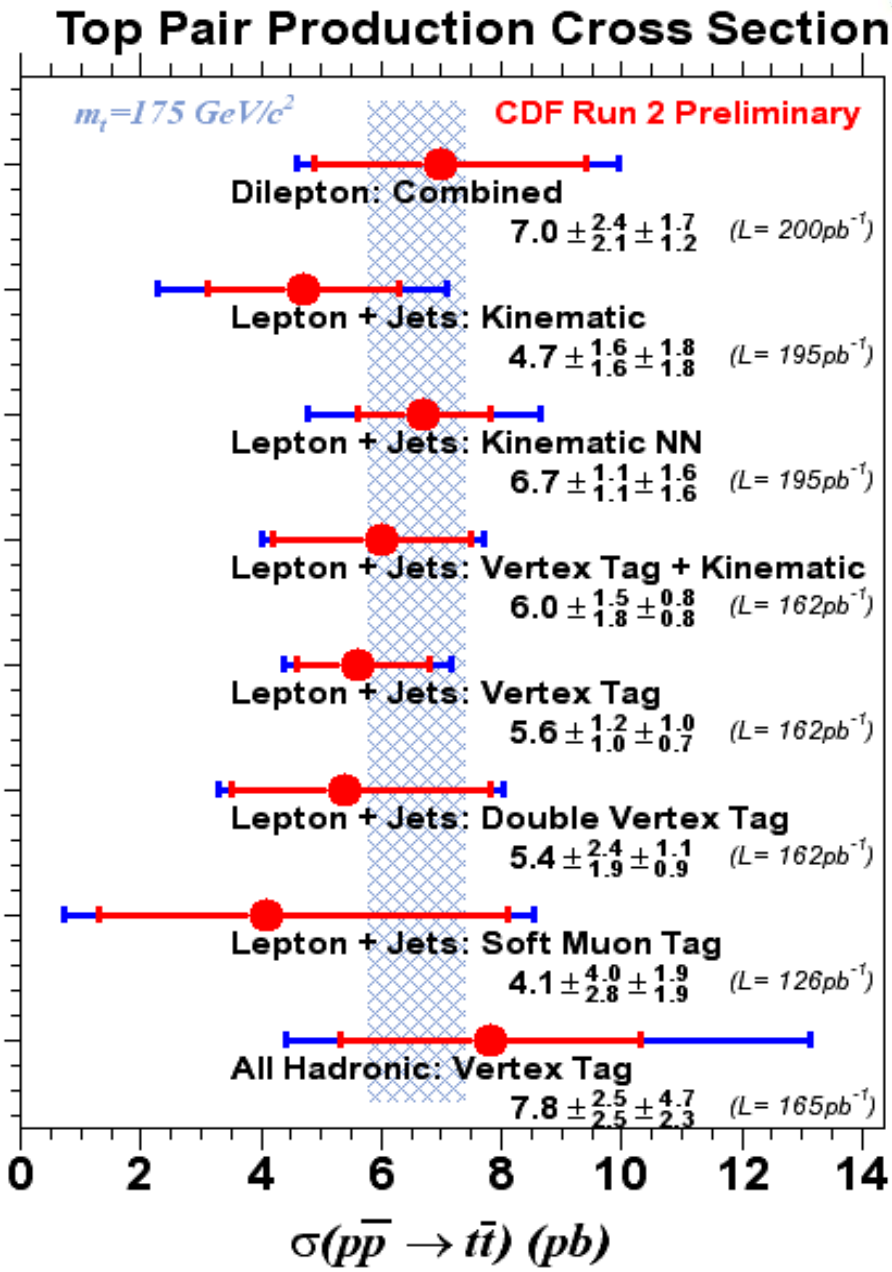
- Systematic Uncertainties
  - dominated by JES: ~28%



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

Cross Section Summary

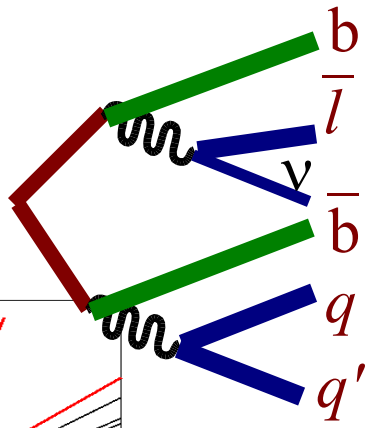




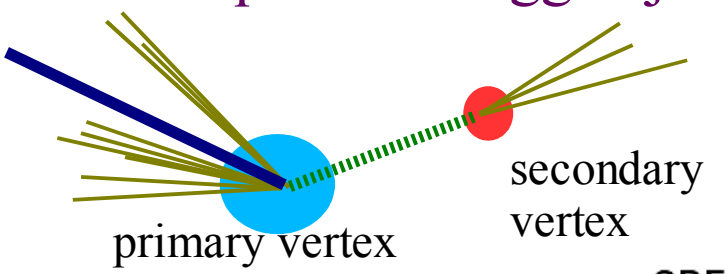
Backup Slides

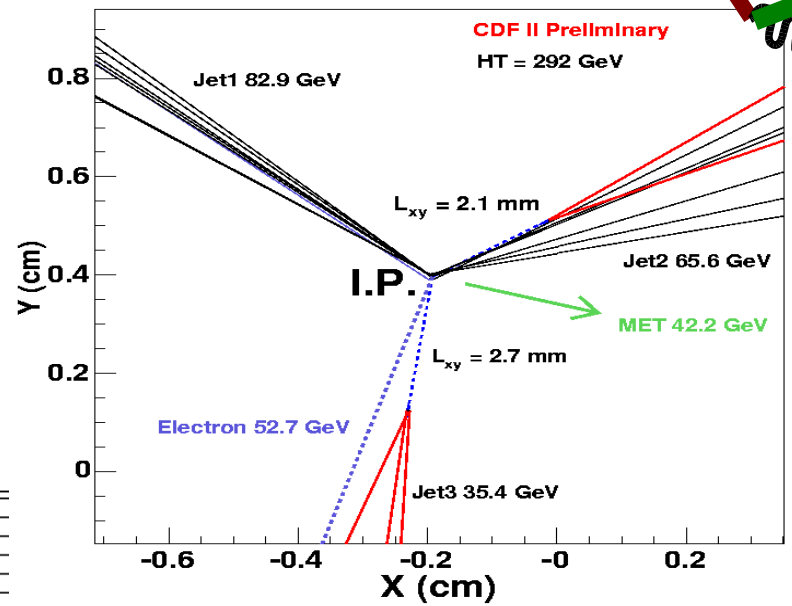
Lepton+Jets with b-tag

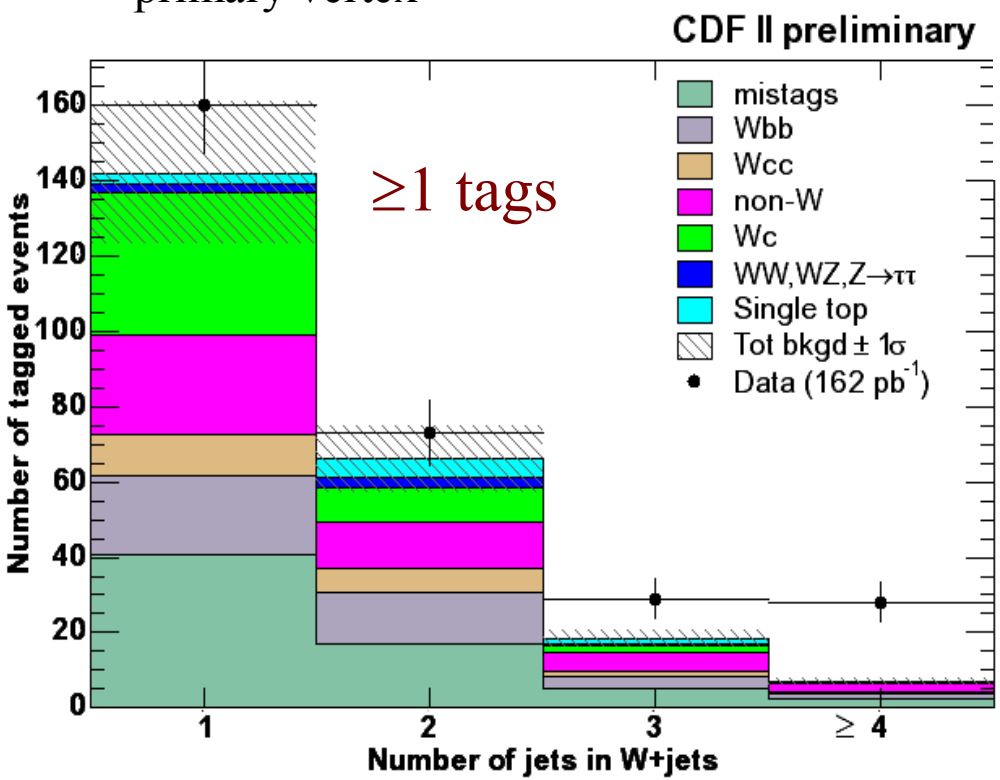
1 lepton (E_T>20GeV), Missing E_T>20GeV, ≥ 3 jets (E_T>15GeV)

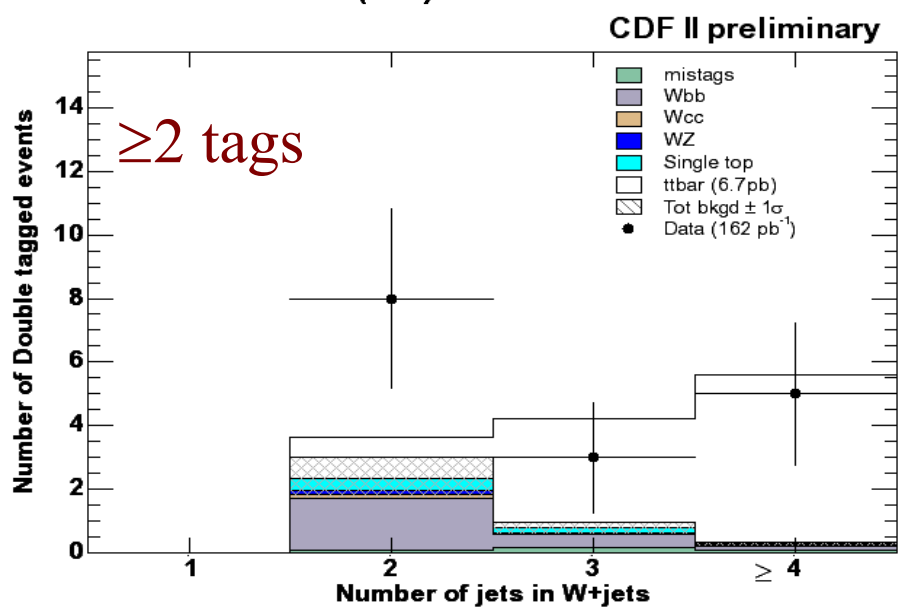


- Reconstruct secondary vertex from decay of B meson
  - Require 1 b-tagged jet

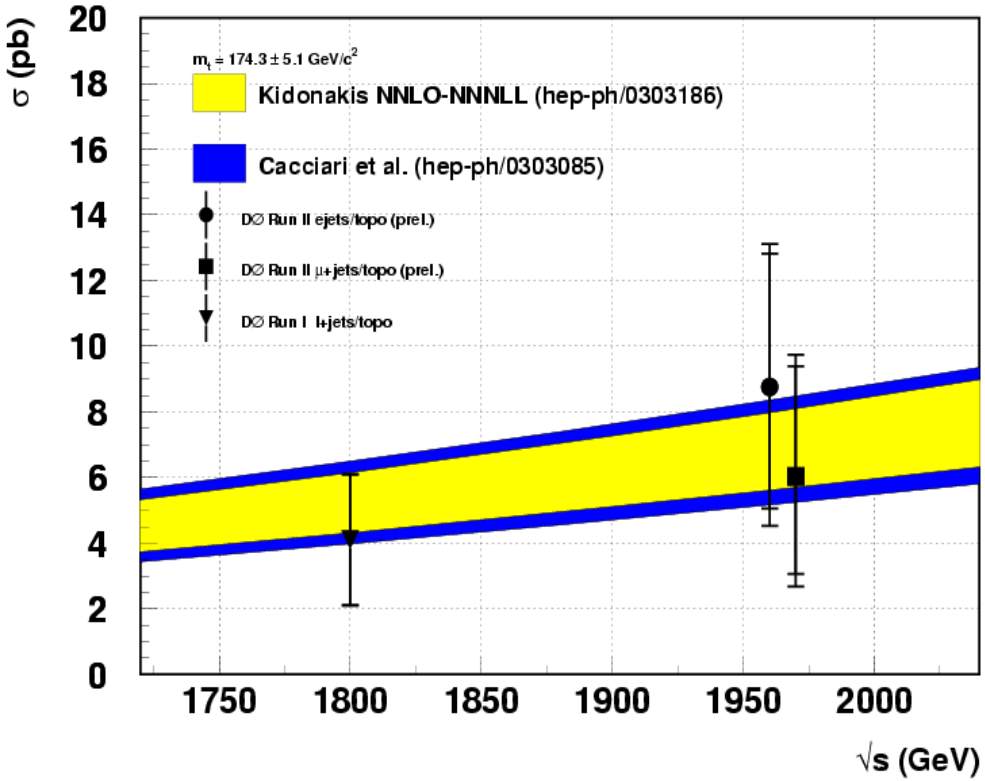


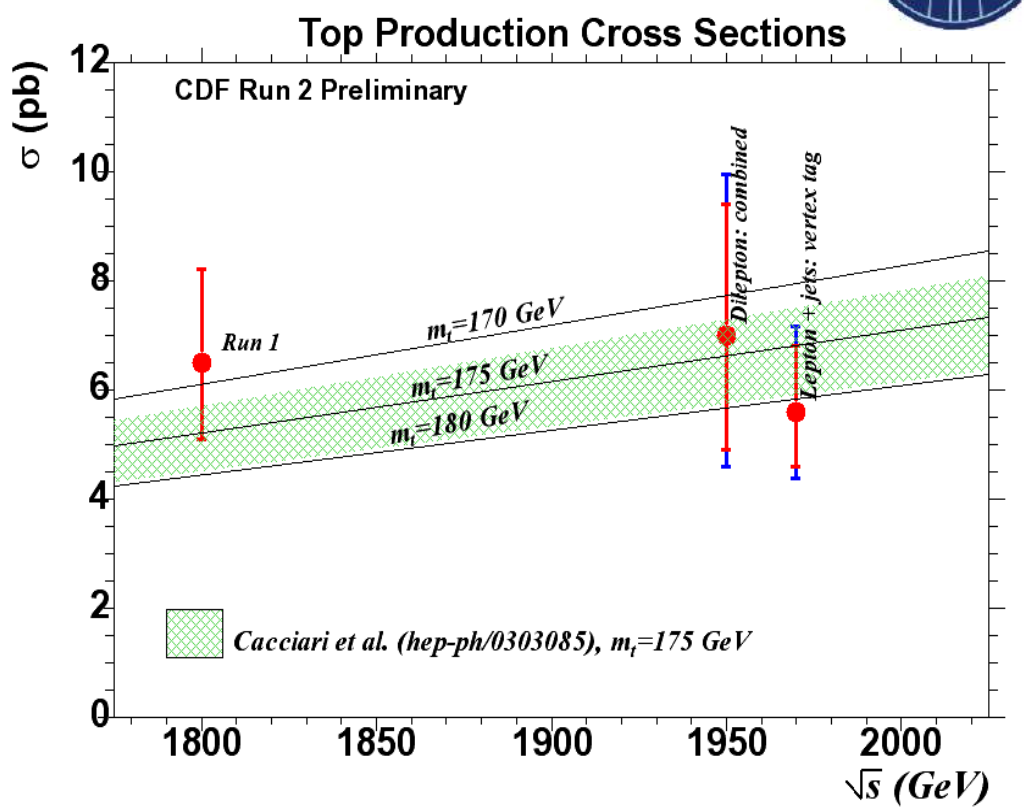






Conclusions





- All measurements consistent with each other, with Run I, and with theoretical prediction
- Uncertainty approaching Run I uncertainty
- Now have over 400pb^{-1} recorded
  - Will be Systematics limited