Top Quark Pair Production Cross Section Combination

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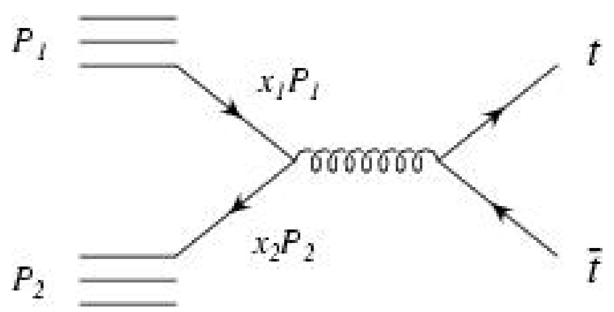
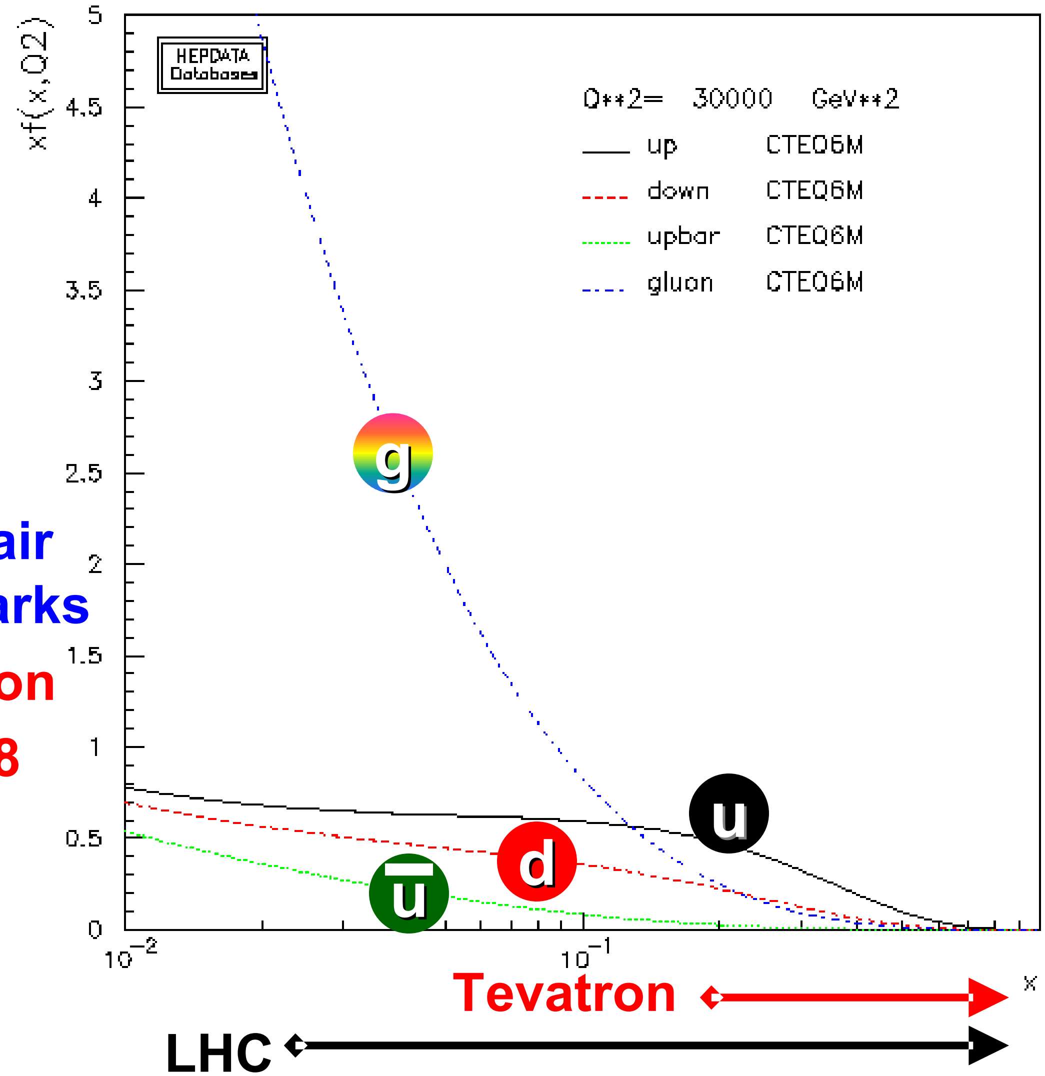
Pair production

Collide parton constituents of proton and (anti-)proton



If partons have enough energy, strong interaction can produce pair of massive (m_{top}=175 GeV/c^2) top quarks

- **Tevatron: proton on anti-proton**
  0.98 TeV beam energy, x>0.18
  90% uubar or ddbar, 10% gg
- **LHC: proton on proton**
  7 TeV beam energy, x>0.025
  10% uubar or ddbar, 90% gg



x= fraction of proton's momentum carried by parton

Theoretical prediction

Calculate parton-level cross sections in perturbative QCD with complete next-to-leading order (NLO) Feynman diagrams

- 5% uncertainty from standard variation of hard process scale from ½ m_{top} to 2 m_{top}

Requires proton parton densities

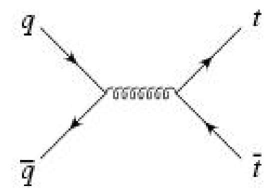
- 7% uncertainty, driven by gluon PDF at large x

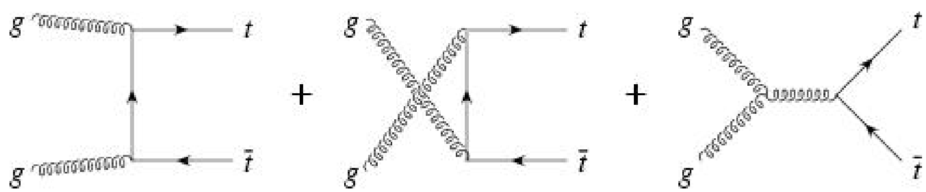
Assumes value for top quark mass

- Significant dependence rather than uncertainty

Cacciari et al. JHEP 0404:068 (2004)
Kidonakis & Vogt PRD 68 114014 (2003)

Leading order Feynman diagrams



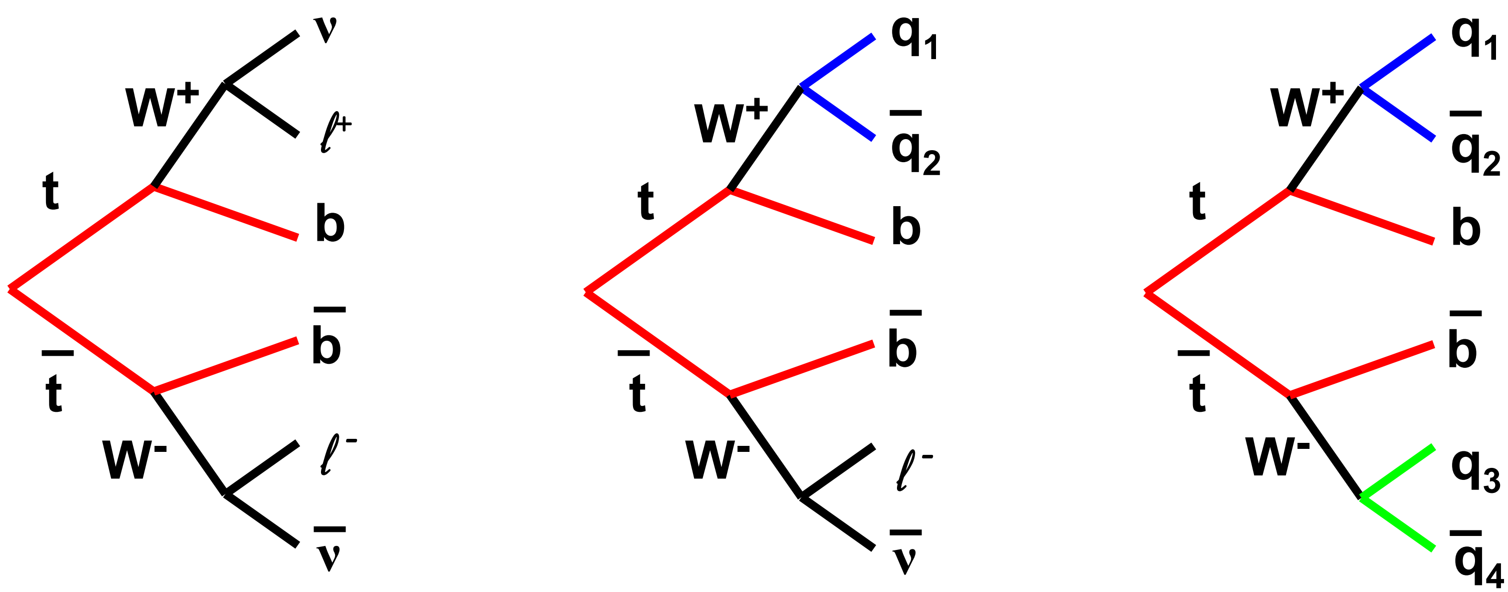


Tevatron √s=1.96 TeV

m_{top} (GeV/c^2)	Predicted σ (pb)		
	Min	Central	Max
170	6.8	7.8	8.7
175	5.8	6.7	7.4

Experimental observation

In standard model, top quark decays to Wb with width 1.4 GeV



	Dilepton	Lepton+Jets	All-hadronic
Signal BR:	Dilepton (11%)	Lepton+Jets (44%)	All-hadronic (46%)
Background:	Z+jets, WW	W+jets	Multi-jet QCD
	PRL 93, 142001 (2004)	PRD 72, 052003 (2005) PRL 97, 082004 (2006) PRD 72, 032002 (2005) PRL 96, 202002 (2006)	hep-ex/0607095

Many measurements in different final states (and stages!)
Here we present preliminary combination of 6 different measurements
Will discuss 3 measurements in lepton+jets in more detail

Combination method

- Use BLUE Method: best linear unbiased estimate
  - Lyons, L. et al, NIM A270 (1988) 110-117
  - Lyons, L. et al, PRD 41, 3 (1990) 982-985
  - Valassi, A, NIM A500 (2003) 391
- Need to construct covariance matrix
  - Statistical uncertainties
  - Systematic uncertainties
  - Statistical correlations
  - Systematic correlations
- Invert matrix and obtain weights for each measurement

$$\sigma = \frac{N_{obs} - N_{bkg}}{AL}$$

Checked combined value really is an unbiased estimate with toy MC pseudo-experiments

$$\delta\sigma = \sigma \frac{\delta A}{A}$$

Evaluate acceptance-like uncertainties for all results wrt combined xs value (3 iterations)

$$\delta\sigma = \frac{\delta N_{bkg}}{AL}$$

Background uncertainty for each result does not depend on xs value

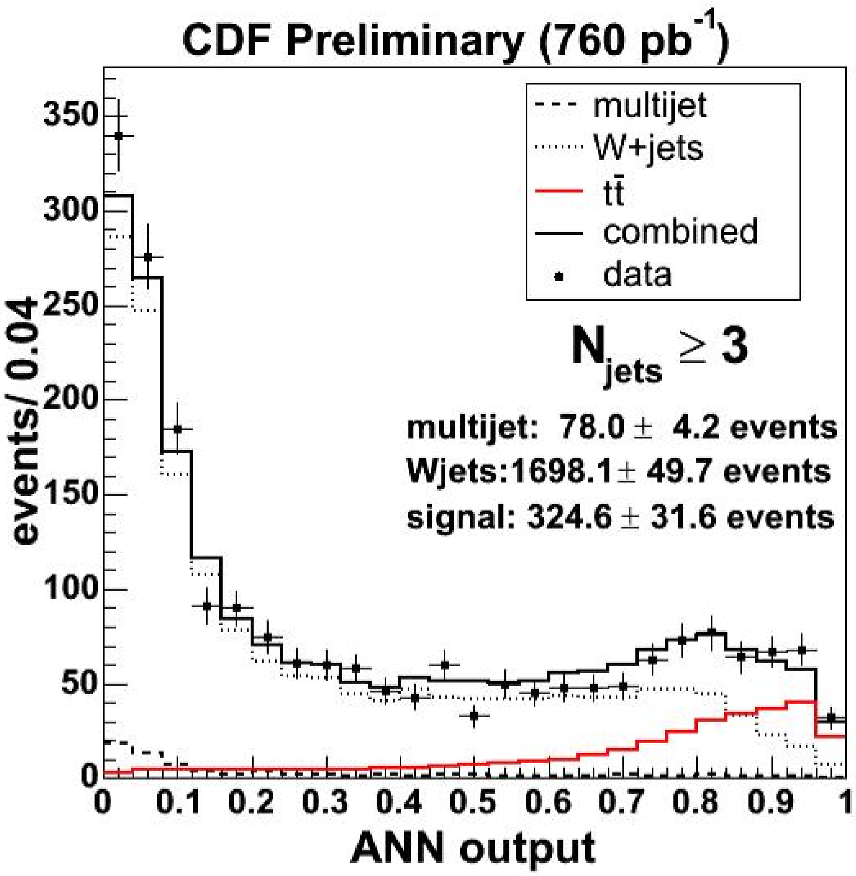
Lepton+Jets: kinematics

Selection: lepton p_T>20 GeV/c, missing E_T>20 GeV, ≥3 jets E_T>15 GeV

$$\varepsilon \times BR(t\bar{t} \rightarrow \ell + jets) \approx 7\%$$

Dominant background from W+jets with 10x rate of Z+jets and real missing energy, but on average less energetic

Discriminate with 7 input artificial neural network



ttbar model: PYTHIA/HERWIG

- 9% uncertainty on fitted signal due to signal variation with jet energy scale
- 5% systematic on signal selection efficiency

W+jets model: leading-order matrix element parton shower ALPGEN+HERWIG

- 11% uncertainty on fitted signal due to background variation with hard scatter scale (Q^2) definition
  - $Q^2=M_W^2+\Sigma p_T^2$ different for each event
  - $Q^2=M_W^2$ same for every event

Lepton+Jets: b-tagging

Identify b and reduce background as only few % of W+jets contain jets from b or c quarks

Identify displaced secondary vertex

50% efficient for inclusive b decay

6% systematic on b-tag efficiency

$$\varepsilon \times BR(t\bar{t} \rightarrow \ell + jets) \approx 4\%$$

25% systematic on W+HF background

$$N_{\text{b-tag}}^{\text{W+HF data}} = N^{\text{W+jets data}} \times \frac{N^{\text{W+HF MC}}}{N^{\text{W+jets MC}}} \times \varepsilon_{\text{b-tag}}^{\text{W+HF MC}}$$

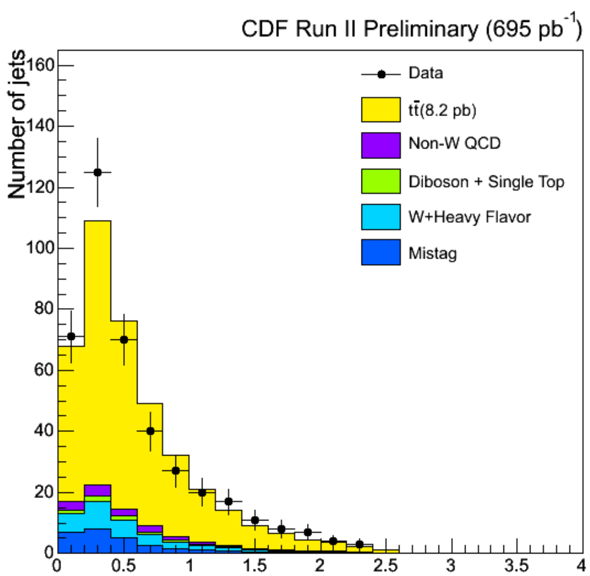
Identify muon

90% efficient for b→μ+X (BR 11%)

10% systematic on b-tag efficiency

$$\varepsilon \times BR(t\bar{t} \rightarrow \ell + jets) \approx 1\%$$

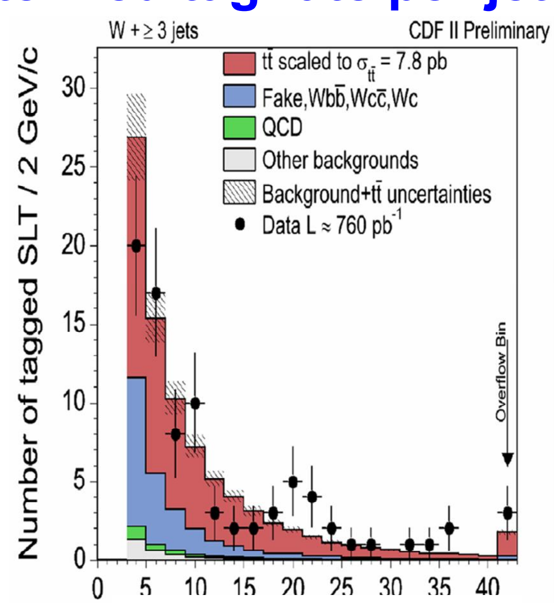
10% systematic on background from false positives estimated by parameterized tag rate per jet



2D displacement of secondary vertex (cm)

Lepton p_T>20 GeV/c
Missing E_T>20 GeV
≥3 jets E_T>15 GeV
H_T>200 GeV

≥1 b-tagged jet



Muon p_T (GeV/*c*)

Lepton+Jets: statistical correlation

Estimate statistical correlation between 3 results due to overlap in selected events by construction of toy MC experiments with same integrated luminosity as data sample

- For each experiment, generate number of signal (background) events in base sample from Poisson with mean equal to expected number of events for signal (background)
- Apply efficiency of b-tag requirements for signal (background) to construct subsets for b-tag samples
- Also track correlation between neural network output, secondary vertex b-tag, muon b-tag, and H_T requirement
- Estimate cross-section for each result

Find statistical correlation of

- 41% between kinematics and secondary vertex b-tag
- 18% between kinematics and muon b-tag
- 21% between secondary vertex and muon b-tag

Stable to 5% to reasonable changes in make-up of toy MC experiments

Summary of 6 measurements

statistically correlated

100% correlated

	Dilepton	Lepton+Jets				All-hadronic
		Kinematics	Secondary vertex b-tag	Muon b-tag	Missing ET +jets	
Integrated luminosity (pb^{-1})	750	760	695	194	311	311
Result (pb)	8.3	6.0	8.2	5.3	6.1	8.0
Statistical (pb)	1.5	0.6	0.6	3.3	1.2	1.7
Stat & Syst (pb)	1.9	1.1	1.1	3.4	1.8	4.2
Systematic Uncertainties						
Acceptance (%)	7.4	4.5	5.5	6.3	8.7	22.4
b-tag (%)	-	-	6.3	9.5	5.8	7.8
Luminosity (%)	5.8	5.8	5.8	5.8	5.8	5.8
Signal model (%)	-	9.2	-	-	-	-
Background (%)	9.6	10.9	3.4	13.0	10.0	42.0
Weight (%)	11	32	50	2	6	-2
Pull	+0.5	-1.1	+0.9	-0.6	-0.6	+0.2

Combination result

Combine all six measurements

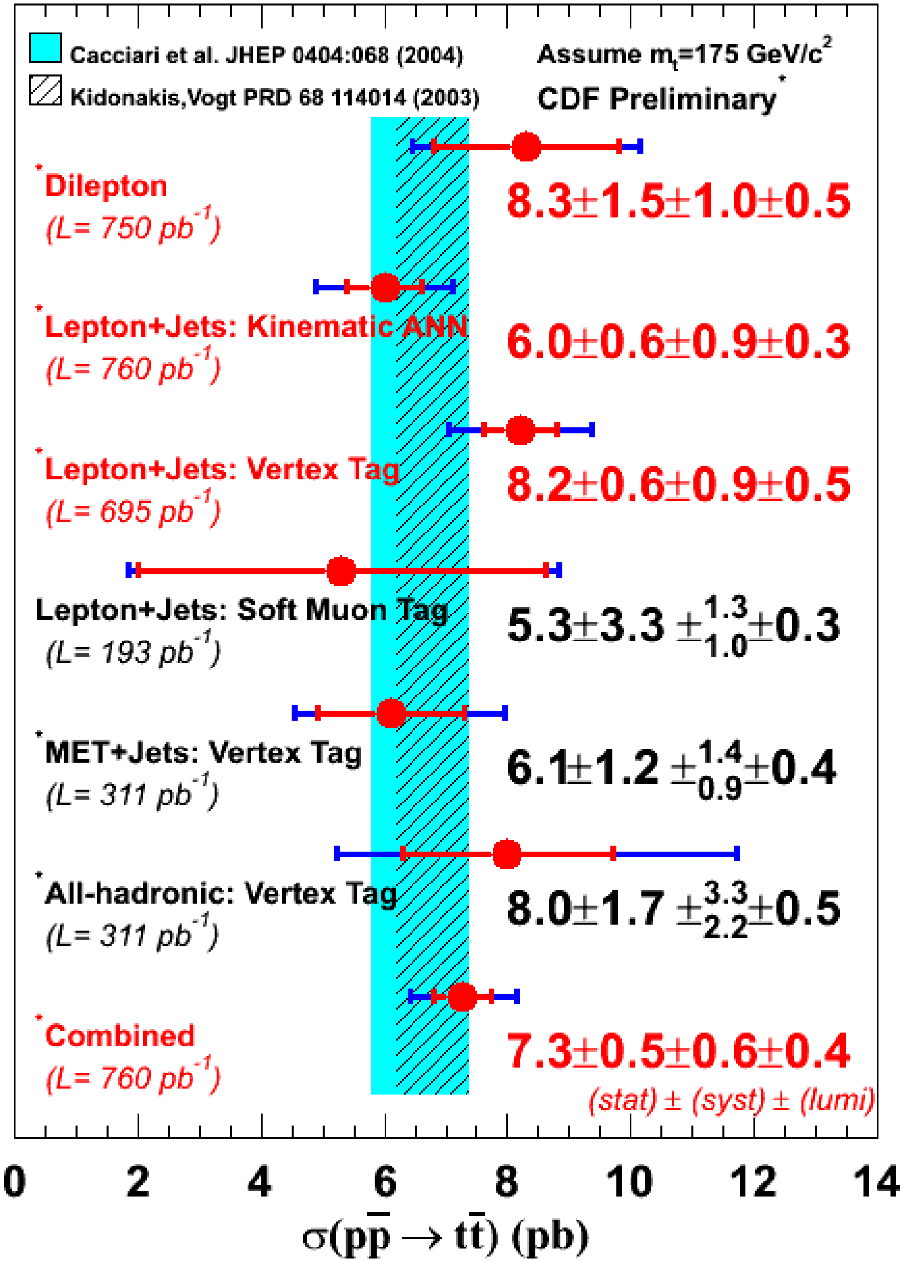
7.32±0.86 pb

Breaking out statistical, systematic and luminosity uncertainties according to BLUE prescription in Valassi et al.NIM A 500 (2003) 391-405

7.32±0.47(stat) ±0.57(syst)±0.43(lumi)pb

χ^2 is 4.9 for 5 degrees of freedom.
Probability is 42% to have less consistent set of measurements

Total Correlation	Kin	SVX b-tag	Muon b-tag	MET	HAD
Dilepton	0.17	0.22	0.07	0.15	0.14
Kinematics	1.00	0.40	0.08	0.17	0.15
Secondary vertex b-tag		1.00	0.09	0.33	0.27
Muon b-tag			1.00	0.07	0.06
Missing ET+jets				1.00	0.18
All-hadronic					1.00



Answers to likely questions

Breakdown of 0.57 pb systematic uncertainty

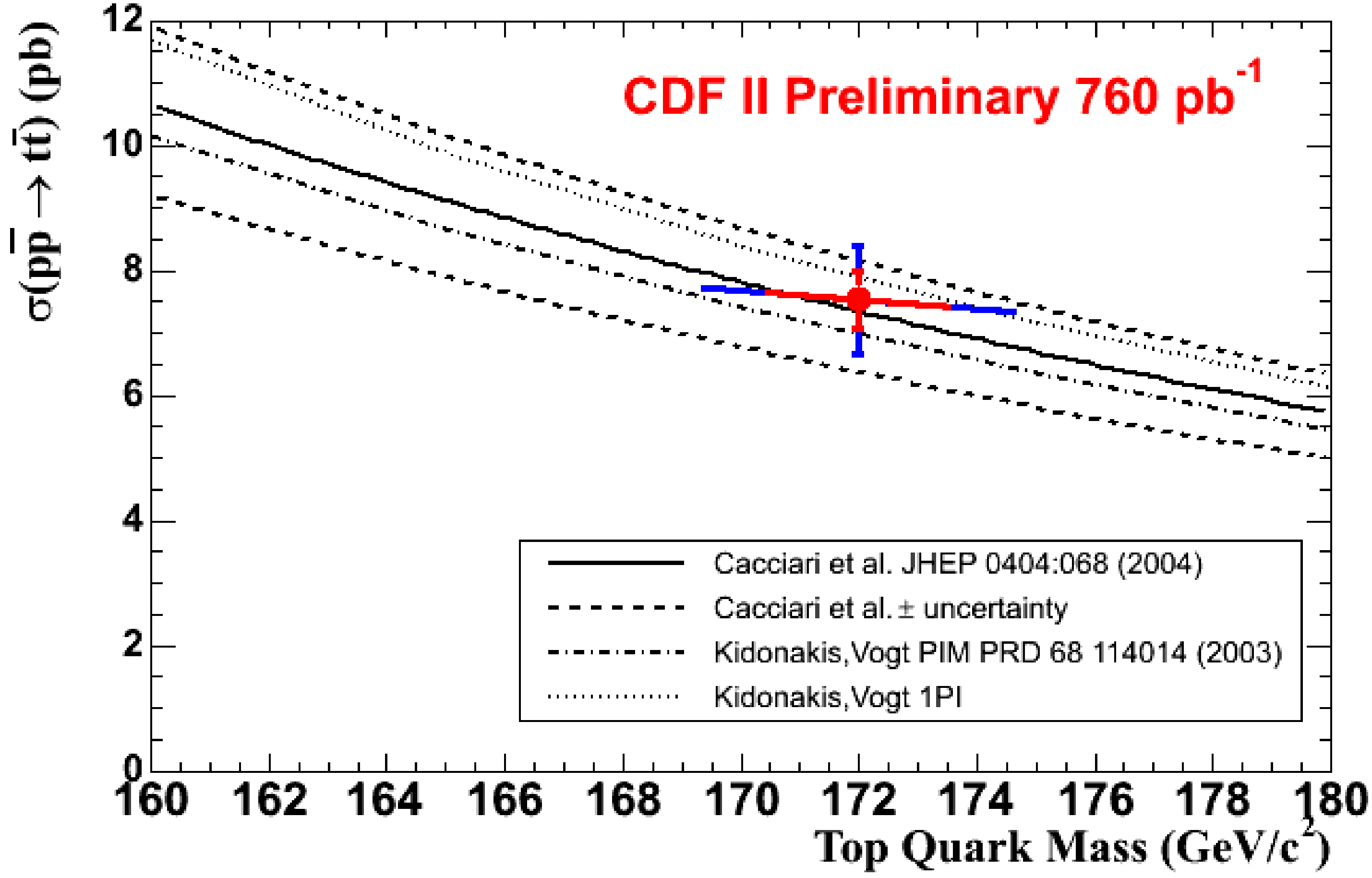
- ❑ Acceptance 0.39 pb
- ❑ Secondary vertex b-tag 0.25 pb
- ❑ Background estimate 0.32 pb
  - ❑ Kinematics signal model 0.18 pb
  - ❑ Kinematics W+jets model 0.20 pb

What is consistency of two best lepton+jets measurements, with b-tagging (secondary vertex) and without b-tagging (kinematics)?

- ❑ Statistical correlation estimated to be 41%
- ❑ Acceptance uncertainty (5%) correlated
- ❑ Secondary vertex b-tag efficiency (6%) uncorrelated
- ❑ Background estimates (3% and 14%) uncorrelated

From combination, find 7% probability for less consistent measurements than those observed

Dependence on top quark mass



Note that experimental selection efficiency (A) decreases as value assumed for top quark mass decreases

$$\sigma = \frac{N_{obs} - N_{bkg}}{AL}$$

Summary & Outlook

Preliminary combination of 6 measurements in dilepton, lepton+jets, and all-hadronic channels leads to 12% uncertainty

$$7.3 \pm 0.5_{(stat)} \pm 0.6_{(syst)} \pm 0.4_{(lumi)} \text{ pb}$$

When compared to single best measurement

- 20% improvement in uncertainty
- 10% improvement in relative uncertainty

Excellent agreement with theoretical prediction

- Equivalent precision between theory and experiment!

Paper in preparation on combination of published measurements

CDF measurements with higher integrated luminosity and reduced systematic uncertainties in preparation

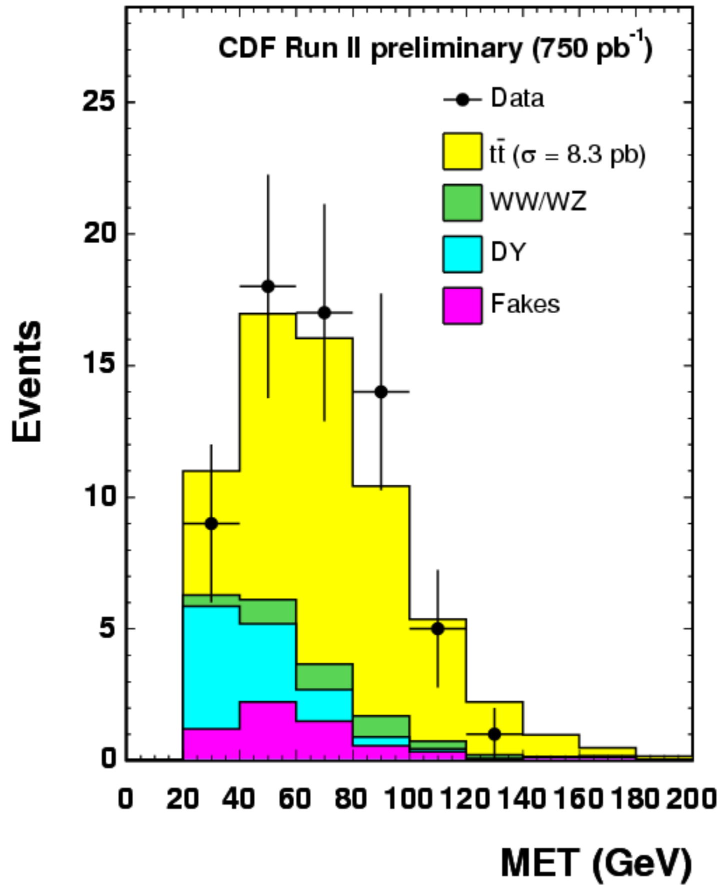
- Muon b-tag and all-hadronic recently updated (not included here)
- Other measurements will be updated soon

Back-up

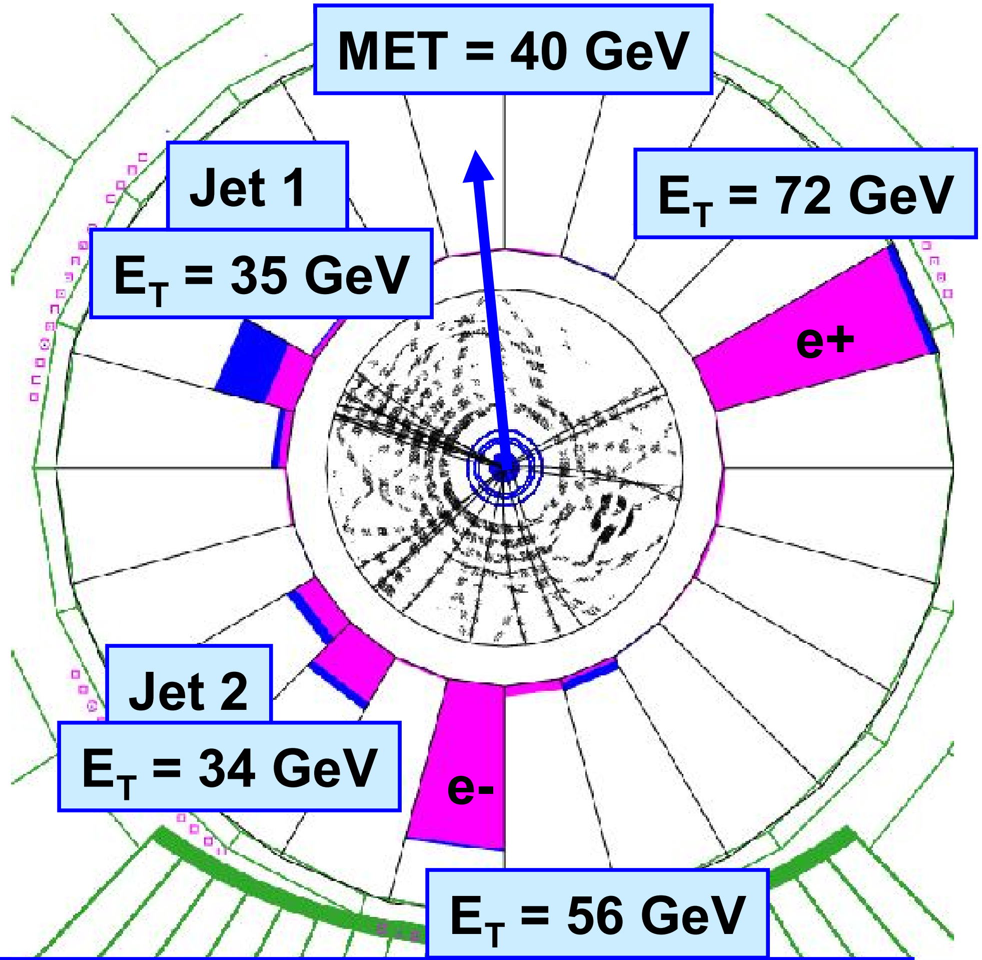
Dilepton

$\varepsilon \times BR(t\bar{t} \rightarrow dilepton) \approx 0.7\%$

- 64 candidates in 750/pb
- 10% uncertainty on background estimate
- 7% uncertainty on signal selection efficiency



Dilepton Candidate



M_{ee} = 118 GeV/c^2 and H_T = 255 GeV

Neutrino+Jets   All-hadronic

Multi-jet trigger

Secondary vertex b-tag

Background estimate from b-tag rate per jet

Significant missing E_T

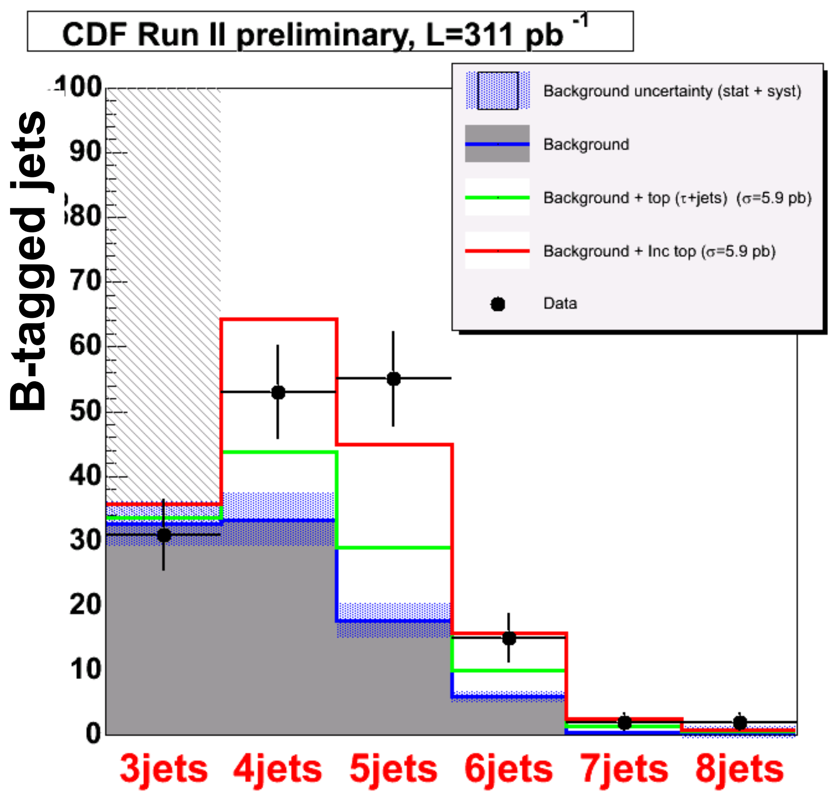
≥4 jets and no electron/muon

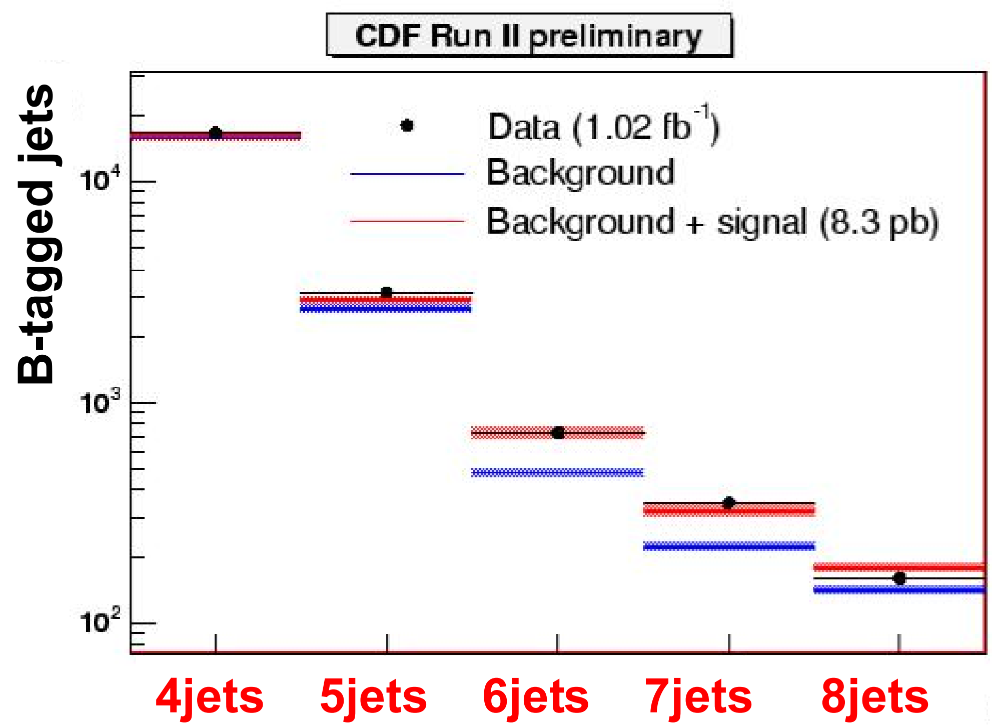
$$\varepsilon \times BR(t\bar{t} \rightarrow \nu + jets) \approx 4\%$$

Kinematic selection

≥6 jets

$$\varepsilon \times BR(t\bar{t} \rightarrow \mathrm{all-hadronic}) \approx 3\%$$





W+HF fraction

- Tevatron: MCFM study of W/Z+HF fraction
  - Stable between LO and NLO
  - Almost independent of scale

MCFM (Tevatron) hep-ph/0202176 (LHC) hep-ph/0308195