Top Quark Production at CDF

SUSY09 at Northeastern

05-10/June/2009

Shulamit Moed, Harvard University

for the CDF collaboration

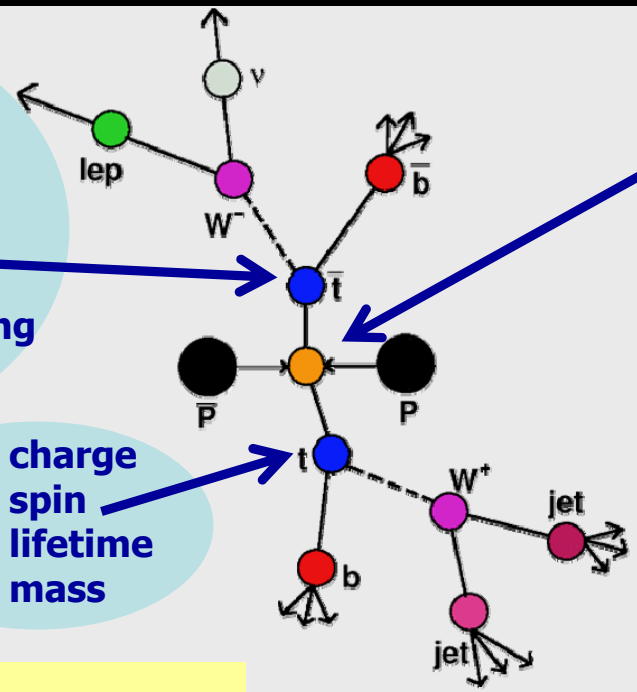
Results with ~3fb^{-1} of integrated luminosity:

- Top pair production cross section
- Forward-backward asymmetry in top pair production
- Single top production
- Searches for ttbar resonances
- Search for heavy top production

Why Is the Top Quark Interesting?

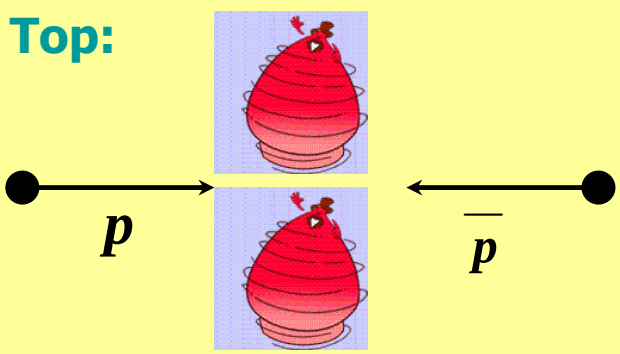
Branching ratios
Rare decays
Non-SM decays
Decay kinematics
W helicity
Anomalous coupling
$|V_{tb}|$

Production cross section
Resonance production
Production mechanisms
Spin polarization



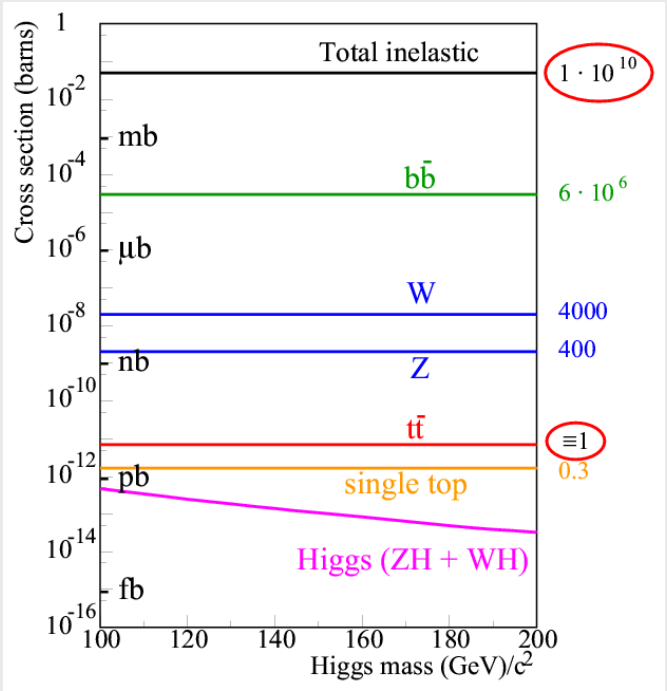
Top charge
Top spin
Top lifetime
Top mass

Top:



1 in 10 billion collisions

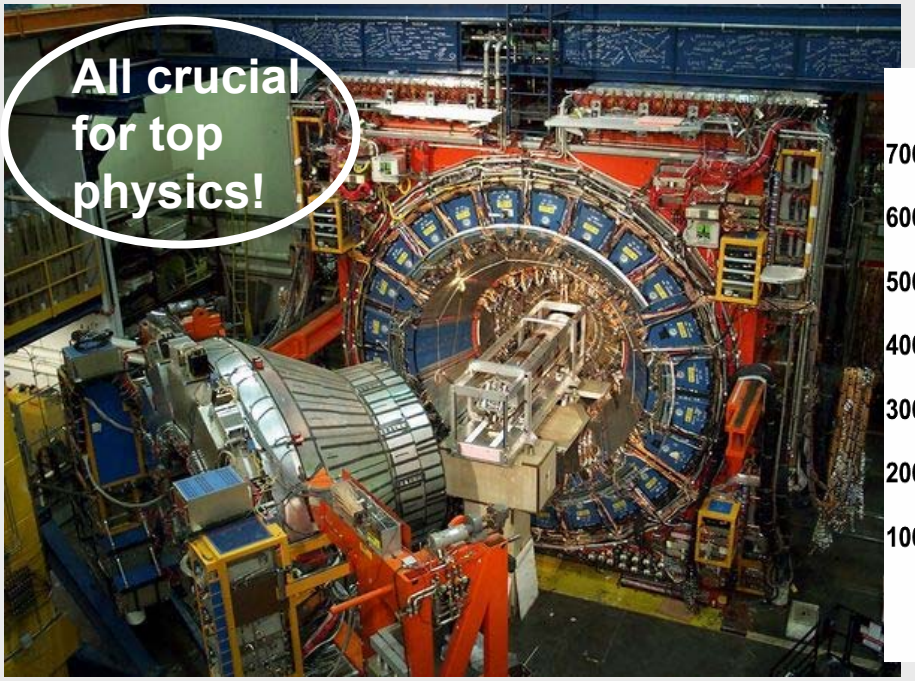
Reducing and understanding the backgrounds – key for production and property measurements

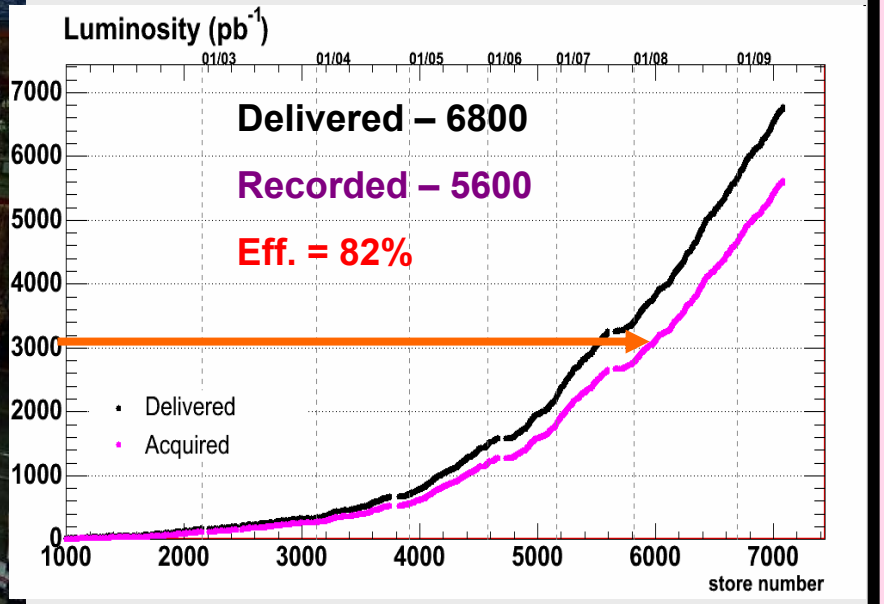


CDF

- Inner silicon tracker – essential for vertexing and b-tagging
- Central outer tracker
- Solenoid
- EM and HAD calorimeters
- Muon system

getting fast!
6 weeks turnaround time to calibrate, validate and process raw data



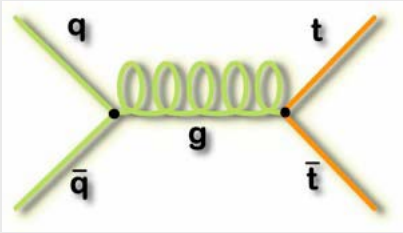


Top Pair Production and Cross Section

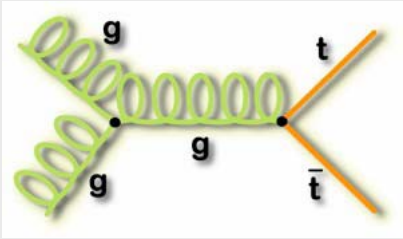
Top pair production

Main mechanism for top physics at Tevatron

~85%



~15%



For top mass = 175 GeV (strong dependency on the top mass)

$$\sigma_{t\bar{t}} = 6.7 \pm 0.8 pb$$

(JHEP 0404:068(2004), PRD 68, 114014 (2003))

@ √s= 1.96 TeV (theoretical):

Confirm theory

understanding background processes in sample

→ basis for every top property measurement.

Several measurements in CDF – new physics might affect different channels differently

How do we measure it?

selected events

$$\sigma_{t\bar{t}} = \frac{\mathcal{N}_{\text{obs}} - B}{\mathcal{A} \cdot \int \mathcal{L}\, dt}$$

estimated bkg

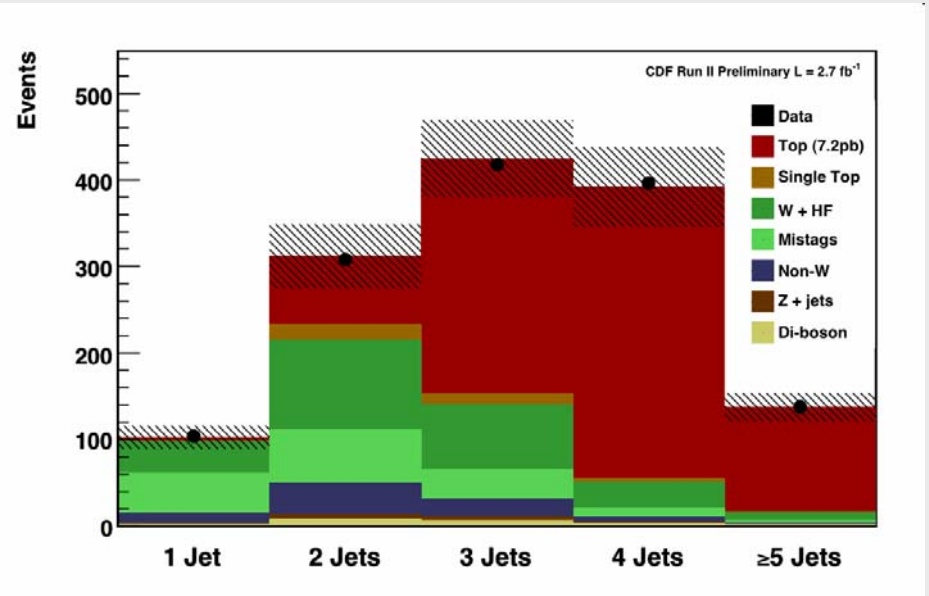
geometric and kinematic acceptance

integrated luminosity

ttbar Cross Section Using b-jet Identification

Background estimation

- Assume tt production cross section, σ_{tt} .
- Estimate backgrounds using σ_{tt} .
- Measure a new σ_{tt}, iterate between pretagged and tagged samples until convergence.



Largest systematics:

- Correction on W+HF Monte Carlo (4%)
- Correction on b-tagging in Monte Carlo (6%)
- Luminosity (6%)

Measured in lepton+jets channel, using 2.7/fb:

$$\sigma_{t\bar{t}} = 7.2 \pm 0.4(stat) \pm 0.5(syst) \pm 0.4(lumi) \quad pb$$

Pair Production Cross Section using Event Kinematics

Neural Network inputs:

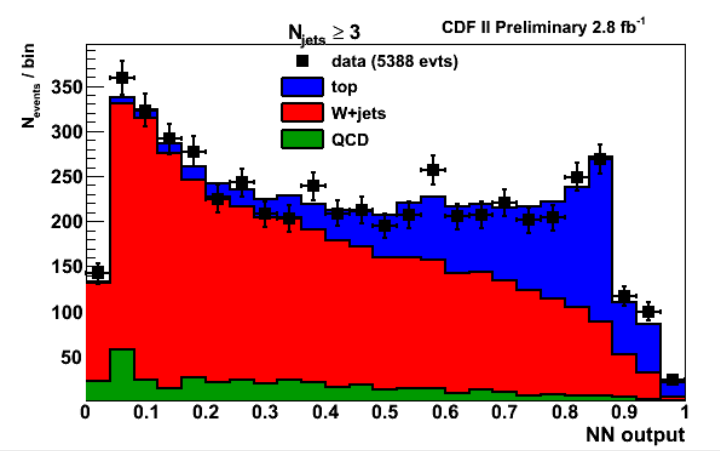
- ΣE_T jets excl. first two
- H_T of the event
- Aplanarity

For 3 highest E_T jets -

- $\Sigma E_T / \Sigma p_z$
- Min dijet mass
- Min dijet separation
- Max η

Measured in lepton+jets channel with 2.8/fb:

Rely on identifying top events through kinematics as opposed to b-jet identification



NN trained to distinguish signal from background and fit templates to data

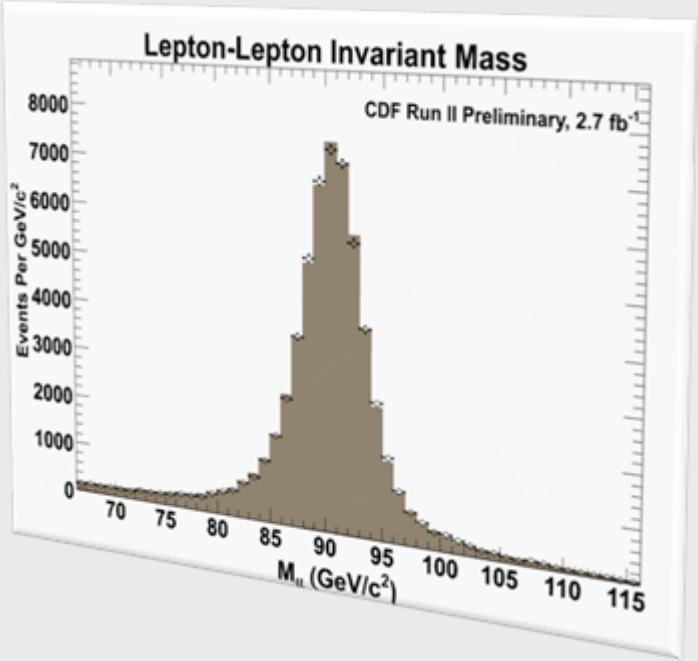
Large Kinematic systematics - Luminosity (6%) and Jet Energy Scale (3%)

$$\sigma_{t\bar{t}} = 7.0 \pm 0.4(stat) \pm 0.4(sys) \pm 0.4(lumi) \quad pb$$

Ratio σ_{tt} / σ_Z

OPTIMIZING ANALYSIS - REDUCING LARGEST SYSTEMATIC

- σ_Z well known theoretically
- Z well modeled in MC
- Z small background
- Luminosity uncertainty cancels out in ratio if use same triggers and data periods



$$R = \sigma_{t\bar{t}}^{measured} \Big/ \sigma_{Z\to ll}^{measured}$$

$$\sigma_{t\bar{t}}^{normalized} = R \cdot \sigma_{Z\to ll}^{theory}$$

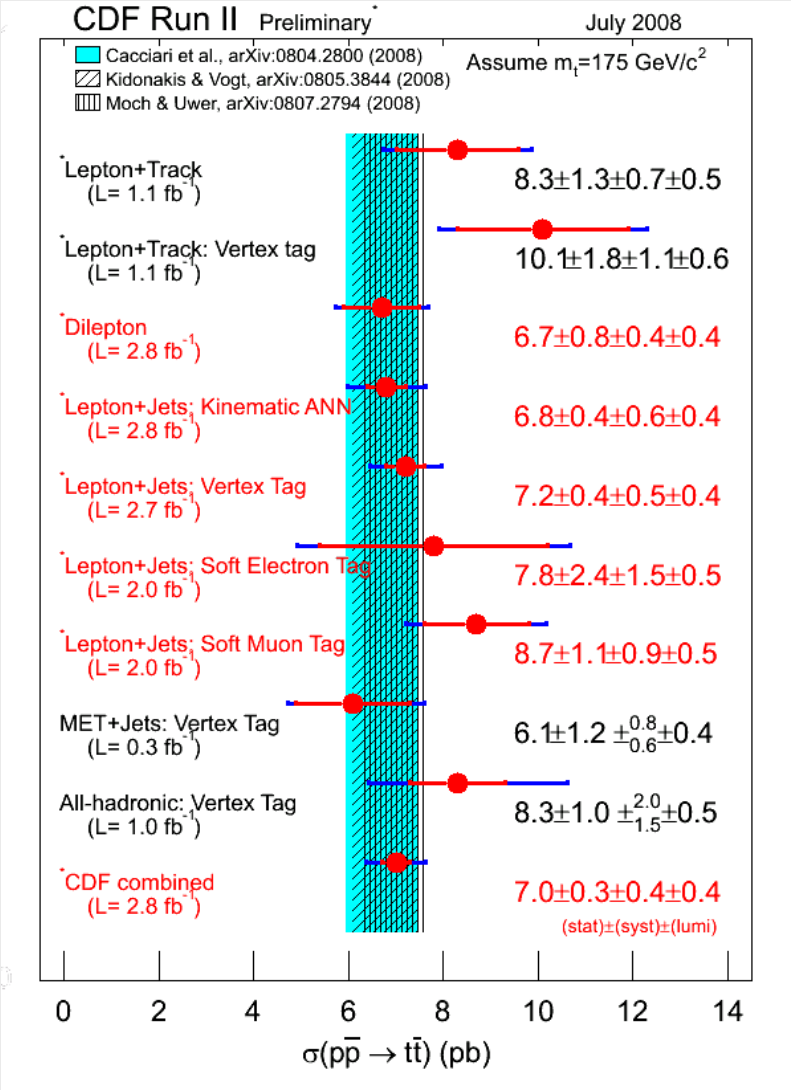
Using NN

σ_{tt}^{ratio} = 6.8 ± 0.4(stat) ± 0.4 (syst) ± 0.1 (theory) pb $\Delta\sigma / \sigma$ = 8%

Using b-tagging

σ_{tt}^{ratio} = 7.0 ± 0.4(stat) ± 0.6 (syst) ± 0.1 (theory) pb $\Delta\sigma / \sigma$ = 10%

Other ttbar Pair Production Cross Section Results



Theoretical uncertainty ~8%

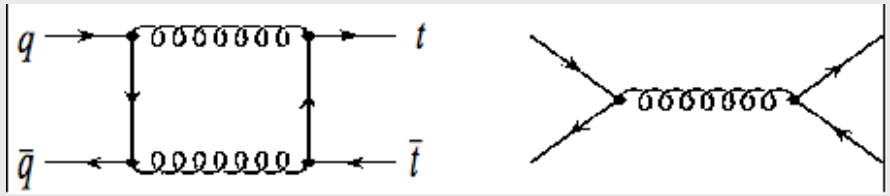
All measurements agree

Forward-Backward Asymmetry in ttbar Production

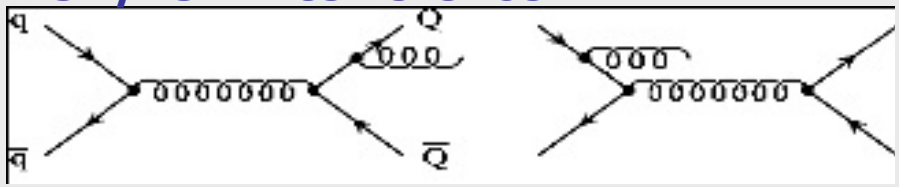
SM predicts a ~5% asymmetry @NLO

(Phys. Rev. D77 014003 (2008), Phys. Rev. D73 014008 (2006))

Box/tree interference

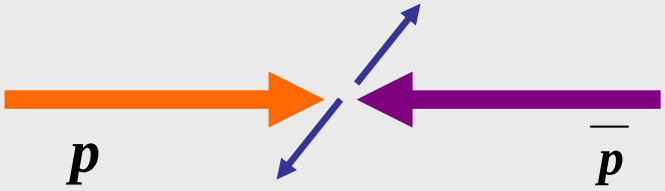


ISR/FSR interference



Is it the top or the anti-top that is preferentially produced in the direction of the incoming proton?

Measured in the lab frame (proton-antiprotn frame)



$$A_{fb} = \frac{N_t(p) - N_t(\bar{p})}{N_t(p) + N_t(\bar{p})}$$

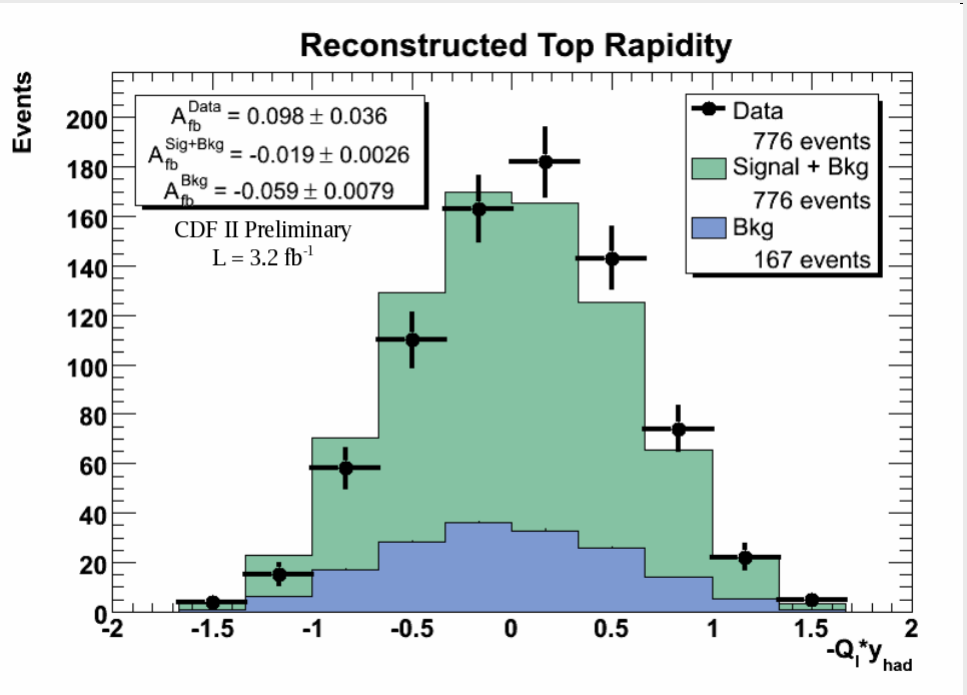
This measurement –

- **Sensitive to new physics**
- **Difficult to perform at the LHC**

Forward-Backward Asymmetry in ttbar Production

- Measuring the rapidity of the hadronic decaying top in the proton-antiproton frame, using the lepton+jets sample
- Correcting for smearing and acceptance effects

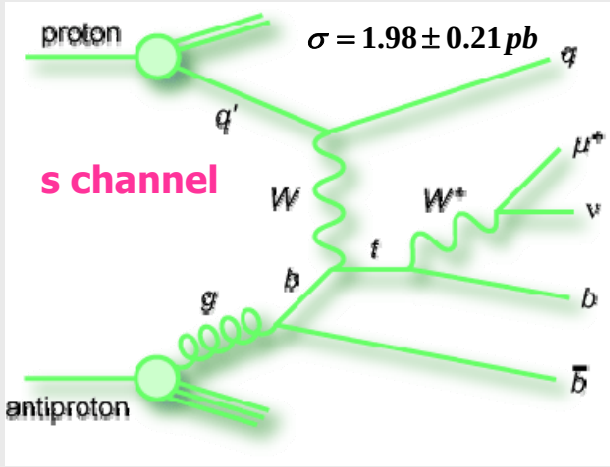
Reconstructed charge*rapidity of the hadronic decaying top (anti-top)



With 3.2/fb:

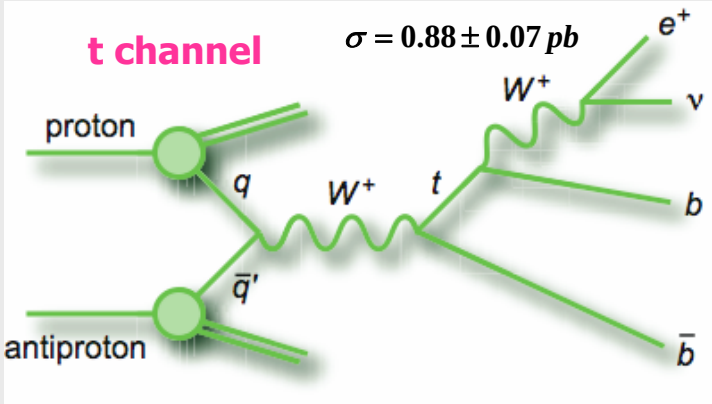
$$A_{fb} = 0.193 \pm 0.065(stat) \pm 0.024(syst)$$

Single Top Cross Section



SM Single top production through an electroweak vertex

$$\sigma \approx 0.4\sigma_{t\bar{t}}$$



- Direct access to the W-t-b vertex
- Sensitive to new physics (FCNC, W′, charged Higgs,…)
- Background to low mass Higgs searches at the Tevatron
  - Essential for associated WH production

Challenging measurement:

Start with Signal:Background (S:B) ~ $1:10^9$

First step:

Trigger and ID clean leptons/MET

- improves S:B by ~ 10^6

High pT lepton triggers (e,μ)

MET + jets triggers (recover non-fiducial leptons + hadronic tau decay)

Second step:

- Topological event selection
- Efficient *b*-tagging
- Careful background estimates
- Advanced analysis techniques to separate signal from background

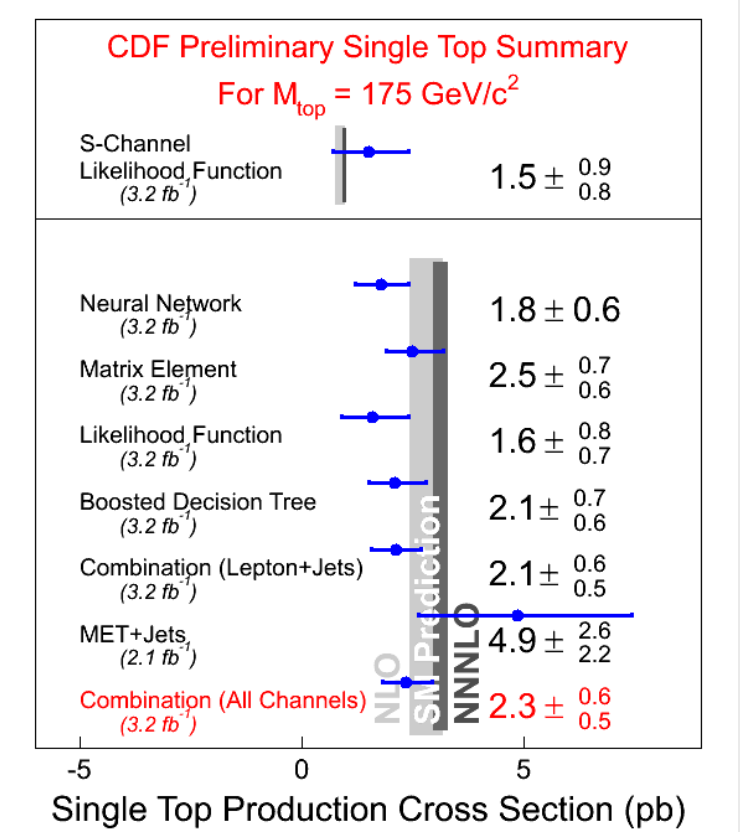
Single Top – Analyses

The different techniques used in CDF:

Matrix element , Missing E_T +Jets, Likelihood function, ANN, Boosted decision trees

Combination using "Super Discriminant"

- **Combine individual analyses into one, use discriminant outputs as input to NN**
- **NN trained to give the best expected p-value**
- **Gained 13% over most sensitive input**



Single Top - Results!

5σ Observation!

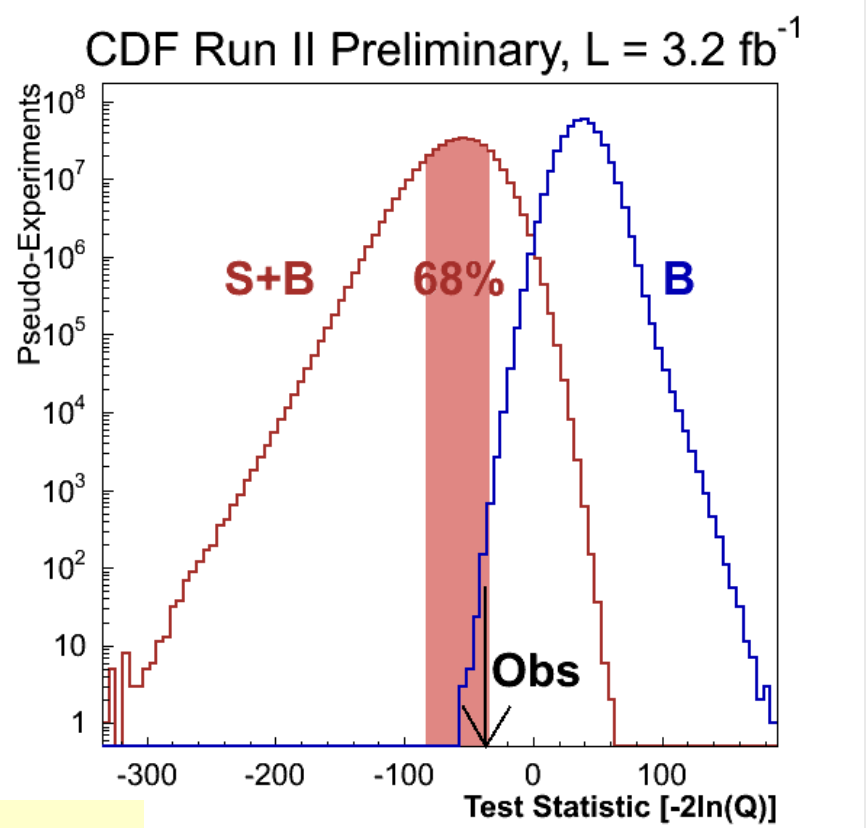
***p*-value = probability of upward fluctuation of background to the data or something even more "signal-like"**
Outcomes ranked as signal-like using -2lnQ

$$Q = \frac{P(\text{data} \mid s+b, \hat{\theta})}{P(\text{data} \mid b, \hat{\hat{\theta}})}$$

Expected: xxx x10 $^{-7}$: 5.9 S.D.
Observed: 3.1 x 10^{-7} : 5.0 S.D.

O(100M pseudoexperiments)

$$\sigma_{s+t} = 2.3^{+0.6}_{-0.5}\ pb$$

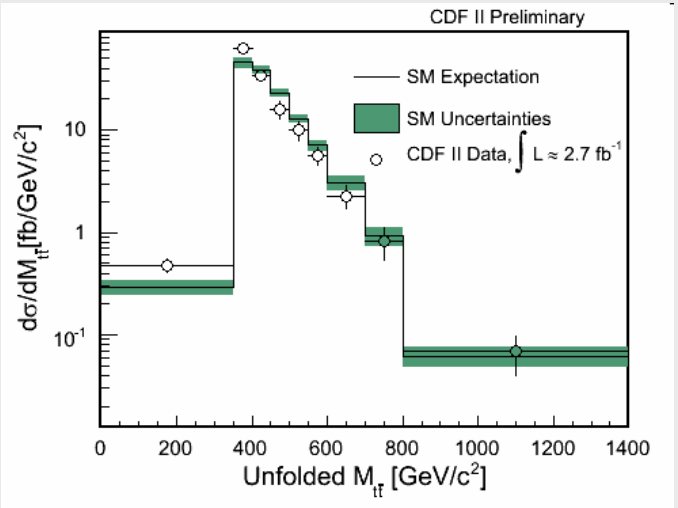


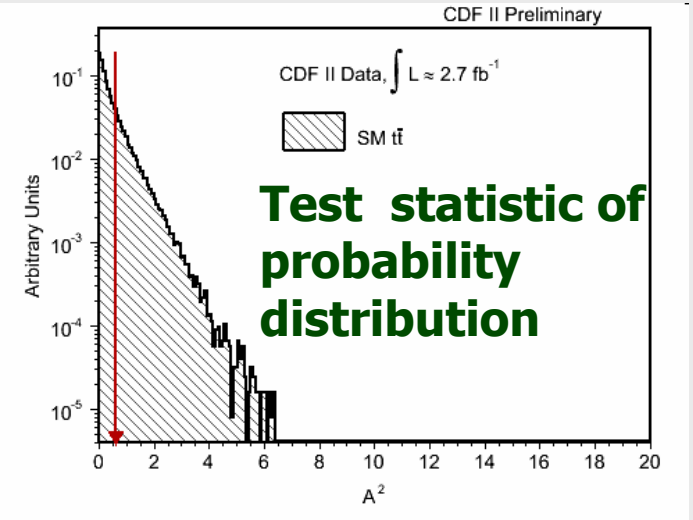
$|V_{tb}|$= 0.91 ± 0.11 (stat+syst) ± 0.07 (theory)

Search For ttbar Resonances

- **With 2.7/fb measure the differential cross section in the ttbar lepton+jets channel:**
- **Reconstruct ttbar invariant mass and unfold to get the true partonic invariant mass using SVD unfolding technique**

(parameterized unfolding matrix w.r.t Jet Energy Scale)





Consistency with SM description → Limits on New Physics:

ratio κ/MPl for gravitons which decay to top quarks in the Randall-Sundrum model, where the mass of the first resonance is fixed at 600 GeV

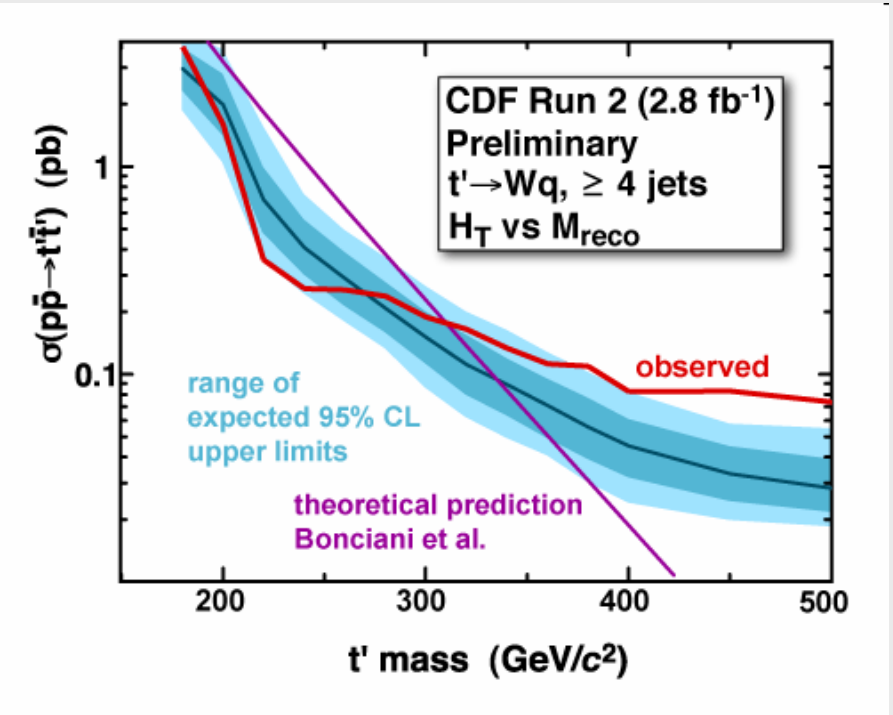
$\kappa/M_{Pl} > 0.16$ at the 95% C.L

Search for Heavy Top

- **Search for possible New Physics events in the lepton+jets channel**
- **Assume the decay t'→Wq**
- **Perform a 2D binned likelihood fit in H_T vs. reconstructed mass (returned by a kinematic fitter) to discriminate signal from SM backgrounds**

With 2.8/fb of integrated luminosity:

Upper limit, at 95% CL, on the production rate for t' as a function of t' mass (red)



Summary

95% CL upper limit on BR: $90 < H^+ < 150$ GeV

$BR(t \to Zq) < 3.7\%$ at 95% CL

$F_0 = 0.62 \pm 0.11$ & $F_+ = -0.04 \pm 0.05$

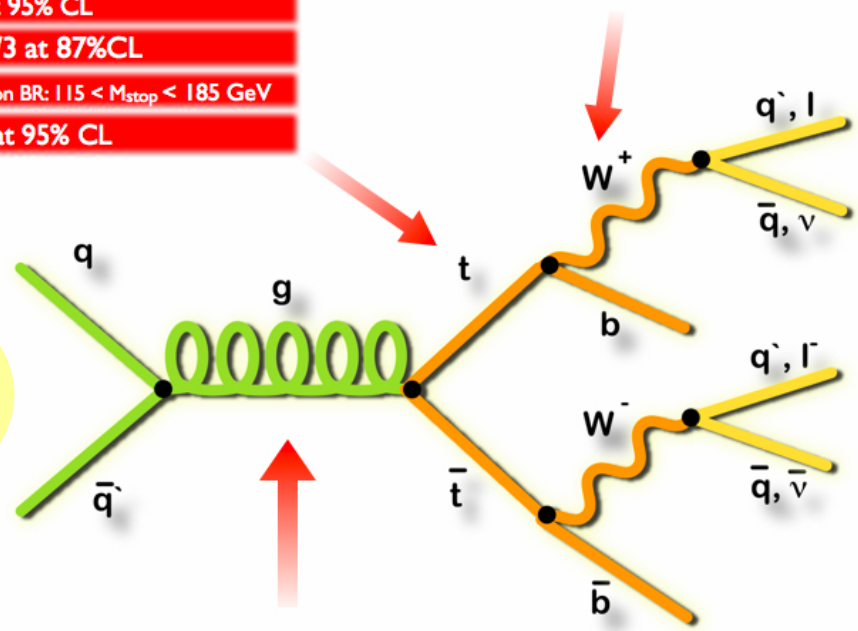
$M_t = 172.6 \pm 0.9_{stat} \pm 1.2_{sys}$ GeV/c^2

$\Gamma_t < 13.1$ GeV at 95% CL

Exclude q = -4/3 at 87%CL

95% CL upper limit on BR: $115 < M_{stop} < 185$ GeV

$M_{t'} < 311$ GeV at 95% CL



Lots of ongoing exciting activities at the CDF top group !

$\sigma_{l+jets} = 6.9 \pm 0.4_{stat} \pm 0.4_{sys} \pm 0.1_{z\text{-}theory}$ pb

$\sigma_{ll} = 6.7 \pm 0.8_{stat} \pm 0.4_{sys} \pm 0.4_{lumi}$ pb

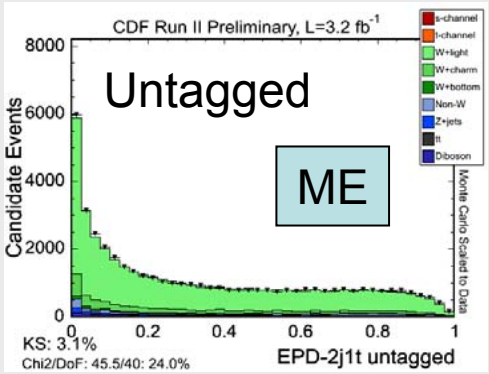
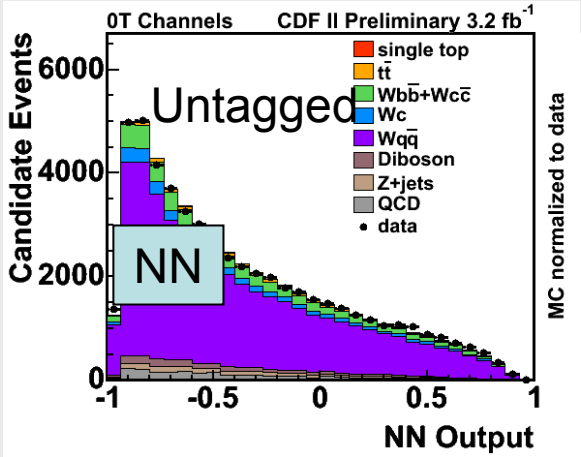
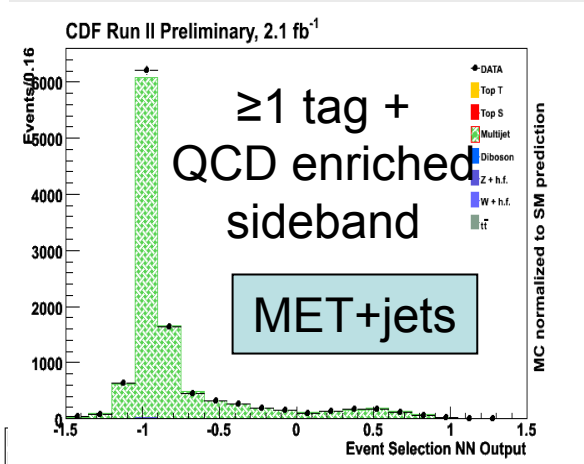
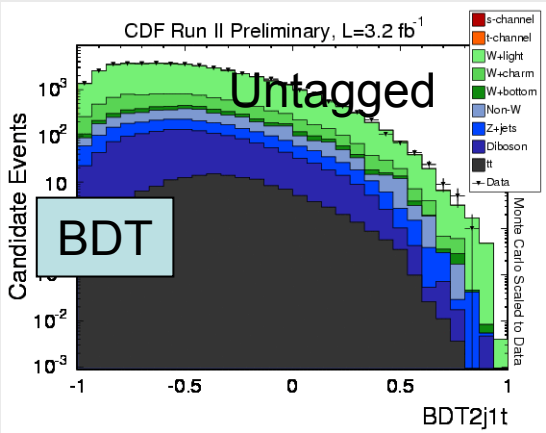
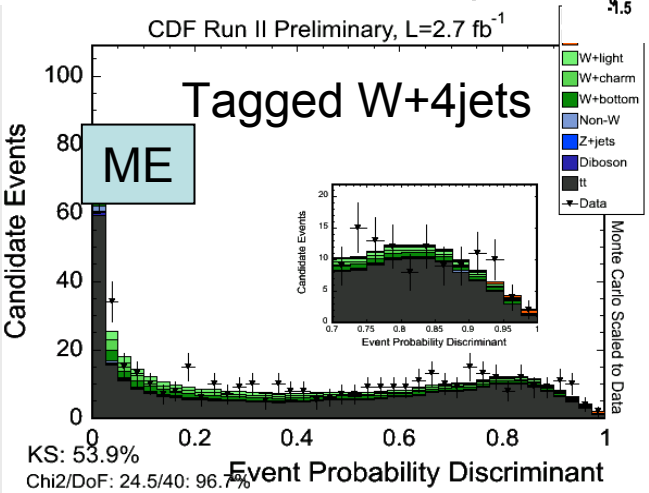
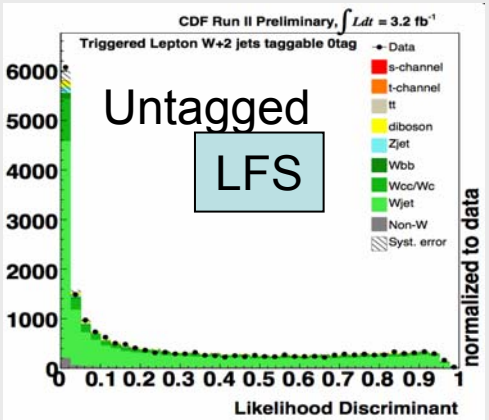
$\sigma_{all\text{-}jets} = 8.3 \pm 1.0_{stat} \pm 2.0_{sys} \pm 0.5_{lumi}$ pb

$F_{gg} = 0.07^{+0.15}_{-0.07}$ (stat+sys)

$A_{fb}^{lab} = 0.19 \pm 0.07_{stat} \pm 0.02_{sys}$

$M_{Z'} < 800$ GeV at 95% CL

Backup

Single Top Control Samples Cross Checks (many…)

Extensive side band cross checks performed to check modeling before unblinding the signal region