Top production at Tevatron

- Experimental setup
- Top production at Tevatron
- Top quark pair cross section and t' search
- Single top quark cross section
- Conclusion and outlook

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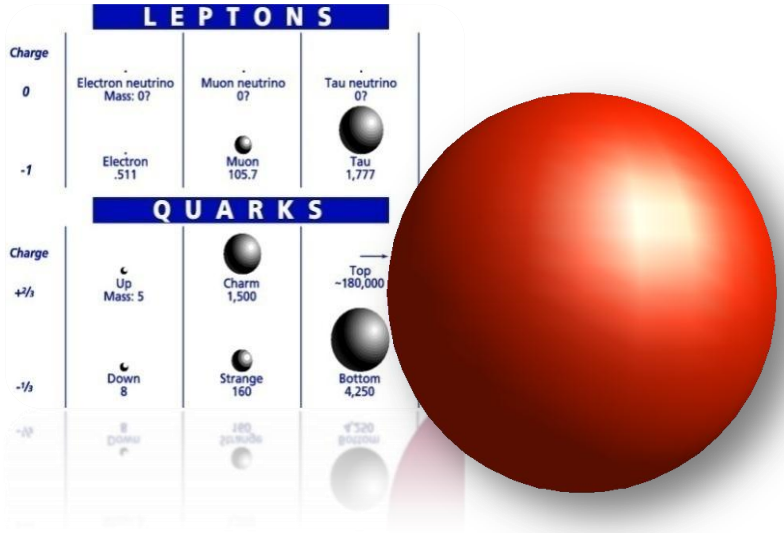
Top Quark Physics

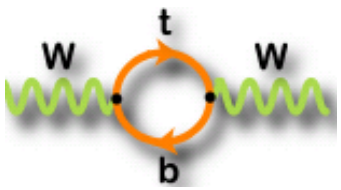
Top Quark is unique

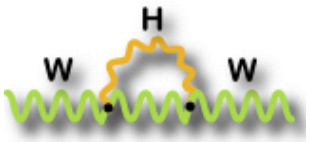
- **Heaviest fundamental particle now**
  - Mass = 173.3 ± 1.1 GeV
  - ~40 times heavier than bottom quark
  - Constrains on Higgs mass
- **Strong coupling to the Higgs**
  - Higgs-top Yukawa coupling

$$g_{Ht} = \sqrt{2}\, m_t / \mathrm{VEV} = \sqrt{2}\ 173.1\ \mathrm{GeV}/246\ \mathrm{GeV} \approx 1$$

  - Closely linked to EWSB: play a significant role in new physics scenarios related to the EWSB
- **Very short lifetime (~ 5×10^{-25} s)**
  - Decays before hadronization and makes it the only "bare quark"
  - Decays almost 100% of the time to *Wb*







$\Delta M_W \sim M_{top}^2$ $\Delta M_W \sim \ln M_H$

Top Quark Physics is a rich field

- **Production rates and properties**
- **Precise test of SM and search for new phenomena**

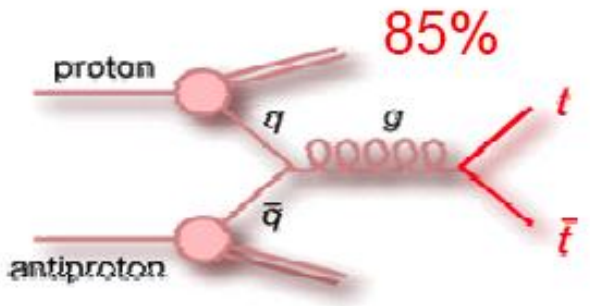
Top Pair Production at Tevatron

Top Quark discovered at Tevatron via strong production

- **Main production mode at Tevatron**

$$\sigma_{NNLO} = 7.46 \pm^{0.48}_{0.67}\ pb$$

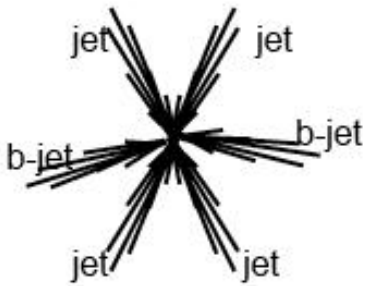
[PRD 78, 034003 (2008)] M_t = 172.5 GeV



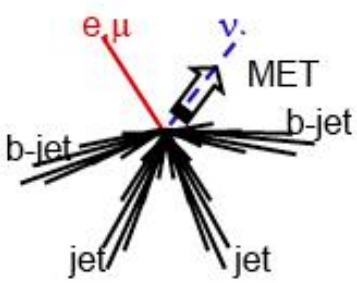
σ_{LHC} ~ 187 pb (7 TeV)

SM Decay:

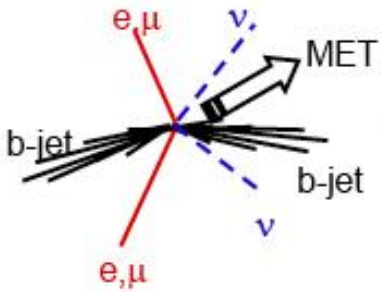
Three different final states:



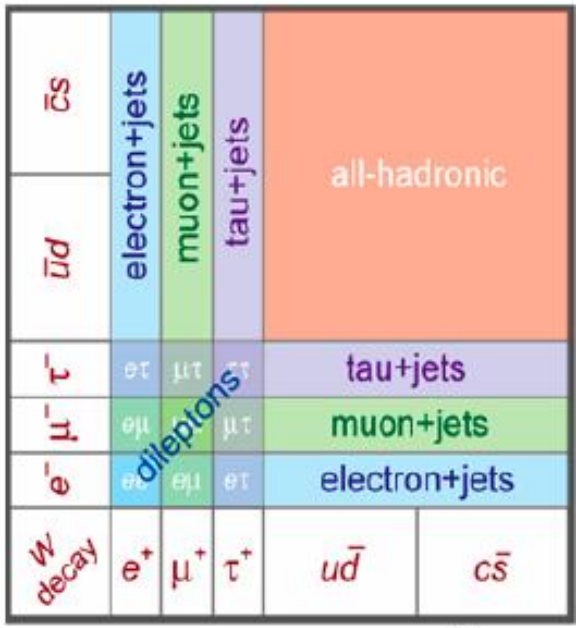
All-hadronic
(BR~46%)
Huge bkgd



Lepton+jets
(BR~30%)
Moderate bkgd



Dilepton
(BR~5%)
Low bkgd



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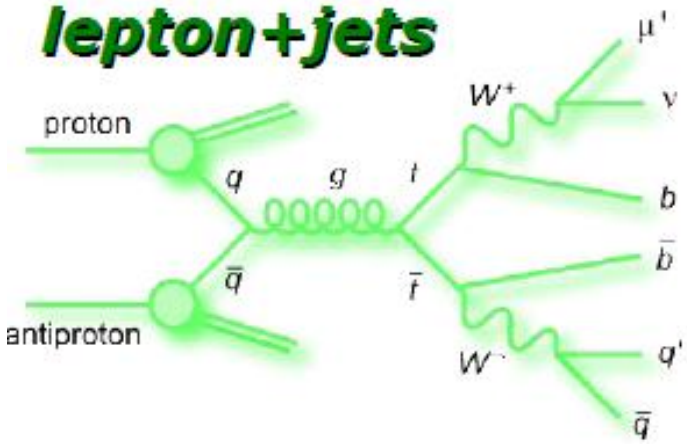
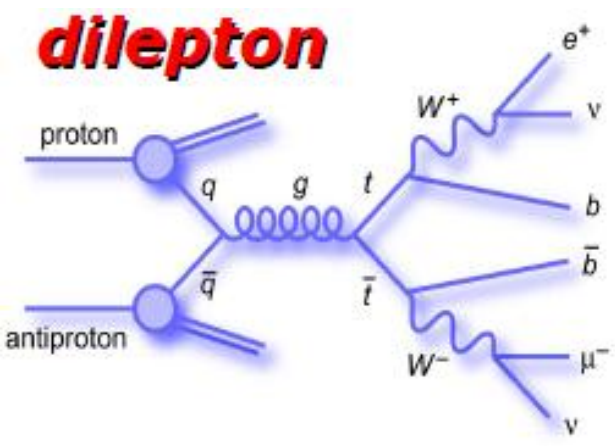
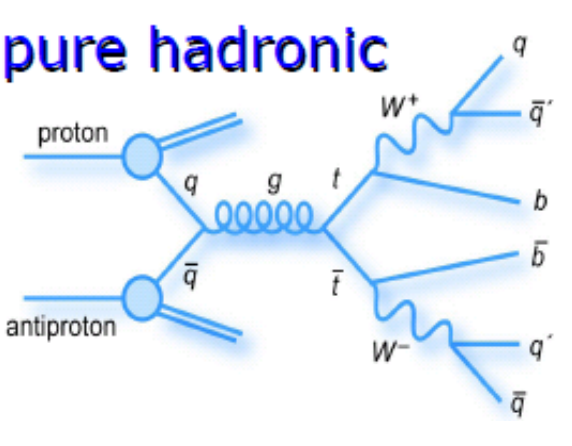
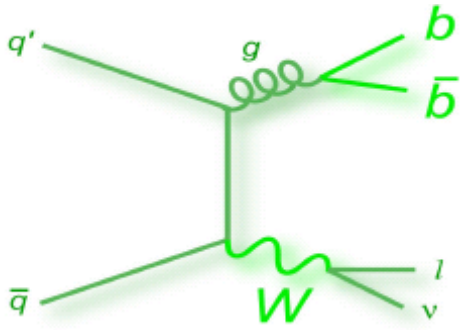
Signal and Background



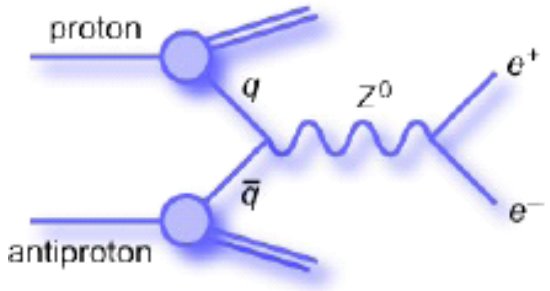




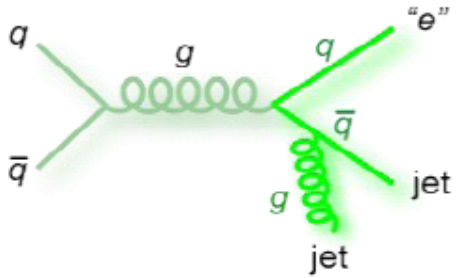
Dominant background: W+jet



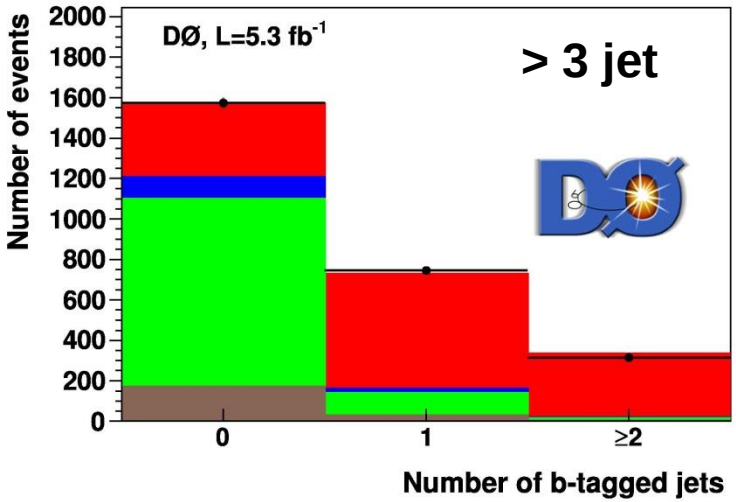
Dominant background: Z+jet

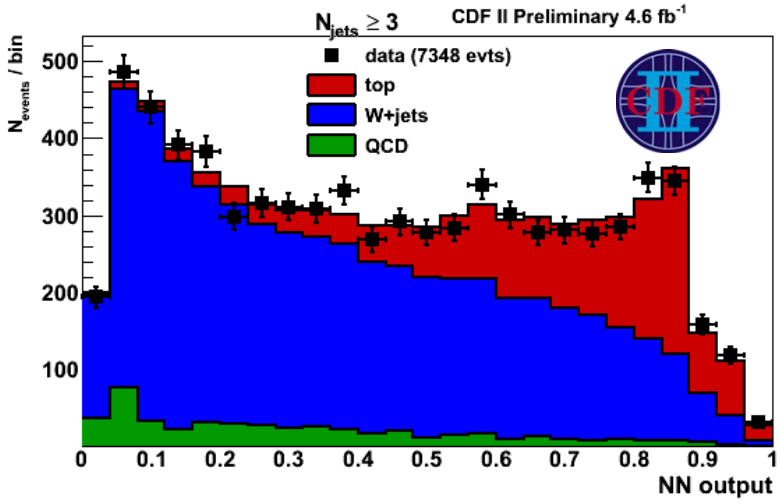


Dominant background: Multijet



Lepton+jets Channel





Two Analysis Methods

- Use b-tagging to suppress background
  - Form binned likelihood from data, $t\bar{t}$ cross section and predicted backgrounds (minimize negative log-likelihood function)
  - D0: $\sigma = 8.13 \pm 0.25(sta)\,^{+0.99}_{-0.86}\,(sys)\ pb$
  - CDF: $\sigma = 7.22 \pm 0.35(sta) \pm 0.56(sys) \pm 0.44(lum)$ pb
- Use kinematic discriminant to distinguish signal from background
  - Topological method (no b-tagging)
  - Fit discriminant output to data in all channels to extract cross section
  - D0: $\sigma = 7.68 \pm 0.31(sta)\,^{+0.64}_{-0.56}\,(sys)\ pb$
  - CDF: $\sigma = 7.71 \pm 0.37(sta) \pm 0.36(sys) \pm 0.45(lum)$ pb

Lepton+jets Channel

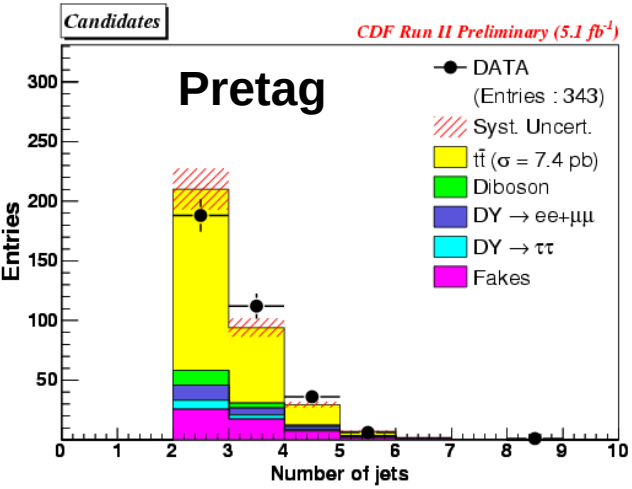
D0 Combination

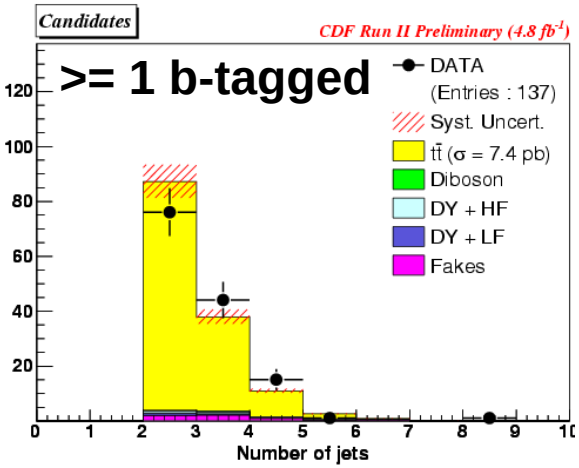
- Use both kinematic information and b-tagging information
- Construct discriminant for channels dominated by backgrounds, otherwise use b-tagging method; multiply likelihood functions in each channel and fit to data
- $\sigma = 7.78\,^{+0.77}_{-0.64}\,(sta + sys + lumi)\,pb$ arXiv:1101.0124 [hep-ex]

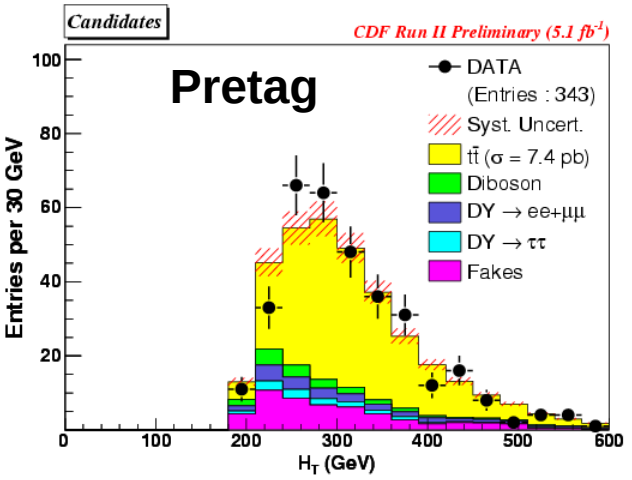
CDF Combination

- Measure ratio of $t\bar{t}$ to $Z/\gamma^* \rightarrow ll$ cross sections to reduce luminosity uncertainty, $\sigma_{theo\,Z/\gamma^*\rightarrow ll} = 251.3 \pm 5.0\,pb$
- B-tagging: $\sigma = 7.32 \pm 0.36(sta) \pm 0.59(sys) \pm 0.14(theo)\,pb$
- Topological: $\sigma = 7.82 \pm 0.38(sta) \pm 0.37(sys) \pm 0.15(theo)\,pb$
- Combined using BLUE method (best linear unbiased estimate)
- $\sigma = 7.70 \pm 0.52\,(sta + sys + theo)\,pb$
- Total uncertainty: 6.8% PRL 105 012001

Dilepton Channel





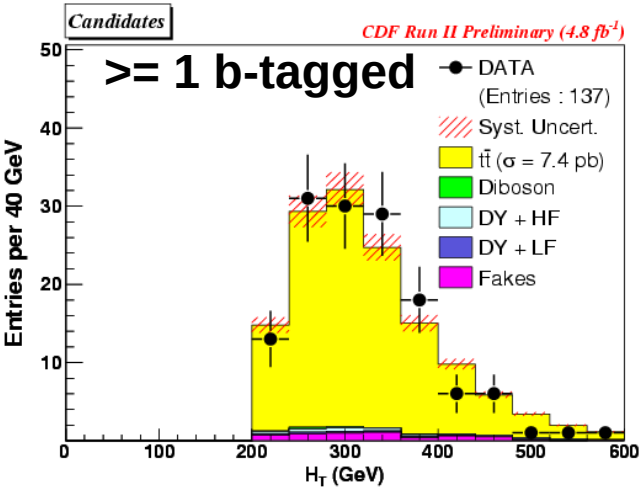


Counting method

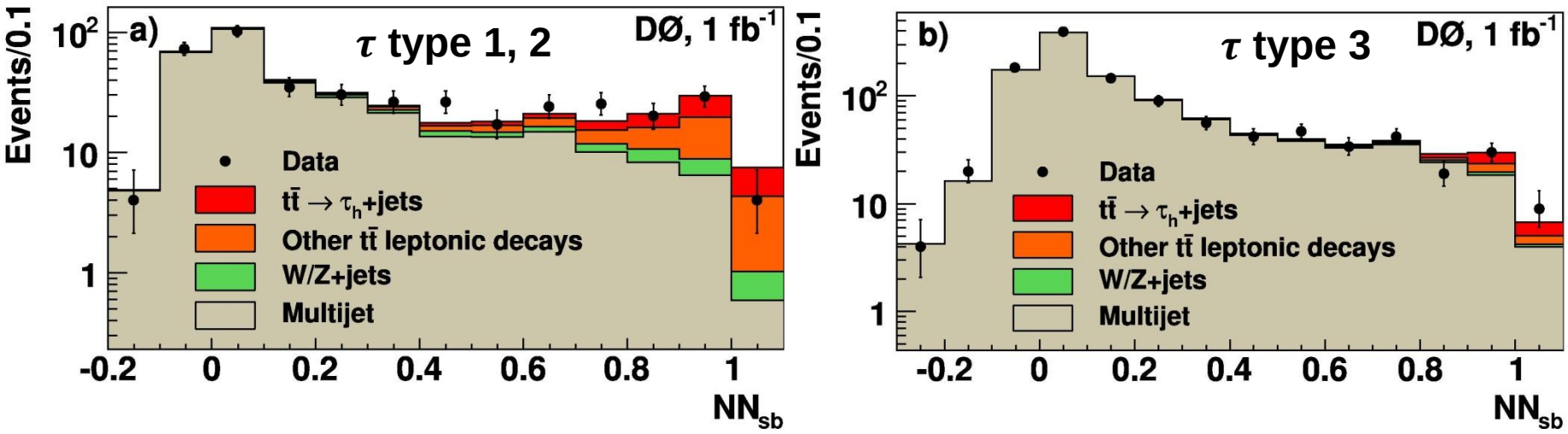
- Two high pT isolated leptons with two jets
- Clean signal although low yields, only channel with favorable S/B
- Subtract expected background from data
- Pretag (not requiring b-tagging):
  $\sigma = 7.40 \pm 0.58(sta) \pm 0.63(sys) \pm 0.45(lum)$ pb
- B-tagged (at least 1 b-tagged jet):
  $\sigma = 7.25 \pm 0.66(sta) \pm 0.47(sys) \pm 0.44(lum)$ pb

CDF Conf. Note 10163

$$\sigma_{t\bar{t}} = \frac{N_{data} - N_{bkg}}{A \cdot \int L \cdot dt}$$



Tau+jets Channel



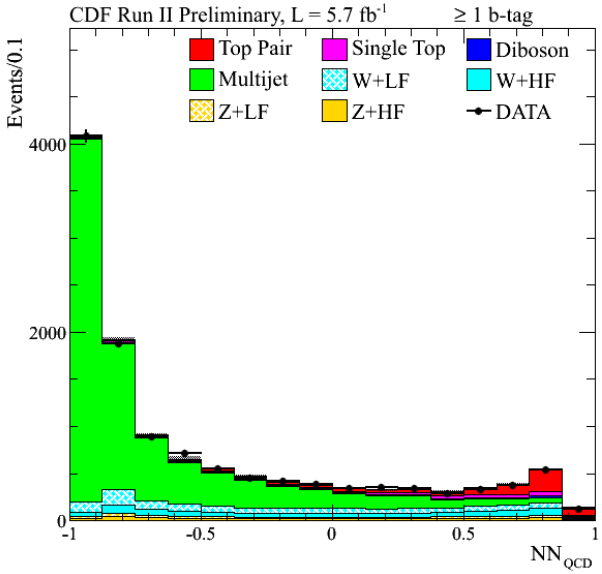
PRD 82 071102

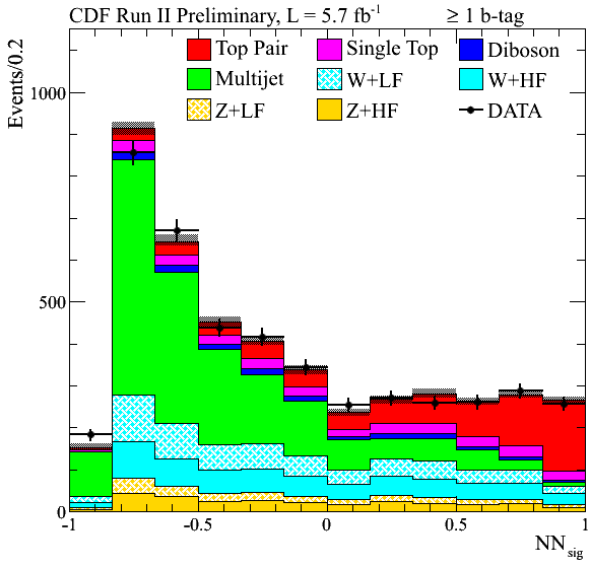
Template fit method

- Challenging final state: semi-hadronic tau with jets
  - Huge multijets background
  - However very sensitive to new physics, e.g. charged Higgs decay (MSSM)
- Multijets background extracted from data
- Form a neural network discriminant with templates fit to data

$\sigma = 6.3\,^{+1.2}_{-1.1}\,(sta) \pm 0.7(sys) \pm 0.4(lum)$ pb (M_{top} = 170 GeV)

Missing E_T+jets Channel





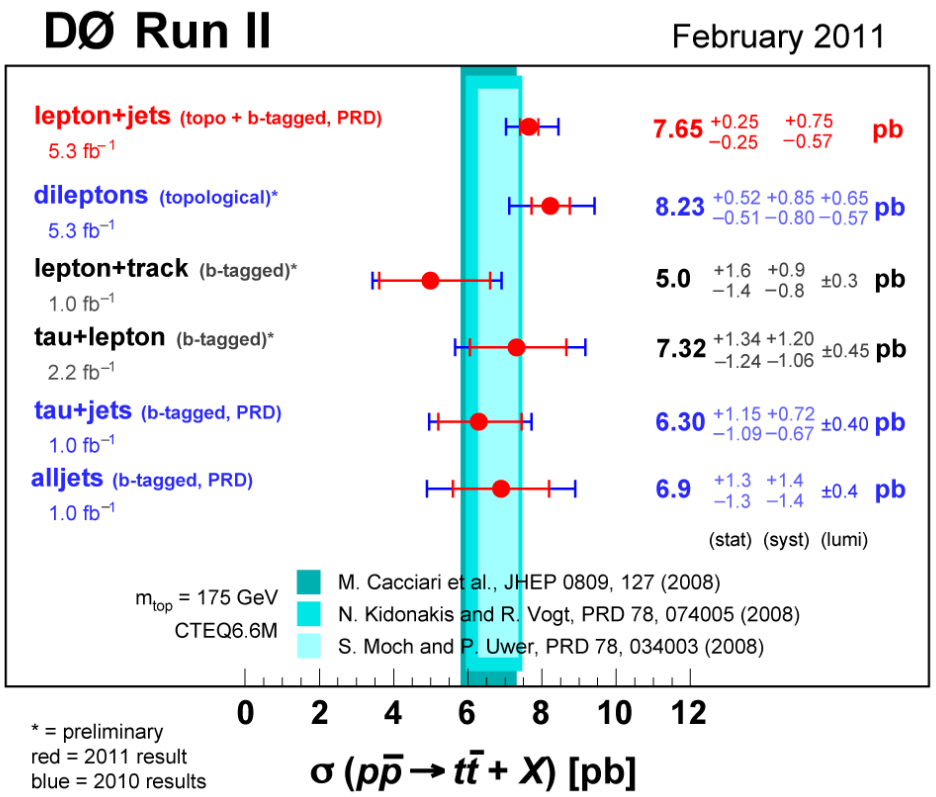
CDF Conf. Note 10237

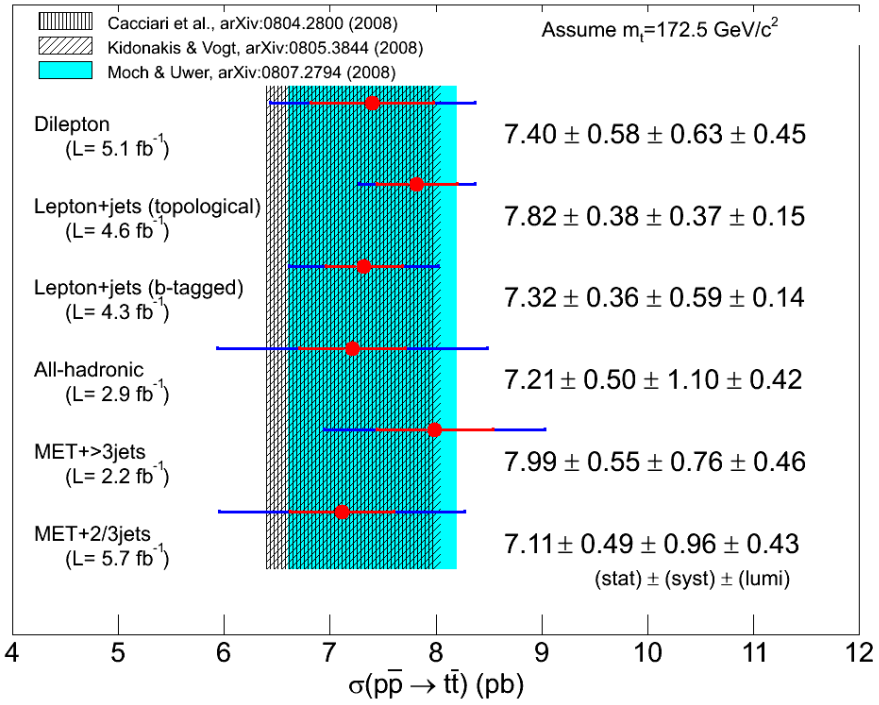
Recover events without identified leptons (complementary)

- One of the most sensitive channel for low mass Higgs search at Tevatron, also SUSY, leptoquark searches
- Multijets background dominates
  - Require b-tagging
  - Use neural network approach (NN_{QCD} > -0.5) to further suppress background
- Form final discriminant NN_{sig} and build binned likelihood from signal, backgrounds and data

$$\sigma = 7.12\,^{+1.20}_{-1.12}\,(sta + sys)\ \text{pb}$$

Summary of Top Pair Production Cross Section

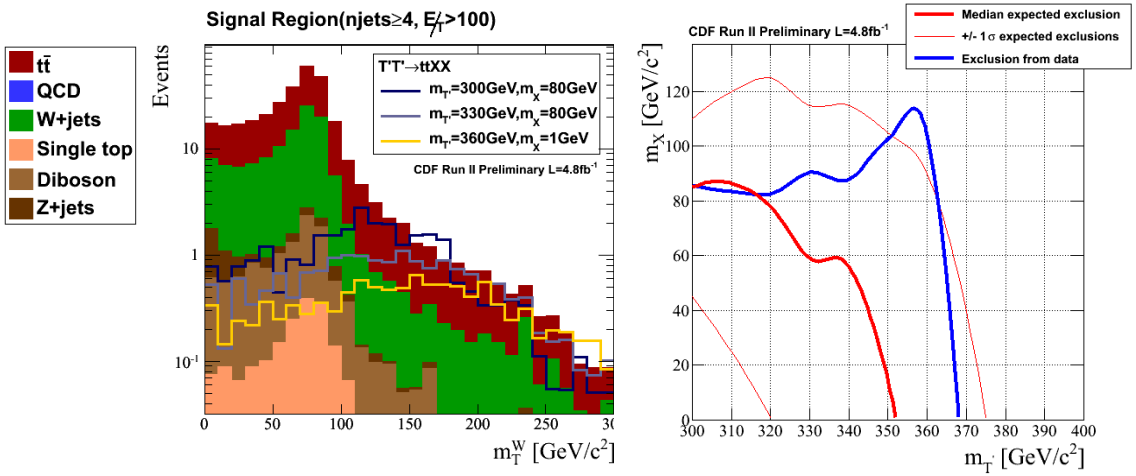




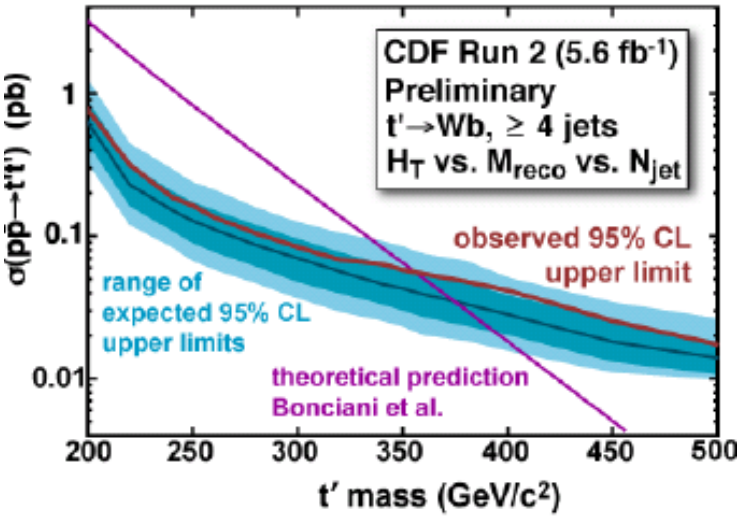
- **All measurements consistent with Standard Model**
  - **Probe new physics**
- **Important to measure different channels**
  - **Different sensitivity to new physics**

t' (4th generation quark) search

CDF Conf. Note 10347



CDF Conf. Note 10395



t' → t + X

- Large missing E_T
- Discriminant variable M_{TW} (transverse mass of leptonically decaying W)
- fit templates of the signal and background shapes to data using binned likelihood
- Derive limit in 2D ($M_{t'}$, M_X) mass points

t' → Wb

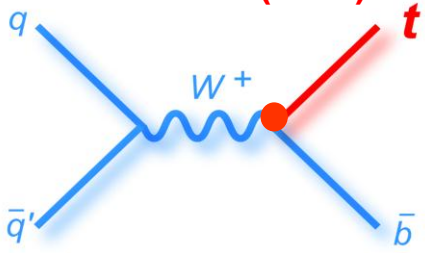
- Heavy top-like particle
- Discriminant variable H_T (total transverse energy) and M_{reco} (reconstructed top mass): more energetic & heavier!
- Maximize binned likelihood fit in H_T and M_{reco} to extract the t' signal and/or set an upper limit
- Exclude $M_{t'} < 358$ GeV @ 95% C.L.

Single Top Quark Production at Tevatron

Electroweak production predicted by the Standard Model

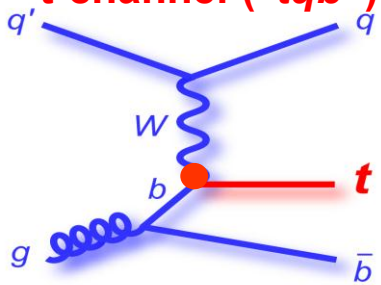
- Observed 14 years after the top discovery (1995 vs. 2009)
  - Experimentally very challenging
  - Signature looks like W+jets (dominant background)
- Another milestone in Tevatron program – "stepping stone" to the Higgs
- Rich testing ground for SM and physics beyond SM
  - Direct measurement of the $|V_{tb}|$ CKM matrix element, measure top width, lifetime
  - Search anomalous couplings, heavy W' boson, FCNC, 4th quark generation…

s-channel ("*tb*")



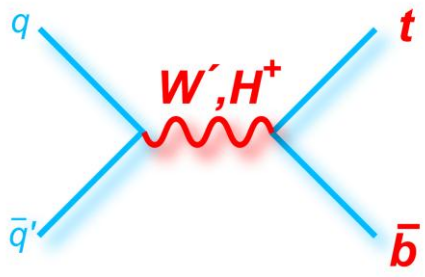
σ_{SM}=1.04±0.04 pb

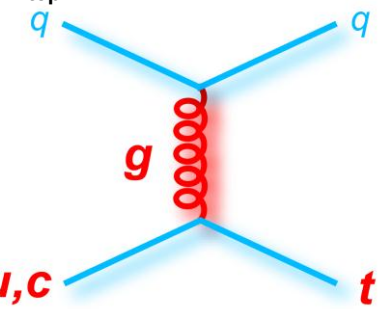
t-channel ("*tqb*")

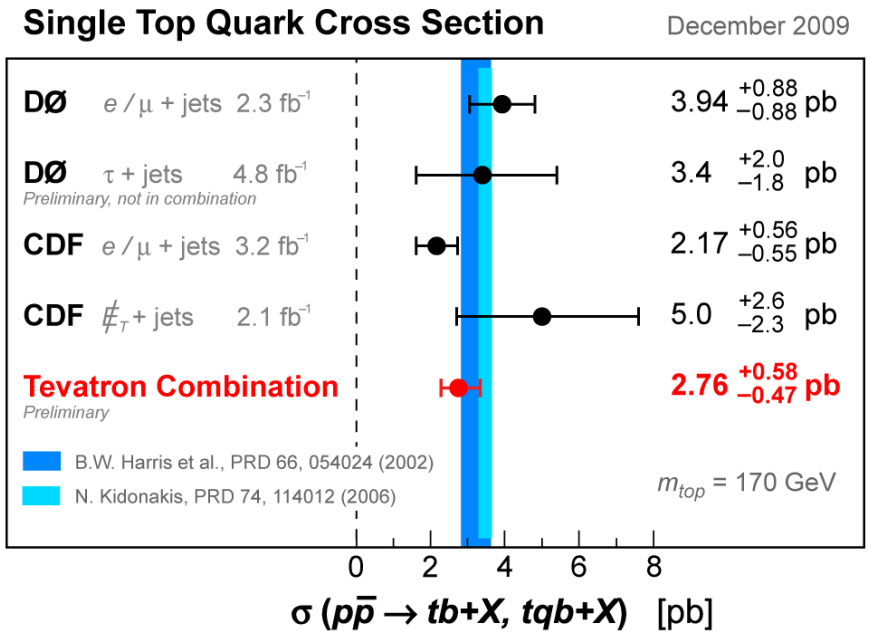


σ_{SM}=2.26±0.12 pb

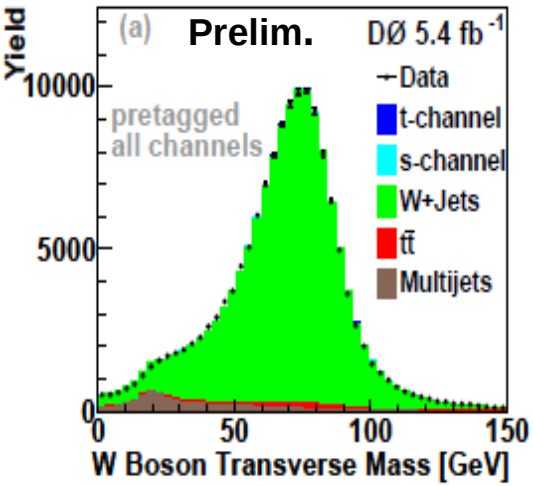
PRD 74 114012 (2006) M_{top} = 172.5 GeV

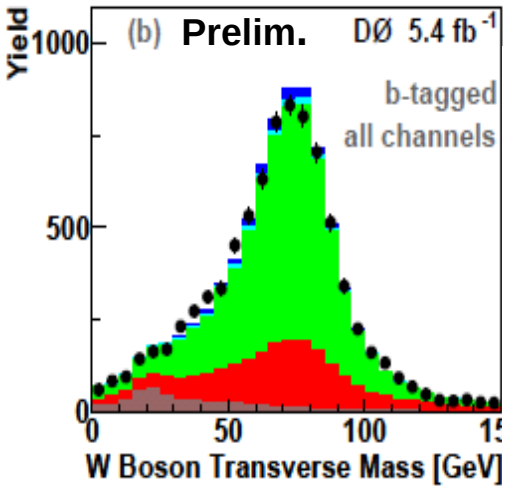


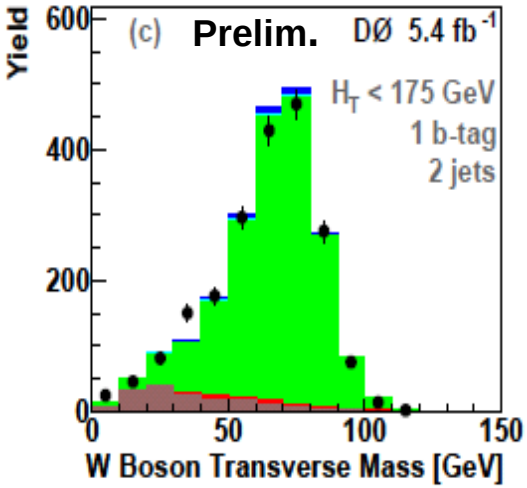


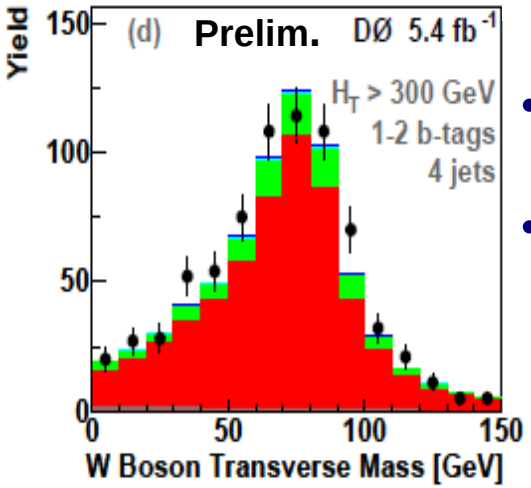


Signal and Background Modeling









W+jets crosscheck $t\bar{t}$ **crosscheck**

Event Yields

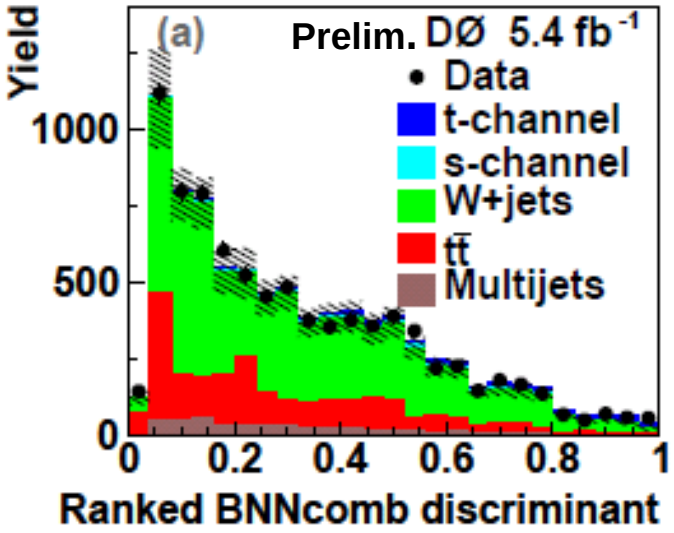
Source	2 jets	3 jets	4 jets
tb	104 ± 16	44 ± 7.8	13 ± 3.5
tqb	140 ± 13	72 ± 9.4	26 ± 6.4
tb+tqb	244 ± 29	116 ± 17	39 ± 9.9
$t\bar{t}$	433 ± 87	830 ± 133	860 ± 163
W+jets	3,560 ± 354	1,099 ± 169	284 ± 76
Z+jets & dibosons	400 ± 55	142 ± 41	35 ± 18
Multijets	277 ± 34	130 ± 17	43 ± 5.2
Total prediction	4,914 ± 558	2,317 ± 377	1,261 ± 272
Data	4,881	2,307	1,283

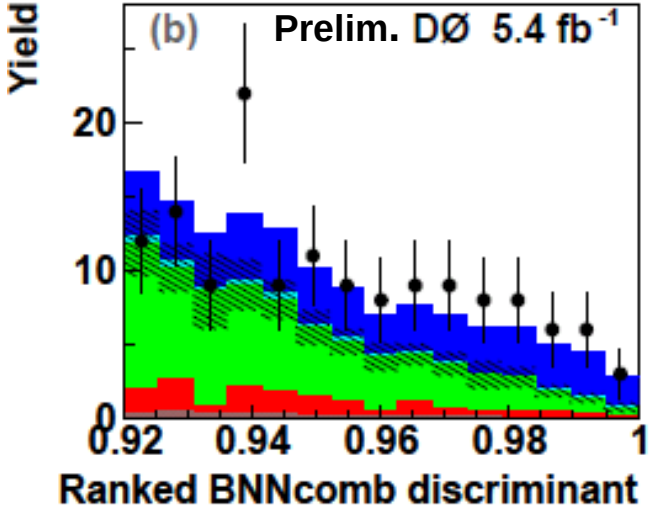
- **Small signal**
  - **S/B ~ 1:20 after b-tagging**
- **Background uncertainty larger than expected signal**
  - **Counting experiment difficult**

Multivariate Analyses

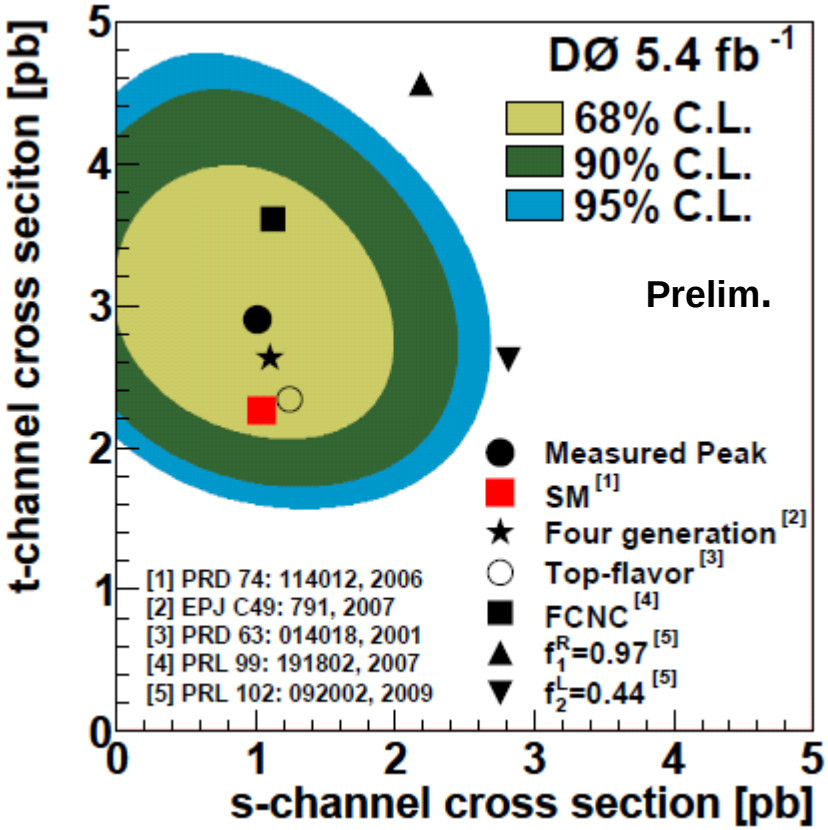
Three methods: optimizing on expected sensitivity using simulations

- **Boosted Decision Trees (BDT)**
  - Common object and event kinematics, angular correlations, jet reconstruction and top quark reconstruction variables
- **Bayesian Neural Network (BNN)**
  - Average over many neural networks, improving performance
  - Use object 4 vectors + B-tagging information + Q*Eta + W transverse mass
- **Neuro-evolution of Augmenting Topologies (NEAT)**
  - Genetic algorithms for training NN
- **Optimize on s+t, s- or t-channel separately**
- **Combined discriminant using BNN improves sensitivity even further!**





t-channel Cross Section



Measure t-channel cross section without assumption of s-channel cross section

- **Simultaneous measurement of s- and t-channel with discriminant optimized for t-channel (s-channel treated as background)**

  $\sigma_t = 2.90 \pm 0.59(sta + sys)$

  $\sigma_s = 0.98 \pm 0.63(sta + sys)$

- **Asymptotic significance calculation**

  Sig_{obs} = 5.5 SD, Sig_{exp} = 4.6 SD

- **t-channel cross section vs. top mass**

m_t	170 GeV	172.5 GeV	175 GeV
tqb	$2.80^{+0.57}_{-0.61}$	$2.90^{+0.59}_{-0.59}$	$2.53^{+0.58}_{-0.57}$

s vs. t-channel cross section sensitive to new physics models

Conclusion

Top Quark cross section being measured at Tevatron with high precision

- Top pair cross section error ~ 6.5%
  - Important for testing both SM and BSM models
- New physics search

Broad top physics programs at Tevatron

- Top production, top properties and searches
  - http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html
  - http://www-cdf.fnal.gov/physics/new/top/top.html

Backup

The Tevatron Accelerator

Tevatron Collider

- Proton-antiproton collider with $\sqrt{s}$=1.96 TeV
- 36x36 bunches with 396ns between crossings
- ~5 collisions per bunch crossing
- $L_{Inst} \sim 3x10^{32} cm^{-2} s^{-1}$

Run I 1992-1995

- Top quark discovered!

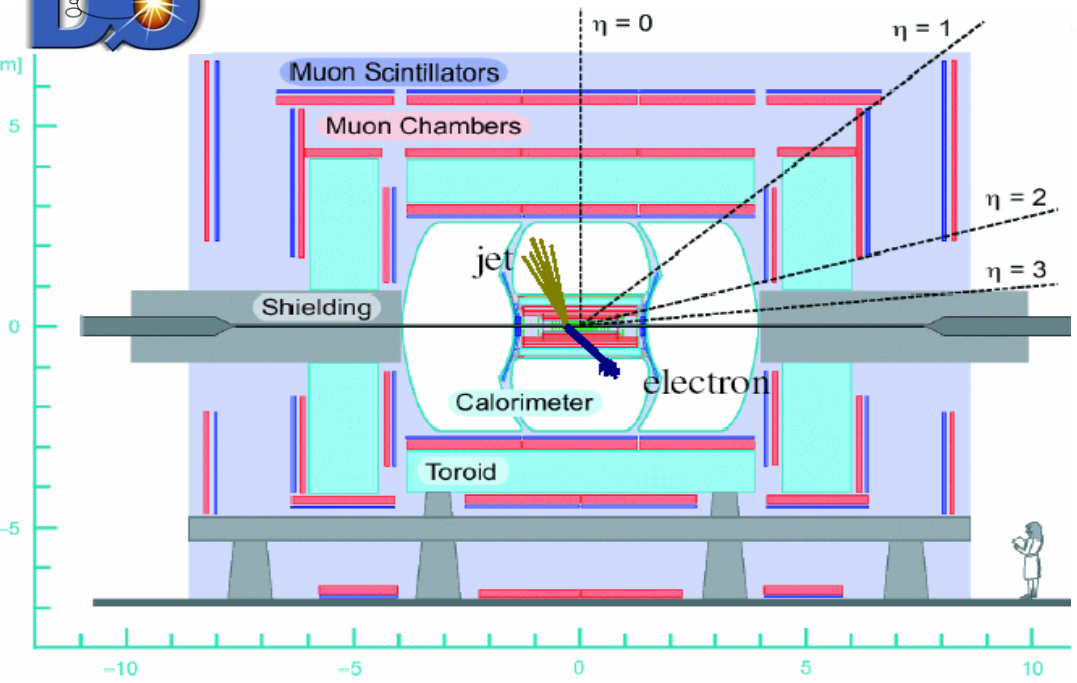
Run II 2001-2011

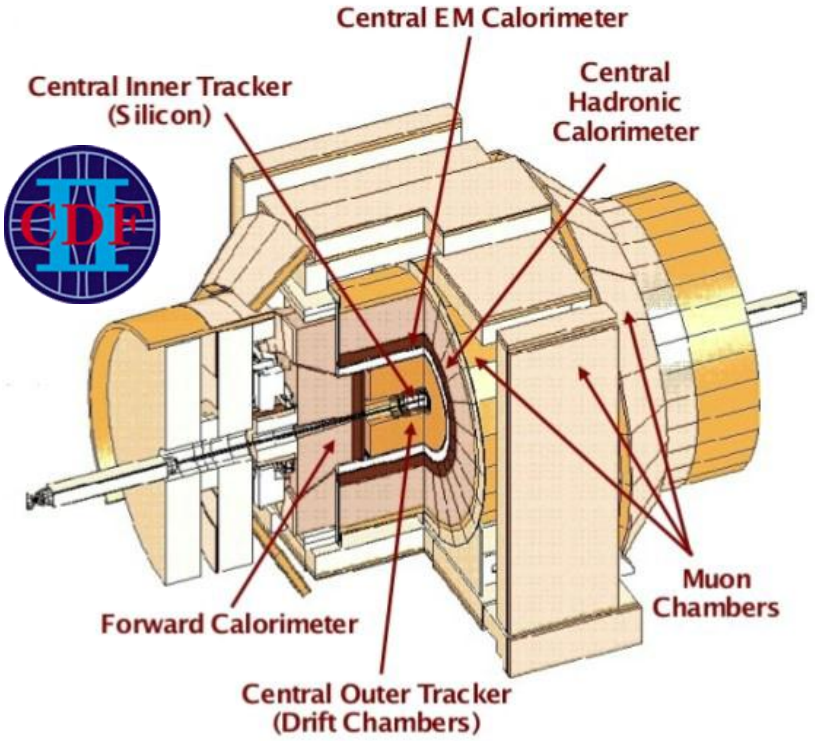
- Single Top quark discovered!
- Many more exciting physics results

Tevatron is running at peak performance!

- ~ 10 fb^{-1} per experiment
- ~ 12 fb^{-1} by end of 2011

The CDF & DØ Detectors





- **Tracking**
  - Momentum measurement of charged particles
  - Vertex and b-jet identification
- **Calorimeter**
  - Energy measurement of jets, electrons and neutrinos
- **Muon system**
  - Momentum measurement of muons
- **Three level trigger system**