Top Quark Production at DØ

Cecilia E. Gerber

University of Illinois

at Chicago

(on behalf of the DØ Collaboration)

DIS meeting

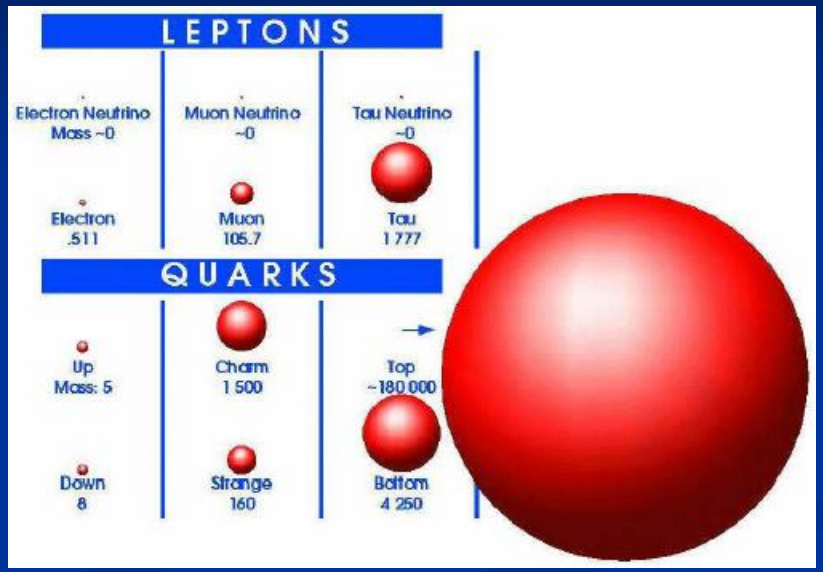
April 11-15, 2011

Outline

- Motivation
- Introduction to top quark production and decay
- Measurements of top quark production cross sections
- Conclusions

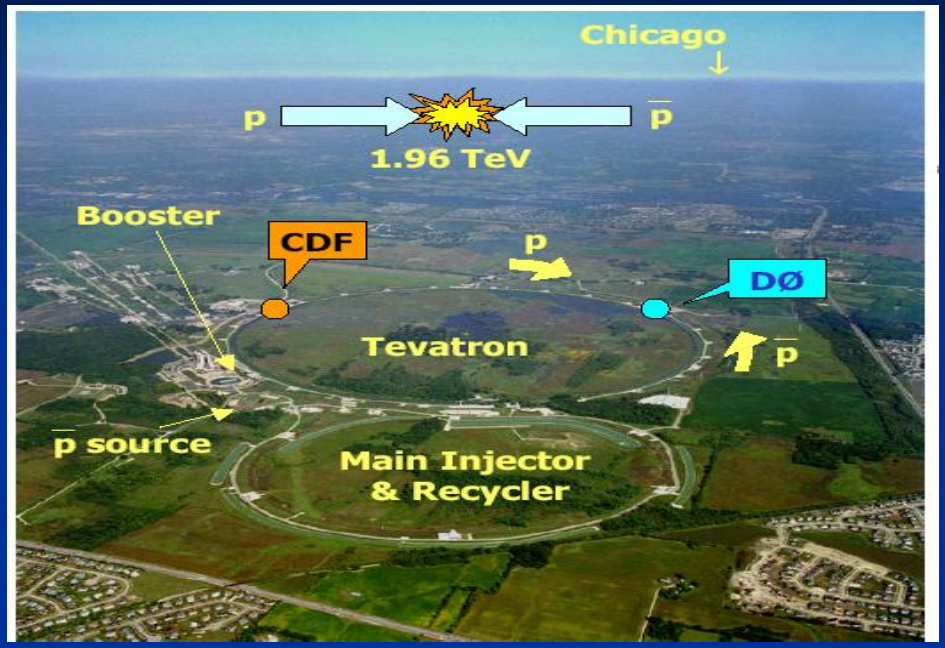
Why study the Top Quark?

- Predicted by the SM and discovered in 1995 by CDF and DØ
  - $m_t \sim 170$ GeV vs $m_b \sim 5$ GeV
- Top-Higgs Yukawa coupling $\lambda_t \approx 1$
  - may help identify the mechanism of EWSB and mass generation.
  - may serve as a window to new physics that might couple preferentially to top.

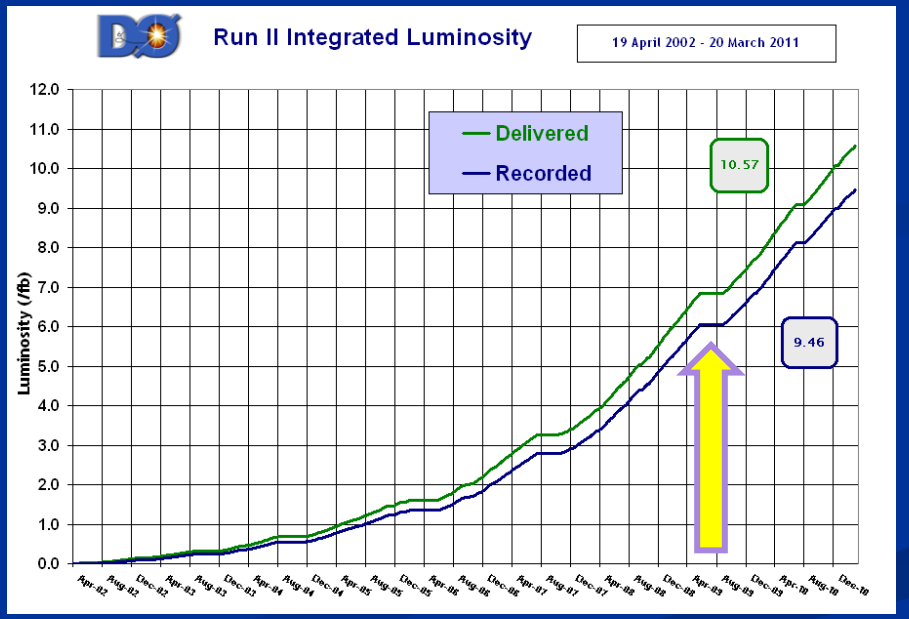


- Successful Tevatron top quark program
  - High precision measurements for the top quark mass, top pair production cross section and decay properties
- Some basic quantities still not measured precisely: spin, width, lifetime
- Electroweak single top quark production predicted by the SM, has been observed in March 2009, 14 years after the pairs observation.

The Fermilab Tevatron



- proton anti-proton collider
  - Until recently, only place where top quarks had been studied
- Data delivered ~11fb^{-1}
  - Recorded ~9.5 fb^{-1}



	Run I	Run IIa	Run IIb
Bunches in Turn	6 × 6	36 × 36	36 ×36
√s (TeV)	1.8	1.96	1.96
Peak L (cm^{-2}s^{-1})	1.6 ×10^{30}	9 ×10^{31}	3 ×10^{32}
∫ Ldt (pb^{-1}/week)	3	17	50
Bunch crossing (ns)	3500	396	396
Interactions/ crossing	2.5	2.3	8

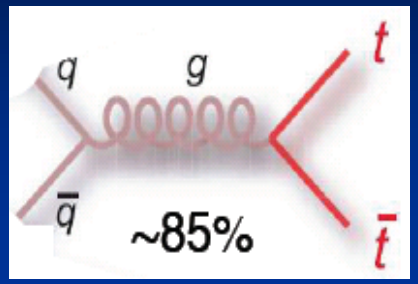
Results based on ~5.5 fb^{-1}

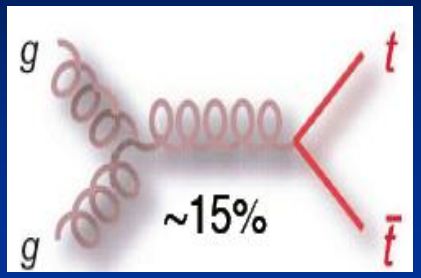
Top Quark Production at the Tevatron

- Top quarks are mainly produced in pairs via the strong interaction

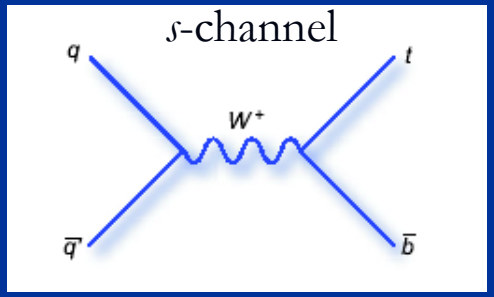
$\sigma_{tt} = 7.46 + 0.48 - 0.67$ pb
Moch & Uwer PRD 78, 034003 (2008)

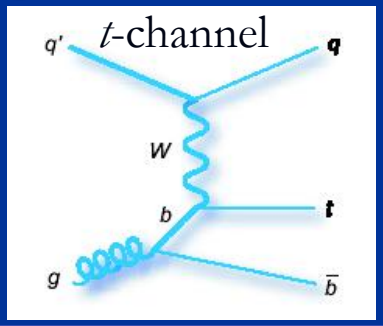
(Calculated for top mass = 172.5 GeV)





- EW Single Top production
  - Experimentally challenging due to large W+jets background in lower jet multiplicities than pair production

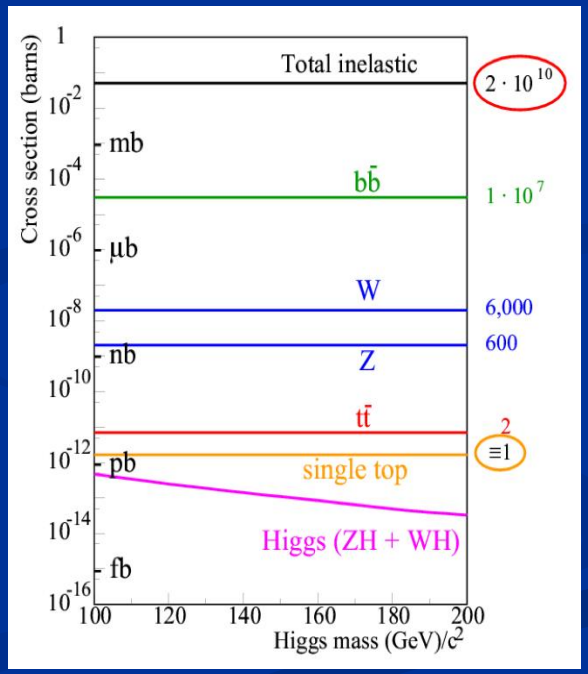




$\sigma_{tb} = 0.88 \pm 0.11$ pb

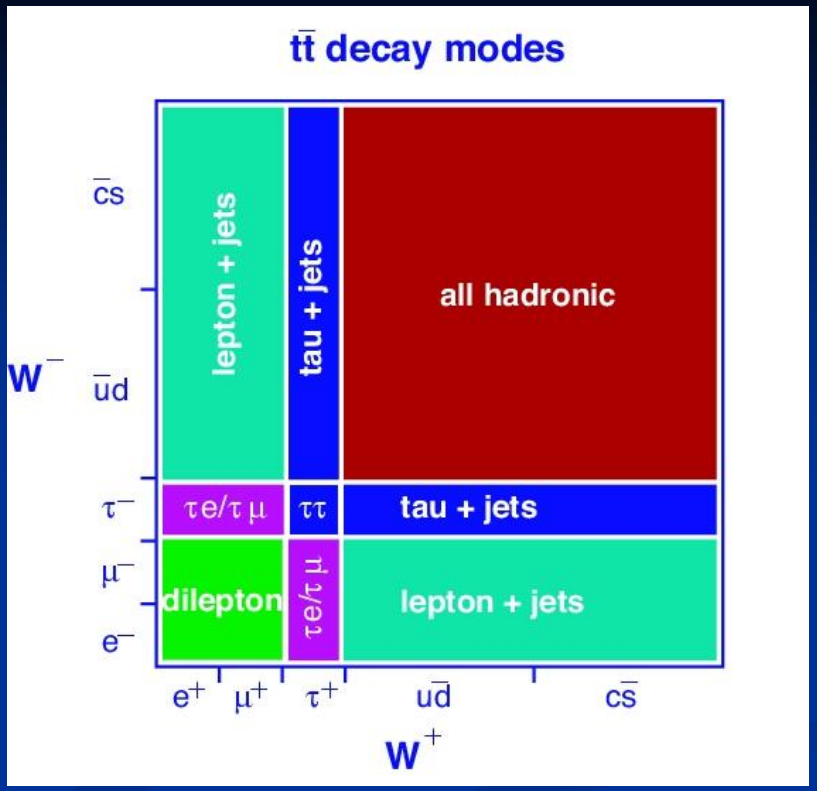
$\sigma_{tqb} = 1.98 \pm 0.25$ pb

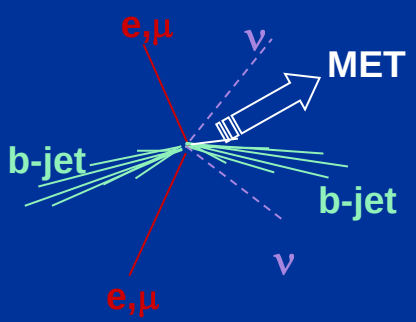
Kidonakis PRD 74 114012 (2006), m_t=172.5GeV
Associated production tW negligible



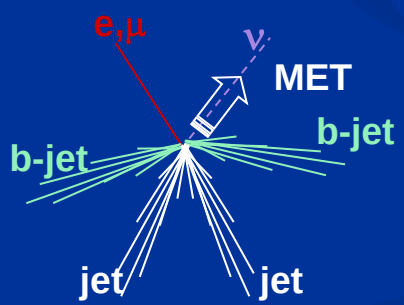
Top Quark Decay

- $m_t > m_W + m_b \Rightarrow$ dominant 2-body decay $t \rightarrow Wb$
- Assuming unitarity of 3-generation CKM matrix $\Rightarrow$ $B(t \rightarrow Wb) \sim 100\%$
- $\Gamma_t^{SM} \approx 1.4$ GeV at $m_t = 175$ GeV
  - Top decays before top-flavored hadrons or tt-quarkonium bound states can form
  - Top spin and kinematics is transferred to the final state

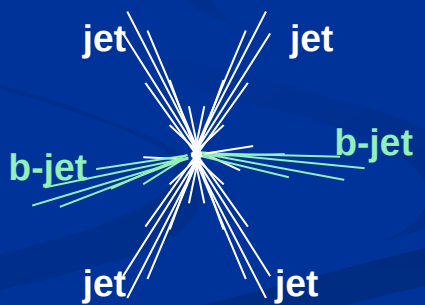




Dilepton
(BR~5%, low bckg)



Lepton+jets
(BR~30%, moderate bckg)



All-hadronic
(BR~46%, huge bckg)

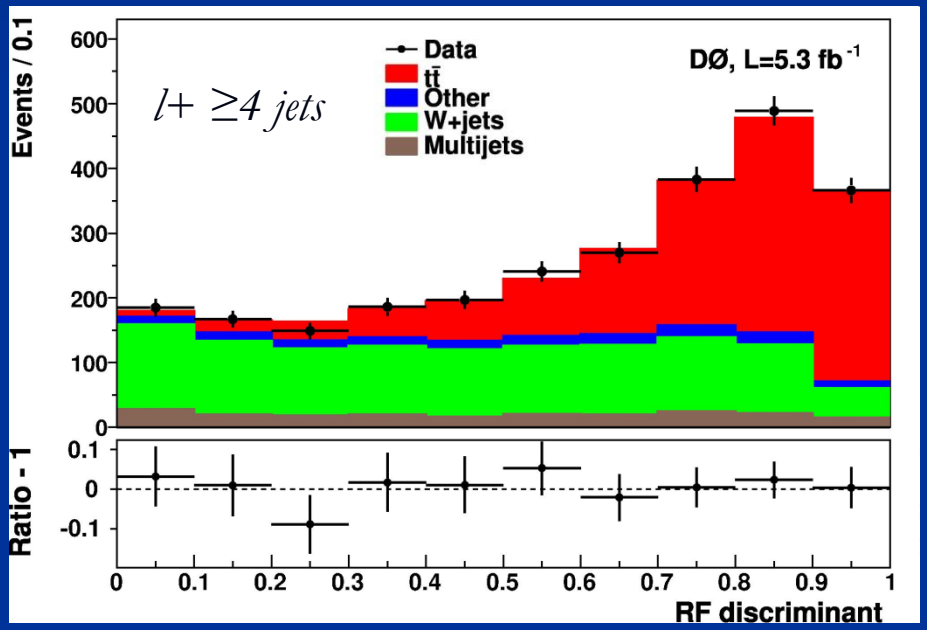
Top Quark Pair Production Cross Section

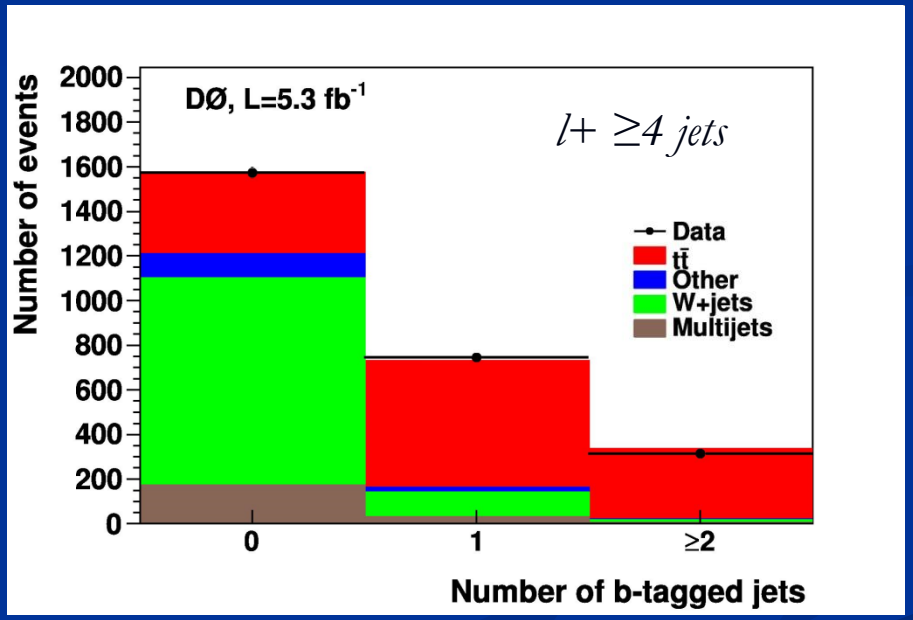
- Test of pQCD at high Q^2
- Sensitive to new physics - Expect higher x-sec if resonant or non-SM production occurs
  - Measure in different channels
  - Measure with different techniques
    - b-tagging method assumes Br(t→Wb)=1
    - Kinematic fit methods are free of this assumption
- Provides sample composition for other top properties measurements
- Gives input for searches for which top events are a dominant background.

- New results available for:
  - Lepton + jets
    - 1 isolated lepton (e or μ)
    - at least two jets
    - Three methods implemented
    - Kinematic (w/o b-tag)
    - Counting (with b-tag)
    - Combined (simultaneous determination with W_{HF}/W_{light})
  - Dilepton (ee, eμ, μμ)
    - Opposite sign leptons
    - ≥1 jet for eμ
    - ≥2 jets for ee and μμ
  - Both channels require significant Missing E_T

Lepton + Jets Results (1)

- Kinematic (w/o b-tag)
  - Use a Random Forest (RF) discriminant to separate signal from backgrounds in events with 2, 3, or ≥4 jets
- Counting (with b-tag)
  - Use b-tagging to separate signal from backgrounds in events with =3 or ≥4 jets, and 0, 1,≥2 b-tags





σ_{tt}= 7.68±0.31(stat) $^{+0.64}_{-0.56}$ (syst) pb

σ_{tt}= 8.13±0.25(stat) $^{+0.94}_{-0.86}$ (syst) pb

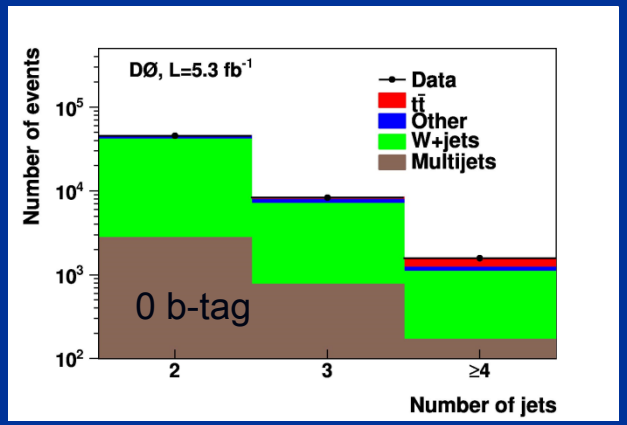
δσ/σ = 9%

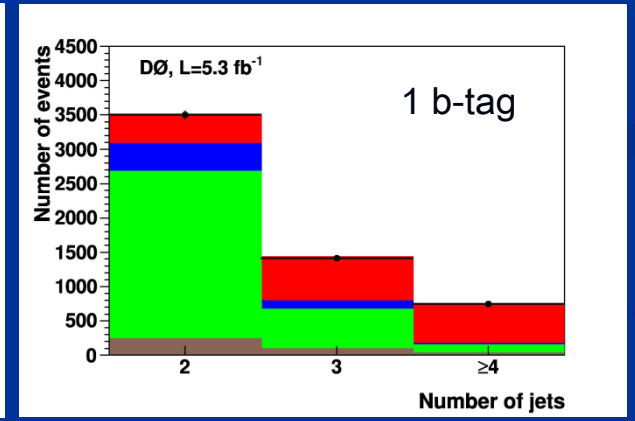
m_t=172.5GeV

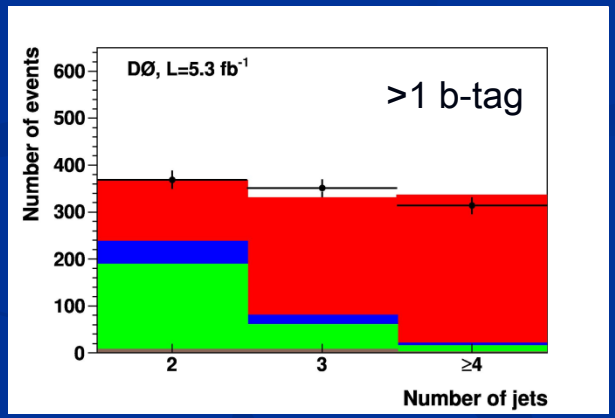
δσ/σ = 11%

Lepton + Jets Results (2)

- Combined
  - Split the sample into events with 2, 3, or ≥4 jets and 0, 1,≥2 b-tags
  - Construct RF discriminants for events with ≥3jets and 0 or 1 b-tags
  - For other channels, count number of b-tagged events.
  - Measure simultaneously the top pairs cross section and the ratio of the production rates for W_{HF}/W_{light}
  - Main constraint on W_{HF}/W_{light} given by the =2 jets channel
  - x-sec obtained from a binned maximum likelihood fit over all analysis channels







m_t=172.5GeV

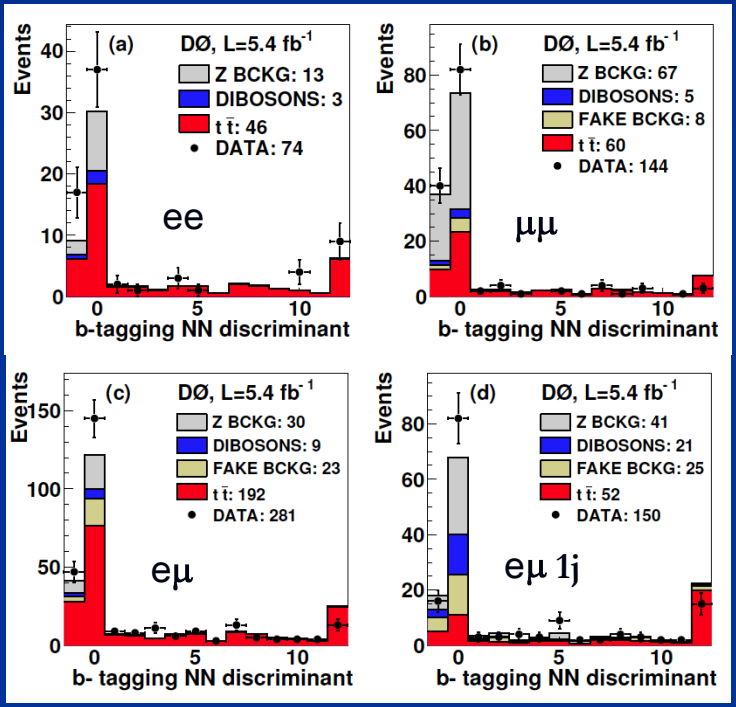
$\sigma_{tt} = 7.78^{+0.77}_{-0.64}$ (stat+syst) pb

$\delta\sigma/\sigma = 9\%$

arXiv:1101.0124v1 [hep-ex] Submitted to PRD

Dilepton

- Measured by simultaneously fitting the b-tagging NN discriminant and maximizing a binned likelihood function over all analysis channels



$\sigma_{tt}(ll) = 7.4^{+0.9}_{-0.8}$ (stat+syst) pb

$\delta\sigma/\sigma = 11\%$

ll&lj Combination

- Lepton + Jets and Dilepton orthogonal samples are combined
  - Uncertainties are included as nuisance parameters constrained by Gaussians of mean zero and width set to 1SD
  - Correlations and anti-correlations are properly taken into account.
  - Measurement is dominated by systematic uncertainties - constrained by data when using the nuisance parameter technique.
  - Largest uncertainties are luminosity, b-tagging and signal modeling.

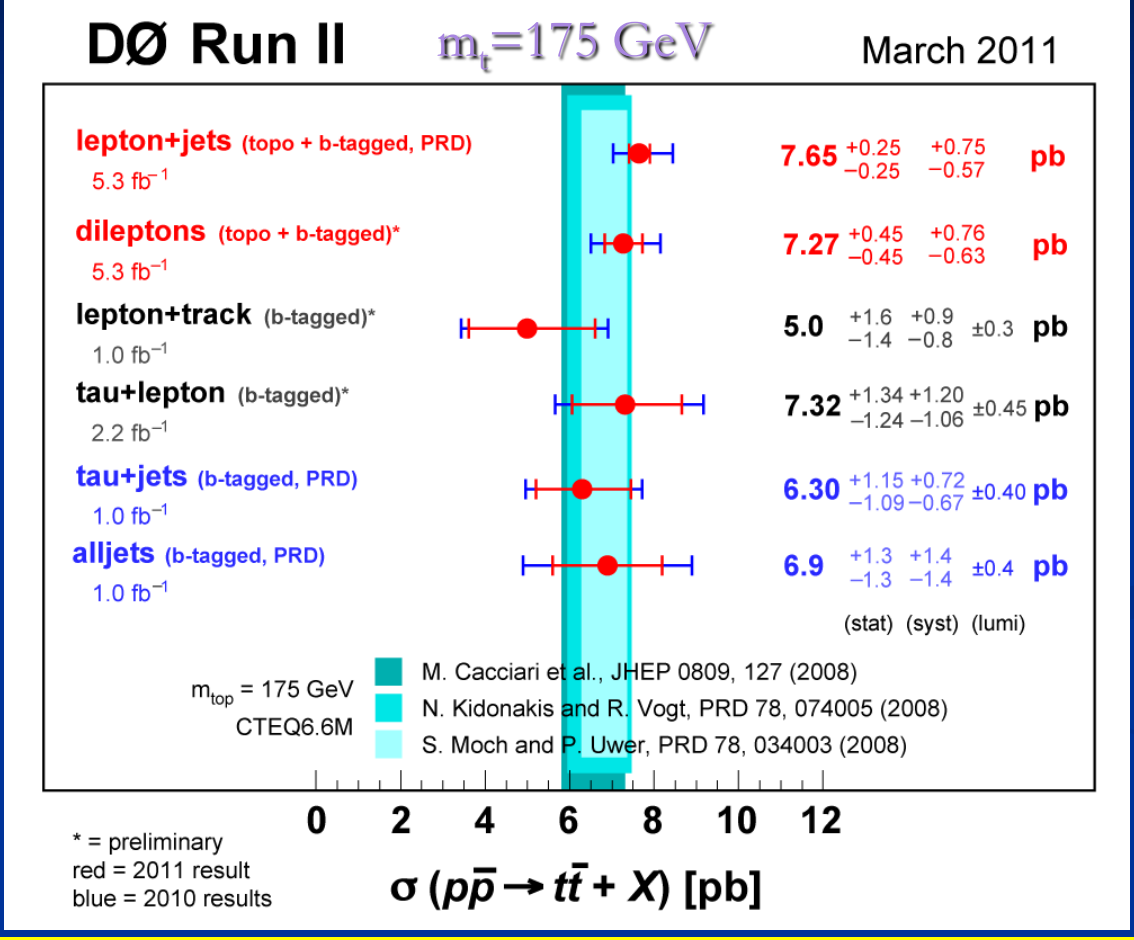
$\sigma_{tt}(ll+lj) = 7.6 \pm 0.6$ (stat+syst) pb

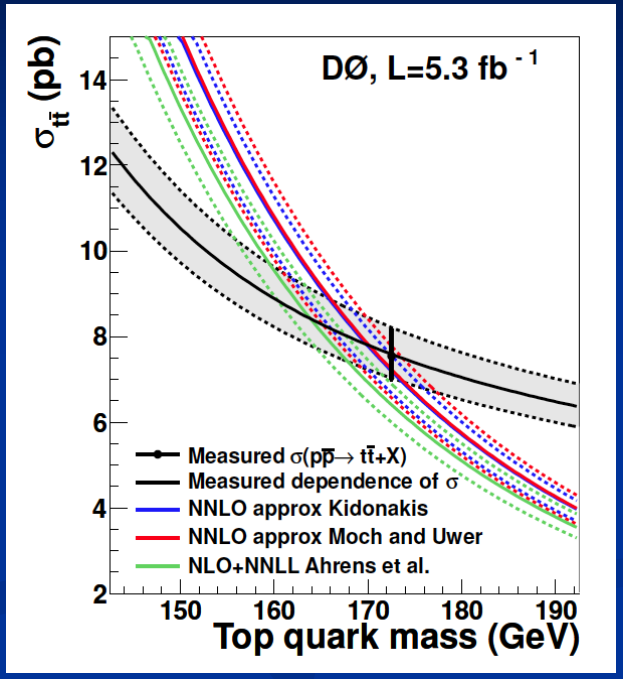
$\delta\sigma/\sigma = 8\%$

$m_t = 172.5$GeV

Most precise dilepton result to-date

Top Pairs Cross Section Summary





- m_t extracted by comparing measured x-sec with SM theory
  - Different experimental and theoretical uncertainties than direct measurements
  - Results in good agreement

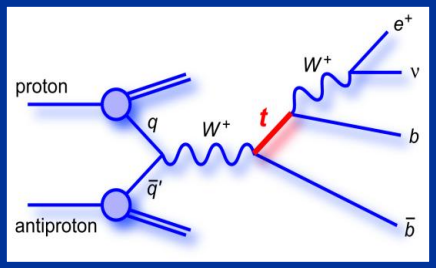
Experimental results reached theoretical precision of ~8%

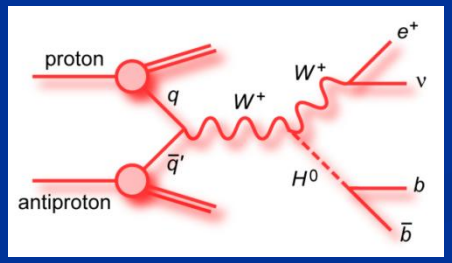
Single Top Production

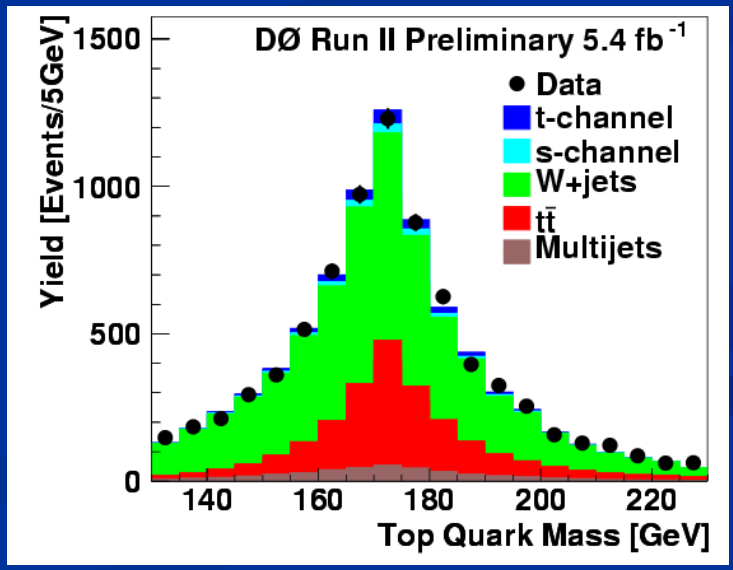
- Probe of the Wtb interaction with no assumption on the number of quark families or unitarity of the CKM matrix
- Cross sections sensitive to beyond-the-SM processes
  - s-channel:
    - Resonances: heavy W' boson, charged Higgs boson, Kaluza-Klein excited W_{KK}, technipion
  - t-channel
    - flavor-changing neutral currents
  - Fourth generation of quarks
- Same final state as WH
  - Same backgrounds
  - Test techniques to extract small signal

- Event Selection
  - One high-p_T isolated electron or muon
  - Large missing transverse energy
  - A b-jet from the top quark decay
  - A second b-jet or a light jet

S:B = 1:220 PreTag
S:B = 1:22 in 1Tag
S:B = 1:16 in 2Tag

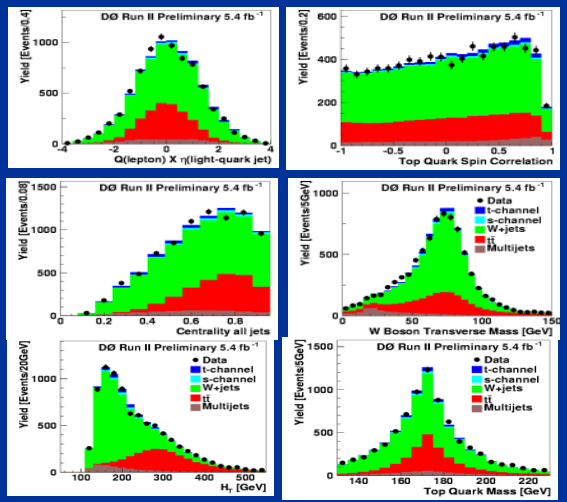




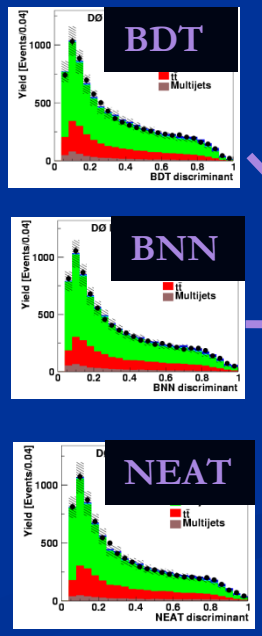


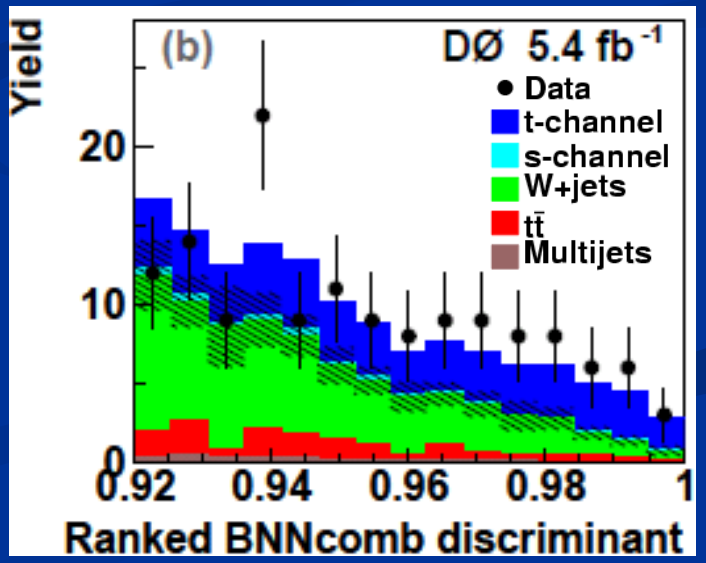
Analysis Strategy

- Combine variables with large discriminating power into discriminant functions that separate signal from background
  - Boosted Decision Trees (BDT)
  - Bayesian Neural Networks (BNN)
  - Neuroevolution of Augmented Topologies (NEAT)
- Correlation between methods ~70%, gain by combining them into CombBNN
- Check discriminant performance using data control samples
- Use ensembles of pseudo-data to test validity of x-sec extraction method



Individual variables

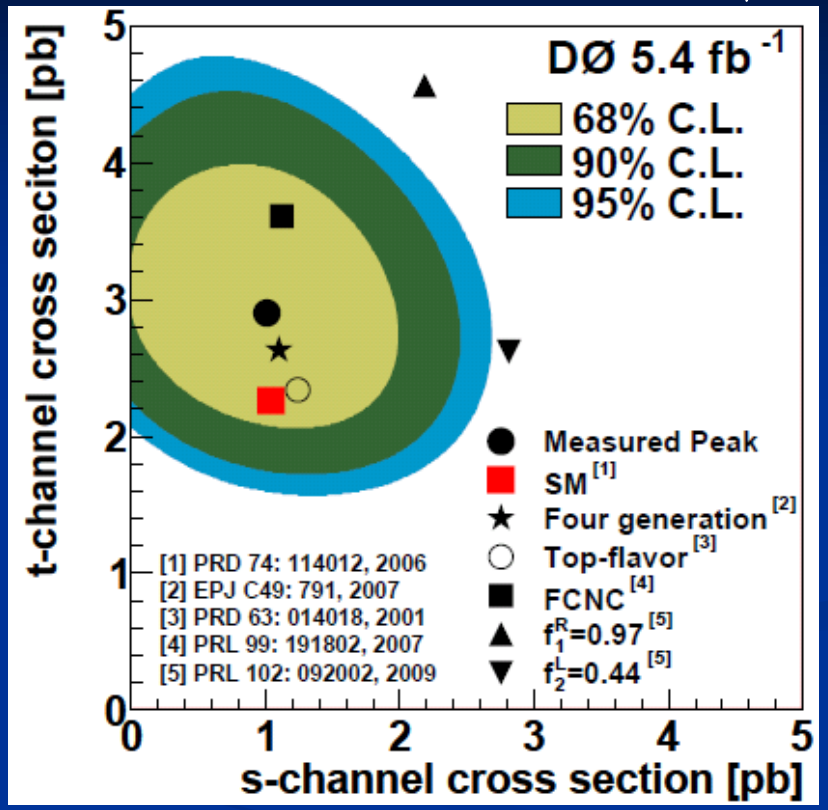




t-channel Cross Section

- MVAs optimized to maximize sensitivity to tqb (tb treated as background).
- (2D) posterior probability density as a function of tqb and tb x-sections
  - Sensitive to new physics
- tqb cross section extracted from a 1D posterior obtained by integrating over the tb axis
  - no assumptions on the s-channel x-sec or the s:t relative rate.

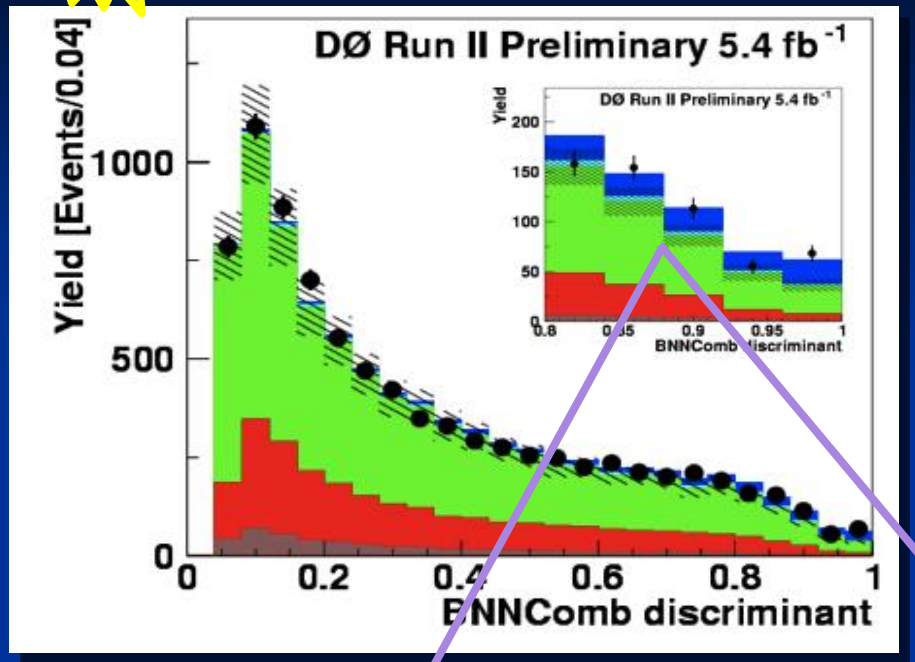
m_t (GeV)	cross section (pb)	
	t channel (tqb)	s channel (tb)
170	2.80+0.57-0.61	1.31+0.77-0.74
172.5	2.90±0.59	0.98+0.62-0.63
175	2.53+0.58-0.57	0.65+0.51-0.50



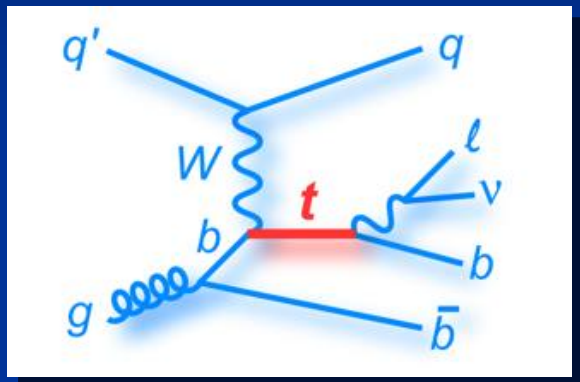
- $\delta\sigma/\sigma$ = 20%, 11% Systematics
  - Dominant systematics: JES, JER, b-tagging efficiency and W + heavy jets normalization

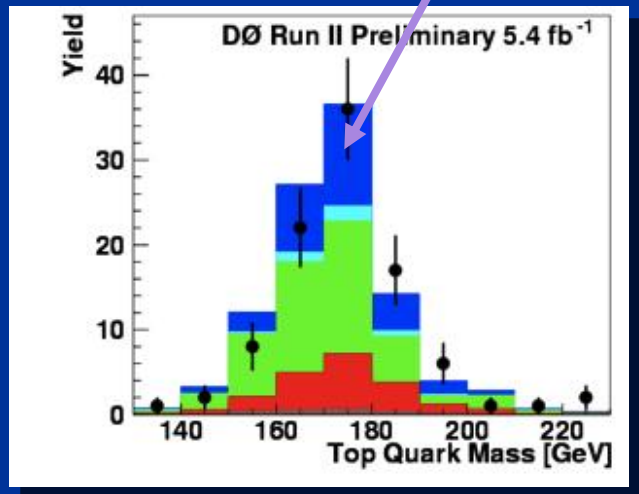
Observed significance > 5SD

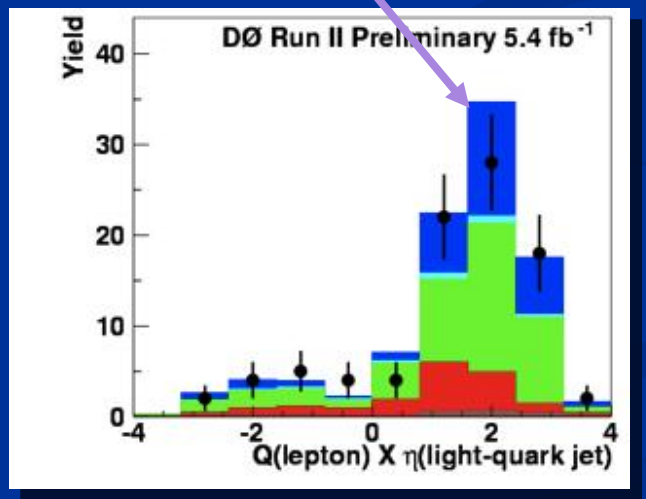
t-channel sensitive distributions



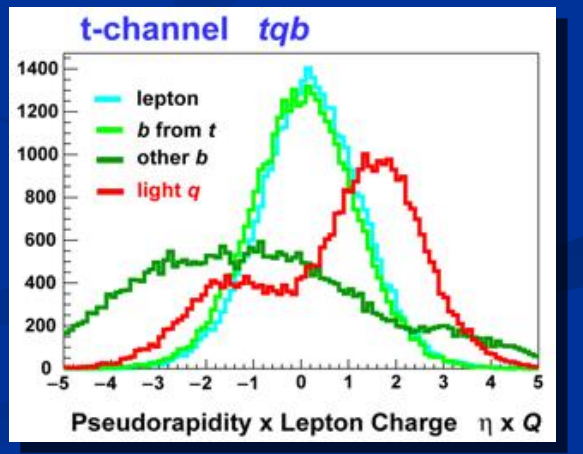
t channel tqb







Parton Level



Conclusions

- The DØ collaboration has done precise measurements of the top quark production via strong and electroweak interactions:

$$\sigma(p\bar{p} \to t\bar{t} + X) = 7.6 \pm 0.6 \text{ pb}$$

NEW!

$$\sigma(p\bar{p} \to tqb + X) = 2.90 \pm 0.59 \text{ pb}$$

NEW!

$$\sigma(p\bar{p} \to tb + X) = 0.98^{+0.62}_{-0.63} \text{ pb}$$

Uncertainty for top pair production reached theoretical precision

Measured Significance for t channel single top production >5 SD

Good agreement with SM predictions