Top Production Cross-Sections at the DØ

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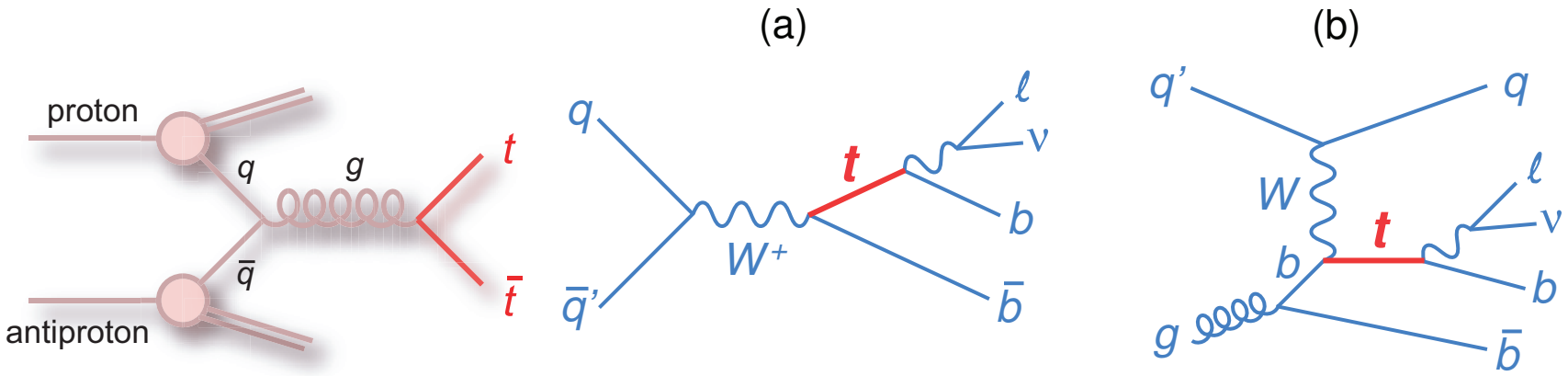
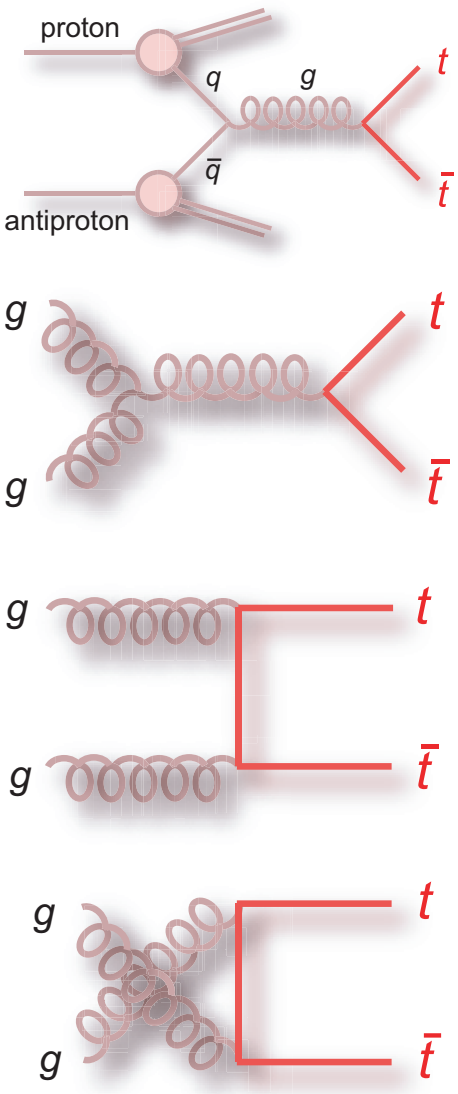
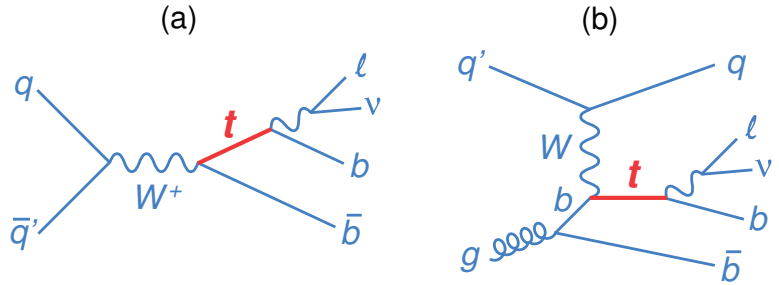
DIS 2009, Madrid



Outline



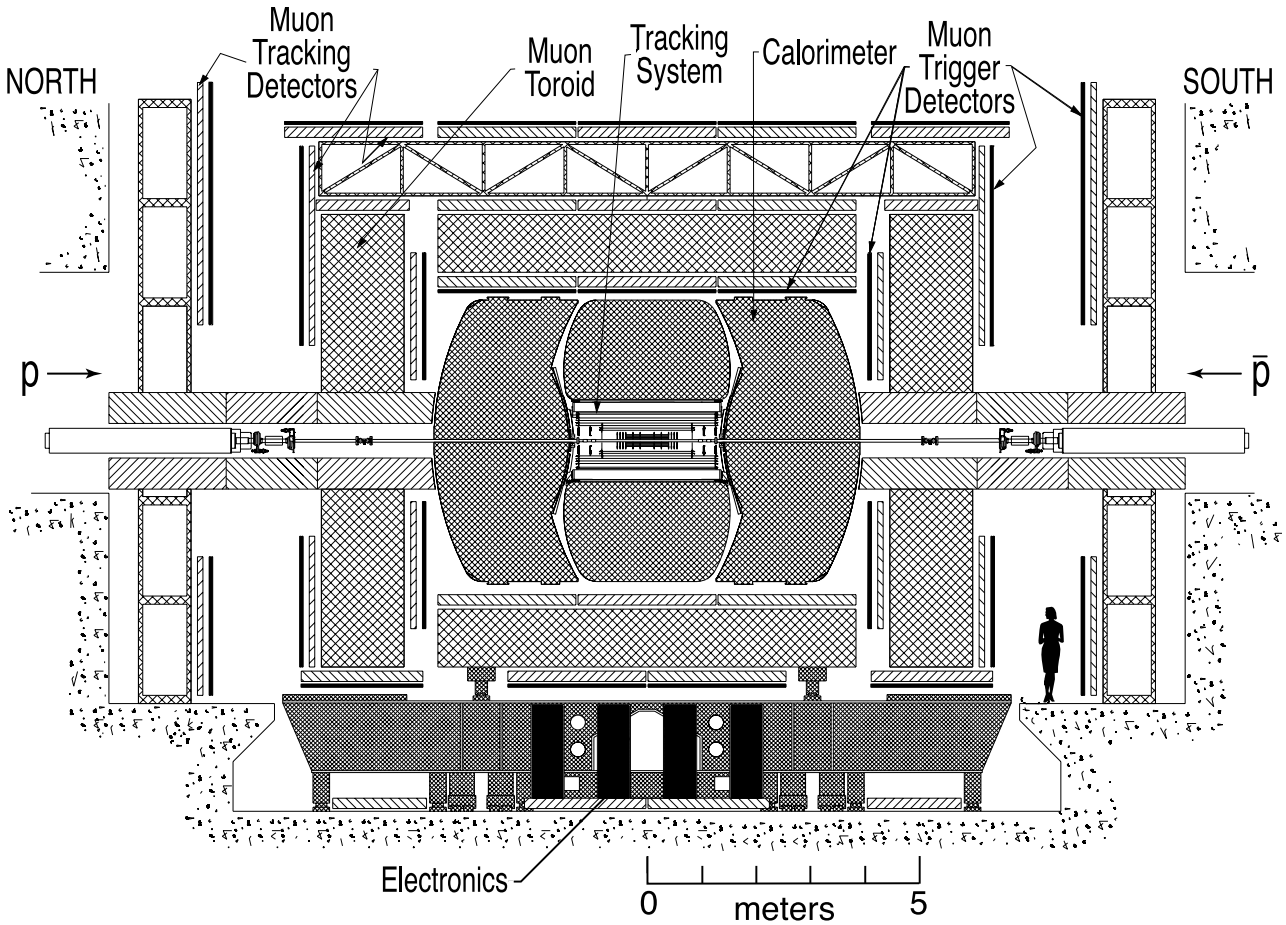
- DØ and Top Quark Introduction.
- Results on the $t\bar{t}$ cross sections measurement, combination and interpretation.
- Observation of the single top quark production.
- Measurements and searches based on the Vtb vertex properties.
- Conclusions.



The Tevatron Accelerator at Fermilab

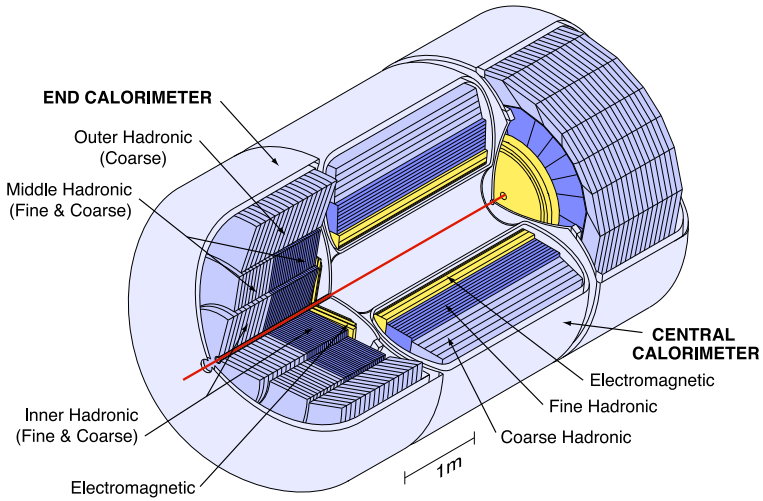
- Tevatron is a $p\bar{p}$ collider operating at $\sqrt{s} = 1.96\,\text{TeV}$.
- Store-begin initial luminosities $\approx 3 \cdot 10^{32}\,\text{cm}^{-2}\,\text{s}^{-1}$
- Run I (1992 – 1996): Run IIa (2001 – 2006, data for this analysis), Run IIb (June 2006 – present)
- Collision rate: $\approx 1.7\,\text{MHz}$, 36×36 bunches at 396 ns spacing.

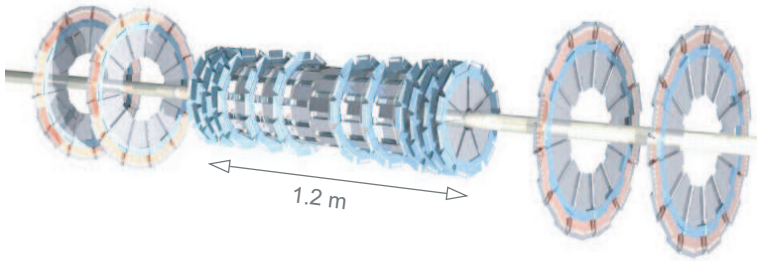
The DØ Detector Overview



- DØ Run II New tracking system in 2 T magnetic field, upgraded Muon Chambers and Calorimeter electronics.
- L1/L2/L3 output rates $\approx$ 2.5 kHz/1 kHz/150 Hz.

The DØ Detector: Tracking, Calorimetry, Muon Chambers



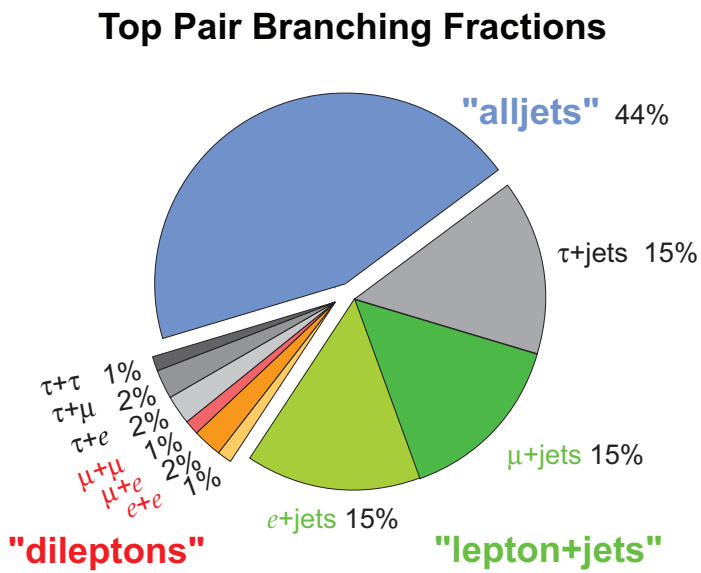


- Silicon Microstrip Tracker + Fiber Tracker: Primary Vertex $\sigma_z \approx 35\,\mu$m, Secondary Vertex impact parameter $\sigma_{xy} \approx 15\,\mu$m.
- EM+Hadronic Uranium/Steel+LqAr Calorimetry covering $|\eta| < 3.0$ (for jets usually $|\eta| < 2.5$) with $\eta \times \phi = 0.1 \times 0.1$ segmentation.
- Muon chambers ($|\eta| < 2.0$).

$t\bar{t}$ Production Cross-section

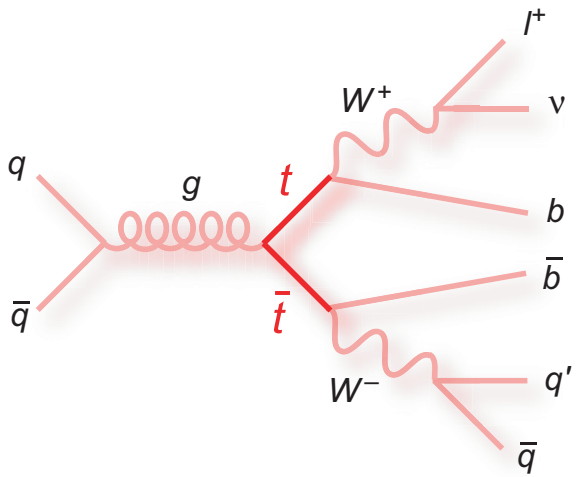
- $t\bar{t}$ pair production tests QCD while the decaying system properties can be used as an electroweak laboratory to search for new physics.
- Top pairs at Tevatron are produced mostly via $q\bar{q}$ anihilation (85%) accompanied by the gg fusion.

- Final state determined by the W decay modes:
  - $\ell\ell$ (good signature, low background, but also low branching fraction)
  - ℓ+jets: ($\ell = e$, μ) larger branching, more background, rich kinematic information.
  - $\tau\ell$: challenging reconstruction, important additional information.
  - Hadronic channels: largest BR, overwhelming background from QCD multijets.

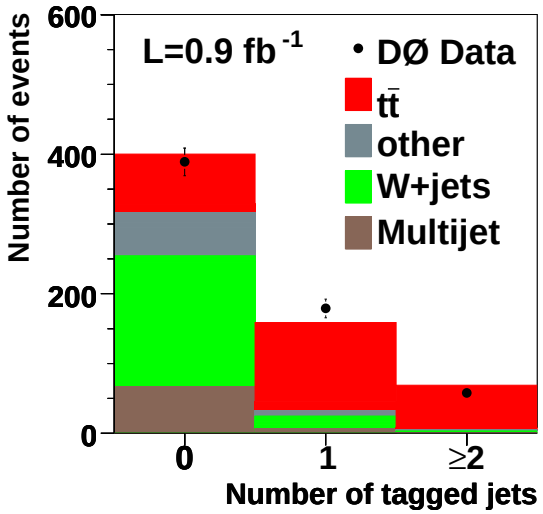


Example: $\sigma_{t\bar{t}}$ in ℓ+jets

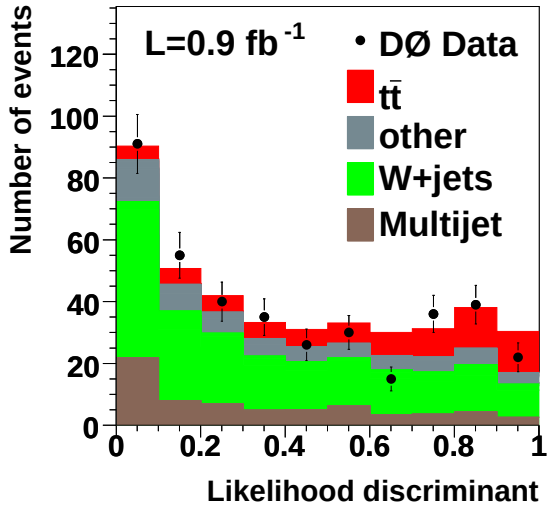
- ℓ+1,2 jets as control, 3 and ≥ 4 jet bins for measurement.
- Require at least one jet as a b-jet using a NN-based tagger.
- Require an isolated lepton and large missing transverse energy.
- Largest physics background: W/Z+jets; include diboson, singletop.
- Simulate most of SM backgrounds, include NLO/LO scale factors.
- Multijet background from data, topological discriminant $\mathcal{D}$ to initially fit the $t\bar{t}$ fraction.



$|f\rangle$ cartoon



n_{tagged} jets in 4jet bin



topological $\mathcal{D}$

Combined $t\bar{t}$ Cross-section

- In total of 14 orthogonal channels, the combined cross-section is fitted using a likelihood function based on Poissons for signal and background yields (sum depends on $\sigma_{t\bar{t}}$) and Gaussians with parameters for allowed coherent systematic shifts.

$$\mathcal{L} = \prod_{i \in \text{subsamples}} \mathcal{P}(n_i, \mu_i) \times \prod_{j \in \text{multijetBG}} \mathcal{P}(n_j, \mu_j) \times \prod_{k \in \text{syst}} \mathcal{G}(\nu_k; 0, 1)\,.$$

- The combined cross-section for the ℓ+jets, $\ell\ell$ and $\tau\ell$ channels $\sigma_{t\bar{t}} = 8.18^{+0.98}_{-0.87}$ pb, with precision systematics-dominated.

- Break-down into individual channels:

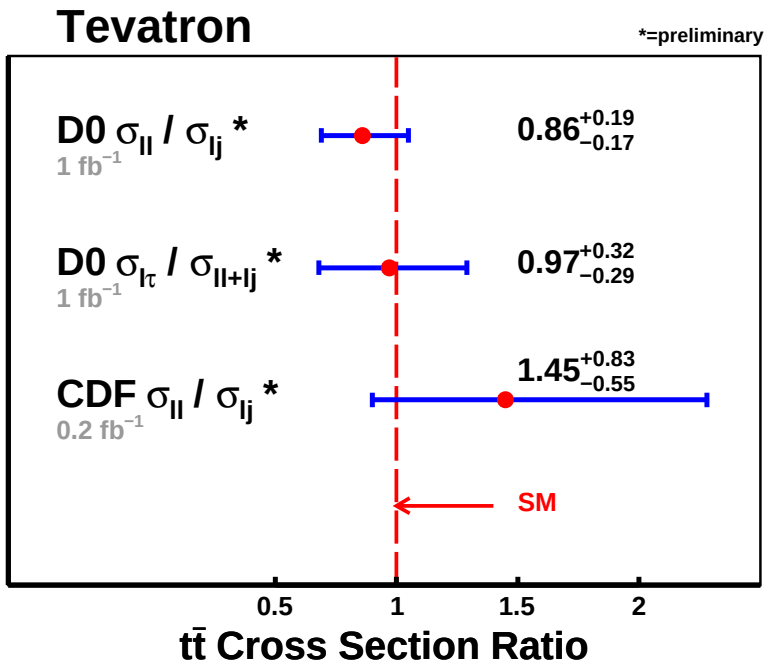
Channel	$\sigma_{t\bar{t}}$
ℓ+jets	$8.46^{+1.09}_{-0.97}$ pb.
$\ell\ell$	$7.46^{+1.60}_{-1.37}$ pb.
ℓ+jets and $\ell\ell$	$8.18^{+0.99}_{-0.87}$ pb.
$\tau\ell$	$7.77^{+2.90}_{-2.47}$ pb.

$t\bar{t}$ Cross-section Ratios

- More thank just a combined cross-section can be achieved!
- Extracted ratios of cross-sections between the channels cancel many systematics

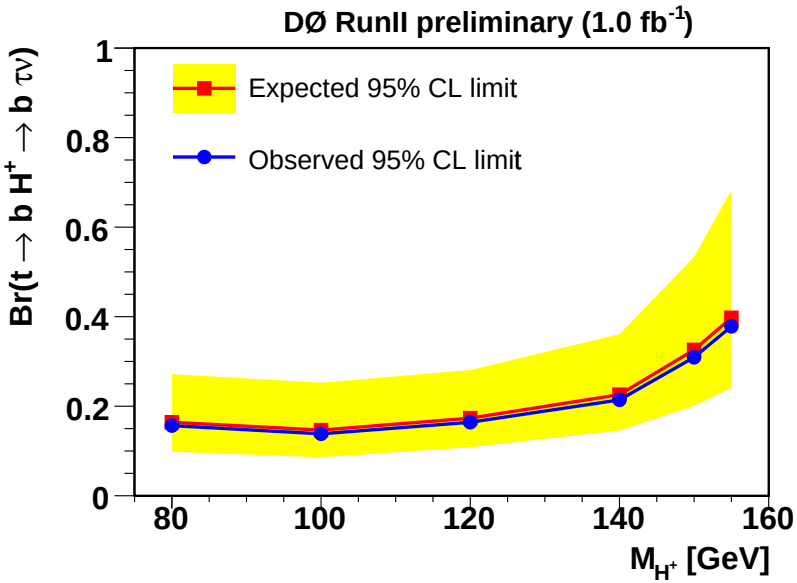
$$R_{\ell\ell/\ell \mathrm{j}} = 0.86^{+0.19}_{-0.17}\,, \qquad R_{\tau\ell/\ell\ell\ell \mathrm{j}} = 0.97^{+0.32}_{-0.29}$$

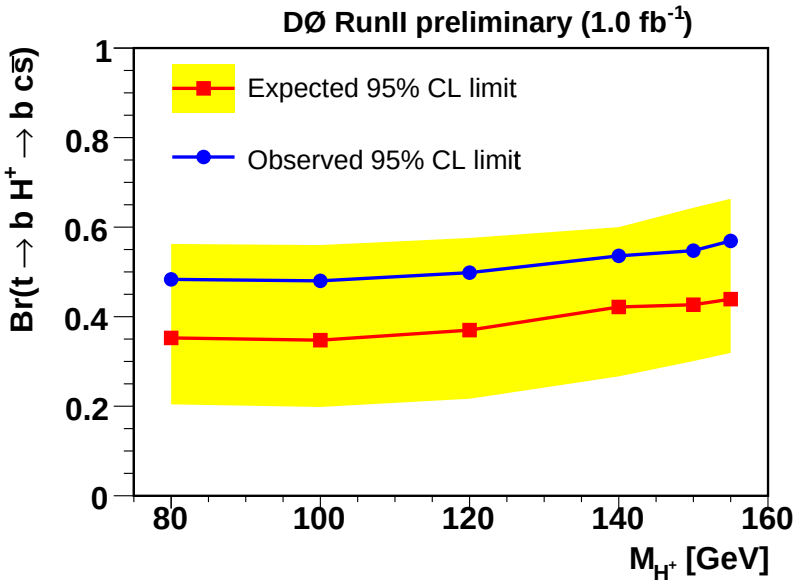
and are consistent with the SM value of 1.



$t\bar{t}$ Cross-section: Implications for Charged Higgs

- Moreover, the measured cross-section ratios can be used to set upper limits on the $B(t \to H^+ b)$ branching ratio.
- Signatures: For $H^+ \to \tau\nu_\tau$: enhanced τ channels ($\Rightarrow$ use $R_{\tau\ell/\ell\ell\ell\mathrm{j}}$)
- For leptophobic $H^+ \to c\bar{s}$: enhanced ℓ+jets channel ($\Rightarrow$ use $R_{\ell\ell/\ell\mathrm{j}}$)
- Expected and observed upper limits:





Submitted to PRD rap. com.

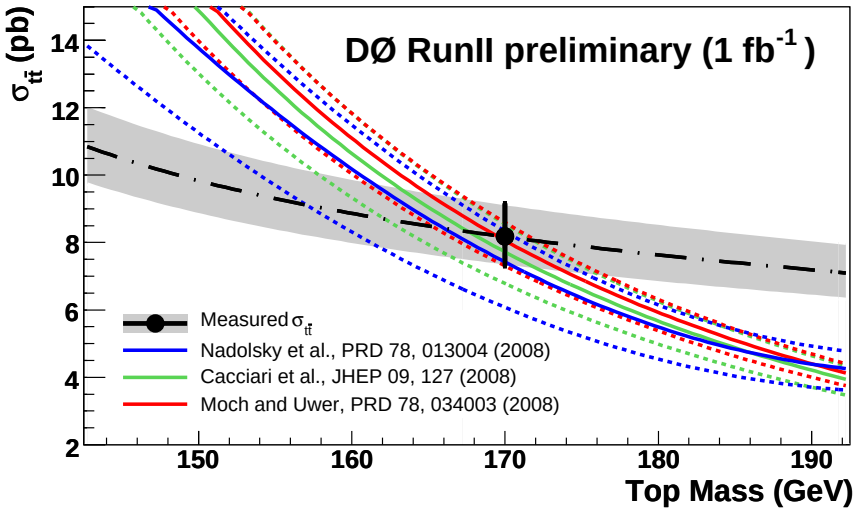
Top Mass from the Cross-section

- Tevatron m_t measurements precise to $\approx 1\,\mathrm{GeV}$, triggering discussions on the definition and interpretations of m_t.
- Complementary information on m_t can be extracted from the $\sigma_{t\bar{t}}(m_t)$ dependence. Different sensitivity to theory and exp. uncertainties.
- Assuming different m_t, the extracted cross-section can be compared to NLO, and approximate NNLO (NLL) calculations.
- m_t definition in calculations is the pole mass; extracted values from $\sigma_{t\bar{t}}$ are in good agreement with the world-average of $173.1 \pm 1.3\,\mathrm{GeV}$.

Calculation	Extracted m_t (GeV)
NLO (1)	$165.5^{+6.1}_{-5.9}$
NLO+NLL (2)	$167.5^{+5.8}_{-5.6}$
approx. NNLO (3)	$169.1^{+5.9}_{-5.2}$
approx. NNLO (4)	$168.2^{+5.9}_{-5.4}$

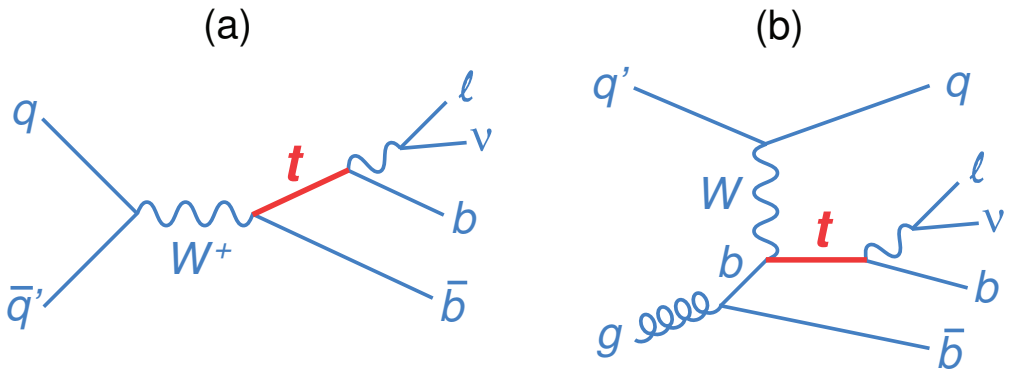
(1) Nadolsky et. al. (2) Cacciari et. al.

(3) Moch–Uwer (4) Kidonakis–Vogt



Single Top Quark Production – Motivation

- Electroweak (single) top quark production had been one of the remaining SM processes to be observed.
- Evidences for single top repoprted by Tevatron colider experiments in 2007 (DØ) and 2008 (CDF).
- Challenging due to much larger background and smaller cross-section.
- Rewarding in providing access to the Vtb vertex properties: a window to new physics!
- Two basic production modes at LO: the s and t-channels.



Single Top Quark Production – Selection

- Select events with an isolated lepton, at least two jets with at least one with $p_{\mathrm{T}} > 25\,\mathrm{GeV}$.
- Missing transverse energy (ν-signature) $> 20(25)$ GeV in two-jet (≥ 3) bin.
- One or two of the jets required to originate from b-hadrons using the secondary vertex information incorporated into a Neural Net b-tagger.
- Selected 4,519 b-tagged events expected to contain 223 ± 30 single top events.
- Acceptances are 3.7% (2.5%) for tb (tbq).
- Expected signal fraction: 3–9%, smaller than background uncertainty $\Rightarrow$ multivariate techniques needed.

Single Top Quark Production – Three Methods

- Boosted Decision Trees, Bayesian Neural-Network, Matrix Element: give consistent results, about 50-60% correlated.
- SM prediction: 3.46 ± 0.18 pb.

		Significance	
Method	Cross-section	Expected	Observed
BDT	$3.74^{+0.95}_{-0.79}$ pb	4.3	4.6
BNN	$4.70^{+1.18}_{-0.93}$ pb	4.1	5.2
ME	$4.30^{+0.99}_{-1.20}$ pb	4.1	4.9

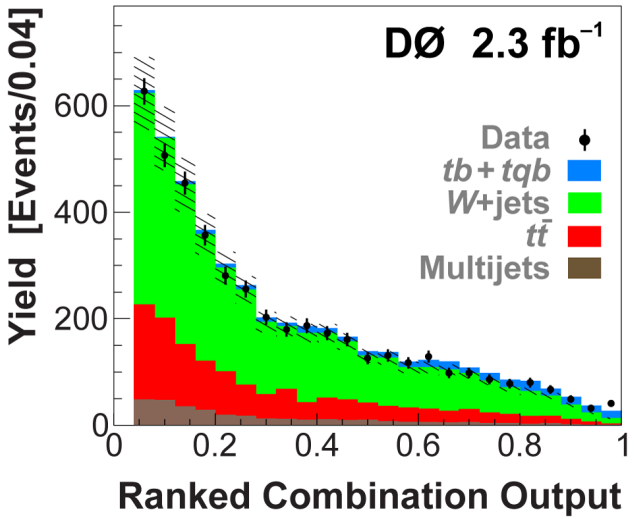
Event Yields in 2.3 fb^{-1} of DØ Data	
e,μ, 2,3,4-jets, 1,2-tags combined	
tb + *tqb*	223 ± 30
W+jets	2,647 ± 241
Z+jets, dibosons	340 ± 61
$t\bar{t}$ pairs	1,142 ± 168
Multijets	300 ± 52
Total prediction	4,652 ± 352
Data	4,519

- Challenge: Expected signal smaller than background uncertainty!

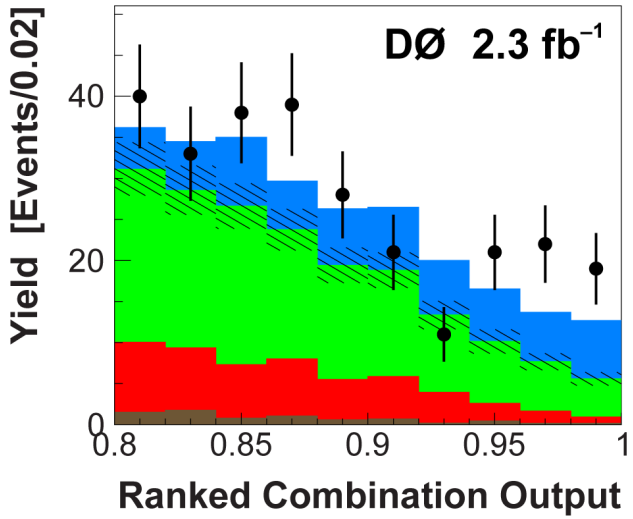
Single Top Quark Production – Three Methods Combined

- The three methods combined into a combined discriminant.

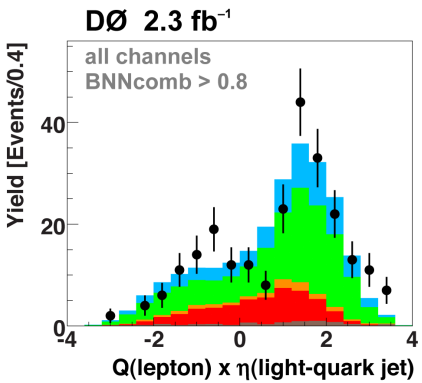
Final Discriminant

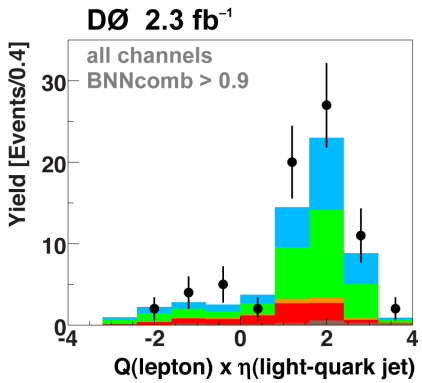


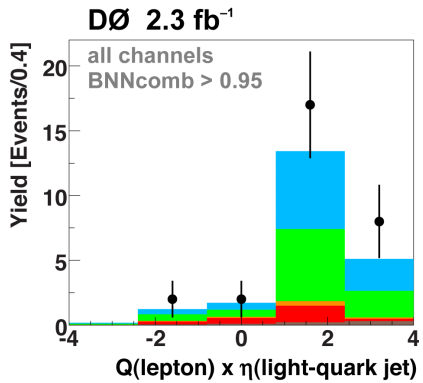
Signal Region



- Signal fraction enhanced as cutting away non-signal region:

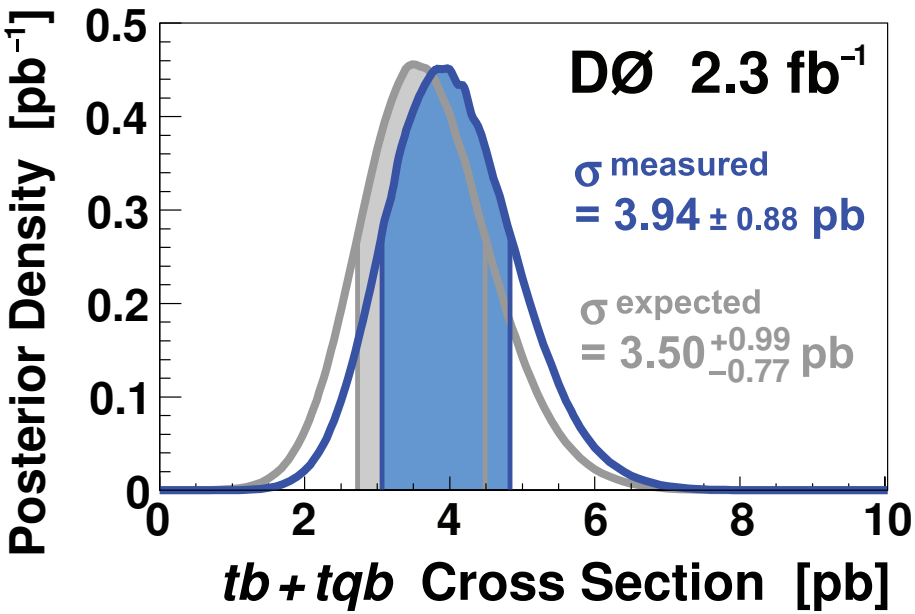




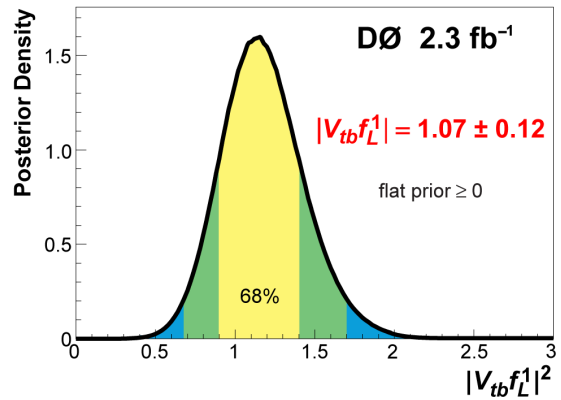


Single Top Quark Production – The Observation

- Based on the luminosity of 2.3 fb^{-1} collected by the DØ detector.
- Combined cross-section: $\sigma(p\bar{p} \to tb + X,\, tbq + X) = 3.94 \pm 0.88$ pb
- Probability to measure such cross-section or higher in absence of signal is 2.5×10^{-7}, corresponding to $5.0\,\sigma$ significance.
- Pseudoexperiments sampling the background with no signal used to measure the expected cross-section.



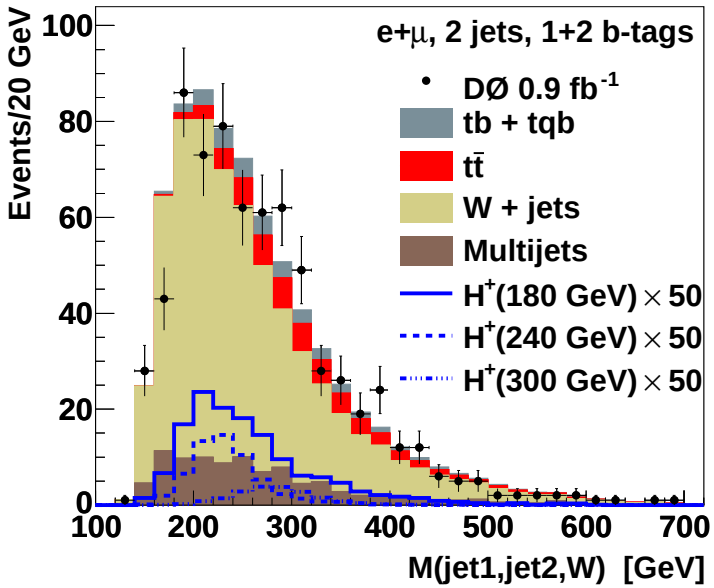
- Extract Bayesian posterior to set limit $|V_{tb}| > 0.78$ at 95% C.L.
- With upper bound removed, we measure $|f_1^L\, V_{tb}| = 1.07 \pm 0.12$.

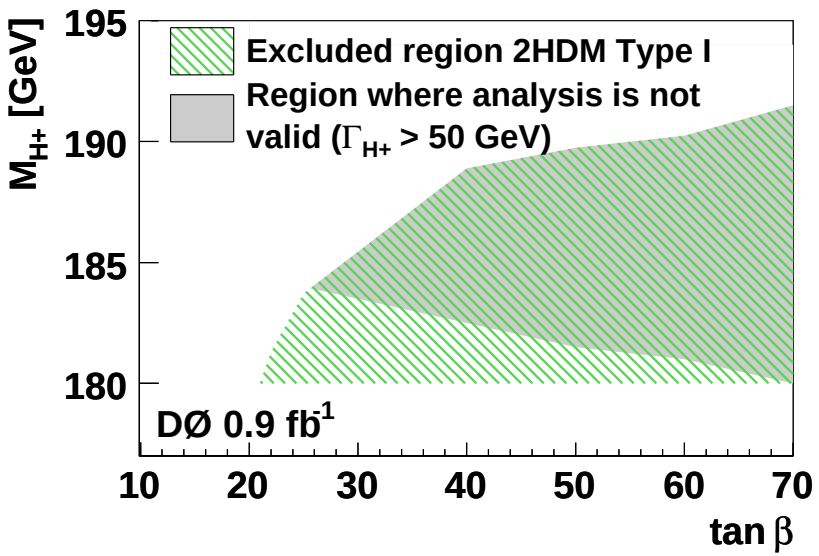


Single Top Quark – Searches For New Physics I

- **Search for charged Higgs bosons decaying to top and bottom quarks in $p\bar{p}$ collisions.**
- The same final state as single top.
- Using the "evidence dataset" of $0.9\,\mathrm{fb}^{-1}$.

arXiv:/0807.089 [hep-ex]



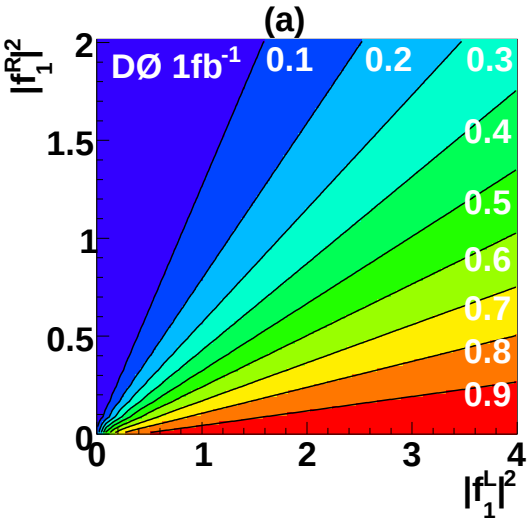


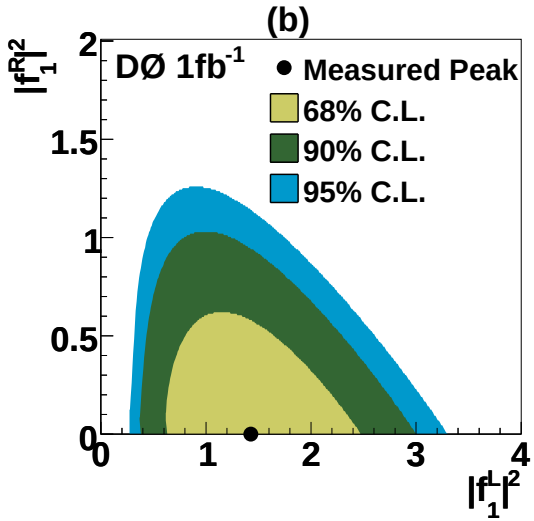
Single Top Quark – Searches For New Physics II/1

- **Search for anomalous top quark couplings with the DØ detector**
- Probing the Vtb vector and tensor vertex structure

$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}V_{tb}\left(f_1^L\mathcal{P}_L + f_1^R\mathcal{P}_R\right)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\,\mathrm{i}\sigma^{\mu\nu}q_{\nu}V_{tb}\left(f_2^L\mathcal{P}_L + f_2^R\mathcal{P}_R\right)tW_{\mu}^{-} + \text{h.c.}$$

- Combines the W-helicity measurement in $t\bar{t} \to \ell + \text{jets}$, $\ell\ell b\bar{b}$ transtaled into anomalous couplings (AC) prior (constrains the ratios of f's), and the AC measurement in single top production (AC changes rate as well as kinematics) using the "evidence dataset" of $0.9\,\text{fb}^{-1}$ with Boosted Decision Trees multivariate technique.

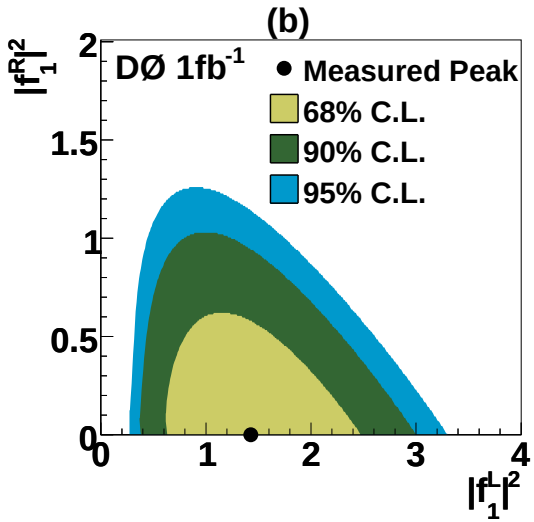


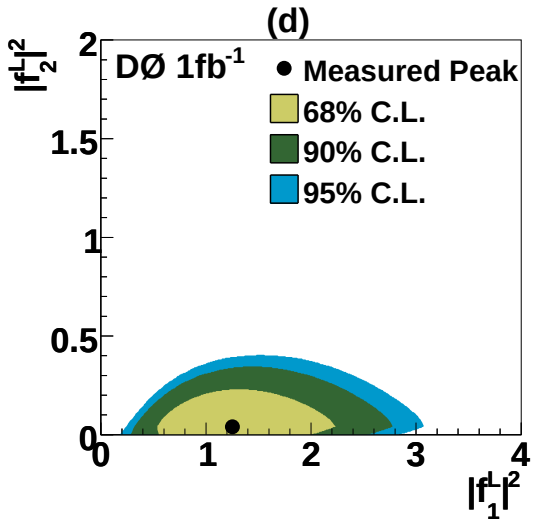


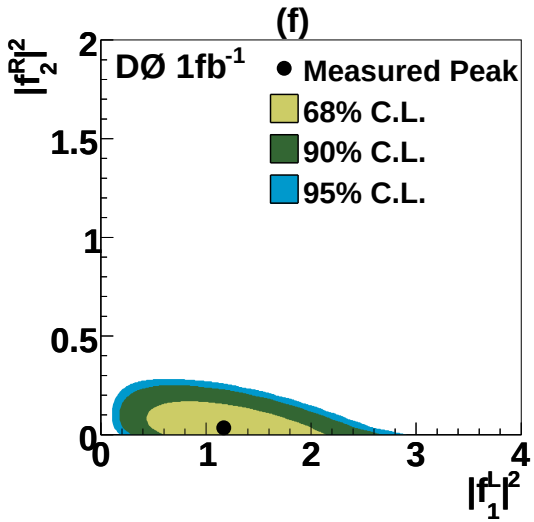
Single Top Quark – Searches For New Physics II/2

- **Search for anomalous top quark couplings with the DØ detector**
- W-helicity prior from independet channels improves the limits.
- SM: $f_1^L = 1$, $f_1^R = f_2^L = f_2^L = 0$.

Phys. Rev. Lett. 102, 092002 (2009)







Limits:

$|f_1^R|^2 < 1.01$ $|f_2^L|^2 < 0.28$ $|f_2^R|^2 < 0.23$

Conclusions

- Many exciting results with the growing Tevatron statistics.
- Observation of the single top production opens new ways in direct studies of the Vtb vertex properties.
- Precise top pairs production cross-section measurement errors become comparable to theory predictions and results from multiple channels are used to set limits on charged Higgs branching ratios as well as serve as top quark mass measurement cross-check.