Top Production at the Tevatron

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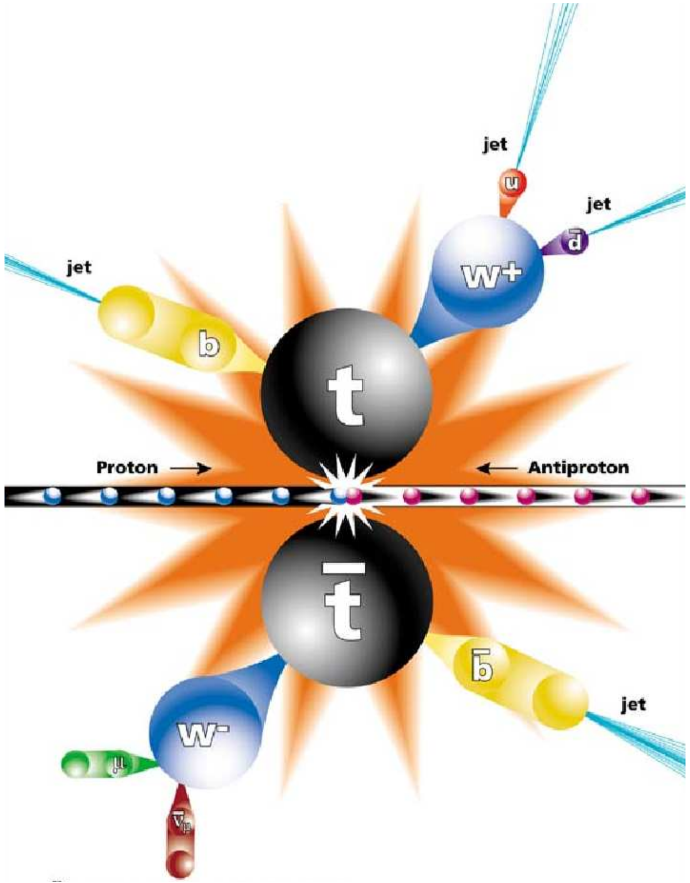
Outline

- Introduction
- Top pair production
- Single top production

Introduction

The Top Quark

- Discovered by CDF and DØ in 1995.
- Completes set of quarks in SM.
- Quantum numbers as for up-type quarks.
- Production and decay properties fully determined within SM.
- Mass is the only free parameter

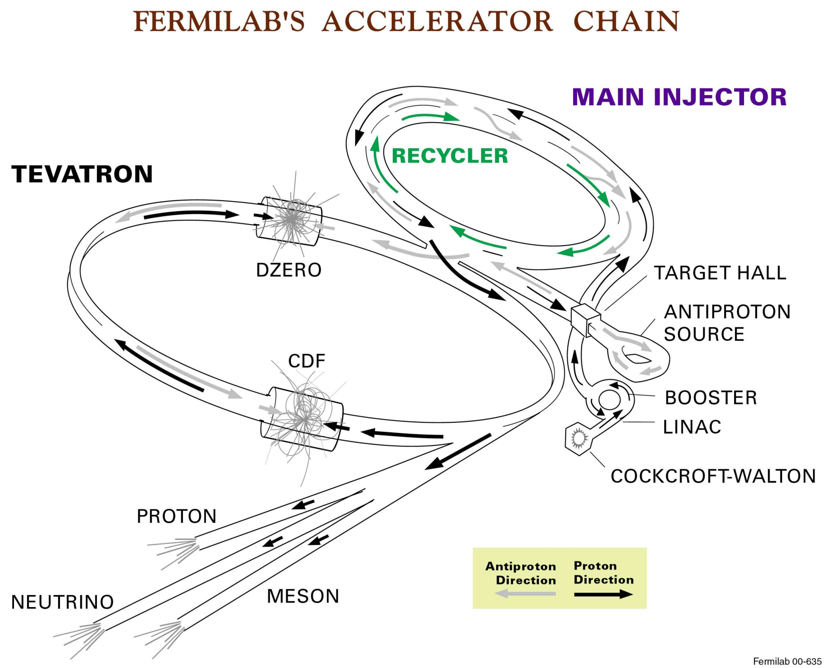


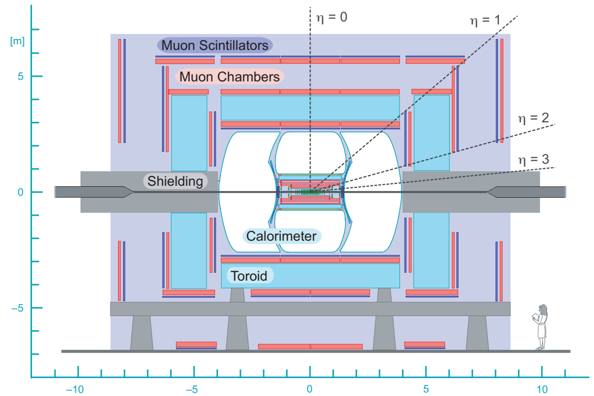
Proving these properties establishes the SM top quark;
Disproving them yields new phyiscs

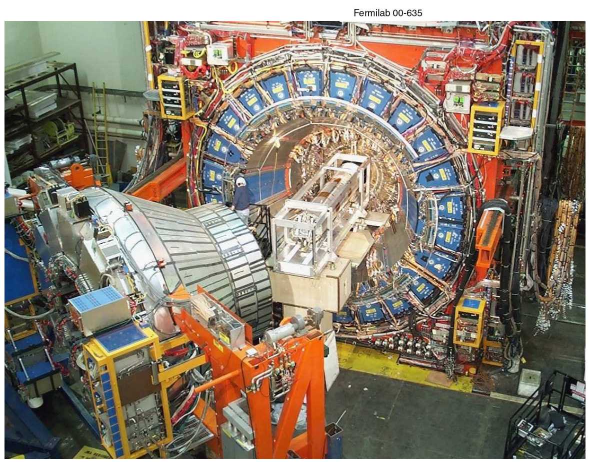
The $p\bar{p}$ Accelerator Tevatron

- Circumfence 6.4 km.
- $p\bar{p}$ collisions
- Run I (1987-1995)
- Run II (since 2001)
  Collision energy 2 TeV
- 2 experiments,
  CDF and DØ,
  record events.

  $\mathcal{L} \sim 7\,\text{fb}^{-1}$ on tape.
  Today: upto $\sim 4.8\,\text{fb}^{-1}$

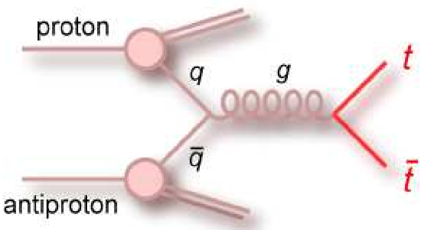




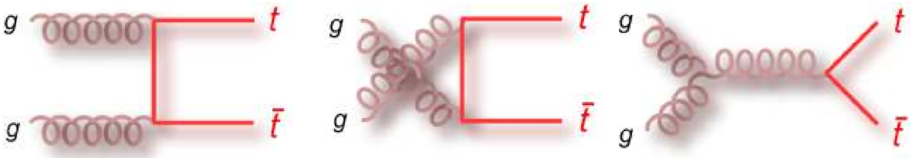


Top Quark Production at the Tevatron

Strong top production



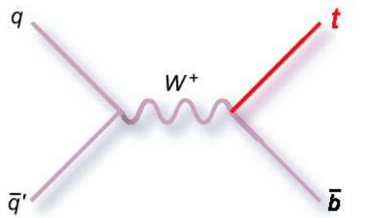
$$85\% \quad q\bar{q} \to t\bar{t}$$
$$15\% \quad gg \to t\bar{t}$$



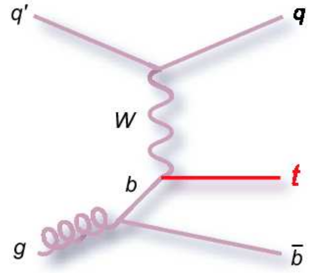
$\sigma(t\bar{t}) \simeq 7.46$pb

Moch and Uwer; $m_t = 172.5$ GeV
PRD 78, 034003 (2008)

Weak top production



Drell-Yan
s-channel



W-g fusion
t-channel

$\sigma(t) = 3.46$pb $= 1.12$pb$+2.34$pb

Kidonakis; $m_t = 170$ GeV
PRD 74, 114012 (2006)

Per integrated luminosity of $\sim 1\,\text{fb}^{-1}$
around 7000 top pairs and 3500 single tops expected.

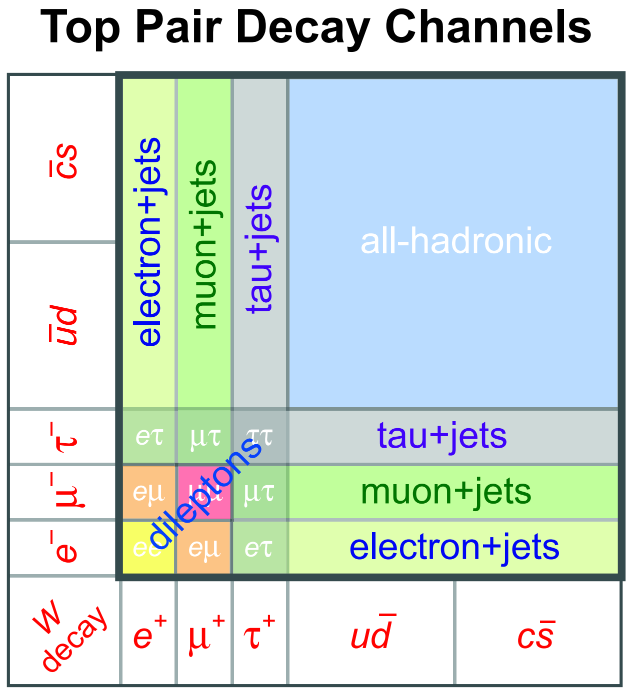
Top Quark Decay

Top quarks decay to bW (nearly) 100%.

Pair Production Signatures

Decay modes are defined by W-decays:

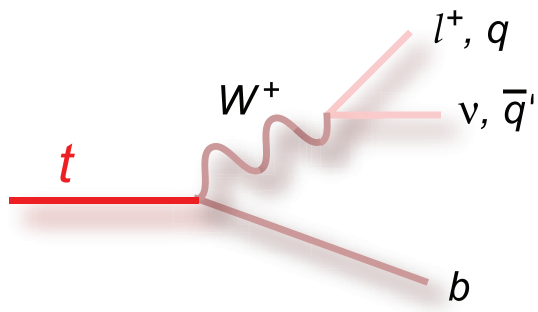
- Dilepton $(2b + 2l + 2\nu)$
- Lepton+jets $(2b + 2q + l\nu)$
- Alljets $(2b + 4q)$



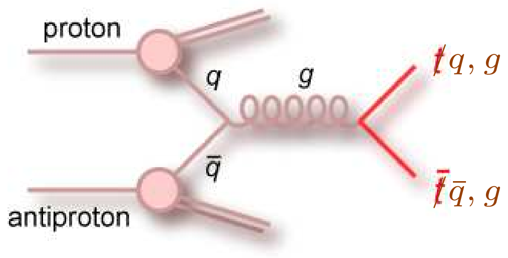
Single Top Signatures

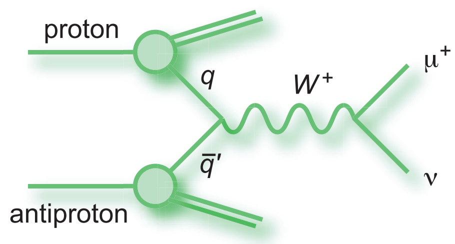
Defined by W-decays and channel;
e.g. leptonic decay:

- s-channel $(2b + l + \nu)$
- t-channel $(b + q + l + \nu)$



Top Quark Pair Production



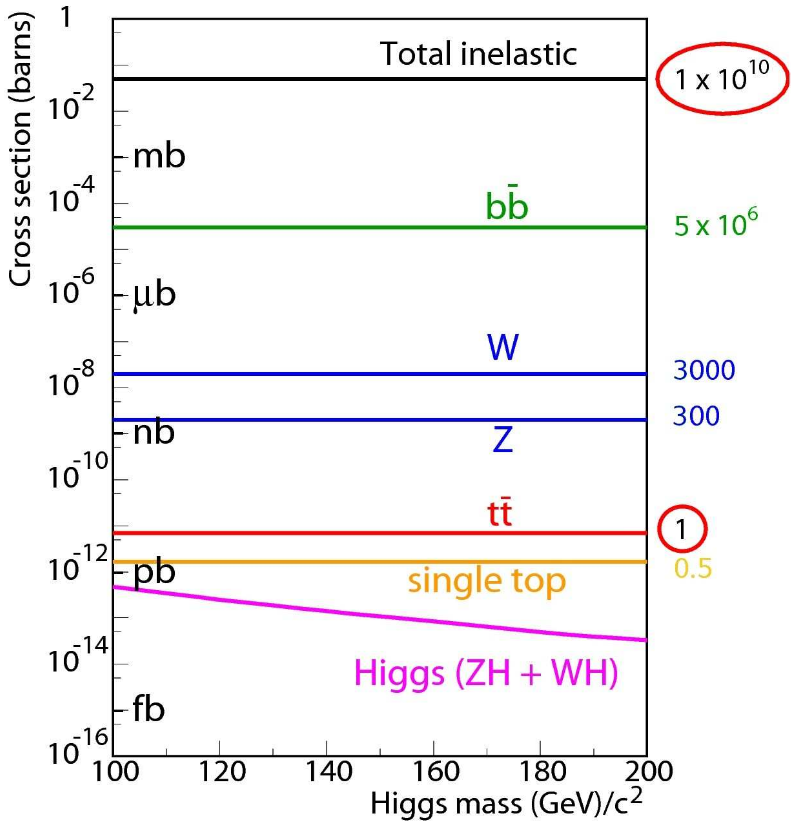


Dominant backgrounds

Same signature / jets faking ℓ or $\not\!\!E_T$

- Multijet events
  ($q\bar{q}$ or gg + gluon radiation)
- W+jets
- Z+jets

the "+jets" helps suppression.



Simulation of multijet events
and of fake rates difficult/unprecise

⇒ Estimation from data.

Top Cross-section over Z Cross-section (CDF: $4.6/4.3\,\mathrm{fb}^{-1}$)

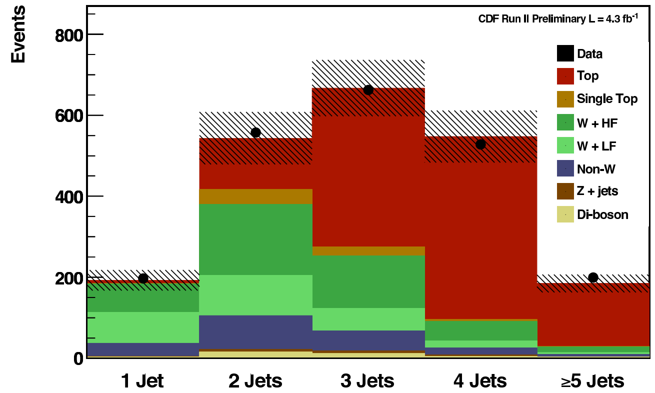
In ℓ+jets channel luminosity uncertainty dominating $\Rightarrow$ measure ratios.

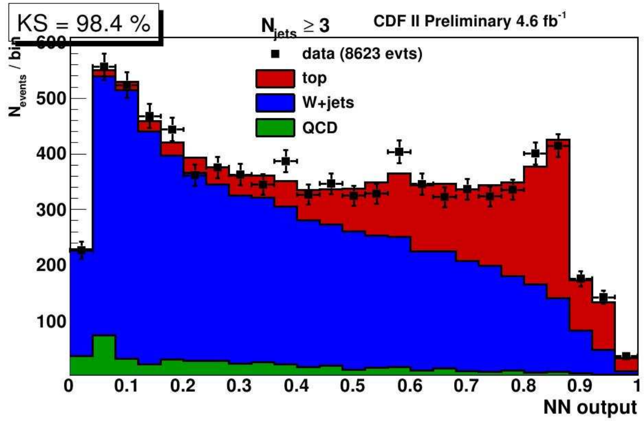
Top Pair

Isolated e or μ, $\not\!\!E_T$ and ≥ 3 jets

a) with identified b-jet:
Backgrounds from data before tagging

b) with topological neural net:
Backgrounds from fit to neural net shapes





Z Boson

- Dilepton events with $66\,\mathrm{GeV} < m_{\ell\ell} < 116\,\mathrm{GeV}$

Results

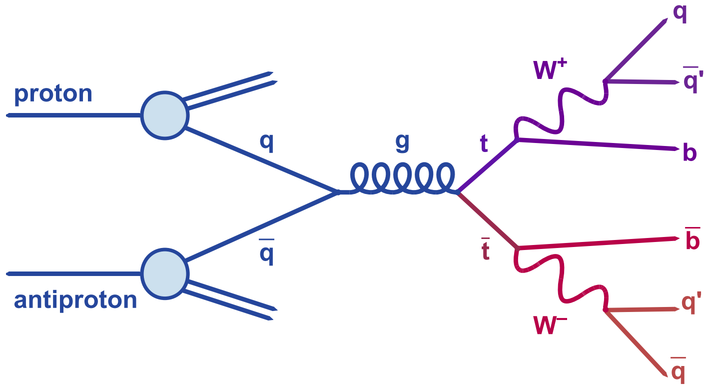
Use theory $Z \to \ell\ell$ cross-section

a) $\sigma_{Z\to\ell\ell}/\sigma_{t\bar{t}} = 35.7 \quad \Rightarrow \quad \sigma_{t\bar{t}} = 7.14 \pm 0.35_{(\mathrm{stat})} \pm 0.58_{(\mathrm{syst})} \pm 0.14_{(\mathrm{theory})}$pb

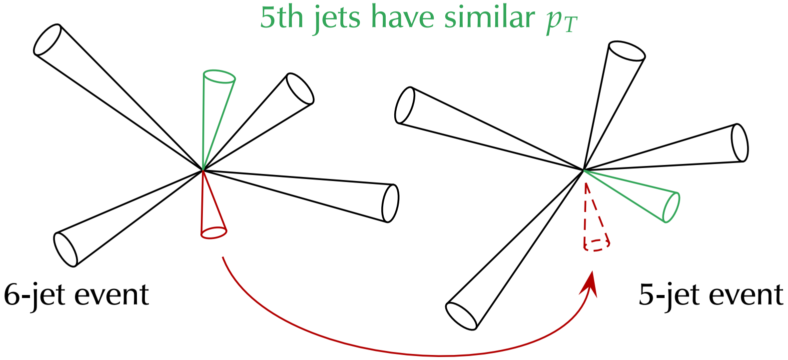
b) $\sigma_{Z\to\ell\ell}/\sigma_{t\bar{t}} = 33.0 \quad \Rightarrow \quad \sigma_{t\bar{t}} = 7.63 \pm 0.37_{(\mathrm{stat})} \pm 0.35_{(\mathrm{syst})} \pm 0.15_{(\mathrm{theory})}$pb

No luminosity uncertainty; 7.0% total uncertainty

Top Cross-section in Alljets Channel (DØ: $1.0\,\text{fb}^{-1}$)

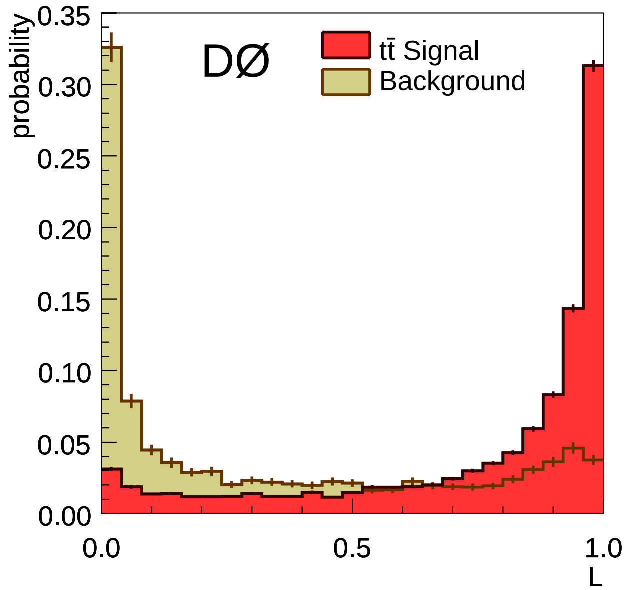


- Select 6-jet events with 2 b-tags
- Background model



⇒ put 6th jet in 5-jet event

  - from 4 and 5jet events adding one jet
  - validated by comparing $4+1$ to 5-jet



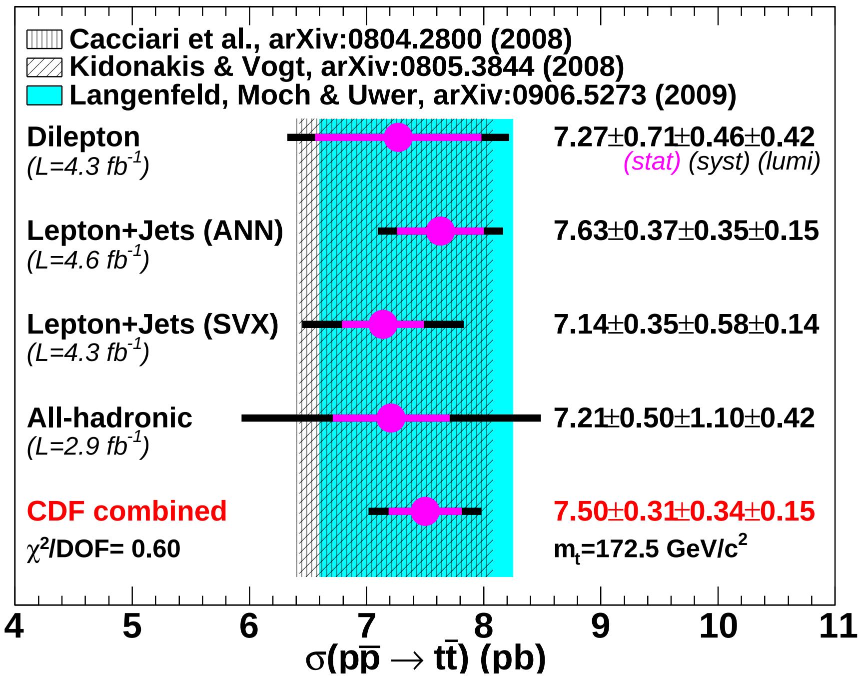
- Cross-section from fit to likelihood

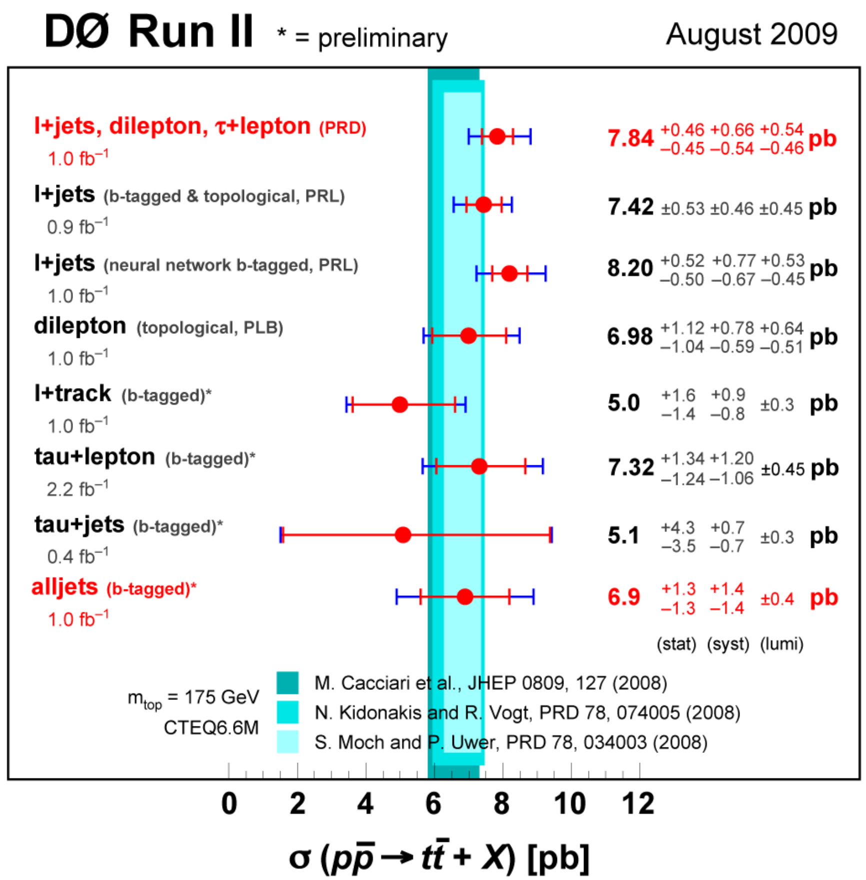
$\sigma_{t\bar{t}} = 6.9 \pm 1.3(\text{stat}) \pm 1.4(\text{syst}) \pm 0.4(\text{lumi})\text{pb}$

Overview of Cross-section Results

- Efficiencies depend on top mass
- Results given for $m_t = 172.5$ GeV (CDF) and $m_t = 175$ GeV (D0)
- Good agreement between channels

CDF

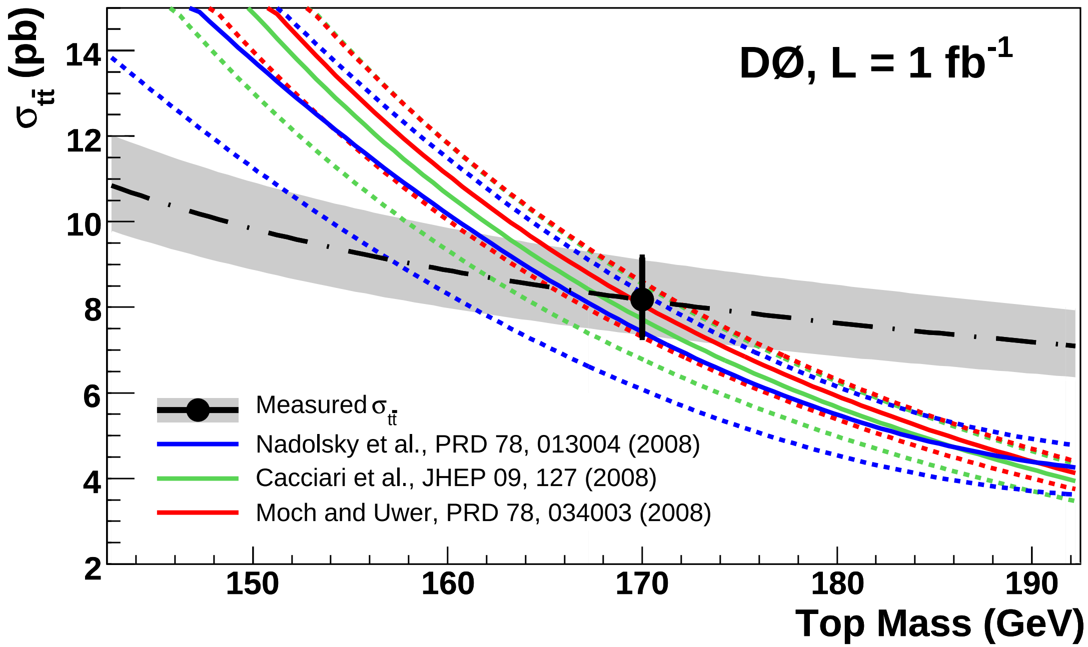




Reached 6.5% total uncertainty

Top mass from cross-section (DØ: $1\,\mathrm{fb}^{-1}$)

- $\sigma_{t\bar{t}}$ depends on the top mass.
- Both the theoretical prediction and the experimental measurements.
- l+jets, dilepton & τ+lepton: $m_t^{\mathrm{Pole}} = 169.1^{+5.9}_{-5.2}$ GeV



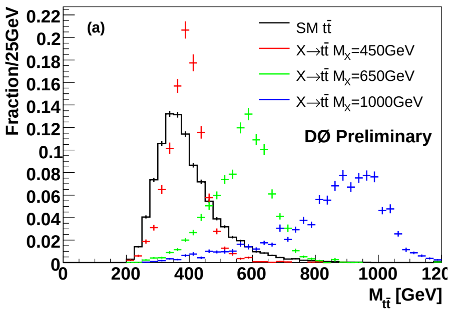
Larger uncertainty, consistent with direct results (see G. Compostella)

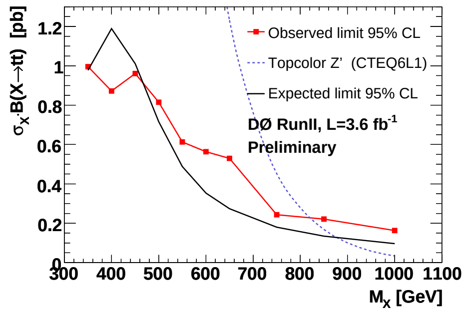
Resonant Top Pairproduction

No resonant top production in SM

Some models contain heavy resonances with decay to $t\bar{t}$

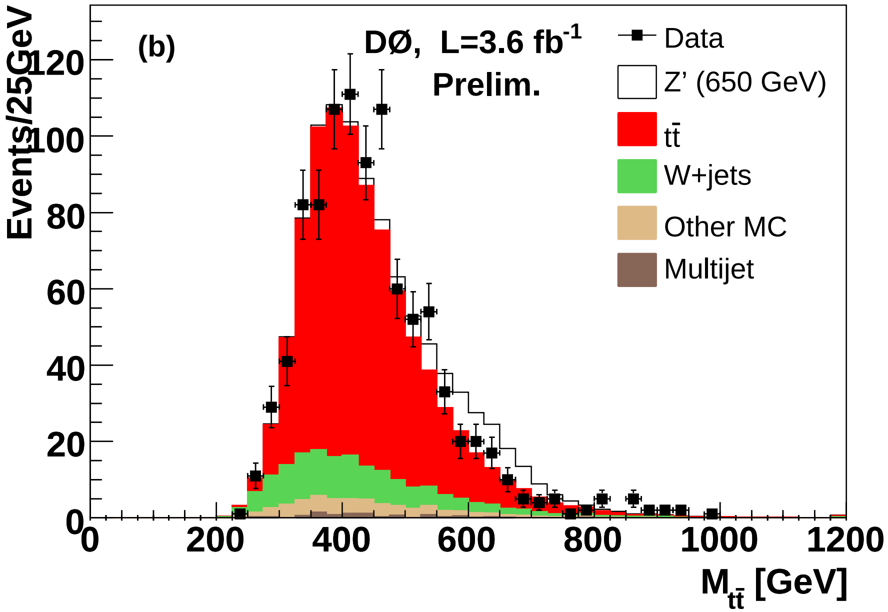
Visible in invariant mass $\dfrac{\mathrm{d}\sigma}{\mathrm{d}M_{t\bar{t}}}$





Search for narrow resonances

- DØ: $M_{t\bar{t}}$ from direct reconstruction
- No significant deviations.
- Limits on $\sigma_X \mathcal{B}(X \to t\bar{t})$.



E.g. topcolor-assisted technicolor:

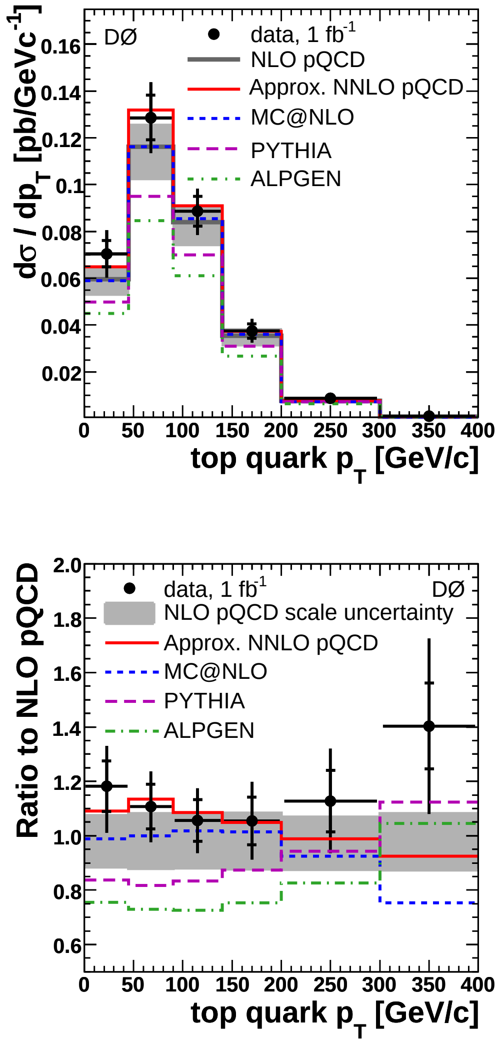
DØ: $M_{Z'} > 820\,\mathrm{GeV}$ (expected 870 GeV)

(DØ: $L = 3.6\,\mathrm{fb}^{-1}$; CDF with $2.8\,\mathrm{fb}^{-1}$: $M_{Z'} > 805\,\mathrm{GeV}$)

Unfolded Differential Cross-section (DØ: $1.0\,\text{fb}^{-1}$)

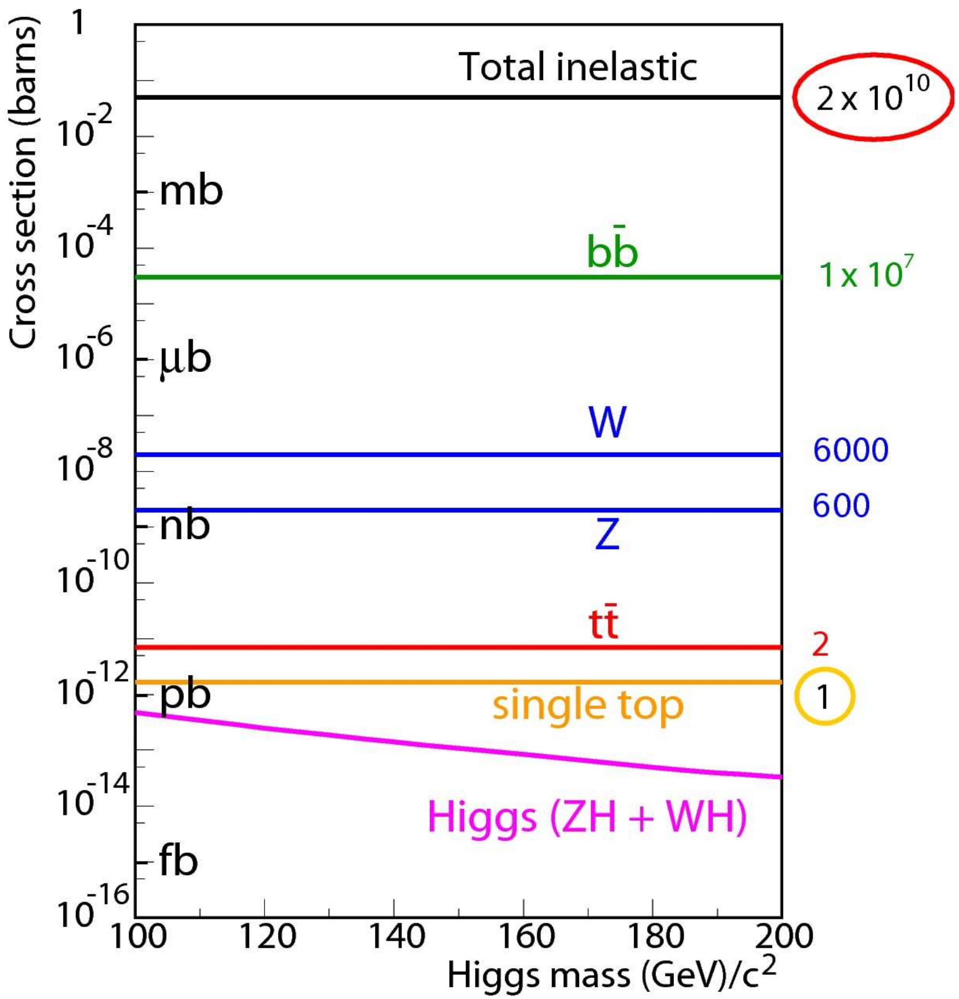
- ℓ+jets events with at least one b-tag
- Kinematic fit used to reconstruct top quark $p_T(t)$
  - Constraints: $2 \times W$-mass, and $m_t = m_{\bar{t}}$
  - Use best jet-parton assignment with best χ^2
- Background is subtracted
  - W+jets measured in events "before" b-tagging
- Regularised unfolding applied to determine $\frac{d\sigma}{dp_T}$

Approx. NNLO and MC@NLO show best agreement
Pythia and Alpgen get observed the shape at high-p_T



Single Top Quark Production

$$\sigma_{t\bar{t}} = \frac{N - B}{\varepsilon \mathcal{L} \cdot \mathrm{BR}}$$



Physics background

- Multijet ($q\bar{q}$ or gg + gluon rad.)
- W+jets
- Z+jets

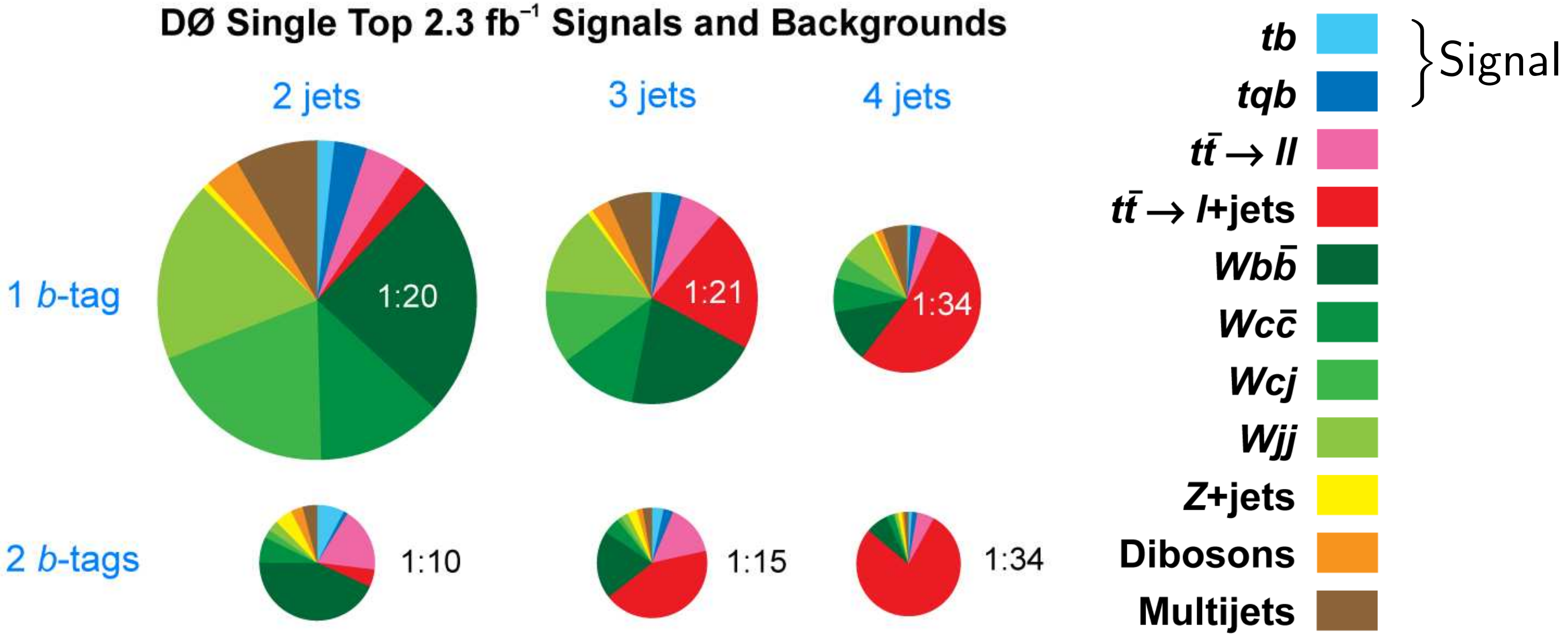
Instrumental background

- Physics object misidentification
- Mismeasurement of energies

Small, but amplified by cross-section.

Single Top Selections

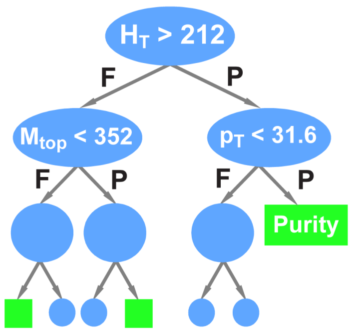
D0 (as an example) requires a lepton, $\not{E}_T$, 2-4 jets at least one identified b-jet:

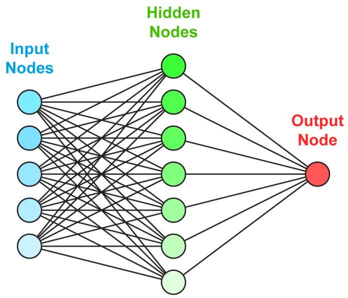


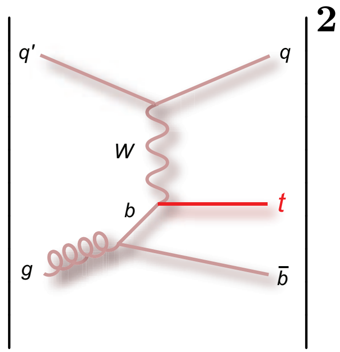
(Area is proportional to sample size)

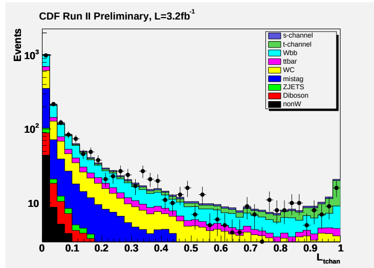
- Signal to Background after selection $1:10$ at best.
- Both experiments employ multivariate techniques

Multivariate Analyses

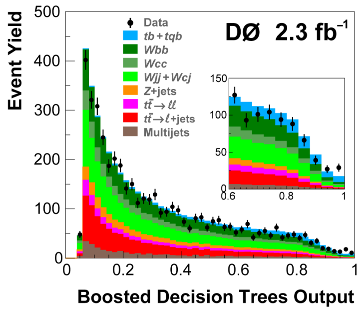


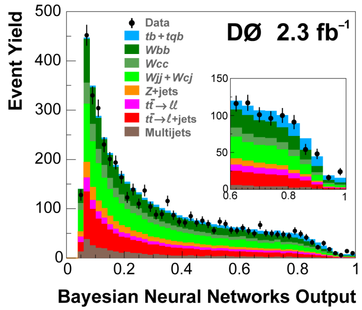


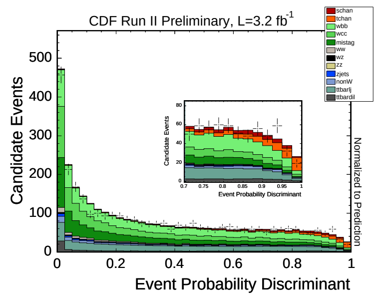


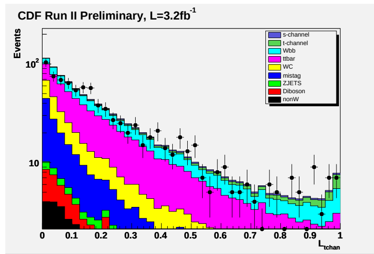


Boosted Dec. Trees | Neural Networks | Matrix Element | Likelihood





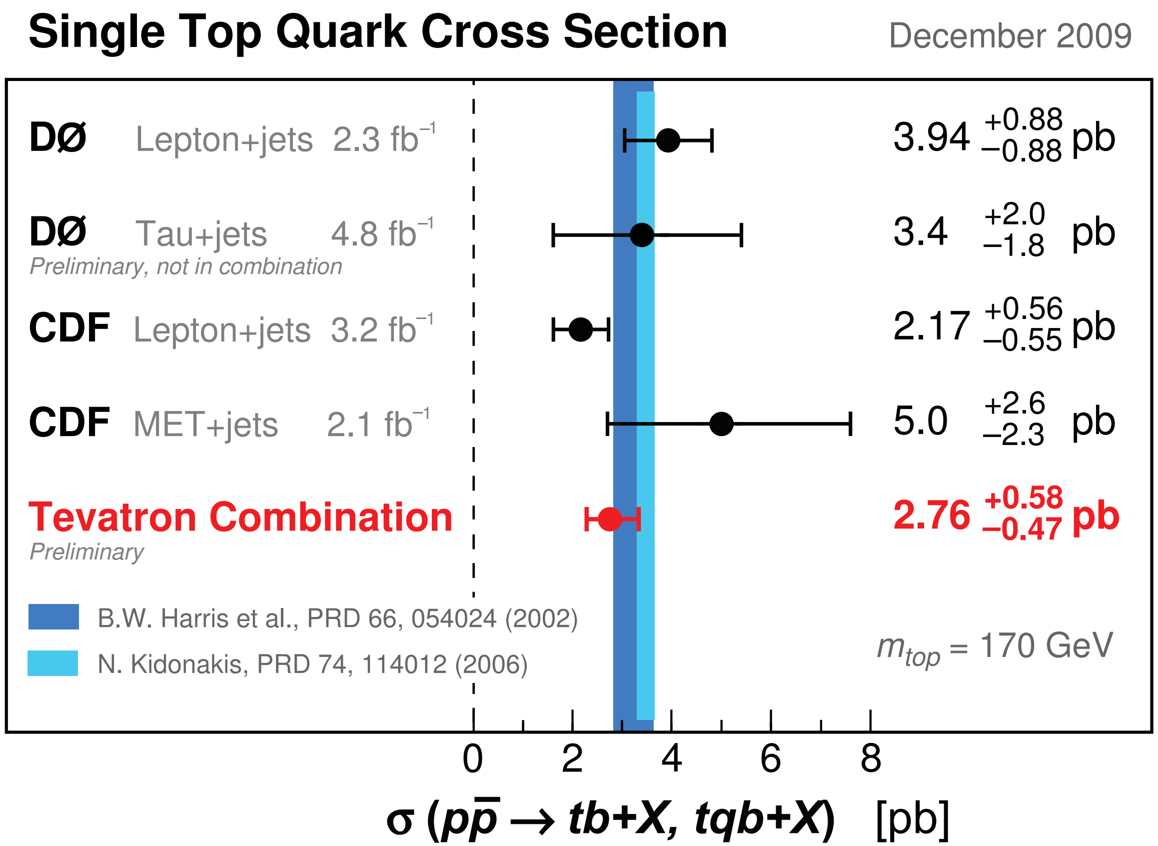


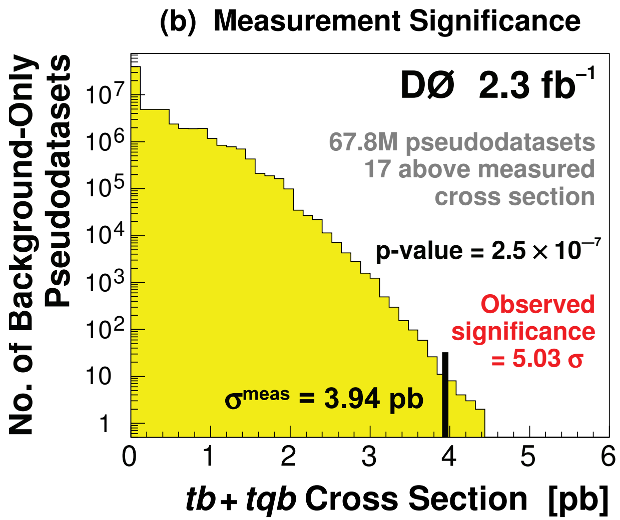


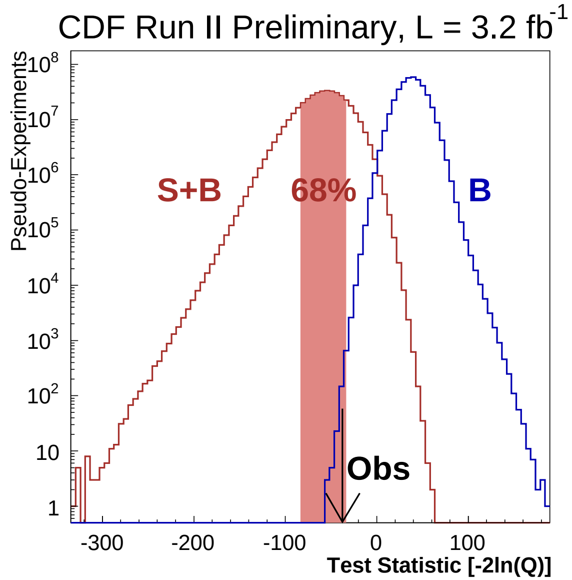
- Each analysis provides a separate measurement of the single top cross-section
- Different multivariate techniques "find" different single top events
- Combination of these analyses improves the significance

Single Top Cross-Section Result

- CDF&DØ observe single top with 5.0σ significance
- Measured cross-sections agree at 1.6σ level
- Since last year new channels were added:







Single Top in τ+jets (DØ: $4.8\,\text{fb}^{-1}$)

- Identify hadronic τ with boosted decision trees
- Based on track quantities, calorimeter energies and shower shapes motivated by

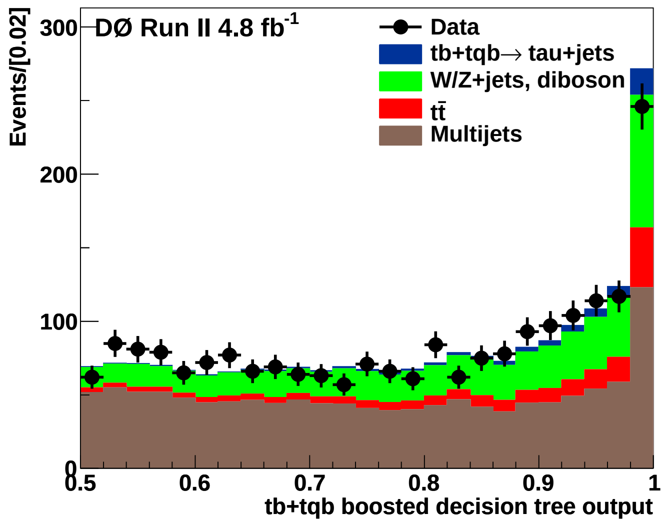
a) $\tau \longrightarrow \pi^{\pm} + \nu_\tau$
b) $\tau \longrightarrow \rho^{\pm} + \nu_\tau$
c) $\tau \longrightarrow 3\pi^{\pm} + \nu_\tau(+\pi^0)$

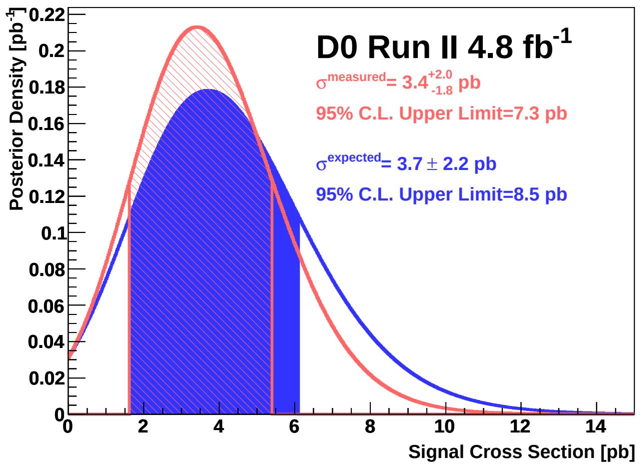
- Training samples constructed from data

τ selection efficiency: $59 \dots 76\%$ at 98% rejection

Then BoostedDT single top analysis performed:

Sensitivity: 1.8σ Observed: $\sigma(t) = 3.4^{+2.0}_{-1.8}$pb





Interpretation as V_{tb}

Assuming SM couplings V_{tb} can be derived:

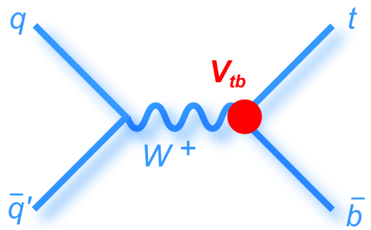
CDF & D0 combined $|V_{tb}| = 0.88 \pm 0.07$

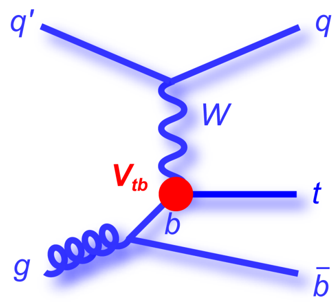
Reduction to physical range yields

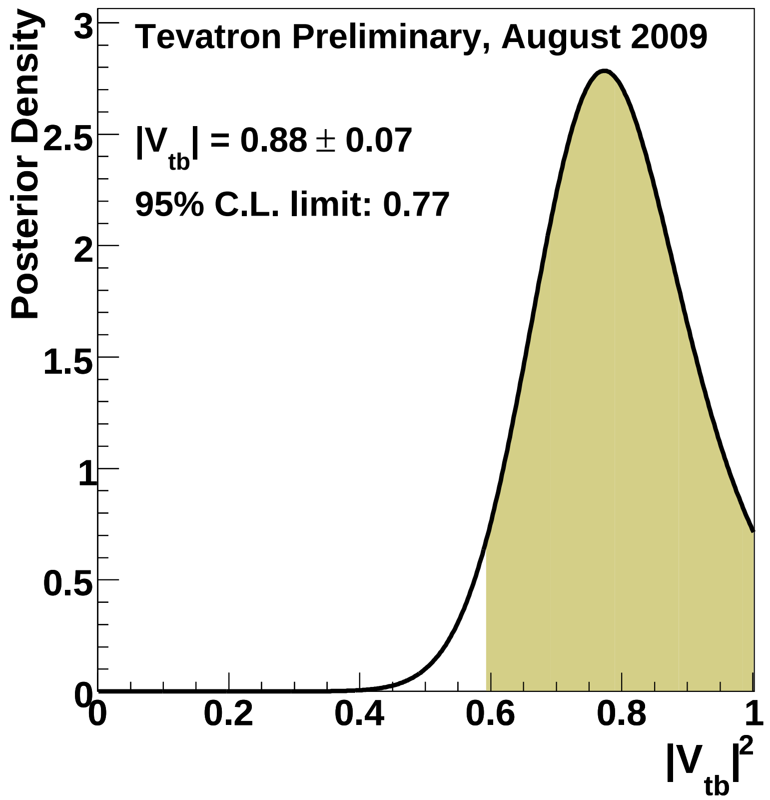
$|V_{tb}| > 0.77$ at 95%C.L.

with no assumption
on the number of generations.

Reminder:
In top pair production *for three generations*
$|V_{tb}| > 0.88$ can be achieved

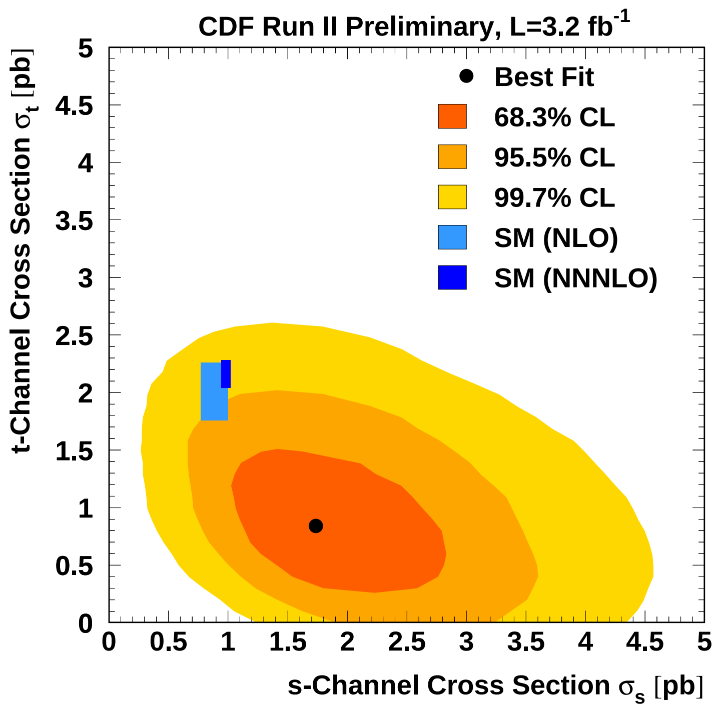


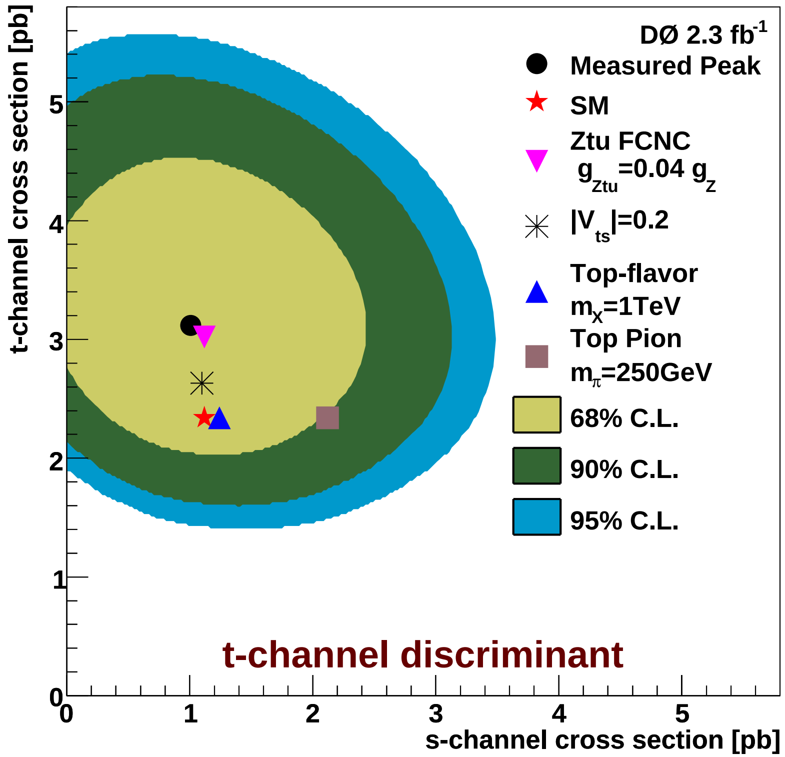




Two Dimensional Results and t-Channel Measurement

- s- and t-channel can be fitted simultaneously
- Results consistent with SM at $1-2\sigma$-level



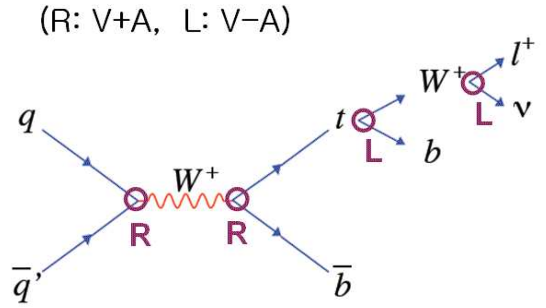


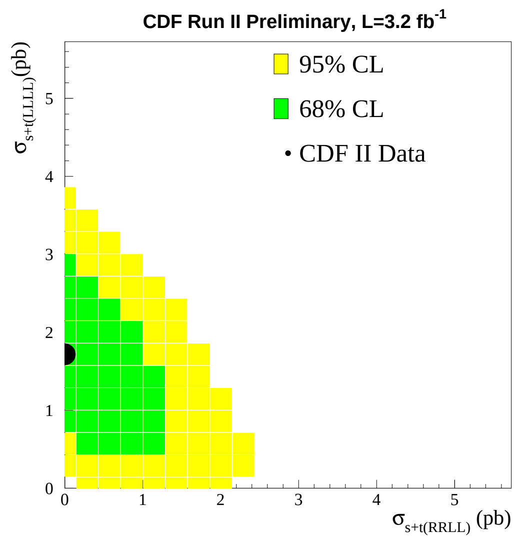
- D0 with specialised t-channel discriminant: $\sigma_{t\text{-channel}}(t) = 3.14^{+0.94}_{-0.80}$pb (4.8σ)

Polarisation of Top Quark

- Polarisation might change in presence of non-SM contributions
- Consider production with right-handed coupling (keeping SM left-handed decay)
- Exotic case changes angle between lepton and jet.
- Train discriminants for SM and exotic (RRLL) (separately)
- Measure two cross-sections: σ_R and σ_L:

$$\mathcal{P} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = -1.0^{+1.5}_{-0}$$





In agreement with pure SM production

Summary

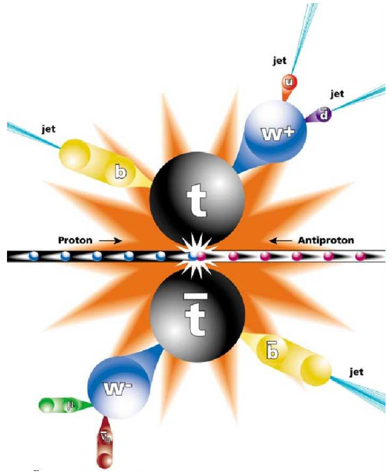
- Presented new and updated measurements related to top quark production
- CDF and D0 have analysed up to $4.8\,\mathrm{fb}^{-1}$ of their data

  Strong/Double Top

  - Discussed various background estimates from data
  - Precision reached on cross-section 6.5%
  - Properties of top production explored

  Electroweak/Single Top

  - Observed at 5σ significance (LaThuile 2009)
  - New channels are being explored
  - Used to verify properties: $|V_{tb}|$, polarisaion, . . .



- No sign of new physics till here

  (G. Compostella will present remaining properties)