Top-antitop production and top properties at DØ

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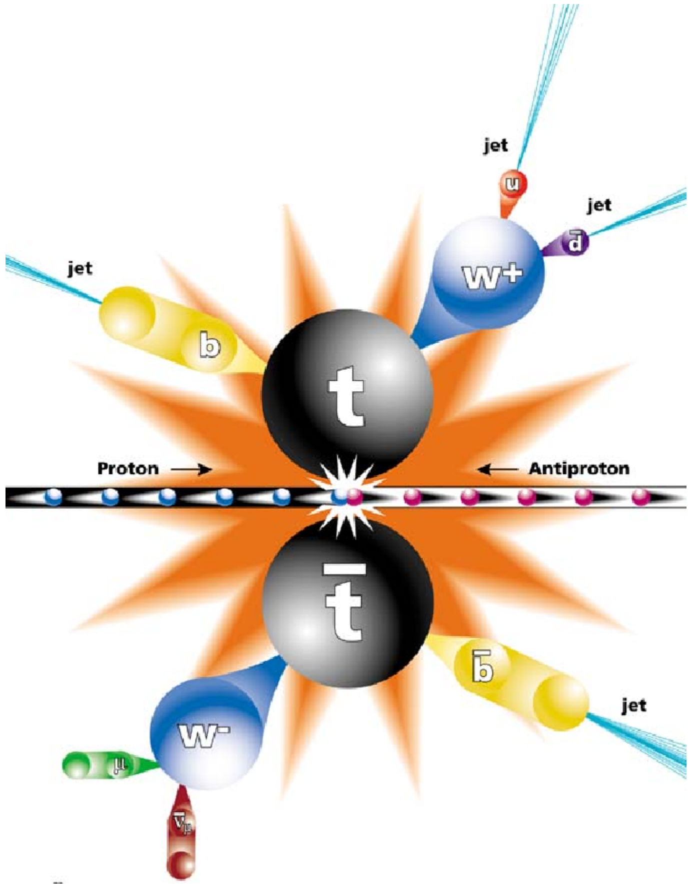
Outline

- Cross-Section
- Top Quark Mass
- Further Properties

Introduction

The Top Quark

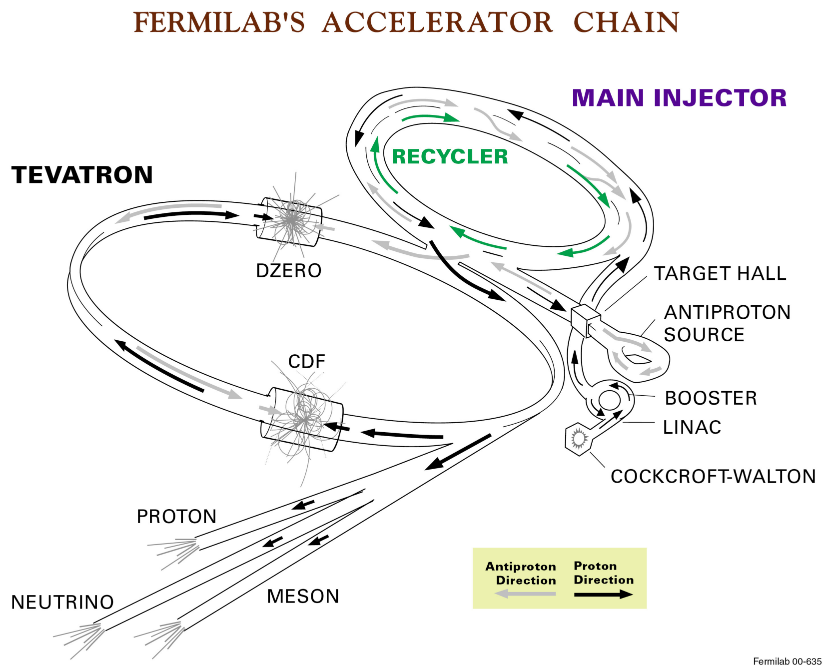
- Discovered by CDF and DØ in 1995.
- Completes set of quarks in SM.
- Quantum numbers as for up-type quarks.
- Production and decay properties fully determined within SM.
- Mass is the only free parameter



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

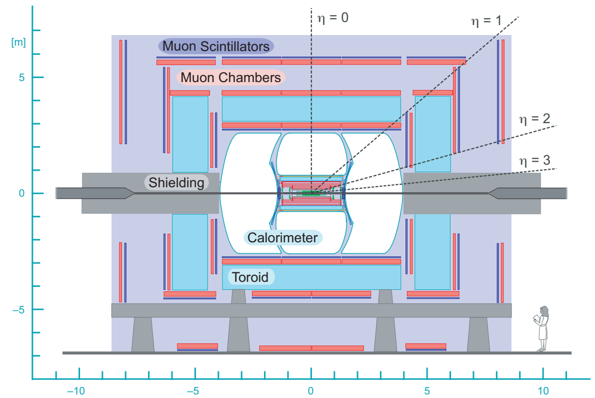
The $p\bar{p}$ Accelerator Tevatron

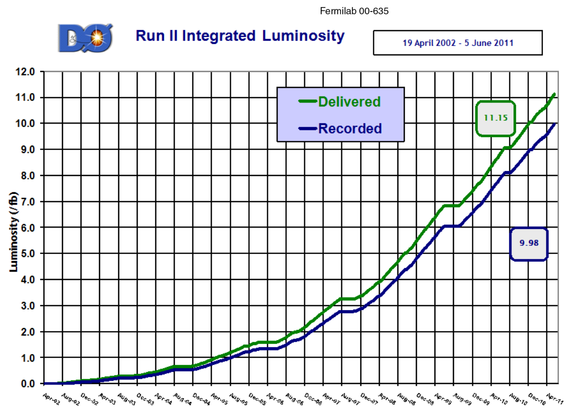
- Circumference 6.4 km.
- $p\bar{p}$ collisions
- Run I (1987-1995)
- Run II (since 2001)
  Collision energy 2 TeV



- 2 experiments,
  CDF and DØ,
  record events.

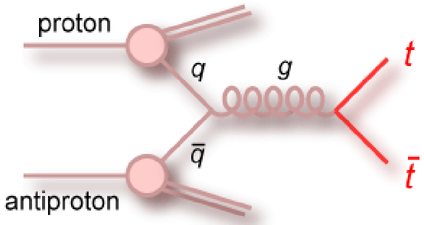
$\mathcal{L} \sim 10\,\text{fb}^{-1}$ on tape.
Today: upto $\sim 5.4\,\text{fb}^{-1}$



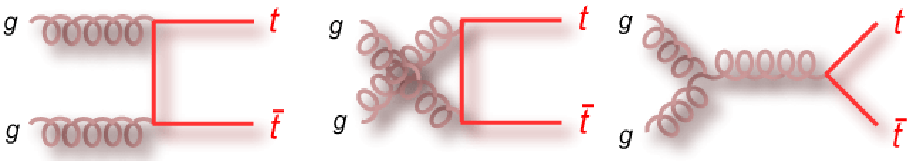


Top Quark Production at the Tevatron

Strong top production



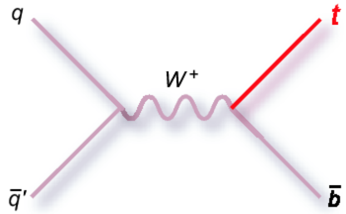
$$85\% \quad q\bar{q} \to t\bar{t}$$
$$15\% \quad gg \to t\bar{t}$$



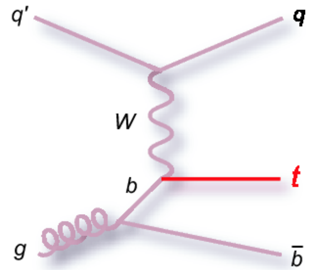
$\sigma(t\bar{t}) \simeq 7.46$pb

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

Weak top production



Drell-Yan
s-channel



W-g fusion
t-channel

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

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.

Signatures

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

$\ell = e, \mu$ with τ named separately

Dominant backgrounds

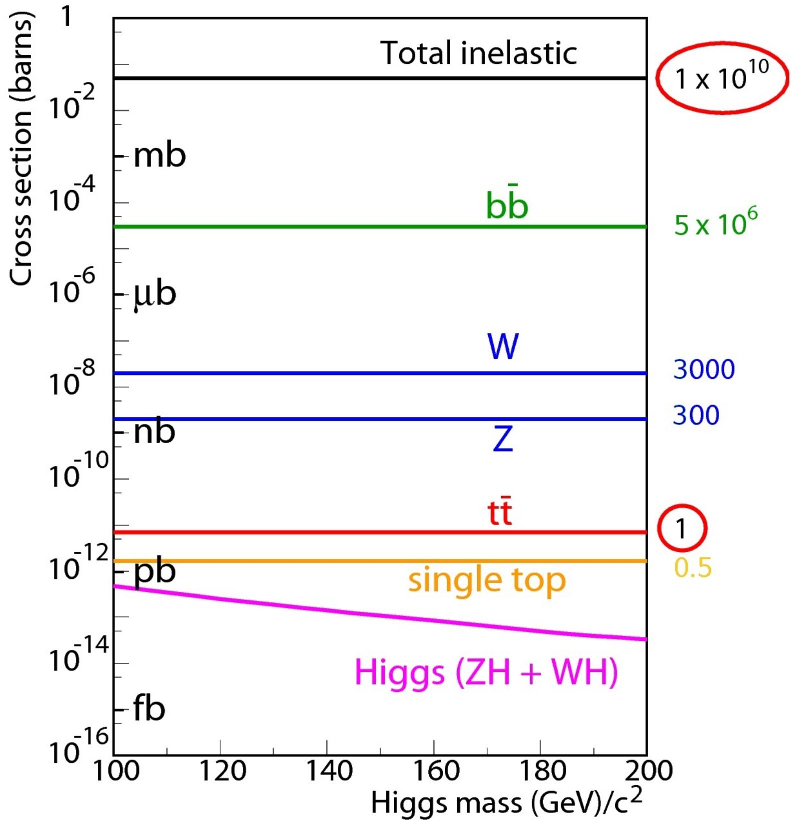
Same signature / jets faking ℓ or $\not\!\!E_T$

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

the "+jets" helps suppression.

Simulation of multijet events
and of fake rates difficult/unprecise

$\Rightarrow$ Estimation from data.

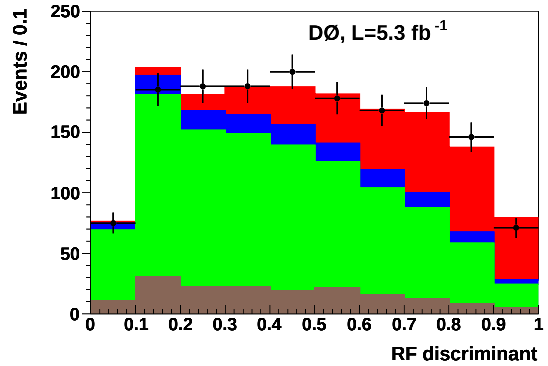


Pair Production Cross Section

ℓ+jets (5.3 fb^{-1})

- Combine kinematic likelihood and b-tagging
- Systematics: Nuisance parameter fit.
- Improved by including background dominated 2 jets and 0-b-tag events

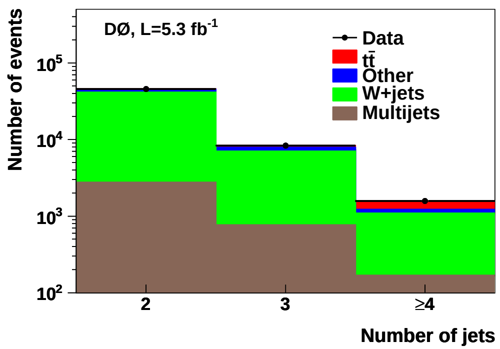
arXiv:1101.0124



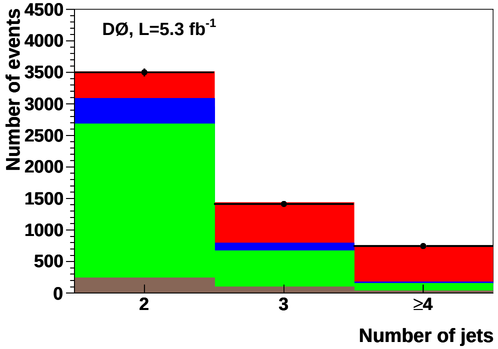
$$\sigma_{t\bar{t}} = 7.78 \pm 0.25_{\text{stat}}{}^{+0.73}_{-0.59\text{syst}}\text{pb} \quad \mp 8.2\ldots9.9\%$$

SM: 7.46pb (assuming $m_t = 172.5$ GeV)

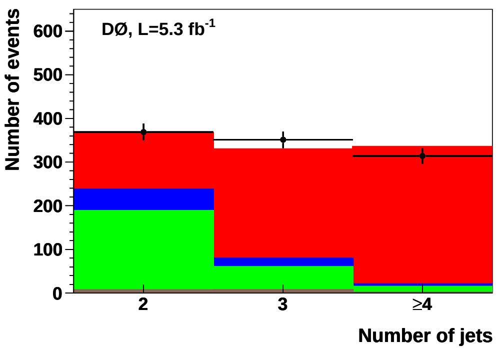
0-b-tag



1-b-tag

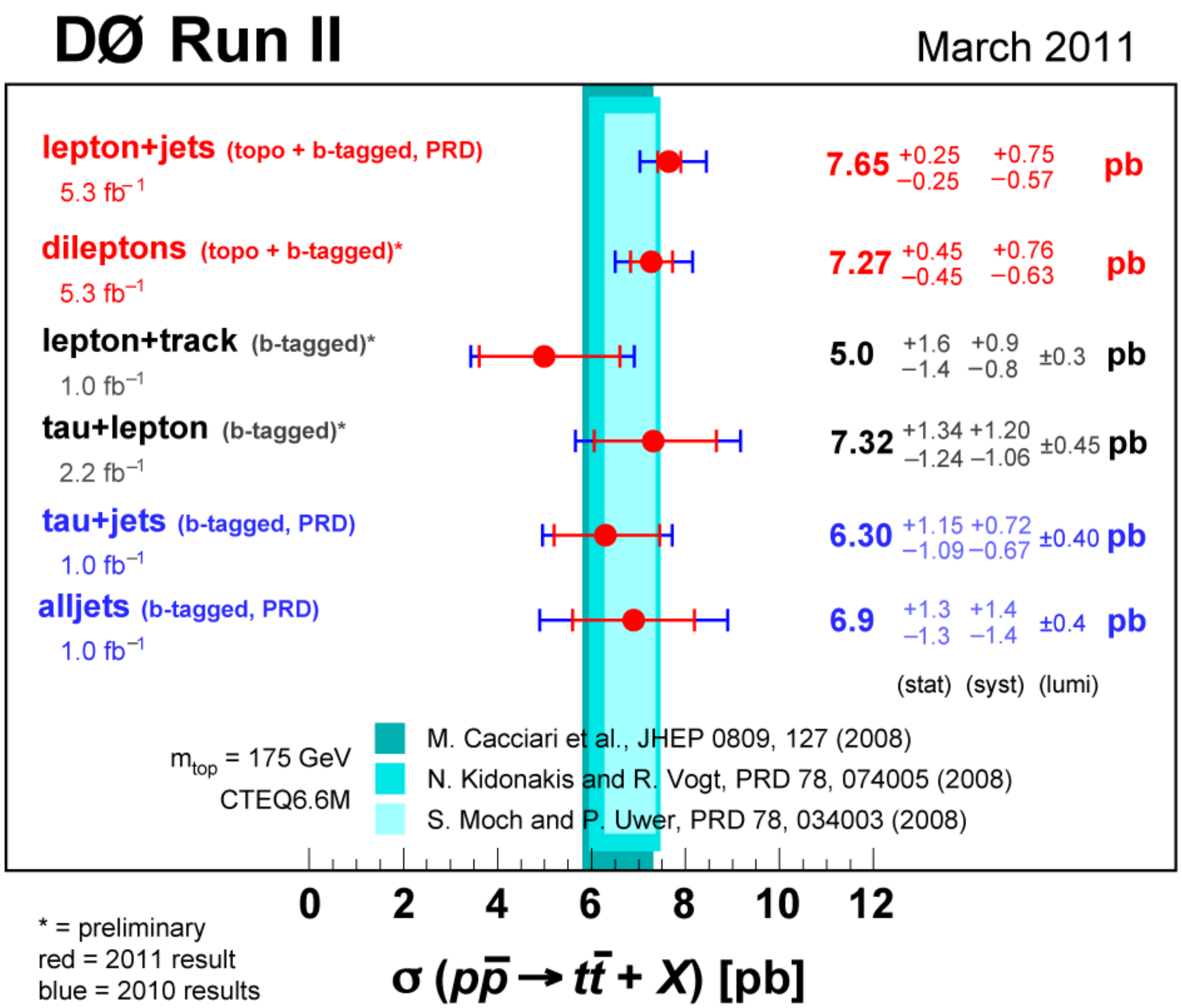


> 1-b-tag



N_{jets}

Overview of Cross-section Results



- up to $5.3\,\text{fb}^{-1}$
- Systematics dominated
- Data and theory uncertainties comparable
- Consistent between channels

Top Quark Mass

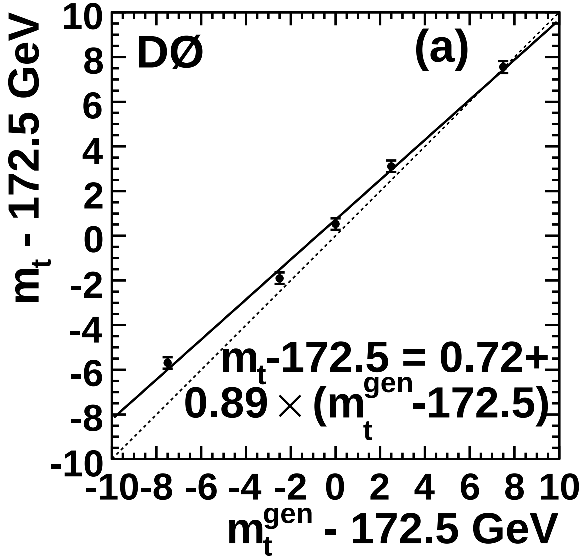
Matrix Element Method

Probabilty for kinematic configuration x depends on m_t and JES:

$$P_{\mathrm{evt}}(x; m_t, \mathrm{JES}) = f_{\mathrm{top}} P_{\mathrm{sig}}(x; m_t, \mathrm{JES}) + (1 - f_{\mathrm{top}}) P_{\mathrm{bkg}}(x, \mathrm{JES})$$

$$P_{\mathrm{sig}} = \frac{1}{\sigma_{t\bar{t}}(m_t)} \int \mathrm{d}q_1\, \mathrm{d}q_2\, \underbrace{\mathrm{d}^n\sigma(q\bar{q} \to t\bar{t} \to y; m_t)}_{\text{Matrix Element}}\ \underbrace{f(q_1) f(q_2)}_{\text{PDFs}}\, \underbrace{W(y, x; \mathrm{JES})}_{\text{Resolution}}$$

- Max. of Likelihood yields m_t and jet energy scale (JES).
- Calibration by comparison to **MC**
- Applied to ℓ+jet and dilepton (no JES in dilepton)



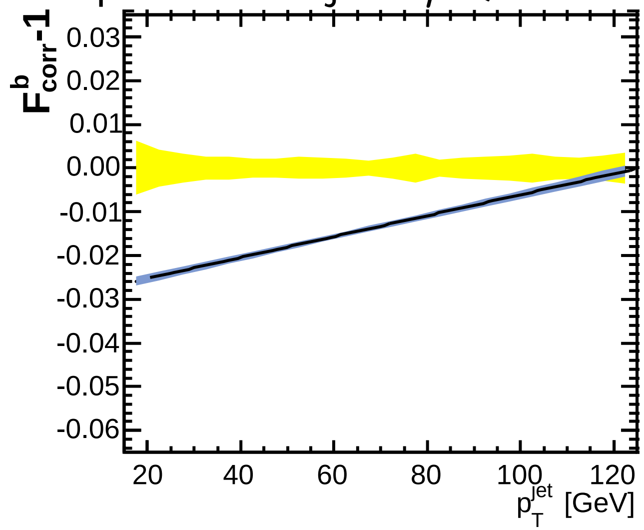
ℓ+jets analysis (RunIIb, $2.6\,\text{fb}^{-1}$)

- Novel flavour dependent jet response corr.
  - based on single particle response
  - for gluon-, light quark jets and b-jets
  - p_T and η dependent
- Combined with RunIIa to full $3.6\,\text{fb}^{-1}$

$m_t = 174.9 \pm 0.83_{\text{stat}} \pm 0.78_{\text{JES}} \pm 0.96_{\text{syst}}$ GeV

arXiv:1105.6287

Example: Corr. b-jets $\eta < 0.4$

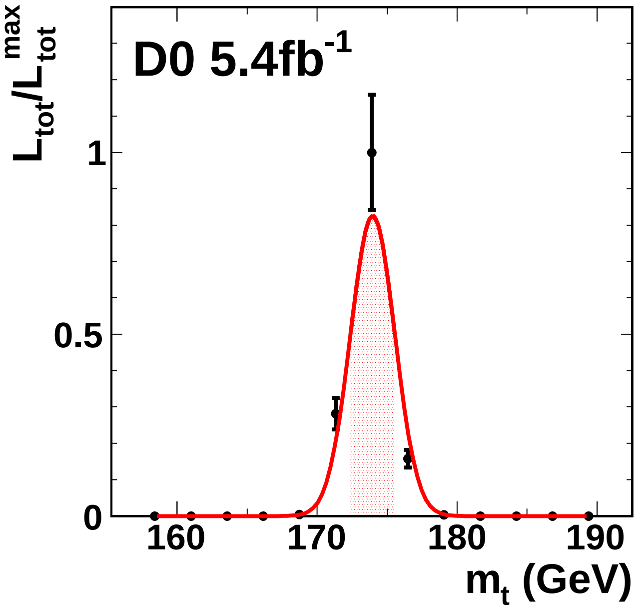


Dilepton analysis ($5.4\,\text{fb}^{-1}$)

- JES from γ+jets yields main uncertainty

$m_t = 174.0 \pm 1.8_{\text{stat}} \pm 2.4_{\text{syst}}$ GeV

arXiv:1105.0320
(most precise dilepton)



$t - \bar{t}$ Mass Difference $(3.6\,\text{fb}^{-1})$

CPT-Theorem claims $m_t = m_{\bar{t}}$

Analysis

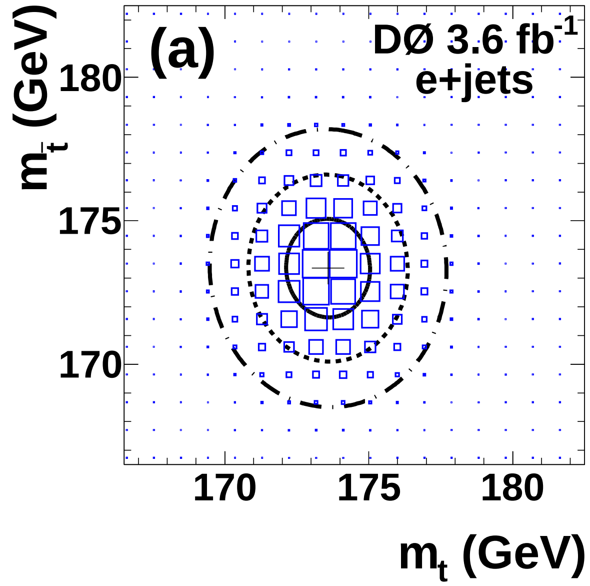
- Identify (anti)top from lepton charge
- Adapt der ME mass measurement
- Dendence on Δm instead of m_t.

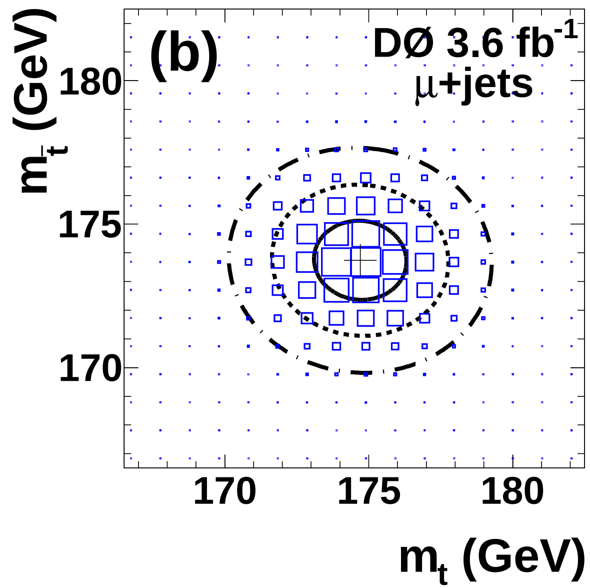
Result

DØ: $\Delta m = +0.8 \pm 1.8\,\text{GeV}$ $\quad \dfrac{\Delta m}{m} = 0.4 \pm 1.0\%$

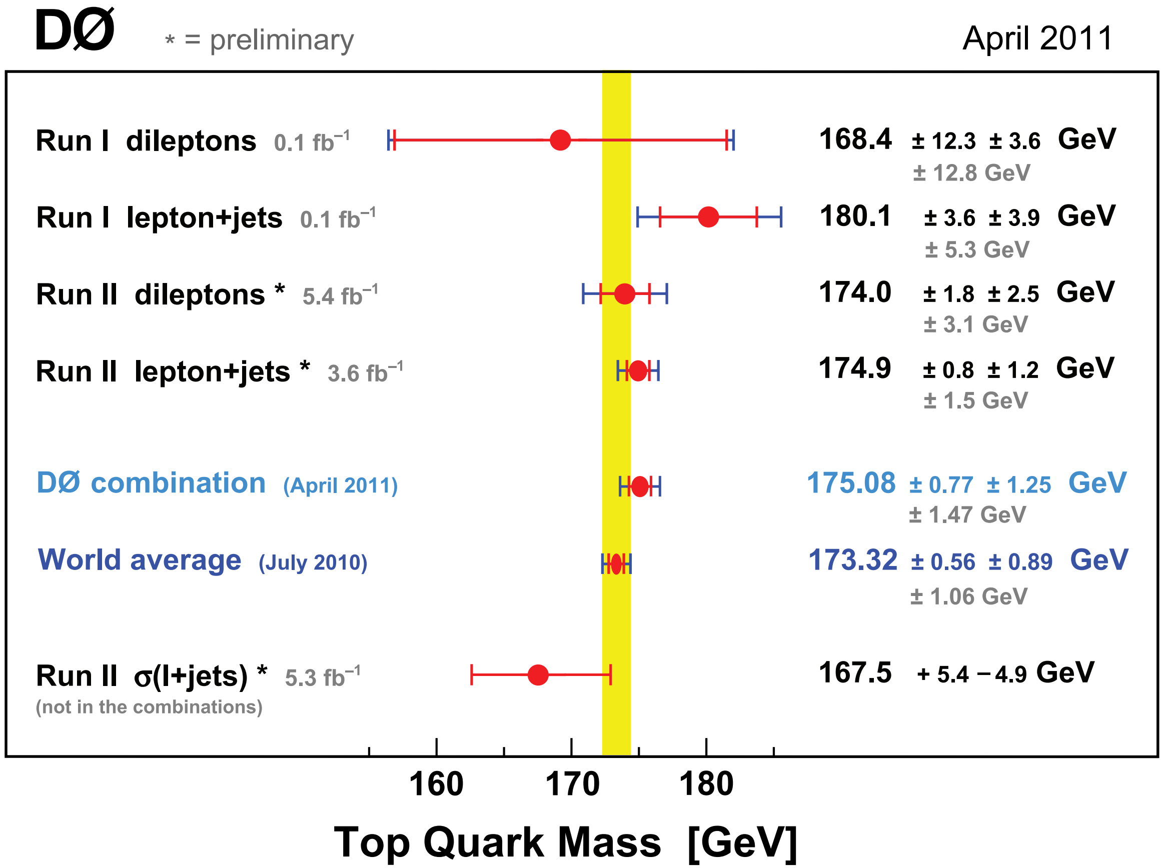
arXiv:1106.2063

Top- and anti-t-quark have the same mass.
Unique result in the SM quark sector.



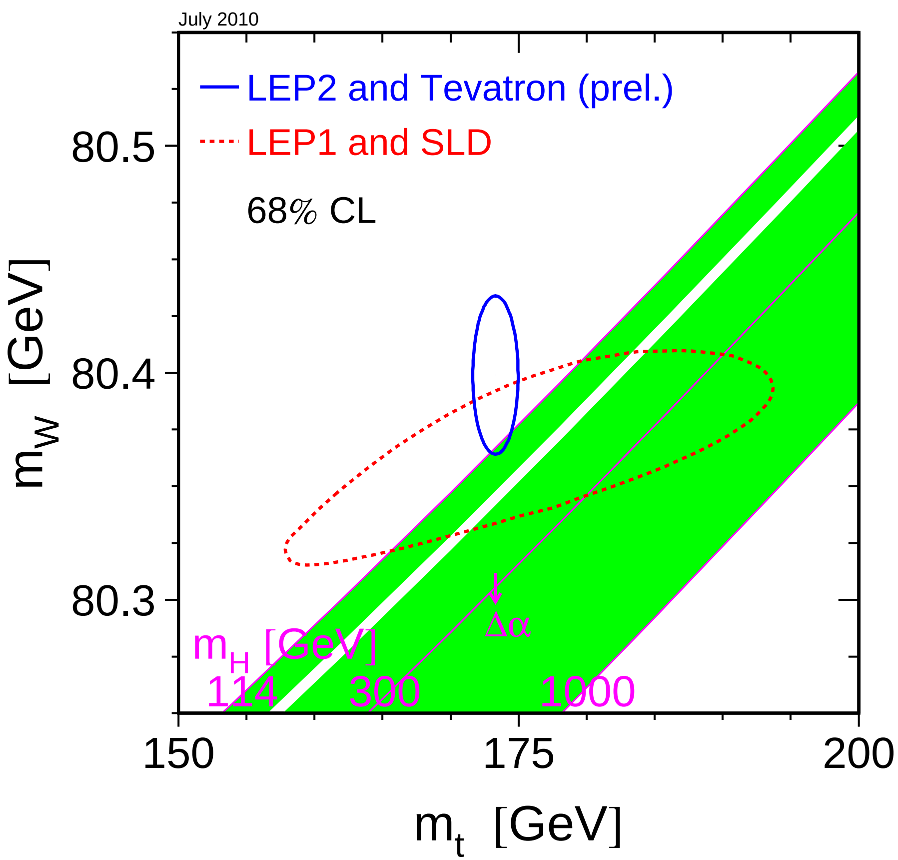


Summary of Mass Results

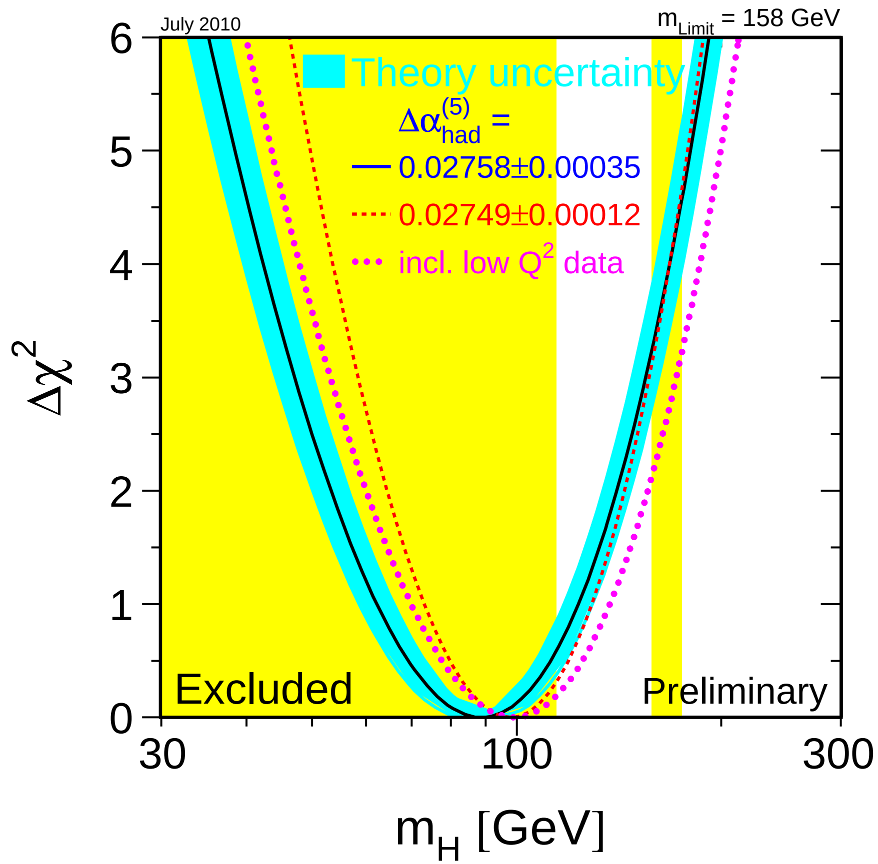


- RunII results systematics limited. Dominating JES and signal modelling.
- Results obtained for decay channels agree

Top Mass in electroweak Fits



Combined m_W und m_t results touch SM region barely



Higgs mass projection

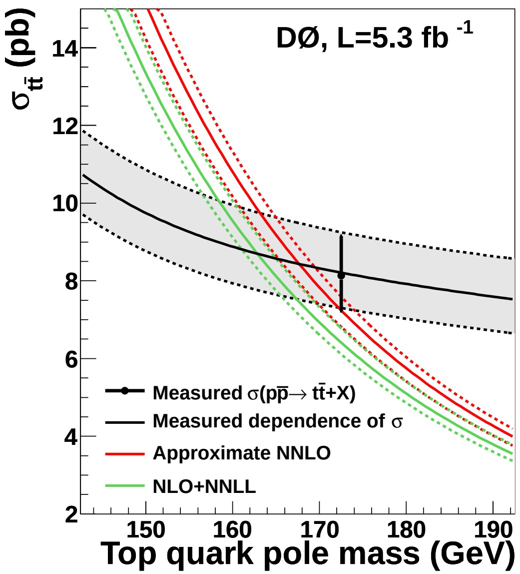
$m_H \leq 158$ GeV (95%CL)

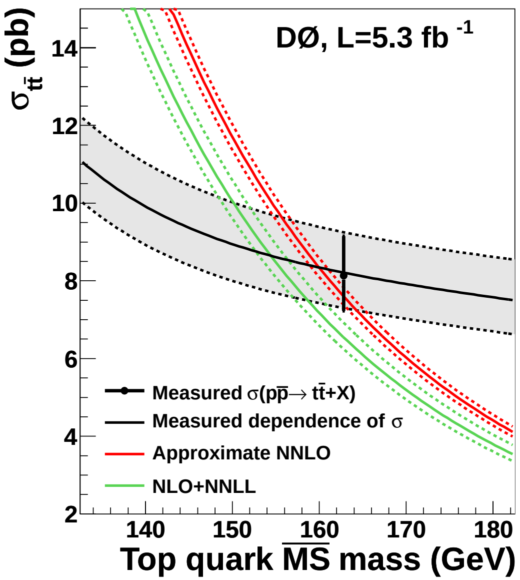
These fits require m_t^{Pole}. Is that what we are measuring? Not exactly.

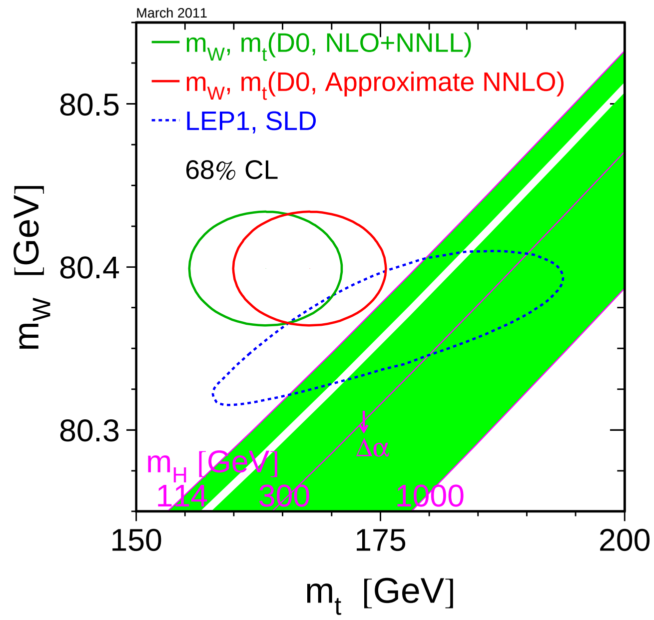
Well defined Mass from Cross-Section

- $\sigma_{t\bar{t}}$ depends on m_t: both the theory and the measurements
- Determination of m_t in well defined mass definition
- Definition uncertainty for exp. mass dependence included in uncertainty

arXiv:1104.2887



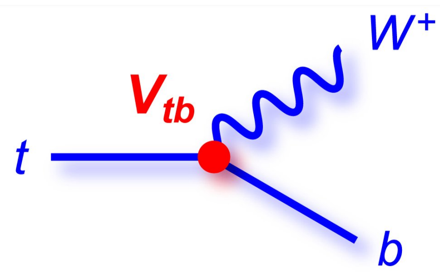




Pole mass	$\overline{\mathrm{MS}}$ mass	
163.0 ± 5.0 GeV	154.5 ± 4.7 GeV	w/ NLO+NNLL, Ahrens et al.
167.5 ± 5.0 GeV	160.0 ± 4.6 GeV	w/ Aprox. NNLO, Moch & Uwer

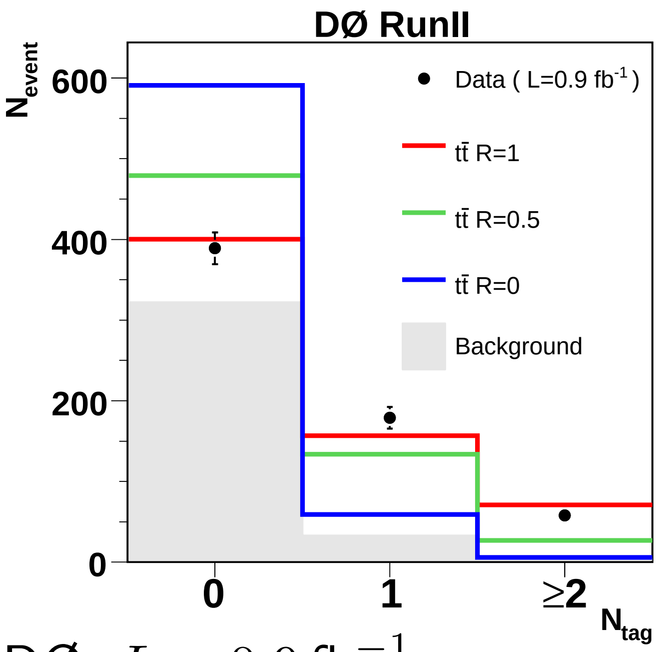
Some tension between the $\sigma_{t\bar{t}}$ predictions and in m_t vs. m_W.

Branching fraction ($1.0\,\text{fb}^{-1}$)



From amount of events with 0,1 and 2 identified b-Jets

$$R = \frac{B(t\to Wb)}{B(t\to Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2+|V_{ts}|^2+|V_{td}|^2} = 0.97 \pm 0.09$$



DØ, $L = 0.9\,\text{fb}^{-1}$

Consequences

Prerequsite for V_{tb} from single top:

$$\frac{|V_{tb}|^2}{|V_{ts}|^2+|V_{td}|^2} > 3.76 \text{ at 95\% C.L.}$$

Top Quark Width (w/ $2.3\,\text{fb}^{-1}$ single top)

$\Gamma_t = \Gamma_t(t\to Wb)/R$

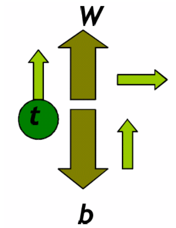
with $\Gamma_t(t\to Wb)$ from recast of $\sigma_{1t,\ t\mathrm{-channel}}$

$\Gamma_t = 1.99^{+0.69}_{-0.55}$ GeV (SM: 1.34 GeV)

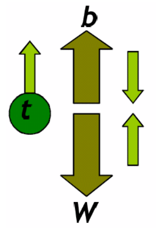
First width measurement; accepted by PRL

W-Helicity in Top Decays

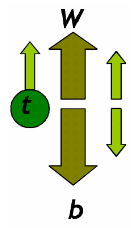
Does the top decay show the expected spin structure?
SM: only lefthanded particles couple to Ws ($V - A$ coupling),
W is lefthanded or longitudinal.



Longitudinal W
SM: $f_0 = 70\%$



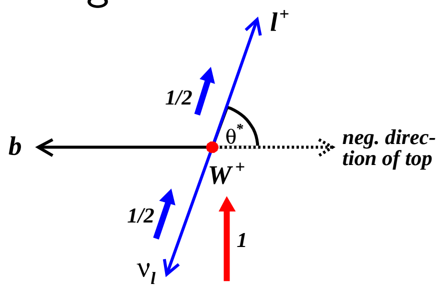
Left-handed W
SM: $f_- = 30\%$



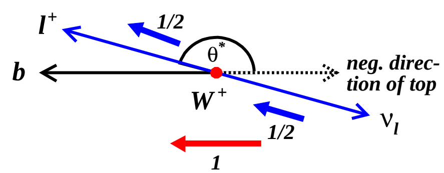
Right-handed W
SM: suppressed ($f_+ \simeq 0$)

In W-restframe lepton from W stays (preferably)

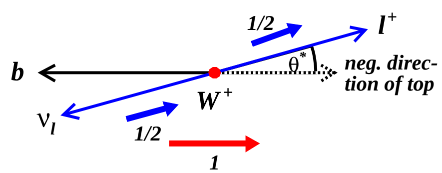
orthogonal to b



along b-direction

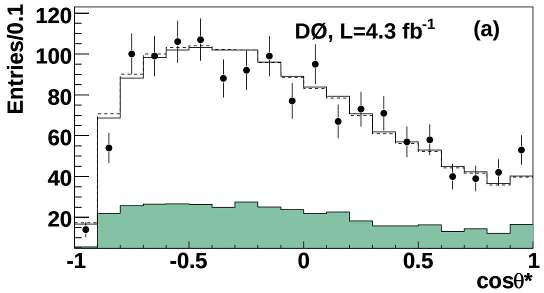


opposite to b-direction

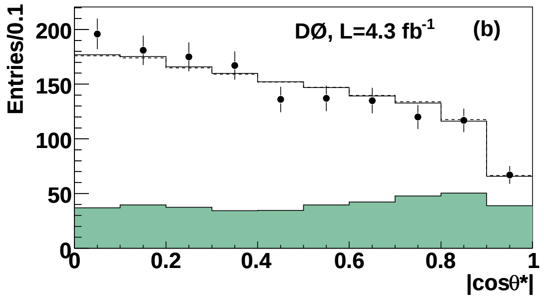


One possible observable: decay angle between b and ℓ; $\cos\theta^*$

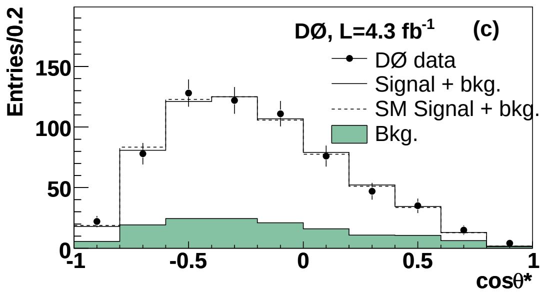
Results from decay angle $\cos\theta^*$ ($5.4\,\mathrm{fb}^{-1}$)



ℓ+jets from $\ell\nu$

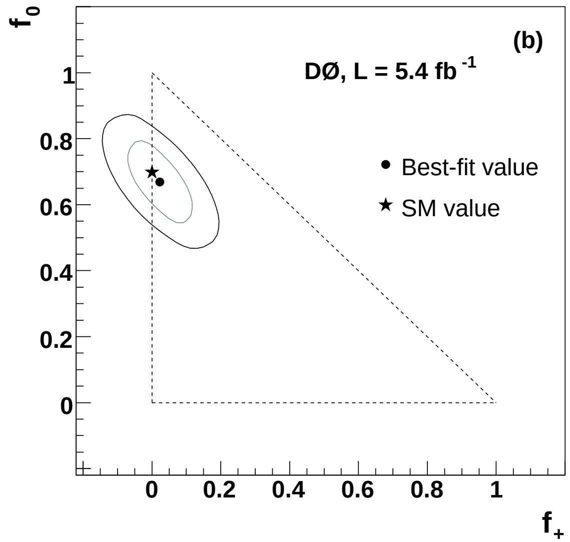


ℓ+jets from qq'



dilepton

- Use ℓ+jets and dilepton
- Compare to templates for left, right handed and longitudinal polarisation
- Fit polarisation fractions: f_0, f_+



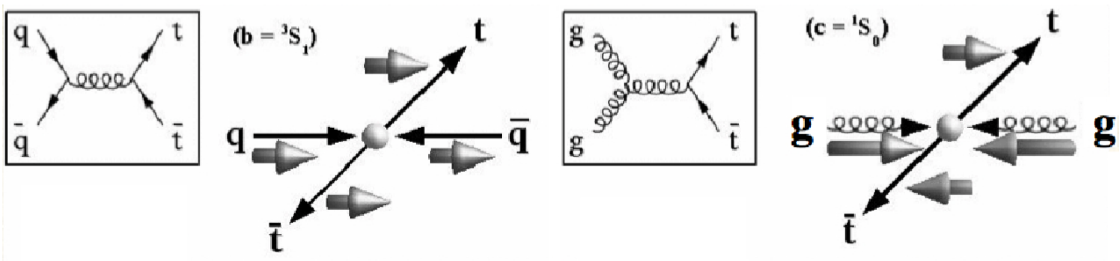
PRL 106, 022001 (2011)

DØ: $f_0 = 0.67 \pm 0.10$ and $f_+ = +0.023 \pm 0.053$

SM: $f_0 = 0.7$ $f_+ \simeq 0$

Spin Correlations ($5.4\,\mathrm{fb}^{-1}$)

The top quark decays before it hadronises. $\Longrightarrow$ Spin imprinted on decay products



Angular Distributions (Dilepton)

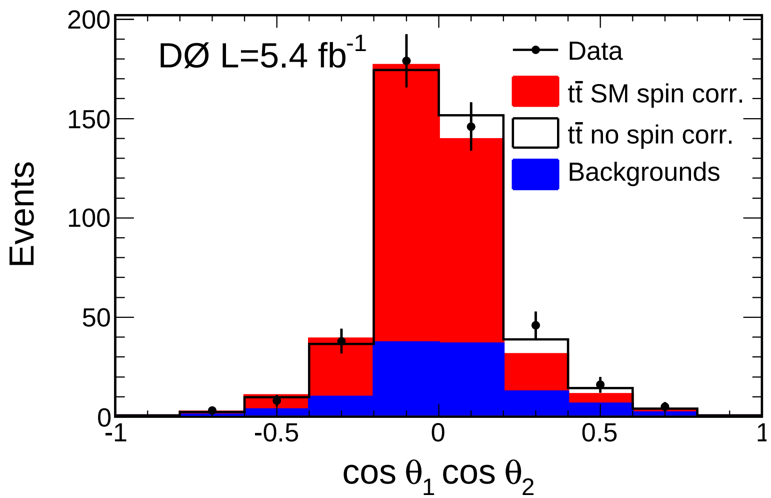
Observable: $\theta_\pm$, angle between $\vec{p}(\ell^\pm)$ and quantisation axis (here beam axis)

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}\cos\theta_+\,\mathrm{d}\cos\theta_-} \sim (1 - C\cos\theta_+\cos\theta_-)$$

Spin corr. strength $\quad C = \frac{N_\mathrm{same}-N_\mathrm{opposite}}{N_\mathrm{same}+N_\mathrm{opposite}}$

$C = 0.10 \pm 0.45$ stat. dominated

NLO SM: $C_\mathrm{beam} \simeq 0.78$ (Bernreuther et al.)

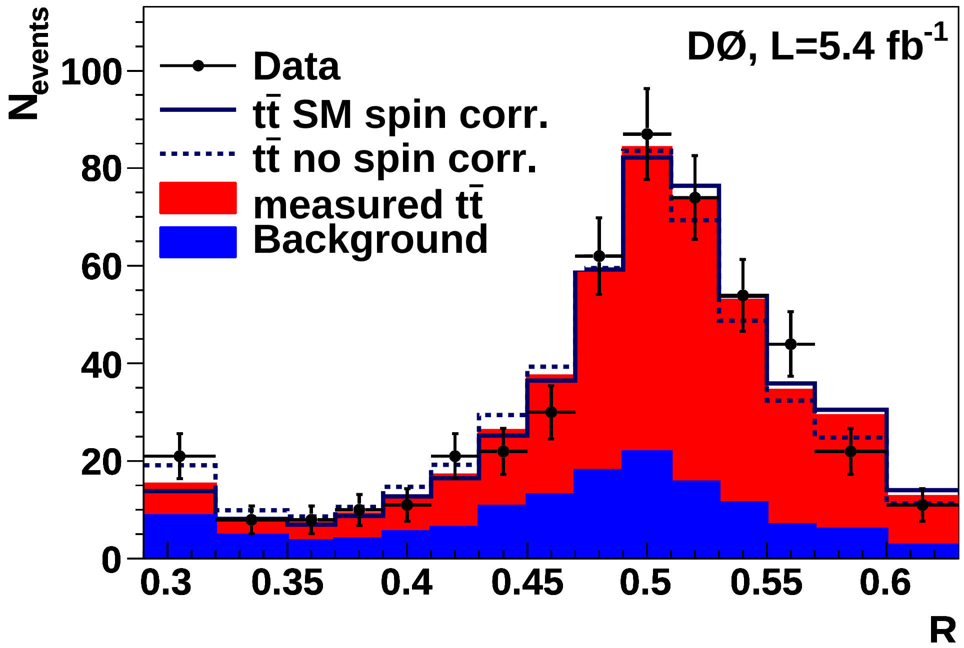


Matrix Element Method (Dilepton)

Eventwise probability for kinematic configuration x to occur

- $P_{\text{sig}}(x|\text{SC})$ with spin correlation.
- $P_{\text{sig}}(x|\text{NoSC})$ without spin correlation.

arXiv:1103.5194



Ratio of probabilities

$$R = \frac{P_{\text{sig}}(x|\text{SC})}{P_{\text{sig}}(x|\text{SC}) + P_{\text{sig}}(x|\text{NoSC})}$$

yields a discriminant.

Fit C from R-distribution:

$5.4\,\text{fb}^{-1}$: $C = 0.57 \pm 0.31$ First result with (expected) significance $> 3\sigma$.

Forward Backward Asymmetry ($4.3\,\mathrm{fb}^{-1}$)

- Initial state is not charge symmetric
- Despite no single graph is asymmetric
  SM: asymmetry from interference at NLO

DØ consideres $A_{FB}^{t\bar{t}} = \dfrac{N_F - N_B}{N_F + N_B}$

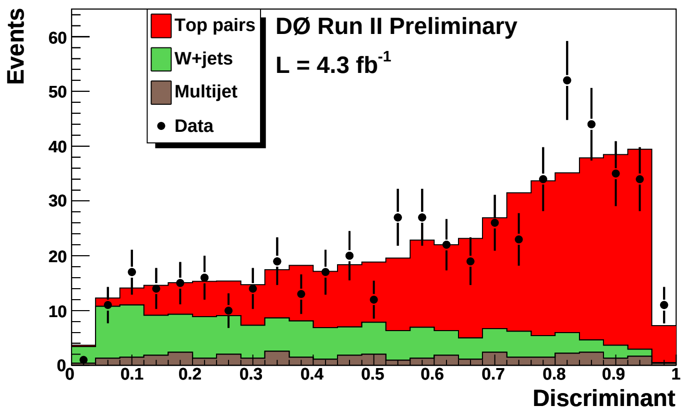
with F: $\Delta y = y_t - y_{\bar{t}} > 0$ and B : $\Delta y < 0$.

- Exp: $\Delta y = Q_\ell(y_\ell - y_{\mathrm{had}})$
- Discriminant to fit W+jets bkg. for $\pm\Delta y$

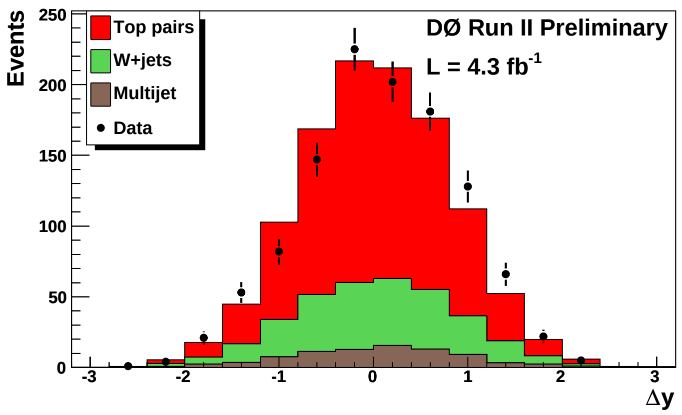
$A_{FB}^{t\bar{t}} = 0.08 \pm 0.04_{\mathrm{stat}} \pm 0.01_{\mathrm{syst}}$

D0 Note 6062-CONF

NLO SM with these cuts: $A_{FB}^{t\bar{t}} = 0.01^{+0.02}_{-0.01}$



Discriminant $\Delta y > 0$



Δy Distribution

Summary

- Top cross-section and properties results with up to $5.4\,\mathrm{fb}^{-1}$
- DØ at the Tevatron check all aspects of the top quark:

Production Properties

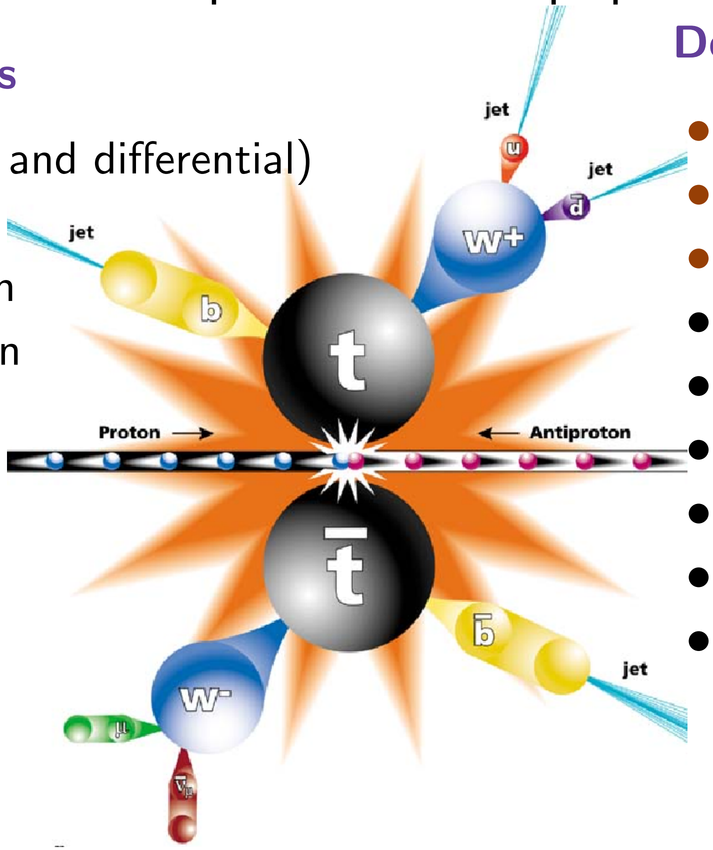
- Cross-section (total and differential)
- Charge asymmetry
- Resonant production
- Gluon fusion fraction

  …

Inherent properties

- Top mass
- Width; lifetime
- Top charge
- sTop or Top′

  …



Decay Properties

- W Helicity
- Spin correlation
- Branching fraction; V_{tb}
- Wtb anomalous couplings
- FCNC
- Invisible decay
- Charged Higgs
- ttH
- W'

  …

- *No evidence for new physics, yet.*