Measurement of the Properties of the Top Quark at DØ

- Introduction
- Mass & Width
- W helicity, Spin correlations
- Asymmetry, Colorflow
- Conclusions & Outlook

Andreas Jung (Fermilab) for the DØ collaboration

XIX International Workshop on Deep-Inelastic Scattering and Related Subjects
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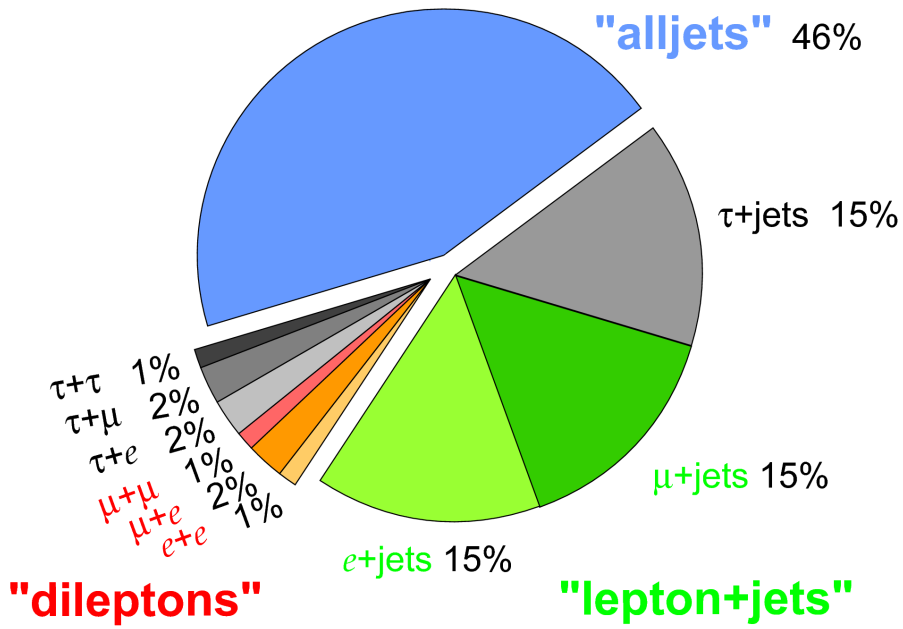
Introduction – Recap

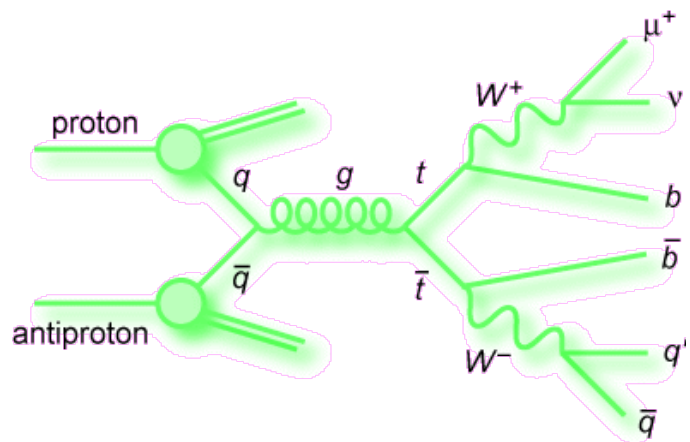
See talks by: Cecilia Gerber & Frédérique Badaud

- Top is the heaviest fundamental particle discovered so far: $m_t = 173.3 \pm 1.1$GeV
- Lifetime: $\tau \approx 5\times10^{-25}$ s, charge: +2/3e
- DØ has collected a large statistics top sample allowing wealth of precise measurements
- Tevatron has access to quantities that are harder to measure at the LHC, because of the initial state: gg vs. $q\bar{q}$

Top Pair Branching Fractions



- Experimental techniques:
  - Sample classified according to W-decay: dilepton, lepton+jets, all jets



Mass of the Top Quark

- Matrix Element method (ME) calculates event probability densities (PD) from differential cross sections and detector resolutions:

$$P(x, m_t) = \frac{1}{\sigma(m_t)} \int \sum \underbrace{d\sigma(y, m_t)}_{\text{LO ME}} \, dq_1 dq_2 \, \underbrace{f(q_1) f(q_2)}_{\text{PDFs}} \, \underbrace{W(y, x, k_{\mathrm{JES}})}_{\text{Transferfunction}}$$

- The Transferfunction relates the PD of measured set x to the partonic set y
- k_{JES} is a global factor for the Jet Energy Scale
- Selection of l+jets events, use b-tagging to increase purity of the sample

Mass of the Top Quark

NEW, Precision

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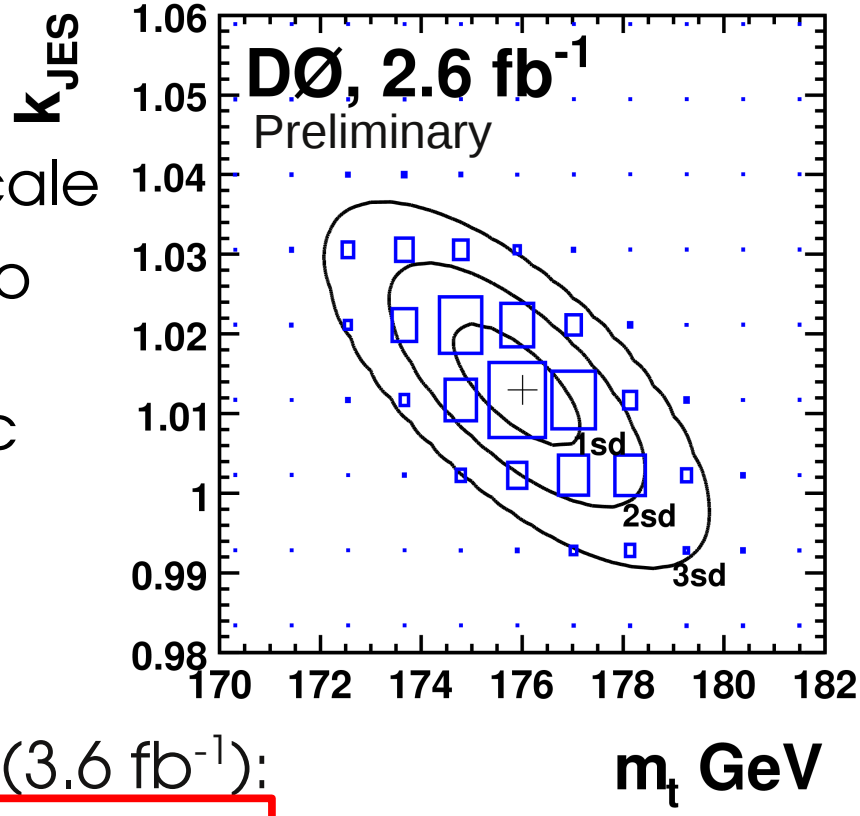
- Measurement is dominated by systematic uncertainty



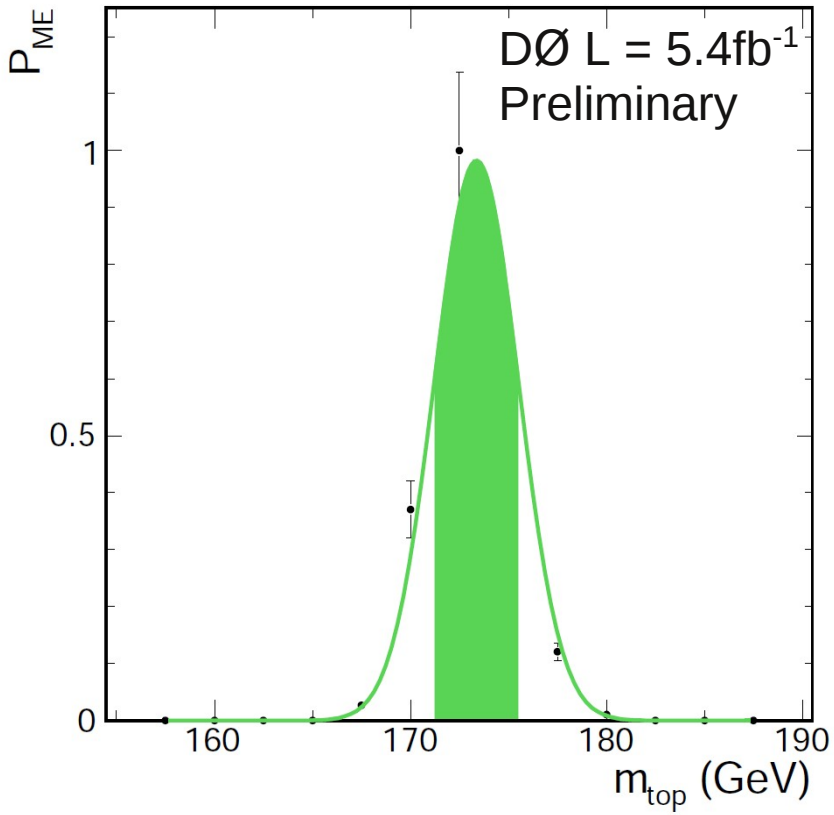
→ Most precise DØ mass measurement (3.6 fb^{-1}):

m_t = 174.9 ± 0.8 (stat.) ± 1.2 (sys.+JES) GeV

Mass of the Top Quark

NEW

- Apply Matrix Element method (ME)
- Select dilepton events (ee, μμ, eμ):
  Very clean sample, limited in statistics
- No in-situ JES as both W bosons decay leptonically
- Measurement is dominated by systematic uncertainty

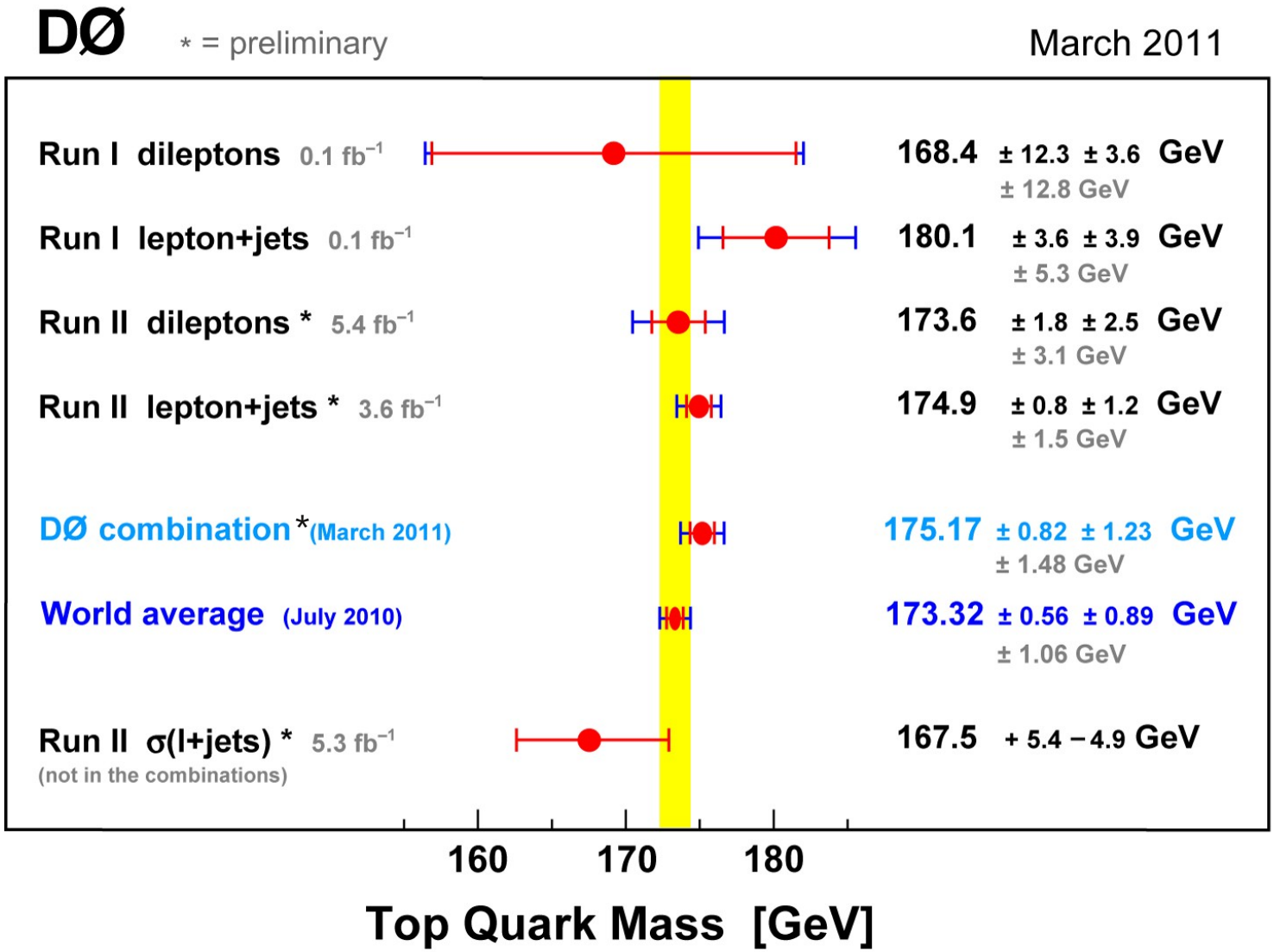


→ Most precise measurement in the dilepton channel (5.3fb^{-1}):

m_t = 173.6 ± 1.8 (stat.) ± 2.5 (sys.) GeV

Mass of the Top Quark

Legacy of Tevatron

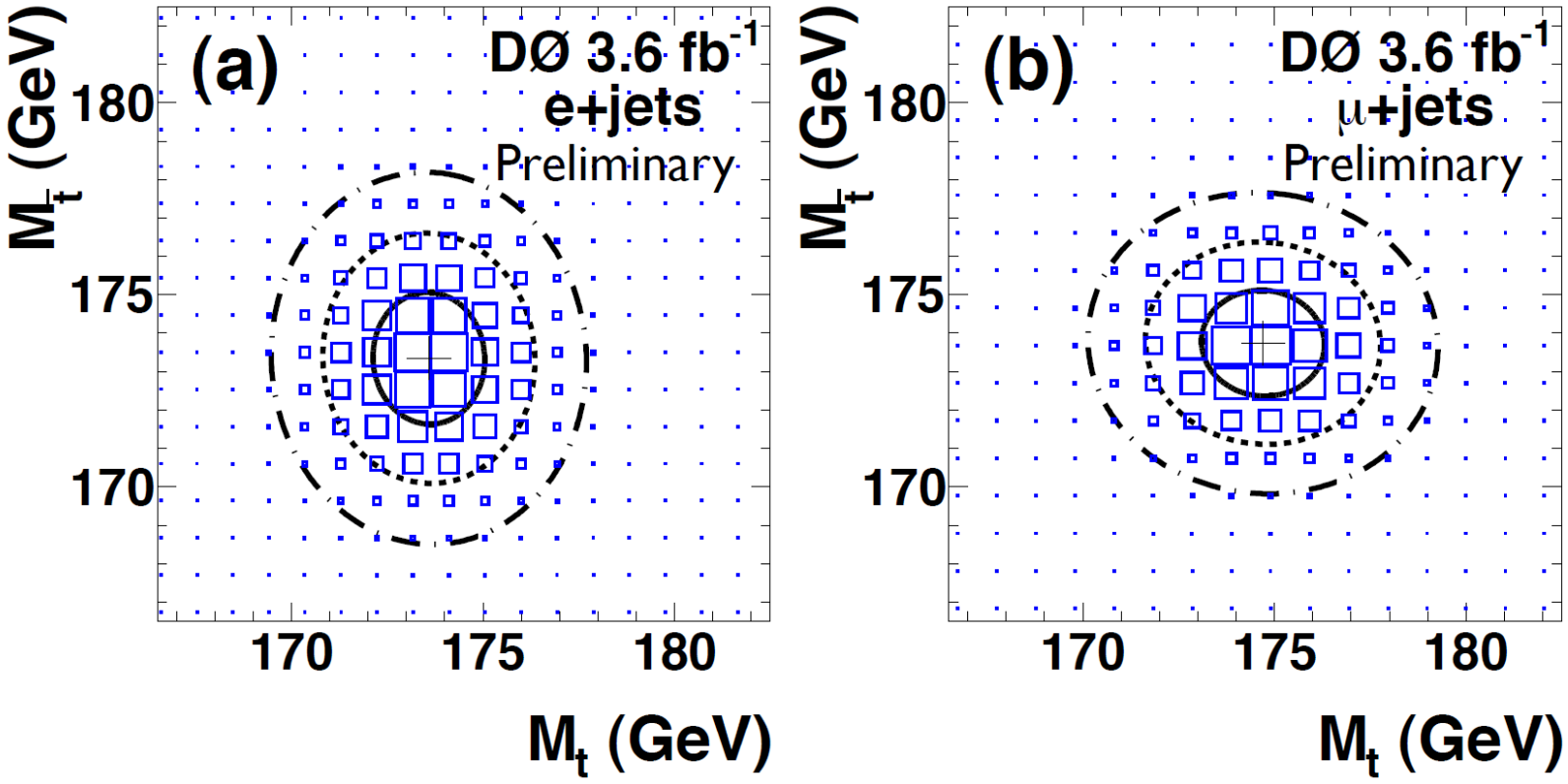


→ Total error of top mass measurement is well below 1%
Basically all of them are systematically limited!

Mass of the Top Quark

NEW

- Very short lifetime of the top quark, top decays before hadronization
- Allows to test CPT invariance at the quark level



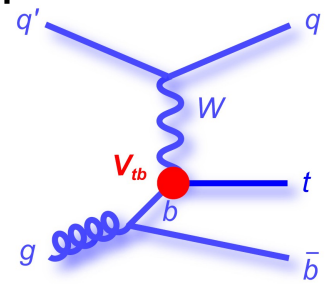
→ Measurement uses 3.6 fb^{-1}:

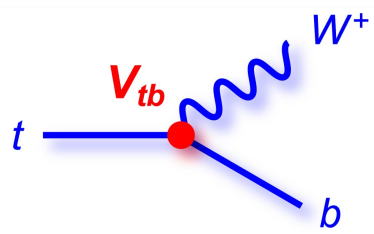
$\Delta M_t = 0.8 \pm 1.8$ (stat.) ± 0.8 (sys.) GeV

Width of the Top Quark

- Total width: $\Gamma_t = \frac{\Gamma(t \to Wb)}{\mathcal{B}(t \to Wb)}$ From t-channel single top cross section measurement; BR measured using $t\bar{t}$ decays
- Γ_t and lifetime $\tau_t = 1/\Gamma_t$ fundamental property of the top quark
- Assume same coupling:

production: decay:





- Extract partial decay width from:

$$\Gamma(t \to Wb) = \sigma(t\text{−channel}) \frac{\Gamma(t \to Wb)_{\mathrm{SM}}}{\sigma(t\text{−channel})_{\mathrm{SM}}}$$

1.26 GeV

2.14 ± 0.18 pb

Width of the Top Quark

Precision

- Total width: $\Gamma_t = \frac{\Gamma(t \to Wb)}{\mathcal{B}(t \to Wb)}$ From t-channel single top cross section measurement; BR measured using $t\bar{t}$ decays
- Γ_t and lifetime $\tau_t = 1/\Gamma_t$ fundamental property of the top quark
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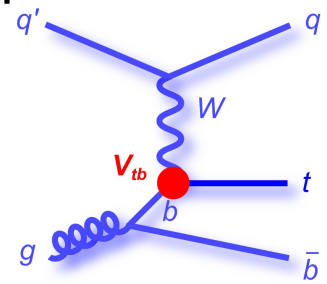
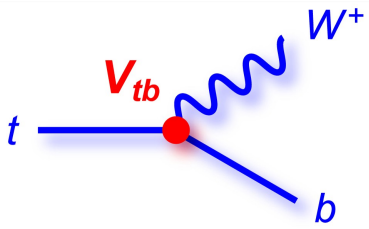
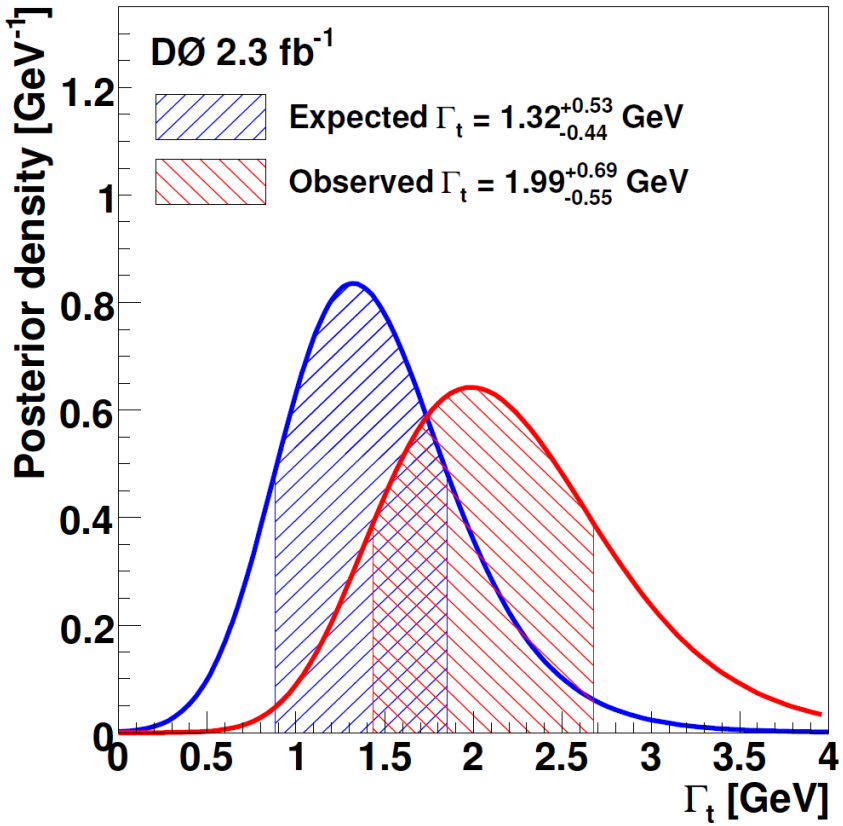




- Extract total decay width from:

$$\Gamma_t = \frac{\Gamma(t \to Wb)}{\mathcal{B}(t \to Wb)}$$

$0.97^{+0.09}_{-0.08}$



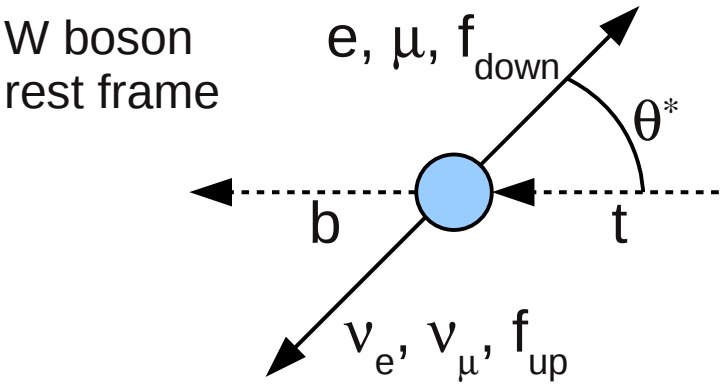
→ Most precise (indirect) determination of Γ_t:

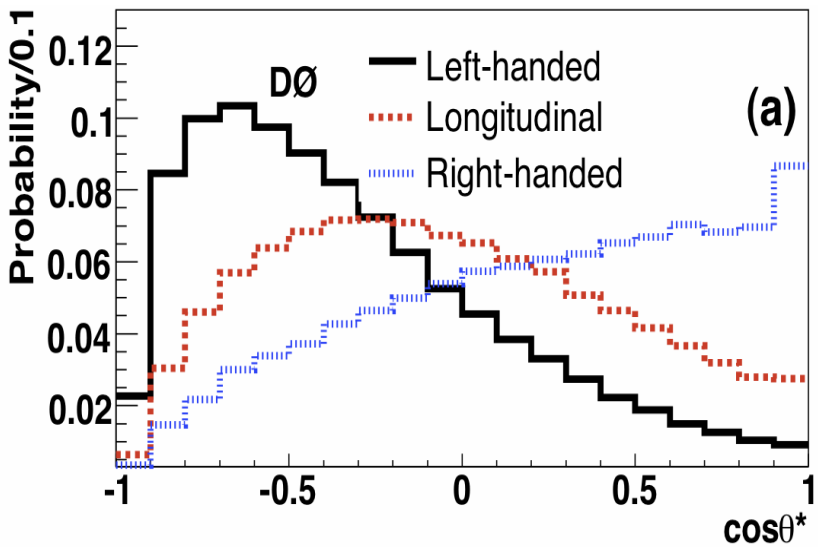
Phys. Rev. Lett. 106, 022001 (2011)

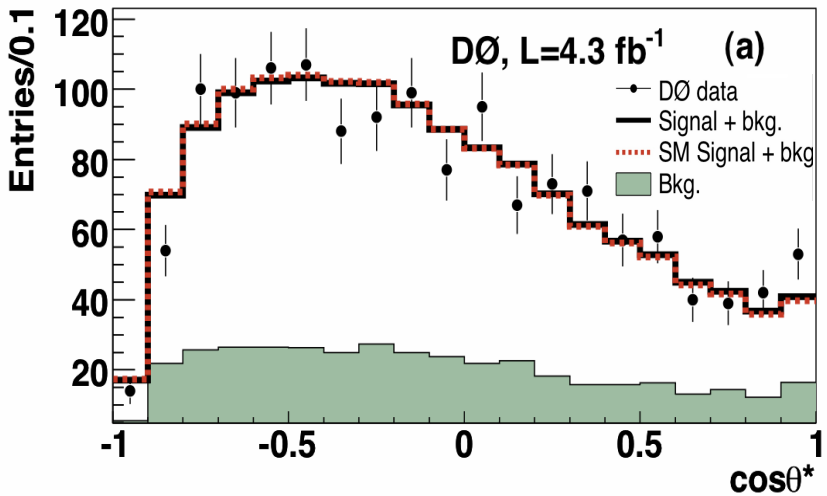
$$\Gamma_t = 1.99^{+0.69}_{-0.55}\ \text{GeV}$$
$$\tau_t = (3.3^{+1.3}_{-0.9}) \times 10^{-25}\ \text{s}$$

W Helicity in Top Decays

- Direct test of the "V – A" nature of weak interaction
- Fraction of W bosons produced in top decays:
  f_0 (longitudinal), f_- (left-handed) and f_+ (right-handed)
- SM: $f_0 = 0.698$, $f_- = 0.301$ and $f_+ = 4.1\times10^{-4}$
- Calculate $\cos\theta^*$ for l+jets and dilepton:







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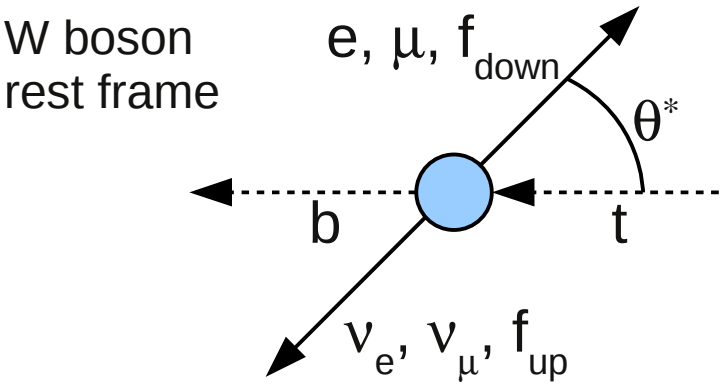
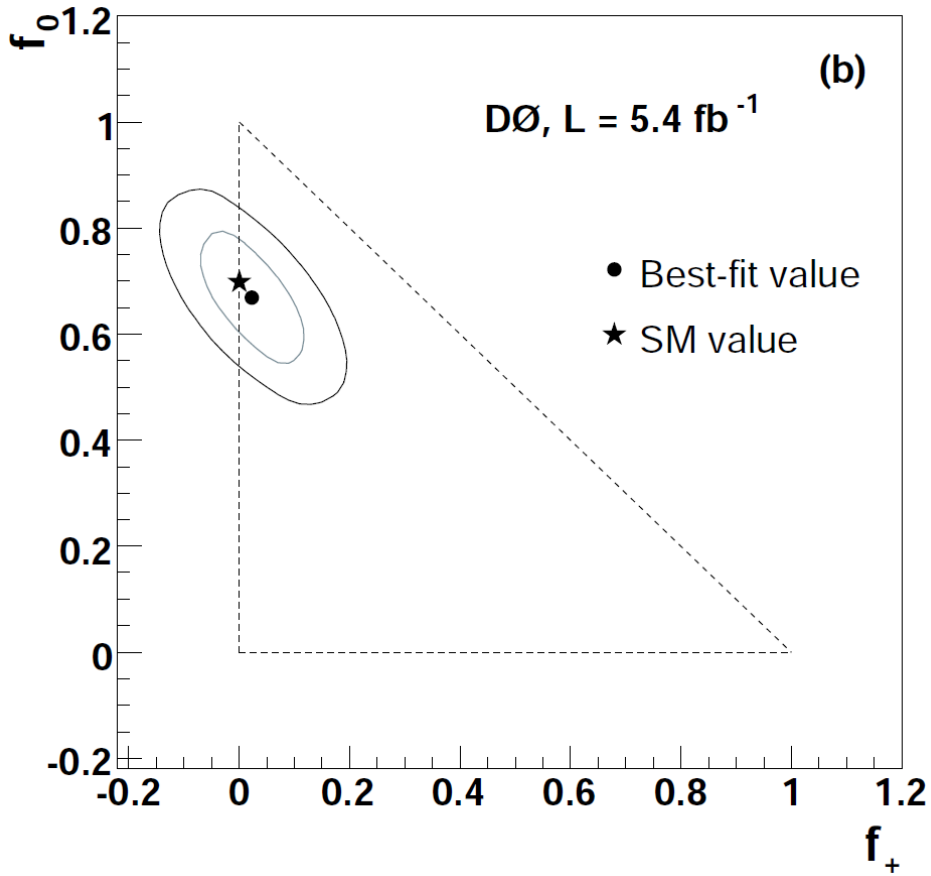




- Use likelihood template fits to derive $f_{"x"}$

→ Result consistent with SM:

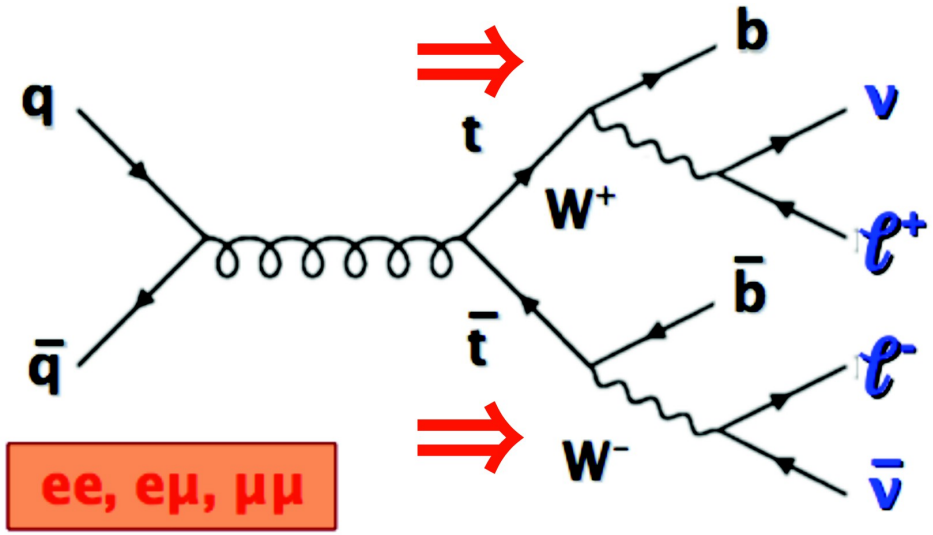
$$f_0 = 0.669 \pm 0.078\ (\text{stat.}) \pm 0.065\ (\text{syst.})$$
$$f_+ = 0.023 \pm 0.041\ (\text{stat.}) \pm 0.034\ (\text{syst.})$$

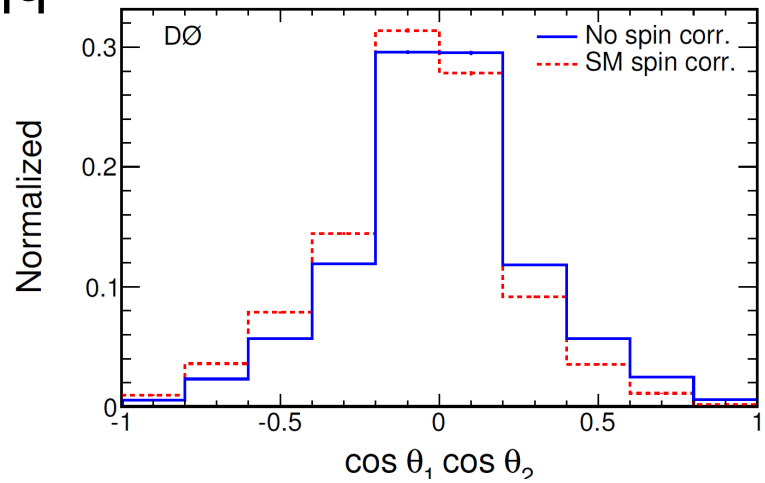
Phys. Rev. D 83, 032009 (2011)

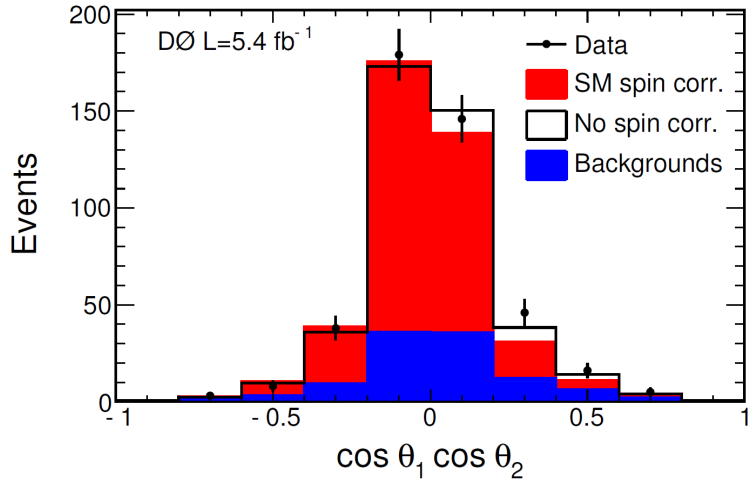
Spin correlations

Complementary

- Very short lifetime prevents spins from being affected by the fragmentation process: Spin correlations affects decay products
- Easier to access at Tevatron because of IS: $q\bar{q}$
- NLO QCD predicts: C = 0.78 + 0.03 – 0.04







→ Correlation strength 5.4 fb^{-1}:

$\boxed{C = 0.10 \pm 0.45 \text{ (stat.+sys.)}}$

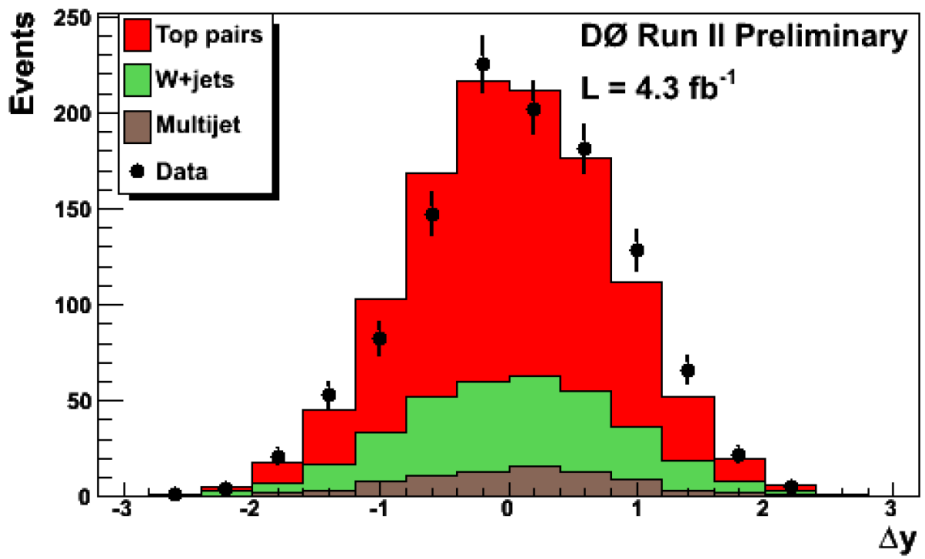
http://arxiv.org/abs/1103.1871

Asymmetry A_{fb}

Complementary

- Forward – backward asymmetry due to NLO QCD
- Easier to access at Tevatron because of initial state:
  $q\bar{q}$ vs. gg (fwd-bwd symmetric)
- Difference between rapidities of the top-quarks is a measure of the asymmetry
- Measure $\Delta y \equiv y_t - y_{\bar{t}}$ and define asymmetry:

$$A_{fb} = \frac{N^{\Delta y>0} - N^{\Delta y<0}}{N^{\Delta y>0} + N^{\Delta y<0}}$$



- Working on an update

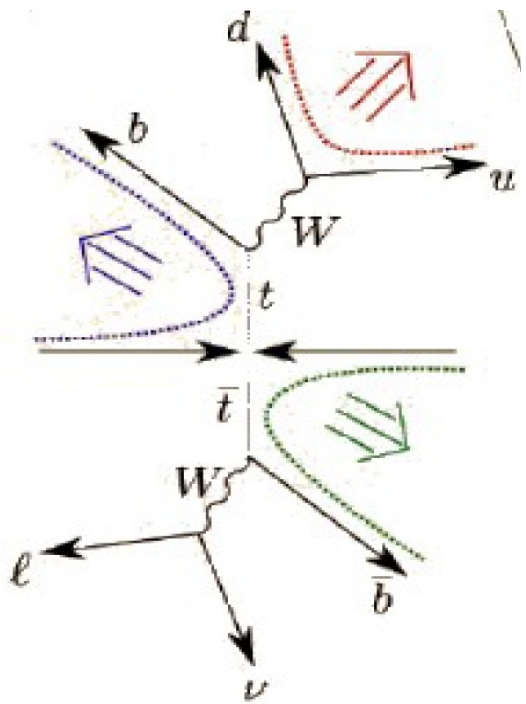
→ Forward – backward asymmetry (4.3 fb^{-1}):

A_{fb} = 8 ± 4 (stat.) ± 1 (sys.) %

Colorflow in $t\bar{t}$ events

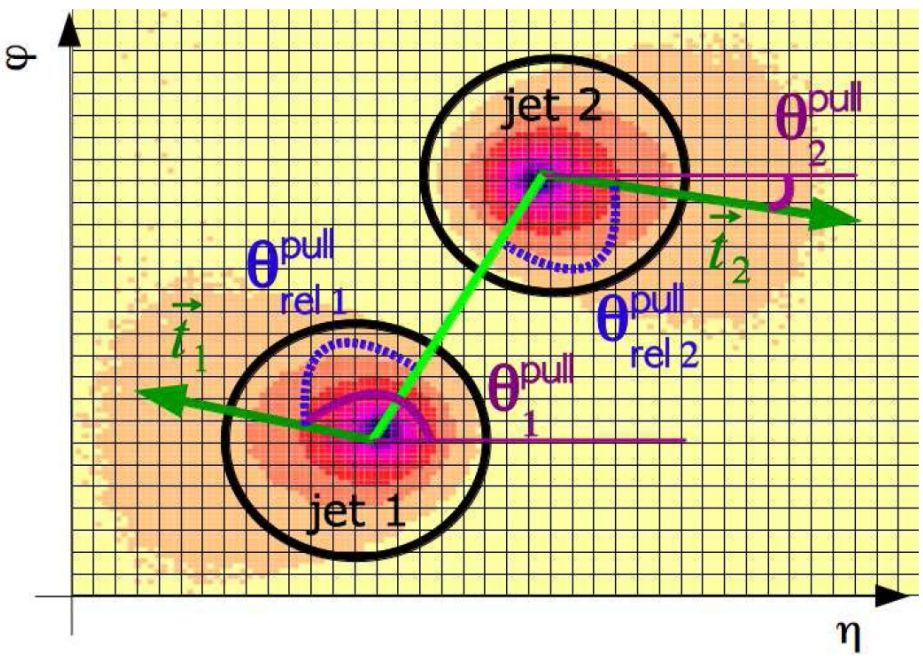
NEW

- Partons are carrying color charge, that provides additional information:
  - Singlet: $H^0 \rightarrow b\bar{b}$ or Octet: $g \rightarrow b\bar{b}$
- Choose $t\bar{t}$ decay channel as an optimal playground:



$W \rightarrow q\bar{q}$ (singlet)

b-jet (octet), color connected to the beam



- Fraction of events with light jets coming from singlet W: $f_{Singlet}$ (=1 in SM)
- Total systematic uncertainty is 0.22, statistically limited

→ $f_{Singlet} = 0.56 \pm 0.38$ (stat.+sys.) ± 0.19 (MC stat.)

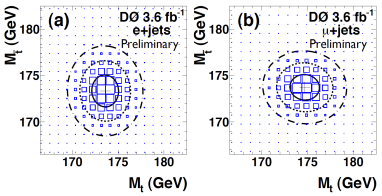
http://arxiv.org/abs/1101.0648

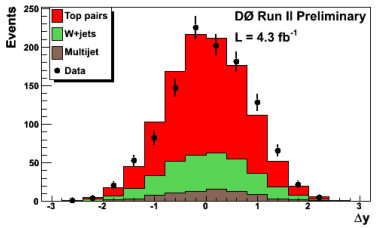
Summary

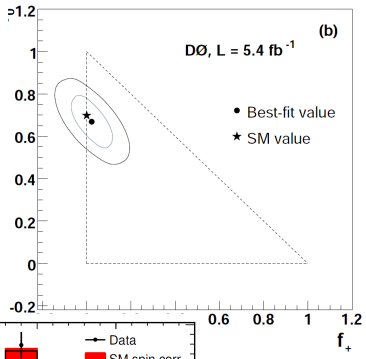
- Presented a wealth of measurements of top properties showing:
  Tevatron is Complementary and Competitive to the LHC

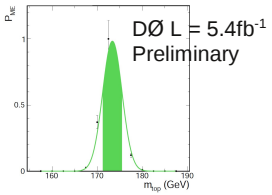
Outlook:

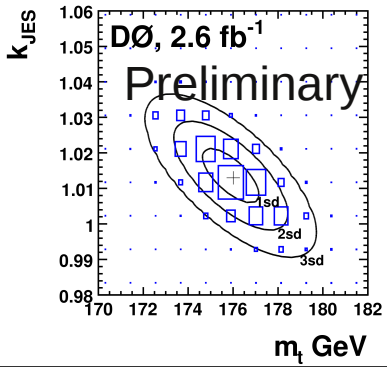
- Final DØ sample will have 2-3x the statistics
- Many new & more precise results in near future
- Tevatron is an exciting place to do Physics
- Tevatron is building up its legacy

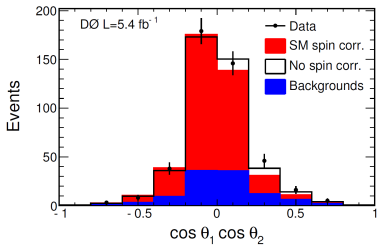


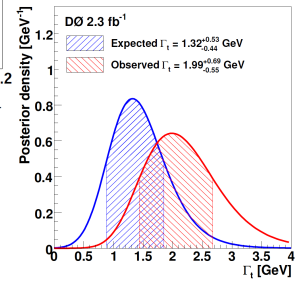












Backup

Mass of the Top Quark

- Top Mass Measurement is dominated by systematics
- Total systematic error close to be below 1GeV, already only 0.7%
- Will go into the legacy of the Tevatron collider

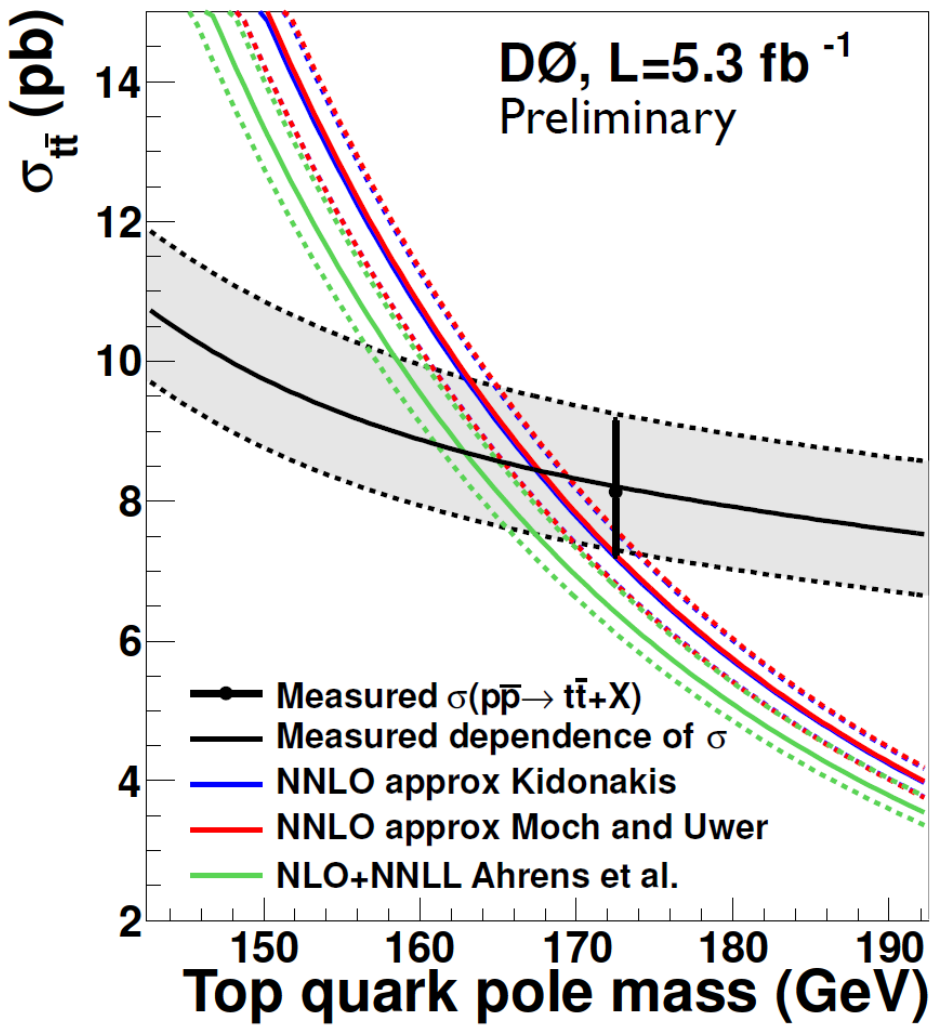
Source	Uncertainty (GeV)
Physics modeling:	
Signal modeling:	
higher order effects	±0.25
ISR/FSR	±0.26
hadronization and UE	±0.58
color reconnection	±0.50
multiple hadron interactions	±0.07
Background modeling	±0.03
W+jets heavy flavor scale factor	±0.07
b-modeling	±0.09
PDF uncertainty	±0.24
Detector Modeling:	
Residual jet energy scale	±0.21
Data-MC jet response difference	±0.28
b-tagging efficiency	±0.08
Trigger efficiency	±0.01
Lepton momentum scale	±0.17
Jet ID efficiency	±0.26
Jet energy resolution	±0.32
Method:	
Multijet contamination	±0.14
Signal fraction	±0.10
MC calibration	±0.20
Total	±1.02

Mass of the Top Quark

NEW

- Mass is convention dependent:
Depends on the renormalization scheme
- Direct mass measurement is close to the pole mass
- Derive m_t^{pole} from intersection of measured $\sigma_{t\bar{t}}$ and theoretical predictions:

Theoretical prediction	$m_t^{\rm pole}$ (GeV)	$\Delta m_t^{\rm pole}$ (GeV)
MC mass assumption	$m_t^{\rm MC} = m_t^{\rm pole}$	$m_t^{\rm MC} = m_t^{\overline{\rm MS}}$
NLO [11]	$164.8^{+5.7}_{-5.4}$	-3.0
NLO+NLL [12]	$166.5^{+5.5}_{-4.8}$	-2.7
NLO+NNLL [13]	$163.0^{+5.1}_{-4.6}$	-3.3
Approximate NNLO [14]	$167.5^{+5.2}_{-4.7}$	-2.7
Approximate NNLO [15]	$166.7^{+5.2}_{-4.5}$	-2.8



→ m_t = 167.5 + 5.4 – 4.7 GeV