Top Quark Properties Measurements in D0

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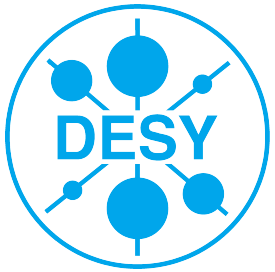
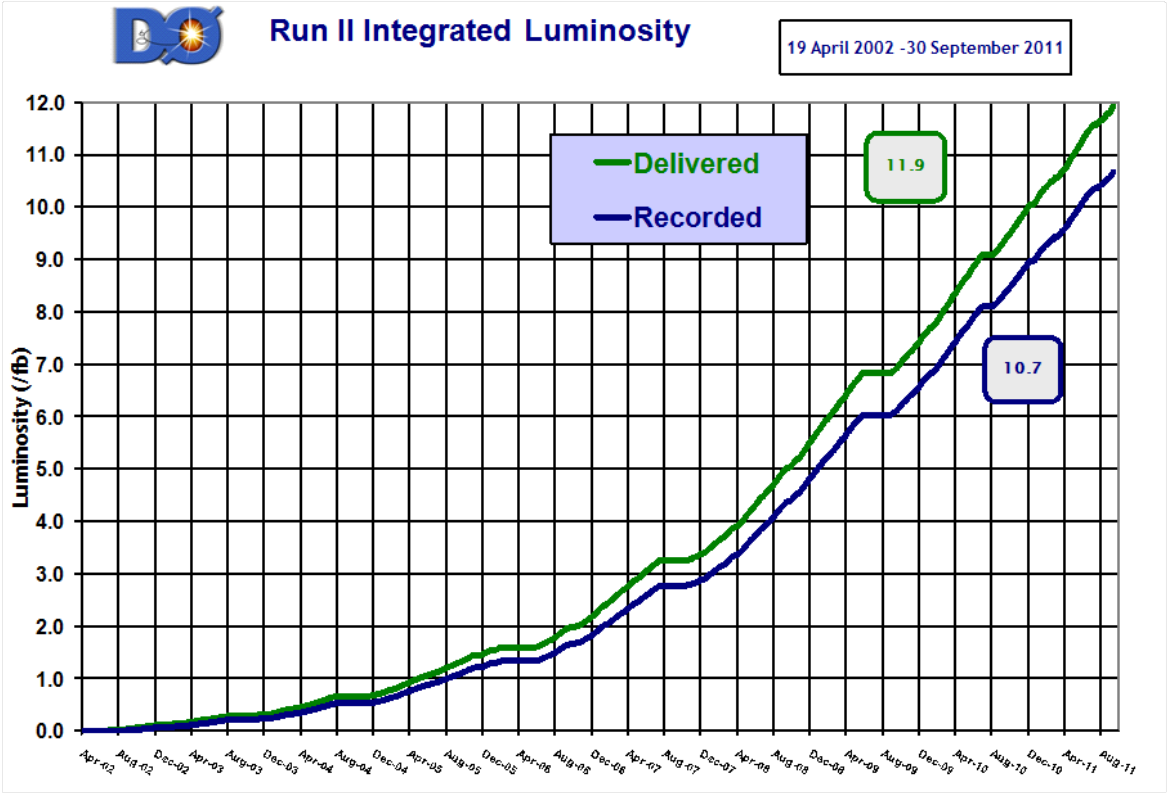


on behalf of the DØ Collaboration

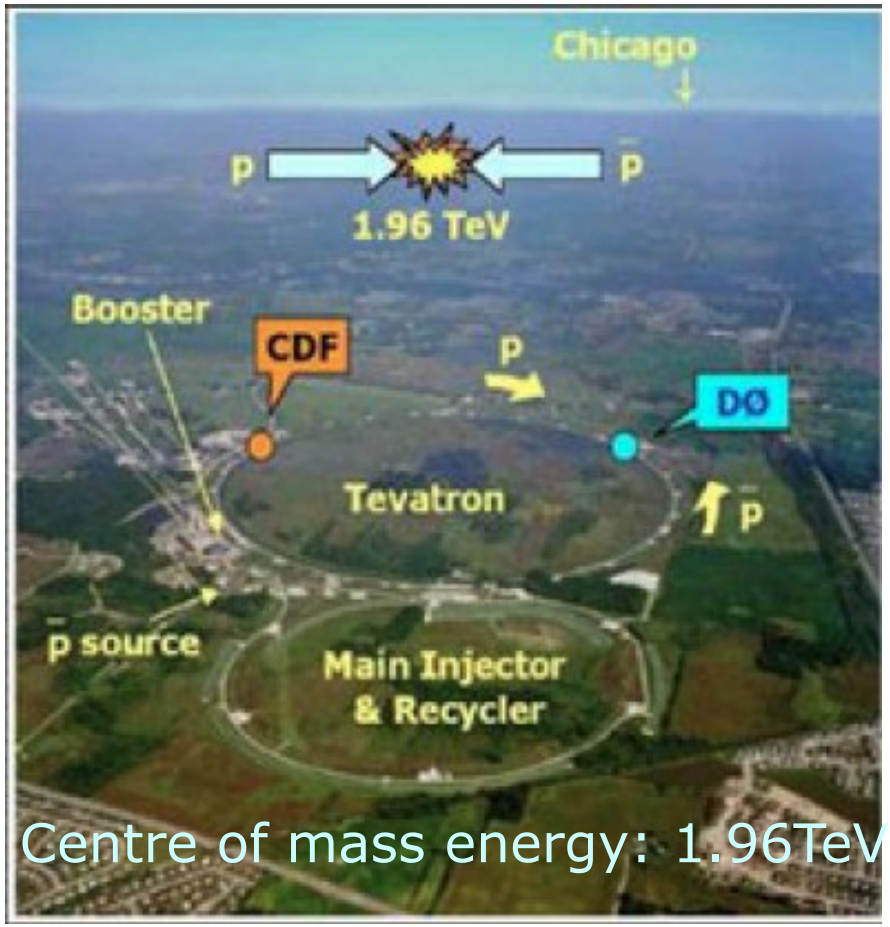
The Tevatron



~11.5fb^{-1} delivered

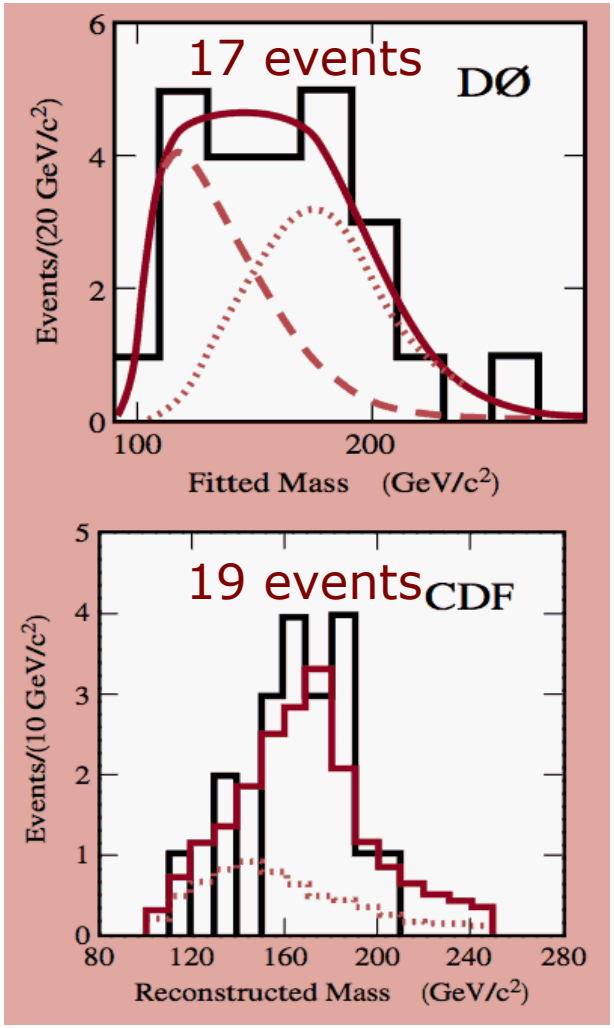
>10fb^{-1} on disk per experiment

Tevatron ended operation on 30.9.2011



The Top Quark

Discovered in 1995 by CDF and DØ at Fermilab (with few events)



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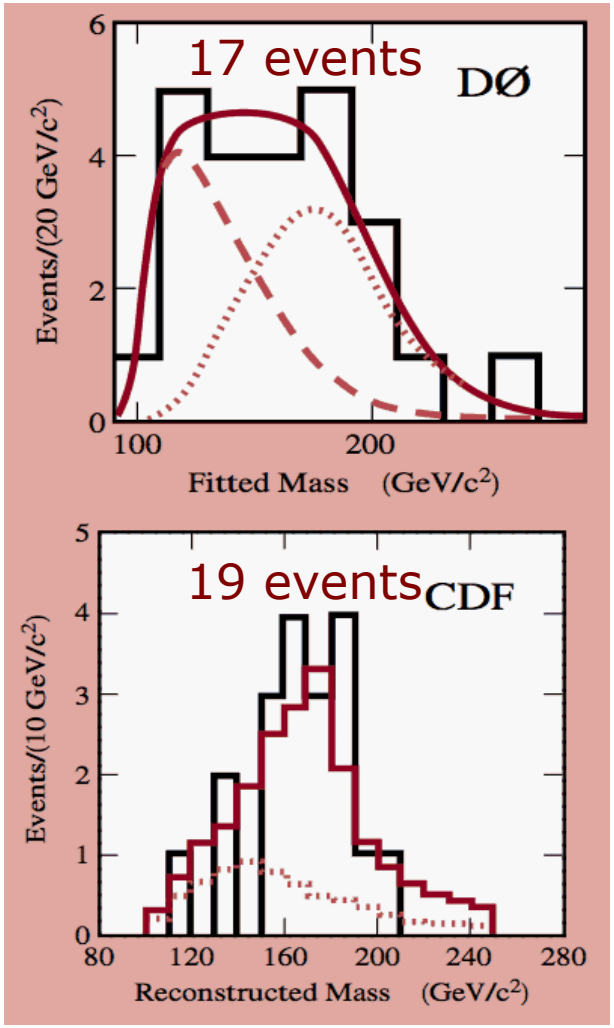
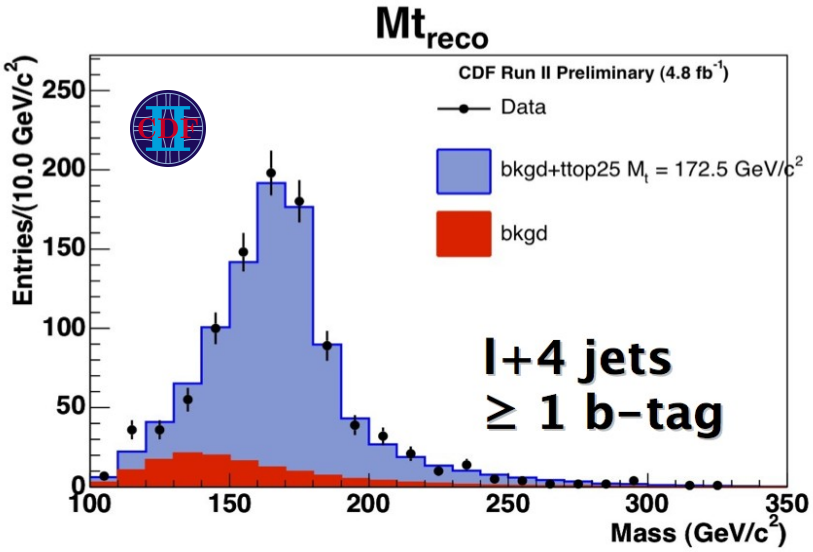
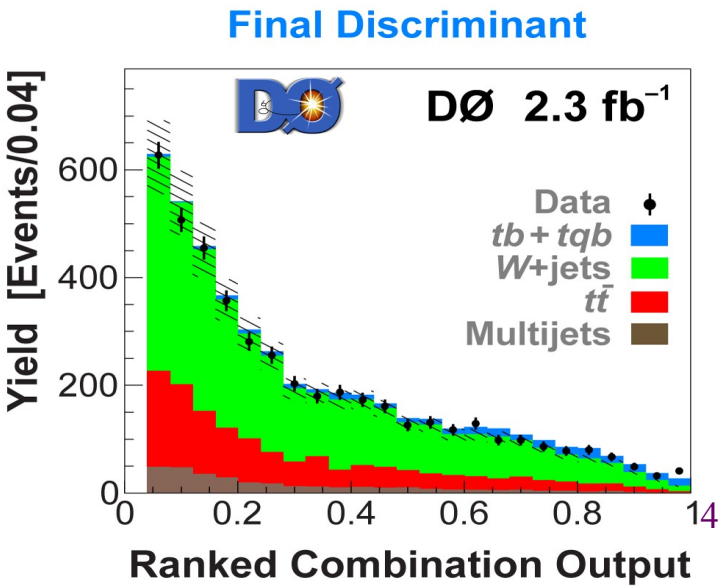


Situation today:

1000s of events!

Rediscovered in 2009 in single top production

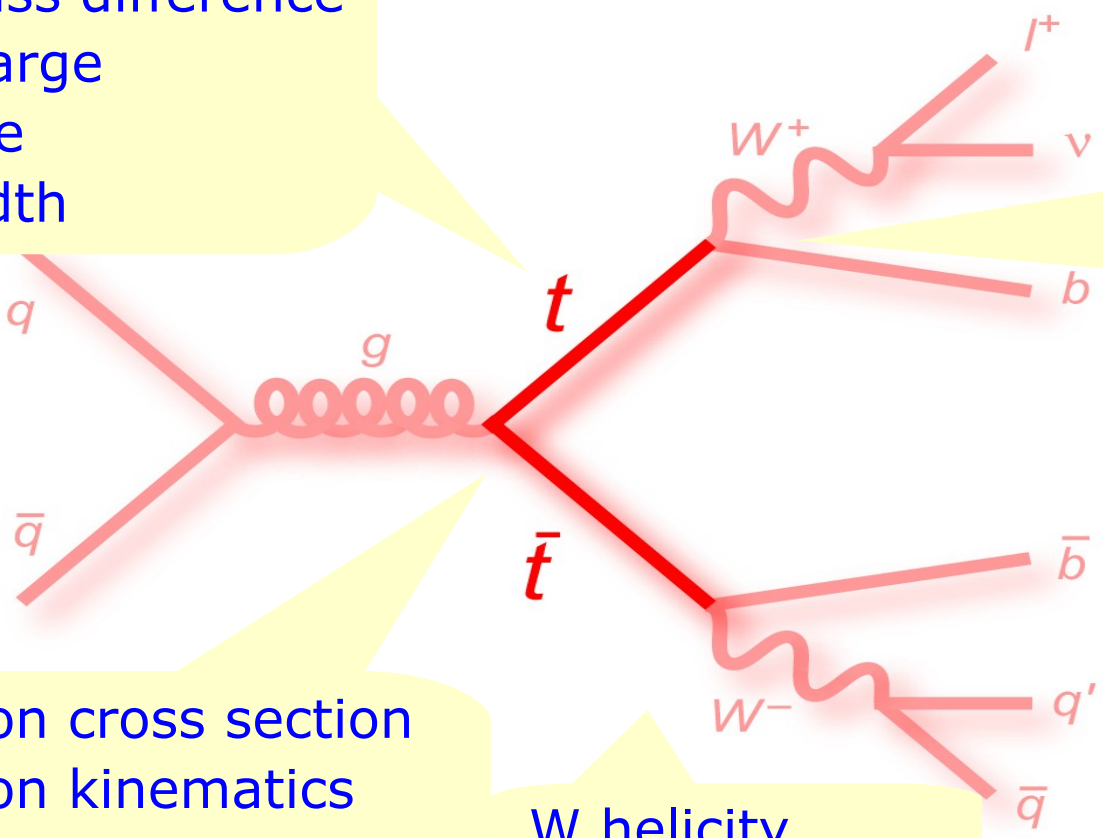




Since 2010 LHC operating → top quark factory

Top Studies

Top mass
Top mass difference
Top charge
Lifetime
Top width



Branching ratios
$|V_{tb}|$
Anomalous coupling
New/Rare decays

Spin correlation
Charge asymmetry
Color Flow

Production cross section
Production kinematics
Production via resonance
New particles

W helicity

s- & t- channel production, properties and searches in single top events

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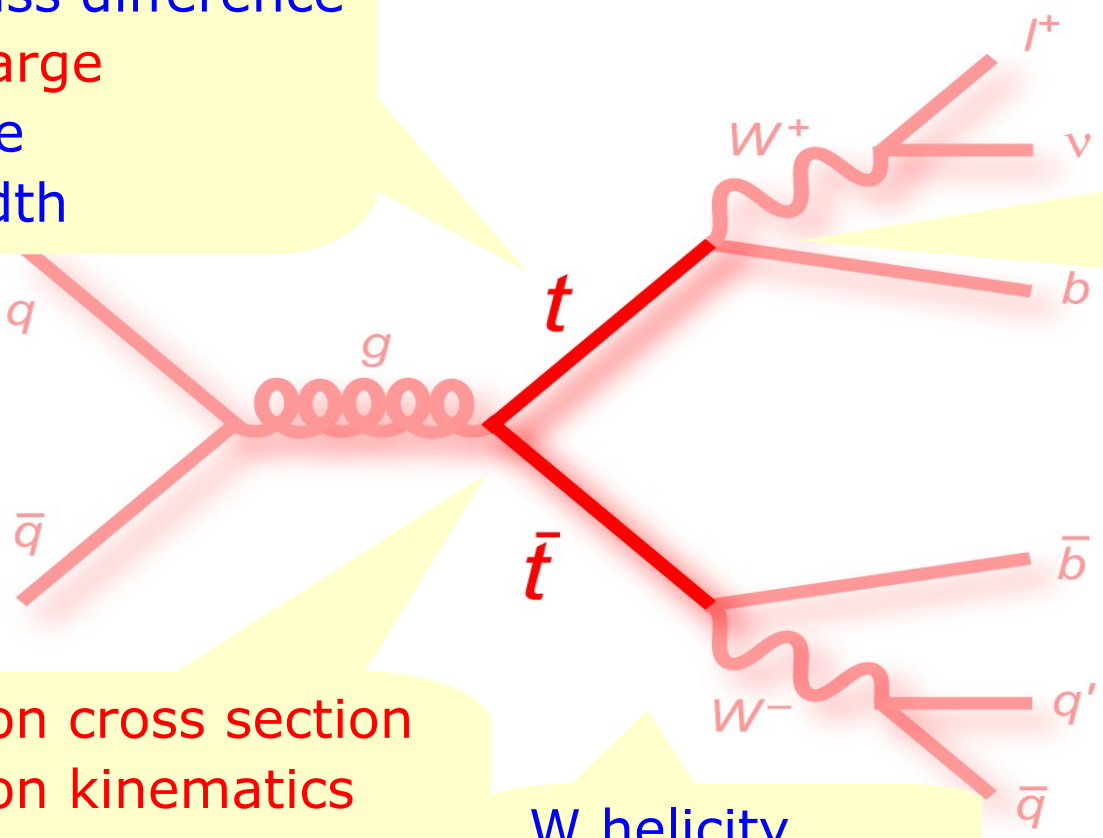

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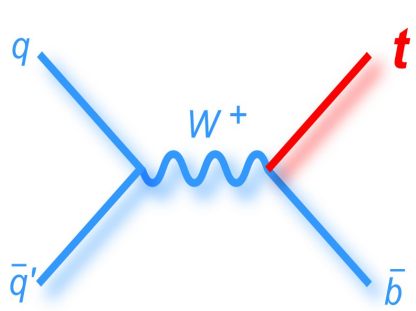
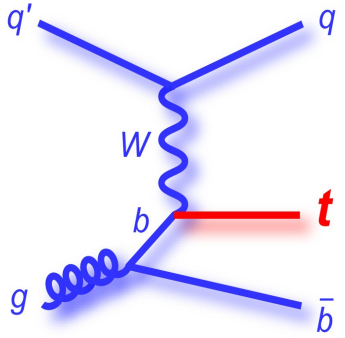
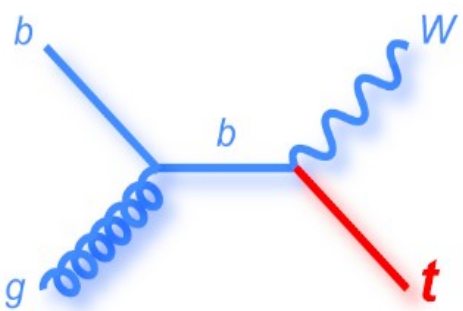
s- & t- channel production, properties and searches in single top events

Single Top: Cross Sections

- Single top quark production via electroweak interaction







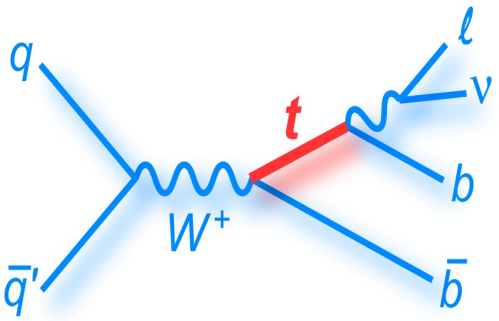
Collider	s-channel: σ_{tb}	t-channel: σ_{tqb}	Wt-channel: σ_{tW}
Tevatron: $p\bar{p}$ (1.96 TeV)	1.04 pb	2.26 pb	0.28 pb
LHC: pp (7 TeV)	4.6 pb	64.6 pb	15.7 pb

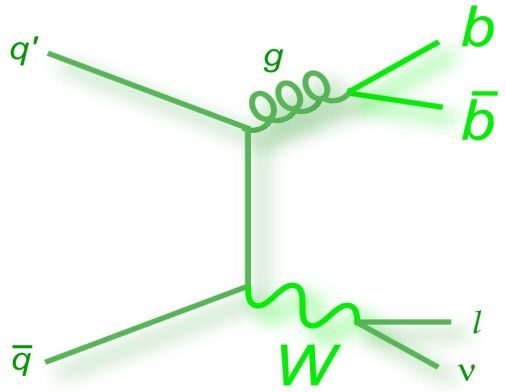
- Wt-channel: negligible at the Tevatron
- s-channel: challenging at the LHC

Single Top: Analysis

- Main background to single top: W+jets → very challenging

Simulated with Comphep (DØ) or POWHEG (CDF) +Pythia

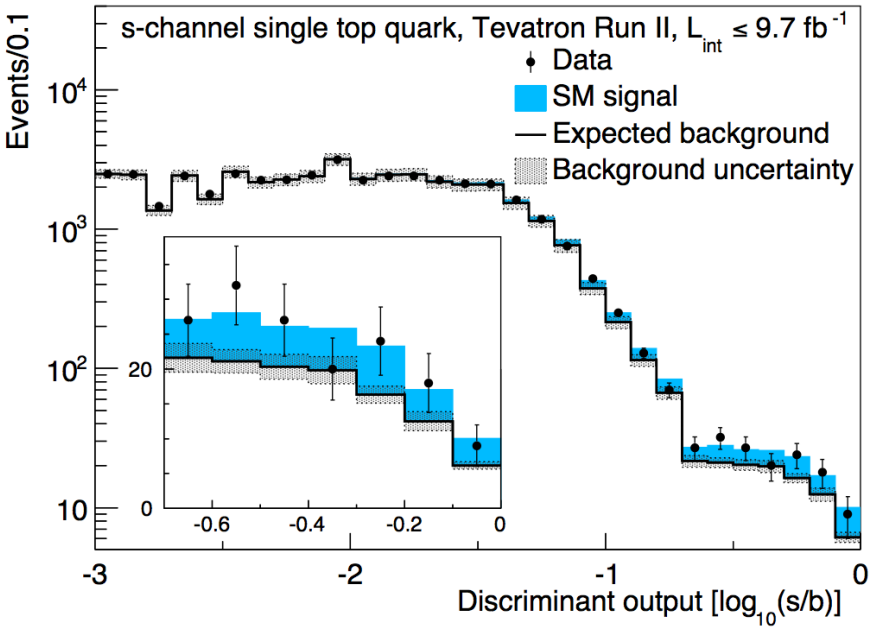




Modeled using Alpgen+Pythia/ Herwig

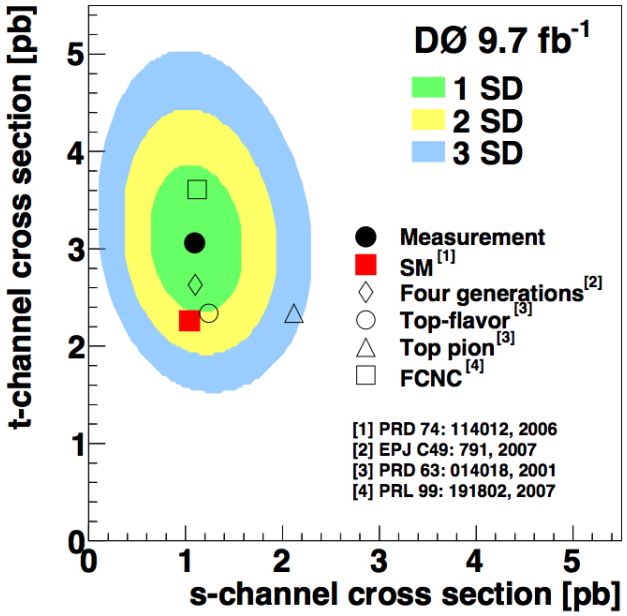
Normalized to Data

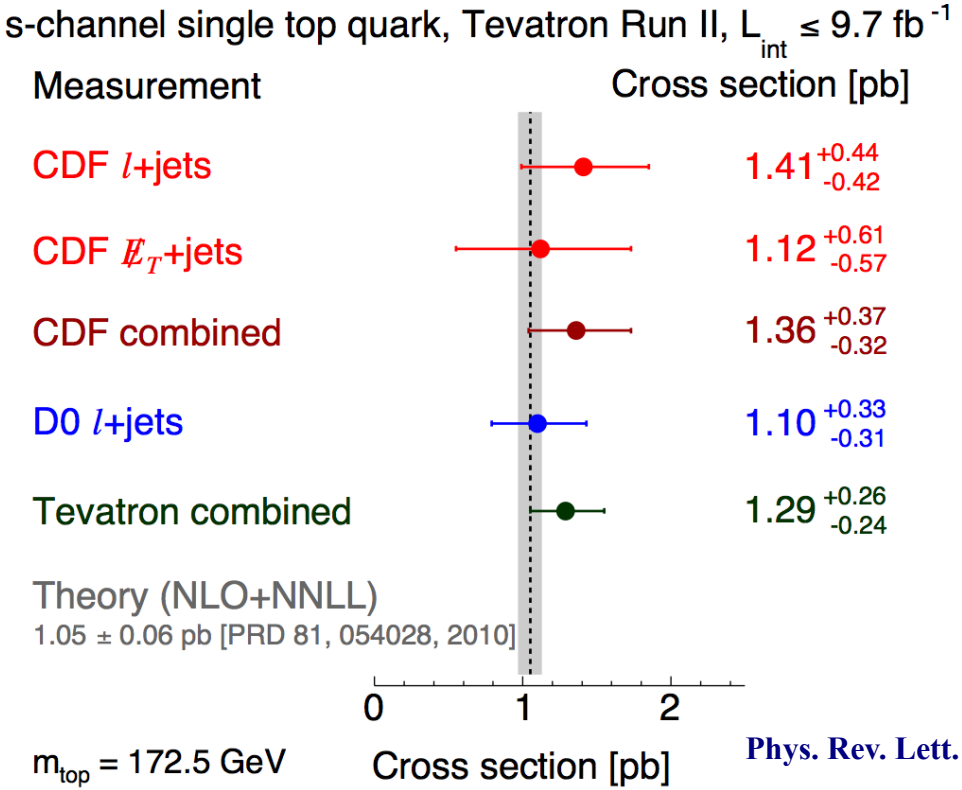
- Select l+jets & $\not\!\!E_T$+jets signature
  - High p_T lepton (l+jets) & high $\not\!\!E_T$
  - 2 jets (CDF) or 2&3 jets (D0)
    - 1 or 2 b-jets
- Build multivariate discriminants, optimized to separate s-channel signal from backgrounds



Single Top: Result

- Combined cross section measurement via Bayesian statistical analysis
- Single top s-channel observation from combined D0 and CDF analyses (observed significance: 6.3 standard deviations)

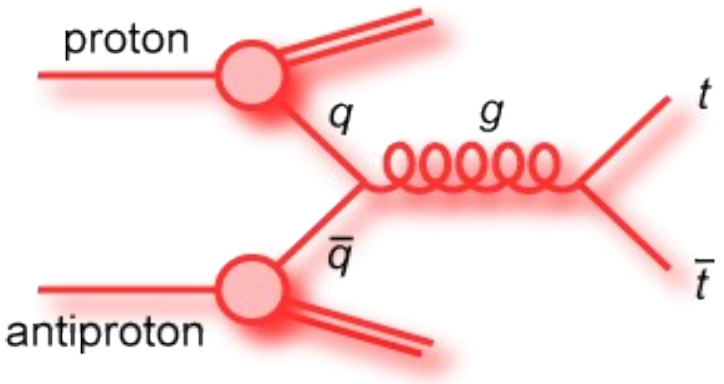


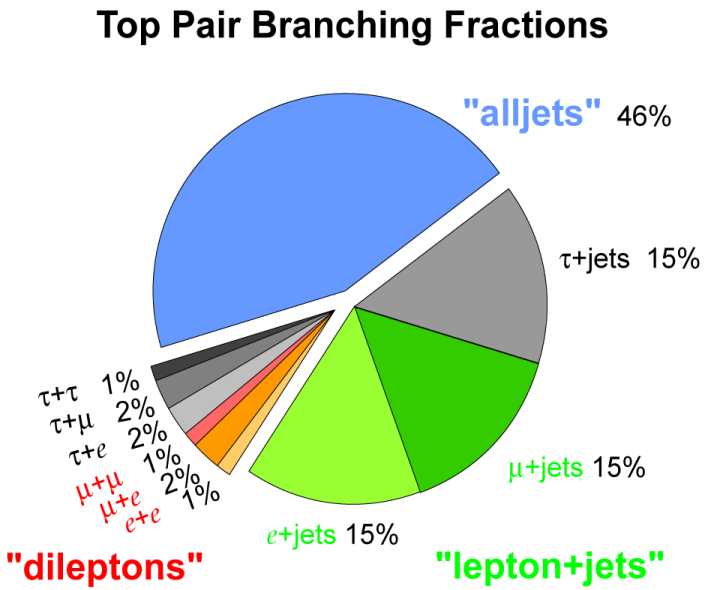


Phys. Rev. Lett. 112, 231803 (2014)

Reminder of some Basics: Production and Final States

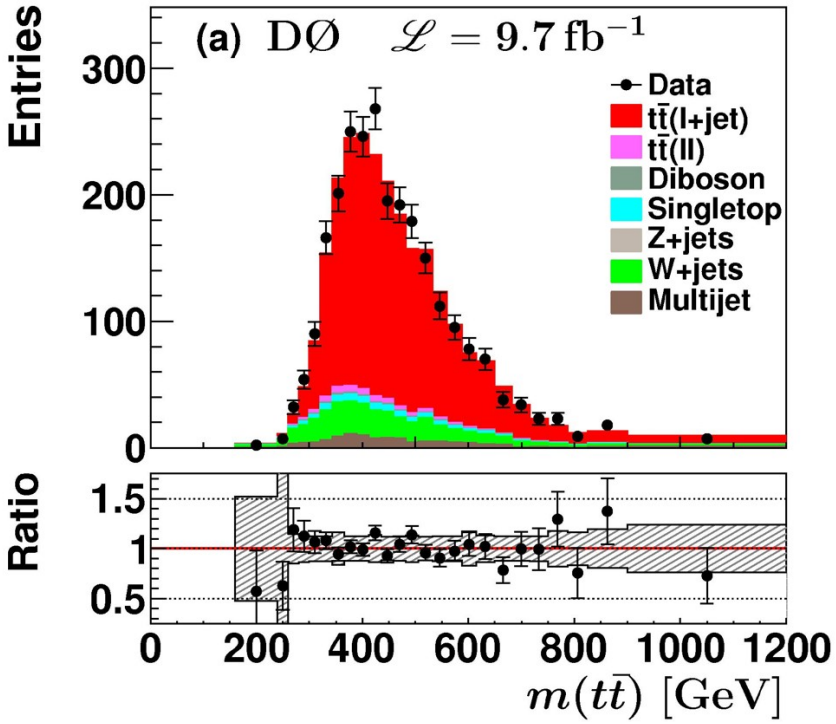
- Most properties measured in $t\bar{t}$ events
- At Tevatron: 85% $q\bar{q}$ annihilation + 15% gg fusion
  - At LHC (7 TeV): 15% $q\bar{q}$ annihilation + 85% gg fusion
- $t\bar{t}$ $W^+bW^-\bar{b}$: Final states are classified according to W decay
  - Most properties measured in dilepton & l+jets final states





$t\bar{t}$ Production Cross Section

- Measurements of inclusive & differential $t\bar{t}$ production cross section
  - Direct test of QCD
- Differential measurements as function of $m_{t\bar{t}}$, $|y^{top}|$, & p_T^{top}
  - In l+jets topology, using full Run II data sample
    - $t\bar{t}$ event reconstruction using constrained kinematic fitter
  - Defined for parton-level top quarks including off-shell effects
    - Correction for detector and acceptance effects using regularized unfolding
      - Full correlation matrix provided



$t\bar{t}$ Production Cross Section: Results

- Inclusive cross section:

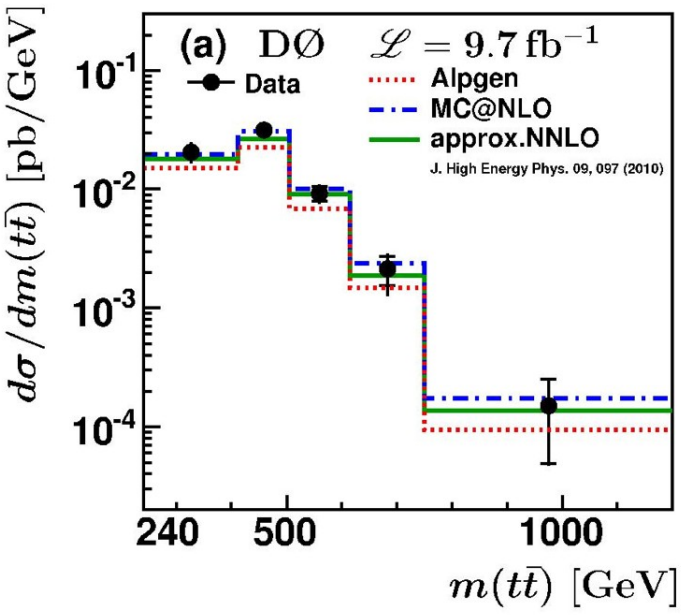
arXiv:/1401.5785 [hep-ex]

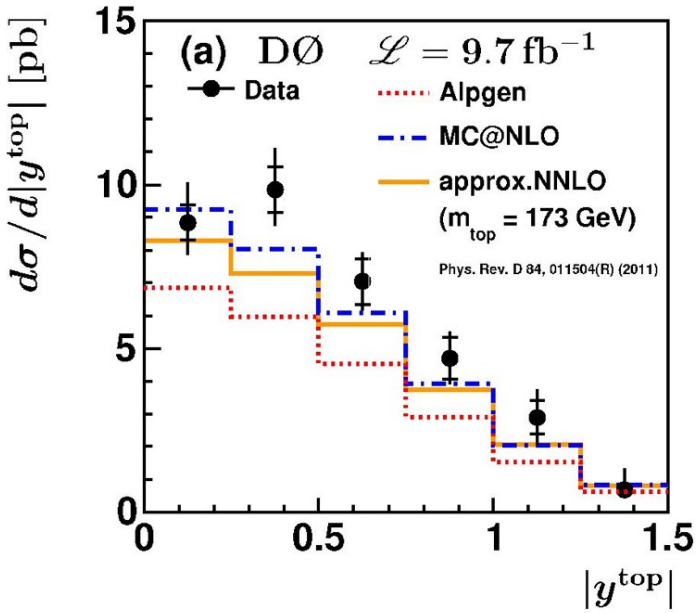
  - Calculated from events with ≥4 jets

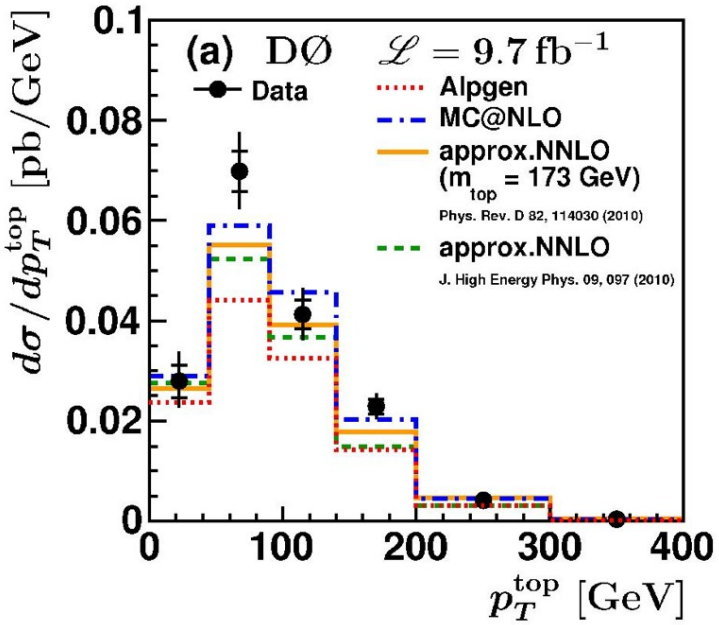
$$\sigma_{\text{tot}}^{t\bar{t}} = 8.3 \pm 0.7\,(\text{stat.}) \pm 0.6\,(\text{syst.}) \pm 0.5\,(\text{lumi.})\ \text{pb}$$

in good agreement with SM prediction

- Differential distributions: (events with ≥4 jets, ≥1 b-tagged)



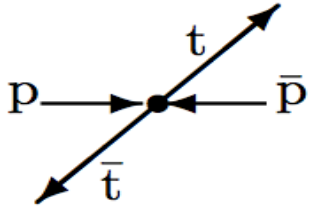


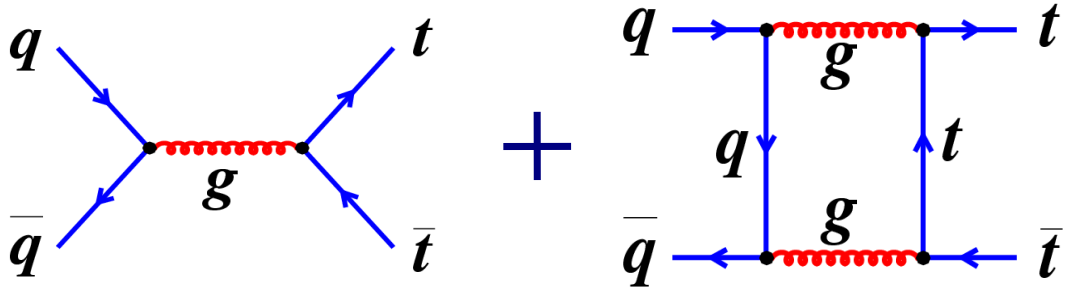


- In general agreement with approx. NNLO & QCD generator predictions

Asymmetry: Idea

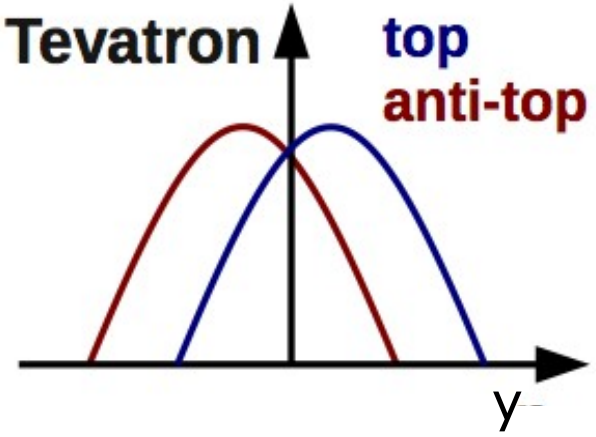
- NLO QCD: Interference between $q\bar{q}$ diagrams → causes $t\bar{t}$ asymmetry
  - Top quarks more likely to go into direction of incoming quark





- Measurement of forward-backward asymmetry:

$$A_{FB}^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$



$\Delta y = y_t - y_{\bar{t}}$

- Also: study of lepton-based asymmetry

$$A_{FB}^{l} = \frac{N(q_l y_l > 0) - N(q_l y_l < 0)}{N(q_l y_l > 0) + N(q_l y_l < 0)}$$

$$y = \frac{1}{2} \ln\left(\frac{E + p_z}{E - p_z}\right)$$

Asymmetry with Leptons

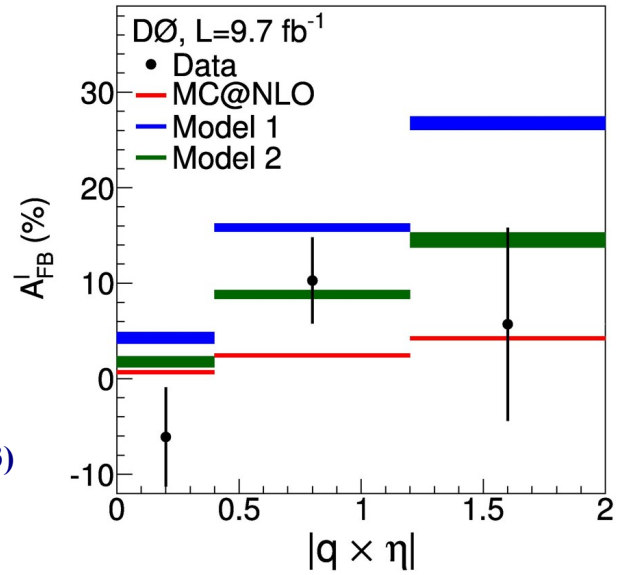
- Measurements in dilepton and l+jets channels
  - Unfolded to production-level
- Inclusive (dilepton & l+jets combined):

$$A_{FB}^{l} = 4.7 \pm 2.3\,(\text{stat}) \pm 1.5\,(\text{syst})\,\%$$

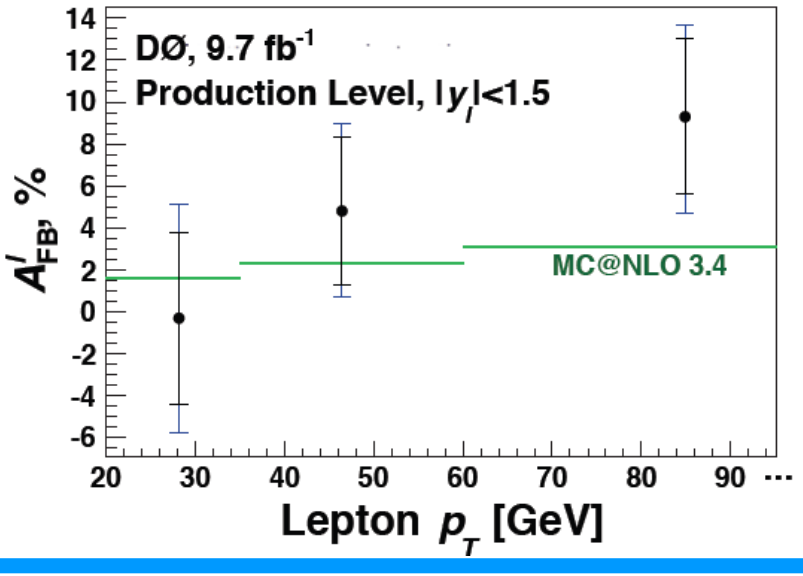
  - Compared to

$$A_{FB}^{l}(NLO + EW) = 3.8 \pm 0.2\,\%$$

Phys. Rev. D 88, 112002 (2013)
arXiv:/1403.1294 [hep-ex]



- As function of eta (dilepton) and lepton p_T (l+jets)
  - Lepton p_T : strongly correlated with $m_{t\bar{t}}$
  - Agreement with MC@NLO prediction

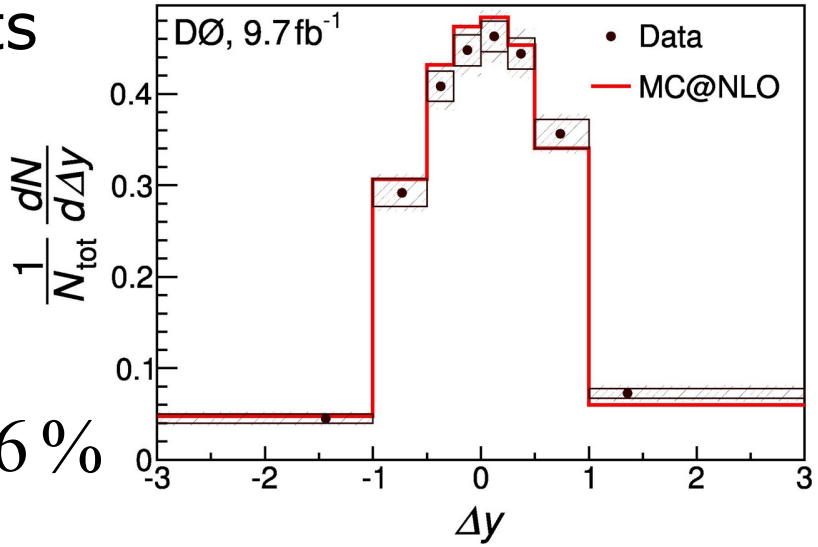


Forward-Backward Asymmetry

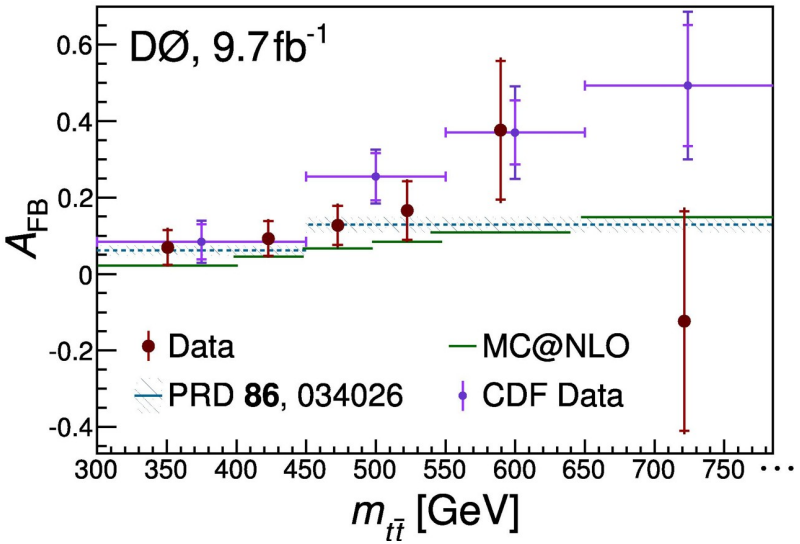
- Reconstruct $t\bar{t}$ system; l+3jets & l+≥4jets
- Inclusive

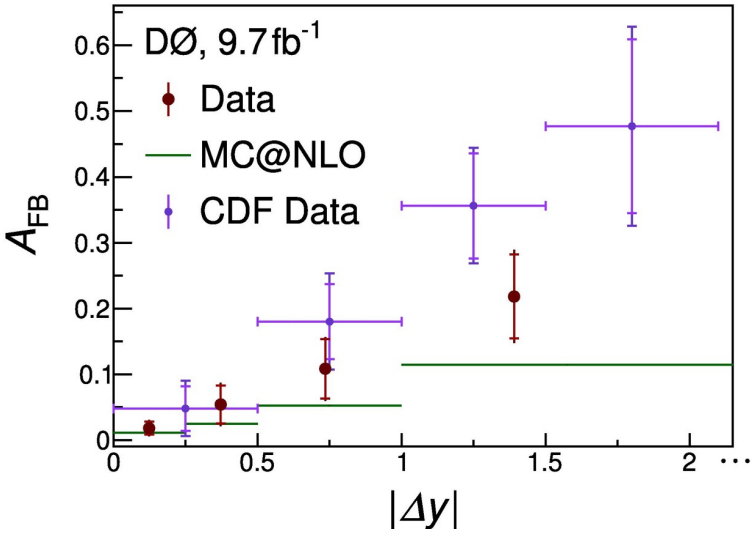
$$A_{FB}^{t\bar{t}} = 10.6 \pm 2.7\,(\text{stat}) \pm 1.3\,(\text{syst})\,\%$$

  - Compared to $A_{FB}^{t\bar{t}}(NLO+EW) = 8.8 \pm 0.6\,\%$



- As function of $m_{t\bar{t}}$ & $|\Delta y|$
  - Agreement with MC@NLO prediction
  - Agreement with CDF as well



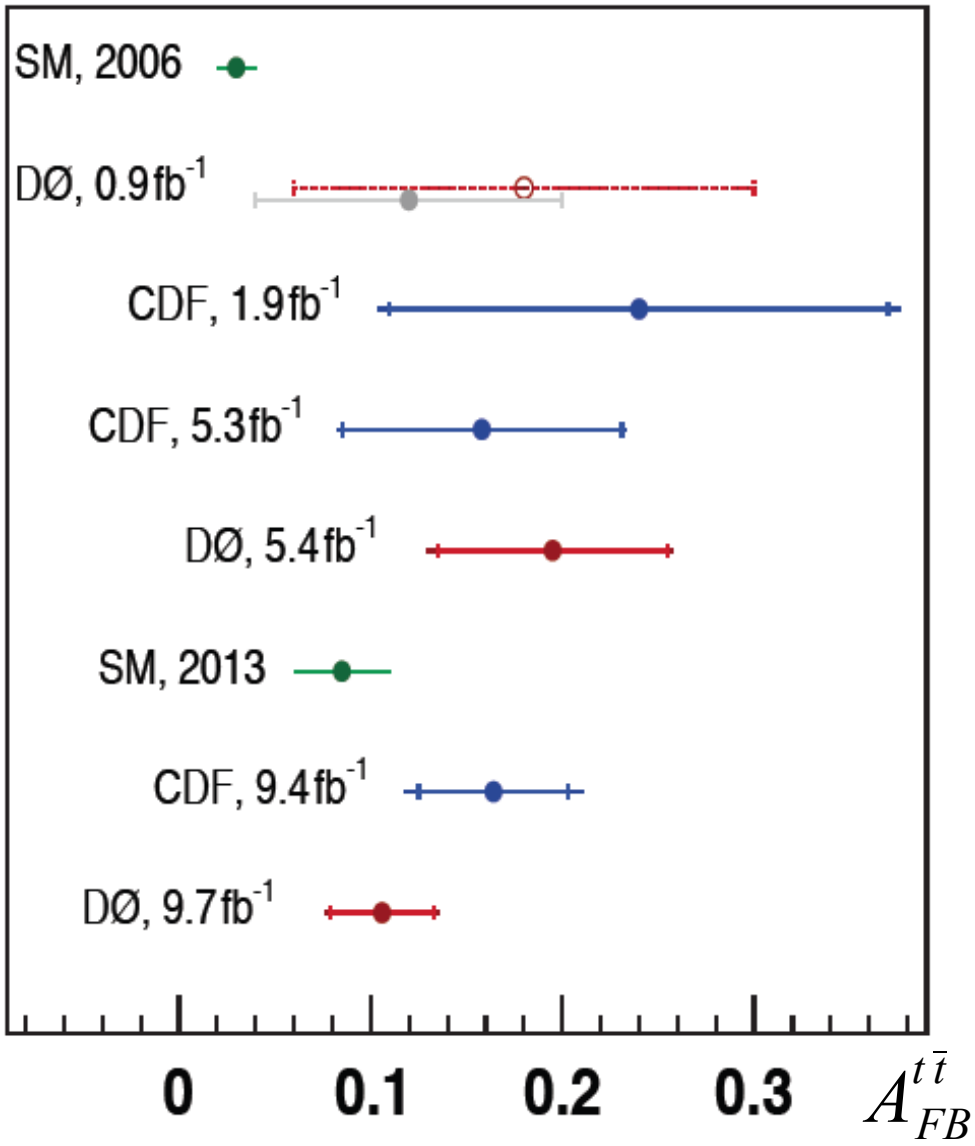


arXiv:/1405.0421 [hep-ex]

Asymmetry: Overview of A_{FB} Results

- Improved SM calculations → higher predicted FB $t\bar{t}$ asymmetry

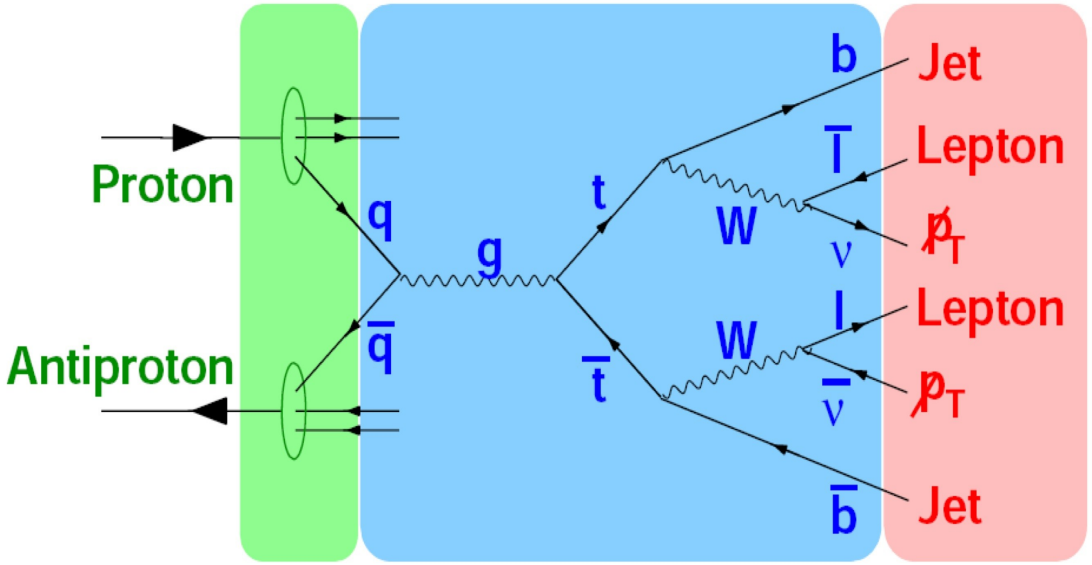
- Measured central value came down
  → now agreement with SM for inclusive asymmetry



Top Quark Mass: Method

- Free parameter of the SM
- Top & W mass: constraint on Higgs mass → self-consistency check

- Matrix element method:
  Use full event kinematics
  → most precise method
- For each event calculate probability to belong to certain top mass



$$P_{sig}(x;m_{top}) = \frac{1}{\sigma_{obs}} \int \sum_{flavors} dq_1\, dq_2\, dy\, f(q_1)\, f(q_2)\, \sigma(y;m_{top})\, W(x,y)$$

PDFs

Matrix element & phase space

Transfer function: mapping of true momenta y to measured momenta x

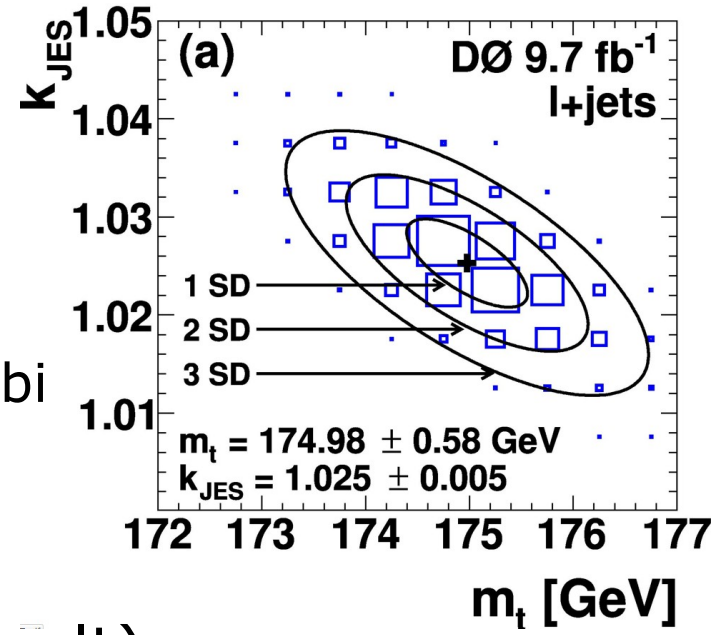
Top Quark Mass: Results

- Matrix element analysis in l+jets channel with full Run II data
  - Improved handling of systematics, speed-up of ME integration
  - Use 4 jets, ≥1 b-tag
  - Use jets from hadronic W decay to constrain JES
- Result:

$$m_t = 174.98 \pm 0.58\,(\text{stat+JES}) \pm 0.49\,(\text{syst})\ \text{GeV}$$

  - 0.43% relative uncertainty!
    - Comparable uncertainty to Tevatron+LHC combi
  - Main systematics from residual JES & hadronization/underlying event

arXiv:/1405.1756 [hep-ex]



- Tevatron+LHC combination (w/o this new result):

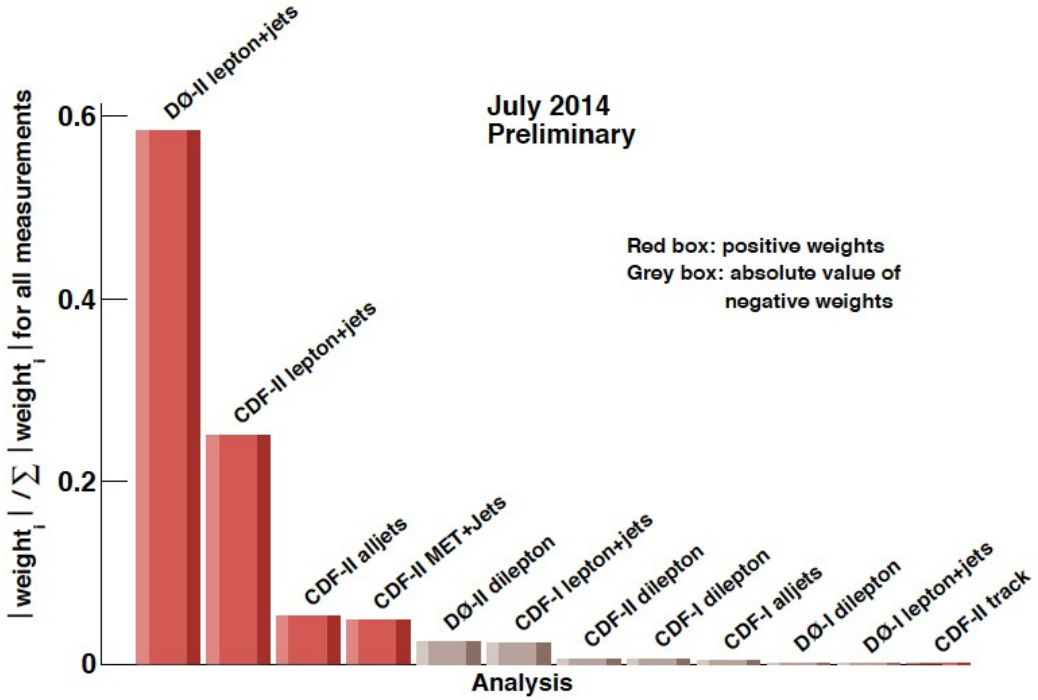
$$m_t = 173.34 \pm 0.27\,(\text{stat}) \pm 0.71\,(\text{syst})\ \text{GeV}$$

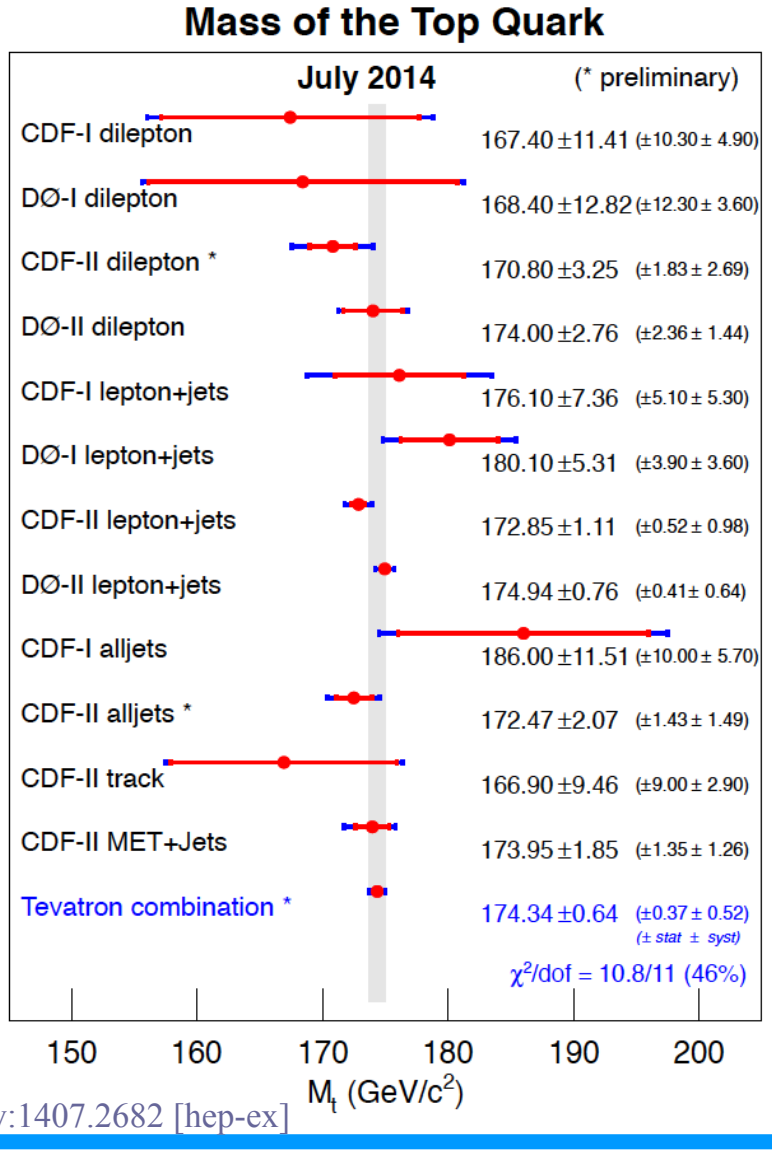
arXiv:1403.4427 [hep-ex]

Top Quark Mass: Combination

- New Tevatron top mass combination with new D0 l+jets result
  - Results using up to 9.7fb^{-1}
  - Run I and Run II results
- Combination performed using BLUE:

$$m_t = 174.34 \pm 0.37\,(\text{stat}) \pm 0.52\,(\text{syst})\ \text{GeV}$$





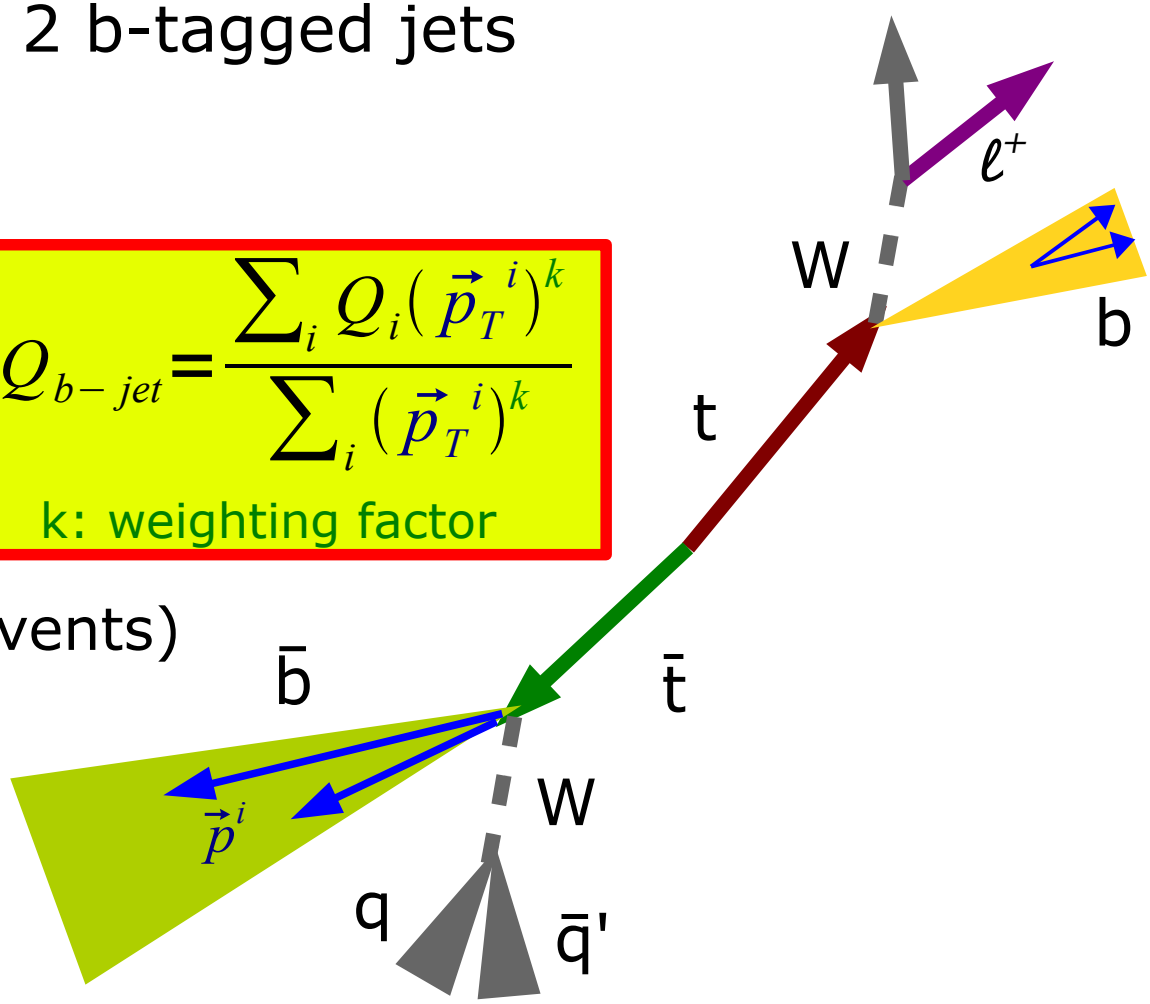
arXiv:1407.2682 [hep-ex]

Top Quark Charge: Analysis

- Exotic model with top charge -4/3 e could be possible (SM: +2/3e)
- Use l+jets events with at least 2 b-tagged jets
- Kinematic fit algorithm:
  assignment of pairings
- b-jet charge:
  weighting technique
  - Use tracks in the jet
  - k set to 0.5 (optimized on $t\bar{t}$ events)
- Determine top charge from
  - Lepton from W
  - b-jet charge

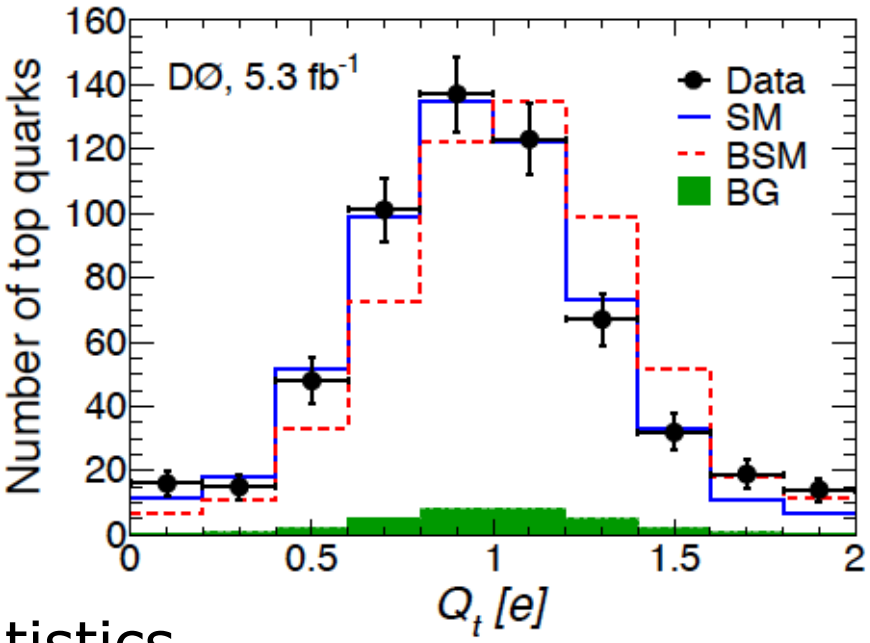
$$Q_{b-jet} = \frac{\sum_i Q_i \left(\vec{p}_T^{\,i}\right)^k}{\sum_i \left(\vec{p}_T^{\,i}\right)^k}$$

k: weighting factor



Top Quark Charge: Results

- Construct SM and exotic top charge template
  → measure SM fraction f
  - Dijet sample used for jet charge calibration

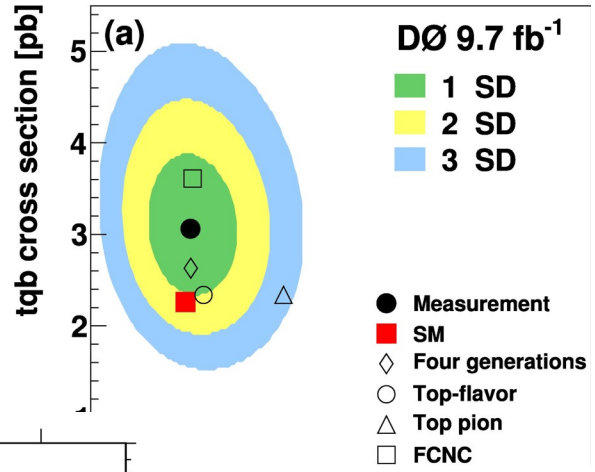


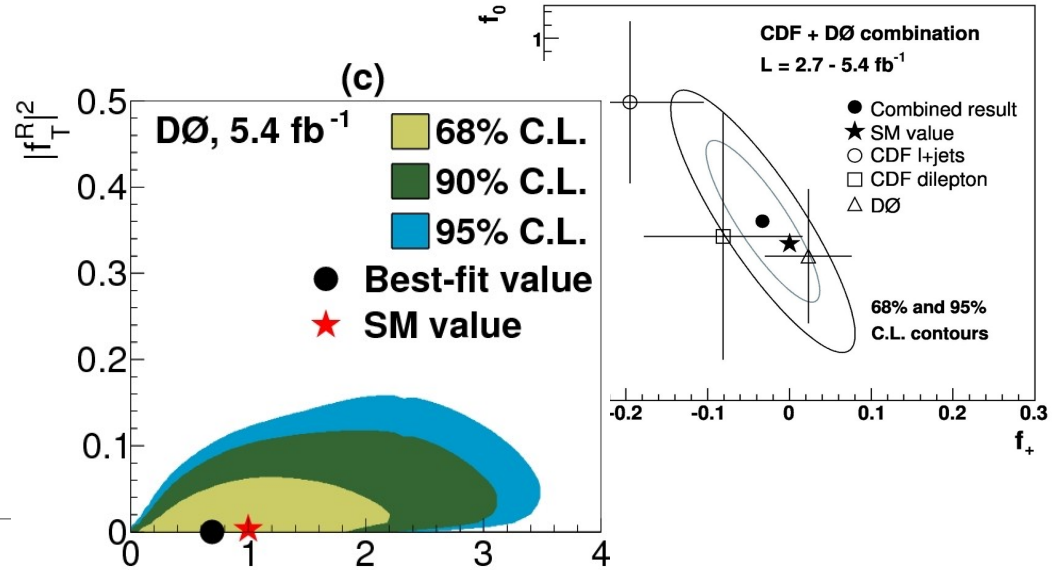
- Template fit:
  f=0.88±0.13(stat)±0.11(syst)
  - Main systematics: dijet sample statistics
- Exotic top charge hypothesis excluded with >5 SD
- Alternative model:
  - $t\bar{t}$ sample:mixture of top and exotic top
    → Upper limit on admixture of exotic tops: f<0.46 @ 95% CL

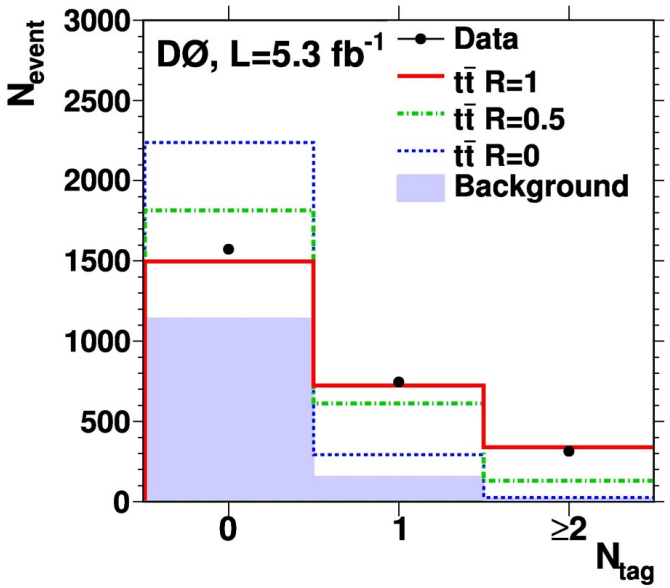
arXiv:1407.4837

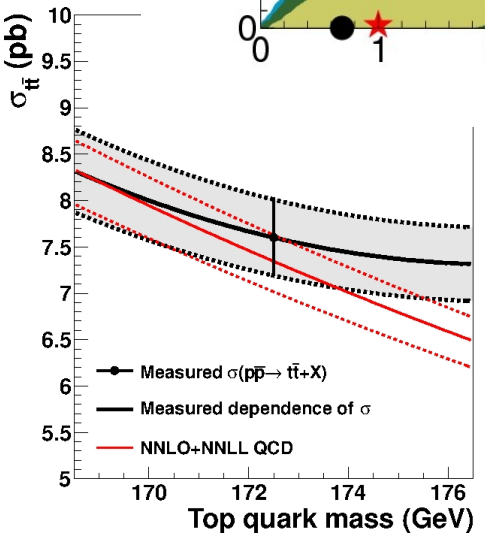
Many more properties

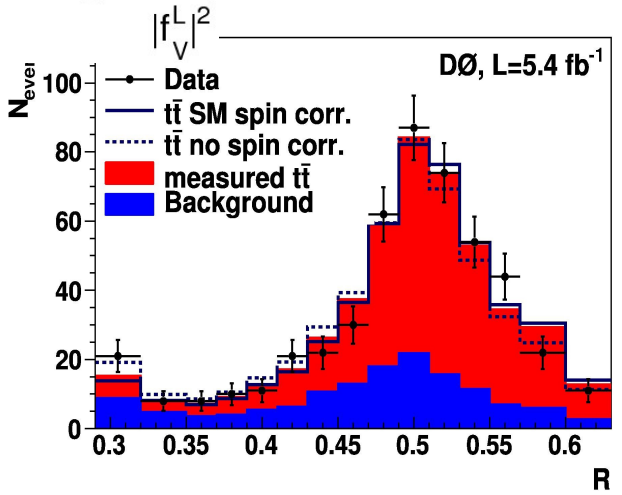
- Only showed newest results, but a lot of first/best/legacy top properties measurements performed at D0











Summary

- Many interesting top quark properties measurements performed at D0
  - Several are Tevatron legacies!
    - Most precise top quark mass
    - Final word from D0 on asymmetry
    - Differential distributions

- Only showed recent results, more here:

http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html

- Work ongoing for more top analyses from D0 to come out soon!
  - And Tevatron & Tevatron+LHC combinations

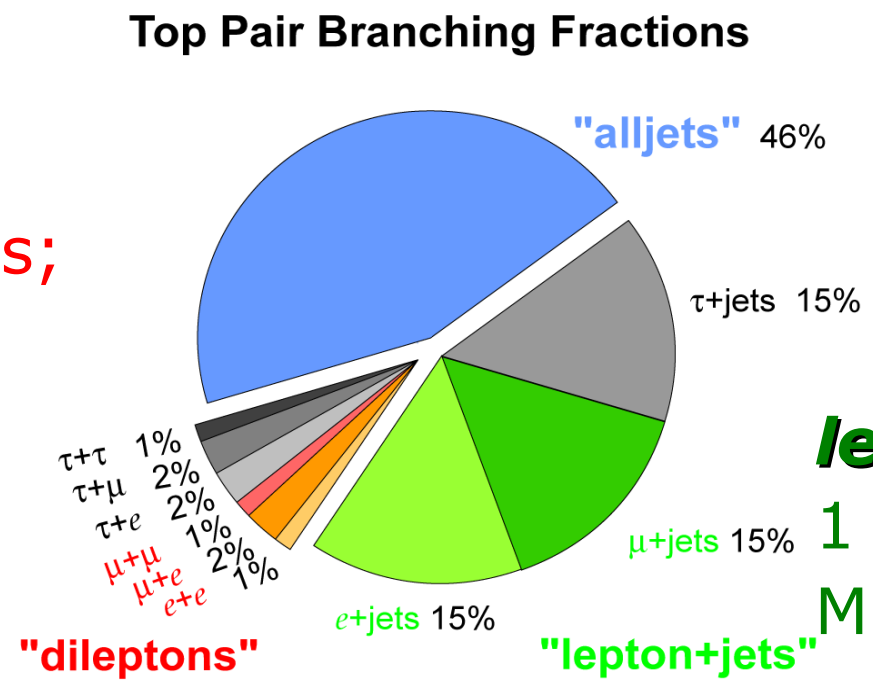
BACKUP

$t\bar{t}$ Final States

$t\bar{t}$ $W^+bW^-\bar{b}$: Final states are classified according to W decay

$B(t \to W^+b) = 100\%$

pure hadronic:
≥6 jets (2 b-jets)



dilepton:
2 isolated leptons;
High missing E_T from neutrinos;
2 b-jets

lepton+jets:
1 isolated lepton;
Missing E_T from neutrino;
≥4 jets (2 b-jets)

Top Quark Mass: Uncertainties

- l+jets:
  Systematic uncertainties

Source of uncertainty	Effect on m_t (GeV)
Signal and background modeling:	
Higher order corrections	$+0.15$
Initial/final state radiation	± 0.09
Hadronization and UE	$+0.26$
Color reconnection	$+0.10$
Multiple $p\bar{p}$ interactions	-0.06
Heavy flavor scale factor	± 0.06
b-jet modeling	$+0.09$
PDF uncertainty	± 0.11
Detector modeling:	
Residual jet energy scale	± 0.21
Flavor-dependent response to jets	± 0.16
b tagging	± 0.10
Trigger	± 0.01
Lepton momentum scale	± 0.01
Jet energy resolution	± 0.07
Jet ID efficiency	-0.01
Method:	
Modeling of multijet events	$+0.04$
Signal fraction	± 0.08
MC calibration	± 0.07
Total systematic uncertainty	± 0.49
Total statistical uncertainty	± 0.58
Total uncertainty	± 0.76

Jet Energy Scale