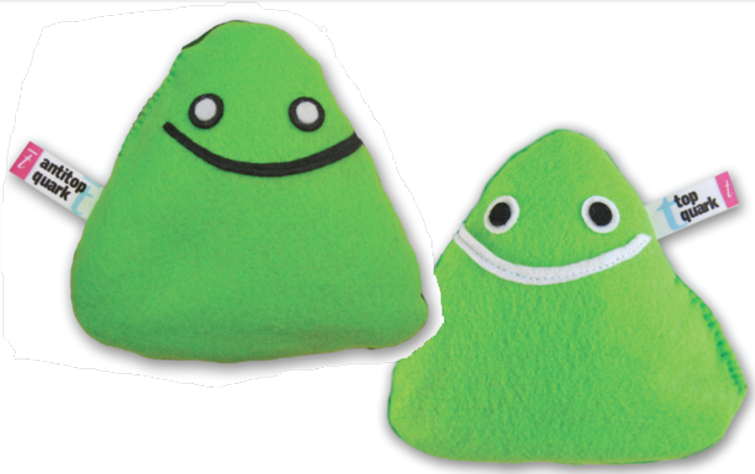
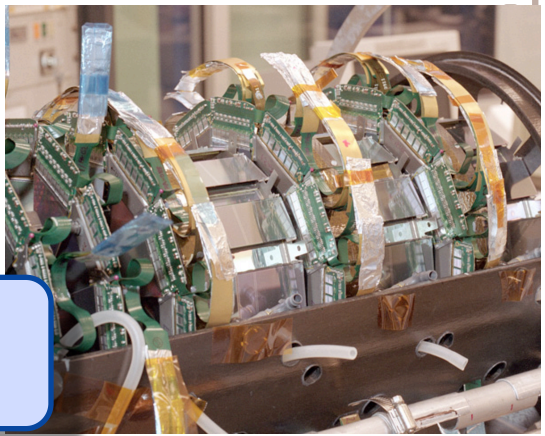
Recent results in the top quark Sector from the DØ experiment

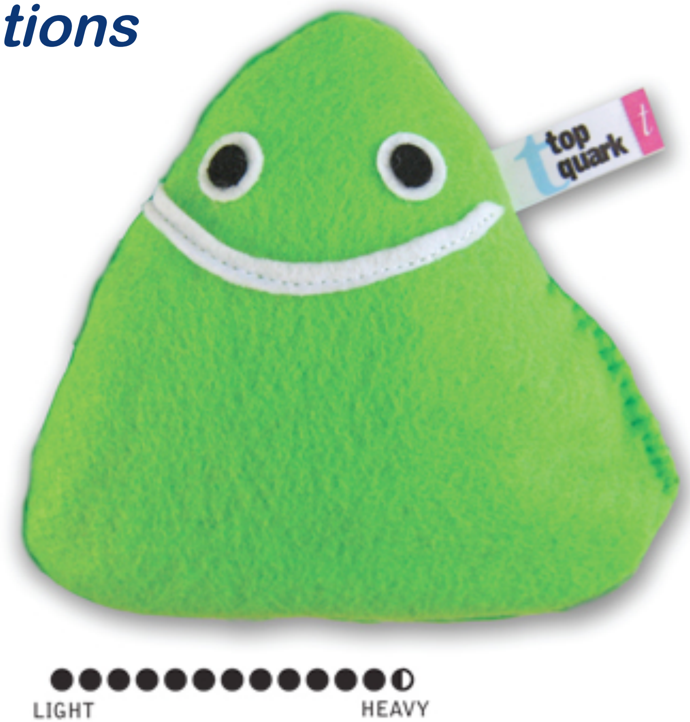




Oleg Brandt (U Heidelberg)
on behalf of the DØ collaboration

What makes top so interesting?

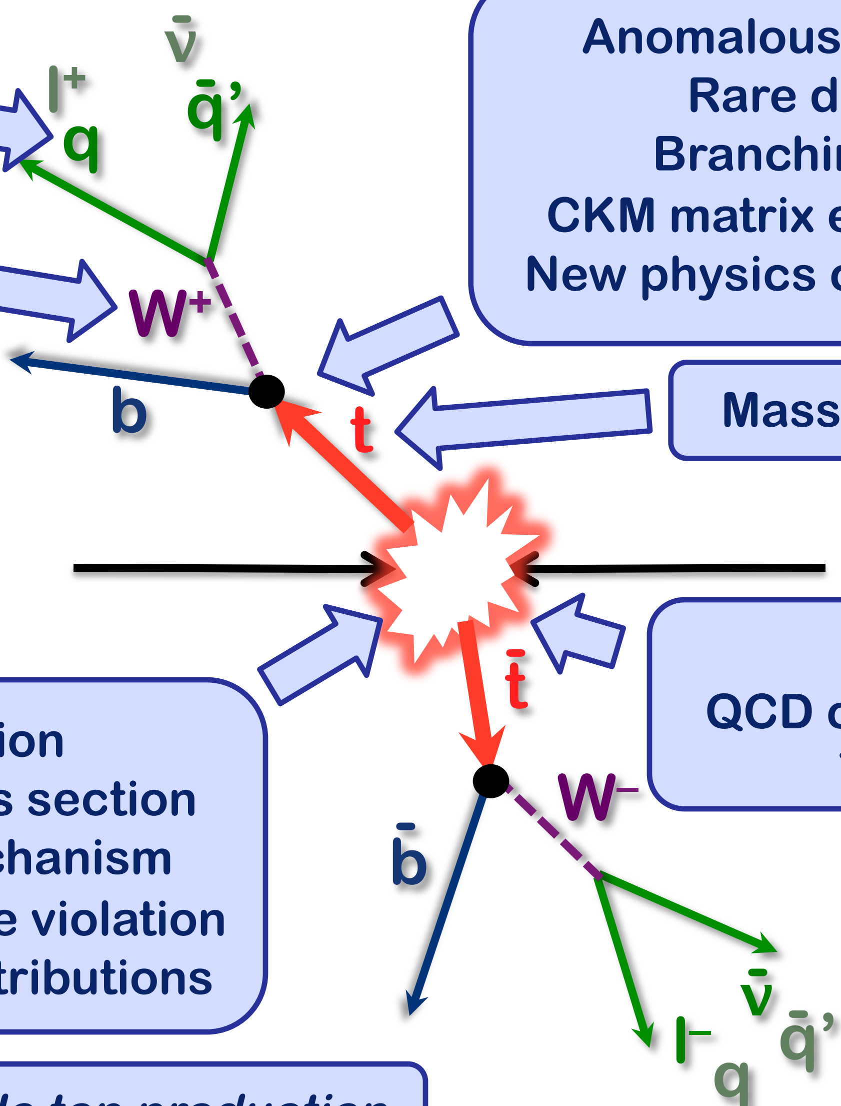
- Compelling arguments that **new physics** can show up in the **top sector:**
  - Top is the **heaviest** quark discovered so far
  - Its **Yukawa** coupling is **0.996±0.006**
    - Special role in EWSB?
  - Since 19 years, our measurements have been *consistent with SM predictions* in the top sector *within uncertainties*
  - D0 and CDF collected **thousands of $t\bar{t}$ events**, enabling **precise studies of top properties**
    - There are recent measurements displaying **tension between Tevatron data and the SM predictions (A_{FB})**



A wealth of top properties

Color flow

W helicity



Anomalous couplings
Rare decays
Branching ratio
CKM matrix element $|V_{tb}|$
New physics contributions

Mass, charge, width

Spin correlation
QCD charge asymmetry A_{FB}
Top polarisation

Cross section
Differential cross section
Production mechanism
Lorentz invariance violation
New physics contributions

+ electroweak single top production

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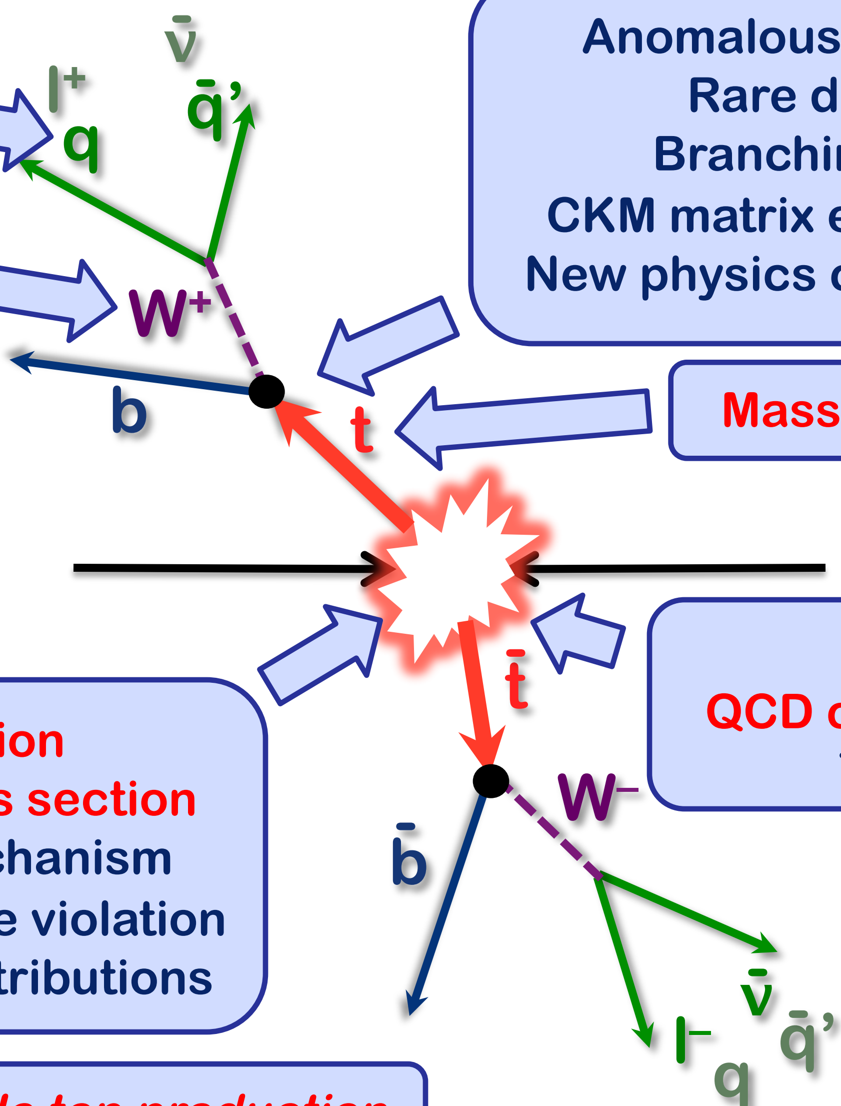

Spin correlation
QCD charge asymmetry A_{FB}
Top polarisation

Cross section
Differential cross section
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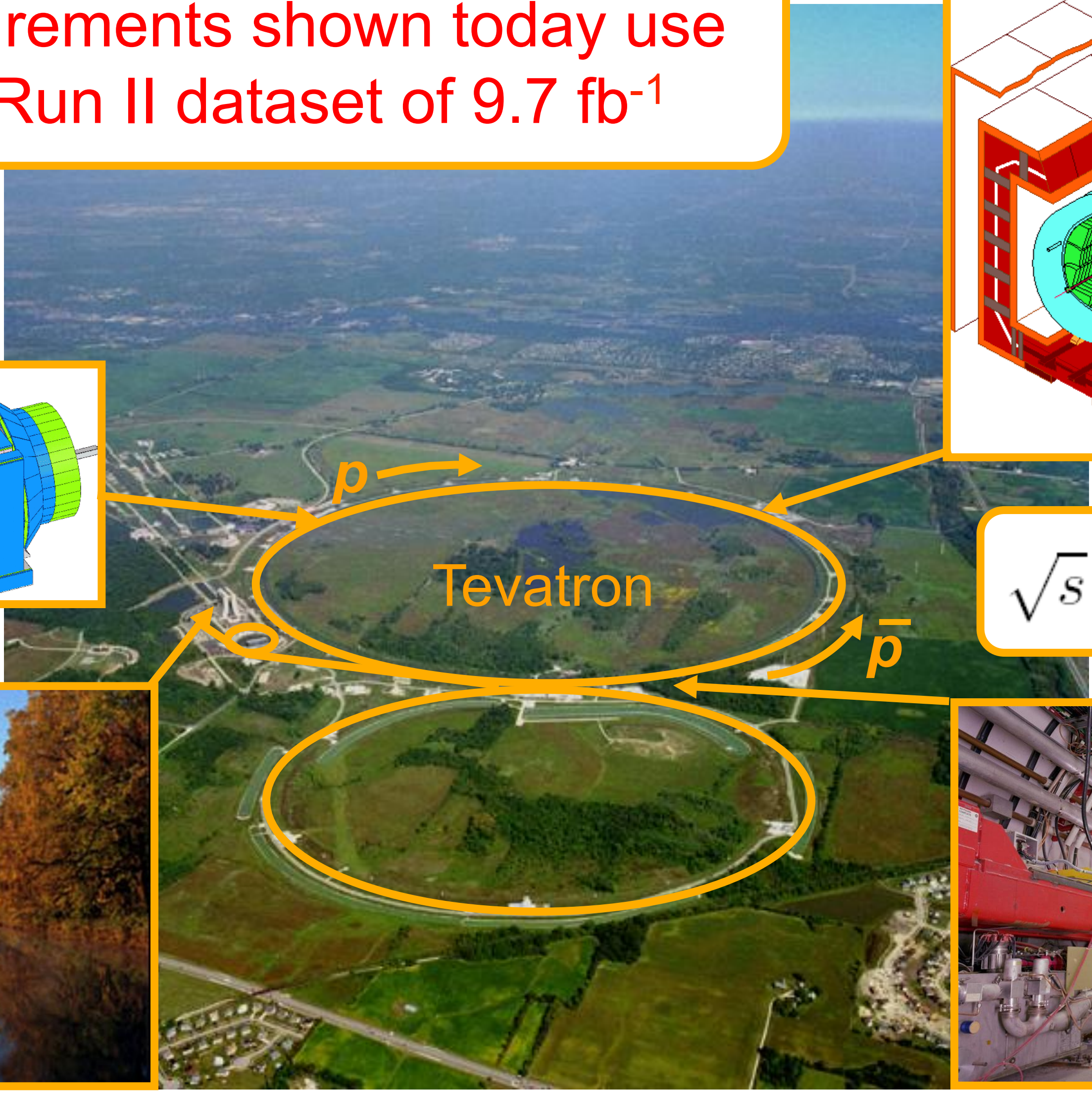
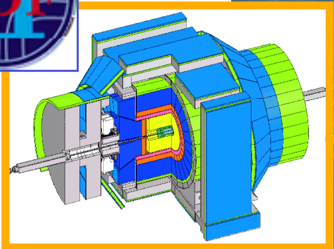
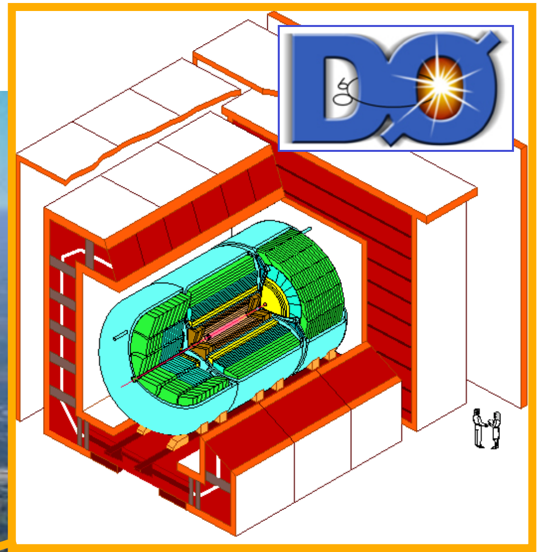
The birth place of the top quark

All measurements shown today use the full Run II dataset of 9.7 fb^{-1}







$$\sqrt{s} = 1.96\,\mathrm{TeV}$$

Initial state @ Tevatron (and LHC)

- **Initial state for top-antitop pair-production rather different between Tevatron and LHC:**

Tevatron	LHC
$p\bar{p}$ initial state → *CP* eigenstate	pp initial state
centre-of-mass energy: 1.96 TeV	centre-of-mass energy: 7 (8) TeV
Initial state: qq (~85%), gg (~15%)	Initial state: qq (~25%), gg (~75%)

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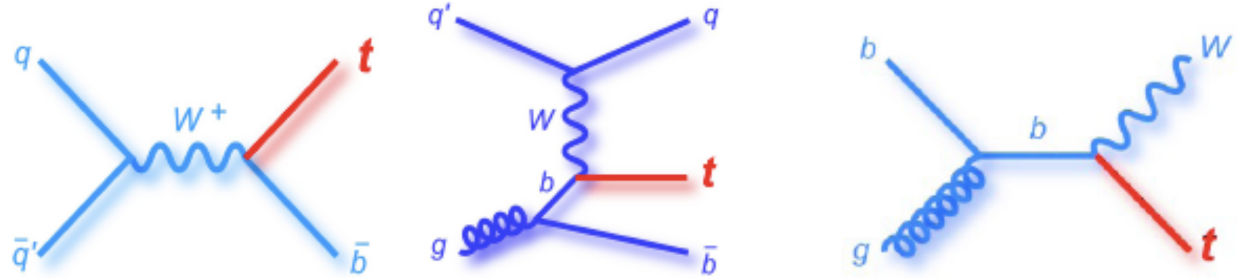
- **Dramatic differences for single top production:**



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

Differential $t\bar{t}$ cross section

- **High-profile measurement:**
  - Tevatron legacy @ $\sqrt{s}$=1.96 TeV in p-pbar with 9.7 fb^{-1}
  - Low acceptance effects due to centrality of events
  - Verify and potentially identify issues with modeling
  - Search for new physics like e.g. axigluons via m_{tt}

arXiv:1401.5785 [hep-ex], submitted to PRD

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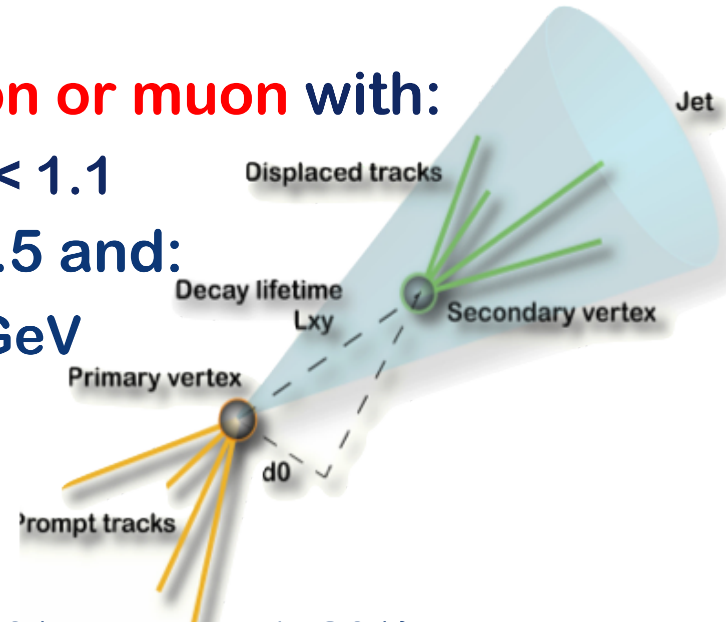
- **Selection overview:**
  - Exactly one tight isolated electron or muon with:
    - p_T > 20 GeV, $|\eta_{muon}|$ < 2, $|\eta_{electron}|$ < 1.1
  - ≥1 jets with cone parameter R=0.5 and:
    - p_T > 20 GeV, leading jet p_T > 40 GeV
  - Reject multijet events with
    - $\not{p}_T > 20$ GeV
    - Topological cuts
  - One or more b-tagged jet ($\varepsilon_b \approx$ 60%, $\varepsilon_{light} \approx$ 1.2%) to further reject backgrounds



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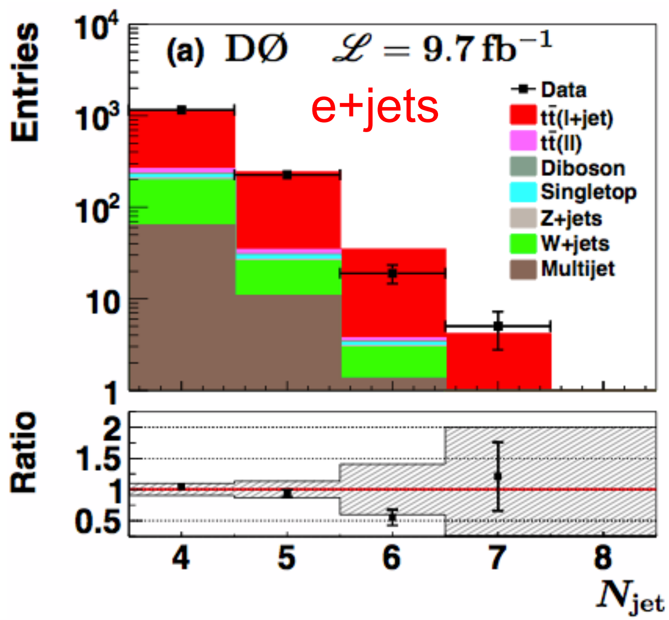
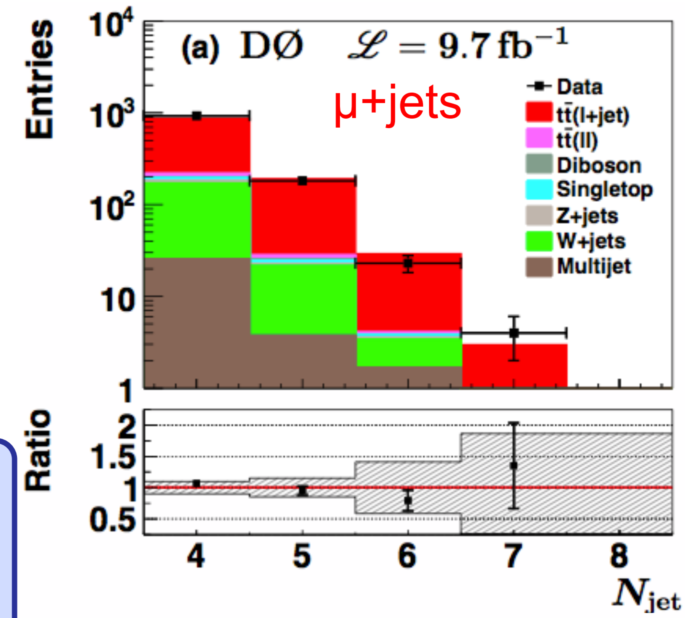
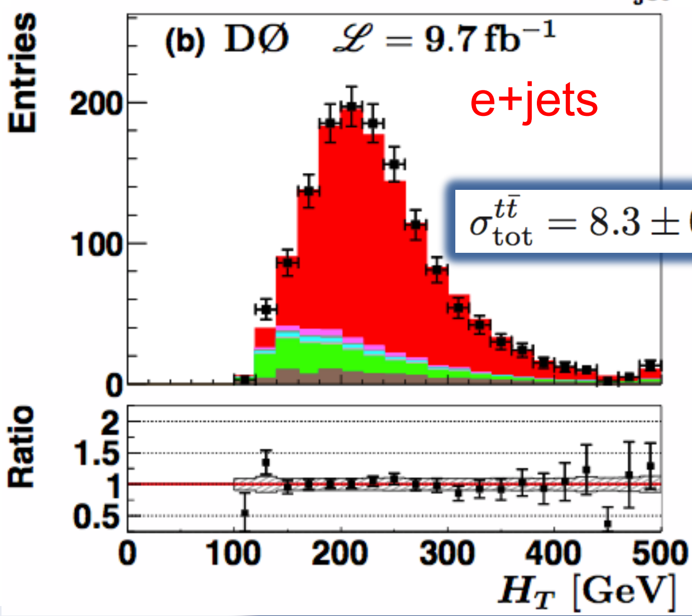
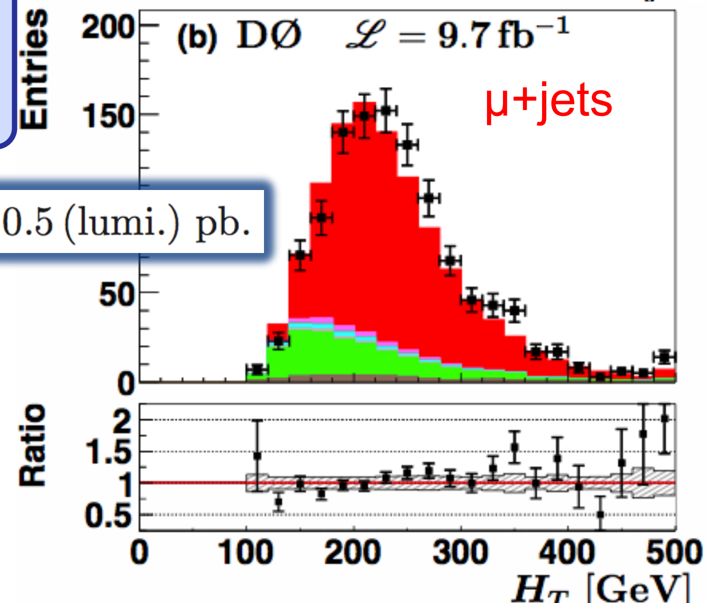
Differential tt cross section





Good description of data by simulations





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

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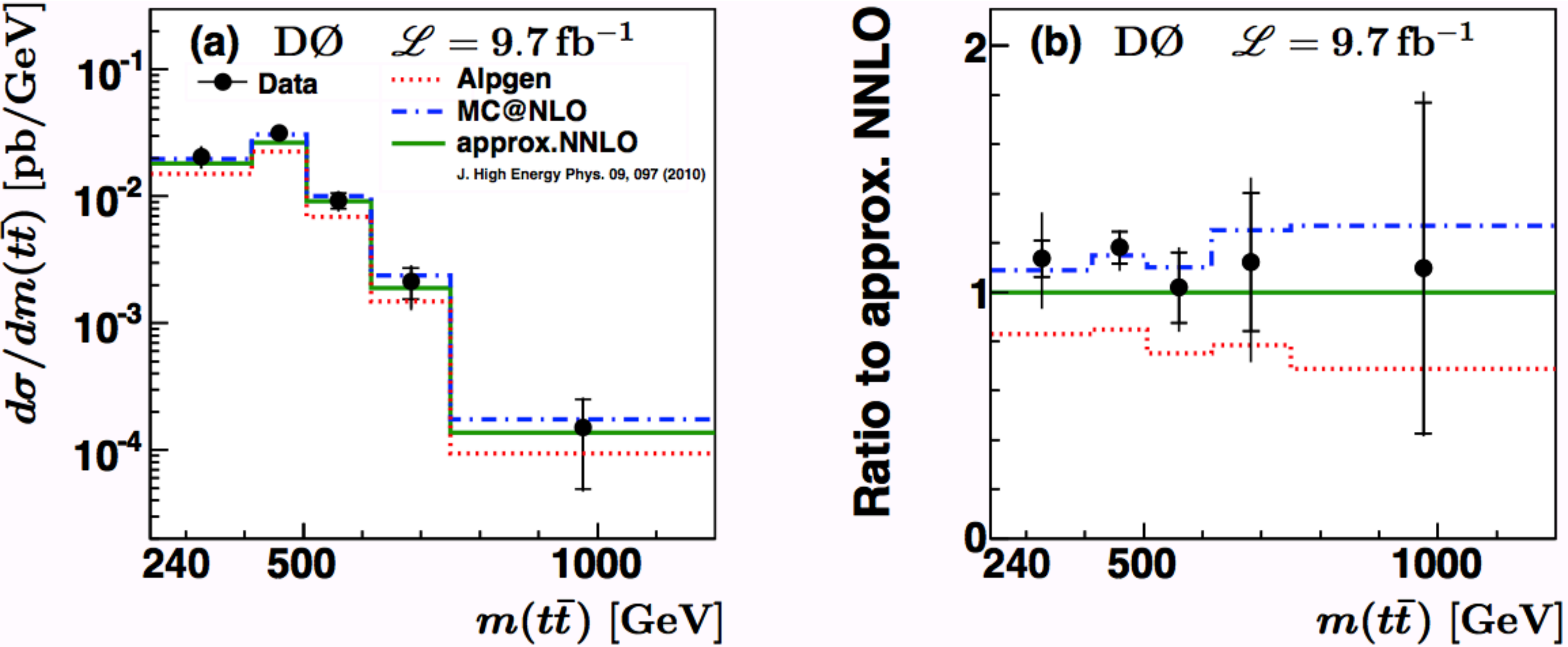
Differential tt cross section



Source of uncertainty	Uncertainties, % δ_{incl}	$\lvert\delta_{\mathrm{diff}}\rvert$
Signal modeling	$^{+5.2}_{-4.4}$	4.0 – 14.2
PDF	$^{+3.0}_{-3.4}$	0.9 – 4.4
Detector Modeling	$^{+4.0}_{-4.1}$	3.1 – 13.7
Sample composition	±1.8	2.8 – 9.2
Regularization strength	±0.2	0.8 – 2.1
Integrated luminosity	±6.1	6.1 – 6.1
Total systematic uncertainty	$^{+9.6}_{-9.3}$	8.5 – 23.1

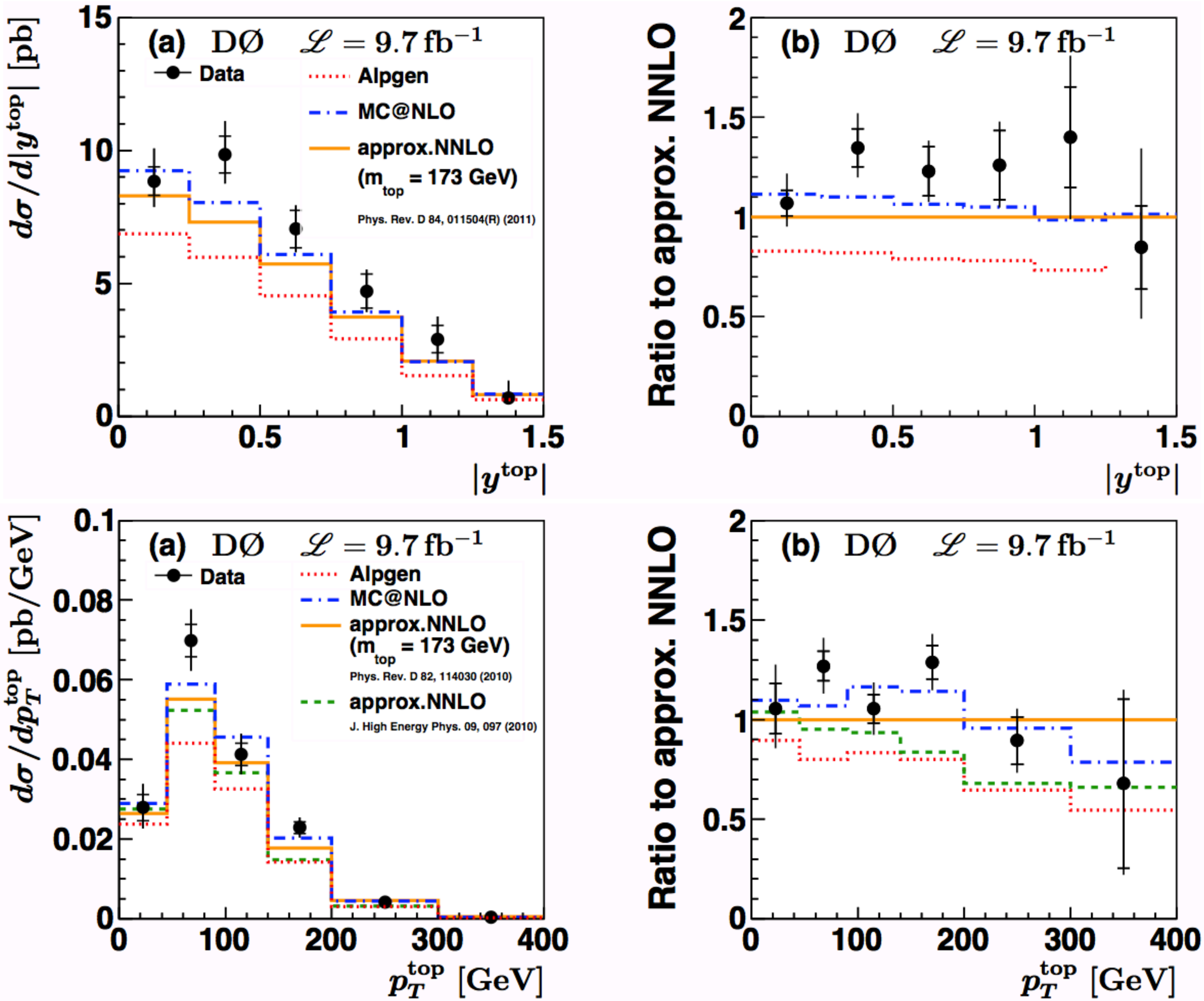
Regularised unfolding using the L-curvature method in TUnfold

$$\frac{d\sigma_i}{dX} = \frac{N_i^{\mathrm{unfold}}}{\mathscr{L} \cdot B \cdot \Delta X_i}$$

arXiv:1401.5785 [hep-ex], submitted to PRD

Differential tt cross section

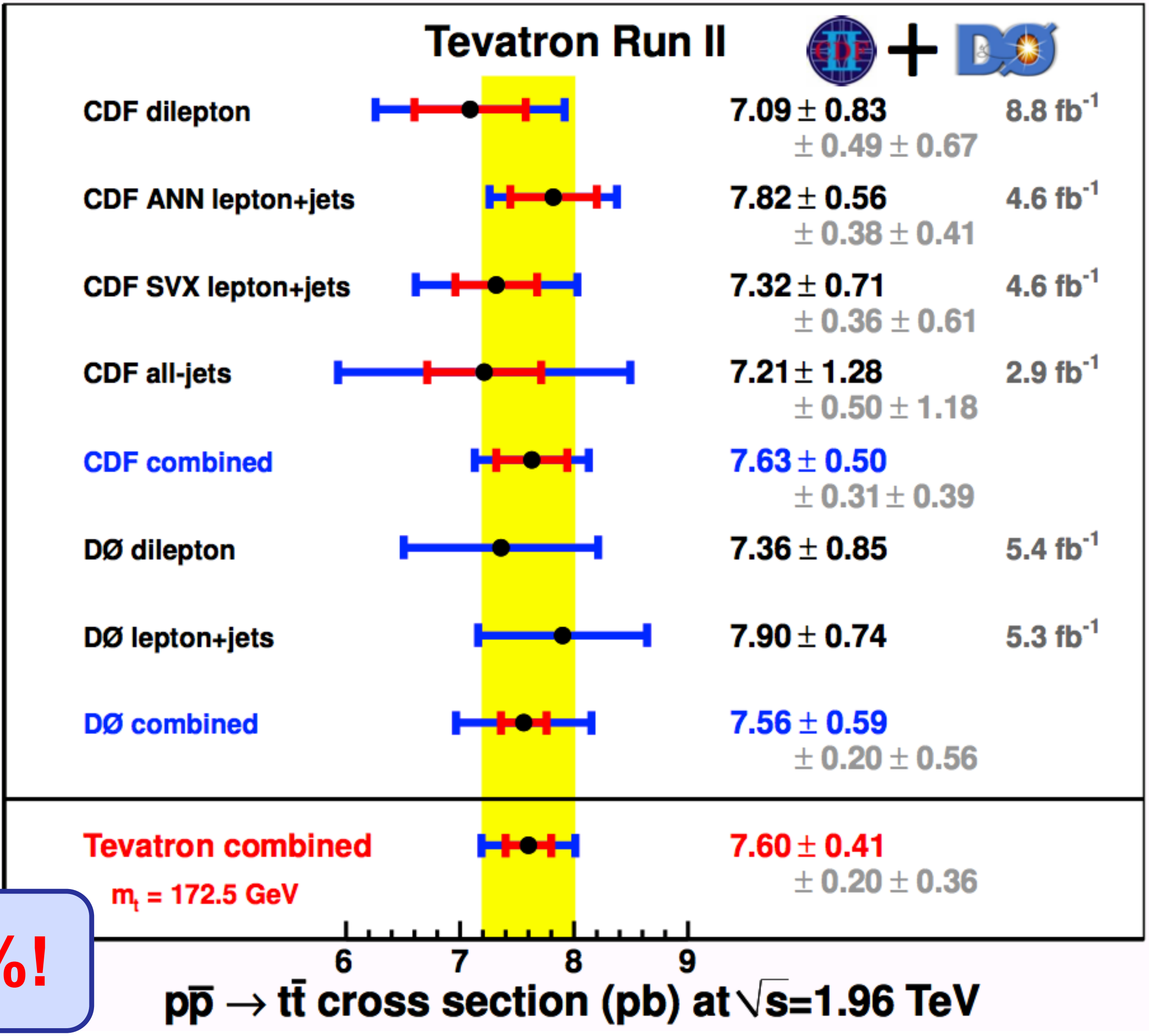
- Alpgen and MC@NLO able to describe the trend well
- approx. NNLO normalised to full NNLO+NNLL



arXiv:1401.5785 [hep-ex], submitted to PRD

Tevatron combination σ_{tt}

- Using up to 8.8 fb^{-1}
- Various analysis techniques
- Considering correlations of systematic uncertainties
- Utilizing the Best Linear Unbiased Estimate (BLUE)

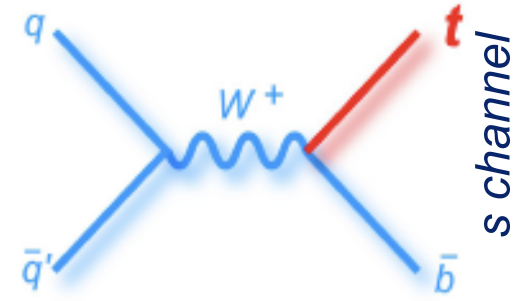


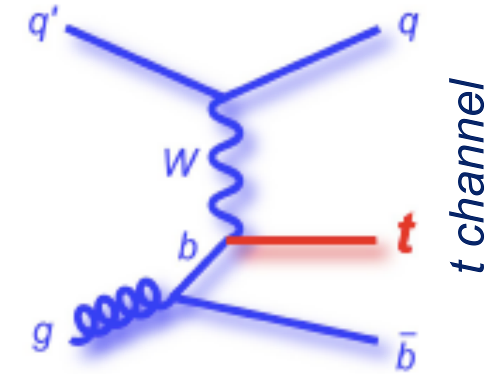
Uncertainty: 5.4%!

arXiv:1309.7570 [hep-ex], accepted by PRD

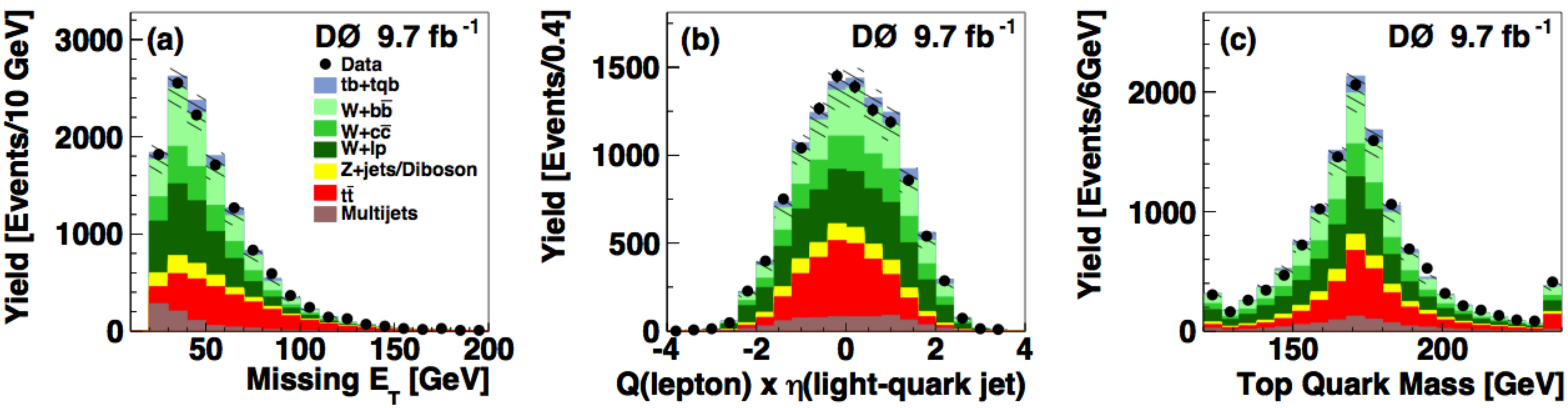
Single top s channel evidence

- **Single top history:**
  - **2009: s+t channel observation**
  - **2011: t channel observation**
  - **2014: s channel evidence → today!**
    - Note that s channel is difficult to observe at the LHC
      - → So far only upper limits exist @ LHC





- **Selection similar to tt, categorise into:**
  - **(2 or 3 jets) x (0, 1, ≥2 b tags)**
  - **Control region: 2 jets & 0 b-tags**
  - **Sensitive to s-channel: 3 jets & ≥2 b tags**

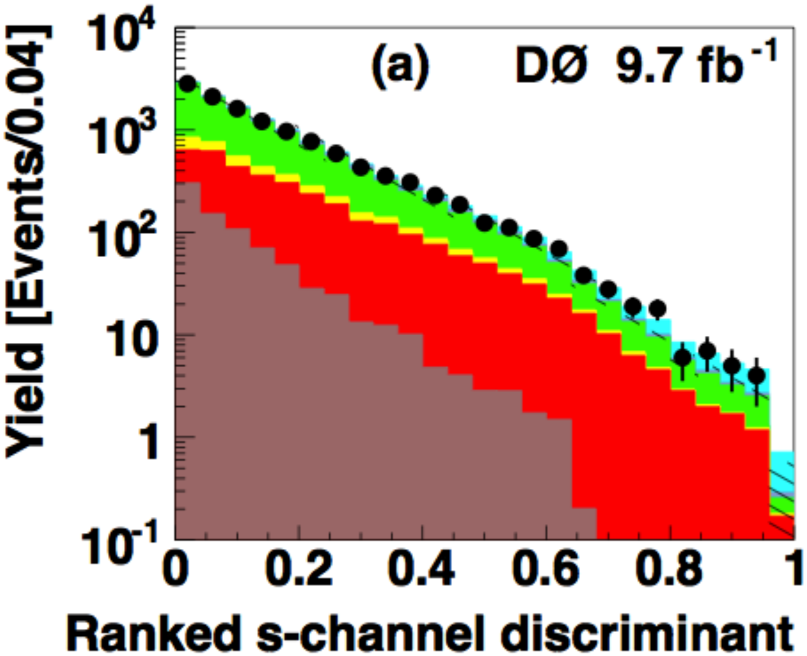


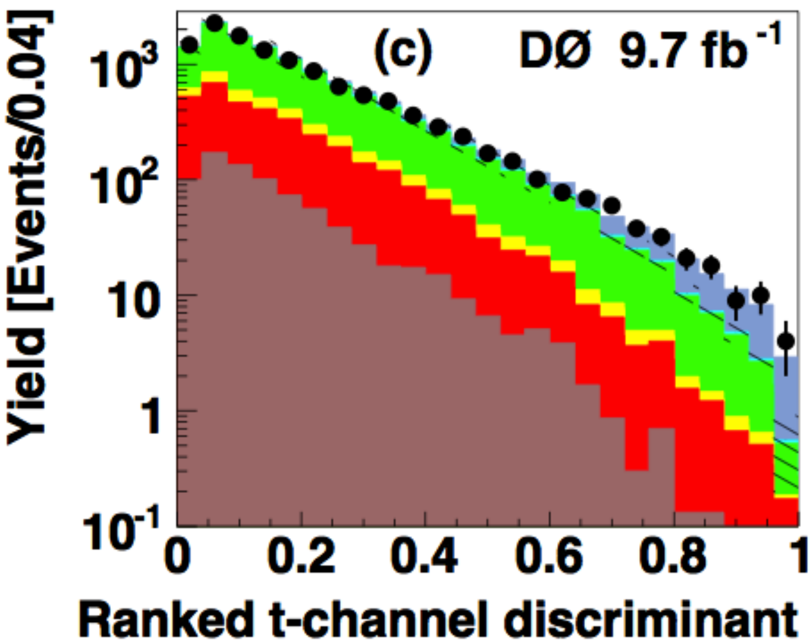
Phys. Lett. B **726**, 656 (2013)

Single top s channel evidence

- Strategy:
  - use three multivariate analyses
    - Matrix elements (ME)
    - Boosted Decision Trees (BDT)
    - Bayesian Neural Networks (BNN)

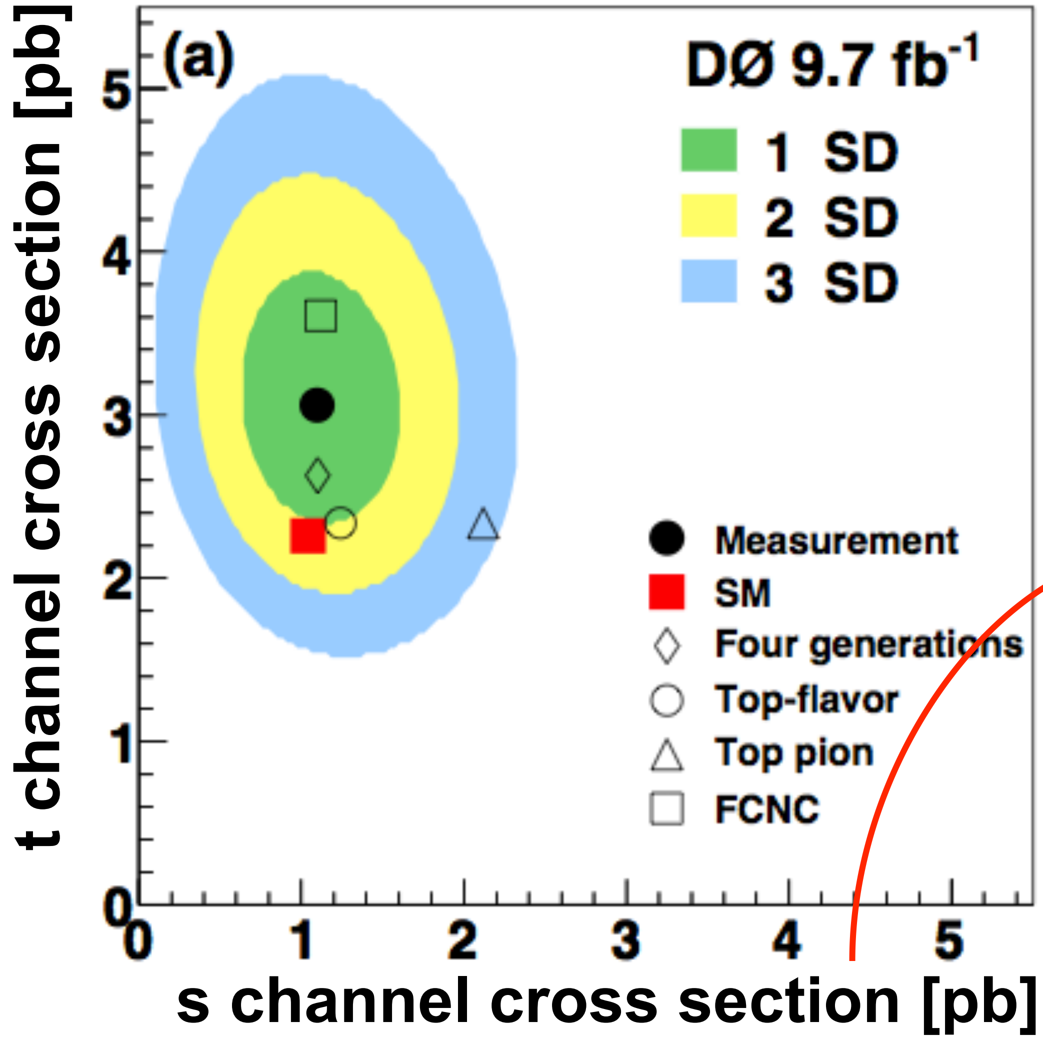
    Combine! ($\rho_{ij} \approx 75\%$)
  - Train separately for s (left) and t (right) channel
    - Simultaneous extraction!

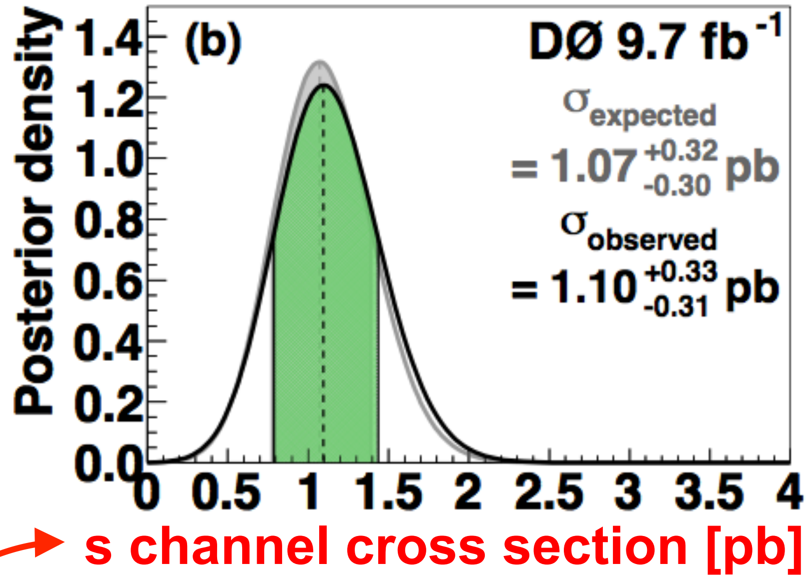




Phys. Lett. B ***726***, *656 (2013)*

Single top s channel evidence





No assumption about t channel normalisation!

Final s channel result:

$$\sigma(p\bar{p} \to tb + X) = 1.10^{+0.33}_{-0.31}\ \text{pb},$$

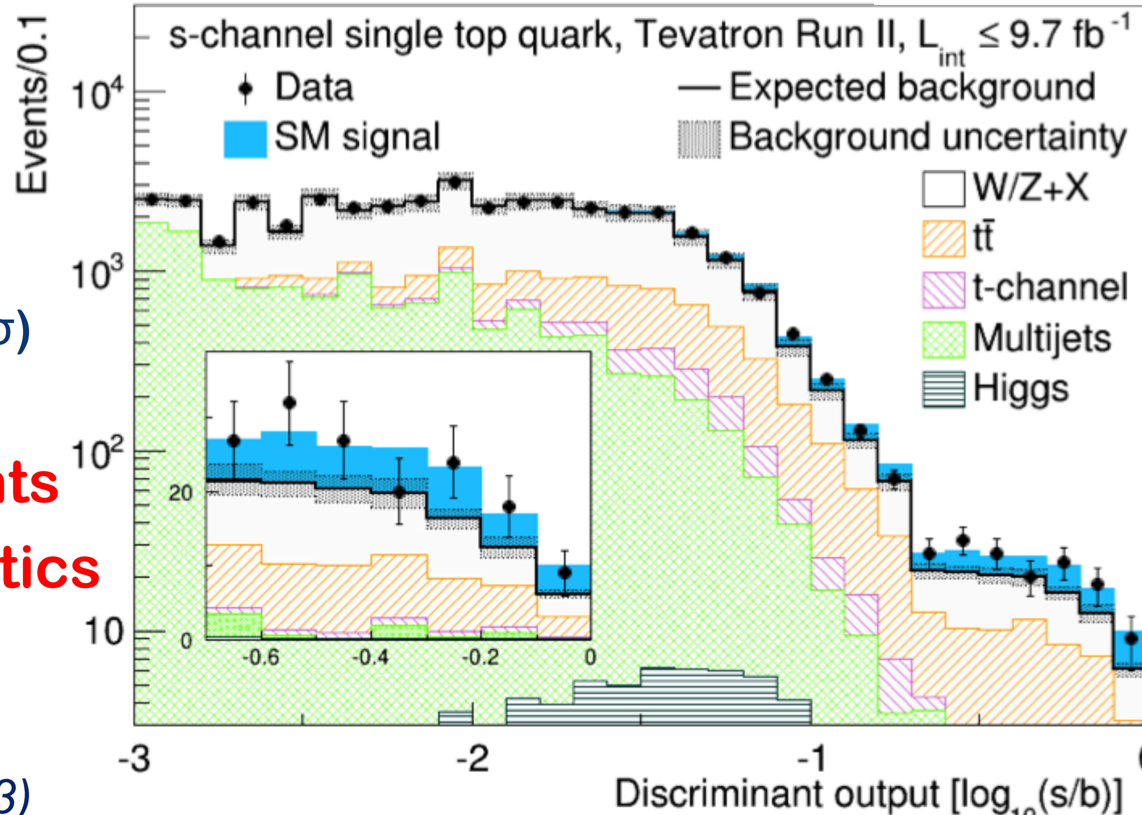
Significance: 3.7σ
First evidence for single top in the s channel!

Phys. Lett. B ***726****, 656 (2013)*

Single top s channel observation

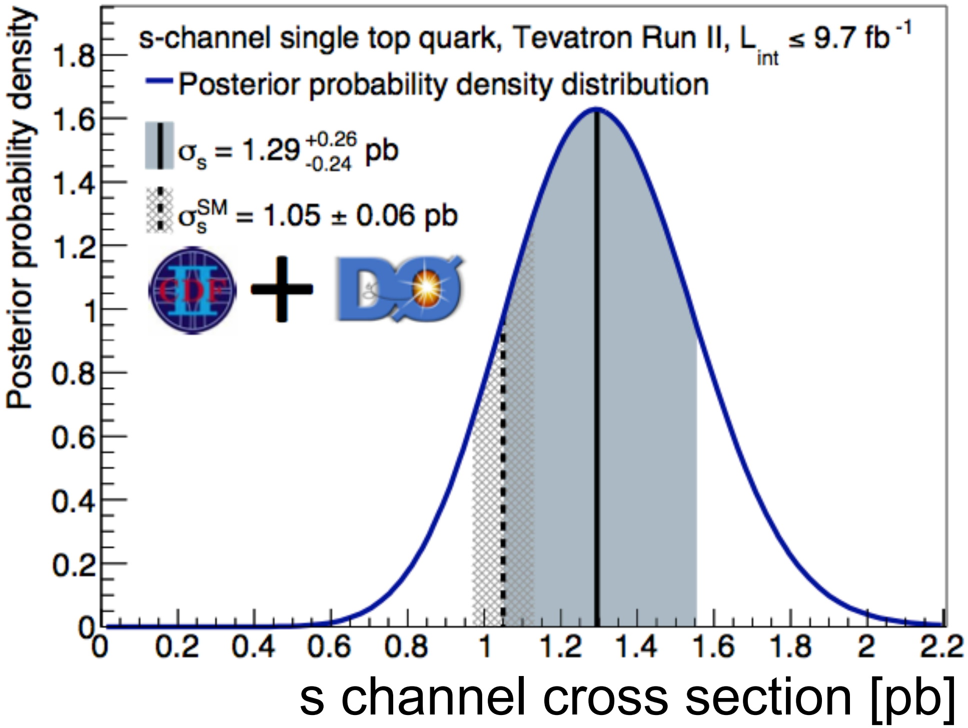
- **Tevatron combination:**
  - DØ measurement using 9.7 fb^{-1} (just shown)
  - CDF measurements using 9.4 fb^{-1} *PRL* ***112****, 231805 (2014)*
    - Similar analysis strategy in the lepton+jets channel
    - In addition: E_T^{miss} + jets channel to increase acceptance
    - Result:
      - $\sigma_s = 1.36^{+0.37}_{-0.32}$ (4.2σ)
      - Expected: 3.4σ
  - Combine discriminants
  - Consider all systematics + their correlations

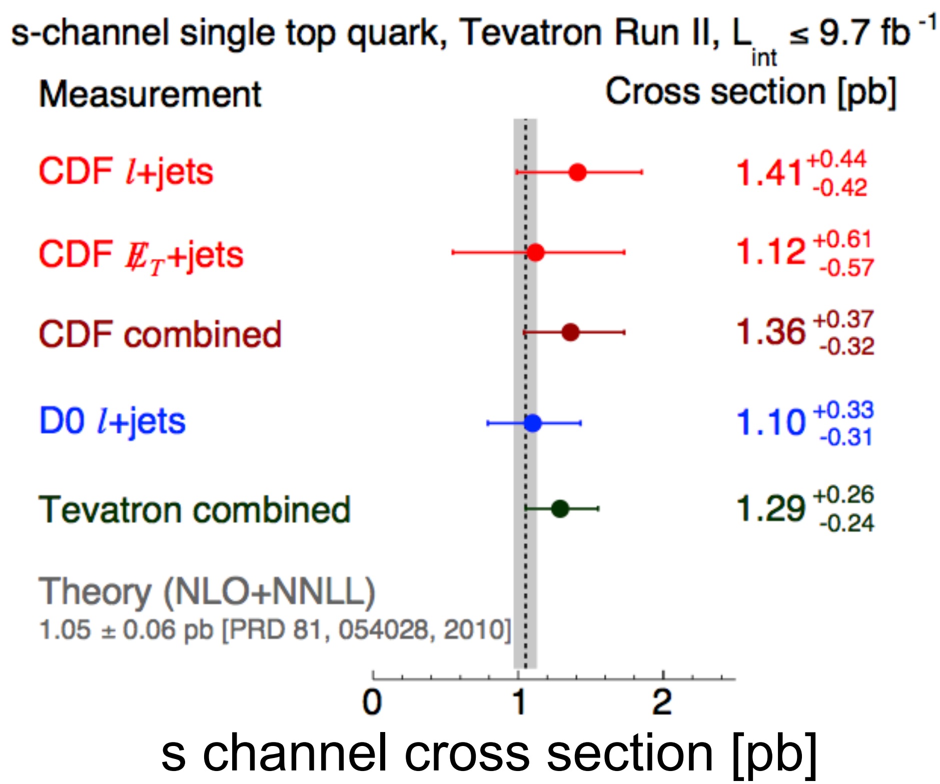
CDF + DØ



Phys. Rev. Lett. ***112****, 231803 (2013)*

Single top s channel observation



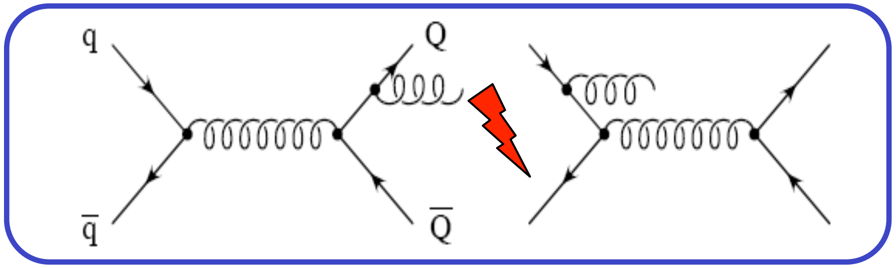


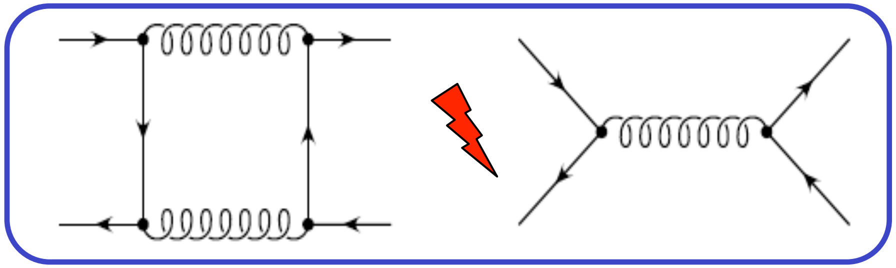
- **About equal contributions from both experiments**
- **Negligible dependence on m_t**
- **Observed significance: 6.3σ**
  - **(Expected significance: 5.2σ)**

Phys. Rev. Lett. ***112****, 231803 (2013)*

Colour charge asymmetry, l+jets

- Theoretical predictions (Tevatron-specific!):
  - At LO, completely symmetric
  - At higher orders, interference terms influence t and tbar production asymmetrically, e.g.:





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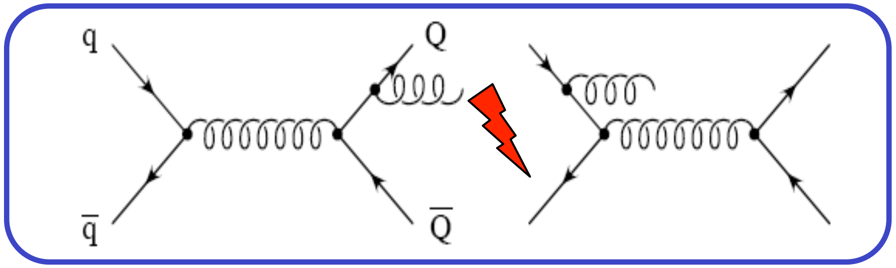

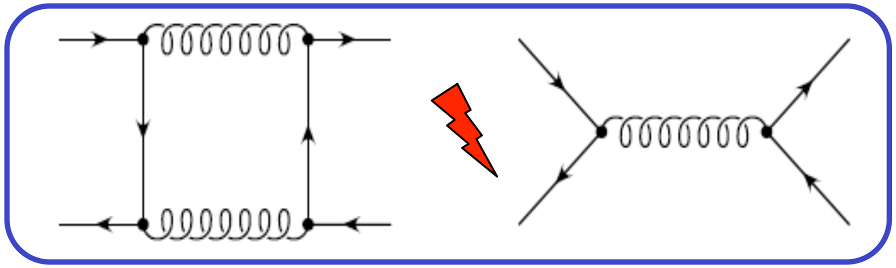

  - New physics contributions to enhance asymmetry?
    - Massive axial vector gluons
    - Massive vector gluons
    - Z', W'
    - Technicolour
    - ?

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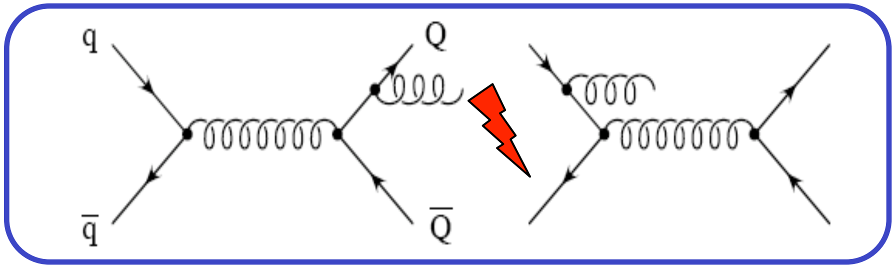

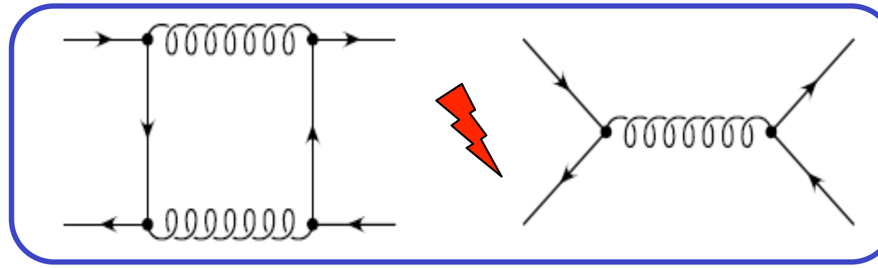

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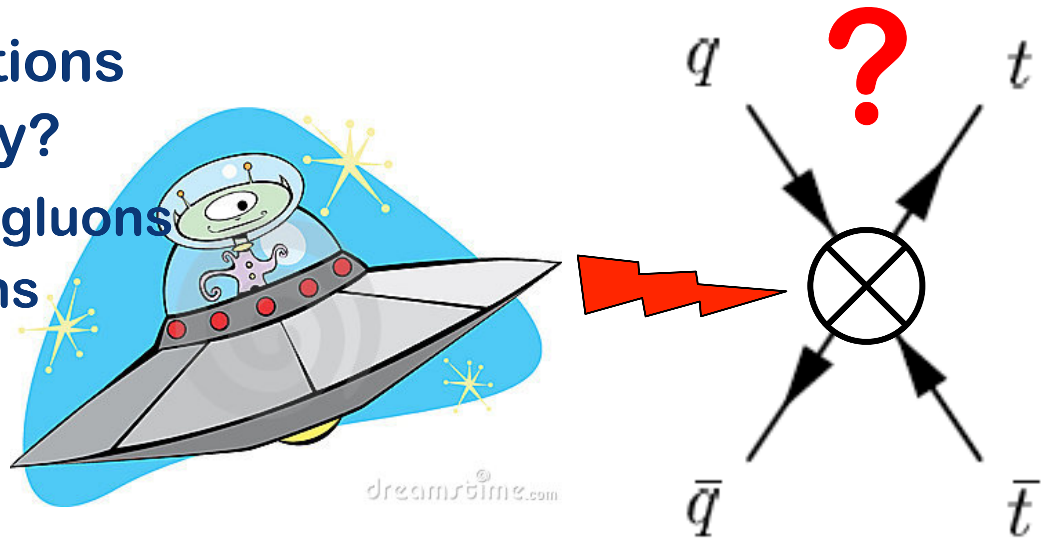


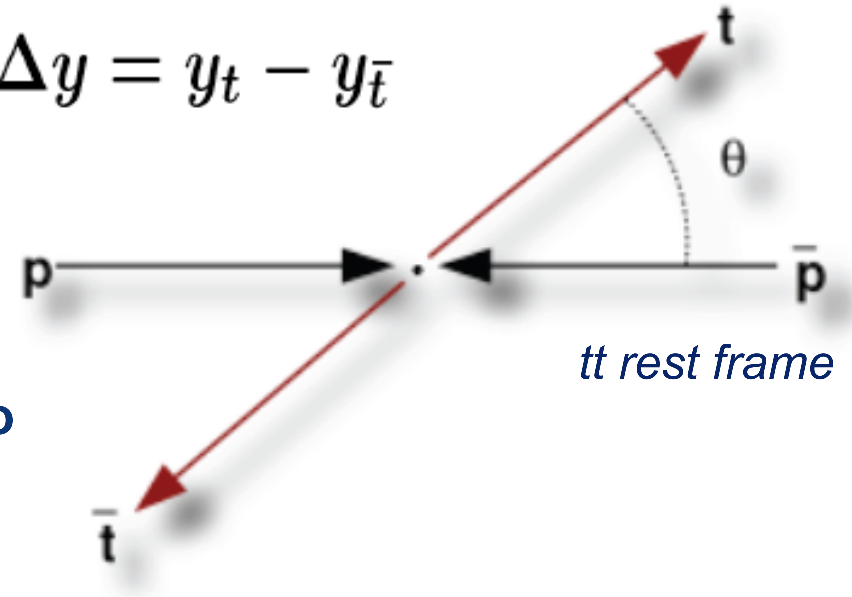
Colour charge asymmetry, l+jets

- Form observable:

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

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

  - Use b-tagged events
  - Use kinematic fitter for reco



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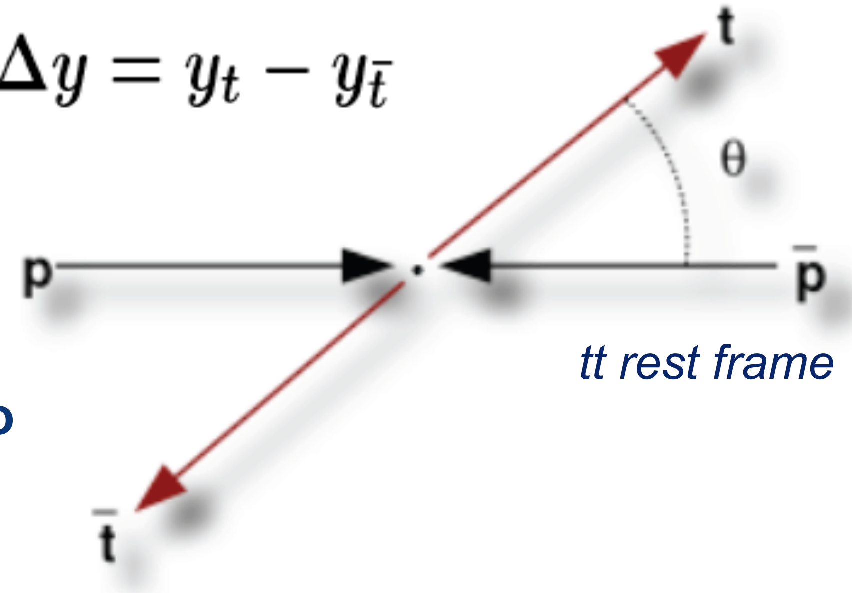

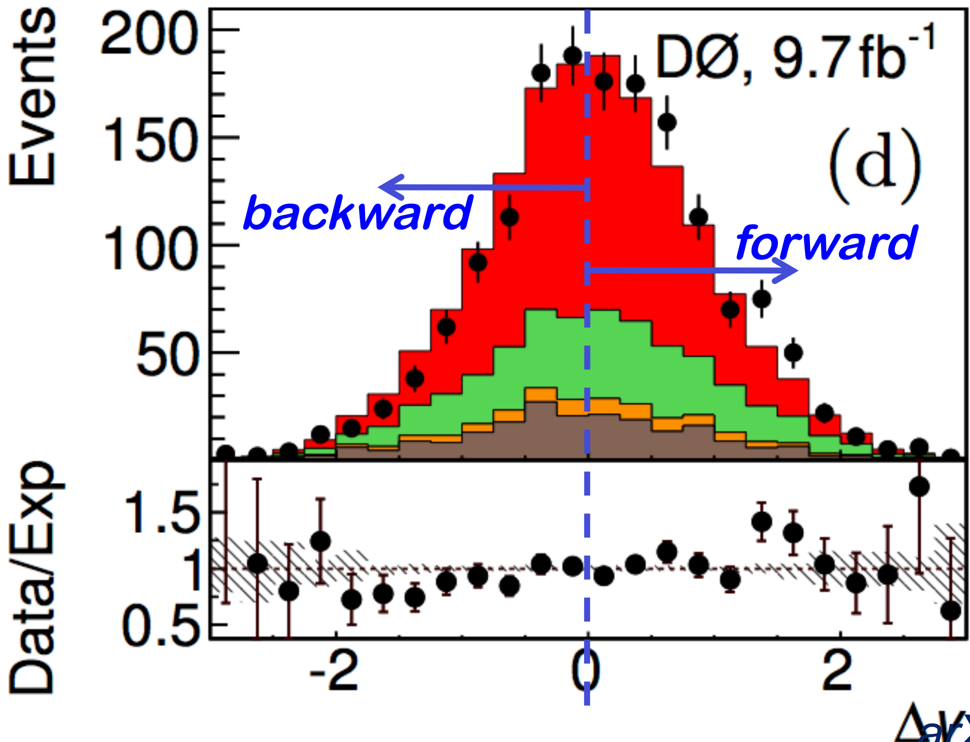

arXiv:1405.0421 [hep-ex], submitted to PRD

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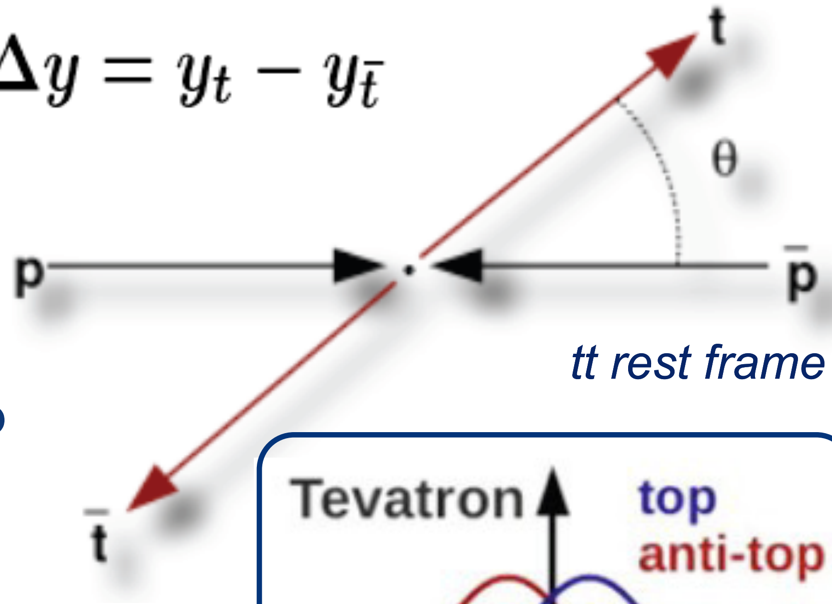

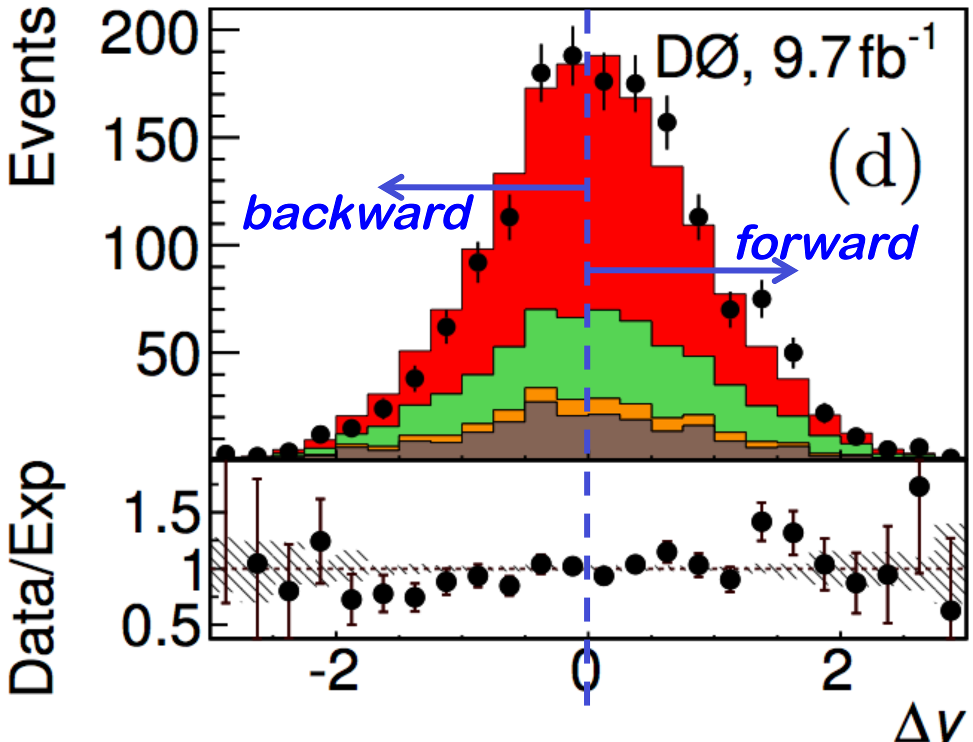

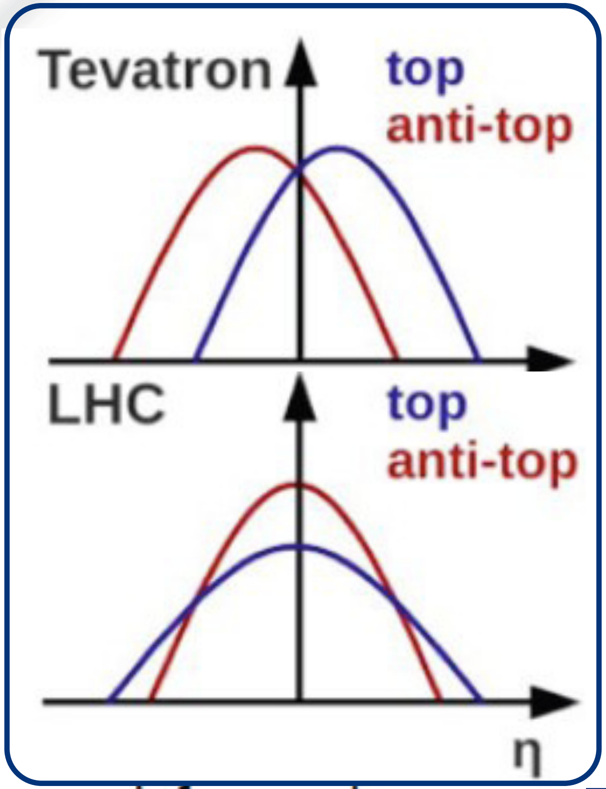

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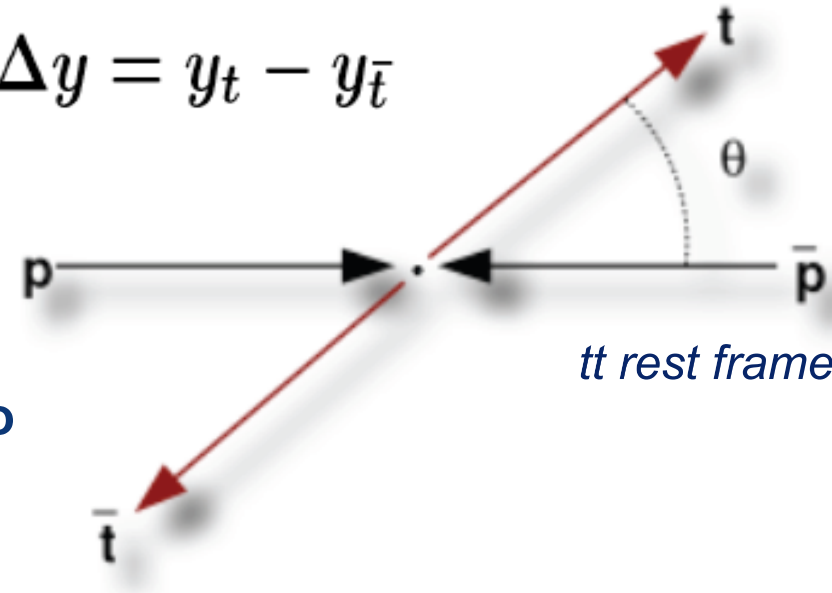
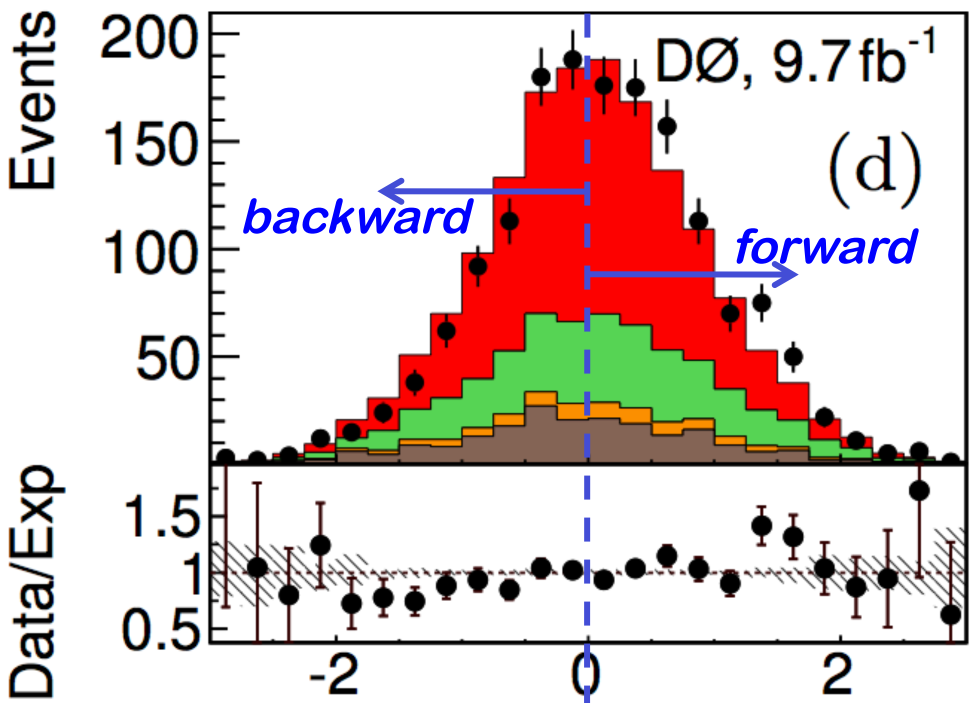
  - **Use kinematic fitter for reco**





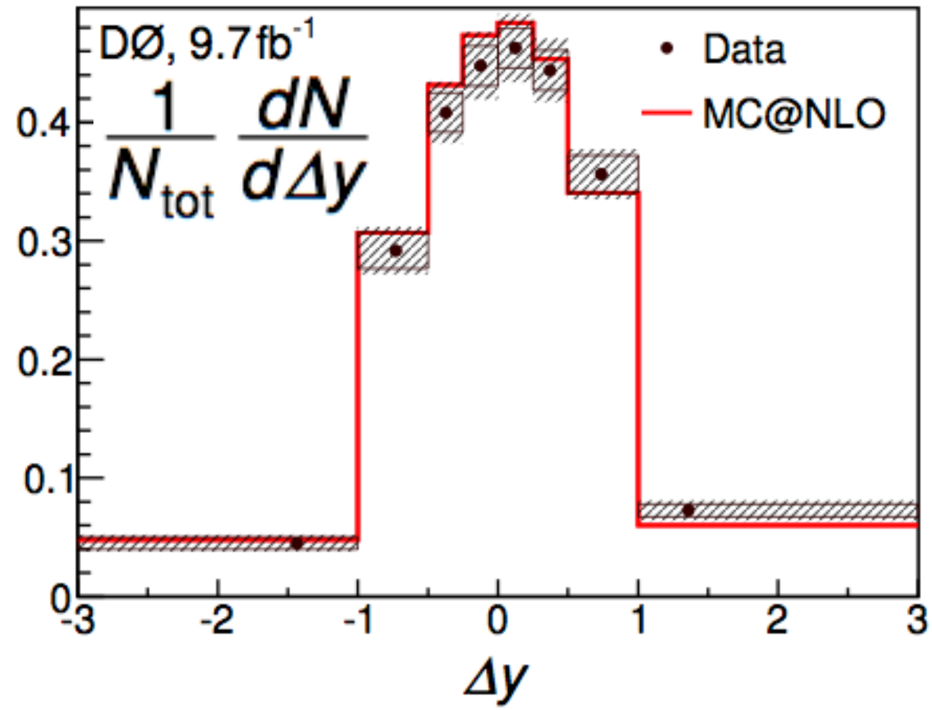
Raw result (not unfolded), after background subtraction:
$A_{FB} = 7.9 \pm 2.1 \pm 0.9\%$

MC@NLO prediction:
$3.6\,\%$

arXiv:1405.0421 [hep-ex], submitted to PRD

Colour charge asymmetry, l+jets

- Typically, A_{FB} at generator level will be diluted at reconstruction level due to
  - Limited detector acceptance
  - Limited resolution on Δy (≈0.7)
- → Unfold Δy to generator level
  - Bin migrations particularly relevant close to Δy = 0
    - Use sufficiently fine binned, regularised unfolding
    - Correct for possible biases with ensemble tests



Result: A_{FB} = 10.6 ± 3.0%

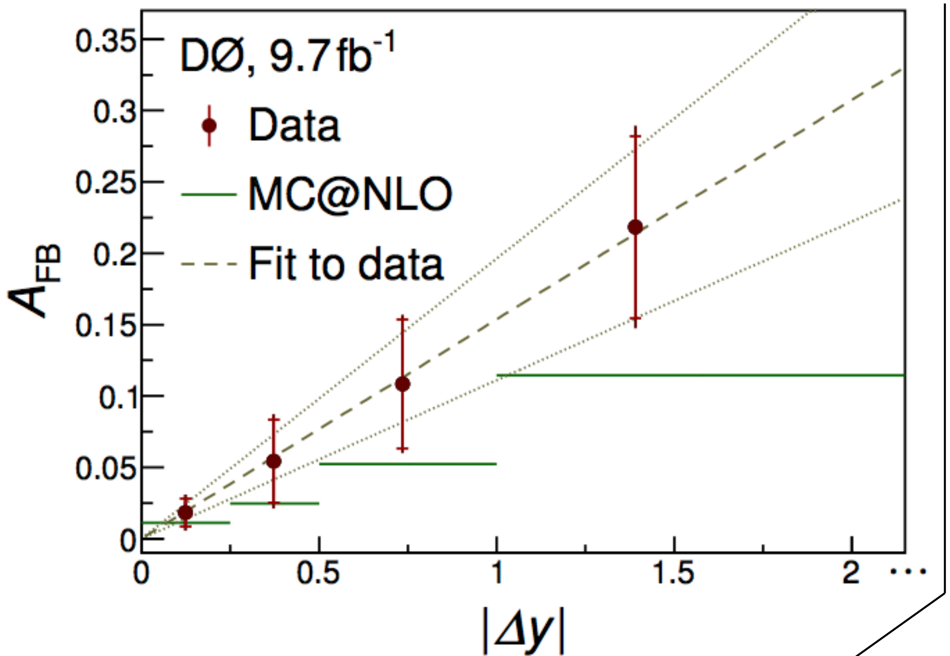
Theory: A_{FB} = 5.0 - 8.8%

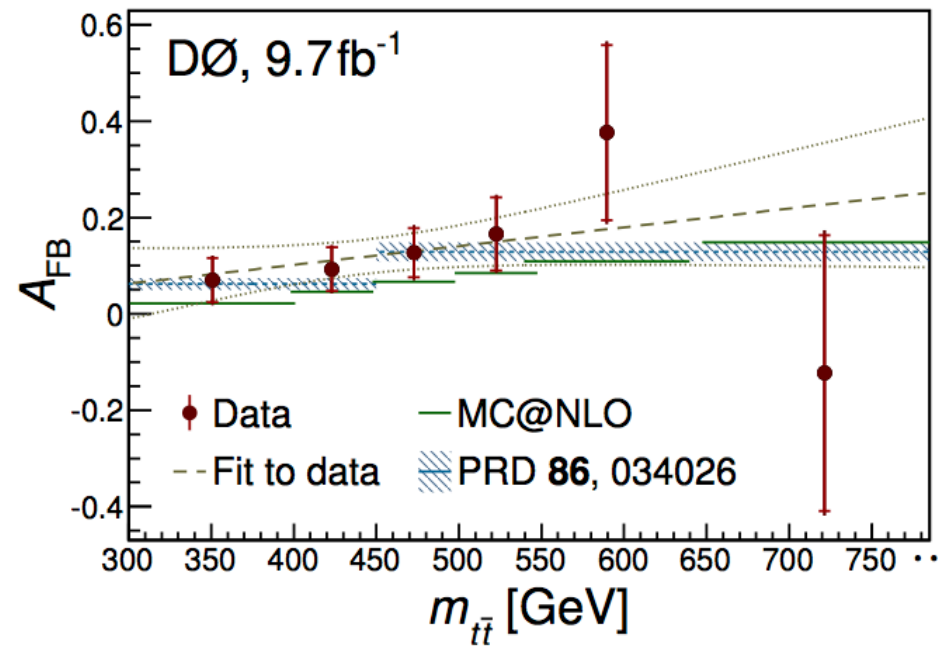
arXiv:1405.0421 [hep-ex], submitted to PRD

Colour charge asymmetry, l+jets

arXiv:1405.0421 [hep-ex]

- **Asymmetry would be enhanced:**
  - **For high m_{tt} for an *s*-channel resonance**
  - **For high $|\Delta y|$ for a *t*-channel anomaly**





Measured slope 0.154 ± 0.043

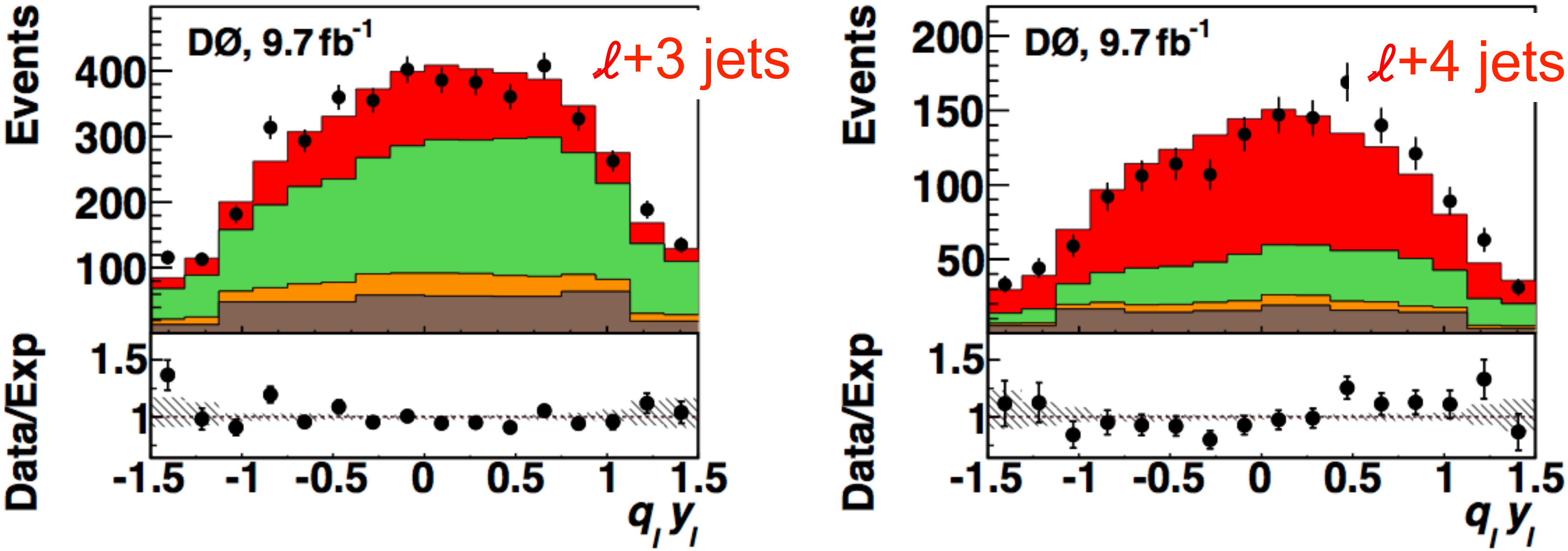
Expected slope 0.080

Parameter	Predicted	Measured
Slope, α	$3.8 \cdot 10^{-4}$	$(3.9 \pm 4.4) \cdot 10^{-4}$
Offset, A_0	$5.3 \cdot 10^{-2}$	$(11.9 \pm 3.6) \cdot 10^{-2}$

Consistent with SM and CDF results

Colour charge asymmetry, l+jets

- Tevatron: tt events are produced centrally
  - → very small polarisation
  - → A_{FB} is passed on to the decay produces of top
- Define forward, backward events via $q_\ell y_\ell < 0$, $q_\ell y_\ell > 0$

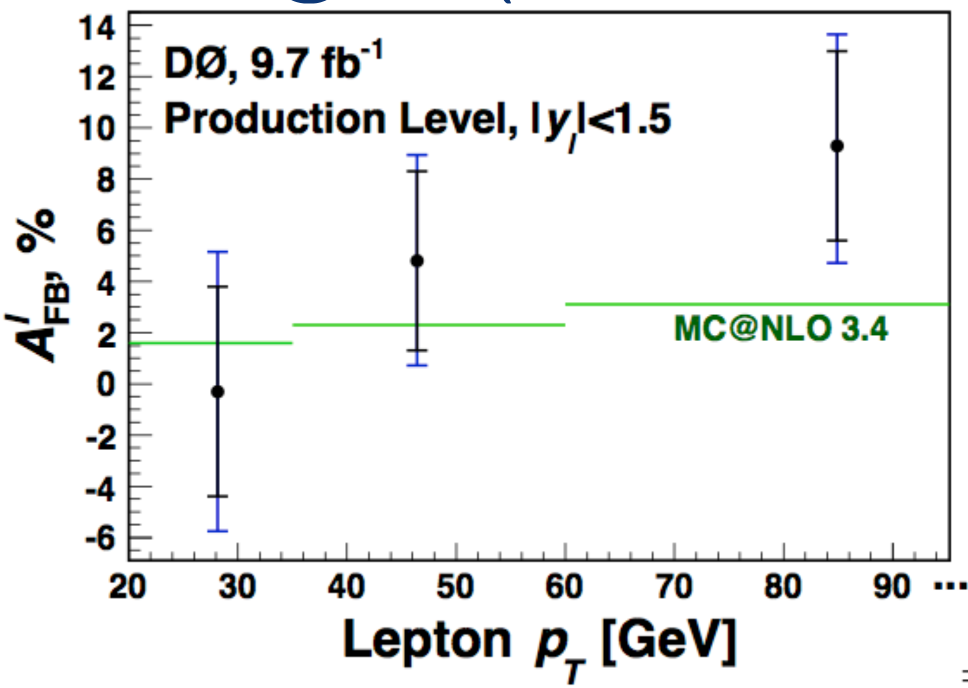


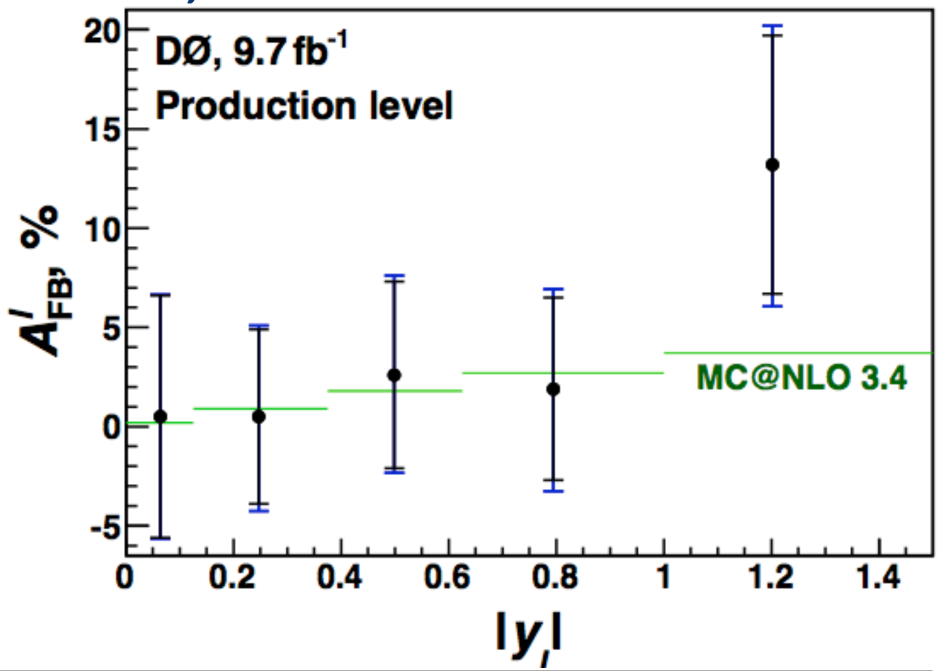
arXiv:1403.1294 [hep-ex], submitted to PRD

  - Bin migrations around Δy=0 are tiny for leptons
  - unfolding straight forward
  - Use same selection with A_{FB} for consistency

Colour charge asymmetry, l+jets

- Final results are consistent with SM prediction by MC@NLO (and with CDF results): *arXiv:1403.1294 [hep-ex]*



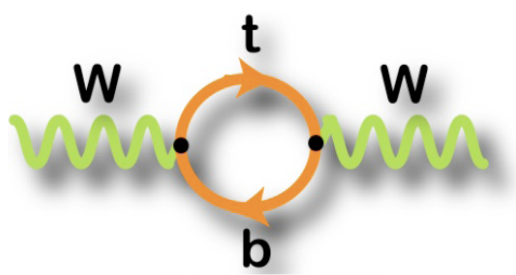


p_T^l range, GeV	A^l_{FB}, % Data	MC@NLO
Inclusive	$4.2 \pm 2.3^{+1.7}_{-2.0}$	2.0
20–35	$-0.3 \pm 4.1 \pm 3.6$	1.6
35–60	$4.8 \pm 3.5^{+2.2}_{-2.1}$	2.3
≥ 60	$9.3 \pm 3.7^{+2.3}_{-2.7}$	3.1

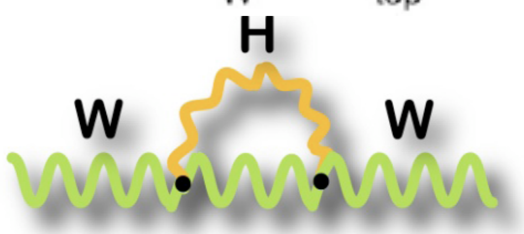
$\lvert y_l \rvert$ range	A^l_{FB}, % Data	MC@NLO
$0 - 0.125$	$0.5 \pm 6.1^{+0.8}_{-0.7}$	0.2
$0.125 - 0.375$	$0.5 \pm 4.4^{+1.3}_{-1.8}$	0.9
$0.375 - 0.625$	$2.6 \pm 4.7^{+1.7}_{-1.5}$	1.8
$0.625 - 1$	$1.9 \pm 4.6^{+2.0}_{-2.3}$	2.7
$1 - 1.5$	$13.2 \pm 6.5^{+2.6}_{-3.0}$	3.7

Top quark mass - motivation

- The **top quark is special:**
  - It is the heaviest quark of the SM!
    - Why is it so heavy?
    - Does it play a special role in EWSB?
  - M_W related to m_t & M_{Higgs}:



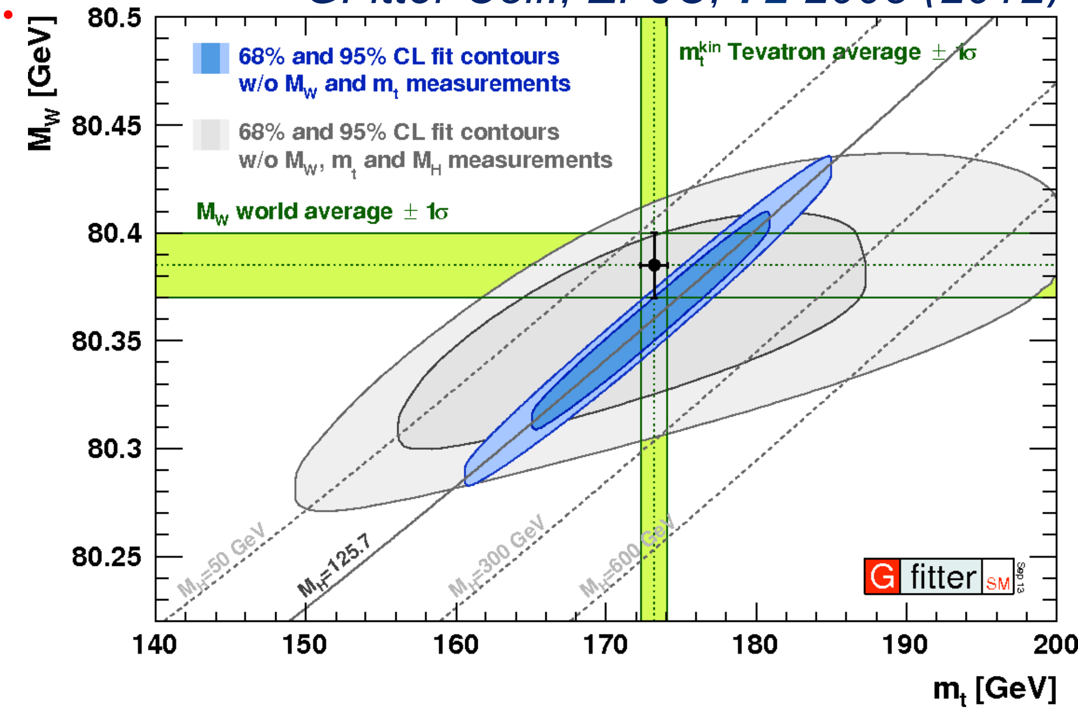
$\Delta M_W \propto M_{top}^2$



$\Delta M_W \propto \ln M_H$

Overconstrain M_W, m_t, and M_{Higgs}
→ Consistency check of the SM!

*GFitter Coll., EPJC, **72** 2005 (2012)*



- **Matrix Element (ME) technique:**
  - Calculate the event probability on an event-by-event basis:

$$P_{\mathrm{evt}}(m_{\mathrm{top}}) \propto f P_{\mathrm{sig}}(m_{\mathrm{top}}) + (1-f) P_{\mathrm{bgr}}$$

$$P_{\mathrm{sig}}(m_{\mathrm{top}}) \propto \int \ldots \mathrm{d}\sigma_{t\bar{t}}(m_{\mathrm{top}})$$

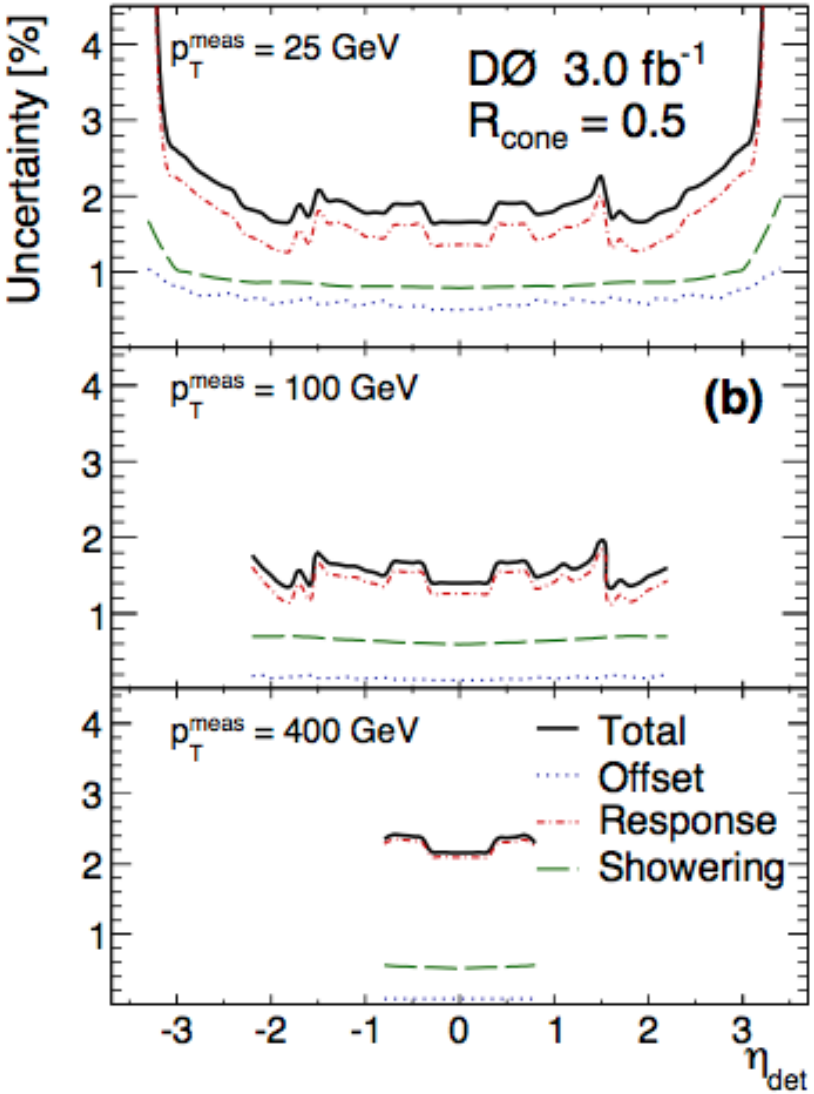
$$\mathrm{d}\sigma_{t\bar{t}} \propto |\mathcal{M}_{t\bar{t}}|^2 (m_{\mathrm{top}})$$

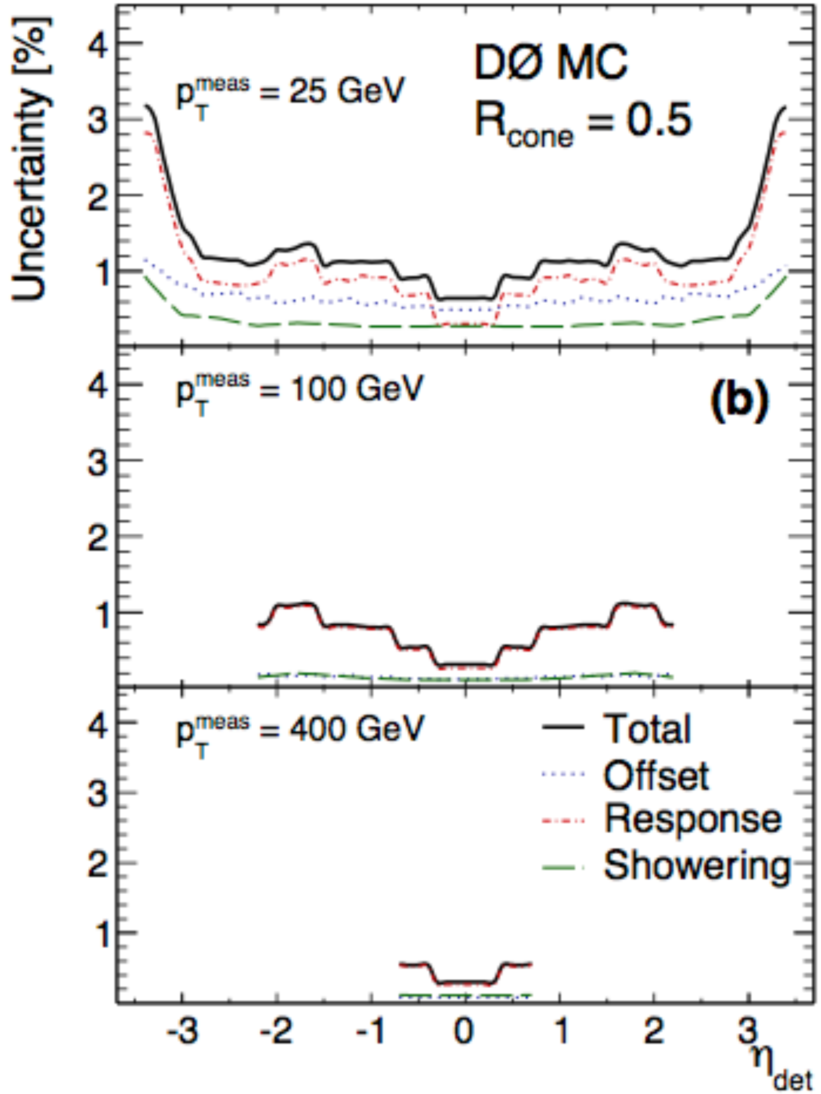
  - **Advantages:**
    - Use 4-vectors with maximal kinematic and topological information → maximal statistical sensitivity
  - **Disadvantages:**
    - High computational demand

Phys. Rev. Lett. ***113***, *032002 (2014)*

Top quark mass – JES calibration

- We use the new jet energy scale (JES) calibration:



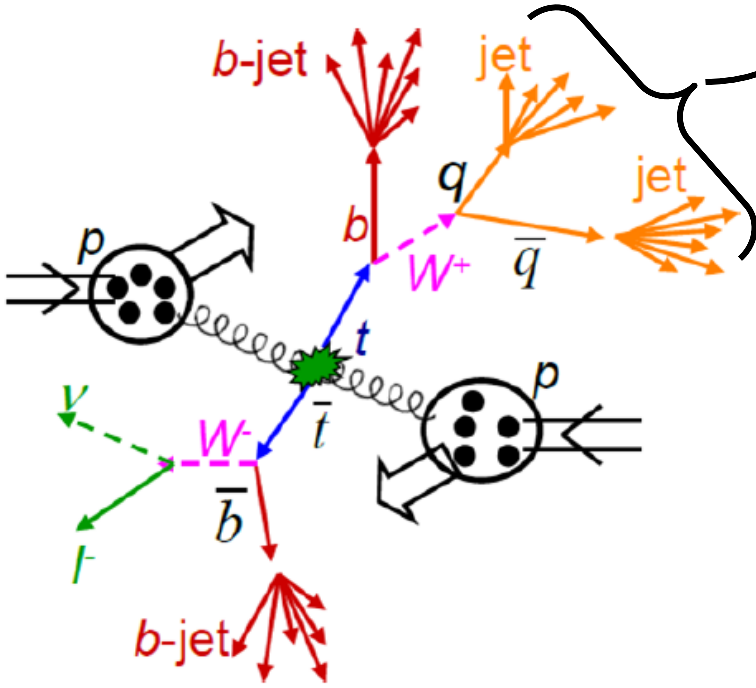


*Nucl. Instrum. Methods A **763**, 442 (2014)*

Figures are representative of all Run II

Top quark mass – JES calibration

- perform an **in situ calibration of the JES:**
  - Constrain energies of the two jets from W to be consistent with M_W
  - Maximise the likelihood in m_t and in the overall scale factor for jet energies k_{JES}!



$M_W \sim k_{JES}$

Phys. Rev. Lett. ***113****, 032002 (2014)*

Top quark mass – improvements

- We numerically calculate a 10 dimensional integral
  Identical to the 3.6 fb^{-1} [1] result except:
  - Use low-discrepancy sequences for the MC integration
    - Deterministic sequence of points in our 10-dim parameter space providing optimal convergence
  - Factorise the JES factor k_{JES} from the ME calculation
    - Include it via the transfer function
  - Reduction of calculation time by o(100)
- Increase the size of calibration samples!
  - Typical statistical component from finite MC stats:

≈0.25 GeV → ≈0.01–0.05 GeV!

Uncertainty (GeV)
±0.25
±0.26
±0.58
±0.28
±0.07
±0.16
±0.07
±0.09
±0.24
±0.21
±0.28

Excerpt from the table of systematic uncertainties of the 3.6 fb^{-1} analysis [1]

Phys. Rev. Lett. ***113****, 032002 (2014)*

[1] *DØ Coll. PRD* ***85*** *032004 (2011)*

Top quark mass – improvements

Results of three years of hard work and countless studies…

Phys. Rev. Lett. **113**, 032002 (2014)

Source of uncertainty	Effect on m_t (GeV)
Signal and background modeling:	
Higher order corrections*	0.15
Initial/final state radiation*	0.09
Hadronization & 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
Data-MC jet response difference	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

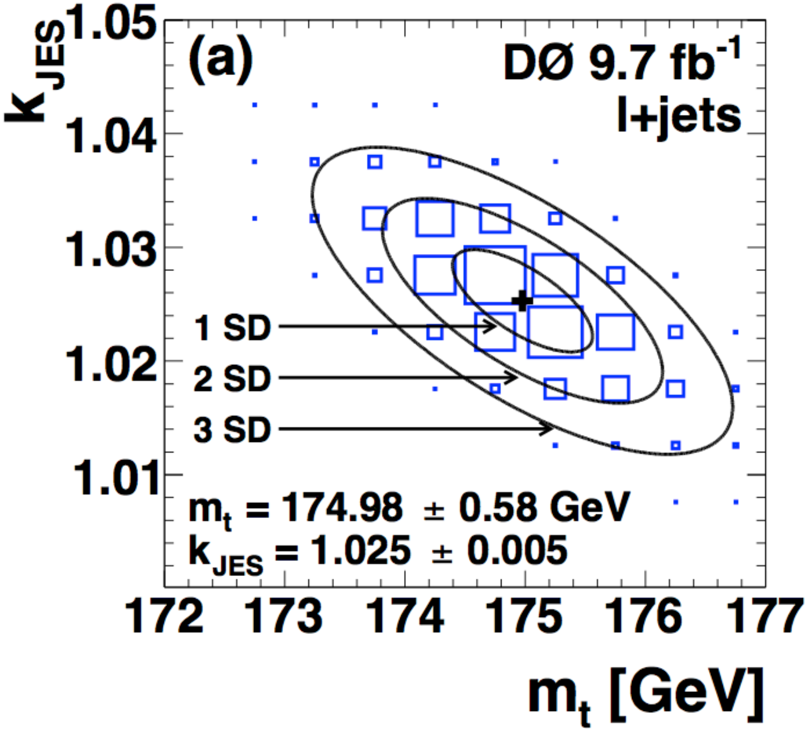
1.02 GeV

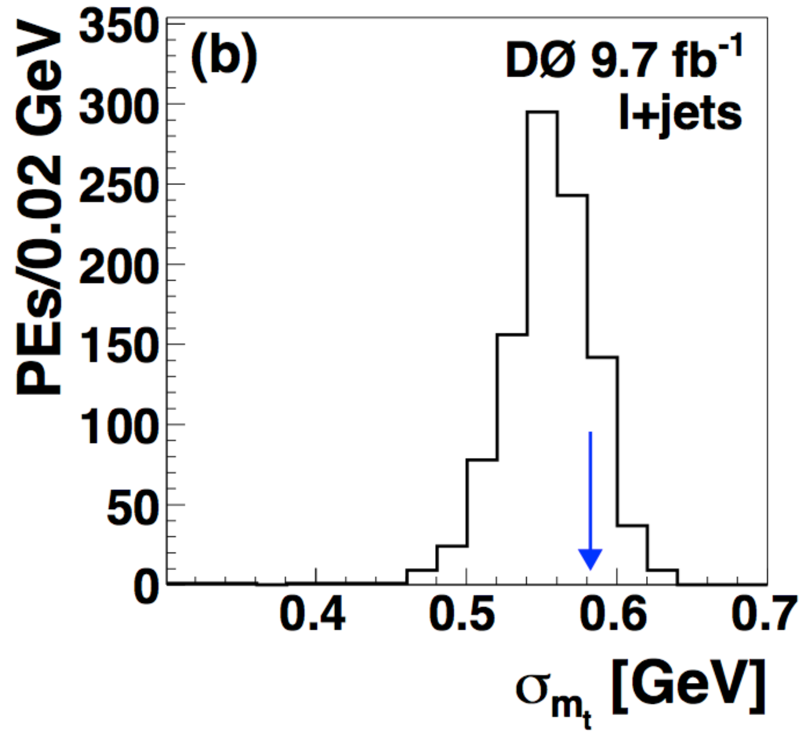
0.49 GeV

Result using 3.6 fb^{-1}: DØ Coll., PRD **84**, 032004 (2011)

Source	Uncertainty (GeV)
Modeling of production:	
Modeling of signal:	
Higher-order effects	±0.25
ISR/FSR	±0.26
Hadronization and UE	±0.58
Color reconnection	±0.28
Multiple $p\bar{p}$ interactions	±0.07
Modeling of background	±0.16
W+jets heavy-flavor scale factor	±0.07
Modeling of b jets	±0.09
Choice of PDF	±0.24
Modeling of detector:	
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 energy resolution	±0.32
Jet ID efficiency	±0.26
Method:	
Multijet contamination	±0.14
Signal fraction	±0.10
MC calibration	±0.20
Total	±1.02

Top quark mass – result





Note: analysis was done blinded in m_t

Final result in l+jets using 9.7 fb^{-1} of data:

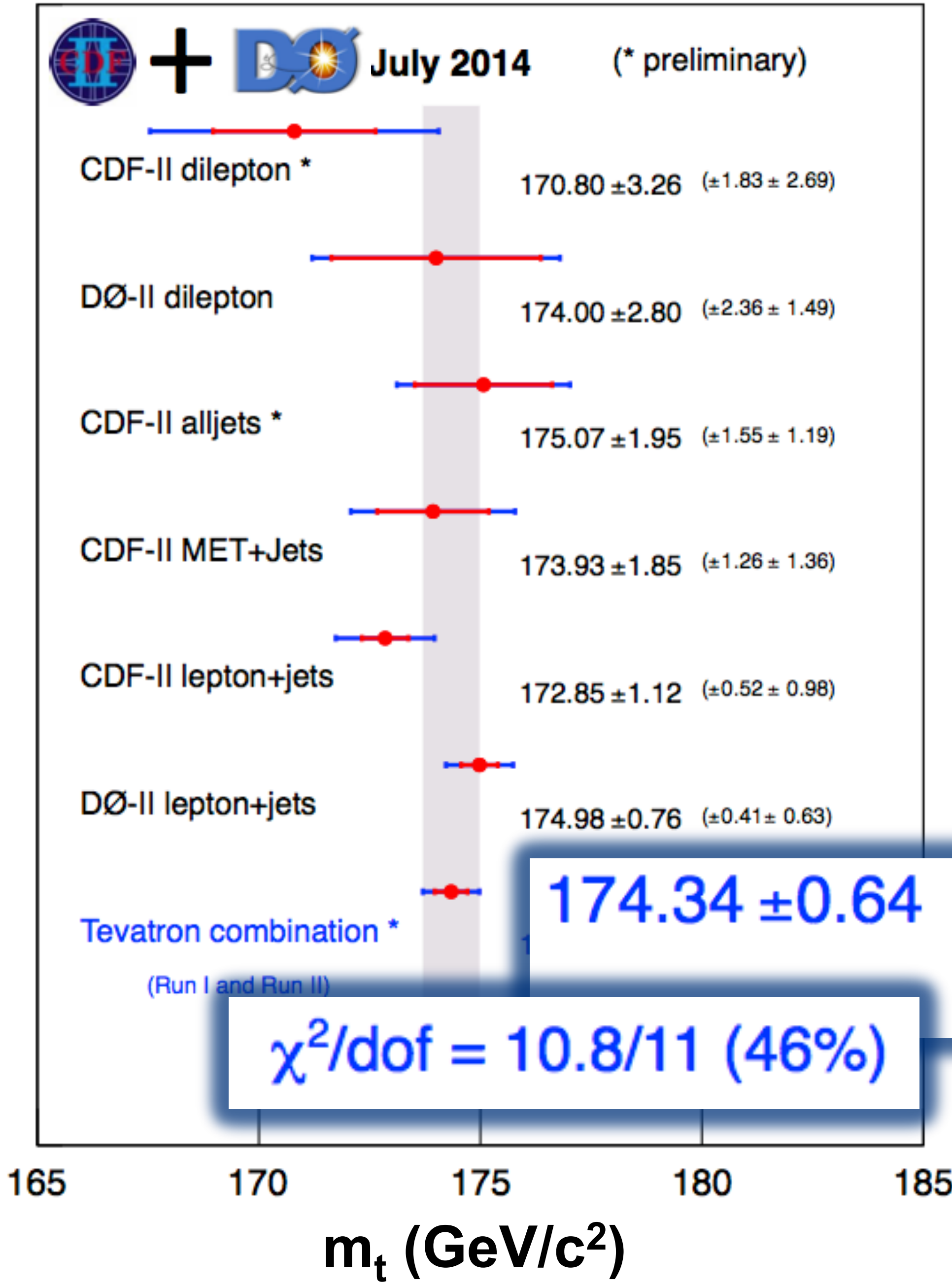
$$m_t \ = \ 174.98 \pm 0.58 \, (\mathrm{stat + JES}) \pm 0.49 \, (\mathrm{syst}) \ \ \mathrm{GeV} \, ,$$

Total uncertainty: 0.43%

→ most precise single measurement of m_t

*Phys. Rev. Lett. **113**, 032002 (2014)*

Top quark mass: Tevatron combination



Done using the established BLUE technique, various cross-checks

Taking into account correlations between uncertainty categories

Expect further improvements as new measurements enter the game

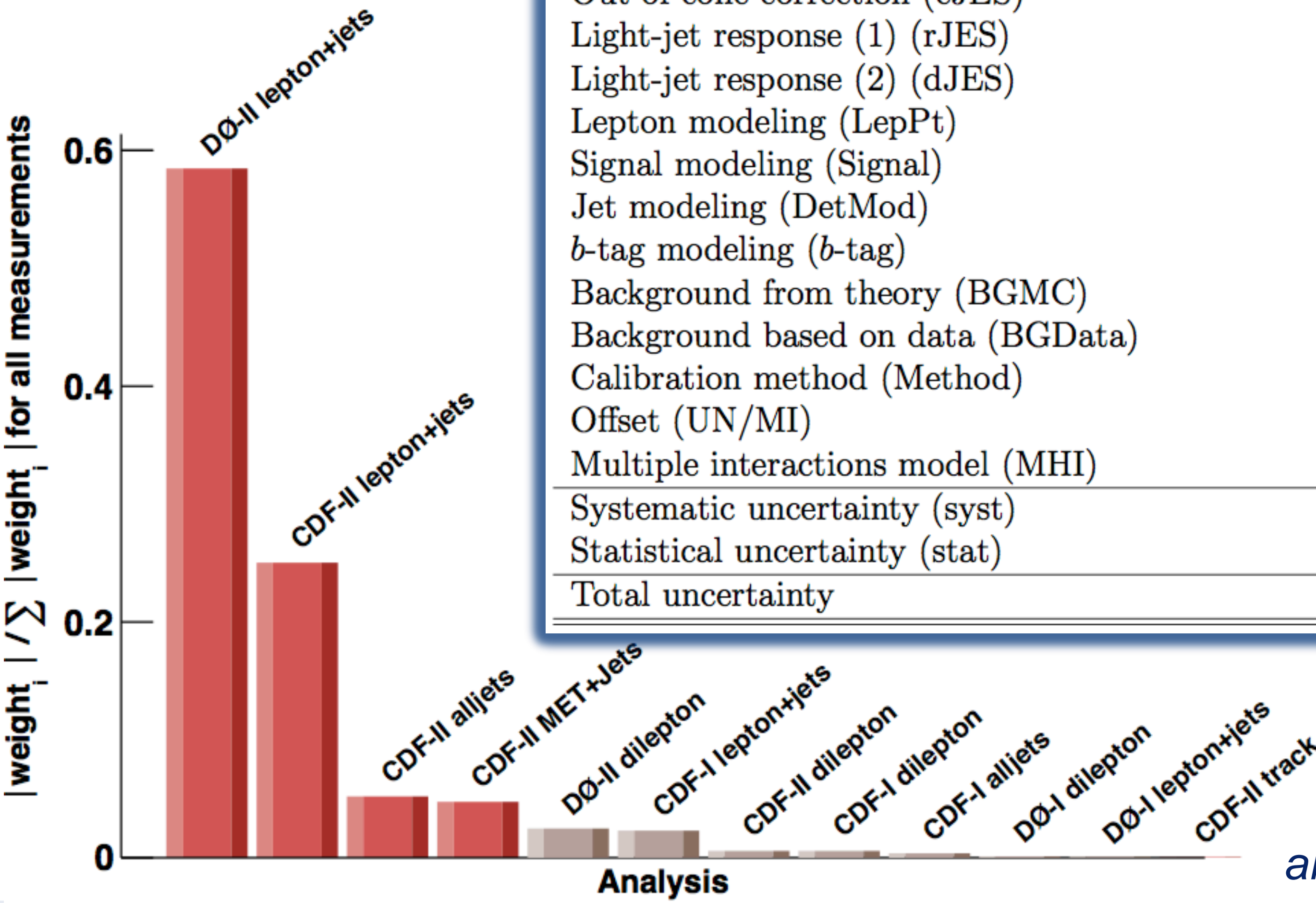
Most precise determination of m_t comes from the Tevatron (yet)

0.37% total uncertainty

arXiv:1407.2682 [hep-ex]

Top quark mass: Tevatron combination

	Tevatron combined values (GeV/c^2)
M_t	174.34
In situ light-jet calibration (iJES)	0.31
Response to $b/q/g$ jets (aJES)	0.10
Model for b jets (bJES)	0.10
Out-of-cone correction (cJES)	0.02
Light-jet response (1) (rJES)	0.05
Light-jet response (2) (dJES)	0.13
Lepton modeling (LepPt)	0.07
Signal modeling (Signal)	0.34
Jet modeling (DetMod)	0.03
b-tag modeling (b-tag)	0.07
Background from theory (BGMC)	0.04
Background based on data (BGData)	0.08
Calibration method (Method)	0.07
Offset (UN/MI)	0.00
Multiple interactions model (MHI)	0.06
Systematic uncertainty (syst)	0.52
Statistical uncertainty (stat)	0.37
Total uncertainty	0.64



arXiv:1407.2682 [hep-ex]

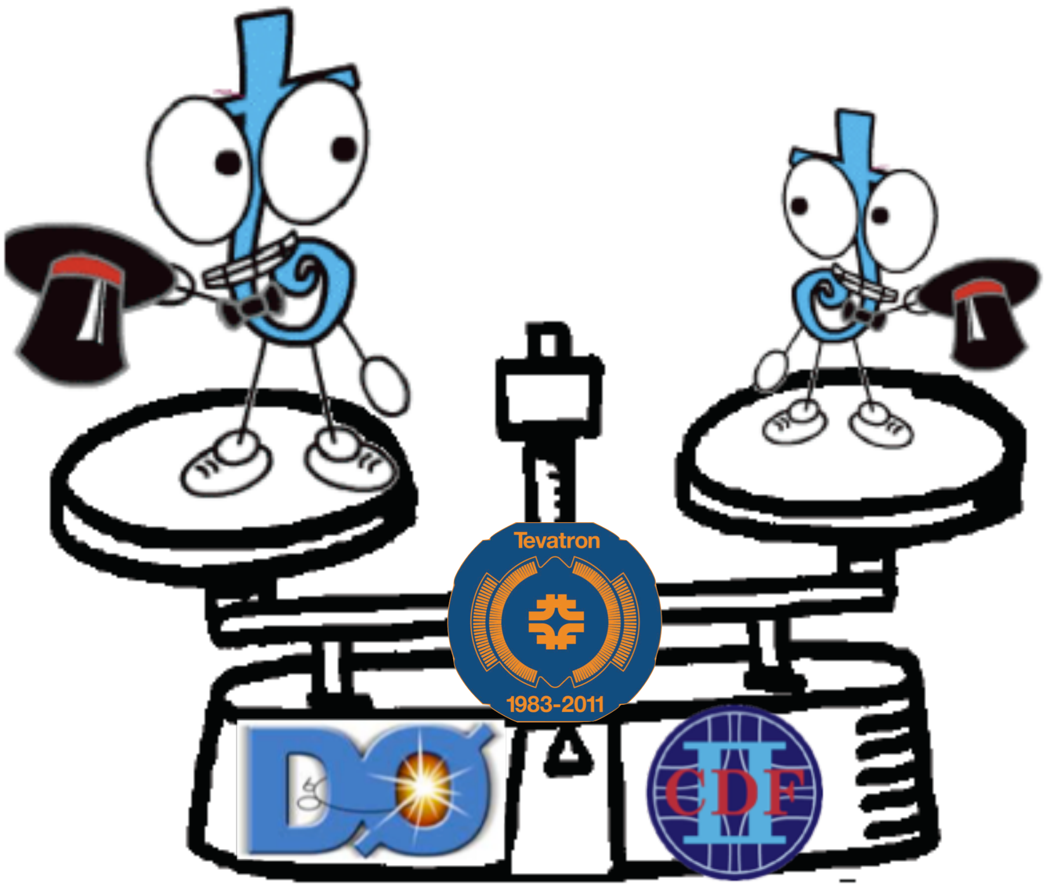
Summary & Outlook

- The era of precision measurements in the top quark sector has begun!
- Many exciting new/updated analyses:
  - Precise differential measurements of σ_{tt} in good agreement with the SM
  - First evidence of single top production in s channel comes from DØ
  - Observation of single top production in s channel at the Tevatron
  - Remarkable progress at pinning down colour charge asymmetry A_{FB}
  - World's most precise single measurement of m_t comes from DØ
  - World's most precise experimental determination of m_t comes from the Tevatron


GAME OVER
Tevatron
1983-2011

Outlook

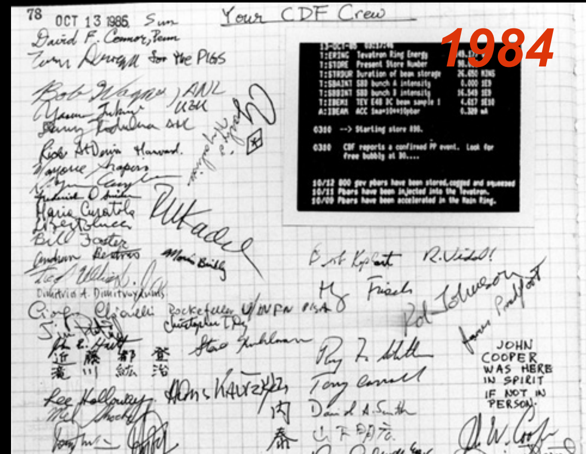
We are looking ahead to more exciting measurements from the Tevatron!



For further info

- DØ top physics results:
  - http://www-d0.fnal.gov/Run2Physics/top/
- Tevatron top-antitop combinations (mass, σ_{tt}, etc)
  - http://tevewwg.fnal.gov/top/
- Tevatron single top combinations
  - http://tevewwg.fnal.gov/singleTop/
- Tevatron physics for the informed public
  - http://www.fnal.gov/pub/today/frontier_science_result


1983


1984
78
OCT 13 1985 Sun
Your CDF Crew
JOHN COOPER WAS HERE IN SPIRIT IF NOT IN PERSON

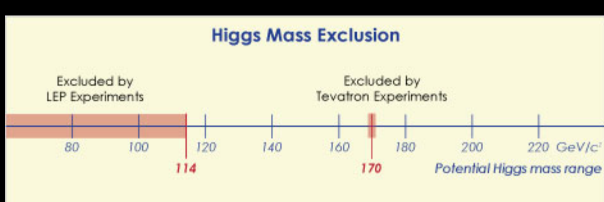

1985

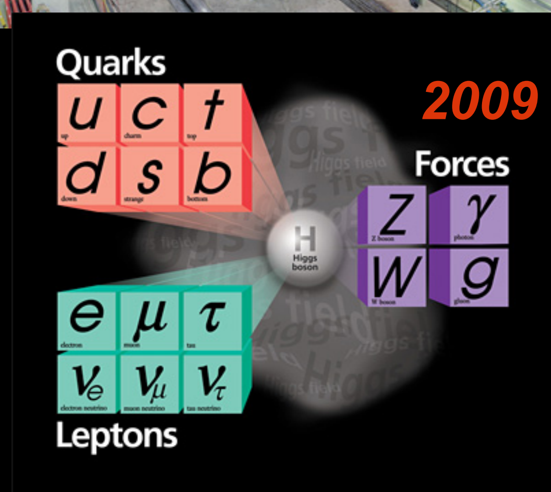

1991

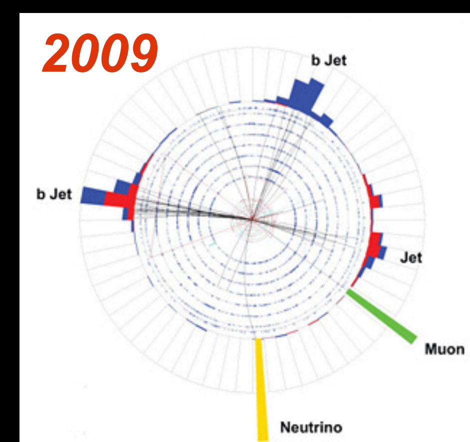

1992


1995
Cultura e Spettacoli
CORRIERE DELLA SERA
Dove vai, cacciatore di quark?
Batavia is center of universe
Alles Quark, oder was?
I predatori del quark perduto
For physicists, last piece of a puzzle
Nation
RICERCA ITALIANA
Truth by Consensus

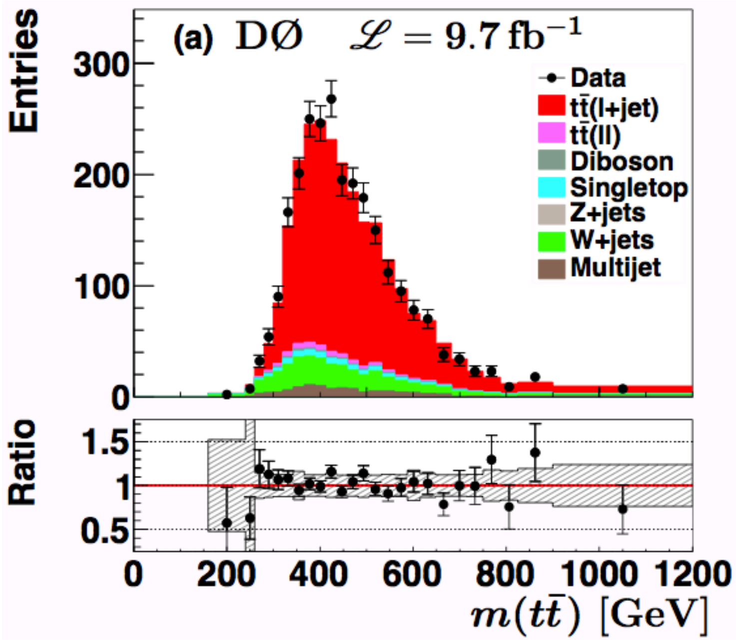
2008

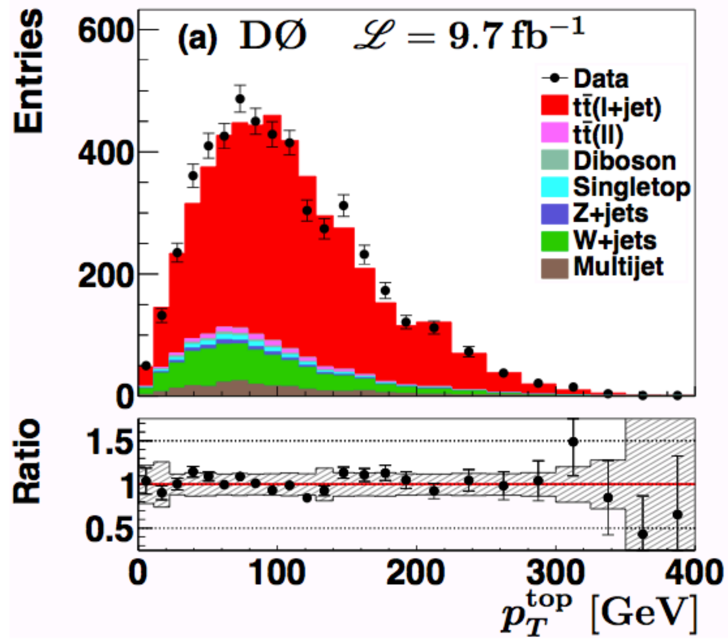

Higgs Mass Exclusion
Excluded by LEP Experiments
Excluded by Tevatron Experiments
80
100
114
120
140
160
170
180
200
220 GeV/c²
Potential Higgs mass range

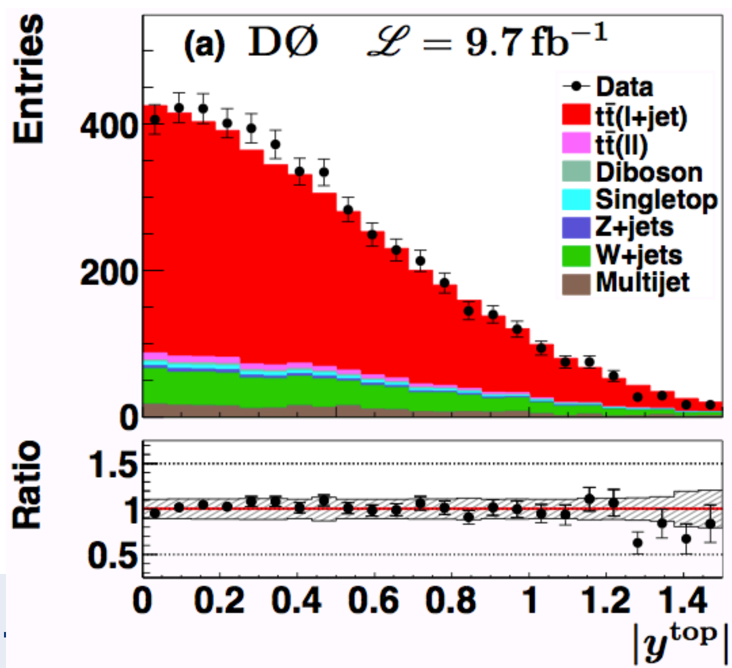

2009
Quarks
u c t
d s b
Forces
Z γ
W g
H
Higgs boson
e μ τ
νe νμ ντ
Leptons


2009
b Jet
b Jet
Jet
Muon
Neutrino

Differential tt cross section







Process	μ+jets	e+jets
Multijet	31.1 ± 10.0	75.1 ± 13.0
W+jets	164.9 ± 3.1	148.8 ± 2.6
Diboson	9.1 ± 0.3	10.5 ± 0.3
Z/γ^*+jets	11.9 ± 0.4	12.4 ± 0.4
Single top	16.1 ± 0.2	21.8 ± 0.3
$t\bar{t}$, $\ell\ell$	22.6 ± 0.2	33.5 ± 0.3
$\sum$ bgs	254.4 ± 10.5	302.1 ± 13.3
$t\bar{t}$, ℓ+jets	838.7 ± 3.2	1088.7 ± 3.8
$\sum$ (sig + bgs)	1093.1 ± 11.0	1390.8 ± 13.8
Data	1137	1403

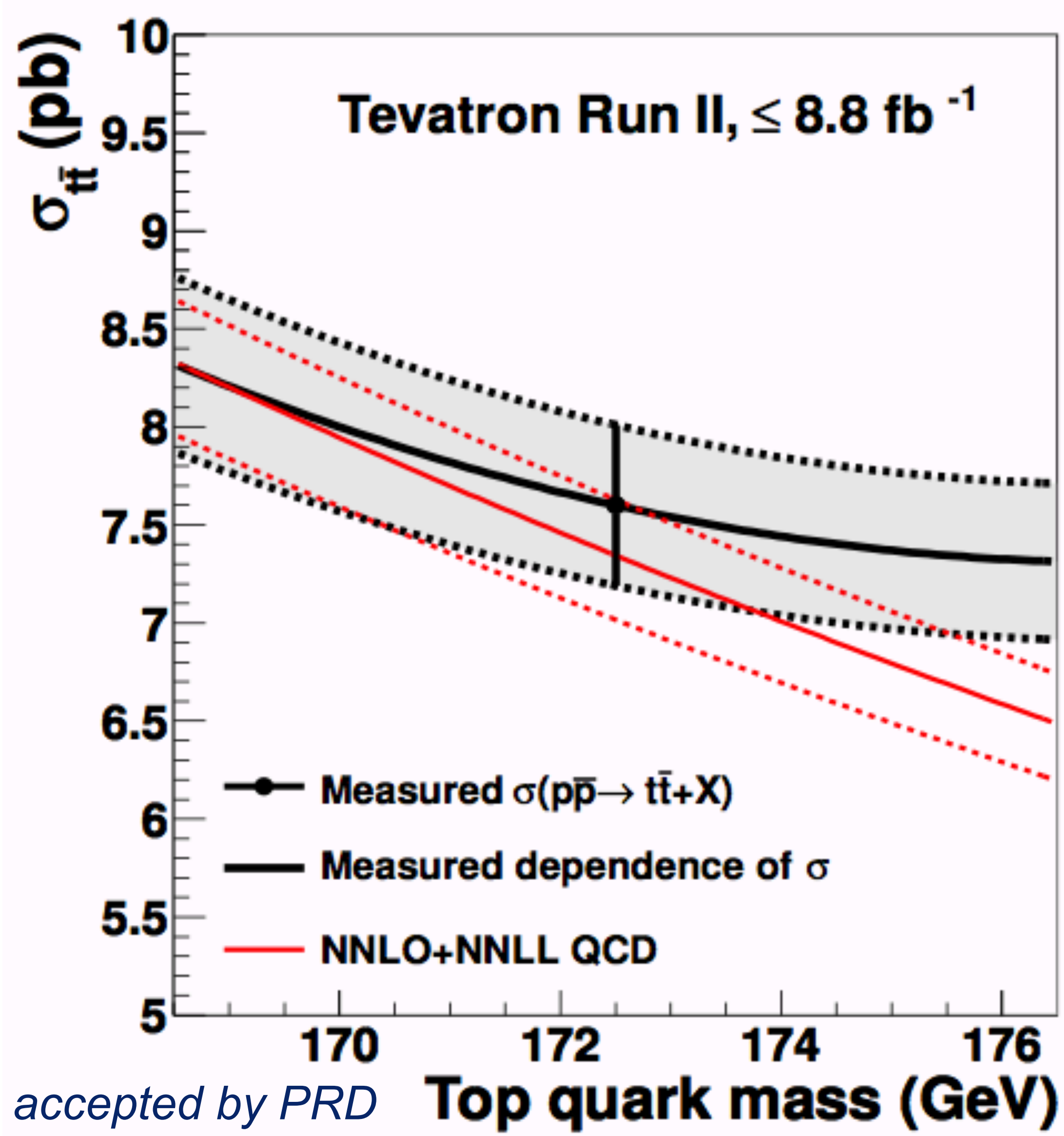
arXiv:1401.5785 [hep-ex], submitted to PRD

Tevatron combination σ_{tt}

	CDF	D0		Tevatron
Central value of $\sigma_{\bar{t}t}$	7.63	7.56		7.60
Sources of systematic uncertainty			Correlation	
Modeling of the detector	0.17	0.22	NO	0.13
Modeling of signal	0.21	0.13	YES	0.18
Modeling of jets	0.21	0.11	NO	0.13
Method of extracting $\sigma_{t\bar{t}}$	0.01	0.07	NO	0.03
Background modeled from theory	0.10	0.08	YES	0.10
Background based on data	0.08	0.06	NO	0.05
Normalization of Z/γ^* prediction	0.13	–	NO	0.08
Luminosity: inelastic $p\bar{p}$ cross section	0.05	0.30	YES	0.15
Luminosity: detector	0.06	0.35	NO	0.14
Total systematic uncertainty	0.39	0.56		0.36
Statistical uncertainty	0.31	0.20		0.20
Total uncertainty	0.50	0.59		0.41

arXiv:1309.7570 [hep-ex], accepted by PRD

Tevatron combination σ_{tt}



arXiv:1309.7570 [hep-ex], accepted by PRD

Single top s-channel evidence

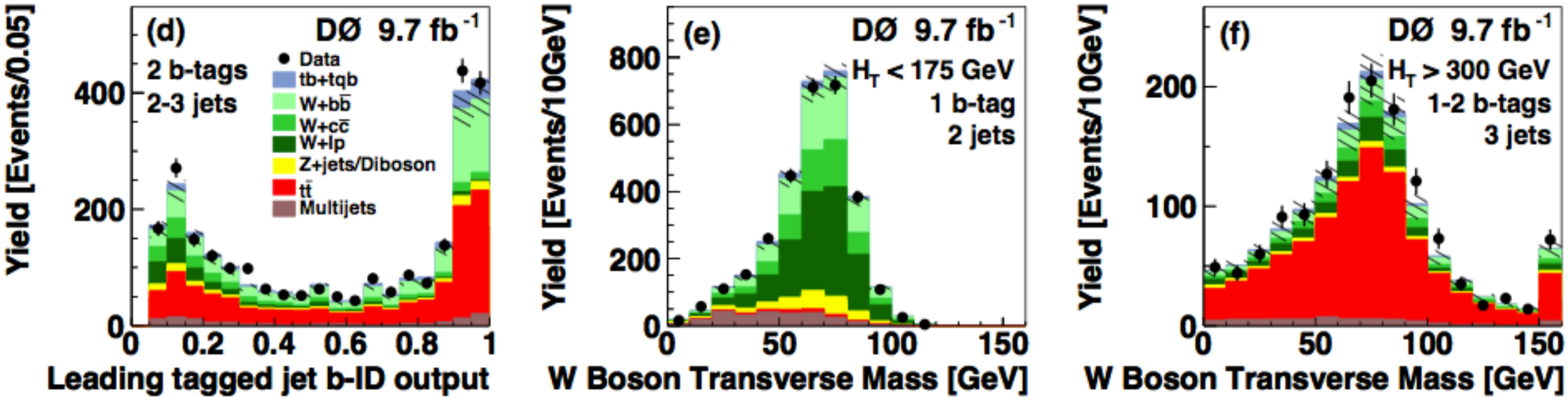
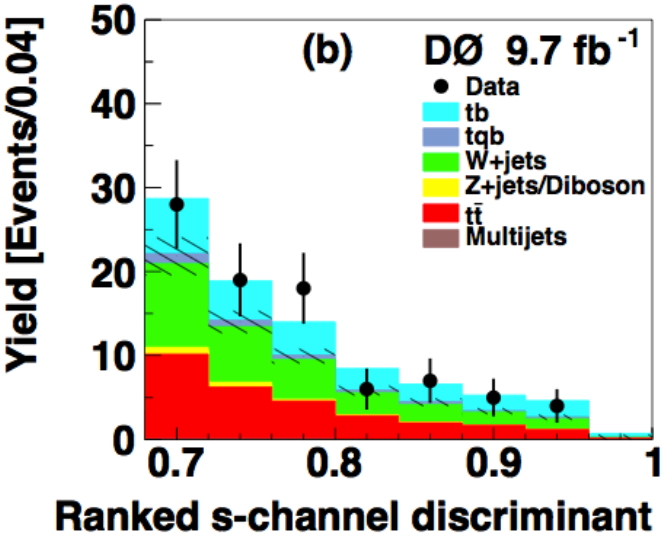
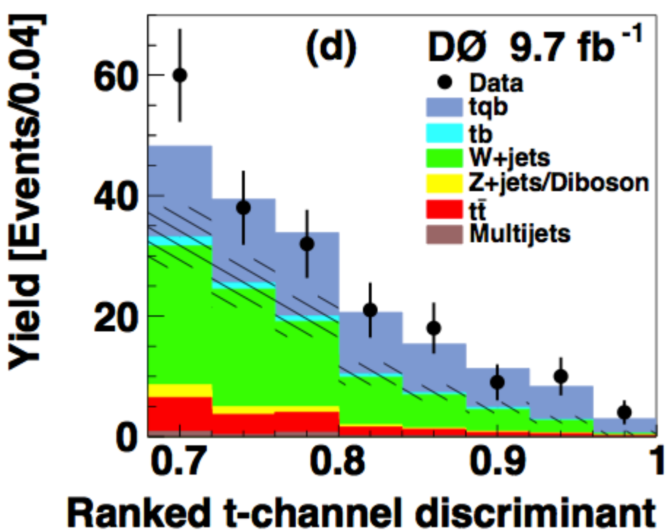


TABLE I: The numbers of expected and observed events in a data sample corresponding to 9.7 fb^{-1} of integrated luminosity, with uncertainties including both statistical and systematic components added in quadrature, before the fit to the data. The s- and t-channel contributions are normalized to their SM expectations for $m_t = 172.5$ GeV. The ratio $S(tb)$:B is the ratio of the number of s-channel signal events, S, to the total number of background events, B, including the t channel, and $S(tqb)$:B is the ratio of the number of t-channel signal events to the total number of background events, including the s channel.

Number of jets	2	2	3	3
Number of b tags	1	2	1	2
s channel	112±23	83±19	33±7	29±7
t channel	248±50	23±5	75±15	32±7
$t\bar{t}$	585±100	275±52	1044±207	767±158
W+jets	4984±369	715±96	1395±120	300±39
Z+jets and diboson	544±67	79±10	156±18	36±5
Multijet	479±73	65±10	188±33	56±9
Background sum	6592±395	1134±110	2784±242	1160±164
Backgrounds + signals	6952±399	1240±112	2891±243	1220±164
Data	6859	1286	2725	1233
$S(tb)$:B	1:61	1:14	1:88	1:41
$S(tqb)$:B	1:27	1:52	1:38	1:38

Single top s-channel evidence



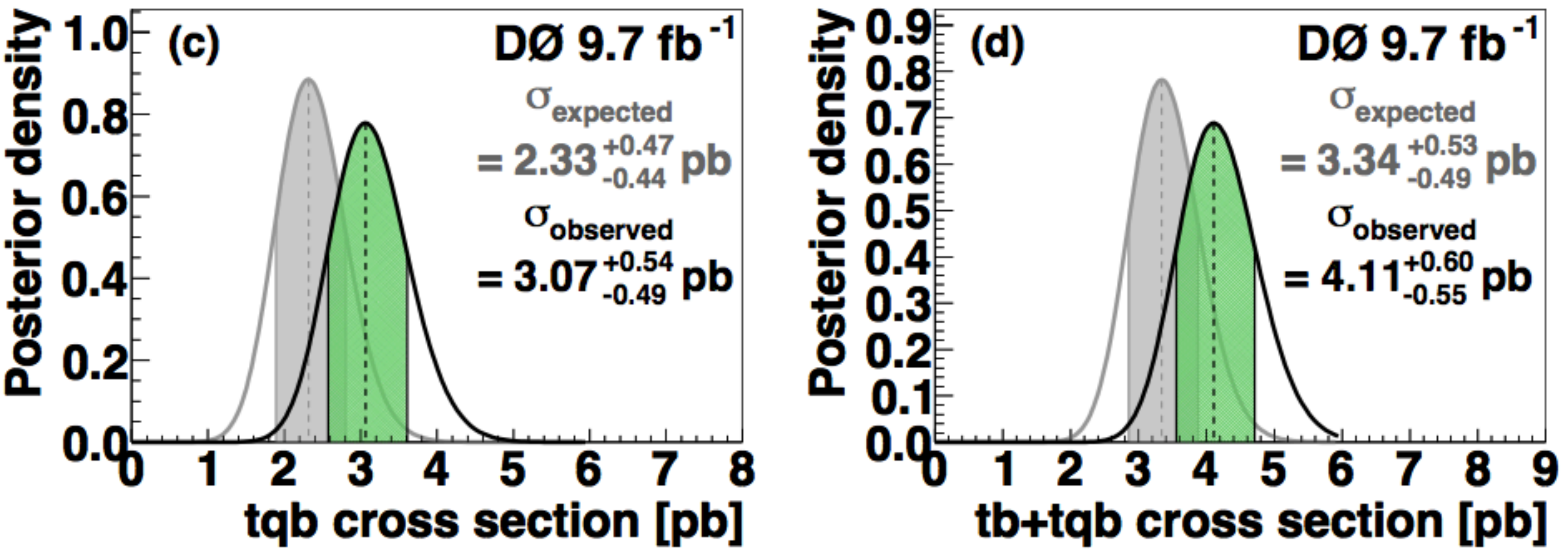


Relative Systematic Uncertainties	
Components for Normalization	
Integrated luminosity [45]	6.1%
$t\bar{t}$ cross section	9.0%
Parton distribution functions	2.0%
Trigger efficiency	(3.0-5.0)%
Jet fragmentation and higher-order effects	(0.7-7.0)%
Initial and final state radiation	(0.8-10.9)%
W/Z+jets heavy flavor correction	20.0%
W+jets normalization to data	(1.1-2.5)%
Multijet normalization to data	(9.2-42.1)%
Components for Normalization and Shape	
Jet reconstruction and identification	(0.1-1.4)%
Jet energy resolution	(0.3-1.1)%
Jet energy scale	(0.1-1.2)%
Flavor-dependent jet energy scale	(0.1-1.3)%
b tagging, single-tagged	(1.0-6.6)%
b tagging, double-tagged	(7.3-8.8)%

Single top s-channel evidence

TABLE III: The expected and observed single top quark cross sections and p values for the individual ME, BNN, and BDT discriminants, and the combined BNN discriminant $D^{\rm comb}$. Here, Z is defined such that a Z standard-deviation upward fluctuation of a Gaussian random variable would have an upper tail area equal to the p value.

Channel	Expected σ (pb)	Observed σ (pb)	Expected p value	Observed p value	Expected Z	Observed Z
ME_s	$1.05^{+0.36}_{-0.34}$	$1.12^{+0.36}_{-0.33}$	8.1×10^{-4}	3.7×10^{-4}	3.2	3.4
BNN_s	$1.06^{+0.41}_{-0.39}$	$1.61^{+0.43}_{-0.40}$	3.3×10^{-3}	1.5×10^{-5}	2.7	4.2
BDT_s	$1.06^{+0.35}_{-0.33}$	$1.56^{+0.40}_{-0.37}$	5.4×10^{-4}	2.3×10^{-6}	3.3	4.6
$D_s^{\rm comb}$	$1.07^{+0.32}_{-0.30}$	$1.10^{+0.33}_{-0.31}$	1.0×10^{-4}	1.0×10^{-4}	3.7	3.7
ME_t	$2.27^{+0.55}_{-0.51}$	$2.15^{+0.54}_{-0.50}$	6.6×10^{-7}	2.8×10^{-6}	4.8	4.5
BNN_t	$2.31^{+0.54}_{-0.50}$	$2.41^{+0.55}_{-0.51}$	2.4×10^{-7}	1.4×10^{-7}	5.0	5.1
BDT_t	$2.36^{+0.53}_{-0.50}$	$3.70^{+0.66}_{-0.60}$	5.4×10^{-8}	3.4×10^{-15}	5.3	7.8
$D_t^{\rm comb}$	$2.33^{+0.47}_{-0.44}$	$3.07^{+0.54}_{-0.49}$	1.0×10^{-9}	7.1×10^{-15}	6.0	7.7
$D_{s+t}^{\rm comb}$	$3.34^{+0.53}_{-0.49}$	$4.11^{+0.60}_{-0.55}$				



Single top s channel observation

Systematic uncertainty	CDF Norm	CDF Dist	D0 Norm	D0 Dist	Corre-lated
Lumi from detector	4.5%		4.5%		No
Lumi from cross section	4.0%		4.0%		Yes
Signal modeling	2–10%	•	3–8%		Yes
Background (simulation)	2–12%	•	2–11%	•	Yes
Background (data)	15–40%	•	19–50%	•	No
Detector modeling	2–10%	•	1–5%	•	No
b-jet-tagging	10–30%		5–40%	•	No
JES	0–20%	•	0–40%	•	No

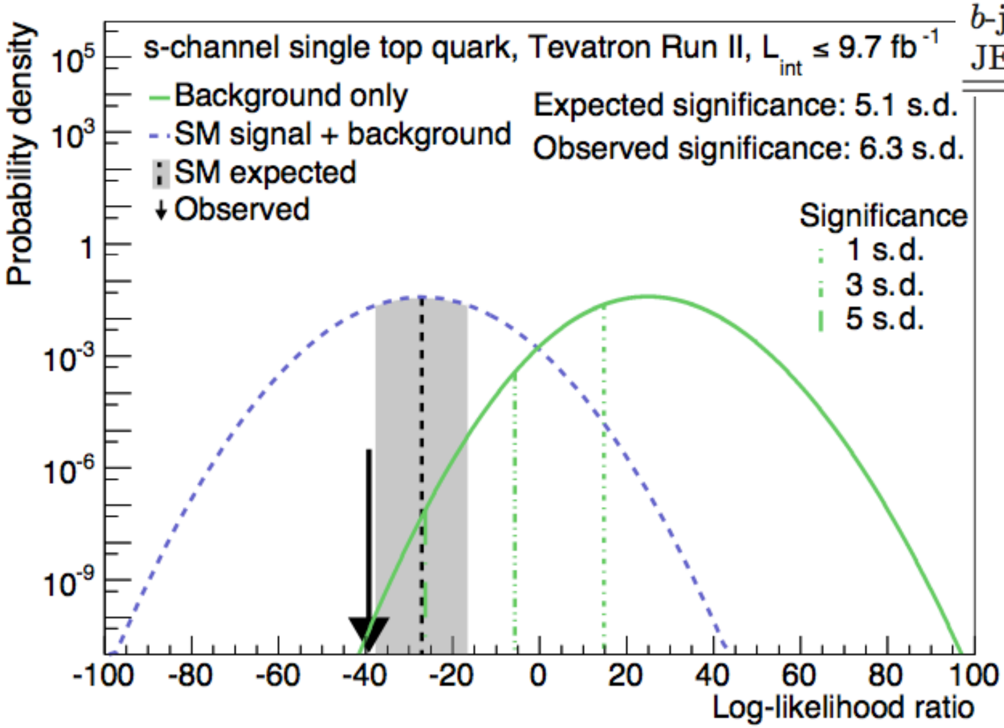
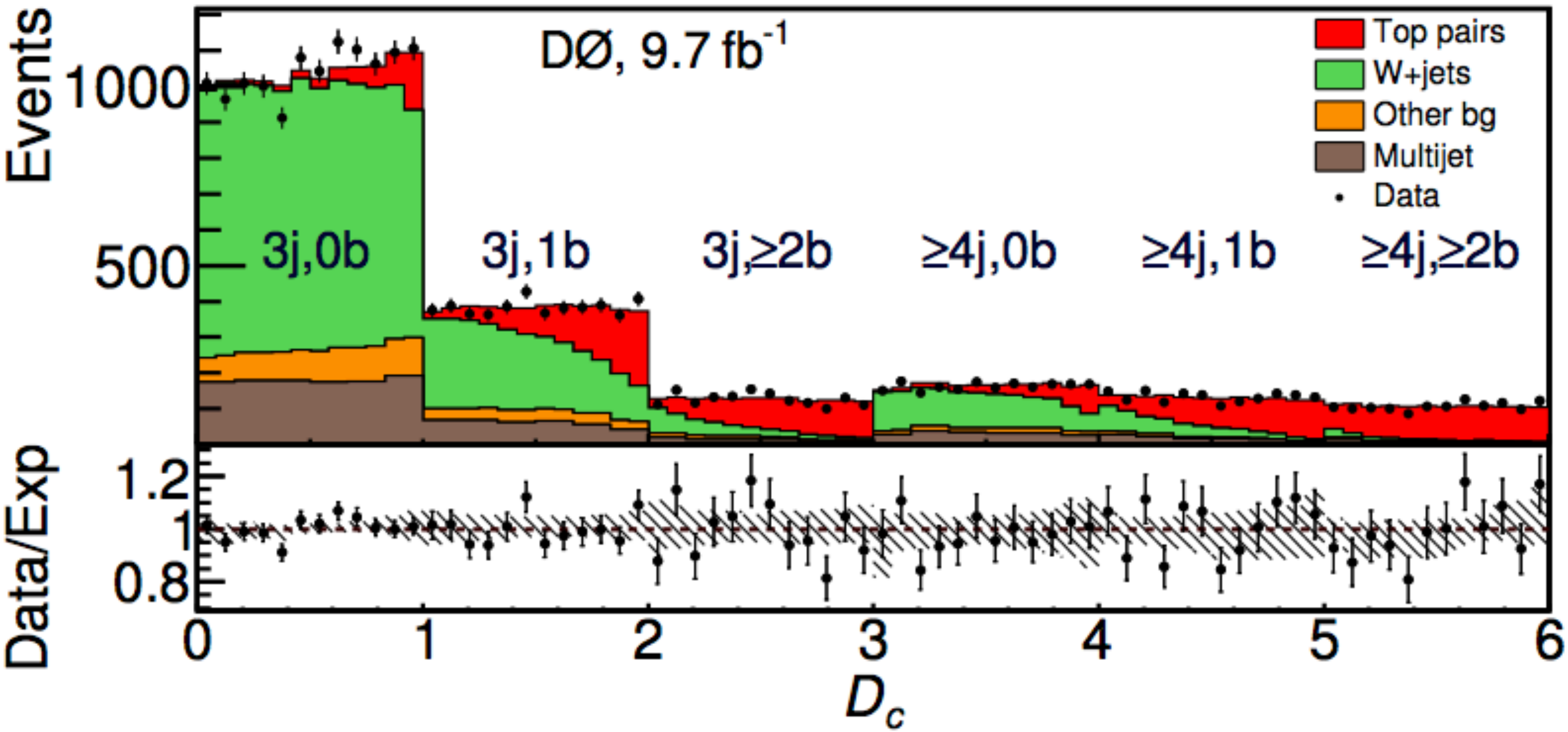


FIG. 5: (Color online) Log-likelihood ratios for the background-only (solid green line) and SM-signal-plus-background (dashed blue) hypotheses from the combined measurement.

Colour charge asymmetry, l+jets



Colour charge asymmetry, l+jets

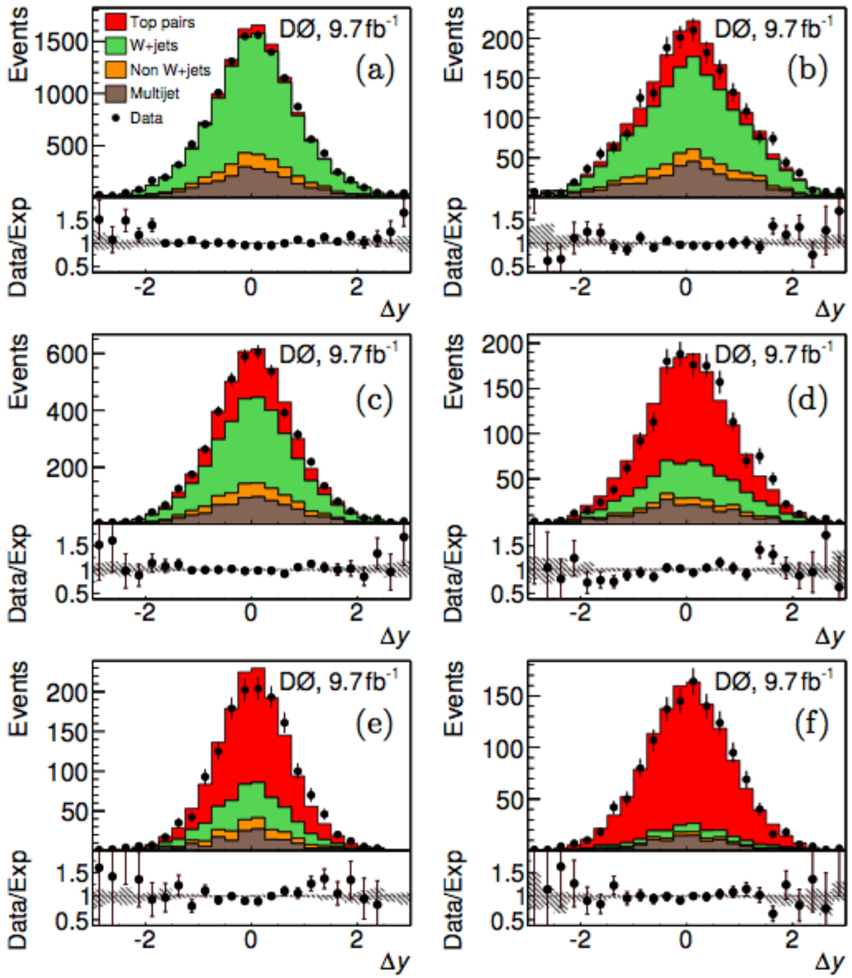


FIG. 3: (Color online). Reconstructed difference between the rapidities of the top and antitop quarks, Δy. The left column shows l+3 jet events, and the right column shows l+≥4 jet events. Rows from top to bottom display events with 0, 1, and ≥2 b tags. Overflows are included in the edge bins. The ratio between the data counts and the model expectation is shown in the lower panels, with the hashed area representing the systematic uncertainties.

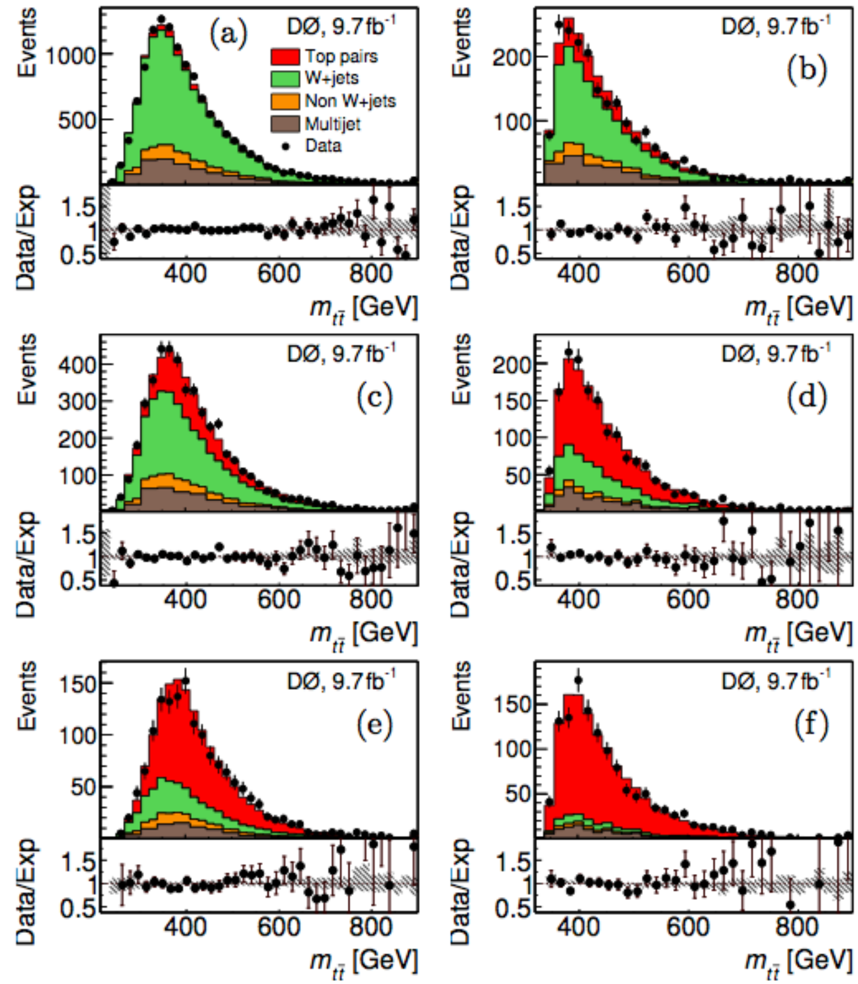


FIG. 4: (Color online). Reconstructed invariant mass of the top quark–antiquark pair, $m_{t\bar{t}}$. The left column shows l+3 jet events, and the right column shows l+≥4 jet events. Rows from top to bottom display events with 0, 1, and ≥2 b tags. The ratio between the data counts and the model expectation is shown in the lower panels, with the hashed area representing the systematic uncertainties.

Colour charge asymmetry, l+jets

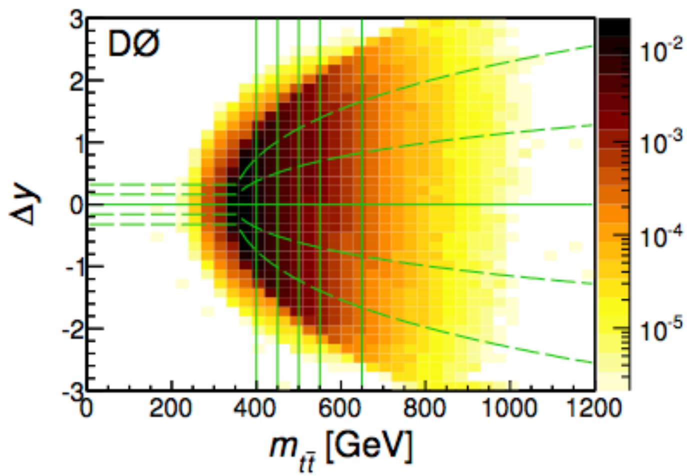


FIG. 5: (Color online). Production-level bins for the 2D measurement in the $(m_{t\bar{t}}, \Delta y)$ plane, overlaid on the distribution in these variables predicted from MC@NLO. The shading reflects the predicted event density in arbitrary units. The solid and dashed lines denote the production-level bins. The solid lines show bins that are used for the final result.

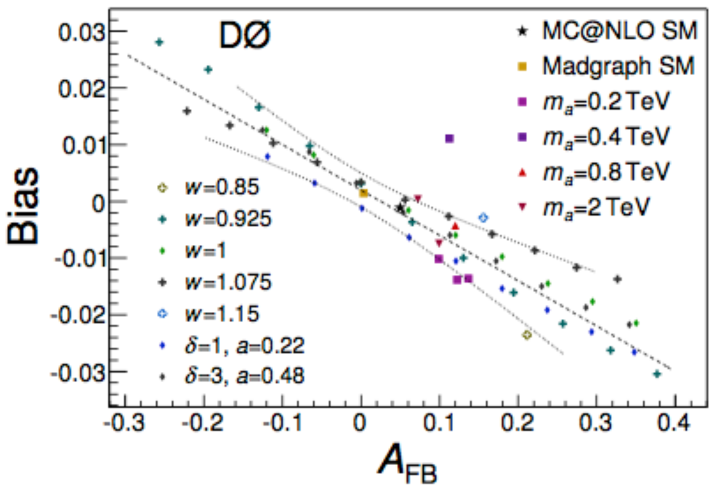


FIG. 6: (Color online). The bias as a function of the input A_{FB}. Axigluon scenarios are indicated in the legend by the mass of the axigluon, m_a. The toy models are labeled by parameters w, a, and δ of Eq. 8. Unless stated otherwise $w = 1$, $a = 0$, and $\delta = 1$. For each set of a, δ, and w, the value of μ is varied to produce different input asymmetries. The dashed line indicates the calibration applied to the inclusive measurement and the dotted lines indicate the assigned calibration uncertainties. The point significantly outside of the dotted lines corresponds to an axigluon mass of 0.4 TeV and is discussed in the text.

TABLE IV: Systematic uncertainties on A_{FB}, in absolute %. For the 2D measurement, the range of changes in A_{FB} over the six $m_{t\bar{t}}$ bins is given.

Source	Reco. level inclusive	Production level inclusive	Production level 2D
Background model	+0.7/−0.8	1.0	1.1–2.8
Signal model	< 0.1	0.5	0.8–5.2
Unfolding	N/A	0.5	0.9–1.9
PDFs and pileup	0.3	0.4	0.5–2.9
Detector model	+0.1/−0.3	0.3	0.4–3.3
Sample composition	< 0.1	< 0.1	< 0.1
Total	+0.8/−0.9	1.3	2.1–7.5

Colour charge asymmetry, l+jets

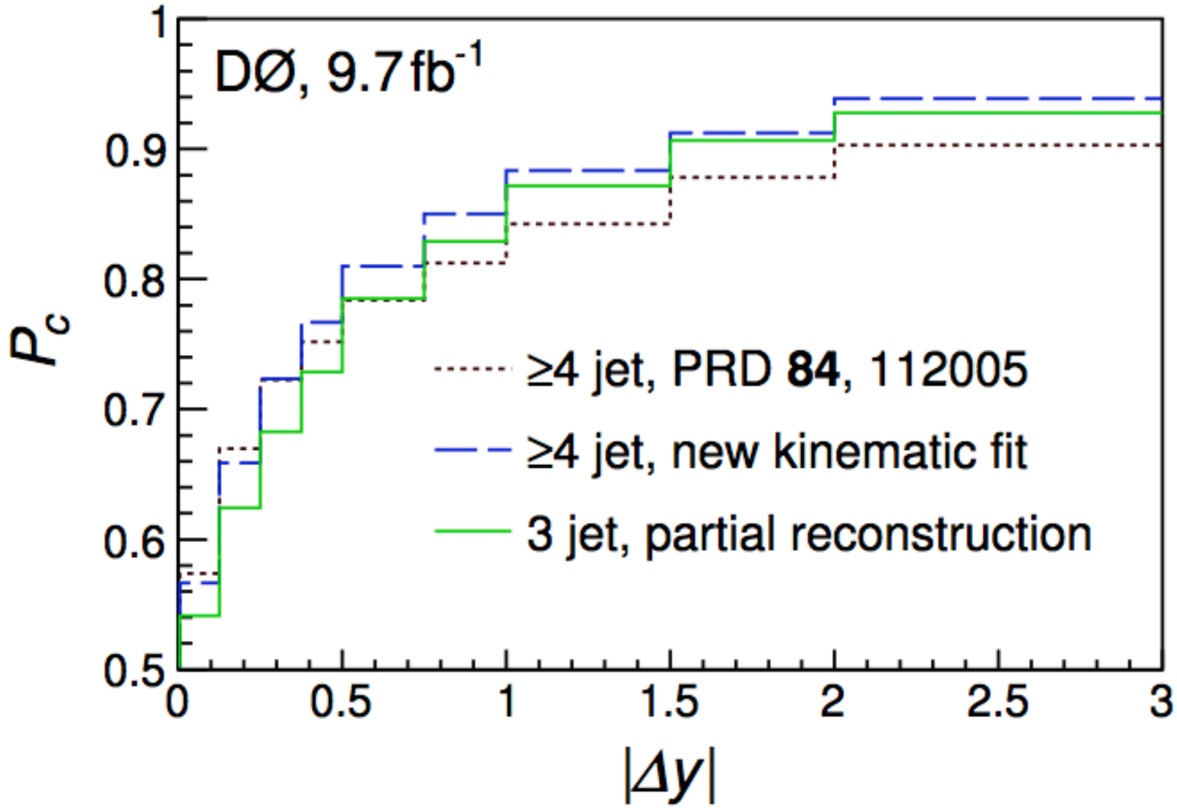


FIG. 1: (Color online). The probability to correctly reconstruct the sign of Δy as a function of the production-level $|\Delta y|$ for the algorithm of Ref. [27] used to measure the $A_{\rm FB}$ in Ref. [4] and the algorithms used to reconstruct $l+\geq 4$ jet events and to partially reconstruct $l+3$ jet events in this paper.

Colour charge asymmetry, l+jets

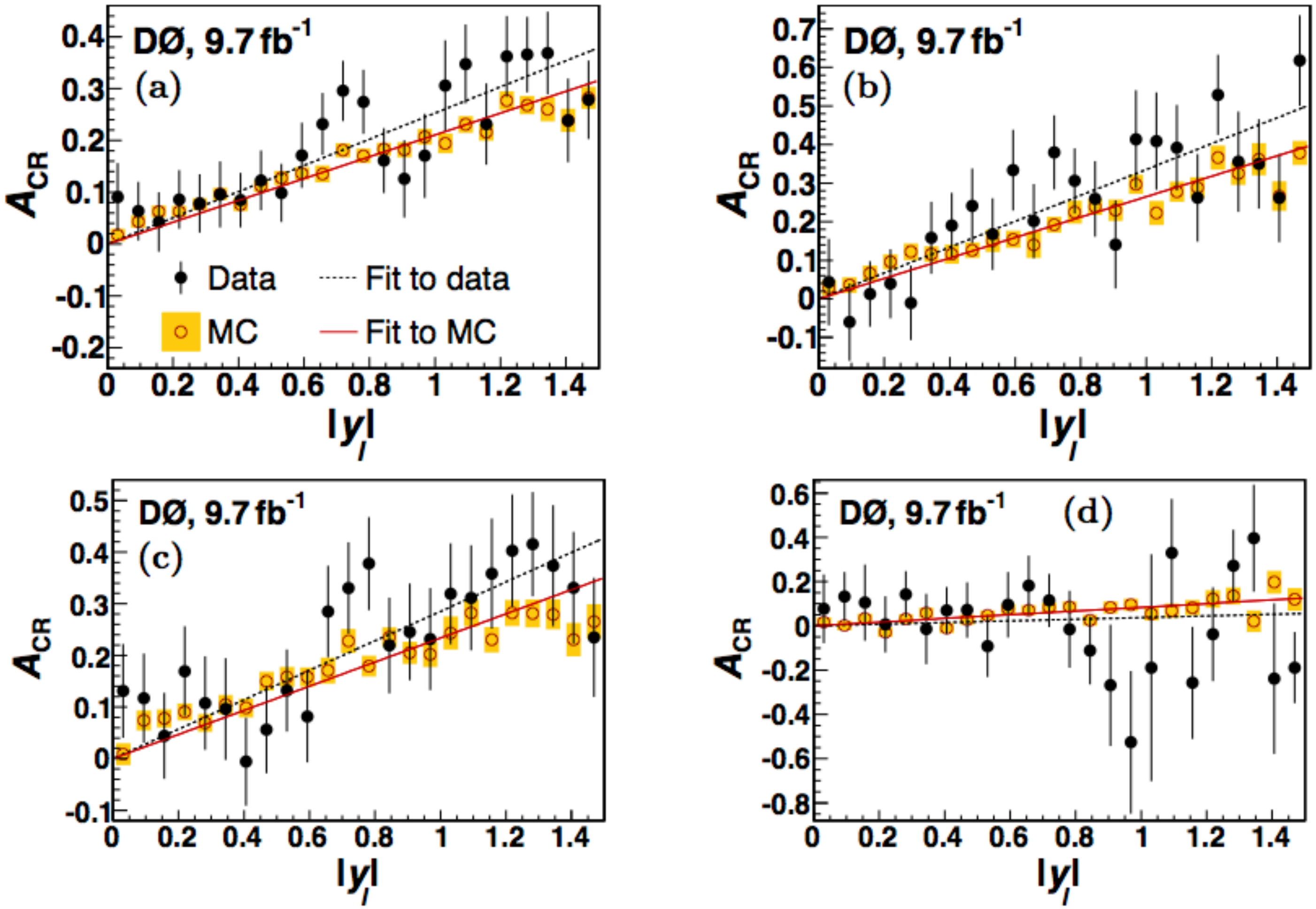
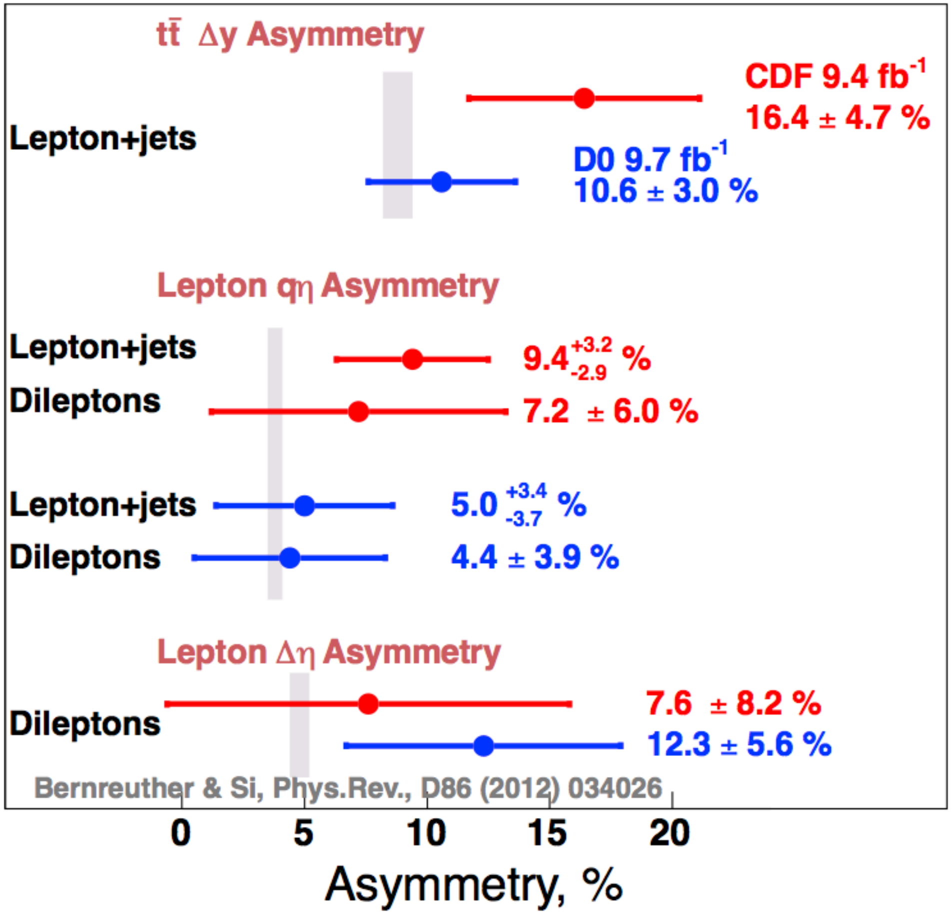
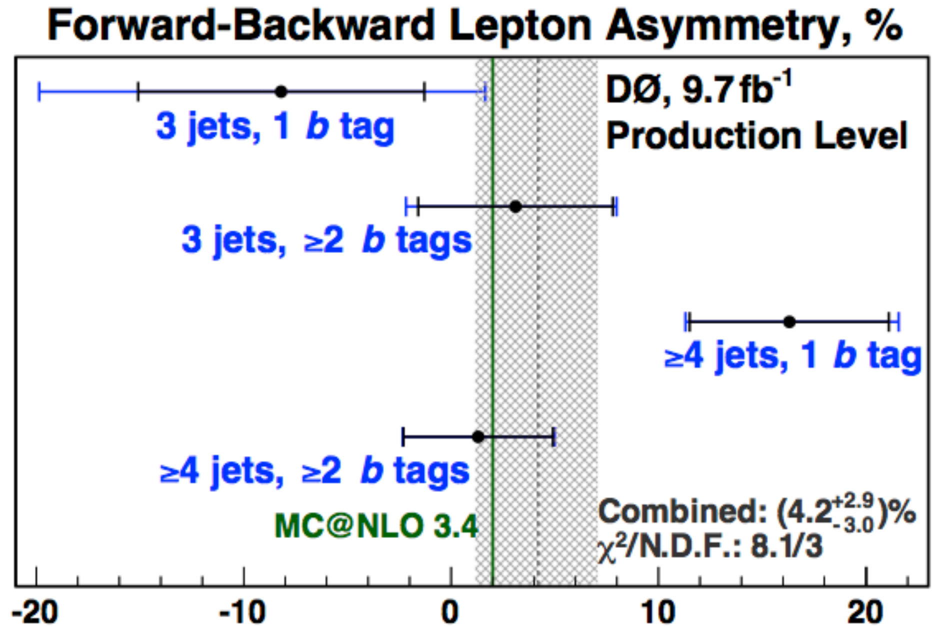


FIG. 5: The asymmetry of leptons from W+jets production as a function of $|y_l|$ for (a) the inclusive sample, (b) $20 \leq p_T^l < 35$ GeV, (c) $35 \leq p_T^l < 60$ GeV, and (d) $p_T^l \geq 60$ GeV. The points show the data from the control region, after the subtraction of the non-W+jets contributions, and the dashed line shows a fit to the functional form $y = ax$. The empty circles and solid line show the nominal W+jets simulation and its fit to the same functional form. The error bars and shaded regions indicate the statistical uncertainties on the data and simulation.

Colour charge asymmetry, l+jets





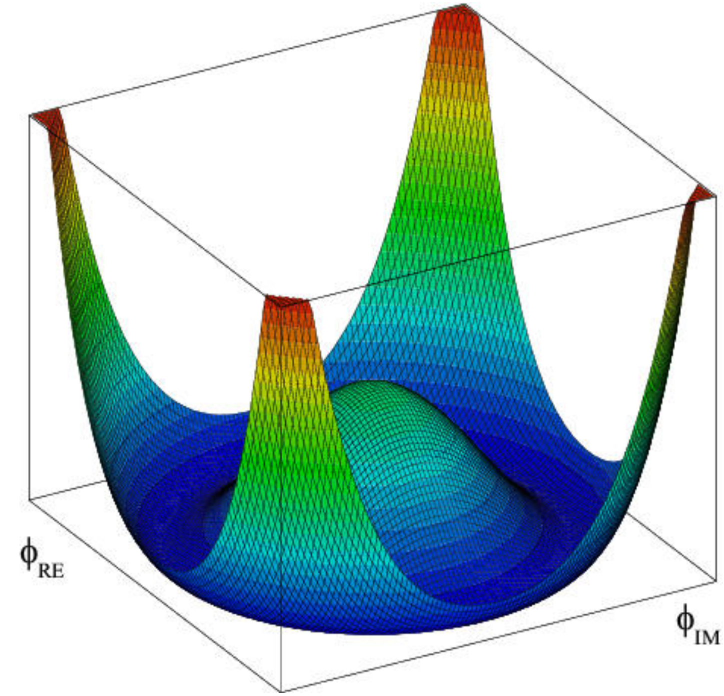
	Absolute uncertainty, %		
	Reconstruction level		Prod. level
Source	Prediction	Measurement	Measurement
Jet reco	−0.1	–	–
JES/JER	+0.1	+0.1/−0.3	+0.2/−0.3
Signal modeling	–	−0.2	+0.6/−0.4
b tagging	±0.1	+0.5/−0.8	+0.8/−1.1
Bg subtraction	n/a	+0.1/−0.3	+0.1/−0.3
Bg modeling	n/a	+1.4/−1.5	+1.3/−1.5
PDFs	–	+0.3/−0.2	+0.1/−0.2
Total	±0.1	+1.5/−1.7	+1.7/−2.0

Motivation

- If this is not enough, the **top quark mass** is a **fundamental parameter of the SM**
- The **fate of our Universe depends on m_t**!
  - Consider the Higgs Lagrangian:

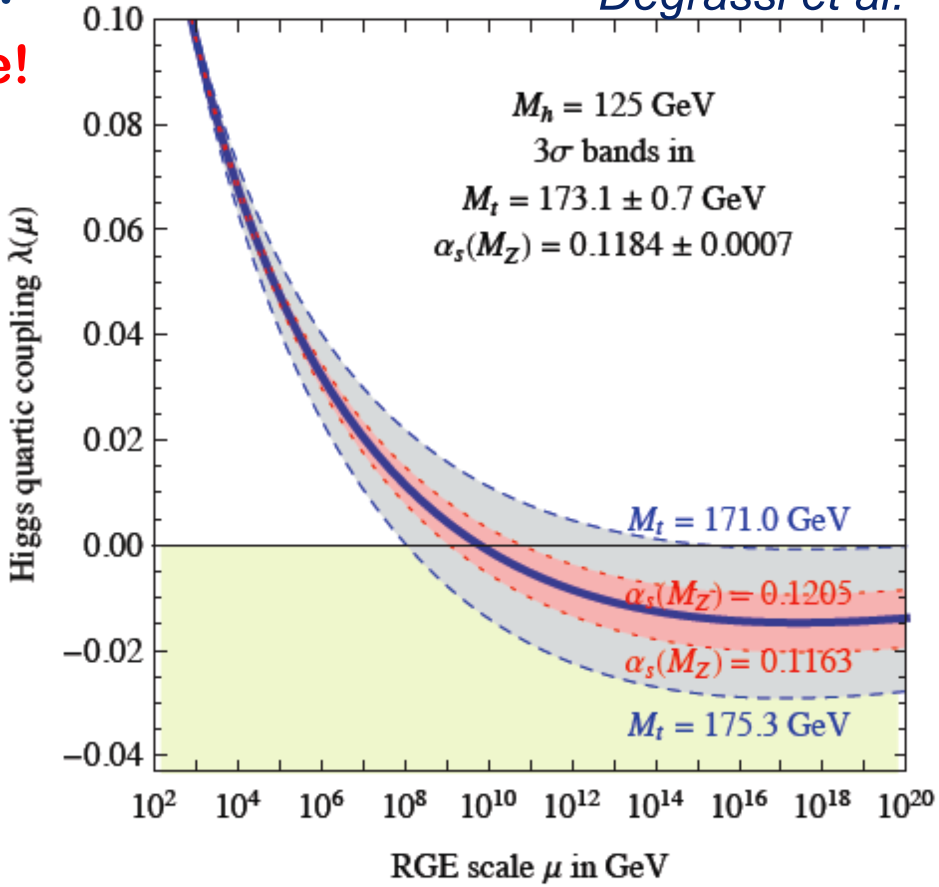
$$\mathcal{L}_H = \left| \left(\partial_\mu - igW_\mu^a \tau^a - i\frac{g'}{2}B_\mu \right) \phi \right|^2 + \mu^2 \phi^\dagger \phi - \lambda(\phi^\dagger \phi)^2,$$

  - The quartic Higgs self-coupling term $\lambda(\phi^\dagger\phi)^2$ is responsible for the mexican-hat shape of the potential
  - This works only if λ is positive…



- λ receives **radiative corrections** from all particles of the SM, **mostly from the top quark**!
  - We can evolve these corrections using running group equation to Planck scale:
    - **λ should remain positive!**

Degrassi et al.

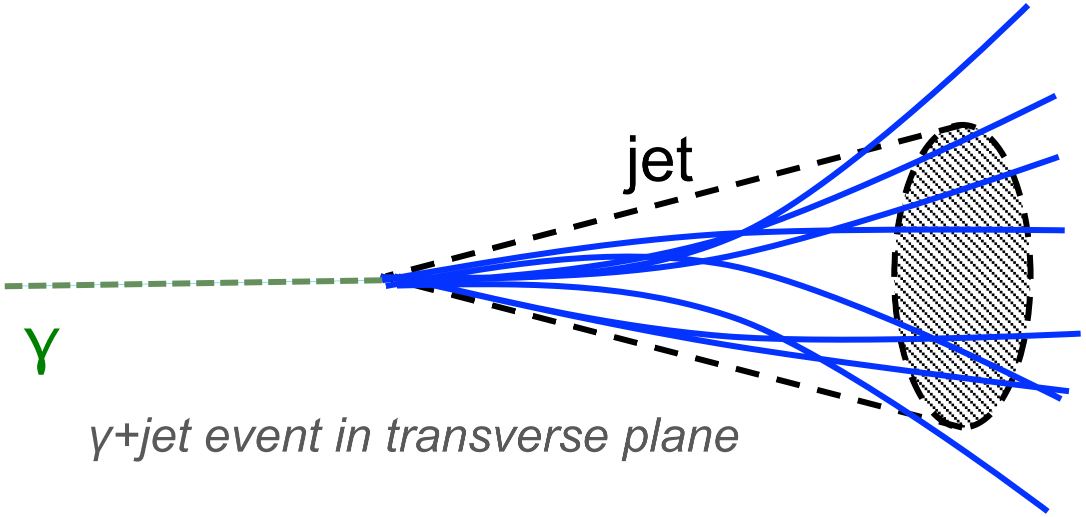


With the current world's best values for m_t and m_{Higgs}:
→ **Our Universe is only metastable!**

The calculation includes NNLO effects, RG equation at NNNLO

Jet energy scale (JES) calibration

- We **calibrate jet energies** at detector level to **particle level** (in data and MC)
- Calibration procedure in a nutshell:
  - Calibrate EM energy scale with $Z \rightarrow e^+e^-$
  - Correct energy scale for electrons to that of photons
  - Use **γ+jet events to calibrate major components of JES**
    - Expect momentum balance in transverse plane



γ+jet event in transverse plane

$$E^{\mathrm{ptcl}} = \frac{E^{\mathrm{meas}} - E_{\mathrm{O}}}{R \cdot S}$$

  - Use γ+jet and dijet events to extend calibration in p_T,η

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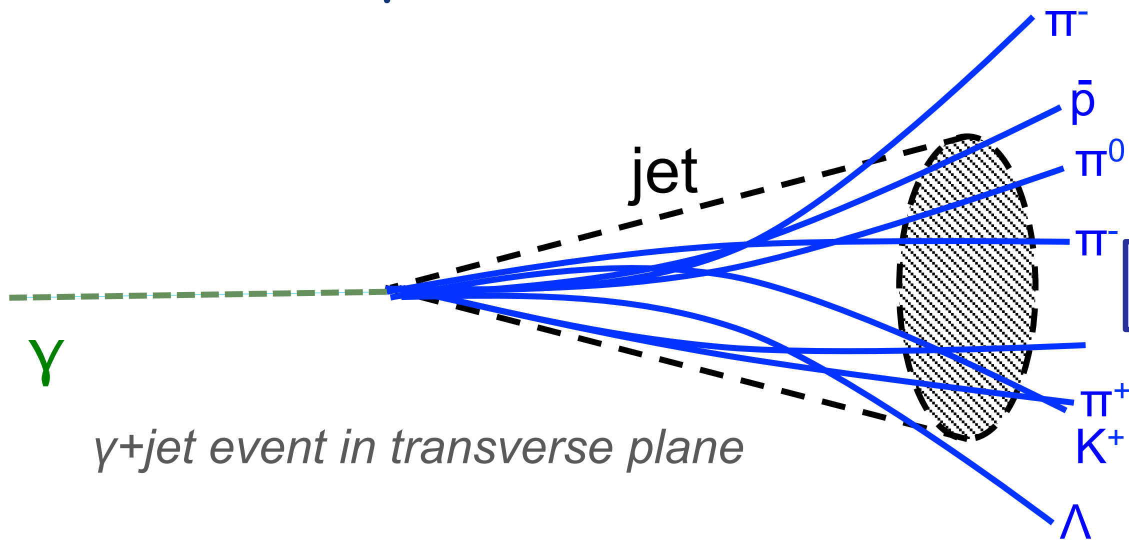

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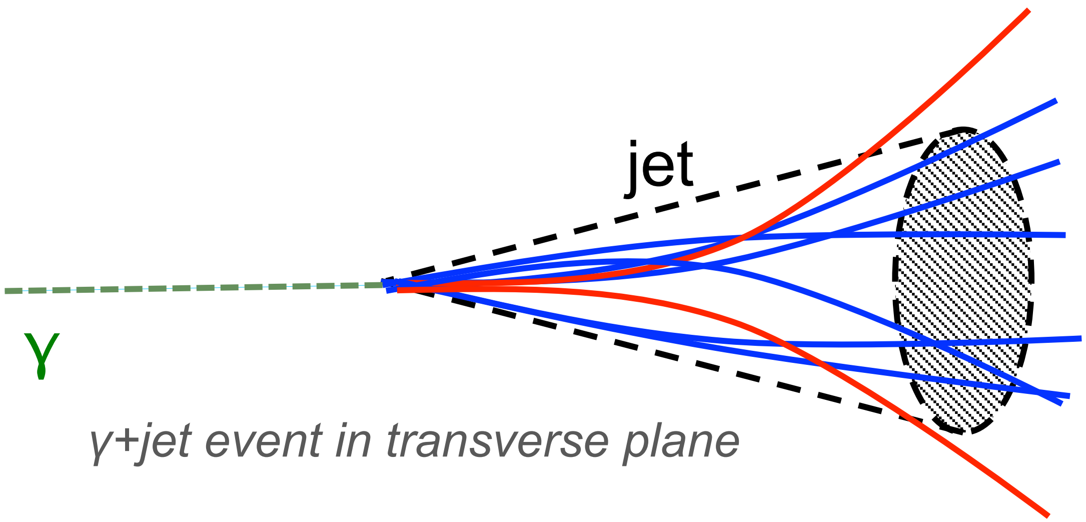


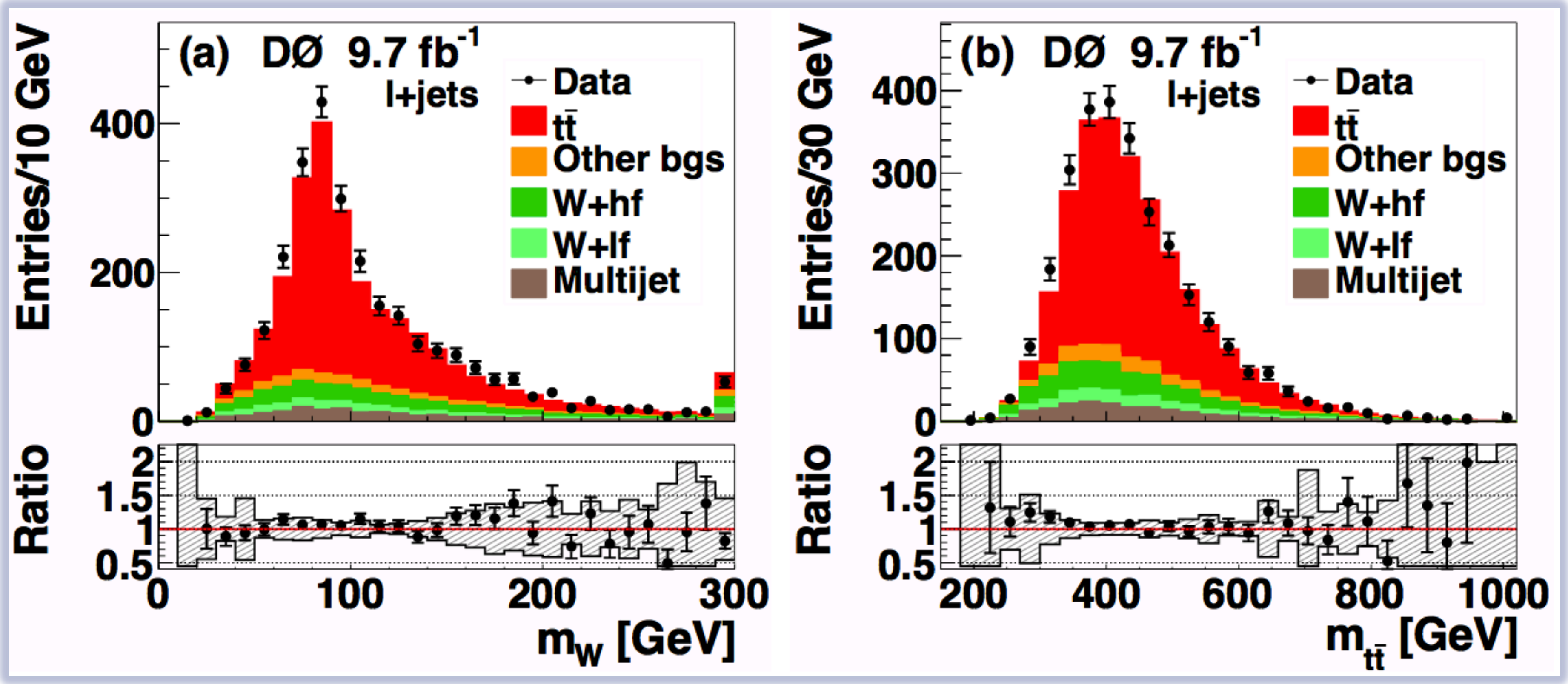
γ+jet event in transverse plane

$$E^{\text{ptcl}} = \frac{E^{\text{meas}} - E_{\text{O}}}{R \cdot S}$$

  - Use γ+jet and dijet events to extend calibration in p_T,η

Top quark mass (post-fit* plots)

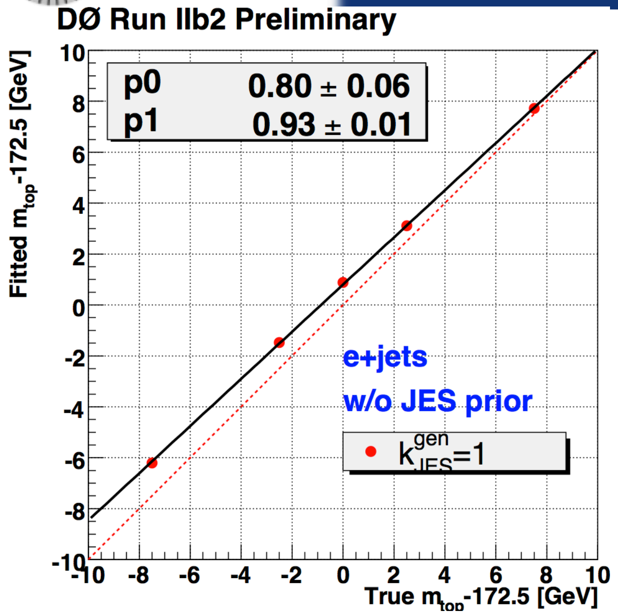
Selection similar to differential σ_{tt} measurement
→ main difference: require exactly 4 jets (LO)

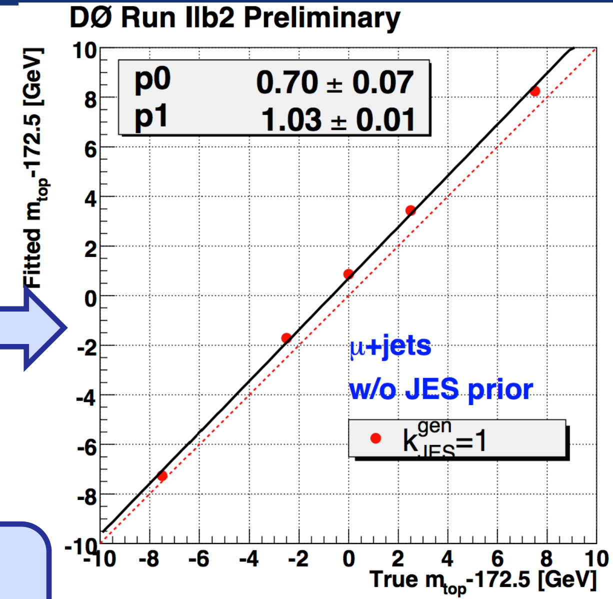


(More data/MC comparisons in backup)

** Measured σ_{tt}, m_t and overall jet energy scale factor are used*

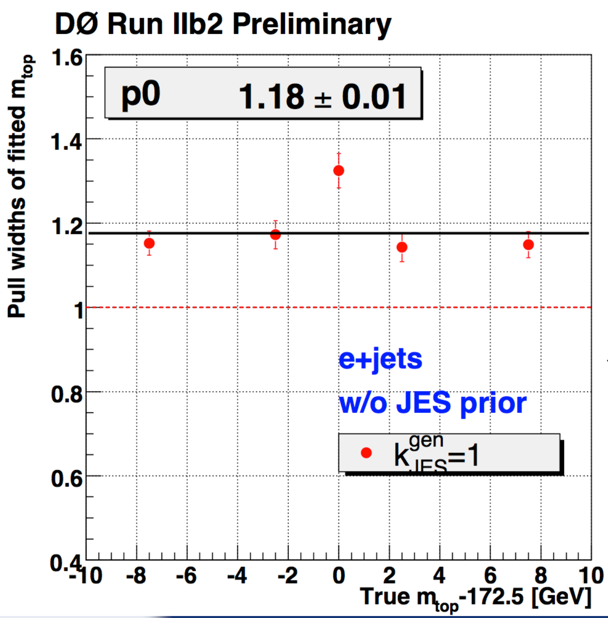
Calibration of method response in m_t

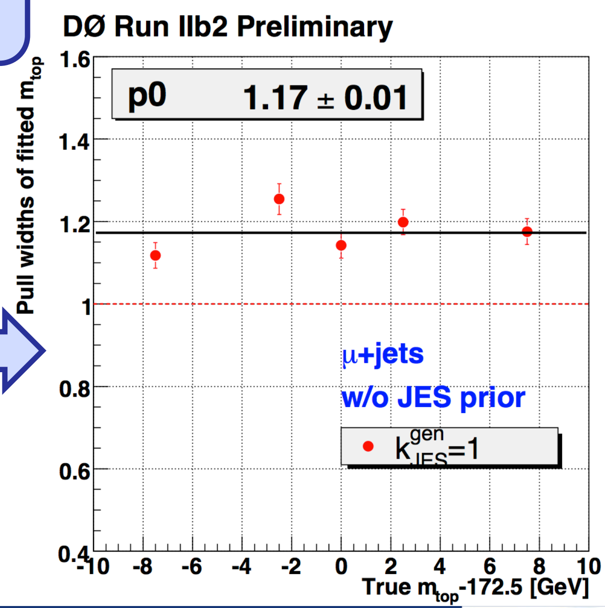




Calibrate m_t & $\sigma(m_t)$

Similar procedure for k_{JES} (not shown)





Calibrate $\sigma(m_t)$

DØ Coll., arXiv:1405.1756 [hep-ex], accepted by PRL

Representative MC simulations for Run IIb2 data

→ cf. backup for others

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Improvement from increased MC samples

- **Keep in mind that, for a given uncertainty, we cite:**
  - max{ statistical uncertainty, |face value of systematic| }

This measurement

Source of uncertainty	Effect on m_t (GeV)
Signal and background modeling:	
Higher order corrections*	0.15
Initial/final state radiation*	0.09
Hadronization & 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
Data-MC jet response difference	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	
Total statistical uncertainty	
Total uncertainty	

statistical component: 0.01 GeV

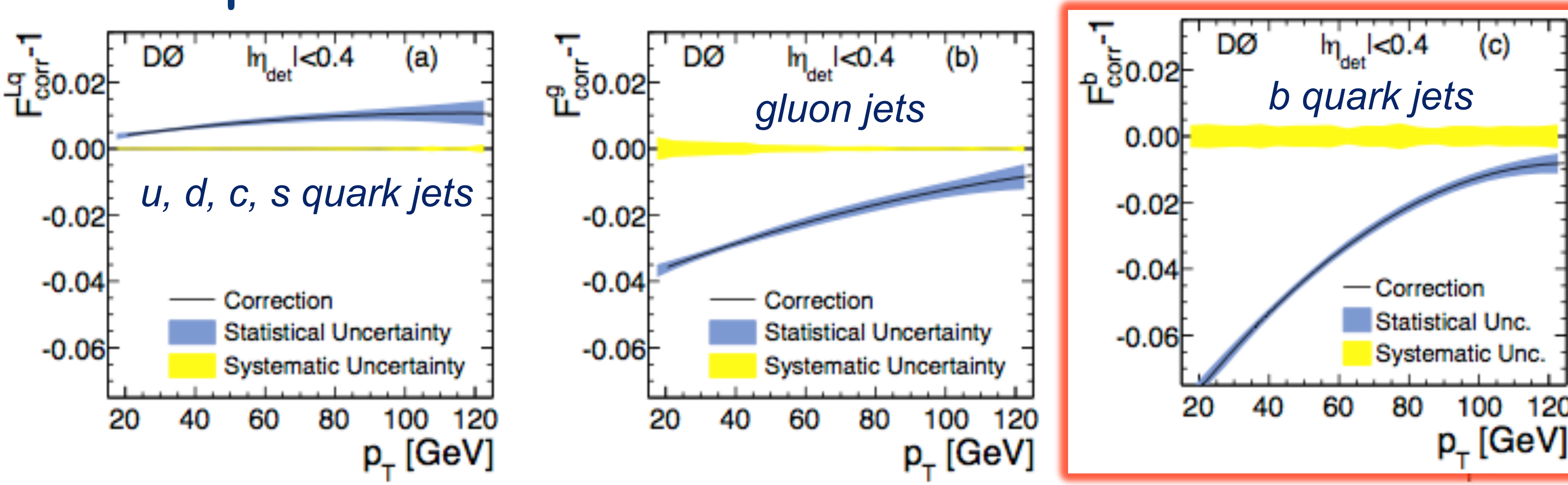
*Result using 3.6 fb^{-1}: DØ Coll., PRD **84**, 032004 (2011)*

Source	Uncertainty (GeV)
Modeling of production:	
Modeling of signal:	
Higher-order effects	±0.25
ISR/FSR	±0.26
Hadronization and UE	±0.58
Color reconnection	±0.28
Multiple $p\bar{p}$ interactions	±0.07
Modeling of background	±0.16
W+jets heavy-flavor scale factor	±0.07
Modeling of b jets	±0.09
Choice of PDF	±0.24
Modeling of detector:	
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 energy resolution	±0.32
Jet ID efficiency	±0.26
Method:	
Multijet contamination	±0.14
Signal fraction	±0.10
MC calibration	±0.20
Total	±1.02

stat. component: ≈1/4 GeV

Improvement from new calibrations

- **Use new JES calibration including flavour-dependent response correction:**

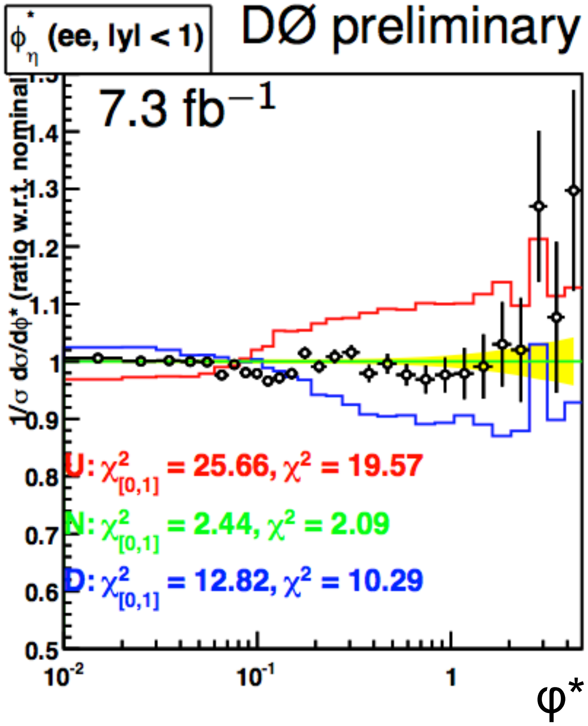


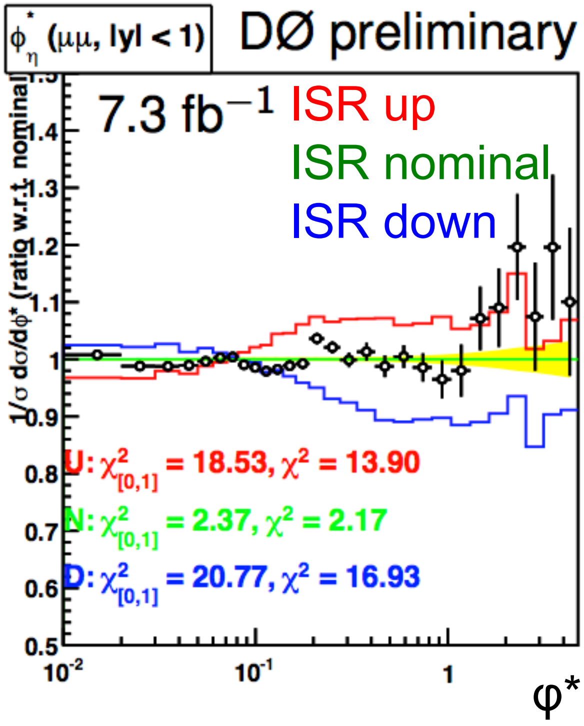
  - → **Uncertainty from flavor-dependent response:**
    - **0.16 GeV (was 0.28 GeV)**
  - **This uncertainty accounts for JES difference between light quark jets and b quark jets**

$$F_{\mathrm{corr}} = \frac{1}{\langle F \rangle_{\gamma+\mathrm{jet}}} \cdot \frac{\sum_i E_i \cdot R_i^{\mathrm{data}}}{\sum_i E_i \cdot R_i^{\mathrm{MC}}}$$

Improvement from $t\bar{t}$ modeling (ISR/FSR)

- Constrain ISR/FSR by studying Drell-Yan events
  - Measurement of $p_T(Z)$ using φ* variable [1]
- Vary ISR/FSR via CKKW renormalization scale in alpgen (ktfac), as suggested in [2]
  - ktfac variations by ±1.5 cover excursions of MC from data





Also tune in other kinematic regions:
- 1<|y|<2
- |y|>2

(cf. backup)

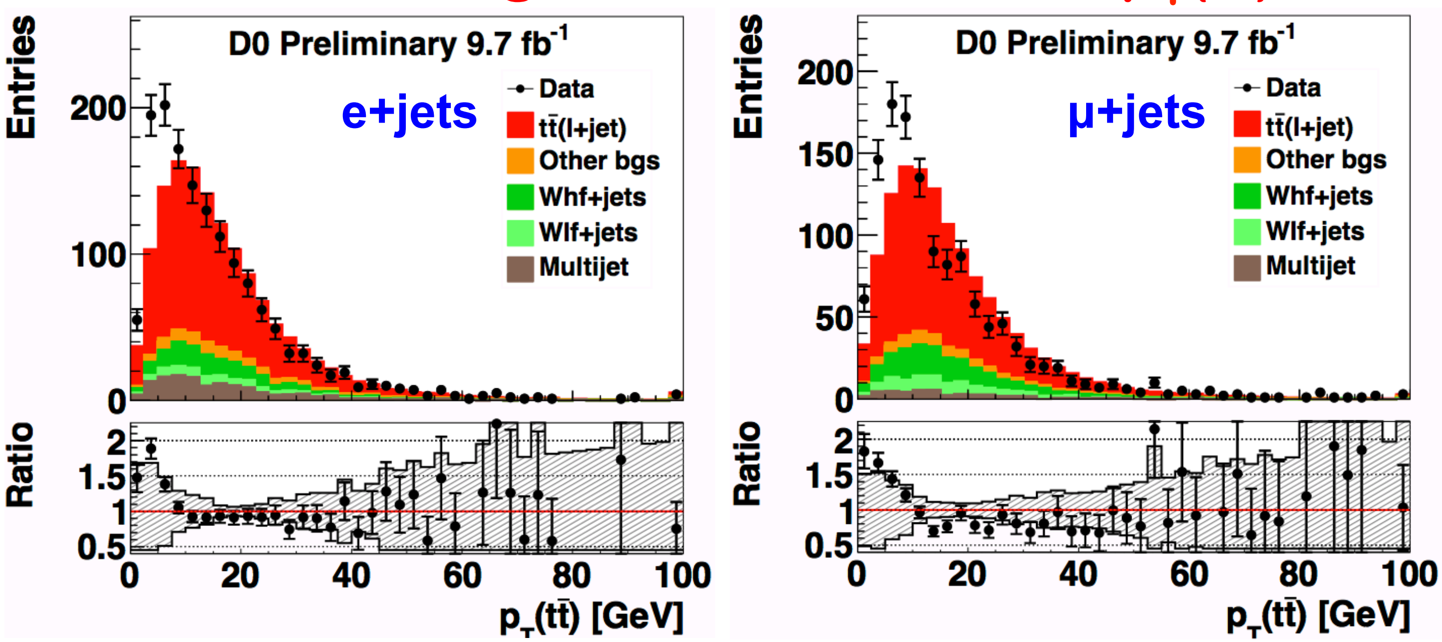
[1] DØ Coll., PRL **106**, 122001 (2011)
[2] M. Mangano, P. Skands et al, EPJ **C72** 2078 (2012)

Improvement from $t\bar{t}$ modeling (ISR/FSR)

- Constrain ISR/FSR by studying Drell-Yan events
  - Measurement of $p_T(Z)$ using φ^* variable [1]
  - Vary ISR/FSR via CKKW renormalization scale in alpgen (ktfac), as suggested in [2]
    - ktfac variations by ±1.5 cover excursions of MC

0.06 GeV

- In addition: reweight $t\bar{t}$ simulations in $p_T(t\bar{t})$ to data



  - Effect may be related to ISR/FSR mismodelling

0.07 GeV

Total: 0.09 GeV (was: 0.26 GeV)

Improvement f. $t\bar{t}$ modeling (hadronisation)

- Factor out the component from different JES
  - Evaluate using the momenta of particle level jets matched to detector level jets with $\Delta R=0.25$
  - Apply default selection at detector level
    - → minimize bias from acceptance etc.
- We also factor out the effect of different $p_T(t\bar{t})$ in:
    - Default (alpgen+pythia)
    - Alternative model (alpgen+herwig)
  - Achieved by reweighting default simulation in $p_T(t\bar{t})$ to match the alternative model
  - This effect is already taken into account in ISR/FSR uncertainty
- → Hadronization and underlying event uncertainty:
  - 0.26 GeV (was: 0.58 GeV)

Top quark mass: Tevatron combination

- Current World average:

$$m_t = 173.34 \pm 0.76\,\text{GeV}$$

arXiv:1403.4427 [hep-ex]

- Assuming no statistical correlation between this result and the combination
  - Taking full uncertainty for the Tevatron average
  - Taking statistical uncertainty only for this measurement
  - Consistency at 1.71 SD level (p-value of 3.1%)

Top quark mass: Tevatron combination

	Run I published					Run II published					Run II prel.	
	CDF			DØ		CDF			DØ		CDF	
	ℓ+jets	$\ell\ell$	all-jets	ℓ+jets	$\ell\ell$	ℓ+jets	Lxy	MEt	ℓ+jets	$\ell\ell$	$\ell\ell$	all-jets
$\int \mathcal{L}\, dt$	0.1	0.1	0.1	0.1	0.1	8.7	1.9	8.7	9.7	5.4	9.1	9.3
Result	176.1	167.4	186.0	180.1	168.4	172.85	166.90	173.93	174.98	174.00	170.80	175.07
In situ light-jet calibration (iJES)	n/a	n/a	n/a	n/a	n/a	0.49	n/a	1.05	0.41	0.55	n/a	0.97
Response to $b/q/g$ jets (aJES)	n/a	n/a	n/a	0.0	0.0	0.09	0.00	0.10	0.16	0.40	0.18	0.02
Model for b jets (bJES)	0.6	0.8	0.6	0.7	0.7	0.16	0.00	0.17	0.09	0.20	0.28	0.20
Out-of-cone correction (cJES)	2.7	2.6	3.0	2.0	2.0	0.21	0.36	0.18	n/a	n/a	1.65	0.37
Light-jet response (1) (rJES)	3.4	2.7	4.0	n/a	n/a	0.48	0.24	0.40	n/a	n/a	1.72	0.42
Light-jet response (2) (dJES)	0.7	0.6	0.3	2.5	1.1	0.07	0.06	0.04	0.21	0.56	0.46	0.09
Lepton modeling (LepPt)	n/e	n/e	n/e	n/e	n/e	0.03	0.00	n/a	0.01	0.35	0.36	n/a
Signal modeling (Signal)	2.6	2.9	2.0	1.1	1.8	0.61	0.90	0.63	0.35	0.86	0.96	0.53
Jet modeling (DetMod)	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.07	0.50	0.00	0.00
b-tag modeling (b-tag)	0.4	0.0	0.0	0.0	0.0	0.03	0.00	0.03	0.10	0.00	0.05	0.04
Background from theory (BGMC)	1.3	0.3	0.0	1.0	1.1	0.12	0.80	0.00	0.06	0.00	0.30	0.00
Background based on data (BGData)	0.0	0.0	1.7	0.0	0.0	0.16	0.20	0.15	0.09	0.20	0.33	0.15
Calibration method (Method)	0.0	0.7	0.6	0.6	1.1	0.05	2.50	0.21	0.07	0.51	0.19	0.87
Offset (UN/MI)	n/a	n/a	n/a	1.3	1.3	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Multiple interactions model (MHI)	n/e	n/e	n/e	n/e	n/e	0.07	0.00	0.18	0.06	0.00	0.30	0.22
Systematic uncertainty (syst)	5.3	4.9	5.7	3.9	3.6	0.98	2.82	1.36	0.63	1.49	2.69	1.55
Statistical uncertainty (stat)	5.1	10.3	10.0	3.6	12.3	0.52	9.00	1.26	0.41	2.36	1.83	1.19
Total uncertainty	7.3	11.4	11.5	5.3	12.8	1.12	9.43	1.85	0.76	2.80	3.26	1.95

Top quark mass: Tevatron combination

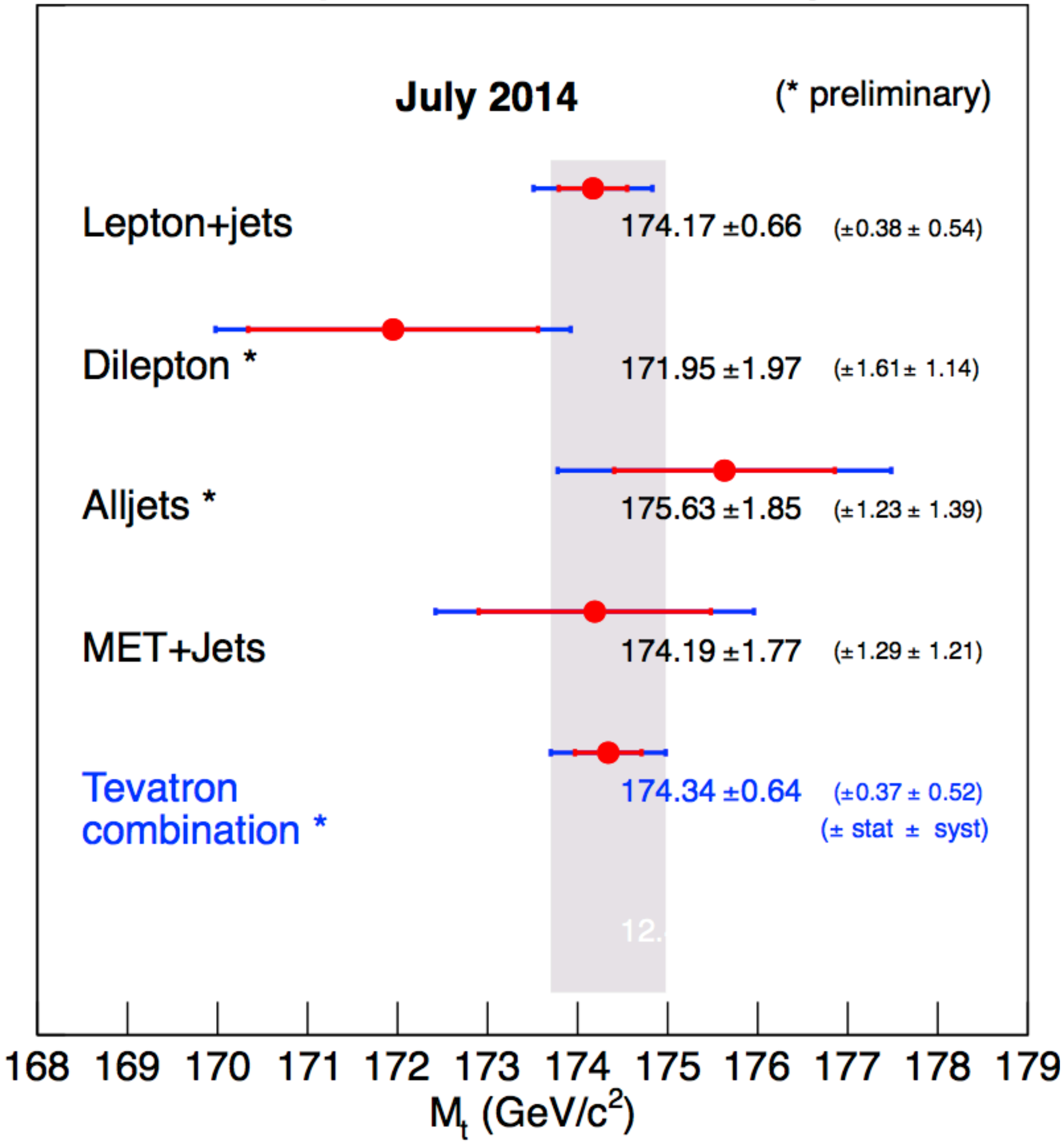
	Run I published					Run II published					Run II prel.	
	CDF			DØ		CDF			DØ		CDF	
	ℓ+jets	$\ell\ell$	all-jets	ℓ+jets	$\ell\ell$	ℓ+jets	L_{XY}	MEt	ℓ+jets	$\ell\ell$	$\ell\ell$	all-jets
CDF-I ℓ+jets	1.00	0.29	0.32	0.26	0.11	0.49	0.07	0.26	0.19	0.12	0.54	0.27
CDF-I $\ell\ell$	0.29	1.00	0.19	0.15	0.08	0.29	0.04	0.16	0.12	0.08	0.32	0.17
CDF-I all-jets	0.32	0.19	1.00	0.14	0.07	0.30	0.04	0.16	0.08	0.06	0.37	0.18
DØ-I ℓ+jets	0.26	0.15	0.14	1.00	0.16	0.22	0.05	0.12	0.13	0.07	0.26	0.14
DØ-I $\ell\ell$	0.11	0.08	0.07	0.16	1.00	0.11	0.02	0.07	0.07	0.05	0.13	0.07
CDF-II ℓ+jets	0.49	0.29	0.30	0.22	0.11	1.00	0.08	0.32	0.28	0.18	0.52	0.30
CDF-II L_{XY}	0.07	0.04	0.04	0.05	0.02	0.08	1.00	0.04	0.05	0.03	0.06	0.04
CDF-II MEt	0.26	0.16	0.16	0.12	0.07	0.32	0.04	1.00	0.17	0.11	0.29	0.18
DØ-II ℓ+jets	0.19	0.12	0.08	0.13	0.07	0.28	0.05	0.17	1.00	0.36	0.15	0.14
DØ-II $\ell\ell$	0.12	0.08	0.06	0.07	0.05	0.18	0.03	0.11	0.36	1.00	0.10	0.09
CDF-II $\ell\ell$	0.54	0.32	0.37	0.26	0.13	0.52	0.06	0.29	0.15	0.10	1.00	0.32
CDF-II all-jets	0.27	0.17	0.18	0.14	0.07	0.30	0.04	0.18	0.14	0.09	0.32	1.00

	Run I published					Run II published					Run II prel.	
	CDF			DØ		CDF			DØ		CDF	
	ℓ+jets	$\ell\ell$	all-jets	ℓ+jets	$\ell\ell$	ℓ+jets	L_{XY}	MEt	ℓ+jets	$\ell\ell$	$\ell\ell$	all-jets
Pull	0.24	−0.61	+1.01	+1.09	−0.46	−1.64	−0.791	−0.24	+1.60	−0.13	−1.11	0.39
Weight [%]	−2.6	−0.7	−0.4	−0.1	−0.14	+28.8	+0.1	+5.5	+67.2	−2.9	−0.66	+6.0

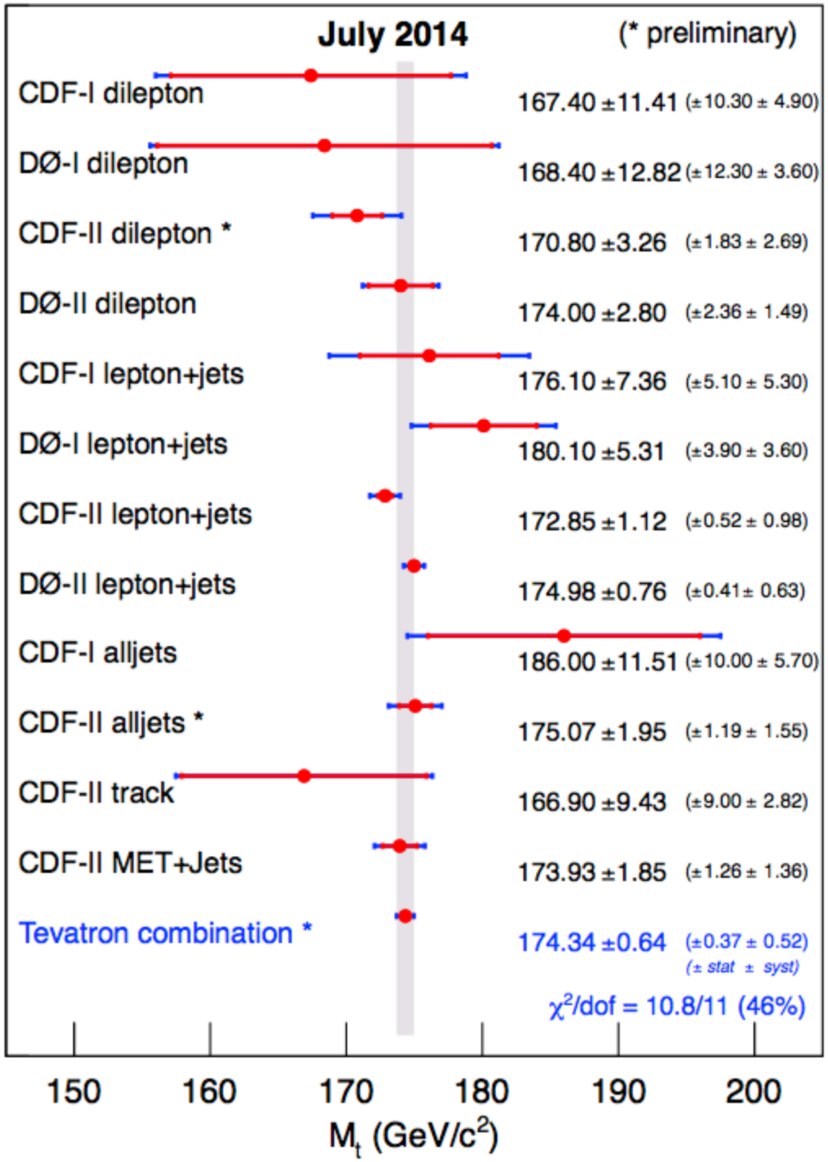
Parameter	Value (GeV/c^2)	Correlations			
		$M_t^{\text{all-jets}}$	$M_t^{\ell+\text{jets}}$	$M_t^{\ell\ell}$	M_t^{MEt}
$M_t^{\text{all-jets}}$	175.63 ± 1.85	1.00			
$M_t^{\ell+\text{jets}}$	174.17 ± 0.66	0.21	1.00		
$M_t^{\ell\ell}$	171.95 ± 1.97	0.21	0.41	1.00	
M_t^{MEt}	174.19 ± 1.77	0.11	0.23	0.18	1.00

Top quark mass: Tevatron combination

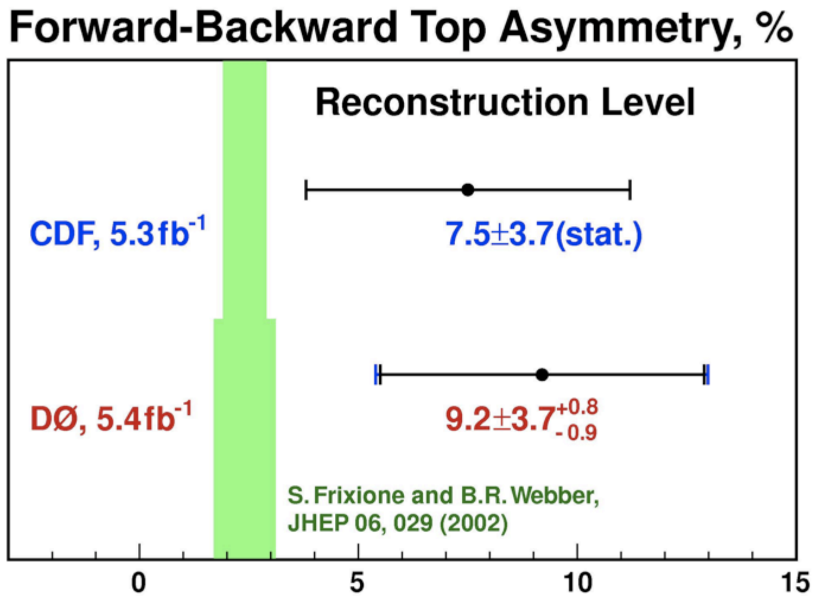
Mass of the Top Quark in Different Decay Channels

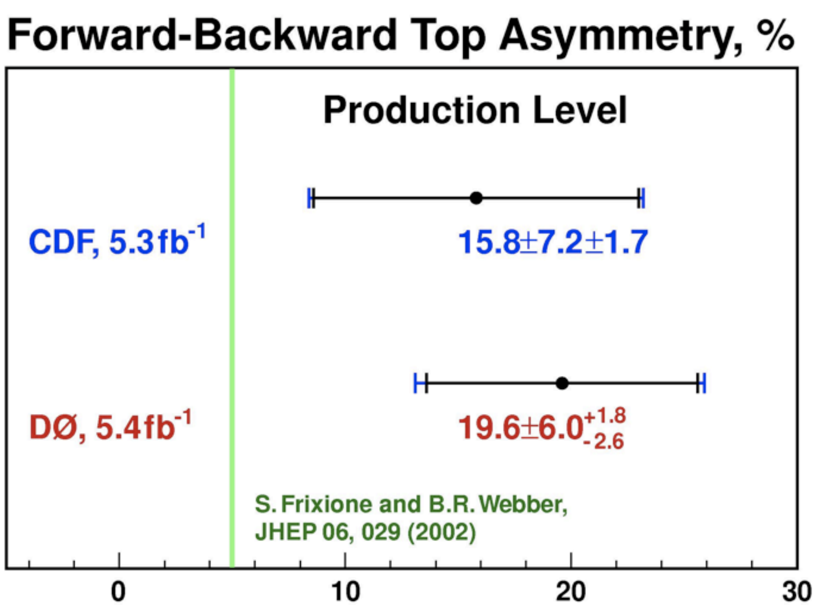


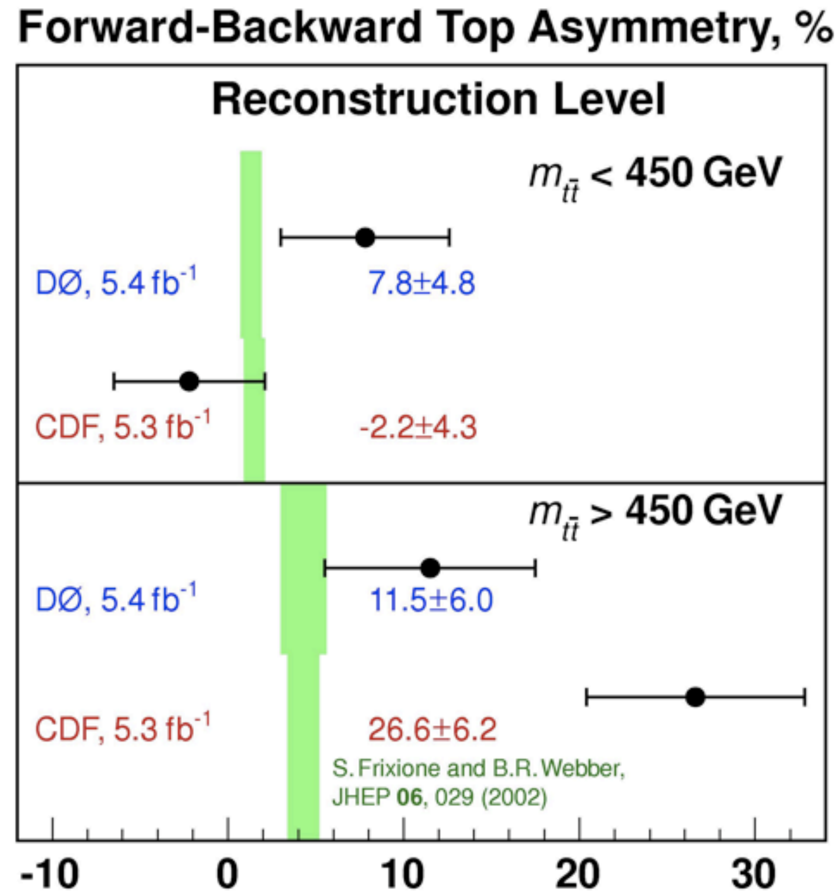
Mass of the Top Quark



Colour Charge Asymmetry (A_{FB})



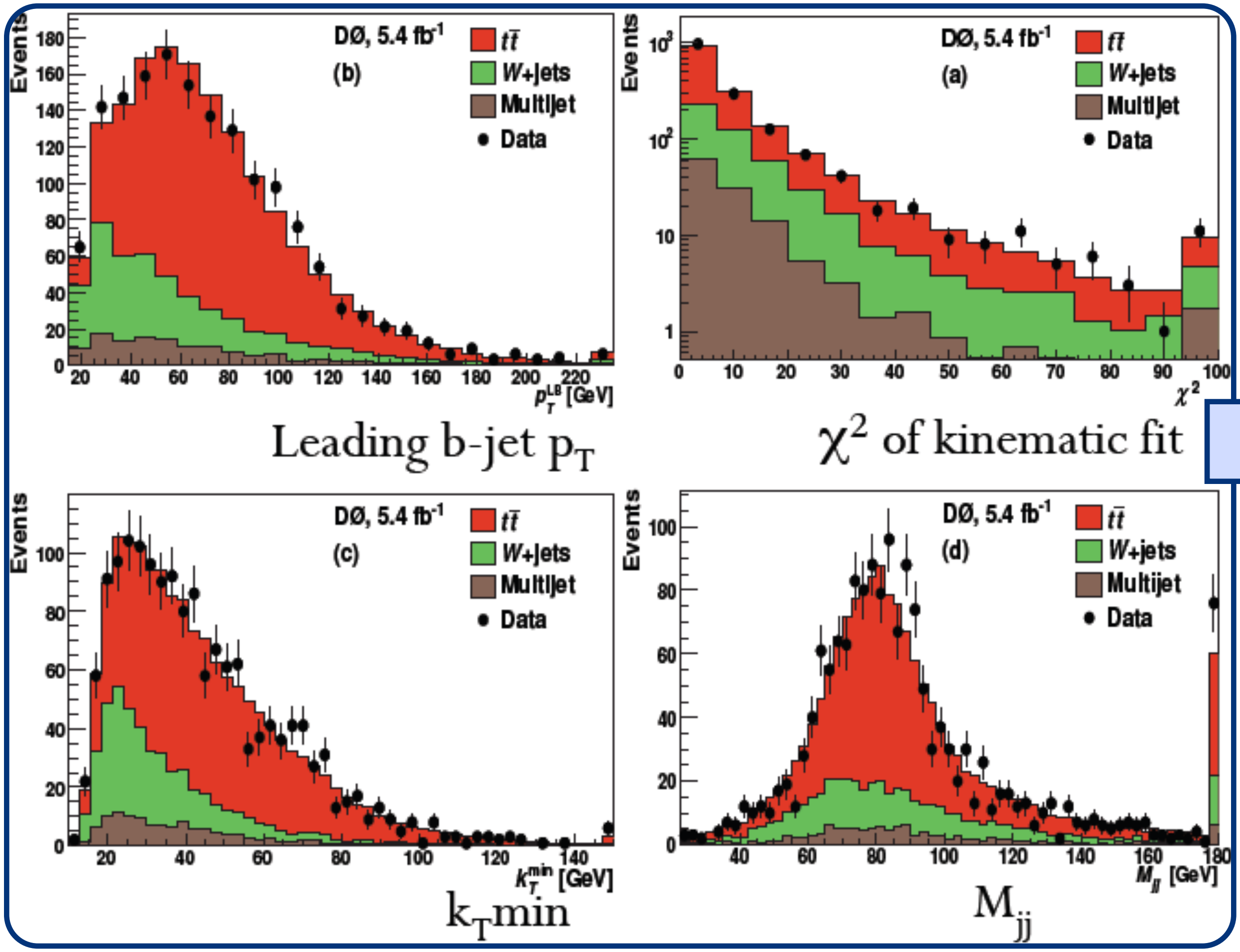


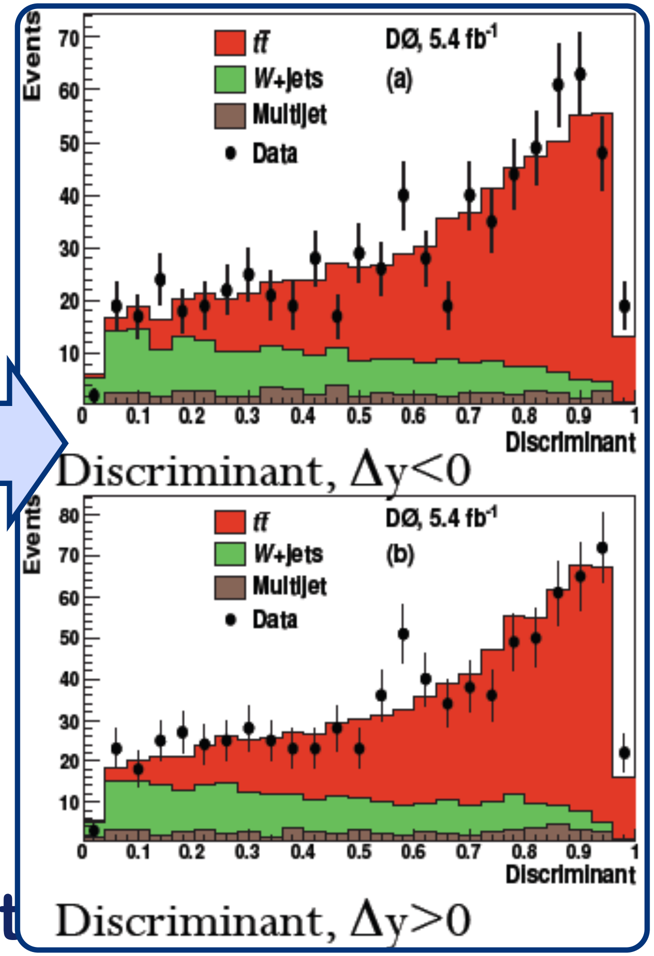


There is a new measurement of A_{FB} by CDF (arXiv:1211.1003, 9.3 fb^{-1})
→ comparison plots are not available yet

Strong charge asymmetry (D0)

- **Strong Colour charge asymmetry (D0, 5.4 fb^{-1})**





$$\underbrace{\Delta y>0}\qquad \underbrace{\Delta y<0}$$

$$A = (9.2 \pm 3.6^{+0.8}_{-0.9})\% \Leftrightarrow A(MC@NLO) = (2.4 \pm 0.3^{+0.7}_{-0.5})\%$$

	$l+\geq4$ jets	$e+\geq4$ jets	$\mu+\geq4$ jets	$l+4$ jets	$l+\geq5$ jets
Raw N_{F}	849	455	394	717	132
Raw N_{B}	732	397	335	597	135
$N_{t\bar{t}}$	1126 ± 39	622 ± 28	502 ± 28	902 ± 36	218 ± 16
$N_{W+\mathrm{jets}}$	376 ± 39	173 ± 28	219 ± 27	346 ± 36	35 ± 16
N_{MJ}	79 ± 5	56 ± 3	8 ± 2	66 ± 4	13 ± 2
$A_{\mathrm{FB}}(\%)$	9.2 ± 3.7	8.9 ± 5.0	9.1 ± 5.8	12.2 ± 4.3	-3.0 ± 7.9
MC@NLO A_{FB} (%)	2.4 ± 0.7	2.4 ± 0.7	2.5 ± 0.9	3.9 ± 0.8	-2.9 ± 1.1

	$l+\geq4$ jets	$e+\geq4$ jets	$\mu+\geq4$ jets	$l+4$ jets	$l+\geq5$ jets
Raw N^{l}_{F}	867	485	382	730	137
Raw N^{l}_{B}	665	367	298	546	119
$N_{t\bar{t}}$	1096 ± 39	622 ± 28	474 ± 27	881 ± 36	211 ± 16
$N_{W+\mathrm{jets}}$	356 ± 39	173 ± 28	198 ± 27	323 ± 36	31 ± 16
N_{MJ}	79 ± 5	56 ± 3	8 ± 2	66 ± 4	14 ± 2
A^{l}_{FB} (%)	14.2 ± 3.8	16.5 ± 4.9	9.8 ± 5.9	15.9 ± 4.3	7.0 ± 8.0
MC@NLO A^{l}_{FB} (%)	0.8 ± 0.6	0.7 ± 0.6	1.0 ± 0.8	2.1 ± 0.6	-3.8 ± 1.2

- **Colour charge asymmetry in $\ell\ell$ channel, D0 (5.4 fb^{-1})**
  - Use lepton-based observables:
    - Experimentally more robust
    - No full kinematic reconstruction of $t\bar{t}$ system necessary
  - "Classical" forward-backward asymmetry:

$$A^{\ell}_{\mathrm{FB}} = \frac{N_\ell(Q\cdot\eta > 0) - N_\ell(Q\cdot\eta < 0)}{N_\ell(Q\cdot\eta > 0) + N_\ell(Q\cdot\eta < 0)}$$

  - Longitudinal asymmetry in spin orientation relative to proton beam direction:

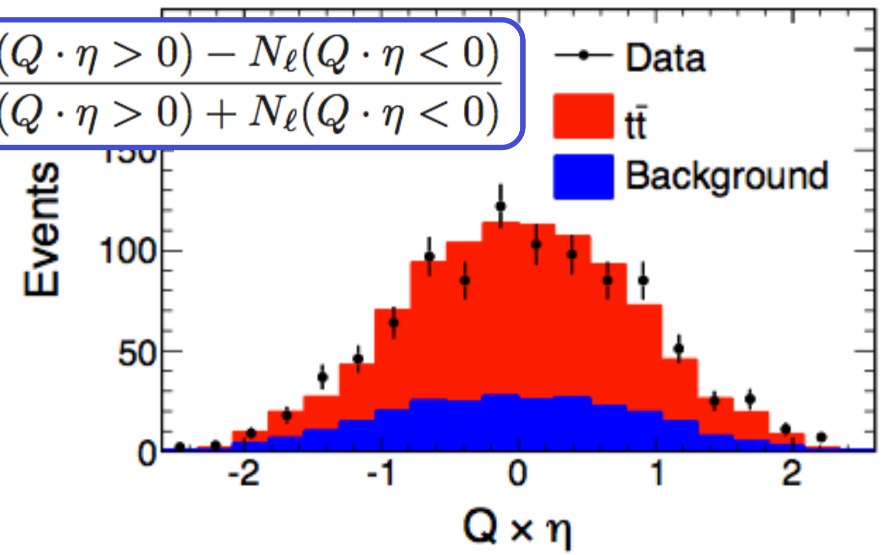
$$A^{\ell}_{\mathrm{CP}} = \frac{N_{\ell^+}(\eta > 0) - N_{\ell^-}(\eta < 0)}{N_{\ell^+}(\eta > 0) + N_{\ell^-}(\eta < 0)}$$

    - Sensitive to *s*-channel exchanges of heavy non-scalar resonances with *CP*-violating couplings to quarks
    - Not sensitive to possible *P* and *CP*-violating effects from an *s*-channel exchange of Higgs bosons

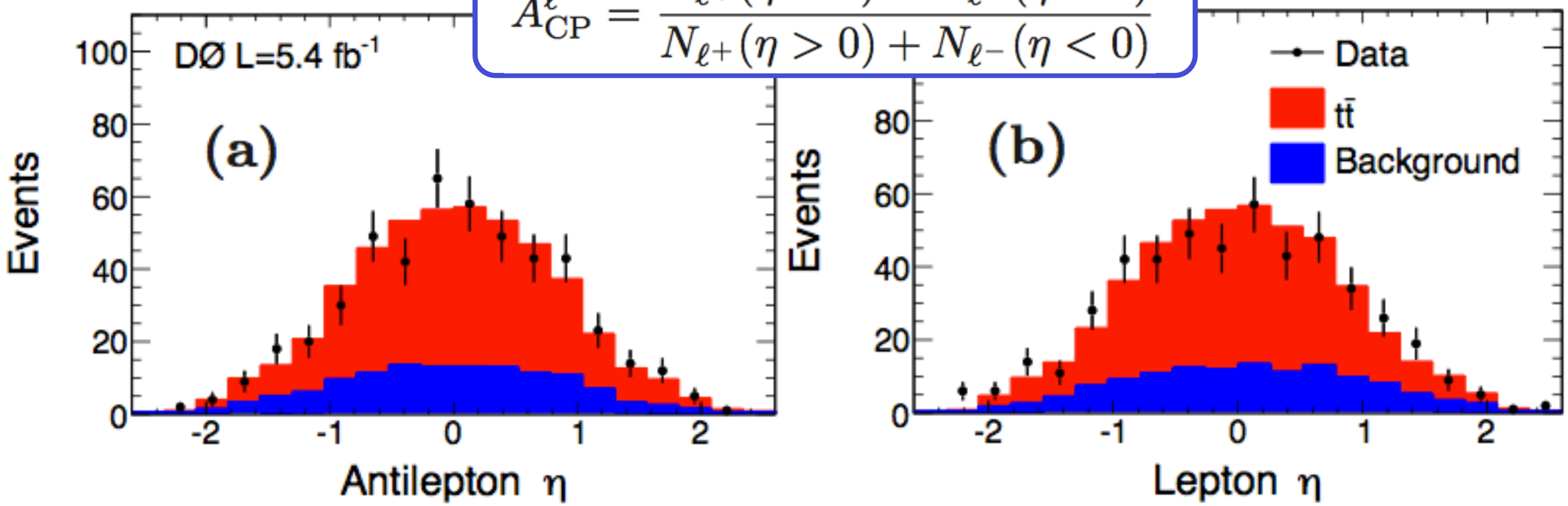
arXiv:1207.0364 [hep-ex] (2012)

Colour charge asymmetry, $\mathcal{U}$

$$A^{\ell}_{\mathrm{FB}} = \frac{N_\ell(Q\cdot\eta > 0) - N_\ell(Q\cdot\eta < 0)}{N_\ell(Q\cdot\eta > 0) + N_\ell(Q\cdot\eta < 0)}$$



$$A^{\ell}_{\mathrm{CP}} = \frac{N_{\ell+}(\eta > 0) - N_{\ell-}(\eta < 0)}{N_{\ell+}(\eta > 0) + N_{\ell-}(\eta < 0)}$$



arXiv:1207.0364 [hep-ex] (2012)

- **Final results:**

Predictions at NLO in pQCD + EW corrections:
*Bernreuter and Si, Nucl. Phys. B **837**, 90 (2010)*

	Raw	Unfolded	Predicted
A^{ℓ}_{FB}	$3.1 \pm 4.3 \pm 0.8$	$5.8 \pm 5.1 \pm 1.3$	4.7 ± 0.1
A^{ℓ}_{CP}	$1.8 \pm 4.3 \pm 1.0$	$-1.8 \pm 5.1 \pm 1.6$	-0.3 ± 0.1

- **Combine with the l+jets channel:**

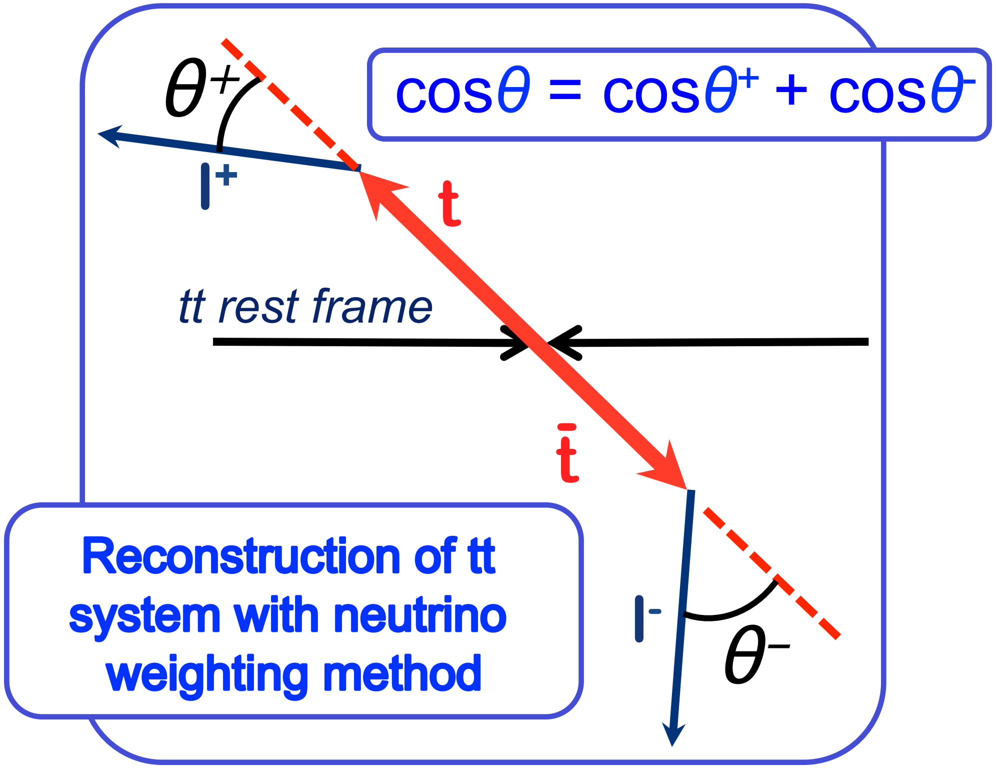
$$A^{\ell}_{\mathrm{FB}} = (11.8 \pm 3.2)\%$$
$$A^{\ell}_{\mathrm{FB}}(\text{predicted}) = (4.7 \pm 0.1)\%$$

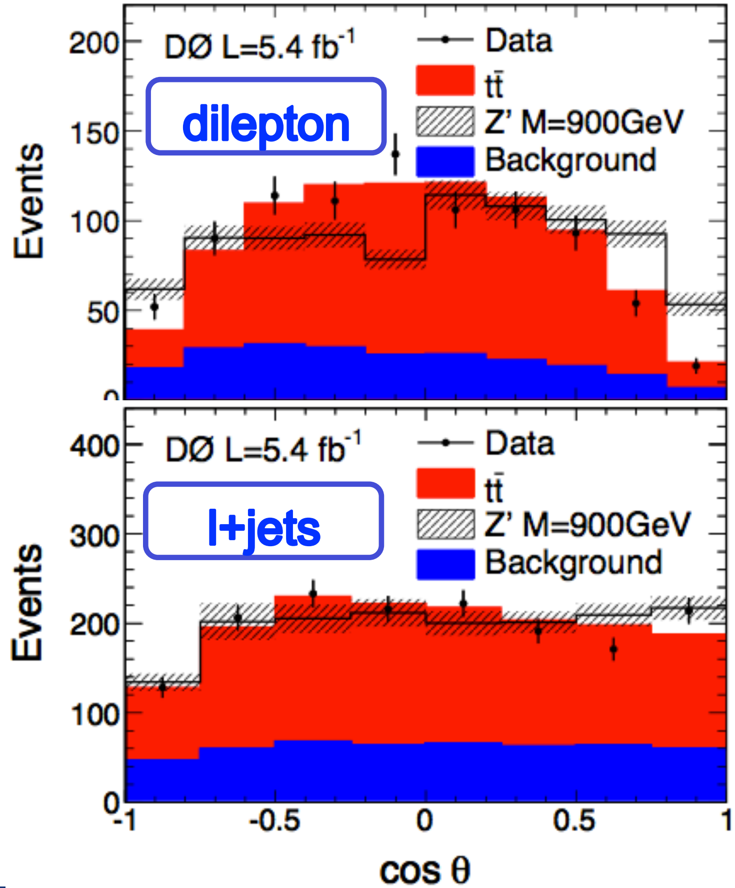
Predictions in l+jets updated to include EW corrections

  - **Relative contributions: 64% / 36% for l+jets / dilepton**
  - **Consistency: 68%**
  - **Disagreement with prediction: 2.2 SD**

arXiv:1207.0364 [hep-ex] (2012)

- **Study of the longitudinal polarisation of top quark:**
  - In the SM, top quarks unpolarised in $t\bar{t}$ events
  - Many BSM models with enhanced A_{FB} also predict non-vanishing longitudinal polarisation of the top





arXiv:1207.0364 [hep-ex] (2012)

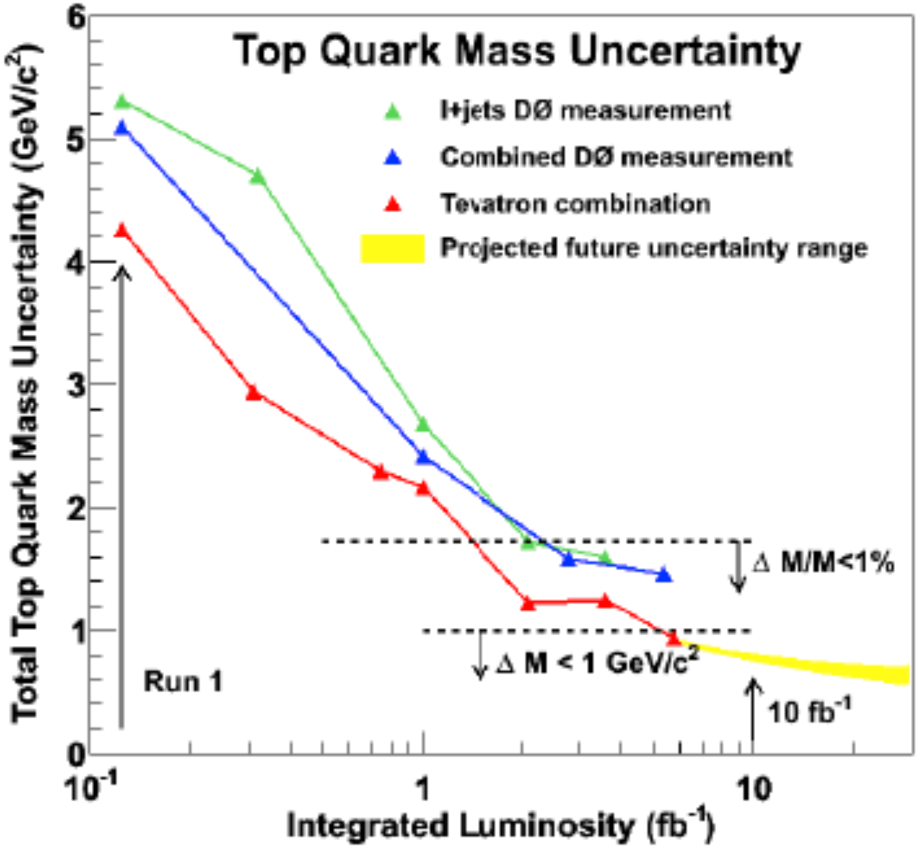
Tevatron Combination

	Tevatron combined values (GeV/c^2)
m_t	173.18
iJES	**0.39**
aJES	0.09
bJES	0.15
cJES	0.05
dJES	**0.20**
rJES	0.12
Lepton p_T	0.10
Signal	**0.51**
Detector Modeling	0.10
UN/MI	0.00
Background from MC	0.14
Background from Data	0.11
Method	0.09
MHI	0.08
Systematics	0.75
Statistics	0.56
Total	0.94

In-situ JES calibration ~ 1/√N (iJES)

Size of calibration samples ~ 1/√N (dJES)

Various signal modeling uncert. ~ √brain effort (Signal)



Relative uncertainty: 0.54%
Expect this limit to be improved…

Indirect measurement of Γ_{top}

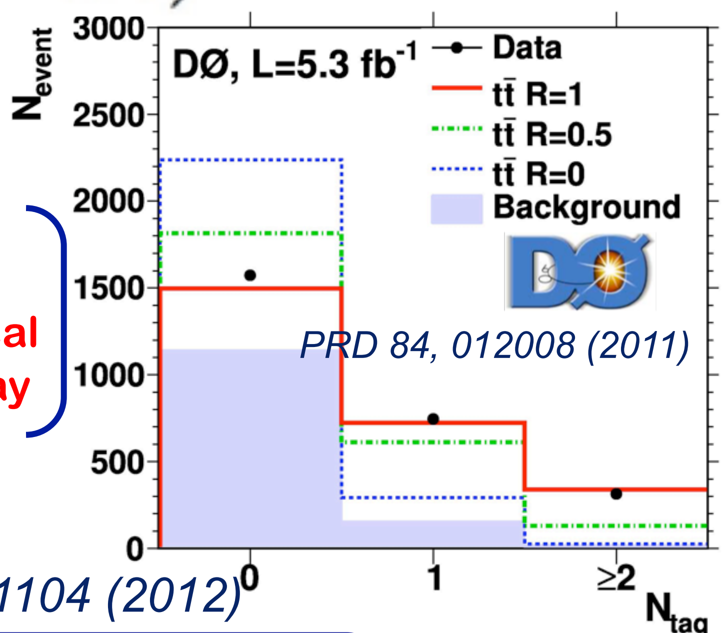
$$\Gamma_t = \frac{\Gamma(t \to Wb)}{\mathcal{B}(t \to Wb)}$$

$\Gamma(t \to Wb)$ ⟵ $\Gamma(t \to Wb) = \sigma(t\text{–channel}) \dfrac{\Gamma(t \to Wb)_{SM}}{\sigma(t\text{–channel})_{SM}}$

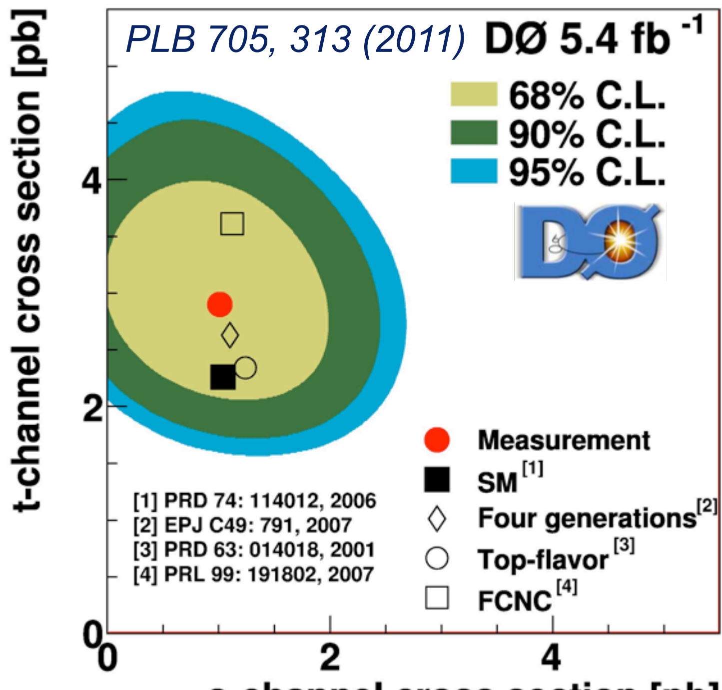
$\mathcal{B}(t \to Wb)$ ⟵ measured in $t\bar{t}$ events

Assume:

Wtb coupling identical in production & decay



Phys. Rev. D **85**, 091104 (2012)

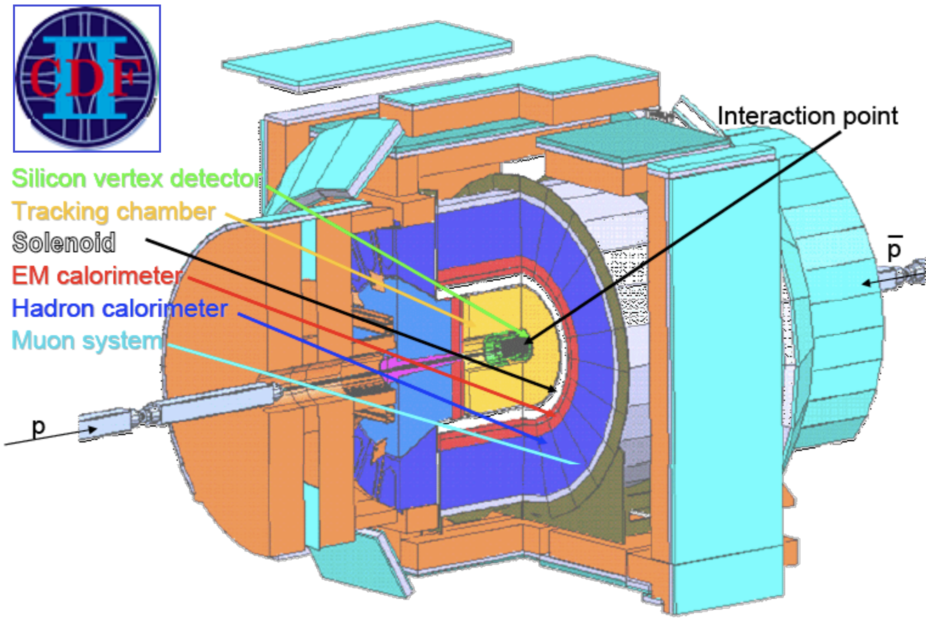


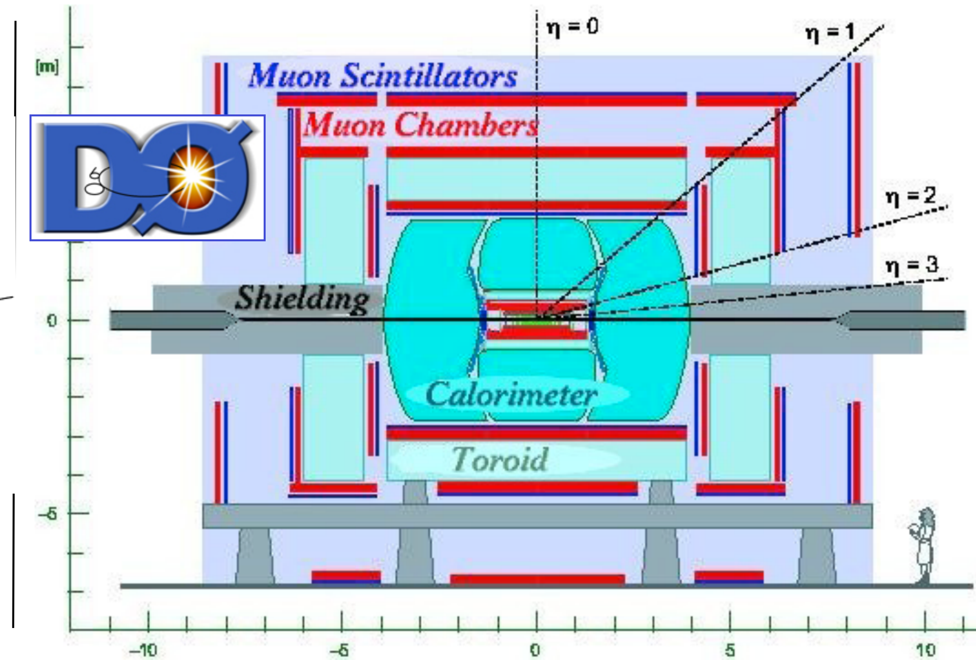
World's most precise (indirect) determination of Γ_t to date

$$\Gamma_t = 2.00^{+0.47}_{-0.43} \text{ GeV}$$
$$\tau_t = (3.29^{+0.90}_{-0.63}) \times 10^{-25} \text{ s}$$

Properly correlate $\sigma(t\text{–channel})$, $\mathcal{B}(t \to Wb)$ → measure Γ_t from LH based on *t*-channel discriminant

The CDF and D0 detectors

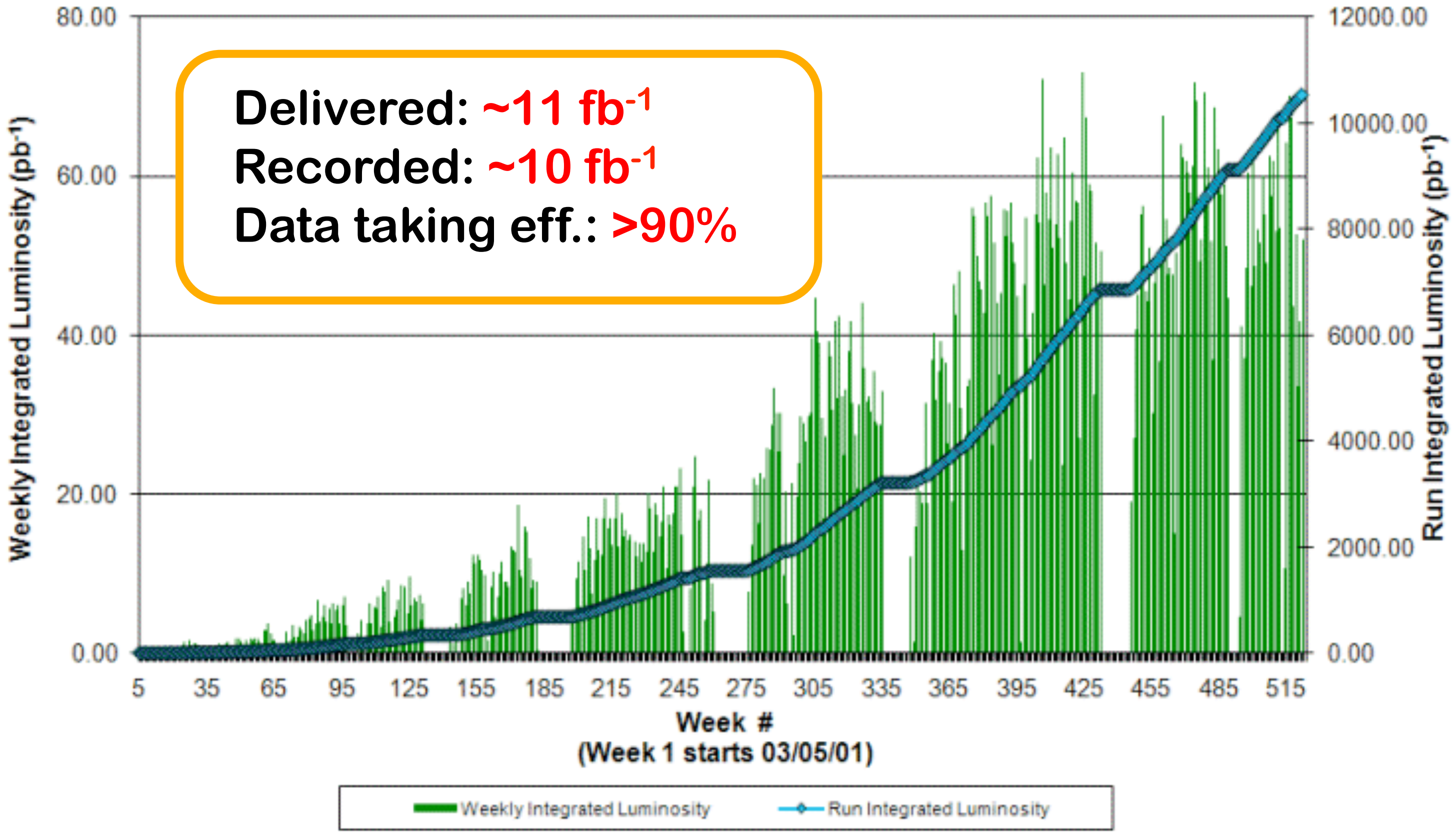




	CDF	DØ
EM calorimeter	14%/√E + 1%	22%/√E + 4%
Hadronic calorimeter	70%/√E + 5%	68%/√E + 5%

Analyzed dataset

- Tevatron has shown a great performance in FY 2010!
- We keep enlarging our calibration samples
  - Better handles on experimental uncertainties:
    - e.g. Jet Energy Scale (JES), Jet Energy Resolution, etc.



Experimental Challenges

- We are interested in parton-level quantities for our top measurements
  - Map the energies of reco-level jets particle jets (D0) / partons (CDF)
  - This is referred to as a Energy Scale (JES) corr'n
  - With the current size of samples:
    - s(JES)/JES ~ 1.5% (D0)
    - s(JES)/JES ~ 3% (CDF)
- And many more:
  - Lepton ID, p_T scale