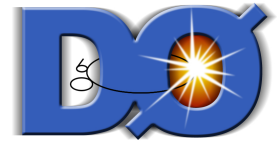
Measurements of $t\bar{t}$ production cross sections

– Standard Model @ LHC 2012 Copenhagen –

Martijn Gosselink

. . . presenting the hard work of the     collaborations

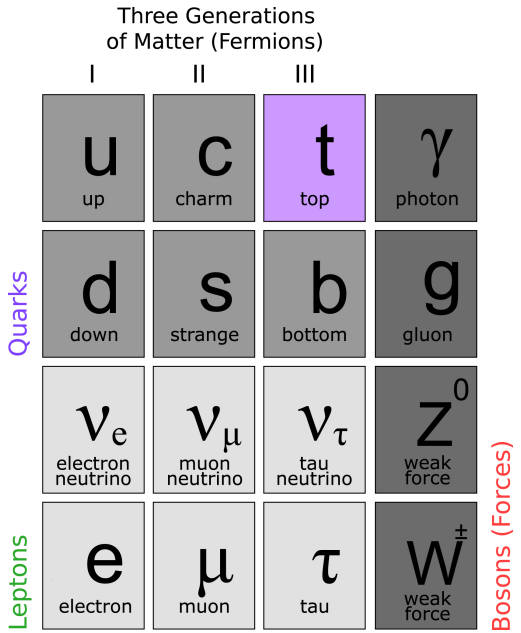
April 11, 2012

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Bundesministerium
für Bildung
und Forschung

Overview

- Inclusive $t\bar{t}$ production cross sections
- Properties derived from $t\bar{t}$ production
- Differential $t\bar{t}$ production cross sections
- My three questions



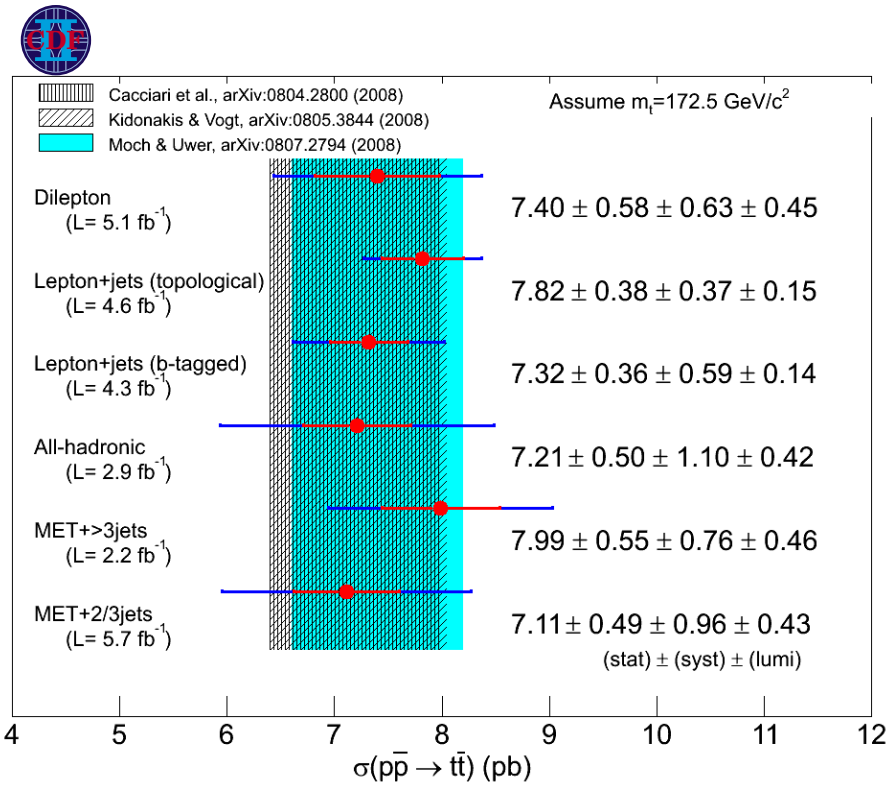
Experimental setup

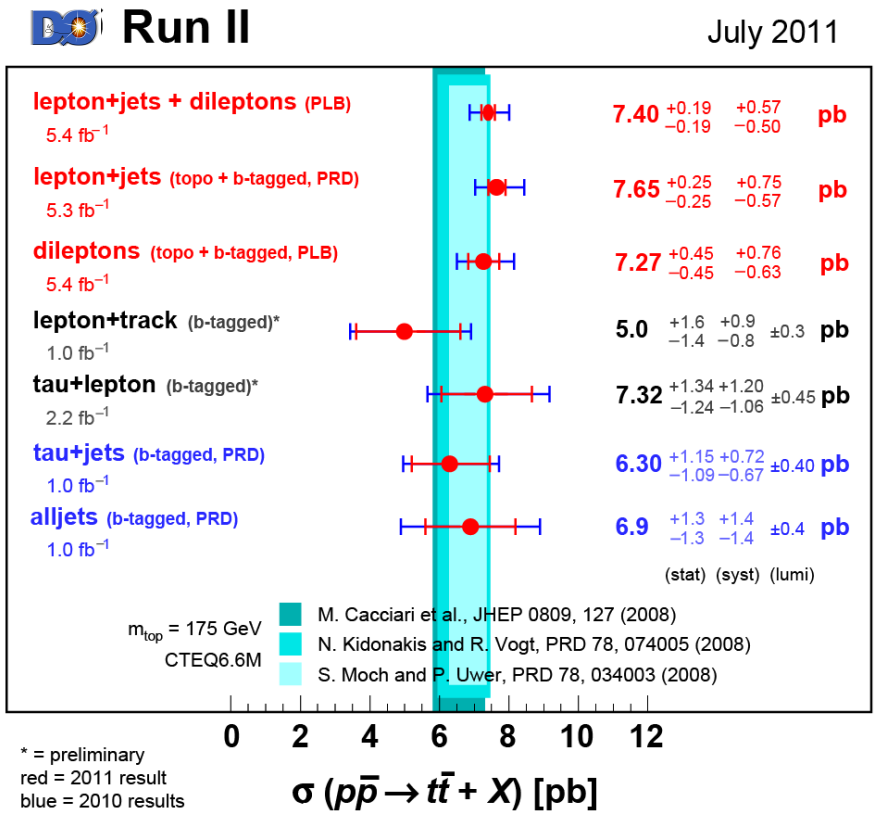
	Tevatron	**LHC**
$\sqrt{s}$	(1.8 &) 1.96 TeV	7 (& 8, . . . , 14) TeV
Main $t\bar{t}$ production mode	$q\bar{q}$ ($p\bar{p}$)	gg (pp)
Detectors	CDF, DØ	ATLAS, CMS
Datasets	2×10 fb^{-1}	2×5 fb^{-1}
$t\bar{t}$ pairs	$2 \times 75\,000$	$2 \times 800\,000$

$\rightarrow$ good conditions to study top quarks

Inclusive $t\bar{t}$ production cross sections

Inclusive cross sections at the Tevatron





combination:
7.5 ± 0.31 (stat.) ± 0.34 (syst.) ± 0.15 (Z theory) pb

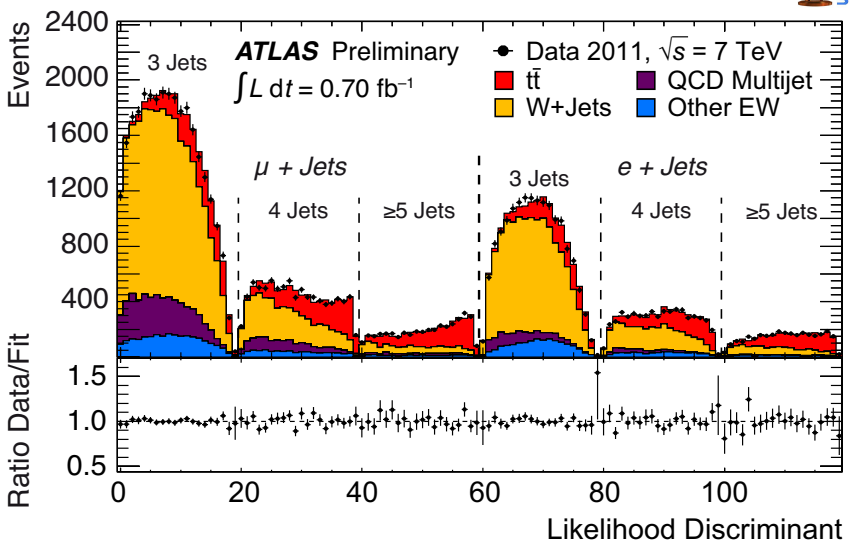
combination:
$7.56^{+0.63}_{-0.56}$ (stat.+syst.) pb

- ∼50 Run-II notes on public cross section websites
- statistical uncertainties $\lesssim$ systematic uncertainties
- experimental uncertainties ∼ theoretical uncertainties
- main uncertainties: jet reconstruction, signal modelling

Inclusive cross sections at the LHC (ℓ + jets)

0.70 fb^{-1} ATLAS-CONF-2011-121

- Event selection:
  - single isolated lepton
  - $\geq$ 3 jets
  - E_T^{miss} with $m_T(W)$ or $m_T + E_T^{miss}$ cut
  - no b-tagging
- Likelihood fit using:
  - lepton η, leading jet p_T, aplanarity, $H_T = \sum_{i=3}^{N_{jets}} |p_{T,i}| / \sum_{j=1}^{N_{objects}} |p_{z,j}|$

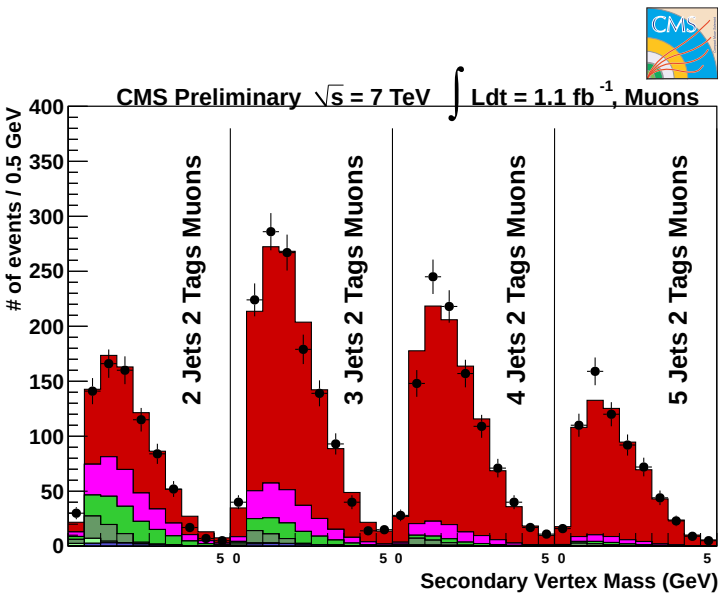


179.0 $\pm$ 3.9 (stat.) $\pm$ 9.0 (syst.) $\pm$ 6.6 (lumi.) pb

Main syst.: signal modelling, JES, ISR/FSR

0.8-1.1 fb^{-1} CMS-PAS-TOP-11-003

- Event selection:
  - single isolated lepton (e 45, μ 35)
  - $\geq$ 1 jets
  - no E_T^{miss}
  - $\geq$ 1 b-tag
- Likelihood fit using:
  - secondary vertex mass



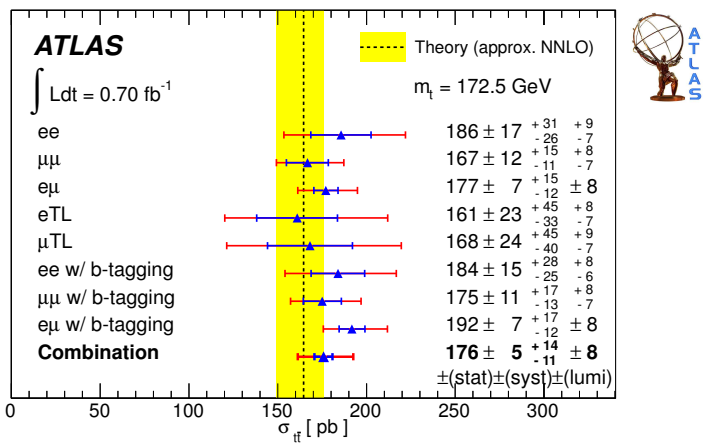
164 $\pm$ 3 (stat.) $\pm$ 12 (syst.) $\pm$ 7 (lumi.) pb

Main syst.: PDF, JES, b-tagging

Inclusive cross sections at the LHC (dilepton)

0.70 fb^{-1} arXiv:1202.4892 [hep-ex]

- Event selection:
  - two oppositely charged, isolated leptons
    veto on $M_{\ell\ell}$ for low mass and M_Z region
  - $\geq$ 2 jets
  - b-tag optional
  - E_T^{miss} and H_T cut
- Combination with profile likelihood
  - ee, $\mu\mu$, eμ, eTL, μTL channels (& b-tag)
  - Drell-Yan background from data in M_Z region

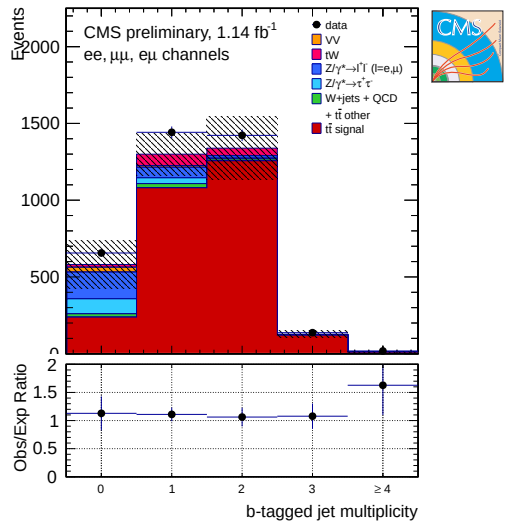


$176 \pm 5\ (\text{stat.})^{+14}_{-11}\ (\text{syst.}) \pm 8\ (\text{lumi.})$ pb

Main syst.: JES, lepton ID, PDF

1.14 fb^{-1} CMS-PAS-TOP-11-005

- Event selection:
  - two oppositely charged, isolated leptons
    veto on $M_{\ell\ell}$ for low mass and M_Z region
  - $\geq$ 2 jets
  - $\geq$ 1 b-tag
  - E_T^{miss} (not for eμ)
- Cut & count method combination
  - ee, $\mu\mu$, and eμ channels
  - Drell-Yan background from data in M_Z region



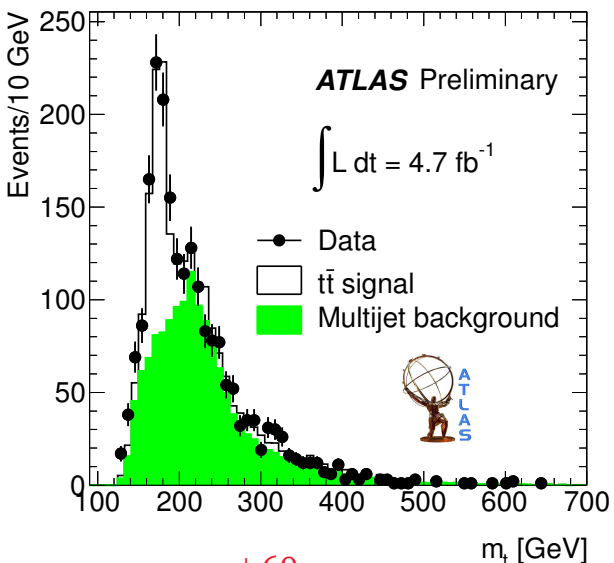
$169.9 \pm 3.9\ (\text{stat.}) \pm 16.3\ (\text{syst.}) \pm 7.6\ (\text{lumi.})$ pb

Main syst.: lepton selection, b-tagging, pile-up

Inclusive cross sections at the LHC (all hadronic)

4.7 fb^{-1} ATLAS-CONF-2012-031

- Event selection:
  - $\geq$ 6 jets (5x55,30) with $\Delta R(jj) > 0.6$
  - $\geq$ 2 b-tags with $\Delta R(bb) > 1.2$
  - $E_T^{miss}/\sqrt{H_T} < 3$
  - no isolated lepton
- Unbinned likelihood fit m_{top}
  - Kinematic fit, cut on χ^2
  - Background estimate: from untagged sample correction factor m_{jjj} light jets vs $b\bar{b}$ from MC

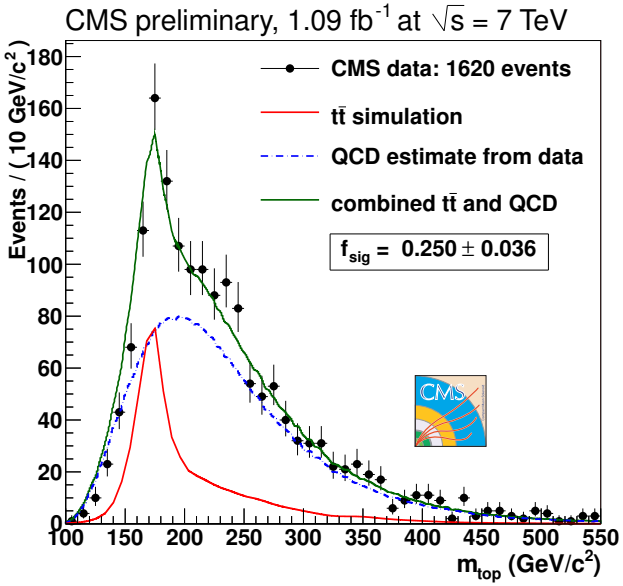


168 ± 12 (stat.) $\pm^{+60}_{-57}$ (syst.) ± 7 (lumi.) pb

Main syst.: JES, b-tagging, radiation

1.09 fb^{-1} CMS-PAS-TOP-11-007

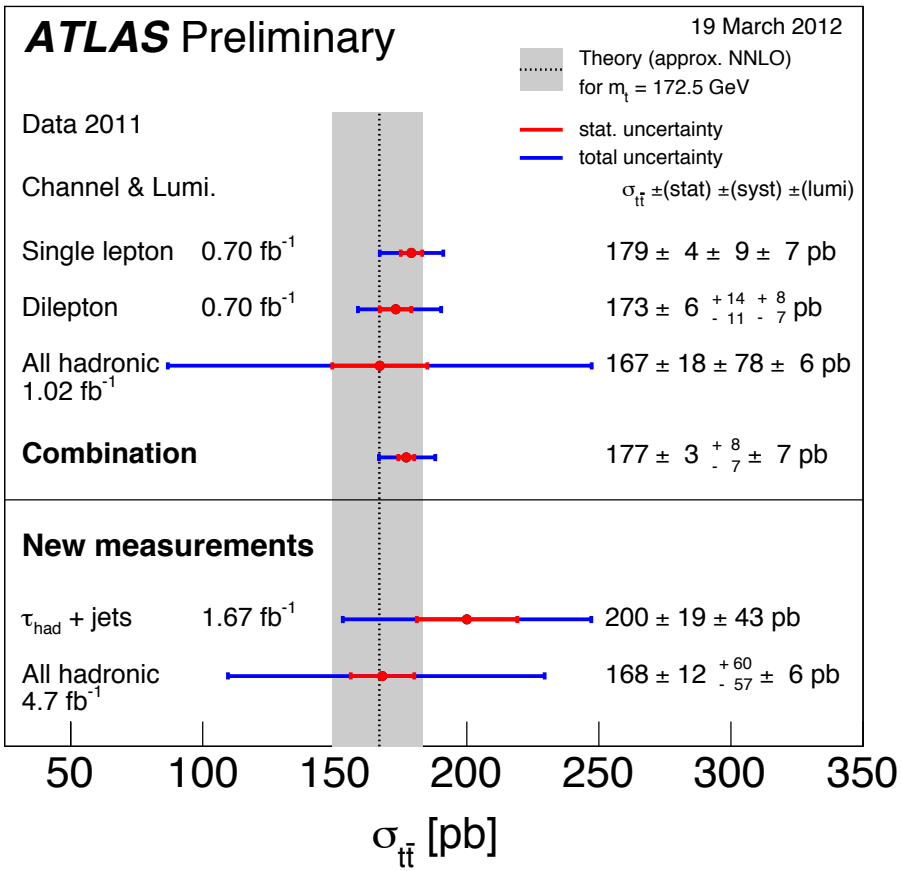
- Event selection:
  - $\geq$ 6 jets (4x60,50,40)
  - $\geq$ 2 b-tags
- Unbinned likelihood fit m_{top}
  - Kinematic fit, cut on $P(\chi^2)$
  - Background estimate: event reweighting light jet b_{tag} prob. $R(|\eta|, p_T) \times R(|\eta|, p_T)$

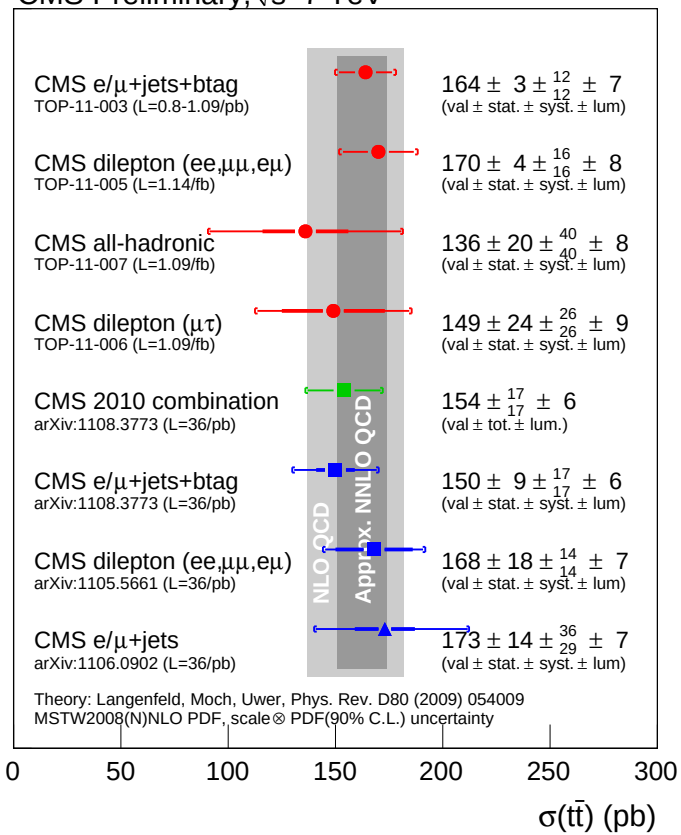


136 ± 20 (stat.) ± 40 (syst.) ± 8 (lumi.) pb

Main syst.: b-tagging, background, JES

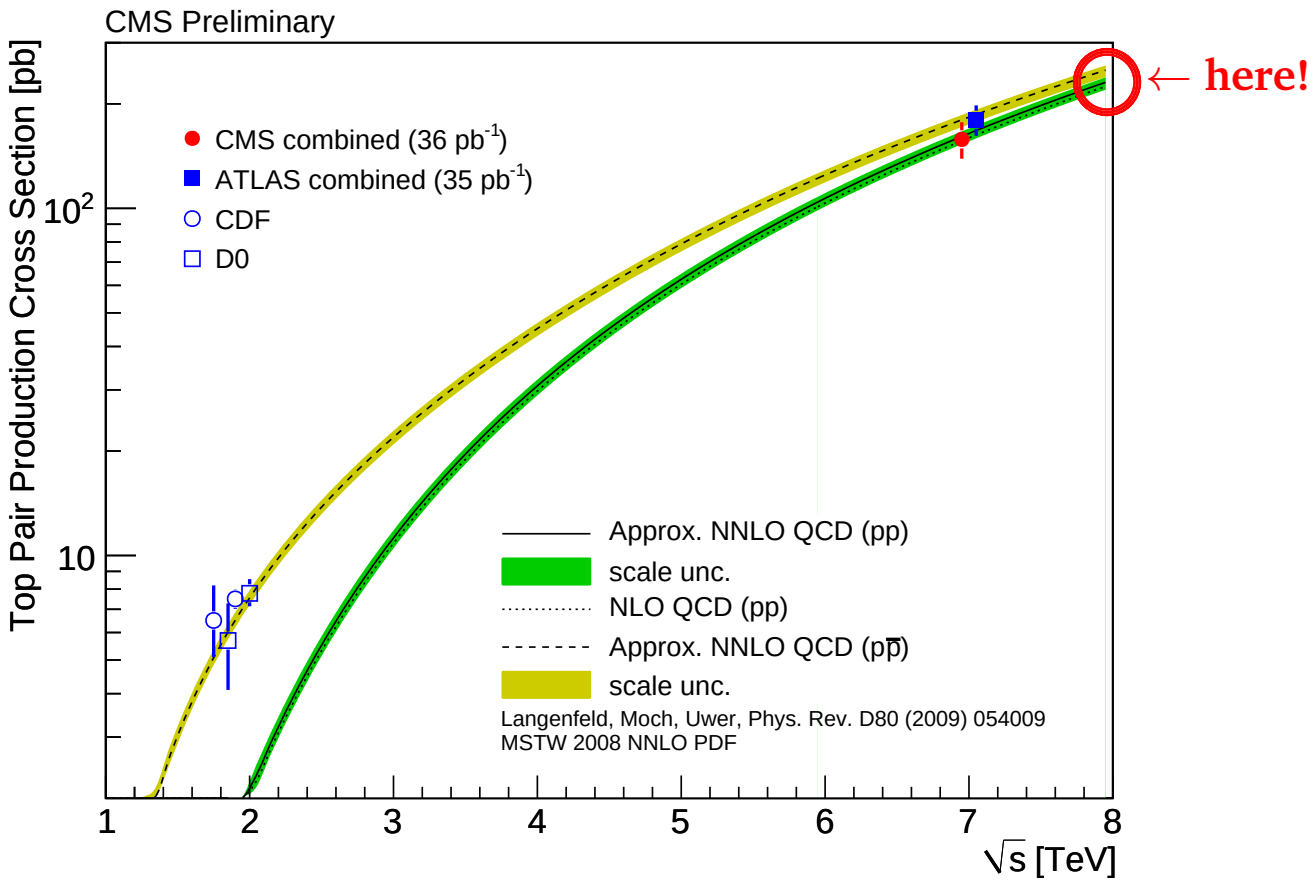
Inclusive cross sections at the LHC





- many channels covered
- statistical uncertainties $\lesssim$ systematic uncertainties
- experimental uncertainties $\sim$ theoretical uncertainties
- main uncertainties: b-tagging, jet reconstruction, signal/background modelling

Towards 8 TeV

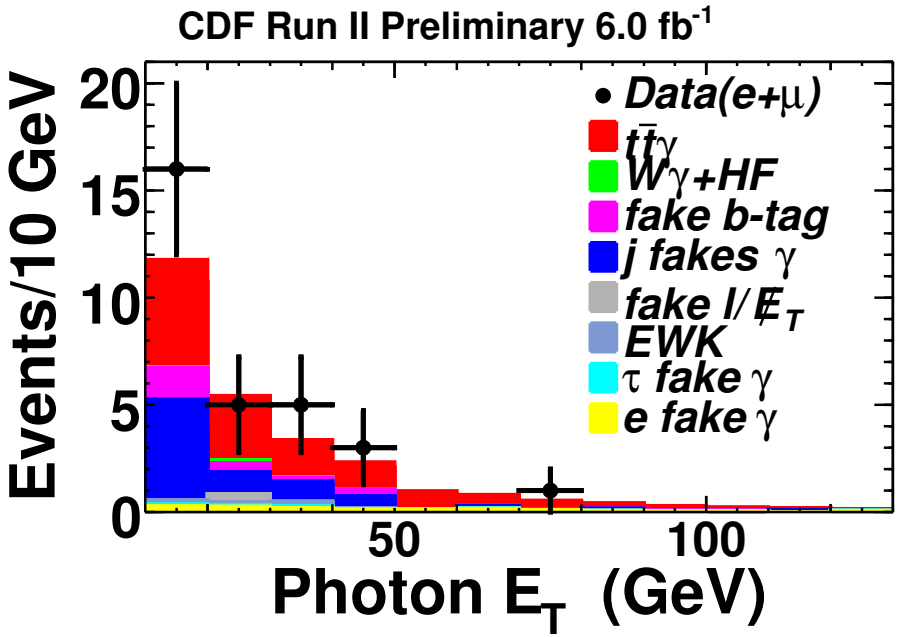


$t\bar{t}\gamma$ production in CDF

ℓ + jets channel (6.0 fb^{-1})

arXiv:1106.3970v5 [hep-ex]

Standard selection + γ with $E_T > 10$ GeV



Observed 30 $t\bar{t}\gamma$ candidate events versus 13.0 ± 2.1 expected events **without** top:

$\rightarrow 3.0\sigma$ evidence

$\sigma_{t\bar{t}\gamma} = \mathbf{0.18 \pm 0.07\,(stat.+syst.)\ pb}$

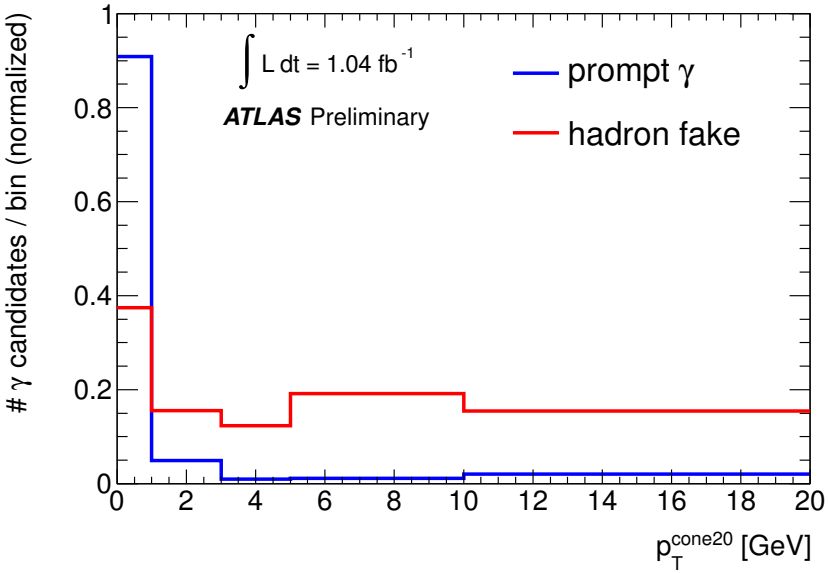
SM prediction: $\sigma_{t\bar{t}\gamma} = 0.17 \pm 0.07$ pb

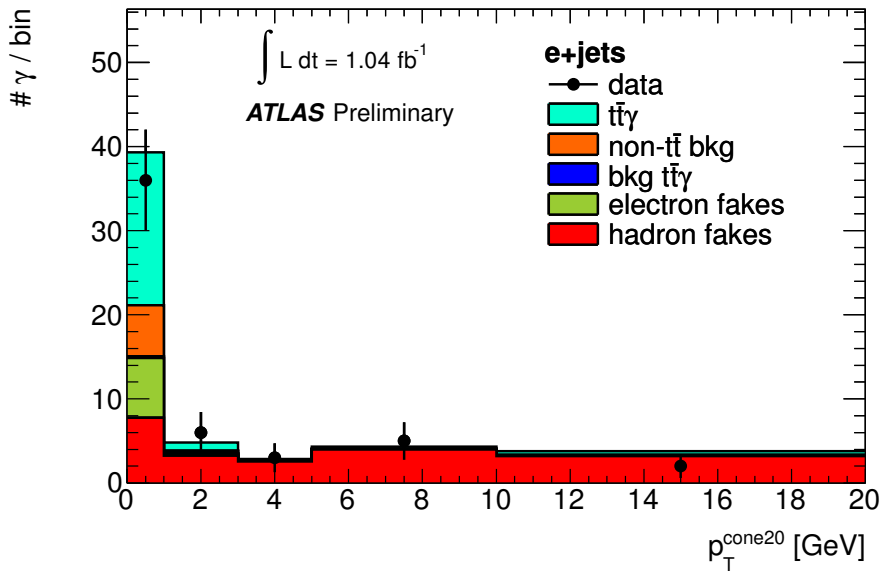
Main syst.: jet faking photons, heavy flavour fractions

$t\bar{t}\gamma$ production in ATLAS

ℓ + jets channel (1.04 fb^{-1}) ATLAS-CONF-2011-153

Standard selection + γ with $E_T > 15$ GeV





- $\mathbf{p_T^{cone20}}$: sum of track p_T inside cone of $\Delta R < 0.20$ around γ
- signal template: WHIZARD+Herwig+Photos

$$\sigma_{t\bar{t}\gamma} \times \mathbf{Br} = \mathbf{2.0 \pm 0.5\,(stat.) \pm 0.07\,(syst.) \pm 0.08\,(lumi.)\ pb}$$

for $p_T(\gamma) > 8$ GeV in dilepton and ℓ + jets decay channels

Main syst.: JES, ISR/FSR

Observed significance 2.7σ (expected: 3.0 ± 0.9)

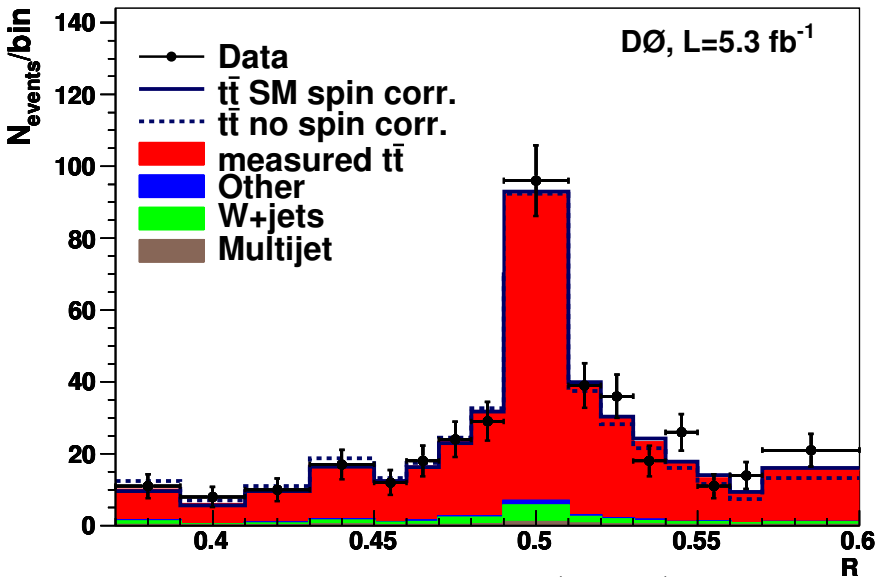
Properties derived from ttbar production

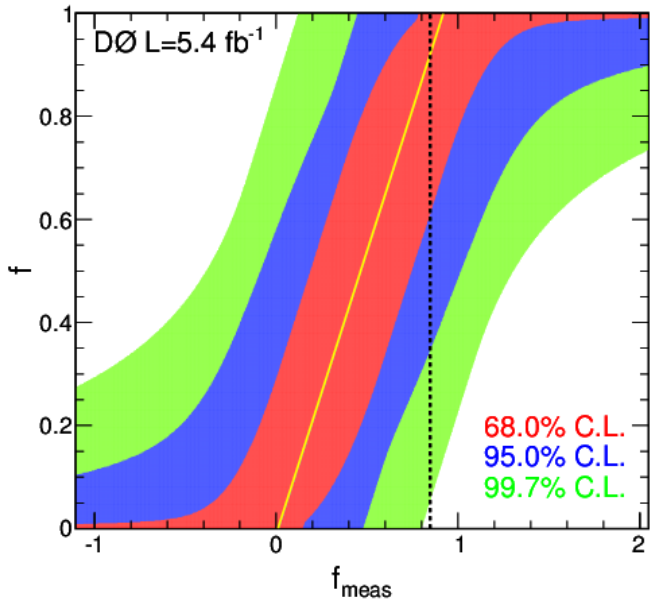
Spin correlations at DØ

Combined dilepton & ℓ + jets channel (5.4 fb^{-1}) arXiv:1110.4194 [hep-ex]

matrix element method:

$$P_{sgn}(x;H) = \frac{1}{\sigma}\int f_{PDF}(q_1)f_{PDF}(q_2)dq_1dq_2\frac{(2\pi)^2|\mathcal{M}(y,H)|^2}{q_1q_2s}W(x,y)d\Phi_6$$





Discriminant: $R = \frac{P_{sgn}(x;H=c)}{P_{sgn}(x;H=c)+P_{sgn}(x;H=u)}$

From correlated/uncorrelated R templates:

$$f^{meas} = 0.85 \pm 0.29\,(stat+syst) \text{ with } \begin{cases} f^{SM} & = 1 \\ f^{uncorr} & = 0 \end{cases}$$

$\rightarrow$ evidence for spin correlations with 3.1σ

Main syst.: MC statistics, PDF

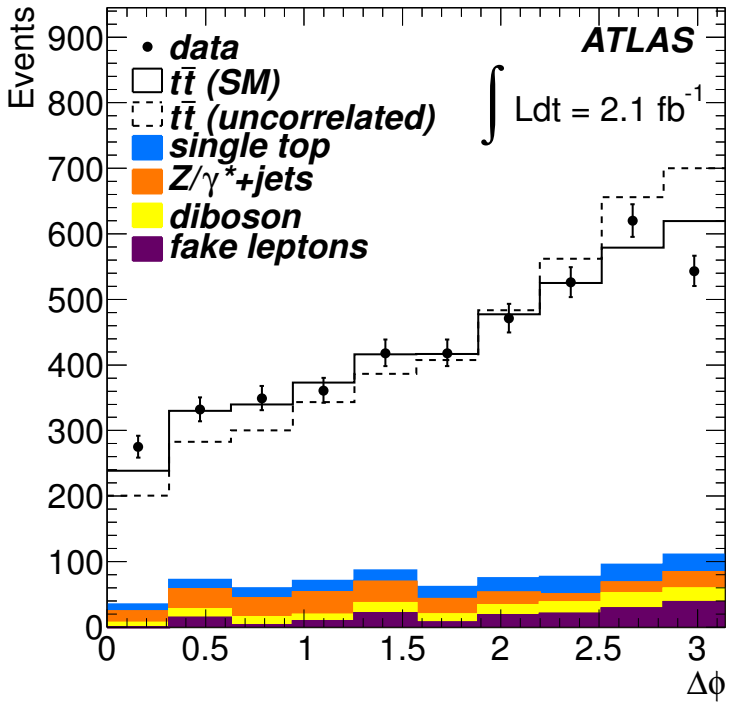
note: $\mathcal{A}^{meas}_{basis} = \mathcal{A}^{SM}_{basis} \cdot f^{meas}$

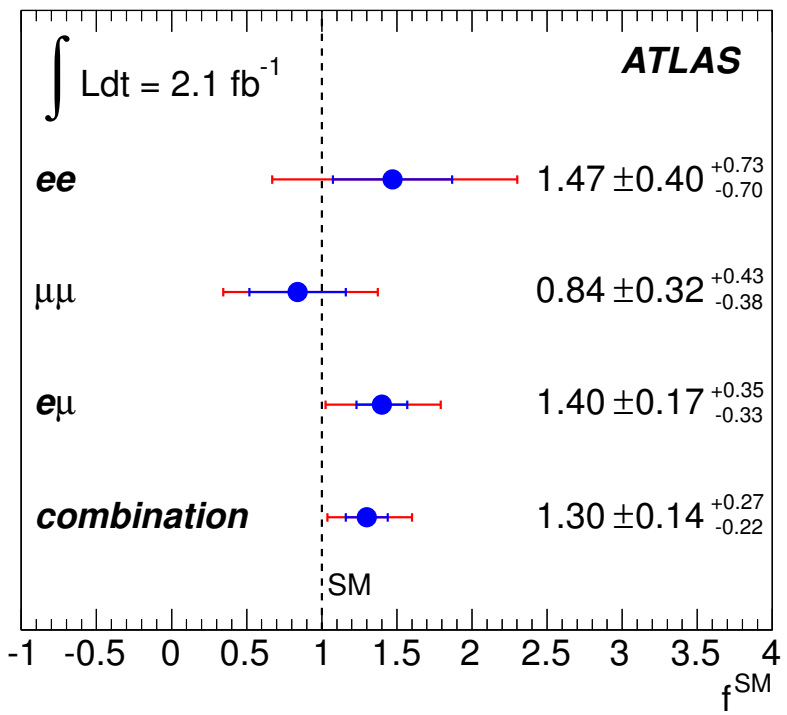
Spin correlations in ATLAS

Dilepton channel (2.1 fb^{-1}) arXiv:1203.4081 [hep-ex]

Template fit

$\Delta\phi$ angle between two $t\bar{t} \to b\bar{b}\ell^-\ell^+\nu\bar{\nu}$ leptons





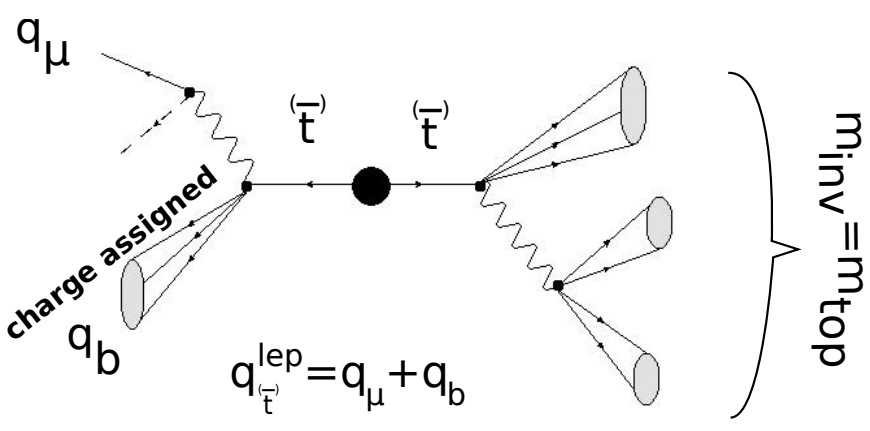
$$f^{meas} = 1.30 \pm 0.14\,(stat.)^{+0.27}_{-0.22}\,(syst.) \text{ with } \begin{cases} f^{SM} & = 1 \\ f^{uncorr} & = 0 \end{cases}$$

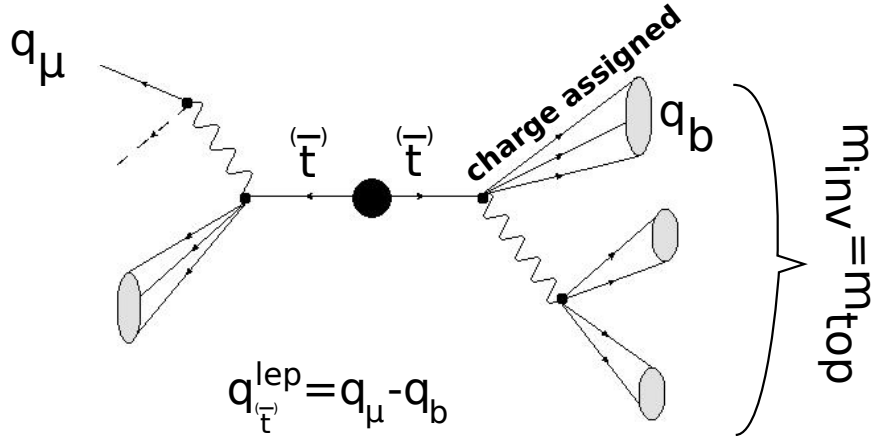
$\to$ zero spin correlations excluded with 5.1σ

Main syst.: fake ℓ, JES, MC statistics, ISR/FSR Note: $\mathcal{A}^{meas}_{basis} = \mathcal{A}^{SM}_{basis} \cdot f^{meas} \to \mathcal{A}_{helicity}, \mathcal{A}_{maximal}$

Top quark charge

$$q_{\text{top}} = +\tfrac{2}{3}e \text{ or } -\tfrac{4}{3}e \text{ ?}$$





use isolated, high-p_T lepton from W decay

+

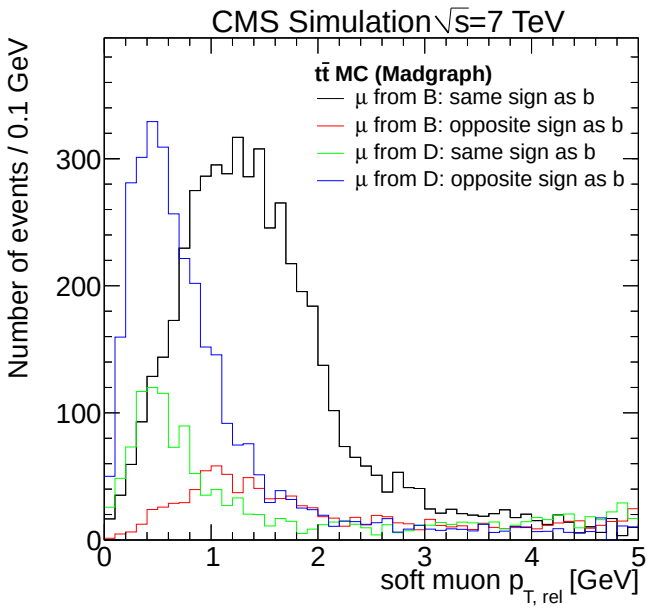
tracks or soft muon from B hadron decay inside b-jet

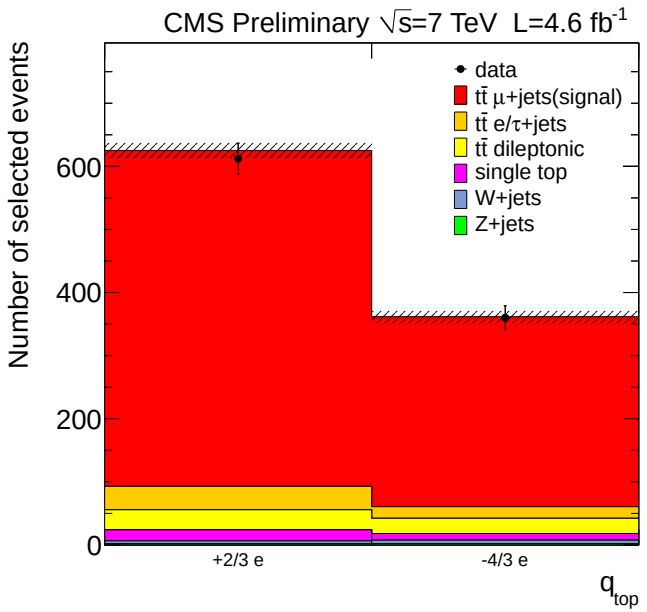
Top quark charge at CMS

μ + jets channel (4.6 fb^{-1}) CMS-PAS-11-031

soft muon method: $q_t = q_\mu \pm q_b$

Correct b-jet charge assignment $P_{bC} = 0.745$





Measured with 972 events:

$$A_{meas} = 0.97 \pm 0.12\,(stat.) \pm 0.31\,(syst.) \text{ with } \begin{cases} A^{SM} & = +1 \\ A^{non\text{-}SM} & = -1 \end{cases}$$

$\rightarrow$ top quark charge $-\frac{4}{3}e$ excluded with high significance

Main syst.: b charge id, matching scale

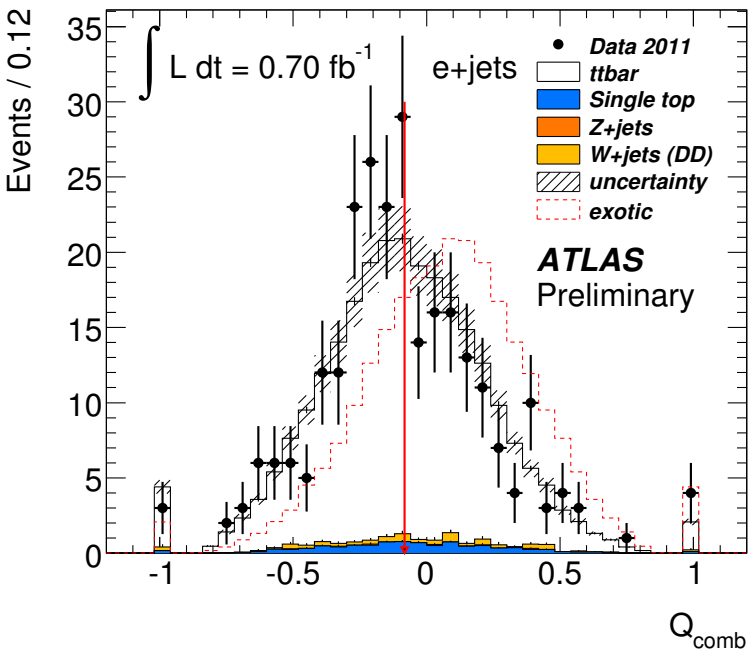
Top quark charge in ATLAS

ℓ + jets channel (0.7 fb^{-1})

ATLAS-CONF-2011-141

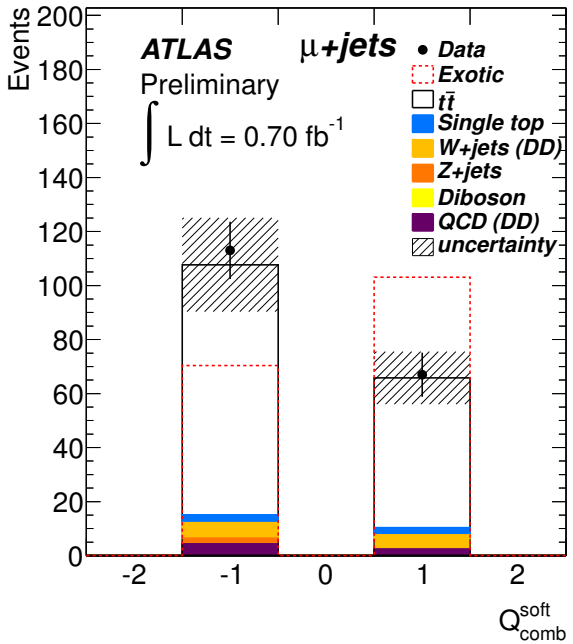
track weighting method

$$Q_{comb} = \frac{\sum_i q_i |\tilde{j}\cdot\tilde{p}_i|^\kappa}{\sum_i |\tilde{j}\cdot\tilde{p}_i|^\kappa} \cdot Q_\ell$$



soft muon method

$$Q^{soft}_{comb} = Q^{soft}_\ell \cdot Q_\ell$$



$$Q_{comb} = -0.082 \pm 0.013\,(stat) \pm 0.011\,(sys)$$
$$SM = -0.082 \pm 0.013\,(stat)$$
$$exotic = +0.083 \pm 0.013\,(stat)$$

Main syst.: jet/E_T^{miss}, ISR/FSR

$$Q^{soft}_{comb} = -0.31 \pm 0.05\,(stat) \pm 0.04\,(sys)$$
$$SM = -0.234 \pm 0.011\,(stat)$$
$$exotic = +0.209 \pm 0.011\,(stat)$$

$\rightarrow$ top quark charge $-\frac{4}{3}e$ excluded with $> 5\sigma$

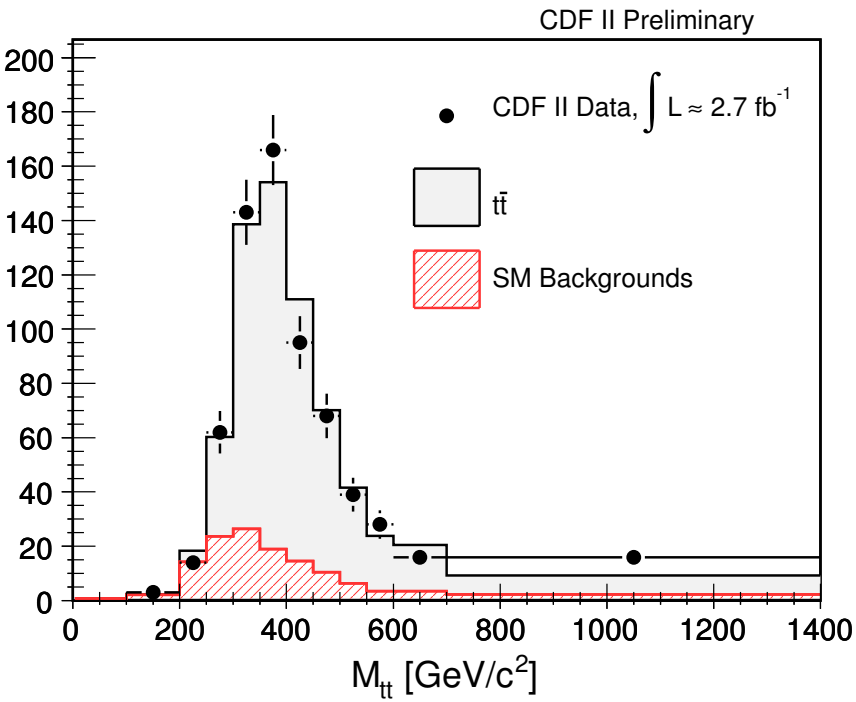
Differential $t\bar{t}$ production cross sections

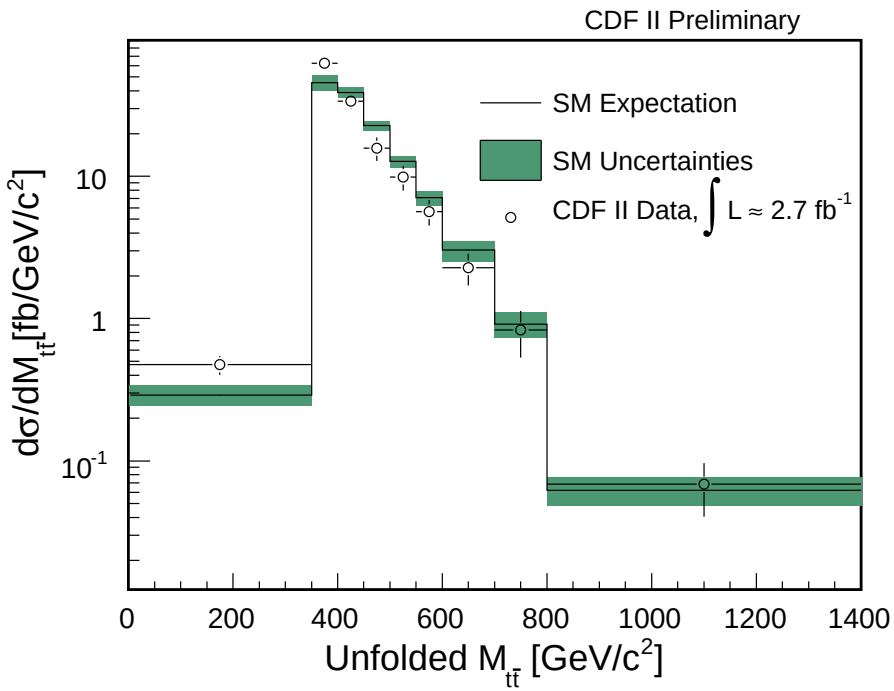
Invariant top quark pair mass in CDF

ℓ + jets channels (2.7 fb^{-1})

arXiv:0903.2850 [hep-ex]

$$\frac{d\sigma_{t\bar{t}}}{dM_{t\bar{t}}}$$





- in-situ jet energy scale calibration (W $\rightarrow$ jj)
- no evidence for a discrepancy w.r.t. Standard Model

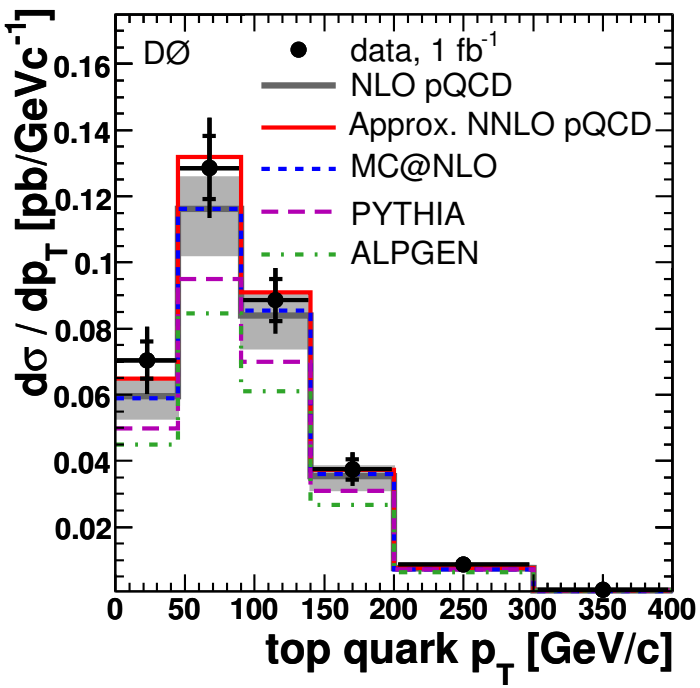
Main syst.: JES, background normalisation, generator, PDF

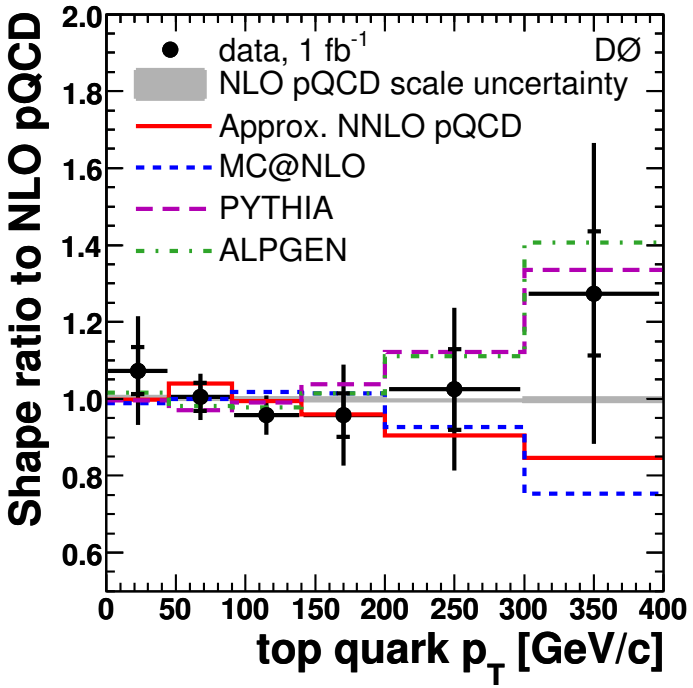
Transverse momentum of top quarks in DØ

ℓ + jets channel (1.0 fb^{-1})

arXiv:1001.1900 [hep-ex]

$$\frac{d\sigma_{t\bar{t}}}{dp_T(t)}$$





- shape properly described
- normalisation for LO generators off

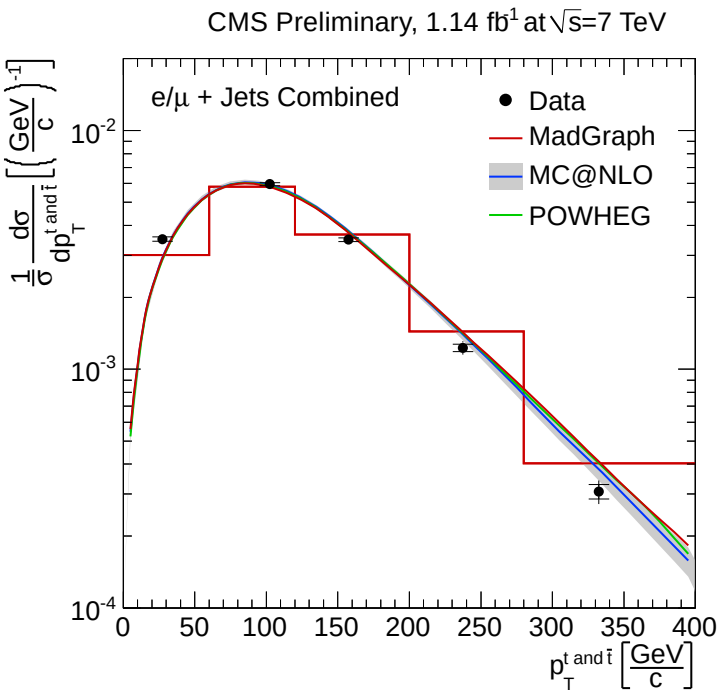
Main syst.: JES, shape/modelling, luminosity

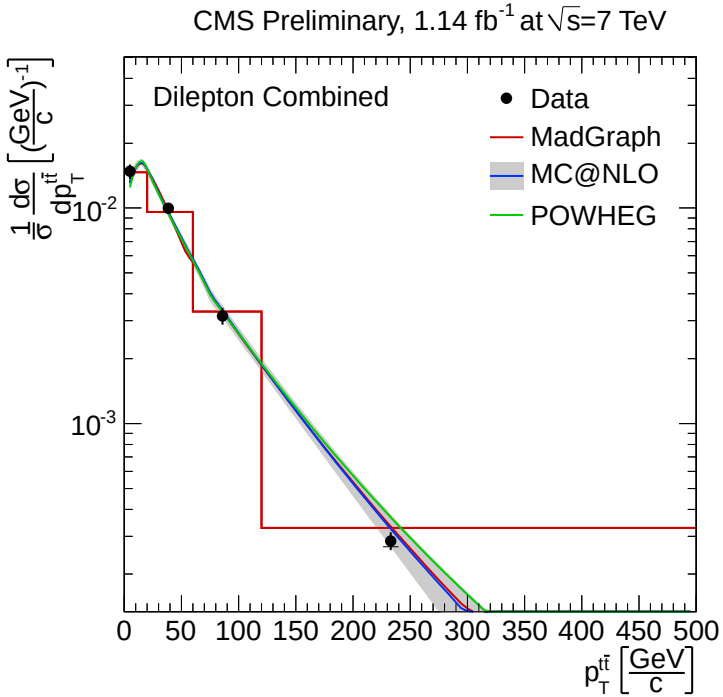
Normalised differential $t\bar{t}$ cross sections in CMS

Dilepton and ℓ + jets channels (1.04 fb^{-1}) CMS-PAS-TOP-11-013

$$\frac{1}{\sigma_{t\bar{t}}}\frac{d\sigma_{t\bar{t}}}{dX}$$

with X the p_T, η/y, and M_{inv} of leptons, top quarks, $t\bar{t}$ pairs





- Normalised to unity → shape measurement
- Reported in the visible phase space, ie: p_T and η cuts on (b-)quarks and leptons
- Good agreement between data and predictions

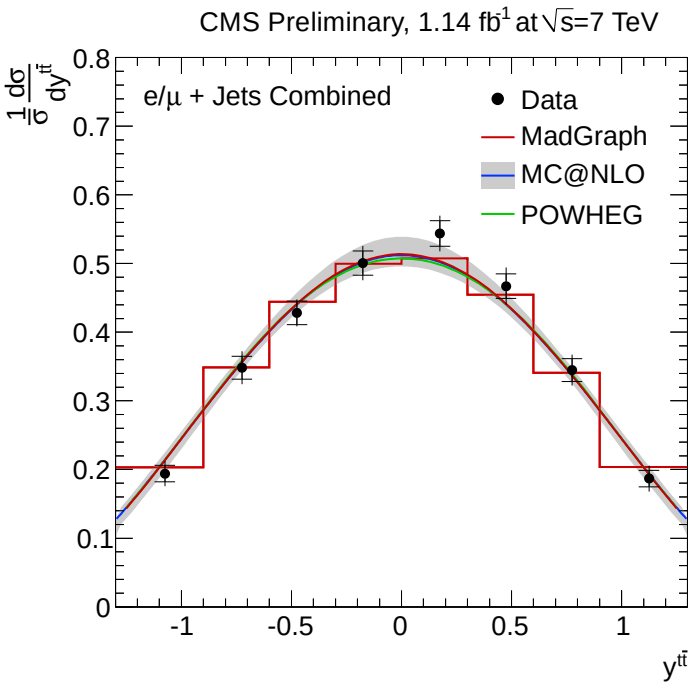
Main syst.: b-tagging, radiation, fragmentation/hadronisation

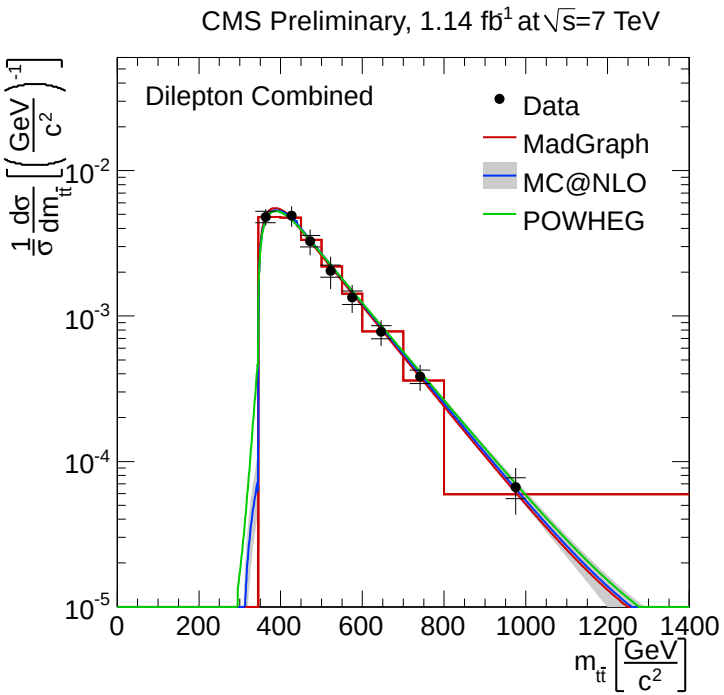
Normalised differential $t\bar{t}$ cross sections in CMS

Dilepton and ℓ + jets channels (1.04 fb^{-1}) CMS-PAS-TOP-11-013

$$\frac{1}{\sigma_{t\bar{t}}}\frac{d\sigma_{t\bar{t}}}{dX}$$

with X the p_T, η/y, and M_{inv} of leptons, top quarks, $t\bar{t}$ pairs





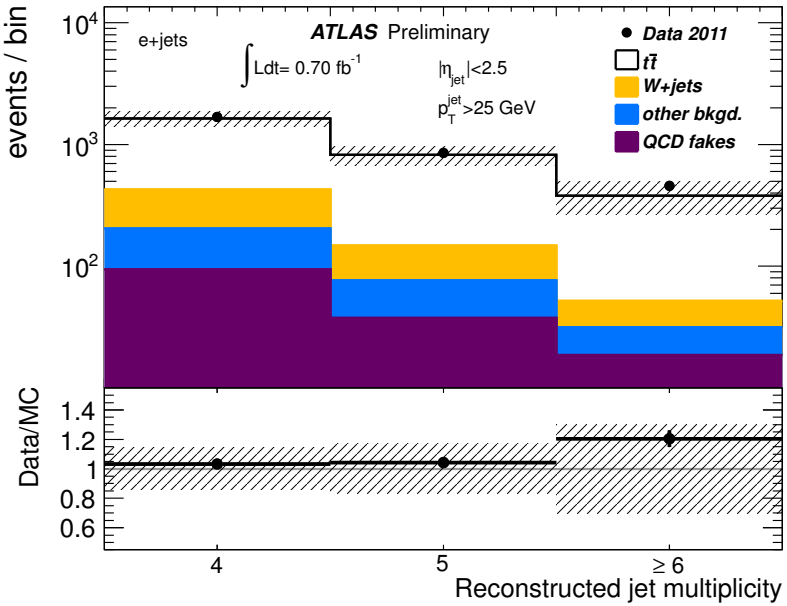
- Normalised to unity → shape measurement
- Reported in the visible phase space, ie: p_T and η cuts on (b-)quarks and leptons
- Good agreement between data and predictions

Main syst.: b-tagging, radiation, fragmentation/hadronisation

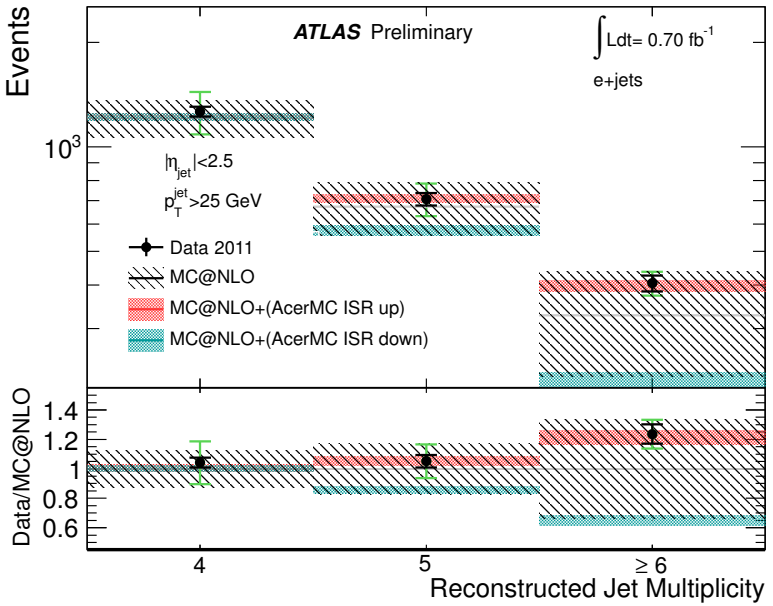
Jet multiplicity in ATLAS

ℓ + jets channel (0.70 fb^{-1}) ATLAS-CONF-2011-142

event yield ℓ + jets selection, jet $p_T > 25$ GeV



background subtracted, jet $p_T > 25$ GeV



- background subtraction, no detector unfolding (yet)
- relative ISR uncertainty AcerMC $\rightarrow$ MC@NLO
- `PARP(67)` = 4, 6 $(\uparrow)$, 1$(\downarrow)$ $\sim$ factor maximum ISR scale
  `PARP(64)` = 1, 0.25$(\uparrow)$, 4$(\downarrow)$ $\sim \alpha_s$ evolution scale factor

$\rightarrow$ can not exclude ISR model yet

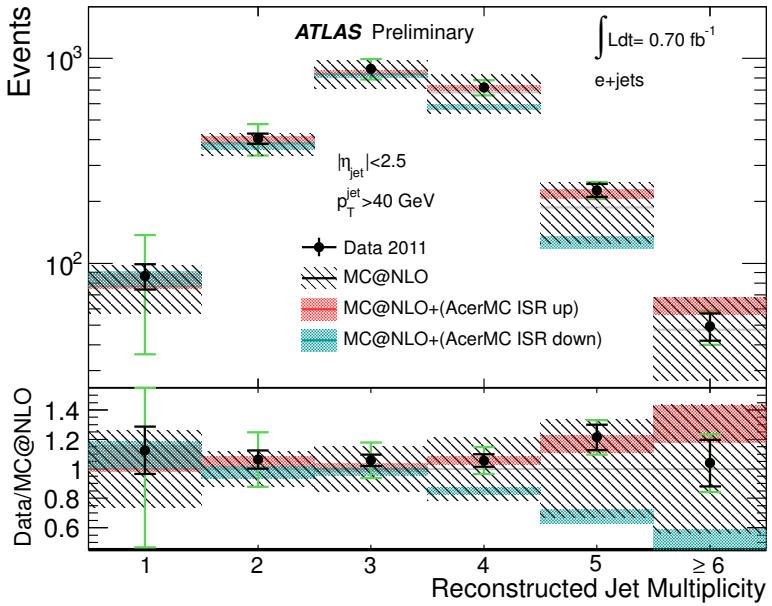
Main syst: jet energy scale, b-tagging, W + jets normalisation

Jet multiplicity in ATLAS

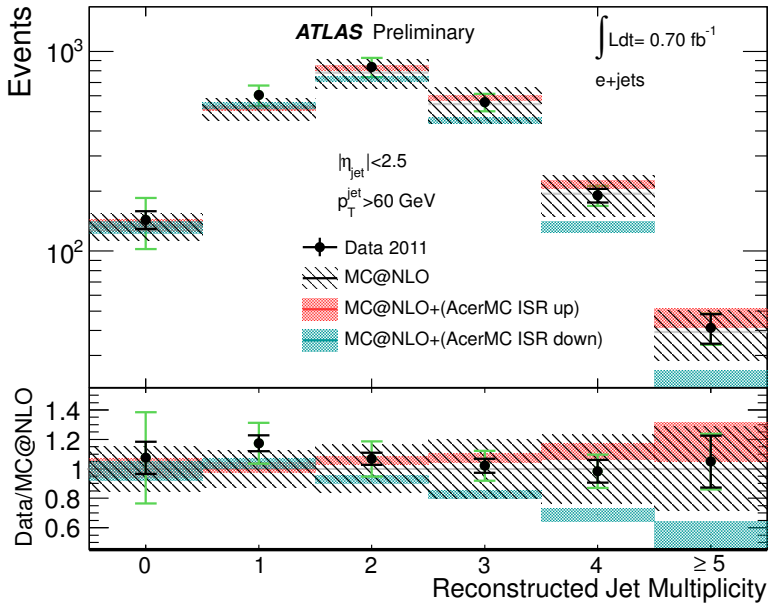
ℓ + jets channel (0.70 fb^{-1})

ATLAS-CONF-2011-142

background subtracted, jet $p_T > 40$ GeV



background subtracted, jet $p_T > 60$ GeV



- background subtraction, no detector unfolding (yet)
- relative ISR uncertainty AcerMC $\rightarrow$ MC@NLO
- `PARP(67)` $= 4, 6 \quad (\uparrow), 1(\downarrow) \sim$ factor maximum ISR scale
  `PARP(64)` $= 1, 0.25(\uparrow), 4(\downarrow) \sim \alpha_s$ evolution scale factor

$\rightarrow$ can not exclude ISR model yet

Main syst: jet energy scale, b-tagging, W + jets normalisation

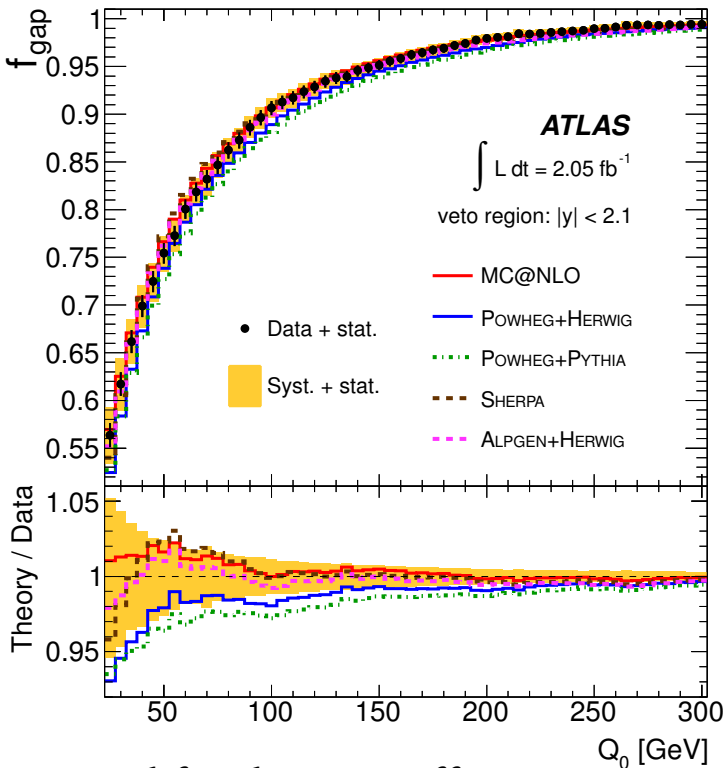
$t\bar{t}$ production with jet veto in ATLAS

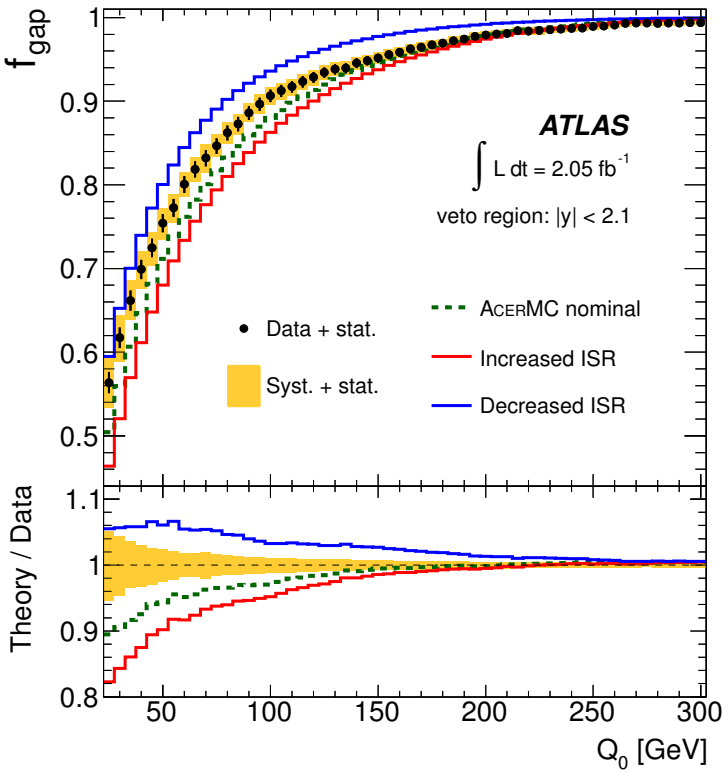
Dilepont channel (2.05 fb^{-1})

arXiv:1203.5015 [hep-ex]

Gap fraction: $\mathbf{f = \frac{n(Q_0)}{N}}$

with $n(Q_0)$ as # events that have **no** jet $p_T > Q_0$





- corrected for detector effects
- different rapidity intervals
- also for Q_{sum}: transverse momentum sum of all jets

→ constrain radiation uncertainty

Main syst.: unfolding, JES/JER

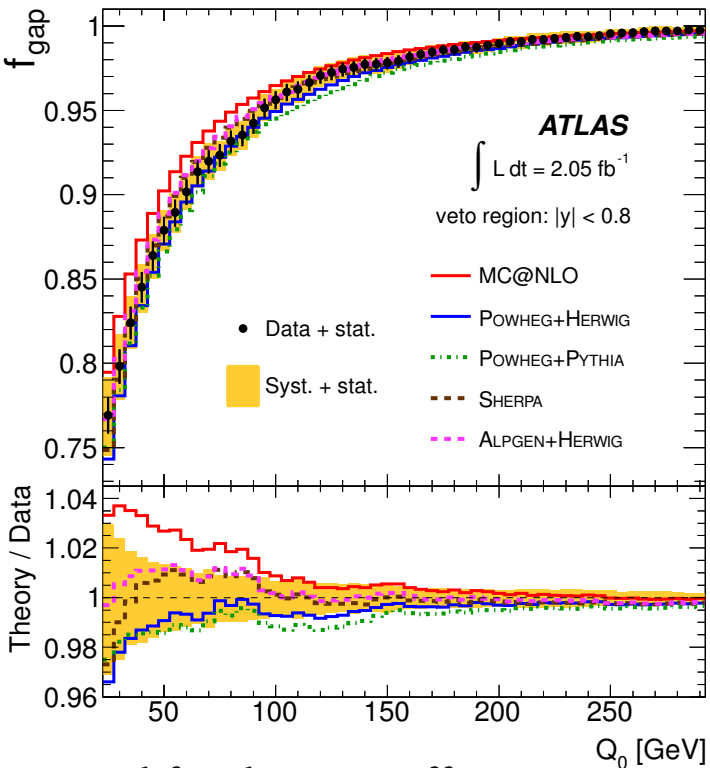
$t\bar{t}$ production with jet veto in ATLAS

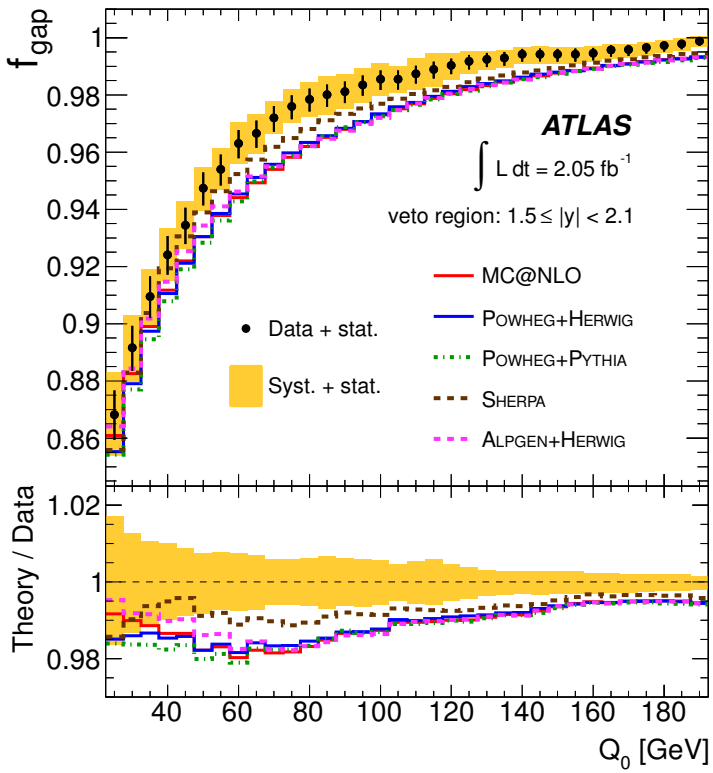
Dilepont channel (2.05 fb^{-1})

arXiv:1203.5015 [hep-ex]

Gap fraction: $\mathbf{f = \frac{n(Q_0)}{N}}$

with $n(Q_0)$ as # events that have **no** jet $p_T > Q_0$





- corrected for detector effects
- different rapidity intervals
- also for Q_{sum}: transverse momentum sum of all jets

→ constrain radiation uncertainty

Main syst.: unfolding, JES/JER

Summary

- Top times!
- Good agreement theory $\leftrightarrow$ experiment
- Differential cross sections: entering next level of precision
- Constraining model uncertanties using $t\bar{t}$ data possible
- A_{fb} results remain remarkable

My three questions...

1. Which obervable on the theorists' wish list is missing?

2. How should measured observables be reported?
   - Full vs visible phase space
   - Parton vs particle level

3. Do we need a 'top quark at particle level' definition?

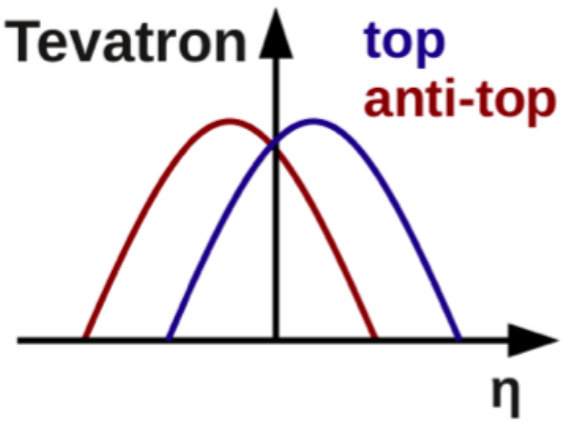
Additional material

Forward–backward asymmetry at DØ

ℓ + jets channel (5.4 fb^{-1}) arXiv:1107.4995v2 [hep-ex]

$$A_{fb} = \frac{N_F - N_B}{N_F + N_B} \text{ with } N_F \ (N_B) \text{ for } \Delta y > 0 \ (\Delta y < 0)$$

$$\Delta y = y_t - y_{\bar{t}} = q(y_{t,lep} - y_{t,had})$$

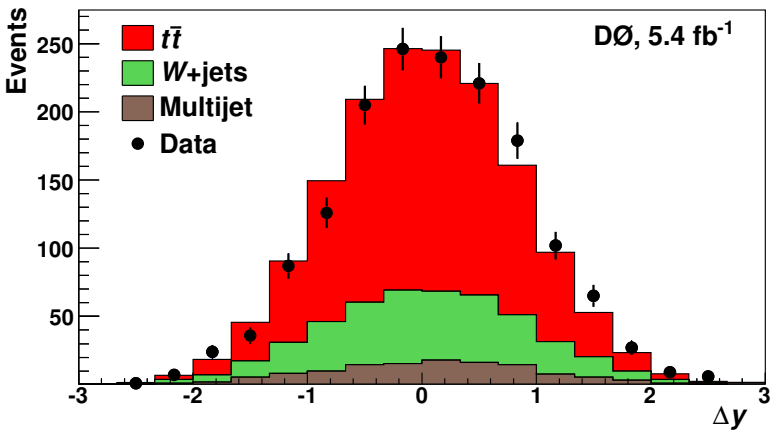


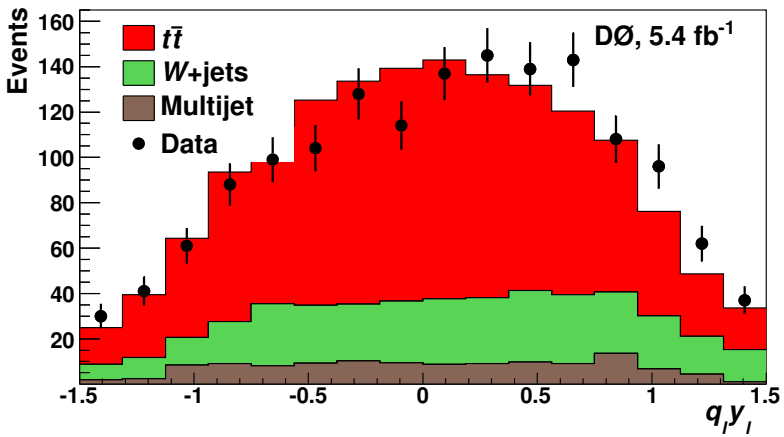
Forward–backward asymmetry at DØ

ℓ + jets channel (5.4 fb^{-1}) arXiv:1107.4995v2 [hep-ex]

$$A_{fb} = \frac{N_F - N_B}{N_F + N_B} \text{ with } N_F \ (N_B) \text{ for } \Delta y > 0 \ (\Delta y < 0)$$

$$\Delta y = y_t - y_{\bar{t}} = q(y_{t,lep} - y_{t,had})$$





	A_{fb}		A_{fb}^{ℓ}	
	reconstruction	production	reconstruction	production
Data	9.2 ± 3.7	$\mathbf{19.6 \pm 6.5}$	14.2 ± 3.8	15.2 ± 4.0
MC@NLO	2.4 ± 0.7	5.0 ± 0.1	0.8 ± 0.6	2.1 ± 0.1

$\rightarrow 2.4\sigma$ (1.9σ) difference at production (reconstruction) level

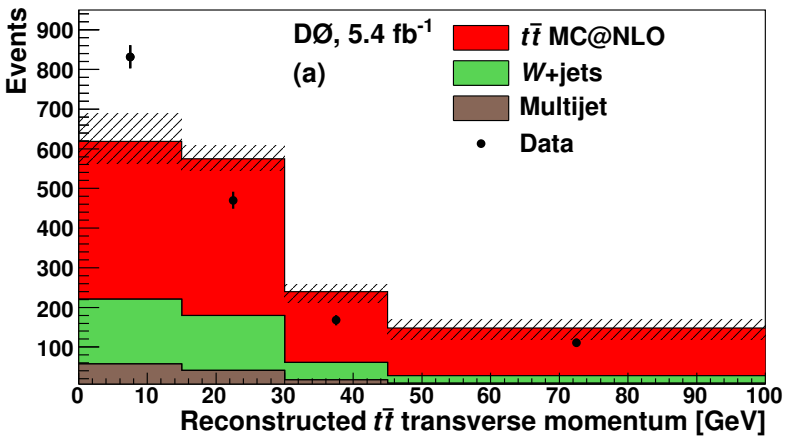
Main syst.: jet systematics, signal modelling, unfolding

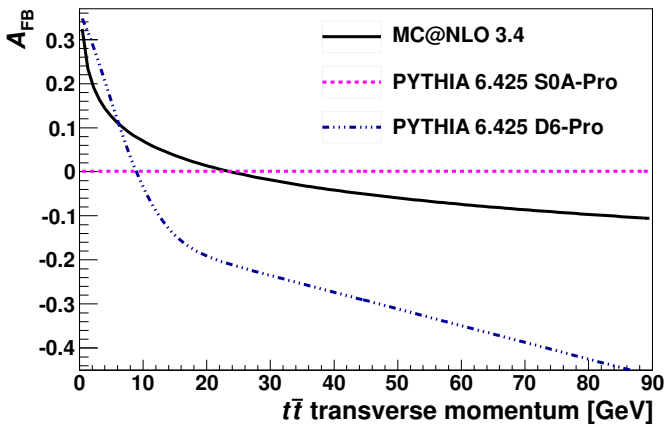
Forward–backward asymmetry at DØ

ℓ + jets channel (5.4 fb^{-1}) arXiv:1107.4995v2 [hep-ex]

$$A_{fb} = \frac{N_F - N_B}{N_F + N_B} \text{ with } N_F \ (N_B) \text{ for } \Delta y > 0 \ (\Delta y < 0)$$

$$\Delta y = y_t - y_{\bar{t}} = q(y_{t,lep} - y_{t,had})$$



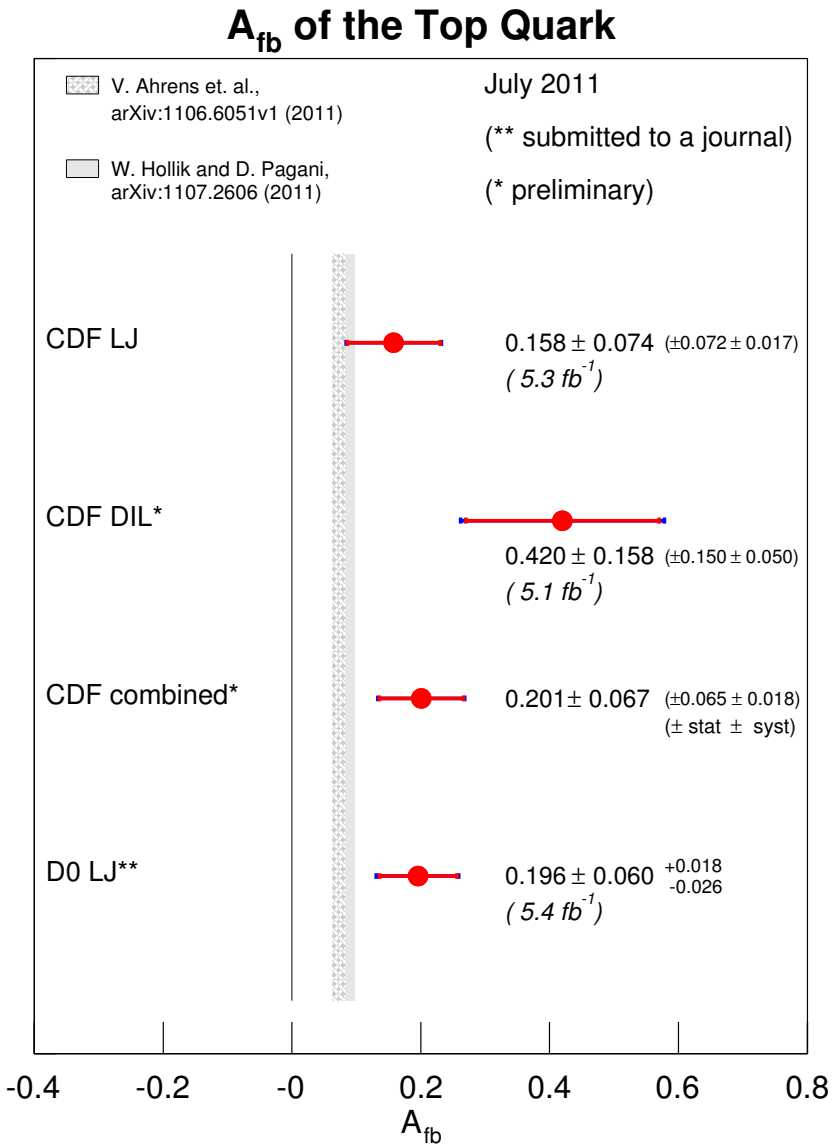


	A_{fb}		A_{fb}^{ℓ}	
	reconstruction	production	reconstruction	production
Data	9.2 ± 3.7	$\mathbf{19.6 \pm 6.5}$	14.2 ± 3.8	15.2 ± 4.0
MC@NLO	2.4 ± 0.7	5.0 ± 0.1	0.8 ± 0.6	2.1 ± 0.1

$\rightarrow 2.4\sigma$ (1.9σ) difference at production (reconstruction) level

Main syst.: jet systematics, signal modelling, unfolding

Forward–backward asymmetry at the Tevatron

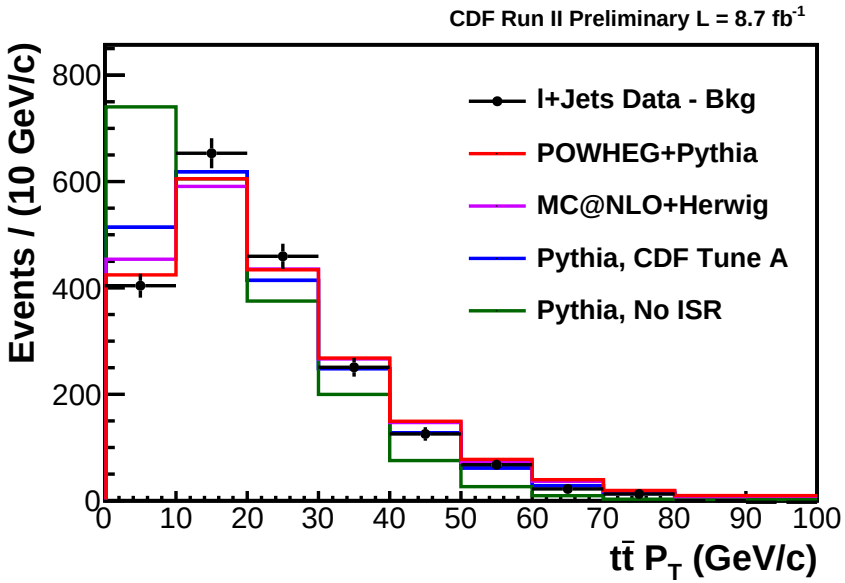


Forward–backward asymmetry differentially in CDF

ℓ + jets channel (8.7 fb^{-1}) CDF Note 10807

$$A_{fb} = \frac{N_F - N_B}{N_F + N_B} \text{ with } N_F \ (N_B) \text{ for } \Delta y > 0 \ (\Delta y < 0)$$

	MC@NLO	POWHEG	MCFM
inclusive	0.067	0.066	0.073
$\Delta y < 1$	0.047	0.043	0.049
$\Delta y > 1$	0.130	0.139	0.150
$M_{t\bar{t}} < 450$	0.054	0.047	0.050
$M_{t\bar{t}} > 450$	0.089	0.100	0.110



Note I:

NLO value used in denominator of A_{fb}

Note II:

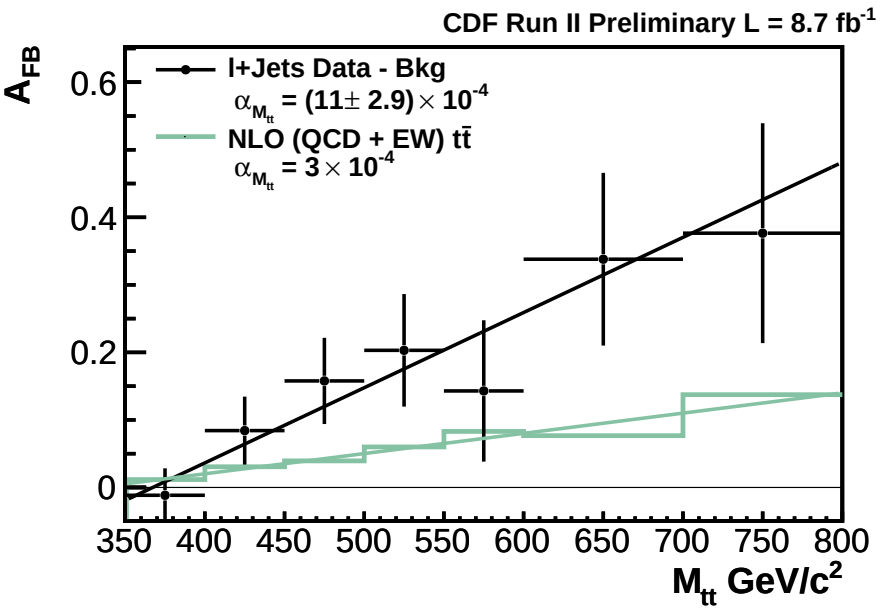
CDF		DØ
reconstruction level	$\leftrightarrow$	raw data
background subtracted	$\leftrightarrow$	reconstructed level
parton level	$\leftrightarrow$	production level

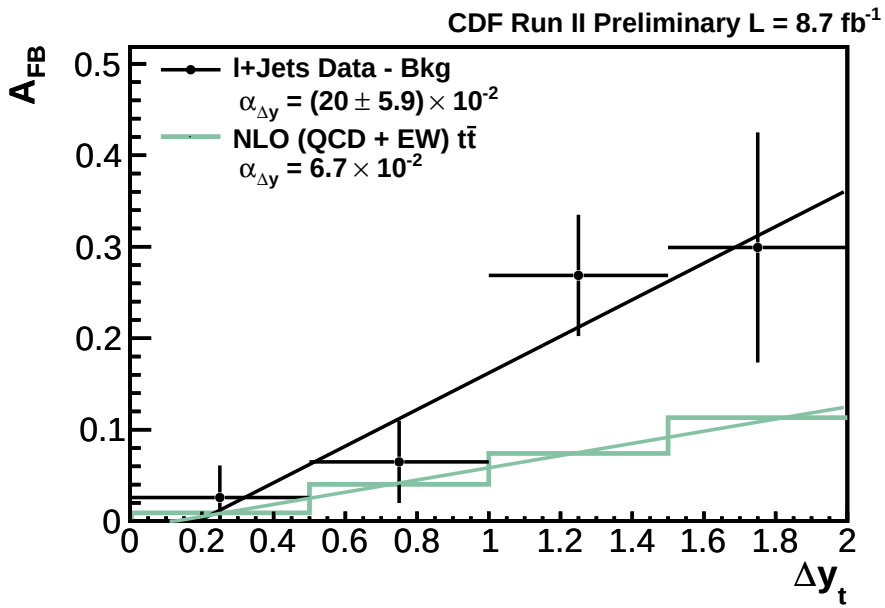
Forward–backward asymmetry differentially in CDF

ℓ + jets channel (8.7 fb^{-1})

CDF Note 10807

Background subtracted distributions





Background subtracted slopes:

- p-value 0.00646 for $M_{t\bar{t}}$
- p-value 0.00892 for Δy

Fully corrected $\mathbf{A_{fb} = 0.162 \pm 0.047}$

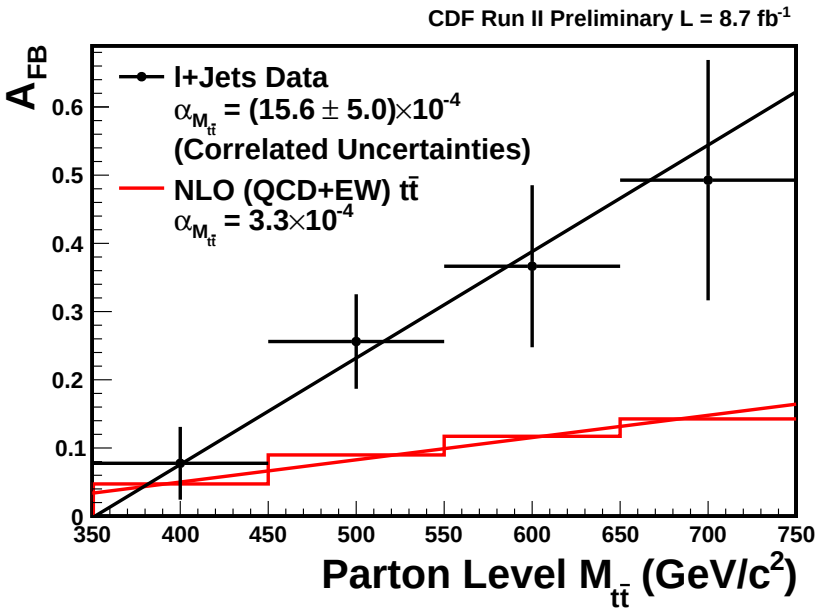
Main syst.: jet systematics, ISR/FSR

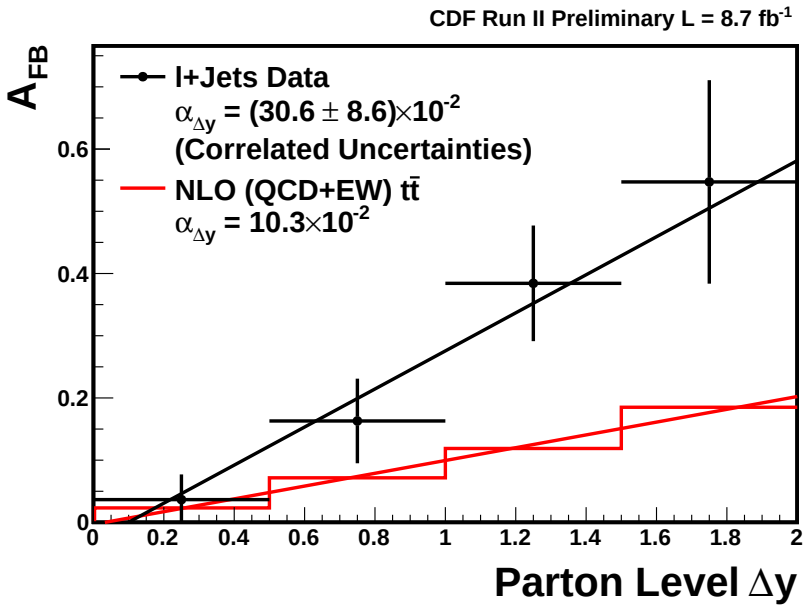
Forward–backward asymmetry differentially in CDF

ℓ + jets channel (8.7 fb^{-1})

CDF Note 10807

Parton level distributions





Background subtracted slopes:

- p-value 0.00646 for $M_{t\bar{t}}$
- p-value 0.00892 for Δy

Fully corrected $\mathbf{A_{fb} = 0.162 \pm 0.047}$

Main syst.: jet systematics, ISR/FSR

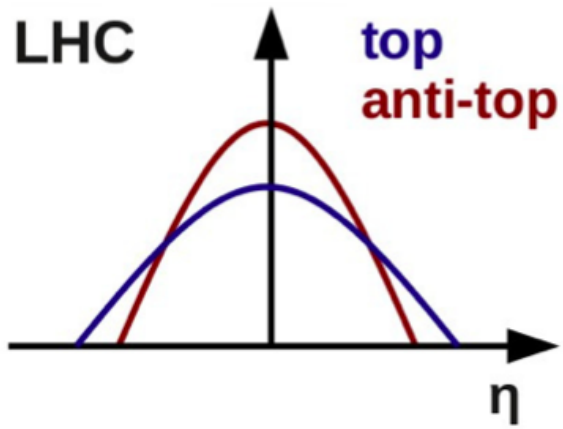
Charge asymmetry in ATLAS

ℓ + jets channel (1.04 fb^{-1})

arXiv:1203.4211 [hep-ex]

$$A_c = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

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

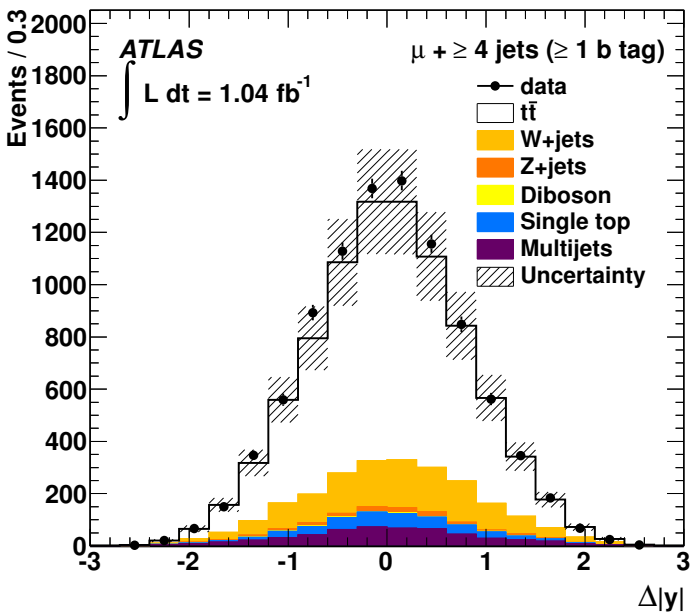


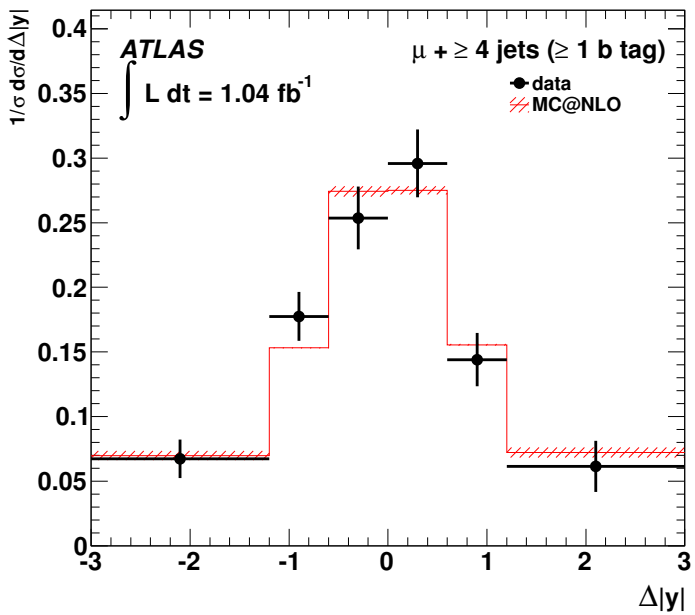
Charge asymmetry in ATLAS

ℓ + jets channel (1.04 fb^{-1}) arXiv:1203.4211 [hep-ex]

$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

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





Measured:

$$A_C = -0.018 \pm 0.028\,(\text{stat}) \pm 0.023\,(\text{syst})$$

MC@NLO prediction: $A_C = -0.006 \pm 0.002$

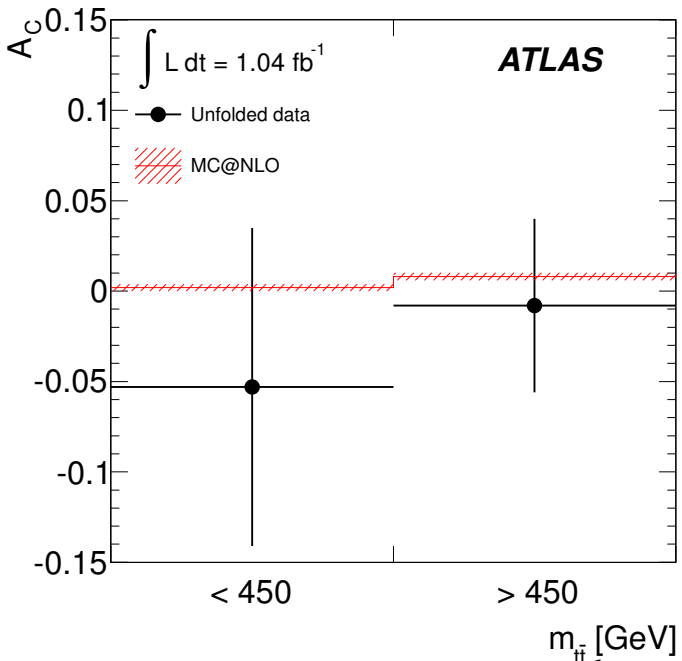
Main syst.: generator, fragmentation, ISR/FSR, JES

Charge asymmetry in ATLAS

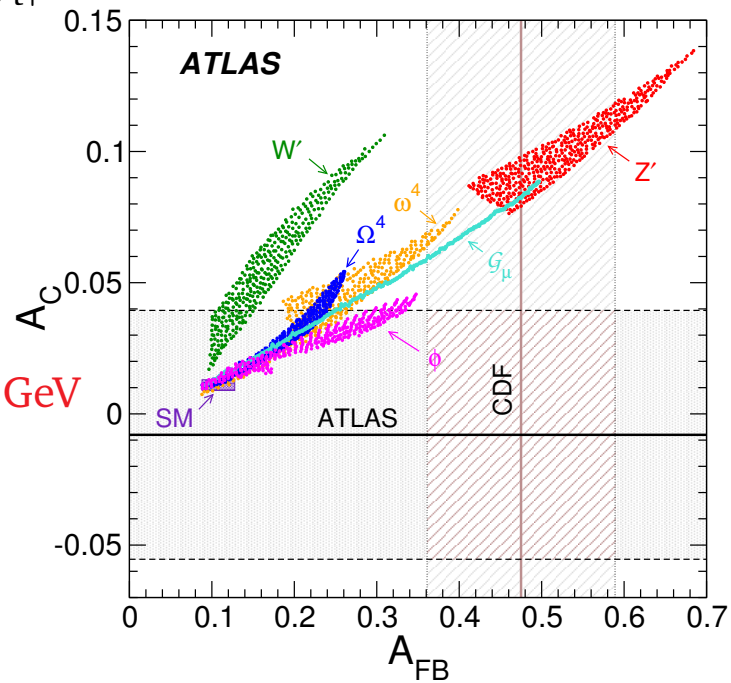
ℓ + jets channel (1.04 fb^{-1}) arXiv:1203.4211 [hep-ex]

$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

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



for $M_{t\bar{t}} > 450$ GeV



Measured:

$$A_C = -0.018 \pm 0.028\,(\text{stat}) \pm 0.023\,(\text{syst})$$

MC@NLO prediction: $A_C = -0.006 \pm 0.002$

Main syst.: generator, fragmentation, ISR/FSR, JES

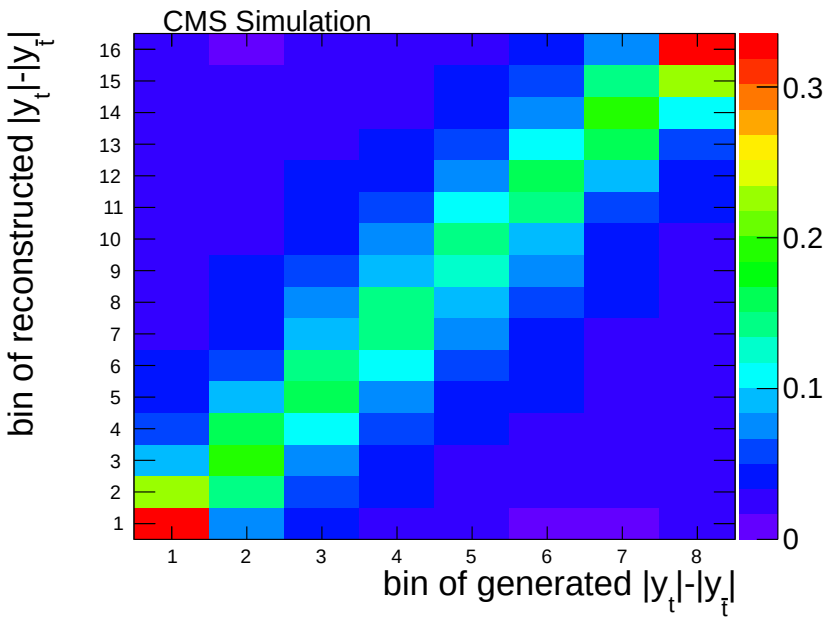
Charge asymmetry differentially in CMS

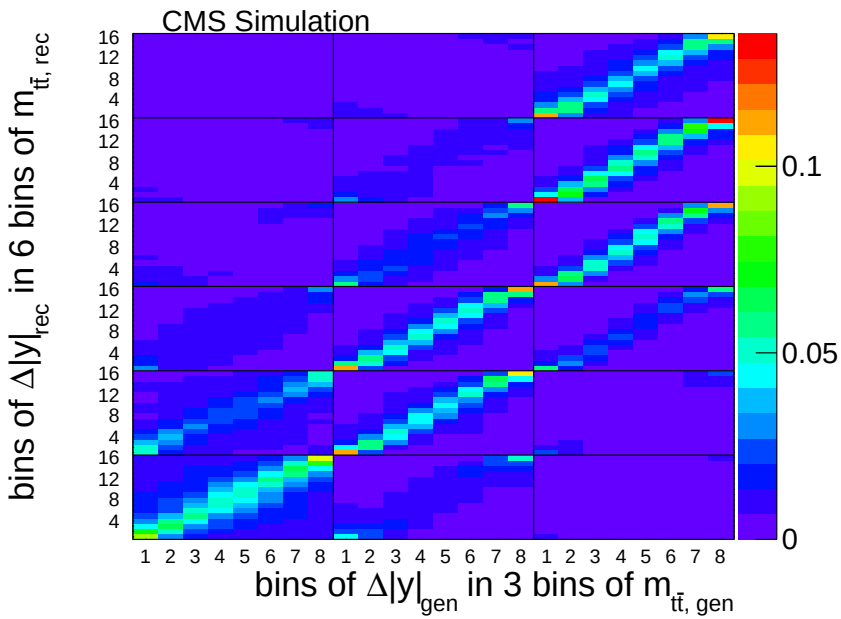
ℓ + jets channel (4.7 fb^{-1})

CMS-PAS-TOP-11-030

$$A_c = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

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





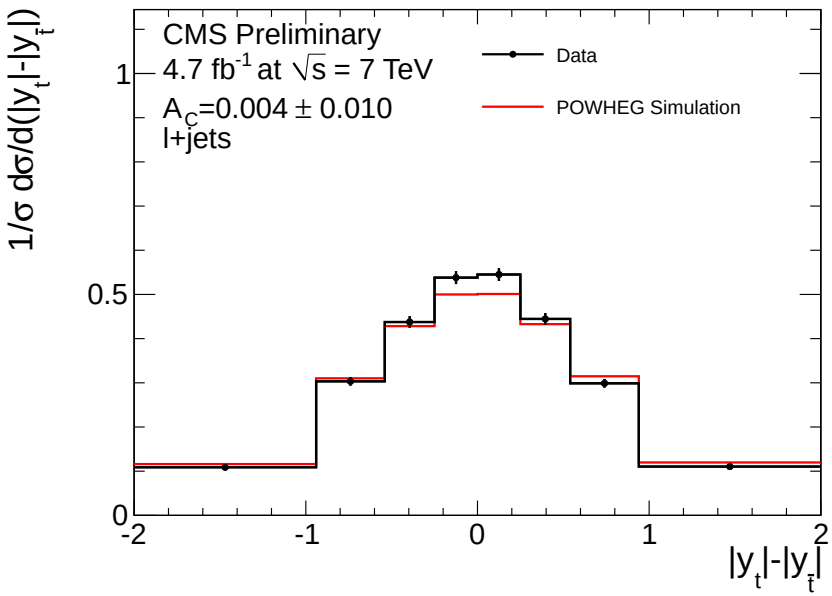
Charge asymmetry differentially in CMS

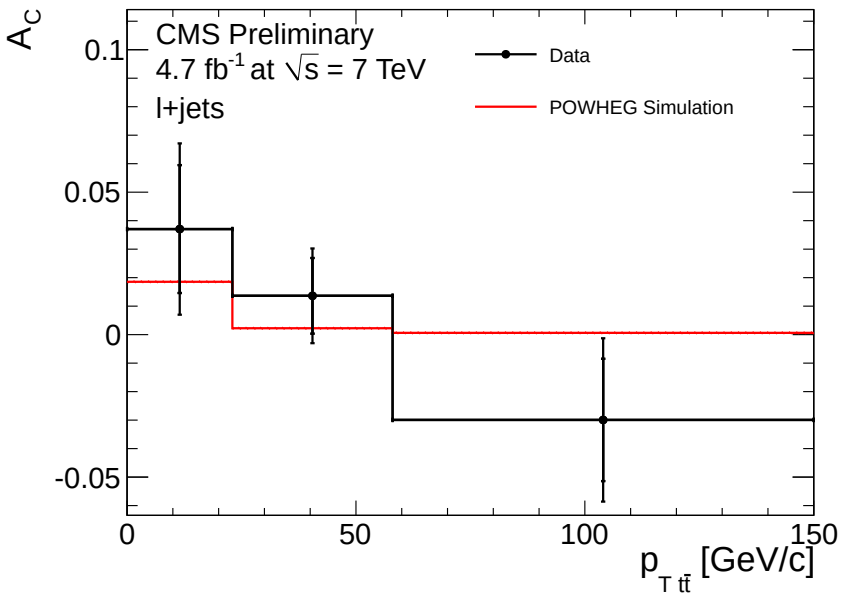
ℓ + jets channel (4.7 fb^{-1})

CMS-PAS-TOP-11-030

$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

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





Measured:

$$A_C = -0.004 \pm 0.010\,(\text{stat}) \pm 0.012\,(\text{syst})$$

SM prediction: $A_C = -0.0115 \pm 0.0006$

Main syst.: unfolding, W + jets, lepton ID

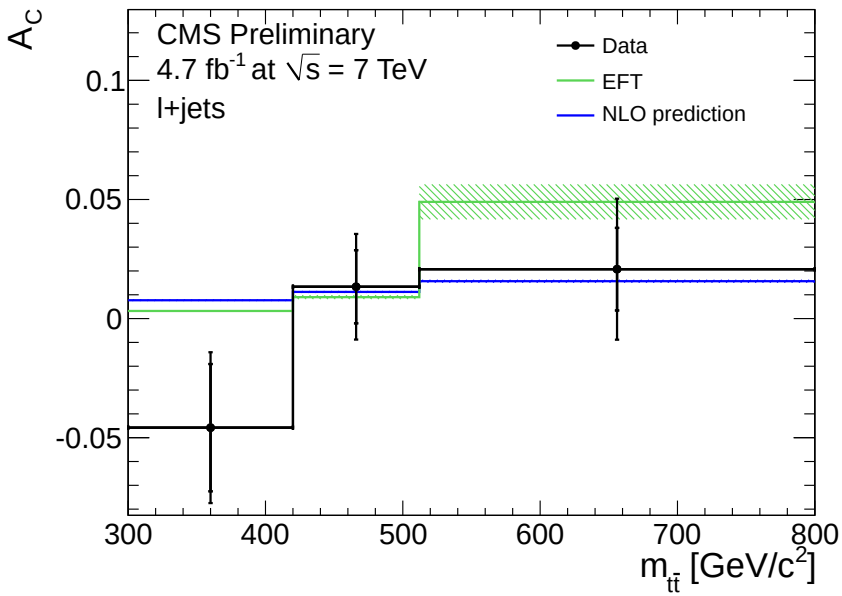
Charge asymmetry differentially in CMS

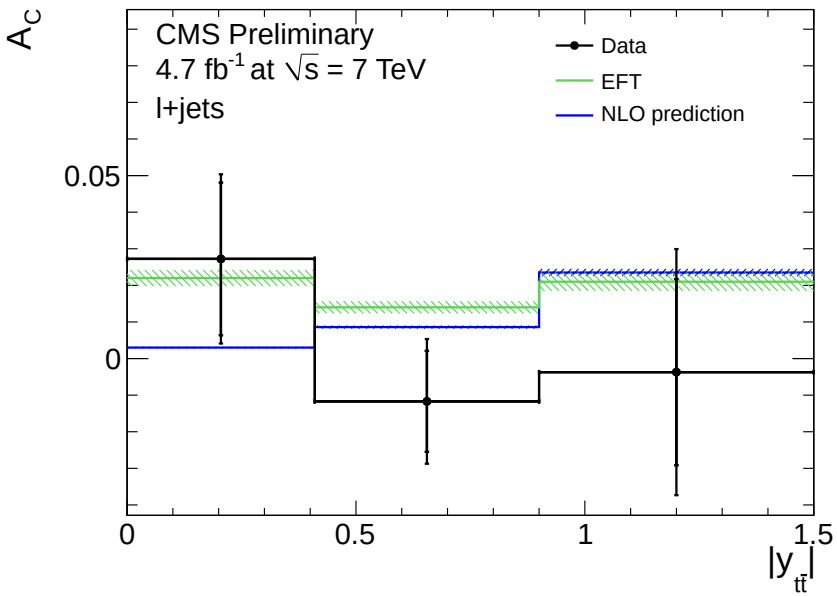
ℓ + jets channel (4.7 fb^{-1})

CMS-PAS-TOP-11-030

$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

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





Measured:

$$\mathbf{A_C = -0.004 \pm 0.010\,(stat) \pm 0.012\,(syst)}$$

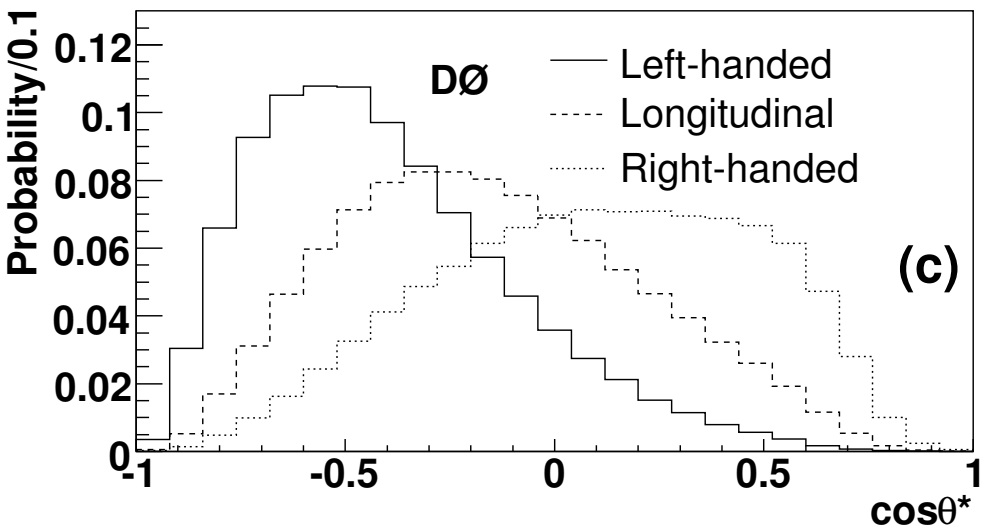
SM prediction: $A_C = -0.0115 \pm 0.0006$

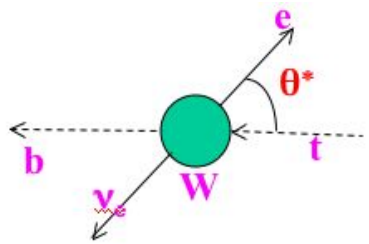
Main syst.: unfolding, W + jets, lepton ID

W boson helicity fractions

Tevatron combination (2.7–5.4 fb^{-1}) arXiv:1202.5272 [hep-ex]

CDF	ℓ + jets	matrix element method	$m_{top} = 175.0$ GeV	2.7 fb^{-1}
CDF	dilepton	$\cos\theta^*$ template fit	$m_{top} = 175.0$ GeV	5.1 fb^{-1}
DØ	dilepton & ℓ + jets	$\cos\theta^*$ template fit	$m_{top} = 172.5$ GeV	5.4 fb^{-1}



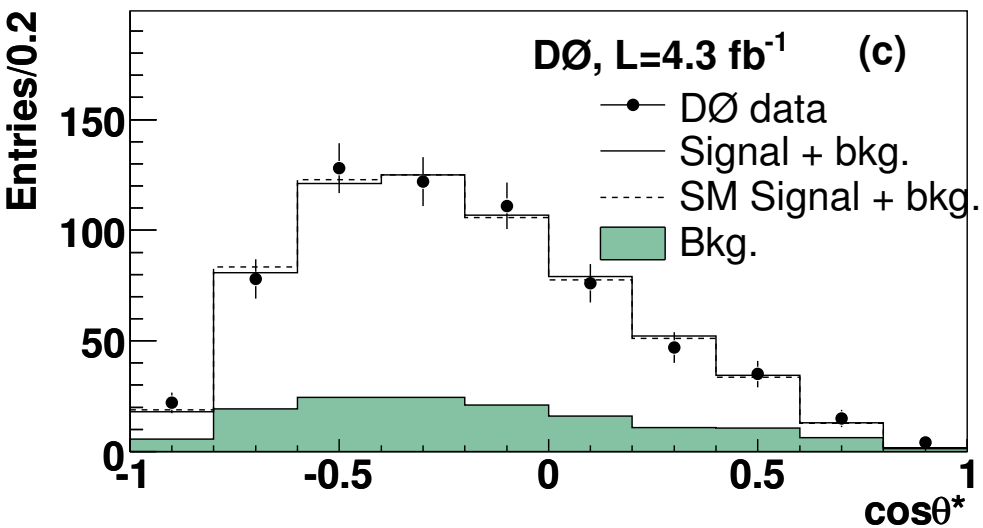


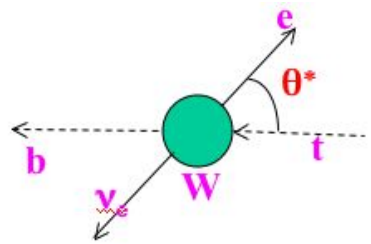
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta^*)f_0 - \frac{3}{8}(1-\cos\theta^*)^2 f_- + \frac{3}{8}(1+\cos\theta^*)^2 f_+$$

W boson helicity fractions

Tevatron combination (2.7–5.4 fb^{-1}) arXiv:1202.5272 [hep-ex]

CDF	ℓ + jets	matrix element method	$m_{top} = 175.0$ GeV	2.7 fb^{-1}
CDF	dilepton	$\cos\theta^*$ template fit	$m_{top} = 175.0$ GeV	5.1 fb^{-1}
DØ	dilepton & ℓ + jets	$\cos\theta^*$ template fit	$m_{top} = 172.5$ GeV	5.4 fb^{-1}





$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta^*)f_0 - \frac{3}{8}(1-\cos\theta^*)^2 f_- + \frac{3}{8}(1+\cos\theta^*)^2 f_+$$

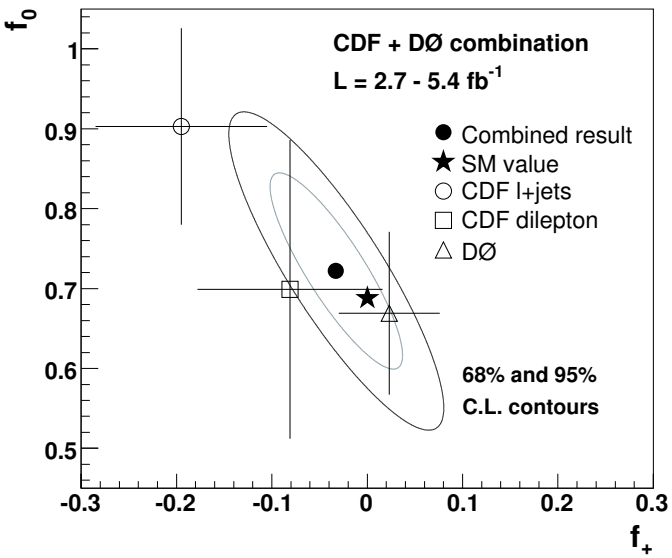
$\rightarrow$ **fit f_0 and f_+ with $f_0 + f_+ + f_- = 1$**

W boson helicity fractions

Tevatron combination (2.7–5.4 fb^{-1}) arXiv:1202.5272 [hep-ex]

CDF	ℓ + jets	matrix element method	$m_{top} = 175.0$ GeV	2.7 fb^{-1}
CDF	dilepton	$\cos\theta^*$ template fit	$m_{top} = 175.0$ GeV	5.1 fb^{-1}
DØ	dilepton & ℓ + jets	$\cos\theta^*$ template fit	$m_{top} = 172.5$ GeV	5.4 fb^{-1}

$\rightarrow$ **fit f_0 and f_+ with $f_0 + f_+ + f_- = 1$**



Measured:

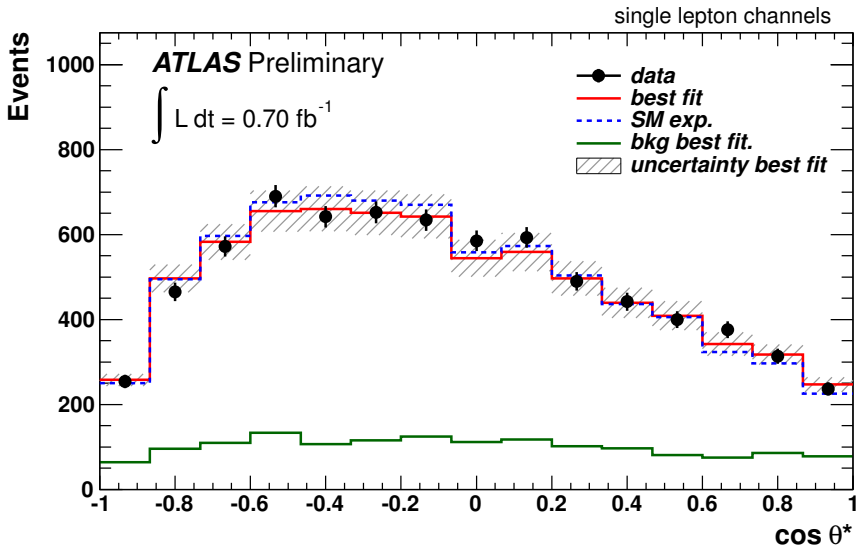
$$f_0 = +0.722 \pm 0.081 \pm 0.062\,(\text{stat.}) \pm 0.052\,(\text{syst.})$$
$$f_+ = -0.033 \pm 0.046 \pm 0.034\,(\text{stat.}) \pm 0.031\,(\text{syst.})$$

SM predictions (NNLO):

$$f_0 = 0.688 \pm 0.004\ (\text{stat.})$$
$$f_+ = 0.0017 \pm 0.0001\ (\text{stat.})$$
$$f_- = 0.310 \pm 0.004\ (\text{stat.})$$

W boson polarisation

Dilepton & ℓ + jets channel (0.70 fb^{-1}) ATLAS-CONF-2011-122



Measured in ℓ + jets:

$$F_0 = 0.57 \pm 0.07\,(\text{stat.}) \pm 0.09\,(\text{syst.})$$

$$F_L = 0.35 \pm 0.04\,(\text{stat.}) \pm 0.04\,(\text{syst.})$$

$$F_R = 0.09 \pm 0.04\,(\text{stat.}) \pm 0.08\,(\text{syst.})$$

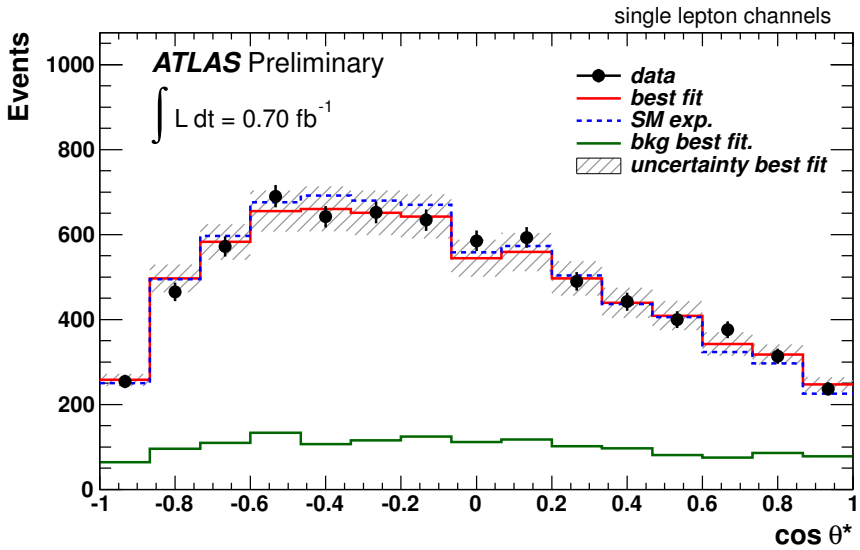
Combined with dilepton channel (fixed F_R):

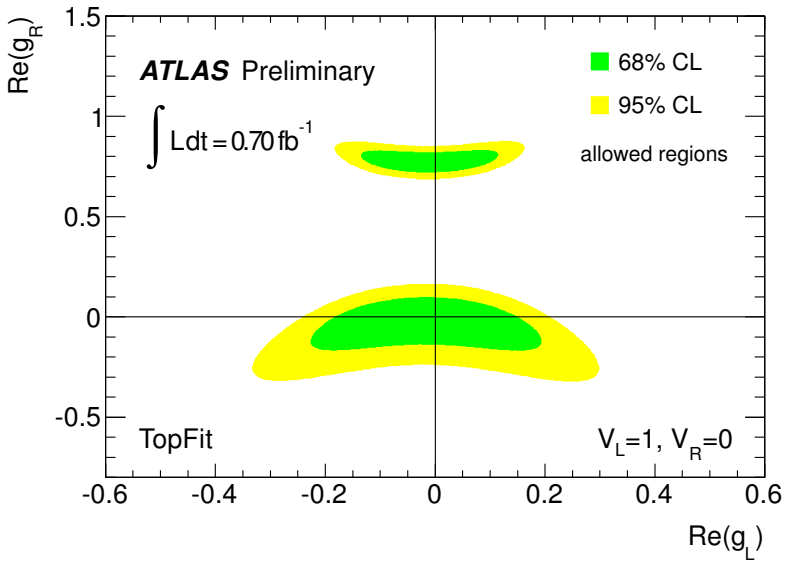
$$F_0 = 0.75 \pm 0.08\,(\text{stat. + syst.})$$

Main syst.: b-tagging, calorimeter readout, signal modelling, ISR/FSR

W boson polarisation

Dilepton & ℓ + jets channel (0.70 fb^{-1}) ATLAS-CONF-2011-122





Angular asymmetries: $A_{\pm} = \frac{N(\cos\theta^* > z) - N(\cos\theta^* < z)}{N(\cos\theta^* > z) + N(\cos\theta^* < z)}$ with $z = \mp(2^{2/3} - 1)$

Measured:

$A_+ = +0.54 \pm 0.02\,(\text{stat.}) \pm 0.04\,(\text{syst.})$

$A_- = -0.85 \pm 0.01\,(\text{stat.}) \pm 0.02\,(\text{syst.})$

SM prediction:

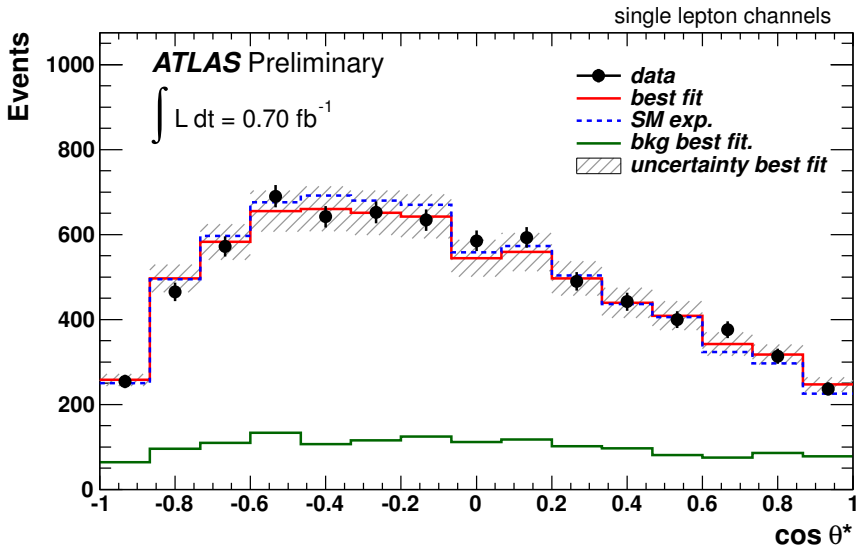
$A_+ = +0.537 \pm 0.004$

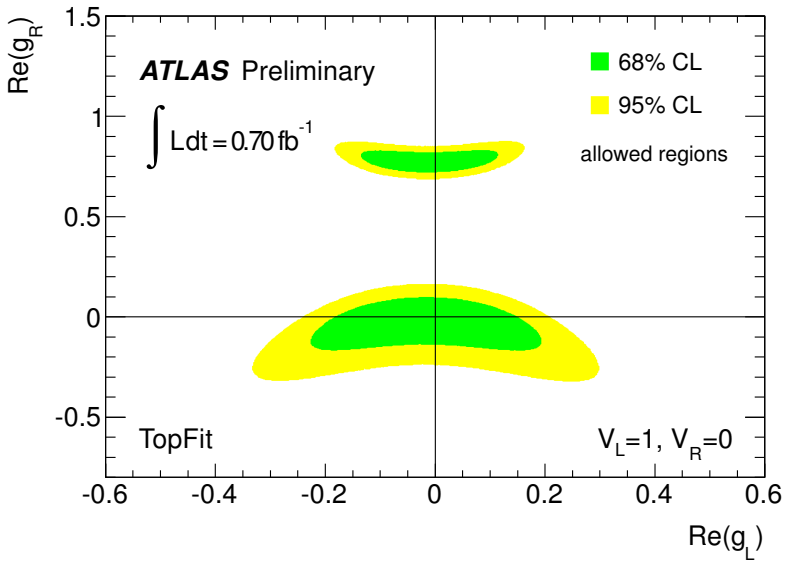
$A_- = -0.841 \pm 0.006$

Main syst.: JES, signal modelling, ISR/FSR

W boson polarisation

Dilepton & ℓ + jets channel (0.70 fb^{-1}) ATLAS-CONF-2011-122





Angular asymmetries: $A_{\pm} = \frac{N(\cos\theta^* > z) - N(\cos\theta^* < z)}{N(\cos\theta^* > z) + N(\cos\theta^* < z)}$ with $z = \mp(2^{2/3} - 1)$

Measured:

$$A_+ = +0.54 \pm 0.02\,(\text{stat.}) \pm 0.04\,(\text{syst.})$$
$$A_- = -0.85 \pm 0.01\,(\text{stat.}) \pm 0.02\,(\text{syst.})$$

Derived from the angular asymmetries:

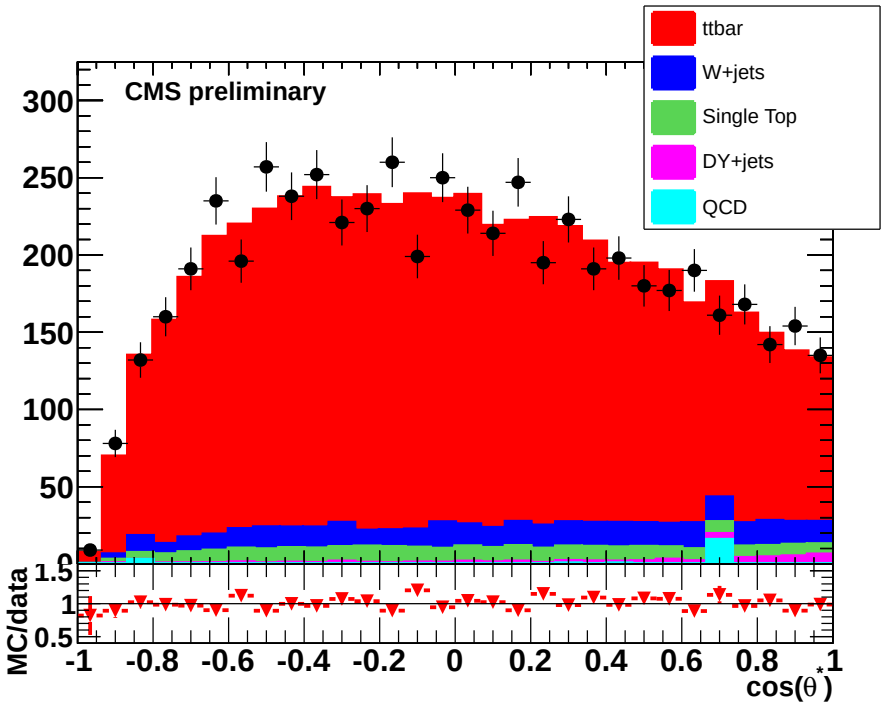
$$F_0 = +0.71 \pm 0.10\,(\text{stat. + syst.})$$
$$F_L = +0.31 \pm 0.07\,(\text{stat. + syst.})$$
$$F_R = -0.01 \pm 0.04\,(\text{stat. + syst.})$$

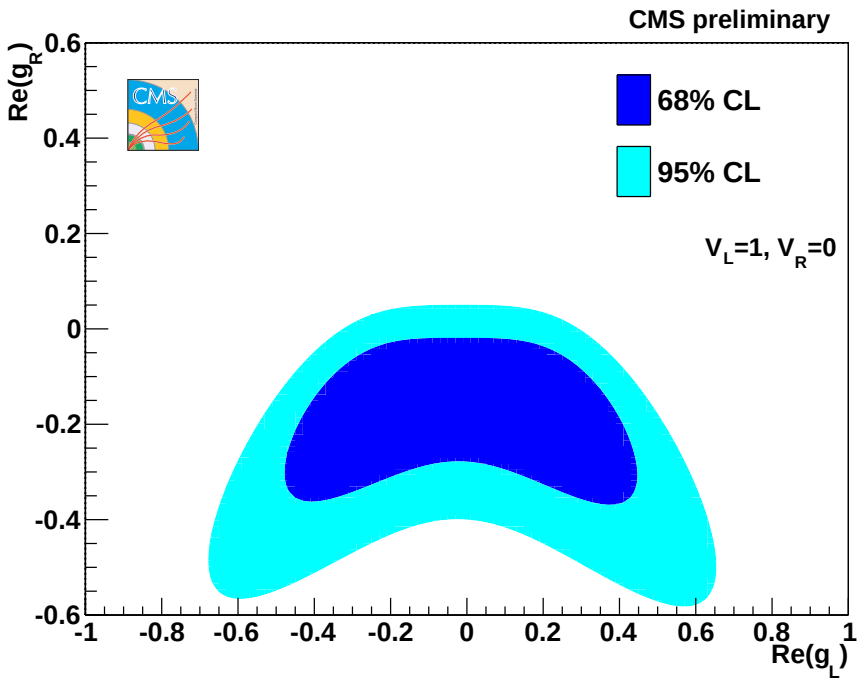
Main syst.: JES, signal modelling, ISR/FSR

W boson polarisation

ℓ + jets channel (2.2 fb^{-1})

CMS-PAS-TOP-11-020





Measured in ℓ + jets:

$$F_0 = 0.567 \pm 0.074\,(\text{stat.}) \pm 0.047\,(\text{syst.})$$
$$F_L = 0.393 \pm 0.045\,(\text{stat.}) \pm 0.029\,(\text{syst.})$$
$$F_R = 0.040 \pm 0.035\,(\text{stat.}) \pm 0.044\,(\text{syst.})$$

Main syst.: background normalisation, JES, radiation