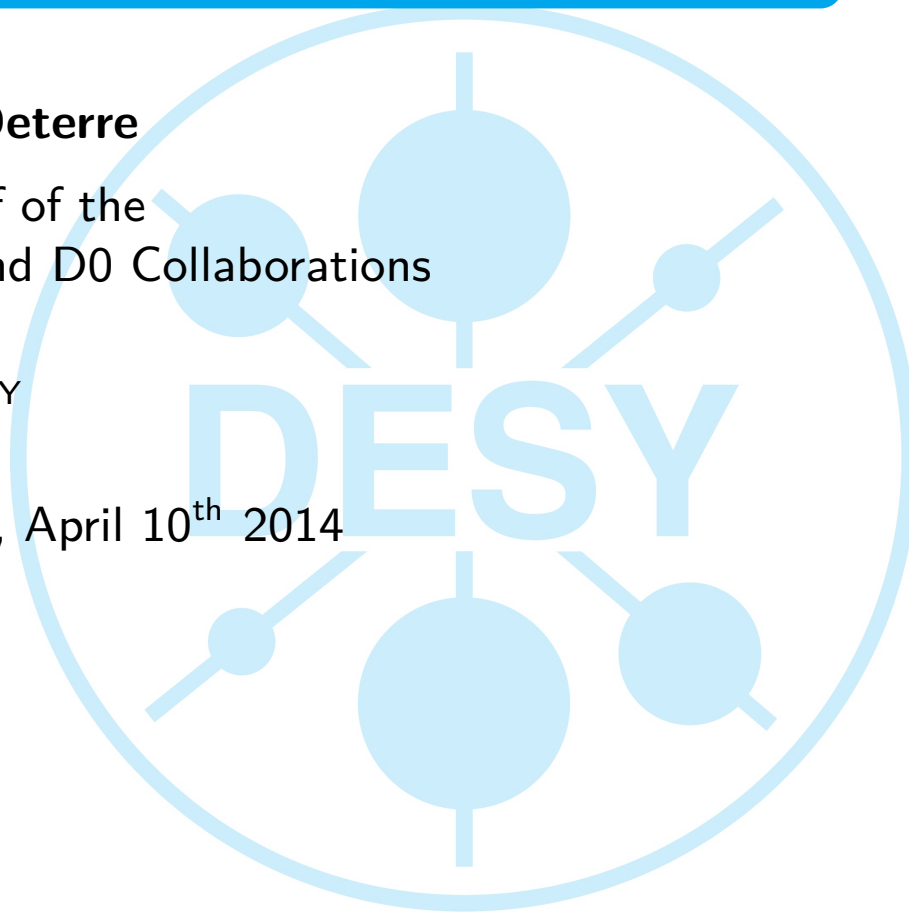
Top properties and new physics studies in $t\bar{t}$ production at the Tevatron and the LHC

Cécile Deterre

on behalf of the
ATLAS, CDF, CMS and D0 Collaborations

DESY

SM@LHC, Madrid, April 10th 2014

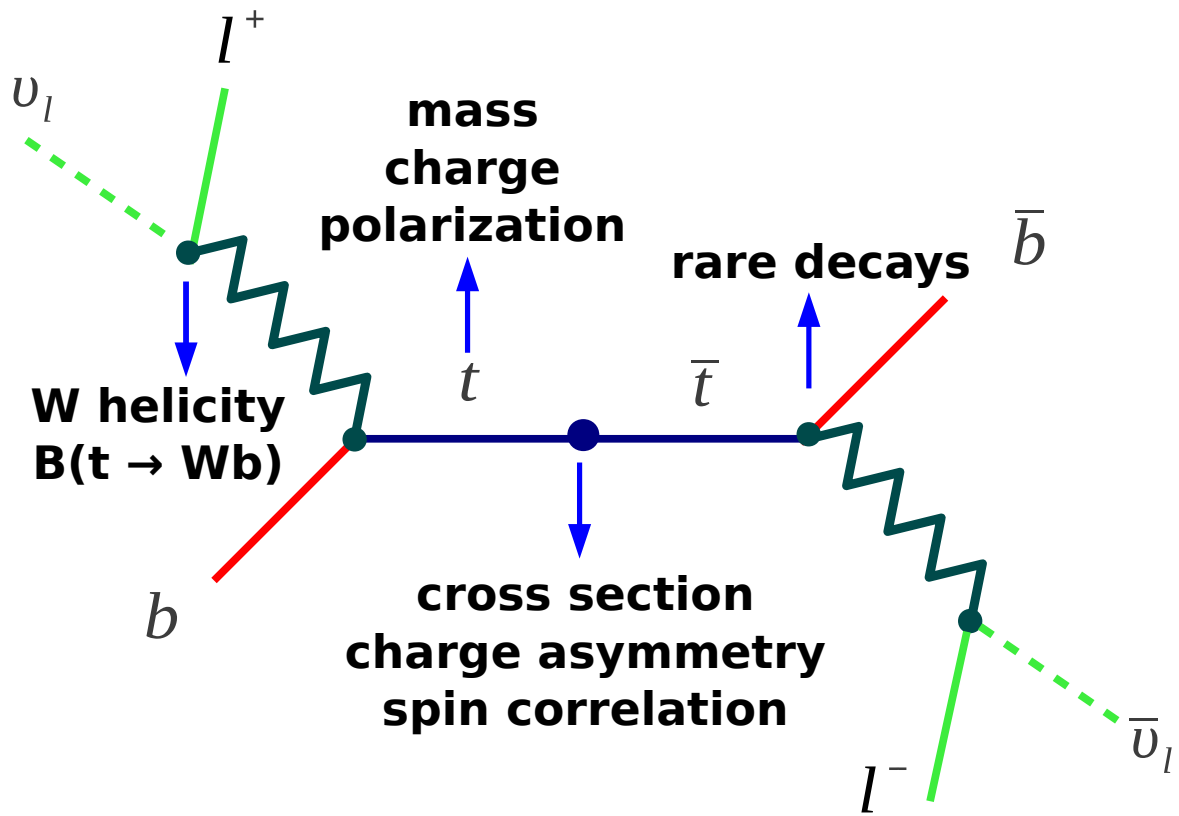


HELMHOLTZ GEMEINSCHAFT

Introduction

Why do we study the properties of the top quark?

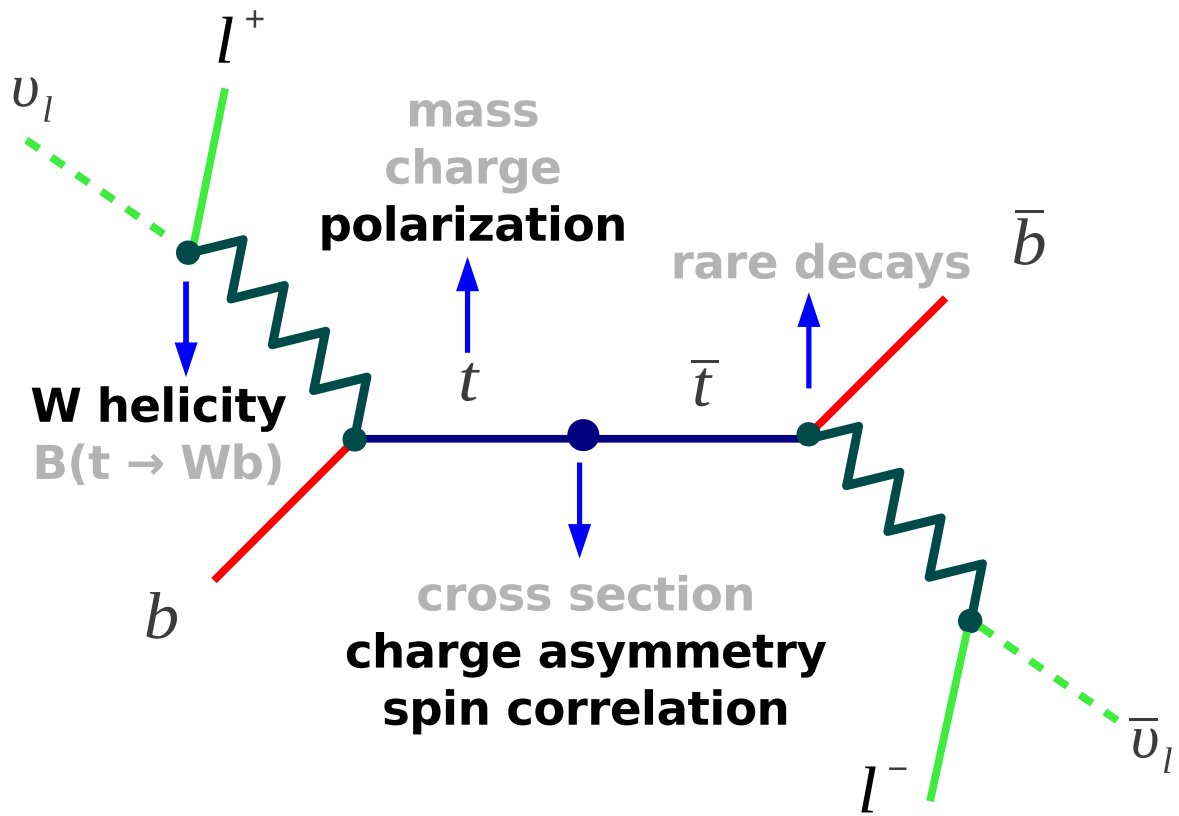
- Strong coupling to the Higgs $\rightarrow$ **special role** in the Standard Model?
- Possibility to study a **quark before hadronization**.
- High statistics $\rightarrow$ precision measurements are possible



Introduction

Why do we study the properties of the top quark?

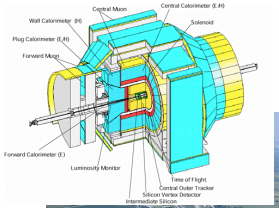
- Strong coupling to the Higgs → **special role** in the Standard Model?
- Possibility to study a **quark before hadronization**.
- High statistics → precision measurements are possible

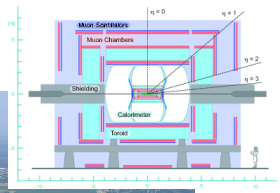


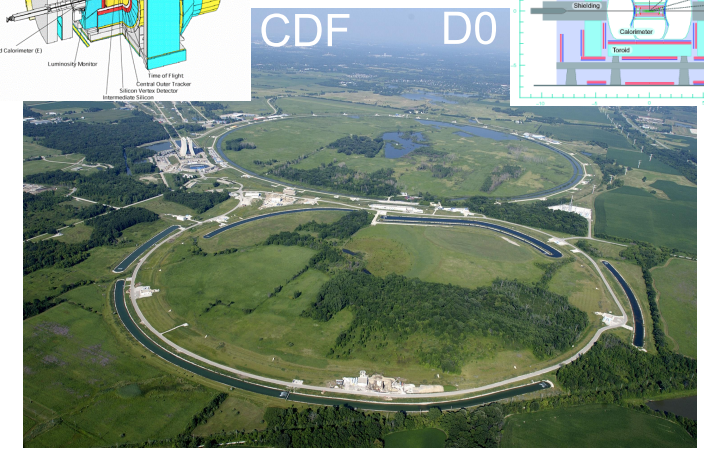
Tevatron vs LHC

Tevatron

$p\bar{p}$ collisions, 1.96 TeV, ~9.7 fb^{-1}

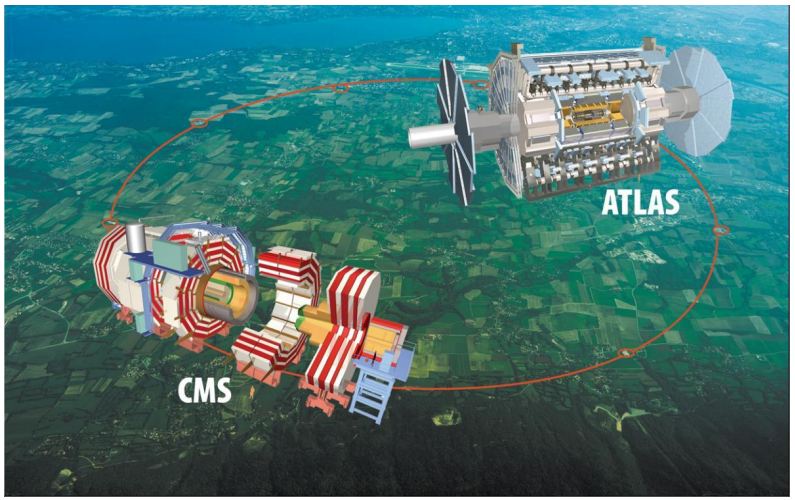




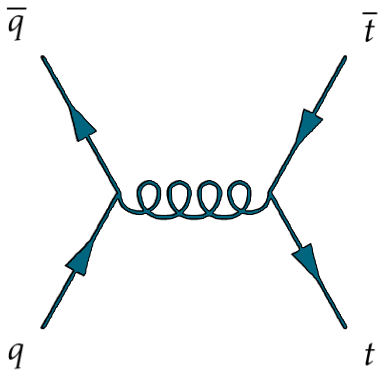


LHC

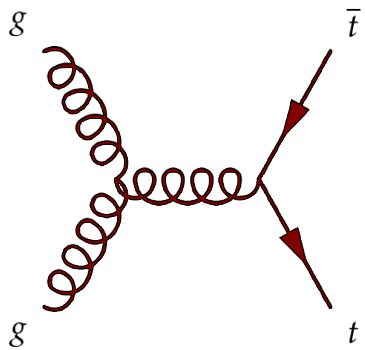
pp collisions, 7 TeV, ~5 fb^{-1}
8 TeV, ~20 fb^{-1}



$q\bar{q}$ annihilation dominates



gg fusion dominates

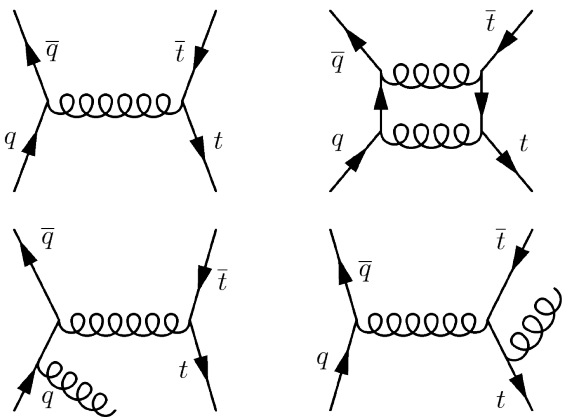


1. Asymmetry measurements
   - Introduction
   - Tevatron results
   - Results from the LHC
2. Polarisation and spin correlation measurements
3. W polarisation
4. Conclusion

Asymmetry - introduction

- Top/antitop emitted preferentially in one direction with respect to the direction of the interacting partons.

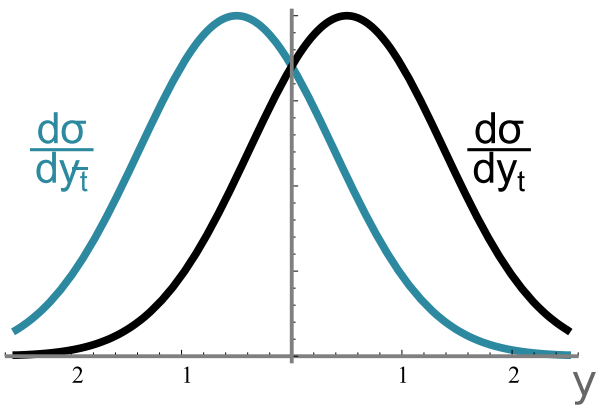
- Effect predicted by the Standard Model at NLO in QCD.
- Only from $q\bar{q}$ and qg initial states.
- Small effect in the SM, could be increased in new physics models.



Asymmetry - top asymmetries

Tevatron

- direction of the quark $\approx$ direction of the proton beam
- **"forward-backward asymmetry"**
- SM predictions between 5 and 9%

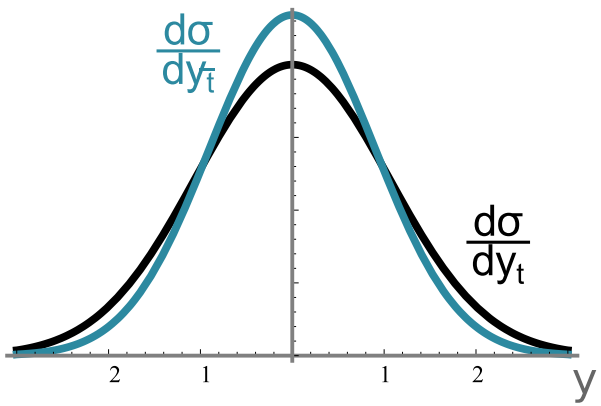


$$A_{FB} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)},$$

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

LHC

- quark more boosted than antiquark (from the sea)
- **"charge asymmetry"**
- SM predictions of $\approx$ 1%



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

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

Asymmetry - lepton asymmetries

- Lepton asymmetries are **complementary observables**:
  - sensitive to new physics in the top decay
  - don't need the kinematic reconstruction of the events
- At the Tevatron, can be measured both in the dilepton and lepton+jets channels.
- At the LHC, only measured for the dilepton channel so far.

Tevatron

- **Lepton pair asymmetry**:

$$A_{FB}^{\ell\ell} = \frac{N(\Delta\eta > 0) - N(\Delta\eta < 0)}{N(\Delta\eta > 0) + N(\Delta\eta < 0)},$$

where: $\Delta\eta = \eta_{l^+} - \eta_{l^-}$

- **Single-lepton asymmetry**:

$$A_{FB}^{\ell} = \frac{N(q\eta > 0) - N(q\eta < 0)}{N(q\eta > 0) + N(q\eta < 0)}$$

LHC

- **Lepton pair asymmetry**:

$$A_{C}^{\ell\ell} = \frac{N(\Delta|\eta| > 0) - N(\Delta|\eta| < 0)}{N(\Delta|\eta| > 0) + N(\Delta|\eta| < 0)},$$

where: $\Delta|\eta| = |\eta_{l^+}| - |\eta_{l^-}|$

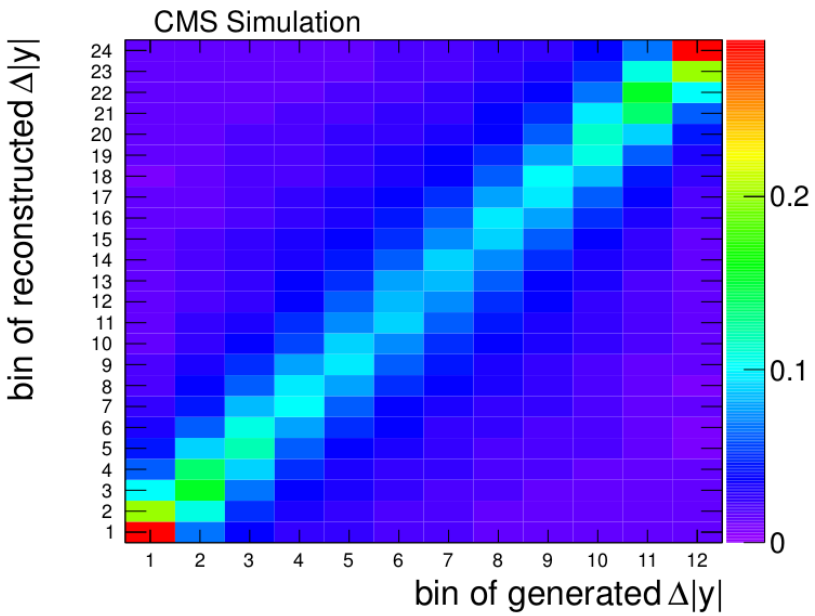
A word about unfolding

- Unfolding used in most asymmetry measurements (and other property studies).
- Goal is to **account for detector effects**, and compare corrected data with predictions at production level.
- For the asymmetry, there can be up to a factor of 2 between the asymmetries at the reco and production level.

Method

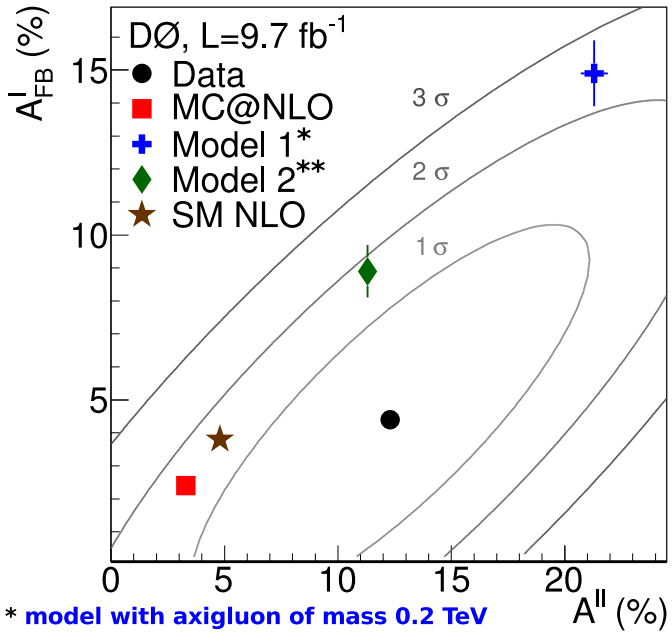
Several methods available (SVD, FBU, iterative Bayesian...).
Common ingredients:

- **response matrix** (migrations between the bins);
- **efficiency correction** (selection and reconstruction efficiency).

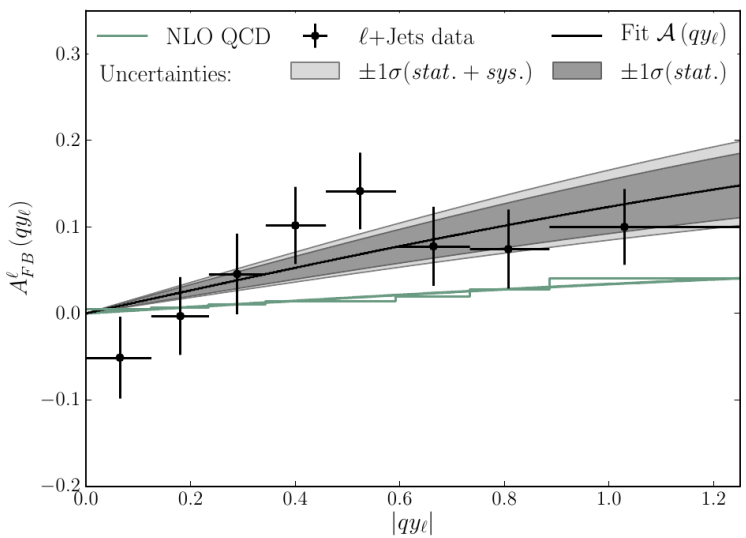


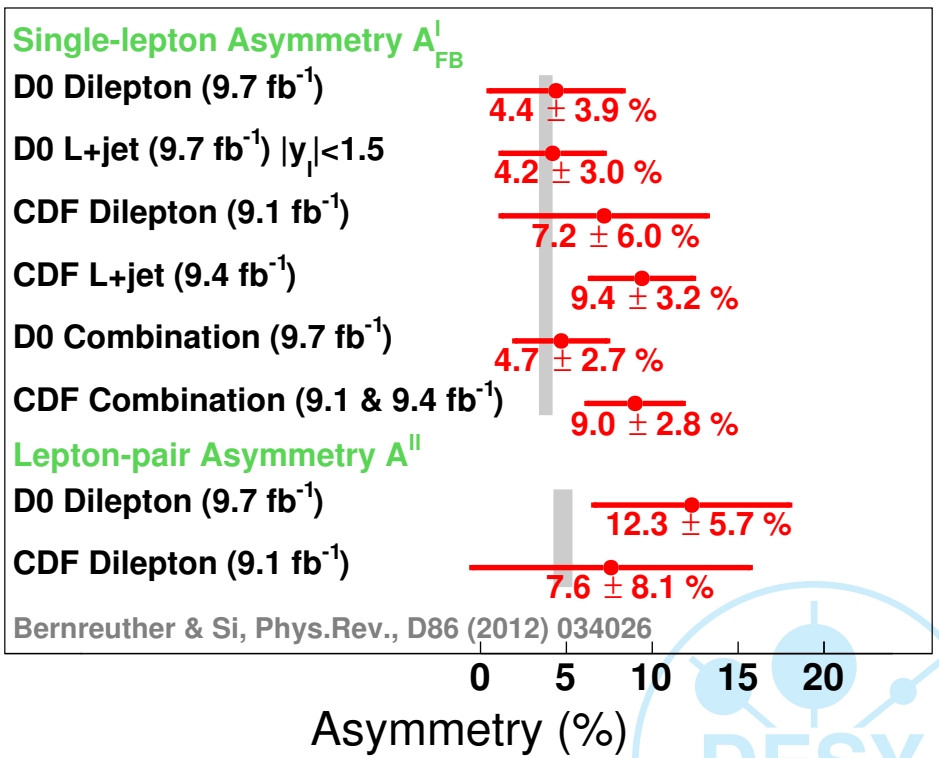
1. Asymmetry measurements
   - Introduction
   - Tevatron results
   - Results from the LHC
2. Polarisation and spin correlation measurements
3. W polarisation
4. Conclusion

Tevatron results - lepton asymmetries



* model with axigluon of mass 0.2 TeV
** model with axigluon of mass 2 TeV
[arXiv:1212.4003]



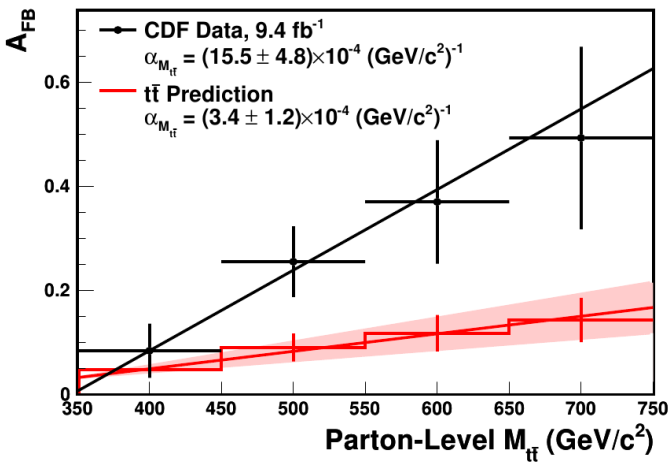


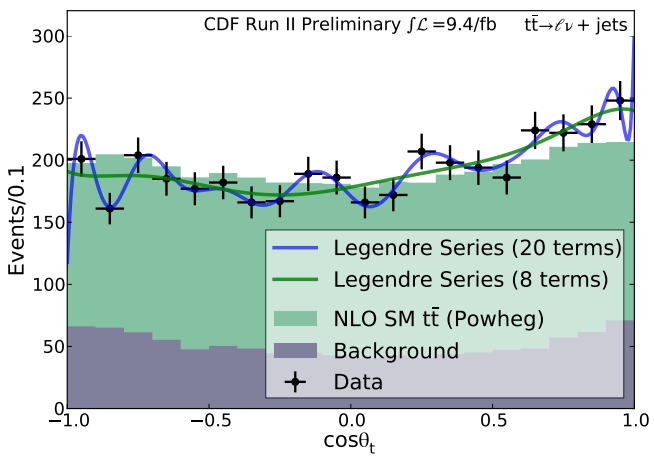
D0 arXiv:1403.1294, subm. to PRD
CDF Conf. Note 11035

Tevatron results - $t\bar{t}$ asymmetries at CDF

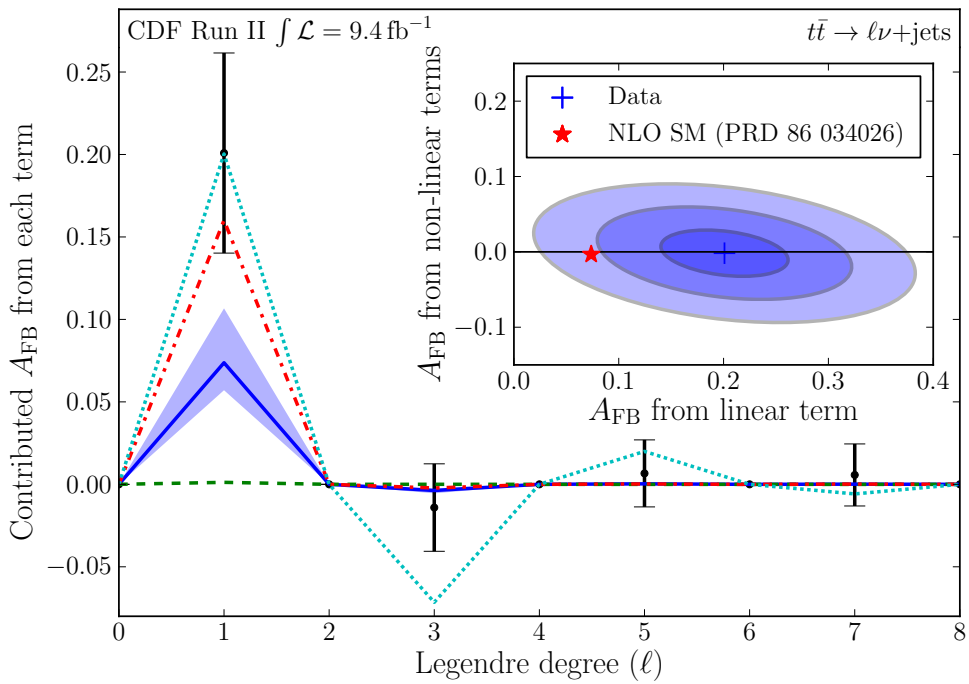
Results - 9.4 fb^{-1} [PRD 87 092002] [PRL 111 182002]

- $\ell + jets$ inclusive measurement: $A_{FB} = 16.4 \pm 4.7\%$
- Differential measurement as a function of $M_{t\bar{t}}$ and $|\Delta y|$.
- Dominant systematic uncertainty: background shape and normalization.





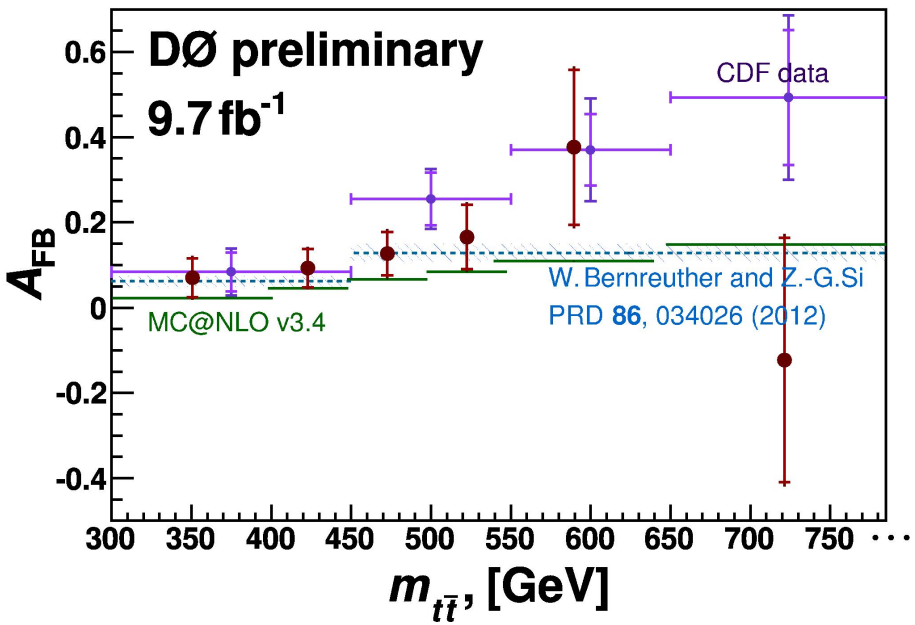
Additional study: angular cross section ($\cos\theta_t$) shows that source of A_{FB} is s-channel-like dynamics.



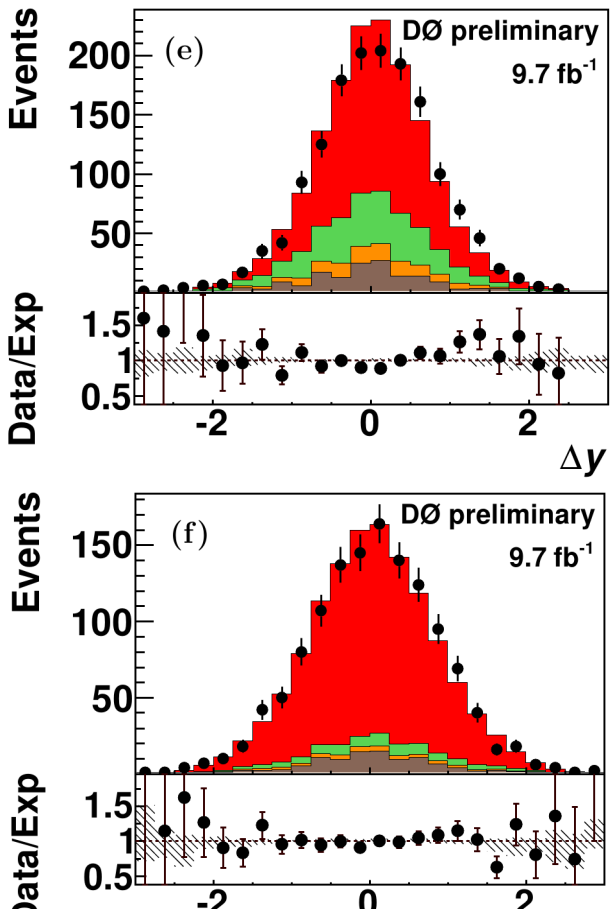
Tevatron results - $t\bar{t}$ asymmetries at D0

Results - 9.4 fb^{-1} [Conf. Note 6425]

- $\ell + jets$ inclusive measurement: $A_{FB} = 10.6 \pm 3.0\%$
- Differential measurement as a function of $M_{t\bar{t}}$.
- Dominant systematics: background modelling.



Channel	Predicted	Measured
3 jets, 1 b tag	4.7	$5.4 \pm 6.0^{+3.3}_{-4.0}$
3 jets, $\geq$2 b tags	5.6	$10.7 \pm 4.2 \pm 0.8$
$\geq$4 jets, 1 b tag	1.9	$11.0 \pm 4.4 \pm 0.8$
$\geq$4 jets, $\geq$2 b tags	3.3	$5.9 \pm 3.3 \pm 0.1$

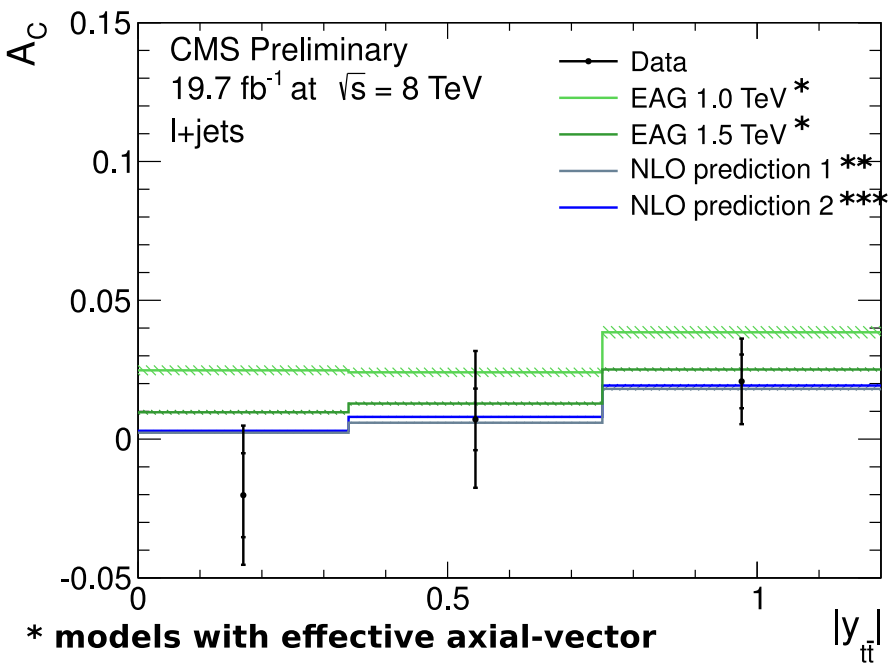


1. Asymmetry measurements
   - Introduction
   - Tevatron results
   - Results from the LHC
2. Polarisation and spin correlation measurements
3. W polarisation
4. Conclusion

CMS measurements

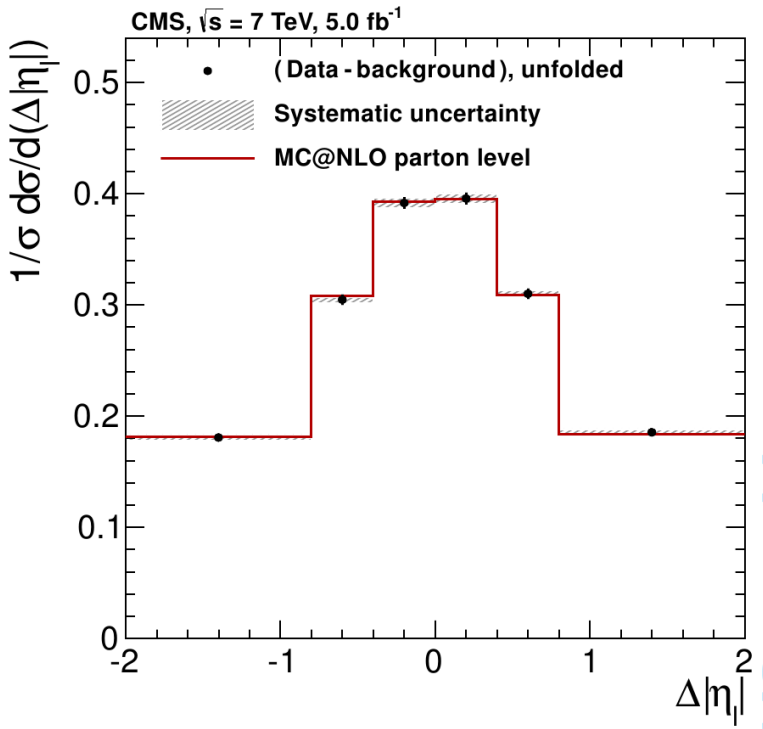
Results

- $\ell + jets$ [PLB 717 (2012) 129, CMS-PAS-TOP-12-033]
  - 7 TeV: $A_C = 0.4 \pm 1.0$ (stat.) ± 1.1 (syst.)%
  - 8 TeV $A_C = 0.5 \pm 0.7$ (stat.) ± 0.6 (syst.)%
- $\ell\ell$ - 7 TeV [arXiv:1402.3803, subm. to JHEP]
  - $A_C = -1.0 \pm 1.7$ (stat.) ± 0.8 (syst.)%
  - $A_C^{\ell\ell} = 0.9 \pm 1.0$ (stat.) ± 0.6 (syst.)%



*** models with effective axial-vector coupling of the gluon** [PRD 85 (2012) 074021]

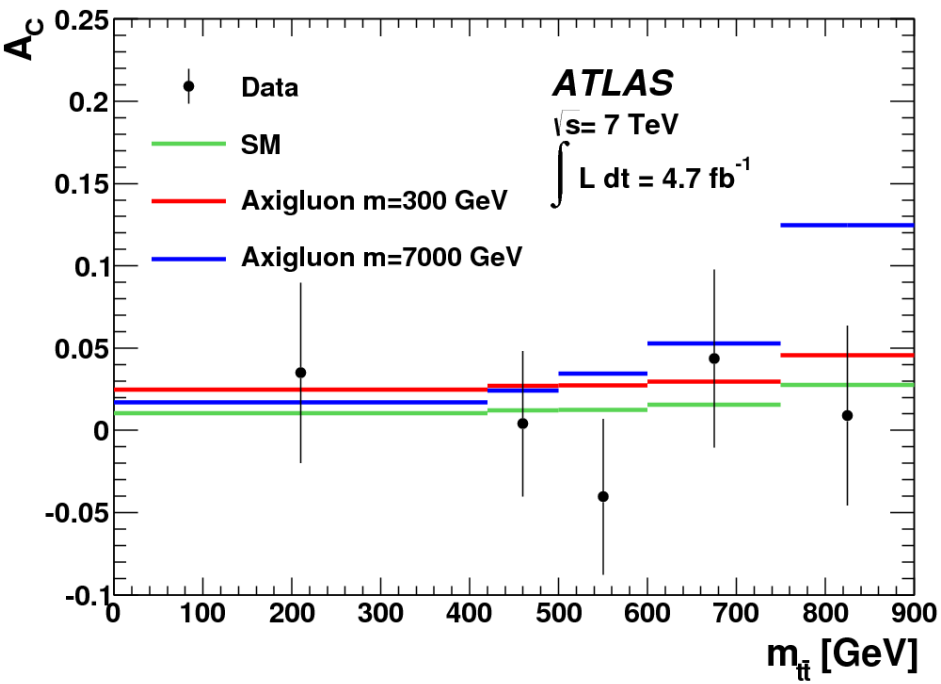
** [JHEP 1201 (2012) 063] *** [PRD 86 (2012) 034026]

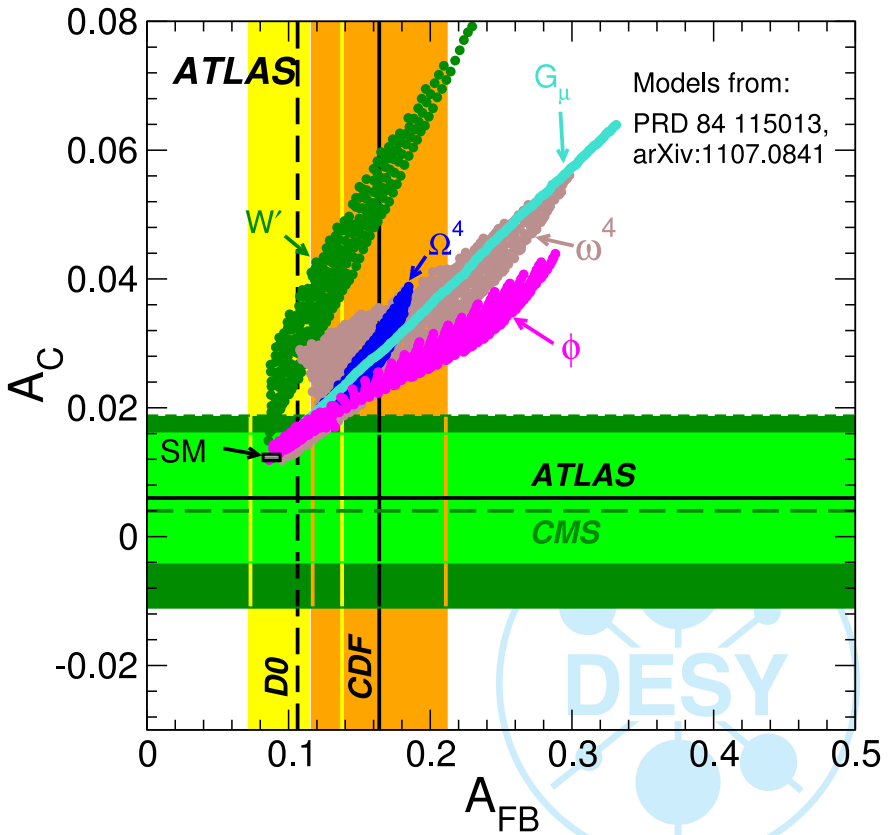


ATLAS measurements

Results - 7 TeV - 4.7 fb^{-1}

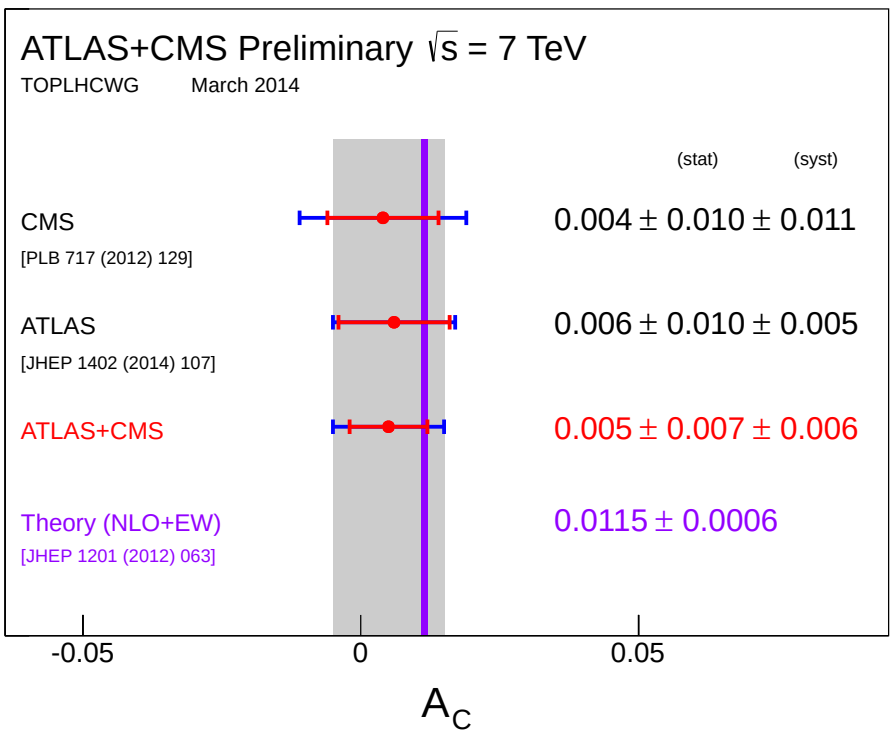
- $\ell + jets$ [JHEP 02 (2014) 107]
  - $A_C = 0.6 \pm 1.0\%$
- $\ell\ell$ [ATLAS-CONF-2012-057]
  - $A_C = 5.7 \pm 2.4$ (stat.) ± 1.5 (syst.)%
  - $A_C^{\ell\ell} = 2.3 \pm 1.2$ (stat.) ± 0.8 (syst.)%





LHC combination

- Combination of ATLAS and CMS 7 TeV $\ell + jets$ results.
- $A_C = 0.5 \pm 0.7$ (stat.) ± 0.6 (syst.)%
- Work on harmonizing systematic uncertainties and understanding correlations.



		ATLAS	CMS	Comb.	Corr.
	A_C	0.006	0.004	0.005	0.058
	Statistical	0.010	0.010	0.007	0
Uncertainties	Detector response model	0.004	0.007	0.004	0
	Signal model	< 0.001	0.002	0.001	1
	W+jets model	0.002	0.004	0.003	0.5
	QCD model	< 0.001	0.001	0.000	0
	Pileup+MET	0.002	< 0.001	0.001	0
	PDF	0.001	0.002	0.001	1
	MC statistics	0.002	0.002	0.001	0
	Model dependence				
	Specific physics models	< 0.001	*	0.000	0
	General simplified models	*	0.007	0.002	0
	Systematic uncertainty	0.005	0.011	0.006	
	Total uncertainty	0.011	0.015	0.009	

[ATLAS-CONF-2014-012] [CMS PAS TOP-14-006]

1 Asymmetry measurements
- Introduction
- Tevatron results
- Results from the LHC

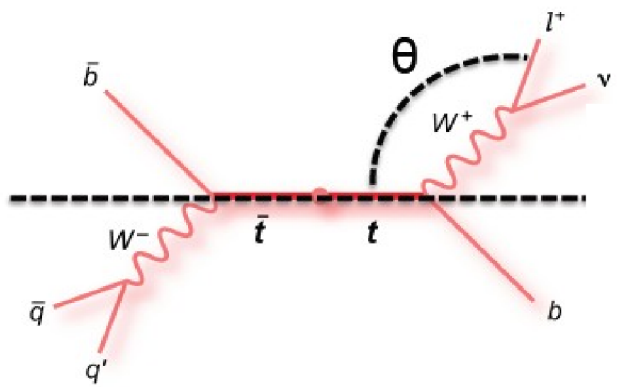
2 Polarisation and spin correlation measurements

3 W polarisation

4 Conclusion

Polarisation and spin correlation

- Top quarks produced in pairs are almost **unpolarised** in the SM, but the spins of the top and antitop are **correlated**.
- The study of these properties through the decay particles can be affected by BSM models either in top production or decay.
- Study the angles of the top decay products.



- Need to define quantization axis
- Depends on the $t\bar{t}$ production mechanism
  $\rightarrow$ Tevatron and LHC measurements are complementary
- For spin correlation, **first evidence at the Tevatron** (3σ obtained at D0).

Polarisation and spin correlation

Double differential cross section:

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_1 d\cos\theta_2} = \frac{1}{4}(1 + \alpha_1 P_1 \cos\theta_1 + \alpha_2 P_2 \cos\theta_2 - C\cos\theta_1\cos\theta_2)$$

where:

- θ is the **polar angle** of the decay particles
- α is the **spin analyzing power** (≈ 1 for charged leptons)
- C is the **spin correlation**: $C = -A\alpha_+\alpha_-$, with

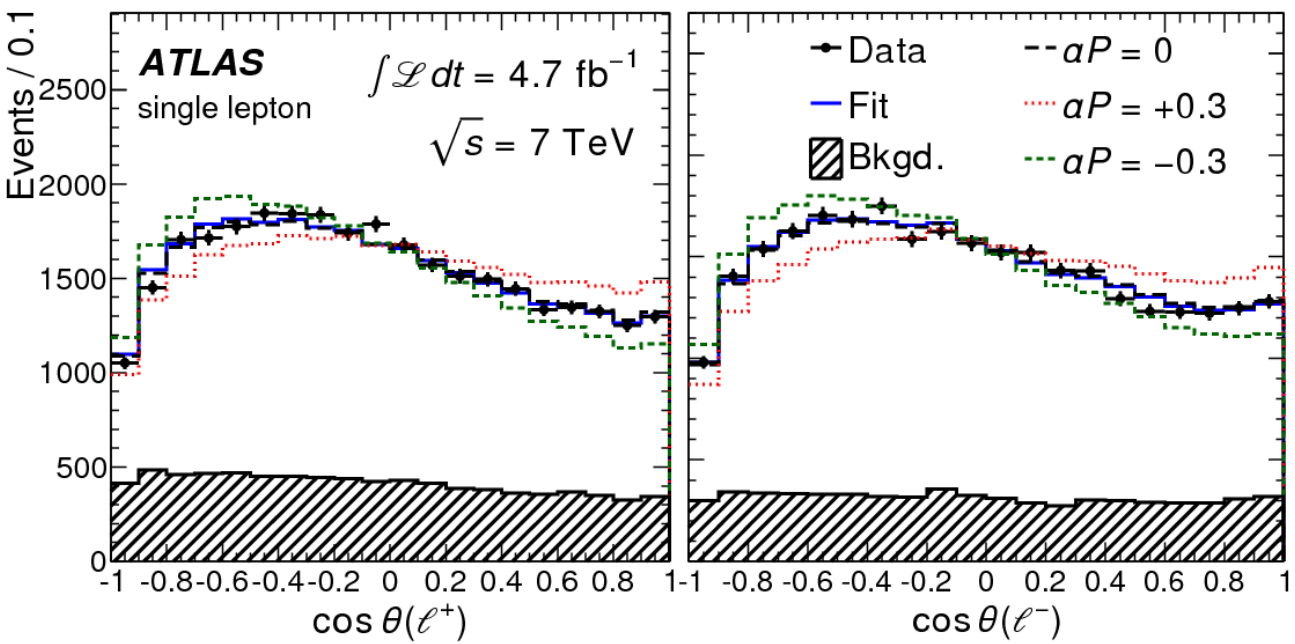
$$A = \frac{N_{like} - N_{unlike}}{N_{like} + N_{unlike}} = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow)}$$

- P the **polarisation** term:

$$P = \frac{A_P}{2} = \frac{1}{2}\frac{N(\cos\theta_l > 0) - N(\cos\theta_l < 0)}{N(\cos\theta_l > 0) + N(\cos\theta_l < 0)}$$

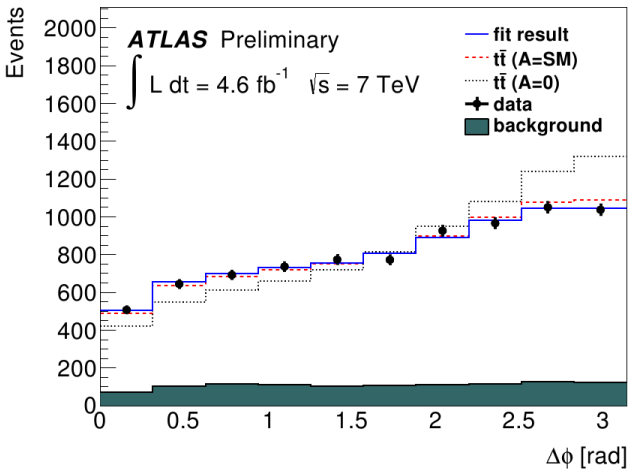
ATLAS polarisation measurement - $\ell\ell + \ell + jets$

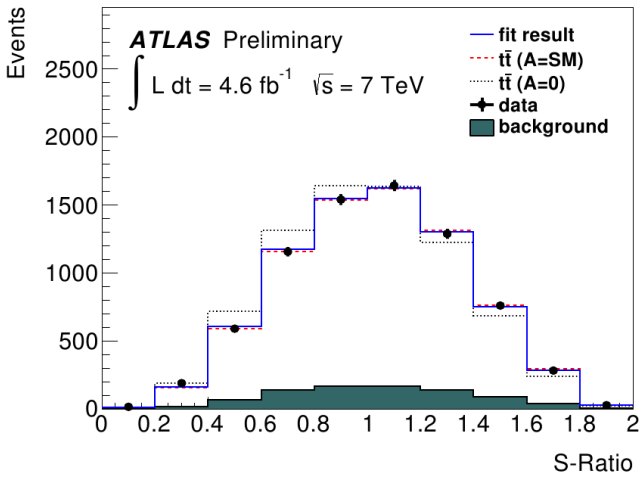
- Produce **templates** with positive and negative polarisation from MC $t\bar{t}$ sample.
- Fit data distribution to templates under **2 scenarios**:
  - CP conserving: same αP for top and antitop
  - CP violating: opposite αP for top and antitop
- **Results obtained:**
  - CP conserving: $\alpha P = -0.035 \pm 0.014$ (stat.) ± 0.037 (syst.)
  - CP violating: $\alpha P = 0.020 \pm 0.016$ (stat.) ± 0.015 (syst.)
- Dominant syst: jet reconstruction and MC modeling.

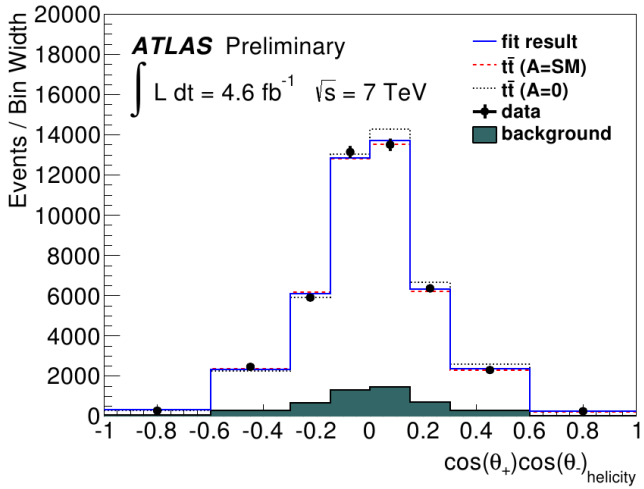


[PRL 111, 232002 (2013)]

ATLAS spin correlation measurement - $\ell\ell$

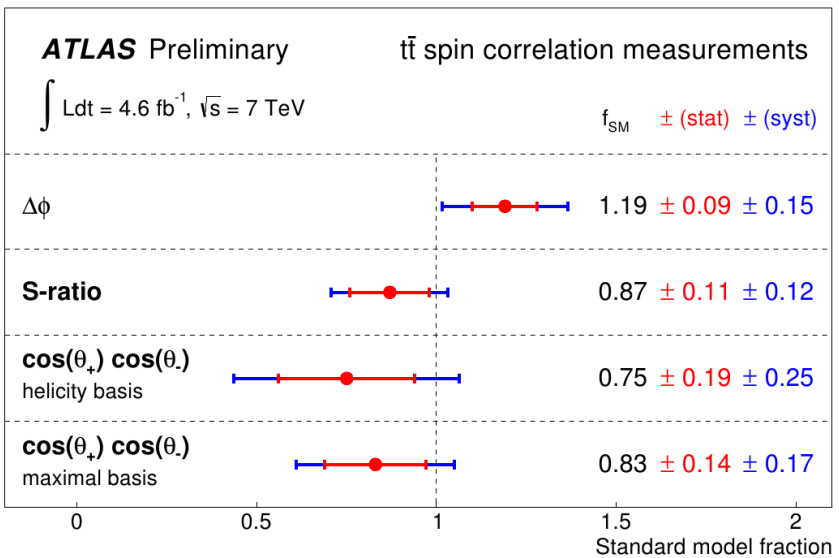






Observables

- $\Delta\Phi$ between the 2 leptons (lab frame)
- $\cos\theta_1 \cos\theta_2$ in the helicity and maximal bases
- S-ratio defined as:
  $(|\mathcal{M}_{RR}| + |\mathcal{M}_{LL}|)_{corr}/(|\mathcal{M}_{RR}| + |\mathcal{M}_{LL}|)_{uncorr}$
- Dominant syst: signal modeling.



[ATLAS-CONF-2013-101]

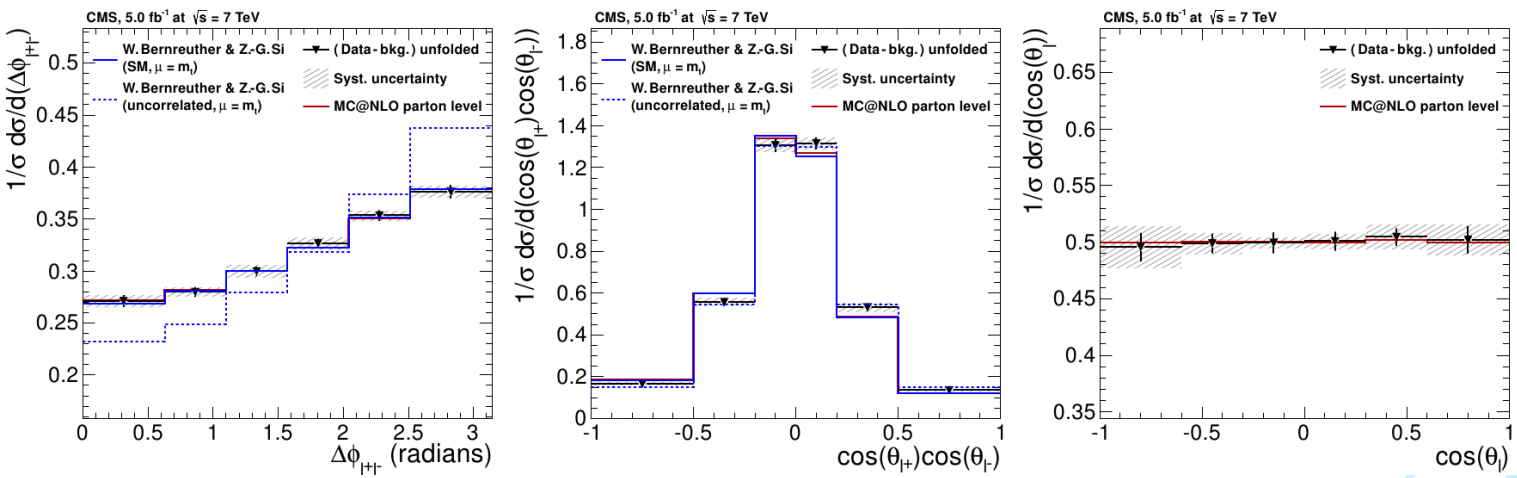
CMS measurement ($\ell\ell$ channel)

- Define 3 asymmetry observables.
- **Unfold all distributions** to parton level.
- Dominant syst: unfolding and signal modeling.

$$A_P = \frac{P}{2} = \frac{N(\cos\theta_l > 0) - N(\cos\theta_l < 0)}{N(\cos\theta_l > 0) + N(\cos\theta_l < 0)}$$

$$A_{\Delta\Phi} = \frac{N(\Delta\Phi_{\ell^+\ell^-} > \pi/2) - N(\Delta\Phi_{\ell^+\ell^-} < \pi/2)}{N(\Delta\Phi_{\ell^+\ell^-} > \pi/2) + N(\Delta\Phi_{\ell^+\ell^-} < \pi/2)}$$

$$A_{c_1c_2} = \frac{N(\cos\theta_1\cos\theta_2 > 0) - N(\cos\theta_1\cos\theta_2 < 0)}{N(\cos\theta_1\cos\theta_2 > 0) + N(\cos\theta_1\cos\theta_2 < 0}$$



Asymmetry	Data (unfolded)	MC@NLO	NLO (SM, correlated)	NLO (uncorrelated)
$A_{\Delta\phi}$	$0.113 \pm 0.010 \pm 0.007 \pm 0.012$	0.110 ± 0.001	$0.115^{+0.014}_{-0.016}$	$0.210^{+0.013}_{-0.008}$
$A_{c_1c_2}$	$-0.021 \pm 0.023 \pm 0.027 \pm 0.010$	-0.078 ± 0.001	-0.078 ± 0.006	0
A_P	$0.005 \pm 0.013 \pm 0.020 \pm 0.008$	0.000 ± 0.001	N/A	N/A

[arXiv:1311.3924, subm. to PRL]

1 Asymmetry measurements
- Introduction
- Tevatron results
- Results from the LHC

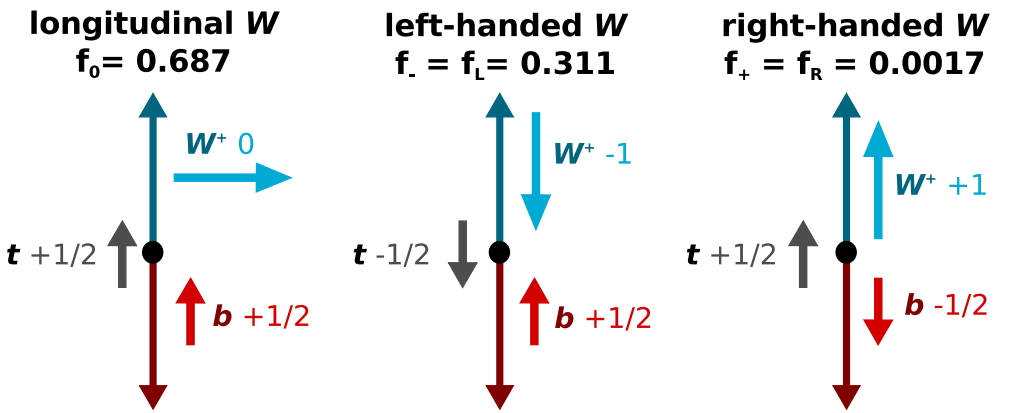
2 Polarisation and spin correlation measurements

3 W polarisation

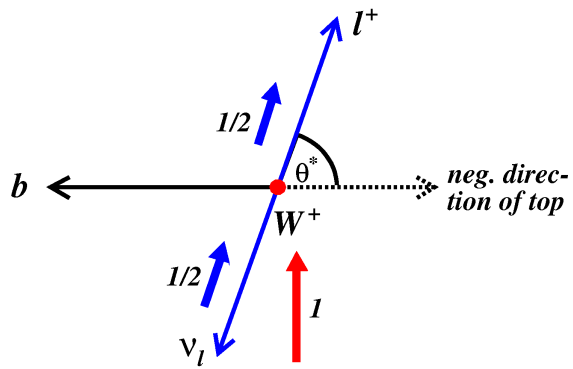
4 Conclusion

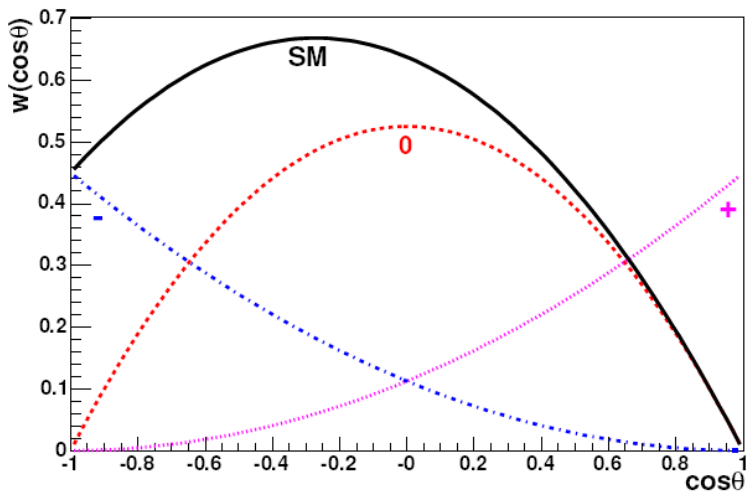
W polarisation

- 3 polarisations possible for the W: longitudinal, left- or right-handed.
- V-A coupling, small b mass and conservation of angular momentum $\rightarrow$ almost no right-handed W.
- Look at the decay angle of the lepton from the W



[PRD81 111503 (2010)]

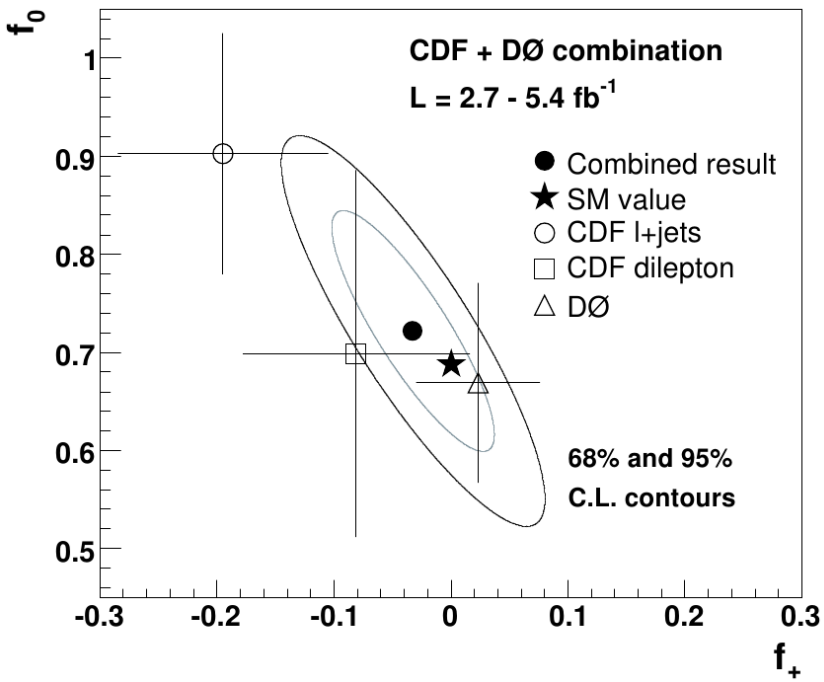


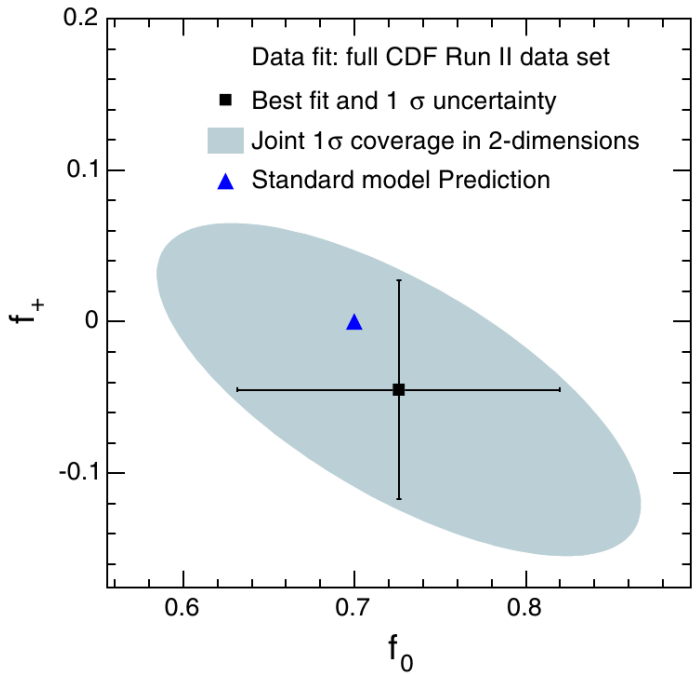


W polarisation - Tevatron results

2012 Tevatron combination [PRD 85, 091104 (2012)]

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

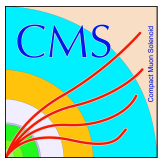




CDF full dataset result [PRD 87 031104(R)]

$f_0 = 0.726 \pm 0.066\ (\text{stat}) \pm 0.067\ (\text{syst})$
$f_+ = -0.045 \pm 0.043\ (\text{stat}) \pm 0.058\ (\text{syst})$

W polarisation - LHC results

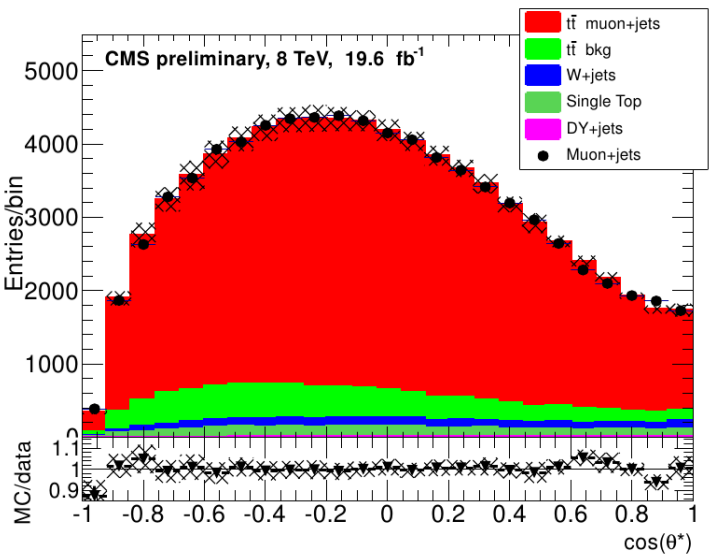


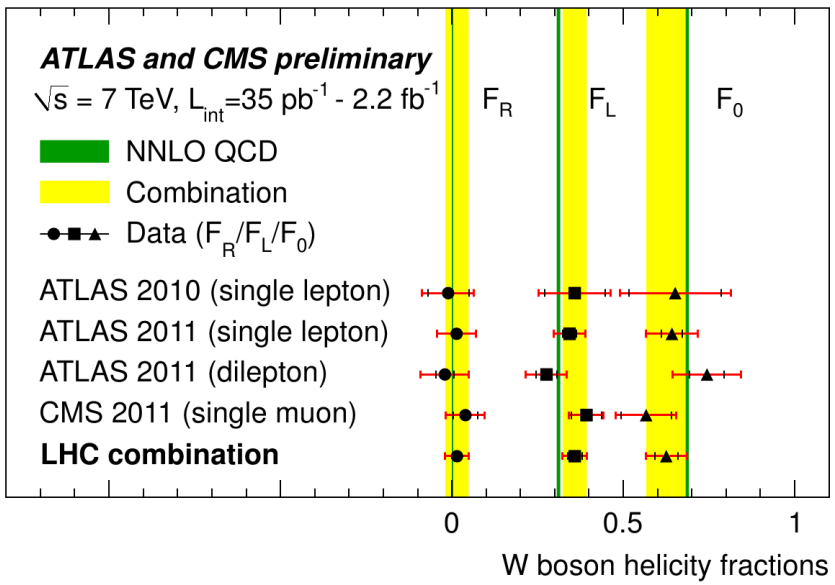
CMS-ATLAS combination

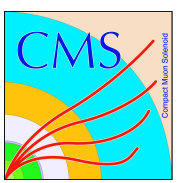
$f_0 = 0.626 \pm 0.034\ (\text{stat}) \pm 0.048\ (\text{syst})$

$f_+ = 0.015 \pm 0.034\ (\text{stat} + \text{syst})$

[ATLAS-CONF-2013-033] [CMS-PAS-TOP-12-025]







CMS 8 TeV [CMS-PAS-TOP-13-008]

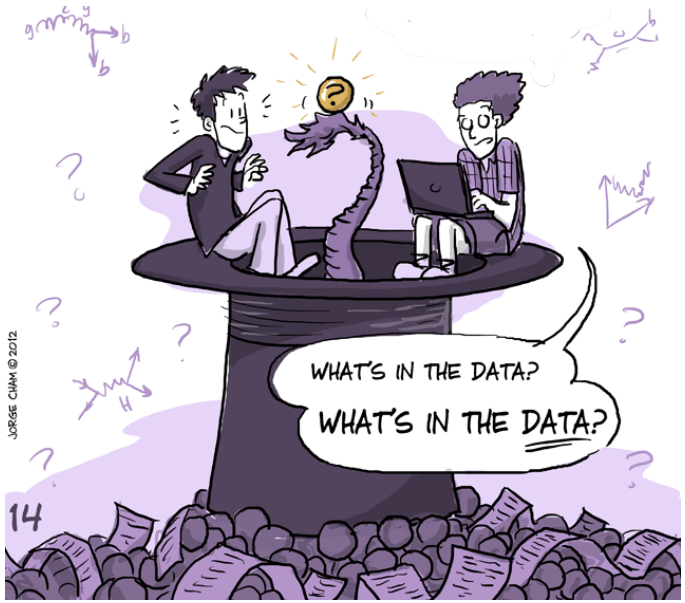
$f_0 = 0.659 \pm 0.015\ (\text{stat}) \pm 0.023\ (\text{syst})$

$f_+ = -0.009 \pm 0.006\ (\text{stat}) \pm 0.020\ (\text{syst})$

Conclusion

- Top quark properties studied in detail at the LHC and Tevatron (more results in the backups: R_b, Wtb anomalous couplings, ...).
- Tension between A_{FB} predictions and measurements reduced.
- All other results are in **good agreement with the SM**.
- 8 TeV data being analyzed at the LHC

  $\rightarrow$ plenty of **new interesting results to come!**



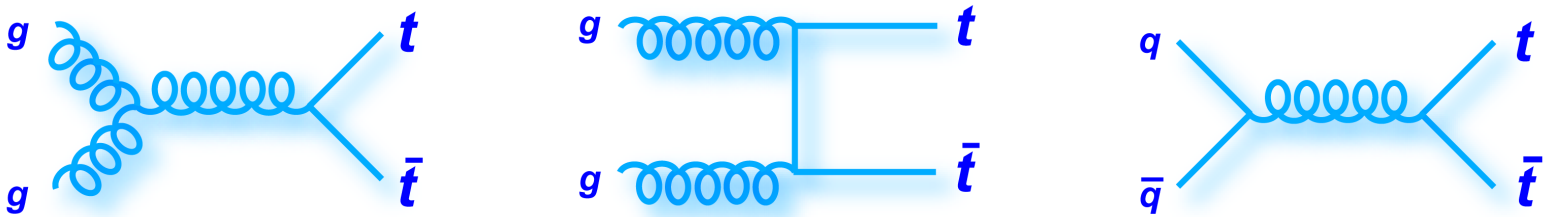
["Piled Higher and Deeper" by Jorge Cham, www.phdcomics.com]

Back-up slides

Top quark production

Production modes

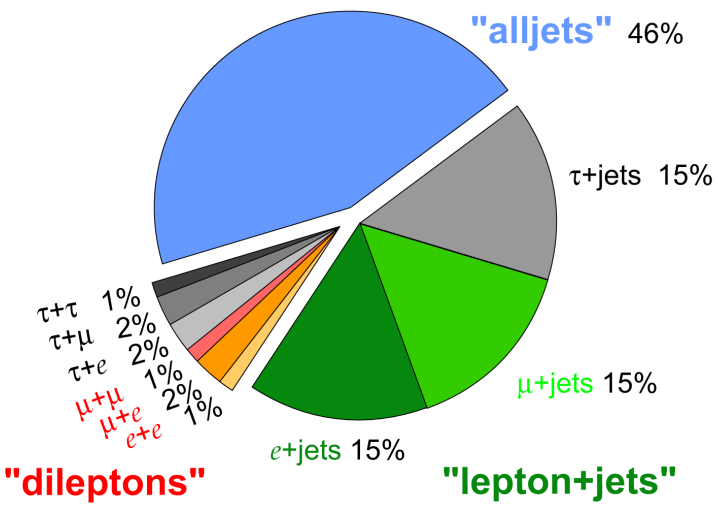
- Weak interaction: single top
- Strong interaction : top-antitop pairs
  $\rightarrow$ leading production mode, studied here

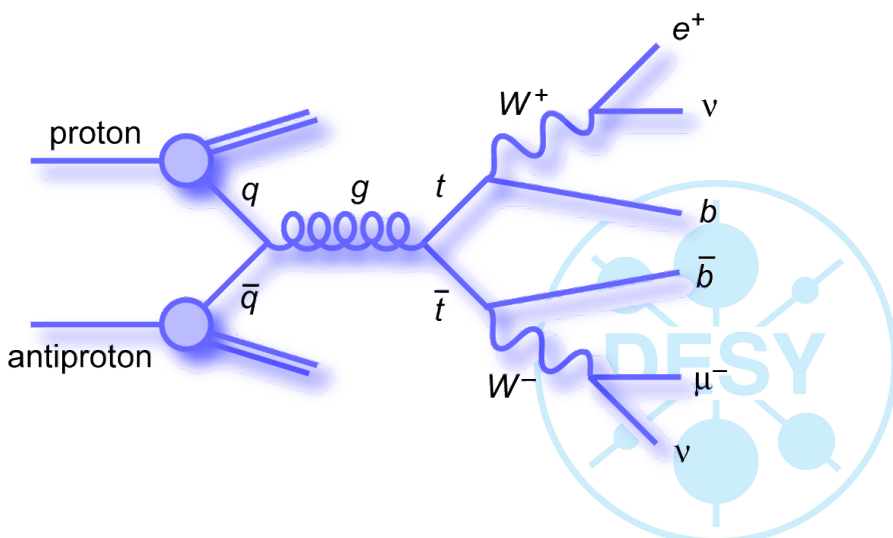


	Production	Approximate NNLO cross section $\sigma_{t\bar{t}}$ ($m_t = 173$ GeV) *[Kidonakis, PRD 82, 2010]*
Tevatron ($p\bar{p}$, 1.96 TeV)	$\approx$ 15% gg, 85% $q\bar{q}$	7.1 ± 0.4 pb
LHC (pp, 7 TeV)	$\approx$ 80% gg, 20% $q\bar{q}$	163 ± 11 pb

Top decays

- All hadronic channel
  - 6 jets in the final state;
  - large branching ratio but high level of background (multijets events).
- **Semileptonic channel**
  - 4 jets, 1 charged lepton and 1 neutrino in the final state;
  - high branching ratio and reasonable background (W+jets events).
- **Dilepton channel**
  - 2 jets, 2 charged leptons in the final state;
  - small branching ratio but very low background.

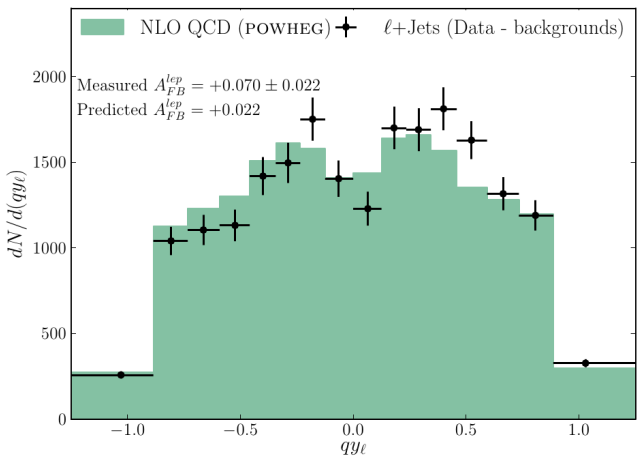


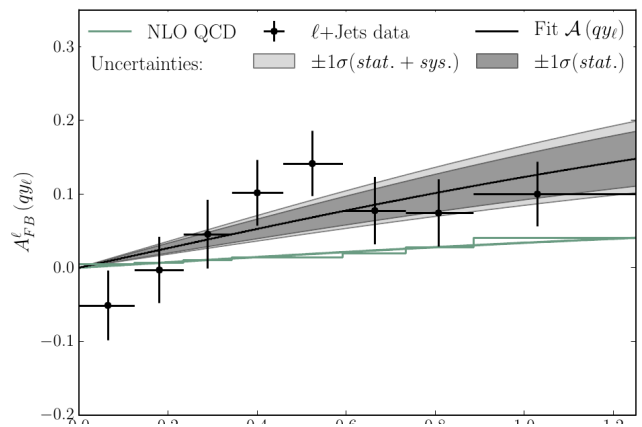


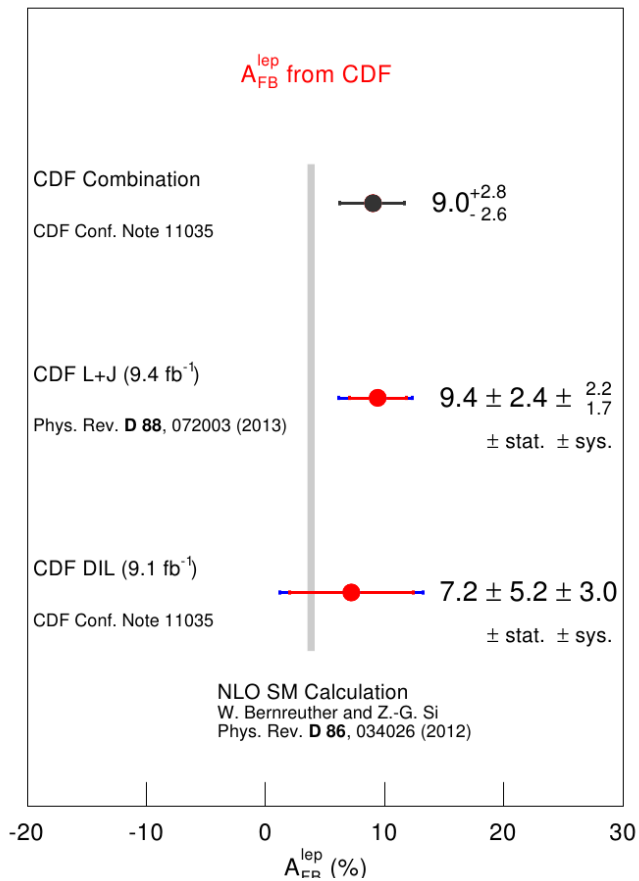
Tevatron results - lepton asymmetries at CDF

Results [CDF Conf. Note 11035]

- A_{FB}^{ℓ} combined $\ell\ell$-ℓ + *jets*:
  $A_{FB}^{\ell} = 0.090^{+0.028}_{-0.026}$
- $A_{FB}^{\ell\ell}$ $\ell\ell$ only: $A_{FB}^{\ell\ell} = 0.072 \pm 0.060$



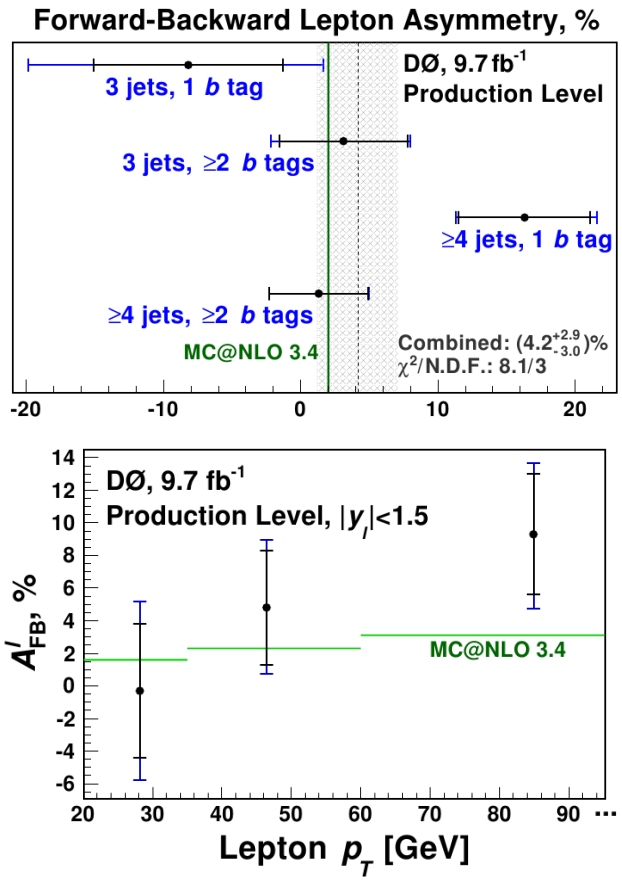


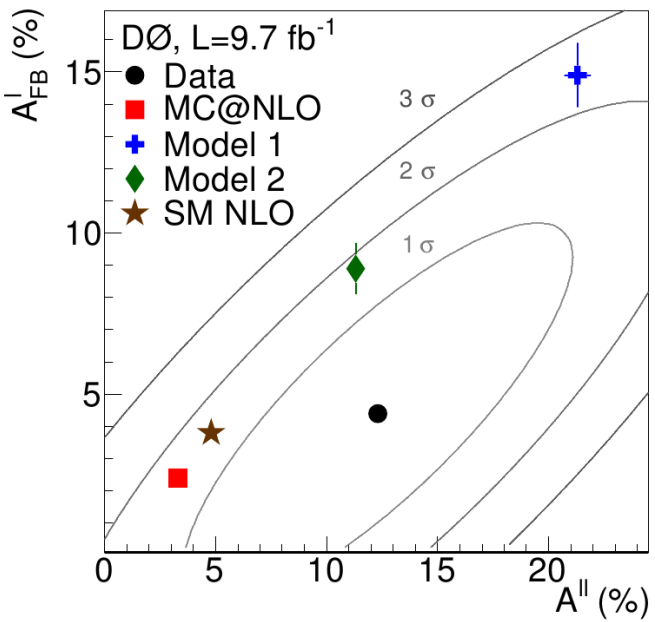


Tevatron results - lepton asymmetries at D0

Results [arXiv:1403.1294, subm. to PRD]

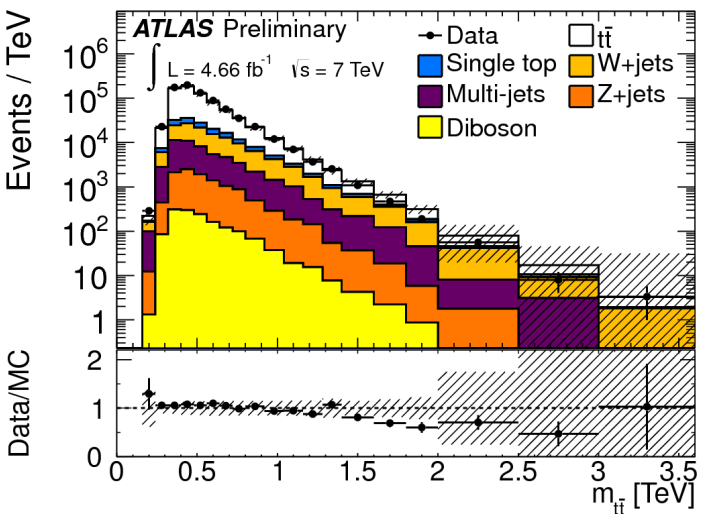
- A_{FB}^{ℓ} combined $\ell\ell$-ℓ + *jets*: $A_{FB}^{\ell} = 0.042 \pm 0.024$
- $A_{FB}^{\ell\ell}$ $\ell\ell$ only: $A_{FB}^{\ell\ell} = 12.3 \pm 5.4$ (stat.) ± 1.5 (syst.) %





Models that could explain the top charge asymmetry

- Production of $t\bar{t}$ pairs via new particles could explain the asymmetry.
- Large asymmetry measured at the Tevatron $\rightarrow$ models favored by theorists have new particles exchanged at tree-level.
- Strong constraints from other measurements:
  - the total cross-section should not be strongly modified;
  - the process should not create a sharp resonance in the invariant mass spectrum.



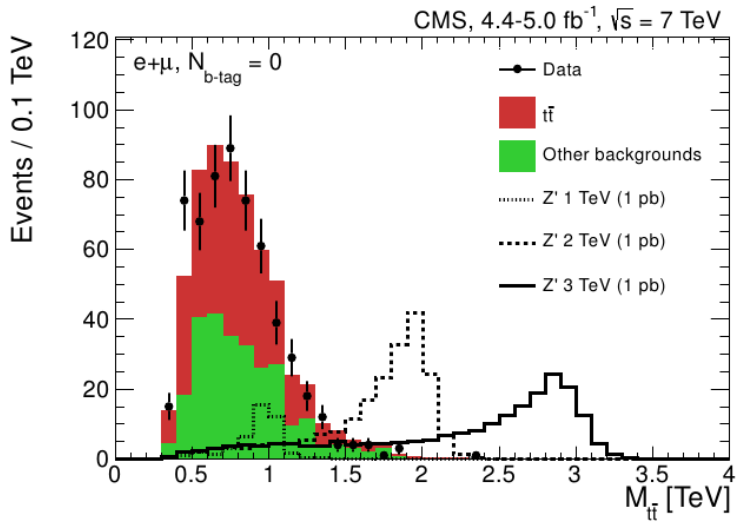


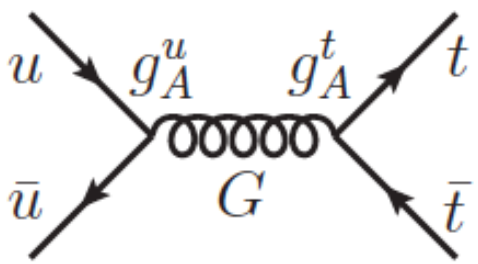
Figure: Left: ATLAS measurement *[ATLAS-CONF-2012-136]*. Right: CMS *[arXiv:1209.4397]*

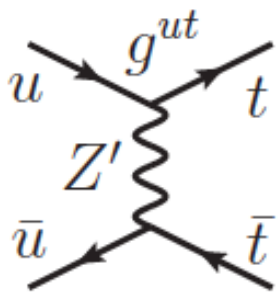
Models that could explain the top charge asymmetry

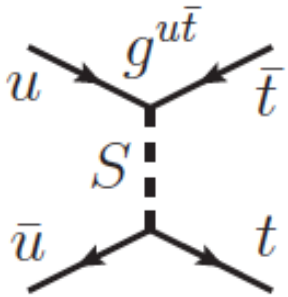
Several models have been developed to satisfy these constraints and explain the Tevatron asymmmetry. *[Aguilar, arXiv:1107.0841]*

New particles are exchanged via:

- s-channel: color-octet vector (axigluons)
  - appear in models like chiral color or extra-dimensions.
  - no peak in the $t\bar{t}$ invariant mass $\rightarrow$ heavy axigluon with large coupling or light with broad width.
- t-channel: color-singlet vector (Z', W')
  - appears in models like topcolor assisted technicolor;
  - constrained by non-observation of like-sign pair production.
- u-channel: color-triplet/-sextet scalars
  - appear in models with extended Higgs sector;
  - strong constraints from dijet production.







Asymmetry predictions

- The asymmetry appears at NLO in QCD $\rightarrow$ non-trivial calculations.
- Can distinguish different contributions *[Pecjak, Top2011]*:

$$\begin{aligned} A_{FB} &= \frac{\sigma_A}{\sigma_S} = \frac{\alpha^2 \widetilde{N_0} + \alpha_s^3 N_1 + \alpha_s^2 \alpha \tilde{N}_1 + \alpha_s^4 N_2 + \ldots}{\alpha^2 \tilde{D}_0 + \alpha_s^2 D_0 + \alpha_s^3 D_1 + \alpha_s^2 \alpha \tilde{D}_1 + \ldots} \\ &= \alpha_s [A_{FB}^{(0)} + \alpha_s A_{FB}^{(1)}] + \alpha A_{FB}^{EW+QCD,(0)} + \frac{\alpha^2}{\alpha_s^2} A_{FB}^{EW,(0)} + \ldots \end{aligned}$$

- The leading order QCD contribution $A_{FB}^{(0)}$ is known.
- The EW contributions could lead to an enhancement of 20%.
- No exact calculation for the higher order QCD contribution. Estimated by soft gluon resummation.

Asymmetry predictions

Kuhn, Rodrigo, 2011; Hollik, Pagani 2010; Bernreuther, Si 2010

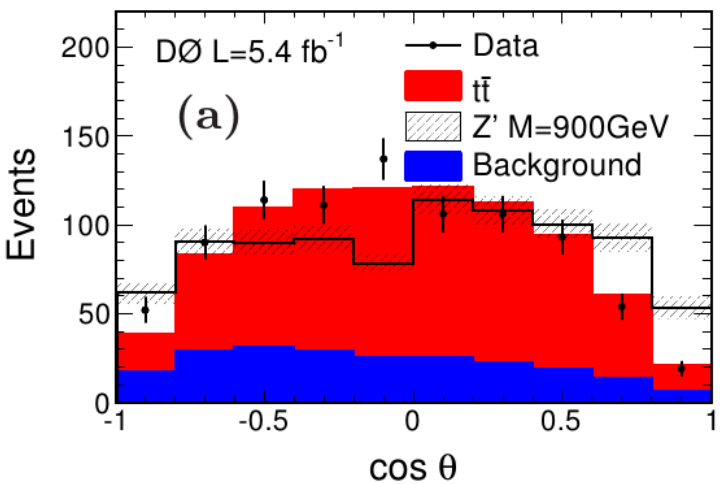
Pecjak, Top2011	$A_{FB}^{t\bar{t}}$ [%]	$A_{FB}^{p\bar{p}}$ [%]
NLO	$7.32^{+0.69+0.18}_{-0.59-0.19}$	$4.81^{+0.45+0.13}_{-0.39-0.13}$
NLO+NNLL [Ahrens et. al.'11]	$7.24^{+1.04+0.20}_{-0.67-0.27}$	$4.88^{+0.20+0.17}_{-0.23-0.18}$
$NNLO_{approx}$ [Kidonakis '11]		$5.2^{+0.0}_{-0.6}$
EW'/NLO' ($\mu = m_t$) [Bernreuther, Si '10]	0.05	0.04
EW/NLO ($\mu = m_t$) [Hollik, Pagani '10]	0.22	0.22
NLO(QCD+EW) [Bernreuther, Si, '12]	8.8±0.6	

$b\bar{b} \to t\bar{t}$ included
Extra photonic corrections
NLO PDFs in numerator,
mixed QCD and EW corrections

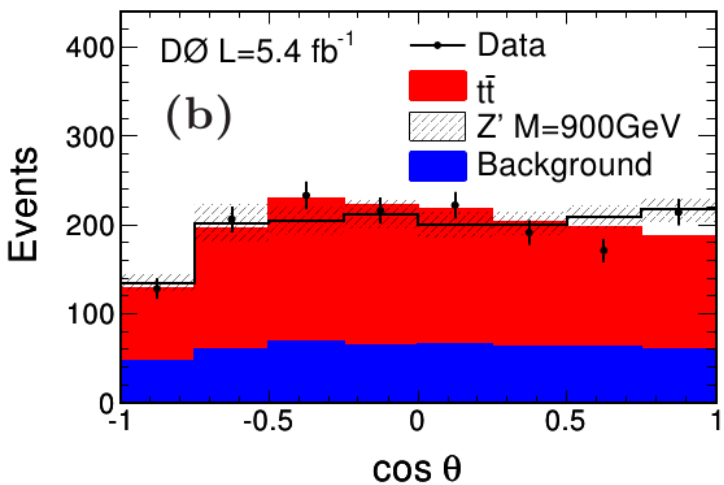
D0 study

- First study of the top polarisation, both in the dilepton and lepton+jets channels. *[PRD 87, 011103(R)]*
- Analysis performed simultaneously with the asymmetry measurement in the dilepton channel:
  - same selection;
  - kinematic reconstruction of the $t\bar{t}$ system is necessary (neutrino weighting).
- Plots at the reconstructed level.

dilepton channel



lepton+jets channel



Definition of the S-ratio

Ratio of leading order matrix elements from the fusion of like-helicity gluons ($g_R g_R + g_L g_L \to t\bar{t} \to (bl^+\nu)(\bar{b}l^-\bar{\nu})$) with and without SM spin correlation:

$$\begin{aligned} S &= \frac{(|\mathcal{M}|^2_{RR} + |\mathcal{M}|^2_{LL})_{corr}}{(|\mathcal{M}|^2_{RR} + |\mathcal{M}|^2_{LL})_{uncorr}} \\ &= \frac{m_t^2\{(t\cdot l^+)(t\cdot l^-) + (\bar{t}\cdot l^+)(\bar{t}\cdot l^-) - m_t^2(l^+\cdot l^-)\}}{(t\cdot l^+)(\bar{t}\cdot l^-)(t\cdot \bar{t})} \end{aligned} \quad (1)$$

where t, $\bar{t}$, l^+ and l^- are the 4-momenta of the top quarks and the charged leptons.

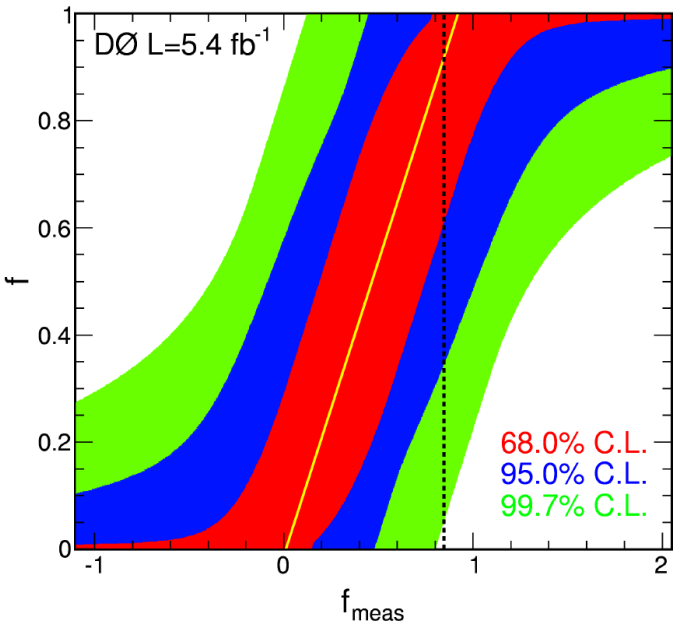
Bases

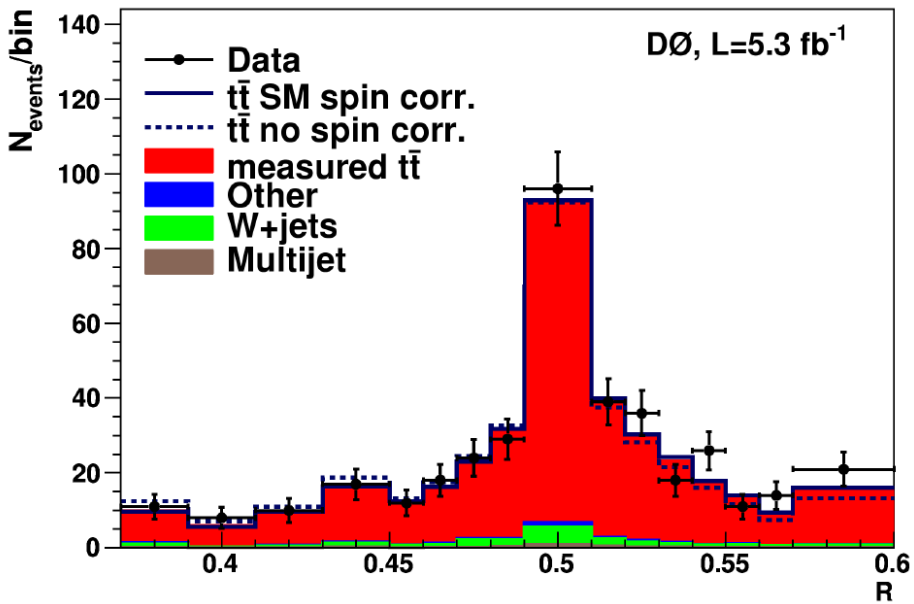
- Helicity basis: the quantization axis is the top direction in the $t\bar{t}$ rest frame.
- Maximal basis: basis optimised for top quarks produced by gg fusion.

D0 spin correlation measurement

Method and results [PRL 108 032004 (2012)]

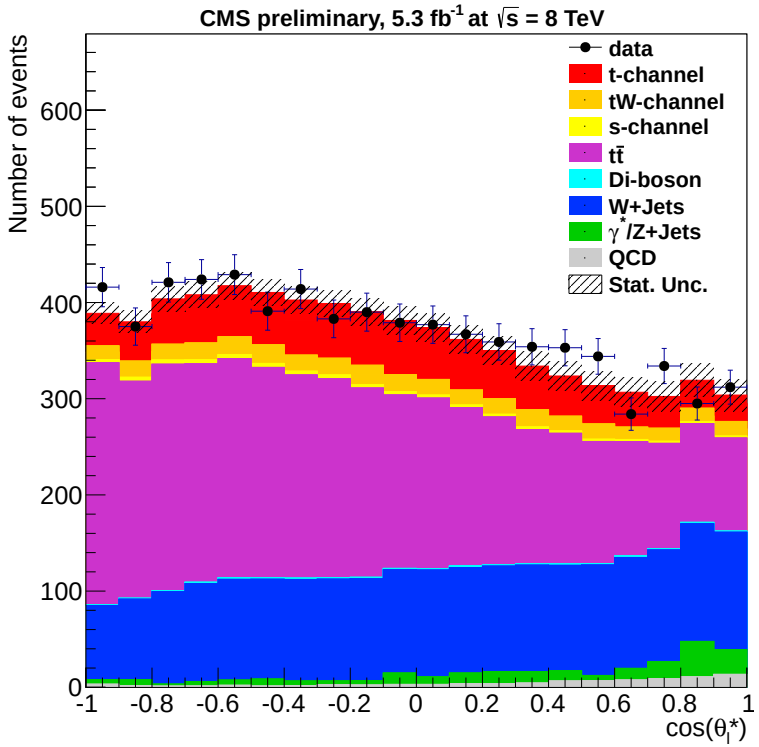
- Measurement in $\ell + jets$ channel using the matrix element method:
  - compute for each event the probability in the hypothesis of correlated or uncorrelated spins;
  - build discriminant $R = \frac{P_{sgn}(x;H=c)}{P_{sgn}(x;H=u)+P_{sgn}(x;H=c)}$.
- Combined with measurement in $\ell\ell$
- Result: $f = 0.85 \pm 0.29$ (stat.+syst.)
- Evidence at 3σ.

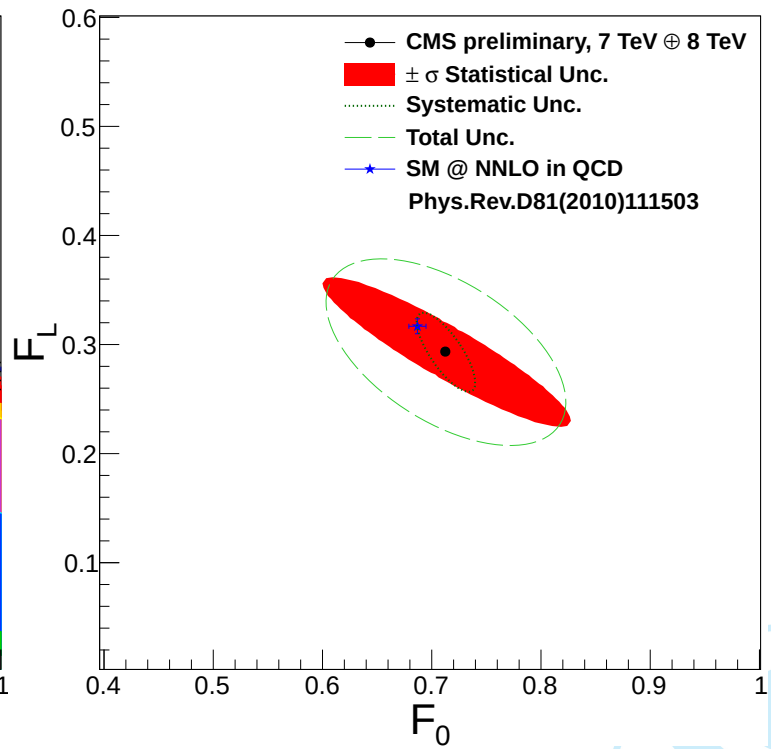




W polarisation from single top - CMS

- First measurement of W polarisation in single-top events.
- Template fit of the $\cos\theta^*$ distribution.





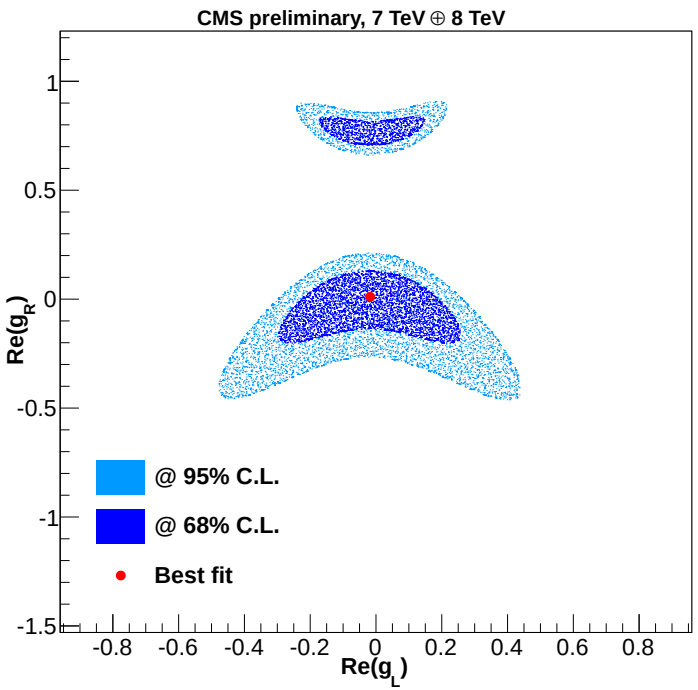
[CMS PAS TOP-12-020]

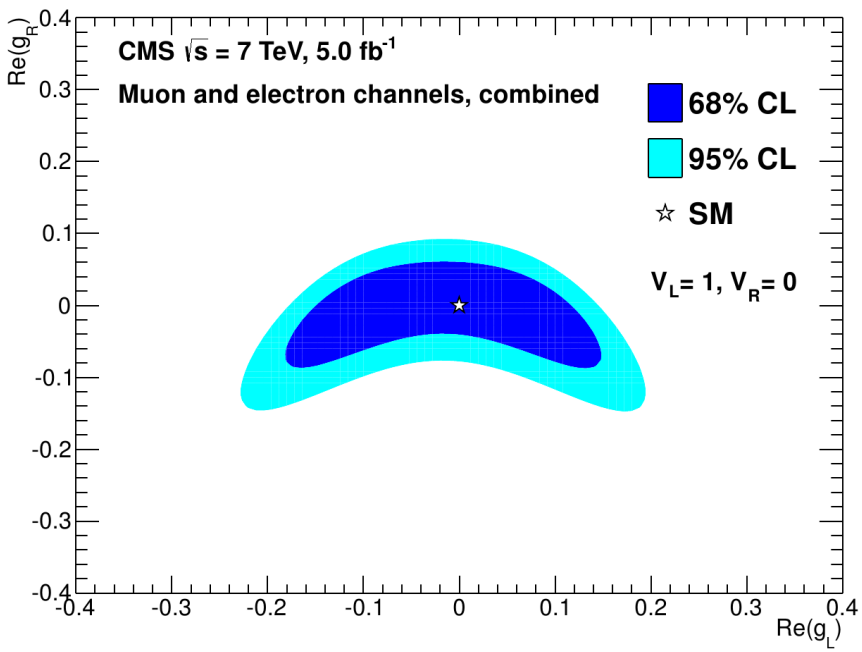
Limit on anomalous couplings - CMS

- Set limits on anomalous couplings:

$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(g_L P_L + g_R P_R)tW_{\mu}^{-} + h.c.$$

- in the SM: $V_L = 1$, $V_R = 0$, $g_L = 0$ and $g_R = 0$





[CMS PAS TOP-12-020]

[JHEP 10 (2013) 167]

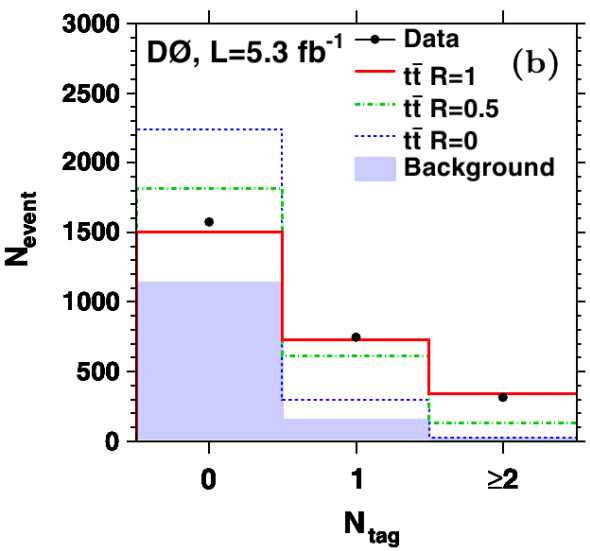
R_b measurements and extraction of V_{tb}

In $t\bar{t}$ decays

Provide a direct measurement of R_b: $R_b = \frac{\mathcal{B}(t\to Wb)}{\mathcal{B}(t\to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2+|V_{ts}|^2+|V_{tb}|^2}$ (q=d,s,b).

Extract $|V_{tb}|$, assuming the CKM matrix unitarity: $R_b = |V_{tb}|^2$.

Indirect constraint from measurement of other CKM elements, and under the unitarity assumption: $R_b \in [0.9982, 0.9984]$.



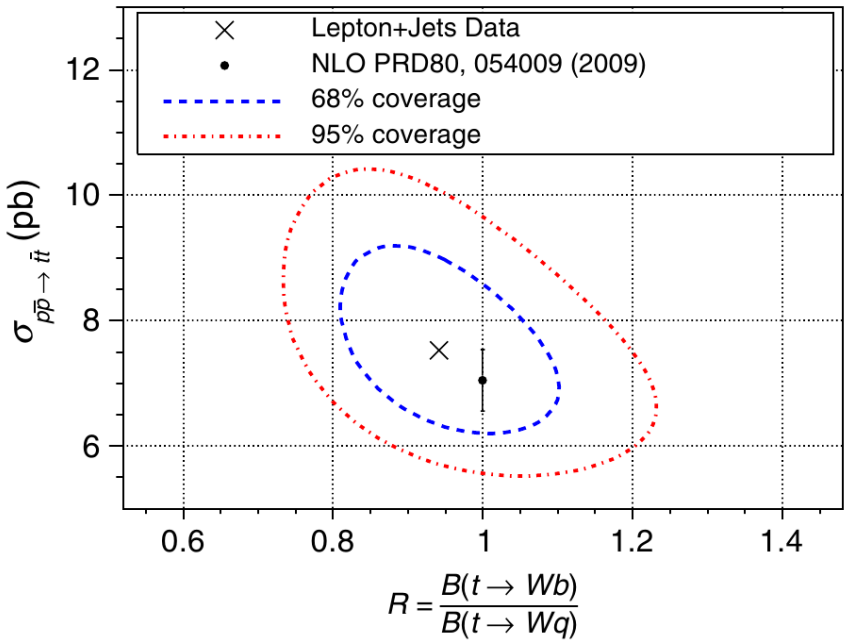
Method

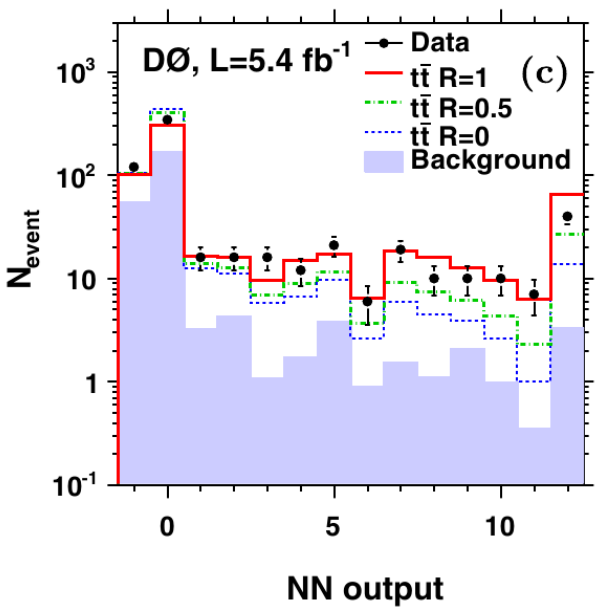
- Identify b-jets in the events.
- Construct templates from b-tagging distributions and samples with modified top branching fractions.
- Fit data to background and different signal templates.

R_b measurements

CDF, 8.7 fb^{-1} [Conf. Note 11048] [PRD 87 111101]

- $\ell + jets$: $R_b = 0.94 \pm 0.09$ (stat.+syst.)
- $\ell\ell$, $R_b = 0.87 \pm 0.07$ (stat.+syst.)





D0, 5.4fb^{-1} [PRL 107 121802]

- Simultaneous measurement in $\ell + jets$ and $\ell\ell$.
- Result: $R_b = 0.90 \pm 0.04$ (stat.+syst.)

CMS, 16.7 fb^{-1}, $\ell\ell$ channel [CMS PAS TOP 12-035]

- $R_b = 1.023^{+0.036}_{-0.034}$ (stat.+syst.)
- $V_{tb} = 1.011^{+0.018}_{-0.017}$ (stat.+syst.)