Top quark properties at the LHC

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Prepared with help from Efe Yazgan (Ghent)

Top2014 conference, Cannes, France, 30/9/2014

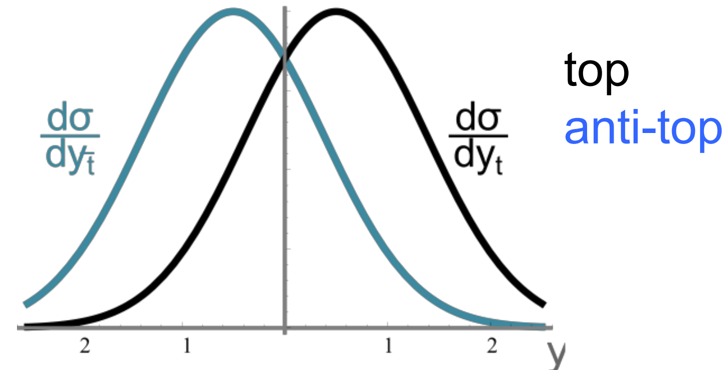
- Many 'properties' of the top quark covered in other dedicated sessions/talks
  - Dedicated session on top mass later today
  - Top couplings and W-helicity: Tamara Vazquez Schroder
  - Rare decays / FCNC: Reza Goldouzian
  - Single top results: Abideh Jafari
- What's left (wrt LHC measurements) – this talk:
  - tT charge asymmetry
  - tT spin correlations
  - Top quark polarisation in tT and single top events
- Cover available measurements for each of these subjects (refs. at end)
  - New ATLAS results on asymmetry at 7 TeV (dilepton), spin correlations at 8 TeV
  - Some comparisons and conclusions

tT production charge asymmetry – introduction

- Well-known Tevatron forward/backward asymmetry in tT events

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

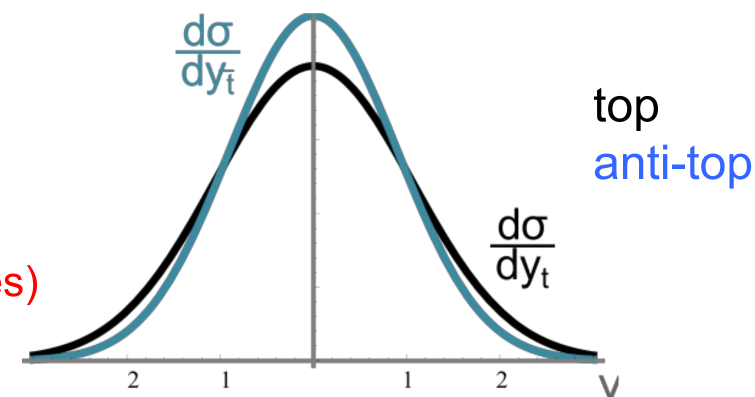
$$\Delta y = y_t - y_{\bar{t}}$$



  - Top quark preferentially follows p beam direction
  - Asymmetry zero at LO, but appears at $O(\alpha_s^3)$)
    - Inteference between Born vs box diagrams, and ISR vs FSR in top-antitop-gluon
  - Historically, A_{FB} bigger than expected in SM (~9%), especially at high m(tT)
    - Less pronounced in recent measurements, especially from D0
- LHC collides pp, not ppbar – no A_{FB} but define analogous charge asymmetry:

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

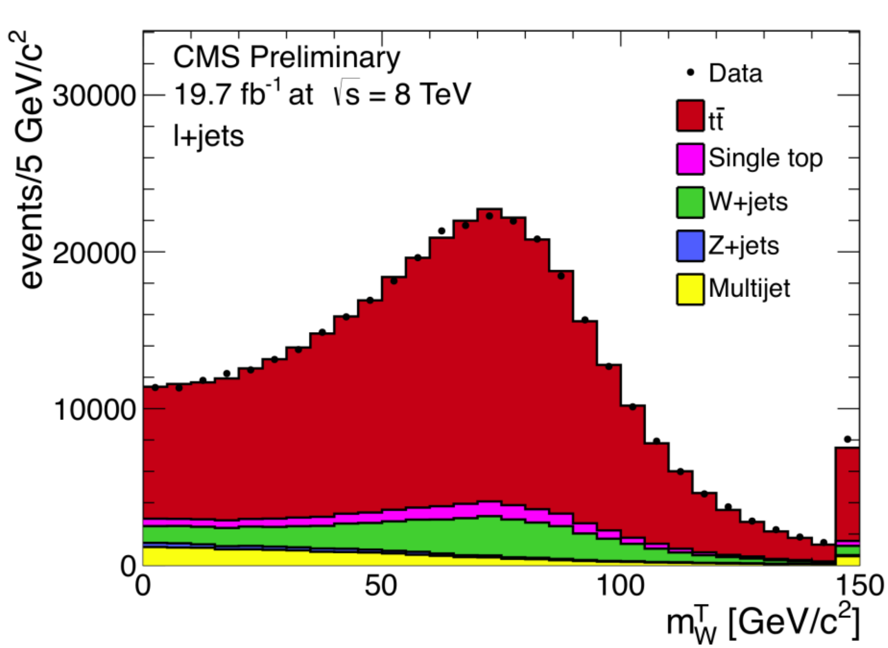
$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$

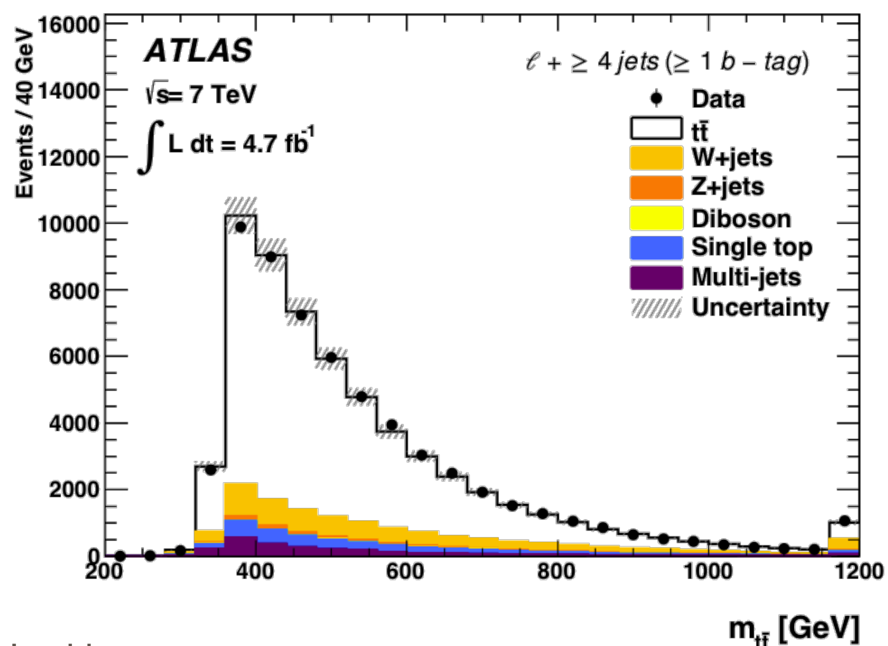


  - SM prediction for inclusive A_c is ~1%
    - Much smaller effect than at Tevatron (gg dominates)
- LHC measurements in l+jets and dilepton

Lepton+jets asymmetry – event selection

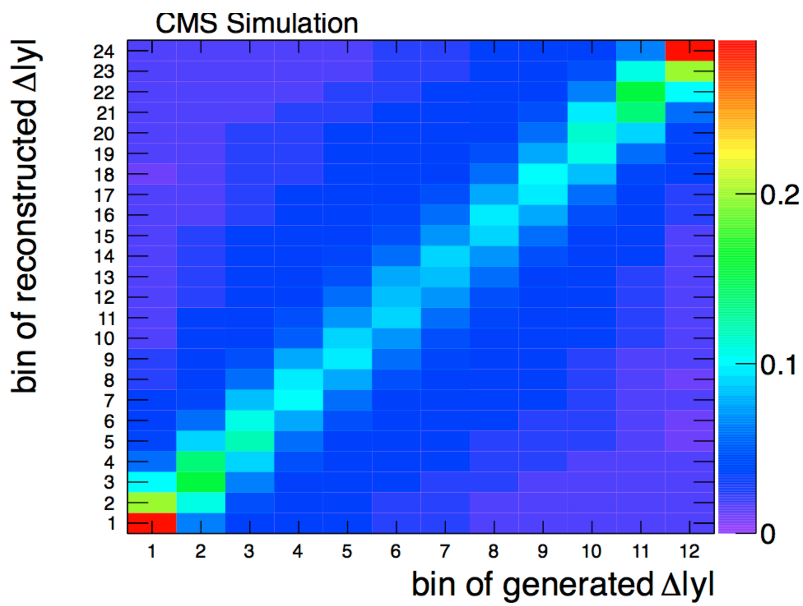
- Measurements from ATLAS (7 TeV) and CMS (7, 8 TeV with similar analysis)
- Select events with e or μ, ≥4 jets with ≥1 b-tags, requirements on E_T^{miss} / m_T^W
  - Samples of ~60k events (2011) with ~20% background (mainly W+jets, single top)
  - W+jet background level estimated from data, exploiting W^+/W^- charge asymmetry (ATLAS) or template fits to m_T^W and M3 (hadronic top mass) variables (CMS)
    - Some backgrounds (W+jets, single top) are asymmetric in reconstructed Δ|y|
  - tT system fully reconstructed exploiting kinematic fit, choice of best combination

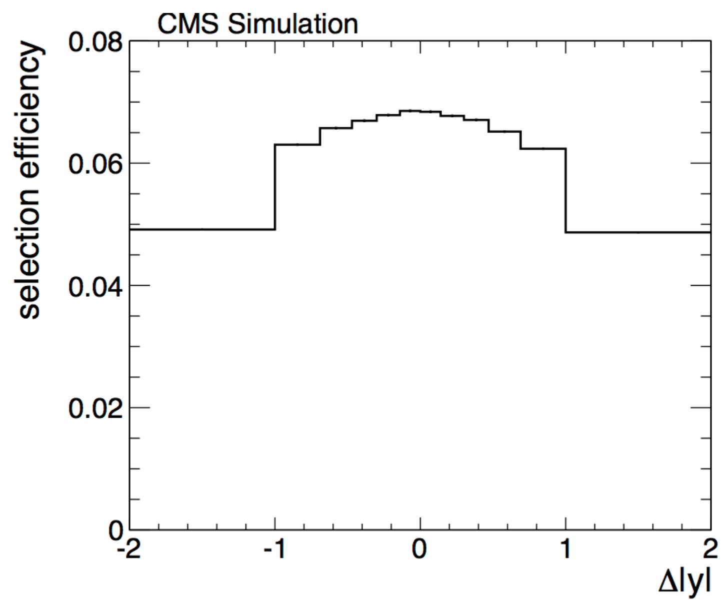




Unfolding to parton-level asymmetry

- Correct reconstructed Δ|y| distribution for background, acceptance, resl^n
  - CMS uses regularized unfolding with matrix inversion (Blobel)
    - Matrix factorises in to migration (resolution) and acceptance corrections





- ATLAS uses Fully-Bayesian Unfolding (FBU) to produce posterior Δ|y| distrib.

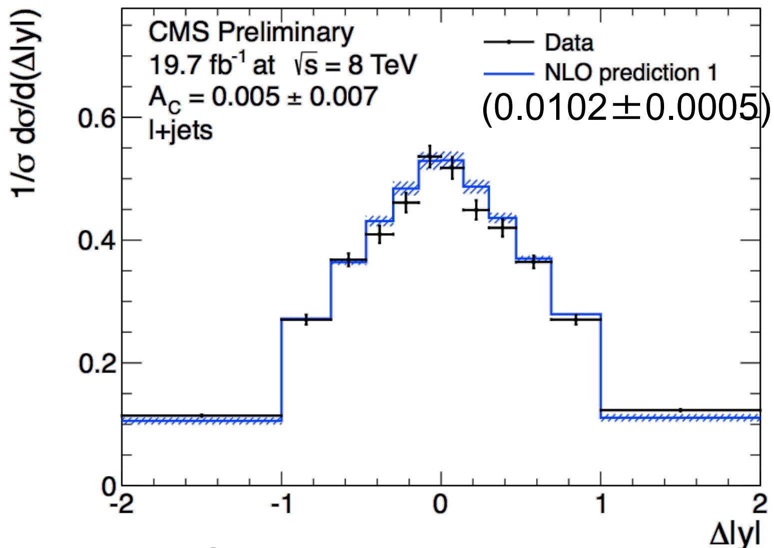
$$p(\mathbf{T}|\mathbf{D},\mathcal{M}) \propto \mathcal{L}(\mathbf{D}|\mathbf{T},\mathcal{M}) \cdot \pi(\mathbf{T})$$

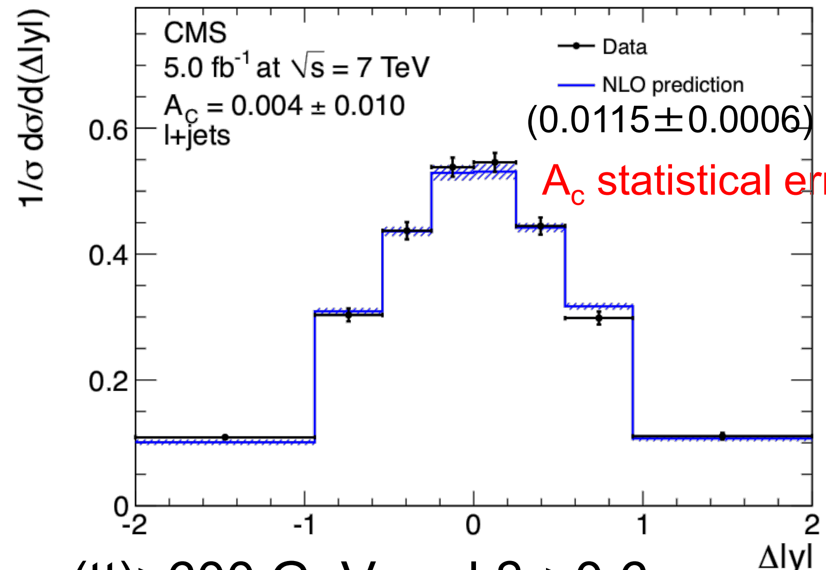
Truth **T**, data **D**, migration matrix **M**, prior π(**T**)

  - Flat prior used for all but A_c vs. p_T(tT) – use curvature prior for regularisation
  - Systematic effects can be marginalised (integrated out) from posterior distrib.

Inclusive A_c – lepton+jet results

- CMS unfolded Δ|y| distributions c.f. NLO+EW prediction (Kühn & Rodrigo)





A_c statistical errors only

- ATLAS quotes inclusive A_C and A_C for m(tt)>600 GeV and β_z>0.6
    - β_z is velocity of tT along z-axis
  - Enhance qqbar contribution and potential effects of new physics

ATLAS l+jets

A_C	Data	Theory
Unfolded	0.006±0.010	0.0123±0.0005
Unfolded with $m_{t\bar{t}} > 600$ GeV	0.018±0.022	$0.0175^{+0.0005}_{-0.0004}$
Unfolded with $\beta_{z,t\bar{t}} > 0.6$	0.011±0.018	$0.020^{+0.006}_{-0.007}$

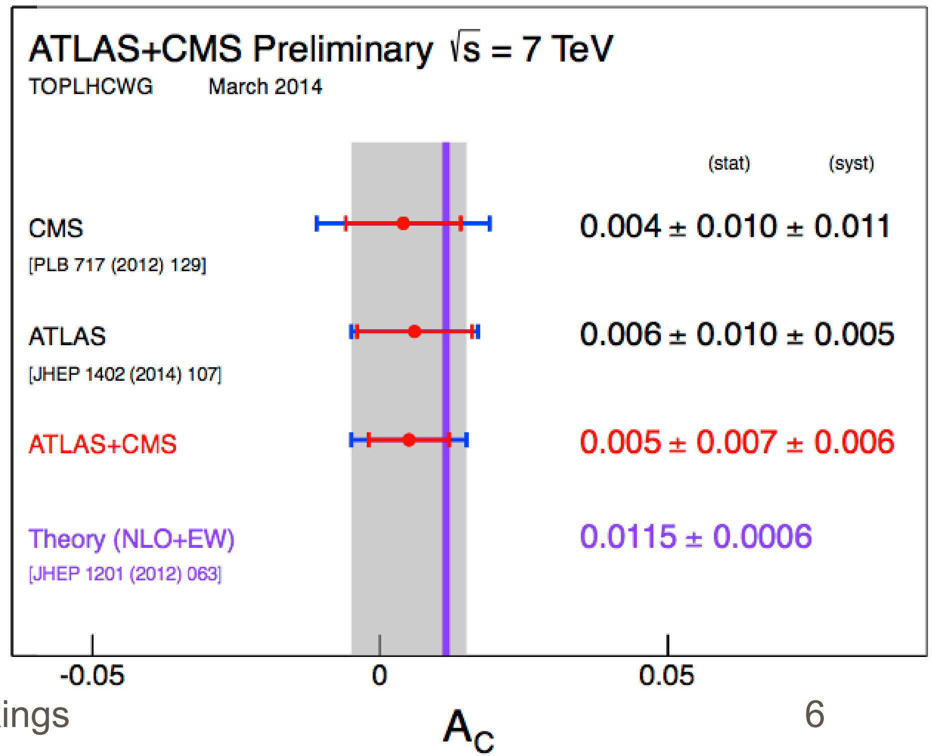
Theory: Bernreuther & Si

  - All inclusive A_c values compatible with zero and with SM predictions

LHC combination of 7 TeV l+jets results

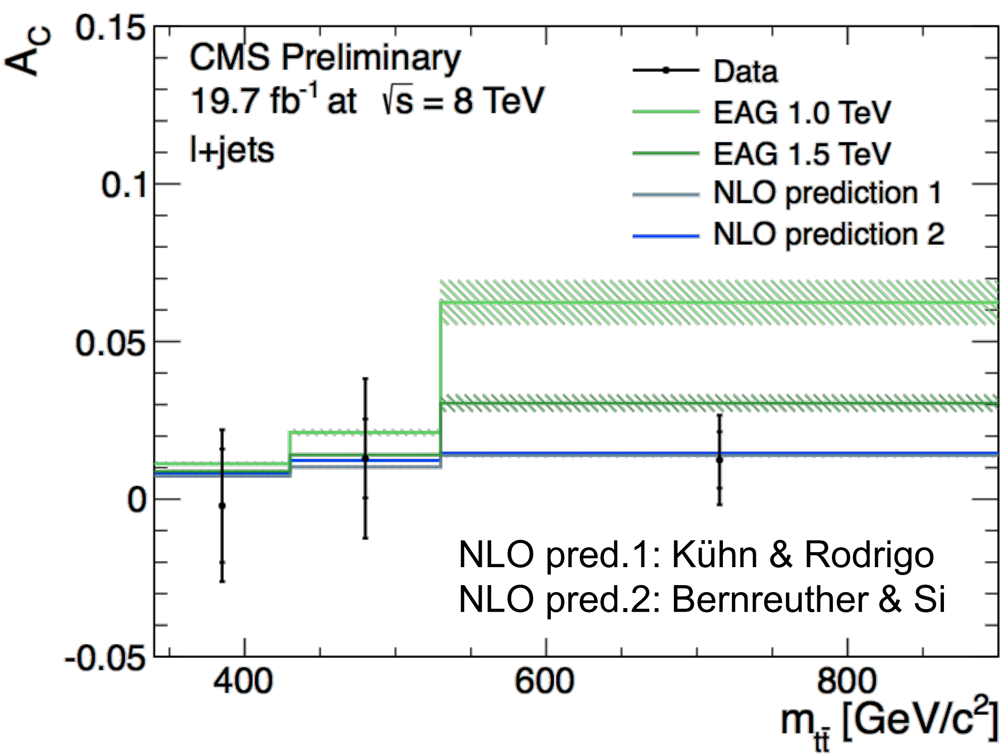
- Combination of unfolded A_c measurements
  - For ATLAS, used separate statistical and systematic uncertainties without the FBU marginalisation procedure
  - Result 0.005±0.007±0.006 improves on ATLAS by 18% and CMS by 40%
    - Dominant systematics: detector/W+jets modelling, insensitive to correlation assumptions
  - Result compatible with both zero and NLO+EW prediction

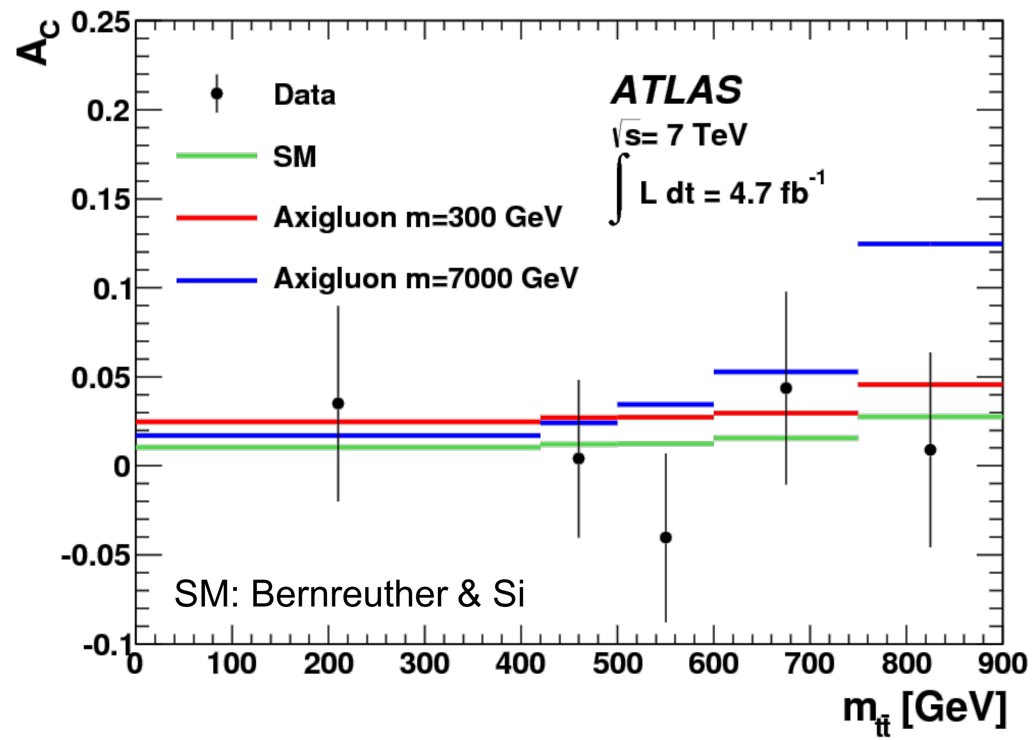
		ATLAS	CMS	Comb.	Corr.
	A_C	0.006	0.004	0.005	0.058
Uncertainties	Statistical	0.010	0.010	0.007	0
	Detector response model	0.004	0.007	0.004	0
	Signal model	< 0.001	0.002	0.001	1
	W+jets model	0.002	0.004	0.003	0.5
	QCD model	< 0.001	0.001	0.000	0
	Pileup+MET	0.002	< 0.001	0.001	0
	PDF	0.001	0.002	0.001	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	



Differential measurements with l+jets events

- Both experiments show results with A_C vs. |y(tT)|, p_T(tT) and m(tT)
  - In unfolding, need to consider migration in Δ|y| and in differential variable
  - Results compared to NLO+EW and BSM models inspired by Tevatron results
    - CMS: BSM effective theory with an anomalous axial-vector gluon coupling (EAG)
    - ATLAS: heavy axigluon exchanged in s-channel



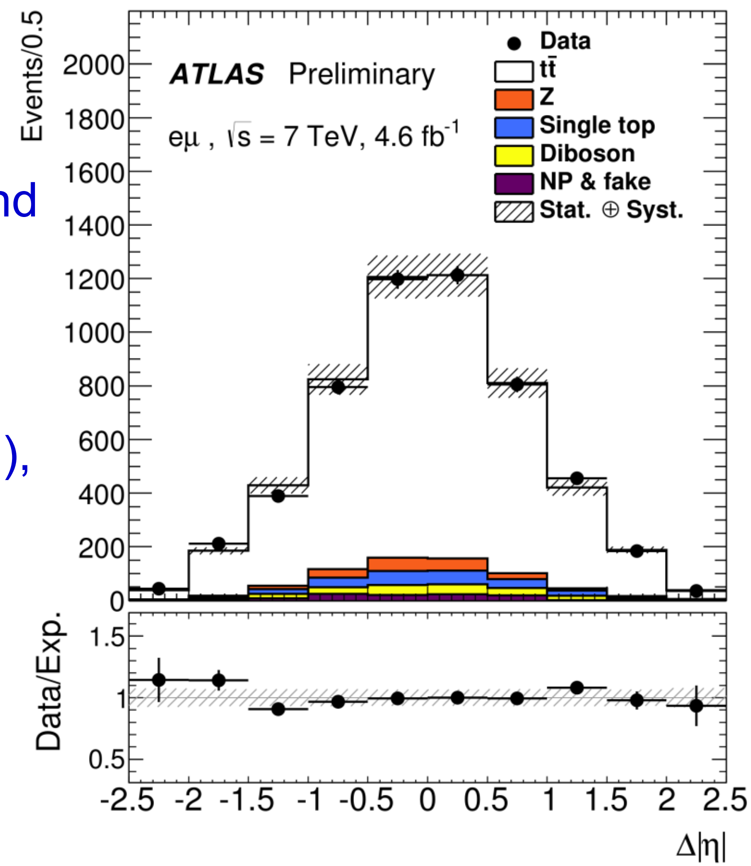


Asymmetry measurements in dileptons (7 TeV)

- Standard dilepton event selections used:
  - 2 leptons (ee, μμ, eμ), Z-veto for ee/μμ, ≥2 jets
    - ≥1 b-tag (CMS), H_T cut for eμ (ATLAS)
- For A_c, need to fully reconstruct tT kinematics
  - 2 neutrinos vs. 1 E_T^{miss}, lepton/b pairing ambiguities
  - CMS uses Analytical Matrix Weighting Technique - find most probable kinematics for m_{top}=172.5 GeV
  - ATLAS uses similar neutrino weighting technique sampling the expected neutrino η distributions
  - Final samples of ~10k events/7.5% background (CMS), or 8k / 15% (ATLAS)
    - Backgrounds from Wt single top, Z+jets, diboson, fakes
- Can also define a lepton asymmetry from lepton ηs:

$$A_C^{\mathrm{lep}} = \frac{N(\Delta|\eta_\ell| > 0) - N(\Delta|\eta_\ell| < 0)}{N(\Delta|\eta_\ell| > 0) + N(\Delta|\eta_\ell| < 0)}.$$

  - Related to A_c, sensitive to anomalous top polarisation
    - No requirement to reconstruct tT kinematics

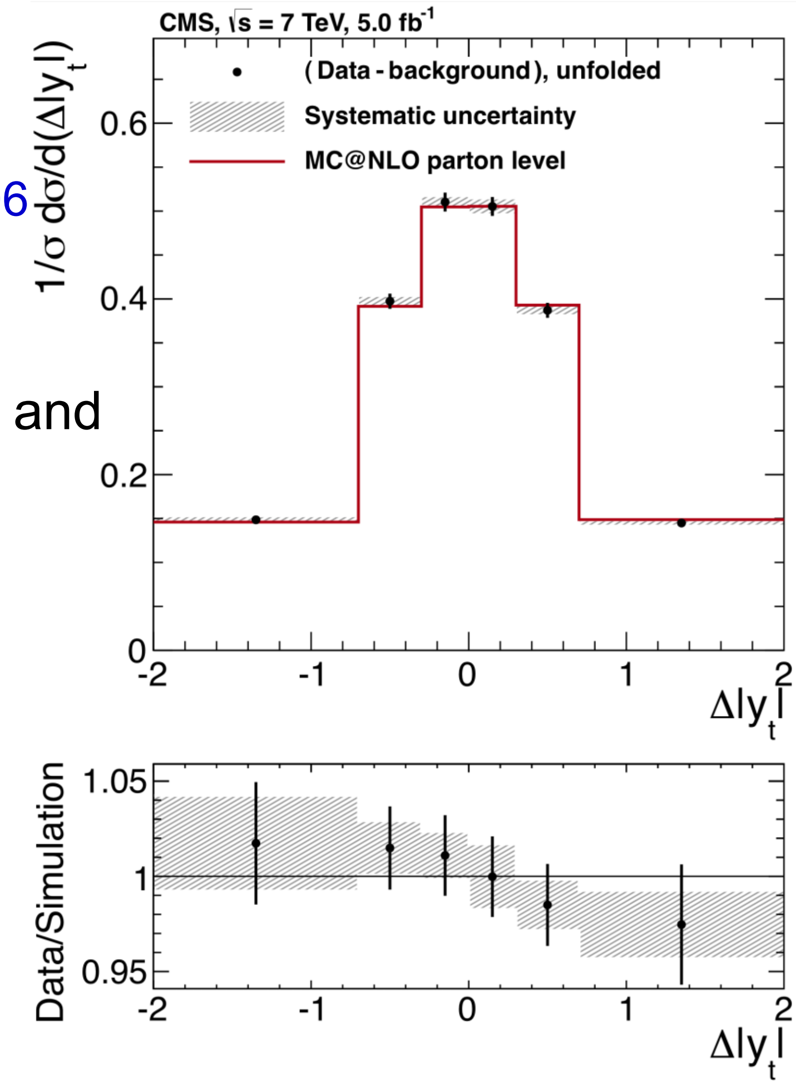


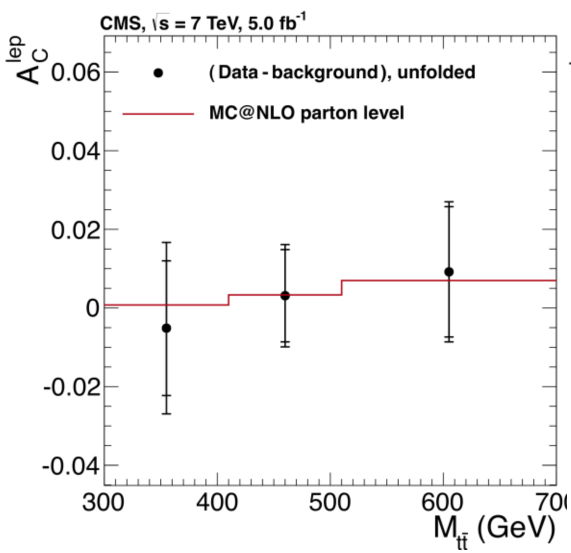
CMS 7 TeV dilepton asymmetry result

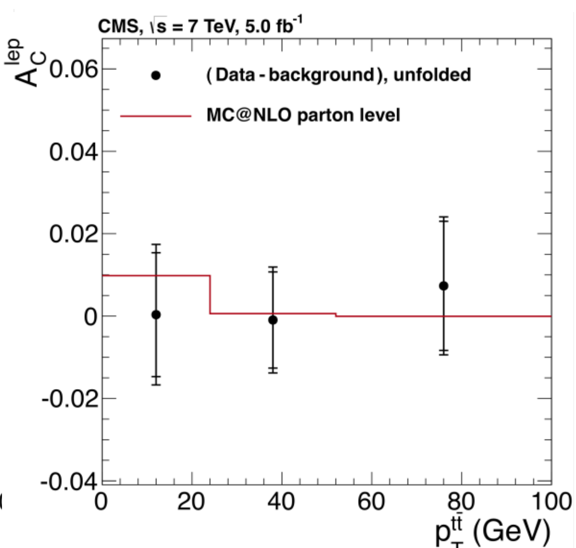
- Unfolding of recon-level Δ|y| and Δ|η| distributions
  - Correct for background, acceptance and resolution
- Inclusive results:

  A_C=-0.010±0.017±0.008, A_C^{lep}=0.009±0.010±0.006
  - Systematics dominated by tT scale uncertainties

- For A_C^{lep}, also show distributions vs. m(tT), p_T(tT) and |y(tT)| - no significant dependencies

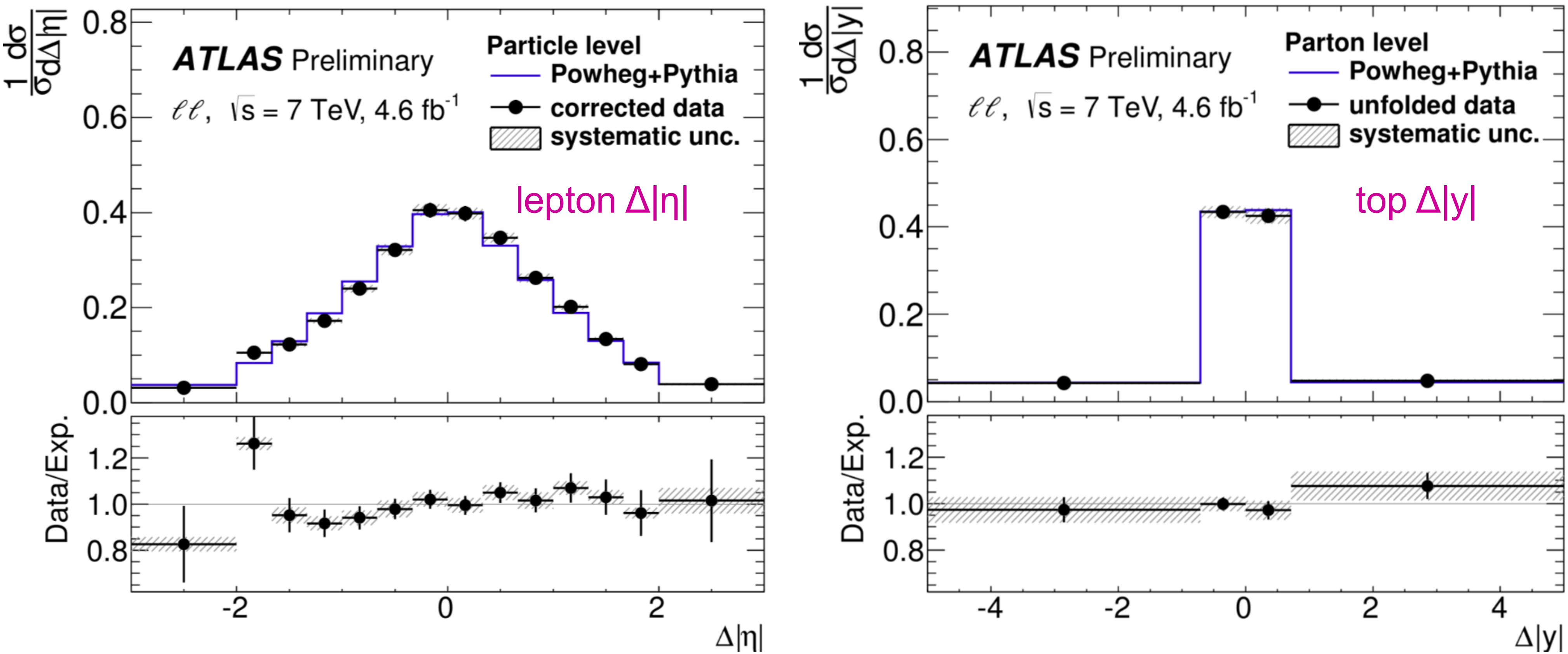






New ATLAS 7 TeV dilepton asymmetry results

- Unfold distributions for lepton Δ|η| (bin-by-bin correction) and top Δ|y| (FBU)
  - Uncertainties are dominated by statistics for Δ|η|
  - Statistical and systematics are ~ equal for top/anti top Δ|y|, dominated by detector and background modelling

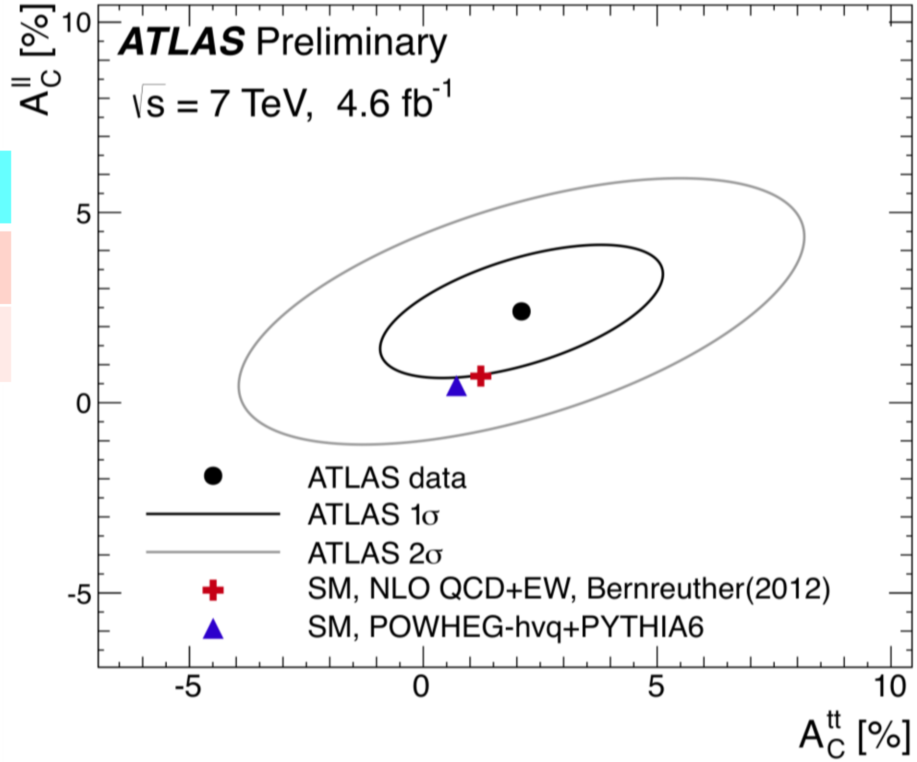


New ATLAS 7 TeV dilepton asymmetry results

- Asymmetries derived from ee/μμ/eμ differential distributions, then combined
  - Results are statistically dominated
  - Compatible with SM for both A_c^{ll} and A_c^{tt}

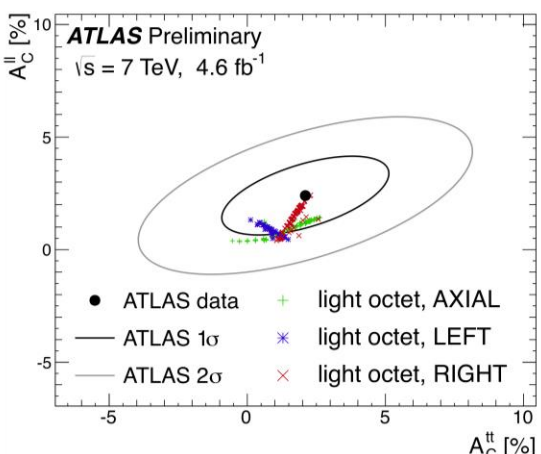
SM: Bernreuther & Zi

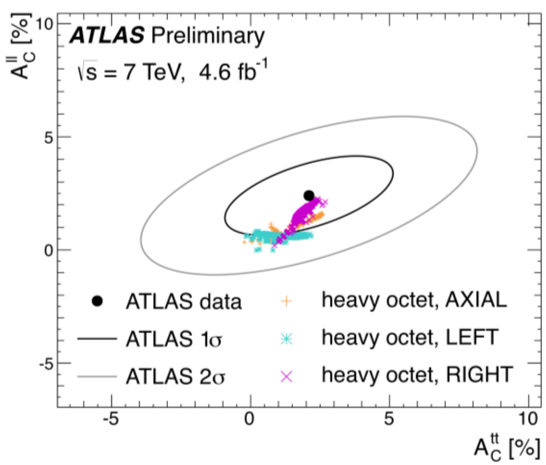
	A_C^{lep}	A_C^{tt}
Result	0.024±0.015±0.009	0.021±0.025±0.017
SM	0.0070±0.0003	0.0123±0.0005



Statistical corl^n 37±5%
Systematic corl^n 100%

- BSM models with s-channel colour octet
  - Tuned to Tevatron and LHC tT data





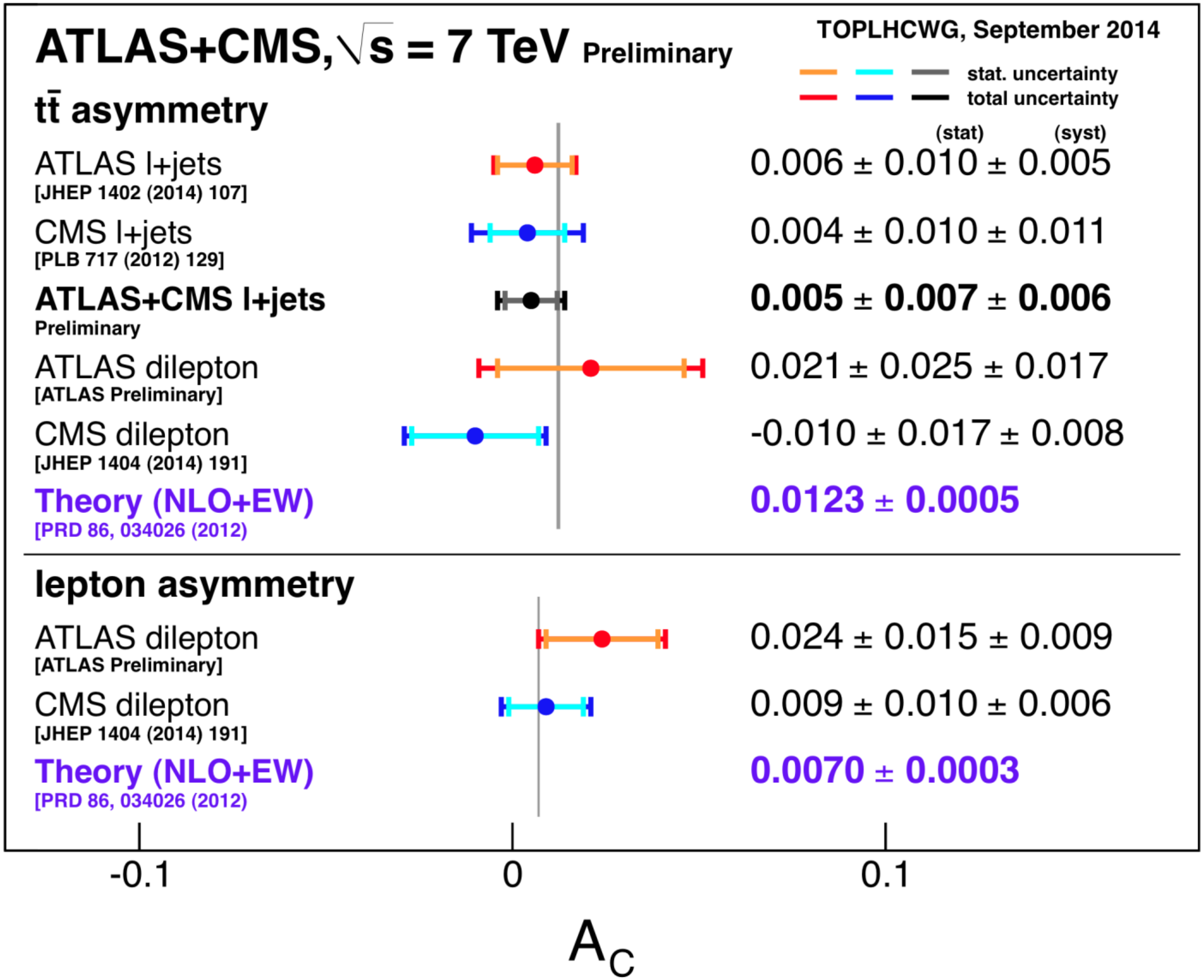
Comments on asymmetry measurements

- Results compared to SM NLO+EW predictions (Kühn & Rodrigo)

	Asymmetry (%)	ATLAS	CMS	LHC comb	NLO+EW
7 TeV	l+jets A_c	0.6±1.0±0.5	0.4±1.0±1.1	0.5±0.7±0.6	1.15±0.06
	dilepton A_c	2.1±2.5±1.7	-1.0±1.7±0.8		1.15±0.06
	Dilepton A_{lep}	2.4±1.5±0.9	0.9±1.0±0.6		0.70±0.03
8 TeV	l+jets A_c		0.5±0.7±0.6		1.11±0.04

- Most precise A_c measurements at level of ~1%, dilepton ~2% or higher
  - Compatible with zero and with SM theory prediction
- A_{lep} measurements compatible with zero – SM asymmetry again small
- Future prospects for 8 TeV and 13-14 TeV
  - Potential to measure $A_C \neq 0$ with combination of 8 TeV analyses...?
  - More statistics for high m(tT), high β_z region – enhanced sensitivity to qqbar
    - But reduced qqbar fraction of 9% at 14 TeV (gg dominates)
  - Not yet systematics limited for inclusive A_c – exploit full statistics
  - Scope for fiducial measurements (e.g 4 vs 5 jet) to reduce unfolding corrections?

Summary of 7 TeV asymmetry measurements

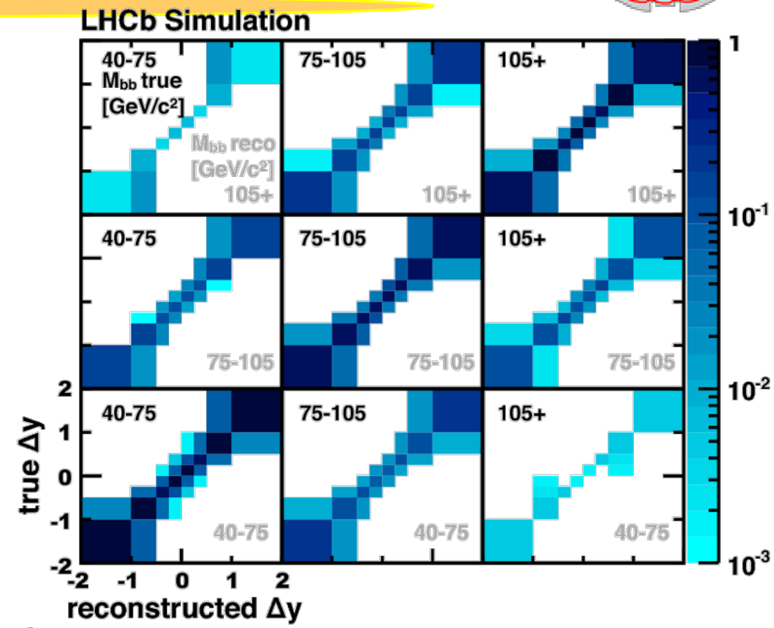


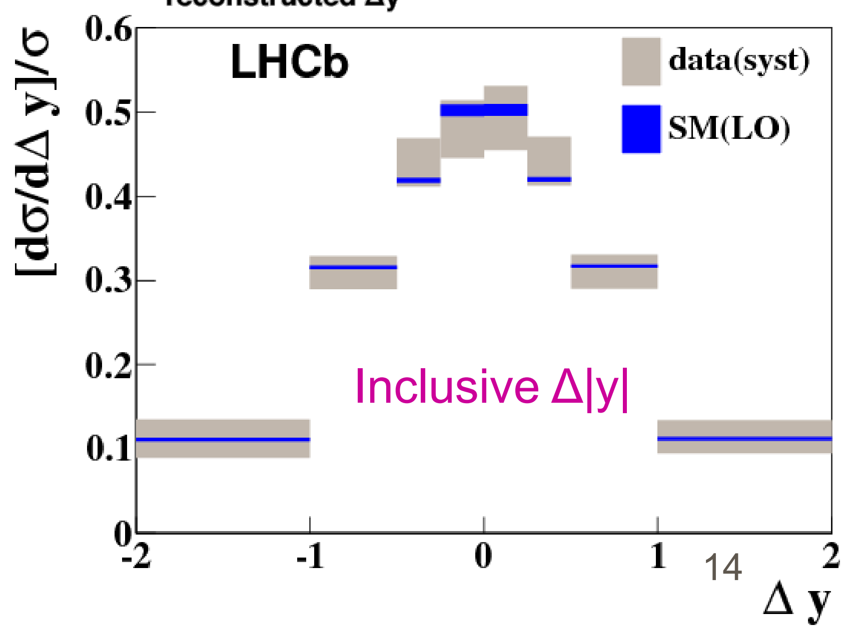
Interlude – bbbar charge asymmetry from LHCb

- LHCb measured b-quark A_C in pp collisions
  - Each b-quark from b-bbar forms a single jet
  - Two b-jets, each 2<y<4, E_T>20 GeV, $\Delta\phi$>2.6 rad
    - Restricted y acceptance of forward geometry
  - Require at least one muon from semileptonic decay to tag charge of b/ bbar
    - Purity of 70.3±0.3%, measured with dimuon events
  - Sample ~400k events, c-cbar contamination ~4%
- Measurement in 3 mass bins: A_C^{bb}(x,y) GeV

$$A_C^{b\bar{b}}(40,75) = 0.4 \pm 0.4\,(\mathrm{stat}) \pm 0.3\,(\mathrm{syst})\%,$$
$$A_C^{b\bar{b}}(75,105) = 2.0 \pm 0.9\,(\mathrm{stat}) \pm 0.6\,(\mathrm{syst})\%,$$
$$A_C^{b\bar{b}}(>105) = 1.6 \pm 1.7\,(\mathrm{stat}) \pm 0.6\,(\mathrm{syst})\%,$$

  - Expected SM asymmetries up to ~1%
    - Additional ~2% contribution around Z mass from Z→bb decays





Top polarisation and spin correlations

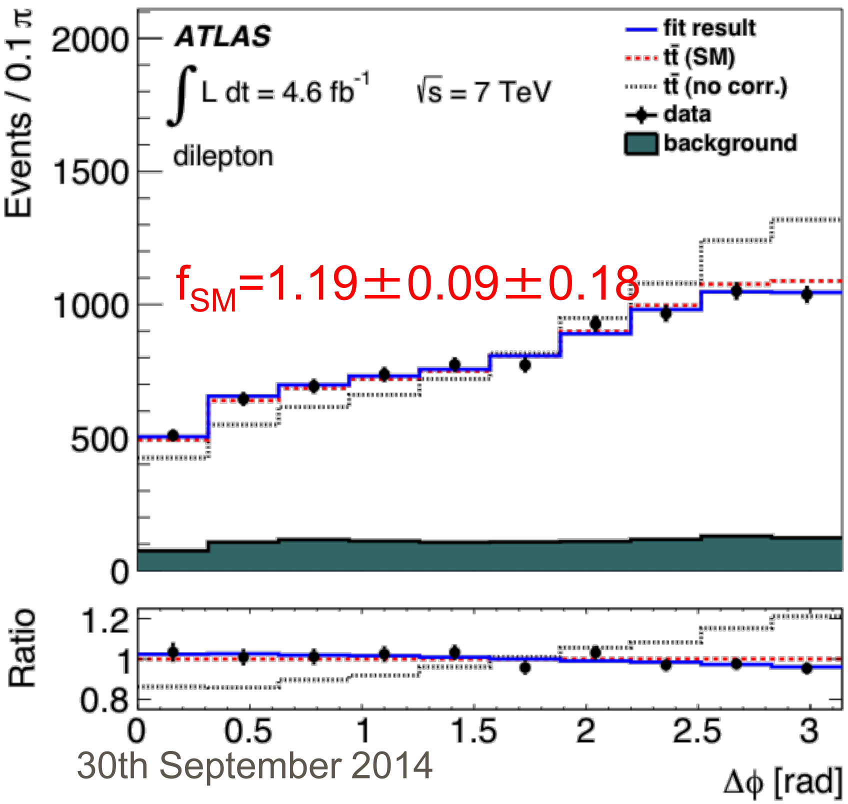
- Top quark lifetime of ~3 10^{-25} sec is much shorter than hadronisation time
  - Top decays as a bare quark, and does not form hadrons
  - Top spin info is not 'corrupted' by QCD interactions, transferred to decay products
- Angular decay distribution: $\frac{1}{\Gamma}\frac{d\Gamma}{d\cos(\theta_i)} = (1+\alpha_i \mathbf{P}\cos(\theta_i))/2$
  - θ_i angle between top decay product i and top polarisation P along chosen axis
  - α_i is spin analysing power: ~±1 for charged leptons, -0.966 / -0.393 for d / b quark
  - Normally use helicity basis, chose quantisation axis as top quark momentum direction in tT rest frame
- Negligible polarisation in SM, but spins of t and T are correlated

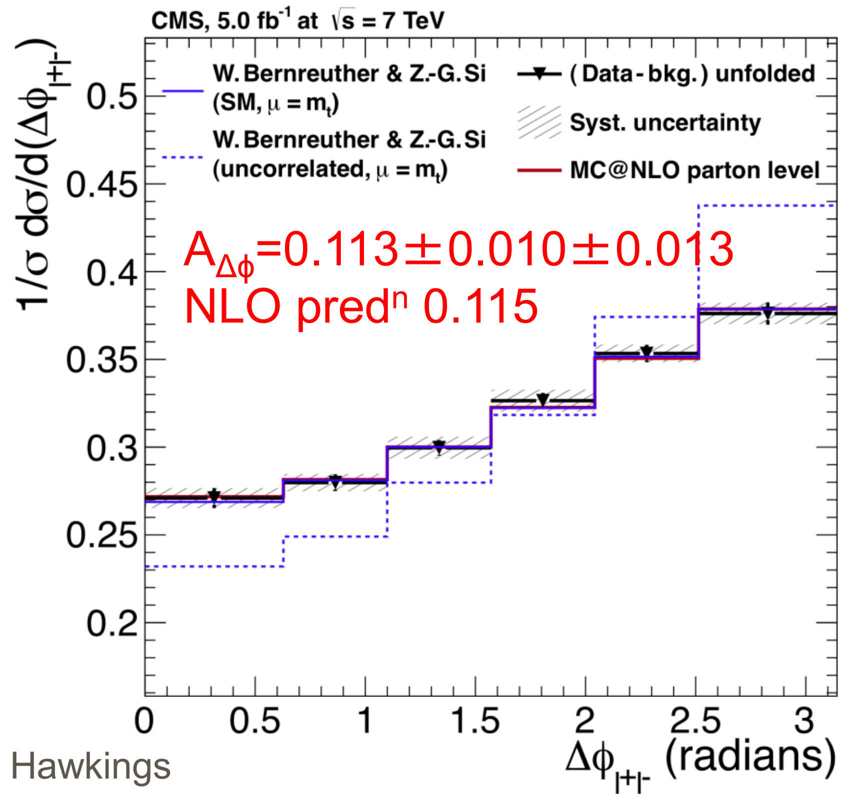
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos(\theta_+)\;d\cos(\theta_-)} = \frac{1}{4}(1 + A\,\alpha_+\alpha_-\cos(\theta_+)\cos(\theta_-)) \qquad A = \frac{N_{\mathrm{like}} - N_{\mathrm{unlike}}}{N_{\mathrm{like}} + N_{\mathrm{unlike}}} = \frac{N(\uparrow\uparrow)+N(\downarrow\downarrow)-N(\uparrow\downarrow)-N(\downarrow\uparrow)}{N(\uparrow\uparrow)+N(\downarrow\downarrow)+N(\uparrow\downarrow)+N(\downarrow\uparrow)}$$

- Can be measured from dilepton $\Delta\phi_{ll}$, or observables involving $\cos\theta_i$
  - $\Delta\phi_{ll}$ is straightforward to measure precisely
  - $\cos\theta_i$ requires full event reconstruction (dilepton or l+jets events)

Spin correlation – $\Delta\phi$ measurements

- Dilepton $\Delta\phi_{ll}$ measured by both experiments with 'standard' dilepton selections
  - ATLAS: template fit at reconstruction level to MCs with and without spin correlation
    - Fit fraction f_{SM} of SM-correlation template: f_{SM}=1 in SM, proportional to correlation strength
  - CMS: subtract background and unfold reconstructed distribution to particle level
    - Compare with NLO predictions at particle level; quantify by asymmetry $A_{\Delta\phi}$ about $\phi=\pi/2$
  - Uncertainties in both cases dominated by tT modelling (particularly top p_T)





New 8 TeV spin correlation $\Delta\phi_{ll}$ from ATLAS

- New result based on full 2012 data sample
  - Dilepton selection (ee,μμ, eμ) optimised wrt 7 TeV
    - More efficient likelihood-based electron ID
    - Require ≥1 b-tagged jet; allows E^T_{miss} cut in ee/μμ to be reduced from 60 GeV to 30 GeV

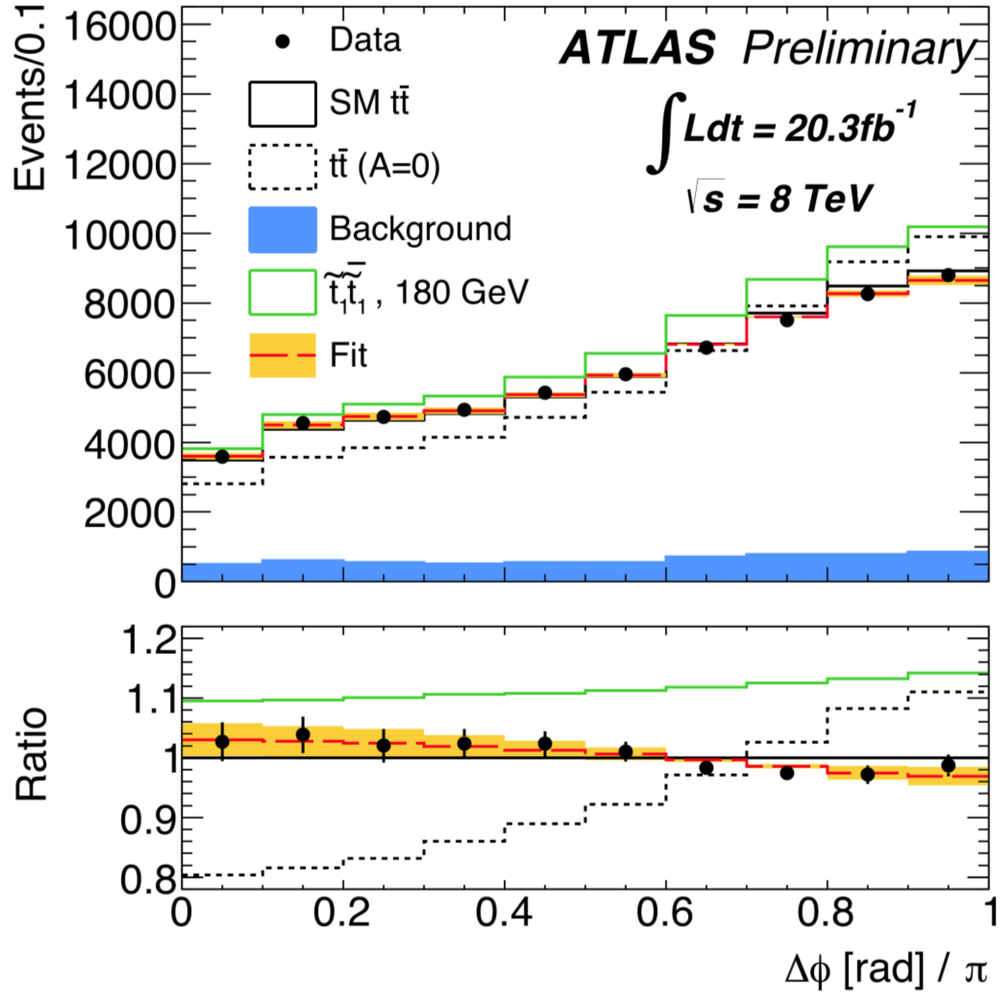
Process	Yield
$t\bar{t}$	54000^{+3400}_{-3600}
Z/γ^*+jets	2800 ± 300
tV (single top)	2600 ± 180
$t\bar{t}V$	80 ± 11
WW, WZ, ZZ	180 ± 65
Fake Leptons	780 ± 780
Total non-$t\bar{t}$	6400 ± 860
Expected (E)	60000^{+3500}_{-3700}
Observed (O)	60424

- Measure f_{SM} from template fit to $\Delta\phi_{ll}$ distribution
  - Systematics-dominated result; tT modelling

Source of uncertainty	Δf_{SM}
Detector modeling	
Lepton reconstruction	± 0.01
Jet energy scale	± 0.02
Jet reconstruction	± 0.01
E_T^{miss}	< 0.01
Fake leptons	< 0.01
b-tagging	< 0.01
Signal and background modeling	
Renormalization/factorization scale	± 0.05
MC generator	± 0.03
Parton shower and fragmentation	± 0.06
ISR/FSR	± 0.06
Underlying event	± 0.04
Color Reconnection	± 0.01
PDF Uncertainty	± 0.05
Background	± 0.01
MC statistics	± 0.04
Total systematic uncertainty	± 0.13
Data statistics	± 0.05

New 8 TeV spin correlation $\Delta\phi_{ll}$ from ATLAS

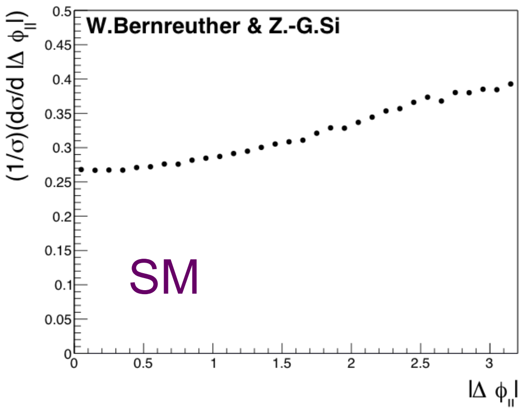
- Result from template fit:
  - $f_{SM}=1.20\pm0.05\pm0.13$
  - Convert to spin correlation strength measurement assuming linear relation: $A_{helicity}=0.38\pm0.04$
    - Compatible with SM value 0.318 ± 0.005 and 7 TeV measurement 0.37 ± 0.08
- Same measurement used to search for stop-pair decays with $\tilde{t}\rightarrow tX^0$
  - See talk of Till Eifert

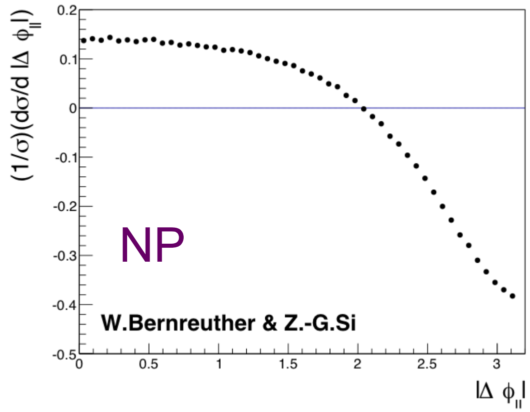


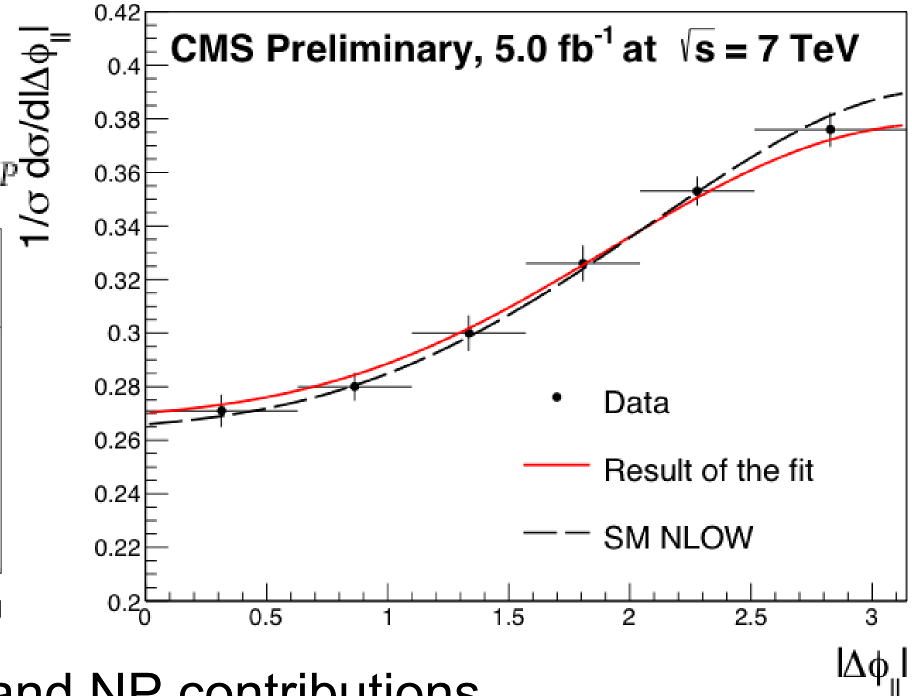
Anomalous contributions to spin correlation?

- Anomalous tTg interaction from heavy particle with mass $M>m_t$
  - Parameterise as a chromomagnetic dipole moment CMDM, strength $Re(\mu_t)$
    - A dimensionless parameter, assumed << 1
- Modifies $\Delta\phi$ with a new-physics contrib^n:

$$\frac{1}{\sigma}\frac{d\sigma}{d|\Delta\phi_{ll}|} = \left(\frac{1}{\sigma}\frac{d\sigma}{d|\Delta\phi_{ll}|}\right)_{SM} + \mathrm{Re}(\hat{\mu}_t)\left(\frac{1}{\sigma}\frac{d\sigma}{d|\Delta\phi_{ll}|}\right)_{NP}$$



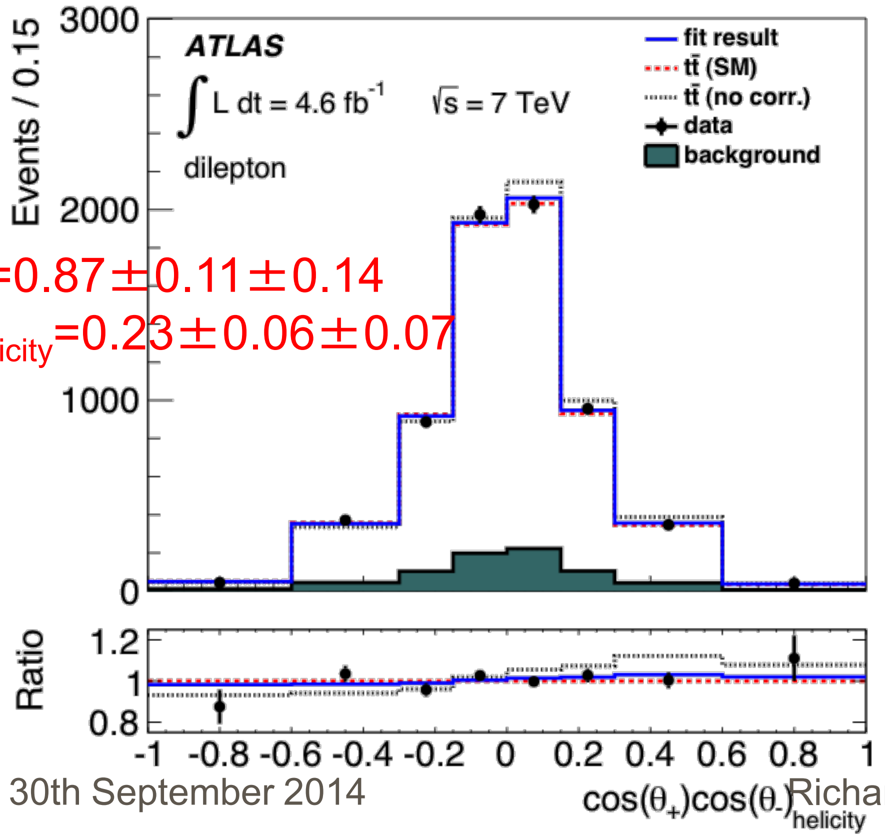




- Fit unfolded $\Delta\phi_{ll}$ distribution to sum of SM and NP contributions
  - Raw fit: $Re(\mu_t)=0.031\pm0.017$, add bias correction and scale variations on SM part
  - Final result $Re(\mu_t)=0.037\pm0.041$; 95% CL exclusion $-0.043 < Re(\mu_t) < 0.117$

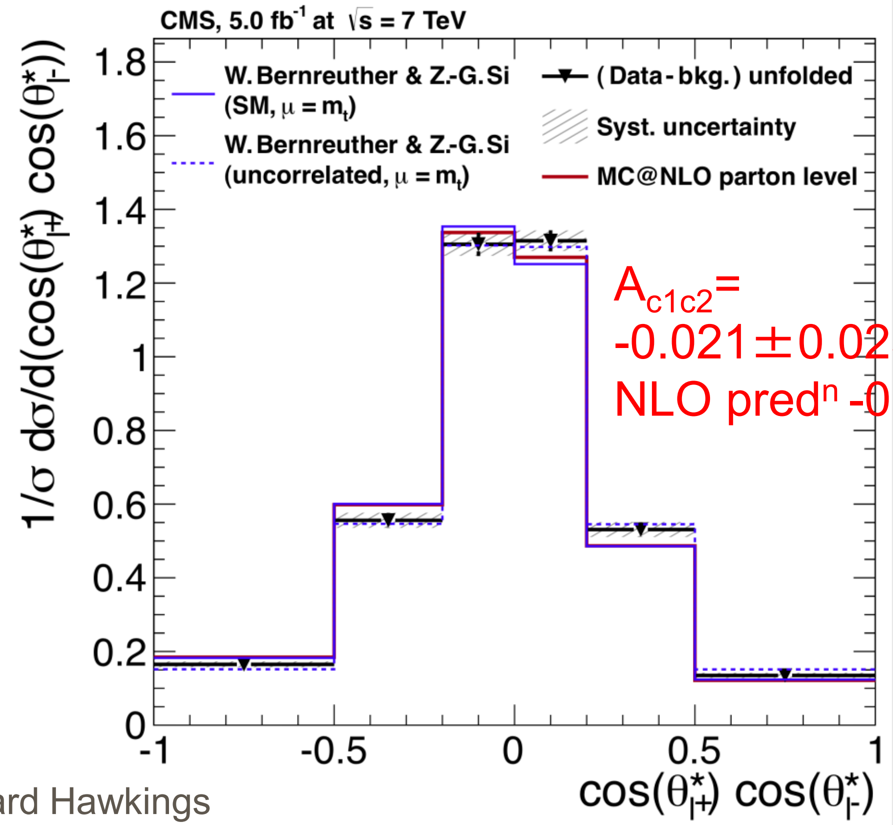
Double-angular distribution for spin correlations

- Measurement of $\cos\theta^*_1 . \cos\theta^*_2$ in dileptons requires full event reconstruction
  - Similar techniques to charge asymmetry – neutrino weighting, AMWT
    - Again, template fit (ATLAS), unfold to particle level (CMS), angles in helicity basis
  - Dominant systematics from JES, tT radiation modelling, unfolding
  - Spin correlation A can be extracted directly from measured distribution



f_{SM}=0.87±0.11±0.14

$A_{helicity}$=0.23±0.06±0.07

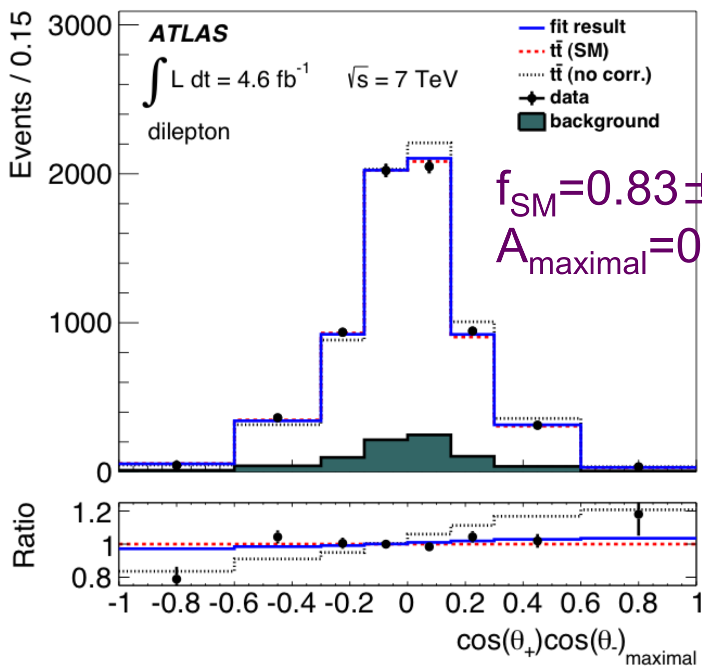


A_{c1c2}=
-0.021±0.023±0.027

NLO pred^n -0.078

Other dilepton spin-correlation distributions

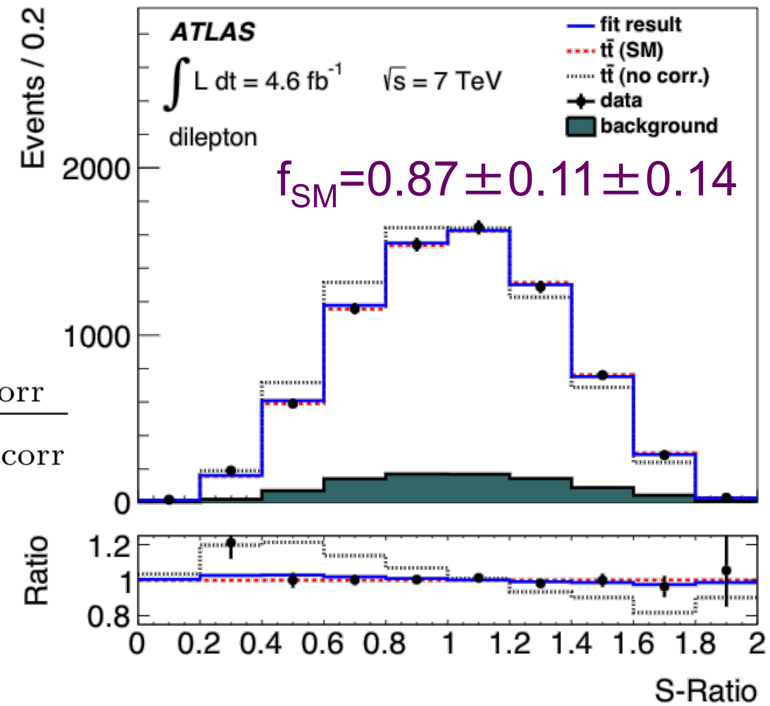
- ATLAS also measured $\cos\theta^*_1 . \cos\theta^*_2$ in 'maximal basis' (best for gg fusion)
  - And 'S-ratio', based on matrix elements for like-helicity gg fusion



f_{SM}=0.83±0.14±0.18

$A_{maximal}$=0.36±0.06±0.08

$$S = \frac{(|\mathcal{M}|^2_{\mathrm{RR}} + |\mathcal{M}|^2_{\mathrm{LL}})_{\mathrm{corr}}}{(|\mathcal{M}|^2_{\mathrm{RR}} + |\mathcal{M}|^2_{\mathrm{LL}})_{\mathrm{uncorr}}}$$



f_{SM}=0.87±0.11±0.14

- Convert f_{SM} to spin corr[l] A assuming linear relation (Δϕ,S-ratio) or directly:

	$\Delta\phi(\ell,\ell)$	S-ratio	$\cos(\theta_+)\cos(\theta_-)_{\mathrm{helicity}}$	$\cos(\theta_+)\cos(\theta_-)_{\mathrm{maximal}}$
	indirect extraction		direct extraction	
$A^{\mathrm{measured}}_{\mathrm{helicity}}$	$0.37 \pm 0.03 \pm 0.06$	$0.27 \pm 0.03 \pm 0.04$	$0.23 \pm 0.06 \pm 0.07$	—
$A^{\mathrm{measured}}_{\mathrm{maximal}}$	$0.52 \pm 0.04 \pm 0.08$	$0.38 \pm 0.05 \pm 0.06$	—	$0.36 \pm 0.06 \pm 0.08$

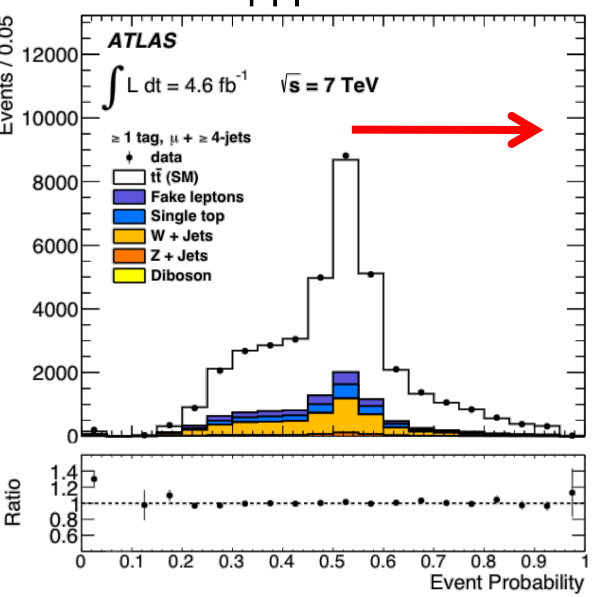
$A_{helicity}^{SM}$=0.31

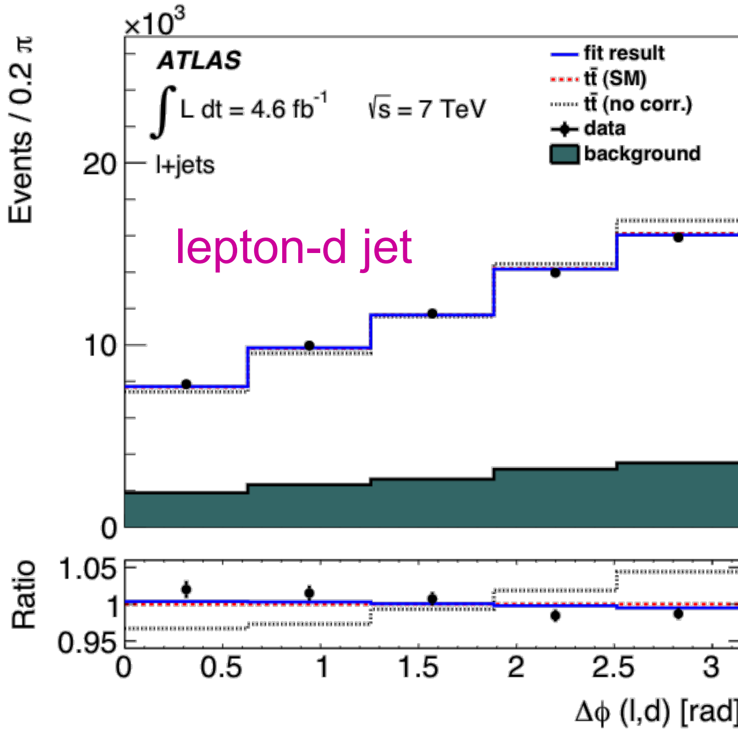
$A_{maximal}^{SM}$=0.44

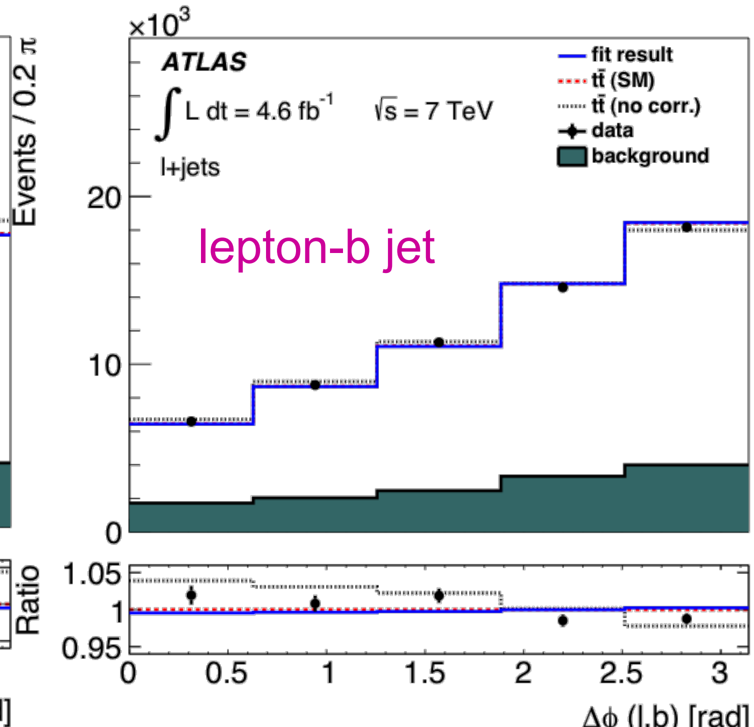
Spin correlations in l+jets events (ATLAS)

- $\Delta\phi$ in l+jet events between l from one top and b or d/s (from W→qq) from other
  - Spin analysing power for d-type quarks is -0.966, for b quarks -0.393
  - Use most likely permutation from kinematic fit – d type quark identified as lower p_T jet (V-A in W decay) or being opposite a moderate b-tag weight c-jet
    - $\Delta\phi$(l,b) and $\Delta\phi$(l,d) have similar power due to less reliable identification of d-quark
  - Fit both distributions simultaneously: $f_{SM}=1.12\pm0.11\pm0.22$ (c.f. dilept. ±0.09 ±0.18)

Event Prob>0.5,
one W→qq perm. favoured



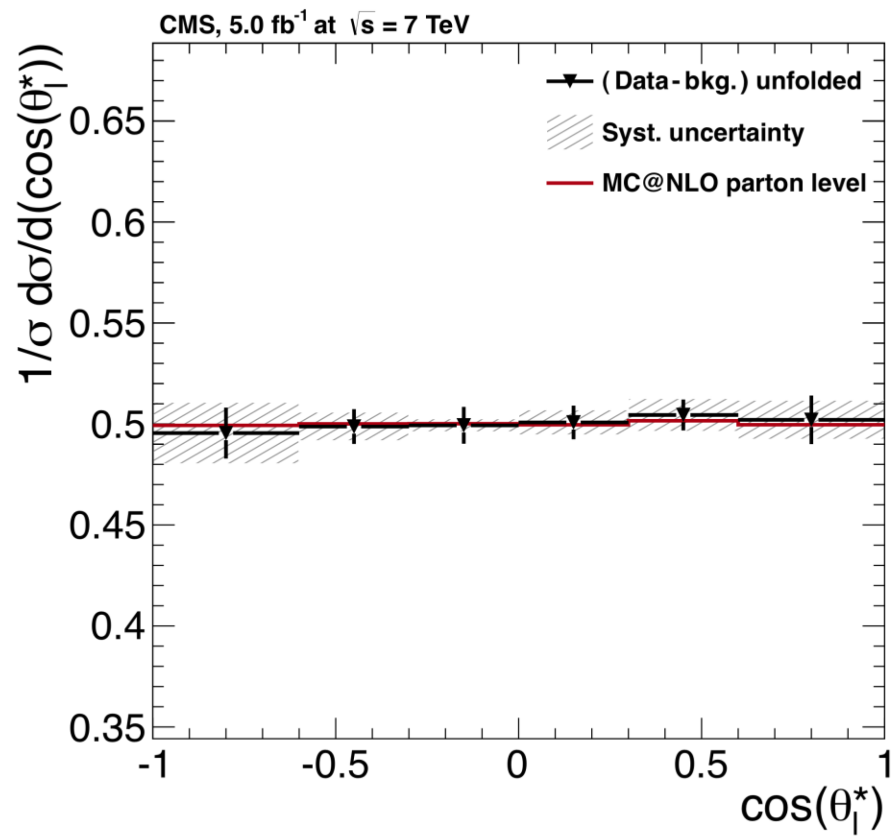




Polarisation measurements - CMS

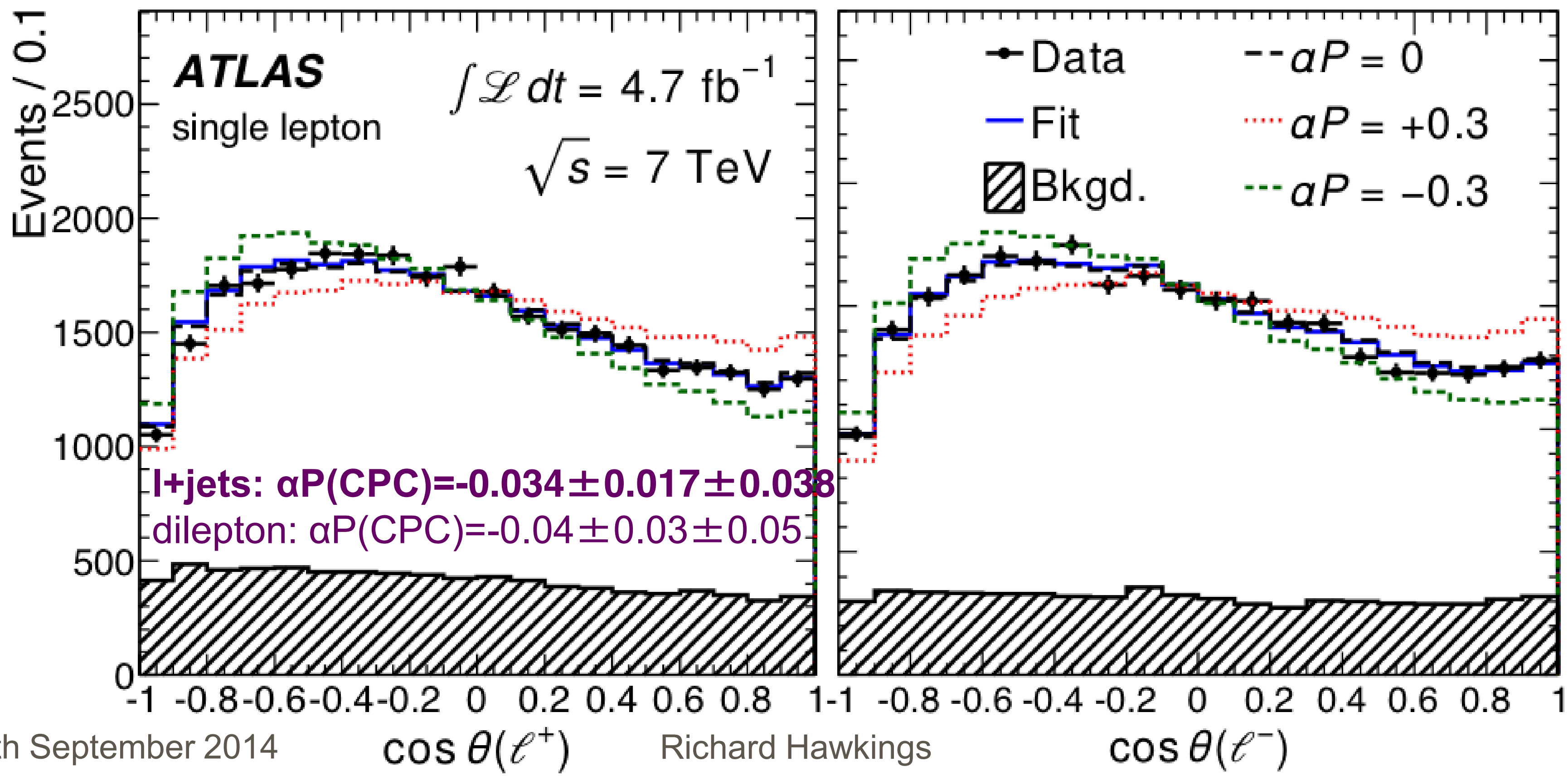
- CMS dilepton analysis also used to measure top quark polarisation
  - Unfold $\cos\theta^*_l$ distribution (+ and – leptons together)
  - No polarisation seen, in agreement with SM
    - Asym. A_P=0.005±0.013±0.014±0.016
    - Polarisation αP=2 A_P
  - Systematics dominated by top p_T modelling

Asymmetry variable	$A_{\Delta\phi}$	$A_{c_1c_2}$	A_P
Jet energy scale	0.002	0.012	0.009
Lepton energy scale	0.001	0.001	0.001
Background	0.003	0.001	0.006
Fact. and renorm. scales	0.001	0.010	0.004
Top-quark mass	0.001	0.003	0.005
Parton distribution functions	0.002	0.002	0.001
Jet energy resolution	<0.001	<0.001	<0.001
Pileup	0.002	0.002	0.004
b-tagging scale factor	<0.001	<0.001	0.001
Lepton selection	<0.001	<0.001	<0.001
τ decay polarization	0.001	0.002	0.001
Unfolding	0.004	0.020	0.002
Total systematic uncertainty	0.006	0.025	0.014
Top p_T reweighting uncertainty	0.012	0.010	0.008



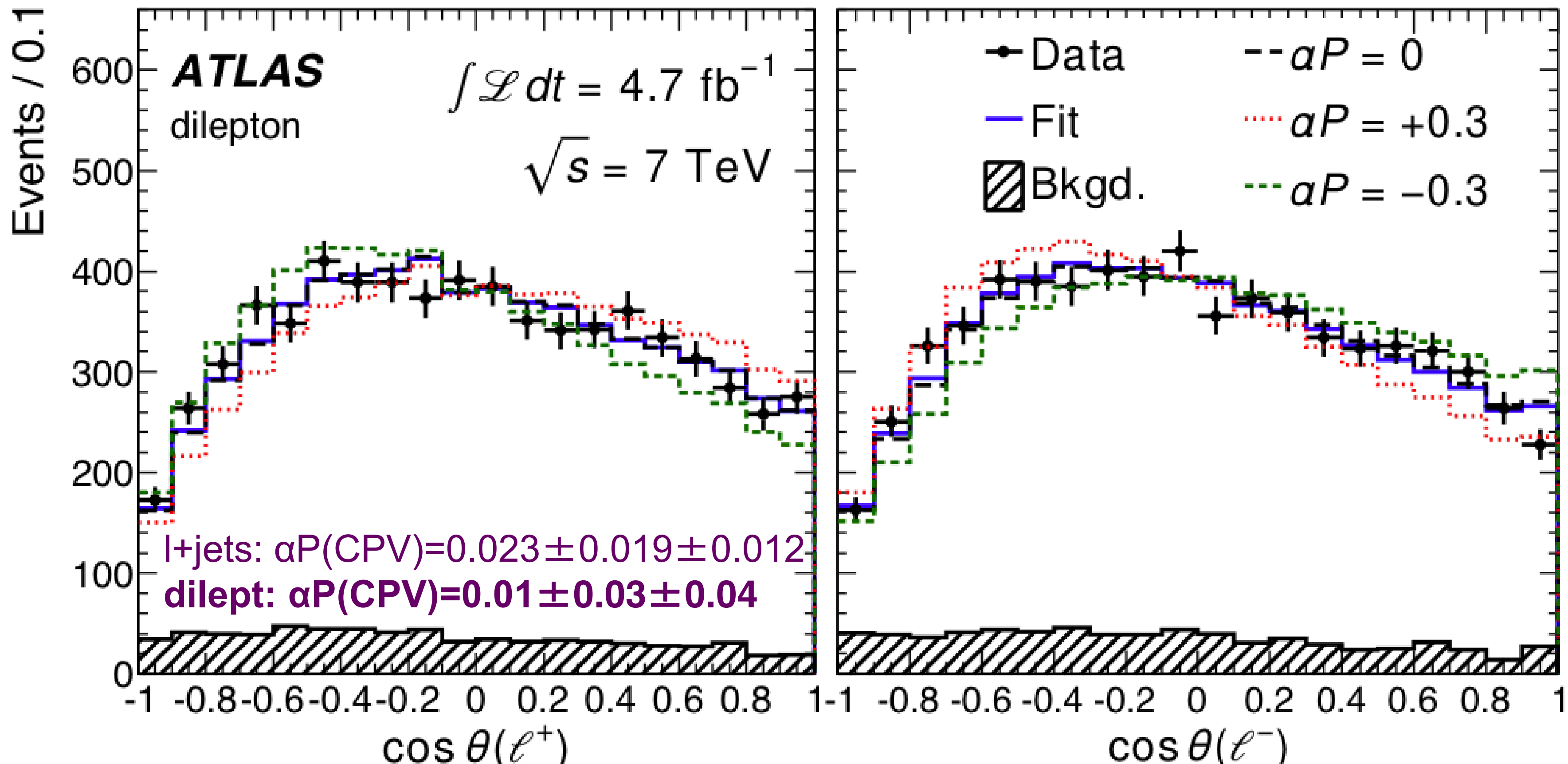
Polarisation measurements – ATLAS (CPC)

- Polarisation measured in dilepton and l+jets channels using templates
  - Non-zero αP templates generated by reweighting in $\cos\theta^*_1$ and $\cos\theta^*_2$ simultaneously to preserve SM spin correlation
  - Separate tests of CP-conserving (same polarisation for top and antitop) and CP-violating (opposite for top and antitop) hypotheses

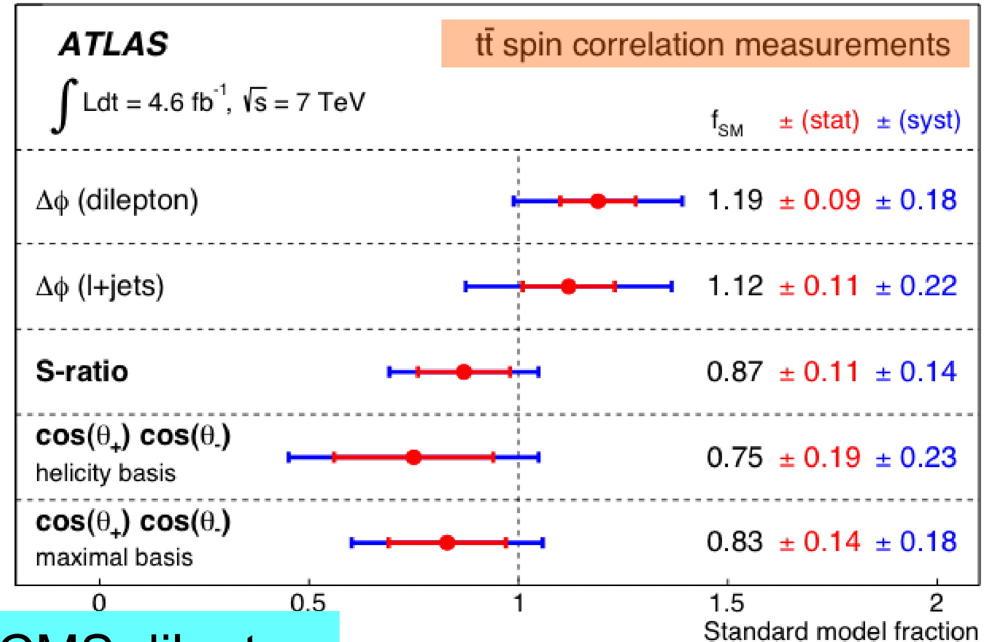


Polarisation measurements – ATLAS (CPV)

- Polarisation measurement with CP-violating hypothesis
  - Opposite effects for top and antitop
  - Systematic effects reduced compared to CPC hypothesis, as sources which do not depend on lepton charge tend to cancel out



Summary of spin 7 TeV tT correl^n/polar^n results



ATLAS dilepton/l+jets

Channel	$\alpha_\ell P_{\rm CPC}$	$\alpha_\ell P_{\rm CPV}$
ee	$0.12 \pm 0.10^{+0.09}_{-0.12}$	$-0.04 \pm 0.12^{+0.18}_{-0.12}$
$e\mu$	$-0.07 \pm 0.04^{+0.05}_{-0.06}$	$0.00 \pm 0.04^{+0.05}_{-0.04}$
$\mu\mu$	$-0.04 \pm 0.06^{+0.07}_{-0.07}$	$0.04 \pm 0.07^{+0.06}_{-0.06}$
Dilepton	$-0.04 \pm 0.03^{+0.05}_{-0.05}$	$0.01 \pm 0.03^{+0.04}_{-0.04}$
e + jets	$-0.031 \pm 0.028^{+0.043}_{-0.040}$	$0.001 \pm 0.031^{+0.019}_{-0.019}$
μ + jets	$-0.033 \pm 0.021^{+0.039}_{-0.039}$	$0.036 \pm 0.023^{+0.018}_{-0.017}$
ℓ + jets	$-0.034 \pm 0.017^{+0.038}_{-0.037}$	$0.023 \pm 0.019^{+0.012}_{-0.011}$
Combined	$-0.035 \pm 0.014^{+0.037}_{-0.037}$	$0.020 \pm 0.016^{+0.013}_{-0.017}$

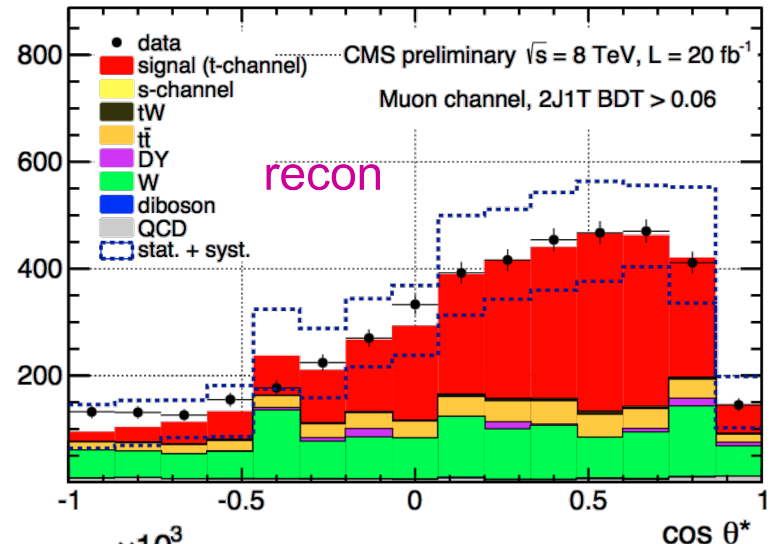
CMS dilepton

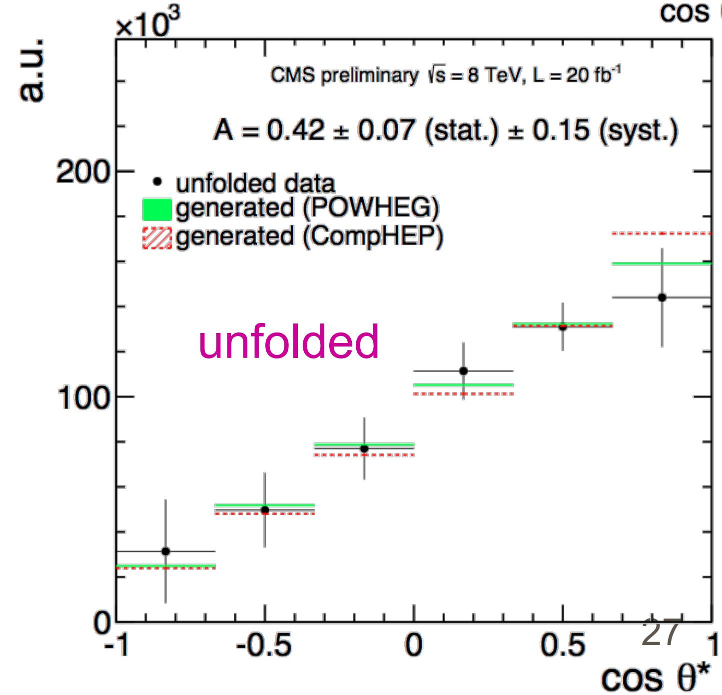
Asymmetry	Data (unfolded)	MC@TNLO	NLO (SM, correlated)	NLO (uncorrelated)
$A_{\Delta\phi}$	$0.113 \pm 0.010 \pm 0.006 \pm 0.012$	0.110 ± 0.001	$0.115^{+0.014}_{-0.016}$	$0.210^{+0.013}_{-0.008}$
$A_{c_1 c_2}$	$-0.021 \pm 0.023 \pm 0.025 \pm 0.010$	-0.078 ± 0.001	-0.078 ± 0.006	0
A_P	$0.005 \pm 0.013 \pm 0.014 \pm 0.008$	0.000 ± 0.001	...	...

- Spin correlations observed in LHC tT events @ 7 TeV, >5σ significance
  - No evidence of polarisation, results sensitive at ±2% level on $\alpha P=2A_P$
  - Already systematics limited, will have to improve to exploit 8 TeV data

Polarisation in single top events – CMS 8 TeV

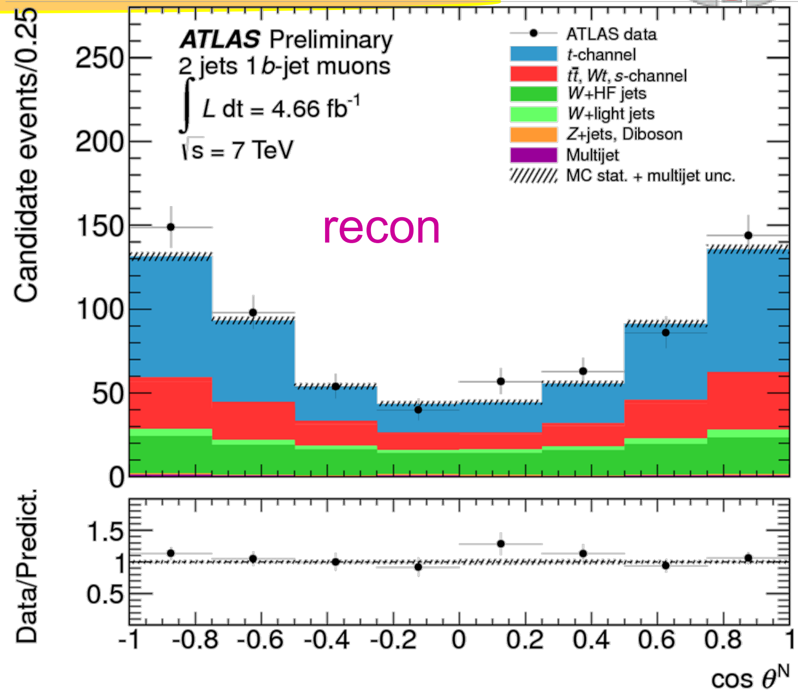
- t-channel single top gives ~100% polarised tops
  - Sensitive test of V-A structure of Wtb coupling
  - Probe by studying cosθ* between lepton and untagged (forward) jet in top rest frame
    - Light quark is ~parallel to top spin direction
- Select events using BDT as for x-sec analysis
  - Sample about 55% pure in t-channel
  - Background, acceptance and resolution effects in reconstructed cosθ* spectrum corrected by unfolding procedure
  - Results compatible with SM expectation
- Measured asymmetry combining e and μ:
  - A_l=0.41±0.06±0.16; polarisation αP=0.82±0.34
    - Systematics dominated by jet energy/resolution
  - Compatible with SM expectation of ~0.9

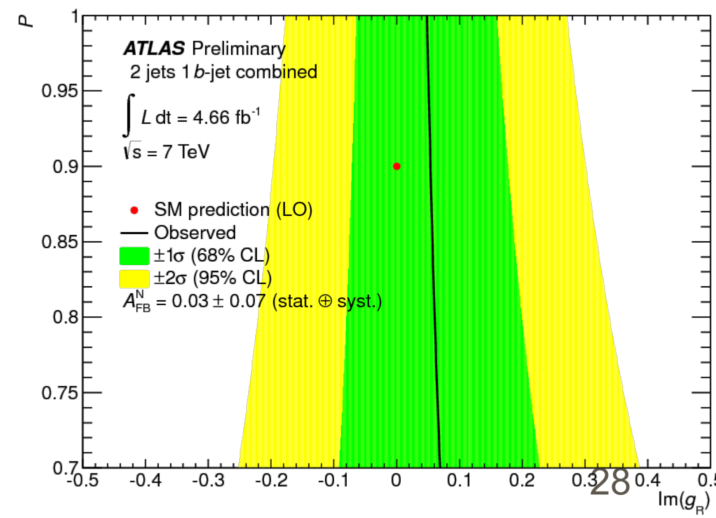




CP-violation in single top events – ATLAS 7 TeV

- More generally, parameterise Wtb vertex:
  - Vector couplings V(L,R) and tensor g(L,R)
  - In SM, V_L=CKM V_{tb} and others are all zero
  - Can be probed by angular analysis in top decay
- Define a new 'normal' direction **N**
  - Normal to spectator quark and W boson direction in top quark rest frame
  - $\cos\theta^N$ between **N** and lepton in W rest frame
  - Asymmetry in $\cos\theta^N$ sensitive to P.Im(g_R), a CP-violating coupling
- Reconstruct top decay kinematics and unfold
  - A_{FB}^N=0.031±0.065±0.030 , consistent with 0
    - Systematics dominated by MC modelling
  - Asumming P=0.9, asymmetry translates to limits -0.20< Im(g_R) <0.30 at 95% CL





Conclusions

- Various top quark properties studied in detail at the LHC, mainly 7 TeV data
- tT charge asymmetry in both lepton+jets and dilepton events
  - Measurements reaching ~1% precision, similar to size expected asymmetry in SM
  - No deviations seen, inclusively or differentially – excitement at Tevatron is not reproduced
- Top spin correlations in dilepton and lepton+jets events
  - Expected non-zero spin correlations are clearly seen
  - Polarisation measurements achieved ~2% precision, no polarisation observed
    - Measurements systematically limited due to top MC modelling
    - Can this be improved for 8 TeV data?
  - First polarisation-related analyses in single top production
- Still plenty of analyses to come at 8 TeV
  - Can a non-zero A_C value be observed?
  - Large datasets will allow more differential asymmetry measurements – hope for some surprises there, or in upcoming 13-14 TeV run

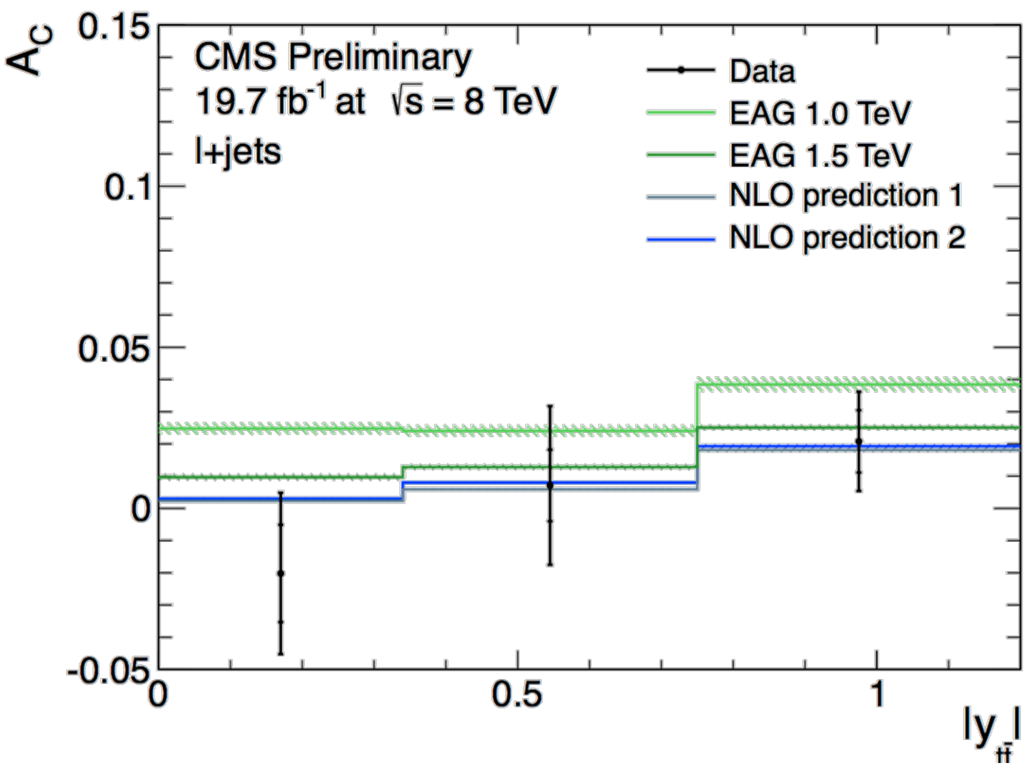
References

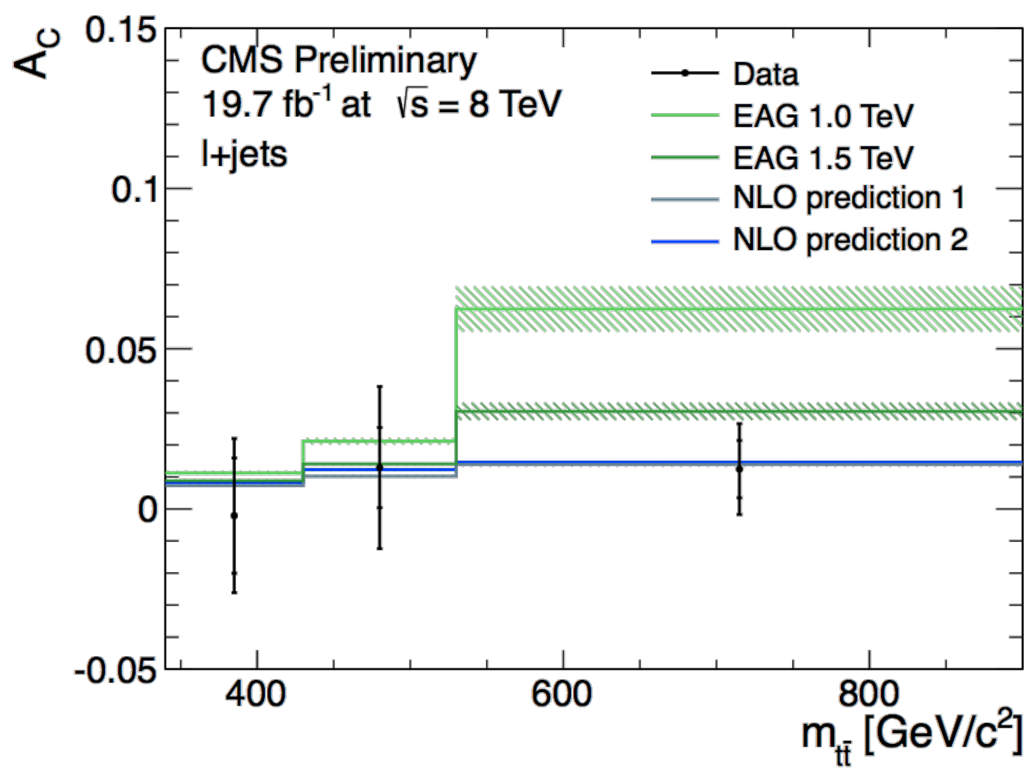
- tT charge asymmetry:
  - CMS l+jets 7 TeV: PLB 717 (2012) 129, arXiv:1207.0065
  - CMS dilepton 7 TeV: JHEP 1404 (2014) 191, arXiv:1402.3803
  - CMS l+jets 8 TeV: CMS PAS TOP-12-033
  - ATLAS l+jets 7 TeV: JHEP 1402 (2014) 107, arXiv:1311.6724
  - ATLAS dilepton 7 TeV: to be submitted to JHEP
  - 7 TeV l+jet combination: ATLAS-CONF-2014-012, CMS PAS TOP-14-006
  - LHCb b-bbar charge asymmetry: PRL 113 (2014) 082003, arXiv:1406.4789
- Spin correlations and polarisation:
  - CMS dilepton 7 TeV: PRL 112 (2014) 182001, arXiv:1311.3924
  - CMS chromomagnetic dipole moment: CMS PAS TOP-14-005
  - CMS polarisation in single top: CMS PAS TOP-13-001
  - ATLAS spin-corl 7 TeV: submitted to PRD, arXiv:1407.4314
  - ATLAS spin corl-8 TeV: ATLAS-CONF-2014-056
  - ATLAS polarisation 7 TeV: PRL 111 (2013) 232002, arXiv:1307.6511
  - ATLAS CP-violation in single top: ATLAS-CONF-2013-032

Additional slides

Differential measurements – CMS l+jets

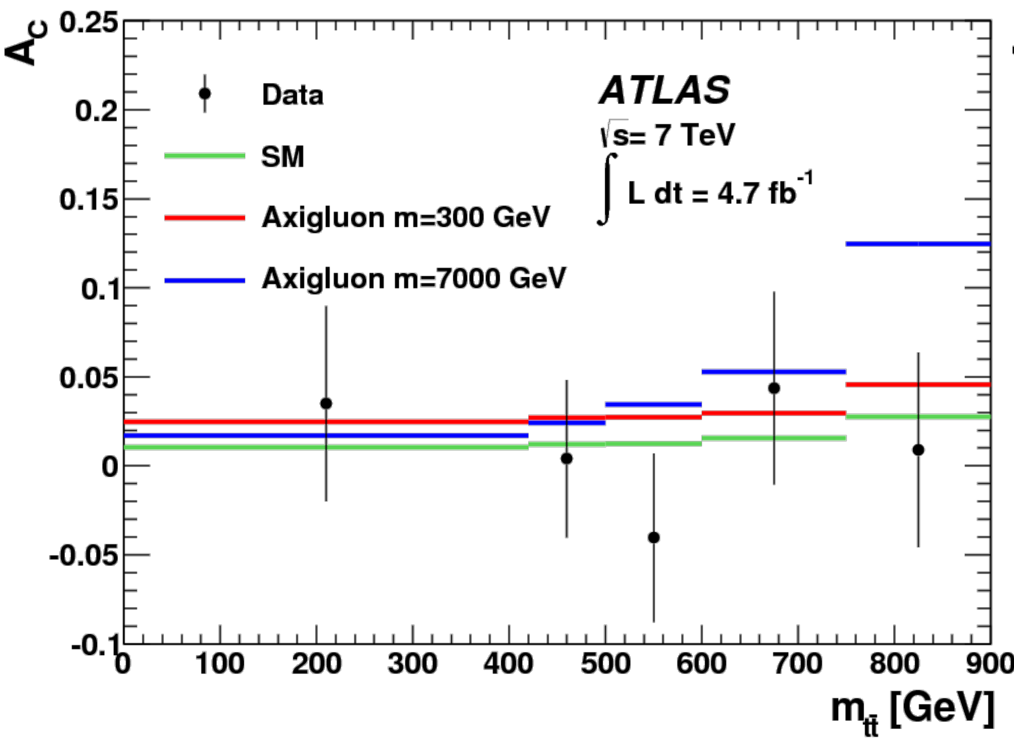
- Results from 7 and 8 TeV measurements vs |y(tT)|, p_T(tT), m(tT)
  - For differential measurements, consider migration in Δ|y| and m(tT), p_T(tT) y(tT)
  - Results compared to NLO and BSM effective theory with an anomalous axial-vector gluon coupling (EAG) with scale 1 or 1.5 TeV
  - Results from 8 TeV vs. |y(tT)| and m(tT) shown here:

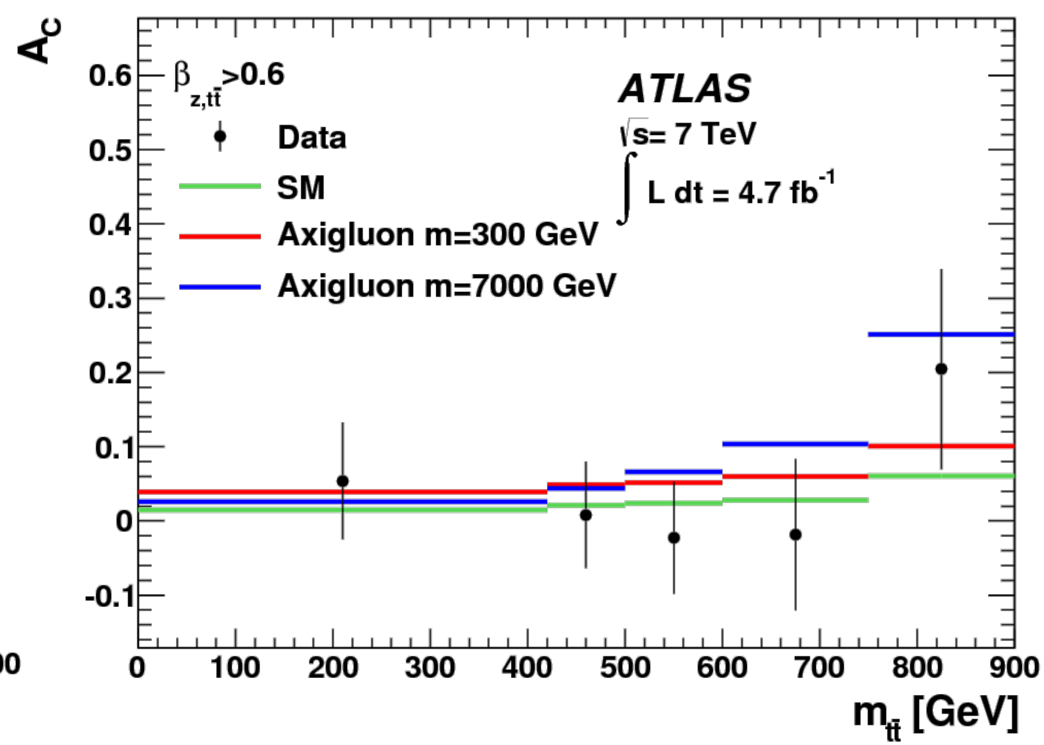




Differential measurements – ATLAS l+jets 7 TeV

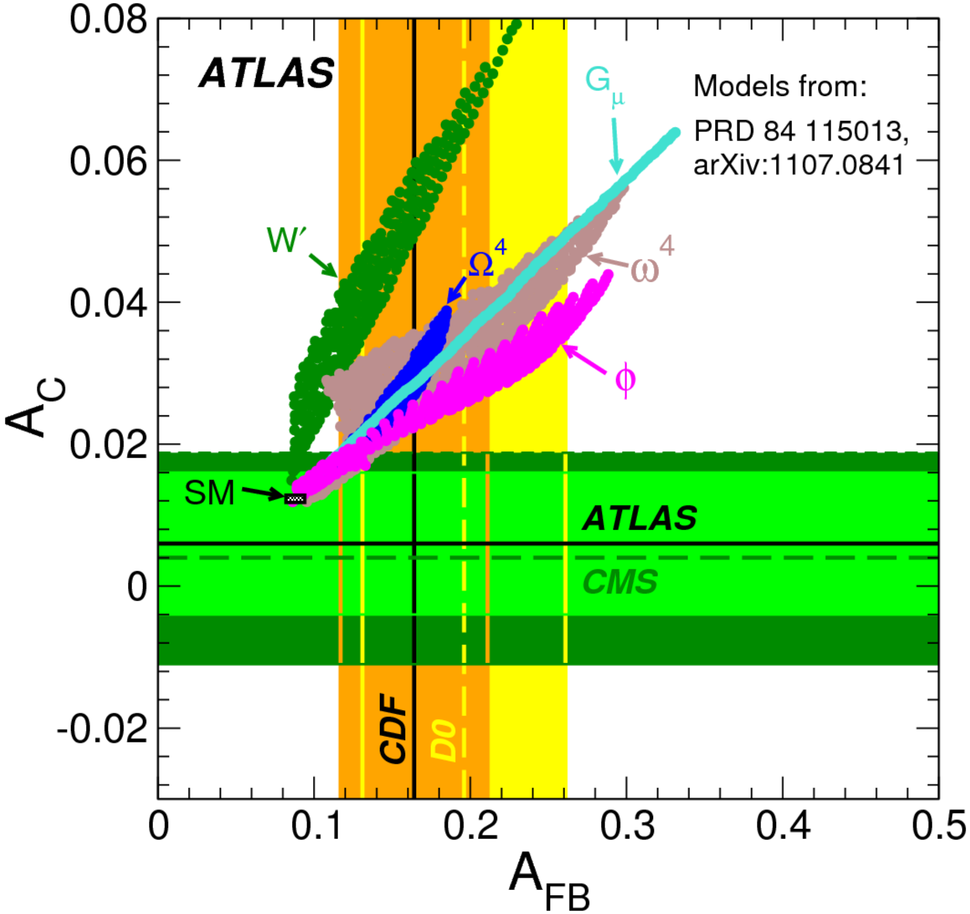
- Results from 7 TeV vs. |y(tT)|, p_T(tT) and m(tT), m(tT) with β_z>0.6
  - Compared to NLO+EW (SM) and heavy axigluon s-channel, tuned to Tevatron
  - Results for m(tT) and m(tT) with β_z>0.6 shown:

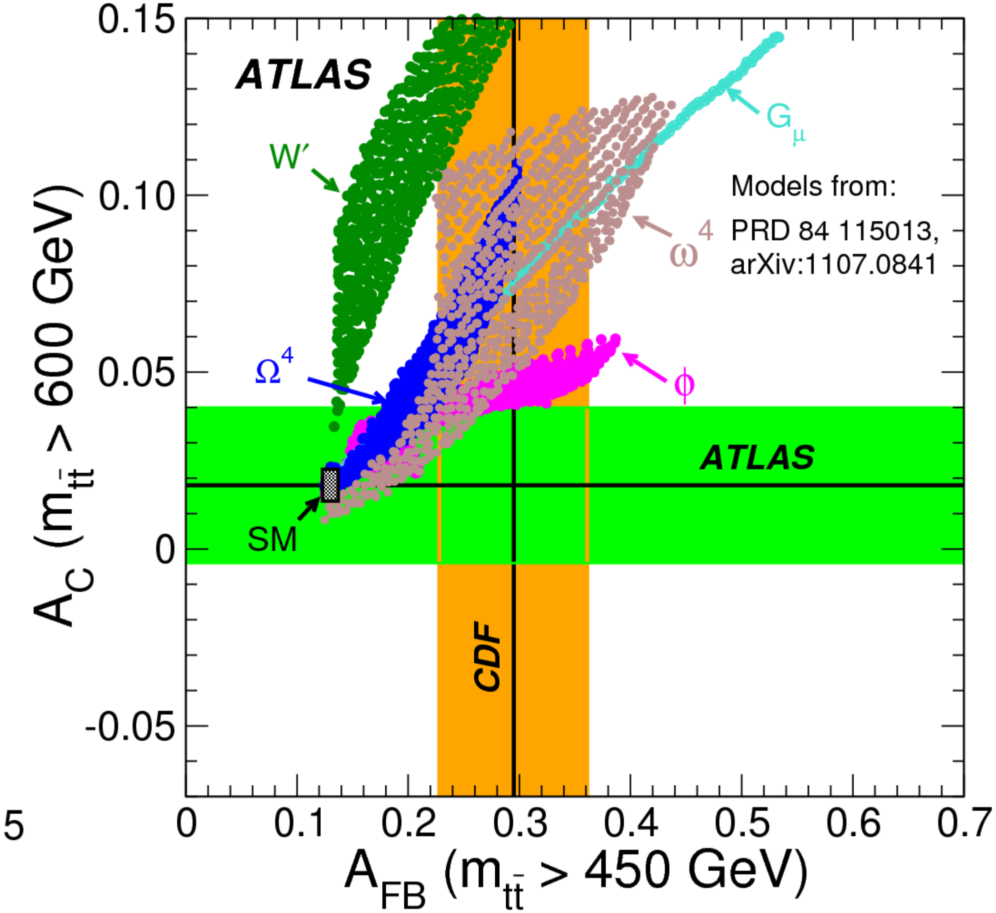




LHC charge asymmetry vs. Tevatron and BSM

- ATLAS shows comparison of results with predictions from BSM models
  - Left plot includes CMS 7TeV result, right plot is for m(tT)>600 GeV

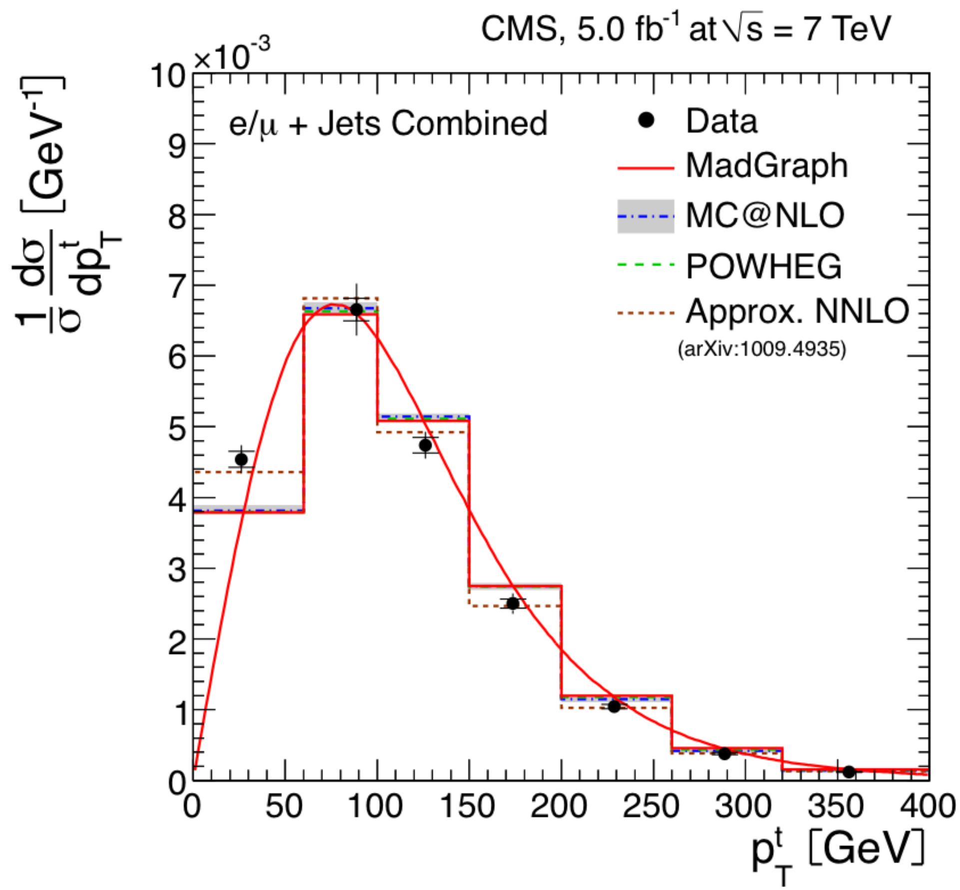




- LHC can exclude several models proposed to explain Tevatron results

CMS top p_T distribution reweighting

- CMS spin-corl/polarisation measurements quotes extra uncertainty due to top p_T
  - Measurements in 7 TeV l+jets and dilepton events show softer distribution in data than MC@NLO and Madgraph
  - Reweighting simulation improves modelling of lepton and jet p_T distributions
  - Also affects the m(tT) distribution and hence the tT spin correlation
    - Fraction of events with (anti-) parallel spin depends on m(tT)
  - Simulation is used only for unfolding, but this still induces a substantial uncertainty
    - Full effect of reweighting is taken as uncertainty



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