ATLAS-CMS tt̄ charge asymmetry combination

CHARGE ASYMMETRY
CMS ATLAS COMBINATION

arXiv:1709.05327

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LHCtopWG open session, November 2nd, 2017

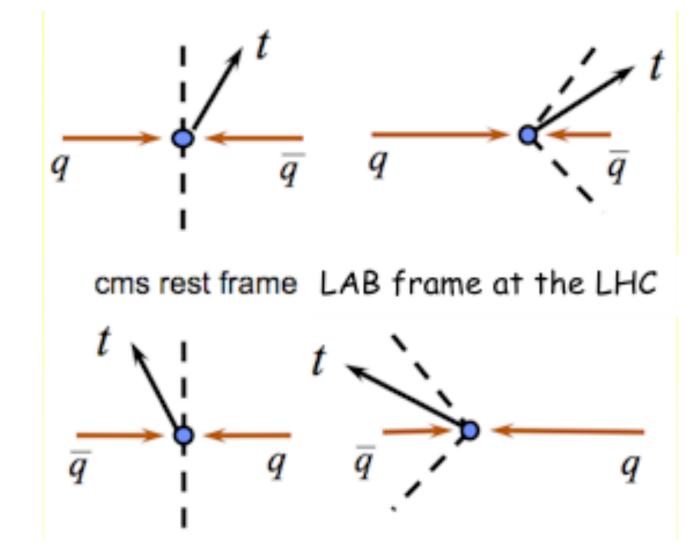# t̄t charge asymmetry at the LHC

- **At NLO, QCD predicts an asymmetry for tt̄ produced via qq̄ (gg fusion is symmetric)**
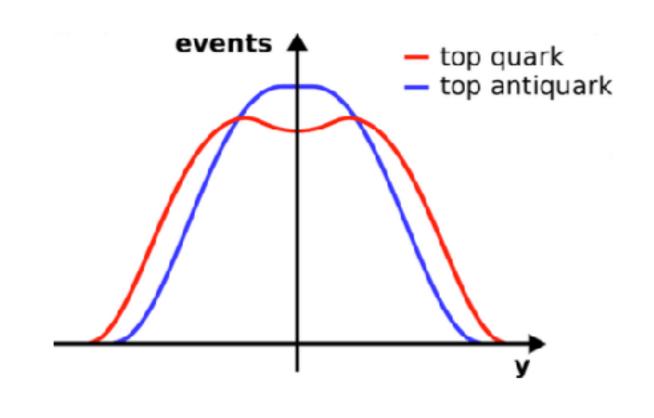 - in the lab frame, top quarks preferentially emitted in the forward/backward directions while antitop quarks are produced more centrally

- **charge asymmetry observable**

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

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

cms rest frame   LAB frame at the LHC

- **SM predictions**

	Inclusive A_C	Centre-of-mass energy	
		$\sqrt{s} = 7$ TeV	$\sqrt{s} = 8$ TeV
Theory predictions	QCD NLO + EW NLO [1]	0.0115 ± 0.0006	0.0102 ± 0.0005
	QCD NLO + EW NLO [3]	0.0123 ± 0.0005	0.0111 ± 0.0004
	QCD NNLO + EW NLO [4–6]		$0.0095^{+0.0005}_{-0.0007}$
Experimental results	ATLAS [10, 12]	0.006 ± 0.010	0.0090 ± 0.0051
	CMS unfolding [11, 14]	$0.004 \pm 0.010 \pm 0.011$	$0.0010 \pm 0.0068 \pm 0.0037$
	CMS template [13]		$0.0033 \pm 0.0026 \pm 0.0033$

Theoretical predictions at LHC

- NNLO inclusive and differential predictions
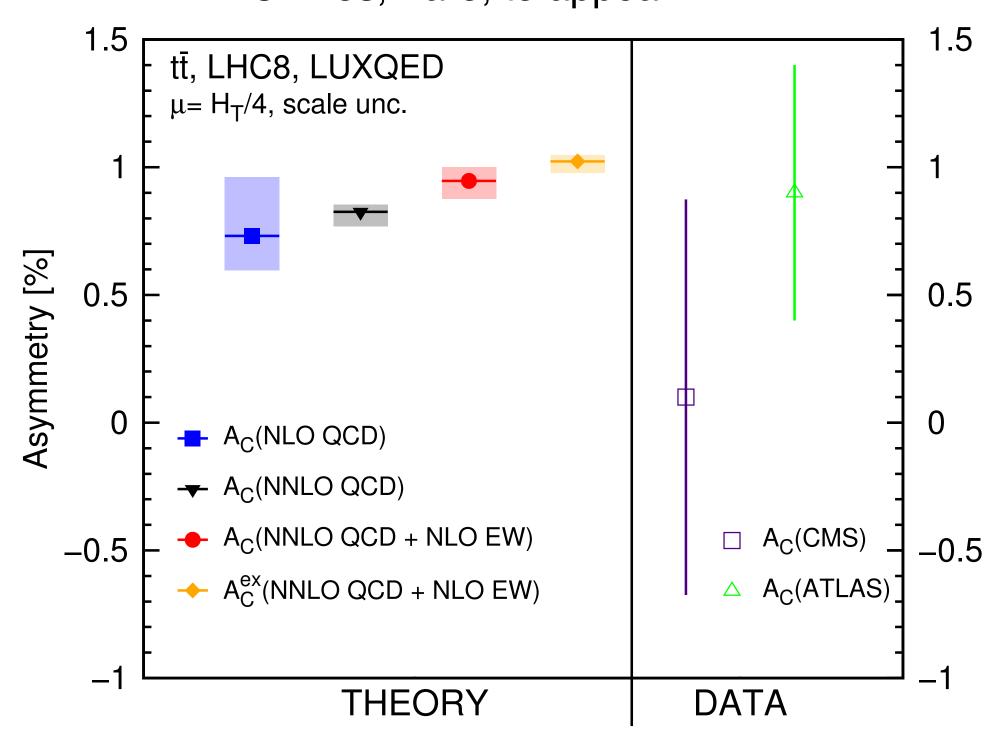 - predictions @ 8 TeV provided by Czakon et al. to us just for this paper. THANKS !

- inclusive predictions
  - Ac: ratio of expanded numerator and denominator
  - Ac exp: expanding the ratio in alpha_s

- SM predictions

Czakon, Heymes, Mitov, Pagani, Tsinikos, Zaro, to appear

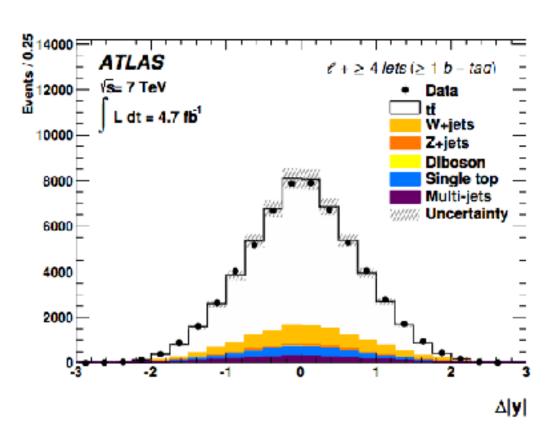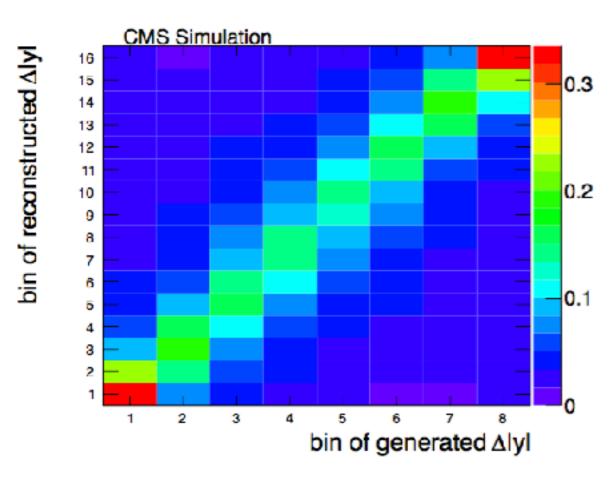| Inclusive A_C		Centre-of-mass energy	
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LHC measurements at 7 TeV

- ## lepton+jets
  - ATLAS inclusive and differential measurements (JHEP 02 (2014) 107)
    A_c = 0.006 ±0.010 (stat. + syst.)
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- ## dilepton
  - ATLAS inclusive measurement (JHEP 05 (2015) 061)
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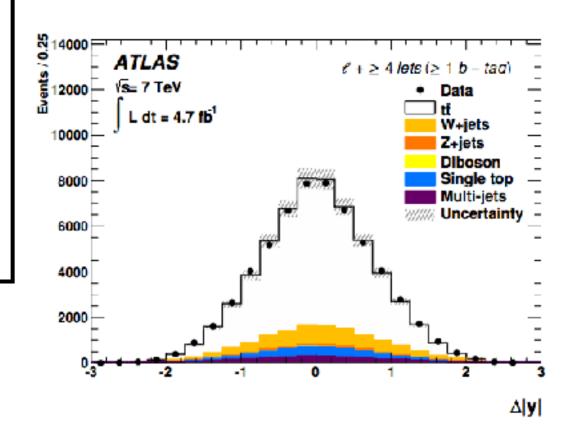 A_c = -0.010 ± 0.017 (stat.) ± 0.008 (syst.)

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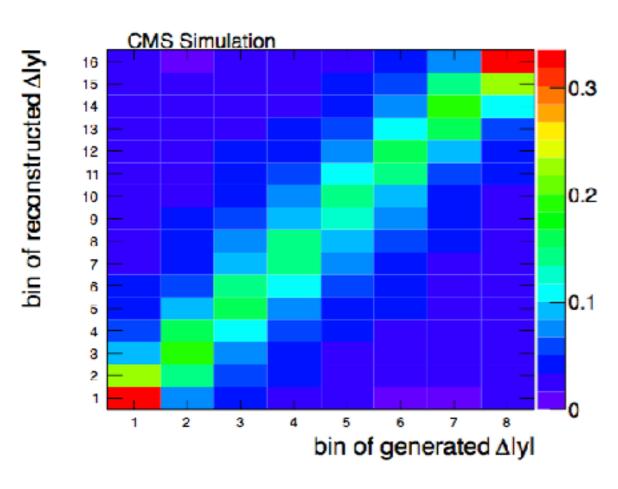 A_c = 0.004 ±0.010 (stat.) ±0.011 (syst.)

  Different binning for the differential measurements: no possible differential combination at 7 TeV

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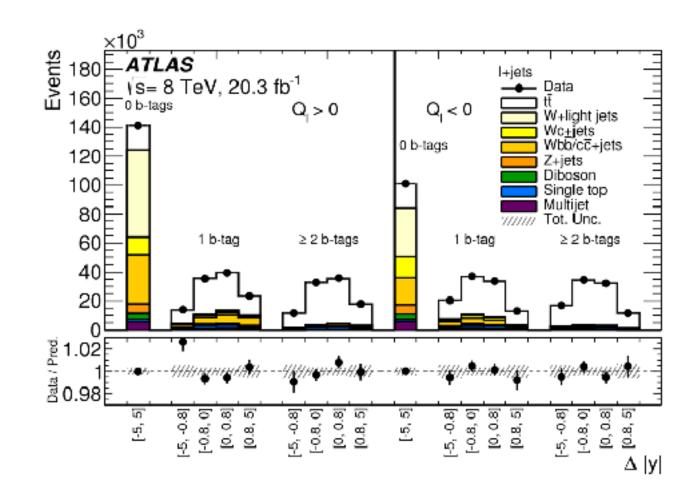 No significant impact on the combination when testing the inclusion of the dilepton channel

LHC measurements at 8 TeV
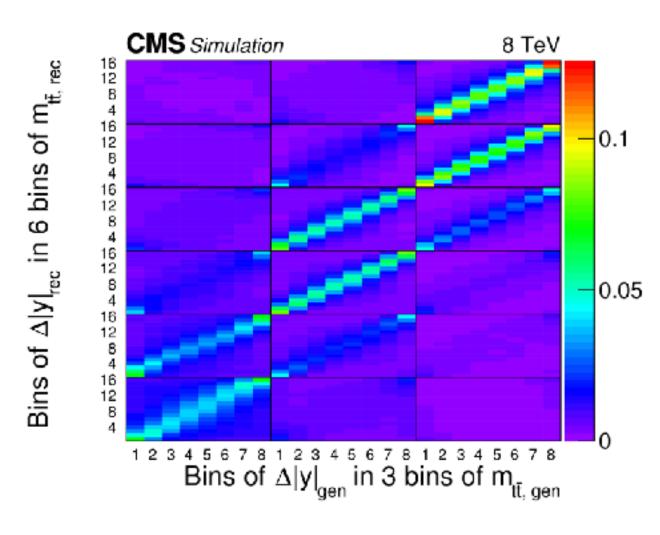
- **lepton+jets**
  - ATLAS inclusive and differential measurements (EPJC-15-09-029)
    $A_C = 0.009 \pm 0.005$ (stat. + syst.)
  - ATLAS inclusive and differential boosted measurements (Phys Lett B 756 (2016) 52)
    $A_C = 0.042 \pm 0.032$ (stat. + syst.)

  - CMS (unfolding analysis) inclusive and differential measurements (Phys. Lett. B 757 (2016) 154)
    $A_C = 0.0010 \pm 0.0068$ (stat.) ± 0.0037 (syst.)
  - CMS (template analysis) inclusive measurements (Phys. Rev. D93 (2016) 034014)
    $A_C = 0.0033 \pm 0.0026$ (stat.) ± 0.0033 (syst.)

- **dilepton**
  - ATLAS inclusive and differential measurements (Phys. Rev. D 94 (2016) 032006)
    $A_C = 0.021 \pm 0.016$ (stat. + syst.)
  - CMS inclusive and differential measurements (Phys. Lett. B 760 (2016) 365)
    $A_C = 0.011 \pm 0.011$ (stat.) ± 0.007 (syst.)

LHC measurements at 8 TeV

- ## lepton+jets
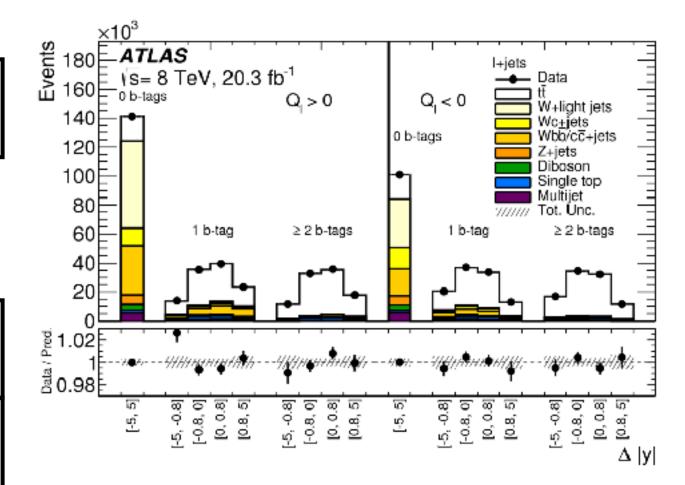
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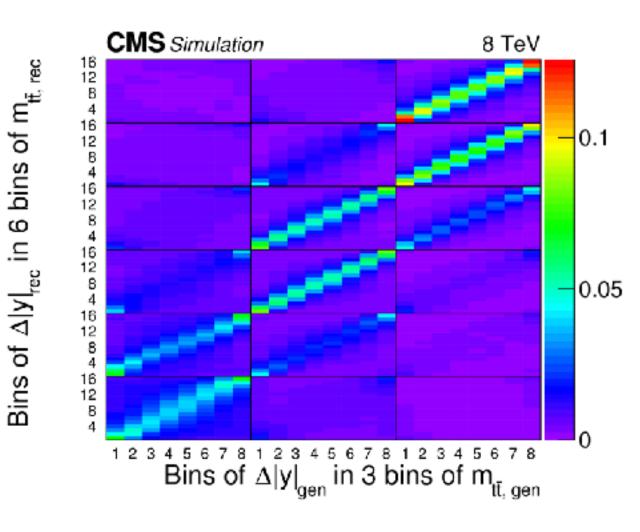
  Differential combination only possible vs $M_{t\bar{t}}$

- ## dilepton

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  No significant impact on the combination when testing the inclusion of the dilepton channel

Measurement highlights

- **Analysis steps**
  - background estimation:
    - main background: W+jets, multijets
  - top kinematics reconstruction
  - unfolding
    - regularized matrix unfolding or Fully Bayesian Unfolding with marginalisation of the systematics
  - systematic evaluation

- **Main steps similar between ATLAS and CMS but numerous differences**
  - default $t\bar{t}$ MC (at 7 TeV)
  - background estimation (external/in-situ W+jets determination)
  - unfolding technique
  - systematic evaluation, systematic constrained or not
    $\Rightarrow$ will need to do assumptions on the correlations between experiments

- **Combination method**
  - using the standard BLUE method with assessment of the correlations between the systematics
  - ATLAS input: uncertainties before marginalisation (7 TeV) or varying one source at a time (8 TeV)
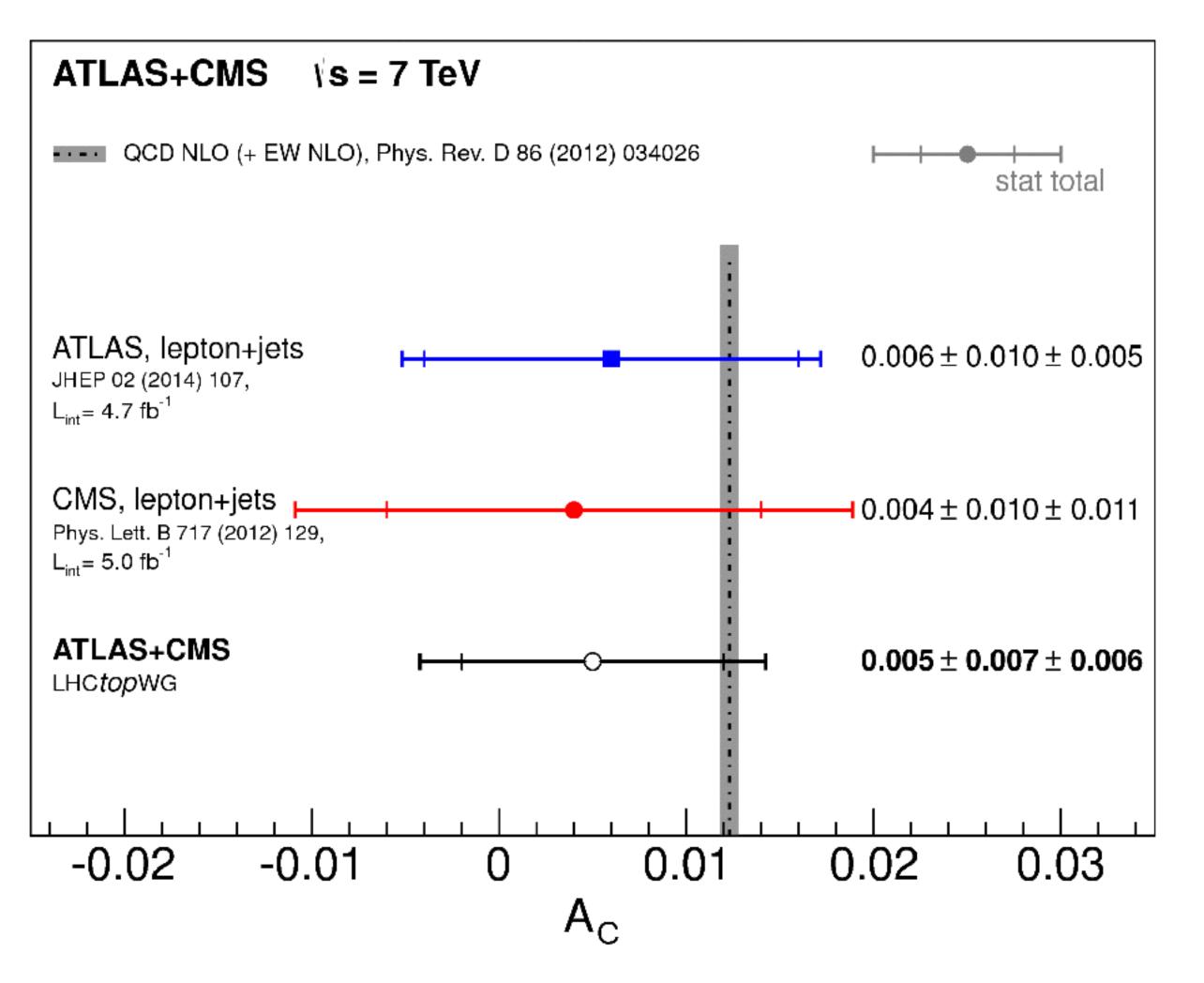
- **7 TeV inputs**
  - coarse breakdown (older results)

	ATLAS	CMS	ρ	Combined
A_C	0.006	0.004	0.058	0.005
Statistical (data)	0.010	0.010	0	0.007
Statistical (simulation)	0.002	0.002	0	0.001
Detector model	0.004	0.007	0	0.004
Pile-up+p_T^{miss}	0.002	<0.001	0	0.001
Signal modelling	<0.001	0.002	0.5	0.001
PDF	0.001	0.002	1	0.001
Multijet	<0.001	0.001	0	0.000
W+jets	0.002	0.004	0.5	0.003
Model dependence				
Specific physics models	<0.001	—	—	0.000
General simplified models	—	0.007	—	0.002
Systematic uncertainty	0.005	0.011		0.006
Total uncertainty	0.011	0.015		0.009

7 TeV inclusive combination result

- **result**
  - weights: 0.65 (ATLAS), 0.35 (CMS)
  - 18% improvement wrt ATLAS, 40% improvement wrt CMS

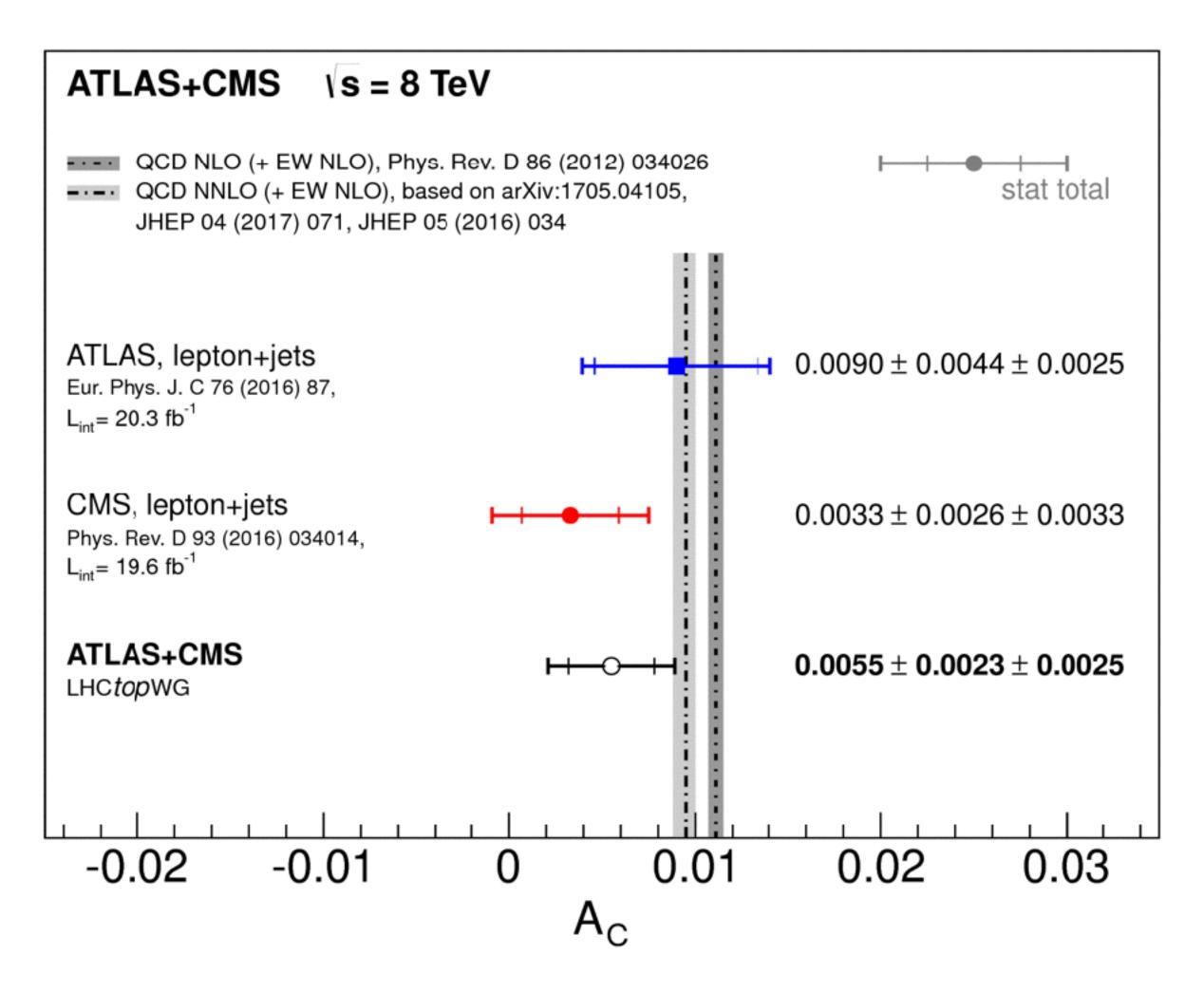# Systematics for 8 TeV inclusive combination

- **8 TeV inputs**
  - finer splitting
  - use CMS template method as CMS input

	ATLAS	CMS	ρ	Combined
A_C	0.0090	0.0033	0.13	0.0055
Statistical (data)	0.0044	0.0026	0	0.0023
Statistical (simulation)	0.0010	0.0015	0	0.0010
Detector model (excluding JES)				
Leptons	0.0003	0.0001	0	0.0001
Jet energy resolution	0.0005	0.0004	0	0.0003
b-tagging	0.0004	0.0007	0	0.0005
Missing transverse momentum	0.0002	—	—	0.0001
Pile-up	—	0.0003	—	0.0002
Jet energy scale				
Uncorrelated JES	0.0010	0.0004	0	0.0005
Partially correlated JES	0.0009	0.0010	0.5	0.0008
Mostly correlated JES	0.0002	0.0004	1	0.0003
Fully correlated JES	0.0009	0.0008	1	0.0008
Signal modelling				
Event generator	0.0004	0.0002	1	0.0003
Parton shower and hadronisation	0.0004	—	—	0.0002
Scale/radiation	0.0009	0.0014	1	0.0012
PDF	0.0007	0.0002	1	0.0004
Integrated luminosity	—	0.0001	—	0.0001
Backgrounds				
Single-top-quark / Z+jets	0.0001	0.0004	1	0.0003
Multijet	0.0005	0.0018	0	0.0011
W+jets	—	0.0002	—	0.0001
Method	0.0003	—	—	0.0001
Systematic uncertainty	0.0025	0.0033		0.0025
Total uncertainty	0.0051	0.0041		0.0034

- **result**
  - weights: 0.39 (ATLAS), 0.61 (CMS)
  - 32% improvement wrt ATLAS, 17% improvement wrt CMS
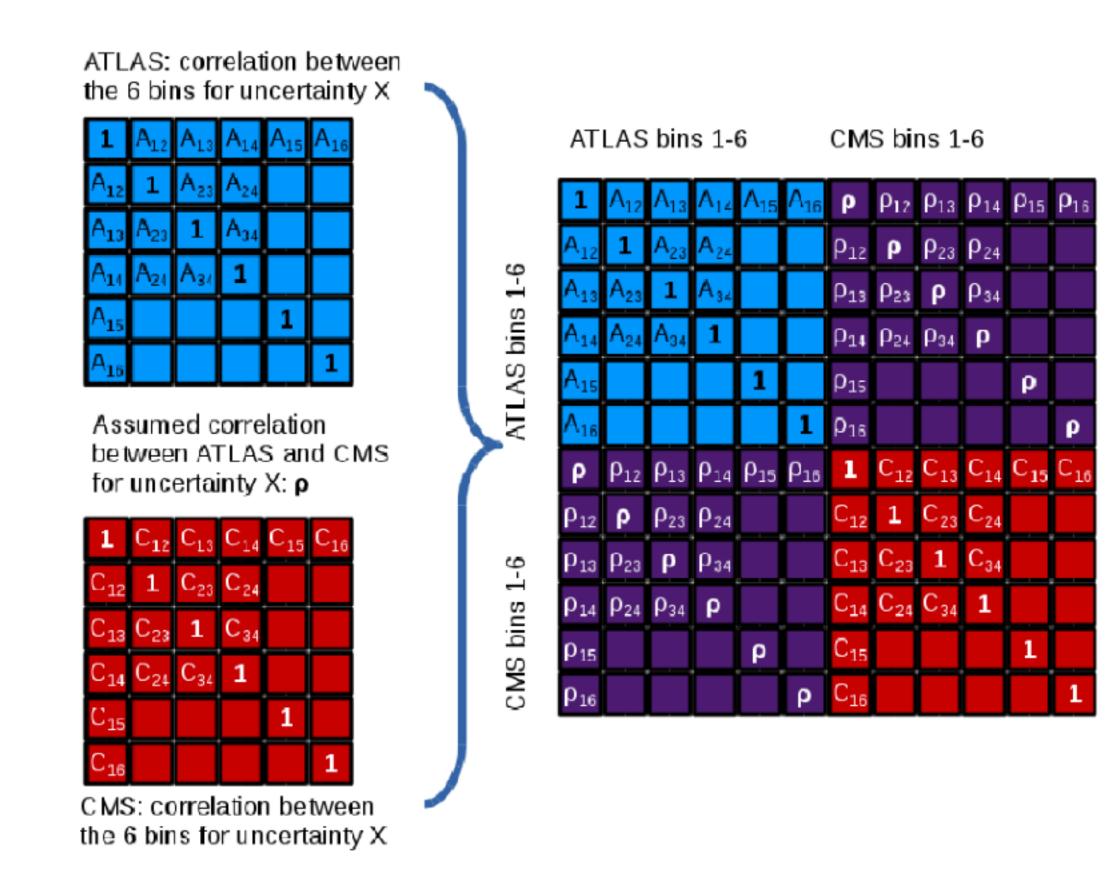
8 TeV differential combination

- ## assessment of the correlations
  - same systematics mapping as for the inclusive combination

  - correlations between bins
    - statistics: from unfolding
    - systematics of source u between bin i and bin j
      * within ATLAS
        projection the posterior probability density into the (i, j) plane
        +/-1 for un-marginalised systematics

      * within CMS

      $$\mathrm{corr}^u(C_i, C_j) = \mathrm{sign}\left[(A_C^u(C_i) - A_C^{\mathrm{nom}}(C_i))\ (A_C^u(C_j) - A_C^{\mathrm{nom}}(C_j))\right]$$

      +1 or -1 for single uncombined source

      * between ATLAS and CMS
        - for the same bin: as for the inclusive measurement (ρu)
        - between bins: average between Atlas and CMS:
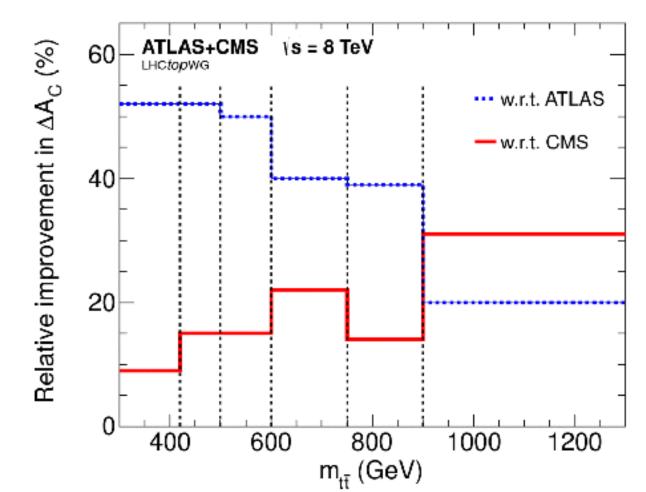
      $$\mathrm{corr}^u(A_i, C_j) = \rho_u\ \frac{\mathrm{corr}^u(C_i, C_j) + \mathrm{corr}^u(A_i, A_j)}{2}$$

ATLAS: correlation between the 6 bins for uncertainty X

Assumed correlation between ATLAS and CMS for uncertainty X: ρ

CMS: correlation between the 6 bins for uncertainty X

ATLAS bins 1-6   CMS bins 1-6

8 TeV differential combination results

- **results**
  - improvements:
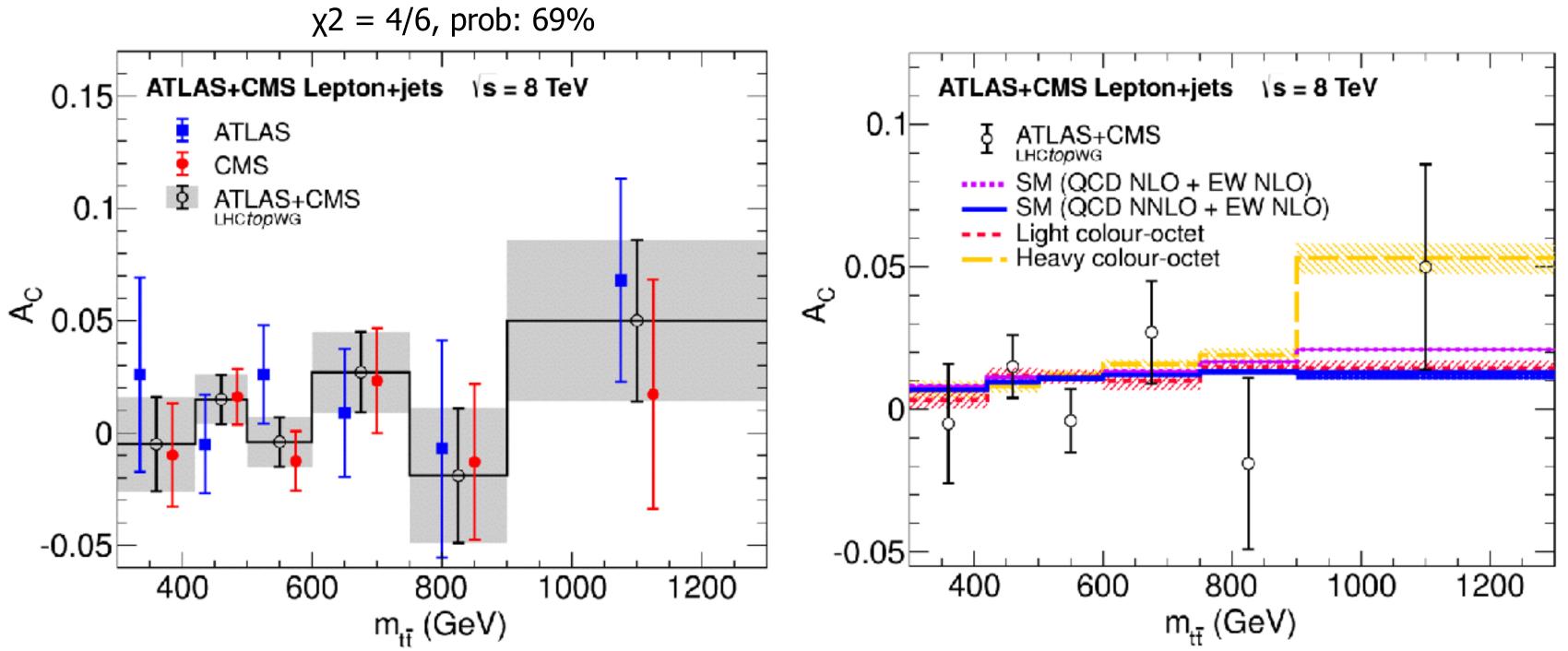   - 20% (bin 6), 51% (bin 1) wrt the ATLAS result
    - 9% (bin 1), 31% (bin 6) wrt the CMS result
  - weights
    - ATLAS: 22% (bin 1), 59% (bin 6)
    - CMS: 41% (bin 6), 78% (bin 1)

Correlations between the combined bins

Bins	L1	L2	L3	L4	L5	L6
L1	1.000					
L2	−0.129	1.000				
L3	−0.100	0.015	1.000			
L4	−0.018	−0.060	−0.098	1.000		
L5	−0.009	−0.074	0.067	−0.342	1.000	
L6	−0.088	−0.040	0.012	0.199	−0.188	1.000

$\chi2 = 4/6$, prob: 69%

Stability test and cross checks

- Several tests performed to test the stability of the results wrt to the assumed correlations

    - statistical only combination: moderate impact of the systematics

    - variation of the default correlation (100% → 50%, 0% → 50%):
        - no impact within the quoted precisions for the inclusive combinations
        - below 0.1 σ_{tot} in each bin for the differential combination

    - specific checks for the differential combination:
        - ATLAS correlation matrix set to +1 or +/- 1 (instead of using the result from the unfolding for the marginalised systematics)
        - correlations between experiment: set to ATLAS correlations or to CMS correlations (instead of the average)
        - changes:
            central values: < 0.4 σ_{tot} (in each bin)
            uncertainties: 0.002 at most

Conclusion

- Combination of the inclusive 7 TeV and 8 TeV ATLAS and CMS results
- Combination of the differential 8 TeV ATLAS and CMS results
  - allow a thorough scrutiny of the two results
  - significant improvement in precision

- Paper submitted to JHEP
  - this is the first ATLAS+CMS combination from the top groups and from the LHCtopWG
  - working on addressing the referee comments