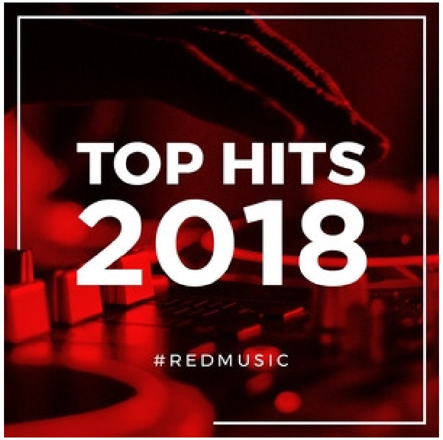
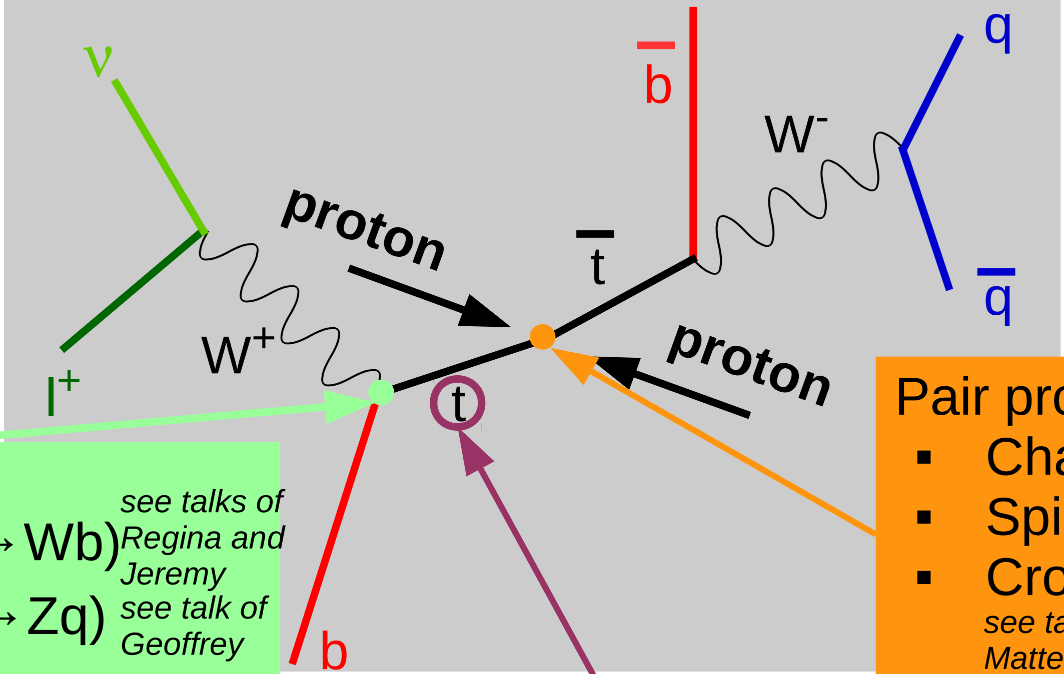
Top (quark) properties



Petra Van Mulders
Vrije Universiteit Brussel – FWO Flanders

on behalf of the ATLAS and CMS Collaborations

Precise measurements of the top quark properties are used to indirectly probe for new physics



Full event:

- Modeling/tuning
  see talks of Emyr and James
- Color flow

Pair production:

- Charge asymmetries
- Spin correlation
- Cross sections (e.g. $t\bar{t}$+X)

see talks of Matteo, Federica, Kostas, Matteo, Daniel, Clara, Alexander, Fabrice, Kirill, …

Decay/coupling:

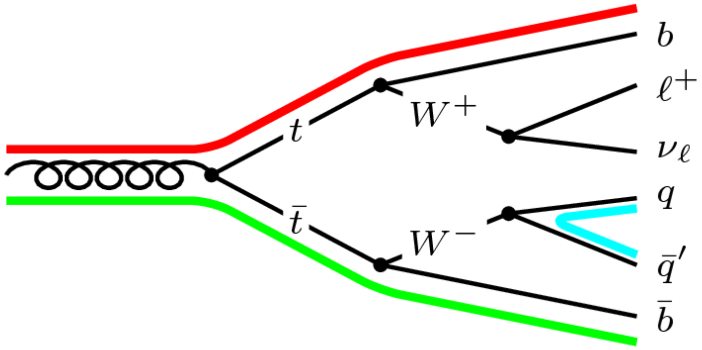
- V_{tb} and BR($t \rightarrow Wb$) *see talks of Regina and Jeremy*
- FCNC (e.g. $t \rightarrow Zq$) *see talk of Geoffrey*
- Γ_t
- W helicity
- Anomalous couplings *see talk of Geoffrey*

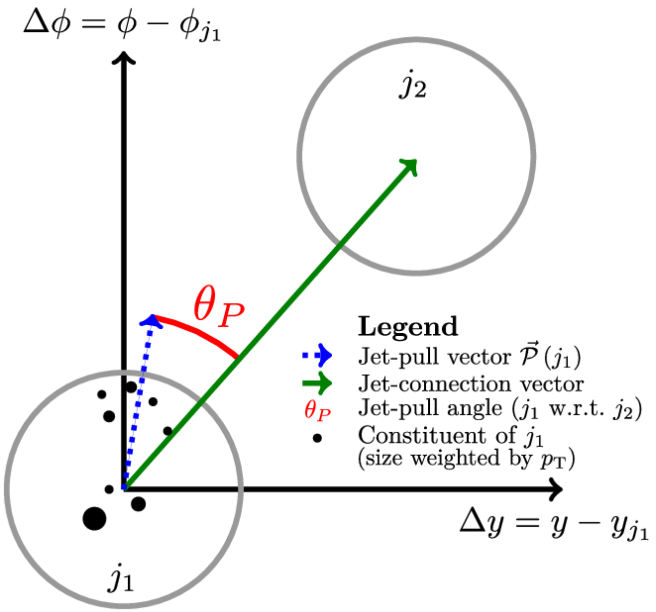
Intrinsic properties:

- Mass *see talk of Stano*
- Charge *see CDF result*

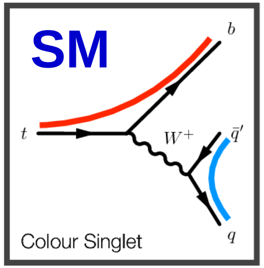
Color flow in top quark pair events

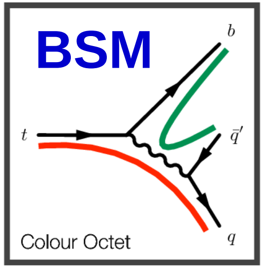
- Color charge is conserved → color connection between initial particles and stable hadrons
- Measuring the color flow is crucial to validate the phenomenological descriptions of this process





- Discriminate between different color flow models





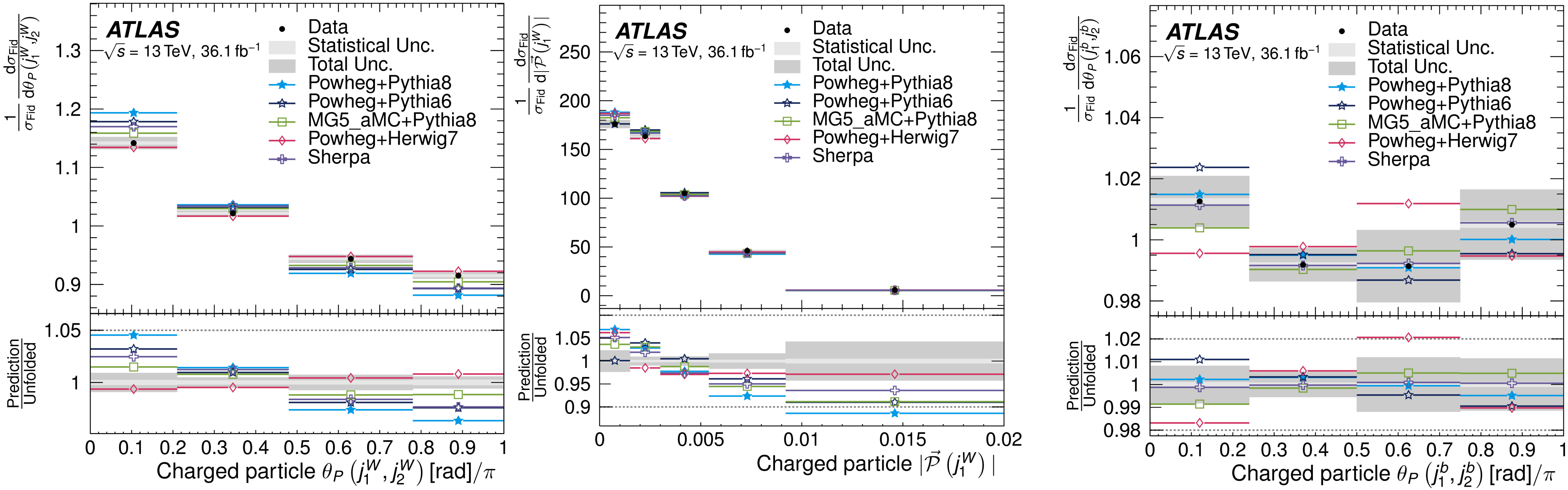
- Jet-pull vector $$\vec{\mathcal{P}}(j) = \sum_{i \in j} \frac{\left|\vec{\Delta r}_i\right| \cdot p_T^i}{p_T^j} \vec{\Delta r}_i$$ used to define

$\theta_P(j_1^W, j_2^W)$, $\theta_P(j_2^W, j_1^W)$, $\theta_P(j_1^b, j_2^b)$ and $|P(j_1^W)|$

Color flow in top quark pair events

Subm. to EPJC

- 'Signal' color flow (left+middle) is best modeled by Powheg+Herwig7
- Data prefers less strong effect (smaller angle) and wider jets (larger magnitude)

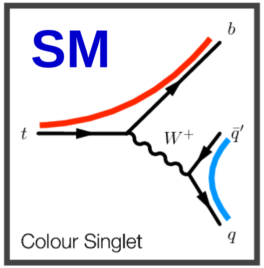


- 'Spurious' color flow (right) is generally well-modeled, except by Powheg+Herwig7

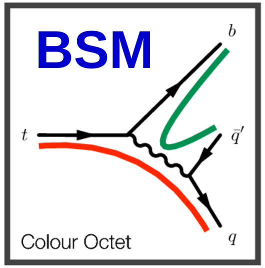
Color flow in top quark pair events

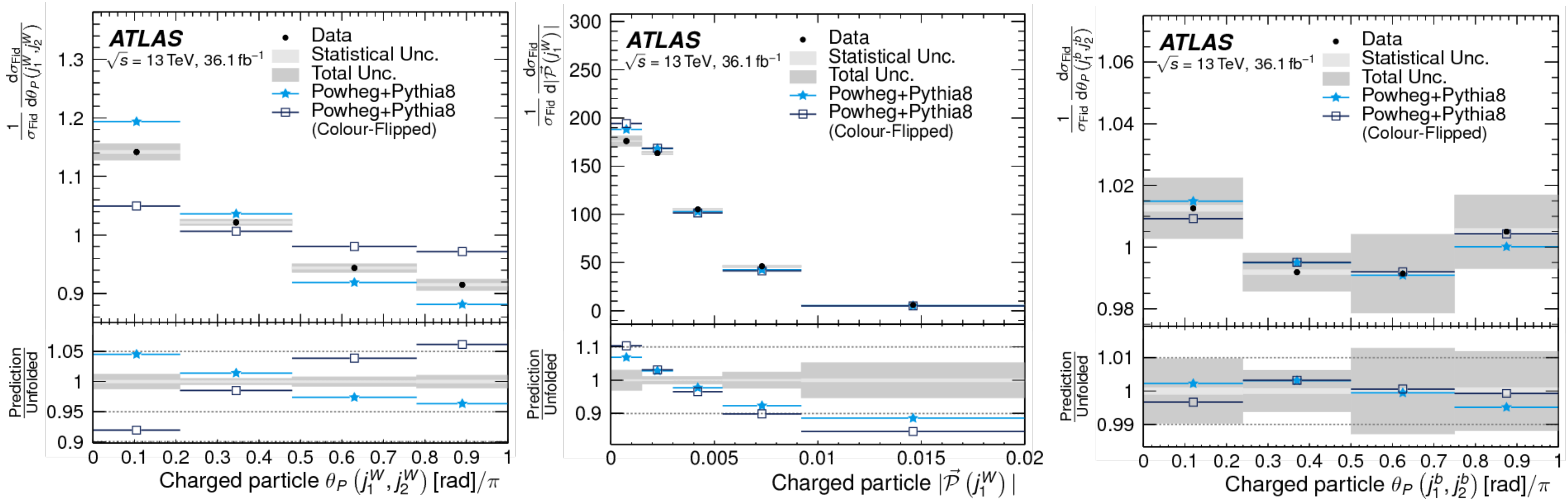
Subm. to EPJC

Powheg + Pythia 8



Powheg + Pythia 8
(colour-flipped)





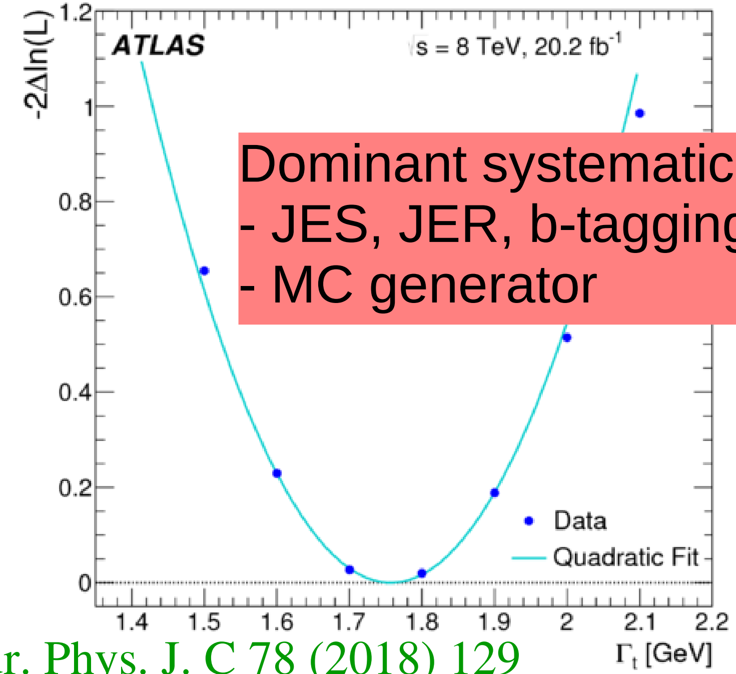
- Data agree more with the SM description than with the colour-flipped model

Direct measurements of the decay width

Γ_t = 1.33 GeV (m_t =172.5 GeV), could be enhanced by non-SM top quark decays

Fit of m_{lb} and $\Delta r_{min}(j_b, j_l)$ distributions

$\Gamma_t = 1.76 \pm 0.33\ (\text{stat.})^{+0.79}_{-0.68}\ (\text{syst.})$ GeV



Dominant systematics:
- JES, JER, b-tagging
- MC generator

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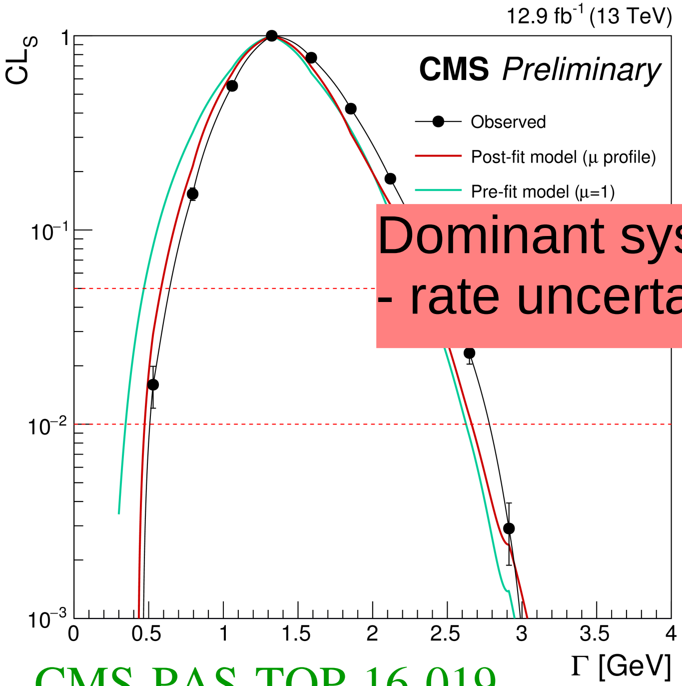
Fit of m_{lb} distribution in event categories

$0.6 \leq \Gamma_t \leq 2.5$ GeV @ 95% C.L.



Dominant systematics:
- rate uncertainties

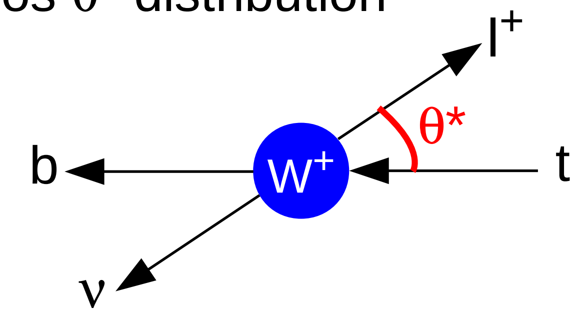
CMS-PAS-TOP-16-019

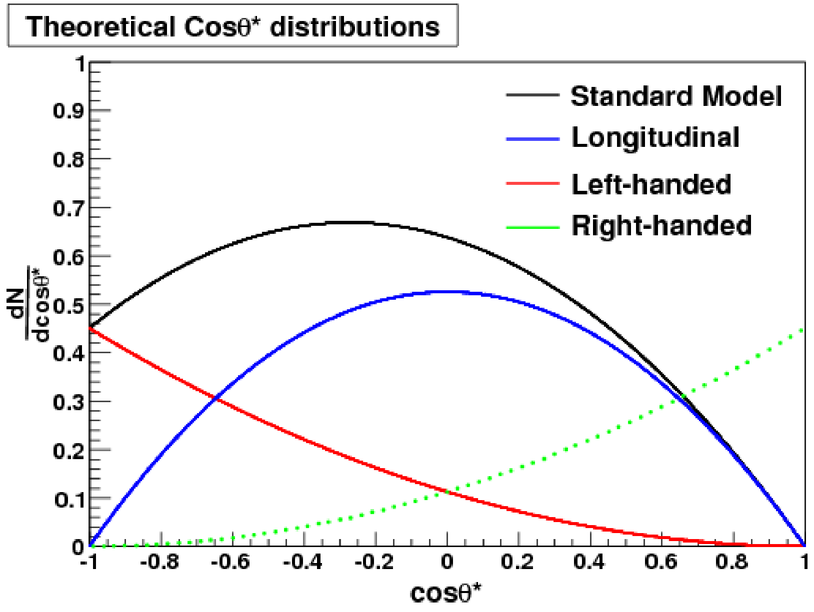
W helicity in the Standard Model

- W boson from the top quark decay is produced with a certain fraction of left-, longitudinal, or right-handed polarization

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}F_L(1-\cos\theta^*)^2 + \frac{3}{4}F_0(\sin\theta^*)^2 + \frac{3}{8}F_R(1+\cos\theta^*)^2$$

- Measure cos θ* distribution

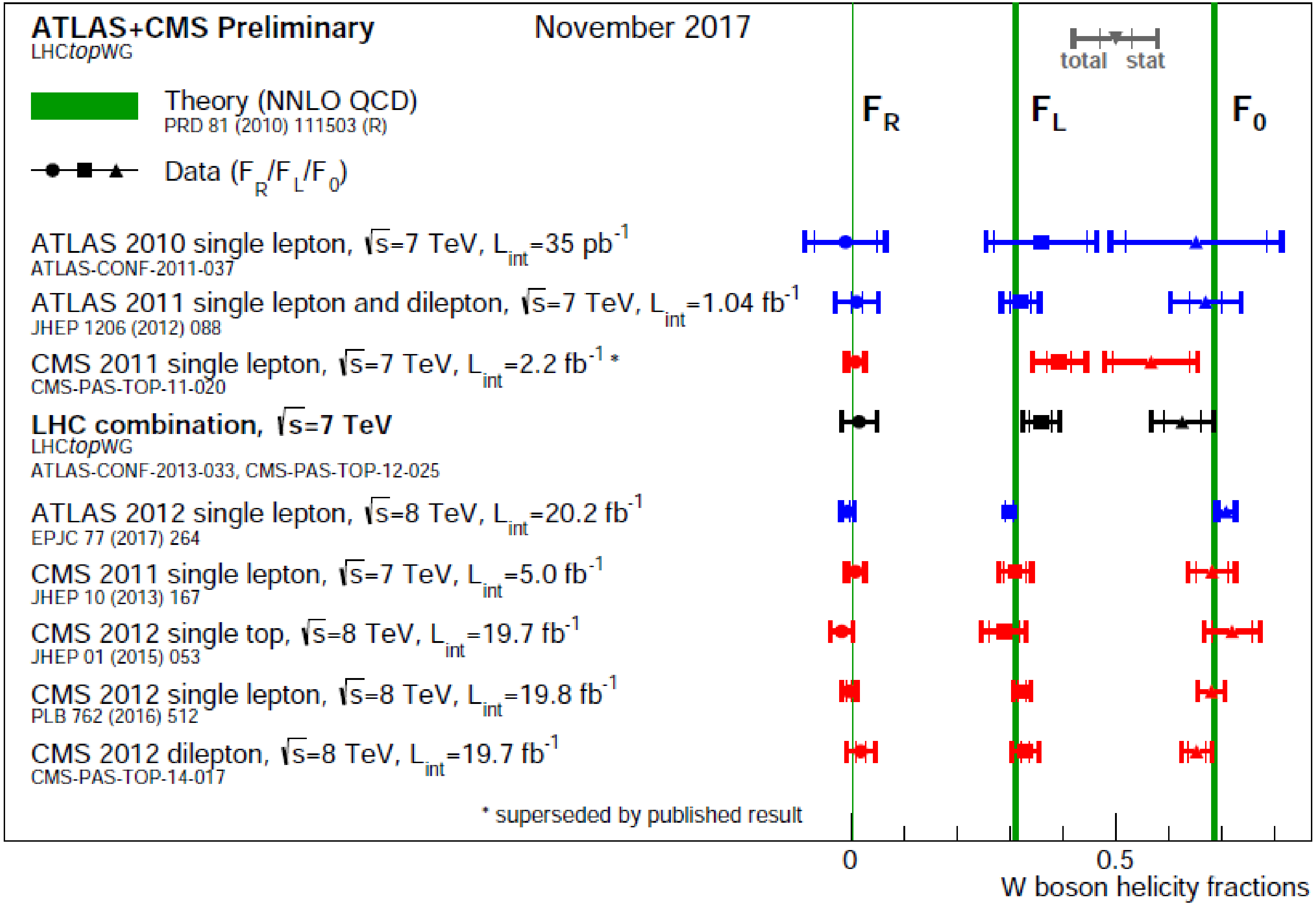




- NNLO prediction (m_t = 172.8 ± 1.3 GeV):

F_L = 0.311 ± 0.005
F_0 = 0.687 ± 0.005
F_R = 0.0017 ± 0.0001

W helicity measurements at the LHC



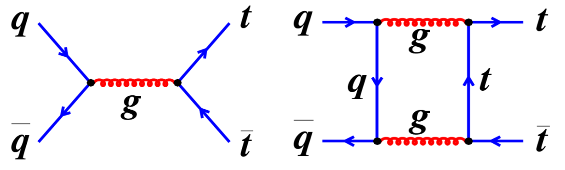
Consistent with SM expectations, relative precision: 2-5%

→ can be used to set limits on anomalous tensor couplings in the Wtb vertex *(see talk of Geoffrey)*

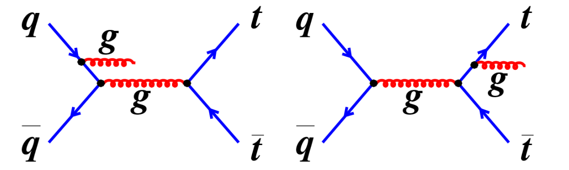
Dominant systematics:
- JER and b-tagging
- radiation and MC generator

Charge asymmetry at the LHC

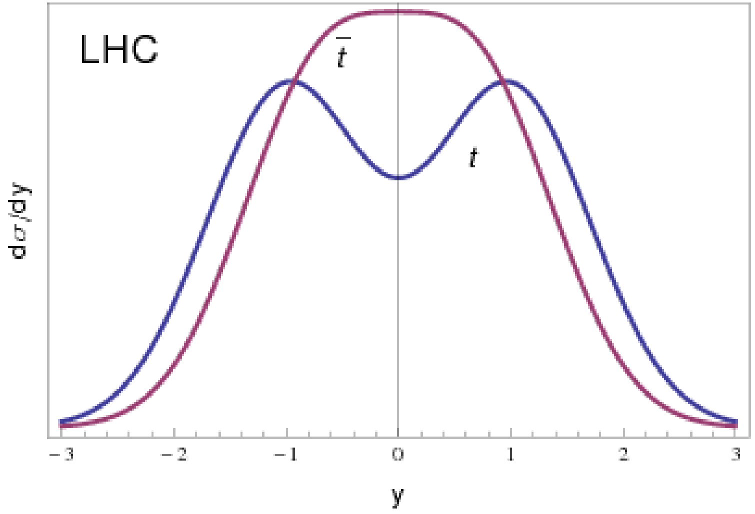
- Top (anti)quark is emitted in direction of incoming (anti)quark due to the boost of the initial (anti)quark
- Not present for gg → $t\bar{t}$ and LO; only small asymmetry for $q\bar{q}$ → $t\bar{t}$ due to interference



Interference between LO and box diagram



Interference between ISR and FSR diagram



Charge of (anti)top is obtained using lepton charge, asymmetry:

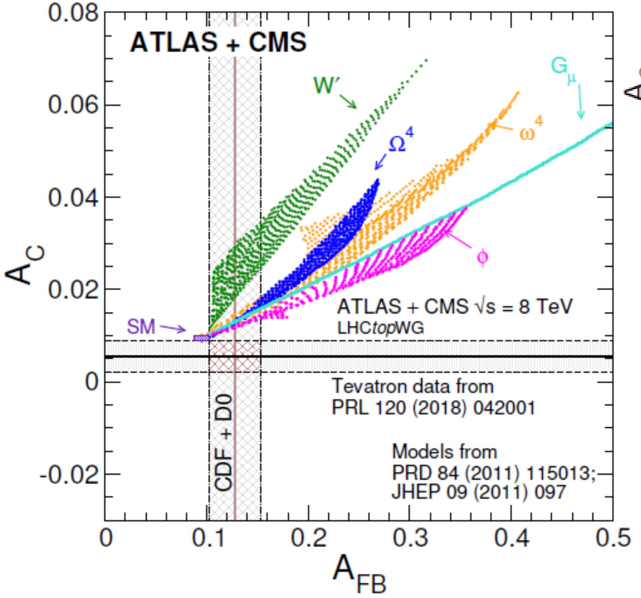
$$A_C = \frac{N^{\Delta|y|>0} - N^{\Delta|y|<0}}{N^{\Delta|y|>0} + N^{\Delta|y|<0}}$$

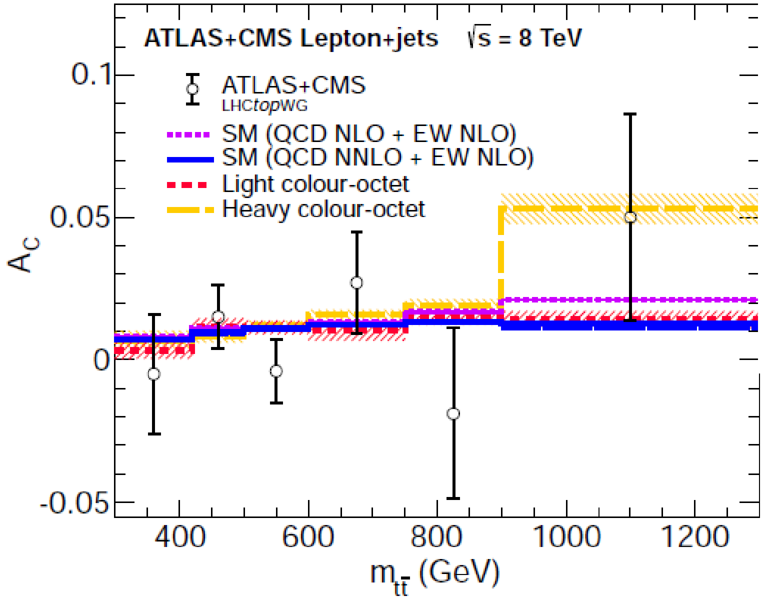
$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$

- At LHC direction of (anti)quark is not known, but quarks (valence+sea) have larger momentum than antiquarks (sea)
  → more top quarks in forward direction
- New physics models can enhance the asymmetry when a new boson is exchanged in the production

Charge asymmetry measurements (7+8 TeV)

- ATLAS+CMS Run 1 combination published → constraints on BSM theories
- Stat. and syst. uncertainties are similar





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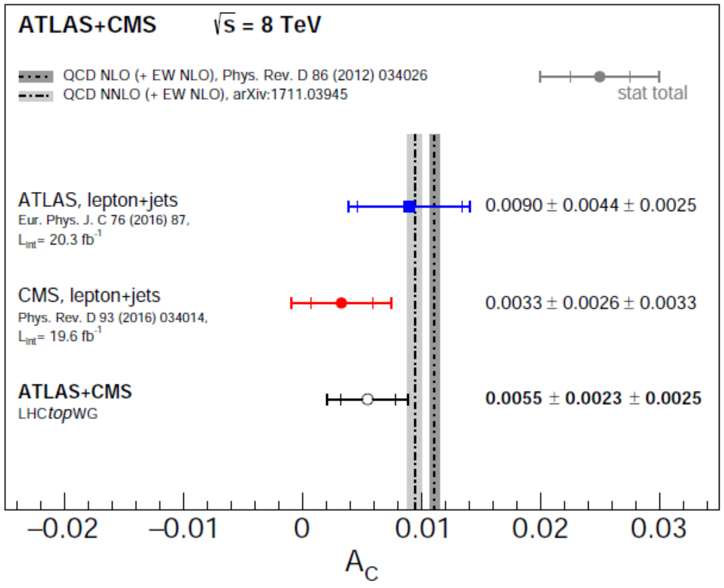


Dominant systematics:
- JES and multijet background
- scale/radiation

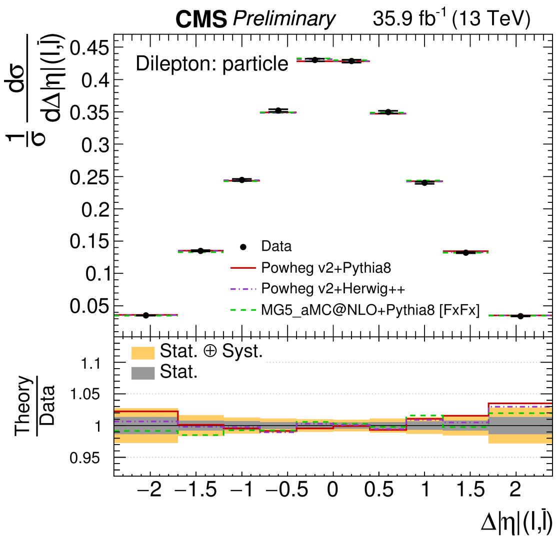
Charge asymmetry measurements at 13 TeV

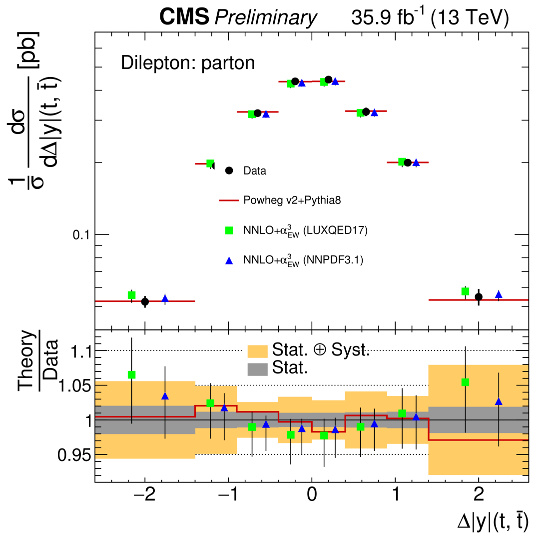
CMS-PAS-TOP-17-014

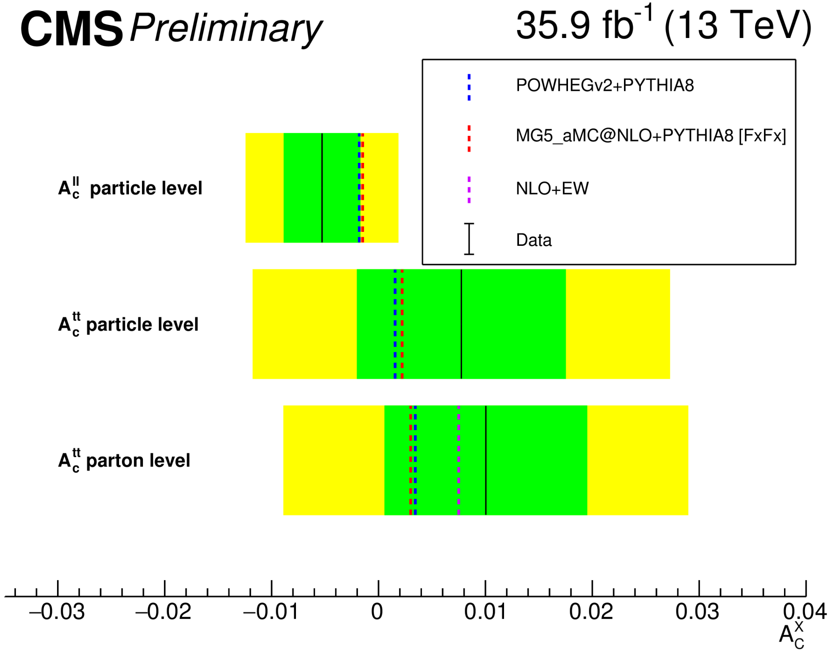
- Charge asymmetry obtained from the normalized parton- and particle-level differential cross section measurement of dilepton $t\bar{t}$ *(see talk of Kostas)*

$$A_c^{l\bar{l}} = \frac{\sigma_{t\bar{t}}(\Delta|\eta|(l,\bar{l}) > 0) - \sigma_{t\bar{t}}(\Delta|\eta|(l,\bar{l}) < 0)}{\sigma_{t\bar{t}}(\Delta|\eta|(l,\bar{l}) > 0) + \sigma_{t\bar{t}}(\Delta|\eta|(l,\bar{l}) < 0)}$$

$$A_c^{t\bar{t}} = \frac{\sigma_{t\bar{t}}(\Delta|y|(t,\bar{t}) > 0) - \sigma_{t\bar{t}}(\Delta|y|(t,\bar{t}) < 0)}{\sigma_{t\bar{t}}(\Delta|y|(t,\bar{t}) > 0) + \sigma_{t\bar{t}}(\Delta|y|(t,\bar{t}) < 0)}$$







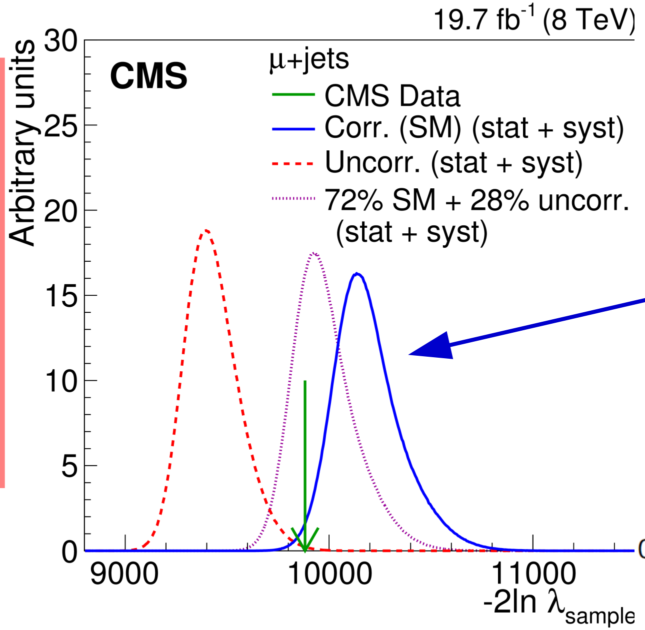
- Results in agreement with the predictions
- First measurement at 13 TeV

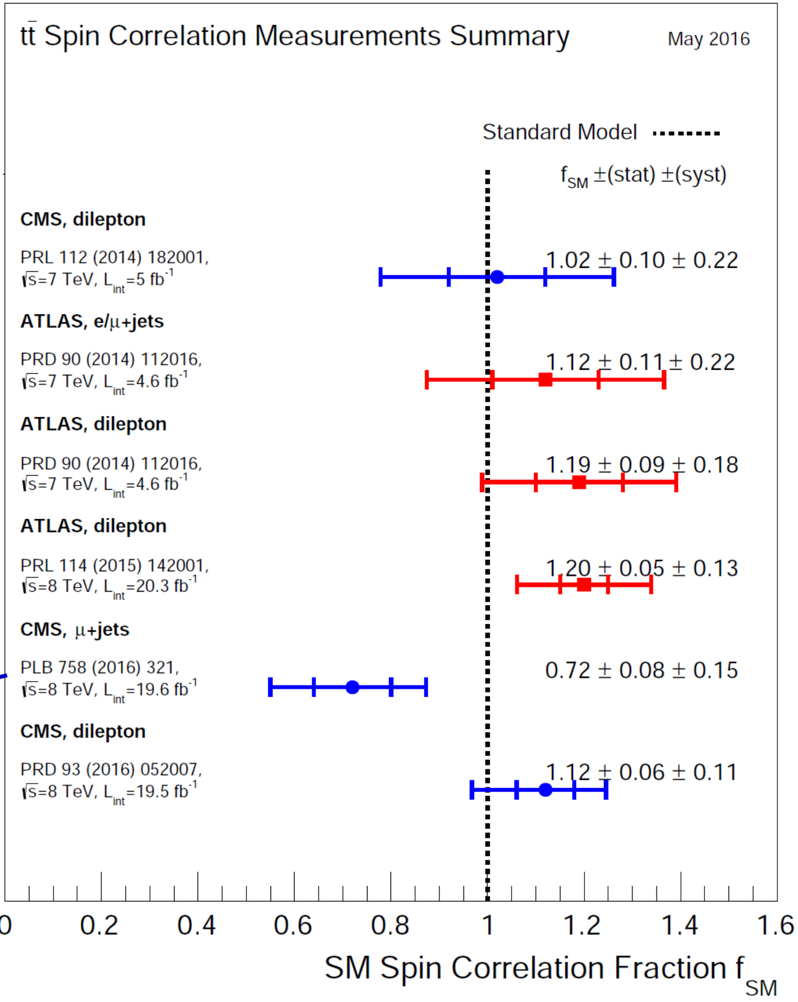
Spin correlation measurements (7+8 TeV)

- Spins of t and $\bar{t}$ are correlated with strength depending on the spin quantization axis and the production process
- Spin correlation can be measured via the angular distributions of decay products or using the matrix element method

μ+jets dominant syst.:
- JES
- scale/radiation

dilepton dominant syst.:
- scale/radiation and parton shower





Full spin density matrix measurement

- 15 spin observables sensitive to different coefficients in the spin density matrix

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$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta^a_+ d\cos\theta^b_-} = \frac{1}{4}(1 + B^a_+\cos\theta^a_+ + B^b_-\cos\theta^b_- - C(a,b)\cos\theta^a_+\cos\theta^b_-)$$

- Measure 6 angles (2 lepton directions and 3 spin quantization axes)

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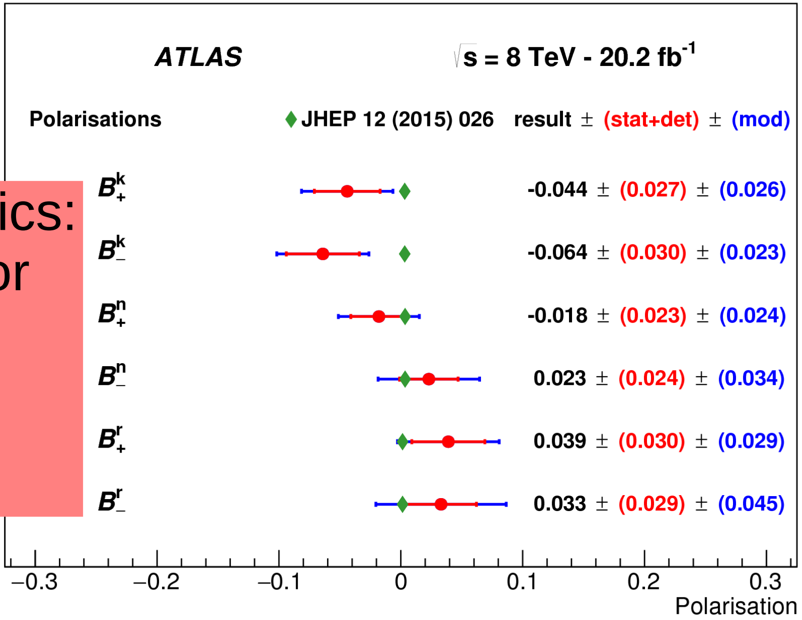
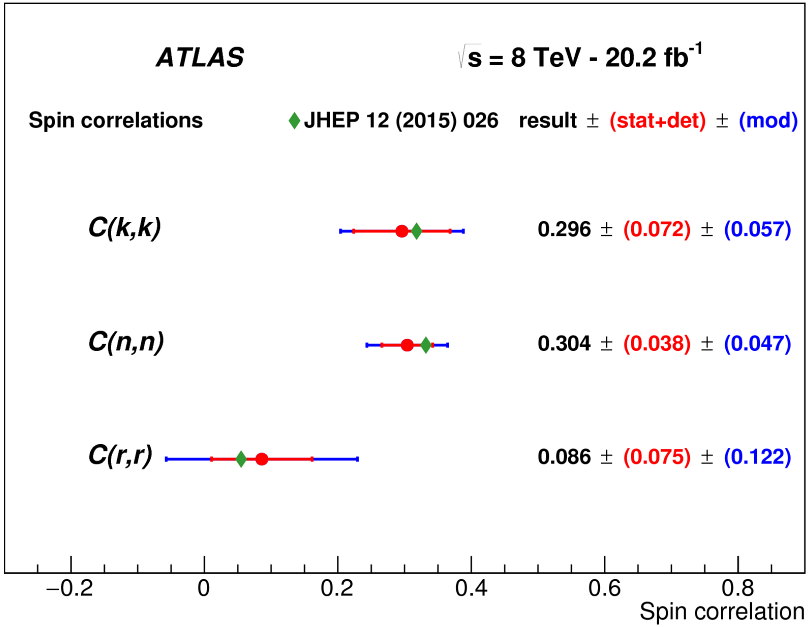
Dominant systematics: scale/radiation, color reconnection, MC generator, parton shower





- Consistent with SM

δB = 3-4%

δC/C= 20-30%

Spin correlation measurement at 13 TeV

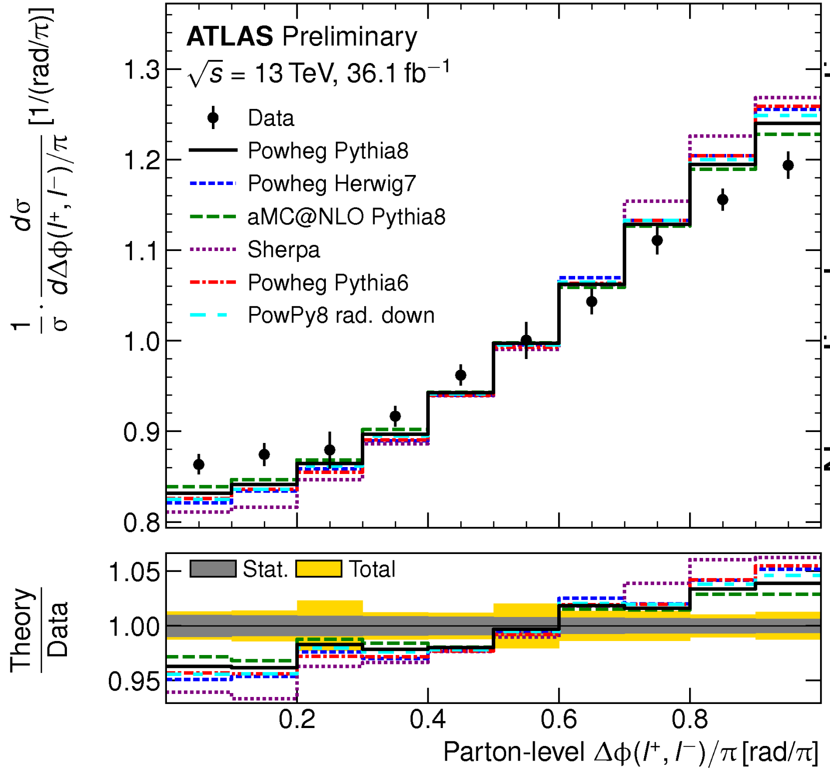
NEW!

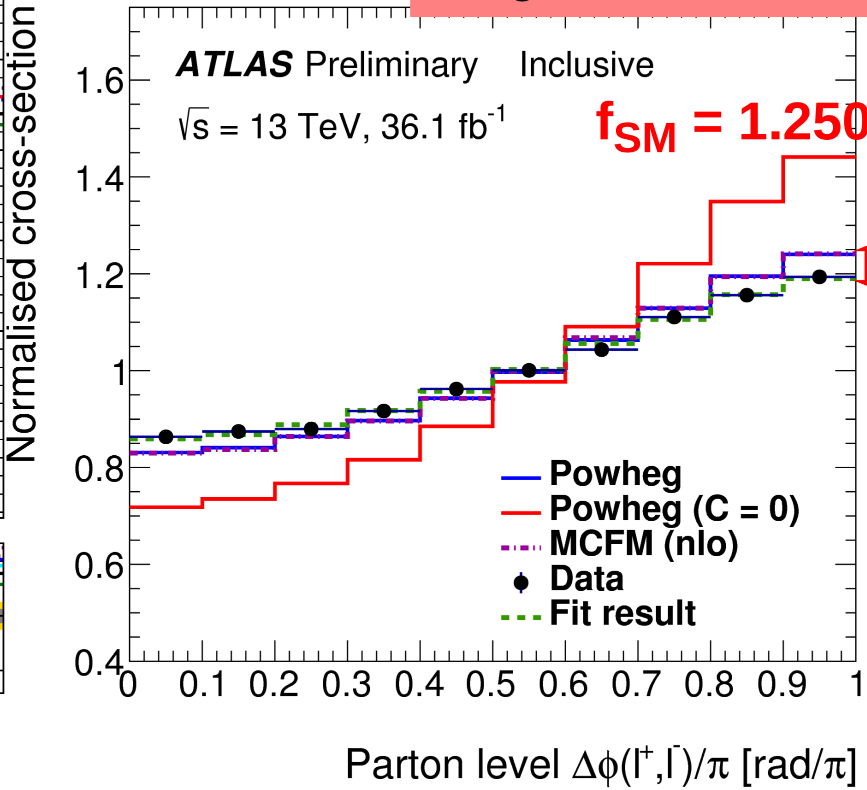
- Absolute and normalized $t\bar{t}$ cross section

ATLAS-CONF-2018-027

- Measured $\Delta\phi(e,\mu)$ distribution

Dominant systematics:
MC generator and scale/radiation





f_{SM} = 1.250 ± 0.026 ± 0.063

3.2σ deviation

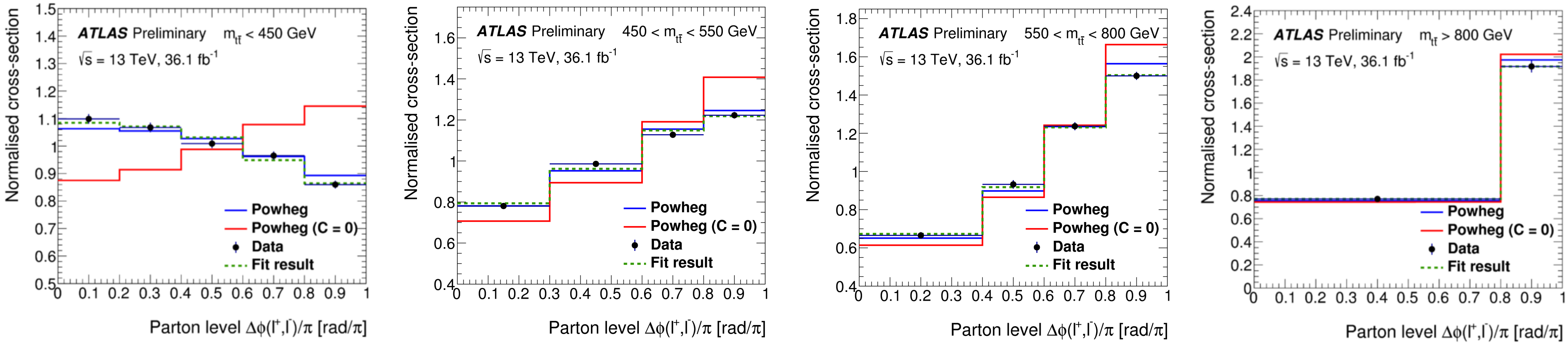
Higher order corrections?
(see talk of Rene yesterday)

Differential spin correlation measurement

NEW!

ATLAS-CONF-2018-027

- Measure spin correlation differentially
- Top quark pairs are mainly produced with (anti)parallel spins at low (high) $m_{t\bar{t}}$



Region	f_{SM}	Significance (incl. theory uncertainties)
$m_{t\bar{t}} < 450$ GeV	$1.11 \pm 0.04 \pm 0.13$	0.85 (0.84)
$450 < m_{t\bar{t}} < 550$ GeV	$1.17 \pm 0.09 \pm 0.14$	1.00 (0.91)
$550 < m_{t\bar{t}} < 800$ GeV	$1.60 \pm 0.24 \pm 0.35$	1.43 (1.37)
$m_{t\bar{t}} > 800$ GeV	$2.2 \pm 1.8 \pm 2.3$	0.41 (0.40)
inclusive	$1.250 \pm 0.026 \pm 0.063$	3.70 (3.20)

- No significant deviations (yet) in bins of $m_{t\bar{t}}$

Summary

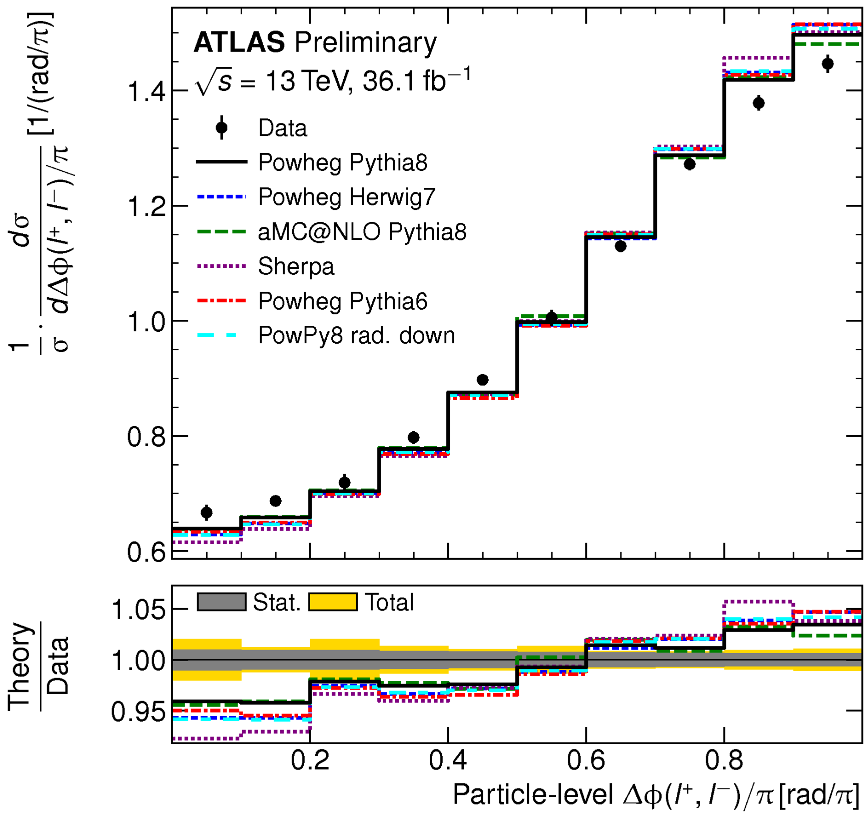
- New measurements for charge asymmetry and spin correlation at 13 TeV
- The spin correlation measured shows a 3.2σ deviation w.r.t. the SM expectation
  → solved with higher order calculations? New physics?
- Most Run 1 and 2 measurements are limited by systematic uncertainties
  → jet energy scale/resolution and modeling: radiation/MC generator/PS
- The 13 TeV measurements use ~25% of the Run 2 data
  → more data will help to understand/reduce the systematic uncertainties
  - Differential cross section measurements constrain modeling uncertainties
  - Progress in tuning MC generators to the data

- More precision measurements in the pipeline → stay on top!

Particle-level Δϕ(l,l) distribution

- Both ATLAS and CMS see a deviation of roughly the same size

ATLAS-CONF-2018-027



CMS-PAS-TOP-017-014