Combination of the W boson polarization measurements in top quark decays using ATLAS and CMS data @ 8 TeV

LHCTOPWG - May 14th, 2020

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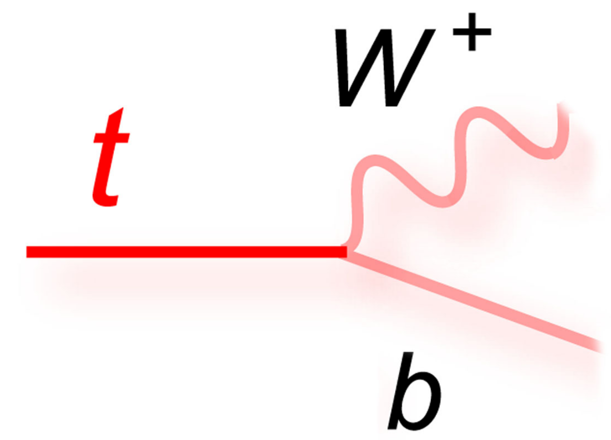
On behalf of the ATLAS and CMS Collaborations

W polarization in top-quark decay

- The top quark decay vertex Lagrangian with EFT generalization:



Vector couplings

Tensor couplings

$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\left(V_{\mathrm{L}}P_{\mathrm{L}} + V_{\mathrm{R}}P_{\mathrm{R}}\right) t\, W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{M_{W}}\left(g_{\mathrm{L}}P_{\mathrm{L}} + g_{\mathrm{R}}P_{\mathrm{R}}\right) t\, W_{\mu}^{-} + \mathrm{h.c.}\,,$$

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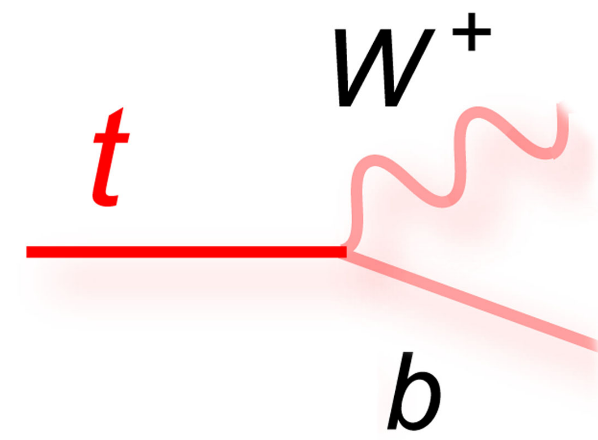

Vector couplings — **Tensor couplings**

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$$V_{\rm CKM} = \begin{pmatrix} V_{\rm ud} & V_{\rm us} & V_{\rm ub} \\ V_{\rm cd} & V_{\rm cs} & V_{\rm cb} \\ V_{\rm td} & V_{\rm ts} & V_{\rm tb} \end{pmatrix}$$

(≈ 1 in SM)

W polarization in top-quark decay

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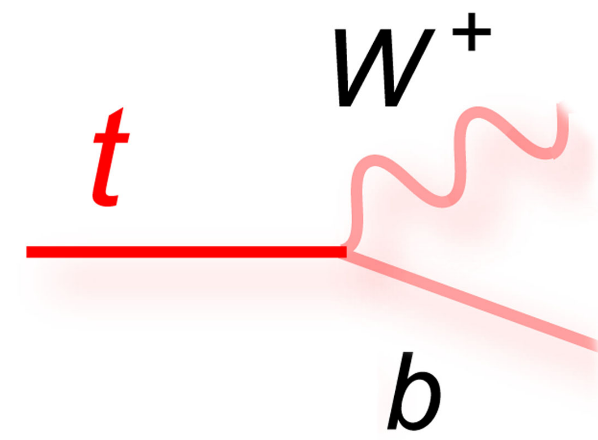

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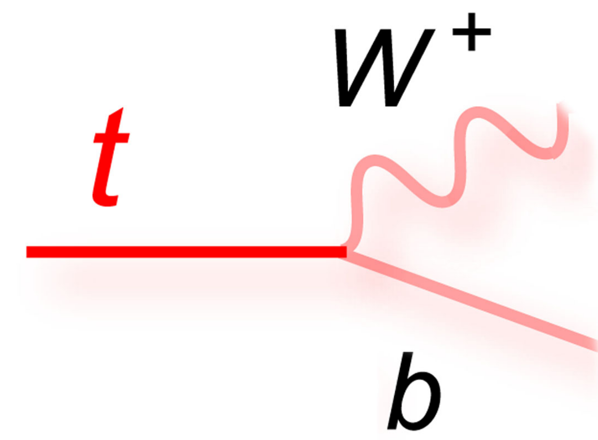
(≈ 1 in SM) (V_{tb}, i.e. $V_{\rm L}$)

Anomalous couplings (≈ 0 in SM at tree level) ($V_{\rm R}$, $g_{\rm L}$, $g_{\rm R}$)

Direct impact on the W boson polarization

W polarization in top-quark decay

- The top quark decay vertex Lagrangian with EFT generalization:



Vector couplings

Tensor couplings

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

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(≈ 1 in SM)

Anomalous couplings (≈ 0 in SM at tree level)

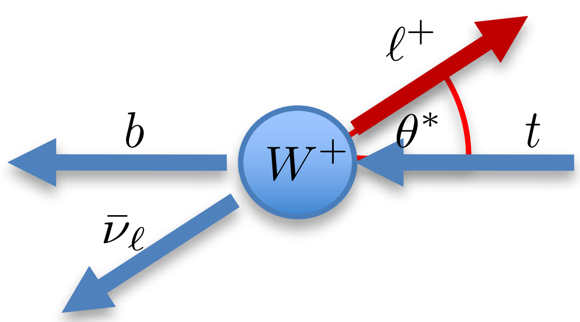
Direct impact on the W boson polarization

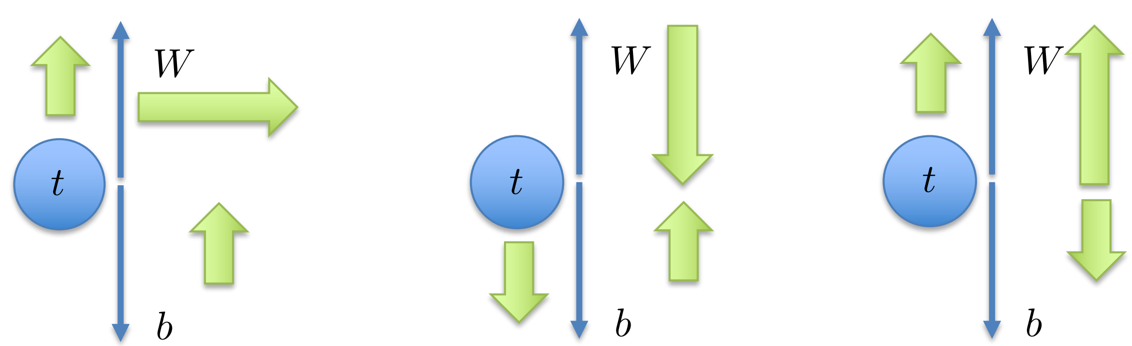
- Measuring W boson polarization with high precision:
  - Good test of the Standard Model prediction
  - Probe for new physics processes

W polarization in top-quark decay

- W polarization in top quark decay is sensitive to **cosθ^*** distribution

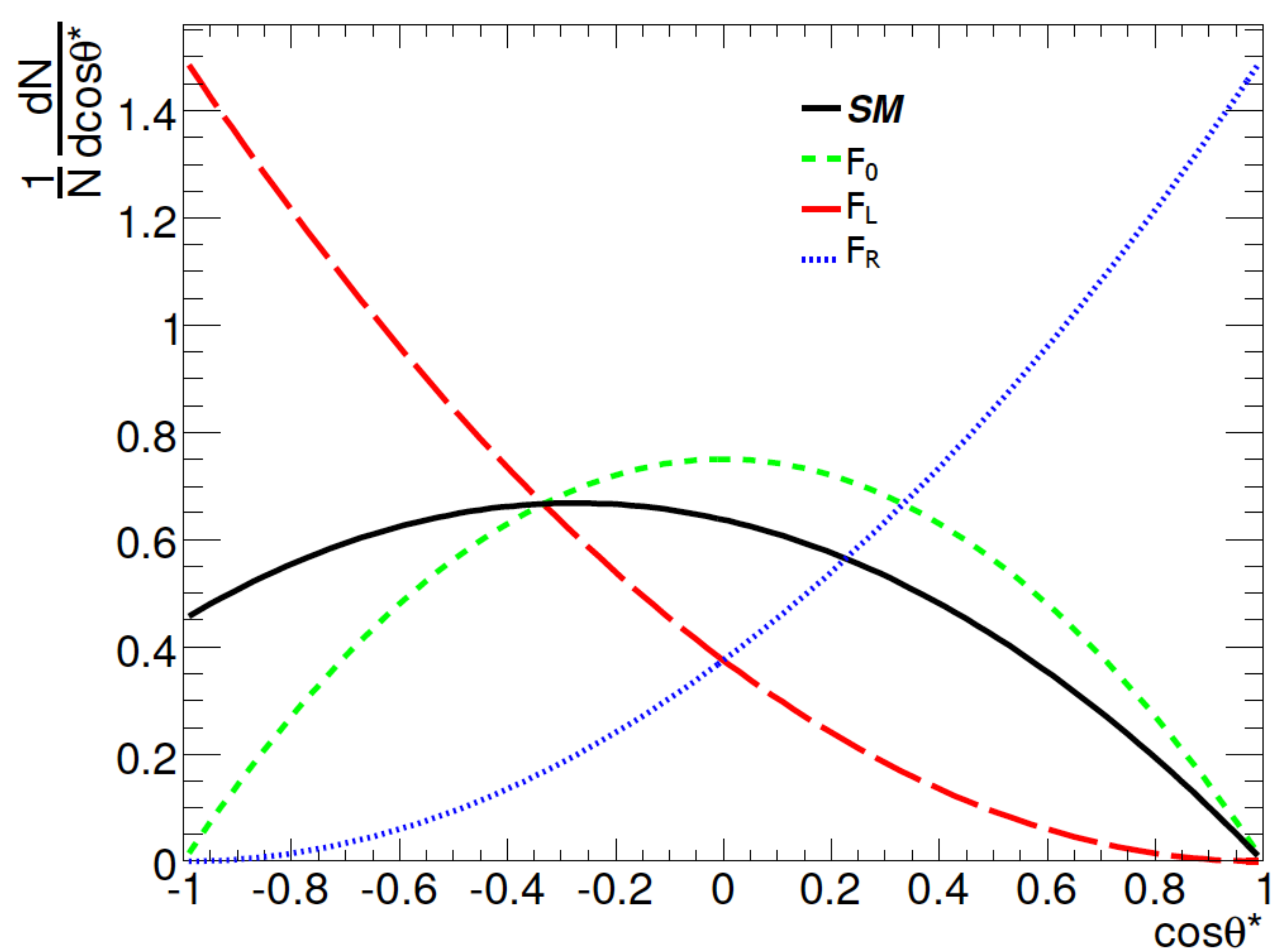
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{4}\left(1-\cos^2\theta^*\right) F_0 + \frac{3}{8}\left(1-\cos\theta^*\right)^2 F_L + \frac{3}{8}\left(1+\cos\theta^*\right)^2 F_R$$



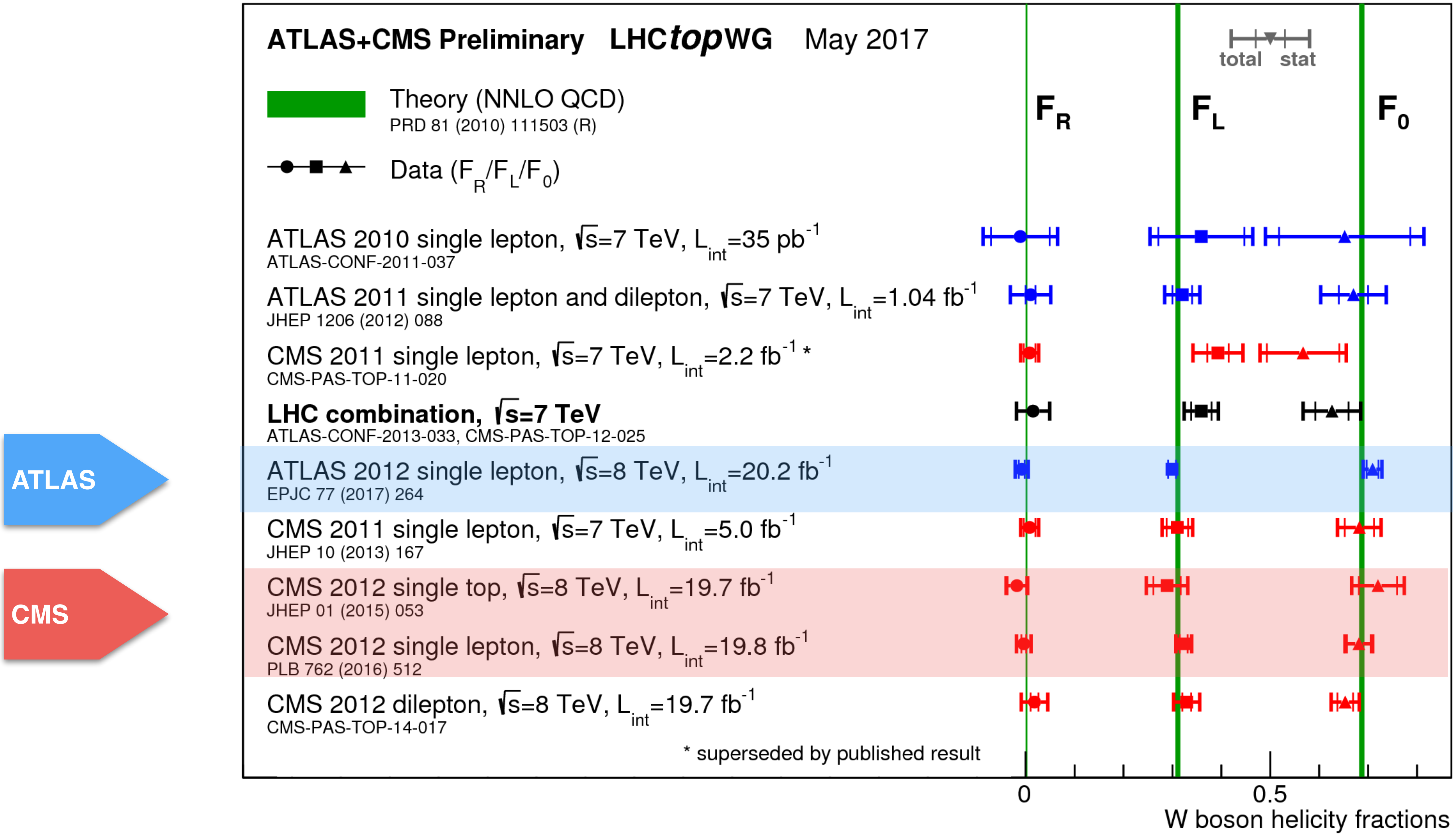


F_0=0.687±0.005 F_L=0.311±0.005 F_R0=0.0017±0.0001

SM NNLO calculation: Phys. Rev. D81, 111503 (2010)



W Helicity measurements at the LHC run 1



Analysis methods @ 8TeV

- Analysis method= template fitting:
- 3 signal templates (obtained from reweighting the SM Cosθ* distribution) + 5 bkg. Cosθ* distributions
- Binned likelihood fit:

$$\mathscr{L} = \prod_{k=1}^{N_{\text{bins}}} \text{Poisson}(n_{\text{data},k}, n_{\text{exp},k}) \prod_{j=1}^{N_{\text{bkg}}} \frac{1}{\sqrt{2\pi}\sigma_{\text{bkg},j}} \exp\left(\frac{-(n_{\text{bkg},j} - \hat{n}_{\text{bkg},j})^2}{2\sigma^2_{\text{bkg},j}}\right)$$

$$n_{\text{exp}} = n_0 + n_{\text{L}} + n_{\text{R}} + n_{W+\text{light}} + n_{W+c} + n_{W+bb/cc} + n_{\text{fake}} + n_{\text{rem. bkg}}.$$

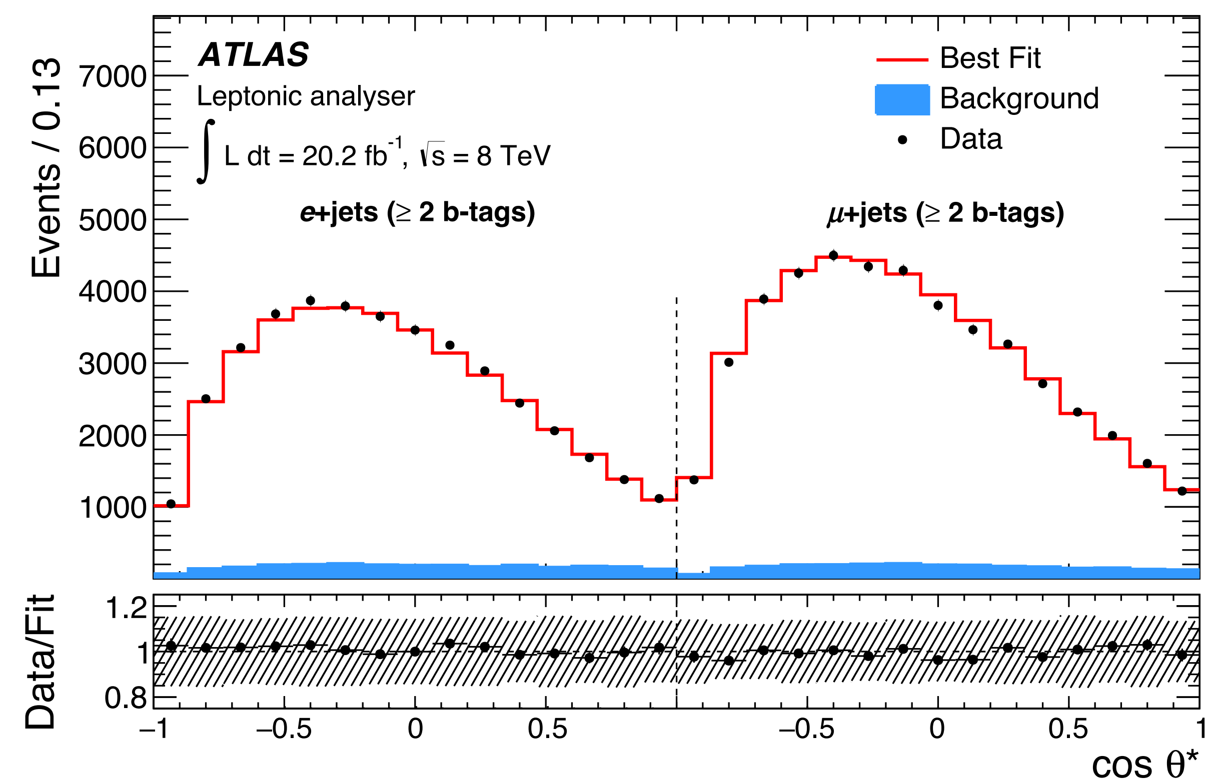
- Fit parameters:
  - Yields of signal (**n0, nL, nR**) and background (W+jets, Lepton fakes, Remaining backgrounds)
- Normalization uncertainties used as Gaussian priors to constrain background normalization
- Background normalization uncertainty effect is reflected in the statistical uncertainty
- W boson polarization extracted as:

$$F_{\text{i}} = \frac{N_i}{N_0 + N_L + N_R}, \qquad n_i = \epsilon_i^{\text{sel}} N_i \qquad \text{for i= 0, L, R.}$$

EPJC 77(2017) 264

top pair (l+jets)

Leptonic analyser (≥2 *b*-tags)
$F_0 = 0.709 \pm 0.012$ (stat. + bkg. norm.) $^{+0.015}_{-0.014}$ (syst.)
$F_L = 0.299 \pm 0.008$ (stat. + bkg. norm.) $^{+0.013}_{-0.012}$ (syst.)
$F_R = -0.008 \pm 0.006$ (stat. + bkg. norm.) ± 0.012 (syst.)



Analysis methods @ 8TeV

- Analysis method: event-by-event reweighting of the SM value of Cosθ* in Monte Carlo

◆ Binned likelihood fit:

$$\mathcal{L}(\vec{F}) = \prod_i \frac{N_{\rm MC}(i;\vec{F})^{N_{\rm data}(i)}}{\left[N_{\rm data}(i)\right]!} \exp\left[-N_{\rm MC}(i;\vec{F})\right]$$

◆ $N_{MC} = \mathbf{N_{tt}} + \mathbf{N_{sing\text{-}t}} + N_{bkg}$

◆ Number of expected **t** events in($\mathbf{N_{MC}}$) in each bin is modified as:

$$w_{t\bar{t}/t,}(\cos\theta^*_{gen};\vec{\boldsymbol{F}}) \equiv \frac{\frac{3}{8}F_L(1-\csc\theta^*_{gen})^2 + \frac{3}{4}F_0\sin^2\theta^*_{gen} + \frac{3}{8}F_R(1+\csc\theta^*_{gen})^2}{\frac{3}{8}F_L^{SM}(1-\csc\theta^*_{gen})^2 + \frac{3}{4}F_0^{SM}\sin^2\theta^*_{gen} + \frac{3}{8}F_R^{SM}(1+\csc\theta^*_{gen})^2}$$

$$N_{t\bar{t}}(i;\vec{\boldsymbol{F}}) \propto \mathcal{F}_{t\bar{t}}\left[\sum_{t\bar{t}\text{ in bin i}} w_{t\bar{t}}(\cos\theta^*_{gen};\vec{\boldsymbol{F}})\right] \qquad N_{sing-t}(i;\vec{\boldsymbol{F}}) \propto \sum_{sing-t\text{ in bin i}} w_t(\cos\theta^*_{gen};\vec{\boldsymbol{F}})$$

- Fit parameters: $\mathbf{F_{tt}}$(normalization of the ttbar yield), $\mathbf{F_0}$ and $\mathbf{F_R}$.
- Background normalizations are fixed —> normalization uncertainty taken as separate systematic
- Final result (l+jets) is **BLUE** combination of **e+jets** and **μ+jets**

For this combination the individual e+jets and μ+jets measurements are used as inputs

JHEP 01 (2015) 053

top pair (l+jets)

Channel	$F_0 \pm$ (stat) $\pm$ (syst)	$F_L \pm$ (stat) $\pm$ (syst)	$F_R \pm$ (stat) $\pm$ (syst)
e + jets	$0.705 \pm 0.013 \pm 0.037$	$0.304 \pm 0.009 \pm 0.020$	$-0.009 \pm 0.005 \pm 0.021$
μ + jets	$0.685 \pm 0.013 \pm 0.024$	$0.328 \pm 0.009 \pm 0.014$	$-0.013 \pm 0.005 \pm 0.017$
ℓ + jets	$0.681 \pm 0.012 \pm 0.023$	$0.323 \pm 0.008 \pm 0.014$	$-0.004 \pm 0.005 \pm 0.014$

+

PLB 762 (2016) 512

single top t-chan. (l+jets)

$F_L = 0.298 \pm 0.028\,(\text{stat}) \pm 0.032\,(\text{syst})$,
$F_0 = 0.720 \pm 0.039\,(\text{stat}) \pm 0.037\,(\text{syst})$,
$F_R = -0.018 \pm 0.019\,(\text{stat}) \pm 0.011\,(\text{syst})$,

Grouping of systematic uncertainties

Uncertasinty source	ATLAS	CMS
Jet energy scale	✓	✓
Jet energy resolution	✓	✓
b-tagging efficiency	✓	✓
Lepton eff.	✓	✓
Jet vertex fraction	✓	**n.a.**
Jet reconstruction eff.	✓	**n.a.**
Top quark mass	✓	✓
Showering & hadronisation	✓	✓
ME generator	✓	
Matching scale	**n.a.**	✓
PDF	✓	✓
Pile-up	**n.a.**	✓
Top-pT reweighting	**n.a.**	✓ *
ISR/FSR (var. h_{damp}, μ_R, μ_F)	✓	—
μ_R, μ_F scale	**n.a.**	✓
Single-top method	**n.a.**	✓ **
MC statistics	✓	✓
Bkg. norm. uncertainty	✓	✓
Stat. uncertainty		✓

– – -

***) Only in CMS l+jets**

****) Only in CMS single-top**

Systematic uncertainty re-evaluation

To harmonize the treatment of the systematic uncertainties evaluation across the input measurements:

- The uncertainty values in the ATLAS measurement **are symmetrized,** as the BLUE algorithm used to perform the combination accepts only symmetric uncertainties

- The top quark pair **modelling uncertainties** in the CMS (e+jets) and CMS (μ+jets) measurements are **recalculated without the contributions from the limited number of events in the samples** used to estimate them.

- Top quark mass:
  - ATLAS measurement used uncertainty of **±0.7 GeV**
  - CMS measurements used an uncertainty of **±1 GeV**
  - to keep consistency across the various input measurements, this effect in the ATLAS measurement is re-estimated using uncertainty of **±1 GeV** in top quark mass

Input correlations: $\rho(F_i,F_j)$

- **Correlations within the same measurement**
  - ATLAS: from covariance matrix of each systematic uncertainty category
  - CMS: $$\rho(F_0, F_L) = \frac{\sigma^2[F_R] - \sigma^2[F_0] - \sigma^2[F_L]}{2\sigma[F_0]\sigma[F_L]}$$

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- **Correlations between the ATLAS and CMS experiments $\rho_{LHC}(F_i,F_j)$**
  - Assuming: $\rho_{LHC}(F_0,F_0) = \rho_{LHC}(F_L,F_L)$ and $\rho_{LHC}(F_0,F_L) = -\rho_{LHC}(F_0,F_0)$
  - Detector modelling, JER, data-driven background estimation and method-specific uncertainty ➜ uncorrelated, $\rho_{LHC}(F_0,F_0)= 0$
  - Radiation & scales, JES ➜ partially correlated, $\rho_{LHC}(F_0,F_0)= 0.5, 0.2$
  - All other sources ➜ fully correlated, $\rho_{LHC}(F_0,F_0)= +1$

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  - All other sources ➜ fully correlated, $\rho_{LHC}(F_0,F_0)= +1$

- **Correlations between measurements within the CMS experiment**
  - Assuming $\rho_{CMS}(F_i,F_j)_{(st,\ \mathbf{e}+jets)} = \rho_{CMS}(F_i,F_j)_{(st,\ \mathbf{mu}+jets)} = \rho_{CMS}(F_i,F_j)_{(st,\ \mathbf{l}+jets)}$
  - In all cases: assuming $\rho_{CMS}(F_0,F_0) = \rho_{CMS}(F_L,F_L)$ and $\rho_{CMS}(F_0,F_L) = -\rho_{CMS}(F_0,F_0)$
  - Data statistics, background estimation, lepton efficiency, MC statistics ➜ uncorrelated
  - All other sources ➜ fully correlated

Input correlations between experiments

$\rho_{LHC}(F_i,F_i) = \rho(F_{i,ATLAS}, F_{i,CMS})$

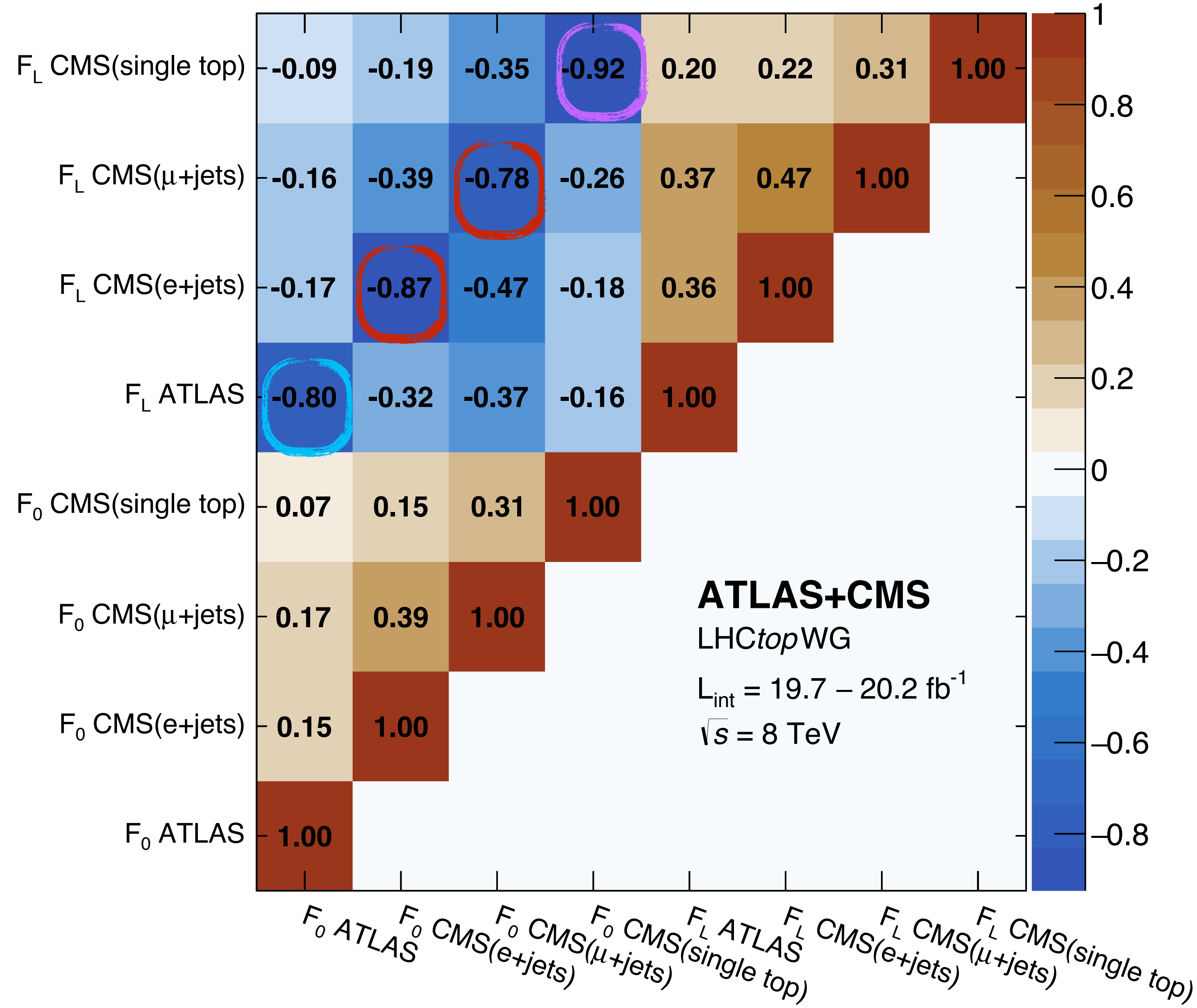
$\rho_{CMS,\ e/mu+jets}(F_i,F_i) = \rho(F_{i,e+jets}, F_{i,mu+jets})$

$\rho_{CMS,\ l+jets/st}(F_i,F_i) = \rho(F_{i,l+jets}, F_{i,st})$

Uncertainty Category	$\rho_{LHC}(F_i, F_i)$	$\rho_{CMS}^{e,\mu+jets}(F_i, F_i)$	$\rho_{CMS}^{st,\ell+jets}(F_i, F_i)$
Samples size and background determination			
Stat+bkg	0.0	$0.0^{\dagger}$	$0.0^{\dagger}$
Size of simulated samples	0.0	0.0	0.0
Detector modelling			
JES	$0.2^{\dagger}$	1.0	1.0
JER	0.0	1.0	1.0
b tagging	0.0	1.0	1.0
JVF	0.0^{*}	0.0^{*}	0.0^{*}
Jet reconstruction efficiency	0.0^{*}	0.0^{*}	0.0^{*}
Lepton efficiency	0.0	0.0	0.0
Pileup	0.0^{*}	1.0	1.0
Signal modelling			
Top quark mass	1.0	1.0	1.0
Simulation model choice	1.0	1.0	1.0
Radiation and scales	$0.5^{\dagger}$	1.0	$1.0^{\dagger}$
Top quark p_T	0.0^{*}	1.0	0.0^{*}
PDF	1.0	1.0	1.0
Single top method	0.0^{*}	0.0^{*}	0.0^{*}

Correlation matrix

- As a cross-check:
  - comparing the **total correlations** from the published input results of each measurement with the corresponding values from the **input correlation matrix**



Measurement	ATLAS	CMS ljets		CMSst
Direct calculation	-0.819	-0.86	-0.79	-0.92
Original publication	-0.55	-0.87		-0.80

Errata: doi.org/10.1140/epjc/s10052-018-6520-7

Results

- The Best Linear Unbiased Estimate (**BLUE**) method is used for the combination

	LHC combination	
	F_0	F_L
Fractions	0.693	0.315
Uncertainty category		
Statistics and background determination		
Stat. + bkg.	0.009	0.006
Simulation stats.	0.005	0.003
Detector modelling		
JES	0.004	0.002
JER	0.004	0.002
b-tagging	0.001	0.001
JVF	0.001	0.001
Jet reconstruction	< 0.001	< 0.001
Lepton efficiency	0.002	0.001
Pile-up	< 0.001	< 0.001
Signal modelling		
Top quark mass	0.003	0.004
Radiation and scales	0.005	0.004
Simul. model choice	0.006	0.005
Top quark p_T	0.001	0.002
PDF	0.001	0.001
Single top method	0.001	< 0.001
Total uncertainty	0.014	0.011

F_0= 0.693 ± 0.009 (stat+bkg) ± 0.011 (syst)

F_L= 0.315 ± 0.006 (stat+bkg) ± 0.009 (syst)

Correlation: -0.85

from unitarity:

F_R= -0.008 ± 0.005 (stat+bkg) ± 0.006 (syst)
upper limit: F_R < 0.007 @ 95% CL

χ^2=4.3 (6 DoF), probability = 64%

~2% uncertainty for F_0!
~3.5% for F_L!

lead by stat+bkg , radiation&scales , MC stats

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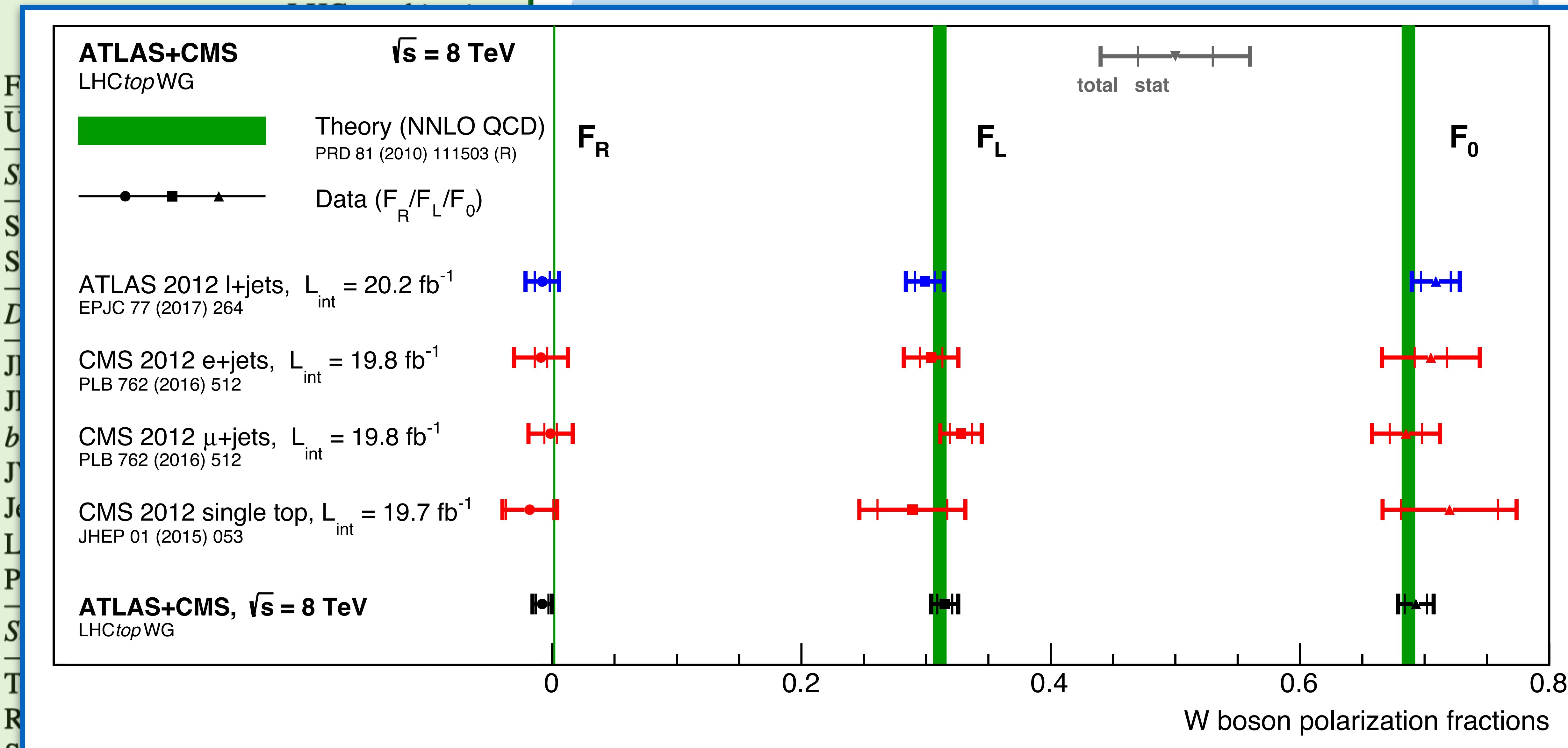

Top quark p_T	0.001	0.002
PDF	0.001	0.001
Single top method	0.001	< 0.001
Total uncertainty	0.014	0.011

~2% uncertainty for F_0!
~3.5% for F_L!

lead by stat+bkg , radiation&scales , MC stats

Stability checks

1

Testing the ρ_{LHC} **(F_i,F_i)** assumption on **JES** uncertainty:

- Default correlation: **0.2**
- Scan: interval of [0.1, 0.4] in step of 0.1

⇒ The helicity fraction values and uncertainties remained unchanged

⇒ χ^2 of the fit, probability and total correlation found to be stable with relative shift < 0.5%

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2

Testing the ρ_{LHC}**(F_i,F_i)** and $\rho_{CMS,\ l+jets/st}$**(F_i,F_i)** assumption on **radiation and scales** uncertainty:

- Default correlation: **0.5** and **1.0** respectively
- Simultaneous Scan: intervals of [0, 0.5] and [0.6,1.0] in step of 0.1, respectively

⇒ the helicity fraction values and uncertainties remained unchanged

⇒ small variations, below the percent level are observed for the total correlation and fit probability

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- Default correlation: **0.5** and **1.0** respectively
- Simultaneous Scan: intervals of [0, 0.5] and [0.6,1.0] in step of 0.1, respectively

⇒ the helicity fraction values and uncertainties remained unchanged

⇒ small variations, below the percent level are observed for the total correlation and fit probability

3

Testing the **JES vs. radiation and scales** simultaneously:

- Default correlation: **0.2** and **0.5** respectively
- Scan: grid of 5x5 in step of 0.1

⇒ stable combination with maximum relative shifts of ~ 2% for χ^2 and probability

⇒ negligible variations in the combined fractions and uncertainties

Stability checks - continued

4

Testing the $\rho_{CMS,\ e/mu+jets}$ **(F_i,F_i)** and $\rho_{CMS,\ l+jets,\ st}$ **(F_i,F_i)** assumption **statistical+background uncertainty**:

- Default correlation: **0**
- Scan: interval of [0, 0.6] in step of 0.1

⇒ The helicity fraction values are varied by a maximum of 1.3%

⇒ for correlation value of 0.7, the fit probability decreases to 28%. For correlation values > 0.7, the fit does not converge

Stability checks - continued

4

Testing the $\rho_{CMS, e/mu+jets}$ **(F_i,F_i)** and $\rho_{CMS, l+jets, st}$ **(F_i,F_i)** assumption **statistical+background uncertainty**:

- Default correlation: **0**
- Scan: interval of [0, 0.6] in step of 0.1

⇒ The helicity fraction values are varied by a maximum of 1.3%

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Using the **pre-combined CMS (l+jets)** instead of **CMS (e+jets)**+ **CMS (mu+jets) as input**

⇒ identical results for helicity fractions / total correlation differs by ~1.5%

⇒ combination weights are very close to the sum of the weights of the combination using individual inputs

Stability checks - continued

4

Testing the $\rho_{CMS,\ e/mu+jets}$ (F_i,F_i) and $\rho_{CMS,\ l+jets,\ st}$ (F_i,F_i) assumption **statistical+background uncertainty**:

- Default correlation: **0**
- Scan: interval of [0, 0.6] in step of 0.1

⇒ The helicity fraction values are varied by a maximum of 1.3%

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In conclusion:

- Results are robust against variations of the poorly known/ unknown input correlations
- The correlations are varied over a large range
- In all cases, the observed deviation from the nominal results are well covered by the uncertainties in the combined result.

1D limits on the anomalous couplings

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- Using **EFTFitter tool**, (**1D**) limits are set on the **real part** of the anomalous couplings as:
  - Each limit obtained by fixing other 3 to SM value
  - EFTFitter inputs are BLUE combination result **(F_0, ΔF_0 , F_L, ΔF_L, ρ)**

	95 % CL interval		
Coupling	ATLAS	CMS	LHC combination
V_R	$[-0.17, 0.25]$	$[-0.12, 0.16]$	$[-0.11, 0.16]$
g_L	$[-0.11, 0.08]$	$[-0.09, 0.06]$	$[-0.08, 0.05]$
g_R	$[-0.03, 0.06]$	$[-0.06, 0.01]$	$[-0.04, 0.02]$

- Similarly, limits are set on the corresponding Wilson coefficients

Nucl.Phys.B812:181-204,2009

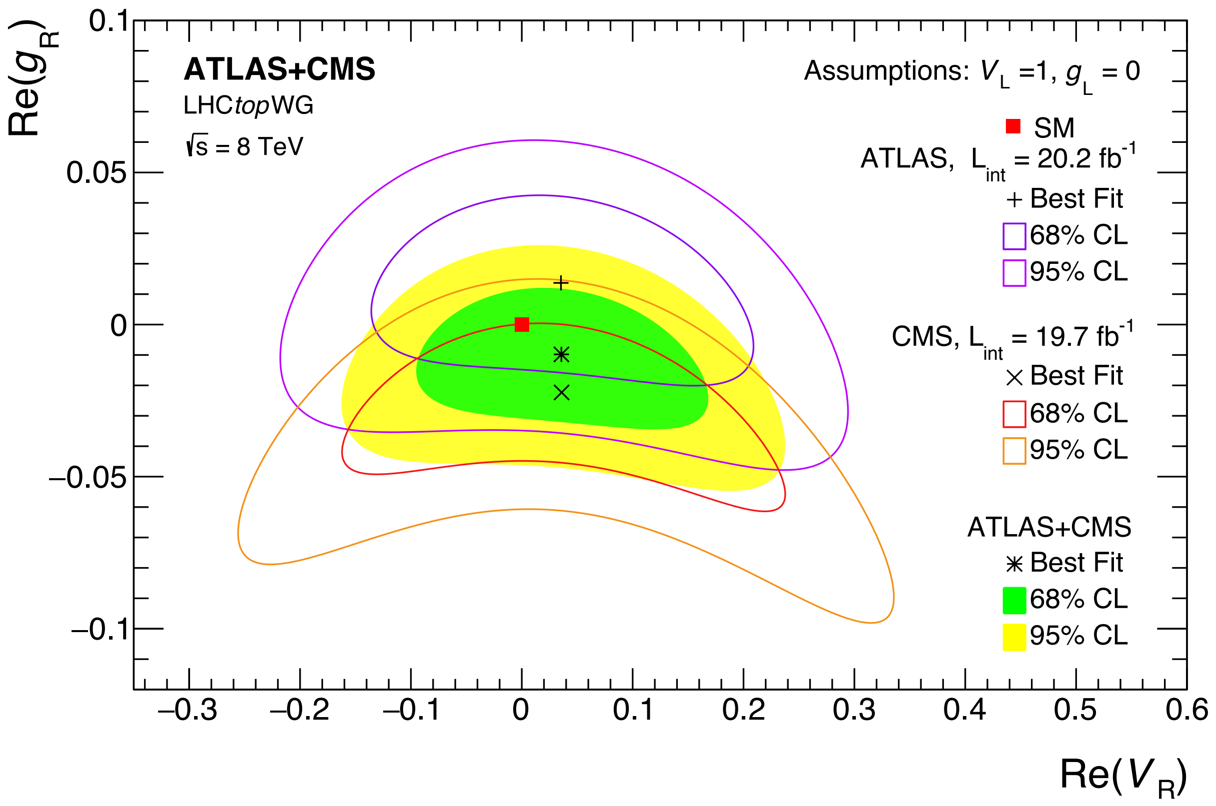
$$\mathcal{L}^{\text{eff}} = \mathcal{L}^{\text{SM}} + \Sigma \frac{C_x}{\Lambda^2} O_x + \mathcal{O}\left(\frac{1}{\Lambda^3}\right) + \ldots$$

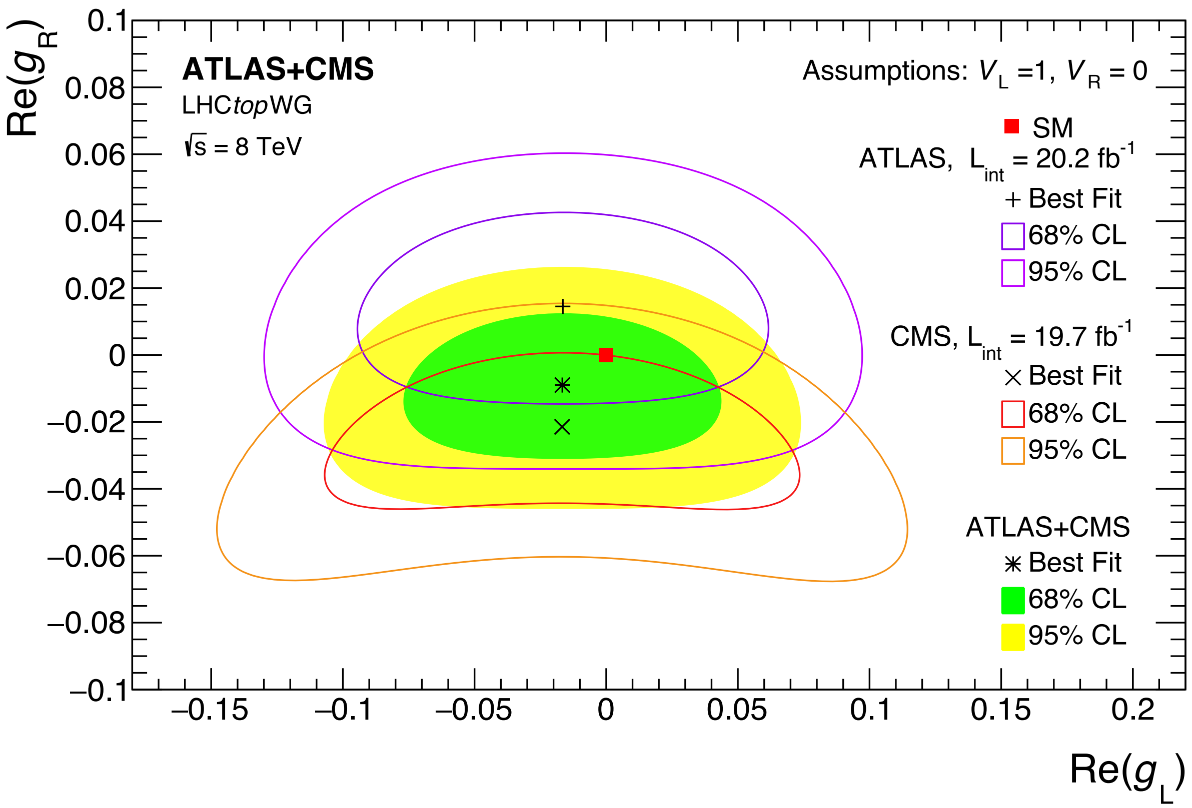
$$\delta V_L = C_{\phi q}^{(3,33)*} \frac{v^2}{\Lambda^2}, \qquad \delta g_L = \sqrt{2} C_{dW}^{33*} \frac{v^2}{\Lambda^2},$$

$$\delta V_R = \frac{1}{2} C_{\phi\phi}^{33} \frac{v^2}{\Lambda^2}, \qquad \delta g_R = \sqrt{2} C_{uW}^{33} \frac{v^2}{\Lambda^2}.$$

	95 % CL interval		
Coefficient	ATLAS	CMS	LHC combination
$C_{\phi\phi}^*$	$[-5.64, 7.68]$	$[-3.84, 4.92]$	$[-3.48, 5.16]$
C_{bW}^*	$[-1.30, 0.96]$	$[-1.06, 0.72]$	$[-0.96, 0.67]$
C_{tW}	$[-0.34, 0.67]$	$[-0.62, 0.19]$	$[-0.48, 0.29]$

2D Limits on the anomalous couplings





The other 2 couplings are fixed to SM predictions

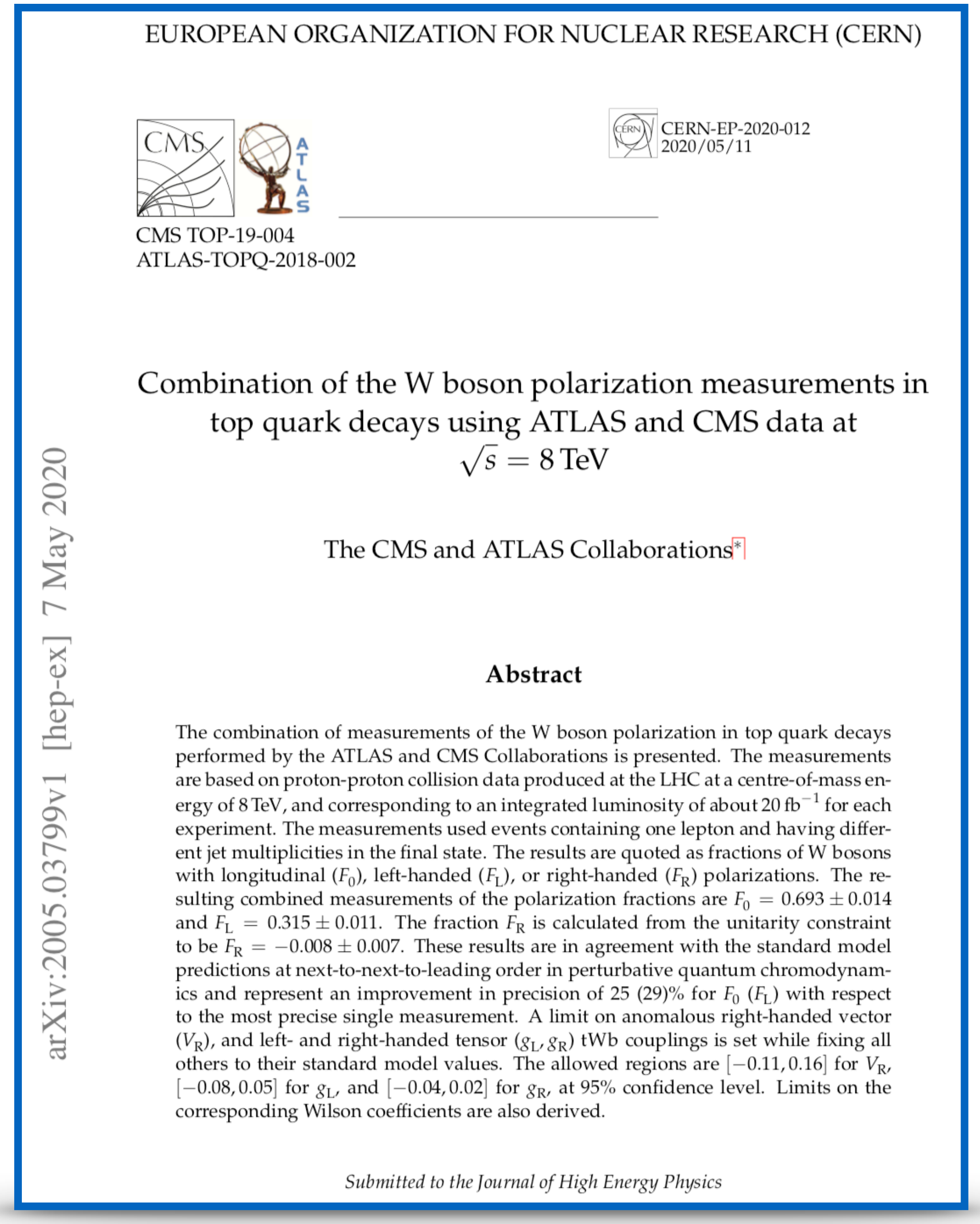
Summary & conclusion

- The combination of ATLAS and CMS measurements of the W boson polarization in top quark decays is presented
- Precision of **~ 2% in F_0**, **~3.5% in F_L** is achieved
- Improvement (*) w.r.t previous most precise individual measurements:
  - **~25% in F_0**
  - **~29% in F_L**
- New couplings exclusion: tightening possibilities of new physics
- W boson helicity fractions:

$$F_0 = 0.693 \pm 0.009(\text{stat+bkg}) \pm 0.011(\text{syst})$$
$$F_L = 0.315 \pm 0.006(\text{stat+bkg}) \pm 0.009(\text{syst})$$
$$F_R = -0.008 \pm 0.005(\text{stat+bkg}) \pm 0.006(\text{syst})$$

- Lead by stat+bkg, radiation&scales, MC stats
- Result is compatible with Standard Model
- Constraints derived on the corresponding Wilson coefficients

arXiv:2005.03799v1 [hep-ex]


EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2020-012
2020/05/11

CMS TOP-19-004
ATLAS-TOPQ-2018-002

arXiv:2005.03799v1 [hep-ex] 7 May 2020

Combination of the W boson polarization measurements in top quark decays using ATLAS and CMS data at $\sqrt{s} = 8$ TeV

The CMS and ATLAS Collaborations*

Abstract

The combination of measurements of the W boson polarization in top quark decays performed by the ATLAS and CMS Collaborations is presented. The measurements are based on proton-proton collision data produced at the LHC at a centre-of-mass energy of 8 TeV, and corresponding to an integrated luminosity of about 20 fb^{-1} for each experiment. The measurements used events containing one lepton and having different jet multiplicities in the final state. The results are quoted as fractions of W bosons with longitudinal (F_0), left-handed (F_L), or right-handed (F_R) polarizations. The resulting combined measurements of the polarization fractions are $F_0 = 0.693 \pm 0.014$ and $F_L = 0.315 \pm 0.011$. The fraction F_R is calculated from the unitarity constraint to be $F_R = -0.008 \pm 0.007$. These results are in agreement with the standard model predictions at next-to-next-to-leading order in perturbative quantum chromodynamics and represent an improvement in precision of 25 (29)% for F_0 (F_L) with respect to the most precise single measurement. A limit on anomalous right-handed vector (V_R), and left- and right-handed tensor (g_L, g_R) tWb couplings is set while fixing all others to their standard model values. The allowed regions are $[-0.11, 0.16]$ for V_R, $[-0.08, 0.05]$ for g_L, and $[-0.04, 0.02]$ for g_R, at 95% confidence level. Limits on the corresponding Wilson coefficients are also derived.

Submitted to the Journal of High Energy Physics

(*) Improvement = $\left(1 - \dfrac{\text{Rel. Unc. of Combination}}{\text{Rel. Unc. of most precise meas.}}\right) \times 100$

Backup slides

Re-grouped uncertainties

	ATLAS ℓ+jets		
	F_0	F_L	$\rho^{\text{l+jets}}_{\text{ATLAS}}(F_0, F_L)$
Measured value	0.709	0.299	
Uncertainty Category			
Statistics and background determination			
Stat. + bkg.	0.012	0.008	−1.00
Simulation stats.	0.009	0.006	−1.00
Detector modelling			
JES	0.005	0.003	−0.94
JER	0.006	0.003	−0.92
b-tagging	0.002	0.001	−0.84
JVF	0.003	0.002	−0.99
Jet reconstruction	< 0.001	< 0.001	−1.00
Lepton efficiency	0.004	0.002	−0.99
Pile-up	*n.a.*	*n.a.*	*n.a.*
Signal modelling			
Top quark mass	0.002	0.007	−1.00
Radiation and scales	0.003	0.006	−0.91
Simul. model choice	0.003	0.004	0.99
Top quark p_T	*n.a.*	*n.a.*	*n.a.*
PDF	0.003	0.004	−1.00
Single top method	*n.a.*	*n.a.*	*n.a.*
Total uncertainties			
Systematic uncertainty	0.014	0.013	−0.82
Total uncertainty	0.019	0.015	−0.82

Re-grouped uncertainties

	CMS e+jets			CMS μ+jets		
	F_0	F_L	$\rho^{e+jets}_{CMS}(F_0, F_L)$	F_0	F_L	$\rho^{\mu+jets}_{CMS}(F_0, F_L)$
Measured value	0.705	0.304		0.685	0.328	
Uncertainty Category						
Statistics and background determination						
Stat. + bkg.	0.028	0.011	−0.87	0.016	0.010	−0.88
Simulation stats.	0.002	0.001	−0.95	0.002	0.001	−0.96
Detector modelling						
JES	0.004	0.003	−1.00	0.005	0.003	−1.00
JER	0.001	0.002	−1.00	0.004	0.003	−1.00
b-tagging	0.001	< 0.001	−1.00	0.001	< 0.001	−1.00
JVF	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Jet reconstruction	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Lepton efficiency	0.001	0.002	−1.00	0.001	0.001	−1.00
Pile-up	0.001	0.001	−1.00	< 0.001	< 0.001	−1.00
Signal modelling						
Top quark mass	0.012	0.008	−0.99	0.009	0.006	−1.00
Radiation and scales	0.007	0.005	−1.00	0.014	0.006	−0.83
Simul. model choice	0.015	0.010	−0.87	0.008	0.004	0.20
Top quark p_T	0.011	0.010	−1.00	< 0.001	0.001	−1.00
PDF	0.004	0.001	−0.92	0.002	0.001	−0.15
Single top method	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Total uncertainties						
Systematic uncertainty	0.024	0.018	−0.93	0.020	0.010	−0.71
Total uncertainty	0.037	0.021	−0.87	0.025	0.014	−0.80

Re-grouped uncertainties

	CMS (single top)		
	F_0	F_L	$\rho^{st}_{CMS}(F_0, F_L)$
Measured value	0.720	0.298	
Uncertainty Category			
Statistics and background determination			
Stat. + bkg.	0.041	0.031	−0.90
Simulation stats.	0.002	0.004	−0.96
Detector modelling			
JES	0.004	0.004	−1.00
JER	0.001	0.001	−1.00
b-tagging	0.006	0.006	−1.00
JVF	*n.a.*	*n.a.*	*n.a.*
Jet reconstruction	*n.a.*	*n.a.*	*n.a.*
Lepton efficiency	< 0.001	< 0.001	0.00
Pile-up	0.003	0.003	−1.00
Signal modelling			
Top quark mass	0.005	0.007	−1.00
Radiation and scales	0.023	0.019	−1.00
Simul. model choice	0.002	0.003	−1.00
Top quark p_T	*n.a.*	*n.a.*	*n.a.*
PDF	0.004	0.004	−0.97
Single top method	0.012	0.015	−1.00
Total uncertainties			
Systematic uncertainty	0.035	0.029	−0.96
Total uncertainty	0.054	0.043	−0.92