EPS-HEP Conference 2021

European Physical Society conference on high energy physics 2021

Online conference, July 26-30, 2021

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

JHEP 08 (2020) 51

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/TOPQ-2018-02/

Véronique Boisvert
on behalf of ATLAS and CMS

ROYAL HOLLOWAY UNIVERSITY OF LONDON

ATLAS EXPERIMENT

29th July 2021

CMS

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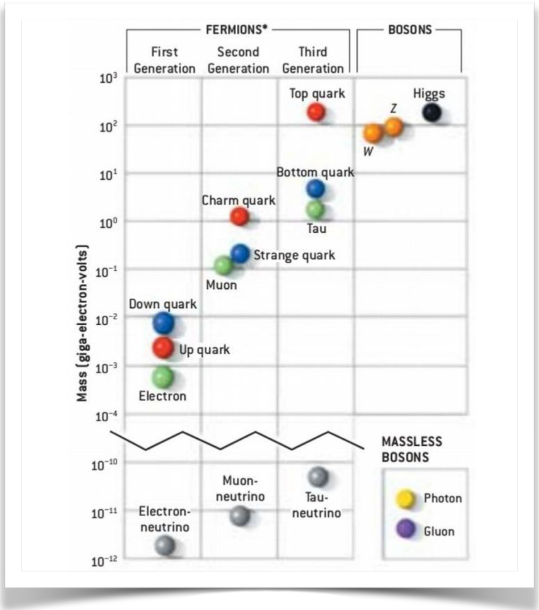
Top events: from precision to searches!

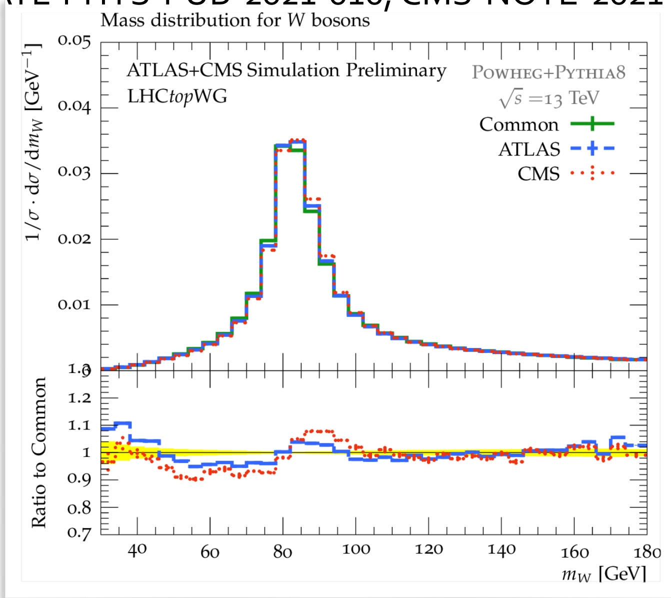
Physics

- LHC is a top quark factory: at 13 TeV about 2 tops every second!
  - plenty of statistics to make precision measurements
- Studying top decay is crucial to the LHC programme:
  - Detailed measurements of QCD, EWK
  - Searches for new physics
- Combining ATLAS and CMS measurements: LHC legacy!
  - Gain in sensitivity from added statistics and complementary approaches
  - But a lot of work!
    - Detailed discussions of each systematic uncertainties
    - Extensive cross-checks of stability of results on assumptions of correlations
    - Published results and on-going activities within the LHCTopWG: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCTopWG

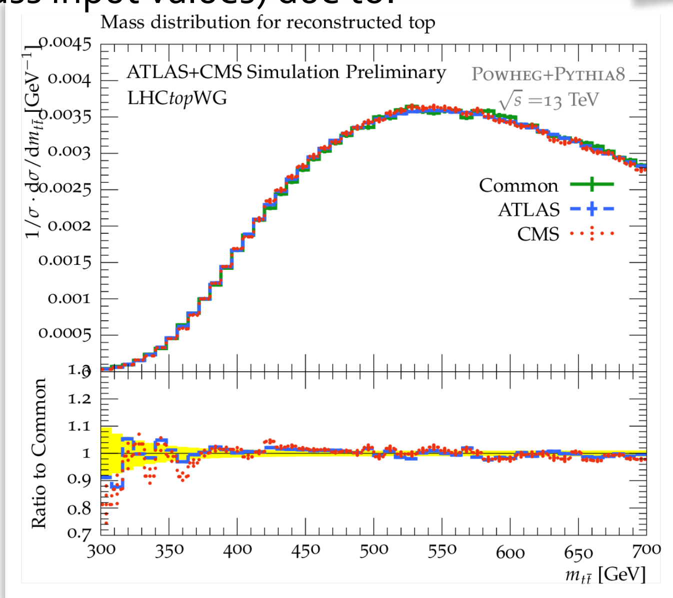


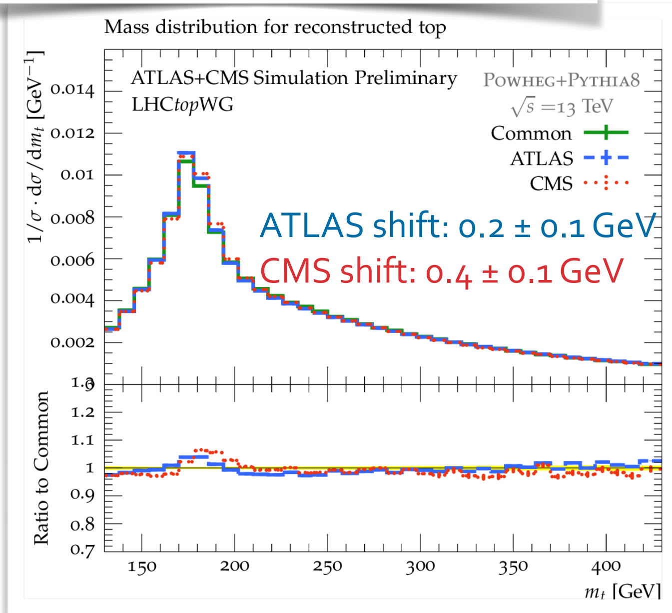
Example: Common ATLAS + CMS MC sample

ATL-PHYS-PUB-2021-016, CMS-NOTE-2021-005



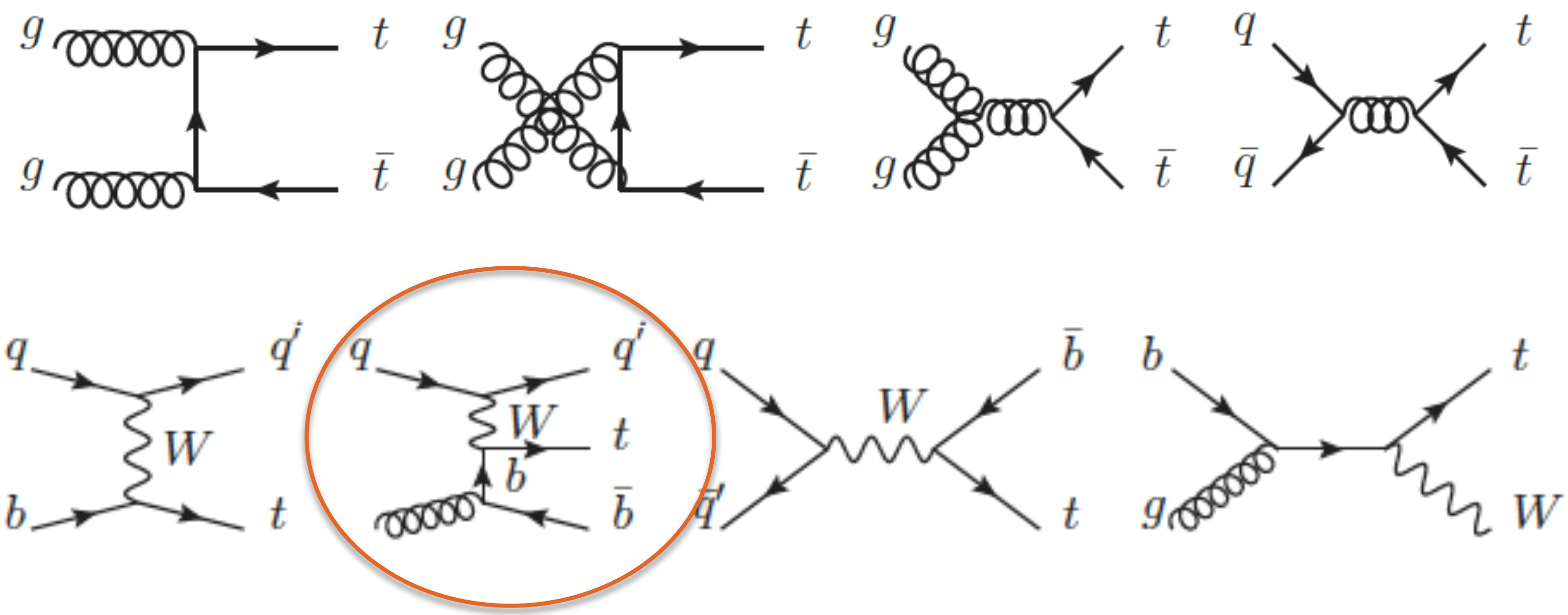
- MC modelling crucial ingredient to all top ATLAS and CMS results and to combining them
- Use same generators (Powheg-Box V2 (HVQ) + Pythia8) but different parameters and systematic uncertainty prescriptions
- Common Settings:
  - Step 1: use same parameters (will not become the defaults ones): done
    - Eg shift in masses (same mass input values) due to:
      - parton shower modelling
      - α_S value
      - colour reconnection modelling
  - Step 2: tune those parameters to ATLAS and CMS data: to do





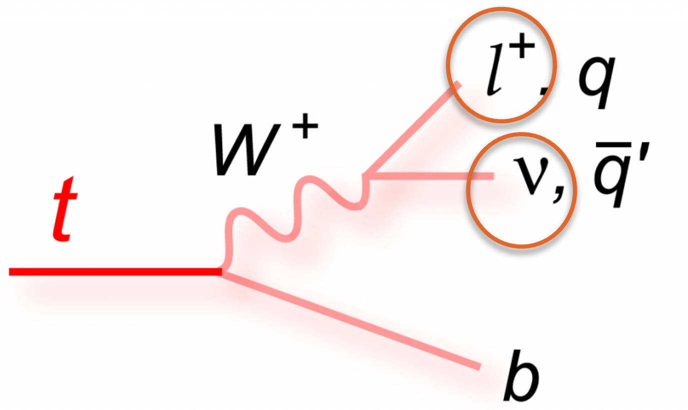
Top production and decay

Production:



single top t-channel

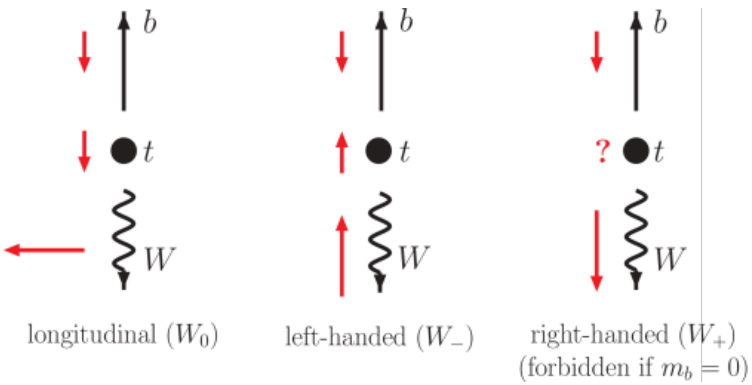
Decay:



lepton+jets channel: electron and muon

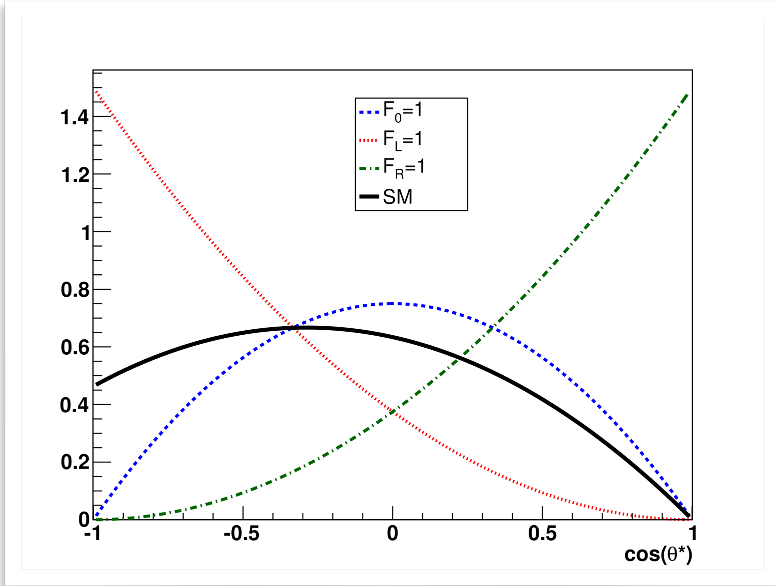
W polarization in top-quark decay

- tWb vertex governed by weak interaction, in SM: V-A structure
  - test of SM prediction
  - probe for new physics



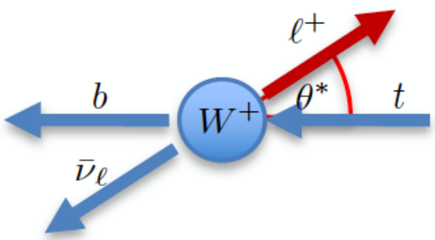
$F_0=0.687\pm0.005$ $F_L=0.311\pm0.005$ $F_R=0.0017\pm0.0001$

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



- Measured using cosθ* distribution:

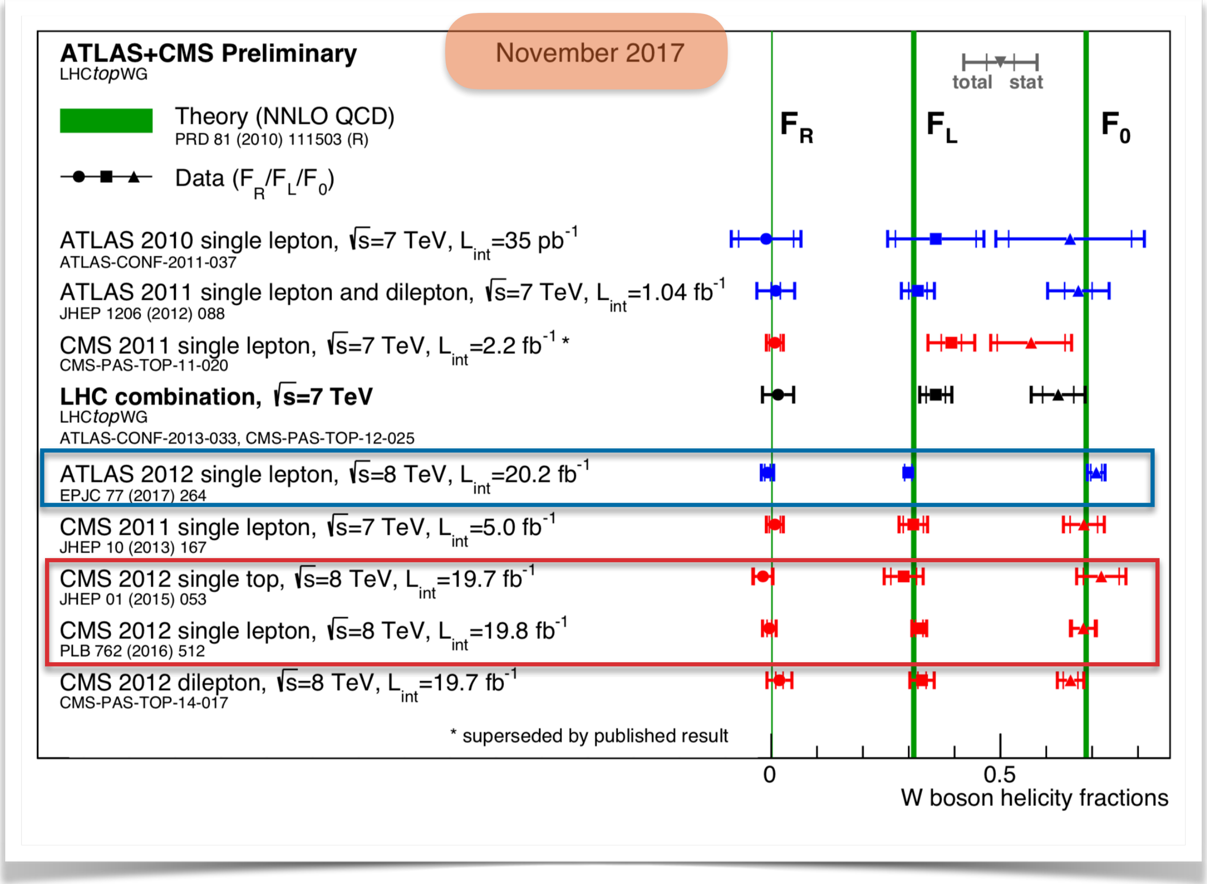
Assume unitarity: $F_0+F_L+F_R=1$
2 independent measurements



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

4 Input Measurements

Physics



best precision of inputs: ~3-5%

1

2

3) e+jets 4) μ+jets

- e+jets, μ+jets: 1 e or μ, ≥4 jets (≥2 b-jets)
- single top: 1 e or μ, =2 jets (=1 b-jet), orthogonal selection
- Kinematic likelihood fit for reconstruction
- Binned likelihood fit: ATLAS: templates, CMS: event-by-event reweighing

Input Systematic Uncertainties

Physics

- l+jets: systematics dominated, single-top: stats dominated
- Modifications:
  - ATLAS uncertainties symmetrised (needed for BLUE)
  - CMS l+jets signal modelling uncertainties recalculated without MC stats (accounted in sample size category)
  - ATLAS top mass uncertainty increased from 0.7 Gev to 1 GeV
- Types of uncertainties:
  - data stat, size of simulated samples, backgrounds
  - detector modelling (lepton, jets, b-tagging, etc.): dominant are jet energy scale, resolution (single-top: b-tagging)
  - signal modelling (generator, radiation, PDF, etc.): dominant are top mass, model, radiation
  - single top: W polarization also impacts single top production, modelling of this included in uncertainty

	ATLAS		
	F_0	F_L	$\rho_{\mathrm{ATLAS}}(F_0, F_L)$
Measured value	0.709	0.299	
Uncertainty category			
Samples size and background determination			
Stat+bkg	0.012	0.008	−1.00
Size of simulated samples	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 efficiency	< 0.001	< 0.001	−1.00
Lepton efficiency	0.004	0.002	−0.99
Pileup	*n.a.*	*n.a.*	*n.a.*
Signal modelling			
Top quark mass	0.002	0.007	−1.00
Simulation model choice	0.003	0.004	0.99
Radiation and scales	0.003	0.006	−0.91
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	−0.80

tables for CMS l+jets and single top in backup

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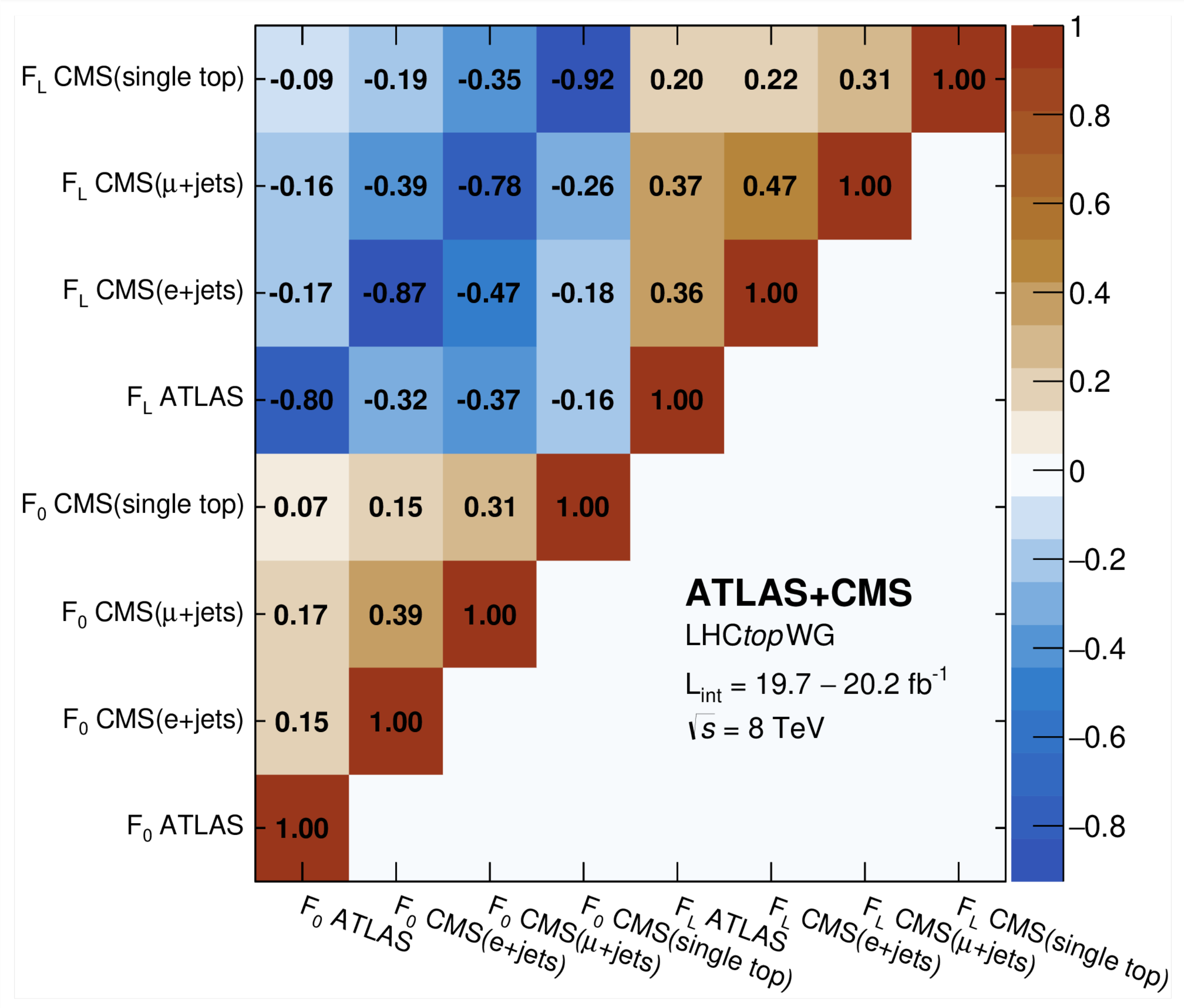
Correlations

Physics

- Correlations within the same measurements:
  - F_0 and F_L highly anti-correlated
  - ATLAS: use covariance matrices, CMS: use $\rho(F_0, F_L) = \frac{\sigma^2(F_R) - \sigma^2(F_0) - \sigma^2(F_L)}{2\sigma(F_0)\sigma(F_L)}$
- Correlations between measurements within CMS:
  - Use: $\rho_{CMS}(F_i, F_j)(st,e+jets) = \rho_{CMS}(F_i, F_j)(st,\mu+jets)$, i,j: 0, L
  - Use: $\rho_{CMS}(F_0, F_0) = \rho_{CMS}(F_L, F_L) = -\rho_{CMS}(F_0, F_L)$
  - data stat, backgrounds, lepton eff, MC stats →uncorrelated
  - All others → fully correlated
- Correlations between ATLAS and CMS:
  - Use: $\rho_{LHC}(F_0, F_0) = \rho_{LHC}(F_L, F_L) = -\rho_{LHC}(F_0, F_L)$
  - detector modelling, method-specific uncertainties →uncorrelated
  - JES: $\rho_{LHC}(F_0, F_0) = 0.2$, radiation and scales: $\rho_{LHC}(F_0, F_0) = 0.5$
  - All others → fully correlated

Summary of total correlations

- F_0 and F_L highly anti-correlated
- ATLAS and CMS l+jets: (anti)correlation ~30-40%
- CMS single top: more correlated with CMS l+jets than ATLAS l+jets



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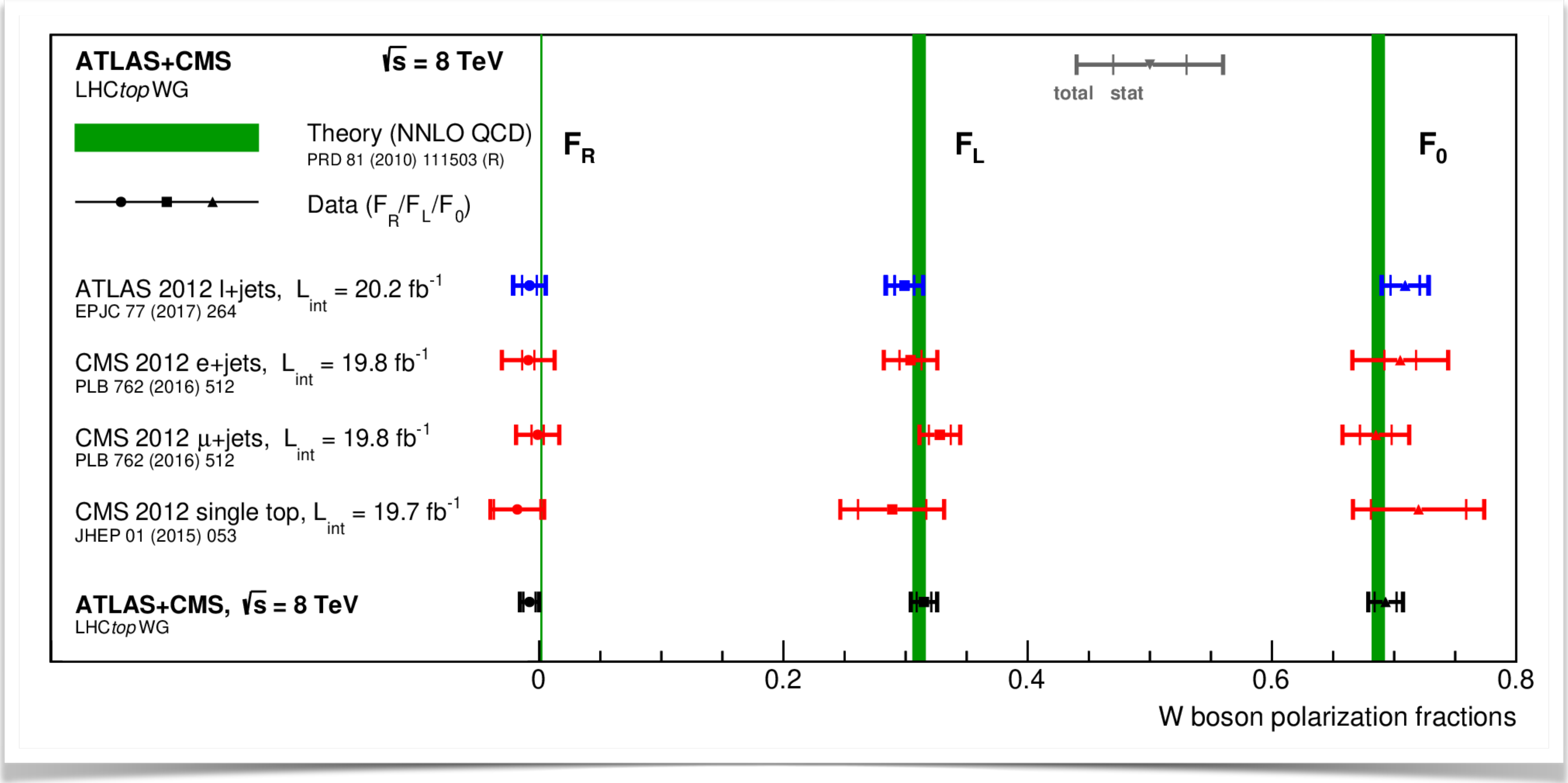
Results

Physics



F_0=0.693 ± 0.009 (stat+bckg) ± 0.011 (syst) (2.0%), 25% more precise than inputs

F_L=0.315 ± 0.006 (stat+bckg) ± 0.009 (syst) (3.5%), 29% more precise than inputs

total correlation: -0.85

using unitarity: F_R=-0.008 ± 0.005 (stat+bckg) ± 0.006 (syst), Feldman-Cousins limit: FR < 0.007 at 95% CL, factor of 2 more precise than inputs

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Systematic uncertainties on combination

Physics

	ATLAS+CMS combination	
	F_0	F_L
Fractions	0.693	0.315
Uncertainty category		
Samples size and background determination		
Stat+bkg	0.009	0.006
Size of simulated samples	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
Pileup	< 0.001	< 0.001
Signal modelling		
Top quark mass	0.003	0.004
Simulation model choice	0.006	0.005
Radiation and scales	0.005	0.004
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

Probing new physics!

- tWb vertex Lagrangian using EFT:

Vector couplings — Tensor couplings

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

$V_{tb}\approx 1$ in SM

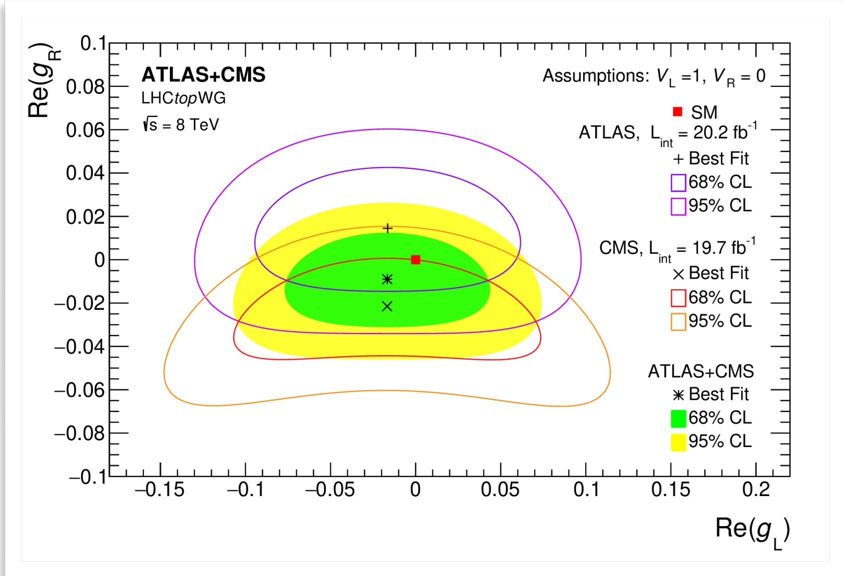
anomalous couplings: ≈0 in SM

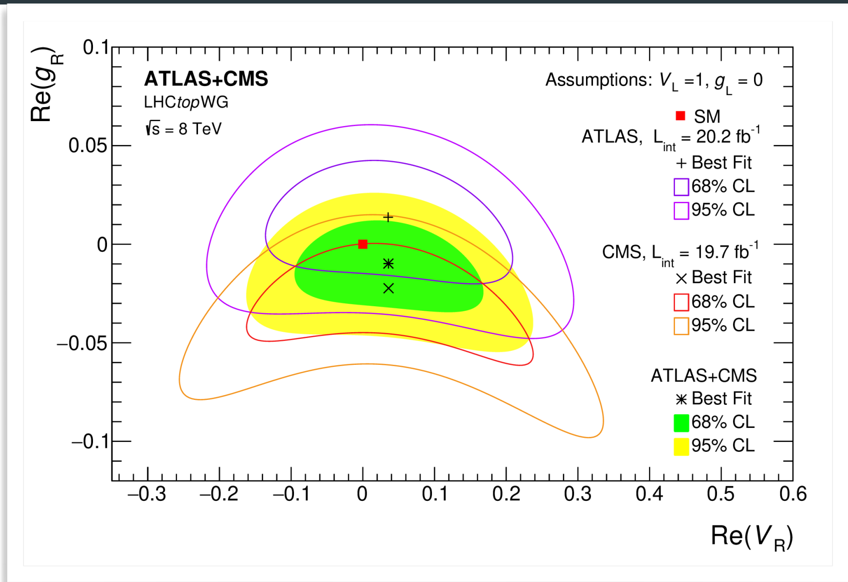
- Fit using EFTfitter, 2 inputs for 4 parameters: fix non-fitted parameters to SM values
- Assume couplings are real and don't introduce new CP violation

	95% CL interval		
Coupling	ATLAS	CMS	ATLAS+CMS combination
$\mathrm{Re}(V_R)$	$[-0.17, 0.25]$	$[-0.12, 0.16]$	$[-0.11, 0.16]$
$\mathrm{Re}(g_L)$	$[-0.11, 0.08]$	$[-0.09, 0.06]$	$[-0.08, 0.05]$
$\mathrm{Re}(g_R)$	$[-0.03, 0.06]$	$[-0.06, 0.01]$	$[-0.04, 0.02]$

Probing new physics!

Physics





- Can also use effective Lagrangian using dimension-six operators and get limits on Wilson coefficients:

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

$$O_{\phi\phi} = i(\tilde{\phi}^\dagger D_\mu \phi)(\bar{t}_R \gamma^\mu b_R),$$
$$O_{tW} = (\bar{q}_L \sigma^{\mu\nu} \tau^I t_R)\tilde{\phi} W^I_{\mu\nu},$$
$$O_{bW} = (\bar{q}_L \sigma^{\mu\nu} \tau^I b_R)\phi W^I_{\mu\nu},$$

	95% CL interval		
Coefficient	ATLAS	CMS	ATLAS+CMS 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]

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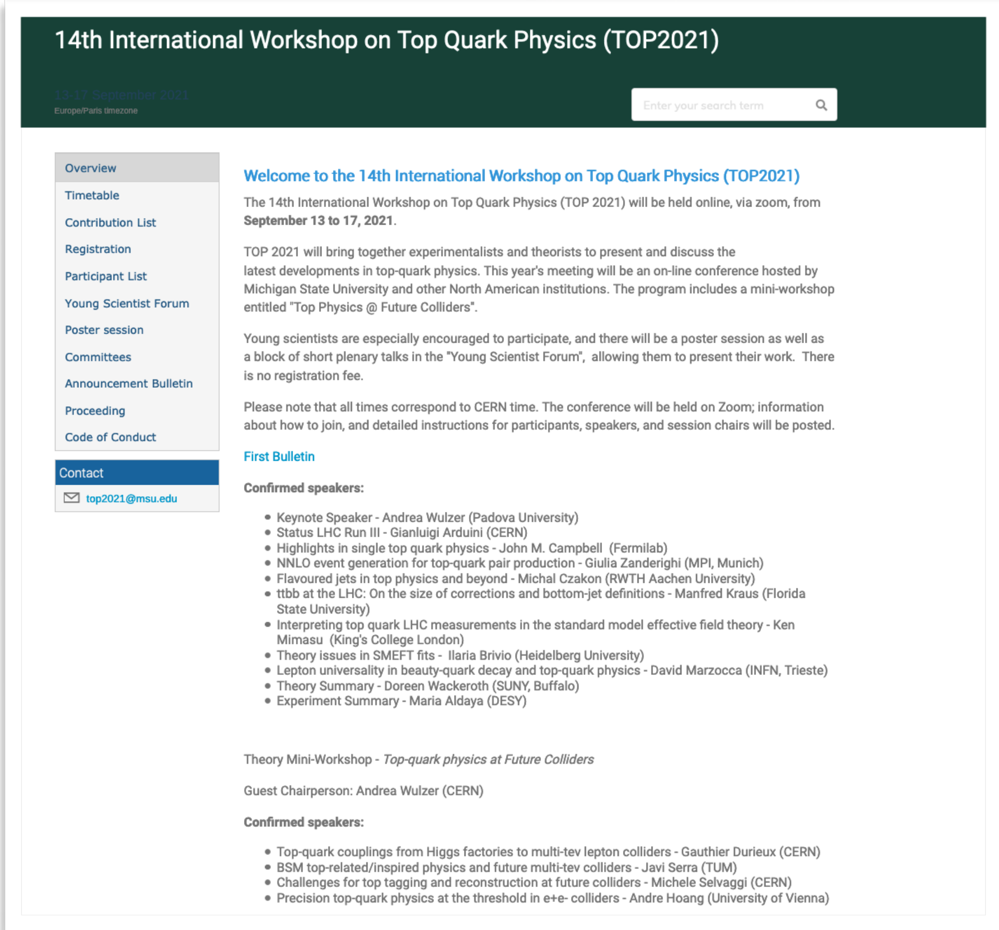
Summary & Conclusions

Physics

- Most precise W polarization measurements are obtained from combining ATLAS and CMS 8 TeV results
- The order 2-3% precision in F_0 and F_L is close to the precision achieved in the theoretical prediction at NNLO (order 1%), and is a ~25% improvement on the input measurements
- Combination also improves significantly the limits on anomalous couplings and Wilson coefficients
- More ATLAS & CMS combinations to come soon:
    - Eg: Run 1 tt cross-section and extraction of top pole mass and strong coupling constant
    - Large effort ongoing on getting tools to harmonize combinations: eg common MC sample



14th International Workshop on Top Quark Physics (TOP2021)

Europe/Paris timezone

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Contribution List
Registration
Participant List
Young Scientist Forum
Poster session
Committees
Announcement Bulletin
Proceeding
Code of Conduct

Contact
top2021@msu.edu

Welcome to the 14th International Workshop on Top Quark Physics (TOP2021)

The 14th International Workshop on Top Quark Physics (TOP 2021) will be held online, via zoom, from **September 13 to 17, 2021**.

TOP 2021 will bring together experimentalists and theorists to present and discuss the latest developments in top-quark physics. This year's meeting will be an on-line conference hosted by Michigan State University and other North American institutions. The program includes a mini-workshop entitled "Top Physics @ Future Colliders".

Young scientists are especially encouraged to participate, and there will be a poster session as well as a block of short plenary talks in the "Young Scientist Forum", allowing them to present their work. There is no registration fee.

Please note that all times correspond to CERN time. The conference will be held on Zoom; information about how to join, and detailed instructions for participants, speakers, and session chairs will be posted.

First Bulletin

Confirmed speakers:

- Keynote Speaker - Andrea Wulzer (Padova University)
- Status LHC Run III - Gianluigi Arduini (CERN)
- Highlights in single top quark physics - John M. Campbell (Fermilab)
- NNLO event generation for top-quark pair production - Giulia Zanderighi (MPI, Munich)
- Flavoured jets in top physics and beyond - Michal Czakon (RWTH Aachen University)
- ttbb at the LHC: On the size of corrections and bottom-jet definitions - Manfred Kraus (Florida State University)
- Interpreting top quark LHC measurements in the standard model effective field theory - Ken Mimasu (King's College London)
- Theory issues in SMEFT fits - Ilaria Brivio (Heidelberg University)
- Lepton universality in beauty-quark decay and top-quark physics - David Marzocca (INFN, Trieste)
- Theory Summary - Doreen Wackeroth (SUNY, Buffalo)
- Experiment Summary - Maria Aldaya (DESY)

Theory Mini-Workshop - *Top-quark physics at Future Colliders*

Guest Chairperson: Andrea Wulzer (CERN)

Confirmed speakers:

- Top-quark couplings from Higgs factories to multi-tev lepton colliders - Gauthier Durieux (CERN)
- BSM top-related/inspired physics and future multi-tev colliders - Javi Serra (TUM)
- Challenges for top tagging and reconstruction at future colliders - Michele Selvaggi (CERN)
- Precision top-quark physics at the threshold in e+e- colliders - Andre Hoang (University of Vienna)

backups

Matching of anomalous couplings with coefficients

J.A. Aguilar-Saavedra / Nuclear Physics B 812 (2009) 181–204

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

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

Input measurements

Table 1: Summary of the published ATLAS and CMS measurements for 8 TeV data. The first quoted uncertainty in the ATLAS measurement includes statistical uncertainties and uncertainties in the background determination, and the second uncertainty refers to the remaining systematic contribution. For CMS measurements, the first uncertainty is statistical while the second is the total systematic uncertainty, including that on background determination.

Measurement	F_0	F_L	F_R
ATLAS (ℓ+jets)	$0.709 \pm 0.012 \pm 0.015$	$0.299 \pm 0.008 \pm 0.013$	$-0.008 \pm 0.006 \pm 0.012$
CMS (e+jets)	$0.705 \pm 0.013 \pm 0.037$	$0.304 \pm 0.009 \pm 0.020$	$-0.009 \pm 0.005 \pm 0.021$
CMS (μ+jets)	$0.685 \pm 0.013 \pm 0.024$	$0.328 \pm 0.009 \pm 0.014$	$-0.013 \pm 0.005 \pm 0.017$
CMS (single top)	$0.720 \pm 0.039 \pm 0.037$	$0.298 \pm 0.028 \pm 0.032$	$-0.018 \pm 0.019 \pm 0.011$

CMS uncertainties and correlations

	CMS e+jets			CMS μ+jets		
	F_0	F_L	$\rho_{CMS}^{e+jets}(F_0, F_L)$	F_0	F_L	$\rho_{CMS}^{\mu+jets}(F_0, F_L)$
Measured value	0.705	0.304		0.685	0.328	
Uncertainty category						
Samples size and background determination						
Stat+bkg	0.028	0.011	−0.87	0.016	0.010	−0.88
Size of simulated samples	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 efficiency	*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
Pileup	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
Simulation model choice	0.015	0.010	−0.87	0.008	0.004	0.20
Radiation and scales	0.007	0.005	−1.00	0.014	0.006	−0.83
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	−0.78

	CMS (single top)		
	F_0	F_L	$\rho_{CMS}^{st}(F_0, F_L)$
Measured value	0.720	0.298	
Uncertainty category			
Samples size and background determination			
Stat+bkg	0.041	0.031	−0.90
Size of simulated samples	0.020	0.012	−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 efficiency	*n.a.*	*n.a.*	*n.a.*
Lepton efficiency	< 0.001	< 0.001	−1.00
Pileup	0.003	0.003	−1.00
Signal modelling			
Top quark mass	0.005	0.007	−1.00
Simulation model choice	0.002	0.003	−1.00
Radiation and scales	0.023	0.019	−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

Coefficients and pulls

Measurement	Coefficients w_{F_0}	w_{F_L}	Pulls
F_0 ATLAS	0.797	−0.292	1.336
F_L ATLAS	0.472	0.038	−1.451
F_0 CMS (e+jets)	0.021	0.134	0.356
F_L CMS (e+jets)	−0.083	0.303	−0.619
F_0 CMS (μ+jets)	0.040	0.179	−0.371
F_L CMS (μ+jets)	−0.555	0.677	1.411
F_0 CMS (single top)	0.141	−0.021	0.524
F_L CMS (single top)	0.167	−0.018	−0.413