TOPLHCWG and single top

Luca Lista
INFN, Napoli

The Top-LHC Working Group

- TOPLHCWG is active since 2011
  - https://lpcc.web.cern.ch/lpcc/index.php?page=top_wg

“ The WG is a forum for:
  - the study of the experimental and theoretical systematics in the measurements of top quark properties
  - the definition of measurements and tools (MC generators, theory calculations, ...) required to address the systematics and carry out the physics programme
  - the combination of the results of the experiments
  - the presentation of the results in a way useful for the theoretical interpretation. ”

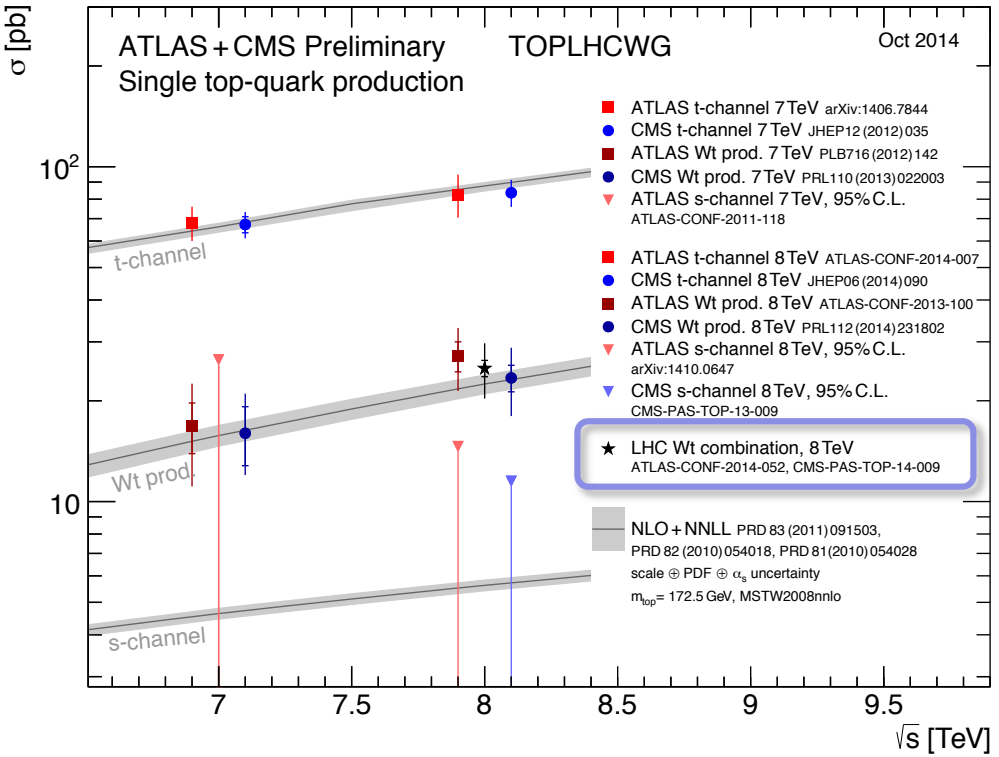
- Members:
  - ATLAS: M.J. Costa (contact), T. Carli, A. Lister (top conveners)
  - CMS: R.Chierici (contact), M.Mulders, A. Meyer (top conveners)
  - LPCC: M. Mangano (LPCC contact)
  - Single-top subgroup: J. Noce Donini (ATLAS), L. Lista (CMS), more recently Reinhard Schwienhorst (ATLAS) joined
  - + many more from other subgroups

Results achieved so far

1. Combination of ATLAS and CMS top-quark pair cross-section measurements using proton-proton collisions at $\sqrt{s}$ = 7 TeV
   ATLAS-CONF-2012-134/ CMS-PAS-TOP-12-003
2. Combination of ATLAS and CMS results on the mass of the top quark using up to 4.9 fb^{-1} of data
   ATLAS-CONF-2012-095/CMS-PAS-TOP-12-001
3. Combination of the ATLAS and CMS measurements of the W-boson polarization in top-quark decays
   ATLAS-CONF-2013-033/CMS-PAS-TOP-12-025
4. Combination of ATLAS and CMS results on the mass of the top-quark using up to 4.9 fb^{-1} of $\sqrt{s}$=7 TeV LHC data
   ATLAS-CONF-2013-102/CMS PAS TOP-13-005
5. Combination of single-top-quark cross section measurements in the t-channel at $\sqrt{s}$=8 TeV with the ATLAS and CMS experiments
   ATLAS-CONF-2013-098/CMS PAS TOP-12-002
6. Combination of the charge asymmetry in t-tbar production at $\sqrt{s}$=7 TeV with the ATLAS and CMS experiments
   ATLAS-CONF-2014-012/CMS-PAS-TOP-14-006
7. World average combination of the top quark mass, including results of the CDF and D0 experiments at the Tevatron, and of the ATLAS and CMS experiments
   ATLAS-CONF-2014-008/CDF-NOTE-11071/CMS-PAS-TOP-13-014/D0-NOTE-6416/arXiv:1403.4427
8. Combination of ATLAS and CMS top-quark cross-section measurements in the e-μ final states using proton-proton collisions at $\sqrt{s}$ = 8 TeV
   ATLAS-CONF-2014-054/CMS-PAS-TOP-14-016
9. Combination of cross-section measurements for associated production of a single top-quark and a W boson at $\sqrt{s}$=8 TeV with the ATLAS and CMS experiments
   ATLAS-CONF-2014-052/CMS-PAS-TOP-14-009

Single-top activity

- Combination of associated tW cross section at √s=8 TeV
  ATLAS-CONF-2014-052/CMS-PAS-TOP-14-009
  > released in October 2014 for TOP2015
- Combination of t-channel cross section √s=8 TeV
  ATLAS-CONF-2013-098/CMS PAS TOP-12-002
  > released in September 2013 for TOP2013, was quickly superseded by updated individual results
- Combination of t-channel cross section √s=7 TeV
  Not approved by ATLAS
  > attempted on in 2012, ATLAS and CMS level of precision were too different



Combination methodology

- Gaussian approximation of uncertainties
- Best Linear Unbiased Estimator (BLUE) method adopted
  - Combination obtained as weighted average of individual inputs, weight minimize a global χ^2 which takes into account correlation terms
  - Relative uncertainties accounted for by iteratively rescaling to combined central value (iterative BLUE)
  - NIM A500 (2003) 391-405, NIM A270 (1988) 110, NIM A764 (2014) 82–93 + corrig.

tW combination at 8 TeV

Systematic uncertainties categorized according to the best knowledge of individual sources

Category	ATLAS		CMS		ρ
Data statistics	Data statistics	7.1%	Fit statistics	8.1%	0.0
Category subtotal		**7.1%**		**8.1%**	**0.0**
Simulation statistics	Sim. statistics	2.8%	Sim. statistics	2.4%	0.0
Category subtotal		**2.8%**		**2.4%**	**0.0**
Luminosity		3.7%		3.0%	—
Category subtotal		**3.7%**		**3.0%**	**0.31**
Theory modeling	ISR/FSR	5.9%	Ren./fact. scale	12.4%	1.0
	tW gen. and PS	11.0%			—
	$t\bar{t}$ gen. and PS	7.5%	ME/PS match. thr.	14.1%	1.0
	PDF	2.5%	PDF	1.7%	1.0
	$tW/t\bar{t}$ overlap	1.4%	DR/DS scheme	2.1%	1.0
			Top p_T reweight.	0.4%	—
Category subtotal		**14.8%**		**19.0%**	**0.66**
Background normalization	bkg. mod.	3.6%	$t\bar{t}$ cross section	1.7%	0.0
			Z+jets	2.6%	—
Category subtotal		**3.6%**		**3.1%**	**0.0**
Jets	JES common	10.0%	JES	3.8%	0.0
	JES flavour	5.0%			—
	Jet id	0.2%			—
	Jet res.	0.7%	Jet resolution	0.9%	0.0
Category subtotal		**11.2%**		**3.9%**	**0.0**
Detector modeling	Lepton modeling	2.4%	Lepton modeling	1.8%	0.0
	MET scale	4.1%	MET modeling	0.4%	0.0
	MET resolution	4.5%			—
	b-tagging	8.4%	b tagging	0.9%	0.5
			Pileup	0.4%	—
Category subtotal		**10.6%**		**2.0%**	**0.17**
Total		**23.3%**		**21.7%**	**0.38**

need more harmonization

Some modification applied w.r.t. the original publication:

- dropped m_t uncertainty from CMS measurement
- Dropped spin-correlation uncertainty from CMS since it has been measured in data to be consistent with SM predictions
- reviewed CMS sim. statistics uncertainty

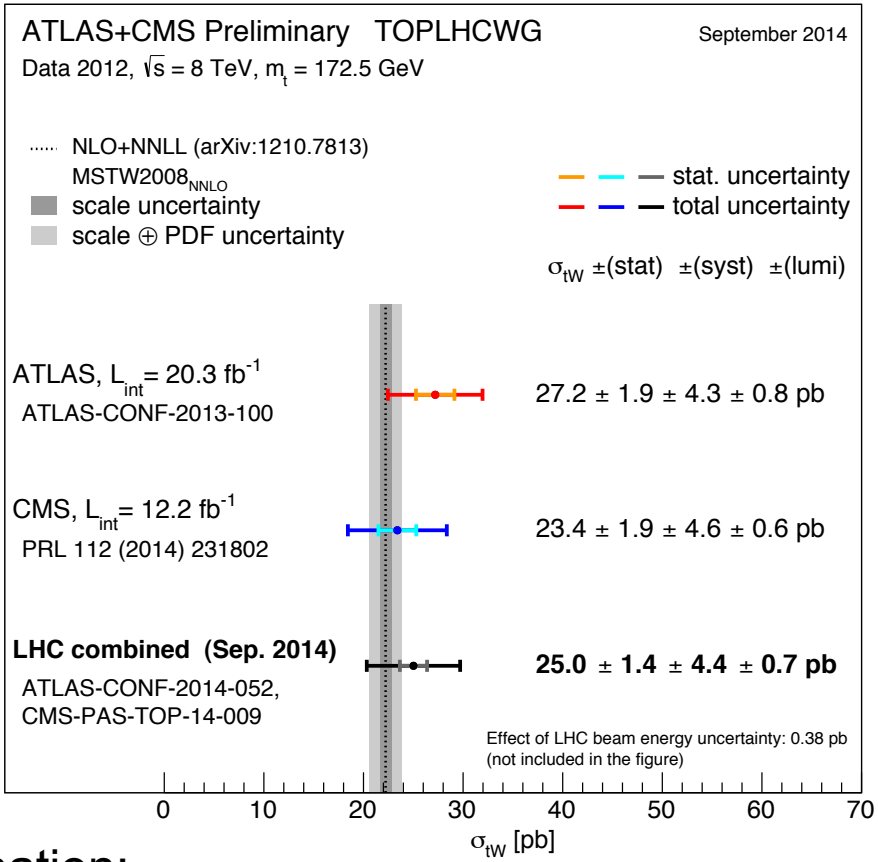
Several systematic uncertainties have been evaluated with different approaches in ATLAS and CMS. Better "harmonization" for future measurements is recommended.

tW combination: result

$$\sigma_{tW} = 25.0 \pm 1.4\ (\text{stat.}) \pm 4.4\ (\text{syst.}) \pm 0.7\ (\text{lumi.})\ \text{pb} = 25.0 \pm 4.7\ \text{pb}$$

- ATLAS and CMS weights: 0.43, 0.57
- Total correlation: 0.38
- χ^2/ndof = 0.37, *p*-value = 0.54
- Combined precision: 19%
  - Individual precisions: 23%, 21% (when reviewed for this combination)

Source	Uncertainty (%)	Uncertainty (pb)
Data statistics	5.5%	1.4
Simulation statistics	1.8%	0.5
Luminosity	2.7%	0.7
Theory modeling	15.8%	4.0
Background normalization	2.3%	0.6
Jets	5.3%	1.3
Detector modeling	4.9%	1.2
Total systematics (excl. lumi)	17.5%	4.4
Total systematics (incl. lumi)	17.7%	4.4
Total uncertainty	18.6%	4.7



$|V_{tb}|$ combination:

$$|V_{tb}|^2 = 1.12 \pm 0.23 \quad |V_{tb}| > 0.79 \text{ at } 95\%\ \text{CL} \quad \text{(Bayesian)}$$

tW combination: stability checks

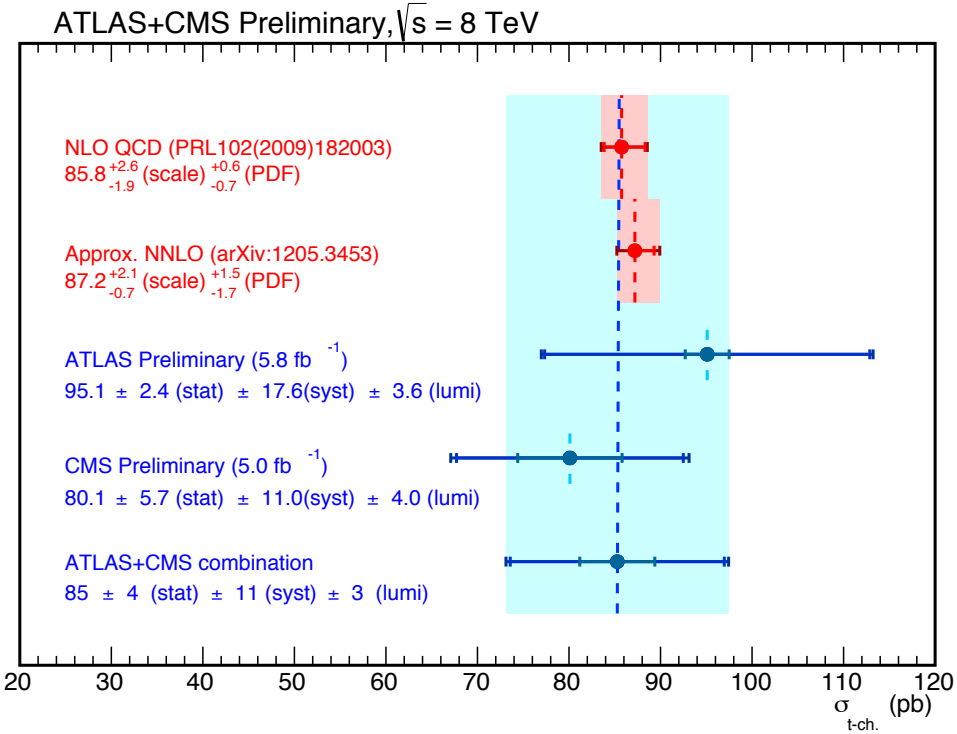
- Some assumptions of correlation coefficients have been varied in reasonable ranges when precise estimates were not available
- The result and its uncertainty is reasonably stable within the applied variations
- No further uncertainty was quoted for the estimated variations

Source	Default ρ	Test ρ	Shift: central value (pb)	Shift: uncertainty (pb)
Luminosity	0.3	0.0/0.5	0.0/0.0	0.0/0.0
$t\bar{t}$ PS	1.0	0.0/0.5	+0.1/0.0	−0.4/−0.2
Theory modeling	0.7	0.0/0.3	+0.1/+0.1	−0.6/−0.3
Background norm.	0.0	0.5/1.0	0.0/0.0	+0.1/+0.1
b-tagging	0.5	0.0/1.0	0.0/0.0	0.0/0.0
Jets	0.0	0.5/1.0	0.0/0.0	+0.1/+0.1

t-channel combination at 8 TeV

- Similar approach to tW combination: categorization of uncertainties, combination with BLUE and stability checks

Category	ATLAS		CMS		ρ
Statistics	Stat. data	2.4%	Stat. data	7.1%	0
	Stat. sim.	2.9%	Stat. sim.	2.2%	0
Total		**3.8%**		**7.5%**	**0**
Luminosity	Calibration	3.0%	Calibration	4.1%	1
	Long-term stability	2.0%	Long-term stability	1.6%	0
Total		**3.6%**		**4.4%**	**0.78**
Simulation and modelling	ISR/FSR	9.1%	Q^2 scale	3.1%	1
	PDF	2.8%	PDF	4.6%	1
	t-ch. generator	7.1%	t-ch. generator	5.5%	1
	$t\bar{t}$ generator	3.3%			0
	Parton shower/had.	0.8%			0
Total		**12.3%**		**7.8%**	**0.83**
Jets	JES	7.7%	JES	6.8%	0
	Jet res. & reco.	3.0%	Jet res.	0.7%	0
Total		**8.3%**		**6.8%**	**0**
Backgrounds	Norm. to theory	1.6%	Norm. to theory	2.1%	1
	Multijet (data-driven)	3.1%	Multijet (data-driven)	0.9%	0
			W+jets, $t\bar{t}$ (data-driven)	4.5%	0
Total		**3.5%**		**5.0%**	**0.19**
Detector modelling	b-tagging	8.5%	b-tagging	4.6%	0.5
	E_T^{miss}	2.3%	Unclustered E_T^{miss}	1.0%	0
	Jet Vertex fraction	1.6%			0
			pile up	0.5%	0
	lepton eff.	4.1%			0
			μ trigger + reco.	5.1%	0
	lepton res.	2.2%			0
	lepton scale	2.1%			0
Total		**10.3%**		**6.9%**	**0.27**
Total uncert.		**19.2%**		**16.0%**	**0.38**



What next?

- What further ATLAS-CMS combinations we can we plan for single-top?
- What improvements should we plan for the ongoing analyses in order to ease the next ATLAS-CMS combinations?

Possible future combinations

Object	Cut
Electrons	$p_T > 25$ GeV and $\|\eta\| < 2.5$
Muons	$p_T > 25$ GeV and $\|\eta\| < 2.5$
Jets	$p_T > 30$ GeV and $\|\eta\| < 4.5$
	$p_T > 35$ GeV, if $2.75 < \|\eta\| < 3.5$
Lepton (ℓ), Jets (j_i)	$\Delta R(\ell, j_i) > 0.4$
E_T^{miss}	$E_T^{miss} > 30$ GeV
Transverse W-boson mass	$m_T(W) > 50$ GeV
Lepton (ℓ), jet with the highest p_T (j_1)	$p_T(\ell) > 40$ GeV $\left(1 - \frac{\pi - \|\Delta\phi(j_1,\ell)\|}{\pi - 1}\right)$

ATLAS fiducial selection

t channel

- Update the combination at 8 TeV with measurements with latest results:
  - ATLAS (ATLAS-CONF-2014-007): fiducial measurement leading to: 82.6 ± 1.2(stat.) ± 11.4(syst.) ± 3.1(PDF) ± 2.3(lumi.) pb
  - CMS (JHEP06(2014)090): 83.6 ± 2.3(stat.) ± 7.4(syst.) pb
  - Need to wait at least for the ATLAS paper publication
  - In order to combine fiducial cross sections ATLAS and CMS should agree on a common definition
- Combination at 7 TeV, now that both have published results?
  - ATLAS (arxiv:1406.7844, accepted by PRD): 68 ± 8 pb
  - CMS (JHEP12(2012)035): 67.2 ± 6.1 pb
  - Compare to theory (PRD 83-2011-091503): 64.6 ± 3.4 pb
- Can't combine $R_t = \sigma_t / \sigma_{t\sim}$: ATLAS measured it at 7 TeV, CMS at 8 TeV
- $R_{8/7} = \sigma_{8TeV} / \sigma_{7TeV}$: measured by CMS at 8 TeV so far

Possible future combinations

tW channel

- Update combination at 8 TeV with published measurements
  - ATLAS result (ATLAS-CONF-2013-100) is still preliminary at the moment
  - Likelihood-based combination may adopted, if technically feasible with a reasonable effort
- Combination at 7 TeV
  - ATLAS (PLB716(2012)142-159): $16.8 \pm 2.9(\text{stat.}) \pm 4.9(\text{syst.})$ pb (± 5.7 pb)
  - CMS (JHEP12-2012-035): 67.2 ± 6.1 pb
  - Comparable uncertainties, precision would gain

s channel

- ATLAS has limtis at 8 and 8 TeV, CMS at 8 TeV
- Hard to imagine a combination before evidence has been found

$|V_{tb}|$ combination

- CMS combined 7 and 8 TeV t-channel measurements already:
  $|f^{L}_{V} V_{tb}| = 0.998 \pm 0.038(\text{exp.}) \pm 0.016(\text{th.})$
- ATLaS+CMS combination requires carful treatment of all correlations
- Not obvious how much we would gain, since tW precision is limited
- CMS would likely dominate if we stay with the present precision
- Improved theory predictions would help ($|f^{L}_{V} V_{tb}| = \sqrt{\sigma/\sigma^{th}}$)

Present $|V_{tb}|$ meas. from single top

- The $|V_{tb}|$ measurement in single-top events provides a unique opportunity to directly probe the top production Wtb vertex: $|V_{tb}| = (\sigma/\sigma^{th}(|V_{tb}|=1))^{1/2}$, assuming $|V_{tb}| \gg |V_{ts}|, |V_{td}|$ or equivalently B(t→Wb) = 1
  - Deviations from the SM are potentially sensitive to new physics
  - Theory uncertainty is not negligible, improvements may help (NNLO)
- Eight measurements in the *t* channel and in tW, the latter with less precision

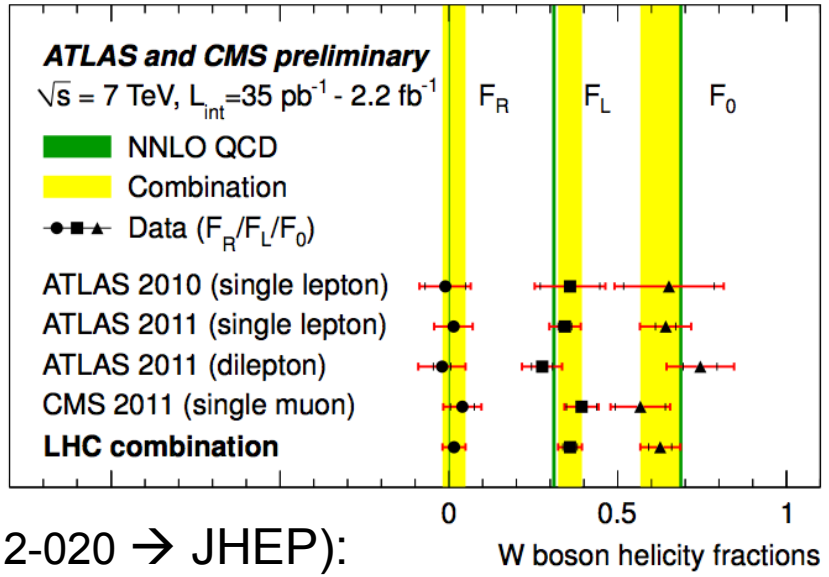
- ATLAS:
  - 7 TeV: $|V_{tb}| = 1.13^{+0.14}_{-0.13}$ (t-ch., 11.9%)
    $|V_{tb}| = 1.03^{+0.16}_{-0.19}$ (tW, 17.0%)
  - 8 TeV: $|V_{tb}| = 0.97 \pm 0.01(\text{stat})^{+0.06}_{-0.07}(\text{syst}) \pm 0.6(\text{gen+PDF})^{+0.02}_{-0.01}(\text{th}) \pm 0.01(\text{lumi})$
    $= 0.97^{+0.09}_{-0.10}$ (t-ch., 9.8%)
    $|V_{tb}| = 1.10 \pm 0.12(\text{exp}) \pm 0.03(\text{th})$ (tW,11.2%)
- CMS:
  - 7 TeV: $|V_{tb}| = 1.020 \pm 0.046(\text{exp}) \pm 0.017(\text{th})$ (t-ch. 4.8%)
    $|V_{tb}| = 1.01^{+0.16}_{-0.13}(\text{exp})^{+0.03}_{-0.04}(\text{th})$ (tW, 14.8%)
  - 8 TeV: $|V_{tb}| = 0.979 \pm 0.045(\text{exp}) \pm 0.016(\text{th})$ (t-ch. 4.9%)
    $|V_{tb}| = 1.03 \pm 0.12(\text{exp}) \pm 0.04(\text{th})$ (tW 12.3%)

  $|V_{tb}| = 0.998 \pm 0.038(\text{exp}) \pm 0.016(\text{th})$ (7+8 TeV t-ch., comb.: 4.1%)
- ATLAS+CMS:
  - 8 TeV: $|V_{tb}| = 1.06 \pm 0.11$ (tW 10.4%)

Possible future combinations

W boson polarization

- Combination performed at 7 TeV for the ttbar polarization (ATLAS-CONF-2013-033, CMS-PAS-TOP-12-025)
  - F_0 = 0.626 ± 0.034 (stat.) ± 0.048 (syst.)
  - F_L = 0.359 ± 0.021 (stat.) ± 0.028 (syst.)
- CMS measured W helicity fractions in single-top topology at 8 TeV (CMS-TOP-12-020 → JHEP):
  - F_0 = 0.720 ± 0.039 (stat.) ± 0.037 (syst.)
  - F_L = 0.298 ± 0.028 (stat.) ± 0.032 (syst.)
- CMS has 8 TeV measurement in tt~ (CMS-PAS-TOP-13-008)
  - F_0 = 0.659 ± 0.015 (stat.) ± 0.023 (syst.)
  - F_L = 0.350 ± 0.010 (stat.) ± 0.024 (syst.)
- Probably the tt~ precision can't be improved adding the single-top measurement. ATLAS result still not approved



Anyway, it's a job for the W-helicity subgroup more than for single-top

Harmonizing syst. uncertainties

Jet Energy Scale

- Agreement reached about how to split JES contributions
- Crucial for top-mass LHC and world combination (arXiv:1403.4427)
- Sub-component whose correlation can be correctly estimated (0% for experimental uncert., 50%-100% for flavour modeling)
- How crucial is this splitting for single top? The splitting would cost time to individual analysts, so far the combinations showed to be insensitive to such level of refinement in the proper estimate of JES correlation

b tagging

- Agreement reached on breakdown of correlated and uncorrelated contributions
  - General physics modeling (ISR/FSR, PS, b frag.), specific physics modeling (p_T spectrum of soft muons, light/charm ration, b/c production) 100%
  - Detector description (JES, pileup. etc.) and method specific: 0%
- So far CMS single-top b-tag uncertainties are evaluated in situ from control samples in data as correction to the MC scale factors, and in this case should be considered fully uncorrelated w.r.t. ATLAS. Nonetheless, a possible correlation has been considered for the assumed baseline simulation. Would be hard to split further the b-tagging uncertainty in the underlying contributions.

Harmonizing theory uncertainties

- Historical differences in theory uncertainties: ATLAS prefers ISR/FSR uncertainty to μ_R/μ_F scale uncertainty adopted by CMS
- Some generator uncertainties are not always considered consistently
- Discussion with ATLAS ongoing in order to harmonize the treatment for future measurements

Theory modeling	ISR/FSR	5.9%	Ren./fact. scale	12.4%	1.0
	tW gen. and PS	11.0%			—
	$t\bar{t}$ gen. and PS	7.5%	ME/PS match. thr.	14.1%	1.0
	PDF	2.5%	PDF	1.7%	1.0
	$tW/t\bar{t}$ overlap	1.4%	DR/DS scheme	2.1%	1.0
			Top p_T reweight.	0.4%	—
Category subtotal		**14.8%**		**19.0%**	**0.66**

Theory uncertainties (cont.)

- Significant effort devoted to agree on reference theory cross sections calculations in order to achieve a consistent evaluation of generator systematic uncertainty
  - Look forward to next NNLO calculations (→F. Caola's talk and arXiv: 1404.7116)
- NLO calculation with automatic tools agreed as baseline generator for forthcoming studies will help
  - MCFM and Hator predictions compared with aMC@NLO and POWHEG.
  - 5FS adopted for t-channel cross section
- PDF4LHC is the PDF uncertainty recipe (CT10(CTEQ6)/ MSTW / NNPDF envelope) plus α_s uncertainty
- μ_R/μ_F uncertainties evaluated with a single PDF choice
- Quote m_t uncertainty when relevant or the assumed m_t value
- m_b uncertainty neglected at the moment, but could be as large as m_t. Included in PDF, so the adopted PDF chooice should be reported to determine the assumed m_b.

Conclusions and remarks

- ATLAS+CMS combinations already provide improved precision in crucial measurements, including single-top
- The required approval time is usually rather long
  - Needs preapproval in the TOPLHCWG and separate approvals by ATLAS and CMS
  - paper-quality of the text is enforced also for preliminary notes
  - Long approval time introduces the risk to make combined results obsolete in a short time (e.g.: t-channel combination at 8 TeV)
- We are getting closer to combinations of legacy measurements which can lead to paper publications of TOPLHCWG results