News Experience from the LHCTopWG

Markus Seidel

CERN

March 26, 2018

The LHC Top working group

Goals

- Combination of the results of the experiments
  $\rightarrow$ improve precision, evaluate compatibility
- Study of the experimental and theoretical systematic uncertainties
- Definition of measurements and tools (MC generators, theory calculations, ...)
- Presentation of the results in a way useful for the theoretical interpretation

Members:

- ATLAS: M. Owen (ATLAS contact), E. Shabalina, R. Schwienhorst (ATLAS top WG conveners)
- CMS: M. Mulders (CMS contact), R. Gonzalez, M. Aldaya (CMS top WG conveners)
- LHCb: S. Farry (LHCb contact)
- LPCC: M. Mangano (LPCC contact)

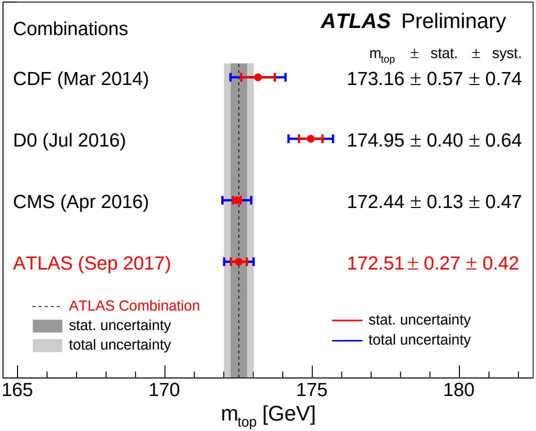
+ combination contacts + task force contributors + theorists

Combination working groups and results

- Top pair cross section
  - ATLAS CONF-2012-134 CMS PAS-TOP-12-003 (7 TeV)
  - ATLAS CONF-2014-054 CMS PAS-TOP-14-016 (8 TeV)
- Single top cross section (all 8 TeV)
  - ATLAS CONF-2013-098 CMS PAS-TOP-12-002 (t-channel)
  - ATLAS CONF-2014-052 CMS PAS-TOP-14-009 (tW channel)
- Top mass (all 7 TeV)
  - ATLAS CONF-2012-095 CMS PAS-TOP-12-001
  - ATLAS CONF-2013-102 CMS PAS-TOP-13-005
  - arXiv 1403.4427 (LHC+Tevatron world combination)
- Charge asymmetry
  - ATLAS CONF-2014-012 CMS PAS-TOP-14-006 (7 TeV)
  - arXiv 1709.05327 (7+8 TeV)
- Differential distributions
- Top quark pair production in association with Z or W
- W helicity
  - ATLAS CONF-2013-033 CMS PAS-TOP-12-025 (7 TeV)

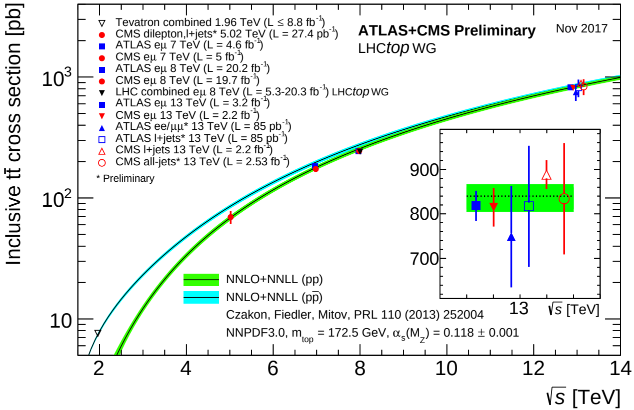
Ongoing combinations

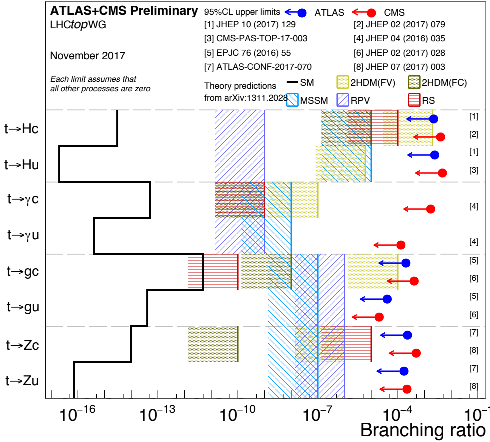
- Top pair cross section
  - Combination of final 8 TeV measurements
- Single top cross section
  - Run-1 combination for all production modes and V_{tb}
- Differential distributions
  - Combination of 8 TeV parton level distributions
  - Preparation for 13 TeV combination
- Top mass — — — — — — — →
  - Preparation for Run-1 combination
  - Longer term: updated world combination



Summary plots

- > 30 plots, updated regularly
  `https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCTopWGSummaryPlots`





Combination method

- Full likelihood combinations difficult to perform after publications
- So far only: BLUE method, linear combination with the smallest overall uncertainty
  - Uncertainties and their correlations need to be known exactly arXiv 1307.4003 arXiv 1610.00422
  - In practice: uncertainties have (stat.) uncertainties, correlations can only be estimated

Estimating the correlations

- Describe uncertainty X by nuisance parameter $-1\sigma \leq \lambda_X \leq +1\sigma$
- If λ_X^{CMS} updated to $+1\sigma$, what follows for λ_X^{ATLAS}?
  - uncertainty for ATLAS needs to be updated in same way $\rightarrow \rho = 1$
    - Sometimes the uncertainty effect is in opposite directions, behaves like $\rho = -1$
  - no prediction on shift in ATLAS possible $\rightarrow \rho = 0$
    (either shift is uncorrelated or starting point was different)
  - uncertain $\rightarrow \rho = 0.5$
- High correlation not always more conservative: can lead to negative weights and reduced overall uncertainty. CMS-internal combinations often restrict $\rho \leq \sigma_{min}/\sigma_{max}$
- Stability checks are performed with variations of correlation assumptions

Charge asymmetry arXiv 1709.05327

	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

Top mass ATLAS CONF-2013-102 CMS PAS-TOP-13-005

Uncertainty Categories			Size [GeV]						Correlation	
			ATLAS		CMS			LHC	ρ_{exp}	ρ_{LHC}
Tevatron	ATLAS	CMS	2011 l+jets	2011 di-l	2011 l+jets	2011 di-l	2011 all jets	comb		
Measured m_{top}			172.31	173.09	173.49	172.50	173.49	173.29		
	Jet Scale Factor		0.27		0.33					
	bJet Scale Factor		0.67							
iJES	Sum (statistical comp.)		0.72		0.33			0.26	0	0
	uncorrelated JES comp.		0.61	0.73	0.24	0.69	0.69	0.29	1	0
dJES	in-situ γ/Z JES comp.		0.29	0.31	0.02	0.35	0.35	0.10	1	0
	intercalib. JES comp.		0.19	0.39	0.01	0.08	0.08	0.07	1	0.5
aJES	flavour JES comp.		0.36	0.02	0.11	0.58	0.58	0.16	1	0.0
bJES	b-jet energy scale		0.08	0.71	0.61	0.76	0.49	0.43	1	0.5
Signal	MC Generator		0.19	0.20	0.02	0.04	0.19			
	Hadronisation		0.27	0.44						
MC	Sum		0.33	0.48	0.02	0.04	0.19	0.14	1	1
	ISR/FSR		0.45	0.37						
		Q^2-scale			0.24	0.55	0.22			
		Jet-Parton scale			0.18	0.19	0.24			
Rad	Sum		0.45	0.37	0.30	0.58	0.33	0.32	1	1
CR	Colour reconnection		0.32	0.29	0.54	0.13	0.15	0.43	1	1
-	Underlying event		0.12	0.42	0.15	0.05	0.20	0.17	1	1
PDF	Proton PDF		0.17	0.12	0.07	0.09	0.06	0.09	1	1
	Jet Resolution		0.22	0.21	0.23	0.14	0.15			
	Jet Reco Efficiency		0.05							
	E_T^{miss}		0.03	0.05	0.06	0.12				
DetMod	Sum		0.23	0.22	0.24	0.18	0.28	0.20	1	0
	b-tagging		0.81	0.46	0.12	0.09	0.06	0.25	1	0.5
LepPt	Lepton reconstruction		0.04	0.12	0.02	0.14		0.01	1	0
Background from MC				0.14	0.13	0.05		0.08	1	1
Background from Data			0.10				0.13	0.04	0	0
Method			0.13	0.07	0.06	0.40	0.13	0.06	0	0
Multiple Hadronic Interactions			0.03	0.01	0.07	0.11	0.06	0.05	1	1
Statistics			0.23	0.64	0.27	0.43	0.69	0.23		
Systematics			1.53	1.50	1.03	1.46	1.23	0.92		
Total Uncertainty			1.55	1.63	1.06	1.52	1.41	0.95		
Comb. Coeff. [%]			22.6	3.6	60.6	-8.4	21.6	χ^2/ndf = 1.8/4		
Pull			-0.80	-0.15	0.41	-0.67	0.19	χ^2 prob = 77%		

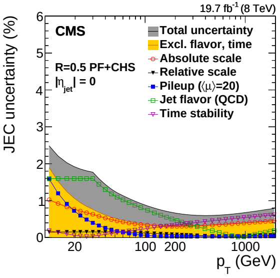
- Correlations need to be defined between ATLAS and CMS (ρ_{LHC}) but even for different measurements within experiments (ρ_{exp}) or between different years (ρ_{year})

Jet/MET task force

- Task: proper grouping of the systematic sources related to JES uncertainties
- Work by ATLAS and CMS Jet/MET groups, to be used by everyone (not only TOP)

ATLAS PHYS-PUB-2014-020 CMS PAS-JME-14-003 (7 TeV) ATLAS PHYS-PUB-2015-049 CMS PAS-JME-15-001 (8 TeV)

Description	Components, CMS	Components, ATLAS	Corr. range
1a. Statistical *in situ* terms	AbsoluteStat, SinglePionHCAL, RelativeStat[FSR][EC2][HF]	[11] Z-jet balance stat./meth. terms (p_T), [13] γ-jet balance stat./meth. terms (p_T), [10] multi-jet balance stat./meth. terms (p_T), η-intercalibration statistical term (p_T,η)	0%
1b. Detector *in situ* terms	AbsoluteScale, SinglePionECAL, RelativeJER[EC1][EC2][HF], RelativePt[BB][EC1][EC2][HF]	Z-jet balance det. term, γ-jet balance det. term, [2] correlated Z/γ-jet balance det. terms (p_T)	0%
2. Absolute balance modeling	AbsoluteMPFBias	[7] Z-jet balance model + mixed terms (p_T), [4] γ-jet balance model + mixed terms (p_T), [2] correlated Z/γ-jet balance terms (p_T), [5] multi-jet balance model + mixed terms (p_T)	0-50%
3. Relative balance modeling	RelativeFSR	η-intercalibration modeling (p_T,η)	50-100%
4. g-jet fragmentation	FlavorPureGluon	Flavor response (p_T,η)	100%
5. b-jet fragmentation	FlavorPureBottom	b-jet response (p_T)	50-100%
6. Other fragmentation types	FlavorPureQuark, FlavorPureCharm	Flavor composition (p_T,η)	0%
7. Pileup	PileupDataMC, PileupPt[Ref][BB][EC1][EC2][HF]	N_{PV} offset (p_T,η,N_{PV}), $\langle\mu\rangle$ offset ($p_T,\eta,\langle\mu\rangle$), p_T term ($p_T,\eta,N_{PV},\langle\mu\rangle$), ρ topology (p_T,η)	0%
8. High-p_T	Fragmentation	High-p_T (p_T)	0%
9. Single-experiment terms	TimeEta, TimePt	Fast simulation closure (p_T,η), punch-through ($p_T,\eta,N_{segments}$)	0%



Each analysis needs to evaluate all uncertainty sources separately!

b tagging task force

- Task: grouping of the systematic sources related to b-tagging

b-tagging uncertainty category	Correlated with top analysis	Correlated between ATLAS and CMS
General physics modelling (parton shower etc.)	YES	YES
Specific physics modelling (B hadron energy spectrum, μ p_T modelling etc.)	NO (ATLAS) YES (CMS)	YES
Detector modelling (calorimeter response, pile-up etc.)	YES	NO
Calibration method specific	NO	NO

(from Liza Mijovic)

- For details, see slides from open meetings May 2014, Nov 2015

Radiation and generators task force

- Task: comparing the definition of systematic sources coming from the modelling of radiation in the MC, and in general for generator settings in the two experiments

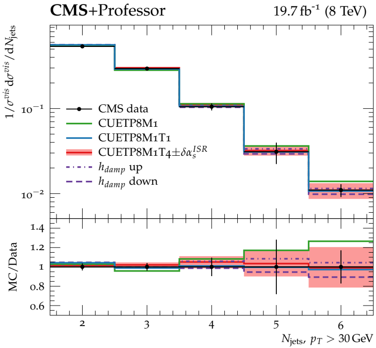
Differences in $t\bar{t}$ modeling uncertainties

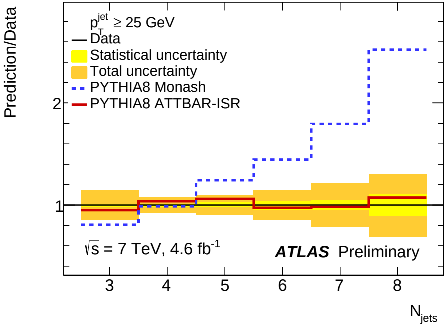
- ME generators
  - Run1: ATLAS Powheg vs. MC@NLO CMS MadGraph vs. Powheg
  - Run2: Powheg vs. MG5_aMCatNLO (but CMS uses FxFx merging)
- Radiation uncertainty
  - ATLAS Tune A14 radiation variation, combined with Powheg $\mu_{F,R}$ and hdamp (2 samples)
  - CMS Powheg $\mu_{F,R}$ (weights) $\oplus$ Powheg hdamp $\oplus$ Pythia ISR $\oplus$ Pythia FSR (1+6 samples)
- Hadronization uncertainty
  - ATLAS Powheg+Pythia 8 vs. Powheg + Herwig 7
  - CMS JEC flavor (Pythia 6 vs. Herwig++) $\oplus$ b fragmentation $\oplus$ BR $B \to \ell \nu X$
- Top p_{T} modeling
  - ATLAS covered by Pythia vs. Herwig CMS explicit variation
- Color reconnection
  - Run1: ATLAS on vs. loCR CMS on vs. off
  - Run2: ATLAS A14 UE variations CMS ERD on/off $\oplus$ new models

Modeling correlations

- Generator uncertainties are usually treated as correlated ($\rho = 1$) by their anticipated effect, sometimes requires a more inclusive regrouping
- Example: radiation uncertainty
  - ATLAS Tune A14 radiation variation, combined with Powheg $\mu_{F,R}$ and hdamp (2 samples)
  - CMS Powheg $\mu_{F,R}$ (weights) $\oplus$ Powheg hdamp $\oplus$ Pythia ISR $\oplus$ Pythia FSR (1+6 samples)

$\rightarrow$ similar net effect: more/less radiation





default/Monash: $\alpha_s^{ISR} = 0.1365$

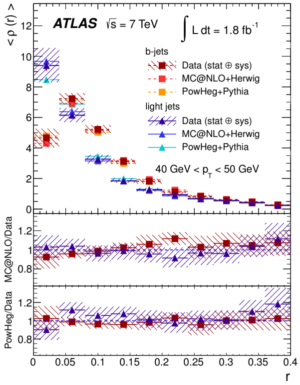
CMS $\alpha_s^{ISR} = 0.1108$

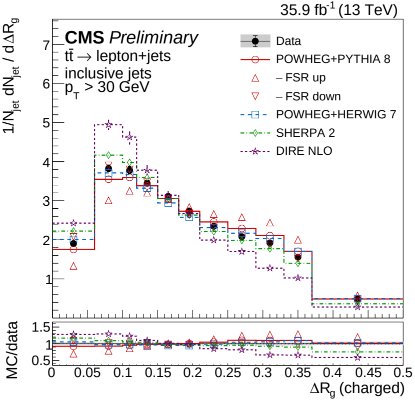
ATLAS $\alpha_s^{ISR} = 0.121$

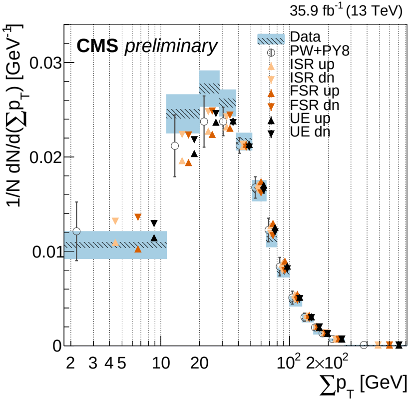
More “auxiliary” measurements

Regular discussion with theorists:

- Which sets of modeling uncertainties should be used?
- Which measurements for constraining them can be done directly in top quark events?



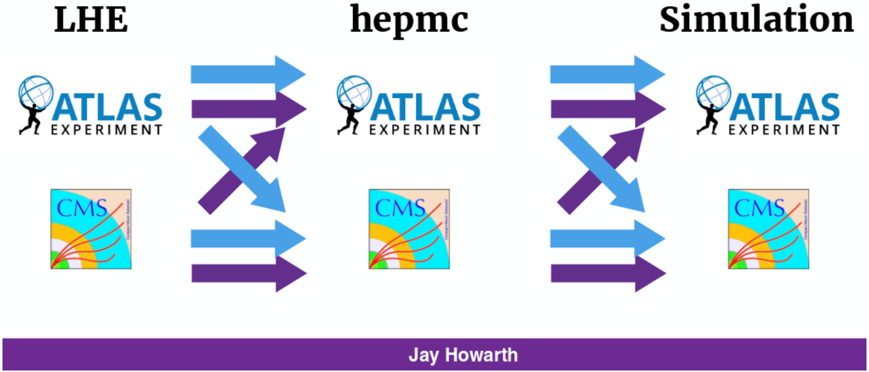




ATLAS arXiv:1307.5749 | CMS PAS-TOP-17-013 | CMS PAS-TOP-17-015 | (many more on jet multiplicity etc.!)

Common MC sample

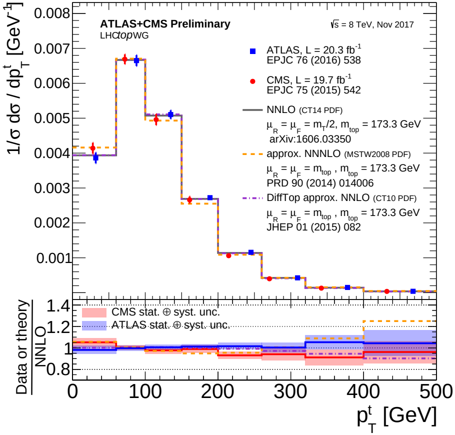
- Working on a common MC sample for correlation studies (selection and systematics)
- Many paths possible:



- First success: ATLAS recreated CMS Powheg+Pythia 8 sample
- Exact requirements are still to be defined (do we need identical event numbers?)
- Do we need both ATLAS and CMS tunes, or can we agree on a neutral one?

Common acceptance and pseudo-tops task force

- Task: defining common conventions for a pseudo-top definition and acceptance where both experiments should quote fiducial cross sections



- 8 TeV **parton** level: Full phase space, top quark definition and binning already compatible
- Pseudo-top = top defined by decay products at particle level, no dependence on generator record
- Definition still work in progress, need improvements
  CMS NOTE-2017-004
- Need to resolve jet clustering: include neutrinos?
- Ideally: define a common Rivet analysis with clear physics goals (theory-input!), optimize binning from combined ATLAS+CMS migration matrix

Summary

- LHCTopWG very successful in core objective: getting combinations done!
  - Main workhorse: BLUE method
  - Lot of thought-work for correlation estimates (experiments, channels, years)
- Study of systematic uncertainties
  - Very complete agreements on treatment of JEC and b tag uncertainties
  - Harmonization of modeling uncertainties often difficult after publication
  - "Helper" measurements performed by both experiments and discussed together
- Combinations of one number ($\sigma_{t\bar{t}}$, m_t) still relatively straightforward
  $\leftrightarrow$ combination of diff. measurements requires even more effort on common definitions
- Next LHCTopWG open meeting: 15-16 May, `https://indico.cern.ch/event/708573/`