Harmony Between ATLAS and CMS

in systematic uncertainty estimations

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Harmonization of Modeling Uncertainties

- Intermittent discussions since ~2016.
- Recent initiative to re-ignite the discussion

- Probably incomplete set of previous presentations (and not listing the ones in the closed sessions)
  - TOP LHCWG Meeting 21 Nov 2016
  - TOP LHCWG Meeting 7 June 2017
  - TOP2021 14 SEP 2021

“I think universal harmony is a pipe dream and it may be more productive to focus on more modest goals, like a ban on yodeling.”

Woody Allen

- Our goal is to achieve universal harmony between ATLAS and CMS top uncertainties.
  - Very long process.
  - But can already have a partial harmony for legacy Run III measurements.
- We started making an inventory including details descriptions for each uncertainty source.
- We will divide the list into easy and difficult and then start attacking each.
- We will start with modest goals: harmonise matrix element and matching uncertainties.
- Next slides only initial notes.

Matrix Element Generator

ATLAS
- Hope to remove Powheg-vs-MadGraph_aMC@NLO; replace with main31 variations. Work in progress.

CMS
- Comparison of two entirely different generators is seen as problematic: convoluted uncertainties.

- A direct comparison of Powheg vs aMC@NLO or FxFx with the current settings is expected to lead to inflated differences which are not fully understood and can't yet be fully translated to meaningful systematic uncertainty.
  - Comparing two different generators also mix in differences in a complicated and indirect way due to the PDF's (correlated with Top pT as well) used for the MEs and PSs (through the matching/merging).
- For the matching with Pythia8 there are more settings that need to be changed, e.g. see http://cdsweb.cern.ch/record/2730443/files/ATL-PHYS-PUB-2020-023.pdf (section 6).
  - ATLAS: To have a more consistent treatment, some analysis started to move to aMC@NLO+Herwig vs Powheg+Herwig as an uncertainty for now (instead of Powheg+P8 vs aMC@NLO+P8).

Matrix Element Generator

ATLAS

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CMS

- Comparison of two entirely different generators is seen as problematic: convoluted uncertainties.

Table from the common MC sample notes ATL-PHYS-PUB-2021-016 and CMS-NOTE-2021-005

Setting name	Setting description	CMS default	ATLAS default	Common proposal (v0.1)	v0.2 Common Proposal
	Pythia 8 version	v240	v230	v240 (CMS) v244 (ATLAS)	
Powheg	Interface parameters in Pythia8 for matching to POWHEG				
pTdef	Flag for hardness criterion (Powheg vs Pythia8)	1	2	1	
emitted	Flag for defining emissions	0	0	0	
pTemt	Flag for which partons are used to define Powheg hardness criteria	0	0	0	
pThard	Flag for how to calculate Powheg hardness criteria	0	0	0	
vetoCount	How many emissions vetoed showers checks after first allowed emission	100	3	50	100
nFinal	Number of outgoing particles for born level process	2	2	2	
veto	Flag for vetoed or unvetoed showers	1	1	1	
MPIveto	Flag for applying veto to Multi Parton Interactions	(0)	0	0	

- The effect of pTdef setting shown to be small in ATL-PHYS-2016-020 (And by eye comparing ATLAS/CMS plots at 8 TeV)
- Need to study the effects more systematically to see if variations of these could be used for ME generator uncertainty.
- ATLAS, now studying the variations of pTdef and pThard. (A reference for such variations but in DY: https://arxiv.org/abs/1608.03577)
- Tables with full settings for Powheg, Pythia8, MG5_aMC, … from ATLAS and CMS needed.
  - Most POWHEG and PYTHIA8 setting for ttbar are already in ATL-PHYS-PUB-2021-016 and CMS-NOTE-2021-005.

Matrix Element Generator - Scale Uncertainties

	ATLAS	CMS	
Scale definition	m_T^t	m_T^t	
PDF	NNPDF23 LO α_s=0.130 QED	NNPDF3.1 NNLO α_s=0.118	
hdamp	1.5 mt	1.1379 mt	
Ptsqmin	0.8 GeV	0.8 GeV	hvq default

CMS: envelope of variations

Systematic	Scale	Variation					
ME μ_R/μ_F	μ_R	↑	↓	↑		↓	
	μ_F			↑	↑	↓	↓

ATLAS variations

- Considered correlated across years.
- Considered uncorrelated between QCD-induced (ttbar) and electroweak-induced (single top) processes.

- In a template fit μ_F and μ_R uncertainties can be considered as separate nuisance parameters, instead of constructing an envelope (if it can be demonstrated that the effect of the combined variation of the scales can be decomposed in a combination of the separate variations, see e.g. HIG-17-027.)
- Alternatively, one could do the fit with the uncorrelated variations as nuisance parameters, and perform the fit with the correlated variations as a cross-check.

Parton Shower Uncertainties

CMS

Source	Handle	Weights	Variation	Note/refs.
Shower scales	ISR (SpaceShower:renormMultFac) FSR (TimeShower:renormMultFac)	Yes Yes	0.5-2.0 0.5-2.0	Scale down FSR variations by $\sqrt{2}$ LEP & CMS $t\bar{t}$ UE ? TOP-15-011, TOP-16-021 TOP-17-013, TOP-17-015
ME-PS matching	h_{damp}	No	$1.379^{+0.926}_{-0.5052}$ m_t	TOP-16-021, GEN-17-001 (CP5)
Soft QCD	UE parameters	No	CP5 up/down	TOP-17-015, GEN-17-001
Color reconnection	MPI based, QCD-inspired gluon move, ERD	No	different models	TOP-17-013, TOP-17-015, GEN-17-002
Fragmentation	momentum transfer from b-quark to B hadron: $x_b = p_T(B)/p_T(b-jet)$	Yes	Vary Bower-Lund par. within uncer. from LEP/SLD fits $StringZ : rFactB =$ $0.895^{+0.184}_{-0.197}$	TOP-16-022 (reweight x_b) No variation for CP5 yet r_b~0.858+/-0.048 (CUETP8M2T4/TOP-18-012)
Flavor response/ Hadronization	PYTHIAvs HERWIG	No	Vary the JES independently per flavor for light, g,c,b	Still PYTHIA6 vs HERWIG++ !
Decay tables	B semi-leptonic BR	Yes	vary semi-leptonic $BR^{+0.77}_{-0.45}$%	Reweight fraction of leptonic bjets by PDG (scale Λ_b to match PDG)

Parton Shower Uncertainties - Shower Scales

CMS

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ATLAS

Same

- Both CMS and ATLAS use PYTHIA8 automated variations through weights.
- ATLAS and CMS plan to study splitting kernels (decorrelated variations for each branching type).

Parton Shower/Scale/Hadronization Uncertainties

- ATLAS Hadronization/PS uncertainty: Powheg+Pythia8 vs Powheg+Herwig7
- May be replaced by variation of PS splitting kernel scales (De-correlated variations of μ_R and non-singular terms for each splitting type g—>gg, g—>qq, q—>qg, Q—>Qg with Q=t, b) and comparison of two properly tuned hadronization models inside the same generator.
  - Possible in Sherpa and Herwig7
    - but Herwig7 at this point may not be practical because of the large number of negative weights in NLO processes. However, developments are in progress.
- CMS also plans to study these.
- Compare string vs cluster models?
  - Requires re-tuning.
- Use Vincia and DIRE as alternatives?
  - Requires re-tuning.
  - Not clear yet if they are adopted to large scale MC production. It's already known that it is ~10x slower than the standard PS.

Parton Shower Uncertainties - hdamp

CMS

ATLAS

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From comparisons to data and w/o tuning

- Nominal ATLAS value = 1.5 m_t and variation up 3 m_t but symmetrize the uncertainty

Parton Shower Uncertainties - UE

CMS

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similar approach but different variables used

```
MultipartonInteractions:pT0Ref [GeV]
MultipartonInteractions:ecmPow
MultipartonInteractions:coreRadius
MultipartonInteractions:coreFraction
ColorReconnection:range
```

CMS

- Different tunes based on different PDFs (and $\alpha_{s\ values}$) to start with.
- Eigentunes for different variables in both experiments.

```
SigmaProcess:alphaSvalue

SpaceShower:pT0Ref
SpaceShower:pTmaxFudge
SpaceShower:pTdampFudge
SpaceShower:alphaSvalue
TimeShower:alphaSvalue
BeamRemnants:primordialKThard

MultipartonInteractions:pT0Ref
MultipartonInteractions:alphaSvalue
BeamRemnants:reconnectRange
```

ATLAS

ATLAS

Parton Shower Uncertainties - Color Reconnection

CMS

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ATLAS

Similar

More details in next slide

New Dedicated Color Reconnection Tunes based on CP5 - GEN-17-002

Measured with high precision using the 7, 8, and 13 TeV data at the LHC.

CMS-TOP-14-022,
Phys. Rev. D 93, 072004 (2016)

Most precise measurement by CMS experiment combining the data at 7 and 8 TeV: $m_t = 172.44 \pm 0.13\,(\text{stat+JSF}) \pm 0.47\,(\text{syst})\,\text{GeV}$,

One of the most dominant systematic uncertainty is due to CR, however calculated by the difference w/ and w/o CR effect which may be extreme and unphysical.
—> Instead, we can compare the predictions of the realistic CR models.

CR1 = QCD-inspired
CR2=gluon-move

- The shift in 13 TeV measurement using CUETP8M2T4 is 0.31 GeV.
  The largest source of systematic uncertainty in this measurement.

Tune	m_t [GeV]	Δm_t [GeV]	m_W [GeV]	Δm_W [GeV]	$\Delta m_t - 0.5\Delta m_W$ [GeV]
CP5	171.93 ± 0.02	0	79.76 ± 0.02	0	0
CP5 ERD	172.18 ± 0.03	0.25	80.15 ± 0.02	0.40	0.05
CP5-CR1	171.97 ± 0.02	0.04	79.74 ± 0.02	-0.02	0.05
CP5-CR1 ERD	172.01 ± 0.03	0.08	79.98 ± 0.02	0.23	-0.04
CP5-CR2	171.91 ± 0.02	-0.02	79.85 ± 0.02	0.10	-0.07
CP5-CR2 ERD	172.32 ± 0.03	0.39	79.90 ± 0.02	0.14	0.32

GEN-17-002
(Paper in preparation)

- Top/W mass values obtained by fitting a Gaussian with an 8 GeV mass window around the peak.
- Largest deviation 0.32 GeV from CP5-CR2 ERD which is similar to the shift found in TOP-17-007 with the hybrid method (that gives the lowest overall uncertainty) using CEUTP8M2T4.
  - However, this doesn't differentiate which models agree with the data well.

ATLAS also uses the same CR models that are tuned to ATLAS data to estimate systematic uncertainties, e.g. in top-quark mass measurements.

ATL-PHYS-PUB-2017-008

Parton Shower Uncertainties - Fragmentation

CMS

ATLAS

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Somewhat different in ATLAS

- Both experiments vary Bowler-Lund fragmentation parameter.
  - In addition, CMS used Peterson fragmentation (historical?) that ATLAS found not to describe the data.
- Variation
  - CMS reweights at generator level through momentum transfer function (x_b).
    - ATLAS use dedicated samples with A4-rb tune.

Parton Shower Uncertainties - Flavor Response/Hadronization

CMS

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ATLAS

Powheg+Pythia8
vs Powheg+Herwig7.1.

- ATLAS:
  - Separate JES uncertainties for light and b jets.
  - POWHEG+PYTHIA8 vs POWHEG+HERWIG7
- CMS:
  - Effect of energy response of different flavours (as part of jet energy corrections)
  - PYTHIA6 ve HERWIG++: From Run I but still working fine for Run II. To be updated.

Parton Shower Uncertainties - Decay Tables

CMS

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ATLAS

different approach (Instead of reweighting ATLAS uses modified EvtGen decay table)

- ATLAS and CMS use variations of B semi-leptonic BRs (within PDG uncertainties).
- ATLAS does modified EvtGen decay table
- CMS does generator-level reweigthing.

What about analyses using profiled uncertainties?

- Uncertainties may be different w.r.t. CR uncertainty in the conventional analysis.
- More difficult to harmonise the uncertainties between two such measurements unless we use same setups and constraints to combine full likelihoods.
- This needs to be discussed in the LHCtopWG.

Summary

- Goal is to achieve full harmony between ATLAS and CMS top uncertainties.
  - Most likely not achievable before the end of Run-3.
- Only initial (and partial) collection of uncertainties presented.
  - e.g. Powheg vs. MadSpin for modelling of top decay or global vs. dipole-recoil not discussed but in the plans.
  - Any thoughts or feedback is welcome.
- Next steps:
  - Make the tables containing full settings for Powheg, Pythia8, MG5_aMC, … from ATLAS and CMS.
  - Inventory including details descriptions for each uncertainty source.
  - Divide the list into easy and difficult and then start working on each.
  - Start with matrix element and matching.