Top modelling systematics in Run 2 for the ATLAS and CMS experiments

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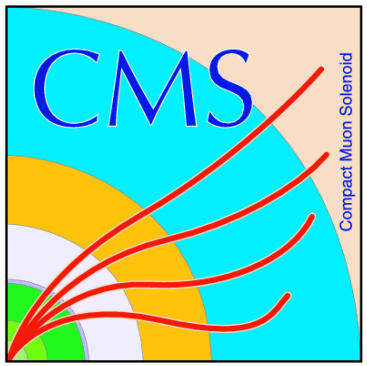


Introduction

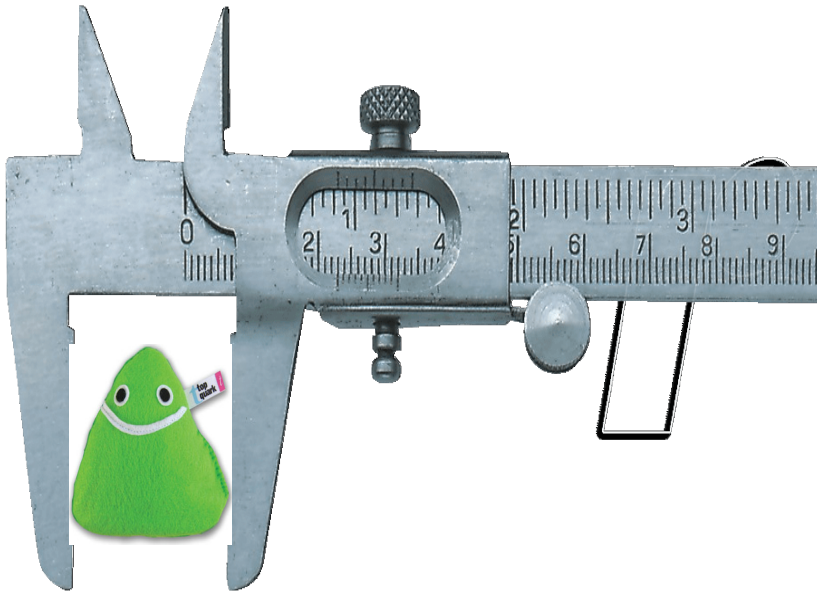
- live in era of top-quark precision measurements:

  ↪ often limited by top quark modelling systematics

- want to be able to combine measurements between experiments

  ↪ need a common approach for Run II

  ↪ need to discuss how to define systematics in the future

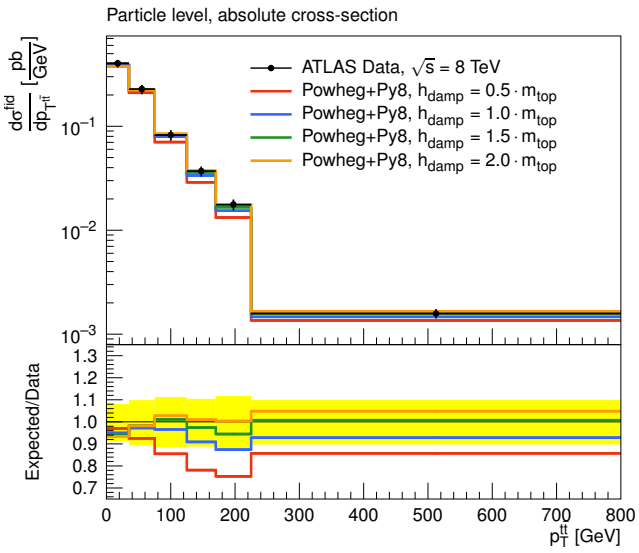


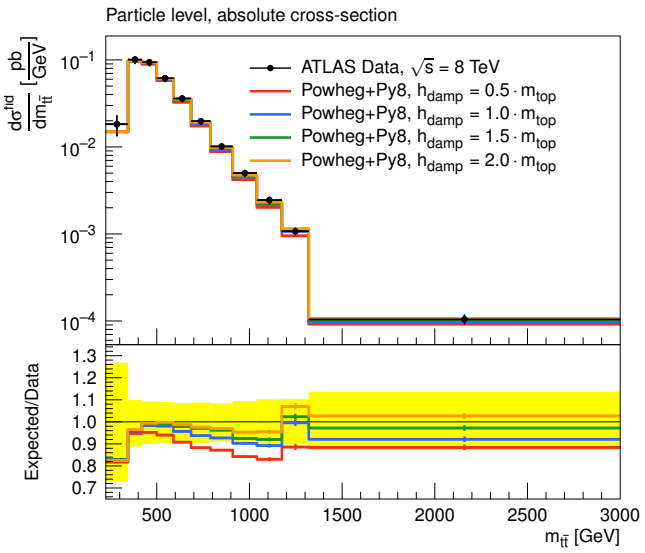
Current status

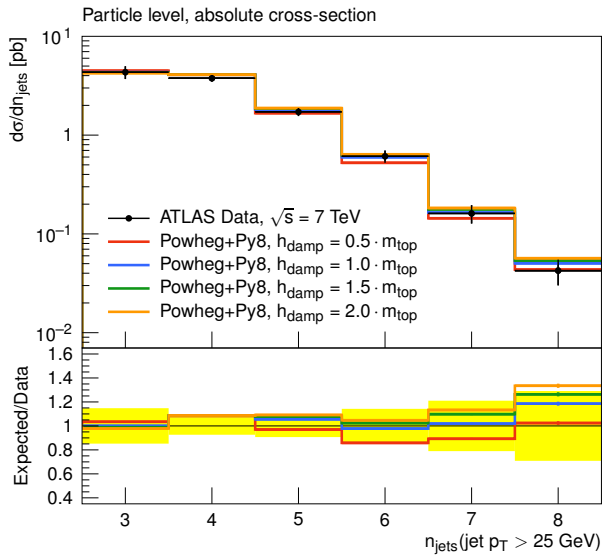
Systematic source	ATLAS	CMS
ME Generator	Powheg/aMC@NLO	Powheg (studying aMC@NLO(FxFx))
Hadronisation	Herwig++/Pythia6 or Herwig7/Pythia8	Herwig++/Pythia8 (not in all analyses)
Scale variations	μ_R, μ_F, h_{damp} and tune variations	vary μ_R, μ_F, independently h_{damp}
Non-pertubative	A14 variation1 (not used yet)	CUET2P8M2T4 variations
PDFs	PDF4LHC eigenvectors	CT14/NNPDF30

ATLAS: "By-eye tuning" of h_{damp} parameter

▸ ATL-PHYS-PUB-2016-020







➔ after switch from Powheg+Pythia6 to Powheg+Pythia8 setup

↪ re-did variation studies of h_{damp} parameters

↪ data allows to exclude extreme h_{damp} values

➔ found that $h_{\mathrm{damp}} = 1.5 \cdot m_{\mathrm{top}}$ describes data best → current ATLAS baseline

➔ need to establish systematic uncertainties that take into account h_{damp} variation

ATLAS: Current setup for radiation systematics

- established new nominal setup with Powheg+Pythia8
- now need proper radiation systematics along with it
- approach here again: “by-eye”:

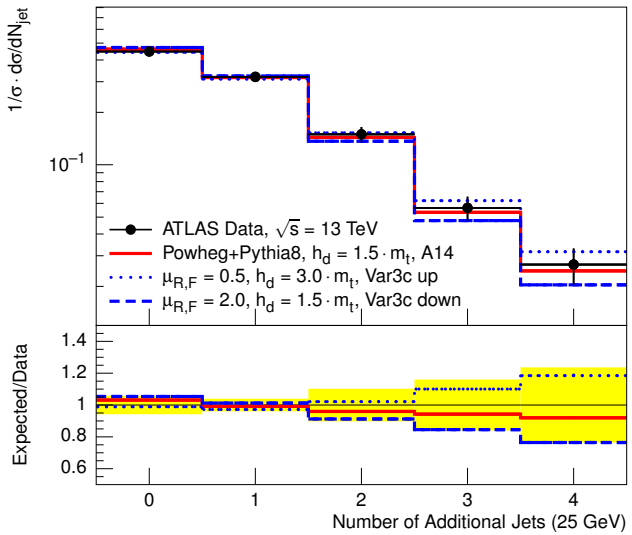
  ↪ vary several parameters, find setup that brackets the data uncertainties

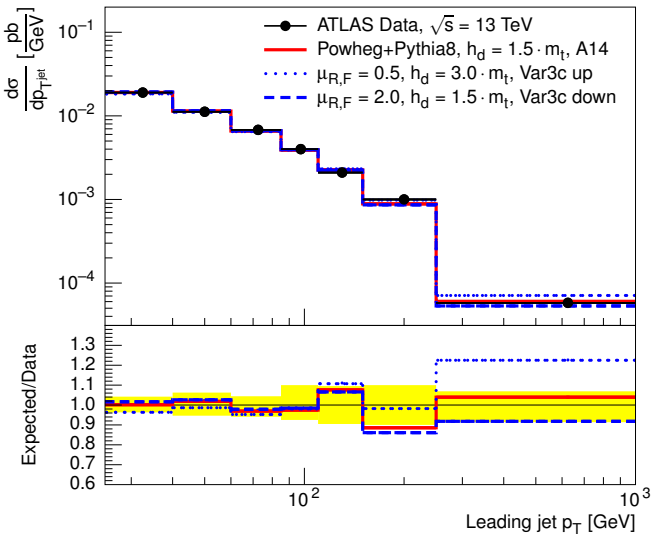
  a) vary the h_{damp} parameter
  b) vary the factorisation and renormalisation scale in the ME
  c) use A14 parton shower tune variations ▸ ATL-PHYS-PUB-2014-021

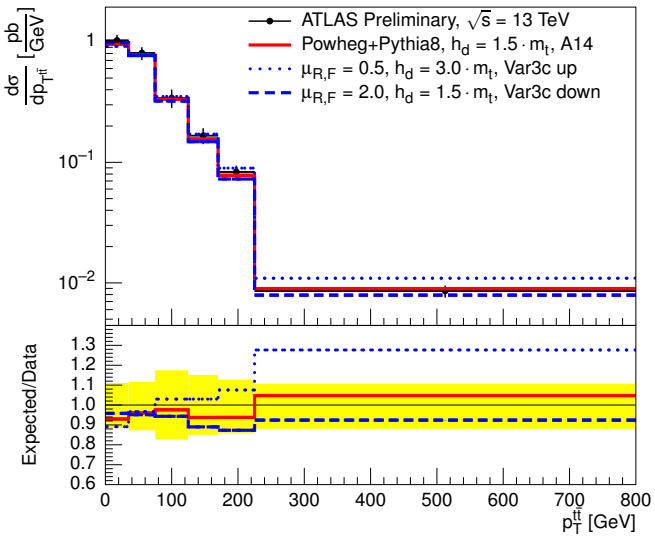
➔ after ▸ MC workshop: should we use this approach in the future?

ATLAS: Current setup for radiation systematics

▸ ATL-COM-PHYS-2017-391



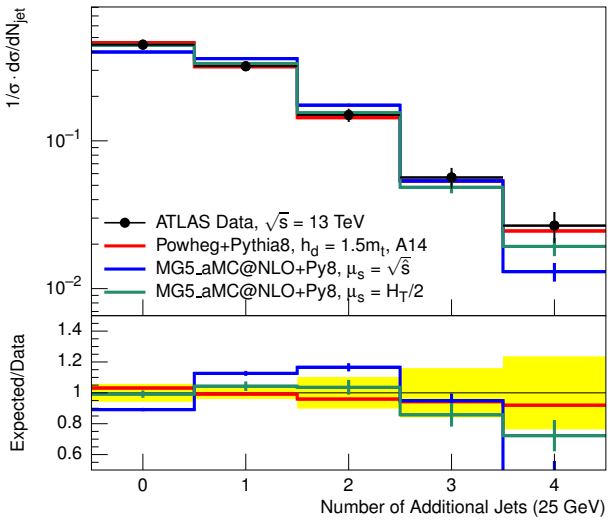


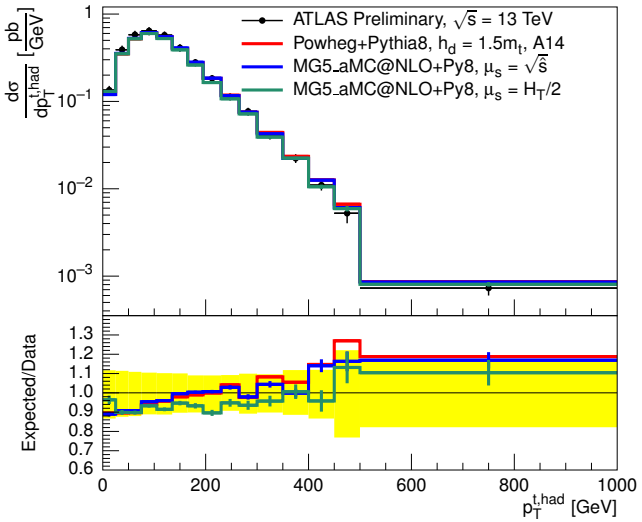


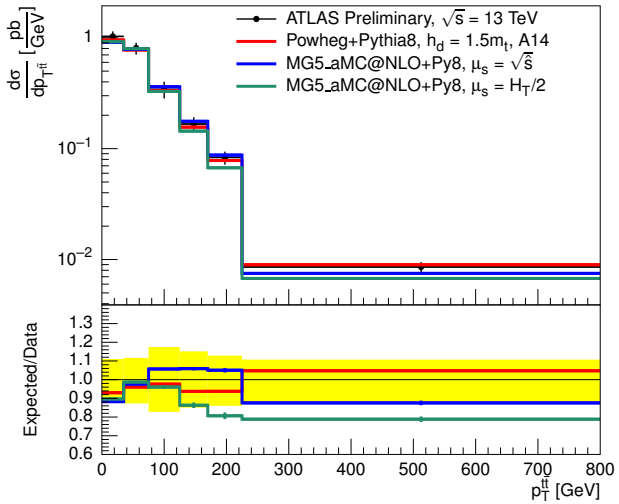
- nominal: A14 tune, $h_{\text{damp}} = 1.5 \cdot m_{\text{top}}$
- high radiation: A14 tune Var 3c up, $h_{\text{damp}} = 3.0 \cdot m_{\text{top}}$, $\mu = 0.5$
- low radiation: A14 tune Var 3c down, $h_{\text{damp}} = 1.5 \cdot m_{\text{top}}$, $\mu = 2.0$

➔ after ▸ MC workshop: should we use this approach in the future?

ATLAS: Matrix-element generator uncertainties

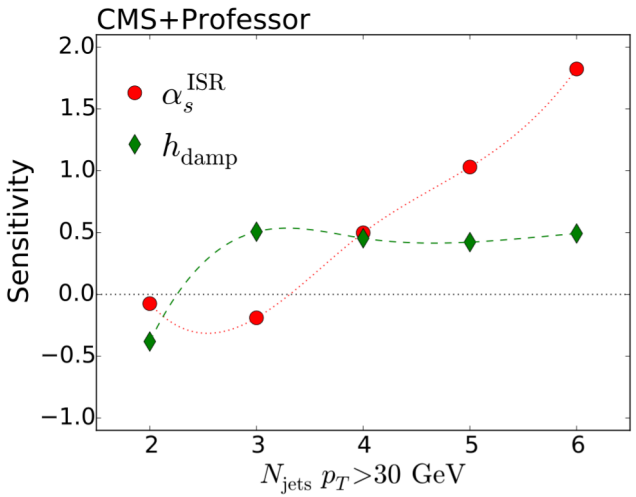


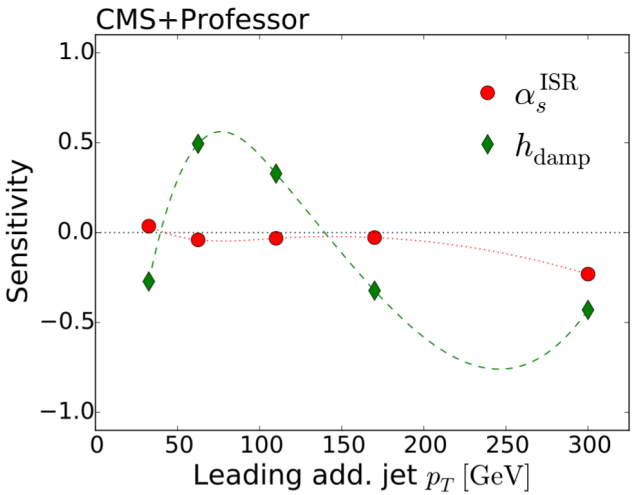


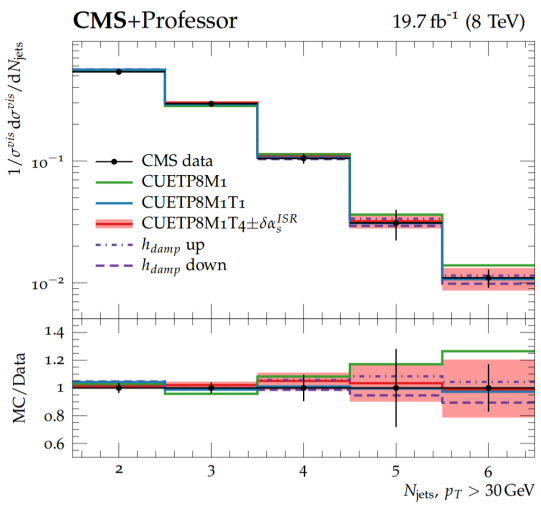


- ongoing work to improve aMC@NLO+Pythia8 setup: ▸ ATL-COM-PHYS-2017-391
- larger sensitivity to functional form of the shower scale
- take full difference between Powheg and aMC@NLO setups as systematic uncertainty

CMS new CUETP8M1T4 tune ▸ TOP-16-021-PAS







Tune h_{damp} and α_S(ISR) to N_{jet} and jet p_{T} distributions

- best values[a]: $h_{\mathrm{damp}} = 1.581^{+0.658}_{-0.585} \cdot m_{\mathrm{top}}$, $\alpha_s^{\mathrm{ISR}} = 0.1108^{+0.0145}_{-0.0142}$
  - ↪ in good agreement with ATLAS settings
  - ↪ h_{damp} variation includes the previous default m_{top} and is compatible with $2 \cdot m_{\mathrm{top}}$
  - ↪ α_S variation compatible with QCD scale variation of 0.5,2.0
- much improved data/MC agreement for N_{jets} with new tune

[a] Sensitivity $= \frac{dMC(p)}{dp} \frac{p_C}{MC(p_C)} \longrightarrow MC(p) =$ bin-entry for parameter p

CMS new CUETP8M2T4 tune ▸ TOP-16-021-PAS

- with results from CUETP8M1T4:

  ↪ tune parameters sensitive to MPI and CR (CUETP8M2T4)

- new tune was applied to MG5_aMC@NLO (FxFx) + Pythia8:

  ↪ gives good data description as well

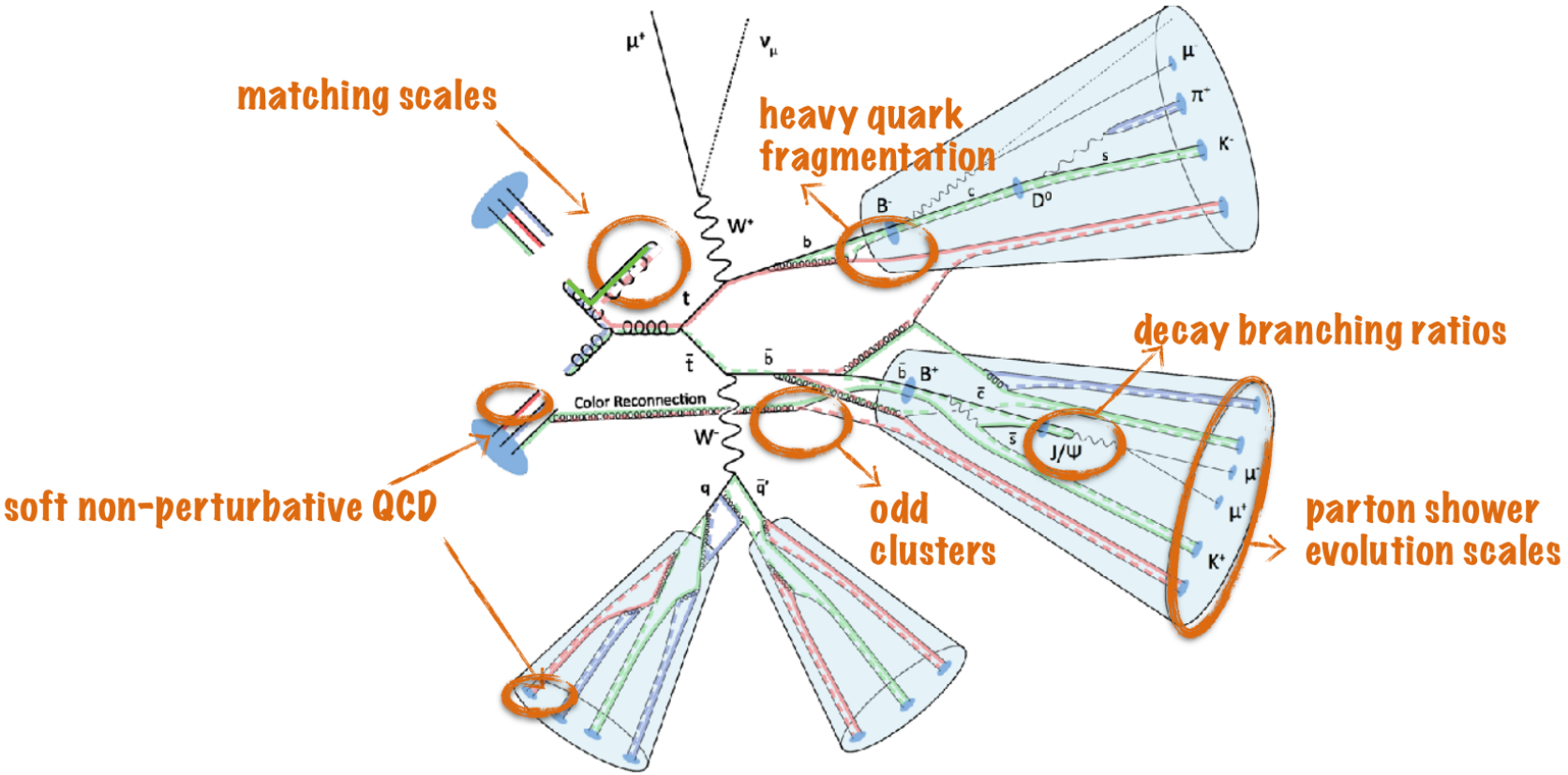
- no big improvement for aMC@NLO (MLM) and aMC@NLO+Pythia8

- agreement checked with many particle and parton level distributions

From summary of CMS tuning:

Tuning a parameter in the parton shower **can potentially bias particular new physics searches,** in particular if the tune is based on the dataset where the search is performed. [...] In particular, the fact that global event variables such as missing E_T and H_T are not changed by the new tune gives us confidence that searches involving missing E_T will not be biased. However, **one should pay particular attention if the new physics search relies on N_{jets},$p_T(t\bar{t})$ or p_T of leading additional jets in $t\bar{t}$-like processes.**

CMS: Modelling uncertainties

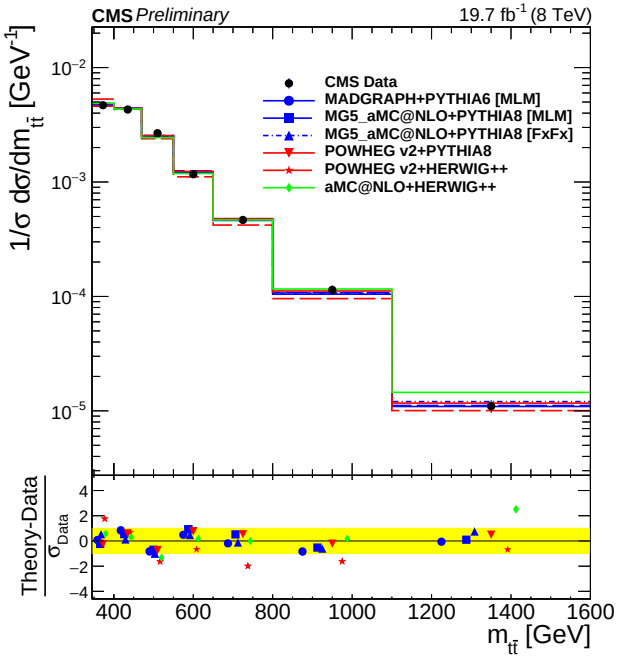


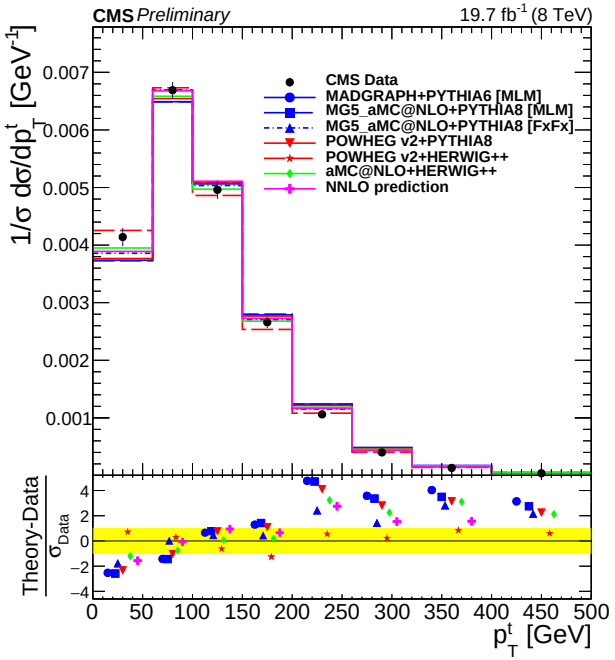
➔ is there a relevant effect not yet thought of that needs implementation in the MCs?

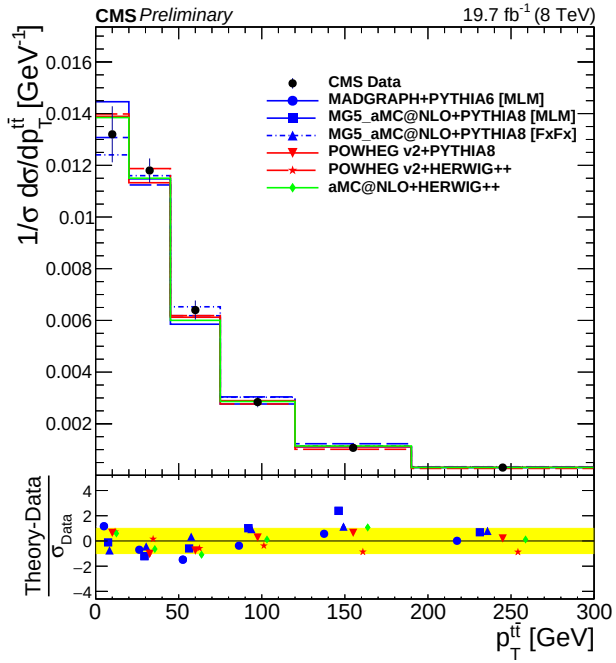
CMS: Proposal for parton shower modelling uncertainties (Run II)

Source	Handle	Weights	Variation	Comment
Shower scales	ISR scale (SpaceShower:renormMultFac)	no	0.5–2.0	see TOP-16-021
	FSR scale (TimeShower:renormMultFac)	no	0.5–2.0	or $\frac{1}{\sqrt{2}}$, $\sqrt{2}$ from LEP
Matching	h_{damp}	no	$1.581^{+0.658}_{-0.585} \cdot m_{\mathrm{top}}$	see TOP-16-021
Soft QCD	Underlying event (MultipartonInteractions:pT0Ref MultipartonInteractions:expPow MultipartonInteractions:range)	no	up/down	MPI and CR strength (does not affect resonance decays)
Odd clusters	Colour reconnection (MPI-based + QCD inspired + gluon move)	no	different simulations	affects resonance decays
Fragmentation	$x_b = p_{\mathrm{T}}(B)/p_{\mathrm{T}}(bjet)$	yes	Bowler-Lund + Peterson parameter unc. based on LEP fits	see TOP-16-022
Flavour response/ hadronisation	Pythia vs. Herwig	no	JES flavour group for light,g,b,c	
Decay tables	semi-leptonic BR	yes	vary BR by 0.77/-0.45% or scale Pythia8 up to PDG BR where needed	see PDG

CMS: Matrix-element generator uncertainties







- ME uncertainties from comparison of Powheg+Pythia8 with aMC@NLO+Pythia8 (FxFx): ▸ TOP-15-011
- better agreement for the transverse momentum of $t\bar{t}$ system with FxFx
- additional uncertainty on top p_T mismodelling

What will we do in the future?

➔ a lot of discussion at the Monte Carlo workshop in May

➔ both experiments are using the “factorisation approach”, but:

↪ changing e.g. the generator can have bigger effects than changing parameters within a single generator

➔ What to do if no generator describes a specific distribution well?

↪ e.g. CMS: top p_{T} uncertainty

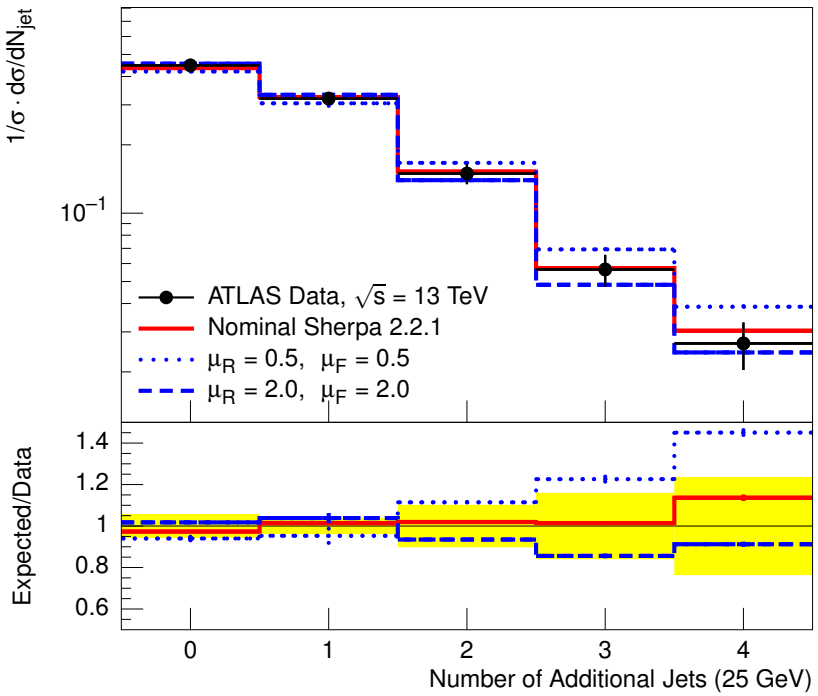
↪ have we included all sources of uncertainty?

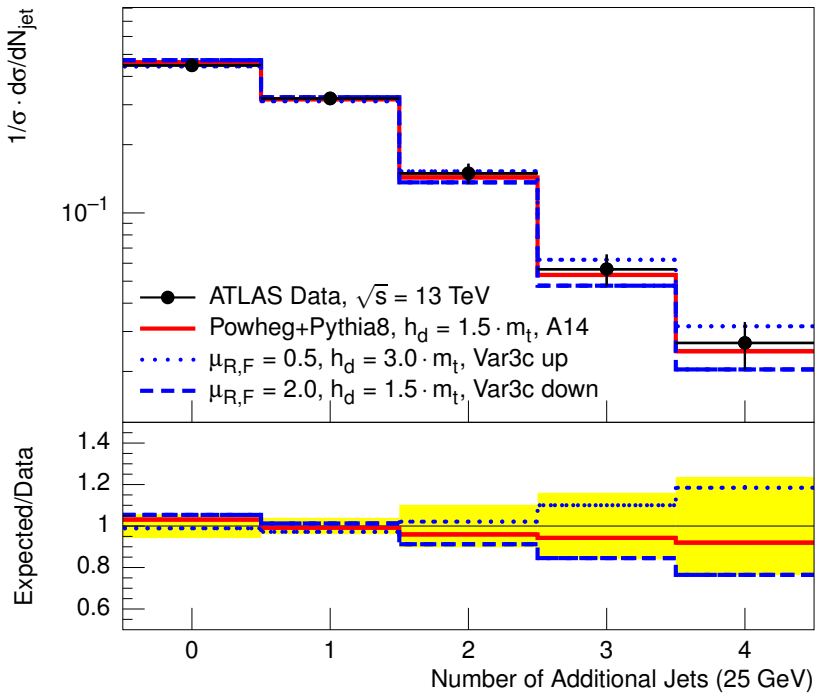
Two main questions:

1. Should we tune parameters like h_{damp}, and what would be an appropriate uncertainty? (new CMS tune: ▸ TOP-16-021-PAS)

2. Or should we take uncertainty variations suggested by theorists, and include them in a profile likelihood fit which will constrain the uncertainties?

To be discussed: ▸ ATL-COM-PHYS-2017-391





➔ left: Sherpa out of the box, only ME scale variations

➔ right: Powheg+Py8, tuned so that data is described well

↪ scale, h_{damp} and tune variations such that bracket data

➔ be careful not to “overtune”: can lead to loss of predictivity

Do most variations within one generator: Herwig7

- fully automated NLO calculations, have ME+PS+Matching all in Herwig7
- parton shower options:

  $\hookrightarrow$ angular-ordered and dipole parton shower (when available for $t\bar{t}$)
- matching algorithms:

  $\hookrightarrow$ MC@NLO-like and Powheg-like matching
- long-term: can study and define systematic uncertainties using Herwig7

Do most variations within one generator: Sherpa

- default: MEPS@NLO with 0,1 jets @NLO, CSShower
- vary ME matching scale (CKKW)
- parton shower: different model (DIRE), vary parton shower recoil scheme, heavy baryon enhancement parameter
- ratiation: can vary several parameters:

  $\hookrightarrow$ vary μ_R, μ_F, resummation scale

  $\hookrightarrow$ vary scale in parton shower

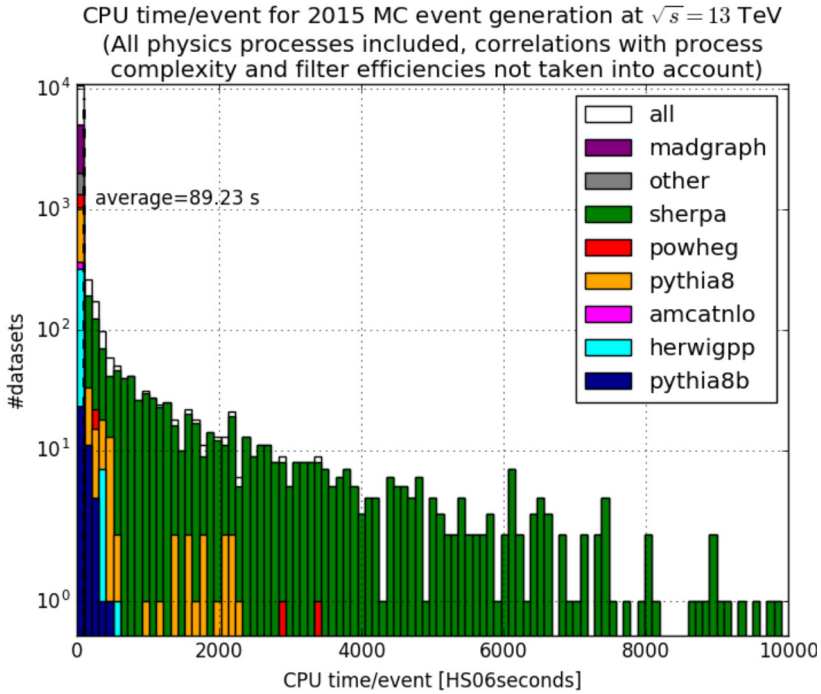
  $\hookrightarrow$ vary α_S scale factore in initial state evolution

Technical issues/ongoing work

➔ large CPU time/event for some generators (e.g. Sherpa) ▸ Talk Josh McFayden HF@LHC, Durham

➔ negative event weights in aMC@NLO:

↪ need to generate **2-3 times more statistics** than for generators without (or little) negative weights (e.g. Powheg)



Efforts just started in ATLAS:

➔ try to use Pythia8 shower weights to improve ISR/FSR prescription

↪ works for Powheg, but for MG5_aMC@NLO it works only with MLM matching

➔ use DIRE with Pythia8

Summary

- ATLAS and CMS have same baseline setup using Powheg+Pythia8

  $\hookrightarrow$ similar parameters for α_s and h_{damp}

- changing the generator can have bigger effects than changing parameters within one generator:

  $\hookrightarrow$ would be better to have more variations in one generator setup

- discussion: how much tuning do we need/is reasonable?

- need also underlying event measurement in $t\bar{t}$ at 13 TeV

  $\hookrightarrow$ first steps in ▸ TOP-15-017

- need measurement of b-fragmentation (b-jet shapes)

  $\hookrightarrow$ first steps in ▸ TOP-12-030