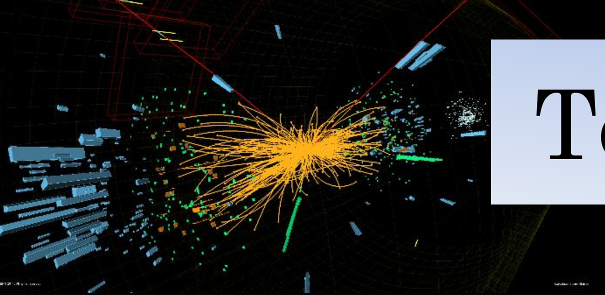
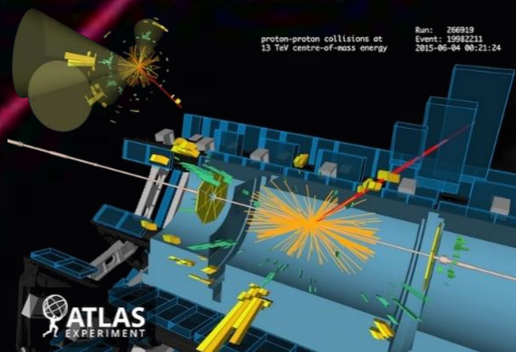


Top modelling in experiments

Dominic Hirschbühl
BERGISCHE
UNIVERSITÄT
WUPPERTAL

Heavy Flavour Production @ LHC
Durham - 08.09.2017



Available generators

Matrix element generation:

Powheg, MG5_aMC@NLO, Herwig7

Multijet merging

- CKKW(-L)
- MLM

NLO matching

- (S-)MC@NLO
- Powheg

Multijet merging @ NLO

- MEPS@NLO (Sherpa)
- FxFx (MG5_aMC@NLO)
- NL^3 / UNLOPS (Pythia8)

Parton shower generators:

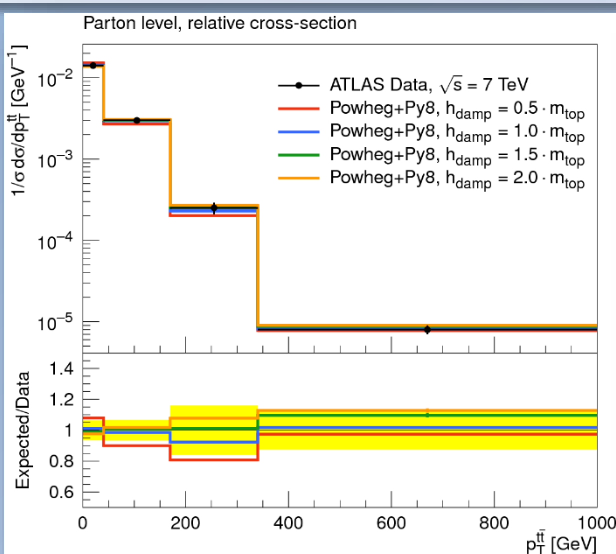
(They do also hadronisation/fragmentation/underlying event etc.)

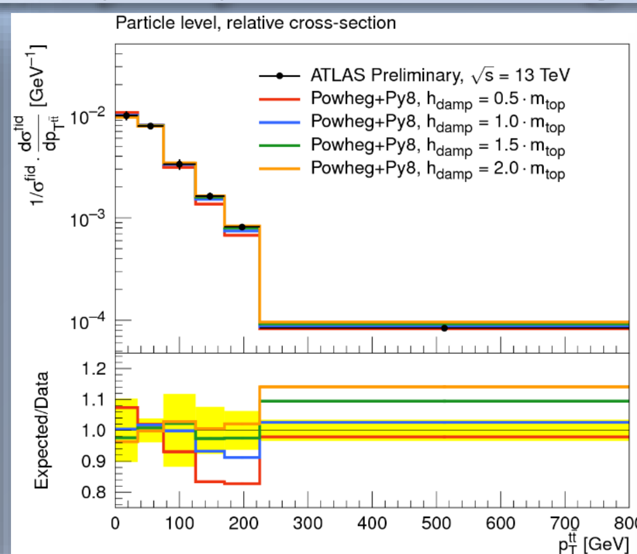
- Pythia8
- Herwig7
- Sherpa

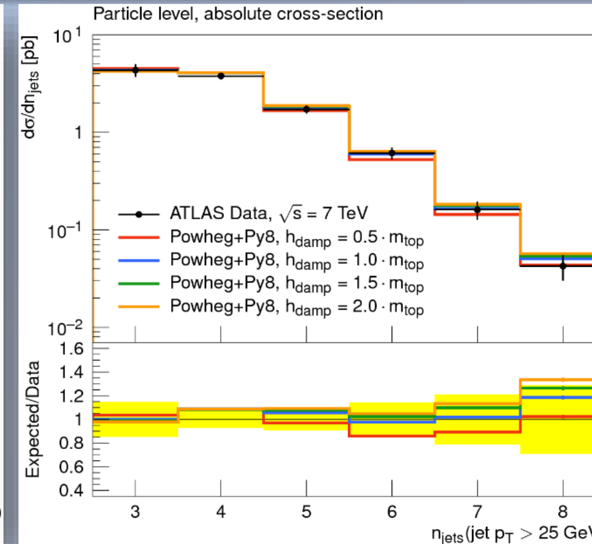
Current setups

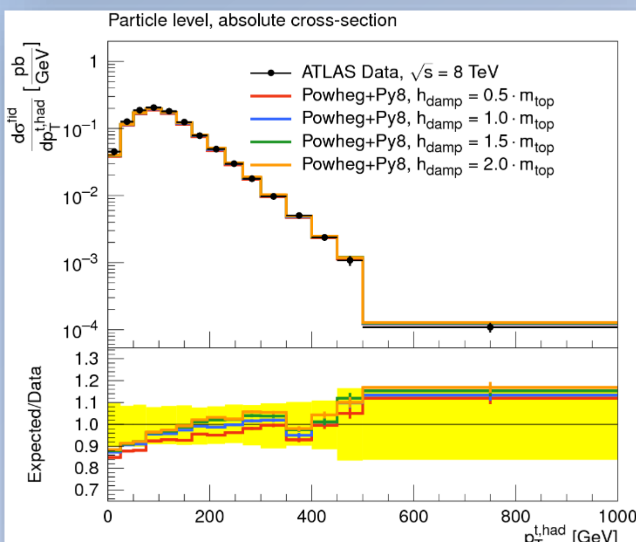
Generator	comment	ATLAS	CMS
Powheg+Pythia8	NLO+PS **default**	A14 + h_{damp}=1.5 „by-eye-tuning“ ATL-PHYS-PUB-2016-020	α_s+h_{damp} +UE tuning CMS-TOP-16-021
Powheg+Herwig++	NLO+PS	„old“ shower generator → Herwig7	
Powheg+Herwig7	NLO+PS	Part of syst. unc.	
MG5_aMC@NLO+Pythia8	NLO+PS	Part of syst. unc.	
MG5_aMC@NLO+Pythia8	LO+PS MLM(+0,1,2,3j)	Not used in Run2	Used for comparisons
MG5_aMC@NLO+Pythia8	NLO+PS FxFx (+0,1,2j)	In validation	Used for comparisons
MG5_aMC@NLO+Herwig++ /Herwig7	NLO+PS		
Sherpa	LO/NLO+PS 0,1j@NLO – 2,3j@LO	Used for comparisons	In validation

„By-eye“-tuning





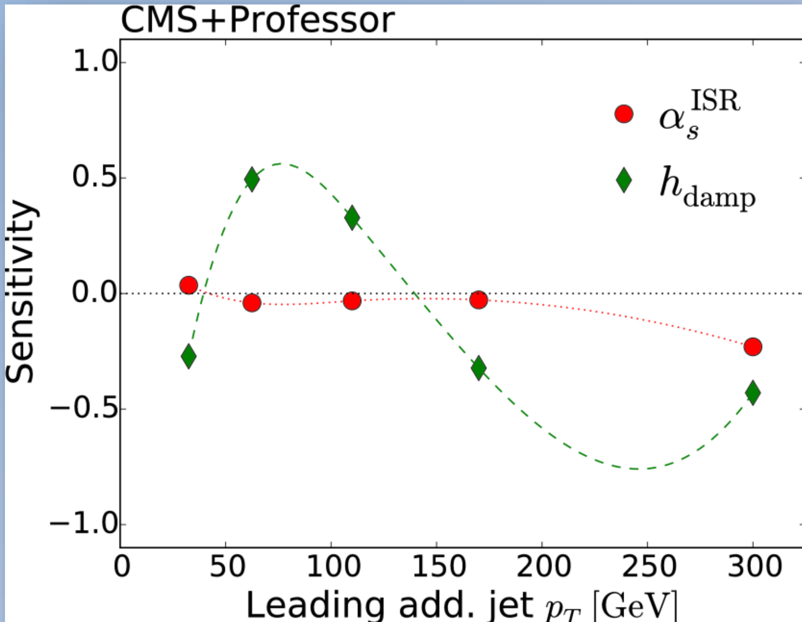


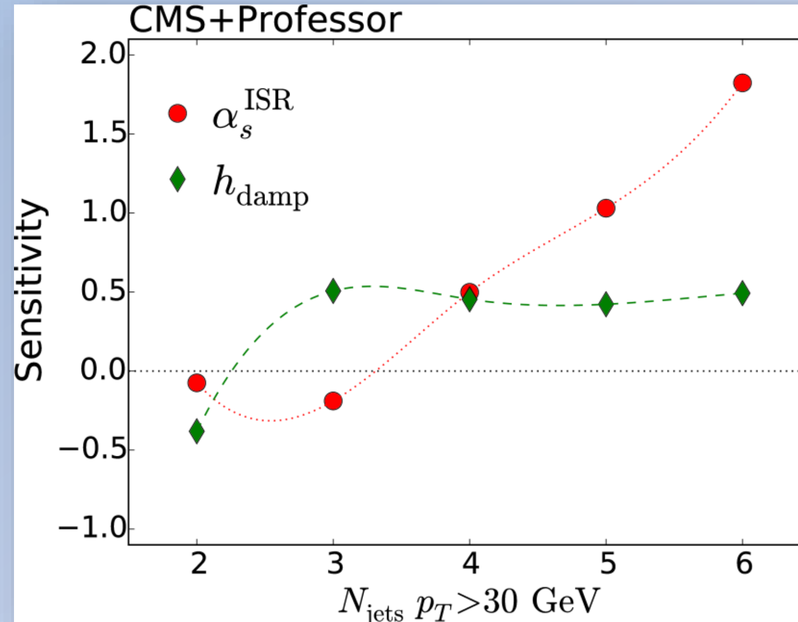


- Tuning done using 8 TeV Rivet routines
- h_{damp} mainly chosen based on $p_T(t\bar{t})$
- Found good agreement with other observables
- Top p_T not affected (as expected)
- Defined radiation systematic based on A14 eigentunes → see later

ATL-PHYS-PUB-2016-020

Professor tune

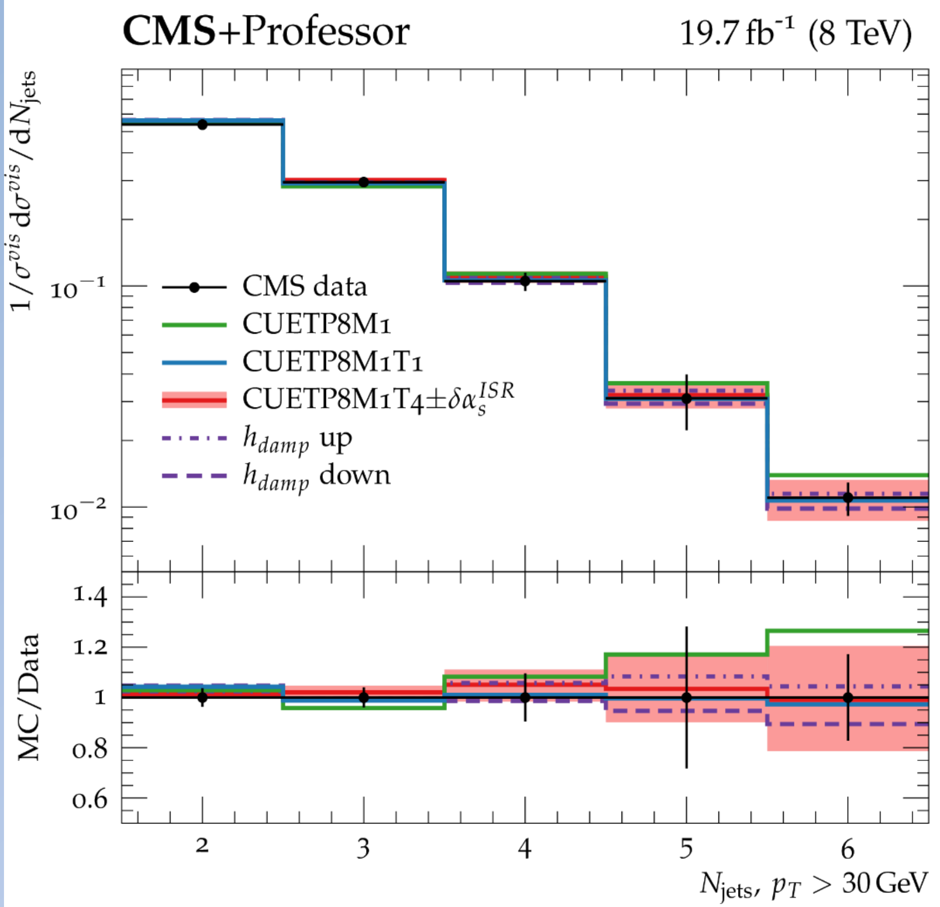




- Want to tune parameters that cannot be obtained from first principles
- Define parameters to vary and range in which to vary
- Produce samples with different parameter sets
- Minimise χ^2value

- In this approach α_s^{ISR} and h_{damp} are fitted

Shower α_s + h_{damp} tuning



$$h_{damp} = 1.581^{+0.658}_{-0.585} \times m_t, \qquad \alpha_s^{ISR} = 0.1108^{+0.0145}_{-0.0142}$$

- Fixing α_s to 0.1108, a new UE tune is derived, optimizing MPI and color reconnections
- Fit to UE observables at 13 TeV
- Predictions with the new tune are compared to independent measurements

CMS-PAS-TOP-16-021

Tunes

CMS top specific tunings

CUETP8M2T4 (CMS-TOP-16-021)

- Combined α_s + h_{damp} + UE tune
- Default for 2016 samples

ATLAS top specific tunes:

A14 + h_{damp} = 1.5 (ATL-PHYS-PUB-2016-020)

- Default setting for 2016/2017 $t\bar{t}$ samples

ATTBAR (ATL-PHYS-PUB-2015-007)

- Tuning of ISR/FSR parameters in addition to the Monash tune using $t\bar{t}$ distributions

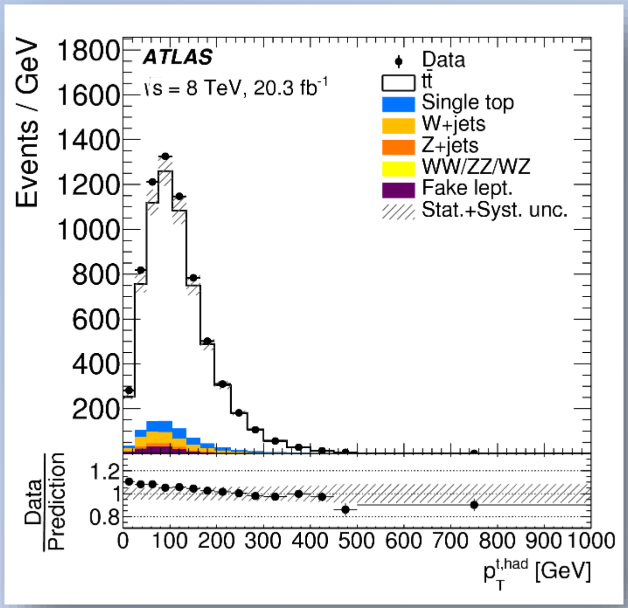
Parameter	$t\bar{t}$+jets	$t\bar{t}$ gap fraction	$t\bar{t}$+jets and $t\bar{t}$ gap fraction (ATTBAR-POWHEG)
hdamp	$1.7^{+0.5}_{-0.3} \cdot m_t$	$2.2^{+2.9}_{-0.7} \cdot m_t$	$1.8^{+0.4}_{-0.3} \cdot m_t$
χ^2_{min}/dof	40/20	11.9/17	52.1/38

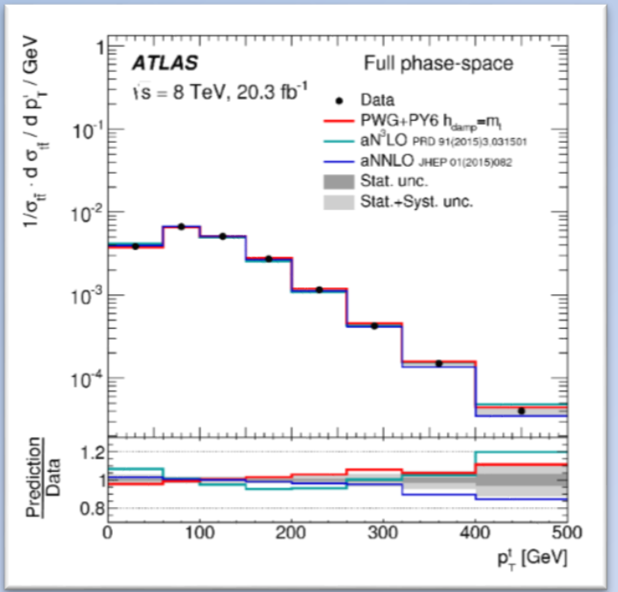
All h_{damp} values are in agreement within the uncertainties
Powheg+Pythia8 setups between ATLAS and CMS very similar

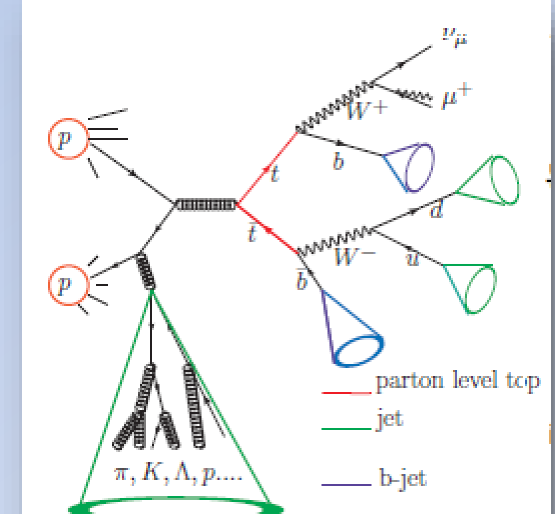
Unfolding / Pseudotop

Standard procedure

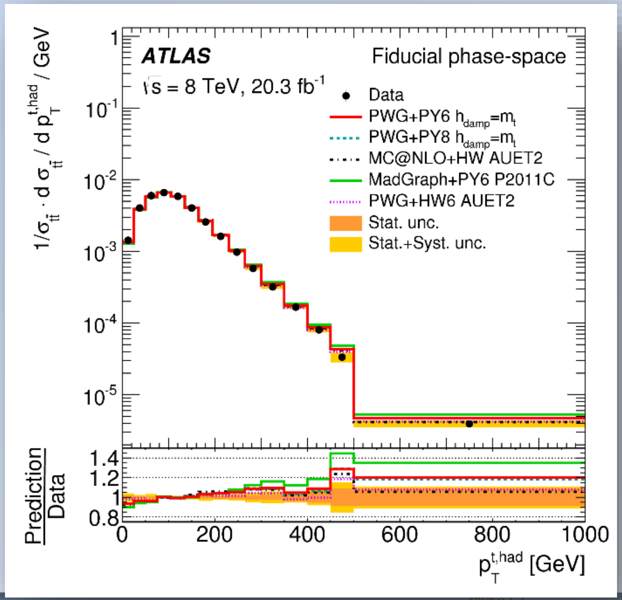
- Select $t\bar{t}$ enriched sample
- Reconstruction of $t\bar{t}$ final state (depending on signature)
- Subtract background
- Unfolding (correction for detector effects and efficiencies)
  - Observables connected with top-quarks
    - Particle level
    - Parton level (last top quark in the decay chain)
  - Event shape observables (like number of jets)





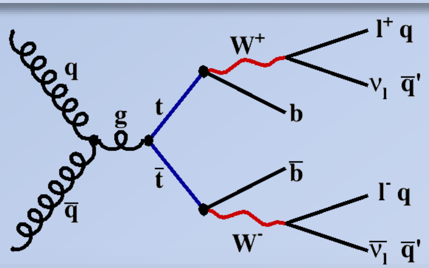


Graphics by Otto Hindrichs



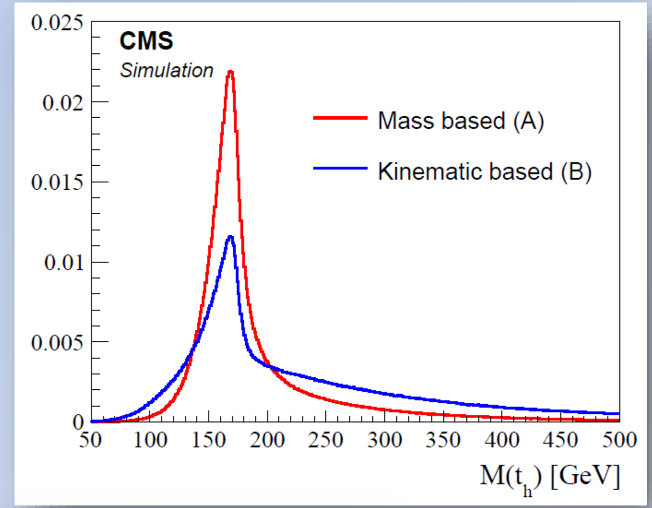
Pseudo-top definitions

Details are given in the Twiki



Single Lepton

- Require exactly 1 electron or muon, >=4 jets, >=2 b-jets
- Leptonic
- W(lep) = lep + MET
  (p_z from W mass and highest p_z from two-fold ambiguity)
- Select the two highest p_T b-jets
- top(lep) = W(lep) + b-jet closest to the lepton
- W(had) = the two highest p_T non-b jets
- Top(had) = W(had) + remaining b-jet



Alternative method for CMS (CMS-NOTE-2017-004)

Minimizing:

$$K^2 = [M(p_\nu + p_\ell + p_{b_\ell}) - m_t]^2 + [M(p_{j_1} + p_{j_2}) - m_W]^2 + [M(p_{j_1} + p_{j_2} + p_{b_h}) - m_t]^2$$

Dilepton

- Require >=2 jets, >= 2 b-jets, exactly 2 opposite sign leptons (el, mu)
- Consider only the 2 leading pt selected neutrinos.
- W-Bosons: Minimise $|m_{\nu_1 \ell_1} - m_W| + |m_{\nu_2 \ell_2} - m_W|$
- Tops : Minimise $|m_{W_1 j_1} - m_W| + |m_{W_2 j_2} - m_W|$

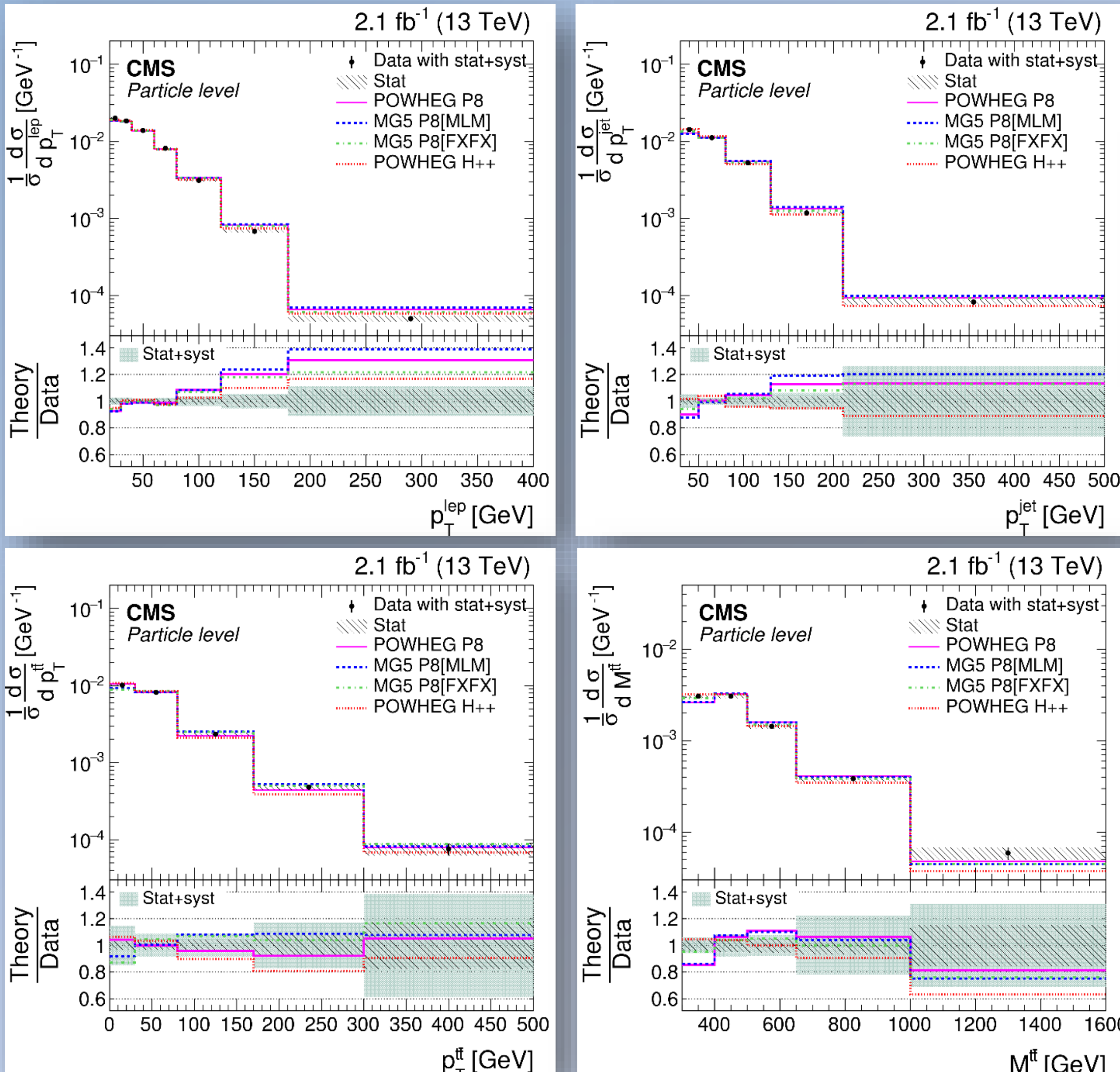
Available measurements @ 13 TeV

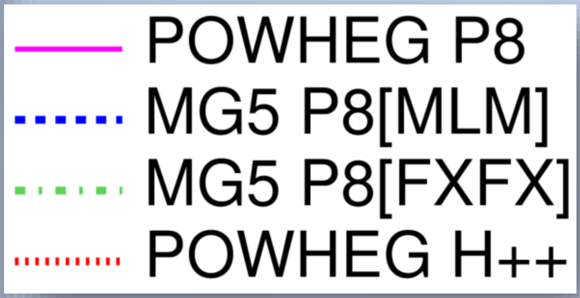
		ATLAS	CMS
dilepton	parton		arXiv:1708.07638 submitted to JHEP
	particle	EPJC 77 (2017) 299 EPJC 77 (2017) 220	arXiv:1708.07638 submitted to JHEP
ℓ + jets	parton		PRD 95(2017) 092001
	particle	arXiv:1708.00727 submitted to JHEP	PRD 95(2017) 092001 PAS-TOP-16-014
All hadronic	parton		PAS-TOP-16-013
	particle	CONF-2016-100	PAS-TOP-16-013

- In the following comparison of published plots
- Studies using Rivet analyses only available for 7 and 8 TeV!

- Big variety of observables, but also a few "standard ones" like top $p_T, p_T(t\bar{t})$, njets etc.

Dilepton - CMS

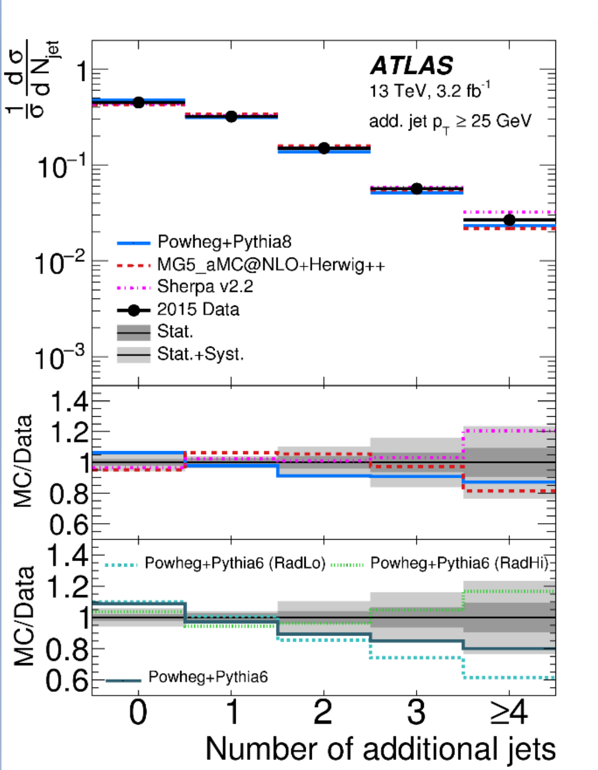


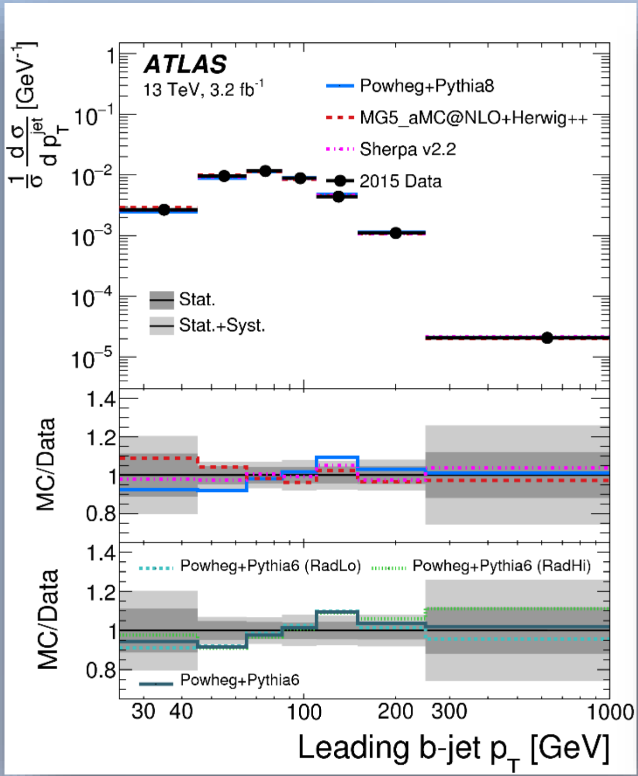


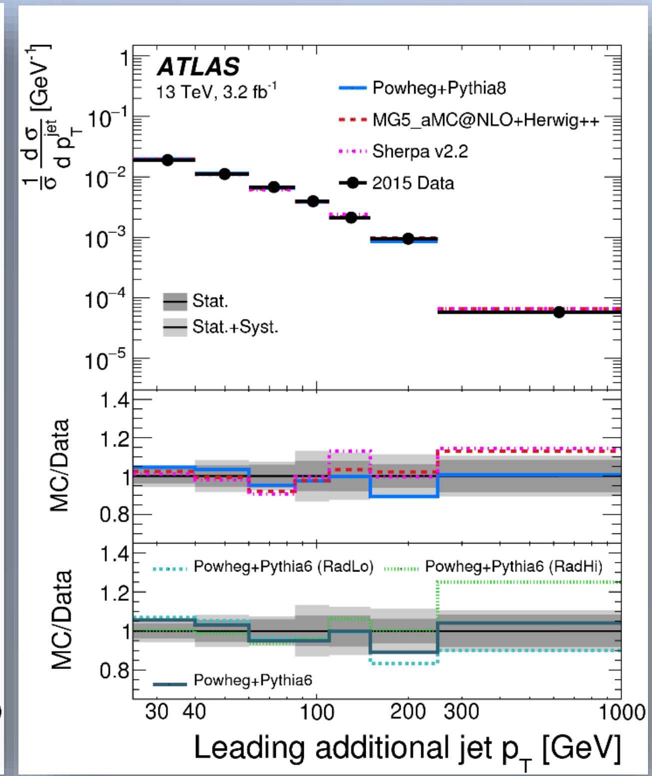
- p_T of top quark and decay products in general too soft – “as usual”
- Powheg+Herwig++ quite different to other generators

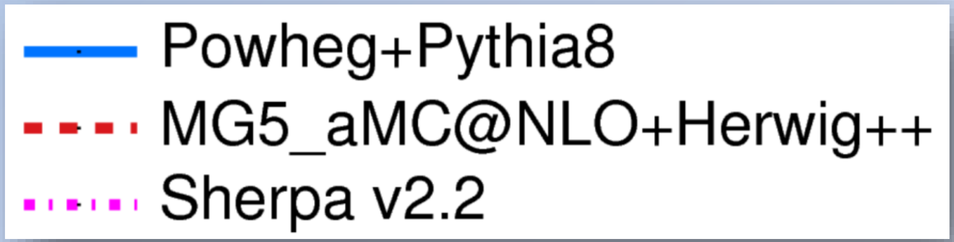
CMS-TOP-16-007

Dilepton channel - ATLAS





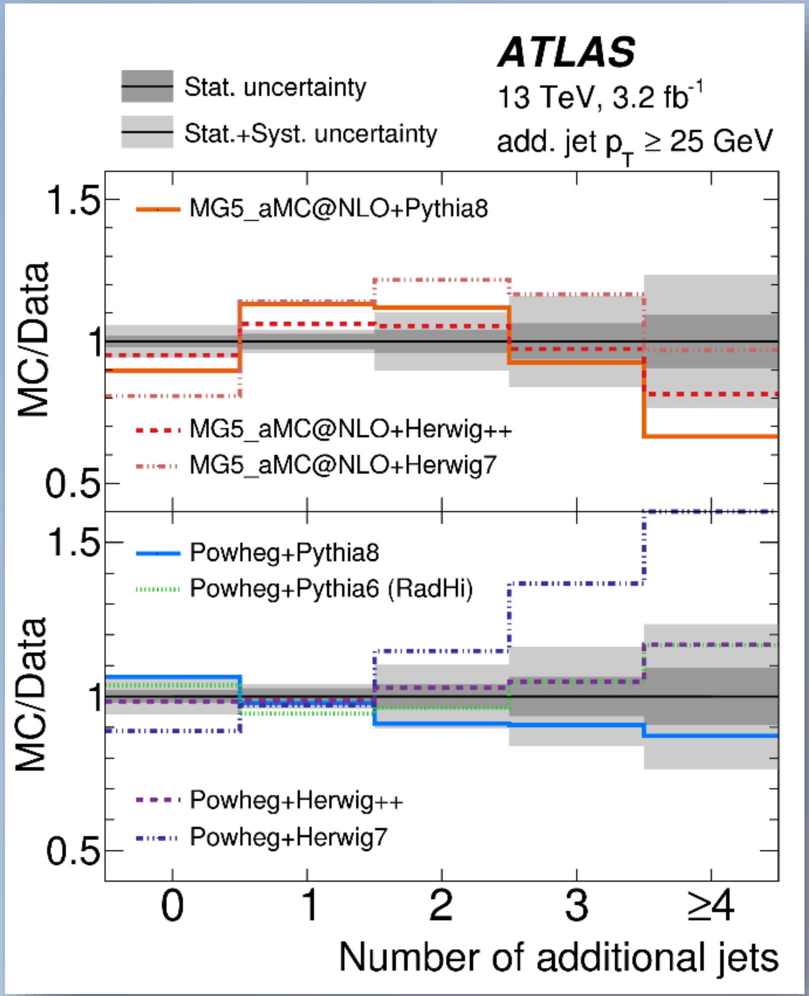


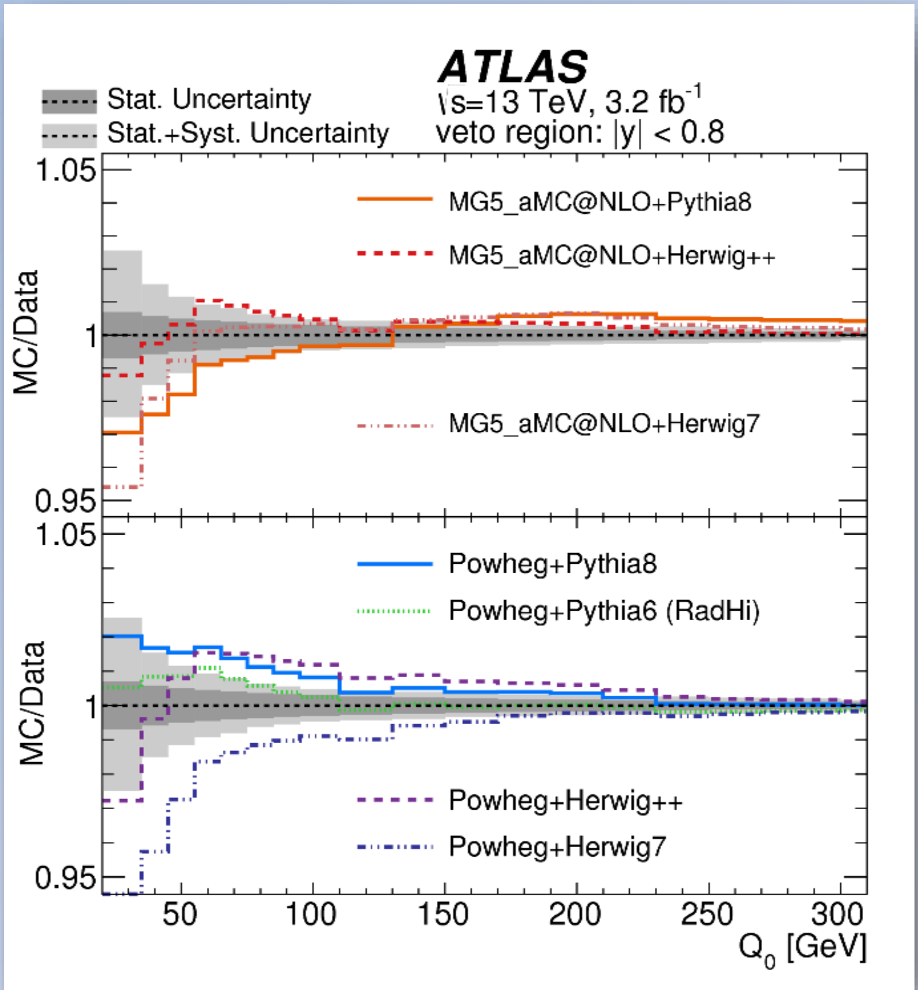


- All three generators within uncertainty bands
- Powheg+Pythia8 improved with respect to Powheg+Pythia6

EPJC 77 (2017) 220

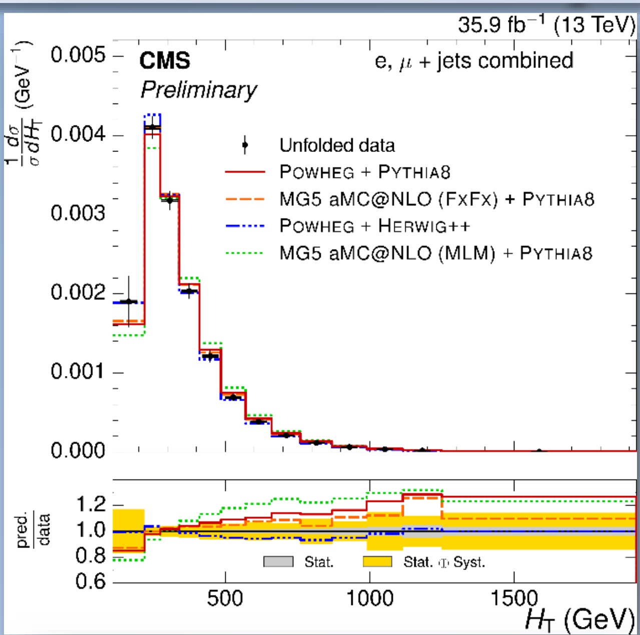
Dilepton channel - ATLAS

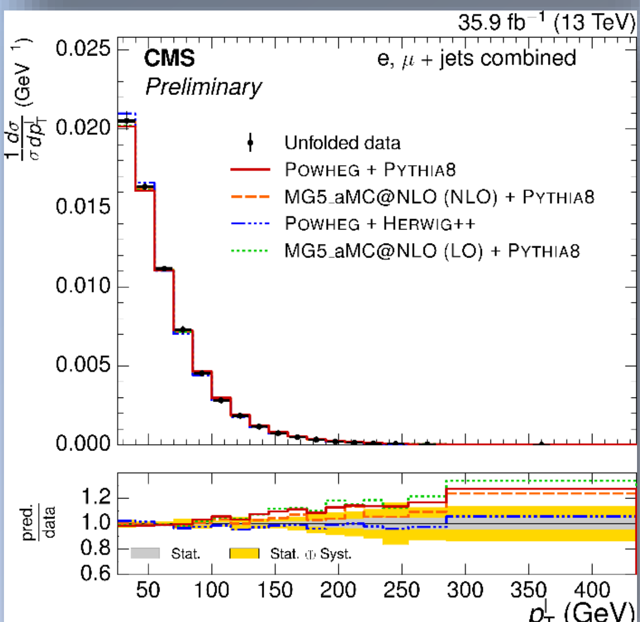


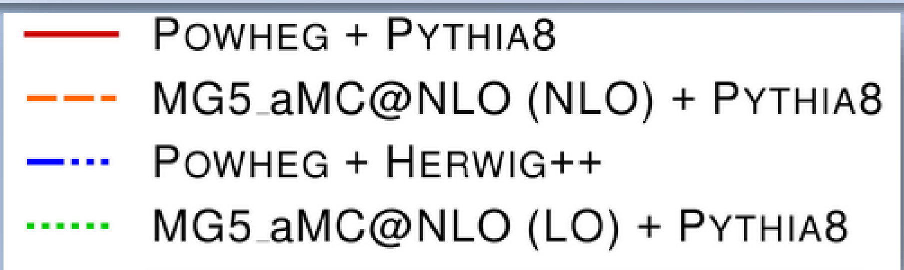


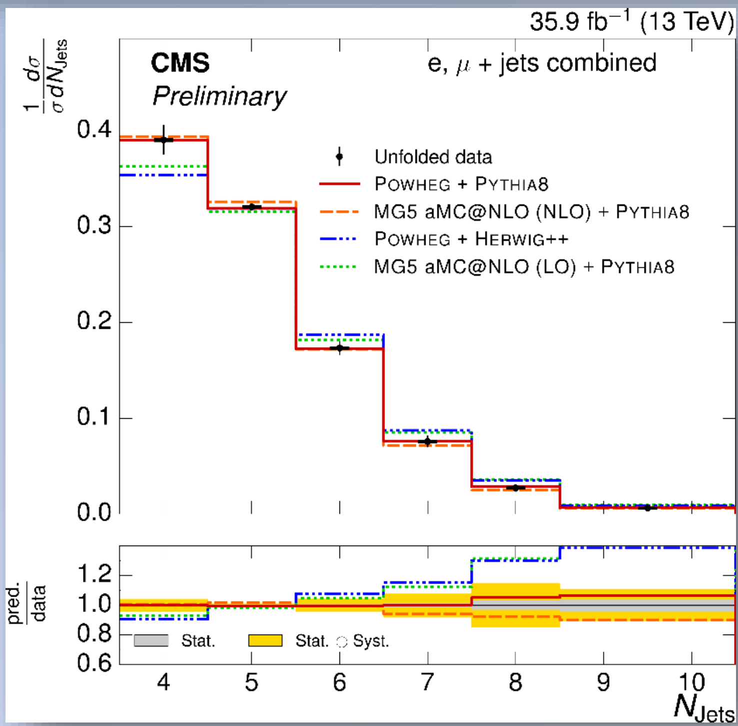
- All three generators do not agree well
- Herwig7 obviously needs more work

Lep+jets channel - CMS





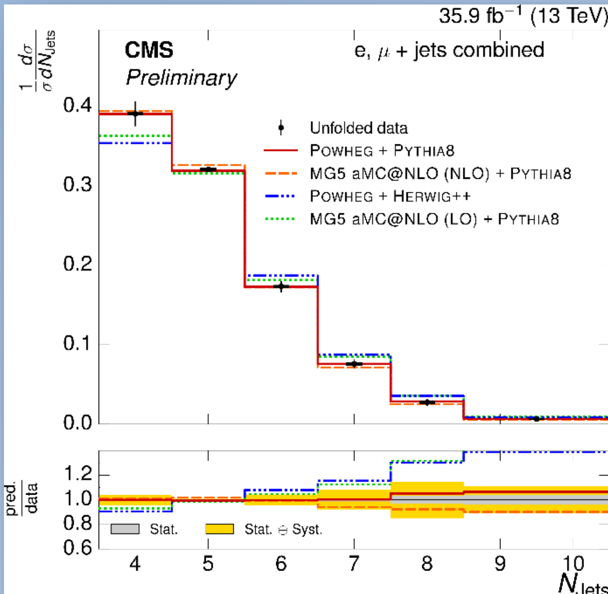


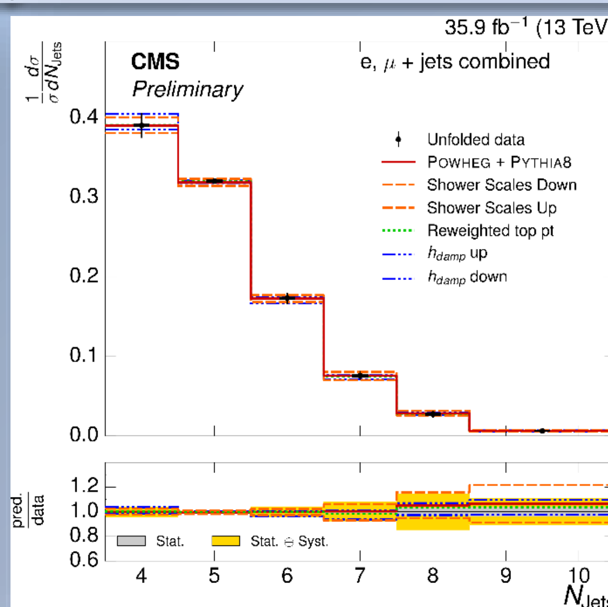


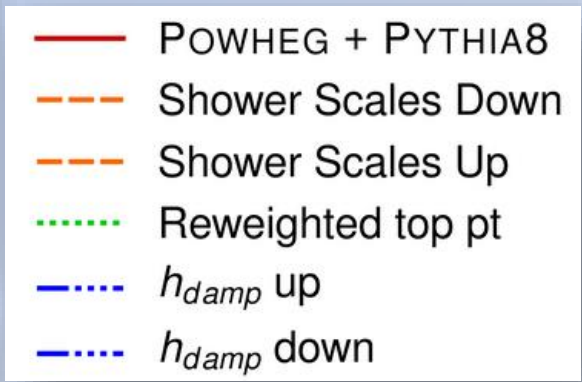
CMS-PAS-TOP-16-014

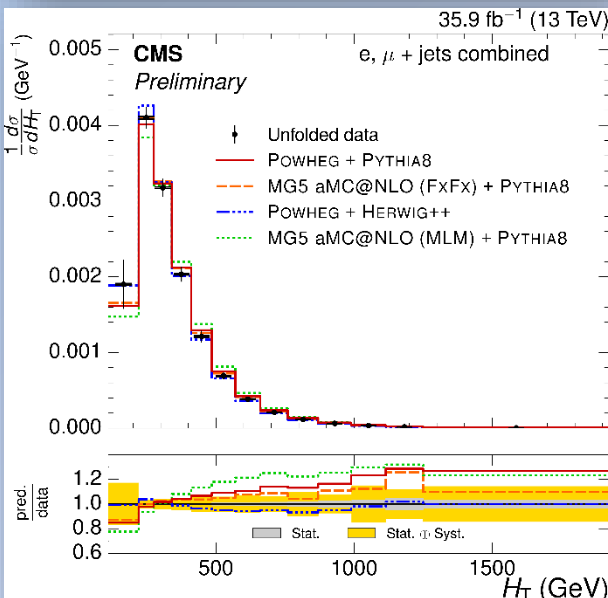
- HT not so well modelled for Powheg+Pythia8
- Njet looks almost perfect for Powheg+Pythia8

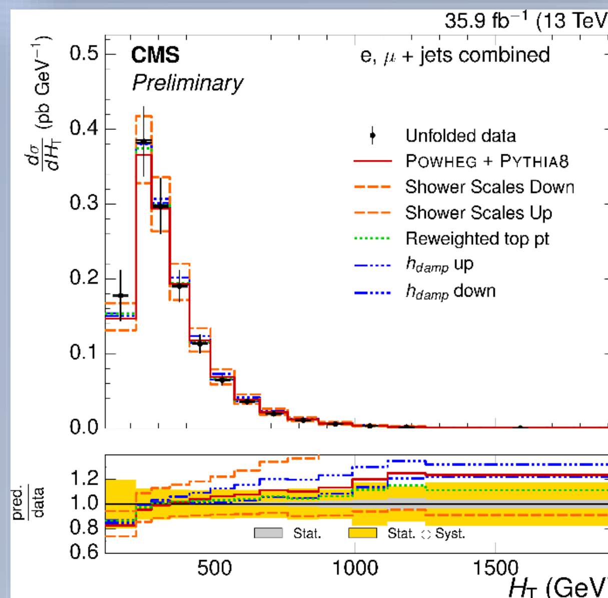
Lep+jets channel - CMS





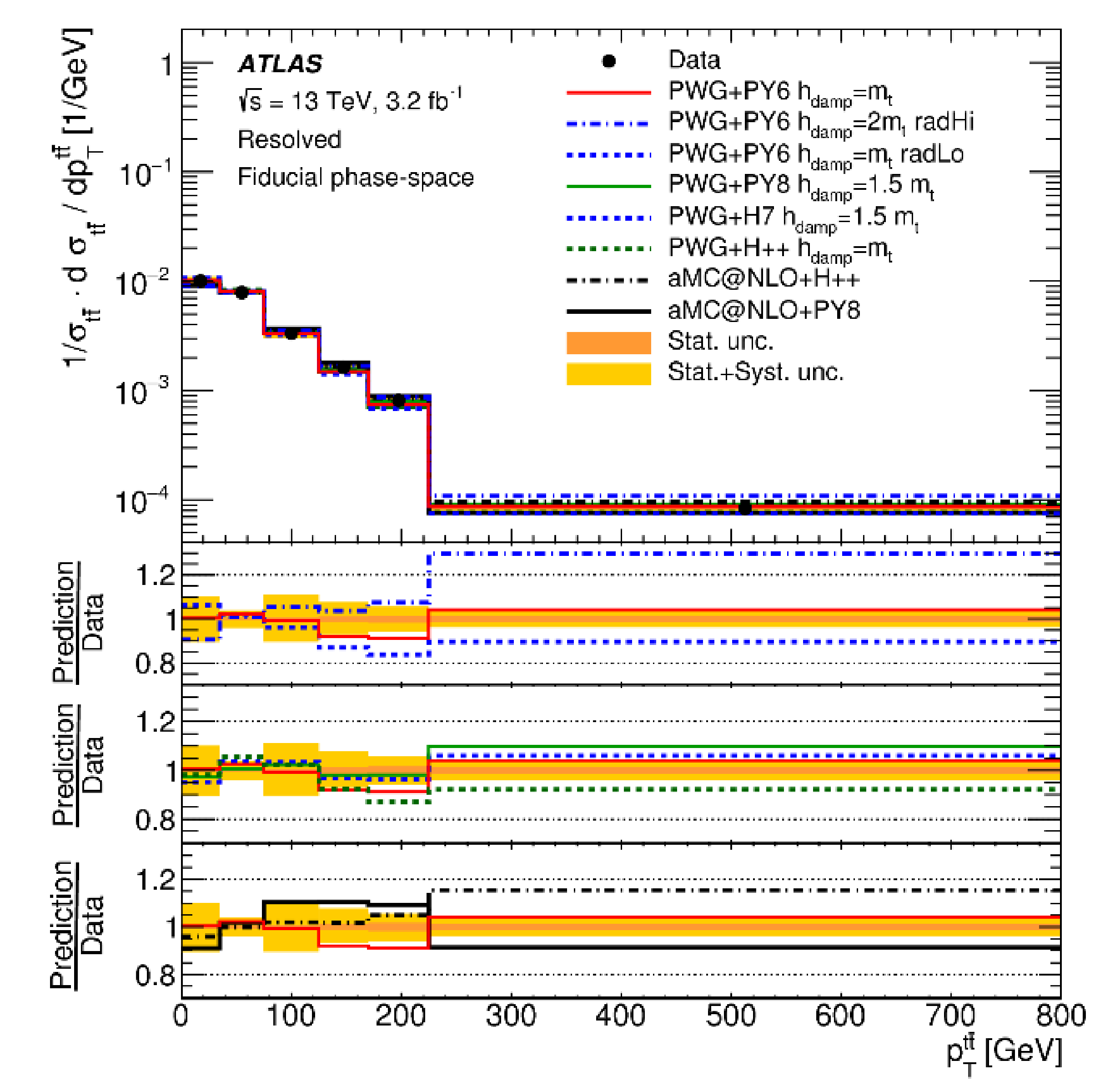






CMS-PAS-TOP-16-014

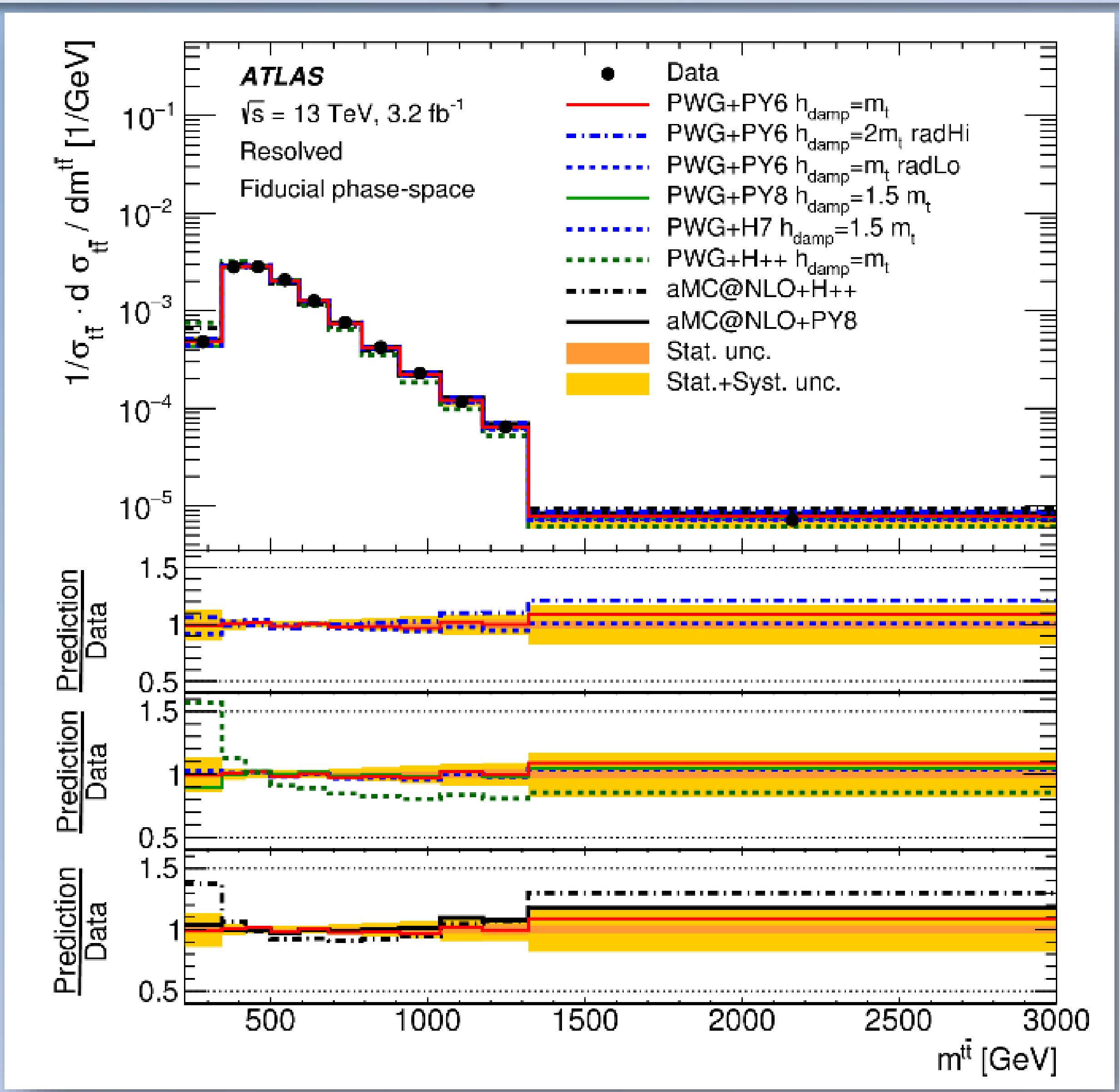
ℓ+jets channel - ATLAS



- Uncertainties are still very big
- MG5_aCM@NLO setups look different

arXiv:1708.00727

ℓ+jets channel - ATLAS

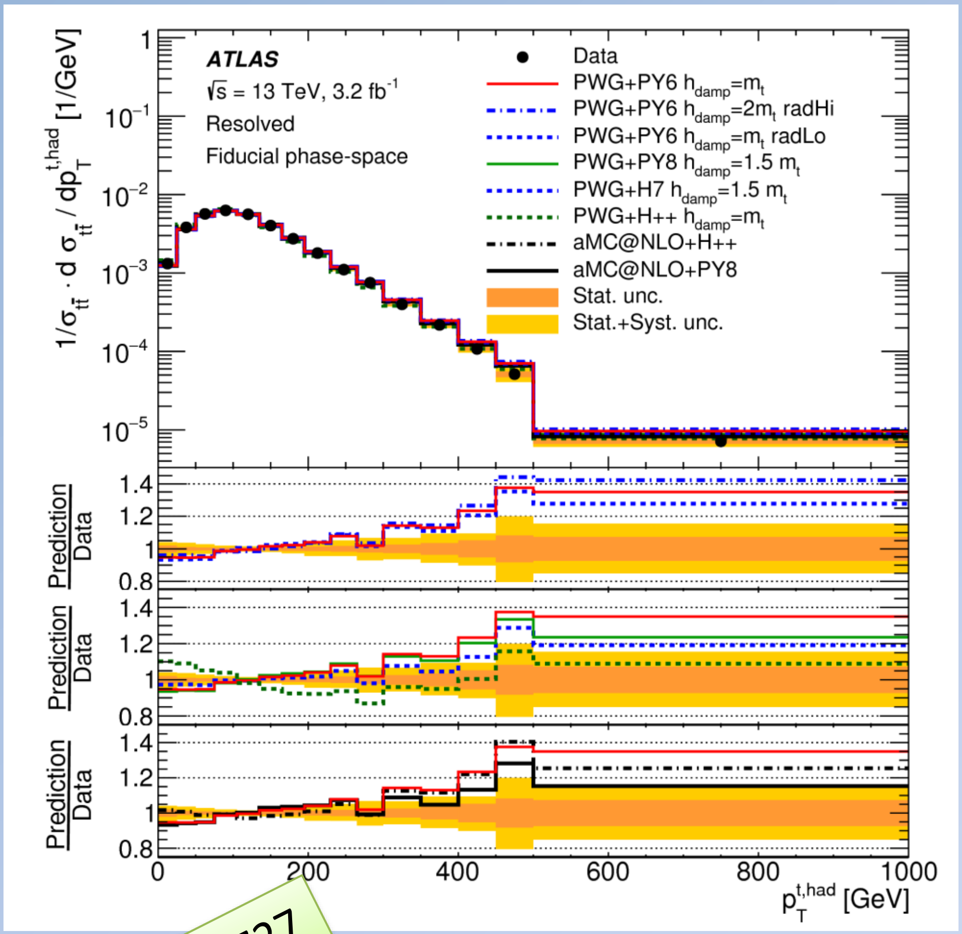


- Uncertainties are still very big
- Herwig++ really off

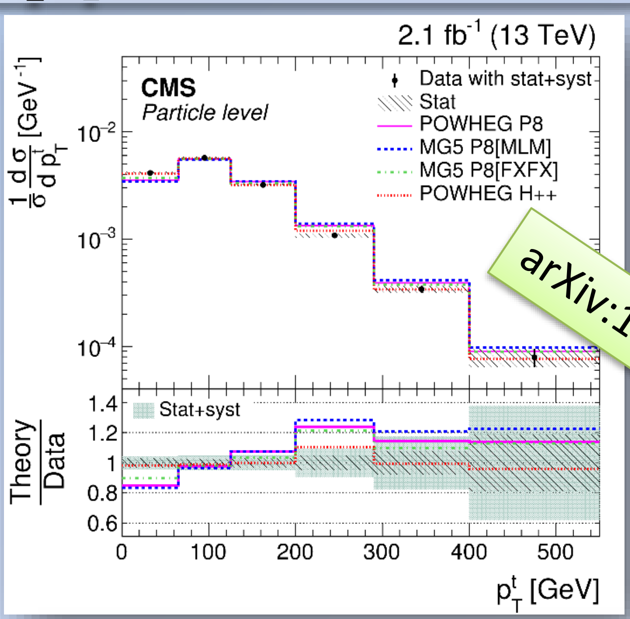
Note: $m(t\bar{t})$ depends on the choice of the jet selection used in the top definitions

arXiv:1708.00727

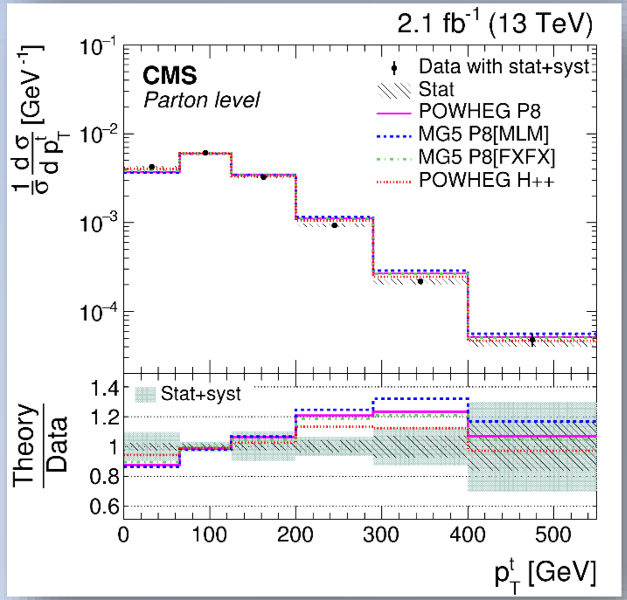
Top quark p_T



arXiv:1708.00727

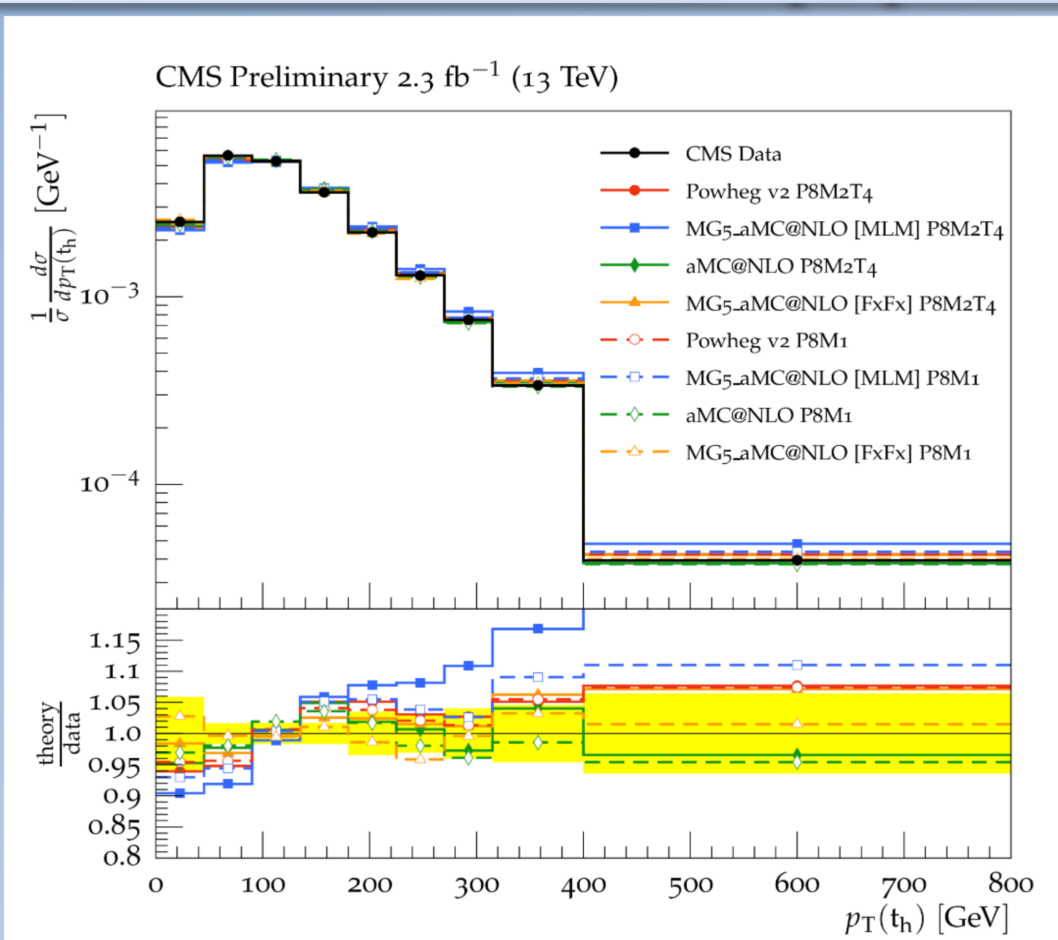


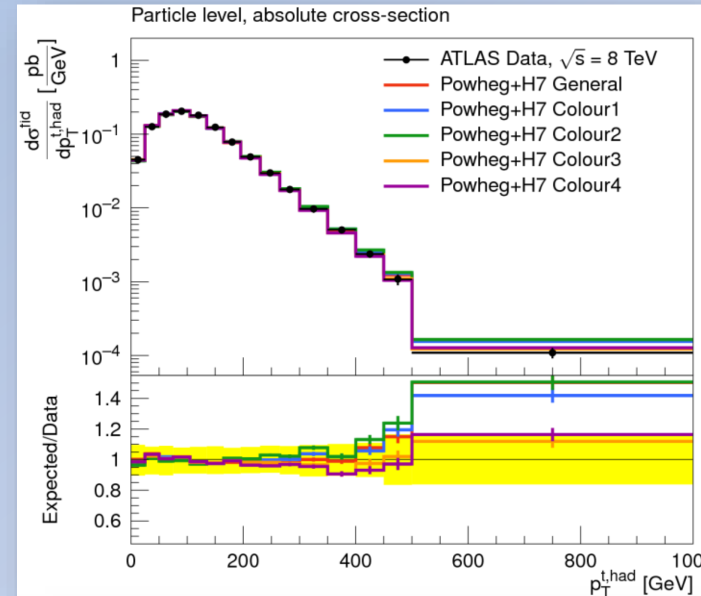
arXiv:1708.07638

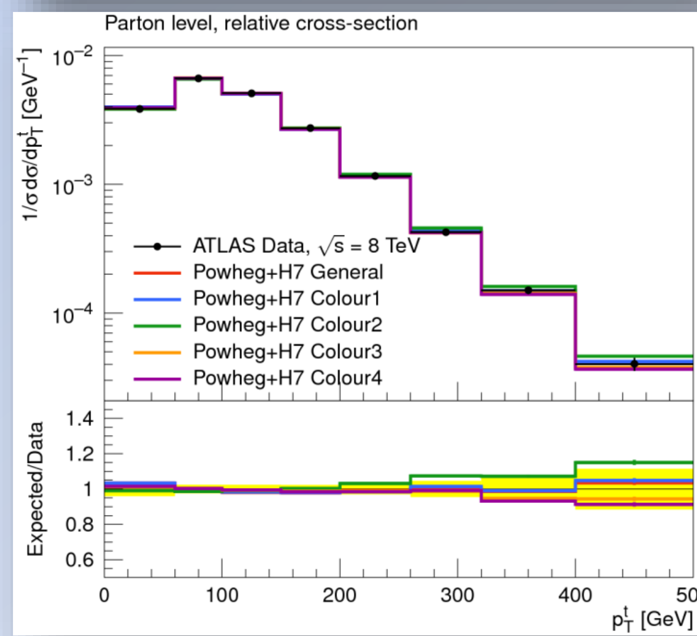


Know slope visible in all generators

Top quark p_T



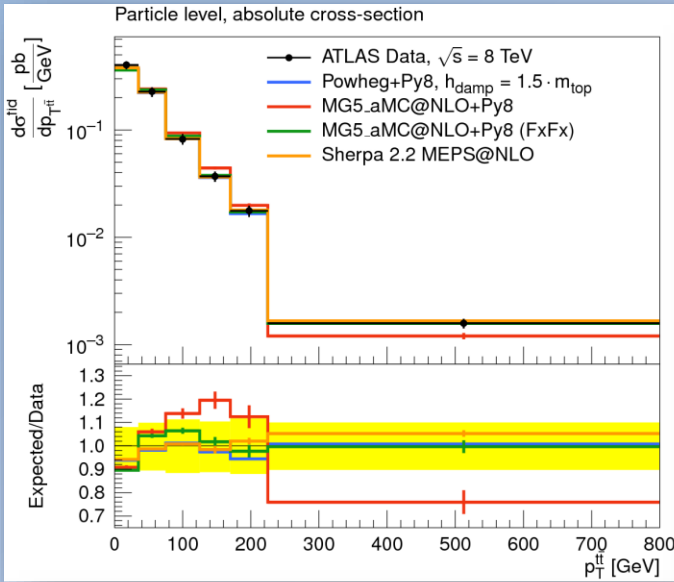


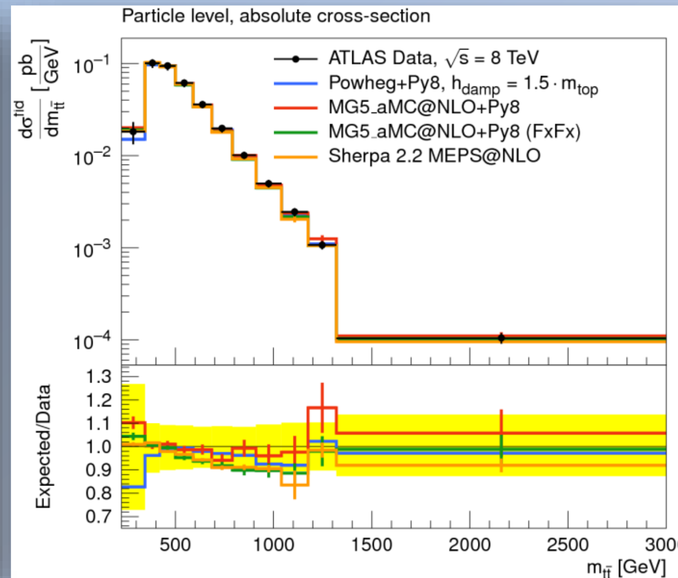


ATL-PHYS-PUB-2016-020

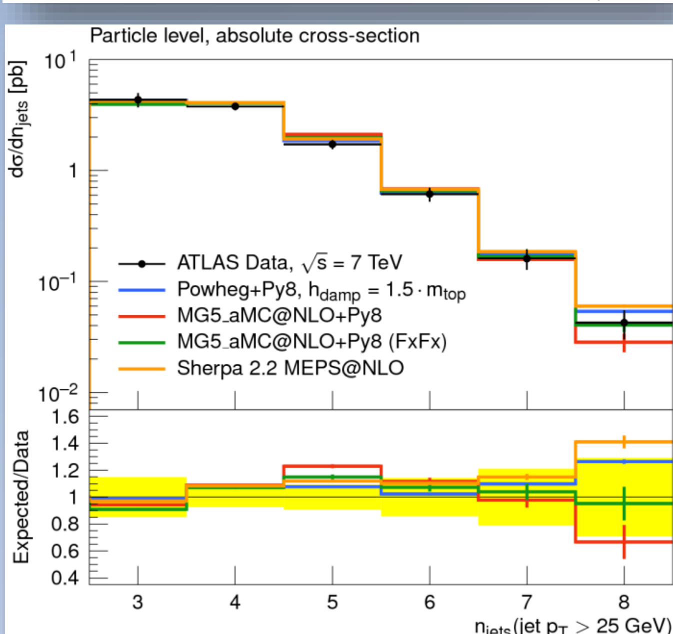
- MG5_aMC@NLO shows best agreement with data
- Herwig7 reconstruction option improves modelling quite a bit → almost no slope anymore

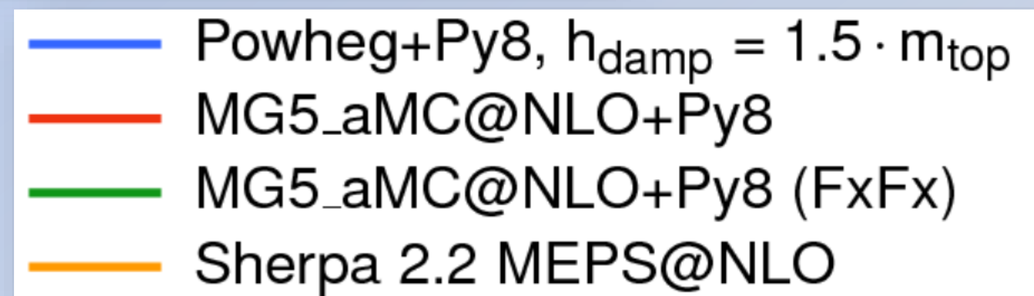
Further studies – New generator setups





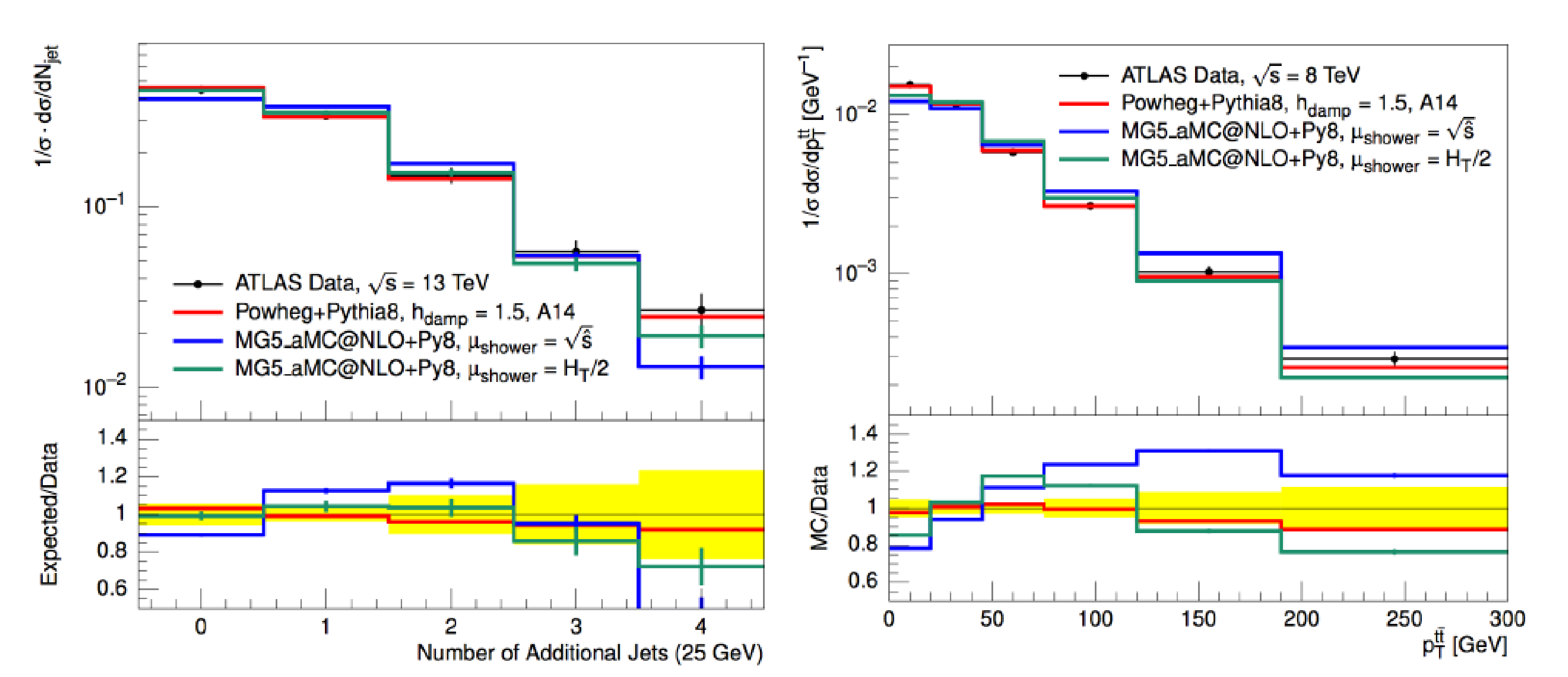
ATL-PHYS-PUB-2016-020





- MG5_aMC@NLO+Pythia8 shows clear problem!
  → see next slide
- Sherpa and FxFx matching/merging shows nice agreement, but not completely validated yet

Further studies – MG5_aMC@NLO+Pythia8



- Study of shower starting scale for MG5_aMC@NLO+Pythia8 with the A14 tune
- New scale shows quite some improvement in number of additional jets

Systematic uncertainties

Idea: Factorise uncertainties off different parts of the event generation

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

Stolen from Andrea Knue

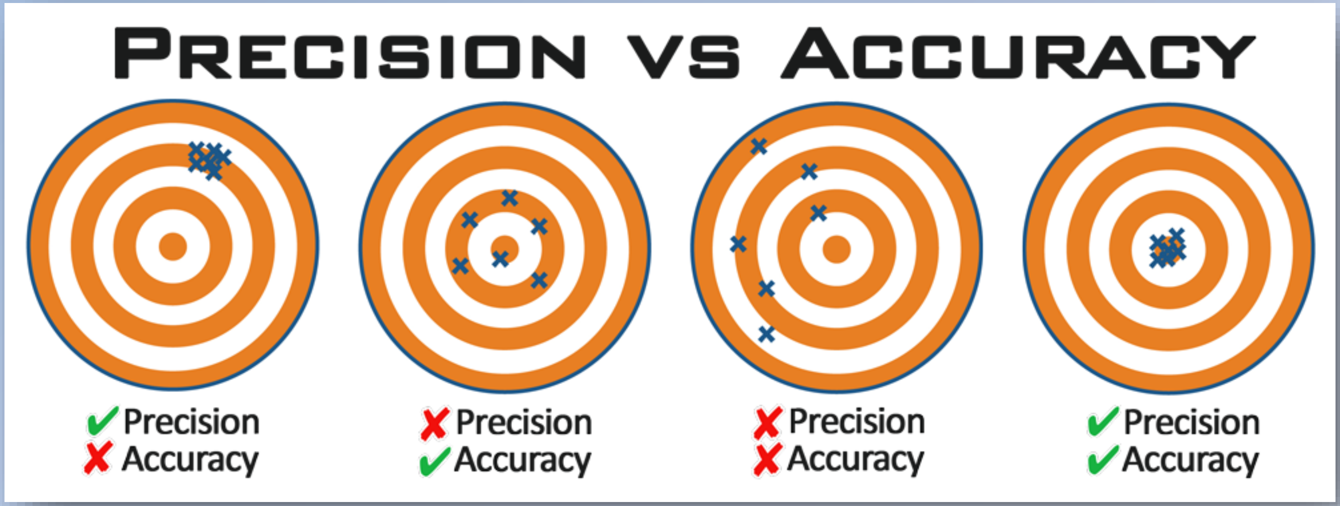
Proposal for parton shower modelling uncertainties from CMS

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

Uncertainty basically based only on one generator

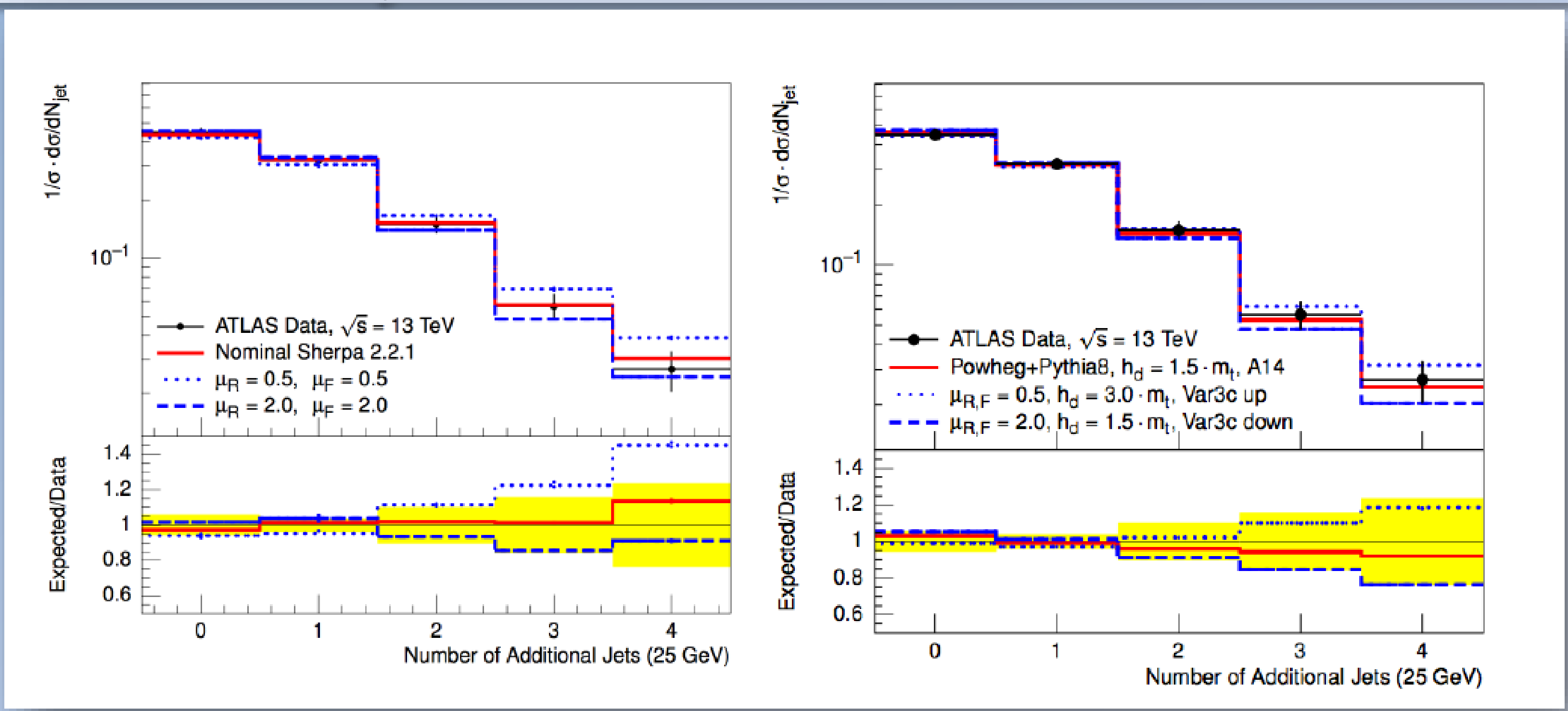
Systematic uncertainties

Interesting discussion in the last ATLAS-CMS workshop about definition of systematic uncertainties.



The main question is, how much should we tune the MC to data and how should the uncertainties be defined.

Systematic uncertainties



Njet distribution in Powheg was tuned to match data
Uncertainty band is designed to bracked data uncertainty
→ „Reweighted MC“ to match data → no predictivity anymore

Sherpa comes „out-of-the-box“, matches Njet distribution in data
Theory uncertainties higher than data uncertainties!

Conclusion

- Many unfolded top distributions available at 7, 8 and 13 TeV

- Both ATLAS and CMS using NLO+PS Powheg + Pythia8 setup as their default
  - Tuned using some unfolded top distributions

- Working on improving other NLO+PS setups, but also on matched/merged ones
  - Sherpa looks very promising, but small bugs, huge event generation time and lack of a systematic recipe avoid yet being promoted to be the default generator

- There is not “top” top model yet, but we are working hard