Top modelling uncertainties in run 2 analyses

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on behalf of ATLAS & CMS

Introduction

- Modelling uncertainties typically dominant or important source in top measurements
- Prescriptions for dealing with modelling uncertainties under constant scrutiny and development
  - ➡ Better understanding of modelling results in improved precision in our measurements
  - ➡ Also important for searches where top is a background in tails of distributions
- Compare prescriptions used in run 2 analyses from ATLAS and CMS
  - ➡ Examples of analyses using newest prescription
  - ➡ Also cover single top, tt+V

Current baseline for top pair production

- Powheg+Pythia8 for both CMS and ATLAS
  - ➡ Baseline for all systematic variations
  - ➡ 2-point/parameter variation systematic approach
- ATLAS
  - ➡ A14 Pythia tune
  - ➡ h_{damp} = 1.5 m_t
  - ➡ ATL-PHYS-PUB-2016-020
- CMS
  - ➡ CUETP8M2T4 top specific Pythia tune
  - ➡ h_{damp} = 1.58 m_t
  - ➡ TOP-16-021
- Other generator combinations
  - ➡ MG5_aMC@NLO
  - ➡ Herwig++/Herwig7
  - ➡ Sherpa+OpenLoops+CS
- Factorisation approach modelling uncertainties
  - ➡ Each source gets its own variation
  - ➡ Source by source comparison in the following slides

Current status

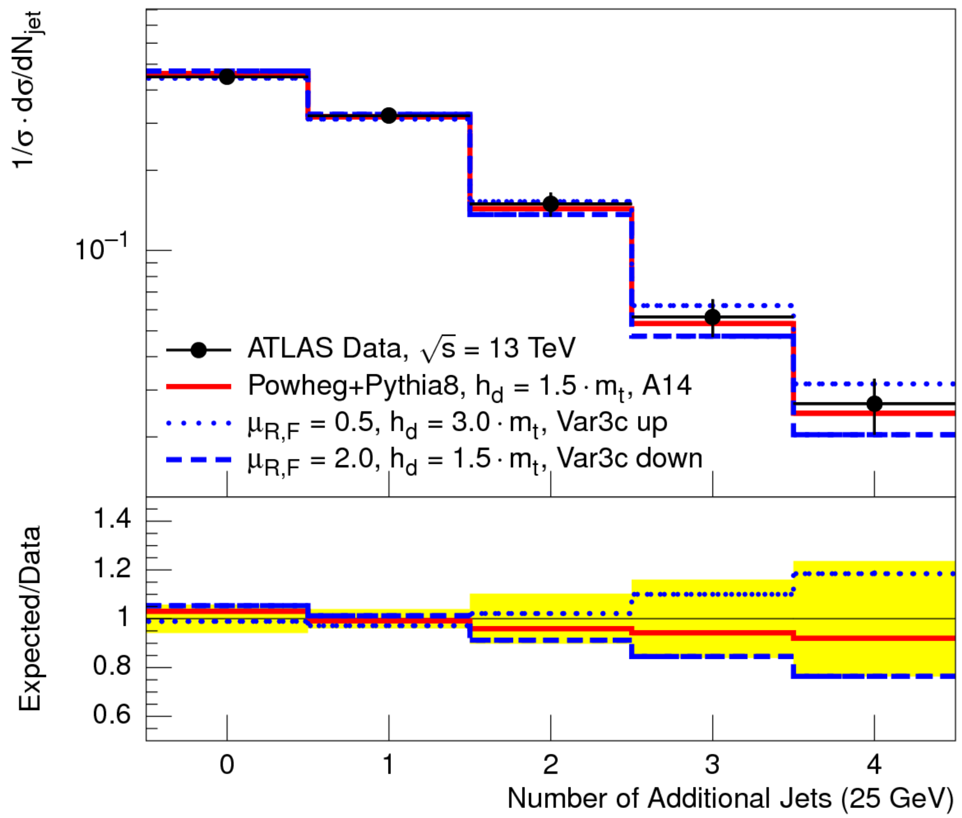
Source	ATLAS	CMS
Radiation/scale	Simultaneous $\mu_{R,F}$, h_{damp}, α_S^{ISR} variations	Individually vary $\mu_{R,F}$, h_{damp}, ISR scale, FSR scale
Shower/ Hadronisation/ Fragmentation	Pythia8 vs Herwig7	Variations in modelling of b jets, Pythia6 vs Herwig++ in JES
ME Generator	Powheg vs MG5_aMC@NLO	Powheg vs MG5+aMC@NLO (FxFx) (only in some analyses)
Non-pertubative	A14 tune variations	CUET2P8M2T4 variations, CR model variations

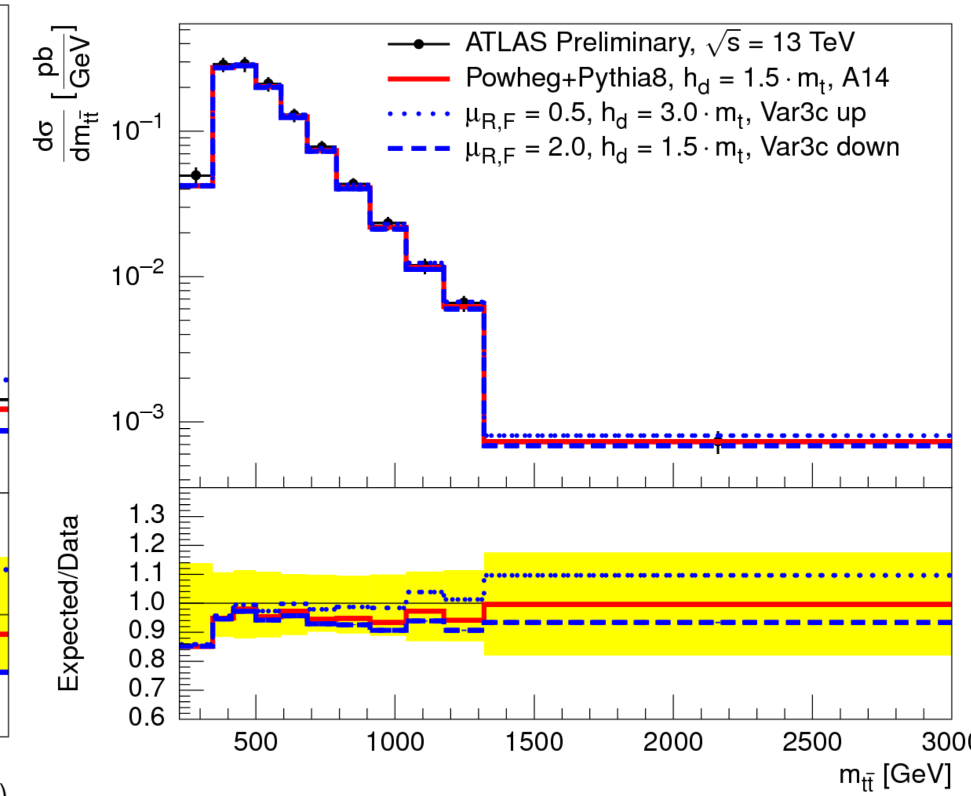
Radiation/scale/ME-PS Uncertainties

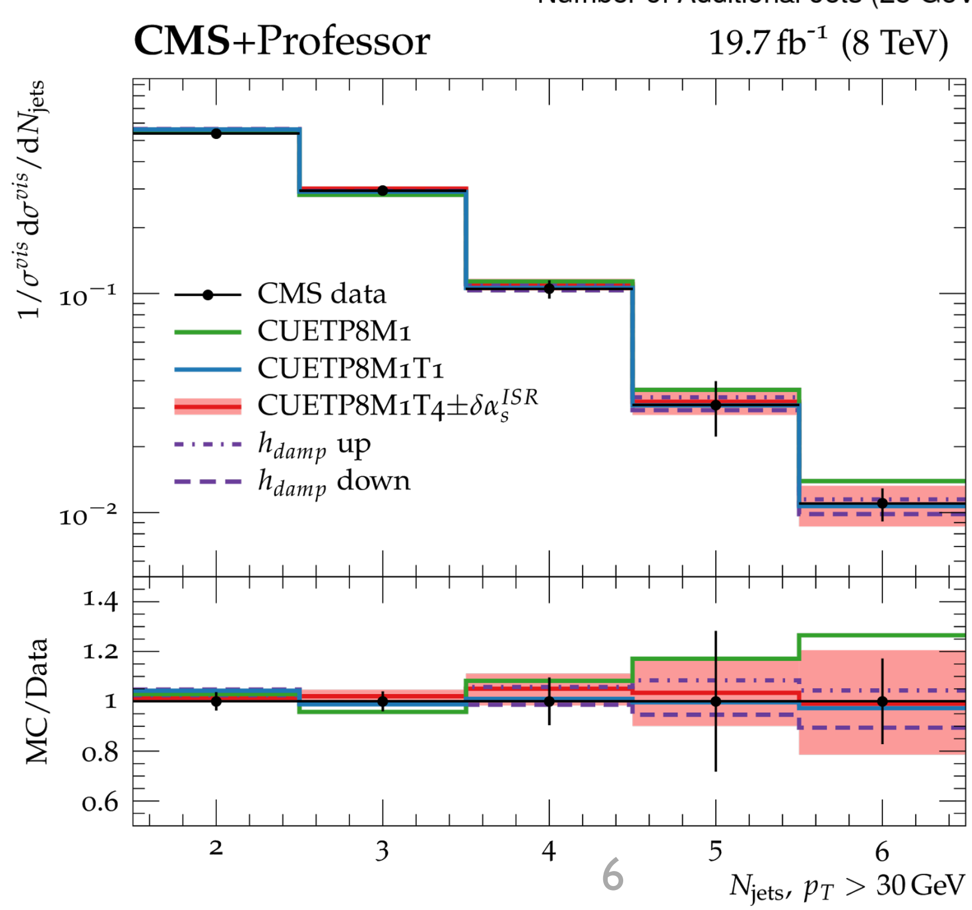
	ATLAS	CMS
Nominal	A14 Tune Var3c $\alpha_S^{ISR} = 0.127$ (SpaceShower:alphaSvalue) $h_{damp} = 1.5\ m_t$ NNPDF3.0 NLO in ME, 2.3 LO in PS	CUETP8M2T4 Tune $\alpha_S^{ISR} = 0.1108$ $h_{damp} = 1.581\ m_t$ NNPDF3.0 NLO (α_S=0.118) in ME, LO (α_S=0.130) in PS
Uncertainty variations	Simultaneous variation of parameters • Up ➡ $\mu_{F,R}$ x 0.5 ➡ $h_{damp} = 3\ m_t$ ➡ Var3c up (0.140) • Down ➡ $\mu_{F,R}$ x 2 ➡ $h_{damp} = 1.5\ m_t$ ➡ Var3c down (0.115)	• ISR scale varied by 0.5/2 (TimeShower::renormMultFac)
		• FSR scale varied by $1/\sqrt{2}$ and $\sqrt{2}$ (SpaceShower::renormMultFac)
		• Envelope of independent and simultaneous variations of μ_R, μ_F by 0.5/2
		• Vary h_{damp} by ~40% ➡ Corresponds to 1 to 2.2 m_t ➡ Uncertainty in tuned value

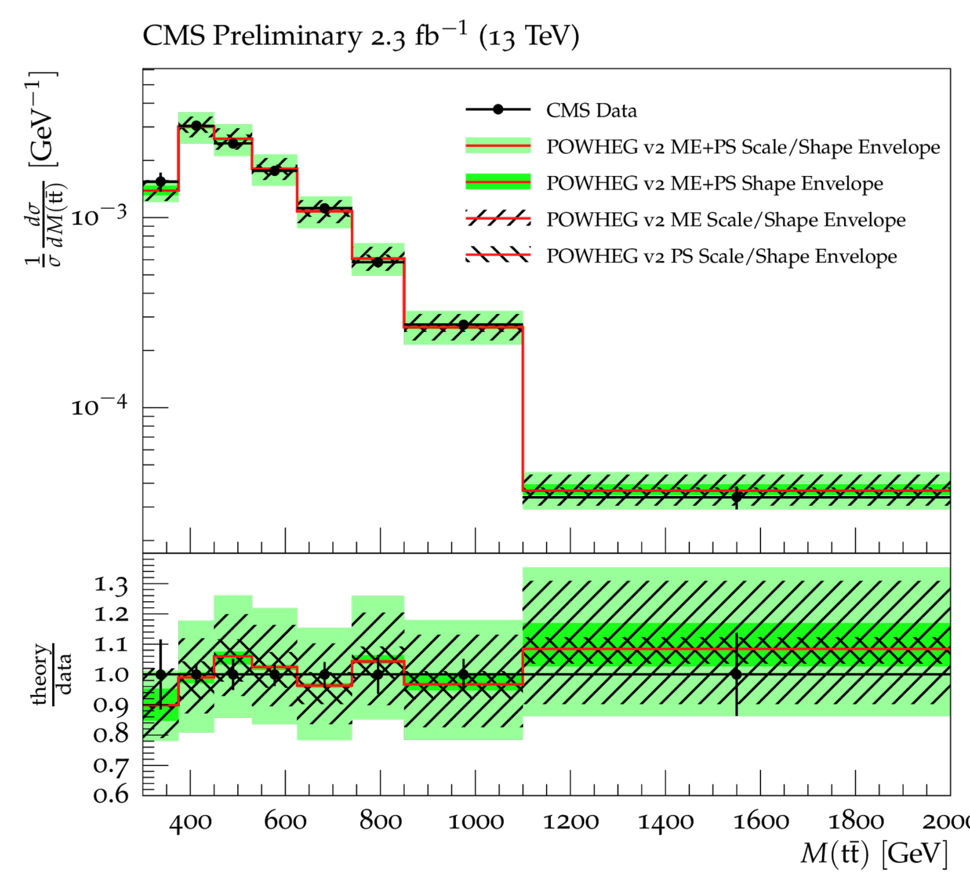
Radiation/scale/ME-PS Uncertainties

- Studies from both ATLAS & CMS justify choices of variations
  - ➡ ATL-PHYS-PUB-2017-007
  - ➡ TOP-16-021









Hadronisation, ME generator, b jet modelling

ATLAS

- Hadronisation/PS
  - ➡ Replace Powheg+Pythia8 with Powheg+Herwig7
  - ➡ Similar comparison performed in deriving JES and corresponding uncertainties ATL-PHYS-PUB-2015_042
- ME generator
  - ➡ Replace Powheg+Pythia8 with MG5_aMC@NLO+Pythia8
- See ATL-PHYS-PUB-2016-020 for more details
  - ➡ Swapping Pythia8 for Herwig7 changes top and $t\bar{t}$ kinematics - better top p_T modelling

CMS

- Flavour response/Hadronisation
  - ➡ Vary JES for each jet flavour, from comparisons between Pythia6 and Herwig++
  - ➡ Comparison here only affects JES
  - ➡ Plans to consider Herwig7
- ME generator
  - ➡ Replace Powheg+Pythia8 with MG5_aMC@NLO (FxFx) + Pythia8
  - ➡ Only in some analyses
- B jet modelling
  - ➡ Vary $x_b = p_T(\text{B hadron}) / p_T(\text{bjet})$
  - ➡ Reweight branching fraction of semileptonic b hadrons to PDG values
- Top p_T
  - ➡ Reweight top p_T to that observed in data

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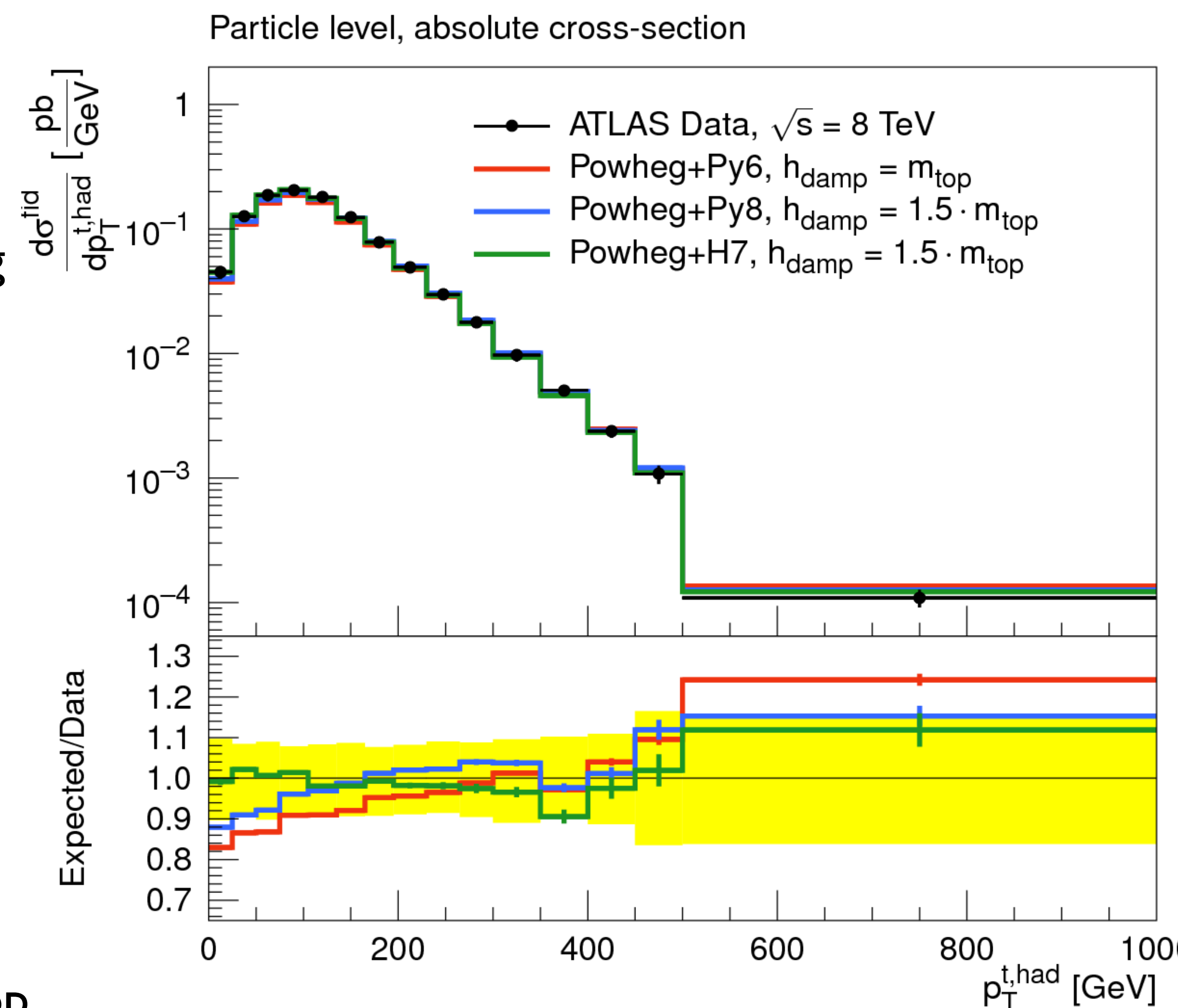


Colour Reconnection, MPI, UE uncertainties

ATLAS

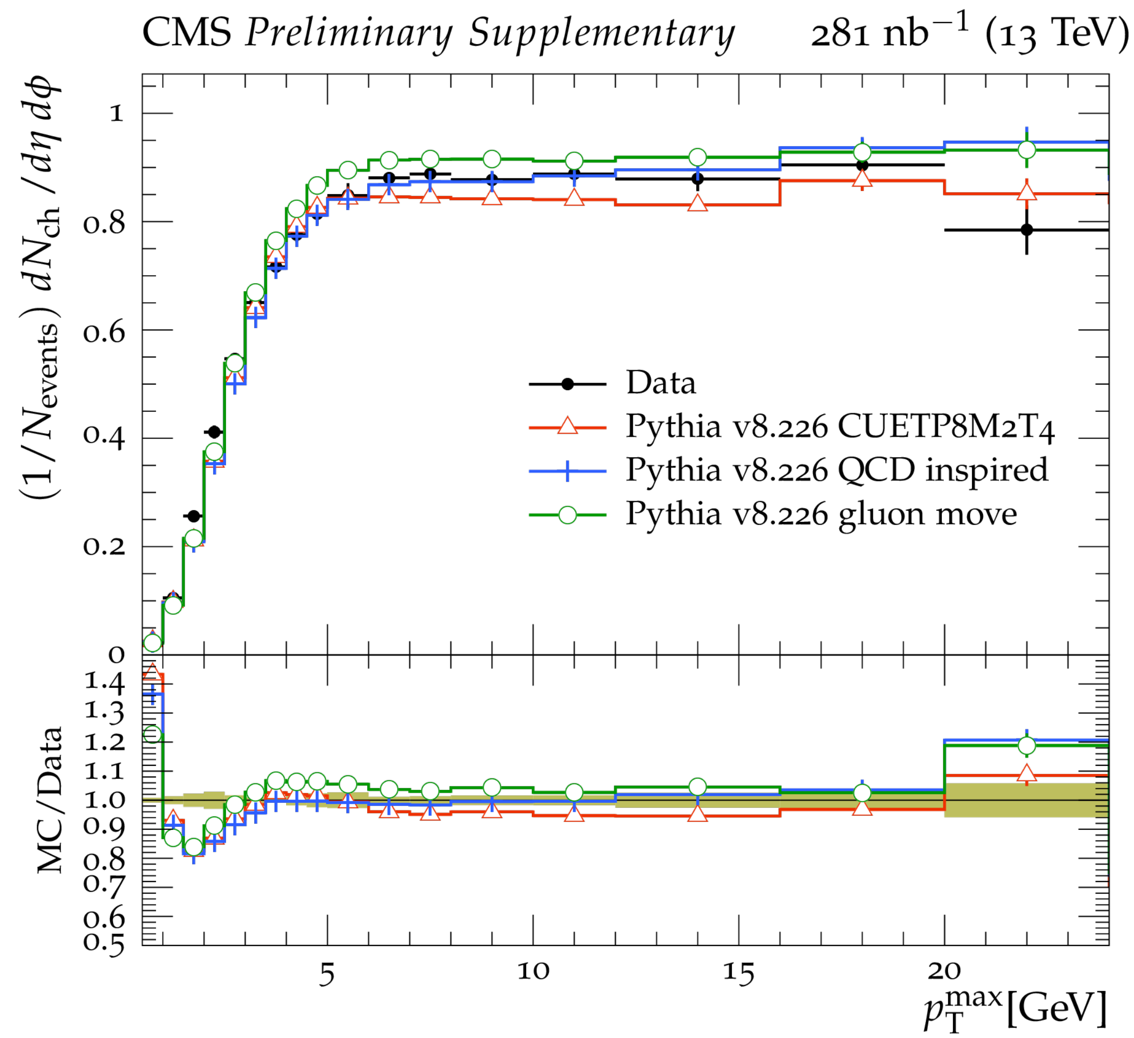
- Variations in A14 tune
  - ➡ ATL-PHYS-PUB-2014-021
  - ➡ Var 1 (MPI+CR), corresponds to varying:
  - ➡ BeamRemnants:reconnectRange
  - ➡ MultipartonInteractions:alphaSvalue
  - ➡ Effort in improving : ATL-PHYS-PUB-2017-008

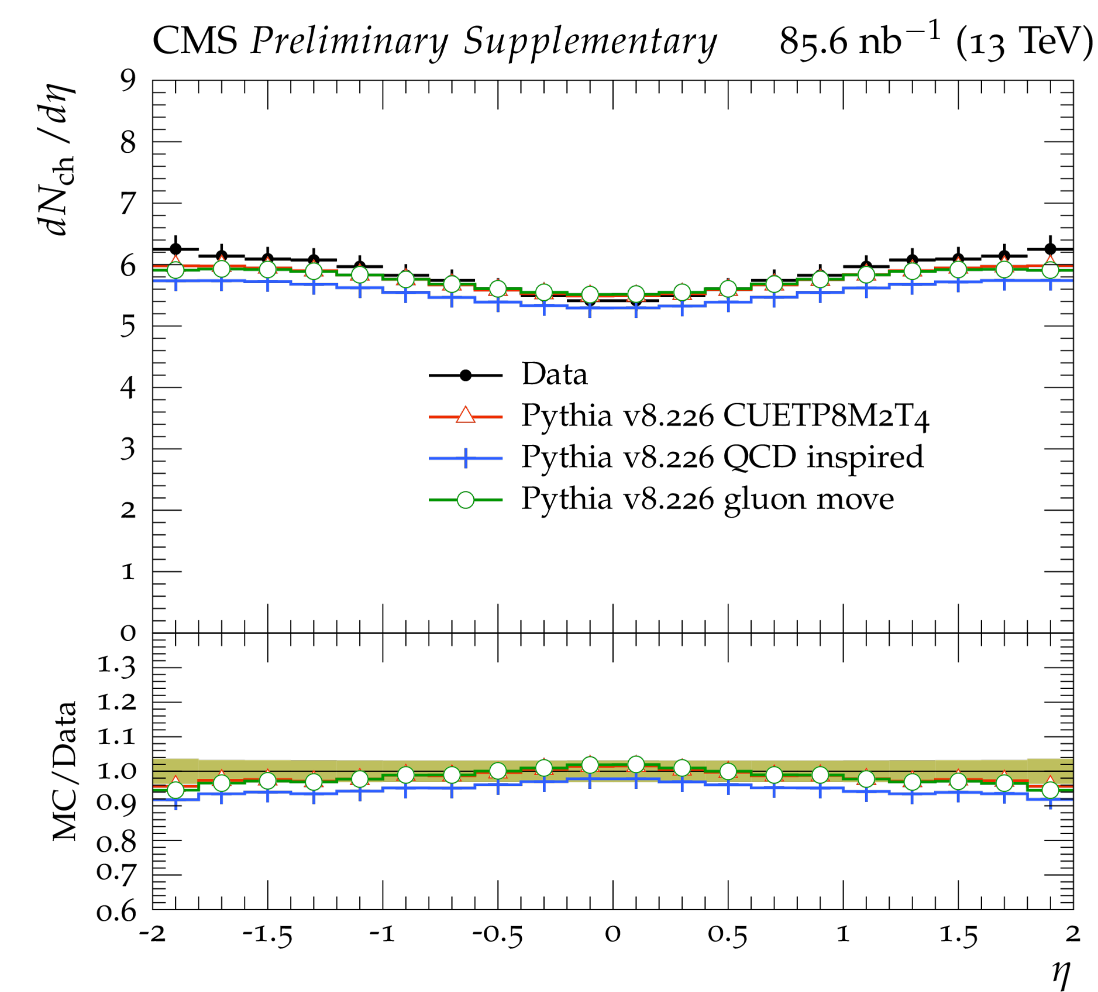
CMS

- Compare nominal simulation with alternative models of CR
  - ➡ Turn ERD on - allows top decay products to be involved in colour reconnection
  - ➡ 'QCD inspired' model - string formation beyond leading color
  - ➡ 'Gluon move' - gluons can be moved to different strings
- Variations of tuned UE parameters in CUETP8M2T4
  - ➡ TOP-16-021
  - ➡ MultipartonInteractions:pT0Ref
  - ➡ MultipartonInteractions:expPow
  - ➡ ColourReconnection:range

CMS : Uncertainties in top mass

- Top mass measurement with run 2 data
  - ➡ TOP-17-007
  - ➡ 172.25 ± 0.08 (stat + JSF) ± 0.62 (syst) GeV
- Dominant uncertainties
  - ➡ Colour reconnection
  - ➡ Modelling of hadronization (Flavour dependent JEC, b-jet modelling)
  - ➡ ME generator, FSR PS scale
- Alternative CR models tuned to 13 TeV UE data
- Fit to charged particle
  - ➡ multiplicity and average p_T sum vs leading charged particle p_T in transMIN and transMAX regions
  - ➡ multiplicity vs pseudorapidity





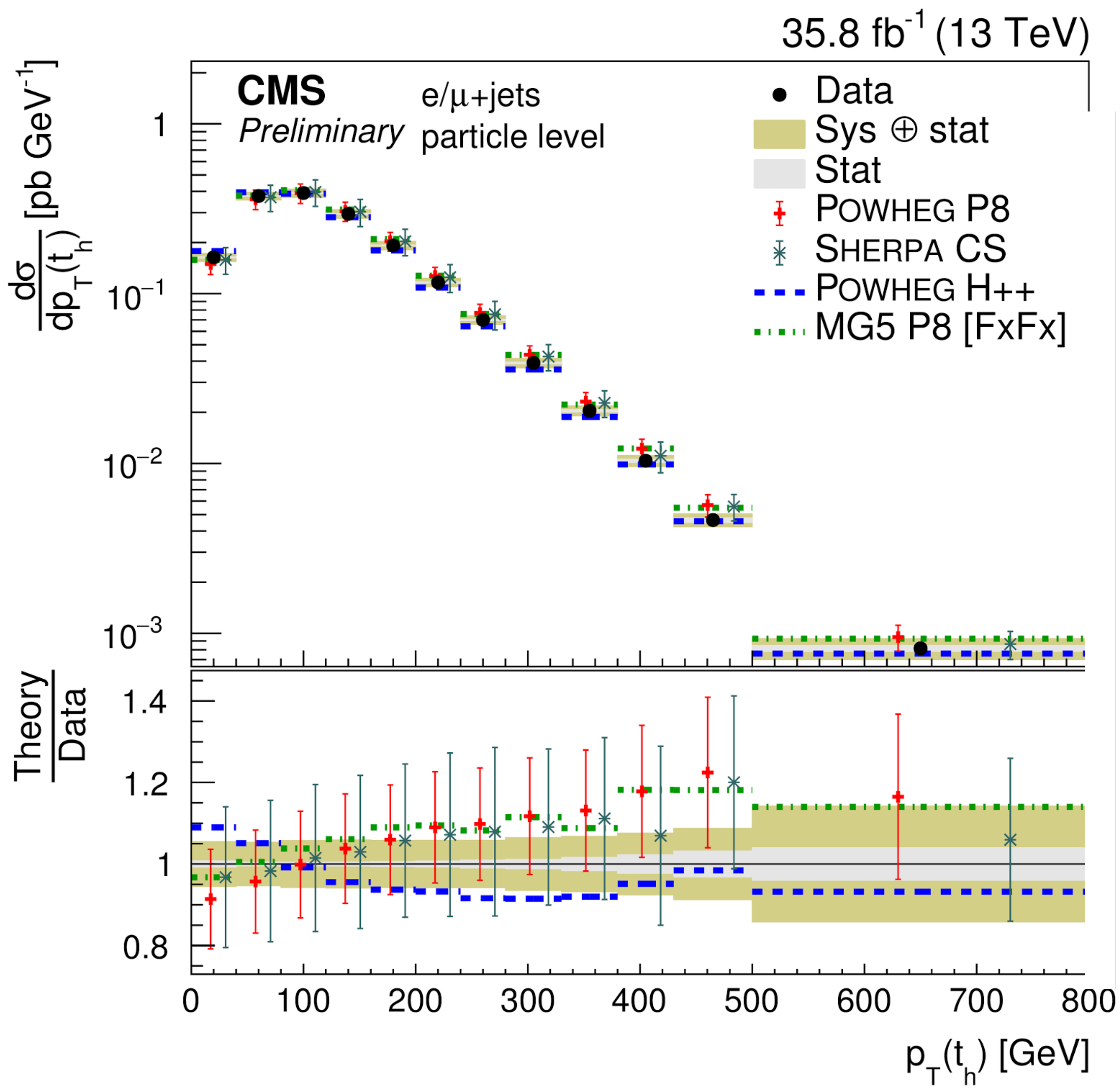
CMS : Effect of CR on top mass measurement

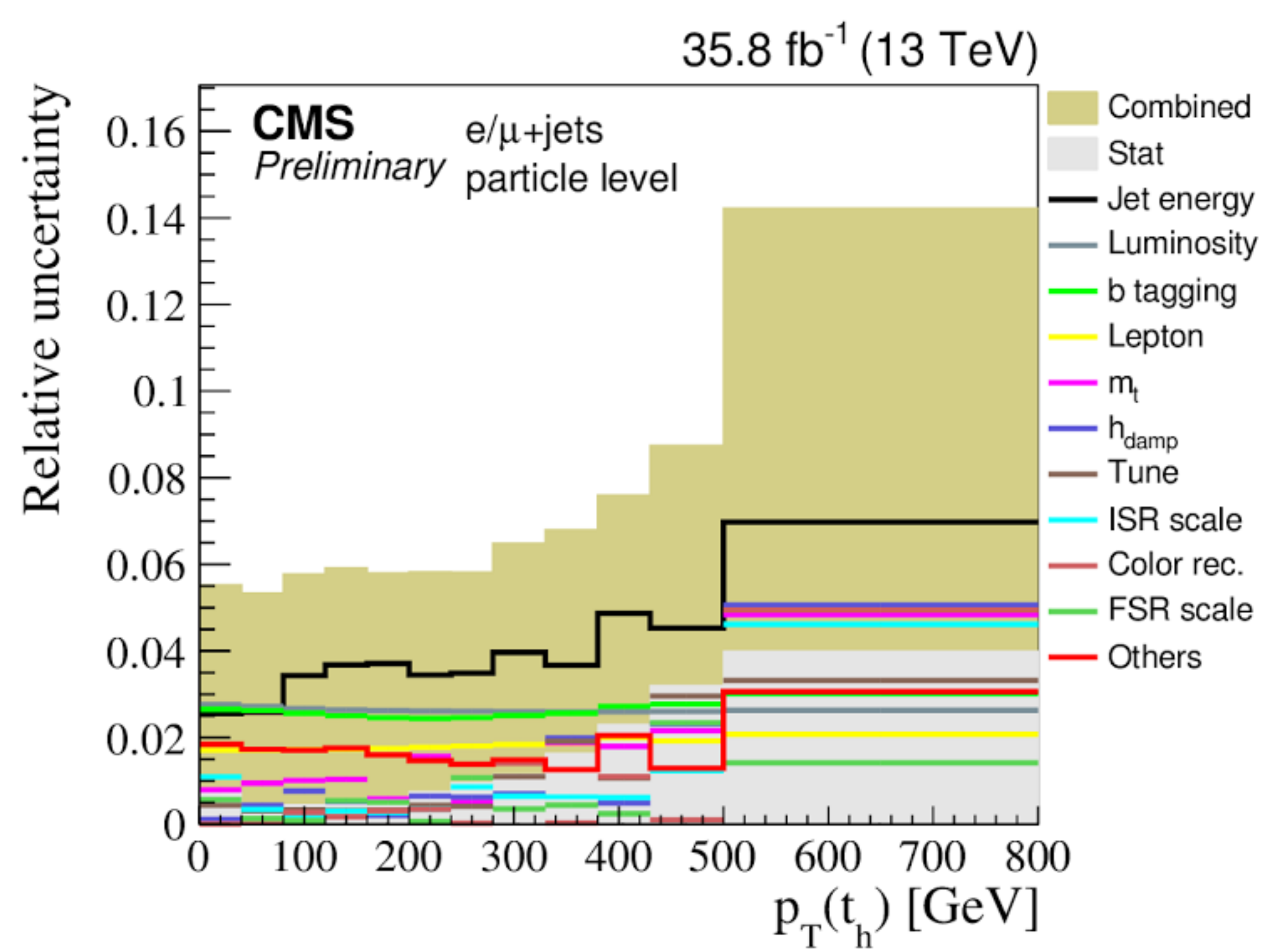
- Use tuned CR models to provide better understood uncertainty
  - ➡ Run 1 method - compare same UE tune with and without CR effects
  - ➡ Uncertainties in CR dominant, and larger compared to run 1…
  - ➡ …but better justified

	2D approach		1D approach	Hybrid	
	δm_t^{2D} (GeV)	$\delta \mathrm{JSF}^{2D}$	δm_t^{1D} (GeV)	δm_t^{hyb} (GeV)	$\delta \mathrm{JSF}^{hyb}$
"'QCD inspired"' (both ERD on)	-0.11	-0.001	-0.19	-0.13	-0.001
"'gluon move"' (both ERD on)	+0.34	-0.001	+0.23	+0.31	-0.001
def. ERD off to def. ERD on	-0.22	+0.008	+0.42	-0.03	+0.005

CMS : Uncertainties in differential cross sections

- Differential cross sections in l+jets at parton and particle level
  - ➡ TOP-16-014 TOP-17-002
  - ➡ Modelling uncertainties in theory predictions typically cover any difference wrt data





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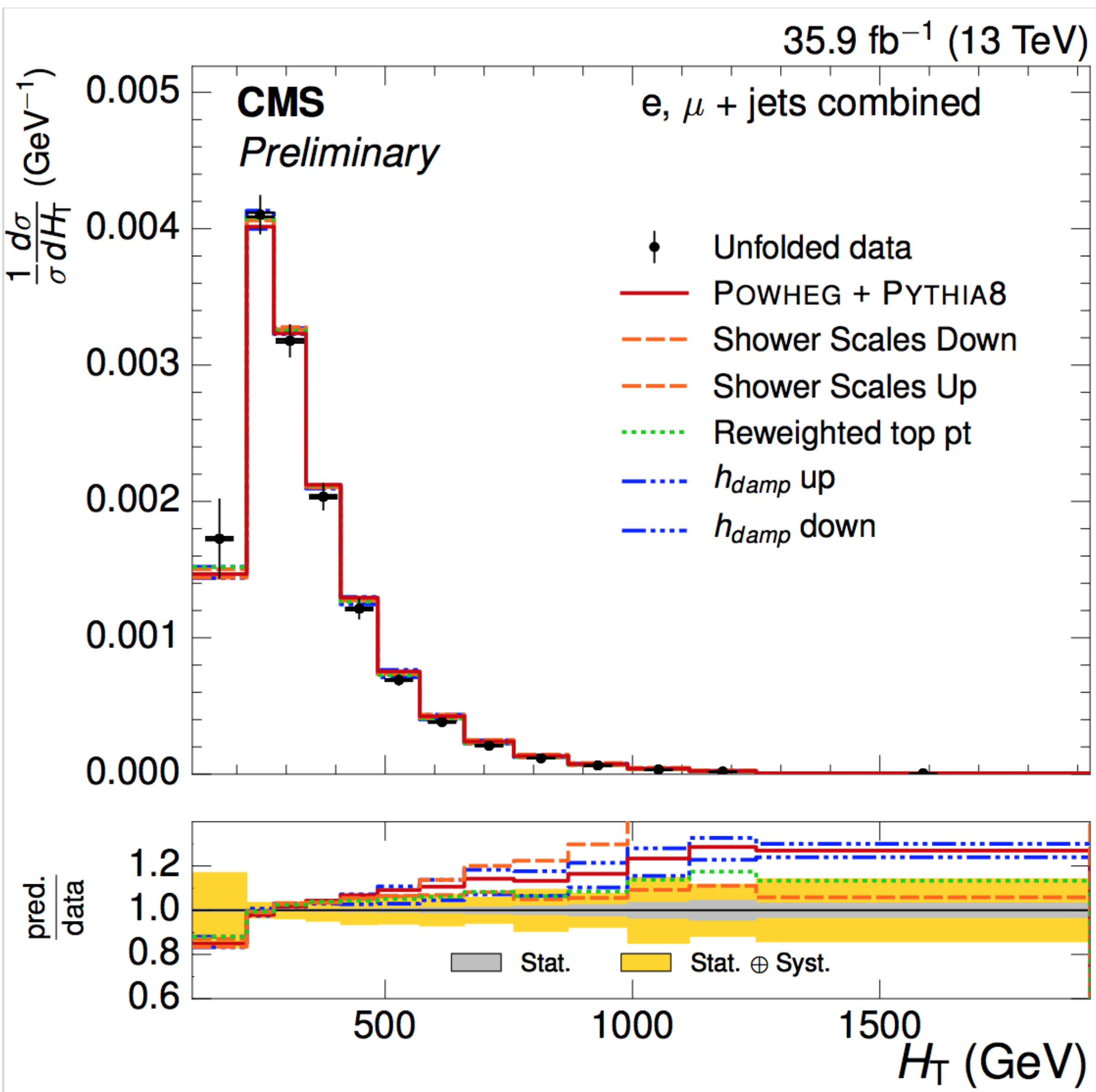
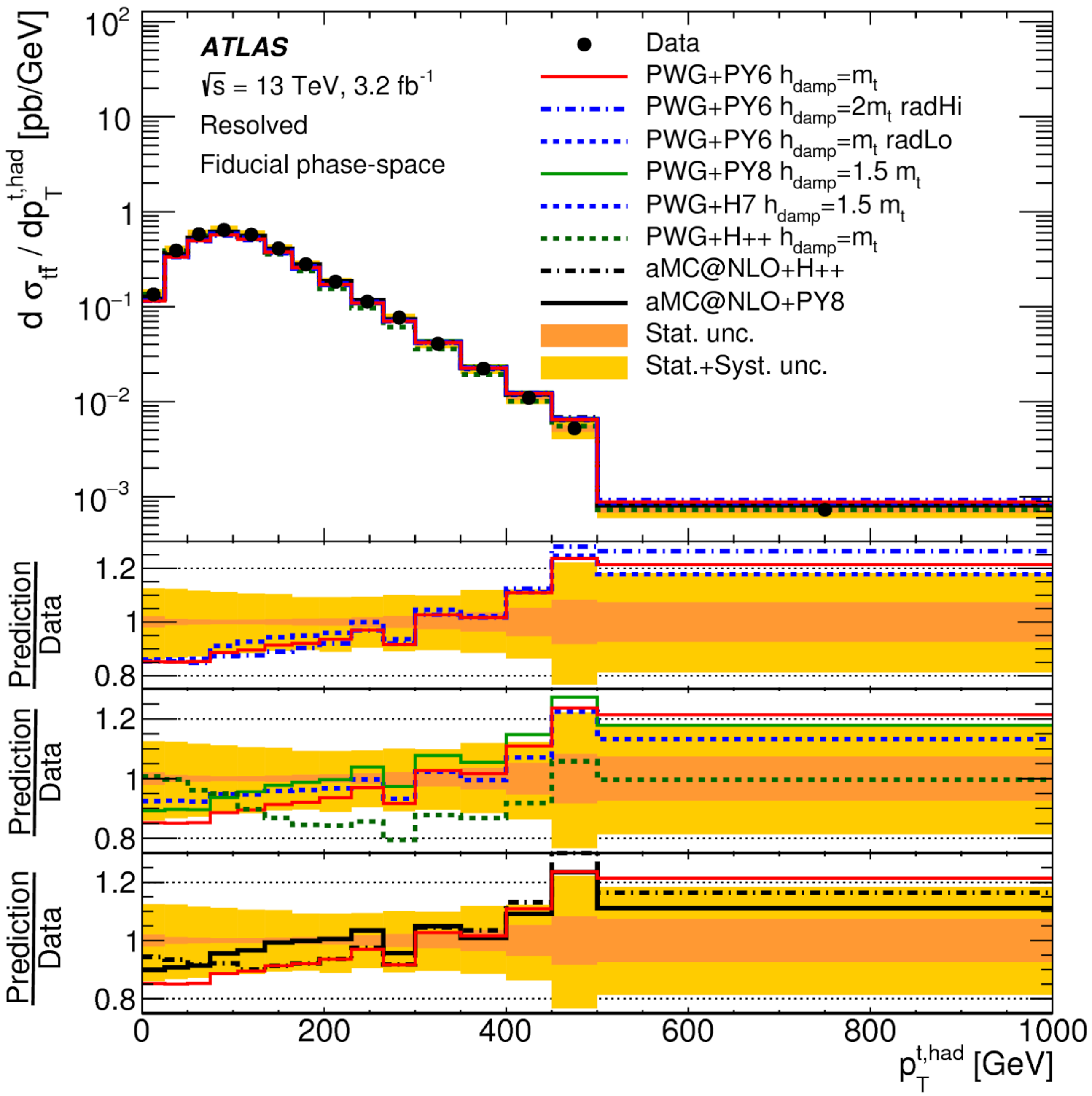
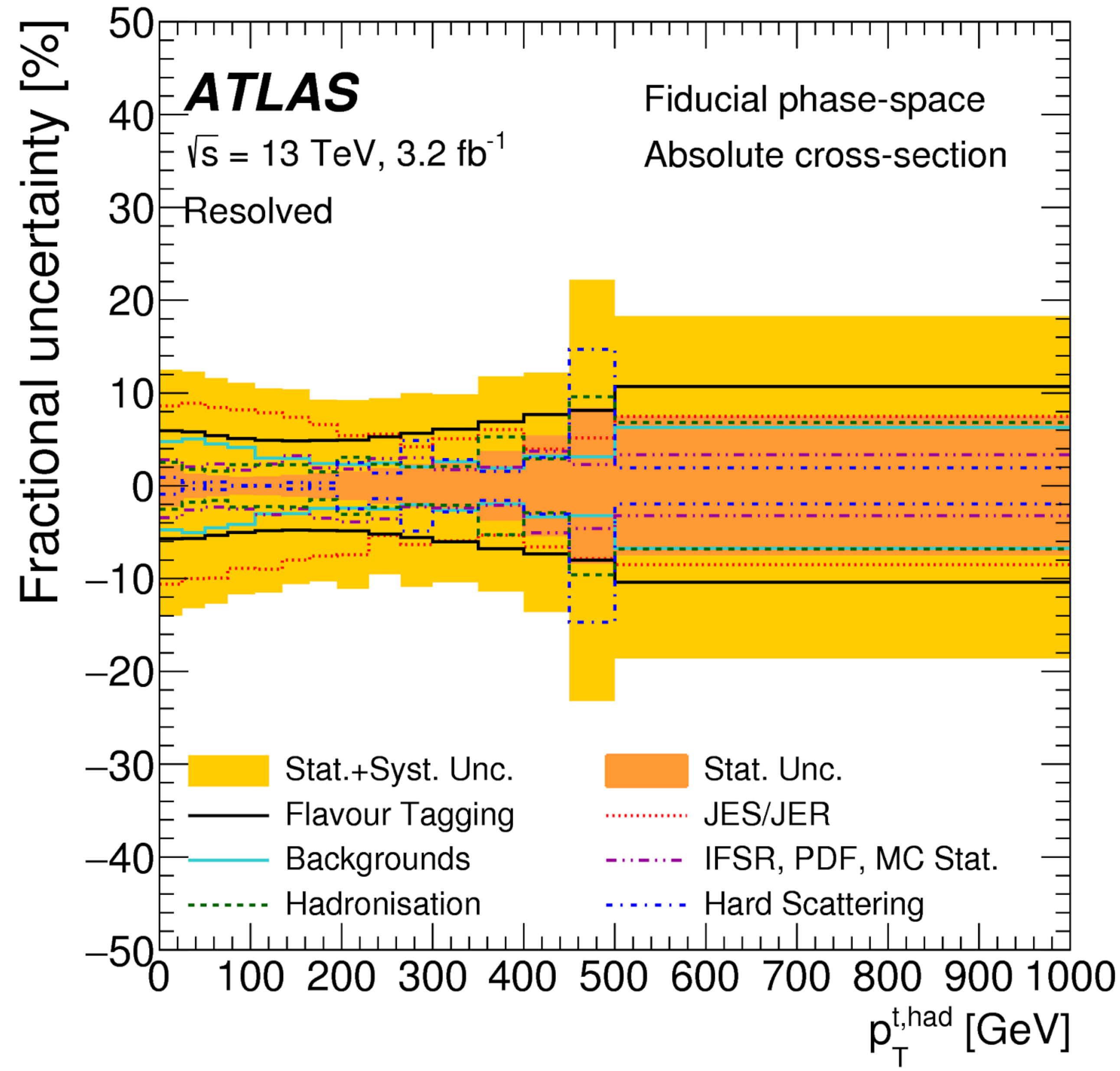


	POWHEG + PYTHIA8		POWHEG + PYTHIA8 including simulation theory uncertainties	
	χ^2 / ndf	p-value	χ^2 / ndf	p-value
N_{Jets}	2.5 / 6	0.87	2.4 / 6	0.88
p_T^W	10 / 7	0.19	6.6 / 7	0.48
p_T^l	36 / 17	< 0.01	16 / 17	0.49
H_T	35 / 13	< 0.01	8.2 / 13	0.83
S_T	26 / 13	0.015	10 / 13	0.7
p_T^{miss}	7.2 / 6	0.3	4.7 / 6	0.58
All	116.7 / 62	< 0.01	47.9 / 62	0.91

ATLAS : Uncertainties in differential cross sections

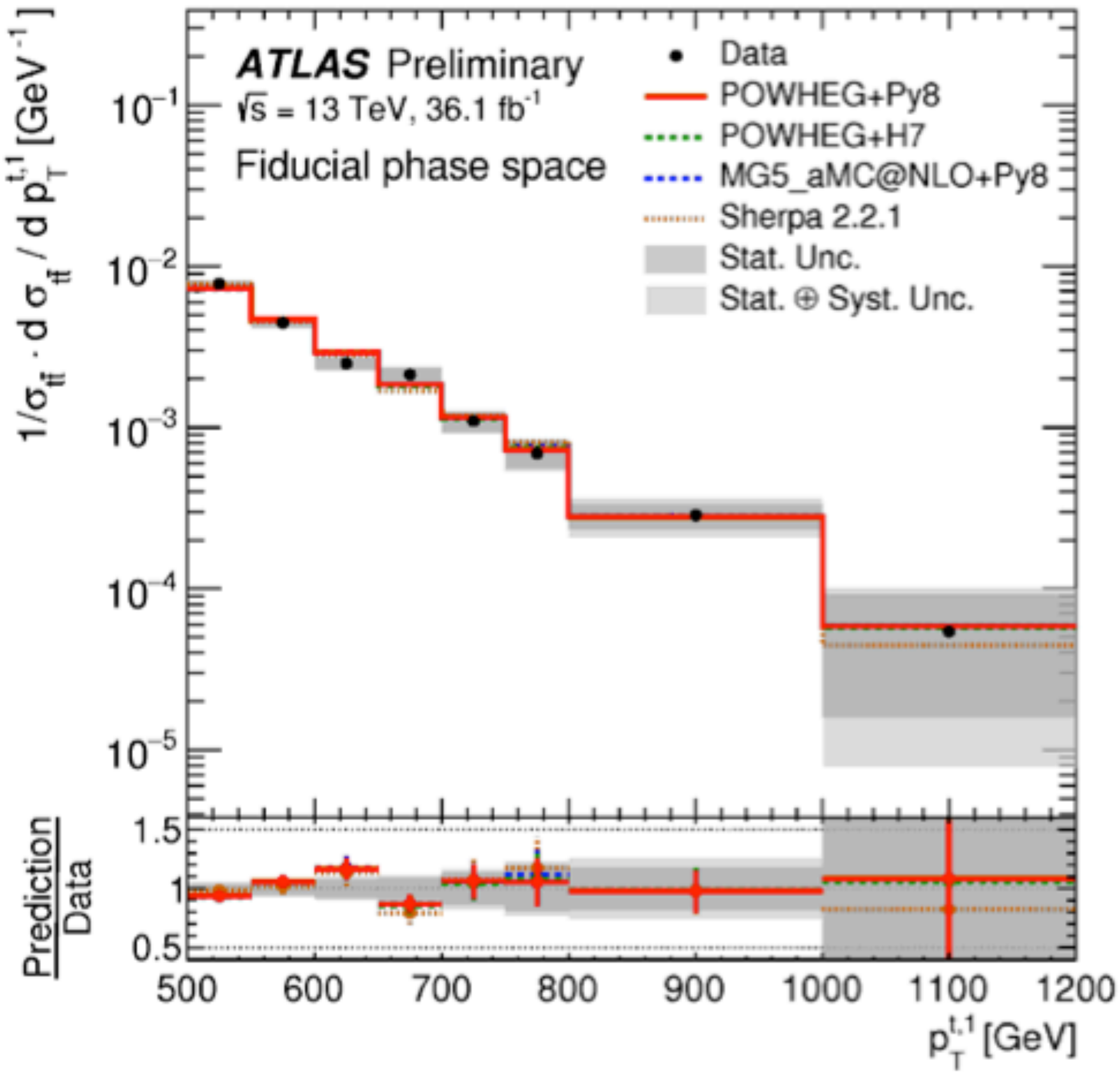
- Similar message from ATLAS
  - ➡ TOPQ-2016-01
  - ➡ Baseline simulation was Powheg+Pythia6
  - ➡ Hadronisation systematic assessed with Herwig++

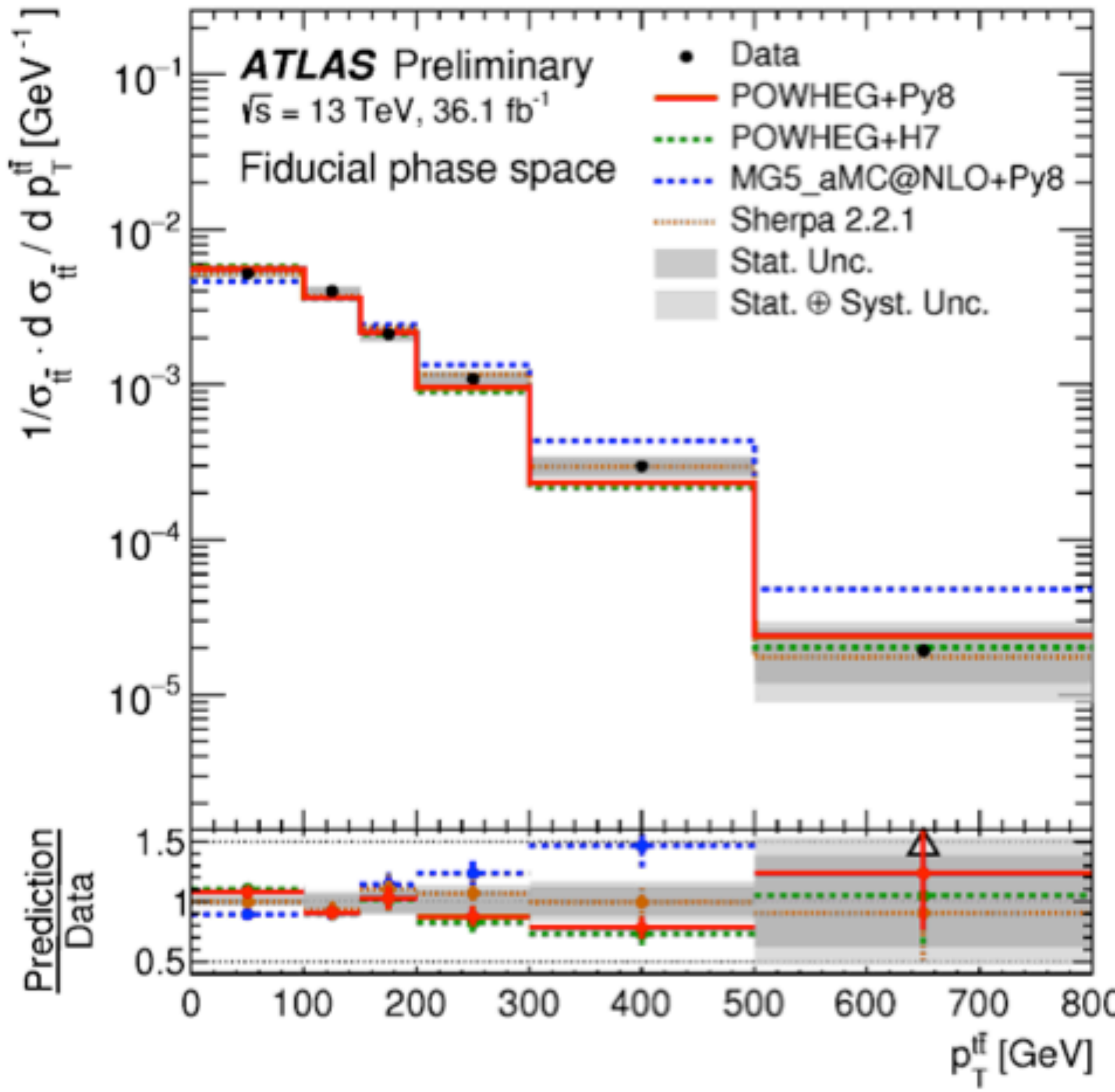




ATLAS : Uncertainties in differential cross sections

- Measurement in di-boosted hadronic channel
  - ➡ Uses most recent uncertainty prescription
  - ➡ Including comparison to latest generators

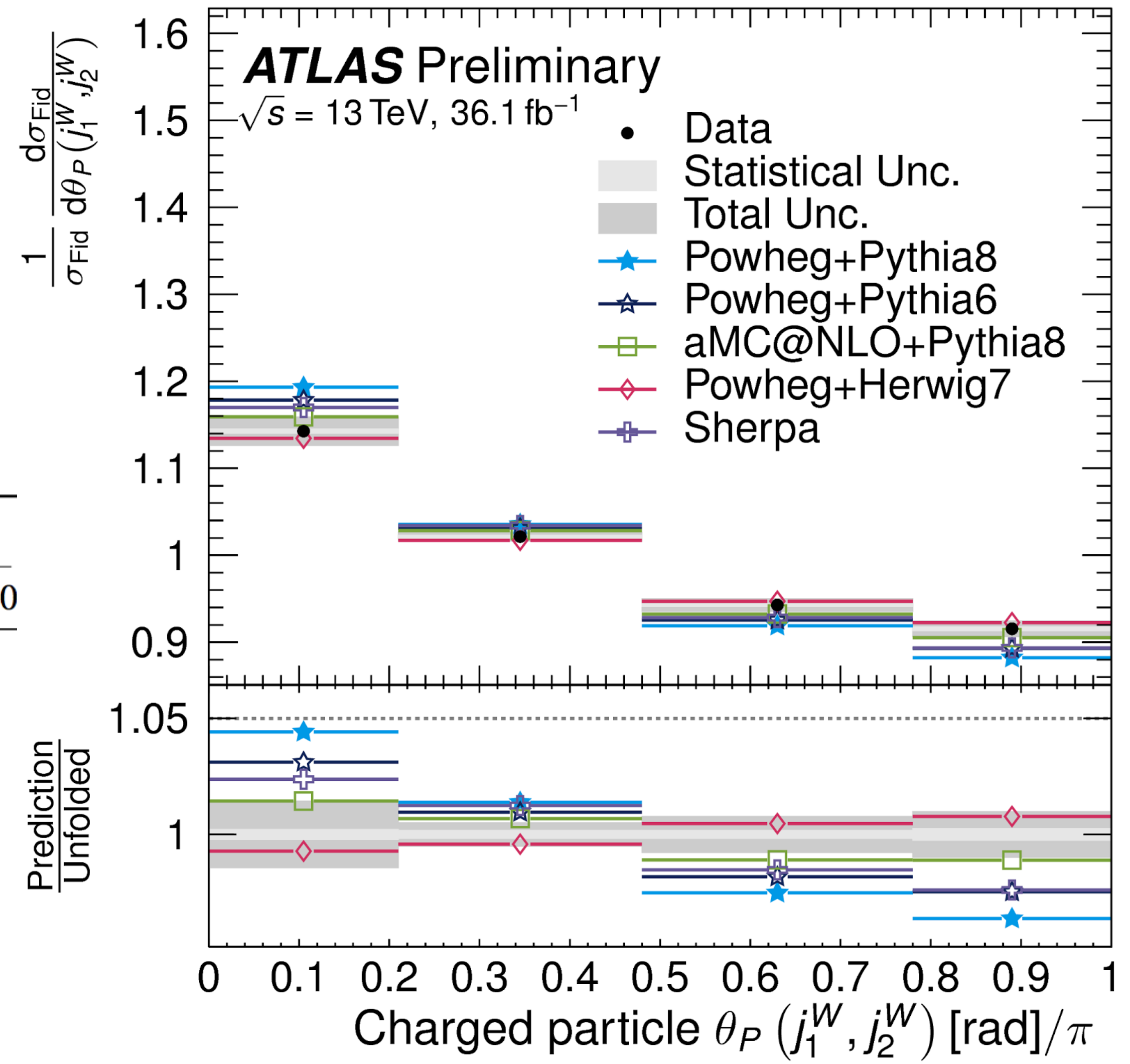




ATLAS - Colour flow

- ATLAS-CONF-2017-069
  - ➡ Uses most recent uncertainty prescription
  - ➡ Modelling uncertainties dominant in this measurement

$\Delta\theta_P\left(j_1^W, j_2^W\right)$ [%]	$\theta_P\left(j_1^W, j_2^W\right)$			
	0.0 – 0.21	0.21 – 0.48	0.48 – 0.78	0.78 – 1.0
Hadronisation	0.63	0.22	0.27	0.09
Generator	0.37	0.24	0.50	0.06
Colour Reconnection	0.11	0.26	0.03	0.53
b-Tagging	0.35	0.12	0.20	0.31
Non-Closure	0.25	0.07	0.08	0.30
ISR / FSR	0.32	0.12	0.15	0.01
Other	0.25	0.20	0.11	0.18
JER	0.12	0.13	0.21	0.03
JES	0.13	0.06	0.13	0.07
Tracks	0.09	0.04	0.05	0.07
Syst.	0.97	0.52	0.68	0.72
Stat.	0.22	0.18	0.17	0.26
Total	0.99	0.55	0.71	0.76



Single top (tW)

- Both ATLAS & CMS using Powheg (v1)
  - ➡ CMS then simulated PS with Pythia 8, ATLAS with Pythia6
  - ➡ Duplicate Removal (DR) to treat interference with $t\bar{t}$
  - ➡ Both migrating to Powheg (v2) + Pythia8

ATLAS

- TOPQ-2015-16
- Modelling uncertainties
  - ➡ Vary $\mu_{F,R}$, and radiation in Perugia tune
  - ➡ Compare DR with DS
  - ➡ ME generator uncertainty
    - ➡Powheg+Herwig++ vs MG5_aMC@NLO+Herwig++
  - ➡ PS/Hadronisation
    - ➡Swap Pythia6 with Herwig++
  - ➡ Modelling of $t\bar{t}$ background

CMS

- TOP-17-018
- Modelling uncertainties
  - ➡ $\mu_{F,R}$, ISR/FSR scale variations
  - ➡ Compare DR with DS
  - ➡ Modelling of $t\bar{t}$ background
    - ➡Including CR, UE, h_{damp} variations

Single top (tW)

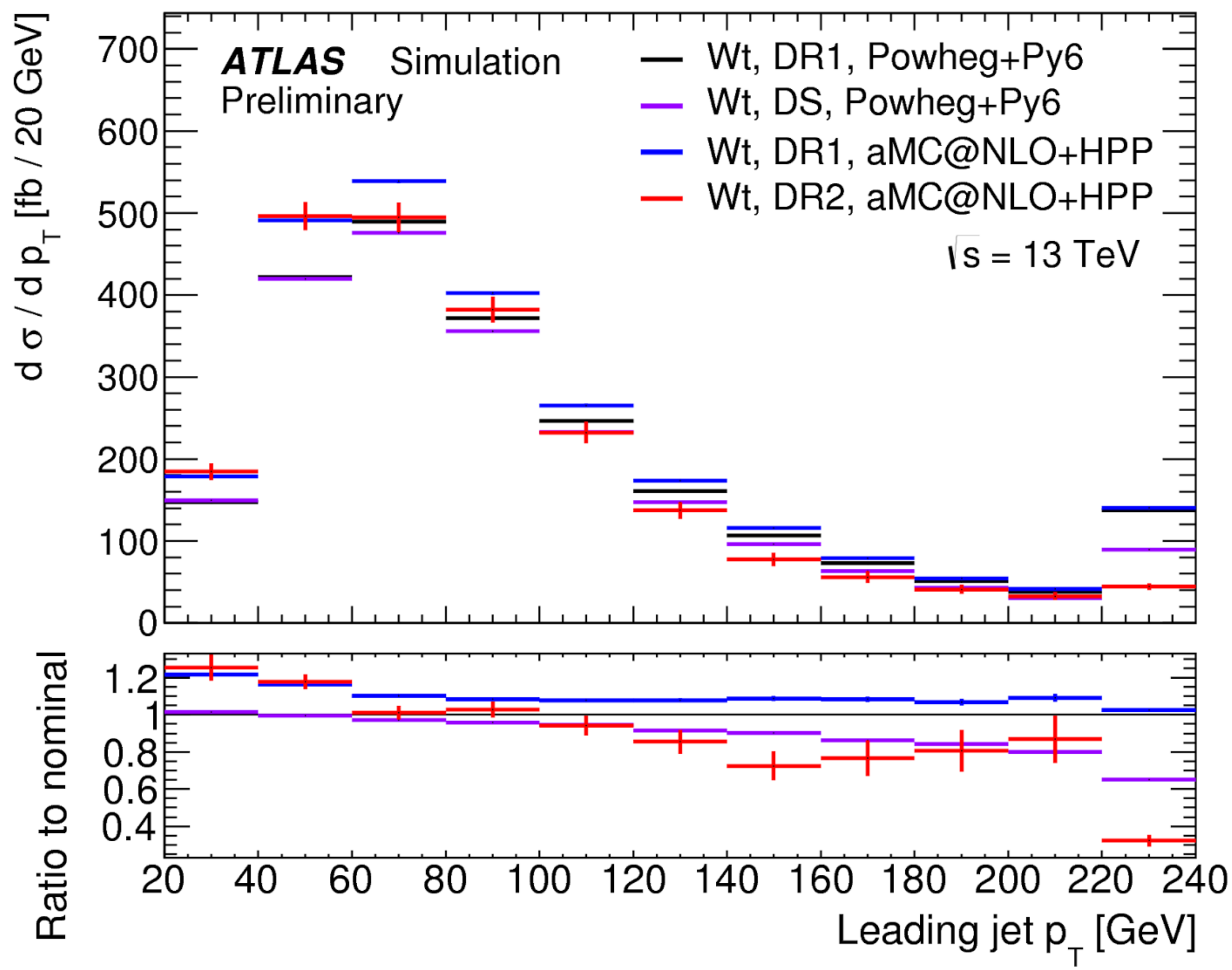
- Not easy to compare side by side in one slide
  - ➡ See Sergio's talk tomorrow for a more detailed comparison of these measurements

Source	$\Delta\sigma_{Wt}/\sigma_{Wt}[\%]$
Jet energy scale	21
Jet energy resolution	8.6
E_T^{miss} soft terms	5.3
b-tagging	4.3
Luminosity	2.3
Lepton efficiency, energy scale and resolution	1.3
NLO matrix element generator	18
Parton shower and hadronisation	7.1
Initial-/final-state radiation	6.4
Diagram removal/subtraction	5.3
Parton distribution function	2.7
Non-$t\bar{t}$ background normalisation	3.7
Total systematic uncertainty	30
Data statistics	10
Total uncertainty	31

Source	Uncertainty (%)
Trigger efficiencies	2.7
Muon efficiencies	3.1
Electron efficiencies	3.2
Jet energy scale	3.2
Jet energy resolution	1.8
b tagging efficiency	1.4
Mistagging rate	0.2
Pileup	3.3
$t\bar{t}$ μ_R and μ_F scale	2.5
tW μ_R and μ_F scale	0.9
Underlying event	0.4
ME/PS matching	1.8
Initial state radiation	0.8
Final state radiation	0.8
Color reconnection	2.0
PDF	1.5
DR-DS	1.3
VV normalization	0.4
Drell–Yan normalization	1.1
Non-W/Z leptons normalization	1.6
$t\bar{t}$V normalization	0.1
MC statistics	1.6
Full phase space extrapolation	2.9
Total systematic (excluding integrated luminosity)	9.5
Integrated luminosity	3.3
Statistical	2.8
Total	10.5

tt-tW interference

- Both ATLAS & CMS compare Duplicate Removal (DR) with Duplicate Subtraction (DS) to derive uncertainty
  - ➡ New treatment available in MG5_aMC@NLO (DR2), explored by ATLAS in ATL-PHYS-PUB-2016-020
- Also, both working on production of WWbb
  - ➡ Currently dilepton (emu) only



Single top (t-channel and tZ)

ATLAS

- t-channel
  - ➡ TOPQ-2015-015
  - ➡ Powheg (v1) + Pythia6
  - ➡ Migrating to Powheg (v2) + Pythia8
- tZ
  - ➡ ATLAS-CONF-2017-052
  - ➡ MG5_aMC@NLO+Pythia6
    - ➡LO
- Follow similar uncertainty prescription as for tW

CMS

- t-channel
  - ➡ TOP-16-003
  - ➡ MG5_aMC@NLO+Pythia8
  - ➡ Similar uncertainty treatment, and include comparisons to generators
  - ➡ Nominal vs Powheg+Pythia8
  - ➡ Nominal vs MG5_aMC@NLO+Herwig++
- tZ
  - ➡ TOP-16-020
  - ➡ MG5_aMC@NLO+Pythia6
    - ➡NLO
  - ➡ $\mu_{F,R}$ x 0.5/2 in ME and PS
- See Lidia's talk tomorrow for comparison of tZ measurements
  - ➡ Modelling of PS a dominant source of uncertainty

tt+V

ATLAS

- TOPQ-2015-22
- MG5_aMC@NLO + Pythia8
  - ➡LO, A14 tune
- Uncertainties
  - ➡ Simultaneous $\mu_{F,R}$ variations
  - ➡ A14 variations (Var3c and Var1)
  - ➡ Compare to Sherpa+CS
  - ➡ Measurement limited by statistical uncertainties

Uncertainty	$\sigma_{t\bar{t}Z}$	$\sigma_{t\bar{t}W}$
Luminosity	2.6%	3.1%
Reconstructed objects	8.3%	9.3%
Backgrounds from simulation	5.3%	3.1%
Fake leptons and charge misID	3.0%	19%
Signal modelling	2.3%	4.2%
Total systematic	11%	22%
Statistical	31%	48%
Total	32%	53%

CMS

- TOP-17-005
- MG5_aMC@NLO + Pythia8
  - ➡ NLO
- Uncertainties
  - ➡ $\mu_{F,R}$ variations only
  - ➡ Found to result in small uncertainty

Source	Uncertainty range	Impact on ttW cross-section	Impact on ttZ cross-section
Luminosity	2.5%	4%	3%
Jet Energy Scale/Resolution	2-5%	3%	3%
Trigger	2-4%	4-5%	5%
B tagging	1-5%	2-5%	4-5%
PU modeling	1%	1%	1%
Lepton ID, efficiency	2-7%	3%	6-7%
μ_R/μ_F scale choice	1%	<1%	1%
PDF choice	1%	<1%	1%
Nonprompt background	30%	4%	< 2%
WZ cross section	10-20%	<1%	2%
ZZ cross section	20%	-	1%
Charge misidentification	20%	3%	-
Rare SM background	50%	2%	2%
ttX background	10-15%	4%	3%
Stat. unc. for nonprompt	5-50%	4%	2%
Stat. unc. rare SM processes	20-100%	1%	< 1%
Total systematic	-	14%	12%

Summary

- ATLAS & CMS have similar baseline Powheg+Pythia8 setup for run 2 $t\bar{t}$ analyses
  - ➡ Similar tuned parameters
- Comparison of uncertainties in top modelling by ATLAS & CMS
- Improved determination of CR uncertainty for CMS top mass measurement
- ATLAS typically includes more comparisons with other NLO+PS setups to derive uncertainties
  - ➡ Backed up by several notes demonstrating differences between the various predictions
- CMS typically includes a more detailed breakdown of uncertainties for $t\bar{t}$ analyses
  - ➡ Related to b-jet response, CR, UE
  - ➡ top p_T modelling
- Single top and tt+V measurements
  - ➡ Modelling uncertainties not so dominant in tt+V measurements
  - ➡ Talks tomorrow on tW and tZ measurements
- Several measurements implementing latest prescriptions
  - ➡ Also including comparison with latest ME/PS generators
  - ➡ Sherpa, MG5_aMC@NLO, Herwig7

BACKUP

CMS : Tuned parameters of CR models

Parameters	CUETP8M2T4	QCD inspired	gluon move
MultipartonInteractions:**pT0Ref**	2.20	2.17	2.30
MultipartonInteractions:**expPow**	1.60	1.31	1.35
MultipartonInteractions:**ecmRef**	7000	7000*	7000*
MultipartonInteractions:**ecmPow**	0.25	0.25*	0.25*
ColourReconnection:**range**	6.59	-	-
ColourReconnection:**junctionCorrection**	-	0.12 (1.20)	-
ColourReconnection:**timeDilationPar**	-	15.9 (0.18)	-
ColourReconnection:**m0**	-	1.2 (0.3)	-
ColourReconnection:**m2lambda**	-	-	1.9 (1.0)
ColourReconnection:**fracGluon**	-	-	1.0* (1.0)
ColourReconnection:**dLambdaCut**	-	-	0.0* (0.0)
PDF set	NNPDF30_LO [JHEP 04 (2015)]	NNPDF30_LO	NNPDF30_LO
SpaceShower:alphaSvalue	0.1108*	0.1108*	0.1108*
Goodness of fit/dof	1.89 [CMS-PAS-TOP-16-021]	1.06	1.69
* = value kept fixed in the fit			