Higher-level comparison of multiple distributions for MC generators

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on behalf of the ATLAS and CMS Collaborations

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Introduction

- ATLAS and CMS have published many papers on top differential cross section for different
  - Processes: top pairs or single top
  - Phase spaces: full and fiducial
  - Final states: l+jets, dilepton, all jets
  - Topologies: resolved and boosted
  - Objects: parton-level top quarks, particle level top proxies, particle level stable leptons and jets
- This is a lot of information available for everyone!
- Goal of this talk: give a global summary focused on what these measurements teach us on the MC generators
  - Based on quantitative assessment ($\chi^2/p-$value) of agreement between measurement and prediction

Few premises

All the results are presented with some caveats:

- MC generator versions and settings are not always the same among (and within) the different experiments
- Error treatment and definition of covariance matrices are not harmonized among (and, again, within) different experiments
- Unless specifically noted, no theory uncertainty is accounted for in the extraction of the p-values
- Focus on $t\bar{t}$ production (single top in backup)

What you will not see:

- Detailed presentations of the measurements

ATLAS and CMS measurements

ATLAS: single- and double- differential (2015+2016 data)

- Lepton+jets, TOPQ-2018-15
  - Top and top-pair related variables
  - Parton and particle level
  - Resolved and boosted (no overlap, independent datasets)
  - Standard cut-count-unfold procedure (regularized iterative bayesian)
- All hadronic resolved, TOPQ-2018-18
- All hadronic boosted, TOPQ-2016-09
  - Single-differential only
  - Generally high uncertainties → excluded from the comparisons
- Dilepton, TOPQ-2018-17
  - Simultaneous extraction of cross-section and btagging probability
  - Lepton-related observables
  - Bin-by-bin unfolding

CMS: up to triple-differential (2016 data)

- Dilepton, TOP-17-014:
  - Single differential only
  - Parton and particle level
  - Top-related and (particle-level only) lepton- and (b)jet-related variables
  - Tikhonov regularization in Tunfold
- Lepton+jets, TOP-2016-014:
  - Particle level
  - No top reconstruction: event/W/lepton kinematic variables only
- Dilepton, TOP-18-004
  - Double and triple differential
  - Parton and particle level (for jet multiplicity)
  - Top related variables and jet multiplicity
- Lepton+jets, TOP-17-002
  - Single and double differential
  - Iterative Bayesian unfolding
  - Top-related variables at parton and particle level and jet-related at particle level
  - Theory uncertainties accounted for in PWGPY and Sherpa predictions
- Lepton+jets and all-hadronic boosted TOP-18-013
  - Single differential for top-related variables at parton and particle level
  - Unfolding with simple matrix inversion
  - Doesn't provide chi2 tables (covariances are on HepData) and general high uncertainties →excluded from the comparisons

General MC settings

Generator	ATLAS	CMS
Powheg-Box (PWG)	v2 with NNPDF3.0NLO PDF set, h_{damp}=1.5m_t. $h_{damp} = H_T/2$ for $ttbb$ 4FS	v2 with NNPDF3.0NLO PDF set and the h_{damp}=1.581m_t
MadGraph5_aMC@NLO (MC@NLO)	V2.2.1, NNPDF3.0NLO	V2.2.2 (FxFx), NNPDF3.0NLO
Sherpa	V2.2.1, NNPDF2.3LO	V2.2.2 NNPDF3.0NLO
Pythia (PY)	Pythia 8.2X using the A14 tune and the NNPDF2.3LO PDF set	Pythia 8.2X using the underlying event tune CUETP8M2T4
PWG+PY Rad. Up	$\mu_{R/F} = 0.5$, $h_{damp} = 3m_t$, Var3cUp from the A14 tune	
PWG+PY Rad. down	$\mu_{R/F} = 2$, Var3cUp from the A14 tune	
Herwig (HW7)	7.0.4 with the H7UE MMHT2014 LO	
HERWIG++ (HW++)		V2.7.1 using the underlying event tune EE5C

Nicely discussed in Andrea's talk

Top production observables

- The five basic variables for top production (p_T and rapidity of the top, $p_T/m/y$ of the $t\bar{t}$ system) already give a lot of insight on
  - The modelling of the hard process (top p_T/y, $\bar{t}t\ \ m/y$)
  - The modelling of the extra radiation ($p_T^{t\bar{t}}$)
  - The sensitivity to PDF (top y, $\bar{t}t\ \ m/y$) and top mass (top p_T, $\bar{t}t\ \ m$)
- Defined, at parton level, using the top quarks in the MC record after FSR and before decay
  - Experimental definition for top-observables straightforward in the l+jets channel, exploiting $\frac{d\sigma}{dX_t} = \frac{d\sigma}{dX_{\bar{t}}} = \frac{d\sigma}{dX_{t_h}} = \frac{d\sigma}{dX_{t_l}} = \frac{1}{2}\left(\frac{d\sigma}{dX_t} + \frac{d\sigma}{dX_{\bar{t}}}\right) = \frac{d\sigma}{dX_{rndm}}$
  - Alternative for all hadronic analyses: measure $\frac{d\sigma}{dX_{t_{1/2}}}$

Top production observables: particle level defintions

- At particle level, proxies are used to access the kinematic of the top quarks
  - Differences in the data/MC agreement can be expected among measurements, since the fiducial phase spaces and/or proxy definitions can enhance sensibilities to specific aspects of the modelling
- Resolved topology:
  - ATLAS use proxies containing constraints on the choice of the jet permutations only on the *W* mass in ljets and top and *W* masses in fullhad
  - CMS use proxies using constraints on *W* and *top* masses
- Boosted topology:
  - Large-*R* jets are 'top-tagged' with either cuts mass or other substructure variables

●: < 0.01
● : < 0.1
● : > 0.1

Parton level top pt

Format: p-value normalised (p-value absolute)
For comparisons with and without MC uncertainties: p-value no-unc/p-value with unc
p-values from χ^2tests: $\chi^2 = (D-T)^{-1}\mathrm{Cov}^{-1}(D-T)$
For normalised, one element and one row/column are removed from $(D-T)$ and Cov

🔴: < 0.01 ATLAS TOPQ-2018-15 and CMS TOP-17-014, TOP-17-002
🟠 : < 0.1
🟢 : > 0.1

Parton level top pt

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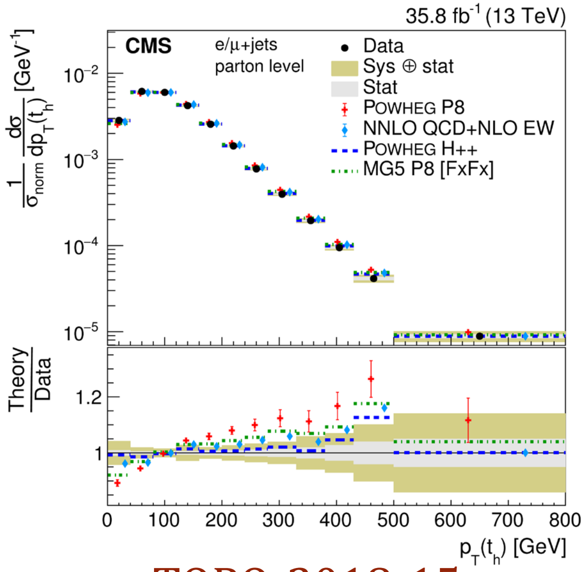
For normalised, one element and one row/column are removed from $(D-T)$ and Cov

Paper	PWG+H++	PWG+H7	MC@NLO+PY8	Sherpa	PWG+PY8	PWG+PY8 Rad. Up	PWG+PY8 Rad. Down	NNLO
CMS dilepton	🟢(🟢)		🔴(🔴)		🔴(🔴)			🟠(🟢)
CMS ljets (resolved)	🟢(🟢)		🟢(🟢)		🟠/🟢 (🟠/🟢)			🟢(🟢)
ATLAS ljets (resolved)		🟢(🟢)		🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)
ATLAS ljets (boosted)		🟠(🟢)		🟠(🟠)	🟠(🟢)	🟠(🟢)	🟠(🟠)	🟠(🟢)

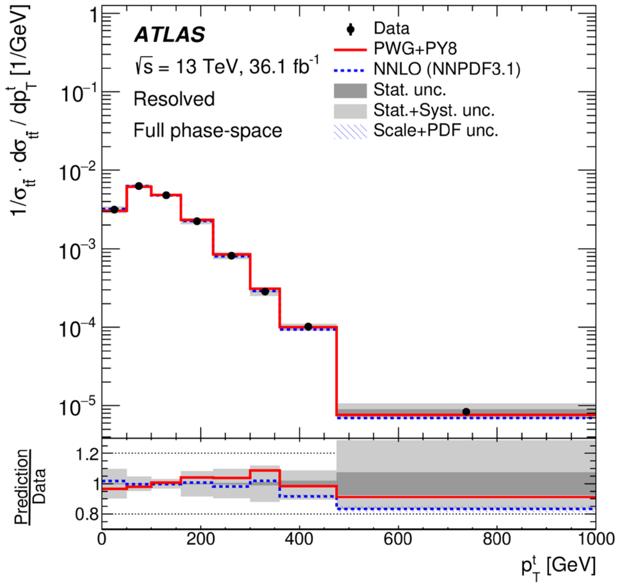
All analyses observe a softer spectrum (but compatible within uncertainties)
- Opposite trend data in ATLAS ljets resolved → slightly overshoots the predictions in the last bin

Among the MC, PWG+HW++/7 consistently give a better description
Improvement confirmed when going NNLO(NNLO+NLO EW for CMS)

TOP-17-002



TOPQ-2018-15



● (red): < 0.01
● (orange): < 0.1
● (green): > 0.1

ATLAS TOPQ-2018-15 and CMS TOP-17-014, TOP-17-002

Particle level top pt

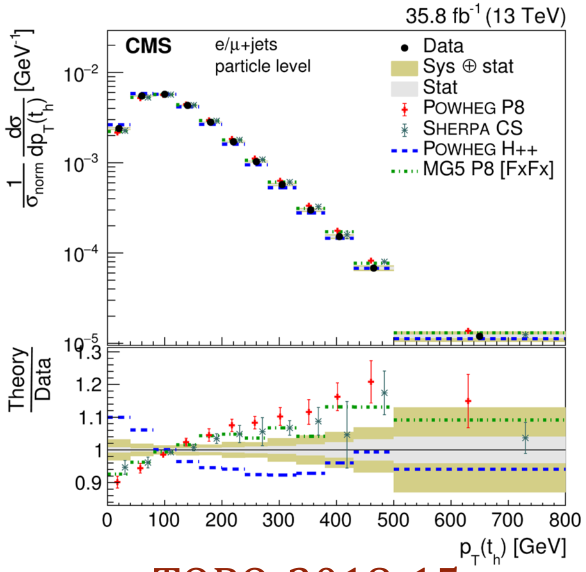
Format: p-value normalised (p-value absolute)

Paper	PWG+H++	PWG+H7	MC@NLO+PY8	Sherpa	PWG+PY8	PWG+PY8 Rad. Up	PWG+PY8 Rad. Down
CMS dilepton	green (green)		red (red)		red (red)		
CMS ljets (resolved)	red (red)		green (green)	green / green (green / green)	red / green (red / green)		
ATLAS ljets (resolved)		green (green)	green (green)	green (green)	green (orange)	green (orange)	green (green)
ATLAS ljets (boosted)		green (green)	green (green)	orange (orange)	green (orange)	orange (red)	green (green)

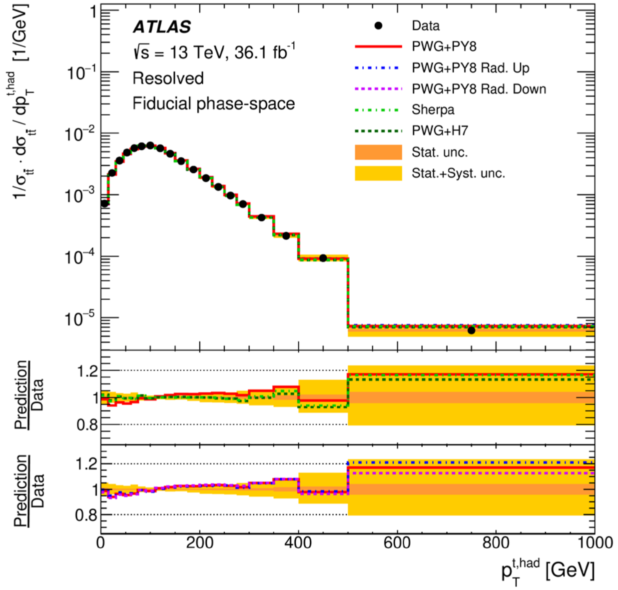
All analyses observe a softer spectrum (but compatible within uncertainties)

- ATLAS measurements show a better overall agreement with the predictions
  - The overshoot seen at parton level is not present
- CMS PWGPY8 has fair agreement only when accounting for the MC uncertainties
  - Good agreement observed with Sherpa and MCatNLO
  - Bad description from PWGH++ (which gave a good description at parton level)

TOP-17-002



TOPQ-2018-15



- red: < 0.01
- orange: < 0.1
- green: > 0.1

ATLAS TOPQ-2018-15, TOPQ-2018-18 and CMS TOP-17-014, TOP-17-002

Parton level $t\bar{t}$ mass

Format: p-value normalised (p-value absolute)

Paper	PWG+H++	PWG+H7	MC@NLO+PY8	Sherpa	PWG+PY8	PWG+PY8 Rad. Up	PWG+PY8 Rad. Down	NNLO
CMS dilepton	green (green)		green (green)		red (green)			red (orange)*
CMS ljets (resolved)	green (green)		green (orange)		green / green (orange / green)			red (red)
ATLAS ljets (resolved)		red (red)		orange (orange)	red (red)	red (red)	red (red)	orange (green)
ATLAS ljets (boosted)		green (green)		green (red)	green (green)	green (red)	red (red)	
ATLAS allhad (resolved)		green (green)	green (green)	green (green)	green (green)	green (green)	green (green)	

*: CMS dilepton provides multiple NNLO predictions with varying PDF sets or mass

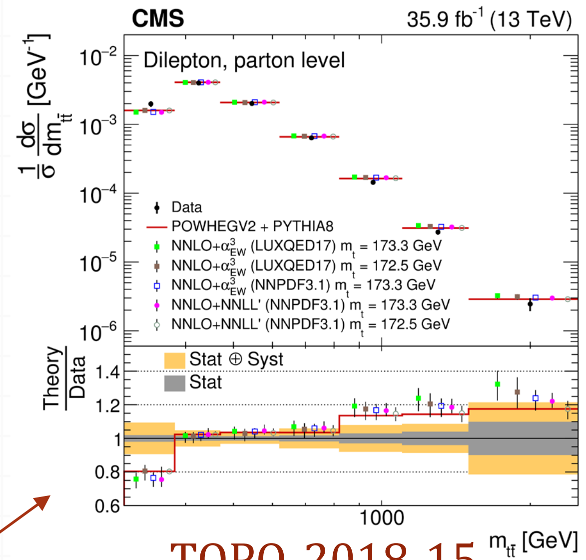
CMS observes that PWG+PY8 is the MC that gives the poorest description in the dilepton measurement

ATLAS resolved gets a fair description only with Sherpa, all the other MC fail at replicating the measurement

- Opposite trends when comparing ATLAS ljets and CMS dilepton with the same predictions
  - Possibly related to the overshoot in top pt? Not completely (particle level behaves similarly)
- The agreement, in **shape mostly**, improves when going **boosted**

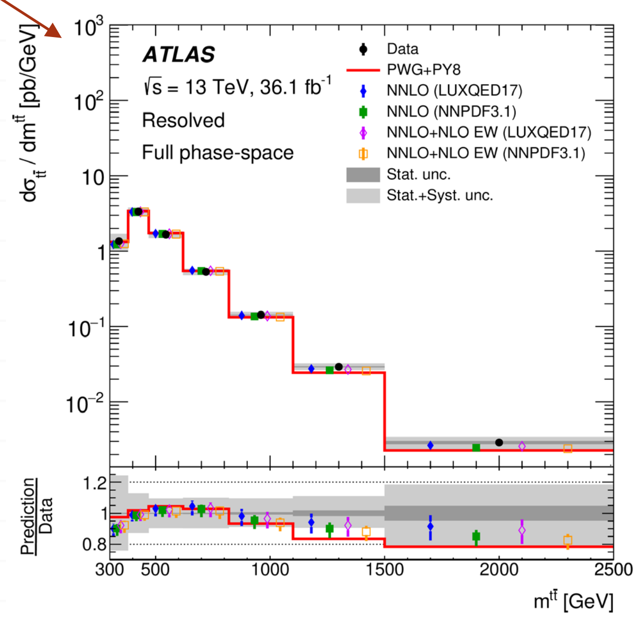
NNLO improvements, if any, are marginal at best for ATLAS only

TOP-17-014



Same binning and NNLO predictions

TOPQ-2018-15



red ●: < 0.01
orange ●: < 0.1
green ●: > 0.1

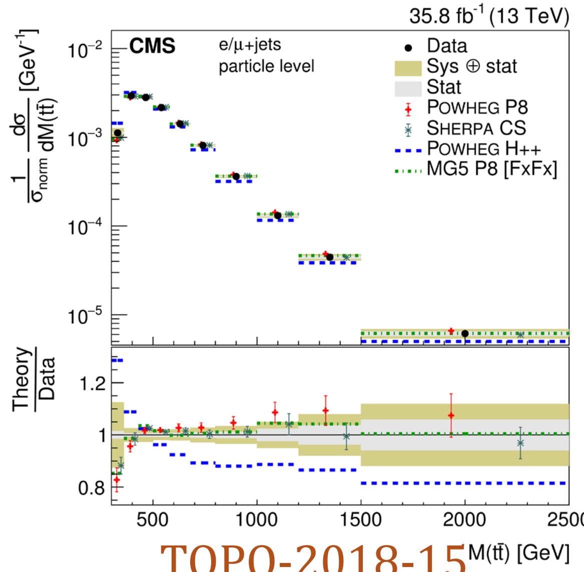
ATLAS TOPQ-2018-15, TOPQ-2018-18 and CMS TOP-17-014, TOP-17-002

Particle level $t\bar{t}$ mass

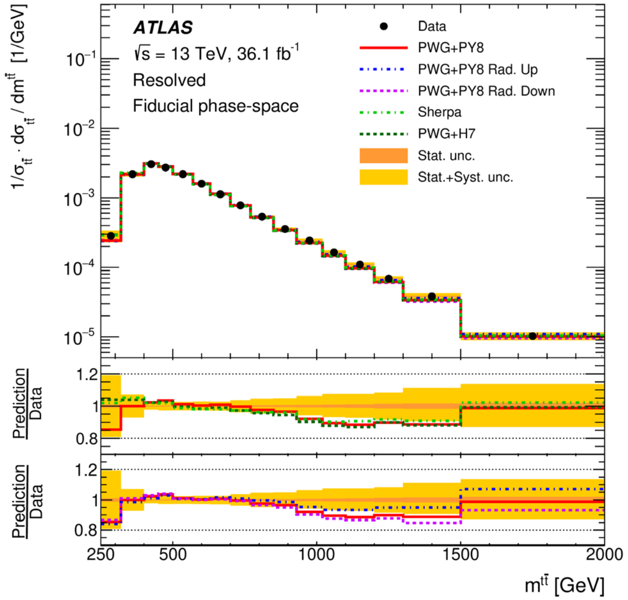
Format: p-value normalised (p-value absolute)

Paper	PWG+H++	PWG+H7	MC@NLO+PY8	Sherpa	PWG+PY8	PWG+PY8 Rad. Up	PWG+PY8 Rad. Down
CMS dilepton	red (green)		green (green)		orange (orange)		
CMS ljets (resolved)	red (red)		green (green)	green/green (green/green)	green/green (green/green)		
ATLAS ljets (resolved)		green (green)	green (green)	green (green)	green (green)	green (green)	green (green)
ATLAS ljets (boosted)		green (red)	orange (green)	green (red)	green (orange)	green (red)	orange (red)
ATLAS allhad (resolved)		green (green)	orange (red)	green (green)	orange (orange)	green (green)	orange (red)

TOP-17-002



TOPQ-2018-15



Well modelled by most of the generators

- Confirmed a trend where PWG+H++ correctly models the parton level but not the particle level
- Other way around for PWGH7
- Among the PWGPY8 variations, Rad. Up seems to be the preferred one

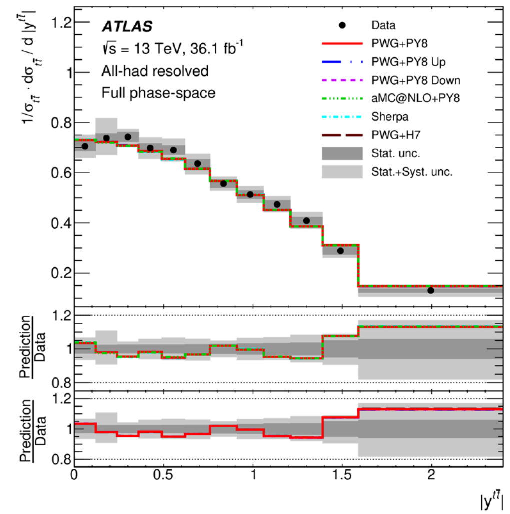
🔴: < 0.01 ATLAS TOPQ-2018-15, TOPQ-2018-18 and CMS TOP-17-014, TOP-17-002,
🟠 : < 0.1
🟢 : > 0.1

Parton level rapidities

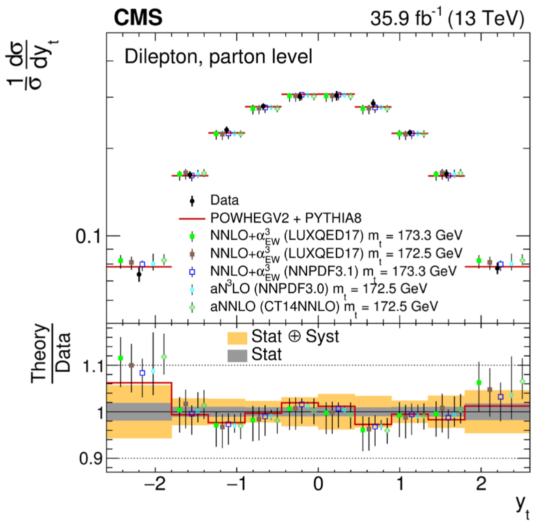
The shape differences are usually smaller than the normalization disagreement.
Format: p-value y_{tt} (p-value y_t) for **normalised only**

Paper	PWG+H++	PWG+H7	MC@NLO+PY8	Sherpa	PWG+PY8	PWG+PY8 Rad. Up	PWG+PY8 Rad. Down	NNLO
CMS dilepton	🟢(🟢)		🟢(🟢)		🟢(🟢)			🟢(🟢)
CMS ljets (resolved)			🟢(🟢)		🟢/🟢 (🟢/🟢)			🟠(🟢)
ATLAS ljets (resolved)		🟢(🟢)		🟢(🟠)	🟢(🟠)	🟢(🟠)	🟢(🟠)	🟢(🟠)
ATLAS allhad (resolved)		🟢	🟢	🟢	🟢	🟢	🟢	

TOPQ-2018-18



TOP-17-014



Rapidities generally well modelled by all the predictions

- In ATLAS ljets resolved the rapidity of the system is better modeled than the rapidity of the top

Both ATLAS and CMS measure **slightly** more “central” top pairs and more “forward” tops

- Confirmed also when looking at the rapidities of the leptons

● (red): < 0.01 ATLAS TOPQ-2018-15, TOPQ-2018-18 and CMS TOP-17-014, TOP-17-002

● (orange): < 0.1

● (green): > 0.1

Particle level $t\bar{t}$ p_T

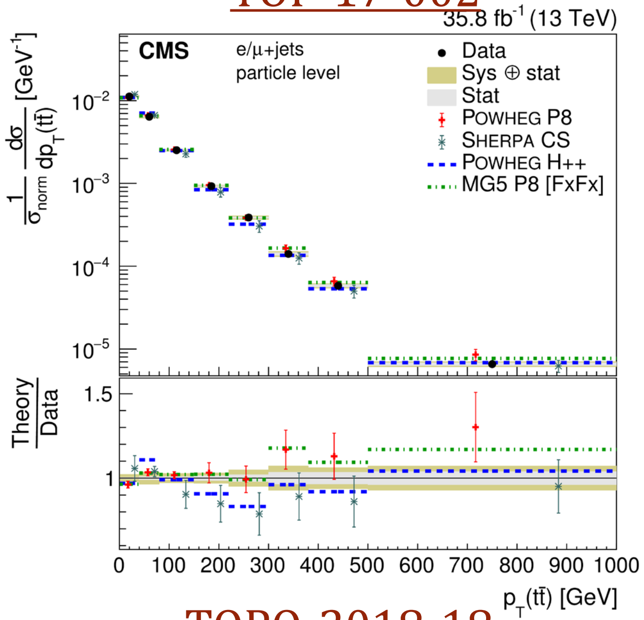
Format: p-value normalised (p-value absolute)

Paper	PWG+H++	PWG+H7	MC@NLO+PY8	Sherpa	PWG+PY8	PWG+PY8 Rad. Up	PWG+PY8 Rad. Down
CMS dilepton	red (red)		orange (orange)		red (red)		
CMS ljets (resolved)	red (red)		orange (red)	red / orange (red / red)	red / green (red / green)		
ATLAS ljets (resolved)		red (red)	red (red)	red (red)	orange (orange)	red (red)	orange (green)
ATLAS ljets (boosted)		orange (red)	red (red)	red (red)	green (red)	red (red)	red (red)
ATLAS allhad (resolved)		green (green)	red (orange)	orange (orange)	green (green)	red (red)	green (green)

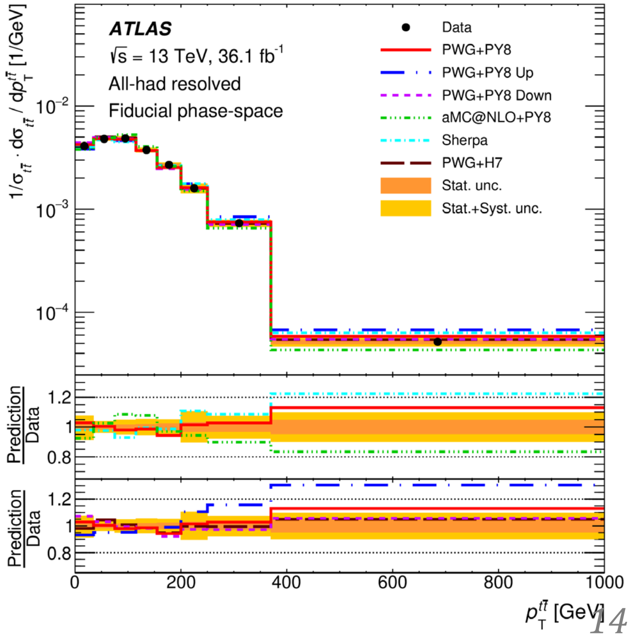
Few generators can model p_T of the $t\bar{t}$ system

- Sensitive to the recoil against the additional radiation
  - NLO is LO for p_T^{tt} → high theory uncertainties (~20% at high values)
- Usually well modelled at low values
- PWGPY8/H7 seem to give the best modelling
  - PWGPY8 rad down behaves better than rad. Up. Other way around for njets

TOP-17-002



TOPQ-2018-18



🔴 : < 0.01
🟠 : < 0.1
🟢 : > 0.1

ATLAS TOPQ-2018-15, TOPQ-2018-18 and CMS TOP-17-014, TOP-17-002

Jet multiplicities

Format: p-value njets for normalised only

Paper	PWG+H++	PWG+H7	MC@NLO+PY8	Sherpa	PWG+PY8	PWG+PY8 Rad. Up	PWG+PY8 Rad. Down
CMS dilepton	🔴		🔴		🟠		
CMS ljets (resolved)	🟠		🟠	🔴/🔴	🟢/🟢		
ATLAS ljets (resolved)		🔴	🔴	🟢	🟢	🟠	🔴
ATLAS ljets (boosted)		🟢		🟠	🟢	🔴	🔴
ATLAS allhad (resolved)		🟢	🔴	🟠	🟠	🟠	🔴

See Seth's talk for more details

At high values, n_{jets} is fully modelled by the PS

- Huge theory uncertainties, almost 50%

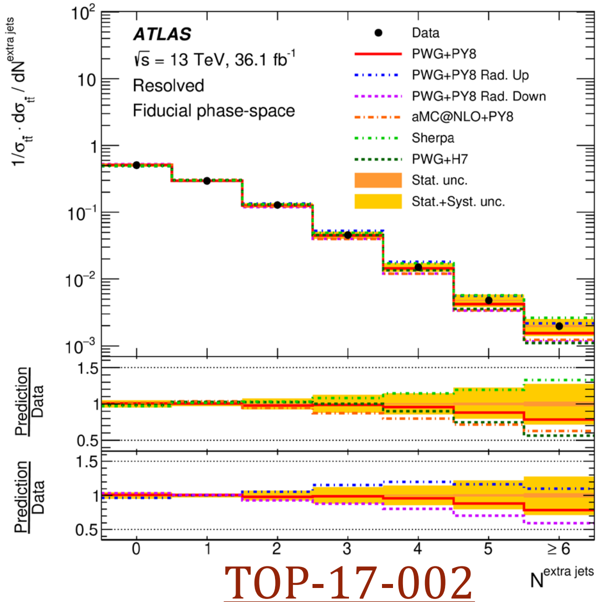
ATLAS observes a general underestimation at high multiplicities, besides Sherpa

- Better behavior when going **boosted**, besides the PwgPy8 radiation variations

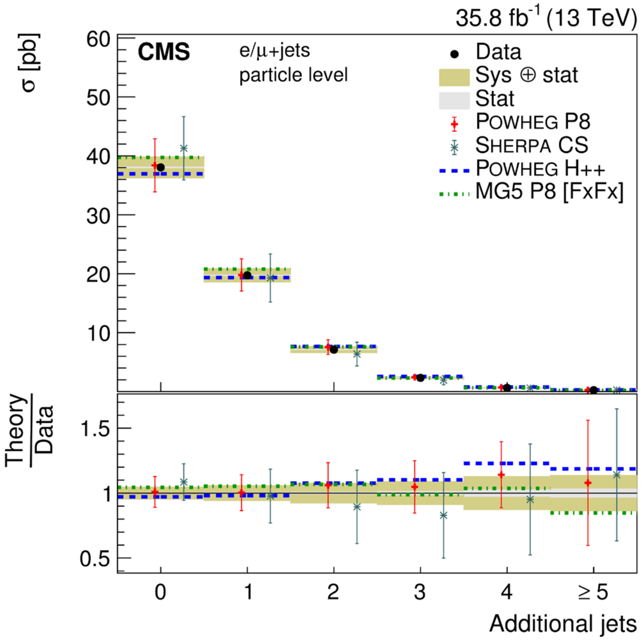
General bad modelling in CMS, with opposite trend wrt ATLAS in the dilepton channel

- Differences can be also traced back to different PwgPy8 settings (+EvtGen), as shown in Giulia's talk

TOPQ-2018-15



TOP-17-002



🔴: < 0.01 ATLAS TOPQ-2018-17 and CMS TOP-17-014, TOP-16-014

🟠 : < 0.1

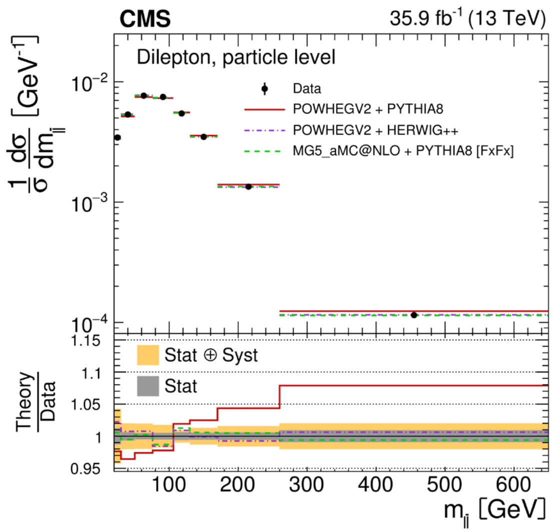
🟢 : > 0.1

Lepton observables

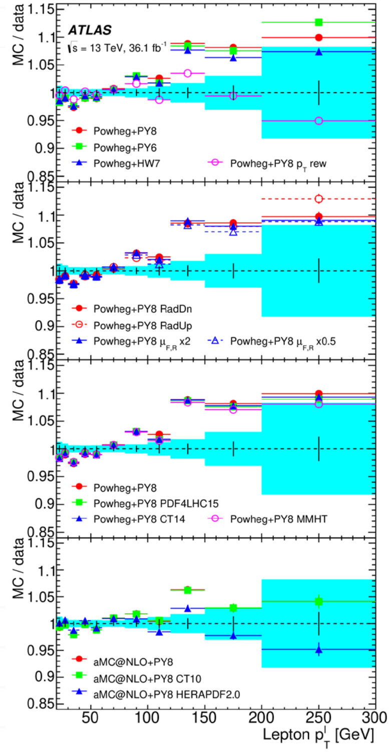
p-values for normalised only

Variable	Paper	PWG+H++	PWG+H7	MC@NLO+PY8	PWG+PY8 (top pt rew)	PWG+PY8 Rad. Up	PWG+PY8 Rad. Down
p_T^l	ATLAS dilepton		🔴	🔴	🔴(🟠)	🔴	🔴
	CMS dilepton	🟢		🔴	🔴		
	CMS ljets	🟢		🟢	🟠/🟢		
η^l	ATLAS dilepton		🟠	🔴	🟠(🟠)	🟠	🔴
	CMS dilepton	🟢		🟢	🟢		
	CMS ljets	🟠		🔴	🟠/🟠		
p_T^{ll}	ATLAS dilepton		🟢	🟢	🟢(🟢)	🔴	🟢
	CMS dilepton	🟠		🟢	🟠		
m_{ll}	ATLAS dilepton		🔴	🟠	🔴(🔴)	🔴	🔴
	CMS dilepton	🟢		🟢	🔴		
y_{ll}	ATLAS dilepton		🟢		🟢(🟢)	🟢	🟢
$\Delta\eta_{ll}$	CMS dilepton	🟢		🟢	🟢		
Global χ^2	ATLAS dilepton		🔴	🔴	🔴(🔴)	🔴	🔴

TOP-17-014



TOPQ-2018-17



No MC can fit simultaneously the 8 ATLAS spectra

Individual leptons badly modelled by most of the generators
- with the exception of the rapidity measured by CMS dilepton and p_T measured in the l+jets channel

Lepton pair rapidity distributions are generally well modelled, while their mass is badly modelled by PWG-based predictions
- Good modelling of p_T^{ll} in contrast with bad modelling of p_T^{tt}

PWG+H++ consistently agrees with the data

red: < 0.01
orange: < 0.1
green: > 0.1

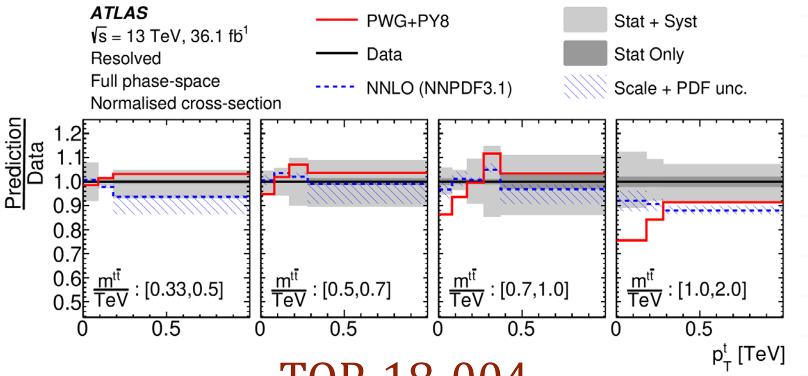
ATLAS TOPQ-2018-15, TOPQ-2018-18 and CMS TOP-17-002, TOP-18-004

Top observables (2D)

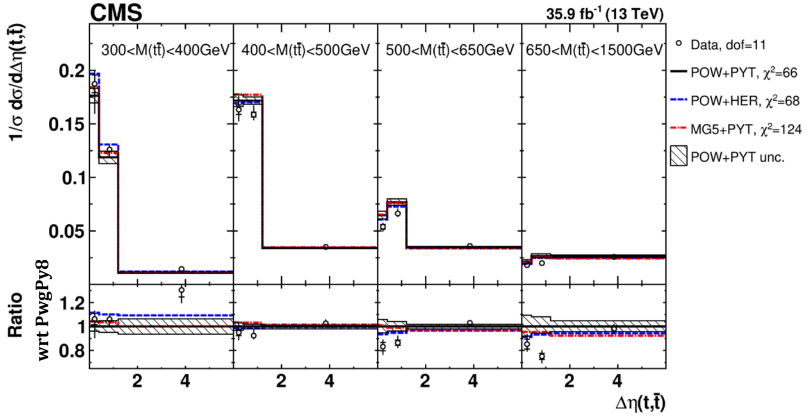
Format (normalised, parton level only): *p*-value resolved(boosted)

Variable	Paper	PWG+H++	PWG+H7	MC@NLO+PY8	PWG+PY8	PWG+PY8 Rad. Up	PWG+PY8 Rad. Down	Sherpa	NNLO
$p_T^t \times m_{tt}$	ATLAS ljets		red (green)		red (green)	red (orange)	red (green)	red (orange)	red (green)
	CMS dilepton	red		red	red				
	CMS ljets	red		red	red / green				
$p_T^{tt} \times m_{tt}$	ATLAS ljets		red		red	red	red	red	red
	ATLAS allhad		orange	red	orange	red	orange	red	
	CMS dilepton	green		orange	green				
$p_T^t \times y_t$	ATLAS ljets		red		red	red	red	red	orange
	CMS dilepton	green		orange	red				
	CMS ljets	green		green	green / green				
$m_{tt} \times y_{tt}$	ATLAS ljets		red		red	red	red	red	red
	ATLAS all had		orange	orange	orange	orange	orange	orange	
	CMS dilepton	green		orange	orange				
	CMS ljets	green		green	green / green				
$p_T^{tt} \times y_{tt}$	ATLAS ljets		red		green	red	red	red	green
$m_{tt} \times \Delta y_{tt}$	CMS dilepton	red		red	red				

TOPQ-2018-15



TOP-18-004



2D distributions are generally badly modelled, especially in ATLAS ljets

- Even for variables that were well modelled by themselves (p_T^t and y_t for example)
- It becomes important looking at the plot, to understand the regions causing issues

CMS sees bad modelling $m_{tt} \times p_T/\Delta y_{tt}$ by nominal predictions:

- higher m_{tt} a larger rapidity separation between t and anti-t leading to softer pT(t)

●: < 0.01 (red)   ATLAS TOPQ-2018-15, TOPQ-2018-18 and CMS TOP-18-004

● : < 0.1 (orange)

● : > 0.1 (green)

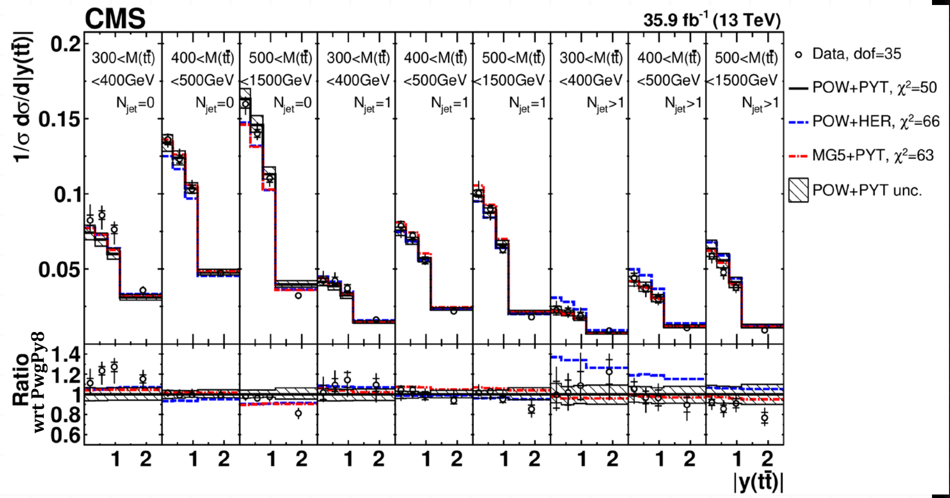
Additional radiation (2D&3D)

Format (normalised, particle level only):

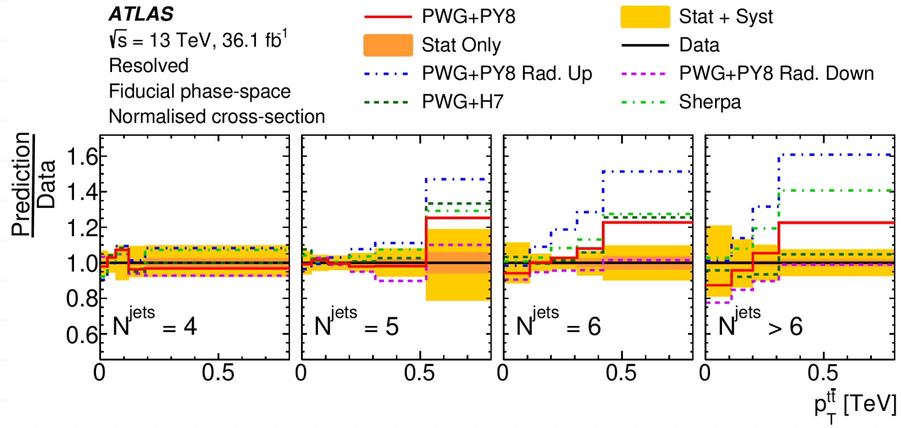
- ATLAS: p-value resolved(boosted);
- CMS dilepton: p-value $N_{jet}^{0,1+}$ $(N_{jet}^{0,1,2+})$

Variable	Paper	PWG+H++	PWG+H7	MC@NLO+PY8	PWG+PY8	PWG+PY8 Rad. Up	PWG+PY8 Rad. Down	Sherpa
$p_T^t \times N_{jets}$	ATLAS ljets		red (green)	red	green (green)	red (red)	red (red)	green (red)
	CMS ljets	red		orange	red / green			red / green
$p_T^{tt} \times N_{jets}$	ATLAS ljets		red (red)	red	red (red)	red (red)	red (red)	red (red)
	ATLAS allhad		orange	red	red	red	red	red
	CMS ljets	red		red	red / red			red / red
$m_{tt} \times N_{jets}$	ATLAS ljets		orange (green)	green	orange (green)	orange (red)	red (red)	green (orange)
	ATLAS allhad		green	red	red	red	red	red
	CMS ljets	red		red	green / green			orange / red
$m_{tt} \times y_{tt} \times N_{jets}$	CMS dilepton	green (red)		orange (red)	orange (orange)			

TOP-18-004



TOPQ-2018-15



No MC can describe $p_T^{tt} \times N_{jets}$, one of the most radiation-sensitive observables

- Strong trends observed in ATLAS in almost all MC in the last bins

CMS finds good agreement when only considering to two bins of extra-radiation

- The modelling get worse when splitting the last bin
- In particular PWGHW can't model at all the ≥ 2 extrajet region in the dilepton channel, especially at high mass

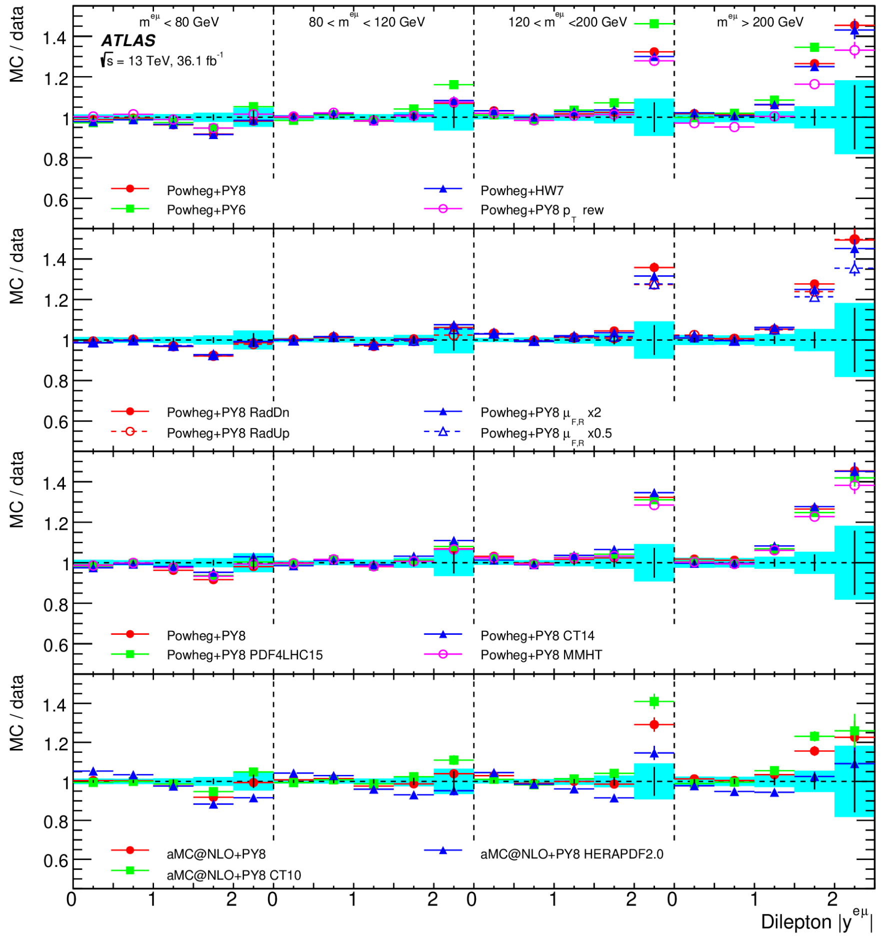
🔴 : < 0.01 ATLAS TOPQ-2018-17

🟠 : < 0.1

🟢 : > 0.1

Lepton observables (2D)

Variable	PWG+H7	MC@NLO+PY8	PWG+PY8 (top pt rew)	PWG+PY8 Rad. Up	PWG+PY8 Rad. Down
$\|\eta^l\| \times m_{ll}$	🟠	🟠	🟠(🟠)	🟠	🟠
$\|y_{ll}\| \times m_{ll}$	🟠	🟠	🔴(🔴)	🔴	🔴
$\|\Delta\phi_l\| \times m_{ll}$	🟠	🟠	🔴(🟠)	🔴	🔴



The rapidity of the lepton as a function of the dilepton mass is fairly modelled by all the predictions

- In 1D, both were among the worse modelled observables

PwgPy8, with different radiation settings, badly models the y_{ll} and $|\Delta\phi_l|$

Most of the predictions predict "more forward" dilepton pairs at high mass

- Other way around for the individual leptons

Summary (1)

- An analysis of quantitative comparisons between several measured differential cross sections and corresponding predictions was presented
  - Particle and parton level spectra, for observables sensitive to different physics effects
- Top production variables ($p_T/m/y$ of the top and $t\bar{t}$ system) at particle and parton-level CMS and ATLAS are in general good agreement with the predictions
  - PWGH++ can describe all the parton level distributions but not the particle-level ones **involving radiation**
    - Lepton observables are well modelled
  - Confirmed a clear **trend of a softer p_T spectrum**, but still compatible with the predictions within the uncertainties
    - PWG and MC@NLO+PY8 systematically excluded at parton level by CMS dilepton
  - Rapidities generally well modelled, with the **data preferring more "central" top pairs and more "forward" tops**
  - For ATLAS, 2D distributions of well modelled 1D spectra are not well modelled
- Radiation-sensitive variables **show more tensions**
  - Best description given by PWG+PY8/H7 and Sherpa (N_{jets} only)
    - Different Pythia radiation variations favoured by different spectra
  - b-jets observables well modelled in ATLAS, while CMS finds good agreement only for the pseudorapidities
    - Not presented here (available in backup), nicely presented in Seth's talk

Summary (2)

- The kinematics of the **individual** leptons are badly modelled by most of the generators
  - PWG+H++ is the one that gives consistently good agreements
  - **Good modelling of p_T^{ll} in contrast with bad modelling of p_T^{tt}**
  - **No prediction can fit simultaneously all the lepton spectra measured by ATLAS**
- Single top (t-channel and Wt, not presented) differential cross section are also measured
  - Measurements are less precise than tt, making all MC predictions always somewhat compatible
  - The MC with full treatment of the tW/tt interference is preferred by ATLAS data
    - Limiting factor for searches and measurements →important to push on this avenue
- **Some tensions noted between ATLAS and CMS,** in regions where the measurement uncertainties are larger
  - Interesting for parton level m_{tt}, where ATLAS ljets and CMS dilepton show opposite trends wrt the same NNLO predictions
- Most comparisons are performed without accounting for theory uncertainties
  - Once done, most “not-compatible” comparisons become “compatible”
- Impossible to draw unique conclusions:
  - Different generators disagree/agree on different observables
  - Varying MC setups and analysis strategies make it impossible to make 1-1 comparisons
  - We can’t even say that NNLO is better than NLO+PS (mass is generally worse modelled by NNLO)

Backup

General MC settings

Generator	ATLAS	CMS
Powheg-Box (PWG)	v2 with NNPDF3.0NLO PDF set, h_{damp}=1.5m_t. $h_{damp} = H_T/2$ for $ttbb$ 4FS	v2 with NNPDF3.0NLO PDF set and the h_{damp}=1.581m_t
POWHEL (PWL)	$ttbb$ 4 and 5FS NPDF3.0NLO, $h_{damp} = H_T/2$	
MadGraph5_aMC@NLO (MC@NLO)	V2.2.1, NNPDF3.0NLO	V2.2.2 (FxFx), NNPDF3.0NLO
Sherpa	V2.2.1, NNPDF2.3LO	V2.2.2 NNPDF3.0NLO
Sherpa $ttbb$	V2.2.1 $ttbb$ 4FS NNLO NNPDF3.0 PDF	
Pythia (PY)	Pythia 8.2X using the A14 tune and the NNPDF2.3LO PDF set	Pythia 8.2X using the underlying event tune CUETP8M2T4
PWG+PY Rad. Up	$\mu_{R/F} = 0.5$, $h_{damp} = 3m_t$, Var3cUp from the A14 tune	
PWG+PY Rad. down	$\mu_{R/F} = 2$, Var3cUp from the A14 tune	
Herwig (H7.0.4)	7.0.4 with the H7UE MMHT2014 LO	
HERWIG++ (H++)		V2.7.1 using the underlying event tune EE5C

ATLAS and CMS measurements

ATLAS: single- and double- differential (2015+2016 data)

- Lepton+jets, TOPQ-2018-15
  - Top and top-pair related variables
  - Parton and particle level
  - Resolved and boosted (no overlap, independent datasets)
  - Standard cut-count-unfold procedure (regularized iterative bayeisian)
- All hadronic resolved, TOPQ-2018-18
- All hadronic boosted, TOPQ-2016-09
  - Single-differential only
  - Generally high uncertainties → excluded from the comparisons
- Dilepton, TOPQ-2018-17
  - Simulatenous extraction of cross-section and btagging probability
  - Lepton-related observables
  - Bin-by-bin unfolding
- $t\bar{t}$+HF dilepton&lepton+jets, TOPQ-2017-12
  - Particle level single differential as function of b-jet multiplicity, global event properties and properties of b-jet pairs
  - Iterative Bayesian unfolding

CMS: up to triple-differential (2016 data)

- Dilepton, TOP-17-014:
  - Single differential only
  - Parton and particle level
  - Top-related and (particle-level only) lepton- and (b)jet-related variables
  - Tikhonov regularization in Tunfold
- Lepton+jets, TOP-2016-014:
  - Particle level
  - No top reconstruction: event/W/lepton kinematic variables only
- Dilepton, TOP-18-004
  - Double and triple differential
  - Parton and particle level (for jet multiplicity)
  - Top related variables and jet multiplicity
- Lepton+jets, TOP-17-002
  - Single and double differential
  - Iterative Bayesian unfolding
  - Top-related variables at parton and particle level and jet-related at particle level
  - Theory uncertainties accounted for in PWGPY and Sherpa predictions
- Lepton+jets and all-hadronic boosted TOP-18-013
  - Single differential for top-related variables at parton and particle level
  - Unfolding with simple matrix inversion
  - Doesn't provide chi2 tables (covariances are on HepData) and general high uncertainties →excluded from the comparisons

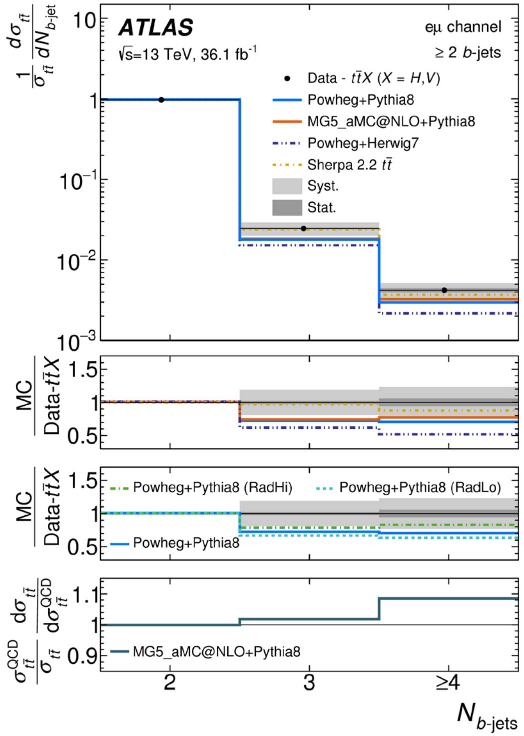
🔴: < 0.01 ATLAS TOPQ-2017-12 and CMS TOP-17-014
🟠: < 0.1
🟢: > 0.1

b-jets observables

Format (normalised only):

- ATLAS: for N_{bjets} (dilepton only) p-value tt (p-value $tt+\geq$ 1bjet), otherwise p-value $tt+\geq$ 1bjet dilepton (p-value $tt+\geq$ 2bjet ljets)
- CMS: p-value tt

Variable	Paper	PWG+H++	PWG+H7	MC@NLO+PY8	PWG+PY8	PWG+PY8 Rad. Up	PWG+PY8 Rad. Down	Sherpa	Sherpa ttbb	PWL+PY8 4FS	PWL+PY8 5FS	PWG+PY8 *ttbb*
N_{bjets}	ATLAS		🔴(🟢)	🔴(🟢)	🔴(🟢)	(🟢)	(🟢)	🟢(🟢)	🟢(🟢)	(🟢)	(🟢)	(🟢)
$p_T^{b_1}$	ATLAS		🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟠(🟢)	🟢(🟢)
	CMS	🔴		🔴	🔴							
$p_T^{b_2}$	ATLAS		🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)
	CMS	🔴		🔴	🔴							
η^{b_1}	CMS	🟠		🟢	🟢							
$p_T^{b_3}$	ATLAS		🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)	🟢(🟢)



See Seth's talk for more details

b-jets observables of paramount importance to improve the tt modelling for exotics, Higgs and $4t$ searches

- Multiplicity well modelled in the $tt+\geq$ 1bjet subspace, well modelled only by **Sherpa** in the total fiducial space
- $p_T^{b_{1/2/3/4}}$ well modelled by all the ATLAS generators, while no generator considered by CMS well describe the data
  - Different phase spaces (CMS is inclusive in nbjets while ATLAS results are for ≥ 1/2 additional bjets)
  - Agreement for CMS data improves for the pseudorapidity

Single top results

- Fewer results published on differential cross sections for single top production

	ATLAS	CMS
	Measurements	
tW	TOPQ-2016-12, particle level	TOP-19-003 (no χ^2 available), particle level
t-channel		TOP-17-023 (no χ^2 available), parton/particle level
tW+tt	TOPQ-2017-05, particle level	
	SIMULATIONS	
Powheg-Box (PWG) *tW*	v1, CT10 PDF, DR and DS	v1, NNPDF3.0, DR and DS
Powheg-Box (PWG) *t*-channel		v2 with NNPDF3.0NLO PDF set, 4FS
Pythia6 (PY6)	v6.428, CTEQ6L1 PDF, Perugia 2012 (P2012) tune and higher/lower rad.	
Pythia8 (PY8)	v8.186 A14 tune, NNPDF2.3LO PDF	V8.205
MadGraph5_aMC@NLO (MC@NLO)	V2.2.2, NNPDF3.0NLO, DR/DR2	V2.2.2, NNPDF3.0NLO, DR, FxFx. 4FS and 5FS
Herwig++	UE-EE-5 tune	
bb4l	Powheg-Box-Res with Pythia 8.226	

●(red): < 0.01 ATLAS TOPQ-2016-12, TOPQ-2017-05 and CMS TOP-19-003
●(orange): < 0.1
●(green): > 0.1

Single top summary

Format p-value inclusive(p-value $m_{lb}^{minimax}$>160 GeV):

Variable	PWG+PY DR	PWG+PY DS	MC@NLO+H++	PWG+H++	PWG+PY6 Rad. Up	PWG+PY6 Rad. Down	MC@NLO+PY8 DR	MC@NLO+PY8 DR2	PWG+PY8 *2b4l*
E_b	●(green)	●(green)	●(green)	●(green)	●(green)	●(green)			
E_{llb}	●(green)	●(green)	●(green)	●(orange)	●(green)	●(green)			
m_{llb}	●(green)	●(green)	●(green)	●(green)	●(green)	●(green)			
$m_{lb}^{minimax}$	●(green) (●(green))	●(green) (●(green))					●(green) (●(green))	●(orange) (●(orange))	●(green) (●(green))

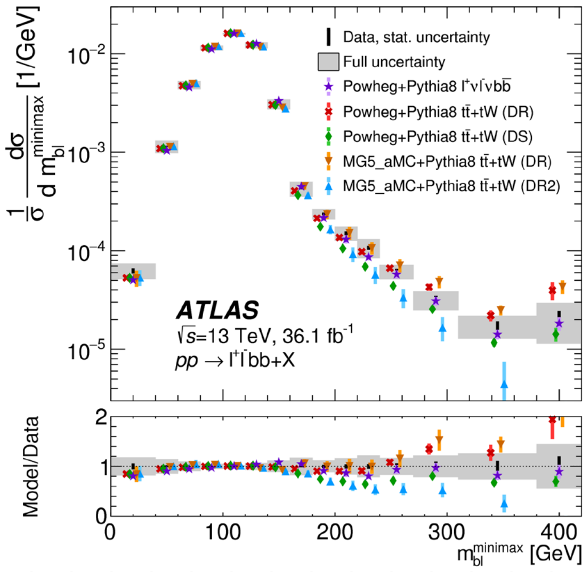
The tt(LO) and tW(NLO) interference is becoming a limiting factor in tt and exotics measurements

- The measurements performed by ATLAS and CMS show general good agreement within the systematic and *theory* uncertainties
- As expected, different schemes diverge at high $m_{lb}^{minimax}$, which is currently the only variable showing great sensitivity

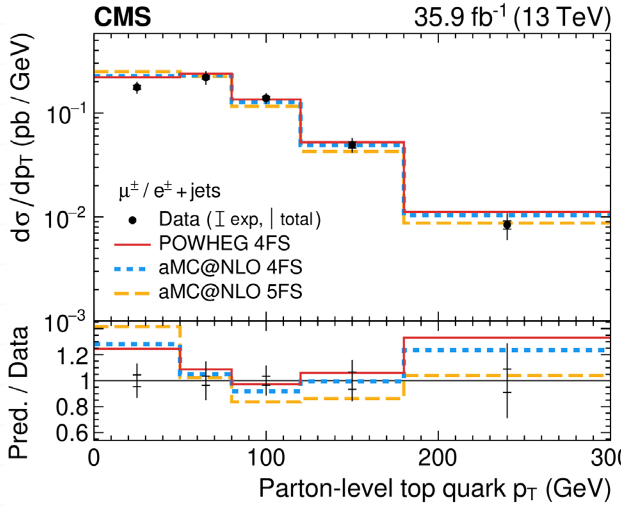
For t-channel, good agreement with the predictions from the 4FS is observed, except for a slight deviation at low top quark pT .

- Bad agreement for 5FS predictions found in the top and $W\ p_T$

TOPQ-2017-05



TOP-17-023



Top production observables: particle level defintions

- At particle level, proxies are used to access the kinematic of the top quarks
  - Differences in the data/MC agreement can be expected among measurements, since the the fiducial phase spaces and/or proxy definitions can enhance sensibilities to specific aspects of the modelling
- ATLAS ljets: PseudoTop and leading top-tagged large-R jet (mass cuts and angular seperations)
- CMS ljets: permutation that minimize the square sum of the reconstructed – nominal mass differences (hadronic and leptonic top, hadronic W)
- CMS all had boosted: the two leading large-R jets (with a mass window cut) are the two top proxies
- CMS l+jets boosted: leading top-tagged large-R jet (mass cuts)
- CMS dilepton: $l\nu$ pairs with mass closer to the W mass and Wb pairs with mass closer to the top mass

●(red): < 0.05
●(orange): < 0.5
●(green): > 0.5

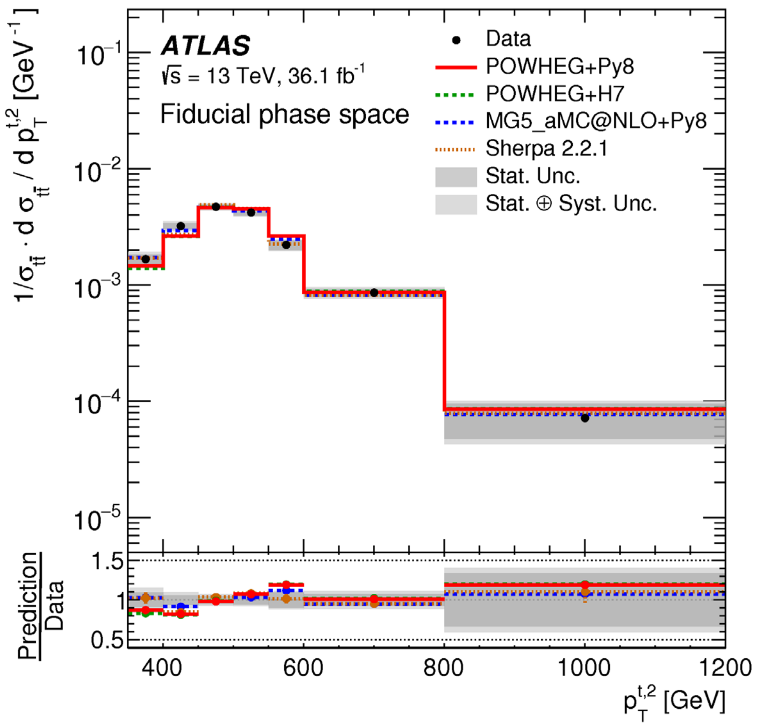
ATLAS TOPQ-2018-15, TOPQ-2016-09, TOPQ-2018-18 and CMS TOP-17-014, TOP-18-013

Particle-level $p_T^{t_{1/2}}$

Format: p-value leading (p-value subleading) for **normalised** cross sections

Paper	PWG+H++	PWG+H7	MC@NLO+PY8	Sherpa	PWG+PY8	PWG+PY8 Rad. Up	PWG+PY8 Rad. Down
CMS dilepton	red (orange)		red (orange)		red (red)		
ATLAS ljets (resolved)		green (green)		green (green)	green (green)	orange (green)	green (green)
ATLAS ljets (boosted)		green (green)		orange (green)	green (green)	orange (green)	green (green)
ATLAS allhad (boosted)			orange (green)	orange (green)	orange (orange)	orange (orange)	orange (green)
ATLAS allhad (resolved)		orange (orange)	orange (red)	red (green)	orange (red)	orange (orange)	orange (red)

TOPQ-2016-09



CMS dilepton show bad agreement with the predictions, with the subleading somewhat better described than the leading

All the considered MC have good agreement with ATLAS ljets and full had boosted

- In ljets, the subleading is better modelled than the leading
- Other way around in the all had boosted
- In all had resolved, Sherpa shows an excellent agreement with the subleading and terrible with the leading

● (red): < 0.01 ATLAS TOPQ-2018-15, TOPQ-2018-18 and CMS TOP-17-014, TOP-17-002

● (orange): < 0.1

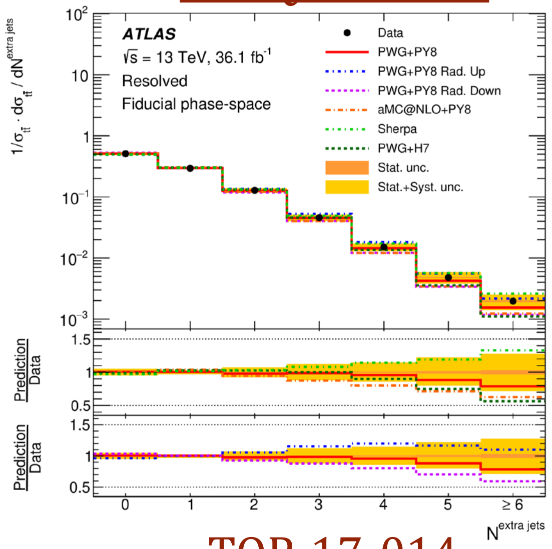
● (green): > 0.1

Jet and subjets multiplicities

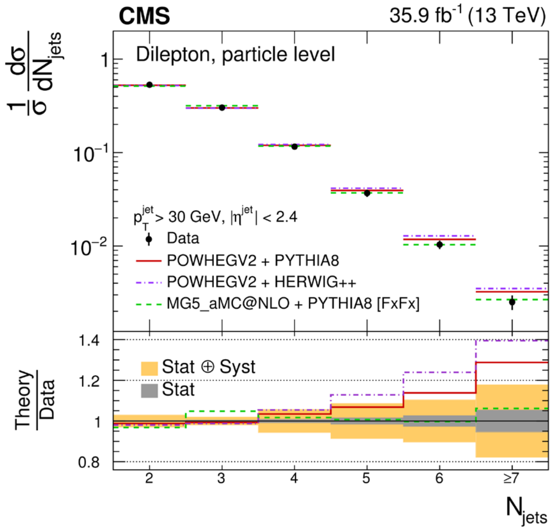
Format: p-value njets (p-value subjets) for normalised only

Paper	PWG+H++	PWG+H7	MC@NLO+PY8	Sherpa	PWG+PY8	PWG+PY8 Rad. Up	PWG+PY8 Rad. Down
CMS dilepton	red		red		orange		
CMS ljets (resolved)	orange		orange	red / red	green / green		
ATLAS ljets (resolved)		red	red (red)	green	green	orange	red
ATLAS ljets (boosted)		green (green)		orange (green)	green (green)	red (green)	red (green)
ATLAS allhad (resolved)		green	red	orange	orange	orange	red

TOPQ-2018-15



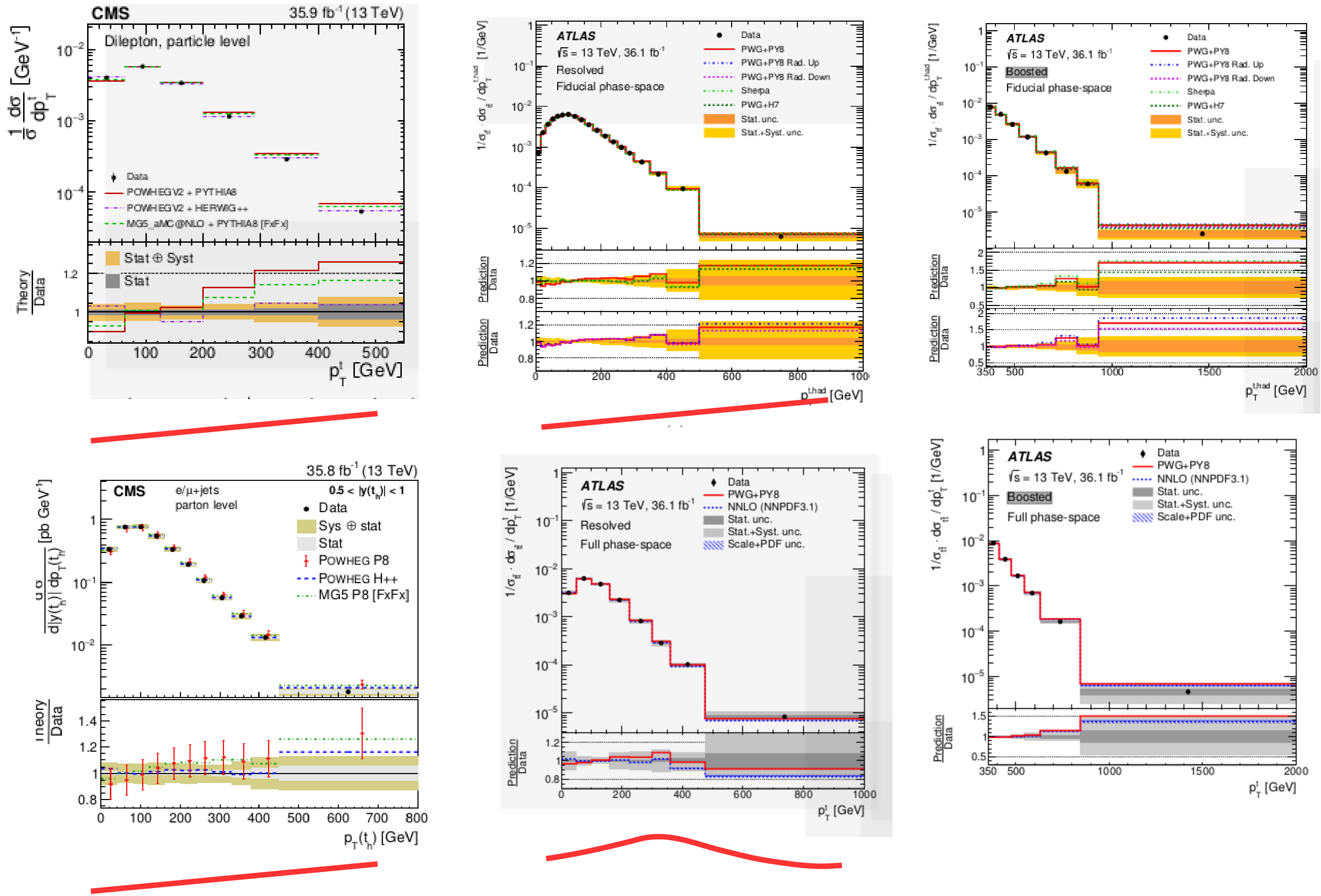
TOP-17-014



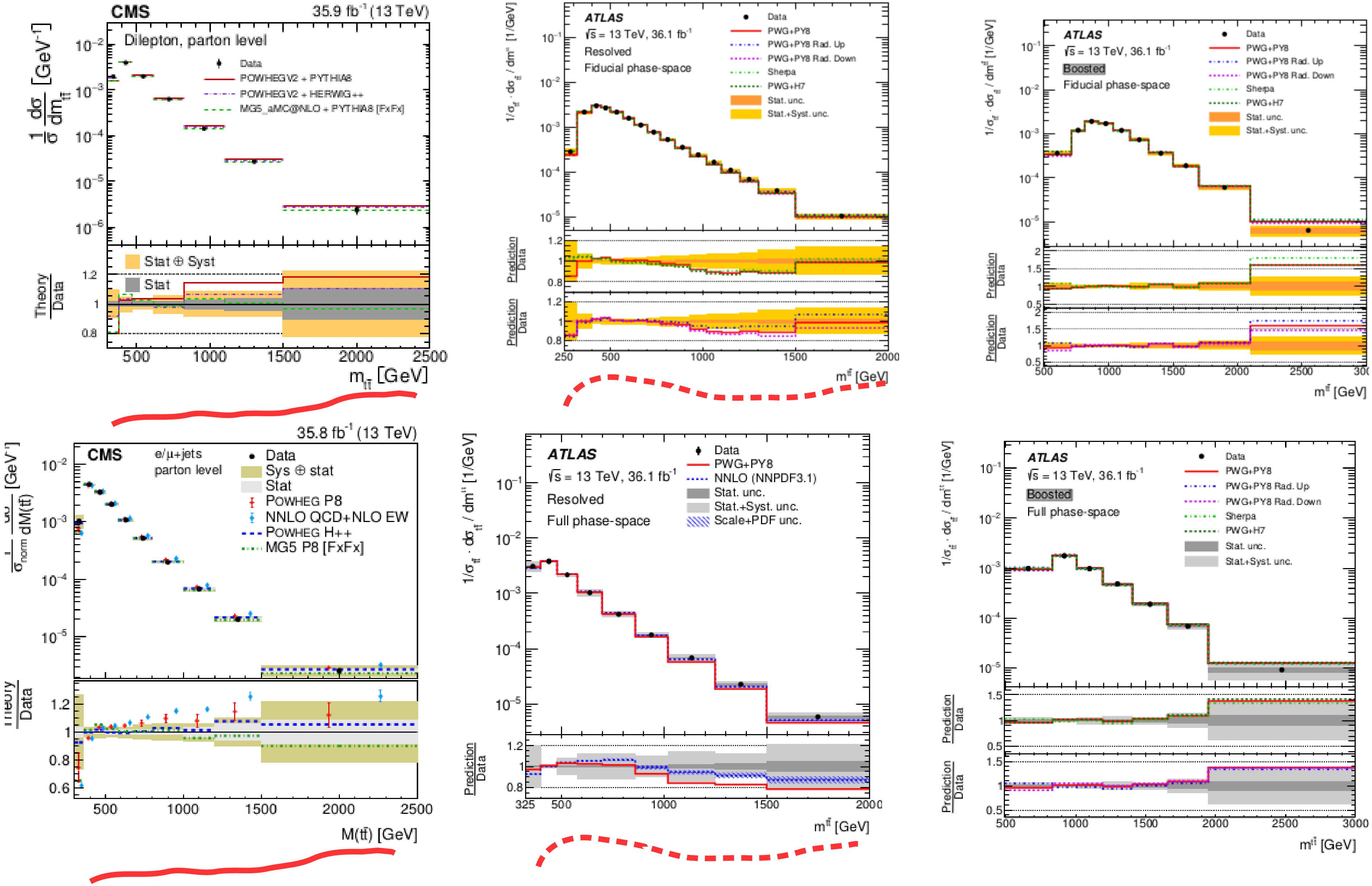
In ATLAS, observed a general underestimation at high multiplicities, besides Sherpa

- PWGPY rad. variations do a bad job at modelling the multiplicity in the boosted topology but give good modelling for the subjets

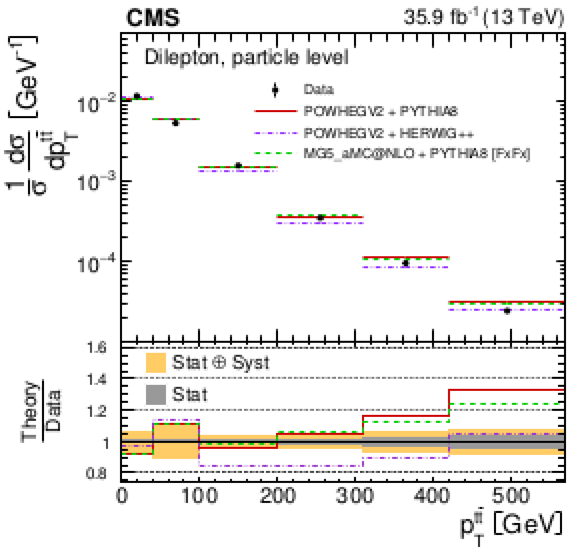
General bad modelling in CMS, with opposite trend wrt ATLAS in the dilepton channel

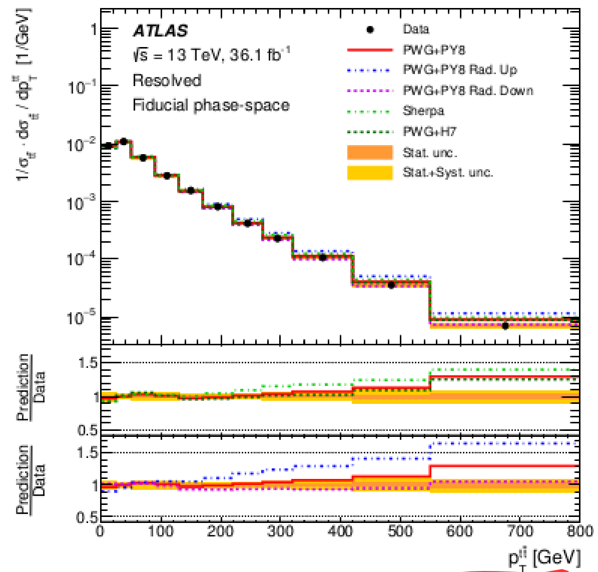


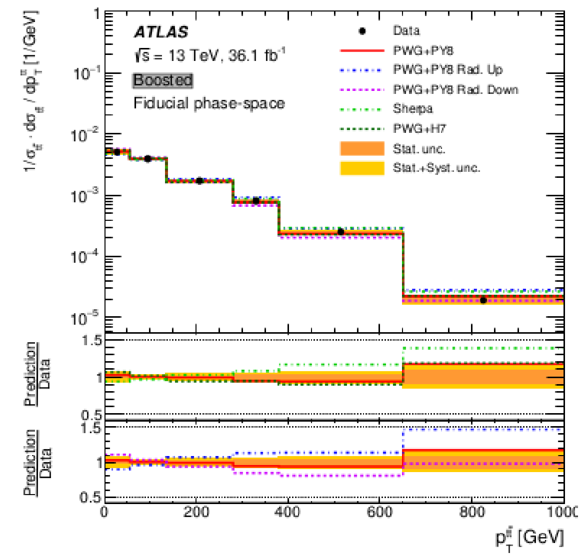
Overall positive slope Theory/Data vs pT(t), a bit more flat around 500 GeV

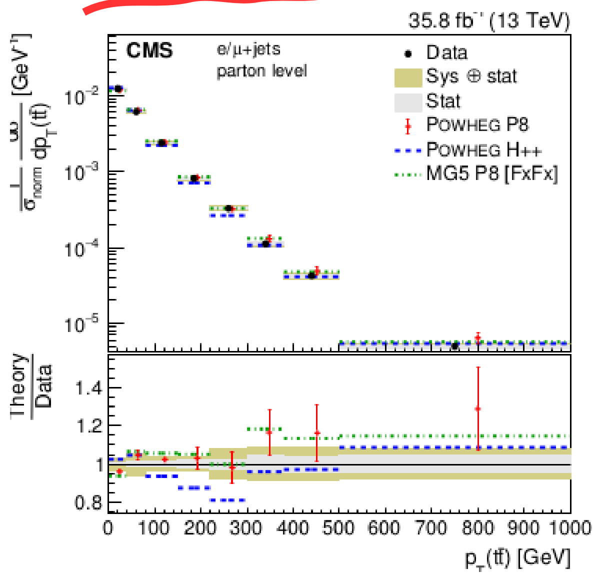


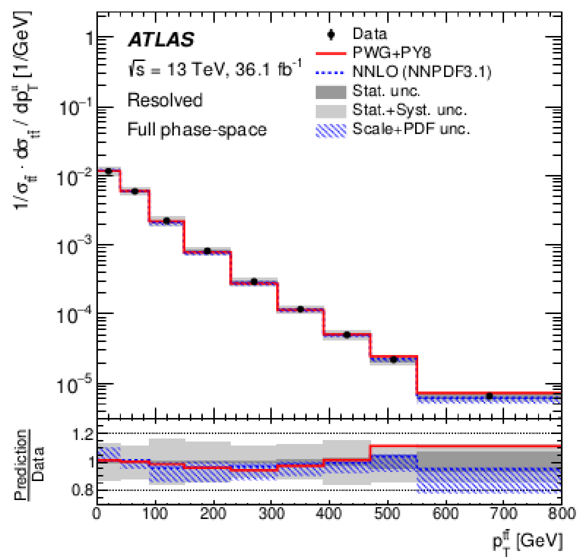
Both ATLAS and CMS see too small prediction near threshold, then positive slope in CMS throughout and ATLAS turning over around 600 GeV to negative slope.



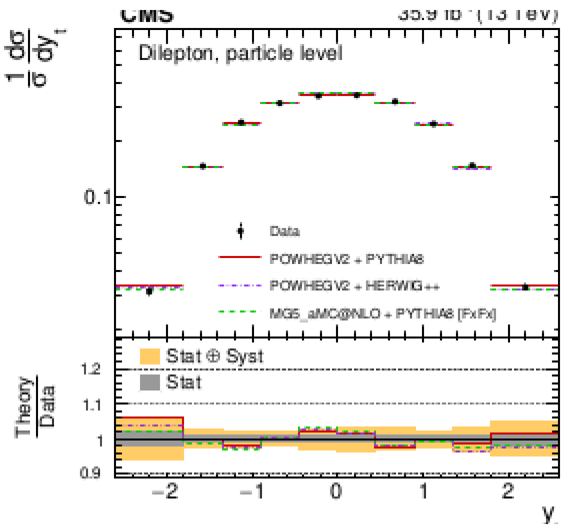


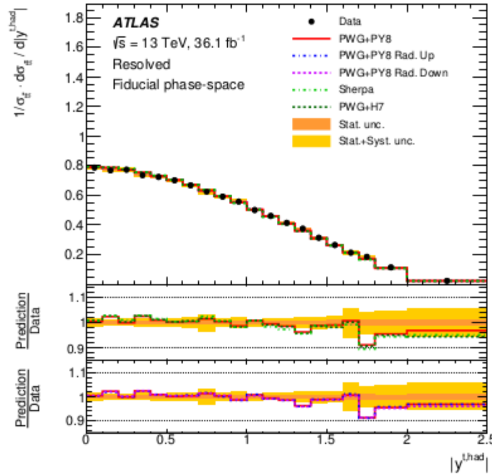


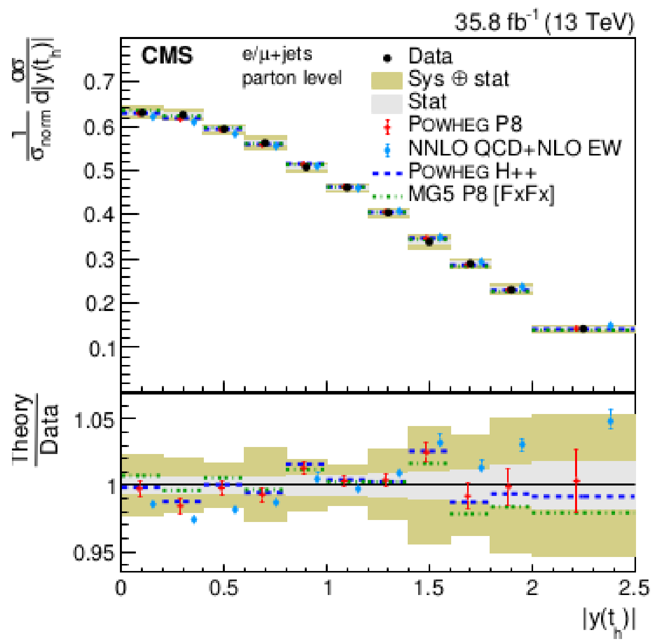


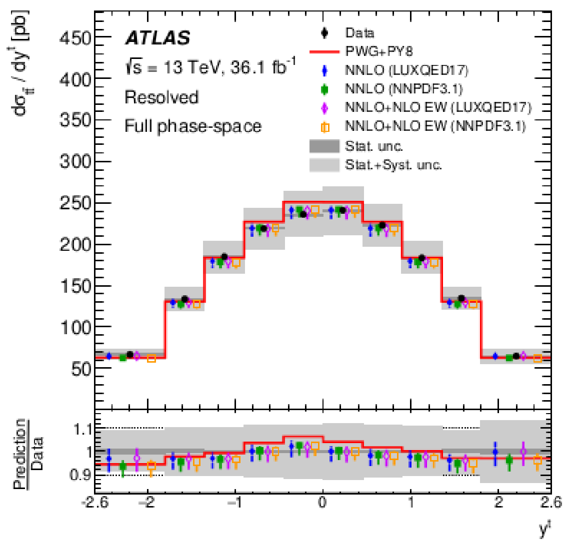


PWG+PYT trend is to slighly overshoot at high pT(tt) above ~400 GeV.









Atlas see data slightly more forward/backward distributed than PWG+PYT, in CMS no clear shape discrepancies visible.