MC simulations for ttbb in ATLAS and CMS

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Motivation

- ttbb is main irreducible background for ttH(H->bb) measurements
- Large uncertainties on the background predictions dominate the uncertainty of the ttH(H->bb) measurement
- ATLAS and CMS plan to publish full Run-2 measurements
  - these future publications shall be combined
- Goal of this effort: define common systematics to allow for future combinations
  - Needed before publication of individual measurements are published as combinations take only published results
  - Effort initiated by ATLAS and CMS Higgs conveners >2 years ago

Documentation

Documented in a LHCHiggsWG1 note:

“Study of ttbb and ttW background modelling for ttH analyses” (link)

- ttbb part will be presented here
- ttW part will be discussed in LHC Higgs WG meeting in October

First feed-back received (thanks a lot!) and updates incorporated. Will appear after this meeting.

Experimental analyses considered

Published Run-2 results:

- CMS based on 36ifb
  - Inclusive xsec
- ATLAS “first full Run-2” based on 139ifb
  - Inclusive xsec and xsec in Higgs pT bins (STXS)

Ongoing efforts to be used for combinations:

- CMS full Run-2 analysis
- ATLAS legacy Run-2 analysis

ttbb MC predictions

Very active theory development covering many different aspects

- see todays talks from Marco and Giuseppe

This talk: comparison of currently used samples in the experiments

tt@NLO ME, 5FS, predictions matched to various PS

- PowHeg
- MG5_aMC@NLO

ttbb@NLO ME, 4FS, predictions matched to various PS

- PowHeg-Box-Res
- Sherpa 2.2.10

Fiducial volume for comparison

phase space relevant for ttHbb measurement with leptonic top decays

Object reconstruction:

Stable final state particles (tau>3*10^{-11} s)

Jets with anti-kT algorithm, R=0.4

b-jets ghost associated B- hadron with pT>5 GeV

Leptons (e, mu):

- dressed with photons in DR<0.1
- removed if close to a jet (DR<0.4)

Object selection:

$|\eta|<2.5$

jet, b-jets: $p_T>25$ GeV

leptons: $p_T>27$ GeV

Event selection:

1 lepton, 4 b-jets, 6 jets (any flavour)

2 lepton, 4 b-jets, 4 jets (any flavour)

Observables

Selection of observables motivated by
- discriminating power between ttHbb signal and ttbb background
- data - MC (dis)agreement observed in the analysis

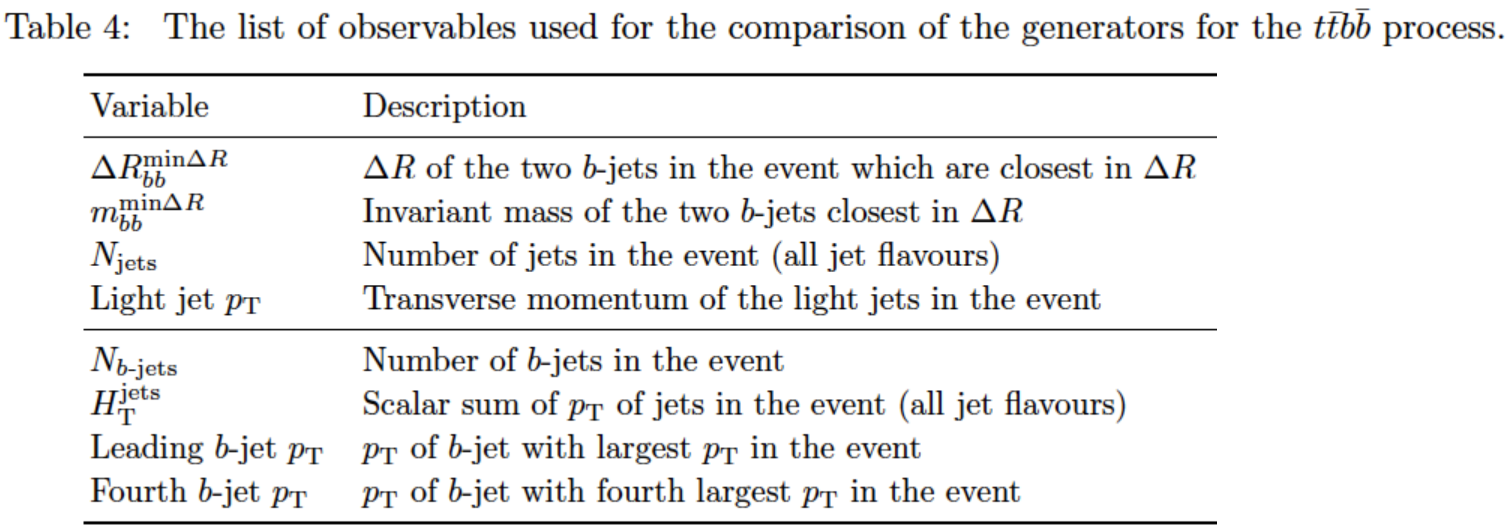


Table 4: The list of observables used for the comparison of the generators for the $t\bar{t}b\bar{b}$ process.

Variable	Description
$\Delta R_{bb}^{\min\Delta R}$	ΔR of the two b-jets in the event which are closest in ΔR
$m_{bb}^{\min\Delta R}$	Invariant mass of the two b-jets closest in ΔR
N_{jets}	Number of jets in the event (all jet flavours)
Light jet p_{T}	Transverse momentum of the light jets in the event
$N_{b\text{-jets}}$	Number of b-jets in the event
$H_{\text{T}}^{\text{jets}}$	Scalar sum of p_{T} of jets in the event (all jet flavours)
Leading b-jet p_{T}	p_{T} of b-jet with largest p_{T} in the event
Fourth b-jet p_{T}	p_{T} of b-jet with fourth largest p_{T} in the event

Fully implemented in a common Rivet routine used by ATLAS and CMS

tt@NLO ME predictions

ATLAS

PowHeg v2 + Pythia8.210(A14), h_{damp} = 1.5 m_{top}

PowHeg v2 + Herwig 7.1.3

MG5_aMC + Pythia8.210(A14)

CMS

PowHeg v2 + Pythia8.230 (CP5), h_{damp} = 1.5 m_{top}

PowHeg v2 + Pythia8.230 (CP5), h_{damp} = 2.305 m_{top}

PowHeg v2 + Pythia8.230 (CP5), h_{damp} = 0.8738 m_{top}

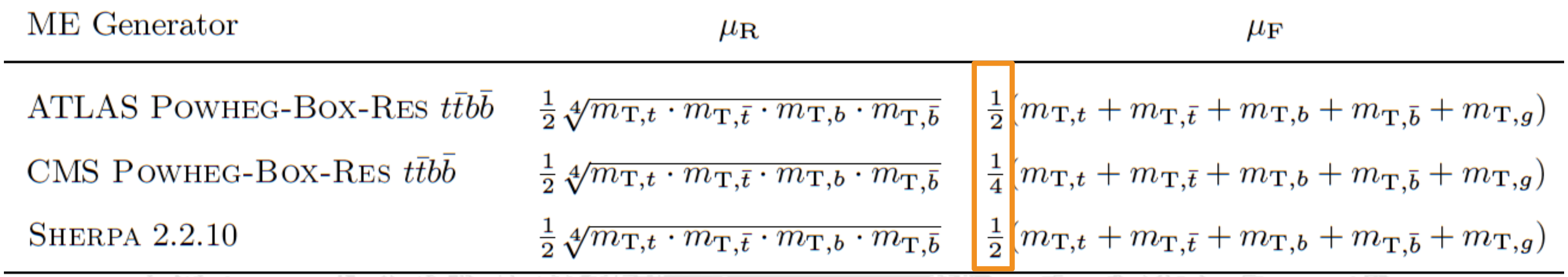
Scale settings for all ME: $\mu_R = \mu_F = \sqrt{0.5 \cdot (m^2_{\mathrm{T},t} + m^2_{\mathrm{T},\bar{t}})}$

5FS NLO PDF sets from NNPDF (ATLAS v3.0, CMS v3.1)

All predictions normalised to the NNLO ttbar production xsec of 451.78 pb

ttbb@NLO ME - PDF & scale settings

All codes use geometric average for renormalisation scale and arithmetic average for factorisation scale



ME Generator	μ_{R}	μ_{F}
ATLAS POWHEG-BOX-RES $t\bar{t}b\bar{b}$	$\frac{1}{2}\sqrt[4]{m_{\mathrm{T},t}\cdot m_{\mathrm{T},\bar{t}}\cdot m_{\mathrm{T},b}\cdot m_{\mathrm{T},\bar{b}}}$	$\frac{1}{2}(m_{\mathrm{T},t}+m_{\mathrm{T},\bar{t}}+m_{\mathrm{T},b}+m_{\mathrm{T},\bar{b}}+m_{\mathrm{T},g})$
CMS POWHEG-BOX-RES $t\bar{t}b\bar{b}$	$\frac{1}{2}\sqrt[4]{m_{\mathrm{T},t}\cdot m_{\mathrm{T},\bar{t}}\cdot m_{\mathrm{T},b}\cdot m_{\mathrm{T},\bar{b}}}$	$\frac{1}{4}(m_{\mathrm{T},t}+m_{\mathrm{T},\bar{t}}+m_{\mathrm{T},b}+m_{\mathrm{T},\bar{b}}+m_{\mathrm{T},g})$
SHERPA 2.2.10	$\frac{1}{2}\sqrt[4]{m_{\mathrm{T},t}\cdot m_{\mathrm{T},\bar{t}}\cdot m_{\mathrm{T},b}\cdot m_{\mathrm{T},\bar{b}}}$	$\frac{1}{2}(m_{\mathrm{T},t}+m_{\mathrm{T},\bar{t}}+m_{\mathrm{T},b}+m_{\mathrm{T},\bar{b}}+m_{\mathrm{T},g})$

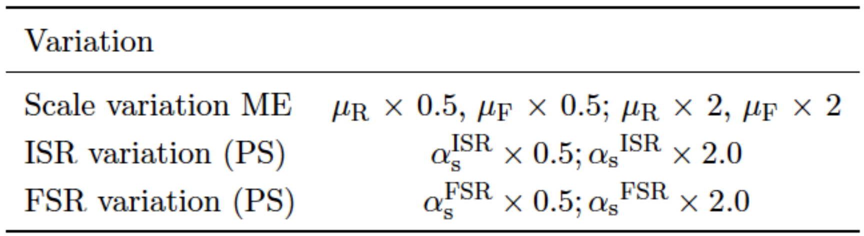
Prefactor for renormalisation scale adapted based on theoretical arguments discussed (here) and comparisons to data (studied here)

Prefactor for factorisation scale differs between experiments
- ATLAS based on theoretical arguments discussed (here) and comparisons to data (here)
- CMS based on private communications with authors

4FS NLO PDF sets from NNPDF with alpha_s 0.118 (ATLAS v3.0, CMS v3.1)

Scale uncertainties for tt@NLO and ttbb@NLO

Variations considered in the studies for this note



Variation	
Scale variation ME	$\mu_{\mathrm{R}} \times 0.5$, $\mu_{\mathrm{F}} \times 0.5$; $\mu_{\mathrm{R}} \times 2$, $\mu_{\mathrm{F}} \times 2$
ISR variation (PS)	$\alpha_{\mathrm{s}}^{\mathrm{ISR}} \times 0.5; {\alpha_{\mathrm{s}}}^{\mathrm{ISR}} \times 2.0$
FSR variation (PS)	$\alpha_{\mathrm{s}}^{\mathrm{FSR}} \times 0.5; {\alpha_{\mathrm{s}}}^{\mathrm{FSR}} \times 2.0$

Independent variations are added quadratically

Estimate of scale uncertainties in published analyses:

CMS: as above

ATLAS: ME and FSR PS scale variations as above

ISR variation in PS simultaneously with variations in ME to cover potential cancellations as suggested in this paper

ttbb@NLO ME - PowHeg internal parameters

Parameters in PowHeg method:

Real emission part of NLO calculation R is split into finite part R_f and singular part R_s
transition between R_s and R_f is regulated via a damping function F = F_{damp} * F_{bzd}

$$F_{\mathrm{damp}} = \frac{h_{\mathrm{damp}}^2}{h_{\mathrm{damp}}^2 + p_{\mathrm{T}}^2}. \qquad F_{\mathrm{bzd}} = \theta\left(\mathrm{h_{bzd}} - \frac{R}{\mathcal{R}}\right)$$

ATLAS:

hdamp = HT/2 following the recommendations here
variations: HT/4, HT studied here, not used in this note
hbzd = 5
variation: hbzd = 2

CMS:

hdamp = 1.379 m_{top}
variations: 2.305 $m_{top.}$ 0.8738 m_{top}
hbzd = 2

ttbb@NLO ME + PS matched predictions

Variations of parton shower, hadronisation, underleying event and matching algorithm

ATLAS:

PowHeg Box Res matched to Pythia8.224 (A14)

PowHeg Box Res matched to Pythia8.224 (A14), dipole recoil

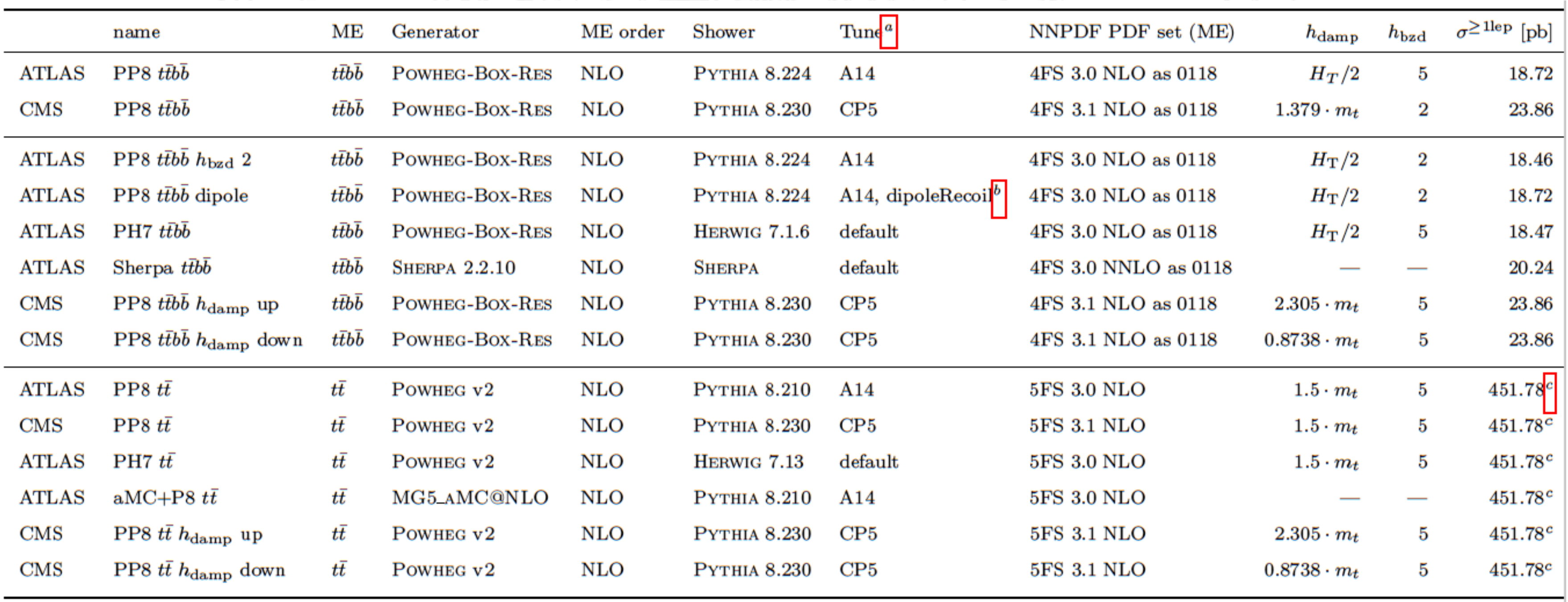
PowHeg Box Res matched to Herwig 7.1.6

Sherpa 2.2.10 default tune

CMS:

PowHeg Box Res matched to Pythia8.230 (CP5)

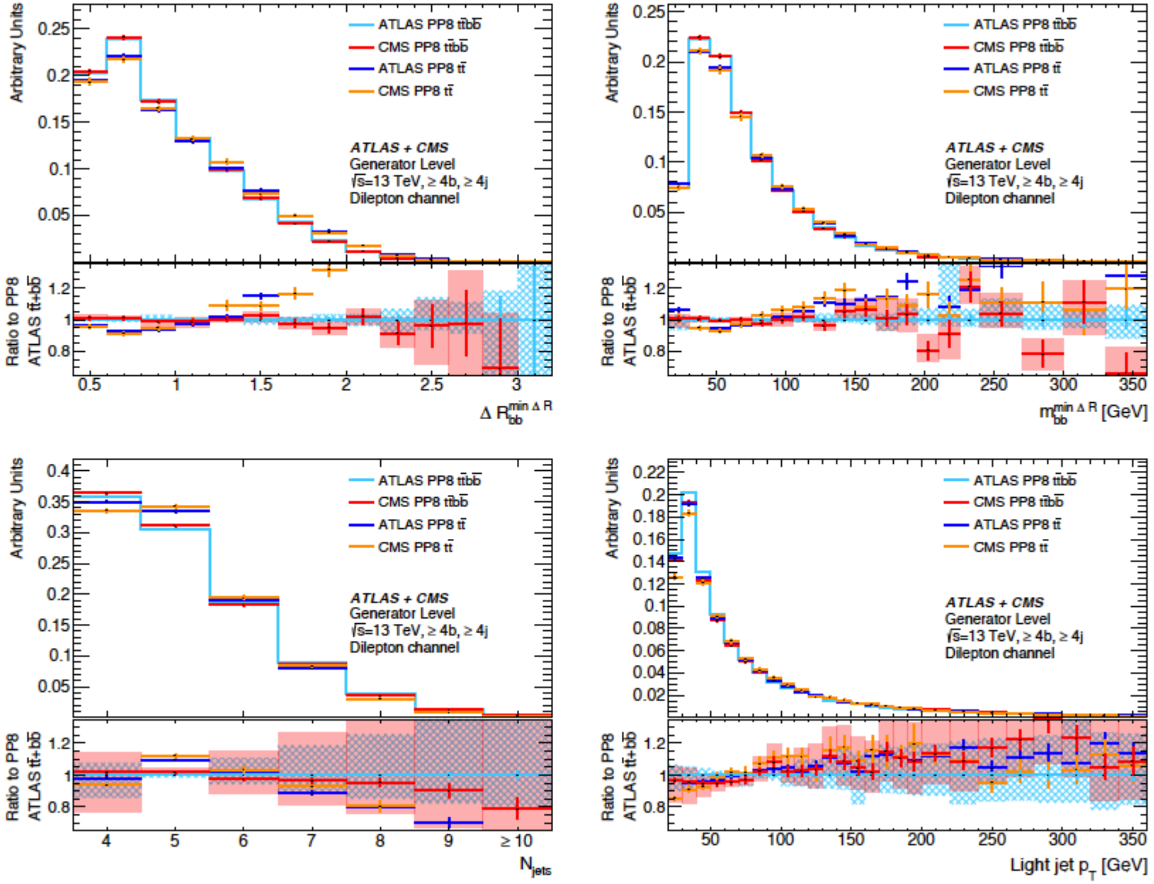
Summary of variations



	name	ME	Generator	ME order	Shower	Tune[a]	NNPDF PDF set (ME)	h_{damp}	h_{bzd}	$\sigma^{\geq 1\mathrm{lep}}$ [pb]
ATLAS	PP8 $t\bar{t}b\bar{b}$	$t\bar{t}b\bar{b}$	Powheg-Box-Res	NLO	Pythia 8.224	A14	4FS 3.0 NLO as 0118	$H_T/2$	5	18.72
CMS	PP8 $t\bar{t}b\bar{b}$	$t\bar{t}b\bar{b}$	Powheg-Box-Res	NLO	Pythia 8.230	CP5	4FS 3.1 NLO as 0118	$1.379 \cdot m_t$	2	23.86
ATLAS	PP8 $t\bar{t}b\bar{b}$ h_{bzd} 2	$t\bar{t}b\bar{b}$	Powheg-Box-Res	NLO	Pythia 8.224	A14	4FS 3.0 NLO as 0118	$H_T/2$	2	18.46
ATLAS	PP8 $t\bar{t}b\bar{b}$ dipole	$t\bar{t}b\bar{b}$	Powheg-Box-Res	NLO	Pythia 8.224	A14, dipoleRecoil[b]	4FS 3.0 NLO as 0118	$H_T/2$	2	18.72
ATLAS	PH7 $t\bar{t}b\bar{b}$	$t\bar{t}b\bar{b}$	Powheg-Box-Res	NLO	Herwig 7.1.6	default	4FS 3.0 NLO as 0118	$H_T/2$	5	18.47
ATLAS	Sherpa $t\bar{t}b\bar{b}$	$t\bar{t}b\bar{b}$	Sherpa 2.2.10	NLO	Sherpa	default	4FS 3.0 NNLO as 0118	—	—	20.24
CMS	PP8 $t\bar{t}b\bar{b}$ h_{damp} up	$t\bar{t}b\bar{b}$	Powheg-Box-Res	NLO	Pythia 8.230	CP5	4FS 3.1 NLO as 0118	$2.305 \cdot m_t$	5	23.86
CMS	PP8 $t\bar{t}b\bar{b}$ h_{damp} down	$t\bar{t}b\bar{b}$	Powheg-Box-Res	NLO	Pythia 8.230	CP5	4FS 3.1 NLO as 0118	$0.8738 \cdot m_t$	5	23.86
ATLAS	PP8 $t\bar{t}$	$t\bar{t}$	Powheg v2	NLO	Pythia 8.210	A14	5FS 3.0 NLO	$1.5 \cdot m_t$	5	451.78[c]
CMS	PP8 $t\bar{t}$	$t\bar{t}$	Powheg v2	NLO	Pythia 8.230	CP5	5FS 3.1 NLO	$1.5 \cdot m_t$	5	451.78[c]
ATLAS	PH7 $t\bar{t}$	$t\bar{t}$	Powheg v2	NLO	Herwig 7.13	default	5FS 3.0 NLO	$1.5 \cdot m_t$	5	451.78[c]
ATLAS	aMC+P8 $t\bar{t}$	$t\bar{t}$	MG5_aMC@NLO	NLO	Pythia 8.210	A14	5FS 3.0 NLO	—	—	451.78[c]
CMS	PP8 $t\bar{t}$ h_{damp} up	$t\bar{t}$	Powheg v2	NLO	Pythia 8.230	CP5	5FS 3.1 NLO	$2.305 \cdot m_t$	5	451.78[c]
CMS	PP8 $t\bar{t}$ h_{damp} down	$t\bar{t}$	Powheg v2	NLO	Pythia 8.230	CP5	5FS 3.1 NLO	$0.8738 \cdot m_t$	5	451.78[c]

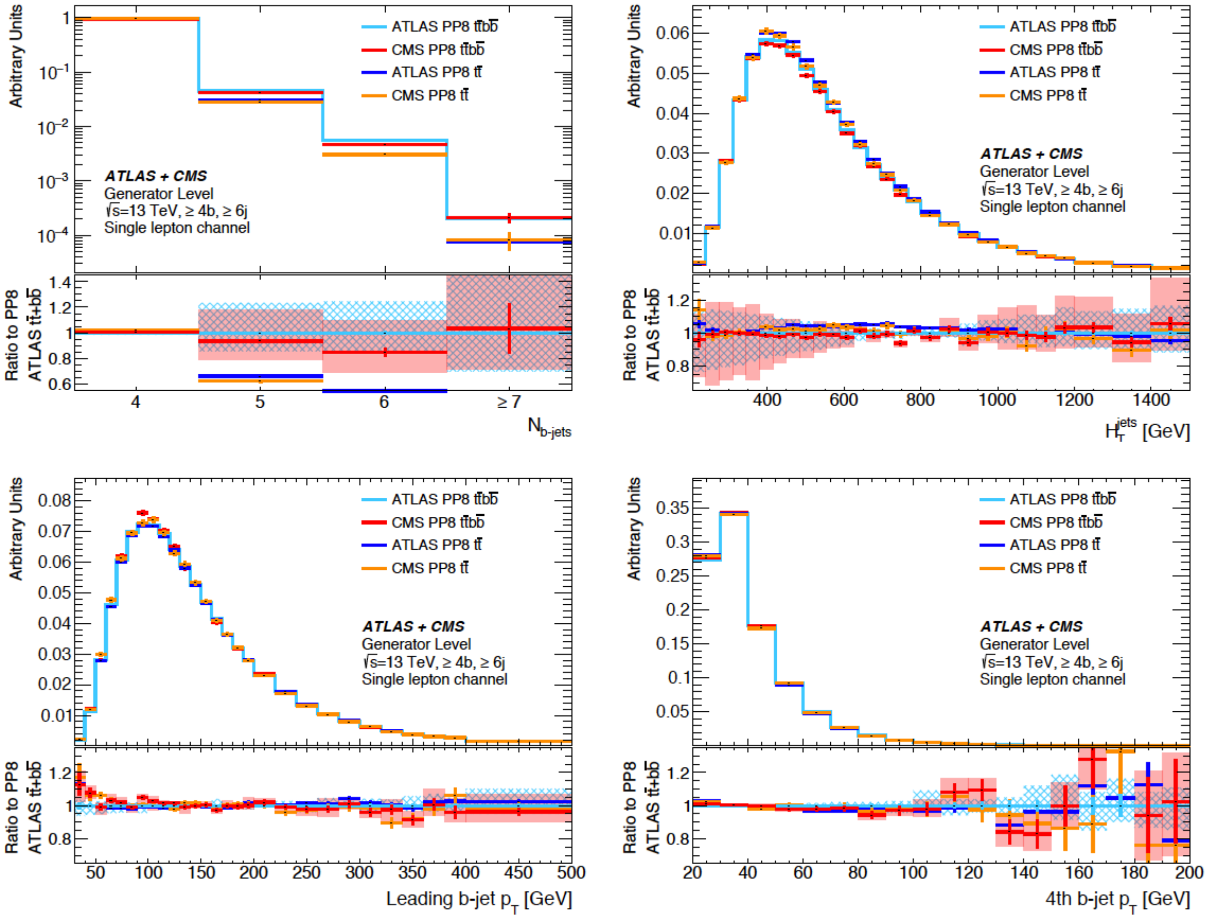
Note: analysis take generator cross sections of ttbb@NLO preditions and
NNLO inclusive cross section for tt@NLO predictions

Comparison of tt@NLO and ttbb@NLO



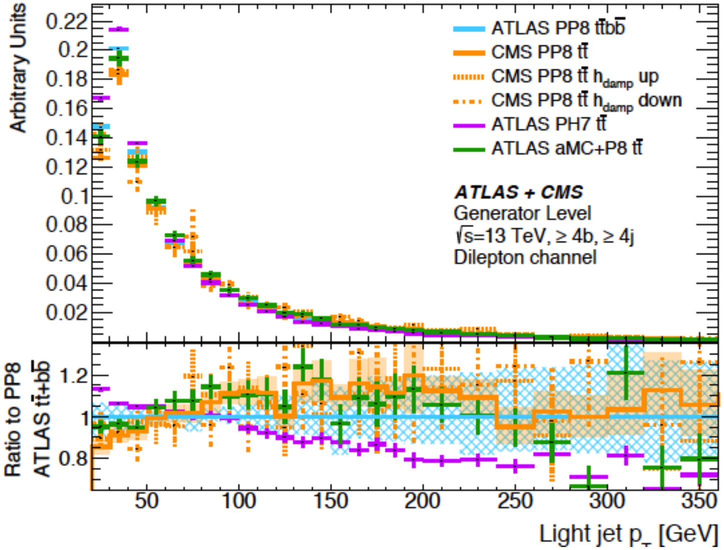
- ATLAS and CMS predictions very similar for nominal tt ME@NLO (5FS) and ttbb ME@NLO (4FS) predictions
  - Parton shower tunes and PowHeg internal parameter settings have minor effect
  - Scale uncertainties are slightly larger for CMS
- Significant differences between tt ME@NLO and ttbb ME@NLO predictions at large DR_bb

Comparison of tt@NLO and ttbb@NLO

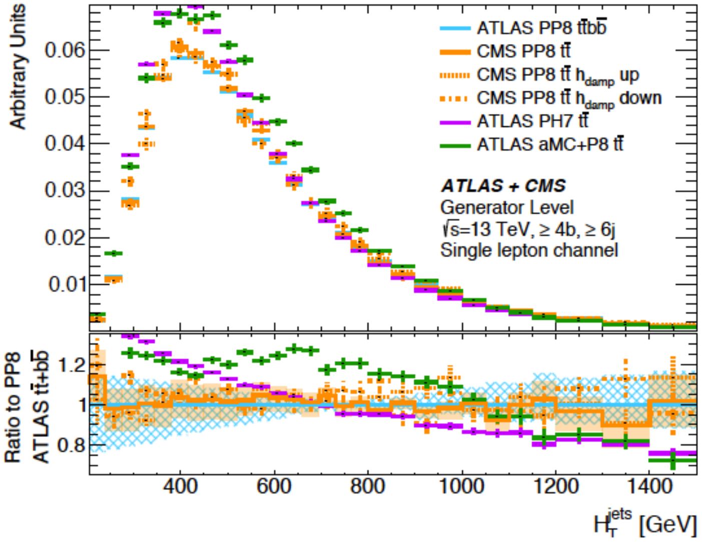


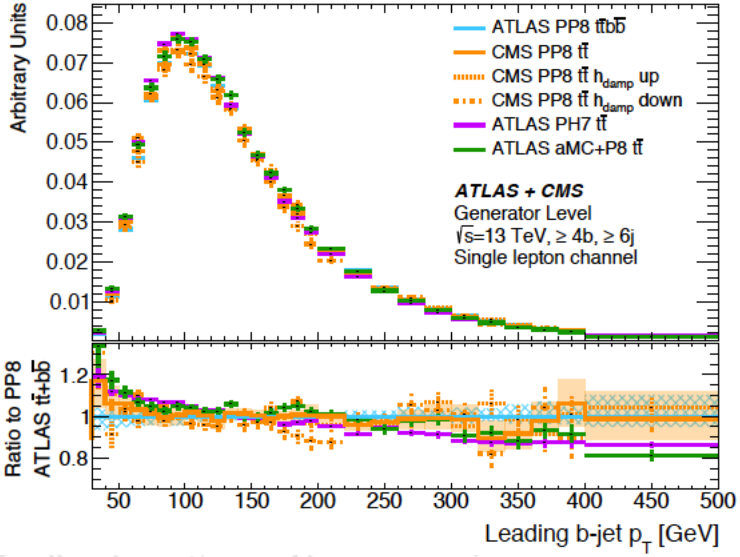
- ATLAS and CMS predictions very similar for nominal tt ME@NLO (5FS) and ttbb ME@NLO (4FS) predictions
    - Parton shower tunes and PowHeg internal parameter settings have minor effect
    - Scale uncertainties are slightly larger for CMS
- Significant differences between tt ME@NLO and ttbb ME@NLO predictions at high b-jet multiplicity

Comparison of uncertainties in published analyses

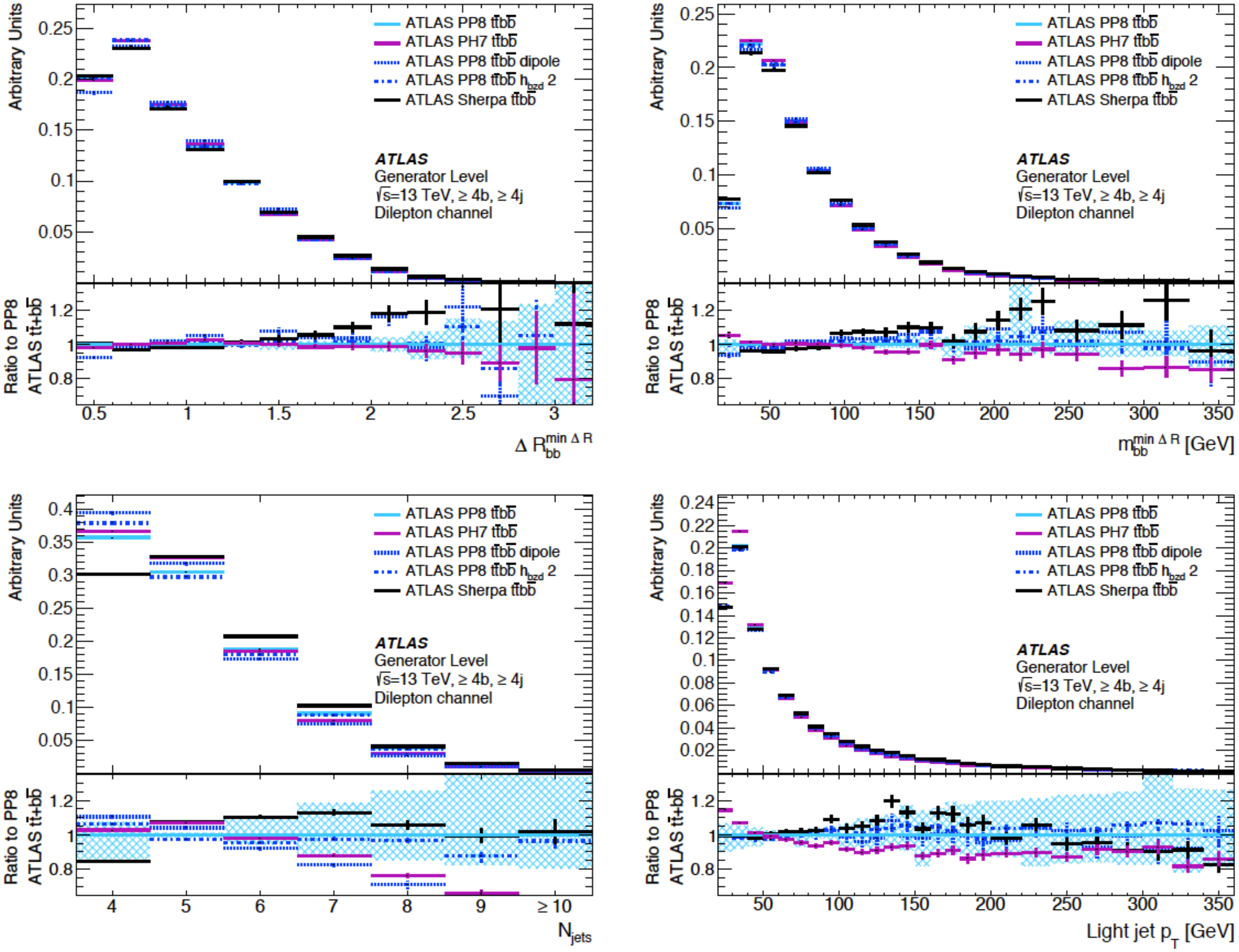


- **ATLAS:**
  - tbb@NLO ttbb as nominal
  - Assign relative uncertainties derived from tt@NLO calculations
  - Variations of NLO generator, parton shower
  - Variations dominated by PS and NLO generator
- **CMS**
  - tt@NLO as nominal
  - Variations of h_{damp}
  - Modeling variations within scale uncertainties except at very low jet p_T / H_T



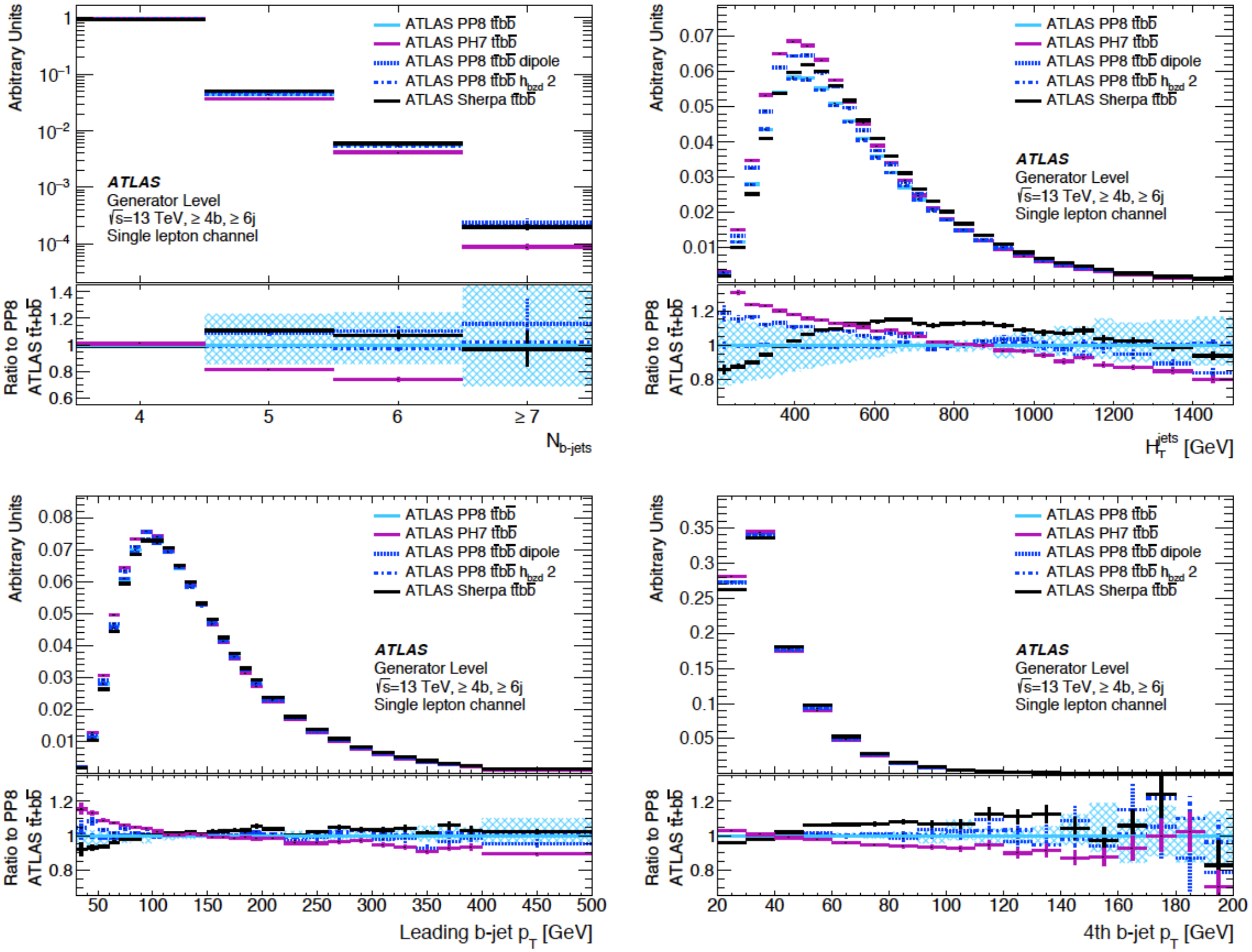


ttbb@NLO variations in ongoing analysis - ATLAS



Jet multiplicity and light jet p_T largely effected by parton shower settings
Sherpa differs in angular correlation (DR)

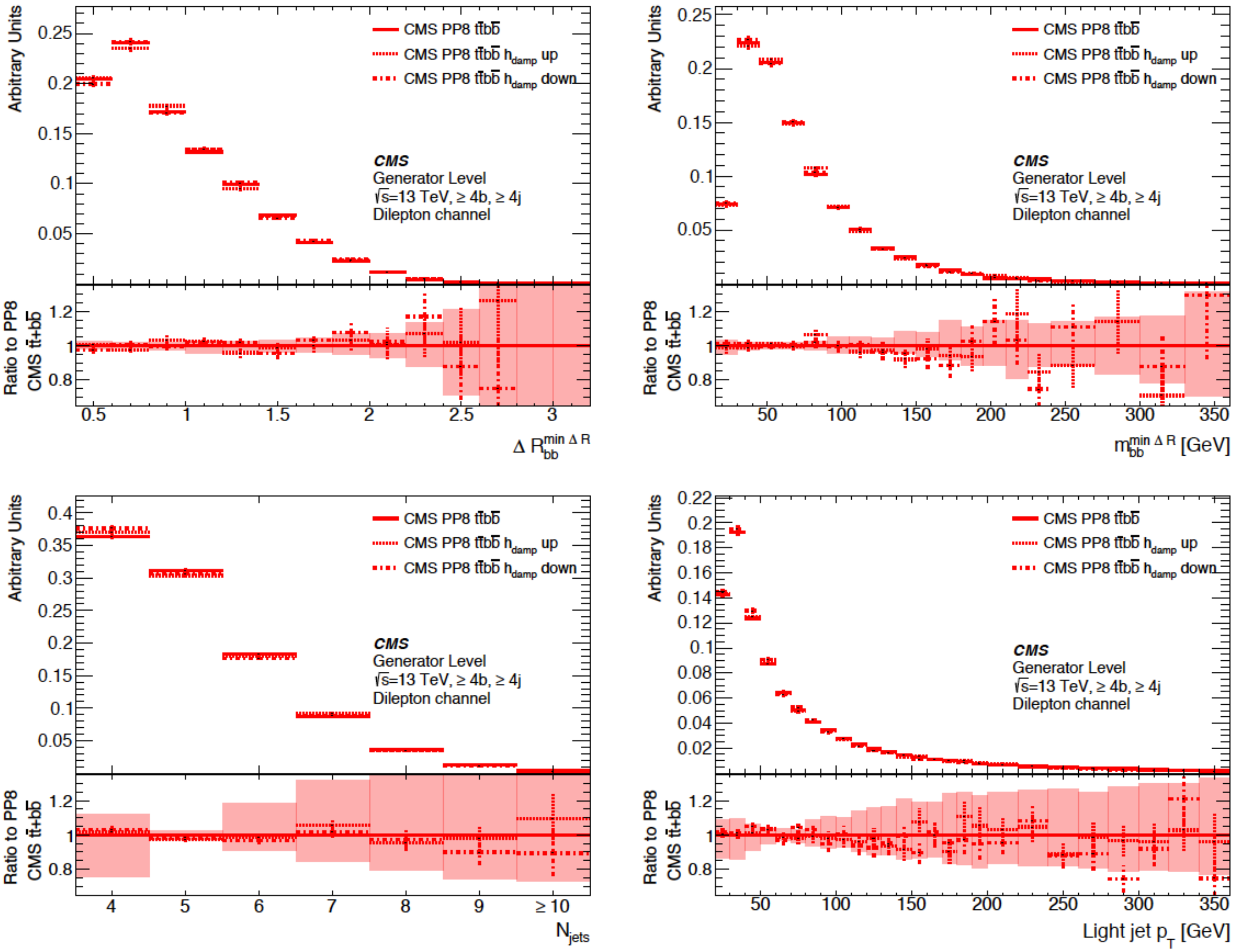
ttbb@NLO variations in ongoing analysis - ATLAS



Significant shape variations between models, in particular for H_T

Model variations exceed scale variations

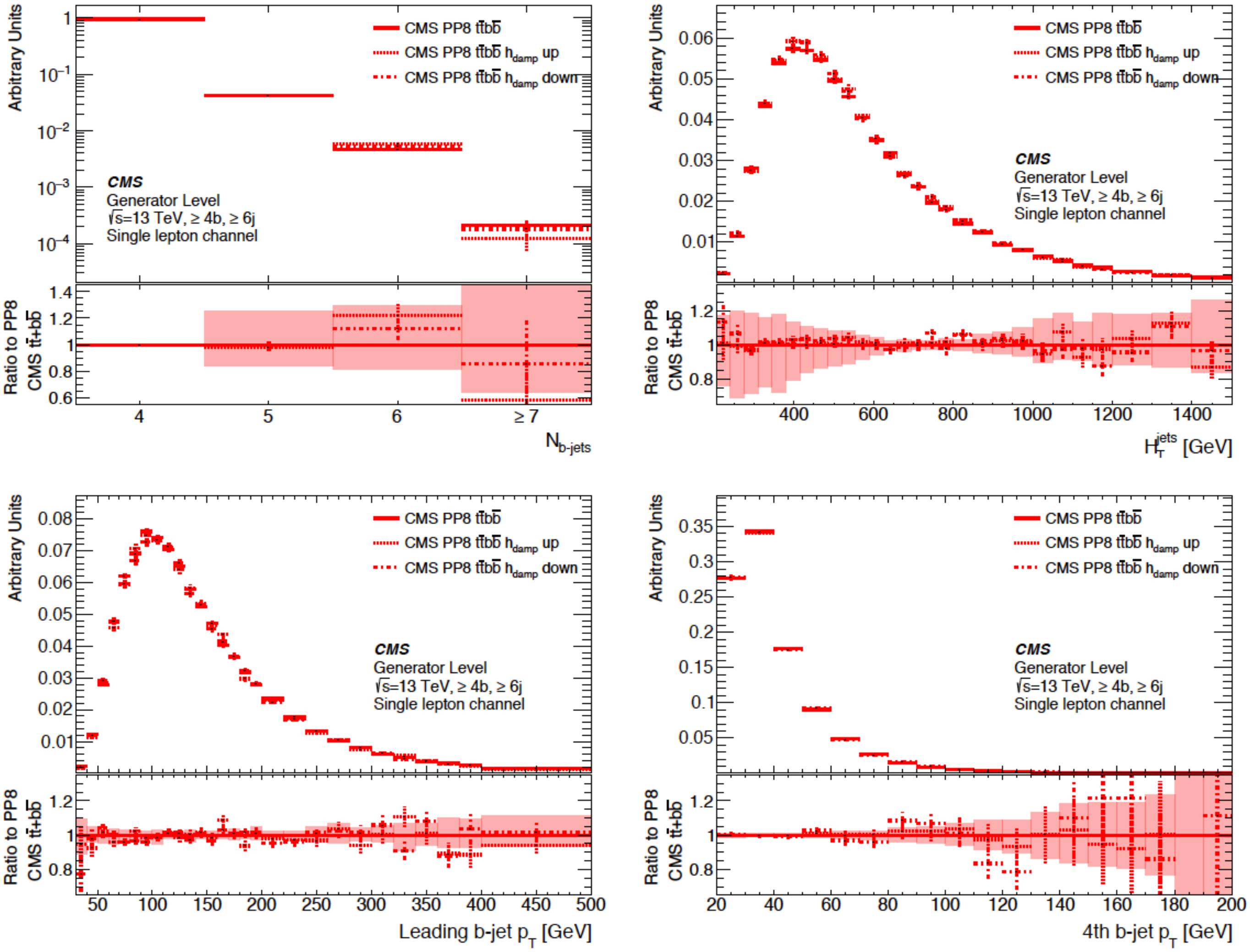
ttbb@NLO variations in ongoing analysis - CMS



Scale variations dominant, no visible effect from h_{damp} variations within MC stats

DESY.

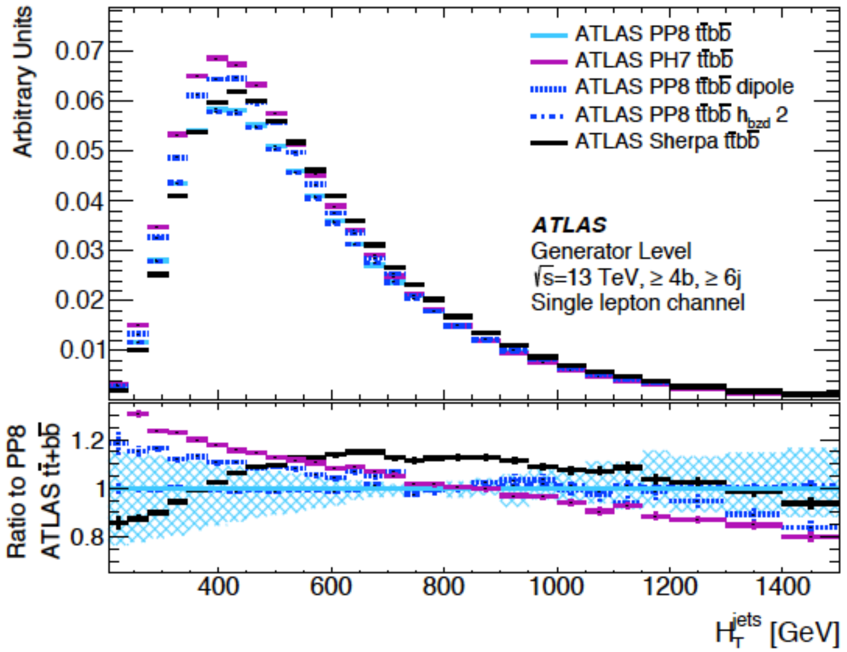
ttbb@NLO variations in ongoing analysis - CMS

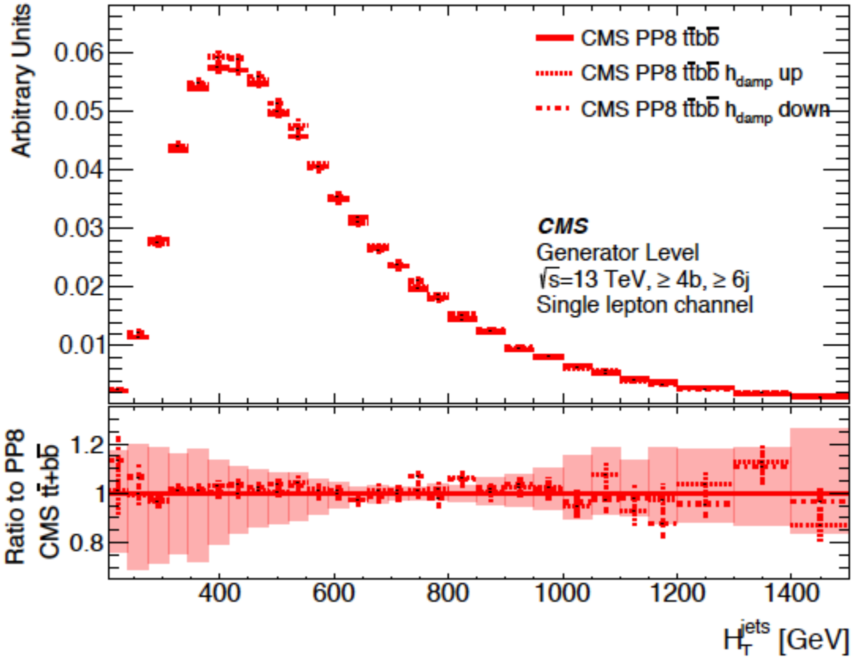


Scale variations dominant, no visible effect from h_{damp} variations within MC stats

ttbb@NLO variations - ATLAS vs CMS

Side-by-side example





Conclusions

Presented comparison of uncertainties considered for ttbb modeling in published and ongoing studies of ATLAS and CMS in view of future combinations of ttHbb results

Significant differences in treatment of model variations observed

- Final systematic models for the ongoing measurements are still under development by the experiments

- However, results based on the current MC samples would not be able to correlate modelling systematics in a possible combination

Back-up