Experimental Perspectives and mis-modelling in top physics

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On behalf of the ATLAS and CMS collaborations

Introduction

Recent measurements from ATLAS and CMS

- Differential cross-section measurements.

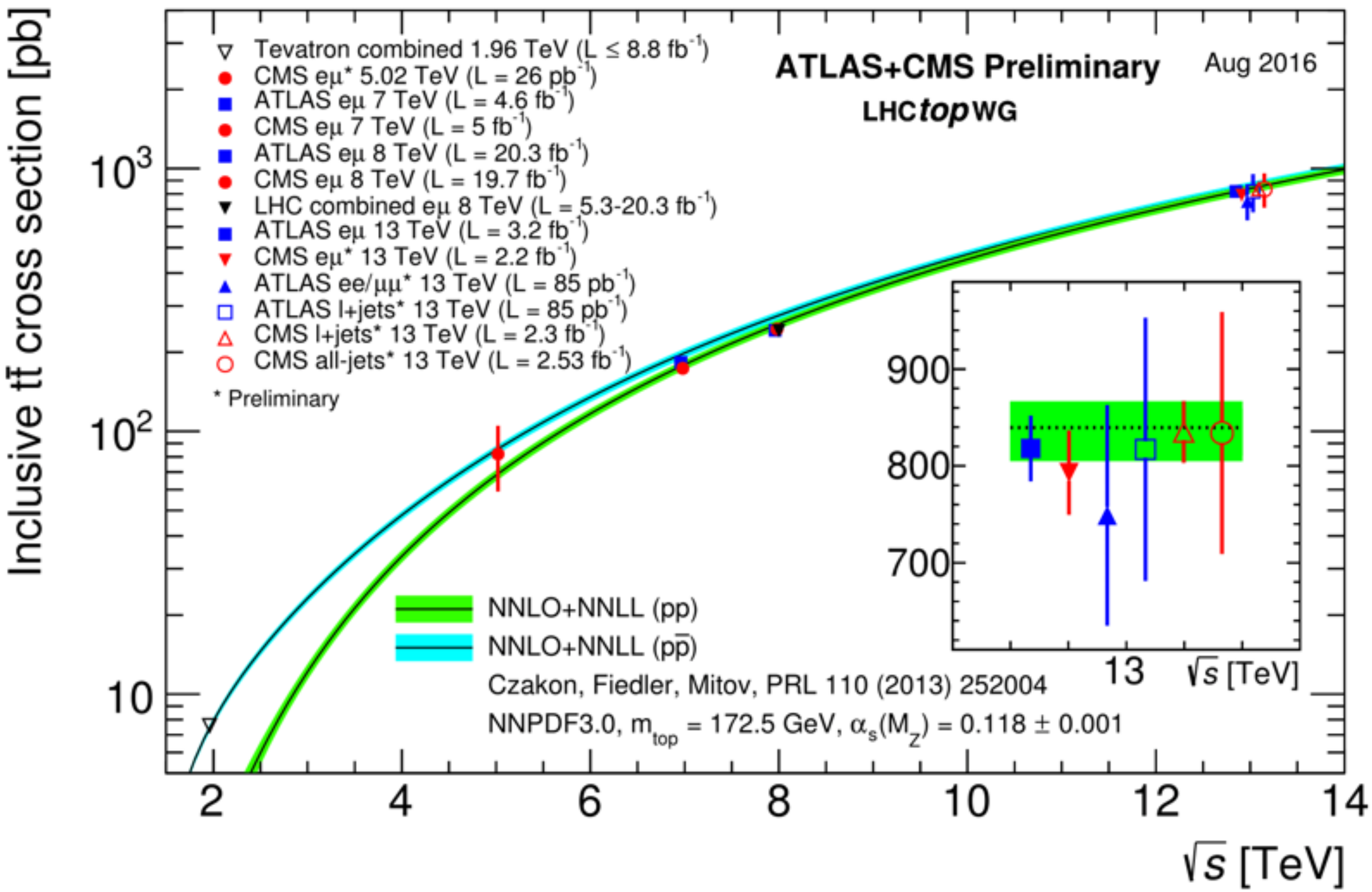
Comparison of results

- Differential cross-sections from Run-1.
- Prospects for Run-2 combinations.

Tuning studies from ATLAS and CMS

- CMS studies on showers.
- Recent ATLAS Tuning studies.

Inclusive cross-section



- Inclusive cross-sections at 5 energies!

Systematic uncertainties

Current Status

- MC modelling uncertainties are typically either the dominating, or at least a significant, source of systematic uncertainty.
- ATLAS and CMS deal with these in different ways (some harmonisation in Run2 relative to Run1).
- Important point for most of this talk:

<u>Better Tuning = Better Experimental Results!</u>

Systematic uncertainties

Core Concept

- Assume we can factorise MC modelling uncertainties into several categories:

Scale	Renormalisation and Factorisation
Matrix Element	Modelling of hard process
Hadronisation	Parton shower and hadronisation
Non-perturbative	Soft effects (e.g. Colour reconnection)
PDF	Parton Distribution Functions

Systematic uncertainties

ATLAS Prescriptions

- Uses either two-point systematic comparison or parameter variations.

	RUN 1	RUN 2
Scale	Powheg μ_R, μ_F, hdamp variations	Powheg μ_R, μ_F, hdamp variations
Matrix Element	Powheg -vs- MC@NLO	Powheg -vs- MG5_aMC@NLO
Hadronisation	Herwig++ -vs- Pythia6	Herwig++(7) -vs- Pythia6(8)
Non-perturbative	Perugia Tunes	A14 Tunes
PDF	Envelope method	PDF4LHC eigenvectors
Other	Mass variations depending on analysis	Mass variations depending on analysis

Systematic uncertainties

CMS Prescriptions

- Tricky to make definitive list, prescriptions vary with √s, time, and analyses.

	RUN 1	RUN 2
Scale	MG5 Q^2 variations	POWHEG μ_R, μ_F variations
Matrix Element	POWHEG -vs- MG5	POWHEG -vs- FxFx
ME - PS	Threshold variatons.	hdamp variations
Hadronisation	b-frag., semi-leptonic B decays, HW6 vs PY6 JER	HERWIG++ -vs- PYTHIA8
Non-perturbative	Tune variations	CUET2P8M4
PDF	CT10 variations	CT14/NNPDF30 variations
Other	Mass variations and pT(t) reweighting	

CMS Differential Measurements

Differential Cross-Sections

1) 13 TeV e/μ + jets: [Submitted to PRD]

- Particle level, experimental phase-space.
- Parton level, full phase-space.
- top, $t\bar{t}$ kinematics vs njets (single and double diff.)
- Focus on MC modelling.

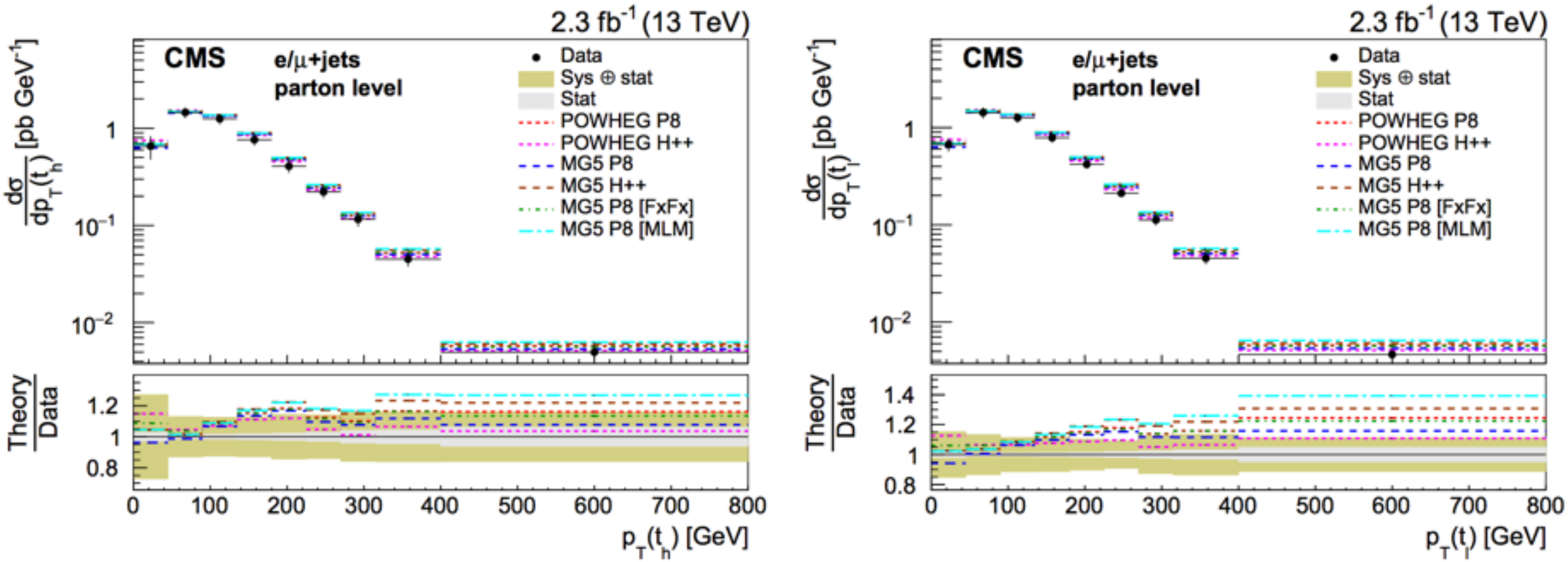
2) 8 TeV eμ + jets: [Submitted to EPJC]

- Parton level, full phase-space, double differential.
- Focus on PDF interpretations.

Not an exclusive list!

13 TeV e/μ + jets

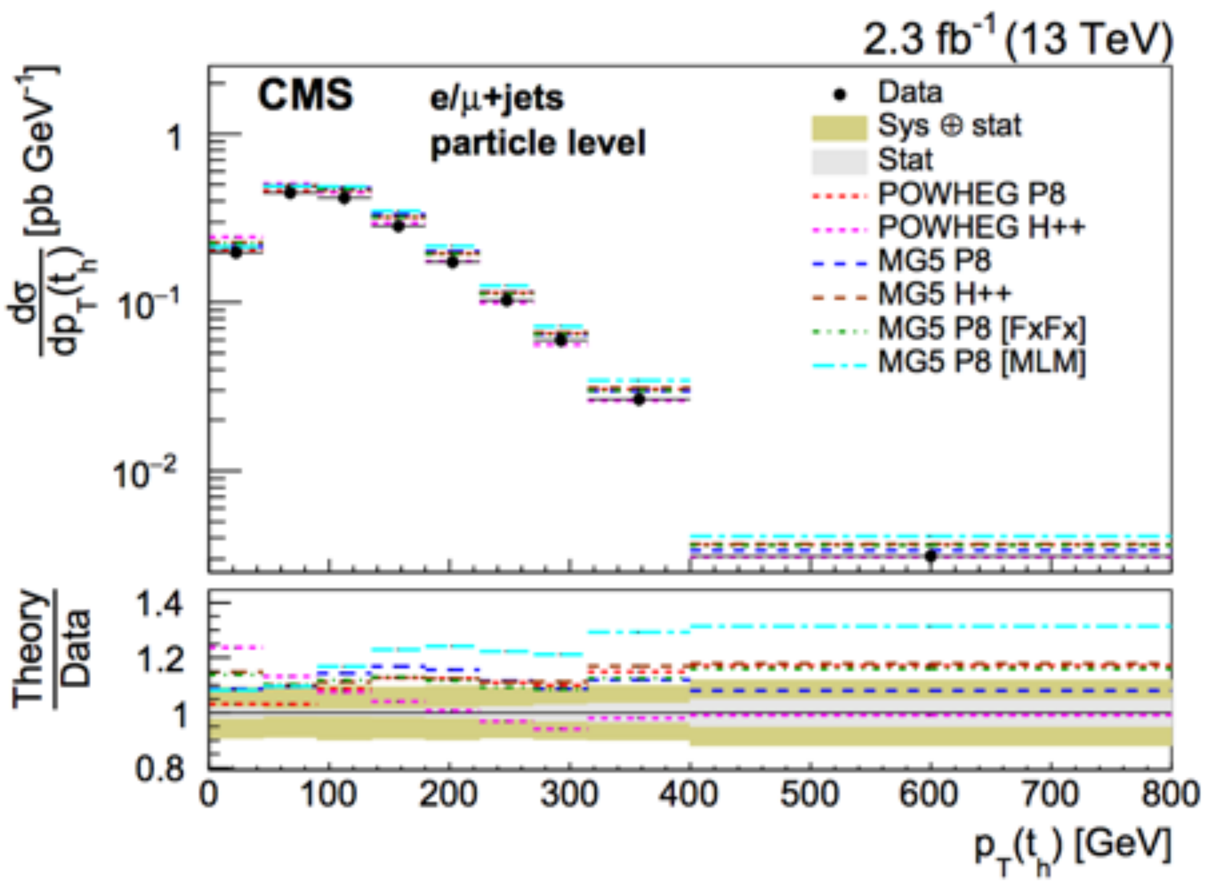
Top p_T modelling (Parton Level):

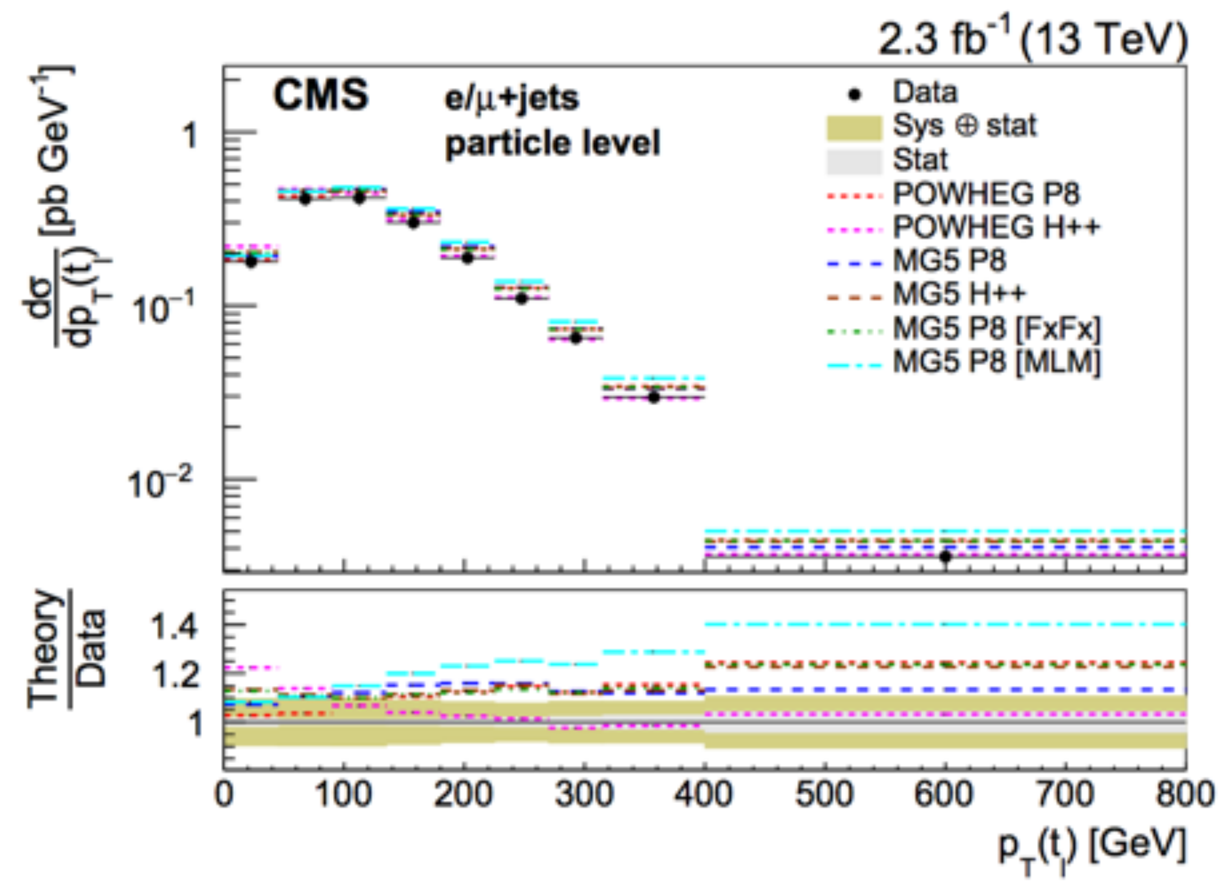


- Difference between $p_T(t_h)$ and $p_T(t_l)$ p-values.
- Many generators failing to describe high p_T behaviour (comparisons/discussion to follow).

13 TeV e/μ + jets

Top p_T modelling (Particle Level):

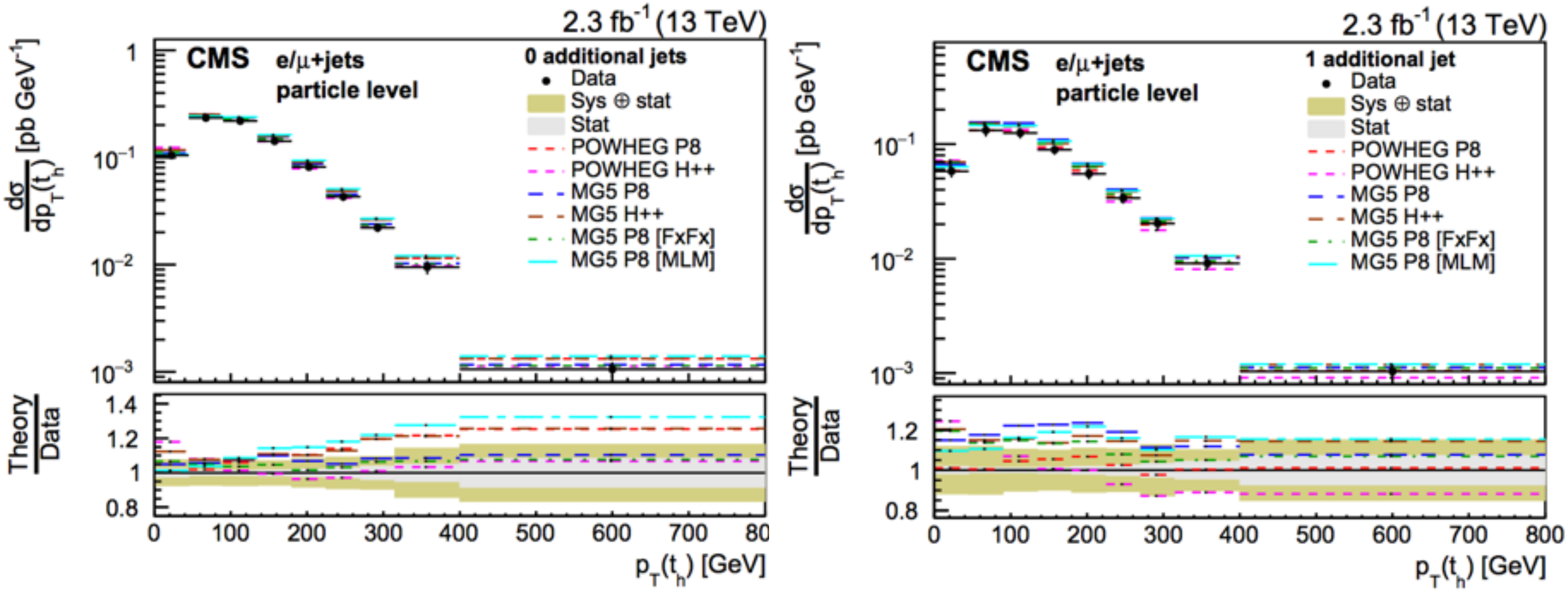




- Similar conclusions from particle level.
- No single ME Generator + Shower combination fully describing behaviour.

13 TeV e/μ + jets

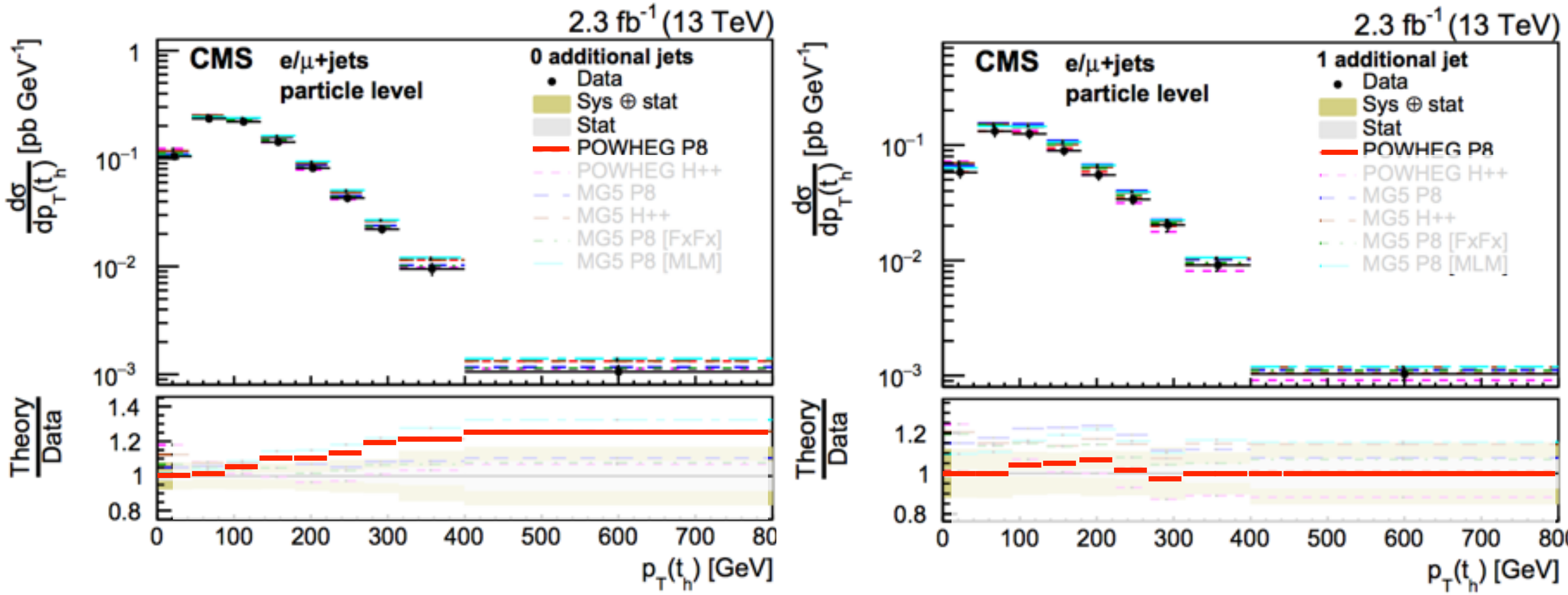
Top p_T modelling (Particle Level):



- Measured with 0,1,2,3+ additional jets
- Some interesting shape changes as Njets is probed (e.g. POWHEG P8 in 0 jets vs 1 additional jets).

13 TeV e/μ + jets

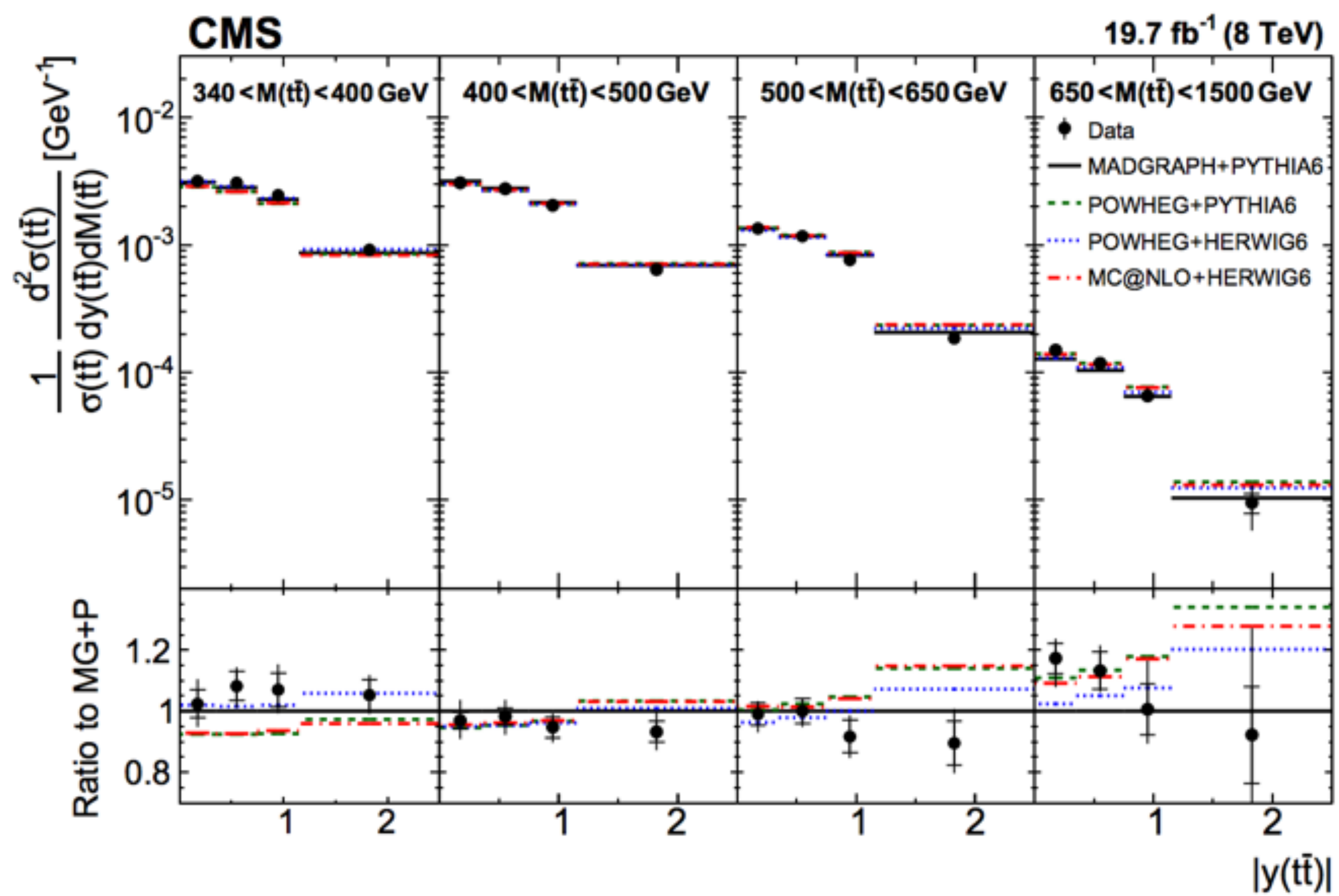
Top p_T modelling (Particle Level):



- Measured with 0,1,2,3+ additional jets
- Some interesting shape changes as Njets is probed (e.g. POWHEG P8 in 0 jets vs 1 additional jets).

8 TeV eμ + jets

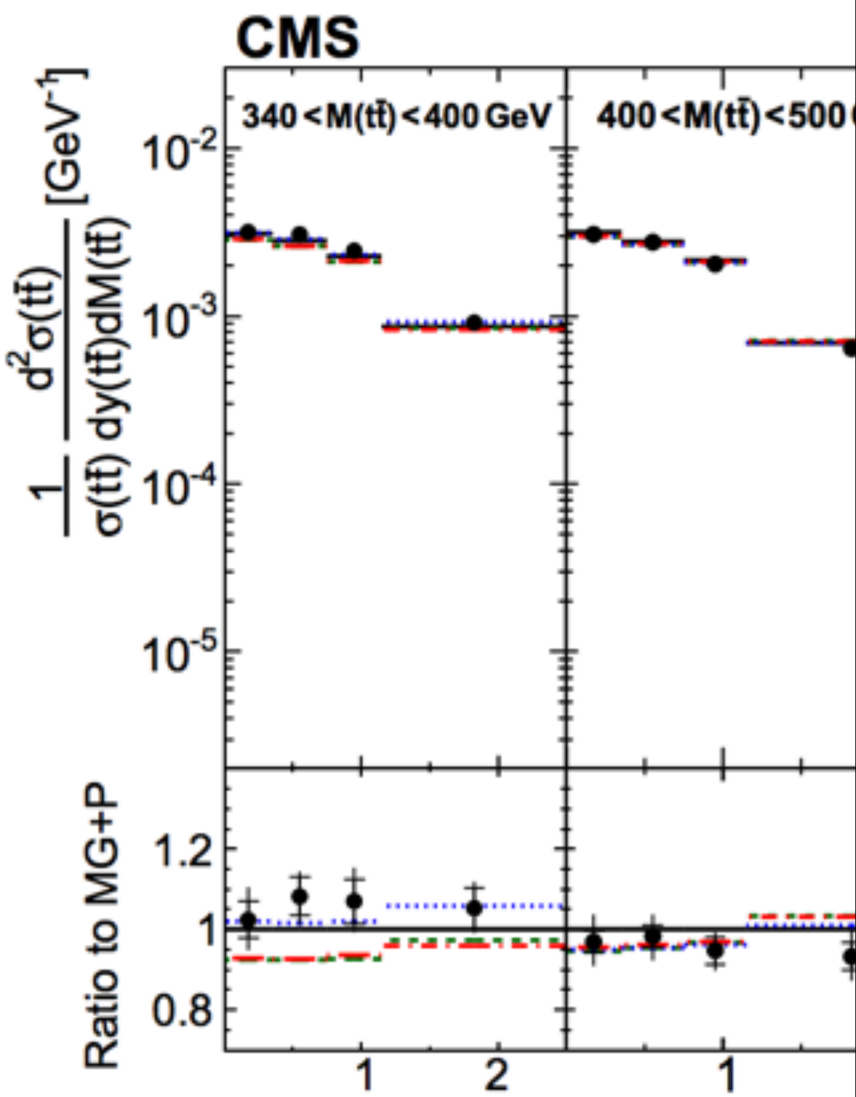
Normalised Parton-level cross-sections

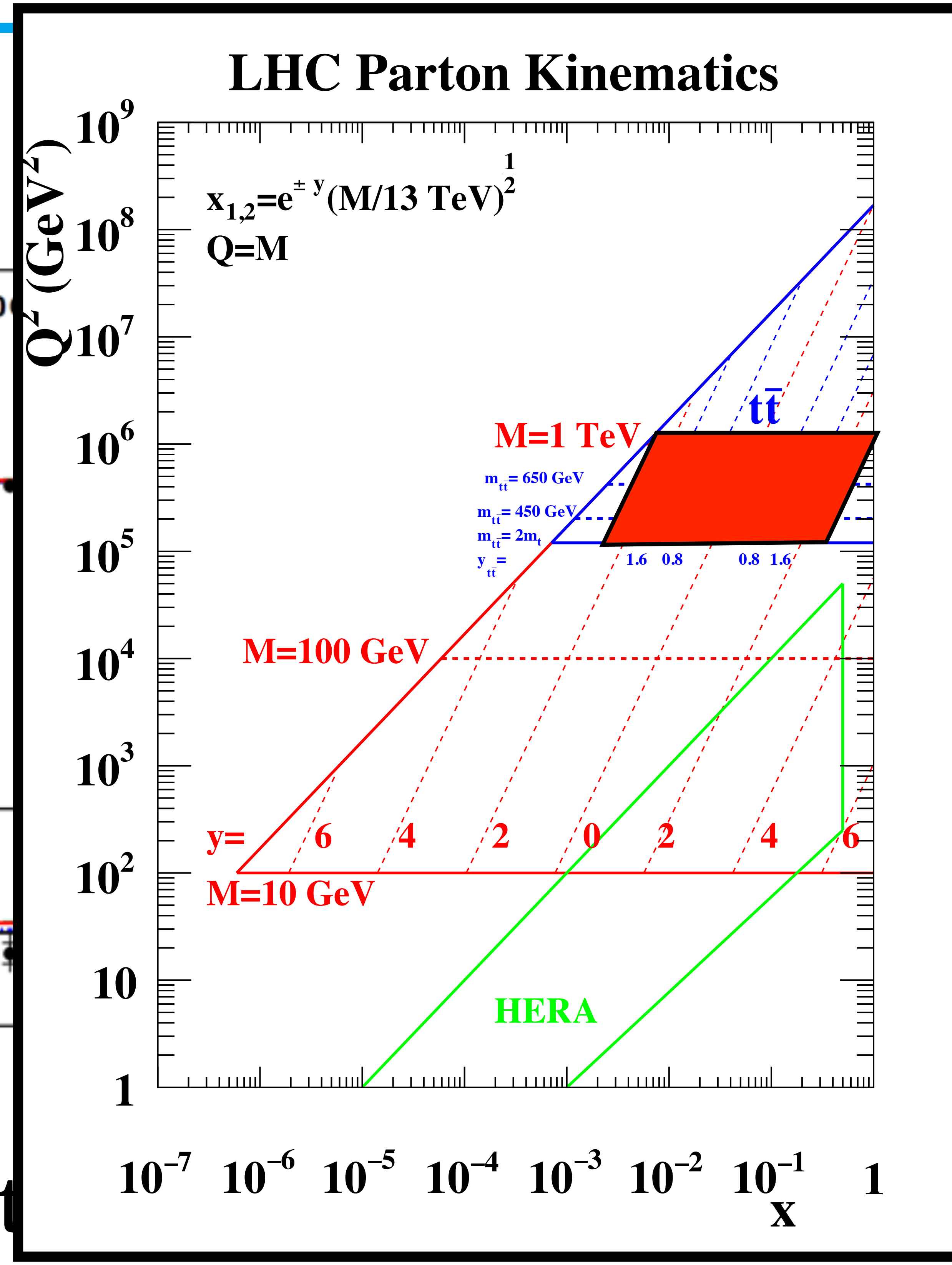


- $|y(t\bar{t})|$ vs. $M(t\bar{t})$ directly probing sensitivity to PDFs

8 TeV eμ + jets

Normalised Parton-level

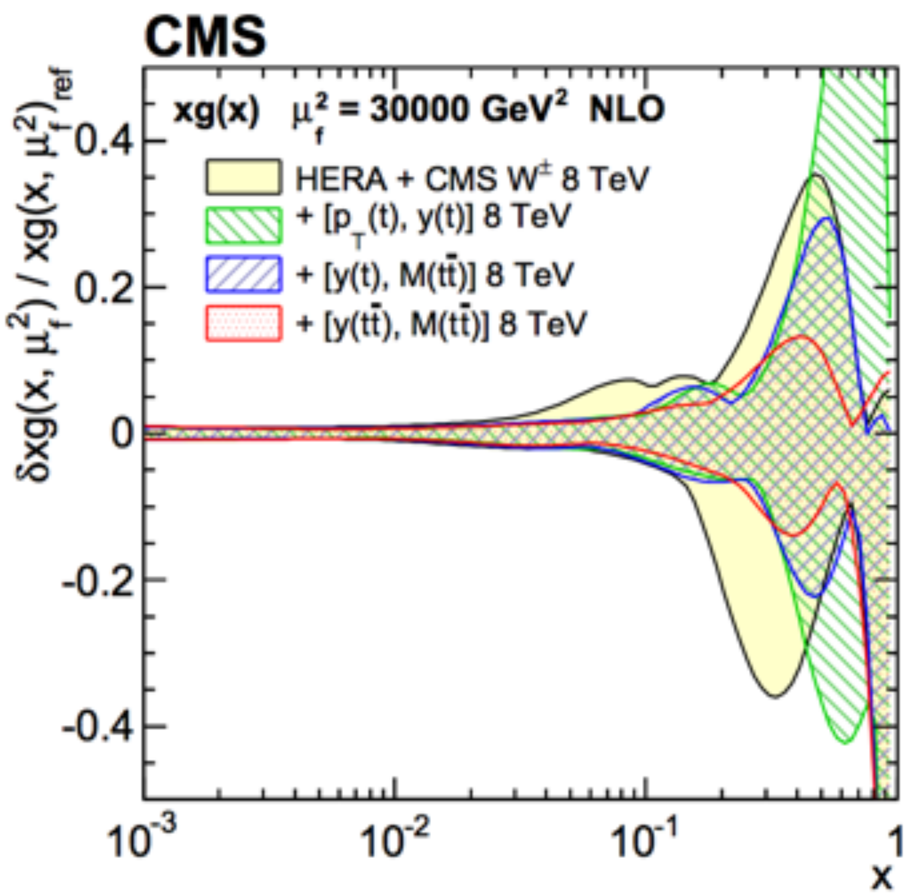


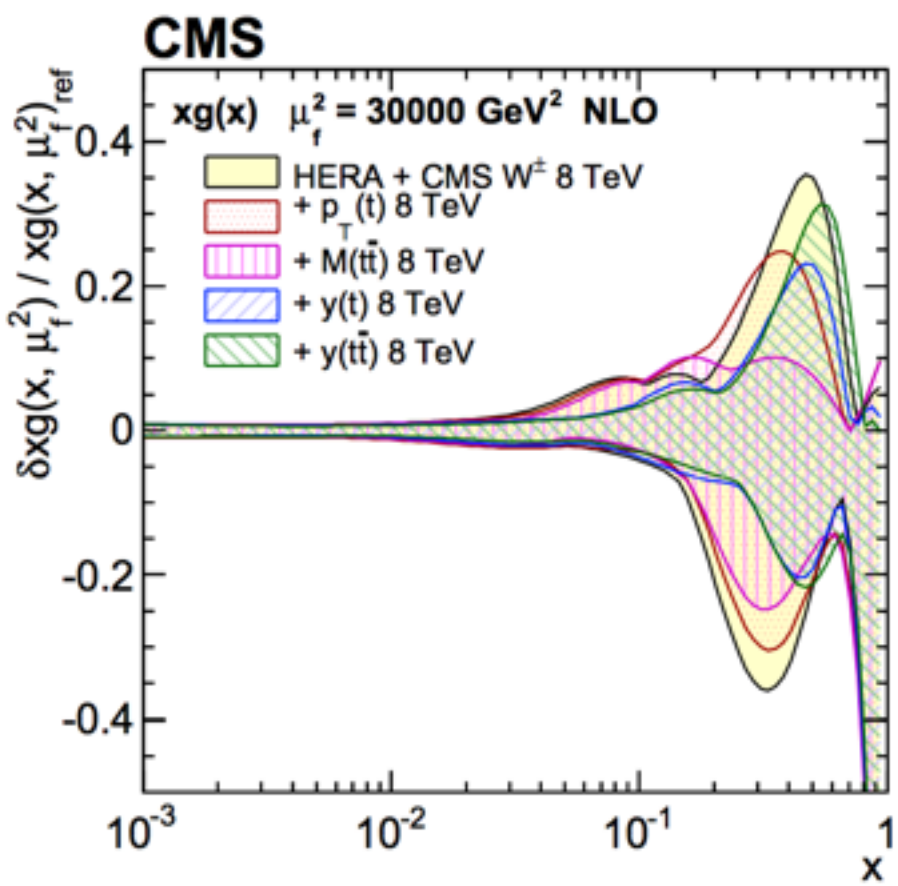


- Directly probing sensit

8 TeV eμ + jets

Impact on the gluon PDF:





- $t\bar{t}$ xsec and DGLAP evolution at NLO.
- 5 flavour (M_b=4.5 GeV, M_c=1.47 GeV).
- Double diff. provides more constraining power.
- Consistent with dijet results.

ATLAS Differential Measurements

Differential Cross-Sections

1) 13 TeV e/μ + jets: [Preliminary]

- Particle level, experimental phase-space.
- hadronic top kinematics.

2) 13 TeV eμ + jets: [Submitted to EPJC]

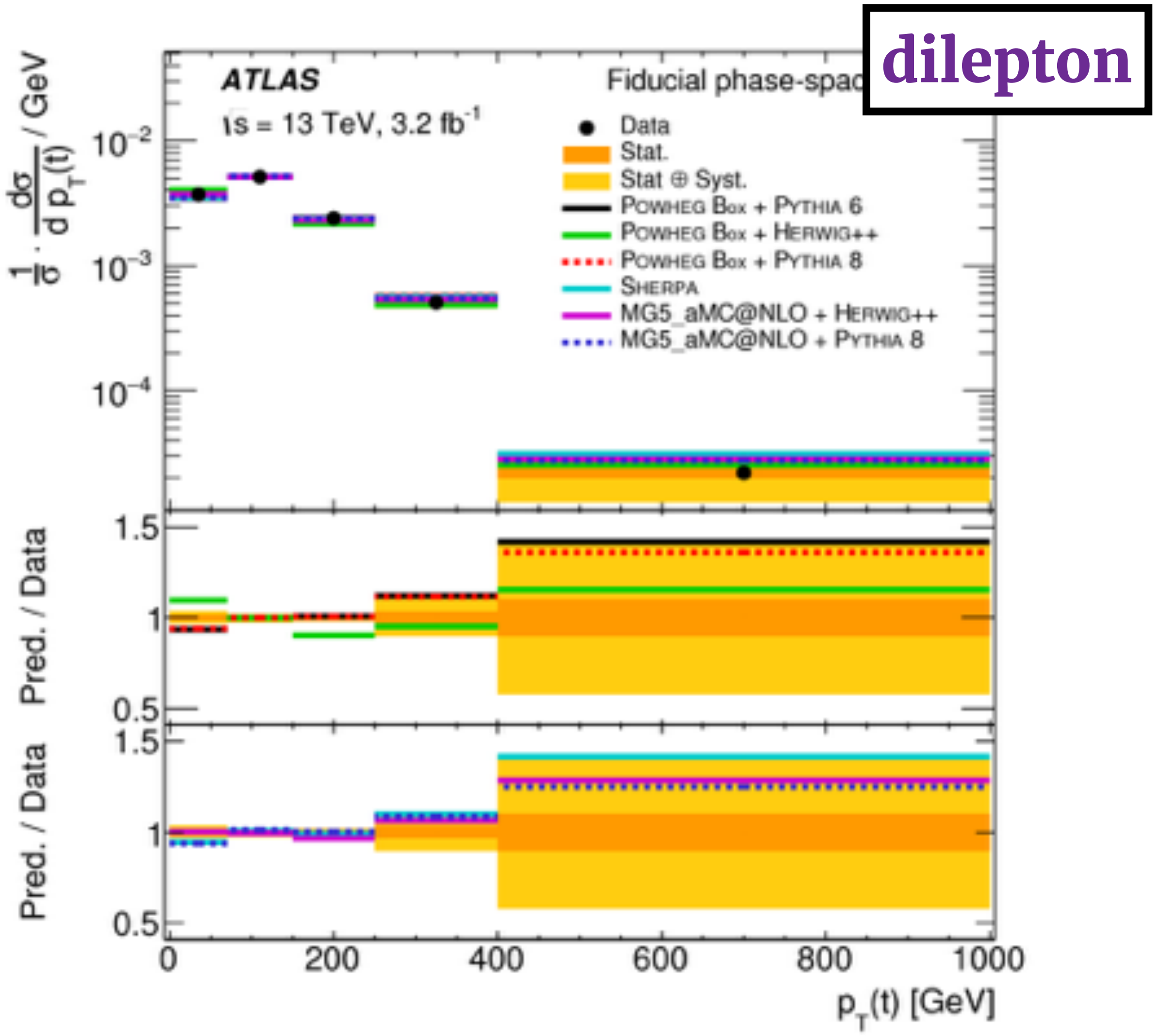
- Particle level, experimental phase-space.
- Jet kinematics and gap fractions.

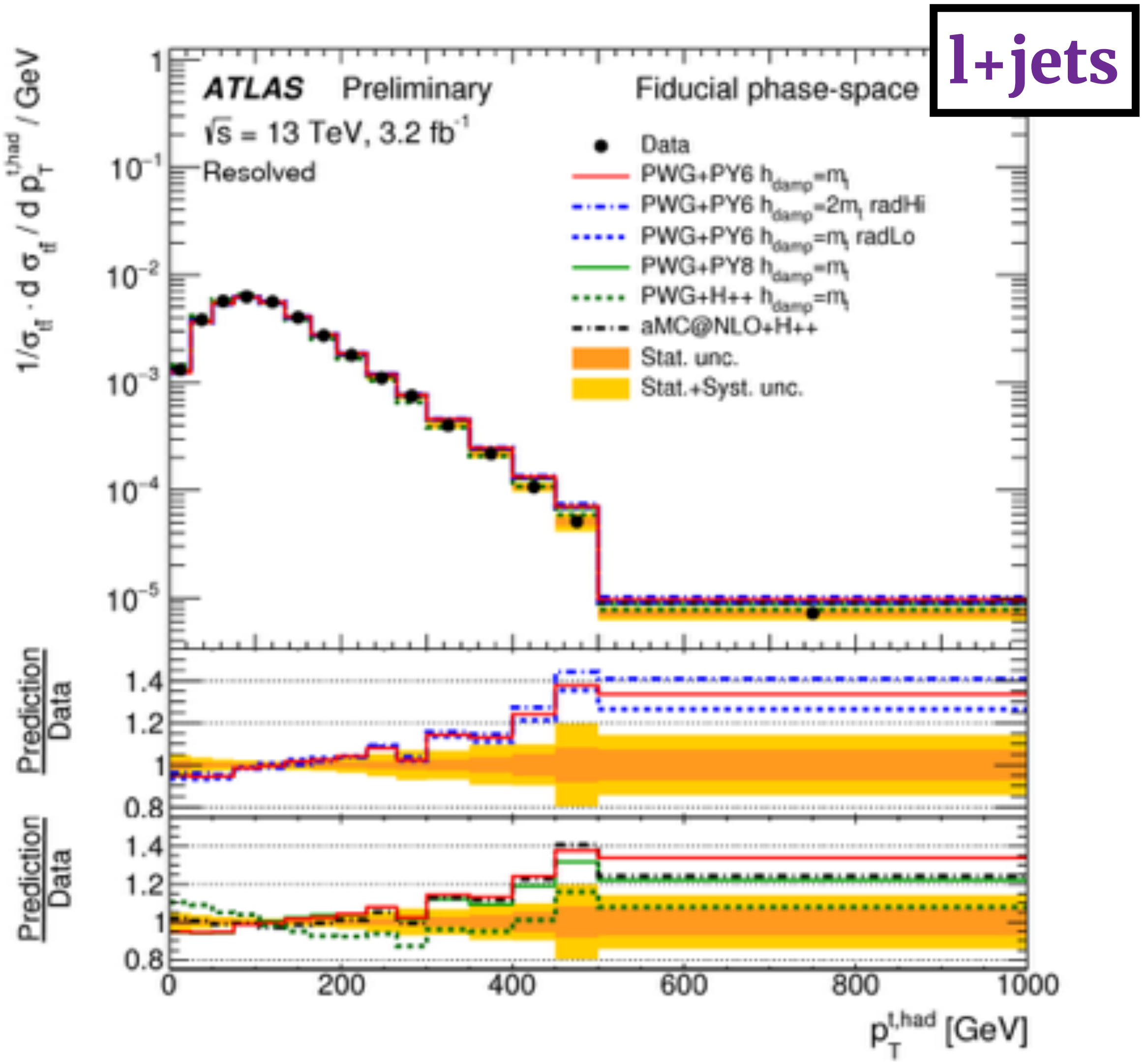
3) 13 TeV eμ: [Submitted to EPJC]

- Particle level, experimental phase-sapace.
- Top and $t\bar{t}$ kinematics compared to MC predictions.

13 TeV eμ + jets and e/μ + jets

Top p_T modelling (Particle Level):

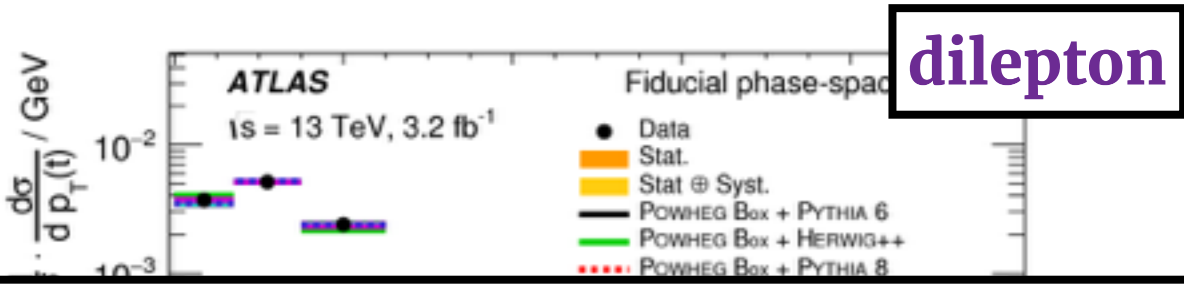


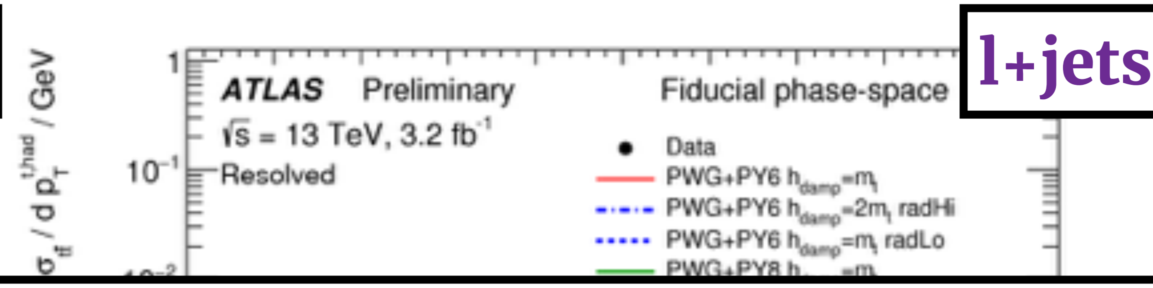


- As with CMS, generators struggling to describe pT(t) shapes (especially the slope).

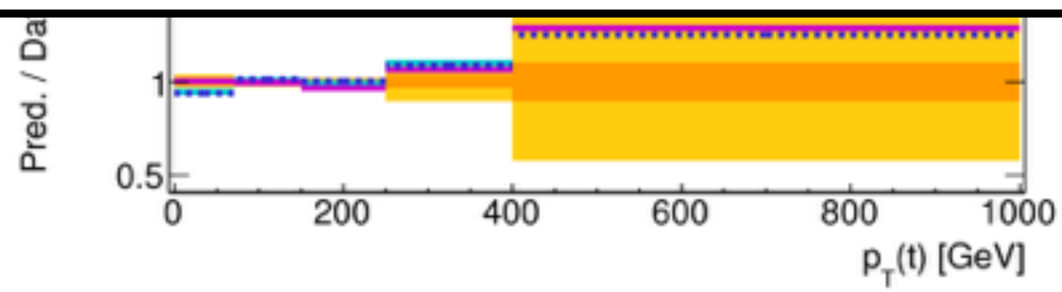
13 TeV eμ + jets and e/μ + jets

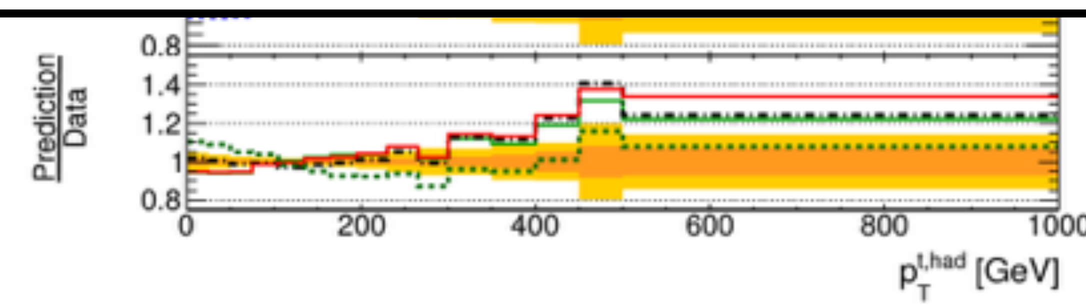
Top p_T modelling (Particle Level):





- Disclaimer: These are early 13 TeV results, more advanced generator usage and studies coming later.

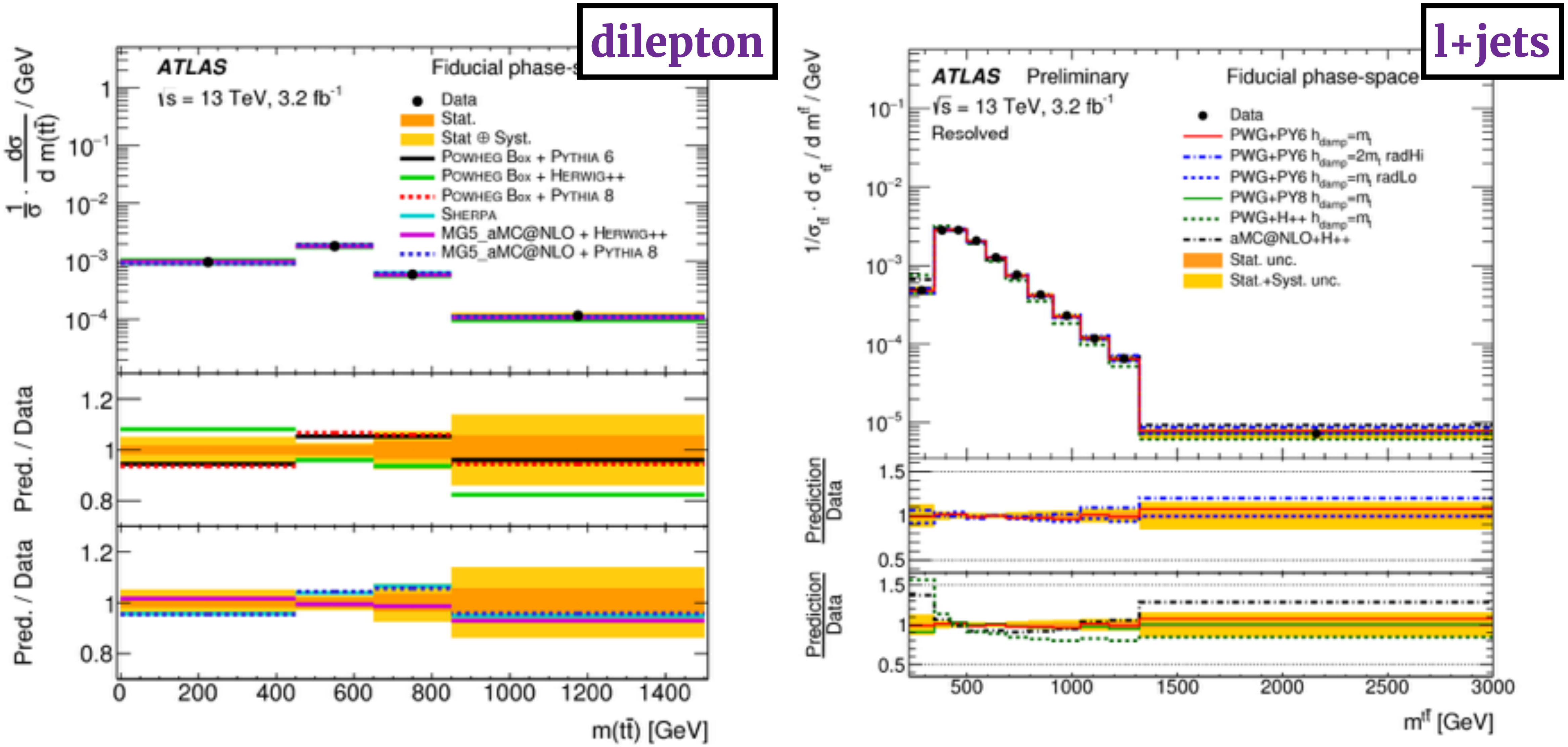




- As with CMS, generators struggling to describe pT(t) shapes (especially the slope).

13 TeV eμ + jets and e/μ + jets

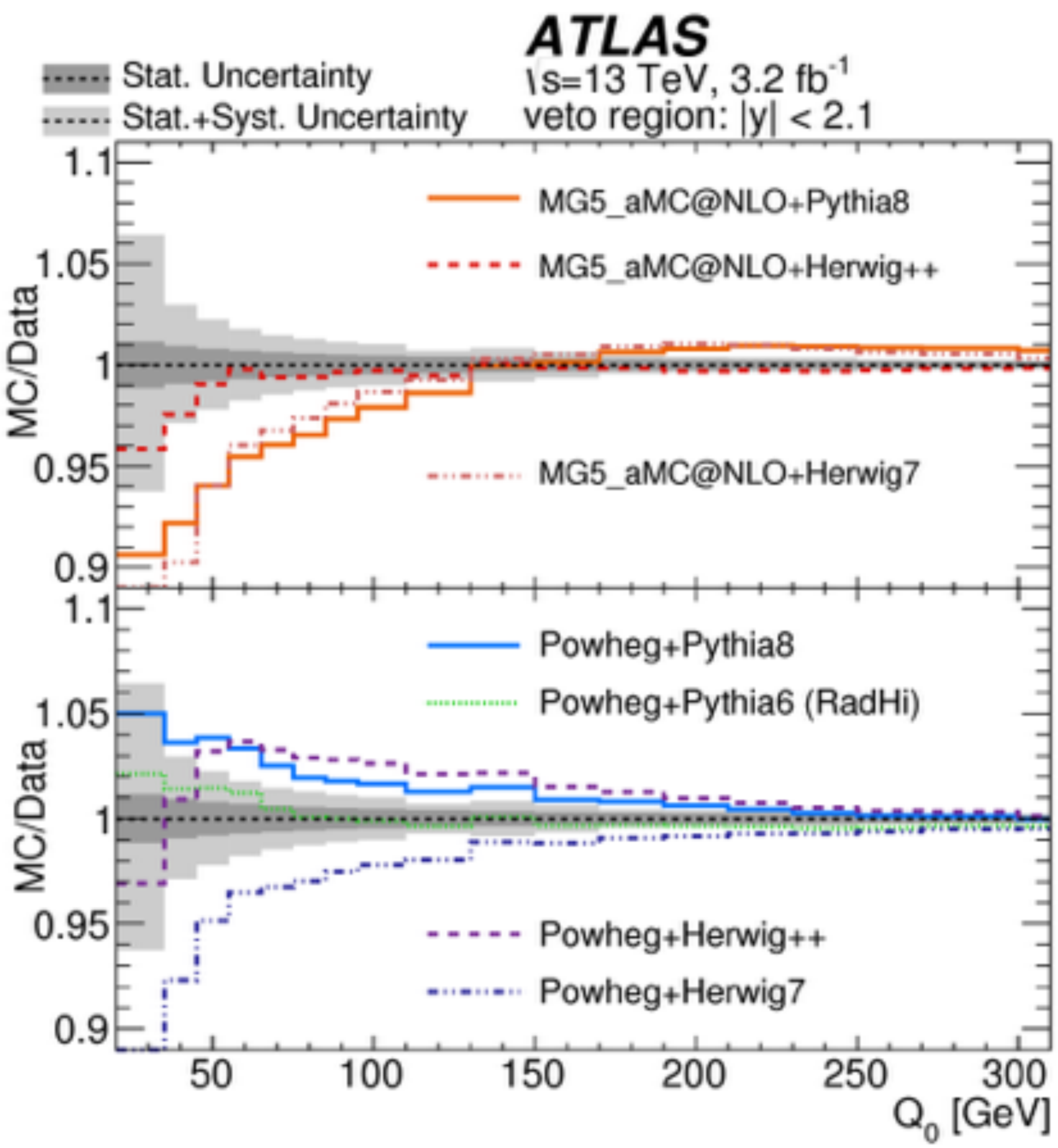
M($t\bar{t}$) modelling (Particle Level):

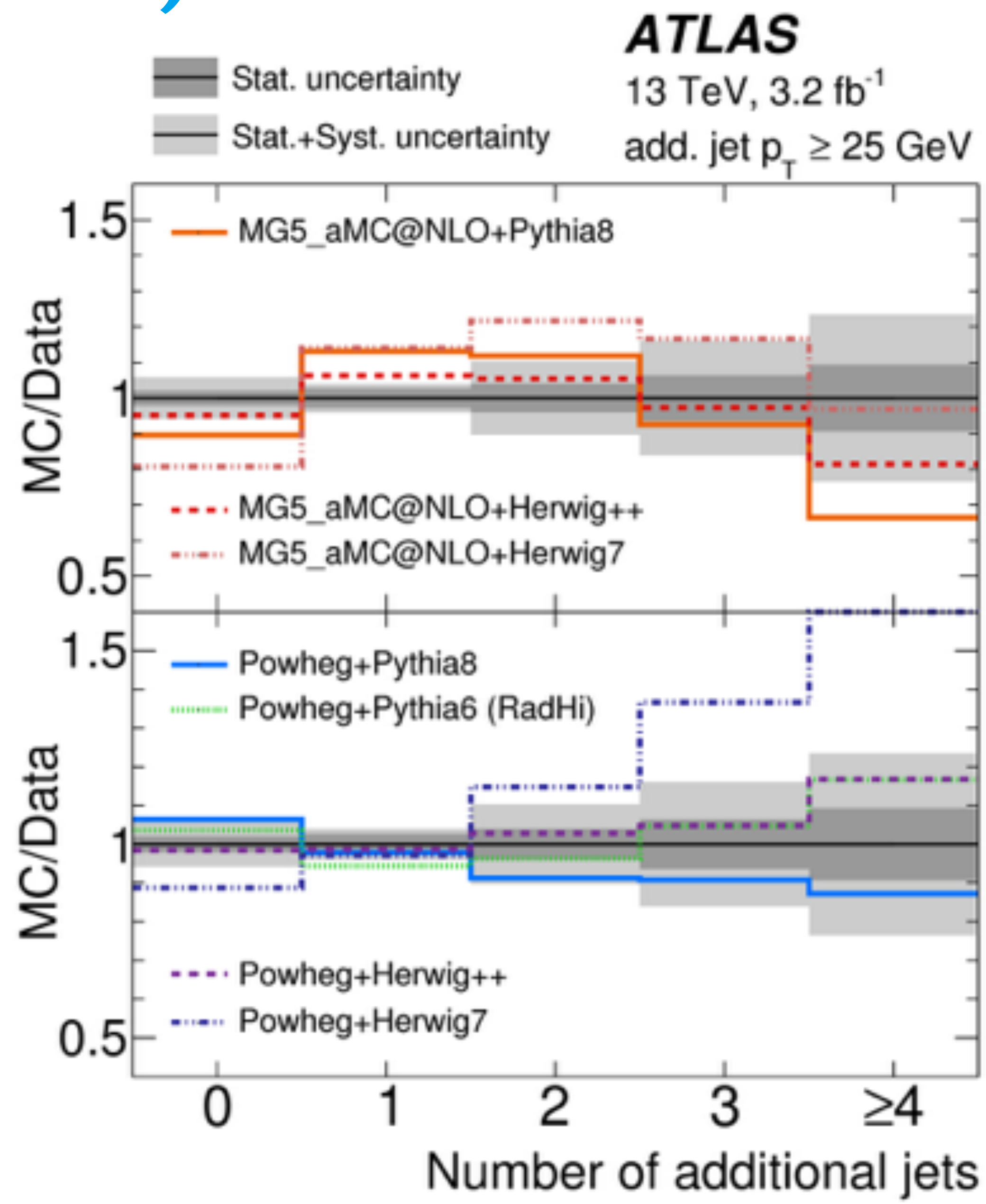


- Things a little better for some $t\bar{t}$ observables, but some setups clearly disfavoured.

13 TeV eμ + jets

Top p_T modelling (Particle Level):



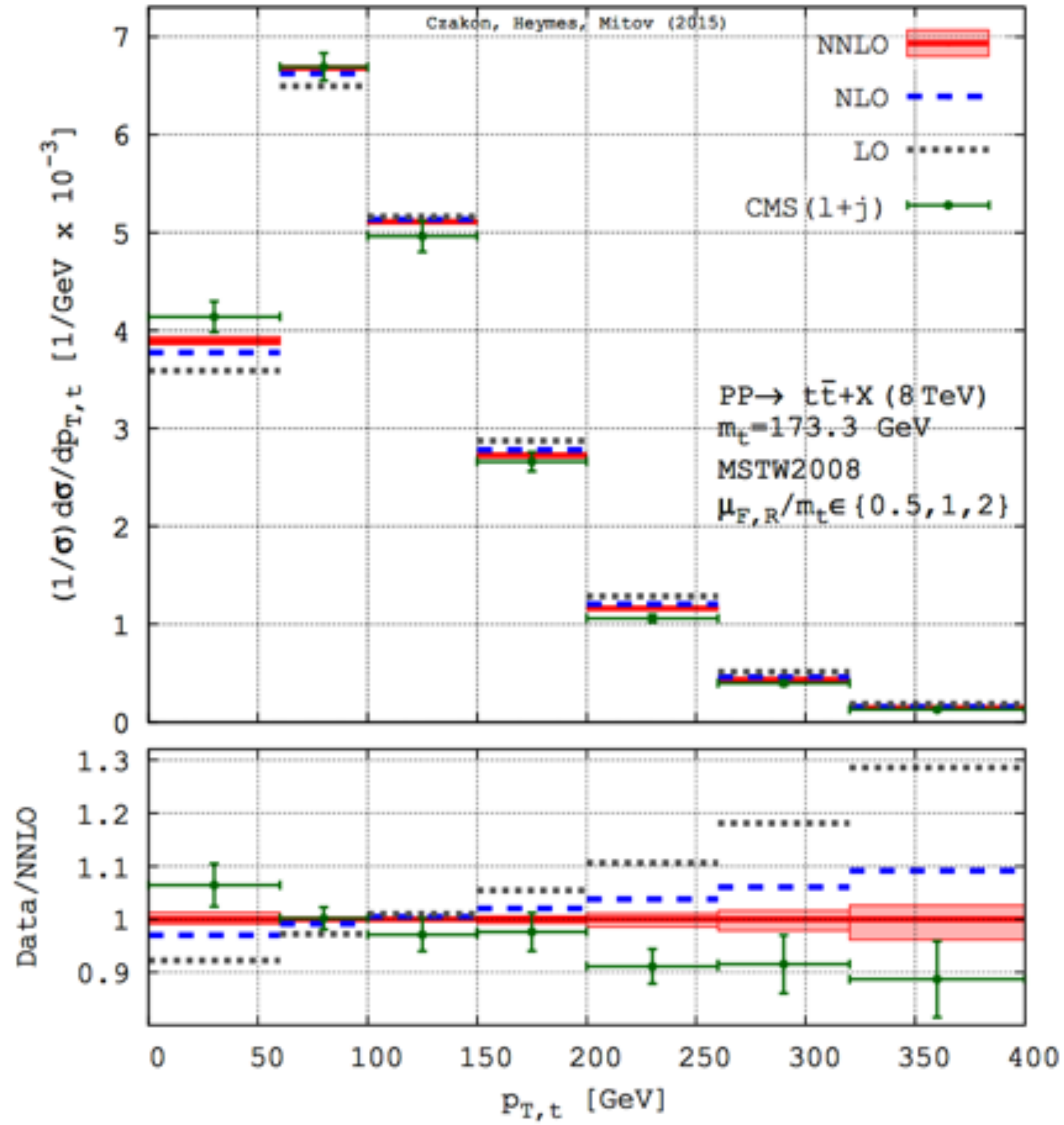


- Problems become more obvious in jet activity.

ATLAS + CMS Comparisons

Top at NNLO:

Czakon, Haymes, Mitov (2015)

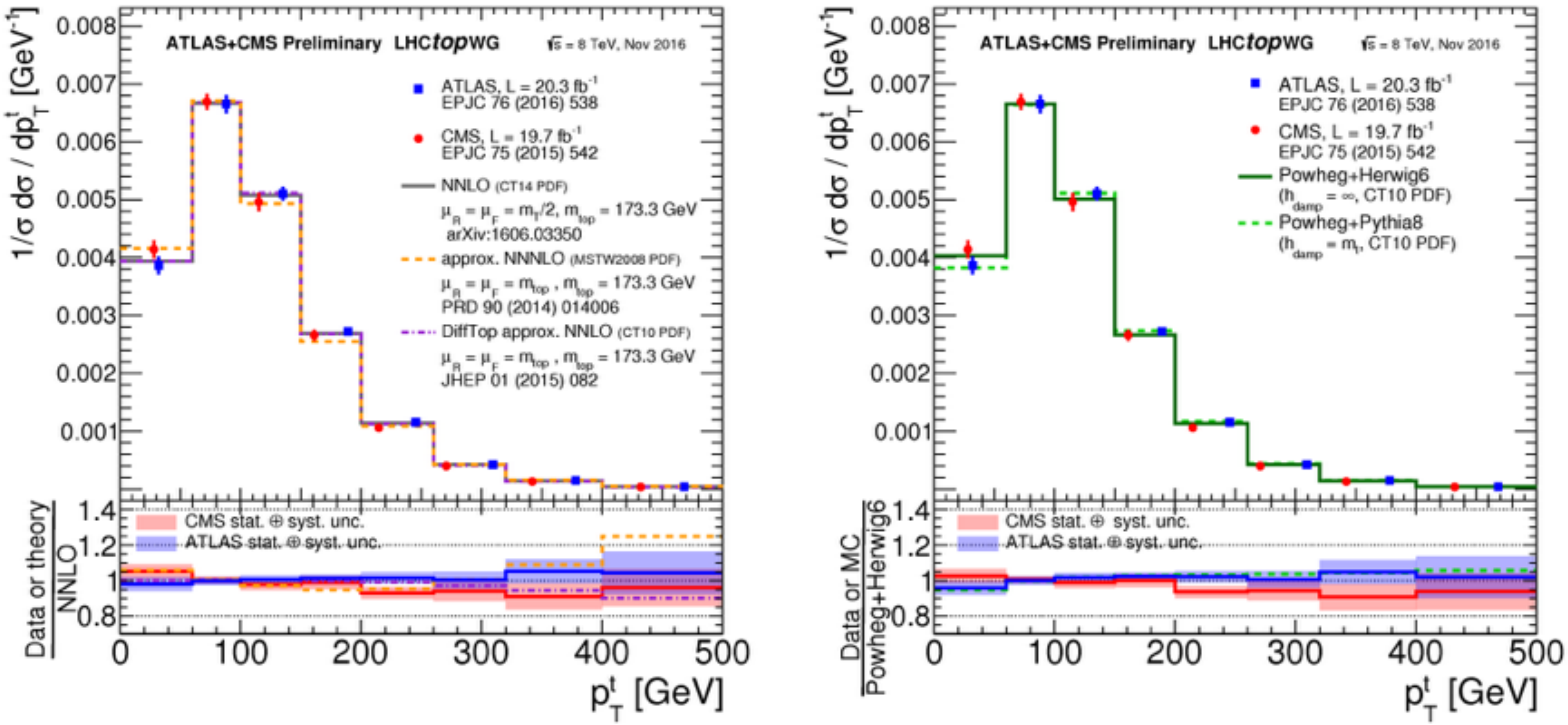


- NNLO predictions necessary to describe top kinematic distributions (for discussion…)

8 TeV e/μ + jets

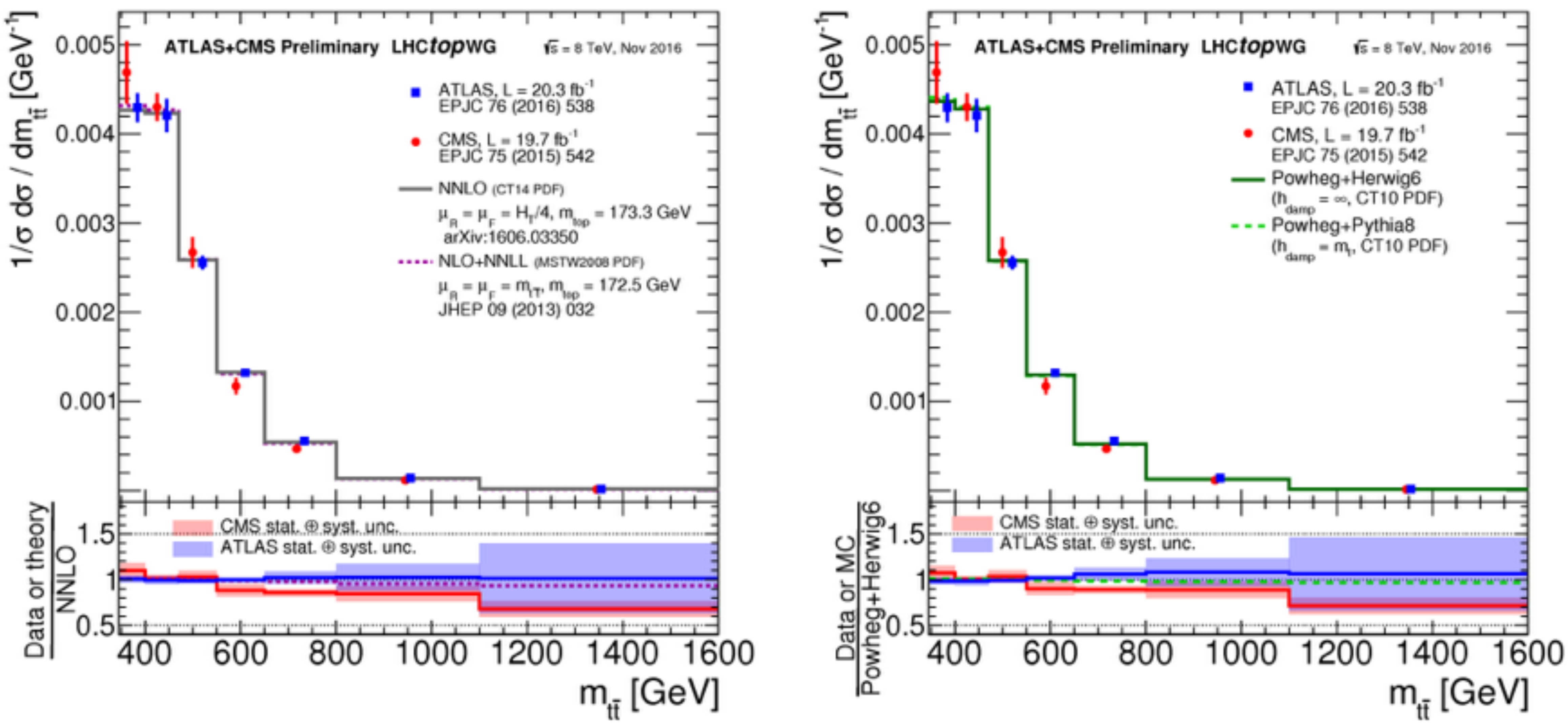
LHCTopWG

Top p_T comparison:



- Work ongoing to understand compatibility between ATLAS and CMS.

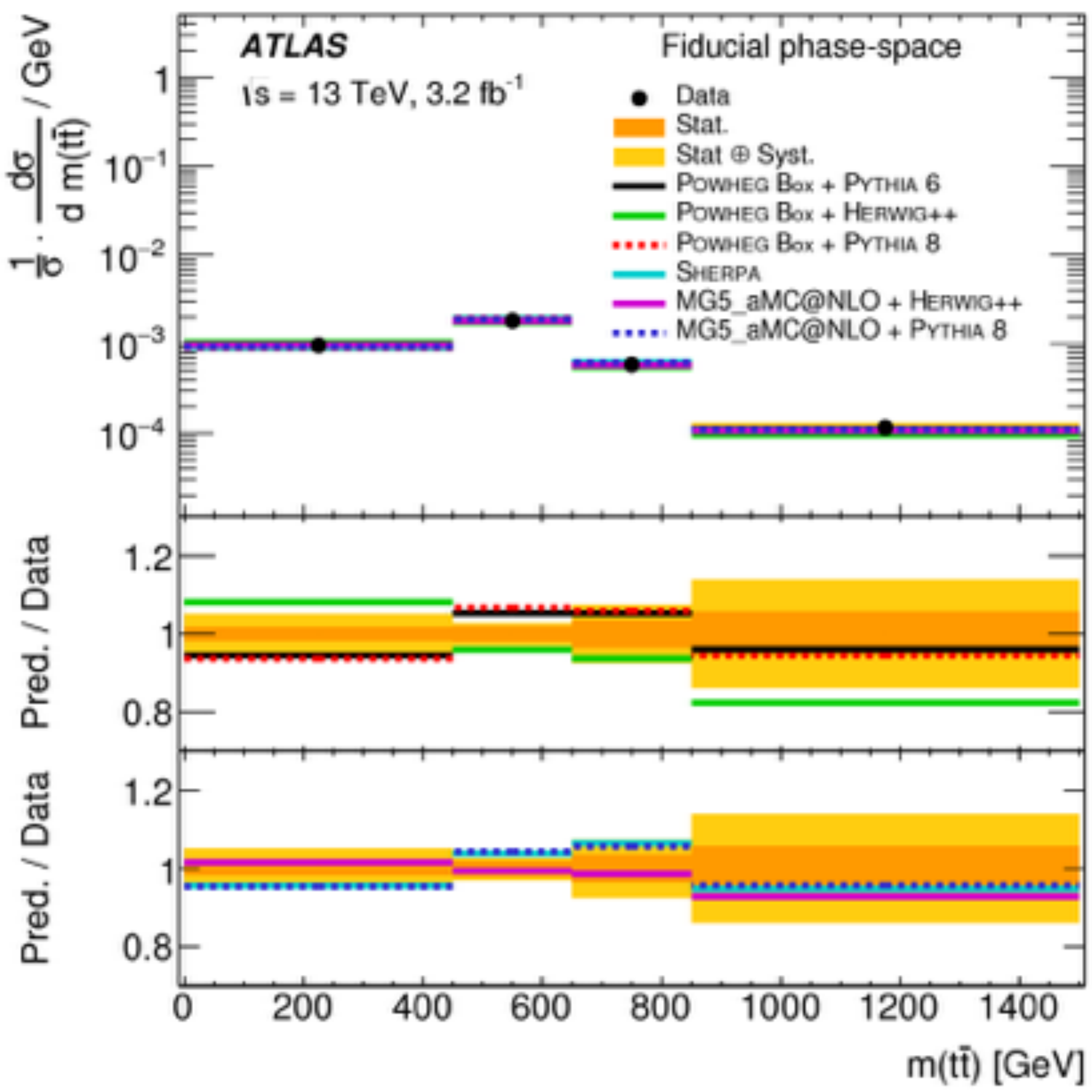
$m(t\bar{t})$ comparison:

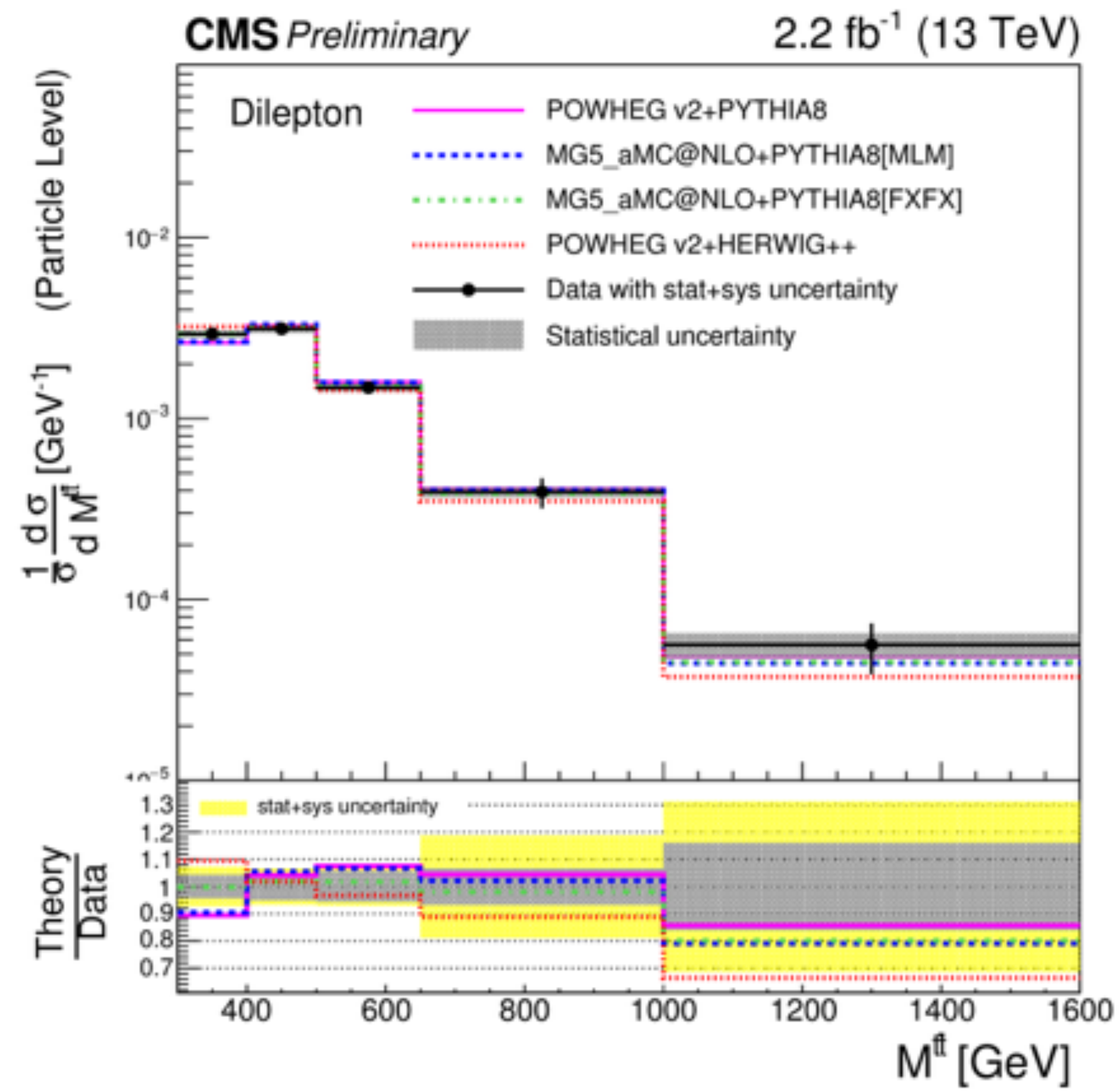


- Similar situation in $m(t\bar{t})$, understanding of correlations between analyses is crucial.

m($t\bar{t}$) comparison:

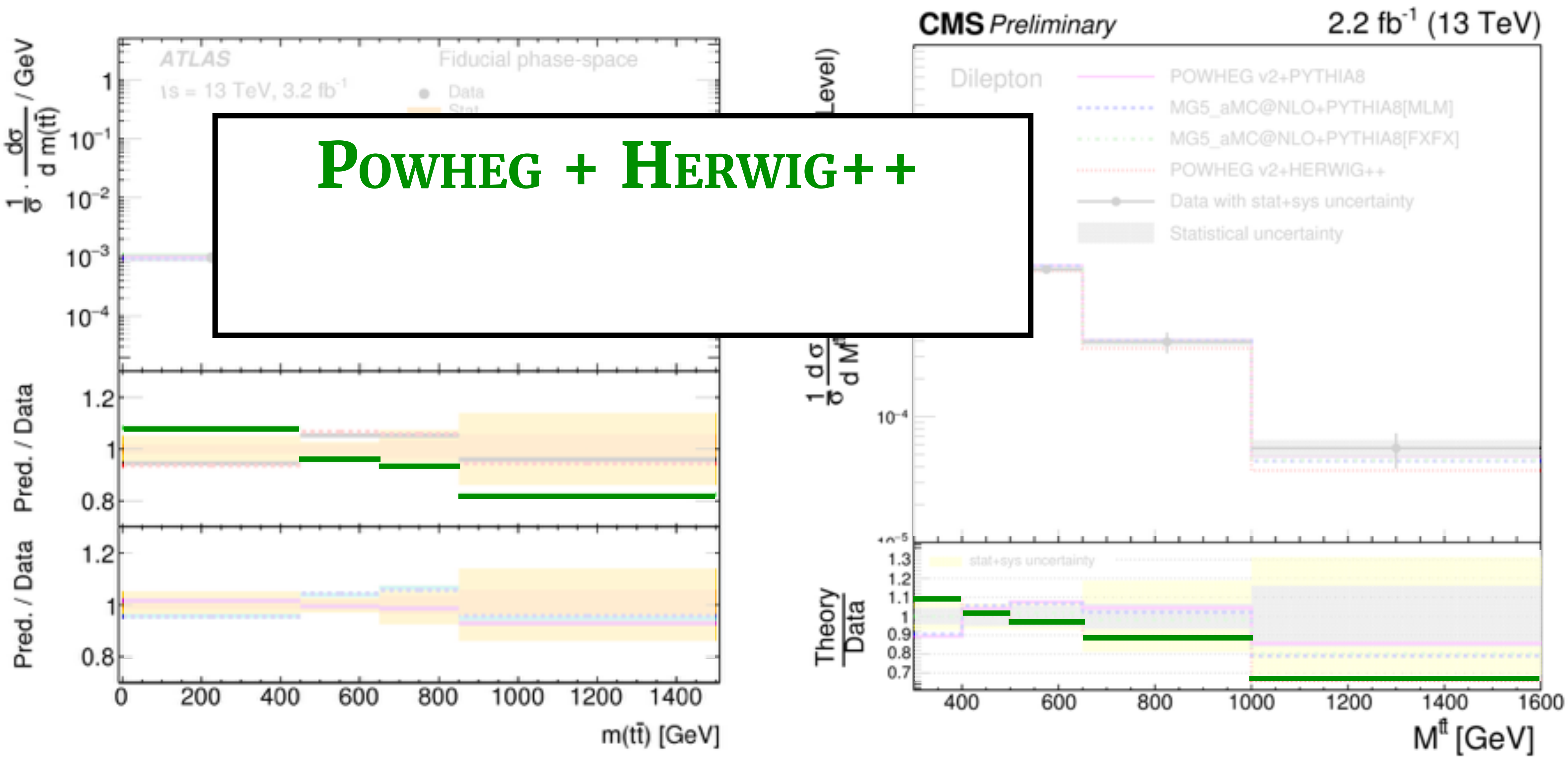
TOP-2016-007





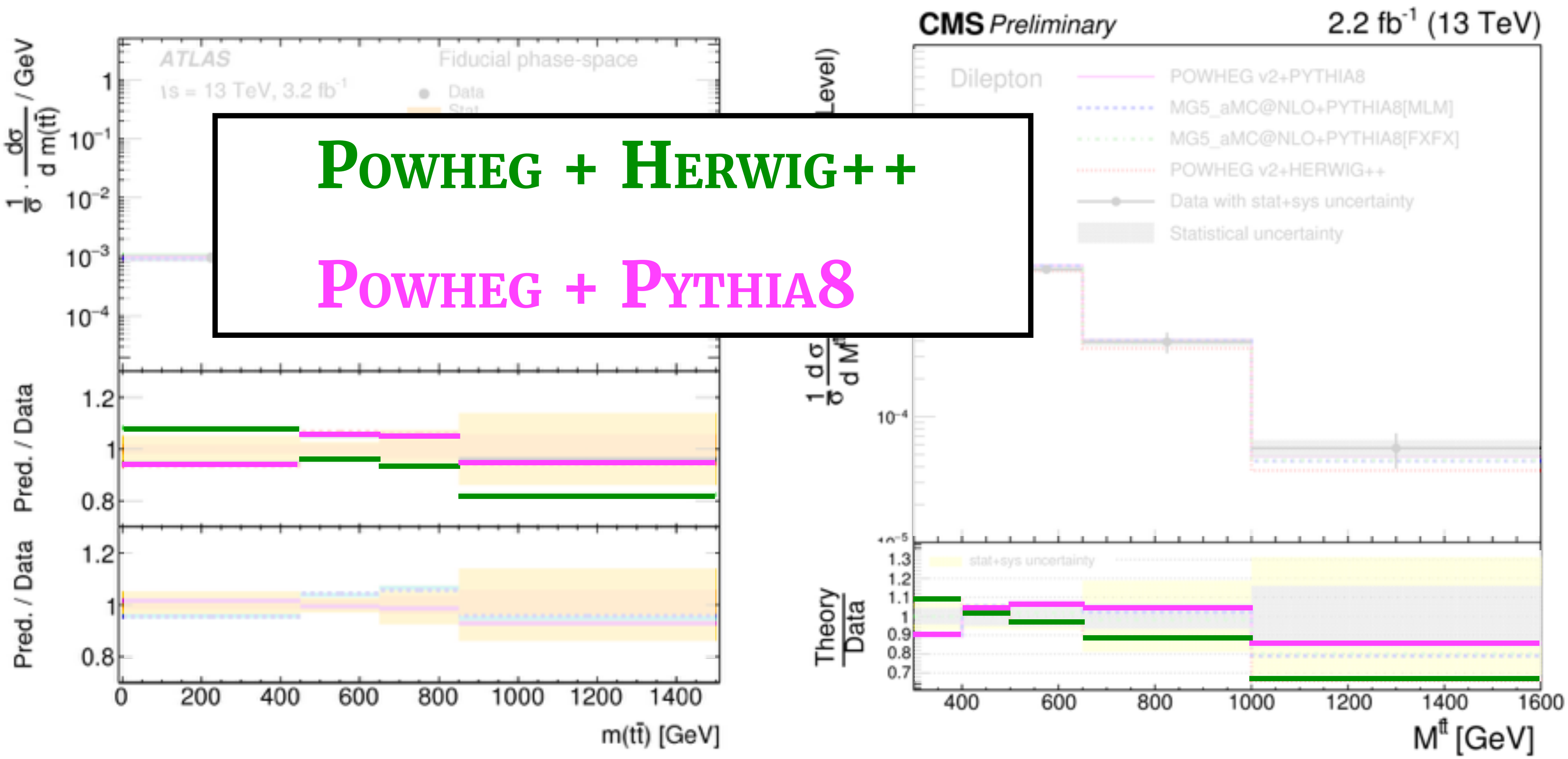
- ATLAS and CMS at 13 TeV see similar trends with data when using comparable generators.

m(tt̄) comparison:



- Different binning and ranges, but trend with POWHEG + HERWIG++ w.r.t data looks similar.

m($t\bar{t}$) comparison:



- Similarly, POWHEG + PYTHIA8 follows similar trends between experiments.

Towards combinations:

- Work ongoing for understanding 8 TeV data.
- Combinations planned for 8TeV (parton) and 13 TeV (particle).

Comparison of results

- Need to carry out full combination to understand agreement between ATLAS and CMS Run1 data.
- Work starting now to also do combinations on 13 TeV data.

CMS Tuning

CMS PAS TOP-16-021:

- Studies on tuning POWHEG + PYTHIA8.
- Jet kinematics and global event observables.
- 8 TeV and 13 TeV data.

RIVET Routines

13 TeV l+jets (particle) [CMS_2016_I1434354]:

- top, $t\bar{t}$ kinematics and jet multiplicities.

8 TeV dilepton (particle*) [CMS_2015_I1397174]:

- Jet kinematics and gap-fraction.

8 TeV l+jets (particle) [CMS_2015_I1473674]:

- Event-level observables (e.g. MET, H_T).

8 TeV l+jets (particle) [CMS_2015_I1388555]:

- top kinematics.

8 TeV l+jets (particle) [CMS_2016_PAS_TOP_15_006]:

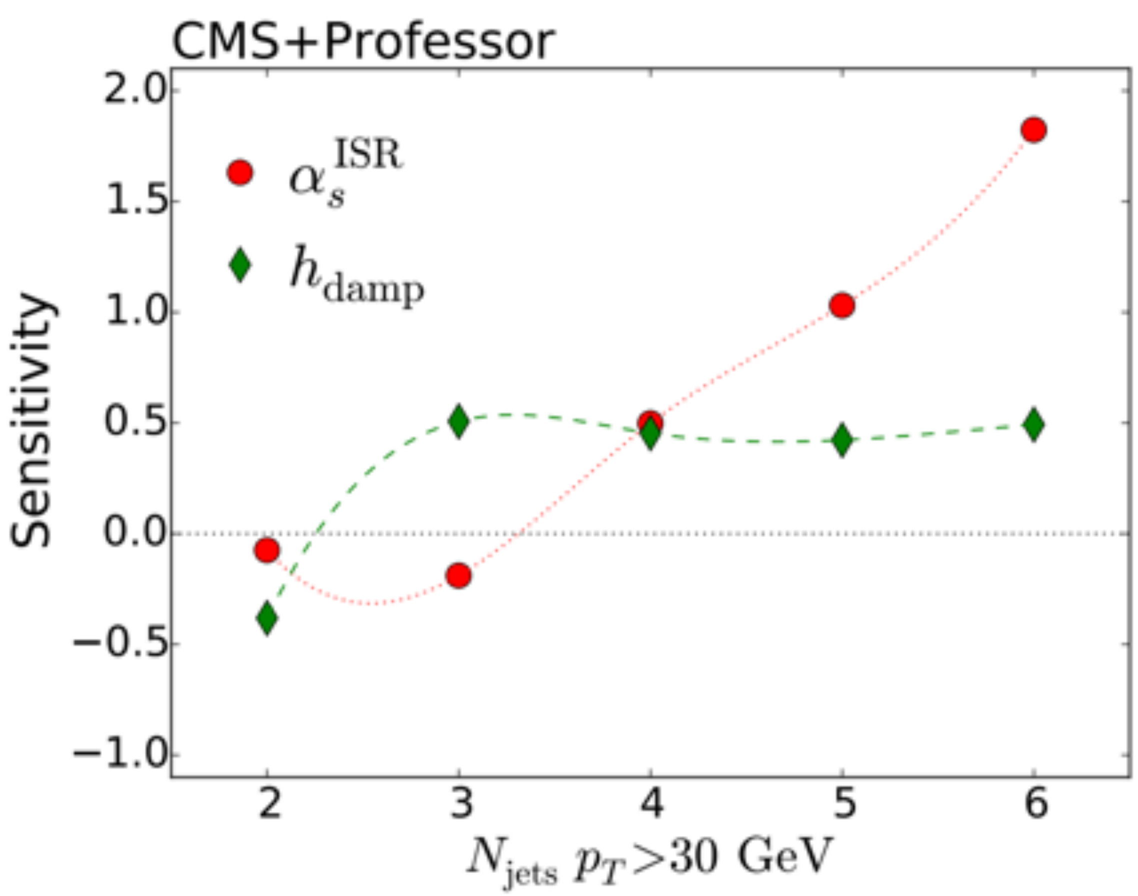
- $t\bar{t}$ differential cross-section vs. njets.

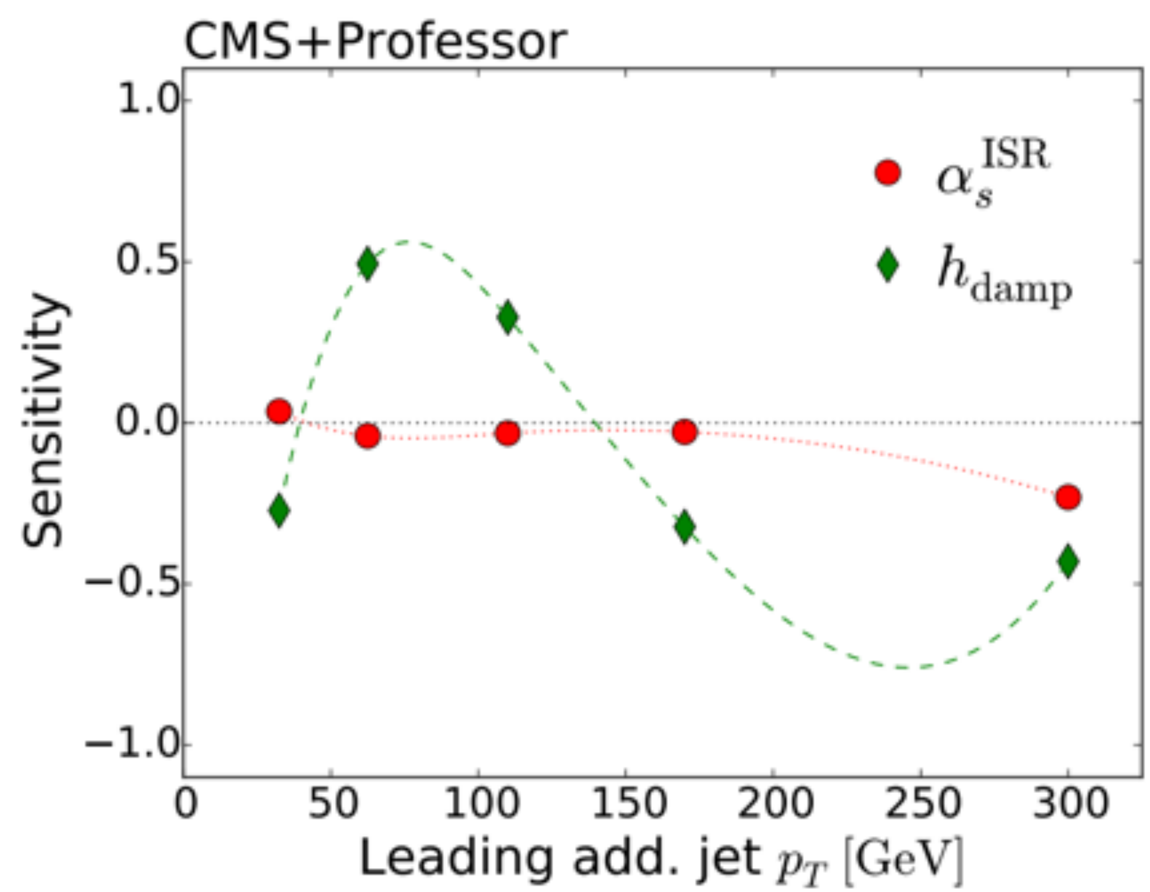
Not an exclusive list!

POWHEG Tuning

Professor:

- 55 anchor points:
  - ➡ `hdamp: 0.25/0.50/1.00/2.00/4.00`
  - ➡ α_S(ISR): `0.05–0.15 (0.01 steps)`

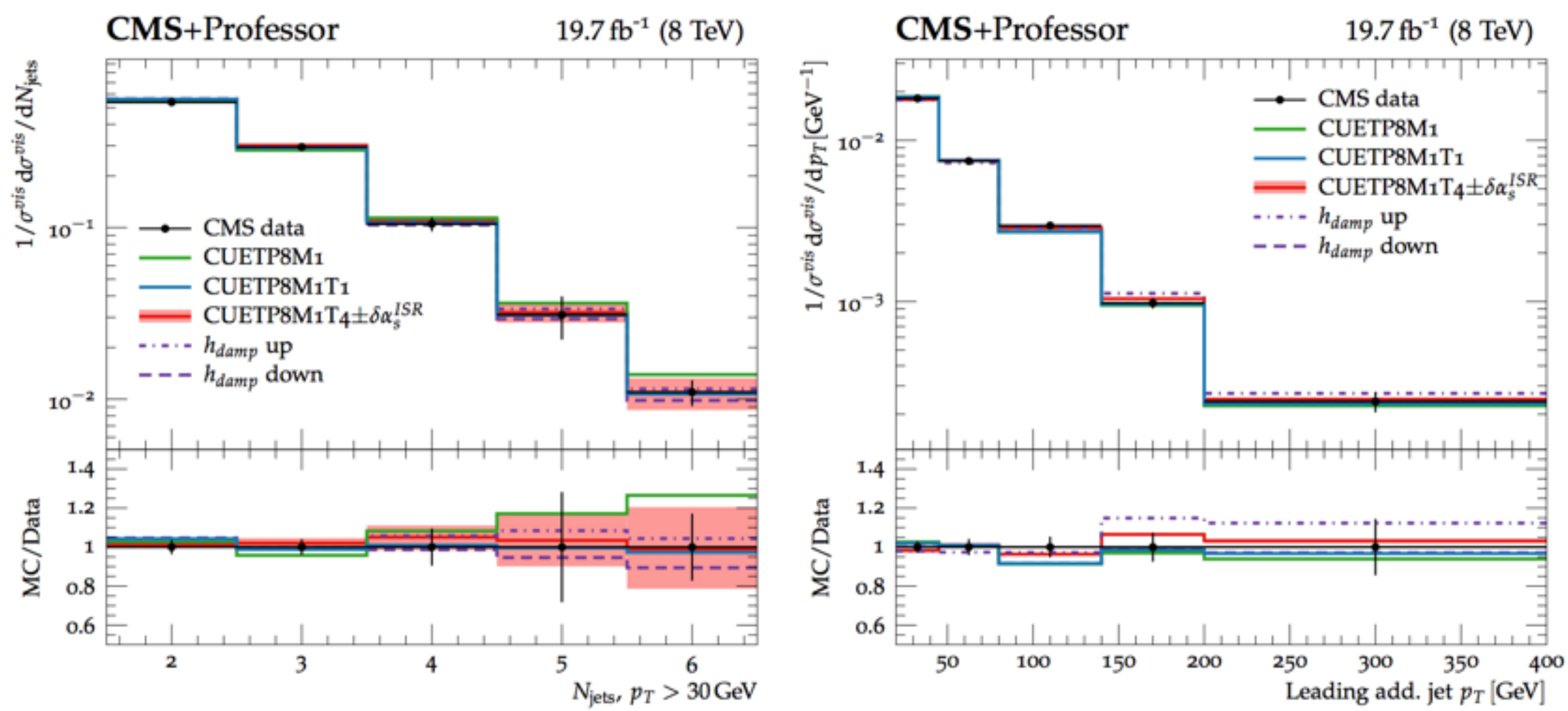




POWHEG Tuning

New Tune results:

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

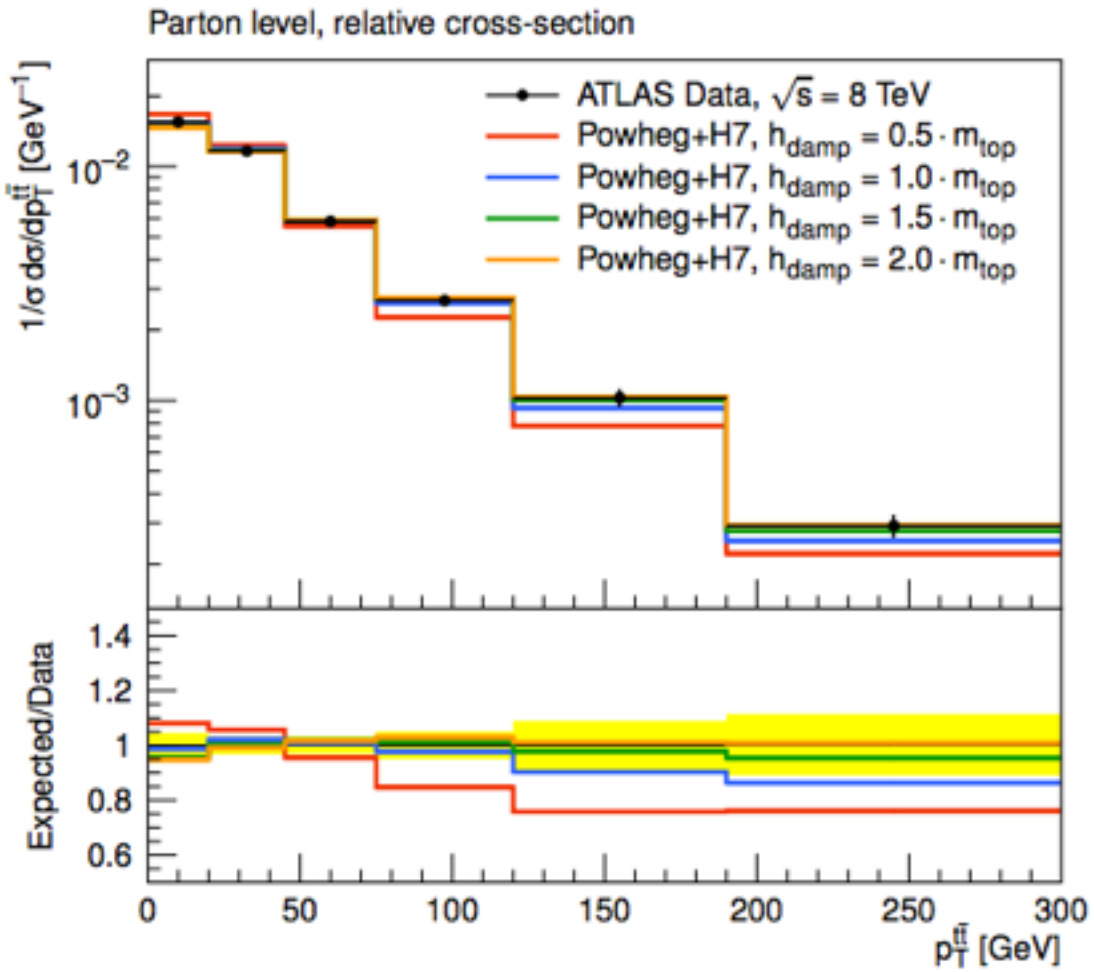


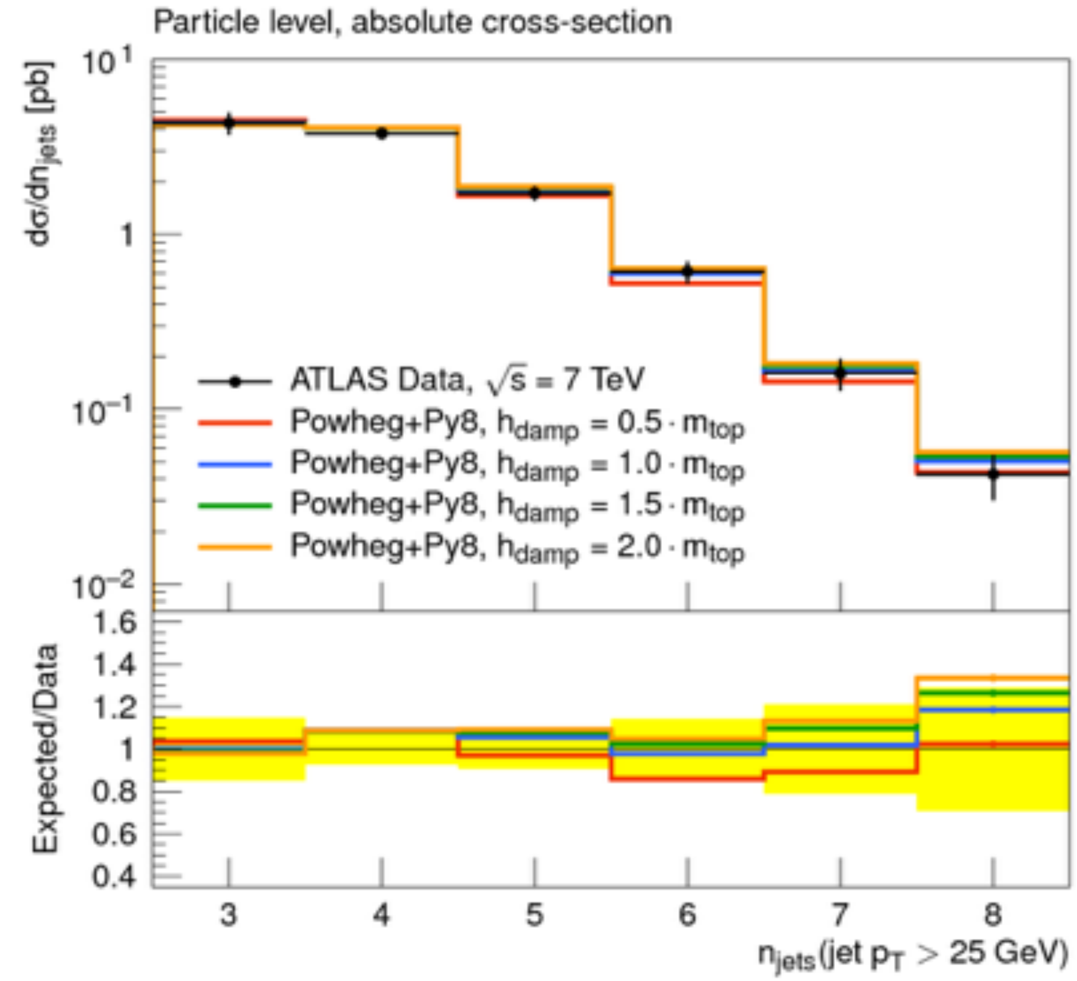
- Data prefers lower setting of α_s(ISR) and higher setting of `hdamp`.

POWHEG Tuning

New Tune results:

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

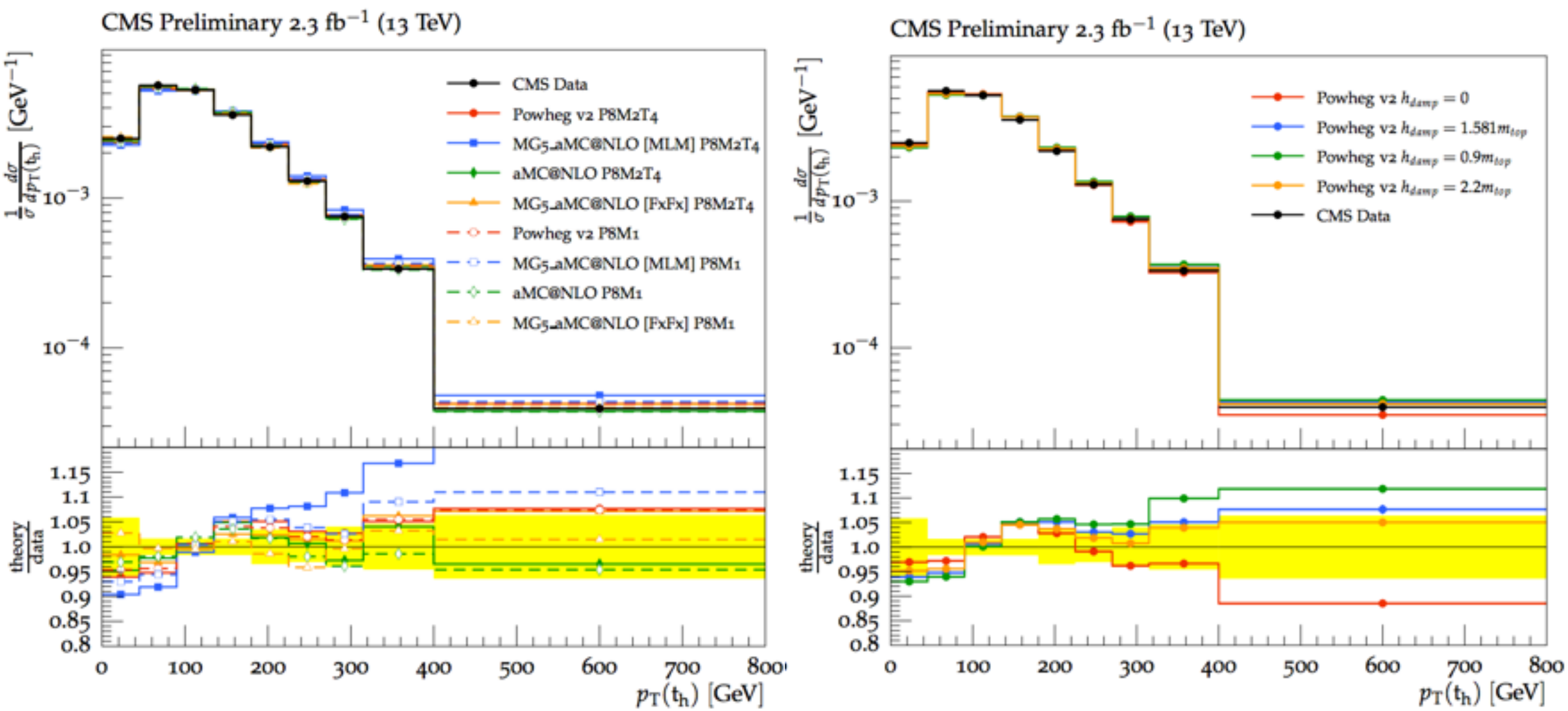




- ATLAS tuning sees comparable results for `hdamp` (see note [ATL-PHYS-PUB-2016-20]).

Monte Carlo settings

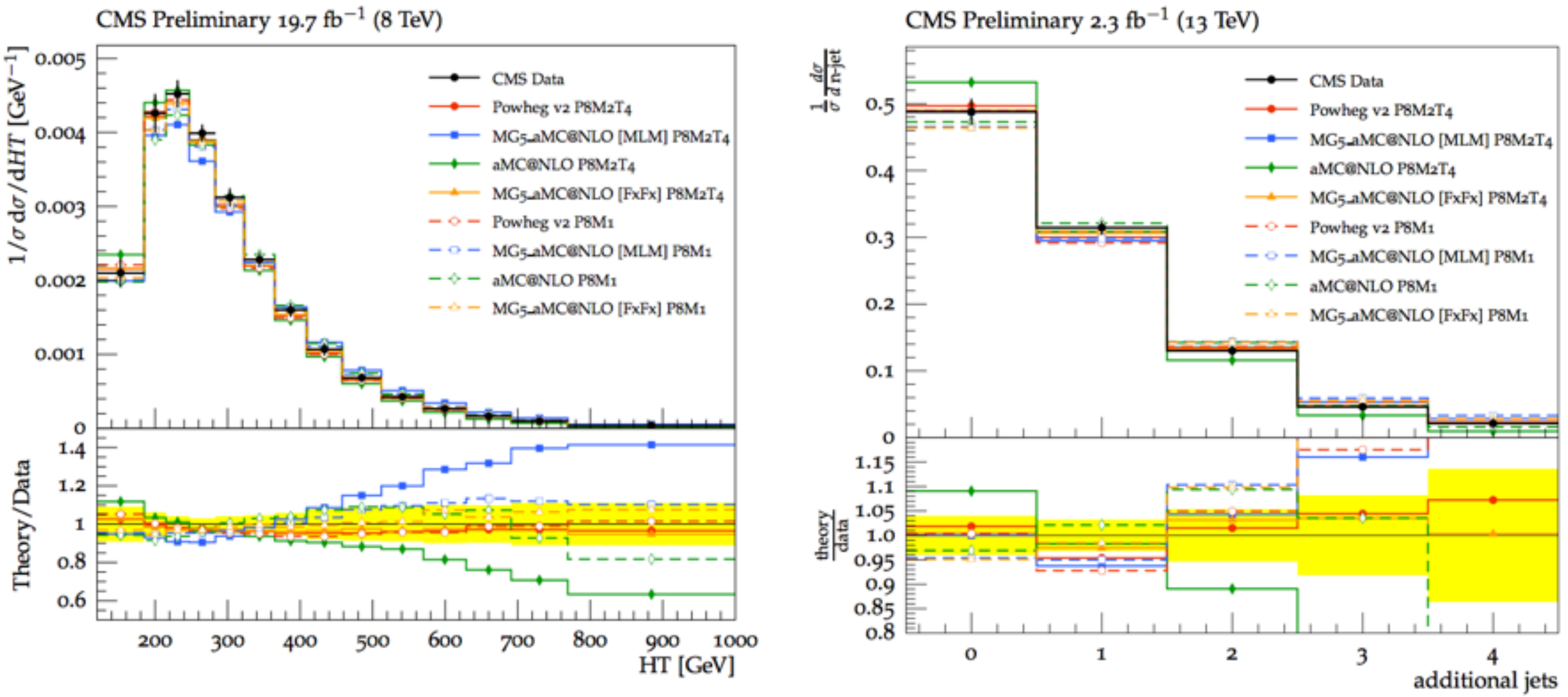
Comparison with other generators:



- LO MG5_aMC@NLO with MLM and new tune fails to describe data.

Monte Carlo settings

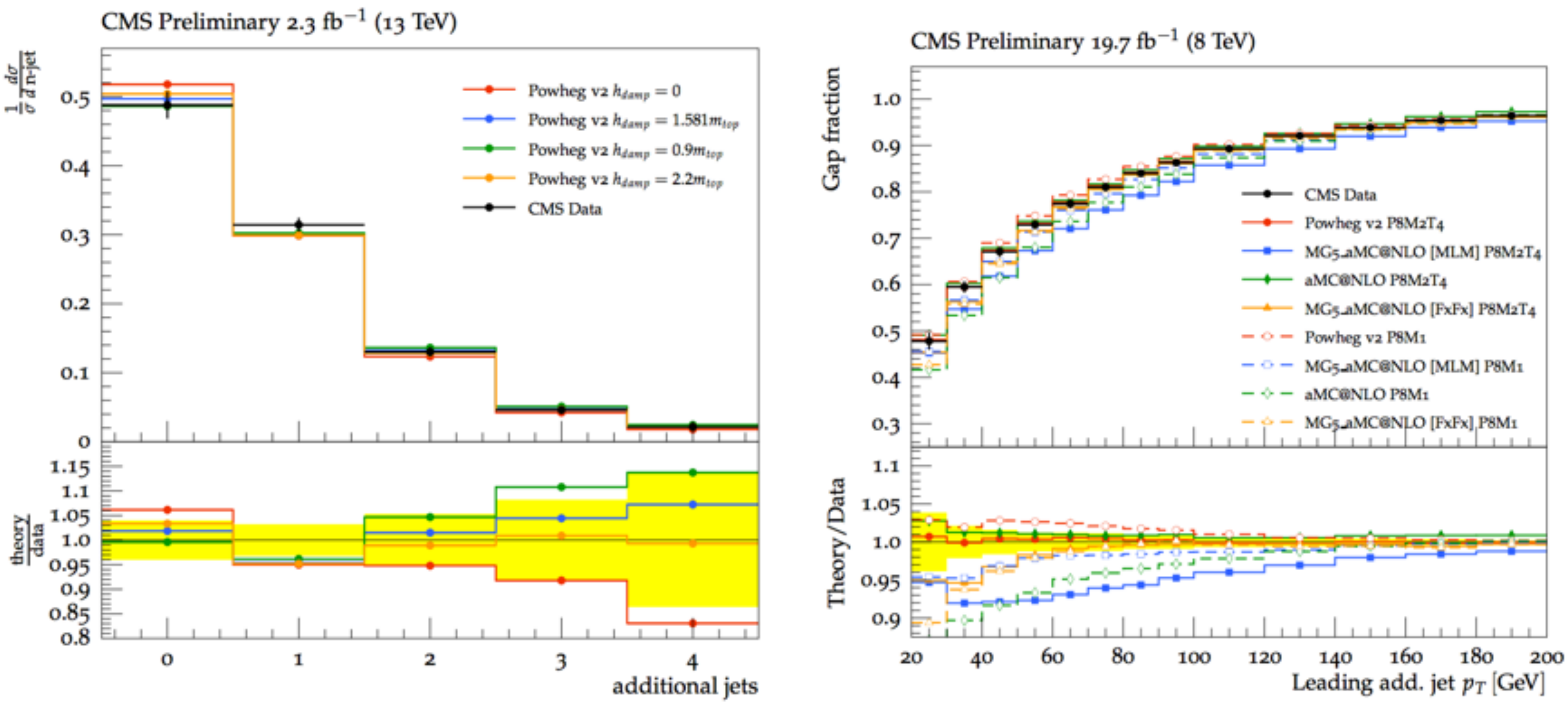
Comparison with other generators:



- Powheg and MG5_aMC@NLO [FxFx] with new tune seem describe most event-level observables well.

Monte Carlo settings

Comparison with other generators:



- Some interesting MG5_aMC@NLO behaviour in gap fraction data.

ATLAS Tuning

ATL-PHYS-PUB-2016-20:

- Studies on tuning Powheg + Pythia8/Herwig7.
- Studies on single-top interference.

ATL-PHYS-PUB-2016-16:

- Studies on MG5_aMC@NLO + Pythia8 with FxFx.
- Studies on Sherpa and Powheg + Herwig7.

ATL-PHYS-PUB-2017-007(new!):

- Studies on MG5_aMC@NLO + Pythia8, 13 TeV data.
- Studies on Sherpa using 13 TeV data.

RIVET Routines

13 TeV differential jet activity in eμ + jets (particle):

- Published, RIVET routine not yet public.

13 TeV top kinematics in l+jets (particle):

- Soon to be published (preliminary result public).

8 TeV l+jets [ATLAS_2015_I1404878]:

- Published, particle and parton.

MC only top kinematics in l+jets (particle):

- Same phase-space as above results.

Not an exclusive list!

Tuning Sherpa 2.2.1

Setup:

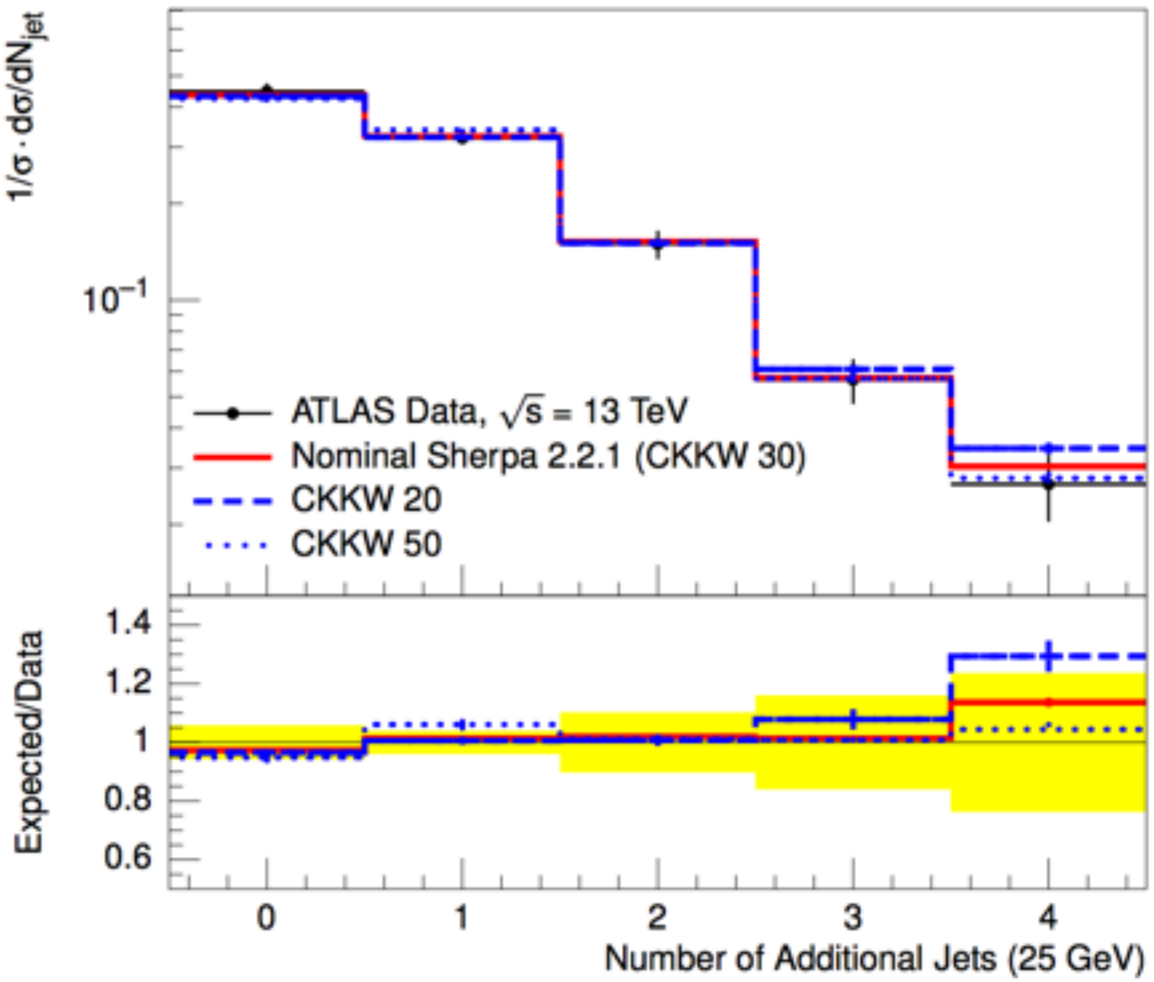
- MEPS@NLO interfaced to Openloops, using default shower.
- Central scale $\mu^2 = m(t)^2 + 0.5(p_T(t)^2 + p_T(\bar{t})^2)$

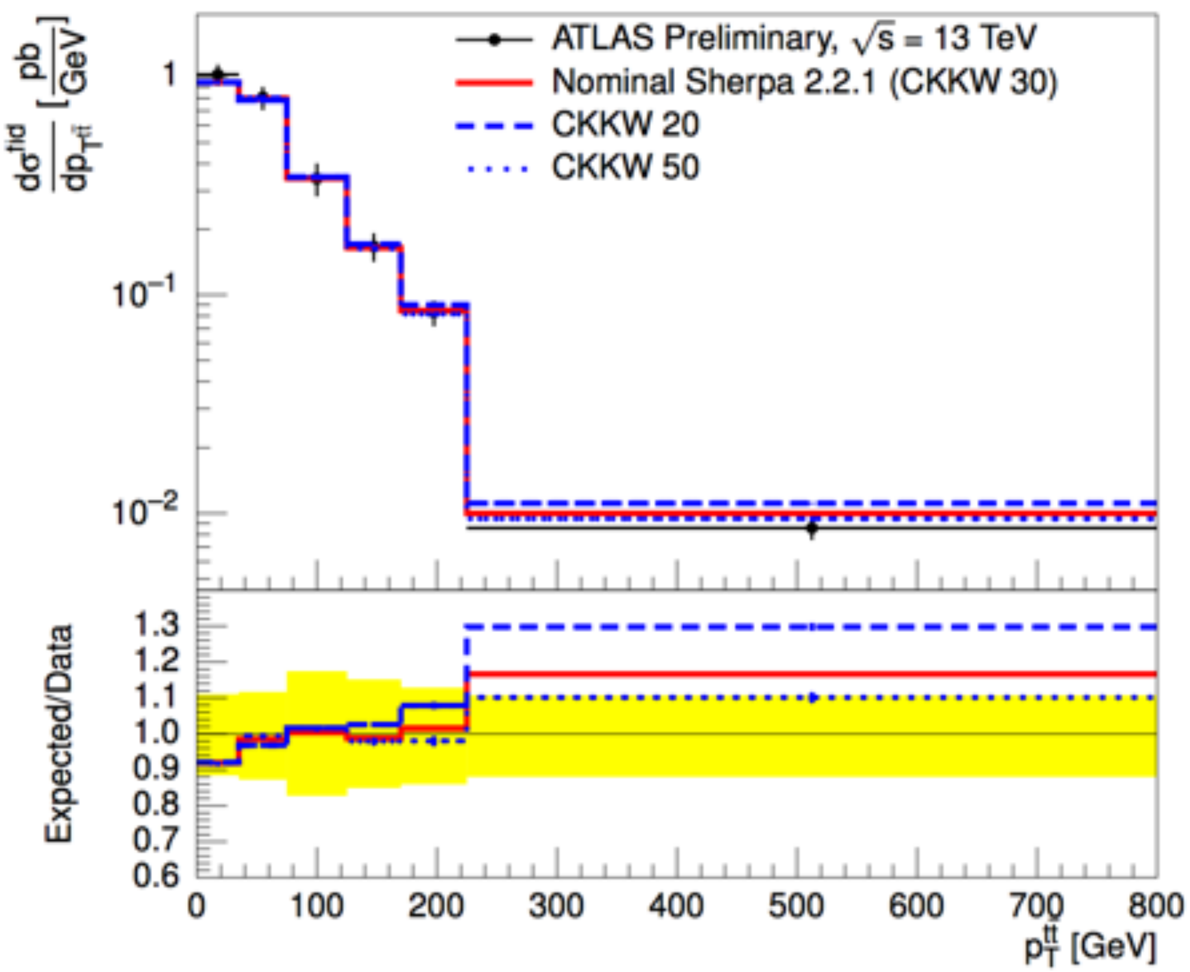
Variations:

- ME matching scale (CKKW): ➡ 20 GeV : 30 GeV : 50 GeV
- Resummation scale (QSF): ➡ 0.5 : 2.0
- Recoil scheme: ➡ default vs. alternative
- α_S SF in initial state evolution: ➡ 0.5 vs. 1.0
- Heavy Baryon Enhancement: ➡ 4 vs. 1
- Scale variations μ_F/μ_R: ➡ 0.5 : 1.0 : 2.0

Tuning Sherpa 2.2.1

Matching Scale:

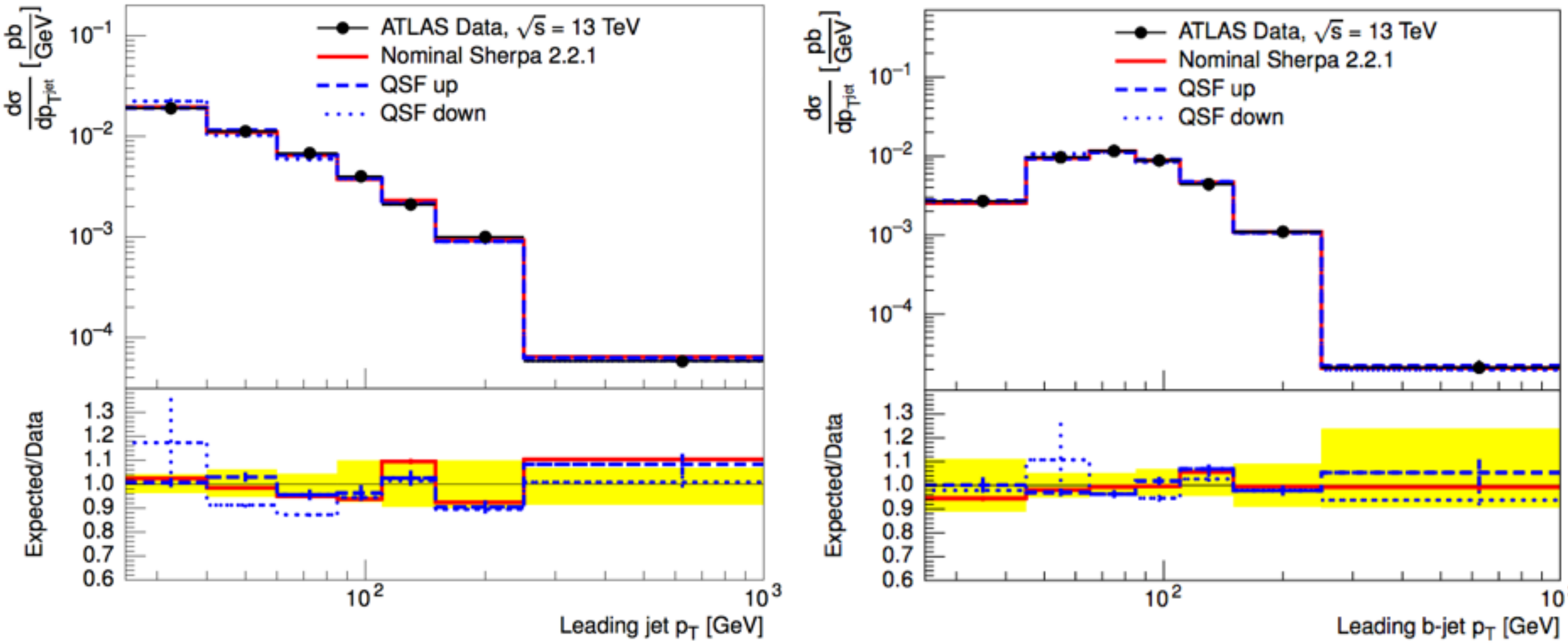




- Small deviations where PS is dominant effect. Perhaps slight $p_T(t\bar{t})$ improvement possible.

Tuning Sherpa 2.2.1

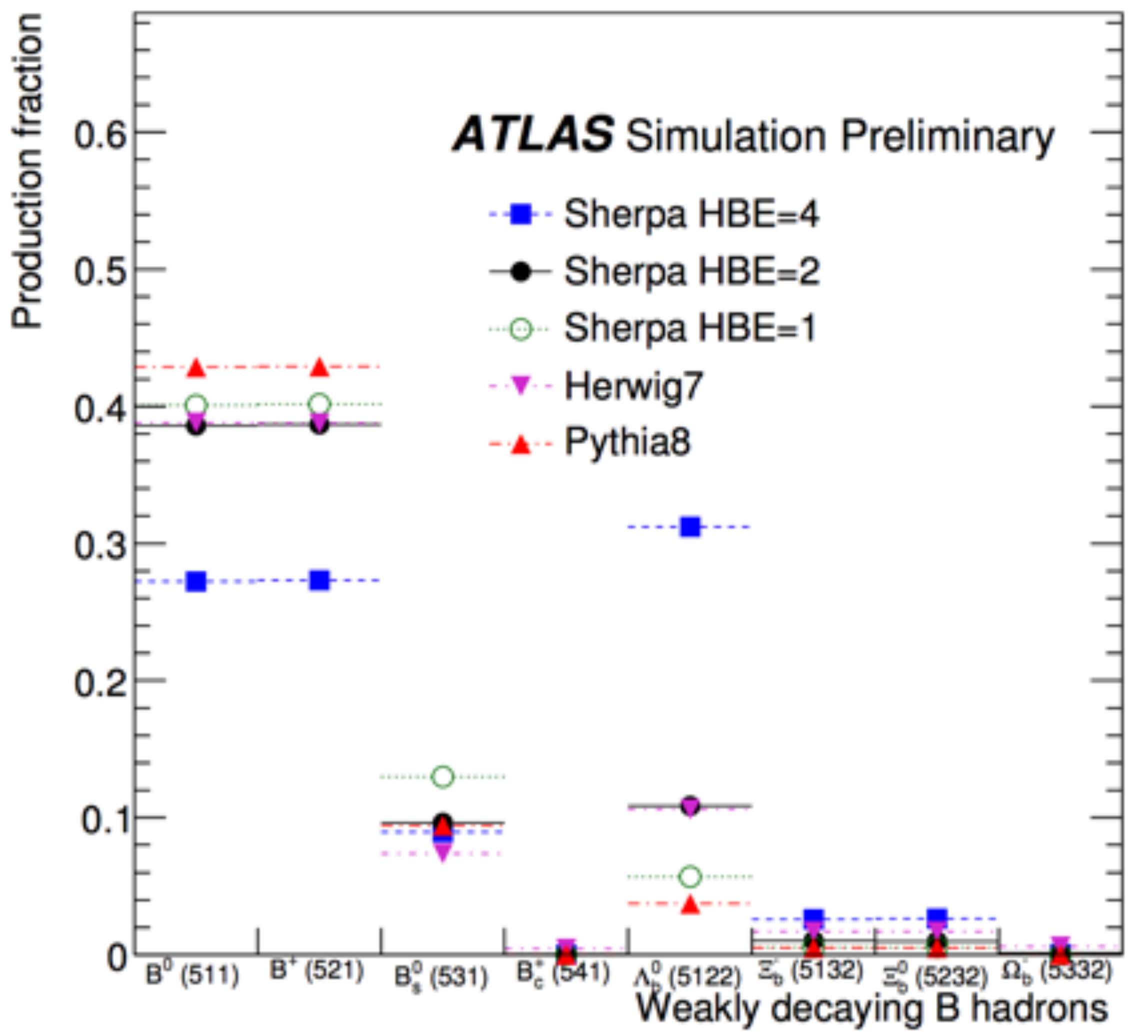
Resummation Scale:

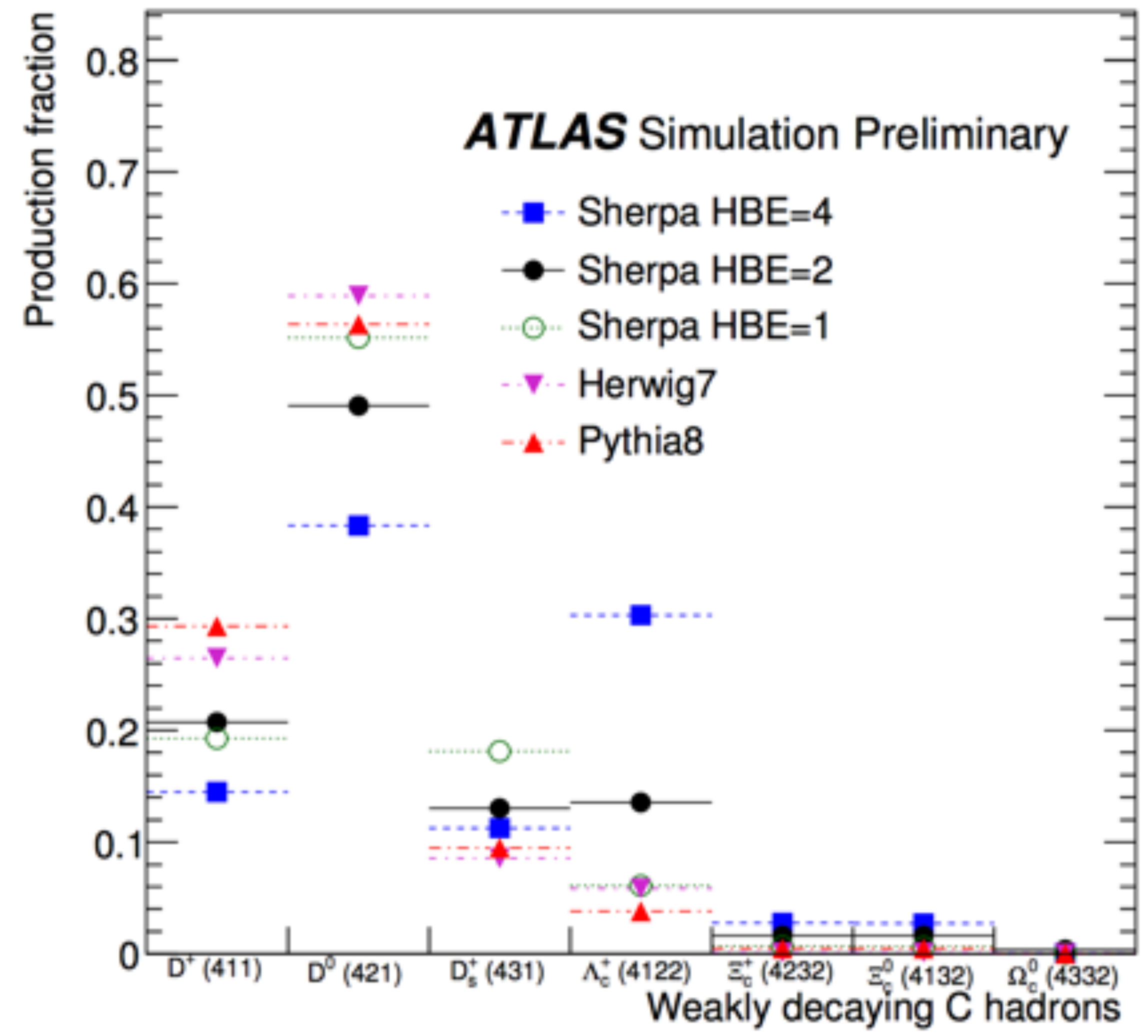


- Maybe slight disagreement with QSF Down at low jet p_T but bjet p_T looks reasonable.

Tuning Sherpa 2.2.1

HBE Simulation only:





- Significant differences in observed heavy flavour species with different settings (and MCs).

Tuning Sherpa 2.2.1

HBE:

Species	SHERPAv2.2 HBE=4	SHERPAv2.2 HBE=1	PYTHIA8	HERWIG 7	World Average[24]
B^+	27.3	40.1	42.9	38.8	40.4 ± 0.6
B^0	27.2	40.1	42.9	38.7	40.4 ± 0.6
B_s^0	9.0	13.0	9.4	7.4	10.3 ± 0.5
Baryons	36.5	6.8	4.8	15.1	8.8 ± 1.2

Table 1: Percentage probability that a bottom quark decays to a bottom hadron of a given species.

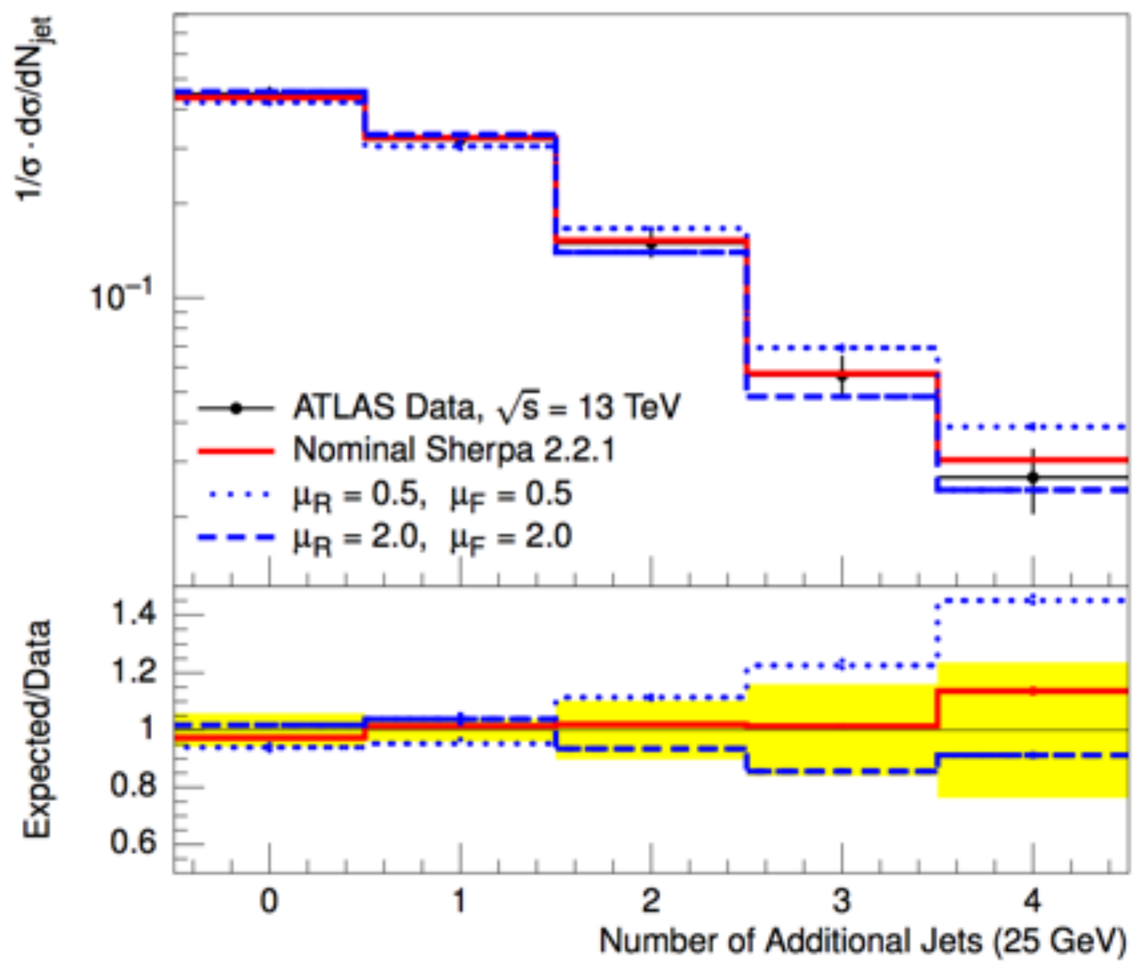
Species	SHERPAv2.2 HBE=4	SHERPAv2.2 HBE=1	PYTHIA8	HERWIG 7	World Average[25]
D^+	14.5	19.3	29.3	26.5	22.56 ± 0.77
D^0	38.5	55.1	56.4	58.9	56.43 ± 1.51
D_s^0	11.3	18.1	9.5	8.5	7.97 ± 0.45
Baryons	35.9	7.5	4.8	6.1	10.8 ± 0.91

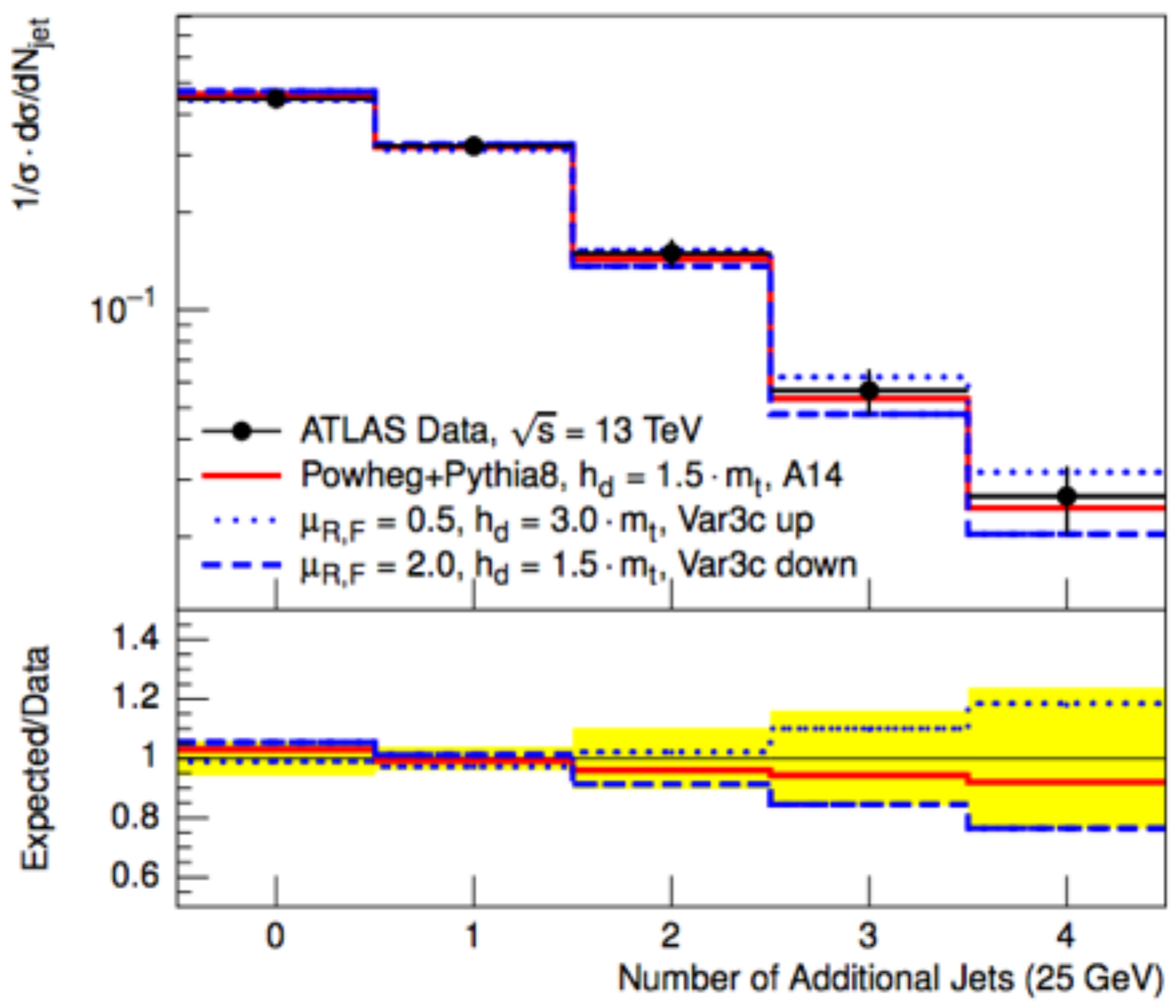
Table 2: Percentage probability that a charm quark decays to a charm hadron of a given species.

- Sherpa 2.2.1 not reproducing fractions as expected with HBE = 4 and should be set to lower value.

Tuning Sherpa 2.2.1

Studies of μ_F/μ_R:





- Nominal Powheg and Sherpa settings agree well with data.

Tuning MG5_aMC@NLO

Setup:

- Parameterised μ_q (since v2.5.3)

Variations:

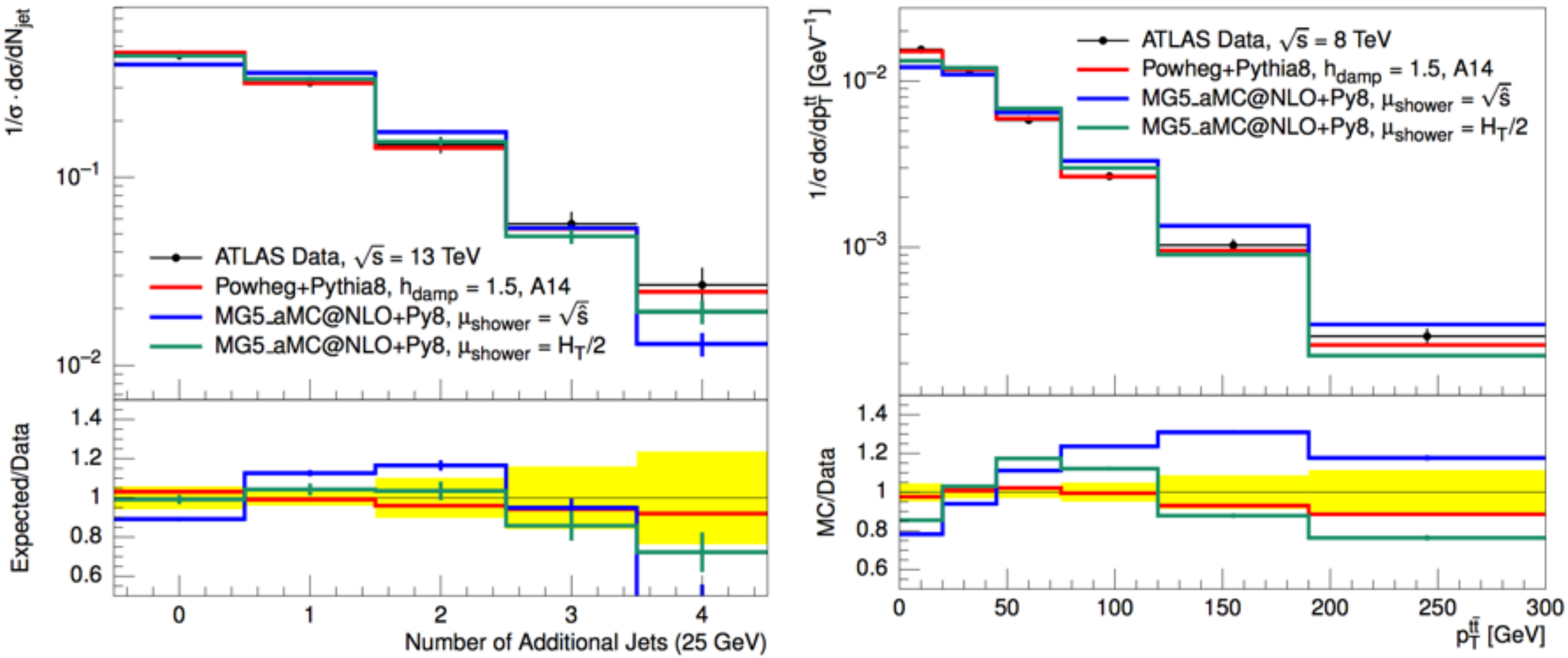
- Shower scale μ_q:
  - ➡ $\sqrt{s} : H_T/2$
- Compared to Powheg Pythia8

FxFx:

- Studies underway (early studies in ATL-PHYS-PUB-2016-016)

Tuning MG5_aMC@NLO

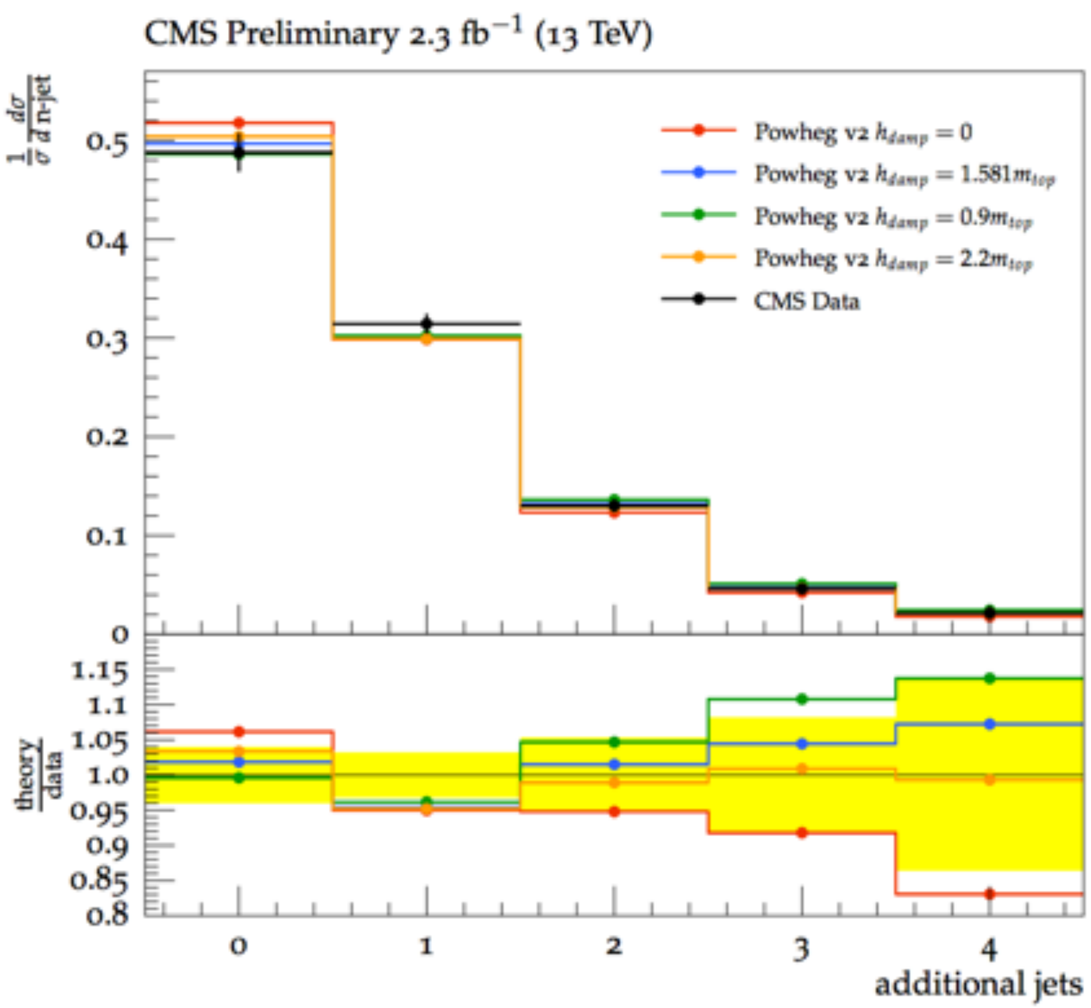
Studies of μ_q:

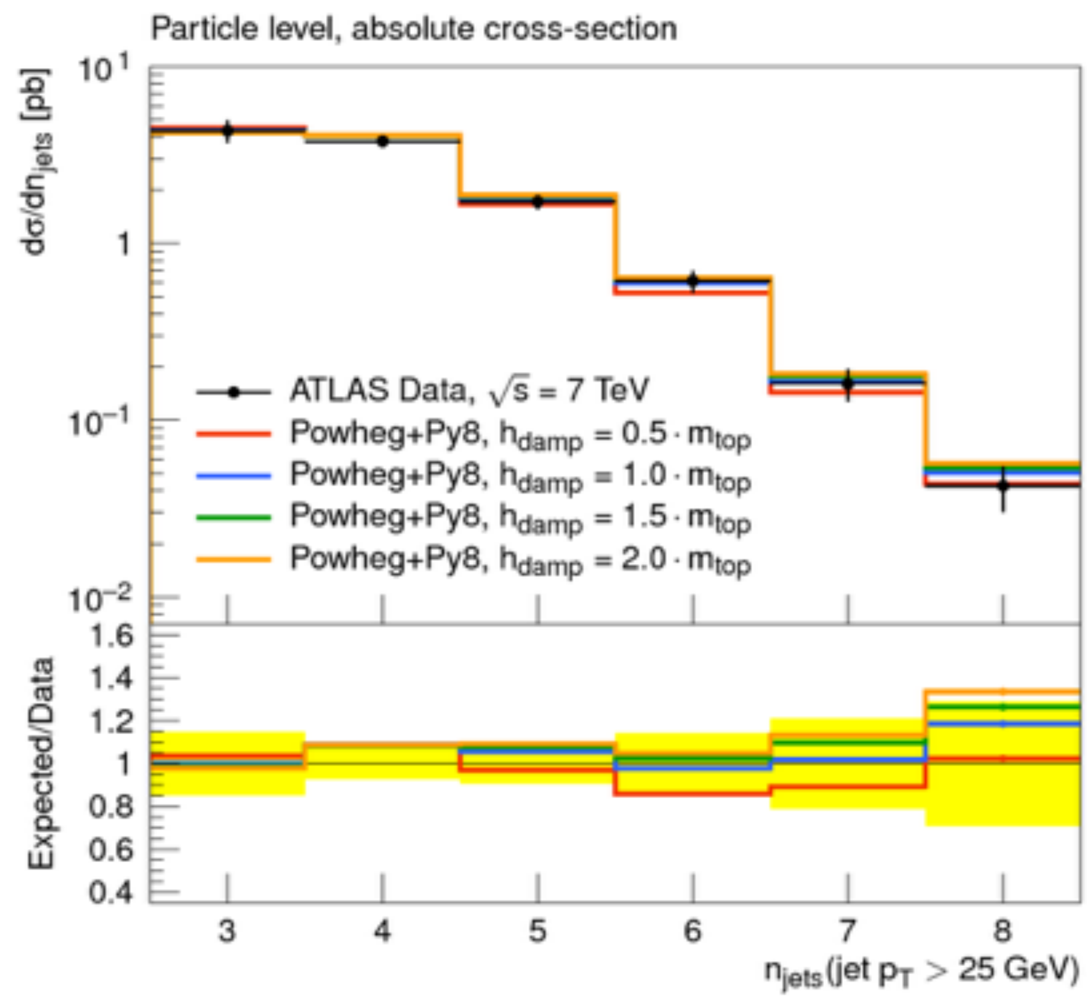


- Difference between setups is a big problem for systematic uncertainties.

Direct Comparisons: POWHEG

Powheg Tuning:

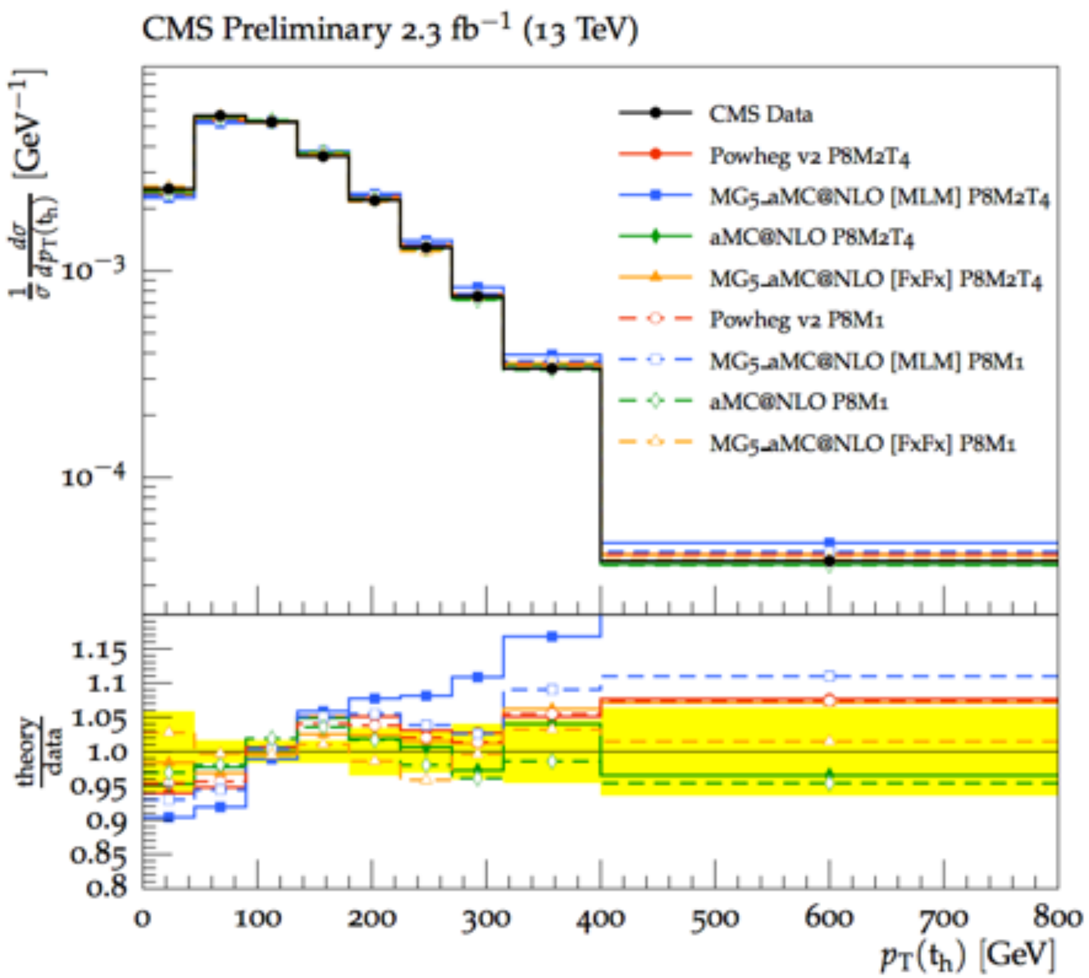


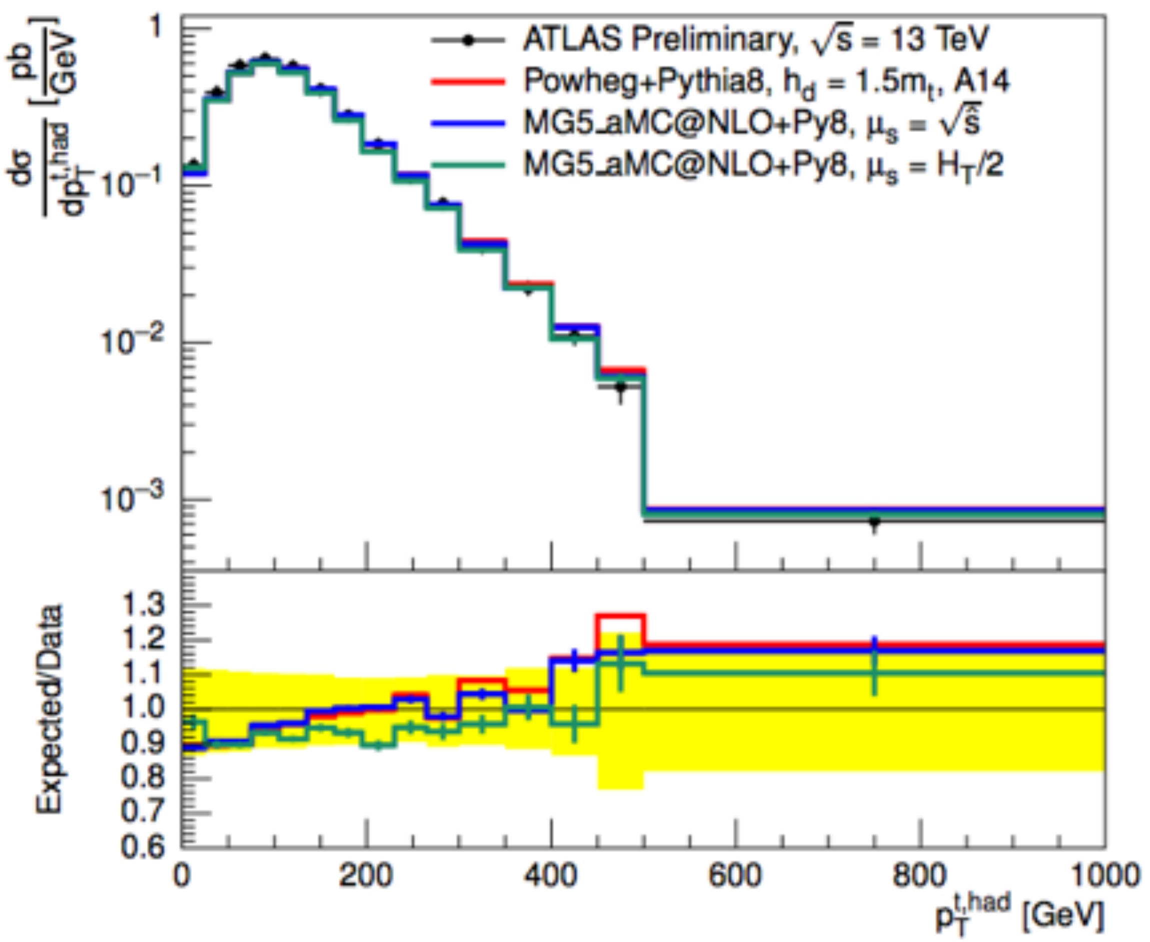


- Tuning results between ATLAS and CMS are in agreement, higher value of hdamp.

Direct Comparisons: All

Generator comparisons:





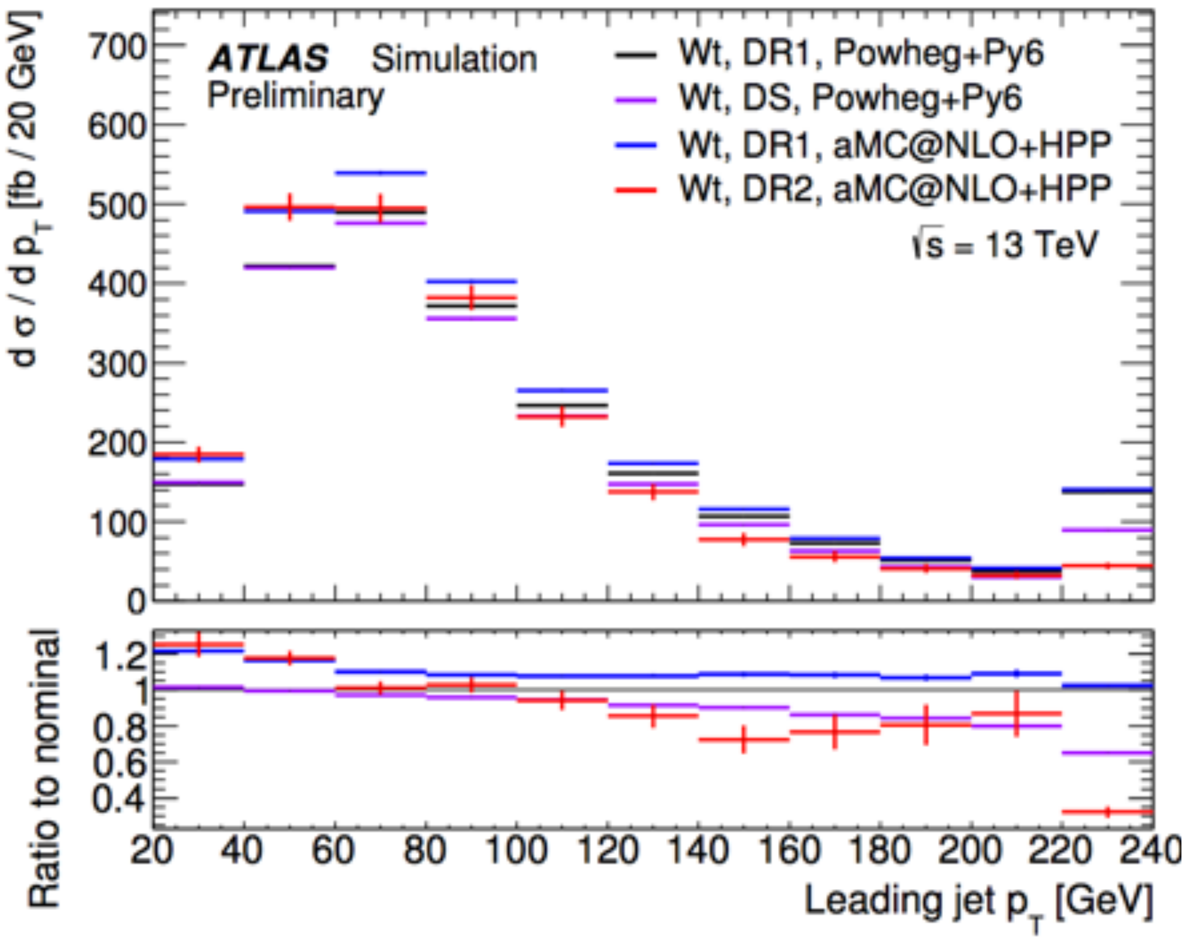
- In comparable generator setups, agreement looks reasonable.

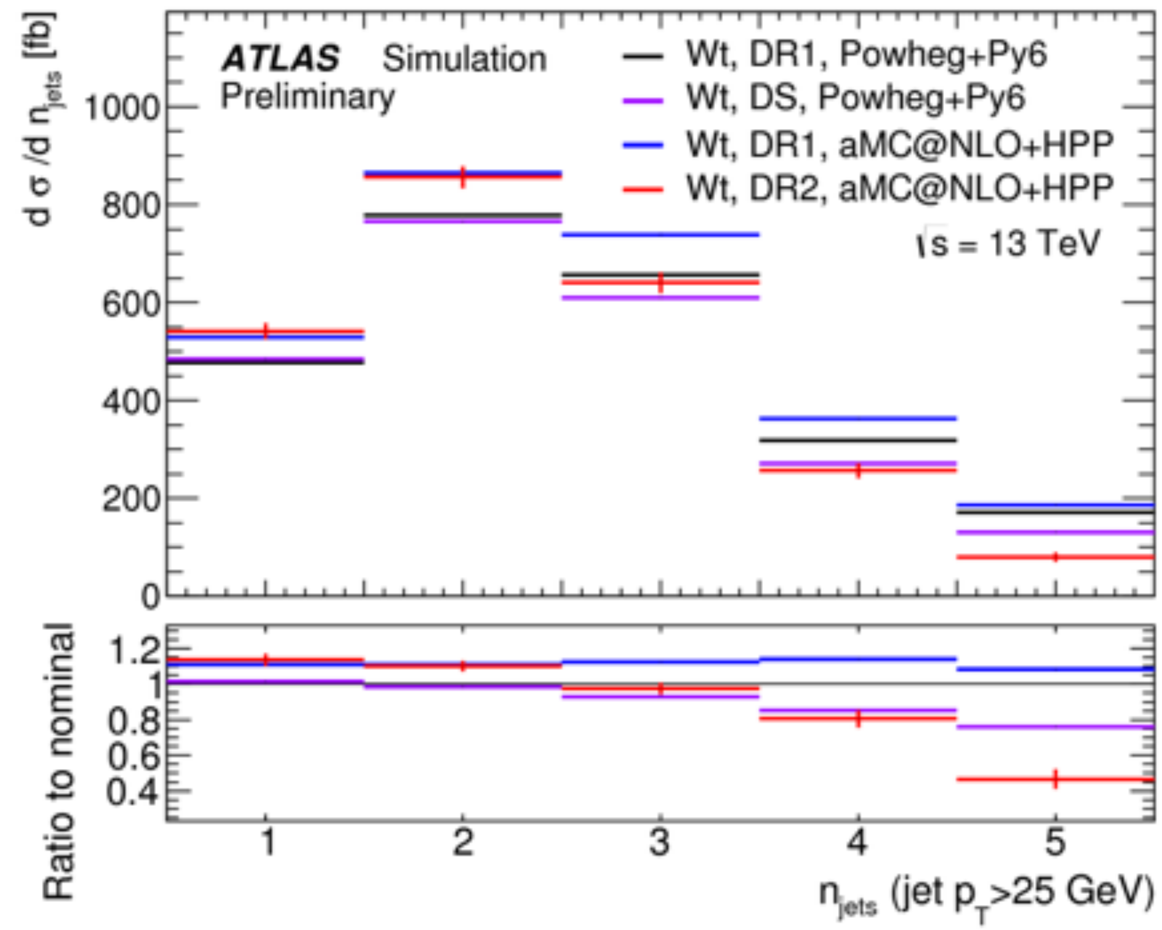
Single Top Modelling

Diagram Subtraction / Diagram Removal

- NLO diagrams from Wt production interfere with LO $t\bar{t}$ diagrams.
- Two methods currently used to deal with this:
  - ➡ Diagram Subtraction (DS)
  - ➡ Diagram Removal (DR)
- Difference is usually taken as a systematic uncertainty (not clear this is conservative).
- Ideally, generate inclusive WWbb to solve this.

Diagram Subtraction / Diagram Removal





- Significant progress on WWbb MC, unfortunately not quite ready for this workshop (difficult to implement with current tools).

Conclusions

Differential measurements:

- Many differential cross-section measurements.
- Beginning to explore double differential.
- Wide array of RIVET routines public (or nearly).

LHC Comparisons:

- Slopes in $p_T(t)$ seem to be largely described by NNLO corrections.
- 13 TeV results tentatively look comparable between ATLAS and CMS (work ongoing).

Conclusions

Tuning Conclusions

- POWHEG + PYTHIA8 well tuned.
- More studies are needed to understand MG5_aMC@NLO configurations (CMS in general looks OK, but not so in ATLAS).
- Currently exploring HERWIG7 as an alternative shower generator.
- Also exploring SHERPA as an alternative generator (attractive due to shower model possibilities).

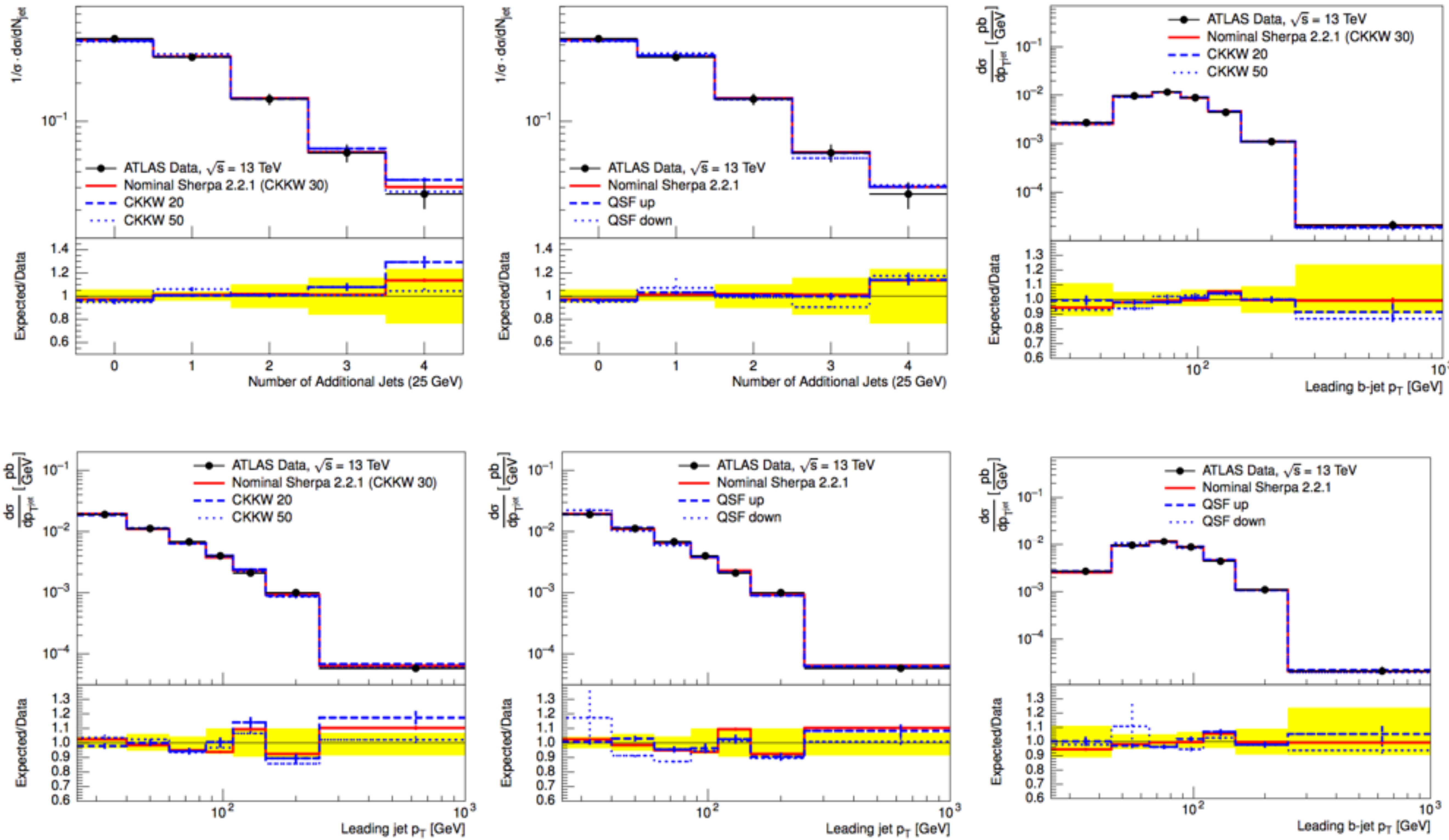
Conclusions

Tuning Conclusions (cont.)

- Having 2 NLO generators that describe the data is **essential to current paradigm** if we want to keep it (i.e. we need to improve MG5_aMC@NLO tuning).
- If/when using alternatives (such as SHERPA or HERWIG7) how can we deal with overestimations? Are there uncovered uncertainties?
- More on UE tuning in Efe and Deepak's talks.

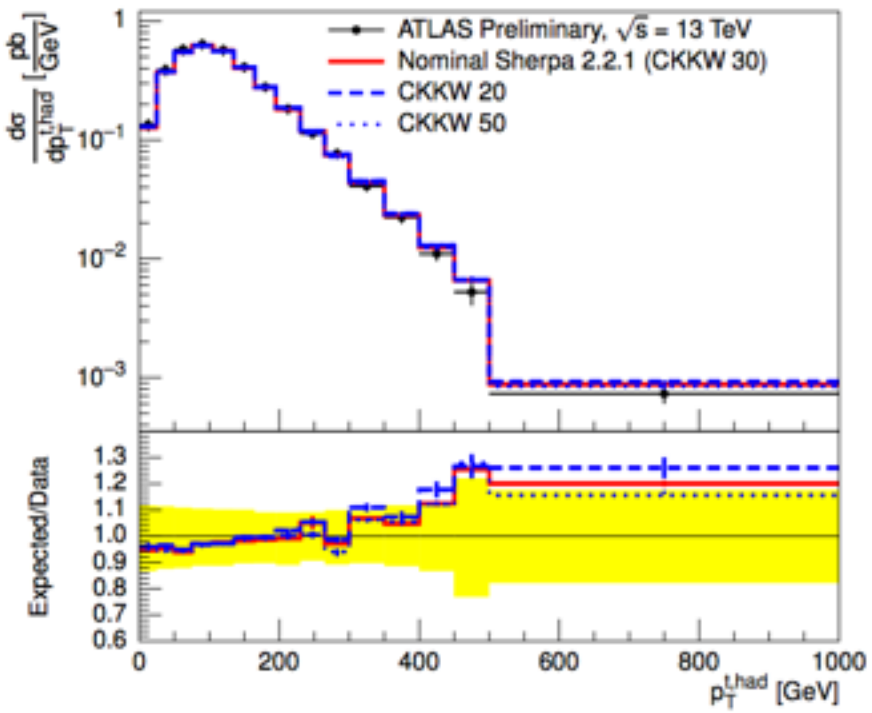
Backup

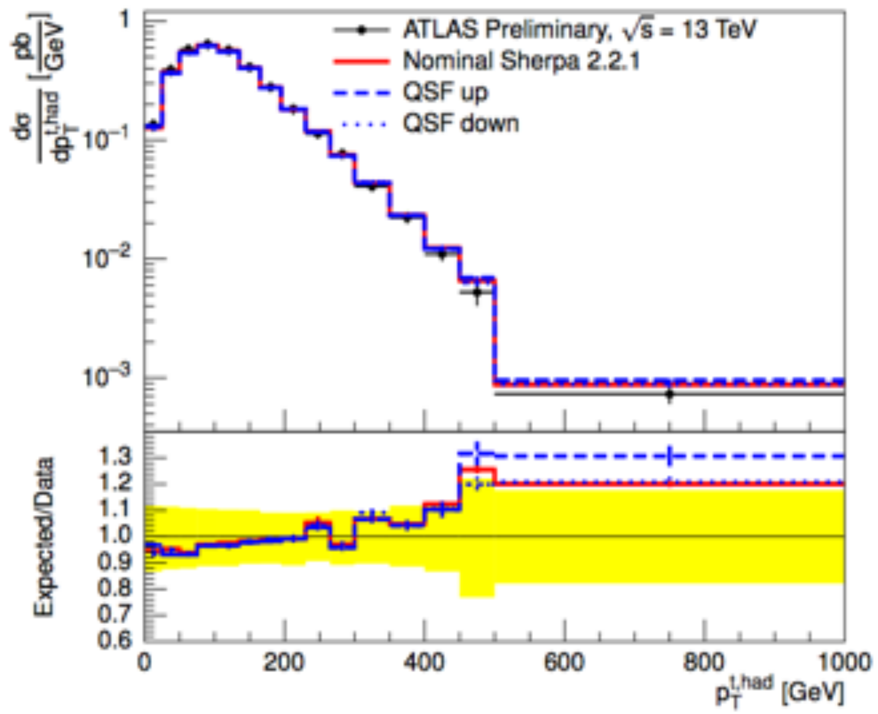
Sherpa 2.2.1

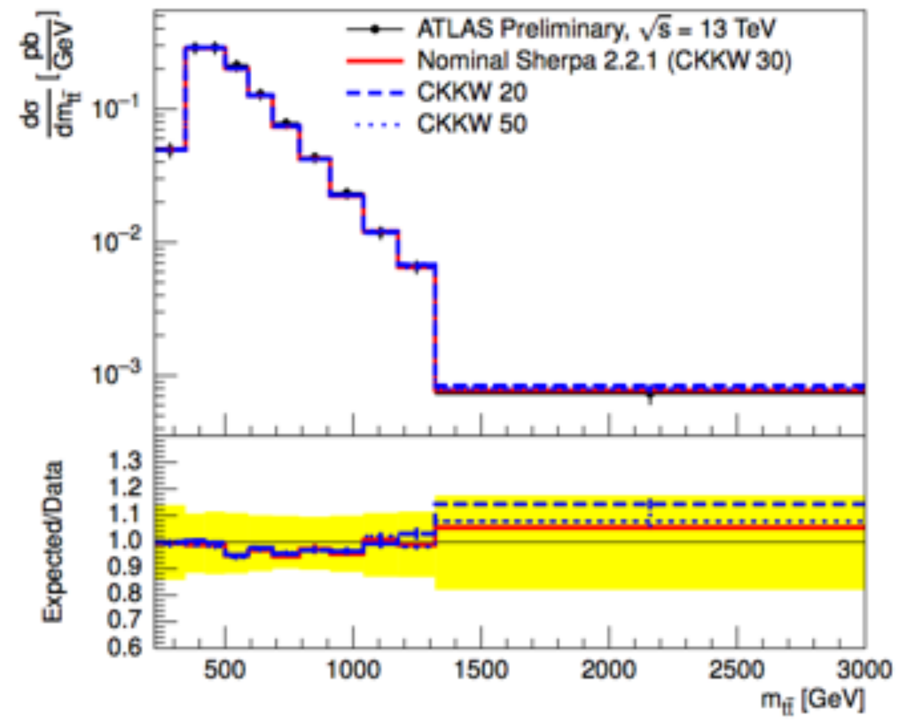


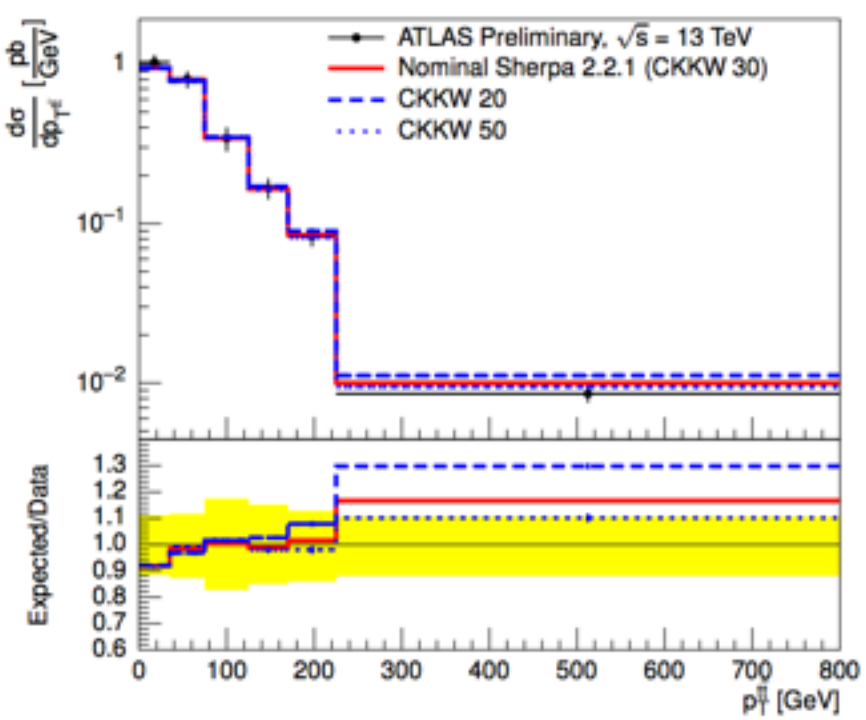
ATLAS Data, $\sqrt{s}$ = 13 TeV
Nominal Sherpa 2.2.1 (CKKW 30)
CKKW 20
CKKW 50
Nominal Sherpa 2.2.1
QSF up
QSF down
$1/\sigma \cdot d\sigma/dN_{jet}$
Expected/Data
Number of Additional Jets (25 GeV)
$\frac{d\sigma}{dp_{T,jet}}$ [$\frac{pb}{GeV}$]
Leading b-jet p_T [GeV]
Leading jet p_T [GeV]

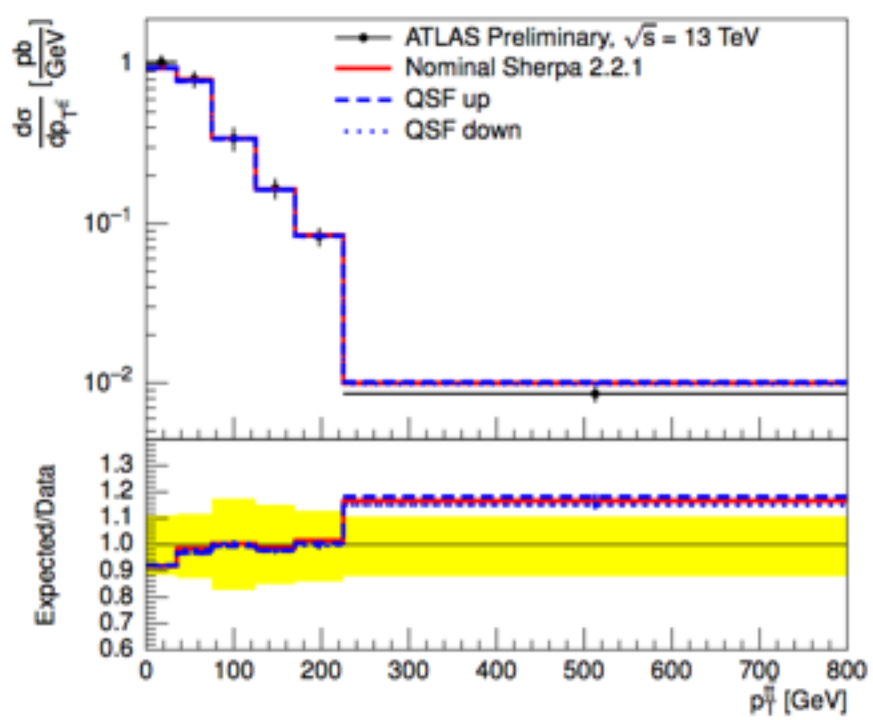
Sherpa 2.2.1

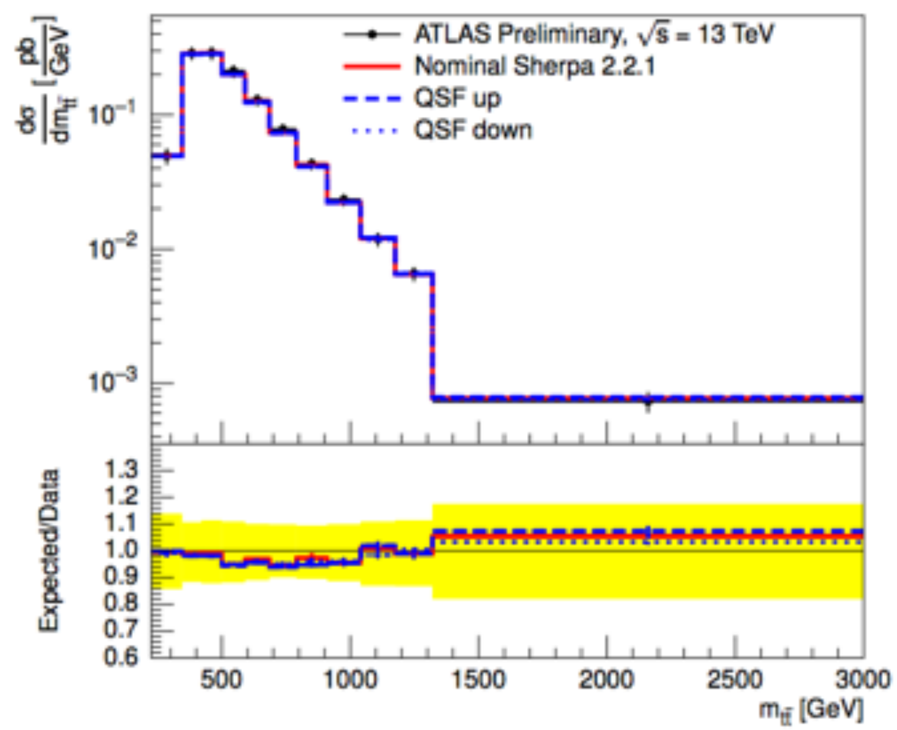

ATLAS Preliminary, $\sqrt{s}$ = 13 TeV
Nominal Sherpa 2.2.1 (CKKW 30)
CKKW 20
CKKW 50
$\frac{d\sigma}{dp_T^{t,had}}$ [$\frac{pb}{GeV}$]
Expected/Data
$p_T^{t,had}$ [GeV]


ATLAS Preliminary, $\sqrt{s}$ = 13 TeV
Nominal Sherpa 2.2.1
QSF up
QSF down
$\frac{d\sigma}{dp_T^{t,had}}$ [$\frac{pb}{GeV}$]
Expected/Data
$p_T^{t,had}$ [GeV]

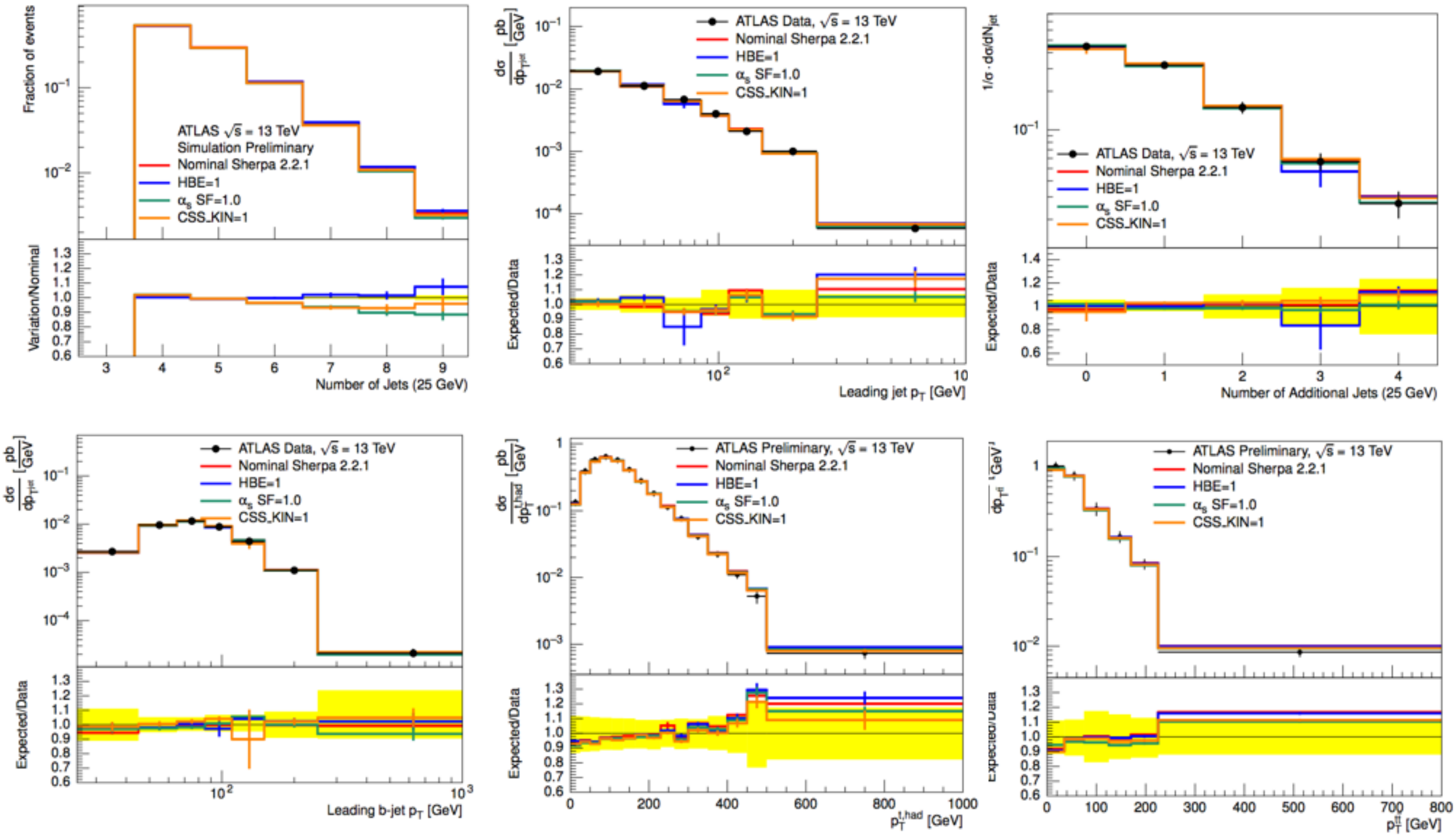

ATLAS Preliminary, $\sqrt{s}$ = 13 TeV
Nominal Sherpa 2.2.1 (CKKW 30)
CKKW 20
CKKW 50
$\frac{d\sigma}{dm_{t\bar{t}}}$ [$\frac{pb}{GeV}$]
Expected/Data
$m_{t\bar{t}}$ [GeV]


ATLAS Preliminary, $\sqrt{s}$ = 13 TeV
Nominal Sherpa 2.2.1 (CKKW 30)
CKKW 20
CKKW 50
$\frac{d\sigma}{dp_T^{t\bar{t}}}$ [$\frac{pb}{GeV}$]
Expected/Data
$p_T^{t\bar{t}}$ [GeV]

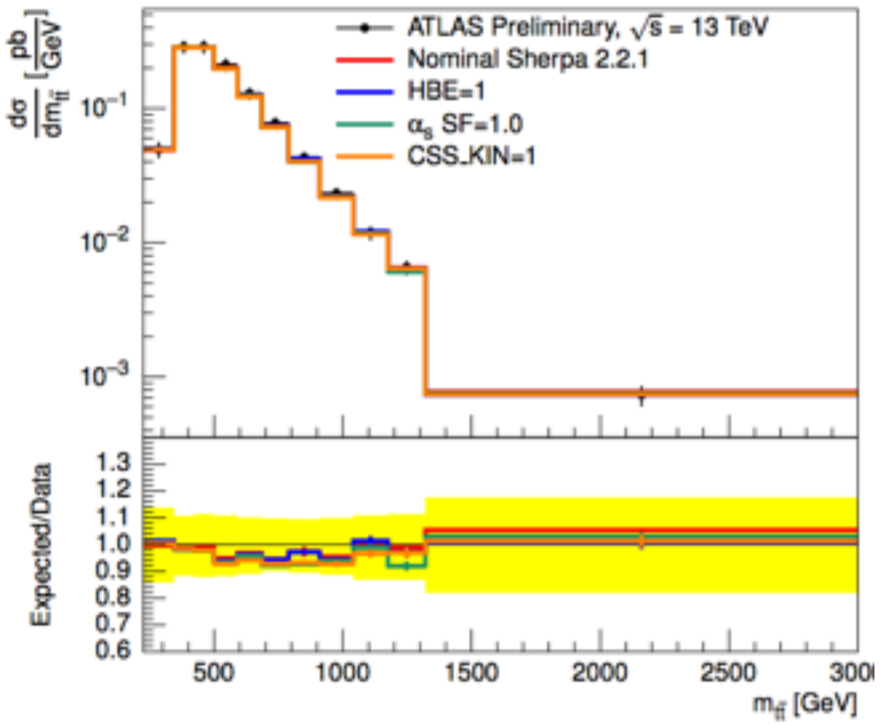

ATLAS Preliminary, $\sqrt{s}$ = 13 TeV
Nominal Sherpa 2.2.1
QSF up
QSF down
$\frac{d\sigma}{dp_T^{t\bar{t}}}$ [$\frac{pb}{GeV}$]
Expected/Data
$p_T^{t\bar{t}}$ [GeV]


ATLAS Preliminary, $\sqrt{s}$ = 13 TeV
Nominal Sherpa 2.2.1
QSF up
QSF down
$\frac{d\sigma}{dm_{t\bar{t}}}$ [$\frac{pb}{GeV}$]
Expected/Data
$m_{t\bar{t}}$ [GeV]

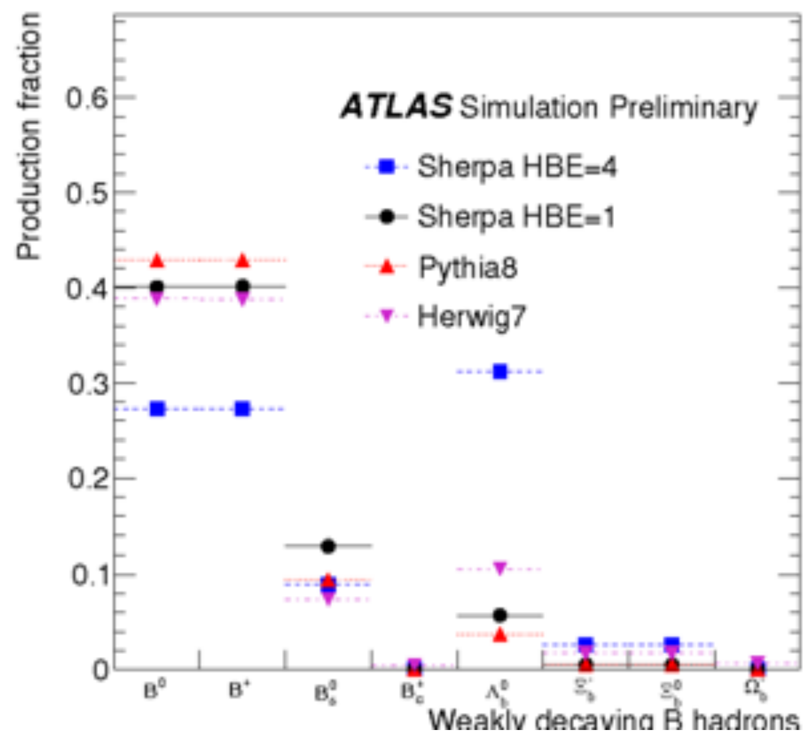
Sherpa 2.2.1


ATLAS $\sqrt{s}$ = 13 TeV
Simulation Preliminary
Nominal Sherpa 2.2.1
HBE=1
α_s SF=1.0
CSS_KIN=1
Fraction of events
Variation/Nominal
Number of Jets (25 GeV)
ATLAS Data, $\sqrt{s}$ = 13 TeV
Expected/Data
Leading jet p_T [GeV]
$1/\sigma \cdot d\sigma/dN_{jet}$
Number of Additional Jets (25 GeV)
Leading b-jet p_T [GeV]
ATLAS Preliminary, $\sqrt{s}$ = 13 TeV
$p_T^{t,had}$ [GeV]
$p_T^{t\bar{t}}$ [GeV]

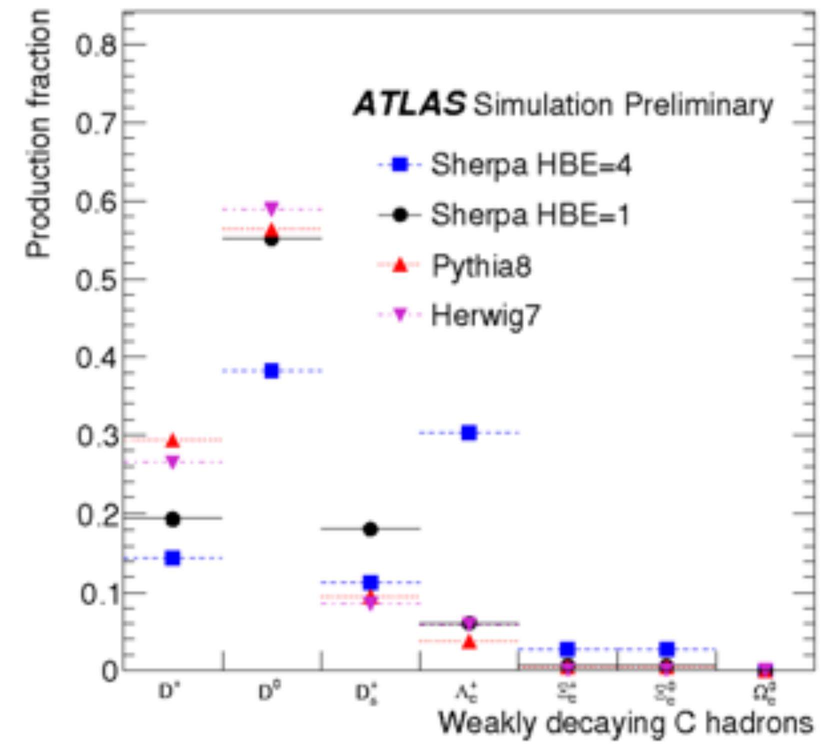
Sherpa 2.2.1



ATLAS Preliminary, √s = 13 TeV
Nominal Sherpa 2.2.1
HBE=1
αs SF=1.0
CSS_KIN=1
Expected/Data
m_tt [GeV]

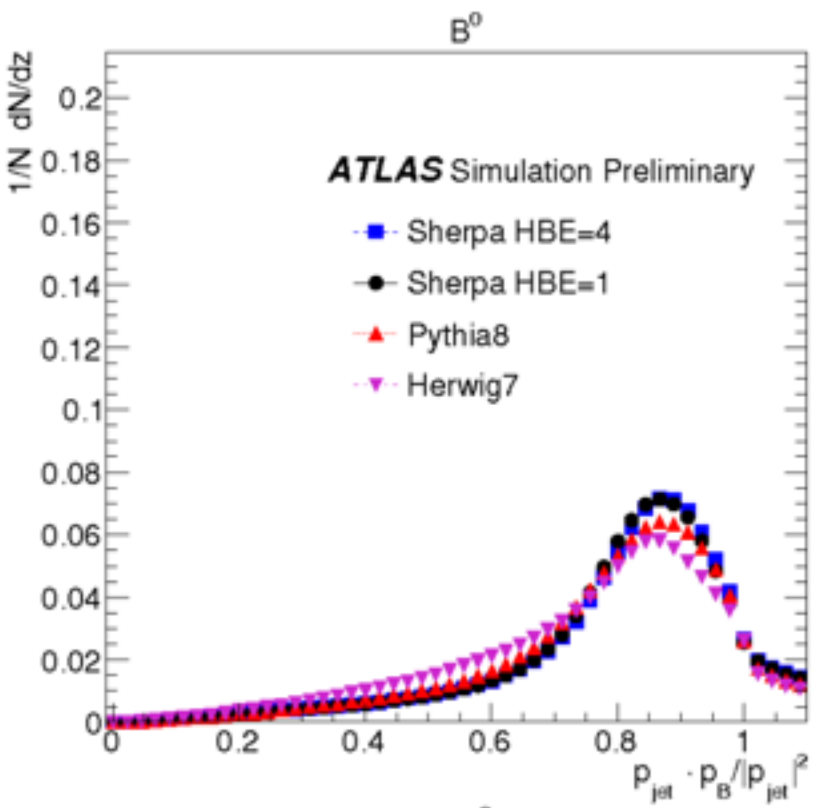


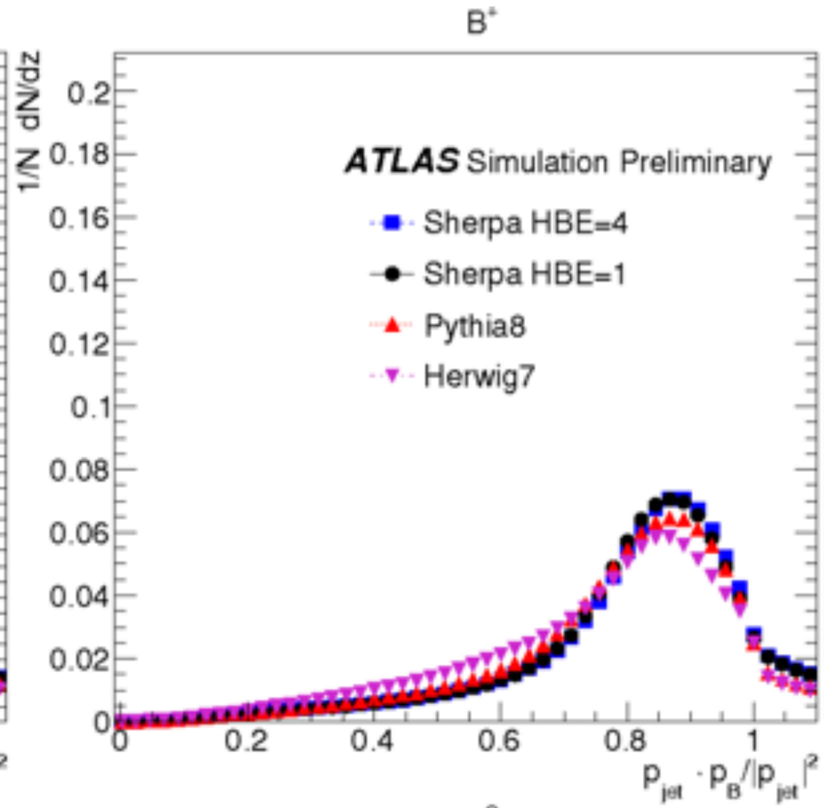
ATLAS Simulation Preliminary
Sherpa HBE=4
Sherpa HBE=1
Pythia8
Herwig7
Production fraction
Weakly decaying B hadrons

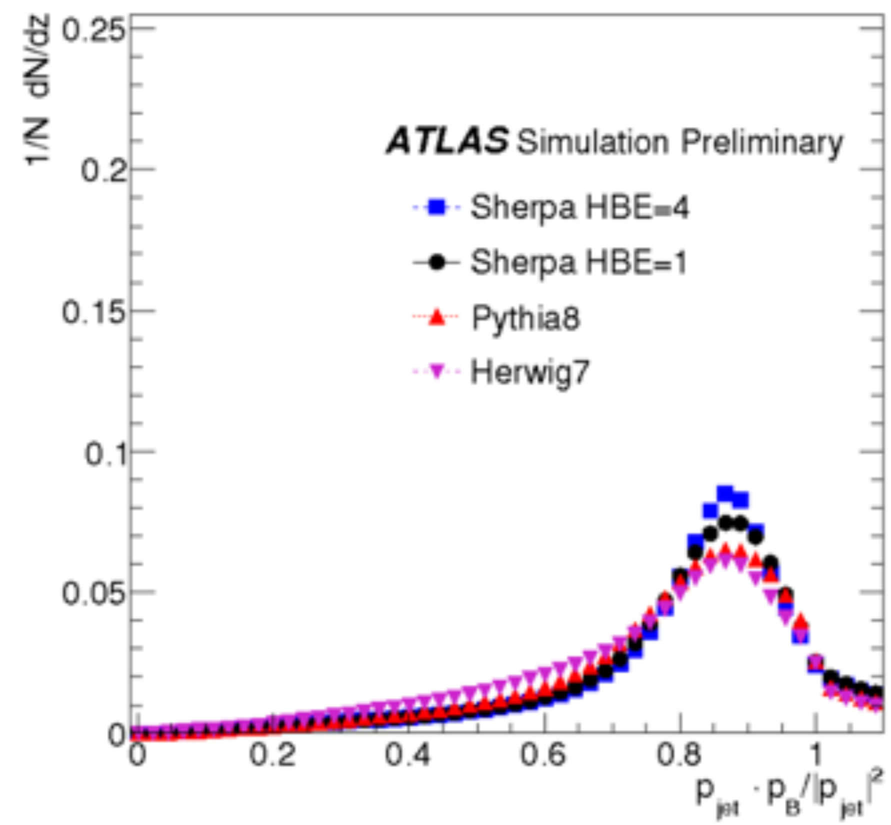


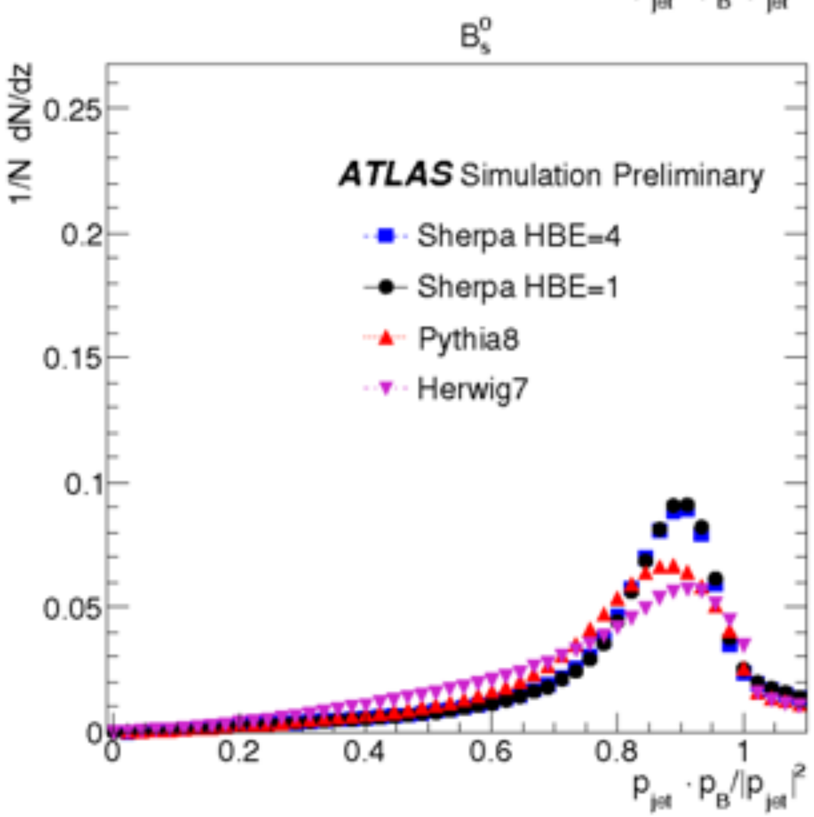
ATLAS Simulation Preliminary
Sherpa HBE=4
Sherpa HBE=1
Pythia8
Herwig7
Production fraction
Weakly decaying C hadrons

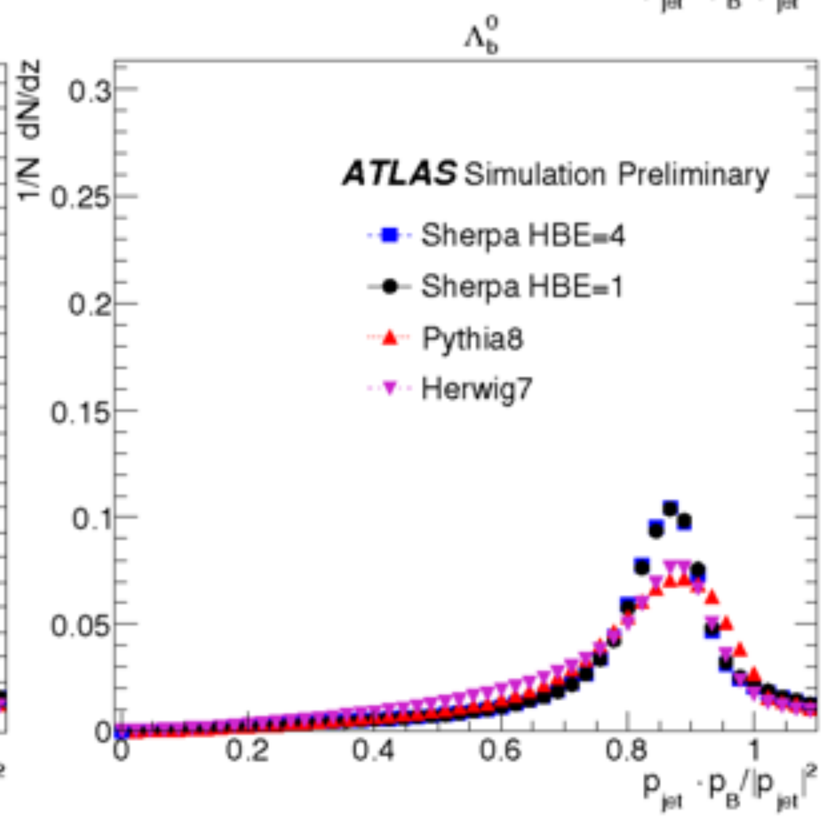
Sherpa 2.2.1


B0
ATLAS Simulation Preliminary
Sherpa HBE=4
Sherpa HBE=1
Pythia8
Herwig7
1/N dN/dz
$p_{jet} \cdot p_B/|p_{jet}|^2$

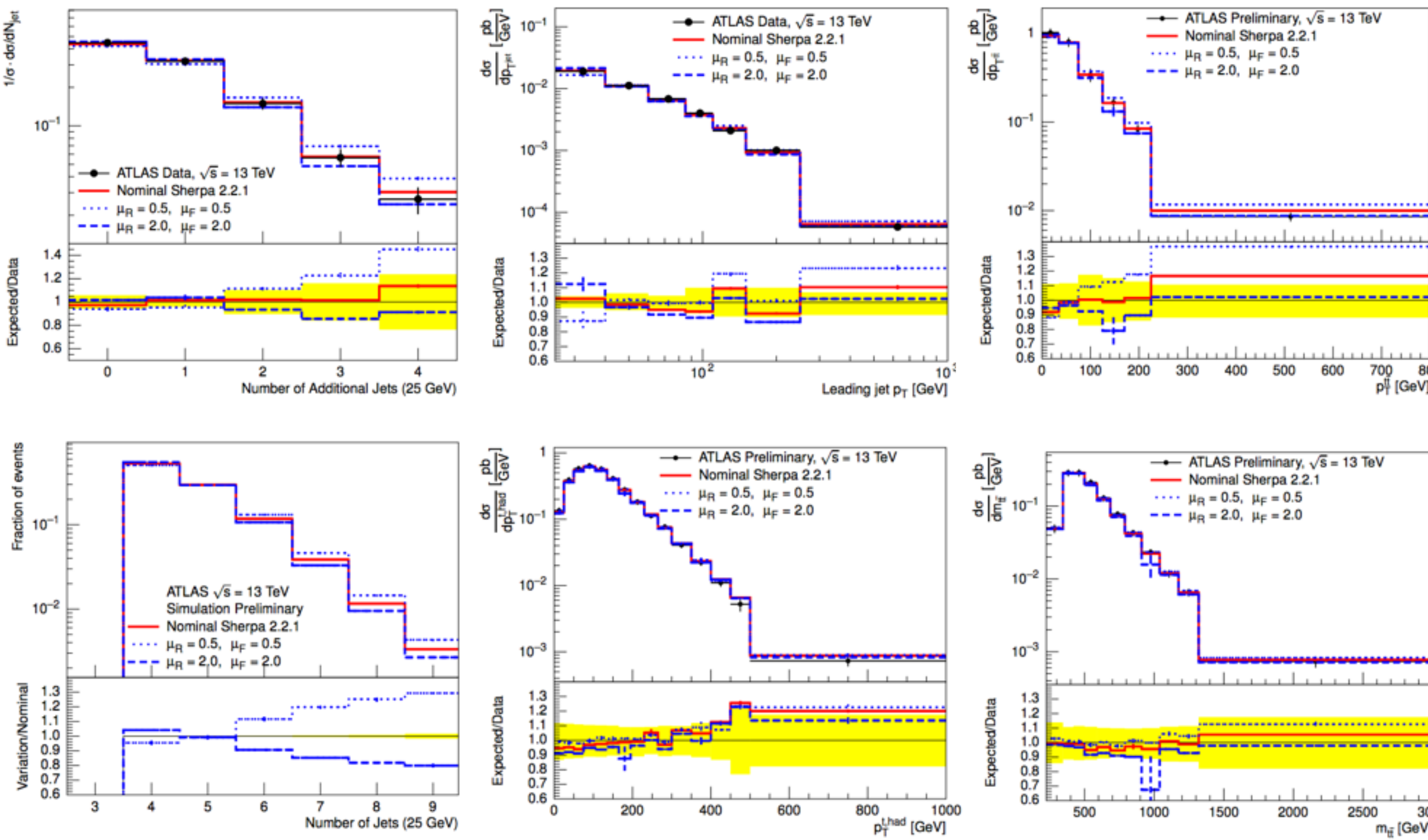

B+
ATLAS Simulation Preliminary
Sherpa HBE=4
Sherpa HBE=1
Pythia8
Herwig7
1/N dN/dz
$p_{jet} \cdot p_B/|p_{jet}|^2$


ATLAS Simulation Preliminary
Sherpa HBE=4
Sherpa HBE=1
Pythia8
Herwig7
1/N dN/dz
$p_{jet} \cdot p_B/|p_{jet}|^2$


B^0_s
ATLAS Simulation Preliminary
Sherpa HBE=4
Sherpa HBE=1
Pythia8
Herwig7
1/N dN/dz
$p_{jet} \cdot p_B/|p_{jet}|^2$

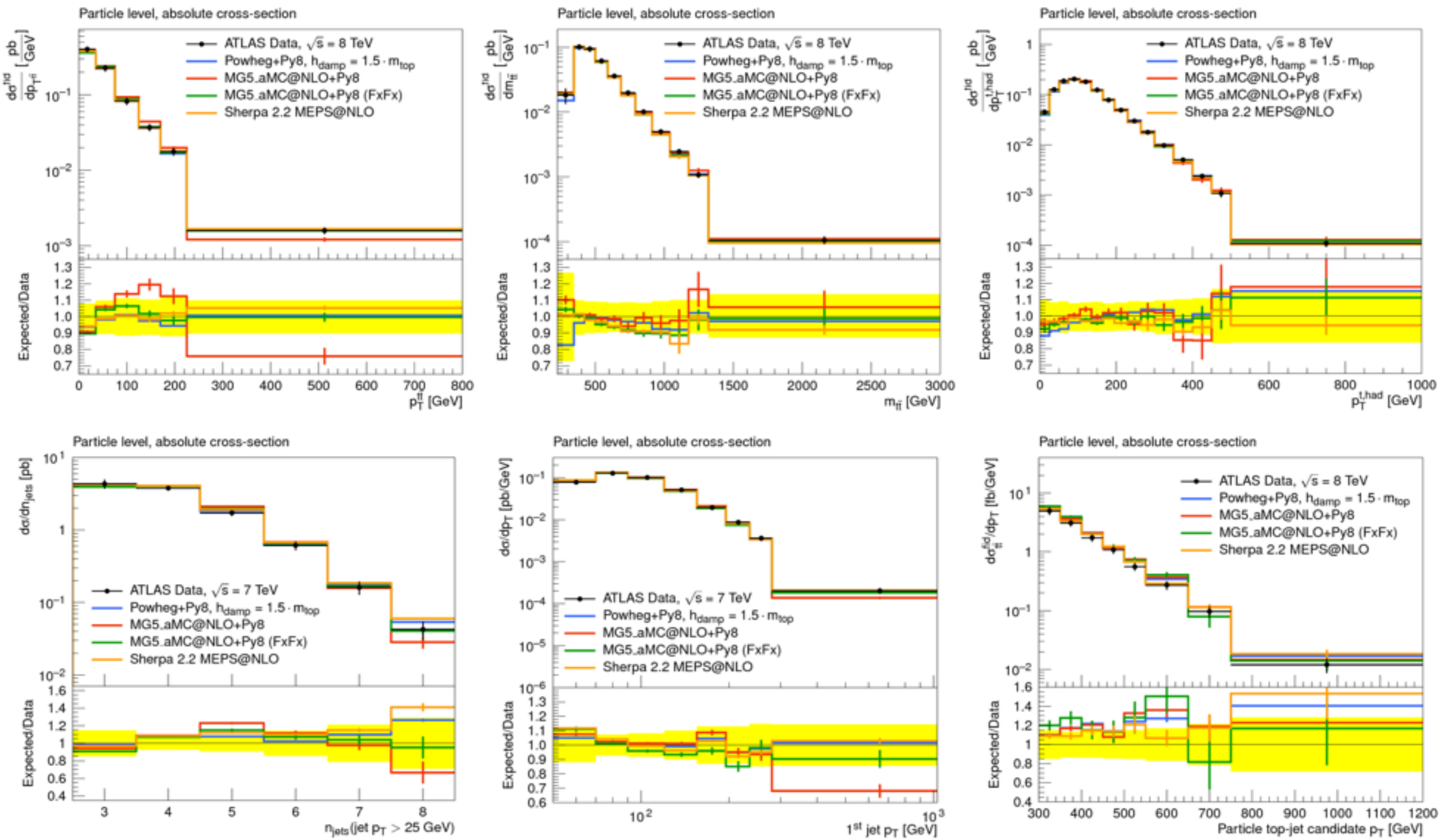

Λ^0_b
ATLAS Simulation Preliminary
Sherpa HBE=4
Sherpa HBE=1
Pythia8
Herwig7
1/N dN/dz
$p_{jet} \cdot p_B/|p_{jet}|^2$

Sherpa 2.2.1



ATLAS Data, √s = 13 TeV
Nominal Sherpa 2.2.1
μR = 0.5, μF = 0.5
μR = 2.0, μF = 2.0
1/σ · dσ/dNjet
Expected/Data
Number of Additional Jets (25 GeV)
Leading jet pT [GeV]
ATLAS Preliminary, √s = 13 TeV
p_T^tt̄ [GeV]
ATLAS √s = 13 TeV
Simulation Preliminary
Fraction of events
Variation/Nominal
Number of Jets (25 GeV)
p_T^t,had [GeV]
m_tt̄ [GeV]

MG5_aMC@NLO: FxFx



CMS Diff. p-values

Distribution	χ^2/dof	p-value	χ^2/dof	p-value	χ^2/dof	p-value
	POWHEG+P8		POWHEG+H++		MG5_aMC@NLO+P8 MLM	
	Order: NLO		Order: NLO		Order: LO, up to 3 add. partons	
$p_T(t_h)$	14.3/9	0.111	26.3/9	<0.01	34.9/9	<0.01
$\lvert y(t_h)\rvert$	4.76/7	0.690	7.61/7	0.368	9.08/7	0.247
$p_T(t_\ell)$	22.9/9	<0.01	40.8/9	<0.01	54.6/9	<0.01
$\lvert y(t_\ell)\rvert$	7.14/7	0.415	10.6/7	0.156	18.2/7	0.011
$M(t\bar{t})$	9.25/8	0.322	173/8	<0.01	13.4/8	0.100
$p_T(t\bar{t})$	2.31/5	0.805	39.6/5	<0.01	48.9/5	<0.01
$\lvert y(t\bar{t})\rvert$	1.37/6	0.967	2.44/6	0.876	14.5/6	0.025
Additional jets	27.6/5	<0.01	16.2/5	<0.01	36.3/5	<0.01
Additional jets *vs.* $p_T(t\bar{t})$	70.3/20	<0.01	95.4/20	<0.01	168/20	<0.01
Additional jets *vs.* $p_T(t_h)$	96.2/36	<0.01	218/36	<0.01	180/36	<0.01
$\lvert y(t_h)\rvert$ *vs.* $p_T(t_h)$	60.1/36	<0.01	212/36	<0.01	128/36	<0.01
$M(t\bar{t})$ *vs.* $\lvert y(t\bar{t})\rvert$	28.2/24	0.251	280/24	<0.01	41.2/24	0.016
$p_T(t\bar{t})$ *vs.* $M(t\bar{t})$	16.7/32	0.988	465/32	<0.01	97.6/32	<0.01
	MG5_aMC@NLO+P8		MG5_aMC@NLO+H++		MG5_aMC@NLO+P8 FxFx	
	Order: NLO		Order: NLO		Order: NLO, up to 2 add. partons	
$p_T(t_h)$	13.1/9	0.159	6.85/9	0.653	5.05/9	0.830
$\lvert y(t_h)\rvert$	9.91/7	0.194	13.5/7	0.060	8.12/7	0.322
$p_T(t_\ell)$	13.4/9	0.147	8.02/9	0.533	7.97/9	0.538
$\lvert y(t_\ell)\rvert$	14.3/7	0.045	7.24/7	0.404	15.9/7	0.026
$M(t\bar{t})$	10.9/8	0.206	34.2/8	<0.01	33.0/8	<0.01
$p_T(t\bar{t})$	40.0/5	<0.01	7.65/5	0.177	27.8/5	<0.01
$\lvert y(t\bar{t})\rvert$	2.72/6	0.843	2.77/6	0.837	3.58/6	0.733
Additional jets	36.2/5	<0.01	15.7/5	<0.01	10.8/5	0.056
Additional jets *vs.* $p_T(t\bar{t})$	237/20	<0.01	192/20	<0.01	87.2/20	<0.01
Additional jets *vs.* $p_T(t_h)$	251/36	<0.01	76.0/36	<0.01	45.6/36	0.132
$\lvert y(t_h)\rvert$ *vs.* $p_T(t_h)$	48.9/36	0.074	100/36	<0.01	49.1/36	0.071
$M(t\bar{t})$ *vs.* $\lvert y(t\bar{t})\rvert$	25.1/24	0.403	53.4/24	<0.01	56.7/24	<0.01
$p_T(t\bar{t})$ *vs.* $M(t\bar{t})$	133/32	<0.01	157/32	<0.01	109/32	<0.01