Measurement of ttbar with additional jets with the ATLAS detector

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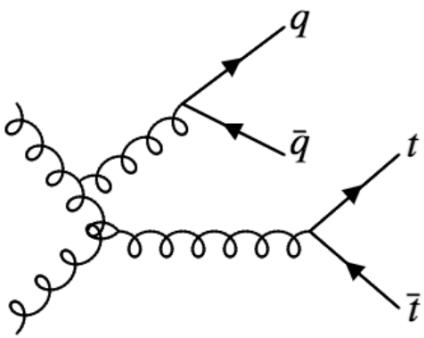
Introduction

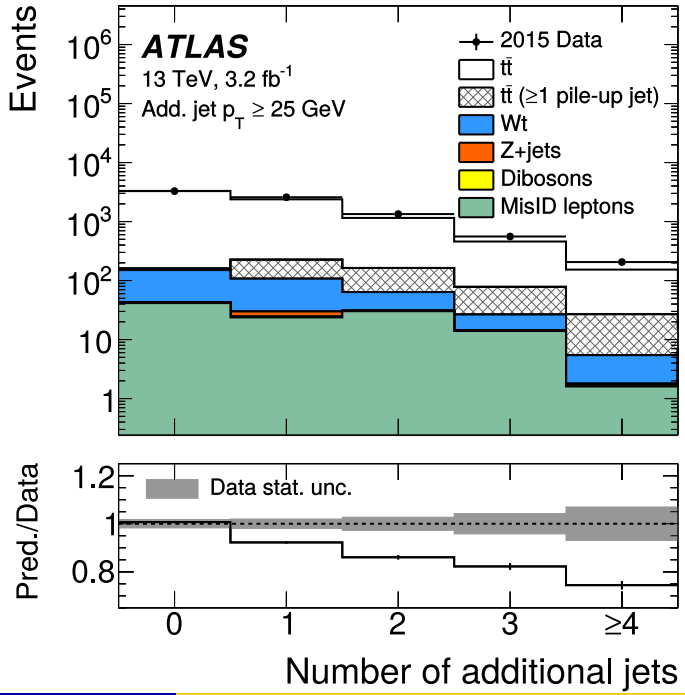
- Measurement of $t\bar{t}$+jets is an important test of QCD
- Especially with additional HF-jets : theoretical challenge due to b-quark mass
  - $\rightarrow$ QCD at very different energy scales
- Background for several interesting physics processes
  - $\rightarrow$ (B)SM 4-tops, $t\bar{t}H(\rightarrow b\bar{b})$, $H^+ \rightarrow t\bar{b}$, etc.
- For better accuracy : need NLO multileg generators
  - $\rightarrow$ additional light or heavy quarks in the Matrix Element
  - $\rightarrow$ more challenging optimisation than NLO+PS setups
- ATLAS measured observables sensitive to additional radiations in $t\bar{t}$ with 13 TeV data
  - $\rightarrow$ jet activity in $t\bar{t}$ events - 3.2fb^{-1}, $e\mu$ channel Eur. Phys. J. C **77** (2017) 220
  - $\rightarrow$ $t\bar{t}$ cross-sections with additional jets - 3.2fb^{-1}, ℓ+jets channel - JHEP **10** (2018) 159
  - $\rightarrow$ $t\bar{t}$ cross-sections with additional HF-jets - 36.1fb^{-1}, $e\mu$ channel - JHEP **04** (2019) 046

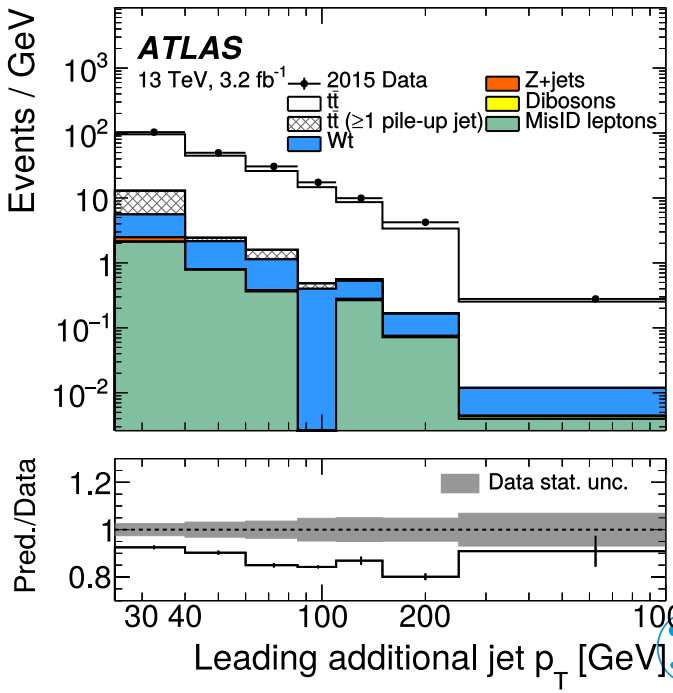
Jet activity in $t\bar{t}$ events

Eur. Phys. J. C **77** (2017) 220

- Selecting $t\bar{t}$ events in $e\mu$ topology : $1e{+}1\mu$, opposite charge, ≥ 2 jets, ≥ 2 b-tag
  - $\rightarrow$ signal modelled using Powheg+Pythia6
- Very pure $t\bar{t}$ sample : S/B $> 95\%$
  - $\rightarrow$ irreducible backgrounds estimated with MC samples
  - $\rightarrow$ fake prompt leptons estimated on data with same-sign leptons events
- Jet-related observables unfolded at particle level, and accounting for pile-up jets
- Main systematics : JES/JER, signal modelling



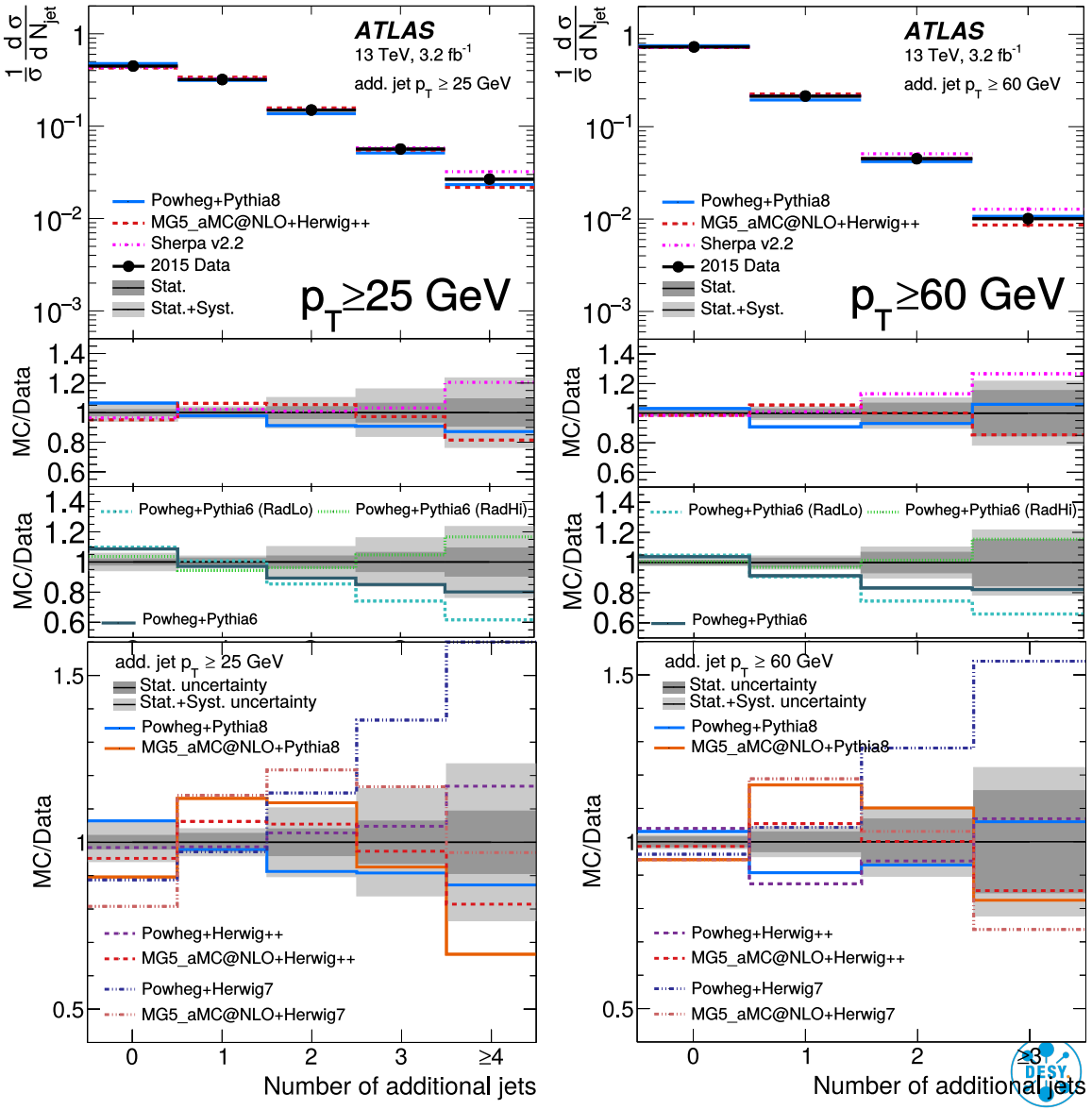




Jet activity in $t\bar{t}$ events : additional jets multiplicity

Eur. Phys. J. C **77** (2017) 220

- $N_{\text{jets}}^{\text{add.}}$ for different p_T^j thresholds
- Clear disagreement for some MC
  - → arch-like scructure for aMC@NLO
  - → too much radiation for Powheg+Hw7
  - → similar for 25 and 60 GeV thresholds
- Food for MC optimisation !
  - → see e.g. ATL-PHYS-PUB-2018-009



Jet activity in $t\bar{t}$ events : jet kinematics

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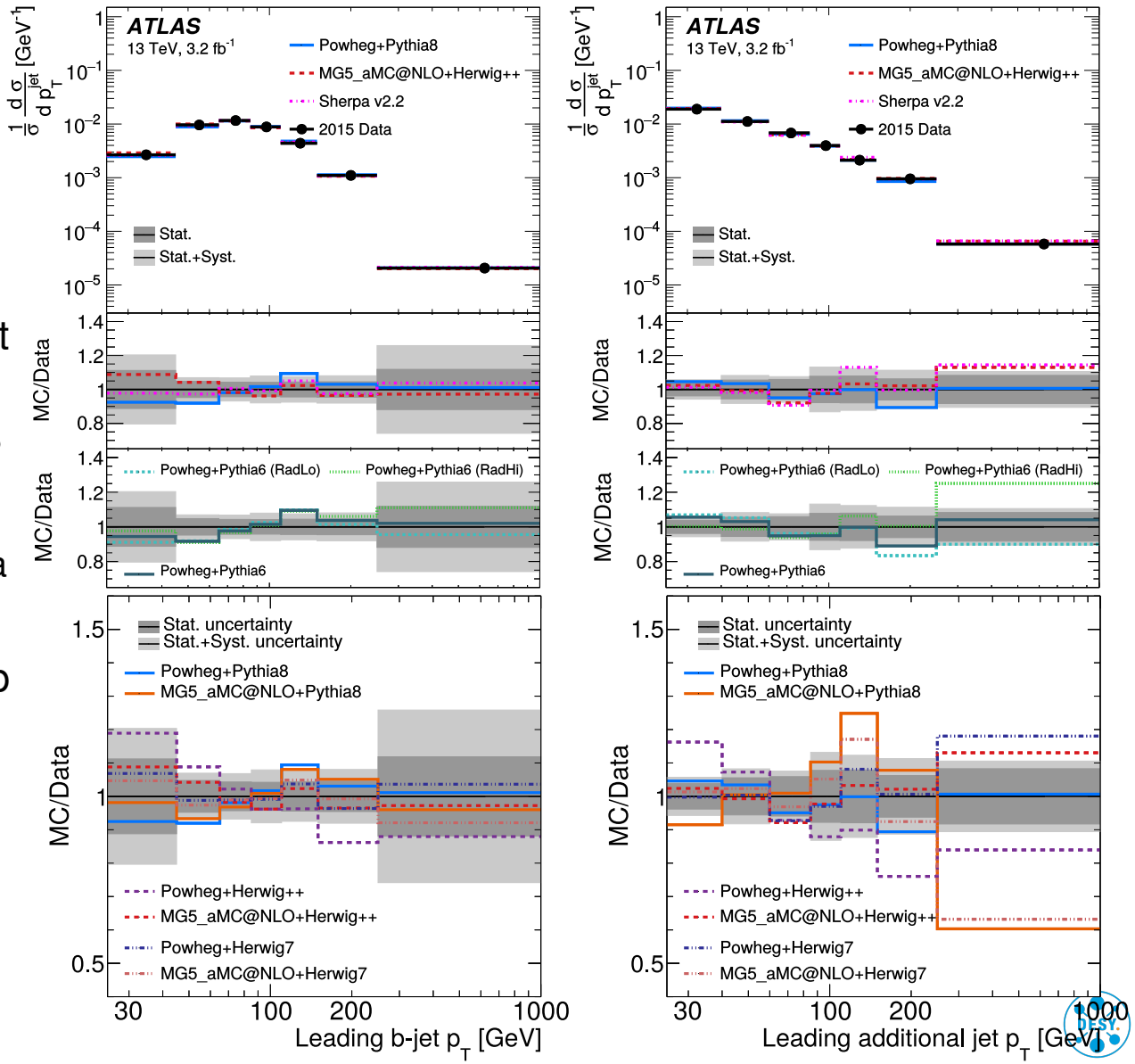
- Jets p_T modelling also important
  - → no predictive power by $t\bar{t}$ MC, additional radiations in the PS
- Leading b : $\simeq$ from top
  - → most MC compatible with data
  - → different slopes
- Leading add. jet : $\simeq$ not from top
  - → worse modelling in some MC, e.g. aMC@NLO



Jet activity in $t\bar{t}$ events : gap fractions

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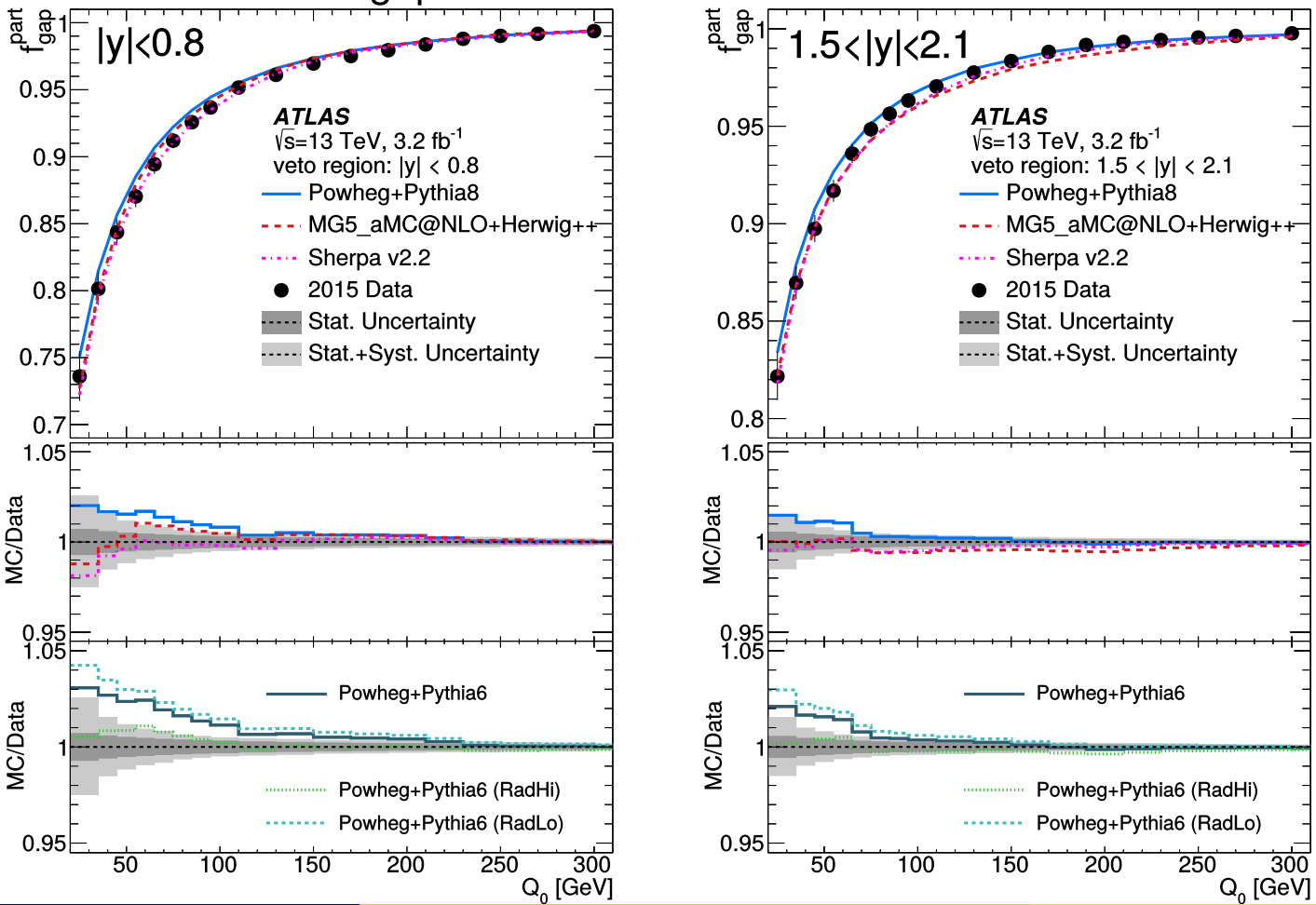
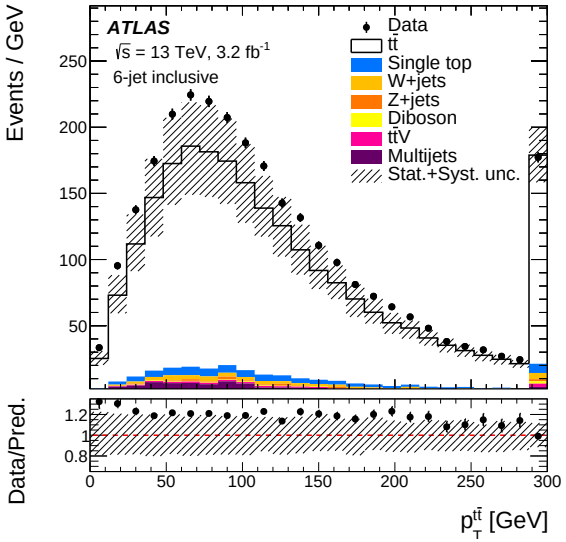
- Rapidity gap fraction Q_0 : event fraction w/o additional radiation above a threshold
  - → usefull indication of additional radiation kinematics
- Better modelling by Powheg+Py8 (A14) than by Powheg+Py6 (Perugia)
  - → Pythia8 A14 tune used gap fractions measured at 7 TeV



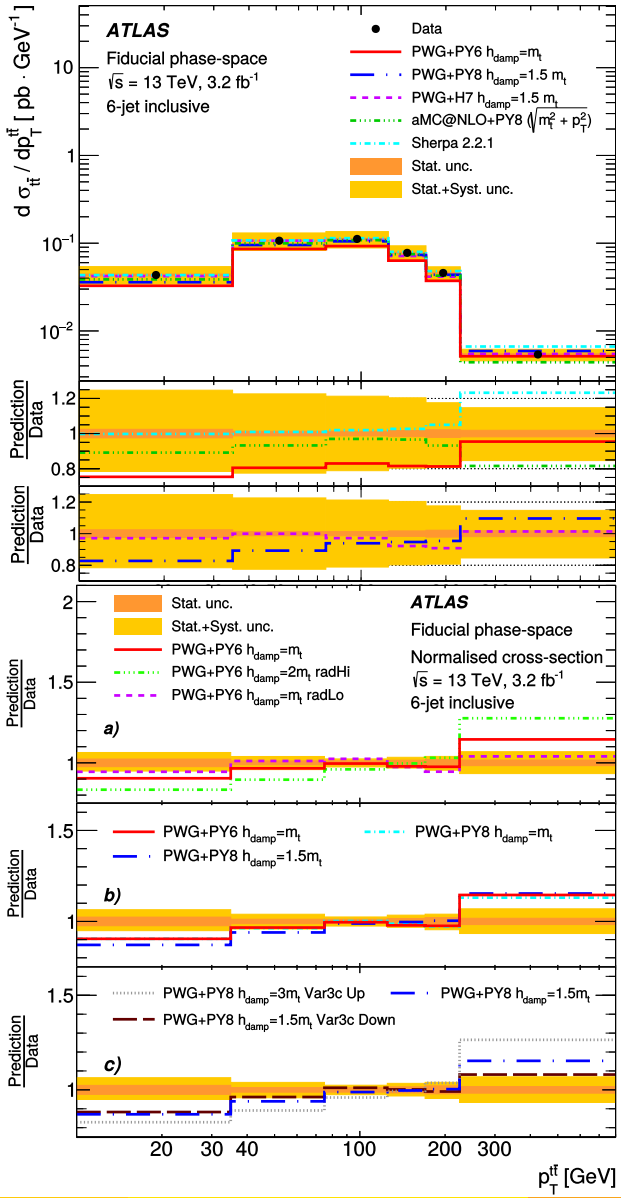
$t\bar{t}$ with additional jets

JHEP **10** (2018) 159

- Reconstruction of $t\bar{t}$ kinematics in ℓ+jets channel
  - → 1e or μ, $N_{jets} \geq 4$, $N_{b-jets} \geq 2$
  - → see presentation by M. Faucci Giannelli for details
- $t\bar{t}$ kinematics measured for different $N_{add.\ jets}$
  - → observables measured for $N_{add.\ jets}$ =0,1, or ≥2
- Some observables are senstitive to additional radiation
  - → e.g. $p_T(t\bar{t})$, here shown for ≥2 add. jets



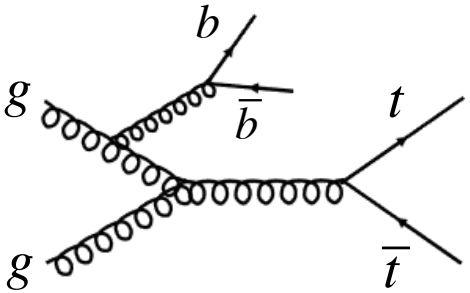
- Clear trend observed in normalised distribution
  - → too hard spectra in Powheg+Pythia6/8 MC

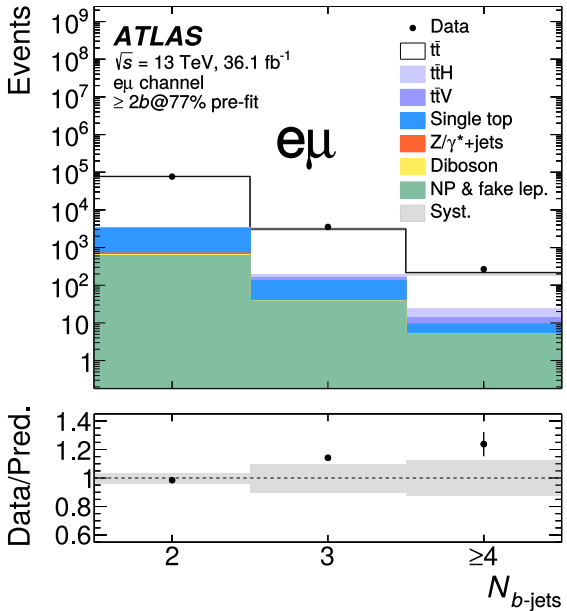


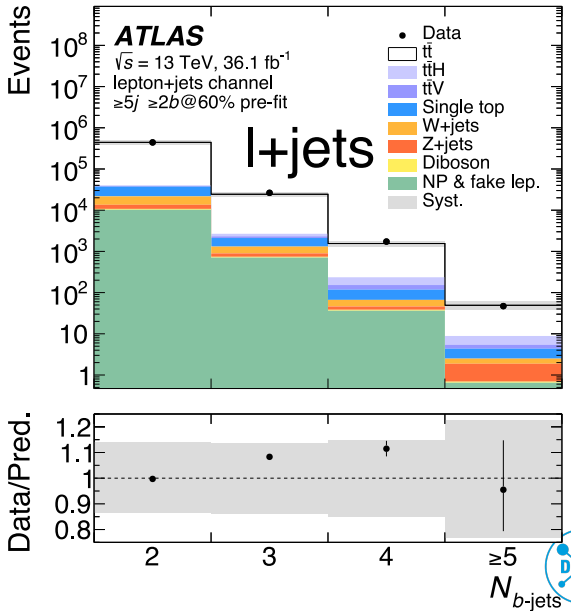
$t\bar{t}$ with additional b-jets

JHEP **04** (2019) 046

- Measurement of additional b-jets in $t\bar{t}$ events, both in ℓ+jets and $e\mu$ channels
  - → $e\mu$: purer but low statistics at high $\mathrm{N}_{b-\mathrm{jets}}$
- Cross-sections in fiducial volumes with ≥ 1 or ≥ 2 additional b-jets
  - → differential : in both volumes for ℓ+jets, in ≥ 1 add. b-jets only for $e\mu$
- Unfolded data compared to MC predictions
  - → subtraction of $t\bar{t}V$ and $t\bar{t}H$ from unfolded $t\bar{t}+b\bar{b}$ spectrum
  - → comparison MC predictions – either $t\bar{t}$ NLO+PS, or $t\bar{t}+b\bar{b}$ NLO
- Dominant systematics : signal modelling, b-tagging







$t\bar{t}$ with additional b-jets : fiducial cross-sections

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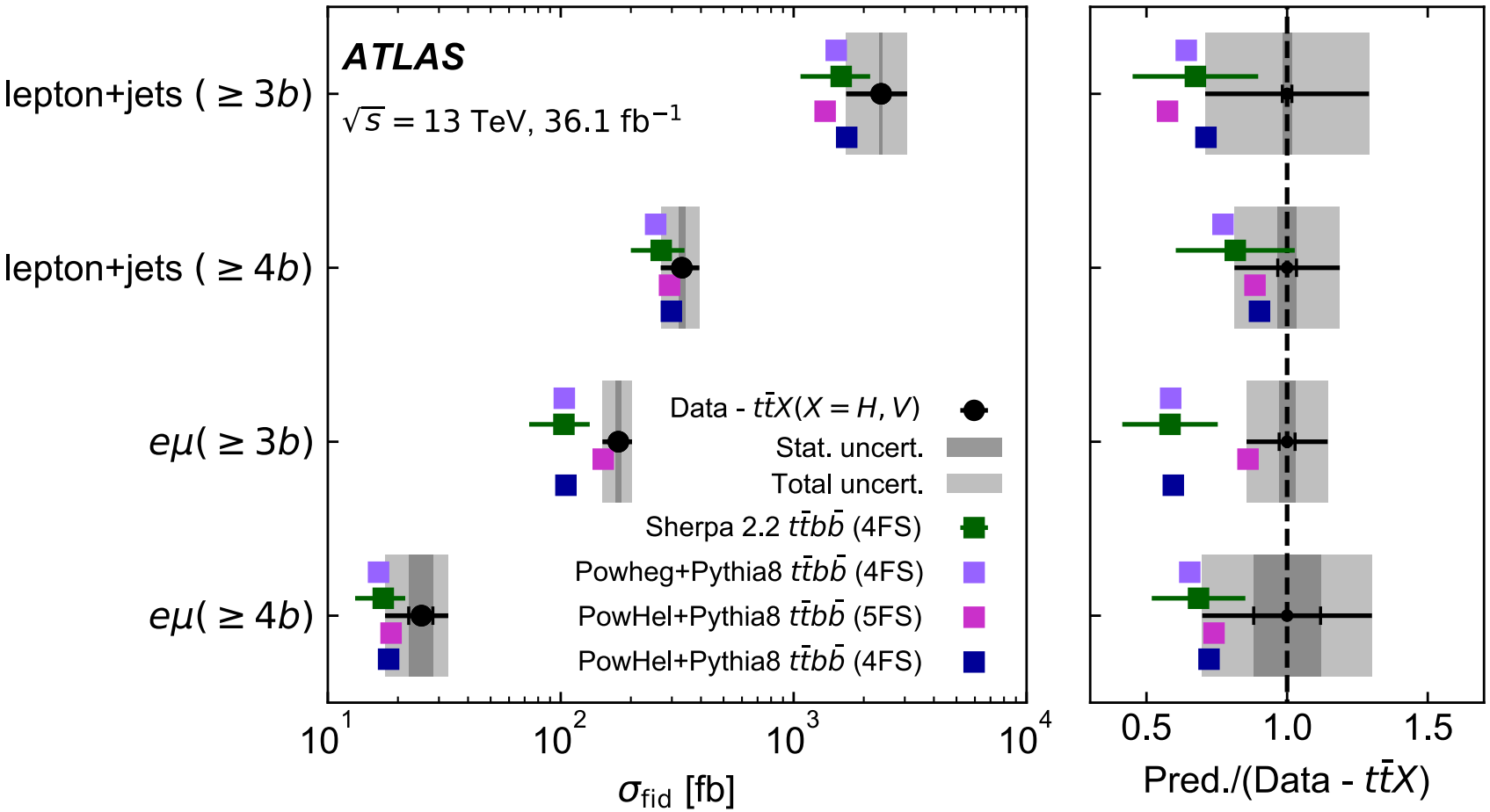
- Measured $t\bar{t}b$ and $t\bar{t}b\bar{b}$ cross-sections compared to $t\bar{t}b\bar{b}$ MC predictions
  - → Sherpa (4FS), Powheg+Py8 (4FS), PowHel+Py8 (4 or 5FS)
  - → PowHel+Py8 doesn't include spin correlations in top decays
- Deviations depend on the considered fiducial volume



$t\bar{t}$ with additional b-jets : b-jets kinematics

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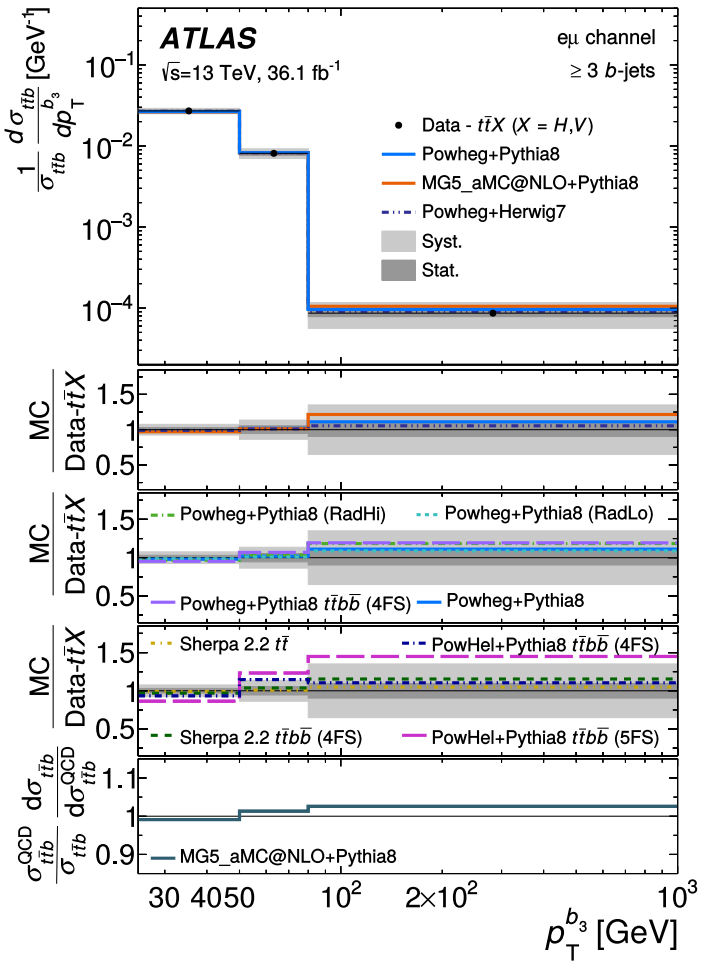
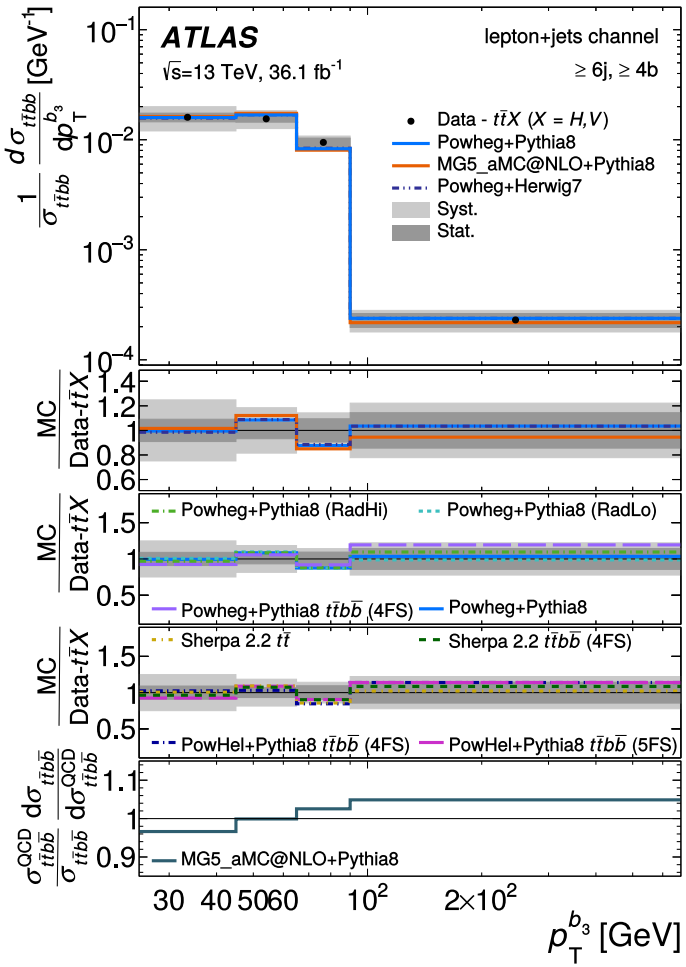
- Normalised differential cross-sections vs. 3rd b-jet p_T
  - → proxy to leading "additional" b-jet
- Most predictions are in agrement with unfolded data
  - → discrepancy for PowHel+Py8 (5FS)





$t\bar{t}$ with additional b-jets : $b\bar{b}$ angular separation

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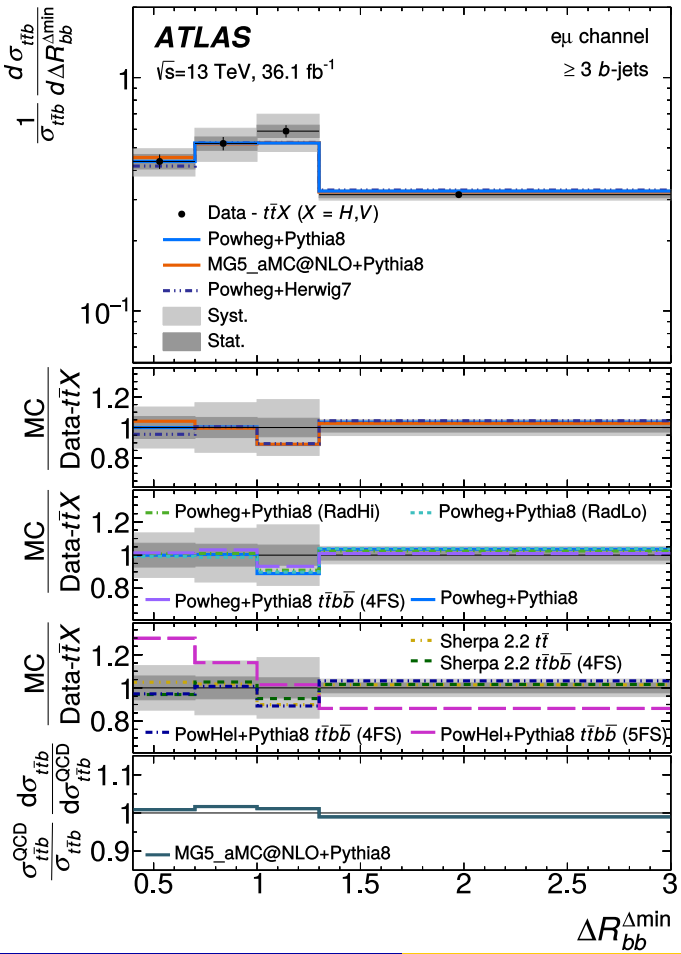
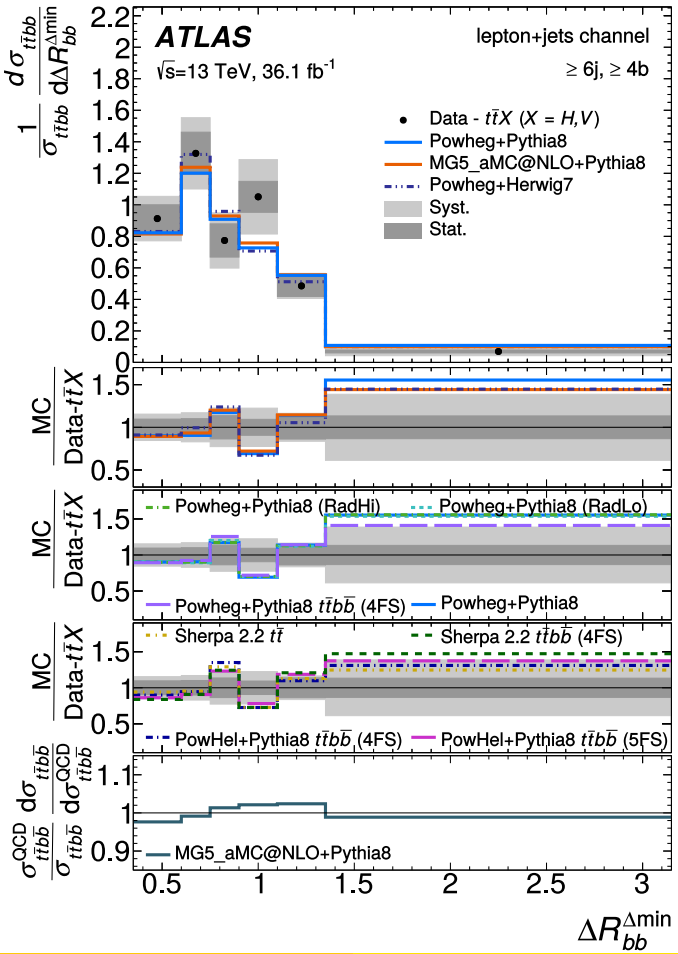
- Normalised differential cross-sections vs. $\Delta R_{bb}^{\Delta\text{min}}$
  - → proxy for ΔR between two additional b-jets - good modelling needed for $t\bar{t}H(\rightarrow b\bar{b})$!
- Most predictions are in agreement with unfolded data
  - → discrepancy for PowHel+Py8 (5FS)





$t\bar{t}$ with additional b-jets : $b\bar{b}$ kinematics

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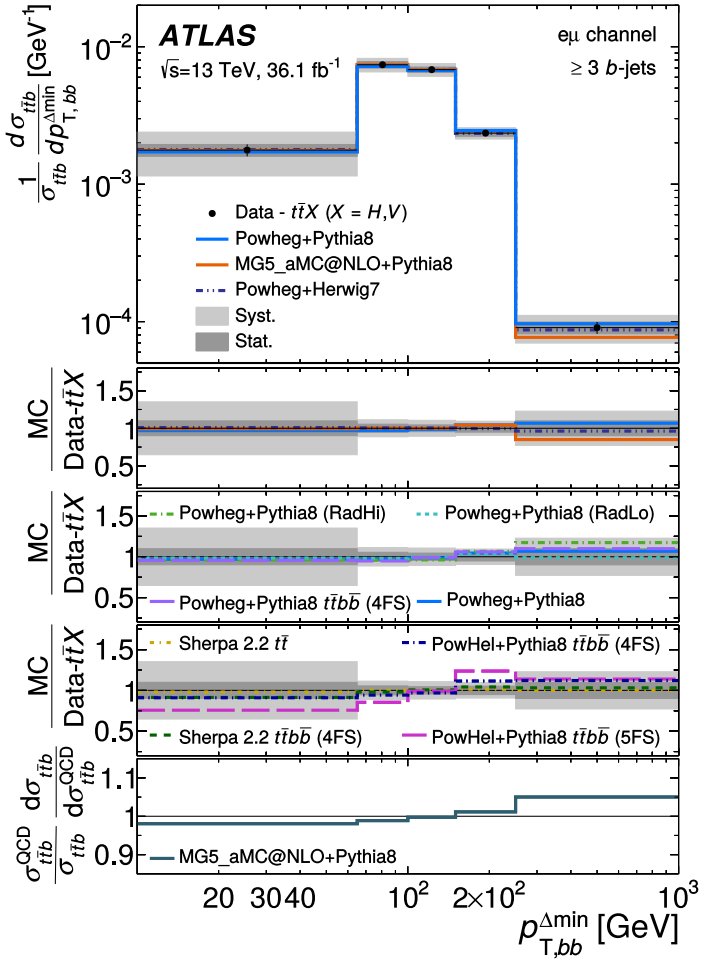
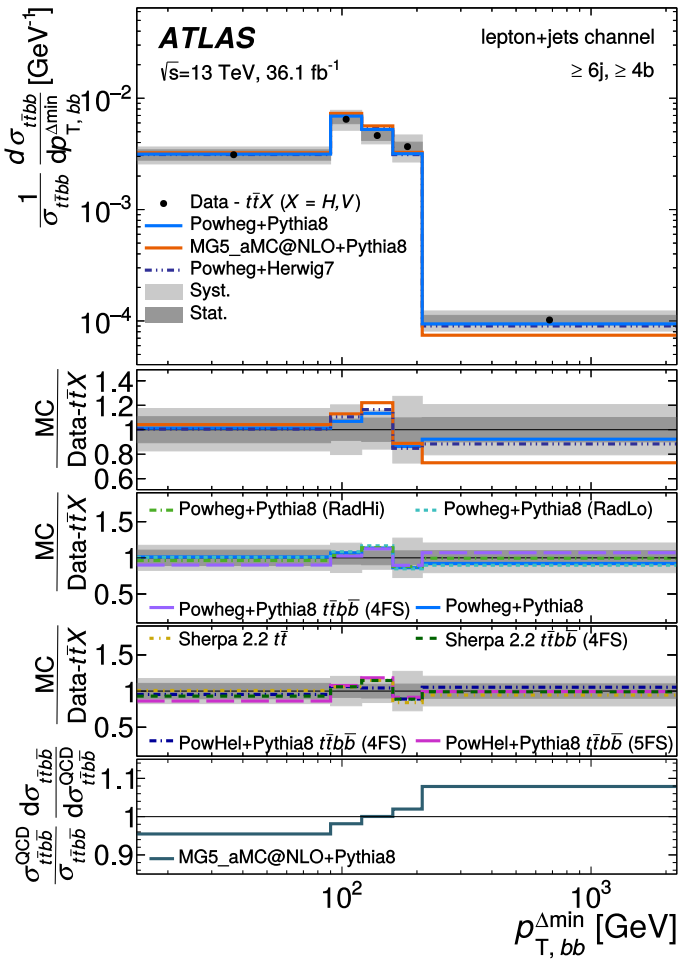
- Normalised differential cross-sections vs. p_T of two closest b-jets
  - → with $\geq 1(2)$ additional b-jets in ℓ+jets ($e\mu$) channel
- Most predictions are in agrement with unfolded data
  - → discrepancy for PowHel+Py8 $t\bar{t}+b\bar{b}$ (5FS), aMC@NLO+Py8 $t\bar{t}$





Conclusion

- Several $t\bar{t}$+jets observables measured by ATLAS at 13 TeV
- Currently : results with up to 36.1 fb^{-1}– more than 100 fb^{-1}to come
- Measurements of additional jets and *b*-jets at particle level
- Signal modelling uncertainties large with current MC
- Iterative improvement between measurements and MC optimisation
- All these unfolded distributions – and more ! – made available as Rivet routines