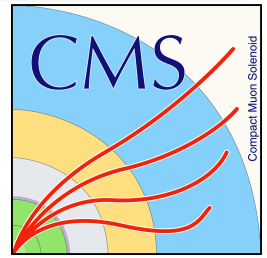
Differential $t\bar{t}$ cross section measurements as a function of variables other than kinematics

O. Hindrichs
On behalf of the ATLAS and CMS collaborations



University of Rochester

TOP2016, OLOMOUC

20.09.2016

The high number of top quark pairs produced at the LHC allows for precise studies of $t\bar{t}$ events:

- $t\bar{t}$ produced with high numbers of additional jets. High sensitivity to SM QCD, but ...
- challenging to predict in perturbative calculations.
- parton shower simulation needs tuning
- good knowledge of underlying event essential for precision measurements of top quark properties m_{t} ...

Measurements of additional jets:

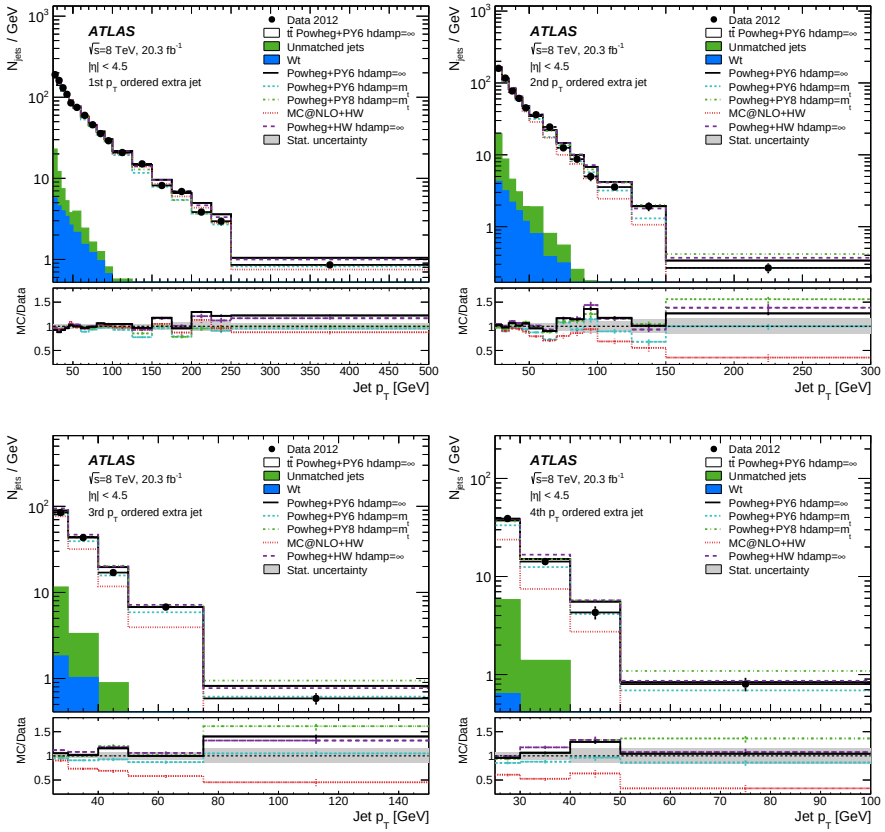
- usually measured at particle level in experimental phase space $\rightarrow$ corrected for detector effects only.
- a full reconstruction of the $t\bar{t}$ system is not necessarily needed.

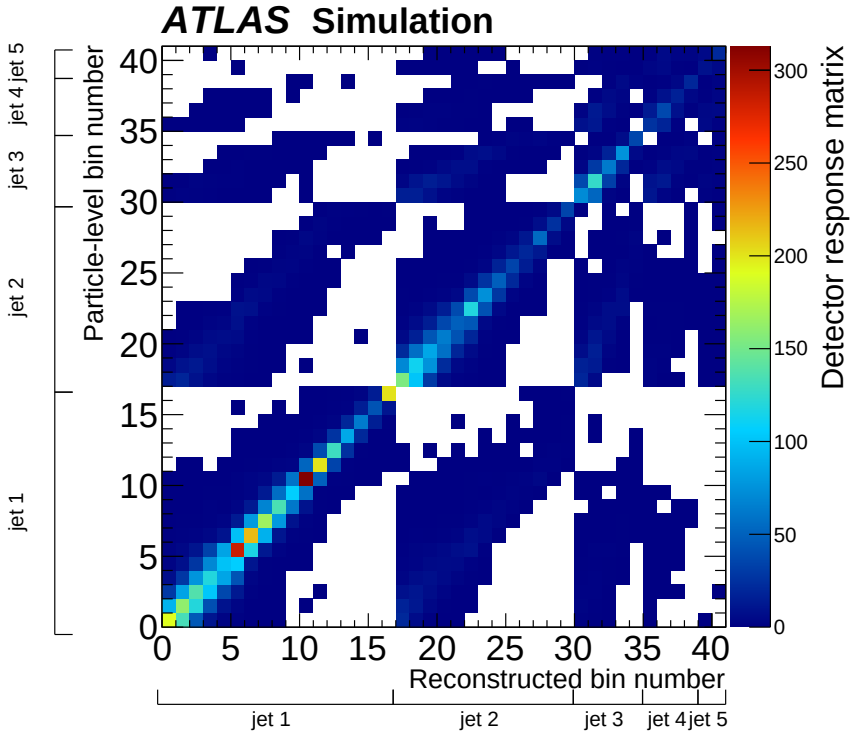
$\rightarrow$ Reduction theoretical uncertainties in the measurements.

ATLAS: JHEP 09 (2016) 074, 20.3 fb^{-1}, 8 TeV

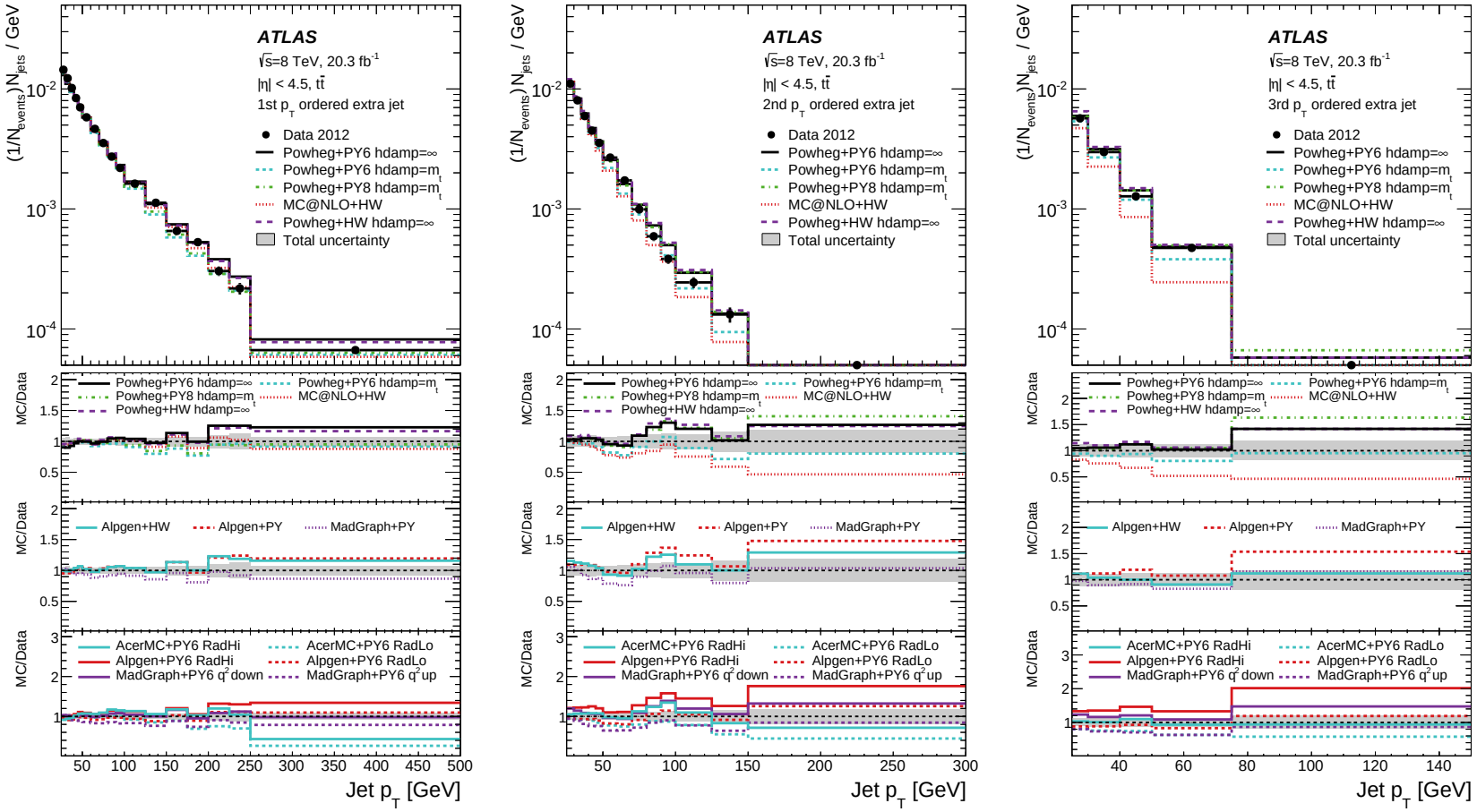
Event selection:

- one electron, one muon, and two b-tagged jets. All with: $p_{\mathrm{T}} > 25$ GeV, $|\eta| < 2.5$.
- additional jets with $p_{\mathrm{T}} > 25$ GeV, $|\eta| < 4.5$ considered.
- two b jets with highest b-tagging value assigned to the $t\bar{t}$ system.
- simultaneous unfolding in jet rank (p_{T} ordering) and p_{T}.



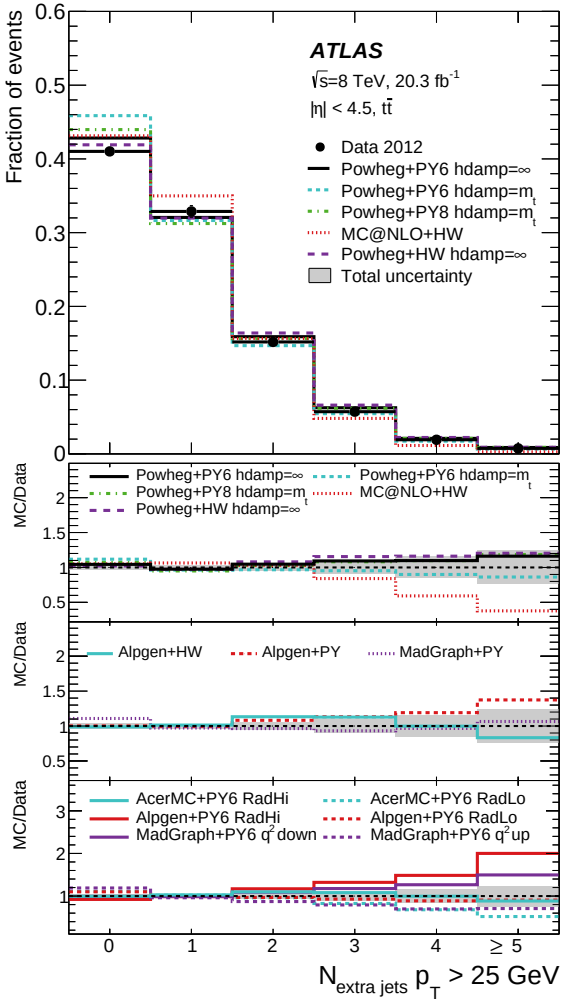


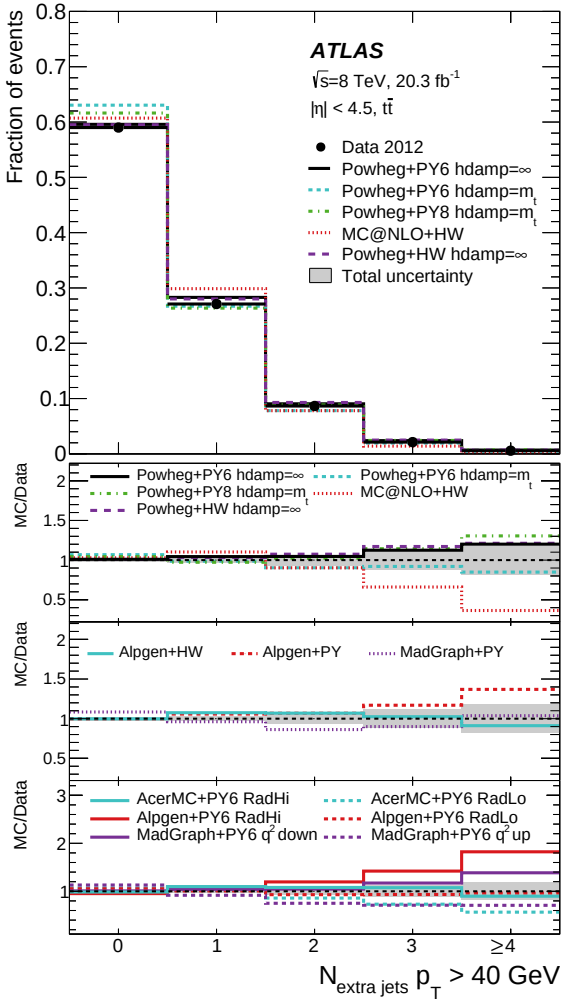
Jet multiplicities

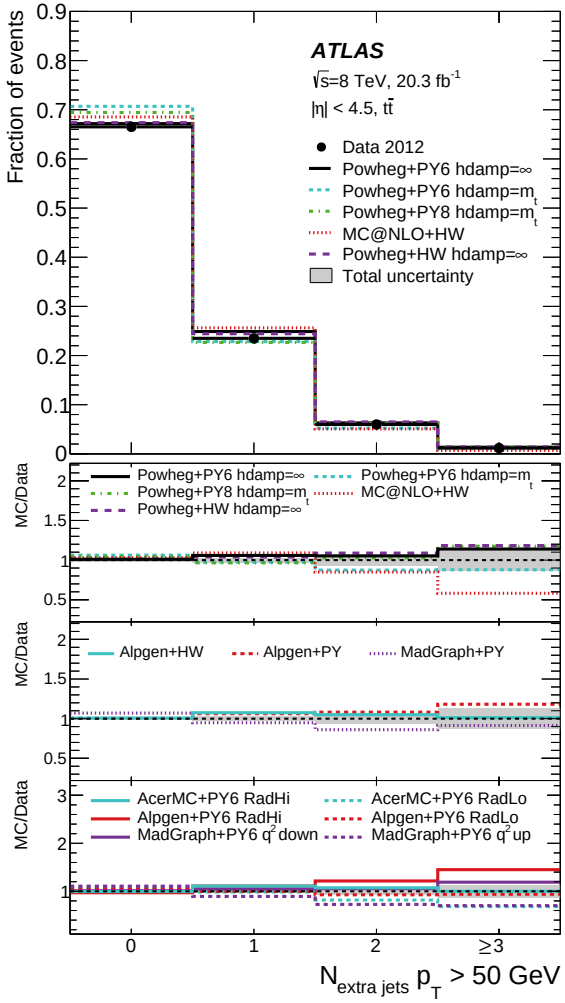


- Powheg and MC@NLO: NLO precision, number of jets > 1 from parton shower.
  $\rightarrow$description becomes worse with jet rank.
- Alpgen: LO precision with up to 3 (with HW) and 4 (with PY6) additional partons.
  $\rightarrow$description better for high rank.

p_{T} of additional jets





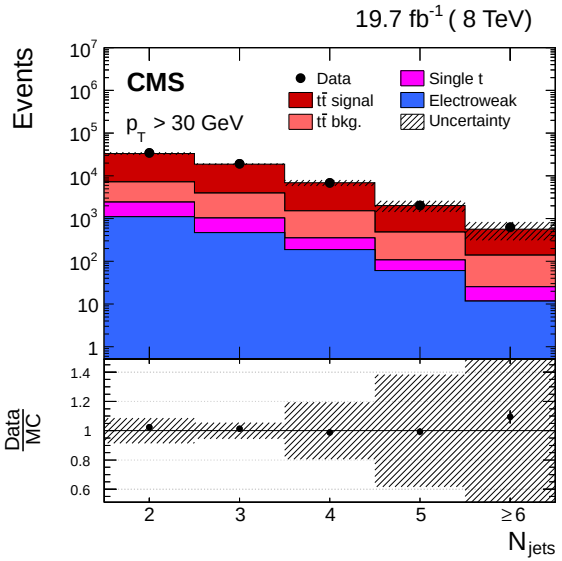


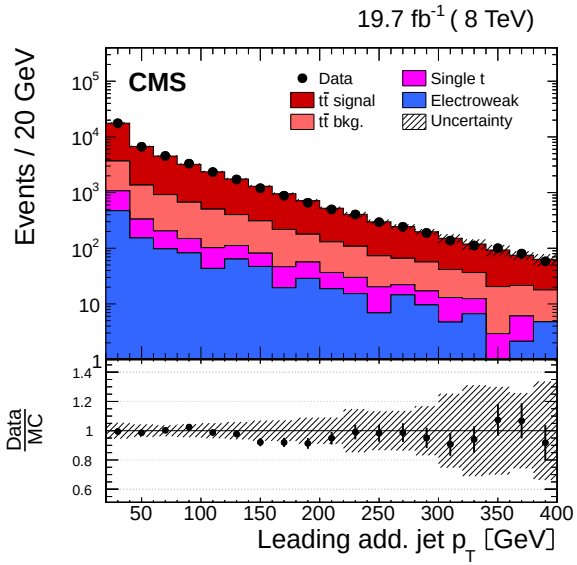
- radHi: $h_{damp} = 2m_{\mathrm{t}}$, scales ($\mu_{\mathrm{r}}$, μ_{f}) half nominal value and high radiation Perugia tune.
- radLo: $h_{damp} = m_{\mathrm{t}}$, scales twice nominal value and low radiation Perugia tune. Effect clearly visible.

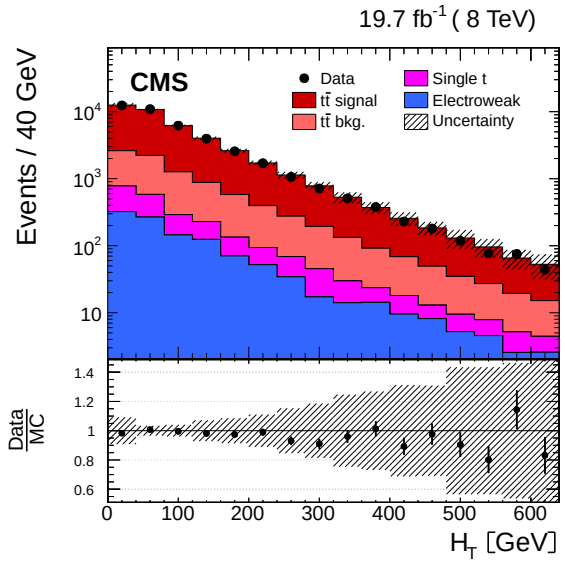
CMS: Eur. Phys. J. C 76 (2016) 379, 19.7 fb^{-1}, 8 TeV

Event selection:

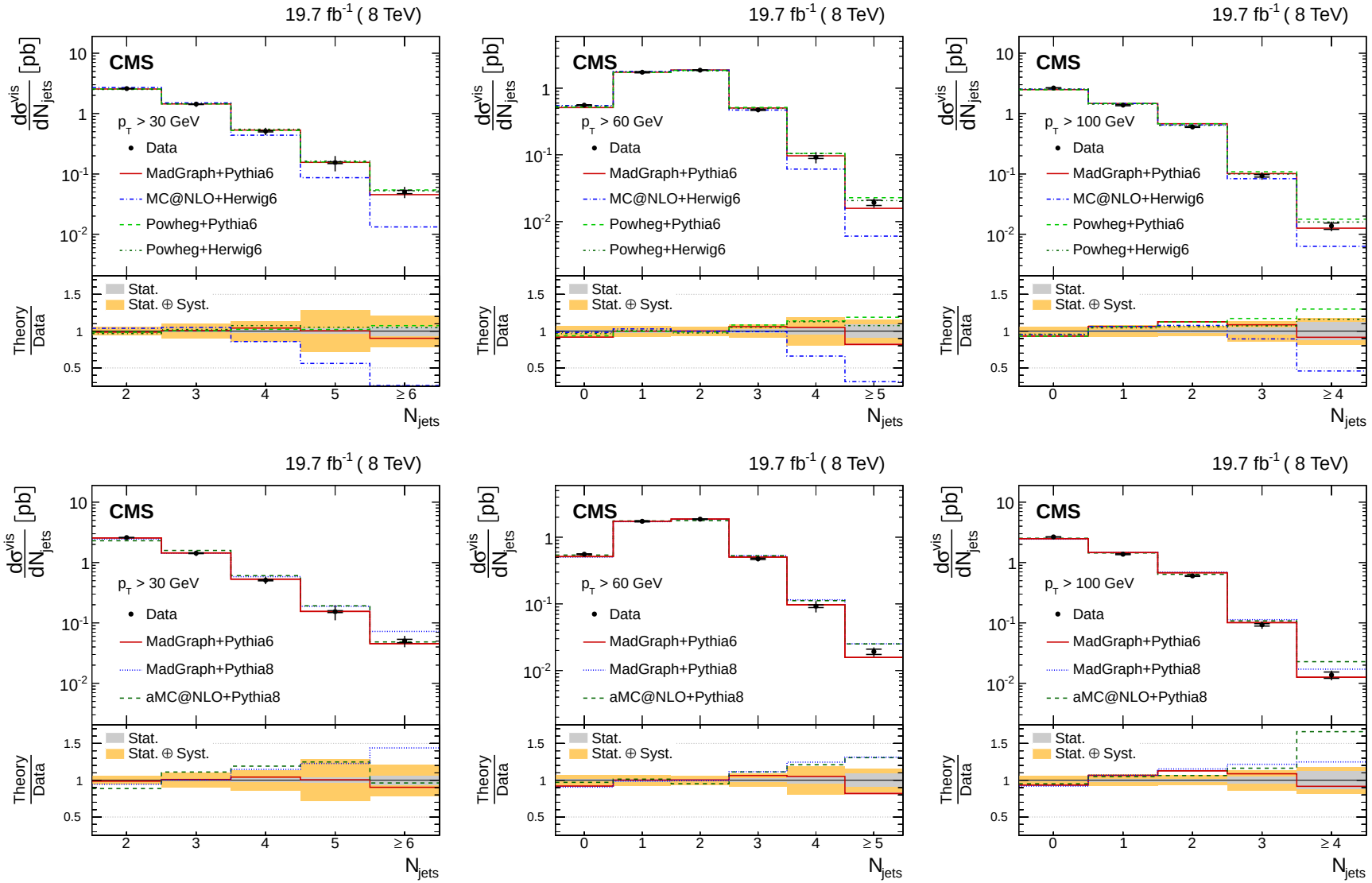
- pair of oppositely charged leptons (e,μ) $p_{\mathrm{T}} > 20$ GeV
- exclude Z peak $|M_{ll} - M_{\mathrm{Z}}| < 15$ GeV in same flavor channels.
- two jets $p_{\mathrm{T}} > 20$ GeV, $|\eta| < 2.4$, at least one b-tagged.
- use kinematic reconstruction to identify b-jets ($p_{\mathrm{T}} > 30$ GeV) from $t\bar{t}$ decay .





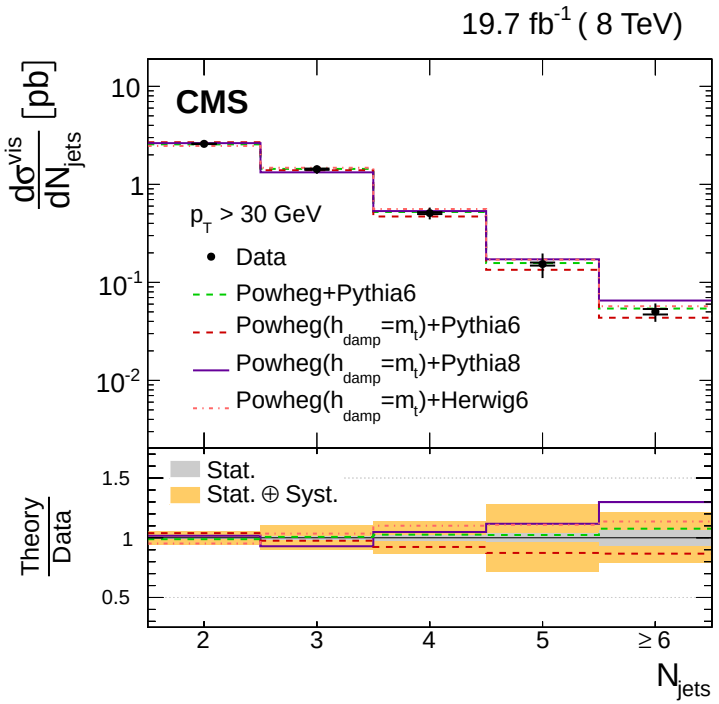


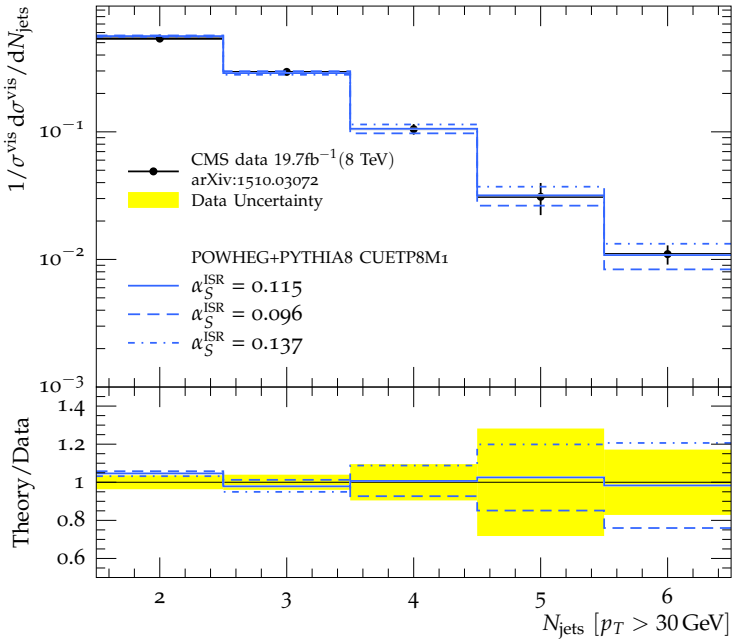
Cross sections at particle level in fiducial phase space.

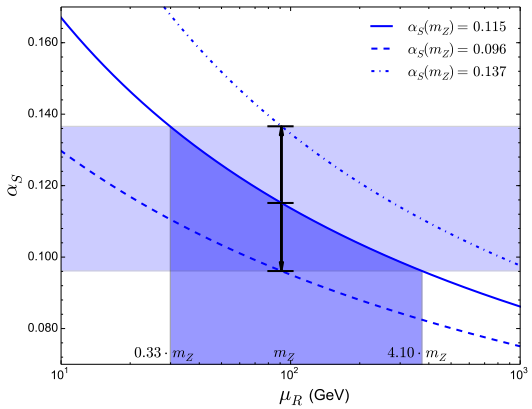


- compared to Madgraph (LO up to 3 add. parton) and aMC@NLO (NLO up to 2 add. partons).
- Pythia8 (CUETP8M1 tune) predicts higher jet multiplicity.

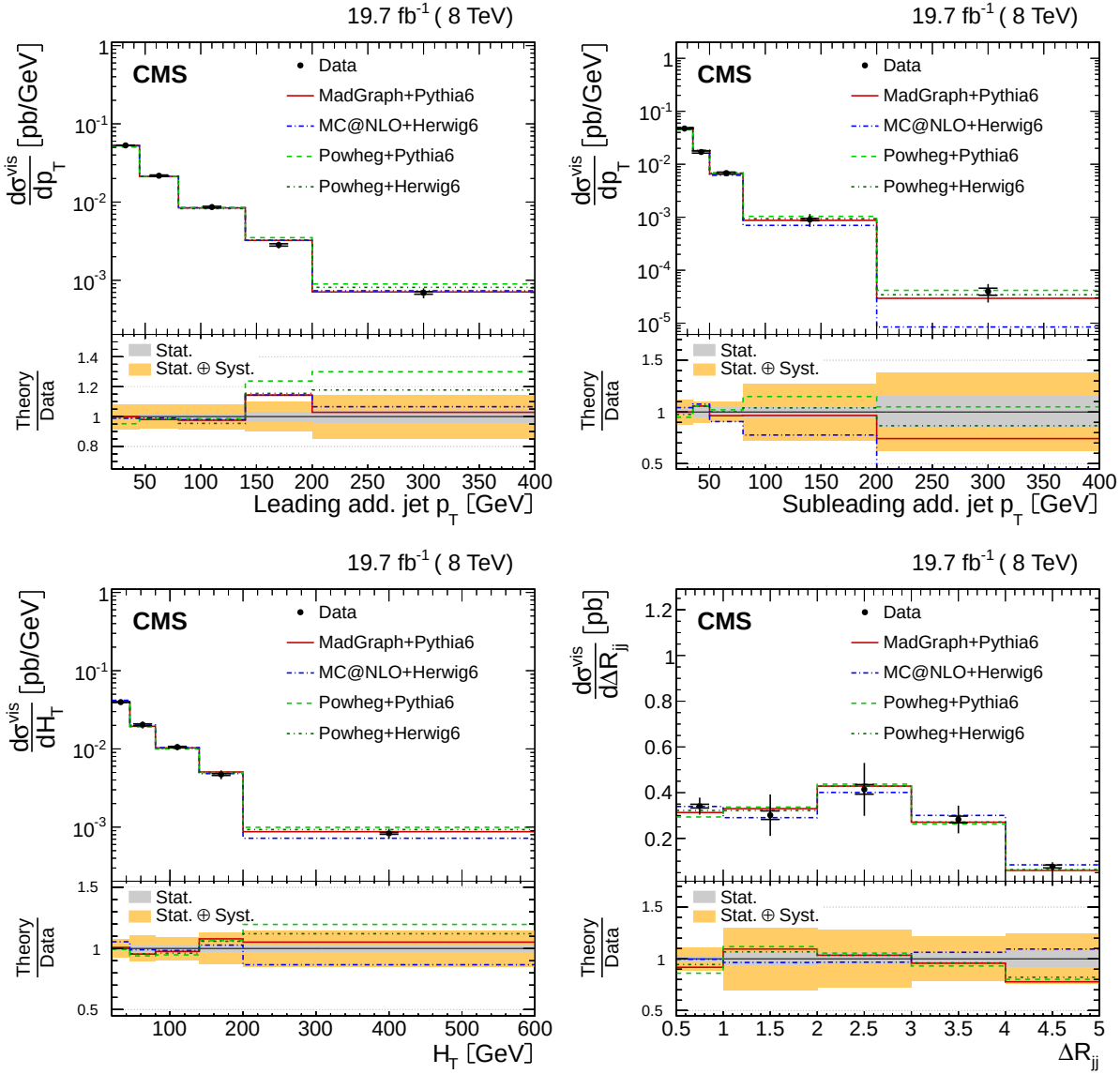
Sensitivity to $\alpha_{\mathrm{s}}^{\mathrm{ISR}}$ and scales







- use distribution of number of jets ≥ 3 to refit $\alpha_{\mathrm{s}}^{\mathrm{ISR}}$.
- default value $\alpha_{\mathrm{s}}^{\mathrm{ISR}} = 0.1365$ (CUETP8M1 tune).

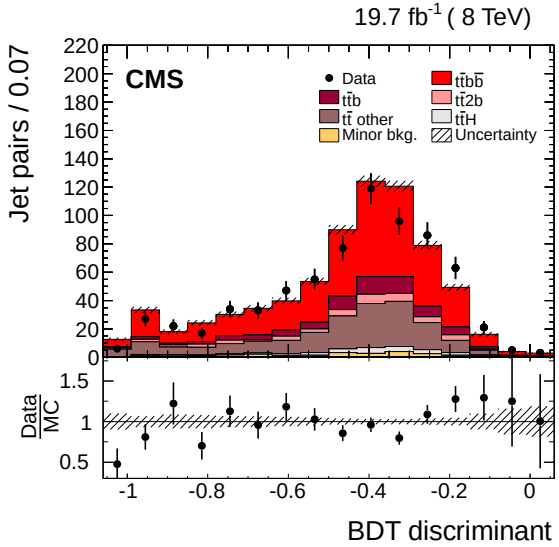


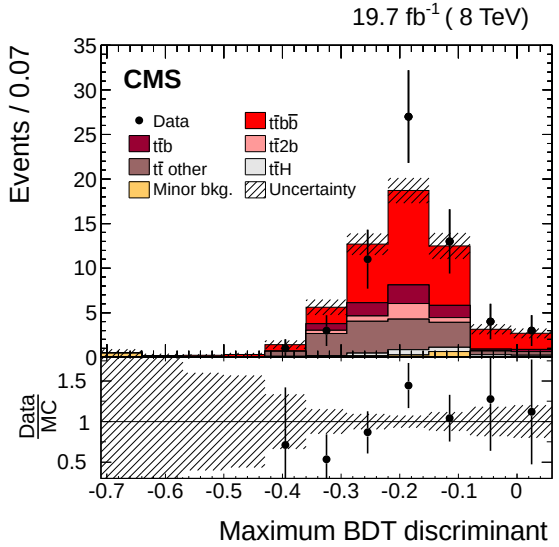
- H_T scalar sum of additional jets p_{T}, ΔR between two leading additional jets
- well described, but Powheg favors harder p_{T} spectrum of leading jet.

Measurements of additional b-jets in $t\bar{t}bb$ events

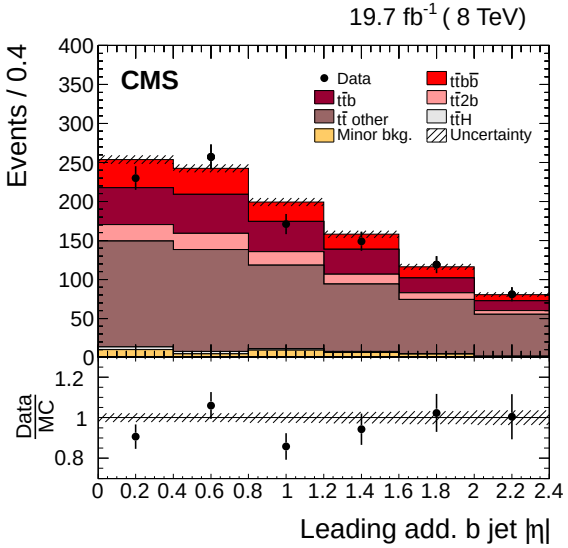
Use BDT to identify the pair additional $b\bar{b}$.

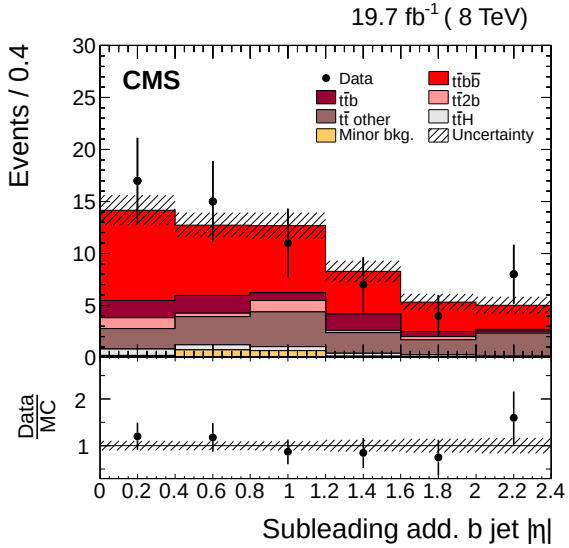
Variables: m_{bl}, $\Delta\Phi(bl, bl)$, $m_{llbb} - mbb$ ... $\rightarrow$40% correct.

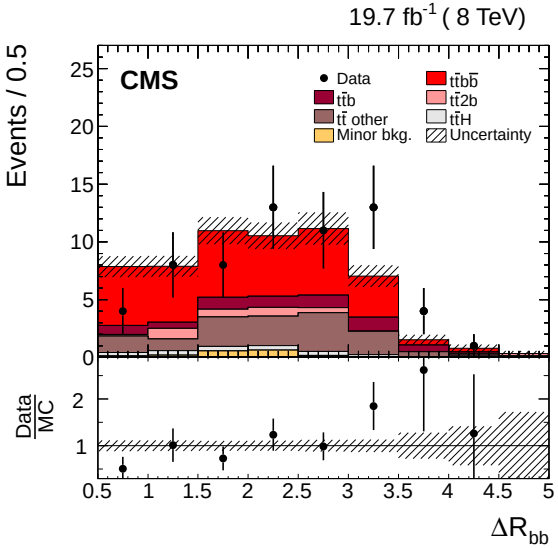




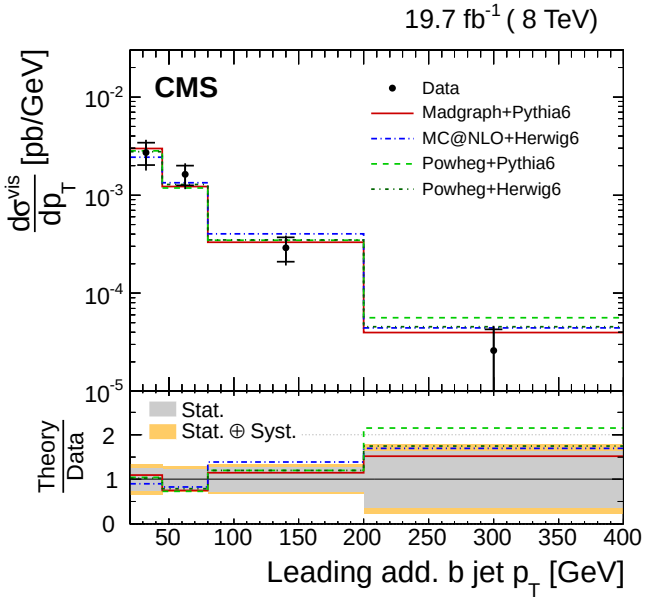
Control distributions:

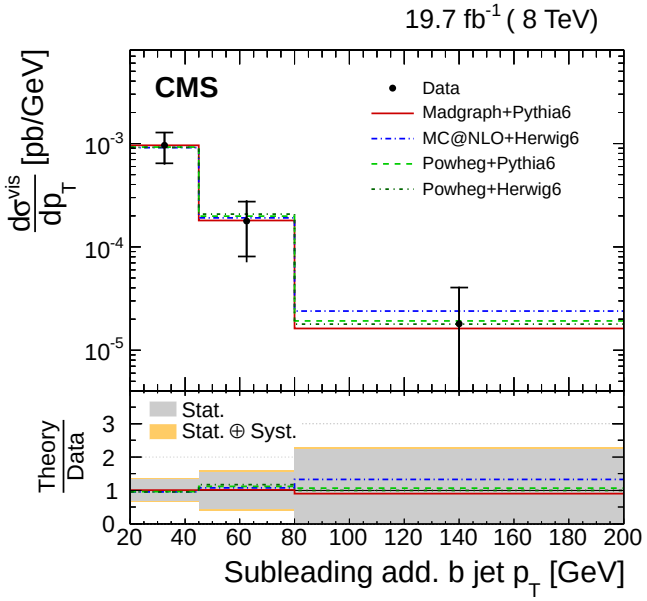


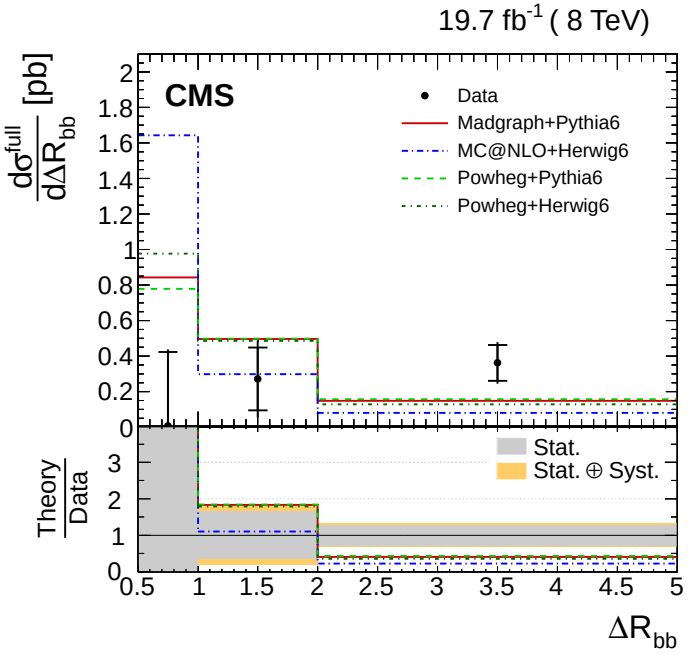




Measurements of additional b-jets in $t\bar{t}bb$ events







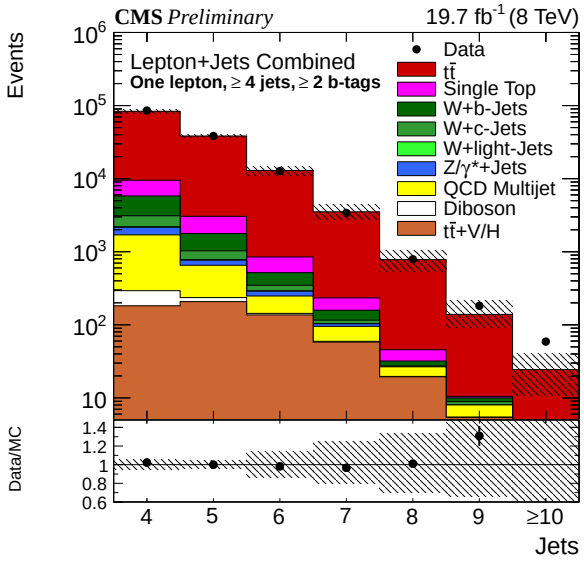
- statistically limited measurement.
- Powheg and Madgraph plus Pythia6 underestimate $t\bar{t}bb$ by 80% (simulations rescaled).
- POWHEL+PYTHIA6 (NLO) calculation underestimate $t\bar{t}bb$ by 30%.
- compatible with dedicated measurement PLB 746 (2015) 132 of $\sigma_{t\bar{t}bb}/\sigma_{t\bar{t}jj}$ and TOP-13-016 in l+jets channel.

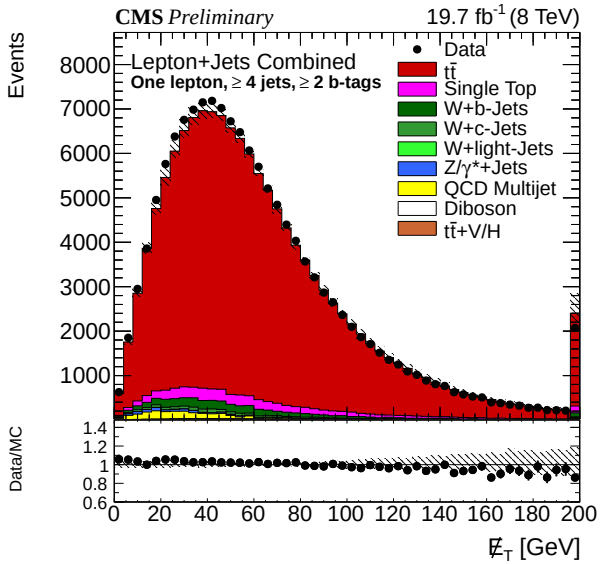
Jet multiplicity in $t\bar{t}$ events, l+jets channels

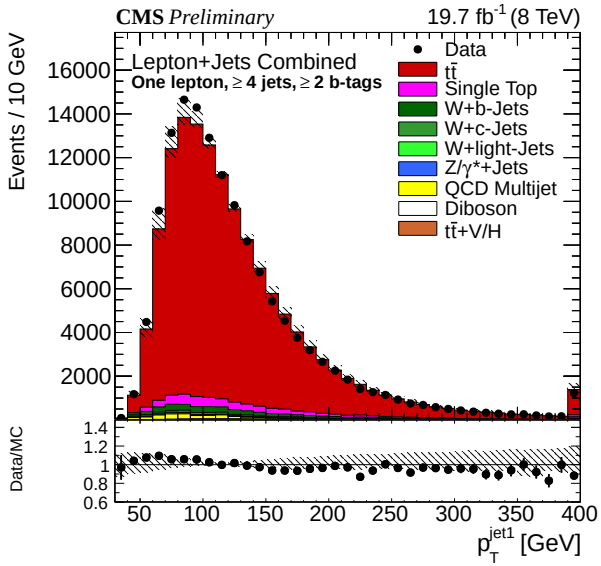
CMS: TOP-15-006, 19.7 fb^{-1}, 8 TeV

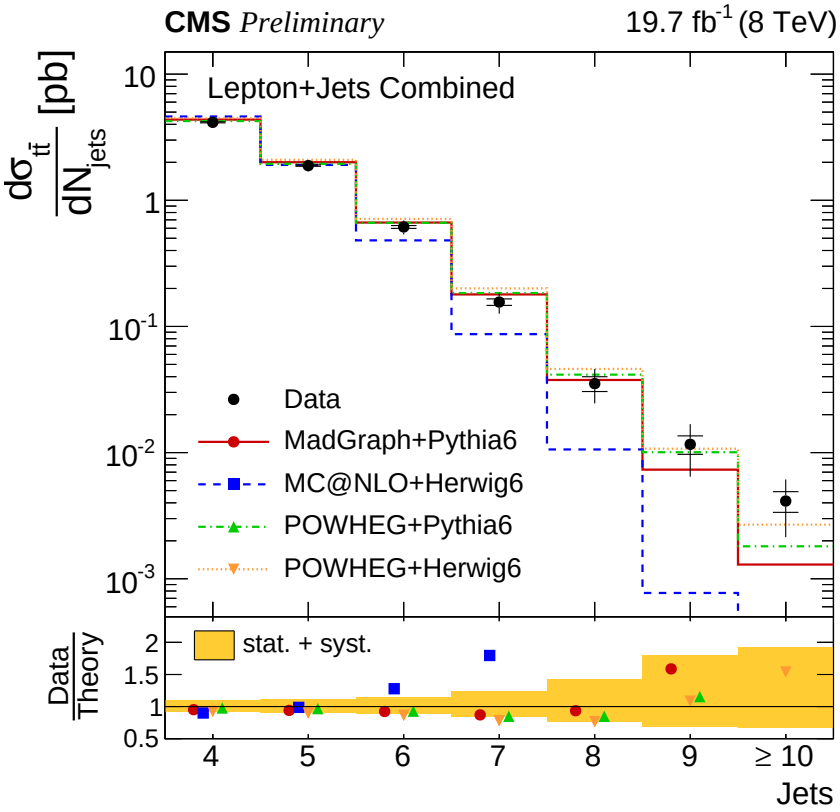
Event selection:

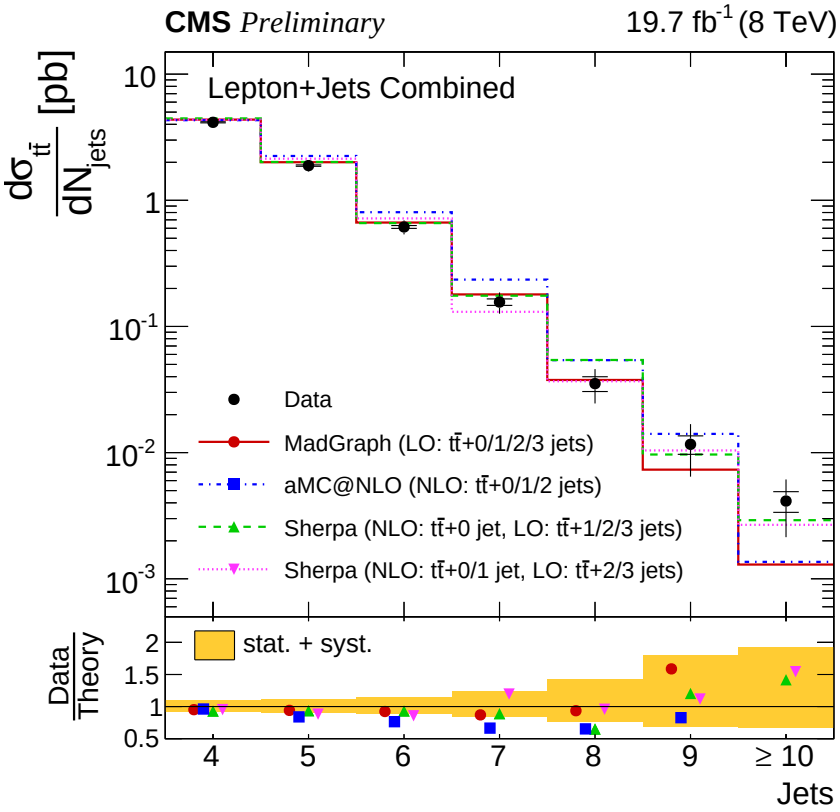
- single electron or muon $p_T > 30$ GeV.
- four jets $p_{\text{T}} > 30$ GeV, $|\eta| < 2.5$, two of them b-tagged.
- no reconstruction of $t\bar{t}$ system applied.









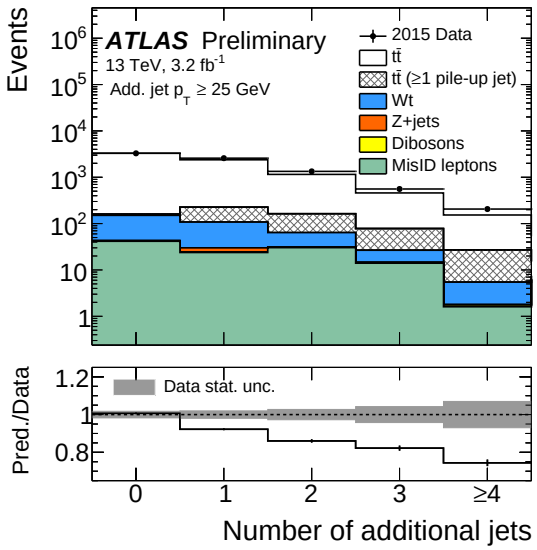


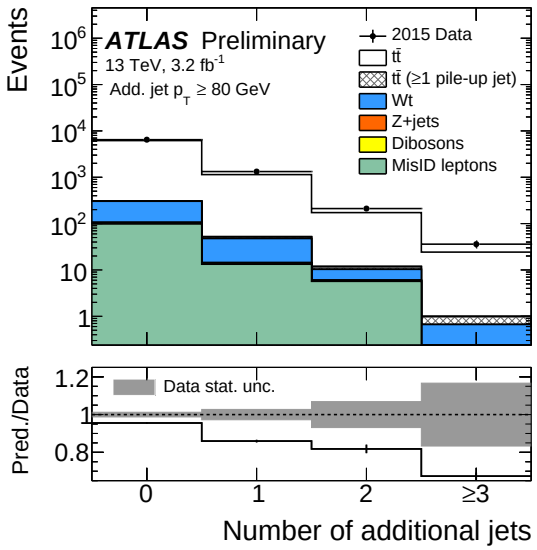
- Powheg+Herwig6/Pythia6 performs well even at high jet multiplicities.
- MC@NLO shows differences.
- all multi-jet samples agree quiet well and describe the data.

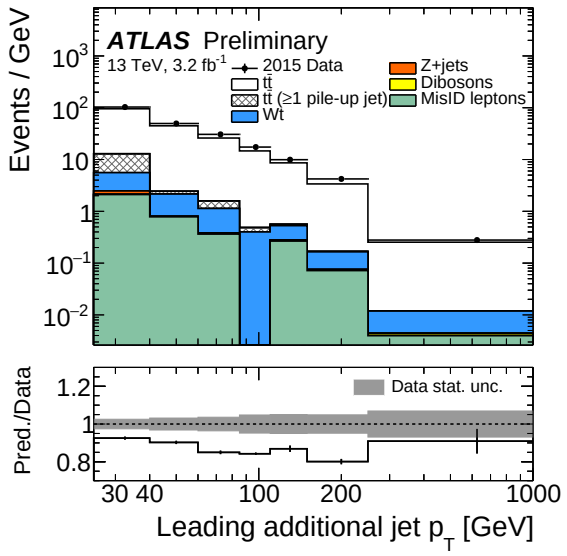
ATLAS: TOPQ-2015-17 to be submitted, 3.2 fb^{-1}, 13 TeV New!

Event selection:

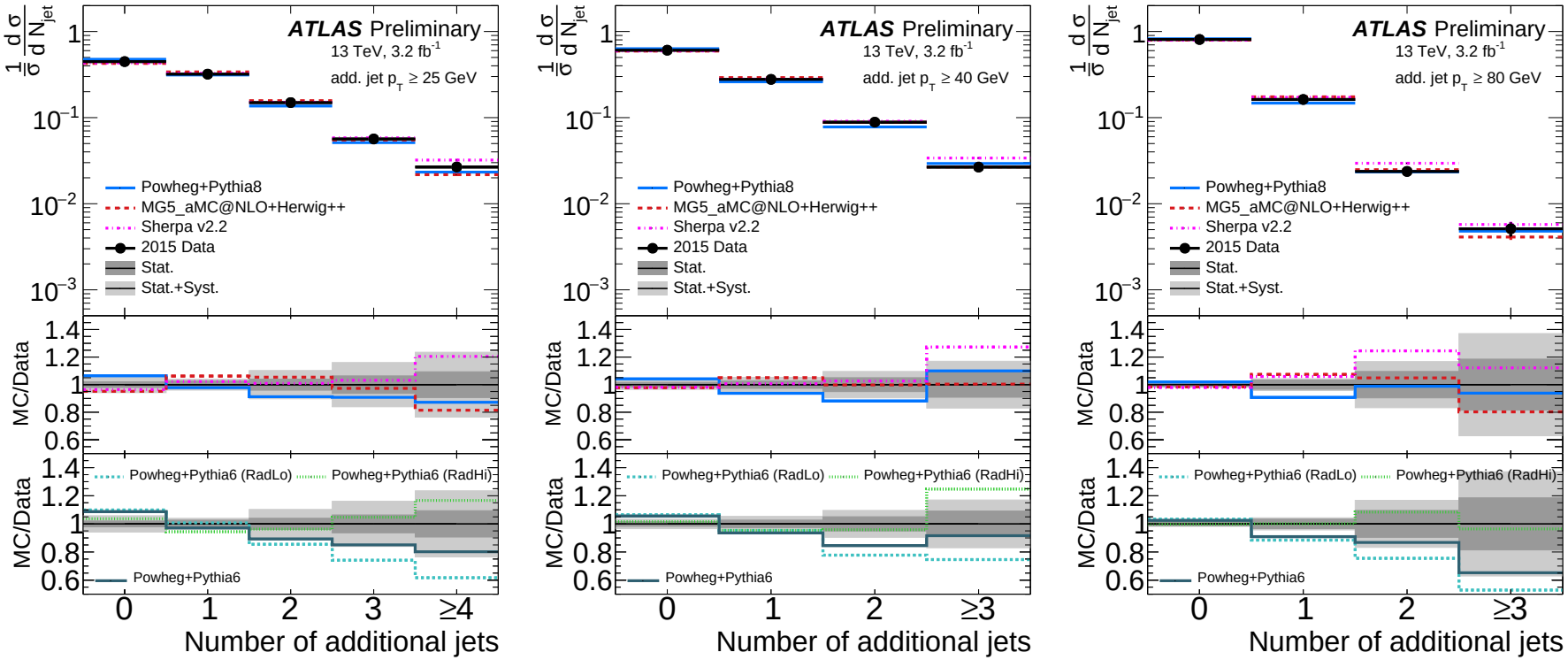
- pair of oppositely charged e and μ.
- two b-tagged jets. $p_{\mathrm{T}} > 25$ GeV, $|\eta| < 2.5$.
- two leading b-jets assigned to $t\bar{t}$ decay. All other jets are considered as additional.





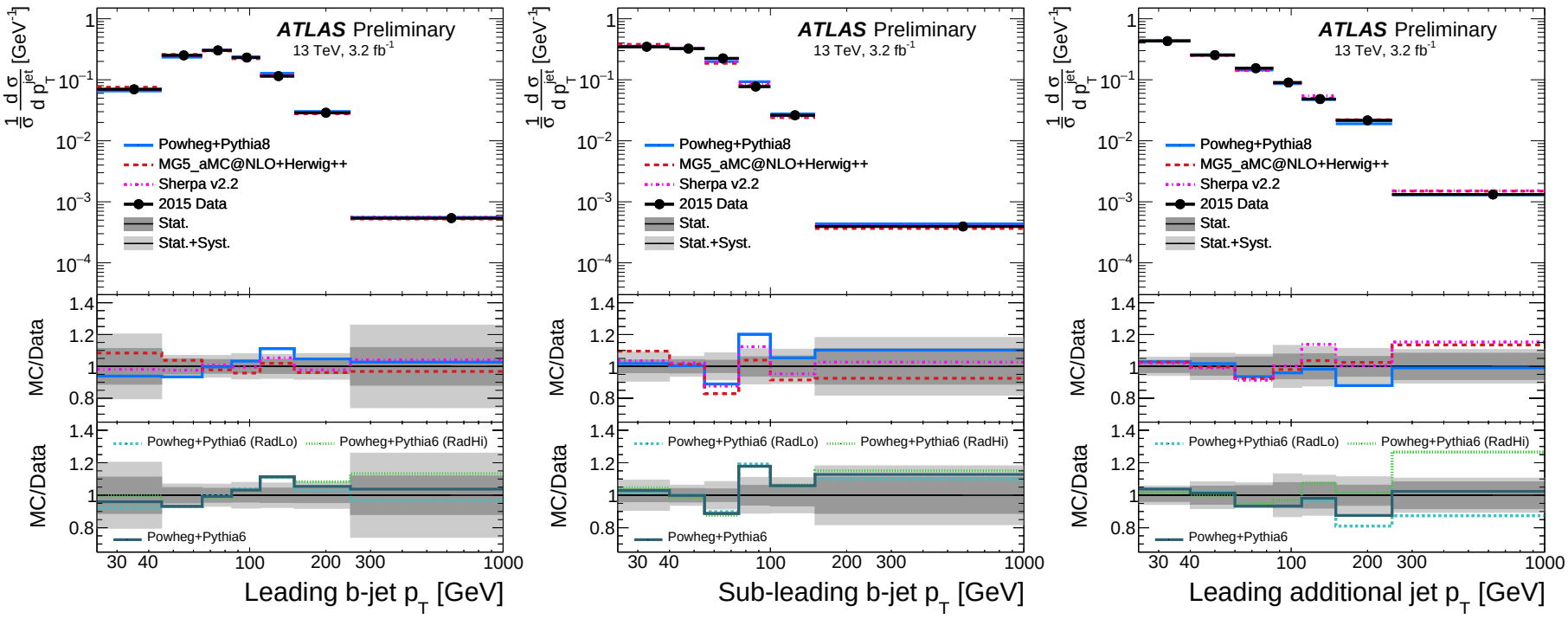


Jet multiplicities unfolded to particle level and normalized to inclusive $t\bar{t}$ cross section:



- Powheg+Pythia8 underestimates jet multiplicity with ATLAS tune.
- again, large effect of parton shower tuning visible (radHi, radLo samples).

Jets p_{T} unfolded to particle level and normalized to inclusive $t\bar{t}$ cross section:

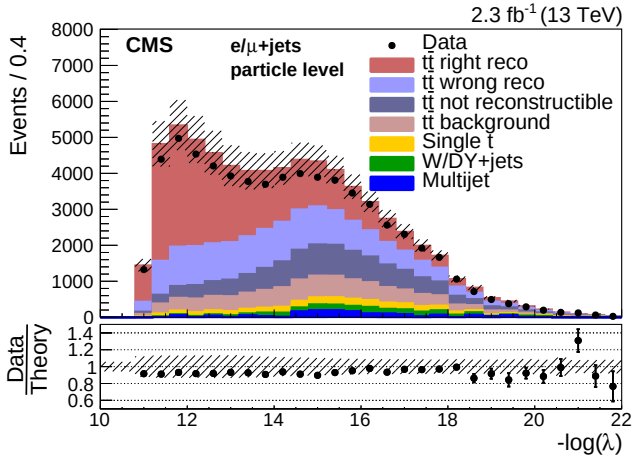


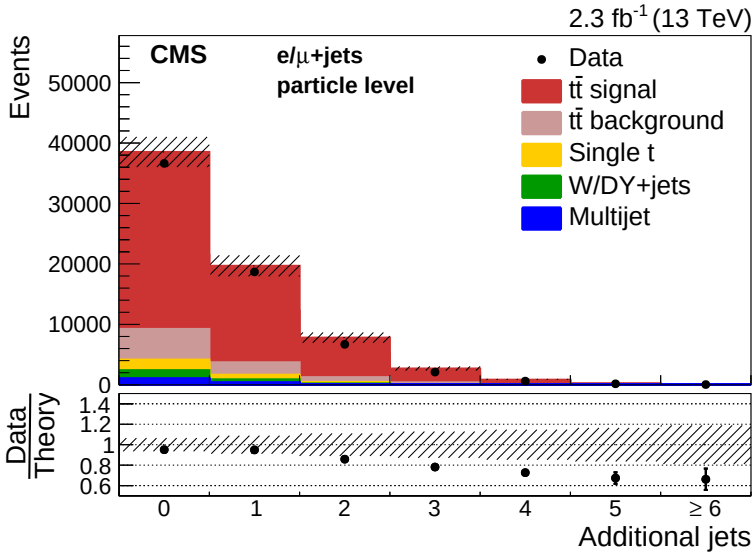
- leading and sub-leading b jet directly related to $t\bar{t}$ system.
- measurements are well described by various simulations and less affected by parton shower tuning (radHi, radLo samples).

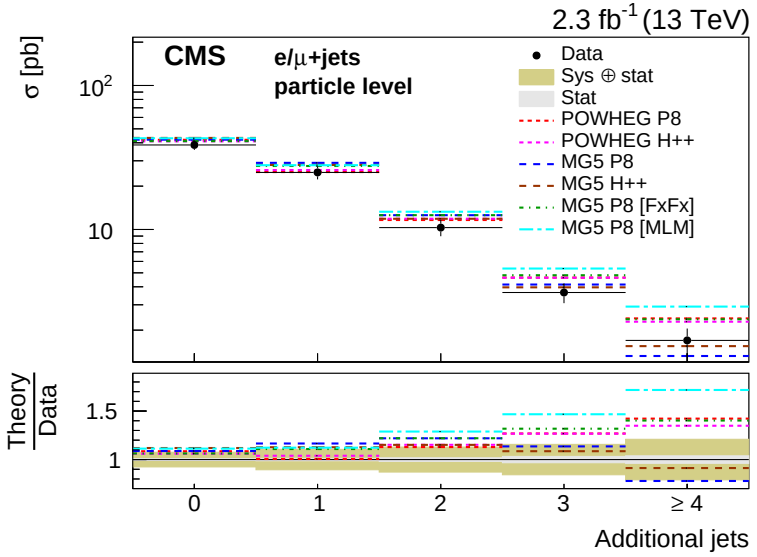
CMS: TOP-16-008 to be submitted, 2.3 fb^{-1}, 13 TeV New!

Event selection:

- exactly one electron or muon $p_T > 30$ GeV.
- four jets $p_{\mathrm{T}} > 30$ GeV, $|\eta| < 2.4$, two of them b-tagged.
- $t\bar{t}$ reconstruction based on m_{t} and m_{W} likelihood.



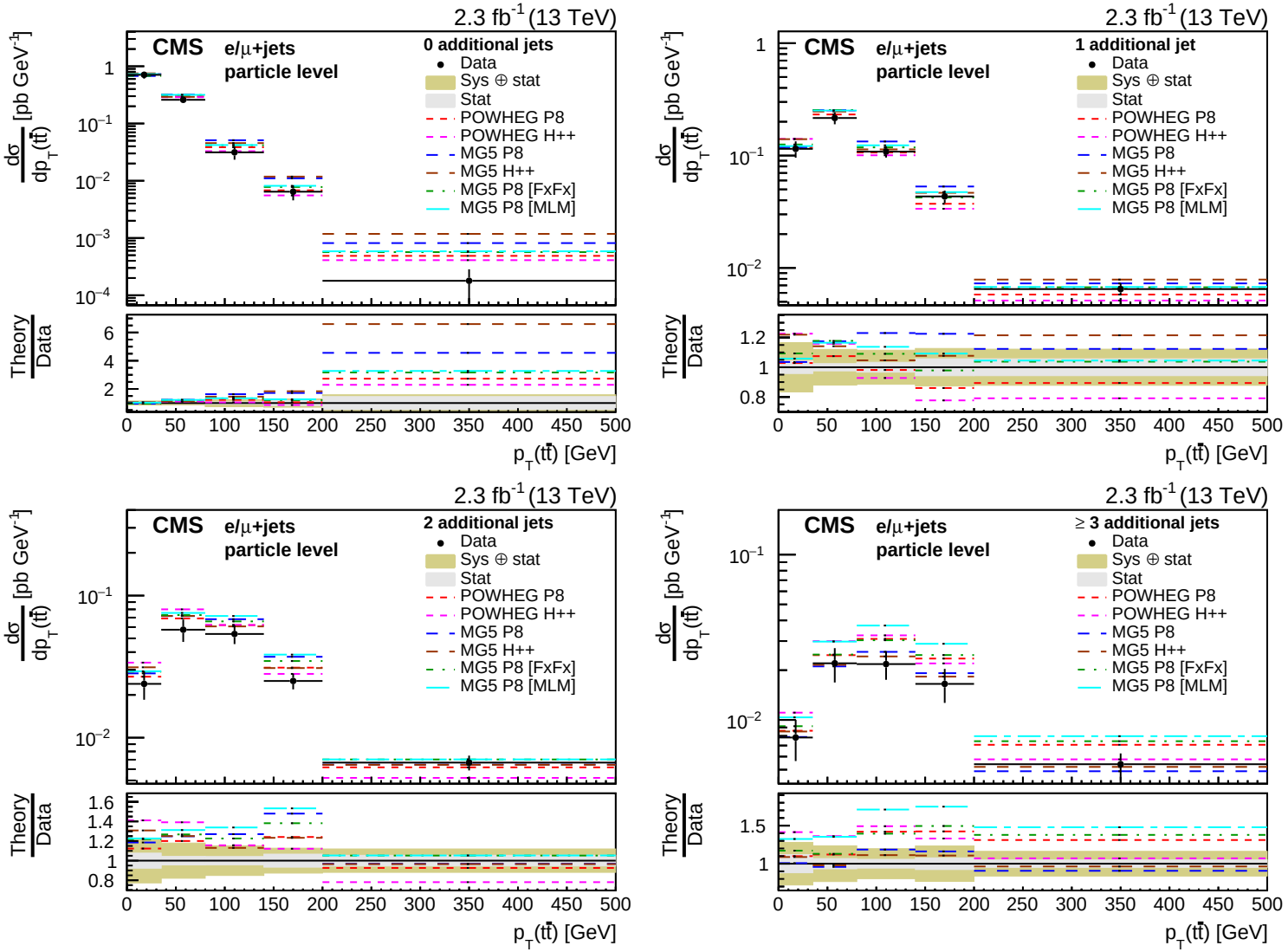




- Pythia8 samples overestimate jet multiplicity (already observed at 8 TeV).

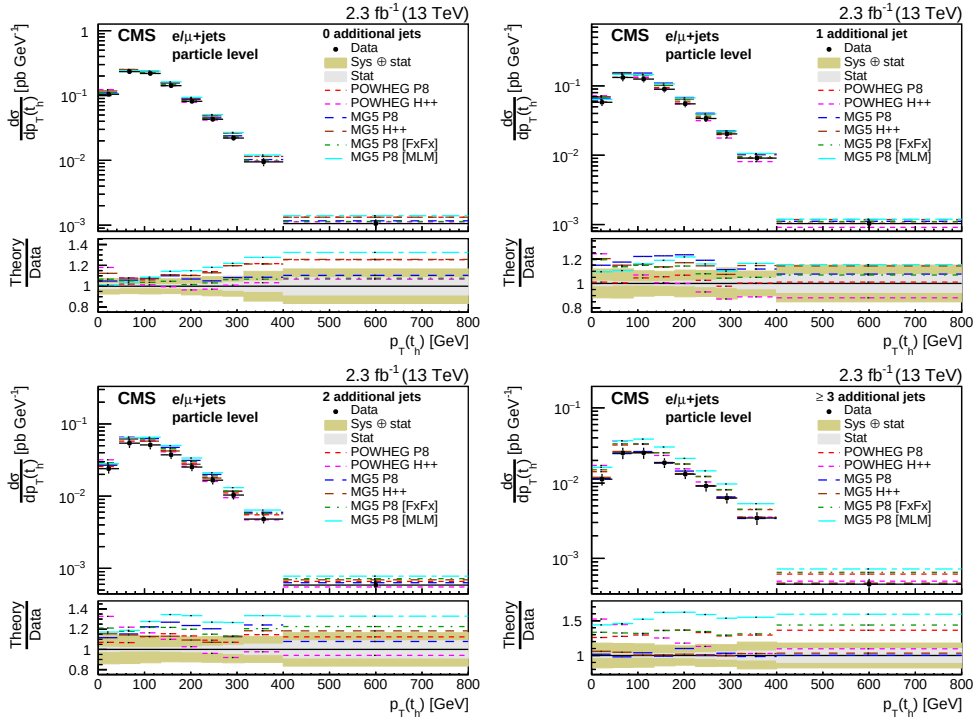
Double-differential cross section as function of additional jets and $p_{\mathrm{T}}(t\bar{t})$

2-dimensional unfolded result:



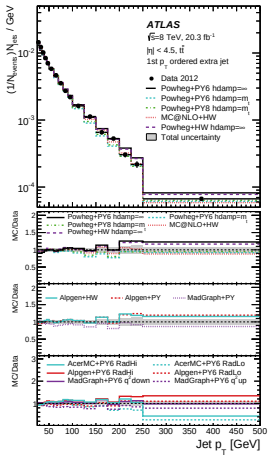
Recoiling of $t\bar{t}$ system against jets reasonbly described by simulations.

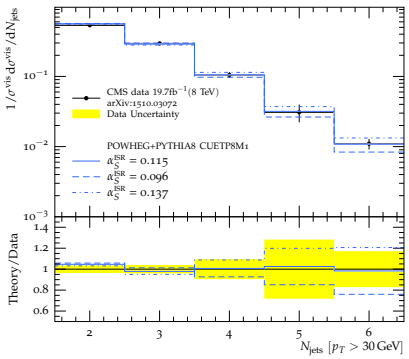
- Cross section as a function of add. jets not well modeled (no theoretical uncertainties considered for comparison): MG5aMC@NLO FxFx performs best.

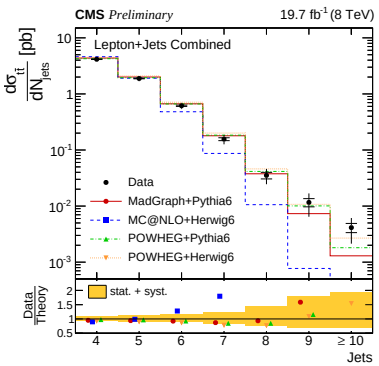


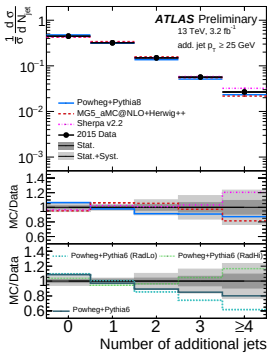
Distribution	χ^2/dof	p-value	χ^2/dof	p-value	χ^2/dof	p-value
	POWHEG+P8		POWHEG+H++		MG5_aMC@NLO+P8 MLM	
	Order: NLO		Order: NLO		Order: LO, up to 3 add. partons	
Additional jets	27.6/5	< 0.01	16.2/5	< 0.01	36.3/5	< 0.01
Additional jets *vs.* $p_T(t\bar{t})$	70.3/20	< 0.01	95.4/20	< 0.01	168/20	< 0.01
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	
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

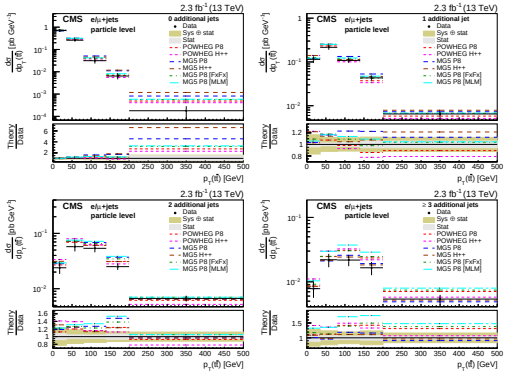
ATLAS and CMS: many measurements of jet multiplicities and kinematics of additional jet:











- measurements especially probe multi-jet and parton shower simulations.
- in general performance of simulations is good and data is reasonably described even at high jet multiplicities.
- choices of scales and parton shower tuning can introduce large uncertainties in predictions.

Backup

ATLAS: Eur. Phys. J. C (2016) 76:11

Measurements of additional b-jets in $t\bar{t}b/bb$ events

Use b-tagging discriminant to extract signal: