Stefano Frixione

Monte Carlos for $t\bar{t}$ associated production

SM@LHC, Pittsburgh, 5/5/2016

This talk covers (N)LO QCD predictions matched to, and possibly multi-jet merged with, parton showers for:

$$pp \to t\bar{t} + nV \qquad V = W^{\pm}, Z, \gamma$$

$$pp \to t\bar{t} + nj$$

I shall discuss neither fixed-order results, that are superseded by NLO+PS ones, nor $t\bar{t}H$ simulations

Conclusions

If you want to have a post-lunch nap, and to retain a single take-home message, it is this:

There is the possibility that we understand $t\bar{t}$+jets production less well than we think

Terminology

- Matching: the showering, without double counting, of matrix elements with a given Born-level parton multiplicity

  NLO: MC@NLO, POWHEG

Terminology

- Matching: the showering, without double counting, of matrix elements with a given Born-level parton multiplicity

Example: $t\bar{t}j$@NLO

- meaningless for $t\bar{t}$ inclusive
- t, $\bar{t}$, hardest jet: NLO
- second-hardest jet: LO
- jets further subleading: LL (ie through MC)

Terminology

- Matching: the showering, without double counting, of matrix elements with a given Born-level parton multiplicity
- Merging: the inclusion in a *single* simulation of *several* matched samples, characterised by different Born-level light-jet multiplicities

  LO: CKKW, CKKW-L, MLM, MEPS@LO, UMEPS

  NLO: FxFx, MEPS@NLO, UNLOPS (GENEVA, MINLO, VINCIA)

Terminology

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- Merging: the inclusion in a *single* simulation of *several* matched samples, characterised by different Born-level light-jet multiplicities

Example: $t\bar{t}$+jets, with NLO matrix elements for $t\bar{t}$, $t\bar{t}j$, $t\bar{t}jj$

- All observables inclusive or exclusive up to two jets: NLO
- third-hardest jet: LO
- jets further subleading: LL (ie through MC)

Terminology

- Matching: the showering, without double counting, of matrix elements with a given Born-level parton multiplicity
- Merging: the inclusion in a *single* simulation of *several* matched samples, characterised by different Born-level light-jet multiplicities

Thus, the scope of merging is much larger than that of matching. Matching should be used instead of merging only if:

- focussing on observables inclusive or characterised by a given number of (extra) jets
- CPU is a serious issue

Terminology

- Matching: the showering, without double counting, of matrix elements with a given Born-level parton multiplicity
- Merging: the inclusion in a *single* simulation of *several* matched samples, characterised by different Born-level light-jet multiplicities

Note: there may exist different merging procedures for the same underlying matching scheme

eg: FxFx and MEPS@NLO merge MC@NLO samples

To keep in mind: spin correlations

Consider eg *on-shell* top production (plus anything else $= X$) and decay

$$x + y \quad \longrightarrow X + t(\longrightarrow e^+\nu_e b)$$

- Decay spin correlations are the non-trivial dependences upon e.g. $(e^+ \cdot b)$
- Production spin correlations are the non-trivial dependences upon e.g. $(x \cdot b)$ or $(X \cdot e^+)$

Decay spin correlations are correctly taken into account if the PSMC contains the top-decay matrix element (I suppose this is always true)

However, production correlations are lost in this way

Spin correlations can be as important as NLO corrections; unless one is capable of simulating full off-shell resonances, they *must* be included

At the NLO, this can be done through a secondary unweighting that employs the full off-shell *tree-level* matrix elements

(SF, Laenen, Motylinski, Webber, hep-ph/0702198)

All codes capable of dealing with $t\bar{t}+X$ production have a module that implements FLMW. Remember to turn it on

$$t\bar{t} + nV$$

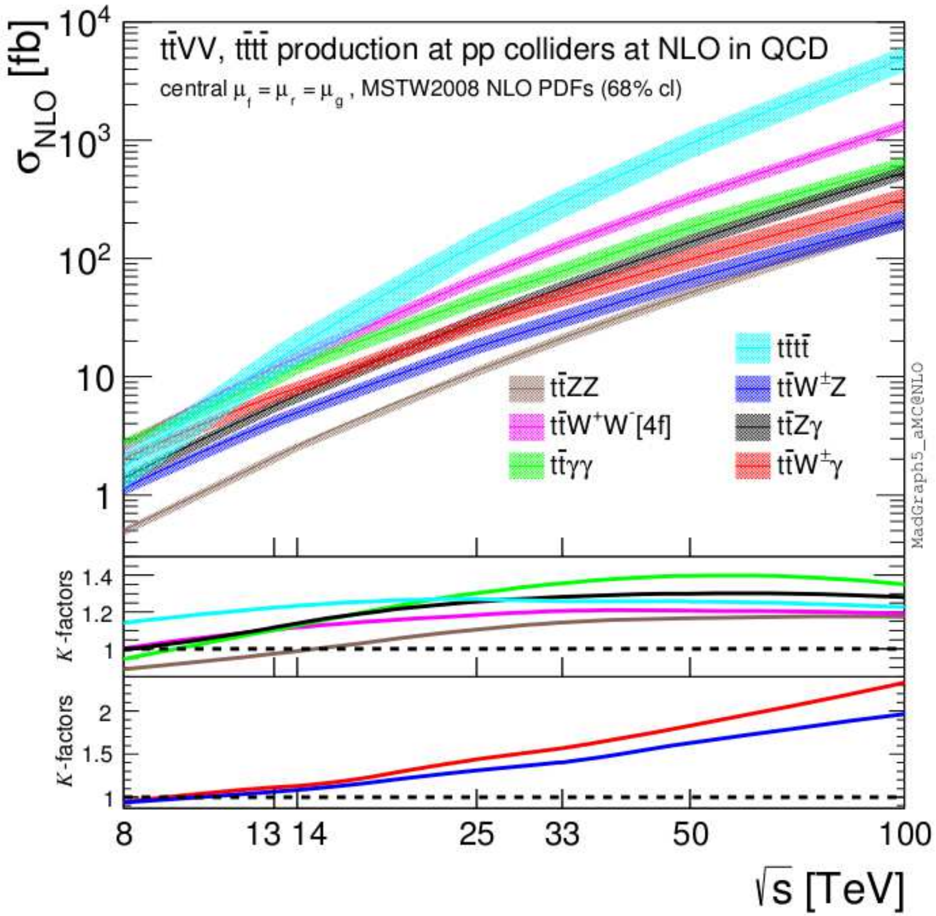
So far only matched predictions have been employed (which is OK)

Fully automated in MadGraph5_aMC@NLO: $t\bar{t}V$, $t\bar{t}Vj$, $t\bar{t}V_1V_2$ studied

1405.0301; Alwall, Frederix, Hirschi, Maltoni, Mattelaer, Shao, Stelzer, Torrielli, Zaro, SF

Process		Syntax	Cross section (pb)	
Heavy quarks+vector bosons			LO 13 TeV	NLO 13 TeV
e.1	$pp \to W^{\pm} b\bar{b}$ (4f)	`p p > wpm b b~`	$3.074 \pm 0.002 \cdot 10^{2}$ $^{+42.3\%}_{-29.2\%}$ $^{+2.0\%}_{-1.6\%}$	$8.162 \pm 0.034 \cdot 10^{2}$ $^{+29.8\%}_{-23.6\%}$ $^{+1.5\%}_{-1.2\%}$
e.2	$pp \to Z b\bar{b}$ (4f)	`p p > z b b~`	$6.993 \pm 0.003 \cdot 10^{2}$ $^{+33.5\%}_{-24.4\%}$ $^{+1.0\%}_{-1.4\%}$	$1.235 \pm 0.004 \cdot 10^{3}$ $^{+19.9\%}_{-17.4\%}$ $^{+1.0\%}_{-1.4\%}$
e.3	$pp \to \gamma b\bar{b}$ (4f)	`p p > a b b~`	$1.731 \pm 0.001 \cdot 10^{3}$ $^{+51.9\%}_{-34.8\%}$ $^{+1.6\%}_{-2.1\%}$	$4.171 \pm 0.015 \cdot 10^{3}$ $^{+33.7\%}_{-27.1\%}$ $^{+1.4\%}_{-1.9\%}$
e.4*	$pp \to W^{\pm} b\bar{b} j$ (4f)	`p p > wpm b b~ j`	$1.861 \pm 0.003 \cdot 10^{2}$ $^{+42.5\%}_{-27.7\%}$ $^{+0.7\%}_{-0.7\%}$	$3.957 \pm 0.013 \cdot 10^{2}$ $^{+27.0\%}_{-21.0\%}$ $^{+0.7\%}_{-0.6\%}$
e.5*	$pp \to Z b\bar{b} j$ (4f)	`p p > z b b~ j`	$1.604 \pm 0.001 \cdot 10^{2}$ $^{+42.4\%}_{-27.6\%}$ $^{+0.9\%}_{-1.1\%}$	$2.805 \pm 0.009 \cdot 10^{2}$ $^{+21.0\%}_{-17.6\%}$ $^{+0.8\%}_{-1.0\%}$
e.6*	$pp \to \gamma b\bar{b} j$ (4f)	`p p > a b b~ j`	$7.812 \pm 0.017 \cdot 10^{2}$ $^{+51.2\%}_{-32.0\%}$ $^{+1.0\%}_{-1.5\%}$	$1.233 \pm 0.004 \cdot 10^{3}$ $^{+18.9\%}_{-19.9\%}$ $^{+1.0\%}_{-1.5\%}$
e.7	$pp \to t\bar{t} W^{\pm}$	`p p > t t~ wpm`	$3.777 \pm 0.003 \cdot 10^{-1}$ $^{+23.9\%}_{-18.0\%}$ $^{+2.1\%}_{-1.6\%}$	$5.662 \pm 0.021 \cdot 10^{-1}$ $^{+11.2\%}_{-10.6\%}$ $^{+1.7\%}_{-1.3\%}$
e.8	$pp \to t\bar{t} Z$	`p p > t t~ z`	$5.273 \pm 0.004 \cdot 10^{-1}$ $^{+30.5\%}_{-21.8\%}$ $^{+1.8\%}_{-2.1\%}$	$7.598 \pm 0.026 \cdot 10^{-1}$ $^{+9.7\%}_{-11.1\%}$ $^{+1.9\%}_{-2.2\%}$
e.9	$pp \to t\bar{t} \gamma$	`p p > t t~ a`	$1.204 \pm 0.001 \cdot 10^{0}$ $^{+29.6\%}_{-21.3\%}$ $^{+1.6\%}_{-1.8\%}$	$1.744 \pm 0.005 \cdot 10^{0}$ $^{+9.8\%}_{-11.0\%}$ $^{+1.7\%}_{-2.0\%}$
e.10*	$pp \to t\bar{t} W^{\pm} j$	`p p > t t~ wpm j`	$2.352 \pm 0.002 \cdot 10^{-1}$ $^{+40.9\%}_{-27.1\%}$ $^{+1.3\%}_{-1.0\%}$	$3.404 \pm 0.011 \cdot 10^{-1}$ $^{+11.2\%}_{-14.0\%}$ $^{+1.2\%}_{-0.9\%}$
e.11*	$pp \to t\bar{t} Z j$	`p p > t t~ z j`	$3.953 \pm 0.004 \cdot 10^{-1}$ $^{+46.2\%}_{-29.5\%}$ $^{+2.7\%}_{-3.0\%}$	$5.074 \pm 0.016 \cdot 10^{-1}$ $^{+7.0\%}_{-12.3\%}$ $^{+2.5\%}_{-2.9\%}$
e.12*	$pp \to t\bar{t} \gamma j$	`p p > t t~ a j`	$8.726 \pm 0.010 \cdot 10^{-1}$ $^{+45.4\%}_{-29.1\%}$ $^{+2.3\%}_{-2.6\%}$	$1.135 \pm 0.004 \cdot 10^{0}$ $^{+7.5\%}_{-12.2\%}$ $^{+2.2\%}_{-2.5\%}$
e.13*	$pp \to t\bar{t} W^{-} W^{+}$ (4f)	`p p > t t~ w+ w-`	$6.675 \pm 0.006 \cdot 10^{-3}$ $^{+30.9\%}_{-21.9\%}$ $^{+2.1\%}_{-2.0\%}$	$9.904 \pm 0.026 \cdot 10^{-3}$ $^{+10.9\%}_{-11.8\%}$ $^{+2.1\%}_{-2.1\%}$
e.14*	$pp \to t\bar{t} W^{\pm} Z$	`p p > t t~ wpm z`	$2.404 \pm 0.002 \cdot 10^{-3}$ $^{+26.6\%}_{-19.6\%}$ $^{+2.5\%}_{-1.8\%}$	$3.525 \pm 0.010 \cdot 10^{-3}$ $^{+10.6\%}_{-10.8\%}$ $^{+2.3\%}_{-1.6\%}$
e.15*	$pp \to t\bar{t} W^{\pm} \gamma$	`p p > t t~ wpm a`	$2.718 \pm 0.003 \cdot 10^{-3}$ $^{+25.4\%}_{-18.9\%}$ $^{+2.3\%}_{-1.8\%}$	$3.927 \pm 0.013 \cdot 10^{-3}$ $^{+10.3\%}_{-10.4\%}$ $^{+2.0\%}_{-1.5\%}$
e.16*	$pp \to t\bar{t} Z Z$	`p p > t t~ z z`	$1.349 \pm 0.014 \cdot 10^{-3}$ $^{+29.3\%}_{-21.1\%}$ $^{+1.7\%}_{-1.5\%}$	$1.840 \pm 0.007 \cdot 10^{-3}$ $^{+7.9\%}_{-9.9\%}$ $^{+1.7\%}_{-1.5\%}$
e.17*	$pp \to t\bar{t} Z \gamma$	`p p > t t~ z a`	$2.548 \pm 0.003 \cdot 10^{-3}$ $^{+30.1\%}_{-21.5\%}$ $^{+1.7\%}_{-1.6\%}$	$3.656 \pm 0.012 \cdot 10^{-3}$ $^{+9.7\%}_{-11.0\%}$ $^{+1.8\%}_{-1.9\%}$
e.18*	$pp \to t\bar{t} \gamma\gamma$	`p p > t t~ a a`	$3.272 \pm 0.006 \cdot 10^{-3}$ $^{+28.4\%}_{-20.6\%}$ $^{+1.3\%}_{-1.1\%}$	$4.402 \pm 0.015 \cdot 10^{-3}$ $^{+7.8\%}_{-9.7\%}$ $^{+1.4\%}_{-1.4\%}$

MadGraph5_aMC@NLO, 1405.0301



13 TeV σ[fb]		SR1	SR2	SR3
	NLO+PS	$1.54^{+5.1\%}_{-9.0\%}{}^{+2.2\%}_{-2.6\%} \pm 0.02$	$1.47^{+5.2\%}_{-9.0\%}{}^{+2.0\%}_{-2.4\%} \pm 0.02$	$0.095^{+7.4\%}_{-9.7\%}{}^{+2.0\%}_{-2.4\%} \pm 0.002$
$t\bar{t}H(H \to WW^*)$	LO+PS	$1.401^{+35.6\%}_{-24.4\%}{}^{+2.1\%}_{-2.2\%} \pm 0.008$	$1.355^{+35.2\%}_{-24.1\%}{}^{+2.0\%}_{-2.2\%} \pm 0.008$	$0.0855^{+34.9\%}_{-24.0\%}{}^{+2.0\%}_{-2.2\%} \pm 0.0007$
$K = 1.10$	$K^{\rm PS}$	1.10 ± 0.02	1.09 ± 0.02	1.11 ± 0.02
	NLO+PS	$0.0437^{+5.5\%}_{-9.2\%}{}^{+2.3\%}_{-2.8\%} \pm 0.0004$	$0.119^{+6.3\%}_{-9.6\%}{}^{+2.1\%}_{-2.5\%} \pm 0.002$	$0.0170^{+5.0\%}_{-8.5\%}{}^{+2.0\%}_{-2.4\%} \pm 0.0003$
$t\bar{t}H(H \to ZZ^*)$	LO+PS	$0.0404^{+36.1\%}_{-24.6\%}{}^{+2.2\%}_{-2.3\%} \pm 0.0002$	$0.1092^{+35.3\%}_{-24.2\%}{}^{+2.0\%}_{-2.2\%} \pm 0.0008$	$0.0152^{+34.7\%}_{-23.9\%}{}^{+1.9\%}_{-2.1\%} \pm 0.0001$
$K = 1.10$	$K^{\rm PS}$	1.08 ± 0.01	1.09 ± 0.02	1.12 ± 0.02
	NLO+PS	$0.563^{+4.6\%}_{-8.8\%}{}^{+2.2\%}_{-2.7\%} \pm 0.007$	$0.669^{+6.0\%}_{-9.4\%}{}^{+2.1\%}_{-2.6\%} \pm 0.008$	$0.0494^{+7.1\%}_{-9.9\%}{}^{+2.1\%}_{-2.5\%} \pm 0.0007$
$t\bar{t}H(H \to \tau^+\tau^-)$	LO+PS	$0.513^{+35.9\%}_{-24.5\%}{}^{+2.2\%}_{-2.3\%} \pm 0.003$	$0.611^{+35.4\%}_{-24.2\%}{}^{+2.1\%}_{-2.2\%} \pm 0.003$	$0.0438^{+35.1\%}_{-24.1\%}{}^{+2.0\%}_{-2.2\%} \pm 0.0003$
$K = 1.10$	$K^{\rm PS}$	1.10 ± 0.02	1.10 ± 0.01	1.13 ± 0.02
	NLO+PS	$5.77^{+15.1\%}_{-12.7\%}{}^{+1.6\%}_{-1.2\%} \pm 0.07$	$2.44^{+13.1\%}_{-11.6\%}{}^{+1.7\%}_{-1.4\%} \pm 0.01$	-
$t\bar{t}W^{\pm}$	LO+PS	$4.57^{+27.7\%}_{-20.2\%}{}^{+1.8\%}_{-1.9\%} \pm 0.03$	$1.989^{+27.5\%}_{-20.0\%}{}^{+1.8\%}_{-1.9\%} \pm 0.007$	-
$K = 1.22$	$K^{\rm PS}$	1.26 ± 0.02	1.23 ± 0.01	-
	NLO+PS	$1.61^{+7.7\%}_{-10.5\%}{}^{+2.0\%}_{-2.5\%} \pm 0.02$	$2.70^{+9.0\%}_{-11.2\%}{}^{+2.0\%}_{-2.5\%} \pm 0.03$	$0.280^{+9.8\%}_{-11.0\%}{}^{+1.9\%}_{-2.3\%} \pm 0.003$
$t\bar{t}Z/\gamma^*$	LO+PS	$1.422^{+36.8\%}_{-24.9\%}{}^{+2.2\%}_{-2.3\%} \pm 0.008$	$2.21^{+36.4\%}_{-24.7\%}{}^{+2.1\%}_{-2.2\%} \pm 0.01$	$0.221^{+35.8\%}_{-24.4\%}{}^{+2.0\%}_{-2.2\%} \pm 0.001$
$K = 1.23$	$K^{\rm PS}$	1.13 ± 0.02	1.23 ± 0.01	1.27 ± 0.01
	NLO+PS	$0.288^{+8.0\%}_{-11.1\%}{}^{+2.3\%}_{-2.6\%} \pm 0.003$	$0.201^{+7.4\%}_{-10.7\%}{}^{+2.1\%}_{-2.3\%} \pm 0.003$	$0.0116^{+6.9\%}_{-10.2\%}{}^{+2.2\%}_{-2.3\%} \pm 0.0002$
$t\bar{t}W^+W^-$	LO+PS	$0.260^{+38.4\%}_{-25.5\%}{}^{+2.3\%}_{-2.3\%} \pm 0.001$	$0.181^{+38.0\%}_{-25.3\%}{}^{+2.2\%}_{-2.2\%} \pm 0.001$	$0.01073^{+37.7\%}_{-25.1\%}{}^{+2.2\%}_{-2.2\%} \pm 0.00008$
$K = 1.10$	$K^{\rm PS}$	1.11 ± 0.01	1.11 ± 0.01	1.08 ± 0.02
	NLO+PS	$0.340^{+27.5\%}_{-25.8\%}{}^{+5.5\%}_{-6.4\%} \pm 0.004$	$0.211^{+27.4\%}_{-25.6\%}{}^{+5.2\%}_{-6.1\%} \pm 0.003$	$0.0110^{+27.0\%}_{-25.5\%}{}^{+5.0\%}_{-5.9\%} \pm 0.0002$
$t\bar{t}t\bar{t}$	LO+PS	$0.271^{+80.9\%}_{-41.5\%}{}^{+4.6\%}_{-4.6\%} \pm 0.001$	$0.166^{+80.3\%}_{-41.4\%}{}^{+4.4\%}_{-4.4\%} \pm 0.001$	$0.00871^{+79.8\%}_{-41.2\%}{}^{+4.2\%}_{-4.2\%} \pm 0.00007$
$K = 1.22$	$K^{\rm PS}$	1.26 ± 0.02	1.27 ± 0.02	1.26 ± 0.03
13 TeV σ[ab]		SR1	SR2	SR3
	NLO+PS	$9.60^{+3.5\%}_{-8.4\%}{}^{+1.8\%}_{-1.8\%} \pm 0.06$	$5.02^{+3.7\%}_{-8.3\%}{}^{+1.8\%}_{-1.7\%} \pm 0.04$	$0.249^{+7.2\%}_{-9.6\%}{}^{+1.9\%}_{-1.8\%} \pm 0.009$
$t\bar{t}ZZ$	LO+PS	$9.71^{+36.3\%}_{-24.5\%}{}^{+1.9\%}_{-1.9\%} \pm 0.02$	$5.08^{+35.9\%}_{-24.3\%}{}^{+1.9\%}_{-1.9\%} \pm 0.02$	$0.250^{+35.5\%}_{-24.2\%}{}^{+1.9\%}_{-1.9\%} \pm 0.004$
$K = 0.99$	$K^{\rm PS}$	0.99 ± 0.01	0.99 ± 0.01	1.00 ± 0.04
	NLO+PS	$62.0^{+9.0\%}_{-10.2\%}{}^{+2.2\%}_{-1.6\%} \pm 0.7$	$27.9^{+9.2\%}_{-10.3\%}{}^{+2.3\%}_{-1.7\%} \pm 0.5$	$0.91^{+7.2\%}_{-9.2\%}{}^{+2.4\%}_{-1.7\%} \pm 0.02$
$t\bar{t}W^{\pm}Z$	LO+PS	$60.2^{+32.2\%}_{-22.6\%}{}^{+2.4\%}_{-2.3\%} \pm 0.3$	$26.4^{+32.0\%}_{-22.5\%}{}^{+2.4\%}_{-2.2\%} \pm 0.2$	$0.893^{+31.9\%}_{-22.4\%}{}^{+2.4\%}_{-2.2\%} \pm 0.009$
$K = 1.06$	$K^{\rm PS}$	1.03 ± 0.01	1.06 ± 0.02	1.02 ± 0.02

$t\bar{t}VV$, $t\bar{t}t\bar{t}$ production, f(N)LO and (N)LO+PS

MadGraph5_aMC@NLO, 1507.05640 (SM and $t\bar{t}H$ bckg studies)

(Maltoni, Pagani, Tsinikos)

So far only matched predictions have been employed (which is OK)

Fully automated in MadGraph5_aMC@NLO: $t\bar{t}V$, $t\bar{t}Vj$, $t\bar{t}V_1V_2$ studied

1405.0301; Alwall, Frederix, Hirschi, Maltoni, Mattelaer, Shao, Stelzer, Torrielli, Zaro, SF

Specific applications in PowHel/HELAC-OneLoop

($t\bar{t}W^{\pm}$, $t\bar{t}Z$ 1208.2665; Garzelli, Kardos, Papadopoulos, Trocsanyi)

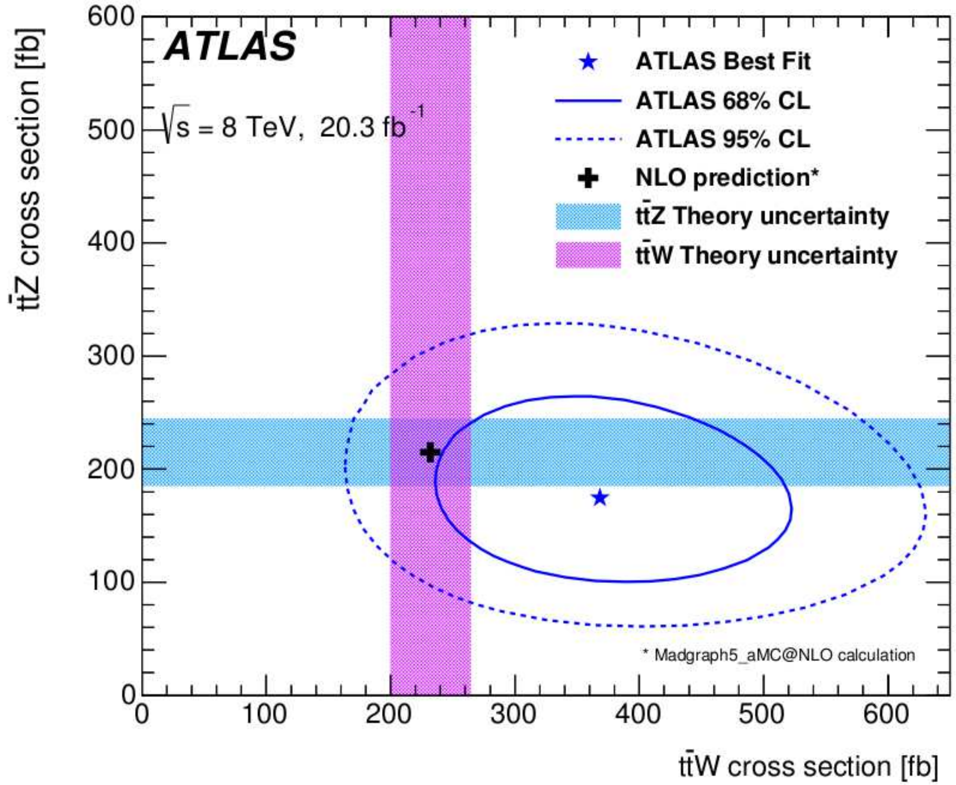
($t\bar{t}\gamma$, $t\bar{t}\gamma\gamma$ 1406.2324, 1408.0278; Kardos, Trocsanyi)

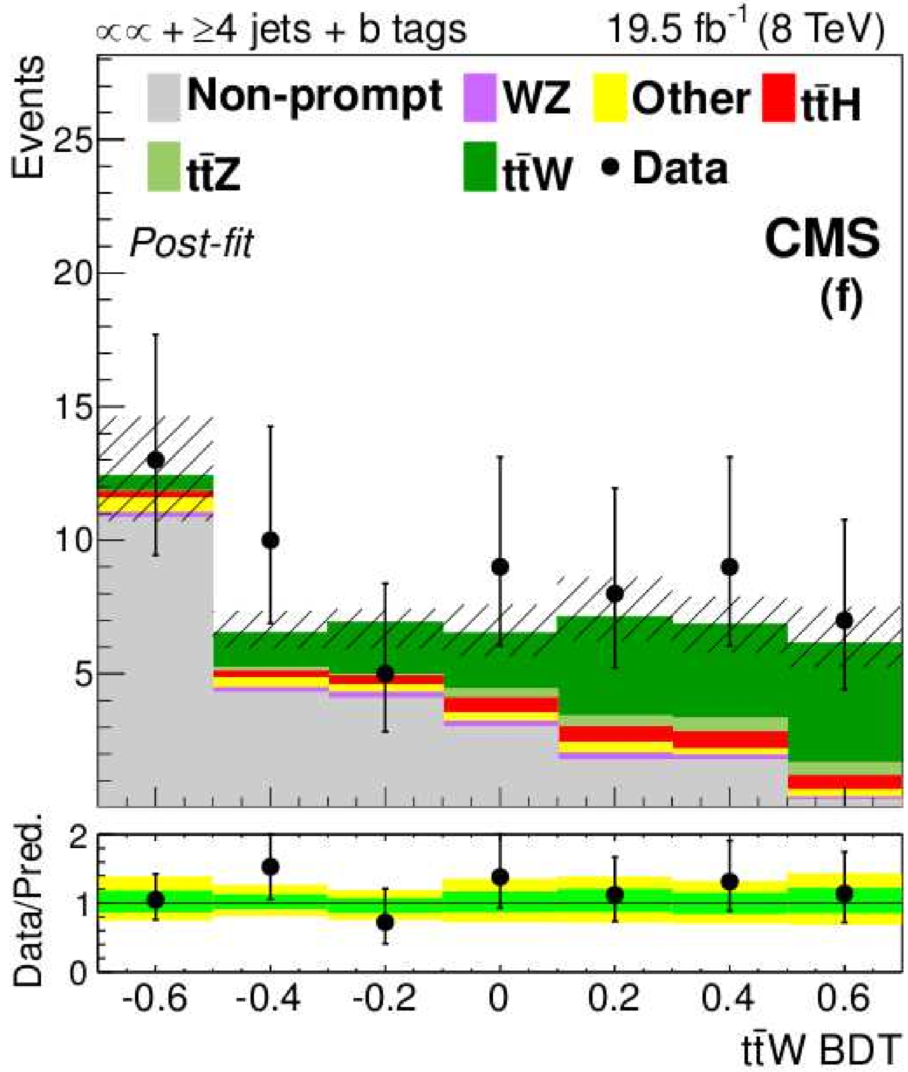
Should be feasible in SHERPA too, depending on OLP

Take-home messages

- Despite their complexity, $t\bar{t}+nV$ can be easily simulated at NLO+PS accuracy in modern MCs – remember spin correlations

- This is just as well, because accuracy is a key word
  (theory inputs are important for measurements)





8 TeV ttW and ttZ measurements

1509.05276 (ATLAS), 1510.01131 (CMS)

Take-home messages

- Despite their complexity, $t\bar{t} + nV$ can be easily simulated at NLO+PS accuracy in modern MCs – remember spin correlations
- This is just as well, because accuracy is a key word
  (theory inputs are important for measurements)
- Merged results not a priority now, but $t\bar{t}V + t\bar{t}Vj$ is feasible @NLO
- When $V = \gamma$: NLO+PS results do not include hadronic-photon contributions

$$t\bar{t} + nj$$

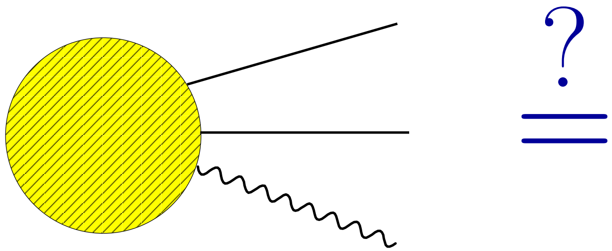
$t\bar{t}$ production is a very jetty process – there is a large probability that the hardest jet is not a top-decay product

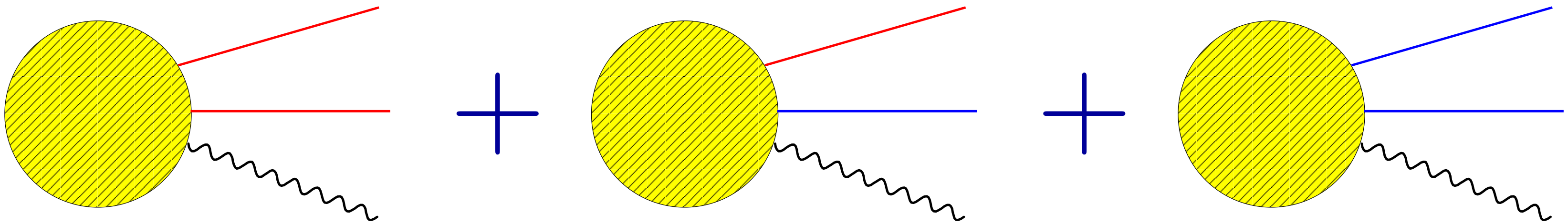
Thus the necessity of having a fairly good understanding of the "extra" QCD radiation

Therefore, the keyword is merging

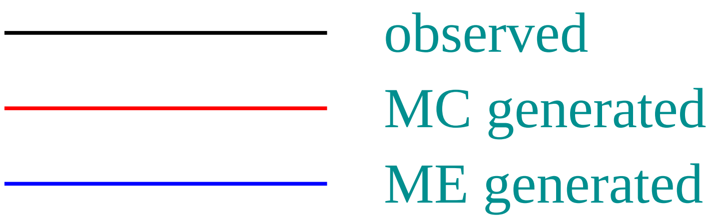
Multi-jet merging: handwaving explanation

Consider some $S + 2j$ observable ($S = t\bar{t}, t\bar{t}V, \ldots$ =wiggly line): the appropriate underlying calculation depends on the jets hardness, unless one is able to define:





with:



- LO

  CKKW: Catani, Krauss, Kuhn, Webber, hep-ph/0109231

  CKKW-L: Lavesson, Lonnblad, hep-ph/0503293

  MLM: Alwall *etal*, 0706.2569

  MEPS@LO: Höche, Krauss, Schumann, Siegert, 0903.1219

  UMEPS: Lonnblad, Prestel, 1211.4827

- NLO

  FxFx: Frederix, SF, 1209.6215

  MEPS@NLO: Höche, Krauss, Schönherr, Siegert, 1207.5030

  UNLOPS: Lonnblad, Prestel, 1211.7278

At least one of these (but typically more) available in
MG5_aMC@NLO (/w PY8, HW++/H7), PY8, HW++/H7, Sherpa

To be kept in mind

- NLO mergings have an underlying matching scheme: MC@NLO for FxFx and MEPS@NLO, own additive for UNLOPS
- One of the chief features of a merging scheme is whether it is unitary or non-unitary. Either way, the total rate carries information, and should *not* be rescaled if possible

$t\bar{t}$ production is a very jetty process – there is a large probability that the hardest jet is not a top-decay product

Thus the necessity of having a fairly good understanding of the "extra" QCD radiation

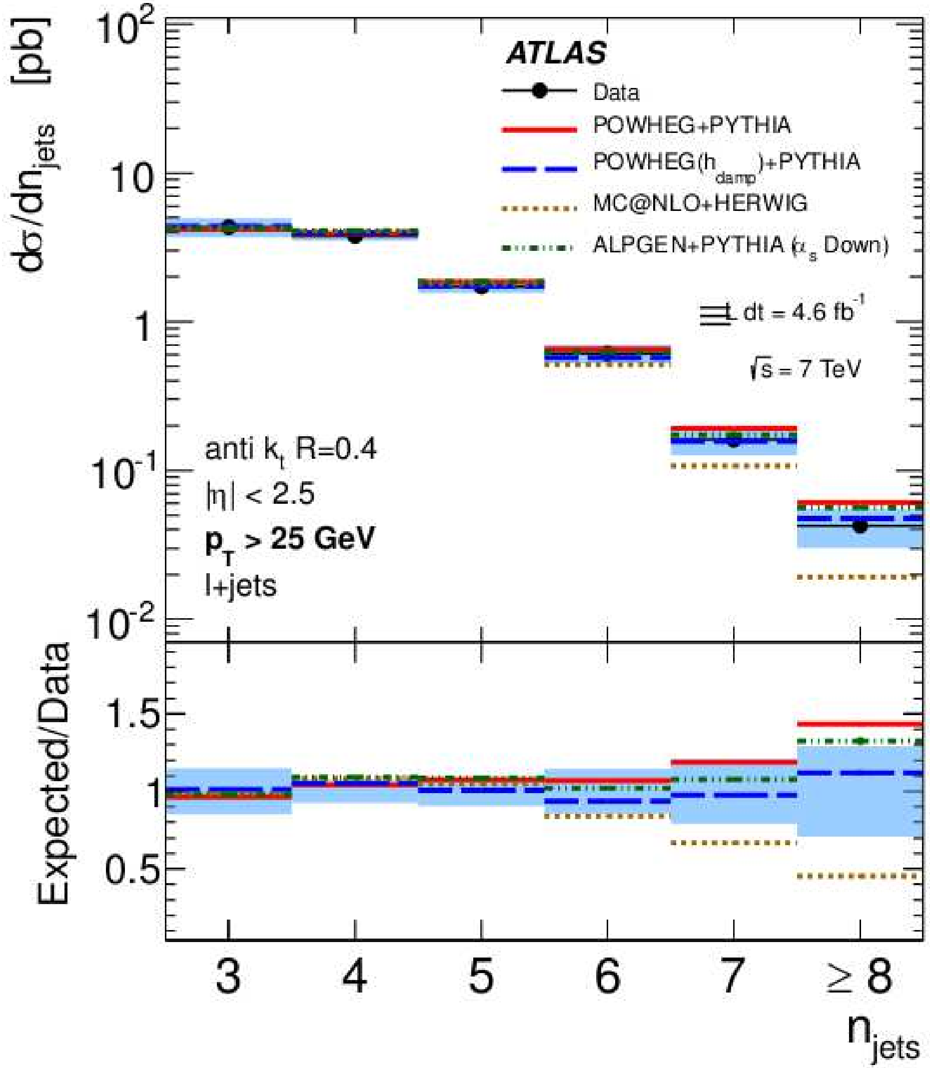
[Aside: even for $t\bar{t}$-inclusive observables, data and theory predictions from $t\bar{t}$-inclusive MCs might not be on the same footing. We should treat the latter erring on the conservative side]

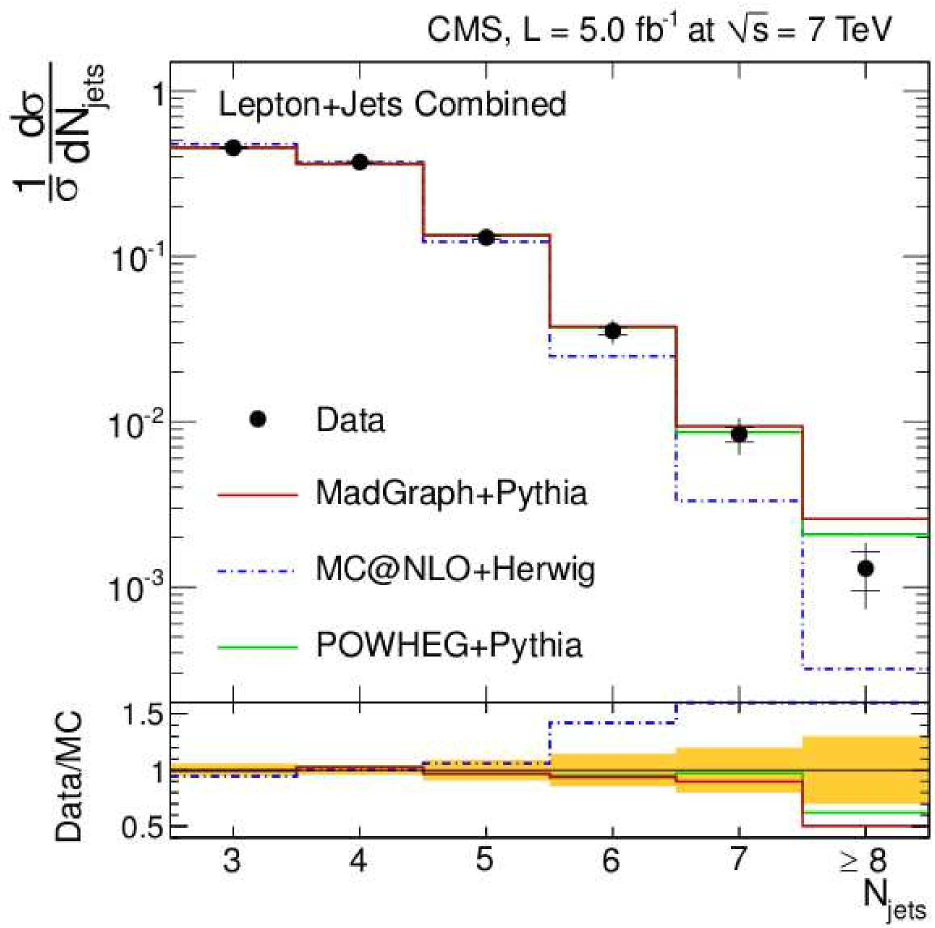
$t\bar{t}$ production is a very jetty process – there is a large probability that the hardest jet is not a top-decay product

Thus the necessity of having a fairly good understanding of the "extra" QCD radiation

Speaking of which: what do the following plots tell us?

$\longrightarrow$





$t\bar{t}$+jets, semileptonic (5^{th} jet is "QCD")

1407.0891 (ATLAS), 1404.3171 (CMS)

identical message (note: MC/data (ATLAS) vs data/MC (CMS))

Q: what do the previous plots tell us?

A: as far as MC@NLO and POWHEG are concerned: *nothing significant*

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Thus: this bit of the conclusions in the ATLAS paper 1407.0891:

> jet. The presented measurements have discriminating power for MC model predictions. At high jet multiplicities, which are dominated by parton-shower emissions, MC@NLO is disfavoured by the data. A similar finding applies to the additional jet p_{T} distributions,

is either:

trivial (data are not described by MC(s) that are not supposed to describe them)

or:

wrong (taken literally, the statement above is a contradiction in terms)

Q: what do the previous plots tell us?

A: as far as MC@NLO and POWHEG are concerned: *nothing significant*

In other words: this observation is relevant *only* as long as one wants to use inclusive $t\bar{t}$ computations eg as backgrounds to searches dominated by multijets

Which should never happen

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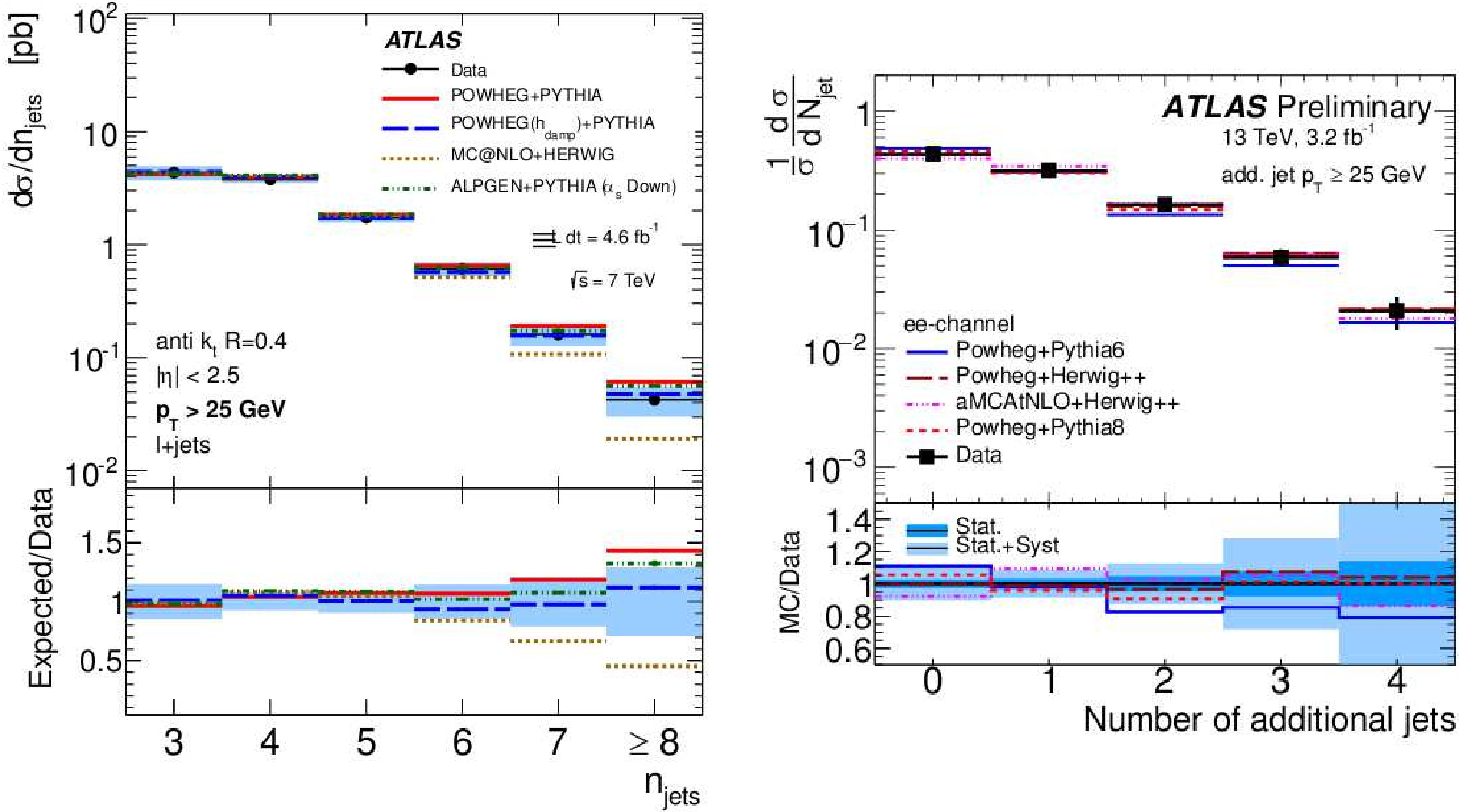
Now, consider this:

$\longrightarrow$



$t\bar{t}$+jets, semileptonic (7 TeV) and dilepton (13 TeV)

1407.0891 (7 TeV), ATLAS-CONF-2015-065 (13 TeV)

So the message at 13 TeV is basically the opposite of that at 7 TeV

Is the different behaviour due to the different CM energies?
The different channels?

No, or not predominantly: the primary reason is the parton shower
(different *showers*, different initial conditions)

Although things seemingly have improved, this improvement
is not significant

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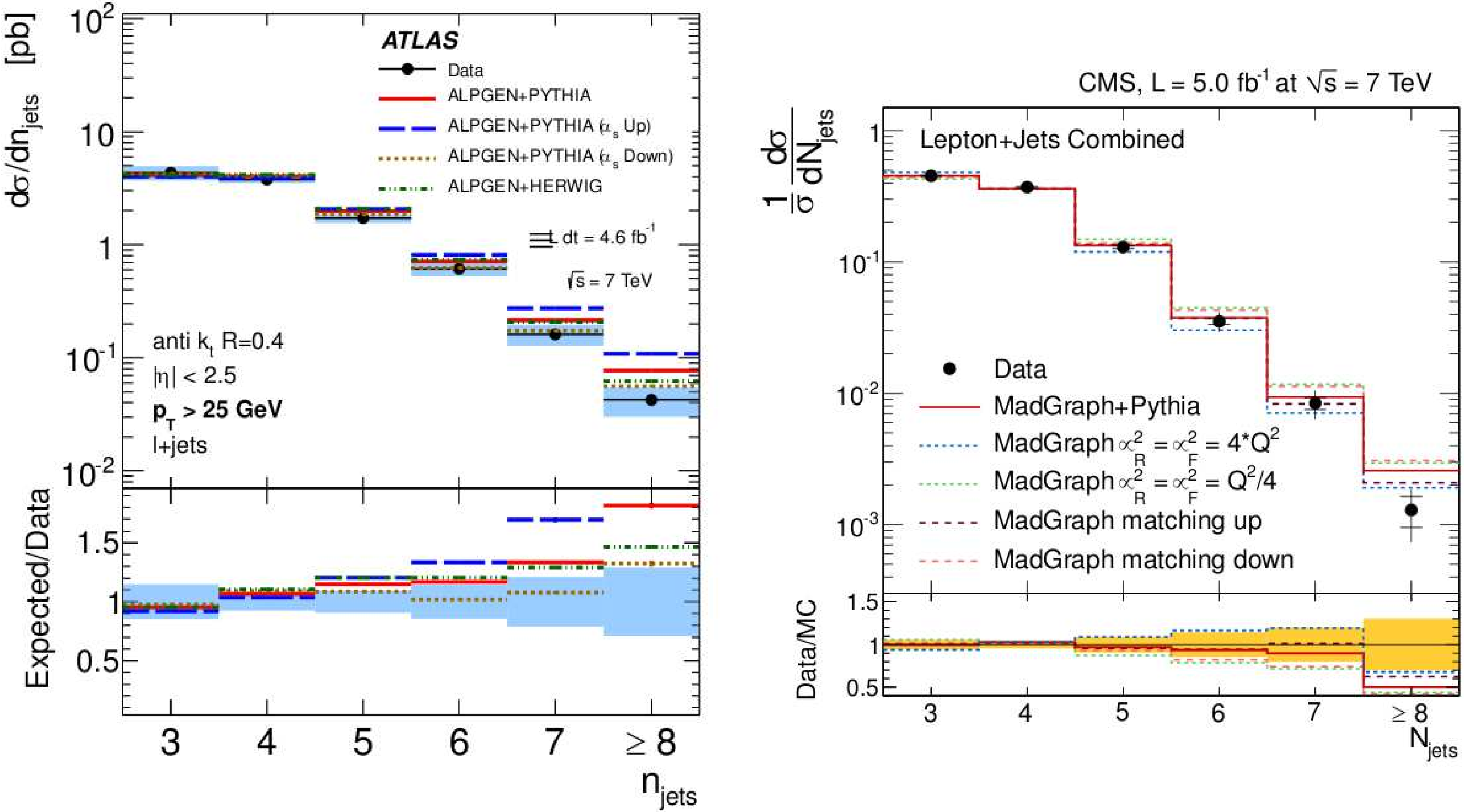
I'd rather worry about what follows:

$\longrightarrow$



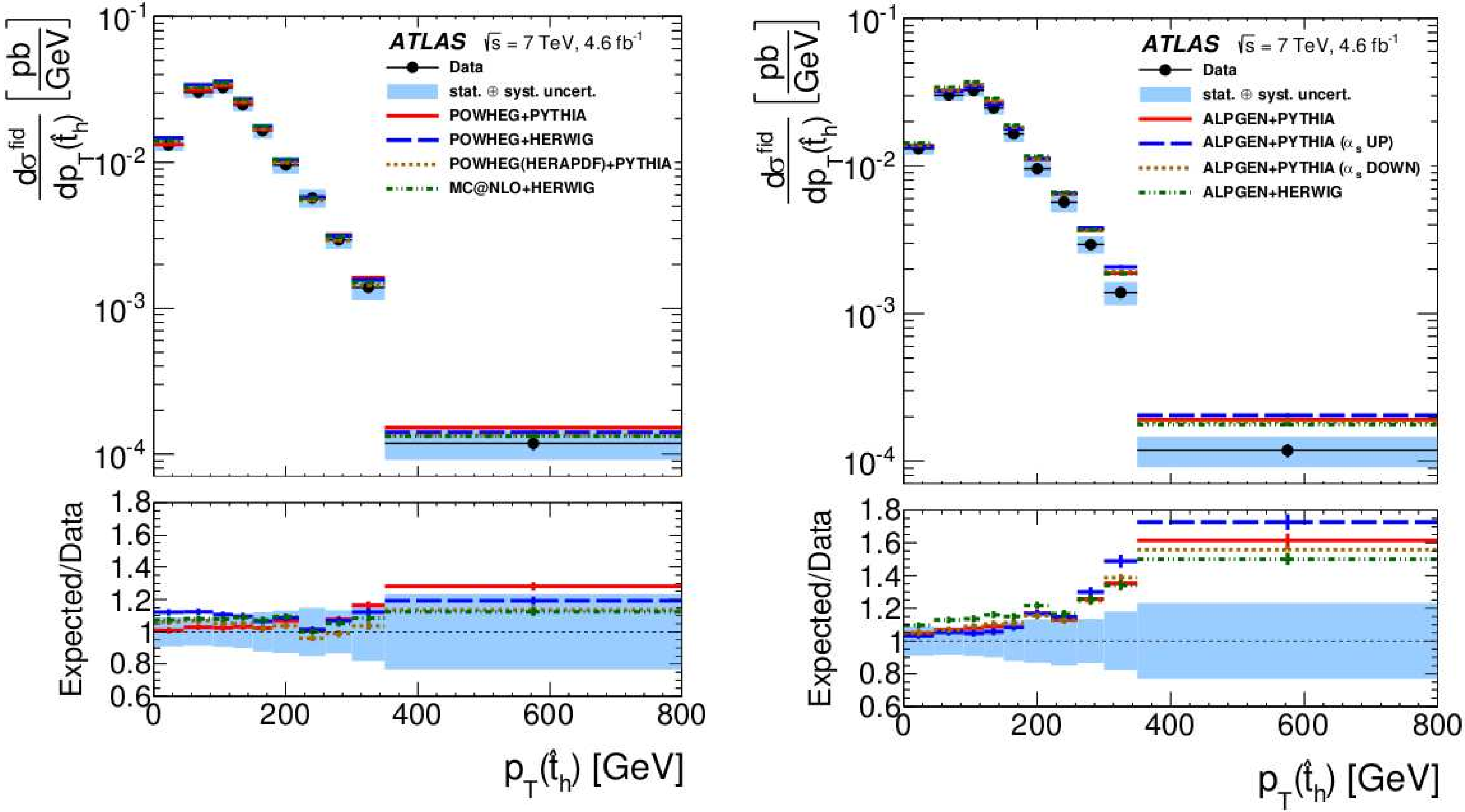
$t\bar{t}$+jets

1407.0891 (ATLAS), 1404.3171 (CMS)

These are multi-jet merged (LO) – too large TH systematics

Some more (potentially) bad news

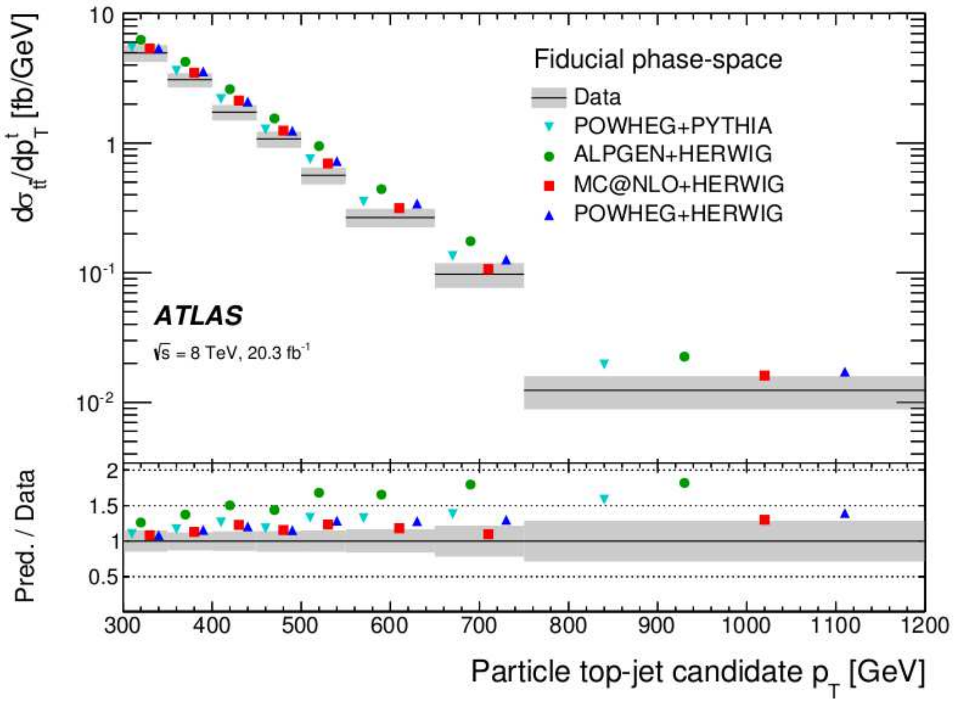
$\longrightarrow$



$t\bar{t}$ inclusive (pseudo-top observables)

1502.05923

Remember that multi-jet merged results are perfectly fine for inclusive observables



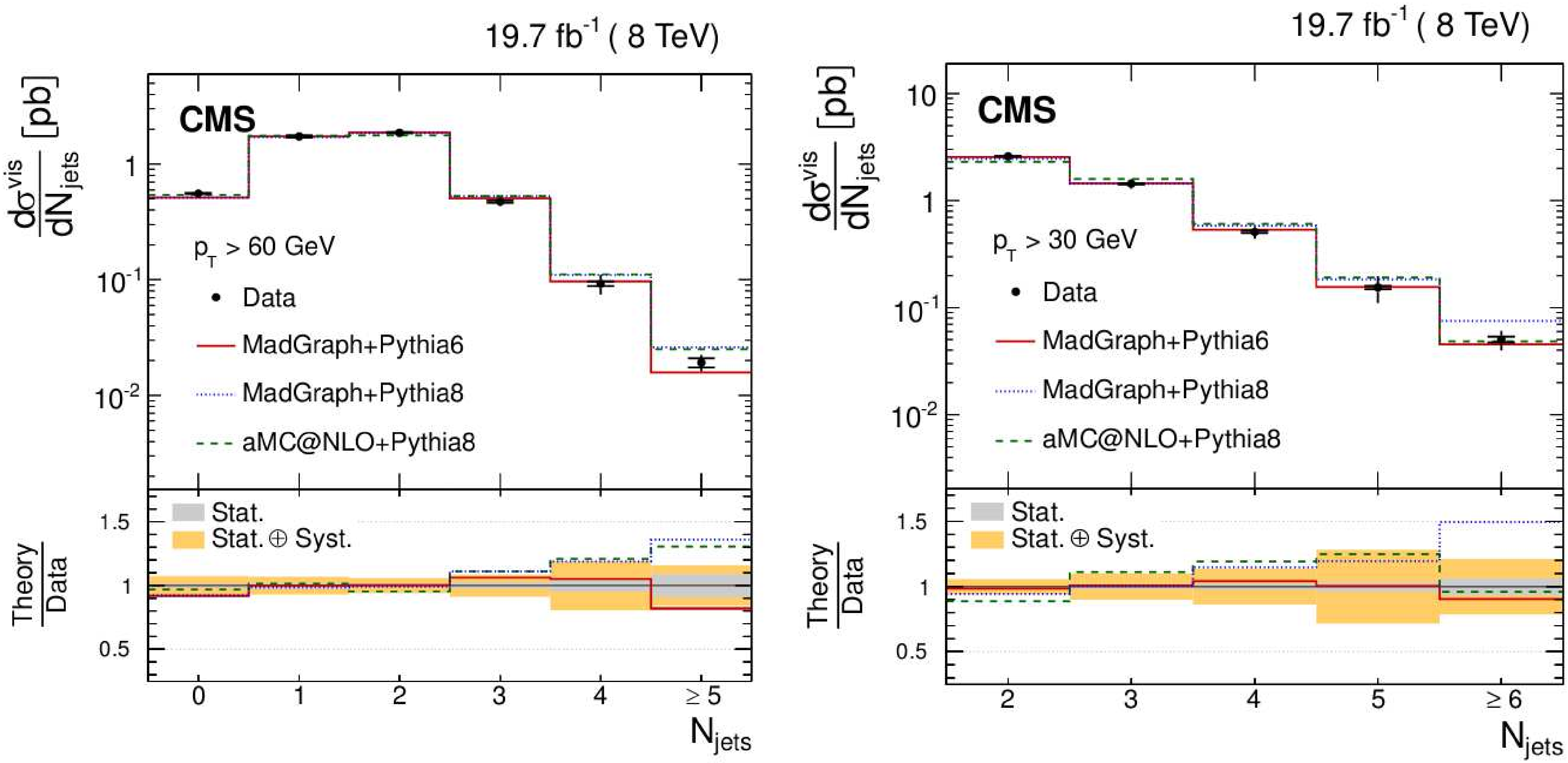
MC generator	PDF	χ^2	p-value
POWHEG+PYTHIA $h_{damp} = m_{top}$ + Electroweak corr.	CT10	9.8	0.28
POWHEG+PYTHIA $h_{damp} = m_{top}$	CT10	13.0	0.11
POWHEG+PYTHIA $h_{damp} = \infty$	CT10	15.6	0.05
POWHEG+PYTHIA $h_{damp} = m_{top}$	HERAPDF	9.4	0.31
POWHEG+PYTHIA $h_{damp} = \infty$	HERAPDF	10.9	0.21
POWHEG+HERWIG	CT10	8.2	0.41
MC@NLO+HERWIG	CT10	12.3	0.14
ALPGEN+HERWIG	CTEQ6	33.1	$5.9 \cdot 10^{-5}$

$t\bar{t}$ inclusive (here particle level)

1510.03818

Rule out Alpgen multi-jet merging (MLM) because of this?

Rather: there is conflicting evidence, which means that there is something we don't understand



$t\bar{t}$+jets

1510.03072

Here, MadGraph and aMC@NLO actually mean LO- and NLO-merged (FxFx)

As they say, the plot thickens...

- NLO follows very closely LO
- NLO is seen to do very well for $W/Z+$jets

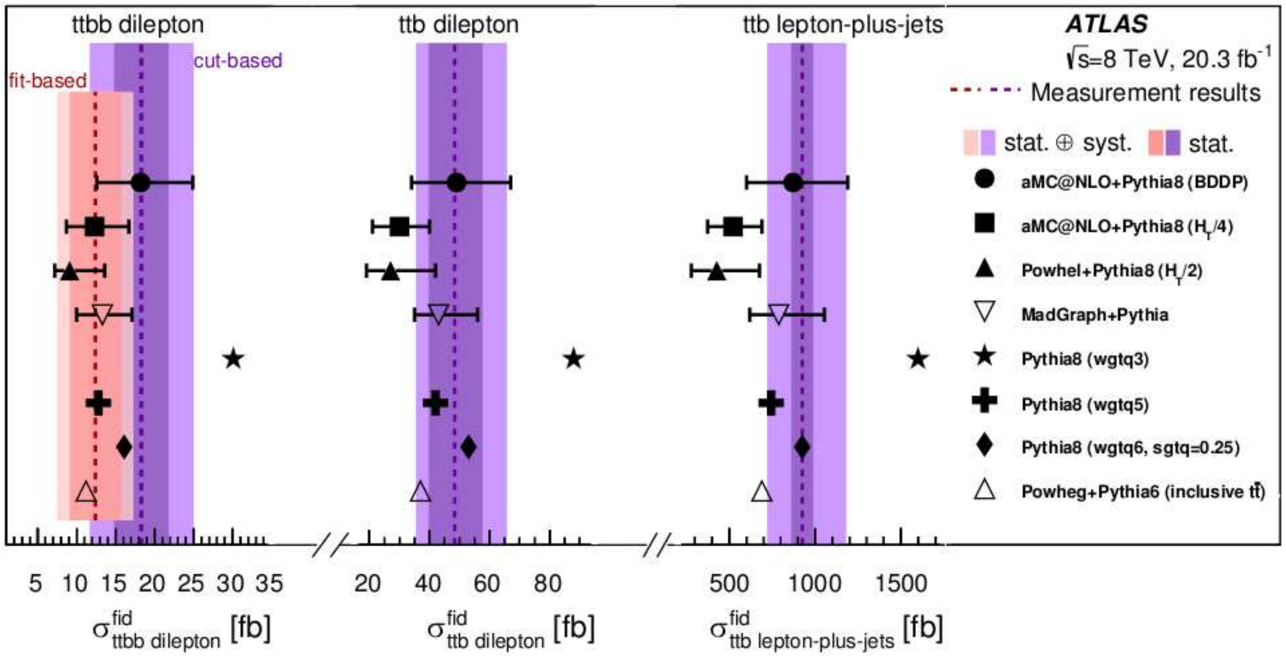
About $t\bar{t}b\bar{b}$

A subset of $t\bar{t}jj$ events is made of $t\bar{t}b\bar{b}$ events

If that's strictly a subset (ie no property of b's is especially relevant) there's nothing to be done

Otherwise, one should try and use computations that feature $t\bar{t}b\bar{b}$ final states at the matrix element level
(in which case, it is sensible to treat the b's as massive)

Personally, I see no compelling case for smooth $t\bar{t}jj \longleftrightarrow t\bar{t}b\bar{b}$ matching
(which anyhow we don't know how to do)



$t\bar{t}b(b)$

1508.06868 – see also 1510.03072 (CMS)

- Still very large scale dependence at the NLO (also owing to functional form)
- Unacceptably large if $t\bar{t}g(\rightarrow b\bar{b})$ – that's pure modelling

In lieu of conclusions

Is there a problem?

- Lots of sophisticated tools at (N)LO+PS are available, and more often than not they perform quite well

- However, there is *perhaps* a mounting evidence that merged simulations in $t\bar{t}$ production do significantly less well than eg in the case of V+jets

In lieu of conclusions

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- However, there is *perhaps* a mounting evidence that merged simulations in $t\bar{t}$ production do significantly less well than eg in the case of $V+$jets

- There is no fundamental reason for this. Note that:
  - Theory-wise, $t\bar{t}$ merged simulations are not well tested
    (top-specific merging features? MC tunes and ME-MC parameter choices?)
  - It is also worth thinking about the role that *inclusive* calculations have in data unfolding