

Experience and new ideas for $t\bar{t}+X$ measurements

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on behalf of ATLAS and CMS*

*Thanks to Maria Aldaya



Outline

- Measurement definitions in $t\bar{t}$ +jets vs $t\bar{t}Hbb$
- Measurements of $t\bar{t}+X$
- MC tunes used for $t\bar{t}Hbb$
- New MC data comparisons

“Particle level” the concept

- Only use **stable final state particles** (hadrons, leptons) from MC predictions in **“visible” phase space** (detector acceptance)
-> minimized dependence on theory
- Define observables based on stable final state particles with large correlation to parton level information
-> example: pseudo top
- Correct measured objects for detector resolution effects = unfold to particle level
-> avoids dependency on model to go from parton to particle (e.g. finite width effects & offshell top)

“Particle level”

the definitions

Stable particles with $\tau > 0.3 \cdot 10^{-10}$ sec in observable η range

Leptons (e, μ , ν) not from hadron decay

e, μ 4-momentum incl. clustering with γ in cone with $R=0.1$

Jets:

clusters all but the prompt particles using anti-kt algorithm with $R=0.4$
(i.e. ν , μ from hadron decays are inside jets)

B-jets:

A stable B-hadron with initial $p_t > 5$ GeV ghost matched to the jet
-> corresponding to non-prompt Bs from electro-weak decays

Analysis dependent. Typical examples are:

Leptons: $p_T > 25$ GeV, $h < 2.5$

Jet $p_T > 25$ GeV, b-jet $p_T > 25$ GeV, $h < 2.5$

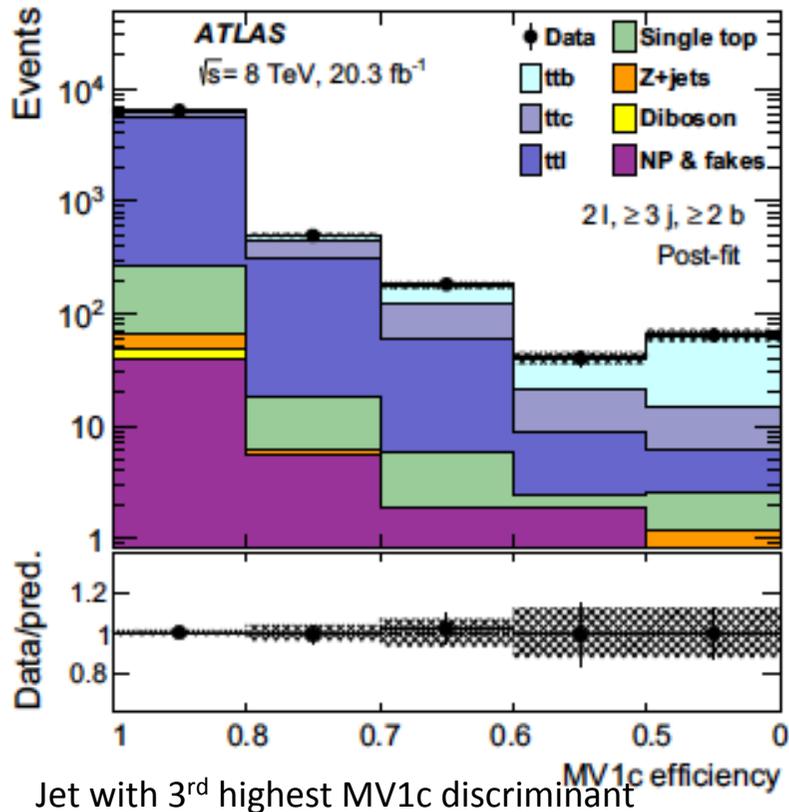
Object definitions:

Kinematic
definitions

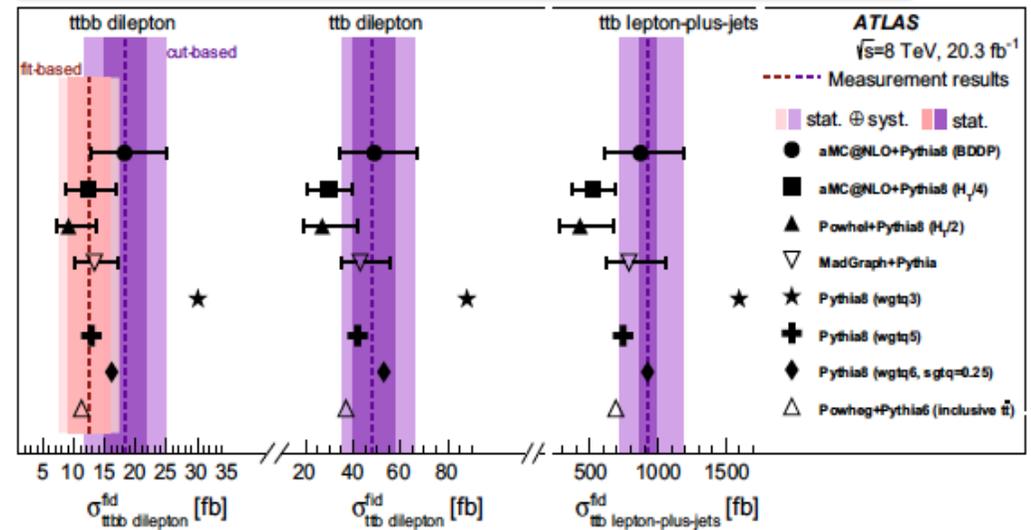
ttbb fiducial xsec

Based on pure particle level definitions

Measurement logic:
 b-, c- and light tagging known from calibration
 Xsecs of ttb, ttc, ttl derived from fit
 Take jet with 3rd highest MV1c discriminant as proxy

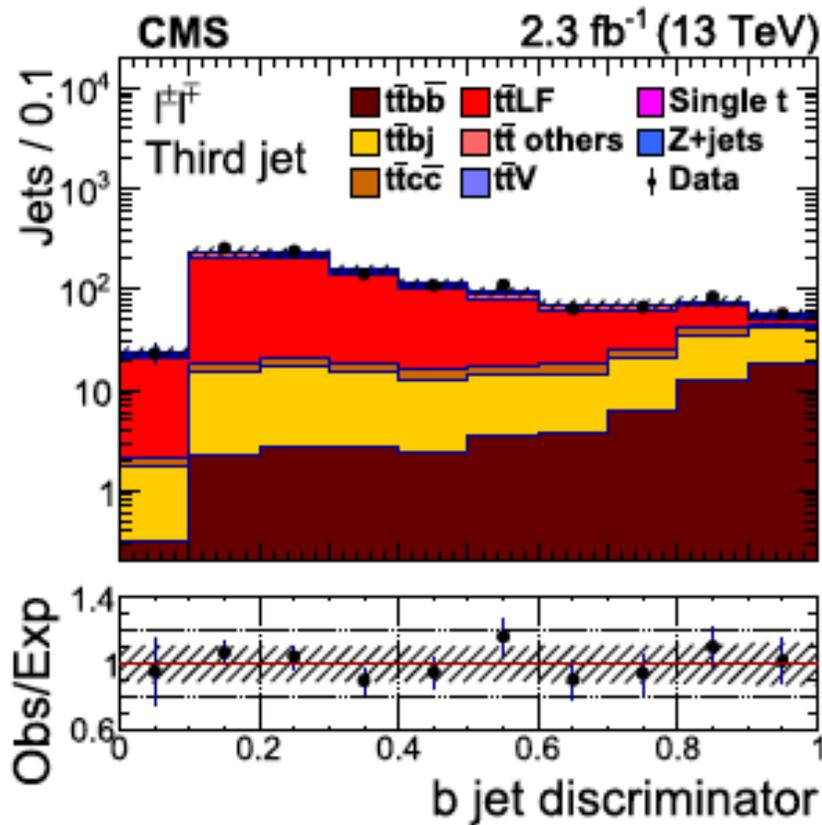


ttb $n_{\text{jets}} \geq 3$ and $n_{b\text{-jets}} \geq 3$
ttc $n_{\text{jets}} \geq 3$ and $n_{b\text{-jets}} \leq 2$ and $n_{c\text{-jets}} \geq 1$
ttl Other events



ttbb visible xsec

Based on pure particle level definitions



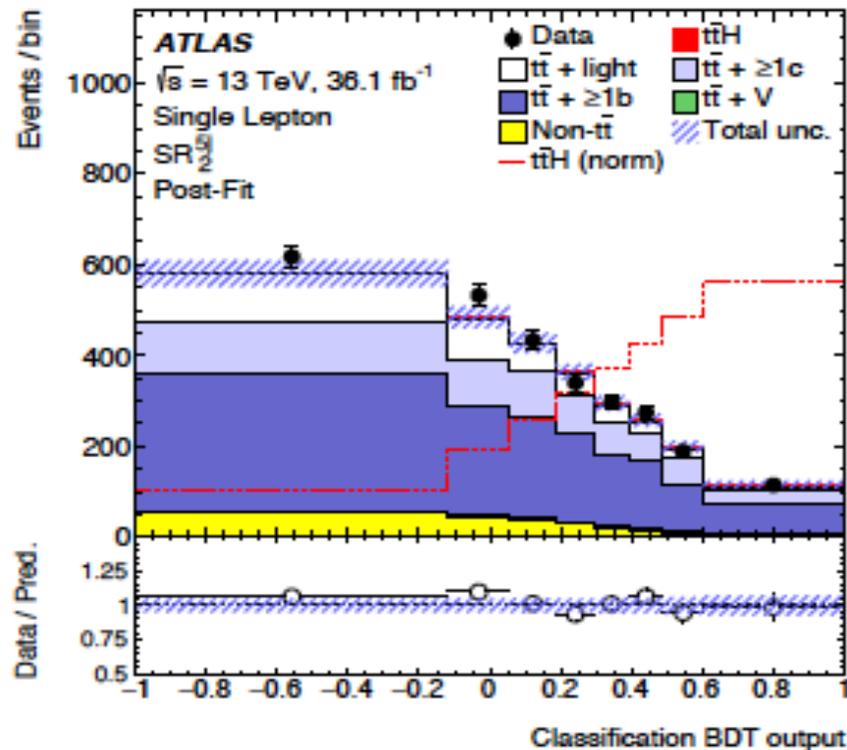
≥ 4 particle level jets within fiducial volume
 ttbb: ≥ 4 b-jets
 ttbj: 3 b-jets, ≥ 1 light jet
 ttcc: 2 b-jets, ≥ 1 cjet

Phase space		$\sigma_{t\bar{t}b\bar{b}}$ [pb]	$\sigma_{t\bar{t}ij}$ [pb]	$\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}ij}$
Visible	Measurement	$0.088 \pm 0.012 \pm 0.029$	$3.7 \pm 0.1 \pm 0.7$	$0.024 \pm 0.003 \pm 0.007$
	SM (POWHEG)	0.070 ± 0.009	5.1 ± 0.5	0.014 ± 0.001
Full	Measurement	$4.0 \pm 0.6 \pm 1.3$	$184 \pm 6 \pm 33$	$0.022 \pm 0.003 \pm 0.006$
	SM (POWHEG)	3.2 ± 0.4	257 ± 26	0.012 ± 0.001

Purer b-jets

$t\bar{t}Hb\bar{b}$: $t\bar{t}$ +jets classifications

use of parton level definitions



Consider only jets not from top decay, i.e.
 $T_{t+\geq 1b}$: ≥ 1 bjet not from top
 $T_{t+\geq 1c}$: ≥ 1 cjet not from top
 $T_{t+\text{light}}$: ≥ 1 light not from top

Selection: 5j, ≥ 3 b-tagged jets at reco level
Particle level event classification based on additional jet
Would a particle level selection reduce model uncertainty?

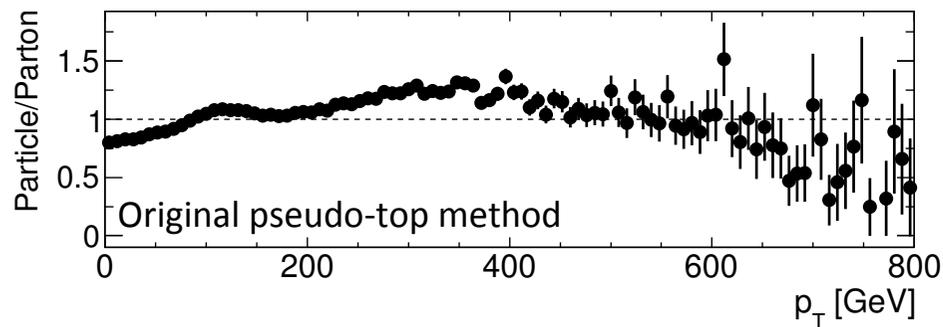
“Pseudo-top”

Approximating the top parton

Assumed top decay products:
2 highest p_T b-jets, lepton, 2 jets

Leptonic top:
b-jets with lowest $dR(\text{jet}, \text{lepton})$,
lepton, E_{tmiss}

Hadronic top:
Remaining b-jet,
2 light jets that best fit m_W



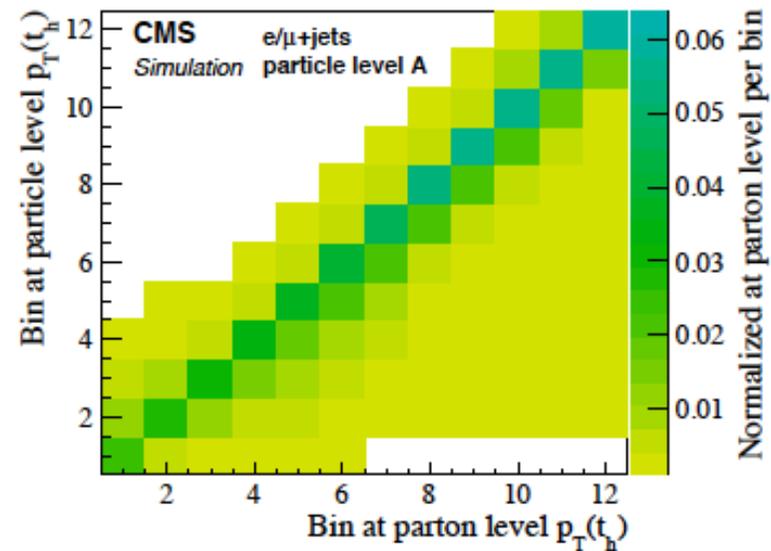
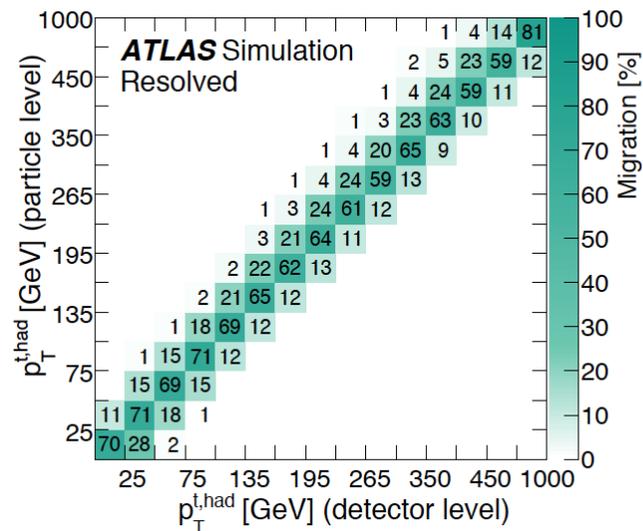
the same method is used on reconstructed objects and particle level objects

“Pseudo-top”

Approximating the top parton

Different methods tried with/without constraints on m_W and m_{top} to optimise for best

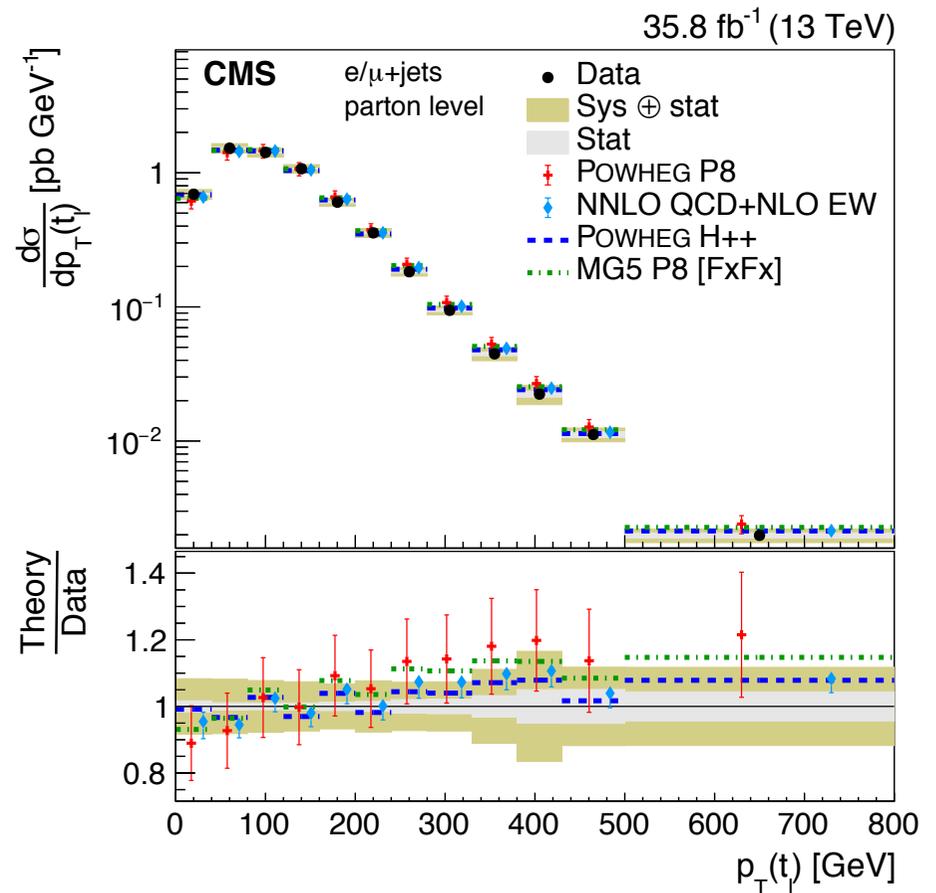
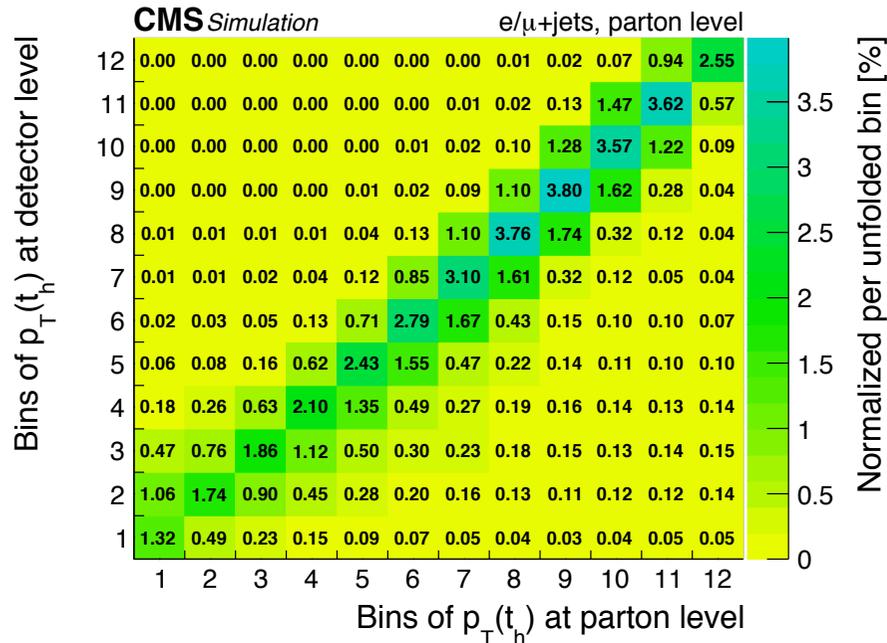
- particle – parton level correlation
- Particle – detector level correlation



Used for all differential $t\bar{t}$ measurements

Parton level

Not well defined for off-shell top production due to finite width
 -> larger model dependence
 No standard definition for top parton in event record
 But technically possible (take last top parton before decay)



ttbar+jets production

Measurements & MC

arXiv:1803.08856

arXiv:1708.00737

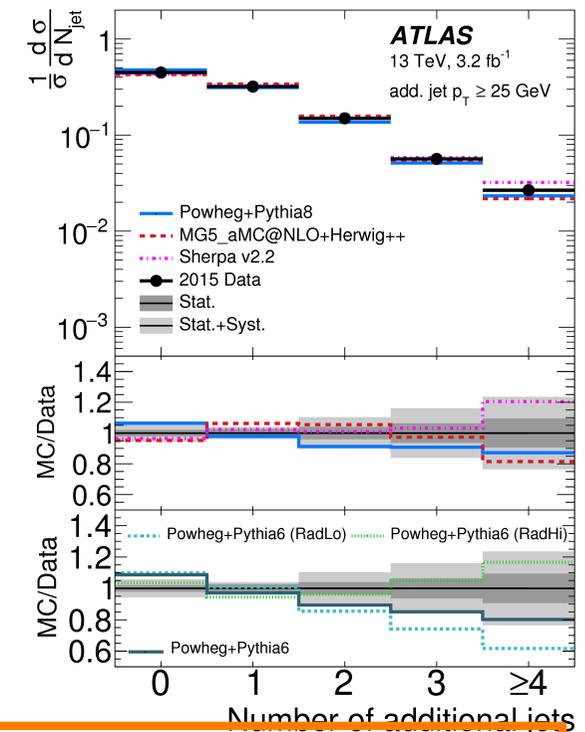
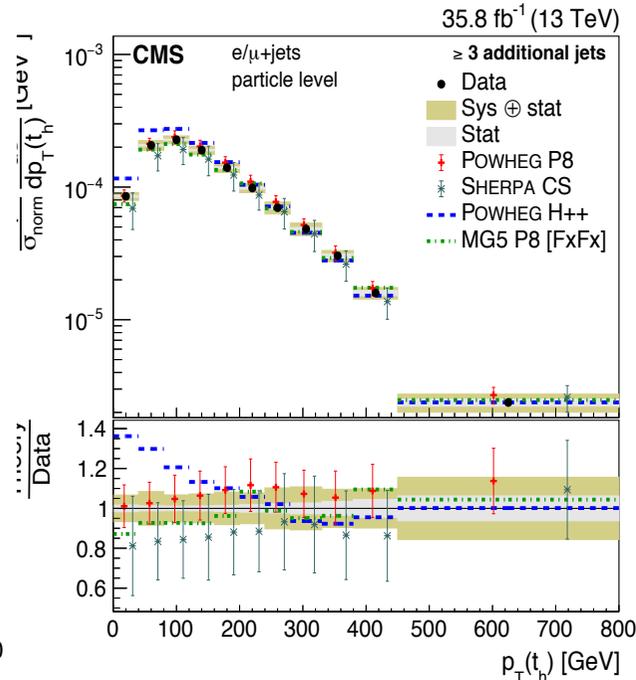
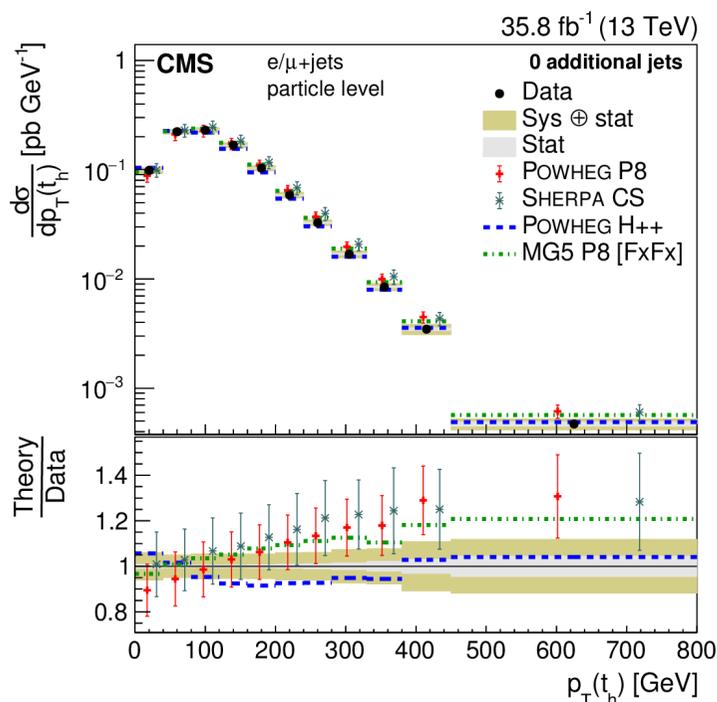
arXiv:1802.06572

arXiv:1610.09978

Measurements of top pair production differential in

- Njet, gap fraction, b-jet pT, additional jet pT
- top pT, ttbar pT, M_{ttbar} , Y_{ttbar} ..

Newest measurements presented in bins of jet multiplicity



Lots of data for inclusive ttbar and ttbar+jets production – confronted with lots of new MCs

ttbar+jets production

Measurements & MC

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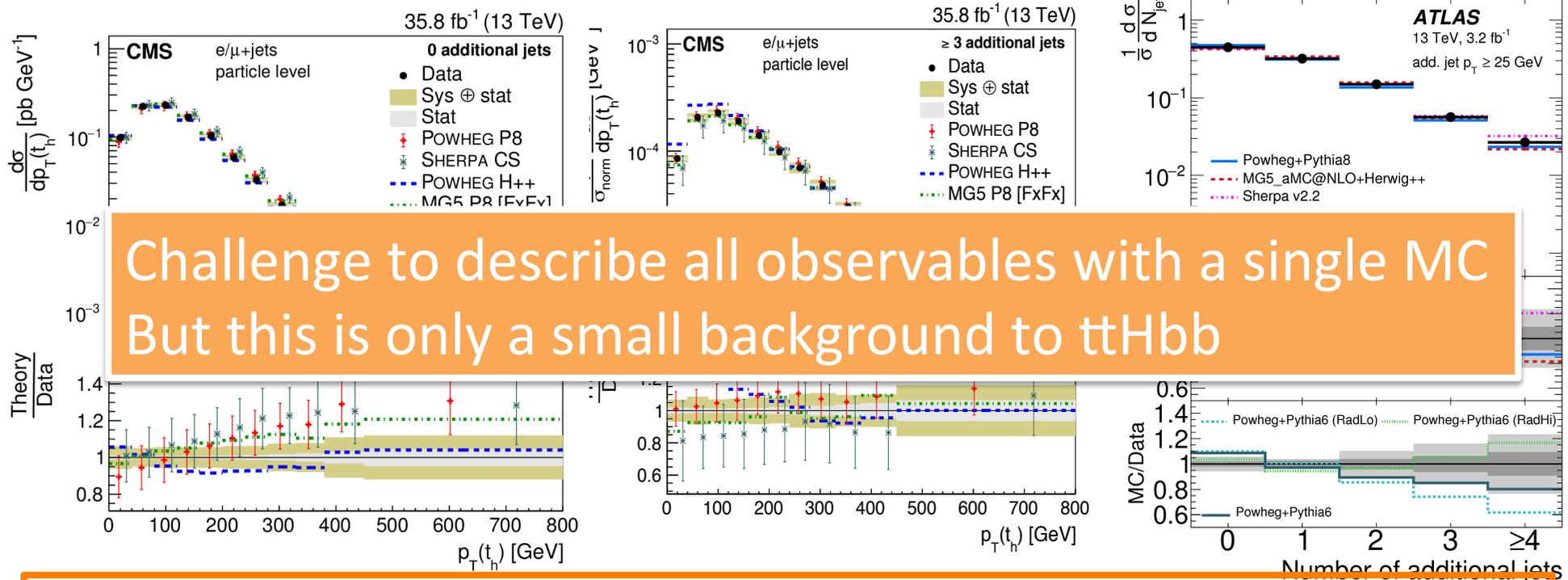
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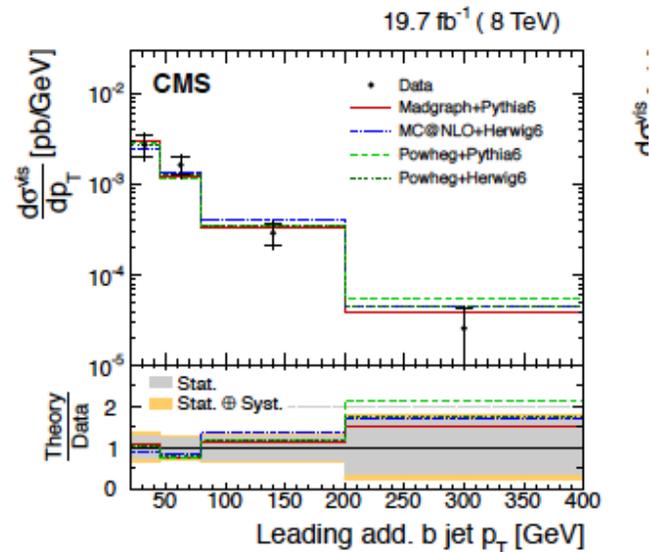


Challenge to describe all observables with a single MC
But this is only a small background to ttHbb

Lots of data for inclusive ttbar and ttbar+jets production – confronted with lots of new MCs

tt+HF production

Fiducial and inclusive xsec for ttb, ttbb production at 8 TeV and 13 TeV
Ratios of ttbb/ttjj at 8 TeV and 13 TeV
Differential xsec for ttb production but with large uncertainties



Very limited data for MC model comparison on ttbar+HF production

MC settings for ttHbb CMS

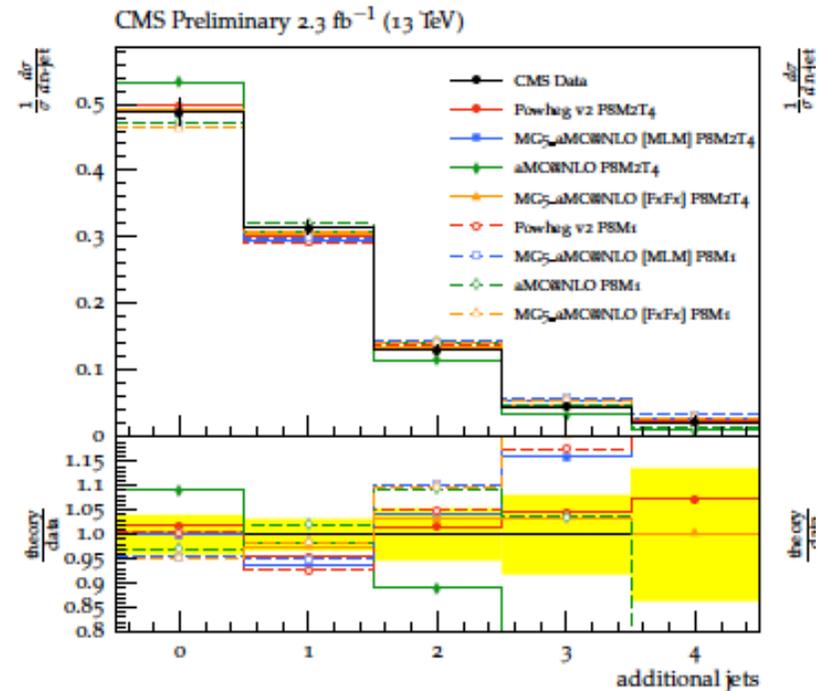
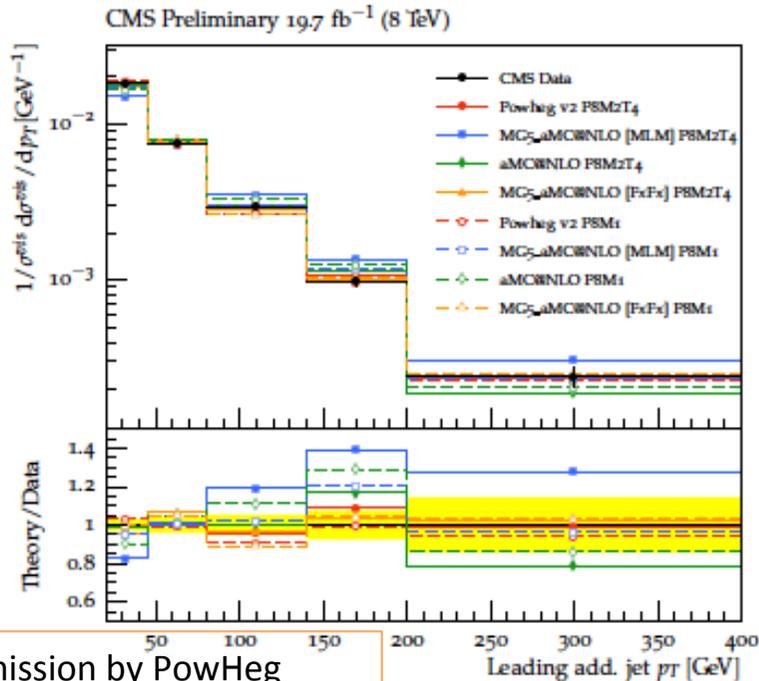
PowHeg + Pythia8 CUETP8M2T4 – special adaption for ttbar

Simultaneous tune of α_{ISR} + hdamp using Professor Tool

Data sets: differential ttbar production measurements @ 13 TeV+8 TeV (Njet, top pt, ttbar pt,....)

$$h_{damp} = 1.581^{+0.658}_{-0.585} \times m_t$$

$$\alpha_s^{ISR} = 0.1108^{+0.0145}_{-0.0142}$$

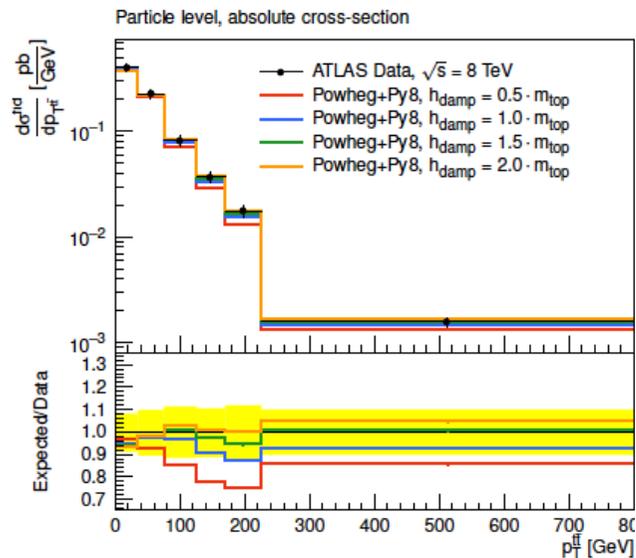


Real emission by PowHeg
 Damped with $h_{damp}^2 / (p_T^2 + h_{damp}^2)$

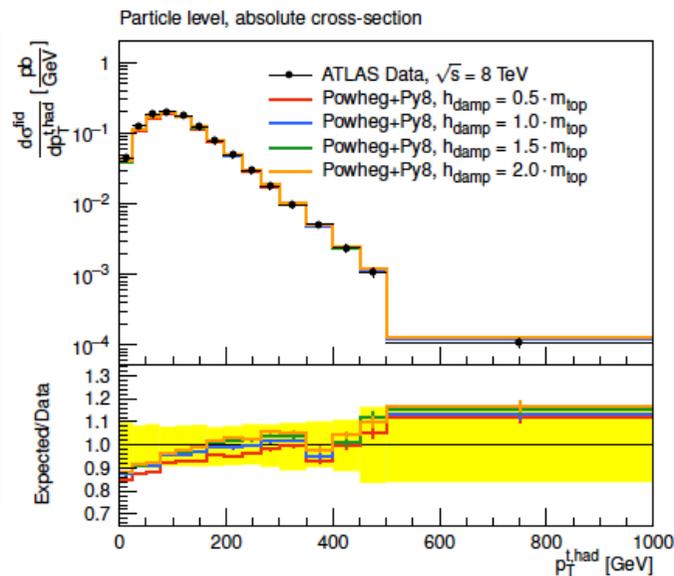
MC settings for ttHbb ATLAS

hdamp

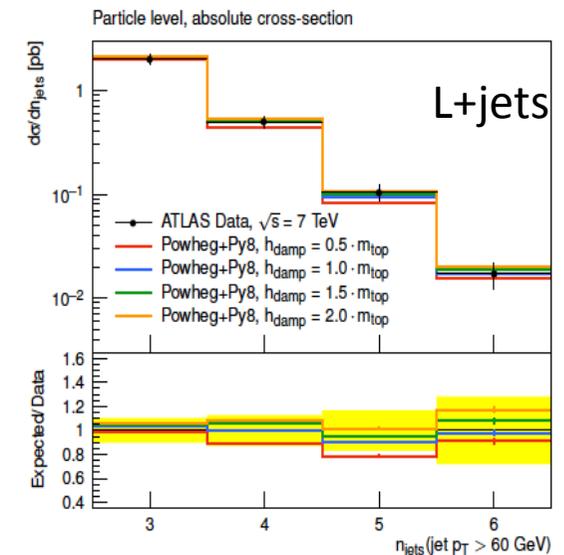
MC samples for most recent ttH papers were tuned to 7 and 8 TeV results



p_T of ttbar system used to set hdamp parameter

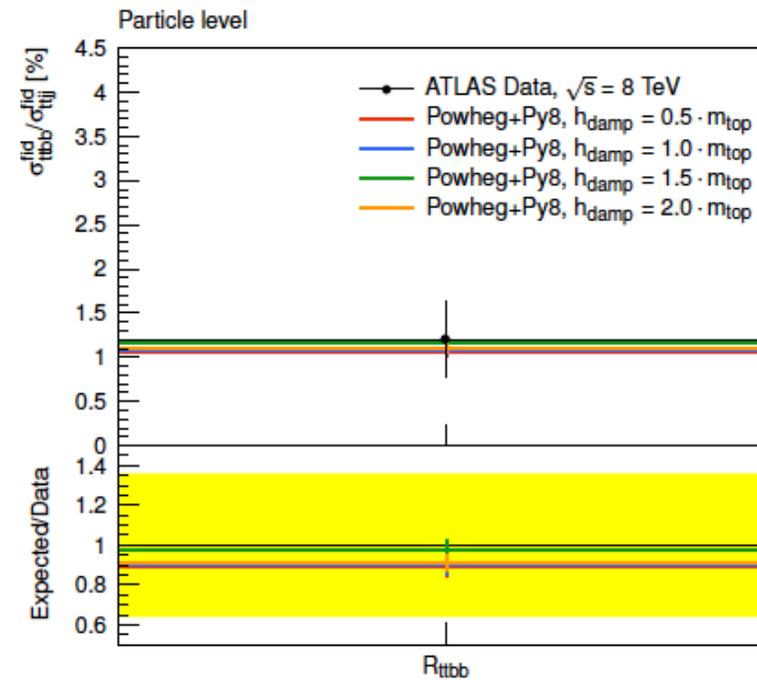
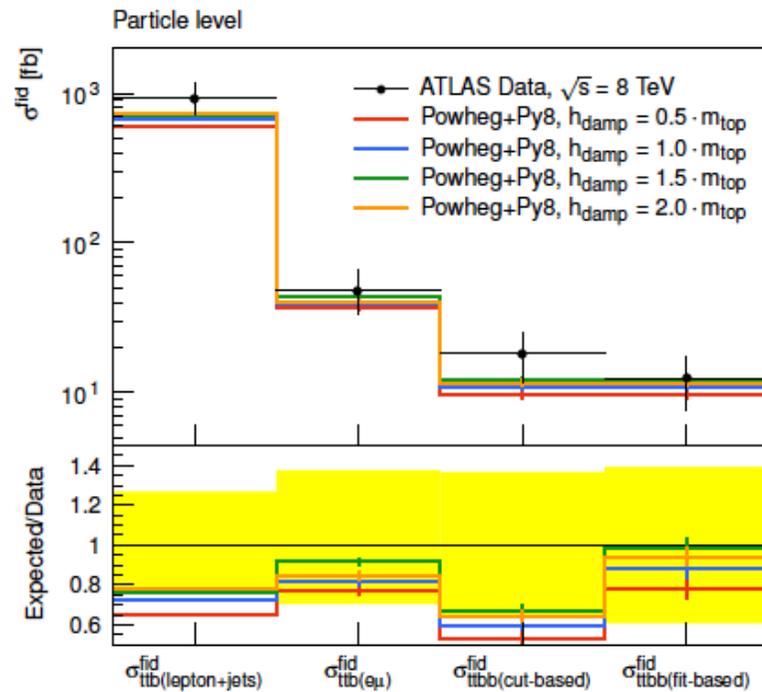


Basically no effect on top p_T

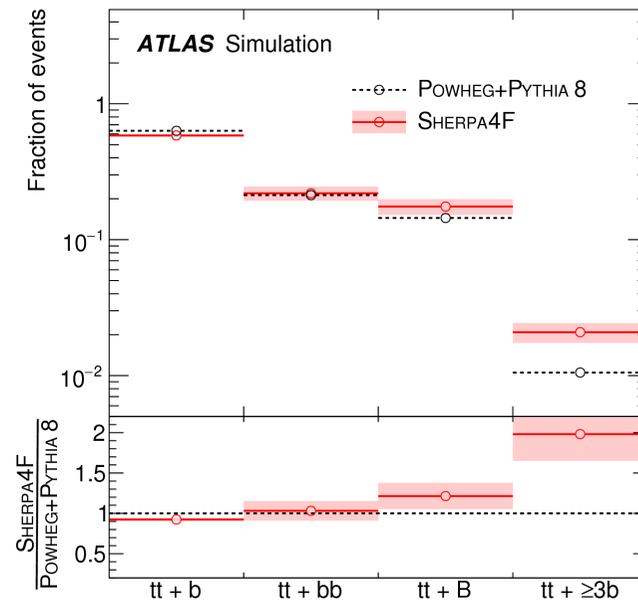


Some effect on N_{jets} , precision of 7 TeV data not good enough to discriminate

Effect of h_{damp} on $ttbb$

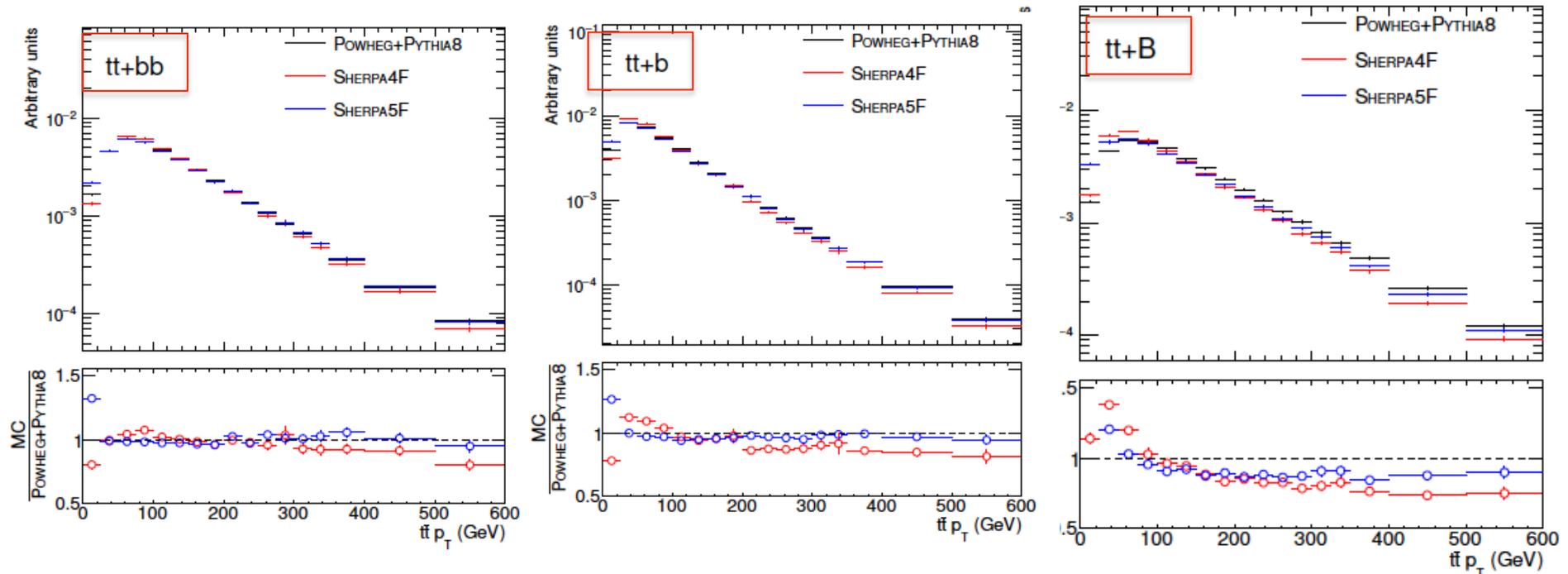


$t\bar{t}+b$ modeling for $t\bar{t}Hbb$



Differences of differential distributions in event categories

Thesis N.Asbah



$\sim <5\%$ difference

PP8 agrees with Sherpa5F
 $\sim 10\%$ difference between
 4F and 5F

Up to 40% difference

Similar observations also for other quantities (top p_T , p_T bb, HT)

Final state with 2 resolved additional b-jets seems less dependent on modelling details

New Observables for ttbb?

- Additional jets and b-jets at particle level
 - Simple in dilepton events but low stats
 - Requires top matching in l+jets: current particle level algorithms are designed for events with 2 bjets -> further development needed
- Top differential distributions in ttbb events

Summary

...mainly addressed questions from Mondays discussion

- Measurement definitions for $t\bar{t}$ xsec and $t\bar{t}Hbb$ differ
- MC used for $t\bar{t}Hbb$ tuned PowHeg+Py8 specifically for top events (no global tunes)
- Measurements for $t\bar{t}+HF$ needed to constrain and validate models

Back-up

Detailed event classification

Shorthand notation for the templates	Particle-level event requirements
<i>ttb</i> lepton-plus-jets	
<i>ttb</i>	$n_{\text{leptons}} = 1, n_{\text{jets}} \geq 5$ and $n_{b\text{-jets}} \geq 3$
<i>ttc</i>	$n_{\text{leptons}} = 1, n_{\text{jets}} \geq 5$ and $n_{b\text{-jets}} = 2$ and $n_{c\text{-jets}} \geq 1$
<i>ttl</i>	Other events
<i>ttb eμ</i>	
<i>ttb</i>	$n_{\text{jets}} \geq 3$ and $n_{b\text{-jets}} \geq 3$
<i>ttc</i>	$n_{\text{jets}} \geq 3$ and $n_{b\text{-jets}} \leq 2$ and $n_{c\text{-jets}} \geq 1$
<i>ttl</i>	Other events
<i>ttbb</i> dilepton fit-based	
<i>ttbb</i>	$n_{\text{jets}} \geq 4$ and $n_{b\text{-jets}} \geq 4$
<i>ttbX</i>	$n_{b\text{-jets}} = 3$
<i>ttcX</i>	$n_{b\text{-jets}} = 2$ and $n_{c\text{-jets}} \geq 1$
<i>ttlX</i>	Other events

ttbb classifications

ttbb xsecs = pure particle level definitions

Jet based classification

Signal:

ttb:1l, ≥ 5 jets, ≥ 3 bjets

ttbb: 2l, ≥ 4 jets, ≥ 2 b-jets

Background:

ttc:1l, 2b-jets, ≥ 1 c-jet

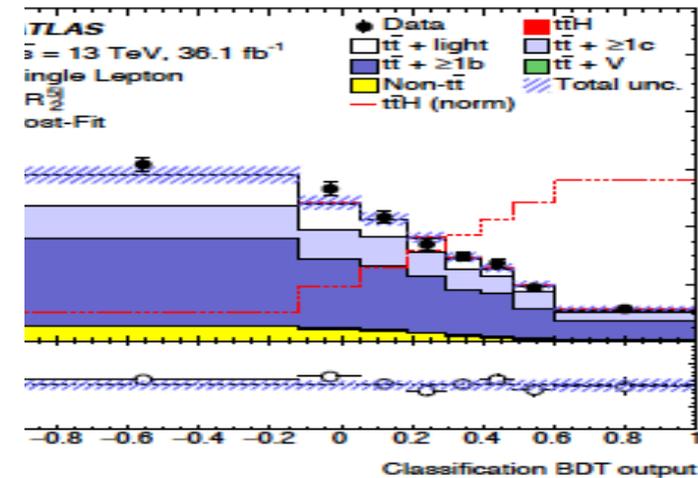
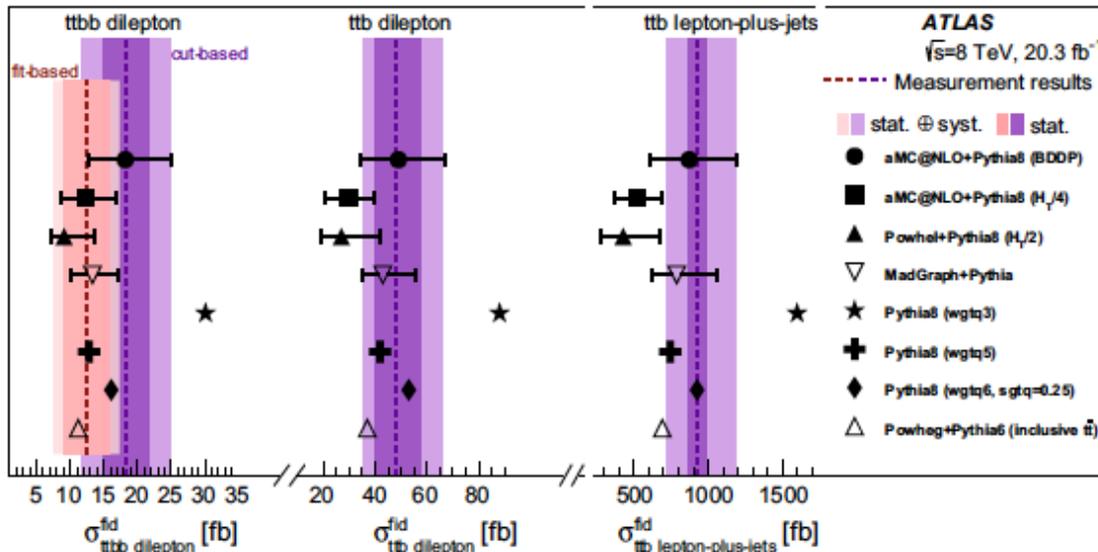
ttHbb = use of parton level definitions

Jet definition on particle level as for top xsec, but consider only jets not from top decay, i.e.

ttb: 1 bjet not from top

Ttbb: 2 b-jets not from top

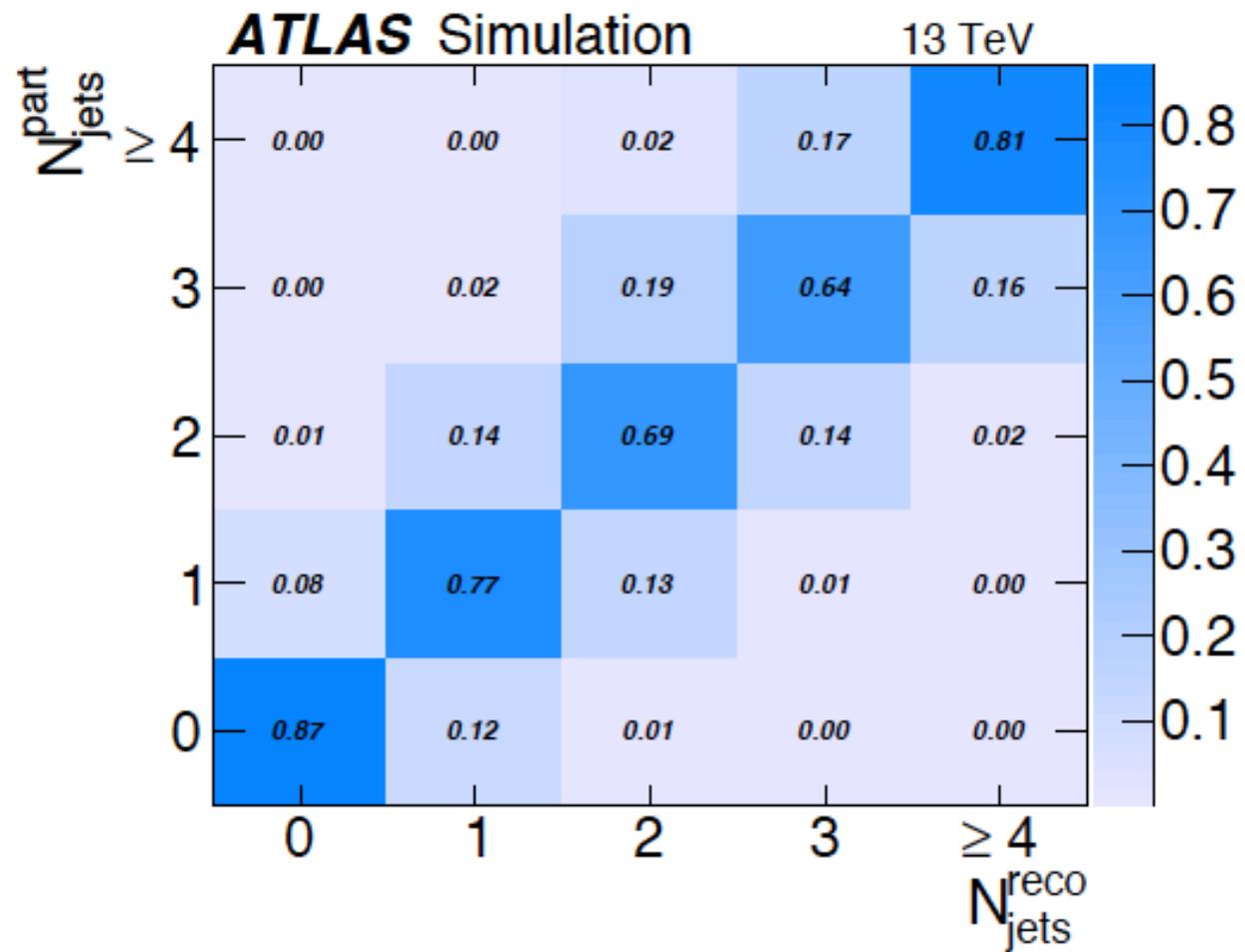
ttB/tt2b: 1 bjet with 2 hadrons not from top

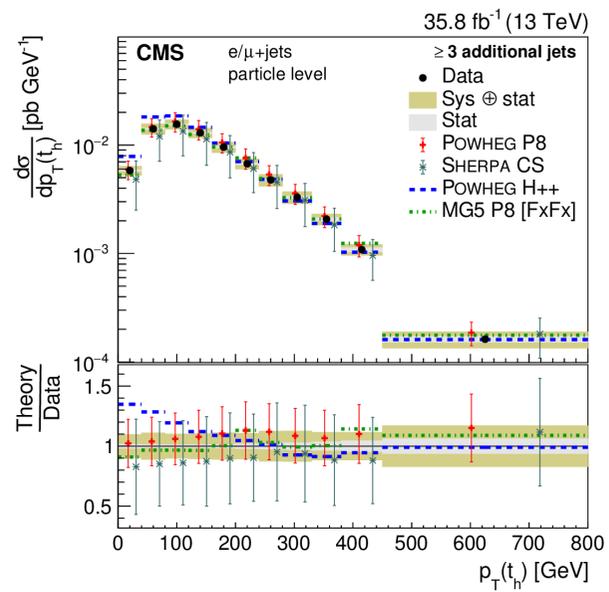
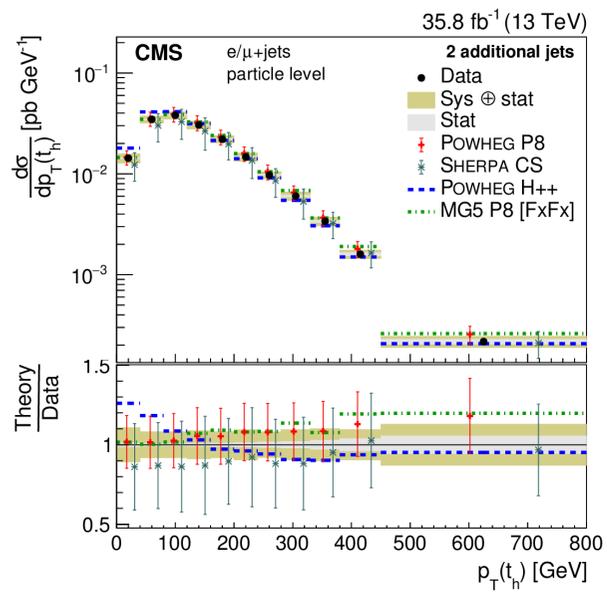
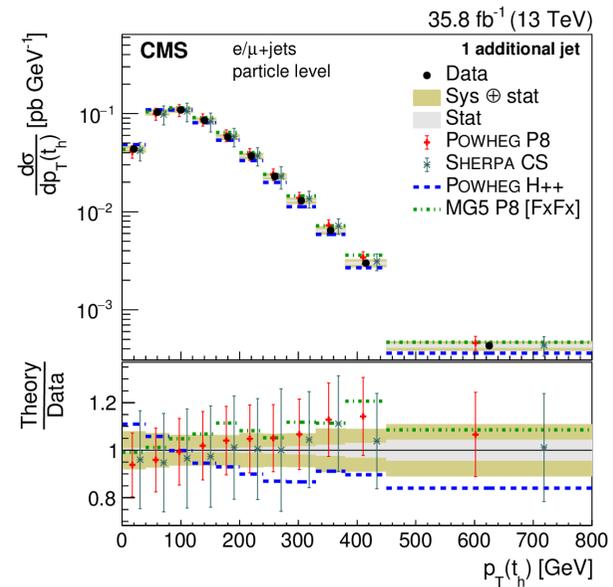
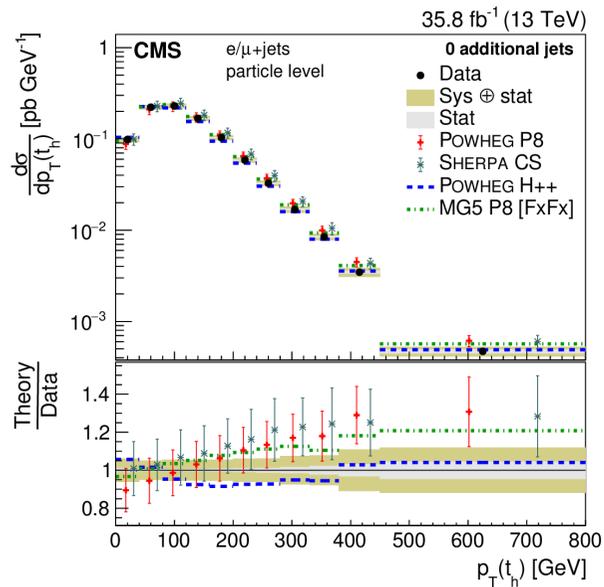


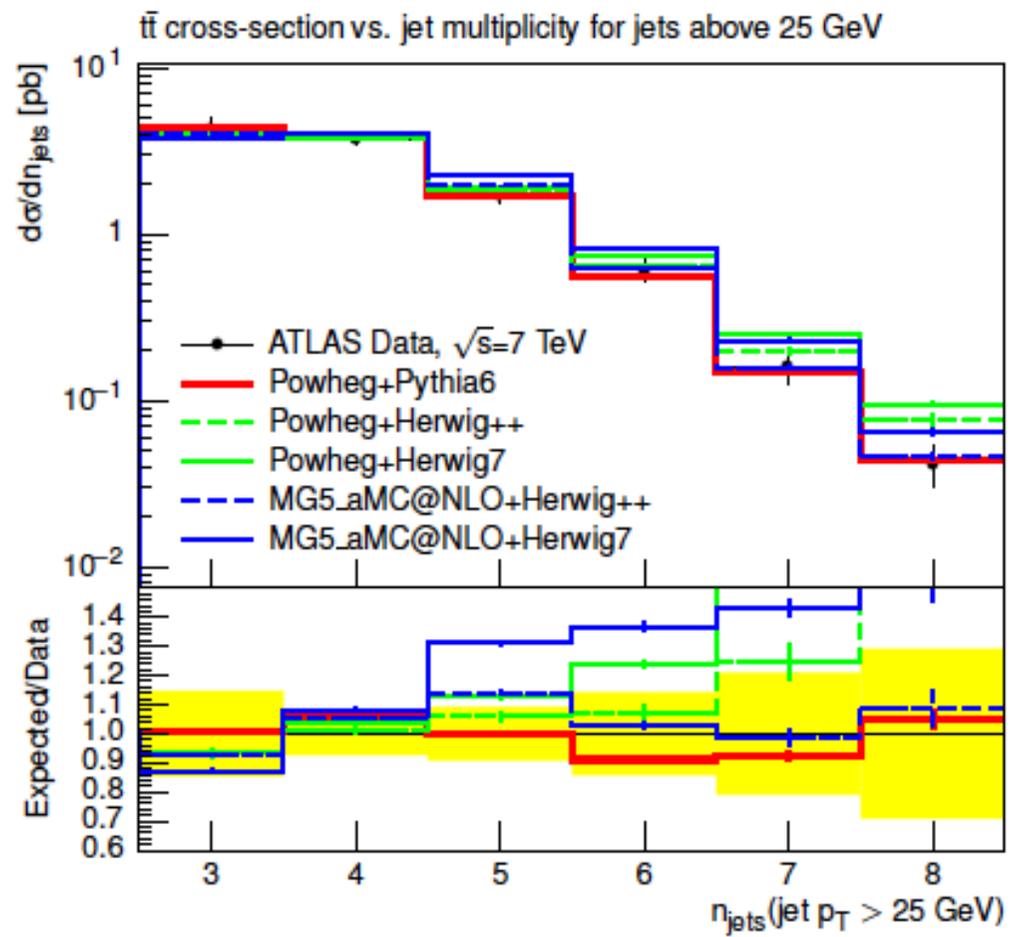
Xsec to find 3(4) particle level b-jets in top events

article level event selection

Classification allows for 2bjet events being tt







Data sets for CUETP8M2T4

Channel	Quantities	\sqrt{s} (TeV)	Int. Lum. (fb^{-1})	Analysis [RIVET] [Reference]
lepton+jets	$p_T(t_h), y(t_h) , p_T(t_\ell), y(t_\ell) $ $p_T(\bar{t}\bar{t}), y(\bar{t}\bar{t}) , M(\bar{t}\bar{t}), N_{\text{add-j}}$	13	2.3	A [CMS_2016_I1434354] [8]
dilepton	$N_j > 30, 60, 100 \text{ GeV}$ p_T^{j1}, p_T^{j2} $m(jj), \Delta R(jj)$ p_T^{bj1}, p_T^{bj2} $m(bb), \Delta R(bb)$ **** $(p_T^{j1}, p_T^{j2}, H_T) \text{ vs}$ GF(inclusive) GF($ \eta < 0.8$) GF($0.8 < \eta < 1.5$) GF($1.5 < \eta < 2.4$)	8	19.7	B [CMS_2015_I1397174] [18]
lepton+jets	MET, H_T, S_T, p_T^W	8	19.7	C [CMS_2016_I1473674] [19]
lepton+jets	$p_T^l, y_l, p_T^{ij}, y_{ij}$	8	19.7	D [CMS_2015_I1388555] [20]
lepton+jets	$N_j > 30 \text{ GeV}$	8	19.7	E [21]