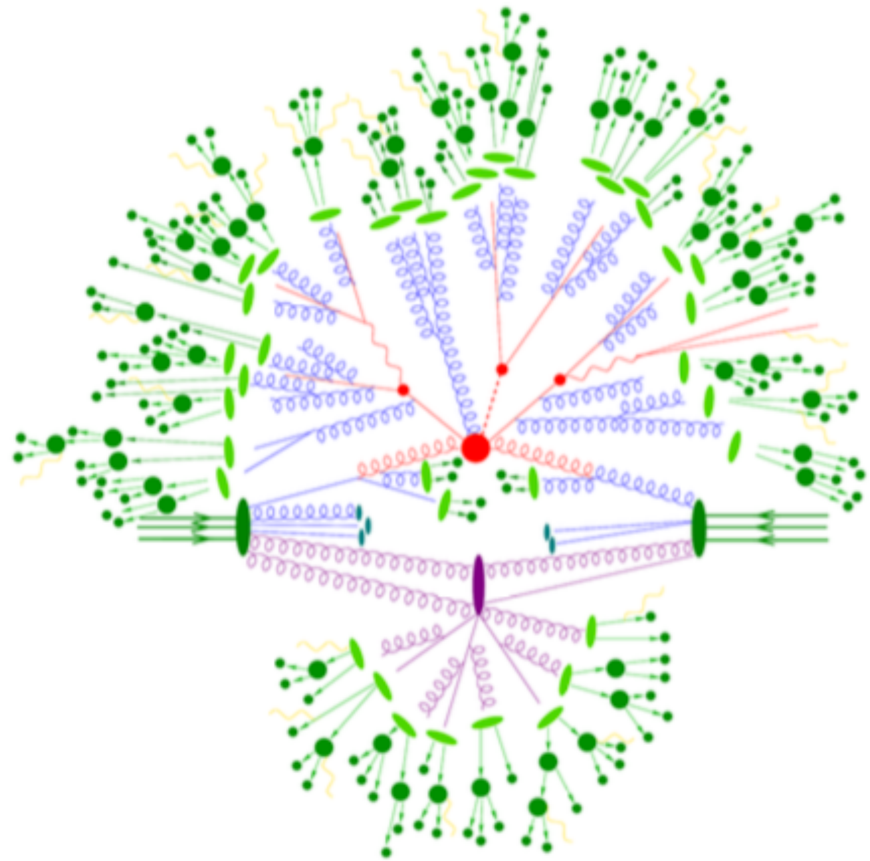
12th International Workshop on TOP Quark Physics
24th September 2019 - Beijing

Modelling and Tuning (ttbar) in ATLAS and CMS

C. Mackay – Brunel University London
On behalf of the ATLAS & CMS Collaborations

Overview

- Importance of top modelling
- Modelling top production
- Modelling in ATLAS & CMS
- Testing the models
  - Measurement of top quark pair differential and double-differential distributions and cross sections in $t\bar{t}$ events
  - Studying the underlying event
  - Extraction and validation of new tunes from underlying-event measurements
- Looking to the future
  - A common MC setup

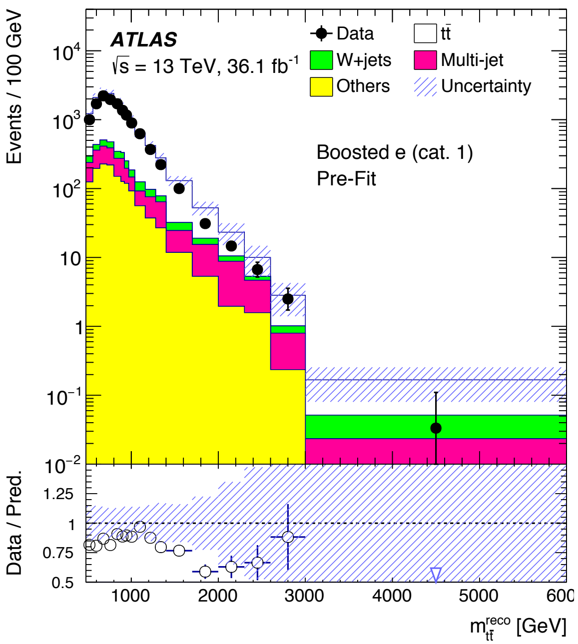


Importance of top modelling

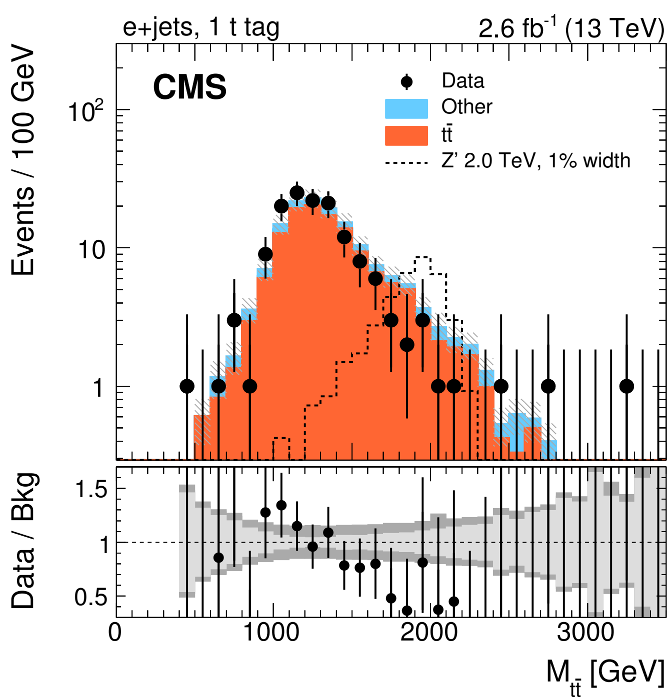
Reduce the uncertainties in our measurements:

- To reduce the uncertainty further must improve the systematical component

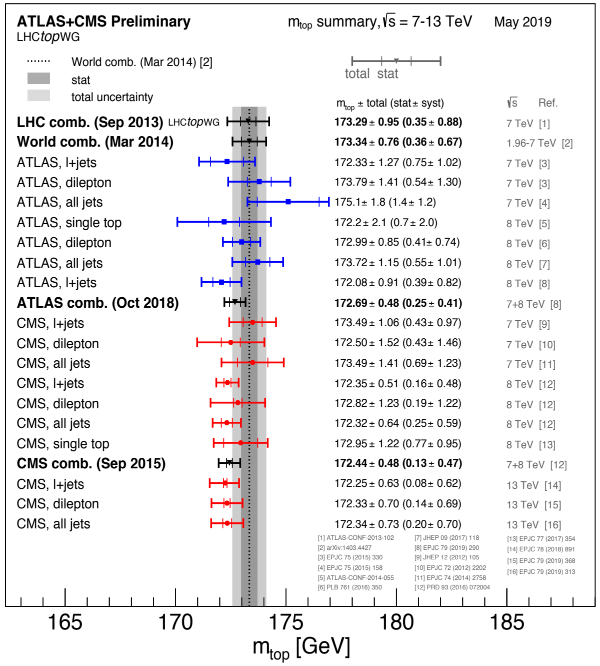
Search for rare processes in less understood regions and extreme phase space: Exotics searches for resonance to ttbar decay



Eur. Phys. J. C78 (2018) 565, https://arxiv.org/abs/1804.10823



JHEP 07 (2017) 001, https://arxiv.org/abs/1704.03366



https://twiki.cern.ch/twiki/bin/view/LHCPhysics/TopMassHistory

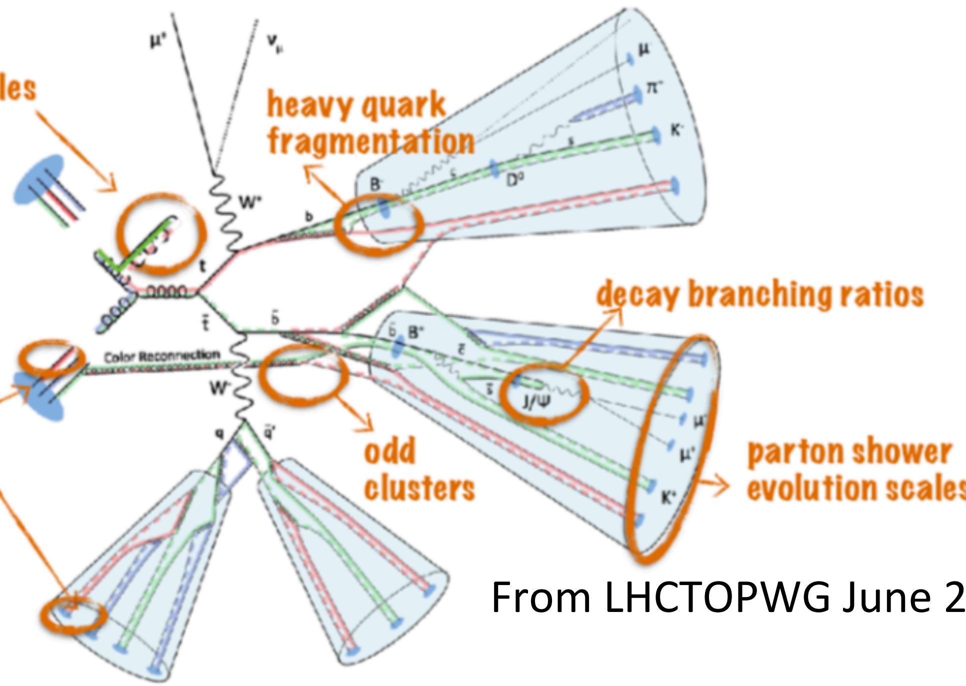
Dominant systematics from MC modelling

Modelling top production

Tuning for tt simulation
ATL-PHYS-PUB-2018-009
ATL-PHYS-PUB-2017-007
CMS-PAS-TOP-16-021

Measuring jet substructure observables
Phys. Rev. D 98, 092014 (2018)

Colour reconnection models
ATL-PHYS-PUB-2017-008
Eur. Phys. J. C 78 (2018) 891



Study of underlying event
Eur. Phys. J. C 79 (2019) 123

From LHCTOPWG June 2017

Top specific tunes
JHEP 06 (2018) 002
CMS-PAS-TOP-16-021

Interference effects
Phys. Rev. Lett. 121 (2018) 152002

Links given in backup

Modelling $t\bar{t}$ in ATLAS & CMS

CMS DP-2019/011 , http://cdsweb.cern.ch/record/2678959

Both experiments use POWHEG-BoxV2 with default scales $\mu_R = \mu_F = \sqrt{(m_t^2 + p_T^2)}$ and slightly different settings:

Showering + hadronization

- Pythia8 v2.30 (settings in backup)
- **ATLAS** EvtGen for decay of HF particles with custom decay tables
- **CMS** Pythia for all decays
- Own dedicated tunes
  ATLAS A14
  CMS CP
- Different PDF sets
  ATLAS NNPDF 2.3 Leading Order
  CMS NNPDF 3.1 Next-to-Next-to Leading Order
  Use different values and orders of running α_S

Setting Name	Setting description	CMS default	ATLAS default
qmass	top-quark mass [GeV]	172.5	172.5
twidth	top-quark width [GeV]	1.31	1.32
hdamp	first emission damping parameter [GeV]	237.8775	258.75
wmass	$W^{\pm}$ mass [GeV]	80.4	80.3999
wwidth	$W^{\pm}$ width [GeV]	2.141	2.085
bmass	b-quark mass [GeV]	4.8	4.95
cmass	c-quark mass [GeV]	1.5	1.55
smass	s-quark mass [GeV]	0.2	0.5
dmass	d-quark mass [GeV]	0.1	0.32
umass	u-quark mass [GeV]	0.1	0.32
taumass	τ mass [GeV]	1.777	1.777
mumass	μ mass [GeV]	0.1057	0.1057
emass	e mass [GeV]	0.00051	0.00051
elbranchin	W-boson electronic branching fraction	0.108	0.1082
sin2cabibbo	quark mixing angle	0.051	0.051

Modelling $t\bar{t}$ in ATLAS & CMS Tunes

ATL-PHYS-PUB-2014-021, https://cds.cern.ch/record/1966419

Submitted to EPJC, https://arxiv.org/abs/1903.12179

ATLAS Pythia8 A14 tunes @ 8TeV

Parameter	Definition	Sampling range
SigmaProcess:alphaSvalue	The α_S value at scale $Q^2 = M_Z^2$	0.12 – 0.15
SpaceShower:pT0Ref	ISR p_T cutoff	0.75 – 2.5
SpaceShower:pTmaxFudge	Mult. factor on max ISR evolution scale	0.5 – 1.5
SpaceShower:pTdampFudge	Factorisation/renorm scale damping	1.0 – 1.5
SpaceShower:alphaSvalue	ISR α_S	0.10 – 0.15
TimeShower:alphaSvalue	FSR α_S	0.10 – 0.15
BeamRemnants:primordialKThard	Hard interaction primordial $k_\perp$	1.5 – 2.0
MultipartonInteractions:pT0Ref	MPI p_T cutoff	1.5 – 3.0
MultipartonInteractions:alphaSvalue	MPI α_S	0.10 – 0.15
BeamRemnants:reconnectRange	CR strength	1.0 – 10.0

CTEQ, MSTW, NNPDF, HERA LO PDF sets
Extracted by varying 10 parameters
Fitting UE and min bias at 7 TeV

Param	CTEQ	MSTW	NNPDF	HERA
SigmaProcess:alphaSvalue	0.144	0.140	0.140	0.141
SpaceShower:pT0Ref	1.30	1.62	1.56	1.61
SpaceShower:pTmaxFudge	0.95	0.92	0.91	0.95
SpaceShower:pTdampFudge	1.21	1.14	1.05	1.10
SpaceShower:alphaSvalue	0.125	0.129	0.127	0.128
TimeShower:alphaSvalue	0.126	0.129	0.127	0.130
BeamRemnants:primordialKThard	1.72	1.82	1.88	1.83
MultipartonInteractions:pT0Ref	1.98	2.22	2.09	2.14
MultipartonInteractions:alphaSvalue	0.118	0.127	0.126	0.123
BeamRemnants:reconnectRange	2.08	1.87	1.71	1.78

CMS Pythia8 CP tunes @ 13 TeV

Parameter description	Name in PYTHIA8	Range considered
MPI threshold [GeV], pT0Ref, at $\sqrt{s} = \sqrt{s_0}$	MultipartonInteractions:pT0Ref	1.0–3.0
Exponent of $\sqrt{s}$ dependence, ϵ	MultipartonInteractions:ecmPow	0.0–0.3
Matter fraction contained in the core	MultipartonInteractions:coreFraction	0.1–0.95
Radius of the core	MultipartonInteractions:coreRadius	0.1–0.8
Range of color reconnection probability	ColorReconnection:range	1.0–9.0

NNPDF3.1 LO/NLO/NNLO PDF sets and α_s for ME and shower as inputs
Extracted by varying 5 parameters
Fitting UE observables at 1.96, 7 & 13 TeV, min bias at 1.96 & 7 TeV
CP1 & CP2 LO tune in backup

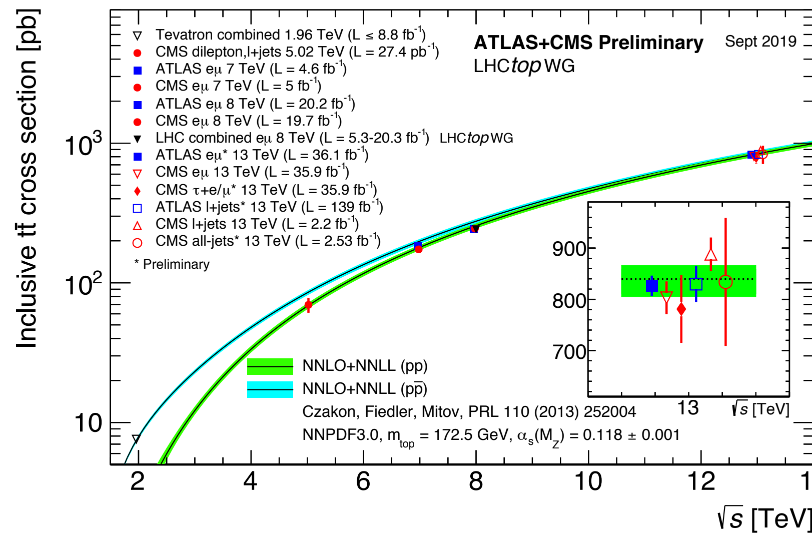
PYTHIA8 parameter	CP3	CP4	CP5
PDF Set	NNPDF3.1 NLO	NNPDF3.1 NNLO	NNPDF3.1 NNLO
$\alpha_S(m_Z)$	0.118	0.118	0.118
SpaceShower:rapidityOrder	off	off	on
MultipartonInteractions:EcmRef [GeV]	7000	7000	7000
$\alpha_S^{ISR}(m_Z)$ value/order	0.118/NLO	0.118/NLO	0.118/NLO
$\alpha_S^{FSR}(m_Z)$ value/order	0.118/NLO	0.118/NLO	0.118/NLO
$\alpha_S^{MPI}(m_Z)$ value/order	0.118/NLO	0.118/NLO	0.118/NLO
$\alpha_S^{ME}(m_Z)$ value/order	0.118/NLO	0.118/NLO	0.118/NLO
MultipartonInteractions:pT0Ref [GeV]	1.52	1.48	1.41
MultipartonInteractions:ecmPow	0.02	0.02	0.03
MultipartonInteractions:coreRadius	0.54	0.60	0.76
MultipartonInteractions:coreFraction	0.39	0.30	0.63
ColorReconnection:range	4.73	5.61	5.18
χ^2/dof	0.76	0.80	1.04

*Hadronization and beam remnants fixed to Monash tune

Testing the models

Large $t\bar{t}$ cross section at LHC allowing:

- detailed studies of the properties of top quark production and decay
- precision tests of the models



- Lepton differential distributions in dilepton events and lepton + jets (ATLAS)

Submitted to EPJC, https://arxiv.org/abs/1908.07305

ATLAS CONF-2019-041 , http://cdsweb.cern.ch/record/2686255

- Study of underlying-event and extraction of tunes (CMS)

Eur. Phys. J. C 79 (2019) 123, https://arxiv.org/abs/1807.02810

Submitted to EPJC, https://arxiv.org/abs/1903.12179

Differential distributions & cross sections

ATLAS CONF-2019-041 , http://cdsweb.cern.ch/record/2686255

Submitted to EPJC, https://arxiv.org/abs/1908.07305

Detailed information in Véronique's talk

Dilepton

	Matrix element	PDF	Parton shower/tune	Comments
1	POWHEG	NNPDF3.0	PYTHIA8 A14	$h_{\text{damp}} = \frac{3}{2}m_t$
	POWHEG	CT10	PYTHIA6 P2012	$h_{\text{damp}} = m_t$
	POWHEG	NNPDF3.0	HERWIG7 H7UE	$h_{\text{damp}} = \frac{3}{2}m_t$
	POWHEG	NNPDF3.0	PYTHIA8 A14	top quark p_T reweighted to [87]
2	POWHEG	NNPDF3.0	PYTHIA8 A14v3cDo	$h_{\text{damp}} = \frac{3}{2}m_t$, $2\mu_{F,R}$ (RadDn)
	POWHEG	NNPDF3.0	PYTHIA8 A14v3cUp	$h_{\text{damp}} = 3m_t$, $\frac{1}{2}\mu_{F,R}$ (RadUp)
	POWHEG	NNPDF3.0	PYTHIA8 A14	$h_{\text{damp}} = \frac{3}{2}m_t$, $2\mu_{F,R}$
	POWHEG	NNPDF3.0	PYTHIA8 A14	$h_{\text{damp}} = \frac{3}{2}m_t$, $\frac{1}{2}\mu_{F,R}$
3	POWHEG	NNPDF3.0	PYTHIA8 A14	$h_{\text{damp}} = \frac{3}{2}m_t$
	POWHEG	PDF4LHC15	PYTHIA8 A14	$h_{\text{damp}} = \frac{3}{2}m_t$
	POWHEG	CT14	PYTHIA8 A14	$h_{\text{damp}} = \frac{3}{2}m_t$
	POWHEG	MMHT	PYTHIA8 A14	$h_{\text{damp}} = \frac{3}{2}m_t$
4	aMC@NLO	NNPDF3.0	PYTHIA8 A14	
	aMC@NLO	CT10	PYTHIA8 A14	
	aMC@MLO	HERAPDF2.0	PYTHIA8 A14	

CMS Lepton + jets

CUETP8M2 $t\bar{t}$ Tune

	POWHEG+PYTHIA 8			POWHEG+HERWIG 7	SHERPA 2	DIRE 2
	FSR-down	Nominal	FSR-up			
$t\bar{t}$ production	NLO	NLO	NLO	NLO	NLO	LO
t/W decay	NLO	NLO	NLO	NLO	LO	LO
Decay emission	LO	LO	LO	LO	LL	nLL
Shower accuracy	LL	LL	LL	LL	LL	nLL
$\alpha_S^{\text{FSR}}(m_Z)$	0.1224	0.1365	0.1543	0.1262	0.118	0.1201
Evolution	One-loop	One-loop	One-loop	Two-loop	Two-loop	Two-loop
Scheme	$\overline{\text{MS}}$	$\overline{\text{MS}}$	$\overline{\text{MS}}$	$\overline{\text{MS}}$	CMW	$\overline{\text{MS}}$

Phys. Rev. D. 98 (2018) 092014 https://journals.aps.org/prd/abstract/10.1103/PhysRevD.98.092014

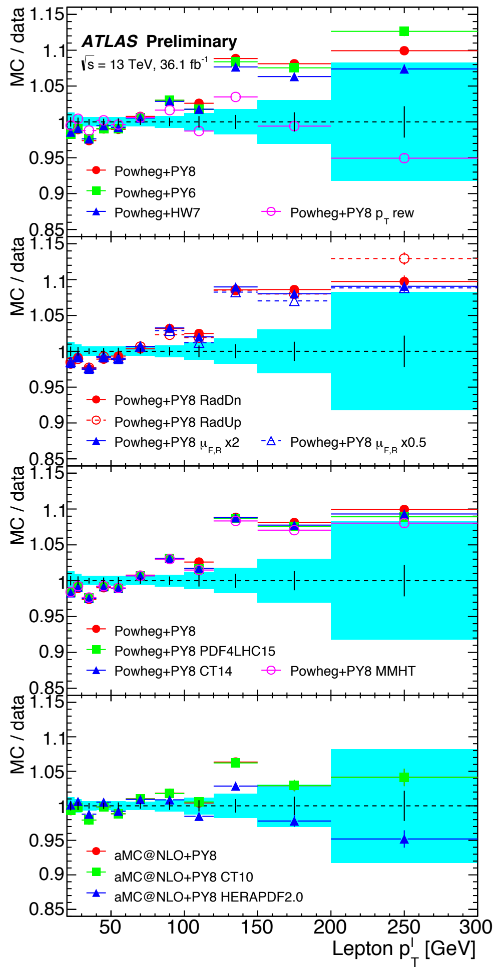
Lepton + jets channels

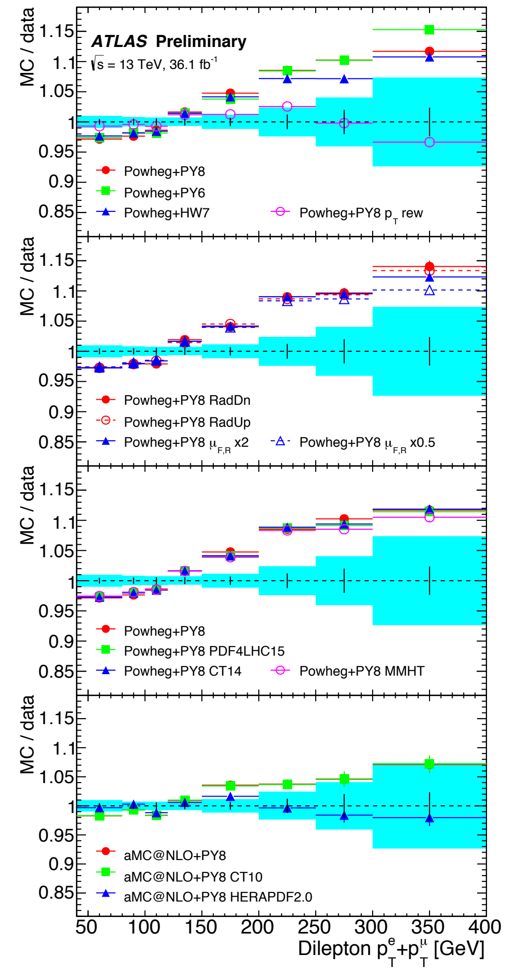
Physics process	Generator	PDF set for hard process	Parton shower	Tune	Cross-section normalisation
$t\bar{t}$ signal	POWHEG-BOX v2	NNPDF3.0NLO	PYTHIA 8.186	A14	NNLO +NNLL
$t\bar{t}$ PS syst.	POWHEG-BOX v2	NNPDF3.0NLO	HERWIG7.0.1	H7-UE-MMHT	NNLO +NNLL
$t\bar{t}$ generator syst.	SHERPA 2.2.1	NNPDF3.0NNLO	SHERPA	SHERPA	NNLO +NNLL
$t\bar{t}$ rad. syst.	POWHEG-BOX v2	NNPDF3.0NLO	PYTHIA 8.186	Var3cDown/Var3cUp	NNLO +NNLL
Single top: t-channel	POWHEG-BOX v1	CT10f4	PYTHIA 6.428	Perugia2012	NLO
Single top: t-channel syst.	POWHEG-BOX v1	CT10f4	PYTHIA 6.428	Perugia2012 radHi/radLo	NLO
Single top: s-channel	POWHEG-BOX v1	CT10	PYTHIA 6.428	Perugia2012	NLO
Single top: tW channel	POWHEG-BOX v1	CT10	PYTHIA 6.428	Perugia2012	NLO +NNLL
Single top: tW channel syst.	POWHEG-BOX v1	CT10	PYTHIA 6.428	Perugia2012 radHi/radLo	NLO +NNLL
Single top: tW channel DS	POWHEG-BOX v1	CT10	PYTHIA 6.428	Perugia2012	NLO +NNLL
$t + X$	MADGRAPH5	NNPDF2.3LO	PYTHIA 8.186	A14	NLO
$W(\to \ell\nu)+$ jets	SHERPA 2.2.1	NNPDF3.0NNLO	SHERPA	SHERPA	NNLO
$Z(\to \ell\bar{\ell})+$ jets	SHERPA 2.2.1	NNPDF3.0NNLO	SHERPA	SHERPA	NNLO
WW, WZ, ZZ	SHERPA 2.1.1	NNPDF3.0NNLO	SHERPA	SHERPA	NLO

Differential distributions

ATLAS CONF-2019-041 , http://cdsweb.cern.ch/record/2686255

- Single differential: good agreement in general but not in all regions
- Both single lepton and dilepton are softer in data than in all Powheg based predictions.
- Reweighting top p_T shows improvement.
- MG5_aMC@NLO + Pythia agree better especially when using HERAPDF2.0





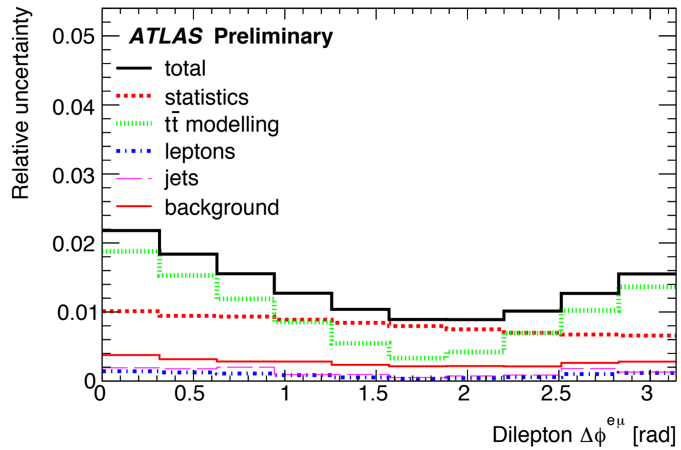
Differential distributions

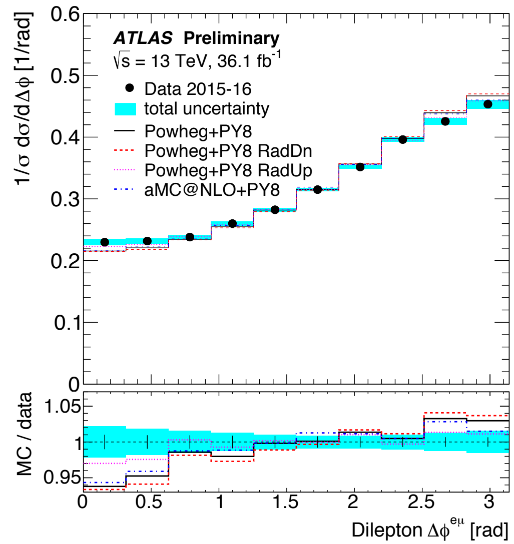
ATLAS CONF-2019-041 , http://cdsweb.cern.ch/record/2686255

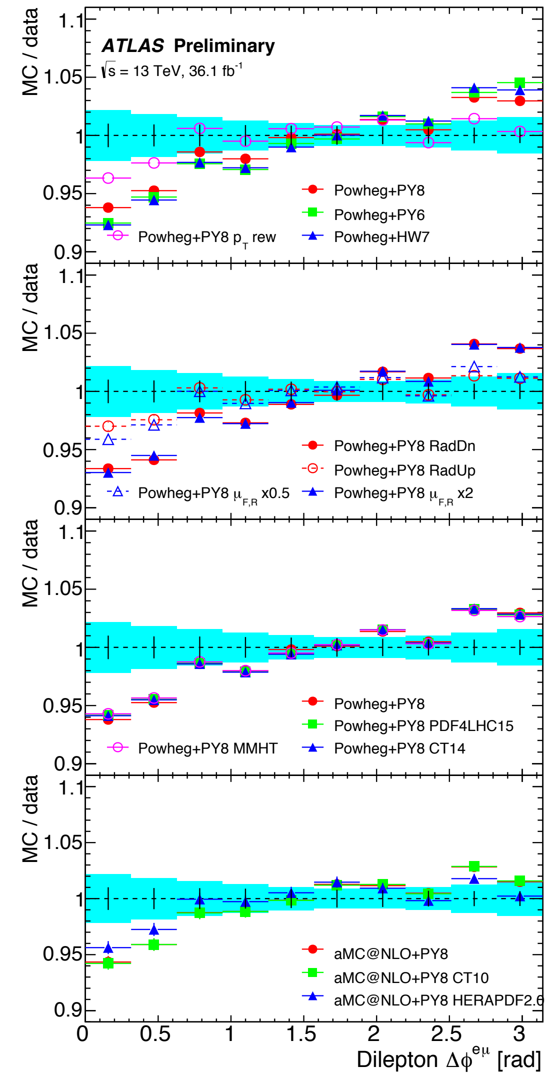
Double differential: similar agreement as seen with single differentials

Differences are more pronounced at high $m^{e\mu}$ for $\Delta\phi^{e\mu}$

Distributions generally well described by NLO matrix-element generators Powheg and aMC@NLO interfaced to Pythia or Herwig





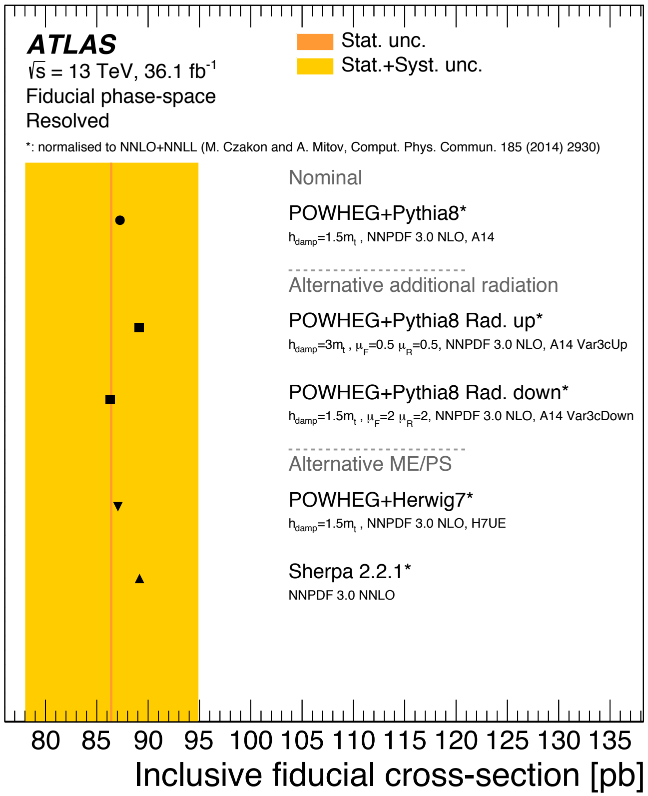


Uncertainties as small as 0.6 % for normalised distributions in some parts of the fiducial region

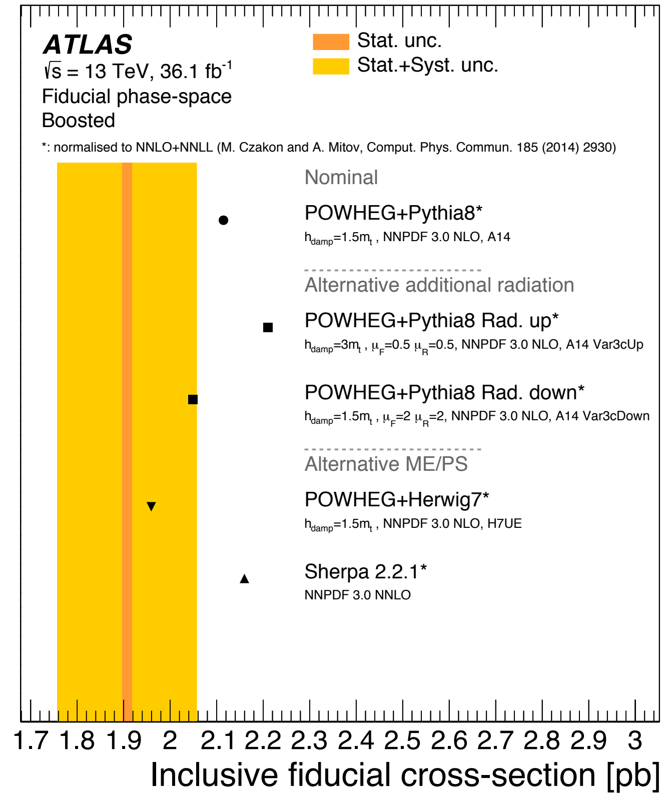
Differential cross sections

Submitted to EPJC, https://arxiv.org/abs/1908.07305

Top cross section measured in the fiducial phase-space in resolved and boosted topologies



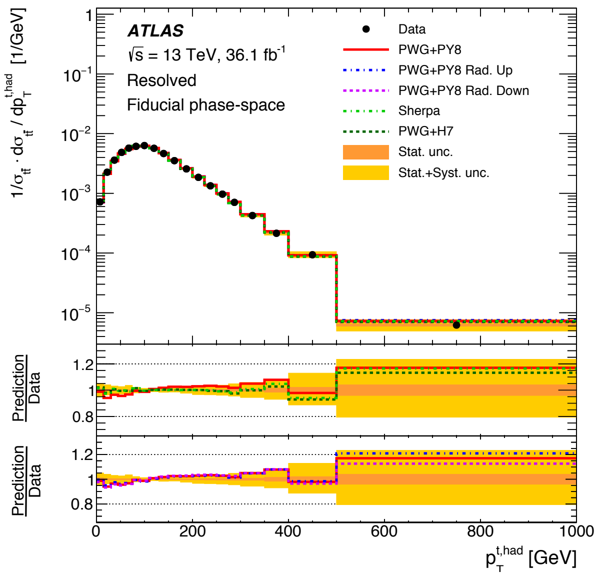
- Cross section scaled to same NNLO+NNLL value for each generator
- Differences due to different acceptance predictions from each model
- Several NLO+PS predictions overestimate the measurement in boosted topology

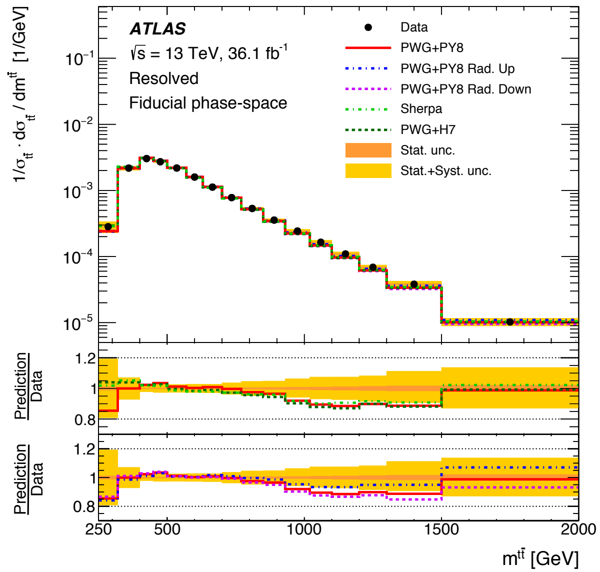


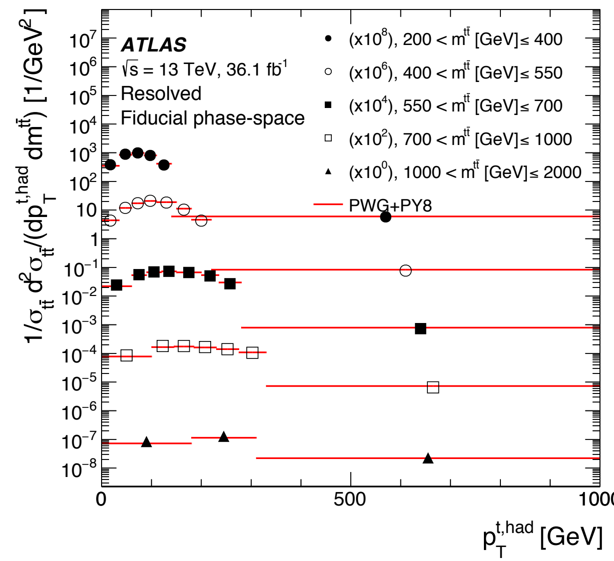
Differential cross sections

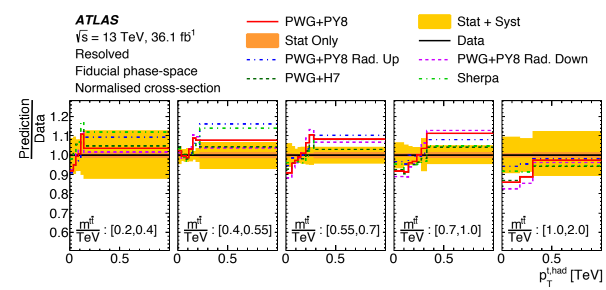
Submitted to EPJC, https://arxiv.org/abs/1908.07305

- MC predictions generally good.
- Measured differential cross-sections discriminate between MC predictions









Sensitivity relevant for tuning and improving the description of the $t\bar{t}$ final state, hence reducing the systematic uncertainties related to top-quark modelling.

Underlying event

Eur. Phys. J. C 79 (2019) 123, https://arxiv.org/abs/1807.02810

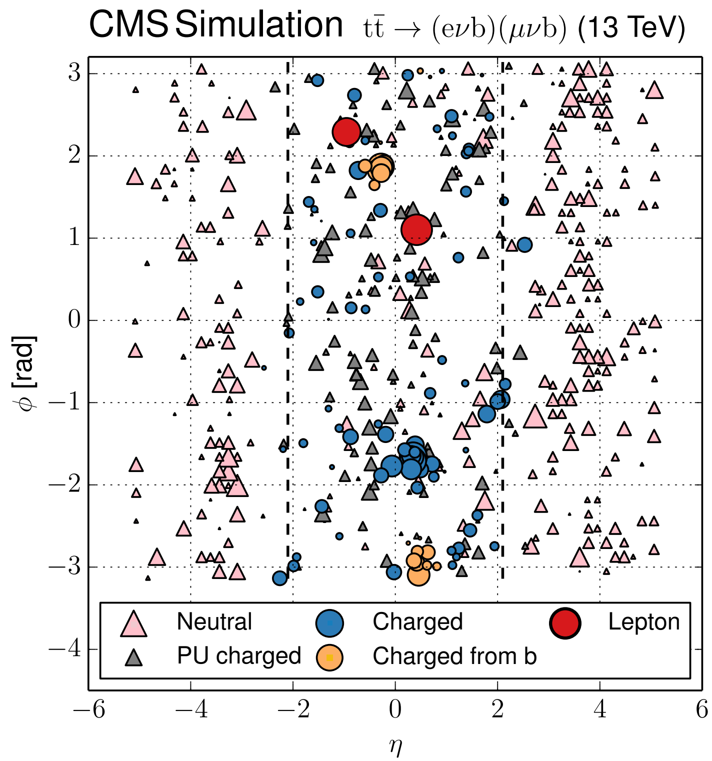
First measurement of UE activity in $t\bar{t}$ dilepton events

UE contribution isolated from:

- charged particles associated with decay products
- pileup interactions

Test universality of UE at different energy scale

- Up to $2m_t$
- Measure properties and unfold to particle level
- > 200 distributions studied
- Measurements indicate it should be valid at even higher scales



Particles of p_T > 900 MeV
Marker area proportional to particle p_T

Underlying event

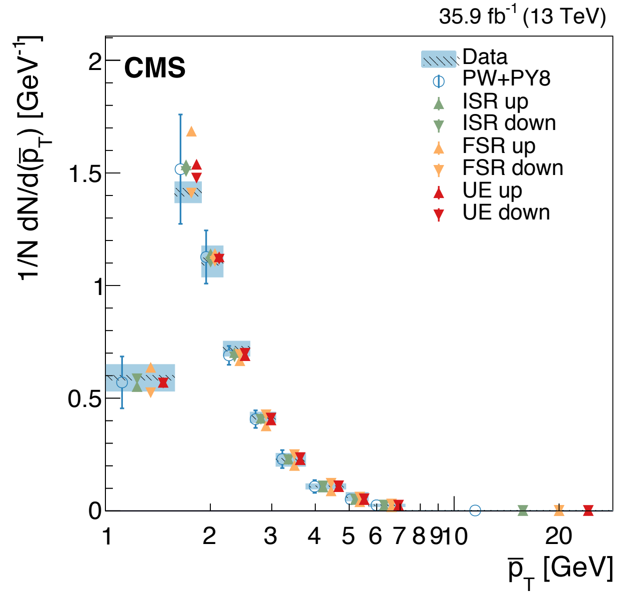
Eur. Phys. J. C 79 (2019) 123, https://arxiv.org/abs/1807.02810

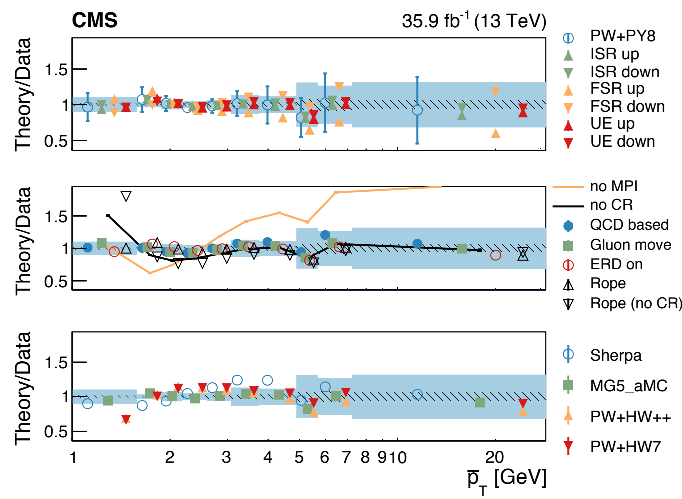
Compare data to several MC simulations

- Variations of Powheg+Pythia8 demonstrate sensitivity to FSR/ISR scales, UE tune etc

> Data favours lower value of $\alpha_s^{FSR}(M_Z)$

- Changing ME generator has little effect
- Sherpa and Herwig simulations show different behaviour to Powheg+Pythia8
- Contribution of MPI essential
- CR more subtle effect

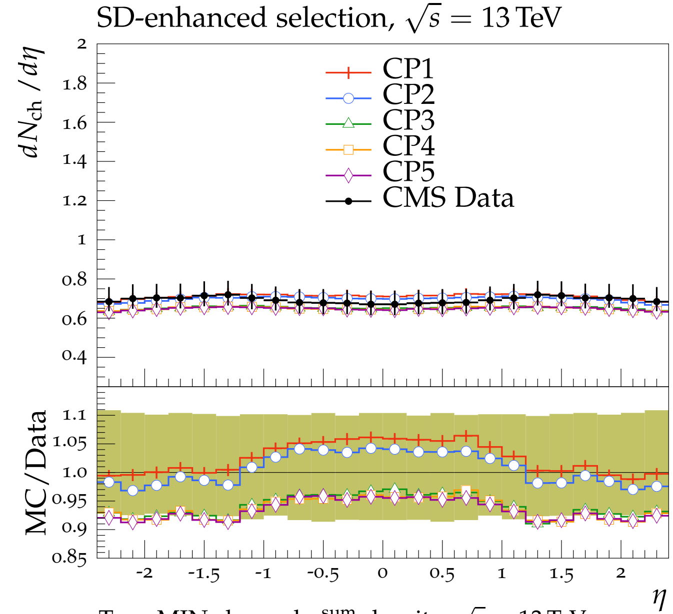


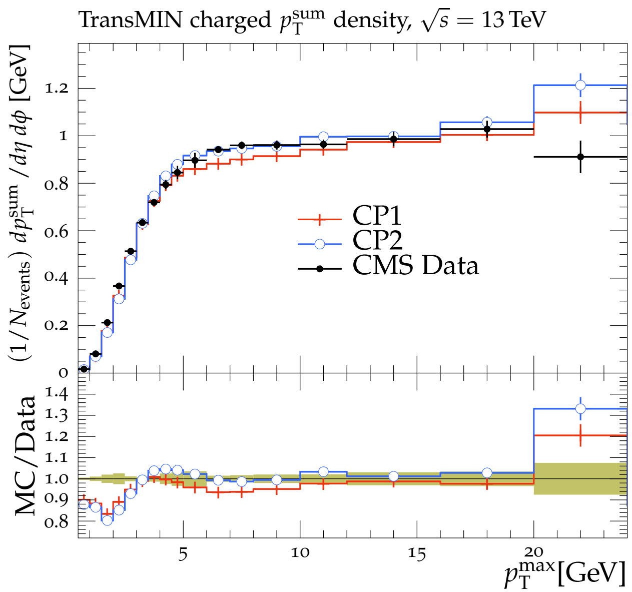


CP Pythia8 tunes

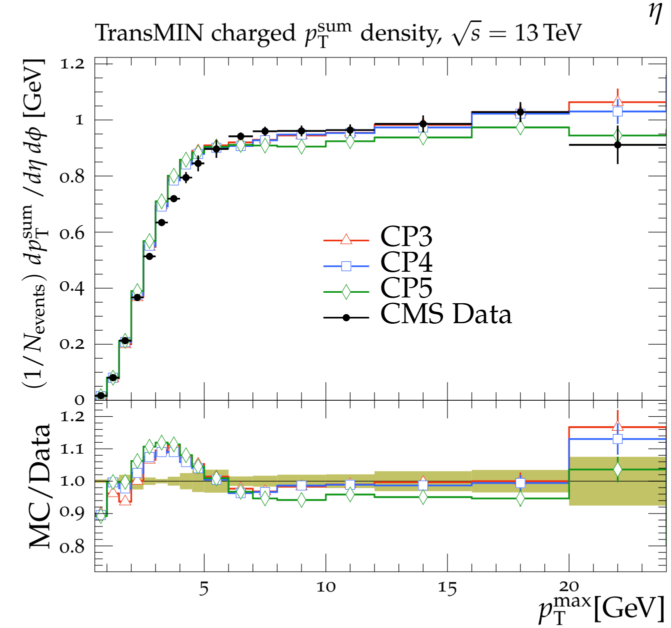
Submitted to EPJC, https://arxiv.org/abs/1903.12179

- All tunes describe UE and min bias data well at lower energies and improve the description at 13 TeV.
- For the first time NNLO PDF set in shower performs equally as well as LO PDF
- Tested with multijet, W/Z and $t\bar{t}$ events





LO PDF & α_s



(N)NLO PDF & α_s

CP Pythia8 tunes

Submitted to EPJC, https://arxiv.org/abs/1903.12179

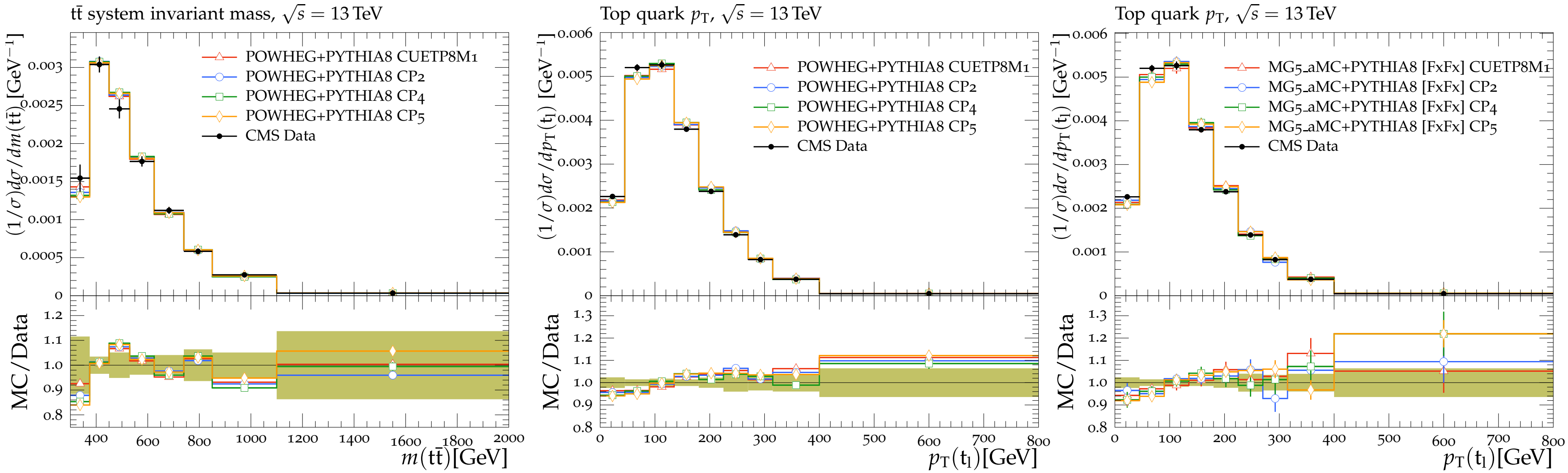
Comparisons using observables in top quark production:

Different generators:

- POWHEG
- MG5_aMC@NLO

with CUETP8M1, CP2, CP4 & CP5 tunes

Similar description for each tune, with both generators
Within ~10% - 20% of data



CP5 used as default for CMS 2017/18 MC production

Looking to the future – a common MC setup

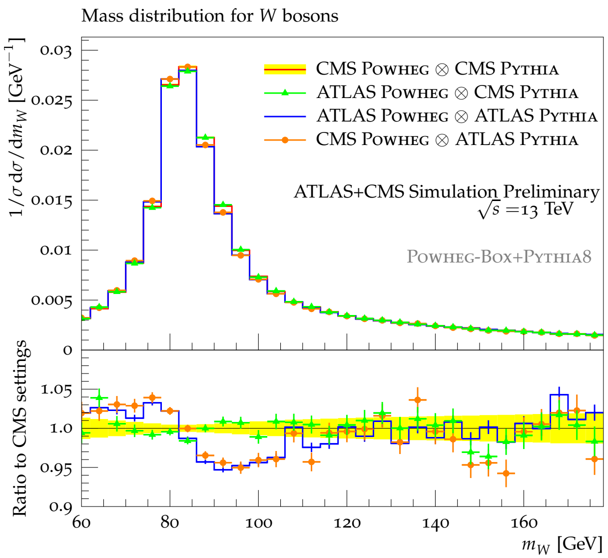
CMS DP-2019/011 , http://cdsweb.cern.ch/record/2678959

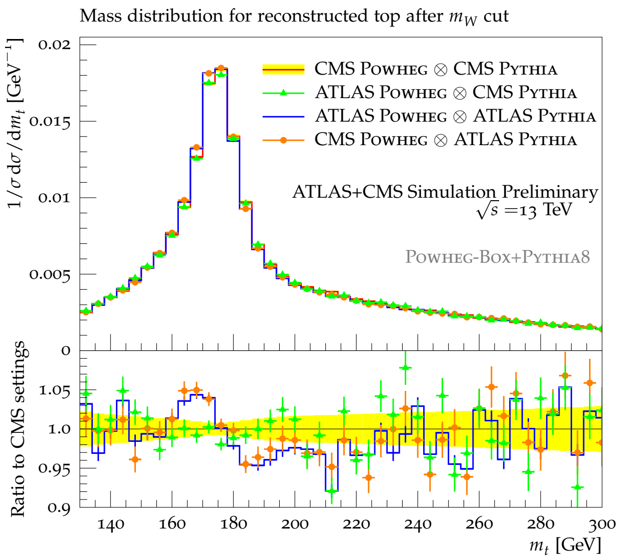
Motivation: understand similarities and differences and develop ability to run CMS MC in ATLAS software and vice versa

Common MC sample crucial for future comparisons and combinations, understanding the systematic uncertainties and saving computing resources

First steps: Using nominal samples from both experiments: Powheg-Box + Pythia 8 (slides 5&6)

Run each experiment's settings in the other experiment's framework





- Experiments able to run each others nominal samples
- General agreement but O(5%) differences in tails or strongly peaked regions
- 'Mix and match' to investigate differences
- ATLAS powheg settings with CMS shower and hadronization and vice versa
- Shows differences are driven by Pythia and EvtGen settings

Next steps: comparisons using ATLAS & CMS data from existing Rivet Routines

Conclusion

- Why is top modelling important?
  - Reduce uncertainty in our measurements
  - Search for rare processes in less well understood regions and extreme phase space
- Testing the models
  - Good agreement between data and MC for many observables
  - Significant improvements in description of UE measurements at $\sqrt{s}$ = 13 TeV have been observed by both experiments
  - Tunes based on higher-order PDF sets are able to give a reliable description of MB and UE measurements
  - Continued optimisation with data provides a better description of the $t\bar{t}$ final state and a reduction of the systematic uncertainties related to top-quark modelling
- Working towards a common MC setup for ATLAS & CMS

Thank you

Backup

Modelling top production

– links to previous studies

Tuning for tt simulation

ATL-PHYS-PUB-2018-009 https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2018-009/

ATL-PHYS-PUB-2017-007 https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2017-007/

CMS-PAS-TOP-16-021 https://cds.cern.ch/record/2235192

Colour reconnection models

ATL-PHYS-PUB-2017-008 https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2017-008/

Eur. Phys. J. C 78 (2018) 891 https://link.springer.com/article/10.1140/epjc/s10052-018-6332-9

Study of underlying event

Eur. Phys. J. C 79 (2019) 123 https://link.springer.com/article/10.1140/epjc/s10052-019-6620-z

Measuring jet substructure observables

Phys. Rev. D. 98 (2018) 092014 https://journals.aps.org/prd/abstract/10.1103/PhysRevD.98.092014

Interference effects

Phys. Rev. Lett. 121 (2018) 15200 https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/TOPQ-2017-05/

Top specific tunes

JHEP 06 (2018) 002 https://link.springer.com/article/10.1007/JHEP06(2018)002

CMS-PAS-TOP-16-021 https://cds.cern.ch/record/2235192

Modelling $t\bar{t}$ in ATLAS & CMS

CMSDP-2019/011 , http://cdsweb.cern.ch/record/2678959

Showering + hadronization

- Pythia8 v2.30
- ATLAS EvtGen for decay of HF particles with custom decay tables
- CMS Pythia for all decays
- Own dedicated tunes
  - ATLAS – A14
  - CMS – CP5
- Different PDF sets

Setting Name	Setting description	CMS default	ATLAS default	PYTHIA 8 default
POWHEG	Parameters for matching to POWHEG matrix element calculations			
pTdef	Flag for hardness criterion (POWHEG vs PYTHIA)	1	2	0
emitted	Flag for defining emissions	0	0	0
pTemt	Flag for which partons are used to define POWHEG hardness criteria	0	0	0
pThard	Flag for how to calculate POWHEG hardness criteria	0	0	0
vetoCount	How many emissions vetoed showers checks after first allowed emission	100	3	3
nFinal	Number of outgoing particles for born level process	2	2	2
veto	Flag for vetoed or unvetoed showers	1	1	0
MPIveto	Flag for applying veto to Multi Parton Interactions	NA	0	0
TimeShower	Final State Radiation Parameters			
mMaxGamma	Maximum invariant mass for $\gamma \to f\bar{f}$	1.0	NA	10
alphaSorder	Order of running for α_s	2	NA	1
alphaSvalue	Value of α_s at Z mass scale	0.118	0.127	0.1365
pTmaxMatch	Flag for setting maximum shower scale algorithm	2	2	1
SpaceShower	Initial State Radiation Parameters			
alphaSorder	Order of running for α_s	2	NA	1
alphaSvalue	Value of α_s at Z mass scale	0.118	0.127	0.1365
pTmaxMatch	Flag for setting maximum shower scale algorithm	2	2	0
rapidityOrder	Force emissions to be ordered in rapidity	on	on	on
rapidtyOrderMPI	Force emissions in secondary scatterings to be ordered in rapidity	NA	on	on
pT0Ref	Reference p_T scale for regularizing soft QCD emissions	NA	1.56	2
pTmaxFudge	Multiplication factor for pTMaxMatch in some instances	NA	0.91	1
pTdampFudge	Multiplication factor for pTDamping scale for high-p_T emissions	NA	1.05	1
MPI	Multi-Parton Interaction Parameters			
alphaSorder	Order of running for α_s	2	NA	1
alphaSvalue	Value of α_s at Z mass scale	0.118	0.126	0.130
ecmPow	Exponent control kinematic dependence of pT0	0.03344	NA	0.215
bprofile	impact parameter profile choice flag for hadron beams	2	NA	3
coreRadius	Inner radius of core when using bprofile = 2	0.7634	NA	0.4
coreFraction	Matter content fraction of core when using bprofile = 2	0.63	NA	0.5
pT0ref	Reference p_T scale for regularizing soft QCD emissions	1.41	2.09	2.28
BeamRemnants				
primordialKThard	Parameter controlling k_T of beam remnant initiators	NA	1.88	1.8
ColourReconnection				
range	Parameter controlling colour reconnection probability	5.176	1.71	1.8
ParticleDecays	Particle Decay Settings			
limitTau0	Only decay particles with lifetimes below $\tau_{0,max}$	on	on	off
tau0Max	$\tau_{0,max}$	10	10	10
allowPhotonRadiation	Allow photon radiation in decays to lepton pairs	on	NA	off

Differential distributions

ATLAS CONF-2019-041 , http://cdsweb.cern.ch/record/2686255

Top quark pole mass results for various PDF sets derived from the $t\bar{t}$ cross-section measurement at $\sqrt{s}$ = 13 TeV. The uncertainties include PDF+α_S, QCD scale and experimental sources. The PDF4LHC result spans the uncertainties of the CT10, MSTW and NNPDF2.3 PDF sets (left).

PDF set	m_t^{pole} [GeV]
CT14	$173.1^{+2.0}_{-2.1}$
CT10	$172.1^{+2.0}_{-2.0}$
MSTW	$172.3^{+2.0}_{-2.1}$
NNPDF2.3	$173.4^{+1.9}_{-1.9}$
PDF4LHC	$172.1^{+3.1}_{-2.0}$

Uncertainty source	Δm_t^{pole} [GeV]
Experimental	1.0
PDF+α_S	$^{+1.5}_{-1.4}$
QCD scales	$^{+1.0}_{-1.5}$
Total uncertainty	$^{+2.0}_{-2.1}$

Uncertainties on the top quark pole mass extracted from the $t\bar{t}$ production cross-section measurement at $\sqrt{s}$ = 13 TeV, using the CT14 PDF set (right).

Differential distributions

ATLAS CONF-2019-041 , http://cdsweb.cern.ch/record/2686255

- The inclusive cross-section has also been combined with previous measurements at √s = 7 and 8 TeV to determine ratios of $t\bar{t}$ cross-sections, and double ratios of $t\bar{t}$ and Z cross-sections, at different energies, which are found to be compatible with predictions using a range of PDF sets.

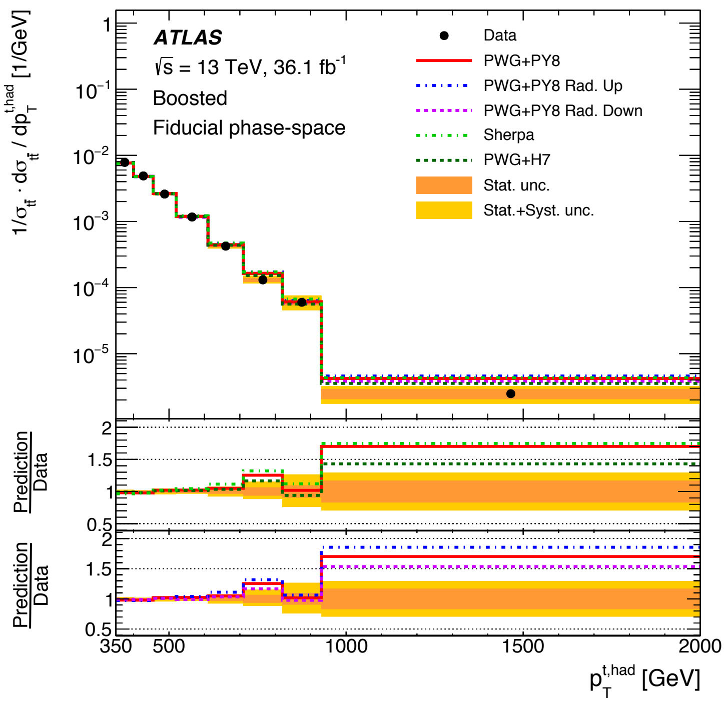
$\sqrt{s}$ values [TeV]	Measured cross-section ratio	NNLO+NNLL prediction
13/7	$4.54 \pm 0.08 \pm 0.10 \pm 0.12$ (0.18)	4.69 ± 0.16
13/8	$3.42 \pm 0.03 \pm 0.07 \pm 0.10$ (0.12)	3.28 ± 0.08
8/7	$1.33 \pm 0.02 \pm 0.02 \pm 0.04$ (0.05)	1.43 ± 0.01

$\sqrt{s}$ values (TeV)	$t\bar{t}/Z$ cross-section double ratio	CT14 prediction
13/7	$2.617 \pm 0.049 \pm 0.060 \pm 0.007$ (0.078)	$2.691^{+0.045}_{-0.058}$
13/8	$2.212 \pm 0.024 \pm 0.049 \pm 0.006$ (0.055)	$2.124^{+0.026}_{-0.035}$

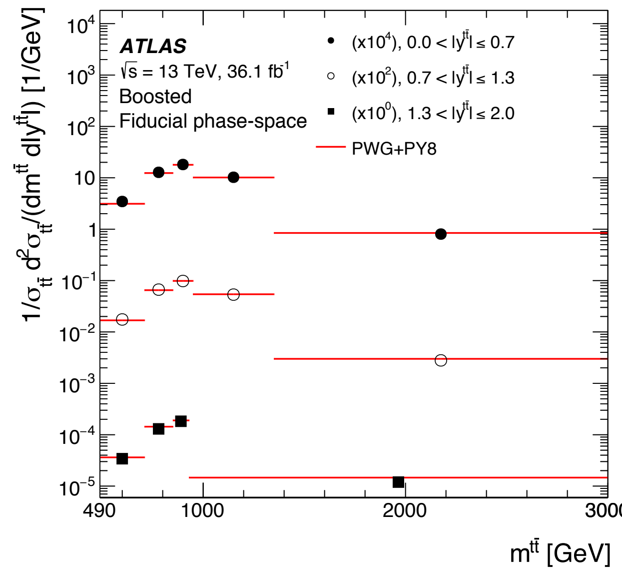
Differential cross sections

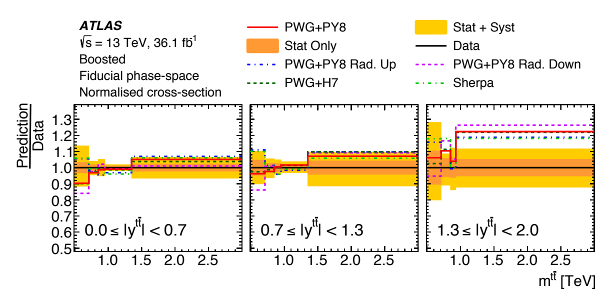
ATLAS TOPQ-2018-15 , https://arxiv.org/abs/1908.07305

Monte Carlo predictions generally good although not always able to describe the measured single- or double-differential cross sections in the entire fiducial phase-space.



For double-differential cross sections tensions between MC and data are seen and overall they are better described using Powheg+Pythia8 in resolved topology and Powheg+Herwig7 in boosted topology





Mismodelling observed in single-differential cross sections where overestimation is made in tails of some distributions

CP Pythia8 tunes

Submitted to Eur. Phys. J. C, https://arxiv.org/abs/1903.12179

CMS Pythia8 (CP) tunes at 13 TeV

- 2 LO tunes CP1 and CP2

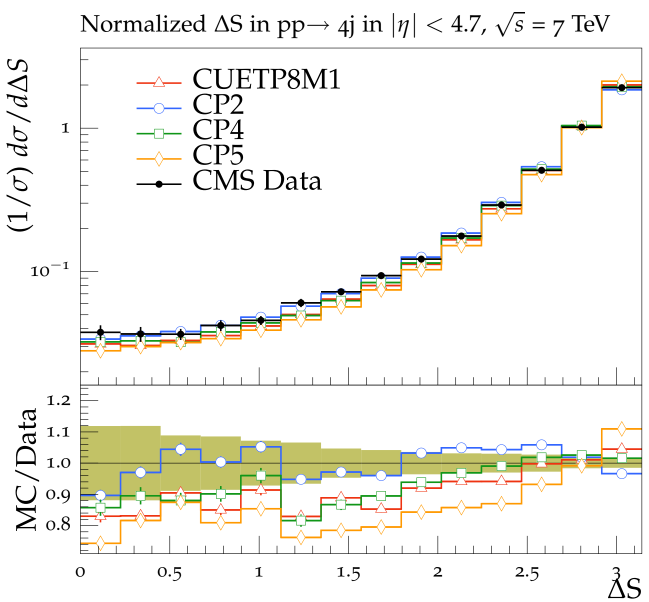
PYTHIA8 parameter	CP1	CP2
PDF Set	NNPDF3.1 LO	NNPDF3.1 LO
$\alpha_S(m_Z)$	0.130	0.130
SpaceShower:rapidityOrder	off	off
MultipartonInteractions:EcmRef [GeV]	7000	7000
$\alpha_S^{ISR}(m_Z)$ value/order	0.1365/LO	0.130/LO
$\alpha_S^{FSR}(m_Z)$ value/order	0.1365/LO	0.130/LO
$\alpha_S^{MPI}(m_Z)$ value/order	0.130/LO	0.130/LO
$\alpha_S^{ME}(m_Z)$ value/order	0.130/LO	0.130/LO
MultipartonInteractions:pT0Ref [GeV]	2.4	2.3
MultipartonInteractions:ecmPow	0.15	0.14
MultipartonInteractions:coreRadius	0.54	0.38
MultipartonInteractions:coreFraction	0.68	0.33
ColorReconnection:range	2.63	2.32
χ^2/dof	0.89	0.54

CP Pythia8 tunes

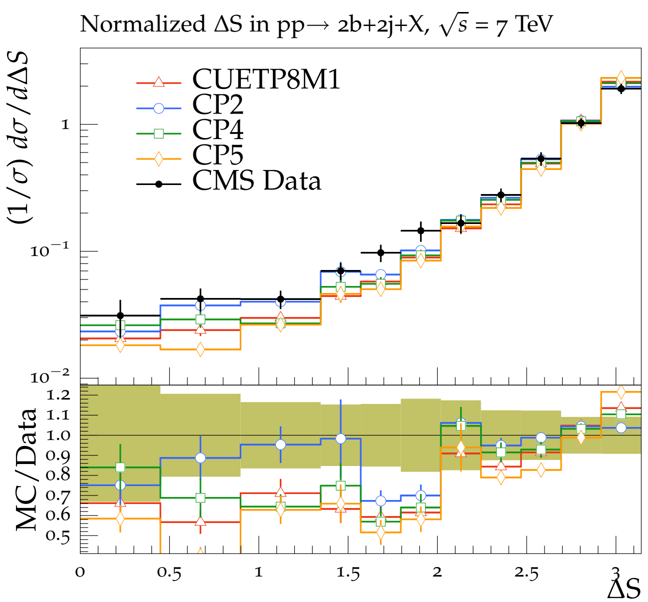
Submitted to EPJC, https://arxiv.org/abs/1903.12179

Comparison to double parton scattering observables, measured in final states at 7 TeV with either:

- Four jets



- Two b jets and two other jets



CP2 LO tune describes the central values better the other tunes

- Due to different values for amount of simulated MPI

CP4 better describe the DPS-sensitive observables than CP5

- Due to different rapidity ordering

CP Pythia8 tunes

Submitted to EPJC, https://arxiv.org/abs/1903.12179

Jet multiplicity

- MG5_&MC@NLO
  - Well described for all tunes
- Powheg
  - Well described for CP5
  - CP4 same configuration but no rapidity ordering for ISR
  - Rapidity ordering included in CUETP8M2T4
- CP5 as default for CMS 2017/18 MC production