Towards a Common ATLAS + CMS ttbar Monte Carlo Sample

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Motivation

- Understand similarities and differences between ATLAS and CMS ttbar Monte Carlo samples

- Develop ability to run CMS Monte Carlo in ATLAS Software and Vice Versa

Use Cases

1. A common benchmark MC sample can be crucial for future detailed ATLAS-CMS comparisons and combinations
    a. Are ATLAS and CMS top mass measurements calibrated to the same / consistent benchmark ?
    b. Are observed top pT slopes wrt to the same slope in MC
2. Answer questions related to size of systematic uncertainties
    a. Are ATLAS radiation up/down shifts comparable to CMS radiation up/down shifts ?
    b. Is ATLAS Pythia vs Herwig comparable to CMS Pythia vs Herwig ?
3. Generate common MC samples for large scale use
    a. Save computing resources and minimize confusion about configurations

First steps

Start with nominal samples from both experiments: Powheg-Box + Pythia8

Run each experiments settings in the others' software framework

<u>Validation</u>

- POWHEG settings validated by running each experiments settings in the other framework with identical random number settings and comparing LHE files
  - Exact event-by-event agreement found between official samples and those produced by other experiment

- Pythia Settings validated with Rivet routine using MC_TTBAR analysis from Rivet 2.5.4
  - Samples succesfully reproduce bulk distributions
  - Event-by-Event HepMC comparison with identical random number settings still under way

Comparison of Settings - POWHEG

Both Experiments using POWHEG-BoxV2, with default scales $\mu_R = \mu_F = \sqrt{(m_t^2 + p_T^2)}$. Slightly different settings

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

Table 1: POWHEG-Box settings used in the ATLAS and CMS default Monte Carlo event generation setups for $t\bar{t}$ production. Only a subset of settings are shown, highlighting differences between the ATLAS and CMS settings.

Comparison of Settings - Showering + Hadronization

Table of Settings in Backup

- Both experiments using Pythia8 v 2.30
- ATLAS using EvtGen for the decay of heavy flavour particles with custom decay tables. CMS using Pythia for all decays
- Both Experiments using their own dedicated tunes
  - ATLAS - A14
  - CMS - CP5
- Different PDF Sets
  - ATLAS - NNPDF 2.3 Leading Order
  - CMS - NNPDF 3.1 Next-to-Next-to-Leading Order
  - Also using different values + orders of running α_s

Comparison of Generated Samples

Compare samples using MC_TTBAR Rivet routine (Rivet v 2.5.4)
Anti-k_T R=0.6 Jets

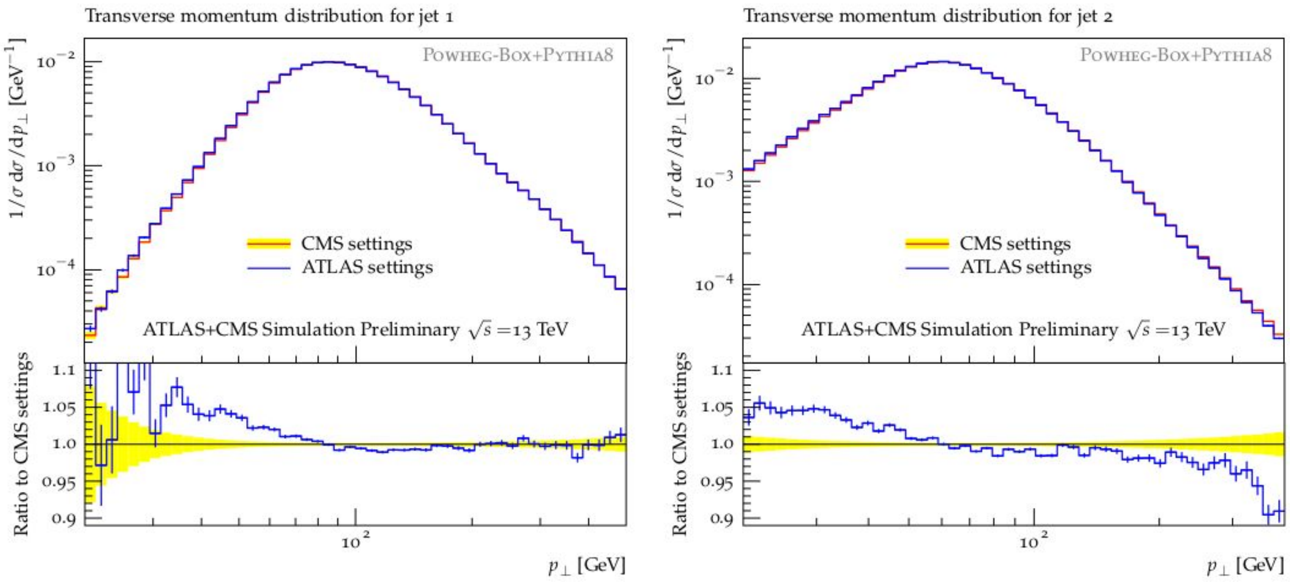
Basic selection in lepton + jets channel.

- ≥ 1 electron or muon p_T > 30 GeV
- > 30 GeV of missing transverse energy

Additional selections applied for some plots

- ≥ 4 jets p_T > 30 GeV
- ≥ 2 jets p_T > 50 GeV
- ≥ 1 jets p_T > 60 GeV
- Require ΔR(jet,lepton) > 0.3
- ≥ 2 light-flavour jets and ≥2 b-jets with p_T > 30 GeV

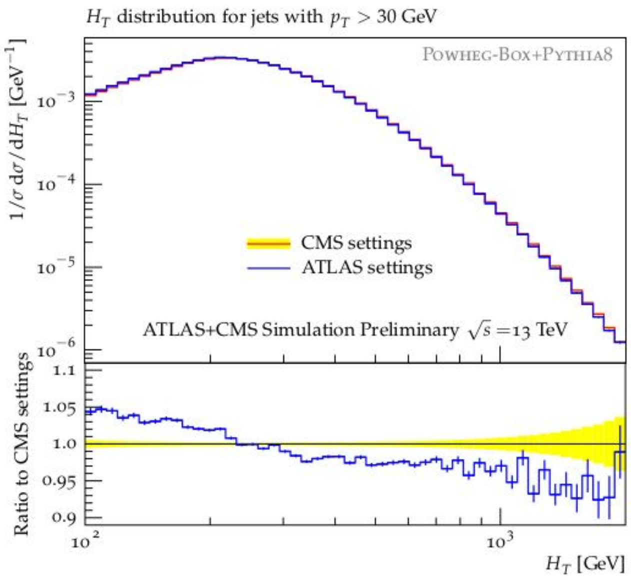
Inclusive Jet Distributions

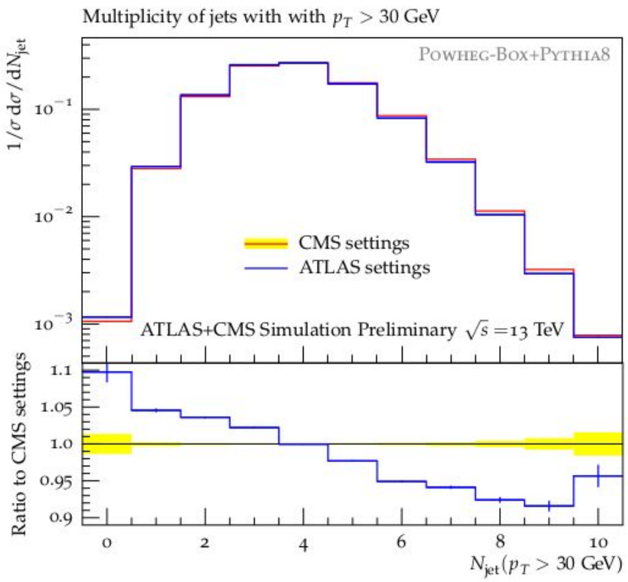


Inclusive jets are somewhat softer with ATLAS settings

Uncertainties are statistical only

(Mostly) Inclusive Jet Distributions





Softer ATLAS spectrum visible in H_T.

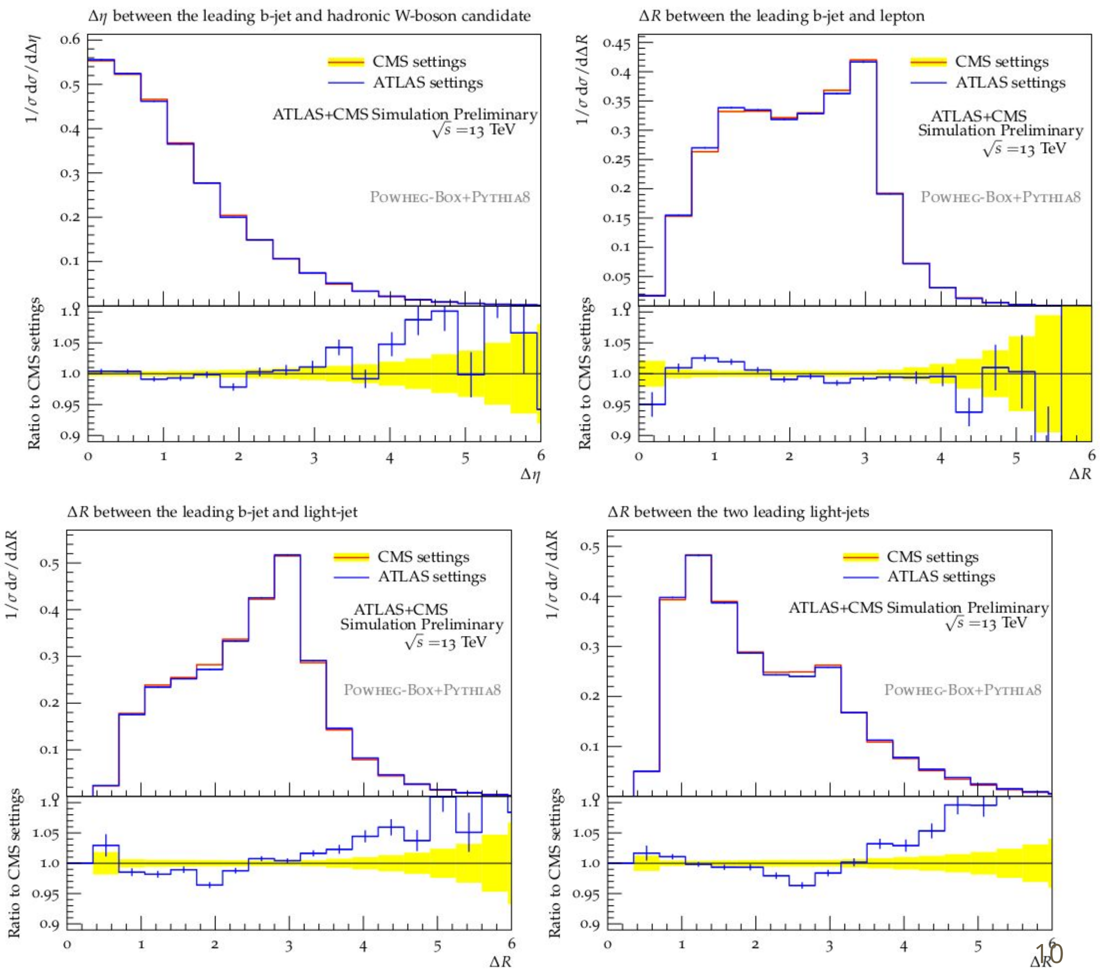
ATLAS settings predict slightly fewer jets with p_T > 30 GeV

Distributions include only jets with p_T > 30 GeV.
Uncertainties are statistical only.

Jet Angular Distributions
(After all cuts on slide 7)

O(10%) differences some jet angular distributions in the tails at large separations

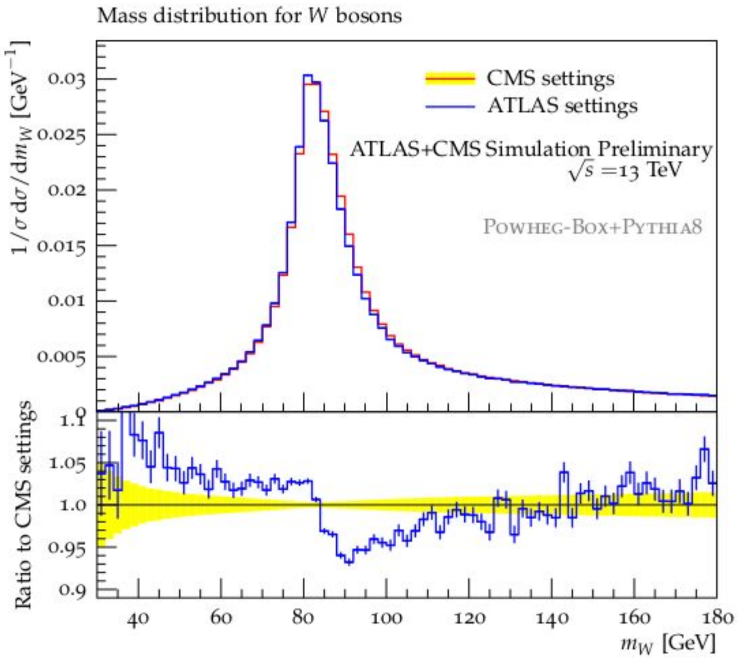
Uncertainties are statistical only

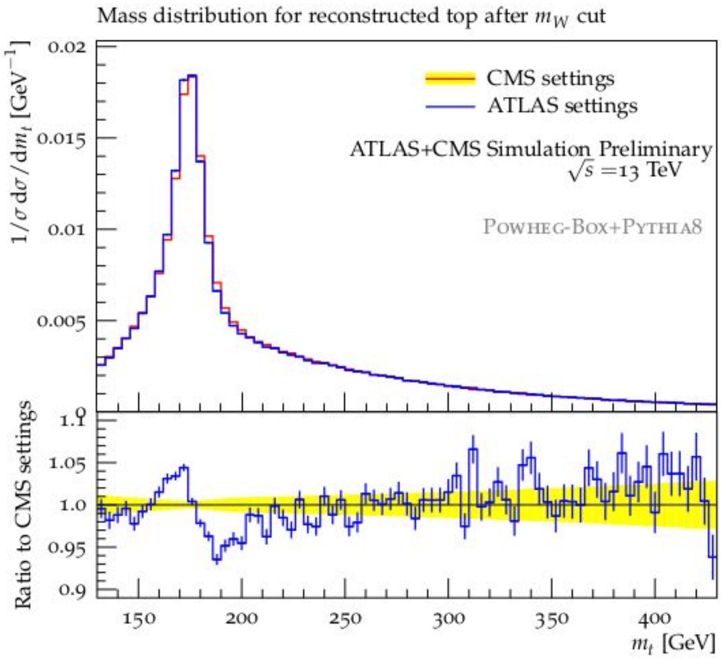


Mass Distributions

W-candidate mass reconstructed as light-jets with invariant mass closest to 80.4 GeV

Top mass reconstructed from combination of hadronic W-candidate + b-jet, for both leading b-jets.
Requires 75 GeV < W-candidate mass < 85 GeV





Mass Peaks Slightly lower in ATLAS settings as Compared to CMS settings

Investigating Sources of Differences

Several alternative generation settings were run in order to understand the broad sources of differences

“Mix-and match” -

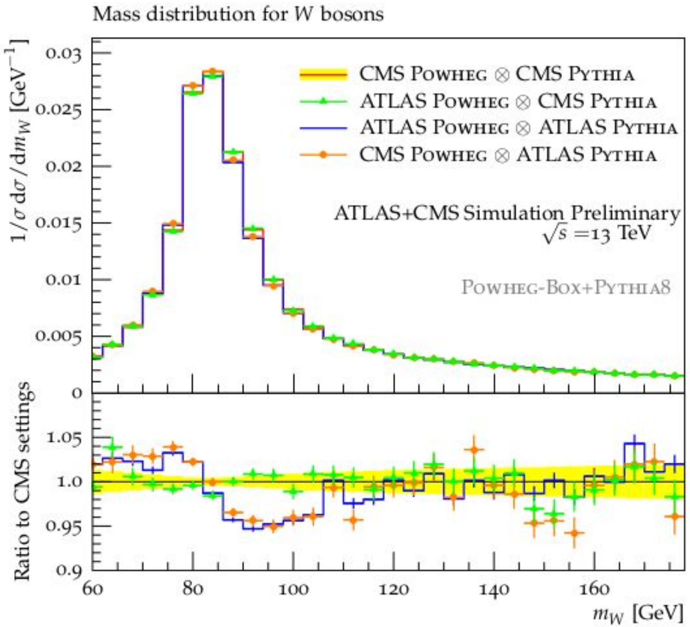
Run combination of ATLAS POWHEG settings + CMS shower and hadronization

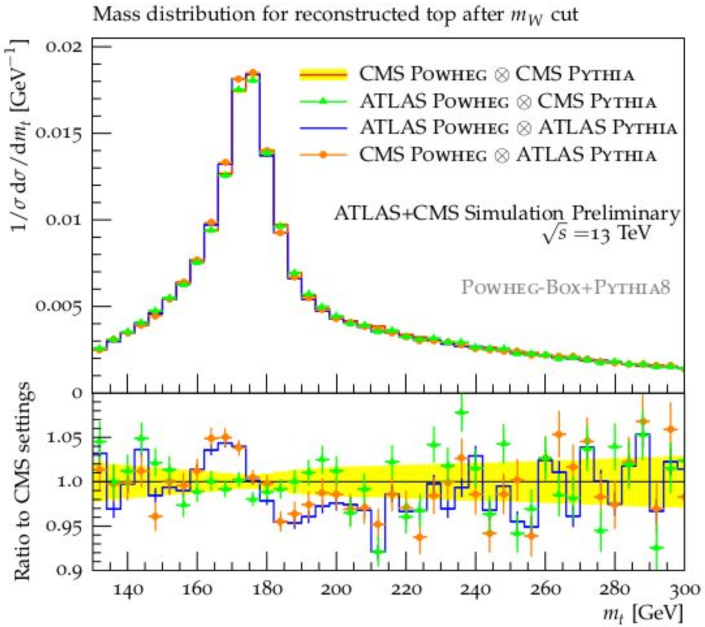
And vice-versa

Source of differences

Samples with same Shower + Hadronization settings tend to group together

Impact of different POWHEG settings not visible in mass plots
same pattern observed in all jet distributions





Differences are Driven by Pythia and EvtGen settings

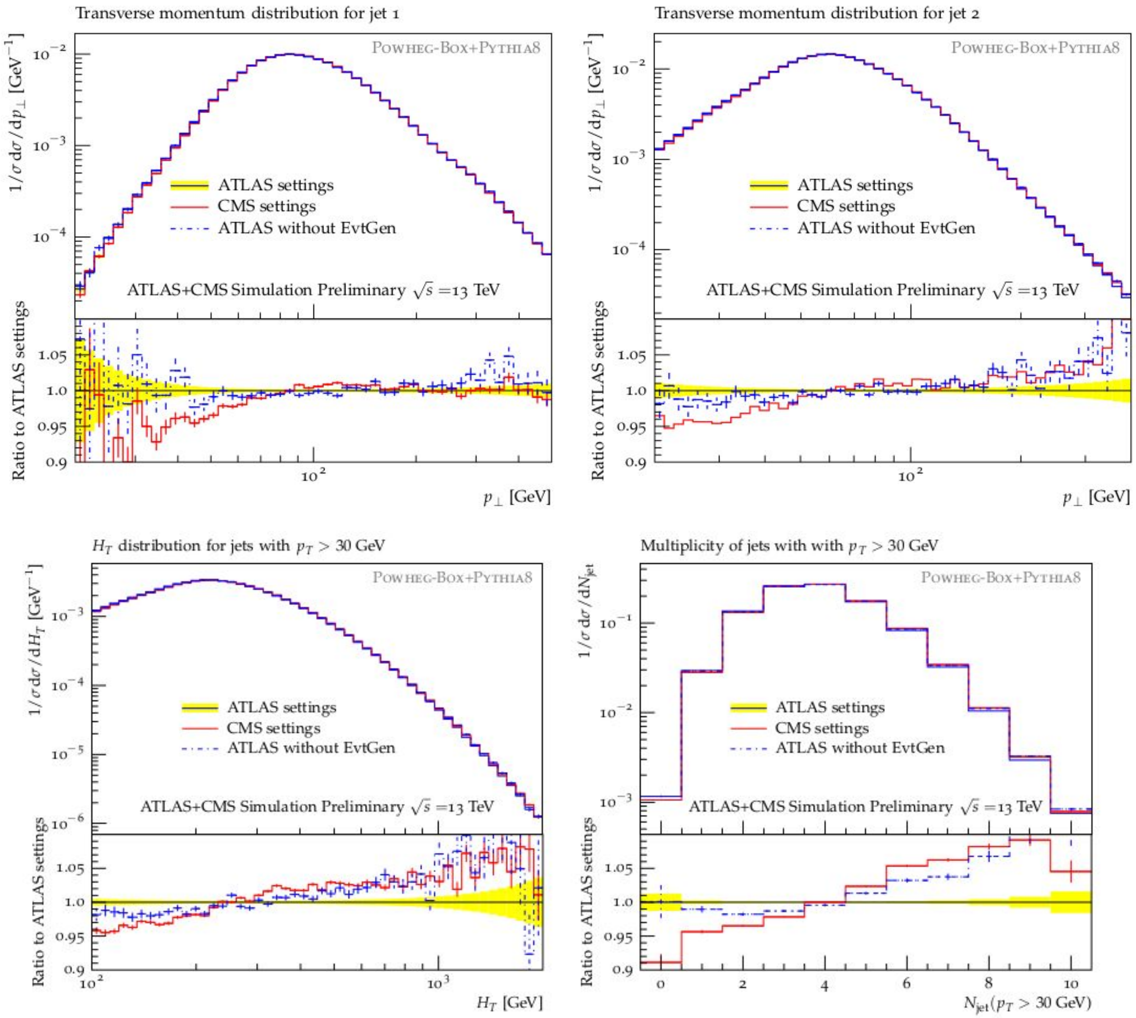
EvtGen Impact

Differences in inclusive jet p_T spectra are impacted by EvtGen usage.

EvtGen usage does not explain the full difference between ATLAS and CMS

Less impact observed with tighter selection criteria, no clear impact on angular distributions

No significant impact on Mass distributions
→ coming from pythia settings



Next steps

Comparisons using ATLAS and CMS data from existing Rivet Routines

More detailed/precise investigation of differences

Summary

ATLAS and CMS have established the ability to run nominal ttbar simulation samples in each other's software frameworks

Similarities and differences between samples have been compared in one phase space which shows general agreement but some O(5%) differences in tails or strongly peaked regions of distributions

- Softer jet spectra in ATLAS when considering inclusive jet selection
- Larger separation between jets in ATLAS
- Reconstructed W-boson, top quark masses shifted slightly lower in ATLAS

Differences driven by showering + hadronization. ATLAS use of EvtGen softens jet spectrum somewhat, but does not explain full difference, mostly negligible difference with tighter selection, no impact on mass peak

Backup

Pythia8 Settings Table

Subset of Pythia 8 (version 8.230) settings used by ATLAS and CMS.

The ATLAS settings use the A14 tune and use the NNPDF 2.3 LO pdf set. CMS settings are of the CP5 tune and use the NNPDF3.1 NNLO pdf set.

By default ATLAS also uses EvtGen for the decay of heavy flavoured hadrons, whereas in the CMS simulation all decays are performed by Pythia.

NA stands for "Not Applied" and reflects the case where default Pythia 8 value is being used.

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