ATLAS Top Modeling: NLO Matching and PS Uncertainties

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ATLAS EXPERIMENT

Motivation

- A summary of the improvements of top-quark pair modelling and uncertainties
  - Comparisons of various samples (new & old) with data

- A look at systematic uncertainty modeling
  - New approaches to evaluating the matching uncertainty
    - Focus on targeting the correct source of the uncertainty
    - Comparisons between different approaches
  - Ways to estimate the Parton Shower uncertainty
  - Comparisons with multi-leg generators (Sherpa 2.2.8)

Phase-space For Studies

- Studies are done measuring the differential cross section in all channels
- All distributions are at particle level
- Comparisons are done using published unfolded $t\bar{t}$ data at $\sqrt{s}$ = 13 TeV
  - dilepton, all-hadronic, l+jets

dilepton	l+jets	all-hadronic
• 1 electron and 1 muon with p_T > 25 GeV • No requirements on jets	• 1 lepton (electron or muon) with p_T > 25 GeV • ≥ 4 jets; p_T > 25 GeV • ≥ 2 b-jets; p_T > 25 GeV	• 0 leptons • ≥ 6 jets with p_T > 55 GeV • == 2 b-jets; p_T > 25 GeV

MC Settings

- Nominal generator uses:
  - **(PWG)**: **Powheg-Box v2** with NNPDF3.0NLO PDF set and the hdamp parameter set to 1.5*m_{top}
  - **(PY)**: **Pythia 8.230** using the A14 tune and the NNPDF2.3LO PDF set **(MEC == ON & grecoil == OFF)**
- Alternative generators use:
  - **(MC@NLO): MadGraph5_aMC@NLO 2.2.1**
  - **(PY*)**: **Pythia 8.230** using the A14 tune and the NNPDF2.3LO PDF set (**MEC == OFF & grecoil == ON**)
    - In l+jets and dilepton samples: (**MEC == OFF & grecoil == OFF**)
  - **(H7.1.3)**: **Herwig 7.1.3** with the H7.1-Default tune
  - **(H7.0.4)**: **Herwig 7.0.4** with the H7UE MMHT2014 LO
  - **Sherpa 2.2.8**
- All generators normalized to the same NNLO XS

Matching Uncertainty

- **Two-point systematic** approach in ATLAS compares two different matrix element generators
  - Powheg+Pythia8 vs aMC@NLO+Pythia8*
  - Is this uncertainty covering what we expect?

- Studies suggest directly comparing the nominal Powheg+Pythia8 and aMC@NLO+Pythia8* leads to an uncertainty that **convolutes two effects:**
    - The NLO matching algorithm (what we want to probe)
    - The matrix element corrections (**MEC**) applied to the top decay

- The subtraction scheme applied in aMC@NLO does not consider MEC, but it is recommended to shower Powheg events including MECs

Three Generator Setups Considered

- Three different MC setups to assess the NLO matching uncertainty:
  - **Powheg+Pythia8 vs aMC@NLO+Pythia8***
    - Requires a difference in Pythia MEC parameters which causes a convolution of two sources of uncertainties (both NLO matching and MEC)
  - **Powheg+Herwig7.1.3 vs aMC@NLO+Herwig7.1.3**
    - No need to adjust any Herwig parameters, but Herwig needs to know if the events were produced with Powheg or aMC@NLO
      - Are there different internal settings used in both cases?
  - **Powheg+Pythia8* vs aMC@NLO+Pythia8***
    - The * refers to the settings employed when showering events generated by aMC@NLO (turning off the MEC and using the global recoil settings)
- **Which approach is the most "correct" to use?**

ME Generator Shorthand Names

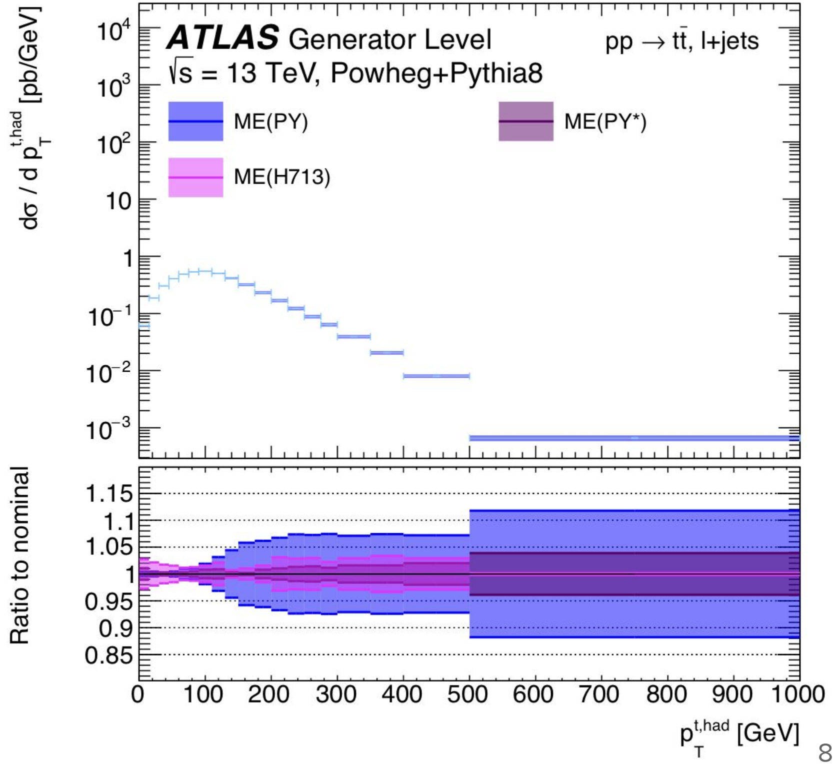
- The matching uncertainties obtained from comparing PWG+**H713** vs MC@NLO+**H713** or PWG+**PY*** vs MC@NLO+**PY*** are expected to reflect the intended systematic
  - The setting for the parton shower is exactly the same
  - **ME(H173)** and **ME(PY*)** are expected to give comparable uncertainty

Name of the uncertainty	Comments
ME(PY)	Old sample (PWG+PY vs MC@NLO+PY*)
ME(H713)	PWG+H713 vs MC@NLO+H713
ME(PY*)	PWG+PY* vs MC@NLO+PY*

Differences on ME Uncertainty

- 3 matching uncertainty approaches shown for the **hadronic top p_T in l+jets channel**
- **ME(PY*)** and **ME(H713)** agree fairly well
  - Supports assumption that showering and hard scatter factorize
- **ME(PY)** gives the largest uncertainty at high p_T
- Agreement is more varied in all-had and dilepton channels (see next slide)

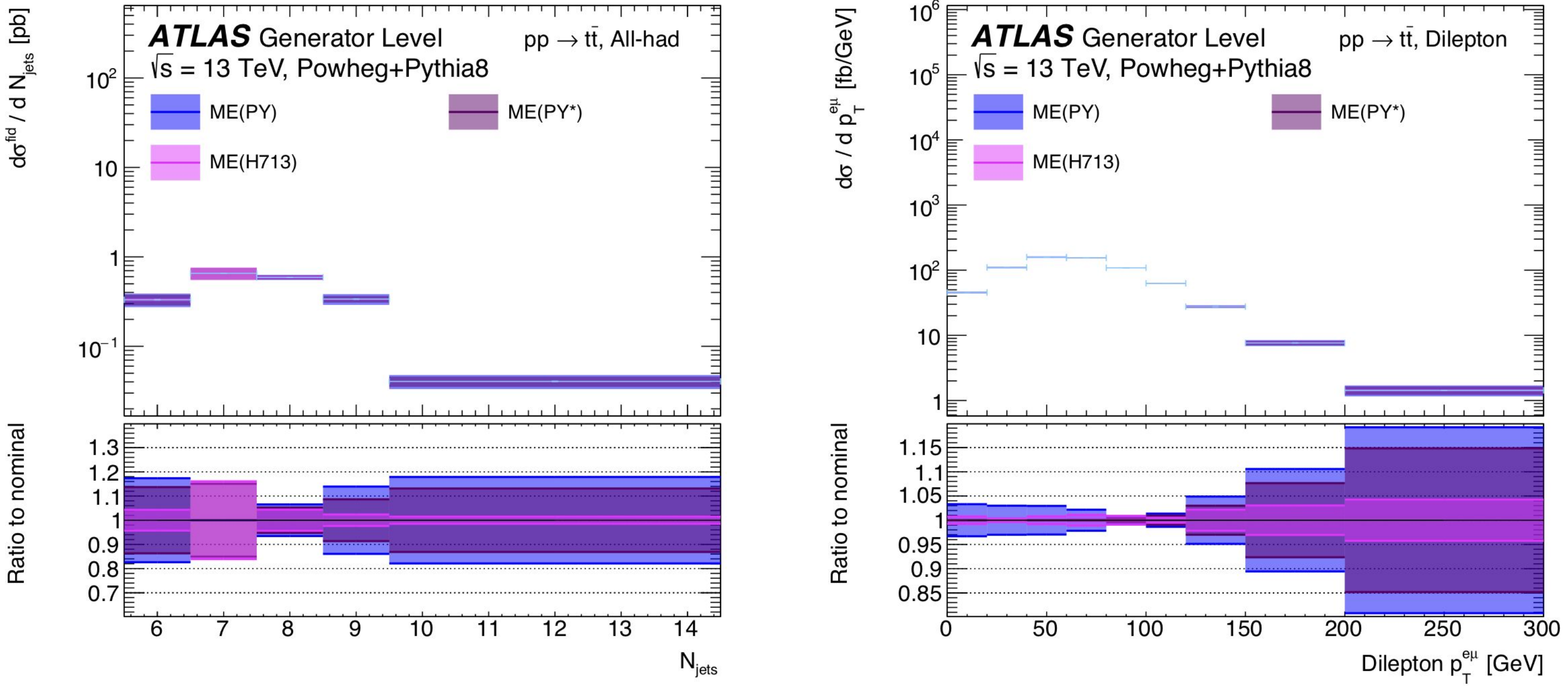
Absolute $t\bar{t}$ cross section vs hadronic top p_T



Differences on ME uncertainty calculation

- In all channels, the band representing **ME(PY)** is the largest
- Large uncertainty in the N_{jets} distribution for **ME(H713)** for N_{jets}= 7 (at which the matching happens "qualitatively")

Absolute $t\bar{t}$ cross section vs N_{jets} (all-had channel) and $p_T^{e\mu}$ (dilepton channel)



Summary of All Considered Uncertainties

	Old Uncertainty Prescription	New Uncertainty Prescription
Matching Unc.	aMC@NLO+Pythia8* vs PWG+Pythia8	aMC@NLO+Pythia8* vs PWG+Pythia8*
Parton shower	PWG+H704 vs PWG+Pythia8	PWG+H713 vs PWG+Pythia8
ISR	Up: hdamp=3*m_{top} , μF=0.5, μR=0.5 , & Var3c up variation Down: μF=2.0, μR=2.0 & Var3c down variation	Seven points envelop (μF,μR)
Hdamp	-	hdamp=3*m_{top}
PDF	PDF4LHC recommendation on PDF 261000	PDF4LHC recommendation on PDF 261000
A14 tune	-	Var3c Up/Down variations
FSR	Pythia8 tune: isr:muRfac=1.0_fsr:muRfac=0.5 and sr:muRfac=1.0_fsr:muRfac=2.0	Pythia8 tune: isr:muRfac=1.0_fsr:muRfac=0.5 and sr:muRfac=1.0_fsr:muRfac=2.0

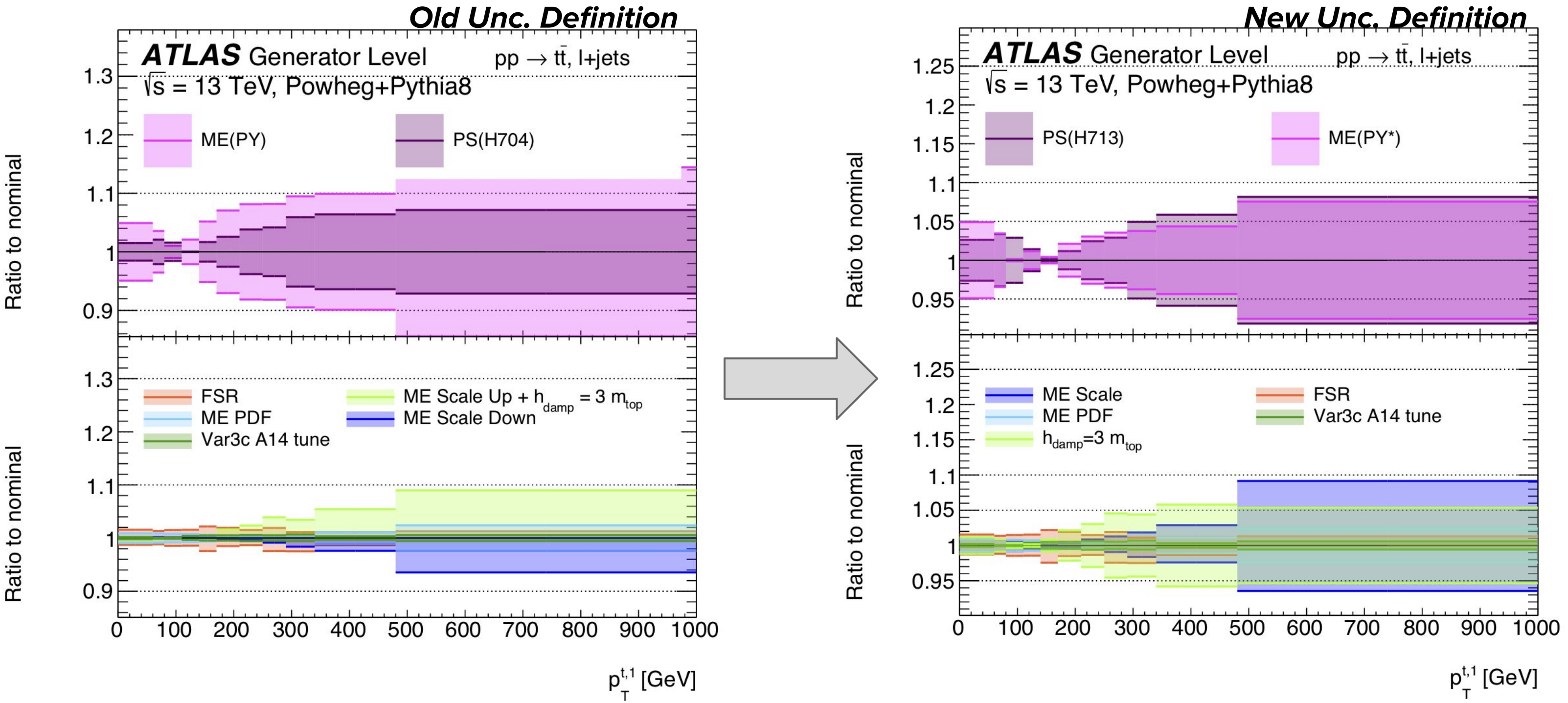
Components split to allow more freedom in profile likelihood fits (avoid unjustified constraints)

N.B. Var3c variation from the [A14] tune

Summary of the Uncertainties on PWG+PY8

- One uncertainty band shown for each uncertainty source
- The PS(H713) uncertainty band is smaller than for PS(H704)

Ratio with respect to the nominal sample vs leading top p_T



Summary of the Uncertainties on PWG+PY8

- Moving away from ad-hoc 2-point theory systematics to per-event variations (internal weights)
  - Need a well defined set of nuisance parameter and variations associated to a single setup

- Given the hdamp variation ($3*m_{top}$), is an additional MC@NLO vs PWG uncertainty needed?
  - Should a different h_{damp} variation than $3*m_{top}$ be considered?
  - Or in the opposite direction w.r.t. the nominal? Is there a recommended range?

- What else can be varied internally for Powheg+Pythia8 ?
  - Input from the generator / theory community is well appreciated

Moving Toward Internal Variations: PWG+PY8

- The following plots show the agreement between PWG+PY8 and data in the three channels

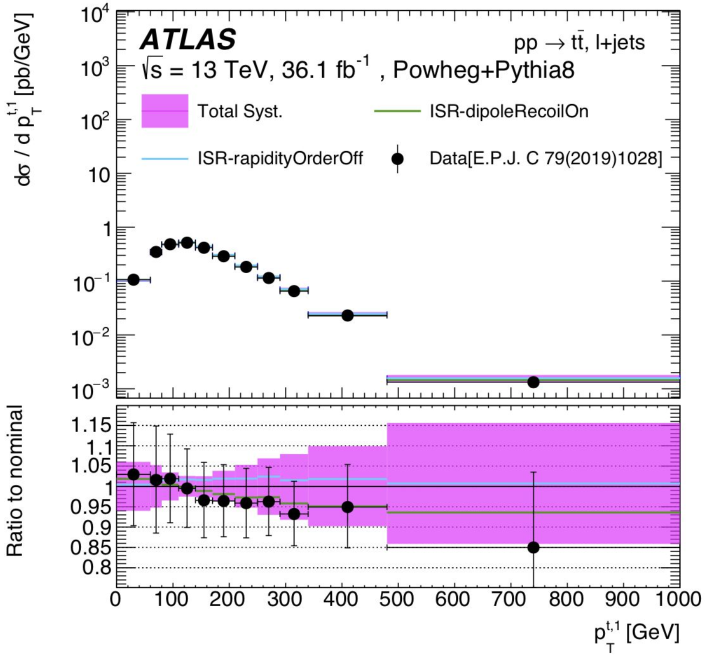
- Syst band contains the sum in quadrature of: scale, PDF, h_{damp}, Var3c, Parton Shower, Matching, and FSR

- Different lines for different settings in the ISR shower
  - **dipoleRecoilON**: Switch on the dipole recoils in ISR shower
  - **rapidityOrderOff**: Switch off the rapidity ordering of emissions in ISR shower

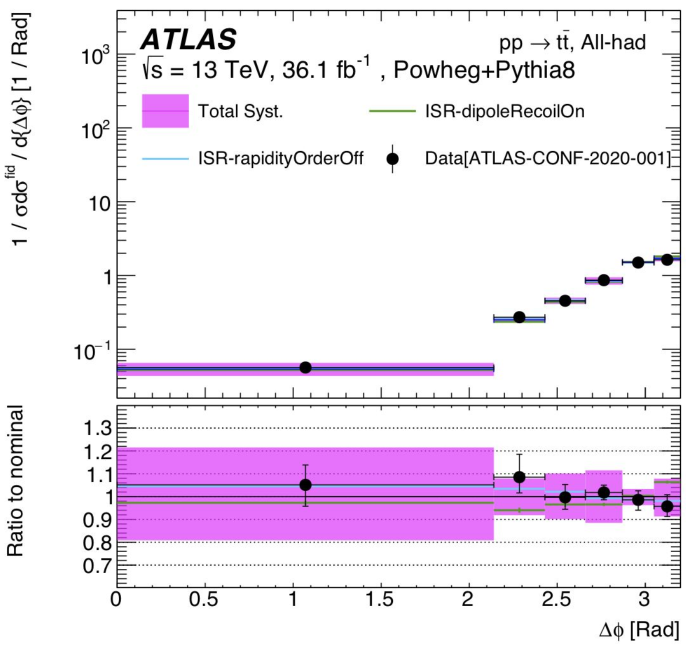
Agreement between PWG+PY8 & data

- Overall a good agreement between data and total systematics uncertainty shown in the pink band as well as with the ISR variations

Absolute $t\bar{t}$ cross section vs leading top p_T in l+jets channel



Normalized $t\bar{t}$ cross section vs ΔΦ ($t\bar{t}$) in the all-had channel

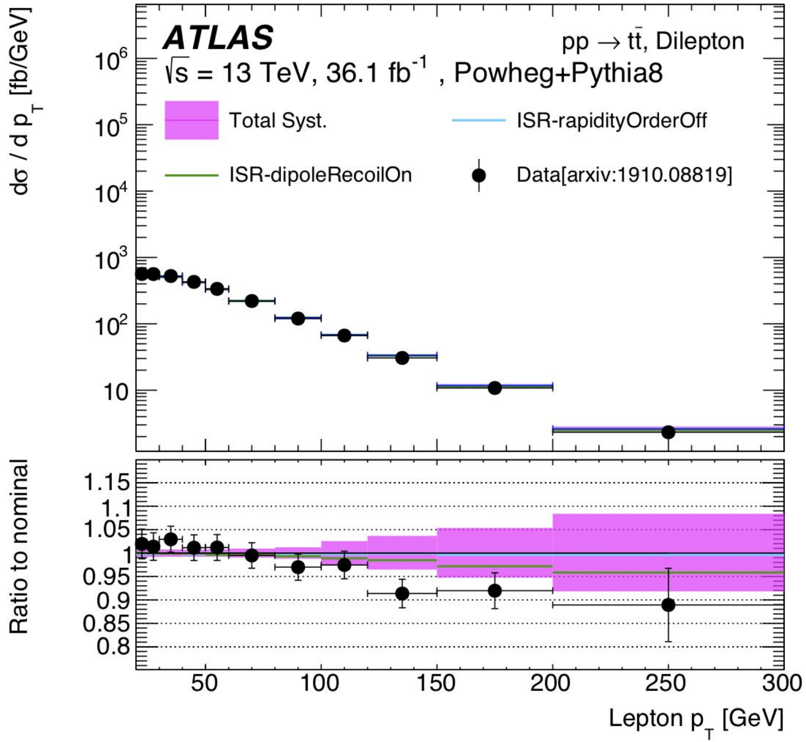


Agreement between PWG+PY8 & data

- The sample with RapidityOrderOff agrees with the nominal PW+PY8

- The sample with DipoleRecoilOn agrees better with data

Absolute $t\bar{t}$ cross section vs leading lepton p_T



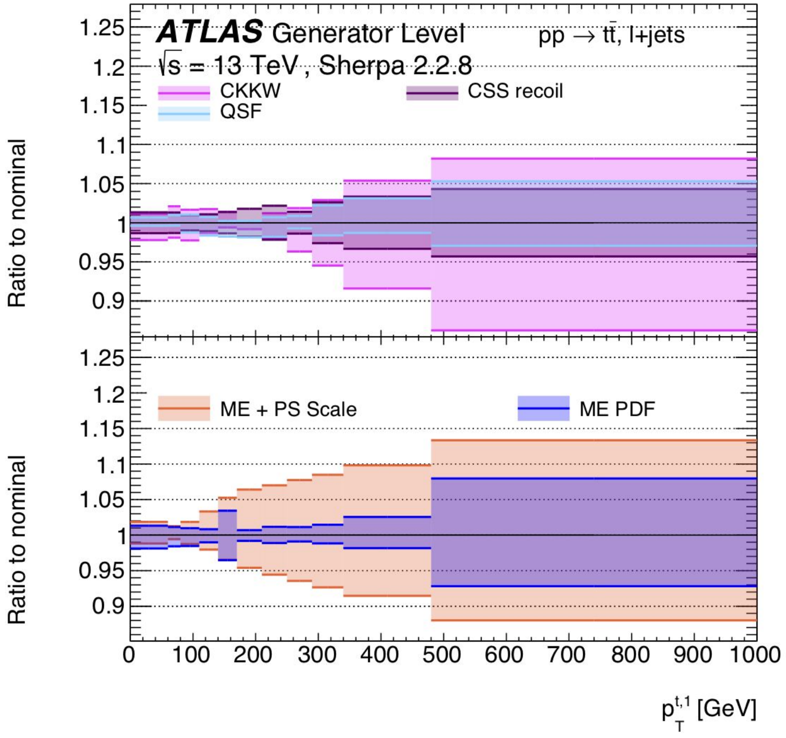
Alternative multi-leg generators: Sherpa

- Investigating multi-leg generators
  - Sherpa 2.2.8 sample with EW virtual corrections
  - $t\bar{t}$ + 0,1j@NLO + 2,3,4j@LO

- Variations of the resummation scales, CKKW matching scale and the dipole recoil scheme are shown in the upper panel

- Internal variations are shown in the lower panel (renormalisation and factorisation scales in the matrix element and the parton shower (ME+PS Scale) and PDF

Ratio with respect to nominal vs the leading top p_T

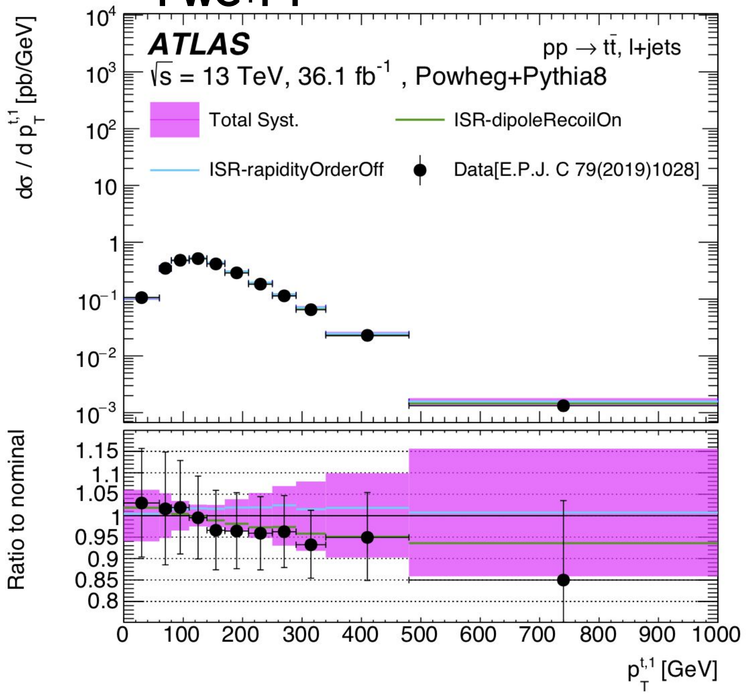


Agreement of PWG+PY8 / Sherpa with data

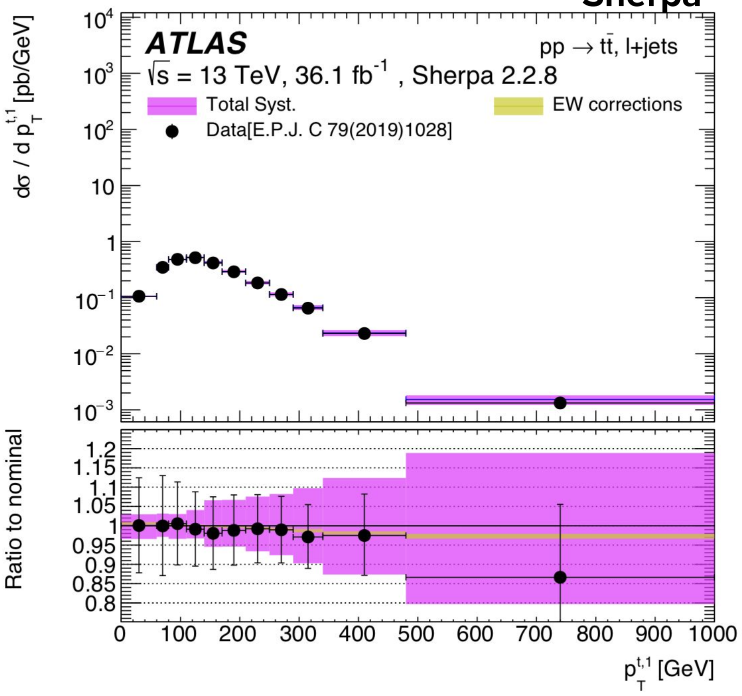
- PWG+PY8 has a larger uncertainty at low-p_T - probably due to the H7/PY8 difference
  - Uncertainties derived using one PS model are probably underestimated (smaller band for Sherpa)
- At high-p_T PWG has a slightly smaller uncertainty - maybe because it is "tuned" it to data!

Absolute $t\bar{t}$ cross section vs leading top p_T

PWG+PY



Sherpa



Conclusions

- Showed comparisons of the nominal MC generator setups and the corresponding systematic uncertainty model used in ATLAS

- The previous evaluation of the matching uncertainty convoluted at least two different effects:
  - The NLO matching algorithm which we want to probe
  - The matrix element corrections (MEC) applied to the top-quark decay

- Investigated other ways to probe the matching uncertainty
  - Does the new approach cover the intended uncertainty?
  - What can be done further to improve this?

Conclusions

- Presented comparison between two versions of Herwig7 for the parton shower uncertainty
  - Overall the difference between PWG+H713 and PWG+PY8 PS(H713) is smaller than the difference between PWG+H704 and PWG+PY8 PS(H704
- Avoiding ad-hoc 2-point systematics where possible in favor of internal weights
  - Need a well defined set of variations associated to a single setup
- hdamp variation:
  - Should we consider a different hdamp variation, different from $3*m_{top}$?
- Looked at alternative setups using Sherpa 2.2.8

Backup