ATLAS Experience of Tuning

Deepak Kar on behalf of many people

HSF Event Generator Tuning Workshop (June 2023)

Initial Remarks

- Tuning efforts in ATLAS has been mostly focussed on Pythia so far.
- Historically ATLAS used their own tune rather than Monash.
- While there are process specific tunes like A3 for minbias, AZNLO for Z p_T, A14 has been the workhorse.

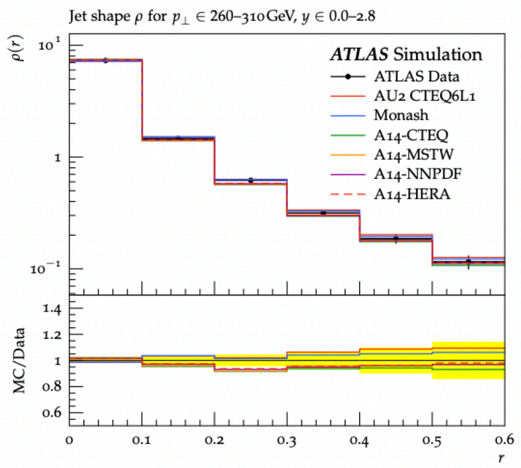
ATL-PHYS-PUB-2014-021

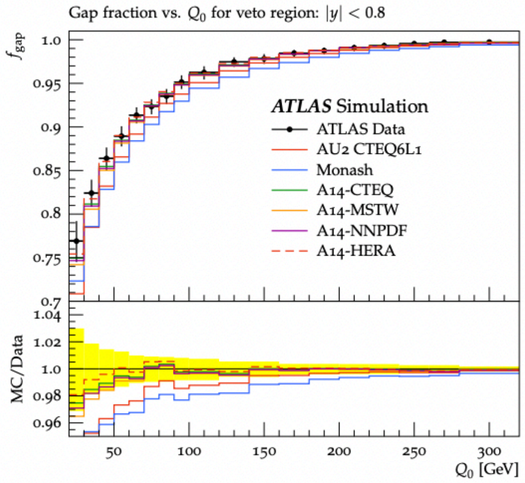
A14

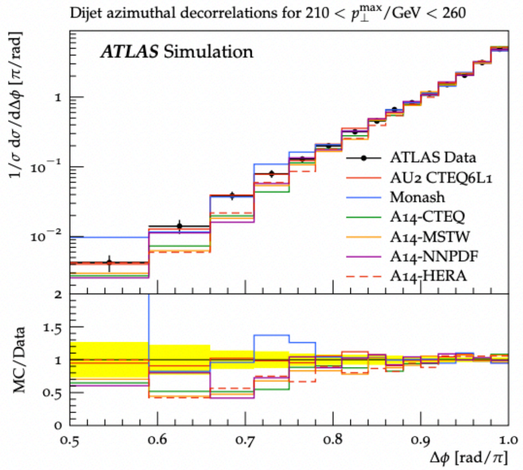
- As the name suggests, was done in 2014, so no Run 2 data, mostly using available Run1 UE, Z and ttbar observables, jet distributions.
- Started with Monash tune and reoptimised a limited set of parameters (α_S , ISR, FSR, MPI, colour reconnection).
- Was Intended as a pragmatic tune for lowest-order BSM generation, to *fake* higher-order corrections not being used then. That's why the high α_S value of 0.140, which is in tension with LEP results. Partially mitigated with a 2-loop running of the strong coupling.
- Provided a set of systematic variation eigentunes, which has been used extensively in ATLAS.

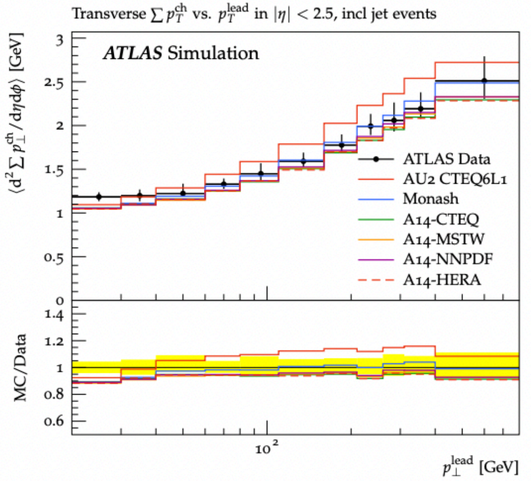
Param	CTEQ	MSTW	NNPDF	HERA
SigmaProcess:alphaSvalue			0.140	
SpaceShower:pT0Ref			1.56	
SpaceShower:pTmaxFudge			0.91	
SpaceShower:pTdampFudge			1.05	
SpaceShower:alphaSvalue			0.127	
TimeShower:alphaSvalue			0.127	
BeamRemnants:primordialKThard			1.88	
MultipartonInteractions:pT0Ref			2.09	
MultipartonInteractions:alphaSvalue			0.126	
BeamRemnants:reconnectRange			1.71	

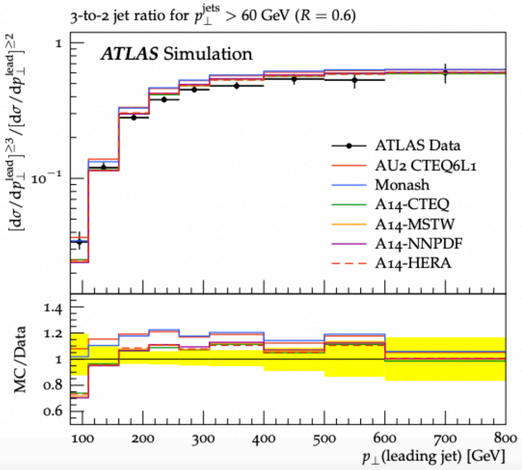
A14 then:

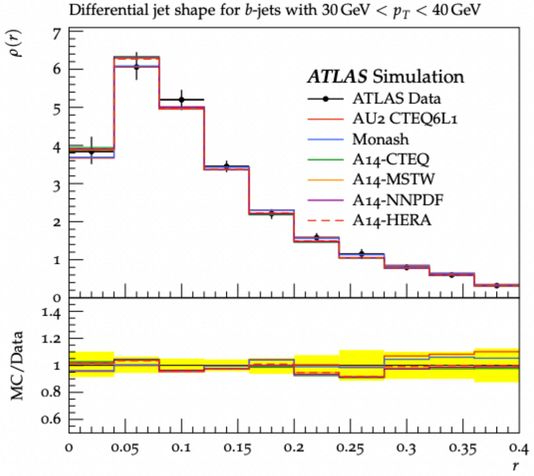

Jet shape ρ for $p_\perp \in 260$–310 GeV, $y \in 0.0$–2.8
ATLAS Simulation
ATLAS Data
AU2 CTEQ6L1
Monash
A14-CTEQ
A14-MSTW
A14-NNPDF
A14-HERA
$\rho(r)$
MC/Data
r

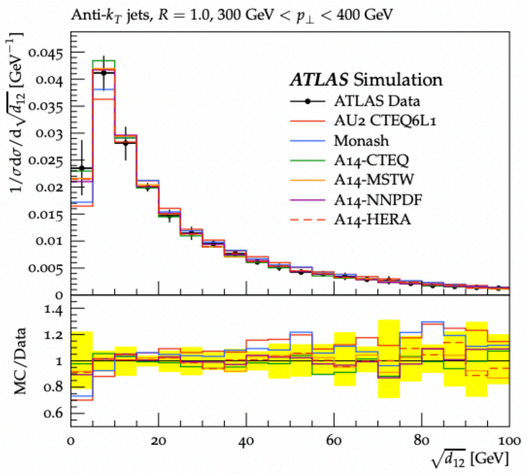

Gap fraction vs. Q_0 for veto region: $|y| < 0.8$
ATLAS Simulation
ATLAS Data
AU2 CTEQ6L1
Monash
A14-CTEQ
A14-MSTW
A14-NNPDF
A14-HERA
f_{gap}
MC/Data
Q_0 [GeV]

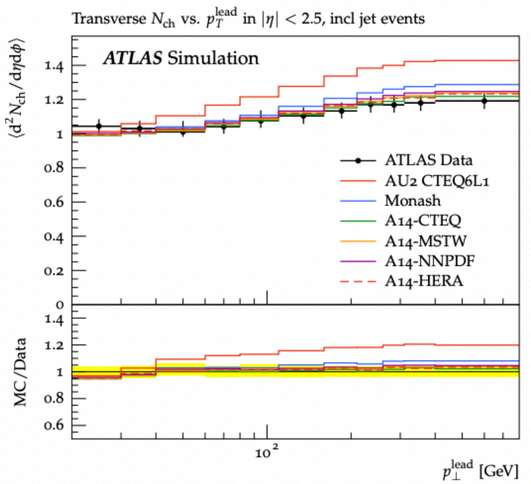

Dijet azimuthal decorrelations for $210 < p_\perp^{max}/\text{GeV} < 260$
ATLAS Simulation
ATLAS Data
AU2 CTEQ6L1
Monash
A14-CTEQ
A14-MSTW
A14-NNPDF
A14-HERA
$1/\sigma\, d\sigma/d\Delta\phi$ [π/rad]
MC/Data
$\Delta\phi$ [rad/π]


Transverse $\sum p_T^{ch}$ vs. p_T^{lead} in $|\eta| < 2.5$, incl jet events
ATLAS Simulation
ATLAS Data
AU2 CTEQ6L1
Monash
A14-CTEQ
A14-MSTW
A14-NNPDF
A14-HERA
$\langle d^2 \sum p_T^{ch}/d\eta d\phi \rangle$ [GeV]
MC/Data
$p_\perp^{lead}$ [GeV]


3-to-2 jet ratio for $p_\perp^{jets} > 60$ GeV ($R = 0.6$)
ATLAS Simulation
ATLAS Data
AU2 CTEQ6L1
Monash
A14-CTEQ
A14-MSTW
A14-NNPDF
A14-HERA
$[d\sigma/dp_\perp^{lead}]^{\geq 3}/[d\sigma/dp_\perp^{lead}]^{\geq 2}$
MC/Data
$p_\perp$(leading jet) [GeV]


Differential jet shape for b-jets with 30 GeV $< p_T <$ 40 GeV
ATLAS Simulation
ATLAS Data
AU2 CTEQ6L1
Monash
A14-CTEQ
A14-MSTW
A14-NNPDF
A14-HERA
$\rho(r)$
MC/Data
r


Anti-k_T jets, $R = 1.0$, 300 GeV $< p_\perp <$ 400 GeV
ATLAS Simulation
ATLAS Data
AU2 CTEQ6L1
Monash
A14-CTEQ
A14-MSTW
A14-NNPDF
A14-HERA
$1/\sigma d\sigma/d\sqrt{d_{12}}$ [GeV^{-1}]
MC/Data
$\sqrt{d_{12}}$ [GeV]


Transverse N_{ch} vs. p_T^{lead} in $|\eta| < 2.5$, incl jet events
ATLAS Simulation
ATLAS Data
AU2 CTEQ6L1
Monash
A14-CTEQ
A14-MSTW
A14-NNPDF
A14-HERA
$\langle d^2 N_{ch}/d\eta d\phi \rangle$
MC/Data
$p_\perp^{lead}$ [GeV]

Update of A14?

- There have been several plans/discussions to update A14 in these years (global recoil settings for Vjets for matched setups, hadronisation/identified particle production settings), but never converged.

- Tried a aMC@NLO matched setup tune (A15-MG5aMC@NLO) by varying ISR, FSR, MPI and hard interaction primordial k_t. No significant improvement observed, so stayed with A14.

- Partly because a clear/obvious improvement was not seen (as above), and partly because there is never a good moment to change a tune which is not horribly broken (i.e. like at the beginning of Run 1). Involves re-deriving the MC scale factors for (most) CP objects, which is a huge enterprise as the CP groups have been perennially lacking in person power.

[JHEP 09 (2014) 145]

AZNLO

- Tuned to the Z-boson p_T and phi* distributions at 7 TeV Fitting intrinsic-k_T, the ISR strong coupling and its cut off Based on the (old) 4C tune and CTEQ6L1 PDFs.

- Model for W p_T and its uncertainties for the 7 TeV W-mass measurement, AZNLO is the Pythia8 tune used to shower Powheg processes involving electroweak boson production (W,Z,H,VV).

- Does not describe the rapidity dependence.

	Pythia8	Powheg+Pythia8
Tune Name	AZ	AZNLO
Primordial k_{T} [GeV]	1.71 ± 0.03	1.75 ± 0.03
ISR $\alpha_{\mathrm{S}}^{\mathrm{ISR}}(m_Z)$	0.1237 ± 0.0002	0.118 (fixed)
ISR cut-off [GeV]	0.59 ± 0.08	1.92 ± 0.12

Not forgetting A3

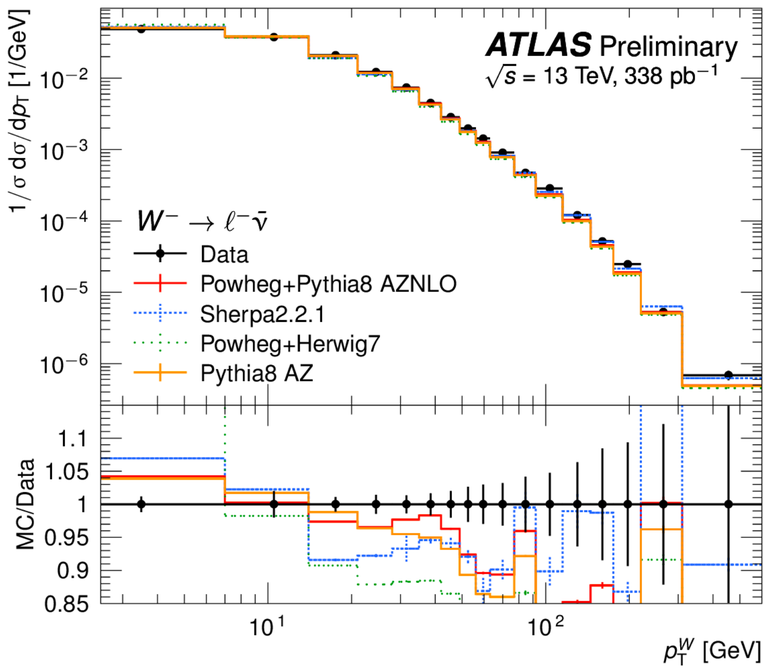
- Using the Donnachie-Landschoff diffractive model to better model inelastic cross-section and minbias distributions.

- Tuned MPI and CR parameters as well.

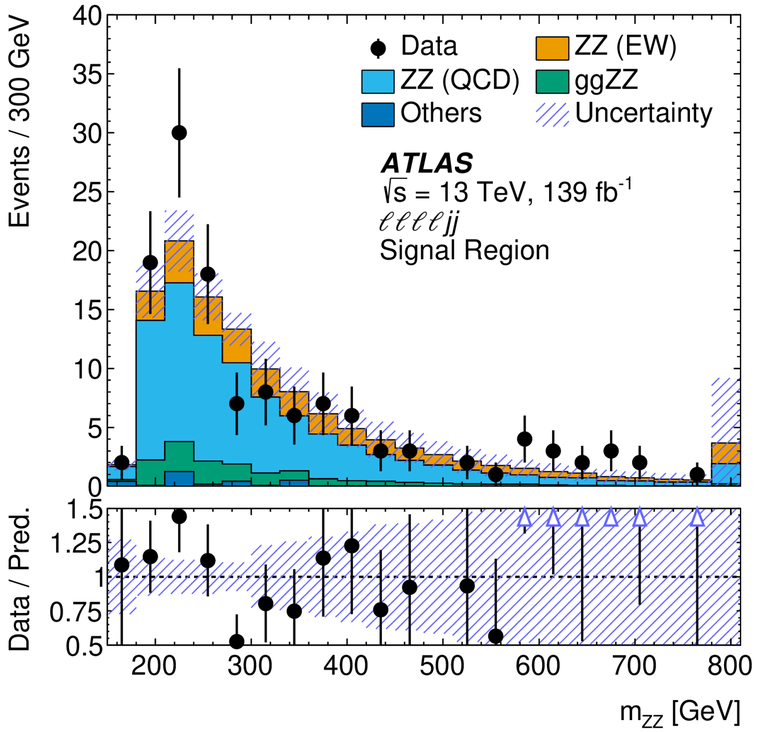
Parameter	A3 value
`MultipartonInteractions:pT0Ref`	2.45
`MultipartonInteractions:ecmPow`	0.21
`MultipartonInteractions:coreRadius`	0.55
`MultipartonInteractions:coreFraction`	0.90
`MultipartonInteractions:a1`	-
`MultipartonInteractions:expPow`	-
`BeamRemnants:reconnectRange`	1.8
`Diffraction:PomFluxEpsilon`	0.07 (0.085)
`Diffraction:PomFluxAlphaPrime`	0.25 (0.25)

	ATLAS data (mb)	SS (mb)	A3 (mb)
At $\sqrt{s} = 13$ TeV	68.1 ± 1.4	74.4	69.9
At $\sqrt{s} = 7$ TeV	60.3 ± 2.1	66.1	62.3

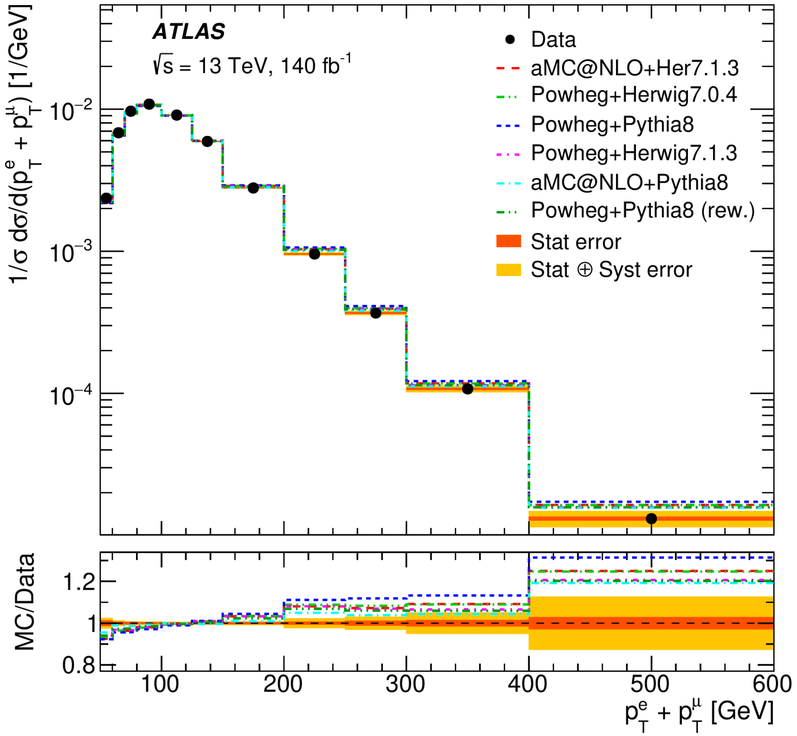
Some examples of Mismodelling



Vector boson p_T, input to W mass measurements and leading SM background to many searches. Link.

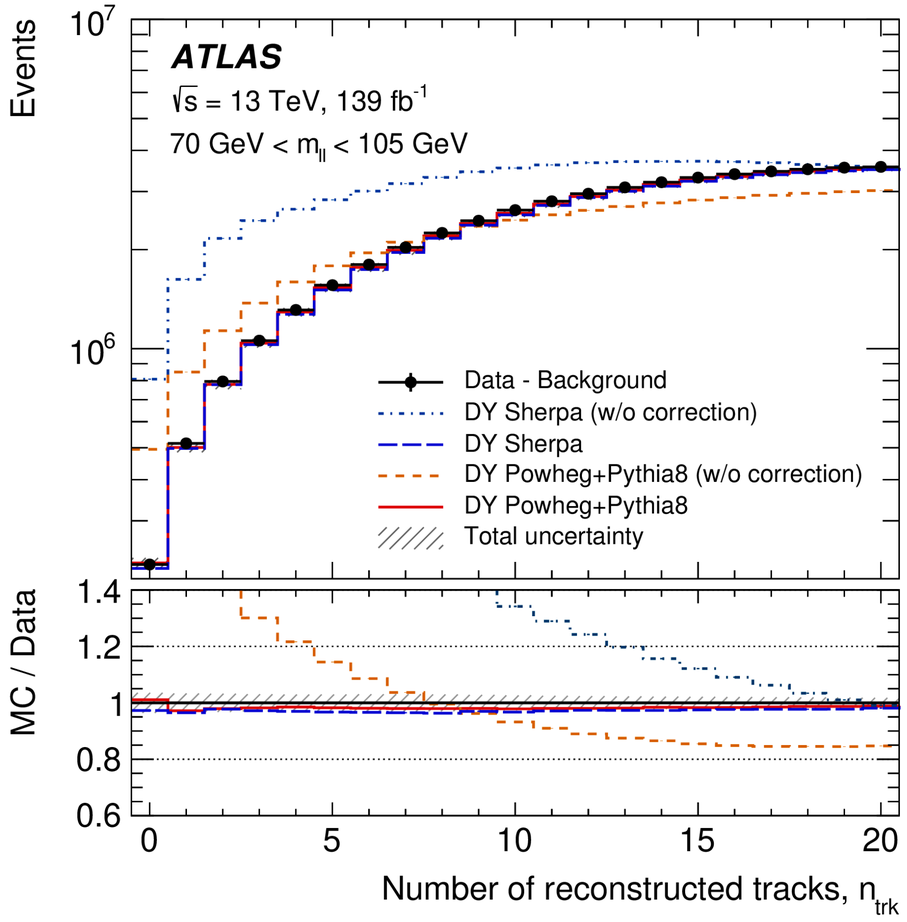


Vector boson fusion processes, again important for many searches and measurements. Link.

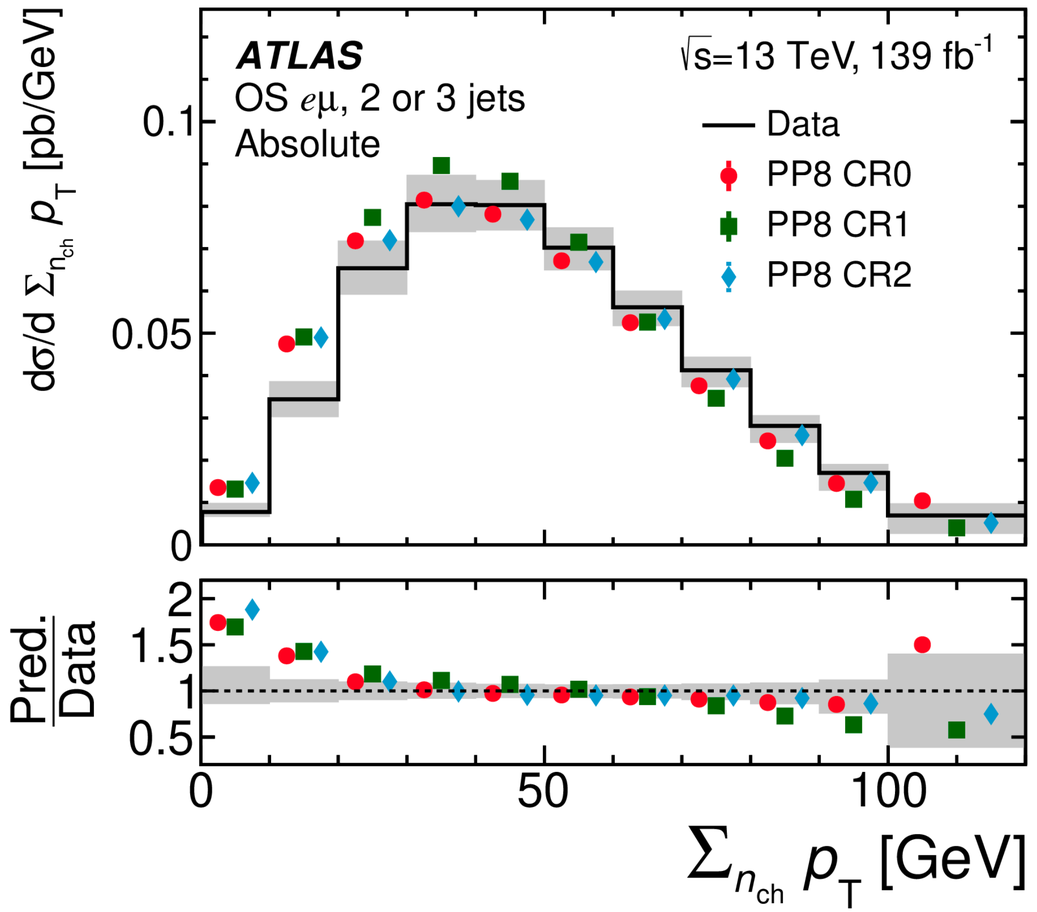


Top quark pair p_T, many attempts over the years without a complete success. NNLO or N3LO does help. Link.

More specific examples:



Large mismodelling at low track multiplicity, affects measurement of exclusive photon-induced processes background. Link.



Colour reconnection in ttbar events, a large source of uncertainty in top mass measurements. Link.

Tuning or Modelling?

- The use of pure Pythia for modelling SM processes has decreased over the years, as V+jets are modelled by Sherpa, top processes by Powheg+Pythia8, only dijet is still using Pythia8. BSM signals are almost always by MadGraph+Pythia8/Herwig7, but modelling issues are less of a concern there.

- So even though many searches/measurements have observed mismodelling, often that's not due to tuning rather missing higher order/EW corrections, matching/merging effects and so on.

- Tt/Wt interference modelling remains an issue, Powheg-bb4l does better. Not a tuning issue *per se*.

- When many people say modelling issues, they mean modelling systematic uncertainties, which although is less *ad hoc* now than say 5 years back, is still *ad hoc*. Should that be our focus?

From then to now …

- Hundreds of new measurements in Rivet (with ATLAS leading the way ;)
- Increased importance of matched and merged NLO setups with a variety of matching and merging schemes. Not obvious that the tune should be matching scheme independent.
- Alternative recoil schemes can have significant impact on some observables (eg top mass).
- Alternative parton shower models: DIRE (dipole resummation) Vincia (Antenna showers).

Looking forward

This is neither a list endorsed by the collaboration, nor a complete plan, but mentioning here to start a discussion/find possible synergies

- Divide and conquer: tune hadronisation/fragmentation first, which has a minimal effect on other observables Changing Pythia8 settings can have unexpected consequences as improving agreement for one observable can make others look worse.
- Any retune requires a robust validation strategy
- Process specific tunes?
- Collaboration with others (LHCEWWG common tuning effort?)
- Baseline/Monash level tunes for new shower setups, i.e Vincia?
- Use common tuning setup for other generators?