TECHNISCHE UNIVERSITÄT DRESDEN
Fakultät Physik Institut für Kern- und Teilchenphysik

Top modelling and its uncertainties in Sherpa

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LHC Top WG Meeting, 24 November 2020

Emmy Noether-Programm
Deutsche Forschungsgemeinschaft
DFG

The art (or ambiguities) of constructing a PS MC

- A parton-shower Monte Carlo is not a fixed-order prediction
  - It is much more powerful!
  - And at the same time much more ambiguous!

Ambiguities = Uncertainties

(and in addition there can be bugs of course)

Let's review how they are addressed in Sherpa …

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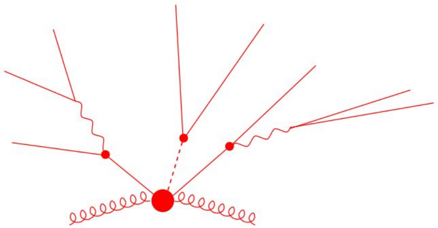
- Typical sources of ~~trouble~~ **ambiguities**:
  - Hard scattering
    - Limited perturbative accuracy
      ⇒ ambiguity in scale and PDF choices
    - Narrow-width approximation instead of full offshell WbWb
      - Diagram overlap between tt and tWb
        ⇒ ambiguity in overlap removal
      - Spin correlations between production and decay MEs in the chain
        ⇒ ambiguity in polarisation treatment
        - particularly tricky for tau decays, as they can be hadronic!
    - NLO EW Combination of NLO QCD and NLO EW corrections
      ⇒ ambiguity in combination between NLO QCD and NLO EW
    - Multi-leg merging of ME & PS
      ⇒ ambiguity in transition



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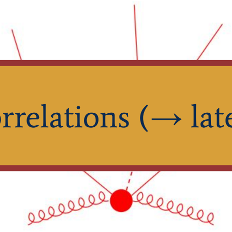
On-the-fly variations of scales and PDFs [1606.08753]

Spin correlations (→ later)



Additive and multiplicative schemes [2005.12128]

Variation of merging scale Q_{cut}

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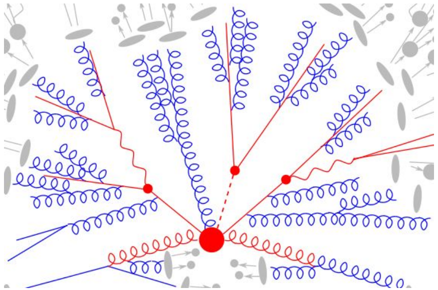
      ⇒ ambiguity which (finite) pieces to keep
    - Kinematics recoil (how to construct $1\to 2$ splittings with $m=0$ away from collinear limit)
      ⇒ ambiguity where to distribute recoil for momentum conservation
    - Evolution variable (direction in which logs are resummed)
      ⇒ ambiguity what "from hard to soft" means exactly
    - Additionally many ambiguities for treatment of quark masses in the above!



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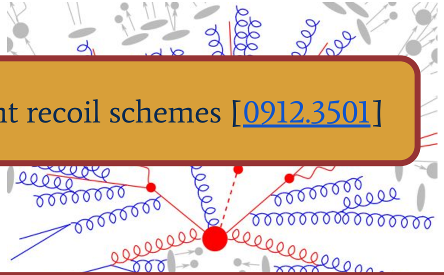

Switch between 2 different recoil schemes [0912.3501]

Switch between different evolution schemes (→ later). Choice of shower starting scale μ_Q.

Only probed to small extent by on-the-fly variations of scales and PDFs! [1606.08753]

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    - B-hadron production from partons
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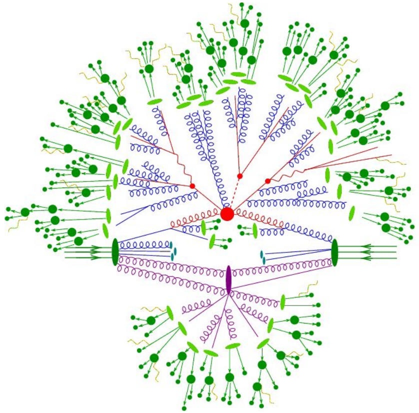
  - Hadron decays: Effective field theories for heavy-flavour decays
    - B-hadron decays
      ⇒ **ambiguity of decay matrix elements** (form factor models)



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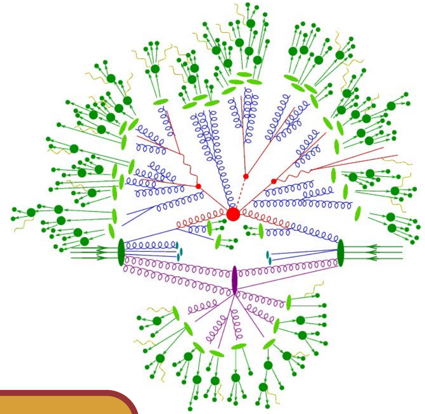
Interface to alternative hadronisation from Pythia6



Several form factor models for important B and D decays.
Branching ratio defaults from PDG, but can be varied.

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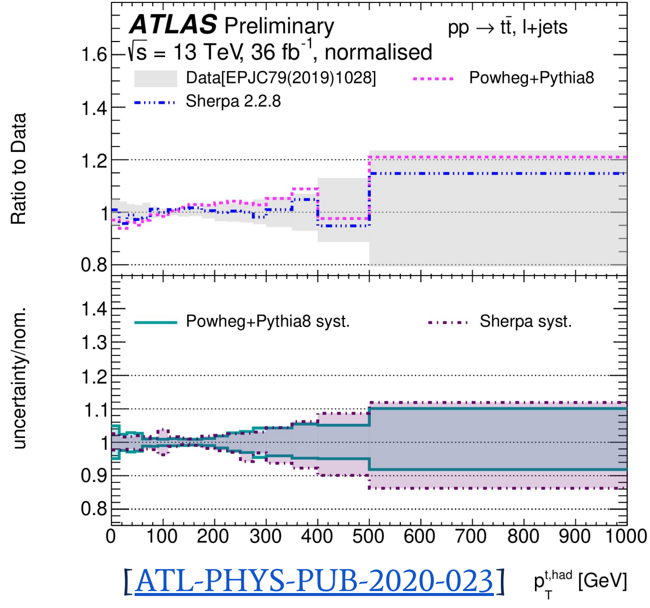
- Typical sources of ~~trouble~~ ambiguities:

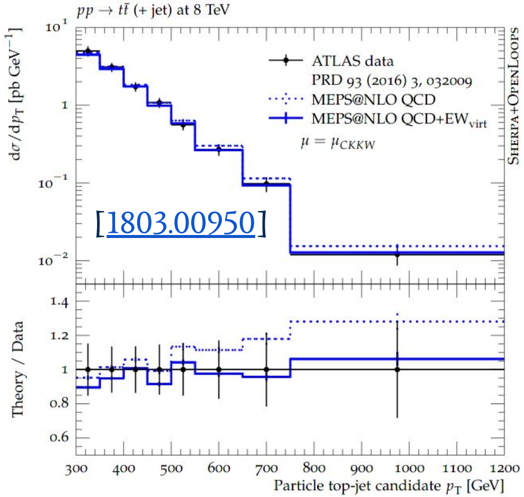
Let's look at some typical Sherpa top setups and their modelling & uncertainties ...

Top pair production

- Multileg NLO QCD merging Sherpa+OpenLoops [1402.6293]
  - tt + ttj (+ ttjj) @ NLO
  - (ttjj +) ttjjj+ ttjjjj @ LO
- Recent ATLAS & CMS studies (→ just shown by Marino):
  Good modelling of tt+jets & interesting uncertainty comparison:
  - PH+Py8: μ^{ME}, PDF^{ME}, hdamp, $\mu^{PS,ISR}$, $\mu^{PS,FSR}$, PS recoil
  - Sherpa tt MEPS@NLO: μ^{ME+PS}, PDF^{ME+PS}, Q_{cut}, α_S, μ_Q, PS recoil
    → Similar order of magnitude, WIP to understand differences.



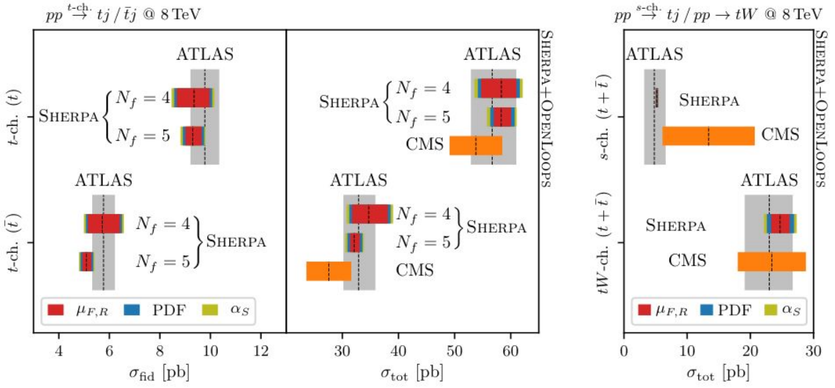
[ATL-PHYS-PUB-2020-023]

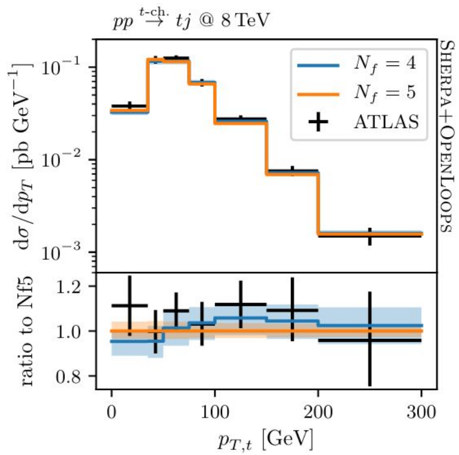


[1803.00950]

- New: NLO EW corrections directly in MC sample
  - using EWvirt approximation in MEPS@NLO
  - typical EW Sudakov effects relevant in high p_T regions
  - now available “for free” as on-the-fly weights in samples
    - since 2.2.9 even in additive and multiplicative scheme
      → useful to define uncertainty!

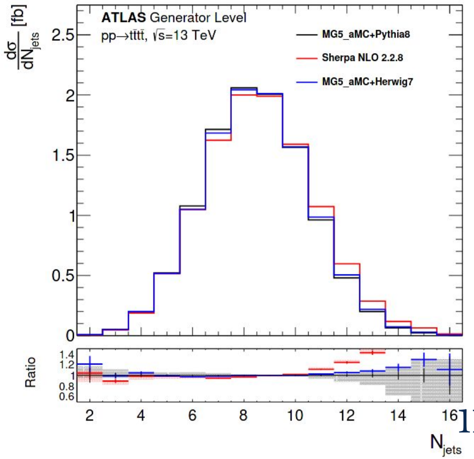
- Single-top production [1711.02568]
    - NLO+PS setup with OpenLoops virtual MEs
    - For t-channel, s-channel, tW using diagram removal approach





- 4-top production
    - NLO+PS samples with OpenLoops virtual MEs
    - Recent ATLAS comparisons with aMC@NLO
    - WIP: include NLO EW (and subleading trees) through EWvirt mechanism

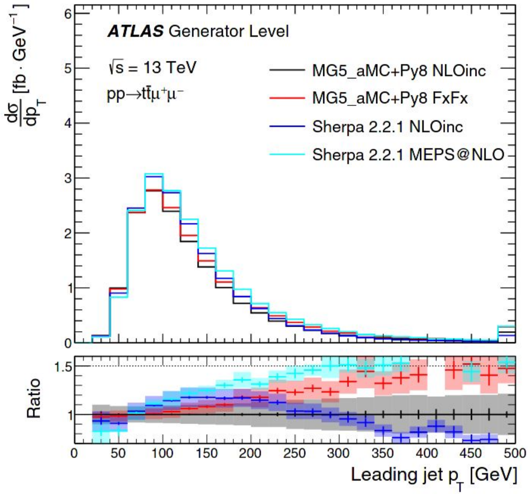
[ATL-PHYS-PUB-2020-024]

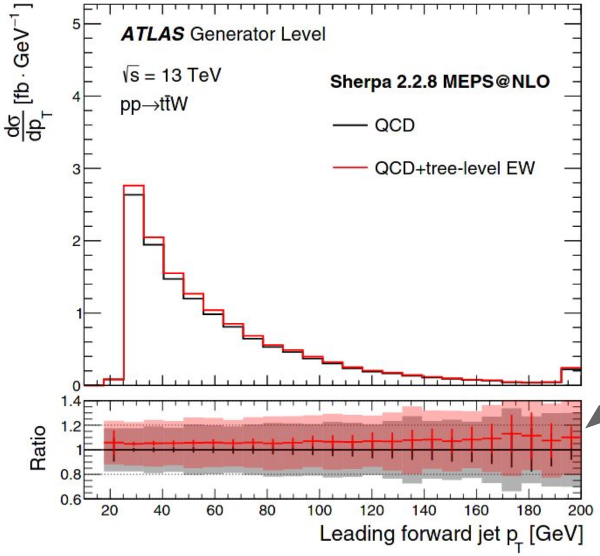


tt + ll and tt + W

- ttV+jets and ttll+jets with Sherpa+OpenLoops
  - MEPS@NLO tt{V,ll} + 0,1j@NLO + 2,3j@LO
  - Merged setups predict higher rates and harder spectra
  - ttV+1j@NLO helps capture large parts of NNLO effects relevant for global normalisation

[ATL-PHYS-PUB-2020-024]





- NLO EW weights available through EWvirt approximation
  - particularly interesting because of subleading EW tree contributions
    - detailed studies ongoing to compare to fixed-order literature
    - EWvirt approach makes this available differentially in MC sample!

- 4FS NLO+PS setup for ttbb with massive b-quarks in 2→4 matrix element

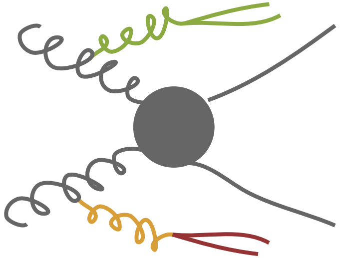
Final state g→bb **dominant**

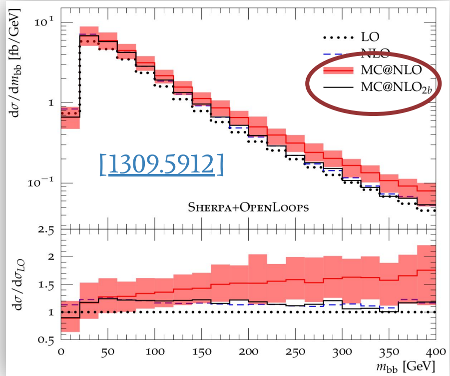
- massive b’s → no (jet) cuts!
- collinear g→bb produced in ME

No initial state b in MEs

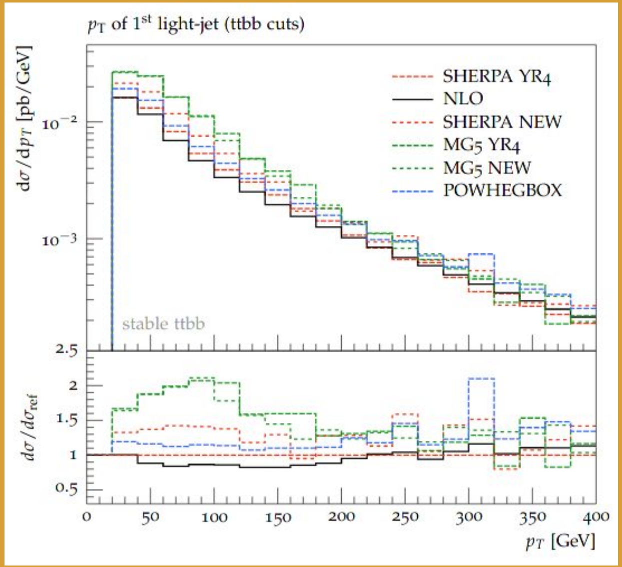
- 4FS PDFs
- IS g→bb in ME

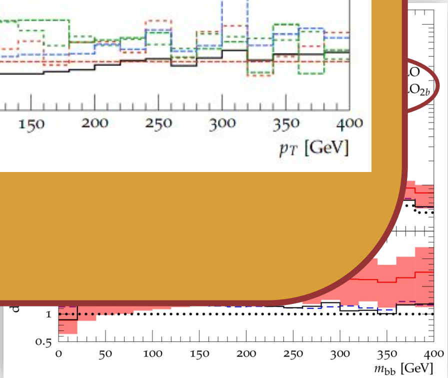
- Matched to parton shower for additional emissions
  - **“double-splitting”** contribution becomes relevant!





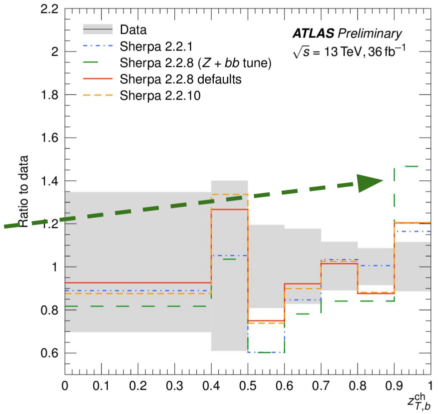
Many ambiguities for ttbb discussed by [Andrea] yesterday and [studied recently] in detail in LHC Higgs XS WG
→ watch for a summary soon!

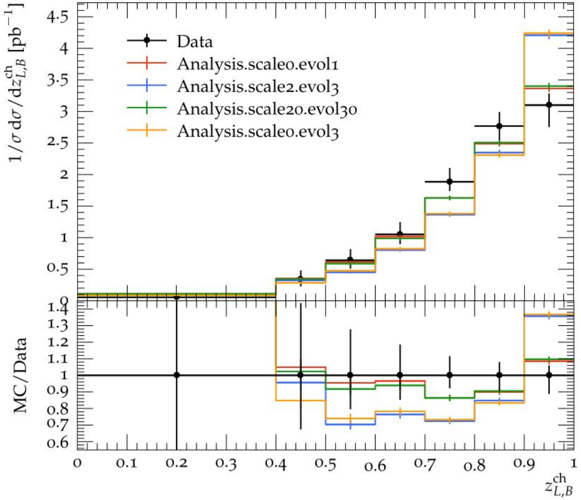




Recent updates: HF shower evolution schemes

- New schemes for evolution variable in HF splittings
  - `CSS_EVOLUTION_SCHEME=3` improves g→bb splitting by appropriate b-mass term in evolution variable
  - also applied to b→bg splitting, although not necessary there
  - worse data/MC agreement in b-fragmentation analysis
    - dominated by b→bg splittings

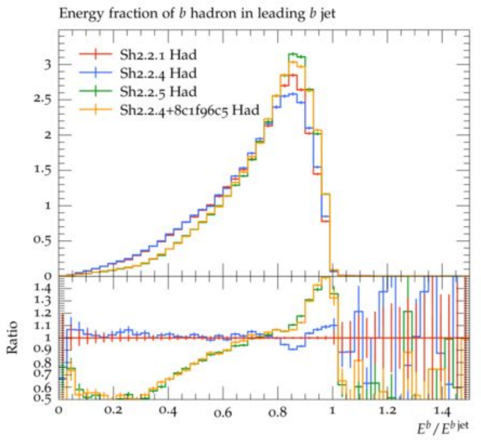




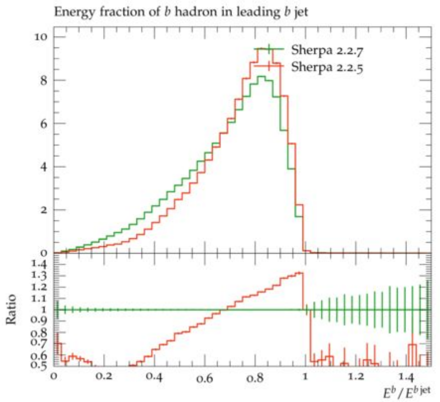
- Future in Sherpa >=2.2.9:
  hybrid scheme ("30")
  - b→bg retains original evolution
    - b-fragmentation in tt improved
  - relevant mass term included only in g→bb
    - relevant e.g. for Zbb

Recent updates: decay showering in Sherpa 2.2.x

- Example of impact from shower splitting functions
  - Sherpa 2.2.5 contained bugfix for showering in coloured decays based on developments in [1709.08615]
  - bugfix contained wrong definition of mass term in shower splitting function
  - Large impact on fragmentation function
  - Details in https://gitlab.com/sherpa-team/sherpa/-/issues/176



- First found in Sherpa 2.2.6 ATLAS validation, fixed in Sherpa 2.2.7:



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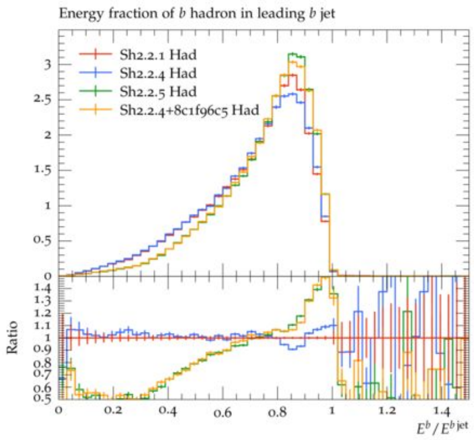

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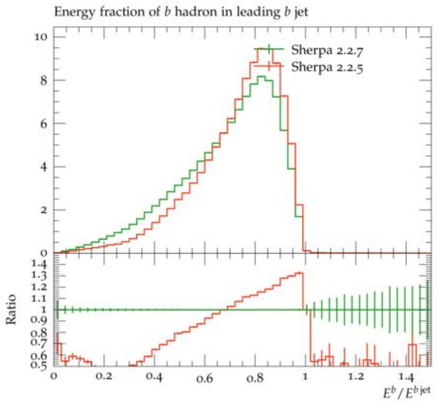


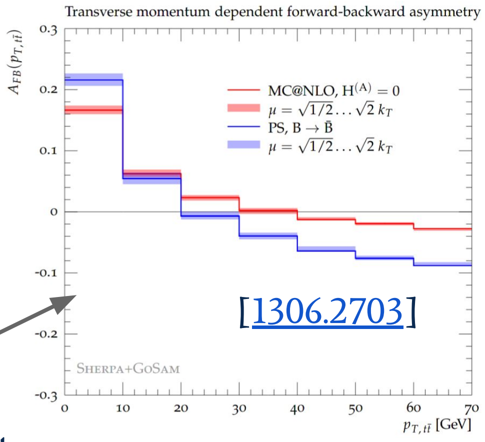
A bug, not an ambiguity.
But difficult to disentangle!

Recent updates: Negative weight improvements

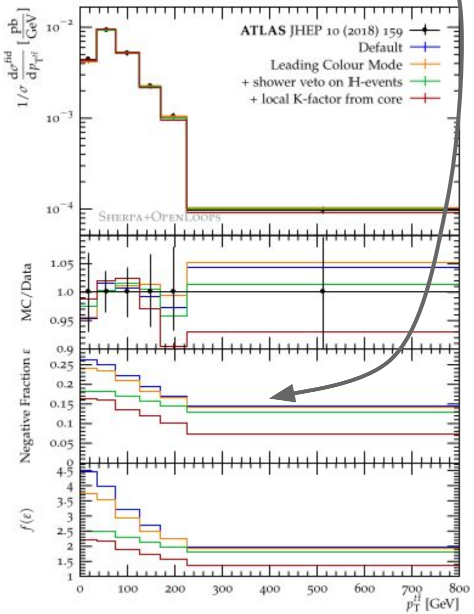
- Recent efforts to find physics compromises which reduce negative weight fraction
- Thorough validation against full options to ensure physics is unchanged

tt+0,1j@NLO+2,3j@LO	Negative Weight Fraction
Default	24.8%
Leading Colour Mode	18.7%
+ shower veto on $\mathbb{H}$-events	14.5%
+ local K-factor from core	12.6%

- Largest effect disabling full-colour mode in matched shower evolution
  - use simple shower kernels instead of exact subtraction dipoles
  - generally no significant impact, but careful with sensitive observables, e.g. forward-backward-asymmetry!



[1306.2703]



- Subleading effect: shower veto on H-events
  - basic idea similar to part of MC@NLO Δ-matching
  - natural within merged sample → no counter terms/folding necessary

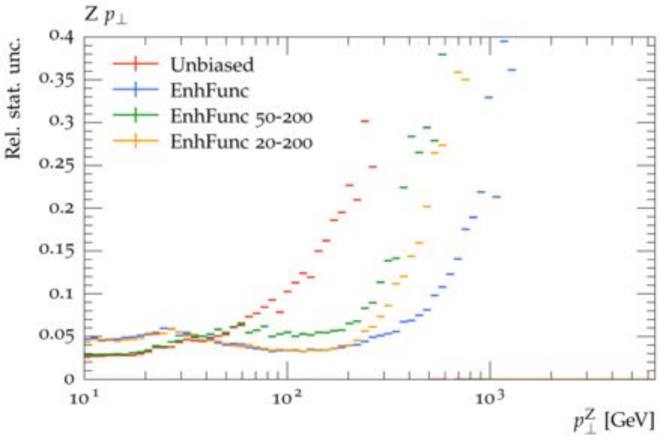
- Experiments often slice samples (e.g. in p_T) to populate non-bulk regions
- Alternative: phase-space biasing of (otherwise) unweighted evts
    - (Re-)Implemented in Sherpa 2.2.8 in two variants (demonstrated here in Z+jets):

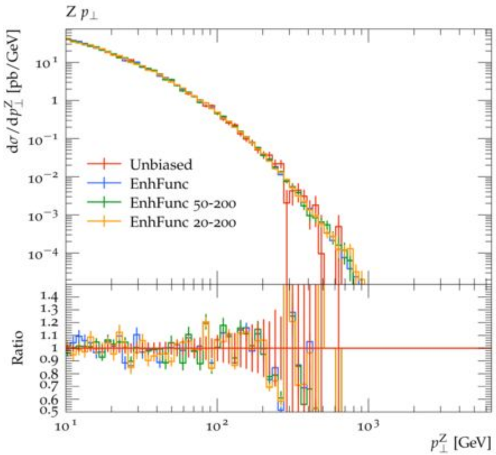
Multiplicative function

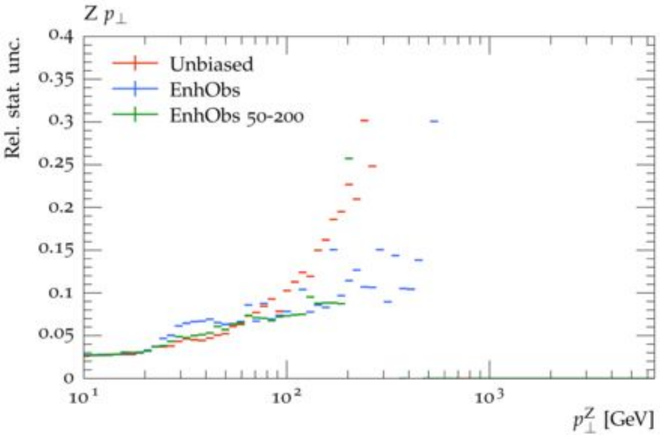
"Enhance_Function"

Flattening in given observable

"Enhance_Observable"







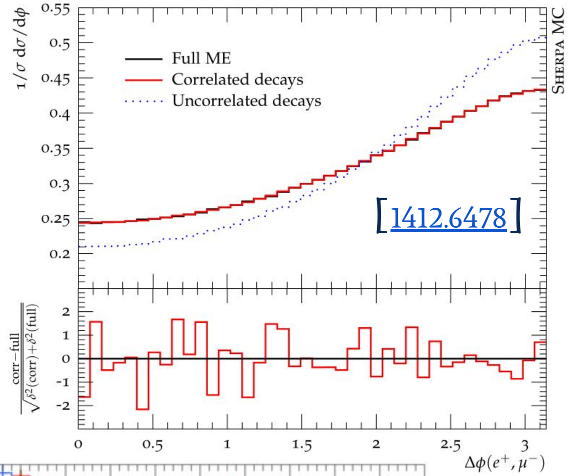
Recent updates: Spin correlations for taus from tops

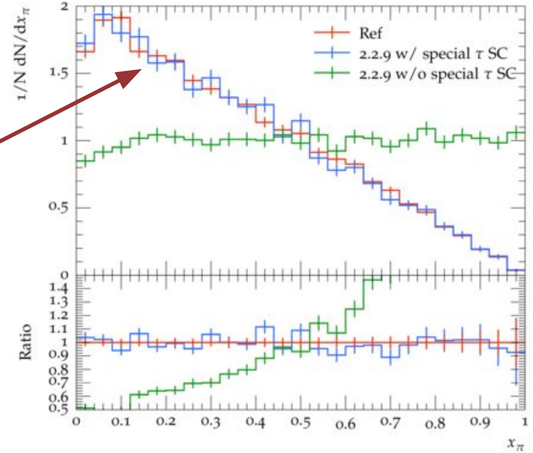
- What are spin correlations?

$$\mathcal{M} \sim j_1^\mu \left[g_{\mu\nu} - \frac{p_\mu p_\nu}{p^2} \right] j_2^\nu = \sum_\lambda \underbrace{j_1^\mu \varepsilon_\mu^*(\lambda)}_{\mathcal{M}_{\text{prod}}(\lambda)} \underbrace{\varepsilon_\nu(\lambda) j_2^\nu}_{\mathcal{M}_{\text{dec}}(\lambda)}$$

- Spin correlations for top and W decays were always fully taken into account in Sherpa

- For taus produced in W decays it was more difficult
  - separate decay chains, because taus decay hadronically
    - » spin correlation algorithm only works recursively
  - dedicated algorithm in Sherpa >=2.2.9 recovers polarisation of taus produced in hard decays
    - » $\tau \to \pi\, \nu$ energy fraction correctly reproduced
    - » important for analyses: $\tau \to$ lepton angular correlations correct





Conclusions

- MC event generators are powerful but ambiguous
  - Even more so with complex features like NLO multi-leg merging or EW corrections

  → Requires careful assessment of systematic uncertainties

- Sherpa is available for wide variety of top physics with state-of-the-art precision
  - Many recent features particularly for LHC top production processes.

Sherpas and tops go together quite naturally :)

Thanks for your attention!