Algorithmic uncertainties in $p_{\mathrm{T}}(V)$ distributions and ratios

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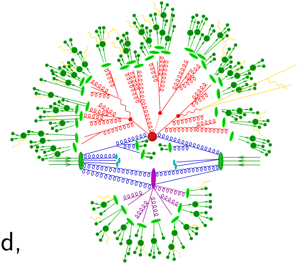


Parametric uncertainties

- reflect dependence on input parameters
  → PDFs, couplings, masses, etc.

Perturbative uncertainties

- reflects the fact that perturbation theory is used, both in the fixed-order calculation or the resummation, large-N_c in the parton shower, etc.
  → neglected higher-order terms

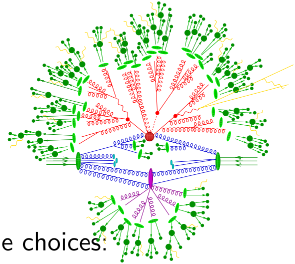
Algorithmic uncertainties

- reflects that choices are made in the implementation of the resummation/parton shower
  → evolution variable, non-singular terms, recoil strategy, matching & merging scheme, ...

Modelling uncertainties

- related to incomplete models of non-perturbative physics processes

Uncertainties in theoretical predictions



Parametric uncertainties

- assess through variation of input parameters within limits given by existing data

Perturbative uncertainties

- use that full result must be independent of scale choices:
  renormalisation & factorisation scales
  resummation scales / profile scales / ...
  → can always only capture scale-dependent terms, never scale-independent ones

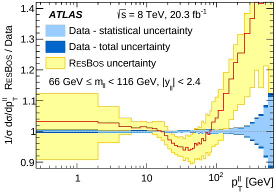
Algorithmic uncertainties

- implement different algorithms
  → always a discrete variation
  → tricky as algorithm development takes up the majority of the time

Modelling uncertainties

- if we knew how physics works in this regime ...

Uncertainties of $p_\mathrm{T}(V)$



Standard uncertainty evaluation

- vary PDFs & α_s, μ_R, μ_F, μ_Q, μ_S, μ_J, μ_B, ...

Missing parametric & perturbative uncertainties

- electroweak parameters and schemes
- heavy quark masses
- PDFs which treat parton masses and thresholds independently

Algorithmic uncertaities

- compare different resummation formalisms / parton showers at the same perturbative order
  → gives an estimate of the size of this dependence
  → the full result is independent of algorithms,
  but cannot necessarily be captured by next logarithmic order
- physics object definition (theory-experiment match)

Proposal to assess algorithmic uncertainties in MCs

- focus on low-p_T region
- tuned comparison (harmonised input parameters, PDFs, α_s, CMW scheme, etc, as far as possible)
- start at LO+PS without any non-perturbative modelling or higher-order corrections
  → baseline for algorithmic dependence
- compare this algorithmic dependence against higher-order effects (eg. from DIRE)
- one-by-one switch on matching and merging
  → assess in how far the algorithmic dependence reduces
  → assess in how far the matching changes the PS resummation
  → assess in how far the merging changes the PS resummation
- in a last step, include non-perturbative corrections

Proposal to assess algorithmic uncertainties in MCs

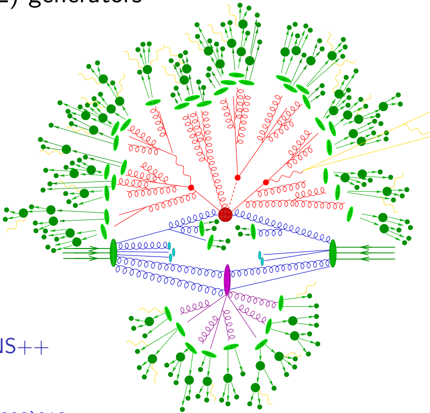
Will any of these findings actually be used?
If so, which ones are the most useful?

Algorithmic uncertainties in SHERPA

The SHERPA event generator framework

JHEP02(2009)007

- Two multi-purpose Matrix Element (ME) generators
  AMEGIC++ JHEP02(2002)044, EPJC53(2008)501
  COMIX JHEP12(2008)039, PRL109(2012)042001
- Two Parton Shower (PS) generators
  CSSHOWER JHEP03(2008)038
  DIRE EPJC75(2015)461
- A multiple interaction simulation
  à la PYTHIA AMISIC++ hep-ph/0601012
- A cluster fragmentation module
  AHADIC++ EPJC36(2004)381
- A hadron and τ decay package HADRONS++
- A higher order QED generator using
  YFS-resummation PHOTONS++ JHEP12(2008)018



Sherpa's traditional strength is the perturbative part of the event

LO, NLO, NNLO, LOPS, NLOPS, NNLOPS, MEPS, MENLOPS, MEPS@NLO

Algorithmic uncertainties

Best available calculations

- NNLOPS $pp \to \ell\ell$
  - NLO+PS accuracy throughout the $p_\mathrm{T}(V)$ spectrum
- MEPS@NLO $pp \to \ell\ell + 0, 1, 2j$@NLO QCD+EW$_\text{approx.}$ $+ 3, 4j$@LO
  - LO+PS accuracy for low $p_\mathrm{T}(V)$
  - NLO+PS accuracy for high $p_\mathrm{T}(V)$ (incl. EW corr.)

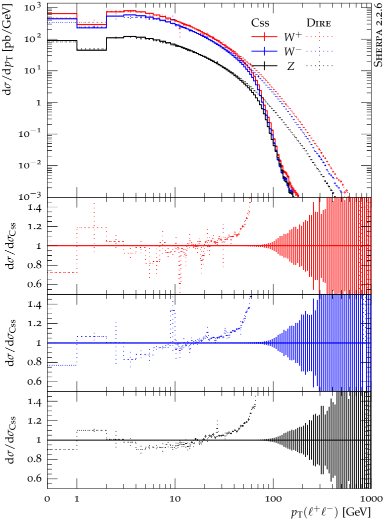
QED corrections

- YFS soft-photon resummation matched to NLO QED for $Z \to \ell\ell$ and $W \to \ell\nu$ FSR (extended to NNLO QED+NLO EW in SHERPA-3.0)

Algorithmic uncertainties – LO+PS – **preliminary**

CSSHOWER VS. DIRE

- incl. xsec. identical
- no higher order corrections, no non-perturbative corrs., no QED corrections
- differences in Sudakov peak region
- IS IR cutoff $\mathcal{O}(2\,\text{GeV})$
- high-p_T differences caused by different evolution variable $\rightarrow$ beyond accuracy
- needs more stats, especially for ratios



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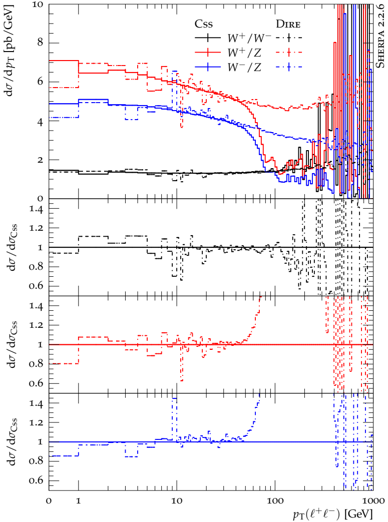

Algorithmic uncertainties – LO+PS – **preliminary**

CSSHOWER recoil schemes

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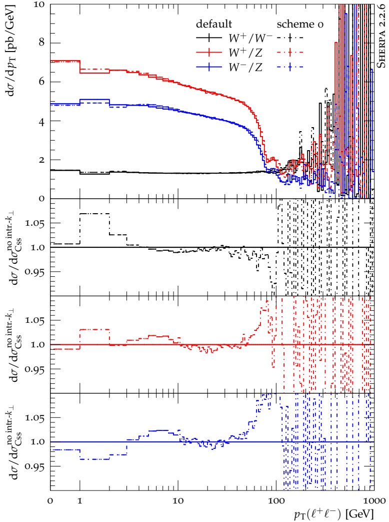
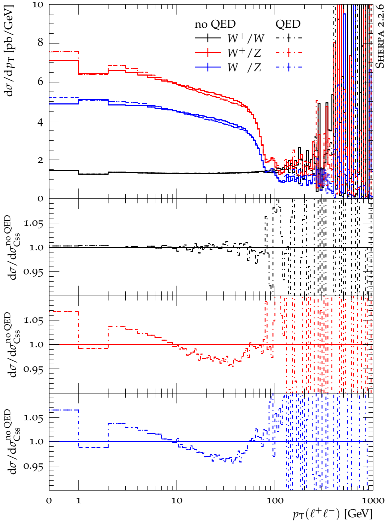


Algorithmic uncertainties – LO+PS – preliminary

CSSHOWER w/ QED or intr. $k_\perp$

- QED effects through soft-photon resummation
  - differs in W and Z
  - induces shift of $\mathcal{O}(5\%)$
- intrinsic $k_\perp$ through simple x- and flavour independent model (Gaussian $k_\perp$-dist.)
  - fills gap below IR cutoff
  - differs in W and Z
  - induces shift of $\mathcal{O}(3\%)$
- non-perturbative models differ significantly between MCs, e.g. in SHERPA MPI will not change $p_\perp(V)$



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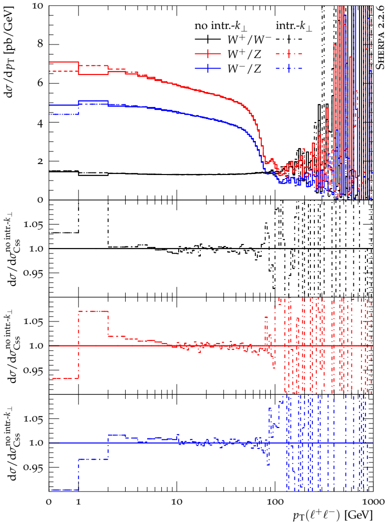

Conclusions

- proposal to quantify algorithmic dependence of parton shower resummation in MCs under discussion
- HERWIG, PYTHIA and SHERPA have each at least two different inhouse parton showers, six different ones between them
- quick study shows there are potential differences of $\mathcal{O}(10\%)$ (stats still lacking) for $p_\mathrm{T}(V_1)/p_\mathrm{T}(V_2)$
- NB: more on algorithmic uncertainties in QED FSR on Thu in C. Gütschow's talk
- NB2: higher theoretical precision achievable in $p_\mathrm{T}(\ell^\pm)$ instead of $p_\mathrm{T}(V)$

Backup