Precision QCD simulations for the LHC with SHERPA

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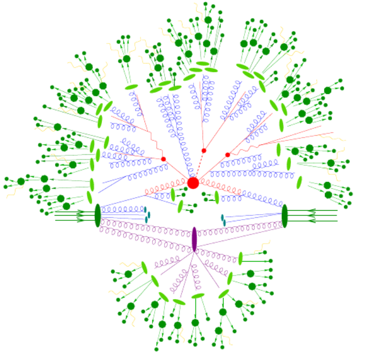
Introduction

SHERPA: MC event generator

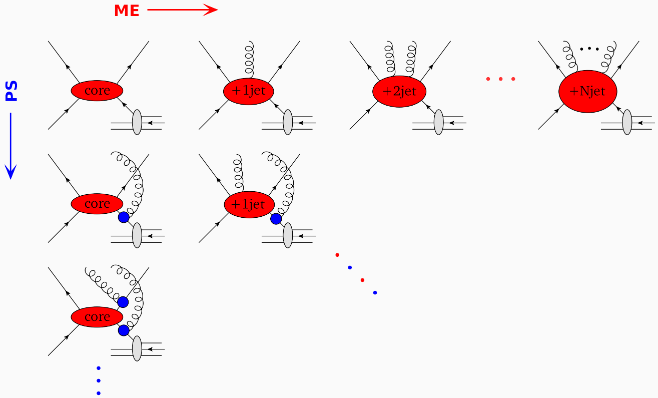
[Gleisberg et al. JHEP 0902 (2009) 007]



- Factorisation of length scales
- Simulate fully differential events
- Non-perturbative ($\gtrsim$ 1 fm)
  - cluster hadronisation
  - hadron decays
  - underlying event
- Perturbative ($\lesssim$ 1 fm)
  - hard interaction
    QCD: $\to$NNLO; EW: $\to$NLO; BSM
  - radiative corrections
    resum soft-collinear logs to (N)LL

- SHERPA's focus: perturbative aspects, matching/merging
  $\to$ systematically improve+combine accuracies of ME and PS
- talk about perturbative news in SHERPA, special focus on variations

Multi-jet merging: MEPS@NLO

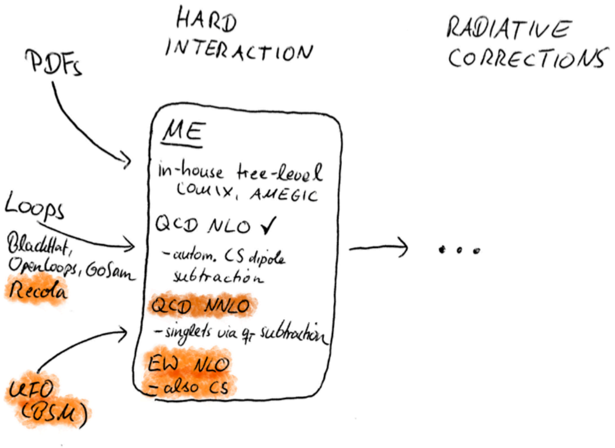


- MEPS@NLO: several NLO ME and PS $\longrightarrow$ one sample
- different jet multiplicities at NLO each matched using MC@NLO (+ further at LO)

[Höche et al. JHEP 0905 (2009) 053, JHEP 1304 (2013) 027]

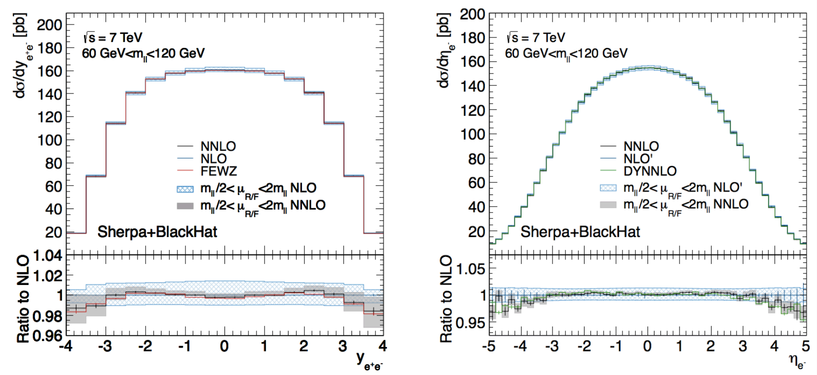
Hard interaction

SHERPA machine, recent and upcoming additions (hard interaction)



NNLO: comparison of SHERPA DY at NNLO with FEWZ/DYNNLO

[Höche et al. Phys. Rev. D 91 (2015) 074015]



- NNLO fully differential (BLACKHAT for one-loop amplitudes)
- perfect agreement with dedicated calculations

  [Gavin et al. CPC 182 (2011) 2388, Catani et al. Phys. Rev. Lett. 103 (2009) 082001]
- strongly reduced uncertainties compared with NLO

NLO EW corrections: virtual approximation for ME+PS simulation

[Kallweit et al. JHEP 1504 (2015) 012 and JHEP 1604 (2016) 021]

- approximate EW NLO corrections in SHERPA NLO QCD multi-jet merging
  SHERPA-2.2.1 public
- add EW virtual corrections and integrated real corrections
  in MC@NLO $\overline{B}$ contribution:

optionally include subleading Born

$$\overline{\mathrm{B}}_{n,\mathrm{QCD+EW_{virt}}}(\Phi_n) = \overline{\mathrm{B}}_{n,\mathrm{QCD}}(\Phi_n) + \mathrm{V}_{n,\mathrm{EW}}(\Phi_n) + \mathrm{I}_{n,\mathrm{EW}}(\Phi_n) + \mathrm{B}_{n,\mathrm{mix}}(\Phi_n)$$

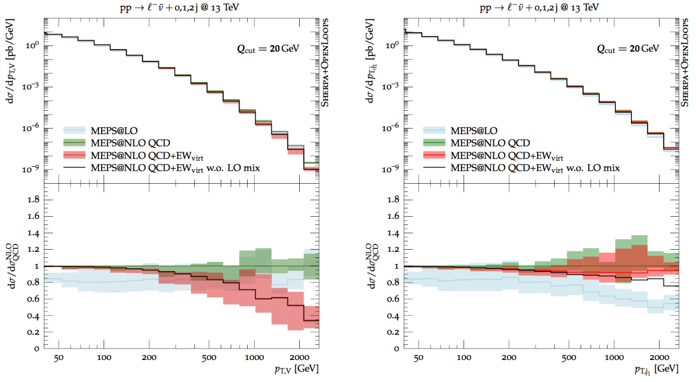
exact virtual contribution

approximate integrated real contribution

- real QED emission recovered through standard tools:
  PS, YFS resummation

NLO EW corrections: virtual approximation for ME+PS simulation

[Kallweit et al. JHEP 1504 (2015) 012 and JHEP 1604 (2016) 021]

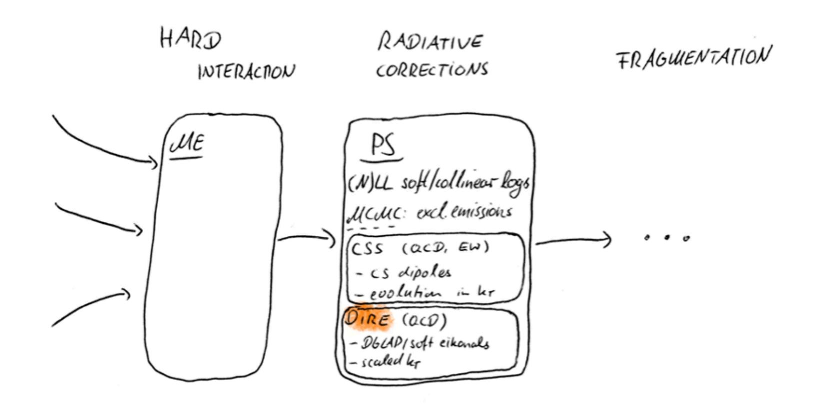


- particle-level events include dominant EW corrections
- full NLO QCD+EW with Sherpa+OpenLoops/Recola soon

  see Benedikt's talk today 5pm

  ["Automation of NLO QCD and EW corrections with Sherpa and Recola"]

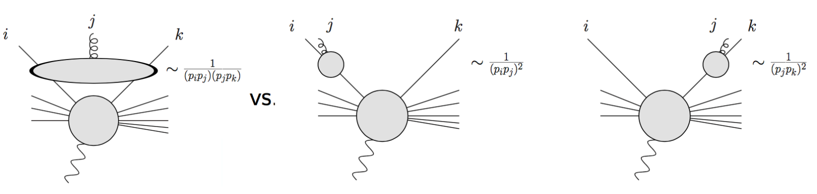
SHERPA machine, recent and upcoming additions (radiative corrections)



- DIRE also implemented in PYTHIA

Dire

[Höche, Prestel 1506.05057]



- dipole shower with (scaled) k_T evolution, but ...
- ... retains parton picture by splitting $2 \longrightarrow 3$ dipoles into sum of $1 \longrightarrow 2$ dipoles (partial fractioning)
- splittings map onto DGLAP in collinear limit
- ongoing new development: NLO splitting kernels

  [Höche, Prestel 1705.00742 and Höche, Krauss, Prestel 1705.00982]
  - motivation: jet substructure for precision measurements
  - start with flavour-changing $q \longrightarrow q' / q \longrightarrow \bar{q}$ splittings

[Höche, Krauss and Prestel 1705.00982]

- redefine Sudakovs, compare LO result:

$$\sum_{b=q,g} \int_0^{1-\epsilon} \mathrm{d}z\, z\, P_{gb}^{(0)}(z) = \int_\epsilon^{1-\epsilon} \mathrm{d}z \left[\frac{1}{2} P_{gg}^{(0)}(z) + n_f\, P_{gq}^{(0)}(z) \right] + \mathcal{O}(\epsilon)$$

- usually RHS used for final-state evolution
- for NLO need use LHS equivalent, otherwise local divergences
- evolving parton “tagged” by factor z instead of symmetry factors

[Höche, Krauss and Prestel 1705.00982]

- subtract two-loop cusp anomalous dimension
  already present in parton shower algorithms due to CMW rescaling

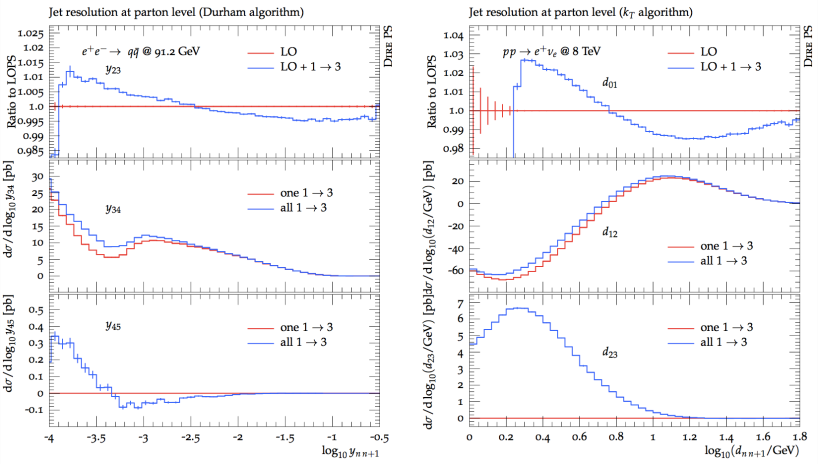
$$\Gamma^{(2)} = \left(\frac{67}{18} - \frac{\pi^2}{6}\right) C_A - \frac{10}{9} T_F$$

- get purely collinear NLO splitting kernels
- A fully differential NLO kernel would look like (MC@)NLO subtraction:

$$P_{qq'}(z) = \left(I + \frac{1}{\epsilon}\mathcal{P} - \mathcal{I}\right)_{qq'}(z) + \int \mathrm{d}\Phi_{+1}\,(R - S)_{qq'}\,(z, \Phi_{+1})$$

- For now, only endpoint simulation (but fill NLO phase space)

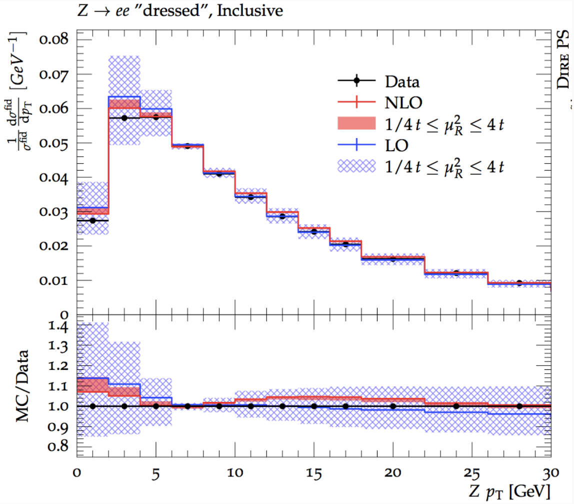
[Höche, Prestel 1705.00742]



- percent-level corrections in jet resolutions

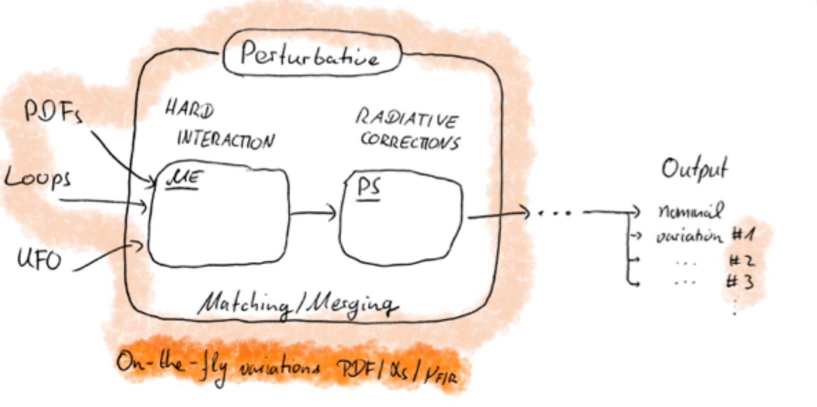
Dire: NLO kernels (Results)

[Höche, Krauss and Prestel 1705.00982]



- reduced scale uncertainties within the shower

Uncertainties



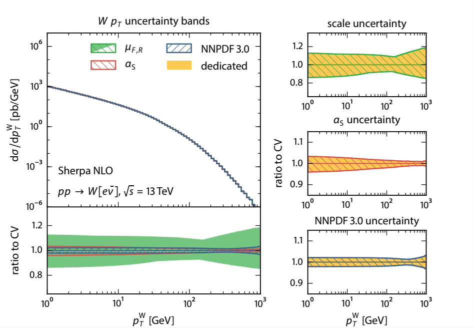
- So far: uncertainty reduction
- Now: calculate 'em

Uncertainties: reweighting pQCD calculations on-the-fly

[EB et al. Eur. Phys. J. C 76 (2016) no.11,590]

- book-keep parameter and scale dependence of perturbative events
  - perturbative coefficients of ME ($\mu_{R/F}$, α_S, PDFs)
  - kinematics/kernel of accepted/rejected shower emissions (α_S, PDFs)

- recompute event weight for varied $\mu_{R/F}$, α_S, PDFs
- store all event weights (`HepMC::WeightContainer`)
- NLO and MC@NLO $\mathcal{O}(\alpha_S)$ SHERPA-2.2 (public)
- full shower, MEPS@NLO SHERPA-2.3



Uncertainties: reweighting pQCD calculations on-the-fly

- account for shower kernel variation $K \to \tilde{K}$ with shift in event weight w:

$$w \to \frac{\tilde{K}}{K}\,w \quad \text{(accepted);} \qquad w \to \frac{\hat{K}-\tilde{K}}{\hat{K}-\tilde{K}}\,w \quad \text{(rejected)}$$

- this has been used first for enhancing photon emissions

  [Höche, Schumann, Siegert Phys Rev D81 (2010) 034026]

- Pythia, Herwig, Vincia same approach (no matching/merging yet)

  [Bellm Phys Rev D94 (2016) 034028]

  [Mrenna, Skands Phys Rev D94 (2016) 074005]

  [Giele, Kosower, Skands Phys Rev D84 (2011) 054003]

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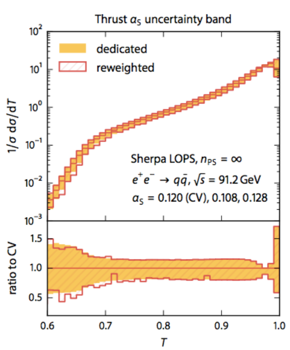

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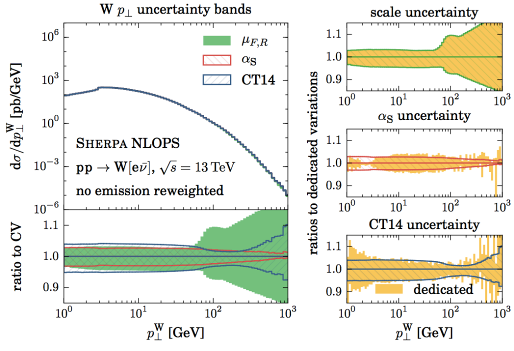

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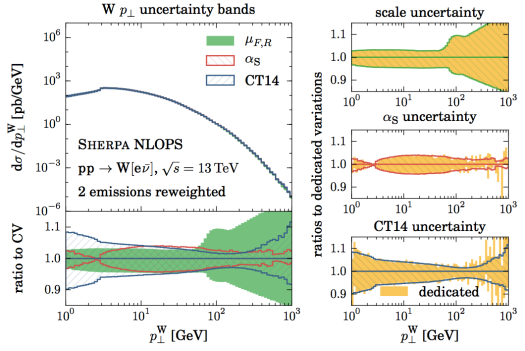

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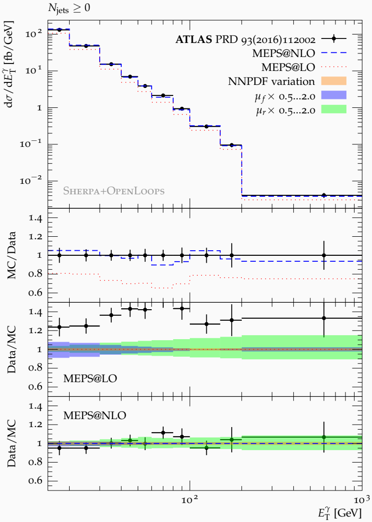
In other SHERPA news ...



$Z + \gamma$ and $\gamma\gamma$ production:

[Krause, Siegert 1708.06283]

[Siegert J.Phys. G44 (2017) no.4, 044007]

- MEPS@NLO: 0, 1 jets NLO
- reduced uncertainties
- good agreement with data

single-top production:

[EB, Krauss, Schönherr, tbp]

- MC@NLO, METS scale setter
- study on b-PDF sensitivity
- study cuts to improve S/B

Conclusion and outlook

Conclusion and outlook

public (Sherpa-2.2.3):

- fully automated MEPS@NLO precicion
  - on-the-fly variations for $\mu_{R/F}$, α_S, PDFs
- NNLO+PS for colour singlets
- QCD+EW NLO virtual approximation
- BSM via UFO

upcoming (Sherpa-2.3 ...):

- full QCD+EW NLO+PS
- variations for shower emissions (that is, official support)
- NLO shower kernels