Higher orders and parton showers

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CERN

CMS workshop on boosted objects

Outline

1. (N)NLO corrections in ME
2. NLO corrections in PS
3. Conclusions

(N)NLO corrections in matrix elements

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(N)NLO corrections in matrix elements

NLOPS

- well established and standard methods
  - MC@NLO
  - POWHEG
- available for all processes of interest in multiple tools

⇒ **NLO for production ME**
emission properties described at LOPS accuracy only

NNLOPS

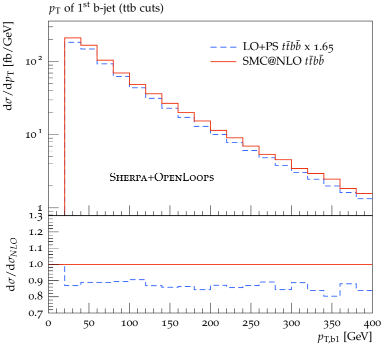
- only exist for singlet production
  - MiNLO-based
  - UN^{2}LOPS
- **unavailable for boosted objects**
  exception: very recent *WH*-implementation

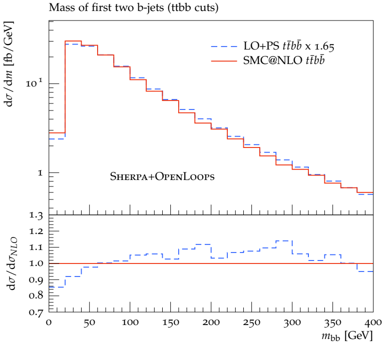
⇒ NNLO for production ME
emission properties described at NLOPS accuracy

NLO corrections in matrix elements

- for complicated processes the small event selection efficiencies can render increased running time of NLOPS prohibative
- detailed validation studies needed to use LOPS as proxy

Moretti, Petrov, Pozzorini, Spannowsky Phys.Rev. D93 (2016) 014019

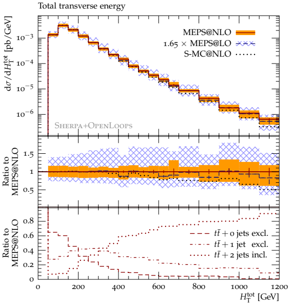


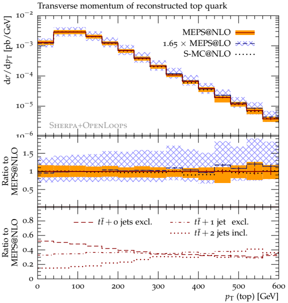


Multijet merging

- multijet merging replaces emission spectrum of (N)LOPS above some merging scale by higher order calculation
  $\rightarrow$ MEPS/MEPS@NLO, MLM/FxFx, UMEPS/UNLOPS
- can be though of as improving splitting functions of (N)LOPS by higher order and beyond-logarithmic corrections above merging scale
- does not improve resummation properties

Höche, Krauss, Maierhöfer, Pozzorini, MS, Siegert in PLB748(2015)74-78

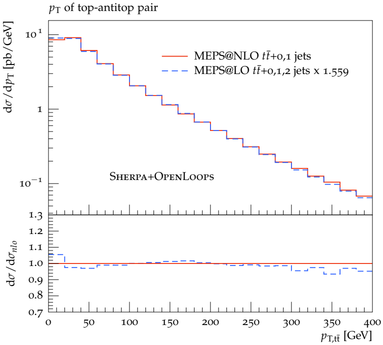


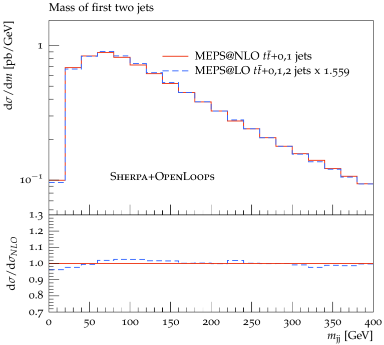


NLO corrections in matrix elements

- for complicated processes the small event selection efficiencies can render increased running time of NLO multijet merging prohibative
- detailed validation studies needed to use LO merging as proxy

Moretti, Petrov, Pozzorini, Spannowsky Phys.Rev. D93 (2016) 014019





Electroweak corrections in particle-level event generation

Kallweit,Lindert,Maierhöfer,Pozzorini,MS JHEP04(2016)021

- incorporate approximate electroweak corrections in SHERPA's NLO QCD multijet merging (MEPS@NLO)
- modify MC@NLO $\overline{\mathrm{B}}$-function to include NLO EW virtual corrections and integrated approx. real corrections

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

- real QED radiation can be recovered through standard tools (parton shower, YFS resummation)
- simple stand-in for proper QCD+EW matching and merging

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$pp \to \ell^- \bar{\nu} + \text{jets}$

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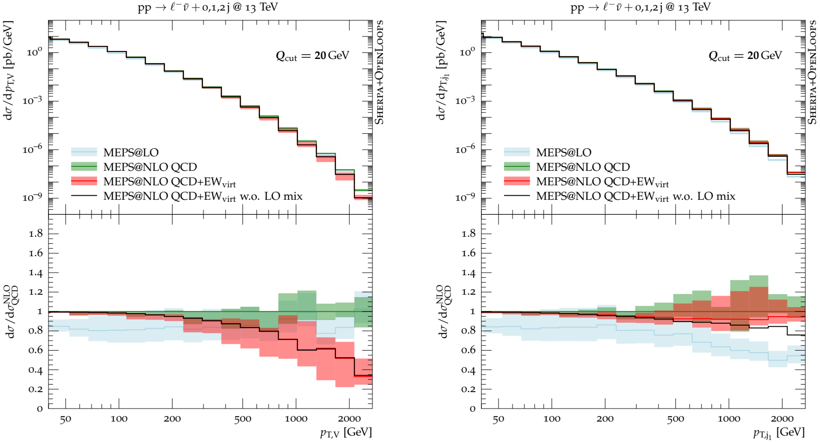
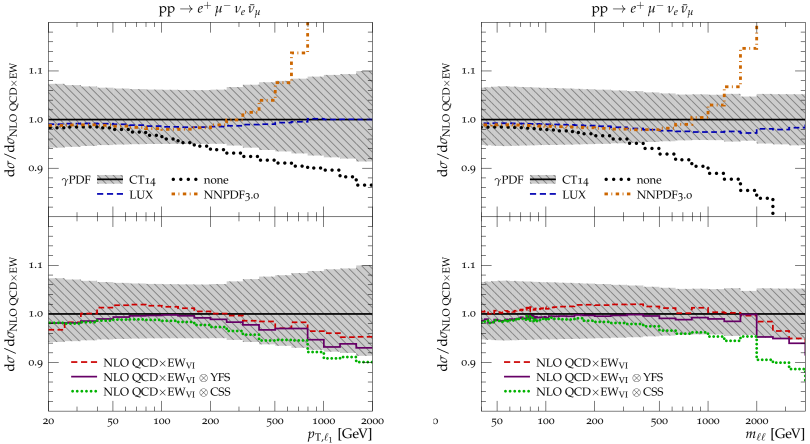


$\Rightarrow$ particle level events including dominant EW corrections

$pp \to \ell^- \bar{\nu} + \text{jets}$

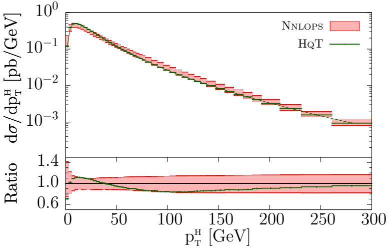
Kallweit,Lindert,Pozzorini,MS arXiv:1705.04664



$\Rightarrow$ NLO QCD$\times$EW$_{\text{VI}}\otimes$YFS very well reproduces full calculation also for processes with very rich EW structure

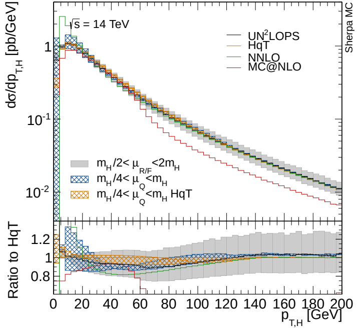
NNLO corrections in matrix elements – NNLOPS

- available only for production of colourless final states
- do not offer improved description of boosted observables beyond $X + j$ NLOPS calculations



Hamilton, Nason, Re, Zanderighi

arXiv:1309.0017

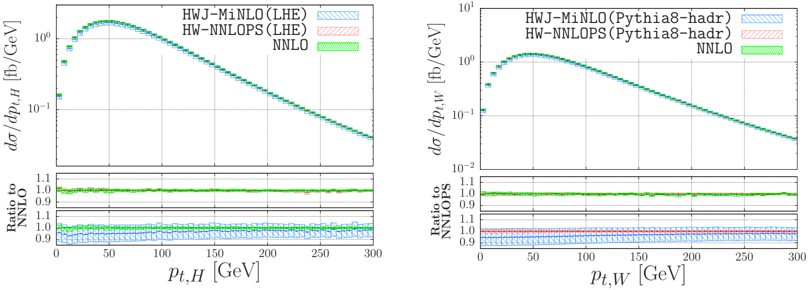


Höche, Li, Prestel arXiv:1407.3773

NNLO corrections in matrix elements – NNLOPS

- exception, production of multiple colourless objects
- so far, only HW production available

Astill, Bizon, Re, Zanderighi arXiv:1603.01620



- **for mathing $X + j$ at NNLOPS we need better parton showers that include NLO splitting functions**

NLO corrections in parton showers

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NLO corrections in parton showers

Höche, Krauss, Prestel arXiv:1705.00982

- LO parton showers already include terms $\propto 1/(1-z) \times \Gamma(2)$
  Catani, Marchesini, Webber Nucl.Phys. B349, 635 (1991)
- include NLO corrections in DGLAP evolution
  use NLO collinear splitting functions

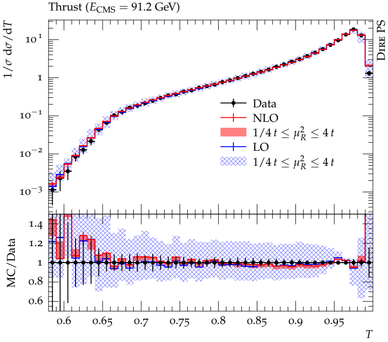
$$P_{ab}(z) = P_{ab}^{(0)}(z) + \frac{\alpha_S}{2\pi} P_{ab}^{(1)}(z)$$

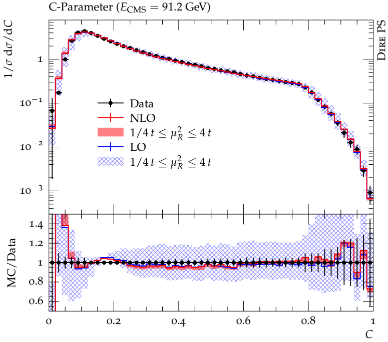
Curci, Furmanski, Petronzio Nucl.Phys. B175, 27 (1980)
Furmanski, Petronzio Phys.Lett. B97, 437 (1980)

- includes triple-collinear splitting functions Höche, Prestel arXiv:1705.00742
- contains flavour changes $q \to q'$ and $q \to \bar{q}$
- does not include higher order corrections to soft evolution yet
- include also soft terms $\propto 1/(1-z) \times \Gamma(3)$
- still leading colour, as no exponentiation of off-diagonal colour MEs
- **this is generally not the same as achieving a higher logarithmic accuracy, not even for the PS evolution variable**

NLO corrections in parton showers

Höche, Krauss, Prestel arXiv:1705.00982

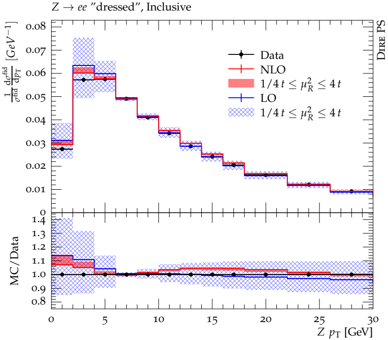


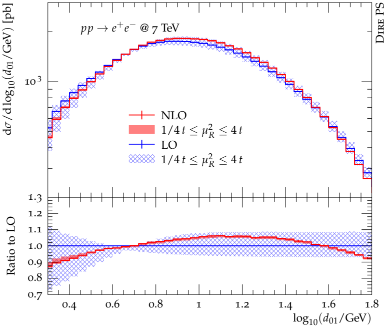


- small effects in event shapes at e^+e^-
- reduced scale uncertainty (commonly not assessed in LO parton showers)

NLO corrections in parton showers

Höche, Krauss, Prestel arXiv:1705.00982

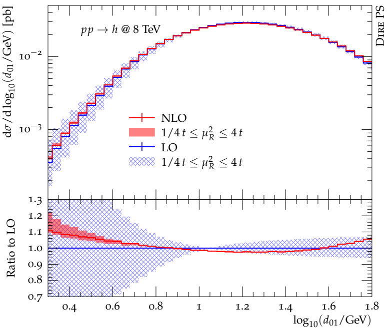


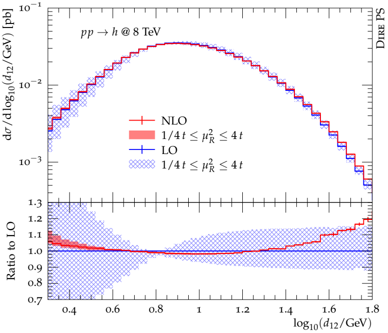


- larger effects in Sudakov shapes in *pp*
- reduced scale uncertainty (commonly not assessed in LO parton showers)

NLO corrections in parton showers

Höche, Krauss, Prestel arXiv:1705.00982





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Conclusions

- NLOPS are the common tools used
- multijet merging improves relative description of multi-emission kinematics and is the highest available precision at the moment
  $\rightarrow$ approximate EW corrections can be incorporated
- NNLOPS for $X + j$ final states mandatory for most boosted analyses not yet available
  a matching procedure not available due to the lack of parton showers of sufficient accuracy
- first developments to include higher order corrections to the splitting functions in parton showers
  $\rightarrow$ NLO collinear DGLAP evolution
  $\rightarrow$ PS does not yet contain full logarithmic structure for matching to NNLO

Thank you for your attention!