

Higher orders and parton showers

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MC@NNLO

Outline

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

(N)NLO corrections in matrix elements

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② NLO corrections in PS

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(N)NLO corrections in matrix elements

NLOPs

- well established and standard tools
 - MC@NLO
 - POWHEG
 - available for all processes of interest
- ⇒ **NLO for production ME**
emission properties described at LOPs accuracy only

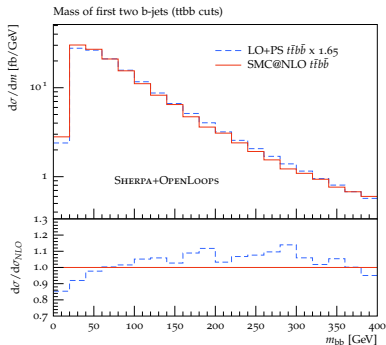
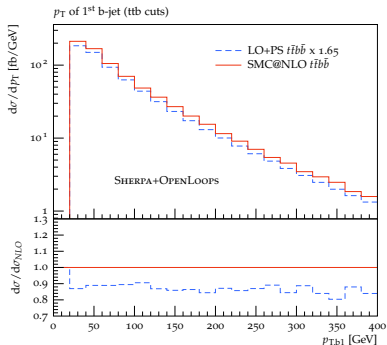
NNLOPs

- only exist for singlet production
 - MiNLO-based
 - UN²LOPs
 - **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 prohibitive
- detailed validation studies needed to use LOPS as proxy

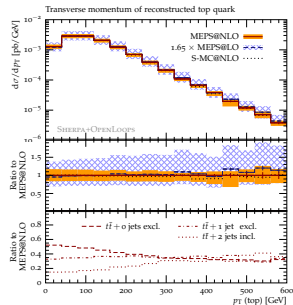
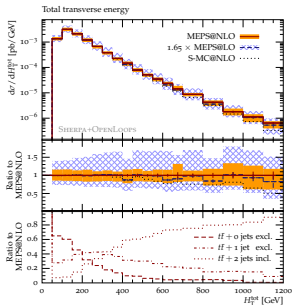
Moretti, Petrov, Pozzorini, Spannowsky Phys.Rev. D93 (2016) 014019



Multijet merging

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

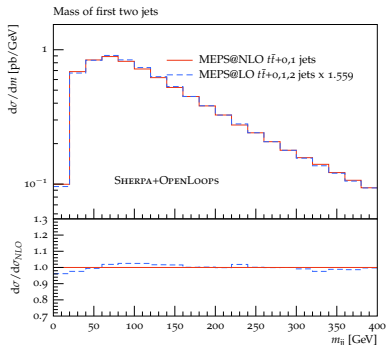
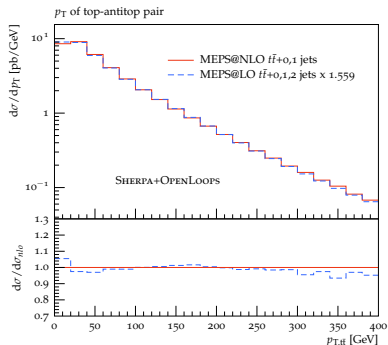
Höche, Krauss, Maierhöfer, Pozzorini, MS, Siegert in PLB748(2015)74-78



NLO corrections in matrix elements

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

Moretti, Petrov, Pozzorini, Spannowsky *Phys.Rev. D*93 (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 \bar{B} -function to include NLO EW virtual corrections and integrated approx. real corrections

$$\bar{B}_{n,\text{QCD}+\text{EW}_{\text{virt}}}(\Phi_n) = \bar{B}_{n,\text{QCD}}(\Phi_n) + V_{n,\text{EW}}(\Phi_n) + I_{n,\text{EW}}(\Phi_n) + B_{n,\text{mix}}(\Phi_n)$$

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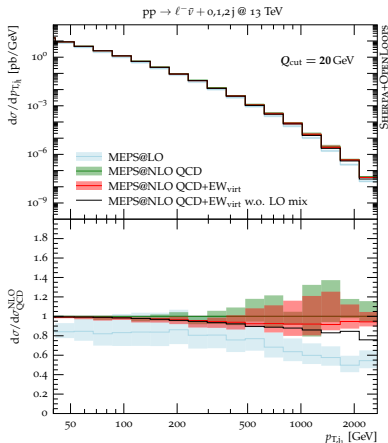
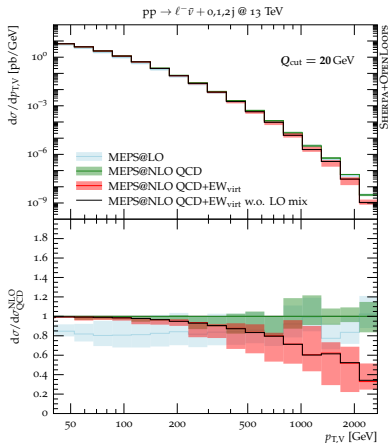
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$pp \rightarrow \ell^- \bar{\nu} + \text{jets}$

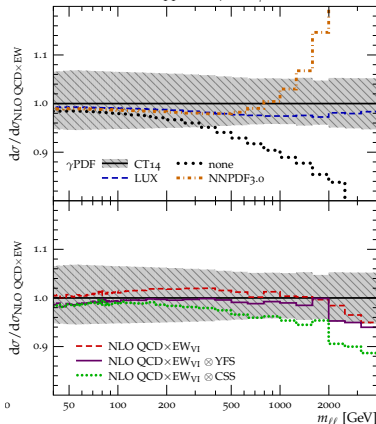
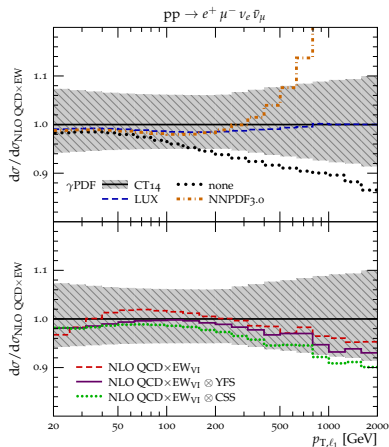
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⇒ particle level events including dominant EW corrections

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

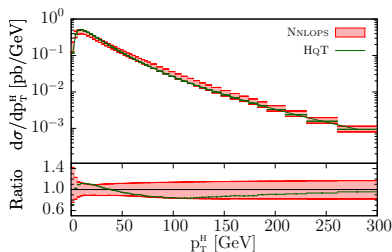
Kallweit, Lindert, Pozzorini, MS arXiv:1705.04664



\Rightarrow NLO QCD \times EW_{V1} \otimes YFS very well reproduces full calculation also for processes with very rich EW structure

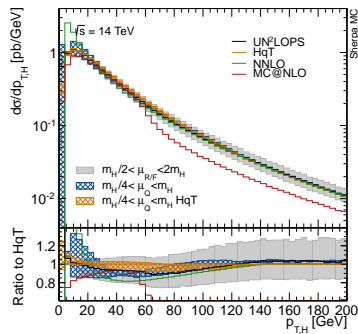
NNLO corrections in matrix elements – NNLOPS

- 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

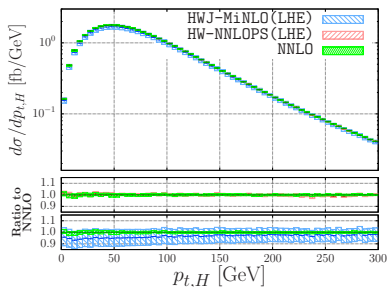
arXiv:1309.0017



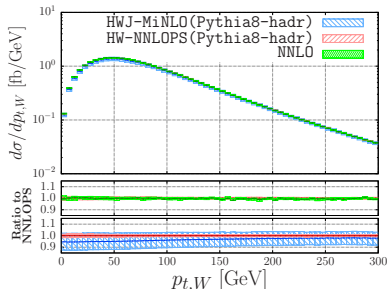
Höche, Li, Prestel arXiv:1407.3773

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 matching $X + j$ at NNLOPS we need better parton showers that include NLO splitting functions

NLO corrections in parton showers

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

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

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

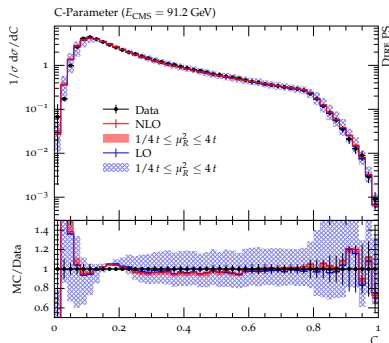
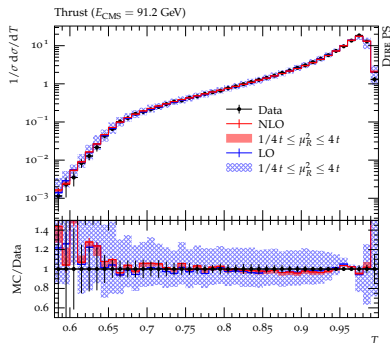
Curci, Furmanski, Petronzio Nucl.Phys. B175, 27 (1980)

Furmanski, Petronzio Phys.Lett. B97, 437 (1980)

- includes triple-collinear splitting functions Höche, Prestel arXiv:1705.00742
- contains flavour changes $q \rightarrow q'$ and $q \rightarrow \bar{q}$
- 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

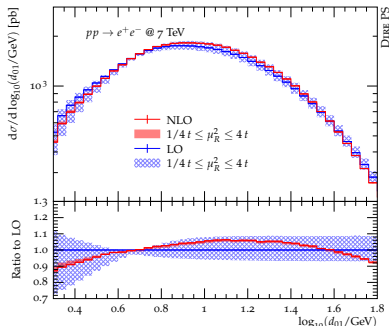
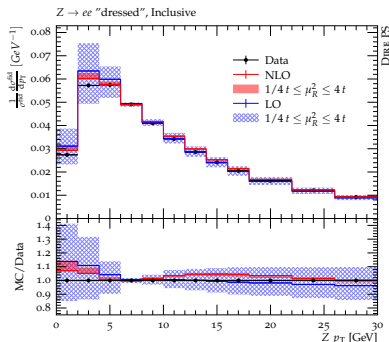
Höche, Krauss, Prestel arXiv:1705.00982



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

NLO corrections in parton showers

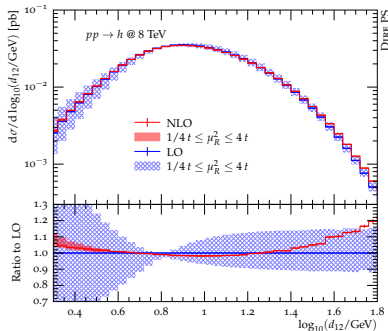
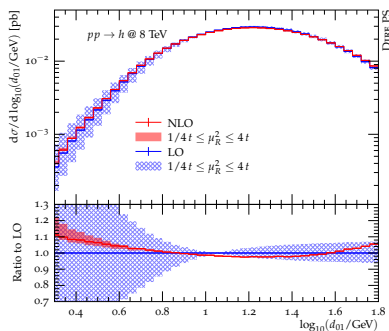
Höche, Krauss, Prestel arXiv:1705.00982



- 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
→ 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
→ NLO collinear DGLAP evolution
→ PS does not yet contain full logarithmic structure for matching to NNLO

Thank you for your attention!