Hadron Level Event Generation at NLO Accuracy with SHERPA

Thomas Gehrmann, Stefan Hoeche, Frank Krauss,
Marek Schoenherr, Frank Siegert

IKTP TU Dresden

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Contents

see also talk by F. Siegert at ICHEP 2010

LO Matrix Elements and Parton Showers

$$\mathrm{d}\sigma_{\text{LO}} = \mathrm{d}\Phi_B\, B(\Phi_B) \left[\Delta^{\mathcal{K}}(t_0, t_{\text{min}}) + \int_{t_{\text{min}}}^{t_0} \mathrm{d}\Phi_{R|B} \mathcal{K}(\Phi_{R|B}) \Delta^{\mathcal{K}}(t_0, t)\right]$$

inclusive $2 \to N$ process
kin. according to $B(\Phi_B)$

$$R^{(\text{PS})}(\Phi_R) = B(\Phi_B)\mathcal{K}(\Phi_{R|B}) = B(\Phi_B) \sum_{ab} P_{ab}(\Phi_{R|B})$$

$$\Delta^{\mathcal{K}}(t_0, t) = \exp\left(-\int_t^{t_0} \mathrm{d}\Phi_{R|B} \mathcal{K}(\Phi_{R|B})\right)$$

LO Matrix Elements and Parton Showers

$$\mathrm{d}\sigma_{\mathsf{LO}} = \mathrm{d}\Phi_B\, B(\Phi_B) \underbrace{\left[\Delta^{\mathcal{K}}(t_0, t_{\mathsf{min}}) + \int_{t_{\mathsf{min}}}^{t_0} \mathrm{d}\Phi_{R|B} \mathcal{K}(\Phi_{R|B}) \Delta^{\mathcal{K}}(t_0, t)\right]}_{=1}$$

$\rightarrow$ cross section unchanged

$$R^{(\mathsf{PS})}(\Phi_R) = B(\Phi_B)\mathcal{K}(\Phi_{R|B}) = B(\Phi_B)\sum_{ab} P_{ab}(\Phi_{R|B})$$

$$\Delta^{\mathcal{K}}(t_0, t) = \exp\left(-\int_t^{t_0} \mathrm{d}\Phi_{R|B}\mathcal{K}(\Phi_{R|B})\right)$$

LO Matrix Elements and Parton Showers

$$\mathrm{d}\sigma_{\text{LO}} = \mathrm{d}\Phi_B\, B(\Phi_B) \left[\Delta^{\mathcal{K}}(t_0, t_{\text{min}}) + \int_{t_{\text{min}}}^{t_0} \mathrm{d}\Phi_{R|B} \mathcal{K}(\Phi_{R|B}) \Delta^{\mathcal{K}}(t_0, t) \right]$$

exclusive $2 \to N$ process
kin. according to $B(\Phi_B)$

approximated real emission ME

$$R^{(\text{PS})}(\Phi_R) = B(\Phi_B)\mathcal{K}(\Phi_{R|B}) = B(\Phi_B) \sum_{ab} P_{ab}(\Phi_{R|B})$$

Sudakov form factor

$$\Delta^{\mathcal{K}}(t_0, t) = \exp\left(- \int_t^{t_0} \mathrm{d}\Phi_{R|B} \mathcal{K}(\Phi_{R|B}) \right)$$

LO Matrix Elements and Parton Showers

$$\mathrm{d}\sigma_{\mathrm{LO}} = \mathrm{d}\Phi_B\, B(\Phi_B)\left[\Delta^{\mathcal{K}}(t_0,t_{\mathrm{min}}) + \int_{t_{\mathrm{min}}}^{t_0} \mathrm{d}\Phi_{R|B}\mathcal{K}(\Phi_{R|B})\Delta^{\mathcal{K}}(t_0,t)\right]$$

inclusive $2 \to N+1$ process
kin. according to $R^{(\mathrm{PS})}(\Phi_R)$

approximated real emission ME

$$R^{(\mathrm{PS})}(\Phi_R) = B(\Phi_B)\mathcal{K}(\Phi_{R|B}) = B(\Phi_B)\sum_{ab} P_{ab}(\Phi_{R|B})$$

Sudakov form factor

$$\Delta^{\mathcal{K}}(t_0,t) = \exp\left(-\int_t^{t_0} \mathrm{d}\Phi_{R|B}\mathcal{K}(\Phi_{R|B})\right)$$

JHEP11(2004)040, JHEP11(2007)070

NLO Matrix Elements and Parton Showers

use POWHEG method → shower independent

$$\mathrm{d}\sigma_{\text{NLO}} = \mathrm{d}\Phi_B \left[B(\Phi_B) + V(\Phi_B)\right] + \mathrm{d}\Phi_R R(\Phi_R)$$

$$\bar{B}(\Phi_B) = B(\Phi_B) + V(\Phi_B) + \int \mathrm{d}\Phi_{R|B} R(\Phi_R)$$

$$\Delta^{RB}(t_0, t) = \exp\left(-\int_t^{t_0} \mathrm{d}\Phi_{R|B} \frac{R(\Phi_R)}{B(\Phi_B)}\right)$$

→ NLO accuracy of the ME preserved
→ (N)LL accuracy of the PS preserved

NLO Matrix Elements and Parton Showers

use POWHEG method $\to$ shower independent

$$\mathrm{d}\sigma_{\text{NLO}} = \mathrm{d}\Phi_B\,\bar{B}(\Phi_B)$$

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$$\mathrm{d}\sigma_{\text{NLO}} = \mathrm{d}\Phi_B\,\bar{B}(\Phi_B)\left[\Delta^{RB}(t_0,t_{\text{min}}) + \int_{t_{\text{min}}}^{t_0} \mathrm{d}\Phi_{R|B}\frac{R(\Phi_R)}{B(\Phi_B)}\Delta^{RB}(t_0,t)\right]$$

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→ NLO accuracy of the ME preserved
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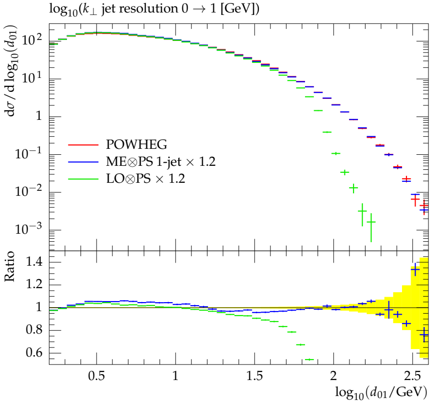
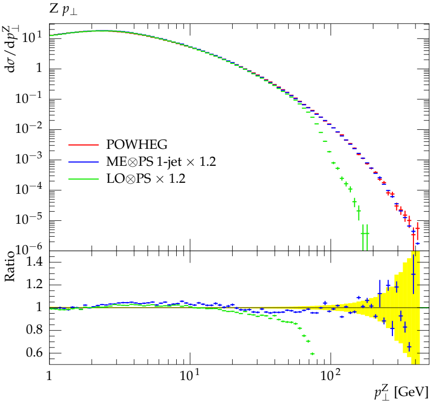
Implementation in SHERPA

- automised tree-level ME generators AMEGIC++ and COMIX
  JHEP02(2002)044, JHEP12(2008)039
- automised Catani-Seymour subtraction term generation
  Eur.Phys.J. C53 (2008) 501-523
- Binoth Les Houches Accord Interface for Loop ME
  Comput.Phys.Commun.181:1612-1622,2010
- automised tree-level multi-channel $\otimes$ factorised phase space generator
- PS based on CS-dipole terms CSSHOWER++
  JHEP03(2008)038

Preliminary Results – $pp \to Z + X$





Multijet Merging

Multijet merging at LO

JHEP05(2009)053

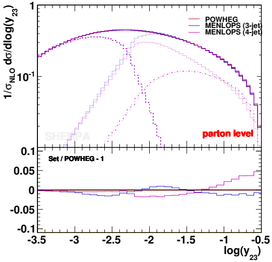
- seperate into ME and PS regimes using IR-safe jet criterion Q_{cut}
- reproduces NLO shapes
- LO total cross section $\rightarrow$ needs K-factor
- LO scale uncertainties on multijet observables

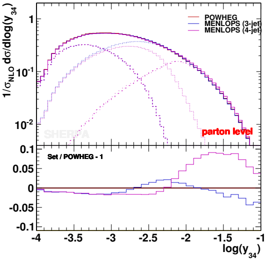
Multijet merging at NLO

JHEP06(2010)039

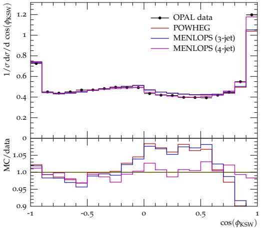
- seperate into ME and PS regimes as above
- replace LO$\otimes$PS by NLO$\otimes$PS for lowest multiplicity
- rescale all higher multiplicites by local K-factor $\bar{B}(\Phi_B)/B(\Phi_B)$
- NLO accuracy on total cross section and inclusive observables

Preliminary Results – $e^+e^- \to hadrons$

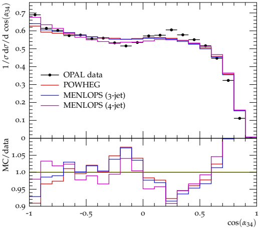




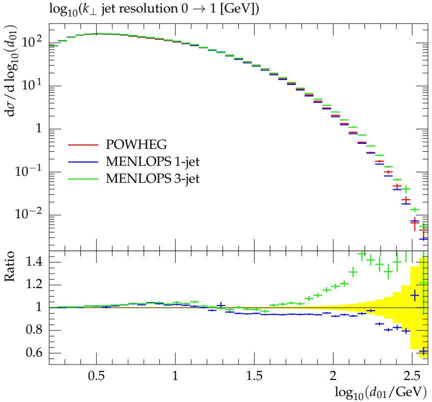
Körner-Schierholz-Willrodt angle (parton level)

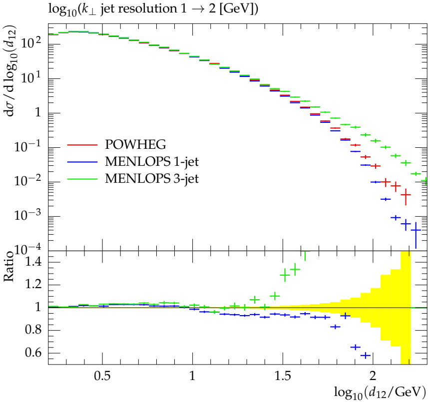


Angle between the two softest jets (parton level)

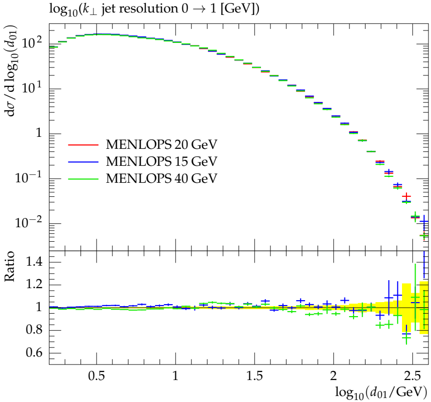


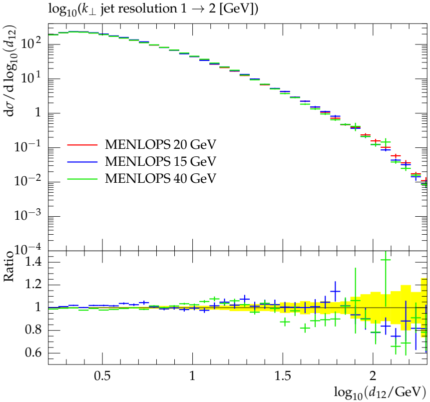
Preliminary Results – $pp \to Z + X$





Preliminary Results – $pp \to Z + X$ – Systematics





Conclusions

- Tree-level merging reprocuces shapes well, but needs K-factor
- POWHEG reproduces full NLO cross section and shape of first emission but fails for additional hard radiation
- Combination of full NLO and higher order tree-level MEs with shower achieves both of the above
- Automisation within reach
- Momentarily NLO accuracy only in core process' observables, not in higher jet multiplicities ...
- ... yet

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Multijet Merging at NLO

- factorisability of the Sudakov form factor

$$\Delta(t_1, t_2) \;=\; \Delta(t_1, t') \cdot \Delta(t', t_2)$$

- multijet merging at LO
- multijet merging at NLO

$$\mathrm{d}\sigma_{\mathsf{NLO}} = \bar{B}(\Phi_B)\left[\Delta^{RB}(t_0, t_{\mathsf{min}}) + \int_{t_{\mathsf{min}}}^{t_0} \mathrm{d}\Phi_{R|B} \frac{R(\Phi_R)}{B(\Phi_B)} \Delta^{RB}(t_0, t)\Theta(Q_{\mathsf{cut}} - Q) \right.$$
$$\left. + \int_{t_{\mathsf{min}}}^{t_0} \mathrm{d}\Phi_{R|B} \frac{R(\Phi_R)}{B(\Phi_B)} \Delta^{\mathcal{K}}(t_0, t)\Theta(Q - Q_{\mathsf{cut}}) \right]$$

JHEP05(2009)053, JHEP06(2010)039

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$$\mathrm{d}\sigma_{\text{LO}} = B(\Phi_B)\Bigg[\Delta^{\mathcal{K}}(t_0,t_{\text{min}}) + \overbrace{\int_{t_{\text{min}}}^{t_0} \mathrm{d}\Phi_{R|B}\,\mathcal{K}(\Phi_{R|B})\,\Delta^{\mathcal{K}}(t_0,t)\,\Theta(Q_{\text{cut}}-Q)}^{\text{PS regime}}$$

$$+ \underbrace{\int_{t_{\text{min}}}^{t_0} \mathrm{d}\Phi_{R|B}\,\frac{R(\Phi_R)}{B(\Phi_B)}\,\Delta^{\mathcal{K}}(t_0,t)\,\Theta(Q-Q_{\text{cut}})}_{\text{ME regime}}\Bigg]$$

$\rightarrow \Big[\ldots\Big] \approx 1$ to (N)LL accuracy only

JHEP05(2009)053, JHEP06(2010)039

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$$\mathrm{d}\sigma_{\mathsf{LO}} = B(\Phi_B)\left[\Delta^{\mathcal{K}}(t_0,t_{\mathsf{min}}) + \int_{t_{\mathsf{min}}}^{t_0}\mathrm{d}\Phi_{R|B}\mathcal{K}(\Phi_{R|B})\Delta^{\mathcal{K}}(t_0,t)\Theta(Q_{\mathsf{cut}}-Q)\right.$$
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