NNLO Drell-Yan pair production with parton showers

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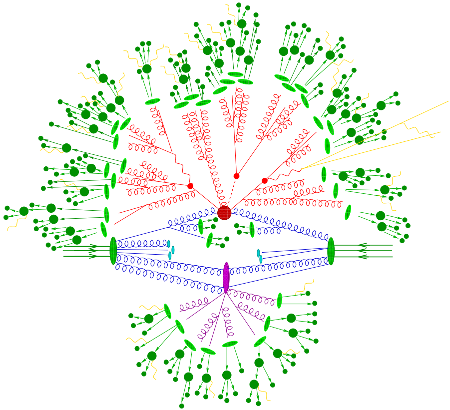
Outline

- Unitary ME+PS merging
- Extension to NNLO
- Application to inclusive $Z/W^{\pm}$+jets production



Unitary Matrix-Element Parton-Shower merging

[Lönnblad,Prestel] arXiv:1211.4827

- PS expression for infrared safe observable, O

$$\langle O\rangle = \int \mathrm{d}\Phi_0\, \mathrm{B}_0\, \mathcal{F}_0(\mu_Q^2, O)$$

$$\mathcal{F}_n(t, O) = \Pi_n(t_c, t)\, O(\Phi_n) + \int_{t_c}^{t} \mathrm{d}\hat{\Phi}_1\, \mathrm{K}_n\, \Pi_n(\hat{t}, t)\, \mathcal{F}_{n+1}(\hat{t}, O)$$

- Add ME correction to first emission $\left(\mathrm{B}_0\mathrm{K}_0 \to \mathrm{B}_1\right)$ & unitarize

$$+\int_{t_c} \mathrm{d}\Phi_1\, \Pi_0(t_1, \mu_Q^2)\, \mathrm{B}_1\, \mathcal{F}_1(t_1, O) - \int_{t_c} \mathrm{d}\Phi_1\, \Pi_0(t_1, \mu_Q^2)\, \mathrm{B}_1\, O(\Phi_0)$$

- ME evaluated at fixed scales $\mu_{R/F}$ $\to$ need to adjust to PS

$$w_1 = \frac{\alpha_s(b\, t_1)}{\alpha_s(\mu_R^2)}\, \frac{f_a(x_a, t_1)}{f_a(x_a, \mu_F^2)}\, \frac{f_{a'}(x_{a'}, \mu_F^2)}{f_{a'}(x_{a'}, t_1)}$$

- Replace B_0 by vetoed xs $\bar{\mathrm{B}}_0^{t_c} = \mathrm{B}_0 - \int_{t_c} \mathrm{d}\Phi_1 \mathrm{B}_1$

$$\langle O\rangle = \left\{ \int \mathrm{d}\Phi_0\, \bar{\mathrm{B}}_0^{t_c} + \int_{t_c} \mathrm{d}\Phi_1 \left[1 - \Pi_0(t_1, \mu_Q^2)\, w_1\right] \mathrm{B}_1 \right\} O(\Phi_0)$$

$$+ \int_{t_c} \mathrm{d}\Phi_1\, \Pi_0(t_1, \mu_Q^2)\, w_1\, \mathrm{B}_1\, \mathcal{F}_1(t_1, O)$$

Extension to NNLO – UN^{2}LOPS

[Lönnblad,Prestel] arXiv:1211.7278
[Li,Prestel,SH] arXiv:1405.3607

- Promote vetoed cross section to NNLO
- Add NLO corrections to B_1 using S-MC@NLO
- Subtract $\mathcal{O}(\alpha_s)$ term of w_1 and Π_0

$$
\begin{aligned}
\langle O\rangle = &\int \mathrm{d}\Phi_0\, \bar{\bar{\mathrm{B}}}_0^{t_c}\, O(\Phi_0) \\
&+ \int_{t_c} \mathrm{d}\Phi_1 \left[1 - \Pi_0(t_1,\mu_Q^2)\left(w_1 + w_1^{(1)} + \Pi_0^{(1)}(t_1,\mu_Q^2)\right)\right] \mathrm{B}_1\, O(\Phi_0) \\
&+ \int_{t_c} \mathrm{d}\Phi_1\, \Pi_0(t_1,\mu_Q^2)\left(w_1 + w_1^{(1)} + \Pi_0^{(1)}(t_1,\mu_Q^2)\right) \mathrm{B}_1\, \bar{\mathcal{F}}_1(t_1,O) \\
&+ \int_{t_c} \mathrm{d}\Phi_1 \left[1 - \Pi_0(t_1,\mu_Q^2)\right] \tilde{\mathrm{B}}_1^{\mathrm{R}}\, O(\Phi_0) + \int_{t_c} \mathrm{d}\Phi_1 \Pi_0(t_1,\mu_Q^2)\, \tilde{\mathrm{B}}_1^{\mathrm{R}}\, \bar{\mathcal{F}}_1(t_1,O) \\
&+ \int_{t_c} \mathrm{d}\Phi_2 \left[1 - \Pi_0(t_1,\mu_Q^2)\right] \mathrm{H}_1^{\mathrm{R}}\, O(\Phi_0) + \int_{t_c} \mathrm{d}\Phi_2\, \Pi_0(t_1,\mu_Q^2)\, \mathrm{H}_1^{\mathrm{R}}\, \mathcal{F}_2(t_2,O) \\
&+ \int_{t_c} \mathrm{d}\Phi_2\, \mathrm{H}_1^{\mathrm{E}}\, \mathcal{F}_2(t_2,O)
\end{aligned}
$$

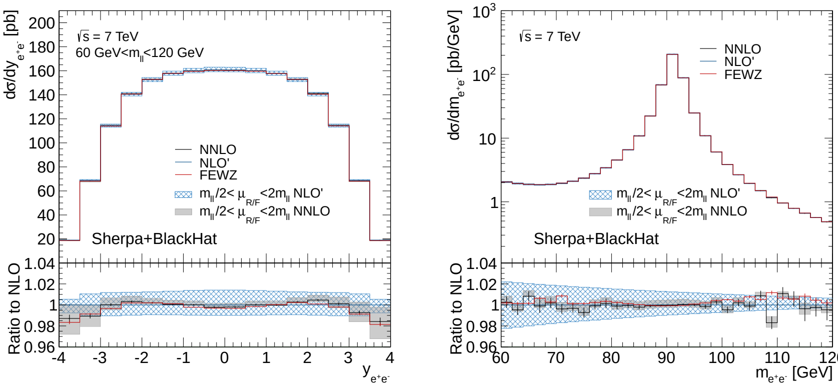
- $\tilde{\mathrm{B}}_1^{\mathrm{R}} = \bar{\mathrm{B}}_1 - \mathrm{B}_1 = \tilde{\mathrm{V}}_1 + \mathrm{I}_1 + \int \mathrm{d}\Phi_{+1}\mathrm{S}_1\Theta(t_2 - t_1)$
  $\mathrm{H}_1^{\mathrm{R}}$ ($\mathrm{H}_1^{\mathrm{E}}$) $\rightarrow$ regular (exceptional) double real configurations

Implementation

- Born, real corrections and subtraction terms from Amegic or Comix
  [Krauss,Kuhn,Soff] hep-ph/0109036, [Gleisberg,Krauss] arXiv:0709.2881; [Gleisberg,SH] arXiv:0808.3674
- Virtual corrections for $Z/W^{\pm}+1$ jet from BlackHat
  [Berger et al.] arXiv:0803.4180, [Berger et al.] arXiv:0907.1984, arXiv:1004.1659, arXiv:1009.2338
- NNLO vetoed cross section dedicated implementation of
  [Becher,Neubert] arXiv:1007.4005 [Gehrmann,Lübbert,Yang] arXiv:1209.0682
  [Gehrmann,Lübbert,Yang] arXiv:1403.6451 arXiv:1401.1222
- Parton shower based on Catani-Seymour dipoles
  [Schumann,Krauss] arXiv:0709.1027
- Combined in Sherpa event generation framework
  [Gleisberg et al.] hep-ph/0311263, arXiv:0811.4622

Comparison with FEWZ and VRAP

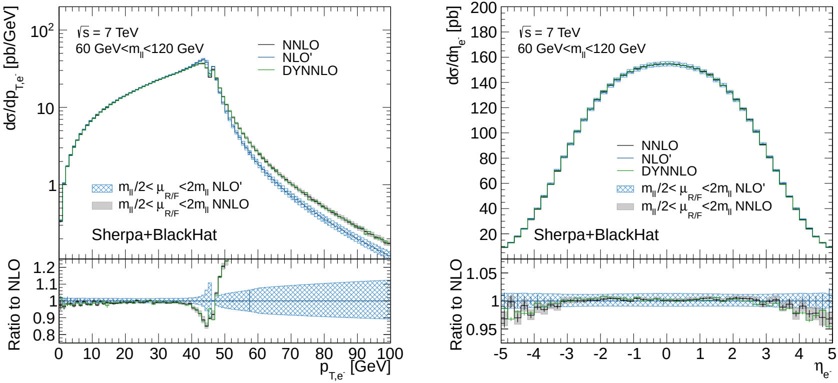
[Li,Prestel,SH] arXiv:1405.3607



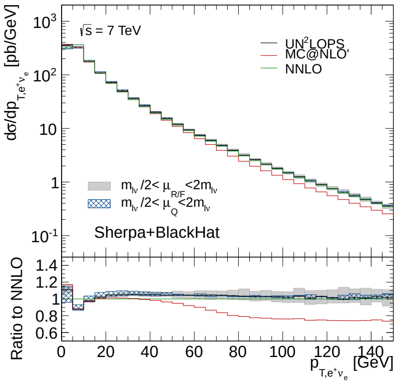
$E_{\rm cms}$	7 TeV	14 TeV	33 TeV	100 TeV
VRAP	$973.99(9)^{+4.70}_{-1.84}$ pb	$2079.0(3)\ ^{+14.7}_{-6.9}$ pb	$4909.7(8)\ ^{+45.1}_{-27.2}$ pb	$13346(3)\ ^{+129}_{-111}$ pb
SHERPA	$973.7(3)\ ^{+4.78}_{-2.21}$ pb	$2078.2(10)^{+15.0}_{-8.0}$ pb	$4905.9(28)^{+45.1}_{-27.9}$ pb	$13340(14)^{+152}_{-110}$ pb

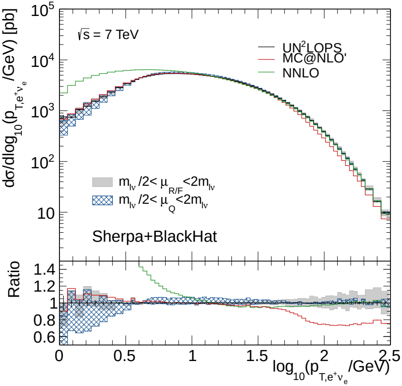
Comparison with DYNNLO

[Li,Prestel,SH] arXiv:1405.3607



Comparison with S-MC@NLO

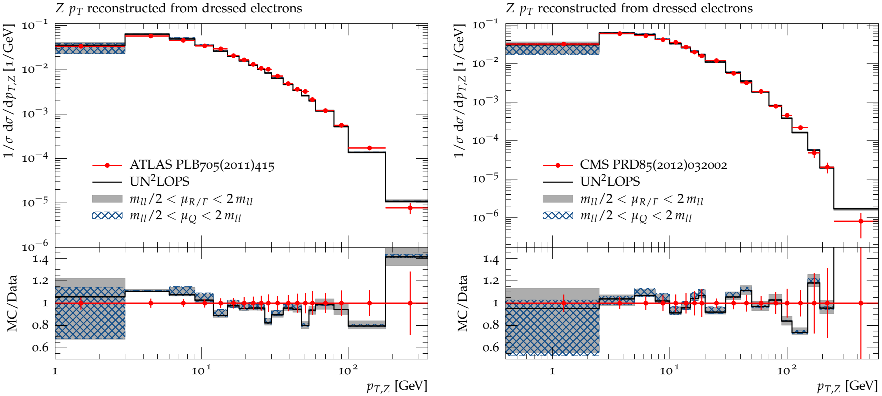




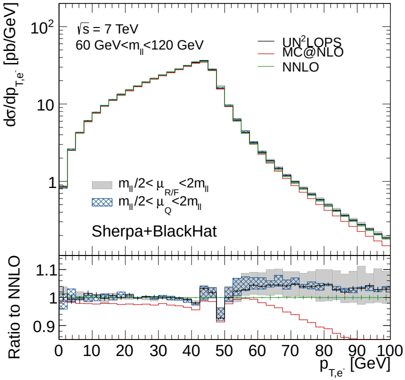
- Good agreement with S-MC@NLO at low $p_{T,W}$
- W+1-jet K-factor at high $p_{T,W}$

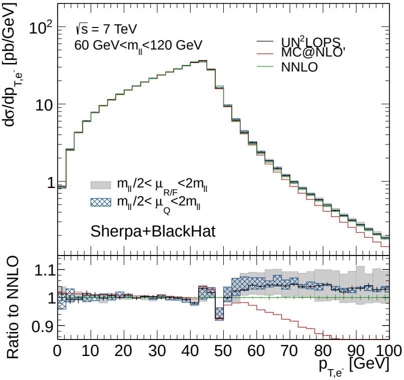
Comparison with experimental data

[Li,Prestel,SH] arXiv:1405.3607



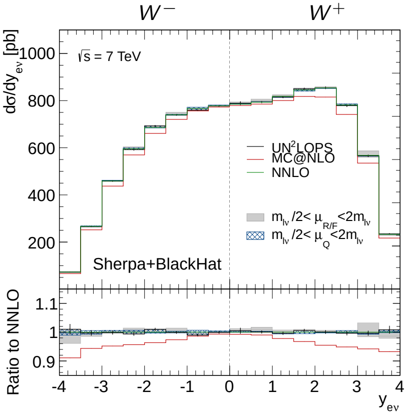
Impact of PDFs

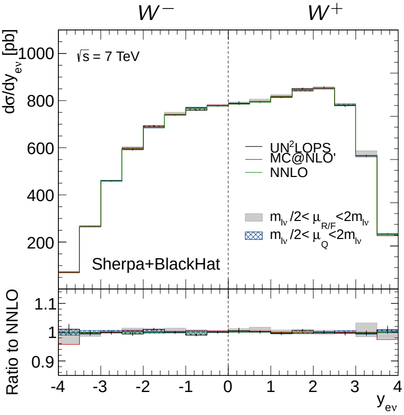




- S-MC@NLO with NLO PDFs
- S-MC@NLO with NNLO PDFs

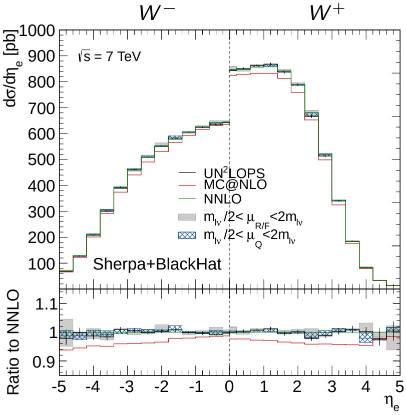
Impact of PDFs

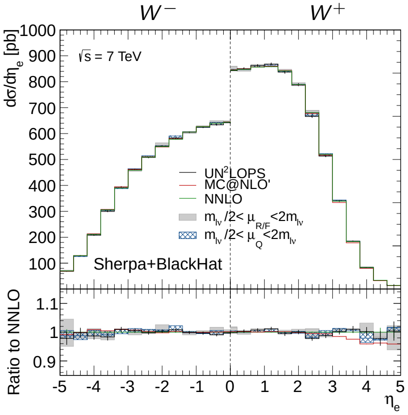




- S-MC@NLO with NLO PDFs
- S-MC@NLO with NNLO PDFs

Impact of PDFs





- S-MC@NLO with NLO PDFs
- S-MC@NLO with NNLO PDFs

Outlook

- First practical implementation of NNLO+PS for DY
- Event generation at both NNLO and NNLO+PS
- Interesting phenomenology (NLO vs NNLO PDFs)
  May hint towards usefulness of NNLO PDFs for PSs
- PS improvement needed for better overall accuracy
  (Formal accuracy of PS preserved by UN^{2}LOPS)
- MC@N^{2}LO possibly needed to improve MC efficiency