Higgs production at NLO in SHERPA

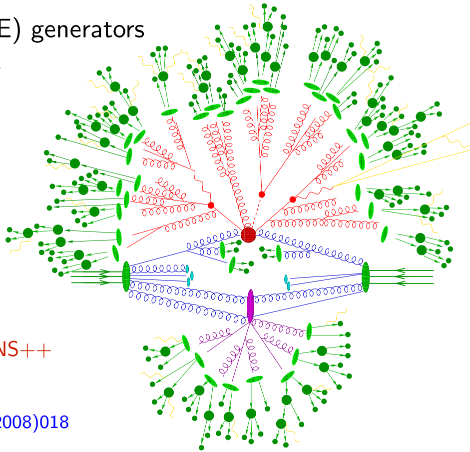
Marek Schönherr

Universität Zürich

Durham, 09/12/2014

The SHERPA event generator framework

JHEP02(2009)007

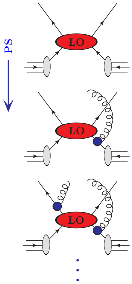


- Two multi-purpose Matrix Element (ME) generators
  AMEGIC++ JHEP02(2002)044, EPJC53(2008)501
  COMIX JHEP12(2008)039, PRL109(2012)042001
- A Parton Shower (PS) generator
  CSSHOWER++ JHEP03(2008)038
- A multiple interaction simulation
  à la Pythia AMISIC++ hep-ph/0601012
- A cluster fragmentation module
  AHADIC++ EPJC36(2004)381
- A hadron and τ decay package HADRONS++
- A higher order QED generator using
  YFS-resummation PHOTONS++ JHEP12(2008)018
- A minimum bias simulation SHRiMPS to appear

Sherpa's traditional strength is the perturbative part of the event

MEPs (CKKW), S-Mc@Nlo, MENloPs, MEPs@Nlo

MePs

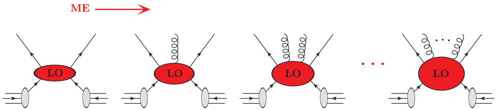


Parton showers

resummation of (soft-)collinear limit
$\to$ intrajet evolution

- matrix elements (ME) and parton showers (PS) are approximations in different regions of phase space
- MePs combines multiple LoPs – keeping either accuracy
- NloPs elevate LoPs to NLO accuracy
- MeNloPs supplements core NloPs with higher multiplicities LoPs

MEPS



Matrix elements

fixed-order in α_s
$\rightarrow$ hard wide-angle emissions
$\rightarrow$ interference terms

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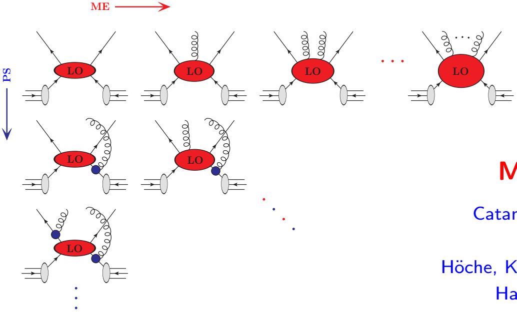

MEPS (CKKW,MLM)

Catani, Krauss, Kuhn, Webber JHEP11(2001)063
Lönnblad JHEP05(2002)046
Höche, Krauss, Schumann, Siegert JHEP05(2009)053
Hamilton, Richardson, Tully JHEP11(2009)038
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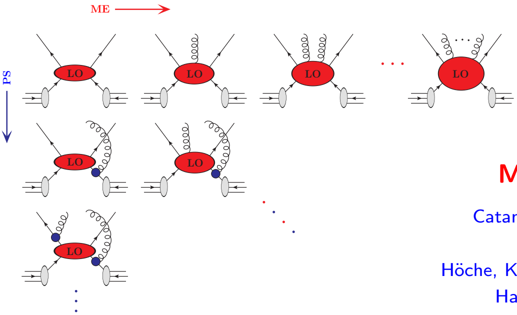

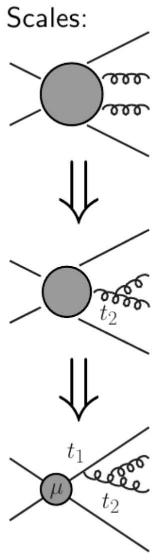

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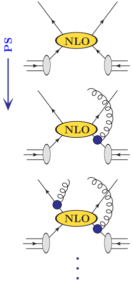
MePs@Nlo



NloPs (Mc@Nlo,Powheg)

Frixione, Webber JHEP06(2002)029
Nason JHEP11(2004)040, Frixione et.al. JHEP11(2007)070
Höche, Krauss, MS, Siegert JHEP09(2012)049

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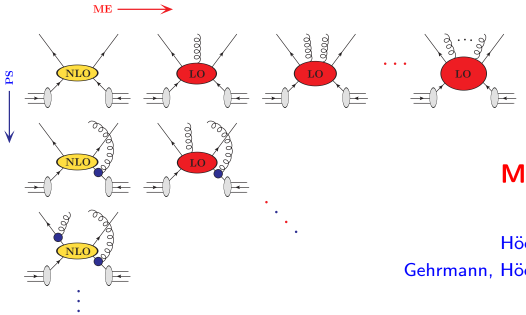
MEPS@NLO



MENLOPS

Hamilton, Nason JHEP06(2010)039
Höche, Krauss, MS, Siegert JHEP08(2011)123
Gehrmann, Höche, Krauss, MS, Siegert JHEP01(2013)144

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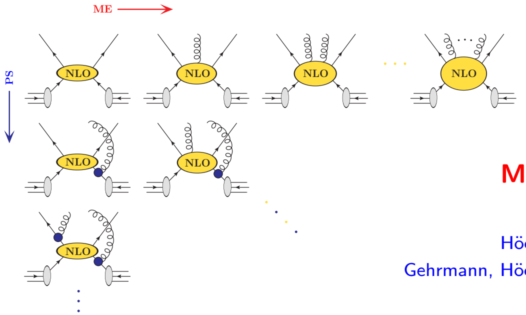

MePs@Nlo

Lavesson, Lönnblad JHEP12(2008)070
Höche, Krauss, MS, Siegert JHEP04(2013)027
Gehrmann, Höche, Krauss, MS, Siegert JHEP01(2013)144
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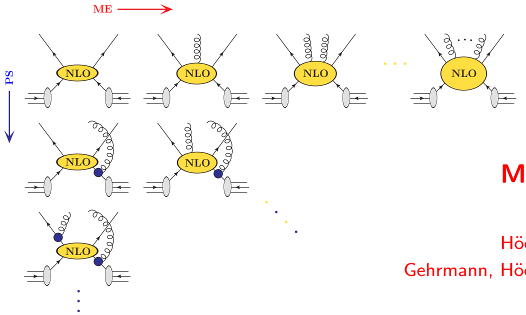
MEPS@NLO



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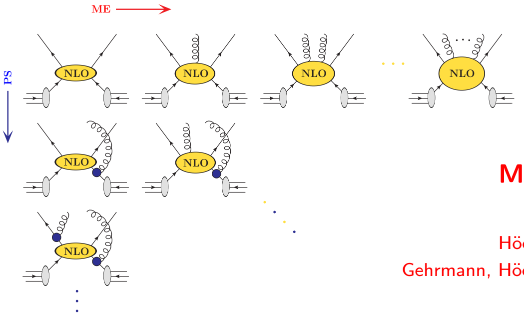
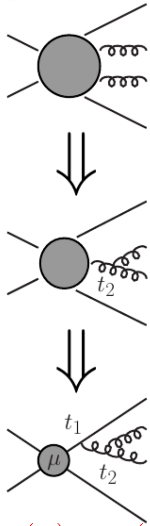
- **MEPS@NLO combines multiple NLOPS – keeping either accuracy**

MePs@Nlo





MePs@Nlo

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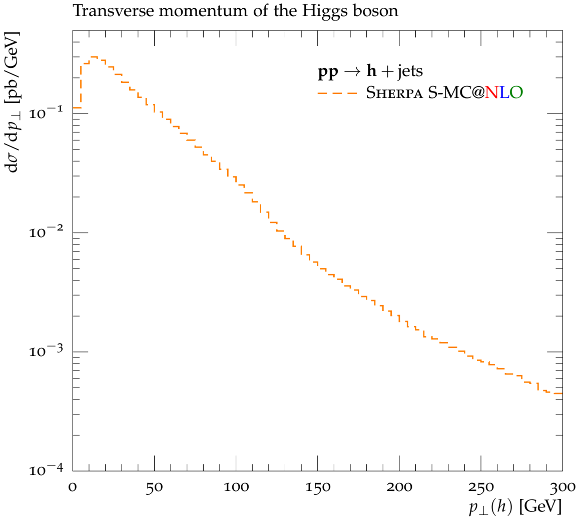
- **MePs@Nlo combines multiple NloPs**

MEPS@NLO



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- NLOPS $pp \to h +$ jet for $Q_{n+1} > Q_{\text{cut}}$
- restrict emission off $pp \to h +$ jet to $Q_{n+2} < Q_{\text{cut}}$
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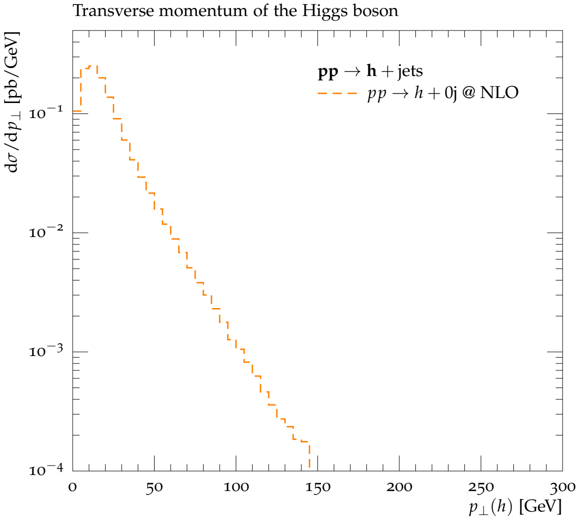
- iterate
- sum all contributions
- eg. $p_\perp(h)$>200 GeV has contributions fr. multiple topologies

MEPS@NLO



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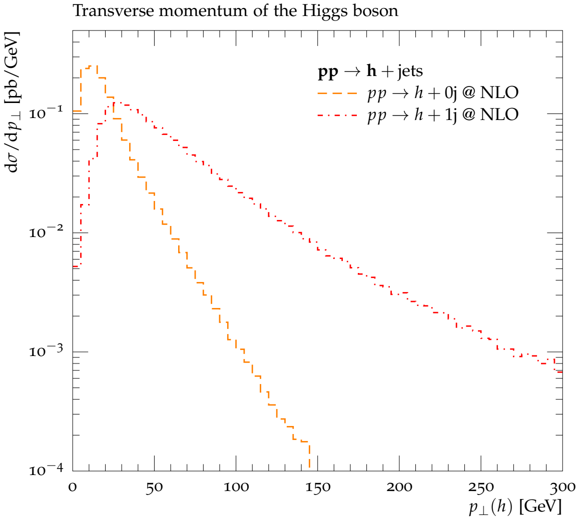

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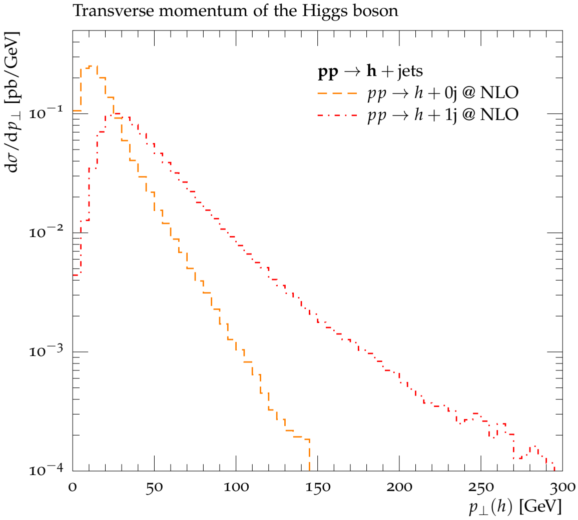

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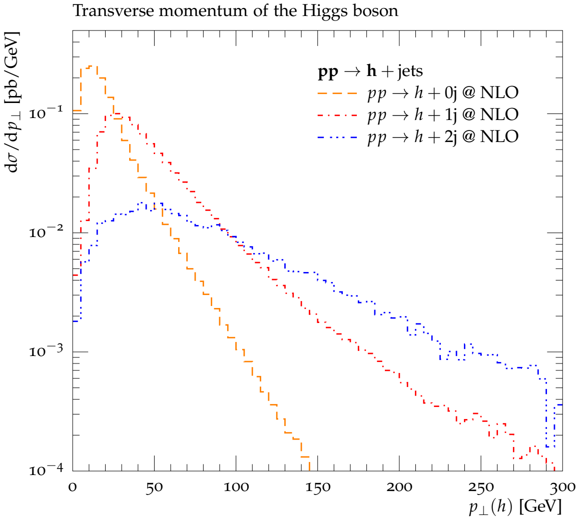

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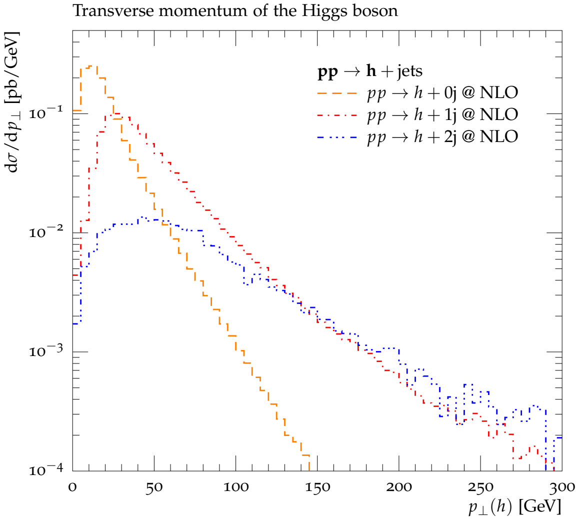

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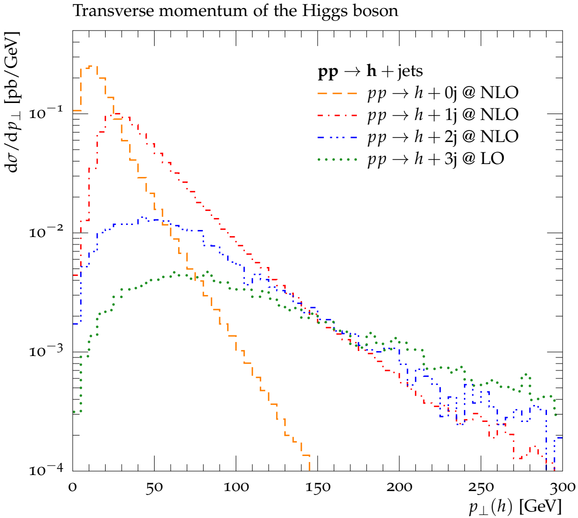

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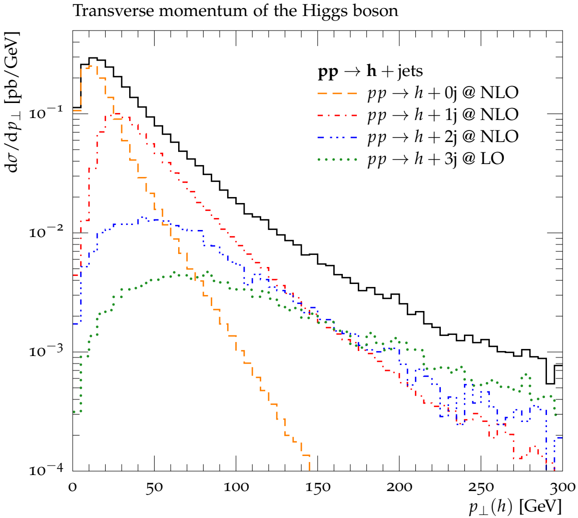

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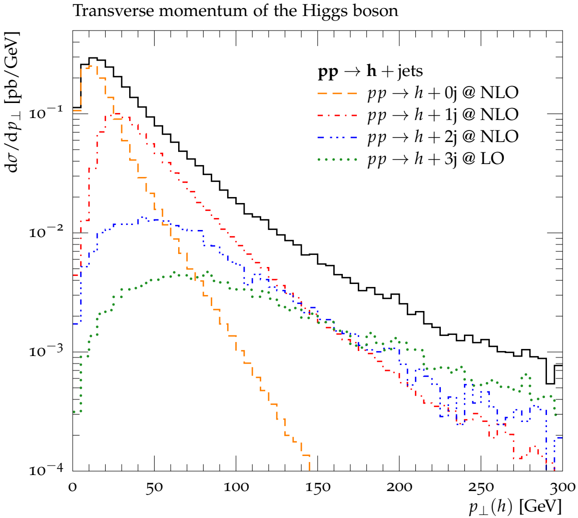

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Parameter / Scale choices – $\mu_{R/F}$, μ_Q

$$\alpha_s^{n+k}(\mu_R^2) = \alpha_s^k(\mu_{\text{core}}^2)\,\alpha_s(t_1)\cdots\alpha_s(t_n) \qquad \mu_{F,a/b}^2 = t_{\text{ext},a/b} \qquad \mu_Q^2 = \mu_{\text{core}}^2$$

Free choices

1. μ_{core} – scale of core process identified through clustering with inverse parton shower
2. $\mu_{R/F}$ beyond 1-loop running
   - calculate with chosen $\mu_{R/F}$
   - include renormalisation and factorisation terms to shift the 1-loop running to above

$$\mathrm{B}_n\,\frac{\alpha_s(\mu_R)}{\pi}\,\beta_0\left(\log\frac{\mu_R}{\mu_{\text{CKKW}}}\right)^{2+n}$$

and

$$\mathrm{B}_n\,\frac{\alpha_s}{2\pi}\,\log\frac{\mu_F}{t_{\text{ext}}}\sum_{c=q,g}\int_{x_a}^{1}\frac{\mathrm{d}z}{z}\,P_{ac}(z)f_c(x_a/z,\mu_F^2)$$

$\to$ same as in UnLoPs — Lönnblad, Prestel JHEP03(2013)166, Plätzer JHEP08(2013)114

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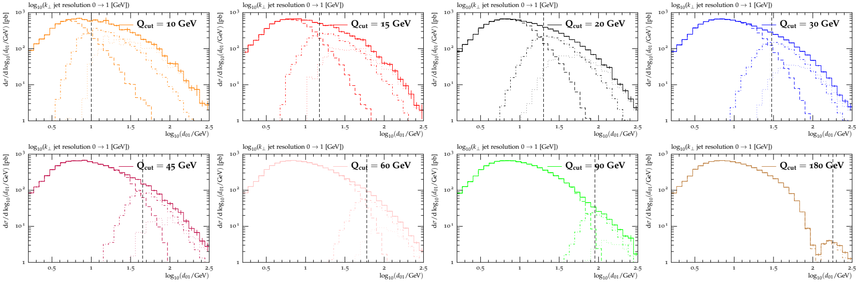
Parameter / Scale choices – Q_{cut}

Merging cut Q_{cut} dependence ($pp \to Z + \text{jets}$ MEPS, up to 2 in ME):



- parton shower is trusted to corectly describe emissions $\lesssim Q_{\text{cut}}$
- changes the region where higher accuracy is used for calculation
  $\to$ part of the uncertainty is due to degraded accuracy for large Q_{cut}
- all samples are identical for $Q < Q_{\text{cut}}^{\text{smallest}}$ and $Q > Q_{\text{cut}}^{\text{largest}}$ by construction
- for $Q \geq 45$ GeV shower approximation breaks down (earlier in other obs.)
- Q_{cut} dependence usually small

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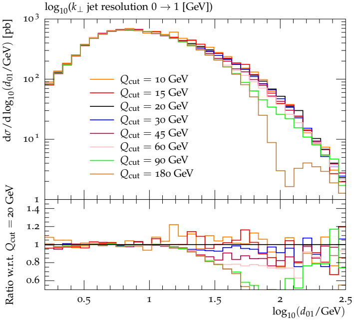

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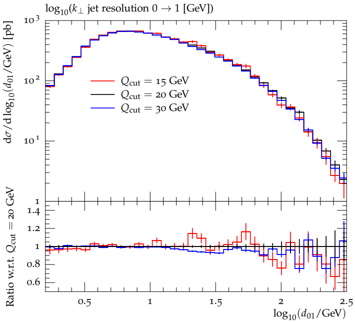

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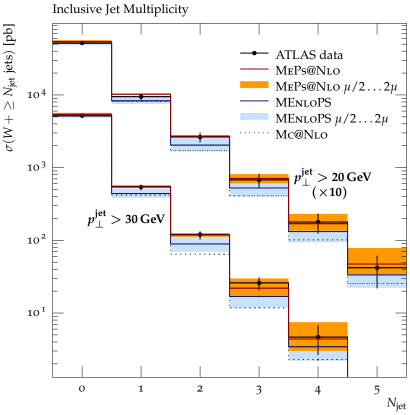
Recent results

Multijet merging at NLO accuracy (MEPS@NLO)

- $pp \to W + $ jets – SHERPA+BLACKHAT
  Höche, Krauss, MS, Siegert JHEP04(2013)027
- $e^+e^- \to$ jets – SHERPA+BLACKHAT
  Gehrmann, Höche, Krauss, MS, Siegert JHEP01(2013)144
- $pp \to h + $ jets – SHERPA+GOSAM/MCFM
  Höche, Krauss, MS, Siegert, contribution to YR3 arXiv:1307.1347
  Höche, Krauss, MS Phys.Rev.D90(2014)014012
  MS, Zapp, contribution to LH'13 arXiv:1405.1067
- $p\bar{p} \to t\bar{t} + $ jets – SHERPA+GOSAM/OPENLOOPS
  Höche, Huang, Luisoni, MS, Winter Phys.Rev.D88(2013)014040
  Höche, Krauss, Maierhöfer, Pozzorini, MS, Siegert arXiv:1402.6293
- $pp \to 4\ell + $ jets – SHERPA+OPENLOOPS
  Cascioli, Höche, Krauss, Maierhöfer, Pozzorini, Siegert JHEP01(2014)046
- $pp \to VH + $ jets, $pp \to VV + $ jets, $pp \to VVV + $ jets
  – SHERPA+OPENLOOPS
  Höche, Krauss, Pozzorini, MS, Thompson, Zapp Phys.Rev.D89(2014)093015

Results – pp → W+jets

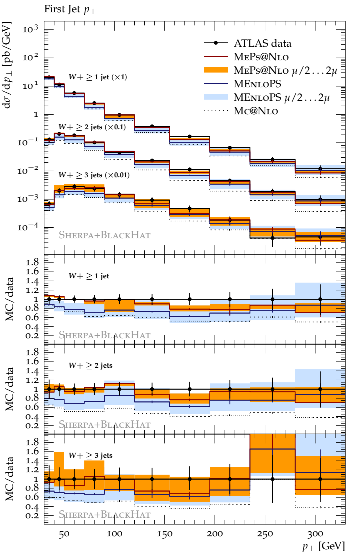


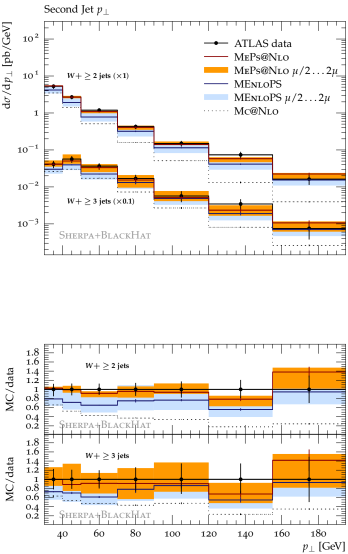
$pp \to W$+jets (0,1,2 @ NLO; 3,4 @ LO)

- $\mu_{R/F} \in [\frac{1}{2}, 2]\, \mu_{\text{def}}$ scale uncertainty much reduced
- NLO dependence for $pp \to W$+0,1,2 jets LO dependence for $pp \to W$+3,4 jets
- virtual MEs from BLACKHAT
- $Q_{\text{cut}} = 30$ GeV
- good data description

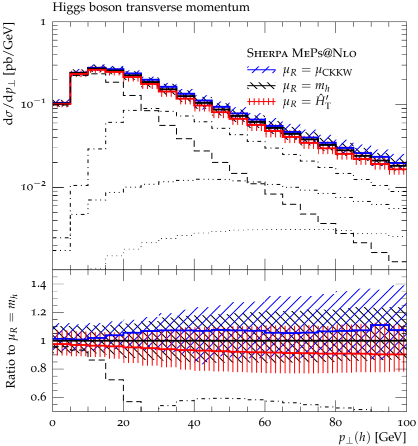
ATLAS data Phys.Rev.D85(2012)092002

Results – pp → W+jets





Results – pp → h+jets



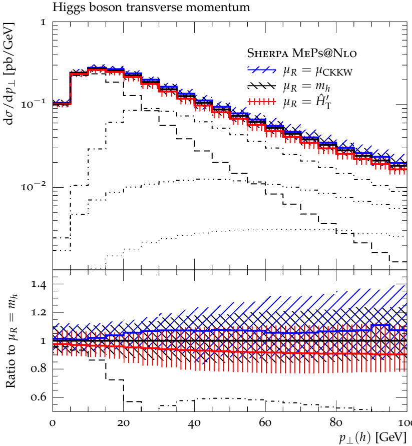
Höche, Krauss, MS, Phys.Rev.D90(2014)014012

$pp \to h$+jets (0,1,2 @ NLO; 3 @ LO)

- $\mu_{R/F} \in [\frac{1}{2}, 2]\,\mu_{R/F}^{\text{def}}$
- $\mu_Q \in [\frac{1}{\sqrt{2}}, \sqrt{2}]\,\mu_Q^{\text{def}}$
- $Q_{\text{cut}} \in \{15, 20, 30\}$ GeV
- virtual MEs from Mcfm (hjj)

use $m_t \to \infty$ limit (EFT)
→ finite m_t effects see Silvan's talk

Results – $pp \to h$+jets



⇒ **difference beyond accuracy**

scale choices: $\mu_F = \mu_Q = m_h$

1. $\mu_R = \mu_{\text{CKKW}}$

   $\alpha_s^{2+n}(\mu_{\text{CKKW}}) = \alpha_s^2(m_h)\,\alpha_s(t_1)\cdots\alpha_s(t_n)$
2. $\mu_R = m_h$
3. $\mu_R = \hat{H}'_T$

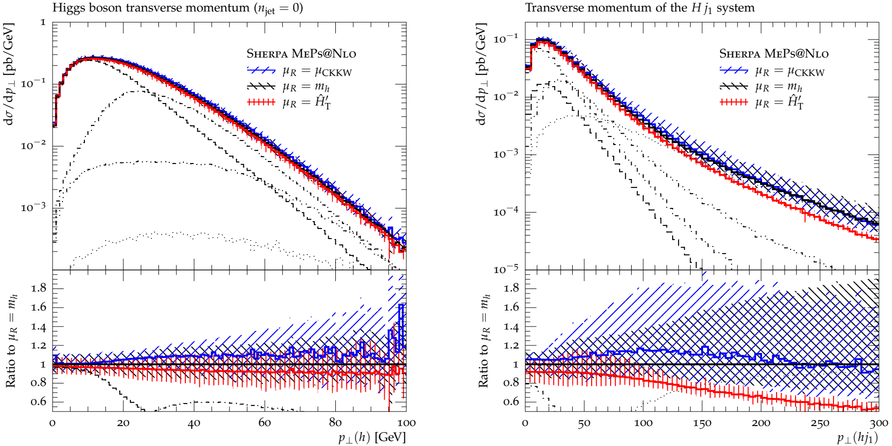
need to include ren. term

$$\mathrm{B}_n\,\frac{\alpha_s(\mu_R)}{\pi}\,\beta_0\,\left(\log\frac{\mu_R}{\mu_{\text{CKKW}}}\right)^{2+n}$$

to restore 1-loop running to μ_{CKKW}
→ otherwise PS-accuracy violated

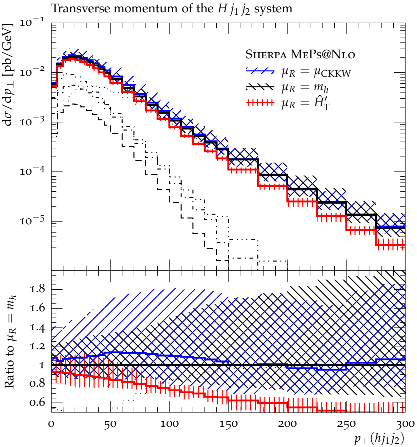
→ same as in UnLoPs approach
Lönnblad, Prestel JHEP03(2013)166
Plätzer JHEP08(2013)114

Results – pp → h+jets



- all predictions identical to MePs@Nlo accuracy
- vastly differing size of uncertainties

Results – pp → h+jets



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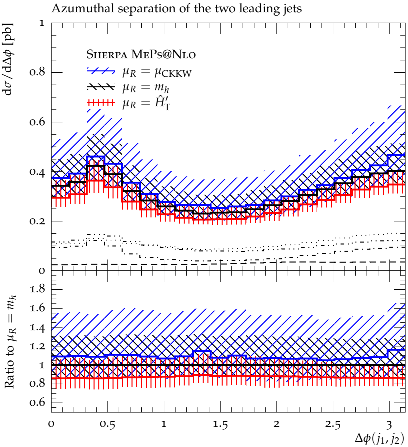
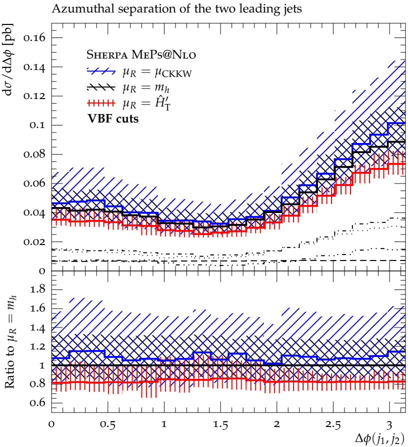
Results – $pp \to h$+jets





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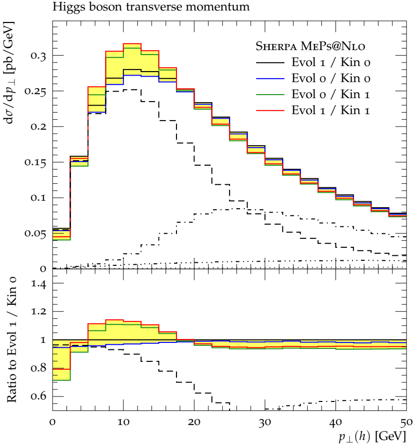


Parton shower uncertainties

- evolution scale

	Final State
0	$2\,p_ip_j\,\tilde{z}_{i,jk}(1-\tilde{z}_{i,jk})$
1	$2\,p_ip_j \begin{cases} \tilde{z}_{i,jk}(1-\tilde{z}_{i,jk}) & \text{if } i,j=g \\ 1-\tilde{z}_{i,jk} & \text{if } j=g \\ \tilde{z}_{i,jk} & \text{if } i=g \\ 1 & \text{else} \end{cases}$

	Initial State
0	$2\,p_ap_j\,(1-x_{aj,k})$
1	$2\,p_ap_j \begin{cases} 1-x_{aj,k} & \text{if } j=g \\ 1 & \text{else} \end{cases}$

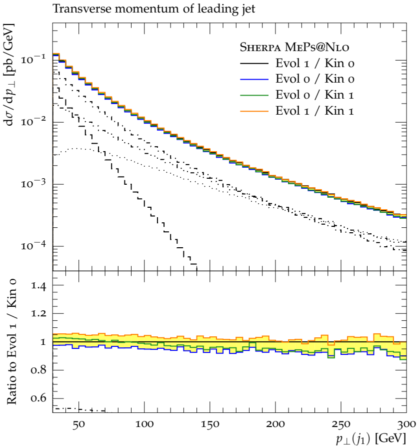
- recoil scheme

0 initial state as if final state + ⊥-boost
Höche, Schumann, Siegert Phys.Rev.D81(2010)034026

1 original CS
Catani, Seymour Nucl.Phys.B485(1997)291-419
Schumann, Krauss JHEP03(2008)038

→ similar ideas in Gieseke, Plätzer JHEP01(2011)024

Results – pp → h+jets



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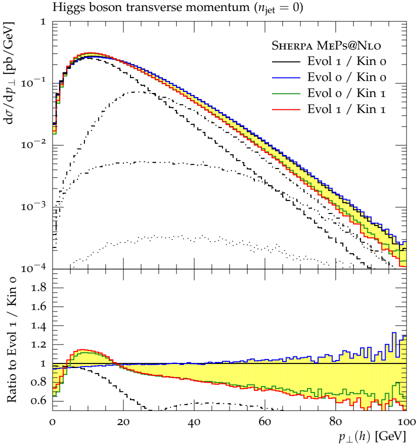

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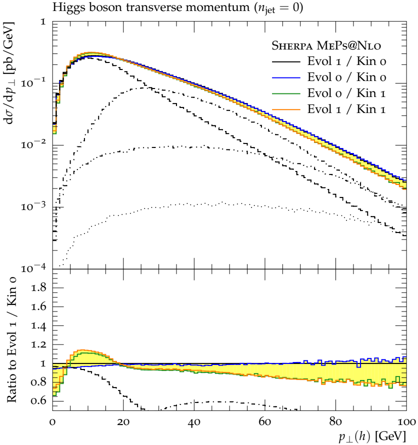

Parton shower uncertainties

- evolution scale

	Final State
0	$2\,p_i p_j\,\tilde{z}_{i,jk}(1-\tilde{z}_{i,jk})$
1	$2\,p_i p_j \begin{cases} \tilde{z}_{i,jk}(1-\tilde{z}_{i,jk}) & \text{if } i,j=g \\ 1-\tilde{z}_{i,jk} & \text{if } j=g \\ \tilde{z}_{i,jk} & \text{if } i=g \\ 1 & \text{else} \end{cases}$
	Initial State
0	$2\,p_a p_j\,(1-x_{aj,k})$
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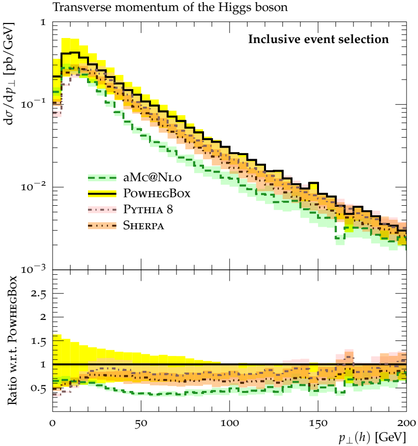
Les Houches comparative study – pp → h+jets



LH'13 (h+dijets study) arXiv:1405.1067

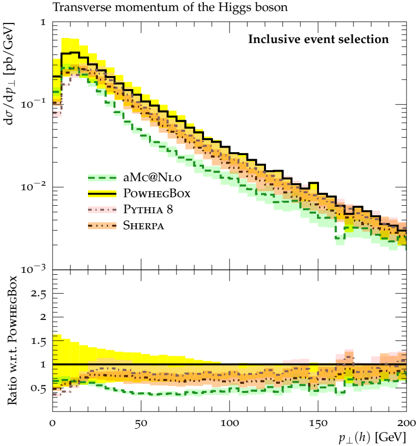
$pp \rightarrow h$+dijets study

- HEJ (BFKL w/ ME-corr.)
- aMC@NLO (FxFx combination)
- POWHEG-BOX (HJJ-MiNLO)
- PYTHIA8 (UNLOPS merging)
- SHERPA (MEPS@NLO merging)

⇒ focus on ggF background to VBF

- two dijet-event selections
  Leading jet / Forward-backward
- two levels of cuts
  Dijet cuts / VBF cuts

Les Houches comparative study – pp → h+jets



LH'13 (h+dijets study) arXiv:1405.1067

$pp \to h$+dijets study

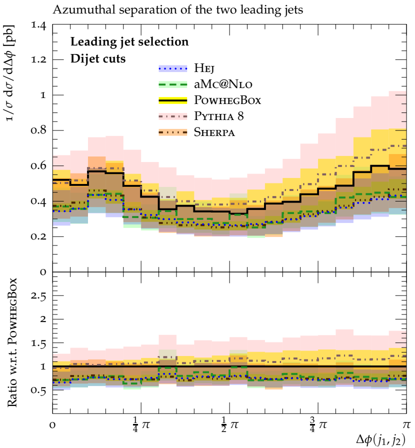
- HEJ (BFKL w/ ME-corr.) **LO**
- aMC@NLO (FxFx combination) **NLO**
- POWHEG-BOX (HJJ-MiNLO) **NLO**
- PYTHIA8 (UNLOPS merging) **NLO**
- SHERPA (MEPS@NLO merging) **NLO**

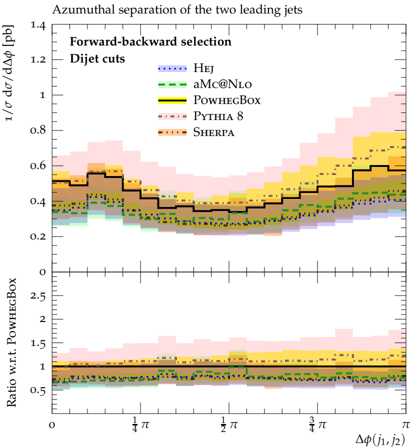
⇒ focus on ggF background to VBF

- two dijet-event selections
  Leading jet / Forward-backward
- two levels of cuts
  Dijet cuts / VBF cuts

- HJJ-MiNLO has no formal accuracy for inclusive observables

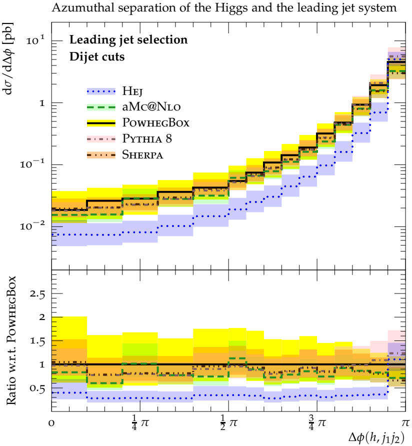
Results – pp → h+jets

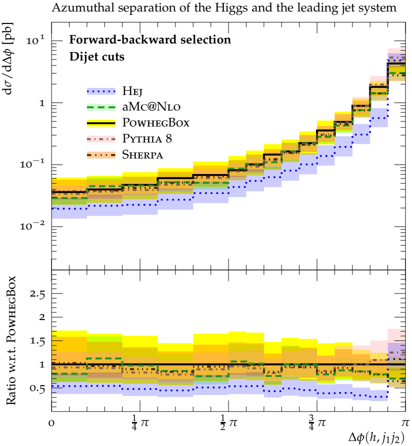




- good agreement in shape between generators, different normalisations
- similar uncertainties

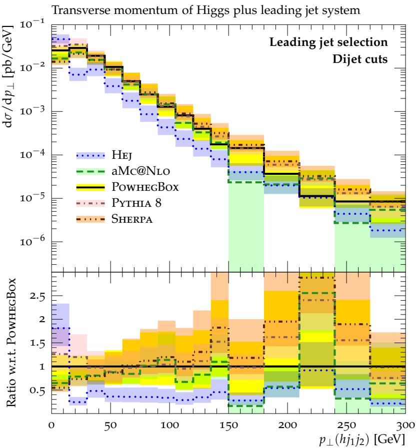
Results – pp → h+jets

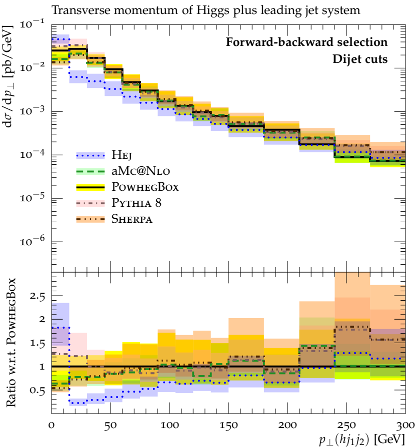




- good agreement between generators, slighlty different shapes
- HEJ has less additional jet activity

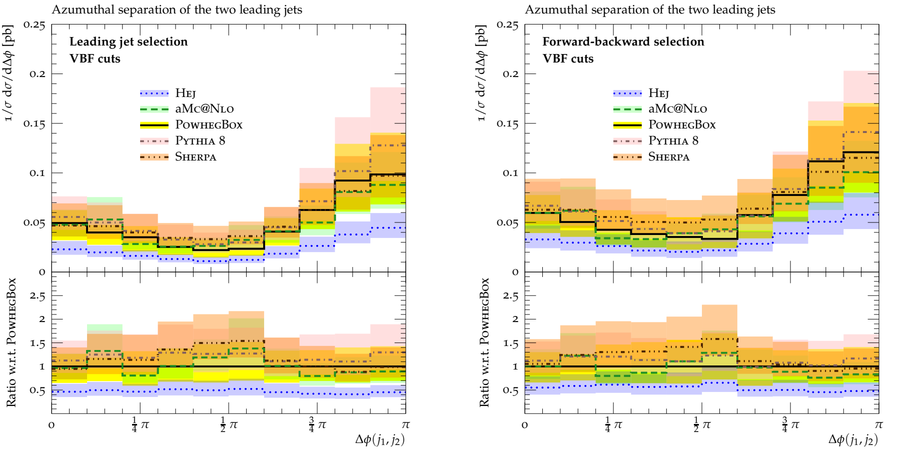
Results – pp → h+jets





- PYTHIA8 and SHERPA have more high-$p_\perp$ activity
- HEJ has less additional jet activity

Results – pp → h+jets



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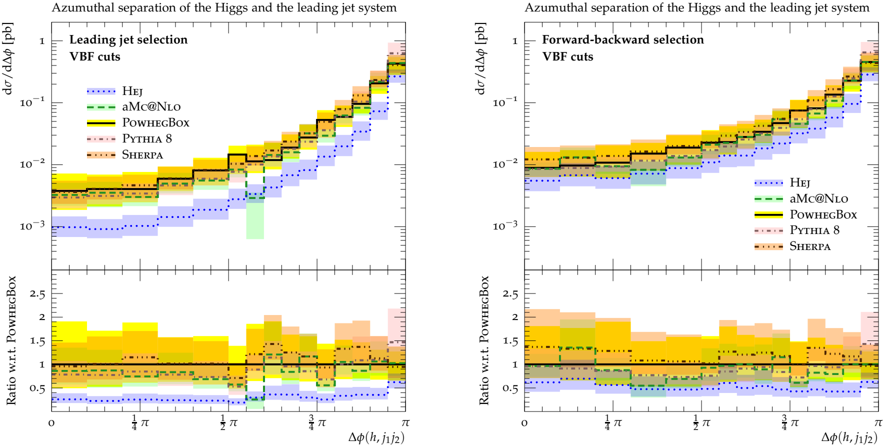

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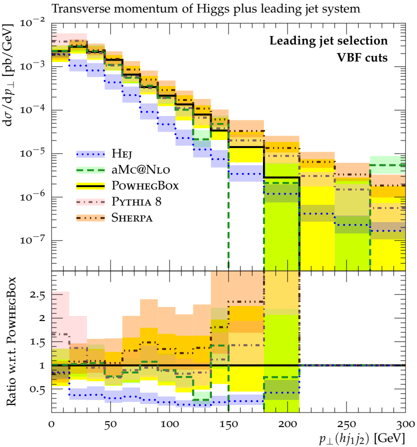

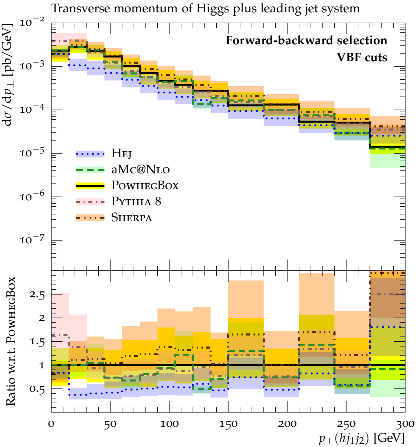

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- HEJ has less additional jet activity

Results – Trilepton production

Höche, Krauss, Pozzorini, MS, Thompson, Zapp Phys.Rev.D89(2014)093015

- trilepton (e, μ) production analysis in VH search regions
  $\to$ focus on theoretical uncertainties
- model all signal and background processes with consistent setup at largest available accuracy at particle level
  $\to$ need to describe lepton isolation and jet veto efficiency simultaneously
- produce bosons on shell, model off-shell effects through Breit-Wigner smearing
  $\to$ QCD/QED corrections to intermediate states and decay products
- most important event selection criteria

	CMS-inspired analysis	ATLAS-inspired analysis
Z veto	$\lvert m_Z - m_{\text{SFOS}}\rvert > 25$ GeV	no SFOS
jet veto	$p_\perp^{\text{jet}} < 40$ GeV	$p_\perp^{\text{jet}} < 20$ GeV

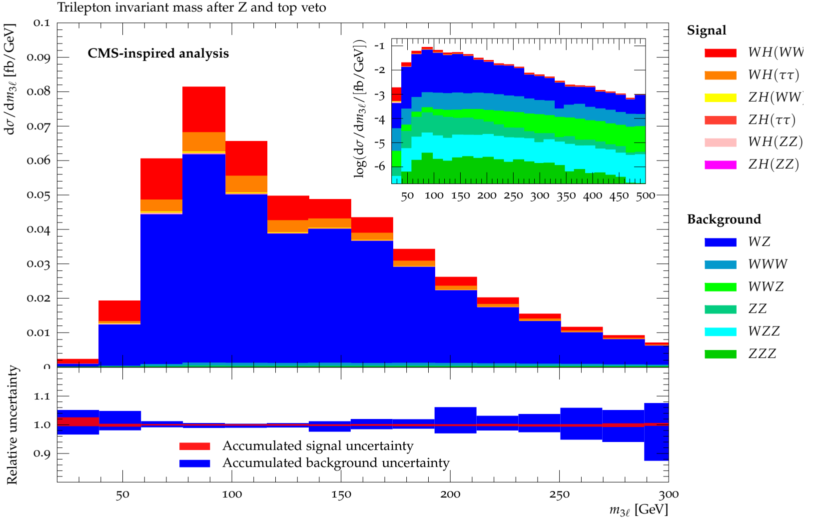
- include $V \to \tau \to e, \mu$ decay chains and possibilities to "loose" leptons
- separate $VVVj(j)$ from tVV and $t\bar{t}W$ by disallowing final state b-quarks

Results – Trilepton production

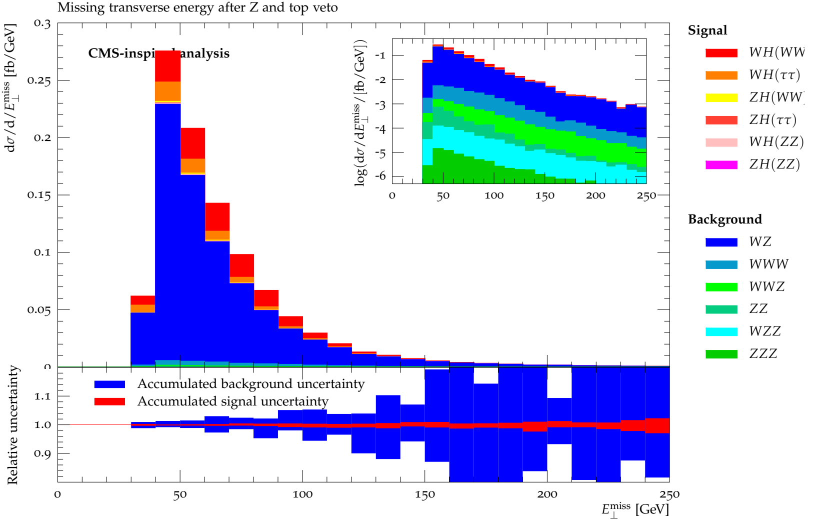
Höche, Krauss, Pozzorini, MS, Thompson, Zapp Phys.Rev.D89(2014)093015

Process	Accuracy	Decays ($\ell = e, \mu, \tau$)
WH+jets	0,1j@NLO, 2j@LO	$H \to WW$, $W \to \ell\nu$, $Z \to \ell\ell$, $\tau \to \ell\nu\nu$
		$H \to \tau\tau$, $W \to \ell\nu$, $Z \to \ell\ell$, $\tau \to \ell\nu\nu$
		$H \to ZZ$, $W \to$ all, $Z \to$ all, $\tau \to$ all
ZH+jets	0,1j@NLO, 2j@LO	$H \to WW$, $W \to$ all, $Z \to \ell\ell$, $\tau \to$ all
		$H \to \tau\tau$, $Z \to \ell\ell$, $\tau \to$ all
		$H \to ZZ$, $Z \to$ all, $\tau \to$ all
WZ+jets	0,1j@NLO, 2j@LO	$W \to \ell\nu$, $Z \to \ell\ell$, $\tau \to \ell\nu\nu$
WWW+jets	0,1j@NLO, 2j@LO	$W \to \ell\nu$, $\tau \to \ell\nu\nu$
WWZ+jets	0j@NLO, 1,2j@LO	$W \to$ all, $Z \to \ell\ell$, $\tau \to$ all
ZZ+jets	0j@NLO, 1,2j@LO	$Z \to \ell\ell$, $\tau \to$ all
WZZ+jets	0j@NLO, 1,2j@LO	$W \to$ all, $Z \to$ all, $\tau \to$ all
ZZZ+jets	0j@NLO, 1,2j@LO	$W \to$ all, $Z \to$ all, $\tau \to$ all

Results – Trilepton production



Results – Trilepton production



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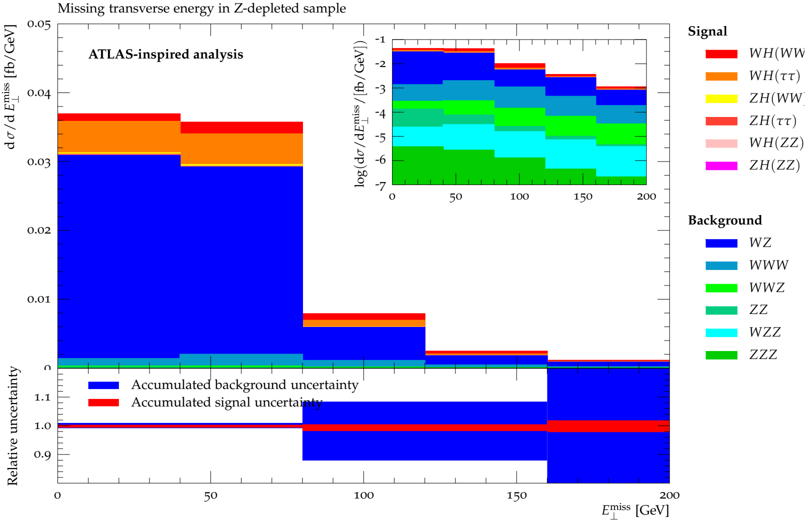

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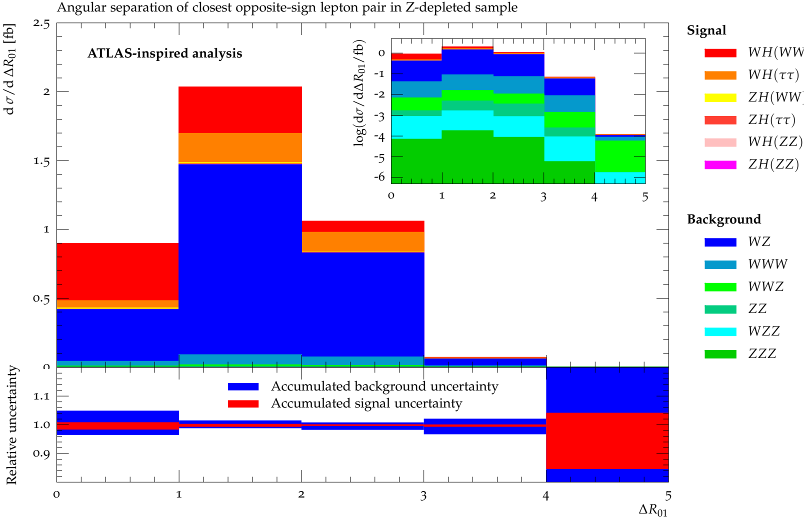

Conclusions

- multijet merging at NLO proceeds schematically as at LO
  $\to$ introduce MC-counterterm to retain NLO accuracy
- preserves NLO accuracy of the ME and accuracy of the PS in resumming hierarchies of emission scales
  $\to$ scale setting essential for recovering PS resummation
  $\to$ core scale can be chosen freely
  $\to$ beyond 1-loop running the scales can of course be freely chosen
- perurbative uncertainties due to $\mu_{R/F}$, μ_Q and Q_{cut} can be assessed in the fixed-order part
- intrinsic parton shower uncertainties can be partially assessed

current release SHERPA-2.1.1

http://sherpa.hepforge.org

Thank you for your attention!

MePs

Parton showers (operate in $N_c \to \infty$ limit):

$$\text{PS}_n(t_c, t_\text{max}) = \Delta_n(t_c, t_\text{max}) + \int_{t_c}^{t_\text{max}} \mathrm{d}t' \mathcal{K}_n(t')\, \Delta_n(t', t_\text{max})$$

Multijet merging at leading order:

$$\mathrm{d}\sigma^{\text{MEPS}} = \mathrm{d}\sigma_n^{\text{LO}} \otimes \text{PS}_n \ldots$$

[illegible]

- restrict the parton shower on $2 \to n$ to emit only below Q_cut
- arbitrary jet measure $Q_n = Q_n(\Phi_n)$
- add the $n + 1$ ME and its parton shower
- multiply by Sudakov wrt. $2 \to n$ process to restore resummation
- iterate
- if $t_n(\Phi_n) \neq Q_n(\Phi_n)$ truncated shower needed to fill gaps

MEPS

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Multijet merging at leading order:

$$\begin{aligned}\mathrm{d}\sigma^{\mathsf{MEPS}} = \mathrm{d}\sigma_n^{\mathsf{LO}} \otimes \mathsf{PS}_n\, &\Theta(Q_{\mathsf{cut}} - Q_{n+1})\\ &+ \mathrm{d}\sigma_{n+1}^{\mathsf{LO}}\, \Theta(Q_{n+1} - Q_{\mathsf{cut}})\, \Delta_n(t_{n+1}, t_n) \otimes \mathsf{PS}_{n+1}\, \Theta(Q_{\mathsf{cut}} - Q_{n+2})\\ &+ \mathrm{d}\sigma_{n+2}^{\mathsf{LO}}\, \Theta(Q_{n+2} - Q_{\mathsf{cut}})\, \Delta_n(t_{n+1}, t_n)\, \Delta_{n+1}(t_{n+2}, t_{n+1}) \otimes \mathsf{PS}_{n+2}\end{aligned}$$

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$$\mathrm{d}\sigma^{\text{MePs}} = \mathrm{d}\sigma_n^{\text{LO}} \otimes \text{PS}_n\, \Theta(Q_{\text{cut}} - Q_{n+1})$$

$$+\, \mathrm{d}\sigma_{n+1}^{\text{LO}}\, \Theta(Q_{n+1} - Q_{\text{cut}})\, \Delta_n(t_{n+1}, t_n) \otimes \text{PS}_{n+1}\, \Theta(Q_{\text{cut}} - Q_{n+2})$$

$$+\, \mathrm{d}\sigma_{n+2}^{\text{LO}}\, \Theta(Q_{n+2} - Q_{\text{cut}})\, \Delta_n(t_{n+1}, t_n)\, \Delta_{n+1}(t_{n+2}, t_{n+1}) \otimes \text{PS}_{n+2}$$

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$$\begin{aligned} \mathrm{d}\sigma^{\mathsf{MePs}} = {} & \mathrm{d}\sigma_n^{\mathsf{LO}} \otimes \mathsf{PS}_n\, \Theta(Q_{\mathsf{cut}} - Q_{n+1}) \\ & + \mathrm{d}\sigma_{n+1}^{\mathsf{LO}}\, \Theta(Q_{n+1} - Q_{\mathsf{cut}})\, \Delta_n(t_{n+1}, t_n) \otimes \mathsf{PS}_{n+1}\, \Theta(Q_{\mathsf{cut}} - Q_{n+2}) \\ & + \mathrm{d}\sigma_{n+2}^{\mathsf{LO}}\, \Theta(Q_{n+2} - Q_{\mathsf{cut}})\, \Delta_n(t_{n+1}, t_n)\, \Delta_{n+1}(t_{n+2}, t_{n+1}) \otimes \mathsf{PS}_{n+2} \end{aligned}$$

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Multijet merging at leading order:

$$\begin{aligned}\mathrm{d}\sigma^{\text{MEPS}} = {} & \mathrm{d}\sigma_n^{\text{LO}} \otimes \text{PS}_n\, \Theta(Q_{\text{cut}} - Q_{n+1}) \\ & + \mathrm{d}\sigma_{n+1}^{\text{LO}}\, \Theta(Q_{n+1} - Q_{\text{cut}})\, \Delta_n(t_{n+1}, t_n) \otimes \text{PS}_{n+1}\, \Theta(Q_{\text{cut}} - Q_{n+2}) \\ & + \mathrm{d}\sigma_{n+2}^{\text{LO}}\, \Theta(Q_{n+2} - Q_{\text{cut}})\, \Delta_n(t_{n+1}, t_n)\, \Delta_{n+1}(t_{n+2}, t_{n+1}) \otimes \text{PS}_{n+2}\end{aligned}$$

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Multijet merging at leading order:

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+ \mathrm{d}\sigma_{n+1}^{\text{LO}}\, \Theta(Q_{n+1} - Q_{\text{cut}})\, \Delta_n(t_{n+1}, t_n) \otimes \text{PS}_{n+1}\, \Theta(Q_{\text{cut}} - Q_{n+2}) \\
+ \mathrm{d}\sigma_{n+2}^{\text{LO}}\, \Theta(Q_{n+2} - Q_{\text{cut}})\, \Delta_n(t_{n+1}, t_n)\, \Delta_{n+1}(t_{n+2}, t_{n+1}) \otimes \text{PS}_{n+2}
\end{aligned}$$

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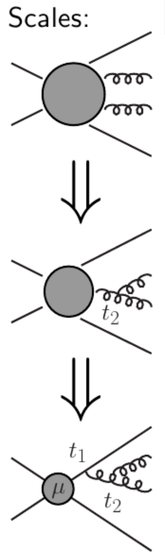
- if $t_n(\Phi_n) \neq Q_n(\Phi_n)$ truncated shower needed to fill gaps

MEPS



Parton showers (operate in $N_c \to \infty$ limit):

$$\text{PS}_n(t_c, t_{\text{max}}) = \Delta_n(t_c, t_{\text{max}}) + \int_{t_c}^{t_{\text{max}}} \mathrm{d}t' \mathcal{K}_n(t')\, \Delta_n(t',$$

Multijet merging at leading order:

$$\begin{aligned} \mathrm{d}\sigma^{\text{MEPS}} &= \mathrm{d}\sigma_n^{\text{LO}} \otimes \text{PS}_n\, \Theta(Q_{\text{cut}} - Q_{n+1}) \\ &\quad + \mathrm{d}\sigma_{n+1}^{\text{LO}}\, \Theta(Q_{n+1} - Q_{\text{cut}})\, \Delta_n(t_{n+1}, t_n) \otimes \text{PS}_{n+1}\, \Theta(\\ &\quad + \mathrm{d}\sigma_{n+2}^{\text{LO}}\, \Theta(Q_{n+2} - Q_{\text{cut}})\, \Delta_n(t_{n+1}, t_n)\, \Delta_{n+1}(t_{n+2}, t \end{aligned}$$

- restrict the parton shower on $2 \to n$ to emit only below Q_{cu}
- arbitrary jet measure $Q_n = Q_n(\Phi_n)$
- add the $n+1$ ME and its parton shower
- multiply by Sudakov wrt. $2 \to n$ process to restore resumma
- iterate
- if $t_n(\Phi_n) \neq Q_n(\Phi_n)$ truncated shower needed to fill gaps

$$\alpha_s^{k+n}(\mu_{\text{R}}) = \alpha_s^k(\mu_{\text{core}})\, \alpha_s(t_1) \cdots \alpha_s(t_n)$$

MePs

Parton showers (operate in $N_c \to \infty$ limit):

$$\mathrm{PS}_n(t_c, t_{\max}) = \Delta_n(t_c, t_{\max}) + \int_{t_c}^{t_{\max}} \mathrm{d}t' \mathcal{K}_n(t')\,\Delta_n(t', t_{\max})$$

Multijet merging at leading order:

$$\begin{aligned}\mathrm{d}\sigma^{\text{MePs}} = {} & \mathrm{d}\sigma_n^{\text{LO}} \otimes \mathrm{PS}_n\,\Theta(Q_{\text{cut}} - Q_{n+1}) \\ & + \mathrm{d}\sigma_{n+1}^{\text{LO}}\,\Theta(Q_{n+1} - Q_{\text{cut}})\,\Delta_n(t_{n+1}, t_n) \otimes \mathrm{PS}_{n+1}\,\Theta(Q_{\text{cut}} - Q_{n+2}) \\ & + \mathrm{d}\sigma_{n+2}^{\text{LO}}\,\Theta(Q_{n+2} - Q_{\text{cut}})\,\Delta_n(t_{n+1}, t_n)\,\Delta_{n+1}(t_{n+2}, t_{n+1}) \otimes \mathrm{PS}_{n+2}\end{aligned}$$

- restrict the parton shower on $2 \to n$ to emit only below Q_{cut}
- arbitrary jet measure $Q_n = Q_n(\Phi_n)$
- add the $n+1$ ME and its parton shower
- multiply by Sudakov wrt. $2 \to n$ process to restore resummation
- iterate
- if $t_n(\Phi_n) \neq Q_n(\Phi_n)$ truncated shower needed to fill gaps Nason JHEP11(2004)040

MEPS@NLO

Parton showers for NLOPS (need to reproduce $N_c = 3$ singular limits for 1st em.):

$$\widetilde{\mathsf{PS}}_n(t_c, t_{\mathsf{max}}) = \tilde{\Delta}_n(t_c, t_{\mathsf{max}}) + \int_{t_c}^{t_{\mathsf{max}}} \mathrm{d}t' \tilde{\mathcal{K}}_n(t')\, \tilde{\Delta}_n(t', t_{\mathsf{max}})$$

Multijet merging at next-to-leading order:

$$\mathrm{d}\sigma^{\mathsf{MEPS@NLO}} = \mathrm{d}\sigma_n^{\mathsf{NLO}} \otimes \widetilde{\mathsf{PS}}_n\, \Theta(Q_{\mathrm{cut}} - Q_{n+1})$$

- NLOPS for $2 \to n$, restricted to emit only below Q_{cut}
- add the NLOPS for $2 \to n+1$
- multiply by Sudakov wrt. $2 \to n$ process to restore resummation
- remove overlap of Δ_n and $\mathrm{d}\sigma_{n+1}^{\mathsf{NLO}}$, iterate

MEPS@NLO

Parton showers for NLOPS (need to reproduce $N_c = 3$ singular limits for 1st em.):

$$\widetilde{\mathsf{PS}}_n(t_c, t_{\mathsf{max}}) = \tilde{\Delta}_n(t_c, t_{\mathsf{max}}) + \int_{t_c}^{t_{\mathsf{max}}} \mathrm{d}t' \tilde{\mathcal{K}}_n(t')\, \tilde{\Delta}_n(t', t_{\mathsf{max}})$$

Multijet merging at next-to-leading order:

$$\begin{aligned} \mathrm{d}\sigma^{\mathsf{MEPS@NLO}} = \mathrm{d}\sigma_n^{\mathsf{NLO}} \otimes \widetilde{\mathsf{PS}}_n\, &\Theta(Q_{\mathsf{cut}} - Q_{n+1}) \\ &+ \mathrm{d}\sigma_{n+1}^{\mathsf{NLO}}\, \Theta(Q_{n+1} - Q_{\mathsf{cut}}) \left(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n)\right) \\ &\qquad \otimes \widetilde{\mathsf{PS}}_{n+1}\, \Theta(Q_{\mathsf{cut}} - Q_{n+2}) \\ &+ \mathrm{d}\sigma_{n+2}^{\mathsf{NLO}}\, \Theta(Q_{n+2} - Q_{\mathsf{cut}}) \left(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n)\right) \\ &\qquad \times \left(\Delta_{n+1}(t_{n+2}, t_{n+1}) - \Delta_{n+1}^{(1)}(t_{n+2}, t_{n+1})\right) \otimes \widetilde{\mathsf{PS}}_{n+2} \end{aligned}$$

- NLOPS for $2 \to n$, restricted to emit only below Q_{cut}
- add the NLOPS for $2 \to n+1$
- multiply by Sudakov wrt. $2 \to n$ process to restore resummation
- remove overlap of Δ_n and $\mathrm{d}\sigma_{n+1}^{\mathsf{NLO}}$, iterate

MePs@Nlo

Parton showers for NloPs (need to reproduce $N_c = 3$ singular limits for 1st em.):

$$\widetilde{\mathsf{PS}}_n(t_c, t_{\mathsf{max}}) = \tilde{\Delta}_n(t_c, t_{\mathsf{max}}) + \int_{t_c}^{t_{\mathsf{max}}} \mathrm{d}t' \tilde{\mathcal{K}}_n(t')\, \tilde{\Delta}_n(t', t_{\mathsf{max}})$$

Multijet merging at next-to-leading order:

$$\begin{aligned}
\mathrm{d}\sigma^{\mathsf{MePs@Nlo}} = {} & \mathrm{d}\sigma_n^{\mathsf{NLO}} \otimes \widetilde{\mathsf{PS}}_n\, \Theta(Q_{\mathsf{cut}} - Q_{n+1}) \\
& + \mathrm{d}\sigma_{n+1}^{\mathsf{NLO}}\, \Theta(Q_{n+1} - Q_{\mathsf{cut}}) \left(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n)\right) \\
& \quad \otimes \widetilde{\mathsf{PS}}_{n+1}\, \Theta(Q_{\mathsf{cut}} - Q_{n+2}) \\
& + \mathrm{d}\sigma_{n+2}^{\mathsf{NLO}}\, \Theta(Q_{n+2} - Q_{\mathsf{cut}}) \left(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n)\right) \\
& \quad \times \left(\Delta_{n+1}(t_{n+2}, t_{n+1}) - \Delta_{n+1}^{(1)}(t_{n+2}, t_{n+1})\right) \otimes \widetilde{\mathsf{PS}}_{n+2}
\end{aligned}$$

- NloPs for $2 \to n$, restricted to emit only below Q_{cut}
- add the NloPs for $2 \to n+1$
- multiply by Sudakov wrt. $2 \to n$ process to restore resummation
- remove overlap of Δ_n and $\mathrm{d}\sigma_{n+1}^{\mathsf{NLO}}$ ... iterate

MePs@Nlo

Parton showers for NLOPs (need to reproduce $N_c = 3$ singular limits for 1st em.):

$$\widetilde{\mathsf{PS}}_n(t_c, t_{\mathsf{max}}) = \tilde{\Delta}_n(t_c, t_{\mathsf{max}}) + \int_{t_c}^{t_{\mathsf{max}}} \mathrm{d}t' \tilde{\mathcal{K}}_n(t')\, \tilde{\Delta}_n(t', t_{\mathsf{max}})$$

Multijet merging at next-to-leading order:

$$\begin{aligned}\mathrm{d}\sigma^{\mathsf{MePs@Nlo}} = \mathrm{d}\sigma_n^{\mathsf{NLO}} \otimes \widetilde{\mathsf{PS}}_n\, \Theta(Q_{\mathsf{cut}} - Q_{n+1}) \\ + \mathrm{d}\sigma_{n+1}^{\mathsf{NLO}}\, \Theta(Q_{n+1} - Q_{\mathsf{cut}}) \left(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n)\right) \\ \otimes \widetilde{\mathsf{PS}}_{n+1}\, \Theta(Q_{\mathsf{cut}} - Q_{n+2}) \\ + \mathrm{d}\sigma_{n+2}^{\mathsf{NLO}}\, \Theta(Q_{n+2} - Q_{\mathsf{cut}}) \left(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n)\right) \\ \times \left(\Delta_{n+1}(t_{n+2}, t_{n+1}) - \Delta_{n+1}^{(1)}(t_{n+2}, t_{n+1})\right) \otimes \widetilde{\mathsf{PS}}_{n+2}\end{aligned}$$

- NLOPs for $2 \to n$, restricted to emit only below Q_{cut}
- add the NLOPs for $2 \to n+1$
- multiply by Sudakov wrt. $2 \to n$ process to restore resummation
- remove overlap of Δ_n and $\mathrm{d}\sigma_{n+1}^{\mathsf{NLO}}$, iterate

MePs@Nlo

Parton showers for NloPs (need to reproduce $N_c = 3$ singular limits for 1st em.):

$$\widetilde{\mathsf{PS}}_n(t_c, t_{\mathsf{max}}) = \tilde{\Delta}_n(t_c, t_{\mathsf{max}}) + \int_{t_c}^{t_{\mathsf{max}}} \mathrm{d}t' \tilde{\mathcal{K}}_n(t')\, \tilde{\Delta}_n(t', t_{\mathsf{max}})$$

Multijet merging at next-to-leading order:

$$\begin{aligned}
\mathrm{d}\sigma^{\mathsf{MePs@Nlo}} = \mathrm{d}\sigma_n^{\mathsf{NLO}} &\otimes \widetilde{\mathsf{PS}}_n\, \Theta(Q_{\mathsf{cut}} - Q_{n+1}) \\
&+ \mathrm{d}\sigma_{n+1}^{\mathsf{NLO}}\, \Theta(Q_{n+1} - Q_{\mathsf{cut}}) \left(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n)\right) \\
&\otimes \widetilde{\mathsf{PS}}_{n+1}\, \Theta(Q_{\mathsf{cut}} - Q_{n+2}) \\
&+ \mathrm{d}\sigma_{n+2}^{\mathsf{NLO}}\, \Theta(Q_{n+2} - Q_{\mathsf{cut}}) \left(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n)\right) \\
&\times \left(\Delta_{n+1}(t_{n+2}, t_{n+1}) - \Delta_{n+1}^{(1)}(t_{n+2}, t_{n+1})\right) \otimes \widetilde{\mathsf{PS}}_{n+2}
\end{aligned}$$

- NloPs for $2 \to n$, restricted to emit only below Q_{cut}
- add the NloPs for $2 \to n+1$
- multiply by Sudakov wrt. $2 \to n$ process to restore resummation
- remove overlap of Δ_n and $\mathrm{d}\sigma_{n+1}^{\mathsf{NLO}}$

MePs@Nlo

Parton showers for NloPs (need to reproduce $N_c = 3$ singular limits for 1st em.):

$$\widetilde{\mathrm{PS}}_n(t_c, t_{\mathrm{max}}) = \tilde{\Delta}_n(t_c, t_{\mathrm{max}}) + \int_{t_c}^{t_{\mathrm{max}}} \mathrm{d}t' \tilde{\mathcal{K}}_n(t')\, \tilde{\Delta}_n(t', t_{\mathrm{max}})$$

Multijet merging at next-to-leading order:

$$\begin{aligned}
\mathrm{d}\sigma^{\mathrm{MePs@Nlo}} = \mathrm{d}\sigma_n^{\mathrm{NLO}} &\otimes \widetilde{\mathrm{PS}}_n\, \Theta(Q_{\mathrm{cut}} - Q_{n+1}) \\
&+ \mathrm{d}\sigma_{n+1}^{\mathrm{NLO}}\, \Theta(Q_{n+1} - Q_{\mathrm{cut}}) \left(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n) \right) \\
&\otimes \widetilde{\mathrm{PS}}_{n+1}\, \Theta(Q_{\mathrm{cut}} - Q_{n+2}) \\
&+ \mathrm{d}\sigma_{n+2}^{\mathrm{NLO}}\, \Theta(Q_{n+2} - Q_{\mathrm{cut}}) \left(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n) \right) \\
&\times \left(\Delta_{n+1}(t_{n+2}, t_{n+1}) - \Delta_{n+1}^{(1)}(t_{n+2}, t_{n+1}) \right) \otimes \widetilde{\mathrm{PS}}_{n+2}
\end{aligned}$$

- NloPs for $2 \to n$, restricted to emit only below Q_{cut}
- add the NloPs for $2 \to n+1$
- multiply by Sudakov wrt. $2 \to n$ process to restore resummation
- remove overlap of Δ_n and $\mathrm{d}\sigma_{n+1}^{\mathrm{NLO}}$, iterate

MePs@Nlo

Parton showers for NloPs (need to reproduce $N_c = 3$ singular limits for 1st em.):

$$\widetilde{\mathrm{PS}}_n(t_c, t_{\max}) = \tilde{\Delta}_n(t_c, t_{\max}) + \int_{t_c}^{t_{\max}} \mathrm{d}t' \tilde{\mathcal{K}}_n(t')\, \tilde{\Delta}_n(t', t_{\max})$$

Multijet merging at next-to-leading order:

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\mathrm{d}\sigma^{\text{MePs@Nlo}} = \mathrm{d}\sigma_n^{\text{NLO}} \otimes \widetilde{\mathrm{PS}}_n\, \Theta(Q_{\text{cut}} - Q_{n+1}) \\
+ \mathrm{d}\sigma_{n+1}^{\text{NLO}}\, \Theta(Q_{n+1} - Q_{\text{cut}}) \left(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n)\right) \\
\otimes \widetilde{\mathrm{PS}}_{n+1}\, \Theta(Q_{\text{cut}} - Q_{n+2}) \\
+ \mathrm{d}\sigma_{n+2}^{\text{NLO}}\, \Theta(Q_{n+2} - Q_{\text{cut}}) \left(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n)\right) \\
\times \left(\Delta_{n+1}(t_{n+2}, t_{n+1}) - \Delta_{n+1}^{(1)}(t_{n+2}, t_{n+1})\right) \otimes \widetilde{\mathrm{PS}}_{n+2}
\end{aligned}$$

- NloPs for $2 \to n$, restricted to emit only below Q_{cut}
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- remove overlap of Δ_n and $\mathrm{d}\sigma_{n+1}^{\text{NLO}}$, iterate

MePs@Nlo

Parton showers for NloPs (need to reproduce $N_c = 3$ singular limits for 1st em.):

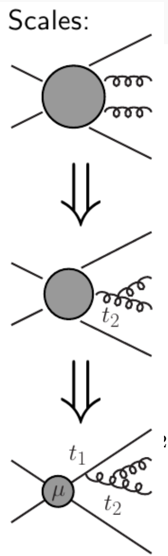
$$\widetilde{\mathsf{PS}}_n(t_c, t_{\mathsf{max}}) = \tilde{\Delta}_n(t_c, t_{\mathsf{max}}) + \int_{t_c}^{t_{\mathsf{max}}} \mathrm{d}t' \tilde{\mathcal{K}}_n(t') \, \tilde{\Delta}_n(t', t_{\mathsf{max}})$$

Multijet merging at next-to-leading order:

$$\begin{aligned}
\mathrm{d}\sigma^{\mathsf{MePs@Nlo}} = {} & \mathrm{d}\sigma_n^{\mathsf{NLO}} \otimes \widetilde{\mathsf{PS}}_n \, \Theta(Q_{\mathsf{cut}} - Q_{n+1}) \\
& + \mathrm{d}\sigma_{n+1}^{\mathsf{NLO}} \, \Theta(Q_{n+1} - Q_{\mathsf{cut}}) \left(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n) \right) \\
& \quad \otimes \widetilde{\mathsf{PS}}_{n+1} \, \Theta(Q_{\mathsf{cut}} - Q_{n+2}) \\
& + \mathrm{d}\sigma_{n+2}^{\mathsf{NLO}} \, \Theta(Q_{n+2} - Q_{\mathsf{cut}}) \left(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n) \right) \\
& \quad \times \left(\Delta_{n+1}(t_{n+2}, t_{n+1}) - \Delta_{n+1}^{(1)}(t_{n+2}, t_{n+1}) \right) \otimes \widetilde{\mathsf{PS}}_{n+2}
\end{aligned}$$

- NloPs for $2 \to n$, restricted to emit only below Q_{cut}
- add the NloPs for $2 \to n+1$
- multiply by Sudakov wrt. $2 \to n$ process to restore resummation
- remove overlap of Δ_n and $\mathrm{d}\sigma_{n+1}^{\mathsf{NLO}}$, iterate

MEPS@NLO



Parton showers for NLOPS (need to reproduce $N_c = 3$ singular li .):

$$\widetilde{\mathrm{PS}}_n(t_c, t_{\mathrm{max}}) = \tilde{\Delta}_n(t_c, t_{\mathrm{max}}) + \int_{t_c}^{t_{\mathrm{max}}} \mathrm{d}t' \tilde{\mathcal{K}}_n(t')\, \tilde{\Delta}_n(t',$$

Multijet merging at next-to-leading order:

$$\begin{aligned}\mathrm{d}\sigma^{\mathrm{MEPS@NLO}} &= \mathrm{d}\sigma_n^{\mathrm{NLO}} \otimes \widetilde{\mathrm{PS}}_n\, \Theta(Q_{\mathrm{cut}} - Q_{n+1}) \\ &+ \mathrm{d}\sigma_{n+1}^{\mathrm{NLO}}\, \Theta(Q_{n+1} - Q_{\mathrm{cut}}) \Big(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)} \\ &\otimes \widetilde{\mathrm{PS}}_{n+1}\, \Theta(Q_{\mathrm{cut}} - Q_{n+2}) \\ &+ \mathrm{d}\sigma_{n+2}^{\mathrm{NLO}}\, \Theta(Q_{n+2} - Q_{\mathrm{cut}}) \Big(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(\\ &\times \Big(\Delta_{n+1}(t_{n+2}, t_{n+1}) - \Delta_{n+1}^{(1)}(t_{n+2}, t_n\end{aligned}$$

- NLOPS for $2 \to n$, restricted to emit only below Q_{cut}
- add the NLOPS for $2 \to n+1$
- multiply by Sudakov wrt. $2 \to n$ process to restore resumma
- remove overlap of Δ_n and $\mathrm{d}\sigma_{n+1}^{\mathrm{NLO}}$, itera

$$\alpha_s^{k+n}(\mu_R) = \alpha_s^k(\mu_{\mathrm{core}})\, \alpha_s(t_1) \cdots \alpha_s(t_n)$$

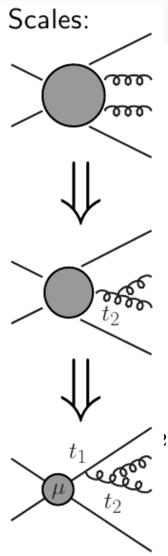
MEPS@NLO

Parton showers for NLOPS (need to reproduce $N_c = 3$ singular li… .):

$$\widetilde{\mathrm{PS}}_n(t_c, t_{\mathrm{max}}) = \tilde{\Delta}_n(t_c, t_{\mathrm{max}}) + \int_{t_c}^{t_{\mathrm{max}}} \mathrm{d}t' \tilde{\mathcal{K}}_n(t') \, \tilde{\Delta}_n(t', \ldots$$

Multijet merging at next-to-leading order:

$$\begin{aligned}\mathrm{d}\sigma^{\mathrm{MEPS@NLO}} = {} & \mathrm{d}\sigma_n^{\mathrm{NLO}} \otimes \widetilde{\mathrm{PS}}_n \, \Theta(Q_{\mathrm{cut}} - Q_{n+1}) \\ & + \mathrm{d}\sigma_{n+1}^{\mathrm{NLO}} \, \Theta(Q_{n+1} - Q_{\mathrm{cut}}) \Big(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)} \ldots \\ & \otimes \widetilde{\mathrm{PS}}_{n+1} \, \Theta(Q_{\mathrm{cut}} - Q_{n+2}) \\ & + \mathrm{d}\sigma_{n+2}^{\mathrm{NLO}} \, \Theta(Q_{n+2} - Q_{\mathrm{cut}}) \Big(\Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(\ldots \\ & \times \Big(\Delta_{n+1}(t_{n+2}, t_{n+1}) - \Delta_{n+1}^{(1)}(t_{n+2}, t_n \ldots\end{aligned}$$



- NLOPS for $2 \to n$, restricted to emit only below Q_{cut}
- add the NLOPS for $2 \to n+1$
- multiply by Sudakov wrt. $2 \to n$ process to restore resumma…
- if $t_n(\Phi_n) \neq Q_n(\Phi_n)$ truncated shower needed to fill gaps

MENLOPS

$$
\begin{aligned}
\mathrm{d}\sigma^{\text{MENLOPS}} = \mathrm{d}\sigma_n^{\text{NLO}} \otimes \widetilde{\text{PS}}_n\, \Theta(Q_{\text{cut}} - Q_{n+1}) \\
+\, k_n(\Phi_{n+1})\, \mathrm{d}\sigma_{n+1}^{\text{LO}}\, \Theta(Q_{n+1} - Q_{\text{cut}})\, \Delta_n(t_{n+1}, t_n) \\
\otimes\, \text{PS}_{n+1}\, \Theta(Q_{\text{cut}} - Q_{n+2}) \\
+\, k_n(\Phi_{n+1}(\Phi_{n+2}))\, \mathrm{d}\sigma_{n+2}^{\text{LO}}\, \Theta(Q_{n+2} - Q_{\text{cut}}) \\
\times\, \Delta_n(t_{n+1}, t_n)\, \Delta_{n+1}(t_{n+2}, t_{n+1})\, \otimes \text{PS}_{n+2}
\end{aligned}
$$

- restrict MC@NLO expression to region $Q < Q_{\text{cut}}$
- add in real radiation explicitly, as in MEPS
- restore logarithmic behaviour by explicit Sudakov
- local K-factor for continuity at Q_{cut}

$$
k_n(\Phi_{n+1}) = \frac{\bar{\mathrm{B}}_n(\Phi_n)}{\mathrm{B}_n(\Phi_n)}\left(1 - \frac{\mathrm{H}_n(\Phi_{n+1})}{\mathrm{R}_n(\Phi_{n+1})}\right) + \frac{\mathrm{H}_n(\Phi_{n+1})}{\mathrm{R}_n(\Phi_{n+1})}
$$

- iterate

MENLOPS

$$
\begin{aligned}
\mathrm{d}\sigma^{\text{MENLOPS}} = {} & \mathrm{d}\sigma_n^{\text{NLO}} \otimes \widetilde{\text{PS}}_n \, \Theta(Q_{\text{cut}} - Q_{n+1}) \\
& + k_n(\Phi_{n+1}) \, \mathrm{d}\sigma_{n+1}^{\text{LO}} \, \Theta(Q_{n+1} - Q_{\text{cut}}) \, \Delta_n(t_{n+1}, t_n) \\
& \quad \otimes \text{PS}_{n+1} \, \Theta(Q_{\text{cut}} - Q_{n+2}) \\
& + k_n(\Phi_{n+1}(\Phi_{n+2})) \, \mathrm{d}\sigma_{n+2}^{\text{LO}} \, \Theta(Q_{n+2} - Q_{\text{cut}}) \\
& \quad \times \Delta_n(t_{n+1}, t_n) \, \Delta_{n+1}(t_{n+2}, t_{n+1}) \otimes \text{PS}_{n+2}
\end{aligned}
$$

- restrict MC@NLO expression to region $Q < Q_{\text{cut}}$
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k_n(\Phi_{n+1}) = \frac{\bar{\text{B}}_n(\Phi_n)}{\text{B}_n(\Phi_n)} \left(1 - \frac{\text{H}_n(\Phi_{n+1})}{\text{R}_n(\Phi_{n+1})}\right) + \frac{\text{H}_n(\Phi_{n+1})}{\text{R}_n(\Phi_{n+1})}
$$

- iterate

MeNloPs

$$
\begin{aligned}
\mathrm{d}\sigma^{\text{MENLOPS}} = {} & \mathrm{d}\sigma_n^{\text{NLO}} \otimes \widetilde{\text{PS}}_n \, \Theta(Q_{\text{cut}} - Q_{n+1}) \\
& + k_n(\Phi_{n+1}) \, \mathrm{d}\sigma_{n+1}^{\text{LO}} \, \Theta(Q_{n+1} - Q_{\text{cut}}) \, \Delta_n(t_{n+1}, t_n) \\
& \quad \otimes \text{PS}_{n+1} \, \Theta(Q_{\text{cut}} - Q_{n+2}) \\
& + k_n(\Phi_{n+1}(\Phi_{n+2})) \, \mathrm{d}\sigma_{n+2}^{\text{LO}} \, \Theta(Q_{n+2} - Q_{\text{cut}}) \\
& \quad \times \Delta_n(t_{n+1}, t_n) \, \Delta_{n+1}(t_{n+2}, t_{n+1}) \otimes \text{PS}_{n+2}
\end{aligned}
$$

- restrict Mc@Nlo expression to region $Q < Q_{\text{cut}}$
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$$
k_n(\Phi_{n+1}) = \frac{\bar{\mathrm{B}}_n(\Phi_n)}{\mathrm{B}_n(\Phi_n)} \left(1 - \frac{\mathrm{H}_n(\Phi_{n+1})}{\mathrm{R}_n(\Phi_{n+1})}\right) + \frac{\mathrm{H}_n(\Phi_{n+1})}{\mathrm{R}_n(\Phi_{n+1})}
$$

- iterate

MENLOPS

$$
\begin{aligned}
\mathrm{d}\sigma^{\text{MENLOPS}} = {} & \mathrm{d}\sigma_n^{\text{NLO}} \otimes \widetilde{\text{PS}}_n \, \Theta(Q_{\text{cut}} - Q_{n+1}) \\
& + k_n(\Phi_{n+1}) \, \mathrm{d}\sigma_{n+1}^{\text{LO}} \, \Theta(Q_{n+1} - Q_{\text{cut}}) \, \Delta_n(t_{n+1}, t_n) \\
& \quad \otimes \text{PS}_{n+1} \, \Theta(Q_{\text{cut}} - Q_{n+2}) \\
& + k_n(\Phi_{n+1}(\Phi_{n+2})) \, \mathrm{d}\sigma_{n+2}^{\text{LO}} \, \Theta(Q_{n+2} - Q_{\text{cut}}) \\
& \quad \times \Delta_n(t_{n+1}, t_n) \, \Delta_{n+1}(t_{n+2}, t_{n+1}) \otimes \text{PS}_{n+2}
\end{aligned}
$$

- restrict MC@NLO expression to region $Q < Q_{\text{cut}}$
- add in real radiation explicitly, as in MEPS
- restore logarithmic behaviour by explicit Sudakov
- local K-factor for continuity at Q_{cut}

$$
k_n(\Phi_{n+1}) = \frac{\bar{\text{B}}_n(\Phi_n)}{\text{B}_n(\Phi_n)} \left(1 - \frac{\text{H}_n(\Phi_{n+1})}{\text{R}_n(\Phi_{n+1})}\right) + \frac{\text{H}_n(\Phi_{n+1})}{\text{R}_n(\Phi_{n+1})}
$$

- iterate

MENLOPS

$$
\begin{aligned}
d\sigma^{\text{MENLOPS}} = {} & d\sigma_n^{\text{NLO}} \otimes \widetilde{\text{PS}}_n\, \Theta(Q_{\text{cut}} - Q_{n+1}) \\
& + k_n(\Phi_{n+1})\, d\sigma_{n+1}^{\text{LO}}\, \Theta(Q_{n+1} - Q_{\text{cut}})\, \Delta_n(t_{n+1}, t_n) \\
& \quad \otimes \text{PS}_{n+1}\, \Theta(Q_{\text{cut}} - Q_{n+2}) \\
& + k_n(\Phi_{n+1}(\Phi_{n+2}))\, d\sigma_{n+2}^{\text{LO}}\, \Theta(Q_{n+2} - Q_{\text{cut}}) \\
& \quad \times \Delta_n(t_{n+1}, t_n)\, \Delta_{n+1}(t_{n+2}, t_{n+1}) \otimes \text{PS}_{n+2}
\end{aligned}
$$

- restrict MC@NLO expression to region $Q < Q_{\text{cut}}$
- add in real radiation explicitly, as in MEPS
- restore logarithmic behaviour by explicit Sudakov
- local K-factor for continuity at Q_{cut}

$$
k_n(\Phi_{n+1}) = \frac{\bar{\text{B}}_n(\Phi_n)}{\text{B}_n(\Phi_n)} \left(1 - \frac{\text{H}_n(\Phi_{n+1})}{\text{R}_n(\Phi_{n+1})}\right) + \frac{\text{H}_n(\Phi_{n+1})}{\text{R}_n(\Phi_{n+1})}
$$

- iterate

MeNloPs

$$
\begin{aligned}
\mathrm{d}\sigma^{\text{MENLOPS}} = {} & \mathrm{d}\sigma_n^{\text{NLO}} \otimes \widetilde{\text{PS}}_n\, \Theta(Q_{\text{cut}} - Q_{n+1}) \\
& + k_n(\Phi_{n+1})\, \mathrm{d}\sigma_{n+1}^{\text{LO}}\, \Theta(Q_{n+1} - Q_{\text{cut}})\, \Delta_n(t_{n+1}, t_n) \\
& \quad \otimes \text{PS}_{n+1}\, \Theta(Q_{\text{cut}} - Q_{n+2}) \\
& + k_n(\Phi_{n+1}(\Phi_{n+2}))\, \mathrm{d}\sigma_{n+2}^{\text{LO}}\, \Theta(Q_{n+2} - Q_{\text{cut}}) \\
& \quad \times \Delta_n(t_{n+1}, t_n)\, \Delta_{n+1}(t_{n+2}, t_{n+1}) \otimes \text{PS}_{n+2}
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- iterate