# Matching and merging in SHERPA

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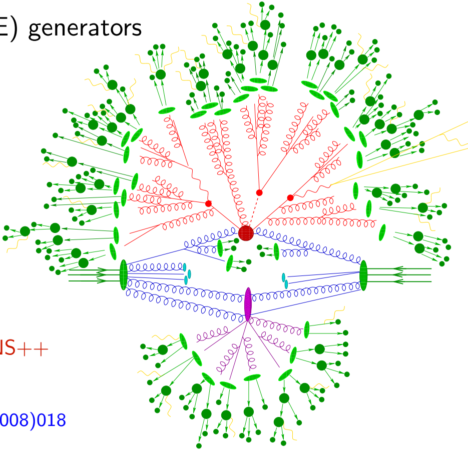
JHEP09(2012)049, Phys.Rev.D86(2012)094042
JHEP04(2013)027, JHEP01(2013)144
Phys.Rev.D88(2013)014040, arXiv:1401.7971, arXiv:1402.6293 *

*in coll. with S. Höche, J. Huang, F. Krauss, G. Luisoni, P. Maierhöfer, S. Pozzorini, F. Siegert, J. Winter

JHEP02(2009)007

# The SHERPA event generator framework

- 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 $\tau$ 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 (operate in $N_c \to \infty$ limit):

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

Multijet merging at leading order:

$$\mathrm{d}\sigma^{\mathsf{MEPS}} = \mathrm{d}\sigma_n^{\mathsf{LO}}$$

- restrict the parton shower on $2 \to n$ to emit only below $Q_{\mathsf{cut}}$
- 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

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

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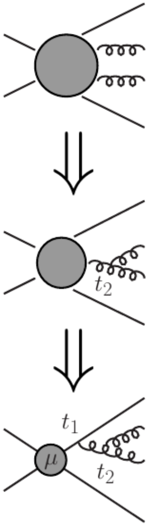
Scales:




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

# MePs

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# MePs@Nlo

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

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

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Multijet merging at next-to-leading order:

$$\begin{aligned}
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& \qquad \otimes \widetilde{\mathsf{PS}}_{n+1}\, \Theta(Q_{\mathsf{cut}} - Q_{n+2}) \\
& + \mathrm{d}\sigma_{n+2}^{\mathsf{NLO}}\, \Theta(Q_{n+2} - Q_{\mathsf{cut}}) \left( \Delta_n(t_{n+1}, t_n) - \Delta_n^{(1)}(t_{n+1}, t_n) \right) \\
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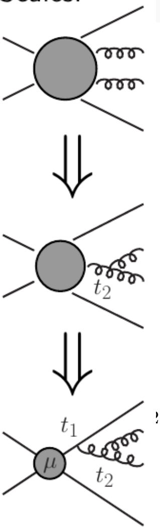
$$\widetilde{\mathsf{PS}}_n(t_c, t_{\mathsf{max}}) = \tilde{\Delta}_n(t_c, t_{\mathsf{max}}) + \int_{t_c}^{t_{\mathsf{max}}} \mathrm{d}t' \tilde{\mathcal{K}}_n(t')\, \tilde{\Delta}_n(t', \ldots$$

Multijet merging at next-to-leading order:

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

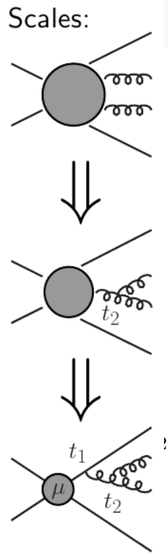
- NLOPS for $2 \to n$, restricted to emit only below $Q_{\mathsf{cut}}$
- add the NLOPS for $2 \to n+1$
- multiply by Sudakov wrt. $2 \to n$ process to restore resumma…
- remove overlap of $\Delta_n$ and $\mathrm{d}\sigma_{n+1}^{\mathsf{NLO}}$, itera…

Scales:




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

# MEPS@NLO




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

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

Multijet merging at next-to-leading order:

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

- NLOPS for $2 \to n$, restricted to emit only below $Q_{\mathsf{cut}}$
- 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

# 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 arXiv:1401.7971

  MS, Zapp, contribution to LH13
- $p\bar{p} \to t\bar{t} +$ jets – SHERPA+GOSAM/OPENLOOPS

  Höche, Huang, Luisoni, MS, Winter Phys.Rev.D88(2013)014040

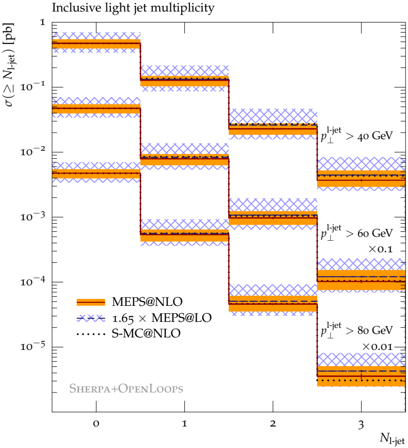
  Höche, Krauss, Maierhöfer, Pozzorini, MS, Siegert arXiv:1402.6293
- $pp \to 4\ell +$ jets – SHERPA+OPENLOOPS

  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 arXiv:1403.7516

# Results – pp $\to$ $t\bar{t}$+jets

Höche, Krauss, Maierhöfer, Pozzorini, MS, Siegert in arXiv:1401.7971




$pp \to t\bar{t}$+jets (0,1,2 @ NLO; 3 @ LO)

- scales:

$$\alpha_s^{2+n}(\mu_R) = \alpha_s^2(\mu_{\text{core}}) \prod_{i=1}^{n} \alpha_s(t_i),$$

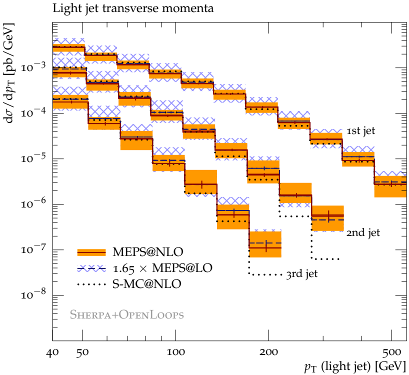
$$\mu_F = \mu_Q = \mu_{\text{core}} \text{ on } 2 \to 2$$

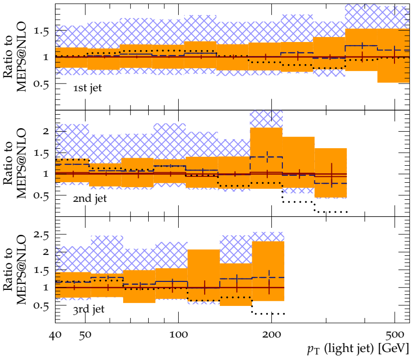
$$Q_{\text{cut}} = 30 \text{ GeV}$$

$$\mu_{\text{core}} = -\frac{2}{\frac{1}{p_0 p_1} + \frac{1}{p_0 p_2} + \frac{1}{p_0 p_3}}$$

- $\mu_{R/F} \in [\frac{1}{2}, 2]\, \mu_{R/F}^{\text{def}}$
- $\mu_Q \in [\frac{1}{\sqrt{2}}, \sqrt{2}]\, \mu_Q^{\text{def}}$
- $Q_{\text{cut}} \in \{20, 30, 40\}$ GeV

# Results – $pp \to t\bar{t}$+jets




- Shapes are stable
- Uncertainties are much smaller where higher accuracy is employed

# Scale choices

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

Free choices

1. $\mu_{\text{core}}$ – 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

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

$\rightarrow$ same as in UNLOPS Lönnblad, Prestel JHEP03(2013)166, Plätzer JHEP08(2013)114

# Scale choices

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

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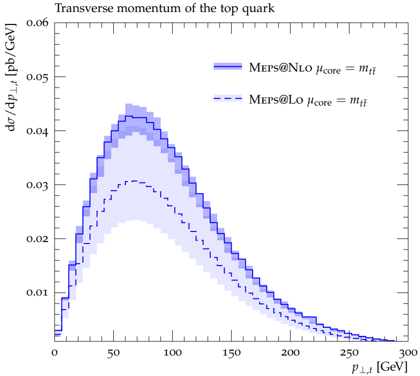
$\to$ same as in UnLoPs Lönnblad, Prestel JHEP03(2013)166, Plätzer JHEP08(2013)114

# Results – $p\bar{p} \to t\bar{t} + \text{jets}$ – $A_{FB}$

Höche, Huang, Luisoni, MS, Winter Phys.Rev.D88(2013)014040

Setup: $p\bar{p} \to t\bar{t}+$ jets

- purely perturbative calculation (no hadronisation, MPI, etc.)
- 0,1 jets @ NLO
  $Q_{\text{cut}} = 7$ GeV
- virtual MEs from GoSam
- perturbative scale variations
  $\mu_{R/F} \in [\frac{1}{2}, 2]\,\mu_{\text{def}}$
  $\mu_Q \in [\frac{1}{\sqrt{2}}, \sqrt{2}]\,\mu_{\text{core}}$
- variation of merging parameter
  $Q_{\text{cut}} \in \{5, 7, 10\}$ GeV




- scale choices: $\alpha_s^{k+n}(\mu_R) = \alpha_s^k(\mu_{\text{core}})\,\alpha_s(t_1)\cdots\alpha_s(t_n)$
  1) $\mu_{\text{core}} = m_{t\bar{t}}$
  2) $\mu_{\text{core}} = \mu_{\text{QCD}} = 2\,|p_i p_j|$
  $i, j \ldots N_c \to \infty$ colour partners, chooses between $s, t, u$

# Results – $\mathrm{p\bar{p}} \to \mathrm{t\bar{t}} + \mathbf{jets}$ – $\mathrm{A_{FB}}$

Höche, Huang, Luisoni, MS, Winter Phys.Rev.D88(2013)014040

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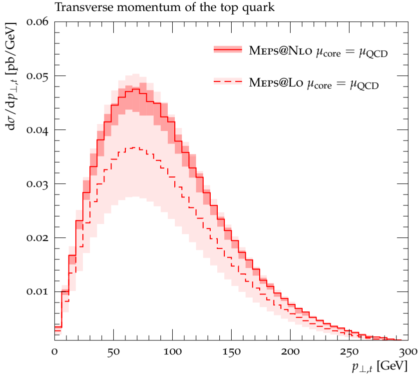


- scale choices: $\alpha_s^{k+n}(\mu_R) = \alpha_s^k(\mu_{\text{core}})\,\alpha_s(t_1)\cdots\alpha_s(t_n)$

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Höche, Huang, Luisoni, MS, Winter Phys.Rev.D88(2013)014040

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- perturbative scale variations
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  $\mu_Q \in [\frac{1}{\sqrt{2}}, \sqrt{2}]\, \mu_{\text{core}}$
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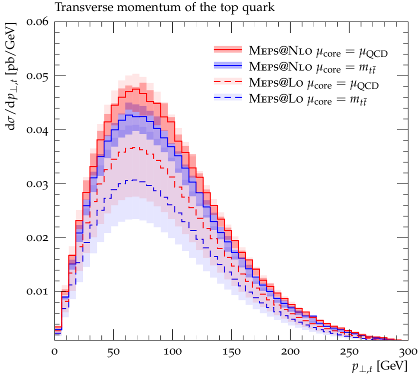


- scale choices: $\alpha_s^{k+n}(\mu_R) = \alpha_s^k(\mu_{\text{core}})\,\alpha_s(t_1)\cdots\alpha_s(t_n)$

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  **2)** $\mu_{\text{core}} = \mu_{\text{QCD}} = 2\,|p_i p_j|$
  $i, j\ \ldots\ N_c \to \infty$ colour partners, chooses between $s, t, u$

# Results – $\mathrm{p\bar{p}} \to \mathrm{t\bar{t}} + \mathbf{jets}$ – $\mathrm{A_{FB}}$

- Definition of forward-backward asymmetry of an observable $\mathcal{O}$

$$A_{\mathsf{FB}}(O) \;=\; \frac{\left.\frac{\mathrm{d}\sigma_{t\bar{t}}}{\mathrm{d}O}\right|_{\Delta y>0} - \left.\frac{\mathrm{d}\sigma_{t\bar{t}}}{\mathrm{d}O}\right|_{\Delta y<0}}{\left.\frac{\mathrm{d}\sigma_{t\bar{t}}}{\mathrm{d}O}\right|_{\Delta y>0} + \left.\frac{\mathrm{d}\sigma_{t\bar{t}}}{\mathrm{d}O}\right|_{\Delta y<0}}$$

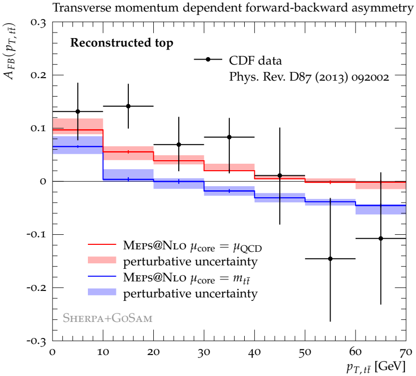
- $A_{\mathsf{FB}}$ is ratio of expectation values
  $\rightarrow$ conventional scale variations by factor 2 will largely cancel for uncertainty on $A_{\mathsf{FB}}$

$\Rightarrow$ use different functional forms of the scale defintion that behave differently in $\Delta y > 0$ and $\Delta y < 0$ for a realistic estimate of uncertainty

# Results – $\mathrm{p\bar{p}} \to \mathrm{t\bar{t}} + \mathrm{jets}$ – $\mathrm{A_{FB}}$

Höche, Huang, Luisoni, MS, Winter Phys.Rev.D88(2013)014040

CDF data Phys.Rev.D87(2013)092002



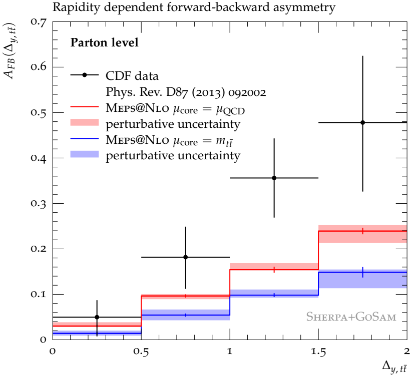

$p\bar{p} \to t\bar{t}$+jets (0,1 @ NLO)

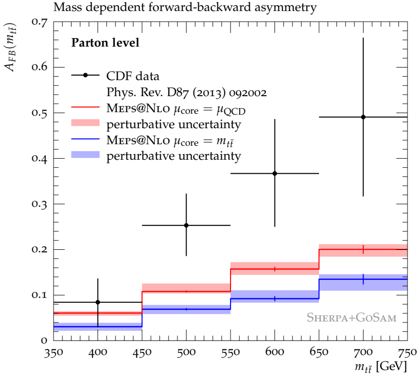
- $A_{FB}(p_{\perp,t\bar{t}})$ NLO accurate in all but the first bin
- tops reconstructed from decay products (jets, lepton, MET)
- no EW corrections

# Results – $p\bar{p} \to t\bar{t} + \text{jets}$ – $A_{FB}$

Höche, Huang, Luisoni, MS, Winter Phys.Rev.D88(2013)014040

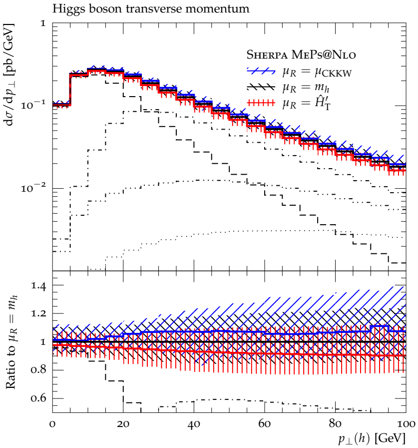
CDF data Phys.Rev.D87(2013)092002




- parton level (exact top quarks)
- no EW corrections ($\approx 20\%$) effected
- right qualitative bahviour, but consistently below data

# Results – pp → h+jets

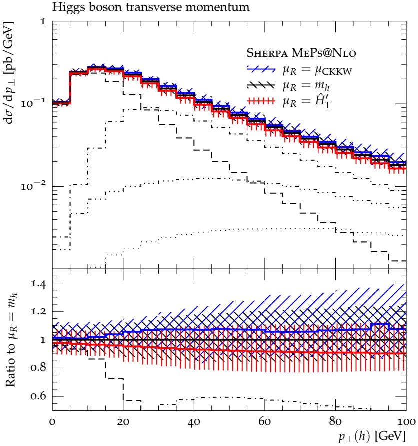



Höche, Krauss, MS, in arXiv:1401.7971

$pp \to h$+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 $(hjj)$

# Results – pp → h+jets




⇒ **difference beyond accuracy**

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

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

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

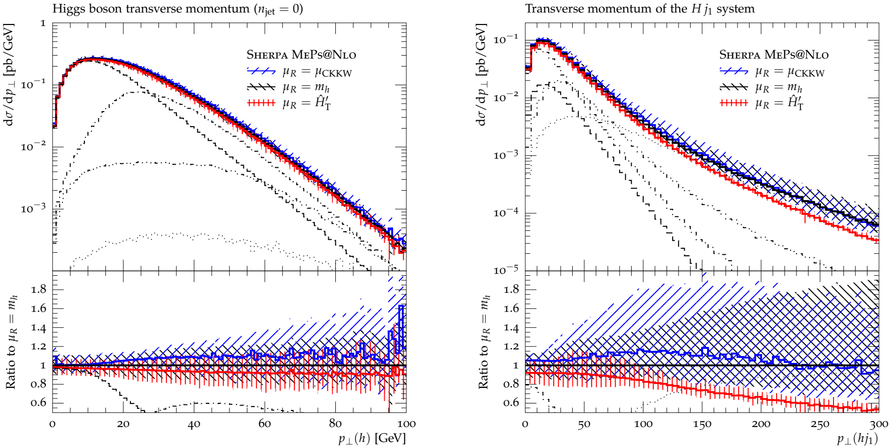
need to include ren. term

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

to restore 1-loop running to $\mu_{\mathrm{CKKW}}$
→ otherwise PS-accuracy violated

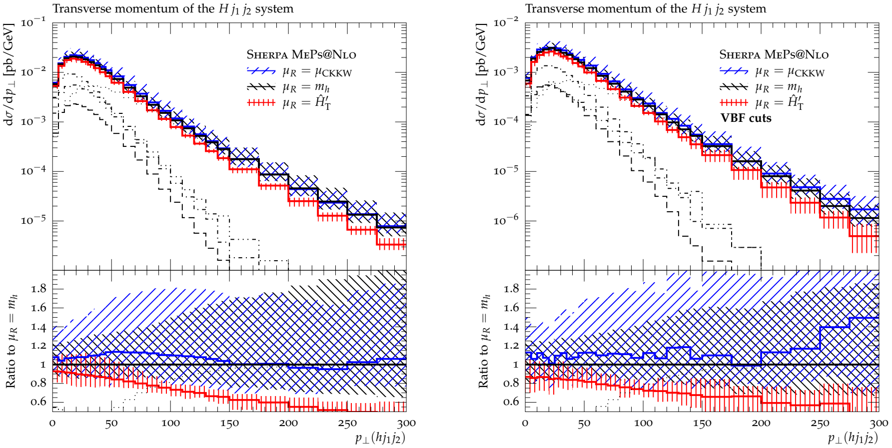
→ same as in UnLoPs approach
Lönnblad, Prestel JHEP03(2013)166
Plätzer JHEP08(2013)114

# Results – pp → h+jets




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

# Results – pp → h+jets

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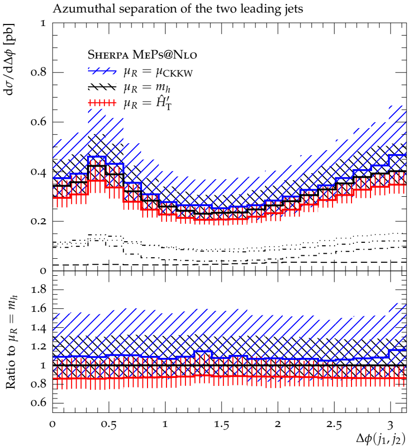


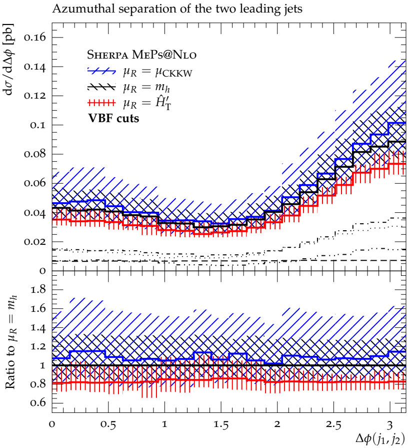


- all predictions identical to MEPS@NLO accuracy
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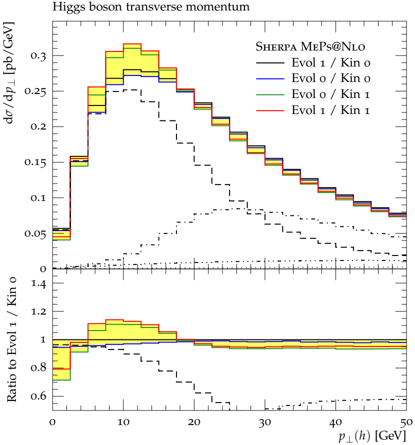
# Results – pp → h+jets




## 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** | $2\,p_ap_j \begin{cases} 1-x_{aj,k} & \text{if } j=g \\ 1 & \text{else} \end{cases}$ |

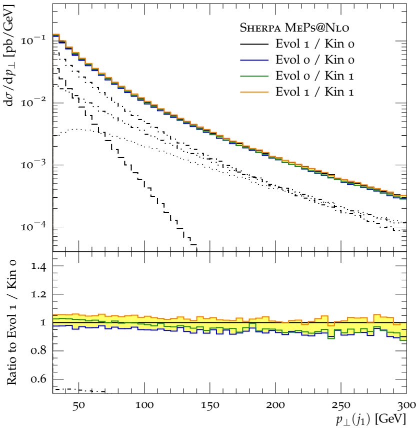
- recoil scheme

**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




## Parton shower uncertainties

- evolution scale

| | Final State |
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| **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** | $2\,p_ap_j\,(1-x_{aj,k})$ |
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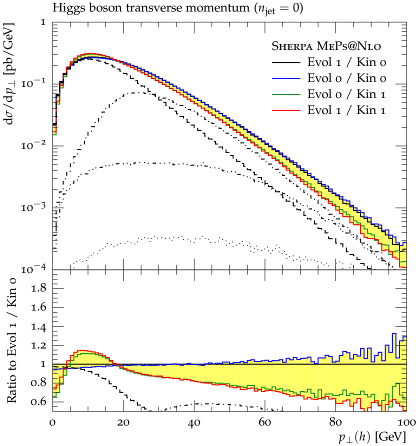


## Parton shower uncertainties

- 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** | $2\,p_a p_j\,(1-x_{aj,k})$ |
| **1** | $2\,p_a p_j \begin{cases} 1-x_{aj,k} & \text{if } j=g \\ 1 & \text{else} \end{cases}$ |

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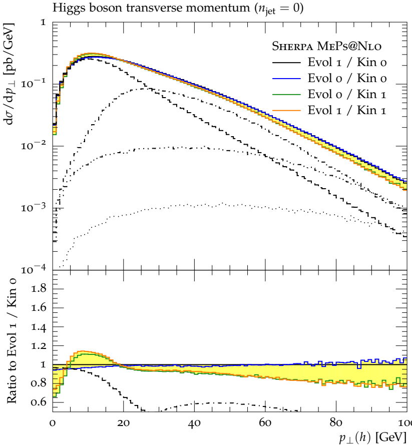


## Parton shower uncertainties

- 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** | $2\,p_ap_j\,(1-x_{aj,k})$ |
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Catani, Seymour Nucl.Phys.B485(1997)291-419

Schumann, Krauss JHEP03(2008)038

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

# Conclusions

- multijet merging at NLO proceeds schematically as at LO
  $\rightarrow$ introduce MC-counterterm to retain NLO accuracy
- preserves NLO accuracy of the ME and accuracy of the PS in resumming hierarchies of emission scales
  $\rightarrow$ scale setting essential for recovering PS resummation
  $\rightarrow$ core scale can be chosen freely
  $\rightarrow$ beyond 1-loop running the scales can of course be freely chosen

current release SHERPA-2.1.1

http://sherpa.hepforge.org

Thank you for your attention!

# MeNloPs

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

- 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 $Q_{\text{cut}}$

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

- iterate

# MENLOPS

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