Parton shower uncertainties

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Reweighting

Parameters

parametric e.g. $\alpha_s(m_Z)$, m_t, PDF

perturbative e.g. NLO, NLL, leading-N_c $\rightarrow$ $\boldsymbol{\mu_R}$, $\boldsymbol{\mu_F}$, $\boldsymbol{\mu_Q}$

algorithmic e.g. evolution variable, recoil schemes, matching scheme

Explicit variations

- can be done for any scale or PDF dependence
- functional form can be changed
- separate run (independent calculation) for every variation

On-the-fly variations Bothmann, MS, Schumann arXiv:1606.08753

- can be done for μ_R, μ_F, α_s & PDF dependence of ME & PS
- functional form can currently not be changed
- full syntax, cf. Manual
```
SCALE_VARIATIONS 0.25,0.25 4.,4.
PDF_VARIATIONS NNPDF30_nnlo_as_0118[all]
```
- store in HepMC weight container using LH'13 naming convention

Reweighting

ME reweighting

- straight forward dependence on μ_R, μ_F, PDF, α_s
- exception: PDF ratios in multijet merging

PS reweighting

$$\mathrm{K}_n(t_2, t_1; k_{\alpha_s}, k_f; \alpha_s, f) = \sum_{ij}\sum_{k} \alpha_s(k_{\alpha_s} t)\, \mathrm{K}'_{ij,k}(t,z)\, \frac{f_{c'}(\frac{\eta_c}{x}, k_f t)}{f_c(\eta_c, k_f t)}$$

- variation $\alpha_s \to \tilde{\alpha}_s$, $f \to \tilde{f}$, $k_{\alpha_s} \to \tilde{k}_{\alpha_s}$ and/or $k_f \to \tilde{k}_f$ gives
  $\to$ probability to accept $P_{\mathrm{acc}} = \frac{\mathrm{K}}{\hat{\mathrm{K}}} \to \tilde{P}_{\mathrm{acc}} = q_{\mathrm{acc}} P_{\mathrm{acc}}$

$$q_{\mathrm{acc}} \equiv \frac{\tilde{\alpha}_s(\tilde{k}_{\alpha_s} t)}{\alpha_s(k_{\alpha_s} t)}\, \frac{\tilde{f}_{c'}(\frac{\eta_c}{x}, \tilde{k}_f t)}{f_{c'}(\frac{\eta_c}{x}, k_f t)}\, \frac{f_c(\eta_c, k_f t)}{\tilde{f}_c(\eta_c, \tilde{k}_f t)}$$

  $\to$ probability to reject $P_{\mathrm{rej}} \to \tilde{P}_{\mathrm{rej}} = q_{\mathrm{rej}} P_{\mathrm{rej}} = 1 - \tilde{P}_{\mathrm{acc}}$

$$q_{\mathrm{rej}} \equiv \left[1 + (1 - q_{\mathrm{acc}})\, \frac{P_{\mathrm{acc}}}{1 - P_{\mathrm{acc}}}\right]$$

- scale compensation terms (LH'13) not included (to aggressive)

Parton shower in single multiplicity

Free choices

- ME scales free μ_R, μ_F
- PS starting scale free μ_Q

Fixed values

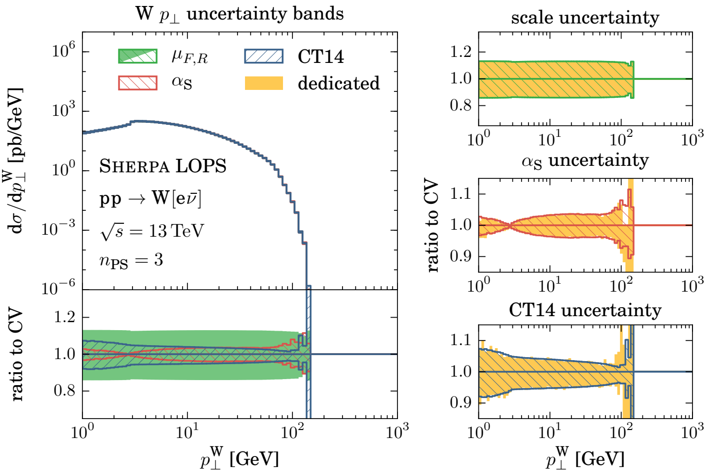
- μ_Q must respect angular ordering wrt. to existing colour lines in the starting configuration, e.g. $\hat{s}$ in dijets is a bad choice
- μ_Q must ensure all radiation is softer than existing colour lines in the starting configuration
- PS α_s argument fixed to CMW considerations
- PS PDF argument should be related to t

NloPs

- consistent evolution between matched emissions and all other emissions
- scales in hard event must not destroy resummation properties

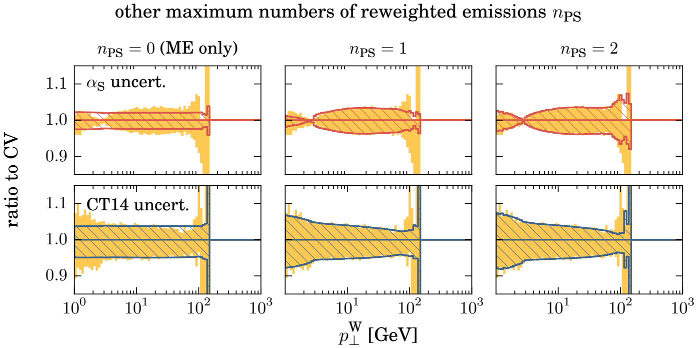
Reweighting – closure test – LoPs

Bothmann,MS,Schumann arXiv:1606.08753



Reweighting – closure test – LoPs

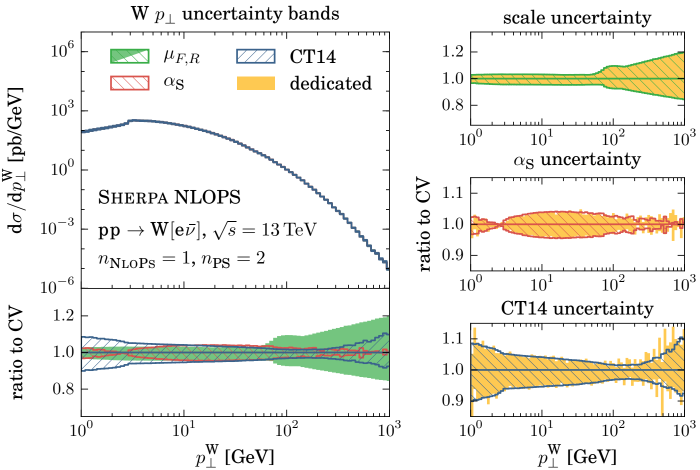
Bothmann,MS,Schumann arXiv:1606.08753



→ reweighting two emission sufficient for this observable

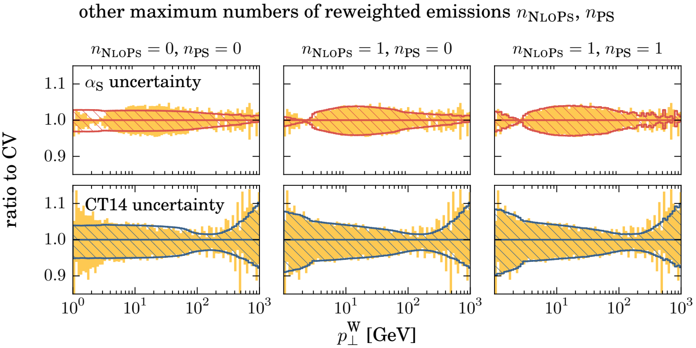
Reweighting – closure test – NLOPS

Bothmann,MS,Schumann arXiv:1606.08753



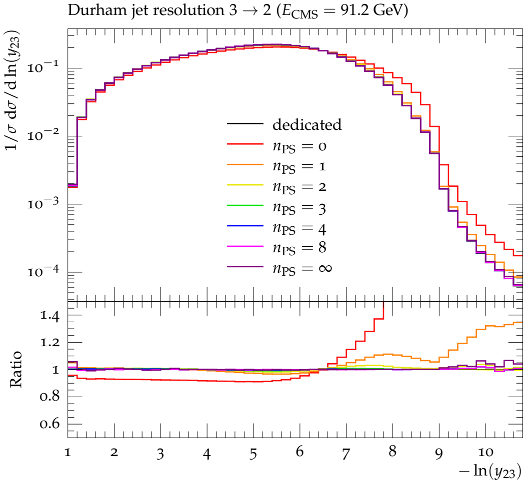
Reweighting – closure test – NLOPS

Bothmann,MS,Schumann arXiv:1606.08753



→ reweighting two emission sufficient for this observable

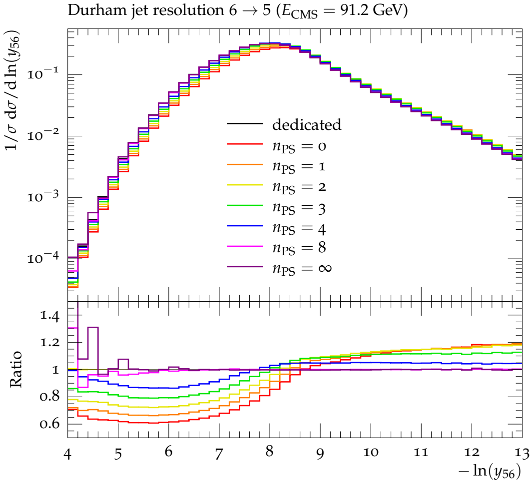
Resummation sensitive observables



closure test with $n_{PS} = 0, 1, 2, 3, 4, 8, \infty$

- $\alpha_s(m_Z) = 0.120$
  $\downarrow$
  $\tilde{\alpha}_s(m_Z) = 0.128$
- n_{PS} needed obs. dependent

Resummation sensitive observables



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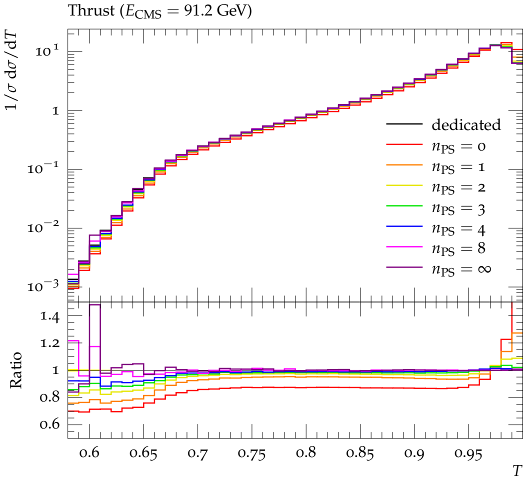
Resummation sensitive observables



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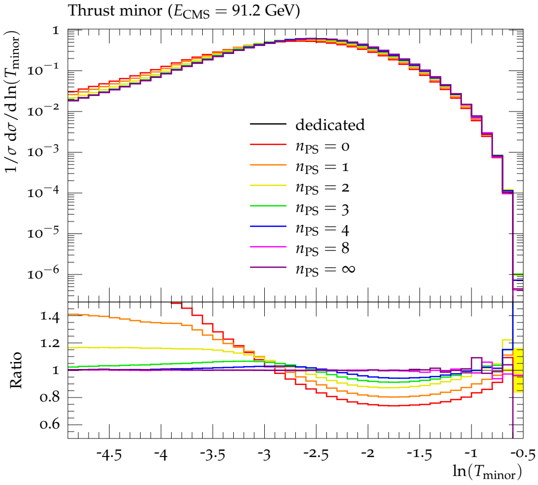
Resummation sensitive observables



closure test with $n_{PS} = 0, 1, 2, 3, 4, 8, \infty$

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- n_{PS} needed obs. dependent

Reweighting in multijet merged calculation

Multijet merging

- separate phase space into two regions
  1) small t, trust PS for emission pattern
  2) large t, replace PS emission pattern by ME

  $\rightarrow$ multijet merging is improvement of PS emission pattern
- higher multi MEs replacing PS need to recover PS resummation
  $\rightarrow$ limits freedom in scale defintions, PDF/α_s parametrisations

$\Rightarrow$ **consistency essential**

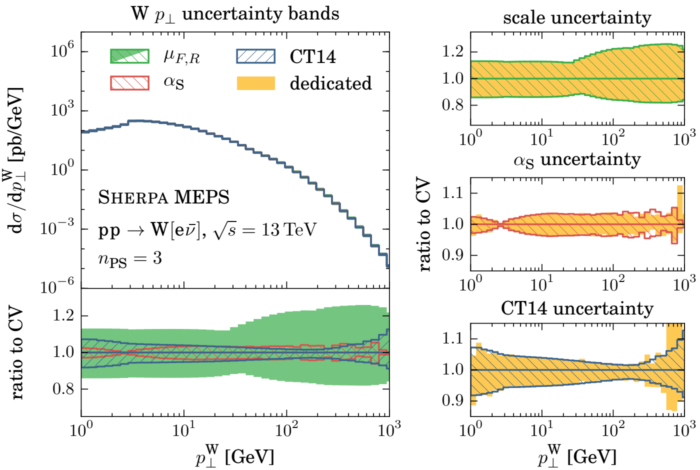
- same scales, same PDF, same α_s in ME and PS

Free choices

- most scales fixed through consistency with parton shower
- freedom in core: $\mu_{R,\text{core}}$, $\mu_{F,\text{core}}$, μ_Q
- freedom in $\mathbb{H}$-events: μ_R, μ_F
- freedom in unordered configurations
- some freedom in Q_cut

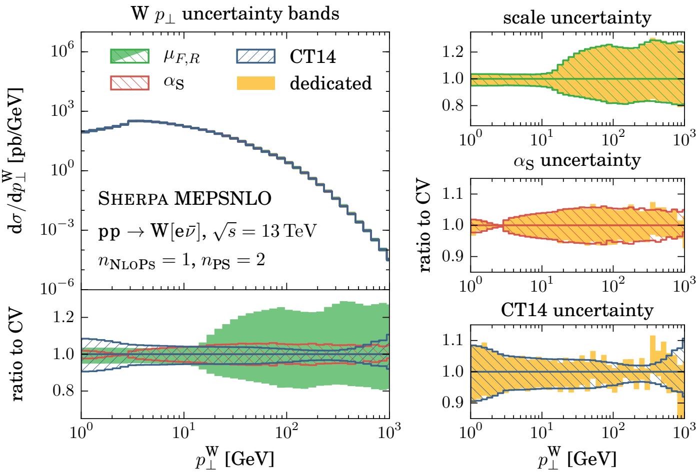
Reweighting – closure test – MEPs

Bothmann, MS, Schumann arXiv:1606.08753



Reweighting – closure test – MEPS@NLO

Bothmann, MS, Schumann arXiv:1606.08753



Timings in $pp \to \ell^+\ell^- + \leq$ 4jets MEPs (LO) – ME only

weighted events

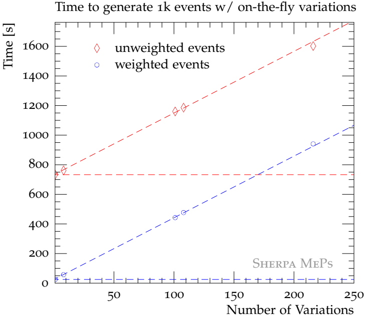
- low baseline per event timing (25s/1k)
- constant offset per computed variation

⇒ 217 vars. → factor 38

(partially) unweighted events

- high baseline per event timing (730s/1k)
- constant offset per computed variation

⇒ 217 vars. → factor 2.2

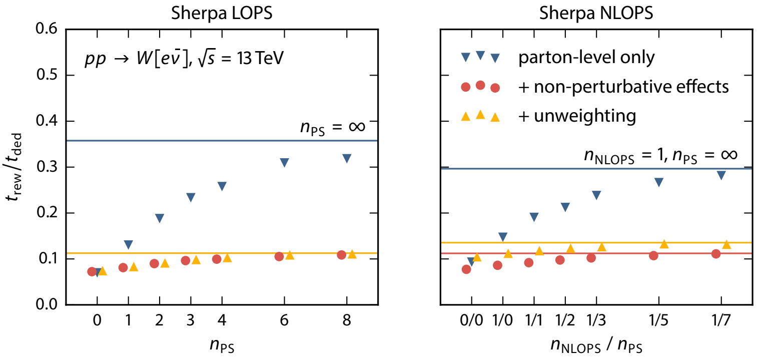


$\mu_{R\|F}$	→	7
PDF (NNPDF30)	→	100
$\mu_{R\|F}$+PDF	→	107
PDF4LHC (old)	→	217

→ time to compute variations independent of event generation mode

⇒ **huge gain for standard (partially) unweighted events**

Timings of parton shower reweightings



- timings independent of weighting/unweighting
- when reweighting the complete evolution 10% gain
  → but spread of weights

SHERPA-2.2.3

- On-the-fly variations for
  - renormalisation and factorisation scales in ME
  - PDF and $\alpha(m_Z)$ parametrisation in ME

  available since SHERPA-2.2.0
- On-the-fly variations for
  - renormalisation and factorisation scales in PS
  - PDF and $\alpha(m_Z)$ parametrisation in PS

  in experimental state available since SHERPA-2.2.1
  (full in SHERPA-2.3.0)
- PS variation is costly due to recalculation of all acceptance and rejection probabilities, cap at $n_{\text{PS}} = 2$ emissions
  beware resummation sensitive observables
- neither HEPMC-2.06 nor HEPMC-3 fully support this
  (only one cross section object, etc.)

http://sherpa.hepforge.org

Thank you for your attention!

Fixed-order variations

- LO trivial

$$\langle O\rangle^{\mathsf{LO}} = \int \mathrm{d}\Phi_B\, \mathrm{B}(\Phi_B)\, O(\Phi_B)$$

- NLO, work in CS subtraction, independent of loop generator

- book-keep 18 weight components (2 VI, 16 KP)
  R and each D_S transform same as B

Fixed-order variations

- LO trivial

$$\mathrm{B}(\Phi_B) \;=\; \alpha_s^n(\mu_R^2)\, f_a(x_a,\mu_F^2)\, f_b(x_b,\mu_F^2)\, \mathrm{B}'(\Phi_B)$$

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- NLO, work in CS subtraction, independent of loop generator

$$\langle O\rangle^{\text{NLO}} = \int \mathrm{d}\Phi_B \left[\mathrm{B}(\Phi_B) + \mathrm{VI}(\Phi_B) + \int \mathrm{d}x'_{a/b}\, \mathrm{KP}(\Phi_B, x'_{a/b})\right] O(\Phi_B) + \int \mathrm{d}\Phi_R \left[\mathrm{R}(\Phi_R)\, O(\Phi_R) - \sum_j \mathrm{D}_{S,j}(\Phi_{B,j}\cdot\Phi_1^j)\, O(\Phi_{B,j})\right]$$

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Fixed-order variations

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- NLO, work in CS subtraction, independent of loop generator

$l_R = \log(\mu_R^2/\tilde{\mu}_{R,\mathrm{ref}}^2)$

$$\mathrm{VI}(\Phi_B) = \alpha_s^{n+1}(\mu_R^2)\, f_a(x_a,\mu_F^2)\, f_b(x_b,\mu_F^2)\left[\mathrm{VI}'(\Phi_B) + c_R'^{(0)} l_R + \tfrac{1}{2}\, c_R'^{(1)} l_R^2\right]$$

- book-keep 18 weight components (2 VI, 16 KP)
  R and each D_S transform same as B

Fixed-order variations

- LO trivial

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$$\begin{aligned}\mathrm{KP}(\Phi_B,x'_{a/b}) = \alpha_s^{n+1}(\mu_R^2)\Big[&\Big(f_a^q c_{F,a}'^{(0)} + f_a^q(x'_a)\, c_{F,a}'^{(1)} + f_a^g c_{F,a}'^{(2)} + f_a^g(x'_a)\, c_{F,a}'^{(3)}\Big) f_b(x_b,\mu_F^2)\\ &+ f_a(x_a,\mu_F^2)\Big(f_b^q c_{F,b}'^{(0)} + f_b^q(x'_b)\, c_{F,b}'^{(1)} + f_b^g c_{F,b}'^{(2)} + f_b^g(x'_b)\, c_{F,b}'^{(3)}\Big)\Big]\end{aligned}$$

$$c_{F,a/b}'^{(i)} = \tilde{c}_{F,a/b}^{(i)} + \bar{c}_{F,a/b}^{(i)}\, l_F$$

$l_F = \log(\mu_F^2/\tilde{\mu}_{F,\text{ref}}^2)$

- book-keep 18 weight components (2 VI, 16 KP)
  R and each D_S transform same as B
  same as used in Sherpa NTuples

Q_{cut} dependence of TeV-scale observables