SHERPA – 2.2.3

Status and Prospects

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Universität Zürich

CERN 02 May 2017

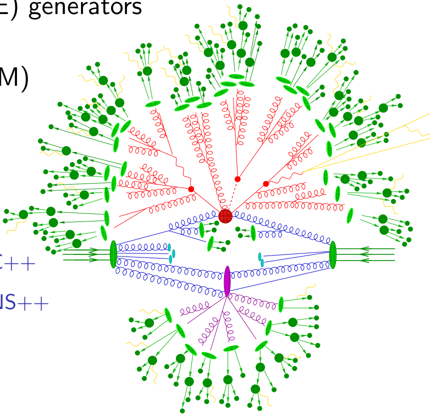
Outline

SHERPA–2.2.3

The SHERPA event generator framework

JHEP02(2009)007

- Two multi-purpose Matrix Element (ME) generators
  AMEGIC++, COMIX
- A hard decays module (W, Z, h, t, BSM)
- Two Parton Shower (PS) generators
  CSSHOWER, DIRE
- A multiple interaction simulation
  à la PYTHIA AMISIC++
- A cluster fragmentation module AHADIC++
- A hadron and τ decay package HADRONS++
- A higher order QED generator using
  YFS-resummation PHOTONS++
- A minimum bias simulation SHRiMPS



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

LO, NLO, NNLO, LOPS, NLOPS, **NNLOPS**, MEPS, MENLOPS, **MEPS@NLO**

Acronyms and nomenclature

Fixed order calculations

- matrix elements only, implies fixed multiplicities
- no parton shower, no non-perturbative physics, no particle level

⇒ LO, NLO, NNLO

Parton shower matched calculations

- combination of fixed order calculation and parton shower for one multiplicity
- particle level predictions, no multijet observables

⇒ LoPs, NloPs, **NnloPs**

Multijet merged calculations

- combination of parton shower matched calculations for increasing final state multiplicities (mostly jets)
- particle level predictions, multijet observables

⇒ MePs(@LO), **MePs@Nlo** (special case MeNloPs)

SHERPA-2.2.3 – (not necessarily new) features

- SHERPA-2.2.3 released Apr '17
- contains bugfixes for all known bugs up to SHERPA-2.2.2
- `UFO` support for BSM physics
- new parton shower DIRE in addition to CSSHOWER
- one-loop matrix elements are interfaced from external codes: BLACKHAT, OPENLOOPS, GOSAM, RECOLA, ...
- on-the-fly scale and PDF variations for ME part in
  - LO, NLO
  - LOPS, NLOPS (S-MC@NLO)
  - MEPS, MENLOPS, MEPS@NLO

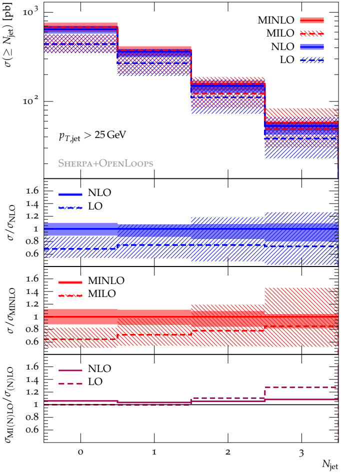
  → use named weights in HEPMC (av. since HEPMC-2.06)
- full scale & PDF variations including parton shower and for NNLO/NNLOPS in SHERPA-2.3.0
- allow to force HEPMC event record into pure tree structure, lost information available through disconnected vertices
- new default PDF: `NNPDF30_nnlo_as_0118` → new tune

SHERPA–2.2.3

NLO QCD calculations – $pp \to t\bar{t} + 3$jets

Höche, Maierhöfer, Moretti, Pozzorini, Siegert arXiv:1607.06934

- First computation of $t\bar{t}$+3 jets at NLO / MiNLO accuracy
- Sherpa NLO MC framework using Comix Gleisberg,Höche arXiv:0808.3674 combined with OpenLoops Cascioli,Maierhöfer,Pozzorini arXiv:1111.5206
- Public results in NTuple format à la BlackHat collaboration arXiv:1310.7439 for easy analysis & recycling available at NERSC (login req'd)
- Scale dependence studied using $H_{T,m} = \sum m_\perp$ and MiNLO Hamilton,Nason,Zanderighi arXiv:1206.3572 extended to massive partons



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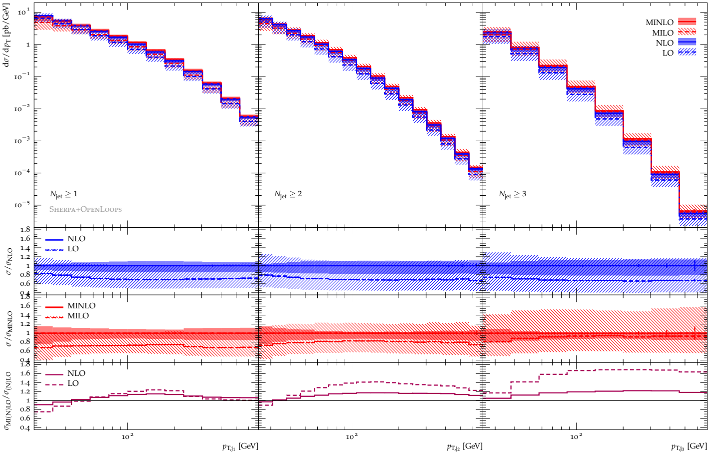


- Inclusive jet-p_T spectra

Higgs physics I

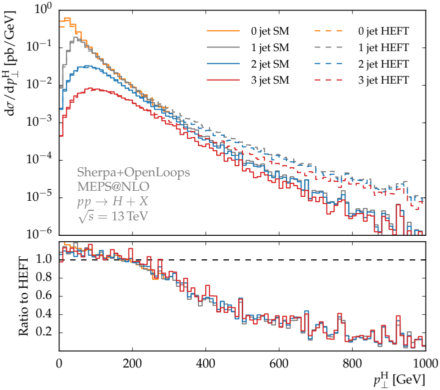
Buschmann, Goncalves, Kuttimalai, MS, Krauss, Plehn JHEP02(2015)038
Kuttimalai, Krauss, Maierhöfer, MS LH'15, LHC HXSWG YR4

$pp \to H +$ jets production (ggF)

- correction factor/weight

$$r_t^{(n)} = \frac{|\mathcal{M}^{(n)}(m_t)|^2}{|\mathcal{M}^{(n)}(m_t \to \infty)|^2}$$

- loops from OpenLoops
- construct MEPs@NLO from reweighted S-MC@NLO
- factorised approach for unknown top mass dependence in V_n, otherwise exact NLO mass dependence



$$\mathrm{d}\sigma_n = \mathrm{d}\Phi_n\, r_t^{(n)} \left[\mathrm{B}_n + \mathrm{V}_n + \int \mathrm{d}\Phi_1\, \mathrm{D}_n\right] \widetilde{\mathrm{PS}}_n + \mathrm{d}\Phi_{n+1} \left[r_t^{(n+1)}\mathrm{R}_n - r_t^{(n)}\mathrm{D}_n\right]$$

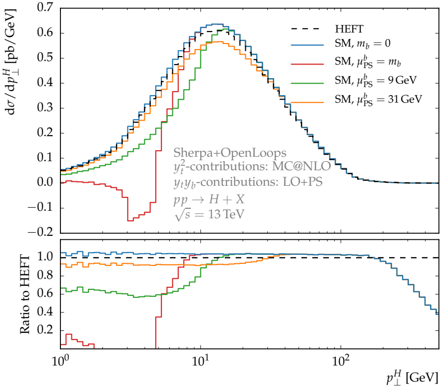
Higgs physics I

Kuttimalai, Krauss, Maierhöfer, MS LH'15, LHC HXSWG YR4

$pp \to H +$ jets production (ggF)

- no reweighted MEPS@NLO for m_b-dep components as
$$\mathrm{V} = \frac{\mathrm{B}}{\mathrm{B}_{\text{HEFT}}}\,\mathrm{V}_{\text{HEFT}}$$
not a good approximation
- LOPS leeds to huge variation when varying starting scale as argued in the literature

  Bagnaschi et.al. JHEP01(2016)090
- MEPS allows to leave starting scale, resummation scale at high value when setting the $Q_{\text{cut}} \sim m_b \Rightarrow$ **small variation**



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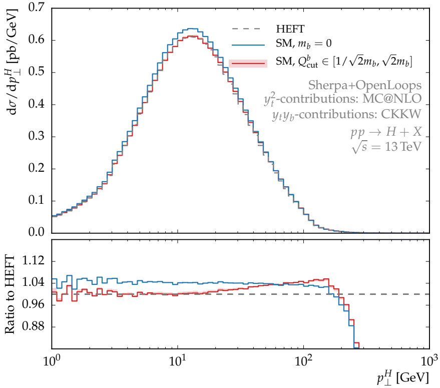
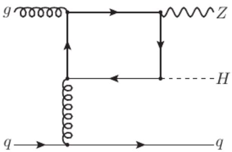


Higgs physics II

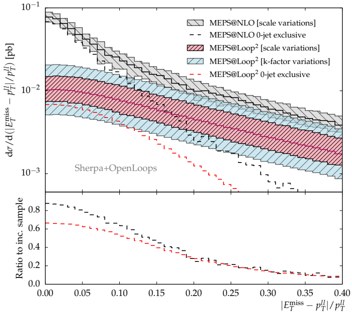
Goncalves, Krauss, Kuttimalai, Maierhöfer PRD92(2015)7,073006

$pp \to Z\,H$ + jets production

- MEPS@NLO for $q\bar{q}$
  MEPS@LOOP^2 for gg
- care for $qg \to ZHq$:



  $\to$ part of NLO ZHj
  $\to$ in loop-induced as gauge inv. subset of NNLO ZHj
- loops from OPENLOOPS



$pp \to Z[\to \ell\ell\,]H[\to \text{inv}]$ + jets

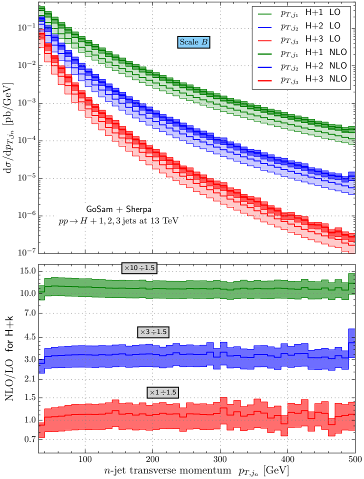
Higgs physics III

Greiner, Höche, Lu

Greiner, Höche, Lui

$pp \to H +$ jets in ggF (HEFT)

- public NTuples for h1j, h2j, h3j @ NLO
  $\to$ fixed-order analysis
  GoSam interfaced for virtuals
- MEPs@NLO preliminary
  $pp \to h + 0, 1, 2, 3j$ @ NLO,
  $4, 5j$ @ LO
  produced for Les Houches '15
  detailed comparison



Higgs physics III

Greiner, Höche, Luisoni, MS, Winter, Yundin JHEP01(2016)169
Greiner, Höche, Luisoni, MS, Winter for LH'15 arXiv:1609:04692

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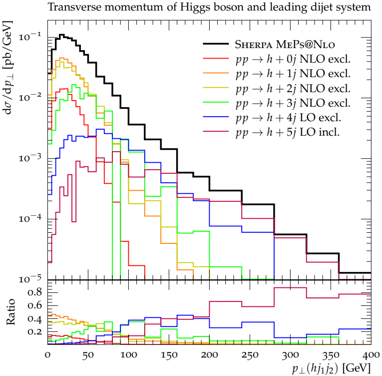


Inclusive photon and diphoton production

Siegert J.Phys.G44(2017)044007
ATLAS STDM-2015-15

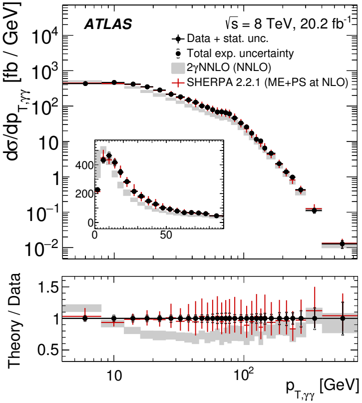
$pp \to \gamma +$ jets

- $pp \to \gamma + 1, 2j$ @ NLO, $3, 4j$ @ LO

$pp \to \gamma\gamma +$ jets

- $pp \to \gamma\gamma + 0, 1j$ @ NLO, $2, 3j$ @ LO

⇒ details in F. Siegert's talk on Thursday



Electroweak corrections in particle-level event generation

- incorporate approximate electroweak corrections in SHERPA's NLO QCD multijet merging (MEPS@NLO)
- modify MC@NLO $\overline{\mathrm{B}}$-function to include NLO EW virtual corrections and integrated approx. real corrections

$$\overline{\mathrm{B}}_{n,\mathrm{QCD+EW_{virt}}}(\Phi_n) = \overline{\mathrm{B}}_{n,\mathrm{QCD}}(\Phi_n) + \mathrm{V}_{n,\mathrm{EW}}(\Phi_n) + \mathrm{I}_{n,\mathrm{EW}}(\Phi_n) + \mathrm{B}_{n,\mathrm{mix}}(\Phi_n)$$

- real QED radiation can be recovered through standard tools (parton shower, YFS resummation)
- simple stand-in for proper QCD+EW matching and merging

⇒ **more details in tomorrow's talk**

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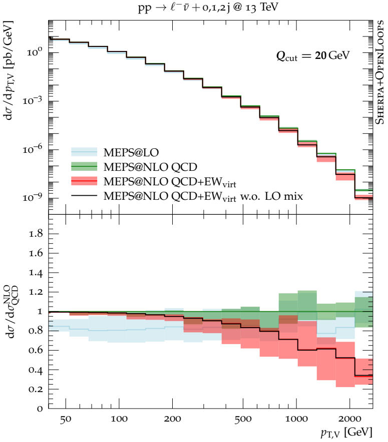
$pp \to \ell^- \bar{\nu} + \text{jets}$

Kallweit,Lindert,Maierhöfer,Pozzorini,MS JHEP04(2016)021



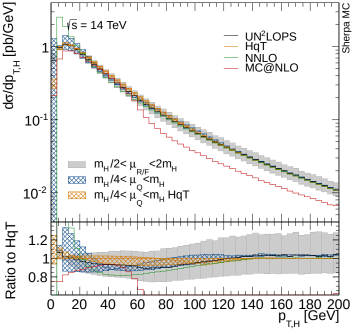
$\Rightarrow$ particle level events including dominant EW corrections

NNLOPs for $pp \to h/W/Z$

Höche, Li, Prestel arXiv:1405.3607, arXiv:1407.3773

- matching NNLO calculation to PS using UN²LOPs scheme basing on $pp \to X + j$ S-MC@NLO and q_T-sub.
- no reweighting
- $q_T = 0$ bin collects all unitarisation effects

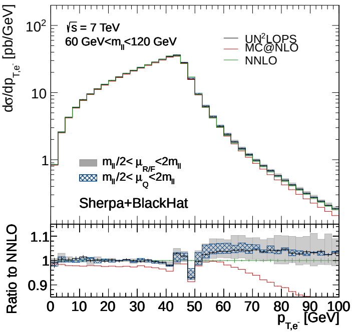
⇒ **more details in tomorrow's talk**



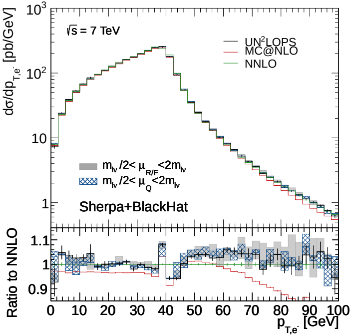
$pp \to H$

NNLOPs for $pp \to h/W/Z$

Höche, Li, Prestel arXiv:1405.3607, arXiv:1407.3773



$pp \to \ell\ell$



$pp \to \ell\nu$

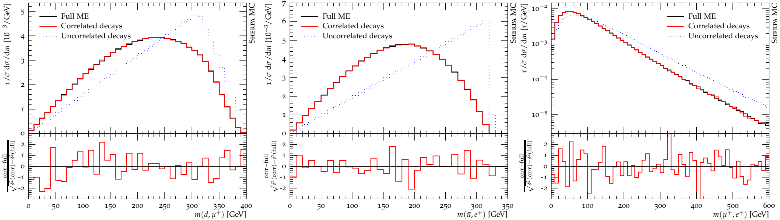
BSM physics

Höche,Kuttimalai,Schumann,Siegert EPJC75(2015)3,135

- full support for UFO model Degrande et.al. CPC183(2012)1201
- Lorentz structures automatically built,
  colour structures mapped on SM/MSSM-like
- automatic identification of all 1→2 and 1→3 decay channels of every unstable particle in the model
  → calculation of all decay widths (LO)
- per default all decay channel used
  → inclusive production
  → mechanism to select individual channels,
  cross section optionally adjusted accordingly
- spin-correlated decay chains of arbitrary length
  using spin density matrices Richardson JHEP11(2001)029,
  Knowles CPC58(1990)271

BSM physics

Höche,Kuttimalai,Schumann,Siegert EPJC75(2015)3,135



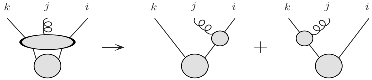
- simple three-step example:
  $pp \to \tilde{u}[\to d\chi_1^+[\to \chi_1^0 W^+[\to \mu^+\nu_\mu]]]\ \tilde{u}^*[\to \bar{u}\chi_2^0[\to e^+\tilde{e}^-[\to e^-\chi_1^0]]]$
- use truncated showers for QCD radiation off intermediate particles
- QED correction for each decay in YFS soft-photon resummation

Parton showers – DIRE

Höche, Prestel EPJC75(2015)461

- combination of parton and dipole shower picture
  → partial fractioning soft eikonal   Catani, Seymour Nucl.Phys.B485(1997)291

$$\frac{p_i p_k}{(p_i p_j)(p_j p_k)} \to \frac{1}{p_i p_j}\frac{p_i p_k}{(p_i + p_k) p_j} + \frac{1}{p_k p_j}\frac{p_i p_k}{(p_i + p_k) p_j}$$



⇒ disentangles soft and coll. limits, allows for systematic improvs.

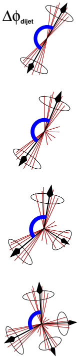
- analytically integrable ⇒ allows comparison to dedicated calcs.
- recovers momentum and flavour sum rules
- recovers anomalous dimensions

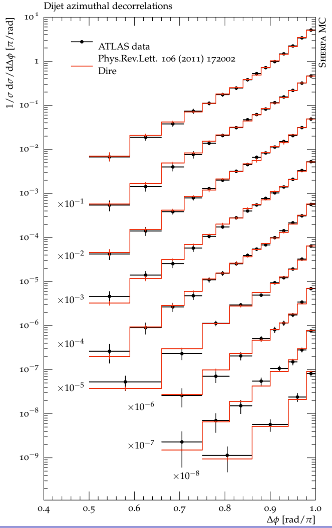
⇒ cannot be used in NLO matching and merging yet

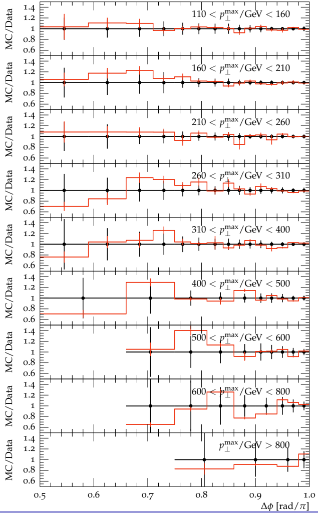
⇒ base design towards higher precision parton showering

Parton showers – DIRE

Höche, Prestel EPJC75(2015)461







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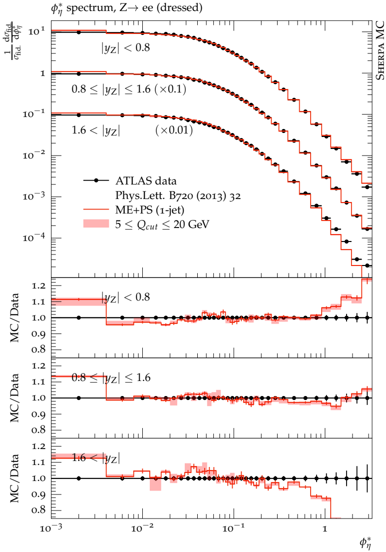
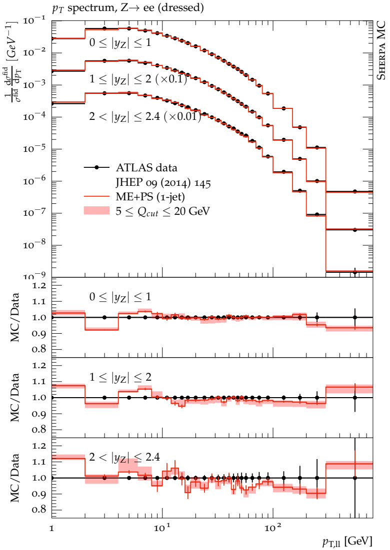
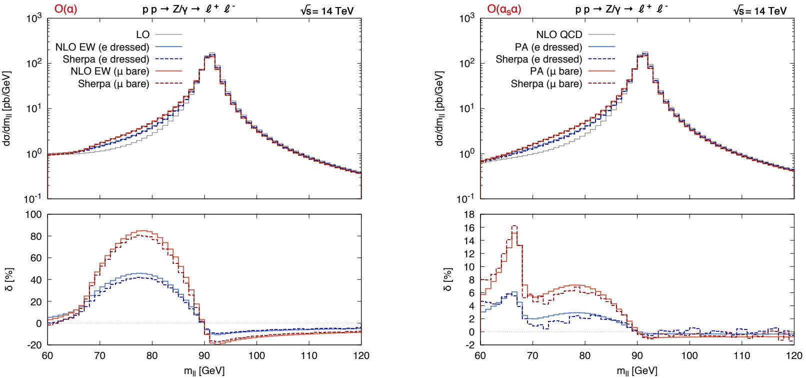




YFS – comparison against dedicated calculations

Huss, MS for LH'15 arXiv:1605.04692

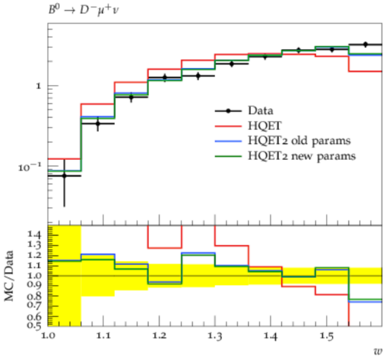


- compare against pole approximation NNLO $\mathcal{O}(\alpha_s\alpha)$

  Dittmaier,Huss,Schwinn Nucl.Phys.B904(2016)216
- very good reproduction of $\mathcal{O}(\alpha)$ and $\mathcal{O}(\alpha_s\alpha)$
- major differences traced to multi-photon emissions in YFS

Hadronisation and hadron decays

- includes ~2000 hadron and τ decay channels
- updated many form factor models and parametrisations
- included new parameter fits
- added sophistication for heavy baryons Λ_b, Ξ_b, etc.
- QED corrections provided through YFS soft-photon resummation



SHERPA-2.2.3

Reweighting

Parameters

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

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

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

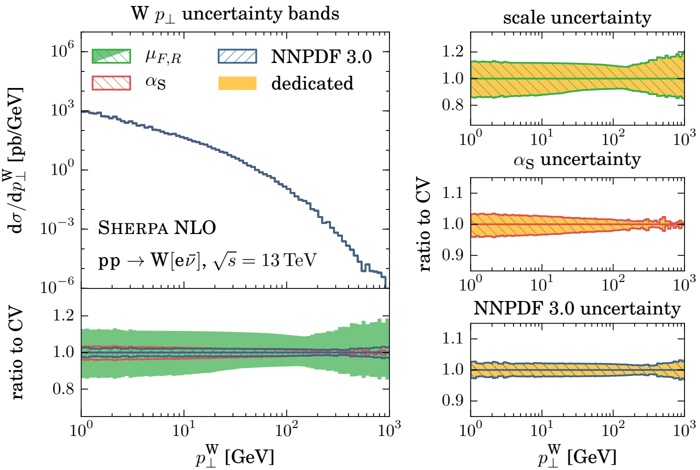
- can be done for μ_R, μ_F, α_s & PDF dependence of ME & PS
- functional form can currently not be changed
- full syntax, cf. Manual

```
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

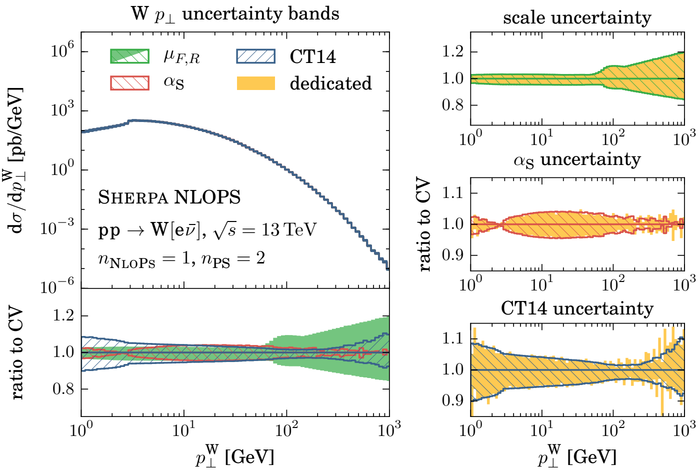
Reweighting – closure test – NLO

Bothmann,MS,Schumann arXiv:1606.08753



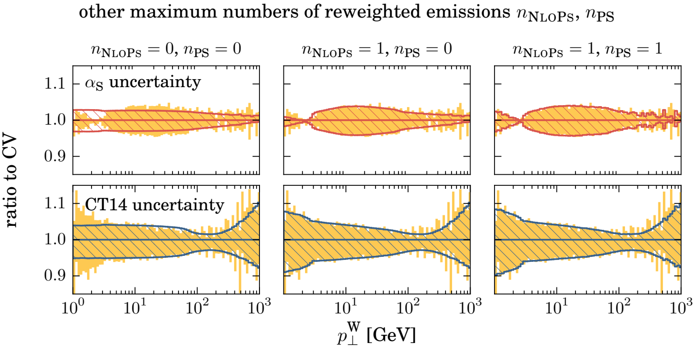
Reweighting – closure test – NLOPS

Bothmann,MS,Schumann arXiv:1606.08753



Reweighting – closure test – NLOPs

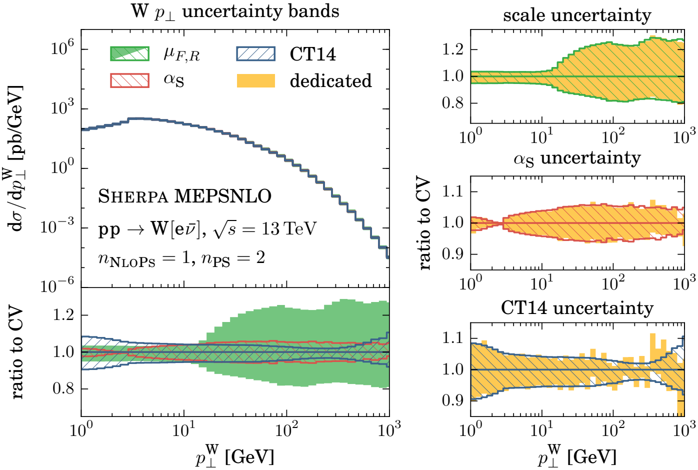
Bothmann,MS,Schumann arXiv:1606.08753



→ reweighting two emission sufficient for this observable

Reweighting – closure test – MEPS@NLO

Bothmann, MS, Schumann arXiv:1606.08753



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

weighted events

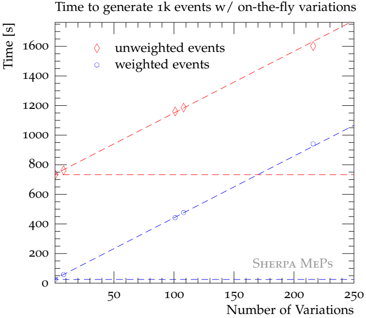
- low baseline per event timing (25s/1k)
- constant offset per computed variation

⇒ 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**

SHERPA-2.2.3

- a new parton shower DIRE
- vastly extended support for UFO BSM format
- multijet merging for loop induced processes further tested, use as:
  - MEPS@LOOP^2
  - reweight MEPS@NLO Higgs production in HEFT with top mass dependence (approximate in virtual corrections only)
- on-the-fly variations of μ_R, μ_F, α_s and PDF for
  - LO, NLO
  - LOPS, NLOPS (S-MC@NLO), NNLOPS through plugin
  - MEPS, MENLOPS, MEPS@NLO
- NLO QCD MEPS@NLO with approx. NLO EW corrections
- default PDF: `NNPDF30_nnlo_as_0118` including corresponding tune of non-perturbative parameters
- new interface to RECOLA for one-loop amplitudes
- **coming in SHERPA-2.3.0:** PS reweighting, full NLO EW, ...

http://sherpa.hepforge.org

Thank you for your attention!