Drell–Yan in SHERPA

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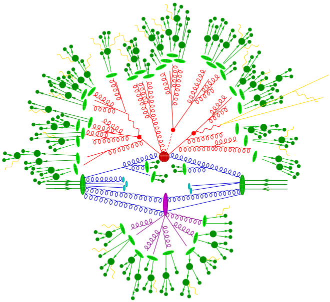
SHERPA



- latest release SHERPA-2.2.10
- includes
  - two matrix element generators
  - two parton showers
  - soft-photon resummation
  - multi-parton interactions
  - hadronisation
  - hadron decays
- typical setup for $V+$ jets

  $\mathrm{pp}\to\ell^+\ell^-+0,1,2j$@NLO QCD+EW$_{\text{approx}}+3,4j$@LO

  including resummed final-state QED corrections in the YFS soft-photon resummation scheme

EW corrections

Kallweit, Lindert, Maierhöfer, Pozzorini, MS arXiv:1511.08692

Approximate EW corrections / $\mathbf{EW_{virt}}$ approximation

- incorporate approximate electroweak corrections in SHERPA's NLO QCD multijet merging (MEPS@NLO)
- taylored to large-p_T regions where EW corrections dominated by virtual W/Z exchange and RG running
- modify MC@NLO $\overline{\mathrm{B}}$-function to include NLO EW virtual corrections

optionally include subleading Born

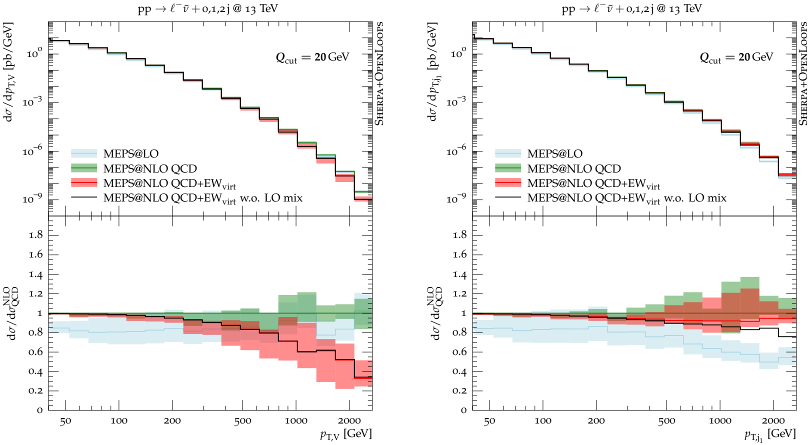
$$\overline{\mathrm{B}}_{n,\mathrm{QCD+EW_{virt}}}(\Phi_n) = \overline{\mathrm{B}}_{n,\mathrm{QCD}}(\Phi_n) + \mathrm{V}_{n,\mathrm{EW}}(\Phi_n) + \mathrm{I}_{n,\mathrm{EW}}(\Phi_n) + \mathrm{B}_{n,\mathrm{sub}}(\Phi_n)$$

exact virtual contribution

approximate integrated real contribution

- real QED radiation can be recovered through YFS resummation
- simple stand-in for proper QCD+EW matching and merging

EW corrections



$\Rightarrow$ particle level events including dominant EW corrections

EW corrections

- approx. EW corrections in EW_{virt} scheme available as alternative event weights (same as scale and PDF variations)
  - separately for EW, EW+subLO, EW+subLO+subLO2, ...
- calculated in three schemes
  - additive

$$\overline{\mathrm{B}}_n^{\text{QCD+EW}} = \overline{\mathrm{B}}_n^{\text{QCD}} + \mathrm{B}_n\,\delta_{\text{EW}}^{\text{approx}} + \mathrm{B}_n^{\text{sub}}$$

  - multiplicative

$$\overline{\mathrm{B}}_n^{\text{QCD}\times\text{EW}} = \overline{\mathrm{B}}_n^{\text{QCD}}\,(1+\delta_{\text{EW}}^{\text{approx}}) + \mathrm{B}_n^{\text{sub}}$$

  - exponentiated (caution: only Sudakov logs exponentiate, not complete EW_{virt})

$$\overline{\mathrm{B}}_n^{\text{QCD}\times\text{EW exp}} = \overline{\mathrm{B}}_n^{\text{QCD}}\,\exp\left(\delta_{\text{EW}}^{\text{approx}}\right) + \mathrm{B}_n^{\text{sub}}$$

not the same as fixed-order multiplicative scheme

EW corrections

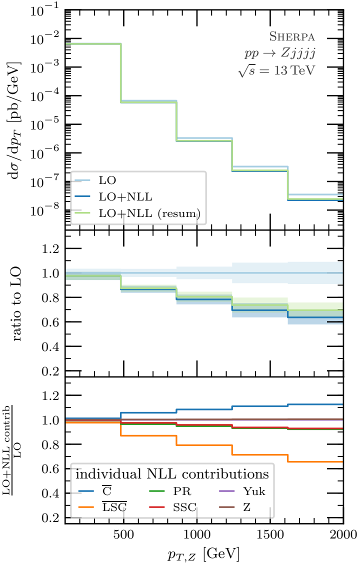
Upcoming in SHERPA-3.0.0

- fixed-order NLO EW

  MS arXiv:1712.07975

- EW Sudakov approximation for parton showered event generation

  Bothmann, Napoletano arXiv:2006.14635



EW clustering

In the interpretation of a $Z+$ jets configuration allow for the possibility that this signature was produced by dijet configuration radiating a Z boson.

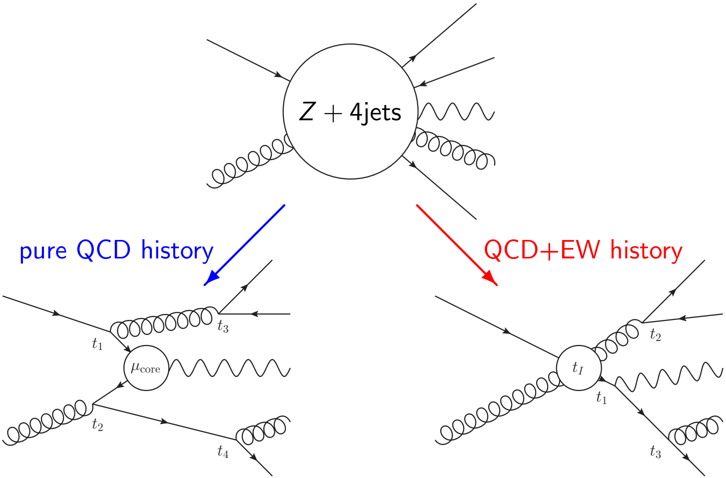
- identify parton shower history to determine CKKW scales and calculate intermediate Sudakov factors

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

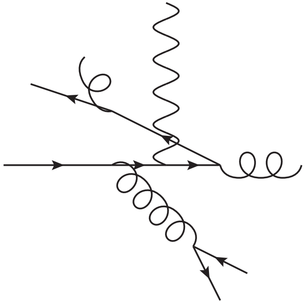
- identifying an EW splitting will "simply skip a step",
  α taken as constant (as in ME), no EW Sudakov applied
- use spin averaged EW splitting functions in $E \gg m$ limit

This affects scale choices, no higher-order EW corrs. introduced.

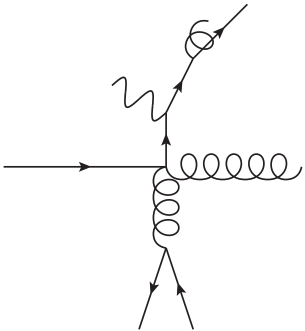
Multijet merging – identifying a history



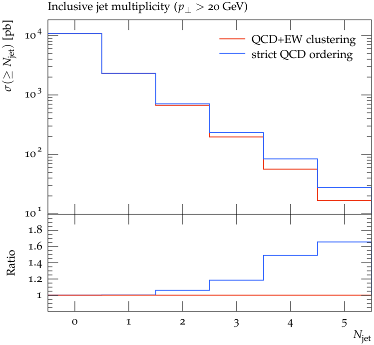
QCD multijet merging – identifying a history

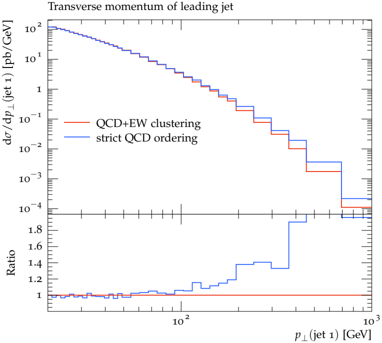


vs.



Importance of electroweak clustering

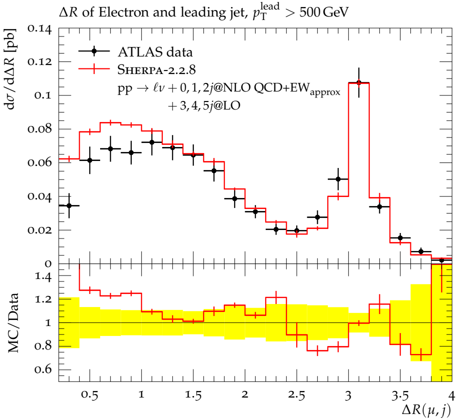


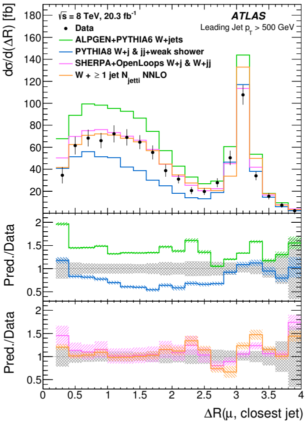


$\Rightarrow$ large impact at high $p_\perp$ and multiplicity

EW clustering

ATLAS arXiv:1609.07045





Electroweak input schemes

For computing reasons, LHC collaborations need need $Z+$jets samples that are useful (properly describe) **all** possible observables

- EW precision measurements (A_i, $\sin\theta$, A_{FB}, …)
- $p_{\mathrm{T}}(\ell\ell)$
- underlying event in DY
- jet properties
- TeV-scale searches/measurements (DM backgrounds)
- *Vjj* properties (VBF-Z backgrounds)
- τ spin correlations in $Z\to\tau\tau$ (strongly dependent on $\sin\theta$)

⋮

Necessitates an input scheme that contains m_Z and $\sin\theta$ and is consistent at NLO EW.

Electroweak input schemes

Historically used inconsistent EW input scheme to have both m_Z and $\sin\theta$ at their measured values.
Fine at LO EW, impossible if higher-order EW effects are to be included.

$\boldsymbol{G_\mu}$ and $\boldsymbol{\alpha(m_Z)}$ schemes have m_Z as input, but value of $\sin\theta$ is off.

New input schemes with m_Z and $\sin\theta$ implemented in SHERPA-2.2.10.

21	input $(G_F, m_Z, \Gamma_Z, \sin\theta)$,	derived $(\alpha, m_W, \Gamma_W, \text{vev})$
22	input $(\alpha(m_Z), m_Z, \Gamma_Z, \sin\theta)$,	derived $(m_W, \Gamma_W, \text{vev})$

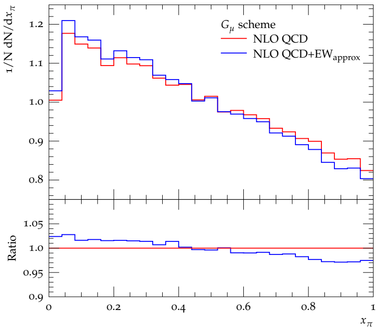
Schemes 21 and 22 also implemented by OpenLoops including appropriate renormalisation Chiesa, Piccinini, Vicini arXiv:1906.11569

$\Rightarrow$ they can be used to include approximate EW corrections in a sample

Impact of EW parameters – τ polarisation

In a consistent setup, having $\sin\theta$ as a dependent parameter may have unintended consequences, eg. τ spin correlations in $Z \to \tau\tau$ events.

Problem not apparent when using `Tool1` for ME, `Tool2` for PS, `Tool3` for τ decays as EW parameters typically not synchronised.



Using scheme with $\sin\theta$ as input fixes this issue.

QED corrections

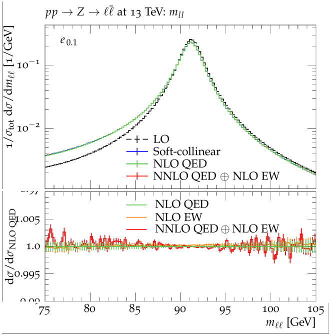
Sherpa employs a soft-photon resummation in the YFS scheme for higher-order QED corrections

up to SHERPA-2.2.10

- YFS ⊗ NLO QED

Upcoming in SHERPA-3.0.0

- YFS ⊗ NNLO QED + NLO EW



Krauss, Lindert, Linten, MS arXiv:1809.10650

Conclusions

- SHERPA-2.2.10 state-of-the-art all-round sample including
  - QCD multijet merging
  - approx. EW corrections taylored to TeV regime (no accuracy for incl. observables)
  - QCD+EW interpretation of multijet final states
  - parton shower QCD resummation
  - YFS soft-photon resummation w/ NLO QED corrections
  - suitable EW input schemes for DY precision observables
- currently most higher-order EW corrections included targeted to TeV scale physics, with the exception of soft-photon resummation
- many other features: elastic photon-induced procs. in EPA, ...
- additional features in upcoming SHERPA-3.0.0

https://sherpa-team.gitlab.io

Backup