

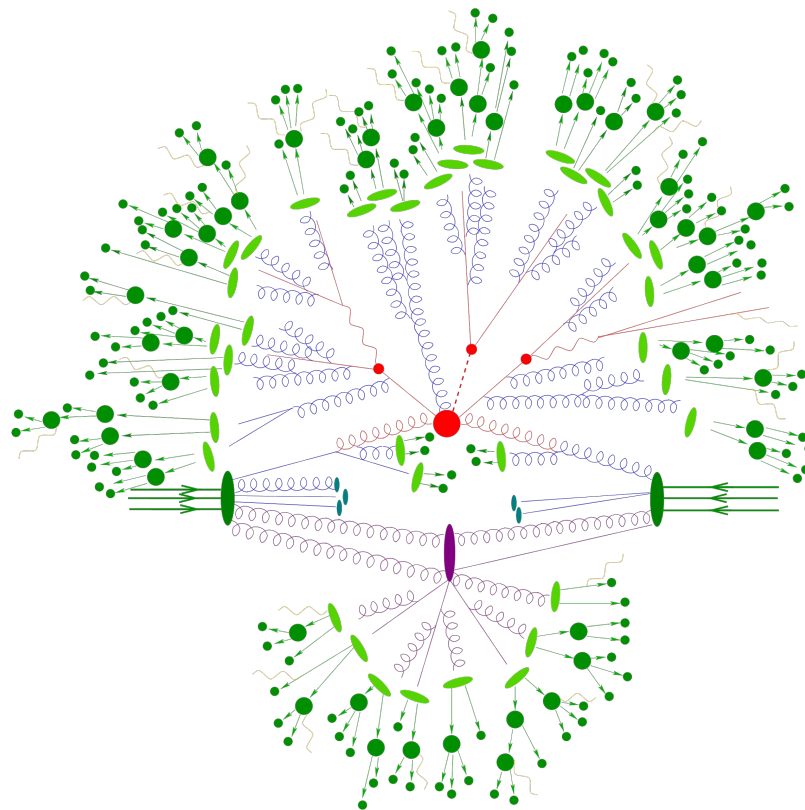
# New developments in Sherpa

Marek Schoenherr, Stefan Hoeche  
for the Sherpa Collaboration

ATLAS Meeting  
June 26, 2020

# The Sherpa framework

- **Hard interaction**
  - LO, NLO QCD/EW, NNLO QCD
  - ME generators Amegic & Comix
- **Radiative corrections**
  - Catani-Seymour based PS
  - Dire, YFS QED resummation
- **Multiple interactions**
  - Sjöstrand-Zijl model
- **Hadronization**
  - Cluster hadronization model
- **Hadron Decays**
  - Phase space or EFTs,
  - YFS QED corrections



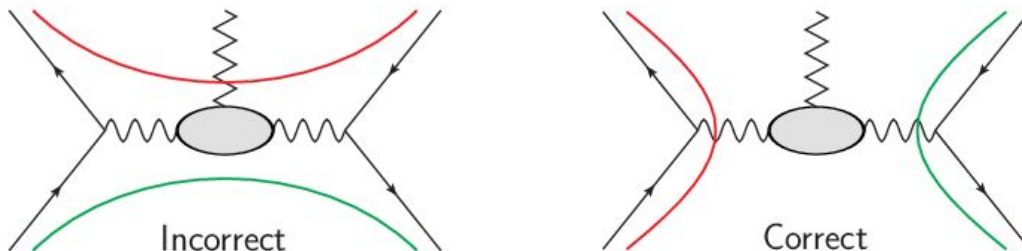
# User interface changes and performance improvements

- Runcard now in YAML format
  - Error messages if parameters wrongly defined
  - Standardized intuitive syntax
- Extended library of analytic loop matrix elements
  - Includes standard candles  $pp \rightarrow W/Z$  that are most performance-critical
- Improved I/O system for faster startup especially when used in MPI-parallelized NLO integration jobs
- Accelerated clustering procedure for MEPS@NLO merging

```
EVENTS: 1M
SCALES: VBF{H_TM2/4}{H_TM2/4}{MU_Q2}
PDF_LIBRARY: LHAPDFSherpa
PDF_SET: PDF4LHC15_nnlo_30
BEAMS: [2212, 2212]
BEAM_ENERGIES: 6500
PROCESSES:
  - 93 93 -> 25 93 93:
    Order: {QCD: 0, EW: 3}
    NLO_Order: {QCD: 1, EW: 0}
    Min_N_TChannels: 2
    NLO_Mode: MC@NLO
    ME_Generator: Amegic
    RS_ME_Generator: Comix
    Loop_Generator: Internal
SELECTORS:
- FastjetFinder:
  Algorithm: kt
  N: 2
  PTMin: 5
  DR: 0.7
```

# Vector Boson Scattering simulations

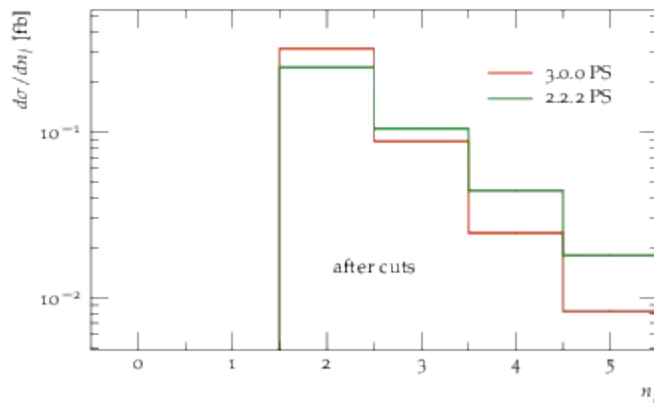
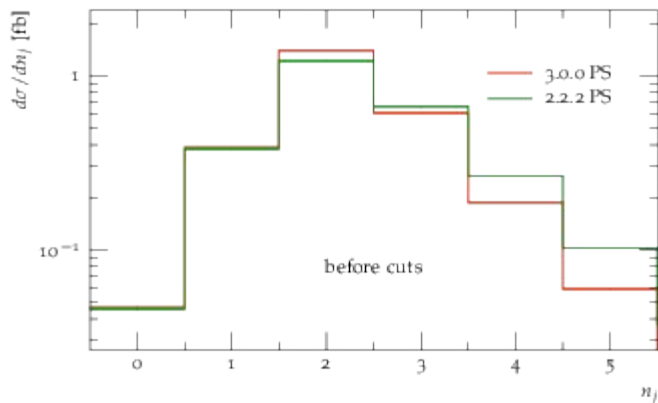
- VBF-like situations require judicious setting of color flow information in interface between fixed-order calculation and parton shower



- Current color selection in Sherpa based on hardcoded probabilities for the most relevant processes, VBF topologies are not included
- Alternative, generic option in future version 3.0.0
  - Identify all possible color flows in core interaction
  - (after ME+PS clustering, e.g.  $pp \rightarrow e^+e^-$  in  $pp \rightarrow e^+e^- + \text{jets}$ )
  - Compute corresponding partial amplitudes [Gleisberg,SH] arXiv:0808.3674
  - Select winner topology probabilistically
- Also specify different starting scales for evolution of disconnected dipoles

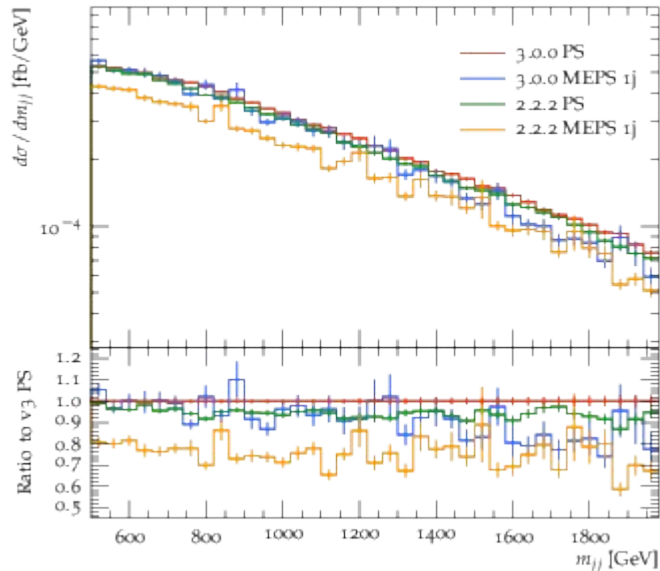
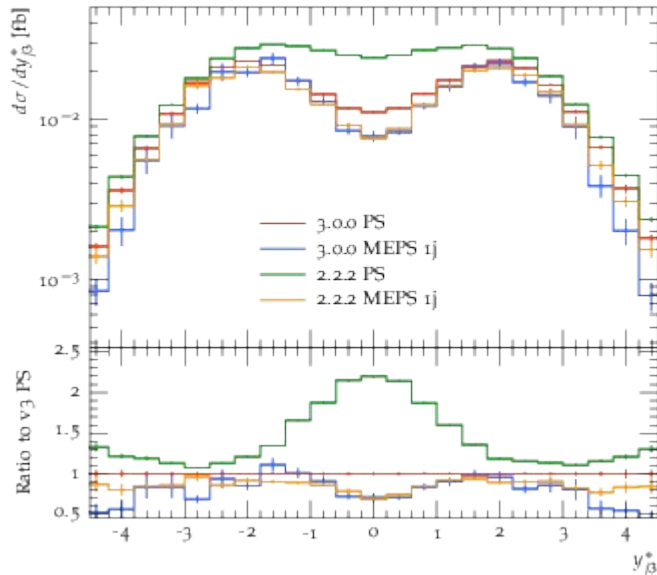
# Example: $W^+W^+$ production, $e^+\mu^+$ channel

- Test new setup in simplest VBS scenario  $\rightarrow$  same-sign WW
- Rivet analysis courtesy of Stefanie Todt (TU Dresden)
  - Two charged dressed leptons (same sign)  $p_T > 27$  GeV,  $|\eta| < 2.5$
  - At least 2 jets with  $p_T > 30$  GeV,  $|\eta| < 4.5$
  - Lepton isolation  $\Delta R_{ll} > 0.3$ ,  $\Delta R_{lj} > 0.3$
  - Lepton invariant mass  $m_{ll} > 20$  GeV
  - Missing transverse momentum  $p_{T,miss} > 30$  GeV
  - Tagjet (lead- $p_T$ ) invariant mass  $m_{jj} > 500$  GeV, rapidity difference  $\Delta y_{jj} > 2$



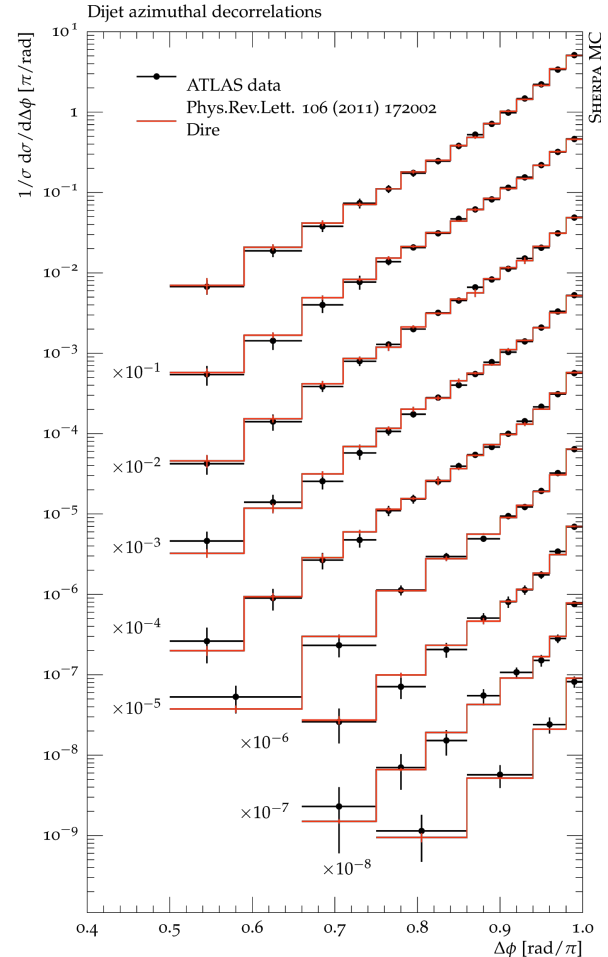
# Example: $W^+W^+$ production, $e^+\mu^+$ channel

- Differential distributions confirm expectation:
  - Third jet produced more centrally and at higher rate in Sherpa 2.2.2
  - PS radiation pattern in Sherpa 2.2.0 corrected by ME+PS merging, but breaking of PS unitarity in CKKW(L) decreases overall event rate
- Sherpa 3.0.0 predicts ~20% larger cross section after cuts



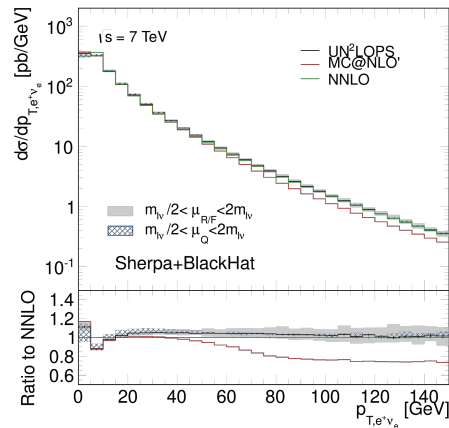
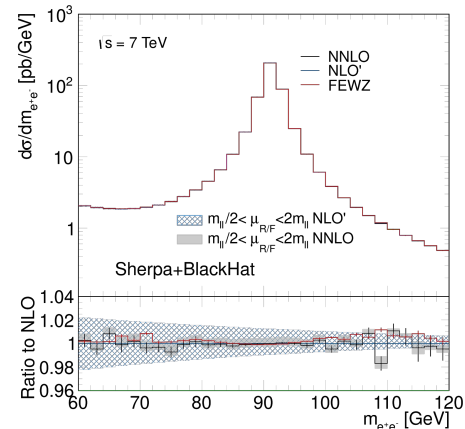
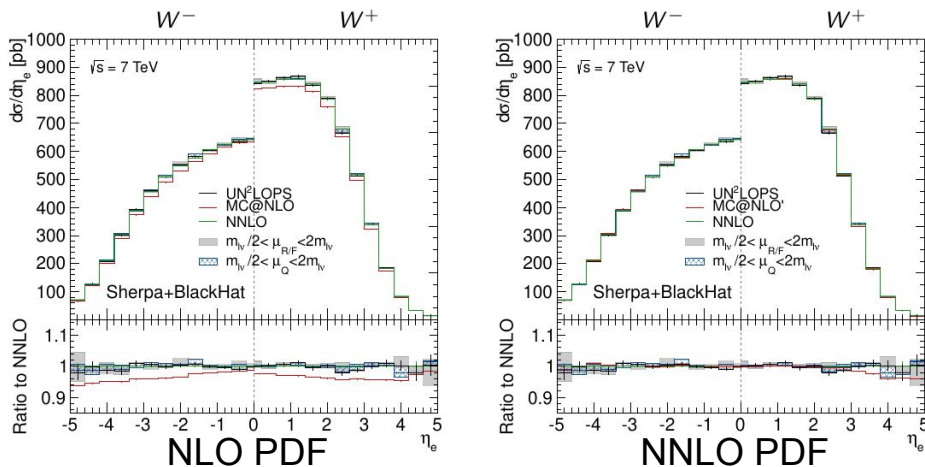
# Dire parton shower

- Full-fledged implementation in Sherpa 3.x
- Currently includes
  - MC@NLO matching
  - MEPS@NLO merging
  - UN<sup>2</sup>LOPS matching
  - Triple collinear splitting functions
- Missing so far
  - Proper treatment of massive initial states
  - Careful re-assessment of evolution variable
  - Fully differential NLO corrections (soft contributions)
- Dire is not yet the default parton shower but can be used for systematics studies



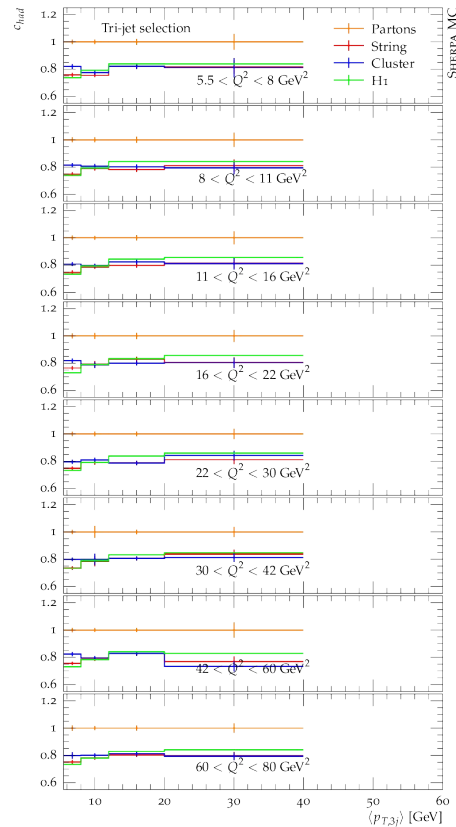
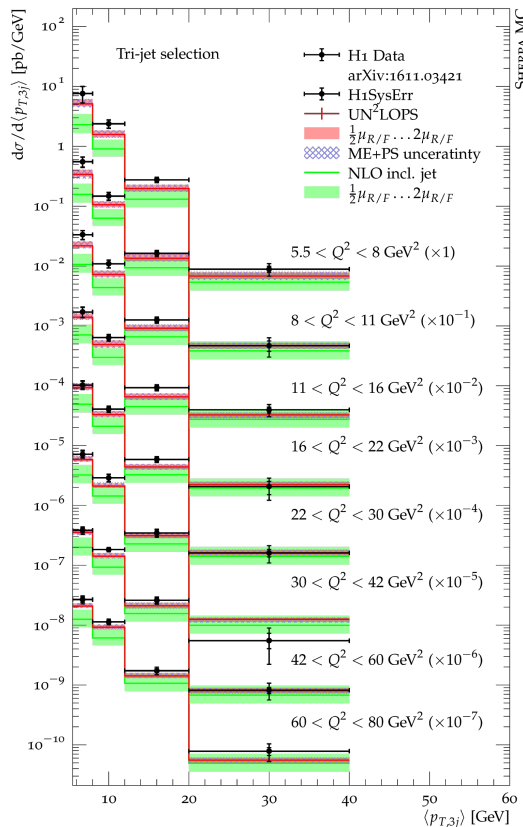
# NNLO simulations at parton level and particle-level

- Standard candles  $pp \rightarrow W/Z$  and  $pp \rightarrow h$  can now be simulated at NNLO accuracy
- Both fixed-order calculation and UN<sup>2</sup>LOPS matching possible
- On-the-fly scale and PDF variations
  - Example: Comparison between NLO/NNLO PDFs



# NNLO particle-level simulation - Usage example

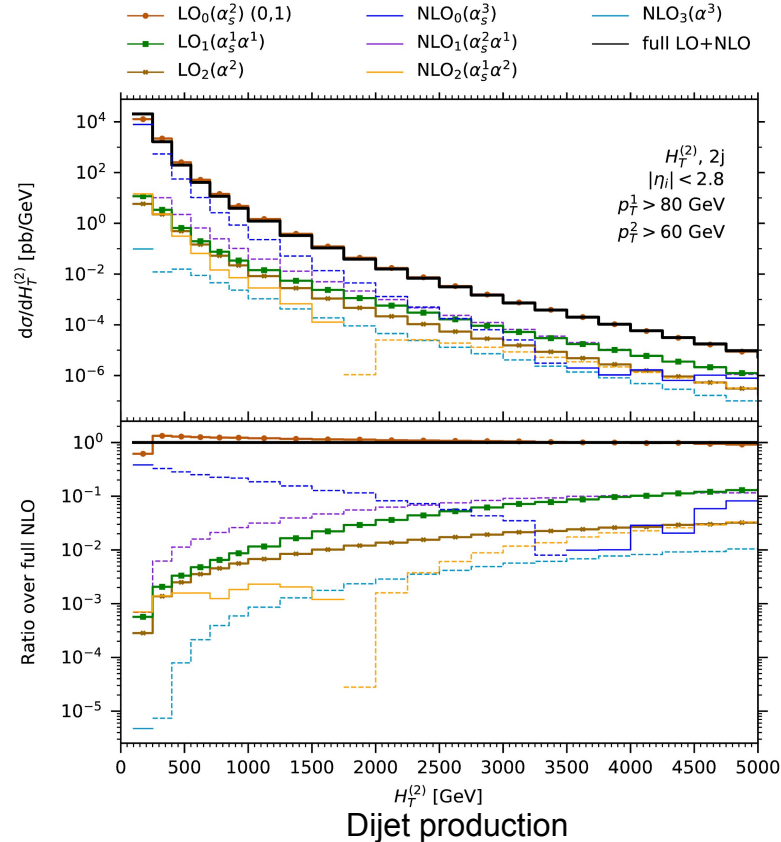
- UN<sup>2</sup>LOPS matching is accurate but inefficient
- Large fraction of negative weighted events require at least 10x more compute time than NLO
- Practical usage:
  - Compute fully differential NNLO/NLO K-factors
  - Compute hadronization Corrections at NNLO



# NLO EW

- Fully automated implementation analogous to NLO QCD calcs
- Currently restricted to fixed-order calcs, not matched to PS yet
- Various options for unique complications in EW sector
  - Various relevant input and ren. schemes
  - Generalised jet definitions
  - Generalised jet flavour tagging (lepton, photon, ...)
  - Specialised photon treatments
  - Strict contribution definition through coupling orders including all contributing flavours

MS arXiv:1712.07975



Reyer, MS, Schumann arXiv:1902.01763

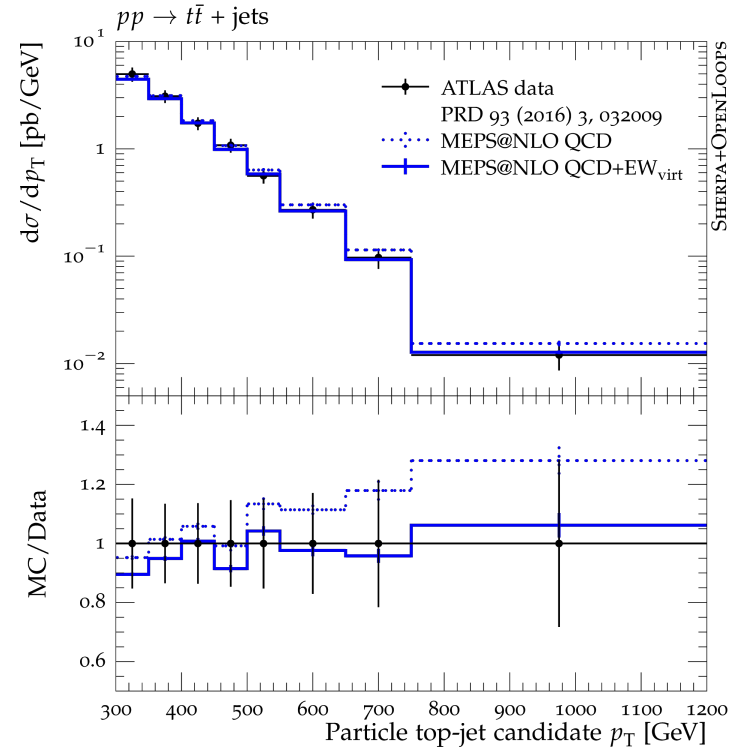
# EWvirt approximation

- Inclusion of approximate EW corrections in multijet merging by augmenting the MC@NLO Bbar function

$$\bar{B}_n^{\text{QCD+EW}}(\Phi_n) = \bar{B}_n^{\text{QCD}}(\Phi_n) + B_n(\Phi_n) \delta_{\text{EW}}^{\text{approx}}(\Phi_n) + B_n^{\text{sub}}(\Phi_n)$$

$$\bar{B}_n^{\text{QCD} \times \text{EW}}(\Phi_n) = \bar{B}_n^{\text{QCD}}(\Phi_n) (1 + \delta_{\text{EW}}^{\text{approx}}(\Phi_n)) + B_n^{\text{sub}}(\Phi_n)$$

- Tailored to describe EW corrections in Sudakov regime
- Real QED emissions recovered through YFS soft-photon resummation
- Simple but effective stand-in for full NLO QCD+EW multijet merging

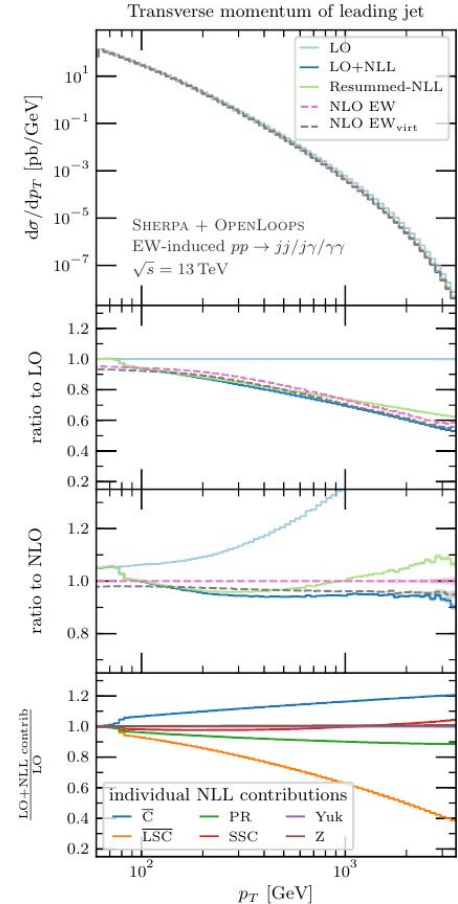


Boosted top-pair production @ 8 TeV  
Gutschow, Lindert, MS arXiv:1803.00350

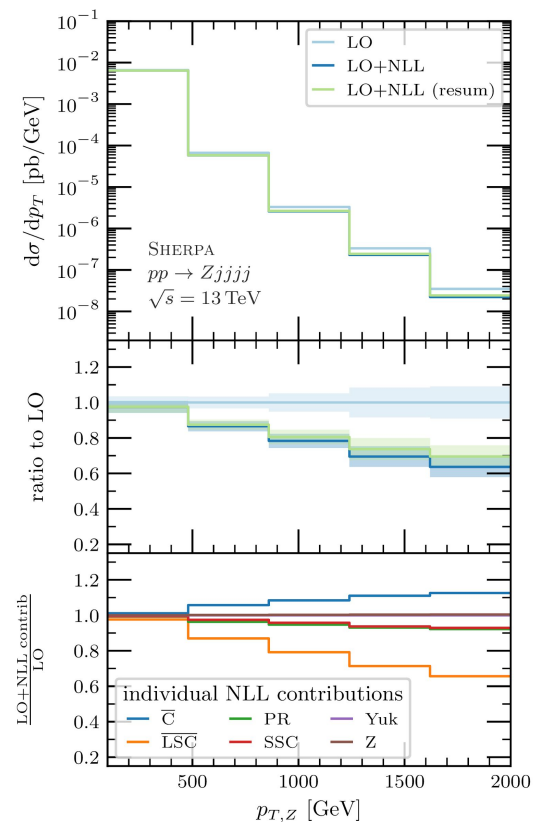
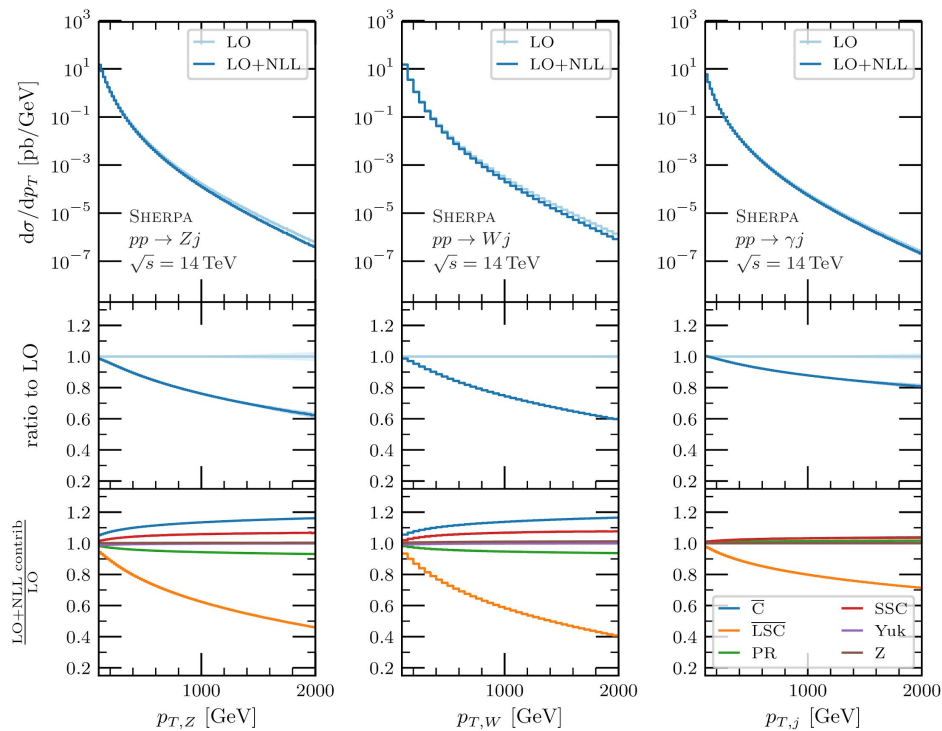
# Universal EW Sudakov approximation

- EW corrections have a universal limit when kin. Invariants (eg.  $p_T$ ) are large wrt  $m_W$ 
  - ➔ EW Sudakov limit
    - Universal double and single logs
- Include logarithms either at fixed-order or exponentiated (difference can be used to attribute a missing higher-order uncertainty)
- Written into HepMC event record in addition to nominal event weight, same as EWvirt approximation
- Sherpa 3.0.0 includes an automated implementation

Bothmann, Napoletano arXiv:2006.xxxxx



# Universal EW Sudakov approximation



# YFS with NNLO QED + NLO EW corrections

- Elevate formal accuracy from of QED FSR from NLO QED to

- $Z \rightarrow \ell\ell$  (NNLO QED + NLO EW)
- $W \rightarrow \ell\nu$  (NLO EW)
- $h \rightarrow \ell\ell$  (NNLO QED + EW)

Krauss, Lindert, Linten, MS arXiv:1809.10650

