FERMILAB-CONF-25-0448-T

Sherpa 3.0 for the EIC

Max Knobbe

MC4EIC

09 July 2025

Sherpa 3.0 released in July 2024 🎉

Bothmann et al, *JHEP* 12 (2024) 156

Event generation with SHERPA 3

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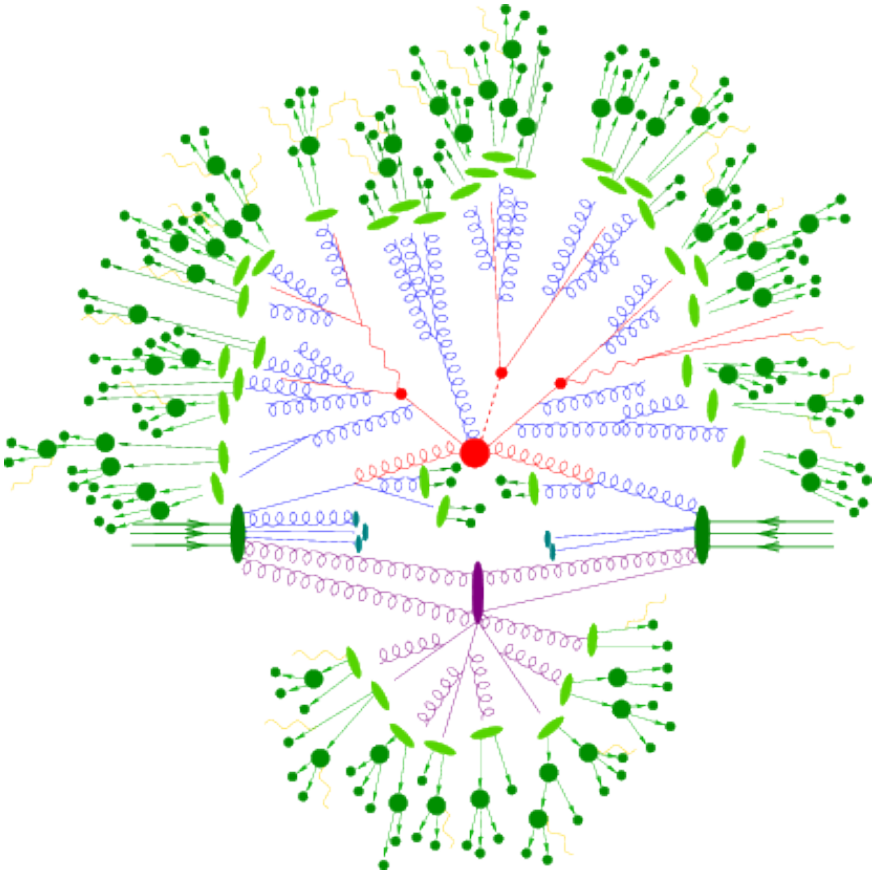
SHERPA

- new Physics features
- More intuitive and flexible user interface
- More efficient CPU footprint
- Modern build system
- Comprehensive, automatic validation suite
- Developed on https://gitlab.com/sherpa-team/sherpa

Sherpa bundles full chain in one tool!



Hard/perturbative components

- Builtin tree level matrix-elements
  - Comix, Amegic
  - Wide range of processes: ee, ep, pp, complex final states
- Higher-order QCD corrections
  - Automated matching/merging
- (Approximate) NLO EW corrections
  - EWvirt, EWsudakov
- Builtin Parton Showers
  - CSS, (Dire), Alaric

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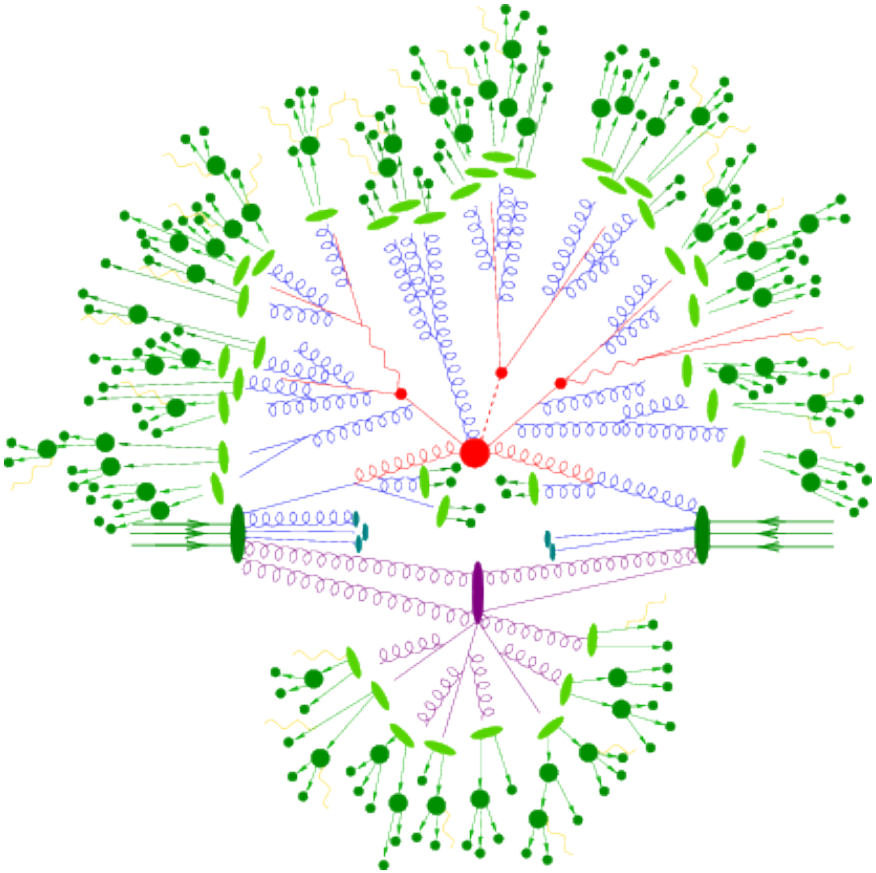
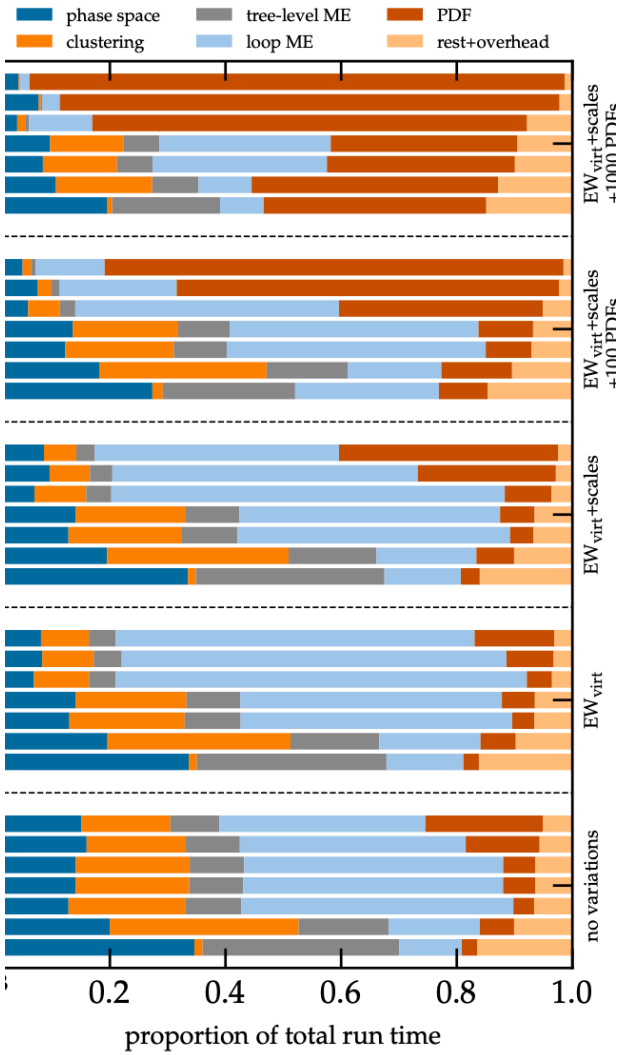


Soft/non-perturbative components

- Fragmentation
  - Ahadic, interface to Pythia8
- Hadron decays
- Multiple interactions
- Soft color interactions
- Higher-order QED effects
  - YFS resummation

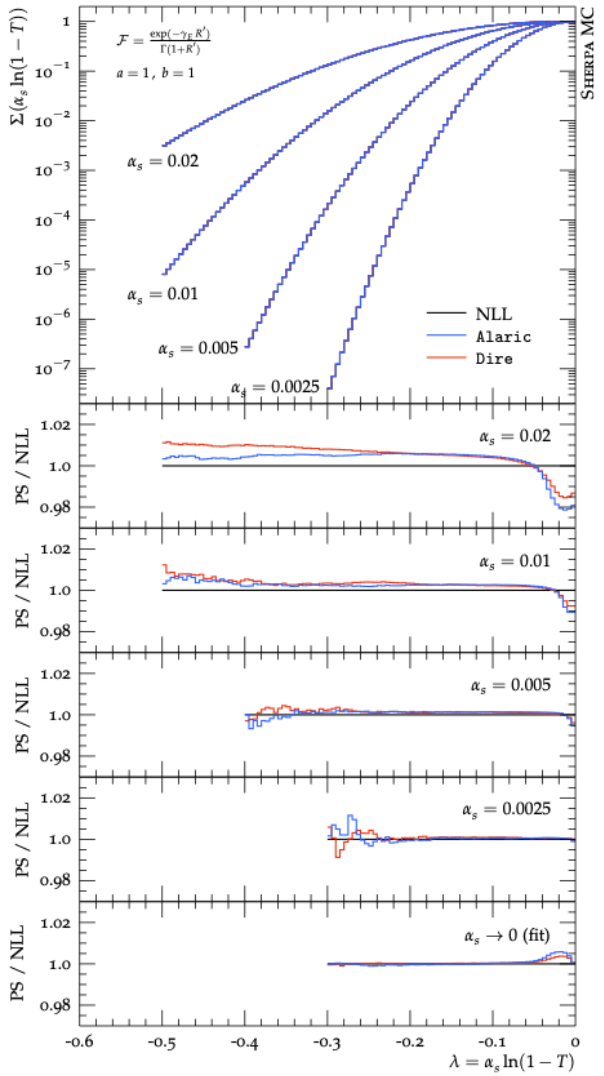
Sherpa code & performance

- roughly 400k lines of code
  - Mostly c++ plus Python3 interface
- development fully open source on gitlab
  - https://gitlab.com/sherpa-team/sherpa
- Input cards in yaml format
- Release format
  - Major: 3.**x**.y
  - Minor: 3.x.**y**
  - Currently at 3.0.1, 3.0.2 imminent
- Extensive performance and maintenance improvements
- Work on implementing GPUs into the toolchain



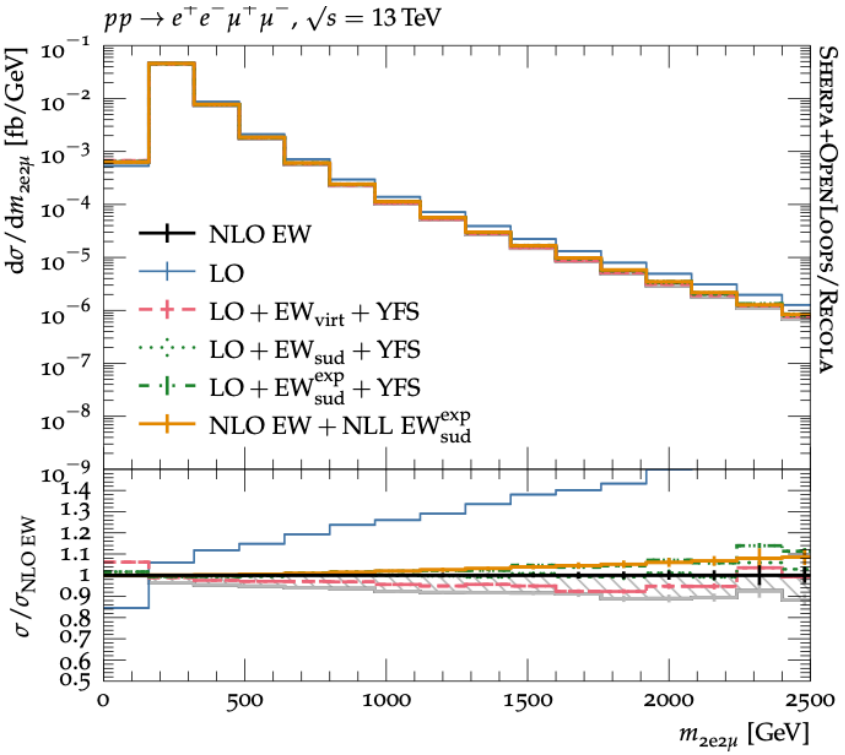
NLL accurate parton shower: Alaric

- Parton showes accuracy measured in log-accuracy
- CSSHOWER and Dire not formally NLL accurate
- Alaric development based on split of soft and collinear dyn.
  - [Herren et al, *JHEP* 10 (2023) 091]
- Extended to massive splittings
  - [Assi, Hoeche, *Phys.Rev.D* 109 (2024) 11, 1]
- Multijet merging
  - [Hoeche, Krauss, Reichelt, *Phys.Rev.D* 111 (2025) 9]
- NLO matching soon
  - [Hoeche, Meinzinger, Reichelt, tbp]



Automatic electroweak corrections

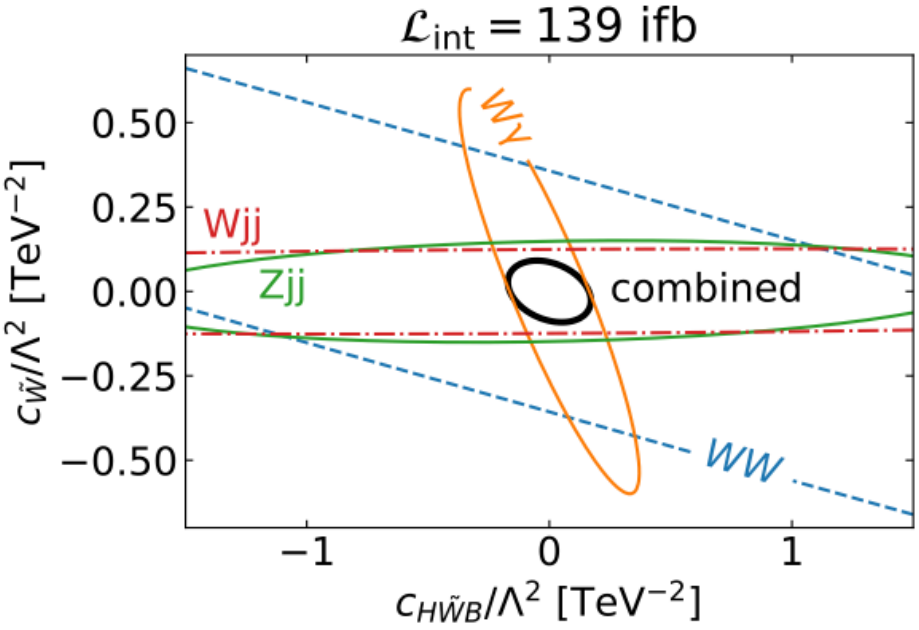
- Fixed order NLO EW automated
  - [Schönherr, *Eur.Phys.J.C* 78 (2018) 2, 119]
- EWvirt approximation uses IR regulated exact virtual cores
  - [Kallweit et al, *JHEP* 11 (2017) 120]
  - expensive, use for low multis.
- Ensued approximates EW Sudakov logarithms
  - [Bothmann Napoletano, *Eur.Phys.J.C* 80 (2020) 11, 1024]
  - Cheap use everywhere else
- YFS resummation of soft and virtual gluons



Bothman et al., *JHEP* 06 (2022) 064

BSM processes

- UFO interface for BSM physics
  - [Hoeche et al. , *Eur.Phys.J.C* 75 (2015) 3, 135]
- Sherpa can be used as signal and background generator
  - Straight forward to have consistent setup
- Support for form factors, custom props, spin correlations, decay tables, multi-jet merging

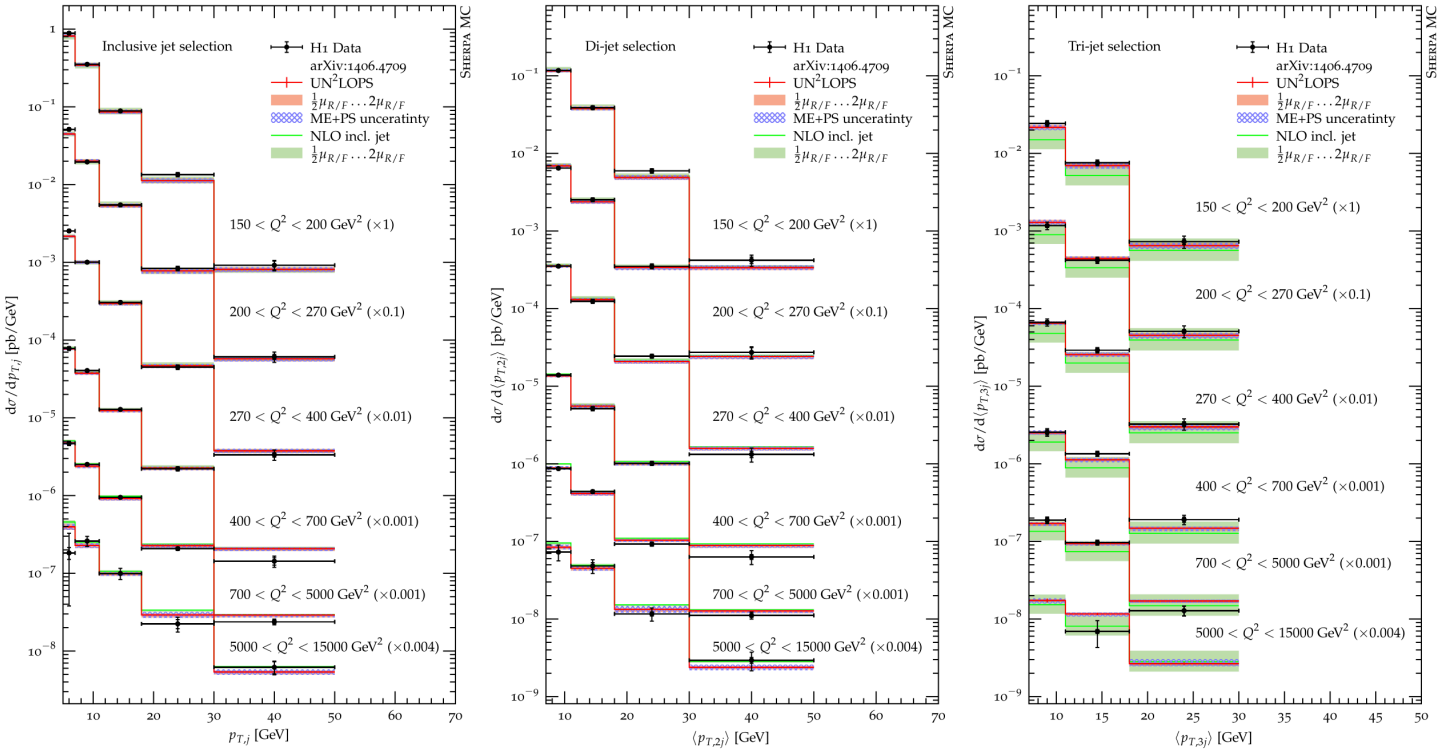


Biekoetter et al, *Phys.Lett.B* 814 (2021) 136079

Sherpa for DIS

Inclusive NC-DIS at NNLO

Phys.Rev.D 98 (2018) 11 [Hoeche, Kuttimalai, Li]



- Parton-shower matched next-to-next-to-leading-order QCD
- Good agreement with fixed order and data

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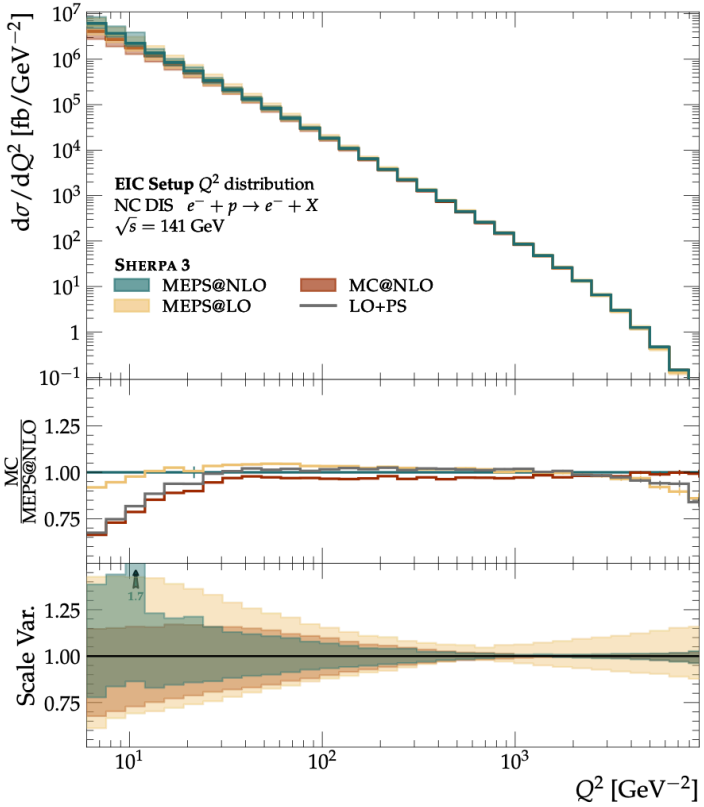
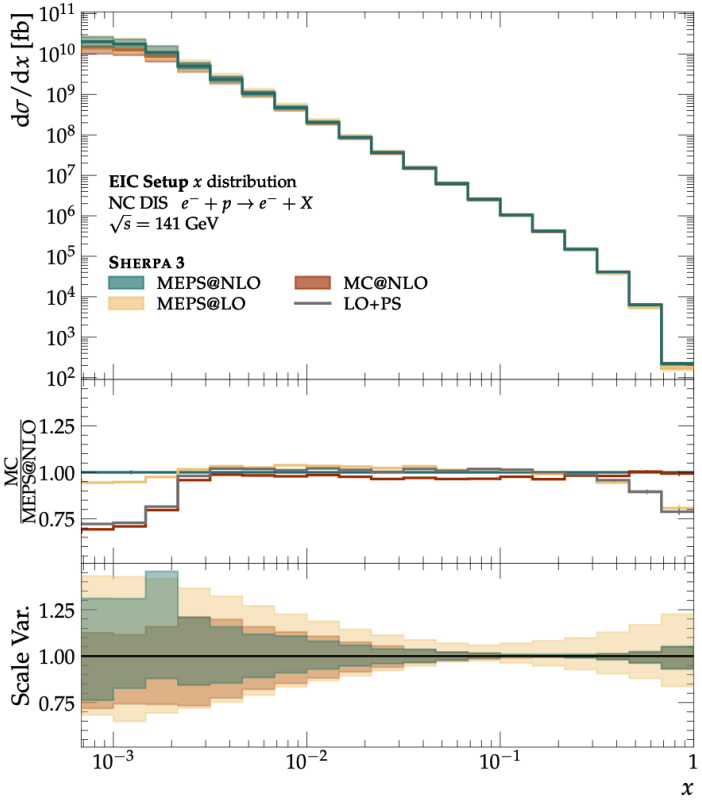
MEPS@NLO neutral and charged current DIS at the EIC

2506.08994 [Meinzinger, Reichelt, Silvetti]





- large corrections for the virtuality and the Bjorken-x distributions

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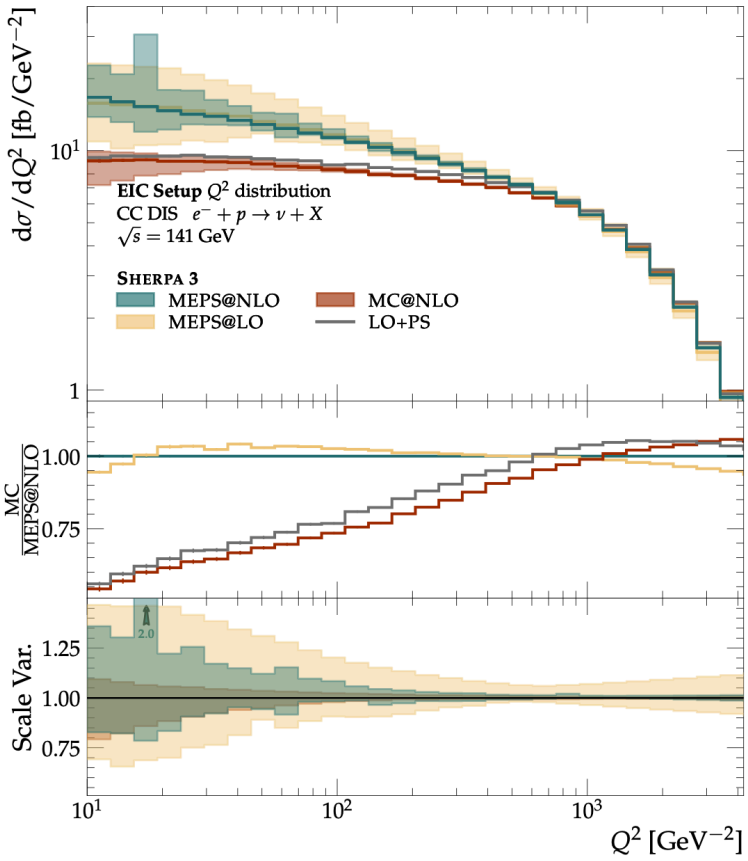

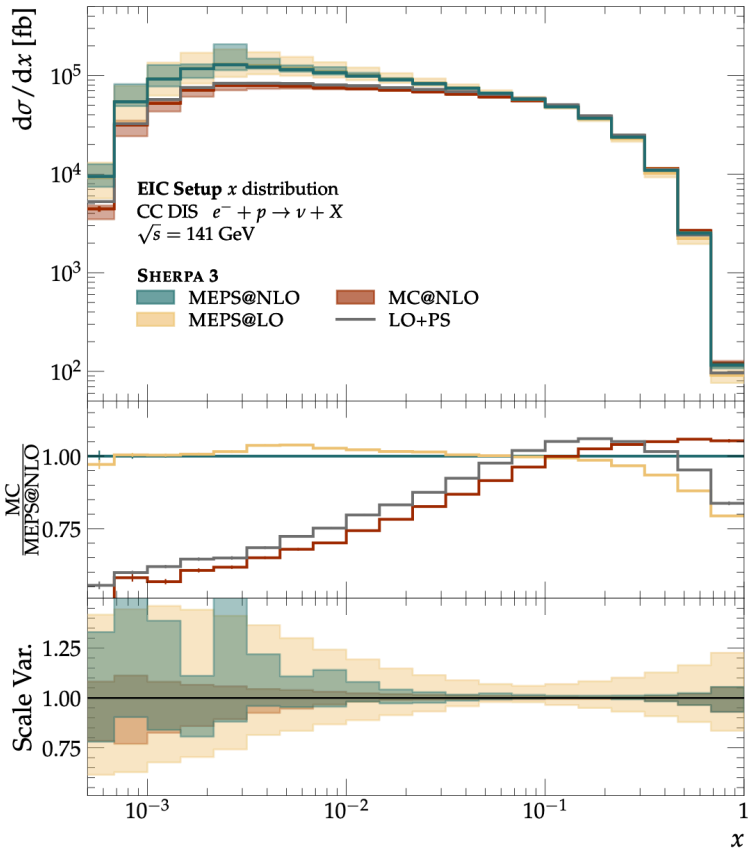

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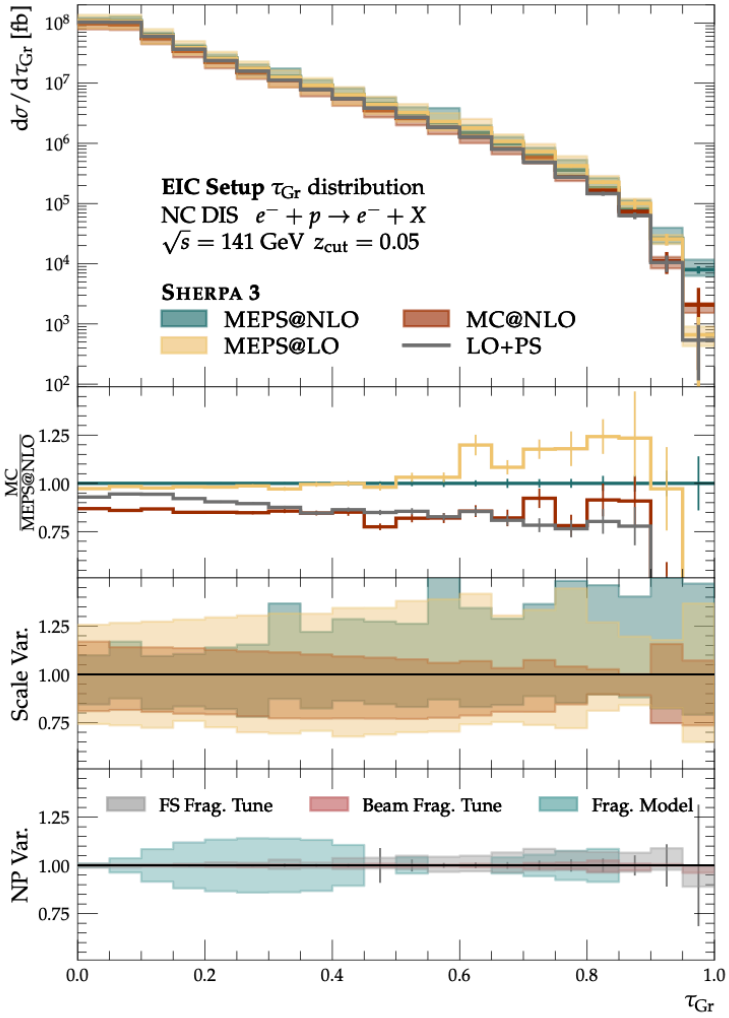
MEPS@NLO neutral and charged current DIS at the EIC

2506.08994 [Meinzinger, Reichelt, Silvetti]

- Recently observed, hadronisation uncertainties significant for EIC sets
- Most significantly, switching model introduces large variations
  - Consistent tune in preparation
- Impact or remaining soft physics models unclear
  - color reconnections?



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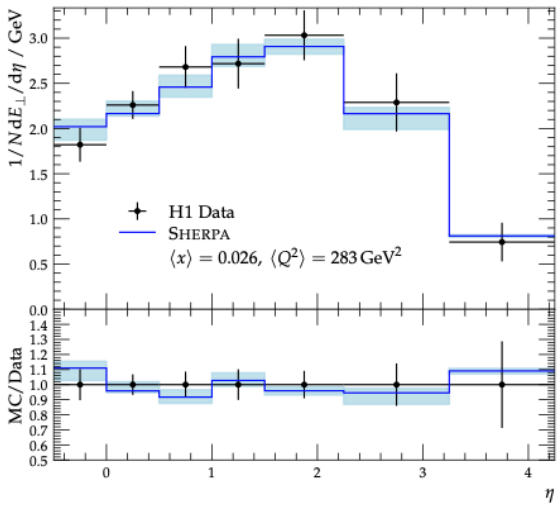
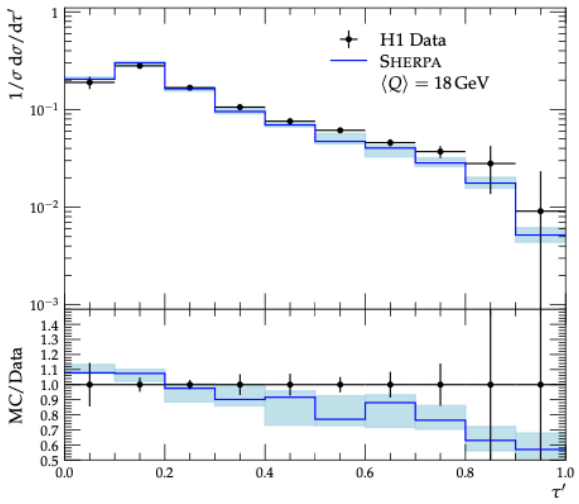
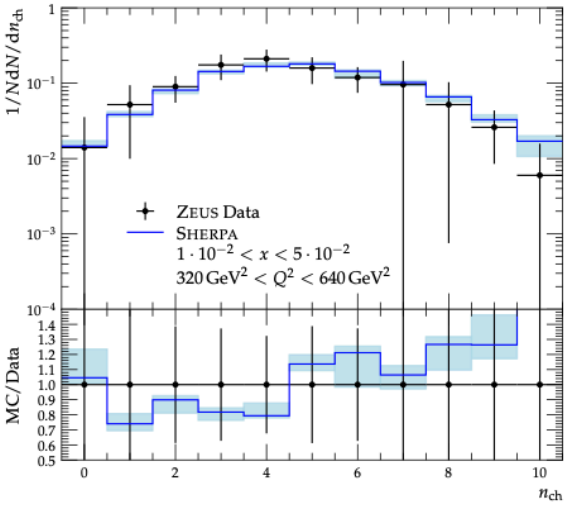
Tuning for DIS

2306.17736 [MK, Reichelt, Schumann]







- relevant components of Cluster model tuned to H1 data
  - Using apprentice and available rivet analysis
  - Relying exclusively on analysis available via Rivet
  - Multiple tunes of similar quality as uncertainty estimates
- Used e.g. for uncertainty estimates for 1-jettiness
- At the moment missing: consistent tune for string fragmentation

Polarized event generation

Polarized cross sections in Sherpa

[Hoppe, Schönherr, Siegert, *JHEP* 04 (2024) 001]

- Physical polarisation states not universally defined
  - Only for on-shell particles
  - Additionally definition is frame dependent

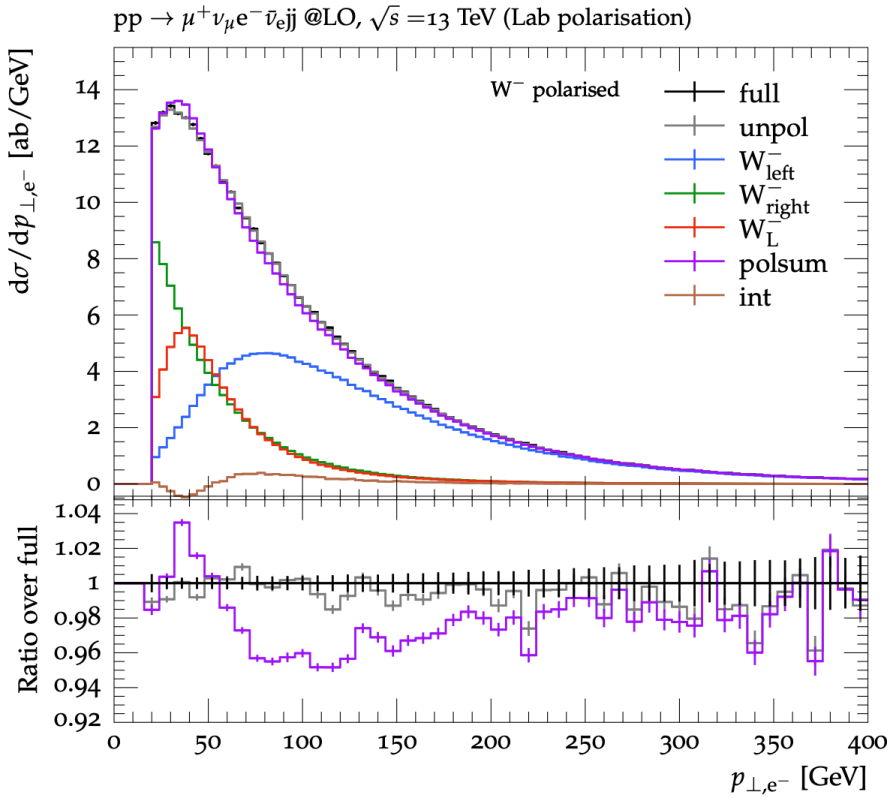
- For W/Z intermediate states we need to make approximations
  - Neglect non-resonant contributions
  - Consider only on-shell bosons
  - Some off-shell effects can be recovered, but intrinsic inaccuracies

- Use Narrow-width approximation

$$\left[\frac{1}{p^2 - m^2 + im\Gamma}\right]^2 \to \frac{\pi}{m\Gamma}\delta(p^2 - m^2)$$

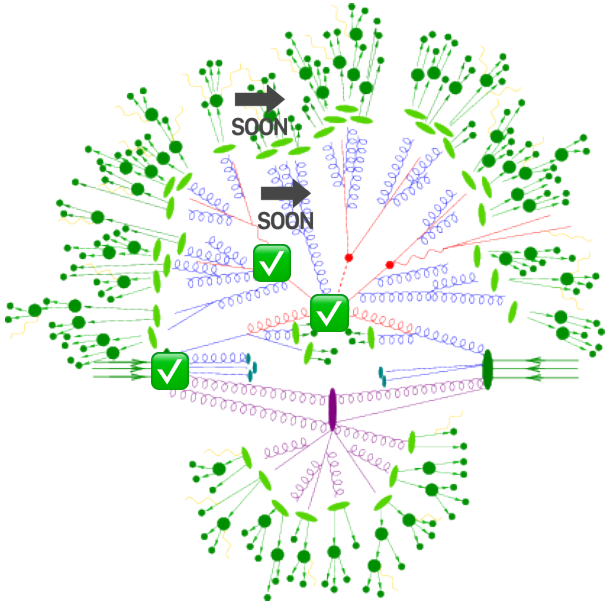
Polarized cross sections, cont'd

- Decompose amplitudes into polarization components
- Three modes, left, right, longitudinal. Unphysical fourth contribution vanishes in NWA.
- Often diagonal terms are dominant
  - Sherpa automatically also takes interference into account
- NWA errors usually small



Towards a fully polarized framework

- Polarized matrix elements ✅
- Polarized intermal vector bosons ✅
- Polarized Parton shower
  - New approach using splitting functions in: [Campbell et al, 2505.10408]
  - Soon to be released
    [Hoeche, Hoppe, Reichelt Siegert]



- Polarized Hadronization
  - First steps taken more development required
    [MK, Krauss]

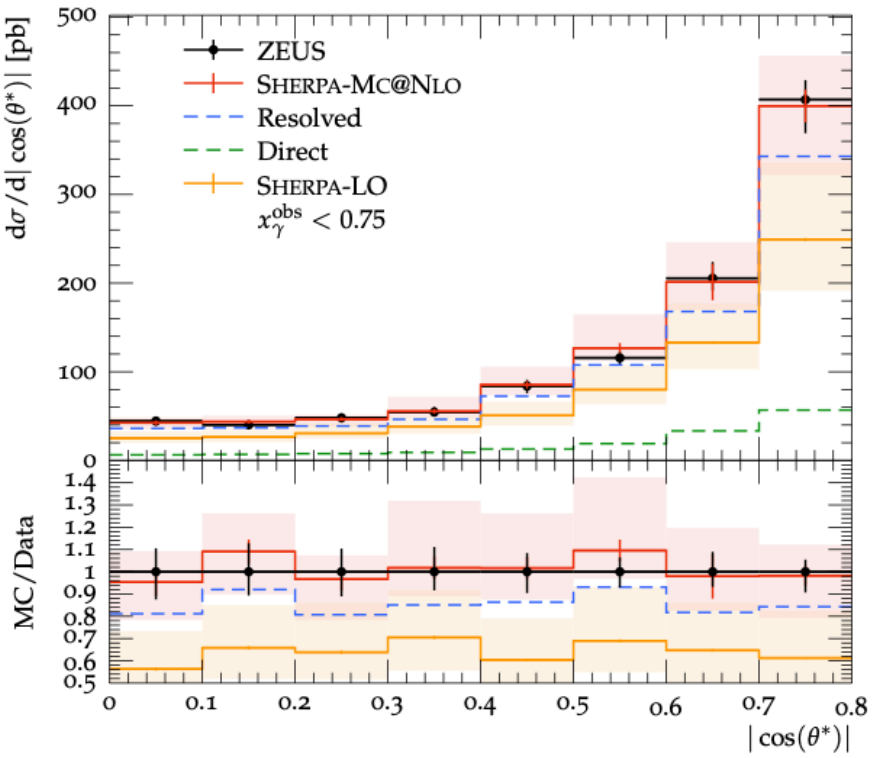
- Fully polarized framework within reach

Photoproduction in Sherpa

Resolves Photons in Sherpa

[Hoeche, Krauss, Meinzinger, *Eur.Phys.J.C* 84 (2024) 2, 178]

- Total jet production cross-section in e-p dominated by Q^2 photoproducion
- For large $Q^2 >> 0$: predictions available for up to N3LO
- For $\cong 0$, only (N)LO + Shower or fixed order NLO
- Available in Sherpa at NLO + PS accuracy



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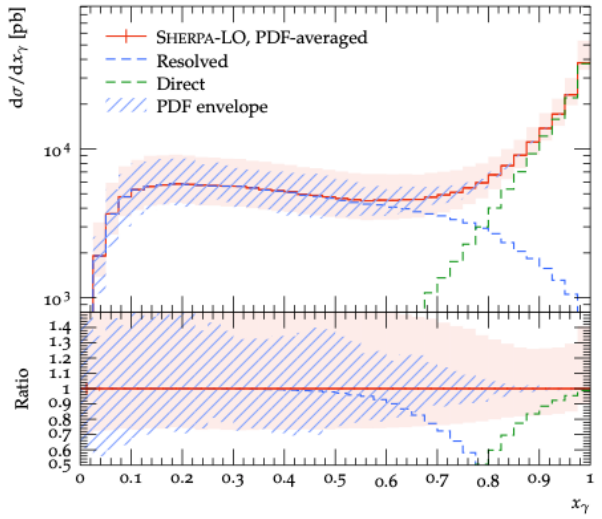
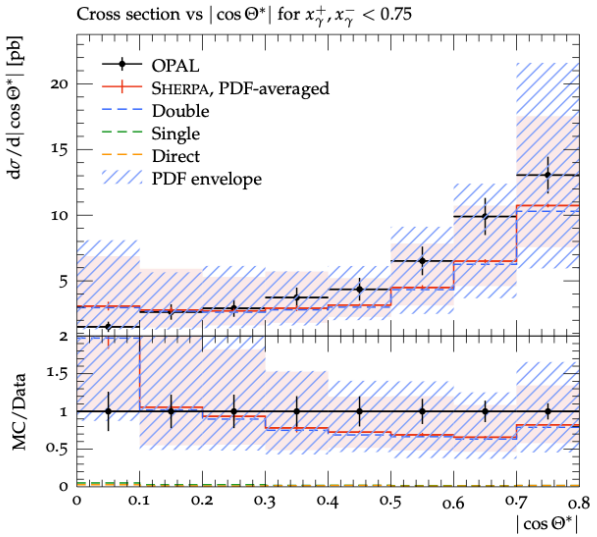
Resolved Photons in Sherpa

[Krauss, Meinzinger, *Phys.Rev.D* 109 (2024) 3, 034037]

- Limiting factor for pheno often the quality of photon pdf
- Currently 11 PDFs directly implemented in Sherpa
  - Currently no standard interface via e.g. LHAPDF
- Deviations up to 50%
- Couplings inconsistent with modern PDFs
- No error estimates





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Conclusions

- Sherpa3 contains a large number of physics improvements
- Well setup for precision calculations for next gen. collider experiments

Other than that:
- More intuitive and flexible user interface
- More efficient CPU footprint
- New HPC/GPU workflows
- Modern build system

Any questions? Ask me or head over to:
https://sherpa-team.gitlab.io

Acknowledgement

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