Photoproduction and Beyond in *ep* Collisions at the EIC

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- introduction
- inclusive QCD results @ HERA
- inclusive QCD results @ EIC
- new physics @ EIC
- outlook

instead of an introduction

(disentangling resolved photons)

electro- vs. photo-production

- consider (inclusive) $ep \to eX$ processes in QCD
- at parton level: resolve proton's partonic structure
  process reads $eq_0 \to eq_1 q_2 q_3 \ldots q_n$ (where q_i = partons)
- however: intermediate photon can fluctuate into hadrons
  ($q\bar{q}$-pairs: ρ^0, ω, ϕ, J/ψ, ..., simple quantum mechanics at work)
  (vector meson dominance model!)
- effectively hadron scattering, involves photon PDF
- experimentally hard to disentangle from "pure" DIS:
  - different flow of final state hadrons (forward/backward)
  - electron kinematics (Q^2) impacts on transition $|\gamma\rangle \to |V\rangle$

electro- vs. photo-production: an MC perspective

- suggestion: use trick out of the MC box
- using the notion of "jet measure" and cluster partons backwards:
  1. calculate distance between any two partons i and j and between any parton i and proton p according to k_T measure:

$$\begin{aligned} d_{ij} &= \min\{E_i^2, E_j^2\}(1-\cos\theta_{ij}) \\ d_i &= E_i^2(1-\cos\theta_{ip}) \end{aligned}$$

  2. cluster smallest distance pair, to a new parton $[ij]$ or absorb i in beam
  3. repeat with step 1 until $2 \to 2$ configuration
- three possible outcomes:
  - $eq_0 \to eq_1$: electro-production, usually at $Q^2 \gg m_p^2$
  - $\gamma q_0 \to q_1 q_2$: (direct) photo-production, usually at $Q^2 \approx 0$
  - $q_0 q_1 \to q_2 q_3$: (resolved) photo-production, usually at $Q^2 \approx 0$

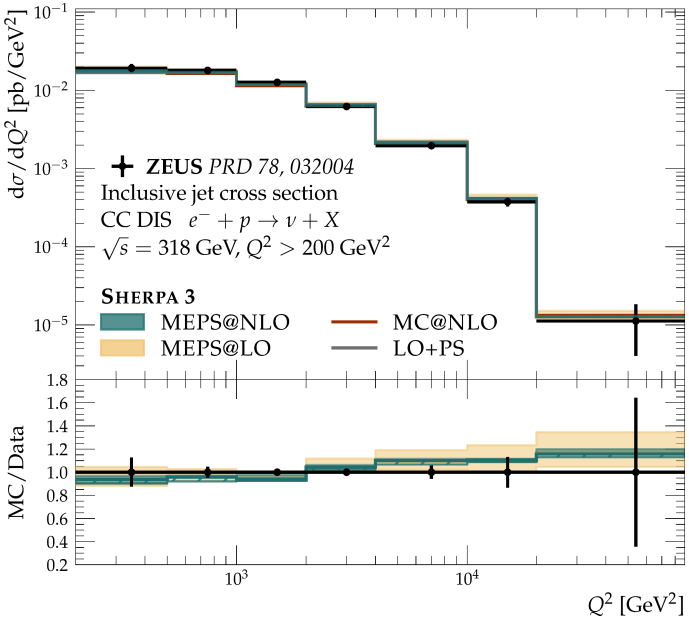
inclusive QCD @ HERA

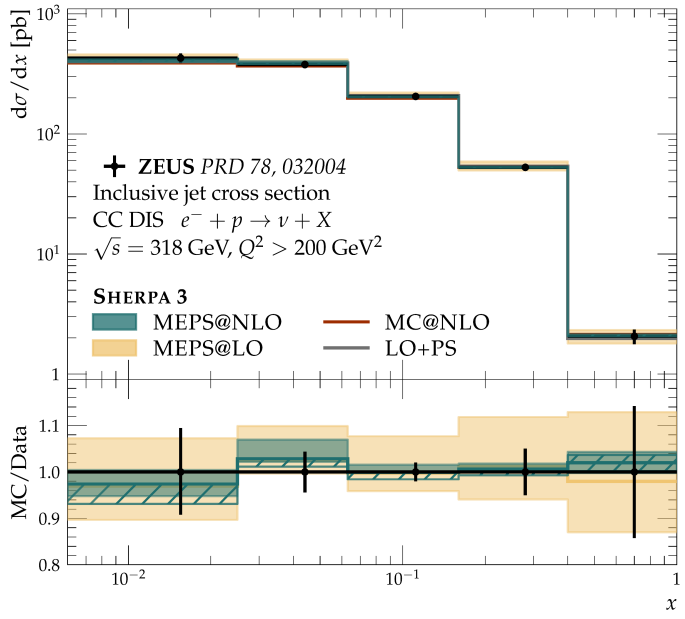
(validating the MC)

neutral and charged current DIS

(see also Meinzinger, Reichelt, Silvetti, 2506.08994)

- consider charged current at HERA
- compare LO with NLO (as well as merged samples)
- Q^2 and x in different MC settings

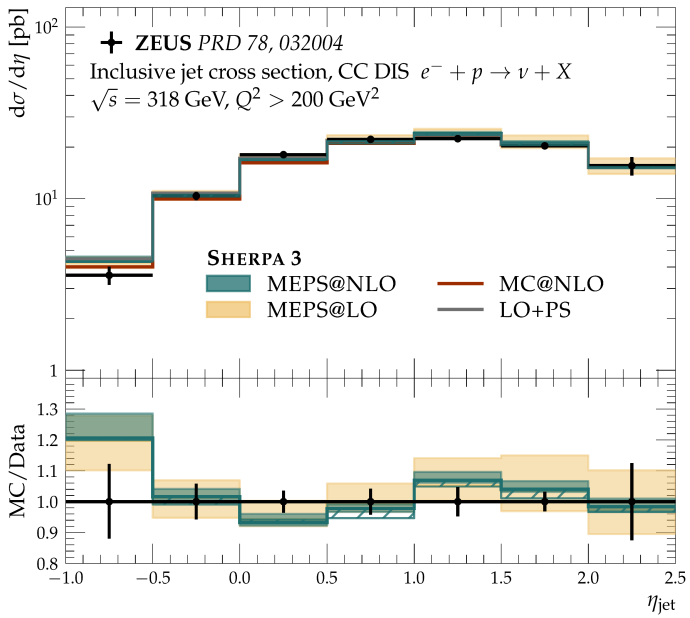


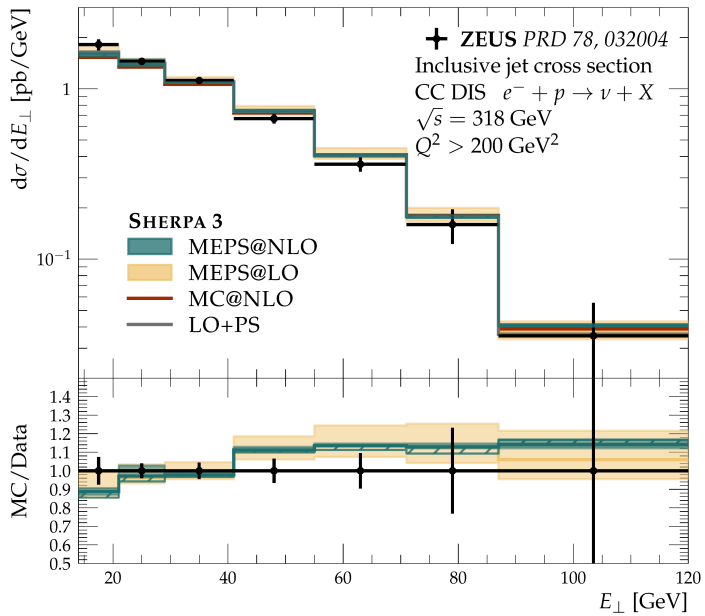


neutral and charged current DIS

(see also Meinzinger, Reichelt, Silvetti, 2506.08994)

- consider charged current at HERA
- compare LO with NLO (as well as merged samples)
- jet-η and -E_T

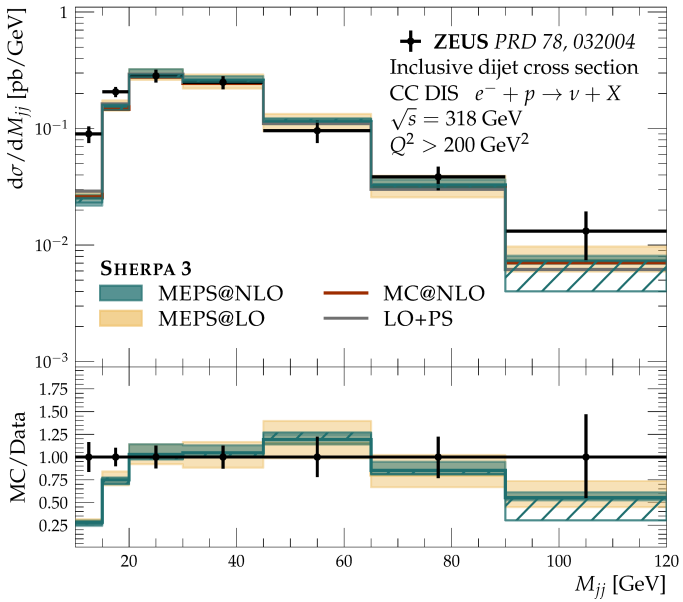


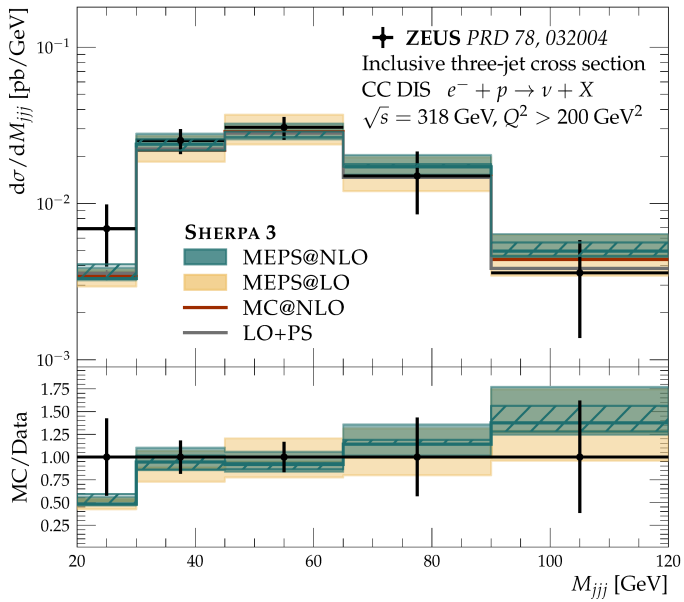


neutral and charged current DIS

(see also Meinzinger, Reichelt, Silvetti, 2506.08994)

- consider charged current at HERA
- compare LO with NLO (as well as merged samples)
- M_{jj} and M_{jjj}

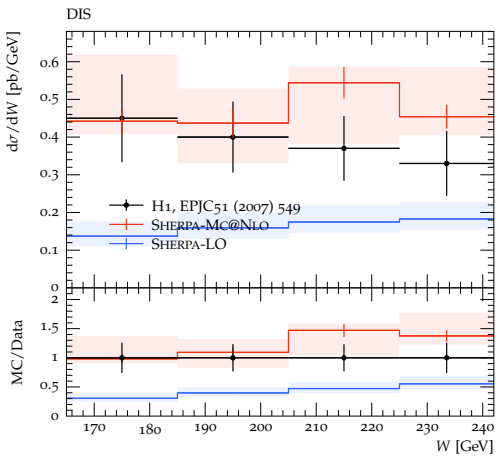


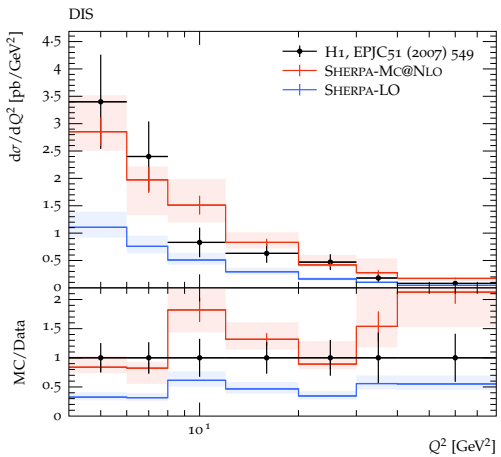


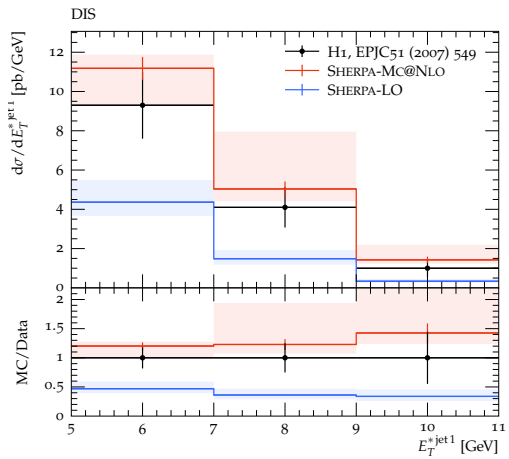
a quick peak to diffraction

(FK Meinzinger, 2407.02133)

- diffraction modelled with pomeron PDF
- compare with data from HERA







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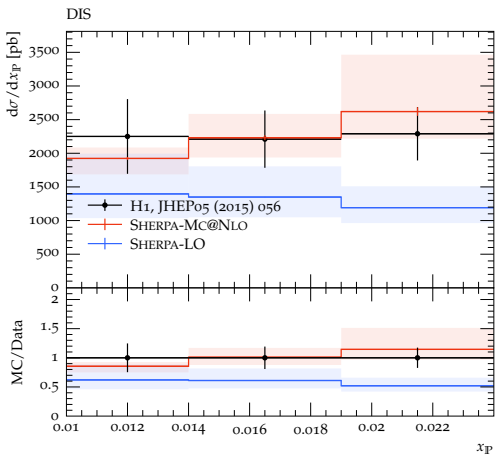

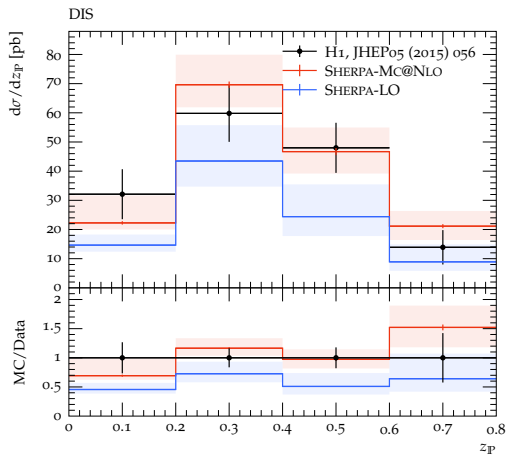

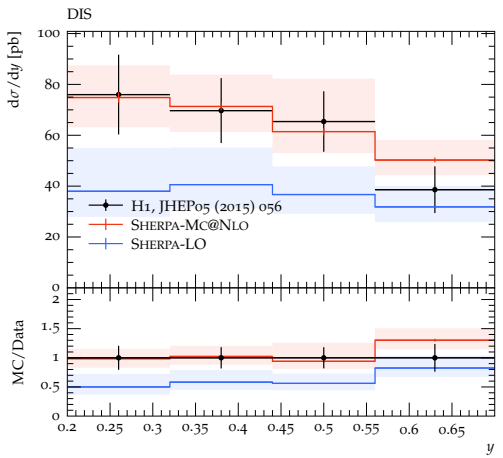

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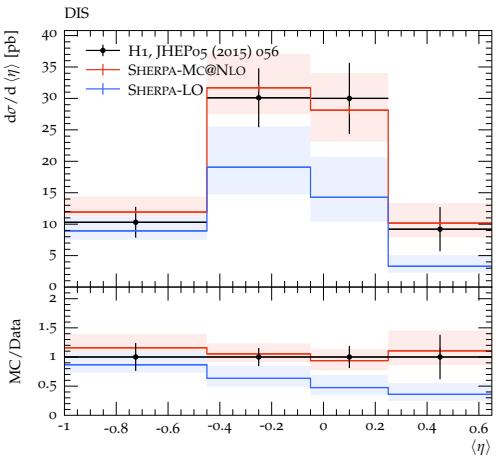
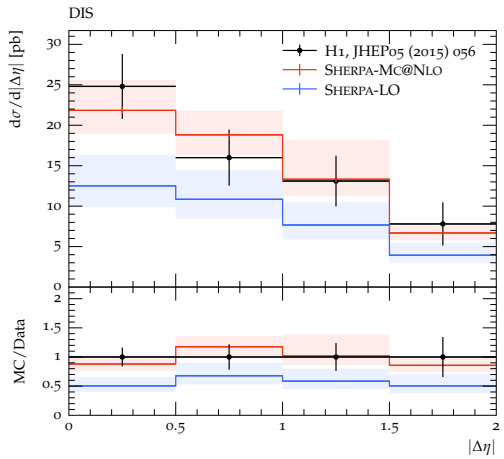
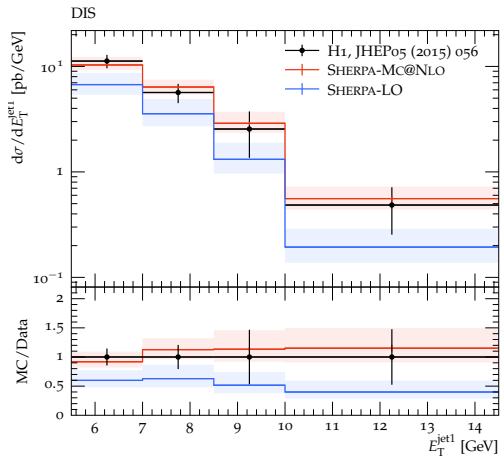


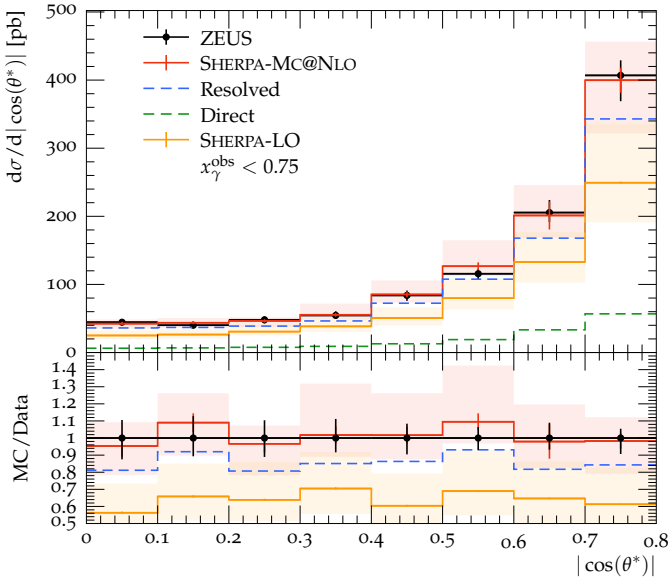


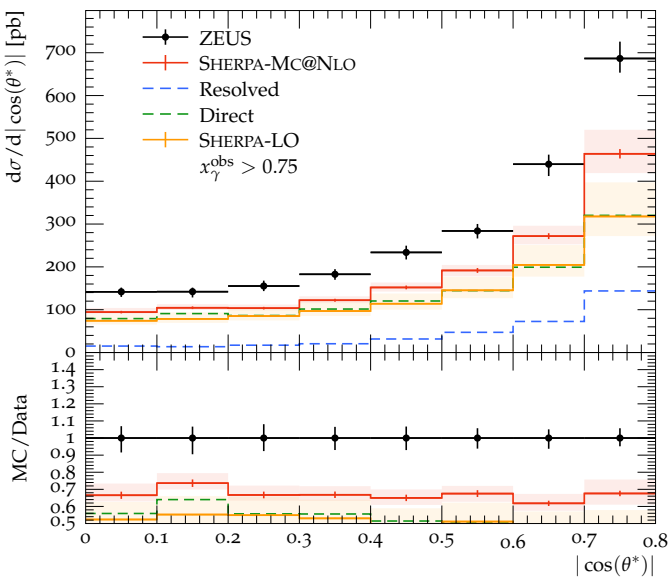


resolved photon production

(see also Hoche, FK, Meinzinger, 2310.18674)

- "resolved" photons (i.e. with QCD structure/PDF) at LEP & HERA
- use x_γ to disentangle direct and resolved photons
- $\cos\theta^* = \tanh\frac{\eta_1-\eta_2}{2}$



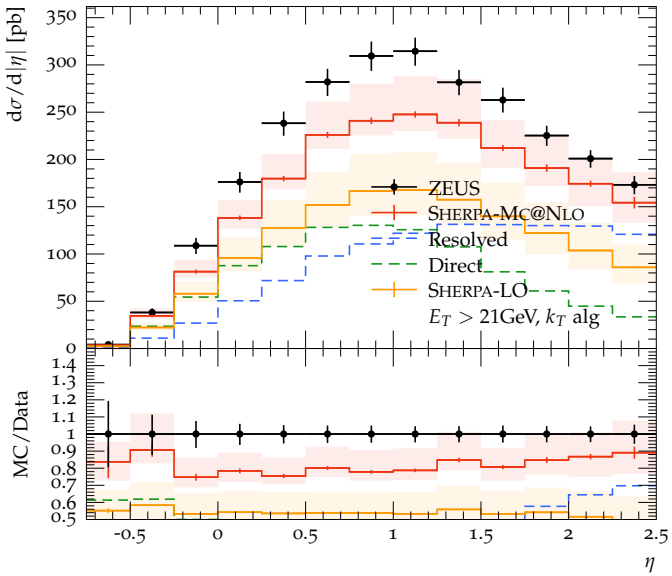


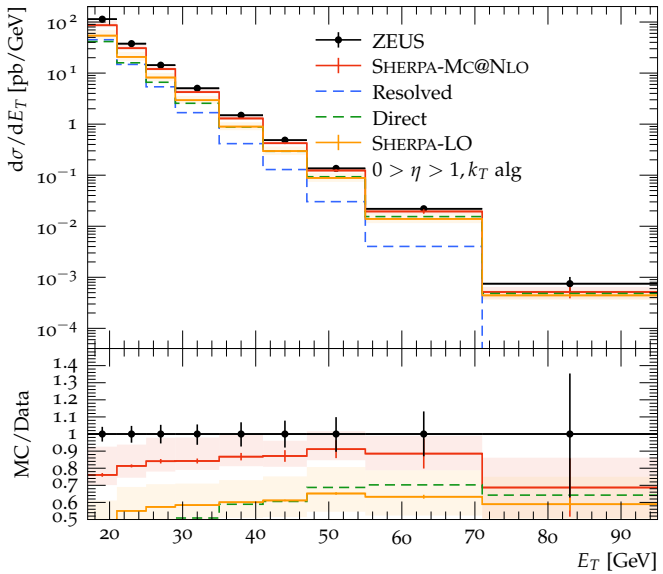
ZEUS, hep-ex/0112029

resolved photon production

(see also Hoche, FK, Meinzinger, 2310.18674)

- "resolved" photons (i.e. with QCD structure/PDF) at LEP & HERA
- use x_γ to disentangle direct and resolved photons
- η, $E_\perp$ of jets



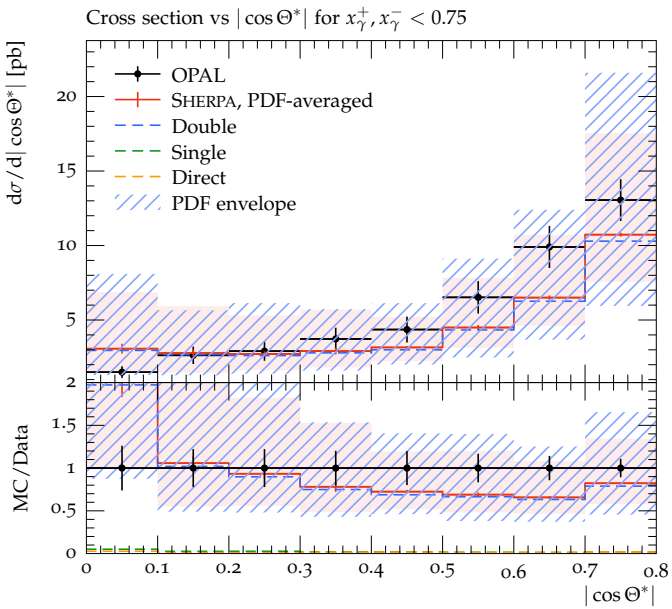


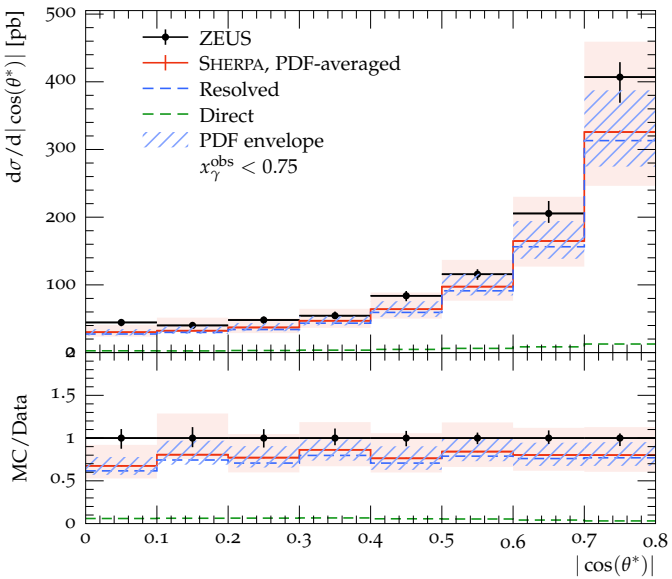
ZEUS, 1205.6153

resolved photon production

(see also Hoche, FK, Meinzinger, 2310.18674)

- "resolved" photons (i.e. with QCD structure/PDF) at LEP & HERA
- use x_γ to disentangle direct and resolved photons
- impact of photon PDFs





OPAL, hep-ex/0301013 ZEUS, hep-ex/0112029

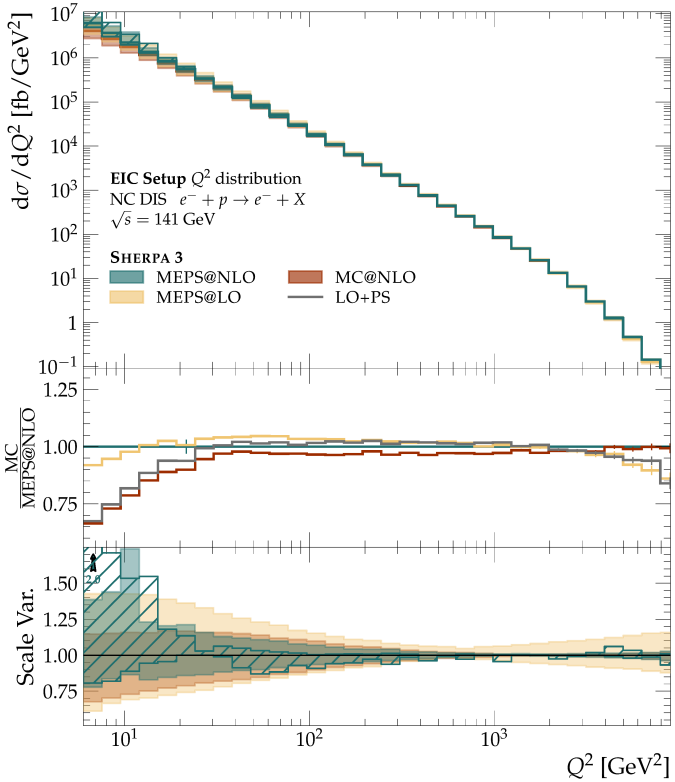
inclusive QCD @ EIC

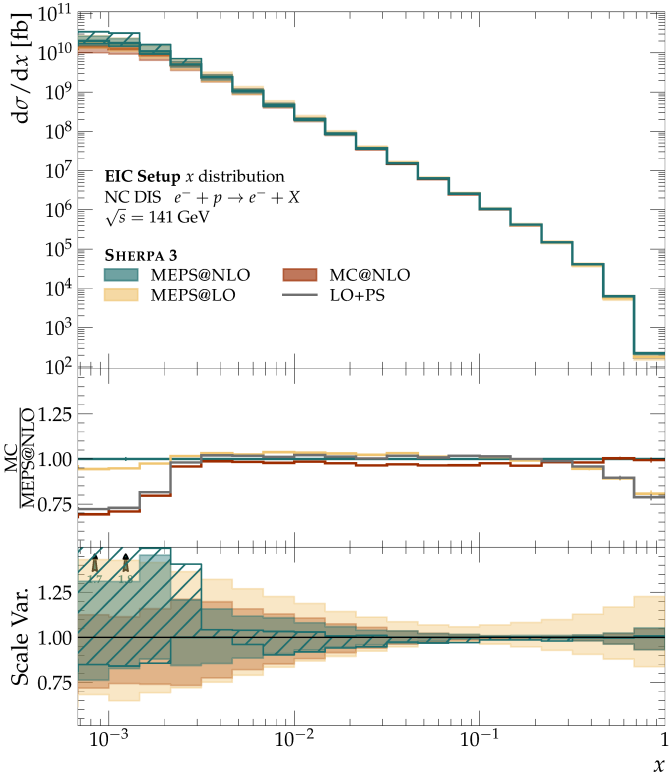
(extrapolating to the future)

neutral and charged current DIS

(see also Meinzinger, Reichelt, Silvetti, 2506.08994)

- consider charged current at HERA
- compare LO with NLO (as well as merged samples)
- inlcusive cross sections in different approximations

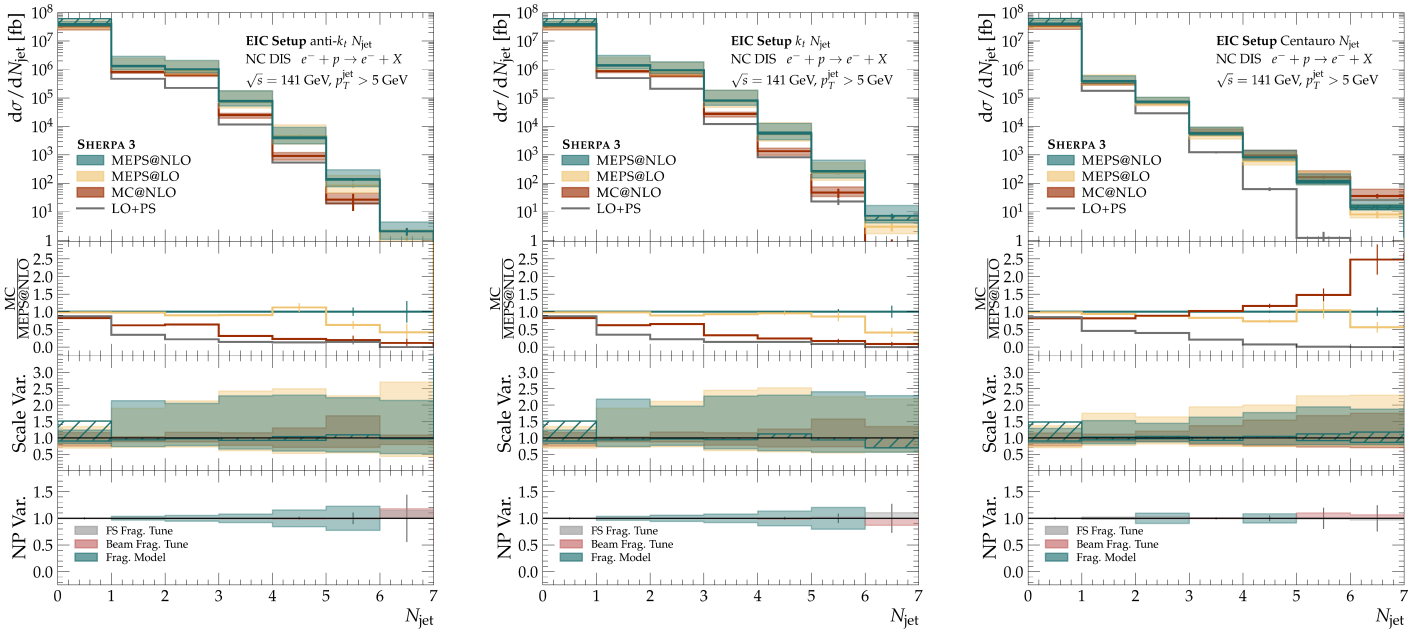




neutral and charged current DIS

(see also Meinzinger, Reichelt, Silvetti, 2506.08994)

- consider charged current at HERA
- compare LO with NLO (as well as merged samples)
- multijet cross sections with different jet definitions



neutral and charged current DIS

(see also Meinzinger, Reichelt, Silvetti, 2506.08994)

- consider charged current at HERA
- compare LO with NLO (as well as merged samples)
- 1-jetiness cross sections with different jet definitions

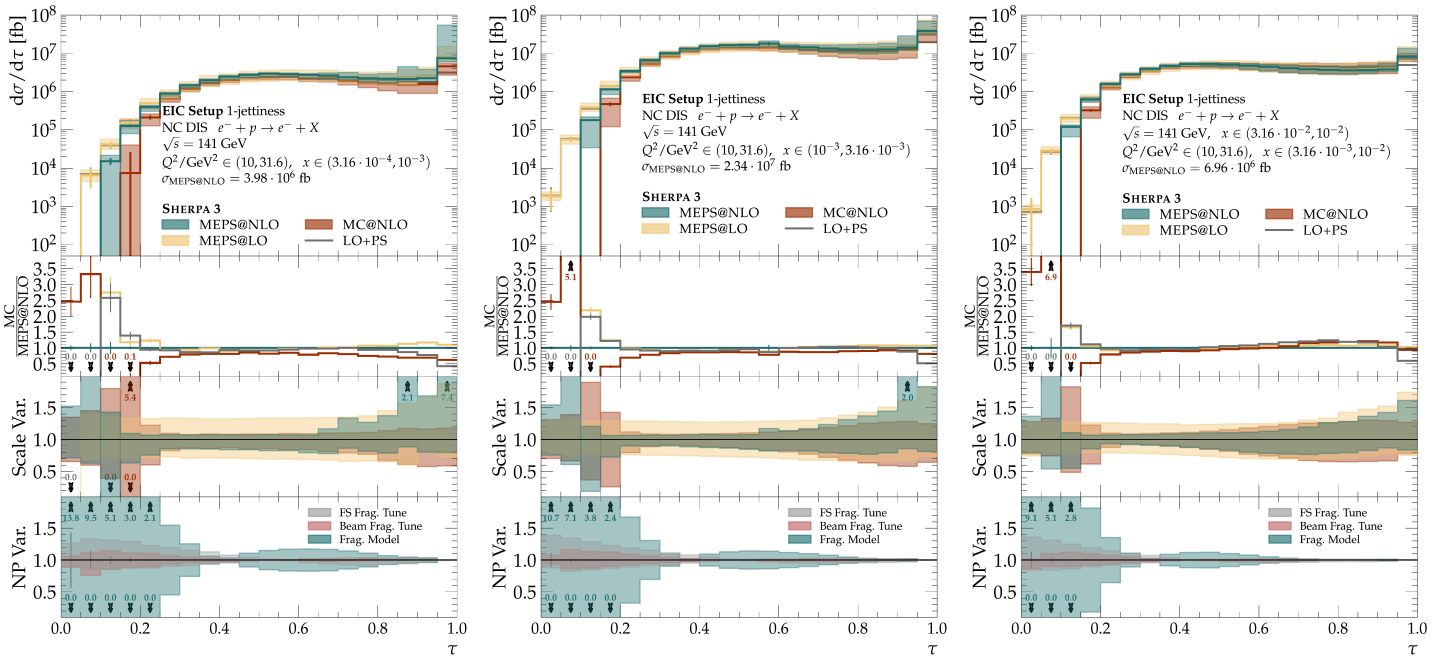
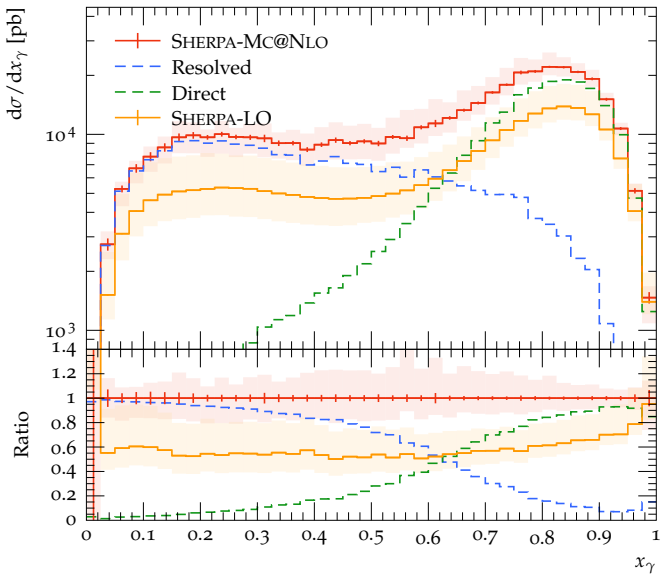


photo-production at EIC

(see also Meinzinger FK, 2311.14571)

- SHERPA simulations at NLO (K-factor $\approx 1.6\ldots2$)
- inclusive quantities: x, $E_\perp$ of leading jet



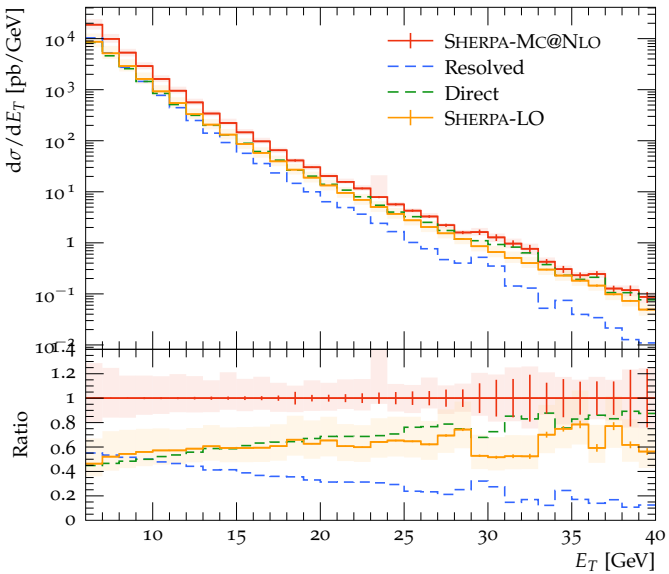
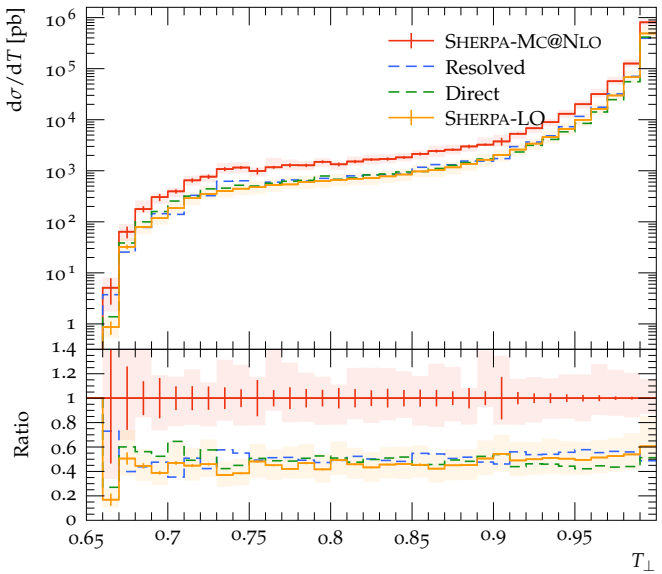


photo-production at EIC

(see also Meinzinger FK, 2311.14571)

- SHERPA simulations at NLO (K-factor $\approx 1.6\ldots2$)
- event shapes: thrust, thrust minor



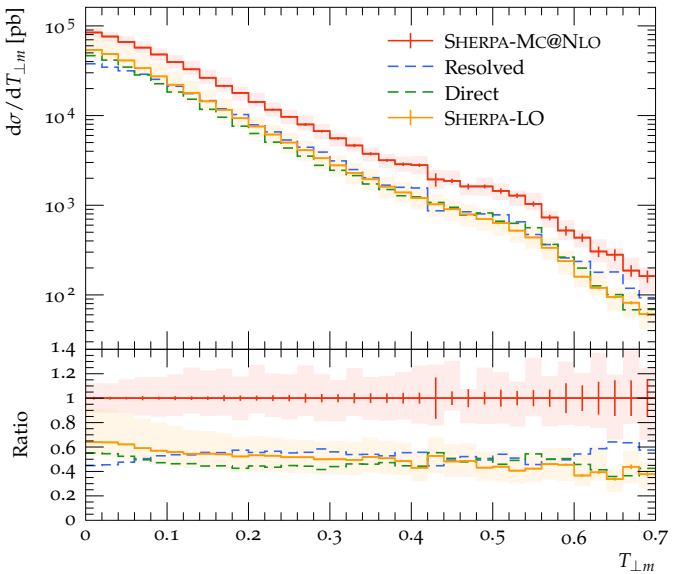
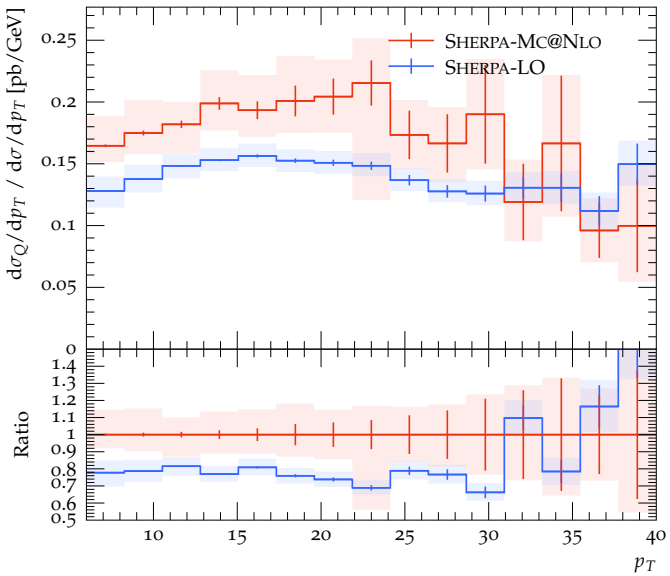
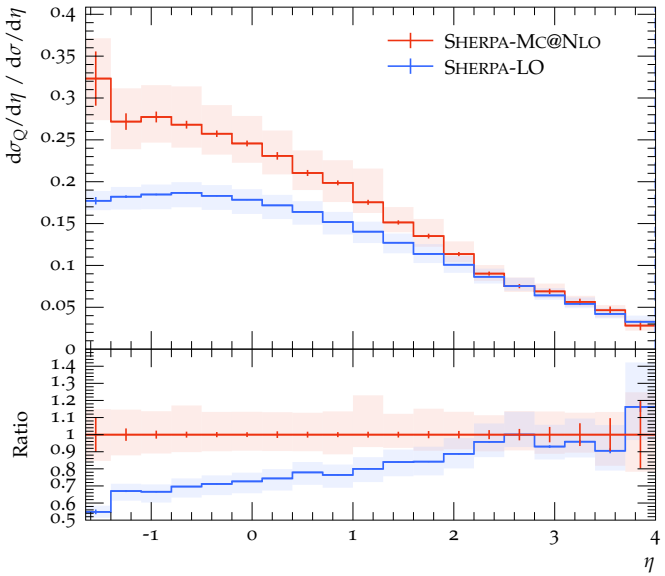


photo-production at EIC

(see also Meinzinger FK, 2311.14571)

- SHERPA simulations at NLO (K-factor $\approx 1.6\ldots2$)
- heavy quark (c, b) production





some new physics?

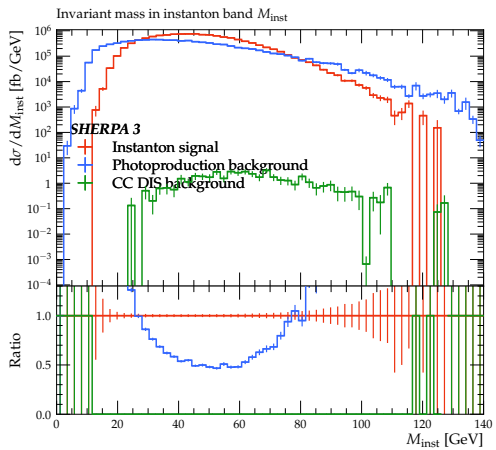
(instantons, anyone)

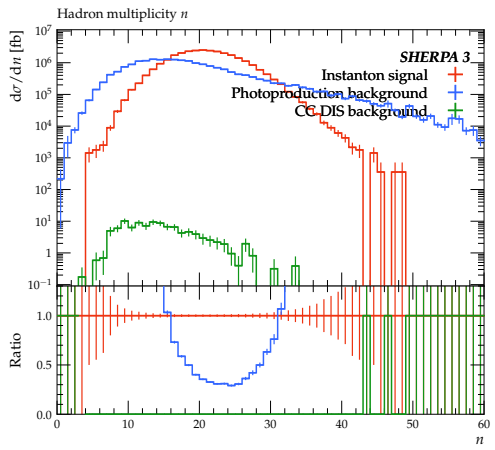
instantons?

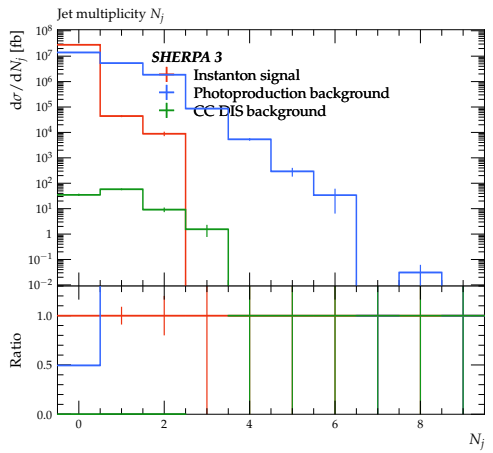
- (non-perturbative) solutions of QCD Lagrangian
- objects with extended size (think radius $\rho \approx 1\text{fm}$)
- cross sections have exp-dependence on $1/\alpha_S$
- massive scale dependence (factor 10) with "reasonable" scales
  (such as $\mu_R = \hat{s} = M_I^2$ or $\mu_R = 1/\rho$)
- instantons will decay isotropically into
  $u\bar{u} + d\bar{d} + s\bar{s} + (c\bar{c}) + (b\bar{b}) + Ng$
- production of heavy flavours subject to instanton mass
- multiplicity of N gluons "Poissonian"

signatures?

- consider production in resolved photo-production, no cuts
- use central scale $\mu_R = 1/\rho$ ($\mathcal{O}(1\ \text{GeV})$)
- inclusive quantities: invariant mass, hadron & jet multiplicity







signatures?

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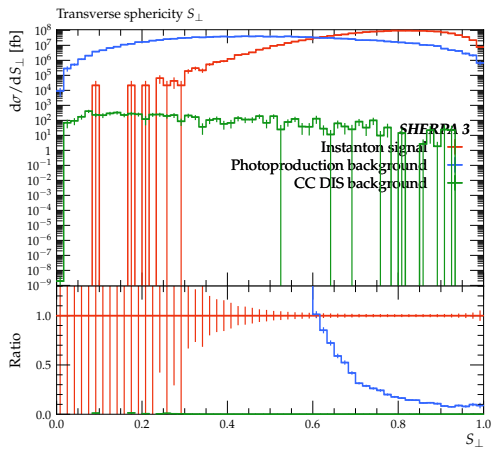
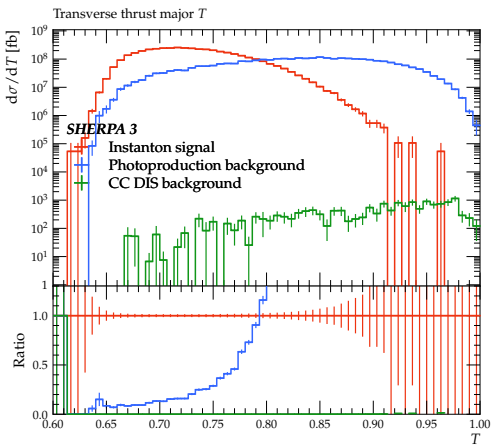
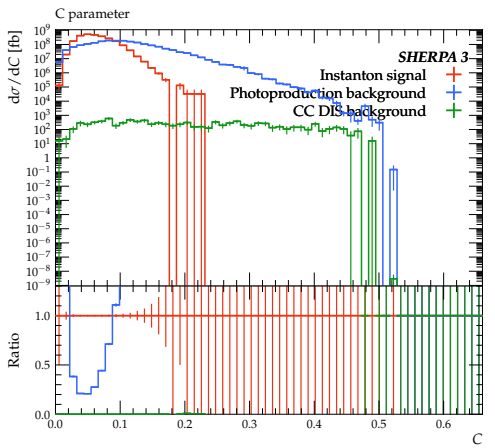
- use central scale $\mu_R = 1/\rho$ ($\mathcal{O}(1\ \text{GeV})$)
- event shapes: sphericity, thrust, C-parameter







summary & outlook

(the now and the future)

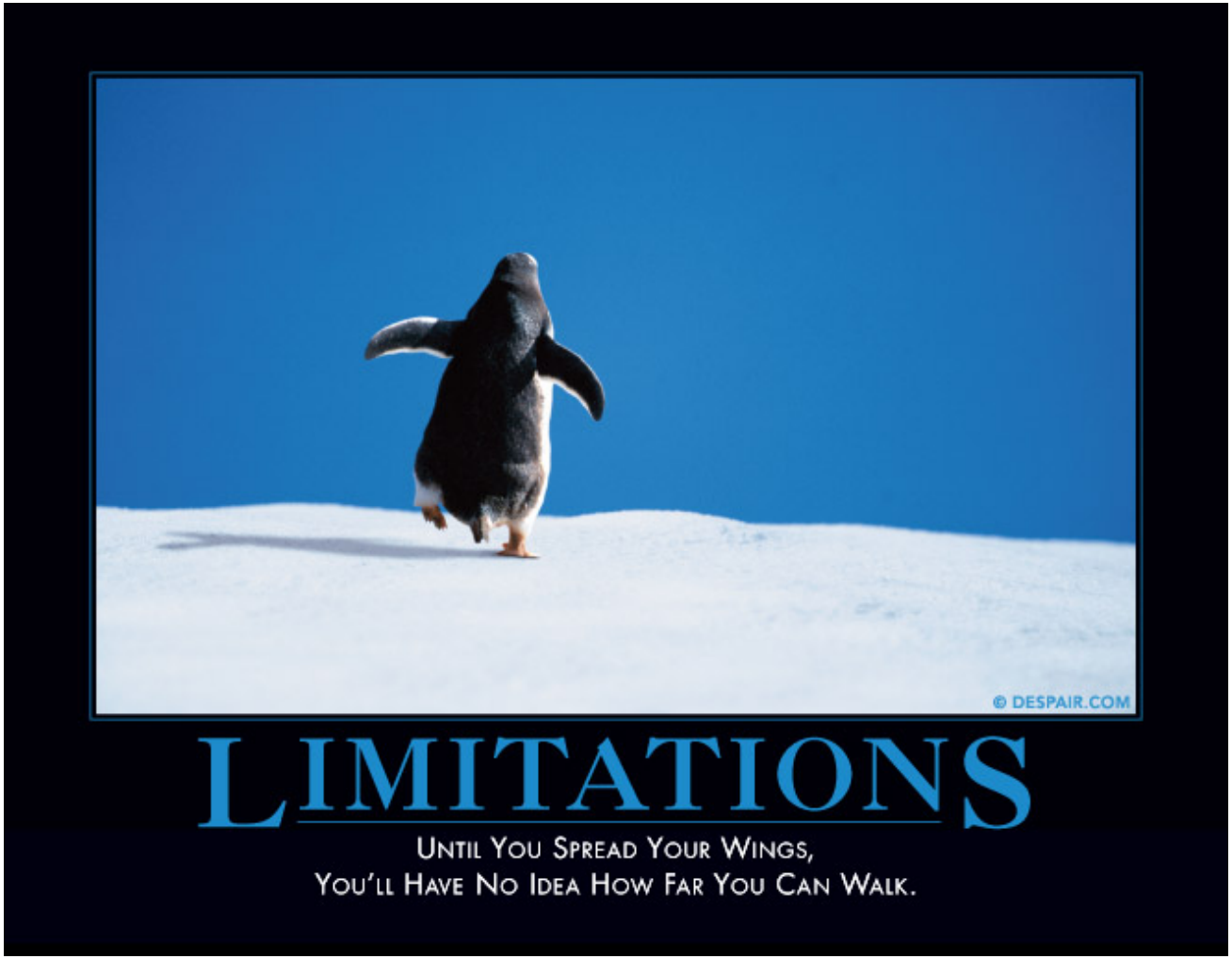
summary

- slowly upgrading DIS MC tools to industrial standard:
  - MC@NLO and MEPS@NLO becoming available
  - added photo-production @ NLO to the capabilities
  - verified/validated vs. HERA data
  - next steps: QED/EW corrections, MC@NNLO, MPIs
- opportunities for improvement beyond pert. theory:
  - *eA* collisions (the big one)
  - needed: updated photon PDFs
  - looking for "weird" physics signals
  - (re-)tuning of soft QCD models to exp. data

    (beam and FS fragmentation, nuclear fission, . . .)

    (add hist. data to HEPDATA +RIVET)
- personal prediction (unlimited youthful optimism):

  MCs will be ready for EIC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YOU'LL HAVE NO IDEA HOW FAR YOU CAN WALK.