Introduction
000

Sherpa for EIC
000000

outlook
000

# SHERPA for EIC

### Frank Krauss

Institute for Particle Physics Phenomenology
Durham University

1.3.2024 – EIC UK – York

Introduction
000

Sherpa for EIC
000000

outlook
000

- introduction

- SHERPA for EIC

- outlook

Introduction
○●○○

Sherpa for EIC
○○○○○○

outlook
○○○

# instead of an introduction

(executive summary)

Introduction
○●○

Sherpa for EIC
○○○○○○

outlook
○○○

# how to build an event generator

- paradigm: "divide et impera"
- divide simulation in distinct phases, with (logarithmically) separated scales
- start with signal event

    (fixed order perturbation theory)

- dress partons with parton shower

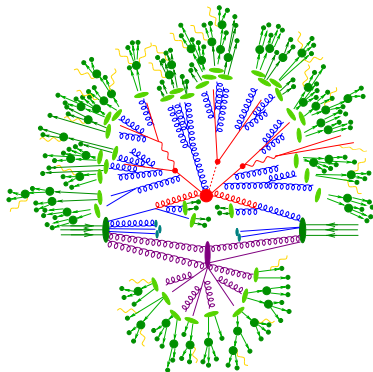    (resummed perturbatkon theory)

- add underlying event

    (phenomenological models)

- hadronize partons

    (phenomenological models)

- decay hadrons

    (effective theories, simple symmetries & data)

Introduction
○○●

Sherpa for EIC
○○○○○○

outlook
○○○

# precision frontier for LHC

✓ NNLO ⊗ parton shower for colour singlet production

(MINNLO: 1309.4634, 1407.2940, . . . , 2208.12660; UNNLOPS: 1405.4607, 1407.3773)

✓ NNLO ⊗ parton shower for heavy quarks

(MINNLO: 2112.04168 ($t\bar{t}$), 2302.01645 ($b\bar{b}$))

✓ MEPS@NLO: NLO multijet merging

(SHERPA: 1207.5030; MADGRAPH: 1209.6215; PYTHIA: 1211.7278; HERWIG: 1705.06700 plus follow-ups & refinements)

✓ all of the above including EW@NLO

(explicit: 1511.08692, 1705.00598, . . . , 2204.07652; Sudakov approximation: hep-ph/0010201, 2111.13453)

✓ (N)NLO ⊗ N$^{1,2,3}$LL ⊗ parton shower

(GENEVA: 1211.7049, 1508.01475, 2102.08390, . . . )

▶ multijet merging with TMDs                    (2107.01224, 2208.02276 (not covered here))

▶ improving parton showers

((next-to leading) logarithmic accuracy, amplitude evolution, . . . (not covered here))

Introduction
○○○

Sherpa for EIC
●○○○○○

outlook
○○○

# simulating *ep* collisions

(preparing for the future: HERA → EIC)

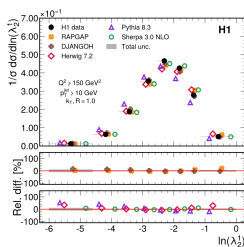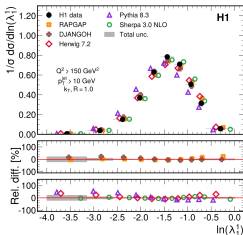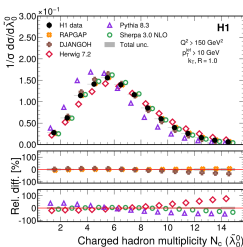Introduction
000

Sherpa for EIC
○●○○○○

outlook
000

## precision QCD studies at HERA

- "old" HERA data and analysis as boot-camp for EIC
- HERA = unique test-bed for (non-)perturbative QCD:
  - large-$Q^2$ DIS has no MPI $\longrightarrow$ initial state showering "clean"
    $\longrightarrow$ beam fragmentation "clean"
  - add HERA data to hadronization tunes?
- also: large photo-production cross section:
  - test hadronic structure of photon (relevant for EIC)
  - nota bene: last fits of photon-PDF are 20 years old
  - new fits urgently needed for EIC

  (that is, if we want to treat collinear factorisation as limiting case for TMD's etc..)

Introduction
ooo

Sherpa for EIC
ooo●ooo

outlook
ooo

# precision high-$Q^2$ QCD studies at HERA

- recent HERA analyses turn to modern MC's
  (HERWIG 7, PYTHIA 8, SHERPA)



H1 in 2303.13620: jet substructure in high-$Q^2$

Introduction
ooo

Sherpa for EIC
ooo●ooo

outlook
ooo

# precision high-$Q^2$ QCD studies at HERA

- recent HERA analyses turn to modern MC's

  (HERWIG 7, PYTHIA 8, SHERPA)



H1 in 2303.13620: jet substructure in high-$Q^2$

Introduction
000

Sherpa for EIC
000●00

outlook
000
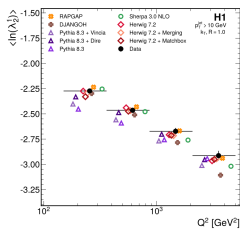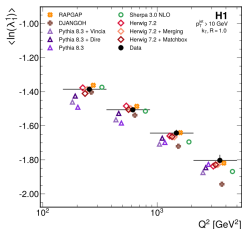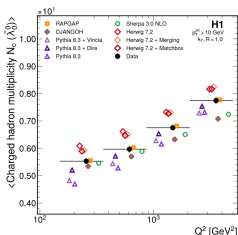
## resolved photon processes

(see also Hoche, FK, Meinzinger, 2310.18674)

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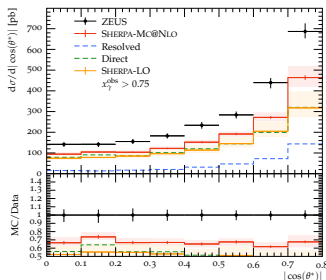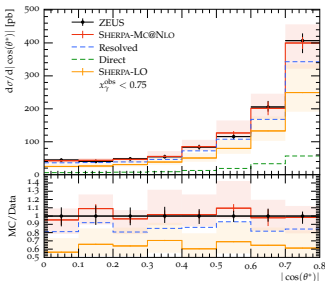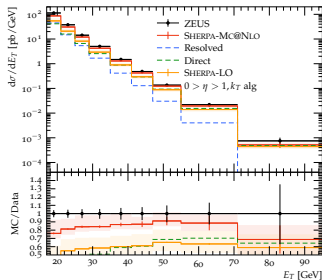- $\cos \Theta^* = \tanh \frac{\eta_1 - \eta_2}{2}$



OPAL, hep-ex/0301013

Introduction
000

Sherpa for EIC
000●00

outlook
000

# resolved photon processes

(see also Hoche, FK, Meinzinger, 2310.18674)

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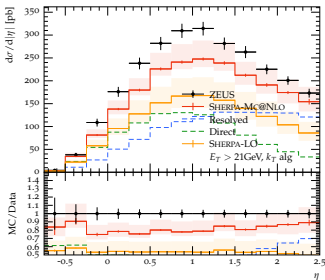- $\cos \Theta^* = \tanh \frac{\eta_1 - \eta_2}{2}$



ZEUS, hep-ex/0112029

Introduction
○○○

Sherpa for EIC
○○○●○○

outlook
○○○

# resolved photon processes

(see also Hoche, FK, Meinzinger, 2310.18674)

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



ZEUS, 1205.6153

Introduction
○○○

Sherpa for EIC
○○○●○○

outlook
○○○

# resolved photon processes

(see also Hoche, FK, Meinzinger, 2310.18674)

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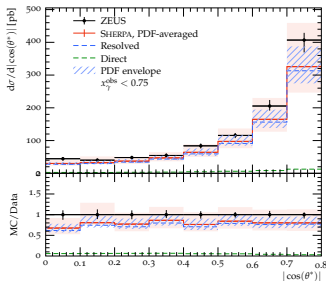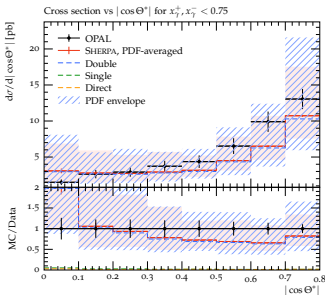


OPAL, hep-ex/0301013  ZEUS, hep-ex/0112029

Introduction
000

Sherpa for EIC
0000●00

outlook
000

# a quick peak to diffraction

(FK Meinzinger, in prep.)

- diffraction modelled with pomeron PDF
- compare with data from HERA (diff.mass)
- sneak preview (LO only) below

Introduction
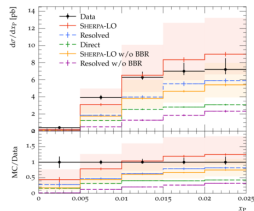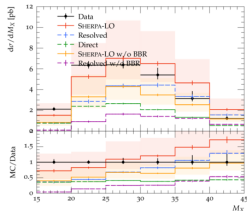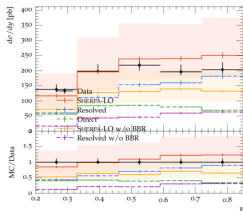○○○

Sherpa for EIC
○○○○○○●

outlook
○○○

# photo-production at EIC

(see also Meinzinger FK, 2311.14571)

- SHERPA simulations at NLO ($K$-factor $\approx 1.6 \ldots 2$)

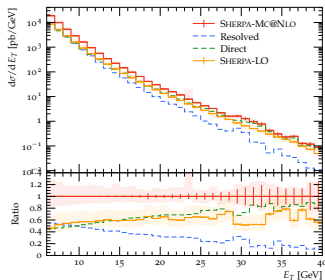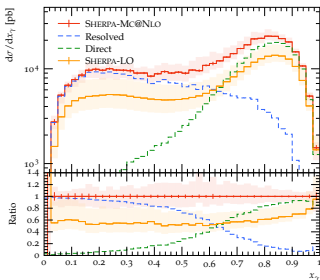- inclusive quantities: $x$, $E_\perp$ of leading jet

Introduction
ooo

Sherpa for EIC
oooooo●

outlook
ooo

## photo-production at EIC

- SHERPA simulations at NLO ($K$-factor $\approx 1.6\ldots2$)

- event shapes: thrust, thrust minor
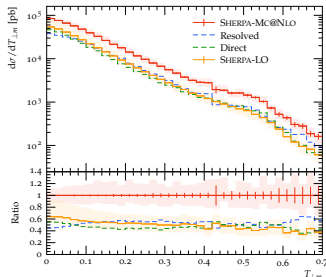
Introduction
ooo

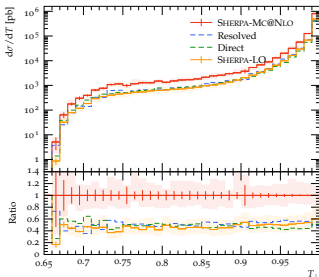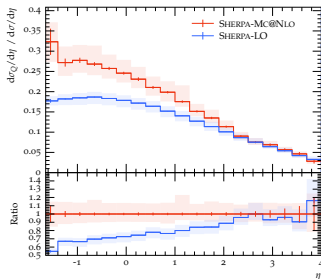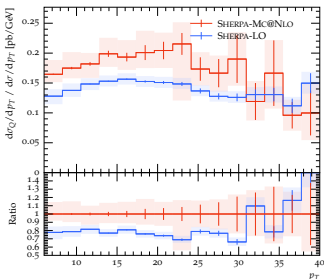Sherpa for EIC
oooooo●

outlook
ooo

# 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

Introduction
○○○

Sherpa for EIC
○○○○○○

outlook
●○○

# summary & outlook

## (the now and the future)

Introduction
ooo

Sherpa for EIC
oooooo

outlook
o●o

## summary

✓ simulations for LHC in healthy shape

(ongoing progress in hunt for ultimate perturbative accuracy, " getting more 'N's' into game")

- how about non-perturbative effects?  (hadronization, MPI's, etc.)
- very limited experience of DIS community with modern MC tools
  - need to use HERA data as boot-camp: RIVET etc.
- photo-production important part of cross section, but:
  - last fit for photon PDF from beginning 2000's
  - no systematic tune of MPI's in $\gamma p$ collisions
  - no systematic tune of forward fragmentation

Introduction
○○○

Sherpa for EIC
○○○○○○

outlook
○○●