

Monte-Carlo event generators for EIC

EICUG THEORY WG MEETING ON MONTE CARLO

Ilkka Helenius

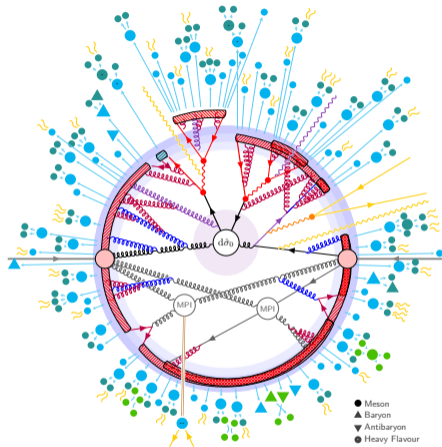
Frank Krauss

February 15th, 2024



Outline

1. Event generators
 - General purpose
 - Specific purpose
2. Validation
 - Rivet analyses
 - Recent projects
3. MC4EIC Workshop in June



[figure by P. Skands]

General-purpose event generators

Simulate full collision events

Exclusive hadronic final states

- Hard parton-level scattering
- Multiparton interactions
- Parton showers, NLO matching & multi-jet merging
- Hadronization, colour reconnection, rescattering

Electron-ion collisions

- DIS: $Q^2 \ll 1 \text{ GeV}^2$
- Photoproduction: $Q^2 \approx 0$
- Heavy-ion target

HERWIG 7

- Current version 7.3.0
- DIS with NLO merging
- Photoproduction in progress

PYTHIA 8

- Current version 8.310
- Photoproduction with PS and MPI
- DIS: Dipole shower, Vincia, Dire

SHERPA 2

- Current version 2.2.15 (3.0.0beta1)
- DIS with matching & merging
- Photoproduction at NLO

Matrix-element generators

- Madgraph5
 - Up to ~ 4 jets for DIS
 - Direct processes in photoproduction
- Powheg
 - Some first studies but currently not applicable

Other relevant tools

- Cascade
 - TMDs
- Sartre
 - Exclusive vector mesons
- Beagle
 - Nuclear remnants
- EpIC
 - Exclusive processes
- eHijing
 - Cold nuclear matter hadronization

Event generator validation

Many processes relevant to EIC available in current event generators

⇒ Should be tested against existing data

- **HERA:** DIS and photoproduction on proton target
Jets, charged-particle production, event shapes, two-particle correlations
- **LEP:** $\gamma\gamma$ collisions, DIS on real-photon target
Jets, charged-particle production
- **LHC:** UPCs with low-virtuality photons on protons and nuclei
Jets, charged-particle production, two-particle correlations

Validation exercise

- Common effort with experimental colleagues to define important observables
- Support from generator developers for run cards and other technicalities
- RIVET analysis crucial for validation of the current generation of MC generators

Rivet analysis for HERA data

- [H1_1994_S2919893](#) - © H1 energy flow and charged particle spectra in DIS
- [H1_1995_I394793](#) - © A Study of the Fragmentation of Quarks in ep Collisions at HERA
- [H1_1995_S3167097](#) - Transverse energy and forward jet production in the low- x regime at H1
- [H1_1996_I421105](#) - © Inclusive D^0 and D^{*+} production in deep inelastic e p scattering at HERA
- [H1_1996_I422230](#) - © Charged particle multiplicities in deep inelastic scattering at HERA
- [H1_1996_I424463](#) - © Transverse momentum spectra of charged particles in DIS (H1 1996)
- [H1_1997_I445116](#) - © Evolution of e p fragmentation and multiplicity distributions in the Breit frame
- [H1_1998_I477556](#) - © Charged-particle photoproduction analysis
- [H1_1999_I481112](#) - © Measurement of D^* meson cross-sections at HERA and determination of the gluon density in
- [H1_1999_I504022](#) - © Forward π^0 meson production at HERA
- [H1_2000_S4129130](#) - © H1 energy flow in DIS
- [H1_2002_I561885](#) - © Measurement of $D^{*\pm}$ meson production in deep inelastic scattering at HERA
- [H1_2005_I676166](#) - © Measurement of beauty production at HERA using events with muons and jets (H1)
- [H1_2006_I699835](#) - © Measurement of Event Shape Variables in Deep-Inelastic Scattering at HERA
- [H1_2006_I711847](#) - © Dijet photoproduction analysis
- [H1_2007_I736052](#) - © Measurement of inclusive production of D^* mesons both with and without dijet production in
- [H1_2007_I746380](#) - Tests of QCD Factorisation in the diffractive production of dijets in deep-inelastic scattering and
- [H1_2009_I810046](#) - © Strangeness Production at low Q^2 in Deep-Inelastic ep Scattering at HERA
- [H1_2013_I1217865](#) - © Charged particle production in deep-inelastic ep scattering at H1
- [H1_2015_I1343110](#) - Diffractive dijets in DIS and photoproduction
- [HERA_2015_I1353667](#) - Combined H1/ZEUS D^* production cross-sections in DIS
- [HERA_2015_I1377206](#) - © Measurement of σ_{red} (F2) of H1 and ZEUS at different beam energies

Rivet analysis for HERA data

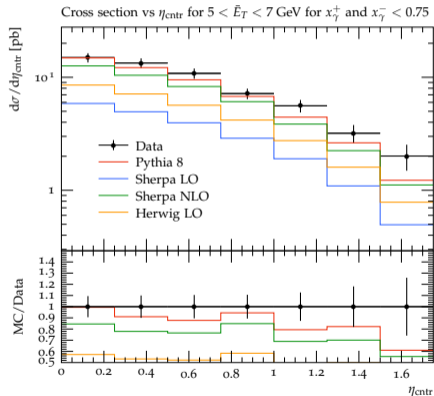
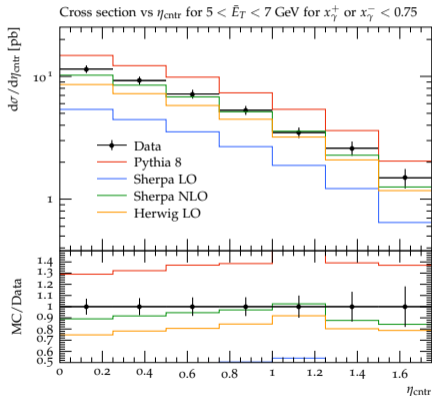
- ZEUS_1995_I392386 - ® Charged particle multiplicity and momentum spectra in Breit frame at ZEUS
- ZEUS_1995_I395196 - ® Neutral strange particle production in deep inelastic scattering at HERA (ZEUS)
- ZEUS_1996_I420332 - ® Measurement of the F2 structure function in deep inelastic e+ p scattering using 1994 data from
- ZEUS_1997_I450085 - ® Dijet photoproduction analysis
- ZEUS_1999_I470499 - ® Forward jet production in deep inelastic scattering at HERA (ZEUS)
- ZEUS_1999_I500267 - ® Measurement of High- Q^2 Neutral-Current e^+p Deep Inelastic Scattering Cross-Sections at HERA
- ZEUS_1999_I508906 - ® Measurement of the $E^{*2}(T, \text{jet}) / Q^{*2}$ dependence of forward jet production at HERA
- ZEUS_2000_I524911 - ® Measurement of azimuthal asymmetries in deep inelastic scattering
- ZEUS_2001_S4815815 - ® Dijet photoproduction analysis
- ZEUS_2008_I763404 - Diffractive photoproduction of dijets
- ZEUS_2008_I780108 - ® Multi-jet cross-sections in charged current $e^\pm p$ scattering at HERA
- ZEUS_2008_I810112 - ® Measurement of D^\pm and D^0 production in deep inelastic scattering using a lifetime tag at HERA
- ZEUS_2010_I875006 - ® ZEUS dijet cross sections in NC DIS
- ZEUS_2011_I945935 - Scaled momentum distributions for K_S^0 and $\Lambda/\bar{\Lambda}$ in DIS at HERA
- ZEUS_2012_I1116258 - ® Inclusive-jet photoproduction at HERA and determination of the strong coupling

- Slow but steady progress on adding new analysis
- Currently 37 HERA analysis included (out of 510)
- Which of these are the most relevant for EIC?
- Are some important analyses missing?

Comparison of Pythia, Sherpa and Herwig for jet photoproduction

IH, P. Meinzinger, S. Plätzer, *in progress*

[OPAL_2003_I611415]

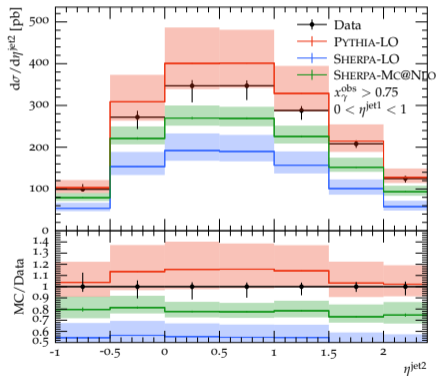
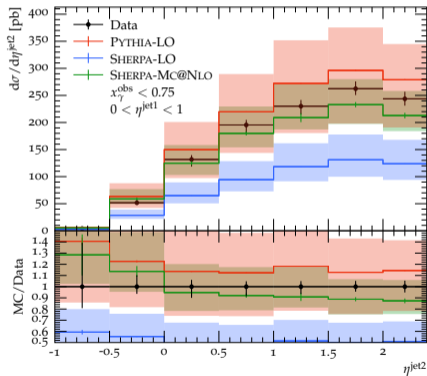


Recent/ongoing projects

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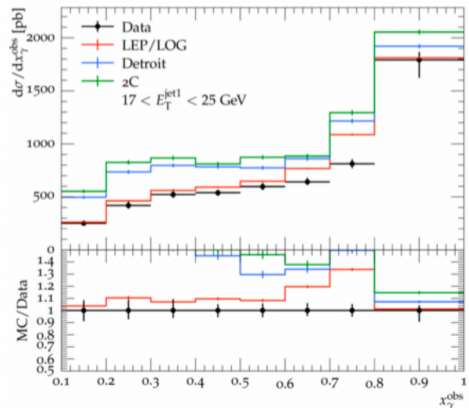
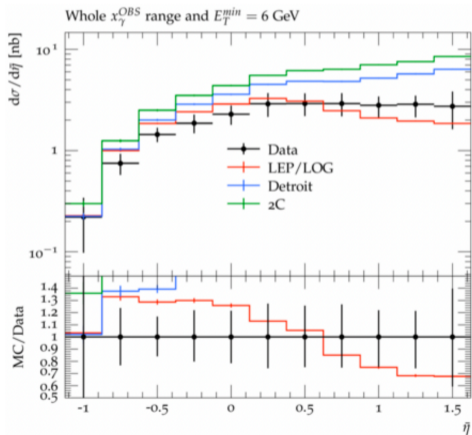
[ZEUS_2001_S4815815]



Recent/ongoing projects

Tuning PYTHIA photoproduction using HERA & LEP data

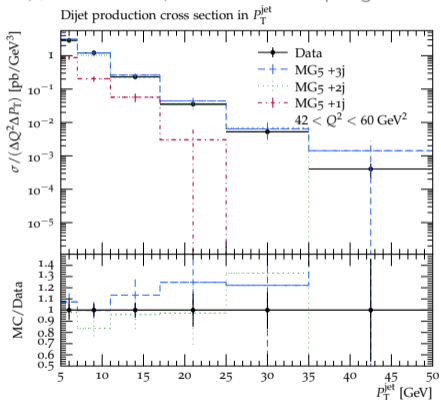
J. Butterworth, IH, J.J. Juan Castella, S. Sanjrani M. Wing: *in progress*



Recent/ongoing projects

Multi-jet merging in DIS with PYTHIA

IH, J. Laulainen, C.T. Preuss: *in progress*

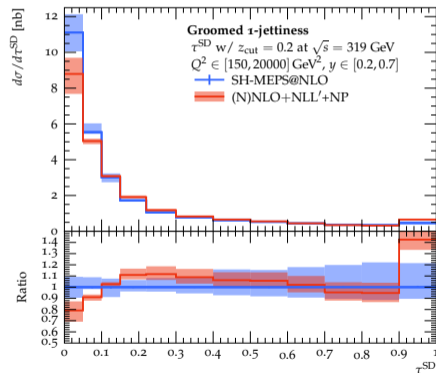


[H1_2002_I588263]

MEPS@NLO with SHERPA

M. Knobbe, D. Reichelt, S. Schumann:

JHEP 09 (2023) 194

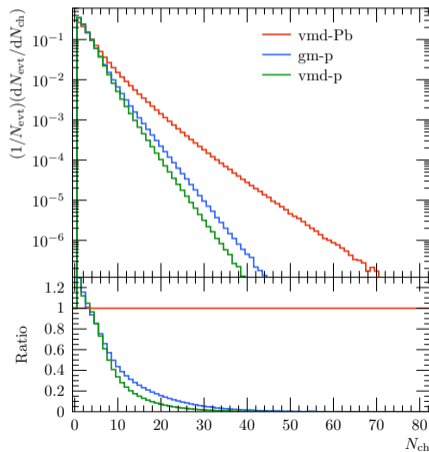
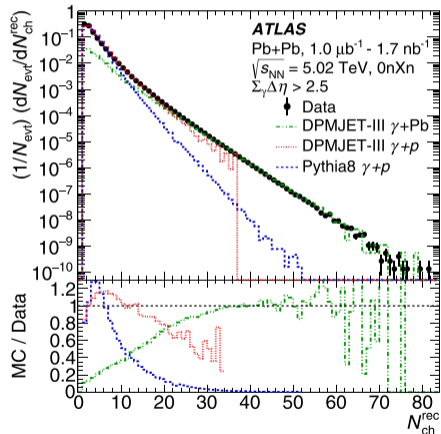


Recent/ongoing projects

Photon-ion collisions with ANGANTYR in PYTHIA using vector-meson dominance

[ATLAS: PRC 104, 014903 (2021)]

IH, M. Uhteim: *in progress*



- Dates: June 5-7 2024
- Location: Durham (in person meeting!)
- Topics to be covered:
 - Status of general purpose event generators for DIS and photoproduction
 - Lessons from the LHC
 - Non-perturbative modelling
 - Tuning/validation with HERA and other data
 - Missing RIVET analyses?
 - Ion targets
 - Specialized tools and interfacing
 - Experimental and theory needs

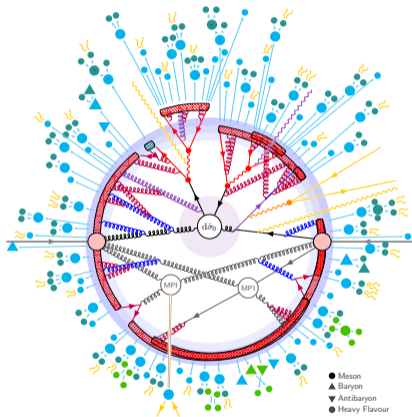
Summary & Outlook

Summary

- Plenty of recent developments on general purpose MC generators
- Validation and tuning required
 - ⇒ Data as RIVET analysis
 - ⇒ Input from experimental side

Outlook

- Many things still to improve
 - Nuclear target
 - Phase-space between DIS and photoproduction



[figure by P. Skands]

Summary & Outlook

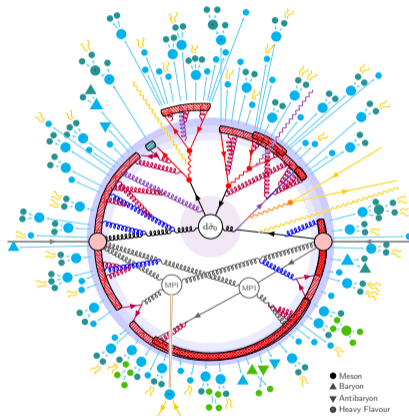
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Outlook

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⇒ See you in Durham!



[figure by P. Skands]