Inclusive QCD: simulating diffraction

MC4EIC workshop, IPPP, Durham Uni
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Outline

1. Brief overview and theory introduction
2. Experimental data
3. Diffractive DIS
4. Diffractive Photoproduction & factorisation breaking
5. Missing analyses and impact of EIC
6. Conclusion

Disclaimer: lists will be incomplete,
focus on latest/recent software

Very brief introduction to Diffraction

as seen at HERA

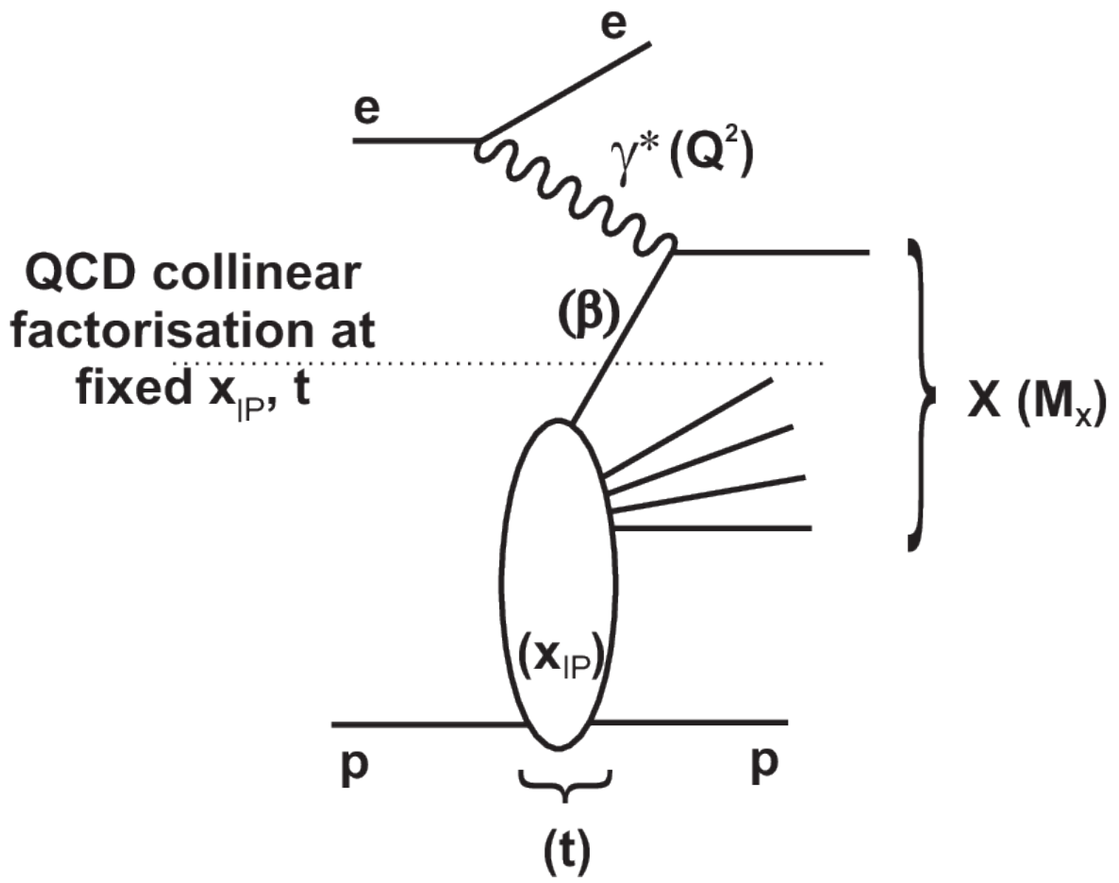
- Process of type $ep \to eX + Y$, where $+$ denotes a separation in rapidity
- Y is an intact proton or a low-mass excitation
- Experimental identification relies on either
  - **large rapidity gaps** or
  - **proton tagging**

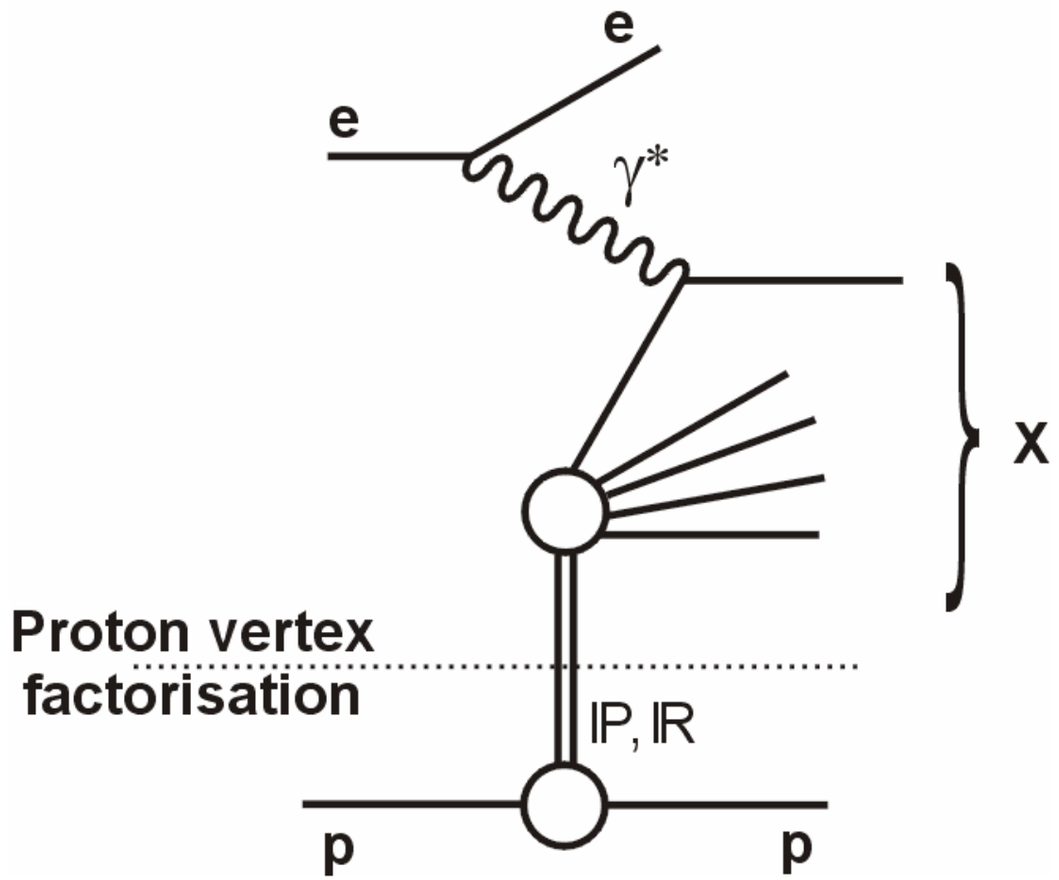
Diffractive processes made up 10% of the total cross-section in DIS!

see [Rev.Mod.Phys. 86 (2014) 3, 1037] for comprehensive review

Factorisation of diffraction

Introduction of Diffractive PDFs





$$d\sigma^{ep\to eXY}(x, Q^2, x_{\mathrm{IP}}, t) = \sum_i f_i^D(x, Q^2, x_{\mathrm{IP}}, t) \otimes d\hat{\sigma}^{ei}(x, Q^2)$$

[Phys. Rev. D 57, 3051]

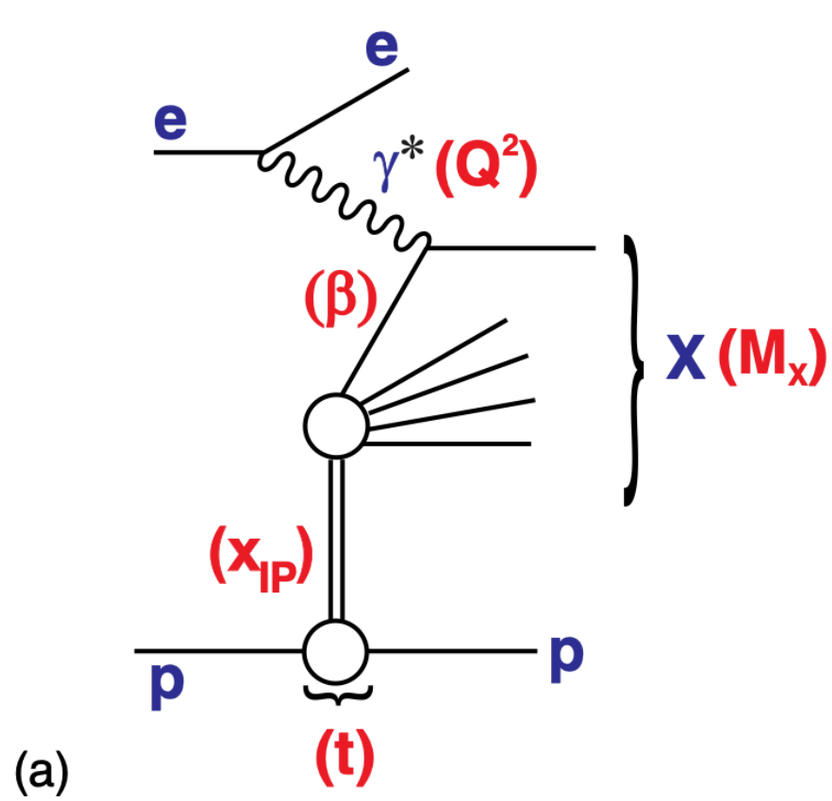
$$f_i^D(x, Q^2, x_{\mathrm{IP}}, t) = f_{\mathrm{IP}/p}(x_{\mathrm{IP}}, t) f_i(\beta = x/x_{\mathrm{IP}}, Q^2)$$

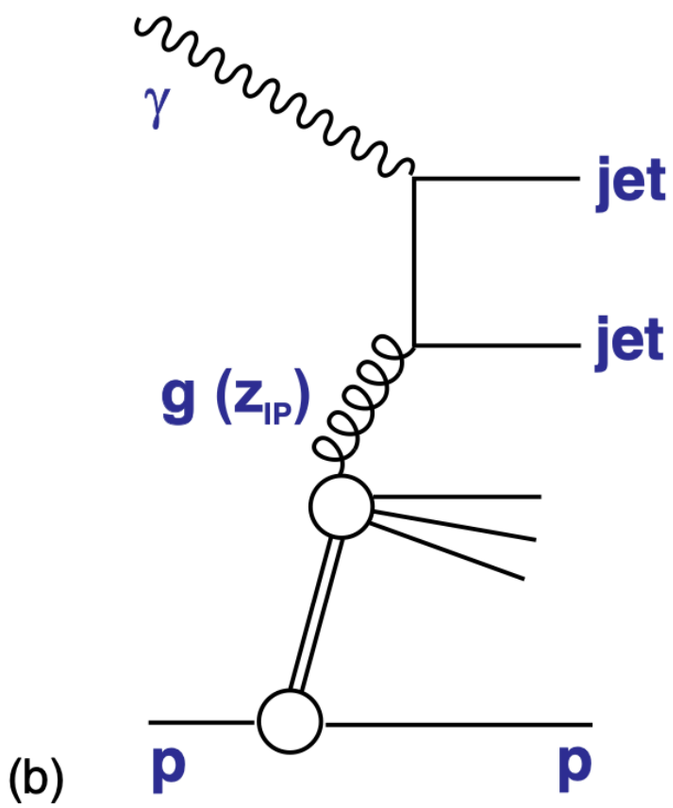
[Phys. Lett. 152B, 256]

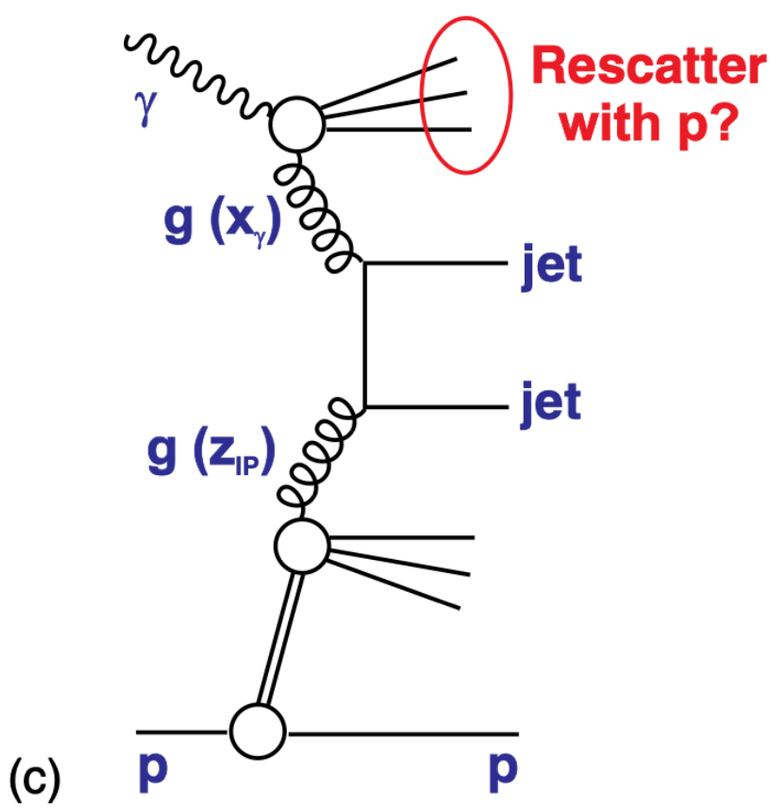
Diffraction

Contributions to the cross-section

taken from [Rev.Mod.Phys. 86 (2014) 3, 1037]







Diffractive DIS

Diffractive Photoproduction

Factorisation formula

- Including the sub-leading Reggeon term, the DPDFs factorise as

$$f_i^D\left(x, \mu_F, x_{I\!P}, t\right) = f_{I\!P/P}\left(x_{I\!P}, t\right) f_{i/I\!P}\left(x, \mu_F\right) + n_{I\!R} f_{I\!R/P}\left(x_{I\!P}, t\right) f_{i/I\!R}\left(x, \mu_F\right)$$

- The Pomeron and Reggeon flux can be fitted with

$$f_{I\!P/P}\left(x_{I\!P}, t\right) = A_{I\!P} \frac{e^{B_{I\!P} t}}{x_{I\!P}^{2\alpha_{I\!P}(t)-1}}$$

- Pomeron PDF needs fitting to data
- Reggeon PDF $\approx$ pion PDF
- Diffractive Photoproduction additionally needs sum over direct- and resolved-photon component

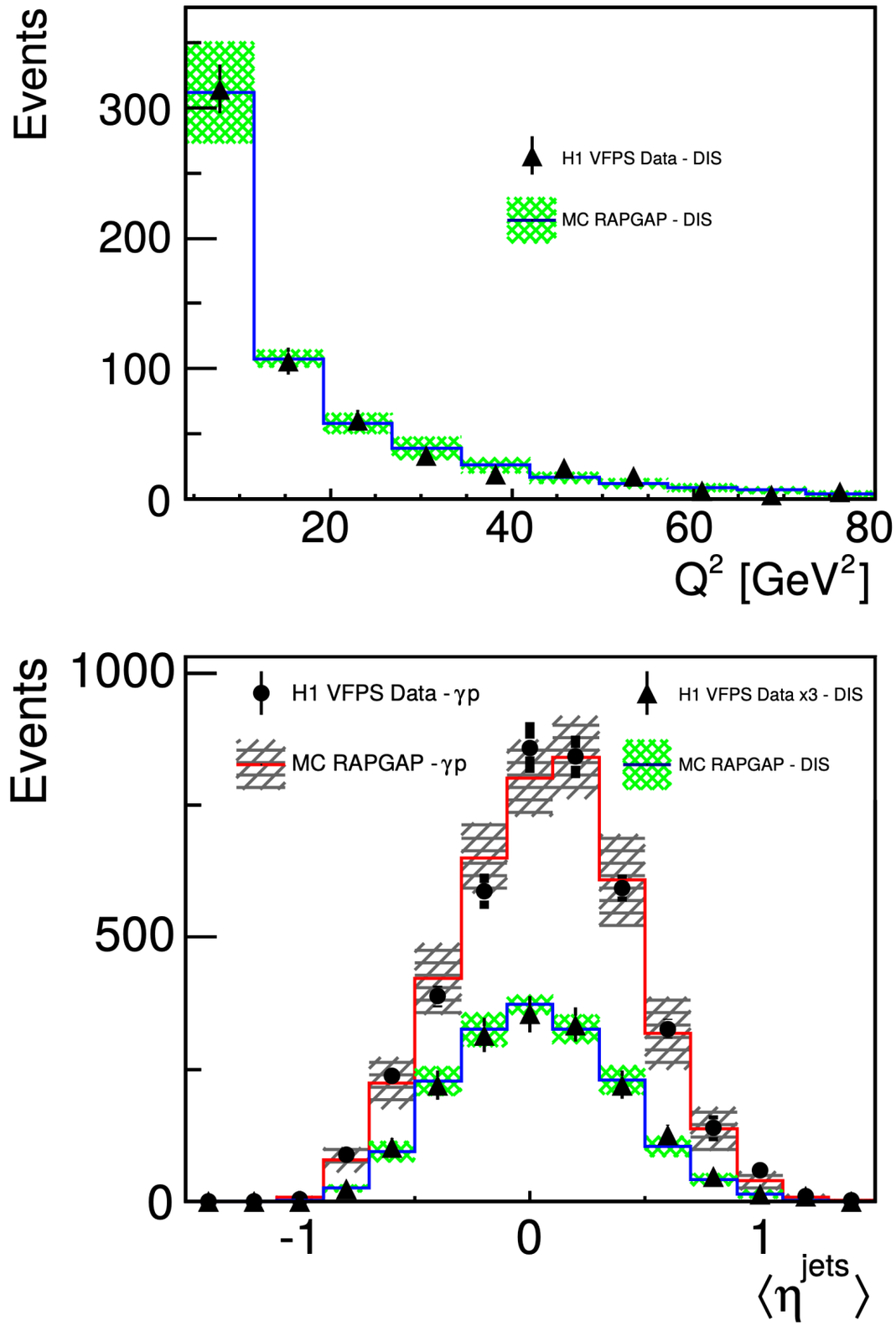
Experimental data

Experimental data

- Dissociative events with $M_Y < 1.6\ \mathrm{GeV}^2$ account for an additional 20% in cross-section; flat in phase space
  - needs to be accounted for in the DPDFs/event generation
- Need to cut on longitudinal proton momentum loss
- LRG method has higher statistics, but Proton Tagging method is cleaner and allows for better reconstruction
- Data mostly inclusive or dijet measurements
- Different fits of DPDFs at NLO from the H1, ZEUS and other collaborations

RAPGAP

- Was de-facto standard for diffraction at HERA
- Based on LO matrix elements and interfaces to PYTHIA
- Works for both, Diffractive DIS and Photoproduction
- Status/future support unknown

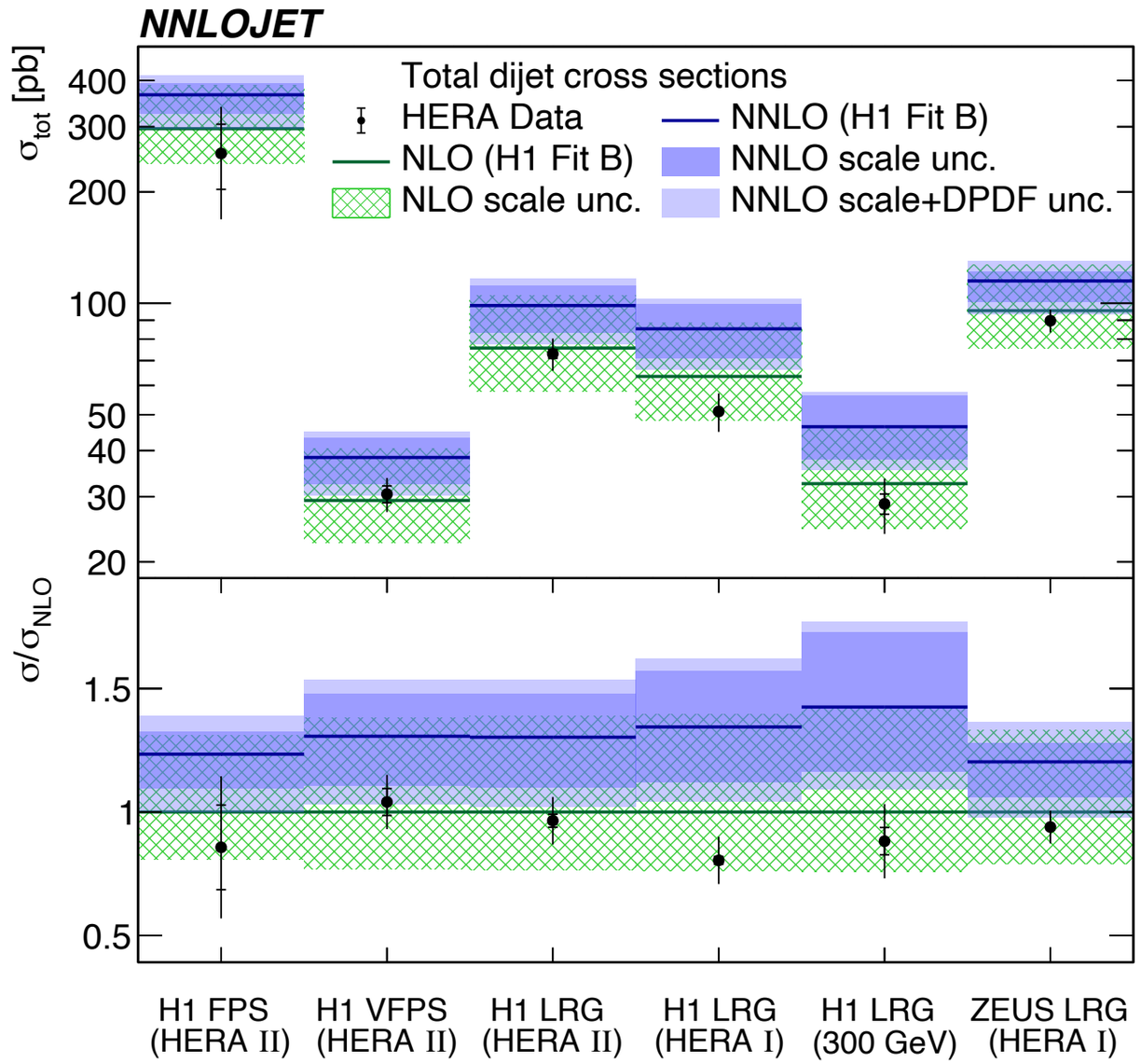


Diffractive DIS

Fixed Order

NNLO in *Eur.Phys.J.C 78 (2018) 7, 538*

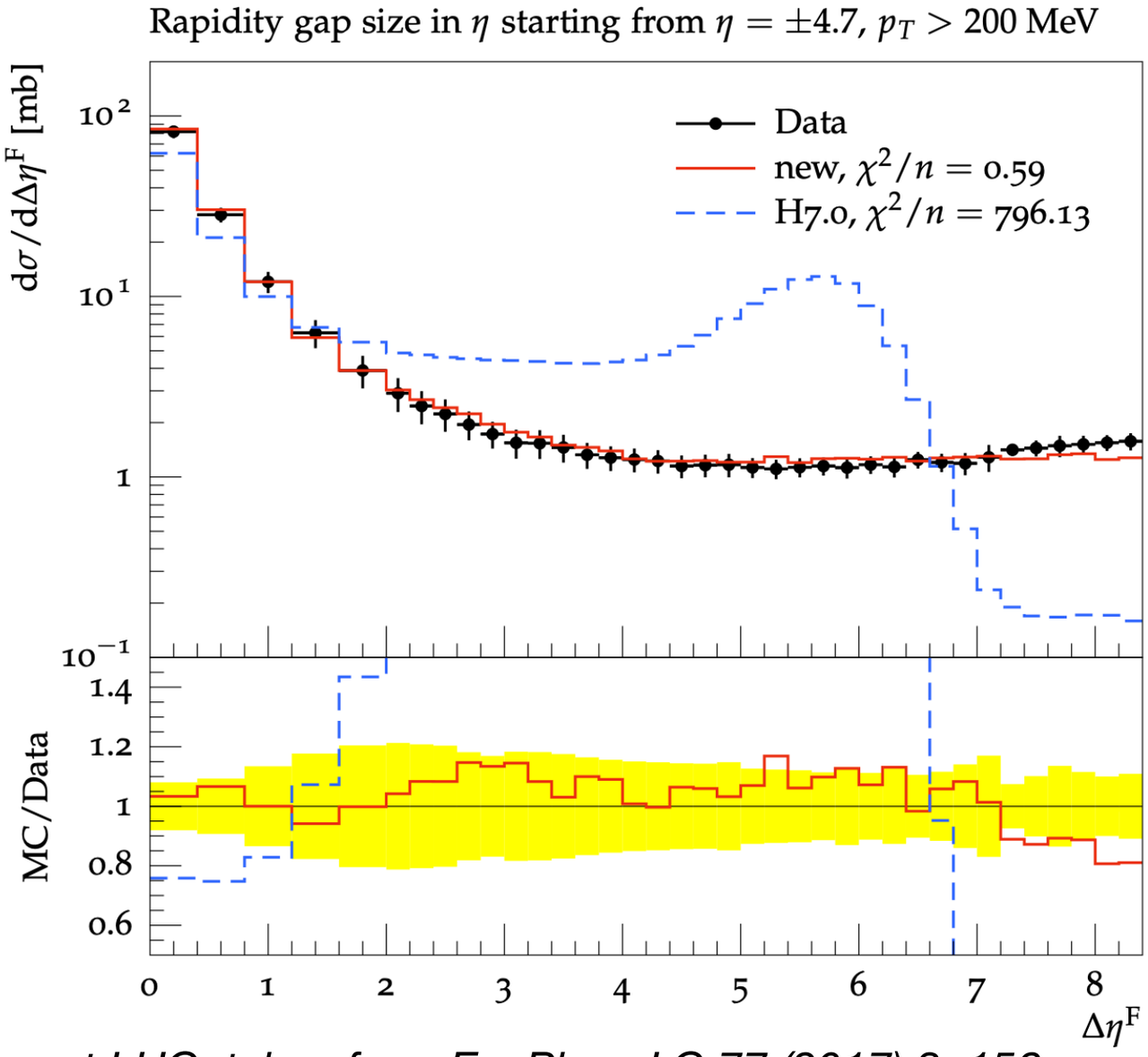
- Fixed Order calculation with NNLOJET, looking at H1 and ZEUS diffractive dijet data
- Review of scale choice and PDF uncertainty
- Large differences in DPDFs between fits to inclusive versus dijet data
- Measurements with different tagging methods are found to be consistent
- Overshoot attributed to the use of NLO DPDFs in the calculation



Event generation

HERWIG in *Comput.Phys.Commun. 144 (2002) 104-110*

- Module POMWIG in Herwig 5.9, allows for diffractive jet production in ep collisions
- More recently, soft diffraction for LHC setups, c.f. *Eur.Phys.J.C 77 (2017) 3, 156*



Rapidity gaps at LHC, taken from Eur.Phys.J.C 77 (2017) 3, 156

Event generation

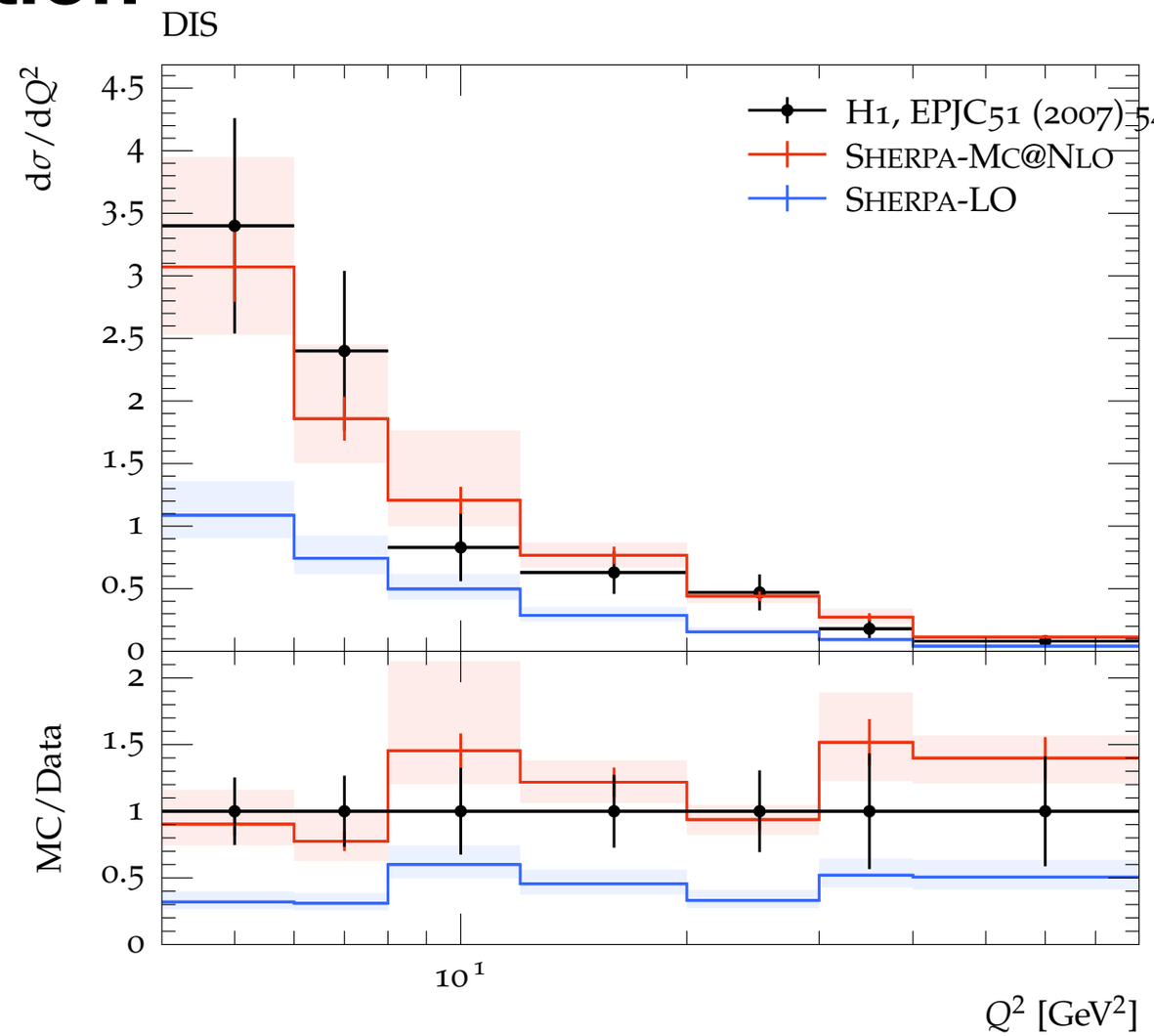
SHERPA, forthcoming publication

- Event simulation at MC@NLO accuracy, will be published in version 3.0.x

- Internal interface to H1 2006 DPDF, more via LHAPDF

- Interface to Rivet and HepMC3

- Hadronisation tuned to LEP data



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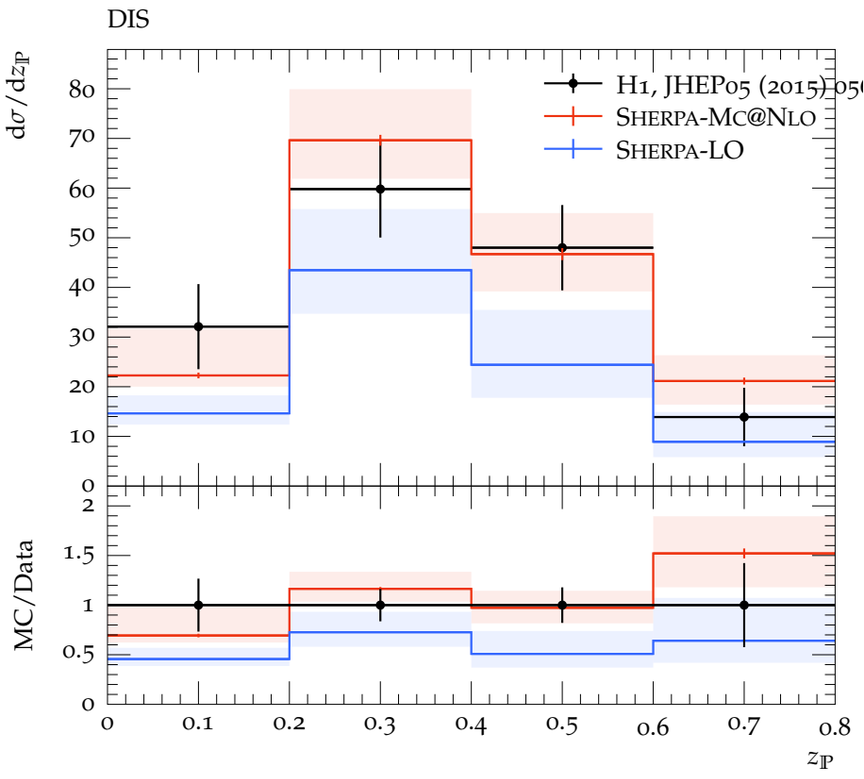
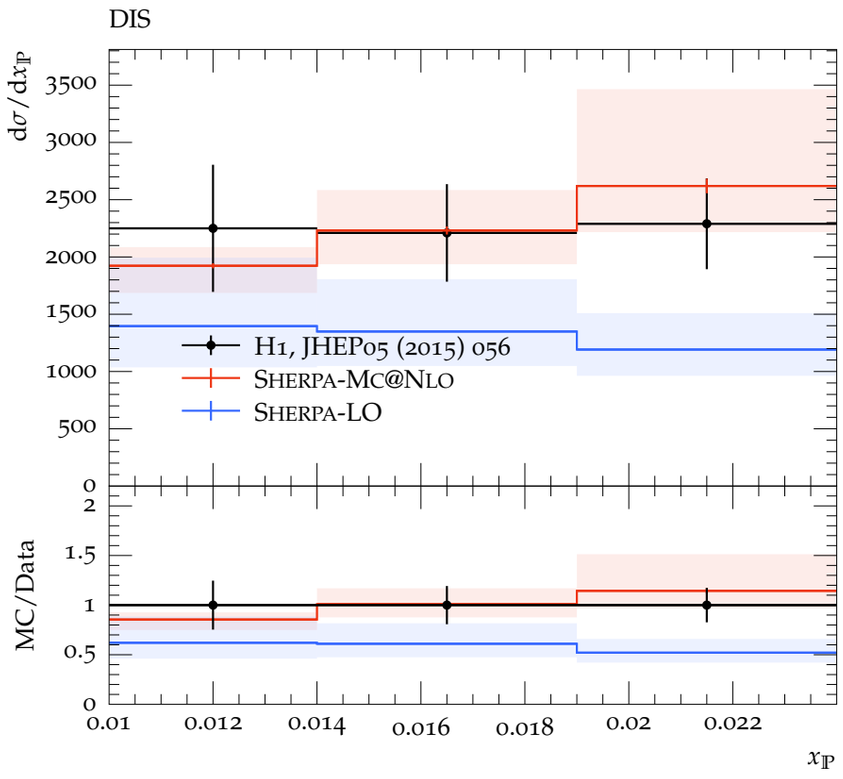
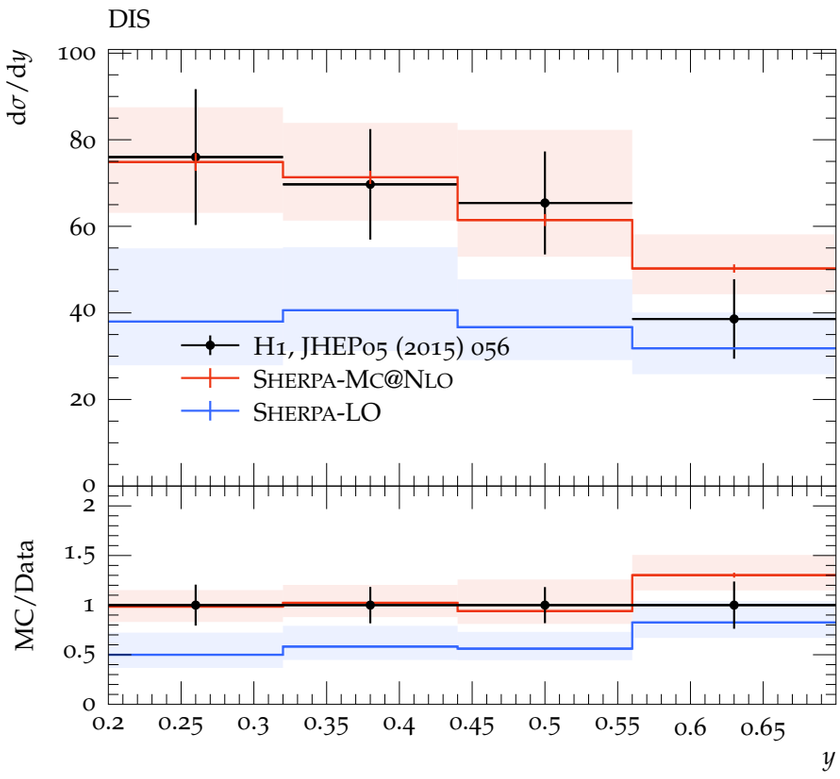




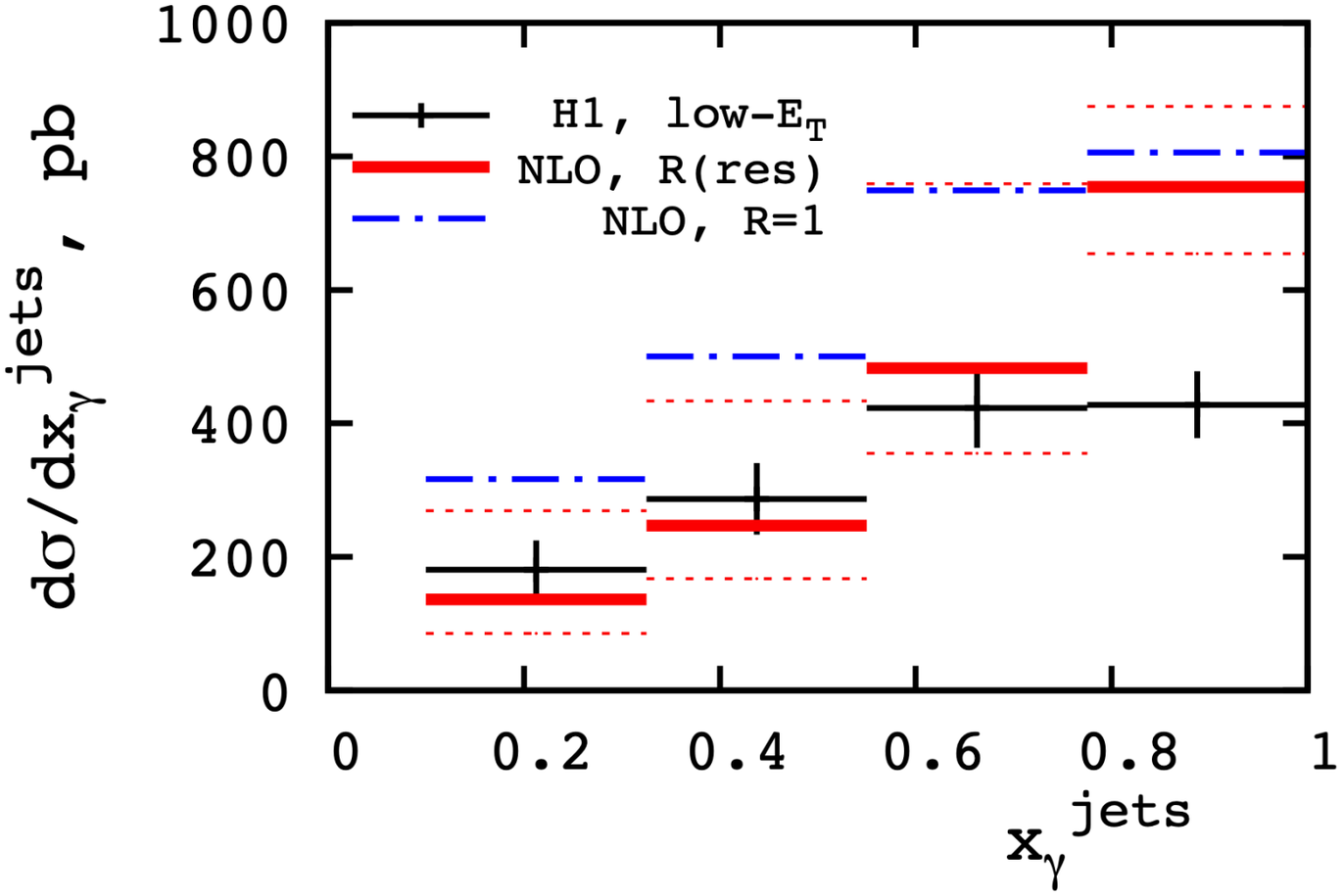


Diffractive Photoproduction

Fixed Order

Publications by Klasen and Kramer at NLO

- Published in *Eur.Phys.J.C 38 (2004) 93-104* and *Mod.Phys.Lett.A 23 (2008) 1885-1907*
- Follow-up study by Guzey and Klasen for the EIC in *JHEP 05 (2020) 074*

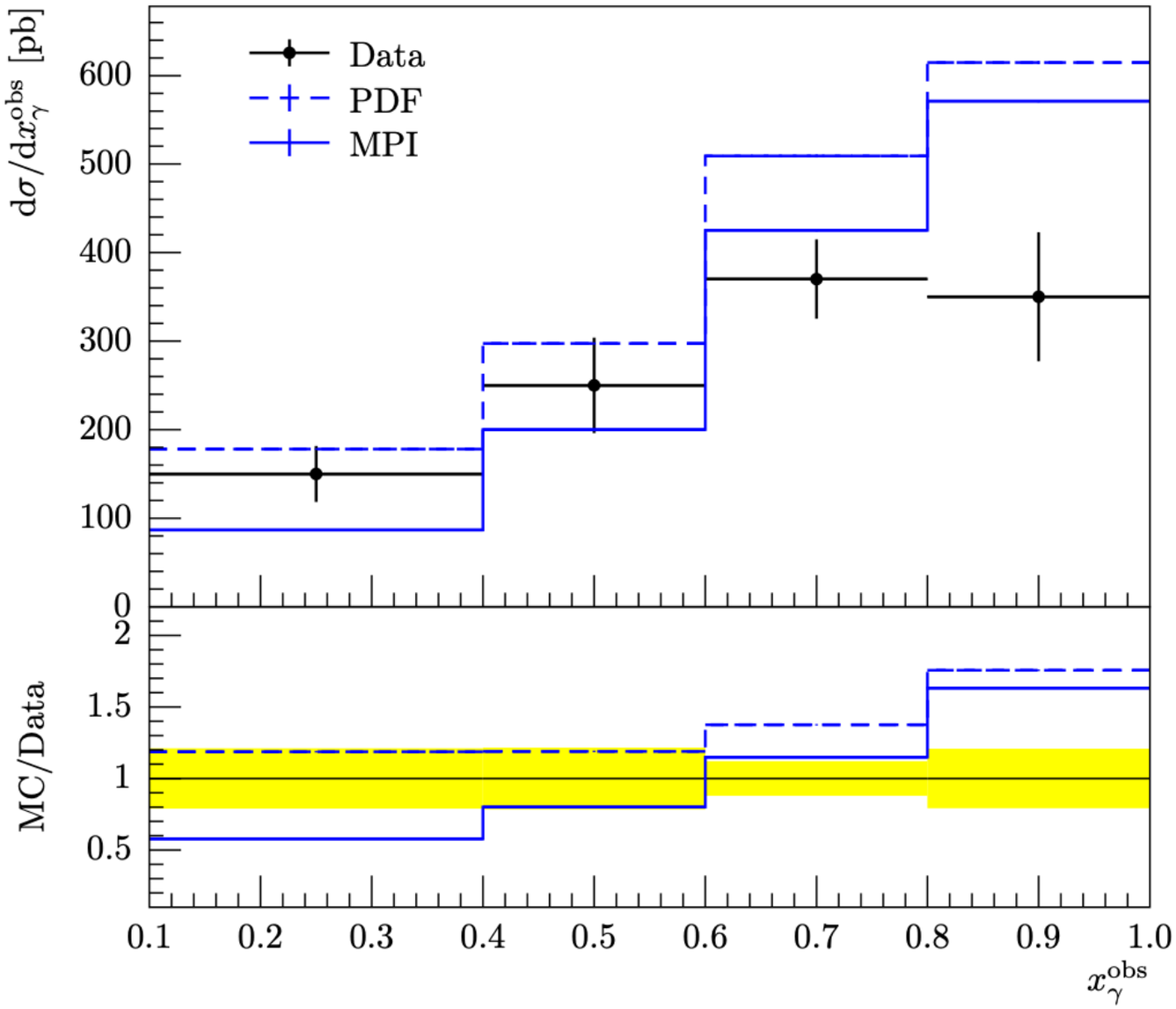


taken from Guzey and Klasen, Eur.Phys.J.C 76 (2016) 8, 467

Event generation

PYTHIA in *Eur.Phys.J.C 79 (2019) 5, 413*

- Leading Order with Parton Shower
- Includes a MPI-based modelling of rapidity gap survival
- Applicable to UPC with proton target too
- Focussed study on scale uncertainty, DPDFs variation and MPI (i.e. gap survival) tuning
- PYTHIA also includes parametrisation of soft diffraction and elastic scattering
- Interface to Rivet and HepMC3



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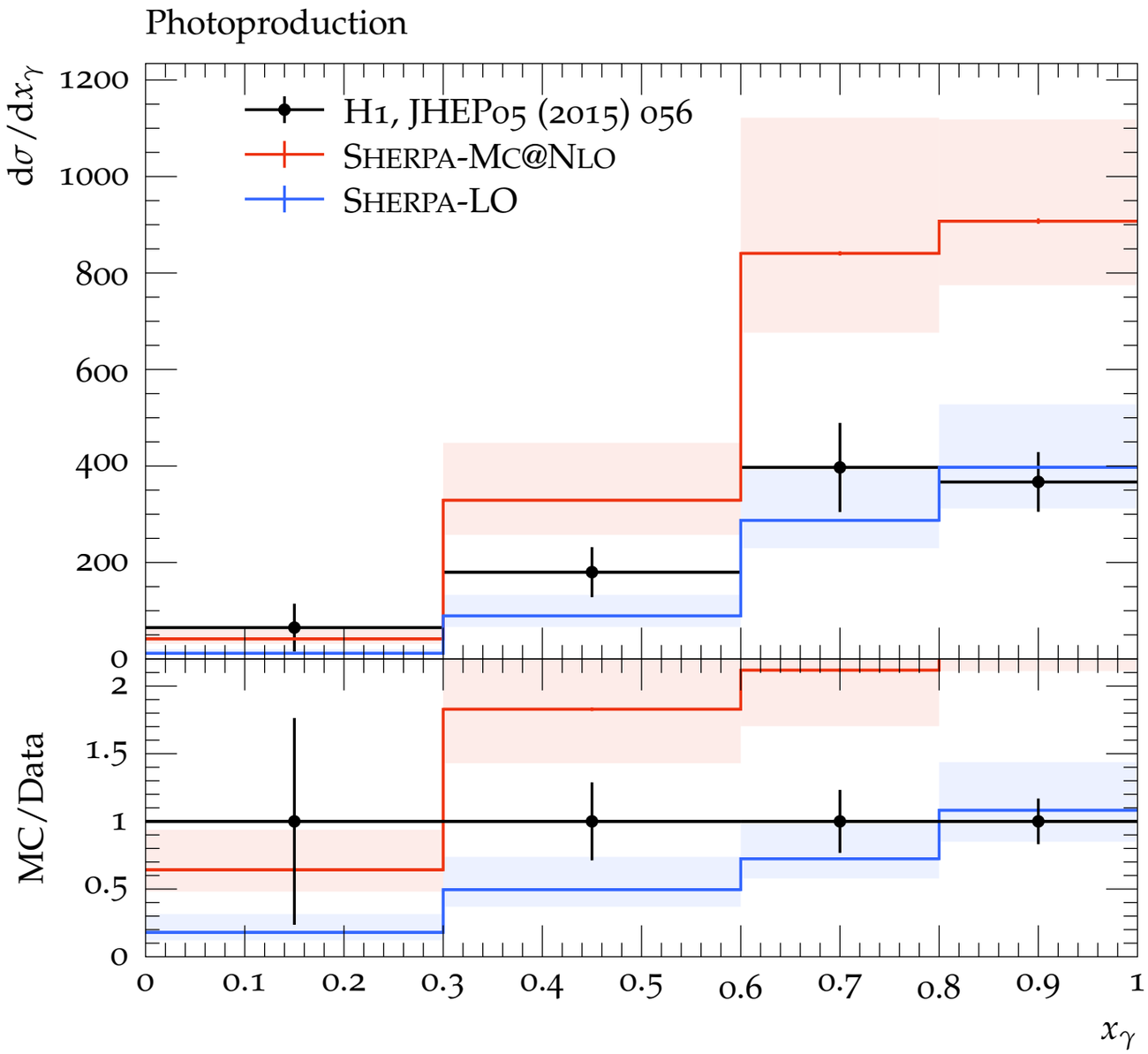
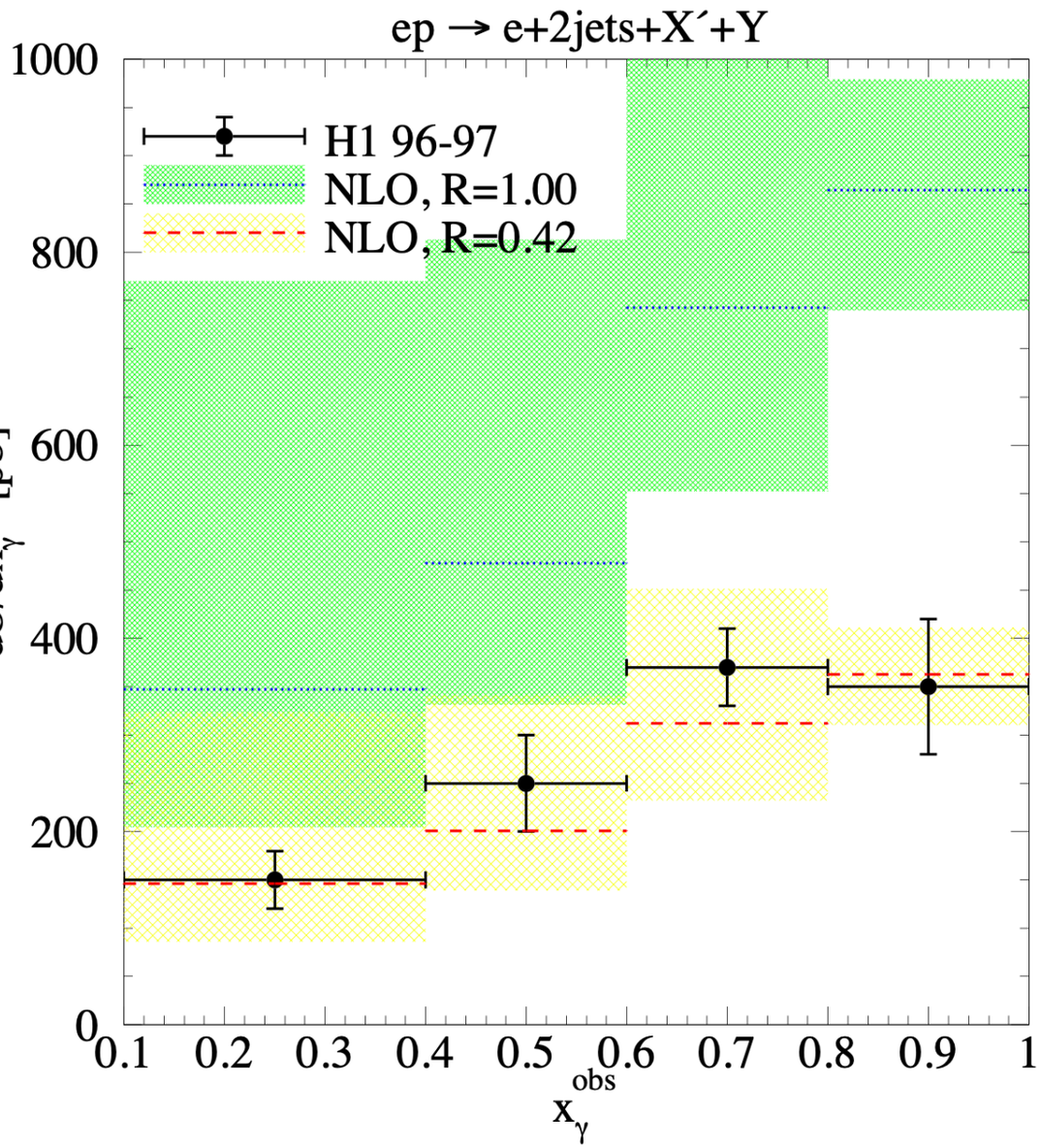
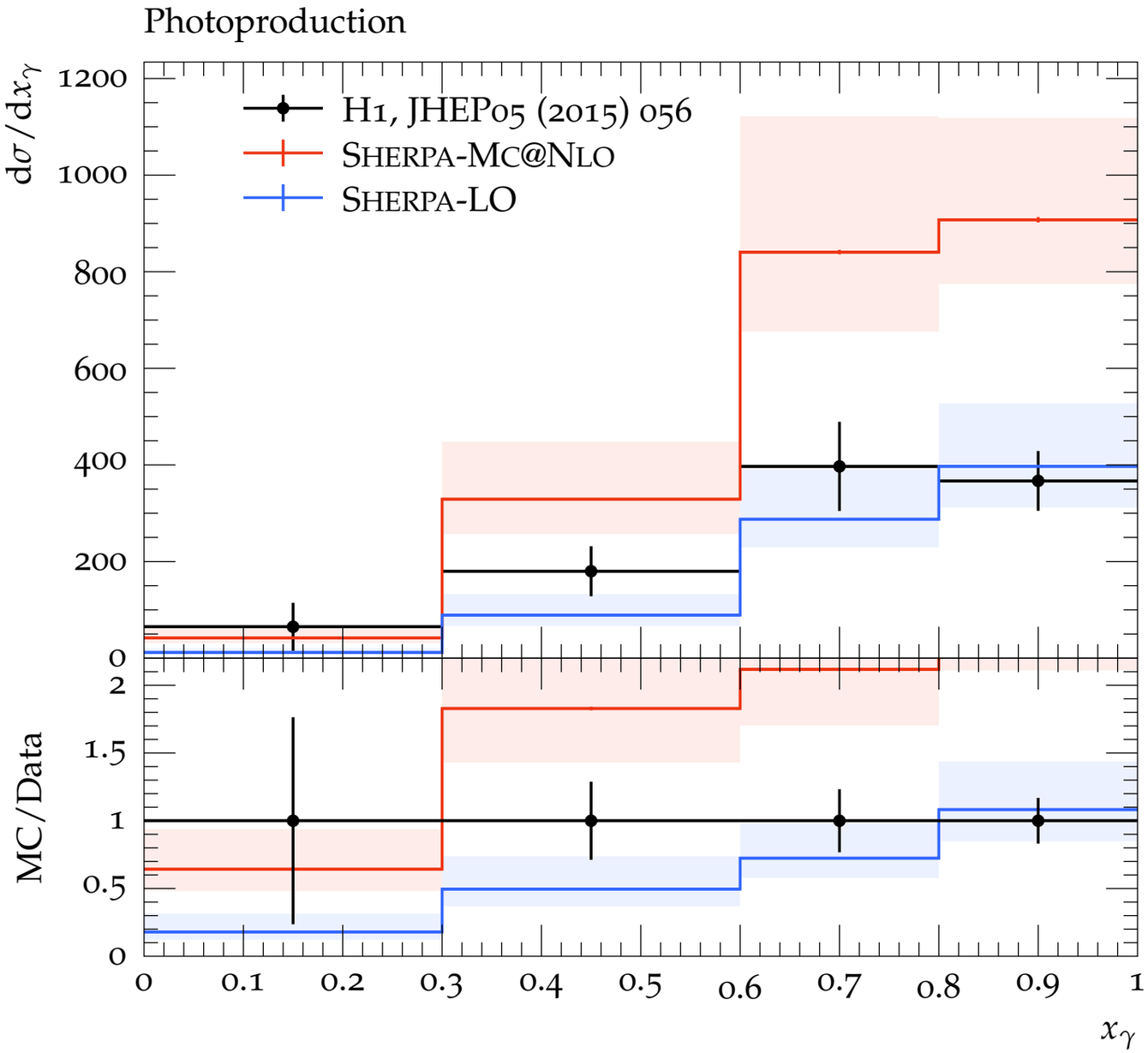


NLO predictions

in Diffractive Photoproduction



taken from [Mod.Phys.Lett.A 23 (2008) 1885-1907]



preliminary Sherpa plot

Factorisation breaking

Factorisation breaking

What effects come into play?

Factorisation breaking has been observed at H1

ZEUS however does **not** support the evidence!

Common explanations include:

- Soft rescattering, i.e. MPIs, between the photon and the proton
- Hadronisation effects
- Different phase space cuts
- DPDFs and their applicability; dependence on used data?
- Photon PDF and its $x_\gamma \to 1$ behaviour?

Different approaches

Eur.Phys.J.C 66 (2010) 373-376

Factorisation breaking in diffractive dijet photoproduction at HERA

A.B. Kaidalov[1], V.A. Khoze[2,3,a], A.D. Martin[2], M.G. Ryskin[2,3]

Abstract We discuss the factorisation breaking observed in diffractive dijet photoproduction by the H1 and ZEUS collaborations at HERA. By considering the effects of rapidity gap survival, hadronisation, migration and NLO contributions, we find that the observed data are compatible with theoretical expectations.

- Different suppression for point-like and hadron-like photon component
- Also argue against inclusion of dijet data in DPDF fits

Different approaches

Eur.Phys.J.C 71 (2011) 1741

- Three-fold comparison between ZEUS and H1 data:
  - Hadronisation corrections
  - Alternative photon distribution function
  - Matching the different phase space
- Result of the study: these effects play only a minor role in the discrepancy

Different approaches

Suppression factors

The suppression of the NLO cross-section has been modelled with

- global factors, $R_{\text{glob}} = 0.5$
- scaling of the resolved component, $R_{\text{res.}} = 0.34$, [*Phys.Lett.B 567 (2003) 61-68*]
- in *Eur.Phys.J.C 76 (2016) 8, 467*, a interpolation between the regimes with

$$S_i^2(x_\gamma) \to \begin{cases} 1\,, & i = c\,, \\ A_q\, x_\gamma + 0.34\,, & i = u, d, s\,, \\ A_g\, x_\gamma + 0.34\,, & i = g\,, \end{cases}$$

- absorptive corrections / MPI modelling

Missing analyses and impact of EIC

Missing analyses

- Diffractive inclusive and dijet cross-sections from both H1 and ZEUS
  - H1: *1006.0946 / 1203.4495 / 1412.0928 / 0708.3217*
  - ZEUS: *0708.1415*
- Diffractive open charm production
  - *hep-ex/0610076* and *hep-ex/0703046*
- Charged current diffractive DIS
  - *hep-ex/0606004*
- Event shape in diffractive DIS
  - *hep-ex/9710027*
- Leading neutron measurements
  - *1001.0532 / hep-ex/0404002 / hep-ex/0702028*

Prospects for the EIC

JHEP 05 (2020) 074

Questions which need to be answered by more data

- Mechanism of factorisation breaking; global or resolved-only?
- Critical evaluation of subleading Reggeon terms
- Diffraction in nuclei
- Pion PDFs from leading neutron production

Conclusion

- Many different measurements, well studied at HERA
- In Diffractive DIS in excellent agreement between theory and experiment
- In Diffractive Photoproduction, inconclusive data regarding the factorisation breaking
  - Different solutions have been discussed, question remains open
- HERA analyses and data complementary to EIC