SHERPA summary at the workshop on photon-induced processes

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Outline

Current status in SHERPA

Validation

Outlook on current efforts in SHERPA

Conclusion

Current status in SHERPA

The Equivalent Photon Approximation [1–3]

Observe that

- for photon virtuality $Q^2 < \Lambda^2_{\text{cut}}$, the photo-absorption cross-section can be approximated by its mass-shell value
- the same domain gives the dominant contribution in photoproduction
- approximate the cross-section by $\mathrm{d}\sigma_{eX} = \sigma_{\gamma X}(Q^2 = 0)\mathrm{d}n$, with $\mathrm{d}n$ the photon spectrum

$\Rightarrow$ after integration, Q^2_{max} is left as process-/experiment-dependent parameter

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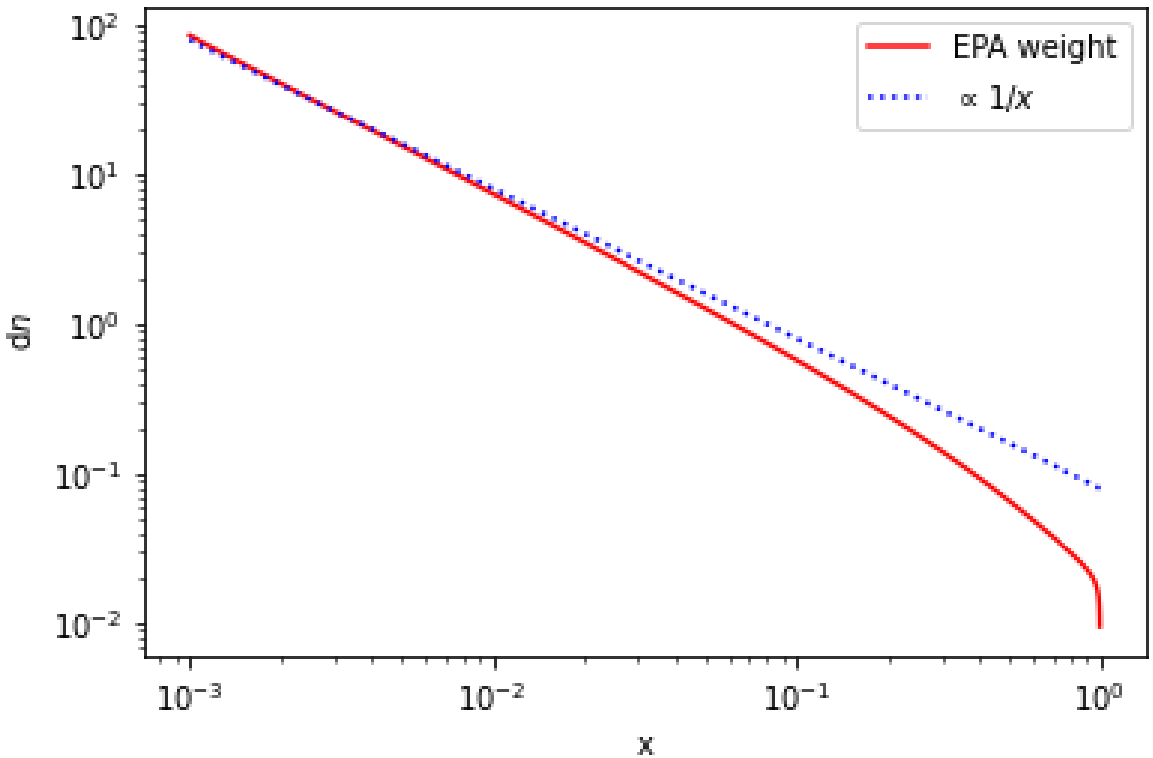
Form factors implemented

- electrons
- protons (only elastic)
- ions (WIP)

Plotting the spectrum for electrons

$$\mathrm{d}n = \frac{\alpha_{\mathrm{em}}}{2\pi}\frac{\mathrm{d}x}{x}\left[(1+(1-x)^2)\log\left(\frac{Q^2_{\mathrm{max}}}{Q^2_{\mathrm{min}}}\right) + 2m_e^2x^2\left(\frac{1}{Q^2_{\mathrm{min}}} - \frac{1}{Q^2_{\mathrm{max}}}\right)\right]$$

with x the energy fraction wrt. the electron, Q^2 the virtualities.



QCD evolution: photon PDFs

The total physical cross-section is given by

[Frixione, Mangano, Nason, Ridolfi] [hep-ph/9702287]

$$d\sigma^{(\gamma H)}(P_\gamma, P_H) = d\sigma^{(\gamma H)}_{\text{point}}(P_\gamma, P_H) + d\sigma^{(\gamma H)}_{\text{hadr}}(P_\gamma, P_H)$$

and the evolution obeys

$$\frac{\partial f_i^{(\gamma)}}{\partial \log \mu^2} = \frac{\alpha_{\text{em}}}{2\pi} P_{i\gamma} + \frac{\alpha_S}{2\pi} \sum_j P_{ij} \otimes f_j^{(\gamma)}$$

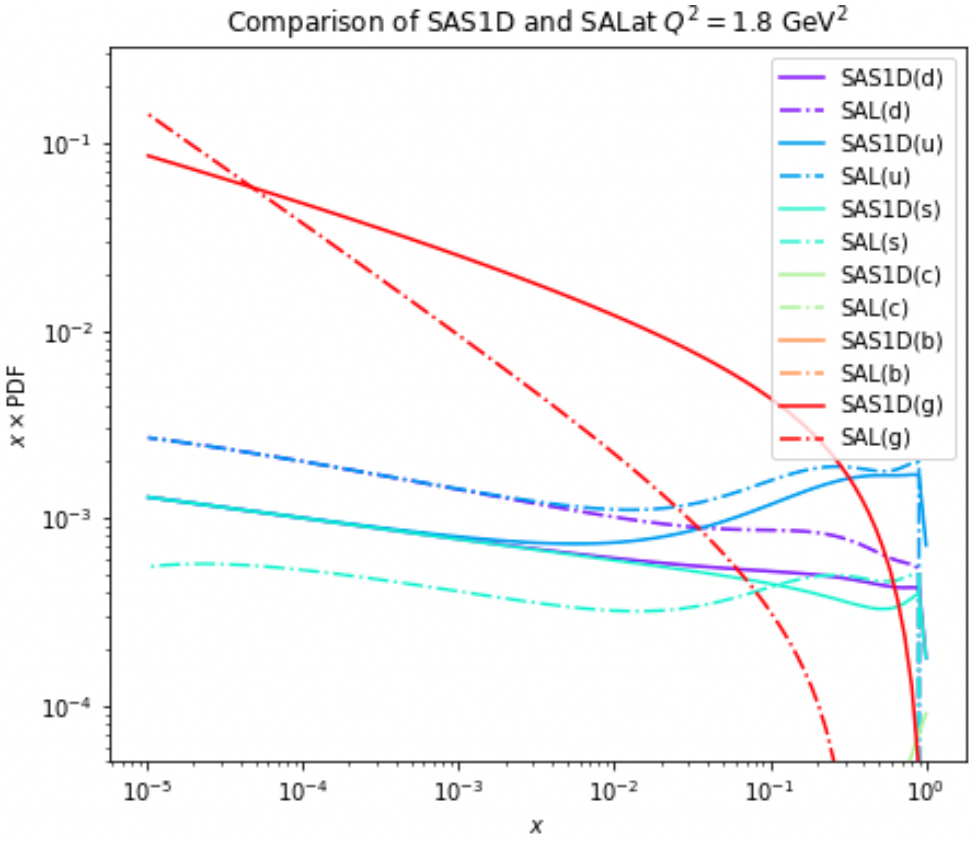
Solution must look like

$$f^\gamma(x, Q^2) = f^\gamma_{pl}(x, Q^2) + f^\gamma_{\text{had}}(x, Q^2)$$

QCD evolution: photon PDFs

Included in SHERPA: Glück-Reya-Vogt [4], Glück-Reya-Schienbein [5], Slominski-Abramowicz-Levy [6], Schuler-Sjöstrand [7, 8]

- need non-perturbative input from ρ^0, ω and ϕ, c.f. VMD
- GRS and SaS also for virtual photon
- many more available, but rather hard to find
- uncertainties of factor $\mathcal{O}(10)$
- *new fit to data possible?*



Photon phenomenology: VMD-type model [9, 10]

Vector-Meson Dominance model – needed for stringent description of event phenomenology

Photonic interaction can be either **bare** or through fermionic fluctuations:

- leptonic $\rightarrow$ negligible for jet production
- **'hard' quarks** $\rightarrow$ $p_\perp^2 \sim Q^2 > 0$ $\rightarrow$ short-lived and perturbatively calculable
- **'soft' quarks** $\rightarrow$ $p_\perp^2 \sim Q^2 \approx 0$ $\rightarrow$ long-lived and non-perturbative $\rightarrow$ meson transition into ρ, ω or ϕ and non-perturbative hadron physics

(Q^2 – virtuality)

Parton content needs more study: resonances when evolving virtuality?

SHERPA phase space setup

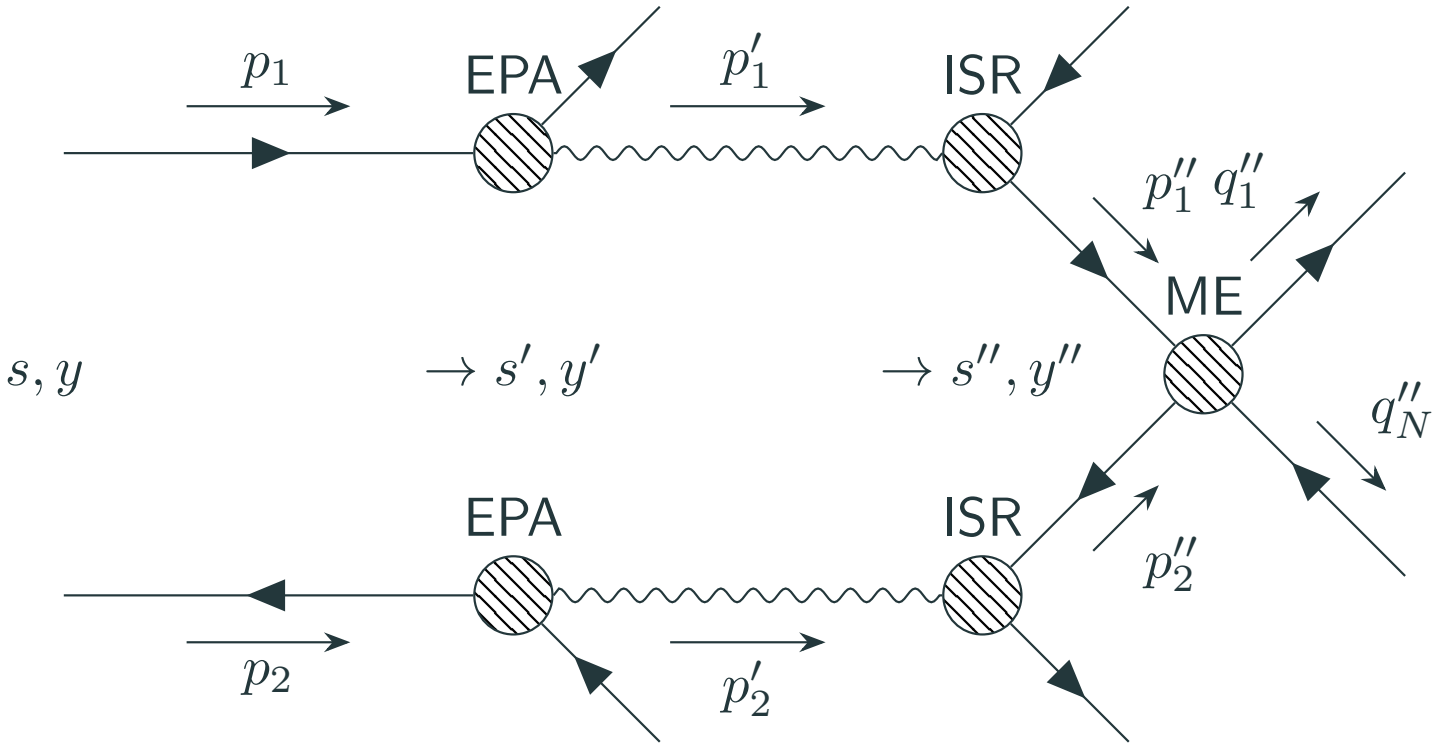


Figure 1: Schematic sketch of the phase space mappings between the Equivalent Photon Approximation (EPA) and the Initial State Radiation (ISR), and the Matrix Element (ME).

Multiple parton interactions

MPIs are non-negligible in photoproduction [Z.Phys.C 72 (1996) 637-646]

Implementation in SHERPA based on [Phys.Rev.D 36 (1987) 2019]

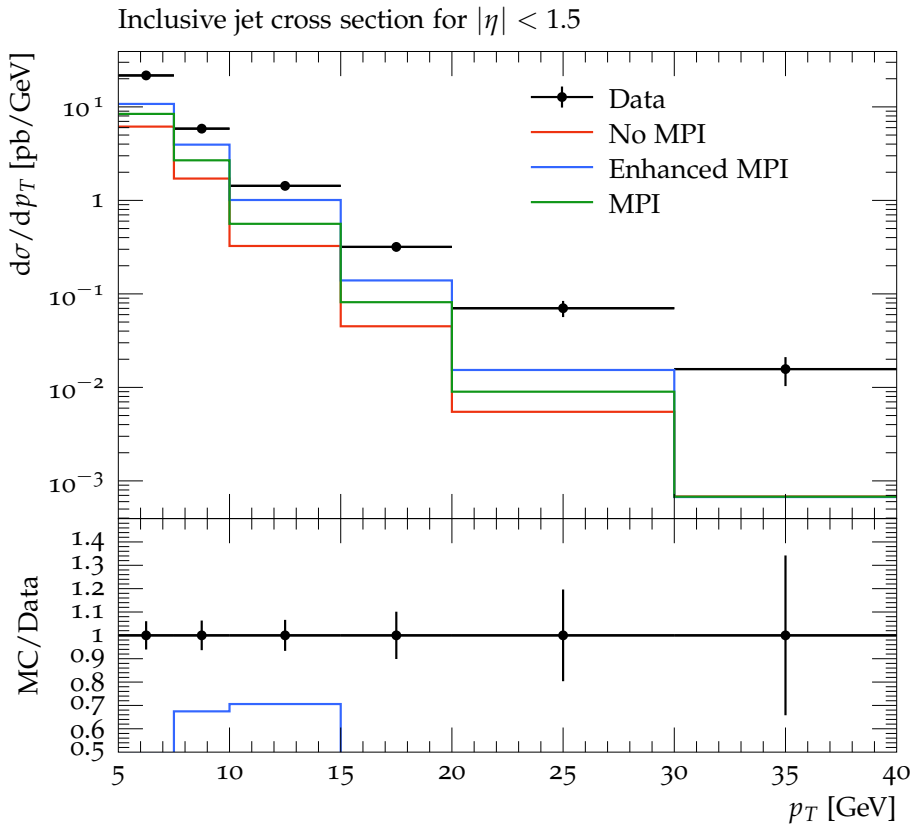


Figure 2: Effect of MPIs on double-resolved photoproduction at LEP.

Currently available in SHERPA

- (Elastic) photon fluxes for protons, electrons
- LUXqed PDFs through the LHAPDF interface
- PDFs for the photon built-in
- multiple-parton-interactions for photons and protons
- "mix and match" in the phase space, i.e. any combination of the above
- NLO corrections in QCD/EW, YFS resummation, parton showers, fragmentation, remnant jet, UFO interface, etc

Elastic, single-dissociative and double-dissociative photoproduction possible now

Photoproduction validated for the next release, SHERPA 3.0.0

Careful tuning still to be done

For the hands-on session, refer to the current manual:
https://sherpa-team.gitlab.io/sherpa/master/index.html

Validation

Some technical remarks

Typical observables are:

- (average) jet transverse energy E_T
- pseudo-rapidity η
- $\cos\Theta^*$, the angle between the two jets (approximately)
- $x_\gamma^\pm$, which is defined as

$$x_\gamma^\pm = \frac{\sum_{j=1,2} E^{(j)} \pm p_z^{(j)}}{\sum_{i\in\mathrm{hfs}} E^{(i)} \pm p_z^{(i)}}$$

Setup:

- LO & MC@NLO (di-)jet production for LEP data and HERA data
- 1M weighted events including 7-point scale variation
- c- and b-quarks are massive
- Disclaimer: preliminary results

SHERPA calculations for LEP at LO – preliminary

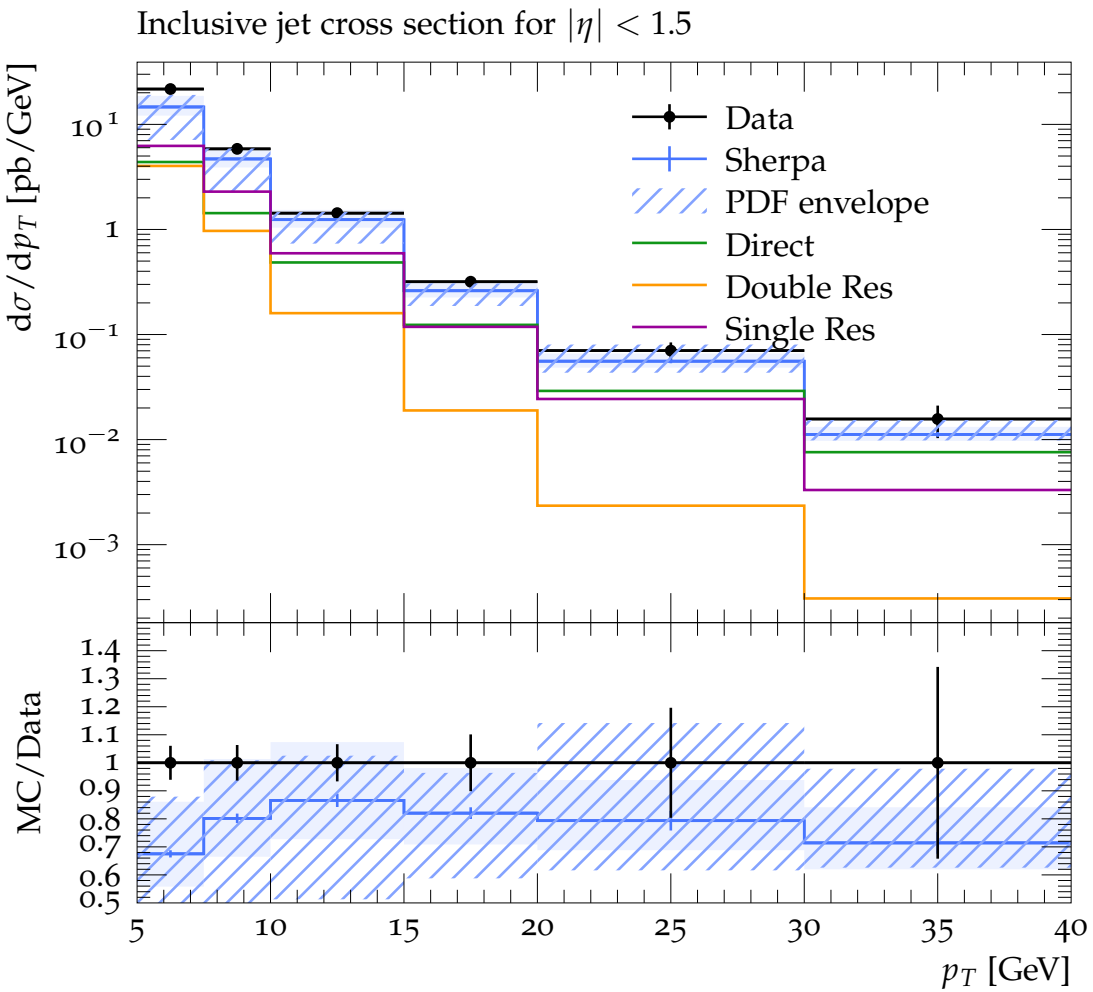


Figure 3: Distribution for jet transverse momentum p_T for LEP at $\sqrt{s} = 206$ GeV, averaged over all 10 PDF sets.

SHERPA calculations for LEP at MC@NLO – preliminary

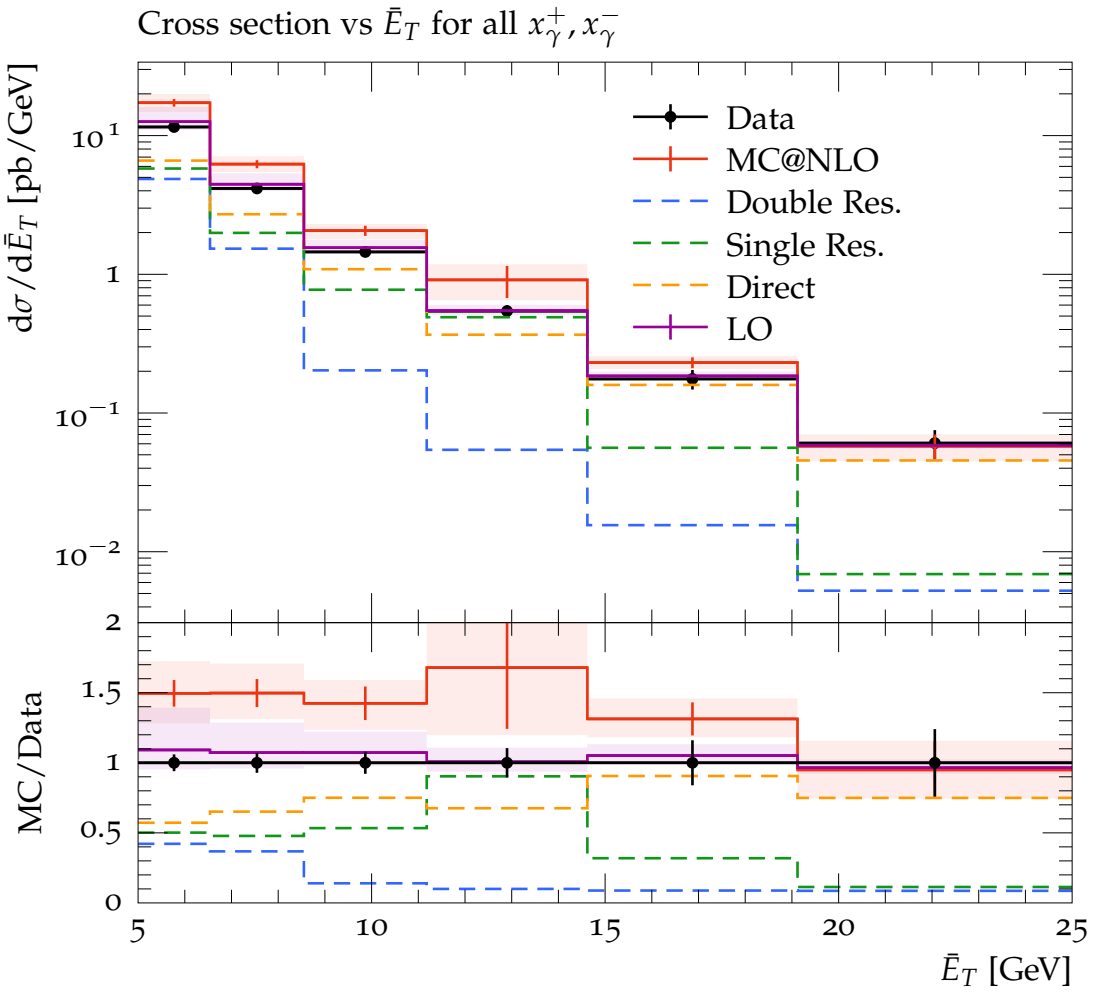


Figure 4: Distribution for average jet transverse energy $\bar{E}_T$ for LEP at $\sqrt{s} = 198$ GeV.

SHERPA calculations for HERA at MC@NLO – preliminary

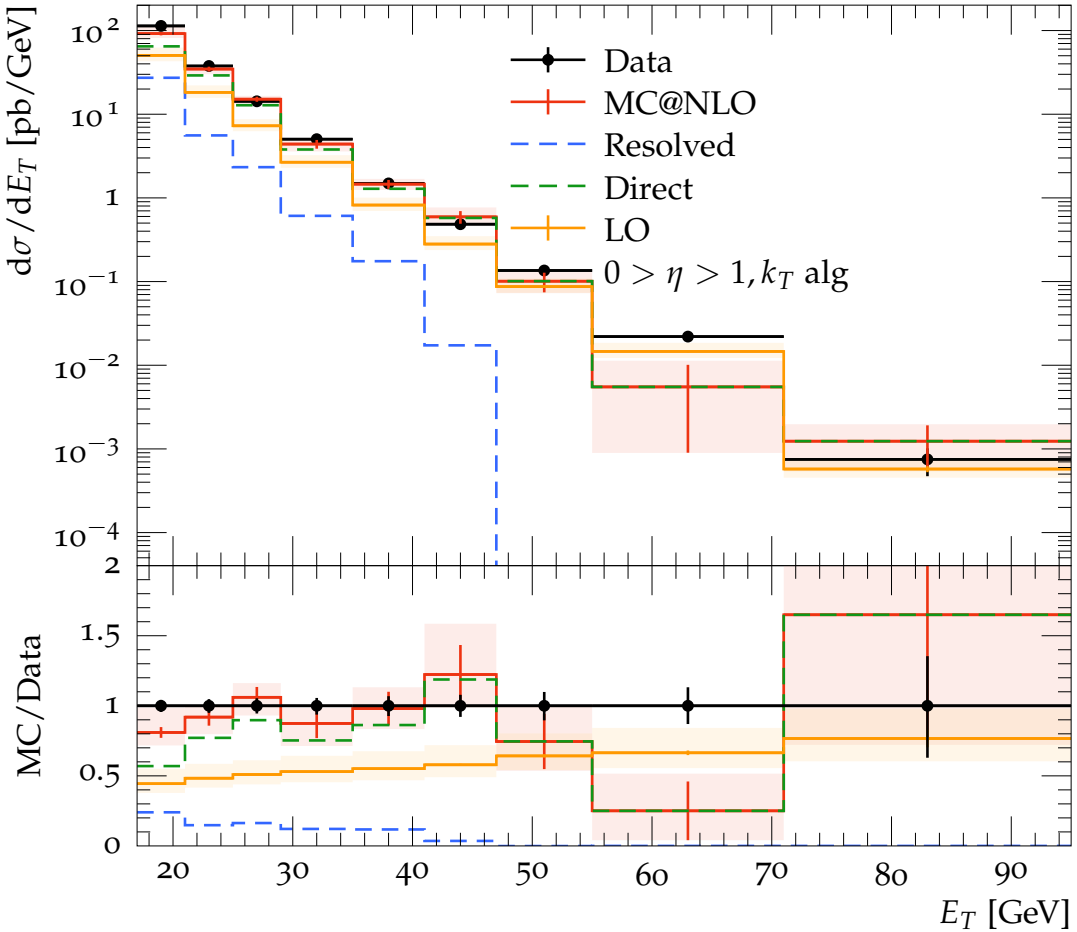


Figure 5: Distribution for jet transverse energy E_T for HERA.

SHERPA calculations for CMS at LO – preliminary

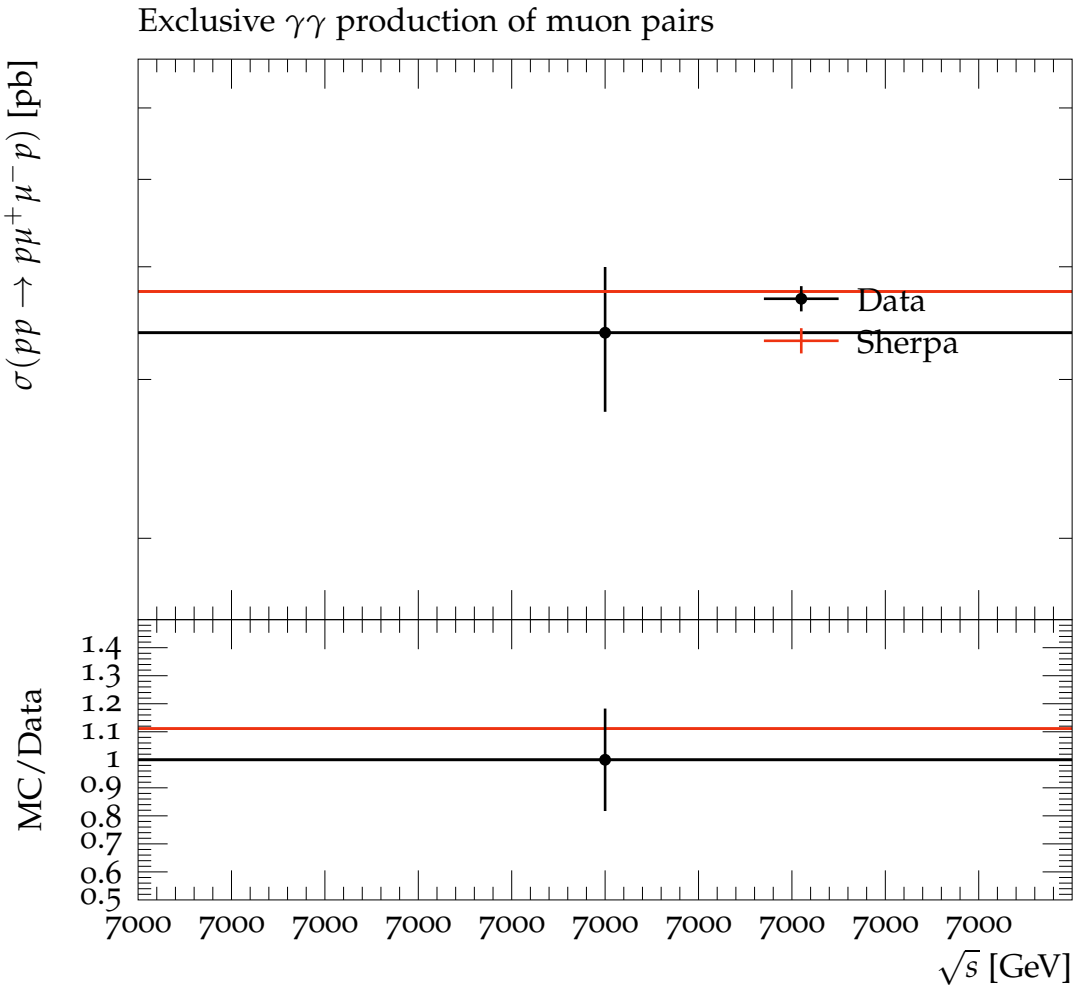


Figure 6: Exclusive two-photon production of muon pairs at CMS.

Outlook on current efforts in SHERPA

Pomeron flux

Following [Eur.Phys.J.C 78 (2018) 4, 309], implemented pomeron flux, PDF available through LHAPDF

Will allow, e.g., search for instanton through forward-proton tagging, c.f. [Eur.Phys.J.C 83 (2023) 1, 35]

Validation in progress with HERA data

Will (probably) reach MC@NLO accuracy too

$\Rightarrow$ bottleneck will be modelling of flux and measurements

Pomeron flux – preliminary

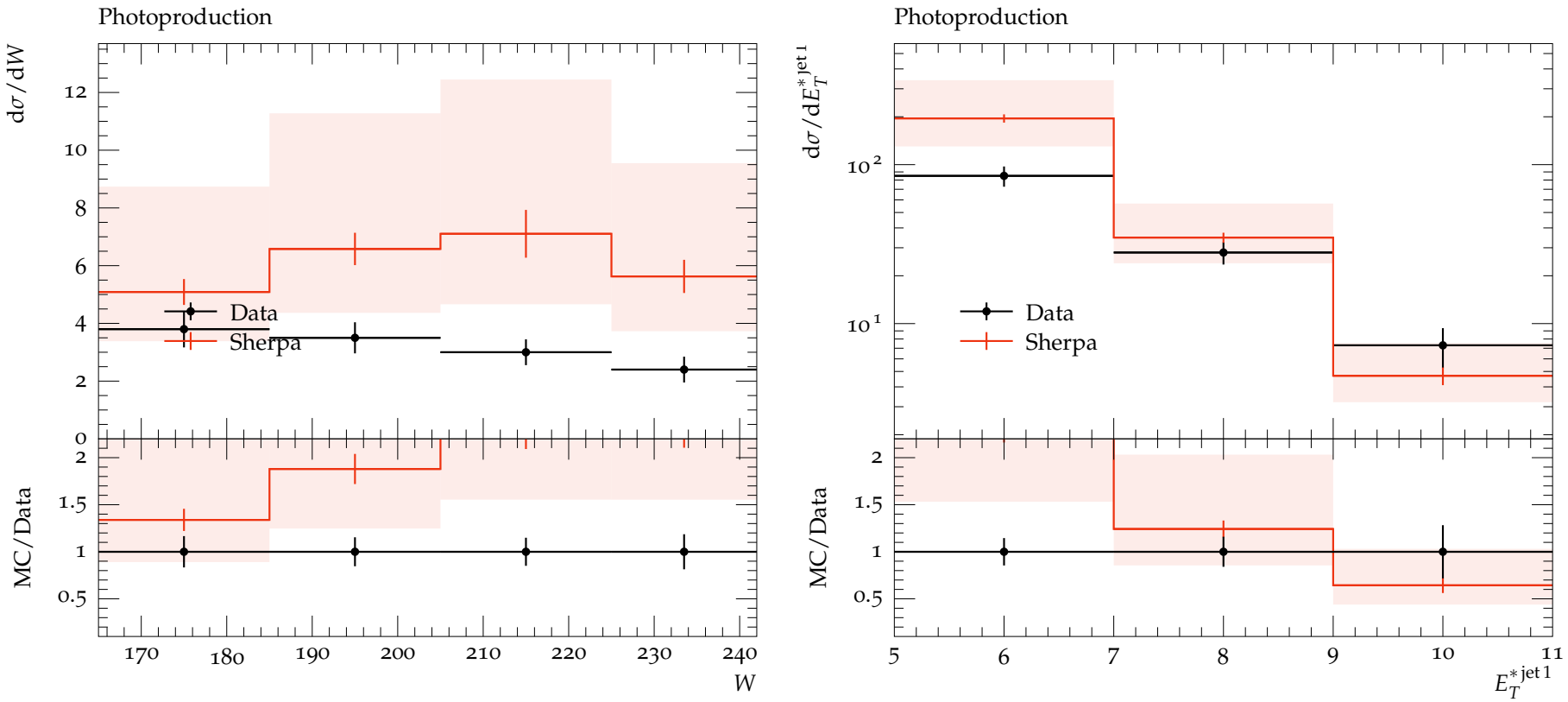


Figure 7: Distribution for partonic CMS energy (left) and leading jet transverse energy E_T (right) for diffractive jets at HERA.

Complete Minimum-Bias Photoproduction

Model extended according to [Z.Phys.C 73 (1997) 677-688]

- Factorise the multi-parton interaction model, i.e. extract parameters for photon and protons separately
- Sample in impact parameter space
- Allow MPIs for photon–photon, photon–proton and proton–proton interactions
- Model includes diffractive and elastic modes
- Also includes probabilities for $\gamma \to V$ transition
- Tuning in progress

Arrive at a fully-inclusive picture of Photoproduction events

Create rapidity gaps from underlying multiple-interactions model
Possibly measure photoproduction activity without veto?

Complete Minimum-Bias Photoproduction

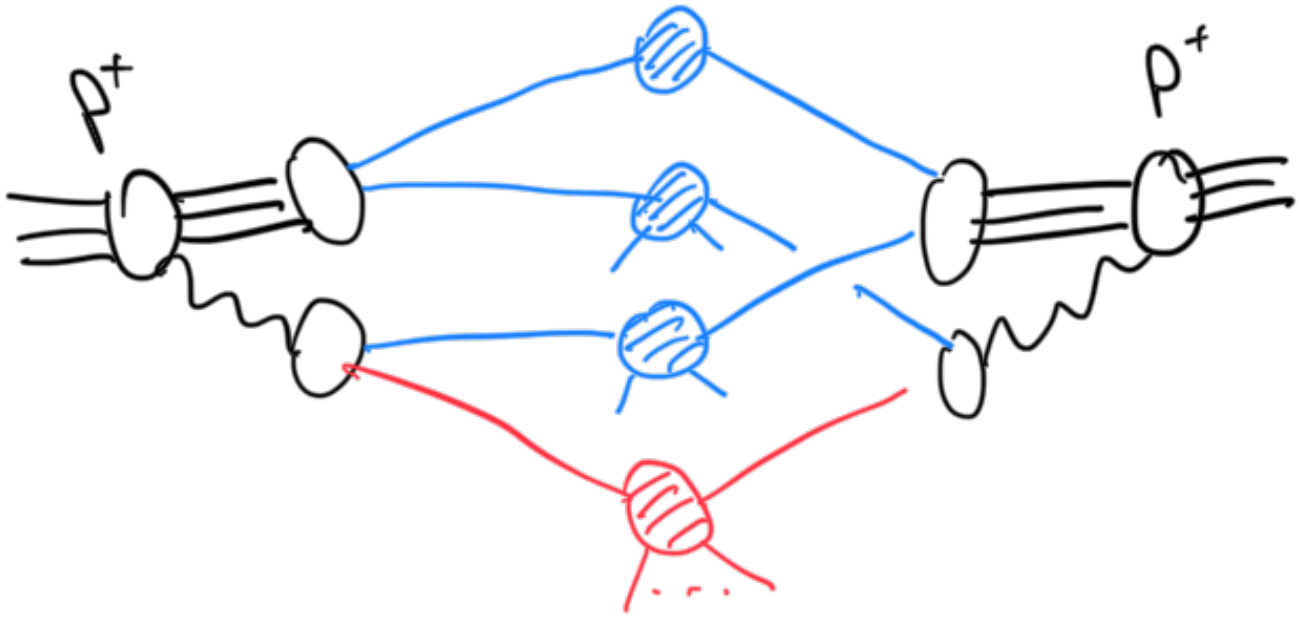


Figure 8: Sketch of the Minimum-Bias modelling in SHERPA for resolved photoproduction at the LHC. In red the hard interaction, in blue the underlying events.

Questions about code base

Questions about code base

Maintainability? Active code development from various groups, in Durham, London, Göttingen, Dresden and at Fermilab

Person power? Right now about 15 people

Future development? Photon physics currently project of my PhD, but is part of the maintenance of SHERPA

Tuning? Currently done with Apprentice, more tunes possible beyond the default

Parton Shower? Included in the same framework, no separate interface necessary

Conclusion

Conclusion

Photoproduction is an interesting physics phenomenon:

- Photoproduction shows interesting interplay with non-perturbative physics
- Simulation in SHERPA validated against LEP, HERA and CMS data
- Available in conjunction with SHERPA's machinery for QED/EW corrections, YFS resummation, ISR/FSR parton showers, fragmentation model, UFO interface, etc.
- Uncertainties in QCD observables dominated by photon PDFs
- $\mathrm{NLO}_{\mathrm{QCD}}$ matching, validation is WIP
- Pomeron flux to study diffractive photoproduction currently being validated
- Multiple-Parton Interactions working, "factorized Minimum Bias" model in preparation
- Tuning remains crucial task (any help appreciated!)

$\Rightarrow$ a few steps towards updating photon physics onto state-of-the-art machinery

Thank you for the attention!

References

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Backup

SHERPA calculations for LEP – preliminary

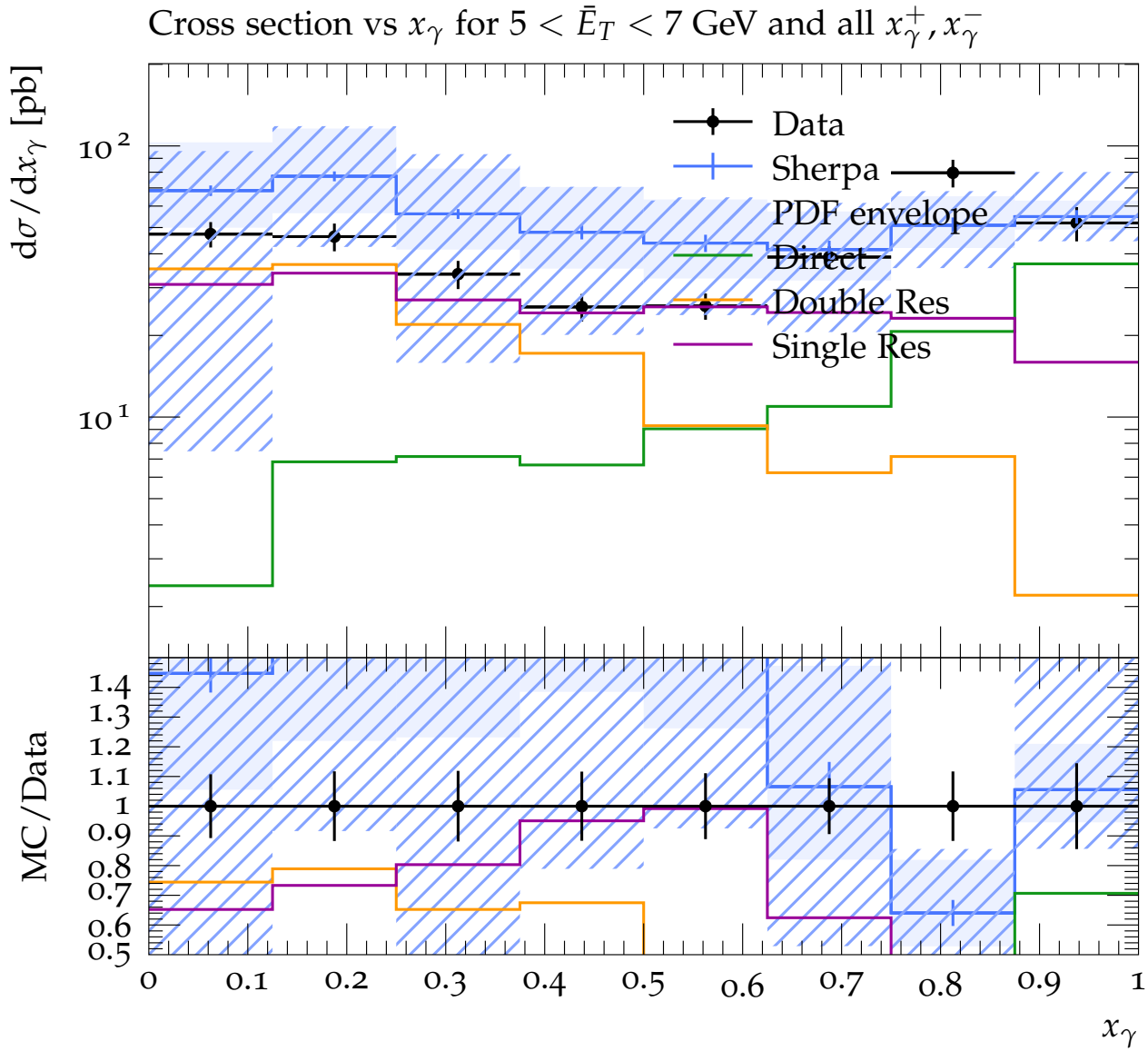

Figure 9: Distributions x_γ for average transverse jet energy $\bar{E}_T \in [11\,\mathrm{GeV}, 25\,\mathrm{GeV}]$

SHERPA calculations for LEP – preliminary

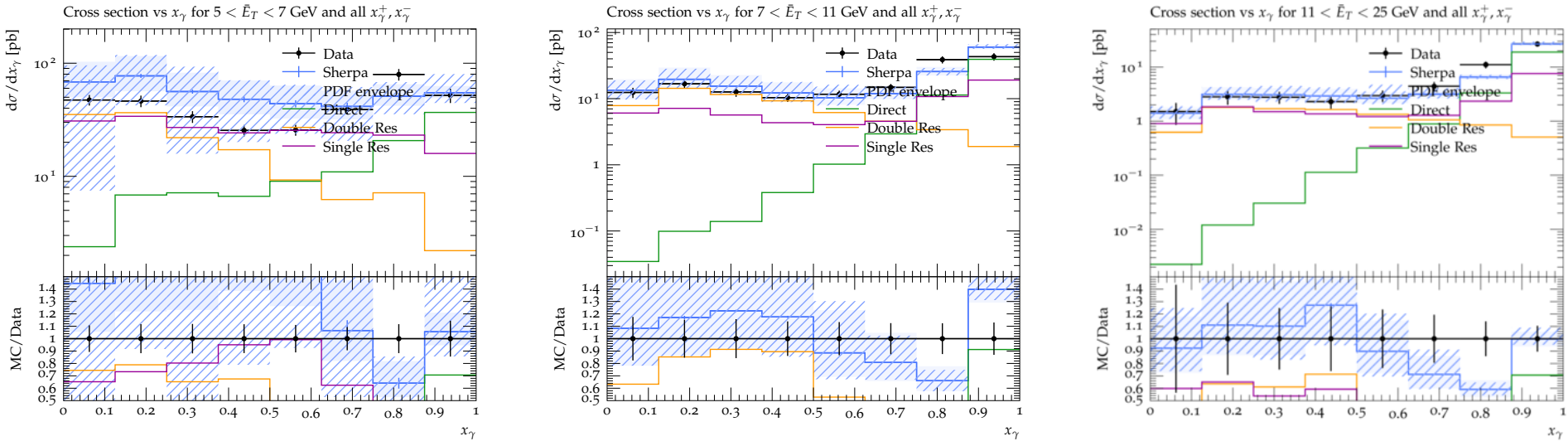

Figure 10: Distributions $x_\gamma^\pm$, collectively denoted as x_γ in different bins of average transverse jet energy: $\bar{E}_T \in [5\,\mathrm{GeV}, 7\,\mathrm{GeV}]$ (left), $\bar{E}_T \in [7\,\mathrm{GeV}, 11\,\mathrm{GeV}]$ (middle), $\bar{E}_T \in [11\,\mathrm{GeV}, 25\,\mathrm{GeV}]$ (right). Results of the SHERPA simulation are compared with results from OPAL at an e^-e^+ c.m.-energy of 198 GeV.

SHERPA calculations for HERA at LO – preliminary

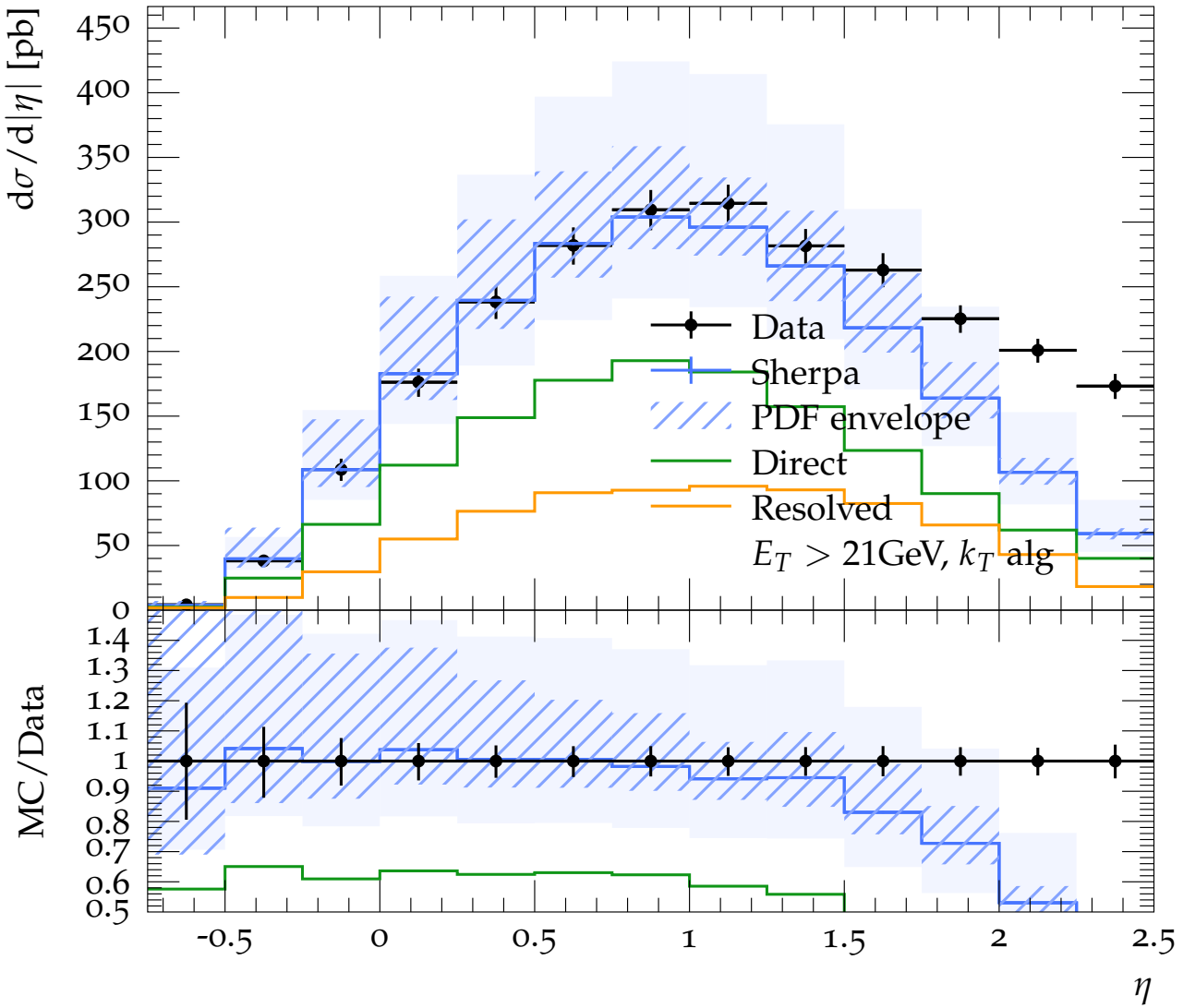

Figure 11: Distribution for jet pseudo-rapidity η for HERA. The drop at $\eta > 1.5$ is due