Sherpa summary: current status of photoproduction

Photon induced processes workshop @ IPPP

Peter Meinzinger

3rd November 2022

IPPP, Durham University

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Intro and motivation

Why do we need photoproduction?

Complementary to high-virtuality photon exchange
⇒ get coherent picture of QCD production
⇒ measure non-perturbative QCD effects

Significant QCD background
⇒ improves signal-to-background ratio

Window into photon physics
⇒ transition from real to virtual photons
⇒ get data for photon PDFs
⇒ sensitive for New Phyics signals

production mode at every collider
⇒ can be applied to very different settings

Components of photoproduction simulation

The Weizsäcker-Williams formula [1]

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

$\Rightarrow$ 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

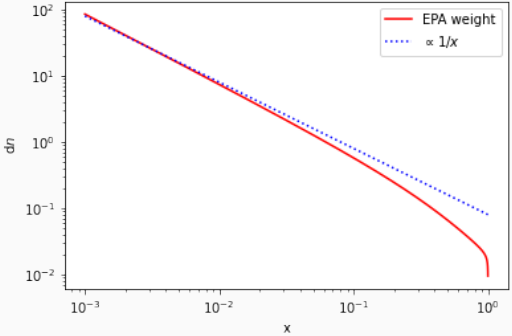
$\Rightarrow$ Calculate $\mathrm{d}n$ from DIS matrix element in approximation $Q^2 \to 0$.

[1] formulated in 1934 [1, 2], see [3] for review

Plotting the spectrum

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

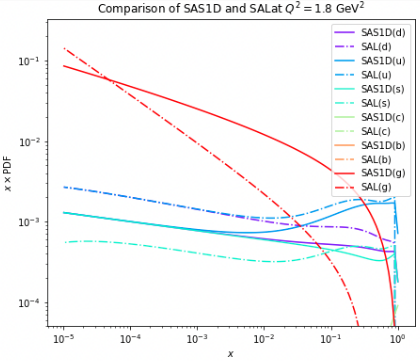
with x the energy fraction, Q^2 the virtualities.



(Quasi-)real photons need parton distribution functions!

The following photon PDF libraries have been included in Sherpa: Glück-Reya-Vogt [4], Glück-Reya-Schienbein [5], Slominski-Abramowicz-Levy [6], Schuler-Sjöstrand [7, 8]

- All librarys at least for the real photon in LO
- Some additionally in NLO
- GRS and SaS also for virtual photon



The phase space setup

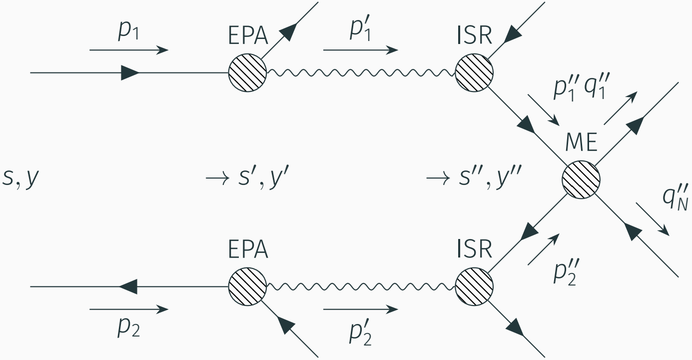


Figure 1: Schematic sketch of the phase space mappings between the Equivalent Photon Approximation (EPA) and the Initial State Radiation (ISR), and the Matrix Element (ME).

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

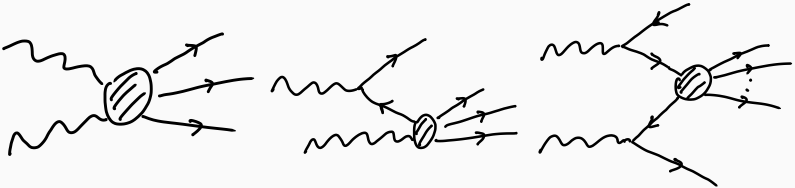
$$x_\gamma^\pm = \frac{\sum\limits_{j=1,2} E^{(j)} \pm p_z^{(j)}}{\sum\limits_{i\in\mathrm{hfs}} E^{(i)} \pm p_z^{(i)}} \tag{2}$$

Setup:

- MEPS@LO for 2(+2) jets for LEP data and LO for HERA data
- 1M weighted events including 7-point scale variation, c and b are massive
- averaged over the available PDF sets
- Disclaimer: preliminary results

Photoproduction cross-section, exemplified for LEP

Three different hard processes: direct, single-resolved and double-resolved: $\sigma_{\text{tot}} = \sigma_{\gamma\gamma} + 2\sigma_{j\gamma} + \sigma_{jj}$



Validated against data from ZEUS, OPAL and L3.

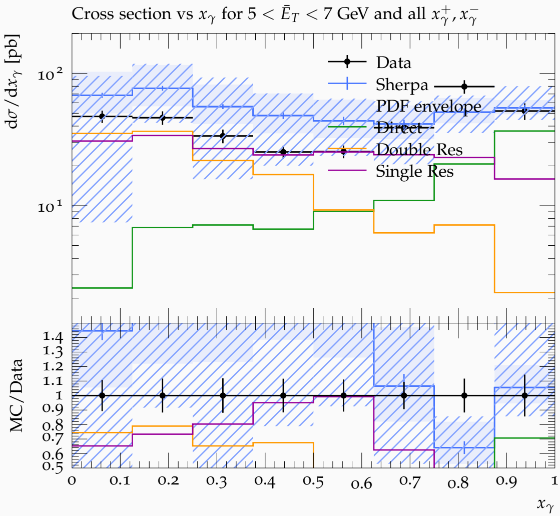


Figure 2: Distributions x_γ for average transverse jet energy $\bar{E}_T \in [11\,\mathrm{GeV}, 25\,\mathrm{GeV}]$ at $\sqrt{s} = 198$ GeV.

Sherpa calculations for LEP – preliminary

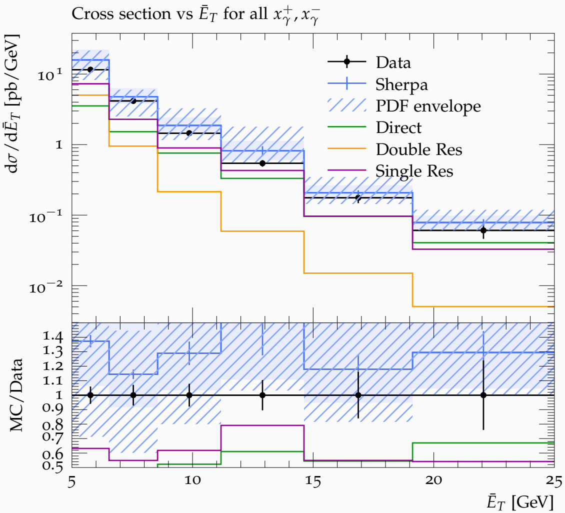


Figure 3: Distribution for average jet transverse energy $\bar{E}_T$ for LEP at $\sqrt{s} = 198$ GeV.

Sherpa calculations for LEP – preliminary

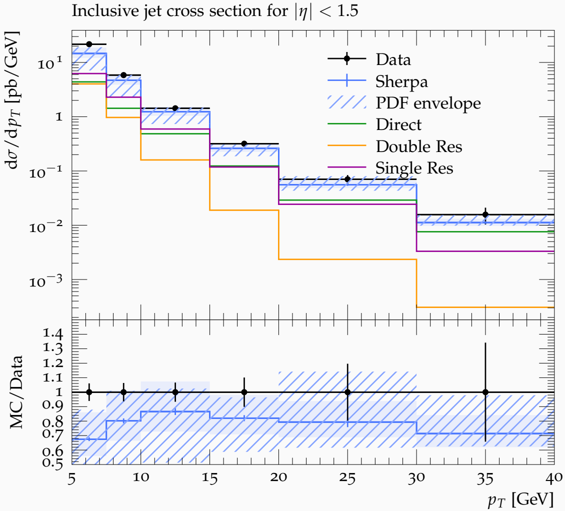


Figure 4: Distribution for jet transverse momentum p_T for LEP at $\sqrt{s} = 206$ GeV.

Sherpa calculations for HERA at LO – preliminary

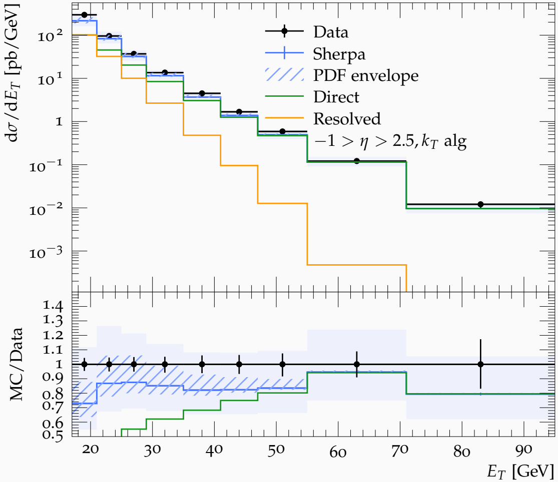


Figure 5: Distribution for jet transverse energy E_T for HERA2.

Sherpa calculations for HERA at LO – preliminary

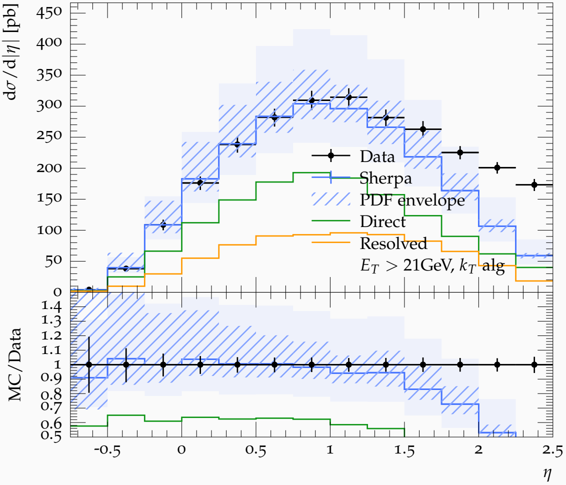


Figure 6: Distribution for jet pseudo-rapidity η for HERA2. The drop at $\eta > 1.5$ is due to the missing underlying event [9].

Notes on LHC physics

LHC physics

- photon flux for proton beams is implemented
- Full FS spectrum available from the ME generators, incl. photon PDFs
- current approximation corresponds to elastic production $pp \to ppX$
- depending on process, the Weizsäcker-Williams approximation breaks down
- diffractive production would need form factors for proton diffraction and $\gamma \to V$ transition probability

Discussion of going NLO

Sherpa calculations for LEP at MC@NLO accuracy – preliminary

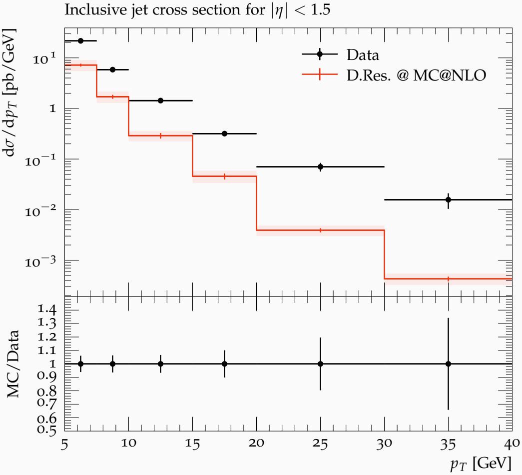


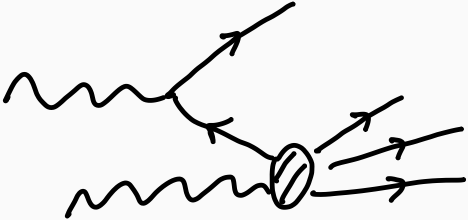
Figure 7: Distribution for jet transverse momentum p_T for LEP at $\sqrt{s} = 206$ GeV. Sherpa simulation is at NLO QCD accuracy using MC@NLO where both photons are resolved.

The difficulty of defining NLO

Photons in the initial state show collinear divergences

$\Rightarrow$ introduces ambiguity and double-counting

Example:



Is a collinear parton the real correction to $\gamma\gamma \to X$?
Or remnant of the PDF?

The difficulty of defining NLO

Cancel the divergences with QED subtraction terms

Pros:

- Would allow fixed order calculation
- builds up on known subtraction schemes

Cons:

- needs QED shower to allow matching in MC@NLO
- is very involved
- needs PDF to construct underlying Born process

Create ”subtraction by PDF”, i.e. make cut at shower cut-off scale

Pros:

- does not need the PDF
- extendible to MC@NLO with standard shower
- start point for consistent matching between the three modes(?)

Cons:

- is very setup-specific

Next steps and outlook

Next steps

1. **Multiple-parton interaction (MPI)**

The data (and literature [9]) suggests that multi-parton interaction are non-negligible!

$\Rightarrow$ need to include an estimator for the number of multiple interaction

2. **Extend for A**

$\Rightarrow$ Needs form factors for each nucleus

3. **$Q^2 > 0$ and non-collinear kinematics**

leave the Weizsäcker-Williams $Q^2 \to 0$ approximation

$\Rightarrow$ extend VMD model?

Next step: extension to virtual photons: VMD-type model [10, 11]

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

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 $\rightarrow$ hadron-hadron physics

(Q^2 – virtuality)

Conclusion

Conclusion

- Photoproduction is an important ingredient for collider phenomenology at high precision
- Simulation in Sherpa validated against LEP and HERA data
- Uncertainties in QCD observables dominated by photon PDFs
- Deviations from data can be attributed to missing MPI model for the photon
- Extension to NLO QCD needs some attention, but is feasible

Thank you for the attention!

References

[1] C. F. v. Weizsäcker. 'Ausstrahlung bei Stößen sehr schneller Elektronen'. In: *Zeitschrift für Physik* 88.9-10 (Sept. 1934), pp. 612–625.

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