Direct Photons with POWHEG

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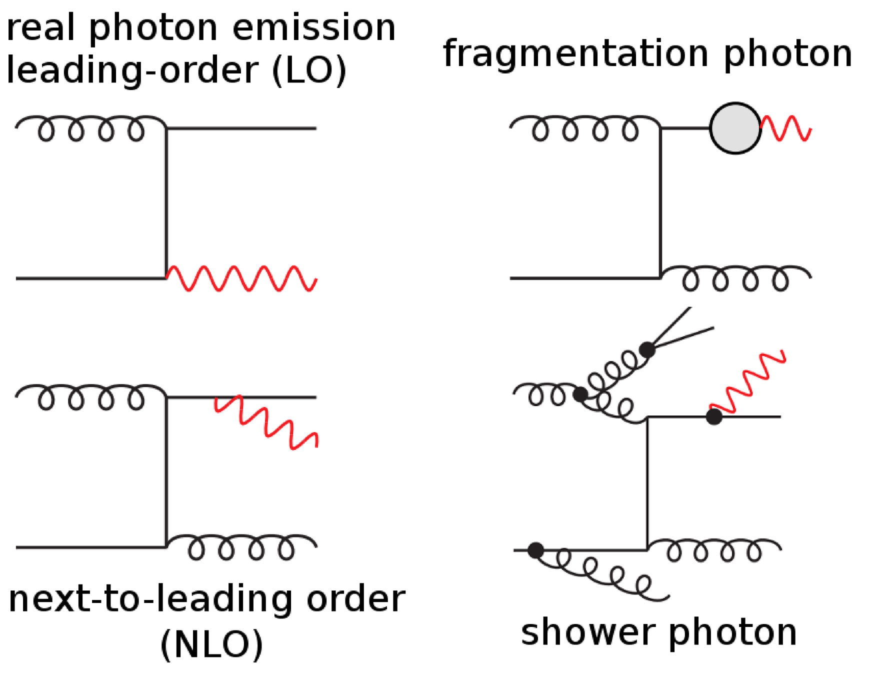
Abstract

We present the POWHEG BOX implementation of the dominant direct photon production processes $qg \to q\gamma$ and $q\bar{q} \to g\gamma$ at next-to-leading order and photon emission as real emissions from QCD Born configurations. Outgoing partons are interfaced with the PYTHIA8 parton shower. Shown are comparisons to the isolated photon cross section measured at ATLAS and kinematic properties of hard photons at low energies, which are relevant for the study of small x physics and nuclear medium effects.

Introduction

Prompt photons provide particular insight into hadronic collisions. Since they give immediate access to the energy scale of a hard scattering, prompt photons allow further constraints of (nuclear) parton distribution functions. Moreover, they provide unambiguous information on hot nuclear matter – in contrast to hard partonic probes, which are strongly affected by the medium.



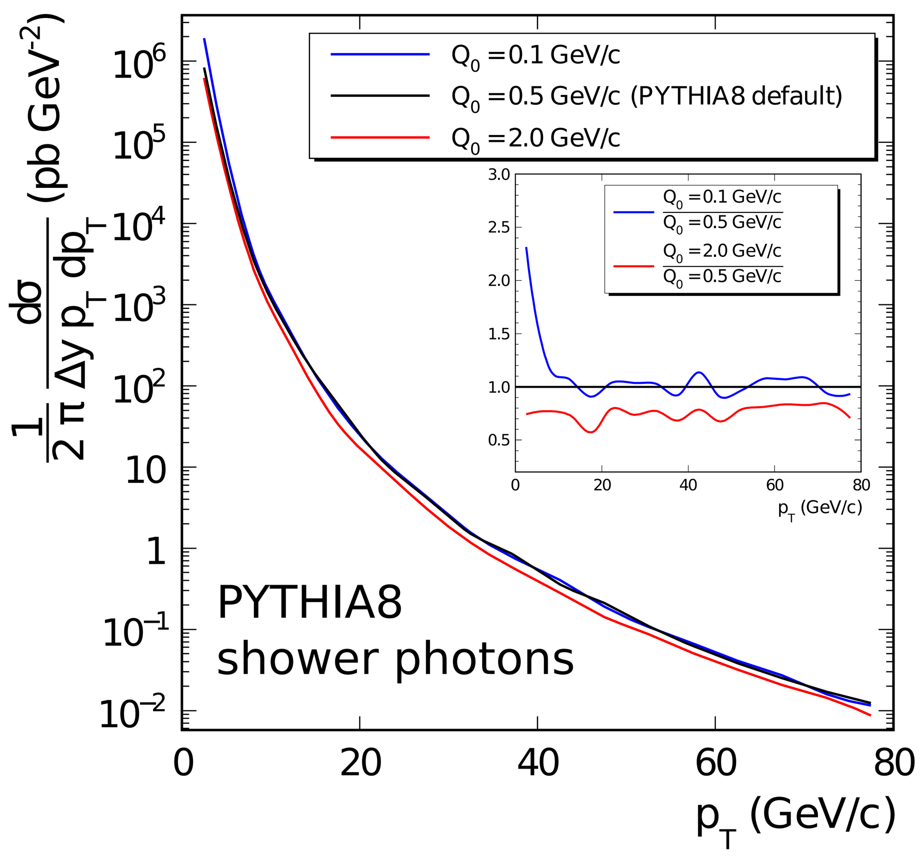
In photon phenomenology, one distinguishes different kinds of photons **depending on how they are generated**:

- Real photon emissions as calculated from matrix elements are called **direct photons**. (Beware: experimental jargon differs)
- In fixed-order calculations, outgoing partons can lead to **fragmentation photons** through a non-perturbative fragmentation function.
- In a shower algorithm, **shower photons** arise from the splitting $q \to q\gamma$.
- Altogether, these photons are called **prompt photons**. Photons from hadron decays are ignored in this context.

Features of direct photons in POWHEG BOX

The **POWHEG BOX** [1] allows to calculate the hard scattering kernel at the order of $\alpha\alpha_s^2$, which has two implications compared to leading order:

- The photon production processes $q\bar{q} \to g\gamma$ and $qg \to q\gamma$ receive corrections by virtual and real QCD emissions.
- Real photon emission off quarks is now included in the hard scattering kernel, i.e. the hardest photons are now described at NLO accuracy. In shower MC event generators like **PYTHIA8** [2], shower photons are only described in a collinear approximation, so that – beyond the LO accuracy of the hard scattering kernel – photon radiation is only provided at leading-log (LL) accuracy.

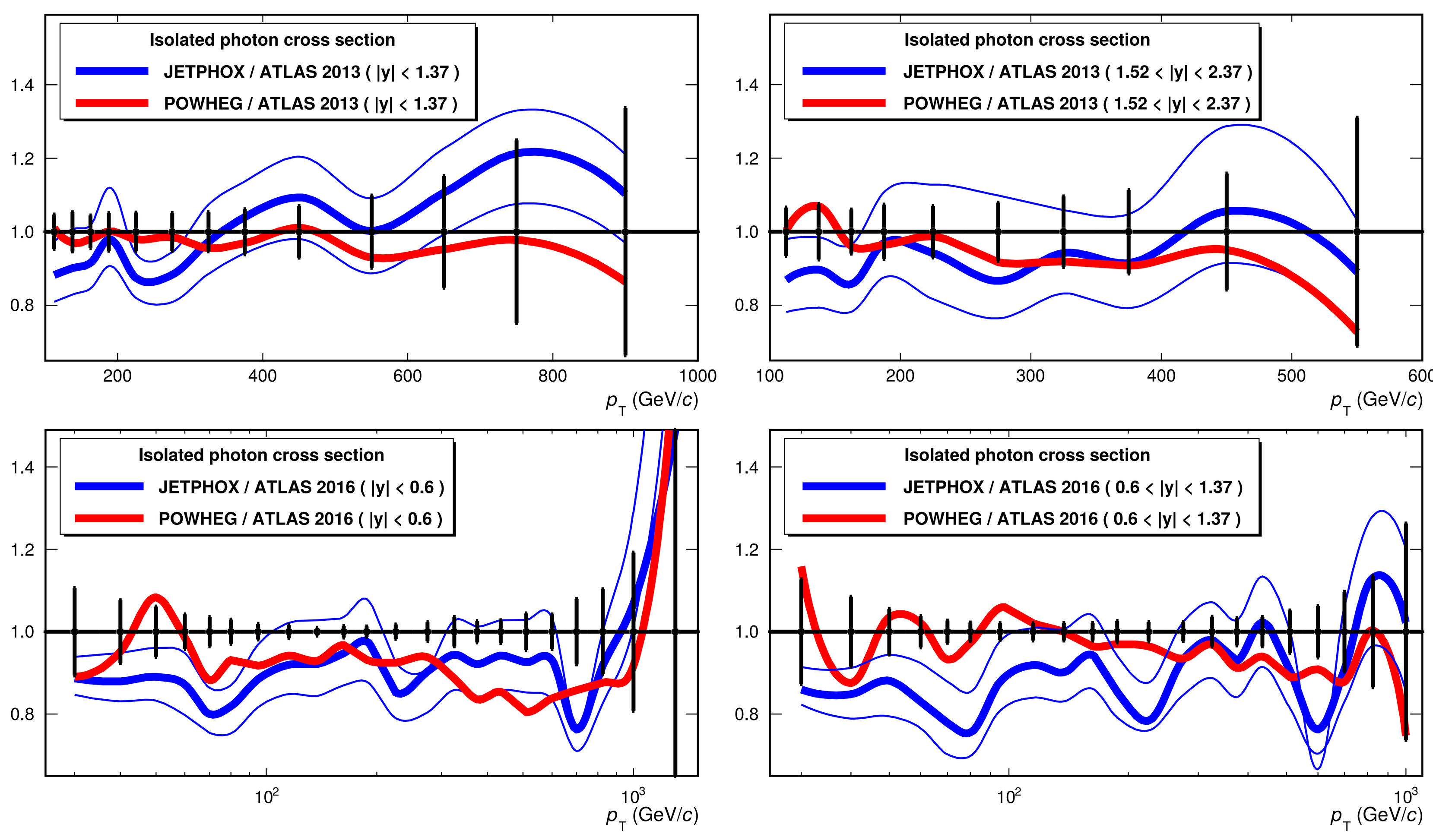


Additional features:

- Photon radiation off quarks has to be regularised by a soft cut-off in LO generators like PYTHIA8 (see figure on the left). This is obsolete at NLO, since virtual corrections cancel against the soft divergence.
- Computation of prompt photons is faster compared with a LO shower algorithm. In our implementation, this is further enhanced by manipulation of the Sudakov form factor and subsequent reweighting [3].
- Fixed order calculations only yield inclusive events (photons + something else). POWHEG can be interfaced with a shower MC, so that full events (with positive weights) are available.

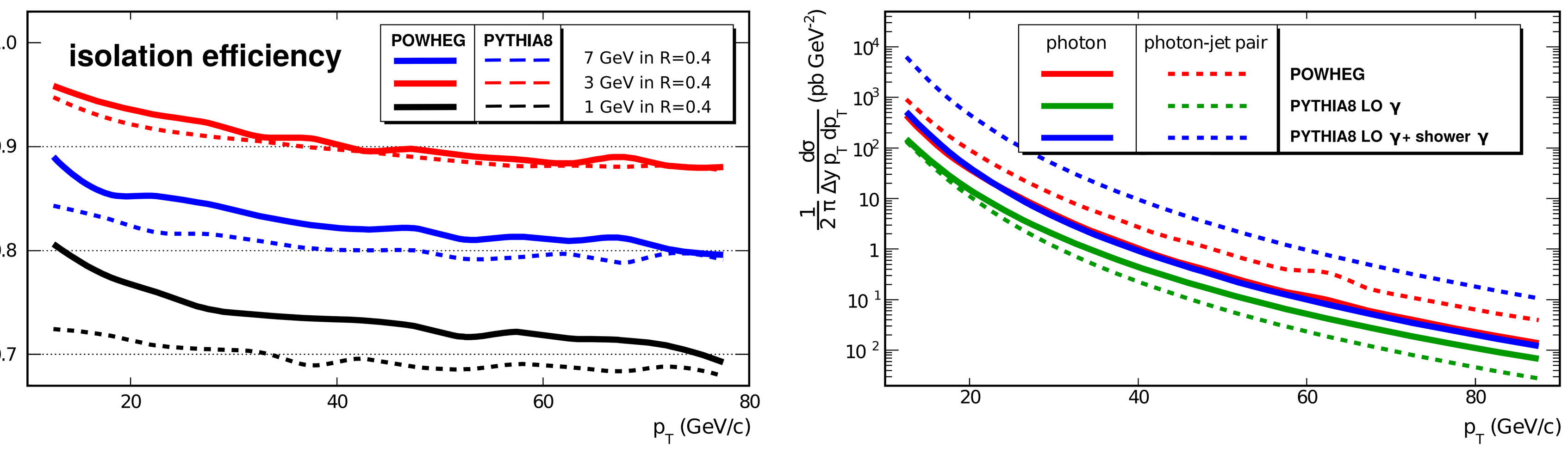
Isolated Photon Cross Section

- A comparison to isolated photon measurements from ATLAS [4][5] shows that POWHEG (+ PYTHIA8 shower) describes the cross section of isolated photons at least as good as the fixed-order prediction from JETPHOX [6].
- The used parton distribution function is *NNPDF2.3 QCD+QED NLO* ($\alpha_s = 0.119$).
- Uncertainties from the POWHEG method and scale variations have not been evaluated. Uncertainties for JETPHOX are given by the thin blue lines corresponding to scale variations ($\frac{1}{2}\,E_T^\gamma < \mu_{R,f,D} < 2\,E_T^\gamma$).
- We understand the larger yield in the momentum regime below 300 GeV/c as a hint for the resummation of threshold logarithms at the leading-log level provided by the PYTHIA8 shower.

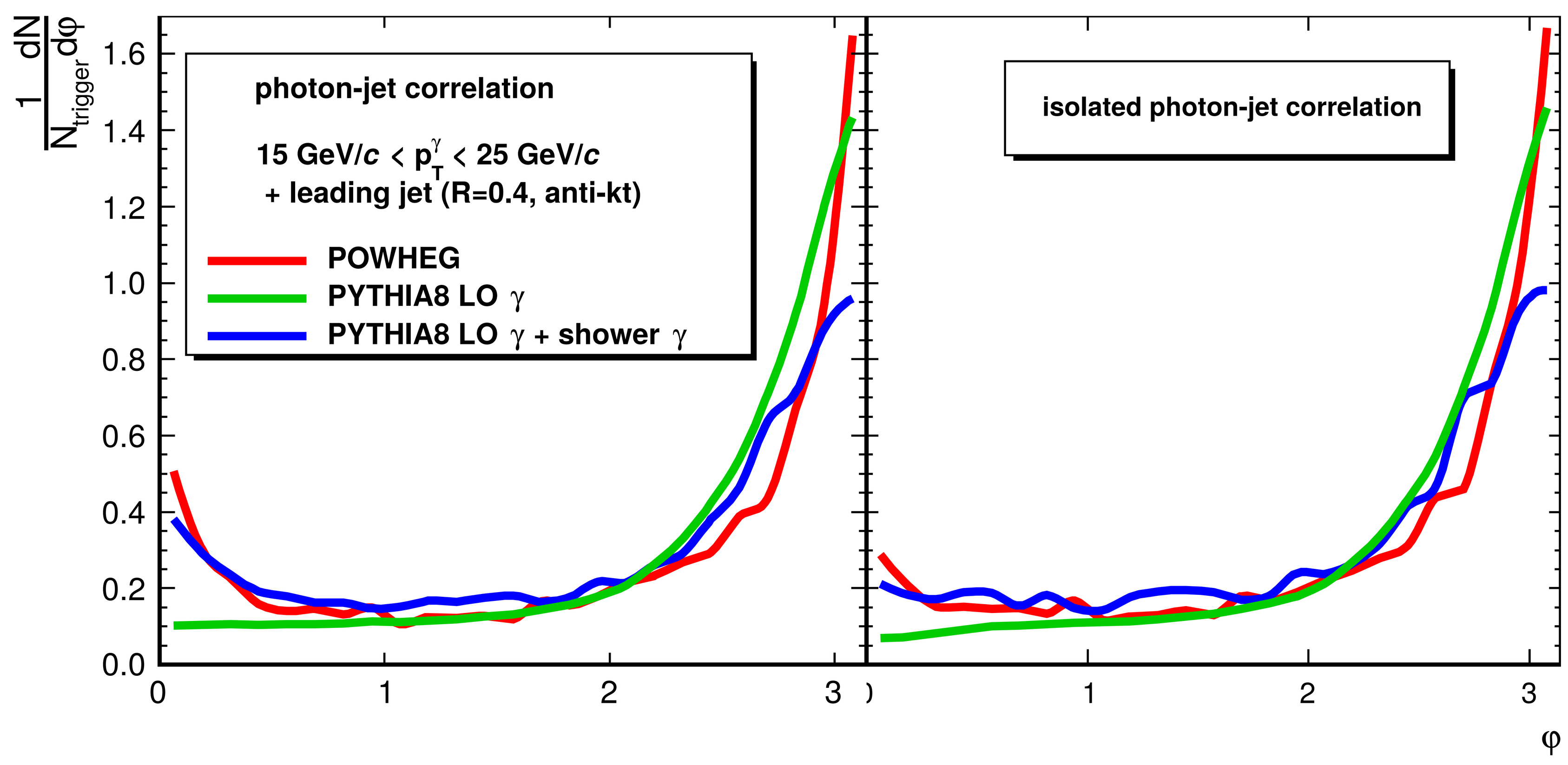


Prompt photon kinematics in the low energy regime

The understanding of prompt photons below 100 GeV is crucial, whether one wants to constrain the proton's gluon content at small x or whether one uses photons as a probe for the Quark-Gluon Plasma as done in the ALICE collaboration.
The mixing of different configurations involving hard photons and partonic energy can be alleviated with an isolation cut. Ensuring that the hadronic energy in a cone with radius R around the photon remains below a certain threshold, one ends up with photons that are closely associated to the initial hard scattering and thus allow to control the energy scale involved.



- The figure on the left shows the fraction of photons surviving different isolation cuts. At low momenta, POWHEG and PYTHIA8 yield different results which hints at a modified kinematic configuration of photons and hadronic energy.
- In the right figure, the prompt (non-isolated) photon cross section of both generators agree. Yet again, the spectrum of the transverse four-momentum sum of the **photon–leading-jet pair** differs notably for the two generators. For comparison in green: LO photon production in PYTHIA8 yields a back-to-back topology of photons and jets, so that the pair sum is lowered.



Azimuthal correlations (figure above) between a prompt photon and the leading jet show subtle differences between events in PYTHIA8 and POWHEG:

- The axes of PYTHIA8 jets are distributed in a broader fashion at the **away side** ($\varphi = \pi$).
- The leading jet in PYTHIA8 events is sometimes found at $\varphi \approx \frac{\pi}{2}$. This hints at preferred large angle radiation in PYTHIA8. However, the bump structure can possibly be caused by occasional jet splitting.
- Again for comparison in green: the LO photon production in PYTHIA8 with the distinct back-to-back topology of photon and jet.
- In the right panel: An isolation cut (1 GeV in a $R = 0.4$ cone) suppresses equally correlations at the **near-side** ($\varphi = 0$). But in this low momentum regime, even such a tight cut can not perfectly flatten the near-side yield.

Conclusions

- Direct photon processes implemented in POWHEG BOX provide both NLO accuracy and a MC shower interface.
- Generated cross sections of isolated photons are consistent with experimental data and fixed-order calculations.
- A comparison between PYTHIA8 and POWHEG shows that the topology of photon energy and hadronic energy differs at low transverse momenta. Here, more differential studies are mandatory, with varying jet parameters and momentum thresholds.

Acknowledgements

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