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# Prompt photon production with POWHEG

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**Abstract**
We present a calculation of prompt photon and associated photon-jet production at next-to-leading order that is consistently matched to parton showers with POWHEG. Specific issues that appear in photon radiation are discussed. Numerical results are compared to pp collision data at RHIC energies and shown to describe the data better than inclusive next-to-leading order calculations or those with leading order Monte Carlo generators like PYTHIA alone.

**Keywords**
Perturbative QCD; parton showers; photons; hadron colliders.

## 1 Introduction

Theoretical calculations of prompt photon production at hadron colliders have a long-standing tradition. Their importance derived originally from understanding perturbative QCD [1], e.g. the fractional quark charges or renormalisation group effects, whereas photon pair production is currently an important background in one of the Higgs-boson discovery channels at the LHC [2, 3]. In heavy-ion collisions, thermal photons are an important probe to determine the effective temperature of the created Quark-Gluon Plasma (QGP) through their characteristic exponential transverse momentum ($p_T^\gamma$) spectrum [4].

Leading-order (LO) calculations, supplemented by parton showers (PS) and hadron fragmentation and implemented in Monte Carlo generators like PYTHIA 8 [5], provide detailed information on the final state and are indispensable tools in the experimental analyses. Inclusive next-to-leading order (NLO) calculations like JETPHOX [6] employ, in contrast, inclusive fragmentation functions (FFs) like BFG II [7] and have a smaller theoretical scale uncertainty. With NLO+PS Monte Carlo methods like POWHEG [8] it is possible to combine the advantages of both approaches. We have recently applied this method to prompt photon and associated photon-jet production [9]. We review the theoretical approach in Sec. 2 and then demonstrate its phenomenological advantages by applying it to PHENIX data from RHIC [10] in Sec. 3. Our conclusions are given in Sec. 4.

## 2 Theoretical approach

The POWHEG method requires first the recalculation of Born processes with spin and colour correlations, in this case for $q\bar{q} \to \gamma g$ and the QCD Compton process $qg \to \gamma q$. Next, the virtual corrections must be recomputed and their ultraviolet and infrared divergences consistently renormalised and subtracted, respectively. The real emission amplitudes must not be subtracted, since POWHEG does so automatically. While the hardest radiation is thus generated first, subsequent emissions are produced by the parton shower implemented, e.g., in PYTHIA [5], leading always to detailed events with positive weights. This method applies not only to QCD radiation, but can be generalised to QED radiation. One must then check that fragmentation photons like those produced in $e^+e^-$ collisions at LEP are as well described with PSs as with inclusive FFs [11].

There are, however, a number of specific issues for photons. First, QED radiation is suppressed with respect to QCD radiation by the smaller coupling, colour factors and multiplicities, so that it must be artificially enhanced. Second, the hard scale is not necessarily the $p_T^\gamma$ of the observed photon, but may be the $p_T$ of an underlying QCD parton. Third, the radiation process $q \to q\gamma$ must be correctly



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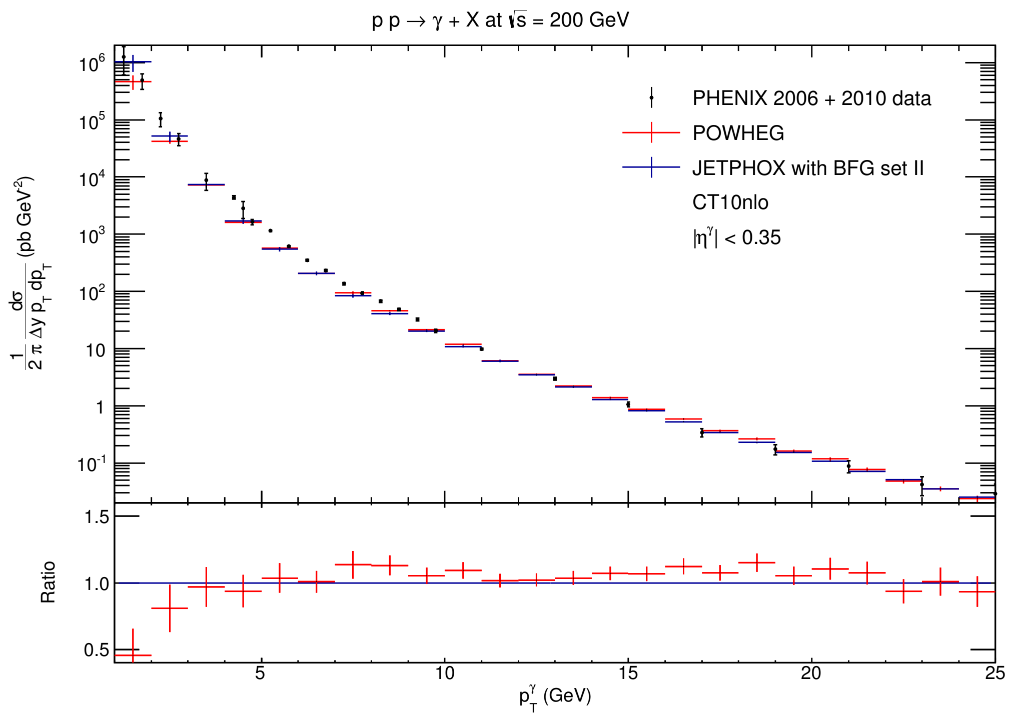


**Fig. 1:** Inclusive photon production in pp collisions at RHIC with a centre-of-mass energy of 200 GeV. PHENIX data (black) are compared with NLO+PS predictions with POWHEG+PYTHIA (red) and NLO predictions with JETPHOX (blue).

symmetrised, i.e. also include the process $q \to \gamma q$. Finally, inclusive photon production $pp \to \gamma + X$ has a collinear divergence at low $p_T^\gamma$, which must be carefully regularised so that sensitivity to the low-$p_T^\gamma$ region important for heavy-ion collisions and independence on the regularisation method are simultaneously maintained.

## 3 Prompt photons and photon-jet correlations at RHIC

We now compare the implementation of prompt photons in POWHEG to data obtained by the PHENIX collaboration in pp collisions at RHIC [10]. These data represent an important baseline for studies of the QGP produced in heavy-ion collisions and should be described by prompt (direct and fragmentation) contributions alone.

In Fig. 1 the inclusive photon distribution in transverse momentum is shown at the RHIC centre-of-mass energy of $\sqrt{s} = 200$ GeV. As expected for this inclusive quantity, both the NLO calculation with JETPHOX (blue) and the NLO+PS calculation with POWHEG+PYTHIA (red) describe the data up to 25 GeV. The two theoretical predictions differ only at very low $p_T^\gamma$, where fragmentation contributions dominate. There, the POWHEG+PYTHIA predictions are lower than those with JETPHOX and seem to agree better with the PHENIX data, although both are consistent with the data within error bars.

A quantity that is more sensitive to the treatment of the photon fragmentation process is the fraction of isolated photons, defined by a hadronic energy fraction of less than 10% of the energy of the photon in a cone of radius $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} \le 0.5$ around it. The comparison with JETPHOX in Fig. 13 of the experimental publication led to the conclusion that neither BFG II nor GRV [12] photon FFs described this fraction correctly, even after accounting for statistical, systematic, and theoretical scale uncertainties [10].

As one can see in Fig. 2, the fraction of isolated photons predicted by POWHEG+PYTHIA describes the data very well, apart from a few fluctuations due to limited Monte Carlo statistics. The fraction

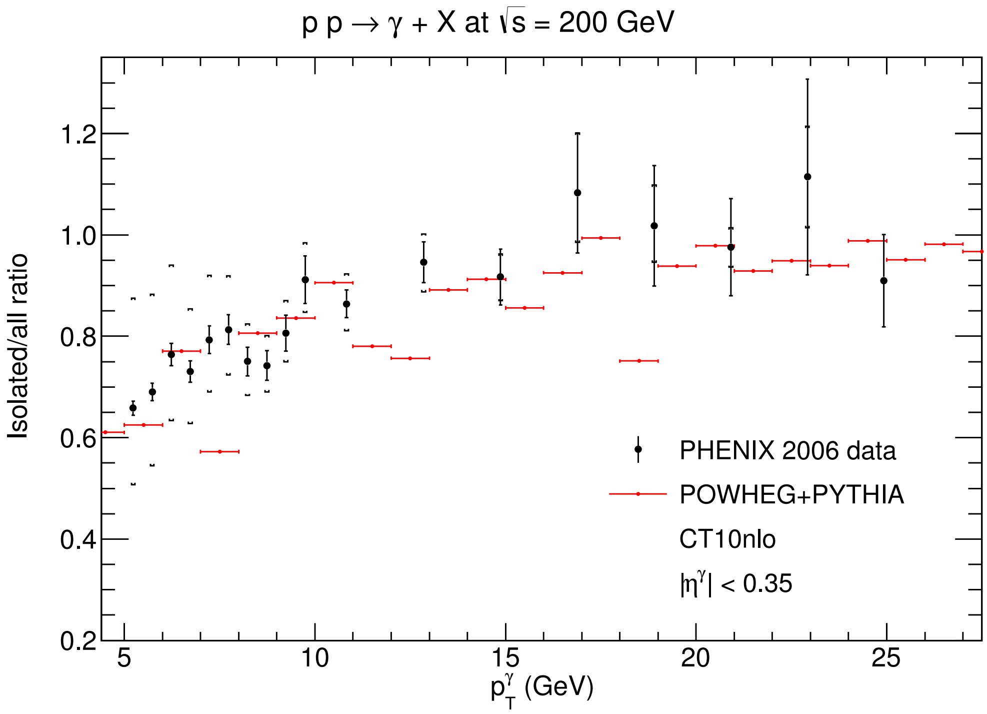


**Fig. 2:** Isolated photon production in pp collisions at RHIC with a centre-of-mass energy of 200 GeV. PHENIX data (black) are compared with NLO+PS predictions with POWHEG+PYTHIA (red).

rises from about 60% at low $p_T^\gamma$, where a substantial fraction of photons does not survive the isolation cut due to collinear parton radiation, to almost unity for intermediate and large $p_T^\gamma$. There, photons are rather produced back-to-back with a recoiling jet and have little near-side hadronic energy.

When both the photon and the recoiling jet are experimentally measured, the two may be correlated either in transverse momentum or in azimuthal angle $\Delta\phi$. Both quantities are sensitive to modifications of the hadronic jet due to rescatterings in the QGP, but also to higher-order perturbative QCD effects [13]. Fig. 3 shows the distribution in azimuthal angle, subtracted for decay photons assuming a Zero-Yield at Minimum (ZYAM) and normalised to the total number of trigger photons. The near- ($\Delta\phi \sim 0$) and away-side ($\Delta\phi \sim \pi$) regions are clearly visible, but only the latter is correctly described by PYTHIA alone, while both are reproduced with POWHEG+PYTHIA. As expected and as we have shown in our original paper [9], the near-side region is dominated by fragmentation photons, which requires a proper matching of NLO and PS contributions.

## 4 Conclusion

To conclude, we have reviewed our recent implementation of prompt photon production in POWHEG. Our calculations now allow for predictions of prompt photon and photon-jet associated production at hadron colliders with reduced theoretical scale uncertainties and sufficient detail of the produced final state. We have successfully applied our calculations to PHENIX data from RHIC. Applications to the LHC will be presented in a forthcoming publication.


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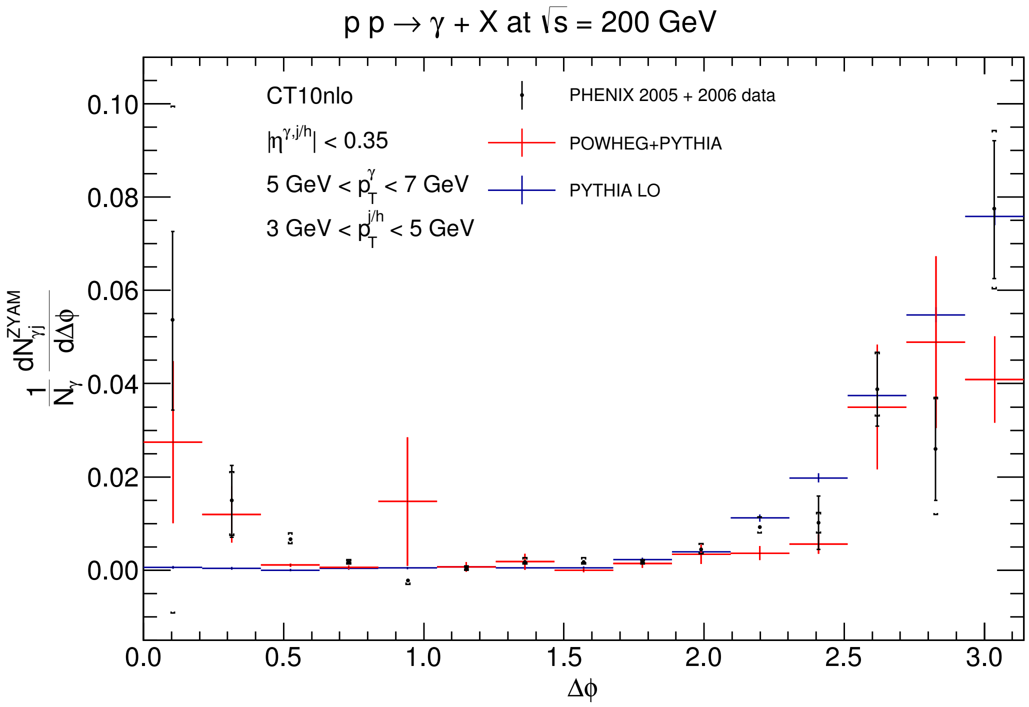


**Fig. 3:** Associated photon+jet production in pp collisions at RHIC with a centre-of-mass energy of 200 GeV. PHENIX data (black) are compared with NLO+PS predictions with POWHEG+PYTHIA (red) and LO+PS predictions with PYTHIA (blue).

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