Direct Photons with POWHEG

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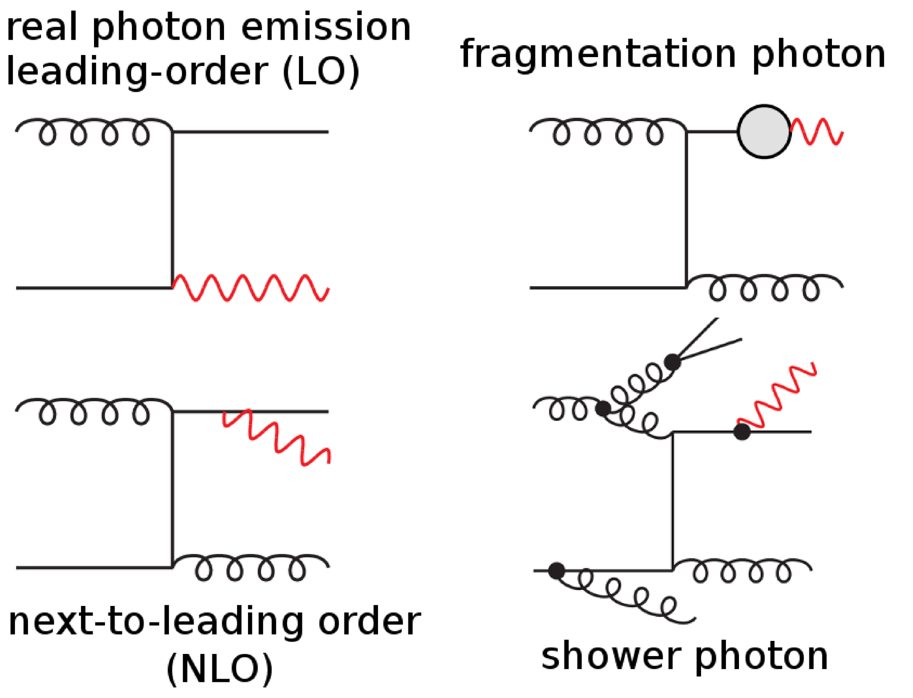
Abstract

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. Partons are interfaced with the PYTHIA 8 parton shower. Shown are comparisons to the isolated photon cross section measured at ATLAS and photon-jet correlations at CMS. Predictions are made for the ratio R_γ of inclusive photons over decay photons, which is a necessary input for the interpretation of thermal radiation off a hot nuclear medium, namely the Quark-Gluon Plasma. The potential of a parton fraction measurement with photons and jets is explored for ALICE, CMS and LHCb.

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.



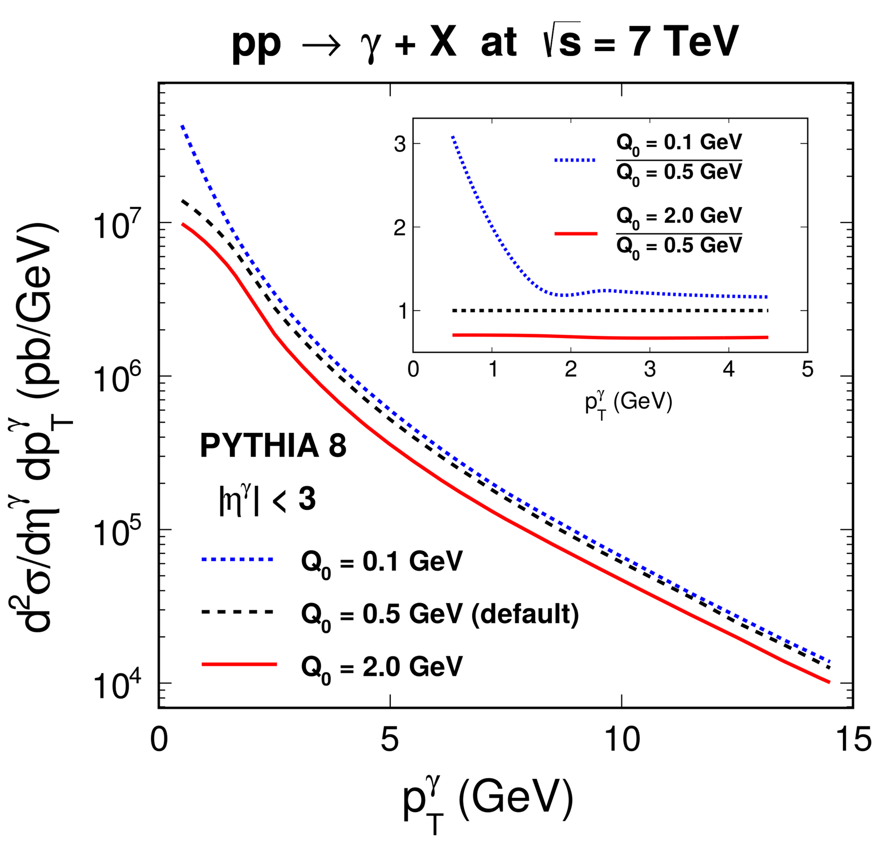
In photon phenomenology, one distinguishes different kinds of photons **depending on how they are generated**:

- 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 a calculation with leading order accuracy:

- 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 **PYTHIA 8** [2], shower photons are only described in a collinear approximation, so that – beyond the LO accuracy of the hard scattering kernel – any radiative correction is only provided with leading-log (LL) accuracy.

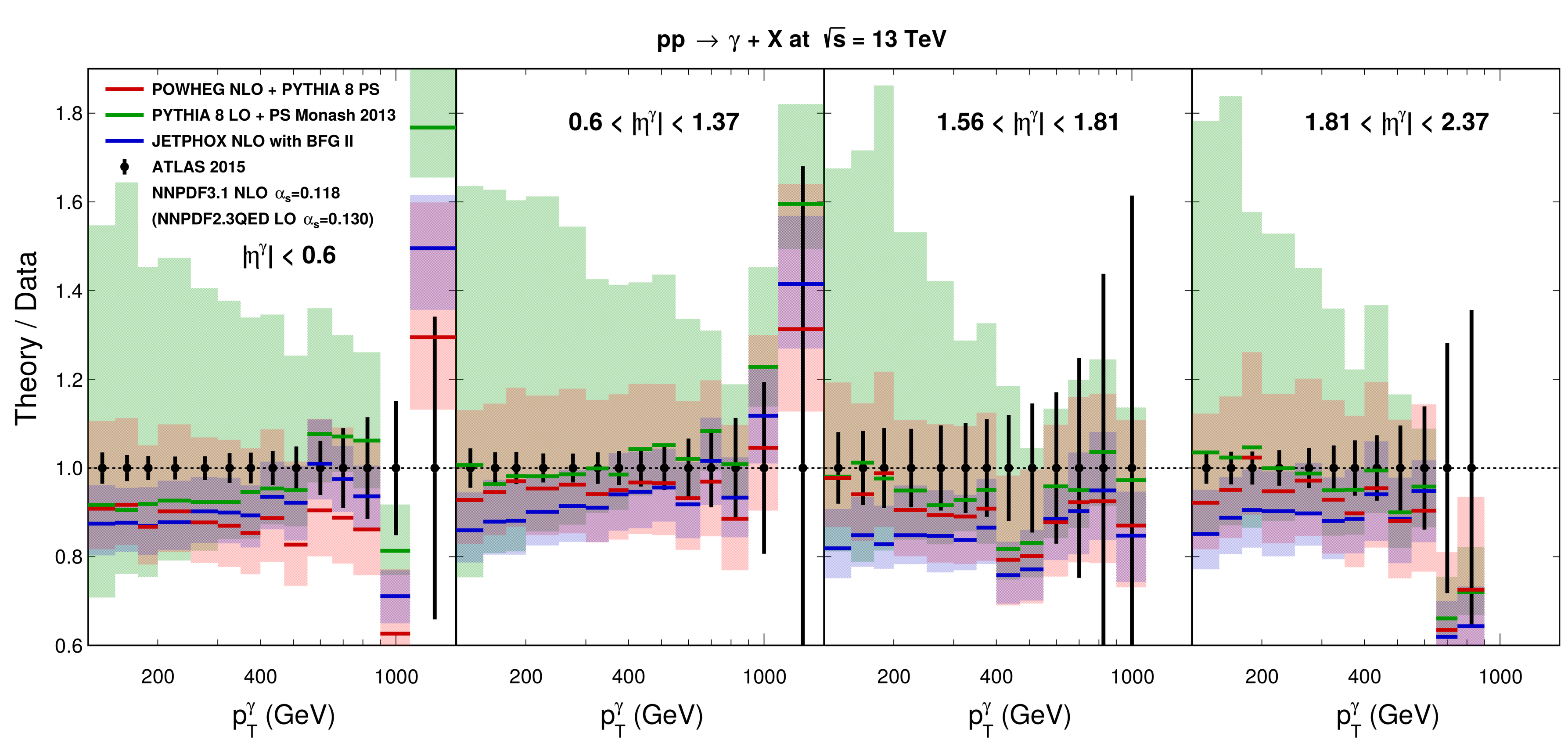


Additional features:

- Photon radiation off quarks has to be regularised by a soft cut-off in LO generators like PYTHIA 8 (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 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 at ATLAS

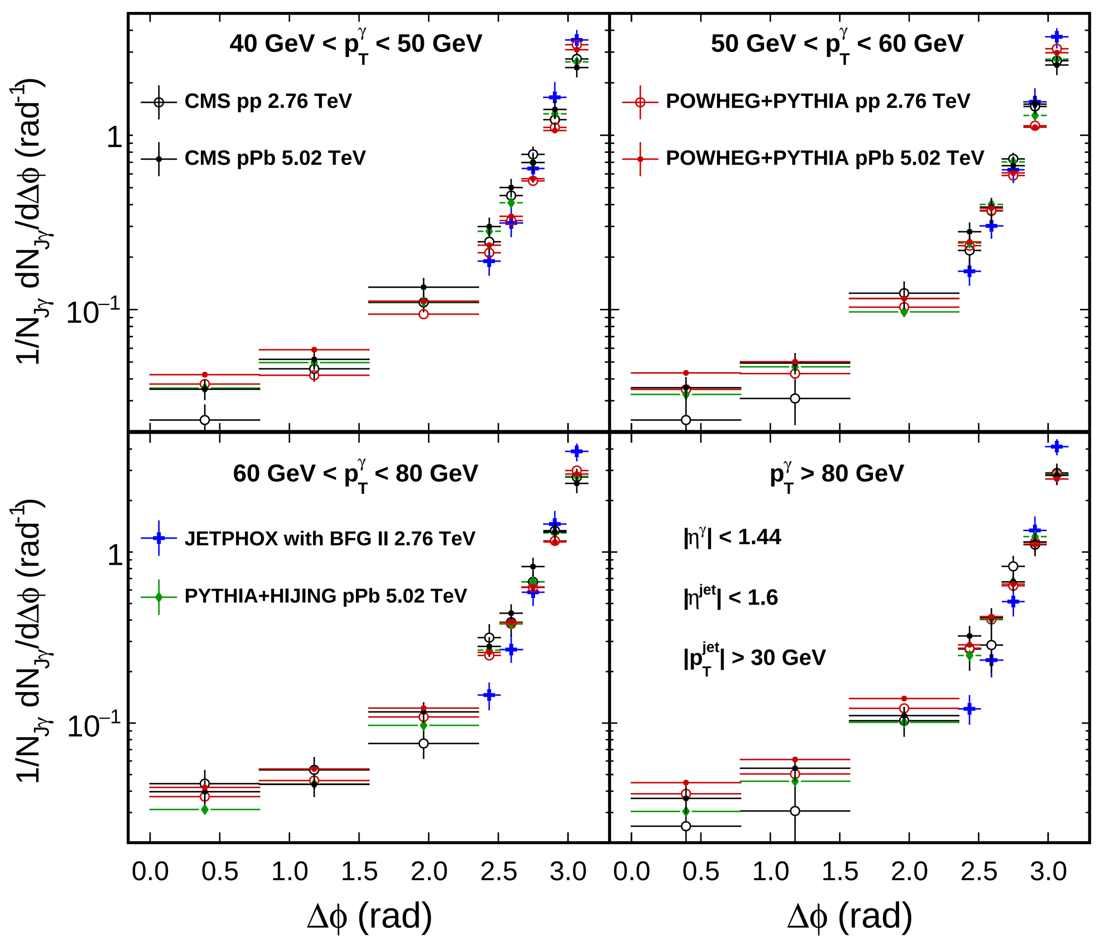
- Allowing only a certain energy flow in the vicinity of the photon, i.e. applying an **isolation cut**, one cuts away the huge amount of decay photons. The remaining **isolated photons** originate mostly from the scattering of two partons and thus, provide much more information about the parton distribution functions of the colliding protons and how partons fragment into photons (as well as possible modifications in nuclear matter).
- A comparison to isolated photon measurements from ATLAS [4] at the highest LHC energies (see ratio below) shows that POWHEG(+ PYTHIA 8 shower) describes the **cross section of isolated photons** slightly better than the fixed-order prediction from JETPHOX [5], except for mid-rapidity.
- Providing only LO accuracy, PYTHIA 8 shows the largest scale uncertainty; the scale uncertainty is much reduced for the NLO generators JETPHOX and POWHEG.



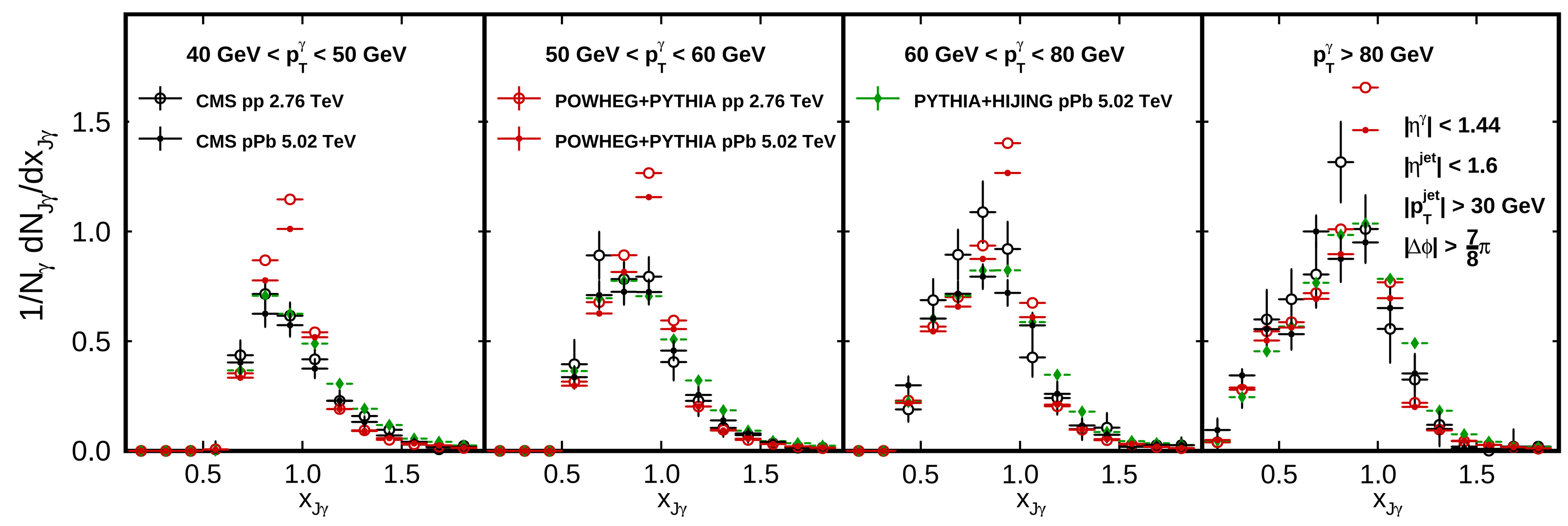
Azimuthal Photon-Jet Correlations

When a photon escapes from a hard scattering, its momentum is balanced by one or more partons that fragment into **jets** of hadrons. The measurement of the **azimuthal angle between a jet and a photon** (see figure on the right) provides further constraints on initial and final state, but especially on the fragmentation of partons into hadrons.

Selecting photon-jet configurations with a large azimuthal distance, i.e. a **back-to-back topology**, one might expect that the jet simply balances the momentum of the photon. Measurements from CMS [6] and simulations of the **jet's transverse momentum relative to the photon's transverse momentum** $x_{J\gamma}$ (figure below) shows that this simplified view does not hold.



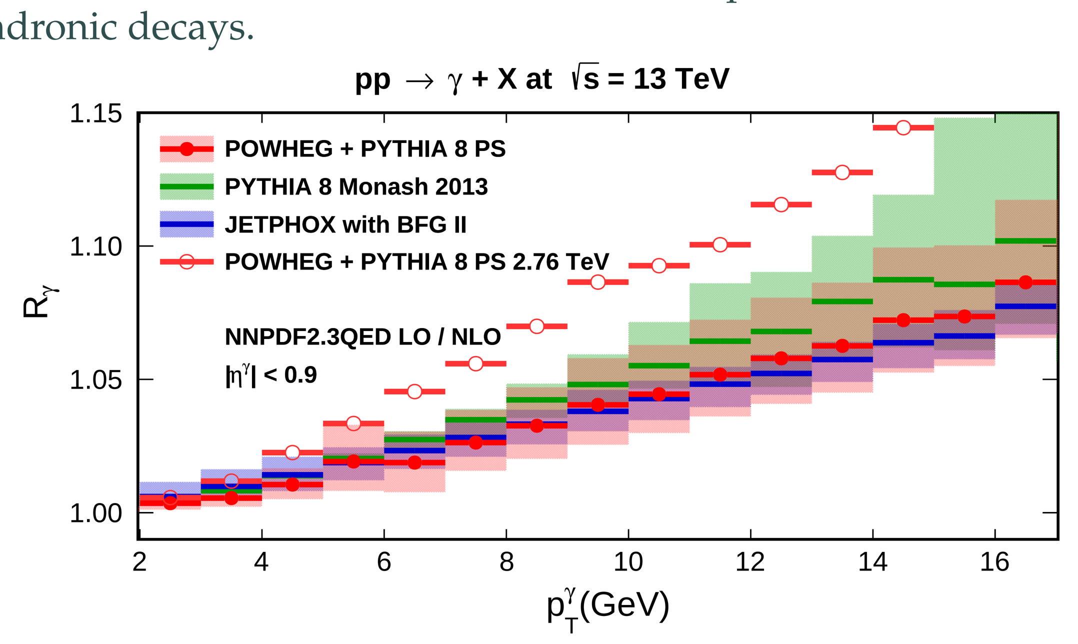
The jets are mostly found with less energy than the photon, which suggests that the jet does not recover the entire hadronic energy. Sometimes however, the jet is more energetic than the photon which suggests more complicated configurations like 1 photon + 3 or more jets.



Baseline for Thermal Photons from a Hot Nuclear Medium

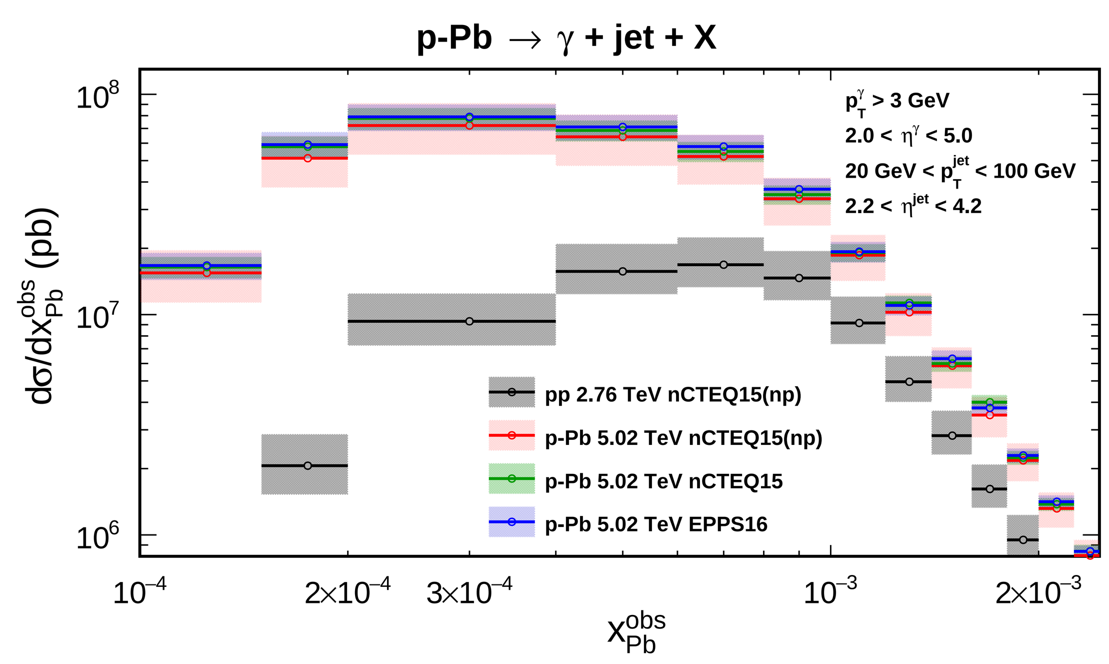
Thermal radiation is one of the signs of a hot nuclear medium. But the bulk of photons in both cold and hot hadronic matter comes from hadronic decays.

Therefore, **one can expose hot medium radiation by an excess in the ratio of inclusive photons over decay photons** R_γ as already performed by ALICE [7]. Still, one has to consider prompt photons from hard parton scatterings, the ones simulated with POWHEG. Therefore, the ratio R_γ including the prompt photons (figure on the right) is a necessary baseline for thermal radiation or any additional photon source.



Constraining Parton Distribution Functions with Photons and Jets

There is poor knowledge of the softest regime of **nuclear parton distribution functions**. Since isolated photons and jets are connected to the parton scatterings, they allow us to tell how much partons we see at a certain energy scale and for a given **parton momentum fraction** x.



Going to smallest photon and jet energies as well as to largest rapidities – possible with LHCb – one is most sensible to the soft end of parton distribution functions. A measurement of $x_{\mathrm{Pb}}^{\mathrm{obs}}$ (figure on the left) may allow further constraints, with $x_{\mathrm{Pb}}^{\mathrm{obs}}$ defined as

$$x_{\mathrm{Pb}}^{\mathrm{obs}} = \frac{p_T^\gamma \exp\left(-\eta^\gamma\right) + p_T^{\mathrm{Jet}} \exp\left(-\eta^{\mathrm{Jet}}\right)}{2E_{\mathrm{Pb}}}.$$

Conclusions

- Direct photon processes implemented in POWHEG BOX provide both NLO accuracy and come with a MC shower interface.
- Simulation results agree with measurements from the LHC and allow necessary predictions such as for the interpretation of thermal signals from a hot medium.
- The results presented here and more are available on arXiv (1709.04154) and are submitted to JHEP.

References

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