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Direct Photon Measurements with the ALICE Experiment at the LHC †

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Abstract: In high-energy hadron collisions, direct photons can be produced in various processes and are of particular interest to study the hot QCD medium since they escape it without being affected. These proceedings present the latest ALICE experiment results concerning direct photon production in proton-proton (pp), proton-lead (p–Pb) and lead-lead (Pb–Pb) collisions. All measurements agree with pQCD calculations at high transverse momentum ($p_{\rm T}$) and show no direct photon excess at low $p_{\rm T}$ in small systems while a low-$p_{\rm T}$ signal is found in central Pb–Pb collisions.

Keywords: direct photons; thermal radiation; isolated photons; pQCD

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1. Introduction

The inclusive production of photons in hadron collisions (denoted by $\gamma_{\rm inc}$) can be classified in two types: whereas decay photons ($\gamma_{\rm dec}$) are emitted by decaying hadrons, mainly π^0 mesons through their $\gamma\gamma$ channel, the rest is called direct photons ($\gamma_{\rm dir}$) so that $\gamma_{\rm dir} = \gamma_{\rm inc} - \gamma_{\rm dec}$.

For $p_{\rm T} \gtrsim 5\,{\rm GeV}/c$ the direct photon production is dominated by $2 \to 2$ prompt processes involving incoming partons (Compton scattering and annihilation Leading Order (LO) processes) as well as parton fragmentation, both well described by perturbative QCD (pQCD) at Next-to-Leading Order (NLO). The fragmentation contribution, by its higher-order nature, can only provide a partial information on the initial hard scattering. However, it can be largely reduced thanks to an isolation method giving access to LO photons, allowing to test pQCD and constrain parton distribution functions (PDFs in pp and nPDFs in heavy-ion collisions) [1].

At lower $p_{\rm T}$ values the direct photon spectrum is mainly fed by thermalisation of the hadron gas following collisions and to a larger extent of the Quark-Gluon Plasma (QGP) expected in ultrarelativistic heavy-ion systems [2]. The production of these thermal photons strongly depends on the hot medium properties, thus they carry information on its space expansion and temperature which are valuable to explore the hadron matter phase diagram [3].

The ALICE photon reconstruction techniques are introduced in Section 2, the latest results on low-$p_{\rm T}$ direct photons are presented in Section 3 and the high-$p_{\rm T}$ isolated photon differential cross section measurement is discussed in Section 4.

2. Reconstructing Photons with ALICE

In the ALICE experiment [4,5], photons can be reconstructed in two ways: either with the energy they deposit in calorimeters or with e^+e^- pairs they produced by conversion in detector material. During LHC Run 1 two calorimeters were installed: the PHOton Spectrometer (PHOS) and the ElectroMagnetic Calorimeter (EMCal). PHOS consists of lead tungstate crystal cells of size $2.2 \times 2.2\,{\rm cm}^2$ covering $|\eta| < 0.13$ and $260° < \varphi < 320°$ in total whereas EMCal is built with lead-scintillator sampling layered cells with $\Delta\eta \times \Delta\varphi = 0.0143 \times 0.0143$ each, covering $|\eta| < 0.7$ and $80^\circ < \varphi < 187^\circ$. Photons are measured in both detectors through electromagnetic showers induced in their material, and adjacent cells with deposited energy are grouped in clusters. Photon selection is mainly based on cluster properties (e.g., their elongation) and on a charged particle veto.

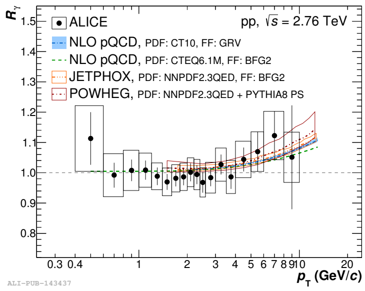
Reconstructing photons from their conversion in detector material is made possible with the Photon Conversion Method (PCM). This technique is based on e^+ and e^- tracks measured by the ALICE innermost detectors, the Inner Tracking System (ITS) and the Time Projection Chamber (TPC), and paired to locate neutral particle secondary vertices V^0 where they were emitted. Photons are selected with criteria on vertex properties (e.g., their topology). The probability for photons to convert in the ALICE material saturates at $\sim 9\,\%$ but the PCM technique allows to reconstruct them within the large acceptance of the TPC, i.e., $|\eta| < 0.9$ and a full azimuth.

3. Direct Photons at Low p_T in pp, p–Pb and Pb–Pb Collisions: The Subtraction Method

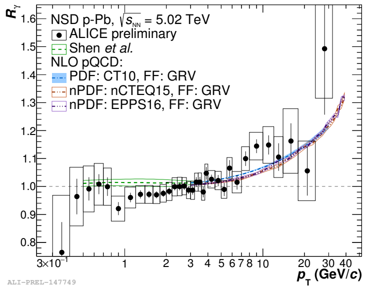
The ALICE Collaboration has been investigating direct photon production at low p_T in Pb–Pb collisions at $\sqrt{s_\mathrm{NN}} = 2.76\,\mathrm{TeV}$ [6], pp collisions at $\sqrt{s} = 2.76\,\mathrm{TeV}$ and $8\,\mathrm{TeV}$ [7] and more recently p–Pb collisions at $\sqrt{s_\mathrm{NN}} = 5.02\,\mathrm{TeV}$. The direct photon signal is obtained by statistically subtracting the decay photon component (γ_dec) from the inclusive photon yield (γ_inc) as $\gamma_\mathrm{dir} = \gamma_\mathrm{inc} - \gamma_\mathrm{dec} = (1 - 1/R_\gamma)\,\gamma_\mathrm{inc}$, where $R_\gamma = \gamma_\mathrm{inc}/\gamma_\mathrm{dec} \equiv (\gamma_\mathrm{inc}/\pi^0_\mathrm{param})/(\gamma_\mathrm{dec}/\pi^0_\mathrm{param})$ is called "direct photon double ratio".

Within this method the decay photon contribution (γ_dec) is computed using a so-called cocktail simulation. Parametrised with measured mother particle spectra (e.g., π^0, η, $K^\pm$) or using transverse mass scaling (e.g., η', ω), the main contribution to this simulation are π^0 mesons producing $\sim 90\%$ of all decay photons at $p_\mathrm{T} \approx 1\,\mathrm{GeV}/c$. The π^0_param term is obtained by parametrising the measured π^0 spectrum with different models [8]. As both γ_inc and π^0 yields can be measured with the same reconstruction techniques presented in Section 2 (PCM, PHOS, EMCal) the use of R_γ has the advantage of partially or completely cancelling several systematic uncertainties. Furthermore, direct photons can be extracted using different reconstruction techniques independently and all measurements can be combined taking care of statistical and systematic uncertainty correlations.

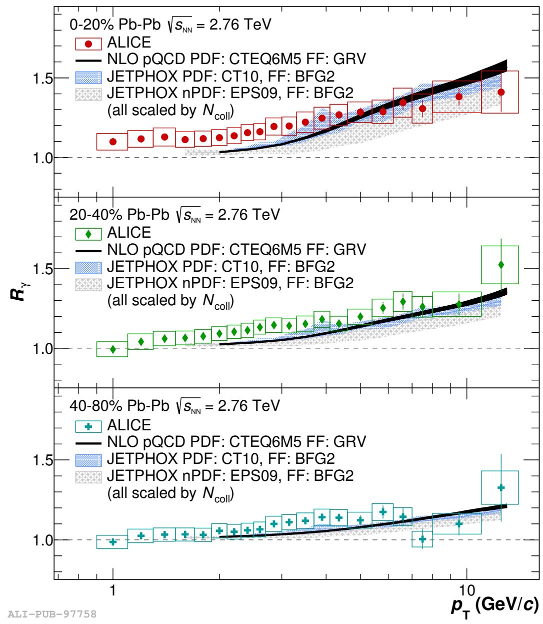
The double ratios measured by ALICE in different collision systems are shown in Figure 1. All results are compared with pQCD calculations at NLO (see [6,7] for details). An agreement with theory is observed for $p_\mathrm{T} \gtrsim 5\,\mathrm{GeV}/c$ in all systems and centrality classes (for Pb–Pb) supporting the prompt photon production scenario. Whereas R_γ is compatible with unity at very low p_T in pp and p–Pb collisions, a significant excess (10–15 %) is observed in the most central Pb–Pb collisions indicating that another source of direct photons is present. It has also been shown [6] that the resulting direct photon yield is compatible with several hydrodynamic models assuming the formation of a QGP and that the medium effective temperature measured by ALICE at the LHC is $\sim 30\,\%$ higher than observed by PHENIX at the RHIC [9], consistently with the expectations comparing collision energies.



(**a**)



(**b**)



(**c**)

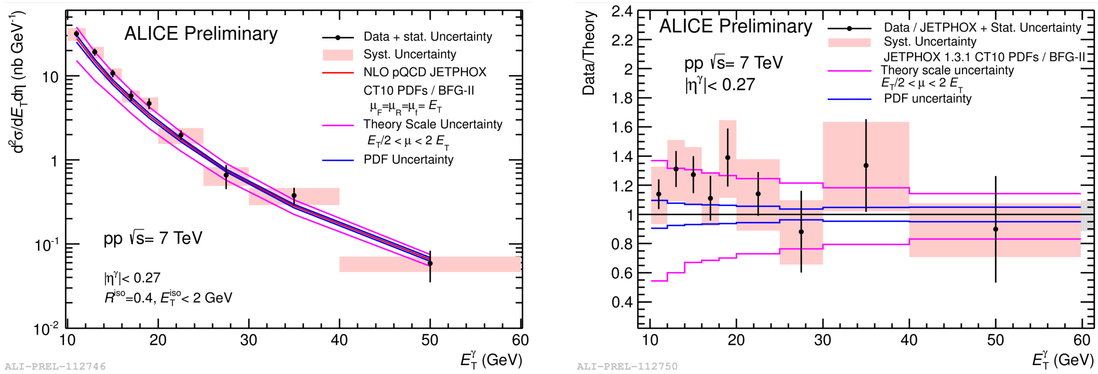
Figure 1. Direct photon double ratios measured in (**a**) pp collisions at $\sqrt{s} = 2.76\,\text{TeV}$ [7], (**b**) p–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02\,\text{TeV}$ and (**c**) Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 2.76\,\text{TeV}$ [6]. All results are compared with theory including pQCD at NLO and hydrodynamic calculations (see [6,7] for details).

4. Direct Photons at High p_{T} in pp Collisions: The Isolation Method

The direct photon high-p_{T} domain has been explored in pp collisions at $\sqrt{s} = 7\,\text{TeV}$ by the ALICE Collaboration using the EMCal reconstruction technique. In order to access LO photons the fragmentation photon contribution must be rejected. However, both cannot be disentangled at the detector level but one can strongly reduce the latter using an isolation method. This technique, which takes advantage of the fact that LO photons are likely produced at the other end of other collision remnants, consists in measuring the total activity $p_{\text{T}}^{\text{iso}}$ in a cone of radius $R_{\text{cone}} = \sqrt{(\eta - \eta_\gamma)^2 + (\varphi - \varphi_\gamma)^2}$ defined around a candidate photon $(\eta_\gamma, \varphi_\gamma)$, summing the transverse momentum of all particles (η, φ) inside. The neutral contribution to this activity is measured with EMCal neutral clusters whereas the charged contribution is determined with tracks from the ITS and TPC detectors. In the work presented here, photons are considered isolated for $R_{\text{cone}} = 0.4$ and $p_{\text{T}}^{\text{iso}} < 2\,\text{GeV}/c$, values determined with pQCD calculations to reduce the fragmentation contribution from 45% to 15% of all direct photons at $E_{\text{T}} = 60\,\text{GeV}$ [1].

Another key parameter to select direct photons is the EMCal cluster elongation mentioned in Section 2. It is denoted by σ^2_{long} and is used to discriminate decay photons (mainly from $\pi^0 \to \gamma\gamma$ inducing elongated clusters with high σ^2_{long} values) and direct photons (circular clusters with low σ^2_{long} values), and therefore to reduce the former contribution. However, the isolated and circular cluster sample still contains a residual contamination of clusters induced, for instance, by single photons from asymmetric π^0 decays. This contamination—in other words, the isolated photon sample purity—is estimated using a double sideband method in the $(p_{\text{T}}^{\text{iso}}, \sigma^2_{\text{long}})$ phase space, assuming no correlation between these parameters and a negligible signal leakage in background bands [10]. These strong hypotheses are carefully investigated and corrected with Monte Carlo simulations.

The cluster raw yield is corrected by this purity and the efficiency accounting for reconstruction, identification and isolation steps, then scaled by the integrated luminosity associated to the measurement. The resulting isolated photon differential cross section in pp collisions at $\sqrt{s} = 7\,\text{TeV}$ is shown in Figure 2 as well as pQCD calculations at NLO [11] for comparison. A reasonable agreement is observed between data and theory from 10 GeV to 60 GeV and this measurement extends the E_{T} reach down compared to previous results published by the ATLAS [10] and CMS [12] collaborations.



(**a**) (**b**)

Figure 2. Isolated photon differential cross section measured in pp collisions at $\sqrt{s} = 7\,\text{TeV}$, (**a**) compared with pQCD calculations at NLO [11] and (**b**) divided by these calculations.

5. Summary

In these proceedings were presented the latest ALICE experiment results about direct photon production in different collision systems. Two methods are used to extract the signal of interest depending on the photon momentum. At low p_{T}, decay photons are statistically subtracted from the inclusive photon yield to obtain the direct photon contribution using several independent reconstruction techniques. These measurements in pp and p–Pb collisions are fully consistent with pQCD calculations at NLO whereas in central Pb–Pb collisions an excess compatible with the presence of QGP is observed. At high p_{T}, the direct photon yield is extracted with an isolation method allowing to strongly reduce the fragmentation and decay photon contributions. This measurement in pp collisions extends the p_{T} reach compared to previous results while showing a good agreement with pQCD throughout the probed p_{T} range. Other collision systems and energies are being investigated currently to get a comprehensive picture of the direct photon production.

References

1. Ichou, R.; d'Enterria, D. Sensitivity of isolated photon production at TeV hadron colliders to the gluon distribution in the proton. *Phys. Rev. D* **2010**, *82*, 014015, doi:10.1103/PhysRevD.82.014015.
2. Gale, C. Photon Production in Hot and Dense Strongly Interacting Matter. *Landolt-Börnstein* **2010**, *23*, 445, doi:10.1007/978-3-642-01539-7_15.
3. Paquet, J.F. Probing the space-time evolution of heavy ion collisions with photons and dileptons. *Nucl. Phys. A* **2017**, *967*, 184–191, doi:10.1016/j.nuclphysa.2017.06.003.
4. Aamodt, K.; Quintana, A.A.; Achenbach, R.; Acounis, S.; Adamová, D.; Adler, C.; Aggarwal, M.; Agnese, F.; Rinella, G.A.; Ahammed, Z.; et al. The ALICE experiment at the CERN LHC. *JINST* **2008**, *3*, S08002, doi:10.1088/1748-0221/3/08/S08002.
5. Alessandro, B.; others. ALICE: Physics performance report, volume II. *J. Phys. G* **2006**, *32*, 1295–2040, doi:10.1088/0954-3899/32/10/001.
6. Adam, J.; others. Direct photon production in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76\,\text{TeV}$. *Phys. Lett. B* **2016**, *754*, 235–248, doi:10.1016/j.physletb.2016.01.020.
7. Acharya, S.; Acosta, F. T.; Adamová, D.; Adolfsson, J.; Aggarwal, M. M.; Aglieri Rinella, G.; Agnello, M.; Agrawal, N.; Ahammed, Z.; Ahn, S. U.; et al. Direct photon production at low transverse momentum in proton-proton collisions at $\sqrt{s} = 2.76$ and $8\,\text{TeV}$. *arXiv* **2018**, arXiv:1803.09857. *Phys. Rev. C* **2019**, *99*, 024912, doi:10.1103/PhysRevC.99.024912.
8. Acharya, S.; Adam, J.; Adamová, D.; Adolfsson, J.; Aggarwal, M.M.; Rinella, G.A.; Agnello, M.; Agrawal, N.; Ahammed, Z.; Ahmad, N.; et al. π^0 and η meson production in proton-proton collisions at $\sqrt{s} = 8\,\text{TeV}$. *Eur. Phys. J. C* **2018**, *78*, 263, doi:10.1140/epjc/s10052-018-5612-8.

9. Adare, A.; Afanasiev, S.; Aidala, C.; Ajitanand, N.N.; Akiba, Y.; Akimoto, R.; Al-Bataineh, H.; Al-Ta'Ani, H.; Alexander, J.; Angerami, A.; et al. Centrality dependence of low-momentum direct-photon production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. *Phys. Rev. C* **2015**, *91*, 064904, doi:10.1103/PhysRevC.91.064904.
10. Aad, G.; Abbott, B.; Abdallah, J.; Abdelalim, A. A.; Abdesselam, A.; Abdinov, O.; Abi, B.; Abolins, M.; Abramowicz, H.; Abreu, H.; et al. Measurement of the inclusive isolated prompt photon cross section in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector. *Phys. Rev. D* **2011**, *83*, 052005, doi:10.1103/PhysRevD.83.052005.
11. Aurenche, P.; Fontannaz, M.; Guillet, J.P.; Pilon, E.; Werlen, M. A new critical study of photon production in hadronic collisions. *Phys. Rev. D* **2006**, *73*, 094007.
12. Chatrchyan, S.; Khachatryan, V.; Sirunyan, A.M.; Tumasyan, A.; Adam, W.; Bergauer, T.; Dragicevic, M.; Eroe, J.; Fabjan, C.; Friedl, M.; et al. Measurement of the Differential Cross Section for Isolated Prompt Photon Production in pp Collisions at 7 TeV. *Phys. Rev. D* **2011**, *84*, 052011, doi:10.1103/PhysRevD.84.052011.