Measurement of Direct Photons in pp and Pb-Pb Collisions with ALICE

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Abstract

The measurement of the direct photon transverse momentum spectrum in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with data taken by the ALICE experiment is presented. The measurement shows a clear direct-photon signal for 0-40% most central collisions below 4 GeV/c that can not be described by next-to-leading-order perturbative QCD (NLO pQCD) calculations. Above this value of p_T the result is in agreement with pQCD predictions. The low p_T signal is expected to have thermal photon contributions. The inverse slope parameter of an exponential fit is extracted as $T_{LHC} = 304 \pm 51^{\text{syst+stat}}$ MeV. For a baseline measurement the analysis is performed for proton-proton collisions at $\sqrt{s}$ = 7 TeV and for peripheral (40-80%) Pb-Pb collisions. Both results show no low p_T direct-photon signal and are in agreement with pQCD calculations.

1. Introduction

Direct-photon production in hadronic collisions can be understood as a superposition of different production sources. In pp collisions, leading order pQCD processes, quark-gluon compton-scattering and quark-anti-quark annihilation are the main components of direct-photon production at high p_T. The second source is photons produced in yet fragmentation [1]. In heavy-ion collisions these prompt photons should be enhanced by the larger number of binary collisions. They may be modified by isospin effects and nuclear shadowing. Fragmentation photons are affected by jet quenching; saturation effects may lead to further modifications for both sources [2, 3].

In addition, final-state production mechanisms have to be considered in heavy-ion collisions. In the QGP phase, photons should be produced by the scattering of hard partons traversing the medium with thermalized partons, as well as by the scattering of thermalized partons. In the hot hadronic gas, produced after hadronization, direct photons should emerge from the scattering of the thermalized hadrons within the gas [2, 3, 4]. The thermalized nature of the production medium (QGP and hadron gas) should be reflected in the p_T distribution of the produced thermal photons.

The measurement of direct photons in pp collision is an important test for the validation of pQCD. In heavy-ion collisions a thermal photon signal is expected. From this signal an average temperature can be extracted. The comparison to pp pQCD results at higher p_T tests the binary scaling behavior of initial hard scatterings.

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[1]A list of members of the ALICE Collaboration and acknowledgements can be found at the end of this issue.

2. Analysis Method

For both analyzed systems (Pb-Pb at $\sqrt{s_{NN}} = 2.76\,\text{TeV}$, pp at $\sqrt{s} = 7\,\text{TeV}$) the same analysis method is used. The Pb-Pb analysis is divided into two bins of centrality (central: 0-40%, peripheral: 40-80%). The direct-photon signal is extracted via the subtraction method (see e.g. [5]):

$$\gamma_{\text{direct}} = \gamma_{\text{inc}} - \gamma_{\text{decay}} = (1 - \frac{\gamma_{\text{decay}}}{\gamma_{\text{inc}}}) \cdot \gamma_{\text{inc}}. \tag{1}$$

The method is based on the measurement of the inclusive photon yield via the reconstruction of their conversion products. For this purpose a secondary vertex finder is used. The algorithm combines oppositely charged tracks with a large impact parameter. If a pair is accepted the conversion point and the momentum of the photon is calculated. The algorithm is generally used to identify weakly decaying particles like Λ or K_s^0.

To optimize the signal to background ratio and to exclude other sources of secondary vertices beside photons (combinatorial background, Λ, K_s^0, etc.), several photon selection criteria comparable to the criteria used in [7] are applied.

The extracted raw photon spectrum is corrected for purity, reconstruction efficiency and conversion probability of photons in the detector estimated from MC simulations.

The decay photon spectrum, γ_{decay}, is obtained by a cocktail calculation. The calculation is based on yield parametrizations of mesons with photon decay branches. The main source of decay photons ($\sim 80\%$) is $\pi^0 \rightarrow \gamma\gamma$. The second largest contribution ($\sim 18\%$) is the decay of the η meson ($\eta \rightarrow \gamma\gamma$). In the analyzed pp collisions both meson yields, π^0 and η, are measured [7]. In Pb-Pb only the π^0 yield is known [8]. In both cases additional sources of decay photons from unknown meson yields (η, η', ω, ϕ and ρ_0) are obtained from m_T-scaling [9].

To minimize the systematic uncertainties the ratio $\frac{\gamma_{\text{decay}}}{\gamma_{\text{inc}}}$ used in formula (1) is calculated via:

$$\frac{\gamma_{\text{inc}}}{\gamma_{\text{decay}}} = \frac{\gamma_{\text{inc}}}{\pi^0} / \frac{\gamma_{\text{decay}}}{\pi^0_{\text{param}}}. \tag{2}$$

The method guarantees an exact cancellation of all normalization factors used in the spectra. Further uncertainties are canceled due to the fact that the π^0 extraction is based on the same set of photon candidates as the inclusive photon yield [5, 6].

3. Results

Figure 1 shows the invariant cross section of inclusive photons produced in pp collisions at $\sqrt{s} = 7\,\text{TeV}$. It is calculated as:

$$E\frac{\mathrm{d}^3\sigma}{\mathrm{d}p^3} = \frac{1}{2\pi} \frac{\sigma_{MB_{OR}}}{N_{\text{events}}} \frac{1}{p_T} \frac{\mathcal{P}}{\mathcal{C}\mathcal{E}} \frac{N^\gamma}{\Delta y \Delta p_T}. \tag{3}$$

In the formula, $\mathcal{P}$, $\mathcal{C}$ and $\mathcal{E}$ are the purity, the conversion probability and the efficiency. They are obtained from MC. $\sigma_{MB_{OR}}$ is the interaction cross section for the MBOR trigger that is used for the pp collisions ($\sigma_{MB_{OR}} = 62.2 \pm 2.2\,\text{mb (syst)}$). N_{events} is the number of MBOR events that were collected and N^γ represents the number of photon candidates. In Fig. 2, the invariant inclusive photon yields for both centralities in Pb-Pb are presented.

In Fig. 3 the double ratio (Eq. (2)) for pp collisions at $\sqrt{s} = 7\,\text{TeV}$ is shown. Over the measured p_T range, the result is consistent with no direct-photon signal. The systematic uncertainties
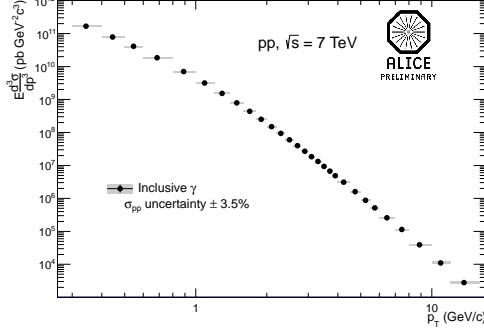
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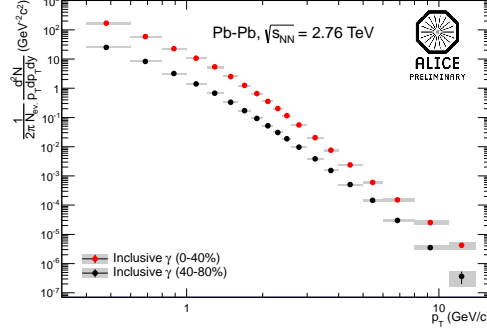Figure 1: Invariant cross section of inclusive photons in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$

Figure 2: (color online) Invariant yield of inclusive photons in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76\,\mathrm{TeV}$ for 0-40% and 40-80% centrality
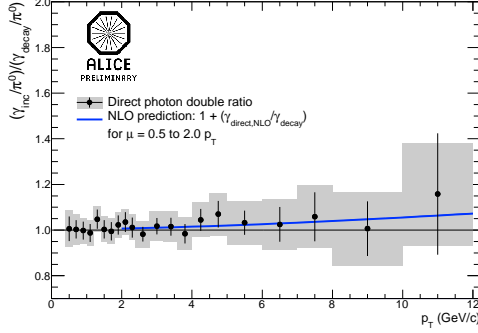

Figure 3: (color online) Direct-photon double ratio in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$ with NLO pQCD predictions
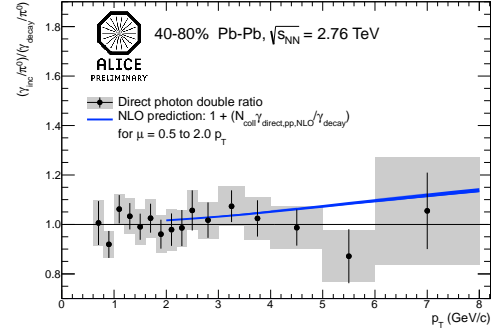

Figure 4: (color online) Direct-photon double ratio in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76\,\mathrm{TeV}$ for 40-80% centrality with NLO pQCD predictions

are too large to make a statement about the production of direct photons. A similar result for peripheral Pb-Pb collisions is presented in Fig. 4. Both measurements are compared to NLO pQCD predictions for direct photons in pp collisions ($\gamma_{\mathrm{direct,NLO}}$ in Eq. 4) [10]. These predictions are reformulated via

$$\mathcal{R}_{\mathrm{NLO}} = 1 + \left(N_{\mathrm{coll}} \cdot \frac{\gamma_{\mathrm{direct,NLO}}}{\gamma_{\mathrm{decay}}} \right) \tag{4}$$

to be comparable to a double ratio. N_{coll} is the average number of binary collisions from a Glauber Monte Carlo calculation (0-40%: $N_{\mathrm{coll}} = 825$, 40-80%: $N_{\mathrm{coll}} = 78$) [11]. In pp it is set to one. Both measurements, pp and peripheral Pb-Pb are in agreement with the NLO results, represented by a blue band.

The situation changes in central Pb-Pb collisions, as shown in Fig. 5. The double ratio shows a clear signal over the whole range of p_{T}. Below 4 GeV/c the direct-photon signal should contain a significant part of photons produced from a thermalized medium. Jet-photon conversions are also expected to contribute in this region. From the double ratio the direct-photon yield is

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extracted using Eq. (1) and shown in Fig. 6. Fig. 6 also shows a direct-photon NLO calculation for pp at $\sqrt{s} = 2.76$ TeV scaled by N_{coll} [10] and an exponential fit to the low momentum part of the spectrum. The inverse slope parameter of the exponential for 0.8 GeV/c $< p_{\text{T}} < 2.2$ GeV/c is extracted as:

$$T_{\text{LHC}} = 304 \pm 51^{\text{syst+stat}} \text{ MeV}. \tag{5}$$

In a similar analysis, PHENIX measures an inverse slope parameter of $T_{\text{RHIC}} = 221 \pm 19^{\text{stat}} \pm 19^{\text{syst}}$ MeV for 0-20% Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV. In hydrodynamic models describing the PHENIX data, the inverse slope of 220 MeV indicates an initial temperature of the QGP above the critical temperature T_C for the transition to the QGP [12, 13]. The ALICE result shows an expected increase in the extracted temperature. This is the first measurement of a direct-photon signal at low p_{T} with real photons.
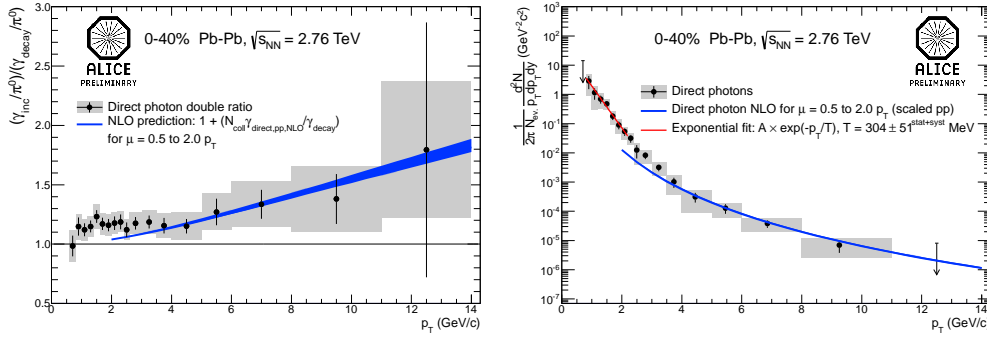

Figure 5: (color online) Direct-photon double ratio in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for 0-40% centrality with NLO pQCD predictions

Figure 6: (color online) Direct-photon invariant yield in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for 0-40% centrality with NLO pQCD predictions and exponential fit

References

References

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