PROCEEDINGS OF SCIENCE

Measurements of direct-photon production in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV and $\sqrt{s_{\rm NN}}$ = 2.76 TeV with the ALICE experiment

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Recent results on direct-photon measurements in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV from central to peripheral collisions, as well as in 0–10% central and 20–40% semicentral Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV with improved significance are presented. A significant direct-photon signal is measured for $p_{\rm T} \gtrsim 2$ GeV/c from central to peripheral Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV which is in agreement with model calculations containing pre-equilibrium photons in the intermediate $p_{\rm T}$ range and prompt photons at high $p_{\rm T}$. No significant direct-photon signal is measured in the low $p_{\rm T}$ interval which is also in agreement with the small thermal-photon signal predicted by state-of-the art models. On the other hand, a direct-photon signal is measured for $p_{\rm T} > 1$ GeV/c with a significance of 3.1 ($1.0 < p_{\rm T} < 1.8$ GeV/c) and 3.4 ($1.0 < p_{\rm T} < 2.3$ GeV/c) in 0–10% and 20–40% central Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV, respectively. Direct photons at both energies are in agreement with state-of-the-art theory calculations over the complete $p_{\rm T}$ range and measured centralities.

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1. Introduction

Direct photons are unique probes to study and characterize the quark-gluon plasma (QGP) as they leave the medium not affected by strong interactions. They are produced throughout all stages of the collision; thus, they carry information about the space-time evolution and the temperature of the medium. Direct photons are all photons except the ones from hadron decays. They include several sources [1]. The prompt photons produced in initial hard scatterings are dominant at high $p_{\rm T}$ ($p_{\rm T} > 4$ GeV/c). Their production can be described by next-to-leading order (NLO) perturvative Quantum Chromodynamics (pQCD) calculations. Next in production time are pre-equilibrium photons, that can be found in the intermediate $p_{\rm T}$ range (2 $< p_{\rm T} <$ 4 GeV/c). Thermal photons from the QGP and hadron gas phase are the dominant contribution at low $p_{\rm T}$ [2–6]. They can be calculated employing state-of-the-art hydrodynamical calculations or by microscopic transport approaches. There are other contributions like photons produced in jet-medium interactions. The spectrum evolves from an exponential shape at low $p_{\rm T}$ to a power-law shape at high $p_{\rm T}$.

Direct-photon production was measured in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV in three centrality classes by combining PCM and PHOS measurements in ALICE [7]. The significance of the measurement at low $p_{\rm T}$ was largely influenced by the 4.5% material budget uncertainty of the PCM measurement. A recent data-driven precision determination of the material budget in ALICE [8] which reduces the uncertainty down to 2.5% is used for the direct-photon measurements in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV and $\sqrt{s_{\rm NN}} = 5.02$ TeV presented in these proceedings from the 2011 and 2015 data samples, respectively.

2. Analysis methods

Photons can be detected in ALICE [9] using the PHOS [10] and the EMCal [11] calorimeters, or via the photon conversion method (PCM) [9]. In PCM, photons are measured by reconstructing the electron positron pairs produced by photon conversions using the ITS [12] and the TPC [13] detectors located in the central barrel of the ALICE experiment inside the L3 magnet. The V0 detectors and Zero Degree Calorimeters (ZDC) are used for triggering and characterization of the collision. In the 2011 run, an online centrality trigger based on the amplitude of the V0 detectors was used to enhance the central and semicentral events, while during the 2015 run a minimum bias (MB) condition was used for the complete data sample. The data samples consist of a total of 75 million MB Pb–Pb collisions for the 2015 run, and 20 million 0–10% central and 8.4 million 20–40% semicentral collisions for the 2011 run. The PCM only measurement is used for the 2015 direct-photon analysis, and the PCM analysis from 2011 is combined with the PHOS 2010 analysis to obtain the improved results in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV.

3. Direct photons in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV and at $\sqrt{s_{\rm NN}} = 5.02$ TeV

Direct-photon yields are measured subtracting from the inclusive-photon yields the estimated contribution from decay photons using a double ratio called R_γ, in order to reduce the systematic uncertainties; i.e. $\gamma_{direct} = \gamma_{incl} - \gamma_{decay} = \gamma_{incl} \cdot \left(1 - \frac{1}{R_\gamma}\right)$, where $R_\gamma = \frac{(N_{\gamma,\rm inc}/N_{\pi^0})_{\rm measured}}{(N_{\gamma,\rm decay}/N_{\pi^0})_{\rm sim}}$. The decay photon spectra are estimated employing the decay cocktail framework [14] using as input the

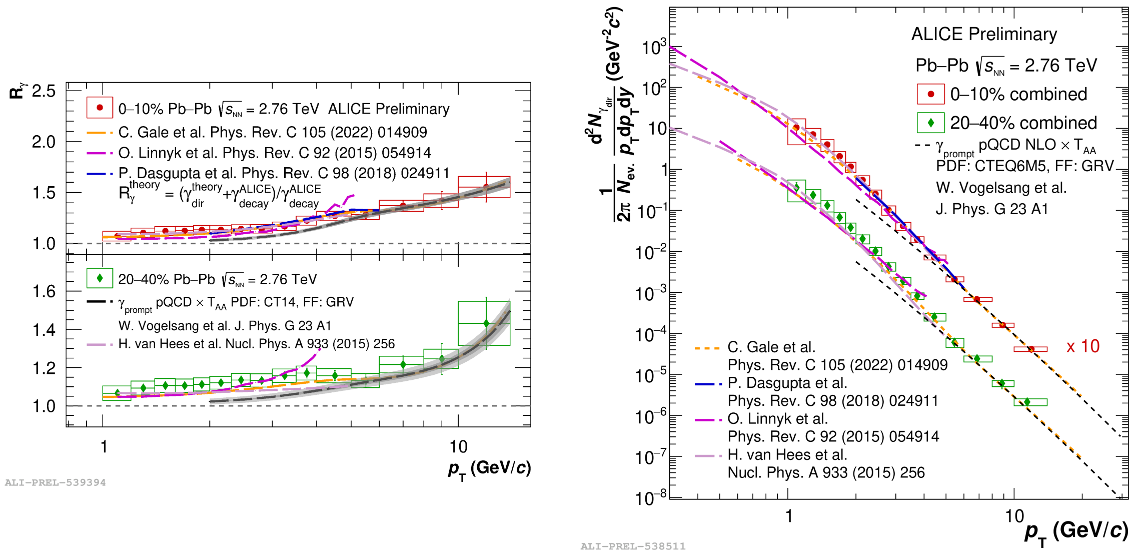

Figure 1: R_γ (left) and direct-photon spectra (right) as a function of p_T for 0–10% central (top) and 20–40% semicentral (bottom) Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV compared different model calculations [2–6].

measured π^0 and η meson spectra [15] (or the π^0 spectra and η/π^0 ratio [16]) and m_T scaling for non measured spectra. The R_γ and corresponding direct-photon spectra are shown in Fig. 1(left) and Fig. 1(right) for central and semicentral Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. In Fig. 2, the same observables are reported for $\sqrt{s_{NN}}$ = 5.02 TeV. In the p_T bins where the γ_{dir} is consistent with zero within total uncertainties, upper limited at 90% CL are given. At large p_T (p_T > 4 GeV/c), the direct-photon signal is attributed to prompt photons, and agrees nicely with the scaled pQCD predictions for central and semicentral collisions at both energies. In the intermediate p_T range (2-4 GeV/c), the direct-photon signals agree better with model predictions that include thermal (and pre-equilibrium) photons. For p_T < 3 GeV/c thermal-photon signals are observed in central and semicentral collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with a significance of 3.1 (1.0 < p_T < 1.8 GeV/c) and 3.4 (1.0 < p_T < 2.3 GeV/c), respectively. At $\sqrt{s_{NN}}$ = 5.02 TeV no significant direct-photon signal is observed at low p_T. Both results are consistent with theoretical model predictions. The direct-photon results at $\sqrt{s_{NN}}$ = 2.76 TeV are in agreement with the previous publication [7] and show a larger significance due to the larger data sample and improved material budget uncertainties [8]. Furthermore, results in 0–10% central Pb–Pb collisions could be obtained.

Ratios of direct-photon spectra to the expectations from the theoretical model of Ref. [6] are calculated for central and semicentral Au–Au and Pb–Pb collisions at $\sqrt{s_{NN}}$ = 0.2, 2.76 and 5.02 TeV [16, 17] (see Fig. 3) with the aim of finding out whether state-of-the-art model calculations describe similarly direct-photon production at different energies. A good agreement between ALICE data and model predictions is observed, while a slight tension may be present at low p_T and semicentral collisions for the PHENIX data. The integrated direct γ yields in the range 1 GeV/c < p_T < 5 GeVc at both energies and different centralities are plotted as a function of the charged particle pseudorapidity density together with the existing measurements [17] in Fig. 4 and expectations from a model calculation [6]. A power-law scaling of direct γ yields vs charged particle

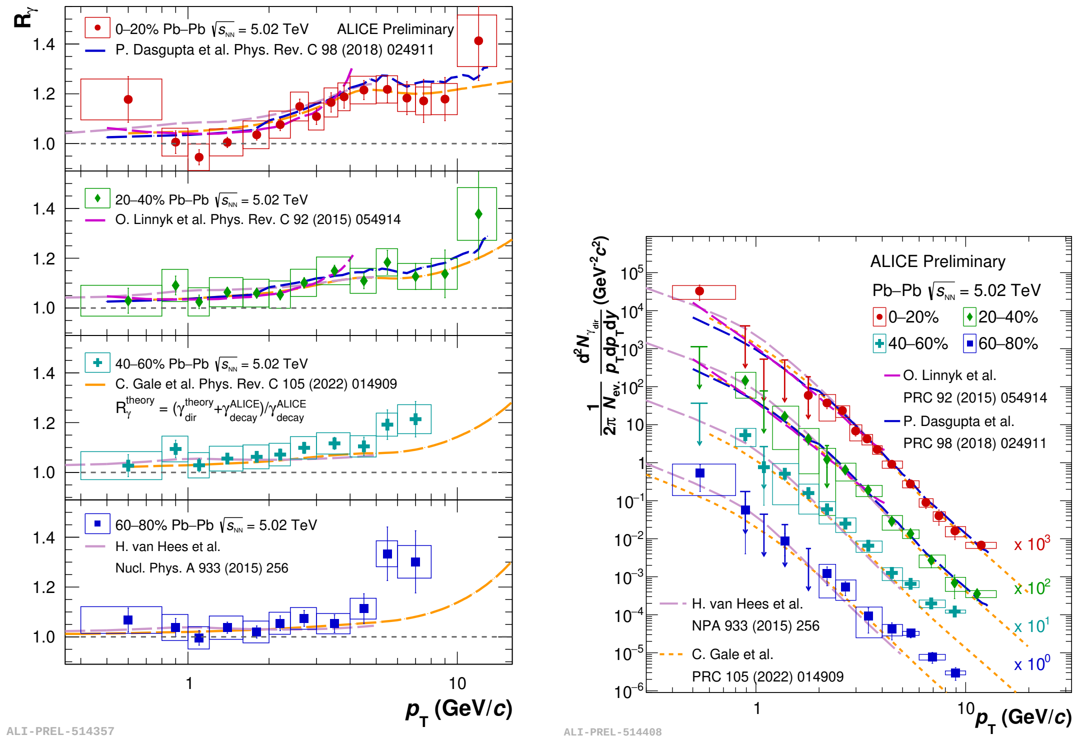

Figure 2: R_γ (left) and direct-photon spectra (right) as a function of p_T from central (top) to peripheral (bottom) Pb–Pb collisions at $\sqrt{s_\mathrm{NN}} = 5.02$ TeV compared to different model calculations [2–6].

pseudorapidity density is observed. The measured yields agree with the theoretical expectations at LHC energies. At RHIC energies, STAR results agree in all centralities with theoretical expectations while an agreement is observed only for central and semicentral collisions for PHENIX results, with an increasing difference between measured and predicted yields developing from semicentral to peripheral collisions.

The non-prompt direct-photon spectra at $\sqrt{s_\mathrm{NN}} = 2.76$ TeV are obtained subtracting the scaled pQCD prompt photon contribution from the direct-photon spectrum in central and semicentral collisions at $\sqrt{s_\mathrm{NN}} = 2.76$ TeV. The thermal spectra are then fitted with an exponential function in order to extract an effective temperature, T_eff, of the medium (see Fig. 4). Exponential function fits in the low p_T range, 1.1 GeV/c < p_T < 2.1 GeV/c, deliver T_eff = 343 ± 32(stat) ± 68(sys) MeV and T_eff = 339 ± 32(stat) ± 68(sys) MeV for central and semicentral collisions. These are the highest effective temperatures measured in heavy-ion collisions [17, 18]. In the intermediate p_T range, 2.1 GeV/c < p_T < 4.0 GeV/c, the effective temperatures are T_eff = 406 ± 19(stat) ± 36(sys) MeV and T_eff = 458 ± 25(stat) ± 40(sys) MeV. The overall larger value of T_eff in the intermediate p_T range with respect to the values in the low p_T range may be explained by an earlier emission time.

4. Conclusions

A first measurement of direct photons in Pb–Pb collisions at $\sqrt{s_\mathrm{NN}} = 5.02$ TeV is presented from central to peripheral collisions. Furthermore, new and improved measurements for central

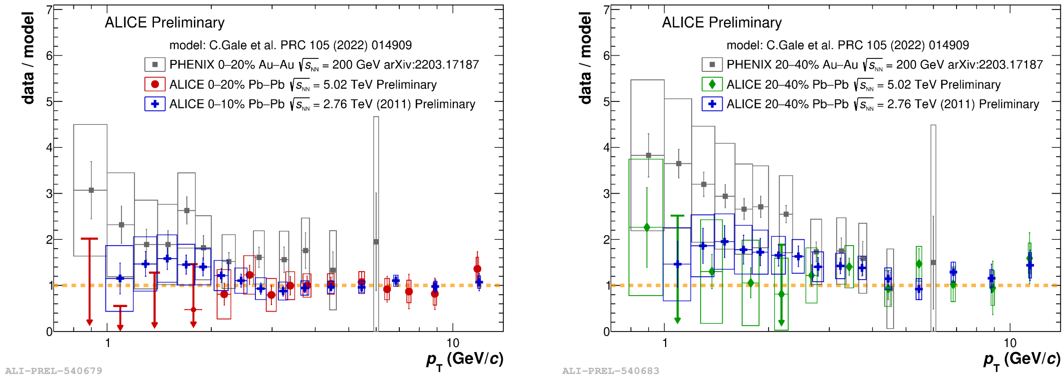

Figure 3: Ratios of direct-photon spectra to the expectations from the calculation of Ref. [6] for central (left) and semicentral (right) Au–Au and Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 0.2, 2.76 and 5.02 TeV.

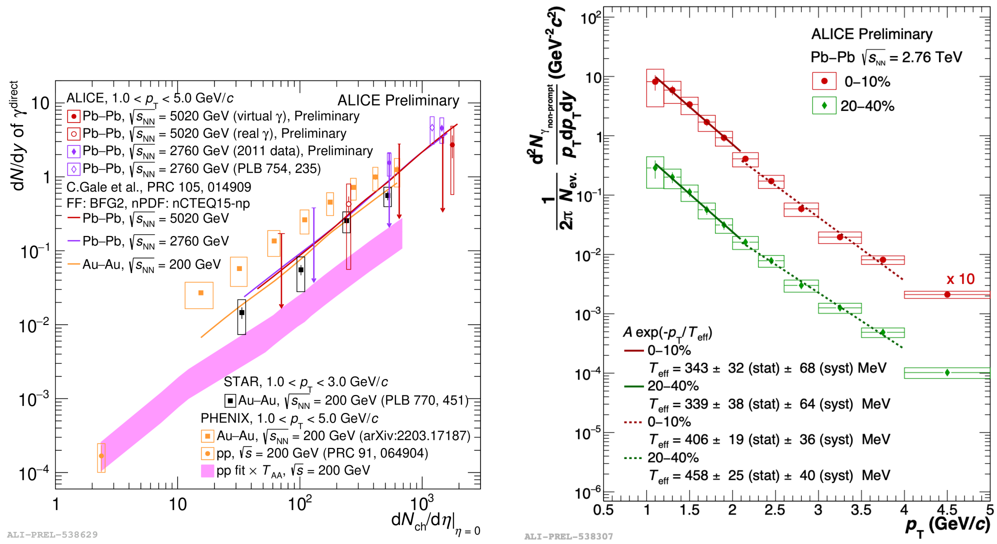

Figure 4: Left: Integrated direct γ yields in the p_{T} range 1 GeV/c < p_{T} < 5 GeVc as a function of the charged particle pseudorapidity density for different collision systems (pp, Au–Au and Pb–Pb) from $\sqrt{s_{\mathrm{NN}}}$ = 0.2 TeV to $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV together with expectations from Ref. [6]. Right: Non-prompt direct-photon spectra in central and semicentral Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV.

and semicentral collisions at $\sqrt{s}$ = 2.76 TeV are also shown. Direct photon spectra at the LHC are in agreement with state-of the-art calculations.

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