Thermal radiation and direct photon production measurements with dielectrons in Pb–Pb and pp collisions

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Abstract. The latest ALICE results on dielectron measurements in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV, and in minimum-bias (MB) and high-multiplicity (HM) pp collisions at $\sqrt{s}$ = 13 TeV with LHC Run 2 data are reported. The results are compared to the predictions of dielectron yields from known hadronic sources and thermal radiation from the medium. The contribution of virtual direct photons is extracted from the data by fitting the measured invariant mass distributions. We present the direct to inclusive photon ratio, as well as the direct photon yield in both pp and central Pb–Pb collisions.

1 Introduction

Electromagnetic probes such as photons and dileptons are well suited to study the whole space–time evolution of the hot and dense matter called quark–gluon plasma (QGP), created in ultra-relativistic heavy-ion collisions. They are produced during all stages of the collision with negligible final-state interactions. In the intermediate mass region (IMR : 1.1 GeV/c^2 < $m_{\rm ee}$ < 2.7 GeV/c^2), thermal radiation from the QGP carries information from the partonic phase of the collision. In the low mass region (LMR : $m_{\rm ee}$ < 1.1 GeV/c^2) , thermal radiation from the hadron gas contributes to the dielectron spectrum mainly through the decay of rho mesons whose spectral function is sensitive to chiral-symmetry restoration [1]. At $m_{\rm ee} \ll p_{\rm T,ee}$, the ratio of direct to inclusive photons can be extracted from the dielectron spectrum. Dielectron production in minimum-bias (MB) pp collisions serves as a vacuum baseline for the studies in Pb–Pb collisions. Recently, pp collisions with high charged-particle multiplicities (HM) were found to exhibit surprisingly similar phenomena, i.e. anisotropic flow [2–4] as observed in heavy-ion collisions. The search for thermal photons in small systems may help to better understand the underlying dynamics in such collisions. The analysis in pp collisions uses the full Run 2 data, with and integrated luminosity of $L_{\rm int,MB} \simeq 30.3$ nb^{-1} for MB and $L_{\rm int,HM} \simeq 6.08$ pb^{-1}. This is increased by a factor of 3.8 and 4.4, for the MB and HM datasets with respect to the previous publication [5], respectively. The Pb–Pb data was collected in 2018, and the analysis uses both the MB and centrality triggers with an integrated luminosity of 83 μb^{-1}. The tracking and identification of electrons are done using the Inner Tracking System (ITS), the Time Projection Chamber (TPC), and the Time-Of-Flight detector at midrapidity ($|\eta_e| < 0.8$) [6].

2 Dielectrons in pp collisions at $\sqrt{s}$ = 13 TeV

Figure 1 shows the invariant mass spectra measured in MB and HM pp collisions at $\sqrt{s}$ = 13 TeV compared with the expectation from known hadronic decays, which we also refer

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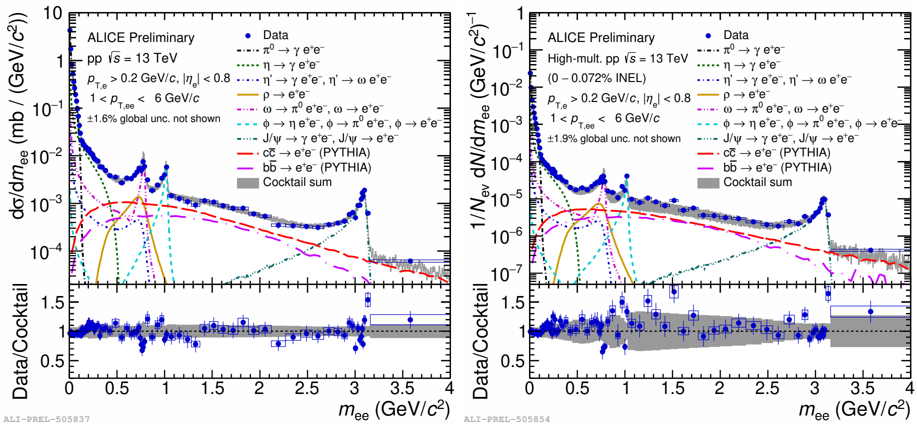

Figure 1. Dielectron production cross section (left) and yields (right) as a function of invariant mass in MB and HM pp collisions at $\sqrt{s}$ = 13 TeV, respectively.

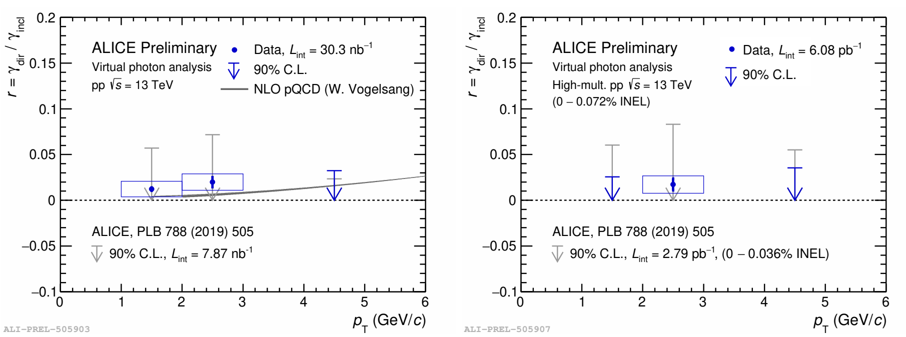

Figure 2. Direct photon fraction r as a function of p_T in MB (left) and HM (right) pp collisions at $\sqrt{s}$ = 13 TeV.

to as the hadronic cocktail. The π^0 and η spectra were measured for MB and HM pp collisions*, and used as input to the cocktail calculations. Dielectrons from semileptonic decays of heavy-flavor (HF) hadrons in MB pp collisions are estimated using the PYTHIA6 event generator. For the HM pp cocktail, an additional p_T-dependent scaling factor is applied for the HF and J/ψ contributions to take into account the multiplicity dependence of heavy-flavor and J/ψ production [7, 8]. The MB data is well described by the cocktail, which establishes the vacuum baseline. In HM pp collisions, the data and the cocktail are consistent and no sign of thermal radiation is observed in the IMR.

The direct virtual photon is measured via the internal conversion technique. The relation between virtual photons and dielectrons is given by the Kroll–Wada formula [9]. The different expected mass shapes of the virtual direct photon contribution and of e^+e^- pairs from light-meson Dalitz decays makes it possible to separate them. The direct photon fraction r defined as the ratio of direct photon yield to the inclusive photon yield $r = \gamma_{dir}/\gamma_{incl} = \gamma^*_{dir}/\gamma^*_{incl}\big|_{m_{ee}=0}$, is extracted from the data by fitting the dielectron invariant mass spectra with a three component function including the light-flavor decay (f_{LF}), direct virtual photon (f_{dir}), and heavy-flavor decay (f_{HF}) contributions: $f_{fit} = r f_{dir} + (1-r) f_{LF} + f_{HF}$. The fraction r as a function of p_T is shown in Fig. 2 for MB pp and HM pp collisions. It can be seen that statistical and system-

*Presented at SQM2022 - The 20th International Conference on Strangeness in Quark Matter atic uncertainties are significantly reduced compared to the previous publication [5]. In MB pp collisions, r is in good agreement with the pQCD calculations and in HM pp collisions, no sign of an increase of r with respect to MB pp collisions is observed.

3 Dielectrons in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV

The left panel of Fig. 3 shows the mass spectrum of dilepton pairs in the 0–10% central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. In the LMR, the results show a hint of an excess above the hadronic cocktail compatible with the prediction of thermal radiation from the hadron gas [10, 11]. The data are compared with different hadronic cocktails, based on two different assumptions for the HF contribution. In the first approach, the HF contribution is estimated using the measured charm and beauty cross sections at midrapidity in pp collisions at $\sqrt{s}$ = 5 TeV [12] scaled with the number of binary collisions. In the second approach, on top of the binary scaling, the HF contribution is weighted by the measured nuclear modification factor R_{AA} of single HF electrons [13]. Due to the large HF background in the IMR, the extraction

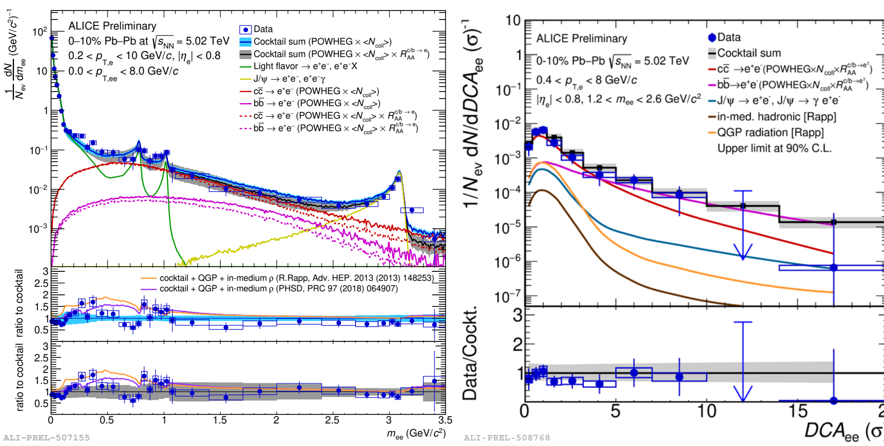

Figure 3. Left: Dielectron m_{ee} spectrum compared with different hadronic cocktails. Right: Dielectron yields as a function of $\mathrm{DCA}_{\mathrm{ee}}$

of a thermal contribution from the QGP is challenging. In order to separate prompt (thermal) and non-prompt (HF) sources, the distance-of-closest approach to the primary vertex of dielectrons ($\mathrm{DCA}_{\mathrm{ee}}$) is used. It is expected that prompt thermal dielectrons have smaller $\mathrm{DCA}_{\mathrm{ee}}$ compared to the one from HF decays. Figure 3 (right) shows the $\mathrm{DCA}_{\mathrm{ee}}$ distribution of dielectrons at IMR and the comparison with cocktail calculations. The data is well described by the cocktail which takes into account the $\mathrm{e}^+\mathrm{e}^-$ HF suppression and thermal radiation from the QGP. At high $\mathrm{DCA}_{\mathrm{ee}}$, the $\mathrm{e}^+\mathrm{e}^-$ dominant contribution comes from beauty hadron decays. By fixing the beauty contribution to reproduce the measured $\mathrm{DCA}_{\mathrm{ee}}$ spectra at high $\mathrm{DCA}_{\mathrm{ee}}$, the charm and prompt (thermal) components can be extracted from the data. The results are compatible with HF suppression, more pronounced for charm than beauty, and a contribution of thermal radiation from the QGP similar to that predicted by models [10].
Finally, Figure. 4 (right) shows the measured ratio $R_\gamma = \gamma_{\mathrm{incl}}/\gamma_{\mathrm{decay}} = 1 / (1 - r)$ extracted in central Pb–Pb collisions. The result is in agreement with that of the real photon analysis via the gamma conversion method (PCM)*.The virtual photon results show smaller (larger) systematic (statistical) uncertainties compared to the ones from PCM. The direct photon yield can be constructed using the inclusive photon spectrum from PCM via $\gamma^{\mathrm{dir}} = \gamma^{\mathrm{incl}}_{\mathrm{PCM}} \times r$, as

*Presented at QM22 - XXIIXth International Conference Quark Matter 2022 shown in Fig. 4 (right). The result is compared with theory calculations including thermal, pQCD and pre-equilibrium photons,[14–17]. It can be seen that all models agree with the data but some tend to overestimate them at low p_{T}.

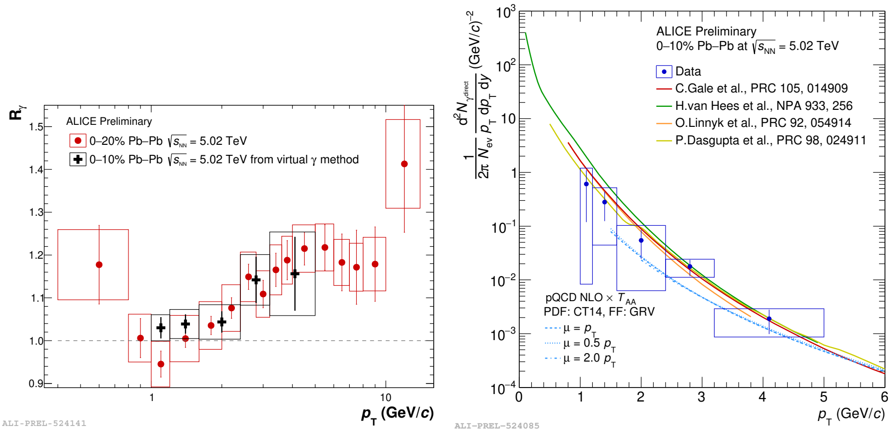

Figure 4. Left: Direct photon excess ratio R_γ as a function of p_{T} measured with virtual (black) and real (red) photons. Right: Direct photon spectrum in most central (0–10%) Pb–Pb collisions compared with theory and pQCD calculation.

4 Summary and outlook

The direct photon fraction measured in MB pp collisions at $\sqrt{s}$ = 13 TeV is consistent with pQCD calculations and no significant increase of it is seen in HM pp collisions. The direct photon yield measured in most central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV can be reproduced by the available theory calculations, although the models tend to overestimate the data at low p_{T}. Furthermore, we presented the first results using a DCA$_{\mathrm{ee}}$ analysis that separates the thermal signal from the HF background.

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