PROCEEDINGS OF SCIENCE

Electromagnetic radiation in pp and PbPb collisions with dielectrons in ALICE

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The latest ALICE results on low p_{T} direct photon measurements via the virtual photon method are presented. Direct photons are measured in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV, and in minimum-bias (MB) and high-multiplicity (HM) pp collisions at $\sqrt{s}$ = 13 TeV with LHC Run 2 data. The virtual direct-photon signal is extracted from the dielectron mass spectra. Direct photon spectrum in Pb–Pb collisions is measured in the range $1 < p_{\mathrm{T}} < 5$ GeV/c and compared with theoretical predictions. In pp collisions, such measurement in minimum-bias events serves as a baseline for Pb–Pb collisions and a fundamental test for perturbative QCD (pQCD) calculations, while studies in high charged-particle multiplicity events allow one to search for thermal radiation in small colliding systems. Direct photon spectra in pp collisions for both event multiplicity classes are measured in the range $1 < p_{\mathrm{T}} < 6$ GeV/c. The MB result was compared with NLO pQCD calculations and the viscous hydrodynamical model. Finally, the first result with the Run 3 pp data at $\sqrt{s}$ = 13.6 TeV, using the upgraded ALICE detector to disentangle the different dielectron sources, is reported.

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1. Introduction

Electromagnetic probes such as photons and dileptons (e^+e^- and $\mu^+\mu^-$) are unique probes 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. Since dielectrons are produced directly by the interactions between partons in the QGP, dielectron measurements can be used to study thermal radiation from the collision fireball. In the intermediate mass region (IMR : 1.1 GeV/c^2 < m_{ee} < 2.7 GeV/c^2), it is expected thermal radiation from the QGP carries information from the partonic phase of the collision. At $m_{ee} \ll p_{T,ee}$, the ratio of direct to inclusive photons can be extracted from the dielectron continuum. Direct photon measurements in pp collisions serve as a vacuum baseline for the studies in Pb–Pb collisions, as no medium effect is expected. As for direct photons, the expected source is basically prompt photons, therefore direct photon production in pp collisions can test perturbative QCD (pQCD) calculation. On the other hand, there is a view that pp collisions might be more than a reference if we look at high charged-particle multiplicities (HM) events, where they exhibit surprising similarities as heavy-ion collisions [1–3]. This motivates a search for the thermal photons and the creation of the QGP in small systems to better understand the underlying dynamics in such collisions.

2. Direct photons in Pb–Pb and pp collisions

The Pb–Pb data was collected in 2018, and the analysis uses both the MB and centrality triggered data with an integrated luminosity of 85 μb^{-1} in the 0-10% centrality class. The analysis in pp collisions used the full Run 2 data, with an integrated luminosity of $L_{\mathrm{int,MB}} \simeq 29.8$ nb^{-1} for MB and $L_{\mathrm{int,HM}} \simeq 5.8$ pb^{-1}, respectively. The tracking and identification of electrons are performed using the Inner Tracking System (ITS), the Time Projection Chamber (TPC), and the Time-Of-Flight detector at midrapidity ($|\eta_e| < 0.8$) [4].

The virtual direct photon is measured via the internal conversion technique [5]. The relation between virtual photons and dielectrons is given by the Kroll–Wada formula [6]. The direct photon fraction r defined as the ratio of direct photon yield to the inclusive-photon yield $r = \gamma_{\mathrm{dir}}/\gamma_{\mathrm{incl}} = \gamma^*_{\mathrm{dir}}/\gamma^*_{\mathrm{incl}}\big|_{m_{ee}=0}$, is extracted from the data by fitting the dielectron invariant mass spectra with a three-component function. The function consists of light-flavour decay (f_{LF}), direct virtual photon (f_{dir}), and heavy-flavour decay (f_{HF}) contributions: $f_{\mathrm{fit}} = r f_{\mathrm{dir}} + (1-r) f_{\mathrm{LF}} + f_{\mathrm{HF}}$. Both f_{LF} and f_{dir} contributions normalised to the data below $m_{ee} = 30$ MeV/c^2, whereas one from f_{HF} normalized to the measured cross-section. A fitting was performed above π^0 mass, where the different expected mass dependences of the virtual direct-photon contribution and of e^+e^- pairs from light-meson Dalitz decays make it possible to separate signal-to-background. Figure 1 (left) shows a fitting example in the range $1 < p_{T,ee} < 2$ GeV/c, one can see a determined free parameter r is about 3%. Afterwards, the direct photon spectrum is calculated by r and decay photon simulation, whose main contributions in decay photons are decays of π^0 and η.

3. Results

Figure 1 (right) shows the direct photon spectrum as a function of p_{T} in central Pb–Pb collisions. The data is compared to a hybrid model that describes all stages of the heavy-ion collisions [7], including the contributions from NLO pQCD calculation (blue dashed line), the pre-equilibrium (red line) and fluid-dynamical phases (orange line). The result is consistent with total contribution (black line) within uncertainty but tends to overestimate data about 1σ.

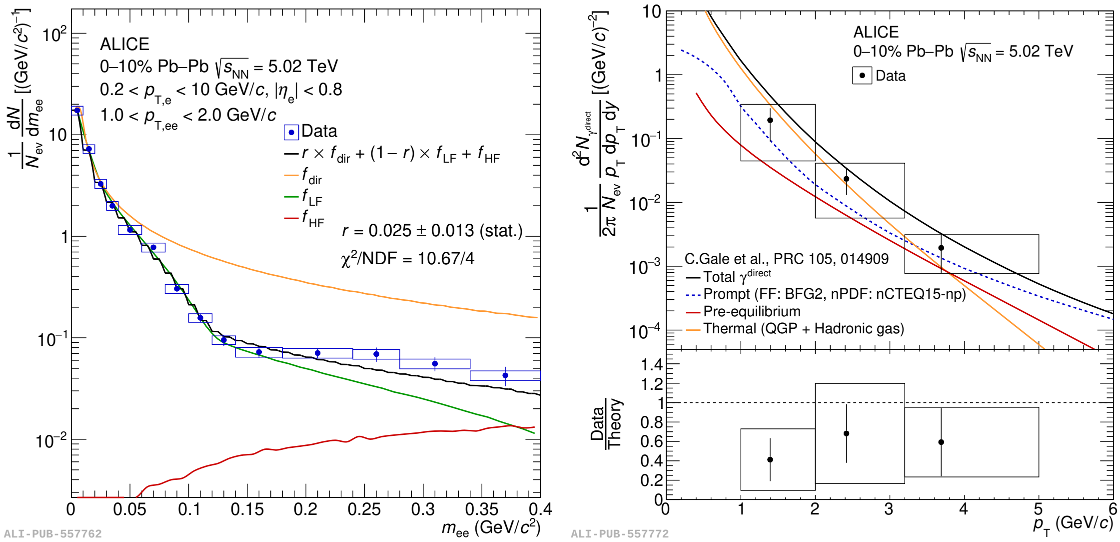

Figure 1: Left: Signal extraction of direct photon signal r in the range $1 < p_{\mathrm{T}} < 2$ GeV/c. Right:Direct-photon invariant yield in the 10% most central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, compared with the predictions from a state-of-the-art model [7]. Both figures were taken from published paper [8] after the conference.

Figure 2 shows direct photon fraction r as a function of p_{T} in two different multiplicity classes. An excess of direct photon signals from zero has been observed with the significance of 3.2σ (MB) and 1.9σ (HM) in the range $1 < p_{\mathrm{T}} < 6$ GeV/c. The MB result is compared with two NLO pQCD calculations by [9] and [10] shown in cyan and green lines, respectively. The uncertainty band of the calculation from [9] is given by the simultaneous variation of the factorisation and renormalisation scale values, μ ($0.5\, p_{\mathrm{T}} < \mu < 2\, p_{\mathrm{T}}$). Ref. [10] is calculated with $\mu = p_{\mathrm{T}}$, and extrapolated down to 0.5 GeV/c, where theoretical uncertainty is large. Both predictions are consistent within uncertainty but tend to underestimate the data below $p_{\mathrm{T}} = 3$ GeV/c. In addition, Ref. [10] includes thermal photon contribution from the viscous hydrodynamical calculation on top of NLO pQCD photons. It turned out the total contribution shown in red gives a slightly better description. As for the HM result, the theoretical prediction is not available at the moment, as we do not know how direct photon scales under the HM environment. Given that major sources of decay photons such as π^0 and η meson show multiplicity dependence [11], extracted direct photon signal immediately implies a direct photon multiplicity dependence. This is clearly seen in Fig. 3, which is the multiplicity dependence of direct photon yields. To interpret this result, a theoretical effort is awaited.

Finally, we presented the new dielectron result in Run 3. During LS2, ALICE upgraded many detector subsystems and the data acquisition system which enabled us to collect much more statistics with improved position resolution with respect to the one from Run 2. These upgrades are crucial for the study of thermal radiation in the IMR, as the dominant background source is electrons from correlated heavy-flavour (HF) hadron decays. Figure 4 shows the dielectron raw yield in the range $m_{ee} < 4$ GeV/c^2 and $p_{T,ee} < 20$ GeV/c. Clear peaks of ϕ, ω, J/ψ and ψ(2S) are visible. The analysed data set was taken during 2022, which exceeds Run 2 statistics by ~30 times. With increased statistics, thermal radiation can be studied more precisely in HM pp collisions. Of course, dielectron analysis in Pb–Pb collisions will benefit as well.

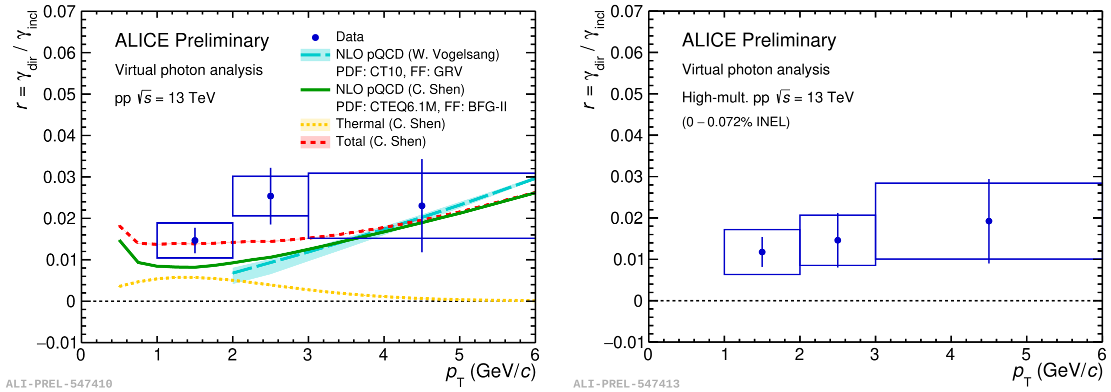

Figure 2: Direct photon fraction as a function of p_T in MB (left) and HM (right) event analysis. Direct photon signal extracted with the significance of 3.2σ (MB) and 1.9σ (HM). Statistical and systematic uncertainties of the data are displayed as vertical bars and boxes, respectively. The MB result is compared with theoretical predictions from [9] and [10].

4. Summary and outlook

The study of electromagnetic radiation with dielectrons via virtual photon method in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and in pp collisions at $\sqrt{s} = 13$ TeV was presented. The direct photon yield measured in 0-10% most central Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV compared with the state-of-the-art model and found to be consistent within uncertainty but theory tends to overestimate the data by 1σ. In pp collisions at $\sqrt{s} = 13$ TeV, direct photons were measured in two different event multiplicity classes. The MB result was compared with two different NLO pQCD calculations and the viscous hydrodynamical model. The NLO pQCD predictions tend to underestimate the data, while the viscous hydrodynamical model assuming QGP describes better. Direct photon in HM pp collisions shows clear multiplicity dependence, which needs to be understood theoretically. Finally, the first look at dielectron raw yield in pp collisions at $\sqrt{s} = 13.6$ TeV from Run 3 was presented. The spectrum was made using only part of the samples collected in 2022, already showing a nice performance. The data-taking is underway and we are entering a precision era.

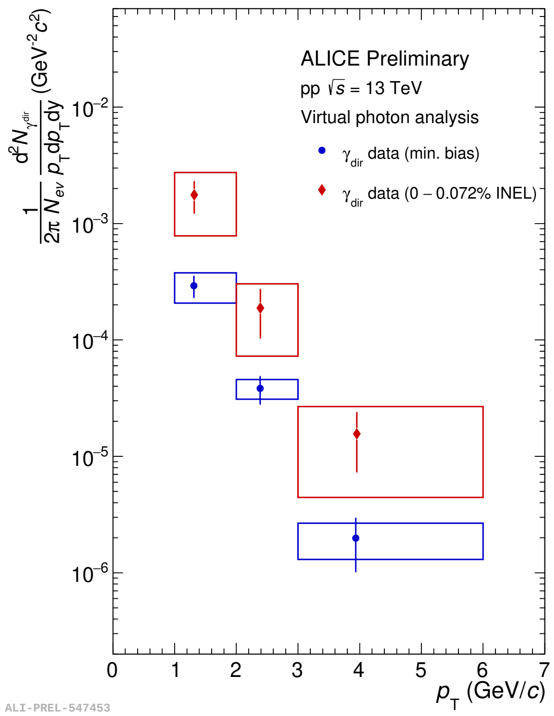

Figure 3: Multiplicity dependence of direct photon as a function of p_{T} in MB (left) and multiplicity dependent p_{T} spectra.

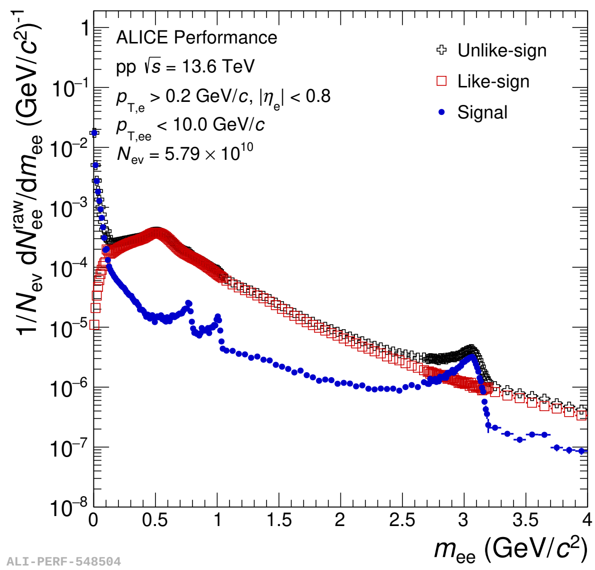

Figure 4: Unlike-sign, like-sign, and raw dielectron signal as a function of m_{ee} in pp collisions at $\sqrt{s}$ = 13.6 TeV, using the data set from Run 3. Analyzed number of events $N_{\mathrm{ev}} = 5.79 \times 10^{10}$ is a part of the statistics collected in 2022, which is already more than 30 times larger than Run 2 full statistics.

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