Low-mass dielectrons in pp, p–Pb and Pb–Pb collisions measured by the ALICE Experiment

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Abstract. Dielectrons produced in ultra-relativistic heavy-ion collisions at the LHC provide a unique probe of the system evolution as they are unperturbed by final-state interactions. The dielectron continuum is extremely rich in physics sources: on top of ordinary Dalitz and resonance decays of pseudoscalar and vector mesons, thermal black-body radiation is of particular interest as it carries information about the temperature of the hot and dense system created in such collisions. The dielectron invariant-mass distribution is furthermore sensitive to medium modifications of the spectral function of short-lived vector mesons that are linked to the potential restoration of chiral symmetry at high temperatures. Correlated electron pairs from semi-leptonic charm and beauty decays provide complementary information about the heavy-quark energy loss.

1 Introduction

In ultra-relativistic heavy-ion collisions, hadronic matter is believed to form a new state of matter comprising deconfined quarks and gluons—the quark-gluon plasma (QGP). Electron-positron pairs are produced during all stages of such collisions and carry information to the detector unperturbed by strong final-state interactions, thus allowing us to study the whole space-time evolution of the system. In the mass region below 1 GeV/c^2 the dielectron spectrum is dominated by Dalitz and resonance decays of pseudo-scalar and vector mesons, whereas e^+e^- pairs in the mass region between 1 and 3 GeV/c^2 originate mainly from the semi-leptonic decays of correlated charm and beauty hadrons. In heavy-ion collisions thermal radiation from QGP and hadron gas contribute to the dielectron spectrum over a broad mass range. The measurements of dielectron production in minimum bias pp collisions serve as an important vacuum reference to quantify any observed modifications in heavy-ion collisions, and the studies in p–Pb collisions are used to investigate cold nuclear matter effects.

We present a summary of the results from the ALICE experiment [1] in all three collisions systems at the LHC: pp, p–Pb and Pb–Pb, including the latest analysis of Run-2 pp collisions at $\sqrt{s}$ = 13 TeV collected with a trigger on high charged-particle multiplicities. Event triggering is based on the information from the Silicon Pixel Detector (SPD) and/or from the V0 scintillators, the latter are also used for centrality estimation in Pb–Pb collisions. Charged particle tracks are reconstructed with the help of central barrel detectors ($|\eta| < 0.8$): the Inner Tracking System (ITS) and the Time Projection Chamber (TPC). Specific energy loss in TPC and in ITS and time-of-flight information from the TOF detector are used for electron identification.

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2 Results in pp collisions at $\sqrt{s}$ = 7 TeV and at $\sqrt{s}$ = 13 TeV

The dielectron invariant mass spectrum has been measured in pp collisions at $\sqrt{s} = 7$ TeV and is shown in Fig. 1 (left). The results are found to be consistent within uncertainties with the expectation from the known hadronic sources (cocktail calculations). The contribution from the semi-leptonic decays of correlated D and B mesons has been estimated with the help of Pythia 6 simulations and scaled to the measured total charm and beauty cross sections [2]. The dielectron production has been also measured as a function of the transverse pair distance of closest approach to the primary vertex ($DCA_{\rm ee}$), defined as the quadratic sum of single track DCA divided by the estimated DCA resolution. The $DCA_{\rm ee}$ distribution is shown in Fig. 1 (right) for the mass range of $0.2 < m_{\rm ee} < 1.1$ GeV$/c^2$. The results are compared to the $DCA_{\rm ee}$ templates obtained from the Monte Carlo simulations of the ALICE detector, and the relative contributions of different sources are normalised according to the hadronic cocktail calculations. The addition of the heavy-flavour contribution is necessary for proper description of the tail of the distribution, so the $DCA_{\rm ee}$ variable allows one to separate prompt and non-prompt dielectron sources.

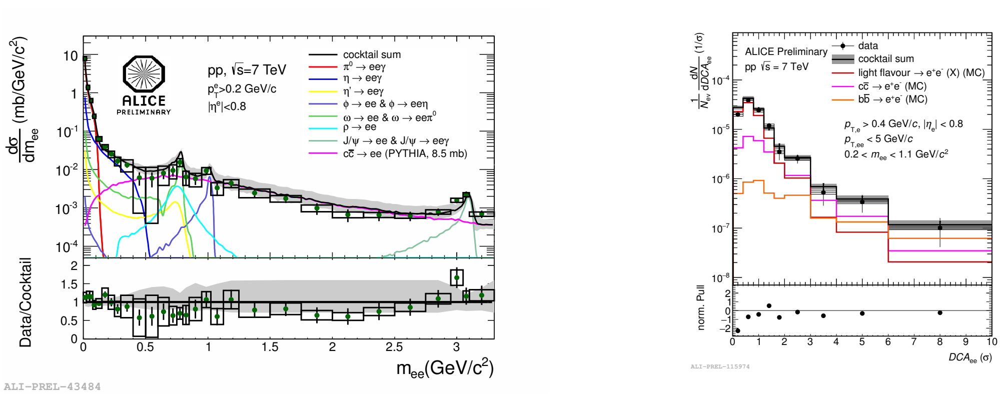

Figure 1. Dielectron invariant mass spectrum in pp collisions at $\sqrt{s} = 7$ TeV compared to the expectation from hadronic cocktail calculations (left), and the $DCA_{\rm ee}$ spectrum in the mass range $0.2 < m_{\rm ee} < 1.1$ GeV$/c^2$ (right)

The first dielectron studies of pp events with high charged-particle multiplicity have been performed in pp collisions at $\sqrt{s} = 13$ TeV collected in 2016. The goal is to reveal new or heavy-ion like phenomena, e.g. production of ρ meson versus multiplicity or presence of thermal radiation, by comparing the dielectron yield in events with high multiplicity (HM) with average minimum bias (MB) pp collisions (Fig. 2 left). Deviations from multiplicity scaling can be caused by modifications of the charged hadron $p_{\rm T}$ spectra [3] and by the unknown hadron chemistry in high multiplicity events. Furthermore, the production of open charm mesons is known to increase faster than linearly with multiplicity for $p_{\rm T} > 1$ GeV$/c$ [4], so the dielectrons from correlated semileptonic charm and bottom decays offer here a unique window at the production of low-$p_{\rm T}$ D and B mesons. To this end, the ratio of dielectron spectra in high multiplicity over minimum bias events is calculated and is normalised by the charged-particle multiplicity ratio of $\langle N_{ch}^{acc}({\rm HM})\rangle / \langle {\rm N}_{\rm ch}^{\rm acc}({\rm MB})\rangle = 4.36$. The results are found to be in agreement with the cocktail expectations (Fig. 2 right) which takes into account the modification of the charged hadron $p_{\rm T}$ spectra and the faster-than-linear production of D mesons. About 5 times more data from 2016 are being analysed in order to investigate the spectrum modification in more details.

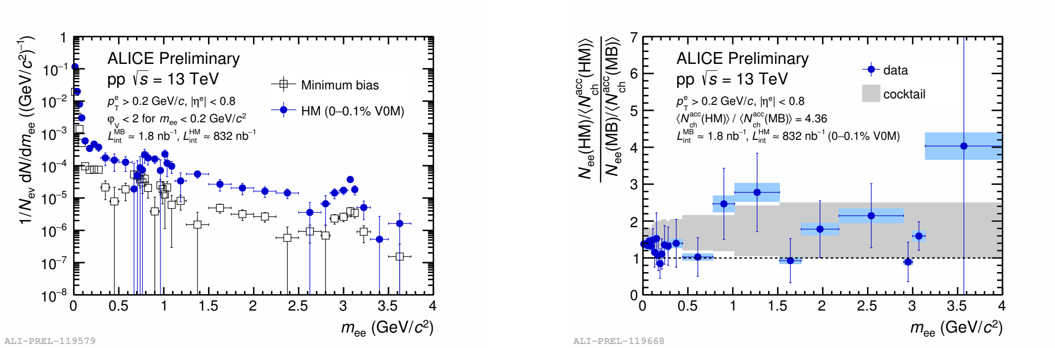

Figure 2. Raw dielectron spectra normalised by number of triggered events (left), and the ratio of dielectron spectra scaled by charged particle multiplicity (right) in pp collisions at $\sqrt{s} = 13$ TeV

3 Results in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV and in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

The dielectron production in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV has been measured as a function of invariant mass and pair transverse momentum (Fig. 3). The total heavy flavour cross-section (extrapolated from measurements in pp collisions at different energies) has been normalised by the average number of binary nucleon-nucleon interactions in p–Pb collisions. The data are found to be in agreement with the cocktail calculations, with a hint for possible lower charm production, which could be caused by cold nuclear matter effects. A larger p–Pb sample was recorded in 2016 and will help to perform detailed differential analysis as a function of invariant mass, pair p_T and DCA_{ee} to conclude on possible cold nuclear matter effects in the future.

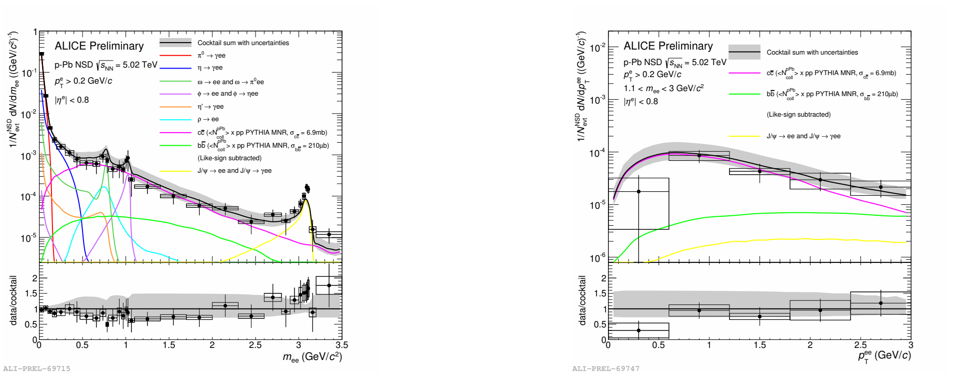

Figure 3. Dielectron spectrum as a function of invariant mass (left) and pair transverse momentum (in the mass region $1.1 < m_{ee} < 3\,\text{GeV}/c^2$, right) in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

In Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV the dielectron production has been measured in the 10% most central collisions as a function of invariant mass (Fig. 4 left). The cocktail calculations are shown for two cases: without the contribution from vacuum ρ meson and with contributions from QGP and hadron gas radiation including modified ρ and ω spectral functions [5, 6]. The data points are consistent with both results within uncertainties, so the current measurement is not yet sensitive to the potential contribution from thermal radiation and in-medium modifications. In the quasi-real photon region ($m_{ee} < 0.3$ GeV/c^2 and $p_T{}^{ee} > 1$ GeV/c) the extraction of the virtual photon fraction (Fig. 4 right) has shown an agreement with the results on real direct photon measurements [7]. Substantial improvements of dielectron measurements are expected following the upcoming ALICE detector upgrades [8], which will allow higher data-taking rates and more effective background rejection.

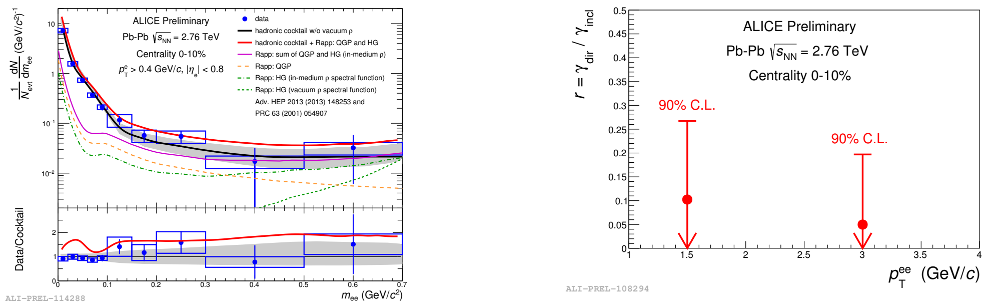

Figure 4. The dielectron mass spectrum compared to the cocktail calculations in central Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV (left), and the fraction of direct over inclusive photons (right)

4 Conclusion and outlook

The results of the low-mass dielectron analysis performed with the ALICE experiment are presented for different collision systems. In pp collisions at $\sqrt{s} = 7$ TeV the dielectron production is described with the cocktail of known hadronic sources as a function of invariant mass and pair DCA_{ee}. The first analysis of dielectron production in high-multiplicity pp collisions at $\sqrt{s} = 13$ TeV has shown an agreement with the expectations from the modification of the p_T spectrum of charged hadrons and production of D mesons versus multiplicity. The results in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV are compatible with the hadronic cocktail expectations within uncertainties. In central Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV the measurement is not yet sensitive to the possible contribution from thermal radiation, and the results on virtual direct photons are in agreement with the real photon measurements.

Finally, novel multi-variative analysis techniques (MVA) have been developed on the Monte Carlo data in order to improve the electron identification and to suppress dielectron pairs from conversions of real photons. Usage of such methods is foreseen in future dielectron analyses.

References

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