PROCEEDINGS OF SCIENCE

Low-mass dielectron measurements in pp, p-Pb, and Pb-Pb collisions with ALICE at the LHC

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In ultra-relativistic heavy-ion collisions, correlated dielectron pairs are of particular interest since they are produced at all stages of the reaction and leave the dense medium without final state interactions. Therefore, the measurement of low mass dielectrons provides information on the properties of the hot and dense medium created in such collisions. Low mass dielectrons have been measured with the ALICE detector at the LHC in pp collisions at $\sqrt{s}$ = 7 and 13 TeV, in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV. An overview of ALICE results obtained with Run-1 and Run-2 data is presented.

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1. Introduction

Ultra-relativistic nuclear collisions allow the study of strongly interacting matter under extreme conditions. A deconfined state of quarks and gluons, the Quark-Gluon-Plasma (QGP), is expected to be formed in such collisions. Dielectron pairs are particularly suited to probe the properties and the time evolution of the created medium since they are produced at all stages of the interaction and are not affected by the strong interaction. In the mass range below 1 GeV/c^2, the correlated e^+e^- pairs are originating mostly from Dalitz and resonance decays of pseudoscalar and vector mesons. The dielectron invariant mass spectrum from short-lived vector mesons is sensitive to medium modifications of their spectral functions, related to the predicted chiral symmetry restoration inside the QGP. In the intermediate mass region from 1 to 3 GeV/c^2, dielectron pairs originate mainly from semi-leptonic decays of hadrons containing charm or beauty quarks, which are affected by parton energy loss in the QGP. Finally, thermal radiation from the QGP and hadron gas contributes to the dielectron yield over a broad mass range and provides information on the thermodynamic properties of the medium. To single out the interesting signal characteristics of the QGP, it is crucial to understand the primordial dielectron pair production. The latter can be studied in proton-proton (pp) collisions. Furthermore, the measurement of dielectron pairs in p–Pb collisions is used to disentangle cold from hot matter effects in heavy-ion collisions.
The data shown in this proceeding were recorded between 2010 and 2016 with the ALICE detector [1] during the pp, p–Pb, and Pb–Pb collisions at $\sqrt{s}$ = 7 and 13 TeV, $\sqrt{s_{\rm NN}}$ = 5.02 TeV, and $\sqrt{s_{\rm NN}}$ = 2.76 TeV, respectively, delivered by the Large Hadron Collider (LHC) at CERN. The data readout was triggered by a minimum-bias interaction trigger based on signals from two forward scintillator hodoscopes (V0A and V0C). These detectors provided also a high-multiplicity trigger for pp collisions at 13 TeV and a centrality trigger for Pb–Pb collisions. Finally, electrons are tracked and identified at mid-rapidity ($|\eta_e| < 0.8$) in the ALICE central barrel with the Inner-Tracking-System (ITS), the Time-Projection-Chamber (TPC) and the Time-Of-Flight detector (TOF).

2. Results in pp collisions at $\sqrt{s}$ = 7 TeV and in p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV

The e^+e^- pair production has been measured in the ALICE acceptance ($|\eta_e| < 0.8$ and $p_{T,e}$ > 0.2 GeV/c) in pp collisions at 7 TeV. The dielectron yield as a function of invariant mass has been found to consistent within uncertainties with a cocktail of known e^+e^- sources based on the measured π^0, η, ω, ϕ and J/ψ spectra [2–5]. The contribution from semi-leptonic decays of D and B hadrons was estimated with PYTHIA 6 [6] and scaled to the measured total charm and beauty cross sections [7, 8]. In addition, the dielectron production has been studied as a function of the pair transverse impact parameter, $\rm DCA_{ee}$, defined by the quadratic sum of the Distance-Of-Closest-Approach to the primary vertex of the two electron tracks divided by two. The $\rm DCA_{ee}$ distribution in the mass range $0.2 < m_{\rm ee} < 1.1\,{\rm GeV}/c^2$ is shown in the left panel of Fig. 1. The measured spectrum is compared to $\rm DCA_{ee}$ templates obtained from full Monte-Carlo simulations of the ALICE detector and normalized to the hadronic cocktail. The contributions from heavy-flavour decays is mandatory to describe the tail of the distribution. This shows that prompt and non-prompt dielectron sources can be separated with the $\rm DCA_{ee}$ variable.

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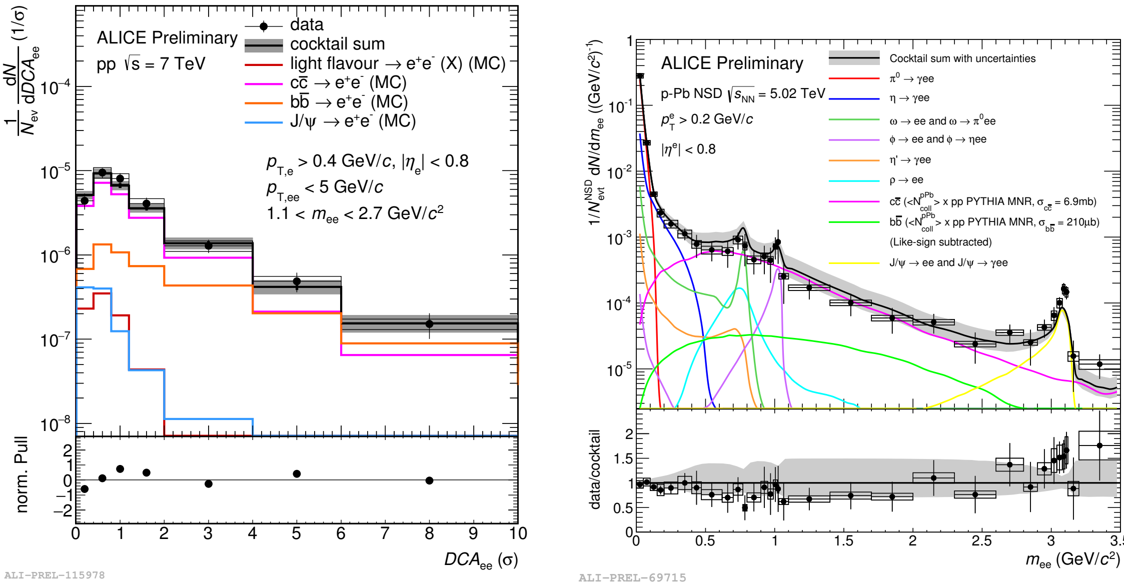

Figure 1: Inclusive e^+e^- yield in pp collisions (left panel) and p–Pb collisions (right panel) as a function of DCA$_{ee}$, in the mass range $1.1 < m_{ee} < 2.7$ GeV/c^2, and as a function of m_{ee}, respectively. The data are compared to cocktails of known e^+e^- sources. Statistical and systematic uncertainties on the data are plotted separately by vertical bars and boxes, respectively. Horizontal bars indicate the bin width. The total uncertainty of the cocktail is represented by a grey band.

The dielectron production in p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV has been studied as function of $m_{\rm ee}$ and the pair transverse momentum $p_{\rm T,ee}$ with the Run-I data collected in 2013. The data are found to be consistent with the cocktail within uncertainties, as can be seen on the right panel of Fig. 1. The heavy-flavour contributions have been scaled to the total cross sections in pp collisions at the same $\sqrt{s_{\rm NN}}$ scaled by the average number of binary collisions in p-Pb collisions. A hint for a smaller charm production can be seen in the data, possibly related to cold nuclear matter effects. Moreover the measured $p_{\rm T,ee}$ distribution in the intermediate mass region provides the possibility, together with the DCA$_{\rm ee}$ variable, to disentangle the contributions from charm and beauty hadron decays. The data recorded in 2016, with about 5 times more statistics, will allow more differential studies as a function of $m_{\rm ee}$, $p_{\rm T,ee}$ and DCA$_{ee}$ and a stronger physics message.

3. Results in high-multiplicity pp collisions at $\sqrt{s}$ = 13 TeV

In high-multiplicity pp events, the measurement of low mass dielectrons gives insight into possible new or heavy-ion like phenomena, like the production or destruction of the ρ meson, the understanding of multiple parton interactions and the presence of possible thermal radiation. For this purpose, the uncorrected dielectron yields measured in minimum-bias (MB) and high-multiplicity (HM) pp collisions at $\sqrt{s}$ = 13 TeV are compared in Fig. 2. The charged-particle multiplicity at mid-rapidity ($|y| < 0.5$) is about 4.36 times larger in HM events than in MB events. The MB raw distribution has been scaled by this number before computing the ratio of the dielectron mass spectra presented in the right panel of Fig. 2. This ratio is in agreement with the cocktail expectations from other measurements, i.e. J/ψ [9] and charged hadron [10] spectra measured in HM and MB pp collisions at $\sqrt{s}$ = 13 TeV and D meson results [11] in pp collisions at $\sqrt{s}$ = 7 TeV. The all 2016 data sample, containing about 5 times more events, is needed to better investigate possible deviations from the cocktail expectation.

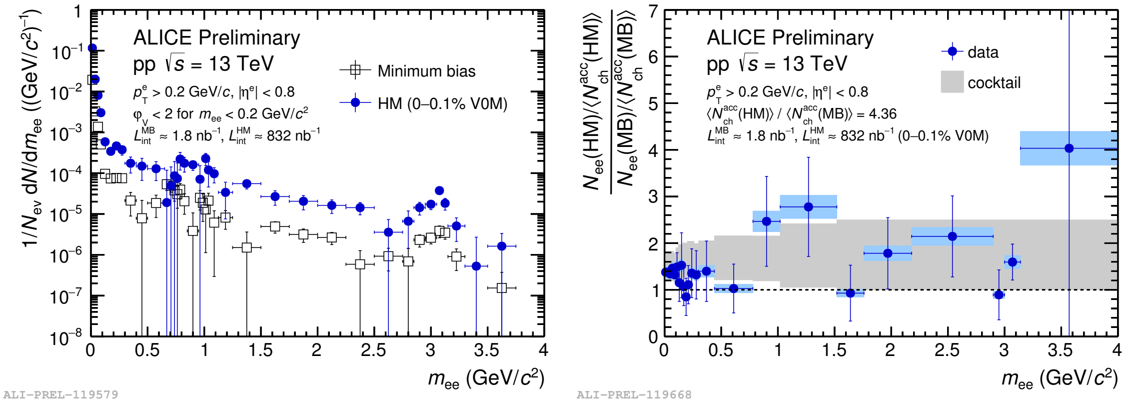

Figure 2: Uncorrected dielectron yields in MB and HM pp collisions at $\sqrt{s}$ = 13 TeV (left panel) and their ratio scaled by the charged-particle multiplicity (right panel). Statistical and systematic uncertainties are plotted separately by vertical bars and boxes, respectively. Horizontal bars indicate the bin width. The expectation from the cocktail is represented by a grey band.

4. Results in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV

The e^+e^- pair production has been measured in the 10 % most central Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV. In the left panel of Fig. 3, the $m_{\rm ee}$ distribution is compared to a cocktail of known hadronic sources without the ρ contribution in black and a cocktail with additional thermal radiation from the medium in red [12, 13]. The data are compatible with both within uncertainties, showing that the measurement is not yet sensitive to possible thermal radiations from the QGP and the hadron gas. The ALICE upgrade [15] will allow more significant measurements.

Finally, in the quasi-real virtual-photon region, at low mass ($m_{\rm ee} < 0.4$ GeV/c^2) and high $p_{\rm T,ee}$ ($p_{\rm T,ee} > 1$ GeV/c), the contribution of virtual direct photons has been extracted from the data by fitting the $m_{\rm ee}$ distributions in two $p_{\rm T,ee}$ bins [14]. The extracted fraction of direct-to-inclusive photon yield ratio is shown on the right panel of Fig. 3. It is found to be compatible with ALICE real photon measurements [16].

5. Conclusion and Outlook

The measured $m_{\rm ee}$ and DCA$_{\rm ee}$ differential yields of correlated e^+e^- pairs have been found to be consistent with a cocktail of know hadronic sources in pp collisions at $\sqrt{s}$ = 7 TeV. The DCA$_{\rm ee}$ variable allows the separation of prompt and non-prompt dielectron sources. In p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV, the $m_{\rm ee}$ and $p_{\rm T,ee}$ spectra are compatible within uncertainties with the hadronic cocktail. A hint for a smaller charm production compared to the number of binary collision scaling is seen. The minimum-bias (MB) p–Pb data recorded in 2016, about 5 times more than in 2013, will allow a detailed study of cold nuclear matter effects.

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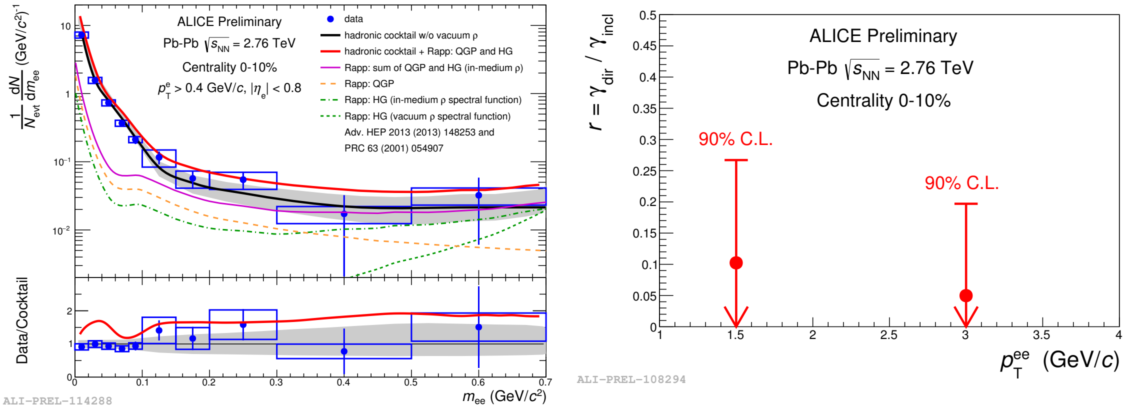

Figure 3: Left panel: inclusive e^+e^- yield in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV as a function of m_{ee} compared to different hadronic cocktails (see text). Statistical and systematic uncertainties on the data are plotted separately by vertical bars and boxes, respectively. The total uncertainty of the cocktail is represented by a grey band. Right panel: extracted fraction of inclusive-to-decay photon yields with its 90% confidence limit.

High-multiplicity (HM) pp collisions can be used to investigate the role of multiple parton interactions, potential modifications of the ρ meson and possible thermal radiations. The comparison of the raw dielectron yields measured in MB and HM pp collisions at $\sqrt{s}$ = 13 TeV is in agreement with the expectations from the hadronic cocktail based on other measurements. The rest of the data collected in 2016 (a factor 5 more) will help to strengthen the physics message.
The results in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV are compatible with cocktails with or without thermal radiations from the medium within uncertainties. The data are not yet sensitive for a possible excess in the ρ region. The virtual direct photon studies is in agreement with the ALICE real photon measurements [16]. The ALICE upgrades [15], in particular the ITS and TPC upgrades, will allow higher data-taking rates with a larger background rejection power to increase substantially the significance of the low mass dielectron smeasurements. In addition, improvements in the analysis procedure itself with machine leaning methods are currently under study.

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