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Dielectron measurements in pp, p–Pb and Pb–Pb collisions with ALICE at the LHC

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Abstract

Electromagnetic probes are excellent messengers from the hot and dense medium created in high-energy heavy-ion collisions. Since leptons do not interact strongly, their spectra reflect the entire space–time evolution of the collision. The surrounding medium can lead to modifications of the dielectron production with respect to the vacuum rate. To quantify modifications in heavy-ion collisions, measurements in pp collisions serve as a reference, while the analysis of p–A collisions allows for the disentanglement of cold nuclear matter effects from those of the hot and dense medium.

In this proceedings, dielectron measurements with the ALICE central barrel detectors are presented. The invariant mass distributions in the range $0 < m_{ee} < 3$ GeV/c^2 are compared to the expected yields from hadronic sources for pp collisions at $\sqrt{s} = 7$ TeV, and for p–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV. The cross section of direct photons measured via virtual photons in pp collisions is compared to predictions from NLO pQCD calculations as a function of the transverse momentum. The status of the analysis of Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV is presented.

Keywords: Heavy-ion collisions; Electromagnetic probes; ALICE

1. Introduction

Dielectrons were proposed several decades ago [1] to be an important source of information from the hot and dense medium, which can be created in heavy-ion collisions. Since dielectrons

[1] A list of members of the ALICE Collaboration and acknowledgements can be found at the end of this issue.

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are emitted throughout the collision process and do not interact via the strong interaction, they are ideal probes for all stages of the collision. Moreover, the measurement of virtual photons, i.e. photons which convert internally into dileptons, allows to reduce systematic uncertainties significantly compared to the measurement of real photons, since the main sources of the background, photons and dielectrons from π^0 decays, can be rejected at finite mass.

However, to access information on the medium in heavy-ion collisions, the dielectron production in the vacuum and possible cold nuclear matter effects need to be evaluated. Therefore, it is necessary to have reference measurements from proton–proton (pp) and proton–nucleus (p–A) collisions.

LHC provided during Run 1 three different collision systems, i.e. pp, p–Pb and Pb–Pb. In this proceedings, preliminary results from pp collisions at $\sqrt{s} = 7$ TeV on the dielectron invariant mass continuum and direct photons measured via virtual photons are summarized. The dielectron continuum as a function of invariant mass and dielectron transverse momentum is compared to the expected hadronic sources of dielectrons in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. In addition, the status of the analysis for Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV will be discussed.

2. Data analysis

ALICE has capabilities for particle identification in the low transverse momentum (p_T) regime that are unique at the LHC. Electrons with the transverse momentum $p_T^e > 0.2$ GeV/c are identified by combined energy loss information from the Time Projection Chamber (TPC) and, in the case of p–Pb and Pb–Pb, the outermost four layers of the Inner Tracking System (ITS). Additionally, the Time-Of-Flight detector (TOF) is used in the range $0.4 < p_T^e < 5.0$ GeV/c to reject kaons and protons. The remaining hadron contamination is at most 1% in pp collisions and up to 10% in Pb–Pb collisions.

When measuring unlike-sign dielectron pairs, N_{US}, one of the main challenges is the estimation of the combinatorial background, which arises from random dielectron combinations and is superimposed on the physics signal. The signal-over-background ratio is in the order of 10^{-2} for pp and p–Pb collisions and about a factor 10 lower in central Pb–Pb collisions for $m_{ee} \approx 0.5$ GeV/c^2. The combinatorial background is measured by the same-event like-sign method. This method holds under the assumption that the physics signal consists only of unlike-sign pairs. The like-sign spectra are normalized via $N_{LS} = 2 \cdot R \cdot \sqrt{N_{++}N_{--}}$, where R is a correction factor for the difference between the acceptance of unlike-sign pairs and like-sign pairs and N_{++} and N_{--} are positive and negative like-sign dielectron pairs, respectively. The acceptance correction is calculated as $R = B_{+-}/(2 \cdot \sqrt{B_{++}B_{--}})$, where B indicates mixed event distributions. R depends on the minimum single electron p_T^e and is consistent with unity within its statistical uncertainties for the pp and the p–Pb analysis for $p_T^e > 0.2$ GeV/c. For $p_T^e > 0.4$ GeV/c in Pb–Pb collisions, the deviation from unity is of the order of 5% for $m_{ee} < 0.1$ GeV/c^2 and approaches unity for increasing mass. The raw signal is calculated as $S = N_{US} - N_{LS}$.

The data are corrected for detector and reconstruction efficiency via Monte-Carlo (MC) simulations. Single electron efficiencies are calculated as a function of (p_T, η, ϕ). Every electron is weighted with its efficiency in a dielectron generator with realistic electron and dielectron kinematics. The expected hadronic sources of dielectrons at the moment of freeze-out, the so-called hadronic cocktail, are calculated based on measured differential cross sections for π^0, η, ϕ and J/ψ in pp collisions, and on the charged pion spectrum in p–Pb collisions. The mass shape of resonances is based on [2] and the Dalitz pair mass distributions are following [3]. To estimate the

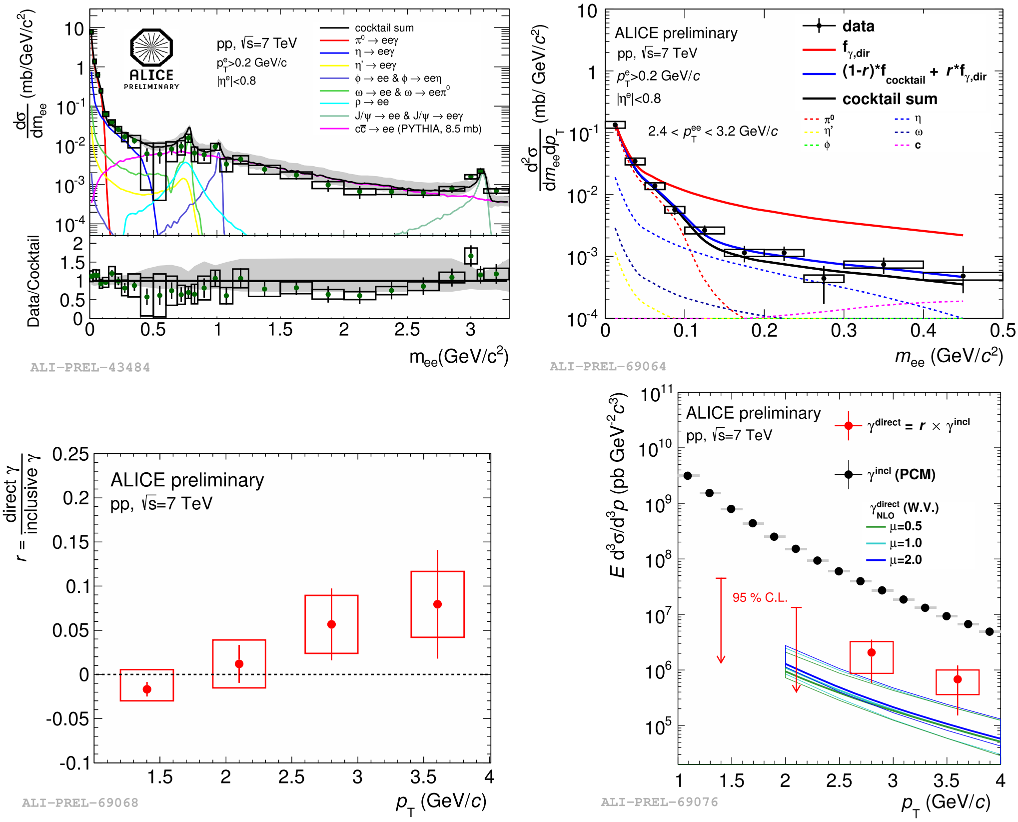

Fig. 1. Upper left: Dielectron invariant mass distribution together with the cocktail calculations for pp collisions at $\sqrt{s} = 7$ TeV. Upper right: Result for two component fit of the m_{ee} distribution. Lower left: Fit parameter r as a function of photon p_{T}. Lower right: Direct photon cross section as a function of transverse momentum together with pQCD NLO calculations. At low p_{T} only upper limits (95% confidence level) can be determined, as indicated by the arrows. The inclusive photon cross section measured via photon conversion method (PCM) is also shown.

expected yield of correlated dielectrons from semi-leptonic decays of open heavy-flavor mesons, the PYTHIA event generator [4], tuned to NLO calculations [5], is used. The pair distributions are normalized to the cross sections measured in pp collisions and scaled by the number of binary collisions for p–Pb collisions. The contribution of open beauty hadrons for pp collisions will be added for the final results. The uncertainties are calculated based on the uncertainties of the input cross sections. See [6] for a compilation of references. Contributions from hadrons, which have not been measured, are estimated by m_{T} scaling of the π^0 cross section.

3. Results

The preliminary results for pp collisions at $\sqrt{s} = 7$ TeV are shown in Fig. 1. In the upper left panel, the dielectron data are compared to the cocktail as a function of invariant mass for integrated pair p_{T}. The hadronic cocktail is consistent with the dielectron data. Virtual photon production is studied in pp collisions. Virtual photons convert internally into dielectrons. The relation between the dielectron invariant mass distribution and the virtual photon yield is given for $p_{\mathrm{T}}^{ee} \gg m_{ee}$ by the Kroll–Wada equation [3].

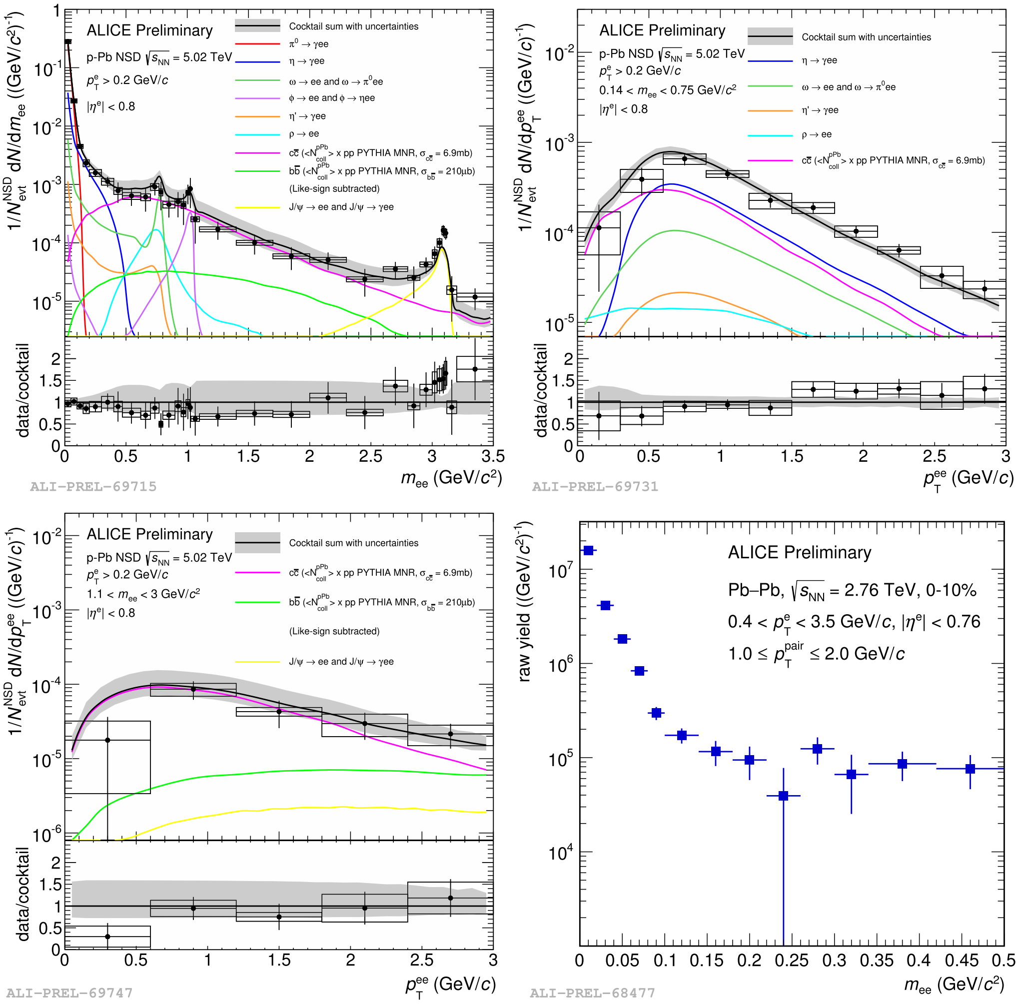

Fig. 2. The dielectron mass distribution is compared to the cocktail calculations for p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV as a function of invariant mass (upper left panel) and as a function of pair transverse momentum for the mass intervals $0.14 < m_{ee} < 0.75$ GeV$/c^2$ (upper right panel) and $1.1 < m_{ee} < 3.0$ GeV$/c^2$ (lower left panel). In the lower right panel, the raw dielectron yield is shown for Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

In the upper right panel of Fig. 1, pp data are compared to the cocktail for $2.4 < p_T^{ee} < 3.2$ GeV$/c$. The different sources are indicated as dashed lines. The function $f_{comb} = (1 - r) f_c + r f_{\gamma,dir}$ is fitted to the data in the region $0.1 < m_{ee} < 0.4$ GeV$/c^2$, where f_c is the cocktail contribution, $f_{\gamma,dir}$ is the photon input from the Kroll–Wada equation and r is the only fitting parameter. r reflects the ratio of direct over inclusive photons. The result for r as a function of the photon p_T is shown in the lower left panel of Fig. 1. Under the assumption that the ratio of direct over inclusive photons is the same for real and virtual photons, the direct photon cross section can be calculated by $\gamma_{dir} = r \times \gamma_{incl}$, where γ_{dir} and γ_{incl} are the direct and inclusive photon yields. The inclusive photon cross section has been measured via photon conversions, see e.g. [8]. In the lower right panel of Fig. 1, the direct photon cross section is shown as a function of the photon p_T. NLO pQCD calculations [7] are consistent with the data.

In the upper left panel of Fig. 2, the dielectron invariant mass spectrum is compared to the cocktail for p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The cocktail is in a good agreement with the data. In the upper right and lower left panels, data are compared to the cocktail distributions as a function of dielectron transverse momentum for $0.14 < m_{ee} < 0.75$ GeV/c^2 and $1.1 < m_{ee} < 3.0$ GeV/c^2, respectively. The data are well described by the cocktail. These two mass regions are of special interest. The mass region $0.14 < m_{ee} < 0.75$ GeV/c^2 is sensitive to hot hadronic medium effects. The region $1.1 < m_{ee} < 3.0$ GeV/c^2 is dominated by semi-leptonic decays of heavy-flavor mesons. In this mass region, heavy quark pair correlations can be studied.

In the lower right panel of Fig. 2, the raw yield as a function of invariant mass is shown for Pb–Pb collisions in 0–10% centrality at $\sqrt{s_{NN}} = 2.76$ TeV. Further analysis of this spectrum will allow the study of the virtual photon yield and for the exploration of a possible low-mass enhancement in Pb–Pb collisions.

4. Summary and outlook

The dielectron invariant mass spectrum measured in pp collisions at $\sqrt{s} = 7$ TeV is consistent with the expectation from hadronic sources. The same is observed for the invariant mass and transverse momentum distributions of dielectrons in p–Pb collisions at 5.02 TeV. The direct photon yield extracted from dielectron data in pp collisions at 7 TeV is consistent with NLO pQCD calculations. The study of dielectron production in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV is ongoing.

At the end of Run 2, statistical uncertainties will be reduced significantly. After the second long shutdown at the LHC, which is expected to end in 2019, ALICE will run with upgraded detector components [9]. The upgrade of the ITS will allow high precision vertexing to measure and reject dielectrons from correlated heavy flavor decays and the continuous read-out of the TPC will allow to take full advantage of the high luminosity at the upgraded LHC. Hence, detailed studies of the dielectrons will become feasible in Pb–Pb collisions.

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