PROCEEDINGS OF SCIENCE

Dielectron measurements in Pb-Pb collisions with ALICE at the LHC

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The measurement of e^+e^- pair production in ultra-relativistic heavy-ion collisions is a unique tool to investigate the temperature of the quark-gluon plasma created in such colliding systems, to study the effect of the predicted chiral symmetry restoration and to investigate coherent photon-photon interactions in hadronic heavy-ion collisions. At low invariant mass, the dielectron production is sensitive to the properties of short-lived vector mesons in the medium related to chiral symmetry restoration. In the intermediate-mass region, the early temperature of the system can be extracted from the mass spectrum of its thermal black-body radiation. However, it is first necessary to understand the very large background of correlated dielectron pairs from semi-leptonic charm and beauty hadron decays. At very low pair transverse momenta, initial photon annihilation processes, triggered by the coherent electromagnetic fields of the incoming nuclei, are expected to play a role particularly in more peripheral collisions. The latest results on dielectron production in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV by the ALICE Collaboration are presented in this article.

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1. Introduction

The production of low-mass dielectrons is the most promising tool for the understanding of the chiral symmetry restoration and of the thermodynamical properties of the Quark-Gluon Plasma (QGP) created in ultra-relativistic heavy-ion collisions. Since dielectrons are unaffected by strong final-state interactions and emitted during all stages of the collision, they carry information about the whole space-time evolution of the medium. The dielectron invariant mass ($m_{\rm ee}$) allows for an approximate chronological view on this evolution. At low invariant mass ($m_{\rm ee}$ < 1.1 GeV/c^2), the dielectron spectrum is sensitive to in-medium modification of the spectral function of the ρ meson and effects related to the chiral symmetry restoration. In the intermediate-mass region (1.1 < $m_{\rm ee}$ < 2.8 GeV/c^2), the dominant contribution of correlated pairs from semileptonic decays of charm and beauty hadrons is sensitive to in-medium effects on heavy-flavour production. Thermal radiation emitted by the system, both during the partonic and hadronic phase, contributes as well to the dielectron yield over a broad mass range and gives insight into the temperature of the medium. Finally, at very low pair transverse momenta initial photon annihilation processes, triggered by the coherent electromagnetic fields of the incoming nuclei, are expected to play a role in more peripheral collisions.
The heavy-ion data shown in this article were recorded with the ALICE detector [1] in 2015 using the Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV 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), used as well for the centrality determination of the collision. Finally, electrons are tracked and identified at mid-rapidity ($|\eta_{\rm e}| < 0.8$) in the ALICE central barrel with the Inner Tracking system (ITS), the Time Projection Chamber (TPC), and the Time-Of-Flight detector (TOF).

2. Reference measurements in proton-proton collisions

The $\rm e^+e^-$ pair production has been measured in the ALICE acceptance ($|\eta_e| < 0.8$ and $p_{\rm T,e} >$ 0.2 GeV/c) in pp collisions at $\sqrt{s} = 7$ and 13 TeV [2, 3]. The dielectron cross sections as a function of invariant mass and transverse momentum have been found to be consistent within uncertainties with a cocktail of known $\rm e^+e^-$ sources based on measured hadronic spectra. The contribution from decays of correlated open-charm and open-beauty hadrons, which have a large lifetime ($c\tau_{\rm D} \approx$ 150 μm, $c\tau_{\rm B} \approx 470\,\mu$m), dominate for $m_{\rm ee} > 0.5$ GeV/c. To disentangle it from contributions from prompt dielectron sources, e.g. light-flavour hadron decays or thermal radiation in Pb–Pb collisions, the dielectron production can been studied as a function of the pair transverse impact parameter, DCA$_{\rm ee}$, defined by the quadratic sum of the Distance-Of-Closest-Approach to the primary vertex of the two electron tracks divided by two. Measurements in pp collisions at $\sqrt{s} =$ 7 TeV show that prompt and non-prompt dielectron sources can be separated with this variable. Using this approach for Pb–Pb collisions is also being investigated, although not presented yet in this article.

3. Results in Pb–Pb collisions

The $\rm e^+e^-$ pair production has been measured in the 20% most central Pb–Pb collisions at

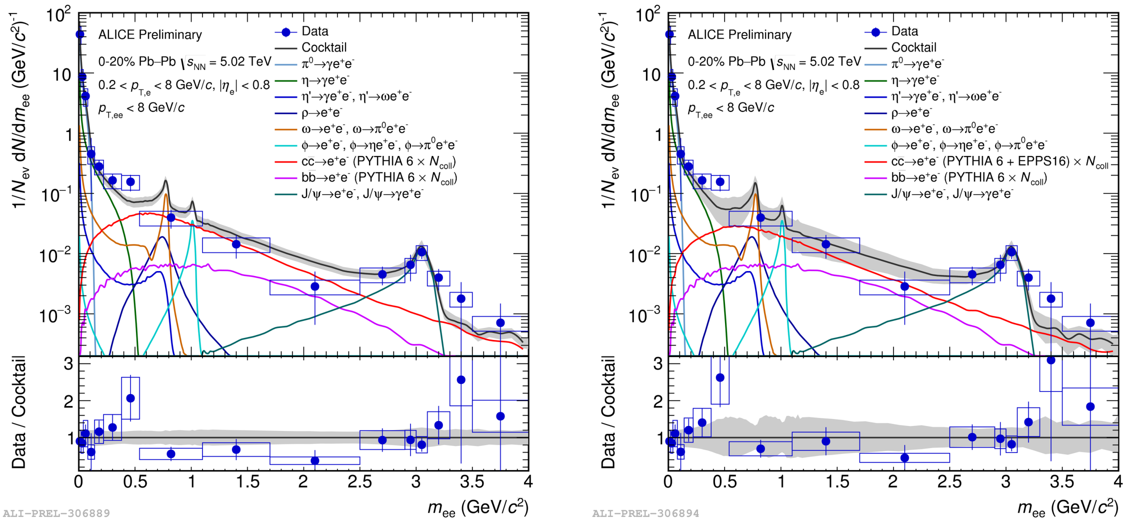

Figure 1: Dielectron yield in the most 0–20% central Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV as a function of $m_{\rm ee}$ in the ALICE acceptance compared to the *vacuum* cocktail (left) and a cocktail including cold-nuclear matter effects for the charm production (right).

$\sqrt{s_{\rm NN}}$ = 5.02 TeV. In the left panel of Fig.1, the measured dielectron yield as a function of $m_{\rm ee}$ is compared to a *vacuum* cocktail of known hadronic sources without any additional thermal radiation from the medium or cold- and hot-matter effects for the heavy-flavour production. An enhancement of a factor 1.15±0.18 (stat.) ± 0.31 (syst.) ± 0.17 (cocktail) is observed in the range $0.15 < m_{\rm ee} < 0.7$ GeV/c^2, consistent with additional thermal dielectron production. More data and a better rejection/understanding of the large heavy-flavour background are nevertheless needed to increase the sensitivity of the measurement. In the intermediate-mass range $1.1 < m_{\rm ee} < 2.5$ GeV/c^2, the data are systematically below the hadronic cocktail. Using the nuclear Parton-Distribution-Function EPPS16 [4] to estimate shadowing effects on the charm production reduces the expected contribution of dielectrons from correlated open-charm hadron decays slightly, and at the same time increases the systematic uncertainties of the hadronic cocktail. With this a better description of the data is achieved, as shown on the right panel of Fig.1.

The dielectron production has been also studied as a function of the pair transverse momentum $p_{\rm T,ee}$ in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV in the 0–40% and 70–90% centrality classes for the $m_{\rm ee}$ range 1.1–2.7 GeV/c^2. The measured yields are compared on Fig.2 to the *vacuum* cocktail, the expected contribution from thermal radiation calculated by Rapp et al.[5], and photo-production of dielectrons estimated with three different calculations. The model by Klusek-Gawenda et al. uses the equivalent photon approximation (EPA) and Wood-Saxon nuclear form factors [7], whereas Zhangbu et al. provide calculations based on (i) a generalized EPA (gEPA) [9] and (ii) a full leading order QED calculation [10]. Effects of the finite detector tracking resolution on $p_{\rm T,ee}$ and $m_{\rm ee}$ are not implemented in these models. A 3.6 sigma excess of dielectrons with respect to the *vacuum* cocktail is observed at low $p_{\rm T,ee}$ ($p_{\rm T,ee} < 0.1$ GeV/c) in peripheral Pb–Pb collisions. The overall yield of this excess is well described by all three photo-production models, whereas the $p_{\rm T,ee}$ shape seems

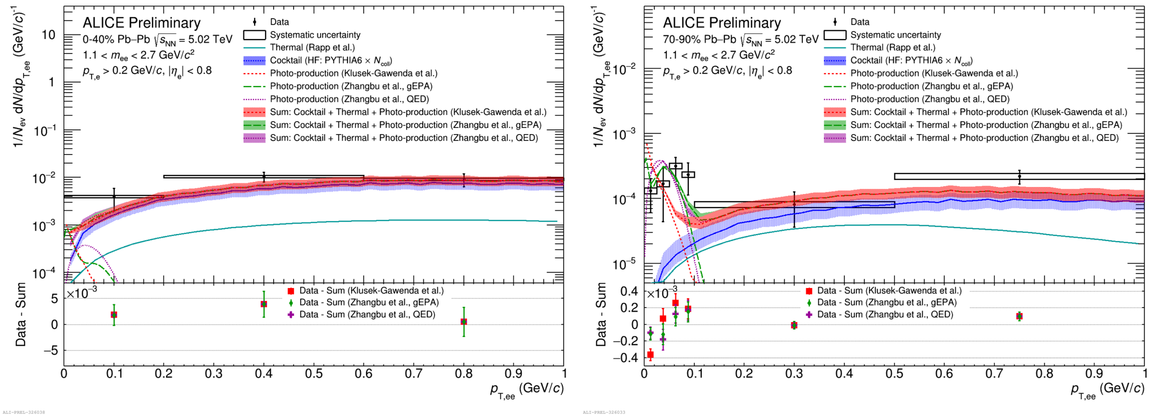

Figure 2: Transverse momentum spectrum of dielectrons in the centrality interval 0–40% (left) and 70–90% (right) compared to the *vacuum* cocktail, along with models of thermal radiation and photo-production.

to be slightly shifted to higher $p_{\mathrm{T,ee}}$ values in data compared to the models, in particular for the one by Klusek-Gawenda et al. No significant excess is observed in 0–40% central Pb–Pb collisions. Similar measurements were performed at lower energies at RHIC by the STAR Collaboration, which observe a low $p_{\mathrm{T,ee}}$ excess of $\mathrm{e^+e^-}$ pairs in peripheral and semi-central Au+Au and U+U collisions described by calculations for coherent dielectron photo-production [11].

4. Conclusion and outlook

The measured dielectron yield in 0–20% most central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV shows an excess at low m_{ee} ($0.15 < m_{\mathrm{ee}} < 0.7$ GeV/c^2) with respect to the expectations from known hadronic sources, which is compatible with an additional contribution from thermal radiation from the medium. The results are nevertheless limited by statistics and the large heavy-flavour background. The analysis of the 2018 data with 10 times more statistics in the 0–10% centrality class is ongoing, as well as analyses as a function of the pair $\mathrm{DCA_{ee}}$ to better understand the non-prompt background.

The low-$p_{\mathrm{T,ee}}$ dielectron production, i.e. $p_{\mathrm{T,ee}} < 1$ GeV/c, has been studied in two centrality classes (0–40% and 70–90%) in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. An excess of dielectrons is observed at very low $p_{\mathrm{T,ee}}$ ($p_{\mathrm{T,ee}} < 0.1$ GeV/c) compared to the expectations from known hadronic decays and thermal radiation in peripheral collisions. This can be regarded as an indication of dielectron production by coherent photon-photon interactions in collisions with hadronic overlap. Comparisons with three different calculations show that the overall yield is well reproduced, whereas different $p_{\mathrm{T,ee}}$ shapes are predicted by the models, which do not include yet detector resolution effects. An extension of the analysis in terms of mass and centrality range is foreseen, which should allow for more differential studies.

The ALICE upgrades, 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 dielectrons measurements [12].

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