PROCEEDINGS OF SCIENCE

J/ψ photoproduction and the production of dileptons via photon-photon interactions in hadronic Pb–Pb collisions measured with ALICE

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Photon-photon and photonuclear reactions are induced by the strong electromagnetic field generated in ultra-relativistic heavy-ion collisions. These processes have been extensively studied in ultra-peripheral collisions with impact parameters larger than twice the nuclear radius. Since a few years, both the photoproduction of the J/ψ vector mesons and the production of dileptons via photon-photon interactions have been observed in A–A collisions with nuclear overlap. Coherent photoproduced quarkonia can probe the nuclear gluon distributions at low Bjorken-x, while the continuum dilepton production could be used to further map the electromagnetic fields produced in heavy-ion collisions and to study possible induced or final state effects in overlapping hadronic interactions. Both measurements are complementary to constrain the theory behind photon induced reactions in A–A collisions with nuclear overlap and the potential interaction of the measured probes with the formed and fast-expanding QGP medium. The latest ALICE results on dielectron production at low masses and pair transverse momenta at midrapidity, as well as on coherent J/ψ photoproduction at mid and forward rapidity, are presented for non-ultraperipheral Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and compared with available models.

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1. Introduction

Photon-photon and photonuclear reactions are induced by the strong electromagnetic field generated by the highly Lorentz-contracted nuclei in ultra-relativistic heavy-ion collisions. The coherent photoproduction of J/ψ vector mesons and the production of dileptons via coherent two photon interactions have been extensively studied in ultra-peripheral collisions (UPC) with impact parameters[1] larger than twice the nuclear radius. Coherently photoproduced quarkonia can probe the nuclear gluon distributions at low Bjorken-x, while the continuum dilepton production could be used to further map the electromagnetic fields produced in heavy-ion collisions. Since a few years, both processes have been observed in hadronic heavy-ion collisions (HHIC). The dilepton production via photon interactions was first measured at RHIC by STAR in peripheral heavy-ion collisions [1] and at the LHC by ATLAS towards central Pb–Pb collisions [2]. Both experiments observed a broadening of the dilepton transverse momentum distributions, or of the dilepton acoplanarity (defined as $1 - \frac{|\varphi^+ - \varphi^-|}{\pi}$ where φ^+ and φ^- are the azimuthal angles of the two leptons) spectra, increasing towards central collisions. The data can be reasonably well reproduced by models including impact parameter dependence of the shape of the initial photon transverse momentum distribution without need of hot-medium effects. The coherent J/ψ photoproduction was measured in hadronic collisions with nuclear overlap first by ALICE in peripheral Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV [3], and later by STAR at RHIC [4] and LHCb at the LHC [5]. Some theoretical challenges remain to compute the expected cross sections, like the survival of the coherence condition for a broken nucleus, the time-ordering of the hadronic and electromagnetic interactions, and the effects of the produced quark-gluon plasma on the J/ψ vector meson. In these proceedings, the first measurement of e$^+$e$^-$ pairs at low masses ($0.4 \leq m_{\mathrm{e^+e^-}} < 2.7$ GeV/c^2) and low pair transverse momenta ($p_{\mathrm{T,ee}}$) at the LHC is presented in hadronic Pb–Pb collisions. Moreover the first p_{T}-differential measurement of coherent J/ψ photoproduction at midrapidity is reported in peripheral Pb–Pb collisions, together with final cross section results towards central Pb–Pb collisions at forward rapidity. The analyses use the full ALICE Run 2 statistics available for Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. The integrated luminosity of the analyzed data samples is about 750 μb^{-1} for the analysis performed at forward rapidity. For the measurements at midrapidity, the total luminosity recorded depends on the centrality range and amounts to 41 μb^{-1} and 20 μb^{-1} for the semi-central (40–50%) and peripheral (50–90%) collisions, respectively. The J/ψ vector meson is reconstructed via its dielectron and dimuon decay channel. Whereas electrons are measured at midrapidity ($|\eta| < 0.9$) in the central barrel, muons are detected in the muon spectrometer at forward rapidity ($-4 < \eta < -2.5$). For an overview of the ALICE experiment, see [6].

2. e$^+$e$^-$ production at low transverse momentum in peripheral Pb–Pb collisions

ALICE reported an excess of e$^+$e$^-$ pairs with respect to the expectations of dielectrons from hadronic sources, i.e. the so-called hadronic cocktail, at very low pair transverse momentum ($p_{\mathrm{T,ee}}$ <0.1 GeV/c) and low mass (m_{ee} < 2.7 GeV/c^2) in semi-peripheral (50–70%) and peripheral (70–90%) Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV [7]. The significance of the excess is larger in most peripheral events. In Fig. 1, the measured $p_{\mathrm{T,ee}}$-differential yields in different m_{ee} ranges

[1]the minimum distance between the centres of the two colliding nuclei in the transverse plane

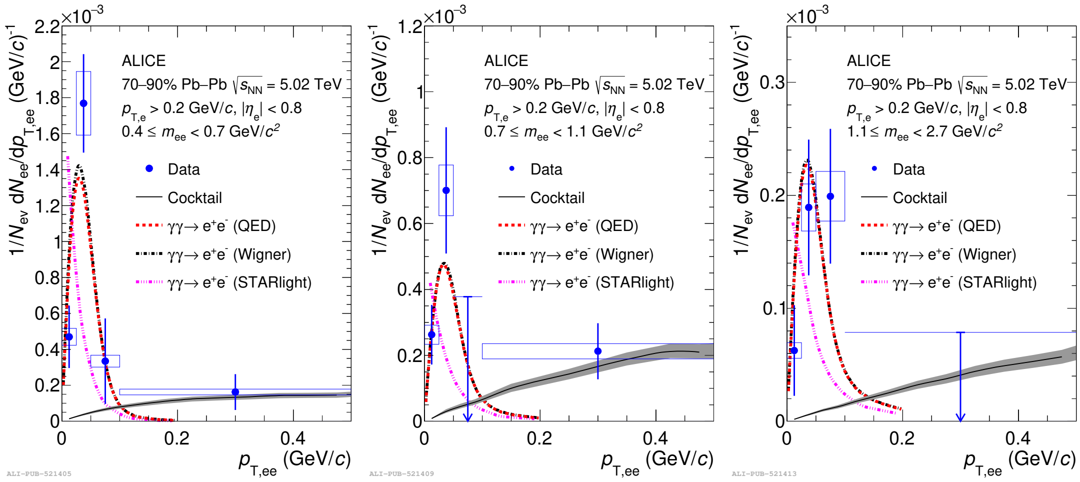

Figure 1: Dielectron $p_{\mathrm{T,ee}}$-differential yields in peripheral (70–90%) Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV for three different m_{ee} ranges, i.e. $0.4 \leq m_{\mathrm{ee}} < 0.7$ GeV/c^2 (left), $0.7 \leq m_{\mathrm{ee}} < 1.1$ GeV/c^2 (middle), and $1.1 \leq m_{\mathrm{ee}} < 2.7$ GeV/c^2 (right), compared with the expected e$^+$e$^-$ contributions from known hadronic decays (grey) and calculations for coherent two-photon production of dielectrons [8–12] folded with the detector resolution [7]. The error bars and boxes represent the statistical and systematic uncertainties of the data, respectively, whereas the grey bands show the uncertainties of the hadronic cocktail. Arrows indicate upper limits at 90% confidence level.

are shown for the 70–90% centrality class. A peak is observed at low $p_{\mathrm{T,ee}}$ and can not be explained by the cocktail shown in grey. The data are compared with different predictions for the production of dielectrons via coherent two photon interactions. On the one hand, the leading-oder QED calculations [8, 9] and expectations from a Wigner approach [10] describe the data well. Both calculations take into account the dependence of the shape of the initial photon transverse momentum distribution with the impact parameter (b) of the heavy-ion collision. On the other hand, predictions from STARlight [11, 12], where such b-dependence is neglected, are disfavoured by the data. The results are in line with the statement that the $p_{\mathrm{T,ee}}$ broadening observed in HHICs in comparison to UPCs originates predominantly from the initial electromagnetic field strength that varies significantly with impact parameter.

3. Coherent J/ψ photoproduction in Pb–Pb collisions with nuclear overlap

In Fig. 2 the measured p_{T}-differential cross sections of coherent photoproduced J/ψ are shown at midrapidity in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV for the 50–70% and 70–90% centrality classes. In the current theoretical approaches, the cross sections in heavy-ion collisions with nuclear overlap are calculated in a similar way as in UPCs as the covolution of the initial photon flux from each colliding nuclei and the photonuclear cross section $\sigma_{\gamma+\mathrm{Pb}\rightarrow \mathrm{J}/\psi+\mathrm{Pb}}$. With respect to UPC calculations, the initial photon fluxes, and/or $\sigma_{\gamma+\mathrm{Pb}\rightarrow \mathrm{J}/\psi+\mathrm{Pb}}$ are modified to account for the nuclear overlap. The data are reproduced by a model where both components were changed [13]. The impact of the nuclear overlap is however small in peripheral collisions.

The dependence of the coherent photoproduced J/ψ cross sections with the centrality (expressed in terms of the mean number of participant nucleons in HHICs) is shown in Fig. 3 at midrapidity

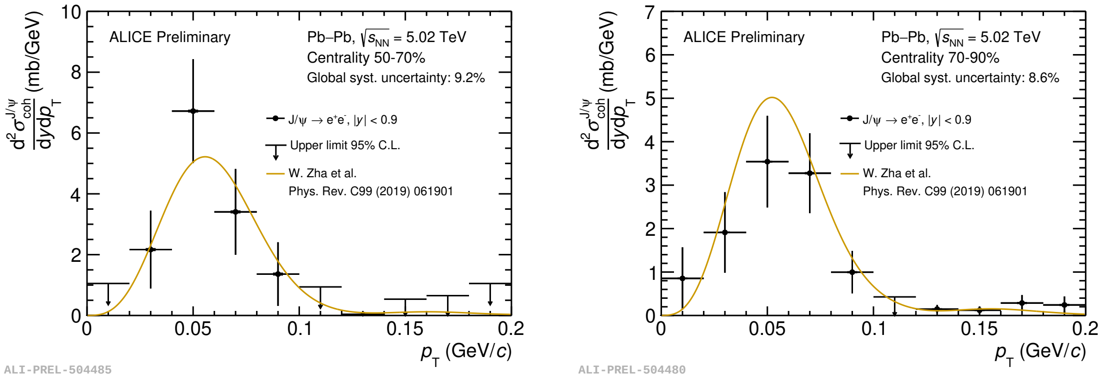

Figure 2: Coherent J/ψ photoproduction cross section as a function of p_T in 50–70% (left) and 70–90% (right) Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV and midrapidity compared to model calculations [13].

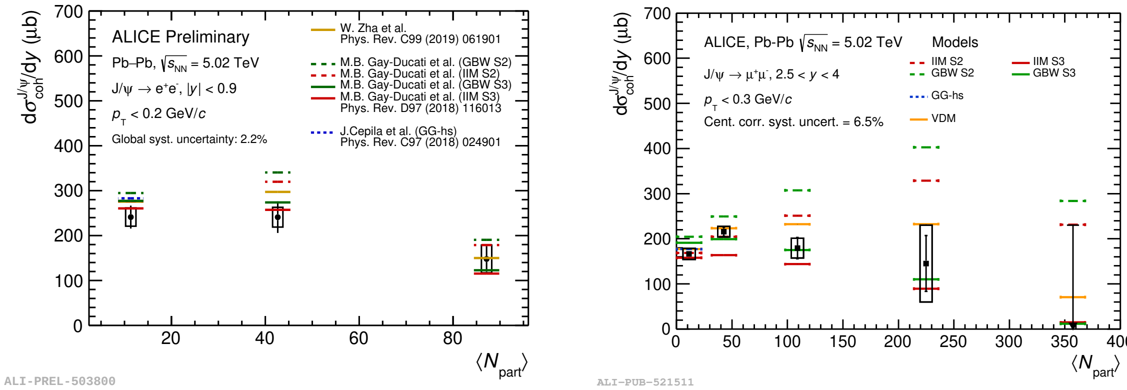

Figure 3: Coherent J/ψ photoproduction cross section as a function of the mean number of participants in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV at midrapidity (left) and forward rapidity [17] (right). The data are compared to different model calculations [13–16], where the VDM model is from Ref. [15].

(left) and forward [17] rapidity (right). At forward rapidity the significance of the measurement is larger than 5σ in the 30–50% centrality class. The semi-central data are described by models with either a modified initial photon flux (VDM [15]) or a modified initial photon flux and $\sigma_{\gamma+\mathrm{Pb}\rightarrow \mathrm{J}/\psi+\mathrm{Pb}}$ (IIM/GBW S3 [16] and the model from Ref. [13]). Predictions from the GG-hs model [14], where the photon flux is estimated in the same way as in the UPC case but the integral is limited to the impact parameter range of the selected centralily class, are only available for the most peripheral centrality interval (70–90%), where the calculations are compatible with data. The same models reproduce the order of magnitude of the cross sections at mid and forward rapidity. A hint for larger J/ψ photoproduction cross section at midrapidity compared to forward rapidity is observed and expected from models.

In Fig. 4 the ratio of the coherent J/ψ photoproduction cross section in heavy-ion collisions with nuclear overlap [17] to the one in UPCs [18, 19] is shown at mid and forward rapidity as a function of the mean number of participants in the HHICs. The ratios are normalised to the width of the centrality interval (ΔC). Similar results are observed at mid and forward rapidity. The data

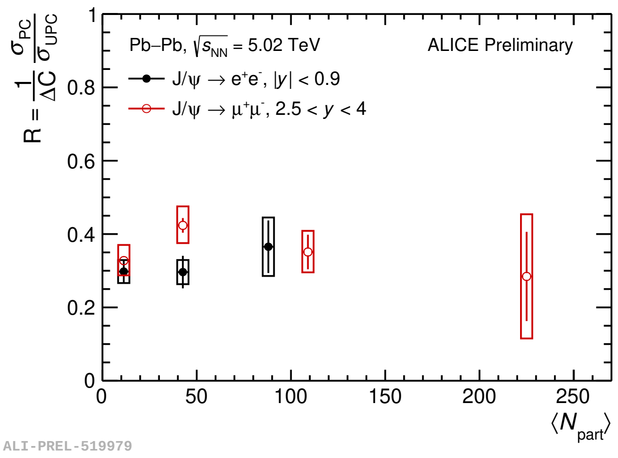

Figure 4: Ratio of the coherent J/ψ photoproduction cross section in heavy-ion collisions with nuclear overlap [17] to the one in UPCs [18, 19] as a function of the mean number of participants in the HHICs for mid (black) and forward (red) rapidity in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV.

do not exhibit a centrality dependence within uncertainties. Therefore no evidence for a decrease of the coherent J/ψ photoproduction cross sections in central Pb–Pb collisions is observed because of the nuclear overlap or the formation of a hot medium within the current experimental uncertainties.

4. Summary and outlook

The first measurements of e^+e^- pairs at low $p_{T,ee}$ ($p_{T,ee}$ < 0.1 GeV/c) and m_{ee} ($0.4 \leq m_{ee} <$ 2.7 GeV/c^2) at LHC energies were performed by ALICE at mirapidity in peripheral (70–90%) and semi-peripheral (50–70%) Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV [7]. The $p_{T,ee}$-differential yields in the most peripheral collisions are reproduced by predictions for dielectron production via coherent two photon interactions including the impact parameter dependence of the shape of the initial photon transverse momentum distributions. The coherent J/ψ photoproduction cross section is measured up to 10–30% central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV at forward rapidity by ALICE [17]. An upper limit is set in the 0–10% centrality class. The first p_T-differential measurement is shown at midrapidity in semi-peripheral (50–70%) and peripheral (70–90%) Pb–Pb collisions. The data are described consistently at mid and forward rapidity by models including modified initial photon flux and/or a modified photonuclear cross section to account for the nuclear overlap.

With a target integrated luminosity of about 10 nb^{-1} for Pb–Pb collisions in Run 3 and 4, high precision p_T-differential measurements of the dielectron production via photon interactions and coherent J/ψ photoproduction will be reached at midrapidity. A significant signal of coherent photoproduced J/ψ is expected in central collisions at both mid and forward rapidity. Finally, the sizeable increase of statistics will allow more differential measurements, i.e. as a function of event plane or rapidity gap between the e^+ and e^- for dielectrons and rapidity-differential cross section measurements for J/ψ, as well as the investigations of new observables like polarization or flow. These measurements could possibly be further extended to other quarkonium states for the first time.

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