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Dielectron measurements in pp and Pb–Pb colllisions with ALICE at the LHC

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Abstract

The production of low-mass dielectrons is one of the most promising tools for the investigation of chiral symmetry restoration and thermal radiation from the QGP created in heavy-ion collisions. To single out the signal characteristics of the QGP, it is crucial to understand the primordial e^+e^- pair production in vacuum, i.e. in inelastic proton-proton (pp) collisions. Low-mass dielectrons have been measured with ALICE at the LHC in pp collisions at $\sqrt{s} = 7$ and 13 TeV, and in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. An overview of the results on dielectron production is presented, together with their implications for the direct-photon and heavy-quark production.

Keywords: Heavy-ion collisions, Electromagnetic probes, Heavy-flavour production, ALICE

1. Introduction

Dileptons are a prime probe of the deconfined state of strongly-interacting matter, the Quark-Gluon Plasma (QGP), produced in ultra-relativistic heavy-ion collisions, as they are not affected by final-state interactions and produced at all stages of the collision. At low invariant mass ($m_{ee} < 1$ GeV/c^2), the dielectron production is sensitive to the properties of vector mesons in the medium and modifications related to chiral symmetry restoration. In the intermediate mass region (IMR, $1.2 < m_{ee} < 2.8$ GeV/c^2), e^+e^- pairs originate mostly from correlated heavy-flavour hadron decays. Thermal radiation from the medium contributes to the dielectron yield over a broad mass range and gives insight into the temperature evolution of the medium. To single out the signal characteristics of the QGP, it is crucial to understand the primordial e^+e^- pair production in vacuum, i.e. in inelastic proton-proton (pp) collisions. Moreover, observations of collective effects in high-multiplicity pp collisions show surprising similarities with those in heavy-ion collisions. The underlying physics processes in such events can be further studied with the measurements of correlated e^+e^- pairs. The data shown in this presentation were recorded between 2010 and 2016 with ALICE during the pp campaigns at the center-of-mass energy $\sqrt{s} = 7$ and 13 TeV as well as the Pb–Pb campaign at the center-of-mass energy per nucleon-nucleon pair $\sqrt{s_{NN}} = 2.76$ TeV at the CERN Large Hadron Collider (LHC).

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2. Direct-photon and heavy-quark production in inelastic pp collisions

Final results on the e^+e^- pair production have been obtained in the ALICE acceptance ($|\eta_e| < 0.8$ and $p_{T,e} > 0.2$ GeV/c, where η_e and $p_{T,e}$ are the pseudorapidity and transverse momentum of electrons or positrons) in inelastic pp collisions at $\sqrt{s}$ = 7 and 13 TeV [1, 2]. The dielectron yield, shown as a function of m_{ee} in the left panel of Fig. 1 for $\sqrt{s}$ = 7 TeV, is found to be well described within uncertainties by a cocktail of known e^+e^- sources based on the measured hadron spectra. In the low-mass region ($0.14 < m_{ee} < 1.1$ GeV/c^2), prompt and non-prompt dielectron sources can be separated with the pair transverse impact parameter (DCA_{ee}), i.e. the average distance of closest approach of the reconstructed electron and positron tracks to the collision vertex, weighted by their respective resolutions [1].
In the quasi-real virtual-photon region, at low mass ($m_{ee} < 0.4$ GeV/c^2) and high pair transverse momentum $p_{T,ee}$ ($p_{T,ee} > 1$ GeV/c), the contribution of virtual direct photons can be extracted from the data by fitting the m_{ee} distributions in $p_{T,ee}$ bins. The resulting ratio of inclusive-to-decay photon cross sections is shown in the right panel of Fig. 1 for $\sqrt{s}$ = 7 TeV. The results at $\sqrt{s}$ = 7 and 13 TeV are found to be consistent with perturbative quantum chromodynamics (pQCD) calculations [1, 2] and ALICE real photon measurements at $\sqrt{s}$ = 8 TeV [3].

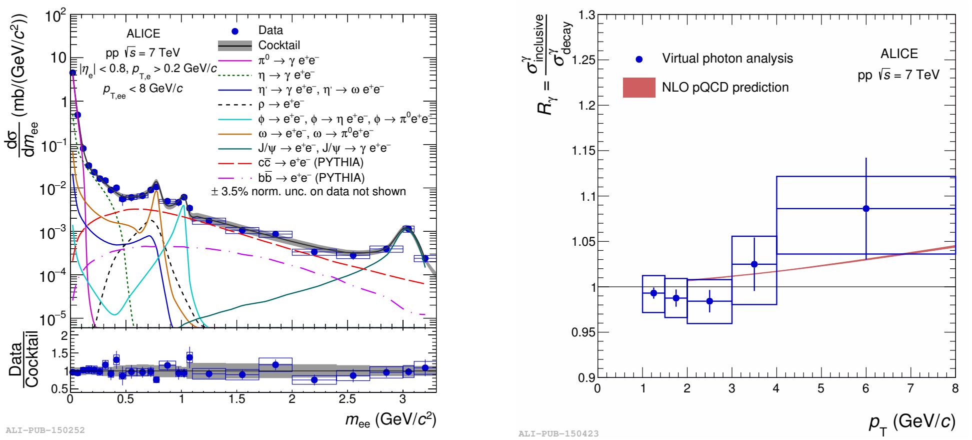

Fig. 1. Left panel: m_{ee}-differential e^+e^- cross section in pp collisions at $\sqrt{s}$ = 7 TeV for $p_{T,e} > 0.2$ GeV/c and $|\eta_e| < 0.8$ compared with a cocktail of expected hadronic sources [1]. Right panel: ratio of inclusive-to-decay photon cross sections measured in pp collisions at $\sqrt{s}$ = 7 TeV compared to pQCD calculations [1, 4].

The heavy-flavour production can be studied with correlated e^+e^- pairs from heavy-flavour hadron decays, dominating the dielectron continuum in the IMR. The e^+e^- yield is sensitive to low-p_T heavy-flavour production and contains information about the initial kinematical correlations between the charm and anti-charm quarks, i.e. the production mechanism, which is not accessible with single heavy-flavour measurements. The $c\bar{c}$ and $b\bar{b}$ cross sections can be estimated from a fit of the data in the IMR. Such fits in pp collisions at $\sqrt{s}$ = 13 TeV are shown as a function of $p_{T,ee}$ in the left panel of Fig. 2 for two different event generators, PYTHIA and POWHEG [2]. Similar model dependencies of the final extracted heavy-flavour cross sections are observed at $\sqrt{s}$ = 7 and 13 TeV. The values are consistent within uncertainties with previous measurements at $\sqrt{s}$ = 7 TeV and with extrapolations from lower energies based on pQCD calculations at $\sqrt{s}$ = 13 TeV, for which they represent the first measurements at this energy.

3. Very soft dielectron production in inelastic pp collisions

Very soft dielectron production in pp collisions remains up to now not very well understood. At the Intersecting Storage Rings at CERN, an excess of dielectron pairs over the expectation from known dielectron

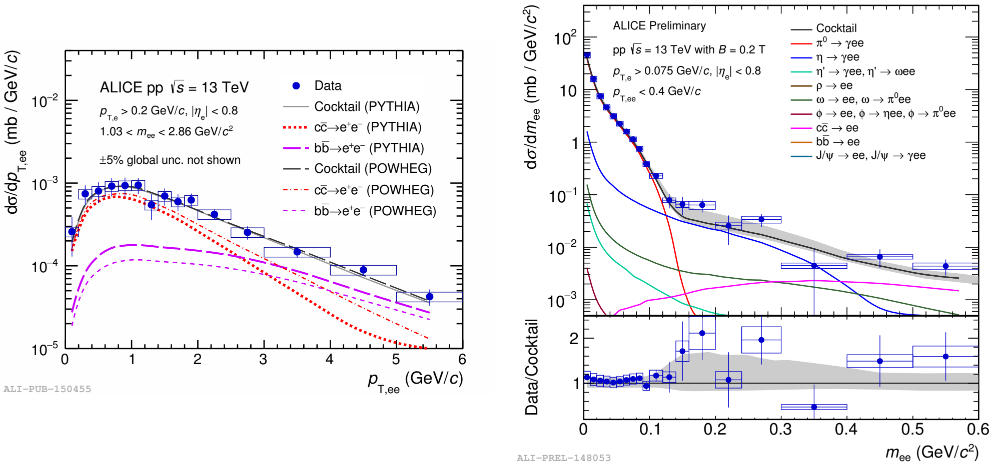

Fig. 2. Left panel: $p_{\mathrm{T,ee}}$-differential $\mathrm{e^+e^-}$ cross section in pp collisions at $\sqrt{s} = 13$ TeV for $p_{\mathrm{T,e}} > 0.2$ GeV/c and $|\eta_{\mathrm{e}}| < 0.8$ fitted with two different MC event generators, PYTHIA and POWHEG [2]. Right panel: m_{ee}-differential $\mathrm{e^+e^-}$ cross section in pp collisions at $\sqrt{s} = 13$ TeV at very low $p_{\mathrm{T,ee}}$ ($p_{\mathrm{T,ee}} < 0.4$ GeV/c) compared to expectations from hadronic sources.

sources has been measured at low invariant mass ($m_{\mathrm{ee}} < 0.6$ GeV/c^2) and small $p_{\mathrm{T,ee}}$ ($p_{\mathrm{T,ee}} < 1$ GeV/c) in pp collisions at $\sqrt{s} = 63$ GeV by the AFS Collaboration [5]. In ALICE, the reconstruction efficiency of low-p_{T} electrons can be increased by reducing the magnetic field of the central barrel solenoid from 0.5 T to 0.2 T. This allows electron background to be better rejected and simultaneously gives the opportunity to access to a similar phase space as the AFS experiment. Such a configuration is planned in ALICE for part of the Pb–Pb campaigns in LHC Run 3 and 4 from 2021 on. In the right panel of Fig. 2, results from pilot runs in pp collisions at $\sqrt{s} = 13$ TeV are shown. The dielectron cross section at low m_{ee} and very small $p_{\mathrm{T,ee}}$ ($p_{\mathrm{T,ee}} < 0.4$ GeV/c and $p_{\mathrm{T,e}} > 0.075$ GeV/c) is compared to a cocktail of known hadronic sources. The data are at the upper-edge of the cocktail systematics where the η contribution is expected to dominate. To reduce the uncertainties of the hadronic cocktail, it is crucial to measure η at very low p_{T} at the LHC.

4. Possible modification of the $\mathrm{e^+e^-}$ production in high-multiplicity pp and Pb-Pb collisions

In high-multiplicity pp collisions, the measurement of low-mass dielectrons could give insight into possible new or heavy-ion like phenomena, e.g. the production or destruction of the ρ meson and the presence of possible thermal radiation. The ratio of dielectron spectra in high-multiplicity and inelastic pp collisions at $\sqrt{s} = 13$ TeV, scaled with charged-particle multiplicity, is shown in the left panel of Fig. 3. The result is consistent with the expectation from the measured light and open-charm hadron spectra at high charged-particle multiplicity represented by the cocktail [2].

The $\mathrm{e^+e^-}$ pair production has been measured in the 10% most central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV. In the top right panel of Fig. 3, the m_{ee} distribution is compared to a cocktail of known hadronic sources without the ρ contribution, whereas in the bottom right panel of Fig. 3 the data-to-cocktail ratio is shown together with the expectations from two theoretical models including thermal radiations from the partonic and hadronic phases [6, 7]. The data are compatible with all scenarios within uncertainties, showing that the measurement is not yet sensitive to possible thermal radiations from the medium.

5. Conclusion and outlook

The final results on dielectron production in pp collisions at $\sqrt{s} = 7$ and 13 TeV in the ALICE acceptance ($p_{\mathrm{T,e}} > 0.2$ GeV/c and $|\eta_{\mathrm{e}}| < 0.8$) are well described by a cocktail of known hadronic sources. The ratio of

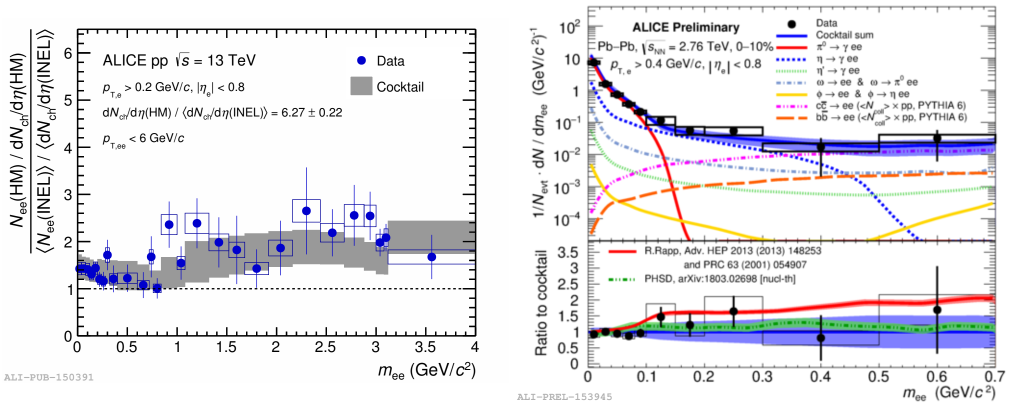

Fig. 3. Left panel: Ratio of dielectron spectra scaled with charged-particle multiplicity in inelastic and high-multiplicity pp collisions at $\sqrt{s}$ = 13 TeV, compared to the expectations from hadronic sources. Right panel: dielectron invariant-mass spectrum in the 0-10% most central Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV compared to cocktails with and without thermal radiation from the medium [6, 7].

inclusive-to-decay photon cross sections extracted from the data is consistent with NLO pQCD calculations at both energies. The charm and beauty cross sections are estimated with two different event generators (PYTHIA and POWHEG) by fitting the data in the IMR. The results provide the first measurements of $d\sigma_{c\bar{c}/b\bar{b}}/dy|_{y=0}$ in pp collisions at $\sqrt{s}$ = 13 TeV. At the same energy, the long-standing puzzle of very soft dielectron production in pp collisions can be investigated with dedicated runs taken with a reduced magnetic field of the ALICE solenoid. The uncertainties of the first preliminary results are still too large to conclude about a possible enhancement. Upcoming runs with reduced field will increase the statistical precision of the data and reduce the systematic uncertainties on the cocktail.

In high-multiplicity pp collisions at $\sqrt{s}$ = 13 TeV, no modification of the dielectron production within uncertainties is observed beyond the established ones of light and open-charm hadrons. In central Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV, the results, which have been published by now [8], are compatible within uncertainties with the expectations from hadronic sources including thermal radiation from the medium. The data, however, are not yet sensitive to a possible excess in the ρ-mass region. The Run 2 Pb–Pb data at $\sqrt{s_{\rm NN}}$ = 5.02 TeV, presently being analyzed, will provide higher statistical accuracy. Additional improvements can come from more advanced analysis techniques including machine learning methods to reject $e^{\pm}$ from γ conversions or to identify $e^{\pm}$. Finally, the ALICE upgrade physics program [9, 10] with a dedicated low-mass dielectron campaign will allow for a detailed investigation of the medium properties.

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