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Measurements of the dielectron continuum in pp, p-Pb and Pb-Pb collisions with ALICE at the LHC

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Abstract

Dielectrons produced in ultra-relativistic heavy-ion collisions provide a unique probe of the whole system evolution as they are unperturbed by final-state interactions. The dielectron continuum is extremely rich in physics sources: thermal radiation is of particular interest as it carries information about the temperature of the hot and dense system created in such collisions. The dielectron invariant mass distribution is sensitive to medium modifications of the spectral function of vector mesons that are linked to the potential restoration of chiral symmetry. Correlated electron pairs from semi-leptonic charm and beauty decays provide information about the heavy-quark energy loss.

A summary of the LHC Run-1 preliminary results in all three collisions systems (pp, p-Pb and Pb-Pb) is presented. Furthermore, the status of the ongoing Run-2 analyses is discussed with a focus on pp collisions collected with a high charged-particle multiplicity trigger, on new analysis methods to separate prompt from non-prompt sources, and on the usage of machine learning methods for background rejection.

Keywords:
dielectrons, QGP, heavy-ion collisions, heavy flavour, electromagnetic radiation

1. Introduction

The study of opposite sign dileptons (pairs of leptons) in ultra-relativistic heavy ion collisions allows us to investigate the electromagnetic radiation released in the hot and dense medium created after the collision. Such an electromagnetic radiation is emitted during all stages of the evolution of the system, and escapes unaffected by strong final state interactions. In particular, dielectrons are an ideal probe at collider experiments, since they are accessible at low p_{T} and midrapidity, i.e. the rapidity region with the highest energy density. Moreover, by studying the different invariant mass regions one can access the different dielectron production mechanisms. In the very low ($m_{\mathrm{ee}} < 0.3$ GeV/c^2) and intermediate ($1.1 < m_{\mathrm{ee}} < 2.8$ GeV/c^2) mass regions, information on the temperature of the late and early system, respectively, can be obtained through the measurement of thermal radiation in the form of direct virtual photons. The in-medium modifications of the spectral functions of short lived vector mesons are investigated in the resonance mass region ($0.3 < m_{\mathrm{ee}} < 1.1$ GeV/c^2). The intermediate mass region (IMR) provides as well complementary information on the production of open heavy flavour through the study of correlated semileptonic decays of D and B mesons.

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2. Low mass dielectrons with ALICE

The ALICE experiment [1] investigates Pb-Pb collisions at the LHC. By studying heavy-ion collisions at energies up to $\sqrt{s_{\rm NN}}$ = 5.02 TeV one can access a region of the QCD phase diagram where the temperatures are expected to be higher compared with other experimental facilities (RHIC, SPS) and the net baryonic density $\mu_{\rm B}$ is close to zero. Experimental results from the LHC can be directly compared to Lattice QCD calculations, applicable only at vanishing $\mu_{\rm B}$. Three main detectors are used to identify electrons: the inner tracking system (ITS), the time projection chamber (TPC) and the time-of-flight detector (TOF). Electrons are selected using the information on the dE/dx in the ITS and TPC. For high background analyses, including Pb-Pb collisions, the TOF information of the track is required, which imposes, due to geometrical acceptance, a mimimum transverse momentum for electrons of 400 MeV/c, otherwise this cutoff is reduced and the acceptance improves down to 200 MeV/c. The dielectron signal is contained in the unlike sign electron pairs (ULS) that is also affected by combinatorial background. This background is removed by subtracting the like sign spectrum (LS) corrected for the acceptance difference relative to ULS. The contribution from photon conversions in the material of the spectrometer, due to misreconstructed momenta, to masses up to 200 MeV/c^2, is removed exploiting the fact that conversion pairs, having only a negligible intrinsic opening angle, have a preferred orientation with respect to the magnetic field. In order to obtain the dielectron yield as a function of mass, the dielectron spectra are corrected by the reconstruction efficiency evaluated with a full Monte Carlo (MC) simulation.

ALICE has investigated the vacuum reference for dielectron production from pp collisions at $\sqrt{s}$ = 7 TeV [2], where preliminary results of the virtual photon contribution have been obtained in the region $1 < p_T^{\rm ee} < 4$ GeV/c and found to be consistent with NLO pQDC calculations. The preliminary dielectron yield from p-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV has been obtained using a differential analysis in mass and $p_{\rm T}^{\rm ee}$ searching for cold nuclear matter effects [3]. In the left panel of Fig. 1, the preliminary dielectron spectrum from Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV [4] is shown compared to a hadronic cocktail, that is the sum of all known hadron sources contributing to the dielectron spectrum, plus the expected contribution from thermal radiation and a broadened ρ spectral function. The light flavour part of the cocktail consists of a fast simulation of several Dalitz and direct meson decays π^0, η, η', ρ, ω, ϕ and J/ψ, based on measurements of π^0 production in Pb-Pb $\sqrt{s_{\rm NN}}$ = 2.76 TeV collisions [5] and m_T scaling for the other mesons. For the heavy flavour part, a PYTHIA6 simulation of pp collisions at $\sqrt{s}$ = 7 TeV using measured cross sections by ALICE is used [6, 7], extrapolated in energy and scaled by the average number of binary collisions. Additionally, the contribution from thermal radiation according to [8], which includes the in-medium ρ, is shown and compared to the Pb-Pb mass spectrum. Good agreement within uncertainties is seen between data and expectation. However, due to the lack of sensitivity of the present data, good agreement is found as well with a vacuum cocktail. In this analysis, an upper limit on the virtual photon production has been estimated at a 90% C. L. as well, covering values of previous photon measurements of RHIC and LHC.

3. High multiplicity pp collisions, DCA analysis and machine learning methods

The dielectron mass spectrum from high multiplicity triggered pp collisions at $\sqrt{s}$ = 13 TeV has been obtained for the first time. The goal is to compare the high multiplicity events with the minimum bias triggered data in order to search for any possible deviation in the mass spectrum when the charged particle multiplicity rises. An enhancement in the low mass region caused by modifications of the $p_{\rm T}$ spectra is expected [9]. Any other effect like modifications in the relative contributions of different mesons, suppression of short lived vector mesons due to final state interaction with comovers or enhancement due to resonance production in π-π annihilation can be studied. The electron reconstruction and identification efficiency is, to better than 4%, independent of the particle multiplicity so it cancels in the ratio and no correction is necessary. In the right panel of Fig. 1, the ratio of the high-multiplicity and minimum bias spectra is shown after normalization by the average charged particle multiplicity. The ratio of the mass spectra is compared to a cocktail expectation. For the light flavour simulation, the high multiplicity events are based on $p_{\rm T}$-differential measurements of charged particle production as a function of multiplicity [9]. Measured values of the enhancement factor of D mesons as a function of its mean p_T [10] are used for the heavy flavour contribution. The data reproduce the enhancement at low mass because of the increase in p_T with multiplicity and they are also compatible with the cocktail expectations at higher masses. The analysis of more data, with five times more statistics, and refinements in the uncertainties of the cocktail ratio are ongoing.

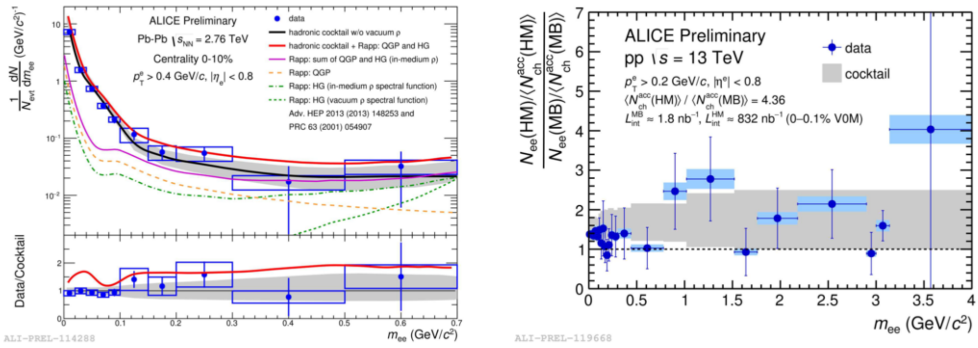

Fig. 1. Left panel: Dielectron invariant mass spectrum from Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV compared to a hadronic cocktail plus the contribution from thermal radiation and a broadened ρ. Right panel: normalized ratio of high multiplicity events over minimum bias from pp collisions at $\sqrt{s} = 13$ TeV compared to the cocktail expectation.

New analysis techniques are being explored for the analysis of dielectrons. By studying the distance of closest approach to the vertex of the dielectron pair (DCA_{ee}), an additional degree of freedom is added to the traditional studies based on the pair mass and p_T. The definition of DCA_{ee} combines the impact parameter in the transverse plane for both electrons and the expected resolution in the measurement. The DCA_{ee} is sensitive to non-prompt sources: due to the relatively long decay path of the D ($c\tau \sim 200$ µm) and B ($c\tau \sim 500$ µm) mesons, their tracks do not point to the primary vertex of the collision. On the other hand, thermal dielectrons are produced at the primary collision vertex. The separation power of the DCA_{ee} is of special importance in view of Run-3 studies of the thermal radiation in the IMR, where the contribution from correlated semileptonic decays is dominant at LHC energies. The DCA_{ee} spectra for pp events at $\sqrt{s} = 7$ TeV are compared to MC templates of the different hadronic sources. In the left panel of Fig. 2, the comparison for the IMR is shown, where heavy flavour contributions overcome the prompt sources. The data are well reproduced by expectations from the cocktail within uncertainties and reflect the much harder DCA_{ee} spectrum of the non prompt semileptonic decays in the IMR, showing the potential of this analysis to evaluate the contribution from heavy flavour sources in our spectra.

Classification methods with supervised machine learning are being tested in the dielectron analyses for the electron identification and the suppression of background pairs. Multi-variate analyses (MVA) using boosted decision trees [11] are used instead of traditional single-variable or two-dimensional selection in order to fully exploit the correlation between variables by using high dimensional dependencies. The identification of electrons with a multivariate approach results in an increase of the signal efficiency while mantaining a high signal purity compared with the low efficiencies of the traditional selection method. Preliminary results show that the machine learning method, optimized for different p_T bins, overcome the traditional selection method over the whole momentum range both in efficiency and in purity.

MVA methods are used as well to perform the background suppression in the dielectron analysis. The idea is to use machine learning methods to perform a background identification before the LS subtraction, thus improving the S/B ratio. In this multivariate analysis the same pair and single leg variables that characterize dielectrons and that are used in the standard selection methods are evaluated and used for classification. The signal of ULS pairs coming from the same mother is classified and distinguished from the background pairs by two different neural networks that are trained to reject two background types: combinatorial background with only one electron originated from a conversion and conversion pairs, respectively. For a better efficiency of the method, a combination of both MVA classifiers is applied as a function of the

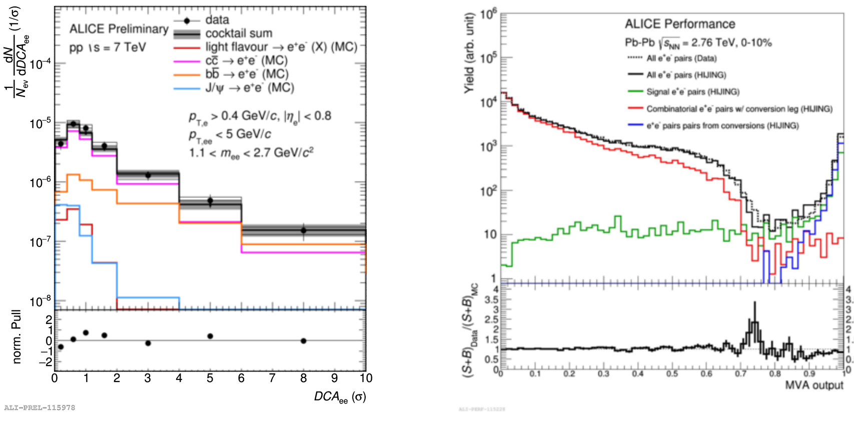

Fig. 2. Left panel: DCA_{ee} spectrum from pp collisions at $\sqrt{s}$ = 7 TeV compared to MC templates for the IMR region. Right panel: MVA output for signal and background pairs from the analysis of Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

dielectron mass. As a secondary output of this method, in order to tune the MC simulations, a novel multivariate reweighting method is applied using further classifiers to adapt the MC simulations to the collision data. In the right panel of Fig. 2, the MVA output is seen for the signal and background pairs showing the separation power of the method. In the bottom part of the figure, the good agreement of data and reweighted MC simulations can be judged from the data to simulation ratio.

4. Conclusions

The ALICE Collaboration obtained preliminary dielectron invariant mass spectra for different collision systems, pp, p-Pb and Pb-Pb. Also for the first time in this kind of analysis, high multiplicity triggered pp collisions are compared with minimum bias events. New analysis methods using the distance of closest approach of the dielectron pair to the event vertex, and machine learning methods for electron identification and background rejection have been used as well. The new analyses and methods will be of particular relevance after the planned upgrade [12] of the ITS and TPC detectors of ALICE for the LHC Run 3 that will facilitate the measurement of the temperature of the early system formed in ultra-relativistic Pb-Pb collisions.

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