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Dielectron Production in pp Collisions at $\sqrt{s}$ = 13 TeV Measured in a Dedicated Low Magnetic-Field Setting with ALICE †

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Abstract: The low-mass dielectron production in pp collisions at $\sqrt{s}$ = 13 TeV was measured by ALICE with a reduced field of the ALICE central barrel solenoid magnet. This increases the reconstruction efficiency of low-p_{T} electrons and allows a better electron background rejection while simultaneously giving the opportunity to access a similar phase space as covered by the AFS experiment at the Intersecting Storage Rings at CERN. There, an excess of dielectron pairs over the expectation from known dielectron sources was measured at low invariant mass and small pair transverse momenta in pp collisions at $\sqrt{s}$ = 63 GeV in 1987. It is shown how the ALICE dielectron analysis of the pp pilot runs at $\sqrt{s}$ = 13 TeV with B=0.2 T is adapted to the reduced-field configuration. Preliminary results are compared to the published reference data recorded with the nominal field, to illustrate the benefits of the low magnetic-field setting. Finally, the invariant-mass and pair-transverse-momentum distributions are compared to the AFS measurement to address a possible excess at low m_{ee} and $p_{\mathrm{T,ee}}$.

Keywords: ALICE; dielectrons; LMR excess; pp collisions at 13 TeV; low-field setup

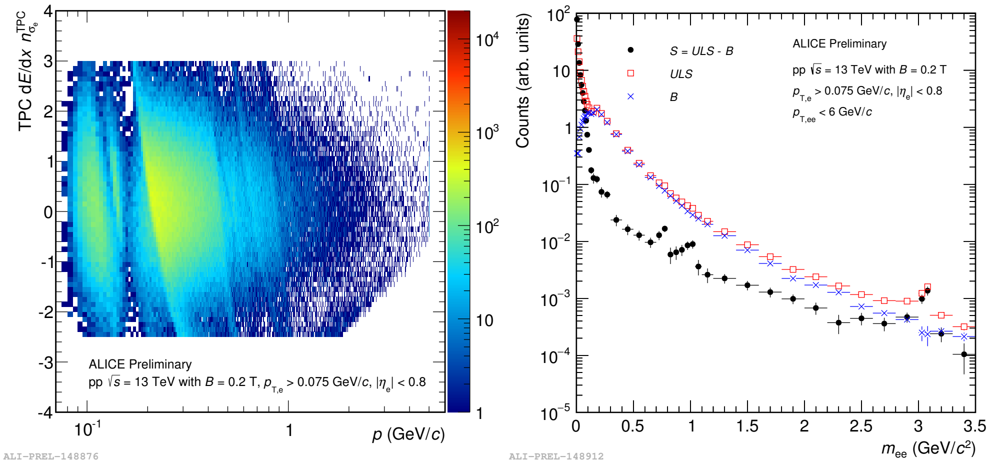
1. Introduction

Low-mass dielectron measurements play an essential role in the study of the Quark–Gluon Plasma (QGP) created in ultra-relativistic heavy-ion collisions. Electron-positron pairs are produced at all stages of the collision. Since these electromagnetic probes are not subject to the strong interaction they have negligible final-state interactions and the hot and dense medium is transparent for them during the whole system evolution. Thus, dielectrons provide valuable information about the strongly interacting matter and possible medium modification of hadrons. To single out the signal characteristics of the QGP, it is crucial to understand the $e^{+}e^{-}$ pair production in vacuum, which can be studied in elementary pp collisions.

The ALICE detector [1] is well-suited to perform these measurements due to its excellent tracking and particle identification capabilities especially at low momenta. However, Dalitz decays and photon conversions lead to a high combinatorial background with a signal-to-background ratio of 1:10 in pp collisions and up to 1:1000 in Pb–Pb events, depending on the invariant mass. Therefore, the minimization of the background is a key aspect of this analysis. The reconstruction efficiency of low-p_{T} electrons can be increased by reducing the magnetic field of the ALICE central barrel solenoid from 0.5 T to 0.2 T. Such a configuration is also planned in ALICE for part of the Pb–Pb campaign in LHC Run 3 and 4 from 2021 on. This allows a better rejection of the combinatorial electron background and simultaneously gives the opportunity to increase the accessible phase space. In addition, non-trivial deviation from the vacuum expectation were observed in pp collisions at very low momenta. In 1987 at the Intersecting Storage Rings (ISR) at CERN, an excess of dielectron pairs over the expectation from known dielectron sources was measured at low invariant mass and small pair transverse momentum in pp collisions at $\sqrt{s}$ = 63 GeV by the AFS experiment [2]. With the reduced magnetic-field setting ALICE can probe a similar phase space for electron and positron pairs in order to confirm a similar excess in elementary pp collisions for the first time at collider energies since the ISR.

2. Data Analysis

The presented analysis was performed on the first successful pilot runs of pp collisions at a center of mass energy $\sqrt{s}$ = 13 TeV taken with the ALICE detector at LHC at CERN in 2016/17 with a reduced field of the L3 solenoid magnet. The data set consists of about 150 million minimum-bias events which corresponds to an integrated luminosity of $L_{\text{int}} = 2.7 \pm 0.1\ \text{nb}^{-1}$. The low magnetic-field setting allows electron identification down to $p_{\text{T}} = 0.075\ \text{GeV}/c$. The electron and positron candidates were selected based on their specific energy loss in the Time Projection Chamber (TPC). However, in the p_{T} regions of high hadron contamination the Time-Of-Flight (TOF) signal was required to ensure a high purity while maintaining a high statistical significance of the sample as shown in Figure 1a. No PID information from the Inner Tracking System (ITS) was used in this analysis, emulating the situation in Run 3 and 4.



(a) (b)

Figure 1. (**a**) Specific energy-loss of electron candidates in the TPC as a function of their momentum after applying all selection criteria. (**b**) Illustration of the like-sign subtraction method. The unlike-sign pairs are shown in red, the like-sign in blue and the resulting signal in black.

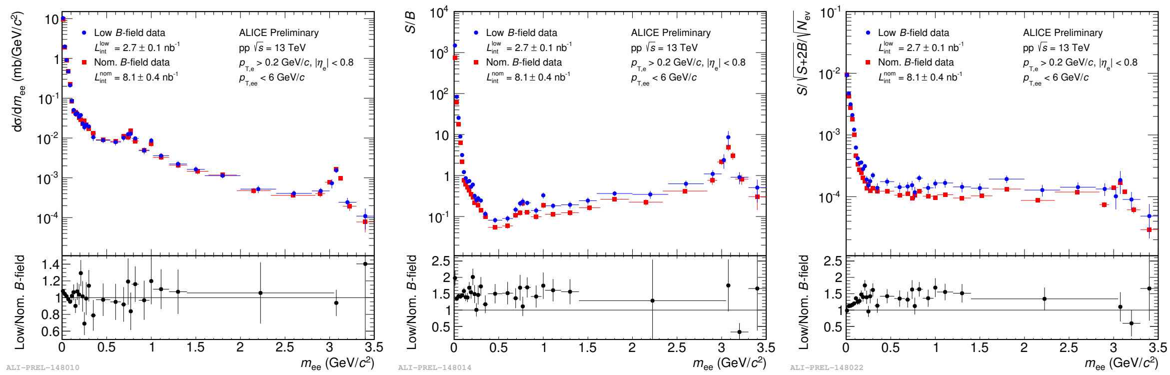
Since the origin of each electron and positron cannot be determined experimentally the initial pairs cannot be resolved. For this reason a combinatorial pairing of all electrons and positrons in an event is performed. However, these pairs are dominated by combinatorial background originating from artificial pairs and only a small fraction arises from physical pairs which contribute to the actual dielectron spectrum. To separate the signal pairs S from the background pairs B the like-sign subtraction method is used. The unlike-sign pairs N_{+-} contain all real signal pairs but also background pairs from the combinatorial pairing or contribution from otherwise correlated pairs. The background including the correlations can be estimated via the like-sign pairs N_{++}, N_{--}. This background estimate is then corrected for the different acceptance of unlike-sign and like-sign pairs. The relative correction factor R is obtained from mixed events which preserves the acceptance difference but suppresses any correlations. Consequently, the signal is obtained by subtracting the corrected like-sign from the unlike-sign pairs which is illustrated in Figure 1b. An acceptance and efficiency correction derived from Monte Carlo simulations is applied. The corrected spectra are compared to a hadronic cocktail consisting of all known hadronic sources contributing to the dielectron spectrum. The cocktail is built in a similar manner as the published dielectron measurement at $\sqrt{s}$ = 13 TeV with nominal field [3].

The ALICE measurement of the η meson down to 0.4 GeV/c has been complemented by an additional constraint for the η contribution at low p_{T} based on the TAPS/CERES measurement [4].

3. Results

3.1. Comparison to the Published Nominal-Field Analysis

To illustrate the effect of the low magnetic-field setting the results are compared to the published Run 2 data [3] recorded at the nominal field using the same lower single-electron selection of $p_{\mathrm{T}} >$ 0.2 GeV/c. Figure 2a shows a good agreement within the statistical uncertainties. No significant difference in mass resolution can be observed between the two field settings. However, the higher tracking and PID efficiency in the low-field setup enhances the conversion rejection capabilities and leads to larger S/B and signal significance per event over the whole mass region, as illustrated in Figure 2b,c.



(**a**) (**b**) (**c**)

Figure 2. Comparison of: (**a**) the differential dielectron cross section $\mathrm{d}\sigma/\mathrm{d}m_{\mathrm{ee}}$ (**b**) the signal-over-background ratio S/B (**c**) and the statistical significance per event as a function of m_{ee} of the low-field analysis (red) to the nominal field analysis [3] (blue) both with a $p_{\mathrm{T}} >$ 0.2 GeV/c.

3.2. Acceptance Gain at Low Field

The gain in phase space for the dielectron measurement achieved by reducing the single-electron p_{T} selection from 0.2 down to 0.075 GeV/c is illustrated in Figure 3. The gray area shows the phase space only accessible in the low-field setting illustrating the increased sensitivity for soft virtual-photon production. Outside this area, a clear increase for pairs with low mass and pair momentum can be observed. In addition, the reconstruction efficiency of low-mass pairs with high transverse momentum increases and concentric structures appear originating from the higher efficiency of the TOF measurement.

3.3. Comparison to the AFS Results

Figure 4a shows the dielectron cross section in pp collisions at $\sqrt{s}$= 13 TeV as a function of m_{ee} for $p_{\mathrm{T,ee}} <$ 0.4 GeV/c with a single-electron selection of $p_{\mathrm{T}} >$ 0.075 GeV/c compared to the hadronic cocktail. A slight increase of the data over the cocktail can be observed in the region of the measured AFS low-mass region (LMR) excess with a statistical significance of 2.2σ over the central value of the cocktail, ignoring systematic uncertainties. The cocktail uncertainties are conservatively derived from the m_{T} scaling hypothesis which knowingly overestimates the η contribution at low momenta [4]. Figure 4b,c show the pair transverse momentum spectra in the pion and η mass region illustrating the location of the enhancement at very low momenta. This may hint at a possible enhancement at LHC energies. It is located at very low p_{T} and is only accessible in the low-field configuration. However, a precise measurement of the η production at low p_{T} is mandatory for a final conclusion.

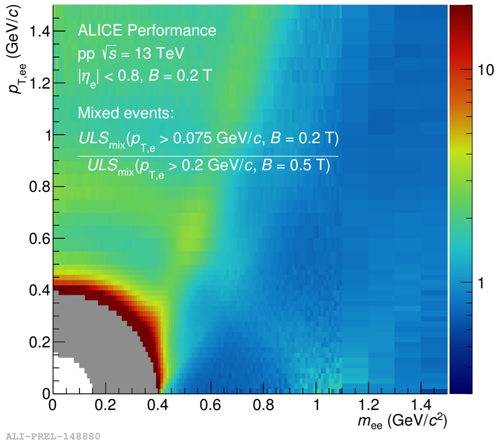
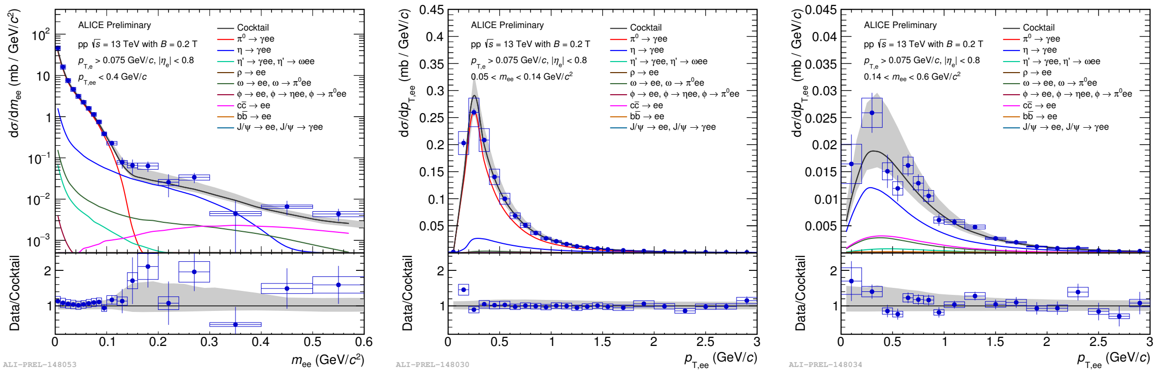


Figure 3. Relative acceptance difference between low- and standard-field configuration as a function of m_{ee} and $p_{\mathrm{T,ee}}$ due to the lower single-electron p_{T} selection and increased TOF acceptance at low momenta.



(**a**) (**b**) (**c**)

Figure 4. The dielectron cross section in pp collisions at $\sqrt{s}$ = 13 TeV as a function of: (**a**) m_{ee} for $p_{\mathrm{T,ee}}$ < 0.4 GeV/c (**b**) $p_{\mathrm{T,ee}}$ in the pion mass region (**c**) $p_{\mathrm{T,ee}}$ in the η mass region with a single-electron selection of p_{T} < 0.075 GeV/c (blue points) compared to the hadronic cocktail (black line) and its different contributions (colored lines). The bottom panels show the ratio of data over cocktail.

ALICE measured the dielectron production in pp collisons at $\sqrt{s}$ = 13 TeV with a low-field configuration as a function of m_{ee} and $p_{\mathrm{T,ee}}$. The measurement is consistent within the statistical uncertainties with the nominal field analysis [3]. However, the low-field setting increases S/B and significance per event while giving access to a new phase space at low momenta by reducing the single-electron selection down to p_{T} >0.075 GeV/c. This enabled a possible observation of LMR excess at LHC energies. For a final conclusion a reduction of the systematic uncertainties of the hadronic cocktail via a precise η measurement at LHC energies is required. An additional data set with the low-field setting was recorded in 2018. This will increase the statistical precision by a factor of three.

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