DIELECTRON PRODUCTION IN PP AND DP COLLISIONS
AT 1.25 GeV/u WITH HADES

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Abstract
Inclusive production of $e^+e^-$-pairs in $pp$ and $dp$ collisions at a kinetic beam energy of 1.25 GeV/u has been studied with the HADES spectrometer. In the latter case, the main goal was to obtain data on pair emission in quasi-free $np$ collisions. To select this particular reaction channel the HADES experimental setup was extended with a Forward Wall hodoscope, which allowed to register spectator protons. Here, the measured invariant mass distributions demonstrate a strong enhancement of the pair yield for $M > 140$ MeV$/c^2$ in comparison to $pp$ data.

1 Introduction
HADES (High Acceptance Di-Electron Spectrometer) is located at GSI, Darmstadt and currently operated at the SIS18 synchrotron at beam energies of 1–2 GeV/u. It is a magnetic spectrometer which is capable to register $e^+/e^-$ particles in a polar angle ranges from 18° up to 88° and has almost full azimuthal coverage. The broad experimental program includes the study of pair production in nucleus-nucleus collisions, elementary reactions ($pp$, $np$, $\pi p$) as well as $pA$, $\pi A$ collisions with the emphasis on properties of vector mesons at finite baryonic densities.

Recently, HADES has performed the study of dielectron production in $^{12}\text{C}+^{12}\text{C}$ collisions at beam energies of 1 and 2 GeV/u. The most important result of these studies was the identification of a dilepton excess above expectations based on meson ($\pi^0$, $\eta$, $\omega$) decays after the chemical freeze-out [1, 2]. In the invariant mass range of $0.15 < M < 0.50$ GeV$/c^2$ and the energy of 1 GeV/u the ratio of this excess compared to the contribution coming from $\eta$ Dalitz is found to be $F = 6.8$. Remarkably, this result is in good agreement with previous DLS data [3].

A question which arises in this context is whether the observed discrepancy between the measured yield and contributions from decays of long lived resonances is due to some unique effect of nucleus-nucleus collisions or incomplete knowledge of dielectron production processes in elementary nucleon-nucleon interactions at this energy regime, in particular the $np$ channel.

Here, the bremsstrahlung process in the $np$ system is of special interest as it was argued to be an important source of lepton pairs; recent consideration of this process within an One-Boson Exchange framework [4] predicts cross section values significantly larger than in a number of previous calculations [5, 6]. However, a final consensus has not been achieved so far, debates concerning the magnitude of the $np$ bremsstrahlung contribution are still ongoing [7].

It is worth to mention that recent transport calculations with cross sections for the bremsstrahlung process tuned to reproduce the predictions of [4] demonstrate good agreement with the DLS and HADES results [8].

This situation clearly calls for experimental data on dielectron production in elementary $NN$ collisions in the energy regime of $\sim$1 GeV. A comparison of $pp$ and $np$ channels is of particular interest.

2 $pp$ and $dp$ experiments
In 2006, the HADES collaboration has performed the study of dielectron production in proton-proton collisions at a kinetic beam energy of 1.25 GeV [9]. Since the selected beam energy is
below $\eta$ production threshold (1.27 GeV), the only sources contributing to pair spectra are $\pi^0$ and $\Delta$ Dalitz decays and small contribution from the bremsstrahlung process, which at such energies is expected to be almost negligible as compared to $np$ case on the basis of radiation multipolarity arguments.

The invariant mass distribution of dielectrons measured in $pp$ collisions is shown in Fig. 1. A selection on pair opening angles larger then $9^\circ$ was applied in order to suppress contributions from conversion photons and $\pi^0$ Dalitz decays. The combinatorial background was reconstructed by means of like-sign pair measurements and subtracted from the raw spectrum. The presented spectrum (and all spectra in this letter) is corrected for the detection efficiency, however, absolute normalization has not yet been made.

Figure 1: Dielectron invariant mass distribution measured in the $pp$ reaction at 1.25 GeV

In 2007, HADES continued its studies on $NN$ reactions with an experiment using deuteron-proton collisions. The main goal of this experimental run was to measure pair production properties in the $np$ channel at the same beam energy per nucleon as in the $pp$ case.

Within impulse approximation (IA) $^{[10]}$ the collision of a high energy deuteron with a nucleon is reduced to the quasi-free nucleon-nucleon interaction: one of the nucleons forming the deuteron does not participate in the reaction and acts as a spectator. Since typical values of Fermi momenta are small compared to those of the beam, the spectator nucleon carries approximately half of deuteron momentum and moves at small polar angle in the laboratory frame. These features allow to tag the quasi-free $np$ channel by requiring a spectator proton at very forward directions. In order to be capable of such technique the HADES setup was upgraded with a Forward Wall (FW) scintillator hodoscope.

The FW is an array which consists of nearly 300 scintillating cells with each 2.54 cm thickness. During the $dp$ experiment it was located 7 meters downstream the target and covered polar angles from $0.33^\circ$ up to $7.17^\circ$. Our Monte Carlo studies show that about 90% of all spectator protons in the reaction under consideration are inside the FW acceptance.

Our main experimental trigger used during the $dp$ experiment was configured in such a way that the dielectron pair was detected in coincidence with a charged particle in the FW. Time of flight and coordinate measurements with the FW detector allowed us to reject spurious
signals (e.g. coming from photons or $e^+/e^-$) and to suppress contributions of quasi-free $pp$ scattering by selecting particles having kinematical properties of the spectator.

Fig. 2 (full circles) present the polar angle distributions in the laboratory frame of charged particles in coincidence with $e^+e^-$-pair production and detected in the FW. Two regions of pair invariant mass are examined separately: $M < 140$ MeV/$c^2$ (left) and $M > 140$ MeV/$c^2$ (right). As one can see, the angular distributions are peaked at very small angles and rapidly drops with growing angle. Such a form of distribution is in qualitative agreement with IA picture previously outlined. Moreover, the distributions associated with two different mass components of dielectron spectra are essentially the same. This observation serves as a basic test of the IA applicability for a treatment of $dp$ reaction in our conditions. The open squares on Fig. 2 demonstrate predictions of the Monte Carlo event generator Pluto [11] which relies on the IA for the simulation of the $dp$ reaction. A detailed description of the Pluto simulations for $pp$ and $dp$ reactions will be given in a forthcoming publication. The results of simulations were scaled to the same integral values as experimental data. As follows from Fig. 2 the Pluto simulations describe the polar angle distribution shapes in both mass regions very well.

Figure 2: Angular distribution of particles in the FW hodoscope, in coincidence with an $e^+e^-$-pair. Left: for invariant mass $M < 140$ MeV/$c^2$, right: $M > 140$ MeV/$c^2$. The full circles represent experimental data, whereas the open squares show predictions of a Pluto simulation.

The invariant mass distribution of $e^+e^-$-pairs collected in the $dp$ experiment with a selection on the quasi-free $np$ component is presented in Fig. 3 (full circles). Apparently there is a drastic difference between $pp$ and $np$ spectra measured with HADES. The pair invariant mass spectra in $np$ spans almost to 700 MeV/$c^2$ and has an enriched pair yield in the region of invariant masses $M > 140$ MeV/$c^2$ as compared to the $pp$ data. Because of Fermi motion inside deuteron, the energy accessible in quasi-free $np$ reactions is larger in comparison with $pp$ collisions. Thus part of the observed difference in pair yield above $\pi^0$ Dalitz region is likely to be caused by subthreshold processes (production of $\eta$ meson and, possibly, baryonic resonances above $\Delta$). The ongoing analysis and comparison with simulation is aimed to separate effects connected with Fermi motion from pure isospin origin.

Besides providing experimental trigger conditions on quasi-free $np$ interactions, the FW allows to perform more detailed investigation of this particular reaction by studying characteristics of pair production as a functions of FW observables (angular/momentum measurements,
multiplicity, etc). One of such applications is to study the dependence of the invariant mass spectrum as a function of the polar angle of the detected spectator proton.

Indeed, at rather large polar angle values (but still in FW acceptance) one can speculate that a number of effects (e.g. final state interaction, violation of IA) can occur and affect the observed dielectron invariant mass distribution. A prompt method to investigate/reject effects of such a kind is to restrict measurements to very small values of spectator polar angle, where it has very small values of transverse momentum, thus ensuring a safe regime of spectator tagging.

The open triangles on the Fig. 3 represent the $e^+e^-$-pair invariant mass distribution associated with spectator protons detected in polar angle less than $1^\circ$. This spectrum was normalized to the same $\pi^0$ yield as in the total spectrum (full circles) in order to facilitate the comparison of the shape of the massive components of both spectra. It is clearly seen that in the region $M > 140 \text{ MeV}/c^2$ the two spectra completely overlap, meaning that the observed intense emission of massive dielectrons does not correlate with the polar angle of spectator proton. Studies of such kind allow to put stricter constraints on theoretical predictions for pair production in $np$ collisions.

![Figure 3: Dielectron invariant mass distribution measured in the quasi-free $np$ reaction at 1.25 GeV. The full circles corresponds to spectator tagging within full FW acceptance, whereas the open triangles are obtained with a selection on a more restricted polar angle range of $\theta_{FW} < 1^\circ$.](image)

3 Summary

In summary, we presented preliminary results on inclusive $e^+e^-$-pair production studied in $pp$ and $dp$ collisions at beam energies of 1.25 GeV per projectile nucleon with the HADES spectrometer. In order to investigate the quasi-free $np$ scattering, the HADES setup was equipped with a Forward Wall hodoscope, which provided the possibility to detect spectator protons at small polar angles. Spectra measured in quasi-free $np$ collisions demonstrate a
strong enhancement of the pair yield above 140 MeV/c² as compared to the pp case. Undoubtedly, the investigation of electron-positron pair production in elementary collisions is a significant step in revealing the nature of excess observed in nucleus-nucleus collisions. More detailed information will be obtained through a comparison of measured spectra with theoretical predictions.

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References

[1] G. Agakichiev et al. [HADES Collaboration], Phys. Rev. Lett. 98 (2007) 052302.
[2] G. Agakishiev et al. [HADES Collaboration], Phys. Lett. B 663 (2008) 43.
[3] R. J. Porter et al. [DLS Collaboration], Phys. Rev. Lett. 79 (1997) 1229.
[4] L. P. Kaptari and B. Kampfer, Nucl. Phys. A 764 (2006) 338.
[5] M. Schäfer, T. S. Biro, W. Cassing and U. Mosel, Phys. Lett. B 221 (1989) 1.
[6] R. Shyam and U. Mosel, Phys. Rev. C 67 (2003) 065202.
[7] R. Shyam and U. Mosel, arXiv:0811.0739 [hep-ph].
[8] E. L. Bratkovskaya and W. Cassing, Nucl. Phys. A 807 (2008) 214.
[9] T. Galatyuk, proceedings of the Meson 2008.
[10] G. F. Chew and G. C. Wick, Phys. Rev. 85 (1952) 636.
[11] I. Fröhlich et al. [HADES Collaboration], arXiv:0708.2382 [nucl-ex].