Probing cold nuclear matter with virtual photons

Michael Weber[1,a,b] and Manuel Lorenz[c] for the HADES Collaboration
[a]*Physik Department E12, Technische Universität München, 85748 Garching, Germany*
[b]*now at University of Houston, Houston, TX, USA*
[c]*Institut für Kernphysik, Goethe-Universität, 60438 Frankfurt, Germany*

We report data on e^+e^- pair emission in p + Nb collisions at energies above the light vector meson production threshold. Invariant mass distributions for the proton beam energy of $E_{kin} = 3.5$ GeV are compared to data from elementary p+p reactions at the same beam energy. The collected statistics and high acceptance for pair momenta from ≈ 50-2000 MeV/c allow for a comparison of fast and slow ω mesons. According to hadronic models, the latter ones should show the strongest modification in the line shape due to the nuclear medium.

1 Introduction

The study of hadron properties inside a strongly interacting medium has attracted plenty of attention both in theoretical and experimental nuclear physics. On the theory side, hadronic models predict already at twice nuclear ground state density strong modifications in the spectral function of the light vector mesons ρ and ω, which are most pronounced at low momenta relative to the surrounding medium [1].
Experimentally, such effects can be tested in proton -, pion - or photon - induced reactions on heavy nuclei. While the modifications are expected to be stronger in heavy ion collisions, cold nuclear matter experiments have the advantage of relative controlled conditions, since the system does not undergo a density evolution during the reaction. We want to put our focus on these reactions. e^+e^- pair spectroscopy is a promising probe for such studies due to the fact that electrons and positrons interact only electromagnetically and their kinematics stays almost undistorted while propagating through the ambient nuclear matter. One has two different observables at hand: the spectral shape in the e^+e^- invariant mass and/or the total yield for different nuclei. A sensible measurement of the shape requires the decay taking place inside the nucleus, which can be studied by requiring low vector meson momenta, in particular for ω and ϕ. The measurement of the yield or production cross section can be connected to the total width of the hadron via double transparency ratios [2,3].
So far, shape measurements in elementary reactions were done for the ρ meson by the

[1]michael.weber@ph.tum.de

CLAS experiment at JLab [4] and the E325 experiment at KEK [5]. However, the results are not conclusive so far. For the ω and ϕ meson several experiments [6–9] reported a sizable broadening of the total decay width inside the medium using double transparency ratios. To contribute to this still unresolved issue the HADES collaboration measured the inclusive e^+e^- pair production in proton induced reactions at $E_{kin} = 3.5$ GeV. The reference spectrum was obtained in p + p reactions and the in-medium effects were extracted from reactions utilizing the heavy nucleus Nb.

2 Experimental setup and measured e^+e^- spectra

The High Acceptance Di-Electron Spectrometer (HADES [10]) is installed at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt and is provided with a proton or heavy-ion beam by the synchrotron SIS18. For the $e^{\pm}$ identification a hadron blind Ring Imaging CHerenkov detector (RICH) is used. Particle identification is supplemented by a time-of-flight measurement in a plastic scintillator wall (ToF) and an electromagnetic shower pattern in the Pre-Shower detector. Additional particle identification power can be gained by the inclusion of the energy loss information of the drift chambers and the scintillator wall.
A proton beam with a kinetic energy of $E_{kin} = 3.5$ GeV was incident on a liquid hydrogen target for the p + p run in 2007 [11] and on a 12-fold Nb target for the p + Nb run in 2008. The event selection was done in two steps. In the first trigger stage (LVL1), events with a charged particle multiplicity in the ToF wall of $M_{ch} \geqslant 3$ were selected. The second trigger stage (LVL2) selected events with at least one lepton candidate indicated by a ring in the RICH detector.

For the offline identification of electrons two independent methods were used. A multivariate analysis based on a neural network algorithm, where all relevant cut criteria are fed into the algorithm delivering a single scalar response value. Secondly, a standard method was used, where the cuts are applied directly on the relevant criteria (hardcuts). For the final spectra the average between the two methods was calculated. The difference between the two methods as well as the differences due to systematic variation of the cuts and self-consistency checks were taken as an estimate of the systematic errors.

All possible combinations of identified $e^{+/-}$ tracks were formed event by event and corrected for detector and reconstruction efficiencies. The latter ones were deduced using Monte-Carlo simulations embedded into real events. Invariant mass spectra of the unlike-sign pairs were then constructed from single $e^{+/-}$ tracks. To increase the purity of the $e^{+/-}$ sample a cut on the single track momentum $0.08 < p_e/(\mathrm{GeV}/c) < 2.00$ was applied. The combinatorial background (CB) was extracted from all like-sign pair combinations inside the same event. Since the CB stems predominantly from external γ-conversion it was reduced by cutting on the pair opening angle ($\alpha_{ee} > 9°$) and on the track fitting quality. By subtracting the CB from the unlike-sign pairs the signal spectrum was obtained.

The measured invariant mass distributions of e^+e^- pairs for p+Nb and p+p reactions, together with a cocktail of several e^+e^- pair sources for the elementary case [11], are shown in the left panel of Fig. 1. Differential cross sections were obtained by normalizingg to elastic collisions for p+p reactions and negative pion production in p+Nb reactions. While the shape of the distributions shows no obvious differences, already in p+p collisions the cocktail fails to describe the data in the intermediate mass region.

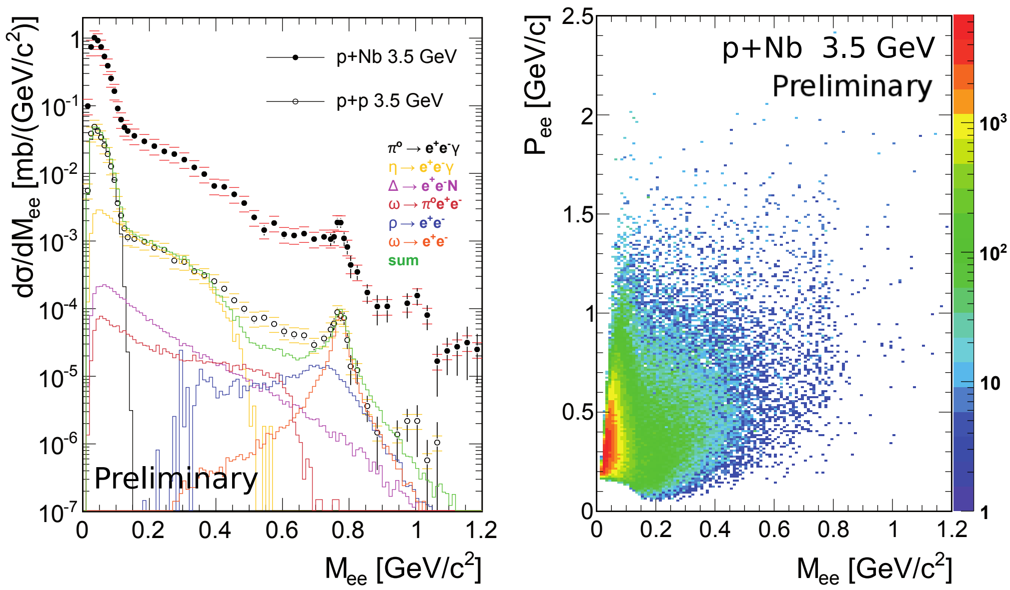

Figure 1: Invariant mass spectra (left) and the momentum dependence (right).

3 Low momentum pairs

The big advantage of the HADES setup compared to previous measurements of dielectrons from cold nuclear matter is the good coverage for low momentum pairs, as depicted in the right panel of Fig. 1. The collected statistics allows to compare a high and low momentum sample for different invariant mass regions as well as for identified ω mesons to the elementary pp data. While it is expected to see hardly any differences in the high momentum sample the low momentum pair should show effects related to the surrounding medium.

It should be stated here that these effects, if any, are not necessarily related to modification of the spectral function since also the production via secondary reactions might play an important role. These reactions then take place at lower average $\sqrt{s}$ and might run into the region were isospin effects become important [12].

4 Summary

We have measured inclusive e^+e^- pair production in p+p and p+Nb collisions at E_{kin} = 3.5 GeV. Already in p+p a e^+e^- cocktail based on model predictions fails to describe the data satisfactorily in the intermediate invariant mass region. Also the ω meson line shapes of the two spectra show no strong deviations. Further hints for in-medium changes of vector mesons in matter might be gained by a separate comparison of fast and slow pairs, which will be published soon in a forthcoming paper.

Acknowledgments

The collaboration acknowledges support by BMBF through grants 06DR9059D, 06FY9100I, 06MT9156 TP5 (Germany), by GSI (TKrue1012, TMFABI 1012, F&E), by the Helmholtz Alliance HA216/EMMI, by HIC for FAIR (LOEWE), by the DFG Excellence Cluster 153 "Universe" (Germany), by the Helmholtz young researcher group VH-NG-330, by MLL München, by grants MSMT LC07050, GAASCR IAA100480803 (Czech Republic), NN202 286038, NN202198639 (Poland), PTDC/FIS/113339/2009 (Portugal), CPAN:CSD2007-00042 (Spain), by CNRS/IN2P3 (France) and by INFN (Italy).

References

[1] M. Post, S. Leupold and U. Mosel, Nucl. Phys. **A 741** 81-148 (2004).

[2] M. Kaskulov, E. Hernandez and E. Oset, Eur. Phys. J. **A 31**, 245 (2007).

[3] P. Mühlich and U. Mosel, Nucl. Phys. **A 773**, 156 (2006).

[4] R. Nasseripour et al. (CLAS Collaboration), Phys. Rev. Lett. **99**, 262302 (2007).

[5] M. Naruki et al., Phys. Rev. Lett. **96**, 092301 (2006).

[6] M. Kotulla et al., Phys. Rev. Lett. **100**, 192302 (2008).

[7] T. Ishikawa et al. (SPring-8 Collaboration), Phys. Lett. **B 608**, 215-222 (2005).

[8] A. Polyanskiy et al. (ANKE Collaboration), Phys. Lett. **B 695**, 74 (2011).

[9] M. H. Wood et al. (CLAS Collaboration), Phys. Rev. Lett **105**, 112301 (2010).

[10] G. Agakishiev et al. (HADES Collaboration), Eur. Phys. J. **A 41**, 243 (2009).

[11] A. Rustamov et al. (HADES Collaboration), AIP Conf. Proc. **1257**, 736 (2010).

[12] W. K. Wilson et al. (DLS Collaboration), Phys. Rev. C **57**, 1865 (1998).