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Inclusive e^+e^- pair production in cold nuclear matter

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We report recent data on e^+e^- pair emission in proton nucleus (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. We observe a constant π^0/ω yield ratio for both systems but an excess in the invariant mass region $150\ MeV/c^2 < M_{ee} < 550\ MeV/c^2$. The excess dependence is investigated on rapidity and transverse momentum.

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1. Introduction

For a better understanding of strongly interacting matter the systematic exploration of the QCD phase diagram at different temperatures and baryochemical potentials is essential. In this context, following questions are emerging: What are degrees of freedom - hadrons or quarks and gluons? Of which order are phase transitions and where are critical points located, if existing? What are the order parameters of the phases - quark and gluon condensates - and how do they change at the phase boundaries?
Since there is no direct access to these questions, indirect methods like the spectroscopy of hadrons embedded in a strongly interacting medium can give insights into the properties of QCD matter. The QCD sum rules [1, 2] connect the integrated spectral functions of hadrons to the QCD condensates which are expected to change from the chirally broken phase (in vacuum) to a chirally restored phase (in dense and hot matter). Experimentally this extreme form of matter at high temperatures and/or densities can be formed in relativistic heavy-ion collisions. However, in these reactions always the whole collision history is probed. A much cleaner environment can be found in nuclear matter at ground state density and zero temperature. Neglecting surface effects it can be studied experimentally in heavy nuclei ($A \gtrsim 100$).
The spectral shapes for hadrons produced in p+A or γ+A reactions can be calculated using hadronic degrees of freedom. Most hadronic many-body theories [3, 4, 5] predict a sizable collisional broadening, a small pole mass shift and the emergence of new structures in the spectral functions of vector mesons. Not only the spectral form can change inside a medium, but also the total yield. Regeneration via secondary reactions in the interior of the nucleus increase the total amplitude of spectral functions. Absorption of hadrons on nucleons and the opening of decay channels, which are possible only inside the nucleus, increase the total width of hadrons and therefore attenuate their yield.

Dileptons from direct decays of low-mass vector mesons allow the undistorted measurement of in-medium hadronic spectral shapes [6]. To ensure the decay taking place inside the nucleus it is essential to investigate short-lived mesons like the ρ meson or longer lived mesons at small momenta. There are no conclusive results about the ρ meson's in-medium properties up to now. The CLAS experiment at JLab [7] claims no shift in the pole mass but some broadening. On the other hand, the E325 experiment at KEK [8] reports no broadening and a mass shift of 9%. For the ω meson, the CBELSA/TAPS collaboration [9] has deduced a sizable broadening inside the medium ($\Gamma_\omega(\rho_0)/\Gamma_\omega \sim 16$) in γ-induced reactions on nuclei by means of the transparency ratio [10, 11]. Utilizing the same method also the ϕ meson was studied by different experiments [12, 13] yielding in different in-medium widths.
In the following we present preliminary results for the analysis of e^+e^- pair production in the p+Nb reaction utilizing the HADES setup at the Helmholtzzentrum für Schwerionenforschung (GSI) in Darmstadt, Germany.

2. The HADES experiment

The High Acceptance Di-Electron Spectrometer HADES consists of an e^+e^- pair spectrometer with ∼40 % geometrical acceptance for light and heavy ion induced reactions on fixed nuclear targets. A detailed description of the spectrometer can be found in Ref. [14]. For the $e^\pm$ identification a hadron blind Ring Imaging CHerenkov detector (RICH) was used. Particle identification was supplemented by time-of-flight measurement in a plastic scintillator wall (ToF) and an electromagnetic shower pattern in the Pre-Shower detector.

In our experiment a proton beam of 2×10^6 particles/s with a kinetic energy of $E_{kin} = 3.5\ GeV$ was incident on a 12-fold Nb target, giving a total interaction probability of 3 %. 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 $M_{ch} \geq 3$ were selected. The second trigger stage (LVL2) selected events with at least one lepton candidate indicated by a ring in the RICH detector.

All possible combinations of identified e^+/e^- tracks have been formed event-by-event and corrected for detector and reconstruction efficiencies. The latter ones were deduced using tracks from Monte-Carlo simulations embedded into real events. Invariant mass spectra of the unlike-sign pairs were constructed from single e^+/e^- tracks. To increase the purity of the e^+/e^- sample a cut on the single track momentum, $0.08 < p_e/(GeV/c) < 2.00$, 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 could be reduced by cutting on the pair opening angle $\alpha_{ee} > 9^\circ$ and on the track fitting quality. By subtracting the CB from the unlike-sign pairs the signal spectrum was obtained.

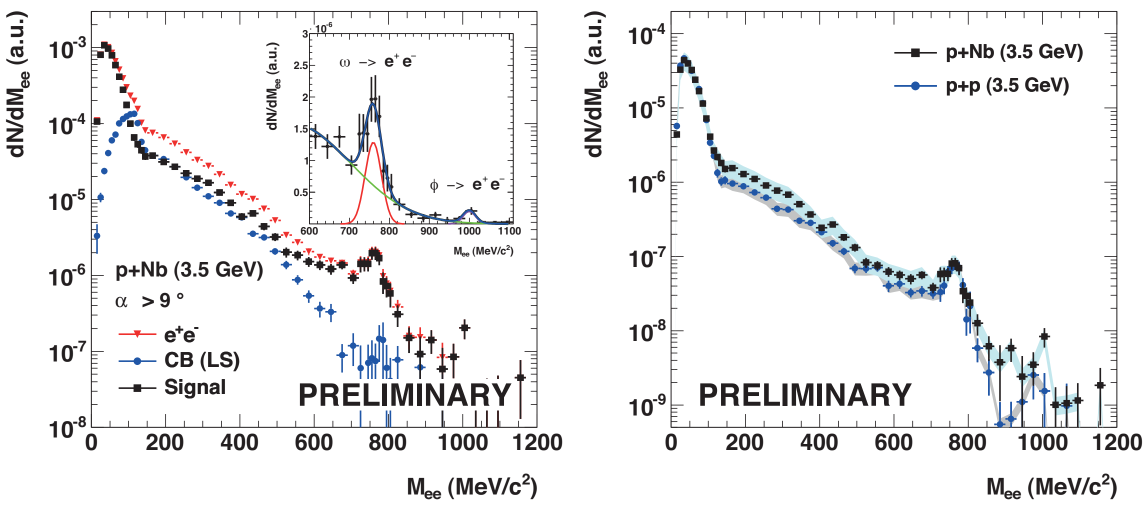

Figure 1: Left: Efficiency corrected invariant mass spectrum of all e^+e^- pairs (red triangles), the combinatorial background (blue dots) and the signal pairs (red squares) for p+Nb collisions at $E_{kin} = 3.5\ GeV$. The inset shows the ω and ϕ region. Right: Efficiency corrected signal spectra for p+p (blue dots) and p+Nb (black squares) collisions. They are normalized to their yield $N_{\pi-yield}$ in the π^0 mass region ($50\ MeV/c^2 < M_{ee} < 120\ MeV/c^2$). The systematic uncertainties are shown by the error bands.

3. Results

The measured invariant mass distributions of e^+e^- pairs are shown in the left panel of Fig. 1. The data points are normalized to the number of recorded LVL1 events. The signal to background ratio is $S/B \simeq 1$ at $M_{ee} \simeq 200\ MeV/c^2$ and increases up to $S/B \geq 10$ at $M_{ee} \simeq 750\ MeV/c^2$.
The low-mass part of the spectrum is dominated by π^0 Dalitz decays ($M_{ee} < 150\ MeV/c^2$), while the intermediate part ($150\ MeV/c^2 < M_{ee} < 550\ MeV/c^2$) can be attributed to $\Delta(1232)$ and η Dalitz decays [15]. The high mass part of the distribution is dominated by the direct decay of the light vector mesons ρ, ω and ϕ. The peak around 780 MeV/c^2 corresponds to the decay of $\omega \rightarrow e^+e^-$ and the peak around 1000 MeV/c^2 corresponds to the decay of $\phi \rightarrow e^+e^-$. A mass resolution of $\frac{\Delta M}{M} \sim 2\%$ is extracted from a fit with a Gaussian distribution (see inset in Fig. 1).
A reference spectrum was obtained in an earlier p+p run at the same beam energy [15]. All e^+/e^- sources could be determined in this collision system by comparing to a hadronic cocktail simulation. In the latter, pions were produced via resonance decays of Δ and N^* resonances, η, ω and ρ in phase space production and Δ through one-π exchange. As input parameters, form factors and mass dependent widths were used for the particle decays. The inclusive cross sections for all sources were deduced from a fit to the invariant mass distributions.
In the right panel of Fig. 1 the invariant mass distribution of the signal in p + Nb collisions is compared to the reference spectrum. In the ω/ρ region the yield is comparable for both reaction systems when normalized to the same π^0 yield. This suggests a similar vector meson production rate in p+Nb reactions as for pions.

The yield in the intermediate mass region ($150\ MeV/c^2 < M_{ee} < 550\ MeV/c^2$) is enhanced by about 50%. To further investigate this enhancement different kinematic observables were studied. In the left panel of Fig. 2 the transverse momentum distributions of e^+e^- pairs in this mass region

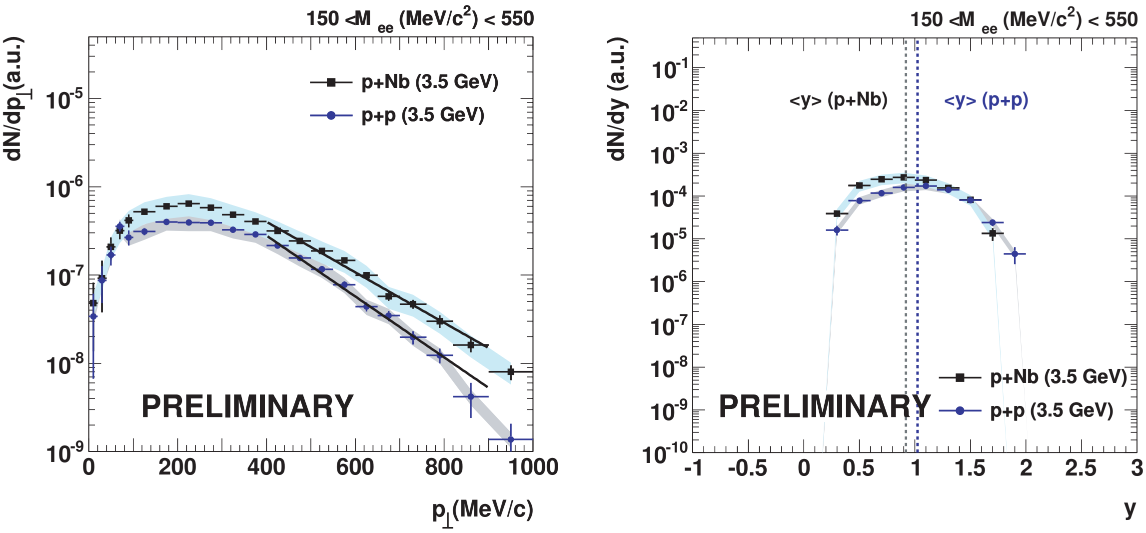

Figure 2: Left: Distributions of transverse momenta (left) and rapidities (right) for p+p (blue dots) and p+Nb (black squares) collisions in the intermediate mass region ($120\ MeV/c^2 < M_{ee} < 550\ MeV/c^2$). The systematic uncertainties are shown by the error bands.

are compared. A fit using

$$dN/dp_\perp \sim e^{-p_\perp/s} \tag{3.1}$$

in the interval 400 $MeV/c < p_\perp <$ 900 MeV yields a smaller inverse slope parameter s for p + p collisions ($s = 126.0 \pm 4.5$) as for p + Nb ($s = 151.8 \pm 5.3$). In the right panel of Fig. 2 the rapidity distributions of this mass interval are shown. The mean value of the rapidity distribution in p + Nb reactions is lower than in the reference spectrum. This hints at an additional slow source with hard $p_\perp$ distribution, like Δ or ηwhich are produced in secondary reactions of pions stemming from primary collisions on the nuclear surface.
The fraction of in-medium decays can be enriched for the longer-lived ω meson via a selection of slow particles. A cut on the laboratory 3-momenta of the e^+e^- pairs at $p_{ee} = 800$ MeV/c would increase the fraction of decays inside the nuclear volume to about 40 %. A further quantitative analysis of the momentum dependence and the comparison to transport model calculations is still ongoing and will be discussed in a forthcoming paper.

4. Summary

We have measured inclusive e^+e^- pair production in p+Nb collisions at $E_{kin} = 3.5$ GeV. The invariant mass distribution shows a clear ω peak with a mass resolution of 2% and an excellent signal to background ratio $S/B \geq 10$ on top of a possible ρ contribution. A comparison to p+p collisions at the same beam energy shows no missing strength in the ω pole mass region, whereas in the intermediate mass region (200 $MeV/c^2 < M_{ee} <$ 600 MeV/c^2) an excess over the elementary p+p processes is obtained, when normalized to the same pion yield. This excess is has a mean rapidity value which is closer to target rapidity as compared to the elementary processes. This hints at an additional slow source produced in secondary reactions inside the nucleus. Final conclusions about production mechanisms of e^+e^- pairs and possible in-medium changes of vector mesons in matter require the determination of cross sections and a comparison to transport models. Work along this line is in progress.

Acknowledgments

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References

[1] M.A. Shifman, A.I. Vainshtein and V.I. Zakharov, Nucl. Phys. **B 147**, 385 (1979).

[2] T. Hatsuda and S.H. Lee, Phys. Rev. **C 46**, 34 (1992).

[3] M.F.M. Lutz, G. Wolf and B. Friman, Nucl. Phys. **A 706**, 431 (2002).

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

[5] P. Mühlich et al., Nucl. Phys. **A 780**, 187 (2006).

[6] R. Rapp et al., Lect. Notes Phys. **814**, 335 (2011).

[7] R. Nasseripour et al., Phys. Rev. Lett. **99**, 272302 (2007).

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

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

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

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

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

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

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

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