Probing dense nuclear matter with electromagnetic and rare hadronic probes

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Probing dense nuclear matter with electromagnetic and rare hadronic probes

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Abstract. We present preliminary results on strangeness and dilepton production in Ar+KCl reactions at 1.76 AGeV. For the first time an $\omega$ signal could be extracted in heavy-ion collisions in this energy region. Furthermore we find a strong enhancement of yield in the low invariant lepton pair mass region over an elementary reference suggesting the onset of non trivial effects of the medium. This hint is supported by a nearly complete vanishing of the OZI suppression of the $\phi$ to $\omega$ ratio which is characteristic for elementary reactions.

1. Introduction

Heavy-ion collisions provide a unique tool to study strongly interacting matter under extreme conditions. While at SPS, RHIC and LHC energies it is common believe that a phase transition between hadronic and partonic degrees of freedom occurs, in the SIS/Bevalac energy regime, a partial restoration of the broken chiral symmetry is expected. The spontaneous and explicit breaking of chiral symmetry are usually related to the light quark and hadron masses. Therefore a (partial) restoration of this symmetry might result in a modification of hadron masses. Moreover, also the hadronic phase of the system differs in its characteristics compared to higher energies, where the produced pions outnumber the existing baryons resulting in a low baryochemical potential $\mu_B$, whereas at SIS/Bevalac energies the pions are hidden in excited baryon states ($\Delta, N^*$) which act as energy accumulators. At a late stage of the reaction these resonances decay and release the pions.

Promising probes for such a strongly interacting system are particles containing newly produced strange quarks due to their steep excitation function, which makes them sensitive to the achieved compression and temperature, as well as dileptons as they do not suffer the strong interaction and therefore deliver undistorted information over the whole time evolution of the collision.

2. Overview of results

Following the pioneering experiments at the Bevalac [1] the production and propagation of strangeness has been investigated by the KaoS, FOPI and by the HADES collaborations. The results of the KaoS collaboration give evidence for a soft equation of state [2], a repulsive K-N potential and the importance of strangeness exchange reactions for subthreshold strangeness production [3]. FOPI data gave a first hint on a large $\phi$ contribution to subthreshold $K^-$ production [4], which was quantified recently by HADES [5].
Both FOPI and HADES data confirm the evidence for a repulsive K-N potential [6, 7] and give evidence for the production of strange resonances [8, 9], as well as multistrange particles [10] already at such low energies.

Besides the unsettled production mechanism of multistrange particles, like the $\Xi^-$, the shape of the $K^-$ spectra is not fully understood. The inverse slope parameter obtained from fits to transverse mass spectra are systematically (10 - 20 MeV) lower compared to the ones from $K^+$. Previous transport model calculations were able to reproduce the slope by introducing a strongly attractive $K^-$-N potential resulting in dominant feeding of the $K^-$ abundance from strangeness exchange reaction like $\pi^0 + \Lambda \rightarrow K^- + p^1$ and consequently resulting in a later emission and freeze-out time for $K^-$ compared to $K^+$ [11]. But in [12] it was shown that the differences in the slope can be explained, within errors, by the superposition of the $K^-$ that are coming from $\phi$ decays and a thermal source of $K^-$ with the same initial slope as the measured one of the $K^+$. As input for the simulation the measured $\phi/K^-$ ratio of $0.37 \pm 0.13$ and inverse slopes of the charged kaons and the $\phi$ meson in the system Ar+KCl at 1.76 AGeV measured with HADES are used [5].

The emission of dileptons has been investigated by the DLS collaboration at the Bevalac [13]. DLS observed a large enhancement over a ”hadronic cocktail” (provided by $e^+e^-$ decay products of long living mesons $\pi^0, \eta, \omega$), in the invariant mass region of $0.15 < M_{ee} < 0.55$ GeV/$c^2$ of $e^+e^-$ pairs in the C+C system and the Ca+Ca system. Transport models were unable to explain this excess for a decade and this situation became known as the ”DLS puzzle”. The situation changed when HADES confirmed the DLS C+C data at 1 AGeV in 2008 [14]. Since then, various theoretical attempts have been proposed to explain the data, but lacking a final conclusion on the origin of the excess. In 2009, HADES data on proton on proton and on proton on quasifree neutron at 1.25 GeV showed that the excess is already present in elementary reactions [15]. Hence the so-called ”DLS-puzzle”, i.e. the unexplained enhancement in the low invariant mass region of $e^+e^-$ pairs in the system C+C, results from an insufficient treatment of radiation from elementary N+N collisions. After first hints to a surprisingly strong pn channel in [16, 17], recent calculations have improved in reproducing these elementary channels but are still missing some yield in the pn channel [18].

In this contribution, we present preliminary results on dilepton production in Ar+KCl collisions at 1.76 AGeV, suggesting an additional excess over the elementary reference. The data set also allows, for the first time at this energy, for a determination of the $\omega$ multiplicity, which is at the moment still preliminary and in the process of being finalized.

3. Data analysis
The event selection was started with a first level trigger requiring a multiplicity $> 16$ in the Time-of-Flight wall, selecting the 35% most central events. It was followed by a second level trigger which selected at least one lepton candidate. Details on the apparatus, the lepton identification and of the experiment can be found in [5, 19].

For minimization of systematic errors, the lepton identification is performed using three independent methods. The dominant background source from $\gamma$ conversion is suppressed using a cut on the lepton pair opening angle $\alpha_{ee} > 9^\circ$. The remaining background is modeled using same-event like-sign pairs in the invariant mass region $M_{ee} < 0.4$ GeV to handle the correlated background resulting from $\pi^0 \rightarrow \gamma\gamma$ decays followed by double conversion. In the higher invariant mass region mixed event pairs normalized to the like-sign background is used in order to reduce statistical fluctuations. The spectrum is normalized to the $\pi^0$ multiplicity estimated using the measured charged pions [20].

1 Note that this reaction is endothermal in vacuum.
4. Low mass dilepton enhancement and up-lifted OZI suppression

As already mentioned, the yield in the low invariant mass region of $e^+e^-$ pairs in the C+C system at 1 AGeV can be explained by a superposition of p+p and p+n data at 1.25 GeV. In order to learn more about the origin of the hadronic contribution and possible medium effects, we investigate how the situation changes as a function of energy and system size. Let us start by comparing the elementary reference to our C+C data set at 2 AGeV. First, we subtract the $\eta$ contribution normalized to the neutral pion multiplicity using TAPS measurements [21]. As one sees in the left side of Fig. 1, where the C+C data at 2 AGeV is divided by the elementary reference provided by $[(p+p)+(p+n)]/2$ at 1.25 GeV (both scaled to the multiplicities of neutral pions), also these data are well described by the reference since the energy dependence is taken out in first order by the normalization to neutral pions. We conclude that the origin of the additional yield scales with energy like the pion production.

If we compare the elementary reference to the Ar+KCl data set at 1.76 AGeV \(^2\) we find an additional excess factor of roughly three. This excess might be interpreted as the onset of non-trivial medium effects.

![Figure 1](image_url)

**Figure 1.** Left: Ratio of dielectron multiplicities in heavy-ion collisions (C+C at 1AGeV: circles, C+C at 2 AGeV: bullets, Ar+KCl at 1.76 AGeV: squares) to dielectron multiplicity in nucleon-nucleon collisions as a function of invariant mass. The $\eta$ contribution in heavy-ion data was subtracted using TAPS data [21]. Right: $\phi$ to $\omega$ ratio as a function of the $\phi$ excess energy for p+p (red triangles), $\pi$+N (magenta stars) and Ar+KCl (green square) data, as well as for a statistical model fit to the system Ar+KCl (blue circle) [26].

To reinforce this statement we look at the $\phi/\omega$ ratio using a preliminary value of the $\omega$ multiplicity and the $\phi$ meson yield from the channel $\phi \rightarrow K^+K^-$ [5]. The $\phi$ meson production cross section in elementary reactions is strongly suppressed due to the Okubo-Zweig-Iizuka (OZI) rule [22, 23, 24] and, according to SU(3) flavor symmetry can proceed only because of a non ideal singlet and octet mixing in the $\phi$ wave and is commonly normalized to the cross section of

\(^2\) The $\eta$ contribution was averaged from TAPS measurements at 1.5 and 2.0 AGeV in the same system [21].
simultaneously measured $\omega$ mesons given as the ratio:

$$R(\phi/\omega) = \frac{d\sigma(A + B \rightarrow \phi X)}{d\sigma(A + B \rightarrow \omega X)} = \tan^2(\delta \Theta_v)f = 4.2 \cdot 10^{-3}f,$$

(1)

where $f$ is the ratio of the available phase space. Historically such ratios have been discussed in terms of strangeness content of the nucleon. While already in elementary reactions a deviation from Eq. 1 was observed [25], our data suggest that in heavy-ion reactions close to threshold the suppression seems to be fully neutralized and is, within errors, in agreement with a statistical model calculation (Fig. 1, right panel). More details on the statistical model fit can be found in [26]. The measured $\phi/\omega$ ratio seems to be affected by the surrounding medium.

5. Summary and Outlook

We present preliminary results on dilepton production in Ar+KCl reactions at 1.76 AGeV. We find a strong enhancement in the low invariant lepton pair mass region over an elementary reference suggesting the onset of effects of the medium. This hint is supported by a nearly complete vanishing of the OZI suppression in the $\phi$ to $\omega$ ratio as well as the production of multiple strange objects like the $\Xi^-$ more than 600 MeV below their free NN threshold. To obtain further systematics of these effects it is planned to take data using medium and heavy sized ion collision systems (AgAg, AuAu) from late 2010 on with HADES.

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[1] S. Schnetzer et al., Phys. Rev. Lett. 49 (1982) 989; Phys. Rev. C. 40 (1989) 640.
[2] C. Sturm et al. (KaoS), Phys. Rev. Lett. 86 (2001) 39.
[3] A. Förster et al. (KaoS), Phys. Rev. C 75 (2007) 024906.
[4] A. Magnarotti et al. (FOPI), Nucl. Phys. A 714 (2003) 89.
[5] G. Agakishiev et al. (HADES), Phys. Rev. C 80 (2009) 025209.
[6] M. L. Bokbokva et al. et al. (FOPI), Phys. Rev. Lett. 102 (2009) 182501.
[7] G. Agakishiev et al. (HADES), arXiv:1004.3881 [nucl-ex].
[8] X. Lopez et al. (FOPI), Phys. Rev. C 76 (2007) 052203.
[9] X. Lopez et al. (FOPI), Phys. Rev. C 81, 061902 (2010).
[10] G. Agakishiev et al. (HADES), Phys. Rev. Lett. 103 132301 (2009).
[11] C. Hartnack, H. Oeschler and J. Aichelin, Phys. Rev. Lett. 90, 102302 (2003).
[12] M. Lorenz et al. (HADES), Proceedings 48th International Winter Meeting on Nuclear Physics, Bormio, Italy, 25-29 Jan 2010.
[13] R. J. Porter et al. (DLS), Phys. Rev. Lett. 79 (1997) 1229.
[14] G. Agakishiev et al. (HADES), Phys. Rev. Lett. 98, 052302 (2007).
[15] G. Agakishiev et al. (HADES), Phys. Rev. C 78 (2009) 025209.
[16] L. P. Kaptari and B. Kämpfer, Nucl. Phys. A 764, 338 (2006).
[17] L. P. Kaptari and B. Kämpfer, Nucl. Phys. A 800, 064003 (2009).
[18] R. Shyam and U. Mosel, arXiv:1006.3873 [hep-ph].
[19] G. Agakishiev et al. (HADES), Phys. Rev. C 81, 061902 (2010).
[20] P. Tlusty et al. (HADES), arXiv:0906.2309 [nucl-ex].
[21] R. Averbeck, R. Holzmann, V. Metag and R. S. Simon, Phys. Rev. C 67, 024903 (2003).
[22] S. Okubo, Phys. Lett. 5, 165 (1963).
[23] G. Zweig, “An SU(3) Model For Strong Interaction Symmetry And Its Breaking. 2”, Cern (1964).
[24] J. Iizuka, Prog. Theor. Phys. Suppl. 37, 21 (1966).
[25] A. Sibirtsev and W. Cassing, Eur. Phys. J. A 7, 407 (2000).
[26] G. Agakishiev et al., arXiv:1010.1675 [nucl-ex].