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Dielectron production in Ar+KCl collisions at $E_{kin} = 1.76$ AGeV

Martin JURKOVIČ[*†] **for the HADES collaboration**
Physik Department E12, Technische Universität München, 85748 München, Germany
E-mail: martin.jurkovic@ph.tum.de

G. Agakishiev[6], A. Balanda[3], D. Belver[15], A. Belyaev[6], A. Blanco[2], M. Böhmer[11], J. L. Boyard[13], P. Cabanelas[15], E. Castro[15], S. Chernenko[6], J. Díaz[16], A. Dybczak[3], E. Epple[11], L. Fabbietti[11], O. Fateev[6], P. Finocchiaro[1], P. Fonte[2,a], J. Friese[11], I. Fröhlich[7], T. Galatyuk[7], J. A. Garzón[15], A. Gil[16], M. Golubeva[10], D. González-Díaz[4], F. Guber[10], T. Hennino[13], R. Holzmann[4], P. Huck[11], A. Ierusalimov[6], I. Iori[9,c], A. Ivashkin[10], M. Jurkovic[11], B. Kämpfer[5,b], T. Karavicheva[10], I. Koenig[4], W. Koenig[4], B. W. Kolb[4], A. Kopp[8], G. Korcyl[3], GK Kornakov[15], R. Kotte[5], A. Kozuch[3,d], A. Krása[14], F. Krizek[14], R. Krücken[11], H Kuc[3], W. Kühn[8], A. Kugler[14], A. Kurepin[10], A. Kurilkin[6], P. Kurilkin[6], P.K. Kählitz[5], V. Ladygin[6], J. Lamas-Valverde[15], S. Lang[4], K. Lapidus[10], T. Liu[13], L. Lopes[2], M. Lorenz[7], L. Maier[11], A. Mangiarotti[2], J. Markert[7], V. Metag[8], B. Michalska[3], J. Michel[7], C. Müntz[7], L. Naumann[5], Y. C. Pachmayer[7], M. Palka[7], Y. Parpottas[12], V. Pechenov[4], O. Pechenova[7], J. Pietraszko[7], W. Przygoda[3], B. Ramstein[13], A. Reshetin[10], J. Roskoss[8], A. Rustamov[4], A. Sadovsky[10], P. Salabura[3], A. Schmah[11], J. Siebenson[11], Yu.G. Sobolev[14], S. Spataro[8,e], H. Ströbele[7], J. Stroth[7,4], C. Sturm[4], M. Sudol[13], A. Tarantola[7], K. Teilab[7], P. Tlusty[14], M. Traxler[4], R. Trebacz[3], H. Tsertos[12], T Vasiliev[6], V. Wagner[14], M. Weber[11], C. Wendisch[5], J. Wüstenfeld[5], S. Yurevich[4], Y. Zanevsky[6]

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(HADES collaboration)

[1]Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud, 95125 Catania, Italy
[2]LIP-Laboratório de Instrumentação e Física Experimental de Partículas , 3004-516 Coimbra, Portugal
[3]Smoluchowski Institute of Physics, Jagiellonian University of Cracow, 30-059 Kraków, Poland
[4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany
[5]Institut für Strahlenphysik, Forschungszentrum Dresden-Rossendorf, 01314 Dresden, Germany
[6]Joint Institute of Nuclear Research, 141980 Dubna, Russia
[7]Institut für Kernphysik, Goethe-Universität, 60438 Frankfurt, Germany
[8]II.Physikalisches Institut, Justus Liebig Universität Giessen, 35392 Giessen, Germany
[9]Istituto Nazionale di Fisica Nucleare, Sezione di Milano, 20133 Milano, Italy
[10]Institute for Nuclear Research, Russian Academy of Science, 117312 Moscow, Russia
[11]Physik Department E12, Technische Universität München, 85748 München, Germany
[12]Department of Physics, University of Cyprus, 1678 Nicosia, Cyprus
[13]Institut de Physique Nucléaire (UMR 8608), CNRS/IN2P3 - Université Paris Sud, F-91406 Orsay Cedex, France
[14]Nuclear Physics Institute, Academy of Sciences of Czech Republic, 25068 Rez, Czech Republic
[15]Departamento de Física de Partículas, Univ. de Santiago de Compostela, 15706 Santiago de Compostela, Spain
[16]Instituto de Física Corpuscular, Universidad de Valencia-CSIC, 46971 Valencia, Spain

[a] also at ISEC Coimbra, Coimbra, Portugal
[b] also at Technische Universität Dresden, 01062 Dresden, Germany
[c] also at Dipartimento di Fisica, Università di Milano, 20133 Milano, Italy
[d] also at Panstwowa Wyzsza Szkola Zawodowa , 33-300 Nowy Sacz, Poland
[e] also at Dipartimento di Fisica Generale, Universita' di Torino, 10125 Torino,, Italy

A detailed understanding of virtual photon emission from hadronic systems at moderate relativistic beam energies is one of the main objectives of the HADES experiment. In this contribution, results on the measurement of the inclusive e^+e^- pair production in Ar+KCl collisions at a beam kinetic energy $E_{\mathrm{kin}} = 1.76$ AGeV are presented. Distributions of e^+e^- pairs in the mass range $0.02 < M_{\mathrm{ee}}/(\mathrm{GeV/c^2}) < 0.9$ are discussed and confronted with transport model calculations.

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[*]Speaker.
[†]with R. Holzmann, F. Křížek and S. Lang

1. Introduction

The High Acceptance Di-Electron Spectrometer (HADES) [1], assembled at the Helmholtz-zentrum für Schwerionenforschung GmbH , was designed to investigate the emission of virtual photons via their decay into dielectrons (e^+e^- pairs) out of the hot and dense collision zone formed in heavy-ion reactions. Dielectrons are a promising probe to investigate both in-medium properties of hadrons and hadronic matter under extreme conditions. At moderate relativistic beam energies in the range of $E_{\text{kin}} = 1-2$ AGeV hadronic matter can be compressed to densities of up to 3 times the normal nuclear density and temperatures of up to $T = 100$ MeV. This extreme phase can last for $\tau \approx 10$ fm/c. In contrast to the high energy experiments at CERN-SPS and RHIC, the fireball formed at these low energies is dominated by nucleons and baryonic resonances; mesons play only a minor role. In this baryon-rich regime a dielectron signal above the "hadronic cocktail" for invariant e^+e^- masses, $M_{\text{ee}} > 0.15$ GeV/c^2, in C+C and Ca+Ca collisions at $E_{\text{kin}} = 1.04$ AGeV was reported by the DLS collaboration [2]. The observed signal strength below the ρ meson pole mass could not be described in a satisfactory way by theoretical model calculations for a long time.

The dielectron production in C+C collisions was recently reinvestigated by the HADES collaboration with higher statistics and better detector resolution at bombarding energies of $E_{\text{kin}} = 1$ and 2 AGeV [3, 4]. The investigation of the excitation function of the pair multiplicity above the π^0 mass shows a similar scaling with the beam energy as the pion production. This points to the $\Delta(1232)$ resonance as a possible source of the extra e^+e^- signal, since it has a significant Dalitz decay branch $\Delta \rightarrow Ne^+e^-$ and is known to be the dominant source of pions at these beam energies. In addition, bremsstrahlung - mainly from n+p collisions - is expected to contribute noticeably, as has been predicted by various models [5, 6, 7].

The interpretation of virtual photon emission in heavy-ion reactions at these energies requires both, a detailed study of their production in elementary p+p and n+p collisions (see [8]) and a variation of the system size at a given beam energy. In this contribution we present preliminary results obtained for a medium sized collision system with about 40 participants.

2. The HADES experiment

A description of the HADES spectrometer can be found in ref. [1]. For the e^+/e^- identification the main detector is the hadron blind Ring Imaging CHerenkov (RICH) detector. In addition, the algorithms for electron identification make use of the measured time of flight in the plastic scintillator Time-of-Flight (ToF) wall and of the registered electromagnetic shower pattern in the Pre-Shower detector to improve the purity of the e^+/e^- sample.

In the experiment a beam of ^{40}Ar ions with a kinetic energy of $E_{\text{kin}} = 1.76$ AGeV was focussed onto a 4-fold segmented KCl target with a total interaction length of 3.3%. The event selection was done online in two steps. In the first trigger stage (LVL1) events exceeding a charged particle multiplicity in the ToF wall of $M_{\text{ch}} > 16$ have been selected. In total $2.2 \cdot 10^9$ LVL1 events have been recorded. The second trigger stage (LVL2) selected events with at least one electron candidate identified by a ring in the RICH detector and matched to a hit in the TOF wall.

The LVL1 trigger condition selected semi-central events with twice the charged pion multiplicity as compared to minimum bias events. This corresponds to a mean number of participating nucleons of about 38.5 and an estimated average neutral pion multiplicity of 3.4 ± 0.4 [9].

The electron/positron identification was performed using three independent algorithms in parallel: (a) a Bayesian approach, (b) hard cuts and (c) a multivariate analysis [1]. For each of the algorithms identified electrons and positrons were combined into pairs. The like-sign pairs from the same event were used to model the combinatorial background (CB), which can be estimated as $CB = 2\sqrt{N_{++}N_{--}}$. It was used for pairs with $M_{\text{ee}} < 0.4$ GeV/c^2 to take into account the correlated background resulting from $\pi^0 \rightarrow \gamma\gamma$ decays followed by double γ conversion. For pairs with higher invariant masses the mixed event background normalised to the same event like-sign background was used to reduce statistical fluctuations in the same event background.

To enhance the signal over background ratio, further constraints were imposed on the pair properties. The dominant background source is γ conversion where photons originate mainly from π^0 decays. Conversion pairs have mostly small opening angles α_{ee} and dominate over the contribution from other e^+e^- sources with small α_{ee} by several orders of magnitude. They can be effectively rejected requiring $\alpha_{ee} > 9^{\text{o}}$ while the signal stays almost unaffected by this cut. Further tracking fakes were removed from the sample selecting uniquely defined tracks which were well reconstructed by the tracking algorithm. Finally a cut on the single e^+/e^- momentum, $0.1 < p_e/(GeV/c) < 1.1$, was applied to increase mainly the purity of the positron sample.

3. Results

The invariant mass distribution of the signal e^+e^- pairs corrected for the detector and reconstruction inefficiencies is shown in Fig. 1. It represents an average of the three independent analyses mentioned above. Systematic errors are given by the horizontal red bars. They consist of the correction on reconstruction efficiency and combinatorial background estimation (20%), of the uncertainty in estimating the π^0 multiplicity (11%) and of the differences in the three analysis

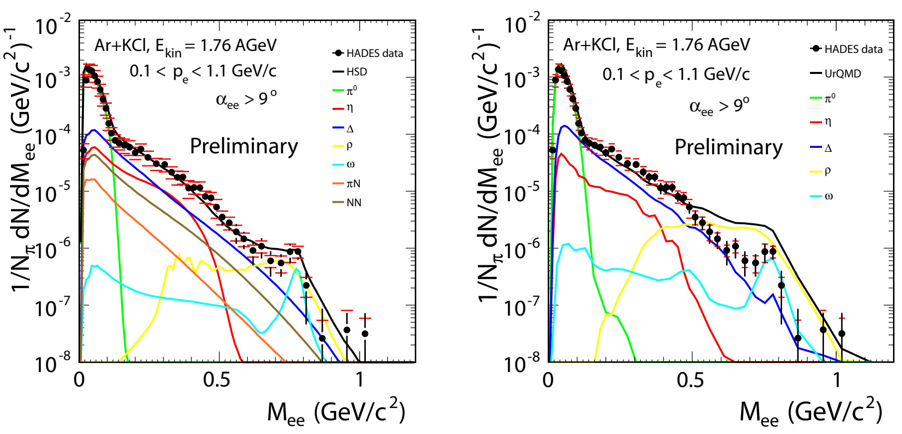

Figure 1: (Color online) Invariant mass distribution of reconstructed e^+e^- pairs compared to the predictions of HSD [10] (left) and UrQMD [11] (right) transport calculations. Statistical and systematical errors of the measurement (symbols) are shown as vertical and horizontal bars, respectively.

methods (typically $10-20\%$). The distribution is presented in the HADES acceptance [1] and normalised to the neutral pion multiplicity assuming $N_{\pi^0} \approx N_\pi = (N_{\pi^+} + N_{\pi^-})/2$, where the charged pion multiplicity was measured in the same experiment [9]. In the nearly isospin-symmetric collision system Ar+KCl this average can be considered as a good estimate of the neutral pion yield. Using this way of normalisation allows to compensate to first order for the bias caused by the centrality selection of the LVL1 trigger condition.

A particularly interesting feature of the presented e^+e^- invariant mass distribution is the peak visible in the vector meson region which can be assigned to direct $\omega \rightarrow e^+e^-$ decays. Hence, vector meson production in heavy-ion collisions could be observed for the first time in the SIS18/Bevalac energy regime although the beam energy was well below the ω meson production threshold for a free nucleon-nucleon collision ($E_{\text{th}}^{NN\rightarrow NN\omega} = 1.89$ GeV).

In Fig. 1 the experimental spectrum is contrasted to the predictions of the HSD [10] and the UrQMD [11] transport calculations employing only vacuum properties of hadrons. Both calculations are normalised to the respective π^0 multiplicity. For $M_{\text{ee}} < 0.15$ GeV/c^2 both calculations suggest a dominant contribution from π^0 Dalitz decays. Above this invariant mass and below the vector meson dominated mass region, the dielectron signal is originating mainly from η and Δ Dalitz decays. In contrast to the UrQMD calculation, the HSD model suggests additional dielectron sources, namely the NN and πN bremsstrahlung. However their contributions are predicted to be less significant in Ar+KCl collisions at the given beam energy. The light vector mesons ρ and ω contribute significantly to the e^+e^- yield only at invariant masses $M_{\text{ee}} > 0.6$ GeV/c^2. While the ω meson production seems to be on the same level in both calculations, the significantly higher strength of the ρ meson in UrQMD clearly overestimates the data. One of the reasons might be improper implementation of the elementary cross section for the ρ meson production used in the transport calculations. The HSD group newly adjusted their parametrisation according to a recent measurement [12] which improves the description of the data in the vector meson mass region.

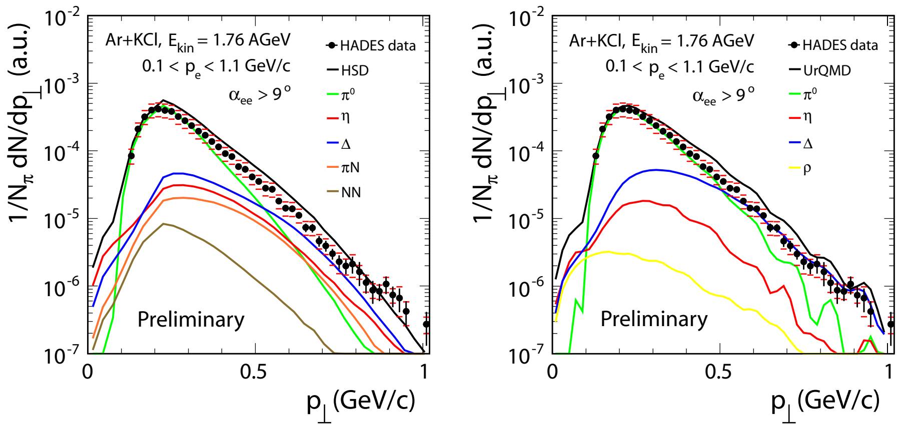

Figure 2: (Color online) Transverse momentum distribution of reconstructed e^+e^- pairs compared to the predictions of HSD [10] (left) and UrQMD [11] (right) transport calculations. Statistical and systematical errors of the measurement (symbols) are shown as vertical and horizontal bars, respectively. No absolute normalisation has been applied to the spectra.

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In Fig. 2 the measured transverse momentum distribution of e^+e^- pairs is contrasted to transport model calculations. At low $p_\perp$ the data are well described by the dominant contribution from π^0 Dalitz decays with slightly better overall result for $p_\perp < 0.3$ GeV/c by the UrQMD group. Besides η Dalitz decay mainly the Dalitz decay of Δ resonance and/or NN and πN bremsstrahlung respectively contribute at high $p_\perp$. These contributions appear significantly "harder" than that of π^0 Dalitz decay and dominate the spectra over the latter one for $p_\perp > 0.5$ GeV/c. Generally, the sum of individual cocktail contributions in both calculations overshoots the data in a wide range of transverse momenta centred around $p_\perp \approx 0.5$ GeV/c.

4. Summary

We reported on the recent measurement of the inclusive e^+e^- production in Ar+KCl collisions at $E_{\mathrm{kin}} = 1.76$ AGeV. The reconstructed invariant mass distribution of dielectrons features for the first time at SIS18 energies a clear peak in the ω mass region. While the invariant mass distribution is fairly well described by two transport models, both of them overshoot clearly the experimental $p_\perp$ distribution for $p_\perp > 200 - 300$ GeV/c. For an improvement of the overall description of experimental heavy-ion data by transport models further investigations are necessary. Especially a consistent description of the Δ Dalitz decay together with the NN and πN bremsstrahlung plays a key role in the baryon rich regime. Their contribution and spectral shape are currently discussed and recent HADES measurements [8] have the potential to provide the information needed to clarify these issues.

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