DILEPTON SPECTROSCOPY WITH HADES AT SIS*

P. SALABURA

Institute of Physics, Jagiellonian University,
Reymonta 4, 30-059 Cracow, Poland

(Received October 9, 1996)

for the HADES Collaboration
IOP Bratislava, Univ. Clermont-Ferrand, Univ. Frankfurt, Univ. Giessen, GSI Darmstadt, Jagiellonian Univ. Cracow, University of Milano, LNS Catania, ITEP Moscow, LPI Moscow, MEPI Moscow, TU Munich, Univ. Nikosia, INP Rez, Univ. Valencia

A High Acceptance DiElectron Spectrometer (HADES) has been proposed for the SIS accelerator at GSI in order to measure e^+e^- pairs produced in proton, meson and heavy ion induced collisions. HADES will be able to operate at the highest luminosities available at SIS in an environment of high hadron and photon background. The physics program includes studies of in-medium properties of vector mesons and electromagnetic form factors of hadrons. A Ring Imaging Čerenkov Counter (RICH) and arrays of pre-shower detectors and TOF wall serve for electron identification. Particle momentum determination is achieved with a magnetic spectrometer consisting of 6 superconducting coils in toroïdal geometry and 2 sets of mini drift chambers for tracking. The detector features have been investigated in detailed simulations. The anticipated mass resolution and geometrical acceptance of the detector amounts to 1% and 40%, respectively for pairs from ρ/ω decay. First experiments are planned for 1998.

PACS numbers: 13.40.-f, 13.40. Gp

Introduction

HADES (High Acceptance DiElectron Spectrometer) is a second-generation apparatus currently under design and construction at GSI Darmstadt. The physics program of HADES includes the investigation of the light vector mesons ρ(770 MeV/c^2), ω(783 MeV/c^2) and ϕ(1020 MeV/c^2) in pp, pA and

* Presented at the "Meson 96" Workshop, Cracow, Poland, May 10–14, 1996.

AA–collisions. The aim of these studies is to explore in-medium modifications of hadron properties, such as the mass shifts or life-times, as predicted by various model calculations [2–7]. Decay of hadrons in hot and dense hadronic matter into dileptons which afterwards are not disturb by strong final state interactions is an ideal tool to study such effects. The comparison of proton, pion and heavy ion induced reactions allows to study these effects as a function of nuclear matter volume and density. In addition, a program to investigate meson and baryon electromagnetic form factors is planned, which will exploit the future availability of pion beams at GSI.

Selected aspects of the HADES physics program

A major part of the HADES physics program is focusing on the suggestion that the mass of vector mesons could be order parameters for chiral symmetry restoration at high density phase of hadronic matter. QCD models, predicts that quark masses (*constituent mass*) are dynamically generated by coupling of bare quarks (*current mass*) to the sea of $q\bar{q}$ pairs. This is characterized by the non zero expectation value of $< q\bar{q} >$, the quark condensate, estimated to be of order $(-230 \pm 25)^3$ MeV^3 [19]. For both u and d quarks bare masses are of order of 5–10 MeV and the respective QCD lagrangian can be approximated assuming massless quarks.

Chiral invariance reflects then the separate conservation of the helicity of left- and right-handed quarks and is just spontaneously broken by this non-zero quark condensate. As a consequence, massless Goldsone bosons appear which can for 2 flavors be identified with pions, (its non-zero mass originates from explicitly symmetry breaking by small current quarks masses) [19] [9]. Some models suggest that the value of the quark condensate decreases almost linearly with nuclear density and practically does not depend on temperature up to a critical temperature $T_c \sim 150$ MeV where it suddenly drops to zero [20][21]. Brown and Rho [6] have suggested that this effect can be experimentally observable by measuring vector meson masses inside nuclear matter since they scale like the cubic root of the quark condensate:

$$\frac{M_\rho^*(\rho)}{M_\rho(0)} = \frac{M_\omega^*(\rho)}{M_\omega(0)} = (\frac{< \bar{q}q >_\rho}{< \bar{q}q >_0})^{1/3} .$$

This would imply that the masses of ρ and ω meson decrease by ~ 80 MeV already at the normal nuclear density. As an appropriate experiment pion induced ω production in a heavy nuclei has been proposed and presented on this conference [22].

For heavy ion collisions at SIS energies, even larger effects are expected. Here, vector mesons are produced below threshold for creation in direct nucleon–nucleon collisions and thus they are strongly related to the high density region of the collision zone [11, 12] (this conference) and [1, 2, 7, 8]. However, interpretation of the dilepton data is much more complicated. Dilepton spectra crucially depend on the hadronic composition of a fireball, its time evolution, in medium hadron properties (life times, masses) electromagnetic form factors and cross sections for meson production near thresholds. In fact, many of these parameters are unknown.

Theoretical predictions are based on transport codes developed in the framework of BUU or QMD models [2, 10]. Important result of BUU calculations indicate that dilepton production in the ρ-ω region is dominated by $\pi^+\pi^-$ annihilation. This annihilation proceeds through formation of short-lived ρ-meson resonances ($c\tau = 1.3$ fm/c) and is extremely sensitive to the in-medium ρ mass. Other dilepton sources such as Δ Dalitz decay ($\Delta \to Ne^+e^-$) are also strongly affected by an actual Δ mass distribution in the nuclear matter. In this latter case the unknown electromagnetic form factor is an additional complication. In the nucleon–nucleon bremsstrahlung process a massive photon is radiated as a result of the strong interactions between two nucleons probing their electromagnetic structure. It is worth to notice, that the proton form factor is also unknown in the region of 4-momentum transfer q, $0 < q^2 < (2 * m_{\rm nucleon})^2$ which is here of special importance.

From this brief discussion it is obvious that in order to describe heavy ion dilepton data we have to learn more about hadronic form factors. Experimentally they can be measured either in elastic electron scattering experiments (space-like $q^2 < 0$) or in dileptonic decays and annihilations ($i.e. \pi^+\pi^-$ annihilations probes the time-like electromagnetic structure of pion). In the $0 < q^2 < 1$ (GeV/c)^2 the interactions of photons to the hadrons is described by the Vector Dominance Model (VDM) [28]. The model predicts, that this coupling proceeds via intermediate vector mesons (ρ (isovector), ω (isoscalar), ϕ) coupling to virtual photons which have the same spin and parity quantum numbers. In this model the photon–hadron coupling is determined by vector meson propagator. For $q^2 > 0$ it exploits a full resonance shape determined by the width of ρ meson $\Gamma_\rho = 151$ MeV. This model works very well for the pion form factor reproducing precisely high precision data [24, 25]. VDM also reproduces measured data for of η-meson form-factor [26]. However, the VDM model in this simple form fails to reproduce the form factor of the ω-meson in the time-like region as obtained from measurement of the $\omega \to \pi^0\mu^+\mu-$ decay [26]. In this case data with much better statistics are badly needed. For heavier hadrons, form factors are even more sensitive to the predictions of VDM because they show the vector mesons resonance structure. Here, there is no experimental data available up to now.

In this field the HADES spectrometer alone or in combination with the other GSI detectors (TAPS or LAND) using pion induced reactions can provide novel data. For example, studying Dalitz decays of the nucleon or its resonances by reaction $\pi^- p \rightarrow n e^+ e^-$, where $e^+ e^-$ pairs are measured with HADES and neutrons with LAND would provide first data on photon-baryon interactions in $0 < q^2 < 1$ $(\mathrm{GeV}/c)^2$ region [27].

Design of the spectrometer

Due to the small electromagnetic coupling the dielectron decay channel of vector mesons is suppressed by a factor of $\approx 10^{-5}$ as compared to the hadronic decay channels. Together with the small subthreshold production cross sections the expected total yield of dielectrons from vector mesons is only of the order of 10^{-6} per central Au+Au collision at 1 AGeV [13]. This demands a system with a large geometrical acceptance, high rate capabilities allowing operation at beam intensities of up to 10^8 particles/s currently available at GSI, sufficient granularity and a highly selective multi-stage trigger scheme. For the fast electron recognition a hadron blind detector with on-line image processing is necessary. Moreover, an excellent invariant mass resolution is required for vector meson identification.

HADES is detector which fullfils these requirements. It is a rotationally symmetric, large acceptance toroidal spectrometer. The design values for the angular and momentum acceptance have been chosen according to the two body decay kinematics at SIS energies assuming thermal emission from a mid-rapidity zone. Dielectrons are emitted over the whole polar angular range with a maximum probability at about 40°. HADES will cover polar angles from 18° to 85°. For masses up to 1.5 GeV/c^2 and transverse momenta up to 1.5 GeV/c this geometry results in a flat acceptance [17–18]. The pair geometrical acceptance of $\sim$ 40% represents an improvement by a factor of 100 as compared to the pioneering experiments performed with the DLS [14] spectrometer at Berkeley.

The proposed strategy for the measurement of dielectrons consists of: electron identification in the dedicated detectors before (RICH) and behind magnetic field (META) and momentum determination in 2 sets of Mini Drift Chembers (MDC). (Fig. 1).

First electron identification over the full acceptance is done by a fast RICH (Ring Imaging Čerenkov Counter) with a gaseous radiator surrounding the target in the forward hemisphere. The Čerenkov light from electrons emitted in a cone is reflected by a spherical aluminized carbon fiber mirror (radius 89.4 cm, thickness 0.2 cm) and focused onto a position sensitive UV detector plane forming rings. The flourocarbon based radiator gas C_4F_{10} ensures high threshold value for Čerenkov light (γ_{th}=18) but still

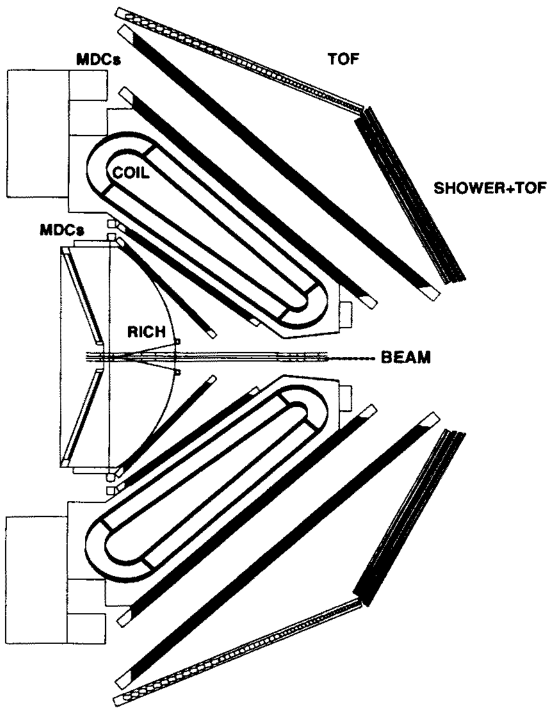
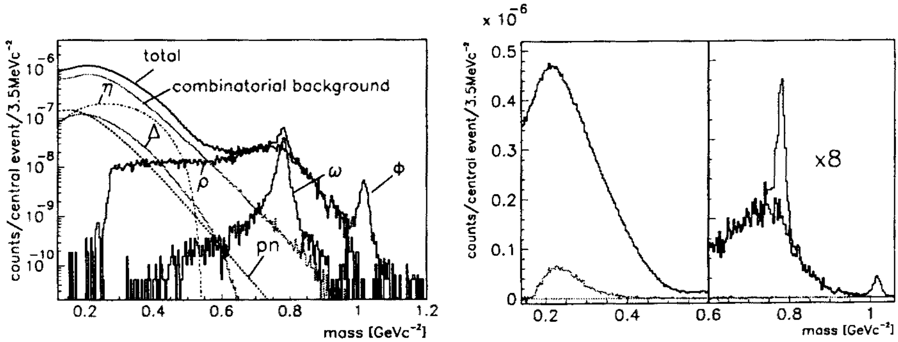


Fig. 1. Azimuthal cross section of the HADES setup. The RICH consists of a gaseous radiator, carbon fiber mirror and the tilted UV detector segments. The target is positioned in the center of the radiator. Two sets of mini-drift chambers (MDCs) in front and behind the magnetic field produced by superconducting coils measure the trajectory. A time of flight wall-(TOF) is foreseen as a first level trigger and for second electron identification. At polar angles <45° TOF wall is accompanied by a pre-shower detector.

yields a sufficient number of Čerenkov photons (10-17 detected photons per electrons are expected for HADES RICH). All protons and practically all pions in the SIS energy range have velocities below the mentioned threshold ($p_{th}^{p} \simeq$ 20 GeV/c, $p_{th}^{\pi} \simeq$ 3.1 GeV/c) and thus will produce no light. The threshold for electrons amounts to $p_{th}^{e} \simeq$ 11.1 MeV/c which is well below the HADES momentum of interest. In order to match the expected reaction rates of 10^6 /sec the UV detector has been designed as multiwire proportional counter (MWPC) with a solid photocathode (CsI).

Momentum analysis is achieved by a trajectory reconstruction in the 2 sets of Mini-Drift Chambers (MDC) positioned in 6 spectrometer sectors. A toroidal field geometry (6 superconducting coils) is the optimal choice for the following reasons: First, while covering the large forward solid angle, a field free region for the RICH can be accommodated inside the toroid. This ensures undisturbed Čerenkov rings. Second, the field geometry is well matched to the dielectron kinematics since the radial 1/r dependence of the field compensates for due to the fact that the mean momentum increases for decreasing polar angles. The resulting invariant mass resolution in the ρ/ω region amounts to less than 1% (σ), which is comparable to the intrinsic width of the ω meson (Fig. 2(b)). The resolution at large momenta is limited by the spatial resolution of the tracking detectors whereas at low momenta it is limited by multiple scattering in the field region.



(a) (b)

Fig.2. Simulated invariant mass spectrum for the main sources for 1 AGeV Au+Au collisions. (a)— individual contributions to the total dielectron mass yield. Dalitz decay of η and Δ and pn-bremsstrahlung are the main contributing sources below 0.5 GeV/c^2. Above 0.5 GeV/c^2 dielectrons from ρ, ω and ϕ mesons dominate the spectrum; (b)— same as (a) after subtraction of the background obtained from like sign pairs. The remaining background contribution is shown separately (dotted histogram). Note the different scale for masses >0.6 GeV/c^2.

The first level trigger on central events is obtained from the multiplicity measurement performed in the scintillator wall surrounding the outer MDCs. Moreover, using the time of flight information for polar angles $> 45^0$ second electron identification is achieved with an efficiency of 96%. At polar angles $< 45^0$ a separation of electrons from pions by time of flight is not possible due to the higher pion momenta. Here, the electron identification is done with a pre-shower detector positioned behind the scintillator strips. One sector of pre-shower detector consists of a stack of 3 gas detectors and two Pb-layers (two radiation lengths each) in between. The lepton identification is performed by means of charge measurements carried out in the position sensitive (pad-readout) gas chambers before and after the lead converter. The gas chambers operate in self-quenching streamer mode, where the produced charge is nearly independent of of the particle energy loss and depends only on the number of charged particles measured in the chamber. Pre-showerw detector single lepton efficiency ranges from 60% at an electron momentum of 300 MeV/c to about 90% at 700 MeV/c.

Conclusions and prospects

With its high counting rate capability and large geometrical acceptance HADES is able to measure e^+e^- pairs for the heaviest systems at the highest SIS energies. With the invariant mass resolution of better than 1%(σ) a clear separation of ω and ϕ from ρ can be achieved. The reduction of combinatorial background results in the signal to background ratio of 10:1 in the ρ/ω region for the most difficult case of 1 AGeV Au+Au collisions. (Fig. 2(b)). With the anticipated performance HADES is and ideal detector to study in-medium modifications of meson masses as a function of nuclear density.

This work has been supported in part by Polish-German Fundation: Stiftung Deutsch-Polnische Zusammenarbeit under contract 528/92/LM, the Bundesministerium für Forschung und Technologie of the Federal Republic of Germany under contracts No: GI475ITEP4, OF474TP4, TM353TP6 and Human Capital and Mobility Program.

REFERENCES

[1] L. Winckelmann, NATO Advanced Study, Bodrum 1993.
[2] Gy. Wolf, W. Cassing, U. Mosel, *Nucl. Phys.*, **A552**, 549 (1993).
[3] C.-M. Ko, Workshop on Dilepton Production in Relativistic HI Collisions, Darmstadt(GSI) 1994.
[4] M. Herrmann, B. Frimann, W. Nörenberg, *Nucl. Phys.* **A545**, 267 (1992).
[5] G. Chanfray, P. Schuck, *Nucl. Phys.* **A489**, 271 (1992).
[6] G.E. Brown, M. Rho, *Phys. Rev. Lett.* **66**, 2720 (1991).
[7] T. Hatsuda, S.H. Lee, *Phys. Rev.* **C46**, R34 (1992).
[8] M. Asakawa, C.M. Ko, *Phys. Rev.* **C48**, R526 (1993).
[9] M. Nowak contribution to this conference.
[10] C. Hartnack contribution to this conference.
[11] V. Metag contribution to this conference.
[12] P. Senger contribution to this conference.
[13] V. Metag, *Prog. Part. Nucl. Phys.* **30**, 75 (1993).
[14] A. Yegneswaran *et al.*, *Nucl. Instrum. Methods* **A290**, 61 (1990).
[15] C. Naudet *et al.*, *Phys. Rev. Lett.* **62**, 2652 (1989).

[16] HADES Letter of Intent, Dec 1991, HADES Design Study, Nov 1992.
[17] HADES, GSI Scientific reports 1992, p. 379, 1993 .
[18] HADES, Proposal for High-Acceptance Di-Electron Spectrometer, 1994.
[19] *International School of Heavy Ion Reactions*, Erice, Italy 1993 ed. by R.A. Broglia, P. Kienle, P.F. Bortignon, Word Scientific, Singapore 1994, p.436.
[20] M. Lutz, S. Klimt, W. Weise *Nucl. Phys.* **A542**, 621 (1992).
[21] G. Boyd *et al.*, *Phys. Lett.* **B 349**, 170 (1995).
[22] W. Schoen *et al.*, contribution to this conference.
[23] J. Carrol, *Nucl. Phys.* **A495**, 409 (1989); H.Z. Huang *et al.*, *Phys. Rev.* **C49**, 314 (1994).
[24] M. Herrmann, B.L. Friman, W. Nörenberg, *Nucl. Phys.* **A560**, 411 (1993).
[25] S.R. Amendolia *et al.*, *Phys. Lett.* **B138**, 454 (1984).
[26] L.G. Landsberg, *Phys. Rep.* **226**, 301 (1985).
[27] M. Soyeur, *Acta Phys. Pol.* **B27**, 401 (1996).
[28] J.J. Sakurai, *Current and Mesons*, The Univeristy of Chicago Press, 1969.
[29] G. Wolf, private communications.
[30] L.A Winkelmann, S. Bass private communications.