SIMULATION OF RECOILLESS PRODUCTION OF ω MESONS*

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(Received October 9, 1996)

Detection of dilepton decay of vector mesons by means of HADES installation is discussed.

PACS numbers: 13.40. Hq, 14.40. Cs

1. Motivation

One of the current topics of nuclear physics is to investigate in-medium effects *i.e.* modifications of hadrons in a dense hadronic environment. QCD inspired models predict a restoration of chiral symmetry with increasing baryon density and temperature [1]. As a consequence, shifts of the vector meson mass in the medium are predicted [2].

In heavy ion collisions at SIS energies, 2-3 times the normal nuclear density and temperatures of $T = 60$–90 MeV can be obtained in a transient state of about 10 fm/c lifetime. At higher beam energies available at the CERN SPS the temperature increases by about a factor of two. Invariant mass spectra obtained with the dilepton spectrometers CERES and HELIOS are currently discussed in the context of possible mass shifts of the ρ meson [3–5]. Because of the limited lifetime of the compressed collision zone in heavy ion reactions, this approach to mass shift measurements is restricted to short lived vector mesons like the ρ meson ($\tau \simeq 1.5$ fm/c). At normal nuclear density and temperature $T = 0$ mass changes are expected to be smaller but still of the order of 10-20 % [2, 6, 7]. However, due to the small ω-width ($\Gamma \simeq 8\mathrm{MeV}/c^2$), even smaller mass shifts can be measured. Consequently, the experiment proposed is focused on the measurement of the ω-mass in nuclei.

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

2. Recoilless production

The ω mesons can be produced on a bound proton inside a heavy nucleus via the reaction

$$\pi^- + p \rightarrow \omega + n \,, \tag{1}$$

making use of the proposed pion beam at SIS [8]. The maximum of the cross section (2.5 mb) is reached at 1.4 GeV/c. In case the neutron carries most of the momentum, the ω meson is relatively slow in the laboratory, which is the rest system of the nucleus. As a consequence, the probability for the ω meson to decay inside the nucleus is enhanced. It should be noted that recoilless ω production requires a mass of the projectile smaller than that of a nucleon, thus excluding the use of a proton beam.

The dilepton decay of vector mesons is a valuable probe for determining their mass in dense matter as dileptons do not suffer final state interaction in the medium. The dileptons can be detected with the High Acceptance DiElectron Spectrometer (HADES) [9].

For simulating the ω meson production inside a nucleus, a simplified model was used. The baryon density distribution was approximated by a two parameter Fermi distribution with maximum density $\rho_0 = 0.16/\text{fm}^3$; the parameters are taken from the measured charge density distribution [10]. Fermi motion of the nucleons is taken into account in a simple Fermi gas model with p_{F}=220 MeV/c. Inelastic scattering of π^-, creation of ρ and ω mesons and dilepton decay channels are simulated using measured cross sections and branching ratios [11, 12].

The mass of the ω meson is calculated assuming Brown–Rho scaling [2, 6]:

$$M^{\omega}_{(\rho)} = M^{\omega}_{(0)} * (1 - 0.3\,(\rho/\rho_0))^{1/3} \,. \tag{2}$$

No further interaction of the ω meson with the nucleus is included, *i.e.* the ω meson inside the nucleus is treated like a free particle with a reduced mass. In a more realistic study the ω-nucleon interaction, in particular the collisional-broadening, has to be taken into account. First theoretical studies [13] indicate that the width increases significantly.

Due to the absorption of π^- mesons inside the nucleus, only a fraction of the nucleus contributes to ω meson creation. As a result, the spatial distribution of meson production is not homogeneous but concentrated in the upstream hemisphere of the nucleus. The spatial distribution of the ω decay is the result of a convolution of its production and propagation. Without restriction on "slow" ω mesons, 78% of the ω mesons decay outside the half density radius of a heavy nucleus like Pb. 14% of the ω mesons

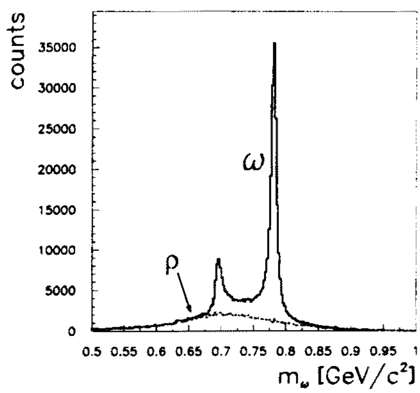

Fig. 1. Dielectron invariant mass spectrum obtained for 1.3 GeV/$c\pi^-$ on Pb. The mass peak at 0.782 GeV/c^2 is due to ω mesons decaying outside the nucleus wheras the shifted peak results from ω mesons decaying inside the inner region of the nucleus with baryon density of about ρ_0. The decay of ω mesons in the nuclear surface fills the invariant mass spectrum between the two peaks. The contribution of the rho meson is also indicated (dashed line).

decay inside the region with $\rho > 0.9 * \rho_0$ resulting in a shifted mass peak (Fig. 1).

The most important 'background' source of dielectrons in the invariant mass region of the ω meson are dielectrons from ρ meson decays (Fig. 1).

The mass of the ρ meson was also varied in the simulation according to the Brown–Rho scaling. Dielectrons from $\pi^0 e^+ e^-$ decay of the ω meson can not contribute to the invariant mass spectra above m_ω-m_π^0=650 MeV/c^2. At $p_\pi^- = 1.3$GeV/c, the production of mesons above m_ω is negligible and no contribution to the dielectron invariant mass spectrum is expected.

3. e^+e^- pair detection with the HADES spectrometer

The event generator was coupled to a GEANT simulation of the HADES spectrometer. This allows to account for the detector resolution and includes multiple scattering, bremsstrahlung processes and energy loss. These latter processes pose a special problem due to the total thickness (2 mm) of the segmented lead target.

External pair creation of photons from π^0 decay and the π^0 Dalitz decay can produce dielectron pairs, but the invariant mass of these dielectrons stays below the π^0 mass. The contribution of combinatorial background from e^+e^- combinations from different π^0 amounts to less than 10% in the invariant mass region of the ω.

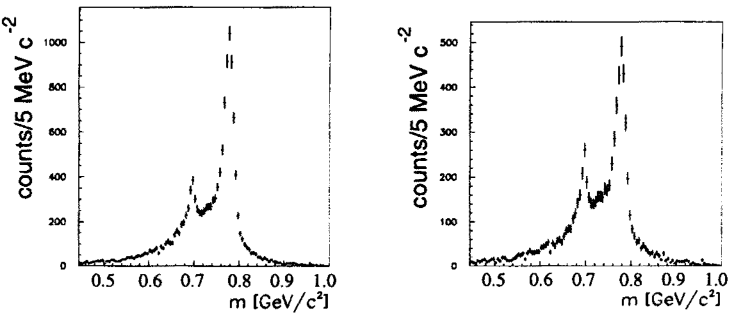

Fig. 2. Restriction on $p_{\omega,\rho} < 0.8$ GeV/c

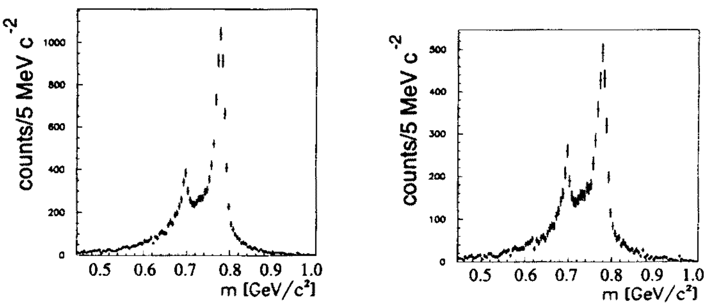

Fig. 3. Reconstructed dielectron invariant mass spectrum of the ρ- and the ω meson based on the simulated HADES Spectrometer. Statistics correspond to 7 days data taking.

The experimental FWHM of the ω mass distribution of about 25 MeV/c^2 is to be compared to the predicted mass shift of about 80 MeV/c^2. A mass shift should be detectable as a double structure, even in the case the mass shift were half as large as predicted. The shifted mass peak gets more pronounced by selecting slow ω mesons (Fig. 3b). In order to account for the momentum dependent ω-N interaction which leads to an increasing width of the ω meson, it will be important to investigate the dilepton spectra for different cuts on the ω momentum.

This article focuses on the mass range of the ω and ρ mesons. However, it should be mentioned that the total spectrum will be measured, including contributions from the η-, ω- and Δ-Dalitz decays.

The HADES project is supported by German BMBF, DAAD, Stiftung Deutsch-Polnische Zusammenarbeit (JUMBO), EC, the French-German collaboration agreement, GSI-Hochschulprogramm and INTAS.

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