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Polarisation of the ω meson in the $pd \to {}^3\text{He}\omega$ reaction at 1360 and 1450 MeV

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ABSTRACT

The tensor polarisation of ω mesons produced in the $pd \to {}^3\text{He}\omega$ reaction has been studied at two energies near threshold. The ${}^3\text{He}$ nuclei were detected in coincidence with the $\pi^0\pi^+\pi^-$ or $\pi^0\gamma$ decay products of the ω. In contrast to the case of ϕ-meson production, the ω mesons are found to be unpolarised. This brings into question the applicability of the Okubo–Zweig–Iizuka rule when comparing the production of vector mesons in low energy hadronic reactions.

The production of the light isoscalar vector mesons ϕ and ω in various nuclear reactions involving non-strange particles are often compared within the framework of the Okubo–Zweig–Iizuka rule [1]. This rule suggests that processes with broken quark lines are suppressed, and therefore the cross section ratio between ϕ and ω production is mainly due to small deviations from ideal mixing of these mesons at the quark level. The ratio of the squares of the production amplitudes for the two mesons, for any hadronic reaction measured under similar kinematic conditions, should be of the order of $R_{\phi/\omega} \approx R_{\text{OZI}} = 4.2 \times 10^{-3}$ [2]. The validity of this estimate has been tested for the $pd \to {}^3\text{He}\omega/\phi$ reaction near threshold, where it was found that $R_{\phi/\omega} \approx 20 \times R_{\text{OZI}}$ [3–5]. This deviation is over a factor of two greater than that found, for example, in

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the case of production in nucleon–nucleon collisions near threshold [6,7]. It is thus unclear to what extent the OZI approach is applicable for this reaction, and further experimental input would be valuable.

In the MOMO study of the $pd \to {}^3\text{He}\phi$ reaction [5], the K^+ and K^- coming from the decay of the ϕ were measured in coincidence with the ^{3}He ejectile. Now the angular distribution of the K^+K^- relative momentum in the rest frame of the ϕ-meson is sensitive to the tensor polarisation (spin alignment) of the spin-one meson. The surprising result from the MOMO experiment is that near threshold the ϕ are produced almost purely in the magnetic substate with $m = 0$ along the beam direction [5]. In the light of the OZI consideration in comparing the cross sections of the ω and ϕ production it should also be interesting to compare the polarisation of these mesons produced in the $pd \to {}^3\text{He}\omega/\phi$ reactions, since any difference in the ω/ϕ polarisation is not expected to depend on the details of the quark mixing but rather on the reaction mechanism.

The only two significant decay channels of the ω meson are $\omega \to \pi^0\pi^+\pi^-$ and $\omega \to \pi^0\gamma$, with branching ratios of 89.1% and 8.7%, respectively [8]. The angular distributions of both decays reflect the spin alignment of the ω. By measuring both these channels, we obtained two different measurements for the ω polarisation in the $pd \to {}^3\text{He}\omega$ reaction.

The measurements of the ω polarisation were carried out at The Svedberg Laboratory in Uppsala, Sweden, using the WASA detector [9,10], which was an integral part of the CELSIUS storage ring. The experiments were done at $T_p = 1360$ and 1450 MeV, corresponding to excess energies of 17 and 63 MeV with respect to the nominal $^3\text{He}\omega$ threshold. The circulating proton beam was incident on deuterium pellet targets [11,12]. The ^{3}He ejectiles were measured in the WASA forward detector (FD), which covered laboratory polar angles from 3° to 18°. This corresponds to 95% of the ^{3}He phase space for ω production at 1450 MeV and 78% at 1360 MeV. The majority of the lost events are those where the ^{3}He are emitted at small laboratory angles such that they escape detection down the beam pipe. The corresponding angular acceptance of the ω mesons covers, in the CM system, the intervals 22°–158° at 1450 MeV and 46°–134° at 1360 MeV.

The forward detector consists of sector-like scintillation detectors forming a window counter (FWC) for triggering, a hodoscope (FTH) for triggering and off-line particle identification, a range hodoscope (FRH) for energy measurements, particle identification and triggering, and a veto hodoscope (FVH) for triggering. A proportional chamber (FPC) for precise angular information is also part of the forward detector. Mesons and their decay products are mainly measured in the central detector (CD) that consists of the Plastic Scintillating Barrel (PSB), the Mini Drift Chamber (MDC), the Super Conducting Solenoid (SCS), and the CsI equipped Scintillating Electromagnetic Calorimeter (SEC). The SEC, which measures the angles and energies of photons arising from meson decay, covers polar angles from 20° to 169°. A schematic overview of the setup is shown in Fig. 1.

The hardware ^{3}He trigger selected events where there was a hit with a high energy deposit in the FWC as well as a hit in either the FTH (March 2005 run) or the FRH (May 2005 run) in the same ϕ angle sector.

The ^{3}He was identified in the FD using the $\Delta E - E$ method, as described in Ref. [13]. Here the light output from the detector layer where the particle stopped was compared with that from the preceding layers. The χ^2 of a particular particle hypothesis was then calculated by comparing the measured energy deposits in all detector layers traversed to those expected for that particle. Particle hypotheses giving a χ^2 larger than a maximum value, chosen to reduce background without losing good events, were rejected [14].

The main focus of the present work is on the $\omega \to \pi^0\pi^+\pi^-$ decay channel, where the large branching ratio (89.1%) gives the highest statistics. To select this channel we require one ^{3}He with a well defined energy and angle in the FD and at least two photons in the SEC. In addition, one photon pair must have an invariant mass close to that of the π^0. The missing mass of the $^3\text{He}\pi^0$ system must be larger than 250 MeV/c^2, i.e., twice the pion mass folded with the experimental resolution, in order to select the events with two additional pions. The two charged pions are included by requiring two or more hits in the PSB. Finally, we require at least one track in the MDC coming from the overlap region between the pellet target and the proton beam. The missing mass of the ^{3}He is shown in Fig. 2(a) for all events fulfilling the above criteria.

The selection requirements lead to an overall acceptance of 14% at both beam energies. In addition to the losses at small angles in the beam pipe, there are losses from the ^{3}He that undergo nuclear interactions before depositing all their energy. Moreover photons from π^0 decay can escape detection in the CD and, finally, there is the limited MDC efficiency ($\approx 50\%$). About 10% (30%) of the events at 1450 (1360) MeV are produced outside the pellet target (mainly in beam-rest gas interactions) and are therefore rejected.

For an ω meson decaying into $\pi^0\pi^+\pi^-$, the spin direction can be specified with respect to an axis directed along the normal to the decay plane. This direction is given by the vector product of the momenta of the π^0 and one of the charged pions in the rest frame of the ω meson. For this purpose, the π^0 was reconstructed from the decay photons, and the charged pion from the precise angular determination in the MDC combined with the information from the ^{3}He and the π^0.

The polarisation can be measured by studying the dependence of the cross section on the angle β between the normal and some quantisation axis in the Gottfried–Jackson frame [15], i.e., the rest frame of the ω. For the Jackson angle the quantisation axis is taken to be along the direction of the proton beam.

We are interested in the elements of the spin-density matrix $\rho_{mm'}$ that represent the tensor polarisation (alignment) of the ω. With an unpolarised beam and target, there is one independent term $\rho_{11} = \rho_{1-1} = \frac{1}{2}(1 - \rho_{00})$ that can be measured. The dependence of the differential cross section on β is of the form:

$$\frac{\mathrm{d}\sigma(\omega \to \pi^0\pi^+\pi^-)}{\mathrm{d}\cos\beta} \propto (1 - \rho_{00}) + (3\rho_{00} - 1)\cos^2\beta. \qquad (1)$$

If the ω mesons are unpolarised, one has that $\rho_{00} = \rho_{11} = \rho_{1-1} = \frac{1}{3}$ and thus an isotropic angular distribution, while the maximum polarisation occurs when $\rho_{00} = 1$ and thus the distribution has a pure $\cos^2$ dependence.

In order to obtain the differential cross section as a function of $\cos^2\beta$, all events fulfilling the selection criteria were divided into eight regions of $|\cos\beta|$. In view of the limited statistics, no account was here taken of the ω direction in the CM system. Any possible dependence on the ω direction will be discussed later. In each region of $|\cos\beta|$ the missing mass of the ^{3}He (MM(^{3}He)) was plotted. The ω candidates show up in a peak near the nominal mass at 782.6 MeV/c^2, as clearly seen in the event distribution shown in Fig. 2(a). The background under the ω peak was estimated in two ways, either by taking a phase-space Monte Carlo simulation of $pd \to {}^3\text{He}\pi^0\pi^+\pi^-$ or by fitting the data to a Gaussian peak on a polynomial background. The difference in the numbers of ω obtained in the two ways is between 2% and 15%.

In Fig. 3, the angular dependence of the ω cross section at 1450 MeV is shown by the filled circles. These have been normalised by an arbitrary factor to give an average value of unity. Our data are clearly consistent with an isotropic distribution. To investigate the situation further, the same exercise was undertaken for events outside the peak region, i.e., $700 < MM(^3\text{He}) <$