Measurement of polarization observables in $\omega$-photoproduction

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Abstract. Near threshold $\omega$ meson photoproduction is studied with the CBELSA/TAPS experiment at the ELSA accelerator of Bonn University. Single ($\Sigma, \Sigma\pi$) as well as double ($G, G\pi, E$) polarization observables are measured using either linear or circular polarized photon beams and a longitudinal polarized proton target.

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INTRODUCTION

Baryon spectroscopy provides important information in the non-perturbative regime of QCD at low and intermediate energies. At these energies constituent quark models, like the Bonn model [1], try to describe the baryon spectrum. This and also other quark models have two main consistencies:

1. The lowest lying resonances $P_{11}(1440)$ (Roper) and $S_{11}(1535)$ are not well reproduced. In particular the parity ordering of these states is wrong.
2. In the higher mass region much more states are predicted than experimentally observed.

The reason for these inconsistencies can be a model deficit. The second may also be to experimental deficits. Most of the experimentally determined resonances had been extracted from pion-nucleon scattering. Some resonances may however be hard to observe in these kind of experiments, due to weak $\pi N$-coupling [2]. One possibility to investigate this issue is the photoproduction of $\omega$ mesons off the proton. The production threshold of the $\omega$ meson is located in the third resonance region, where many of the “missing” states are expected. Due to the fact that the $\omega$ is isoscalar ($I=0$), the s-channel production of this meson is only associated with the decay of $N^*(I=1/2)$ states and not the decay of $\Delta^*$ ($I=3/2$) states, which greatly simplifies the contributing excitation spectrum. However the vector meson character of the $\omega$ implies that at least 23 observables have to be measured to disantangle all contributing resonances, instead of 8 in the pseudoscalar case. It can be hoped however, that fewer than 23 observables already provide significant constraints.

In any case, the measurement of polarization observables will provide important information about the “production mechanism” of the $\omega$ meson [3]. $\omega$ mesons can be produced via “diffractive” scattering in the t-channel, i.e. via an exchange of a Pomeron (Fig. 1 (left)) or a Pion (Fig. 1 (middle)). Former analyses, like the measurement of differen-
tial cross sections [4], photon asymmetries [5, 6] and decay asymmetries (pion asym-
metry) [6] additionally show evidence for s-channel contributions (Fig. 1 (right)). The
measurement of further (double) polarization observables will further clarify the role of
s-channel resonances, and it is one goal of current experiments to investigate this.

FIGURE 1.  $\omega$ production via t-channel $0^+$ (Pomeron) exchange (left), t-channel $\pi^0$ exchange (middle)
and s-channel intermediate excitation (right).

POLARIZATION OBSERVABLES

The cross section for vector meson photo production can be written very similar to the
pseudoscalar case. For the situation of the presented experiment (using either linear or
circular polarized photons and a longitudinal polarized target) it has the form:

$$
\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} (1 - P_{\gamma,l} \Sigma_\pi \cos 2\phi_\pi + P_{\gamma,T}^z G_\pi \sin 2\phi_\pi - P_{\gamma,T}^z P_{\gamma,\odot} E)
$$

where the polarization independent cross section is denoted by $\sigma_0$, the degree of linear
polarization by $P_{\gamma,l}$, the degree of circular polarization by $P_{\gamma,\odot}$ and the degree of lon-
gitudinal target polarization by $P_{\gamma,T}^z$. $\phi$ is the azimuthal angle of the vector meson. For
the neutral decay of the $\omega$ ($\omega \rightarrow \pi^0 \gamma$), asymmetries for the decay pion can also be mea-
sured. These asymmetries correspond to the observables $\Sigma_\pi$ and $G_\pi$ and are obtained by
replacing the azimuthal angle of the $\omega$ meson ($\phi$) by the azimuthal angle of the decay-$\pi^0$
($\phi_\pi$). The observables are defined as in Ref. [3].

EXPERIMENT AND RESULTS

The experiment was performed at the tagged photon beam of the ELSA accelerator in
Bonn, using electron beams of $E_0 = 2.4$ GeV or $E_0 = 3.2$ GeV. Linear polarized pho-
ton, with a maximum degree of polarization of about 53%, were produced via coherent
bremsstrahlung from a 500 $\mu$m thick diamond crystal. Circular polarized photons were
generated by bremsstrahlung of longitudinal polarized electrons, having a degree of po-
larizion of more than 60% . For double polarization measurements the Bonn Frozen
Spin Target [7], having an average degree of polarization of about 70% with relaxation
times of about 500 hours, was used. In order to get rid of systematic errors, two different
linear polarization planes with an azimuthal angular offset of 90° were adjusted and also
target and circular polarization directions where flipped at regular intervals. Surrounding
the target was a three layer scintillating fiber detector, covering the angular acceptance
of the Crystal-Barrel calorimeter. The Crystal-Barrel detector consists of 1230 CsI(Tl)
crystals of 16 radiation lengths. It covers the polar angular range of 30° - 150°. In the
forward direction the setup is supplemented by two further calorimeters, namely the For-
ward detector and the MiniTAPS detector, where both of them are equipped with plastic
scintillator pads for charge identification. The whole detector setup covers almost 96% of the solid angle around the target. It is well suited for photon detection, i.e. the detection of the neutral decay of the $\omega$ meson ($\omega \to \pi^0\gamma$).

For the event reconstruction three uncharged and one charged reconstructed particles were demanded. After applying basic kinematic cuts, a $\pi^0\gamma$ invariant mass distribution as shown in Fig. 2 was obtained. Monte Carlo simulation of signal, as well as of background events showed that the main background channel in the $\omega$ invariant mass range originated from $2\pi^0$ production. These background events can also carry asymmetries, making it necessary to correct for them.

![Figure 2]($\pi^0\gamma$ invariant mass distribution ($E_\gamma = 1300 - 1400$ MeV) compared to the simulated decomposition into $\omega$ signal and $\pi^0$ and $2\pi^0$ background. The cut range for asymmetry determination is indicated by the vertical lines.)

The polarized target provides a further complication to the analysis. The Bonn frozen spin target consists of butanol ($C_4H_{10}O$) molecules, where only the quasi-free hydrogen atoms can be polarized and only the polarization of these atoms can be measured via NMR techniques. This is the reason why one has to correct the measured target polarization by the so called “dilution factor”. The effective dilution factor strongly depends on the widths of the applied kinematic cuts and on the polar angle of the meson. This is determined by separate measurements on carbon and hydrogen targets, via scaling measured carbon and hydrogen spectra to fit the measured butanol spectra in each energy and polar angular bin\(^1\). Several methods to obtain the dilution factor are under investigation.

With these corrections one gets preliminary results for the measured observables as shown in Fig. 3.

The data set for data measured with linear polarized photons is yet incomplete and thus exhibits large statistical errors. Nevertheless, evidences for s-channel contributions to the production of the $\omega$ meson, as reported in [4, 5, 6], seem to be further confirmed by the measurement of the “new” double polarization observable $E$. Polar angle dependencies of $E$, particularly at energies close to threshold, have been observed in the data.

\(^1\) For example the, out of the 4-momentum of the measured meson, calculated proton mass spectrum.
FIGURE 3. Preliminary results for the polarization observables $\Sigma$, $\Sigma$, $G$, $G_\pi$ and $E$. The data sample includes only a fraction of the complete data set. The observables not measured with a polarized target are compared to [5] (dots, only $\Sigma$) and two energy bins of [6] (triangles, $\Sigma$ and $\Sigma_\pi$). The curves are predictions of the Bonn-Gatchina PWA group [3]. The solution for only considering t-channel production of the $\omega$ is shown by the dotted lines and the solution for dominant contributions from s-channel resonances is shown by the continuous lines.

whereas [3] expects linear dependence on $\cos \theta^\text{CMS}_{\omega}$ if only t-channel contributions were involved.

SUMMARY

Former analyses [4, 5, 6] claimed evidence for s-channel contribution in photo production of $\omega$ mesons in addition to t-channel production. New (double) polarization data were taken with the CBELSA/TAPS experiment during the last years (and data taking is ongoing). Preliminary results on the Beam-Target helicity observable $E$ provides further indication for s-channel contributions, in accordance to the mentioned analyses.

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