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Polarization observables in ω photo-production

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Abstract. The total cross section of ω photo-production off proton shows several bumps in the incoming photon energy range 1.1–2.5 GeV, which can be ascribed to the contribution of intermediate proton excited states in the s-channel of the reaction. At the same time, differential cross sections show a diffractive behavior, which is interpreted in terms of t-channel exchange contributions. A complete understanding of the ω photo-production process requires a simultaneous investigation of both t-channel exchange terms and s-channel contributions. The measurement of the angular distributions of omega decay products allows to extract the values of the spin-density-matrix elements (SDME) and to evaluate the contribution of natural/unnatural parity exchange terms. The use of polarized beam and/or target allows to measure polarization observables which can help to identify the intermediate proton excited states involved in the process. Results of SDME and polarization observables will be shown as an overview about ω photo-production.

1. Introduction

Photo-production of ω meson is one of the reaction channels ideal for the investigation and the characterization of the proton excitation spectrum. The energy threshold ($E_\gamma^{lab} = 1.1$ GeV) lies in the so-called third resonance region and only high energy excited states may be involved in the production process. Moreover, the ω meson has isospin $I_\omega = 0$ and only N^* excitations can participate to the production process. At the same time, the ω meson has spin J = 1 and it can directly couple to the photon. As a consequence, the production process is expected to go not only through excitation of proton states but also (and mainly, on threshold) through other mechanisms, such as particle exchanges in the t-channel of the reaction. A complete understanding of ω photo-production requires simultaneously the characterization of the dynamics of the production in the t-channel and the identification of the resonant contributions in the s-channel of the reaction.

2. Cross section and unpolarized decay angular distributions

The total cross section of ω photo-production is shown in figure 1. Data show a bump at threshold for a centre-of-mass energy of about 1.7 GeV. A second bump structure is visible at higher energies ($E_\gamma \simeq 2$ GeV, corresponding to a center-of-mass energy of about 2.15 GeV). These bump structures

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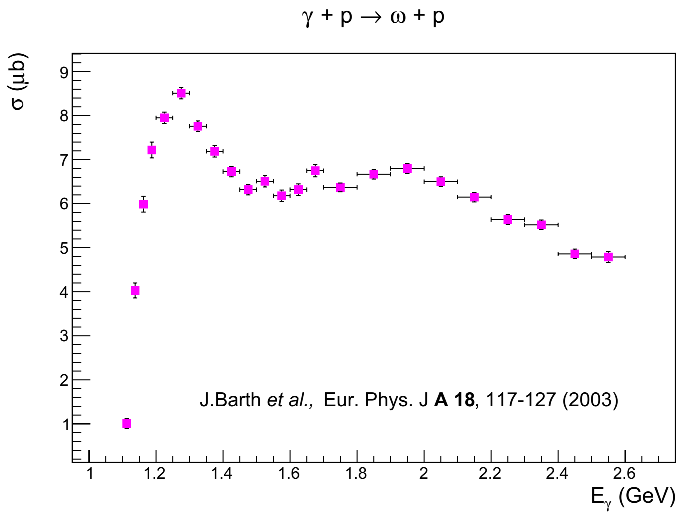

Figure 1. Total cross section of ω photo-production off protons: data from [1]. The cross section shows a prominent peak at threshold and a second bump structure at $E_\gamma \simeq 2\,\mathrm{GeV}$. Both the structures can be interpreted in terms of resonant contributions in the s-channel of the reaction.

could be ascribed to resonant contributions in the s-channel of the reaction. On the other hand the differential cross section in Fig. 2 shows the diffractive behavior typical for vector mesons photo-production, with the cross section falling down with increasing transfer momentum t. The solid line corresponds to a fit of the data points at low t by an exponential function. At higher values of t, data points show an energy dependent bump structure. The diffractive behavior at low t was explained at the beginning in the frame of the vector dominance model, in which the photon transforms in flight into a vector meson, which elastically scatters on the proton target. More recent formulations interpret the diffractive behavior in terms of particles exchange in the t-channel of the reaction. Two main options are considered: the Pomeron exchange (usually called *shape natural-parity* exchange term) and pseudo-scalar meson exchange (usually called *shape unnatural-parity* exchange term). The relative contribution of natural with respect to unnatural parity exchange term can be estimated through the measurement of the angular distributions of the decay products of the ω meson or, equivalently, through the measurement of the Spin Density Matrix Elements (SDMEs). Measurements by SAPHIR [1] and CLAS [2] show that the pseudo-scalar exchange contribution, which is negligible for center-of-mass energy $\sqrt{s} > 5\,\mathrm{GeV}$, becomes dominant at lower energy. Still, the bumps in the total cross section and the energy dependence both of the differential cross section and of the SDMEs are hints of contributions of proton excited states and other experimental observables must be measured to access information about resonant contributions in the s-channel of the reaction.

3. Beam asymmetry

In the last decade, results of ω photo-production by linearly polarized photons have been published. The polarized cross section can be written as a function of the unpolarized one, as it follows:

$$\left(\frac{d\sigma}{d\Omega}\right)_{pol} = \left(\frac{d\sigma}{d\Omega}\right)_{unp} \{1 - P(E_\gamma)\Sigma(E_\gamma, \theta^*_\omega)\cos 2\varphi\}$$

where φ is the difference between the azimuthal angle of the reaction plane and of the polarization vector of the incoming photon. $P(E_\gamma)$ is the degree of the polarization of the photon beam. $\Sigma(E_\gamma, \theta^*_\omega)$

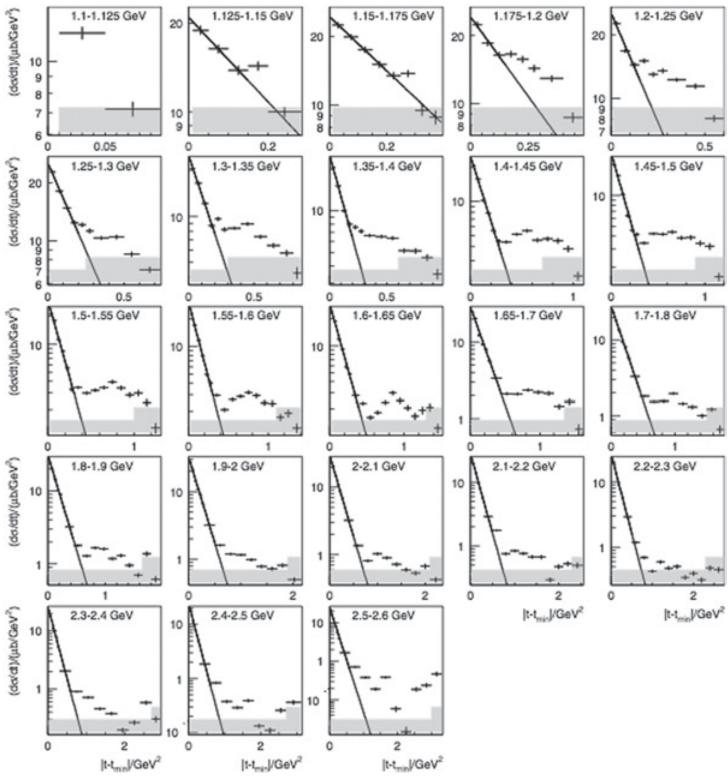

Figure 2. Differential cross section of ω photo production off protons (Fig. 6 from [1]). Data show the typical diffractive behavior: the cross section falls down with increasing transfer momentum. Solid line: fit of the data at low t by an exponential function.

is the Beam Asymmetry. The beam asymmetry is expected to be null if only t-channel exchange terms contribute to ω photo-production and any deviation from the null behavior is a clear signature of contributions from s- and u-channel. Figure 3 shows the actual status about measurements and theoretical descriptions of Σ for the reaction $\vec{\gamma}p \to \omega p$. Results from some members of the GRAAL collaboration (blue circles, $\omega \to \pi^+\pi^0\pi^-$) [3] are compared with results from CBELSA/TAPS collaboration (green squares, $\omega \to \pi^0\gamma$) [4] and they are not in agreement in the whole energy/angular angel. Data are compared with several theoretical descriptions (references are given in the caption) but none of them is able to describe the experimental results in the full energy range. At the same time, the data points are affected by too large errors in order to be able to distinguish among the several theoretical descriptions. This motivated the GRAAL collaboration to a new analysis of the full data set and to a new measurement of the beam asymmetry. The main goal is to extract the beam asymmetry in the two decay modes of the ω meson ($\omega \to \pi^0\gamma$ and $\omega \to \pi^+\pi^0\pi^-$) as a check on the stability of the results, to significantly increase the precision of the results and to give stronger constrains to the theoretical models. The details of the analysis, the results and their interpretation can be found in [10]. As an example of the quality of the new analysis, results of Σ for the ω meson identified through its neutral decay are shown in Fig. 4. The new high precision results are supposed to strongly contain the theoretical models and their inclusion in the data base of coupled-channel analysis is encouraged.

In order to get a better understanding of the photo-production of the ω meson, the measurement of new polarization observables is also necessary to constrain the theoretical models.

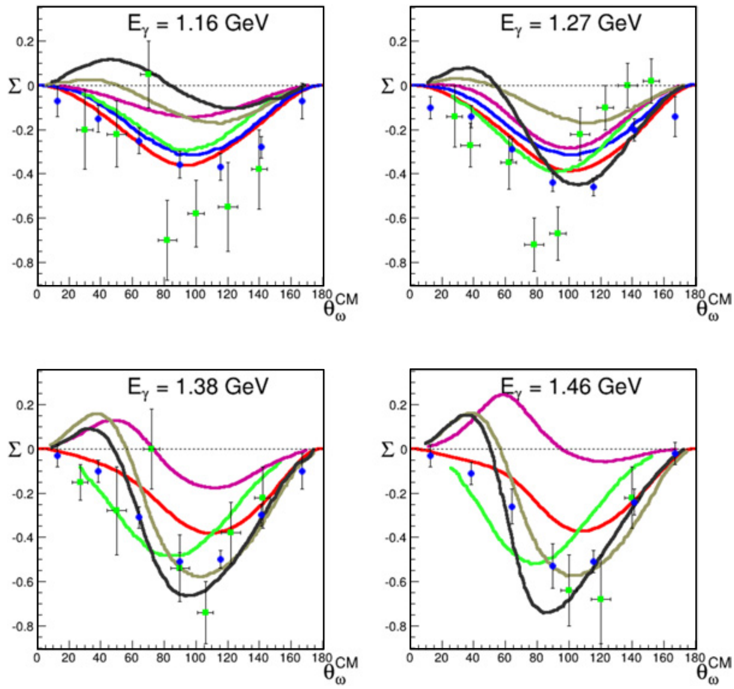

Figure 3. Results of the beam asymmetry Σ in ω photo-production off proton by some members of the GRAAL collaboration [3] (blue circles, $\omega \to \pi^+\pi^0\pi^-$) and by the CBELSA/TAPS collaboration [4] (green squares, $\omega \to \pi^0\gamma$). Data are compared with several theoretical descriptions. Black line: Gießen model [5] including resonant contributions with $J^P = 1/2^-$ and $3/2^-$. Gray line: Gießen model [5] including resonant contributions with $J^P = 1/2^+$ and $3/2^+$. Purple line: Gießen model [6] including resonant contribution with angular momentum up to J = 5/2. Light green line: Bonn-Gatchina model [7] including the contribution of two P_{13} states. Blue line: model by A.I.Titov [8], including the contribution of the $P_{13}(1720)$ and of the $F_{15}(1680)$. Red line: model by Q.Zhao [9], including the contribution of the $P_{13}(1720)$.

4. Beam-target helicity asymmetry

The first measurement of the double polarization observable E (helicity asymmetry) has been recently performed by the CBELSA/TAPS collaboration [11] (Fig. 5). The measurement is performed by using a circularly polarized photon beam and a longitudinally polarized target. The target polarization is flipped along the longitudinal axis, in order to verify if the ω photo-production process is more probable when beam and target spins are in the parallel configuration or in the anti-parallel one. The helicity asymmetry E can be written as:

$$E = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

and the results could have a first intuitive interpretation: if $E < 0$, the production of ω goes mainly through S = 3/2 amplitudes; if $E > 0$, the production of ω goes mainly through S=1/2 amplitudes. Results from CBELSA/TAPS show that the helicity asymmetry is mainly negative. They are compared with predictions from Bonn-Gatchina model [12]. The red line correspond to predictions where only t-channel exchange contributions are considered. The green line include also s- and u-channel terms: in particular, it includes the contribution of two P_{13} resonant states. The model predicts E being positive, on the contrary of what is experimentally observed. Also in the case of the helicity asymmetry E, the inclusion of the experimental results in the data based of couple-channel analysis is encouraged.

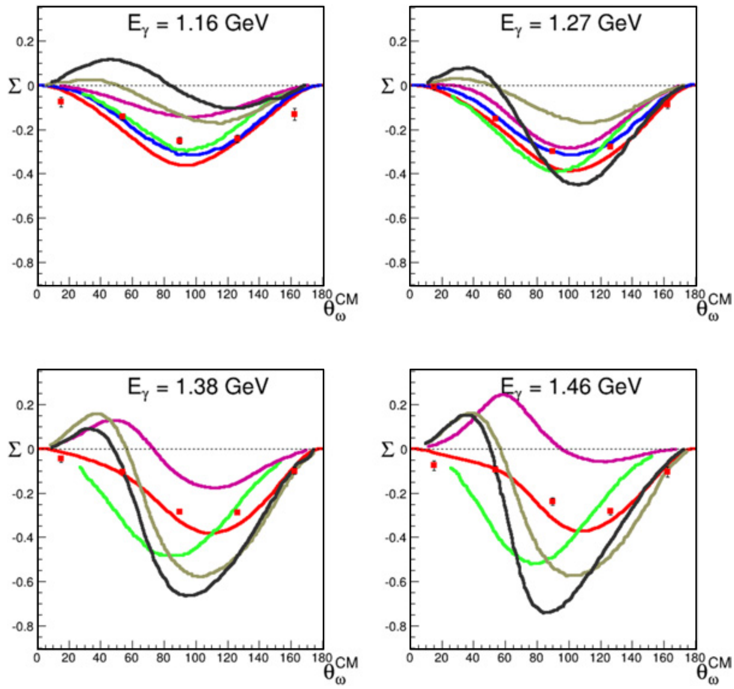

Figure 4. Results from the new analysis of the GRAAL collaboration [10] (red squared, $\omega \to \pi^0\gamma$) compared with several theoretical descriptions (same legend as in Fig. 3).

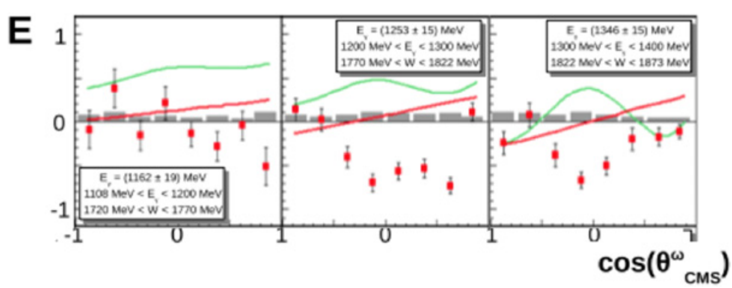

Figure 5. Results for the helicity asymmetry E in ω photo-production off proton by the CBELSA/TAPS collaboration [11]. Results are compared with predictions from Bonn-Gatchina [12]. Red line: only t-channel exchange contribution. Green line: contributions also from s- and u-channel.

5. Conclusion

It has been pointed out that measured total and differential cross sections of ω photo-production show the importance of resonant contributions in the s-channel of the reaction and of t-channel exchange terms, respectively. The only way to access more detailed information about the processes involved in the production of ω's consists in the measurement of polarization observables.

At first, the measurement of the angular distributions of the decay products of the ω meson allows to estimate the contribution of natural/unnatural parity exchange terms in the t-channel. It has been discovered that π^0 exchange is dominant at threshold, while it was know to be negligible at higher energies ($\sqrt{s} > 5\,\text{GeV}$).

At second, polarization observables help in the identification of the resonant state contributions. The models are not able to describe the experimental results on Σ [10] and on E [11] and the inclusion The models have to be constrained by high precision experimental results and by results on new polarization observables. They are not able to describe the experimental results on Σ [10] and on E [11] and the inclusion of these new data in the data base of coupled-channel analysis is encouraged.

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