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ω PHOTOPRODUCTION AT GRAAL

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The study of meson photoproduction on the nucleon is a very important tool to complete the puzzle of baryon excited states. GRAAL aim is the measurement of cross sections and of beam asymmetries for all the photonuclear reactions accessible in the energy range from 600 MeV up to 1.5 GeV. In the following preliminary results of the Σ beam asymmetry for ω photoproduction on the free proton in Hydrogen and on the quasi-free nucleon in Deuterium are shown. GRAAL is the first experiment in which both the charged and the radiative decay of ω meson are studied. Since the beam asymmetry is independent of the decay mode, the comparison of the results from the two channel allows an important check on data consistency. Results on the free proton are in good agreement with theoretical prediction from Zhao model and confirm the presence of $P_{13}(1720)$ state. The analysis performed for the radiative decay is applied to the process of ω photoproduction on the quasi free nucleon in Deuterium.

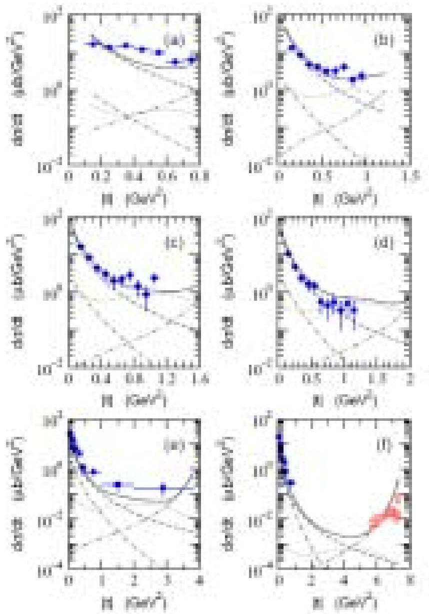
1. Introduction

A deep understanding of the nucleon structure and of the baryonic spectrum plays a fundamental role in extracting information on the quark interactions at low energy. In the energy range corresponding to the resonances region it is not possible to use a perturbative QCD approach and Constituent Quark Models (CQMs) have been introduced to describe the observed baryonic spectra.[1] First studies of the nucleon resonances were performed using pion probes which gave access to the experimental observation of those excited states that are well coupled to the pion channel. Most of the theoretical spectra predict the existence of more excited states than the observed ones. The un-observed states are often called *missing resonances* and are thought to have a week pion coupling. Their existence may be searched using electromagnetic probes and looking for final states including pseudo-scalar and/or vector mesons.[2] This is the research field in which GRAAL experimental activity takes place. In the following preliminary results on ω photoproduction on the nucleon at GRAAL will be shown.

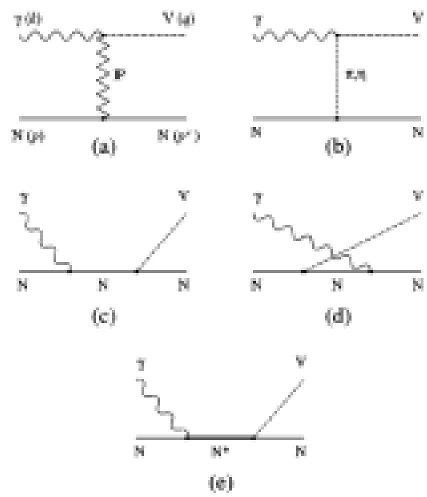
2. The Reaction $\gamma + p \rightarrow \omega + p$: Previos Results

First cross section measurements for the ω photoproduction process on the proton were performed by Crouch, Eisenberg and Ballam in '60s-'70s. In Fig.1(a) differential cross sections are showed as a function of the module of the transferred quadri-momentum t for different incident photon enrgies, in logarithmic plots.[3] It can be observed that the differential cross sections quickly fall off with the increasing of t with a typical diffractive behaviour. This behavior is explained in term of reaction mechanisms in the t channel. The first term is the t channel exchange of a particle having the same quantum numbers of the vacuum called Pomeron (Fig.1(b).a); it is an exchange with parity $P = (-1)^J$, the so-called natural parity. The second term is the t channel exchange of a pseudo-scalar meson (fig.1(b).b). It is an exchange with parity $P = (-1)^{J+1}$, the so-called unnatural parity. The contribution of the Pomeron exchange and of the pseudo-scalar meson exchange terms are shown in Fig.1(a) with dot-dashed and dashed line, respectively. The behaviour of the differential cross-sections for higher values of t is ascribed to the reaction mechanisms in the s and u channels: the direct or crossed Born terms and the presence of intermediate resonant states (Fig.1(b).c; 1(b).d and 1(b).e). The contribution of s and u channels terms in general and of the resonant intermediate states in particular can be easier observed in another polarization observable: the Σ beam asymmetry. In Fig.2, theoretical predictions from the Zhao model for the Σ beam asymmetry for ω photoproduction on the proton are showed.[4]

The Σ beam asymmetry should be flat and null if the only contribution of reaction mechanisms in the t channel is taken into account. If also contributions from s and u channels terms are regarded, an angular distribution of the Beam Asymmetry for different energy values can be observed (solid line in Fig.2). In particular the beam asymmetry seems to be sensible also to the contribution of individual



(a) Differential cross sections for $\gamma p \to \omega p$ reaction as a function of $|t|$ at E_γ = (a) 1.23 GeV, (b) 1.45 GeV, (c) 1.68 GeV, (d) 1.92 Gev, (e) 2.8 GeV and (f) 4.7 GeV. Theoretical calculations: pseudoscalar-meson exchange (dashed); Pomeron exchange (dot-dashed); direct and crossed nucleon terms (dot-dot-dashed); N^* excitation (dotted); the full amplitudes (solid line).



(b) Diagrams of the reaction mechanisms involved in the ω photoproduction reaction on the nucleon: a) Pomeron exchange in the t channel; b) pseudo-scalar meson in the t channel; c) Born term; d) crossed Born term; e) intermediate resonant states in the s channel.

Fig. 1. Differential cross sections and production reaction mechanisms in ω photoproduction on the nucleon.

intermediate resonant states such as the $P^{13}(1720)$. In fact the predictions for the angular distribution significantly change, if the contribution of this resonant state is negletted (dotted line in Fig.2). The measurement of the Σ beam asymmetry in ω photoproduction on the proton allows the extraction of informations on the contribution of intermediate resonant states involved in the photoproduction mechanism.

3. GRAAL Experiment

3.1. *The photon beam*

GRAAL experiment was located at the European Synchrotron Radiation Facility (ESRF) in Grenoble and it has been closed in December 2008. It has a polarized

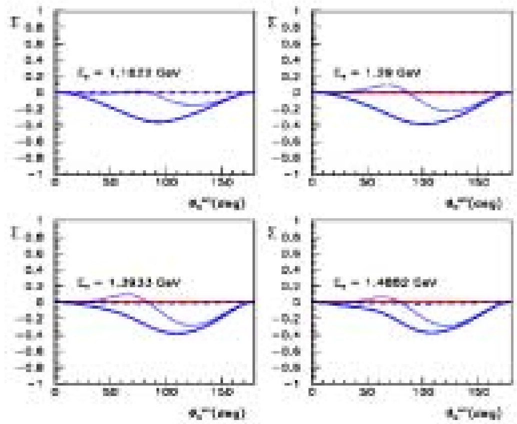


Fig. 2. Theoretical predictions of the Σ beam asymmetry for ω photoproduction from Zhao model: contributions from the t channel with dashed line; contributions from s and u channels with solid lines; contribution from s and u channel without the the contribution from the $P_{13}(1720)$ resonant state with dotted line.

photon beam which cover an energy range from 500 MeV up to 1.6 GeV that corresponds to the second and the third resonance regions. The polarized photon beam is obtained by the Compton backscattering technique of linearly polarized photons from an Argon laser against the electrons circulating inside the ESRF storage ring with an energy of 6.04 GeV. Since the electrons are ultra-relativistic particles, for the helicity conservation the backscattered photon must curries out an important fraction of the incident photon polarization. Moreover a half lambda plate is placed after the laser to rotate the photon beam polarization of 90°, from vertical to horizontal. The rotation is performed each 20 minutes to collect the two datasets (vertical and horizontal polarization) in the same experimental conditions. The backscattered photon energy measurement is performed with an internal tagging device with a resolution of 16 MeV of FWHM.

3.2. *LAGRANγE detector*

Once the polarized photon beam is produced and tagged, it impinges on a liquid Hydrogen or Deuterium target where photonuclear reactions take place. The almost 4π LAGRANγE detector is placed around the target. The detector can be divided into two parts: the central part consists of 2 cylindrical wire chambers for the tracking of charged particles, a plastic scintillator barrel for proton-pion discrimination and the BGO electromagnetic calorimeter for photon detection; the forward part consists of 2 planar wire chambers for tracking of charged particles, a plastic scintillator wall for proton-pion discrimination and a sampling calorimeter wall for photon-neutron discrimination.

The most important characteristics of GRAAL detector for the study of ω photoproduction processes are: an excellent photon detection with an energy resolution of 3% of FWHM at 1 GeV, due to the very high performance of the BGO electromagnetic calorimeter; a good energy measurement for the proton both from the BGO in the central part and from ToF measurement in the forward direction; a good neutron energy measurement from its ToF in the forward direction; very good resolution for the charged particles angular coordinates ($\Delta\theta \simeq 2°; \Delta\phi \simeq 2°$).

3.3. *The extraction of the Σ beam asymmetry at GRAAL*

The differential cross section of a polarized reaction can be expressed in terms of the unpolarized one

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

where P is the polarization degree of the photon beam (that is known if it is known the photon beam energy) and $\Sigma\left(\theta^*_\omega, E_\gamma\right)$ is the Beam Asymmetry; ϕ is the azimuthal angle of the reaction plane in the laboratory system. The experimental distribution of the number of selected events with a given polarization ($N_{V,H}$) is related to the flux of incoming photons with the same polarization ($K_{V,H}$), and to the detection and events reconstruction efficiency ($\varepsilon(\phi)$):

$$N_{\parallel,\perp}\left(E_\gamma, \theta^*_\omega\varphi\right) = K_{\parallel,\perp}\left(E_\gamma\right)\varepsilon(\phi)\left(1 \mp P\Sigma\left(\theta^*_\omega, E_\gamma\right)\cos(2\phi)\right)$$

The Σ Beam Asymmetry can be extracted in an efficiency independent way by considering the ratio of the number of selected events for the vertical polarization normalized by the flux, over the sum of the same quantity for vertical and horizontal polarization for fixed values of the energy and of the polar coordinate:

$$\frac{\frac{N_V}{K_V}}{\frac{N_V}{K_V} + \frac{N_H}{K_H}} = \frac{1}{2}\left(1 + P\Sigma\cos(2\phi)\right)$$

A typical azimuthal distribution of this ratio for ω photoproduction on free proton is reported in Fig.3.

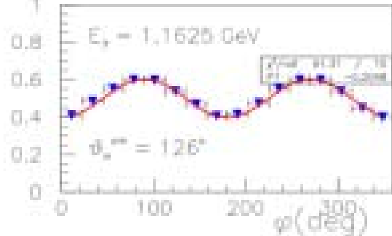


Fig. 3. The azimuthal distribution for the extraction of the Σ beam asymmetry.

4. ω Photoproduction on Free Proton

The ω meson is characterized by two most important decay channels: the charged decay ($\omega \rightarrow \pi^+\pi^0\pi^-$) with 88.8% of branching ratio and the radiative decay ($\omega \rightarrow \pi^0\gamma$) with 8.5% branching ratio. At the present, GRAAL is the only experiment which analyses both the charged and the radiative decay of the ω meson. Fist efforts have been performed for the study of the radiative decay, since the detector is optimized for photon detection. Then the study of the charged decay allowed an important increasing of the statistics. The Beam Asymmetry is related to the production mechanism so it is independent from the decay investigated. A comparison of the results obtained for the two decay modes is an important check on procedures and data consistency.

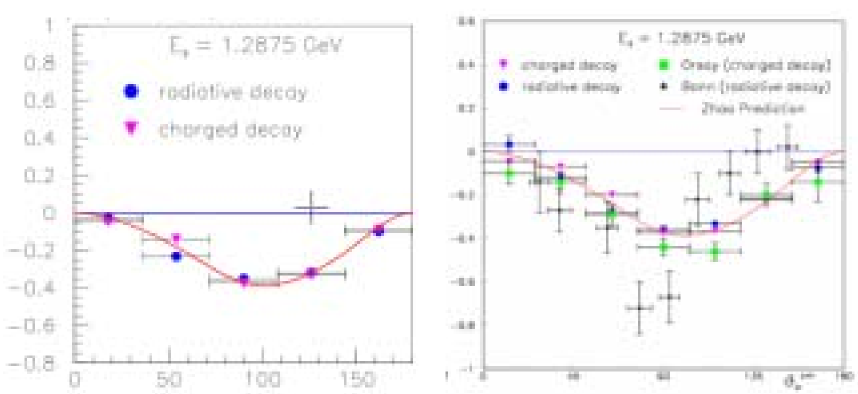
The main background for ω photoproduction - when ω is identified by its radiative decay - comes from the following competitive reactions:

$$\vec{\gamma} + p \rightarrow \pi^0 + \pi^0 + p \quad ; \quad \vec{\gamma} + p \rightarrow \Delta^+ + \pi^0 \rightarrow \pi^0 + \pi^0 + p$$

when a photon in the final state is missed; or

$$\vec{\gamma} + p \rightarrow \pi^0 + p$$

when a false signal of the detector is interpreted as a third photon in the final state. In both cases events of ω photoproduction can be selected by kinematical



(a) GRAAL results for ω photoproduction on the free proton for the radiative (blue full circles) and the charged (plum full triangles) decay.

(b) Comparison with previously published results for ω photoproduction on free proton. Results from: the radiative decay (blue full circles); the charged decay (plum full triangles); Orsay (green full squares); Bonn (black full stars).

Fig. 4. Results for the Σ beam asymmetry for ω photoproduction on free proton.

considerations. When the charged decay is investigated, the competitive channels are:

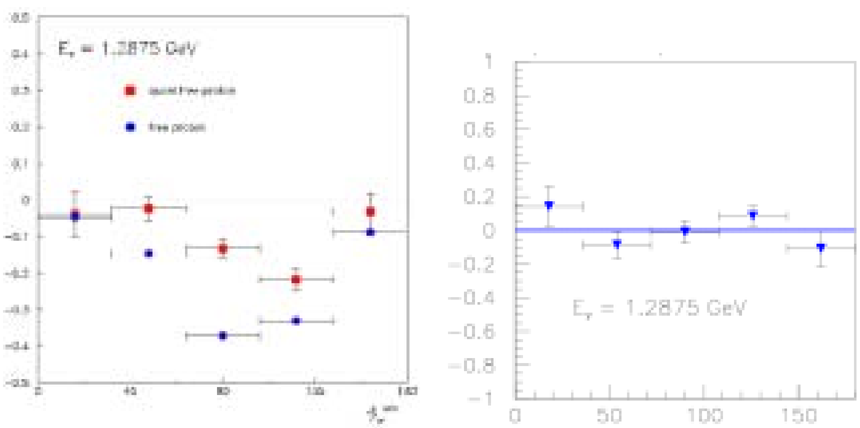
$$\vec{\gamma} + p \rightarrow \pi^+ + \pi^0 + \pi^-$$

$$\vec{\gamma} + p \rightarrow \eta + p \rightarrow \pi^+ + \pi^0 + \pi^-$$

They are physical background for this reaction and there is no way to disentangle events of ω photoproduction from the background. In this case a fitting procedure is necessary to estimate the number of ω events. As an example, preliminary results on the Beam Asymmetry for a single energy bin are shown in Fig.4. The comparison between results from radiative decay (blue full circles) and charged decay (plum full trianlges) in Fig.4(a) shows that the two independent analysis give results in a very good agreement and it is a very important check on data and procedure consistency. The comparison with previously pubblished results is shown in Fig.4(b). Data are compared with Orsay results and Bonn results.[56] In both cases not a very good agreement is observed.

5. ω Photoproduction on Quasi-Free Nucleon in Deuterium

In the case of quasi-free nucleon in Deuterium, the only radiative decay is studied with the same procedure used for the free proton case. Preliminary results for the



(a) Results on the Σ beam asymmetry in ω photoproduction on the free proton (blue full circles) and the quasi-free proton (red full squares). These previous resulsts suggest that final state interaction can not be neglетted for the quasi-free proton.

(b) Very preliminary results for the Σ beam asymmetry for ω photoproduction on quasi-free neutron. An increasing of the statistics is required to a more clear interpretation of the results.

Fig. 5. Resulst on the Σ beam asymmetry in ω photoproduction on the quasi-free nucleon in Deuterium.

quasi-free proton (red full squares) are compared with results on the free proton (blue full circles) in Fig.5(a). Results seem to show that final state interactions can not be negletted in the quasi free proton case. Then results for the quasi-free neutron can not be used to infer results for the free neutron case. Further efforts to study ω photoproduction on the quasi-free nucleon are needed. A better identification of the selection creteria is under investigation for the quasi-free proton case. The increasing of the statistics for the quasi-free neutron case is required to obtain more stable results.

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