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MESON PHOTOPRODUCTION ON THE NEUTRON AT GRAAL

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Using a Deuterium target, the GRAAL experiment has collected meson photoproduction data. The data have been analysed in the quasi free regime. The results of the quasi free process on the proton reproduce quite well the results previously obtained with a Hydrogen target. The preliminary results on the quasi free neutron for π^0 and η photoproduction are presented and discussed.

1. Introduction

In recent years the development of high duty-cycle accelerators coupled with the use of large solid angle detectors has allowed to obtain a large wealth of experimental information in the study of the photo and electroproduction of mesons from the proton. The attempt is to try and extract from photoproduction variables some of the properties (and sometimes the actual existence) of the excited nucleon states that cannot be accessed via pion scattering, either because the resonances largely overlap, or beacause of a weak coupling to the specific pion-nucleon channel.

Polarisation degrees of freedom in photoproduction processes play a crucial role, offering a complementary approach to the barion spectroscopy and are particularly important as they are very sensitive to the details of the interaction, via an interference mechanism allowing to access resonance properties that are difficult to extract from differential cross section measurements where a single contribution often dominates the transition amplitude[1,2,3,4].

The detailed description of the photon-nucleon interaction requires a complete data set containing, at least, eight independent observables: the cross section, the

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three single polarisation observables (beam, target and recoil nucleon) and four, appropriately chosen, double polarisation observables[5]. The properties of the resonances can then be extracted from the photoproduction data via partial wave analysis and multipole decomposition, in the framework of different approaches[6,3] and the comparison of the calculated observables to the experimental data becomes a strong constraint to the theoretical models[4,7] determining the role and the properties of the included resonances.

The Graal collaboration undertook this experimental task in the last few years, providing a large amount of precise polarisation data (Σ beam asymmetries) and cross sections for various meson photoproduction reactions on the proton. In particular, the π^0 and η photoproduction were studied in the 550-1500 MeV energy range[8,9,10] bringing essentials constraints to the theoretical models and to partial wave analysis[11].

In order to bring in complementary information and towards a full multipole analysis including the isospin structure, data on meson photoproduction from the neutron are of the utmost importance. The simplest way to perform this task experimentally is to use a Deuterium target and to analyse the collected data in the quasi free kinematical regime where one of the target nucleons acts as a spectator to the photoproduction process occurring on the other nucleon.

2. Experimental Set-up

The Graal experiment is based on the use of a monochromatic and polarised photon beam obtained through the Compton back scattering of laser light out of the 6.04 GeV electrons circulating in the ESRF storage ring. A full description of the beam characteristics can be found in[10]. The coupling of the Graal beam with a large acceptance detector covering $0.95 \cdot 4\pi$ solid angle with cylindrical simmetry (Lagranγe) is the ideal tool in order to measure polarisation degrees of freedom, in particular Σ beam asymmetries, with reduced systematic errors. The Lagranγe detector is divided in two parts: a central part based on the BGO *Rugby ball* calorimeter that covers laboratory angles $25^o < \theta_{lab} < 155^o$ and has an excellent energy resolution for photons[12] and a high detection efficiency (∼60%) for neutrons[13] and a forward part($\theta_{lab} < 25^o$) equipped with two plane wire chambers, two scintillator walls and a *Forward shower* detector having a good neutron detection efficiency (∼22%) with momentum determination via time-of-flight measurement (∼750 ps resolution for neutrons)[14].

3. Data Analysis

The Graal experiment collected data with a 6 cm lenght Deuterium target in three different periods, from november 2003 to december 2005. Both the 514 nm green line (giving rise to a 550-1100 MeV tagged photon beam) and the 351 nm UV line (800-1500 MeV tagged photons) from the Argon laser were used producing typical γ intensities of $\sim 2 \cdot 10^6 s^{-1}$. Data taking was triggered by the coincidence between a tagging signal and the total energy measured by the *Rugby ball*, the latter being required to be greater than 160 MeV. This condition gave rise to a data acquisition rate $\sim 100s^{-1}$.

The beam polarisation direction can easily be modified by rotating the laser polarisation. During data taking the polarisation was rotated approximately every 20 minutes by 90^o defining two orthogonal polarisation states, parallel ($\|$) and perpendicular ($\perp$).

Data on the photoproduction from quasi free protons and from quasi free neutrons were simultaneously recordered and analysed in a similar way: two neutral signals in the BGO *Rugby ball* were required to produce the π^0 invariant mass in the range $0.09 - 0.175 GeV/c^2$ or the η invariant mass in the range $0.35 - 0.70 GeV/c^2$ (initial preliminary selection). The chosen range allows to estimate clearly the background under the π^0 (η) peak (Fig. 1).

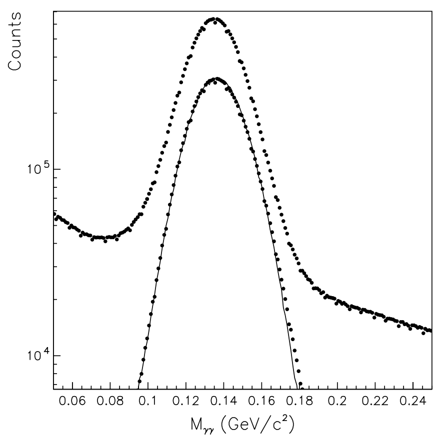

Fig. 1. Invariant mass of the two photons from π^0 decay before and after the kinematical cuts.

Together with the two photons in the BGO, a proton or neutron signal was required to be detected either in the forward direction (in that case the proton being identified via ΔE vs. T.O.F. and the neutron requiring a T.O.F. greater than 13.5 ns), or in the BGO *Rugby ball* itself (The proton being identified via E vs. ΔE and the candidate neutron by requiring crystal multiplicity less than five). The quasi free kinematic was selected by excluding all the events containing any other signal in the detector. The following event selection requires the fulfilment of the two body kinematics for the π^0 (η) and the nucleon participating to the reaction, indicated with N:

(1) $\Delta\theta$ vs. $\Delta\phi$ where $\Delta\theta = \theta_N - \theta_M$ is the difference between the measured participant nucleon polar angle and the polar angle required to fulfill the two-body kinematics calculated from E_γ, the measured energy E_m^{meson} and the meson production angle, while $\Delta\phi$ is the difference of the measured azimuth angles of the photoproduced meson and N.

(2) the ratio E_c^{meson}/E_m^{meson} vs. M_x where E_c^{meson} is the meson energy calculated from the meson and N measured angles and M_x is the missing mass calculated from E_γ and $E^m eson_m$.
(3) when the nucleon is in the forward direction ($\theta_N < 25^o$) the difference between the measured and the calculated time-of-flight vs. the energy balance $E_b = E_\gamma + m_N - E_{meson} - E_N$

The distributions are fitted with a bidimensional gaussian function: the means μ_1, μ_2 and the standard deviations σ_1 and σ_2 of the generic variables v_1 and v_2 are obtained. If the two gaussians are uncorrelated the cut applied to v_1 and v_2 is: $\frac{(v_1-\mu_1)^2}{\sigma_1^2} + \frac{(v_2-\mu_2)^2}{\sigma_2^2} < K$. If the two variables are correlated, the correlation parameter C is extracted and the cut is defined as $\frac{(v_1-\mu_1)^2}{\sigma_1^2} + \frac{(v_2-\mu_2)^2}{\sigma_2^2} - 2C\frac{(v_1-\mu_1)(v_2-\mu_2)}{(\sigma_1\sigma_2} < K$, where K is empirically determined and its value is K=6 for π^0 and K=9 for η.

Since the backgrounds and the detector resolutions are a function of the energy of the incoming photon, the cuts are extracted and applied as a function of the energy bins. Once the events are selected the beam asymmetry $\Sigma(E_\gamma,\theta_{cm})$ can be extracted from the behaviour of the ratio:

$$\frac{N_\parallel/k_\parallel}{N_\parallel/k_\parallel + N_\perp/k_\perp} = \frac{1}{2}\left(1 + P\Sigma cos(2\phi)\right), \tag{1}$$

where $N_\parallel$, $N_\perp$ are the counts obtained with the two beam polarisation states, $k_\parallel$, $k_\perp$ the corresponding beam intensities, $P(E_\gamma)$ is the degree of linear polarisation of the beam at a given energy, $\Sigma(E_\gamma, \theta_{cm})$ is the asymmetry as a function of the incoming photon energy and of the center of mass angle of the meson and ϕ is the meson azimuthal angle. For each energy bin the obtained distribution is fitted and $\Sigma(E_\gamma, \theta_{cm})$ is obtained. In Fig. 2 two examples of such distributions are given.

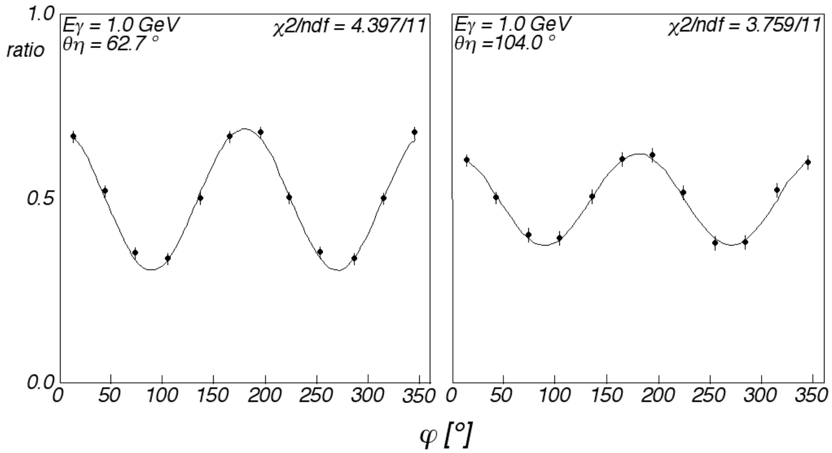

Fig. 2. The azimuthal distribution of the ratio (1) for the η photoproduction on the quasi free proton (*left*) and quasi free neutron (*right*) in the given bin of E_γ and θ_η^{cm}.

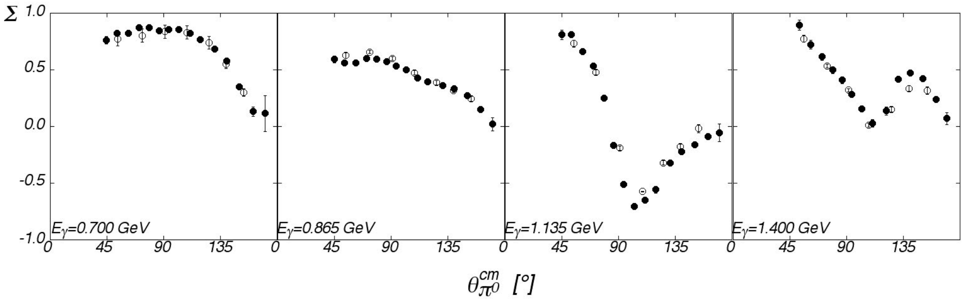

Fig. 3. Comparison of the Σ beam asymmetries for π^0 photoproduction on the free proton (black dots) and quasi free proton (open dots). The data are preliminary.

4. Results

In Fig. 3 the results on the beam asymmetry obtained from the quasi free proton are compared to the values obtained by the Graal Collaboration on the free proton[10] for the photoproduction of π^0. In Fig. 4 the same comparison is performed for the η photoproduction channel (previous data from Ref. 8). Here the comparison is performed at a fixed angle θ_{cm} as a function of the energy of the incoming photon (the energy of the two data sets being slightly different).

We can see that for both photoproduction processes the asymmetry values obtained from the quasi free proton reproduce well the values obtained from the free proton. We can say, insofar as the beam asymmetry is considered, that the proton bound in the Deuteron behaves as a free proton when the quasi free kinematical regime is selected. Bearing this in mind we can now consider the results of the meson photoproduction on the quasi free neutron representative of the "free neutron" case. In Fig. 5 the Σ beam asymmetry for the π^0 photoproduction on the neutron is compared with the MAID2003[15] and SAID standard solution[16] predictions. The beam asymmetry is always positive at all energies and angles. We can see that there

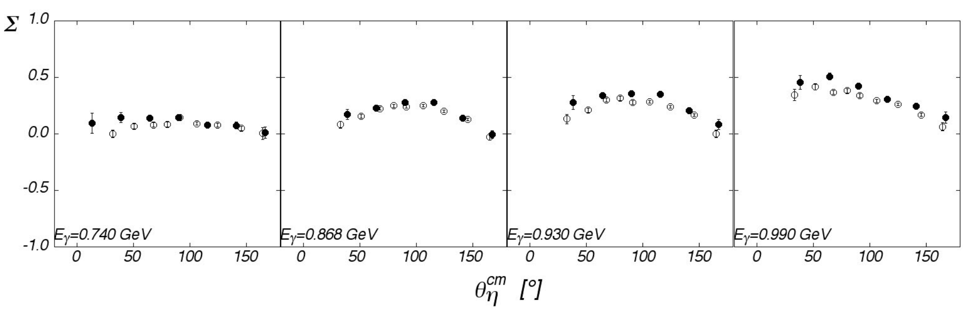

Fig. 4. Comparison of the Σ beam asymmetries for η photoproduction on the free proton (black dots) and quasi free proton (open dots).The data are preliminary.

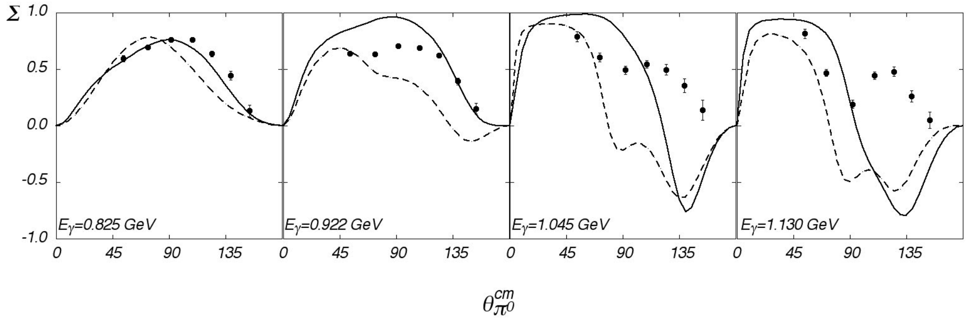

Fig. 5. Preliminary data of the Σ beam asymmetry for the π^0 photoproduction on the neutron compared with the MAID2003 (full line) and SAID standard solution (dashed line) predictions.

is a reasonable agreement with the data at low energies, but above $\sim$ 900 MeV the two predictions, be they in excellent agreement with the experimental data in the case of the free proton for all energies and angles[10], fail to reproduce the data, both underestimating the asymmetry especially at backward angles.

In Fig. 6 the results obtained for the beam asymmetry for η photoproduction are compared with the available MAID2001 prediction, that overestimates the Σ values especially in the range from 950 to 1250 MeV. The η photoproduction from the nucleon can proceed only through isospin I=1/2 intermediate states. The failure of the MAID2001 prediction in the case of the neutron (differently from the proton case) in describing the beam asymmetry is representative of the need to introduce other N^* resonances in the calculation of the reaction amplitude. This need is further reinforced if we consider the results presented in Fig. 7: here the total center-of-mass energy of the η-p and η-n systems is compared in the case of backward-angles ($110^o < \theta_{cm} < 140^o$) η photoproduction. A narrow peak appears in the case of photoproduction from the neutron around 1650 MeV/c^2. This peak is absent

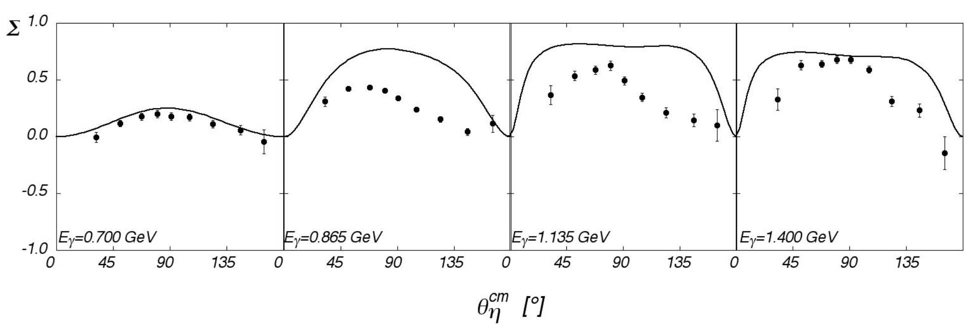

Fig. 6. Σ beam asymmetry for the η photoproduction on the neutron compared with the MAID2001 predictions. Preliminary data.

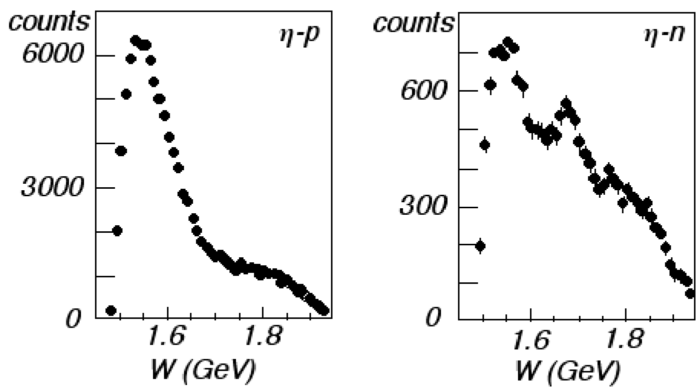

Fig. 7. total center-of-mass energy for η-p (*left*) and *eta*-n (*right*) systems when the η meson is detected between 110 and 140 degrees.

when the photoproduction from the proton is considered. The interpretation of this peak is controversial: its width is small and most of the detected width can be ascribed to the Fermi motion and to the detector resolution.

The role of the D_{15} (1675) intermediate state in η photoproduction is discussed by Tiator[17]. Its coupling to the η-neutron channel is dramatically dependent on the model: the modified isobar model MAID2003 gives a good representation of the cross section but not of the beam asymmetry and needs a large η-n branching ratio while in the corresponding reggeized model the D_{15} does not play any important role. The observed resonant structure could also be ascribed to a P_{11} narrow state (non-strange crypto-pentaquark) belonging to the anti-decuplet proposed by Diakonov *et al.*[18] but with a slightly lower mass and with a very high (40%) branching ratio to the η-neutron channel[19]. In any case, further experimental investigation is needed and particularly the precise determination of the differential cross sections.

5. Conclusions

The GrAAL experiment is producing precise data on the Σ beam asymmetry in the photoproduction of the pseudo-scalar mesons π^0 and η from quasi free nucleons. Some preliminary data based on the analysis of a reduced data set are presented here. For both reactions the values obtained for the quasi free proton (bound in Deuteron) case reproduce well the values obtained with a Hydrogen target and are well described by the available theoretical predictions. When the Σ beam asymmetry on the neutron is considered, the situation changes and the available models fail to reproduce the data above 900 MeV incoming photon energy. Moreover, an unexpected narrow peak appears in the final state total energy when the η photoproduction from the neutron is selected at backward angles. The nature of this peak is not clear and needs further experimental investigation (mainly differential cross sections and more statistics) before reaching any definite conclusion.

References

1. M. Benmerrouche, N.C. Mukhopadhyay, J.F. Zhang, *Phys. Rev. D* **51**, 3237 (1995).
2. B. Saghai, F. Tabakin, *Phys. Rev. C* **55**, 917 (1997).
3. D. Drechsel, O. Hanstein, S.S. Kamalov, L. Tiator, *Nucl. Phys. A* **645**, 145 (1999).
4. T. Feuster, U. Mosel, *Phys. Rev. C* **59**, 460 (1999).
5. W.-T. Chiang, F. Tabakin, *Phys. Rev. C* **55**, 2034 (1997).
6. R.A. Arndt, I.I. Strakowsky, R.L. Workman, *Phys. Rev. C* **53**, 430 (1996).
7. B. Saghai, Z. Li, *Eur. Phys. J. A* **11**, 217 (2001).
8. J. Ajaka *et al.* [GrAAL Collaboration], *Phys. Rev. Lett.* **81**, 1797 (1998).
9. F. Renard *et al.* [GrAAL Collaboration], *Phys. Lett. B* **528**, 215 (2002).
10. O. Bartalini *et al.* [GrAAL Collaboration], *Eur. Phys. J. A* **26**, 399 (2005).
11. A.V. Anisovich *et al.*, *Eur. Phys. J. A* **25**, 427 (2005).
12. P. Levi Sandri *et al.*, *Nucl. Instr. and Meth. A* **370**, 396 (1996).
13. O. Bartalini *et al.*, *Nucl. Instr. and Meth. A* **562**, 85 (2006).
14. V. Kouznetsov *et al.*, *Nucl. Instr. and Meth. A* **487**, 128 (2002).
15. "MAID web page" *http://www.kph.uni-mainz.de/MAID/.*
16. "SAID web page" *http://gwdac.phys.gwu.edu/.*
17. L. Tiator, Contribution to this Proceedings.
18. D. Diakonov, V. Petrov, M. Polyakov, *Z. Phys. A* **359**, 305 1997.
19. Y. Azimov *et al.*, *Eur. Phys. J. A* **25**, 325 (2003).