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Measurement of the cross-section asymmetry of deuteron photodisintegration process by linearly polarized photons in the energy range $E_\gamma = 0.8$–1.6 GeV

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Abstract. The first measurements of the cross-section asymmetry Σ for the deuteron photodisintegration process at a cm angle of 90° up to 1.6 GeV were performed at Yerevan Electron Synchrotron. These results are in reasonable agreement with previous measurements at lower energy. Our data show agreement with the asymptotic meson exchange model predictions in the energy range 0.8–1.6 GeV.

PACS. 25.20.Lj Photoproduction reactions – 24.70.+s Polarization phenomena in reactions – 21.45.+v Few-body systems

1 Introduction

The exclusive deuteron photodisintegration reaction is one of the important processes to study the problems of nuclear and particle physics.

In the low energy region $E_\gamma = 0.1$–0.6 GeV the process $\gamma d \to pn$ has been investigated over many years. Beginning from 1980 we study this process with polarized photons, measuring the asymmetry Σ [1], as well as in double polarization experiments [2] up to the photon energy $E_\gamma = 1.0$ GeV. The results were compared with various theoretical models, based on the meson, nucleon and isobar degrees of freedom [1].

During the last few years the interest in studying the process $\gamma d \to pn$ at energies above $E_\gamma = 1.0$ GeV is growing. This is mainly explained by the possible contribution of new degrees of freedom (quark, gluon) expected already at energies as small as $E_\gamma = 1.4$ GeV.

Such assumption is followed from the results of measurement performed at SLAC [3] and TJNAF [4] in the energy range $E_\gamma = 1.4$–4.0 GeV, where at $\theta_p{}^* = 90°$ a scaling-like behavior for the cross-section of the process $\gamma d \to pn$ was observed. This result is in agreement with the prediction of the constituent quark counting rules ($d\sigma/dt \sim S^{-11}$) [5].

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Theoretical models have been developed also for energies $E_\gamma > 1.0$ GeV trying to describe the existence of early scaling in the reaction $\gamma d \to pn$ within the framework of models based on meson-baryons [6–8] or quark-gluon degrees of freedom [9–11]. Among these models only two models, in the energy range up to $E_\gamma = 4$ GeV and the angular interval $\theta_p{}^* = 36°$–$90°$, seem to explain the behavior of the differential cross-section of the process $\gamma d \to pn$ [3, 4], the asymptotic meson-baryon exchange model and its modification [7,8], and the QCD rescattering model [11].

The authors of these two models note the necessity of the measurement of spin observables, which can give the possibility to discriminate between the single quark counting rules and the theoretical models.

Until now the theoretical predictions are existing only for the cross-section asymmetry Σ, of the process of photodisintegration of deuteron with linearly polarized photons at an energy E_γ above 1.0 GeV, in the asymptotic meson exchange model [7] and QCD model of nuclear reduced amplitude [9], where three possibilities are mentioned.

– Within the framework of deuteron photodisintegration asymptotic amplitude model with gauge invariance (GIAM) [7] based on the meson hadron degrees of freedom, it was assumed that the deuteron wave function, used for the computation, contains the nucleon $|NN\rangle$ and also resonance's configuration $|NN^*\rangle$. Together with some diagrams for the asymptotic am-

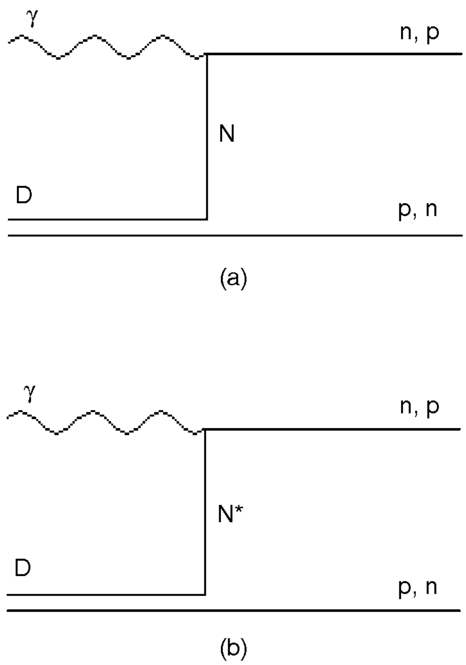

Fig. 1. Diagrams corresponding to the contribution of NN (a) and NN^* (b) configurations.

plitude of deuteron photodisintegration with contribution of NN configuration, fig. 1(a), there are also in fig. 1(b), the unique diagrams with contribution of resonance's configuration. The ratio of the dNN to the dNN^* vertex form factor $\mathrm{G}_{N(N^*)}$ in [7] is determined by a single parameter $\alpha(\alpha = \mathrm{G}_{N^*}/\mathrm{G}_N)$. In case of only NN configuration, $\alpha = 0$.

The dependence of the cross-section asymmetry Σ on E_γ was calculated in the GIAM model [7] for $\theta_\mathrm{p}{}^* = 90°$ in the energy range $E_\gamma = 1.0$–3.0 GeV and $\alpha = 0$ to 30. In the model [7] there is also a prediction for the angular dependence of Σ in the interval $\theta_\mathrm{p}{}^* = 0°$–$180°$ for two energies $E_\gamma = 1.5$ and 2.5 GeV for $\alpha = 0$ and $\alpha = 10$.

- Within the framework of the model based on deuteron photodisintegration meson theory, providing GI and the hadron helicity conservation (HHC) [7,9], the dependence of the cross-section asymmetry $\Sigma(90°)$ on E_γ was calculated in the energy range $E_\gamma = 1.0$–3.0 GeV [7].
- The hypothesis of hadron helicity conservation (HHC) [9], is an important assumption of perturbative QCD. For the process $\gamma\mathrm{d} \to \mathrm{pn}$ with polarized photons, HHC at the scaling regime, independently of the deuteron structure (description of the composite system), gives the value $\Sigma = -1$ ($\theta_\mathrm{p} = 90°$ cms) for the cross-section asymmetry [7,9].

In this paper we present the results of the measurement, for the first time, of the cross-section asymmetry Σ of the deuteron photodisintegration process by linearly polarized photons in the energy range $E_\gamma = 0.8$–1.6 GeV and $\theta_\mathrm{p} = 90°$ in the cms [12].

2 Instrumentation and methods

2.1 Experimental setup

The experiment was carried out on the linearly polarized photon beam generated by coherent bremsstrahlung of 4.5 GeV electrons of the Yerevan Synchrotron, on a internal 100 μm diamond crystal target [1]. The experimental setup is shown in fig. 2. The external beam is shaped by a system of collimators and sweeping magnets and it is $(10\times10)\,\mathrm{mm}^2$ wide at the target position. The beam monitoring system is based on the thirty-channel pair spectrometer (PS-30), which consists of a bending magnet, a set of removable converters and eleven telescopes of scintillation counters. The 6×5 unmixed combinations of the coincidences between the electron and positron telescopes of the PS-30 define the thirty measured energy points with regular steps $\Delta E_\gamma/E_\gamma = 2.2\%$ in the wide energy range $(E_\gamma{}^{\max} - E_\gamma{}^{\min})/E_\gamma = 0.7$, which allows the full bremsstrahlung spectrum above 0.15 GeV to be scanned by five measurements. During the experiment a particular emphasis has been placed on maintaining the stability of the coherent peak position (checks of the coherent peak were carried out every 40–50 s). Figure 3 shows results of a measurement of the coherent bremsstrahlung spectrum for $E_\mathrm{e} \approx 4.1$ GeV and $E_{\gamma^\mathrm{peak}} \approx 1.25$ GeV and the fig. 4, the corresponding calculated distribution of the polarization. The calculated mean polarization for the peak energy region is $\bar{P}_\gamma \approx 0.6$.

In this experiment the new liquid deuterium target of a 300 mm long has been used, that allows to increase the detection yield as compared the 90 mm one, used in previous experiments [1]. The protons are detected by the magnetic spectrometer (MS) consisted of a double focusing system, a bending magnet, a telescope of four trigger counters, three scintillation momentum hodoscope counters (H_1, H_2, H_3), consisting respectively of 8, 14 and 16 elements with the width of 26, 22 and 35 mm, allowing the full reconstruction of the momentum and the trajectory. The angular and momentum acceptances and corresponding resolutions of the MS are $\Delta\Omega = 7 \times 10^{-3}$ str, $\Delta P/P = 17\%$ and $\sigma_\theta = 1.3°$, $\sigma P/P \approx 1.8\%$, respectively. The protons are identified by the time of flight on the 9 m flight base. Time resolution about 1 ns is sufficient up to 1.8 GeV/c for $(\pi - p)$ separation.

The neutrons are detected by a time of flight hodoscope detector (NS-18) fig. 2, which was a 3×6 matrix (6 rows, 3 column) of scintillation counters, each $23 \times 23 \times 30\,\mathrm{cm}^3$ viewed by a photomultiplier at the end. Six anticoincidence counters (for the detection of charged particles) are mounted in front of NS, each counter covering wholly one line of 3 counters of the matrix. For the γ-quanta rejection a lead converter of the 2 cm thickness is placed in front of the veto counters.

The time-of-flight method between protons and neutrons arms fig. 5 is effective for the subtraction of the accidentals (the level of accidentals is below 25% in the considered photon energy range).

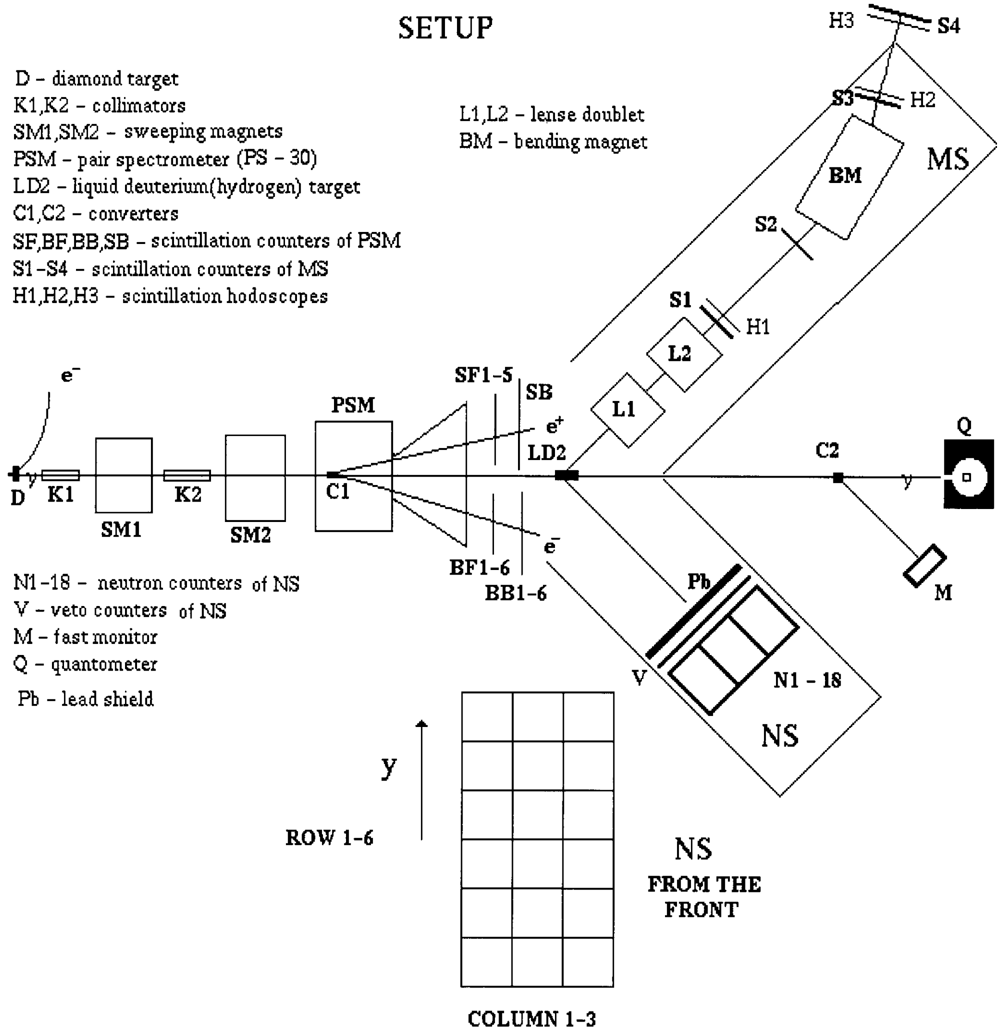

Fig. 2. Experimental Setup. In the frame, the neutron spectrometer NS-18 from the front.

2.2 Data analysis

The extraction of the $\gamma d \to pn$ process from the background of multiparticle processes ($\gamma d \to N\Delta$, $\gamma d \to \pi NN$ and $\gamma d \to \pi\pi NN$), caused by the high energy range of the bremsstrahlung spectrum fig. 3, is carried out based on the spectra of neutrons in NS-18 within and out of the kinematic region of the process $\gamma d \to pn$.

A Monte Carlo simulation was used to determine the kinematical range of the detection of the neutrons from the reaction $\gamma d \to pn$, and the shape of the multiparticles background contribution, as a function of the neutron azimuthal angle φ_n. The neutrons and protons were detected by the neutron (NS-18) spectrometer in coincidence with the magnetic spectrometer (MS) fig. 2, for the kinematics of the $\gamma d \to pn$ process at the cms angle $\theta_p = 90°$.

The simulation was carried out for the process $\gamma d \to pn$, and for the background reactions $\gamma d \to p\Delta(\Delta \to n\pi)$, $\gamma d \to pn\pi$ and $\gamma d \to pn\pi\pi$, within phase space approach (FOWL). Figure 6 shows the results of the calculation at photon energy $E_\gamma = 1.25\,\text{GeV}$.

Figure 6 shows the distribution of neutrons calculated by the Monte Carlo (MC) method for the three-multiparticle background and for the $\gamma d \to pn$ reactions detected in the 6 rows counters (each row containing 3 counters) of the NS-18 spectrometer, with the corresponding SDP (second-degree polynomial) fits. The normalization for the background has been carried out at the coordinate $Y = \pm 60\,\text{cm}$ of the neutron spectrometer, where the effects of multiscattering processes (multifiring and mixing [13], see below) from the neutrons of the reaction $\gamma d \to pn$ are minimal. The normalization for the (MC) of the $\gamma d \to pn$ has been done through the experimental yield of the reaction $\gamma d \to pn$ (see fig. 7).

As we can see in fig. 6 the measured value of the background, in the experiment, in the 4 rows of counters with the corresponding SDP fitted distribution, is closer in the shape to the neutron distribution of the reaction $\gamma d \to pn\pi$, than to the distribution of SDP fit of the reactions $\gamma d \to p\Delta(\Delta \to n\pi)$ and $pn\pi\pi$.

The observed increase of the measured background compared with the calculated one, can be connected with

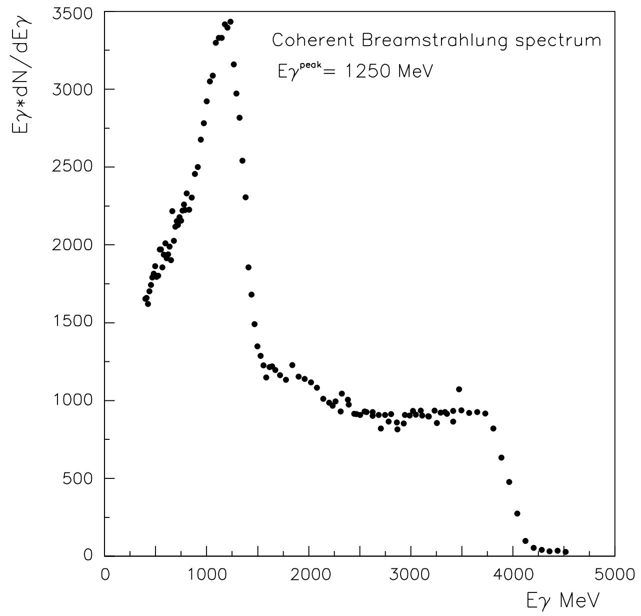

Fig. 3. The coherent bremsstrahlung spectrum for $E_e = 4.1\,\text{GeV}$ and $E_{\gamma\text{peak}} = 1.25\,\text{GeV}$ measured with the PS-30.

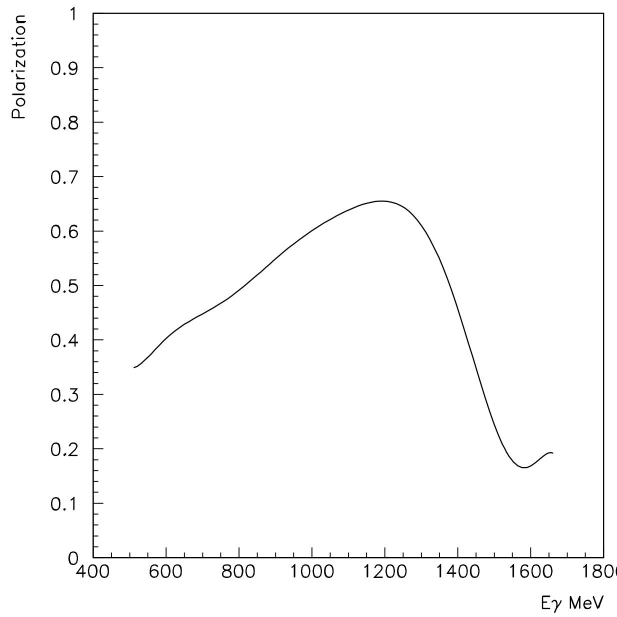

Fig. 4. The calculated energy distribution of the polarization for the peak energy region $E_{\gamma\text{peak}} = 1.25\,\text{GeV}$.

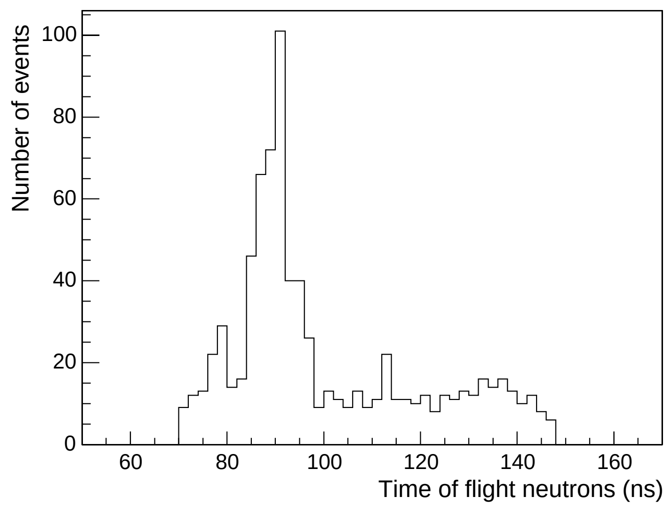

Fig. 5. TOF spectrum of the coincidence between the proton and neutron arms (zero of the time scale is arbitrary).

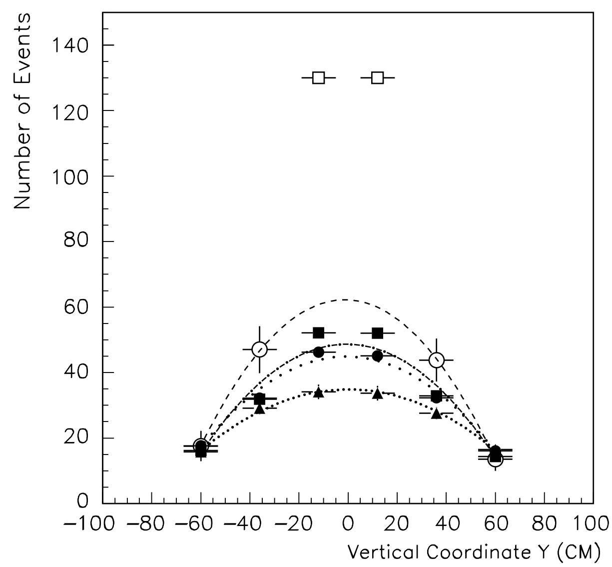

Fig. 6. Monte Carlo distributions of neutrons in the rows of NS-18 for the process: □ $\gamma\text{d} \to \text{pn}$, ● $\gamma\text{d} \to N\Delta$, ■ $\gamma\text{d} \to \pi NN$, $\gamma\text{d} \to \pi\pi NN$ and ◯ experimental background.

the multiscattering processes (multifiring and mixing) in hodoscope neutron detectors [13].

It is known that the number of events from the effects of multifiring and mixing is approximately proportional to the number of incident neutrons registered in the neutron counter. Consequently the contribution of multifiring and mixing processes in the background can be considered as being proportional to the yield of the reaction $\gamma\text{d} \to \text{pn}$.

Therefore, we note that the observed increase of the background due to multiscattering effects cannot lead to additional systematic error in the determination of the cross-section asymmetry (Σ) of the $\gamma\text{d} \to \text{pn}$ process (see the formula of Σ). This increase can only give, if there is no correction of these effects (our case), a drop of the real yields of neutrons.

Figure 7 shows (for $E_\gamma = 1.25\,\text{GeV}$) the measured distribution Y in 6 rows of neutron counters of the spectrometer NS-18, and the SDP fit of the experimental background contribution in the 4 rows of neutron counters. The background of the $\gamma\text{d} \to \text{pn}$ process was obtain by integrating this SDP fit curve in the interval $-24\,\text{cm} < Y < 24\,\text{cm}$ of central rows counters.

The level of the background in the range of detection of the process $\gamma\text{d} \to \text{pn}$ depends on the photon energy E_γ. In the energy interval of our experiment $E_\gamma = (0.8\text{–}1.6)\,\text{GeV}$, this background level has respectively, at maximum, the value (10–50)% (with an error $< 15\%$).

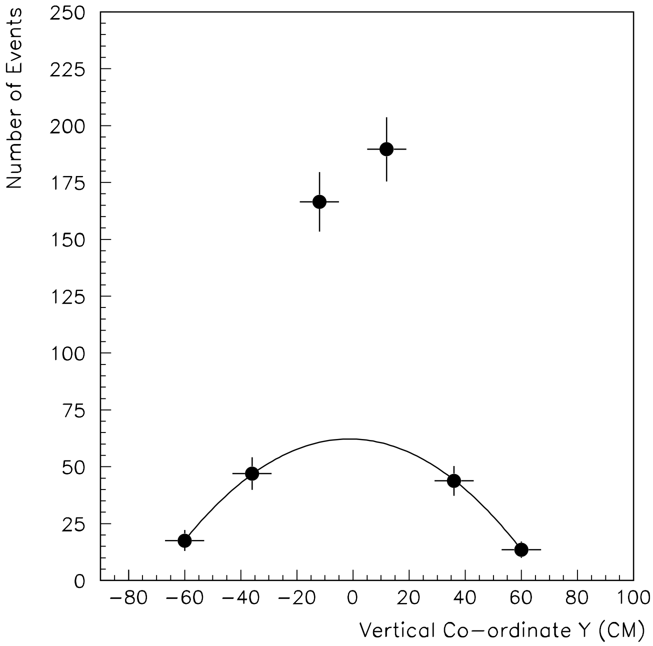

Fig. 7. Experimental distribution of the neutrons in the rows of NS-18. - The curve is the SDP fit of the background and • for experimental distribution.

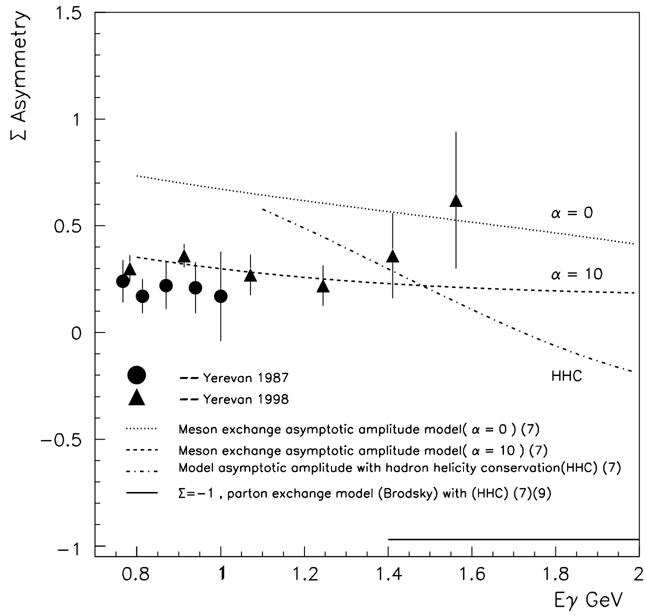

Fig. 8. The energy dependence of the cross-section asymmetry Σ for $\theta_p = 90°$ in the cms.

This method of determination of the experimental yields of the γd $\to$ pn reaction, is used in the cases of incident polarized photons (perpendicular $N\uparrow$, and parallel $N\to$ to the reaction plane).

The experimental normalized yields ($N_n \uparrow\to$) were obtained from the photons intensity spectra ($\mathrm{d}N_\gamma \uparrow\to /\mathrm{d}E_\gamma$) for each orientation, and the photon energy acceptance of the apparatus. The mean value of the photon polarization $\bar{P}(E_\gamma)$ has been calculated from the energy distribution of the polarization $P_\gamma \uparrow\to (E_\gamma)$ by the method described in [14].

3 Results and summary

The cross-section asymmetry Σ is determined using the reaction yield $N_n \to$ and $N_n \uparrow$ for photon polarization parallel and perpendicular to the reaction plane:

$$\Sigma = (N_n \to - N_n \uparrow)/(\bar{P}_\gamma \uparrow N_n \to + \bar{P}_\gamma \to N_n \uparrow), \quad (1)$$

where $\bar{P}_\gamma \uparrow$, ($\bar{P}_\gamma \to$) is the mean value of the photon polarization in the E_γ acceptance.

The data obtained for the asymmetry Σ in the kinematic range $E_\gamma = 0.8$–1.6 GeV and $\theta_p{}^* = 90°$ are presented in the fig. 8. The energy resolution RMS (E_γ) for the photons varies from 40 to 140 MeV depending on E_γ. The error bars include the statistical uncertainties and the uncertainty of the calculated photon polarization (5%).

Our results are compared with the predictions of theoretical models (see the introduction).

- For Σ we observe better agreement with the asymptotic meson exchange model predictions [7] in the measured energy range.
- We note a possible increase for Σ at $E_\gamma > 1.4$ GeV. This increase, if confirmed in future measurements, may indicate a change in the production mechanism for these energies. In the model GIAM [7] N^*-resonance's contribution is connected with the value of parameter α (see introduction). The calculated values of Σ in the case where NN^* configuration is absent ($\alpha = 0$), are for E_γ up to 2.5–3.0 GeV higher than those in the cases of $\alpha > 0$ (see in fig. 8 the values of Σ for $\alpha = 0$ and $\alpha = 10$). It would be interesting to see, if the observed possible increase of Σ is connected with the canceling of the N^*-resonance's contribution ($\alpha = 0$) in the amplitude of deuteron photodisintegration process for $E_\gamma > 1.4$ GeV.
- Our results in the energy range $E_\gamma = 1$–1.6 GeV show the values $\Sigma > 0$, in strong disagreement with the HHC hypothesis ($\Sigma = -1$). This result is the first test of HHC for exclusive photoreaction in the regime of scaling ($E_\gamma > 1.4$ GeV, for $\gamma_d \to$ pn).

In future work, we plan to reduce the statistical errors on Σ for energies higher than $E_\gamma = 1.4$ GeV and to make a measurement of Σ at $E_\gamma = 2$ GeV. We plan also to measure Σ at $E_\gamma = 1.5$ GeV and $\theta_p = 45°$ in the cms and compare this value with the corresponding predictions of the asymptotic meson exchange model [7].

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References

1. F.V. Adamian et al., JETP Lett. **39**, 239 (1984). J. Phys. G. Nucl. Part. Phys. **17**, 1189 (1991).
2. F.V. Adamian et al., J. Phys. G. Nucl. Part. Phys. **14**, 831 (1988). R.O. Avakian et al., Jadernaja Fizika **52**, 313, 618 (1990).
3. J. Napolitano et al., Phys. Rev. Lett. **61**, 2530 (1988). J. E. Beltz et al., Phys. Rev. Lett. **74**, 646 (1995).
4. C. Bochna et al., Phys. Rev. Lett. **81**, 4576 (1998).
5. V.A. Matveev et al., Lett. Nuovo Cimento **7**, 719 (1973). S.J. Brodsky et al., Phys. Rev. Lett. **31**, 1153 (1973).
6. T.S.H. Lee, ANL Report PHY-5253-TH (1988).
7. S.I. Nagorny et al., Sov. J. Nucl. Phys. **55**, 189 (1992). *Procedings of the 14th AIP Conference Few Body Problems in Physics Williamsburg 1994 (AIP, New York, 1994)*, p. 757.
8. A.E.L. Dieperink, S.I. Nagorny, Phys. Lett. B **456**, 9 (1999).
9. S.J. Brodsky, J.R. Hiller, Phys. Rev. C **28**, 475 (1983).
10. L.A. Kondratjuk et al., Phys. Rev. C **48**, 2491 (1993).
11. L.L. Frankfurt et al., Phys. Rev. Lett. **84**, 3045 (1999)
12. F. Adamian et al., Preprint YERPHI-1541 (15)-99, 1999. Abstracts *XVth Particles and Nuclei International Conference Uppsala, Sweden 1999*, p. 93 (PANIC99, Nucl. Phys. A **663-664** (2000)).
13. G. Arustamian et al., Preprint YERPHI-401 (8)-80, 1980, G. Betti et al., Preprint DL/P 243, 1975.
14. H. Akopian et al., Preprint YERPHI-908 (59)-86, 1986. D. Lohmann et al., Nucl. Instrum. Methods Phys. Res. A **343**, 494 (1994).