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Proposal Title

STUDY OF $\gamma d \rightarrow pn$, AND $\gamma d \rightarrow p\Delta^0$ REACTIONS FOR SMALL MOMENTUM TRANSFERS

Contact Person

Name: Patrizia ROSSI

Institution: Laboratori Nazionali di Frascati

Address: Casella Postale 13

Address: Via E. Fermi, 40

City, State ZIP/Country: I-00044 FRASCATI (Rome) Italy

Phone: +39 -6 9403320 **FAX:** +39 -6 9403559

E-Mail → BITnet: VAXLNF::ROSSI **Internet:**

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PROPOSAL TO THE CEBAF PAC6

STUDY OF $\gamma d \rightarrow pn$, AND $\gamma d \rightarrow p\Delta^0$ REACTIONS FOR SMALL MOMENTUM TRANSFERS

N. Bianchi, G.P. Capitani, E. De Sanctis,[1] A. Fantoni, A. Ebolese, P. Levi Sandri,V. Muccifora, E. Polli, A.R. Reolon, and P. Rossi[1,2]
INFN-Laboratori Nazionali di Frascati, P.O. Box 13, I-00044 Frascati, Italy

M. Anghinolfi, P. Corvisiero, L. Mazzaschi, V. Mokeev, G. Ricco, M. Ripani, M. Sanzone, M. Taiuti, and A. Zucchiatti
Dipartimento di Fisica dell'Università e INFN-Sezione di Genova, Via Dodecaneso Genova, Italy

A. Kaidalov, L.A. Kondratyuk, and M.I.Krivoruchenko
Institute of Theoretical and Experimental Physics, Moscow 117259, RUSSIA

V. Burkert, B. Mecking and A.Yegneswaran
CEBAF, Newport News, VA, USA

H. Crannell, J. O'Brien, S. Matthews, and D. Sober
Catholic University of America, Department of Physics , Washington D.C. 20064

H. R. Avakian, and V. H. Giourdjian
Yerevan Physics Institute, Armenia

1 **Co-spokesperson**

2 **Contact person**

ABSTRACT

We propose to measure the differential cross section for the $\gamma d \to pn$, and $\gamma d \to p\Delta^0$ reactions in the region of small momentum transfers and suitable kinematical conditions and over the energy range from 0.8 to 1.5 GeV, in order to check the predictions of the Regge phenomenology and of the quark-gluon string model.

We propose also to collect data in the low energy interval 0.5-0.8 GeV to overlap measurements at other laboratory and to test the different theoretical models of deuteron from low energies, where pion exchange phenomena are dominant, to higher energies, where quark phenomena are expected to appear.

We propose to use the CEBAF Large Acceptance Spectrometer (CLAS) and the photon tagger which will allow to obtain data with reduced uncertainties over a broad kinematical region. The experiment can run mostly concurrently with PR-89-045, "Studies of kaon photoproduction on deuterium". We request 70 hours in addition to the one assigned to PR-89-045 for data taking at low photon energy. We expect that data accumulated in angular bins of about 10° and energy bins of 100 MeV will have 0.7% and 2.5% statistical errors (neglecting background), respectively at the lower and higher end of the energy range.

1. PHYSICS MOTIVATIONS

One of the central issues in nuclear physics is the question of whether the quark structure of the nucleus is detectable. Therefore, the experimental identification of quark effects in nuclei would constitute important progress towards the understanding of the nucleus in terms of fundamental strongly interacting particles and would clarify the mechanisms underlying the transition from the nucleonic degrees of freedom to the quantum chromodynamics (QCD) based description of the nucleus.

To this respect the study of deuteron with electromagnetic probes of high energies has very interesting features. The deuteron is the simplest nucleus, and allows the best separation of nuclear structure ambiguities from reaction mechanism ambiguities.

Cross sections for photodisintegration of deuteron have been measured up to 4.2 GeV and discussed theoretically with a number of models. The richest bulk of data was taken with unpolarized bremsstrahlung photons, and refers to the total and differential cross section measurements.[1,2] The data available in the literature at photon energies below about 400 MeV cover a broad angular range, while those at higher energy are limited to a few angles. In particular, above 1 GeV there are only the data of the two recent SLAC experiments: NE8,[3] for which $0.7< E_\gamma <1.7$ GeV and $\vartheta_{C.M.}= 90°, 114°$, and 143°, and NE17[4] for which $1.5< E_\gamma <4.2$ GeV and $\vartheta_{C.M.}= 37°, 53°, 90°$. A comprehensive list of measurements and calculations on this reaction published before 1991 can be found in the recent review by H. Arenhovel and M. Sanzone.[2]

The major feature of the total and differential cross sections is a smooth falloff with energy above an incident photon energy of about five MeV, except for the prominent Δ peak at approximately 280 MeV. It is worth noting that, the lack of an accurate knowledge of the incoming photon flux has caused large discrepancies, up to 50%, among the experimental results on the absolute cross section obtained with bremsstrahlung photon beams. In fact, it has been shown that, just selecting the experiments which used monochromatic photons, it was posssible to reduce drastically the discrepancy and to provide an experimental data set on differential and total cross sections, which lies in a band of relative width of a few percent at lower energy and about $\pm10\%$ in the Δ region.[5]

Conventional meson-exchange models were used for the description of deuteron photodisintegration below 800 MeV. In those calculations, the reaction amplitude was usually expanded in terms of the leading diagrams or a limited number of coupled channels was taken into account. Within present experimental accuracy one finds a resonable description of the total cross sections below 400 MeV though larger experimental errors and greater theoretical uncertainties and model dependences prevent to draw definite conclusion whether or not the present theoretical framework suffice to describe this process. Anyway, at present there are no calculations available which describe the whole set of information which one can deduce from the experiments.

At higher energies the uncertainties of conventional models become larger as expected because of the opening of multi-pion channels and the more essential role of the relativistic effects. Moreover, it is not clear whether the conventional theory with nucleon meson and isobar degrees of freedom alone will be able to describe the experimental results or some basic ingredients (like quark-gluon degrees of freedom), which are still missing in the current theory, are of fundamental importance. This would not be surprising, since at energies above the Δ region the wave length of the photon becomes comparable to the expected distance between quarks in the nucleus.

Therefore, in recent years the interest has shifted towards probing possible quark and gluon degrees of freedom at the higher energies available experimentally, and the efforts have focused on extending meson-exchange calculations to higher energy scales, and QCD to lower energy scales, to see which gives a better description of experimental data.

At high energy, it is usefull to distinguish two different kinematical regions: *i*) high momentum transfers [$t \gg 1$ (GeV/c)^2], and *ii*) small momentum transfers [$t \leq 1$ (GeV/c)^2] (in the following s and t and u are the usual Mandelstam variables).

In the region *i*) according to quark-dimensional counting rules, the cross section of the reaction at constant centre-of-mass angle should be very fast decreasing function of energy:[6]

$$\frac{d\sigma}{dt}(\vartheta_{c.m.}=90°) \sim s^{-11} \qquad (1)$$

This predictions have been compared with the data from the two recent SLAC experiments NE8[3] and NE17.[4] At photon energies above 1.4 GeV and $\vartheta_{C.M.}$=90°, and 55° the data are not inconsistent with the constituent counting rules, while at 37° the energy dependence of the cross section is in strong disagreement with this model.

In the region *ii*), that is at sufficiently high energy and small t or u, the photodisintegration amplitude is dominated by the exchange of 3 valence quarks in t- or u-channel with any number of gluons exchanged between them. In the Regge language this dominant contribution corresponds to the fermion Regge pole. Then, we have examined the process in the framework of the the Regge phenomenology and the quark-gluon-string (QGS) model (which correponds to $1/N_f$ expansion of QCD), obtaining an expression for the cross section which predicts a different behaviour of the cross section with energy and is able to describe quite well the NE8 and NE17 experiments (see par. 2.1).

Moreover, a few of us have evaluated the ratio of the forward and backward values of the cross section for the reaction d(γ,p)n in the framework of the QGS model and Regge phenomenology finding a good agreement with the scarce data available in the literature only at intermediate energies (see par. 2.2).

We consider both these results very encouraging and think that one should deeply check the capability of this simple model do describe the process. Without doubt, we need more data in the energy range accessible at CEBAF, where it might be possible to investigate the transition from the conventional nuclear physics description to the quark-gluon description based on QCD or QCD inspired models. A proposal has been approved by CEBAF (PR-89-012) for a measurement of the energy dependence of the cross section for the d(γ,p)n reaction at three angles ($\vartheta_{C.M.}$= 30°, 53°, and 90°) from 1.5 to 4.0 GeV in 0.5 GeV steps in Hall C. This measurement represents the natural extension of works begun at SLAC by the NE8 and NE17 experiments in order to determine whether the energy dependence of the cross section is consistent with that expected from the constituent counting rules. However, to better discriminate between this simple rule and other theoretical models, it would be helpful to have data over a broad angular and energy ranges and with low statistical and systematic uncertainties (we note that the fulfillment of the last request is made easy by he use of tagged photons).

Therefore, we propose a measurement of the cross section for the γd→pn, and γd→pΔ^0 reactions by using the Hall B tagged photon beam to obtain accurate data between 800 and 1500 MeV and suitable kinematical conditions in order to:

a) Test if γd→pn and γd→pΔ^0 reactions obey to the same energy behavior which is predicted for hadronic reactions by the QGS model, checking whether the energy behavior of these reactions at fixed t is consistent with the contributions of the nucleon and Δ trajectories, respectively;

b) Verify the QGS model prediction of the appearence of the forward and backward peaks in the angular distributions of the γd→pn reaction; and

c) Measure the values of the forward-to-backward ratio of the cross sections.

These measurements might run concurrently with the approved experiment "Studies of kaon photoproduction on deuterium", PR-89-045, which has identical target and detector configuration. Moreover,

d) We propose to extend the data collection down to 500 MeV to overlap measurements at other laboratories and provide an accurate data set over broad angular and energy ranges to test the different theoretical models of deuteron from low energies, where pion exchange phenomena are dominant, to higher energies,where quark phenomena are expected to appear.

If the answer to the previous items will be encouraging, one might propose an extention of the measurements at the higher energies available at CEBAF in order to fully verify the prediction of the QGS model.

2. REGGE PHENOMENOLOGY AND QUARK-GLUON STRING MODEL

The necessary condition for using the Regge phenomenology is the absence of resonance structures in the cross sections. This suggests that the region of applicability of the Regge phenomenology might be wider for photonuclear than for photonucleon reactions.

The deuteron photodisintegration cross section has structures only near the Δ-resonance, and, essentially, no structures at higher energies. Then, the Regge approach might be applied to this reaction starting from the low energies.

Therefore, it is useful to look at the deuteron photodisintegration with the high-energy-physicist eye, trying to extrapolate this point of view to the intermediate energy region. At sufficiently high energy and small t or u, the photodisintegration amplitude is dominated by the exchange of 3 valence quarks in t- or u-channel (see Fig.1a) with any number of gluons exchanged between them. In the framework of $1/N_c$ expansion in QCD, this is the consequence of the dominance of the planar-quark-gluon graph. This expansion was first considered by t'Hooft [7] who proposed to analyze the properties of non-abelian quantum field theory in the large N_c limit. Then, the behaviour of different quark-gluon graphs according to their topology was discussed by Rossi and Veneziano.[8] To describe different binary reactions at high energy, Kaidalov[9] has proposed the so-called QGS model. This model is based on the properties of $1/N_f$ expansion in QCD and can be considered as a microscopic model for Regge phenomenolgy, which, in its turn, is based on fundamental properties of scattering amplitudes such as analiticity, unitarity and crossing-symmetry.

In the Regge language, the dominant contribution of 3-quark-exchange corresponds to the fermion Regge pole [see Fig. 1b where the wavy line describes the exchange of a Reggeon, which is an assembly of 3 quarks plus many gluons with angular momentum $\alpha(t)$]

The analysis of binary hadronic reactions[9,12] showed that this picture works very well at high energies. However, due to the duality property of scattering amplitudes,[8] this approach can work also in the intermediate energy region.[10,11] If in the direct s

channel the resonance behaviour is essential, the duality property ensures rather good interpolation of the amplitude in average by its Regge asymptotics. Recently, A.B. Kaidalov[10] has shown that this approach can describe the reactions $pp \to \pi^+ d$ and $\bar{p}d \to \pi^- p$ (which are also dominated by the 3-quark-exchage diagrams similar to one shown in Fig.1a) in the full energy range, starting almost from the threshold. These results encouraged us to use the QGS model for deuteron photodisintegration starting from low photon energies.

2.1 Two-body deuteron photodisintegration cross section

Let us parametrize the cross section in the form:

$$\frac{d\sigma_R}{dt} = \frac{1}{64\pi s}\,\frac{1}{P^2_{c.m.}}\left(|T(s,t)|^2 + \frac{1}{R}\,|T(s,u)|^2\right), \qquad (2)$$

where $P_{c.m.}$ is the photon momentum in the centre-of-mass system, $T(s,t)$ and $T(s,u)$ are the photodisintegration amplitudes and R is the forward-to-backward ratio of the cross section values. The use of Eq. (2) can be justified for $|t| \leq 1$ (GeV/c)^2 when the first term is dominant or for $|u| \leq 1$ (GeV/c)^2 when the second term is dominant. The energy behaviour of $T(s,t)$ for fixed t, which corresponds to the fermion Regge pole exchange, can be written as:[11]

$$T(s,t) \approx F(t)\left[\frac{s}{s_0}\right]^{\alpha_N(t)} exp\{-i\,\frac{\pi}{2}\,(\alpha_N(t) - \frac{1}{2})\}, \qquad (3)$$

where $\alpha_N(t)$ is the trajectory of the N Regge-pole, $F(t)$ is the residue of the pole, s_0 is equal to the square of the deuteron mass, m_d^2, and the factor in the brackets is the phase factor. [$T(s,u)$ is given by Eq. (3) substituting t with u]. The baryon Regge trajectory deduced from the data on πN backward scattering is known to have some non linearity:[12]

$$\alpha_N(t) = \alpha_N(0) + \alpha_N'(0)\,t + \frac{1}{2}\,\alpha_N''t^2\,, \qquad (4)$$

where $\alpha_N'(0) = 0.9$ GeV^{-2}, $\alpha_N'' = 0.25$ GeV^{-4}, and the intercept for the nucleon Regge trajectory α_N (which is relevant in this case) is $\alpha_N(0) = -0.5$. Therefore the energy behaviour of the cross section for small t and high photon energy is predicted to be:

$$\frac{d\sigma_R}{dt} \sim \frac{|\,T(s,t)\,|^2}{s^2} \sim \left[\frac{s}{s_0}\right]^{2\alpha_N(t)-2} , \qquad (5)$$

which is much more flat dependent on s as compared with the region *i*) of large $|t|$ or $|u|\sim s \gg m^2$. In particular, for example, at t=0, one has:

$$d\sigma_R/dt \sim s^{-3} . \qquad (5')$$

The dependence of the residue F(t) on t can be taken from ref.[10]:

$$F(t)= B\,[\,\frac{1}{m_N^2-t}\,exp(R_1^2\,t\,)+ C\,exp(R_2^2\,t\,)\,]\ , \qquad (6)$$

where the first term in the square brackets takes into account the nucleon pole in the t-channel and the second term is related to the contribution of non nucleon degrees of freedom in deuteron.

The cross section in eq.(5) is a fast decreasing function of the photon energy and t. At fixed $\vartheta_{C.M.}$ and in a limited energy region its energy behaviour can be parametrized as a simple power law: $d\sigma/dt \sim s^{-n}$. In Fig.2 this parametrization is shown for the given angles (details of the calculation can be found in ref. 13). As it is seen, we have different powers at different angles (specifically: n=-5.4 for ϑ=0°, n= -9.1 for ϑ=37°, n= -10.3 for ϑ= 53°, and n= -11.8 for ϑ= 90°), in distinction from the quark counting rules which predicts n=-11 at all angles. In Fig.2 the data points shown are the new data obtained by the NE17 experiment at SLAC:[4] the good agreement between our predictions and the experimental points is encouraging.

2.2 Forward-to-backward ratio of the deuteron photodisintegration cross section

Another interesting case arises when, in the study of the differential cross section for the deuteron photodisintegration, protons emerging in the forward and backward directions are detected. This is because at these angles the reaction is sensitive to the spin-dependent transition operators, the deuteron D state, noncentral forces in the nucleon excited states, and possible non-nucleonic phenomena.

Unfortunately, these measurements at extreme angles are difficult and, consequently, only a few data are available. From the results of experimental works available in the literature it has deduced the experimental forward-to-backward ratio of the cross section shown in Fig.3.

In ref. 14 some of us have examined this behaviour and compared it to the prediction of the QGS model. For a sake of simplicity, these authors considered the inverse reaction $p+n \to \gamma+d$ showing that the simplest description of the deuteron photodisintegration occurs when the wave length of the photon is much smaller than the radius of the nucleon, $\lambda \ll R_N$ or $E_\gamma R_N \gg 1$. In this case the emission of photons is expected to be incoherent, and the angular distribution of photons emitted by each constituent quark will have the form $\sin^2\vartheta/(1 - v/c \cdot \cos\vartheta)^2$, where ϑ is the angle between the momenta of the photon and the quark. If the energy is high enough, $v/c \to 1$ and the photon will be predominantly emitted under small angles. Consequently, the angular distribution should have two peaks well separated, corresponding to the emission from proton (forward peak) or neutron (backward peak), with a depletion of the differential cross section around 90°.

In a naive quark model and in the non-coherent limit the forward-to-backward ratio of the cross section will be given by the following expression, which is determined by the quark charges z_i (here the subscripts u and d stay for up and down quarks):[14]

$$R = \frac{(d\sigma/d\Omega)_{0^\circ}}{(d\sigma/d\Omega)_{180^\circ}} = \frac{2z_u^2 + z_d^2}{2z_d^2 + z_u^2} = 1.5\,, \tag{7}$$

which is in a pretty good agreement with the experimental determination (see Fig.3).

In the the QGS model, in ref. [14] it has been shown that the ratio R is a function of the energy s and can be written as follows:

$$R(s) = \frac{(4+\gamma^2(x))}{(1+4\gamma^2(x))} \tag{8}$$

where $\gamma^2(x) = f_d(1-x)/f_u(1-x)$, f_d and f_u are the d and u quark distribution functions in the proton and x is the fraction of the momentum of the nucleon beard in a diquark (the remaining third quark has the fraction $(1-x)$ of the momentum). Eq. (8) is a generalization of Eq. (7) for the realistic case of the ratio f_d/f_u depending on x, and it is equal to Eq.(7) for $f_d/f_u = 1/2$. This ratio can be taken from deep inelastic scattering experiments.

The prediction for the energy dependence of the ratio R is shown in Fig 3 as a solid line: for low energies $R \approx 1.5$, that is a value in close agreement with experimental data. As energy increases, R tends to 4.

From the experimental point of view it is worth noting that the forward-to-backward ratio can, in principle, be related to the QGS model not only at ϑ=0° and ϑ=180° but also at some fixed angles in the C.M. $\vartheta_p^{C.M.}=\vartheta_f\neq0°$ and $\vartheta_p^{C.M.}=180°-\vartheta_f$ which gives $|t_f|=|u_f|$. Moreover, it is important to stress that the CLAS detector can allow the simultaneous measurement of this ratio, and therefore, can provide a value of R with reduced sistematic error.

2.3 Δ^0 photoproduction on deuteron

The CLAS detector gives also the opportunity of investigating the deuteron photoreaction with pions in the final state. Among these processes, the reaction :

$$\gamma\, d \rightarrow p(\text{forward})\, \Delta^0(\rightarrow \pi^- p), \tag{9}$$

which has three charged particles in the final state has a special interest. In fact, from the point of view of the QGS model and Regge phenomenology this reaction at small t should be dominated by the Δ-type pole (I =3/2) in the t-channel (see Fig. 4). The intercept of the Δ Regge trajectory

$$\alpha_\Delta(t) = \alpha_\Delta(0) + \alpha_\Delta'(0)t, \tag{10}$$

is $\alpha_\Delta(0)\approx0$, so the differential cross section of the reaction (9) at $t=0$ decreases as s^{-2} with increasing s

$$\frac{d\sigma}{dt} \propto \left(\frac{s}{s_0}\right)^{2\alpha_\Delta(t)-2} \propto s^{-2} \tag{11}$$

Therefore, asymptotically this cross section is higher then the cross section of the reaction γd$\rightarrow$p(forward)n which at t=0 decreases as s^{-3} with increasing s (see eq.(5')).

In this case the deuteron plays a role of the nuclear filter of the different t-channel exchanges. In fact, in the case of the reaction (9), it selects the contribution of the Δ trajectory, whereas in case of the (p,n) final state it selects the contribution of the nucleon trajectory. Therefore, the study of these reactions provides an interesting possibility of separating nucleon and delta trajectories in hadronic reactions with photons.

The kinematics of the reaction (9) in the photon energy region (0.5-2) GeV is very favorable for the two-step mechanism of Fig. 4c. In fact, the pions in the intermediate state have momenta in the laboratory frame between 0.22 to 0.4 GeV and, therefore, can easily produce a Δ isobar on the spectator nucleon. This means that the graph of Fig. 4c should be dominant in this interval of energy. Under the considered kinematics conditions, we havė in the final states a fast proton emitted in the forward hemisphere and two slower particles from the Δ decay.

In Fig. 5 we present the distributions over the pion-proton invariant mass from the Δ decay at different angles between the photon and the fast proton. As it is seen, the Δ peak is clearly evident at the angles $\vartheta_{C.M.}<25°$. The typical values of the differential cross section integrated over the Δ peak are by one order of magnitude larger than the differential cross section of the reaction $\gamma d \rightarrow pn$.

3. EXPERIMENTAL CONSIDERATIONS

We propose an initial measurement of the differential cross section for the $d(\gamma,p)n$, and $\gamma d \rightarrow p\Delta^0$ reactions in suitable kinematical conditions and over the energy range from 0.8 to 1.5 GeV, in order to check the predictions of the Regge phenomenology and of the QGS model [in particular, we will verify the validity of eqs. (2), (5'), (8), and (11)].We propose also to collect data in the low energy interval 0.5-0.8 GeV to overlap measurements at other laboratory and to test the different theoretical models of deuteron from low energies, where pion exchange phenomena are dominant, to higher energies, where quark phenomena are expected to appear.

We propose to use the CEBAF Large Acceptance Spectrometer (CLAS) and the photon tagger which will allow to obtain data with reduced uncertainties over a broad kinematical region. A trigger for an event will be a proton count in one of the scintillators. It is expected that the data acquisition system will be able to accept all events triggered by a charged particle in the scintillation counters. Therefore the experiment can run mostly concurrently with PR-89-045, "Studies of kaon photoproduction on deuterium". We request 70 hours in addition to the one assigned to PR-89-045 for data taking at low photon energy.

3.1 Monte Carlo simulation

The response of the CLAS detector to deuteron photodisintegration events has been simulated with a Monte Carlo calculation.The following assumptions were made:

1. A tagged photon beam with 10^7 photons per second is used. Endpoint energy is 1.6 GeV; the tagged energy interval is (0.8-1.5) GeV, as provided in the PR-89-045 proposal. Data for lower energy photons, (0.5-0.8) GeV, can be accumulated simultaneously by periodically enabling the low (photon) energy part of the tagging system.

2. Standard CLAS detection system; choice of polarity such that forward going protons are deflected away from the beam line. Acceptance and resolution effects for charged particles taken into account.
3. The deuteron photodisintegration process is identified via the detection of the proton, only: γ+d$\rightarrow$p+X. The missing mass of the unobserved final state X is determined from photon energy and proton momentum and angle. Neutron detection in the calorimeter may be useful for checking in a fraction of the kinematical range.
3. The following contributions to the missing mass spectrum have been considered:

   (a) Deuteron photodisintegration;

   (b) Pion photoproduction on deuterium (quasifree production and 3-body phase space to simulate correlated production);

   (c) Quasi-deuteron process in the target windows (approximately 5% contribution);

   (d) Accidental coincidences between untagged high energy photons and protons from either pion production processes or protons from photon interactions in the target windows;

   (e) Accidental coincidences between untagged photons in the regular tagging range and protons from pion production processes. The untagged photons are caused by the inefficiency (assumed to be 3%) of the tagging counters;

   (f) Protons from a two-step process in the deuterium target, specifically γ+d$\rightarrow\pi^+$+n+n followed by π^++d$\rightarrow$p+p. In the backward direction, the combination of these processes can result in higher energy protons than the deuteron photodisintegration process.
4. The same number of events is generated for every process. The various contributions to the missing mass spectra are weighted according to their probability and added to form the resulting final spectrum. Crude cross section models have been used to derive the weight factors, typically neglecting the variation of the cross section with the C.M. angle. The exception is deuteron photodisintegration where the variation of the differential cross section with energy and angle were taken from experimental data.

In Fig 6 we show the missing mass distributions at 0.5, 1.0 and 1.5 GeV and for three intervals of the proton emission angle in the laboratory. The results are summarized: the detection of the deuteron photodisintegration process in CLAS with the missing mass technique is possible over the entire kinematical range considered. The signal/noise ratio is always 10 or greater.

A preliminary study was also made of the process γ+d$\rightarrow$p+Δ^0 ($\rightarrow$p+π^-). Detection of any two of the three charged particles yields a high detection efficiency (see Fig. 7). No background studies were made. Because two charged particles are detected the signal/noise ratio is expected to be better than in the case of the deuteron photodisintegration. In the analysis of the $p+p+\pi^-$ events, there will be an uncertainty caused by which proton is the proton-1. This will effect the definition of the C.M. angle. In some cases, both protons can be combined with the π^- to form a Δ. This will be investigated further.

3.2 Choice of particular kinematics

Our aim is to provide an accurate data set over broad angular and energy ranges to test the different theoretical models of deuteron from low energies, where pion exchange phenomena are dominant, to higher energies, where quark phenomena are expected to appear. In particular, we want to test if $\gamma d \rightarrow pn$ and $\gamma d \rightarrow p\Delta^0$ reactions obey to the same energy behavior which is predicted for hadronic reactions by the QGS model, checking whether the energy behavior of these reactions at fixed t is consistent with the contributions of the nucleon and Δ trajectories, respectively.

Fig. 8 shows the differential cross section for the $\gamma d \rightarrow pn$ reaction as a funtion of E_γ for fixed t. The curves represent the sum of eq. (2) and a contibution which takes into account the tail of the Δ-resonance [for more details see ref. [15] eq. (8)]. Since the cross section decreases fastly with increasing t, a convenient check of the model is to measure the differential cross section at t and $u = 0.00 \pm 0.03$, 0.20 ± 0.02, 0.40 ± 0.01 $(GeV/c)^2$. To this end one has to select protons emitted in the C.M. intervals 20-50° and 130-160°.

As far as the forward/backward ratio is concerned, eq (8) can be tested at some fixed angles $\vartheta_f \neq 0°$ and $(180 - \vartheta_f)$ or fixed $|t| = |u|$.

In Table I are given the proton angles which satisfy these requirements in the kinematics above chosen.

3.3 Statistical and systematic errors

The goal of the experiment is to collect enough data to give a statistical error comparable to the systematic error. The main contributions to the systematic uncertainties are: photon beam flux≈1-2%, target density ≈1%, geometric acceptance ≈1-2%, hadron losses <1%, for a total systematic error of about ≤3%.

3.4 Counting rates

In evaluating the time estimates for the measurement, we used the counting rates given in Table II and determined assuming:

Tagged Beam Intensity = 10^7/sec, for the interval (0.8-1.5) GeV, that is
≈ 10^6/sec for 100 MeV wide energy bin

Target Thickness = 5 cm of liquid deuterium (density 0.8 g/cm^2).

Then, for 570 hours of beam time the statistical accuracy varies respectively between 0.7% at the lower end and 2.5% at the higher end of the energy range. We observe that the number 570 hours follows from the sum of the 500 hours that we will use to collect data with photon of energy between 0.8 and 1.5 GeV (this is the time assigned to the proposal PR-89-045), plus 70 hours to collect data for lower energy photons (0.5-0.8) GeV.

3.5 Trigger rates due to inelastic channels

A concern about the trigger rate is the large cross sections for the three-body processes which will produce a high rate of charged particles in the trigger counter. This rate produced by tagged photons within CLAS acceptance can be estimated as follows:

Beam intensity = 10^7 /sec

Total cross section = 300 μb

Target thickness= $2.4 \cdot 10^{23}$ at/cm^2

Singles rate = $(3\cdot10^7/sec)\ (300\cdot10^{-30}\ /cm^2)\ (9/4\pi\ sr)\ (2.4\cdot10^{23}\ at/cm^2) \approx 520/sec.$

which should be well tolerated by the processing rate of the CLAS detector.

However, this rate could be reduced by adding counters at the end of the focal plane to veto electrons associated to photons at the lower and upper end of the bremsstrahlung spectrum.

SUMMARY

We propose a measurement of the cross section for the deuteron photodisintegration into the n+p and p+Δ^0 channels by using the Hall B tagged photon beam to obtain accurate data between 800 and 1500 MeV and suitable kinematical conditions in order to:

a) Test if $\gamma d \rightarrow pn$ and $\gamma d \rightarrow p\Delta^0$ reactions obey to the same energy behavior which is predicted for hadronic reactions by the QGS model, checking whether the energy behavior of these reactions at fixed *t* is consistent with the contributions of the nucleon and Δ trajectories, respectively.

b) Verify the QGS model prediction of the appearence of the forward and backward peaks in the angular distributions of the $\gamma d \rightarrow pn$ reaction; and

c) Measure the values of the forward-to-backward ratio of the cross sections;

Moreover, we propose to:

d) Extend the data collection down to 500 MeV to overlap measurements at other laboratories and provide an accurate data set over broad angular and energy ranges to test the different theoretical models of deuteron from low energies, where pion exchange phenomena are dominant, to higher energies, where quark phenomena are expected to appear.

We propose to use the CEBAF Large Acceptance Spectrometer (CLAS) and the photon tagger which will allow to obtain data with reduced uncertainties over a broad kinematical region. The data for higher energy photons, (0.8-1.5) GeV can be accumulated concurrently with the approved experiment "Studies of kaon photoproduction on deuterium", PR-89-045, which has identical target and detector configuration. The data for lower energy photons, (0.5-0.8) GeV, by periodically enabling the low photon energy part of the tagging system. The beam time needed for the latter measurement is 70 hours.

We expect that data accumulated in angular bins of about 10° and energy bins of 100 MeV will have 0.7% and 2.5% statistical errors (neglecting background), respectively at the lower and higher end of the energy range.

COLLABORATION

The Frascati-Genova collaboration has considerable experience in performing experiments with real photons in the 100-1200 MeV region. The group has implemented two monochromatic photon beams at Frascati, one from positron in-flight annihilation on a hydrogen target[16] and the other from the tagging of the bremsstrahlung produced on an internal target by the electrons circulating in the ADONE storage ring.[17] Moreover, it has performed a few different measurements of the differential cross section for the d(γ,p)n reaction between 100 and 300 MeV, providing the complete detector system, electronics and data acquisition software.[18,19]

The ITEP collaborators have developed the QGS model and applied it succesfully to the description of the reactions $pp \rightarrow \pi^+ d$ and $\bar{p}d \rightarrow \pi^- p$, which are also dominated by the 3-quark-exchange diagramto the one in Fig. 1a.

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TABLE I

E_γ (MeV)	$\theta_p^{c.m.}$ (f) (deg)	θ_p^{L} (f) (deg)	$\theta_p^{c.m.}$ (b) (deg)	θ_p^{L} (b) (deg)	$\|t\| = \|u\|$ $(GeV)^2$
500	20	14.45	160	150.13	0.46
	30	21.78	150	136.13	0.42
	40	29.22	140	123.03	0.37
	50	36.82	130	110.85	0.30
600	20	14.03	160	148.95	0.42
	30	21.14	150	134.55	0.36
	40	28.37	140	121.19	0.29
	50	35.78	130	108.88	0.21
700	20	13.64	160	147.84	0.37
	30	20.57	150	133.07	0.31
	40	27.62	140	119.49	0.22
	50	34.84	130	107.08	0.12
800	20	13.3	160	146.79	0.34
	30	20.05	150	131.69	0.26
	40	26.94	140	117.91	0.16
	50	34.00	130	105.42	0.03
900	20	12.98	160	145.79	0.30
	30	19.58	150	130.38	0.22
	40	26.31	140	116.43	0.10
	50	33.22	130	103.84	0.05
1000	20	12.69	160	144.84	0.27
	30	19.14	150	129.14	0.17
	40	25.73	140	115.04	0.04
	50	32.50	130	102.43	0.13

TABLE I (continued)

E_γ (MeV)	$\theta_p^{c.m.}$ (f) (deg)	θ_p^L (f) (deg)	$\theta_p^{c.m.}$ (b) (deg)	θ_p^L (b) (deg)	$\lvert t\rvert = \lvert u\rvert$ $(GeV)^2$
1100	20	12.42	160	143.92	0.24
	30	18.74	150	127.97	0.13
	40	25.19	140	113.73	0.02
	50	31.84	130	101.07	0.21
1200	20	12.17	160	143.05	0.21
	30	18.36	150	126.84	0.09
	40	24.69	140	112.48	0.08
	50	31.22	130	99.79	0.29
1300	20	11.93	160	142.20	0.19
	30	18.01	150	125.77	0.05
	40	24.22	140	111.30	0.13
	50	30.63	130	98.57	0.36
1400	20	11.71	160	141.38	0.16
	30	17.67	150	124.74	0.01
	40	23.78	140	110.17	0.19
	50	30.09	130	97.42	0.44
1500	20	11.50	160	140.59	0.14
	30	17.36	150	123.75	0.02
	40	23.37	140	109.09	0.24
	50	29.57	130	96.32	0.51

TABLE 2

Eγ GeV	<Δθ> at <Eγ> t=0	<dσ/dt> μb/GeV2 t=0	N (cts/h) t=0	<Δθ> at <Eγ> t=0.2	<dσ/dt> μb/GeV2 t=0.2	N (cts/h) t=0.2	<Δθ> at <Eγ> t=0.4	<dσ/dt> μb/GeV2 t=0.4	N (cts/h) t=0.4
1.4-1.5	16-19	0.075	4.3	7-11	0.144	5.5			
1.3 -1.4	17-21	0.09	5.6	8.5-12.5	0.164	6.8			
1.2-1.3	19-23	0.128	8.7	10-14	0.210	9.5			
1.1-1.2	20.5-25.5	0.171	12.5	12-16.5	0.287	14			
1.0-1.1	23-28.5	0.236	18.4	14-19	0.385	20			
0.9-1.0	26-32	0.34	30.1	16-22	0.518	31			
0.8-0.9	29.5-37	0.516	51.0	19-26	0.794	52			
0.7-0.8				23-31	1.28	93			
0.6-0.7				28-38	2.352	204	8-18	3	131
0.5-0.6							19-26	5.53	278

TABLE 2 (continued)

$E\gamma$ GeV	$<\Delta\theta>$ at $<E\gamma>$ **u=0**	**$<d\sigma/dt>$** $\mu b/GeV^2$ **u=0**	N (cts/h) **u=0**	$<\Delta\theta>$ at $<E\gamma>$ **u=0.2**	**$<d\sigma/dt>$** $\mu b/GeV^2$ **u=0.2**	N (cts/h) **u=0.2**	$<\Delta\theta>$ at $<E\gamma>$ **u=0.4**	**$<d\sigma/dt>$** $\mu b/GeV^2$ **u=0.4**	N (cts/h) **u=0.4**
1.4-1.5	121-128	0.05	2.9	144-154	0.09	3.4			
1.3-1.4	118.5-126	0.06	3.7	141-151	0.107	4.5			
1.2-1.3	116-124	0.085	5.7	138-148	0.139	6.3			
1.1-1.2	113-121	0.114	8.3	134-144	0.181	8.8			
1.0-1.1	109.5-118	0.164	12.8	130-140	0.251	13.1			
0.9-1.0	105.5-114.5	0.251	22.2	126-136	0.361	21.3			
0.8-0.9	100-110	0.4	40	120-131	0.553	36.4			
0.7-0.8	93-105/	0.74	81	114-125.5	0.877	64			
0.6-0.7				105.5-119	1.808	157	141-162	2	87
0.5-0.6				94.5-110.5	3.85	387	128-147	4.3	216

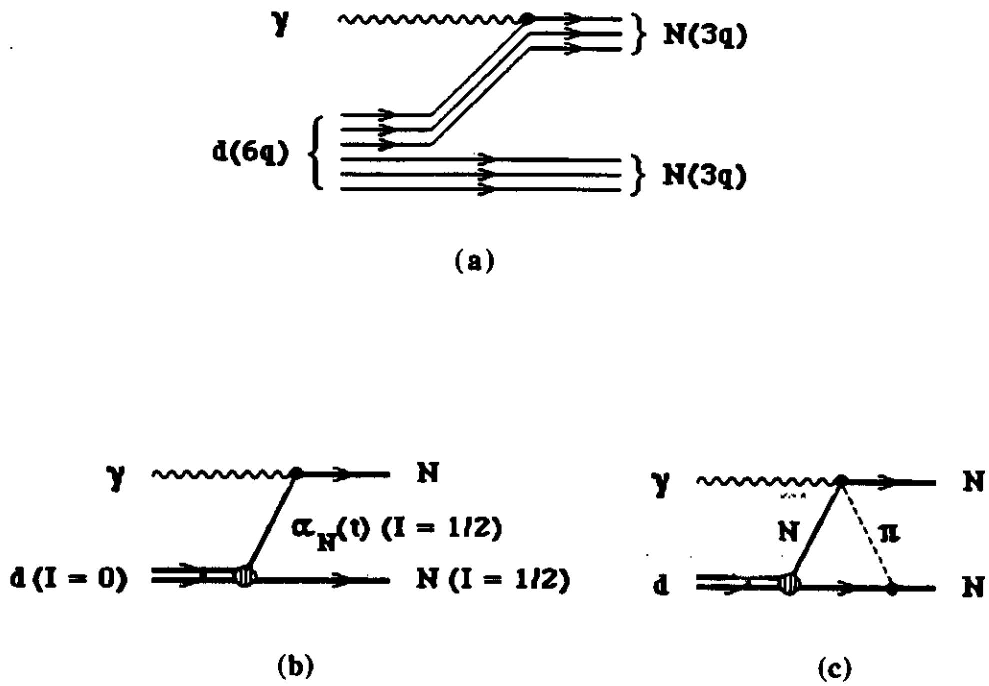


Fig. 1 The deuteron photodisintegration amplitude is dominated, at sufficiently high energy and small t or u, by the exchange of 3 valence quarks in t- or u-channel (a) with any number of gluons exchanged between them. In the Regge language the dominant contribution of 3-quark-exchange correponds to the fermion Regge pole [(b) where the line $\alpha_N(t)$ describes the exchange of a Reggeon]. The exchange of the Reggeon with isospin 1/2 is only possible. At large energies the diagram of (b) includes the contribution of the graph (c).

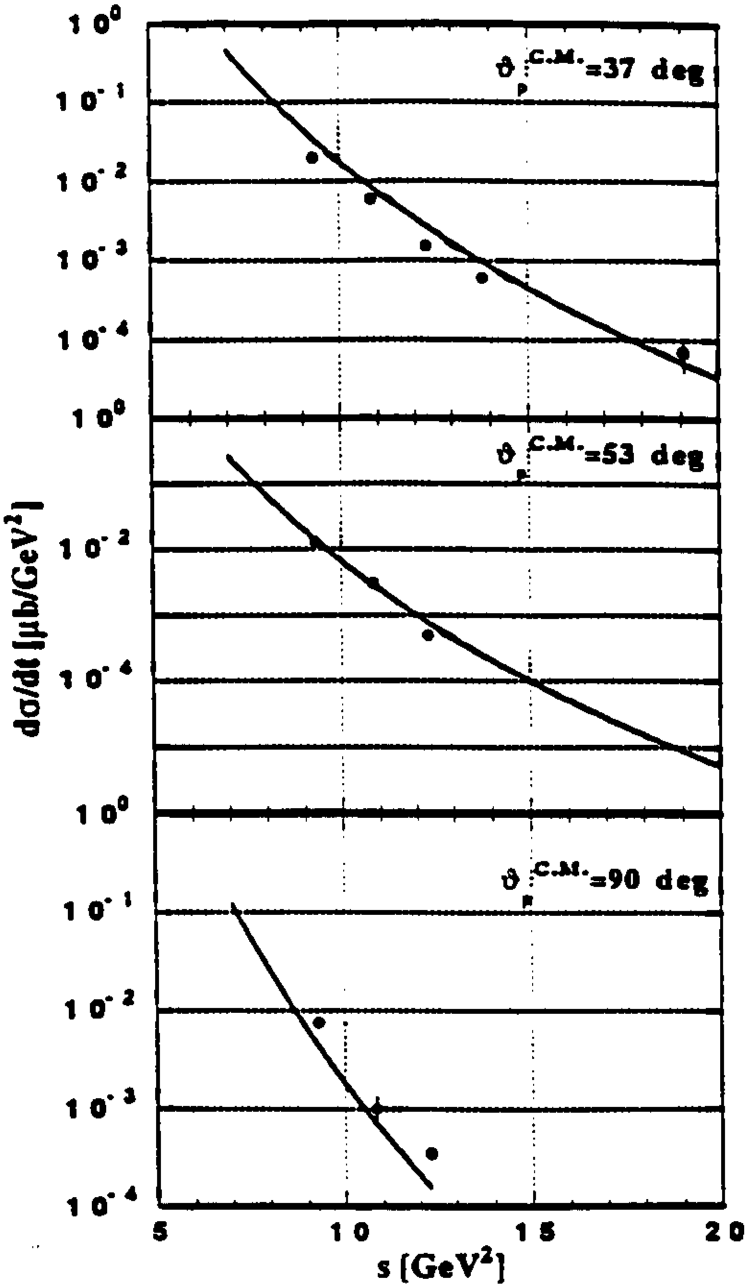


Fig. 2 Comparison of the prediction of our calculations (solid line curve) with the preliminary data (circles) of the NE17[4] experiment.

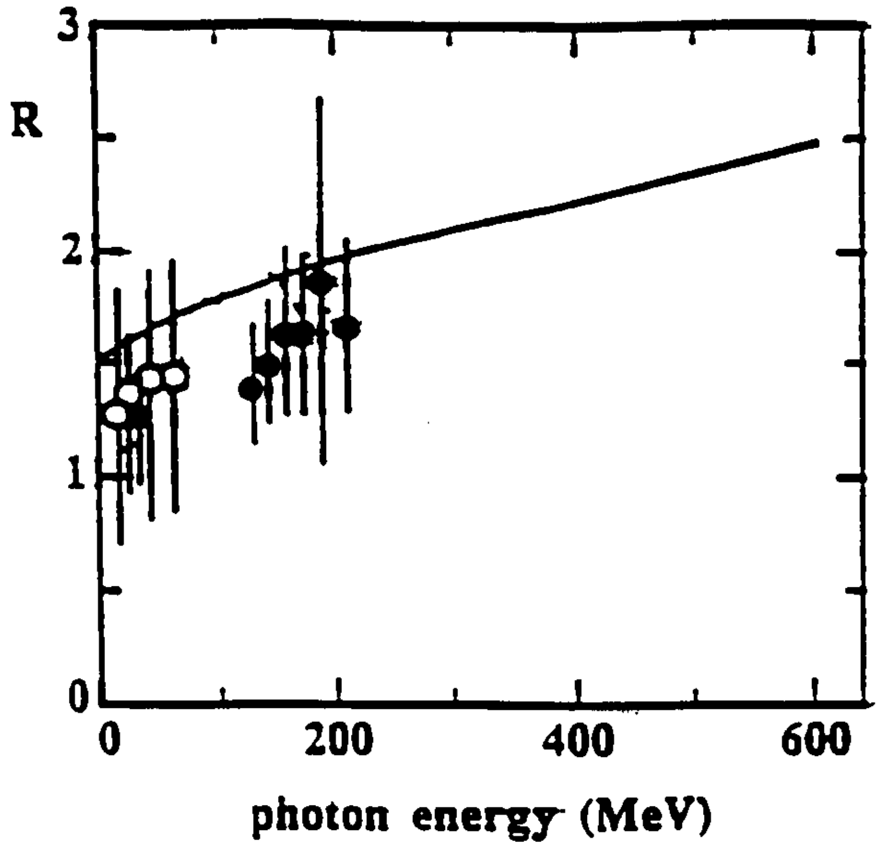
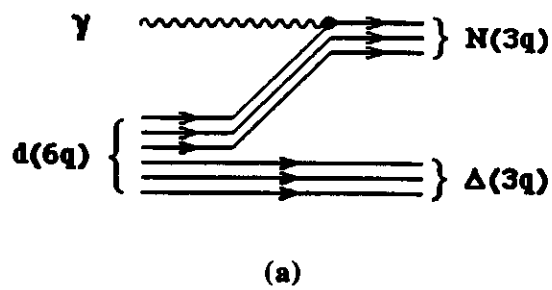


Fig. 3 Forward-to-backward ratio of the differential cross-section values for the deuteron photodisintegration process. [Data points: ●, P. Levi Sandri et al., Phys. Rev. C **39**, 1701 (1989); ○ ,M.P. De Pascale et al. Phys. Lett. **119B**, 30 (1982); ,C. Dupont et al., Nucl. Phys. **A445**, 13 (1985)]. The solid line is the prediction of the QGSM discussed in the text.



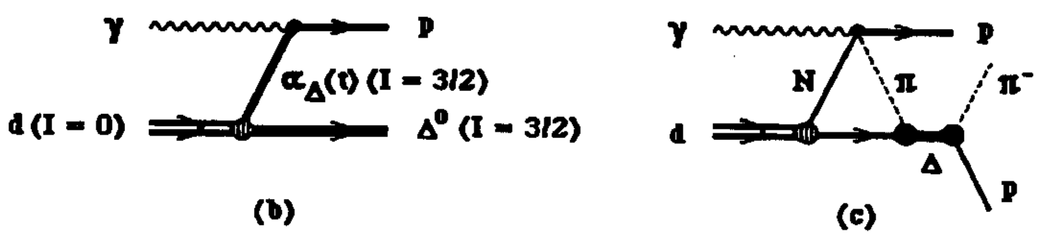


Fig.4 The reaction γ+d→p+Δ is dominated by the exchange of 3 valence quarks in t-channel (a) with any number of gluons exchanged between them. In the Regge language the dominant contribution of the 3-quark-exchange correponds to the fermion Regge pole [(b) where the line $\alpha_{\Delta}(t)$ describes the exchange of a Reggeon]. The exchange of the Reggeon with isospin 3/2 is only possible. At large energies the diagram (b) includes the contribution of the graph (c).

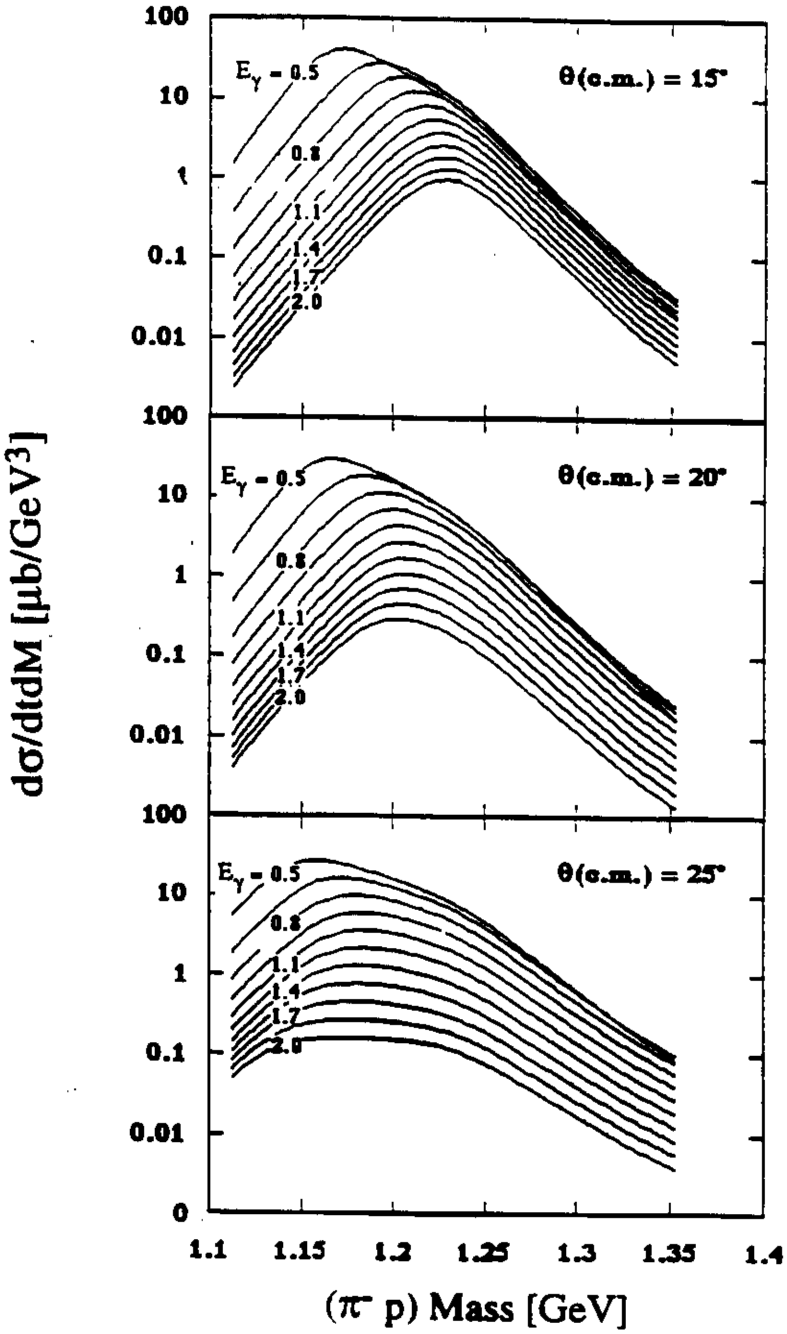


Fig. 5 Distribution over the pion-proton invariant mass from the Δ decay at 3 different angles (15°, 20°, 25°) in the C.M. between the photon and the fast proton.

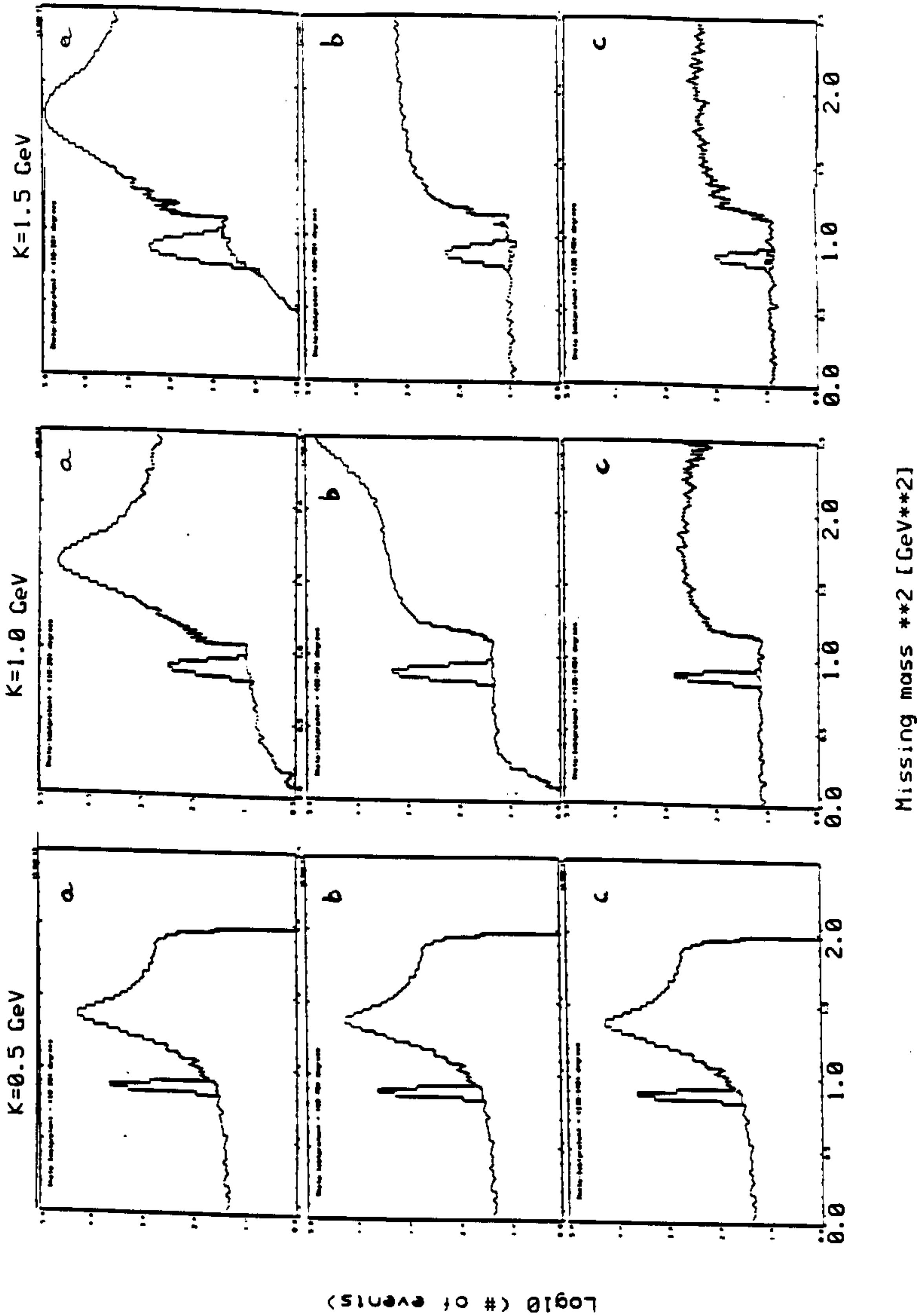


Fig. 6 Missing mass distribution at 0.5, 1.0 and 1.5 GeV for the $\gamma+d\rightarrow p+X$ for proton angle in the 10°-20° (a), 60°-70° (b) and 130°-140° (c) intervals.

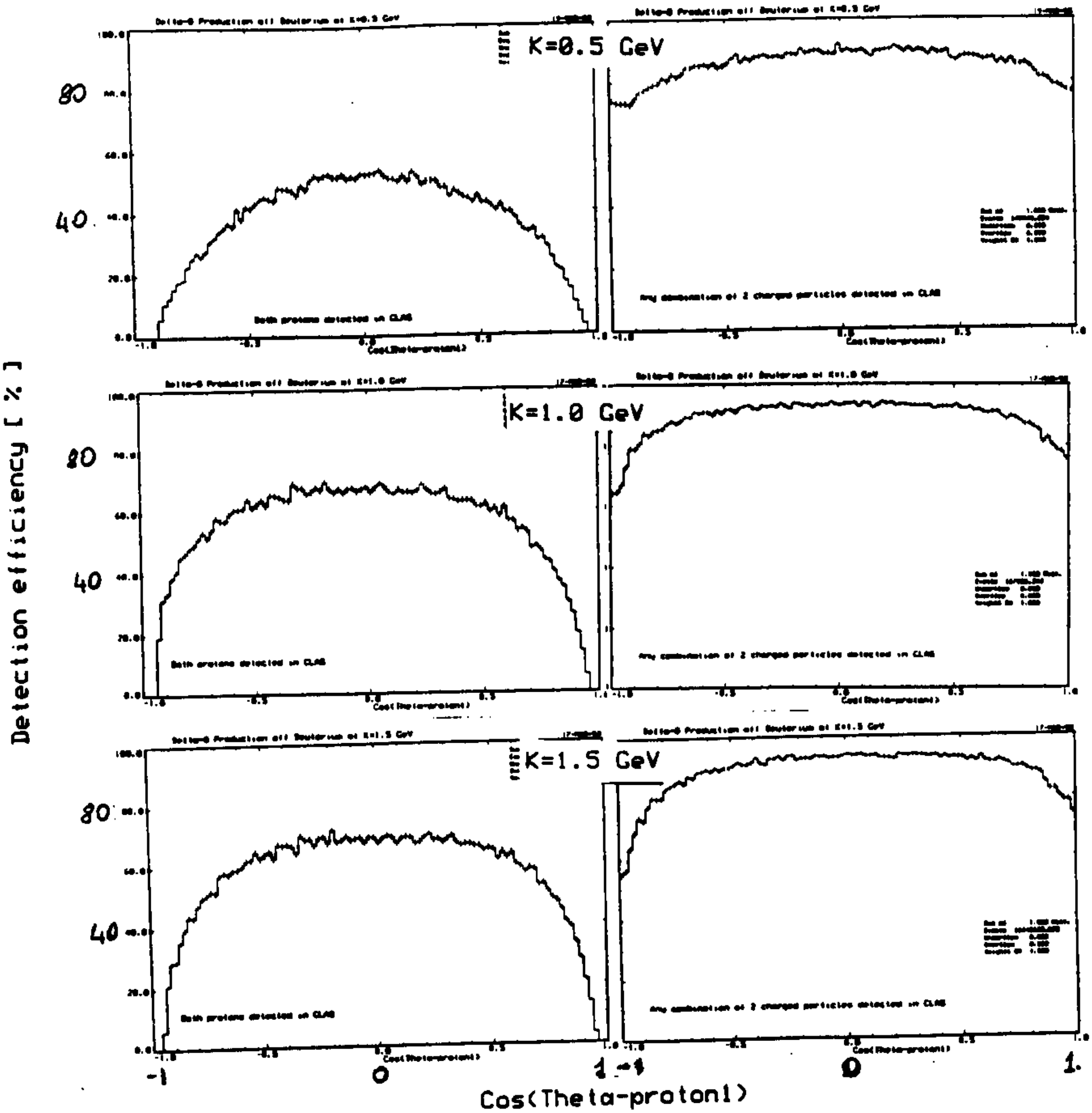


Fig. 7 CLAS detection efficiency for the coincidence of proton-1 and proton-2 (left plots) and for the coincidence of any of the three charged particles (right plots) as a funtion of the C.M. angle of proton-1 at 0.5, 1.0, and 1.5 GeV.

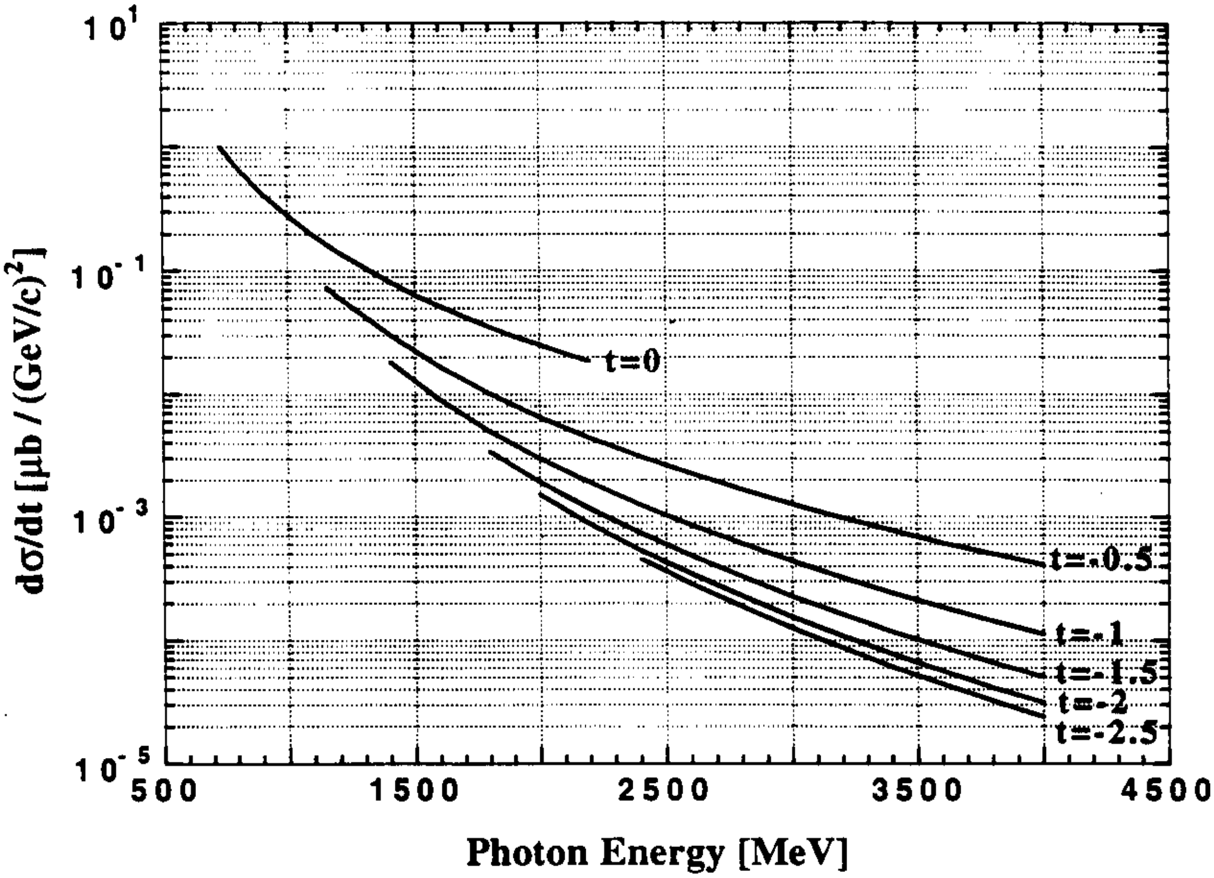


Fig. 8 Differential cross section for deuteron photodisintegration at t = 0.0, -0.5, -1.0, -1.5, -2.0, -2.5 (GeV/c)^2 as a function of the photon energy.