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POLARIZATION IN ELECTRON SCATTERING EXPERIMENTS AT CEBAF

V. Burkert
Continuous Electron Beam Accelerator Facility (CEBAF)
12070 Jefferson Avenue
Newport News, VA 23606

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V. Burkert
CEBAF, Newport News, Va. 23606, USA

ABSTRACT

Some aspects of a tentative program for using high current polarized electron beams as well as solid state targets with high nucleon and deuteron polarization in nuclear physics experiments at CEBAF are briefly discussed.

INTRODUCTION

In the long history of electron scattering from nucleons and nuclei little use has been made of intense polarized electron beams and polarized nucleon or nuclear targets. This may partly be due to the lack of appropriate polarized electron sources, partly due to the cumbersome procedure that has been involved in using polarized solid state targets in high current electron beams. In recent years, however there has been enormous progress both, in the development of high current polarized electron injectors, as well as in the development of target materials with high polarization and high radiation resistivity, which will make polarization experiments a powerful tool in the study of the electromagnetic structure of nucleons and light nuclei.

PROGRAM AT CEBAF

Current ideas on using polarized beams and targets at CEBAF include programs to measure photo- and electroexcitation of baryon resonances, the electric formfactor of the neutron, a separation of the electric monopole and quadrupole formfactors of the deuteron, and experiments to study electroweak interference effects in electron scattering from nucleons and nuclei(1). Due to the limited time for this presentation I want to restrict the discussion to the first three topics.

ELECTROEXCITATION OF NUCLEON RESONANCES

Virtual photons are an ideal probe of the electromagnetic structure and of the spin structure of the nucleon. At high enough energies and four-momentum transfers, transverse photons are sensitive to spin 1/2 objects like quarks, whereas longitudinal photons are sensitive to spin 0 objects like pions or diquarks. The ultimate aim of electron scattering experiments in the nucleon resonance mass region is to study the $\gamma_V NN^*$ vertex. Since excited states of the nucleon are generally broad and overlap, the identification of single resonances requires a study of the resonance decay and therefore calls for coincidence measurements. Obviously, a high duty factor electron machine of several GeV maximum energy will be ideally suited for this purpose.

In our present understanding, nucleons are composed of valence quarks and sea quark-antiquark pairs, bound by gluon exchange. In the mass region of nucleon resonances the $\gamma_V NN^*$ vertex contains information on quark-gluon interaction at large and intermediate distances (confinement regime) and quark distribution in excited nucleonic systems. The theoretical tools for extracting this information in an unambiguous way are not available yet. The main objective at present is to provide stringent tests of the single quark transition approach, which is generally used in quark model calculations, and to determine parameters which are closely related to the quark-gluon dynamics in the non-perturbative regime. The precise knowledge of resonance transitions in free nucleons provides the necessary data base for a study of possible modification in resonance parameters due the nuclear environment in nuclei. Previous experiments have studied single pseudoscalar meson production using unpolarized electron beams and unpolarized hydrogen targets. The cross section is given by

$$d\sigma/d\Omega_\pi = \sigma_u + \epsilon\sigma_L + \epsilon\sigma_t\cos2\phi + \sqrt{2(\epsilon+1)\epsilon}\ \sigma_I\cos\phi$$

where the σ_i are related to the photon wave polarization and are functions of Q^2, W, θ_π^*. The process $\gamma_v N \rightarrow \pi N'$ is generally described by 6 parity conserving complex helicity amplitudes and requires at least 11 independent measurements to be fully determined. Measuring the four terms specifying the unpolarized cross section, does therefore not provide sufficient information to conduct a model independent extraction of the contributing amplitudes. Yet, some attempts have been undertaken to extract the transverse helicity 1/2 and helicity 3/2 photocoupling amplitudes for some of the dominant resonances, using additional information from elastic πN scattering. The results of these attempts are shown in Fig.1, and may be summarized(2) as follows:

- The photocoupling amplitudes of the most prominent resonances, the $P_{33}(1232)$, $D_{13}(1520)$, $S_{11}(1535)$, and $F_{15}(1688)$ have been extracted from proton data for Q^2 up to 3 $(GeV/c)^2$.
- The excitation of the $P_{33}(1232)$ remains dominantly magnetic up the highest Q^2.
- The $D_{13}(1520)$ and the $F_{15}(1688)$ exhibit a rapid change from helicity 3/2 to helicity 1/2 dominance in the initial $\gamma_v N$ system, in qualitative accordance with quark model calculations.
- It is interesting to note that the helicity 1/2 amplitudes show a weak Q^2 dependence for $Q^2 > 0.5 (GeV/c)^2$, whereas the helicity 3/2 amplitudes strongly decrease with Q^2. This is in qualitative agreement with calculations within the framework of single quark transition models(SQTM).
- The coupling of longitudinal photons to these resonances is weak, with the possible exception of the $P_{11}(1440)$.

The data are clearly insufficient to extract the photocoupling amplitudes of the weak resonances. Very little information exists on electroexcitation of neutron resonances and there is a complete lack of information on higher mass resonances ($W > 1700$ MeV/c^2). In general the results of existing analyses suffer from systematic uncertainties, due to limited experimental information.

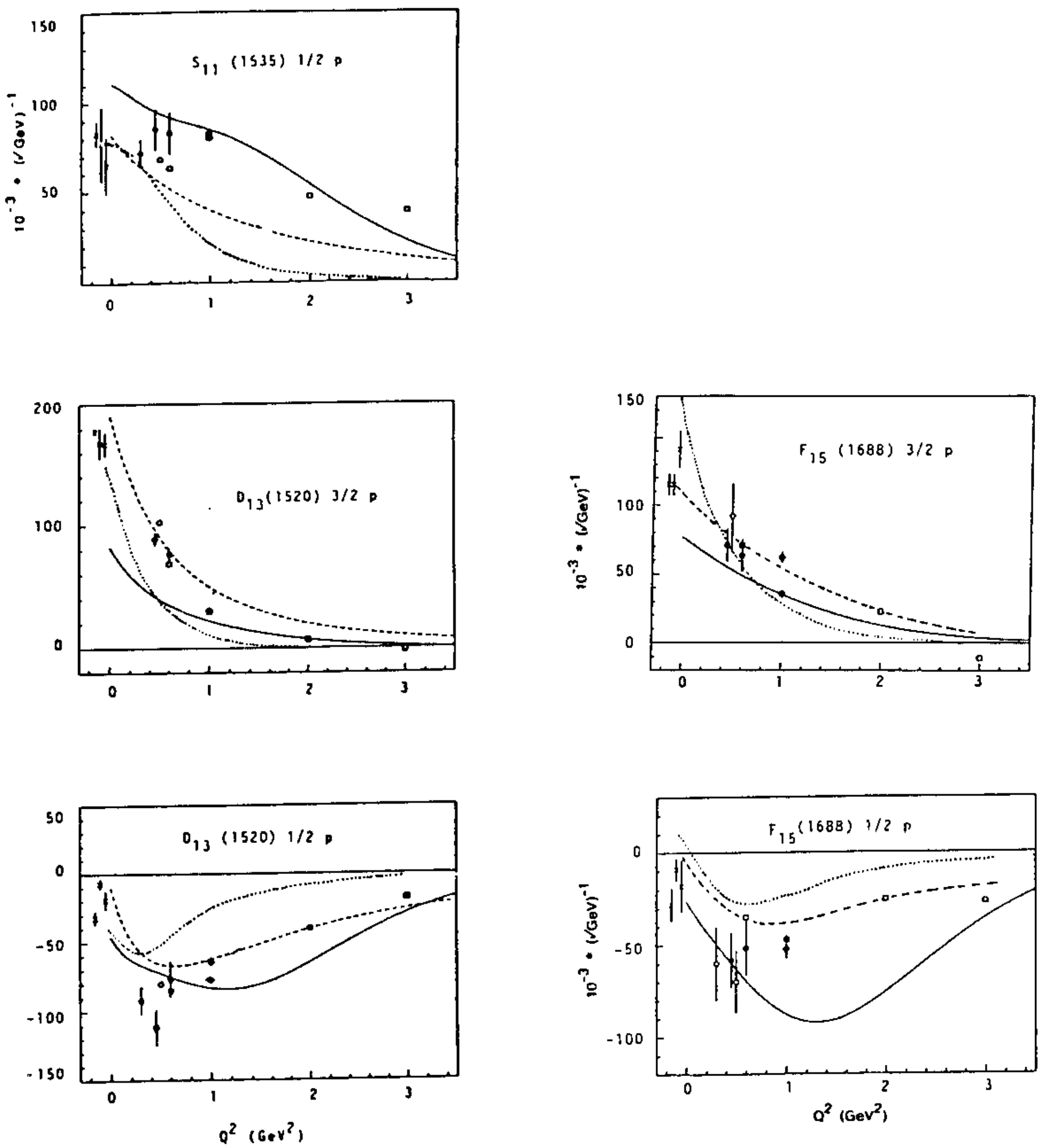

Figure 1. Q^2 dependence of the helicity 1/2 and helicity 3/2 transverse photoexcitation amplitudes for various proton resonances. Data from BONN(•), DESY(▫), and NINA(◊). BONN analysis of DESY(▪) and NINA(♦) data. The crosses indicate results of three analyses of photoproduction data. The curves represent SQTM calculation by Foster & Hughes[12] (dashed lines), Pfeil & Schroeder[13] (solid lines), and Forsyth & Babcock[14] (dotted lines).

PROSPECTS OF NUCLEON RESONANCE STUDIES AT CEBAF

Some of the features that make CEBAF an ideal laboratory for this kind of experiments are listed in Table I. In conjunction with the appropriate experimental equipment, high statistics coincidence measurements will become feasible, to cover complete angular distribution in the hadron decay system. In the initial $\gamma_v N$ system, a large range in the four momentum transfer Q^2, the invariant mass W of the hadronic system, and of the photon polarization ϵ will be covered. In general the cross section for electroproduction of single pions is given by

Table I. Parameters of the CEBAF and proposed experimental equipment

Maximum Energy	E	> 4 GeV
Unpolarized e^- current	I_e	$> 100\mu A$
Duty Factor	η	$= 100\%$
Polarized e^- current	I_p	$> 100\mu A$
Electron Polarization	P_e	$> 40\%$
Polarized Protons	P_p	$= 50$ to 90%
Polarized Deuterons	P_d	$= 30$ to 60%

$$\frac{d\sigma}{d\sigma_o dE' d\Omega_\pi} = \Gamma_T \left[\frac{d\sigma_o}{d\Omega_\pi} + \frac{d\sigma_e}{d\Omega_\pi} + \frac{d\sigma_t}{d\Omega_\pi} + \frac{d\sigma_{et}}{d\Omega_\pi}\right]$$

where σ_o refers to the unpolarized case, σ_e enters if the beam is polarized, σ_t is due to the target polarization, and σ_{et} refers to the case where both beam and target are polarized. Using polarized beams and polarized targets will enable one to perform 13 sensible asymmetry measurements at a given Q^2, W and ϵ, in addition to the 4 unpolarized measurements. Such an experimental program leads to a highly redundant data set and would provide the material for a rather complete and largely model independent analysis. To pursue such a program will require extensive experimental work at CEBAF. For studying specific aspects of nucleon electroexcitation, it will, however, often be sufficient to perform experiments under selected kinematical conditions.

Polarization measurements are particularly sensitive to interferences of amplitudes from different partial waves. Measurements of polarization asymmetries may therefore be a powerful tool in extracting information on weakly excited resonances if they interfere with stronger resonance amplitudes. Fig. 2 shows the sensitivity of the target asymmetry in single π^o production to the excitation of the $P_{11}(1440)$. Despite the fact that this resonance is clearly visible in photoproduction experiments, it has barely been seen in electroproduction experiment. By choosing a suitable orientation of the target polarization and by carefully selecting the kinematics of the decay particles, interference effects may become large and may exhibit large effects even from weak resonances.

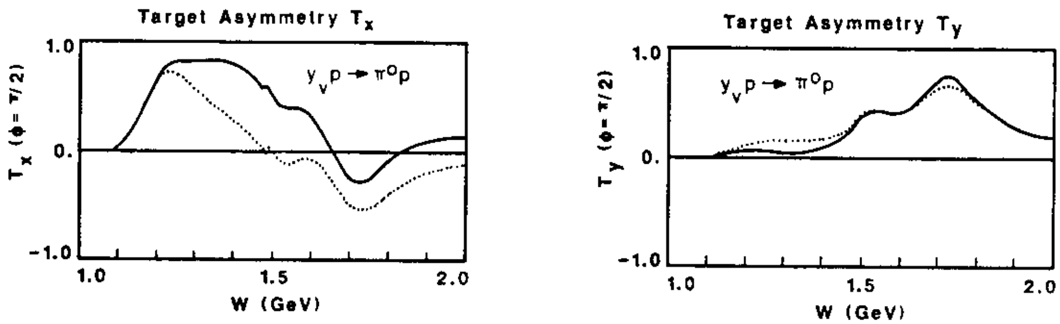

Figure 2. Sensitivity of the target asymmetries T_x (target polarization in electron scattering plane, perpendicular to γ_v) and T_y (target polarization perpendicular to the electron scattering plane) to the excitation strength of the $P_{11}(1440)$ at $Q^2=1.(GeV/c)^2$. The prediction is based on an analysis(3) of DESY data. Solid lines:with P_{11}; dashed lines: without P_{11}.

ELECTRIC FORMFACTOR OF THE NEUTRON

Precise knowledge of the neutron electric formfactor G_E^n is important for testing microscopic models of the nucleon. It would also remove considerable uncertainties in the interpretation of electron nucleus scattering data where G_E^n enters as a fundamental quantity. Present information comes from various sources and is limited to $Q^2<1.(GeV/c)^2$: The slope dG_E^n/dQ^2 at $Q^2=0.$ was found to be positive in scattering of thermal neutrons off electrons in atoms. Quasielastic electron deuteron scattering has been used to measure the magnetic formfactor but failed to allow for an extraction of the electric formfactor. The most precise values of G_E^n are believed to be extracted from elastic electron deuteron scattering. This method requires, however, the adoption of a specific wavefunction, the choice of which strongly influences the resulting G_E^n. To circumvent this, it has been proposed to measure the polarization transfer in quasielastic scattering of polarized electrons from neutrons in unpolarized deuterium[4]. Measuring the recoil neutron polarization requires a second scattering experiment (neutron polarimeter) with an a priori not well known analyzing power and efficiency. These quantities have to be determined independently.

We consider as an alternative but otherwise equivalent method quasielastic scattering of polarized electrons from polarized neutrons in vector polarized deuterium[1], where the scattered electrons and the recoil neutrons are measured in coincidence. For an orientation of the neutron spin in the electron scattering plane, perpendicular to the direction of γ_v, the polarized cross section writes as

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 \left(1+P_e P_n A^n\right) \qquad A^n = \frac{2G_E G_M \sqrt{\tau/(\tau+1)}\,\mathrm{tg}\left(\theta_e/2\right)}{\left(G_E^2 + \tau G_M^2\right) / (1+\tau) + 2\tau^2 G_M^2 \mathrm{tg}^2\left(\theta_e/2\right)}$$

(P_e = electron polarization, P_n = neutron polarization, $\tau = Q^2/4M_n^2$)

Since G_M^n is known, A^n and hence G_E^n can be determined by measuring the cross section asymmetry for opposite spin orientation of the incident electrons. $A^n(Q^2)$ is shown in Fig. 2 for two electron scattering angles and two parameterizations of G_E^n, both of which are consistent with present data at Q^2>0.3(GeV/c)^2. With realistic figures on presently achievable electron and neutron polarization as well as on the electron current which present polarized deuterium targets are able to handle, one obtains the running time for a measurement of A^n with a given accuracy as shown in Fig. 3. Measurements of G_E^n for Q^2 up to 2(GeV/c)^2 seem feasible at CEBAF energies. If one relieves the required accuracy to $\delta A = \pm 0.04$, even higher Q^2 values may be anticipated. A unique feature of this method is that by measuring the corresponding quantities for free protons and for protons bound in deuterium one has very sensitive means for correcting the obtained values of A^n and G_E^n for nuclear effects.

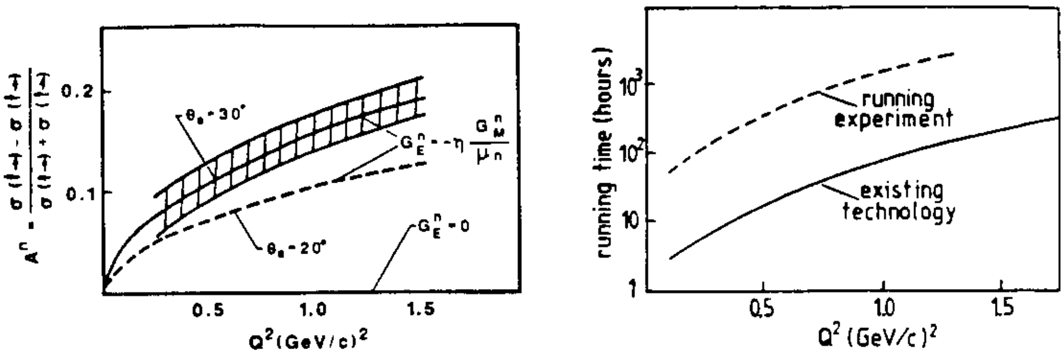

Figure 3. Left: Expected neutron asymmetry for two parameterizations of the electric formfactor and for two electron scattering angles. The hatched band indicates $\delta A^n = \pm 0.02$. Right: Expected running time at a given Q^2 at CEBAF energies. The dashed line is based on $P_n = 0.4$, $I_e = 0.3$ nA, and a 1.6 cm long ND_3 target. The solid line assumes a 6 nA electron current.

ELECTRIC MONOPOLE- AND QUADRUPOLE FORMFACTORS OF THE DEUTERON

It is well known from various model calculations that at $Q^2 > 0.5$ $(GeV/c)^2$, the deuteron isoscalar formfactors are sensitive to short range effects like the presence of mesonic exchange currents in the $\gamma_V DD$ coupling, and to 6-quark contributions in the deuteron wavefunction. Measurements of unpolarized elastic cross sections enable a measurement of the magnetic formfactor G_M only. A separation of all 3 elastic formfactors requires a polarization experiment. It has been proposed(4) to measure the recoil deuteron tensor polarization t_{20} in unpolarized eD scattering, using a second scattering reaction. Such a measurement has been carried out at low Q^2 values(5). The efficiency of presently available deuteron polarimeters, however, is low, typically 10^{-4}. Although a factor of approximately 10 improvement seems feasible in the Q^2 range from 0.5 to 1.0 $(GeV/c)^2$, by using deuteron proton scattering as an analysing reaction(6), it is presently unclear what the efficiency and analyzing power of such a polarimeter will be at larger deuteron energies. We consider for CEBAF use of a tensor polarized solid state ND_3 target. In general, the polarized cross section for elastic eD scattering writes as

$$(d\sigma/d\Omega)_{pol}=(d\sigma/d\Omega)_M(A_{pol}(Q^2) + B_{pol}(Q^2)tg^2(\theta_e/2)$$

where A_{pol} and B_{pol} take on different forms, depending on the orientation of the spin quantization axes with respect to the electron scattering plane and the direction of the virtual photon(7):

If the spin is aligned parallel to the virtual photon direction

$$A_{\parallel} = G_C^2 + \frac{4}{9}\eta^2 G_Q^2 - \frac{4}{3}\eta G_C G_Q + \eta G_M^2 \;;\quad B_{\parallel} = \eta(1+\eta)G_M^2 \;;\quad \eta = \frac{Q^2}{4M_D^2}$$

Experimentally, it is convenient to measure the ratio $R=\sigma_{pol}/\sigma_{unpol}$ rather than the absolute cross section, since systematic uncertainties largely cancel in this ratio. Fig. 4 shows $R_{\parallel}$ (Q^2) for various model calculations. In combination with $A(Q^2)$ and $B(Q^2)$ as measured in unpolarized scattering, measurements of $R_{\parallel}$ (Q^2) enable a separation of all 3 formfactors. The At CEBAF energies measurements of $R_{\parallel}$ with a sensitivity of $\delta R=\pm 0.1$ for Q^2 up to $2(GeV/c)^2$ appear feasible.

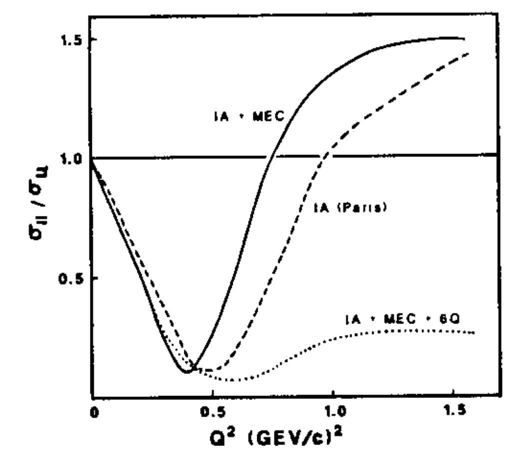

Figure 4. Ratio of polarized and unpolarized elastic eD scattering cross section for an alignment of the deuteron spin parallel to the quantization axis. The charge- and quadrupole formfactors of Haftel et al.(8) have been used, the magnetic formfactor is from measurements at Saclay(9) and Bonn(10) extrapolated to higher Q^2. The dashed line is a prediction which includes 6-quark clusters in the deuteron wavefunction(11).

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