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A. TITLE:

Deformation of the Nucleon

B. CONTACT PERSON:

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C. THIS PROPOSAL IS BASED ON A PREVIOUSLY SUBMITTED LETTER OF INTENT

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Deformation of the Nucleon

D. ATTACH A SEPARATE PAGE LISTING ALL COLLABORATION MEMBERS AND THEIR INSTITUTIONS

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CEBAF Proposal

Deformation of the Nucleon

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Abstract

We propose to do an inclusive measurement $\vec{H}(\vec{e}, e')$ in the region of the delta resonance . We plan to separate the longitudinal piece of the cross section via a measurement of the asymmetry using polarized beam and target. The longitudinal cross section of the delta resonance is sensitive to L=2 amplitudes which can be related to the deformation of the nucleon wave function suggested by bag models.

1 Introduction

In spherically symmetric quark models, the electromagnetic transition of the nucleon to the delta ($N(938) \rightarrow \Delta(1232)$) is a pure M1 spin-flip transition. These types of models have been quite successful in predicting a whole range of fundamental observables, such as the mass spectrum and the magnetic moments of baryons [1][2]. However several independent arguments favor a deformed bag solution for the nucleon and the delta.

The value for the axial-vector coupling constant g_A and the ratio of the pion-nucleon-delta coupling constant to the pion-nucleon-nucleon coupling constant $G_{\pi N\Delta}/G_{\pi NN}$ are incompatible with experiment if calculated in the spherically symmetric quark model. S.Glashow [3] first suggested that the discrepancy in g_A can be accounted for by introducing a tensor force in the nucleon which results in a D-state admixture in the nucleon wave function. Later, V.Vento et al. [4] showed that with the introduction of a D-state admixture of $\approx 30\%$ both discrepancies can be accounted for. The finite neutron charge radius is another indication of admixture of D-state in the nucleon [5].

The presence of a deformed bag is made plausible by several model predictions. In potential quark models color magnetic effects from one-gluon exchange may lead to a mixing of S and D states [6]. In chiral bag models the pion couples to the quarks primarily at the poles of the nucleon spin. The pressure exerted by the pion at the poles leads to an oblate deformation of the nucleon [7]. It has been shown that in bag models a bag deformation leads to a lower ground state energy than the spherical solution [8]. In the Skyrme model, the $N_c \rightarrow \infty$ limit of QCD, the nucleon again acquires a significant deformation [9].

The recent data on deep inelastic muon-proton scattering [10] appear to indicate that much of the proton spin is not carried by the valance quarks; it has been suggested [11] that part of the spin is due to $L \neq 0$ components, a possibility that one could hope to elucidate by a study of the D-state.

The consequences of such a D-state are not easily observed for the nucleon as its spin is 1/2. However one of the observable consequences of a D-state contribution in the nucleon wave function is that the $N \rightarrow \Delta$ transition can no longer be described with a pure M_{1^+} amplitude. It gets contributions from the S_{1^+} (longitudinal), and the E_{1^+} amplitudes (transverse) arising through $L = 2$ transitions. These amplitudes are measurable experimentally, and test the fundamental assumption of a D-state contribution in the nucleon wave function. One observable that is sensitive to the longitudinal $L = 2$ amplitude is the inclusive longitudinal cross section of the $N \rightarrow \Delta$ transition.

2 Status

The only inclusive separated data on the delta resonance have been taken at Bonn [12] and are displayed in figure 1. These data were taken with the intent to extract information on the large M1 amplitude via a Rosenbluth separation. No statements can be made on the small longitudinal cross section given the large errors of the data and the systematic errors entering through the method employed. These systematic errors are rather large because in Rosenbluth separations the subtraction of a large transverse cross section enhances the systematic uncertainties in the small longitudinal piece.

A rather limited set of data on S_{1^+}/M_{1^+} and E_{1^+}/M_{1^+} has also been obtained from $p(e,e'p)\pi^\circ$ coincidence experiments [13] [14]. These data indicate that S_{1^+}/M_{1^+} is ≈ -5 to -10% and $E_{1^+}/M_{1^+} \approx$ -4 to +4%. However, the data show significant discrepancies as a function of the photon four momentum Q^2 and their accuracy is limited by systematic errors (Figure 2). One should keep in mind that all these measurements were taken in order to establish the general behaviour of nucleon resonances. They predate the theoretical considerations outlined in the introduction.

A proposed experiment at the Bates linear accelerator [15] plans to measure the quadrupole contribution in the $N \rightarrow \Delta$ transition via a simultaneous exclusive measurement of the $p + \pi^0$ and the $p + \gamma$ channel using out of plane detection and polarized electrons at Q^2 of 0.07 and 0.12 $(\mathrm{GeV}/c)^2$. For this type of experiment the systematic errors due to the small out-of-plane changes of the cross section again will impose restrictive limitations on the $L = 2$ amplitude extractable.

We propose to do an inclusive measurement $\vec{H}(\vec{e},e')$ in the region of the delta resonance separating out the longitudinal piece through a measurement of the asymmetry, as proposed by T.W. Donnelly and A.S. Raskin [16]. This would be the first measurement of this kind. Relative to a Rosenbluth separation a measurement of the asymmetry has the advantage that a small piece of the cross section can be extracted through an interference term with the large amplitude. Moreover the asymmetry also gives the relative sign of the two amplitudes.

The formalism for dealing with polarized targets and beams is given by T.W. Donnelly and A.S. Raskin [16]. In their notation the cross section and asymmetry for the inclusive measurement of a transition with quantum numbers $1/2^+ \rightarrow 3/2^+$ are written as

$$\frac{d^2\sigma}{d\Omega dE'} = \Sigma \pm \Delta \quad \text{and} \quad A = \frac{\Delta}{\Sigma} \tag{1}$$

where

$$\Sigma = 4\pi\sigma_m f_{\mathrm{rec}}^{-1}\left\{v_L F_{C2}^2 + v_T(F_{E2}^2 + F_{M1}^2)\right\} \tag{2}$$

and

$$\Delta = 4\pi\sigma_m f_{\mathrm{rec}}^{-1}\left\{\frac{1}{2}v_T'(F_{M1}^2 - F_{E2}^2 - 2\sqrt{3}\,F_{M1}F_{E2})\cos\theta^* - v_{TL}'F_{C2}(F_{M1} + \sqrt{3}F_{E2})\sin\theta^*\cos\phi^*\right\} \tag{3}$$

The angles ϕ^* and θ^* are defined in Figure 3. σ_m is the Mott cross section and f_{rec}^{-1} the usual recoil factor. The kinematical factors are defined as

$$v_L = \left(\frac{Q^2}{q^2}\right)^2; v_T = -\frac{1}{2}\frac{Q^2}{q^2} + \tan^2\frac{\theta}{2} \tag{4}$$

$$v_T' = \sqrt{-\frac{Q^2}{q^2} + \tan^2\frac{\theta}{2}} \cdot \tan\frac{\theta}{2}; v_{TL}' = \frac{1}{\sqrt{2}}\frac{Q^2}{q^2} \cdot \tan\frac{\theta}{2} \tag{5}$$

θ is the electron scattering angle and q the 3-momentum of the virtual photon. The relations of the form factors to the amplitudes in the πN system are:

$$F_{M1}^2 = \frac{4W^2}{\alpha m_\pi m_N^2} \cdot M_{1^+}^2 \tag{6}$$

$$F_{E2}^2 = \frac{4W^2}{\alpha m_\pi m_N^2} \cdot 3E_{1^+}^2 \tag{7}$$

$$F_{C2}^2 = \frac{4W^2}{\alpha m_\pi m_N^2} \cdot 2S_{1^+}^2 \tag{8}$$

W is the invariant mass of the πN-system, m_π the pion mass, m_N the nucleon mass and α the fine structure constant.

The above formalism does not describe the non-resonant contributions in the response function. These amplitudes however are present and arise predominantly from the $\pi + n$ channel which contains both Born terms and resonant terms, and which is not separated from the main (66%) decay channel, $\Delta \rightarrow \pi_o + p$, which is almost purely resonant. Calculations [17] estimate the background contribution to be of the same order as the resonant $L = 2$ component. However determining the relative phase between the resonant and the non-resonant terms via a measurement of the response over the entire Δ-resonance and the determination of the Q^2 dependence of the response put stringent limits on the non-resonant background. Further calculations that will elucidate this point are in progress [18] [19].

3 Experiment

Below we present the layout of an experiment to be performed at Hall C. We propose to perform an inclusive measurement of the asymmetry across the Δ-resonance with $\theta^* = \pi/2$ and $\phi^* = 0$. In this case the first term in equation 3 vanishes, and the asymmetry is proportional to F_{C2}/F_{M1}. The nucleon spin is then aligned in the electron scattering plane, and perpendicular to $\vec{q}$, the direction of the virtual photon.

The apparatus to be used is identical to the one discussed in the proposal of our collaboration to measure G_{en} via $\vec{d}(\vec{e}, e'n)$ [20], except that no neutron detection is needed. Details are found in the G_{en} proposal. We assume a polarized NH_3 target which is planned to be able to point the polarization direction to an arbitrary angle in the scattering plane. It is designed to stand a beam current of 100nA on a 5cm target cell, resulting in a luminosity of $1.8 * 10^{36}$ (nucleons $cm^{-2} * sec^{-1}$). The target polarization is about 0.8 resulting in an effective polarization of 0.14 due to the dilution of protons in nitrogen. The polarization of the beam is assumed to be 0.5.

The assumed parameters of the electron spectrometer are the current values of the HMS in Hall C. A solid angle of 6.4msr, a momentum bite of 20% and a momentum resolution of 10^{-3} are used. The large momentum bite allows the entire delta resonance to be scanned in one setting of the scattered electron energy. Even more it allows covering the response function up to values of 1440 MeV and beyond in invariant mass, the region of the "Roper" resonance [21].

For the rate calculation, a parametrization of $G^*_M(q^2_\mu)$ [22] that fits the existing data (Figure 4) is used to calculate M_{1^+} and a Breit Wigner ansatz [13] is employed to describe the shape of the resonance. For S_{1^+}/M_{1^+} we assume an average value of -8% suggested from past measurements (see Figure 2). Half the peak cross section is taken to estimate the average rate.

In table 1 we list the relevant kinematic parameters and rates for the proposed measurement. A statistical accuracy of 5% in $\Delta A/A$ is assumed in the calculation of the running times. In the measurements of the Q^2 points taken at 3 GeV incident energy a beam current of only 50nA is assumed. These measurements will be taken at very small scattering angle where one has to sacrifice solid angle. This however is not a serious limitation as the count rates are rather high in these kinematics. Table 1 shows that in relatively short time an important measurement can be done over a sizeable Q^2-range. This is important as QCD calculations become increasingly feasible at higher Q^2. The higher momentum transfers may in particular reduce the pionic contributions which dominate [23] at low Q^2 and which make problematic an interpretation of the $L = 2$ amplitude in terms of a core quadrupole deformation.

The Nitrogen in the proposed target is partially polarized. The contribution in the asymmetry at the operation temperature is approximately 2% of that expected from 1H. Measurements will be made from a pure nitrogen target also from NH_3 where the proton polarization has been suppressed.

The main advantage of the experiment proposed here is due to the exploitation of polarization observables. For a measurement of the asymmetry, only the electron spin has to be flipped. Change of the target polarization via a change of the RF frequency may only be desirable as a check. The target magnetic field never needs to be reversed. Under these circumstances, the experience with polarized hadron beams shows that extremely small systematical errors can be achieved. The main uncertainty in the asymmetry, besides statistics, will come from the knowledge of target polarization (2% has been achieved in past measurements via NMR) and beam polarization. Neither of these systematical errors will be a limiting factor. Even if the D-state contribution is much smaller than assumed, the experiment will not be limited by systematical errors.

In conclusion it is possible to do an important measurement of the longitudinal quadrupole contribution of the $N - \Delta$ transition in the Q^2-range of $0.2 - 1.4(GeV/c)^2$ at CEBAF using a 3-4 GeV longitudinally polarized electron beam and a polarized hydrogen target. The required spectrometer, beam and target can be expected to be available shortly after turn on of CEBAF. An experiment of fundamental interest can therefore be done at an early stage.

4 Beam time request

Based on the estimates given in table 1 we request 120 hours for checkout and 240 hours for data taking to perform this measurement.

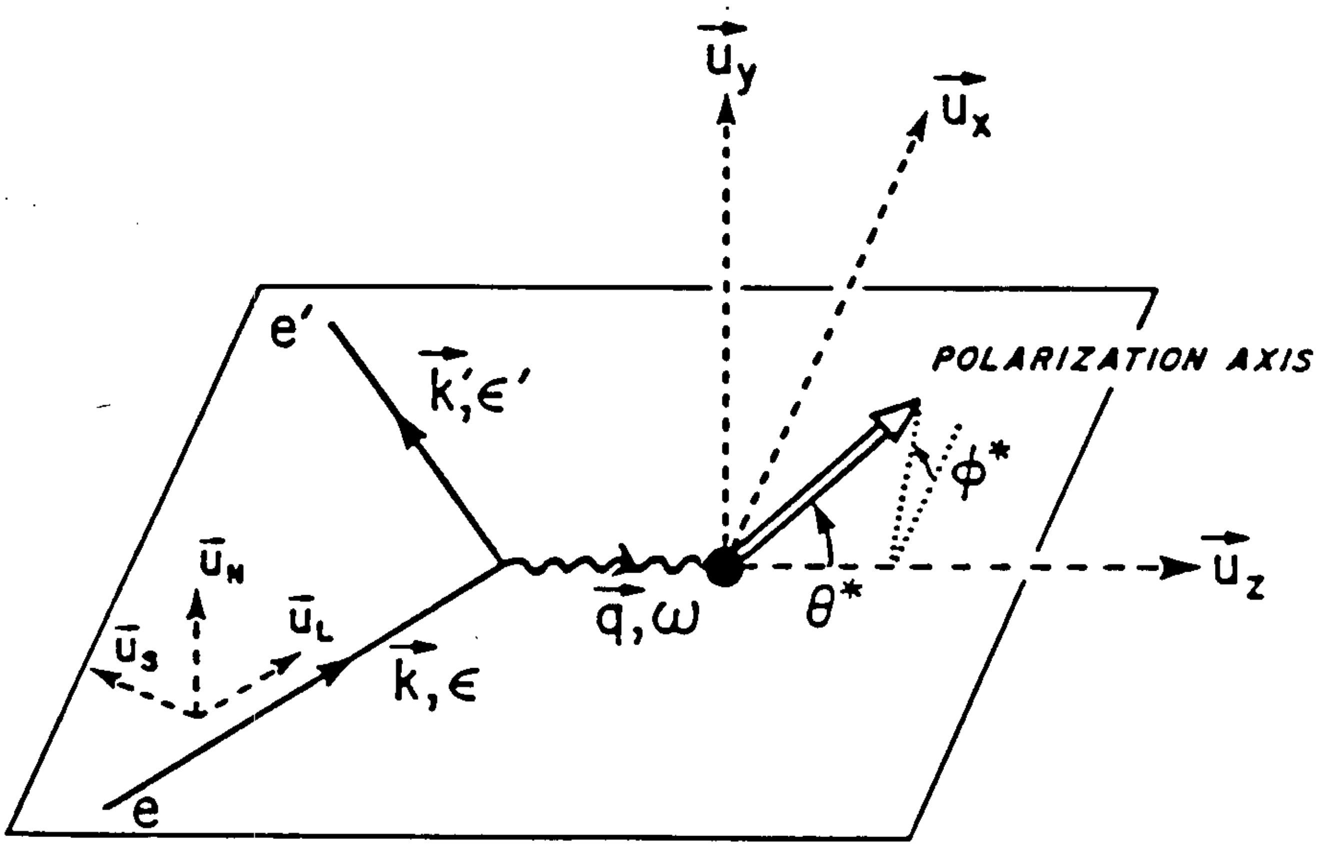
5 Commitment of participants

The experiment outlined in this proposal is not a "stand-alone" experiment. It depends on the hardware (polarized target, beam polarimeter) to be developed for the G_{en} experiment proposed by the same collaboration. The G_{en}-experiment is the prime motivation for undertaking the difficult development of a polarized target. It may be likely, however, that this Δ-experiment would be carried out before the G_{en}-experiment. It uses strictly the same target and spectrometer, but is less complicated due to its single arm nature and the absence of a neutron detector. To a degree, this Δ-experiment might be seen as a "tune-up" experiment for the measurement of G_{en}.

Table 1:

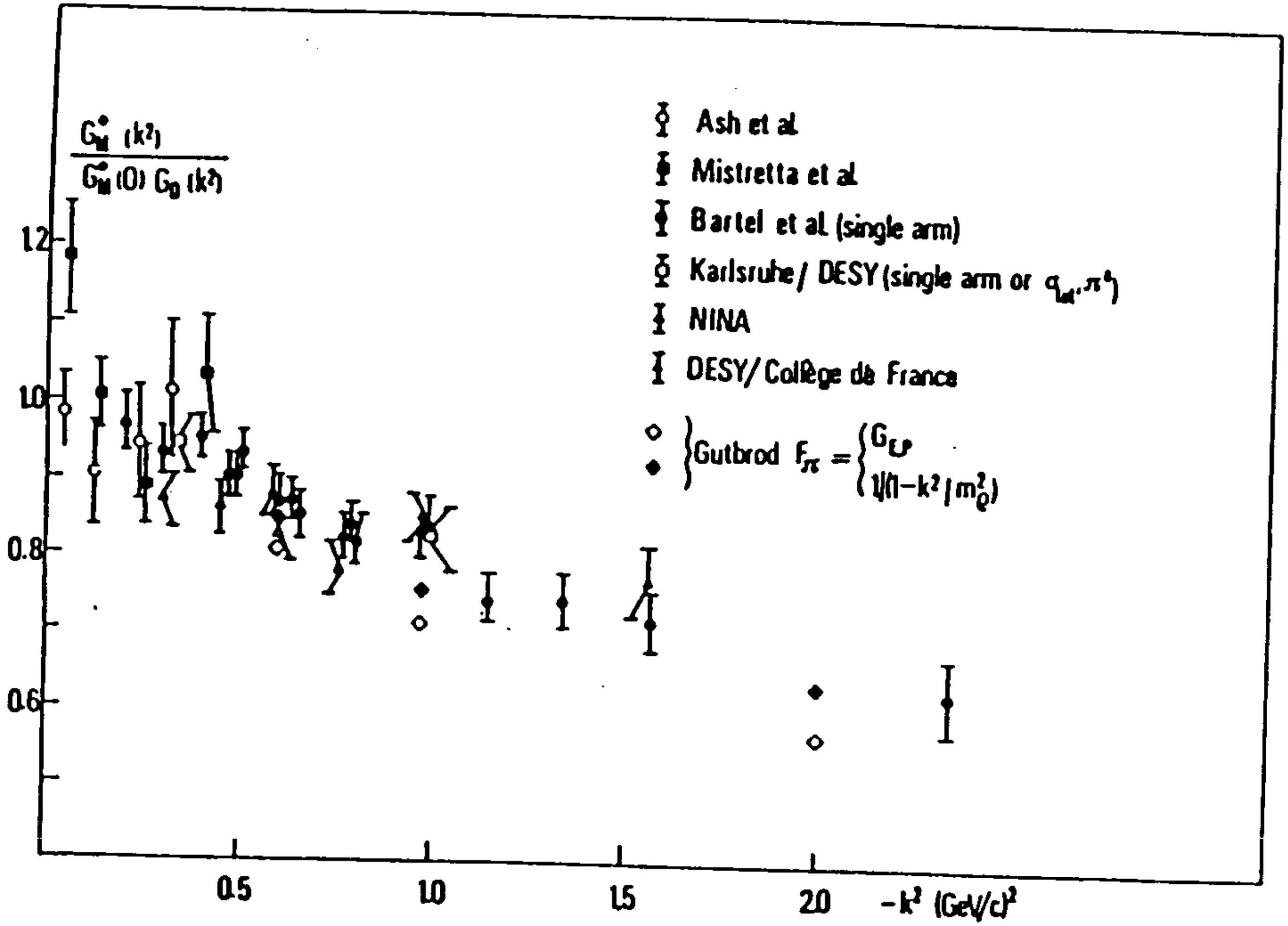
Luminosity for Q^2 0.2-0.5 GeV/c^2	=	$0.9 * 10^{36}(cm * sec)^{-1}$
Luminosity for Q^2 0.6-1.2 GeV/c^2	=	$1.8 * 10^{36}(cm * sec)^{-1}$
Beam polarization	=	0.5
Target polarization	=	0.14
Relative error in the asymmetry	=	5%

E (GeV)	Q^2 $(GeV/c)^2$	$\theta_{e'}$ deg	$\theta_{\vec{q}}$ deg	$A * 10^2$ %	rate kHz	running time h
3	0.2	9.5	-40	-1.3	9.0	1.8
3	0.3	11.5	-42	-1.6	3.0	3.2
3	0.4	13.4	-42	-1.8	1.5	5.6
3	0.5	15.2	-42	-2.0	0.74	9.2
4	0.6	12.2	-43	-1.6	1.60	6.6
4	0.8	14.3	-42	-1.9	0.50	15
4	1.0	16.3	-41	-2.1	0.20	30
4	1.2	18.1	-40	-2.4	0.08	60
4	1.4	20.0	-38	-2.6	0.04	109
						240
Total running time including overhead						360



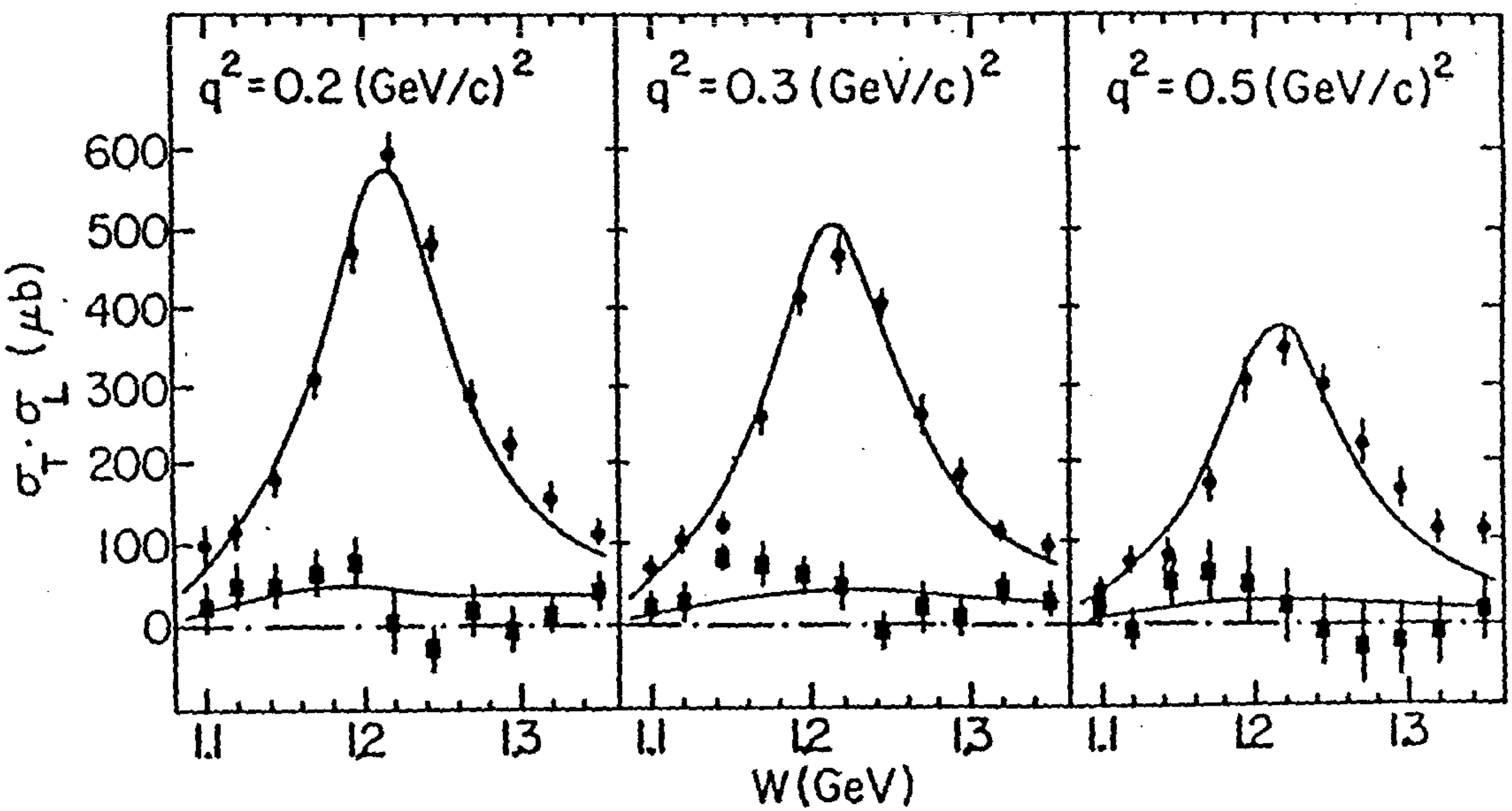
$\vec{u}_y$
$\vec{u}_x$
POLARIZATION AXIS
e'
$\vec{k}', \epsilon'$
ϕ^*
$\vec{u}_N$
$\vec{u}_z$
θ^*
$\vec{q}, \omega$
$\vec{u}_S$
$\vec{u}_L$
$\vec{k}, \epsilon$
e

Figure 3



Ash et al.
Mistretta et al.
Bartel et al. (single arm)
Karlsruhe / DESY (single arm or
NINA
DESY/ Collège de France
Gutbrod
1.2
1.0
0.8
0.6
0.5
1.0
1.5
2.0

Figure 4



q^2 = 0.2 (GeV/c)^2
q^2 = 0.3 (GeV/c)^2
q^2 = 0.5 (GeV/c)^2
600
500
400
300
200
100
0
σT·σL (μb)
1.1
1.2
1.3
W (GeV)

Figure 1

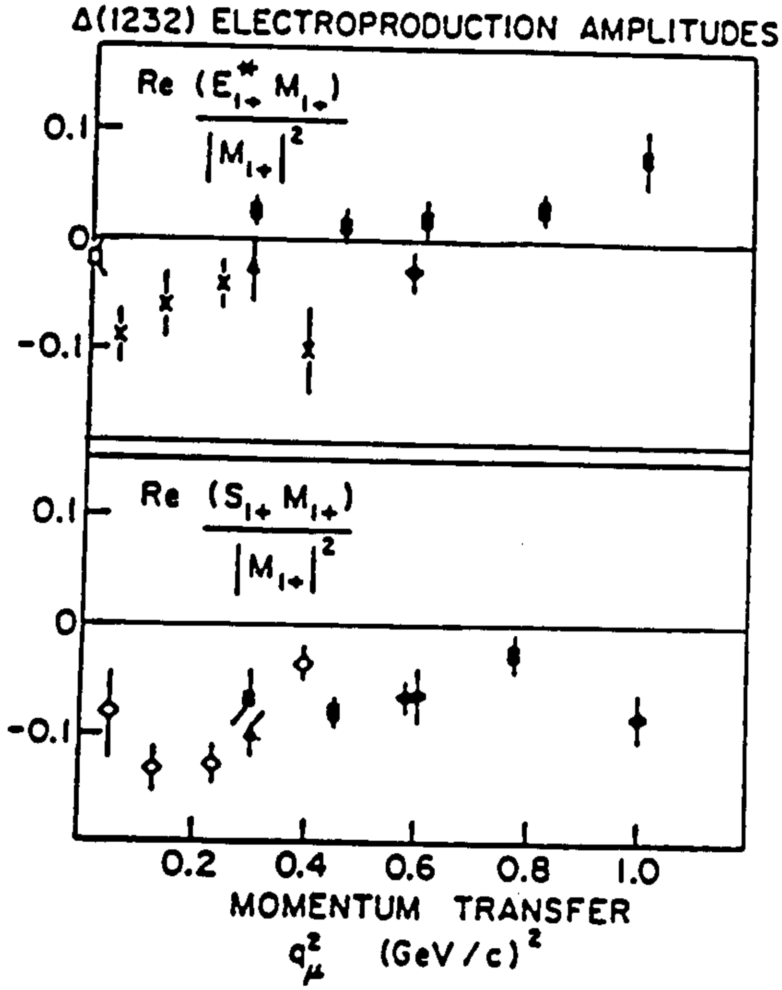

Δ(1232) ELECTROPRODUCTION AMPLITUDES
Re (E*1+ M1+) / |M1+|²
0.1
0
-0.1
Re (S1+ M1+) / |M1+|²
0.1
0
-0.1
0.2
0.4
0.6
0.8
1.0
MOMENTUM TRANSFER
q²μ (GeV/c)²

Figure 2

References

[1] A. Chodos, R.L. Jaffe, K. Johnson, C. B. Thorn, and V. F. Weisskopf. *Phys. Rev. D*, 9:3471, 1974.

[2] A. Chodos, R.L. Jaffe, K. Johnson, and C. B. Thorn. *Phys. Rev. D*, 10:2599, 1974.

[3] S.L. Glashow. *Physics*, 96A:27, 1979.

[4] V. Vento, G. Baym, and A.D. Jackson. *Phys. Lett.*, 102B:97, 1981.

[5] P. Fishbane et al. *Phys. Rev. D*, 11:1338, 1975.

[6] N. Isgur et al. *Phys. Rev. D*, 25:2394, 1982.

[7] Z.Y. Ma and J. Wambach. *Phys. Lett.*, B132:1, 1983.

[8] R.D. Viollier, S.A. Chin, and A.K. Kerman. *Nucl. Phys.*, A407:269, 1983.

[9] E. Braaten, S.-M. Tse, and C. Willcox. *Phys. Rev. Lett.*, 56:2008, 1986.

[10] J. Ashman et al. *Phys. Lett.*, 206B:364, 1988.

[11] P.G. Ratcliffe et al. *Phys. Lett. B*, 192:180, 1987.

[12] K. Baetzner, U. Beck, K.H. Becks, Ch. Berger, J. Drees, G. Knop, M. Leenen, K. Moser, Ch. Nietzel, E. Schloesser, and H.E.Stier. *Phys. Lett.*, 39B:575, 1972.

[13] R. Siddle, B. Dickinson, M. Ibbotson, R. Lawson, H.E. Montgomery, V.P.R. Nuthakki, O.T. Tumer, W.J. Shuttleworth, A. Sofair, R.D. Hellings, J. Allison, A.B. Clegg, F. Foster, G. Hughes, P.S. Kummer, and J. Fannon. *Nucl. Phys.*, B35:93, 1971.

[14] J.C. Alder, F.W. Brasse, E. Chazelas, W. Fehrenbach, W. Flauger, K.H. Frank, E. Ganssenauge, J. Gayler, V. Korbel, J. May, M. Merkwitz, C. Courau, G. Tristram, and J. Valentin. *Nucl. Phys.*, B46:573, 1972.

[15] L.S. Cardman, R. A. Eisenstein, S.Dolfini, S. Kumano, R.M. Laszewski J. Mandeville, A.M. Nathan, W. K. Pitts, C.N. Papanicolas, D. G. Ravenhall, J. Wambach, S.E. Williamson, A. Bernstein, G. Dodson, P. Dunn, J. Flanz, S. Kowalski, W. Sapp, and W. Turchinetz. *Bates Research Proposal*, 87-09:, 1987.

[16] T.W. Donnelly and A.S. Raskin. *Annals of Physics*, 169:247, 1986.

[17] G. von Gehlen. *Nucl. Phys. B*, 20:102, 1970.

[18] S.Nozawa, T.-S. H. Lee, and B. Blankleider. *PSI preprint*, PR-89-14:, 1989.

[19] B. Blankleider. *priv. com.*, 1989.

[20] D.Day, M. Farkondeh, K. Giovanetti, J. Lichtenstadt, R. Lindgreen, J.S. McCarthy, R.Minehart, B. Norum, D. Pocencic, R. Sealock, J.Jourdan, G. Masson, and I. Sick. *CEBAF proposal*, 1989.

[21] R.A. Arndt, S. Ford, and Roper. *Phys. Rev. D*, 32:1085, 1985.

[22] J.M. Laget. *Can. J. Phys.*, 62:1046, 1984.

[23] S. Kumano. *Physics Letters B*, 214:132, 1988.

Figure captions

Fig.1 Inclusive separated data from reference [12].

Fig.2 Compilation of the present information on the S_{1+} and the E_{1+} amplitudes as a function of Q^2.

Fig.3 Coordinate system used in the description of inclusive $\vec{A}(\vec{e}, e')$ measurements.

Fig.4 Existing information on $G_M^*(Q^2)$