AC02-83ER40114

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EXCITED BARYONS*

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CONF-8606241--4

DE87 003926

ABSTRACT

I give below a summary report on sessions of the working group on excited baryons at the CEBAF 1986 Workshop. It contains a tour of the theoretical horizon, some examples, experimental specifics and recommendations for interesting experiments in this area.

1. INTRODUCTION

Theoretical frontiers in particle physics can be visualized in two distinct horizons at the high-energy and low-energy ends. In the former, the main goal is to go beyond the standard $SU(3)\otimes SU(2)\otimes U(1)$ model, which is comprised of the demonstratably correct Glashow-Weinberg-Salam theory and hopefully correct quantum chromodynamics (QCD), ultimately to a grand unification of all interactions. Here one wants to find new experimental signatures which would hint at the need for new theoretical enterprise or confirm extant theoretical expectations. Examples of such discoveries would be finding top quarks, Higgs particles, evidences for techniparticles, discoveries of supersymmetric remnants and so on. At the other end lie possible experimental discoveries of nonzero neutrino mass, lepton flavor-violating decays, proton decay, etc. A truly remarkable opportunity at the low-energy end is the development and testing of the nonperturbative version of the QCD. From this, we would <u>have</u> to understand the structure of hadrons in their "free" state, or as aggregates in

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[*] Invited talk at the CEBAF 1986 Workshop, Newport News, VA.

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the environment of the atomic nucleus, where modifications of properties of free hadrons remain distinctly possible. Out of this should emerge an ultimate understanding of the atomic and molecular matter, from which stars, galaxies and the large-scale structure of the universe evolve. The Continuous Electron Beam Accelerator Facility, or CEBAF, now being built at Newport News, VA, would provide us with the opportunity to study critically the electromagnetic structure of hadrons in the excitation energy region of a few GeV, which is rich in resonances. Thus, for particle physics, it will provide an ample supply of electroweak data to test the nonperturbative domain of the QCD. In the context of nuclear physics, the hope is to build on the quark-gluon picture of free hadrons and uncover new phenomena and understanding of the multi-hadron environment. Finally, by duality, all of these should be intimately connected with the high-energy aspect of the QCD.

The task of our working group at the CEBAF 1986 Workshop was to examine experimental concepts, discussed in the book entitled Research Program at CEBAF (1985) [RPAC-85], in the area of excited baryons; we were also asked to suggest new ideas or modifications that might have a strong bearing on the design of future experimental halls and equipment. On the theoretical side, our desire was to take stock of theoretical issues that might motivate future works on the electromagnetic structure of baryons at CEBAF. We had five theoretical contributions: from Pfeil, Thomas, Browniowski, Manley and this author. Experimental contributions were twice as many: from Burkert, Mecking, Crannell, McCarthy, Stoler, Gastaldi, Schwille, Miskimen, Perdrisat and Minehart. I discuss some of these as I go along. Due to lack of time, I would not be able to do justice to these talks here. The reader should consult contributions of these authors in these proceedings or in RPAC-86. An important achievement of our working group was the formation of an ambitious collaboration of several universities and institutions (ten at the time of this Conference). This was called the LAD (Large Acceptance

Detector) collaboration. Interested readers may contact B. Mecking, R. Whitney (both of CEBAF), or H. Crannell (Catholic U.) for further information on this collaboration and its current status. For this development alone, our working group has justified its long working hours. I shall return to the role of LAD in the excited baryon spectroscopy, a little later.

In the next few pages, I shall try to give an overview of the main themes of our working group and its recommendations. I have to avoid here too much technical details. My hope is to help people, who were not at our sessions, understand its issues, and to impress on Ingo Sick, our conference conscience, on its importance. It should also serve, for members of our working group, as an interesting point of reference for further discussions.

Let me divide the remainder of my summary in the following fashion: theoretical horizon, some examples, experimental specifics, suggestions and recommendations. Some overlap with my introductory talk is unavoidable, and is, indeed, necessary!

2. THEORETICAL HORIZON

At present, theorists firmly believe that the correct theory for strong interaction is QCD. It is a non-Abelian gauge theory, which is thought to provide a fundamental basis to understand all strong interaction phenomena in nature. At high energy, the effective gauge coupling α_s of the theory becomes small, and deep inelastic scattering of leptons from hadrons reveals point-like quark structure of hadrons. The vanishingly small "strong" coupling at high energy incorporates the phenomenon of "asymptotic freedom". At the low-energy side of this theory, the coupling constant becomes large, providing for the "infrared slavery" of quarks. In effect, hadrons become prisons from which quarks cannot be liberated in a free, isolated state. This, at once, "explains" why colored states are not produced in nature. [One, of course, discounts here experiments of Fairbank and collaborators[1] at Stanford, who seemed to have detected fractional charges in niobium.]

QCD allows one, at high energy, to use perturbative methods to test the theory by confronting it with experiments. For example, one can look for processes in which photon (or gluon)-quark Compton scattering or its crossed reactions, occur as parton subprocesses. Another example is to test scaling in the Drell-Yan process, $q\bar{q} \rightarrow \gamma^* \rightarrow \ell^-\ell^+$, seen in $pp \rightarrow \ell^-\ell^+X$. Such tests[2] are thought to be quite successful, even though they can never match the stringency of tests of quantum electrodynamics.

Unfortunately, the situation at low energy is less than satisfactory. Here we are in the nonperturbative regime of QCD. Lattice methods[3] are currently believed to be the only reliable way to test QCD ideas in this difficult region. The lattice approach starts with the problem of dealing with the Feynman path integral for the thermodynamic partition function involving the Euclidean action $S(A_\mu, \psi, \bar{\psi})$, where A_μ is the glue field and ψ, $\bar{\psi}$ are quark fields. It then imposes a short-distance cut-off by introducing a space-time lattice with $N_t \times N_s^3$ sites for the lattice spacing, a. One then evaluates expectation values of operators, using a Monte Carlo strategy. Eventually, a physics result is hoped for in the continuum limit in which $a \rightarrow 0$. Due to limitations of the present-day numerical calculations, we are a long way from the real world of excited baryons. According to a recent observation of a specialist[4], one needs "Cray Millenia" before truly reliable results can be obtained and confronted with experiment.

In the interim, a variety of models are being developed as candidates for the desirable QCD-motivated low-energy approach to hadron structure. We may start with the old nonrelativistic SU(6) picture known since the sixties[5]. Here nearly all meson and baryon resonances observed are embraced in a few multiplets of representation of $SU(6)_q \otimes SU(6)_{\bar{q}} \otimes O(3)$. Thus, most baryons are in the S- and D-wave

56-plets and a P-wave 70-plet. Most mesons are in the S- and P-wave 36-plets. Color provides here the antisymmetry needed by the Fermi-Dirac statistics of quarks. In the limit of mass degeneracy in a given multiplet, the p, n, λ quarks are degenerate and inter-quark forces are spin-independent.

Beyond the simple group theory, a variety of hadron models exist that emphasize at least some aspects of QCD relevant at the nonperturbative level. Thus, bags of different types[6-8] have quark and gluon confinement by fiat and they may or may not incorporate chiral symmetry. Quark shell-models also emphasize confinement, and strong spin-dependent color magnetic forces suggested by QCD. Solitons[9], such as Skyrmions, arise in a natural way in theoretical approaches in which QCD is equivalent to a meson theory in some well-defined context, as proved[10] by 't Hooft and Witten, following pre-QCD ideas of Skyrme[11]. Skyrmions thus serve as interesting dynamical models for baryons. Finally, the theory of strings[12] presents yet another new frontier, with many theoretical attractions. At present it begs the question: "Where are the quarks, gluons, etc., in these models?" It is a bit like a set of violins waiting for a Mozart or a Beethoven!

Out of this bewildering variety of hadronic pictures at low energy, perhaps an interesting one for the excited baryon spectroscopy is the quark shell model. In its most "modern" version, advocated by De Rújula, Georgi and Glashow[13], and refined by Isgur, Karl and collaborators[14], the baryon Hamiltonian is of the form

$$H = \sum_i m_i + H_o + H_{hyp} , \qquad (1)$$

where

$$H_o = \sum_i \frac{p_i^2}{2m_i} + V_{conf} , \quad V_{conf} = \sum_{i<j} V^{ij}_{conf} , \qquad (2)$$

$$V^{ij}_{conf} \simeq \frac{1}{2} K r_{ij}^2 , \qquad (3)$$

$$H^{ij}_{hyp} = \frac{2\alpha_s}{3m_i m_j} \left\{ \frac{8\pi}{3} \vec{S}_i \cdot \vec{S}_j \delta^3(\vec{r}_{ij}) + \frac{1}{r_{ij}^3} \left[\frac{3\vec{S}_i \cdot \vec{r}_{ij} \vec{S}_j \cdot \vec{r}_{ij}}{r_{ij}^2} - \vec{S}_i \cdot \vec{S}_j \right] \right\}, \qquad (4)$$

with i being the quark index. The parameters of the theory are $m_i (i = u,d,s)$, K and α_s. The interaction (4) is the well-known hyperfine interaction, familiar in atomic and nuclear physics; in the quark context, it arises in the nonrelativistic limit of the one-gluon exchange between a quark pair. A nuclear physicist looking at Eq.(4) is immediately reminded of the rich nuclear literature on the D-state contribution to the ground-state wave function of deuteron, due to the tensor force arising out of the one-pion exchange between nucleons. The color magnetic tensor force in (4), not surprisingly, also gives rise to the SU(6)-violating D-states in the nucleon and delta, in an entirely analogous fashion.

The power of the Isgur-Karl approach is in its ability to correlate an enormous amount of baryon spectroscopic data (the corresponding meson theory is equally powerful for mesons). It provides us with a natural framework to discuss, say, the electromagnetic transition properties between a pair of baryons. It also predicts baryon states with definite electromagnetic (and strong) properties that can be confronted with the powerful experimental tools to be available at CEBAF. In short, the Isgur-Karl theory is to baryon spectroscopy, what the nuclear many-particle shell model is to nuclear spectroscopy.

Before concluding this section, I would like to give a pictorial connection, due to G. Karl, between various models of hadrons as a way of orienting your ideas on excited baryon spectroscopy at CEBAF (Fig.1).

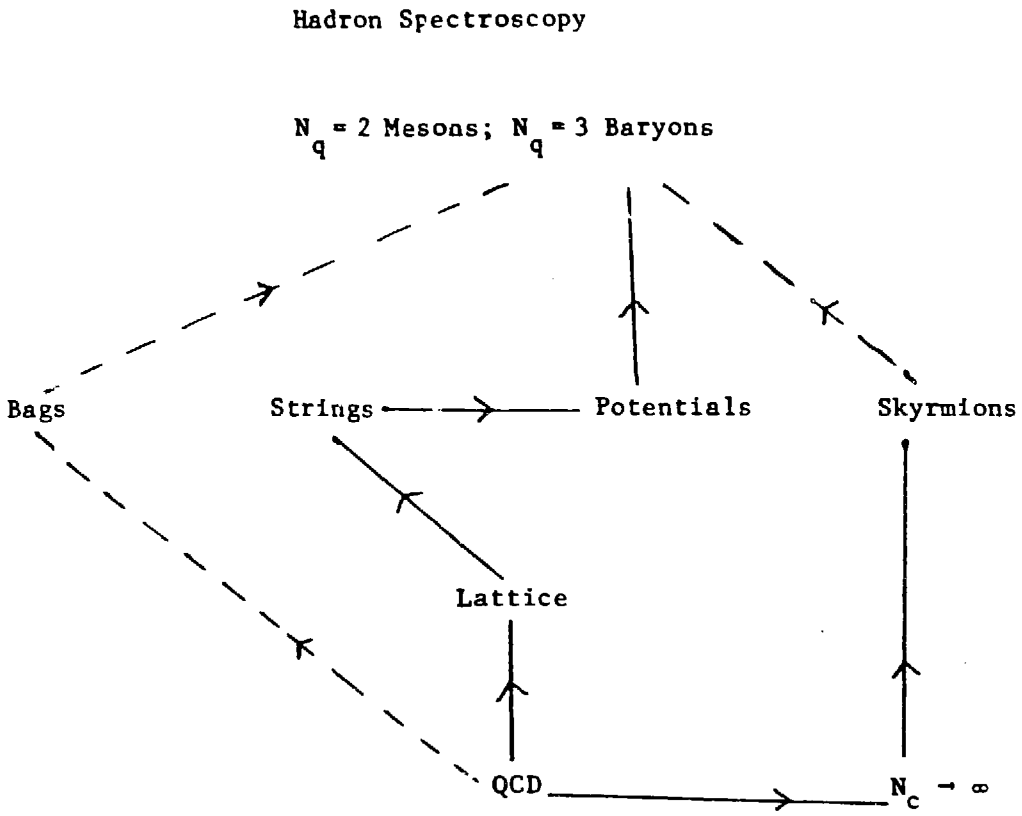

Fig.1: Schematic relation between some approaches to hadron structure and its connection to hadron spectroscopy [after G. Karl[15]]. Solid lines are direct connections, dashed lines are suggestive linkages.

Concerning the hadronic modelling in the direct context of CEBAF physics, we had two contributions at our working group. Broniowski[16] reported on the work of the Maryland School. This group treats the structure of N(939), Δ(1232) and the Roper resonance in the chiral soliton model. An interesting point of this work is the explicit inclusion of quarks, thus differing from the Skyrme approach in its pure form. Broniowski showed that spectroscopic properties of the N and Δ are successfully reproduced, within 20%, in their work, but those of the Roper resonance are not. The contribution of Manley[17] examined implications of the quark shell model on the spectrum of non-strange baryon resonances. It also explored their inelastic decay modes. Manley[17] emphasized some resonances predicted in this model that decouple from the πN channel. These would be prime candidates for study via γN → 2πN and γN → 3πN reactions, where γ is a real or virtual photon. More on this a little later.

3. CONCRETE CASES OF INTEREST FOR CEBAF EXPERIMENTS - SOME EXAMPLES

From the survey of recent theoretical approaches to the hadron (specifically, baryon) structure given above, it is clear that a complete theory of the hadron structure based on the interactions of quarks and gluons is unknown at this time, even as there are many models of this with interesting features. Thus, in the non-relativistic quark shell model, the relativistic effects are ignored, and the confinement mechanism is oversimplified. The correctness of the residual interaction is not proved, it is only tested through its phenomenological implications. In bags, the quark confinement is by fiat, and there is not enough dynamics. Quantum corrections to the soliton theory are uncertain. How to go from the large number of colors to only three in the "real-life" QCD is not clear. To quote Witten[10], "Although QCD is equivalent to a meson theory, this is not a simple theory such as the nonlinear sigma model or Skyrme model. It is an extremely complex and unknown theory with an infinite number of elementary fields." With the present state of computation, the lattice gauge theory is far away from predicting realistic answers for baryon spectroscopy. Strings carry ideas for future developments. In short, critical experimental tests are needed at CEBAF energies in order to sort out predictions of different models pertaining to the quark-gluon structure of hadrons. In this section, we shall discuss a few concrete examples of such tests possible at CEBAF. Some of these were emphasized in contributions of Pfeil, Broniowski, Thomas and this author to the excited baryon working group.

1) The Nucleon to Delta (1232) Transition Amplitudes

The photon transition matrix elements between the nucleon and delta (1232) have been a subject of intense theoretical and experimental research over many years. In simple quark models (SU(6), $SU(6)_W$), the nucleon and delta are spherical. Hence the electric quadrupole (E2) transition amplitude is zero. This is the statement of the theorem due to Becchi and Morpurgo[18]. In Table 1, we display predictions of different hadronic models for the ratio E2/M1, M1 being the dominant magnetic dipole transition amplitude. Notice the wide spread of this quantity in different models. It is amusing to recall a result due to Carlson[19] from the asymptotic QCD. He has shown that the hadronic helicity conservation constraint of the theory alone is enough to predict this ratio: it is unity! While this result has no obvious bearing at CEBAF energies, it demonstrates the importance of measuring the electric quadrupole transition amplitude accurately.

Even more interesting is the prospect of measuring the E2 and the scalar quadrupole S2 (or equivalently, the longitudinal quadrupole L2) amplitude for arbitrary mass squared of virtual photons in the nucleon to delta transition. The SU(6), $SU(6)_W$ arguments again imply these to be zero, while more realistic hadronic models predict their nonzero values as functions of virtual photon mass squared.

Table 1. Predictions for the Ratio E2/M1 for the Nucleon to Delta photon Transition in Various Models

Model	Prediction
SU(6), $SU(6)_W$ [Ref.18]	0
Quark shell model (Ref.20]	$\sim -3\times10^{-3}$
MIT Bag [Ref.21]	0
Chiral Bag [Ref.22]	$\sim -9\times10^{-3}$
Skyrmion [Ref.23] & Maryland Soliton [Ref.16]	$\sim -5\times10^{-2}$
Asymptotic QCD [Ref.19]	1

Using the presently available experimental information on the M1 and E2 multipole amplitudes for real photons in the nucleon to delta transition, extracted by Pfeil and Schwela[24], and by Berends and Donnachie[25], from cross-section and polarization data, we[26] have tried to extract the ratio E2/M1. Our primary concern in this analysis has been the model-dependence of the separation of the background effects from those of the resonance. Using an approach pioneered by Olsson, we have fitted two gauge couplings g_1 and g_2 pertaining to the $\gamma N\Delta$ vertex, by computing the background contributions at the tree level, and by insisting on unitarity via the Watson theorem. We have obtained $E2/M1 = (-1.5 \pm 0.2)\times10^{-2}$. The error obtained here has been found to be too optimistic to reflect all theoretical uncertainties of the effective Lagrangian theory. A more thorough analysis[27] has subsequently given us this ratio between - 0.5% to - 1.6%.

A theoretical investigation of the longitudinal/scalar multipole amplitude in the nucleon-delta transition in the context of the quark shell model by Bourdeau and this author[28] has revealed an interesting problem. While the L2 and S2 amplitudes are not independent and related by gauge invariance, the actual model calculation in the truncated Isgur-Karl basis does not obey this constraint, a problem known[29] in other areas of many-body physics. Our contribution[28] to the RPAC-86 emphasizes this point. We believe the S2 amplitude is less sensitive to the truncation of the quark model space and should be confronted with experiment at CEBAF.

In the CEBAF 1986 workshop, Pfeil[30] clarified some of the problems in extracting multipole (helicity) amplitudes from the existing data. Burkert[31] and McCarthy[32] dealt with the importance of polarized targets and beams at CEBAF in extracting interesting amplitudes like E2 and S2. Miskimen[33], Perdrisat[34] and Minehart[35] discussed recent proposals at Bates, SLAC-NPAS and other labs on measuring these amplitudes. It became clear from these discussions how important CEBAF will be in attacking problems of this kind.

2) The Electromagnetic Structure of the Roper (1440) Resonance

The Roper resonance belongs to the N = 2, 56, 0 multiplet in the SU(6) scheme. Its mass is between 1400 and 1490 MeV and full width 120 to 350 MeV, with sizeable $N\pi$ and $N\pi\pi$ decay channels. It has been recently suggested by Arndt that it might be actually split into two resonances. [In our conference, Pfeil[30] criticized this line of argument.] Its mysterious electromagnetic properties have been discussed at length in the RPAC-85. From the analysis of the older DESY and NINA data at $Q^2 = 1$ GeV^2, there is a strong suggestion[31] that the coupling of this resonance to the longitudinal photon is appreciable. We heard at the CEBAF-1986 Conference new proposals from Perdrisat[34] and Minehart[35] on the possibility of studying this resonance at Bates and SLAC-NPAS, but these pre-CEBAF prospects did not look very encouraging.

Burkert[31] presented arguments at this conference on how the measurement of target asymmetries under special experimental conditions would be sensitive to the strength of the Roper excitation.

We refer the reader to the contribution[31] of Burkert to the RPAC-85 for details. Clearly, the possibility of utilizing beam and target polarizations at CEBAF makes these experiments front-line possibilities.

From the theoretical point of view, the Roper resonance will be a test case for many models. Thus, soliton models have difficulty in handling properties of this resonance, as we heard from Broniowski[16]. Quark shell model calculations[30], used by Burkert, require serious scrutiny in the context of the role of the non-resonant background, and the truncation of the quark model space, in determining the longitudinal transition amplitude. We need to understand large differences[30] among predictions of the helicity amplitude $A_{1/2}$ as a function of Q^2, by different authors, all utilizing quark shell models.

3) Where are Missing B^*'s?

Isgur has noted recently that quark shell models predict more baryon resonances than seen experimentally so far. For example, positive parity $(N = 2)$ N^* and Δ^* states predicted exceed those that are seen. One possibility of this is that the quark shell model is not counting correctly the relevant degrees of freedom; the other is that these resonances are indeed there, as yet to be discovered. Manley, in his contribution, emphasized the CEBAF interest in the excitation energy region around 2 GeV where such states are copiously predicted. Isgur and collaborators have stressed that many of these states are mixed between and within SU(6) multiplets (reminiscent of the complex configuration mixing in nuclear physics) and hence they decouple from the πN channel. These are good candidates to be studied by the $\gamma N \rightarrow B^* \rightarrow \Delta\pi$, ρN, ωN, etc., avoiding the πN channel which is dynamically unfavorable. Isgur has given a helpful table of photoproduction amplitudes of precisely such resonances in the 2 GeV excitation energy region. We reproduce here this table for ready reference of our readers.

Table 2. Quark shell model estimates of the photoproduction amplitudes of some baryon resonances around 2 GeV by Isgur and collaborators. Coupling amplitudes to the strongest channels are also shown. (From Isgur[39]).

State	Photoproduction Amplitudes				Strong Coupling Amplitudes			
	$A^p_{3/2}$	$A^p_{1/2}$	$A^n_{3/2}$	$A^n_{1/2}$	$N\pi$	$\Delta\pi$	$N\rho$	$N\omega$
$N\,\frac{5}{2}^+(1955)$	+9	-67	-45	-22	0	-7	-8	+12
$N\,\frac{5}{2}^+(2025)$	-3	+2	+51	+15	1	-7	+7	-11
$\Delta\,\frac{5}{2}^+(1975)$	+76	+61			1	+6	-13	na
$N\,\frac{3}{2}^+(1870)$	+6	-19	-6	-21	3	-4	+1	-10
$N\,\frac{3}{2}^+(1955)$	+4	-16	-39	+6	1	-9	+6	-9
$N\,\frac{3}{2}^+(1980)$	-5	+19	+22	-20	1	+9	-7	+3
$N\,\frac{3}{2}^+(2060)$	0	-1	-15	+2	1	+5	-3	+9
$\Delta\,\frac{3}{2}^+(1975)$	-7	+18			0	-8	+5	na
$N\,\frac{1}{2}^+(1890)$		-20		-1	4	+3	-5	+6
$N\,\frac{1}{2}^+(2055)$		+7		+3	1	+2	-1	-5

Manley[37] and Mecking[38] emphasized that the predicted photoproduction amplitudes (Table 2) for a few of these missing resonances could be very large and extremely favorable for exploration at CEBAF. Multiparticle final states make these experiments very suitable for exploration by the large acceptance detector (LAD).

Clearly, discovery and identification of the "missing" resonances and measurements of their photo- and electroproduction amplitudes are of high priority at CEBAF. The effective excitation region between

2 to 3 GeV should be very valuable to explore. It should provide critical tests for the nonrelativistic quark shell model and bring out new insights on the effective quark interaction.

4) B^* in Nuclear Environment

During the last ten years lepton and meson factories have provided us with insights on the production of Δ(1232) inside the nucleus and its propagation in the nuclear medium. From our experiences in this field thus far, we are apt to ask following questions for excitation of any baryon resonance B^* in the nuclear medium, by real or virtual photons to be available at CEBAF:

a) Is the γBB^* vertex modified in the nuclear medium?

b) How does a particular B^* propagate in the nuclear medium? What is the effect of the nuclear medium on its decay width?

c) How do we handle theoretically and experimentally the production of many hadrons in the final state in the nuclear interior?

d) Are there any interesting physics for nuclear production of the Δ(1232) at CEBAF energies?

e) Is there an early onset of scaling inside the nucleus?

Questions like these were asked at the workshop, but answers were not plentiful. Undaunted by this, Stoler went ahead and produced computer simulations for CEBAF kinematics. Reproduced here is a typical rate estimate (Table 3) from his study concerning $^4He(e,e'p\pi^-)X$ reactions. Stoler concludes[38]: "It appears that charged pion photoproduction experiments involving delta and B^* production in nuclei will be feasible at CEBAF." Amen, but we need more work in the meantime, both on theory and on experimental feasibility.

Table 3. Laboratory kinematic conditions and counting rates for the experiment ^{4}He(e,e$'$,pπ^-)X designed to separate the longitudinal and transverse components of the differential response. The pion decay angle in the delta frame is 160°. Pion and proton angles are relative to the incident electron direction. Γ is the virtual flux factor, ϵ, virtual photon polarization. The cm pπ energy is 1250 MeV. [After Stoler[36]].

E_e (GeV)	E'_e (GeV)	θ_e (deg)	ϵ	Γ	P_p (MeV/c)	θ_p (deg)	P_π (MeV/c)	θ_π (deg)	(dN/dt)pπ (hr^{-1})
1.9	1.3	20	0.9	3	842	29°	144	159	500
0.87	0.35	60	0.44	.3	842	15°	144	145	50

My feeling is that the production of excited baryons, beyond the well-known Δ(1232), *in complex nuclei at CEBAF kinematics* is a virgin research area. We do not expect to get immediate guidance from theorists as to what to look for. Survey experiments may be needed to get first insights into this new area of research. Physics Advisory Committees may have to allow expeditions into unchartered waters before new physics becomes visible on this research horizon!

Anhang: In my summary, I have been avoiding any discussion of production of strange baryons and their resonances at CEBAF. This interesting subject had been partially covered in the working group on hypernuclear physics chaired by Ed Hungerford. Thomas[40] contributed a paper to our session discussing the possibility of Λ^*(1405) as "intertruder" state. He suggested that experiments at CEBAF could test whether this is a pure 3q state or a $\bar{K}N$ bound state. Schwille[41] reported on dibaryons.

Due to lack of time, we could not take up the topic of the search for pre-existing nucleon resonances in nuclei. An example of this would be the question of the $\Delta\Delta$ and other BB* components of the deuteron wave function. We also could not discuss the possibility of exciting multi-quark exotic clusters in complex nuclei and electroweak physics connected to the test of the standard model at CEBAF kinematics. Clearly more work is needed to clarify these interesting issues. I apologize for any other unintentional omissions in the physics of excited baryons in the CEBAF context.

4. EXPERIMENTAL SET-UP AT CEBAF FOR EXCITED BARYON RESEARCH: SOME OPTIONS

Given the physics objectives discussed above, we can suggest some experimental options that are worthy of further considerations by interested physicists. [Here the present author is completely out of his elements! Volker Burkert and other experimental colleagues in attendance at the CEBAF 1986 Workshop are prime movers for this section.] These options are by no means exhaustive; they are presented with the hope that they would serve at least as talking points for future discussions.

(a) Physics objective: Measurement of electromagnetic transition form factors for $W \leq 2$ GeV/c^2, $Q^2 \leq 3(\text{GeV}/c)^2$.

Process: $\gamma_v B \to B'\eta$, $B'\gamma$ (B: Nucleon, B': baryon of interest).

Target: cryogenic H_2 or D_2 with high cryo power. Polarized solid state targets (NH_3, ND_3) with high cooling are also desirable. Temperature range: $T \sim 0.25$ to 1°K. Magnetic field needed is 3.5 to 5.0 Tesla. Beam current I_e: Unpolarized $I_e \sim 30$ nA to ~ 100 μA. Polarized $I_e \sim 30$ nA to 100 μA.

Detectors: 4 - 6 GeV e^- spectrometer of moderate resolution, large solid angle, large momentum acceptance. One hadron spectrometer with $p_m \leq 3.5$ GeV/c. Particle identification, out of plane capability desirable. Resolution $\leq 5 \times 10^{-3}$. The spectrometer called VAS I is a suitable candidate for the hadron spectrometer.

(b) Physics objective: Study of $\gamma_v B \to B'\pi\pi$. Here an additional spectrometer is needed to detect the second hadron, of lower momentum compared to that in the case (a). The spectrometer called VAS II is a candidate for use in this case.

(c) Physics objective: $\gamma B \to B'\pi\pi$: Search for unseen states. One needs here the tagged photon facility. Large acceptance detector (LAD) is needed for the detection of hadrons in the final state.

(d) Physics objective: Study of B^* in nuclei.

Target: D_2, light nuclei. Beam: Unpolarized $I_e \sim 10\ \mu A$.

Detectors: For the process $A(e,e',p\pi)X$, one needs one e^- spectrometer of moderate to poor resolution, one hadron spectrometer for the large-momentum proton and another hadron spectrometer for the low-momentum pion, both of moderate resolution.

Contributions of Burkert[31] and Stoler[36] to the RPAC-86 should be consulted for further details. Burkert and Mecking discuss in depth the designs of the VAS and LAD devices respectively.

5. CONCLUDING REMARKS

In the early nineties, experiments will begin at CEBAF. From careful considerations of the state of particle and nuclear physics at this time and with reasonable extrapolation of this to the not too distant future, it is safe to expect that the nonperturbative quark-gluon structure of hadrons either in free states, or as constituents of nuclear matter, will remain a subject of great intellectual interest at the time when CEBAF delivers its beams to experimental halls. Quoting Feynman again, "one powerful way of experimentally investigating the strongly interacting particles (hadrons) is to look at them, to probe them with a known particle; in particular, the photon (no other is known as well)." This is precisely what we have been discussing so far.

With the polarized targets and beams at CEBAF, a new era of exploring baryon structure will begin. It will produce new understandings of the role of color magnetism and other quark-quark interactions, suggested by QCD. It will allow us to explore the electroweak structure of known baryon resonances to great precision and to find those resonances which are predicted to exist, but have eluded experimental discovery thus far.

We strongly recommend this new world to our future explorers.

I thank Franz Gross for his kind invitation to the CEBAF-1986 Workshop. Special thanks are due to all contributors to the truly exciting sessions of the excited baryons at this workshop. I am particularly grateful to V. Burkert, W. Pfeil and P. Stoler for many helpful discussions. I also thank J.S. O'Connell and A. Halprin of the Lewis Center for Physics. My research is supported by the U.S. Department of Energy.

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