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SECTION II: REVIEWS (Signatures indicate the material has been reviewed. Additional comments may be offered below)

Supervisor	**Date**
Division Associate Director	**Date** 7/21/87
Director	**Date**

COMMENTS:

the operation of large acceptance detectors, the low duty-cycle limits the luminosity and therefore the count rate that can be achieved.

Several developments have occurred or are presently underway that will make the operation of a large acceptance detector easier:

a) Electron accelerators with 100% duty-cycle are being built. Since accidental coincidences will be reduced compared to present accelerators, this will clearly extend the kinematical range for coincidence experiments (for all experimental set-ups). For the operation of a large acceptance detector, it means that high luminosity and counting rates can be achieved.

b) Due to the enormous effort of the high-energy physics community, the quality and versatility of large acceptance detectors has improved dramatically. The operation of a modest large acceptance detector will also become feasible for the smaller size groups working in intermediate energy nuclear physics.

In view of these technical developments, it seems worthwhile to reexamine the physics motivation for the investigation of reactions with several particles in the final state. In the following, examples will be given for reactions which are of special interest for CEBAF:

a) Hadronic final states in inclusive electron scattering off nuclei. Single arm electron scattering and (e,e'p) coincidence experiments have generated puzzles that can only be solved by a detailed investigation of the hadronic final state. (Examples for existing single arm electron scattering data are given in figures 1 and 2.) Using a large acceptance detector, a bias-free investigation can be carried out by triggering on the scattered electron only. In the off-line analysis, the inclusive scattering cross section can then be decomposed into its hadronic channels. With increasing energy loss for the electron, the following phenomena can be studied:

(1) Electron scattering at high negative y (y= momentum component of the struck nucleon parallel to the direction of the virtual photon $\vec{q}$) yields higher cross sections than expected from standard nuclear models. The excess cross section can be explained by high momentum components in the nuclear wave function (→ emission of a single nucleon) or by interaction of the virtual photon with quark clusters /PIR81/ (→ emission of nucleon pairs or nucleon clusters like deuterons etc.). The two possibilities can be distinguished by observing the hadronic final state.

(2) quasi-free electron scattering off bound nucleons (requiring the hadronic final state to contain a recoiling nucleon around the direction of $\vec{q}$). A long-standing problem is the failure of the Coulomb sum rule to account correctly for the number of protons in the nucleus. This has

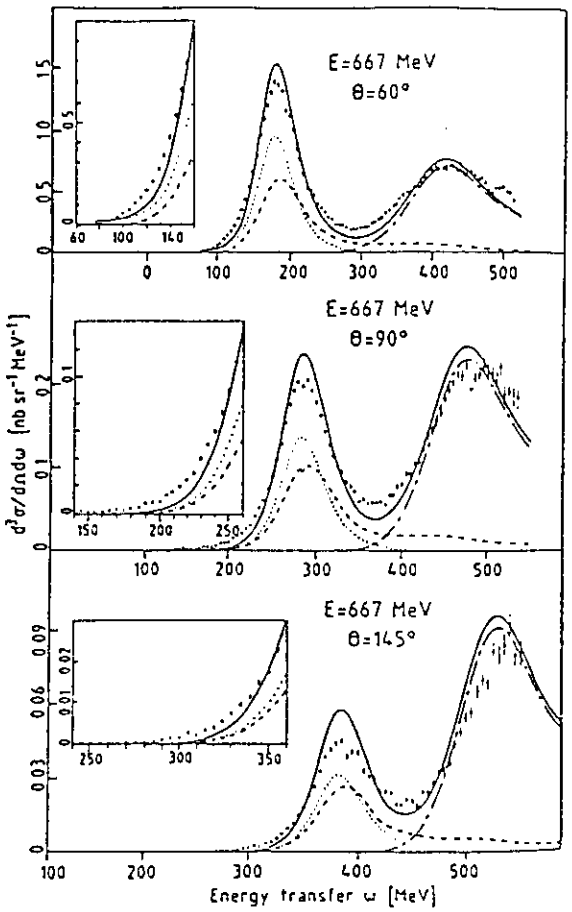

Fig. 1 Cross sections for inclusive electron scattering off ^{3}He (data from /MAR85/)

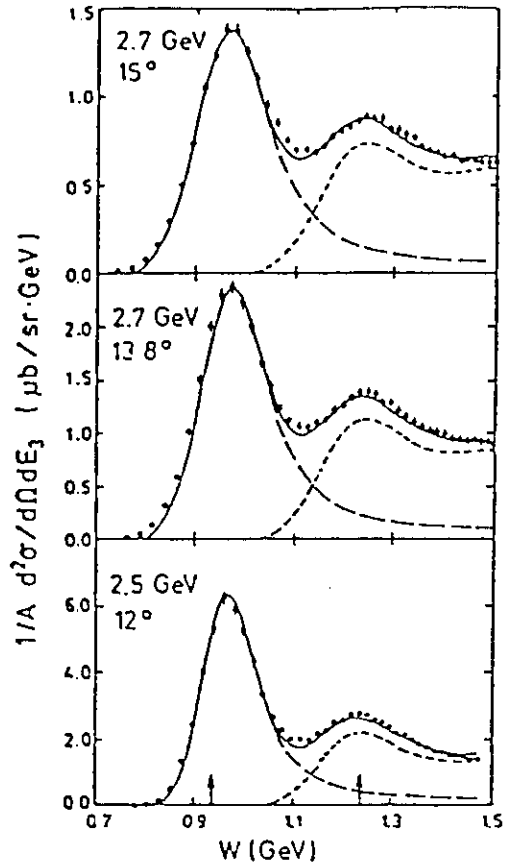

Fig. 2 Cross sections for inclusive electron scattering off Li (data from /GLA79/)

been interpreted as a change of the nucleon form factor in the nuclear medium /CEL85/. In an alternative explanation /MUL86/ the virtual photon interacts directly with the quarks that have a large probability (40% for ^{12}C !) to be in a six-quark bag, thus taking strength away from the quasi-elastic peak. The quantum numbers and the masses of the 6-quark states have been taken from the MIT bag model. Figure 3 shows the transverse structure function of ^{12}C with the predictions of this model. Even underneath the quasi-elastic peak, the model predicts a sizeable contribution from 6-q cluster absorption. At low excitation energy, this process will lead to the emission of NN-pairs, for higher excitation energies to NΔ and $\Delta\Delta$ final states.

(3) multi-nucleon emission (requiring the hadronic final state to contain $\geq$2 nucleons). Two nucleon emission is assumed to be responsible for filling in the dip between the quasi-free peak and the Δ-peak; there should also be strength in the Δ-region due to Δ-excitation with

subsequent Δ-N interaction. The simultaneous emission of four nucleons due to an intermediate double Δ-state has been predicted to be an important contribution to the absorption of pions and photons in the Δ-region /BRO82/.

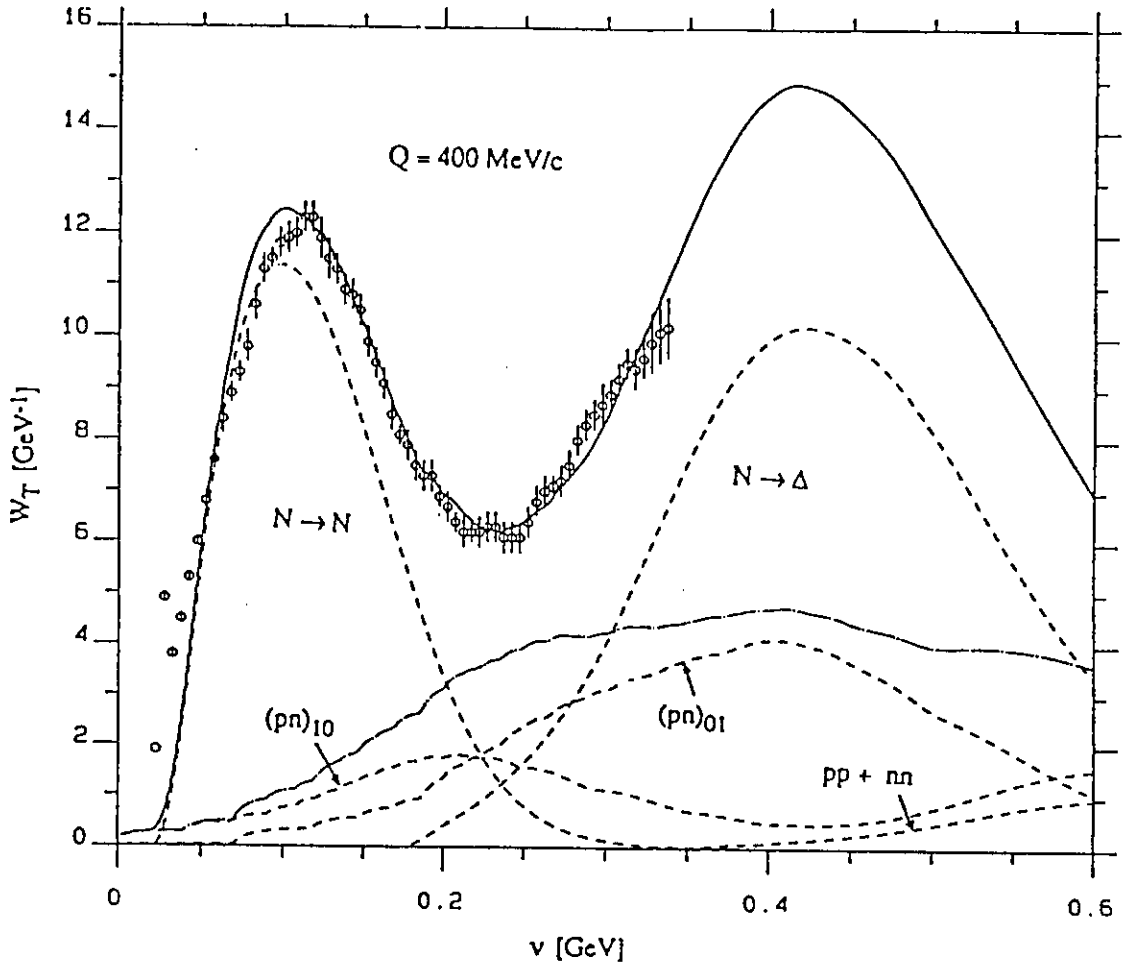

Fig.3 Transverse structure function of ^{12}C at q=450 MeV/c. The dot-dashed line gives the total contribution of photon absorption on 6-quark bags (from /MUL86/).

(4) production and propagation of non-strange (Δ and higher nucleon resonances) and strange (Λ, Σ and their excited states) 3-quark objects in nuclei (requiring the hadronic final state to be a πN, ηN, $\pi\pi$N, KΛ etc. system in the appropriate mass range). Modifications of the properties of these resonances in the nuclear medium can be studied. Especially promising is the $\Lambda^*(1520)$ which can be produced with reasonable counting rates in the reaction $\gamma+p \rightarrow K^+ + \Lambda^*(1520)$. Because of its small natural width (15.6 MeV), a small change of its structure in the nuclear medium should be easier to observe than e.g.

in the case of the $\Delta(1232)$. Compared to the $K^-p \to \Lambda^*$ production channel, the electromagnetic production $\gamma+p \to K^+\Lambda^*$ and the observation of the $\Lambda^* \to \Lambda+\gamma$ decay mode is much less sensitive to initial and final state interactions. By varying the Λ^* production kinematics and the size of the nuclear target, the decay length can be tuned so that the resonance will preferentially decay inside or outside of the nucleus (for $p_{\Lambda^*} = 1$ GeV/c, the mean decay length is 8 fm).

b) Photo- and electro-excitation of the higher nucleon resonances.

Our knowledge of the electromagnetic structure of the nucleon resonances is limited to those resonances that decay into πN. Once the mass and quantum numbers of these resonances are known from elastic πN scattering, their electromagnetic properties can be determined by measuring the details of the $\gamma N \to N^* \to \pi N$ process. With increasing excitation energy and increasing phase space for multi-particle emission, the πN decay channel becomes rare. This is demonstrated in fig. 4 which shows $\sigma_{tot}(\gamma p \to \text{hadrons})$ broken down into single and multiple pion channels. The properties of the known nucleon resonances can be essentially understood on the basis of the harmonic oscillator quark model (with QCD motivated additions like a one-gluon exchange term). The model predicts, however, many additional states which have not been observed. A plausible explanation /ISG84/ is that these states decouple from the πN elastic channel and can, therefore, not be observed in elastic πN scattering. Since, on the other hand, the photocoupling is still strong, photoexcitation becomes a very promising (also the only available) formation mechanism. Typical

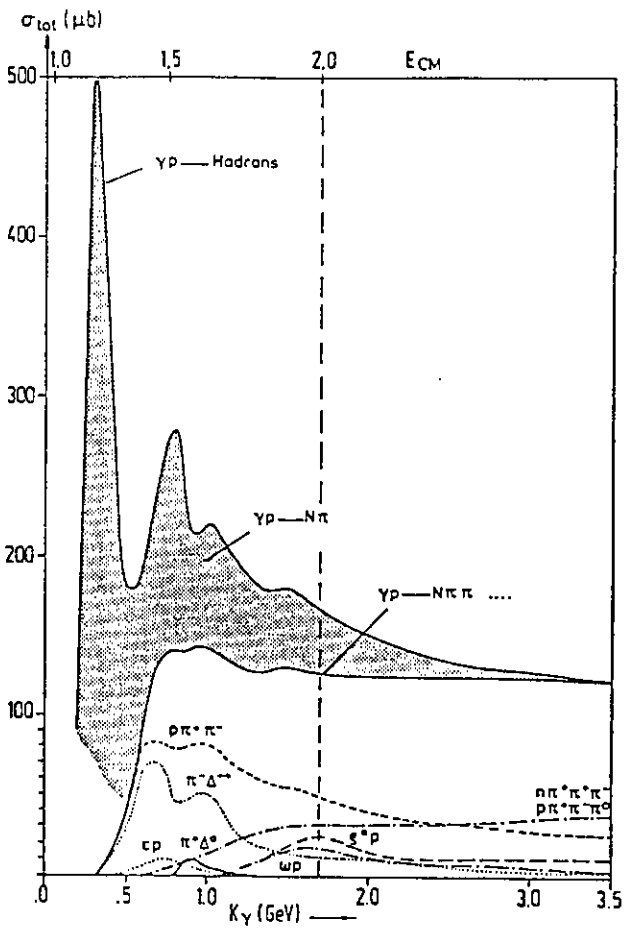

Fig. 4 Total cross section for $\gamma+p \to$ hadrons as a function of the primary photon energy (data from /LUE71/)

decay channels are:

$$\gamma\, N \to N^* \to \pi\, \Delta \to \pi\, \pi\, N$$
$$N^* \to N\, \rho \to \pi\, \pi\, N$$
$$N^* \to N\, \omega \to \pi\, \pi\, \pi\, N$$

To avoid the dominant diffractive vector meson production, the best place to look for these resonances seems to be backward production. In addition to hunting for new resonances, one can test microscopic models for the known resonances by measuring their photocoupling and electromagnetic transition form factor.

c) Photo- (and electro-) excitation of vector mesons

$\gamma\, N \to V\, N$ ($V = \rho, \omega, \phi$ and their excited states)

An important goal of this program is to measure the γ-V coupling constant to get information on the hadronic content of the photon and its variation with Q^2 /BAU78/. In addition, the vector meson coupling to the nucleon can be determined. In boson exchange models of the nucleon-nucleon interaction, this quantity is of fundamental importance for the short range part of the NN-interaction. The A-dependence in nuclear production of vector mesons gives direct information on the total vector-meson - nucleon cross section. Searching for excited vector mesons will test microscopic models for the mass spectrum of light $q\bar{q}$ systems; these experiments will be very difficult because of the large widths of these objects and their complicated decay modes.

d) Hyperon production: $\gamma\, N \to K\, \Lambda\, (\Sigma)$ and excited Λ and Σ states

The cross sections and coupling constants for these reactions have to be known for the analysis of the electromagnetic excitation of hypernuclei. Especially important are measurements with a polarized proton target and the determination of the Λ polarization. Note that the Λ is self-analyzing: by observing the weak $\Lambda \to p + \pi^-$ decay, the Λ spin can be determined from the π^- angular distribution in the Λ rest frame.

e) Exclusive photoreactions on few-body systems (γ = real or virtual photon)

$$\gamma\, d \to N\, N\, \pi \qquad\qquad \gamma\, {}^3He \to p\, p\, n$$
$$\to \Delta\, \Delta \to N\, N\, \pi\, \pi \qquad\qquad \to \pi\, (3N)$$

The basic properties of bound 3-quark systems are best studied in few-body nuclei because the nuclear structure can be calculated exactly (at least in the framework of a non-relativistic potential model). Interesting problems are the off-shell behavior of the γNN^* vertex, the pre-existence of Δ's in the nucleus /LIP87/, the existence of dibaryons /LOC86/ and of 3-body forces in ${}^3He$ /SIC86/.

f) Interaction parameters of unstable particles.

As already mentioned in the case of the Λ^* and the vector mesons, the measurement of the A-dependence of total production cross sections for unstable particles will determine their total hadronic cross sections. In contrast to hadronic production reactions, the electromagnetic production offers the big advantage that the interaction of the incident projectile is so weak that the A-dependence of the cross section can be interpreted directly in terms of the interaction of the produced particle. Especially interesting is a comparison of the hadronic interaction of the $\eta(549)$ and $\eta'(958)$ which are supposed to be different mixtures of the same SU(3) states /LEN87/. The large η' mass is attributed to a sizeable exotic (gluonic or hybrid) component; this should show up as a difference in the hadronic behavior of η and η'.

A comprehensive study of the reactions b) - e) requires the use of polarized beams (longitudinally polarized electrons, linearly and circularly polarized photons) and polarized targets (polarized protons, vector- and tensor-polarized deuterons).

B. GENERAL DESIGN CONSIDERATIONS FOR A LARGE ACCEPTANCE SPECTROMETER

A large acceptance detector should be suitable for a broad range of photonuclear experiments using electron and photon beams. Therefore, it should have the following properties:

1. Homogeneous coverage of a large angular and energy range for charged particles, photons and possibly neutrons.

   a) To account for the Lorentz boost, the angular range for particle detection should be asymmetrical. A reasonable range is roughly $10° \leq \theta_{lab} \leq 150°$

   b) Detection thresholds for charged particles:
      $p \gtrsim 100$ MeV/c for pions
      $p \gtrsim 250$ MeV/c for protons

   c) Photon detection for $E_\gamma \gtrsim 50$ MeV to cover photons from hadron (like π^0, η, η' etc.) decays. Angular definition to match the angular resolution for charged particles.

   d) Open geometry for the installation of a long time-of-flight path for neutron detection.

2. Good momentum and angular resolution

   a) $\Delta p/p \simeq 1$ % b) $\Delta\theta \simeq 5$ mrad

3. Good particle identification properties for electrons, pions, kaons, protons, and deuterons over the whole momentum range.

4. No magnetic field in the target region to provide unobstructed space for the installation of polarized (solid state or gaseous) targets requiring their own guiding field or other complicated equipment (cryogenic or track sensitive targets, vertex detectors etc.).

5. High luminosity and count rate capability:

   a) Electron beam: the detector should be able to operate with an electron beam on target at a luminosity of $\simeq 10^{33} cm^{-2} \cdot sec^{-1}$.

   b) Photon beam: the detector should be able to operate with a tagged bremsstrahlung photon beam ($N_\gamma \simeq 10^7$/sec). Since the background conditions are much more favorable than for an electron beam, this should give no additional constraints.

6. Accelerator requirements.
   To achieve the highest possible luminosity and count rates in a large acceptance detector, an electron beam with 100% duty-cycle will be necessary. The electron beam currents required range from a few nA for the production of a tagged photon beam to $\simeq 100\ \mu A$ for experiments using a polarized gas target. For the latter type of experiments, very high beam quality (low emittance and negligible halo) will be absolutely essential.

C. EXPECTED COUNTING RATES

a) (e,e'X)

The counting rates for inclusive electron scattering have been estimated for the experimental conditions presented in figs. 1 and 2. A luminosity of $10^{33} cm^{-2} sec^{-1}$ (per nucleon) has been assumed.

(1) $^{12}C(e,e')$ for $E_o = 2$ GeV and $\theta_e = 15°$
The total rate of electrons scattered into the angular interval 14°-16° is $\simeq$100/sec in the energy interval (1.3-2.0) GeV.

(2) $^{3}He(e,e')$ for $E_o = .667$ GeV and $\theta_e = 145°$
The total rate of electrons scattered into the angular interval 140°-150° is 2/sec in the energy interval (0.15-0.40) GeV. The

Saclay experiment had approximately 9 events/sec at a luminosity of $\simeq 1.5 \cdot 10^{36}$ $cm^{-2} sec^{-1}$. In a large acceptance spectrometer, the lower luminosity is essentially compensated by the larger solid angle (500 msr vs. 5 msr) and the larger momentum acceptance (full momentum range vs. $\Delta p/p=0.4$).

This comparison shows that hadronic final states in inclusive electron scattering can be investigated with counting rates that are comparable to previous single-arm experiments. The big advantage of using a large acceptance detector is that the information on the hadronic final state will be available for later off-line analysis.

b) photon induced reactions

Combining a tagged photon beam with an intensity of 10^7 γ/sec and a hydrogen target of 0.5 g/cm^2 ($\simeq$7 cm liquid) yields a total hadronic counting rate of $\simeq$400 events/sec (E_γ = 2 GeV, σ_{tot} = 140 μb). On the basis of our present knowledge of the total cross sections, the following event rates in single channels can be expected:

single π-production	80 events/sec
ρ-production	75 events/sec
$\pi\Delta$ production	30 events/sec
ω-production	20 events/sec
η-production	4 events/sec
Λ-production	3 events/sec
Σ^o-production	1 event/sec
ϕ-production	1 event/sec

This count rate is sufficient even for the investigation of rare processes.

D. SUMMARY

The physics motivation for the investigation of electron- and photon-induced multiple particle reactions at CEBAF has been examined. Experiments that were discussed include a bias-free investigation of the hadronic final state in inclusive electron scattering, the photoexcitation of nucleon resonances and the production and interaction of hyperons. The requirements for the accelerator and the detector have been outlined. The CEBAF superconducting accelerator with its high duty-cycle and excellent beam quality will be ideally suited for the operation of a large acceptance detector. Counting rates that can be achieved using a large acceptance spectrometer have been estimated for typical reactions. The rates are comparable to present single arm electron scattering experiments. The experiments are technically feasible and complementary to the high resolution set-up.

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