PHYSICS WITH CLAS AT ENERGIES UP TO 12 GEV[1]

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1. INTRODUCTION:

An energy increase of CEBAF into the 8-12 GeV range will benefit the physics program with CLAS in at least three areas: first, it increases the accessible range in four-momentum transfer for the study of exclusive reactions and form factor measurements to $Q^2 = 6$ -10 GeV^2. Second, it extends the phase space available for the production of heavy mesons with masses greater than 1.5 GeV, and for total hadronic masses $W < 4$ GeV. Third, it will allow to fully reach the deep inelastic regime, with momentum and energy transfers needed for the study of transitions into the regime where pQCD may be applicable for inclusive as well as specific exclusive processes.

The boundaries of the physics program are defined by the capabilities of the CLAS detector. These include:

- large acceptance (but not 4π)
- high luminosity at large acceptance
- detection of several (but not many) hadrons in the final state
- hadron detection out-of-plane
- operation of polarized solid state targets for electrons (NH2, ND3) and photons (HD)

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For the following discussion we assumed that CLAS will be upgraded in several important aspects:

- full ø coverage for the charged particle tracking (without magnetic analysis) and the detection of high energy photons
- extension of scattering angle coverage down to angles of about 5 degrees
- extend particle identification, especially kaon/pion separation from 2 to 5 GeV/c
- implement photon tagging capabilities at high energies, which one currently limited to 6 GeV electron beam energies

2. THE N* PROGRAM AT HIGHER ENERGIES

2.1 Resonance transition form factors

The N* program at high momentum transfers has focused on the study of the $\Delta(1232)$ using the $p\pi^0$ channel, and the N*(1535) using the $p\eta$ channel. However, both states show some peculiarities, which make it desirable to study the high Q^2 behavior of other states as well: The Δ (1232) excitation falls off much more rapidly with Q^2 than other resonance. Its leading order pQCD amplitude may be very small and very high Q^2 may be required to study the transition to dominant pQCD behavior. The N*(1535) has been questioned as to whether it is a normal 3-quark resonances, or perhaps dynamically generated. To avoid these difficulties it is desirable to complement the measurements with the study of other states. The CLAS N* program at 4 GeV has already shown that [1] resonances

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[1] Contributions by the following members of the CLAS Collaboration are acknowledged: W. Brooks, D. Cords, A. Freyberger, H. Funsten, M. Ito, D. Jenkins, F. Klein, B. Mecking, M. Mestayer, G. Mutchler, C. Salgado, and S. Stepanyan. Many of the topics discussed in this contribution were already included in the ‘White paper on CEBAF at higher energies!’

in the mass region from 1.5 - 1.8 GeV are strongly excited in the dominant $n\pi+$ decay channel, as well as the $N\pi\pi$ channels, e.g. $\Delta^{++}\pi^-$. Because of the large acceptance of CLAS there is no preference for the favored neutral meson channels such as $p\pi^0$ where the proton is emitted in a relative small cone around the virtual photon direction. Charged pion production as well as multi-pion channels can be measured equally well. This will allow measurement of resonances such as N*(1520), N*(1680), Δ(1620) or Δ(1700) at high Q^2.

2.2 Search for missing quark model states

The CLAS N* program has already shown evidence for copious non-diffractive production of $p\omega$ events, for masses around 2 GeV, likely from intermediate resonance excitation [1]. The study of their internal structure requires the measurement of their resonance transition form factors. At energies of about 8 GeV sufficient kinematical flexibility can be achieved for these measurements.

2.3 Guonic baryon excitations

The search for gluonic baryons is an important aspect of baryon spectroscopy at high energies. These states have the same quantum numbers as ordinary 3-quark states. The only known way to distinguish gluonic and quarkic excitations is from the expected different Q^2 falloff of their transition form factors [2]. For example, in the case of the lightest predicted P_{11} state, the gluonic state has a Delta-like quark structure with the quarks in a relative s-state, while the ordinary 3_quark state is a radial excitation with different spin-favor structure of the electromagnetic transition. The model predicts very different form factors for these alternatives. Gluonic states are likely rather heavy (masses > 1.5 - 2.0 GeV). Measurement of their transition form factors in a sufficiently large Q^2 range requires electron energies of 6 - 8 GeV.

3. THE SPIN STRUCTURE OF THE NUCLEON

3.1 Higher moments of $g_1(x, Q^2)$

The first moments of the polarized structure function $g_1(x)$ have been measured for neutrons and protons. However, at moderate momentum transfer, measurements of higher moments are important for a full understanding of the $1/Q^2$ corrections to the Bjorken sum rule (A. Schäfer, Workshop on CEBAF at Higher Energies, 1994, pg. 321). They provide access to the quantities a_2 and d_2, which are defined as:

$$\int x^2 g_1(x, Q^2)dx = 1/2a_2 + 0(M^2/Q^2)$$

$$\int x^2 g_2(x,Q^2)dx = 1/2\ a_2 + 1/3d_2 + 0(M^2/Q^2)$$

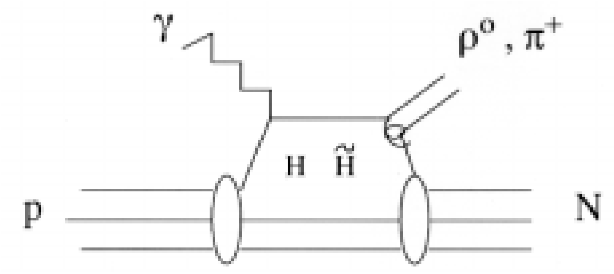
a_2 contains information on the momentum distribution of polarized quarks, and how the momentum is split between valence and sea quarks: If a_2 is large, the valence quarks carry a large fraction. If a_2 is small, most of the spin is carried by sea quarks or gluons. d_2 is sensitive to non-perturbative contributions. The integrals are saturated by contributions from x>0.15, and high statistics at large x is needed for an accurate determination of these moments. Such a program is ideally suited for a large acceptance detector such as CLAS when operated at high luminosities, and electron beams of 10 - 12 GeV.

3.2 Flavor-tagged polarized structure function.

At high energies new information on the nucleon structure functions may be obtained from measurements of π^+, π^-, K^+, K^-, etc., in coincidence with the scattered electron. On a statistical basis the struck quark may be identified (flavor tagging). As a result, the fragmentation functions A^h, (x, z) may be determined for various final state hadrons: $h = \pi$, K, ρ ...etc. Simulation of the fragmentation processes will be important in order to understand the sensitivity of these measurements to the parton distribution of interest.

4. NON-FORWARD PARTON DISTRIBUTIONS OF THE PROTON

These NFPD have generated much interest very recently and are described in various contributions to this workshop (A. Radyushkin, C. Carlson, M. Guidal). The NFPD are generalizations of the parton distributions measured in deep inelastic scattering. They are related, e.g. to diagrams like this:



In this example, H measures the quark distribution (ρ^0), while H measures the quark helicity distribution in π^0 production. Measurement of H requires selecting longitudinal vector mesons. This can be achieved by analyzing the decay angular distribution, e.g. in $\rho^0 \rightarrow \pi^+ \pi^-$. This program is very well suited for CLAS, especially with improved hermiticity for particle detection at forward angles. It is important that pQCD can be used to analyze the process. This can be tested by studying the Q^2 dependence of the inclusive cross section, which, e.g. for longitudinal ρ^0 production should behave like:

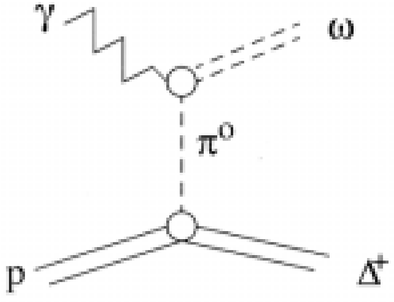
$$\frac{d\sigma}{dt} \sim \frac{1}{Q^6}$$

The NFPD are not only functions of t, but of as other kinematical quantities as well. Cross checks whether the regime of applicability of these NFPD has been reached are due to sum rules, which relate the measured quantities to vector and axial vetor form factors of the nucleon. Energies of 10 GeV and greater appear well suited for such a program.

5. PHOTOPRODUCTION AND ELECTROPRODUCTION OF MESONS

5.1 Meson transition form factors

Similar to the measurement of nucleon transition form factors, the measurement of electromagnetic transition of mesons allows probing of hadron structure models such as the flux tube model [3]. In some cases, e.g. for the ω , the radiative decay $\omega \rightarrow \pi^0 \gamma$ is important. The transition form factor $F_{\gamma\pi\omega}$ (t) can be measured. To avoid the strong diffractive contributions to the p ω final state, the $\Delta^+\omega$ final state may be better suited:



This reaction requires measurement of a more complex final state. Similar measurements may be done for the a2, b1, and other mesons as well.

5.2 ø - meson production at high energies

QCD predicts that longitudinal photons transform into smaller size ($q\bar{q}$ pairs with increasing momentum transfer. This prediction may be tested in the production of vector mesons if the longitudinal and transverse response functions are separated. A separation is possible by studying the decay distribution of vector mesons, e.g. in

$$ep \rightarrow \ ep\phi,\ \phi \rightarrow K^{+} K^{-}$$

The angular distribution of the $K^{+}K^{-}$ final state is sensitive to the transverse/longitudinal nature of the photon.

If one measures the t dependence of the longitudinal component of phi production off photons, the slope b in

$$\frac{d\sigma}{dt} \sim e^{-b|t|}$$

provides information on the size of the ($q\bar{q}$ pair involved in the process. Shrinkage is evident in a hardening of the slope b (magnitude of b decreases). Since other, competing processes are present as well, an energy of 10 GeV is needed to optimize the kinematical sensitivity to this QCD phenomenon.

Measurement of the t-dependence of ϕ photoproduction tests ‘diffractive’ scattering, and allows a better understanding of the nature of the Pomeron.

Exclusive meson photoproduction at high momentum transfer t is an important source of information for obtaining a better understanding of the obvious scaling behavior of many exclusive processes.

5.3 Mesons with gluonic excitation (hybrids).

The search for gluonic excitation in the meson sector ($q\bar{q}$ G), is a focus of hadron spectroscopy and npQCD studies of hadron structure. Some of the hybrid states are predicted to have exotic quantum numbers, which cannot be excited in the $q\bar{q}$ system. These states are predicted to have masses around 1.8 - 2GeV. To produce them copiously in photoproduction reactions, photon energies of 6 - 10 GeV are needed. At high meson masses the final state will often be rather complex. Identification of the reaction requires detection of many photons or charged particles. Hermiticity of the detector will be essential. Although CLAS will not be the ideal instrument for such a program we anticipate that some reactions may be investigated with CLAS after a detector upgrade. Some of the reactions that may be suited for CLAS are:

$$\gamma p \rightarrow \rho b_{1}^{+}\pi^{-},\ N\pi\eta,\ N\pi\eta',\ K(\lambda'\Sigma)\pi$$

It will be especially important for this program to extend the coverage at forward angles for tracking and neutral particle detection (photons and neutrons).

5.4 Strangeonia spectroscopy.

Experimentally ($s\bar{s}$ resonances are very poorly known, although reliable predictions for the $s\bar{s}$ spectrum exist in the flux tube model. Also, decay modes have been calculated for all $s\bar{s}$ states up to 2.2 GeV (4), and some states are predicted to be narrow. The poor experimental situation is largely due to the small fraction of $s\bar{s}$ states produced in hadronic processes. The ($q\bar{q}$ nature of the photon, should make such a program feasible at an energy-upgraded CEBAF.

Gluonic excitations ($s\bar{s}$ G) have been predicted in the flux tube model as well as in Lattice QCD calculations. The first exotic ($s\bar{s}$ G) state with $J^{PC}1^{-+}$ is predicted in LQCD with a mass of 2GeV. High photon rates are needed for such a program as well as improved K/π separation and photon detection at forward angles. Options for these upgrades are discussed in other contributions to this workshop (B. Mecking, R. Jones, P. Stoler, and V. Burkert).

6. NUCLEAR STUDIES WITH CLAS AT HIGH ENERGIES

We have so far concentrated on experimental programs to study the structure of hadrons. However, nuclear studies will benefit from an energy upgrade as well. A focus of the nuclear program with CLAS will be the study of short range structure of light nuclei. High momentum transfer is needed, and the suppression of final state interaction at high momenta will allow less model-dependent analyses than have been possible at lower energies.

Ideally suited for CLAS are investigations of multi-nucleon knockout phenomena. Emission of up to five protons have already been observed in electron scattering off the aluminum windows of the CLAS target cell The breakup of nuclei into multiple nuclear fragments such as deuterons, tritons, He-3, and so on at high momentum transfer will provide us with a vast amount of information on the nuclear structure at short distances. The measurement of nucleon and nucleon resonance propagation in the nuclear medium will give complementary information.

Color transparency is a short range phenomena of special interest. A limited program has been approved for CLAS at lower energies to study two nucleon knockout from light nuclei. This program is ideally suited for CLAS at energies of 8 - 10 GeV, where sufficiently high Q^2 be reached. Color transparency can also be studied efficiently in coherent vector meson production off nuclei, which, again, is well suited for CLAS.

7. CONCLUSION

There exist a wide range of physics opportunities for CLAS at energies around 8 - 12 GeV. These cover the measurement of:

- higher moments of polarized structure function, inclusive or with additional mesons in coincidence,
- the measurement of non-forward parton distribution involving vector mesons in the final state,
- the excitation of nucleon resonances at high momentum transfer,
- ϕ meson production and the study of $s\bar{s}$ spectroscopy,
- the search for gluonic excitations of mesons and baryons, and
- short range phenomena in nuclei such as color transparency and multi-nucleon knockout.

Part of this program will require, or at least greatly benefit from, improvements in the hermiticity of CLAS for the detection of charged particles and photons, especially at forward angles. Also, higher photon rates and higher luminosity in electroproduction experiment will be important to compensate for the lower rates at high momentum transfers.

[1] V. Burkert, talk presented at the joint JLAB/ECT workshop on N* physics, May 1998.
[2] Zp. Li, V. Burkert, Zh. Li, Phys. Rev. D.46, 70 (1992)
[3] N. Isgur and Patton