FEW-BODY FORM FACTORS AT HIGHER JLAB ENERGIES

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ABSTRACT

Prospects for elastic scattering off few-body systems with higher beam energies at Jefferson Lab are presented. The elastic structure function $A(Q^2)$ data of the deuteron and the helium isotopes can be extended to very large momentum transfers using reasonable beam times and planned spectrometer upgrades. The new measurements will be critical in the search for a transition between the conventional meson-nucleon and the quark-gluon constituent descriptions of the few-body systems.

An upgrade of JLAB to beam energies between 6-12 GeV will offer unique opportunities to advance our understanding of the structure of few-body nuclear systems: the deuteron and the isotopes of helium. Large momentum transfer measurements of the elastic form factors of the few-body systems, in particular, should be able to explore a possible transition from meson-nucleon to quark degrees of freedom and to test predictions of dimensional quark scaling and perturbative quantum chromodynamics (PQCD).

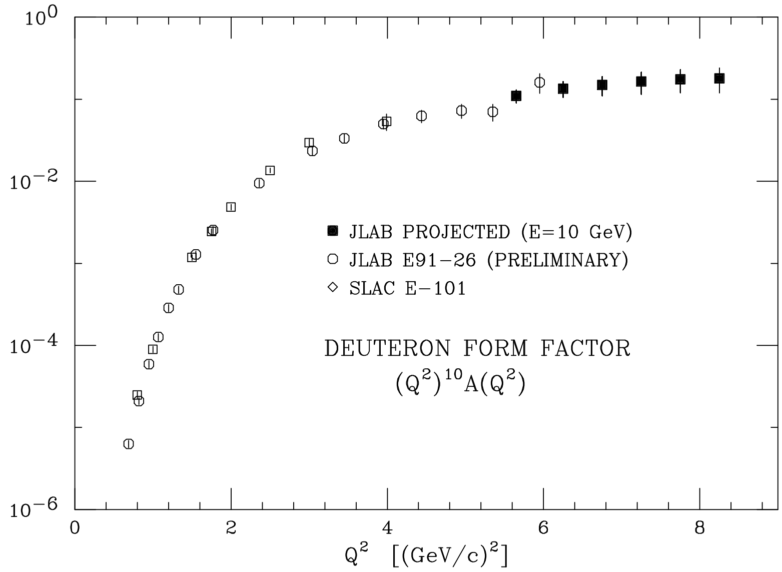

Figure 1: Existing and JLAB projected data for the deuteron form factor $A(Q^2)$, multiplied by a dimensional quark scaling $(Q^2)^{10}$ factor (see text), using a 10 GeV upgraded beam.

The starting point of the conventional theoretical approach of elastic scattering from few-body systems [1] is the impulse approximation (IA), where the incident electron interacts with one of the nucleon constituents of deuterium or helium. The light-nucleus form factors are then convolutions of the nuclear wave function with the form factors of the constituent nucleons. At large momentum transfers the effects of relativity cannot be ignored and either corrections to the IA or fully relativistic approaches, as in the deuteron case [2], have been developed. It has long been understood and overwhelmingly supported by the available data that the few-body form factors are sensitive to the presence of meson exchange currents (MEC) and isobar configurations that augment the IA picture [1].

It is widely recognized that at distances much less than the nucleon size, the underlying quark substructure of the nucleons cannot be ignored. This has lead to the formulation of the so called hybrid quark models [3] that treat few-body nuclei as quark clusters when the internucleon separations become smaller than $\sim$1 fm. At sufficiently "large" momentum transfers, the few-body form factors are expected to be calculable in terms of only quark and gluon constituents within the framework of PQCD. The first attempt for a quark-gluon description of elastic form factors was based on the dimensional scaling quark model (DSQM) [4]. The underlying dynamical mechanism during elastic scattering is the hard rescattering of the constituent quarks via exchange of hard gluons. The Q^2 dependence of this process is then predicted by simply counting the number n of gluon propagators (n=5 for deuterium, 8 for ^{3}He, and 11 for ^{4}He), which implies that the elastic structure functions $A(Q^2)$ of the few-body systems should follow the power law: $\sqrt{A(Q^2)} \sim (Q^2)^{-n}$. This prediction was later justified in the PQCD framework, where it was shown [5] that in

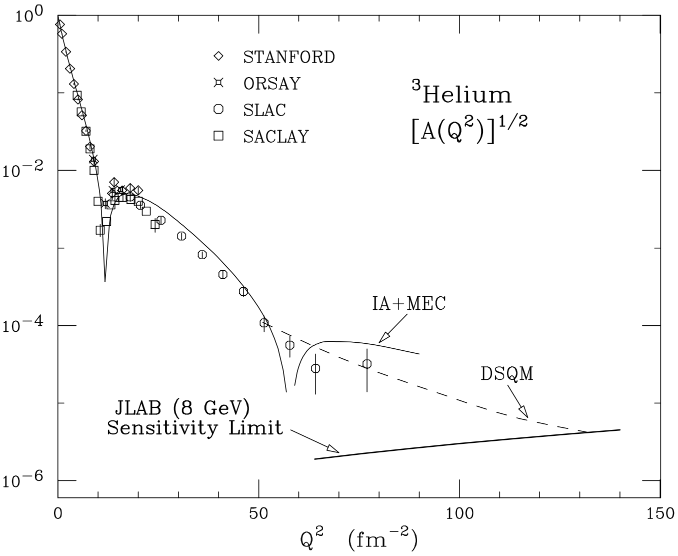

Figure 2: The sensitivity limit ($\pm$25% stat. error in about a week of beam time) for a future $A(Q^2)$ measurement of ^{3}He with an upgraded 8 GeV JLAB beam. Also shown are existing data and large momentum transfer predictions of IA+MEC and quark scaling.

leading-order: $\sqrt{A(Q^2)} = [\alpha_s(Q^2)/Q^2]^5 \sum_{m,n} d_{mn}[\ln(Q^2/\Lambda^2)]^{-\gamma_n-\gamma_m}$ where $\alpha_s(Q^2)$ and Λ are the QCD strong coupling constant and scale parameter, $\gamma_{m,n}$ and d_{mn} are QCD anomalous dimensions and constants. Although there have been serious arguments [6] questioning the applicability of DSQM and PQCD ideas at momentum transfers accessible by the present electron accelerators, JLAB preliminary results on the deuteron $A(Q^2)$ form factor and on deuteron photodisintegration appear to be consistent with the power law fall-off of dimensional scaling, necessitating the need for future deuteron and helium form factor and photodisintegration measurements at JLAB.

Figure 1 shows existing $A(Q^2)$ SLAC data [7a] and preliminary JLAB Hall-A (from experiment E91-26) data multiplied by $(Q^2)^{10}$ showing an apparent approach to a scaling value as predicted by quark scaling. It should be noted, that at the same time, the data are described well by the conventional relativistic IA with inclusion of $\gamma\pi\rho$ MEC [2]. It is evident that higher Q^2 measurements will be critical in testing this scaling approach trend. Higher JLAB energies in the range 6-12 GeV are essential for such measurements. To separate elastic from inelastic scattering and to suppress backgrounds, recoil deuterons should be detected in coincidence with scattered electrons. A possible scenario would be to use the proposed SHMS and existing HMS Hall-C spectrometers. Assuming a 15 cm long liquid deuterium target and a 10 GeV beam in excess of 100 μA, $A(Q^2)$ can be measured up to ~ 9 (GeV/c)^2, in one month of beam time, as shown in Fig. 1.

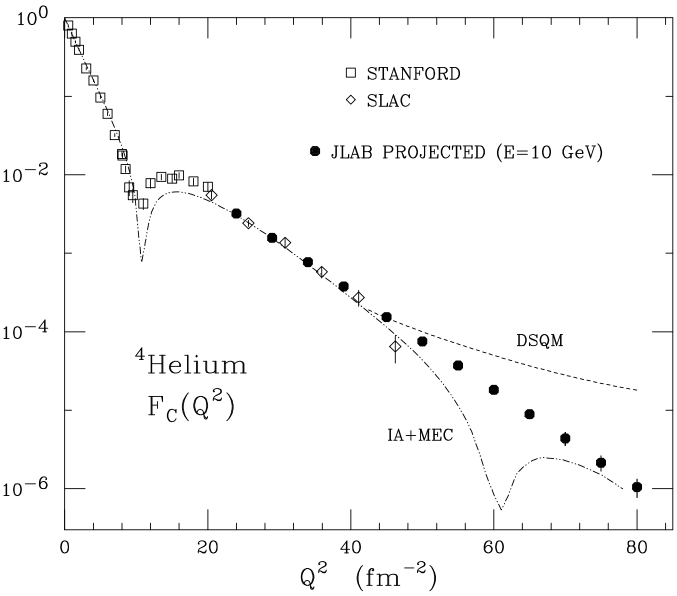

Figure 3: Existing and JLAB projected data, using a 10 GeV upgraded beam, for the ^{4}He charge form factor $F_c(Q^2)$. Also shown are large momentum transfer predictions of IA+MEC and quark scaling.

The existing data on the ^{3}He $A(Q^2)$ [7b], shown in Figure 2, are in agreement with the meson-nucleon (IA+MEC) calculations [1] at low Q^2 but are fairly inconclusive at the largest momentum transfers. They are consistent with a change in slope, indicative of an onset of scaling, but, at the same time, cannot exclude the presence of a second diffraction minimum as predicted by the conventional meson-nucleon theory. As in the case of deuterium, more measurements at higher Q^2 would be crucial in testing the quark scaling prediction and any possible breakdown of the meson-nucleon framework. A future energy upgrade of CEBAF to 8 GeV will also allow for new ^{3}He measurements that could double the Q^2 range of the existing data with a ten-fold better sensitivity. The sensitivity limit is defined as the lowest $[A(Q^2)]^{1/2}$ value that can be measured with $\pm 25\%$ statistical error in a week of beam time and is shown for an 8 GeV beam of 100μA current in Fig. 2 (this limit would be even lower with a 10-12 GeV beam). The new measurements assume use of the high power cryotarget of Hall-C with a 15 cm long, high-density ^{3}He target cell and the proposed upgraded spectrometer facility of the Hall.

Higher JLAB beam energies will be also instrumental in extending the existing ^{4}He charge form factor $F_c(Q^2) = [A(Q^2)]^{1/2}$ measurements [7b]. The availability of a 10 GeV beam would be sufficient to also double the Q^2 range of the available data, as shown in Figure 3, in approximately one month of beam time. The new data could reveal the existence of a second diffraction minimum as predicted by the IA+MEC theory. The new measurements will also require a long ^{4}He high-density target cell, the proposed SHMS spectrometer, and a beam current in excess of 100 μA.

In summary, higher JLAB energies could extend our knowledge of the elastic form factors of few-body systems to larger momentum transfers with measurements requiring reasonable beam times and planned spectrometer upgrades. The new measurements will study an expected transition from the conventional meson-nucleon to the constituent quark-gluon description of the few-body nuclear systems and may provide crucial input for understanding nuclear structure within the framework of perturbative quantum chromodynamics.

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