Deuteron Electro-Disintegration at Very High Missing Momenta

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1 Motivation

The deuteron(^{2}H) was discovered in 1931 by Harold Urey, and it remained a mystery until the discovery of the neutron by James Chadwick ~~on~~ the following year. Since then, the deuteron has been under intensive research in an attempt to understand what binds the atomic nucleus. Being a ~~the~~ simple~~st~~ *np* bound state, the deuteron serves as a starting point to study the strong nuclear force at the subfermi level which is currently not well understood. At Such small internucleon distances ~~correspond to a repulsive core in~~ the NN potential is expected to exhibit a repulsive core in which the interacting nucleon pair begins to overlap. The overlap is directly related to two- nucleon ~~nucleon~~ short range correlations (SRC) observed in $A \geq 2$ nuclei[5]. Short-distance studies of the deuteron are also important in determining ~~whether or~~ to what extent the description of nuclei in terms of nucleon/meson degrees of freedom must be supplemented by the inclusion of explicit quark effects[7].

In ~~To study the~~ nuclear structure studies in general, electron-nucleon scattering serves as the most valuable tool since the interaction is described by the theory of Quantum Electro-Dynamics (QED), which is well-understood and capable of making accurate predictions. Electron scattering experiments can be separated into inclusive or exclusive scattering experiments ~~type.~~ In the first of these, only the electron is detected in the final state (single-arm experiments), and so one studies the nucleus in question by integrating over all possible final states[1]. In the exclusive type, ~~a second (or more)~~ one or more particles are ~~is~~ detected in coincidence with the scattered electron which allows one to investigate ~~study~~ properties unique to the specific reaction in question. In deuteron ~~the~~ electro-disintegration ~~of deuteron~~, for example, one detects the scattered electron in coincidence with a proton and the missing neutron is reconstructed from four-momentum conservation. This reaction proves to be the most direct way of probing the internal structure of the deuteron since it is possible to deduce the internal momentum of the nucleons from the neutron missing momentum.

With the 12 GeV Upgrade at Jefferson Lab, the short-range ($\leq$ 1 fm) structure of the deuteron will become experimentally accessible giving us an insight on ~~important inquiries such as~~ the deuteron wavefunction beyond relative internal momenta of 400 MeV/c. Also, at such high energies, one will be able to probe the limits of nucleonic degrees of freedom before Quantum Chromodynamics (QCD) effects start playing a more significant role.[5]

2 Theoretical Framework of D(e,e'p)n

Deuteron ~~The~~ electro-disintegration of deuteron ~~is an electromagnetic process well described by QED. It~~ can be pictorially described by a Feynmann diagram (See Figure 1)

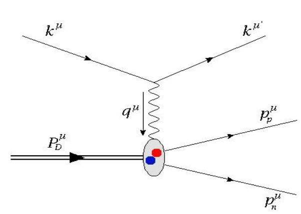

Figure 1: Feynmann diagram of deuteron electro-disintegration

where the incoming the electron interacts with the stationary deuteron to first order approxiwhat to you mean with this ? here you should write the general e,e'p cross section with its response functions for unpolarized scattering

mation, via the exchange of a virtual photon. Given the relatively weak coupling constant for this process, higher order Feynmann diagrams involving multiple photon exchanges may be neglected.

The photon interacts with the deuteron through various interfering processes which must be taken into consideration if one wishes to extract meaningful information about this nucleus. The simplest is the Plane-Wave Impulse Approximation (PWIA) in which the internal proton is knocked out by the photon while the spectator neutron scatters as a free particle (plane wave) with a momentum equal to that of when it was in the deuteron, therefore, it gives an accurate description of the internal momentum of the deuteron. (See Figure 2)

In PWBA the virtual photon is absorbed by the proton which is detected. Both the final state proton and neutron are described by plane waves, hence they do not interact with each other … (more details)

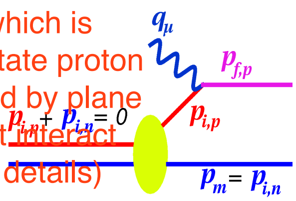

Figure 2: Feynmann diagram for PWIA, where the proton(red) is knocked by the photon, and the neutron(blue) scatters as a spectator

No this additional process is taken into account coherently with the direct proton knock-out, but still plane waves

Alternatively, in the Plane-Wave Born Approximation (PWBA, not shown) the photon instead knocks out the neutron, while the proton is a spectator.

In a process known as Meseon Exchange Currents (MEC), the photon may also couple to the virtual meson being exchanged between the nucleons, ~~which after absorption, becomes a real meson.~~ (See Figure 3)

no, that would be pion production

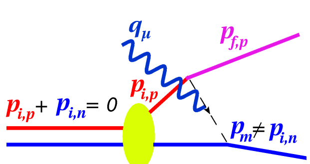

Figure 3: Feynmann diagram for MEC, where the virtual photon couples to the exchange meson (dashed line) causing the spectator neutron(blue) to re-scatter off the proton(red)

In another competing process, either nucleon in the deuteron may be excited into a Δ or N^* resonance, which re-scatters to the groundstate with the spectator nucleon. This process is known as

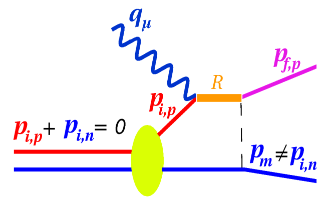

Figure 4: Feynmann diagram for IC, where the proton(red) is excited by the photon into an intermediate state (orange) R. The excited state decays and rescatters off the neutron(blue) in the process

Isobaric ~~Currents~~ (IC). (See Figure 4)
Finally, there are Final State Interactions (FSI) in which the ejected proton and scattered neutron undergo subsequent interaction causing further re-scattering and thereby altering the neutron momentum in the final state. (See Figure 5) From the processes described above,

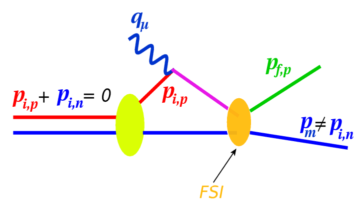

Figure 5: Feynmann diagram for FSI, where the proton(red), after excitation by the photon, undergoes subsequent interactions (orange) with the neutron(blue) resulting in a re-scattering of both final state particles.

only the PWIA gives an accurate description of the deuteron internal momentum. Therefore, it is of utmost importance to study at which kinematic settings are these competing processes suppressed(MEC, IC), or at least under control(FSI).[5] From theoretical calculations of the MEC scattering amplitude, the meson exchange propagator, characterizing the virtual exchanged meson in Figure 3 is proportional to $(1 + \frac{Q^2}{m_{meson}^2})^{-1}$, where the mass of the meson is $m_{meson}^2 \approx 0.17(\mathrm{GeV/c}^2)^2$[3], therefore, at high Q^2 MEC is expected to be suppressed. Suppression of IC is possible by probing the lower side of the quasi-elastic peak (choosing Bjorken scale $x_{Bj} \geq 1$), which is maximally away from the inelastic threshold of Δ electroproduction[6].(See Figure 6)
In the high energy limit($Q^2 \geq 1$ (GeV/c)^2), the Generalized Eikonal Approximation (GEA) is established for FSI. In this approximation, the potentially infinite number of re-scattering dia-

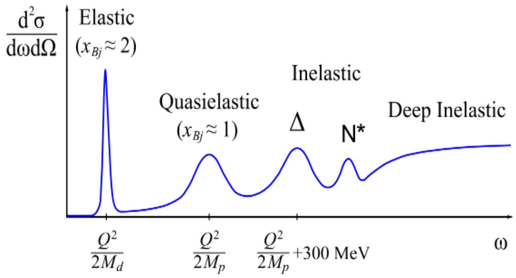

Figure 6: Qualitative inclusive electron scattering cross section for deuteron versus the virtual photon energy ω for a fixed momentum transfer Q^2 [2]

grams in FSI can be treated using effective Feynmann rules simplifying the problem to a finite set of re-scattering diagrams[4]. The GEA predicts a strong angular dependence of FSI with scattering angle between spectator nucleon and virtual photon, which opens a kinematic window at which FSI are reduced[6].(See Figure 7)

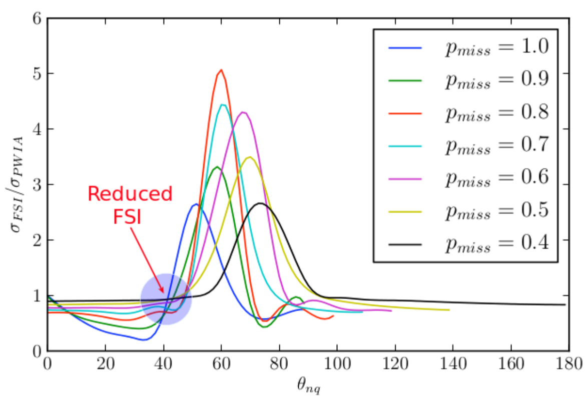

Figure 7: Ratio of FSI/PWIA cross-section vs. scattering angle between spectator neutron and virtual photon, θ_{nq}, for various missing momenta up to 1 GeV/c [6]

This kinematic window gives, for the first time, a possibility to study the short-range structure of the deuteron at high missing momenta without the overwhelming effects of FSI.

References

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