Deuteron Electro-Disintegration at Very High Missing Momenta

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1 Physics Motivation

High-energy, exclusive electro-disintegration of the deuteron at missing momenta up to ≈ 1 GeV/c is considered as the most effective process to probe two nucleon dynamics at short space time distances. The latter condition is essential for probing the limits of nucleonic degrees of freedom in strong interaction dynamics. These are the distances at which the repulsive core of the strong interaction becomes dominant and a host of new dynamical effects such as the role of the non-nucleonic components and the transition from hadronic to quark-gluon degrees of freedom become increasingly important.

1.1 Importance of these studies for the field

NN Dynamics: The proposed measurement will provide important data beyond the region of nuclear forces dominated by tensor-interactions. It will allow an unprecedented access to the dynamics of the repulsive core. Presently the phenomenology of hard exclusive two-body baryonic scattering[1] indicates the dominance of quark-interchange mechanism of scattering at sub-fermi distances. Proposed experiment for the first time will allow to check this conjecture of bound NN system.

Non-nucleonic Degrees of Freedom: Starting from $p > \sqrt{M_\Delta^2 - M_N^2} \approx$ 800 MeV/c one expects increasing contribution from the $\Delta - \Delta$ component to the deuteron wave function. The strength of this component is related to the hidden- color component in the deuteron wave function[2]. The proposed experiment will cover the NN to $\Delta\Delta$ transition region and from theoretical point of view may allow to constrain the overall contribution of hidden-color components in the deuteron wave function.

Gluonic Degrees of Freedom in Nuclei: Deep inelastic scattering at small x and large Q^2 as well as production of J/Ψ from the deuteron are sensitive to the gluonic component of the deuteron. These reactions are sensitive to the deuteron wave function at sub-fermi distances and the ability to distiguish possible nonlinear gluonic effects in these reactions requires a well understood deuteron wave function at $\leq 1fm$ separations. The proposed experiment will provide this data and will prepare a groundwork for experiments discussed for possible Electron-Light-Ion Collider machine[3].

1.2 Present status of the field

Presently the deuteron has been probed up to the 500 MeV/c relative momentum region which is dominated by tensor part of the NN interaction[4, 5]. By measuring at large Q^2 (~ 3.5 GeV^2), long-range two-body effects such as meson-exchange currents are ruled out. These data clearly show the onset of high-energy (eikonal) regime of the scattering which allows to separate clearly the final state interaction from reaction-mechanism and wave function effects. The highest Q^2 was achieved in a Hall B experiment[4]. However, the accuracy of the data does not allow unambiguous discrimination between models with different predictions for the strength of tensor scattering in the NN system. Preliminary data from Hall A measurements at $Q^2 = 3.5$ GeV^2 however shows clear possibility in separating the wave function from FSI.

Future analysis of existing data will provide improved constraints on several theoretical uncertainties of the theoretical frameworks used to calculate electro-disintegration reaction. This work includes the ongoing analysis of JLab experiment E-01-020[5] as well as planned study of inclusive and exclusive deuteron electrodisintegration using wealth of the available data from CLAS[6].

1.3 Theory Support of the Experiment

Presently there exist an active theory research in developing the models of high energy electro-disintegration reactions (for recent progress see Ref.[7, 8, 9, 10, 11, 12]. Some of the researchers also involved in the research program of Electron-Ion Collider, thus results of our experiment will naturally used for the physics relevant to EIC.

2 Experimental Program

We plan to measure the D(e,e$'$p)n cross section at kinematic settings centered on the following missing momenta: $p_m = 0.5$, 0.6, 0.7, 0.8,0.9 and 1.0 GeV/c. Electrons will be detected in SHMS and the ejected protons in HMS. For each setting the electron arm will remain unchanged and the electron kinematics will be fixed at $Q^2 = 4.25$ (GeV/c)^2 and at $x_{bj} = 1.35$.

Small recoil momenta of the order of 0.1 GeV/c will be measured for $Q^2 = 3.5$ (GeV/c)^2 as well as at $Q^2 = 4.25$ (GeV/c)^2. These data will be used for normalization measurements since at these values contributions of FSI, MEC and IC are small and the cross sections are large. In addition we will also measure the ^{1}H(e,e$'$p) hydrogen elastic reaction as a cross check of spectrometer acceptance models, an additional study of target boiling effects and a systematic check of error in beam energy, spectrometer's central momentum and angle setting using the kinematics of the elastic reactions.

The detailed kinematics can be found in Tab. 1 below. Clearly the different central momentum settings have considerable overlap. We plan to use this overlap to obtain a continuous data set of cross sections between a missing momentum of 0.5 and 1.0 GeV/c.

p_m	E_f	ϑ_e	$\lvert\vec{q}\rvert$	p_f	ϑ_p	ϑ_{pq}	ϑ_{nq}
0.5	9.322	11.68	2.658	2.305	53.47	8.21	41.19
0.6	9.322	11.68	2.658	2.251	55.60	10.34	42.31
0.7	9.322	11.68	2.658	2.189	57.63	12.37	42.06
0.8	9.322	11.68	2.658	2.121	59.61	14.35	41.07
0.9	9.322	11.68	2.658	2.047	61.56	16.30	39.67
1.0	9.322	11.68	2.658	1.969	63.49	18.23	38.02

Table 1: Central kinematic settings for the proposed experiment. The incident energy assumed is $E_i = 11.0$GeV. The electron kinematics is held fixed at $x_{bj} = 1.35$ and $Q^2 = 4.25$(GeV/c)^2.

3 Count-Rates

The coincidence count-rates for electrons in SHMS and protons in HMS have been estimated using the Hall-C monte-carlo program SIMC [13]. The coincidence cross section has been calculated within the PWIA using the V18 momentum distribution and included radiative effects. The following cuts have been applied for the rate estimates:

electron solid angle : $-0.05 \leq \vartheta_e \leq 0.05$, $-0.025 \leq \varphi_e \leq 0.025$, angles are in radians

electron momentum acceptance : $-0.08 \leq \Delta p/p \leq 0.04$

proton solid angle: $-0.06 \leq \vartheta_p \leq 0.06$, $-0.035 \leq \varphi_p \leq 0.035$

proton momentum acceptance : $-0.1 \leq \Delta p/p \leq 0.1$

Bjorken-x: $1.3 \leq x_{bj} \leq 1.4$

missing momentum : missing momentum bin width = ±0.02 GeV/c

missing energy : $-10 \leq \epsilon_m \leq 25$ MeV

momentum transfer : $Q^2 = 4.25 \pm 0.25$ $(\mathrm{GeV/c})^2$

A 15 cm liquid deuterium target and a current of 80μA have been assumed, which results in a luminosity of $L = 3.2 \cdot 10^{38}$ $\mathrm{cm}^2 \cdot \mathrm{sec}^{-1}$. Figure 1 shows the corresponding, estimated statistical errors compared to calculated cross sections using different models for the deuteron wave function and final state interactions.We expect that this experiment is dominated by the statistical error since one typically obtains a systematic error of the order of 5 - 7%. The expected statistical errors range from 5% for the lower missing momenta to 20% for 1.0 GeV/c. Given that this kinematic region can be considered as an unexplored new territory we believe that a 20% measurement is still very valuable. Proton and electron singles rates are well within the capabilities of the spectrometer detector systems. The resulting signal to noise ratio is generally large and we do not anticipate any background problems.

4 Beam Time Request

The beam time request is in Table 2. The beam time on target required to achieve the necessary statistics includes the following items:

- Time to determine the spectrometer pointing at each setting
- Time for target and spectrometer changes

The two low p_m measurements are calibration measurements that overlap with the Hall A experiment.

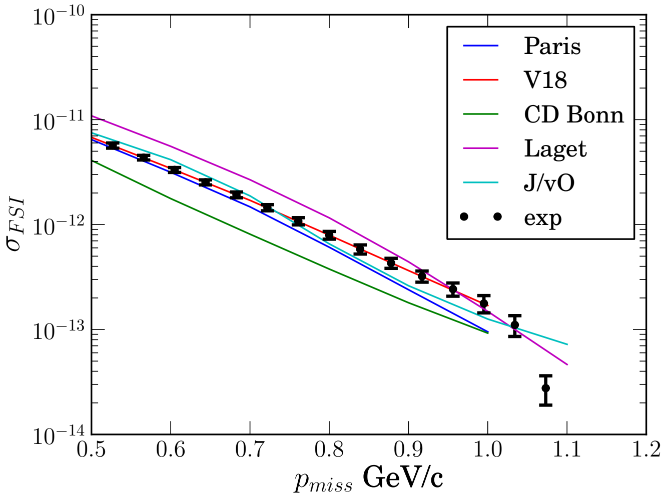

Figure 1: The expected statistical error as a function of missing momentum compared to a range of calculations including FSI and different models for the deuteron wave function.

p_m GeV/c	Data Taking	Overhead	Sub-total
0.1 ($Q^2 = 3.5$ (GeV/c)^2)	3.75	2.0	5.75
0.1	3.75	2.0	5.75
0.5	40.63	2.0	42.63
0.6	46.75	2.0	48.75
0.7	66.88	2.0	68.88
0.8	59.38	2.0	61.38
0.9	82.00	2.0	84.00
1.0	136.75	2.0	138.75
Optics Commissioning			16
Target Commissioning			16
^{1}H(e,e$'$p) calibrations	2.0	4.0	6.0
TOTAL			488.13

Table 2: Beam Time Overview (all times are in hours)

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