High Recoil Momenta in Quasi-Elastic Scattering

Malek Mazzouz, Jean Mougey, Eric Voutier (Spoke-/Contact-person)

Laboratoire de Physique Subatomique et de Cosmologie, Grenoble, France

Jian-Ping Chen, Bob Feuerbach, Dave Gaskell, Javier Gomez, Ole Hansen, Mark Jones, John LeRose, Douglas Higinbotham, Bob Michaels, Bodo Reitz, Arun Saha (Spokeperson), Bill Vulcan, Bogdan Wojtsekhowski, Steve Wood

Jefferson Laboratory, Newport News, Virginia, USA

Martin Epstein

California State University, Los Angeles, Cilfornia, USA

Ron Gilman, Kathleen McCormick, Xiaodong Jiang

The State University of New Jersey, Piscataway, New Jersey, USA

Sabine Jeschonnek

The Ohio State University, Lima, Ohio, USA

Jean-Marc Laget

CEA Saclay, Gif-sur-Yvette, France

Richard Lindgren

University of Virginia, Charlottesville, Virginia, USA

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Abstract

Recent quasi-elastic (e,e′p) experiments in few-body systems showed that the reaction process is dominated by the re-interaction of the knocked-out proton with the residual nucleus, corresponding to the propagation of an on-shell nucleon in the nuclear medium. However, at very high recoil momentum, experimental data in helium deviates from theoretical calculations and indicate a large excess of strength leading to an apparent saturation of the cross section. The same theoretical approach in the deuterium predicts a similar behaviour originating from the interference between the $\gamma^* p$ and the $\gamma^* n$ amplitudes. This experiment proposes to measure the D(e,e′p) quasi-elastic cross section for a fixed virtual photon over the complete recoil momentum phase space. Within 8 days of beam time, this experiment will provide a benchmark data basis for the understanding of the high momentum saturation of the cross section from its standard interpretation up to the most exotic descriptions.

Contents

1 Introduction

Since the very first experiments at Frascati [1], Saclay [2], and Nikhef [3] the (e,e′p) reaction has been proven a powerful tool for the investigation of the nuclear structure. The advent of high energy electron beams with high intensity and duty cycle opened the access to the high momentum region, expected to reveal peculiar features of the nucleon substructure. Indeed, large virtual photon momentum q allows to access distance scale $\sim \hbar/q$ that are comparable and even smaller than the nucleon radius. In addition, the (e,e′p) reaction mechanism at large q is expected to be simpler because of the natural decrease of the effects of Meson Exchange Currents (MEC) built into meson propagators and form factors. Therefore, one can expect to probe more reliably high initial momenta in the nucleus, that is small inter-nucleon distances, and learn about the origin of the short-range repulsion of the NN interaction from its standard representation up to the most exotic descriptions.

A set of experiments involving this general framework have been taking data on few and many body systems at the Continuous Electron Beam Accelerator Facility (CEBAF) at the Jefferson Laboratory. Experiments on D [4] and ^{3,4}He [5–7] nuclei did confirm a minimum contribution of MEC and Isobaric Currents (IC) but, in opposite to original expectations, show that the quasi-elastic scattering at high recoil momentum (equivalent to the initial momentum in the spectator nucleon model) is dominated by the Final State Interactions (FSI) of the struck nucleon with the residual nucleus [7]. At the top of the quasi-elastic peak ($x = 1$), large transferred momenta q correspond to large enough excitation energy ω to open the on-shell nucleon rescattering channel that overwhelms the plane wave amplitude [8]. One observes a moderate quenching of the cross section below 300 MeV/c and a large enhancement above ∼400 MeV/c. The strength at small recoil momentum is shifted towards the high recoil momentum region, as a natural consequence of unitarity. It however persists a region above 750 MeV/c where all modern calculations fail to reproduce the cross section which exhibits an intriguing flat behaviour.

The **goal** of this proposal is to set the **experimental basis** for the understanding of this **very high recoil momentum behaviour** by investigating the **D(e,e′p) quasi-elastic cross section** at a fixed virtual photon momentum over the complete allowed recoil momentum phase space.

The next section is a detailed presentation of the physics motivations of this proposal, followed by the description and the justification of the selected experimental method. The last sections present the beam time request and the eventual relation to previously proposed experiments at the Jefferson Laboratory.

2 Physics Motivations

In the Plane Wave Impulse Approximation (PWIA) picture (Fig. 1), the cross section for the (e,e′p) reaction can be factorized into two contributions: one representing the probability that a virtual photon interacts with a bound proton, that is the off-shell *ep* cross section [9], and one representing the probability to find a proton with given initial momentum P_m and binding energy E_m, that is the spectral function [10,11] of the target nucleus. In this simple picture, the residual nucleus does not participate to the interaction and remains a spectator of the reaction process. Therefore, the recoil momentum P_r of the residual nucleus is strictly identical to the opposite of the initial proton momentum such that fundamental properties of the nuclear structure can be accessed by measuring the recoil momentum dependence of the (e,e′p) cross section.

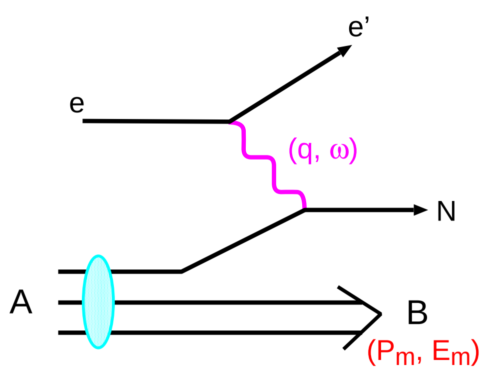

Figure 1. Feynman diagram corresponding to the PWIA picture of the A(e,e′N)B reaction.

However, experiments at the previous generation of electron accelerators have shown that this picture was too naive. Additional reaction mechanisms contribute to the cross section and eventually break the simple factorization scheme. These comprise the Final State Interactions (FSI) between the struck proton and the residual nucleus, the interaction between the electromagnetic and nuclear fields mediated by meson exchange currents, and the virtual excitation of the first nucleon resonance via isobaric currents. In this small q regime, a separation of the different components of the cross section is necessary in order to disentangle the effects of these reaction mechanisms and access further the PWIA amplitude.

The high momentum transfer regime of the quasi-elastic (e,e′p) reaction is expected to be simpler. Indeed FSI, MEC, and IC are multistep processes which involve the propagation of virtual particles inside the nuclear medium. The subsequent amplitudes are depending on the momentum transfer via the corresponding propagators and form factors, and should therefore decrease accordingly with increasing momentum transfer.

Access to high momentum transfer in quasi-elastic scattering requires high beam energy and intensity that became available only with the advent of the CEBAF at the Jefferson Laboratory (JLab). Several experiments on diverse nuclei have been performed in the three JLab halls with the aim of investigating the high initial momentum region, significant from the short distance scale in the nucleus. Particularly, the E89-044 experiment [5] has measured the quasi-elastic ^{3}He(e,e′p) cross section up to about 1.2 GeV/c recoil momentum.

2.1 Lessons from the Helium Experiment

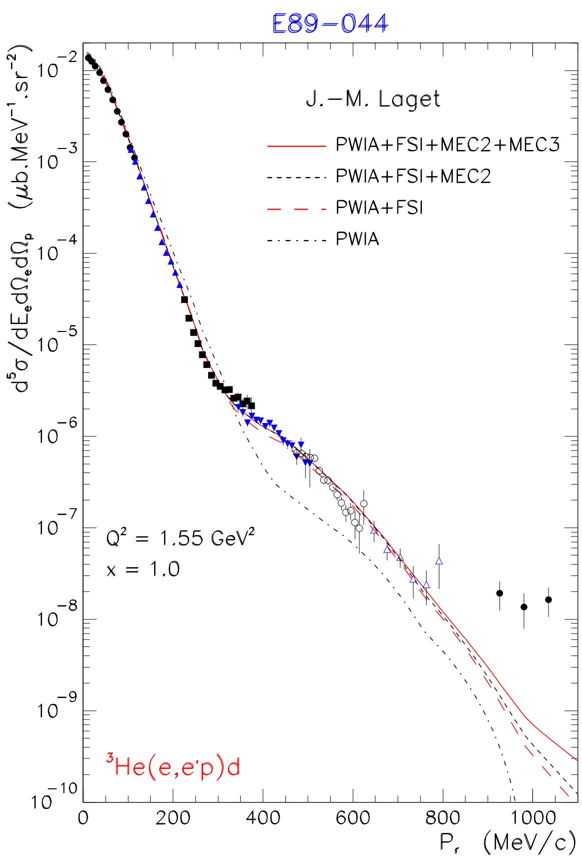

Figure 2. Reduced cross section of the ^{3}He(e,e′p) process as a function of the momentum of the recoil particle: data points from the E89-044 experiment [7] are compared to theoretical calculations within a diagrammatic approach framework [8].

The E89-044 experiment [5] has been taking data in JLab/Hall-A from december 1999 up to april 2000 with the aim of investigating the origin and the magnitude of the high momentum components of the nuclear wave function in the ^{3}He nucleus. Following the common belief at the time of the proposal submission (1989), the quasi-elastic kinematics was selected and a measurement of the longitudinal-transverse interference response function together with a separation of the longitudinal and transverse responses were projected.

The Σ_1 part [7] – corresponding to the detection of a proton in the $e\gamma^*$ plane on the right side of the virtual photon – of this experimental program is shown on Fig. 2 associated to theoretical calculations [8] within the framework of different approximations [12] to the (e,e′p) reaction mechanism. In agreement with previous studies of the ^{3}He(e,e′p) reaction [13,14], experimental data are consistent with a PWIA approach up to 150 MeV/c. After this limit, systematic deviations from the PWIA calculation are observed: a moderate quenching of the cross section is noticed up to about 300 MeV/c, and is followed by a very large enhancement over the remaining part of the explored phase space. The major reason for this behaviour comes from the effects of the re-interaction of the knocked-out proton: FSI reduce the cross section below 300 MeV/c and are shown to dominate the process up to about 800 MeV/c; as expected, MEC and IC contributions turn out to be small. This feature is a direct consequence of the propagation in the nuclear medium of an on-shell nucleon with moderate initial momenta, and corresponds to the overlap amplitude of the nuclear wave function with the singularity of the intermediate nucleon propagator. Beyond 800 MeV/c, all calculations, even those considering refined effects of the 3-body forces, underestimate dramatically the cross section; the ratio experiment/theory reaches about 50 at the largest recoil momentum.

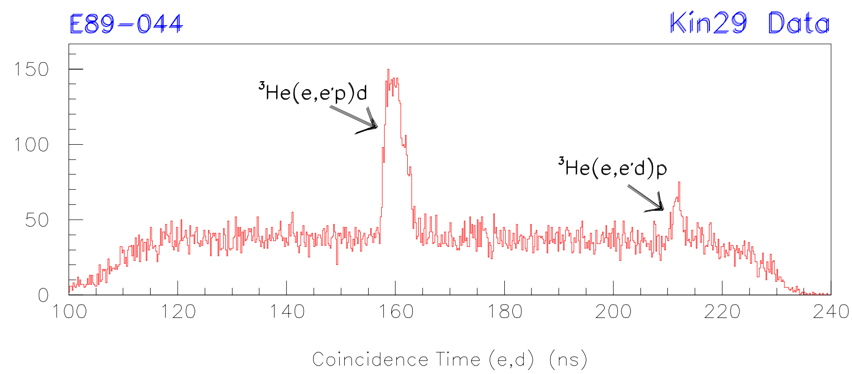

Figure 3. Experimental coincidence time spectra [15] of the largest recoil momentum kinematics of the E89-044 experimental program [5].

This unexpected behaviour motivates numerous checks of the experimental data that confirm this feature. In addition, it has been possible to extract the cross section with a different experimental approach. Indeed, at the largest recoil momentum kinematics, the momenta of the knocked-out proton and of the recoil deuteron are very close. Thanks to the acceptance of the Hall-A HRS spectrometers, it is then possible to measure simultaneously these two particles. This appears on Fig. 3 where the spectra of the time difference between the electron and hadron spectrometers exhibit two sharp peaks corresponding to the ^{3}He(e,e′p) and the ^{3}He(e,e′d)p reactions. From the measured ^{3}He(e,e′d)p reaction a simple jacobian transformation allows to infer the ^{3}He(e,e′p)d cross section of the 2-body break-up channel. The deduced cross section is compared on Fig. 4 to the direct measurements. Since the direct proton and the recoil deuteron are measured via the HRS spectrometer on the same side of the virtual photon (ϕ=180°), the proton corresponding to the measured deuteron is located on the opposite side of the virtual photon (ϕ=0°). Therefore the deduced cross section is not strictly comparable to Σ_1 data. It tells only about the order of magnitude of the direct proton cross section and confirms and extends further the observed behaviour towards an apparent saturation of the cross section.

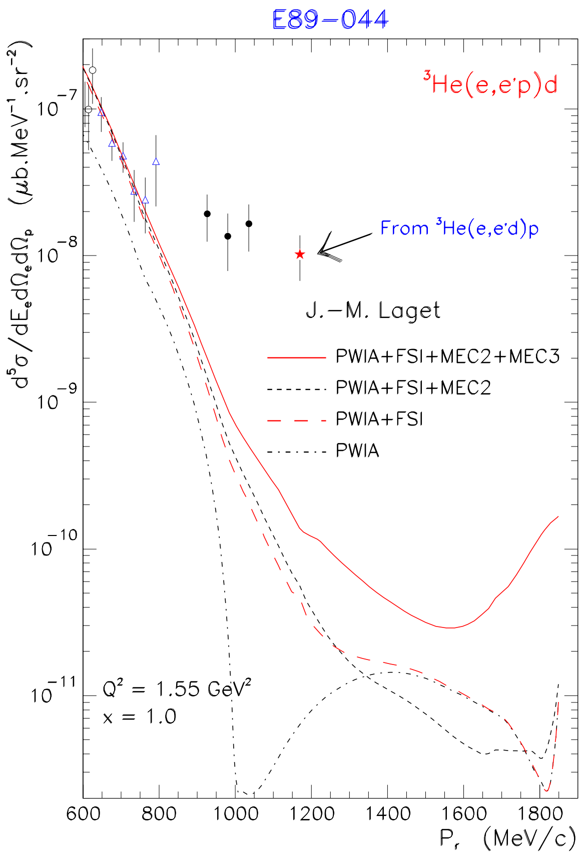

Figure 4. High recoil momentum cross section of the ^{3}He(e,e′p) reaction: the experimental data point deduced from the ^{3}He(e,e′d)p measurement [15] is compared to the direct measurements [7] of the ^{3}He(e,e′p)d channel and theoretical calculations [8].

To date, there is no understanding of this striking disagreement between experiment and theory. The calculations extrapolated over the allowed phase space (Fig. 4) seem to indicate a similar behaviour but the predicted cross section remains too low. They clearly miss some reaction amplitude(s) which origin could vary from the $\gamma^* pn$ amplitude – responsible from the increase of the cross section close to the kinematical boundary – or additionnal FSI contributions... up to some exotic configurations involving the nucleon substructure. This experiment proposed to provide the necessary guidance for the understanding of this behaviour by investigating the (e,e′p) dynamics at high recoil momenta in the most elementary nuclei i.e. the deuterium where reaction mechanisms are expected to be simpler and more accurately known.

The deuterium has been and is still a privileged laboratory nucleus to investigate our understanding of the nuclear structure. From the traditional study of the NN interaction up to the most recent investigations of relativistic effects [16,17], deuterium experiments are important and necesseray steps to built a coherent picture of the nucleus.

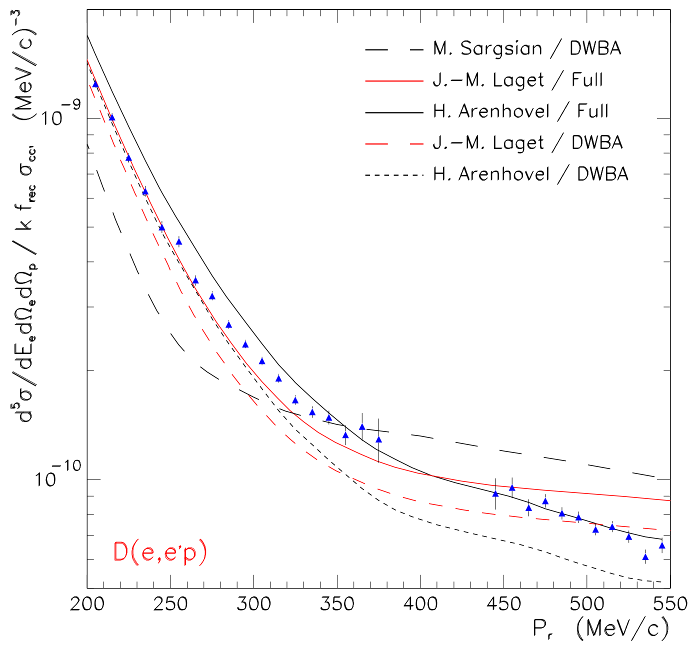

Figure 5. Comparison of different theoretical calculations of the D(e,e′p) reduced cross section to experimental data [4] for a selected region of the explored recoil momentum phase space.

Several JLab experiments [18–26] have been or will be studying photo- and electro-disintegration of the deuterium. In the context of this proposal, the recently published data [4] of experiment [22] are particularly interesting. Part of the data are shown on Fig. 5 for a selected region of the experimental phase space. Large deviations from PWIA are necessary to reproduce data: MEC and FSI contribute dominantly to the reaction process, the bulk of the effects coming from FSI. These findings are in complete agreement with the previously reported results [7] of the ^{3}He experiment [5], the different magnitude of MEC coming from the difference between the virtual photon momenta: $Q^2 = 0.67$ (GeV/c)^2 and $Q^2 = 1.52$ (GeV/c)^2 for the deuterium and helium experiments, respectively. The full calculations from H. Arenhovel (integrated over the experimental acceptance) and J. - M. Laget (point like acceptance) give the best description of data, and confirm the importance of the on-shell nucleon rescattering mechanism. However, 550 MeV/c is the highest recoil momentum probed by this experiment which then does not allow comparison in the very high reoil momentum region of interest of this proposal. Nevertheless, the diagrammatic approach of J. - M. Laget [12], shown to be in a fair agreement with a wide range of experimental data [8] can be extrapolated to investigate the very high recoil momentum region.

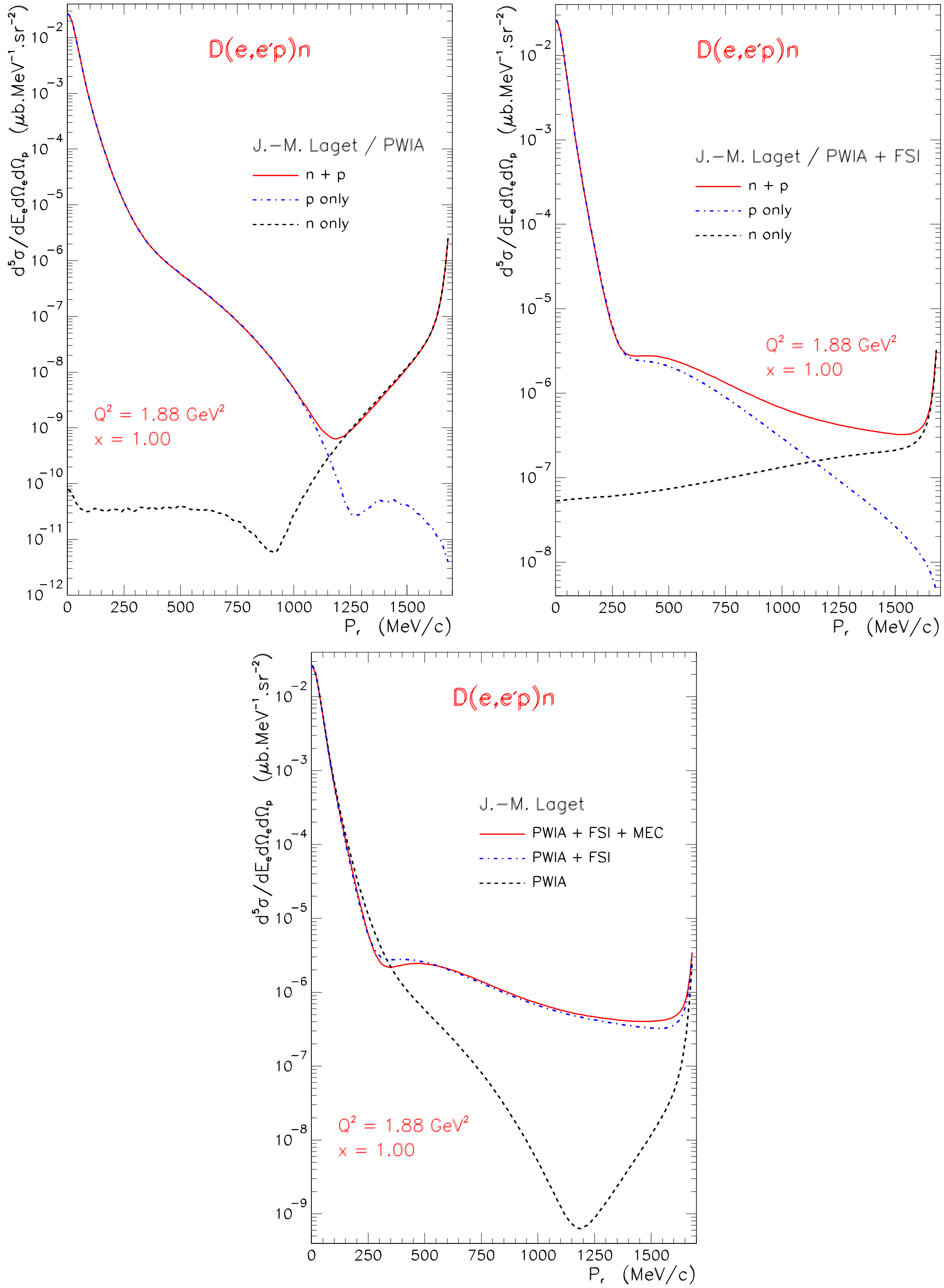

Figure 6. D(e,e′p) cross section for different approximations of the reaction mechanism over the full phase space of the selected kinematics at constant Q^2 and x.

The top-left panel of Fig. 6 shows the D(e,e′p) cross section in the quasi-elastic regime, for an incident beam momentum $P_0 = 5.7$ GeV/c and a constant vir-

tual photon momentum $q = 1.7$ GeV/c, calculated in the PWIA approach. Two different diagrams are considered involving separately the coupling of the virtual photon to the proton ($\gamma^* p$) and to the neutron ($\gamma^* n$). The proton amplitude that dominates the cross section up to about 1000 MeV/c recoil momentum decreases exponentially with P_r, as a consequence of the small probability of finding a deuteron configuration with high initial momentum proton. On the opposite, the neutron amplitude increases with P_r. Indeed, let P_i be the initial momentum of the neutron, in the PWIA approach we have $\vec{P_r} = \vec{q} + \vec{P_i}$ such that at large q, small P_r corresponds to large P_i which are less probable while large P_r are sensitive to small initial momentum neutron. Therefore the behaviour of the neutron and the proton amplitudes in the PWIA approach obviously reflects the deuteron spectral function.
The top-right panel of Fig. 6 consider additional FSI mechanisms where the knocked-out nucleon scatters on its partner. FSI add strength at high recoil momentum, up to several orders of magnitude when high initial momenta are involved in the PWIA amplitude. A new feature appears at very high P_r where the inteference between the $\gamma^* p$ and the $\gamma^* n$ amplitudes start to develop significant effects. The resulting total cross section exhibits an almost flat behaviour that resembles the one experimentally observed for the ^{3}He nucleus [7,15].
The bottom panel of Fig. 6 shows the full neutron and proton amplitude from the PWIA up to the full calculation. As expected MEC are very marginal in this kinematics and the dominant effects come from FSI.
These figures suggest further that the interference between the neutron and proton FSI amplitudes are responsible for a quasi-constant cross section over a wide recoil momentum range. This has **never been observed nor experimentally tested**. A still ambiguous comparison with the ^{3}He data [7,15] shows that if the projected U-shape of the cross section is not strongly questionned, the **level** where the horizontal part of the **U-shape** occurs is a **matter of deep interest**.

3 Proposed Experiment

This experiment proposes to measure the D(e,e′p) cross section in the quasi-elastic regime, investigating the dynamics of the (e,e′p) process for a fixed virtual photon over the full recoil momentum range. According to recent calculations [8,27,28], FSI are supposed to develop large contributions that result in a tremendous increase of the cross section, partly seen in the ^{3}He nucleus [7,15] though not yet understood. The proposed experimental program will provide the basis for the understanding of this high momentum behaviour. Particularly, experimental data will confirm/infirm and test the magnitude of the approximately constant value of the cross section: a flat behaviour will sign the interference between the $\gamma^* p$ and the $\gamma^* n$ amplitudes which magnitude is controlled by FSI, and consequently would support that the observed discrepancy in the ^{3}He experiment [5] originates from a bad description of the $\gamma^* pn$ amplitude; any deviation from a flat behaviour would indicate additional effects or reaction mechanisms beyond *basic* FSI, MEC and IC, and associated to ^{3}He results [7,15] may open a window on quark effects in nuclei. Independently on these conclusions the accuracy of the projected data shown on Fig. 7 will discriminate between the different scenarios and approximations to the reaction cross section, improving the knowledge and understanding of the (e,e′p) dynamics in the quasi-elastic regime which is of particular interest in the context of the Color Transparency program of the JLab-12 GeV upgrade [29].

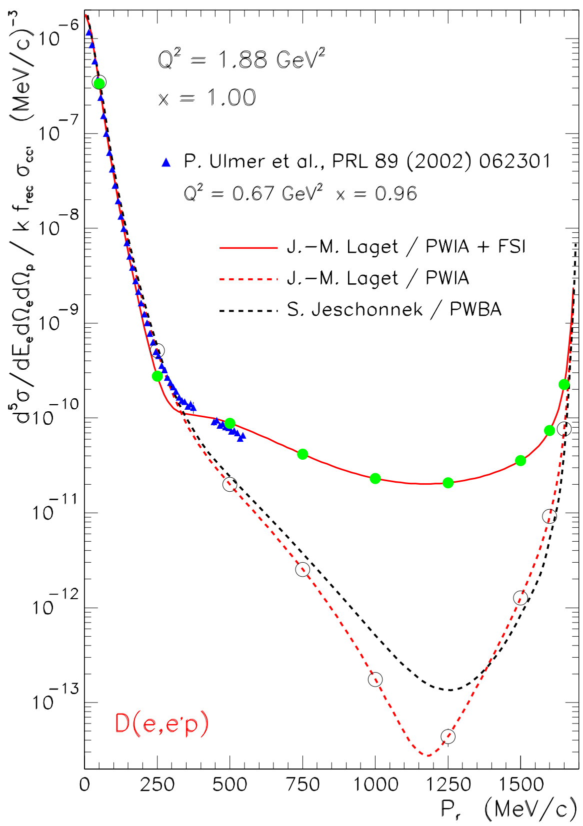

Figure 7. Theoretical reduced cross section for the kinematics of this proposal; the projected data with the corresponding errors are plotted assuming the PWIA (black open circles) and the PWIA+FSI (closed green circles) cross section of J.-M. Laget [8]; recent data from JLab on the deuterium [4] are represented by blue triangles. The agreement between the PWIA and PWBA caculations should be noticed, especially on both edges of the phase space where either the $\gamma^* p$ or the $\gamma^* n$ PWIA amplitude dominates.

3.1 Methodology Motivations

The selected experimental method involves the measurement of the electro-disintegration of the deuteron at the top of the quasi-elastic peak ($x = 1$) for a fixed virtual photom momentum $q = 1.7$ GeV/c, while the proton is detected in-plane on the right side of the virtual photon ($\phi = 180°$). The cross section can then be studied as a function of the only remaining free kinematics parameter i.e. the momentum of the recoil neutron.

Selection of the quasi-elastic scattering

The choice for quasi-elastic scattering is dictated by the today control of the (e,e′p) reaction mechanisms. Current experimental data [4,7,23,25] show that the quasi-elastic cross section at high recoil momentum is strongly enhanced by FSI resulting from the propagation of an on-shell nucleon in the nuclear medium. This mechanism dominates the imaginary part of the FSI amplitude and is maximum near $x = 1$. This maximum of the on-shell singular part of this integral occurs at $x = 1$, when one can absorb the virtual photon on a nucleon at rest. This nucleon absorbs the virtual photon momentum and rescatters at 90° on the neutron (relative angle between the outgoing proton and neutron in the laboratory frame). Therefore the rescattering amplitude is, to a very large extent, free of off-shell uncertainty. The real part which is sensitive to delicate off-shell extrapolations turns out to cancel [8]. This sets the dominant FSI reaction mechanism on a strong theoretical ground relying on the world data set of the NN interaction. Moving from the quasi-elastic peak reduces the imaginary part of the FSI amplitude and increases sensitivity to loosely controlled off-shell effects as well as MEC and IC. Therefore, the quasi-elastic kinematics is the best place to investigate eventual deviations from *standard* calculations.

Selection of a fixed virtual photon

Similar arguments lead to the choice of a fixed virtual photon momentum, beyond the experimental convenience of having a unique setting for the electron spectrometer all along data taking. Indeed, FSI can be parametrized [8] as a function of the T_{NN} matrix amplitude which depends on the relative energy between the interacting nucleons. This experiment corresponds to a relative energy about 800 MeV where the on-shell scattering amplitude is well constrained by experimental NN data. Constant x and q yields a constant energy transfer and therefore a unique FSI parametrization for the whole data set which once again facilitates the interpretation of the measurements. The selected $q = 1.7$ GeV/c is a compromise between the minimum detectable proton momentum and the requirement to perform a reliable measurement in the rising part of the cross section close to $P_r = q$ while keeping marginal MEC and IC.

This experiment proposes to take data in the Hall C of JLab using the standard experimental equipment of the Hall: the 4 cm LD_2 target, the HMS spectrometer for the detection of scattered electrons, and the SOS spectrometer for the detection of knocked-out protons. The kinematics of the experiment is given in Tab. 1 for a 5.7 GeV/c electron beam. The HMS momentum and angle select a single setting for the whole data taking, corresponding to a $q = 1.7$ GeV/c virtual photon momentum and an $\omega = 1.0$ GeV energy transfer. The recoil momentum distribution is obtained by varying the SOS momentum and angle over the -48.25° – -121.68° and 1695.9 – 284.0 MeV/c ranges.
Quasi-elastic events are selected from the spectra of the reconstructed missing energy

$$E_m = m_p - M + \sqrt{(\omega + M - E_p)^2 - \left(\vec{q} - \vec{P_p}\right)^2} \qquad (1)$$

where m_p and M are the proton and deuteron mass and E_p is the total proton energy. Thanks to the momentum resolution of the spectrometers (10^{-3}) and the beam energy knowledge ($5{\cdot}10^{-4}$), a typical resolution of 10 MeV in missing energy can be achieved, which is good enough to separate quasi-elastic events from pion electro-production.

P_{recoil} (MeV/c)	θ_e (dg)	P_e (MeV/c)	θ_p (dg)	P_p (MeV/c)
50			-48.25	1695.9
250			-55.00	1660.0
500			-63.49	1553.4
750			-72.24	1389.8
1000	15.24	4696.5	-81.66	1179.2
1250			-92.57	921.8
1500			-107.09	591.4
1600			-115.62	409.2
1650			-121.68	284.0

Table 1. Electron and proton spectrometers settings of the different kinematics of the experiment.

Overall, this proposal is a standard coincidence experiment that takes advantage of the current capabilities of the HMS and SOS spectrometers and that does not require any particular detector development.

4 Beam Time Request

4.1 Counting Rates

P_{recoil} (MeV/c)	τ_{e^-} (Hz)	τ_p (Hz)	$\tau_{ep}^{Acc.}$ (h^{-1})	τ_{ep}^{True} (h^{-1})
50		$6.3{\cdot}10^{+2}$	$1.50{\cdot}10^{+1}$	$1.88{\cdot}10^{+7}$
250		$2.9{\cdot}10^{+2}$	$6.98{\cdot}10^{+0}$	$2.10{\cdot}10^{+4}$
500		$1.7{\cdot}10^{+2}$	$4.58{\cdot}10^{+0}$	$7.54{\cdot}10^{+3}$
750		$2.0{\cdot}10^{+2}$	$5.98{\cdot}10^{+0}$	$3.80{\cdot}10^{+3}$
1000	$9.7{\cdot}10^{+3}$	$5.4{\cdot}10^{+2}$	$1.60{\cdot}10^{+1}$	$1.54{\cdot}10^{+3}$
1250		$6.0{\cdot}10^{+3}$	$1.79{\cdot}10^{+2}$	$7.05{\cdot}10^{+2}$
1500		$1.7{\cdot}10^{+4}$	$4.93{\cdot}10^{+2}$	$2.99{\cdot}10^{+2}$
1600		$4.5{\cdot}10^{+4}$	$1.34{\cdot}10^{+3}$	$1.76{\cdot}10^{+2}$
1650		$1.5{\cdot}10^{+5}$	$4.33{\cdot}10^{+3}$	$9.29{\cdot}10^{+1}$

Table 2. Singles and coincidence rates in the HMS and SOS spectrometers for a 10^{38} $cm^{-2}{\cdot}s^{-1}$ luminosity; the constant value of electron singles results from the fixed position of the HMS spectrometer for the whole data taking.

This experiment will use a 100 μA electron beam together with the 4 cm LD_2 target yielding a 10^{38} $cm^{-2}{\cdot}s^{-1}$ luminosity, currently achieved with that target. The corresponding single and coincidence rates are given in Tab. 2. They have been estimated using a Monte Carlo program, taking into account the spectrometers acceptance matching for coincidences. The physics rate assumes the full calculation of J.-M. Laget [8], and the accidental rate, a $\Delta t = 100$ ns time window corresponding to the full width of the time coincidence window. It is noticed that, apart the smallest recoil momentum point where the beam intensity has to be reduced to 1 μA, the rates dont put any specific constraint on the detectors, and that the physics rate remains reasonable over the full recoil momentum phase space. However, the accidental rate turns out to be quite significant above 1500 MeV/c and will consequently impact the data taking time.

4.2 Experimental Errors

Statistics

The statistical error is calculated according to Eq. 2 which takes into account the contamination of the physics rate from accidentals,

$$\left(\frac{\delta\sigma}{\sigma}\right)^{Stat.} = \sqrt{\frac{1}{\tau_{ep}^{True}} \left[1 + \frac{\Delta\tau}{\Delta t}\left(1 + \frac{\Delta\tau}{\Delta t}\right)\frac{\tau_{ep}^{Acc.}}{\tau_{ep}^{True}}\right] \frac{1}{T}} \quad (2)$$

where $\Delta\tau = 4$ ns is the typical width of the coincidence timing peak and T represents the data taking time. The resulting errors are given in Tab. 3 where it can be seen that accidentals essentially affect the highest recoil momentum point. The data taking time has been adjusted considering a 1 h minimum acquisition time per setting and a maximum statistical error about 2 %.

P_{recoil} (MeV/c)	Time (h)	$(\delta\sigma/\sigma)^{Stat.}$ (%)	$(\delta\sigma/\sigma)^{Syst.}$ (%)	$\delta\sigma/\sigma$ (%)
50	1	< 1.0		5.0
250	1	< 1.0		5.0
500	2	< 1.0		5.0
750	3	1.0		5.0
1000	7	1.0	5.0	5.1
1250	15	1.0		5.1
1500	25	1.2		5.1
1600	34	1.5		5.2
1650	79	2.0		5.4

Table 3. Expected statistical and systematical errors of the proposed experimental program.

Systematics

The main sources of systematical error are the precise knowledge of the in-beam target density and of the five-fold differential solid angle of the experimental setup. A specific study of the target boiling effect at the beginning of the experiment should insure the knowledge of the target density with a 2 % accuracy. In addition, the single rates in each arm will be used for the monitoring of the luminosity, taking advantage of the fixed position of the electron spectrometer for the complete duration of the experiment. The accurate knowledge of the spectrometers optics together with calibration measurements and spectrometer surveys are the main tools for the control of the solid angle of the spectrometers which can be further simulated using Monte Carlo programs. A conservative 3 % accuracy per arm can be expected from such a process. Alltogether, the total expected systematical error is about 5 %, quite better than the required mimimum error for a conclusive end.

4.3 Data Taking

The summary of the beam time request of this experiment is given in Tab. 4. In addition to the data taking time, overhead time is considered for each kinematics tuning of the spectrometer, specific studies, and calibrations. The total request amounts for **192 h** of beam time.

Task	Time (h)
Data Taking	167
Spectrometer Motion	9
Target Boiling Study	4
Beam Energy Measurement	4
Calibrations	8
Total	**192**

Table 4. Summary of the beam time request.

5 Relation to Other Experiments

Several experiments have been looking at the electro-disintegration of the deuterium. This proposal is related to experiments E94-004 [22], E94-019 [23], and E01-020 [25].

E94-004

The E94-004 experiment, already discussed in this proposal, did measure the momentum distribution in the deuterium up to 550 MeV/c at $x = 0.96$ and $Q^2 = 0.67$ (GeV/c)^2 (Fig. 5 and Fig. 7). Together with the ^{3}He experiment [5], these data are the first evidence of large to dominant FSI effects in the (e,e′p) reaction but the limited recoil momentum range of E94-004 does not allow to address the specific issues of this proposal.

E94-019

The E94-019 experiment has been taking data in Hall B to investigate the onset of Color Transparency in few body systems and focussed on the Q^2 dependence of the ratio of the electro-disintegration cross section at 400 MeV/c recoil momentum with the 200 MeV/c cross section. A large data set was obtained which maximum momentum is limited to 500−600 MeV/c. Therefore there is no overlap with the current proposal which focus is beyond this limit.

E01-020

The goal of the E01-020 experiment is a complete study of the dynamics of the (e,e′p) reaction by measuring the x distribution at fixed Q^2 and recoil momentum and the R_{LT} interference response function at the quasi-elastic peak. The main features of FSI should be at work in this experiment as well as in the present proposal. However, the maximum recoil momentum investigated is 500 MeV/c, well below the scope of this proposal.

6 Conclusion

The present experiment proposes an original study of the dynamics of the (e,e′p) reaction in the deuterium investigating the recoil momentum distribution in the quasi-elastic regime at a fixed virtual photon momentum. There are indications from previous experiments that large FSI effects should dominate the cross section, particularly the interference between the $\gamma^* p$ and $\gamma^* n$ amplitudes would be responsible for a rise of the cross section at very high recoil momentum. However, the only experimental data so far in this momentum region comes from the ^{3}He experiment [7,15] where large deviations from theroretical calulations start to develop about 750 MeV/c. This experiment will explore the complete recoil momentum phase space from 0 MeV/c up to q in the deuterium where the reaction mechanisms are expected to be better under control. A possible deviation from current theoretical calculations, together with the ^{3}He data, may indicate the presence of exotic effects like the influence of the quark substructure of the nucleons.

This proposal corresponds to a standard coincidence experiment that is essentially ready to run. The total beam time request amounts to **8 days** using a 100 μA electron beam of 5.7 GeV/c, a 4 cm LD_2 cryogenic target and the HMS and SOS Hall C spectrometers for the detection of the scattered electron and knocked-out proton, respectively. This experiment may also be ran in Hall A with better but not required resolutions, and at the expense of a larger beam time dictated by a compromise with the highest achievable electron momentum and the smallest detectable proton momentum.

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