Study of J/ψ Photoproduction off Deuteron

(Letter of Intent)

A.J. Freese
Argonne National Laboratory, Lemont, IL 60439, USA
L. Guo
Florida International University, Miami, FL 33199, USA
Ch. Hyde
Old Dominion University, Norfolk, VA 23529, USA
Y. Ilieva*
University of South Carolina, Columbia, SC 29205, USA
B. McKinnon
University of Glasgow, Glasgow G12 8QQ, UK
P. Nadel-Turonski
Stony Brook University, Stony Brook, NY 11794, USA
M. Sargsian
Florida International University, Miami, FL 33199, USA
S. Stepanian
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
N. Zachariou
Edinburgh University, Edinburgh EH9 3JZ, UK
Z. Zhao
Duke University, Durham, NC 27708, USA

May 22, 2017

*ilieva@sc.edu

Abstract

Exclusive near-threshold photoproduction of J/ψ off the deuteron provides attractive opportunities to study interesting physics. Final-state interactions allow a direct access to the elementary $J/\psi N$ cross section, while the two-gluon exchange mechanism makes it possible to study aspects of the gluonic structure of the deuteron, such as the deuteron gluonic form factor, the deuteron hidden color component, and the gluonic structure of final-state interactions. While one measurement of the near-threshold quasi-elastic J/ψ production off the deuteron has been done in the past, data on final-state interactions do not exist. With its high luminosity and large acceptance, the CLAS12 detector offers a window of opportunity to measure near-threshold photoproduction of J/ψ off the deuteron.

This letter of intent addresses measurement of the differential cross section, and possibly some polarization observables, of the coherent and the incoherent production. The incoherent process $\gamma d \to J/\psi pn$ will be measured in untagged real photoproduction, where all the final state particles (neutron, proton, and the electron-positron pair from the J/ψ decay) are detected and the photon is reconstructed via 4-momentum conservation. With the Forward Tagger (FT), the incoherent and the coherent reactions will also be accessed through quasi-real photoproduction, where small-Q^2 photons are measured with the Forward Tagger and all but one final-state particles are detected in the CLAS12.

We will be able to measure J/ψ production on the neutron by measuring a high-energy ($p > 1$ GeV/c) neutron in the CLAS forward calorimeters in the fully exclusive quasi-real photoproduction.

This letter of intent is a preparation for a run-group proposal joining Run Group B (RG B). The measurement considered here does not require any additional detection system than already planned for RG B. Although, data for this LOI can be also taken with Run Group F, the focus of this letter is run group B due to the longer beam time and higher luminosity. This letter of intent is an extension of the E12-12-001 experiment.

1 Introduction

With the 12-GeV Jefferson-Lab upgrade providing beam energies above the threshold for photoproduction of J/ψ off the nucleon, interest in near-threshold J/ψ photoproduction has risen in both the experimental and the theoretical communities. The near-threshold exclusive photoproduction off the proton will be studied in several approved experiments in Halls A, B, and C. There are some physics aspects of the J/ψ production dynamics that these studies will not be able to address and that can be answered by using deuteron as a target. While the next section discusses the physics aspects driving the study of J/ψ photoproduction off the deuteron, this program will provide the very first measurements of this process from threshold up to 11 GeV. In this respect the first data from the measurements discussed here, will allow to explore very specifically the extent to which CLAS12 can address the physics topics laid out below. At this time there are no other letters of intent or proposals at JLab involving exclusive J/ψ photoproduction off deuteron. E12-07-106, conditionally approved in Hall C, will measure the A-dependence of the quasi-free J/ψ photoproduction via inclusive J/ψ measurement in an untagged-photon beam experiment on several nuclear targets, including deuteron and proton.

The advantage of the studies presented here originates in the exclusivity of the measurement, which would allow for more precise quantification of FSI contributions to the incoherent process and for exact treatment of the Fermi momentum of the target nucleon. Also, we will provide a direct measurement of the elementary production off the bound neutron. This Letter of Intent is also a precursor for future CLAS12 experiments of J/ψ photoproduction off heavier nuclear targets.

The interest in near-threshold photoproduction of J/ψ off the nucleon stems from the kinematic characteristic of this process. The photon-beam threshold energy is 8.20 GeV, which leads to a small coherence length of the $c\bar{c}$ fluctuation, $l_c \cong 2E_\gamma^{lab}/4m_c^2 = 0.36$ fm [1]. The large mass of the charmed quark and the large minimum momentum transfer $|t_{min}| = 1.7$ $(\text{GeV}/c)^2$ at threshold energy imply that the reaction occurs with a small transverse-size probe and at a small impact parameter. In coherent production off deuteron, the coherence length is even smaller and $|t_{min}|$ at threshold is larger. Thus, the expectation is that close to threshold the production cross section is sensitive to short-distance correlations in the wave function of the target and to multi-gluon exchange mechanisms [1, 2]. Moreover, final-state interactions (FSI) in incoherent J/ψ photoproduction off the deuteron provide access to the elementary $J/\psi N$ scattering cross section.

2 Physics Motivation

The 11-GeV electron beam available in Hall B allows to study near-threshold photoproduction of J/ψ in exclusive scattering off deuteron. There are three main physics topics of interest:

- Assess in a more direct way (than in J/ψ photoproduction off the free proton) the magnitude of the elementary $J/\psi N \to J/\psi N$ elastic cross section by means of final-state interactions in the incoherent photoproduction.
- Assess the two-gluon form-factor of deuteron by means of coherent photoproduction $\gamma d \to J/\psi d$.
- Study J/ψ photoproduction off the neutron by means of quasi-free photoproduction off the bound neutron $\gamma d \to J/\psi n p_s$, where p_s denotes a spectator proton.

As the above studies would need input for the elementary $\gamma p \to J/\psi p$ production, the measurement of differential cross sections, and possibly polarization observables, in photoproduction off deuteron is well timed as several approved experiments will measure the $\gamma p \to J/\psi p$ reaction prior to or concurrent with the deuteron measurement presented here. Moreover, we will be able to estimate the elementary cross sections on both bound proton and neutron from our data sample

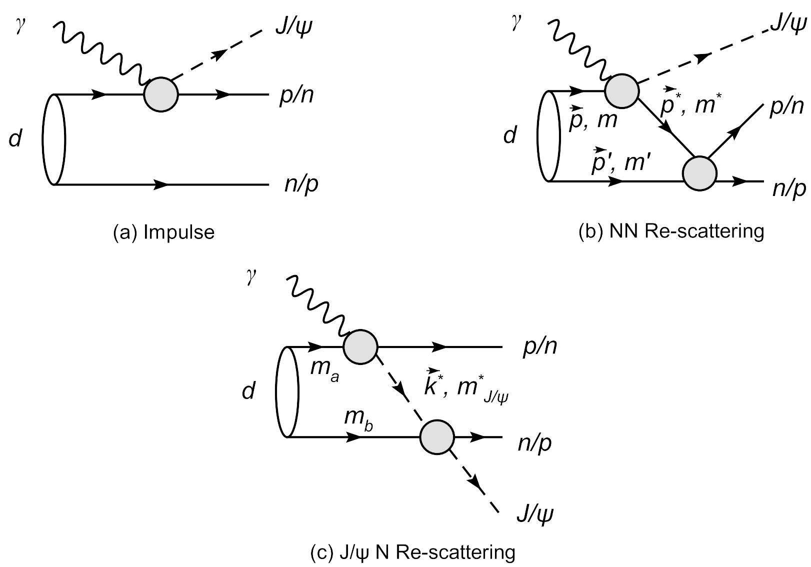

Figure 1: Top Left: A diagram representing the quasi-free mechanism contributing to the incoherent photoproduction of J/ψ off deuteron. Top Right: A diagram representing the NN final-state interaction. Bottom: A diagram representing the $J/\psi N$ FSI. In an exclusive measurement, a relatively clean QF sample of events can be obtained by selecting events with a low-momentum nucleon (such as below 200 MeV/c). An event sample dominated by FSI can be obtained by selecting events with two high-momentum nucleons. The figure is from Ref. [4], which describes a theoretical model of the incoherent photoproduction of J/ψ off deuteron that includes quasi-free production and only single re-scattering mechanisms.

2.1 Final-State Interactions in Incoherent J/ψ Photoproduction off Deuteron

The study of $J/\psi N$ final-state interactions (FSI) is one of the major drivers of the program laid out here. In a simple picture, the near-threshold incoherent reaction $\gamma d \to J/\psi pn$ can be considered to proceed via the following mechanisms (see Fig. 1): (a) quasi-free production off the proton or the neutron, (b) two-step mechanism in which J/ψ is produced in a first step in the quasi-free mechanism off one of the nucleons, followed by a nucleon-nucleon rescattering, NN FSI, and (c) two-step mechanism in which J/ψ is produced in a first step in the quasi-free mechanism off one of the nucleons and than rescatters off the other nucleon, $J/\psi N$ FSI. The $J/\psi N$ FSI is of particular interest since it provides the most direct experimental access to the $J/\psi N$ elastic cross section, which is otherwise difficult to measure. With CLAS12 and photon-beam energies from threshold up to 11 GeV, the J/ψ beam produced in the first step of this

FSI has momentum in the range from 5 GeV/c to 10 GeV/c (see bottom left panel of Fig. 3), which provides access to total center-of-mass energies of the $J/\psi N$ system from 4.6 GeV to 5.7 GeV. While we will be able to extract the differential cross section for FSI as a function of t or of the scattered-nucleon angle with respect to the direction of the 3-momentum transfer to the pn system, the extraction of the $J/\psi N$ cross section from these data will be model dependent. On one hand, QF events produced on high-momentum target nucleon will contribute to our FSI event sample, on another hand the NN FSI will also contribute (although we could select a very limited kinematics where both of these physics backgrounds are suppressed).

The near-threshold incoherent process at $|t| \geq 1$ (GeV/c)^2 has been analysed in the eikonal approximation in [3]. The analysis considers not only the QF and the single-rescattering mechanisms shown in Fig. 1, but also double-rescattering diagrams. The sensitivity of the reaction to the value of the $J/\psi N$ cross section is demonstrated in the angular dependence of the ratio

$$R = \frac{\sigma(p_n = 600 \text{ MeV/c})}{\sigma(p_n = 200 \text{ MeV/c})}, \tag{1}$$

where p_n denotes the momentum of the neutron off which J/ψ rescatters, on the neutron angle relative to the 3-momentum transfer to the pn system. This angular dependence for several values of $\sigma_{J/\psi N}$ is shown in Fig. 2. One observes large sensitivity at neutron angles around 30°. The large angular acceptance of CLAS12 should allow us to evaluate the cross-section ratio at such neutron angles. Moreover, we will be able to map cross section ratios not only for $J/\psi n$, but also for $J/\psi p$ FSI.

The near-threshold incoherent process has also been analysed in the coupled-channel model of [4]. The study considers $J/\psi n$ rescattering and studies the dependence of the cross section of the incoherent process on the $J/\psi N$ potential. Calculations with potentials of various strengths obtained from effective theory approach and lattice QCD have been performed. The study finds that the cross section for forward-scattered protons is more sensitive to the strength of the potential than the cross section for backward scattered protons and identifies kinematics where the $J/\psi N$ FSI dominates the QF and the NN FSI. The most advantageous kinematics is at forward proton scattering angles and energy of the J/ψ in the center-of-mass of the $J/\psi N$ system below ≈200 MeV. One should mention that the cross-section predictions of this theoretical analysis do not account for the experimental possibility to reduce the QF contribution by eliminating low-momentum nucleon events. The latter should help to improve the sensitivity of the cross section to the $J/\psi N$ interaction at larger proton angles. Nonetheless, the opportunity to measure the incoherent process with various event topologies will provide access to small nucleon scattering angles. The only limitation will arise from statistics, as nucleons scattered at small angles in the first step of the $J/\psi N$ FSI absorb large momentum transfer and the cross section at these angles is suppressed due to the nucleon form factor. Thus, the possibility to increase the sensitivity to the physics of interest for larger nucleon scattering angles is an important aspect of this exclusive measurement.

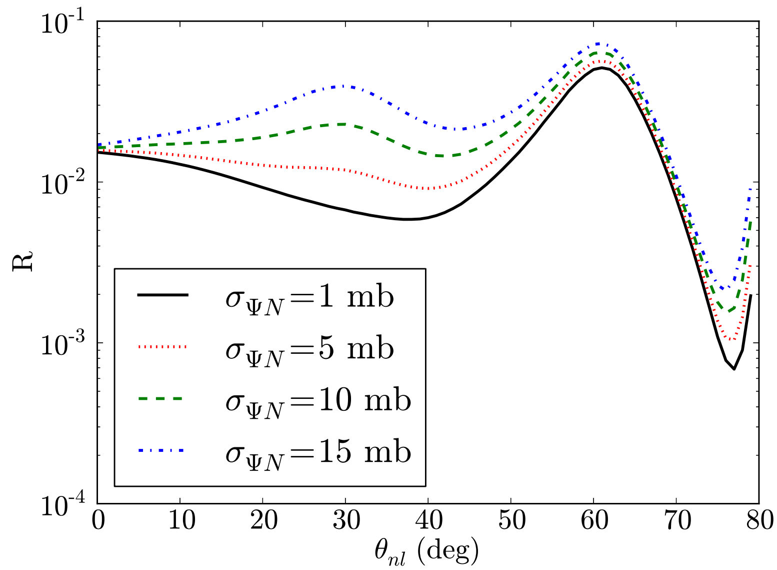

Figure 2: Predictions of the model from [3] for the ratio of Eq. 1 as a function of the neutron angle relative to the 3-momentum transfer to the pn system. the various curves are obtained for different values of $\sigma_{J/\psi N}$. The quasi-free cross section has been calculated using a two-gluon parametrization. One observes large sensitivity at neutron angles around 30°.

The measurement of the incoherent process over a broad range of scattering angles and momenta of the outgoing nucleons will also provide opportunities to select kinematics where the process is sensitive to scattering off small-size configurations in the deuteron, such as short-range correlations.

2.2 Quasi-Free J/ψ Photoproduction off Neutron

The measurement of this cross section and its comparison against the cross section for production off the proton is an alternative test of the J/ψ production dynamics close to threshold. If multi-gluon exchange mechanisms indeed dominate the reaction cross section near threshold, the ratio of the proton and neutron cross sections should be unity. We will map the t dependence of the neutron cross section and the proton-neutron cross-section ratio. As there have not been neutron-target data in past experiments, the published theoretical analyses of near-threshold J/ψ photoproduction off the nucleon consider that proton and the neutron cross sections are the same.

2.2.1 Coherent J/ψ Photoproduction off Deuteron

The photon-beam energy threshold for the coherent production $\gamma d \to J/\psi d$ is 5.66 GeV, which is smaller than in production off the nucleon. The minimum momentum transfer to the deuteron at threshold beam energy, $|t_{min}|$ is 3.31 (GeV/c)^2, which is larger than in production off the nucleon. These suggest that the coherence length and the impact parameter for deuteron targets are even smaller than for a proton target. At photon energy of 11 GeV, $|t_{min}| = 0.26$ (GeV/c)^2, which means that the minimum momentum transfer decreases very quickly as the photon energy increases. Thus, in order to be able to study the short-range structure of deuteron in J/ψ production, one should be able to perform a statistically-significant measurement very close to threshold. The total center-of-mass energy from threshold up to 11 GeV varies from 4.98 GeV to 6.69 GeV, which is comparable to the J/ψ rest mass.

Coherent J/ψ photoproduction provides an opportunity to test for reaction dynamics beyond the impulse approximation (in which the reaction amplitude is proportional to the product of the deuteron form factor and the elementary amplitude for production off the nucleon). It also allows to test predictions describing the reaction cross section in terms of a two-gluon form factor of the target by mapping experimentally the t dependence of the invariant cross section $d\sigma/dt$, and to possibly extract the deuteron two-gluon form factor from these data. Such a model has been developed for the elementary exclusive photoproduction off the proton [5] using the concept of gluon general parton distributions (GPDs). A comparison of model predictions with old data at $E_\gamma = 11$ GeV shows a reasonable agreement. This modeling can be extended to coherent production off the deuteron and the two-gluon exchange dominance can be tested for this process. Since the reaction cross section is a sum of spin-flip and spin-non-flip amplitudes, further insight can be gained from the beam-spin asymmetry of this reaction which is sensitive to the interferences between these amplitudes. Measurement of the coherent process with quasi-real photons (*i.e.* low-Q^2 scattered electrons) will allow to extract this observable.

The biggest challenge for the study of the coherent production close to threshold is the cross section suppression due to the fast decreasing deuteron form factor as t increases. While the J/ψ production would be increased by about a factor of four compared to the free-proton production [1], the probability that the deuteron remains intact after absorbing a momentum transfer t is much smaller than the probability for a proton to do so after absorbing the same momentum transfer. Thus, we expect reduced counting rates compared to the ones expected for free-proton J/ψ production. To some extent, this situation can be improved by not detecting the final-state J/ψ as described in the next section.

[1] In the impulse approximation of the coherent J/ψ photoproduction off deuteron, the invariant cross section is approximately equal to four times the product of the invariant cross section of J/ψ photoproduction off the nucleon and the deuteron form factor.

3 CLAS12 and Experimental Capabilities

The proposed program will make use of the beam time allocated for the current Run-Group B proposals with 11-GeV electron beam and a luminosity of 10^{35} $s^{-1}cm^{-2}$. Thus, it will be carried out using the baseline equipment in Hall B as well as the Central Neutron Detector (CND) and the Forward Tagger (FT). We will make use of the CLAS12 capabilities to detect and identify charged hadrons in the polar-angle range from 5° to 125°, to detect and identify neutrons in the Forward Electromagnetic Calorimeter (FEC) in the polar-angle range from 5° to 40°, to detect neutrons in the CND at angles above 40°, and to detect and identify electrons and positrons in the polar-angle range from 5° to 40° in the forward detector (primarily the High-Threshold Cherenkov Counter, HTCC). most of the studies will be done by detecting the electron-positron pair from the J/ψ decay and will make use of the standard electron trigger in CLAS12. If a trigger given by an electron in the FT and a hadronic track in CLAS12 is feasible, the program will also make use of such a trigger.

Due to the multiple final-state particles in the reactions of interest, the corresponding yields can be extracted from different event topologies as described below. The kinematic ranges of the outgoing particles were obtained by using a phase-space event generator. The Fermi momentum of the nucleons in the deuteron was randomly generated according to the Paris potential. The spectator nucleon was always generated on its mass shell, while the mass of the target nucleon was such that the sum of the total energies of the two nucleons yielded the deuteron rest mass.

3.1 Quasi-free J/ψ photoproduction off the bound neutron

The kinematic distributions of the final-state particles in the reaction $\gamma d \to J/\psi n(p)$, where (p) denotes the spectator nucleon are shown in Fig. 3. Since Run Group B does not intend to detect low-momentum recoils, the acceptance of CLAS12 for the low-momentum spectator protons (with momenta from 0. MeV/c to 200 MeV/c) is negligible. However, the proton-spectator momentum range from 0. MeV/c to 200 MeV/c contains the majority of quasi-free events as can be seen on the top right pannel of Fig. 3. This means that the most feasible approach to measure this reaction is via quasi-real photoproduction. In this case, the low-Q^2 scattered electron is detected in the Forward tagger, the scattered neutron is detected in the forward electromagnetic calorimeter, and J/ψ is identified by detecting the e^+e^- pair from its decay and reconstructing the pair's invariant mass. The top left panel of Fig. 3 shows that the neutron scatters at polar angles below 50° in lab system. The geometrical acceptance of the FEC covers angles from 5° to 35° and this detector will be the primary means to detect the majority of the outgoing neutrons. The small fraction of neutrons with momenta below 2 GeV/c, scattered at polar angles above 40° can be detected with the central-neutron detector built to support the n-DVCS program. The bottom panels of Fig. 3 shows the kinematics of the outgoing J/ψ (left) and of the momentum correlation of the decay electron and positron

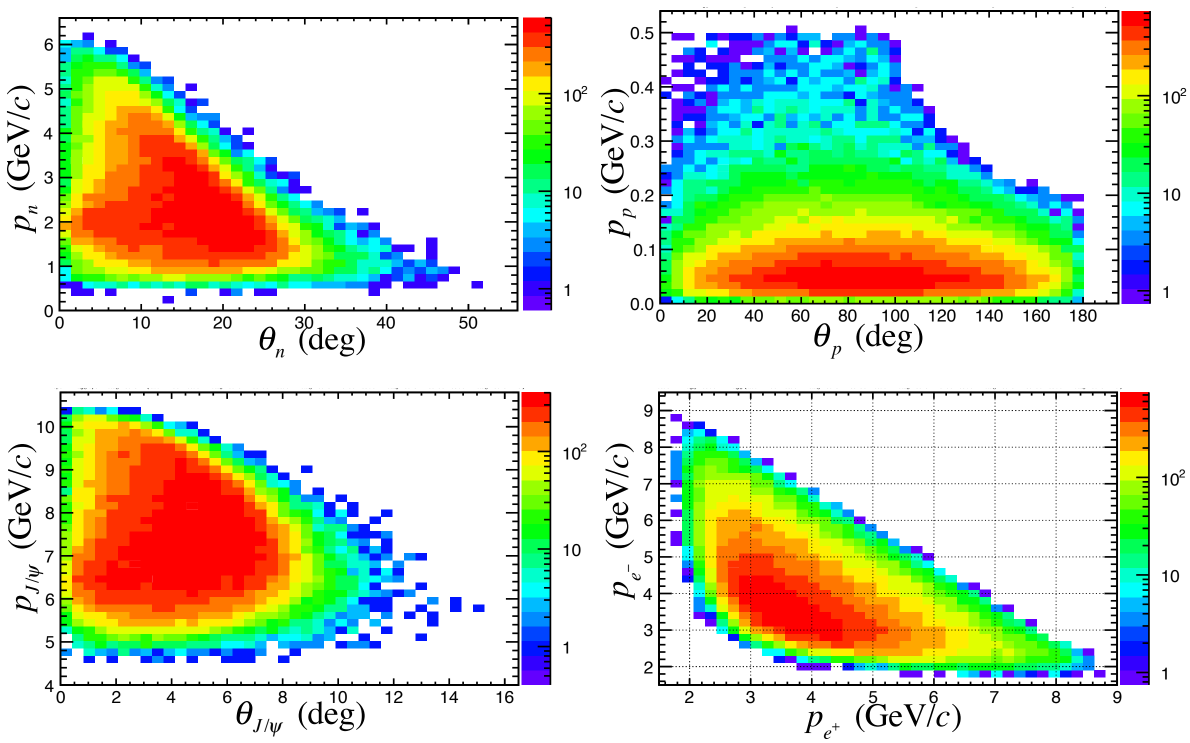

Figure 3: Top Left: Momentum versus polar scattering angle in lab system of the scattered neutron in the reaction $\gamma n_{bound} \rightarrow J/\psi n$ for photon energies from threshold up to 11 GeV. Top Right: Momentum versus polar scattering angle in lab system of the spectator proton in the reaction $\gamma d \rightarrow J/\psi n(p)$. Bottom Left: Momentum versus polar scattering angle in lab system of the scattered J/ψ in the reaction $\gamma n_{bound} \rightarrow J/\psi n$ from threshold up to 11 GeV. Bottom Right: The kinematic correlation p_{e^-} vs. p_{e^+}. All distributions are produced by taking into account that the e^+e^- will be detected in the limited polar angular range of $(5^\circ, \quad 35^\circ)$.

(right). Due to the nearly identical masses of the proton and neutron, the kinematics of the J/ψ and its decay products is very similar to the kinematics of J/ψ produced off the free proton, *i.e.* in the reaction $\gamma p \to J/\psi p$. The E12-12-001 proposal demonstrated that CLAS12 is very well suited to detect and identify the J/ψ mesons produced in the latter. Since by far the majority of the bound neutrons have momenta below 200 MeV/c, the target-neutron momentum causes only minor alterations of the overall J/ψ kinematics. Thus, we will have a good J/ψ kinematic coverage and identification.

3.2 Final-State Interactions in incoherent J/ψ photoproduction off deuteron

In order to access the $J/\psi N$ interaction cross section, we need to be able to detect the outgoing particles produced in the mechanism depicted in the bottom panel of Fig. 1, where J/ψ is produced in the elementary reaction $\gamma N_{1,bound} \to J/\psi N_1$ in a first step and then it re-scatters off the other nucleon via the reaction $J/\psi N_{2,bound} \to J/\psi N_2$. Here the label 1(2) of the scattered nucleon is only introduced in order to distinguish between the nucleon involved in the first step from the nucleon involved in the second step of the FSI. The final-state particles in this two-step mechanism are exactly the same as in the quasi-free J/ψ photoproduction off the bound nucleon. In each case, we are looking at incoherent photoproduction $\gamma d \to J/\psi pn$. However in quasi-free production, one of the outgoing nucleons is a low-momentum nucleon, while in FSI, both the outgoing nucleons carry high momenta. While the extraction of the $J/\psi N$ cross section from FSI yields does require theoretical input, *i.e.* it will be model dependent, since experimentally it is not possible to kinematically separate between various FSI leading to the final state of interest, it is important to assess the possibility to separate between quasi-free and FSI events.

The kinematics of the outgoing particles in case of a two-step mechanism involving $J/\psi N$ rescattering is shown in Fig. 4. The top two panels of Fig. 4 show that the two final-state nucleons produced in the FSI of interest have momenta in the range of up to 5–6 GeV/c. While N_1 scatters predominantly at polar angles below 50°, N_2 scatters over a much broader angular range, up to 160° [2]. The J/ψ kinematic distribution (bottom left panel of Fig. 4) also shows an interesting trend. While the momentum range is similar to the one for the QF mechanism, the angular range of a re-scattered J/ψ is about two times wider, *i.e.* J/ψ scattered at angles above 10° could not have been produced in a QF production or in a NN rescattering, but only in a $J/\psi N$ rescattering. The latter provides some experimental means to obtain a FSI interaction sample dominated by $J/\psi N$ rescattering. These distributions, coupled with the CLAS12 acceptance for protons and neutrons, suggest that the FSI of interest can be measured in the following ways:

[2] In fact the nucleon produced in the second-step elastic $J/\psi N$ scattering, covers the full polar angle from 0° to 180°, which is a characteristic of elastic scattering. The actual angular range shown in the figure is narrower due to the limited CLAS12 angular acceptance for e^+, e^-, and N_1.

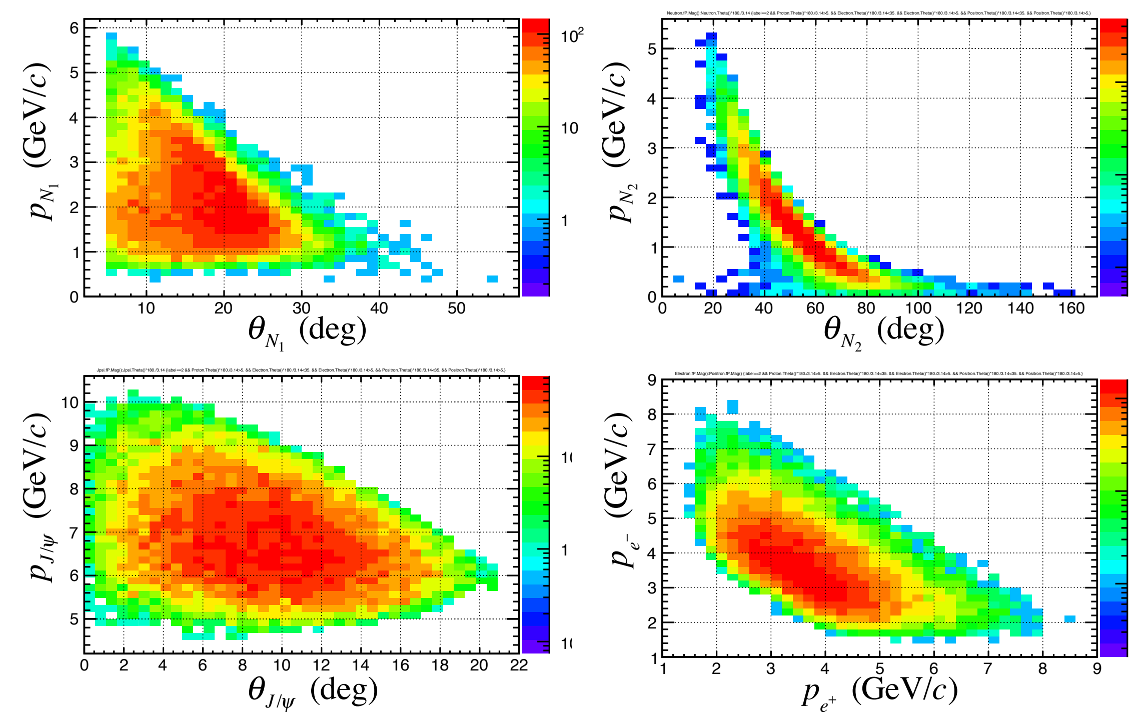

Figure 4: Top Left: Momentum versus polar angle in lab system of the nucleon N_1 produced in the first step of the FSI of interest. Top Right: Momentum versus polar angle in lab system of the nucleon N_2 produced in the second step of the FSI of interest. Bottom Left: Momentum versus polar angle in lab system of the J/ψ produced in the FSI of interest. Bottom Right: The kinematic correlation p_{e^-} vs. p_{e^+}. All distributions are produced by taking into account that the e^+e^- will be detected in the limited polar angular range of $(5^\circ,\ 35^\circ)$ and that the final state proton will be detected at polar angles above 5°. The distributions are produced with beam-photon energies from threshold up to 11 GeV.

1. Untagged Real Photoproduction: All final state particles are detected and the beam photon is reconstructed from four-momentum conservation (scattered electron is very forward and not detected. This approach will yield access predominantly to $J\psi p$ rescattering, as the neutron produced in the first step is predominantly forward scattered and will be detected in the FEC, while the large CLAS12 acceptance for protons will allow to detect the protons produced in the second step over the full CLAS12 polar-angle range. The momenta of both nucleons fit very well with the nominal CLAS12 specifications for efficient neutron and proton PID.

   This technique will yield a more limited yield for $J\psi n$ rescattering, due to the fact that a significant number of final-state neutrons will scatter at angles above 35°. The momenta of these neutrons are up to 3 GeV/c. While the central-neutron detector can detect neutrons scattered at angles above 40°, (a) it provides a good n/γ separation for neutrons below 1 GeV/c, which means an increased background in our yields of events with neutrons having momenta between 1 GeV/c and 3 GeV/c, and (b) it has a neutron detection efficiency of 10% – 15%. A more detailed simulation studies (to be performed at proposal development) will show the expected counting rates at various kinematics. The experiment itself will provide the full information about the level of backgrounds due to poor neutron identification in the central neutron detector above 1 GeV/c and will allow for the development of refined techniques for background reduction in the offline data analysis.

2. Quasi-real Photoproduction: This approach makes use of detecting a small-angle scattered electron in the forward tagger, which allows to reconstruct the four-momentum of the low-Q^2 quasi-real photon. With the beam photon detected, one of the final-state particles can be undetected and the reaction identified by the missing-mass technique.

   There are three event topologies, which can be explored with this technique: (a) $\gamma d \to pnX$, where $X \equiv J/\psi$, (b) $\gamma d \to pJ/\psi X$, where $X \equiv n$, and (c) $\gamma d \to nJ/\psi X$, where $X \equiv p$. The first event topology will provide more events in the $J\psi p$ rescattering sample as the suppression factor due to the $J/\psi \to e^+e^-$ branching ratio will be eliminated. This will likely come at the cost of an increased background, which may be further reduced in the offline analysis by applying kinematic constraints on the reconstructed X. The second event topology will provide more events in the $J\psi n$ rescattering sample and may turn out to be the main way to access this yield. The third topology will provide more events to the $J\psi p$ rescattering sample and can also be used for systematic checks of the extracted cross sections as the CLAS acceptance for the topologies of untagged real photoproduction and quai-real photoproduction will be very different. This topology also allows kinematic access to forward scattered protons, which was shown in [4] to be advantageous for the $J/\psi N$ interaction study.

3.3 Coherent J/ψ photoproduction off deuteron

Figure 5 shows the kinematics of the scattered deuteron, J/ψ, and the electron (positron) from the meson decay for photon energies from threshold up to 11 GeV. One can see that

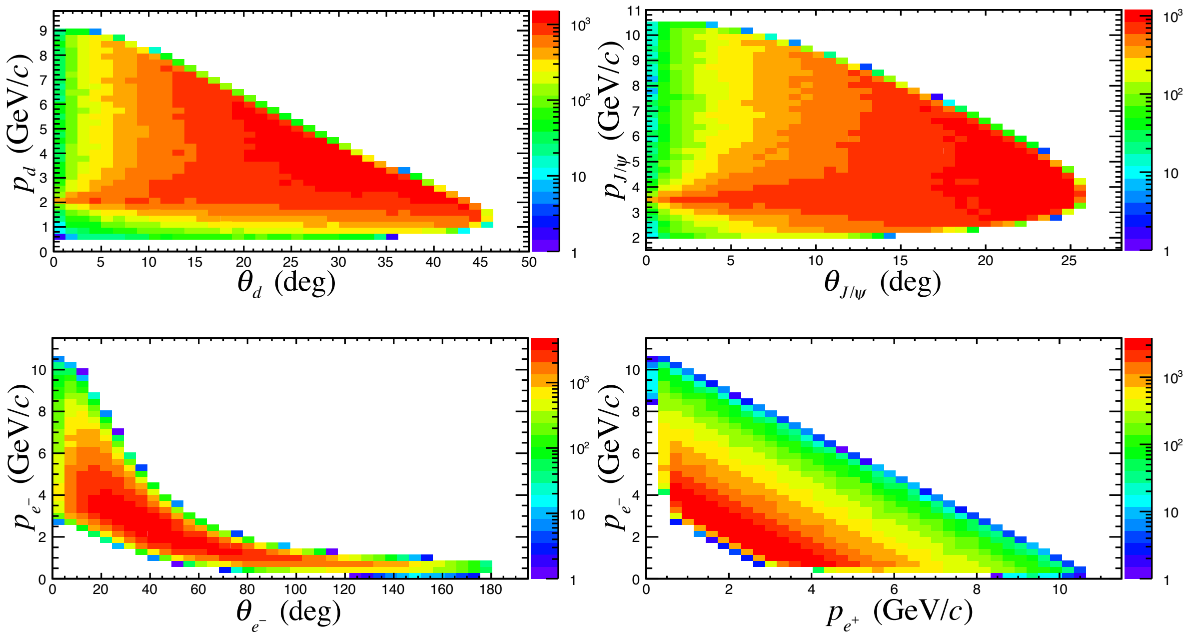

Figure 5: Top Left: Momentum versus polar scattering angle in lab system of the scattered deuteron in the reaction $\gamma d \to J/\psi d$ for photon energies from threshold up to 11 GeV. Top Right: Momentum versus polar scattering angle in lab system of the scattered J/ψ in the reaction $\gamma d \to J/\psi d$ for photon energies from threshold up to 11 GeV. Bottom Left: Momentum versus polar scattering angle in lab system of the electron from the decay $J/\psi \to e^+e^-$. The kinematic correlation p vs. θ of the decay positron is exactly the same as the one of the electron. Bottom Right: The kinematic correlation p_{e^-} vs. p_{e^+} within the geometrical acceptance of the forward High-Threshold Cherenkov Counter and the Forward Electromagnetic Calorimeter.

the vector meson produced in this process covers a wider polar angular range than the range covered in photoproduction off the nucleon. However, J/ψ produced in FSI also covers similar wider range. Given that, it is clear that the yield extraction for this process must be based on the detection of the scattered deuteron. The top left panel of Fig. 5 shows that the scattered deuterons span a momentum range from 0.5 GeV/c up to 9. GeV/c and polar angles up to 45°. Although, the CLAS capabilities, deuteron form factor, and reaction dynamics will limit these kinematics ranges, we expect to be able to identify most of the final-state deuterons. With the deuteron detected, there are two possible ways to proceed:

1. Untagged real photoproduction: Detect the decay electron and positron pair from the J/ψ decay, identify the meson via invariant mass, and reconstruct the photon via four-momentum conservation. In this case, the scattered beam electron moves at very forward angles and is not detected neither in CLAS nor in the forward tagger. The yields extracted from this analysis are expected to be very small, largely due the deuteron form factor and the small branching ratio of $J/\psi \to e^+e^-$, and to a much smaller extent to the limited angular acceptance of CLAS12 for e^+/e^- ($5°$, $35°$).

2. Quasi-real photoproduction: Select events with a detected deuteron and a small-angle scattered electron in the forward tagger. The latter allows to select quasi-real photons with a very small Q^2. The J/ψ will be then identified via the missing-mass technique. The major advantage of this approach over the untagged real photoproduction is that it does not rely on detecting the $J/\psi \to e^+e^-$ decay and should result in larger event yields. The major challenge would be the background. Detailed simulation studies and real data on exclusive J/ψ photoproduction off a proton target from the first CLAS12 production run, will be used to establish techniques for background reduction. The beam-spin asymmetry for the coherent process off deuteron can be also extracted from the quasi-real photoproduction event sample.

Detailed simulations involving realistic reaction cross section and CLAS12 acceptance should provide count rate estimates and the expected statistical significance of the foreseen measurements. Those will also provide insight into possible yield extraction from other event topologies.

References

[1] S.J. Brodsky, E. Chudakov, P. Hoyer, and J.M. Laget, Phys. Lett. B 498, 23 (2001).

[2] J.M. Laget and R. Mendez-Galain, Nucl. Phys. A 581, 397 (1995).

[3] A.J. Freese and M.M. Sargsian, Phys. Rev. C 88, 044604 (2013).

[4] , J.J. Wu and T.-S. H. Lee, Phys. Rev. C 88, 015205 (2013).

[5] L. Frankfurt and M. Strikman, Phys. Rev. D 66, 031502(R), 031502 (2002).