

J/ψ -meson–nucleon scattering length from threshold photoproduction on light nuclei

Igor I. Strakovsky^{1,*}, William J. Briscoe¹, Philipp Gubler², Jackson R. Pybus³,
Axel Schmidt¹, and Alexander Somov⁴

¹*Institute for Nuclear Studies, Department of Physics, The George Washington University, Washington, DC 20052, USA*

²*Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Naka, Ibaraki 319-1195, Japan*

³*Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*

⁴*Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA*



(Received 11 December 2025; revised 25 February 2026; accepted 28 April 2026; published 4 June 2026)

The quality of recent Short-Range Correlations/Color-Transparency (SRC/CT) Collaboration J/ψ photoproduction data off a ^4He target from Hall D at Jefferson Laboratory, combined with the feasibility of measuring the reaction close to the free-nucleon energy threshold, opens the door to using incoherent J/ψ photoproduction to explore a variety of interesting physics aspects. An example is the estimation of the J/ψ p scattering length $|\alpha_{J/\psi p}|$ on the bound proton, obtained using the vector meson dominance model. The new experiment E12–25–002, conducted by the SRC/CT Collaboration, was recently approved in Hall D with the GlueX spectrometer, which will significantly enhance the number of reconstructed J/ψ mesons. Using a plane-wave theoretical model to generate quasidata, we estimated that the experiment could achieve a result of $|\alpha_{J/\psi p}| = 3.08 \pm 0.45$ mfm. This value can be compared to an extraction based on the free proton data from the GlueX Collaboration, $|\alpha_{J/\psi p}| = 3.08 \pm 0.55$ mfm. A comparison between the two would provide an opportunity to evaluate the effects of medium modification in light nuclei.

DOI: [10.1103/ndmt-2brb](https://doi.org/10.1103/ndmt-2brb)

I. INTRODUCTION

The first threshold J/ψ photoproduction measurements on a proton target by the GlueX Collaboration [1] have enabled a determination of the J/ψ -proton scattering length (SL) using Sakurai's vector meson dominance (VMD) model [2]. The J/ψ is a member of the vector meson family and has the same spin (J), parity (P), and charge conjugation (C) quantum numbers as the photon: $J^{PC} = 1^{--}$. It is assumed that a real photon can fluctuate into a virtual vector meson (J/ψ in our case), which then scatters off a nearby proton. The phenomenological analysis of the GlueX threshold data [1], making use of VMD, resulted in a scattering length $|\alpha_{J/\psi p}| = (3.08 \pm 0.55)$ mfm [3], a value much smaller than the size of a hadron (≈ 1 fm). It is possible that such a small value results from a violation of the VMD assumption in the heavy-quark sector. An intuitive understanding of this violation may be obtained from the “young” meson effect. [4]. Due to the small size difference between the young and “old” J/ψ , the measured and predicted SL values are very small. J/ψ is created by the photon at the threshold; therefore, it is most probable that J/ψ is not fully formed, and its radius is smaller

than that of normal (old) J/ψ [4]. Therefore, a stronger suppression of the J/ψ - p interaction is observed [5]. In a recent study, the effect of the VMD assumption was critically examined within the formalism of the Dyson-Schwinger equations, which can be considered an alternative interpretation of the “young age” effect in more formal terms [6]. Similarly, an analysis of the same GlueX data using multiple hadronic models [7] found that the VMD could be strongly violated. On the other hand, the GlueX total cross-section data are reasonably well predicted by the recent theoretical study of vector-meson photoproduction from threshold to high energies reported by Tang *et al.* [8], which models the reaction through Pomeron exchange with an explicit implementation of a quark loop (shown in Fig. 1 of Ref. [8]). This approach, which is not fit to the data, yields a scattering length of $|\alpha_{J/\psi p}| = 6.34$ mfm, a value more than twice as large. The model is less successful, however, at reproducing the differential cross section at high $|t|$, as expected for a model that considers Pomeron exchange.

A potential violation of the VMD assumption could also be at play in the case of the ϕ -nucleon SL, for which recent photoproduction [9] and femtoscopy [10] show a significant disagreement. Theoretical computations [11–13] of this quantity likewise exhibit a wide spread, suggesting that the ϕ nucleon interaction is, at the moment, still far from being properly understood. An alternative constraint can be obtained from the ϕ meson mass shift and decay width in nuclear matter, which, within the linear-density approximation, is related to the real and imaginary parts of the ϕ -nucleon SL [14]. The mass shift of -3.4% reported by the KEK-E325 experiment [15], for instance, corresponds to an attractive real part of the ϕ nucleon SL, with a magnitude of about half that obtained

*Contact author: igor@gwu.edu

Published by the American Physical Society under the terms of the [Creative Commons Attribution 4.0 International](https://creativecommons.org/licenses/by/4.0/) license. Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI. Funded by SCOAP³.

by the ALICE Collaboration. A recent reanalysis of the same data in Ref. [16], however, yielded a reduced mass shift with significantly larger uncertainties, suggesting that it is still difficult to draw definite conclusions based on the presently available data.

The evaluation of $\gamma A \rightarrow J/\psi pX$ cross sections of light nuclei is challenging. The first results on ${}^4\text{He}$ were recently reported by the Short-Range Correlations/Color-Transparency (SRC/CT) Collaboration at Jefferson Laboratory [17]. Unfortunately, the low statistics do not allow for a sufficiently precise determination of the total near-threshold cross sections to be used as input to determine $|\alpha_{J/\psi p}|$ on the bound proton. However, a higher-statistics follow-up experiment on ${}^4\text{He}$ is planned [18]. Here, we generate quasidata based on the anticipated statistical precision of this follow-up measurement to assess the precision achievable in extracting $|\alpha_{J/\psi p}|$.

II. THEORETICAL DEVELOPMENTS

Theoretically, the J/ψ - N SL in vacuum has been studied in QCD sum rules, effective hadronic models, and lattice QCD approaches, while finite density effects on its value have remained largely unexplored. Note that the SL is defined as the scattering amplitude at threshold and is therefore generally a complex number. While the real part describes the nature (attractive vs repulsive) and strength of the interaction, the imaginary part encodes the possibility of scattering into an inelastic channel. In QCD sum rule studies [19–22], the SL can be extracted either by directly computing the forward J/ψ - N scattering amplitude [19] or via the J/ψ mass shift in dense matter $\Delta m_{J/\psi}(\rho)$ [20–22], which, within the linear density approximation, can be related to the real part of the SL by

$$\text{Re}\alpha_{J/\psi p} = -\frac{\mu \Delta m_{J/\psi}(\rho)}{2\pi\rho}, \quad (1)$$

where μ is the reduced mass of the J/ψ - N system. In these works, the SL is related mostly to expectation values of gluonic operators of a one-nucleon state, demonstrating its usefulness as a probe of the gluonic structure of the nucleon, and is in line with an early prediction of a nuclear-bound quarkonium state due to a “QCD van der Waals interaction” caused by multiple gluon exchanges [23,24] and the QCD multipole expansion [25] (note, however, the recent Ref. [22], in which the relevance of quark-type operators is discussed). The above QCD sum rule studies obtain negative mass shifts of the order of 5 MeV at normal nuclear matter density ρ_0 , which translates into SL values of around $\text{Re}\alpha_{J/\psi p} \approx 0.1$ fm.

In one example of an effective hadronic model approach [26], the D and D^* loop contributions to the J/ψ self-energy are computed with density dependent D and D^* masses obtained from the quark-meson coupling model [27]. This generates an attractive J/ψ - N interaction and density-dependent pole masses, shifted by about -20 MeV at ρ_0 , leading to an SL value of $\text{Re}\alpha_{J/\psi p} \approx 0.4$ fm. A more rigorous effective field theory treatment, including a power counting scheme, was introduced in Ref. [28]. However, more constraints on the different low-energy constants will be essential for this theory to demonstrate real predictive power.

Furthermore, attempts to compare various hadronic models with the GlueX photoproduction data of Refs. [1,29] have been made [7,30]. The obtained conclusions with respect to the SL, however, exhibit a large spread, ranging from a few fm [30] to values of the order of 1 fm [7], which could be related to both a possible violation of the VMD assumption in the charm quark sector and an insufficient precision of the experimental data.

Finally, lattice QCD has made progress toward a more quantitative understanding of the J/ψ - N interaction. While the first attempts had to rely on the quenched approximation with rather heavy pion masses [31], the most recent calculations use $N_f = 2$ [32] or $N_f = 2 + 1$ [33] active quark flavors and a pion mass approaching the physical point; however, they yield somewhat contradictory results. The calculations in Ref. [32] of energy levels of the J/ψ - N system in a finite box found results consistent with almost noninteracting J/ψ and N , corresponding to a vanishing (or very small) SL. On the other hand, in Ref. [33] the J/ψ - N potential was calculated using the method proposed by the HAL QCD Collaboration [34], which turns out to be attractive, with a long-range part consistent with a two-pion exchange mechanism. The SLs corresponding to this potential are obtained as $0.30(2)_{-2}^{+0}$ and $0.38(4)_{-3}^{+0}$ fm for the spin 3/2 and 1/2 channels, respectively.

With all these widely scattered results, both more stringent experimental constraints and a better theoretical understanding of the J/ψ - N interaction and the J/ψ photoproduction mechanism are clearly needed to obtain a complete picture of the physics governing these phenomena.

III. QUASIDATA FOR J/ψ PHOTOPRODUCTION AT THE THRESHOLD ON LIGHT NUCLEI

The underlying cross-section model for the quasidata is the same as that deployed in Refs. [17,18]. The model assumes the photoproduction of a J/ψ from a bound proton in the plane-wave impulse approximation, whereby the J/ψ production cross section is factorized from a spectral function that defines the probability that a bound proton has an initial momentum $\vec{p}_i$ and initial energy ε_i . The cross section can be written:

$$\frac{d\sigma}{dt d\varepsilon_i d^3\vec{p}_i} = \frac{p_{\gamma,\mu} p_i^\mu}{\varepsilon_\gamma \varepsilon_i} \cdot \frac{d\sigma}{dt}_{\gamma p \rightarrow J/\psi p} \cdot S(\vec{p}_i, \varepsilon_i), \quad (2)$$

where $p_{\gamma,\mu} = (\varepsilon_\gamma, \vec{p}_\gamma)$ is the four-momentum of the incoming photon beam, $p_{i,\mu} = (\varepsilon_i, \vec{p}_i)$ is the initial four-momentum of the bound proton, t is the Mandelstam variable defined by $t \equiv (p_{\gamma,\mu} - p_{J/\psi,\mu})^2$ where $p_{J/\psi,\mu}$ is the four-momentum of the final state J/ψ , $\frac{d\sigma}{dt}_{\gamma p \rightarrow J/\psi p}$ is the J/ψ photoproduction cross section from a single proton, and $S(\vec{p}_i, \varepsilon_i)$ is the spectral function.

Naively, it seems that the “nuclear effects” should be rather small for a ${}^4\text{He}$ target. The bound state properties of nucleons inside ${}^4\text{He}$ are already accounted for and characterized by the use of the spectral function in Eq. (2). There could be some effect from a slight mass change of the J/ψ in a dense medium, but one guesses that this is a small effect that might

TABLE I. Parameter values used in the cross section described in Eqs. (2) and (3).

Parameter	Value
σ_0	5.9 nb
β	1.19
Λ	1.35 GeV

even be hard to estimate, as there is not really “dense matter” in ^4He , but rather just four nucleons.

Following Refs. [35,36], we parametrize $\frac{d\sigma}{dt} \gamma p \rightarrow J/\psi p$ using the form

$$\frac{d\sigma}{dt} \gamma p \rightarrow J/\psi p = \sigma_0 (1 - \chi)^\beta \frac{F(t)}{\int_{t_{\min.}}^{t_{\max.}} F(t) dt}, \quad (3)$$

where χ is an energy fraction parameter defined by

$$\chi = \frac{m_{J/\psi}^2 + 2m_{J/\psi}m_p}{s - m_p^2}, \quad (4)$$

where $m_{J/\psi}$ is the J/ψ mass; m_p is the proton mass; s is the Mandelstam variable defined by $(p_{\gamma,\mu} + p_{i,\mu})^2$; $F(t)$ is a form factor assumed to have a dipole form, i.e., $F(t) = (1 - t/\Lambda^2)^{-2}$; $t_{\min.}$ and $t_{\max.}$ are the kinematic limits of t given the photon energy ε_γ ; and σ_0 , β , and Λ are tunable parameters. The values of these parameters used for this work were determined in Ref. [18] based on a fit to the high-luminosity GlueX data [29], and are listed in Table I. This fit has a total chi squared of 84.9, with 42 degrees of freedom. Figure 1 shows how this cross-section model compares to the total and differential cross-section data from Ref. [29].

We used the same approach to the ^4He spectral function as in Ref. [17], divided into a mean-field component calculated using variational Monte Carlo techniques [37], and a short-range correlation component estimated using the generalized contact formalism [38–40].

To generate quasidata, an estimate of the tagged-photon flux in the experiment was required. The Hall D photon beam is produced through the coherent bremsstrahlung process, which leads to a “coherent peak” in the produced photon flux at an energy that can be tuned by adjusting the diamond radiator [41]. Though the exact flux distribution will depend on the chosen radiator settings and tagger detector placement, we estimated the flux distribution based on the assumptions provided in Ref. [18]. Details can be found in the Appendix. Our flux distribution estimate results in a total integrated coherent flux of 5.6×10^6 photons/s, as well as a total incoherent flux of 4.6×10^7 photons/s, for a total tagged flux of 5.2×10^7 photons/s. We assume an experimental duration, $t_{\text{expt.}}$ of 80 days of full flux on a 30-cm liquid ^4He target (total thickness, $n_{\text{tar.}}$ of 5.68×10^{23} nuclei/cm ^{2}). We also assume that the reconstructed yields will be reduced by both nuclear attenuation—final-state particles can be absorbed or rescattered by spectator nucleons before emerging from the nucleus—and by experimental efficiency. Based on the results of the Glauber model calculation performed in Ref. [17], we assume a conservative nuclear transparency factor, T , of 60%, independent of kinematics. We assume a reconstruction

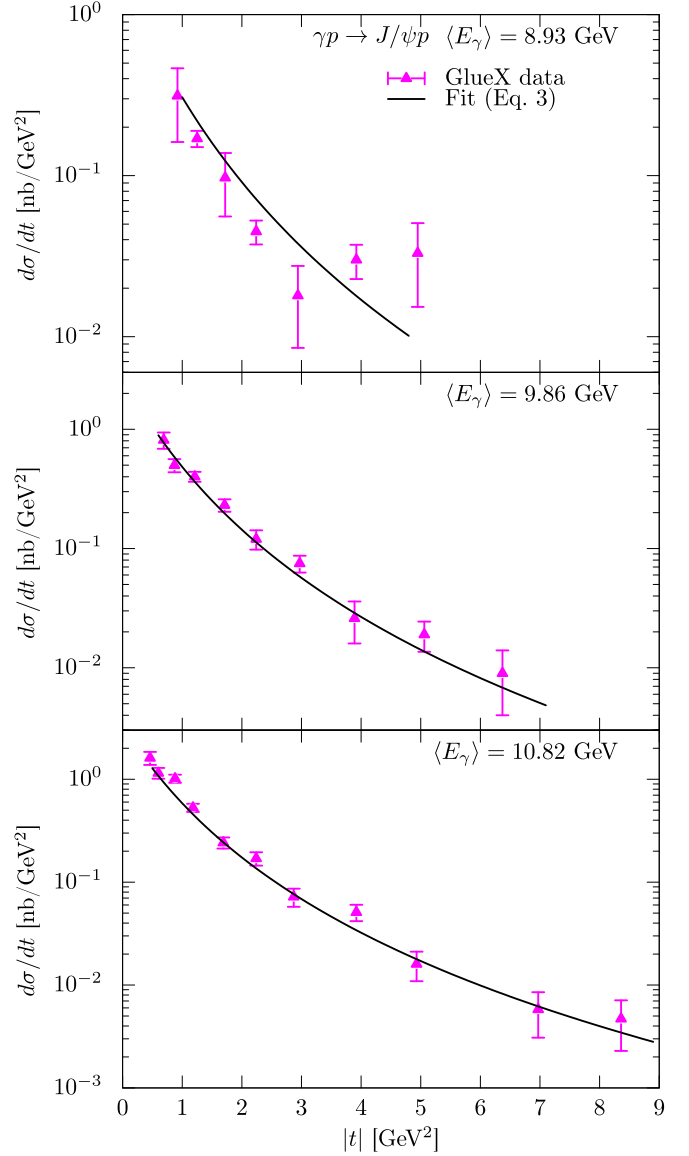


FIG. 1. Comparison of the cross-section model in Eq. (3) (with parameters listed in Table I) and the total (top panel) and differential (lower three panels) $\gamma p \rightarrow J/\psi p$ cross-section data from high-luminosity GlueX (from Ref. [29]).

efficiency, ϵ , of 15%, also based on Ref. [17]. Our estimate of the yield in a given bin can be written:

$$Y_{\text{bin}} = b_{e^+e^-} \cdot \epsilon \cdot T \cdot n_{\text{tar.}} \cdot t_{\text{expt.}} \cdot \int_{\text{bin}} \Phi(\varepsilon_\gamma) \sigma(\varepsilon_\gamma) d\varepsilon_\gamma, \quad (5)$$

where $b_{e^+e^-} = 6\%$ is the branching fraction for J/ψ decay into e^+e^- [42], and $\Phi(\varepsilon_\gamma)$ is the photon flux distribution. Our estimated yields for E12–25–002, in 18 bins of ε_γ , are shown in Fig. 2, and are similar to the estimates made in Ref. [18]. We do not consider subthreshold quasidata in the analysis.

To estimate the uncertainty per bin, we combine the Poisson statistical uncertainty with 14% systematic uncertainty, as suggested in Ref. [18], covering the effects of $\pi^+\pi^-$ contamination, background subtraction, cut depen-

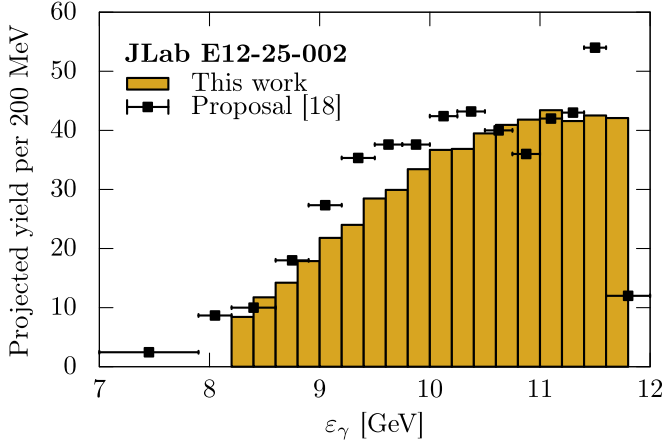


FIG. 2. Projected yields for $\gamma^4\text{He} \rightarrow J/\psi pX$ as a function of beam photon energy ε_γ . Our estimate, shown as brown bars, is comparable to the estimate in the proposal for E12–25–002 [18], represented by black points. The horizontal bars indicate the binning of Ref. [18].

dence, uncertainty on the Bethe-Heitler reference reaction, and efficiency.

The J/ψ cross section and corresponding uncertainty obtained using simulated quasidata are shown in Fig. 3 as a function of the center-of-mass (CM) momentum q of the J/ψ . In computing the CM momentum, we neglected Fermi-motion effects; these can be incorporated into an experimental analysis by binning the data directly in q and deconvoluting the nuclear spectral function. The uncertainties associated with this procedure are expected to be significantly smaller than those arising from the determination of the total cross section.

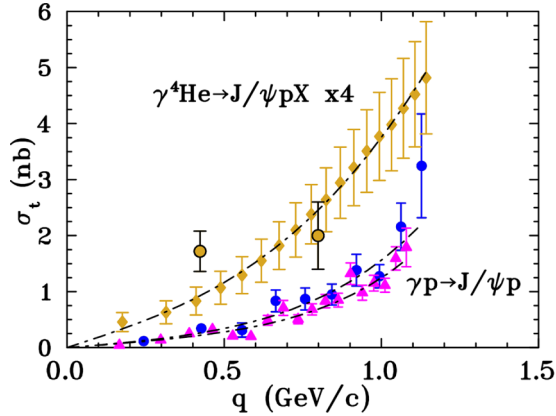


FIG. 3. The total $\gamma p \rightarrow J/\psi p$ cross section σ_t as a function of the J/ψ CM momentum includes measurements of the GlueX Collaboration with small statistics (blue filled circles, 469 ± 22 events) [1,3] and with high statistics (magenta filled triangles, 2270 ± 58 events) [29]. Quasidata for the total $\gamma^4\text{He} \rightarrow J/\psi X$ cross section obtained from GCP are shown as brown diamonds. Experimental results from the SRC/CT Collaboration are indicated by filled circles with black rings [17]. The black dash-dotted curves represent polynomial fits to the proton data [Eq. (8)] and to the light nucleus (^4He) data [Eq. (9)].

The scattering length and its associated uncertainties are then extracted from a fit to these cross sections, as described in the next section.

IV. J/ψ NUCLEON SCATTERING LENGTH: PHENOMENOLOGICAL ANALYSIS

For the evaluation of the *absolute value* of J/ψ p SL, we apply the VMD approach that links the near-threshold photoproduction total cross section of $\gamma p \rightarrow J/\psi p$ and elastic $J/\psi p \rightarrow J/\psi p$ [5,43]. To avoid adding additional theoretical uncertainties, we do not (i) determine the sign of SL, (ii) separate the Re and Im parts of SL, or (iii) extract total angular momentum 1/2 and 3/2 contributions for the $J/\psi N$ system. The limitations of VMD are listed in Refs. [6,44,45].

Traditionally, the total cross section, σ_t , for near-threshold binary inelastic reactions

$$a b \rightarrow c d \quad (6)$$

with

$$m_a + M_b < m_c + M_d \quad (7)$$

is expressed as a series in *odd* powers of the CM momentum q of the J/ψ meson

$$\sigma_t = a q + b q^3 + c q^5, \quad (8)$$

where the linear term reflects the contributions of two independent S -wave amplitudes with a total spin of 1/2 and/or 3/2. Contributions to the cubic term originate from both P -wave amplitudes and the energy (W) dependence of S -wave amplitudes, while the fifth-order term arises from D -wave amplitudes as well as from the W dependencies of the S - and P -wave amplitudes.

For a nuclear target, Eq. (8) retains the same structure, but the fit is performed for σ_t/Z instead of just σ_t :

$$\sigma_t/Z = a q + b q^3 + c q^5, \quad (9)$$

where Z is the charge of the nuclear target (in the case of ^4He , $Z = 2$). In this analysis, we determine q from ε_γ assuming a stationary nucleon target, i.e., neglecting Fermi motion effects.

The absolute value of SL is determined by the interplay between strong (hadronic) and electromagnetic dynamics:

$$|\alpha_{J/\psi p}| = h_{J/\psi p} B_{J/\psi}, \quad (10)$$

where the hadronic component is given by

$$h_{J/\psi p} = \sqrt{a}, \quad (11)$$

and the parameter a is the linear term obtained from the best fit to the total cross section σ_t of the V photoproduction Eqs. (8) and (9). The purely electromagnetic, VMD-motivated kinematic factor is

$$B_{J/\psi}^2 = \frac{\alpha m_{J/\psi} k}{12\pi \Gamma(J/\psi \rightarrow e^+e^-)}, \quad (12)$$

where α is the fine-structure constant, $m_{J/\psi}$ is the mass of J/ψ ($m_{J/\psi} = 3096.900 \pm 0.006$ MeV) [42], k is the photon CM momentum, and $\Gamma(J/\psi \rightarrow e^+e^-)$ is the J/ψ partial decay width to e^+e^- , $\Gamma(J/\psi \rightarrow e^+e^-) = 5.53 \pm 0.10$ keV [42].

TABLE II. The J/ψ p scattering lengths extracted from the GlueX measurements on a free proton and from the planned SRC/CT experiment on a ^4He target. The second column lists the minimal momentum $q_{\min.}$ for J/ψ accessible in the photoproduction experiments. The third column gives the linear coefficient a obtained from fits to the J/ψ production cross sections using Eqs. (8) and (9). The fourth column presents the corresponding scattering lengths, derived from the parameter a via the phenomenological approach.

Target	$q_{\min.}$ (MeV/cycle)	a [$\times 10^{-6}$ $\mu\text{b}/(\text{MeV}/\text{cycle})$]	$ \alpha_{J/\psi p} $ (fmf)
^1H	244 [1]	0.46 ± 0.16 [3]	3.08 ± 0.55 [3]
^1H	166 [29]	$0.43 \pm 0.10^\dagger$	2.98 ± 0.25
^4He	176	0.46 ± 0.13	3.08 ± 0.45

[†]There is the fit of high-luminosity GlueX data published in [29].

V. MEASUREMENTS WITH THE GLUEX DETECTOR AT JLAB

The photoproduction of the J/ψ meson was studied using the GlueX detector, which is located in Hall D at Jefferson Laboratory. GlueX is a forward magnetic spectrometer designed to carry out experiments with a photon beam of up to 12 GeV. The photon beam is produced via the bremsstrahlung process from the primary electron beam delivered by the Continuous Electron Beam Accelerator Facility. J/ψ mesons are reconstructed through the decay channel $J/\psi \rightarrow e^+e^-$. Charged particles are tracked using the central drift chamber, positioned inside the solenoid magnet, together with a set of forward planar drift chambers. Lepton identification is performed using the forward and barrel calorimeters, which also provide pion rejection by applying selection criteria on the ratio p/E , where p is the particle momentum and E is the energy deposited in the calorimeters. Timing information from scintillating detectors, the start counter surrounding the target, and the forward time-of-flight wall further contributes to particle identification.

The first measurement of J/ψ photoproduction on the proton was performed by the GlueX experiment using the small datasets collected in 2016 and 2017. This initial analysis yielded 469 ± 22 reconstructed J/ψ events [1]. A subsequently conducted, significantly larger data sample resulted in 2270 ± 58 reconstructed candidates, collected from 2016 to 2018, with the analysis reported in Ref. [29]. The J/ψ photoproduction cross section as a function of the J/ψ CM momentum is shown in Fig. 3. The scattering lengths extracted from the data are listed in Table II and demonstrate good agreement between the higher-statistics analysis and the initial publication.

The stability of the leading linear term a from Eq. (8) is demonstrated by comparing low (high) luminosity GlueX cases $a = 0.46 \pm 0.16$ nb/GeV/cycle [3] ($a = 0.43 \pm 0.10$ nb/GeV/cycle).

Following GlueX, a short Jefferson Laboratory experiment was performed to study short-range correlations using photon beams. Data were collected on deuterium, helium, and carbon targets. This experiment obtained a small data sample consisting of 120 ± 15 reconstructed J/ψ events and reported the

first measurements of near- and subthreshold J/ψ production from nuclear targets [17].

Recently, the SRC/CT Collaboration proposed a new experiment (E12-25-002), “Threshold J/ψ photoproduction as a probe of nuclear gluon structure” [18], which was approved by the Jefferson Laboratory Program Advisory Committee in 2025 to run for 85 days in Hall D using the GlueX spectrometer. The experiment plans to collect 80 days of production data on a liquid ^4He target. The experiment will feature an upgraded forward electromagnetic calorimeter based on high-resolution, high-granularity lead-tungstate crystals, as well as a new GEM-TRD detector to reduce background from e/π misidentification. With a longer run duration and better optimization in experimental settings, the experiment aims to increase the statistics for J/ψ production from bound protons by a factor of approximately 10 compared to the earlier SRC experiment. This will enable precision measurements of the incoherent J/ψ photoproduction cross section at threshold, providing the first stringent constraints on nuclear modifications of gluon structure or other exotic effects. Based on our analysis of the quasidata described in Sec. III, we estimate that the total cross-section data from the experiment will allow for a competitive determination of the $J/\psi - p$ scattering length, with an uncertainty on the order of 0.45 fmf. The total cross section for the quasidata is shown in Fig. 3, and the corresponding scattering length is listed in Table II.

VI. SUMMARY

The GlueX detector in Hall D at Jefferson Laboratory provides a unique opportunity to study the photoproduction of J/ψ mesons over a broad kinematic range near threshold. The scattering length for $J/\psi - p$ production on a free proton has already been extracted from measurements performed by the GlueX collaboration. The SRC/CT Collaboration carried out the first measurements of the J/ψ photoproduction cross section on light nuclear targets using a small sample of J/ψ mesons. A recently approved experiment will increase the available statistics by roughly an order of magnitude. We evaluated the feasibility of extracting the scattering length for this new experiment using quasidata. Within the VMD and the plane-wave approximation framework, we demonstrated that the upcoming measurement will enable the first determination of the scattering length on a bound proton.

ACKNOWLEDGMENTS

This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Awards No. DE-SC0016583 and No. DE-AC05-06OR23177. Research presented in this article was supported by the Laboratory Directed Research and Development program of Los Alamos National Laboratory (J.R.P.) under Project No. 20240866PRD2. P.G. is supported by Japan Society for the Promotion of Science KAKENHI Grants No. JP22H00122 and No. JP25H00400.

DATA AVAILABILITY

There are no publicly available research data or software supporting this manuscript. Requests for further information or data should be sent to the authors.

APPENDIX: FLUX MODEL

To estimate yields for the future Jefferson Laboratory Experiment E12–25–002 [18], we made a rough estimate of a flux distribution, $\Phi(\varepsilon_\gamma)$, given by

$$\Phi(\varepsilon_\gamma) = \Phi_{\text{coh.}}(\varepsilon_\gamma) + \Phi_{\text{incoh.}}(\varepsilon_\gamma). \quad (\text{A1})$$

Switch

$$\Phi_{\text{incoh.}}(\varepsilon_\gamma) = \Phi_a + (\Phi_b - \Phi_a) \frac{\varepsilon_\gamma - \varepsilon_a}{\varepsilon_b - \varepsilon_a} \varepsilon_a < \varepsilon_\gamma < \varepsilon_b, \quad (\text{A2})$$

$$\Phi_{\text{coh.}}(\varepsilon_\gamma) = \Phi_c \frac{\varepsilon_\gamma - \varepsilon_d}{\varepsilon_c - \varepsilon_d} \varepsilon_d < \varepsilon_\gamma < \varepsilon_c, \quad (\text{A3})$$

with $\varepsilon_a = 6.0$ GeV and $\varepsilon_b = 10.8$ GeV describing the tagger energy range, $\varepsilon_d = 7.5$ GeV describing the start of the coherent peak, $\varepsilon_c = 8.0$ GeV describing the coherent edge, and flux constants $\Phi_a = 1.2 \times 10^7$ photons/GeV/s, $\Phi_b = 4 \times 10^6$ photons/GeV/s, and $\Phi_c = 2.24 \times 10^7$ photons/GeV/s. Under this assumption, the total integrated coherent flux is 5.6×10^6 photons/s, while the total incoherent flux is 4.64×10^7 photons/s, resulting in a total tagged flux of 5.2×10^7 photons/s. We estimate that this roughly corresponds to the tagged flux produced by a 12-GeV, 160-nA primary electron beam incident on a 4×10^{-4} radiation length diamond radiator. The precise tagged-flux distribution in the experiment will depend on the experimental settings and the placement of the various elements of the tagger detector.

-
- [1] A. Ali *et al.* (GlueX Collaboration), First measurement of near-threshold J/ψ exclusive photoproduction off the proton, *Phys. Rev. Lett.* **123**, 072001 (2019).
 - [2] J. J. Sakurai, Theory of strong interactions, *Ann. Phys. (NY)* **11**, 1 (1960).
 - [3] I. Strakovsky, D. Epifanov, and L. Pentchev, J/ψ p scattering length from GlueX threshold measurements, *Phys. Rev. C* **101**, 042201 (2020).
 - [4] E. L. Feinberg, Hadron clusters and half-dressed particles in quantum field theory, *Usp. Fiz. Nauk* **132**, 255 (1980); *Sov. Phys. Usp.* **23**, 629 (1980).
 - [5] I. I. Strakovsky, W. J. Briscoe, L. Pentchev, and A. Schmidt, Threshold upsilon-meson photoproduction at the EIC and EicC, *Phys. Rev. D* **104**, 074028 (2021).
 - [6] Y. Z. Xu, S. Chen, Z. Q. Yao, D. Binosi, Z. F. Cui, and C. D. Roberts, Vector-meson production and vector meson dominance, *Eur. Phys. J. C* **81**, 895 (2021).
 - [7] D. Winney *et al.* (Joint Physics Analysis Center), Dynamics in near-threshold J/ψ photoproduction, *Phys. Rev. D* **108**, 054018 (2023).
 - [8] L. Tang, H.-Y. Xing, M. Ding, and C. D. Roberts, Exclusive photoproduction of light and heavy vector mesons: Thresholds to very high energies; L. Tang, H. Y. Xing, M. Ding, and C. D. Roberts, *Eur. Phys. J. C* **86**, 284 (2026).
 - [9] I. I. Strakovsky, L. Pentchev, and A. Titov, Comparative analysis of ωp , ϕp , and $J/\psi p$ scattering lengths from A2, CLAS, and GlueX threshold measurements, *Phys. Rev. C* **101**, 045201 (2020).
 - [10] S. Acharya *et al.* (ALICE Collaboration), Experimental evidence for an attractive $p - \phi$ interaction, *Phys. Rev. Lett.* **127**, 172301 (2021).
 - [11] Y. Lyu, T. Doi, T. Hatsuda, Y. Ikeda, J. Meng, K. Sasaki, and T. Sugiura, Attractive $N - \phi$ interaction and two-pion tail from lattice QCD near physical point, *Phys. Rev. D* **106**, 074507 (2022).
 - [12] L. M. Abreu, P. Gubler, K. P. Khemchandani, A. Martinez Torres, and A. Hosaka, A study of the ϕN correlation function, *Phys. Lett. B* **860**, 139175 (2025).
 - [13] A. Feijoo, M. Korwieser, and L. Fabbietti, Relevance of the coupled channels in the ϕp and $\rho^0 p$ correlation functions, *Phys. Rev. D* **111**, 014009 (2025).
 - [14] P. Gubler, M. Ichikawa, T. Song, and E. Bratkovskaya, Production and in-medium modification of ϕ mesons in proton-nucleus reactions from a transport approach, *Phys. Rev. C* **111**, 034908 (2025).
 - [15] R. Muto *et al.* (KEK-PS-E325 Collaboration), Evidence for in-medium modification of the ϕ meson at normal nuclear density, *Phys. Rev. Lett.* **98**, 042501 (2007).
 - [16] M. Ichikawa *et al.* (KEK-PS E325 Collaboration), Analysis of spectral modification of ϕ mesons at finite density using a transport approach in the 12 GeV pA reactions, *Prog. Theor. Exp. Phys.* **2025**, 093D01 (2025).
 - [17] J. R. Pybus, L. Ehinger, T. Kolar, B. Devkota, P. Sharp, B. Yu, M. M. Dalton, D. Dutta, H. Gao, O. Hen, *et al.*, First measurement of near-threshold and subthreshold J/ψ photoproduction off nuclei, *Phys. Rev. Lett.* **134**, 201903 (2025).
 - [18] J. R. Pybus, D. Dutta, H. Gao, O. Hen, I. Korover, T. Kolar, A. Schmidt, A. Somov, H. Szumila-Vance, D. Androić, *et al.*, Threshold J/ψ photoproduction as a probe of nuclear gluon structure, [arXiv:2510.22076](https://arxiv.org/abs/2510.22076).
 - [19] A. Hayashigaki, J/ψ nucleon scattering length and in-medium mass shift of J/ψ in QCD sum rule analysis, *Prog. Theor. Phys.* **101**, 923 (1999).
 - [20] F. Klingl, S. s. Kim, S. H. Lee, P. Morath, and W. Weise, J/ψ and η_c in the nuclear medium: QCD sum rule approach, *Phys. Rev. Lett.* **82**, 3396 (1999); **83**, 4224(E) (1999).
 - [21] S. s. Kim and S. H. Lee, QCD sum rules for J/ψ in the nuclear medium: Contributions from dimension-six operators, *Nucl. Phys. A* **679**, 517 (2001).
 - [22] S. Yeo, I. W. Park, and S. H. Lee, Long-range $N - J/\psi$ interaction from an operator product expansion perspective, *Phys. Rev. D* **112**, 094044 (2025).
 - [23] S. J. Brodsky, I. A. Schmidt, and G. F. de Teramond, Nuclear bound quarkonium, *Phys. Rev. Lett.* **64**, 1011 (1990).
 - [24] S. J. Brodsky and G. A. Miller, Is J/ψ - nucleon scattering dominated by the gluonic van der Waals interaction? *Phys. Lett. B* **412**, 125 (1997).

- [25] A. Sibirtsev and M. B. Voloshin, The interaction of slow J/ψ and ψ' with nucleons, *Phys. Rev. D* **71**, 076005 (2005).
- [26] G. Krein, A. W. Thomas, and K. Tsushima, J/Ψ mass shift in nuclear matter, *Phys. Lett. B* **697**, 136 (2011).
- [27] P. A. M. Guichon, A possible quark mechanism for the saturation of nuclear matter, *Phys. Lett. B* **200**, 235 (1988).
- [28] J. T. Castellà and G. Krein, Effective field theory for the nucleon-quarkonium interaction, *Phys. Rev. D* **98**, 014029 (2018).
- [29] S. Adhikari *et al.* (GlueX Collaboration), Measurement of the J/ψ photoproduction cross section over the full near-threshold kinematic region, *Phys. Rev. C* **108**, 025201 (2023).
- [30] M. L. Du, V. Baru, F. K. Guo, C. Hanhart, U. G. Meißner, A. Nefediev, and I. Strakovsky, Deciphering the mechanism of near-threshold J/ψ photoproduction, *Eur. Phys. J. C* **80**, 1053 (2020).
- [31] K. Yokokawa, S. Sasaki, T. Hatsuda, and A. Hayashigaki, First lattice study of low-energy charmonium-hadron interaction, *Phys. Rev. D* **74**, 034504 (2006).
- [32] U. Skerbis and S. Prelovsek, Nucleon- J/ψ and nucleon- η_c scattering in P_c pentaquark channels from LQCD, *Phys. Rev. D* **99**, 094505 (2019).
- [33] Y. Lyu, T. Doi, T. Hatsuda, and T. Sugiura, Nucleon-charmonium interactions from lattice QCD, *Phys. Lett. B* **860**, 139178 (2025).
- [34] S. Aoki *et al.* (HAL QCD Collaboration), Lattice QCD approach to nuclear physics, *Prog. Theor. Exp. Phys.* **2012**, 01A105 (2012).
- [35] J. Xu and F. Yuan, Gluonic probe for the short-range correlation in nucleus, *Phys. Lett. B* **801**, 135187 (2020).
- [36] Y. Hatta *et al.*, Sub-threshold J/ψ and Υ production in γA collisions, *Phys. Lett. B* **803**, 135321 (2020).
- [37] N. Rocco and A. Lovato (private communication).
- [38] J. R. Pybus, I. Korover, R. Weiss, A. Schmidt, N. Barnea, D. W. Higinbotham, E. Piasetzky, M. Strikman, L. B. Weinstein, and O. Hen, Generalized contact formalism analysis of the $^4\text{He}(e, e'pN)$ reaction, *Phys. Lett. B* **805**, 135429 (2020).
- [39] A. Schmidt *et al.* (CLAS Collaboration), Probing the core of the strong nuclear interaction, *Nature (London)* **578**, 540 (2020).
- [40] R. Weiss, I. Korover, E. Piasetzky, O. Hen, and N. Barnea, Energy and momentum dependence of nuclear short-range correlations—Spectral function, exclusive scattering experiments and the contact formalism, *Phys. Lett. B* **791**, 242 (2019).
- [41] S. Adhikari *et al.* (GlueX Collaboration), The GlueX beamline and detector, *Nucl. Instrum. Methods Phys. Res. Sect. A* **987**, 164807 (2021).
- [42] S. Navas *et al.* (Particle Data Group), Review of particle physics, *Phys. Rev. D* **110**, 030001 (2024).
- [43] I. I. Strakovsky *et al.* (A2 Collaboration at MAMI), Photoproduction of the ω meson on the proton near threshold, *Phys. Rev. C* **91**, 045207 (2015).
- [44] B. Z. Kopeliovich, I. Schmidt, and M. Siddikov, Suppression versus enhancement of heavy quarkonia in pA collisions, *Phys. Rev. C* **95**, 065203 (2017).
- [45] K. G. Boreskov and B. L. Ioffe, J/ψ meson photoproduction in the peripheral model, *Yad. Fiz.* **25**, 806 (1977); *Sov. J. Nucl. Phys.* **25**, 331 (1977).