Hard Photodisintegration of a Proton Pair in ^{3}He

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Abstract

Hard photodisintegration of the deuteron has been extensively studied in order to understand the dynamics of the transition from hadronic to quark-gluon descriptions of the strong interaction. In this work, we discuss the extension of this program to hard photodisintegration of a pp pair in the ^{3}He nucleus. Experimental confirmation of new features predicted here for the suggested reaction would advance our understanding of hard nuclear reactions. A main prediction, in contrast with low-energy observations, is that the pp breakup cross section is not much smaller than the one for pn break up. In some models, the energy-dependent oscillations observed for pp scattering are predicted to appear in the $\gamma\,^3\text{He} \to pp + n$ reaction. Such an observation would open up a completely new field in studies of color coherence phenomena in hard nuclear reactions. We also demonstrate that, in addition to the energy dependence, the measurement of the light-cone momentum distribution of the recoil neutron provides an independent test of the underlying dynamics of hard disintegration.

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1 Introduction

We define the hard photodisintegration of a nucleon pair as a process in which a high energy photon is absorbed by a nucleon pair leading to pair disintegration into two nucleons with transverse momenta greater than about 1 GeV/c. In this process the Mandelstam parameters s, the square of the total energy in the c.m. frame, and $t \approx u$, the four-momentum transfers from the photon to the nucleons, are large. With s above the resonance region, and $-t, -u \geq 1$ GeV^2, the kinematics are in the transition region, in which the short distance scales probed might make it appropriate to formulate the theory in terms of quark and gluon rather than hadronic degrees of freedom.

High-energy photodisintegration of a nucleon pair provides an efficient way to reach the hard regime. To obtain the same s in NN scattering, one needs an incident nucleon lab momentum about a factor of two larger than that of the photon. Photodisintegration of a pn pair, the deuteron, has now been extensively measured at high energies [1–8]. In this work, we investigate a related process, the hard photodisintegration of a pp pair, in the ^{3}He nucleus.

Deuteron photodisintegration cross sections are available for photon energies up to 5 GeV (but only 4 GeV at $\theta_{\text{c.m.}} = 90°$) [1–5] including, for energies up to 2.5 GeV, "complete" angular distributions [6,7] and recoil polarizations [8]. Figure 1 shows the measured energy dependence of $s^{11}\frac{d\sigma}{dt}$ for 90° c.m. The quark counting rule prediction [9–11], that this quantity becomes independent of energy, is observed clearly. High-energy deuteron photodisintegration cross sections at other angles are also in good agreement with scaling once $p_T \geq 1.3$ GeV/c.

The good agreement of the data with the quark counting rule prediction contrasts with observations [12,13] that pQCD underestimates cross sections for intermediate energy photo-reactions – examples include the deuteron elastic form factor [14], meson photoproduction [15] and real Compton scattering [16]. Thus, it seems that although the observation of the scaling in a given reaction indicates the onset of the quark-gluon degrees of freedom, the appropriate underlying physics has a mixture of perturbative and nonperturbative QCD aspects. A variety of theoretical models exist for deuteron photodisintegration which explicitly account for quark-gluon degrees of freedom in the reaction with an attempt to incorporate the nonperturbative QCD effects. [1] Hidden color degrees of freedom of the nucleus might play an important role in determining the normalization of hard-scattering nuclear amplitudes [14,18].

The reduced nuclear amplitude (RNA) formalism [19] attempts to incorporate

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[1] Note that to date there are no successful meson-baryon calculations for the high energy data. For a recent review, see [17].

some of the soft physics not described by pQCD by using experimentally determined nucleon form factors to describe the gluon exchanges within the nucleons. It neglects diagrams in which gluon exchanges between the nucleons lead to non-color singlet intermediate "nucleon" states, diagrams which might be important in pQCD calculations. Ideally, the RNA calculation should be normalized to the scaling behavior at asymptotic energies, where both yield the same result. In practice, the normalization must be to data, but at energies sufficiently large. An estimate of the necessary photon lab energy is obtained by requiring the momentum transfer to each nucleon to be above 1 GeV, which yields [20]

$$\frac{1}{2} M_d E_\gamma \left[1 - \sqrt{\frac{2E_\gamma}{M_d + 2E_\gamma}} |\cos\theta_{\text{c.m.}}| \right] \geq 1 \, \text{GeV}^2 \, . \tag{1}$$

The two-quark coupling (TQC) model [21] is based on the idea that the photon interacts with a pair of quarks being interchanged between the two nucleons. An analysis of this hard interaction then shows that the reaction has leading kinematic dependences proportional to nucleon form factors, taken to be the dipole form factor, to the fourth power times a phase space factor times a propagator, $(s - \Lambda^2)^{-1}$, where $\Lambda \approx 1$ GeV. There is no absolute normalization predicted by the model; instead it is normalized to the data at one point. The formula manages to largely reproduce the energy and angle dependences of hard deuteron photodisintegration, for $E_\gamma > 2$ GeV, once this one normalization parameter is fixed. With the propagator $(s - \Lambda^2)^{-1}$, instead of the factor p_T^{-2} in the similar RNA formula, the energy and angle dependences are softened, improving the agreement with the data.

The quark-gluon string model (QGS) [22] views the reaction as proceeding through three-quark exchange, with an arbitrary number of gluon exchanges. The cross section is evaluated using Regge theory techniques, and is sensitive to the Regge trajectory used. While Regge theory has been shown to be an efficient description of high-energy, small-t reactions, it has not typically been applied to the large momentum transfers being discussed in this article. The best fit of the data is obtained in a calculation that uses a nonlinear trajectory, as opposed to the more familiar linear trajectory.

The QCD hard rescattering model (HRM) [23] assumes that the photon is absorbed by a quark in one nucleon, followed by a high momentum transfer interaction with a quark of the other nucleon leading to the production of two nucleons with high relative momentum. Summing the relevant quark rescattering diagrams demonstrates that the nuclear scattering amplitude can be expressed as a convolution of the large angle pn scattering amplitude, the hard photon-quark interaction vertex and the low-momentum nuclear wave function. Since the pn hard scattering amplitude can be taken from large angle pn scattering data, the HRM model allows calculation of the absolute cross

section of the $\gamma d \rightarrow pn$ reactions using no adjustable parameters.
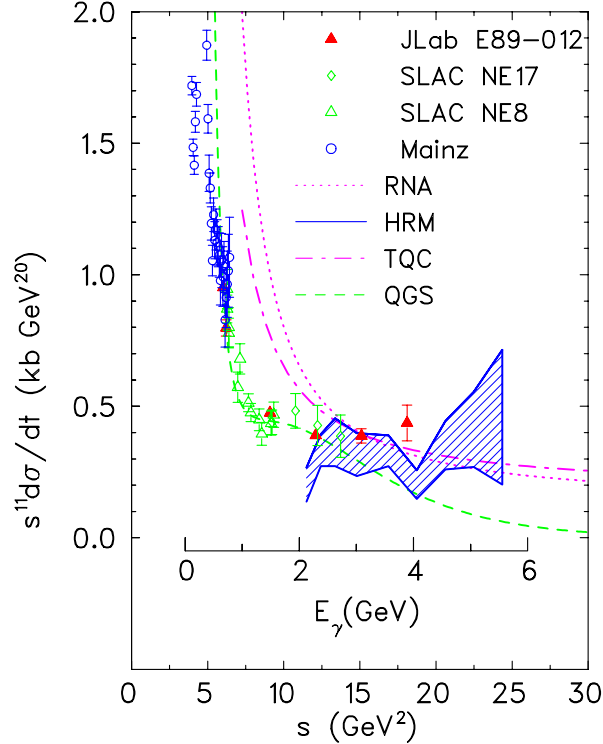

Fig. 1. *The energy dependence of $s^{11}\frac{d\sigma}{dt}$ for $90°$ c.m. photodisintegration of the deuteron. The HRM result is shown as a shaded band. The QGS calculation is the long dashed line. The RNA result is the dotted line, normalized to the data point at 3 GeV. The dot dash line shows the TQC formula, normalized to the 3 GeV data point. The experimental data is labeled by the laboratory and the experiment number.*

Figure 1 demonstrates the comparison of the calculations based on the models discussed above with the available data for deuteron disintegration at $\theta_{\text{c.m.}}$ = 90°. RNA, TQC and QGS calculations require normalization to the data. The HRM does not require such a normalization factor, however the poor accuracy of hard-scattering pn data restricts the overall accuracy of the calculation to the level of 20% – this is shown as an error band in the figure. Each of the models describes some part of the data, but no model describes all of the data. Therefore further studies to advance our understanding of hard photodisintegration reaction dynamics are needed. [2]

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[2] We also note a recent study of deuteron photodisintegration in a constituent quark model [24].

2 Breaking a pp Pair

In the present work we suggest a new venue for studying the dynamics of hard nuclear reactions. We propose to extend the studies of hard photodisintegration reactions from the pn system of the deuteron to the pp system. Namely, we propose the investigation of the reaction $\gamma\,^3\mathrm{He} \to pp + n$ in which we define the measurement conditions so that the neutron in $^3\mathrm{He}$ can be considered, at least approximately, as a static spectator, while two protons are produced at $90°$ in the c.m. frame of the γpp system. [3]

The *advantage* of this program is that although many of the considered models do not predict the absolute cross section, still they can predict the relative cross section of the hard $\gamma(pp) \to pp$ reaction as compared to the $\gamma(pn) \to pn$ reaction. The pn data from the deuteron already exist, and will be used in this article to provide an overall normalization so that absolute $\gamma^3\mathrm{He}$ cross sections, rather than just the s dependence of the γpp cross section, can be predicted. The nucleus $^3\mathrm{He}$ has been used successfully to observe the absorption reaction $\pi^- pp \to np$[25] at much lower energies than appear here. Thus the use of $^3\mathrm{He}$ as a source of a pp target has a successful history. [4]

RNA model:. In the RNA approach [19], the differential cross section is proportional to the squares of form factors, one for each nucleon, evaluated at the momentum transfer for that nucleon in the weak-binding limit. The remainder, the "reduced" cross section, is assumed to be independent of the substructure of the nucleons. This gives

$$\frac{d\sigma}{dt} \simeq F_{N_1}^2(-t_1) F_{N_2}^2(-t_2) \left.\frac{d\sigma}{dt}\right|_{\text{reduced}} , \qquad (2)$$

for the process $\gamma(N_1 N_2) \to N_1 N_2$, with t_i the square of the four-momentum transfer to nucleon N_i. The ratio of cross sections for $\gamma(pp) \to pp$ and $\gamma(pn) \to pn$ is then given by the ratio of nucleon form factors squared, $F_p^2(-t_N)/F_n^2(-t_N)$ $(t_N \approx \frac{t}{2})$, times the ratio of the reduced cross sections. The ratio of form factors can be obtained from data for G_M and G_E [26]; we use the leading twist form factor F_1 for each nucleon, for which the ratio F_{1p}/F_{1n} is approximately -2. The ratio of reduced cross sections is taken to be 4, the square of the charge ratio. These estimations yield $\gamma(pp) \to pp$ cross section approximately 16 times

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[3] This can be done experimentally by selecting events in which the reconstructed missing neutron momentum is less than 100 MeV/c.

[4] Measurements of the pn break up in $^3\mathrm{He}$ are also possible, and would remove some uncertainty in the nuclear physics aspects of the calculation. For example, sensitivity to the high momentum component of the nuclear wave function would be reduced.

larger than the RNA prediction for $\gamma d \to pn$ cross section. The absolute normalization for the $\sigma_{RNA}(\gamma(pp) \to pp)$ can be obtained from comparison of $\sigma_{RNA}(\gamma d \to pn)$ with available data.

To estimate the cross section of $\gamma\,^3\mathrm{He} \to pp + n$, we shall multiply the above estimates of the cross section of the disintegration of the pp pair, $\sigma(\gamma(pp) \to pp)$, by a factor that combines the relative probability of a pp pair in the $^3\mathrm{He}$ wave function with a correction from the integration over the slow neutron's momentum. Note that no new normalization with the experimental data is needed, since we use the normalization factors obtained from the comparison of the $\gamma d \to pn$ cross sections with the data.

To estimate this factor we observe that in RNA the amplitude results from the pp wave function at small separations. Therefore, as a simple estimate we use the parameter $a_2(A)$ which characterizes the probability of two-nucleon correlations in the nuclear wave function – $a_2(A = 3) \approx 2$ [27,28] – multiplied by $1/3$, which accounts for the relative abundance of pp pairs in the two-nucleon short-range correlation. The integration of the neutron momentum up to $100\,\mathrm{MeV/c}$ leads to an additional factor of $1/2$. Thus, these estimations yield an overall factor of $\approx 1/3$ by which $\sigma(\gamma(pp) \to pp)$ should be scaled in order for it to correspond to the $\gamma\,^3\mathrm{He} \to pp + n$ cross section. The overall factor of $1/3$ is a conservative estimate; the inclusion of three-nucleon correlations in $^3\mathrm{He}$ would increase this factor. Thus, in the RNA approach, $d\sigma(\gamma\,^3\mathrm{He} \to pp + n)$ / $d\sigma(\gamma d \to pn) = 16/3$.

TQC model: Estimates for the $\sigma(\gamma(pp) \to pp)$ to $\sigma(\gamma(pn) \to pn)$ cross-section ratio in the TQC model are underway [21]. We expect the same $^3\mathrm{He}$ correction factor of $1/3$ that we apply to the RNA model.

QGS model: In the QGS model, since the break-up cross section is defined by the effective Regge trajectory, we would expect the Regge trajectories to be similar, so the $\sigma(\gamma(pn) \to pn)$ and $\sigma(\gamma(pp) \to pp)$ cross sections are of similar magnitude [31]. We assume that this is multiplied by the same $^3\mathrm{He}$ correction factor of $1/3$ that we apply to the RNA model.

HRM model: The differential cross section within the HRM model is [29]:

$$\frac{d\sigma}{dt\,d^3p_n} = \left(\frac{14}{15}\right)^2 \frac{8\pi^4 \alpha_{EM}}{s - M_{^3\mathrm{He}}^2} \frac{d\sigma^{pp}(s_{pp}, t_N)}{dt} \times$$

$$\frac{1}{2} \left| \sum_{spins} \int \Psi^{^3\mathrm{He}}(p_1, p_2, p_n) \sqrt{M_N} \frac{d^2 p_{2T}}{(2\pi)^2} \right|^2 , \tag{3}$$

where $s = (P_\gamma + P_{^3\mathrm{He}})^2$, $t = (P_p - P_\gamma)$ $s_{pp} = (P_\gamma + P_{^3\mathrm{He}} - P_n)^2$, and $t_N \approx \frac{1}{2}t$. The pp elastic cross section is $d\sigma^{pp}/dt$. The momentum of the recoil neutron is p_n. In the argument of the ^{3}He nuclear wave function, $\vec{p}_1 = -\vec{p}_2 - \vec{p}_n$ and $p_{1z} \approx p_{2z} \approx -\frac{p_{nz}}{2}$ near $90°$. The pp scattering cross section was obtained from a fit to the existing pp data [30]. The overall factor $(\frac{14}{15})$ is obtained based on the quark-interchange model of hard NN scattering utilizing the $SU(6)$ wave function of nucleons. This introduces an uncertainty in the estimates of the cross section at the level of $10 - 20\%$. The ^{3}He wave function is that of Ref.[27], obtained by solving the Faddeev equation with a realistic NN potential. The predicted cross section is made singly differential by integrating over neutron momentum, up to 100 MeV/c.
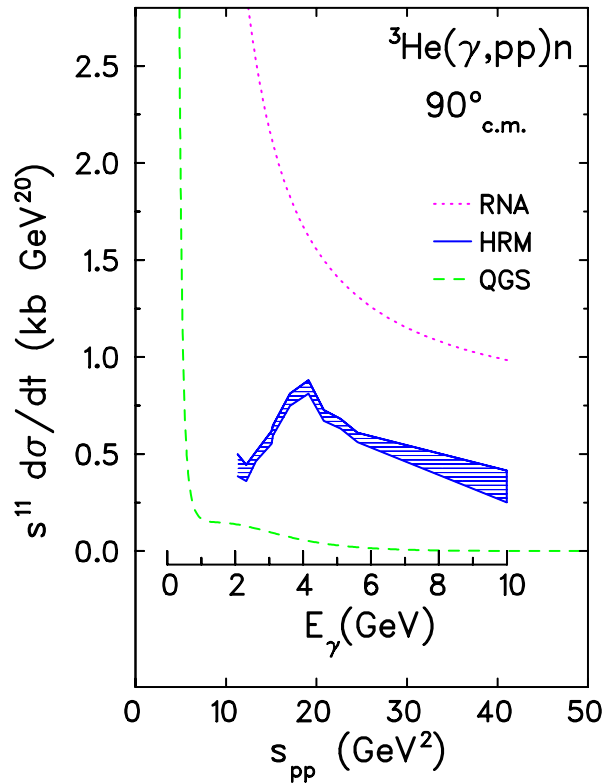

Fig. 2. *Predictions for γ $^3He \to pp+n$ at $\theta_{c.m.} = 90°$. The line types are the same as for Figure 1. The horizontal scale is s for the γpp system; the photon energy scale is also shown.*

Figure 2 shows predictions based on the models considered above for $90°$ two-body break-up kinematics. The γ ^{3}He$\to pp + n$ cross section has been integrated over the neutron momentum up to 100 MeV/c.

These predictions ignore nuclear corrections due to the soft rescattering of the nucleons in the final state. We argue here that they are only small corrections in the kinematics discussed. For energetic protons rescattering on the slow spectator neutron, the mean squared value of the momentum transferred during the soft rescattering is $200 - 250$ MeV^2/c^2. Restricting the neutron

momenta to ≤ 100 MeV/c significantly reduces the soft-rescattering. This effect can be reliably calculated within the eikonal approximation. Preliminary estimates yield $5 - 10$ % corrections in the range of $40 - 90°$ c.m. angles.

Another correction is due to primary reactions on the pn pair, with subsequent soft $pn \rightarrow np$ charge-exchange rescattering of the energetic neutron with the slow spectator proton. In the energy range of this study, the charge-exchange soft rescattering is suppressed by a factor of $1/s$ as compared to the non-charge-exchange soft rescattering, and results in only a $1 - 2$ % correction. This estimate takes into account the larger probability of pn than pp pairs in ^{3}He.

It is important to note that the models considered above predict a sizable cross section for the break up of the pp pair, larger than that for the pn pair, for two of the three models shown. This prediction is rather striking since at low energies it is well known [32] that photodisintegration of the pp system is suppressed as compared to pn.

Within a mesonic description of the interaction, the $90°$ break up of a pp pair will be significantly suppressed as compared to pn since for the pp pair the exchanged mesons are neutral and do not couple to the photon. In a quark-gluon picture, the exchanged particles are quarks, and the suppression will be absent. As a result an experimental observation of a larger cross section for the pp break-up reaction will be an indication of the dominance of quark-gluon dynamics in the reaction.

3   Oscillations with Energy

The possibility that the final-state high-p_T proton pair is formed due to the hard interaction of the two outgoing protons might produce energy oscillations, as seen in the pp cross section. The quark counting rule predicts $\frac{d\sigma}{dt} \sim s^{-10}$ for high-energy, large-angle $pp \rightarrow pp$ elastic scattering. The pp elastic data are globally consistent over a large number of decades with the power law [30,33]. However, it was already noted in 1974 [34] that a more detailed examination of the data indicated significant deviations from scaling. The deviations are known as "oscillations" and were interpreted as resulting from interference between the pQCD amplitude and an additional nonperturbative component.

Ralston and Pire [35] suggested that the interference is between a small size configuration pQCD scattering and an independent scattering of **all** valence quarks discussed by Landshoff [36], governed by the so-called chromo-Coulomb phase. Brodsky and deTeramond [37] suggested that the oscillations are due to the presence of two broad resonances (or threshold enhancements) which

interfere with the standard pQCD amplitude. For a review of wide-angle processes, see [38].

Whatever is the correct interpretation of the oscillation, if the hard two-body break-up reaction proceeds through the hard interaction of two protons, similar oscillations could be seen in the $\gamma\,^3\text{He} \to pp+n$ cross section, normalized by a factor of s^{11}, as a function of the incident photon energy, in the same region of s where pp oscillations are observed. Figure 3 compares the energy dependence of pp cross section with that of $\gamma\,^3\text{He} \to pp+n$ cross section at 90^0 $\gamma - (pp)$ center of mass scattering ($-\frac{t}{s_{pp}} \approx \frac{1}{2}$), calculated within the HRM model, which assumes the dominance of the contribution of hard pp rescattering in the photodisintegration reaction. Note that according to Eq.(3) the pp cross section that enters in the $\gamma +^3\text{He} \to pp+n$ cross section is defined at s_{pp} and $t_N \approx \frac{t}{2}$. As a result, in Figure 3 one compares with pp cross sections defined at $\approx 60^0$ ($-\frac{t_N}{s} \approx \frac{1}{4}$) [30]. In contrast to the situation displayed in Figure 3, the precision of the pn and the $\gamma d \to pn$ data is insufficient to show if oscillations are indeed present for those reactions.

Brodsky and de Teramond [37] suggested that the oscillations and also the associated large values of the A_{NN} spin correlations observed in pp scattering [39] are due to the presence of broad resonances associated with the onset of the strangeness and charm thresholds in the intermediate state of the $pp \to pp$ amplitude. If this is correct, then one would also expect to see similarly strong spin-spin correlations in the emerging proton pair at the corresponding invariant mass. The observation of the large cross sections predicted here then leads to important related polarization measurements. One also would expect the production of doubly-charged final states with baryon number $B = 2$ containing charmed hadrons in $\gamma He^3 \to nX$ at missing mass $m_X > 5$ GeV. The threshold for open charm production is $\sqrt{s} > 6$ GeV, $E_{lab}^\gamma = \frac{s - M_{He3}^2}{2M_{He3}} > 4.5$ GeV.

4   The α_n Distribution

The recoil neutron in $\gamma\,^3\text{He} \to pp+n$ gives an additional degree of freedom for checking the underlying mechanism of hard pp pair production. The observable which is best suited for this purpose is the light-cone momentum distribution of the recoil neutron, defined as a function of $\alpha_n = \frac{E_n - p_n^z}{m_{3He}/3}$. We use here light-cone variables in which the α's are defined as follows:

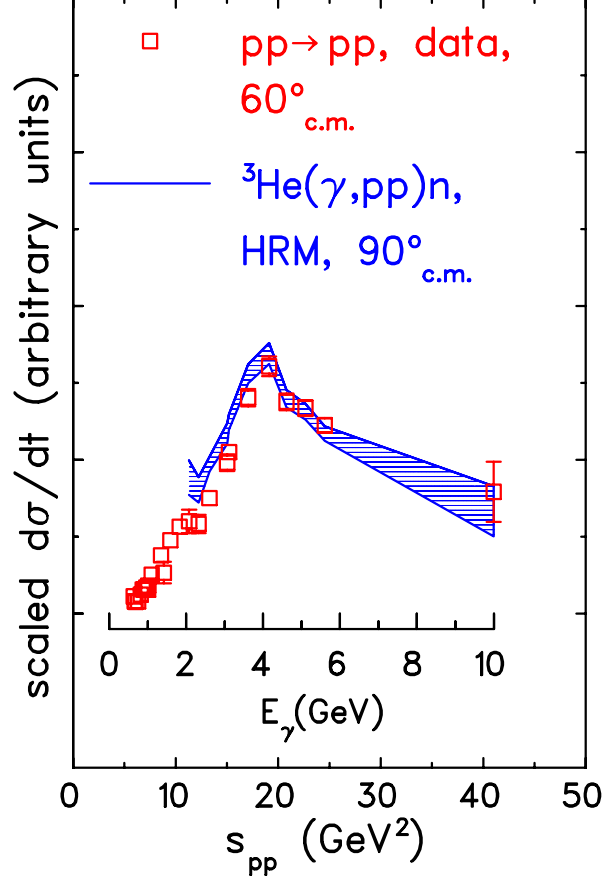$$\alpha = A\frac{E^N - p_z^N}{E^A - p_z^A} \approx \frac{E_N - p_z^N}{m_N},\tag{4}$$

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Fig. 3. *Energy dependence of the $\gamma\,{}^3He \to pp + n$ cross section predictions multiplied by s^{11}, compared with the energy dependence of the $pp \to pp$ cross section multiplied by s^{10} and rescaled by an overall constant, to emphasize the similarity in the energy dependences. The horizontal scale is s for the γpp and pp systems; the photon energy scale is also shown. The different angles for the two reactions are chosen to match the momentum transfers, as discussed in the text. The shaded band is the HRM result, which is based on the pp elastic data.*

where the z direction is chosen in the direction of the incident photon beam.

With the above definitions, α for the incident photon is exactly zero, while α for the ^{3}He target is 3. Conservation of α allows α_n to be determined from the measurement of the light-cone fractions of the protons:

$$\alpha_\gamma + \alpha_{{}^3\text{He}} = 0 + 3 = \alpha_{p_1} + \alpha_{p_2} + \alpha_n. \tag{5}$$

Therefore:

$$\alpha_n = 3 - \alpha_{p_1} - \alpha_{p_2}. \tag{6}$$

An important feature of high-energy small-angle final-state rescattering is that it does not change the light-cone fractions of the fast protons – see e.g. [40].

As a result, the experimentally determined α_n coincides with the value of α_n in the initial state and unambiguously measures the light-cone fraction of the two-proton subsystem in the ^{3}He wave function. Furthermore, in the ^{3}He wave function the c.m. momentum distribution of the NN pair depends on the relative momentum of the nucleons in the pair, so one can probe the magnitude of the momentum in the pp pair involved in the hard disintegration.

To illustrate the sensitivity of the α_n distribution to the mechanism of the high-p_T disintegration of a pp pair, we compare in Fig. 4 the α_n dependence of the differential cross section $\frac{d\sigma}{dt d^2 p_T d\alpha_n/\alpha_n}$ calculated in the framework of the RNA and HRM models. The calculations are done for a scattering of two protons in the final state at fixed initial photon energy $E_\gamma = 4$ GeV and $\theta_{c.m.} = 90°$. Within the RNA approximation (solid line), the α_n distribution is calculated for configurations in which the relative transverse momentum of the pp pair is equal to the transverse momentum of the final protons $p_T \sim GeV/c$. The estimate within the HRM model is done using Eq.(3). In the latter case, the internal momenta in the pp pair contributing to the cross section are ≤ 300 MeV/c. The results presented in Fig. 4 provide substantially different predictions for the α_n distribution. Qualitatively, the much broader distribution of α_n in the RNA model is due to selection of large momenta of protons in the ^3He wave function, which leads to a broader distribution of neutron momenta.

Another feature of the α_n distribution is that the strong s dependence, $\sim s^{-11}$, of the hard disintegration cross section will tend to suppress (increase) the contribution from those values of α_n which increase (decrease) the effective $s_{pp} \approx 2E_\gamma M_d \frac{3-\alpha_n}{2} + M_d^2$ involved in the $\gamma + pp$ subprocess. As a result one expects the α distribution to be asymmetric about $\alpha_n = 1$. The extent of the asymmetry depends strongly on the exponent in the s dependence of hard disintegration cross section. To illustrate this phenomenon, in Fig. 4 we compare the α_n distributions within the RNA and HRM models, rescaled in one case by s_{pp}^{11} (bold solid and dashed lines) and in other case by s_d^{11} ($s_d = 2E_\gamma M_d + M_d^2$) (thin lines). This comparison demonstrates that the measurement of the α_n asymmetry will give us an additional tool in verifying the energy (s) dependence of the disintegration cross section.

5 Experiments

Data for ^{3}He photodisintegration have already been obtained by the CLAS collaboration, up to energies of 1.5 GeV, but no results are available as yet [41]. As the onset of scaling in deuteron photodisintegration is just above 1 GeV, it will be interesting to see if there is a similar onset for ^{3}He, and, if so, what is the ratio of ^{3}He to deuteron photodisintegration cross sections.
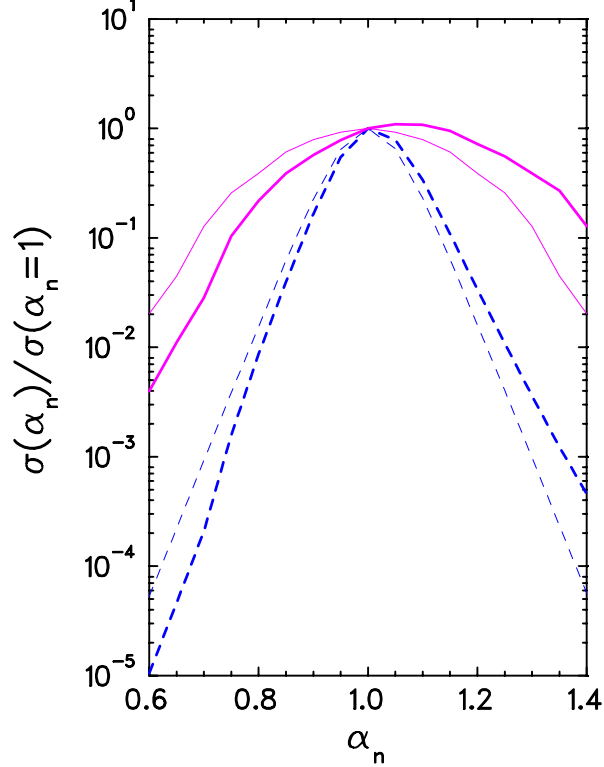
Fig. 4. *The α_n dependence of the $\gamma\,^3He \to pp+n$ cross section calculated within RNA (bold solid line) and HRM (bold dashed line) models. $\sigma(\alpha_n)$ corresponds to the differential cross section scaled by s_{pp}^{11}. Thin solid and dashed lines correspond to the same calculations scaled by s_d^{11}. All calculations are normalized to one at $\alpha_n = 1$.*

Studying the $\gamma\,^3\mathrm{He} \to pp+n$ reaction to significantly higher energies requires measuring a small cross section reaction that generates two high transverse momentum protons. It is only possible in Hall A of the Thomas Jefferson National Accelerator Facility using Bremsstrahlung photons, produced by the electron beam passing through a photon radiator. The maximum energy of the Bremsstrahlung beam is essentially equal to the incident electron kinetic energy. The two outgoing protons, each with about half the incident beam energy, can be detected in coincidence with the two existing high resolution spectrometers (HRS). The energy dependence of the differential cross section for $\theta_{\mathrm{c.m.}} \approx 90°$ can be measured up to $E_\gamma \approx 5\,\mathrm{GeV}$ with the existing equipment, if the cross sections are as large as predicted here. In contrast, it has only been possible to measure deuteron photodisintegration up to 4 GeV at $\theta_{\mathrm{c.m.}} \approx 90°$, due to the rapid decrease of its cross section. If the large predicted cross sections are verified, polarization measurements will be possible to ≈ 4 GeV. A measurement of A_{NN} of the two outgoing protons would be particularly interesting in view of the observed dramatic spin effects in elastic $pp \to pp$, and will require a dedicated measurement with polarimeters in both spectrometers. With the proposed 12 GeV upgrade, including the proposed higher momentum spectrometer for Hall A, it would be possible to extend the measurements up to about 7 GeV in a matter of weeks, limited by the maximum momentum in

the HRS spectrometer.

6 Summary and Outlook

A unique signature of quark-gluon degrees of freedom in hard photodisintegration reactions is the prediction of a sizable cross section, larger for pp than for pn pairs. If the hard photodisintegration process can be factorized so that it depends on the NN scattering amplitude, then the oscillations apparent in pp scattering could be reflected in the measured cross sections. Comparing the predictions presented here to data could put our understanding of deuteron photodisintegration on a firmer basis, and would be a significant step toward a general understanding of hard nuclear photo-reactions at intermediate energies.

The observation of oscillations with energy would give us a new tool in studies of color coherence phenomena in hard nuclear reactions. The investigation of A dependence of the reaction extended to nuclei with $A > 3$ would allow a study of the nature of these oscillations. For instance, if the oscillations are the result of the interplay of soft and hard scattering amplitudes, one expects more absorption for the soft part of the total amplitude – a phenomenon known as a nuclear filtering.

We also observe that determining the shape and the asymmetry of the α_n distribution in the hard $\gamma\,^3He \to pp + n$ reaction gives an additional experimental tool in studying the dynamics of the high energy disintegration of a NN pair.

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