Update to Proposal 03-005

Hard Photodisintegration of a Proton Pair

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A Hall A collaboration proposal

ABSTRACT

This is an update of Jefferson Lab Hall A proposal PR-03-005. We propose to measure the $\gamma\ ^3\mathrm{He} \rightarrow pp{+}n$ reaction. Developments since PAC 23 make this proposed comparison of pp to pn hard photodisintegration more compelling.

1 Background

Proposal 03-005, "*Hard Photodisintegration of a Proton Pair*", is, as indicated by the title, aimed at measuring the *hard* photodisintegration of a pp pair. The new γpp measurements, on a ^{3}He target, will be compared to γpn measurements, using existing $\gamma d \rightarrow pn$ data. The comparison of these two sets of data is a sensitive test of the underlying reaction mechanism. The proposal was favorably reviewed, but not approved by PAC23. We quote from the PAC 23 report:

- *Two proposals (P03-005 and P-03-007) were judged worthy of approval by the PAC but were ultimately recommended for deferral. They could not be fit into the beam time allocation for Hall A.*
- *The PAC would like to see this experiment performed, but due to limitations in the available beam time, the proposal cannot be accepted at this time.* **Recommendation:** *Defer*

There have been several developments in hard photodisintegration of nucleon pairs since PAC 23. We believe that these developments make this experiment more compelling. In the following sections, we will discuss the new developments, and present a new time request. For brevity, we omit much of the discussion contained in the original proposal; the original proposal is attached to this document for ease of reference.

2 Physics Motivation

This proposal is intended to deepen our understanding of hard photodisintegration. The proposed data would be the first for hard pp photodisintegration. In the original proposal we demonstrated how the validity of the impulse approximation, in which the photodisintegration amplitude factorizes and can be related to the NN elastic scattering amplitude, can be tested. The comparison of the energy dependence of the data with the high-energy elastic pp scattering data will be made; in these pp data, there are significant oscillations around the scaling behavior that point to an interference between long- and short-range mechanisms. In some models, correlated energy oscillations are also predicted in the hard photodisintegration of the pp pair.

By comparing with existing pn photodisintegration data, the reaction dynamics of hard two-nucleon photodisintegration will be studied. Although many of the considered models do not predict the absolute cross section, still they can predict the ratio of cross sections of the hard $\gamma(pp) \to pp$ reaction to the hard $\gamma(pn) \to pn$ reaction. The pn data from the deuteron already exist, and can be used to provide an overall normalization so that absolute γ^3He cross sections, rather than just the s-dependence of the γpp cross section, can be predicted.

2.1 Recent Developments

There are several recent developments that highlight the strong theoretical and experimental interest in photodisintegration. We argue that each of these developments increases the interest in this experiment. These developments include:

- Theoretical interest in $\gamma d \to pn$ remains intense. A new calculation [2] has appeared that considers photodisintegration as arising from a quark interchange mechanism (QIM); the calculation uses a Constituent Quark Model (CQM). In the QIM, the photon couples to one quark which is exchanged for a quark from the second nucleon to share the momentum. The authors state that their work is not yet ready for serious confrontation with data, that it is intended to investigate theoretical issues. The parameters of the model are based on a fit to NN elastic scattering data. Nevertheless, Figure 1 indicates that at least for $\theta_{\mathrm{c.m.}} = 90°$ the model can generate significant cross sections, about as large as the data. Also shown are previous calculations. The Reduced Nuclear Amplitudes (RNA) [3] and Two Quark Coupling (TQC) [4] models are alternative evaluations of QIM, that absorb soft physics into nucleon form factors. The Quark Gluon String Model [5] is a Regge theory evaluation of three-quark exchange diagrams. The Hard Rescattering Model (HRM) uses pQCD to relate photodisintegration to elastic pn scattering, assuming QIM dominance of both reactions. Existing models are also being extended [7, 8] with calculations of polarization observables in $\gamma d \to pn$.

- As of this writing, a theoretical paper [9] is being prepared on $\gamma\ {}^3\mathrm{He} \to pp+n$. This is a joint work of S.J. Brodsky, L. Frankfurt, R. Gilman, J.R. Hiller, G.A. Miller,

E. Piasetzky, M. Sargsian, and M. Strikman; it includes theorists who have worked on two of the five nonperturbative quark models that have been applied to $\gamma d \to pn$. The motivation for the article is the recognition that a comparison of $\gamma\ {}^3\mathrm{He} \to pp + n$ to $\gamma d \to pn$ can put our understanding of the underlying physics of hard photodisintegration on a firmer basis; the article includes predictions in the RNA and HRM models, and an estimate for the QGS model. Figure 2, taken from [9], shows the predicted $\gamma\ {}^3\mathrm{He} \to pp + n$ excitation function. Anatoly Radyushkin is also re-evaluating his analysis of hard pp photodisintegration. Very preliminary results suggest that the pp photodisintegration is related to the forward – backward asymmetry of the pn photodisintegration angular distribution, which is about 30 %, leading to a small result at $\theta_{\mathrm{c.m.}} = 90°$. Because the results are preliminary, we do not show a curve in Figure 2.

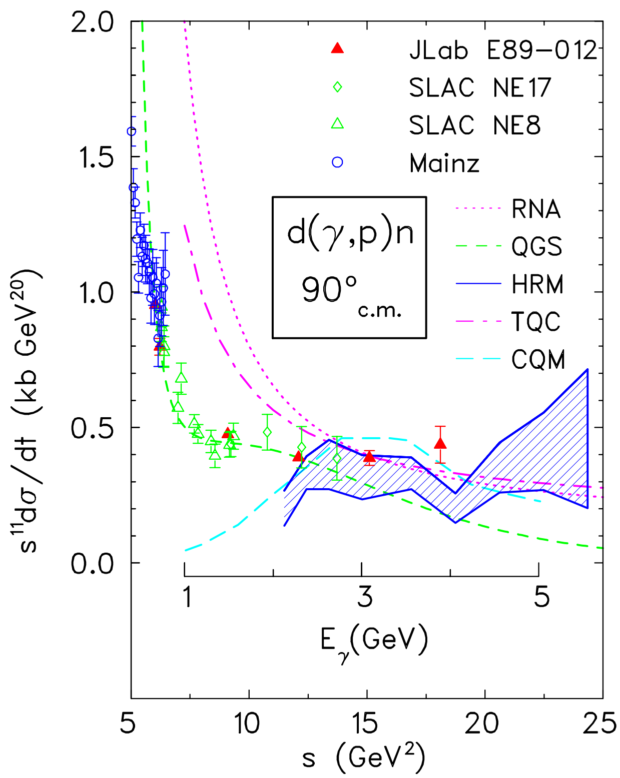

Figure 1: The predicted $\theta_{\mathrm{cm}} = 90°$ excitation function for $\gamma d \to pn$. All existing quark model calculations are shown. See text for details. Data are from [1].

(Figure 3 shows the angular distribution prediction in the HRM model. We reproduce it here as there were mistakes in the figure generated for proposal 03-005, though not in the figure shown to the PAC at the defense.) As compared to the estimates presented to the PAC in PR-03-005, the RNA predictions has become larger, with a more detailed evaluation; $R = d\sigma/d\Omega(\gamma\ {}^3\mathrm{He} \to pp + n)\ /\ d\sigma/d\Omega(\gamma d \to pn)$ ≈ 4. The ratio arises from factors in the cross section of 4 from the reduced γpp

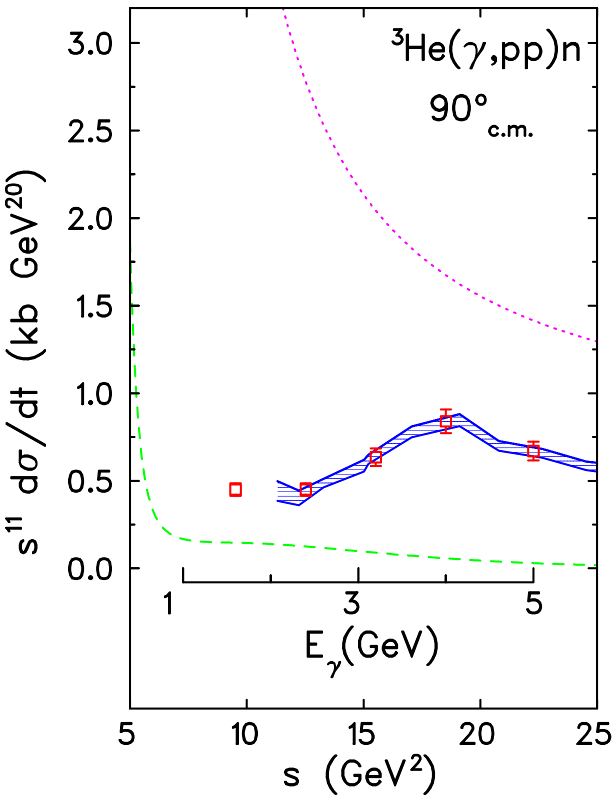

Figure 2: The $\theta_{\rm cm} = 90°$ excitation function for $\gamma\ ^3$He $\rightarrow pp + n$. The absolute normalizations of all the calculations shown are either fixed from the theory or fixed from the $\gamma d \rightarrow pn$ data. This figure is taken from [9]. The points shown are the expected results for this experiment, if the cross sections agree with the HRM. The calculations are indicated by the same curve types shown in Fig. 1.

vs. γpn cross sections, 4 from the larger p vs. n form factor, and 1/3 from putting the pp pair in the ^{3}He nucleus. The HRM prediction has decreased, with $R \approx 2$, but shows stronger oscillations. The oscillations were suppressed by a missing flux factor in the calculation shown in the original proposal. The QGS estimate, not by the QGS authors, but instead from [9], is $R \approx 1/3$. This number arises from the Regge trajectories being similar for the two reactions, but the ^{3}He nuclear corrections being the same as in the RNA model. The numbers for R mentioned above should be contrasted with the low energy data, for which $\gamma\ ^3$He $\rightarrow pp + n$ is about an order of magnitude smaller than $\gamma d \rightarrow pn$.

- Of four high-energy polarization observables in $\gamma d \rightarrow pn$, two, p_y and $C_{z'}$, were consistent with vanishing [10], in agreement with hadron helicity conservation (HHC) limits [11]. Measurements of the Σ asymmetry from Yerevan [12] show a trend of the data to approach 1, with large uncertainties, as the energy increases to 1.5 GeV; the HHC limit is -1 [13]. Measurements of $C_{x'}$ from Jefferson Lab [10] are, in the region $E_\gamma = 1.5 - 2.5$ GeV, consistently about 0.1, with uncertainties about 0.1, so that each point is about 1σ from 0. The interpretation of the Yerevan data has now been called into question [8]. The limit of -1 is appropriate for an isoscalar photon coupling, but if an isovector photon coupling dominates, the phase relations between the amplitudes change, and the limit becomes +1! Thus, at this point, it appears that the only thing one can say is that, in the limit of HHC, Σ will become a constant in the range -1 to 1, and that the constant will indicate the relative importance of isoscalar and isovector couplings. In summary, the experimental evidence in $\gamma d \to pn$ against HHC appears to be thin.

We do not intend to suggest by these comments that pQCD is a likely explanation for the $\gamma d \to pn$ data; the problems of consistently generating large enough cross sections in pQCD are well known. What we are suggesting is that the otherwise good agreement between pQCD expectations and the $\gamma d \to pn$ data at the largest momentum transfers makes it more plausible that the important physics can be represented in a model combining pQCD with some soft physics, such as the models discussed here.

- Experimental interest in NN photodisintegration remains large. Several new measurements of the $\gamma d \to pn$ reaction are in progress. Analysis is nearly final for Hall B cross section measurements [14]. Hall A experiment E00-007 [15] measured an angular distribution for recoil proton polarization in $\gamma d \to pn$ at $E_\gamma \approx 2$ GeV in October, 2002; data analysis is underway. Cross sections and the Σ asymmetry were measured at SPring-8 [16]; more data will be taken in the next few months. Energies were from 1.5 – 2.4 GeV, and lab angles were from $0^\circ - 23^\circ$, corresponding to a maximum c.m. angle of about $40^\circ - 45^\circ$, depending on the energy. Data analysis has started. A program of cross sections, Σ asymmetry measurements, and double polarization observables is also starting at LEGS, for energies up to 470 MeV [17]. There is also ongoing interest in Σ asymmetry measurements in $\gamma d \to pn$ in Hall B [18]; such measurements are needed to access the large angle, hard scattering regime, which is not now reached at SPring-8.

- Analysis of Hall B measurements of $\gamma\ {}^3\mathrm{He} \to pp + n$ is now underway [19]. Data were taken for $\gamma {}^3\mathrm{He}$ up to 1.5 GeV, but have not yet been analyzed for hard photodisintegration with two high-energy outgoing protons. It is expected that there will be sufficient counts to analyze the hard two-proton channel to energies above 1 GeV, but the maximum energy for the analysis depends on the cross section. For an energy exceeding 1 GeV, reaching into the region in which the $\gamma d \to pn$ data start to exhibit scaling, one would naively expect[1] that the $\gamma\ {}^3\mathrm{He} \to pp + n$ channel would show the beginnings of an s^{-11} fall off, similar to the $\gamma d \to pn$ data,

[1] Most of the theories developed for $\gamma d \to pn$ are not valid in the energy range 1 – 2 GeV; while the QGS calculation is valid in this energy range, we only have an estimate of its prediction from [9], not a firm prediction from its developers.

or perhaps a change in the ratio of $\gamma\ ^3\text{He} \to pp + n$ to $\gamma d \to pn$ cross sections, from the small ratio known at low energies to the larger ratios predicted by the nonperturbative quark models presented here. Our view is that these Hall B data only begin to reach into the scaling region, and make possible the comparison of hard pp to hard pn photodisintegration over a much wider energy range. This should allow a firmer interpretation of the measurements proposed herein. The lack of results as yet should not defer the present proposal, as the cross sections for E_γ up to 1.5 GeV do not lead to a unique determination of the higher energy cross sections proposed here.

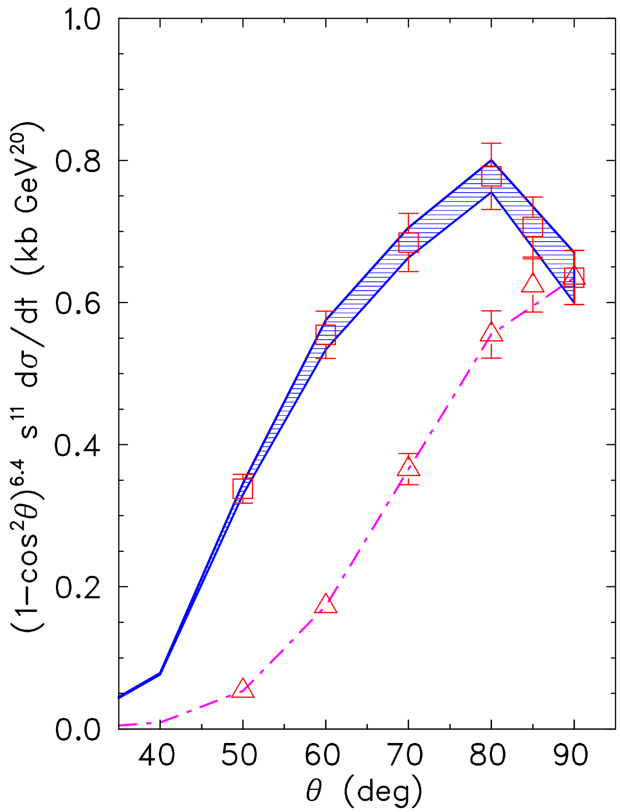

Figure 3: The predicted $\gamma\ ^3\text{He} \to pp + n$ angular distribution at 3.2 GeV. The HRM model is shown as the colored region, while the dot-dashed line represents the angular dependence of the $\gamma d \to pn$ data, normalized to the $\theta_{\text{c.m.}} = 90°$ HRM point.

In summary, there remains intense interest in understanding hard deuteron photodisintegration, with new models being developed, new polarization calculations available, and several experimental programs underway. The present experiment is unique in its focus on using $\gamma\ ^3\text{He} \to pp + n$ to allow a comparison of hard pp to pn photodisintegration. The different predictions of the various models show that the comparison will illuminate the underlying physics.

Table 1: *Kinematics and estimated cross sections and rates for the $\theta_{\text{c.m.}}$ = 90° excitation function.*

measurement	$E_e \approx E_\gamma$ [GeV]	$\theta_{\text{c.m.}}$ [deg]	θ_p [deg]	P_p [GeV/c]	$\frac{d\sigma}{d\Omega}$ [pb/Sr]	rate [cts/Hr]
0	1.6	90	57.26	1.43	4700	5600
1	2.4	90	51.34	1.92	400	425
2	3.2	90	47.27	2.36	60	65
3	4.0	90	44.08	2.78	12	14
4	5.0	90	40.90	3.31	2.	2.

3 Experimental Details

3.1 Proposed Measurements

We focus on this proposal on using the two HRS spectrometers in Hall A to detect in coincidence two high-momentum outgoing protons, from $\gamma\ ^3\text{He} \to pp + n$. In the original proposal, we requested time for a cross section excitation function at $\theta_{\text{c.m.}} = 90°$ and an angular distribution at 3.2 GeV. In this update we again propose these measurements, with some modification of the details. The new request is for one day at 1.6 GeV beam energy, to nearly overlap the Hall B measurements and to measure the recoil proton polarization. In formulating the original proposal, we had expected that the polarization measurements might become attractive after measuring the cross sections. Our viewpoint on this issue has changed, due to the theoretical developments concerning the Σ asymmetry in $\gamma d \to pn$, due to the relatively small time required to make an initial exploratory measurement in $\gamma\ ^3\text{He} \to pp + n$ for lower beam energies, and due to the long time scales involved in proposing, scheduling, running, and analyzing experiments, and followup experiments.

3.2 Rates and Time Estimates, Beam Time Request

In PR-03-005, we requested ≈13 days to measure the $\theta_{\text{c.m.}} = 90°$ excitation function and the 3.2 GeV angular distribution. We are requesting additional time so that, if the HRM model is correct, then we can make a statistically significant determination of the 20 % decrease in $s^{11} ds/dt$ from 4 to 5 GeV – see Figure 2. With 5 % point-to-point systematics, it is necessary to maintain $<$ 5 % statistics, for the 4 GeV point, and 5 % statistics for the 5 GeV point. We are also requesting 1 additional day so that we can measure a cross section, and the recoil polarizations, at 1.6 GeV photon energy, to provide some overlap with the anticipated Hall B $\gamma\ ^3\text{He} \to pp + n$ data, and a comparison with the $\gamma d \to pn$ polarization data. Table 1 shows the kinematics, along with the estimated (HRM) cross sections and coincidence rates.

Table 2: Polarimeter parameters and expected uncertainties for the measurement.

measurement	$E_e \approx E_\gamma$	ϵA^2	χ	Time	$\Delta C_{x'}$	Δp_y	$\Delta C_{z'}$
	[GeV]		[deg]	[days]	[abs]	[abs]	[abs]
0	1.6	0.012	146	1	0.07	0.07	0.09
1	2.4	0.008	180	4	0.11	0.13	–

We now turn to the polarization measurement. Table 2 shows the polarimeter performance, and the expected uncertainties for 1 and 4 day measurements at $\theta_{\mathrm{c.m.}} = 90°$ and $E_\gamma = 1.6$ and 2.4 GeV, respectively. Because there is a significant amount of overhead time associated with measuring a cross section at 1.6 GeV, we plan on 1 day at this energy, to allow a polarization measurement as well[2]. This measurement will provide initial exploratory information for the polarizations in $\gamma\,{}^3\mathrm{He} \to pp + n$, and will allow an initial comparison with $\gamma d \to pn$ polarizations at an energy at which the $\gamma d \to pn$ polarizations have all become small. The QGS model will also be tested, as it should be valid at this energy, and there are already QGS calculations for the $\gamma d \to pn$ polarizations in these kinematics.

We do not request any time for the 2.4 GeV polarization measurement. If the cross sections are large, perhaps close to the RNA prediction and significantly larger than the HRM prediction, then there will easily be sufficient extra time in running the experiment to measure the 2.4-GeV recoil polarizations[3]. If the cross sections are similar to the HRM estimate or smaller, then no polarization measurement at 2.4 GeV will be performed. As indicated in Table 2, due to spin precession, $\chi \approx 180°$, a measurement of $C_{z'}$ at 2.4 GeV would have large uncertainties.

The total time request is shown in Table 3. The overhead time includes 4 hours for beam energy measurements, 4 hours for accelerator pass changes, 8 hours for accelerator Linac energy changes, and 5 hours total for the five angle changes in the angular distribution at 3.2 GeV.

In addition, we request two days, one day for set up and one day for efficiency calibrations, using *ep* elastic scattering. Finally, we ask for just under two days for a limited amount of electrodisintegration time, to ensure that the calculations are under control. The set up, calibration, and electrodisintegration measurements are all run without the radiator; by scheduling these days before a maintenance period, the radiator could easily be installed in the cryotarget during the maintenance, without loss of beam time. Oth-

[2]In terms of scheduling the actual run, we would generally plan on scheduling the beam energy changes one day apart in any case, to ensure adequate time for a measurement while providing predictability about planned accelerator interruptions to the other Halls. Thus, in practice measuring the polarization requires little additional time here, once it has been decided to measure the cross section.

[3]Indeed, if the cross sections are as large as suggested by the RNA model, we will be able to improve statistics at 5 GeV, to measure an additional angle at 4 GeV, and to measure the recoil polarization components at 3.2 GeV.

Table 3: Time request for this proposal. The total time at 1.6 GeV is reduced from the sum of the three components since the cross section can be measured at the same time as the polarization.

measurement	E_γ	Cross Section time	Polarization time	Overhead Time	Total
	[GeV]	[days]	[days]	[days]	[days]
0	1.6	0.1	1.0	0.2	1.2
1	2.4	0.1	–	0.3	0.4
2,5-9	3.2	3.6	–	0.5	4.1
3	4.0	3.0	–	0.5	3.5
4	5.0	8.0	–	0.3	8.3
radiator out					1.5
set up / calibrations					2.0
TOTAL					22.0

erwise, about three extra days[4] will need to be scheduled to warm up the cryotarget, install the radiator, and cool down the cryotarget.

4 Administrative Details

The experiment requires only existing equipment and beam time. There is no need for any new equipment or development. The experiment could run almost any time.

References

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[4] Our view is that it is an insignificant scheduling detail whether or not three additional days of beam time are needed. Many experiments require months of hall downtime so that equipment can be set up and tested. These downtimes are not generally considered part of the PAC approved beam time, and these three days should also not be a concern of the PAC.

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5 Appendix 1

A copy of the original proposal will be attached to this update.