Measurements of the Target Single-Spin Asymmetry A_y in the Quasi-Elastic $^3\mathrm{He}^\uparrow(\mathrm{e},\mathrm{e}'\mathrm{n})$ Reaction

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Abstract

In the last decade, a distinct difference was found between the neutron electric form factors extracted at low Q^2 using polarized deuteron vs. polarized ^{3}He. This discrepancy was resolved by using Faddeev calculations of ^{3}He to make the extraction. One experiment that clearly showed that the Faddeev calculations were correctly describing ^{3}He was the measurement of a large A_y (e,e'n) asymmetry at a Q^2 of 0.2 [GeV/c]^2; an asymmetry which in PWIA is exactly zero and which other calculations had predicted would be small. We propose to make the first measurement of this asymmetry at large Q^2 of 0.75 [GeV/c]^2 and 1.0 [GeV/c]^2 where the A_y asymmetry is again *expected* to be small. Any non-zero result is an indication of effects beyond simple IA and will test models used to extract neutron form factors from ^{3}He at large Q^2. Though state of the art calculations are not yet available for this observable, several theory groups are currently active in calculating the $^3\vec{\mathrm{He}}(\vec{e}$,e'n)X reaction for the recent Hall A G_E^n experiment. In the process, they will also calculate the single-spin asymmetry A_y in the $^3\mathrm{He}^{\uparrow}$(e,e'n) reaction and have explicitly stated that this observable will serve as a sensitive test of their models (i.e., testing the validity of the use of the models to extract the neutron form factors at high Q^2). This measurement is an extension of the approved and scheduled inclusive A_y experiment. The required neutron detector already exists and will be installed in Hall A for the (e,e'N) experiment which will immediately follow the A_y experiment. No additional beamtime is requested.

1 Physics

In plane-wave impulse approximation the target single-spin transverse asymmetry in the quasi-elastic reaction $^3He^{\uparrow}$(e,e'n) is exactly zero which makes it an ideal reaction for testing our understanding of reaction mechanisms. In fact, it was this reaction channel that showed at a Q^2 of 0.2 $[GeV/c]^2$ the predictive power of the Bochum group Faddeev calculations. While Laget and Nagorny were predicting a rather small A_y asymmetry; the Bochum group's calculation correctly predicted the large measured asymmetry of 0.50 ± 0.05 [1]. This same calculation was used to fix the discrepancy between extractions of G_E^n done with ^{3}He and with Deuterium. The reason for the large A_y asymmetry as well as the ^{3}He/Deuterium discrepancy, was FSI effects that were much larger than anticipated.

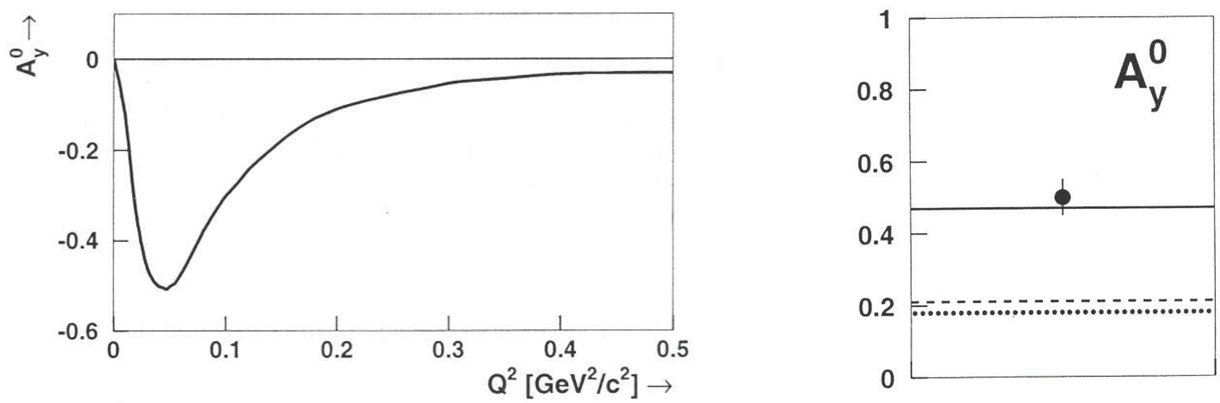

Figure 1: The left figure shows the original prediction of the A_y asymmetry from Jean-Marc Laget [2] for the semi-inclusive $^3He^{\uparrow}$(e,e'n) reaction. The right figure shows the measured induced asymmetry A_y together with acceptance averaged theoretical predictions of Golak, Laget, and Nagorny for the NIKHEF 0.2 $[GeV/c]^2$ data. The solid curve corresponds to the full calculation of Golak [3], while the dotted and long-dotted curves to the full calculations from Laget and from Nagorny [4–6]. The induced asymmetry is equal to zero in PWIA in all three models.

At Jefferson Lab, many experiments have been performed using polarized ^{3}He as an effective neutron target including a recently completed measurement to determine G_E^n at large Q^2. Yet, at large Q^2 there have been no asymmetry measurements done to test those extractions. By simply measuring the (e,e'n) reaction parasitically during the scheduled inclusive (e,e') experiment, we will provide high precision data points at Q^2 of 0.75 $[GeV/c]^2$ and 1.0 $[GeV/c]^2$ for the single-spin asymmetry A_y. This will test the state of the art calculation that can be done at this Q^2. It is clear that any calculation that is used for form factor extractions must correctly predict this asymmetry if it is to be trusted. Rocco Schiavilla, Misak Sargsian [7] and Jean-Marc Laget [8] are working on high-Q^2 A_y calculations for us. The Bochum group [9] agree that A_y is a good observable to test theoretical frameworks at low Q^2 and fully support this proposal.

1.1 Comments from Misak Sargsian

Presently, calculations are in progress to estimate the nuclear effects in the extraction of neutron form-factors from $Q^2 \geq 1$ GeV^2 $^3\vec{He}(\vec{e},e'n)X$ reactions.

These calculations are done within Generalized Eikonal Approximation (GEA)[10, 11] in which the scattering amplitude is expressed as a sum of the amplitudes containing no, single and double rescattering of the knocked-out nucleon with the residual two nucleons.

GEA is based on the effective Feynman diagram rules, which self-consistently accounts for the recoil effects due to final state interaction.

For the G_E^n project, calculation of the $^3\vec{He}(\vec{e},e'n)X$ reaction involves the final state interaction diagrams that includes both direct $np \to np$ and charge exchange $pn \to np$ contributions. The latter is essential for a correct estimate of nuclear effects in extraction of the neutron form-factors. This is due to the fact that in charge-exchange contributions the electron scatters from a proton which has a much larger cross section at the kinematics relevant for the G_E^n experiment.

The peculiarity of charge-exchange rescattering is that it is a predominantly helicity flip interaction and in non-polarized reactions its contribution is nearly negligible. Therefore, there are few options for an independent check of the reliability of the calculation involving the charge-exchange rescattering term.

In this respect, the measurement of the single-spin asymmetry in the $^3He^{\uparrow}(e,e'n)X$ reaction provides a unique opportunity for an independent check of the charge-exchange mechanism of the final state interactions. The asymmetry in $^3He^{\uparrow}(e,e'n)$ is not only related to the final state interaction processes in the $^3\vec{He}(\vec{e},e'n)$ reaction, but it is also defined predominantly by the spin-flip part of these rescatterings.

Within the program of calculating the $^3\vec{He}(\vec{e},e'n)$ reaction, the single-spin asymmetry in the $^3He^{\uparrow}(e,e'n)X$ reaction will also be calculated and compared with the data.

This comparison then will allow for an improved estimate of the nuclear effects in extraction of the neutron form-factors from $^3\vec{He}(\vec{e},e'n)$ reactions.

1.2 Comments from Jean-Marc Laget

The full three body model of Gloeckle and collaborators [3] takes into account the full dynamics of the three body interactions, particularly the coupling between the open channels, and sums up the complete multiple-scattering series. The partial wave expansion of the three body final state is easily manageable at low Q^2 and low energies, where the number of partial waves is small. At high energy and high momentum transfer, the method becomes less predictive, since the number of partial waves increases beyond what is manageable with the present generation of computers.

The diagrammatic model [2] is based on the expansion of the reaction amplitude into a series of a few dominant processes. It does not rely on a partial expansion, but truncates the multi-scattering series. It is valid at all energies in the vicinity of the singularities of each diagram.

Thus by comparing the two models at low Q^2 and low energy one can get an estimate of the error on the predictions of the diagrammatic model at high Q^2, when it is used far from its singularities.

So far the prediction for A_y of the two models disagree in the NIKHEF kinematics (Figure 1), although the order of magnitude is comparable.

The curve in Figure 1 was obtained with a version of the diagrammatic model [2] that was valid at low virtuality Q^2 of the photon, but that took only into account the single scattering processes beyond the quasi-free one.

During the past few years the following improvements have been made [12, 13]:

1- Implementation of all the two loop diagrams, beyond the the one loop single scattering ones. Among them the nucleon-nucleon double scattering process plays a significant role in the continuum spectrum, more particularly near the two body break-up threshold. This process enhances the imaginary part of the amplitude and is expected to play a role in the induced asymmetry A_y.

2- Implementation of the full relativistic nucleon electromagnetic current, with the fits to the latest experimental values of the nucleon form factors.

3- Implementation, at high energy, of the imaginary absorptive part in the nucleon-nucleon scattering amplitudes on top of its expansion in terms of real phase shifts.

These improvements and upgrades of the code, in the JLab energy and momentum ranges, lead to a very good agreement with recent unpolarized cross sections of the ^{3}He(e,e'p) reactions [14, 15] and ^{3}He(e,e'pp) reaction [16].

Single spin asymmetries as well as double spin asymmetries are already calculated in the (e,e'p) channels. It is straightforward to adapt and customize the (e,e'p) code to the (e,e'n) channel, but this takes time, particularly to cross check the modifications.

Single and double spin asymmetries in the (e,e'n) channel will be available when the experiment is completed and analyzed, and hopefully before.

1.3 Comments from the Bochum Group

I am very happy that our work on full inclusion of final state interactions is mentioned in the proposal. I fully agree with the statements in the proposal that the induced asymmetry A_y is a good observable to test a theoretical framework at relatively small Q^2.

It is clear that our nonrelativistic Faddeev framework will not be useful for the high-Q^2 kinematics proposed by T. Averett et al. But again it is true that a good description of A_y

by a given theoretical approach gives us the hope that the extraction of any information on ^{3}He based on the same theoretical framework is reliable. So I fully support the proposal.

From my personal point of view it would be great if a measurement of A_y at lower Q^2 takes place. I would like to remind you of one important thing. There was actually some controversy about the geometry in Poolman's thesis. It is not clear if the comparison between the theoretical predictions (I mean all calculations, not only ours) and the data was fully correct. I think it would be very useful if you could get a high quality data point with well documented geometry for the $^3\vec{He}$(e,e'n) reaction. In the last few years new theoretical groups appeared, which would be happy to test their methods for such a demanding observable as A_y.

2 Experimental Equipment and Methods

We propose to measure the target single-spin asymmetry A_y in Jefferson Lab Hall A for the $^3He^{\uparrow}$(e,e′n) reaction via quasi-elastic electron scattering from a vertically (normal to the scattering plane) polarized ^3He target. This experiment will be conducted parasitically to the inclusive A_y experiment, E05-015 [17]. The quasi-elastically scattered electrons will be detected in one of the high resolution spectrometers (HRS) with the knocked-out neutrons detected in a neutron detector for $Q^2 = 0.75$ [GeV/c]^2 and 1.0 [GeV/c]^2. Figure 2 shows (schematically) the experimental configuration for the A_y measurement in both (e,e′) and (e,e′n) processes for the 1.0 [GeV/c]^2 point. All directions are in the horizontal scattering plane. The following sections describe the kinematics and components of the experimental setup. For this parasitic experiment, no new equipment is needed.

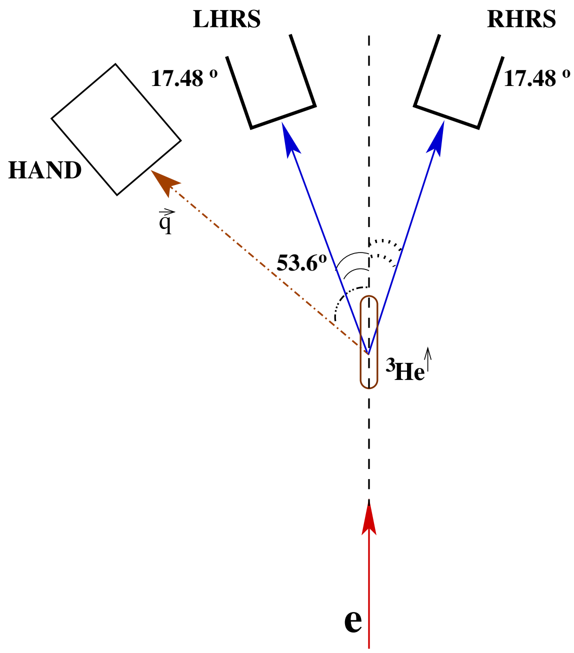

Figure 2: Schematic layout of the experimental configuration. The LHRS and RHRS for detecting quasi-elastically scattered electrons for experiment E05-015 $^3He^{\uparrow}$(e,e′) production running and HAND for the proposed $^3He^{\uparrow}$(e,e′n) parasitic measurement at $Q^2 = 1.0$ [GeV/c]^2.

The neutron detector will be centered on the momentum transfer vector as defined by the spectrometers shown in Figure 2. During the E05-015 experiment, the RHRS will be at two angles 14.8° and 17.5°. The beam-time will be split between the 0.75 [GeV/c]^2 (1.5 days) and 1.0 [GeV/c]^2 (5.5 days) points. During the measurement, the target spin will be reversed every 20 minutes to suppress possible systematic effects.

2.1 Vertically Polarized ^{3}He Target

For the proposed measurement of A_y, we will utilize the vertically polarized ^{3}He target, which is being upgraded for the BigBite family of experiments [18]. These experiments are scheduled to run in 2008. The upgrade takes advantage of the improvements that were made for the G_E^n experiment E02-013 [19], including hybrid optical pumping. During E02-013, an in-beam target polarization of up to 50% was achieved. For the approved Transversity E06-010/E06-011 [20, 21] and A_y experiments, an additional pair of Helmholtz coils and RF coils have been acquired for polarization along the vertical direction. A new oven system is also being designed to allow for higher oven temperatures and three directions of optical pumping: longitudinal, transverse and vertical. A schematic layout of the upgraded target system is shown in Figure 3 viewed from the side and beam directions.

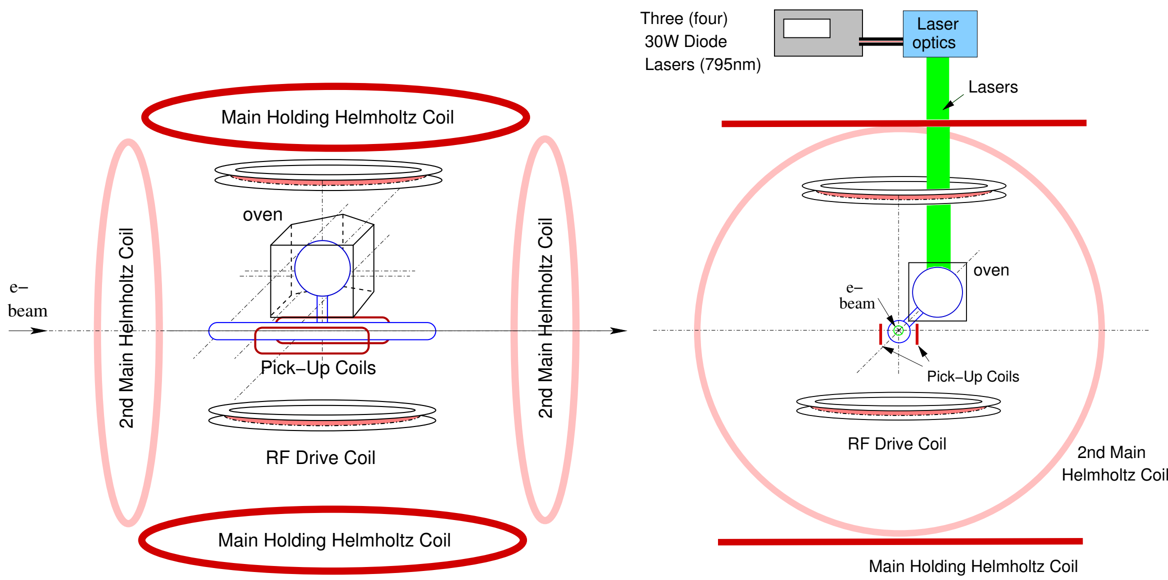

Figure 3: Schematic layout of the vertically polarized ^{3}He target, side view (left) and beam view (right).

In order to minimize systematic effects in the measurement of A_y, the target spin will be reversed about every 20 minutes. The technique of fast spin reversal has already been developed and tested for the upcoming experiments. The maximum polarization achievable with fast spin-flip is lowered due to AFP loss of polarization compared to operating the target without fast spin-flip. The polarization is expected to be about 5–10% lower (relative); however, the target polarization should still be above 40% with the hybrid targets. The target polarization will be monitored with NMR and EPR. The relative uncertainty in the polarization is about ±4%.

2.2 High Resolution Spectrometers

For the A_y experiment, both the HRS's will be used to detect inclusive quasi-elastically scattered electrons from polarized ^{3}He. The RHRS will detect electrons for the two highest Q^2 points. With the LHRS, data will also be taken at a lower Q^2 point of 0.55 [GeV/c]^2 for 0.5 days. We plan to use the RHRS to detect the quasi-elastically scattered electrons for the $^3He^{\uparrow}$(e,e'n) reaction and the neutron detector described in the next section for the neutron.

2.3 Hall A Neutron Detector (HAND)

The Hall A Neutron Detector (HAND) shown in Figure 4 was first used in the Short-Range Correlations (SRC) experiment E01-015 [22], which ran between January and March of 2005. HAND is a large volume neutron detector that consists of 88 plastic scintillator bars, which are divided up into four planes. Each bar is viewed by two photomultiplier tubes, one on each end. In the first three planes, the dimensions of the bars are 10 x 10 x 100 cm^3 (W x H x L), whereas, the height of the bars in the fourth plane are 25 cm. The neutron detector also has a veto detector located in front of the first plane. The veto detector consists of 64 plastic bars that are 2 cm thick and is organized into 32 rows of two end-to-end overlapping paddles.

For this proposal, the neutron detector will be located 6.0 meters from the target (i.e., the distance between the target and the front of the first scintillator plane of HAND) between 53° and 66° left of the beam line. At 6.0 m, the detector's in-plane and out-of-plane angular acceptances are ± 5° and ± 15° as determined from the SRC experiment. In front of HAND, there will be a lead wall comprised of iron (4 cm thick) and lead (5.1 cm). The distance between the back face of the wall and the front face of HAND is 56 cm. The BigBite spectrometer will be located right of the beam line and not in front of HAND as was done for the SRC experiment. The experimenters do not expect the absence of a deflection magnet to significantly impact the single rates on the neutron detector due to the thickness of the lead shielding.

During experiment E05-102 [23], HAND will be used with the HRS to detect the quasi-elastic $^3\vec{He}(\vec{e}$,e'n) process. This parasitic measurement will be used to make a high-precision extraction of G_E^n at Q^2 = 0.36 [GeV/c]^2. The E05-102 experiment is scheduled to acquire data right after the A_y experiment is completed. Hence, the neutron detector will already be in Hall A and set up to acquire data during the inclusive A_y measurement.

In December 2008, the A_y and (e,e'N) experiments are scheduled to share a joint commissioning time of 5 days, which is dedicated for the commissioning of HAND and the BigBite spectrometer. The experimenters for E05-102 plan to take data with hydrogen to preform the detector checkout with first-pass beam at 1.23 GeV. This measurement should not impact Halls B or C, since neither are scheduled to use energy at first-pass next December. A few hours on ^{3}He also will allow us to reproduce the NIKHEF point at Q^2 = 0.2 [GeV/c]^2. The detailed kinematics of this low Q^2 point can be found in Table 1. For the inclusive A_y experiment, this calibration point will also provide a quick check that all

Figure 4: Shown is the Hall A Neutron Detector (HAND). This device has been successfully used in Hall A and is being prepared for the upcoming ^{3}He(e,e′N) experiment (E05-102).

the systems are working correctly with a large physics asymmetry.

E_0 [GeV]	E' [GeV]	θ_{lab} [deg]	Q^2 [GeV/c]^2	$\|\vec{q}\|$ [GeV/c]	$\theta_{\vec{q}}$ [deg]
1.232	1.125	21.89	0.20	0.460	65.89

Table 1: Kinematics for $Q^2 = 0.2$ [GeV/c]^2 calibration point.

For the data acquisition, we plan to read out the neutron detector crates for every HRS event as was done for the SRC experiment. Hence, the HRS will be used to form the main trigger. This is possible due to the low singles rate as shown in the kinematic table in the following section. This is exactly how the E05-102 experiment will run; hence, this proposal does not require any new equipment.

2.4 Kinematics and Rate Estimate

We plan to collect the data parasitically at the two highest Q^2 points of the inclusive A_y experiment. The full kinematics and expected rates are shown in Table 2. The rate estimates are based on a 38 cm long ^{3}He target and a 12 μA beam with a conservative target polarization of 40%. The estimate assumes we will cut out the target windows, hence the target length of 38 cm.

E_0 [GeV]	E' [GeV]	θ_{lab} [deg]	Q^2 [GeV/c]^2	$\|\vec{q}\|$ [GeV/c]	$\theta_{\vec{q}}$ [deg]	(e,e′) rate [kHz]	(e,e′n) rate [Hz]	Total Events
3.567	3.167	14.80	0.75	0.954	58.02	0.630	6.3	7.71×10^5
3.567	3.034	17.48	1.00	1.133	53.56	0.165	1.7	7.86×10^5

Table 2: Kinematics and estimated count rates for 1.5 days at 0.75 [GeV/c]^2 and 5.5 days at 1.0 [GeV/c]^2.

2.5 Systematic Uncertainties

The proposed measurement will share most of the systematics for the inclusive A_y measurement. The dominant systematic uncertainty is caused by the uncertainty in the target polarization (≈ 4%), followed by backgrounds. The main source of background for the parasitic measurement is the (e,e'p) reaction and proton conversion into a neutron in the lead wall. This process will be checked during the calibration point with hydrogen. From experience during the SRC experiment, this background isn't expected to be signficant.

3 Summary

By installing the Hall A Neutron Detector during the A_y experiment, we will be able to make a high precision measurement of the A_y asymmetry at intermediate Q^2. This result will test calculations which are used to extract neutron information from polarized ^{3}He. By working together with the scheduled inclusive A_y and exclusive (e,e'N) experiments, this measurement can be done without additional beamtime. Also, one spokesperson from both the A_y and (e,e'N) experiments has joined this proposal.

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