STATUS OF THE JEFFERSON LAB RSS EXPERIMENT (E01-006)

P. M. MCKEE

(for the RSS Collaboration)
Physics Dept, University of Virginia
PO Box 400714
382 McCormick Rd.
Charlottesville, VA 22904-4714
E-mail: pmm3w@virginia.edu

Experiment E01-006 ran in Hall C of Jefferson Laboratory, Newport News, Virginia, for six weeks in early 2002. It featured a continuous beam of polarized electrons at 5.759 GeV hitting a polarized target of solid ammonia. Two types of ammonia, $^{15}NH_3$ and $^{15}ND_3$, were used so that proton and deuteron structure functions could be measured. Additionally, the polarization axis of the target was changed during the experiment to enable measurement of both longitudinal and transverse structure functions. Details and early analysis results will be presented.

1. Introduction

In considering scattering of a lepton from a nucleon, the cross section for such an interaction may be written in terms of a leptonic and a hadronic tensor. The fundamental interaction is the exchange of a virtual photon between the lepton and the nucleon. The leptonic tensor is known exactly through QED, but since the nucleon is not a fundamental particle, the hadronic tensor can be constrained but not written directly. The typical approach is to write the hadronic tensor in terms of four *structure functions* that are functions of the kinematics of the interaction. The kinematic variables chosen are typically W, the mass of the final hadronic state, and Q^2, the 4-momentum squared of the virtual photon.

Two of the structure functions, $F_1(W, Q^2)$ and $F_2(W, Q^2)$, are known as the unpolarized structure functions and contribute to the cross section in all scattering events. The other two structure functions, $g_1(W, Q^2)$ and $g_2(W, Q^2)$, are known as the polarized structure functions, and only contribute to the cross section if both the lepton and nucleon are polarized.

The unpolarized structure functions were the first to be studied, in the

1970's and 1980's, and are now well known over a large kinematic range.

The polarized structure functions were studied next. They are most easily measured by determining the cross section asymmetry between two states that differ in either target or beam polarization direction.

In the 1980's and 1990's, the polarized structure functions were measured in the so-called Deep Inelastic region, where $Q^2 > 1.0$ (GeV/c)^2 and $W > 2$ GeV. In this region, they have been measured fairly accurately.

Experimental interest has now turned to the polarized structure functions below the deep inelastic limits, a region in which the nucleon resonances dominate the interaction and the structure functions exhibit rapid changes.

2. The RSS Experiment

Experiment E01-006 at Jefferson Laboratory was designed to measure the polarized (or spin) structure functions in the region of the nucleon resonances, and ran for six weeks in early 2002. In order to shorten communications when referring to the experiment, the nickname RSS was created, standing for Resonance Spin Structure.

2.1. *Beam*

A distinction of Jefferson Lab among similar facilities is that it provides a continuous beam instead of a pulsed beam, for experimental use. As a result, instantaneous detector rates are kept low, while not sacrificing target luminosity, and therefore statistical precision.

The RSS Experiment made use of the polarized beam available at Jefferson Lab. The beam is produced by illumination of a strained GaAs cathode with circularly polarized laser light. By changing the direction of the laser polarization, the beam helicity was flipped many times a minute on a pseudo-random basis. This renders the asymmetry measurement immune to slow drifts in detector efficiency or acceptance and to changes in target or beam polarization.

The average polarization of the beam was around 68%, and was monitored by a Møller polarimeter installed in the entrance tunnel to Hall C. Beam current and position were monitored with the standard Hall C instruments, and with a Secondary Emission Monitor (SEM), located immediately upstream of the target. The beam energy was 5.759 GeV, and current ranged from 100 to 200 nA.

In measuring a cross section difference, care must be taken to suppress sources of false asymmetry. In terms of the beam, it is necessary to know how many electrons of each helicity have been sent through the target, and to keep these two numbers as close as possible. The net charge asymmetry, which indicates the disparity between the two helicity states, was measured to be 4×10^{-6}.

2.2. *Polarized Target*

Ideally, the spin structures of both the proton and neutron would be measured. However, no polarizable pure neutron targets exist. It is instead customary to measure the scattering from a proton target and either a deuteron or a ^{3}He target, and then to extract the neutron structure function from the combination of the two, after applying nuclear corrections.

For RSS, a solid, cryogenic, polarized target was used with $^{15}NH_3$ and $^{15}ND_3$ as the target materials. The technique of Dynamic Nuclear Polarization was used to enhance the polarization, in which microwave irradiation is used to drive transitions in nucleon-electron systems in the material. This method results in nuclear polarization of both the nitrogen and the hydrogen in ammonia. For this reason, ^{15}N was used because its polarization is carried by a single unpaired proton which polarizes weakly compared to the hydrogen in the ammonia due to the small ^{15}N magnetic moment. Measurement of this polarization signal is also more accurate than that of ^{14}N. The raw asymmetries are then corrected for the contribution arising from the polarized nitrogen.

The target polarization was measured by an NMR system, using pickup coils embedded in the material. Figure 1 shows a typical deuteron signal representing approximately +24% polarization. The structure of the signal is unique to the deuteron material, and arises because of quadrupole splitting of the deuteron in the electric field of the crystal. The proton signal is fundamentally gaussian.

Interaction of the beam with the target material causes damage to the material that degrades its ability to polarize. This damage is cumulative, but can be repaired by annealing the material at a temperature near 100K for tens of minutes. This procedure was usually required after 10 to 12 hours of beam, but was often scheduled earlier to coincide with other experimental or laboratory activities. Figure 2 depicts a typical anneal cycle on negatively polarized proton material.

The average target polarization for the proton target material, $^{15}NH_3$, was around 80%, and for the deuteron material, $^{15}ND_3$, around 20%.

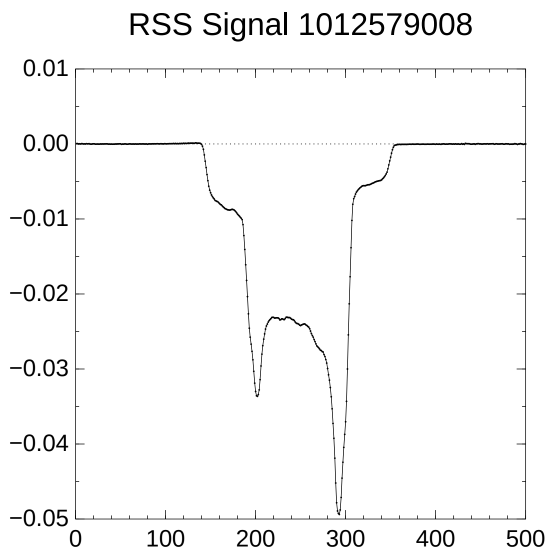

Figure 1. Typical NMR signal for polarized $^{15}ND_3$.

2.3. *Spectrometer*

Scattered electrons were detected inclusively in the High Momentum Spectrometer (HMS), a part of the Hall C standard equipment. The HMS features a large acceptance, due to its use of superconducting quadrupole magnets. Particles are detected and identified by a combination of hodoscope planes, wire chambers, a gas Čerenkov detector, and a lead glass calorimeter.

The HMS was used at two central momentum settings: 4.095 GeV/c, which accepted scattering from $1.48 < W < 1.95$ GeV, and 4.723 GeV/c, with $0.83 < W < 1.59$ GeV. The scattering angle was 13.1°, and the average Q^2 was 1.3 GeV^2.

3. Data

Approximately 520 production runs and several hundred calibration runs were taken during the running time of RSS. Approximately 160 million triggers were registered on the proton targets (longitudinal and transverse), and approximately 350 million triggers on deuteron targets. Tracking and particle identification is currently underway. A strong proton signal can be seen in the data presented in Figure 3.

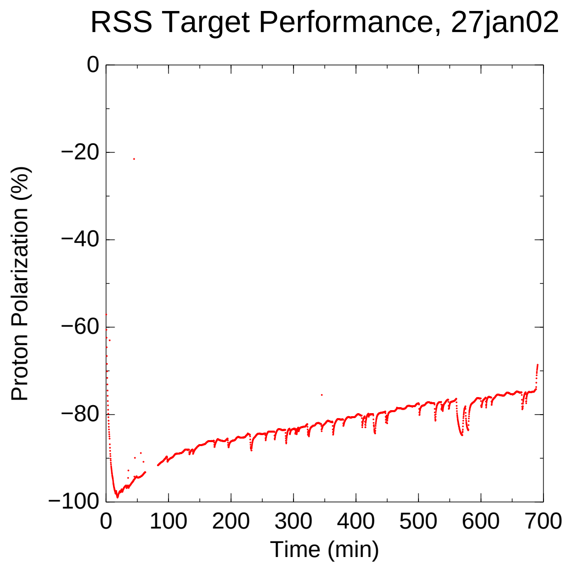

Figure 2. Typical polarization performance of the proton material, $^{15}NH_3$.

Calibration of the spectrometer optics is also underway. One tool added to the target apparatus for this experiment is a split crosshair target made of tungsten wire. Translation of the target along any direction transverse to the beam or rotation in either of two directions can be measured by studying scattering from this target.

4. Outlook

Many interesting physics topics can be investigated as the analysis of the RSS data progresses. First and foremost is the study of the W dependence of the transverse and longitudinal polarized structure functions of the proton and deuteron in the resonance region. This measurement will add significantly to world data on these functions, and will provide the first precision measurement of the transverse structure functions for the proton and deuteron.

Beyond this, it is interesting to inspect the transverse structure functions for deviation from pure twist-2 behavior, indicating the onset of twist-3 or higher effects.

A third and final topic is that of duality. A structure function exhibiting local duality shows agreement between its average value in the resonance

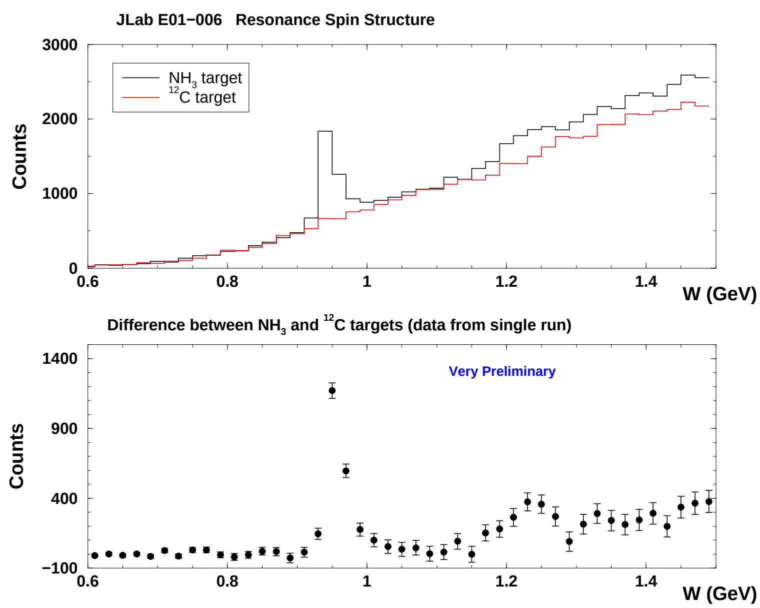

Figure 3. Proton signal from ammonia ($15NH^3$) target material. Top panel shows data from an ammonia run and from a carbon run used for calibration purposes. The carbon data has been normalized to the ammonia spectrum at W=0.8 GeV. Bottom panel shows the carbon spectrum subtracted from the ammonia.

region and an extrapolation of its deep inelastic counterpart. For the unpolarized structure function F_2, local duality has been observed by Jefferson Lab experiment E97-010. The RSS data will provide a test for the presence of local duality in the polarized structure functions.

5. Acknowledgments

This work was supported by Department of Energy contract DE-FG02-96ER40950, and by the Institute of Nuclear and Particle Physics of the University of Virginia. The Southern Universities Research Association (SURA) operates the Thomas Jefferson National Accelerator Facility for the United States Department of Energy under contract DE-AC05-84ER40140.