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Mainz Microtron MAMI

Collaboration A1: "Virtual Photons"

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Addendum to Experiment A1/2-93

Measurement of Polarized Protons from Quasielastic Electron Scattering

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Abstract

We propose to make a high statistics study of polarization transfer on ^{1}H and ^{4}He in parallel kinematics in order to search for modification of the nucleon form factor in the nuclear medium. We request a change of initial target, ^{4}He instead of ^{16}O, and initial running time of 240 hours. We will use the existing Mainz ^{4}He target.

1 Discussion

Experiment A1/2-93 was initially proposed with the goal of better understanding the nuclear response for quasi-elastic $(e, e'p)$ scattering. At the time of the proposal, some outstanding issues were the apparent quenching of the longitudinal response, the possibility of a change in size of the nucleon, and changes of the nucleon form factor in the nucleus.

During the past few years new measurements have been made and a re-analysis of previous data has been carried out. Jourdan [1, 2] has suggested that quenching of the longitudinal response may be significantly less than previously thought, and that previous data are consistent (within errors) with no quenching. He concludes that there is no evidence of a change in the nucleon size.

Likewise, measurements of y-scaling [3, 4, 5] have placed limits on the change in the form factors, especially the magnetic form factor [11]. The change in the magnetic form factor is limited to about 3%, while the electric form factor is limited to a change of about 10% by y-scaling, and about 4% from the Coulomb sum rule [1], although the stringency of this limit remains controversial.

Measurements comparing hydrogen and deuterium [6, 7, 8, 9] and on ^{12}C [10] also showed no evidence of a change in the proton form factor in the nuclear medium.

In 1997, TJNAF experiment 89-033 studied $^{16}\mathrm{O}(\vec{e}, e'\vec{p})$. This experiment, a Hall A collaboration experiment led by Rutgers and William & Mary, measured the ratio of transverse to longitudinal polarization and induced polarization to the g.s., p(3/2) and s(1/2) states. The polarization ratio should reflect the ratio of the electric to magnetic form factors of the proton in the nucleus. The preliminary result indicates that within the statistics of the experiment (about 10%), the ratio was that expected for no change of the form factors from the free value.

Thus the experimental determination of possible modification of the nucleon form factor inside the nucleus remains important. The Adelaide group (A. W. Thomas et al.) have recently presented new calculations of both the free nucleon form factors and the in-medium form factors [11, 12, 13]. Their model gives a good description of the free nucleon form factors. Using the quark meson coupling model (QMC), they calculate expected modifications of the form factors in the nuclear medium. The model has two very interesting predictions. First, the magnetic form factor changes only about 1% for a Q^2 of 0.4 $(\mathrm{GeV/c})^2$, while the electric form factor changes about 5%, meaning that both are consistent with the limits set by y-scaling, and the electric form factor is just one standard deviation from the Coulomb sum rule limit. It thus predicts a change in the ratio of the form factors, which can be determined with a polarization measurement. Surprisingly, they also predict that the change in the form factor is almost as strong in ^{4}He as ^{16}O, and indeed, that there is little A dependence. They do predict, however, large changes with Q^2.

This somewhat surprising prediction that ^{4}He shows changes as large as heavier nuclei has led us to reconsider the best way to proceed with A1/2-93. First, it is clear that only a very good statistics measurement will be useful, since a large change in the form factor has been excluded. The Lu et al. prediction that effects in ^{4}He will be comparable to heavier nuclei is most interesting. Helium has the strong advantage that more reliable theoretical calculations can be made than for heavier nuclei. The effects of final state interactions, which make interpretation of the result more difficult, are reduced. This strongly argues for a high statistics measurement of spin transfer on ^{4}He as the first measurement for this experiment with a measurement of longitudinal to transverse polarizations.

Effects of final state interactions are expected to be negligible for ^{4}He in parallel kinematics [14]. We plan to take data at p_{miss} of 0 MeV/c. The large acceptance of spectrometers A and C gives coverage of missing momentum from -100 MeV/c to 100 MeV/c. The measured ratio does not depend on the exact value of the beam polarization or integrated luminosity, making it insensitive to most systematic effects.

Because we wish to first study the low missing momentum region at the highest density possible, ^{4}He has both theoretical and experimental advantages over a waterfall ^{16}O target. At low missing momentum there is a substantial background for the waterfall target due to hydrogen. The waterfall target is also thinner than the helium target, giving a substantially greater running time. The g.s. is a p-shell, which is harder to handle theoretically. The question of correctly describing the effect of final state interactions is more difficult.

In addition, TJNAF experiment 93-049 (Ent, Ulmer, van den Brand, co-spokespersons) is expected to run in late 1999. 93-049 is an identical proposal to study the spin transfer at higher Q^2 - 0.8 to 3.2 $(GeV/c)^2$. A1/2-93, will measure at a Q^2 of 0.4 $(GeV/c)^2$. The combination of the two will allow a more complete mapping of the Q^2 dependence.

We still plan to continue the ^{16}O experiment, regardless of the result on ^{4}He. However, the result from helium will give us a much better knowledge of the likely size of effects to be seen in oxygen and will guide our choice of kinematics and running time for oxygen.

2 Time Estimate

Any change of the form factor is expected to change the G_E/G_M ratio only a few percent. Thus we wish to aim for a statistical precision of 2% or better to be sensitive to the expected change. However, in order to confirm that the understanding of the spectrometer is sufficient to keep the systematic uncertainty smaller than 2%, we wish to both bin the helium data and take sufficient data on hydrogen to determine both the G_E/G_M ratio and study the spin precession. We will use one spectrometer setting with two momentum bins for helium. This will give a final statistical uncertainty of about 1.5%. We will use two spectrometer settings for hydrogen, one the same as helium, and a second 10% move the position on the focal plane, each binned into two bins.

We will use the existing Mainz ^{4}He target, a cooled high pressure gas target which has a thickness of 200 mg/cm^2. We assume a beam current of 15 μA and polarization of 80%. The beam energy will be 750 MeV, with $\omega = 240$ MeV, corresponding to an electron scattering angle of 66° and proton angle of 41°.

The coincidence rate has been estimated using MCEEP, which gives a rate of about 200 Hz. Currently the Mainz data acquisition rate is limited to about 200 Hz, about the expected rate.

The statistical precision on the ratio of $P_T/P_L = R$ is given by

$$\sigma(R)/R = \sigma(\epsilon_T/\epsilon_L)/(\epsilon_T/\epsilon_L)sin(\chi)$$

where χ is the spin precession angle and $\epsilon_{L,T}$ is the measured asymmetry in the polarimeter. Assuming that the polarizations are approximately the same as for free ep scattering, P_L=0.56 and P_T=-0.47. With 80% polarization, an average analyzing power of 0.5, and $\chi = 217°$, the measured asymmetries will be $\epsilon_T = 0.175$ and $\epsilon_L = 0.115$. The uncertainty on the asymmetry is given by $\sqrt{2/N_s}$, where N_s is the number of good scatters in the analyzer. The relative uncertainty of R is then

$$\sqrt{(2/N_s)(1/\epsilon_T^2 + 1/\epsilon_L^2)}$$

For a 2% relative uncertainty, the number of good scatters is then about 5×10^5. The fraction of events which scatter usefully, including losses due to tracking inefficiency and other losses, is about 2%. The total number of coincidences required is about 2.5×10^7. At 200 Hz data acquisition rate, the total time per bin is 35 hours, for a total of 70 hours on ^{4}He. The hydrogen rate will be greater than the 200 Hz data acquisition rate, so the time for it for similar statistics will also be about 35 hours per bin. With two ^{4}He bins and four hydrogen bins, the total time will be 210 hours data taking. We would like to allow a contingency time of 2 days. The target change will take about two days as well. The total time requested is then about 11 days running and 2 days for the target change, for a total of 13 days.

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