Forward Spectrometer for Large Acceptance Experiments in Hall A at Jefferson Lab for the 12-GeV Upgrade

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Abstract

The high precision measurements of the ratio of the proton elastic form factors using recoil polarization method are one of the most successful results performed at Jefferson Lab. The measurements have been performed up to $Q^2 = 9\ GeV^2$, close to the limit for the 6 GeV beam energy presently available there. An upgrade to 12 GeV is approved for the electron beam at Jefferson Lab and 12-GeV beam delivery is presently scheduled on 2015. A new large-acceptance forward spectrometer in Hall A would allow the extension of the measurement of the ratio of the proton form factors up to $Q^2 = 15\ GeV^2$. Such a spectrometer has been designed and it will allow other interesting experiments in the 12 GeV era in Hall A at Jefferson Lab.
A brief description of the designed new apparatus and the physics that it will allow, in particular the measurement of the ratio of the proton form factors, is shortly presented here.

1 Introduction

Form factor data of the nucleons are of great interest as a testing ground of QCD, as results from lattice QCD calculations become increasingly accurate and realistic. The two Sachs form factors G_{Ep} and G_{Mp}, required to describe the nucleon charge and magnetic distribution have been traditionally measured by Rosenbluth separation. G_{Ep} data obtained by this method have suffered from large inconsistencies, now understood with the measurements using the recoil polarization method, which showed that the ratio G_{Ep}/G_{Mp} is in fact not constant, as resulted by Rosenbluth separation, and it decreases by a factor of 3.7 over the Q^2 range from 1 to 5.6 GeV^2 [1, 2].

This results are illustrated in Fig. 1 and are also compared with Rosenbluth separation data.
An experiment, namely E012-07-109, has been approved at Jefferson Lab to extend the measure of the ratio of the proton elastic form factors, using the recoil polarization method, up to $Q^2 = 15\ GeV^2$ in the 12-GeV era of CEBAF, the electron beam at Jefferson Laboratory [3]. According to the present schedule, 12-GeV beam will be available in the year 2015. Critical Decision Three (CD-3) from US Department of Energy, corresponding to the start of construction, is expected in the year 2008.
To obtain sufficient statistics for such large momentum transfer, the recoil proton will need to be detected in a new large-acceptance detector. This new detector will include a single dipole magnet, a polarimeter with three sets of tracking chambers, and a hadron calorimeter. The tracking system of the magnet and of the polarimeter will be realized using Micro Pattern Gaseous detectors, for example Gas Electron Multiplier (GEM) [5] or MICROMEGA [6]. The hadron calorimeter will be already available well in advance with respect to the scheduled time of the experiment.

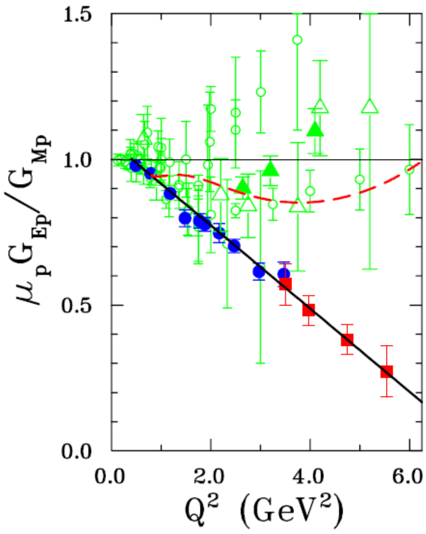

Figure 1: Comparison of the $\mu_p G_{Ep}/G_{Mp}$ from the previous polarization data at Jefferson Lab and Rosenbluth separation. Squared and filled-circle points correspond to different periods of data taking. Dashed curve is a re-fit of Rosenbluth data [4], solid curve is an updated form of the fit in [2].

The new large acceptance spectrometer in Hall A will allow other interesting experiments, such as, for example, Semi-Inclusive Deep Inelastic Scattering (SIDIS) on polarized target to measure spin-dependent Distribution Functions (DFs) of the nucleon.

2 Proton Form Factors using Recoil Polarization Method

In the one-photon exchange approssimation the scattering of longitudinally polarized electrons from unpolarized hydrogen results in transfer of polarization to the recoil proton with two components, P_t perpendicular to, and P_l, parallel to the proton momentum in the scattering plane [7, 8]:

$$I_0 P_t = -2\sqrt{\tau(1+\tau)} G_E G_M \ tan(\theta_e/2) \quad (1)$$

$$I_0 P_l = \frac{1}{m_p}(E_e + E_e^{'})\sqrt{\tau(1+\tau)} G_M^2 \ tan^2(\theta_e/2) \quad (2)$$

where $\tau = Q^2/4m_p^2$, E_e, $E_e^{'}$, and θ_e are the initial and final electron energy and scattering angle, and $I_0 \sim G_E^2 + \frac{\tau}{\epsilon} G_M^2$.
Measuring simultaneously these two components and taking their ratio gives the ratio of the form factors:

$$\frac{G_E}{G_M} = -\frac{Pt}{Pl}\frac{(E_e + E_e^{'})}{2m_p} \ tan(\theta_e/2) \quad (3)$$

Using the polarization technique, the form factor ratio G_E/G_M at a given Q^2 can be obtained without measuring the absolute cross sections and without change of beam energy or detector angle, thus eliminating important sources of systematic uncertainties. Radiative corrections have been shown to be very small for polarization observables [9]. The analyzing power of the polarimeter and the beam polarization that appear as a coefficient to P_t and P_l cancels out in Eq. 3 and their knowledge is not needed. However the efficiency of the experiment requires that these quantities must be maximized to take precision data in the minimum time as possible.

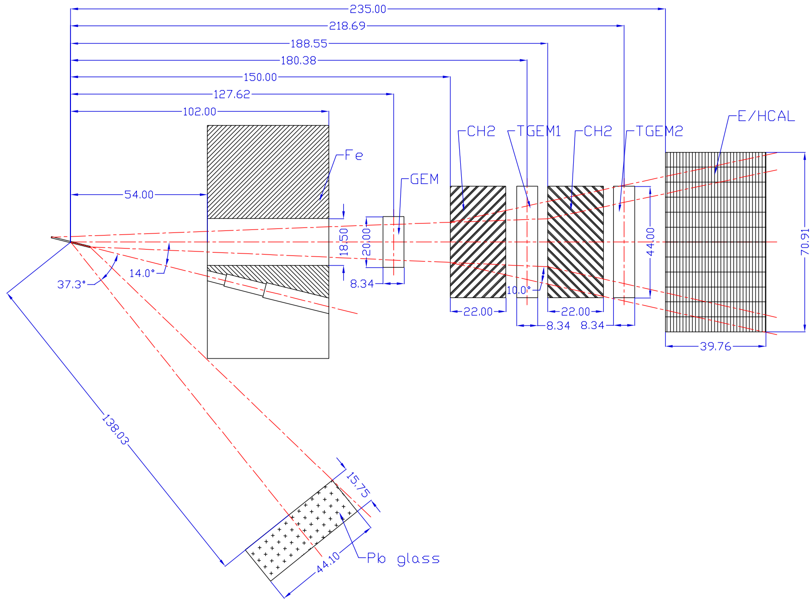

Figure 2: The Experimental Setup for the experiment E012-07-109.

3 Hall A Experimental Setup

The experiment will be performed in Hall A, one of the three experimental halls presently at Jefferson Lab. The electron beam will pass through a 40 cm long Liquid H_2 target in a scattering chamber. The electron will be detected in a recently-built electromagnetic calorimeter. The layout of the experimental setup is shown in Fig. 2

A non-superconducting magnet, type 48D48, is placed close to the target providing a solid angle > 33 msr. The magnet can view a target of 40 cm length. The magnet is followed by a polarimeter and a hadron calorimeter. The polarimeter consists of two CH_2 analyzers with tracking chambers on the back side of each analyzer. The hadron calorimeter, with an energy resolution of about 30% for high energy protons, has two important functions. First, the calorimeter provides a trigger with a high threshold of 4 GeV to reduce the Data Acquisition (DAQ) rate. Second, it provides both coordinates of the hadron shower with an accurancy of 15 mm, greatly facilitating the tracking analysis in presence of a very high hit multiplicity.

The tracking of this new Large Acceptance Forward Angle Spectrometer will be performed using Micro Pattern Gaseous chambers. One option for the construction of the chambers is the Gas Electron Multiplier (GEM) technology. Each chamber gives two coordinates (x,y) by means of two layers of readout strips on which charge from the chamber is collected. Also a rear tracker will be realized to be used for the polarimeter.

The typical foil thickness and hole diameter in thin GEM technology are both $50-70$ μm an the pitch is 100 μm. The amount of material can be as low as 50 mg/cm^2. The front GEM tracker will cover an area of about 40×75 cm^2. Rear tracker for the polarimeter will cover an area of about 80×150 cm^2. An angular resolution of 0.2 $mrad$ is required, a value similar to the contribution of the multiple scattering in the air between the target and the tracker. This can be achieved, for example, with a distance of about 50 cm between side GEM chambers. A complete drawing of the designed Large Acceptance Forward Angle is shown in Fig. 3.

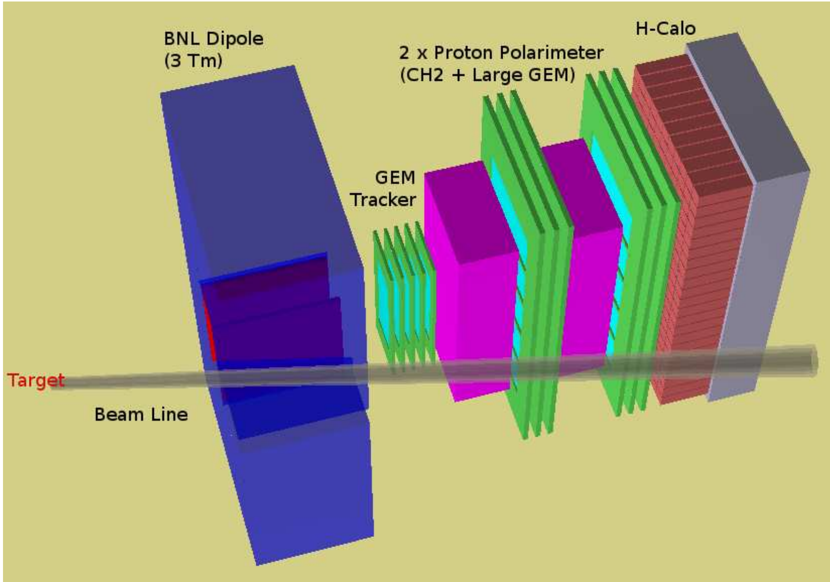

Figure 3: Drawing of the Large Acceptance Forward Angle Spectrometer.

4 Other Experiments with Large Acceptance Forward Angle Spectrometer

The Large Acceptance Forward Angle Spectrometer to be used for the experiment E012-07-109 will allow several other interesting experiments in the 12-GeV era of Jefferson Lab, as for example Semi-Inclusive Deep-Inelastic-Scattering on polarized targets to measure spin-dependent Distribution Functions of the nucleon. Furthermore, the study of the neutron form factor ratio at $Q^2 = 7\ GeV^2$ will be also possible with the new spectrometer, as well as experiments of photoproduction of J/Ψ from proton.

5 Summary

Knowledge of the proton form factors is crucial for the understanding of the structure of the nucleon. Form factor data are required for tests of QCD. Phenomenological models have been challenged by elastic form factor data obtained at Jefferson Lab.
An experiment has been approved at Jefferson Lab to perform the measurement of G_{Ep}/G_{Mp} at $Q^2 = 12.9$ and $14.8\ (GeV/c)^2$ through a measurement of the polarization transfer in the elastic reation $H(\overrightarrow{e}, e'\overrightarrow{p})$. The experiment will run in the 12-GeV era at Jefferson Lab and it requires a new Large Acceptance Forward Angle Spectrometer. The dipole of the spectrometer, type 48D48, is available from the fixed target AGS program at BNL. The polarimeter will be developed from the existing polarimeter built for previous experiments. The new and the key part of the detector is the set of tracking chambers, these will be built using the GEM technology, similar to the chambers used in the COMPASS experiment.

References

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