NUCLEON FORM FACTORS PROGRAM WITH SBS AT JLAB

BOGDAN WOJTSEKHOWSKI

*Thomas Jefferson National Accelerator Facility
 Newport News, Virginia 23606 USA*

Published 18 December 2014

The physics of the nucleon form factors is the basic part of the Jefferson Laboratory program. We review the achievements of the 6-GeV era and the program with the 12-GeV beam with the SBS spectrometer in Hall A, with a focus on the nucleon ground state properties.

Keywords: Nucleon; form factors; flavor decomposition.

PACS Numbers: 14.20.Dh, 13.40.Gp

1. The high Q^2 nucleon form factor experiments

The nucleon structure investigation using high energy electron scattering has been a successful field where many discoveries have been made since the 1956 observation of the proton form factor.¹ To a large extent, this success has been due to the dominance of the one-photon exchange mechanism of electron scattering, which allows reliable interpretation of the experimental data.² By the early 90s, the form factor data sets for the proton and the neutron were found to be mainly proportional to the one form factor, $F_{Dipole} = (1 + Q^2/0.71[GeV^2])^{-2}$ for all four: magnetic and electric for the proton, and magnetic and electric for the neutron.³

The most decisive studies of the partonic structure of nucleon could be performed when the dominant part of the wave function is a 3-quark Fock state. This requires large momentum transfer, $Q^2 > 1 \text{ GeV}^2$, when the contribution of the pion cloud is suppressed. The SLAC experimental data⁴ on the proton Dirac form factor F_1^p have been found to be in fair agreement with a scaling prediction⁵ based on perturbative QCD: $F_1^p \propto Q^{-4}$, where Q^2 is the negative four-momentum transfer squared.

The experimental results⁶ from Jefferson Laboratory (JLab) for the ratio of the proton Pauli form factor F_2^p and the Dirac form factor F_1^p have been found to be in disagreement with the scaling law $F_2^p/F_1^p \propto 1/Q^2$ suggested in Ref. 5.

This is an Open Access article published by World Scientific Publishing Company. It is distributed under the terms of the Creative Commons Attribution 3.0 (CC-BY) License. Further distribution of this work is permitted, provided the original work is properly cited.

A JLab high precision experiment made use of the double polarization method, which was first proposed in Ref. 7. This method is less sensitive to the two-photon exchange contribution and, due to the interference nature of the double polarization asymmetry, has large sensitivity to the small electric form factor. The data for $\mu_p G_E^p / G_M^p$ shown in Fig. 1(left) present an amazing drop of G_E^p , which also means that F_1^p and $Q^2 \times F_2^p$ for the proton have different Q^2 dependencies.

The measurement of the proton to the neutron cross section ratio in the quasi-elastic knockout from the deuteron was used in JLab's precision measurement of the neutron magnetic form factor.⁸ With the recent JLab experiment on the neutron electric form factor,⁹ the data on all four nucleon form factors have become available in the Q^2 region of 3-quark dominance. Analysis of the flavor contributions to the nucleon form factors using the data was performed.¹⁰ The flavor decomposition allowed us to make two new observations:

- The contributions of the **up** quarks and **down** quark to the magnetic and electric form factors of the proton all have different Q^2 dependencies.
- The contribution of the **down** quark to the F_1^p form factor at $Q^2=3.4 \text{ GeV}^2$ is three times less than the contribution of the **up** quarks (corrected for the number of quarks and their charge).

The second observation suggests that the probability of proton survival after the absorption of a massive virtual photon is much higher when the photon interacts with an **up** quark, which is doubly represented in the proton. This may be interpreted as an indication of an important role of the **up-up** correlation. At high Q^2 a correlation usually enhances the high momentum component and the interaction cross section. The relatively weak **down** quark contribution to the F_1^p indicates a suppression of the **up-down** correlation or a mutual cancellation of different types of **up-down** correlations. The QCD-based calculations of the nucleon form factors in the Dyson-Schwinger Equations approach¹¹ revealed a key role of the diquark in high Q^2 electron-nucleon elastic scattering.

2. Future experiments in Hall A with SBS

Accurate measurement of the FFs at large Q^2 will be possible during the next few years at Jefferson Lab, where the 12-GeV energy upgrade is almost completed.¹² In 2007 we proposed a configuration of a large acceptance spectrometer at a small angle to the beam.¹³ This large luminosity moderate acceptance spectrometer, SBS, become a key component of the form factor program in Hall A at JLab. The program includes the measurements of three ratios: the proton electric form factor to the proton magnetic form factor,¹⁴ the neutron electric form factor to the proton magnetic form factor,¹⁵ and the neutron electric form factor to the neutron magnetic form factor.¹⁶ For absolute normalization of the form factor values, the precision measurement of the proton magnetic form factor will also be performed in Hall A.¹⁷ A summary of experimental parameters is shown in Table 1.

Fig. 1. Left: Existing data and projected data accuracy for the ratio of the $\mu_p G_E^p / G_M^p$. Right: Ratio of the **up** and **down** quark contributions to the proton form factor F_1^p .

Table 1. Future measurements of the FFs in Hall A at JLab (approved experiments). Projected range of Q^2 and accuracy relatively the dipole FF at maximum value of Q^2 .

Form factor	Reference	Q^2 range, GeV ²	$\Delta G / F_{Dipole}$ (stat/syst) at max Q^2
G_E^p	14	5-12	0.08 / 0.02
G_M^p	17	4.8-14.0	0.01 / 0.02
G_E^n	16	1.5-10.2	0.09 / 0.03
G_M^n	15	3.5-13.5	0.06 / 0.03

3. Flavor decomposition of the form factor F_1^p and GPDs at very large Q^2

At Q^2 above 10 GeV², measurement of the electric form factors, especially the G_E^n , becomes difficult. However, due to the large value of $Q^2/4M_N^2$, the F_1 could be obtained with a relatively small uncertainty just from the value of the magnetic form factor:

$$F_1 = (G_E + Q^2/4M_N^2 \times G_M) / (1 + Q^2/4M_N^2) \quad (1)$$

The flavor decomposition of F_1 also could be accomplished accurately. Fig. 1(right) shows projected data points and a systematic error corridor for assumed uncertainty in G_E^p of ± 0.1 . Here we used the Kelly fit form factors for illustration purposes. We would like to note that the ratio F_1^d / F_1^u could potentially cross the zero line, which would require a significant change of GPDs parametrization because the currently used form does not allow negative values of GPDs, see e.g. the reference.¹⁸

Acknowledgments

The author would like to thank the organizing committee of the “International Workshop on e+e- collisions from Phi to Psi” for the invitation to present a talk. This work was supported in part by the U. S. National Science Foundation, and by Department of Energy (DOE) contract number DE-AC05-06OR23177, under which

the Jefferson Science Associates operates the Thomas Jefferson National Accelerator Facility.

References

1. E.E. Chambers and R. Hofstadter, Phys. Rev. **103**, 1454 (1956).
2. M.N. Rosenbluth, Phys. Rev. **79**, 615 (1950).
3. P. Bosted, Phys. Rev. C **51**, 409 (1995).
4. R.G. Arnold *et al.*, Phys. Rev. Lett. **57**, 174 (1986); A.F. Sill *et al.*, Phys. Rev. D **48**, 29 (1993).
5. G.P. Lepage and S.J. Brodsky, Phys. Rev. Lett. **43**, 545 (1979); **43**, 1625(E) (1979).
6. M.K. Jones *et al.*, Phys. Rev. Lett. **84**, 1398 (2000); O. Gayou *et al.*, Phys. Rev. C **64**, 038202 (2001); O. Gayou *et al.*, Phys. Rev. Lett. **88**, 092301 (2002); V. Punjabi *et al.*, Phys. Rev. C **71** (2005) 055202; A. Puckett *et al.*, Phys. Rev. Lett. **104**, 242301 (2010); A. Puckett *et al.*, Phys. Rev. C **85** (2012) 045203.
7. A.I. Akhiezer, L.N. Rosenzweig and I.M. Shmushkevich, Sov. Phys. JETP **6**, 588 (1958); A.I. Akhiezer and M. P. Rekalo. Sov. J. Part. Nucl., **3**:277, 1974; R.G. Arnold, C.E. Carlson, and F. Gross, Phys. Rev. C **23**, 363 (1981).
8. J. Lachniet *et al.*, Phys. Rev. Lett. **102**, 192001 (2009).
9. S. Riordan *et al.*, Phys. Rev. Lett. **105**, 262302 (2010).
10. G. Cates *et al.*, Phys. Rev. Lett. **106**, 252003 (2011).
11. C.D. Roberts *et al.*, Eur. Phys. J. **ST 140**, 53 (2007); I.C. Cloët *et al.*, Few-Body Systems **46**, 1(2009).
12. Thomas Jefferson National Accelerator Laboratory, <https://www.jlab.org>
13. Super Bigbite Spectrometer, <http://hallaweb.jlab.org/12GeV/SuperBigBite/>
14. JLab experiment E12-07-109, E. Brash, E. Cisbani, M. Jones, M. Khadaker, L. Pentchev, C.F. Perdrisat, V. Punjabi, and B. Wojtsekhowski *et al.*, http://www.jlab.org/exp_prog/PACpage/PAC32/talks/wojtsekhowski.pdf
15. JLab experiment E12-09-019, J. Annand, G. Gilman, B. Quinn and B. Wojtsekhowski *et al.*, http://www.jlab.org/exp_prog/PACpage/PAC34/talks/09-019.pdf
16. JLab experiment E12-09-016, G. Cates, S. Riordan, and B. Wojtsekhowski *et al.*, http://www.jlab.org/exp_prog/PACpage/PAC34/talks/09-016.pdf
17. JLab experiment E12-07-108, J. Arrington, E. Christy, S. Gilad, B. Mofit, V. Sulkosky and B. Wojtsekhowski *et al.*, http://www.jlab.org/exp_prog/PACpage/PAC32/talks/PR12-07-108.pdf
18. M. Diehl and P. Kroll, Eur.Phys.J. **C73** (2013) 2397; arXiv:1302.4604.