New possible insight into JLab proton polarization data puzzle by DIS

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Abstract. It is demonstrated that the JLab proton polarization data puzzle could be solved by the new sum rule giving into a relation proton and neutron Dirac and Pauli form factors in the space-like region with a difference of the differential proton and neutron cross sections describing just Q^2 distribution in deep inelastic electron scattering process.

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The proton electromagnetic (EM) structure is described by two form factors (FF's) dependent on the squared four-momentum transfer $t = -Q^2$. The most natural are Dirac $F_{1p}(t)$ and Pauli $F_{2p}(t)$ FF's obtained in a parametrization of the matrix element of the EM current

$$\langle p^{'}|J_{\mu}^{EM}|p\rangle = \bar{u}(p^{'})\{\gamma_{\mu}F_{1p}(t) + i\frac{\sigma_{\mu\nu}(p^{'}-p)_{\nu}}{2m_p^2}F_{2p}(t)\}u(p) \tag{1}$$

according to a maximum number of linearly independent covariants to be constructed from proton momenta and spin parameters.

The most suitable in extracting of experimental information are Sachs electric $G_{Ep}(t)$ and magnetic $G_{Mp}(t)$ FF's, giving in the Breit frame charge and magnetization distributions within the proton, respectively. Both sets of FF's are related

$$G_{Ep}(t) = F_{1p}(t) + \frac{t}{4m_p^2}F_{2p}; \quad G_{Mp} = F_{1p} + F_{2p}, \tag{2}$$

similarly for the neutron

$$G_{En}(t) = F_{1n}(t) + \frac{t}{4m_n^2}F_{2n}; \quad G_{Mn} = F_{1n} + F_{2n}. \tag{3}$$

The proton EM FF data in the space-like region ($t < 0$) have been obtained (see Fig. 1) from the measured cross-section (in DESY, SLAC and Bonn)

$$\frac{d\sigma^{lab}(e^- p \to e^- p)}{d\Omega} = \frac{\alpha^2}{4E^2}\frac{\cos^2(\theta/2)}{\sin^4(\theta/2)\frac{1}{1+(\frac{2E}{m_p})}\sin^2(\theta/2)}\left[A(t) + B(t)\tan^2(\theta/2)\right], \tag{4}$$

where $\alpha = 1/137$ and E - incidental energy

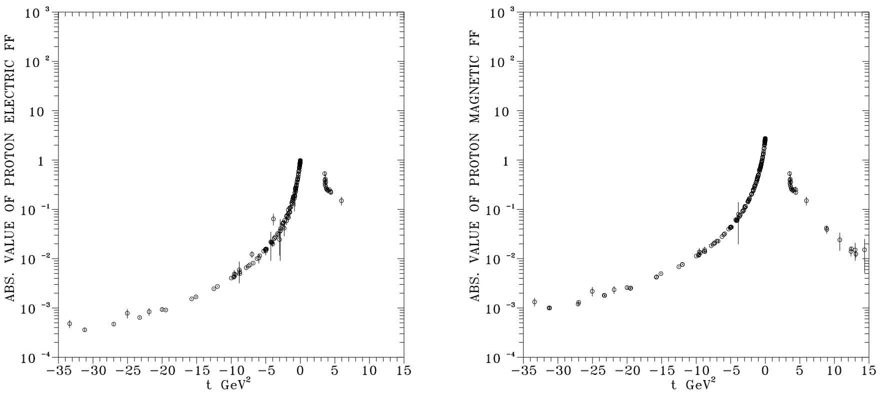

FIGURE 1. Compiled proton electric and magnetic FF data.

$$A(t) = \frac{G_{Ep}^2(t) - t/4m_p^2 G_{Mp}^2(t)}{1 - t/4m_p^2} \qquad B(t) = -2 \cdot t/4m_p^2 G_{Mp}^2(t) \tag{5}$$

by so-called Rosenbluth technique, employing a linear $\tan^2(\theta/2)$ dependence of (4).

Large progress has been recently done in the obtaining of the ratio (see Fig. 2)

$$\frac{G_{Ep}}{G_{Mp}} = -\frac{P_t}{P_l}\frac{(E+E^{'})}{2m_p}\tan(\theta/2). \tag{6}$$

in the space-like ($t = -Q^2 < 0$) region by measuring [1, 2] simultaneously transverse

$$P_t = \frac{h}{I_0}(-2)\sqrt{\tau(1+\tau)}G_{Ep}G_{Mp}\tan(\theta/2) \tag{7}$$

and longitudinal

$$P_l = \frac{h(E+E^{'})}{I_0 m_p}\sqrt{\tau(1+\tau)}G_{Mp}^2\tan^2(\theta/2), \tag{8}$$

components of the recoil proton's polarization in the electron scattering plane of the polarization transfer process $\vec{e}^- p \to e^- \vec{p}$, where h is the electron beam helicity, I_0 is the unpolarized cross-section excluding σ_{Mott} and $\tau = Q^2/4m_p^2$. As one can see from Fig. 2, these ratio data are in strong disagreement with the data obtained by Rosenbluth technique.

Due to the fact that $G_{Mp}^2(t)$ in (5) is multiplied by $-t/4m_p^2$ factor, i.e. as $-t$ increases, the measured cross-section becomes dominant by $G_{Mp}^2(t)$ part contribution making the extraction of $G_{Ep}^2(t)$ more and more difficult, the independent determination of $G_{Mp}(t)$ and $G_{Ep}(t)$ by Rosenbluth technique has been done [3] only up to $8.7 GeV^2$ and the extraction of G_{Mp} at higher values of Q^2 up to $\sim 31\ GeV^2$ assumes G_{Ep}=G_{Mp}/μ_p. As a result one could believe more to experimental data on G_{Mp} in space-like region than to experimental data on G_{Ep} and the disagreement of ratios in Fig. 2 is caused by contradicting behaviours of $G_{Ep}(Q^2)$ and on no account by $G_{Mp}(Q^2)$.

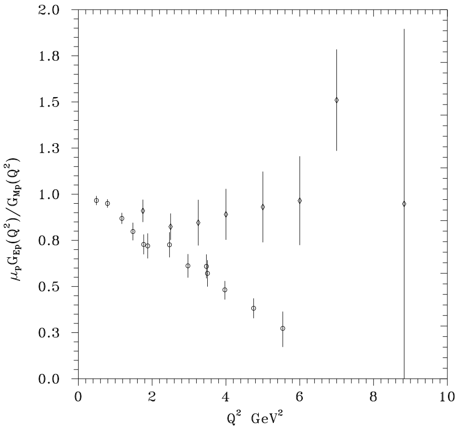

FIGURE 2. The JLab proton polarization data on ratio $\mu_p G_{Ep}/G_{Mp}$ (circles) and the same ratio calculated from data on G_{Ep} and G_{Mp} obtained by Rosenbluth technique (diamonds).

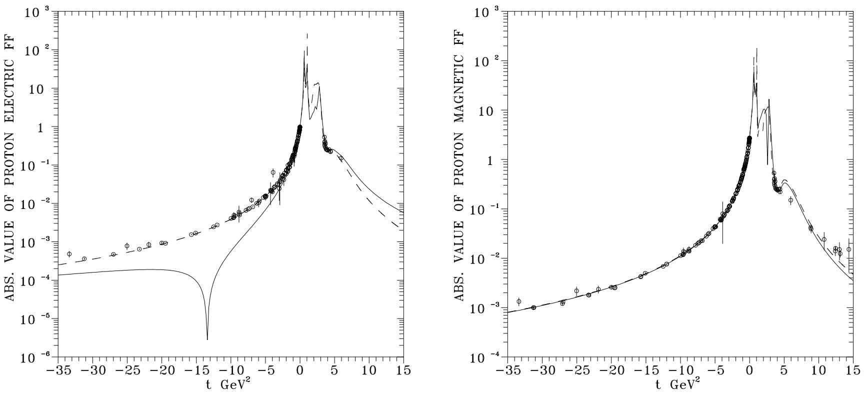

FIGURE 3. The predicted different behaviours of G_{Ep} in $t < 0$ region dependent on the fact if Rosenbluth technique data (dashed line) or JLab proton polarization data (full line) are used in the analysis

We have carried out a test of this hypothesis in framework of the ten-resonance Unitary and analytic model of nucleon EM structure [4], which is formulated in the language of isoscalar $F^s_{1,2}(t)$ and isovector $F^v_{1,2}(t)$ parts of the Dirac and Pauli FF's and comprises all known nucleon FF properties.

First, we have carried out the analysis of all proton and neutron data obtained by Rosenbluth technique together with all proton and neutron data in time-like region.

Then all $|G_{Ep}(t)|$ space-like data obtained by Rosenbluth technique were excluded and the new JLab proton polarization data on $\mu_p G_{Ep}(Q^2)/G_{Mp}(Q^2)$ for 0.49 GeV^2 $\leq Q^2 \leq$ 5.54 GeV^2 were analyzed together with all electric proton time-like data and all space-like and time-like magnetic proton, as well as electric and magnetic neutron data.

The results of the analysis are presented in Fig. 3 from where it is seen that almost nothing is changed in a description of $G_{Mp}(t)$, $G_{En}(t)$ and $G_{Mn}(t)$ in both space-like and time-like regions, and also $|G_{Ep}(t)|$ in the time-like region. There is only a difference in behaviours of $G_{Ep}(t)$ in $t < 0$ region dependent on the fact if old data obtained by

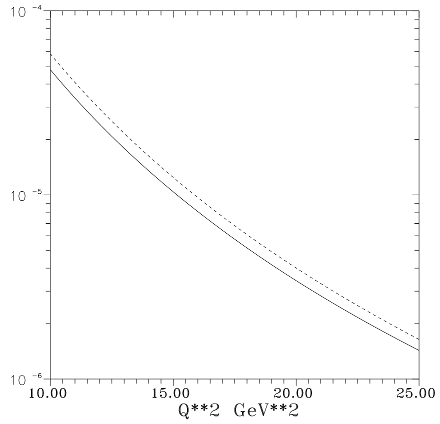

FIGURE 4. A prediction of two different behaviours of the right-hand side in (9) following from two different behaviours of G_{Ep} in Fig. 3.

Rosenbluth technique are used (dashed line) or the new JLab proton polarization data are analysed (full line).

In order to distinguish which of these behaviours of $G_{Ep}(t)$ in the space-like ($t < 0$) region is correct we suggest to employ new sum rule [5]

$$\begin{aligned} F_{1p}^2(-Q^2) + \frac{Q^2}{4m_p^2} F_{2p}^2(-Q^2) - \\ -F_{1n}^2(-Q^2) - \frac{Q^2}{4m_n^2} F_{2n}^2(-Q^2) = \\ = 1 - 2\frac{(Q^2)^2}{\pi\alpha^2}\left(\frac{d\sigma^{e^-p\to e^-X}}{dQ^2} - \frac{d\sigma^{e^-n\to e^-X}}{dQ^2}\right), \end{aligned} \tag{9}$$

giving into a relation proton and neutron Dirac and Pauli FF's in the space-like region with a difference of the differential proton and neutron cross-sections describing Q^2 distribution in DIS. Evaluating Dirac and Pauli FF's on the left-hand side corresponding to the old (dashed line) and new (full line) space-like behaviour of $G_{Ep}(t)$ in Fig. 3 one predicts the corresponding behaviours of the difference of deep inelastic cross sections in Fig. 4. By a measurement of the latter the true $t < 0$ behaviour of $G_{Ep}(t)$ can be chosen.

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REFERENCES

1. M. K. Jones et al, *Phys. Rev. Lett.* **84** (2000) 1398.
2. O. Gayon et al, *Phys. Rev. Lett.* **88** (2002) 092301.
3. L. Andivakis et al, *Phys. Rev.* **D50** (1994) 5491.
4. S. Dubnička, A. Z. Dubničková, P. Weisenpacher, *J. Phys.* **G29** (2003) 405.
5. E. Bartoš, S. Dubnička, E. A. Kuraev, *Phys. Rev.* **D70** (2004) 117901.