Analysis of the elastic *ep*-scattering and violation of the discrete symmetries

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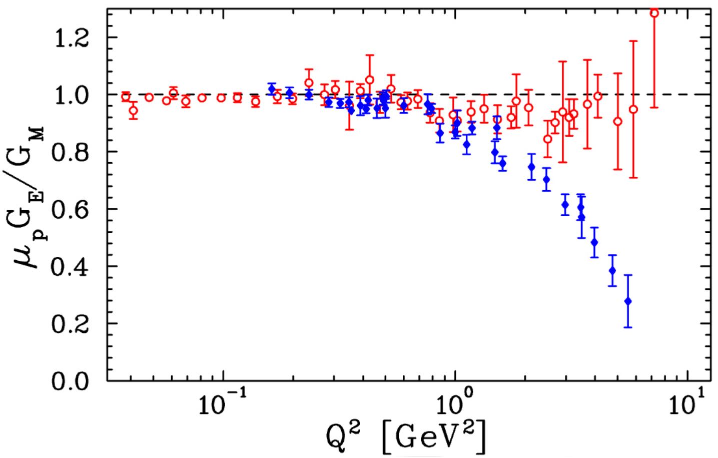
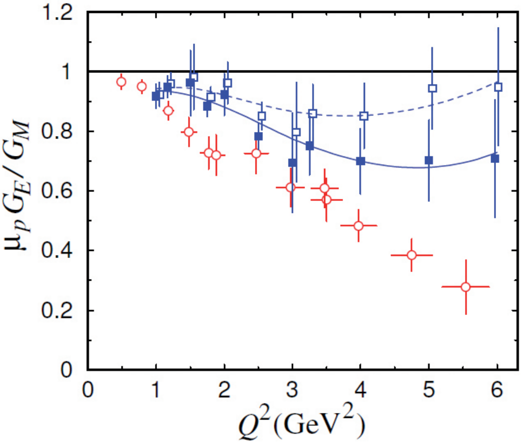
"Non-Rosenbluth"behavior of the proton electromagnetic form factors:

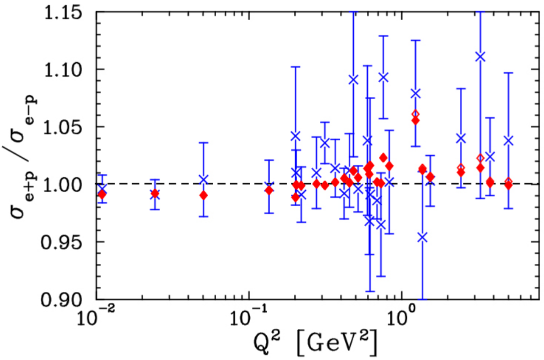


- J. Arrington, W. Melnitchouk, and J. A. Tjon, Phys. Rev. C **76**, 035205 (2007)

Conventional approach to the solution of this problem is two-photon exchange:



Asymmetry between $e^- p$- and $e^+ p$-scattering:



- The data (crosses) are taken from *J. Arrington*, Phys. Rev. C 69, 032201(R) (2004) and references therein.

So the "non-Rosenbluth"behavior problem can't be considered as the solved.

- Hypothesis about *CP*-violation in the electromagnetic processes in the composite systems with strong interaction.
    1. J. Bernstein, G. Feinberg and T. D. Lee, Phys. Rev. **B1650** 139 (1965)
    2. V.M. Dubovik, A.A. Cheshkov, ZhETF. **51**, 165 (1966)
    3. Okun L. B., Sov. Phys. Usp. **9** 574 - 601 (1967)
- Measurements of the electric dipole moments of the nucleons.
    1. C. A. Baker at al., Phys. Rev. C **72**, 034612 (2005)
    2. Y. N. Srivastava, A. Widom, J. Swain, and O. Panella, Phys. Rev. D **82**, 094003 (2010)

In this work we suggest to analyse the results of the elastic $e^- p$-scattering from the point of view of hypothesis about CP-violation in the proton as composite system.

The matrix element of proton electromagnetic current with regard to the self-adjointness, the current conservation low and CP-symmetry:

$$\begin{aligned}\langle \vec{p}\,,\, m|j_\mu(0)|\vec{p}\,'\,,\, m'\rangle = \sum_{m''} \langle m|D^{1/2}(p,p')|m''\rangle \times \\ \times \langle m''|f_{10}(Q^2)\,K'_\mu + i\,f_{30}(Q^2)\,R_\mu|m'\rangle\;,\end{aligned} \tag{1}$$

$$K'_\mu = (p+p')_\mu\;,\;\; R_\mu = \epsilon_{\mu\,\nu\,\lambda\,\rho}\,p^\nu\,p'^{\,\lambda}\,\Gamma^\rho(p')\;, \tag{2}$$

$$f_{10}(Q^2) = \frac{2MG_E(Q^2)}{\sqrt{4M^2+Q^2}}\;,\quad f_{30}(Q^2) = -\frac{4G_M(Q^2)}{M\sqrt{4M^2+Q^2}}\;. \tag{3}$$

- A. F. Krutov and V. E. Troitsky, Physics of Particles and Nuclei. - 2009. V.40.- P.136-161.

Rosenbluth's cross section:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott}\left[A(Q^2) + B(Q^2)\tan^2\left(\frac{\theta}{2}\right)\right] , \tag{4}$$

Ratio of electric and magnetic form factor in the polarized *ep*-scattering:

$$\frac{R(Q^2)}{\mu_p} = \frac{G_E(Q^2)}{G_M(Q^2)} = -\frac{P_t}{P_l}\frac{(E+E')}{2M}\tan\left(\frac{\theta}{2}\right) , \tag{5}$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{Mott} = \frac{\alpha^2\cos^2\Big(\theta/2\Big)}{4E^2\sin^4\Big(\theta/2\Big)[1+2\xi\sin^2\Big(\theta/2\Big)]} , \tag{6}$$

$$A(Q^2) = \frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1+\tau} , \tag{7}$$

$$B(Q^2) = 2\tau G_M^2(Q^2) , \tag{8}$$

where $\xi = E/M$, $\tau = -Q^2/4M^2 = t/4M^2$.

The matrix element of electromagnetic current with regard to the self-adjointness, the current conservation low and CP-violation:

$$\langle\vec{p},m|j_\mu(0)|\vec{p}\,',m'\rangle = \sum_{m''}\langle m|D^{1/2}(p,p')|m''\rangle\langle m''|\Big[f_{10}(Q^2)\,K'_\mu + \\ + f_{11}(Q^2)(ip_\mu\,\Gamma^\mu(p'))\,K'_\mu + f_{20}(Q^2)A_\mu + i\,f_{30}(Q^2)\,R_\mu\,\Big]|m'\rangle\;, \tag{9}$$

where

$$A_\mu = \Gamma_\mu(p') - \left(\frac{K'_\mu}{K'^2} + \frac{K_\mu}{K^2}\right)(p_\lambda\,\Gamma^\lambda(p'))\;,\quad K_\mu = (p-p')_\mu\;, \tag{10}$$

$f_{11}(Q^2)$ - electric dipole form factor, $f_{20}(Q^2)$ - anapole form factor

Cross section of the non-polarized *ep*-scattering:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott}\Big[a(Q^2) + b(Q^2)\,\tan^2\left(\frac{\theta}{2}\right) + \\ + f_{11}(Q^2)\,f_{20}(Q^2)\,D(\tau,\theta) + f_{20}^2(Q^2)\,F(\tau,\theta)\Big]\;, \tag{11}$$

where

$$a(Q^2) = \frac{g_E^2(Q^2) + \tau\,g_M^2(Q^2)}{1+\tau} + f_{11}^2(Q^2)\,\tau\,M^2\,(1+\tau)\;, \tag{12}$$

$$b(Q^2) = 2\tau\,g_M^2(Q^2)\;, \tag{13}$$

$$F(\tau,\theta) = \frac{x}{2\sqrt{\tau}\,(\tau+1)}\left(\sqrt{\frac{1}{x}+\tau+1} + 2\sqrt{\tau}\,(\tau+1)\right)\;, \tag{14}$$

$$D(\tau,\theta) = \frac{M^5\,(E+E')\,(\xi-\xi'+8\tau+10\tau\xi)}{8}\,(1+x(1+2\xi))\;, \tag{15}$$

$$x = \tan^2\left(\theta/2\right)\;,\quad \xi' = \frac{E'}{M}\;,$$

Ratio of the polarizability:

$$\frac{P_l}{P_t} = -\,\frac{g_M(Q^2)}{g_E(Q^2)}\,\frac{(E+E')}{2M}\,\tan\left(\frac{\theta}{2}\right)\times$$
$$\times\left[\frac{1+\alpha\, f_{20}^2(Q^2)/g_M^2(Q^2)}{1+\beta\,\left(f_{11}(Q^2)\, f_{20}(Q^2)\right)/\left(g_M(Q^2)\, g_E(Q^2)\right)}\right]\,, \tag{16}$$

where

$$\alpha = \frac{\sqrt{\tau+1}}{8\sqrt{x}\,\tau\,\left(\sqrt{x\,\tau}+\sqrt{x\,\tau+x+1}\right)}\,,\quad \beta = \frac{1}{M^2(\tau+1)}\,.$$

Approximation:

$$f_{11}(Q^2) \approx 0\,. \tag{17}$$

Cross section of the non-polarized *ep*-scattering in this approximation:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott}\left[a(Q^2) + b(Q^2)\,\tan^2\left(\frac{\theta}{2}\right) + g_A^2(Q^2)\,F(\tau,\theta)\right]\,, \tag{18}$$

where

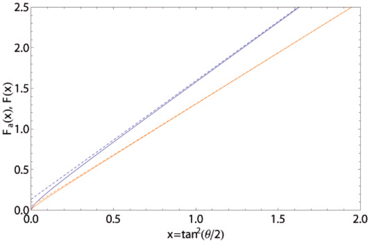
$$f_{20}(Q^2) = \frac{g_A(Q^2)}{\sqrt{1+\tau}}\,. \tag{19}$$

Kinematical function:

$$F(\tau,\theta) = \frac{x}{2\sqrt{\tau}\,(\tau+1)}\left(\sqrt{\frac{1}{x}+\tau+1}+2\sqrt{\tau}\,(\tau+1)\right)\,, \qquad (20)$$

The linear asymptotic of the function F at large $x=\tan^2(\theta/2)$:

$$F_a(\tau,x) = x\left(1+\frac{1}{2\sqrt{\tau\,(\tau+1)}}\right)+\frac{1}{4\sqrt{\tau}\,(\tau+1)^{3/2}}\,. \qquad (21)$$



In the region of the experimental angles kinematical function F is close to linear function F_a.

$$\frac{\alpha}{1+\tau}\frac{g_a^2(Q^2)}{g_m^2(Q^2)} \ll 1\,.$$

- At small Q^2 $\frac{g_a^2(Q^2)}{g_m^2(Q^2)} \ll 1$ because the conflict between the non-polarized and polarized scattering is not observed.
- At middle and large Q^2 kinematical function $\alpha \ll 1$.

In these approximations:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \Big[a(Q^2) + g_A^2(Q^2)\, c(\tau) + \\ + \left(b(Q^2) + g_A^2(Q^2)\, d(Q^2)\right) \tan^2\left(\frac{\theta}{2}\right)\Big] , \quad (22)$$

where

$$a(Q^2) = \frac{g_E^2(Q^2) + \tau\, g_M^2(Q^2)}{1+\tau} , \quad b(Q^2) = 2\,\tau\, g_M^2(Q^2) , \quad (23)$$

$$c(Q^2) = \frac{1}{4\sqrt{\tau}\,(\tau+1)^{5/2}} , \quad d(Q^2) = \frac{1}{\tau+1} + \frac{1}{2\sqrt{\tau}\,(\tau+1)^{3/2}} , \quad (24)$$

$$\frac{P_l}{P_t} = -\frac{g_M(Q^2)}{g_E(Q^2)}\,\frac{(E+E')}{2M}\,\tan\left(\frac{\theta}{2}\right) . \quad (25)$$

Connection between the new form factors and the measured in experiments functions $R(Q^2), A(Q^2)$ and $B(Q^2)$:

$$
\begin{aligned}
R(Q^2) &= \mu_p \frac{g_E(Q^2)}{g_M(Q^2)} = 1 - 0.13(Q^2 - 0.04)\ . \\
(1+\tau)\, A(Q^2) &= g_E^2(Q^2) + \tau\, g_M^2(Q^2) + g_A^2(Q^2)\,(1+\tau)\, c(Q^2)\ , \\
B(Q^2) &= 2\,\tau\, g_M^2(Q^2) + g_A^2(Q^2)\, d(Q^2)\ .
\end{aligned}
\tag{26}
$$

The new form factors in terms of the measured in experiments functions:

$$
\begin{aligned}
g_A^2(Q^2) &= \frac{(\tau+1)\, A(Q^2) - \Big(\big(R(Q^2)/\mu_p\big)^2 + 1\Big) B(Q^2)/2}{\Big(\big(R(Q^2)/\mu_p\big)^2 + 1\Big) d(Q^2)/2 - (\tau+1)\, c(Q^2)}\ , \\
g_M^2(Q^2) &= \frac{1}{2\tau}\big(B(Q^2) + g_A^2(Q^2)\, d(Q^2)\big)\ , \\
g_E^2(Q^2) &= g_M^2(Q^2)\Big(\frac{R(Q^2)}{\mu_p}\Big)^2\ .
\end{aligned}
\tag{27}
$$

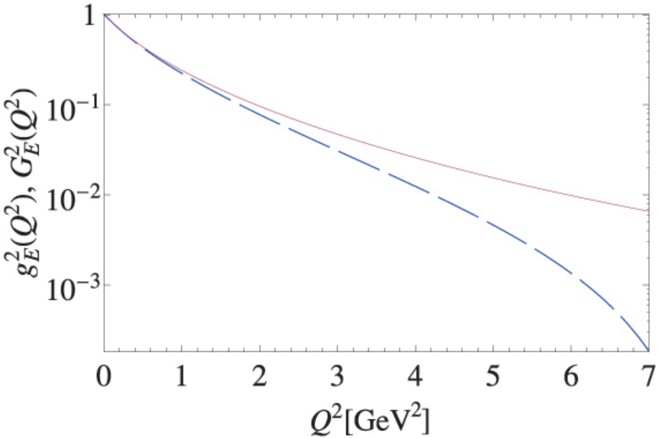
It's possible to performed the estimation of the new form factors in terms of the known analytical fits for $R(Q^2), A(Q^2)$ and $B(Q^2)$:

- O. Gayou at al., Phys.Rev. C 64, 038202,(2001)

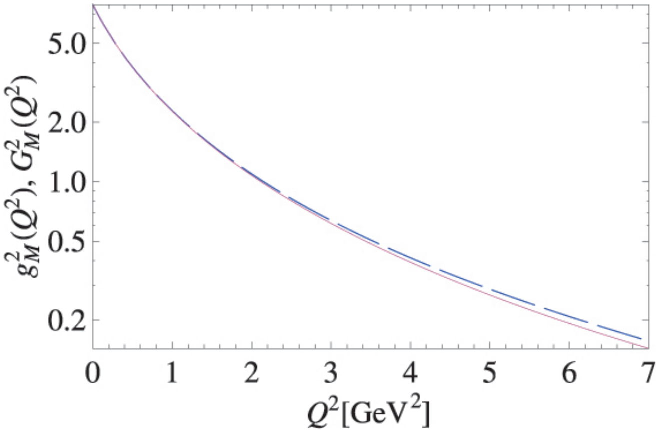
$$R(Q^2) = 1 - 0.13(Q^2 - 0.04)\ .$$

- M. Gari, W. Krümpelmann // Z. Phys. A -Atoms and Nuclei. - 1985. V.322. - P.689-693

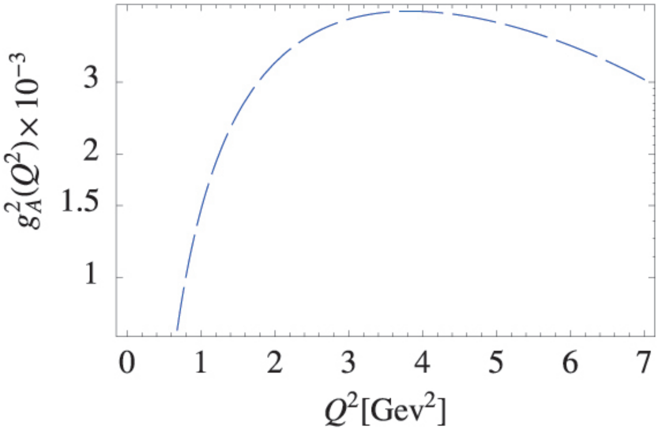
Electric form factors



Magnetic form factors



Anapole form factor



Conclusions

1. The analysis of the elastic non-polarized and polarized *ep*-scattering is performed in the framework hypothesis about *CP*-violation in the electromagnetic process in the composite systems with strong interaction.
2. It's shown that the Rosenbluth's behavior is conserved in the non-polarized *ep*-scattering in the region of the modern experiments.
3. It's shown that hypothesis about *CP*-violation leads to the emergence of the additional anapole form factor in the cross section of the non-polarized *ep*-scattering.
4. The estimation of the new values of the proton form factors is produced.

Acknowledgements

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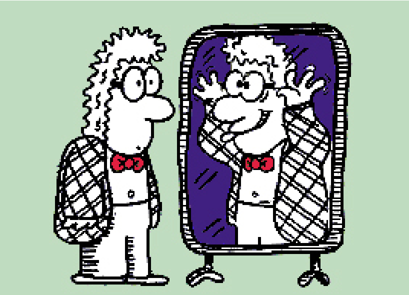

Thank you for your attention