"Non-Rosenbluth" behavior of the proton form factors and the violation of the CP-symmetry

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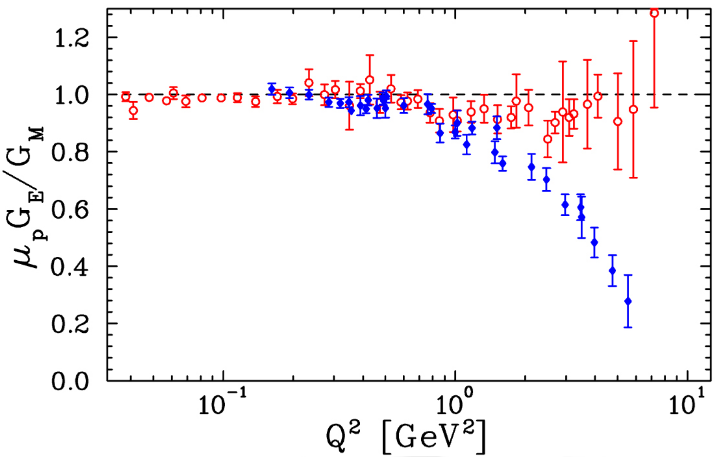
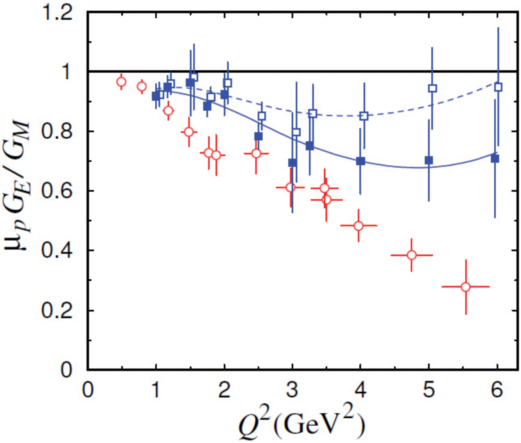
"Non-Rosenbluth"behavior of the proton electromagnetic form factors:



- 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:



- So the "non-Rosenbluth"behavior problem can't be considered as solved.
- Hypothesis about CP-violation in the electromagnetic processes in the composite systems with strong interaction.
- Measurement of parity nonconservation and an anapole moment in cesium. (Woods C. S. et al. Science **275** 1759 (1997))
- Measurements of electric dipole moment of the nucleons.

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 electromagnetic current with regard to the self-adjointness, the current conservation low and CP-symmetry:

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

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

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

- 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:

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

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:

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

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 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:

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

$$\frac{P_l}{P_t} = -\,\frac{g_M(Q^2)}{g_E(Q^2)}\,\frac{(E+E')}{2M}\,\tan\left(\frac{\theta}{2}\right)\left[1 + \frac{\alpha}{1+\tau}\,\frac{g_A^2(Q^2)}{g_M^2(Q^2)}\right]\,, \tag{19}$$

where

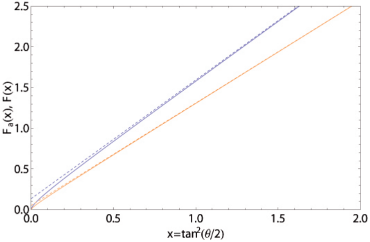
$$f_{20}(Q^2) = \frac{g_A(Q^2)}{\sqrt{1+\tau}}\,. \tag{20}$$

Kinematical function:

$$F(\tau,\theta) = \frac{x}{2\sqrt{\tau}(\tau+1)}\left(\sqrt{\frac{1}{x}+\tau+1}+2\sqrt{\tau}(\tau+1)\right)\,, \qquad (21)$$

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

$$F_a(\tau,x) = x\left(1+\frac{1}{2\sqrt{\tau(\tau+1)}}\right)+\frac{1}{4\sqrt{\tau}(\tau+1)^{3/2}}\,. \qquad (22)$$



In the region of the experimentol angles kinematical function 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 midle and large Q^2 kinematical function $\alpha \ll 1$.

In these approximations:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \left[a(Q^2) + g_A^2(Q^2)\, c(\tau) + \right.$$
$$\left. + \left(b(Q^2) + g_A^2(Q^2)\, d(Q^2)\right) \tan^2\left(\frac{\theta}{2}\right)\right] , \tag{23}$$

where

$$a(Q^2) = \frac{g_E^2(Q^2) + \tau\, g_M^2(Q^2)}{1+\tau} , \quad b(Q^2) = 2\,\tau\, g_M^2(Q^2) , \tag{24}$$

$$c(Q^2) = \frac{1}{4\sqrt{\tau}\,(\tau+1)^{5/2}} , \quad d(Q^2) = \frac{1}{\tau+1} + \frac{1}{2\sqrt{\tau}\,(\tau+1)^{3/2}} , \tag{25}$$

$$\frac{P_l}{P_t} = -\frac{g_M(Q^2)}{g_E(Q^2)}\,\frac{(E+E')}{2M}\,\tan\left(\frac{\theta}{2}\right) . \tag{26}$$

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

$$
\begin{aligned}
R(Q^2) &= \mu_p \frac{g_E(Q^2)}{g_M(Q^2)} = 1 - 0.13(Q^2 - 0.04)\,. \\
(1+\tau)\,A(Q^2) &= g_E^2(Q^2) + \tau\, g_M^2(Q^2) + g_A^2(Q^2)\,(1+\tau)\,c(Q^2)\,, \\
B(Q^2) &= 2\,\tau\, g_M^2(Q^2) + g_A^2(Q^2)\,d(Q^2)\,.
\end{aligned}
\tag{27}
$$

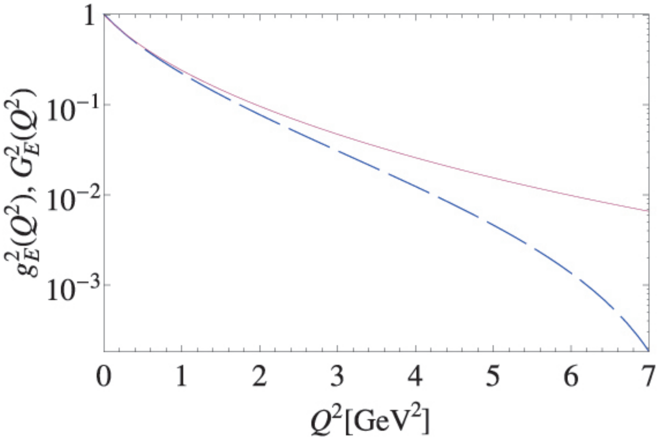
The new form factors in terms of the measured in experiments functions:

$$
\begin{aligned}
g_A^2(Q^2) &= \frac{(\tau+1)\,A(Q^2) - \Big(\big(R(Q^2)/\mu_p\big)^2 + 1\Big)B(Q^2)/2}{\Big(\big(R(Q^2)/\mu_p\big)^2 + 1\Big)d(Q^2)/2 - (\tau+1)\,c(Q^2)}\,, \\
g_M^2(Q^2) &= \frac{1}{2\tau}\big(B(Q^2) + g_A^2(Q^2)\,d(Q^2)\big)\,, \\
g_E^2(Q^2) &= g_M^2(Q^2)\left(\frac{R(Q^2)}{\mu_p}\right)^2 .
\end{aligned}
\tag{28}
$$

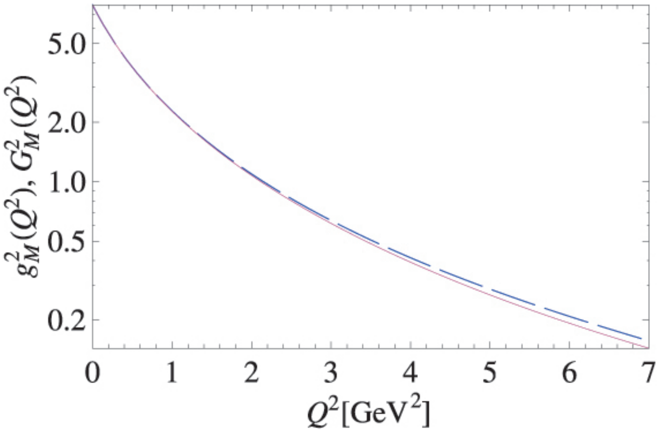
It's possible to performed the estimation of the new form factors in terms of the known analytical fits for $A(Q^2), B(Q^2)$ and $R(Q^2)$:

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

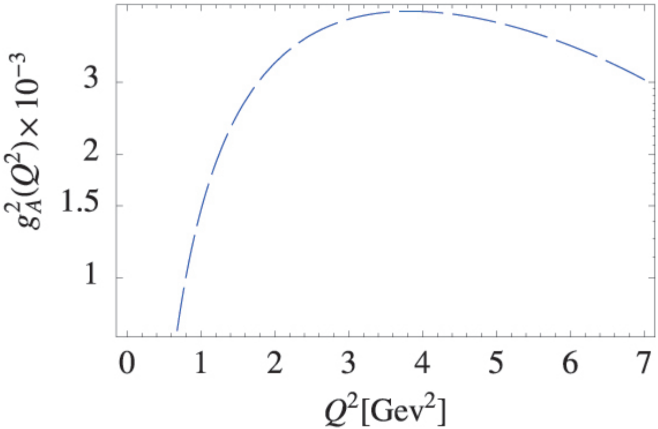
Electric form factors



Magnetic form factors



Anapole form factor



Conclusions

1. The analyses of the elastic non-polarized and polarized *ep*-scattering is performed in the framework hypothesis about *CP*-violation in the electromagnetic proceses 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 emergency of the additional anapole form factor in the cross section of the non-polarized *ep*-scattering.
4. It's show that contradiction between polarized and non-polarized experiments is eliminated.
5. The estimation of the new values of the proton form factors is produced.

Acknowledgements

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Thank you for your attention