Recent results of two-boson-exchange effects in the parity-violating elastic electron-proton scattering*

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Abstract The results of two-boson-exchange effects in the parity-violating elastic electron-proton scattering are reported based on a simple hadronic model. The corrections are calculated including the nucleon and $\Delta(1232)$ intermediate states. And the numerical results are also compared with the recent results reported by other group and other methods.

Key words two-boson-exchange, parity-violation,elastic electron-proton scattering, strange quark form factor

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1 Introduction

The study of strange quark form factors of proton has attracted much interest during the last decade. Experimentally, the parity-violating elastic electron-proton scatter provides a good method to extract such quantities. Significant progresses have been made during the last ten years[1—4] and the non-zero strange quark form factors are indicated from the precise measurement of parity asymmetry $A_{\rm PV}=\dfrac{\sigma^{\rm R}-\sigma^{\rm L}}{\sigma^{\rm R}+\sigma^{\rm L}}$ in polarized electron-proton scattering. Such precise measurements call for precise theoretical estimate of the radiative corrections. On another hand, it has been showed that the two-photon-exchange effects play important role in the unpolarized elastic electron-proton scattering[5, 6]. It is a natural question to ask how about the two-boson-exchange effects in the parity-violating elastic electron-proton scattering will be. In this letter, we report such results based on a simple hadronic model.

For parity-violating elastic electron-proton scattering, the asymmetry $A_{\rm PV}$ at the tree level is expressed as

$$A_{\rm PV}^{1\gamma+\rm Z}=-\frac{G_{\rm F}Q^2}{4\pi\alpha\sqrt{2}}\frac{A_{\rm E}+A_{\rm M}+A_{\rm A}}{[\varepsilon(G_{\rm E}^{\gamma,\rm P})^2+\tau(G_{\rm M}^{\gamma,\rm P})^2]}, \qquad (1)$$

with

$$A_{\rm E}=\varepsilon G_{\rm E}^{\rm Z,P}G_{\rm E}^{\gamma,\rm P}, \qquad A_{\rm M}=\tau G_{\rm M}^{\rm Z,P}G_{\rm M}^{\gamma,\rm P},$$
$$A_{\rm A}=-(1-4\sin^2\theta_{\rm W})\sqrt{\tau(1+\tau)(1-\varepsilon^2)}G_{\rm A}^{\rm Z}G_{\rm M}^{\gamma,\rm P},$$

and $\tau=Q^2/(4M^2), \varepsilon\equiv[1+2(1+\tau)\tan^2\theta_{\rm Lab}/2]^{-1}$, where $Q^2=-q^2$ is the momentum transfer and $\theta_{\rm Lab}$ is the laboratory scattering angle. The form factors are defined by the matrix elements of currents

$$\langle p'|J_\mu^{\rm Z}|p\rangle=\overline{u}(p')[F_1^{\rm Z,P}\gamma_\mu+F_2^{\rm Z,p}\frac{{\rm i}\sigma_{\mu\nu}}{2M}q^\nu+G_{\rm A}^{\rm Z}\gamma_\mu\gamma_5]u(p),$$
$$\langle p'|J_\mu^{\gamma}|p\rangle=\overline{u}(p')[F_1^{\gamma,\rm P}\gamma_\mu+F_2^{\gamma,\rm p}\frac{{\rm i}\sigma_{\mu\nu}}{2M}q^\nu]u(p),$$

with

$$G_{\rm E}^{\gamma(\rm Z),P}=F_1^{\gamma(\rm Z),P}-\tau F_2^{\gamma(\rm Z),P}, G_{\rm M}^{\gamma(\rm Z),P}=F_1^{\gamma(\rm Z),P}+F_2^{\gamma(\rm Z),P}.$$

Using the contents of currents at quark level and assuming the charge symmetry

$$J_\mu^{\rm em}=\sum_{\rm f=u,d,s}Q_{\rm f}\overline{q}_{\rm f}\gamma_\mu q_{\rm f}, \quad J_\mu^{\rm Z}=\sum_{\rm f}\overline{q}_{\rm f}(g_{\rm V}^{\rm f}+g_{\rm A}^{\rm f}\gamma_5)q_{\rm f},$$
$$G_{\rm E,M}^{\rm u,d,s/p}=G_{\rm E,M}^{\rm d,u,s/n}, \qquad (2)$$

the $A_{\rm PV}$ can be re-expressed as

$$A_{\rm PV}^{1\gamma+\rm Z}=A_1+A_2+A_3, \qquad (3)$$

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Fig. 2. Two-boson-exchange corrections with N and Δ intermediate states to parity-violating asymmetry as functions of ε from 0.1 to 0.9 at $Q^2 = 0.1$, 1.0, 3.0, and 5.0 GeV^2.

Fig. 3. TPE and γZ-exchange corrections with N and Δ as intermediate states to parity-violating asymmetry as functions of ε. The above is for N case and the below is for Δ case. Dotted line denotes corrections coming from the interference between 1γ-exchange and 2γ-exchange, dashed lines denote corrections coming from the interference between 1Z-exchange and 2γ-exchange and solid lines denote the corrections coming from the interference between 1γ-exchange and γZ-exchange.

To extract the strange quark form factor from the experimental data, the correction at the zero momentum approximation should be subtracted to avoid the double counting. We do this as[8, 9] and define the correction $\delta_{\rm G}$

$$\overline{G}^{\rm s}_{\rm E}+\beta\overline{G}^{\rm s}_{\rm M}=(G^{\rm s}_{\rm E}+\beta G^{\rm s}_{\rm M})(1+\delta_{\rm G}), \quad (5)$$

where $\overline{G}^{\rm s}_{\rm E}+\beta\overline{G}^{\rm s}_{\rm M}$ are the form factors extracted from the experimental $A_{\rm PV}$ after considering two-boson exchange effects.

The results for such defined $\delta_{\rm G}$ are showed in Table 1 where the large corrections indicate the importance of two-boson-exchange effects.

Table 1. The corrections $\delta_{\rm G}$ to $G^{\rm s}_{\rm E}+\beta G^{\rm s}_{\rm M}$ for HAPPEX, $A4$, and $G0$ experiments. (I, II), (III, IV), and (V, VI) refer to the HAPPEX, $A4$, and $G0$ data, respectively.

	I	II	III	IV	V	VI
$Q^2/\rm GeV^2$	0.477	0.109	0.23	0.108	0.232	0.410
ϵ	0.974	0.994	0.83	0.83	0.986	0.974
$\delta_{\rm N}(\%)$	0.25	0.34	0.86	1.30	0.288	0.275
$\delta_{\Delta}(\%)$	−0.59	−1.53	0.21	0.66	−0.90	−0.60
$\delta(\%)$	−0.34	−1.19	1.07	1.96	−0.61	−0.30
$\delta_0(\%)$	1.03	2.62	1.51	3.13	1.82	1.417
$\delta_{\rm G}(\%)$	−25.52	−75.23	−2.76	−2.27	13.12	20.62

The same effects are calculate by[11] recently and similar properties are found. Moreover, the GDPs method[12] is also used to discuss the two-boson-exchange effects, and the authors got different property for the γZ contribution and argued such difference may come from the large momentum region. These suggest the two-boson-exchange effects in ep scattering call for further study. And how to to combine the GDPs methods and hadronic model is still an open issue.

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