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ScienceDirect
Progress in Particle and Nuclear Physics 61 (2008) 162–167
Progress in Particle and Nuclear Physics
www.elsevier.com/locate/ppnp

Review

Predictions of polarization observables in $e^+e^- \to p\bar{p}$ by eight- and ten-resonance U&A models

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Abstract

Polarization effects in $e^+e^- \to p\bar{p}$ process for longitudinally polarized proton/antiproton in the final state are reinvestigated and analyzed by eight- and ten-resonance unitary and analytic (U&A) models of nucleon electromagnetic structure. Explicit forms of components of the single-spin and double-spin polarization of the created proton/antiprotons are presented and their sensitivity of behavior is demonstrated graphically by using eight- and ten-resonance U&A models of the nucleon electromagnetic structure.

1. Introduction

Prior to the year 2000 all data on form factors (FFs) $G_{Ep}(t)$ and $G_{Mp}(t)$ in the space-like ($t < 0$) region were obtained by measuring the differential cross-section of elastic scattering on proton in the laboratory frame utilizing the Rosenbluth technique [1]. Both FFs have more or less dipole behavior and their ratio in error bars is equal to one.

More recently at JLab [2–4] by means of a double polarization experiment a great success was achieved, measuring simultaneously transverse and longitudinal components of the recoil proton's polarization in the electron scattering plane of the polarization transfer process. The data on the ratio in the region $0.3\ \text{GeV}^2 \le Q^2 \le 5.6\ \text{GeV}^2$ are obtained, which clearly demonstrate a remarkable fall of $G_{Ep}(t)$ with increased Q^2 in comparison with $G_{Mp}(t)$ and so, this data are in a rather strong disagreement with the data obtained by Rosenbluth technique for $Q^2 > 1\ \text{GeV}^2$.

The latter example revealed an importance of investigation of polarization effects in particle physics.

The dependence of the polarization of emitted baryons in the electron–positron annihilation into baryon–antibaryon on the polarization of colliding $e^- + e^+$ beams has been studied in [5]. All polarization effects for baryon spin $1/2$ were calculated, assuming one-photon exchange approximation. Here we are concerned with the theoretical reinvestigation of polarization phenomena of the reaction $e^+e^- \to p\bar{p}$ taking into account all new experimental data on electric and magnetic Sachs form factors $G_{Ep}(t)$ and $G_{Mp}(t)$.

The above-mentioned process is interesting as it has noticeable polarization effects even if there are no polarized particles in the initial state. The appearance of polarization effects is due to $G_{Ep}(t)$ and $G_{Mp}(t)$ being complex with

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0146-6410/$ - see front matter
doi:10.1016/j.ppnp.2007.12.014

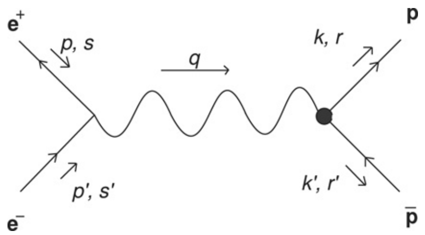

Fig. 1. The one-photon exchange diagram of the $e^+e^- \to p\bar{p}$ process.

nonzero relative phase. On that account there are also nontrivial polarization effects in the scattering of longitudinally polarized electrons on unpolarized target.

This contribution is devoted to the analysis of polarization effects in the process $e^+e^- \to p\bar{p}$ calculated in the framework of the one-photon exchange approximation.

In terms of two electromagnetic (EM) FFs $G_{Ep}(t)$ and $G_{Mp}(t)$ single-spin and double-spin polarizations of the recoil proton (antiproton) are recalculated explicitly and by using the eight- and ten-resonance U&A model of the nucleon EM structure [6] their behaviors are presented graphically.

2. The structure of the electromagnetic current of the transition $\gamma^* \to p\bar{p}$

The matrix element of the process $e^+e^- \to p\bar{p}$ in the framework of the one-photon exchange approximation to be presented in Fig. 1 is defined by the formulae

$$\begin{aligned}
\mathcal{M} &= \frac{e^2}{k^2} j_\mu J_\mu, \\
j_\mu &= \bar{u}(-p)\gamma_\mu u(p'), \\
J_\mu &= \bar{u}(k)\left[F_{1p}(t)\gamma_\mu - F_{2p}(t)\frac{\sigma_{\mu\nu}k_\nu}{2m_p}\right]u(-k'),
\end{aligned} \tag{1}$$

where $t = q^2 \geq 4m_p^2$. The c.m. system of the reaction $e^+e^- \to p\bar{p}$ is the most suitable for the analysis of polarization effects.

The EM currents j_μ and J_μ are conserved $q \cdot j = q \cdot J = 0$ and the matrix element $\mathcal{M}$ is completely determined by the product of spatial components of the currents $\vec{j}$ and $\vec{J}$.

The electromagnetic current $\vec{J}$ can be expressed through two-component spinors φ_1 and φ_2

$$\vec{J} = \sqrt{t}\varphi_1^+\left[G_{Mp}(t)(\vec{\sigma} - \vec{n}\vec{\sigma}\cdot\vec{n}) + \frac{2m_p}{\sqrt{t}}G_{Ep}(t)\vec{n}\vec{\sigma}\cdot\vec{n}\right]\varphi_2, \tag{2}$$

where we denote

$$\vec{F} = \sqrt{t}\left[G_{Mp}(t)(\vec{\sigma} - \vec{n}\,\vec{\sigma}.\vec{n}) + \frac{2m_p}{\sqrt{t}}\,G_{Ep}(t)\vec{n}\,\vec{\sigma}.\vec{n}\right], \tag{3}$$

$\vec{\sigma}$ are Pauli matrices, $\vec{n} = (0, 0, 1)$ is the unit vector along the three-momentum $\vec{q}$ of the proton, $\vec{m} = (-\sin\vartheta, 0, \cos\vartheta)$ is the unit vector of the incoming electron (see Fig. 2) and

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

In order to find the corresponding cross-section, one has to calculate $|\mathcal{M}|^2$. The differential cross-section of the reaction $e^+e^- \to p\bar{p}$ in terms of EM FFs, for the case of unpolarized particles, has the form

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4s}\left(\frac{1}{\tau}|G_{Ep}|^2\sin^2\vartheta + |G_{Mp}|^2[1+\cos^2\vartheta]\right), \quad \alpha = \frac{e^2}{4\pi};\ \tau = \frac{t}{4m_p^2}. \tag{4}$$