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POLARIZATION IN THE $p\bar{p} \to e\bar{e}$ PROCESS AND QUASI-NUCLEAR BOUND STATE

V. A. Meshcheryakov, G. V. Meshcheryakov, and Chan Kuang Tuet

Earlier, the existence of a quasi-nuclear $p\bar{p}$ state with a low binding energy was suggested. The influence of this state on the electromagnetic form factor of the proton is discussed. Its contribution to the integral asymmetry of the $p\bar{p} \to e\bar{e}$ process has been calculated. Measuring the integral asymmetry even far from the $p\bar{p}$ reaction threshold was demonstrated to be important for detecting the quasi-nuclear state.

Experiments on the LEAR unit in CERN gave a considerable body of data on $p\bar{p}$ interaction at low energies. Among numerous new results, elastic $p\bar{p}$ scattering [1] and the $p\bar{p} \to e\bar{e}$ process at low $p\bar{p}$ system energies [2] should be mentioned. Both results are difficult to explain in terms of generally accepted models. In elastic $p\bar{p}$ forward scattering, the ratio of the real-to-imaginary part of the amplitude, $\rho = \mathrm{Re}\,T/\,\mathrm{Im}\,T$, has an oscillatory character at momenta $P_L < 1$ GeV/s. At the reaction threshold, $\rho \sim -1$, and this ratio, therefore becomes zero in the specified interval of momenta three times. Such a behavior of ρ cannot be fully explained either by potential models or by dispersion relations [3]. In [4], an analytic model of the amplitude of elastic $p\bar{p}$ forward scattering involving pole terms corresponding to the bound $p\bar{p}$ system state resulting from strong interaction has been constructed. The suggestion of the existence of a quasi-nuclear state made it possible to explain the experimental data. In [1], the differential cross section of $p\bar{p} \to e\bar{e}$ annihilation was used to calculate to a high accuracy the absolute value of the Sux electromagnetic form factor of the proton $|G|$ near the $p\bar{p}$ threshold [2] in the range 3.52 GeV^2 $< s <$ 4.2 GeV^2, where s is the Mandelstam variable. Within this interval, $|G_E| \simeq |G_M| = |G|$. It was shown that the behavior of $|G|$ did not coincide with that predicted by the model of vectorial dominance endowed with the unitary property [5], according to which $|G|$ as a function of s should monotonically decrease in the studied interval of s values. At $s \simeq 4M^2$, where M is the mass of the proton, $|G|$ decreases sharply, and at s of about 4 GeV^2, it passes through a minimum and even begins to increase. There is no generally accepted explanation for these observations, although attempts at obtaining them were made (see [6]). The suggestion that near the $p\bar{p}$ threshold of elastic scattering there exists a quasi-nuclear state with quantum numbers $^3S_1$ or $^3D_1$ should make a contribution to the formula describing the behavior of the electromagnetic form factor of the proton in the same energy region. Such a relation can be inferred from the unitary property of the form factor. Its general form can be written as

$$\mathrm{Im}\langle 0|j_\mu|N\overline{N}\rangle = \sum_n \langle 0|j_\mu|n\rangle\langle n|T^+|N\overline{N}\rangle, \tag{1}$$

where j_μ is the nucleon electromagnetic current, and $|n\rangle = |2\pi\rangle, \ldots, |N\overline{N}\rangle$ is the complete system of admissible intermediate states. It is obvious that the $|N\bar{N}\rangle$ state from the complete $|n\rangle$ system makes a contribution to the imaginary part of the form factor against the background of all states from $|n\rangle$ with masses lower than $|N\bar{N}\rangle$. Approximating the contributions of the states preceding the $|N\bar{N}\rangle$ one by delta functions in (1), we obtain the model of vectorial dominance. "Smearing" out the delta functions in some way in condition (1) (the condition of the unitary property of the form factor), e. g., by means of the equality

$$\delta(x) = \frac{1}{\pi} \lim_{\varepsilon \to +0} \frac{x}{x^2 + \varepsilon},$$

we obtain models endowed with the unitary property. In what follows, we will use such a model from [5], because in conformity with general principles, this model leads to complex values of the Sux form factors of the proton $G_{M,E}$ at $s > 4M^2$ and correctly describes the last values of the form factor of the neutron [7]. The formulas of this model have the form

$$G_{M,E}(s) = \sum_{k=1} \frac{\varepsilon_k(s), \beta_k(k)}{(s - a_k - \delta_k \sqrt{s_k - s})^2},$$

where $\varepsilon_k(s) = \varepsilon_k^1 + \varepsilon_k^0 s$; $\beta_k(s) = \beta_k^1 + \beta_k^0 s$; ε_k corresponds to G_M; β_k corresponds to G_E; $k = 1, 2, 3$ correspond to the ρ, ω, ϕ mesons; masses a_k, widths δ_k, and thresholds s_k were taken from the experimental data [8]; the ε_k^i and β_k^i parameters except ε_2^0 and ε_3^0 were determined from the experimental Dirac and Pauli form factor values and their derivatives at $s = 0$; and ε_2^0 and ε_3^0 were found by a χ^2 analysis of the near-threshold data reported in [9]. The parameter values are given in Table 1. Earlier, for the contribution of the quasi-nuclear state to G [10], we obtained the formula

$$\begin{aligned} G_{p\overline{p}}(z) = \frac{(1-z_1^2)^2}{(z_2 - z_1^2)(z^2 z_1^2 - 1)} &= A_1 \Big\{ \Big(\frac{1}{z - (z_\rho)_1} - \frac{1}{z - (z_\rho)_2} \Big) - \Big(\frac{1}{z + (z_\rho^*)_1} - \frac{1}{z + (z_\rho^*)_2} \Big) \Big\} \\ &+ A_2 \Big\{ \Big(\frac{1}{z - (z_\rho)_1} + \frac{1}{z - (z_\rho)_2} \Big) - \Big(\frac{1}{z + (z_\rho^*)_1} + \frac{1}{z + (z + (z_\rho^*))_2} \Big) \Big\}, \end{aligned} \quad (2)$$

where

$$z = \sqrt{\frac{4(s-\alpha)}{s(4-\alpha)}} - \sqrt{\frac{\alpha(s-4)}{s(4-\alpha)}}.$$

Table 1

k	a_k	δ_k	s_k	ε_k^1	ε_k^0	β_k^1	β_k^0
1	0.585	0.12	0.079	0.900	−0.487	−0.286	0.192
2	0.608	0.012	0.176	−0.117	−2.97	0.151	0.003
3	1.040	0.003	0.980	0.817	3.23	0.379	0.535

The final expression for the form factor of the proton is

$$G = G_w + G_{N\overline{N}},$$

where $G_w = (1/2)(G_M + G_E)$. The free parameters in (2) were found from the experimental data of [2] ($A_1 = 0$, $A_2 = 0.012$, and $\alpha = 0.23$). This gave $E_b \cong \Gamma \cong$ 2–5 MeV for the binding energy and the width of the quasi-nuclear bound state [8]. In [7], in experimental studies of $|G|$ and the cross-section of annihilation $e\bar{e} \to \Sigma_i h_i$, we have found that $E_b = 30 \pm 10$ MeV and $\Gamma = 40 \pm 10$ MeV. Our estimate of the binding energy and the width of the quasi-nuclear state falls within a 95% confidence interval of these measurements and is not at variance with experimental data being fully within the confidence interval of the "3σ" empirical rule. The further studies of this quasi-nuclear state ("barionium") require experiments with polarized protons and antiprotons. We have calculated integral asymmetry $A_{\perp,\perp}$ for perpendicularly polarized p and $\bar{p}$,

$$A_{\perp,\perp} = \frac{(4M^2/q^2)|G_E|^2}{4|G_M|^2 + (4M^2/q^2)|G_E|^2},$$

with and without the "barionium" [11] (see Fig. 1). The presence of the "barionium" manifests itself in the characteristic structure of maxima and minima of $A_{\perp,\perp}$ at the energies 3.52 GeV$^2 \le s \le$ 12 GeV^2. But even

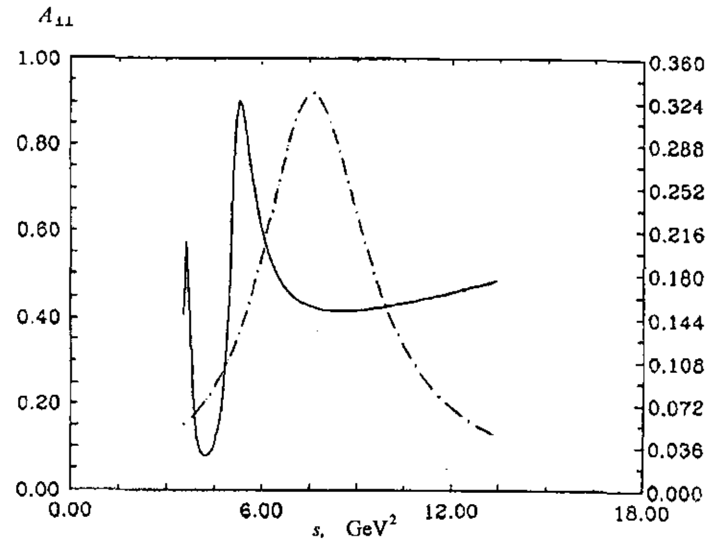

Fig. 1

Integral asymmetry of the $p\bar{p} \to e\bar{e}$ process: the solid curve was obtained taking into account the quasi-nuclear state (the left axis), and the dashed curve, without taking this state into account (the right axis).

far from the threshold, at $s \sim 11$ GeV^2, the influence of the "barionium" causes an approximately twofold decrease in $A_{\perp,\perp}$. These calculations give a quantitative estimate of "barionium" effects on polarization phenomena and confirm the importance of their experimental study. A similar conclusion was drawn in [4, 6, 10].

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Department of Quantum Statistics and Field Theory