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INVESTIGATION OF THE NUCLEON ELECTROMAGNETIC STRUCTURE BY POLARIZATION EFFECTS IN $e^+e^- \to N\bar{N}$ PROCESSES

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Изучение электромагнитной структуры нуклонов поляризационными эффектами в $e^+e^- \to N\bar{N}$ процессах

Изучаются поляризационные эффекты процессов $e^+e^- \to N\bar{N}$ с разных точек зрения. Найден явный вид компонент вектора поляризации нуклона, образующегося при аннигиляции неполяризованных e^+e^- встречных пучков. При помощи двух известных видов унитарной и аналитической ВМД модели электромагнитной структуры нуклонов графически продемонстрирована чувствительность поведения компонент вектора поляризации нуклона.

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Investigation of the Nucleon Electromagnetic Structure by Polarization Effects in $e^+e^- \to N\bar{N}$ Processes

Polarization effects in $e^+e^- \to N\bar{N}$ processes are investigated from various aspects. Explicit form of components of the vector polarization of the created nucleon N in the annihilation of unpolarized e^+e^- colliding beams is presented. The sensitivity in a behaviour of the vector polarization components of the nucleon is demonstrated graphically by using two recent formulations of the unitary and analytic VMD model of the nucleon electromagnetic structure.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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1 Introduction

A complete observation of the electromagnetic structure of hadrons is possible only in polarization experiments. In particular, for the zero spin hadrons ($\pi^{\pm}, K, \bar{K}, ^4He, etc.$) electromagnetic form factors can be determined (up to the phase) just by the measurement of the differential cross-sections with unpolarized particles.

On the other hand, the electromagnetic structure of a particle with spin 1/2 is completely described by the electric $G_E(s)$ and magnetic $G_M(s)$ form factors (ff) and they can be determined (in the space-like region) by measurements of an elastic electron scattering differential cross-section, employing a linear $\cot^2 \vartheta_e/2$ dependence of the latter (ϑ_e- is the electron scattering angle in the laboratory system). However polarization effects are unavoidable also in this case.

One cannot determine the proton electric ff very accurately for higher values of the momentum transfer squared $s = -Q^2$ ($Q^2 \geq 3GeV^2$) by a measurement of the differential cross-section of a scattering of the unpolarized ep because in the latter region proton magnetic ff is dominating.

A situation gets even worse with the neutron electric ff $G_E^n(s)$ which is in the absolute value essentially smaller than the magnetic neutron ff $G_M^n(s)$ for all $s < 0$. Therefore a reliable determination of the neutron electric ff $G_E^n(s)$ for $s \leq -2GeV^2$ is a basic problem of the hadron electrodynamics. At present unadjusted knowledge of the $G_E^n(s)$ prevents a quantitative analysis of the role of the non-nucleon degrees of freedom in nuclei, like isobar, quark and mesonic exchange currents contributions.

So, for determinating a relative sign of electric and magnetic nucleon ff's, especially neutron ff's and for a more accurate determination of $G_E^n(s)$ polarization experiments also in the space-like region are to be performed.

An important role of polarization effects in a measurement of the nucleon electromagnetic (e.m.) ff's was already stressed long time ago [1]. Especially, due to reality of nucleon e.m. ff's in the space-like region, polarization effects in the framework of one-photon exchange approximation for elastic eN- scattering are very peculiar.

On that account there are nontrivial polarization effects in the scattering of longitudinally polarized electrons on a polarized target. But polarization of scattered nucleons is also different from zero if longitudinally polarized electrons are scattered on an unpolarized nucleon target. We would like to note here that the latter polarization effects are specified by a product of electric and magnetic nucleon ff's.

An experimental investigation of polarization effects in the electron-hadron interactions is just at the early stage. There are only results from SLAC elastic and inelastic scattering experiments [2] of polarized electrons on a polarized proton target carried out in 1976 with the aim of separating G_E^p and G_M^p and also for obtaining furher information on nucleon resonance ff's.

A great excitement was caused by the results [3] on measurements of asymmetry in deep inelastic scattering of polarized muons on polarized protons, the interpretation of which caused the so-called "spin crisis."

A measurement [4] of deuteron tensor polarization in elastic ed-scattering, with asymmetry [5] determined in the scattering of unpolarized electrons on a deuteron target with tensor polarization rendered possible to find deuteron quadrupole ff in the region of momentum,

where one expected the most remarkable manifestation of the quark structure of the deuteron.

Significance of investigations of polarization effects in scattering of electrons on protons, deuterons and other light nuclei is expected only to grow. This is connected with the progress in a polarization target $(p, d, ^3He, ^6Li, etc.)$ technique, on the one hand, and on the other hand with the construction of intensive electron accelerators with continuous beams (ELSA, CEBAF, MAMI). In programs of the latter serious attention is paid to scattering experiments with polarized electrons on polarized protons and deuterons with the expectation of a reliable determination of e.m. ff's of nucleons and deuterons.

It is obvious that an experimental investigation of the e.m.structure of hadrons contains also a measurement of the e.m. ff's of hadrons in the time-like region by using $e^+e^- \to A\bar{A}$ reactions, where $A = \pi^+, K^+, K^0, p, n, etc.$.

We would like to note that in $e^+e^- \to A\bar{A}$ processes a measurement of the e.m. ff's of baryons is possible only above the threshold of creation of baryon-antibaryon pairs, i.e. for $s \geq 4m_B^2$. On the other hand behaviour of baryon e.m. ff's according to the idea of the standard VMD model is determined by vector-meson contributions essentially just in the unphysical region below the baryon-antibaryon threshold at the range $s \simeq m_V^2$, where m_V is the vector-meson mass.

In principle the e.m. ff's of nucleons for $0 < s \leq 4m_N^2$ can be measured in reactions

$$\begin{aligned} \pi^- + p &\to n + e^+e^- \\ \bar{p} + p &\to \pi^0 + e^+e^- \\ p + \bar{n} &\to \pi^+ + e^+e^-. \end{aligned}$$

Creation of e^+e^- pairs in π^-p- collisions has been already employed

[6] for extracting information on the pion and nucleon e.m. structure in the $0 < s \leq 4m_N^2$ region.

There is a fundamental peculiarity of the time-like region, in which due to the unitarity condition the imaginary part of the hadron e.m. ff's is for $s > s_0$ (s_0 is the lowest threshold) different from zero.

Especially, the complexity of ff's for $s > 4m_B^2$ (B means baryons) determines special features of polarization effects in reactions like $e^+e^- \to B\bar{B}$ even in the framework of the one-photon approximation. As a result the polarization effects in such crossing reactions like $e^+e^- \to p\bar{p}$ and $e^-p \to e^-p$ are completely different. This difference consists in the fact that there are noticeable polarization effects in $e^+e^- \to p\bar{p}$ process even if there are no polarized particles in the initial state. The appearance of polarization effects is due to G_E^p and G_M^p with nonzero relative phase being complex.

This paper is devoted to the analysis of polarization effects in processes like $e^+e^- \to B\bar{B}$ in the framework of the one-photon exchange approximation.

In terms of two e.m. ff's G_E and G_M we calculate vector polarization components of $B(\bar{B})$ in $e^+e^- \to B\bar{B}$ process.

Of course, the measurement of the polarization of nucleons created in $e^+e^- \to N\bar{N}$ process with small values of cross sections is an exceptionally difficult experimental task. More perspective seems to be the measurement of asymmetries in a reversed process $N\bar{N} \to e^+e^-$ arising with polarized annihilated nucleons [7]. A completely different situation is in the reaction $e^+e^- \to \Lambda\bar{\Lambda}$, where the measurement of polarization of $\Lambda(\bar{\Lambda})$ can be carried out without any problems because it is reduced to the investigation of asymmetry in the decay $\Lambda \to p + \pi^-$.

A theoretical analysis of polarization effects in the reaction $p\bar{p} \to$

e^+e^- has been carried out in papers [7], [8]. In more detail these problems have been investigated in [7], where an explicit form of the differential cross section for annihilation of polarized antiprotons on polarized protons in the framework of the one-photon exchange approximation is obtained. P-odd effects in $p\bar{p} \to e^+e^-$ due to $\gamma - Z^0$ interference has been investigated in [9]. General analysis [10] of P-violation effects in inclusive processes like in $e^+e^- \to BX$ has shown that P-odd effects can be created here even in the framework of one-photon approximation because of the nonconservation of P-parity in a decay of created hadrons.

In this paper the dependence of polarization states of created baryons in $e^+e^- \to B\bar{B}$ on the polarization of colliding leptons is investigated. The formulae obtained here exhaust all polarization effects of baryons with spin 1/2 in $e^+e^- \to B\bar{B}$. Always, where it is possible, we are stressing the general character of obtained results. Numerical estimates of polarization effects are carried out in the framework of the most accomplished up to now the unitary and analytic VMD model of the nucleon electromagnetic structure. Polarization effects appear to be very sensitive to the chosen variant of the latter model. The vector polarization components of N in $e^+e^- \to N\bar{N}$ are strongly dependent on s in a vicinity of the $N\bar{N}$ threshold. The polarization effects are rather large in absolute value.

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

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

$$\begin{aligned} \mathcal{M} &= \frac{e^2}{k^2}\ell_\mu J_\mu, \\ \ell_\mu &= \bar{u}(-k_2)\gamma_\mu u(k_1), \\ J_\mu &= \bar{u}(p_1)[F_1(s)\gamma_\mu - F_2(s)\frac{\sigma_{\mu\nu}k_\nu}{2M}]u(-p_2), \end{aligned} \tag{1}$$

where $s = -Q^2 \geq 4M^2$, M is the baryon mass, $F_1(s)$ and $F_2(s)$ are the Dirac and Pauli e.m. ff's of the baryon B, respectively; the definition of four momentum is shown in Fig.1 and the electron mass is further neglected. The c.m. system of the reaction $e^+e^- \to B\bar{B}$ is the most

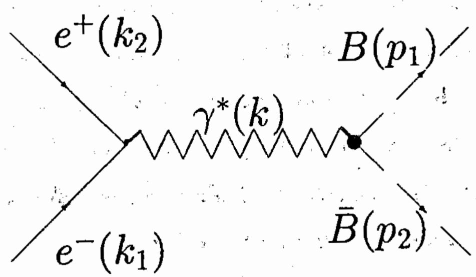

Figure 1:

suitable for the analysis of polarization effects.

The differential cross-section in the latter system is connected with the matrix element (1) as follows

$$\frac{d\sigma}{d\Omega} = \frac{|\mathcal{M}|^2}{64\pi^2 s}\cdot\beta, \quad \beta = \sqrt{1-4M^2/s}. \tag{2}$$

Electromagnetic currents ℓ_μ and J_μ are conserved, therefore in the c.m. system $\ell_0 = J_0 = 0$. Consequently the matrix element $\mathcal{M}$ is determined

only by spatial components of currents

$$\begin{aligned} \mathcal{M} &= -\frac{e^2}{s}\vec{\ell}\cdot\vec{J} \\ |\mathcal{M}|^2 &= \frac{e^4}{s}\ell_{ik}W_{ik}, \end{aligned} \tag{3}$$

where

$$\ell_{ik} = \ell_i\ell_k^* \quad W_{ik} = J_iJ_k^*.$$

For the tensor ℓ_{ik}, following the standard method of QED, one can obtain the general expressions, corresponding to annihilation of a polarized e^+e^- - pair

$$\ell_{ik} = (1+\vec{L_1}\cdot\vec{L_2})(\delta_{ik}-\hat{m}_i\hat{m}_k)-(L_{1i}^\perp L_{2k}^\perp+L_{1k}^\perp L_{2i}^\perp)+i(L_1^\parallel+L_2^\parallel)\varepsilon_{ikl}m_l, \tag{4}$$

where $\vec{m}$ is the unit vector along the three momentum of the electron, $\vec{L_1}$ and $\vec{L_2}$ are three vectors of electron and positron polarization (in the rest frame of these particles), notation $\perp$ and $\parallel$ mean transversal and longitudinal parts of $\vec{L}$ according to the vector $\vec{m}$.

At the accelerators of colliding beams the transversal polarization arises that in principle can transform into the longitudinal one (Siberian "snake").

One can see from (3) that just the longitudinal polarization of one of the colliding beams gives the antisymmetric contribution to ℓ_{ik} which is important in investigating polarization effects in $e^+e^- \to B\bar{B}$.

The electromagnetic current $\vec{J}$ is convenient to express trough two-component spinors φ_1 and φ_2

$$\vec{J} = \sqrt{s}\varphi_1^+\left[G_M(s)(\vec{\sigma}-\vec{n}\vec{\sigma}\cdot\vec{n})+\frac{2M}{\sqrt{s}}G_E(s)\vec{n}\vec{\sigma}\cdot\vec{n}\right]\varphi_2 \tag{5}$$

$$G_M(s) = F_1(s)+F_2(s), \quad G_E(s) = F_1(s)+\frac{s}{4M^2}F_2(s),$$

where $\vec{n}$ is the unit vector along the three momentum $\vec{q}$ of the baryon.

Since combinations $(\vec{\sigma} - \vec{n}\vec{\sigma}\cdot\vec{n})$ and $\vec{n}\vec{\sigma}\cdot\vec{n}$ are orthogonal, there are no interference terms of the type $[G_E \cdot G_M^*]$ in the differential cross section of the process $e^+e^- \to B\bar{B}$ with unpolarized baryons.

The spin structure of the current $\vec{J}$ is connected with the specification of the angular momentum of created $B\bar{B}$ - pairs. More specifically, the conservation laws of the P-parity and total angular momentum in process $\gamma^* \to B\bar{B}$ (γ^* is the virtual photon) allows the creation of $B\bar{B}$ only in two states with $\ell = 0$ and $\ell = 2$ (ℓ is the angular momentum of the $B\bar{B}$ system). To obtain the value of the total angular momentum of the $B\bar{B}$ system to be one, the total spin of $B\bar{B}$ in both states must be equal to one. As a result, the C-parity in the transition $\gamma^* \to B\bar{B}$ is conserved automatically.

The combinations $\varphi_1^+\vec{\sigma}\varphi_2$ and $\vec{n}\varphi_1^+\vec{\sigma}\cdot\vec{n}\varphi_2$ are vectors because the intrinsic parity of the $B\bar{B}$ system is negative (the Beresteckij theorem [11]). As a result total P- parity is conserved in $\gamma^* \to B\bar{B}$ transition.

Then one can rewrite the current $\vec{J}$ in the following form

$$\vec{J} = \sqrt{s}\varphi_1^+\left[G_d(s)(3\vec{n}\vec{\sigma}\cdot\vec{n} - \vec{\sigma}) + G_s(s)\vec{\sigma}\right]\varphi_2 \qquad (6)$$

$$G_M = G_s - G_d, \quad \frac{2M}{\sqrt{s}}G_E = G_s + 2G_d,$$

where the form factor G_s describes the creation of $B\bar{B}$ in the s -state and G_d in the d - state.

3 Θ - dependence of the differential cross section of process $e^+e^- \to B\bar{B}$

As a result of the polarization states of created particles, the tensor W_{ij} consists of the sum of three tensors as follows

$$W_{ij} = W_{ij}^0 + W_{ij}^1 + W_{ij}^2,$$

where W_{ij}^0 corresponds to the creation of unpolarized particles, W_{ij}^1 to the creation of polarized B or $\bar{B}$ and W_{ij}^2 to the creation of both polarized baryons B and $\bar{B}$.

The general structure of these tensors can be found requiring P-invariance of the electromagnetic interactions of hadrons.

Really, for the tensor W_{ij}^0 one can write the expression

$$W_{ij}^0 = \delta_{ij}w_1(s) + \hat{n}_i\hat{n}_j w_2(s), \qquad (7)$$

where $w_{1,2}$ are real structure functions (sf's).

To find the connection between sf's w_1 and the e.m. ff's G_M and G_E, we use the relation

$$W_{ij}^0 = Tr F_i F_j^+, \qquad (8)$$

where

$$\vec{F} = G_M(s)(\vec{\sigma} - \vec{n}\vec{\sigma}\cdot\vec{n}) + \frac{2M}{\sqrt{s}}G_E(s)\vec{n}\vec{\sigma}\cdot\vec{n}.$$

Consequently, one gets

$$w_1(s) = 2|G_M(s)|^2, \quad w_2(s) = 2\left[-|G_M|^2 + \frac{4M^2}{s}|G_E(s)|^2\right]. \qquad (9)$$

So, the Θ - dependence of the differential cross section of the $e^+e^- \to B\bar{B}$ process is determined as folows

$$|\mathcal{M}|^2 \approx (\delta_{ij} - m_i m_j)W_{ij}^0 = \qquad (10)$$
$$= \left[(1+\cos^2\Theta)|G_M(s)|^2 + \sin^2\Theta\frac{4M^2}{s}|G_E(s)|^2\right].$$

We would like to note that the typical Θ - dependence of the cross section of process $e^+e^- \to B\bar{B}$

$$\frac{d\sigma}{d\Omega} \approx a(s) + b(s)\cos^2\Theta$$

is caused by

- the spin one of the virtual photon
- the one-photon exchange approximation of $e^+e^- \to B\bar{B}$ process
- the C- and P- invariance of electromagnetic interactions of hadrons.

A similar Θ - dependence will be valid also for the inclusive process $e^+e^- \to h\bar{X}$ (h means the chosen hadron). Just the $\cos^2\Theta$- dependence of cross sections of $e^+e^- \to B\bar{B}$ and $e^+e^- \to h\bar{X}$ processes leads through the crossing symmetry to the $\cot^2\Theta_e/2$ - dependence of cross sections of electron elastic and inelastic scattering on hadrons. We have already mentioned that the linear dependence of the cross section of process $e^-p \to e^-p$ on $\cot^2\Theta_e/2$ is used for separating of contributions of ff's G_E^p and G_M^p.

Analogously, the $\cos^2\Theta$ - dependence of $d\sigma/d\Omega$ for $e^+e^- \to B\bar{B}$ can be employed for separating of the contributions of ff's $|G_M(s)|^2$ and $|G_E(s)|^2$. The Θ - dependence of the cross section of $e^+e^- \to B\bar{B}$ process in terms of form factors $G_s(s)$ and $G_d(s)$ has the following form

$$\frac{d\sigma}{d\Omega} \approx 2|G_s|^2 + (5 - 3\cos^2\Theta)|G_d|^2 + 2(1 - 3\cos^2\Theta)ReG_sG_d^*,$$

i.e. G_s leads to the pure isotropic angular distribution. We would like to draw an attention to the form of the matrix element (10) from which it immediately follows that the s - dependence of the differential cross section $e^+e^- \to B\bar{B}$ is determined only by $G_M(s)$.

4 Polarization of the baryon B in $e^+e^- \to B\bar{B}$ process

Owing to the fact that polarized states of a particle with spin 1/2 are described by pseudovectors, the general (p_1 is used for baryon, p_2- for antibaryon) form of the tensor W^1_{ij} (linear in p) is possible to write down as follows

$$W^1_{ij} = i\varepsilon_{ijl}p_l w_3(s) + i\varepsilon_{ijl}n_l(\vec{p}\cdot\vec{n})w_4(s) + (E_in_j + E_jn_i)w_5(s), \qquad (11)$$

$$E_i = \varepsilon_{iml}p_mn_l.$$

This structure is valid for an arbitrary process $e^+e^- \to B_1\bar{B}_2$, where for B_1 and $\bar{B}_2$ there are no restrictions on the spin and P- parity. Formula (11) describes the vector polarization of the baryon which completely exhausts polarization states of a particle with spin 1/2. If the spin of the baryon is greater than 1/2, then it is characterized by the quadruple, octupole, etc. polarization.

Formula (11) is valid also for the inclusive creation of baryons $e^+e^- \to BX$. However, then structure functions w_3 - w_5 are dependent already on two invariant variables, $w_{3-5} = w_{3-5}(s, m^2)$, where m is the invariant mass of the X system.

There is a similar situation also for the inclusive scattering of electrons $\vec{A}(e,e')X$, where $\vec{A}$ means the vector polarization of the particle A. In this case the polarization contribution to the cross section is also characterized by three sf's.

A common feature of processes $e^+e^- \to BX$ and $e^-\vec{A} \to e^-X$ is the fact that the sf's w_3 and w_4 (coupled with antisymmetric tensors) give nonzero contributions to both reactions only in that case if the initial lepton is polarized. If leptons are unpolarized, then only the sf

w_5 appears. In this sense one can find a principal difference between the electron scattering on hadrons and the creation of hadrons in e^+e^- - annihilation.

The problem consists in the following. As a result of the unitarity condition, e.m. ff's of hadrons are complex in $e^+e^- \to B_1\bar{B}_2$. But, for $s \leq 0$ they are real because of the electromagnetic current being hermitian and electromagnetic interactions of hadrons being C- invariant.

Therefore already two particle contributions to the inclusive cross section $e^+e^- \to BX$ are responsible for the nonzero contribution of the "symmetric" sf w_5. In the electron scattering, two- particle contributions don't appear in the sf w_5 owing to e.m. ff's being real. Besides, the situation is not changed even for multiparticle reactions, since due to the general theorem [12] based on the T - invariance of electromagnetic interactions sf $w_5(s, m^2) = 0$ for $e^-\vec{A} \to e^-X$ in the whole kinematical region of deep inelastic scattering.

Turning back to the process $e^+e^- \to B\bar{B}$ we note that there are all three sf's w_3 -w_5 different from zero and they are defined by the following combinations of e.m. ff's

$$\begin{aligned} \frac{1}{s}w_3 &= 2Re[G_E \cdot G_M^*]/\tau \\ \frac{1}{s}w_4 &= 2|G_M|^2 - 2Re[G_E \cdot G_M^*]/\tau \\ \frac{1}{s}w_5 &= -2Im[G_E \cdot G_M^*]/\tau \end{aligned} \qquad (12)$$

where $\tau \equiv s/4M^2$. The sf $w_5(s)$ is nonzero, as one can expect, only if the relative phase of complex ff's G_E and G_M is different from zero. The latter ensures the nonzero polarization of the created baryon in the annihilation of unpolarized e^+e^- to be as follows

$$P_y = -\frac{\sin 2\Theta \cdot Im[G_E(s) \cdot G_M^*(s)]/\tau}{|G_E(s)|^2 \sin^2\Theta/\tau + |G_M(s)|^2(1+\cos^2\Theta)}. \qquad (13)$$

The y-axis is orthogonal to the scattering plane defined by the vectors $\vec{m}$ and $\vec{n}$ as shown in Fig.2.

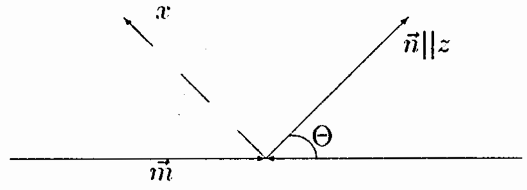

Figure 2:

The structure functions w_3 and w_4 are different from zero only if at least one of the colliding leptons is longitudinally polarized, and they determine components of the vector polarization $\vec{P}$ in the plane of reaction $e^+e^- \to B\bar{B}$ in the form

$$P_x = -\frac{2\sin\Theta \cdot Re[G_E(s) \cdot G_M^*(s)]\tau}{|G_E(s)|^2 \sin^2\Theta/\tau + |G_M(s)|^2(1+\cos^2\Theta)} \qquad (14)$$

$$P_z = \frac{2\cos\Theta|G_M(s)|^2}{|G_E(s)|^2 \sin^2\Theta/\tau + |G_M(s)|^2(1+\cos^2\Theta)}, \qquad (15)$$

if the longitudinal polarization of a lepton is equal to 100%.

For the complete determination of e.m. ff's of baryons with spin 1/2 for $s > 0$ it is necessary to know the following four combinations of ff's

$$|G_E|^2, \quad |G_M|^2, \quad Re[G_E \cdot G_M^*], \quad Im[G_E \cdot G_M^*].$$

They can be measured as follows. At a fixed value of s one has to measure $d\sigma/d\Omega$ of the process $e^+e^- \to B\bar{B}$ at two values of the angle Θ (this allows determination of $|G_E|^2$ and $|G_M|^2$) and two components of the polarization of one of the final particles

$$P_y(\Theta = 45°) \to Im[G_E \cdot G_M^*] \quad and \quad P_x(\Theta = 90°) \to Re[G_E \cdot G_M^*].$$

Since the measurement only of the differential cross-section with unpolarized particles provides $|G_E|^2$ and $|G_M|^2$, then the P_z - component can be unambiguously predicted on the base of the latter as follows

$$P_z = \frac{2\cos\Theta}{1+\cos^2\Theta+\sin^2\Theta\cdot R}, \tag{16}$$

$$R = \frac{1}{\tau}\frac{|G_E|^2}{|G_M|^2}.$$

This structure of P_z can be used verifying the one-photon exchange approximation in the process $e^+e^- \to B\bar{B}$.

If for $\tau \gg 1$ ff's G_E and G_M have equal falling, then for P_z we have

$$P_z = \frac{2\cos\Theta}{1+\cos^2\Theta}, \tag{17}$$

$$P_z = \pm 1 \quad (for \quad \cos\Theta = \pm 1),$$

i.e. P_z does not depend on ff's. Further we notice that the angular dependence of all vector polarization components is known to be

$$P_x\frac{d\sigma}{d\Omega} \simeq \sin\Theta, \quad P_y\frac{d\sigma}{d\Omega} \simeq \sin 2\Theta, \quad P_z\frac{d\sigma}{d\Omega} \simeq \cos\Theta, \tag{18}$$

i.e. it is enough to measure the polarization components only at one value of the angle Θ. The measurements at several values of the angle can be used for checking the validity of the one-photon exchange approximation.

Finally, we would like to demonstrate to what extent the behaviour of the components of the vector polarization (13)-(15) is sensitive to the employed global model of the nucleon e.m. structure.

For the latter we use two formulations of the unitary and analytic vector-meson-dominance (VMD) model of the nucleon e.m. ff's proposed [13], [14] recently, which differ in a method of incorporating the

asymptotic behaviour as predicted by QCD (up to logarithmic corrections) for nucleons. In the first formulation [13] a two-cut approximation of the correct ff analytic properties is incorporated into the standard VMD model, which leads to factorization of the resultant expressions into the asymptotic part and the finite energy part. Then the correct asymptotic behaviour is achieved simply by changing the powers of the corresponding asymptotic terms. In the construction of the second model [14], first, the standard VMD model is transformed to be automatically normalized and to have the QCD asymptotics. And only then the unitarization of the VMD model, with eight (compared with fourteen in the previous formulation of the model) free parameters.

Both models reproduce the existing experimental information almost equally well. However, the predicted behaviour of the vector polarization components from both global models (see Fig.3 and Fig.4) is completely different.

The latter result shows that the measurement of polarization of nucleons in $e^+e^- \to N\bar{N}$ process can be used for discrimination of already existing global models of the nucleon e.m. structure. It can unambiguously prefer the most realistic approach from all existing up to now global models of the nucleon e.m. structure.

5 Summary

Starting with the review of the present status of polarization effects in electromagnetic interactions of hadrons, the paper is completely devoted to polarization effects in $e^+e^- \to N\bar{N}$ process. Since many features of the nucleons are common for all baryons with spin 1/2, the determination of the structure of the e.m. current in the two-

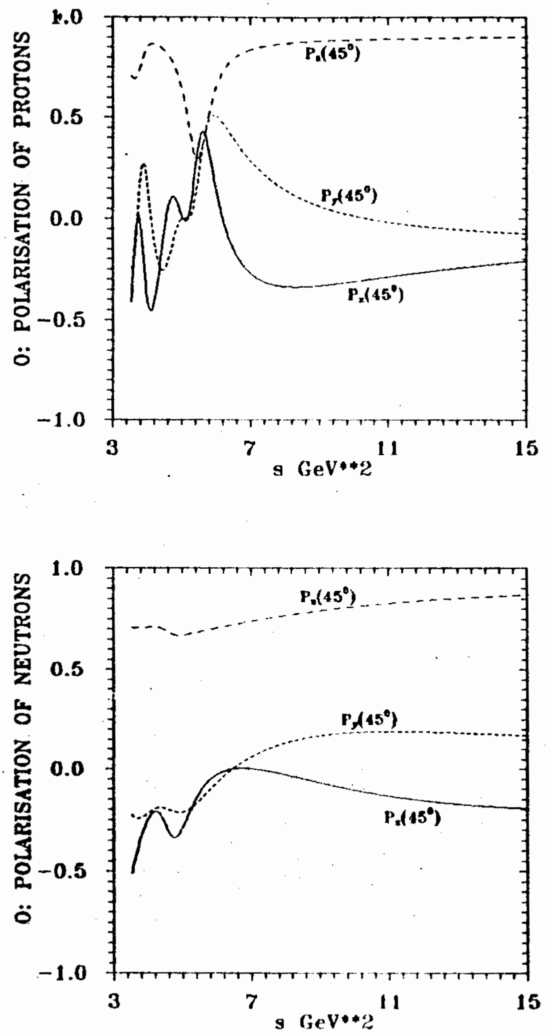

Fig.3. A prediction of the vector polarization component (13)-(15) behaviour by the old (therefore at the beginning of y- axis description O:) formulation [15] of the unitary and analytic VMD model of the nucleon e.m. structure

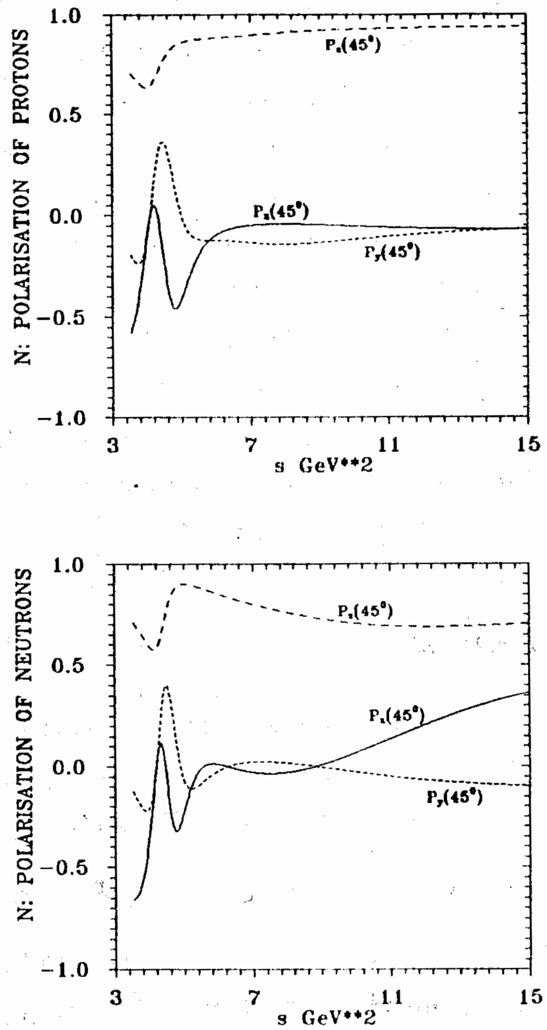

Fig.4. A behaviour of the vector polarization components (13)-(15) for created nucleons in $e^+e^- \rightarrow N\bar{N}$ process as predicted by the new formulation [14] of the unitary and analytic VMD model of the nucleon e.m. structure.

component spinor formalism, derivation of the Θ- dependence of the corresponding differential cross section and the calculation of explicit formulae for vector polarization components of a created baryon in the annihilation of unpolarized e^+e^- colliding beams are carried out on a more general level. The sensitivity of the vector polarization components is demonstrated only for nucleons as there are two formulations of the unitarity and analytic VMD model of the nucleon e.m. structure which appear to be very suitable for the latter aim.

Measurement of polarization effects in $e^+e^- \to N\bar{N}$ processes with small values of cross sections represents an exceptionally difficult experimental work. However, all considerations of this paper show that such measurements are highly desirable.

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