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RADIATIVE CORRECTIONS TO P-ODD ASYMMETRIES IN DEEP-INELASTIC SCATTERING OF POLARIZED LEPTONS AND ANTILEPTONS ON NUCLEONS

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RADIATIVE CORRECTIONS TO P-ODD ASYMMETRIES IN DEEP-INELASTIC SCATTERING OF POLARIZED LEPTONS AND ANTILEPTONS ON NUCLEONS

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Радиационные поправки к P-нечетным асимметриям в глубоконеупругом рассеянии поляризованных лептонов и антилептонов на нуклонах

В рамках кварк-партонной модели и модели Вайнберга-Салама вычислены радиационные поправки низшего порядка к P-нечетным асимметриям $A^{\mp}$ и B в процессах глубоконеупругого рассеяния поляризованных лептонов и антилептонов на нуклонах. Показано, что при $E = 280$ ГэВ и $q^2 = 100$-300 ГэВ^2 радиационная поправка для асимметрии B составляет около 50%, а для асимметрии A^- достигает 20% в некоторых частях кинематической области, но не превосходит 10% в кинематической области выполненного эксперимента группы SLAC.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Bardin D.Yu., Fedorenko O.M.,
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Radiative Corrections to P-Odd Asymmetries in Deep-Inelastic Scattering of Polarized Leptons and Antileptons on Nucleons

Based on a simple quark-parton model of strong interaction and on the Weinberg-Salam theory, the lowest-order radiative corrections to the P-odd asymmetries $A^{\mp}$ and to charge asymmetry B in deep-inelastic scattering of polarized leptons on unpolarized nucleons are calculated. It is shown that at $E = 280$ GeV and $q^2 = 100$-300 GeV^2 the radiative corrections to asymmetry B is about 50%, and to asymmetry A^- reaches 20% at some kinematical points, but does not exceed 10% in the region of the SLAC experiment.

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

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1. INTRODUCTION

The recent discovery in experiments [1,2] of the parity-violation lepton-hadron interaction has completed an important step in experimental investigation of the weak neutral current structure. In an experiment, performed by Stanford group [2], the P-odd asymmetry in deep inelastic scattering of longitudinally polarized electrons on deuterons was measured. (For the theory see refs. [3-10]). The result of this experiment is well-consistent with predictions of SU(2) × U(1) gauge theory by Salam and Weinberg [11] at $\sin^2\Theta_W = 0.224 \pm 0.020$ [2]. The latter value is close to the corresponding values determined from the neutrino data [12]. The results of experiment [2] are obtained at relatively small transfer momenta $q^2 = 1.6\ \mathrm{GeV}^2$. There are now some proposals to measure P-odd asymmetries at most high q^2, which can be reached today in deep-inelastic μN-scattering [13].

The theoretical analysis of P-odd asymmetries was performed so far in the Born approximation [3-8], only diagrams with one-γ and one-Z exchange being taken into account [14]. For the case of scattering on an isoscalar target, neglecting the isoscalar contribution, one can obtain a prediction within Weinberg-Salam model (WSM), but without any strong interaction model [14]

$$A^{\mp} = \frac{1}{\lambda} \cdot \frac{d^2\Sigma^{\mp}(\lambda) - d^2\Sigma^{\mp}(-\lambda)}{d^2\Sigma^{\mp}(\lambda) + d^2\Sigma^{\mp}(-\lambda)} \simeq \mp\, 9 \cdot 10^{-5} q^2\, \mathrm{GeV}^{-2}, \qquad (1)$$

where λ is the longitudinal polarization of the initial lepton (antilepton), and $d^2\Sigma^{\mp}$ is the double differential inclusive cross-section of $\ell^{\mp}N$ deep-inelastic scattering.

Using quark-parton model (QPM) it is easy to take into account the isoscalar current contribution and derive some explicit expressions not only for $A^{\mp}$ asymmetries but also for beam conjugation asymmetry

$$B = \frac{d^2\Sigma^+(\lambda) - d^2\Sigma^-(-\lambda)}{d^2\Sigma^+(\lambda) + d^2\Sigma^-(-\lambda)}. \qquad (2)$$

So, the Born approximation WSM and QPM predictions for $A_0^{\mp}$ and B_0 at $\sin^2\Theta_W = 1/4$, are

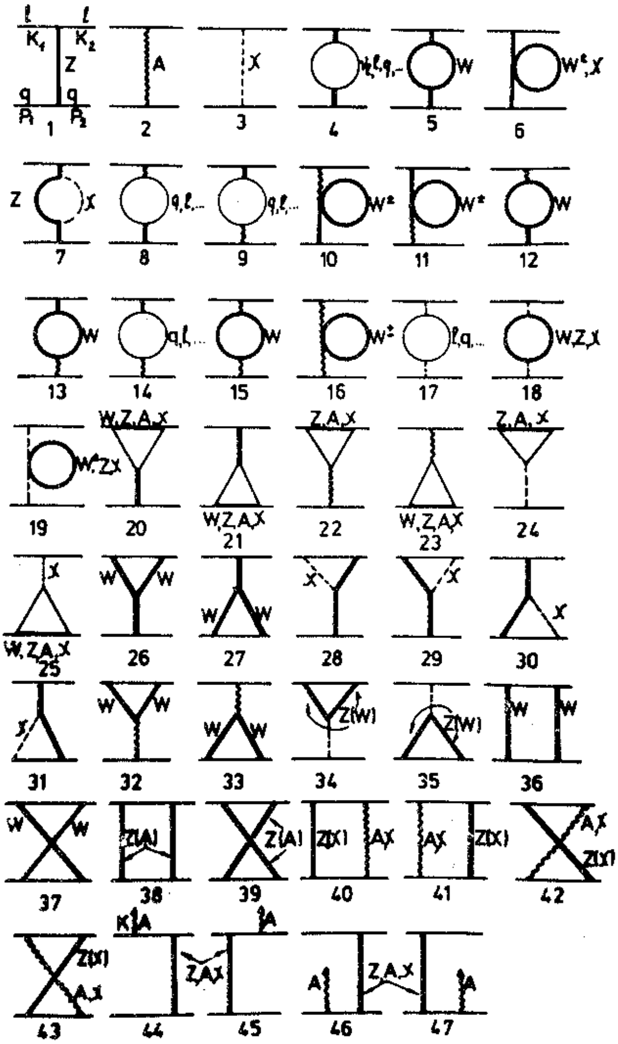
$$\hat{A}_0^{\mp} = \mp 0{,}72 \cdot 10^{-4} q^2 \ \mathrm{GeV}^{-2},$$
$$B_0 = -1{,}62 \cdot 10^{-4} R(y) q^2 \cdot \mathrm{GeV}^{-2}. \qquad (3)$$

With $R(y) = y(2-y)/T_0$, $T_0 = 1 + (1-y)^2$, y (as x in the following) is the usual scaling variable.

Conserning radiative corrections (RC) to asymmetries in the literature there are some statements that RC do not generate asymmetries [2] or are very small [9]. In those models, where the Born contribution to $A^{\mp}$ is zero asymmetry appears just due to higher-order weak processes [9]. QCD-corrections to asymmetries, as shown in [10] are small; they do not exceed 10% even at $q^2 = 10^4$ GeV^2.

In this paper, using WSM and QPM we show, that RC generate some additional contribution to the Born one to the asymmetries $A^{\mp}$ and explain the reason of rather essential RC. The latter as is shown, reach 20% and exceed the reached accuracy in the measurement of A^- which is now about 10%. For this reason the RC should be taken into account at data processing.

Thus, we calculate here the lowest-order RC to $A_0^{\mp}$ and B_0 within WSM and QPM. But it is well known fact, that within QPM one can take unambiguously into account only RC to the lepton current and bubbles inserted in the virtual photon or Z-boson lines [16]. However, in order to obtain a finite answer for RC in one-loop approximation within some gauge model it is necessary to consider all possible one-loop diagrams [17] and perform the whole renormalization program. On this way we are forced to consider quarks as free particles on the mass-shell. It is evident that it is difficult to estimate the extent of applicability of such an approach. In an attempt to overcome this difficulty we calculate two radiatively corrected asymmetries. In the first case asymmetries $A_1^{\mp}$ were derived from the differential cross section $d^2\Sigma_1^{\mp}$ calculated up to one-loop level using all diagrams in fig. 1 and realizing the whole renormalization program. In the second case, asymmetry $\bar{A}_1^{\mp}$



ℓ K1 ℓ K2 Z q P1 q P2 1
A 2
X 3
ℓ,q,.. 4
W 5
W±,X 6
Z X 7
q,ℓ,... 8
q,ℓ,... 9
W± 10
W± 11
W 12
W 13
q,ℓ,... 14
W 15
W± 16
ℓ,q,... 17
W,Z,X 18
W,Z,X 19
W,Z,A,X 20
W,Z,A,X 21
Z,A,X 22
W,Z,A,X 23
Z,A,X 24
X W,Z,A,X 25
W W 26
W W 27
X 28
X 29
X 30
X 31
W W 32
W W 33
Z(W) 34
Z(W) 35
W W 36
W W 37
Z(A) 38
Z(A) 39
Z(X) A,X 40
A,X Z(X) 41
A,X Z(X) 42
Z(X) A,X 43
K A 44
Z,A,X A 45
A Z,A,X 46
A 47

Fig. 1

was derived from cross section $d^2\bar{\Sigma}_1^{\mp}$, in the calculation of which we leave only finite renormalized parts of a small number of diagrams. The latter are firstly a part of RC to the lepton current-lepton bremsstrahlung (diagrams 44 and 45, fig. 1) and vertex electromagnetic corrections (diagrams of type 22 with additional virtual γ-quantum) and secondly, a part of bubbles - vacuum polarization (diagram 14) and $Z\gamma$-mixing (diagrams 8 and 9). In what follows, this set of diagrams will be referred to as the restricted set of diagrams.

We have compared these two asymmetries $A_1^{\mp}$ and $\bar{A}_1^{\mp}$ and found that at $E = 280$ GeV and $q^2 > 100$ GeV^2 they satisfy the following inequality

$$|(A_1^- - \bar{A}_1^-)/A_0| < 0{,}1 \cdot |(A_1^- - A_0)/A_0|. \qquad (4)$$

Ineq. (4) means that the small number of diagrams left in the calculation of $d^2\bar{\Sigma}_1^-$ describes the lion's share of radiative corrections to A^- and that all other diagrams, the account of which in QPM is rather questionable, give a contribution smaller than 10%. If calculations in QPM are regarded nevertheless as a real estimation of inaccuracy of calculations [16] of RC using the restricted set of diagrams, then ineq. (4) means that this inaccuracy does not exceed 10% over RC itself. The simple formulas, describing the contributions of above diagrams to $d^2\Sigma_1$ are given in paper [18]. Here we prove inequality (4) for A^- by direct calculations in WSM and QPM.

In the next section we give a scheme for calculating a contribution to $d^2\Sigma_1^{\mp}$ from diagrams with the exchange by virtual particles $W^{\pm}$, Z, χ-bosons, leptons and γ-quanta (V-contribution). In Sec.3 we present the general steps of the calculation and list general formulas for contributions to $d^2\Sigma_1^{\mp}$ from the diagrams with real photon emission (R-contribution). In the last Section we show and discuss the numerical results for asymmetries $A^{\mp}$ and B.

2. INCLUSIVE CROSS-SECTION OF THE PROCESS IN ONE-LOOP APPROXIMATION

The calculation of the inclusive cross section $d^2\Sigma_1^{\mp}$ for the processes

$$\ell^{\mp} + N \rightarrow \ell^{\mp} + \text{hadrons} \qquad (5)$$

with polarized initial leptons or antileptons to order α^3 will be done by the following scheme: Find the one-loop approximation for the amplitude of the process

$$\ell^{\mp} + q \rightarrow \ell^{\mp} + q, \tag{6}$$

where q is the point particle with arbitrary mass M and charge $Q = f \cdot e$ (e is the electron charge). In the obtained expression fix the weak-interaction constant g_F up to one-loop approximation and get divergence-free expression for the differential cross section $d^2\sigma_V$ of the process (6) up to order α^3. Next calculate the contribution to the cross section from the diagrams with real photon emission $d^2\sigma_R$

$$\ell^{\mp} + q \rightarrow \ell^{\mp} + q + \gamma . \tag{7}$$

In the sum $d^2\sigma_R + d^2\sigma_V$ replace the initial parton momentum by $\xi \cdot P$, where P is the momentum of the initial nucleon. Multiply this sum by the distribution function $f_i(\xi)$ of an i -th kind of partons over momenta, integrate over ξ and sum over all types of partons involved in reactions. In the final step average the cross section over proton and nucleon, i.e., find the cross section at scattering on an isoscalar target.

1. V -Contribution

The contribution to the amplitude of processes (6) from the virtual particle exchange diagrams up to the one-loop approximation has been calculated in paper /17/. The calculation was done in the unitary gauge by the dimensional regularization method /19/. The renormalization program was realized through the counterterm Lagrangian method /20/. The expression for the amplitude has been derived in the approximation

$$m_i^2 \ll I \ll M_W^2 , \tag{8}$$

where I is an invariant of the amplitude, $m_i = (m, M)$ is any mass of scattered particles, M_W is the weak W -boson mass. The l.h.s. of the inequality is the necessary condition to apply the QPM, the r.h.s. is valid at current energies and simplifies essentially the resulting formulas.

Let us write the amplitude of (6) in approximation (8) up to one-loop level (diagrams 1-43, fig. 1) in terms of form factors $\mathcal{F}$:

$$M_V^{\mp} = C_Z \cdot [\, O_\alpha \times O_\alpha \mathcal{F}_1^{\mp} - 4|Q|(1-R) O_\alpha \times \gamma_\alpha \mathcal{F}_2^{\mp} - 4(1-R)\gamma_\alpha \times O_\alpha \mathcal{F}_3^{\mp} + \tag{9}$$

$$+ 16|Q|(1-R)^2 \gamma_\alpha \times \gamma_\alpha \mathcal{F}_4^{\mp}] + C_A(\gamma_\alpha \times \gamma_\alpha \bar{\mathcal{F}}_4^{\mp} + \gamma_\alpha\gamma_5 \times \gamma_\alpha\gamma_5 \mathcal{F}_5^{\mp}),$$

with

$$R = 1 - e^2/g^2, \quad O_\alpha = \gamma_\alpha(1+\gamma_5), \quad \alpha_W = q^2/M_W^2,$$

$$C_Z = \frac{ig^2 S_Q N}{16 M_W^2 (1 + R\alpha_W)}, \quad C_A = \frac{ie^2 \cdot Q \cdot N}{q^2}. \tag{10}$$

Here symbol $\times$ means the direct product of Dirac matrices, $S_Q = 1$ for u and c -quarks, $S_Q = -1$ for d and s -quarks, N is the standard normalization factor due to external fermion lines. In this notation, the Born γ -exchange amplitude, for example, has the form for $\ell^- q$ -scattering

$$C_A \bar{u}(k_2)\gamma_\alpha u(k_1)\bar{u}(p_2)\gamma_\alpha u(p_1) \to C_A \gamma_\alpha \times \gamma_\alpha$$

and for $\ell^+ q$ -scattering

$$C_A \cdot \bar{u}(-k_1)\gamma_\alpha u(-k_2)\bar{u}(p_2)\gamma_\alpha u(p_1) \to C_A \gamma_\alpha \times \gamma_\alpha .$$

After removing ultraviolet divergences [17] the amplitude (9) still contains infrared diverhences which appear through the pole terms P_{IR} and G_{IR} for the space- time dimsnension $n=4$. The first pole P_{IR} corresponds to the genuine infrared divergences, which cancel out by the contribution of soft photons from process (7) (diagrams 44-47 of fig. 1)

$$P_{IR} = \frac{1}{n-4} + \frac{1}{2}C + \ln\frac{M_W}{2\sqrt{\pi}\,\eta}, \tag{11}$$

where C is the Euler constant, and η is an arbitrary parameter with mass dimensionality.

Infrared divergences G_{IR} result from renormalization on the mass shell of W -boson. Pole G_{IR} is given by the formula [17]

$$G_{IR} = 4\left(1 + \frac{M_W^2 + m_\mu^2}{M_W^2 - m_\mu^2} \cdot \ln\frac{m_\mu}{M_W}\right)P_{IR} + \ln\frac{M_W}{m_\mu} + 2\ln^2\frac{m_\mu}{M_W}, \qquad (12)$$

where m_μ is the muon mass.

Let us write down the infrared structure of form factors $\mathcal{F}_i^{\mp}$ in formula (9)

$$\mathcal{F}_1^{\mp} = 1 + \frac{g^2}{16\pi^2}\left[-2\frac{1-R}{1+R\alpha_W} \cdot (1-\alpha_W + 2R\alpha_W) \cdot G_{IR}\right] + \frac{\alpha}{2\pi}\delta^{\mp} \cdot P_{IR},$$

$$\mathcal{F}_{2,3}^{\mp} = 1 + \frac{g^2}{16\pi^2} \cdot \left[2\frac{(1-R)^2\alpha_W}{1+R\alpha_W} \cdot G_{IR}\right] + \frac{\alpha}{2\pi}\delta^{\mp} \cdot P_{IR}, \qquad (13)$$

$$\mathcal{F}_4^{\mp} = 1 + \frac{g^2}{16\pi^2} \cdot \left[2 \cdot \frac{(1-R)(1+\alpha_W)}{1+R\alpha_W} G_{IR}\right] + \frac{\alpha}{2\pi}\delta^{\mp} \cdot P_{IR},$$

$$\bar{\mathcal{F}}_4^{\mp} = 1 + \frac{\alpha}{2\pi}\delta^{\mp} \cdot P_{IR}.$$

Here

$$\delta^{\mp} = 2 + 2Q^2 - 2p_1p_2Q^2\mu(p_1;p_2) - 2k_1k_2\mu(k_1;k_2) \pm Q \cdot [2p_1k_1\mu(k_1;-p_1) + \qquad (14)$$
$$+ 2p_1k_2\mu(k_2;p_1) + 2p_2k_1\mu(k_1;p_2) + 2p_2k_2\mu(-k_2;p_2)],$$

with

$$\mu(k;p) = \int_0^1 \frac{d\alpha}{[k\alpha + p(1-\alpha)]^2}.$$

In formulas (13) only singular contributions are written down; form factor $\mathcal{F}_5$ is singularity-free.

Divergences containing the pole term G_{IR} are removed through fixing of the weak interaction constant g up to one-loop approximation. In paper [21], calculating RC to deep inelastic neutrino-nucleon scattering, we have found a relation constraining the product of two infinite unobservables g and G_{IR} by the observable quantity - total lifetime of muon τ_μ.

$$g^2 = g_F^2 \cdot \left(1 + \frac{\alpha}{2\pi} G_{IR}\right),$$

$$R = R_F + \frac{\alpha}{2\pi}(1-R_F)G_{IR}\ ^{*}. \qquad (15)$$

Here

$$g_F^2 = g_F^2(r_\mu) = (8M_W^2/\sqrt{2})\cdot 10^{-5}\cdot 1{,}0245/M_P^2, \quad 1-R_F = \mathrm{Sin}^2\Theta_W^F = 4\pi\alpha/g_F^2$$

is the physical value of the parameter $\mathrm{Sin}^2\Theta_W$, M_P is the proton mass. Inserting eq. (15) into amplitude (9) and restricting to the order α^3 we reach the G_{IR}-free result.

For the differential cross section of scattering process (6) at an i-th parton we have the expression

$$\left(\frac{d^2\Sigma_V}{dx\,dy}\right)_i^{\mp} = \left(\frac{d^2\Sigma_0}{dx\,dy}\right)_i^{\mp}\cdot\left(1+\frac{\alpha}{\pi}\delta_i^{\mp}P_{IR}\right) + K\frac{\alpha}{2\pi}xf_i(x)(Q_i^2\cdot[\bar{T}_4^{\mp} \pm R(y)T_5^{\mp}] +$$

$$+\frac{\alpha_W|Q_i|}{8(1-R_F)}\{\frac{1\mp\lambda}{2}[1\pm R(y)]T_1^{\mp} + \frac{1\mp\lambda}{2}(b_i-1)T_2^{\mp} + \frac{a-1}{2}[1-\lambda R(y)]\cdot T_3^{\mp} +$$

$$+\frac{a-1}{2}(b_i-1)T_4^{\mp} + \frac{1}{2}[b_i(a\mp\lambda)+(\pm1-a\lambda)R(y)]\bar{T}_4^{\mp} + \frac{1}{2}[1\mp a\lambda \pm b_i(a\mp\lambda)R(y)]T_5^{\mp}\}),$$

with

$$\left(\frac{d^2\Sigma_0}{dx\,dy}\right)_i^{\mp} = Kxf_i(x)[Q_i^2 + \frac{\alpha_W|Q_i|}{8(1-R_F)}\{b_i(a\mp\lambda)+(\pm1-a\lambda)R(y)\}],$$

$$K = \frac{2\pi\alpha^2 S_N}{Y^2}\cdot T_0.$$

The Born approximation cross section $d^2\Sigma_0^{\mp}$ is derived taking into account the square of γ-exchange diagram and interference of Z- and γ-exchange diagrams (diagrams 1 and 2 of fig. 1). The square of Z-exchange diagram should be ignored in approximation (8). Other notations in (16) are

$$S_N = 2M_N E, \quad a = 1-4\,\mathrm{Sin}^2\Theta_W^F, \quad b_i = 1-4|Q_i|\,\mathrm{Sin}^2\Theta_W^F, \quad Y = xyS_N. \qquad (17)$$

where M_N is the nucleon mass, E is the incident lepton energy, and T_i are finite renormalized parts coming from all one-loop diagrams 1-43 of fig. 1.

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*It is necessary to remember that eq. (15) contains also some finite parts besides singular ones. For this reason the procedure of fixing g changes the finite parts of form factors $\mathcal{F}_i$ of the amplitude (9).

2. R-Contribution

The calculation of the contribution to the cross section $d^2\Sigma_1$ from diagrams 44-47 of fig. 1 with real-photon emission is carried out in a manner of paper /22/. As usual, we separate the infrared- divergent part $d^2\sigma_R^{IR}$ out of the cross-section $d^2\sigma_R$:

$$d^2\sigma_R = d^2\sigma_R^{IR} + d^2\sigma_R^F , \tag{18}$$

where $d^2\sigma_R^F$ is the infrared-free part. Calculating R-contribution in approximation (8) it is necessary to take into account besides the square of sum diagrams 44-47 with γ-exchange only interference of these diagrams with γ- and Z-exchanges.

The infrared divergent part of (18) arising from bremsstrahlung process (5) in scattering on i-th parton is derived in the form

$$\left(\frac{d^2\Sigma_R^{IR}}{dx\,dy}\right)_i^{\mp} = \left(\frac{d^2\Sigma_0}{dx\,dy}\right)_i^{\mp} \frac{\alpha}{\pi}\cdot(-\delta_i^{\mp} P_{IR} + \delta_i^{s\,\mp}) + \left(\frac{d^2\Sigma_{TR}}{dx\,dy}\right)_i^{\mp} . \tag{19}$$

In eq. (19) δ^s are factorized and $d^2\Sigma_{TR}$ nonfactorized contributions to $d^2\Sigma_R^{IR}$.

$$\left(\frac{d^2\Sigma_{TR}}{dx\,dy}\right)_i^{\mp} = \frac{\alpha}{\pi}\cdot\left(\frac{d^2\Sigma_0}{dx\,dy}\right)_i^{\mp}\Big|_{xf_i(x)\to\int\limits_x^1 \frac{\xi f_i(\xi)-xf_i(x)}{\xi-x} I_i^{\mp}(\xi)d\xi} , \tag{20}$$

where

$$I_i^{\mp}(\xi) = 2\left(\ln\frac{Y}{m^2}-1\right) \pm Q_i\left\{2\ln\frac{S_N}{X_N} - \frac{\xi X_N}{\xi S_N - Y}\ln\frac{(\xi S_N - Y)^2}{m^2\tau_i} + \right.$$

$$\left. + \frac{\xi S_N}{\xi X_N + Y}\ln\frac{(\xi X_N + Y)^2}{m^2\tau_i}\right\} + Q_i^2\left\{-1-\frac{M_i^2}{\tau_i} + \frac{Y}{\xi S_X^N}\ln\frac{\xi^2 (S_X^N)^2}{M_i^2\tau_i}\right\}, \tag{21}$$

$$S_X^N = S_N - X_N,\quad X_N = S_N(1-y),\quad \tau_i = V + M_i^2,\quad V = S_X^N\xi - Y .$$

For factorized part δ^s we have found the following expression

$$\delta_i^{s\,\mp} = I_i^{\mp}(x)\ln\frac{v_{max}}{M_i M_W} + \ln\frac{X_0\cdot S_0}{m^2 M_i^2} - \frac{\pi^2}{6} + \frac{1}{2}\ln\frac{m^2}{Y}\ln\frac{S_0^2 X_0^2}{m^2 M_i^4 Y} - \frac{1}{2}\ln^2\frac{S_0}{X_0} \pm$$

$$\pm Q_i\{2\ln\frac{S_0}{X_0}\ln\frac{M_i^2}{Y}+2\Phi(-\frac{r_x}{y_1})-2\Phi(-r_x y_1)+y[\ln(1+\frac{r_x}{y_1})\ln(\frac{S_N}{m^2}(x_1+r_y))+$$

$$+\Phi(1+\frac{r_x}{y_1})-\frac{\pi^2}{6}]+\frac{1}{r_y}[\ln\frac{y(x+r_y)}{x}\ln\frac{S_N y r_y(x+r_y)}{m^2}-\frac{\pi^2}{6}+\Phi(\frac{y(x+r_y)}{x})]\}+ \quad (22)$$

$$+Q_i^2[1-\frac{\pi^2}{3}+\ln\frac{Y}{M_i^2}-\ln^2\frac{Y}{M_i^2}+\ln\frac{v_{max}}{M_i^2}+\Phi(x_1)-\frac{1}{2}\ln^2\frac{x_1\cdot Y}{M_i^2}+2\ln x\cdot\ln\frac{Y}{M_i^2}],$$

where

$$S_0=x\cdot S_N,\quad X_0=xX_N,\quad v_{max}=V|_{\xi=1},\quad y_1=1-y,$$

$$x_1=1-x,\quad r_x=1/x-1,\quad r_y=1/y-1,\quad \Phi(x)=-\int_0^x t^{-1}\ln|1-t)|\,dt$$

is the Spence function.

The contribution to $d^2\sigma_R^F$ from the square of γ-exchange bremsstrahlung was presented in ref./16/, and from interference of γ- and Z-exchanges was calculated straightforwardly using SCHOONSHIP system/24/.

3. Derivation of Final Formulae for $A_1^{\mp}$ and B_1

So, the contribution to the cross-section of the considered reaction (5) from the scattering processes on the i-th parton up to one-loop approximation is as follows

$$(\frac{d^2\Sigma_1'}{dx\,dy})_i^{\mp}=(\frac{d^2\Sigma_V}{dx\,dy})_i^{\mp}+(\frac{d^2\Sigma_R^{IR}}{dx\,dy})_i^{\mp}+(\frac{d^2\Sigma_R^F}{dx\,dy})_i^{\mp}. \quad (23)$$

To obtain the final expressions for cross sections of processes (5) up to order α^3 one should sum (23) over all partons and antipartons in the nucleon. Define the one-loop approximations for asymmetries $A^{\mp}$ and B by the formulae

$$A_1^{\mp}=\frac{1}{\lambda}\cdot\frac{d^2\Sigma_1^{\mp}(\lambda)-d^2\Sigma_1^{\mp}(-\lambda)}{d^2\Sigma_1^{\mp}(\lambda)+d^2\Sigma_1^{\mp}(-\lambda)}, \quad (24)$$

$$B_1(\lambda)=\frac{d^2\Sigma_1^{+}(\lambda)-d^2\Sigma_1^{-}(-\lambda)}{d^2\Sigma_1^{+}(\lambda)+d^2\Sigma_1^{-}(-\lambda)}, \quad (25)$$

where $d^2\Sigma_1^{\mp}$ is the cross section of process (5) obtained by summing over parton types and averaged over proton and neutron of $d^2\Sigma_1'$ of eq. (23). In numerical calculations we restrict ourselves only to taking into account the valence u and d quarks, parton spectra being taken from ref. [23].

III. DISCUSSION

In figs. 2 and 3 we present asymmetries $A_0^{\mp}$ (dash-dotted lines) and $\bar{A}_1^{\mp}$ (solid line) in deep inelastic scattering of longitudinally polarized muons on the isoscalar nucleon at incident lepton energy $E=280$ GeV for three fixed $q^2=100$, 200, 300 GeV^2 as a function of y. The parameter $\sin^2\Theta_W^F$ was chosen equal to 1/4. To illustrate ineq. (4) we show also symmetry A_1^- (dotted lines) calculated with all diagrams of fig. 1.

We note that ineq. (4) does not hold for A_1^+ because of small RC to A_0^+ from the restricted set of diagrams. Nevertheless, A_1^+ is very close to $\bar{A}_1^+$ presented in fig. 3 in absolute value and exhibits a similar to $\bar{A}_1^+$ behaviour, in particular, rather prominent y-dependence near kinematical boundaries. From figs. 2 and 3 one can see also that RC to A^- reaches 20% of the value (3) and similar to the isoscalar contribution reduces the prediction (1). On the contrary, RC to A^+ does not exceed 7%. (Computations performed for the case of eN-scattering in the kinematical region of experiment [2]: $E=20$ GeV, $q^2=1$ and 2 GeV^2 and $0.1\leq y\leq 0.3$ showed [18] that there RC to A_0^- does not exceed 10%).

In the analysis of RC to asymmetries $A^{\mp}$ it is convenient to introduce two radiative factors δ_1 and δ_2 defined by the formula

$$d^2\bar{\Sigma}_1^{\mp} = d^2\Sigma_0^{\mp}\Big|_{\lambda=0}\cdot\left[1+\delta_1^{\mp}+(1+\delta_2^{\mp})\cdot\lambda\cdot A_0^{\mp}\right], \qquad (26)$$

which results in the simple expression

$$\bar{A}_1^{\mp} = \frac{1+\delta_2^{\mp}}{1+\delta_1^{\mp}}\cdot A_0^{\mp}\ . \qquad (27)$$

As it is seen, RC would not generate the contribution (additional to the Born one) to the asymmetry only if $\delta_1^{\mp}=\delta_2^{\mp}$.

Radiative factors $\delta_{1,2}^{\mp}$ are presented in fig. 4. One can see that δ_2^- differs essentially from δ_1^-. A large part

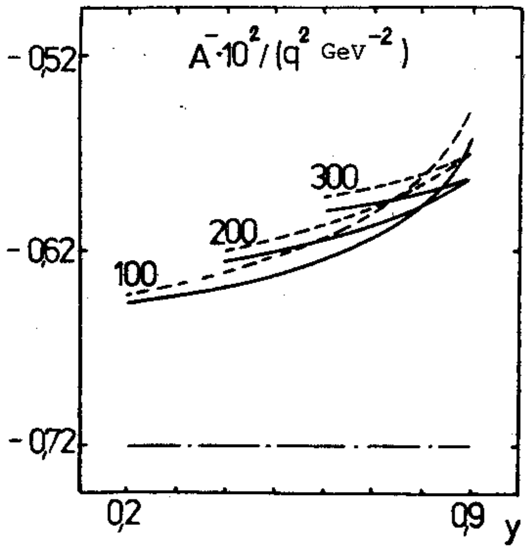
$A^{-}\cdot 10^{2}/(q^{2}\ \mathrm{GeV}^{-2})$
-0,52
-0,62
-0,72
300
200
100
0,2
0,9
y

Fig. 2

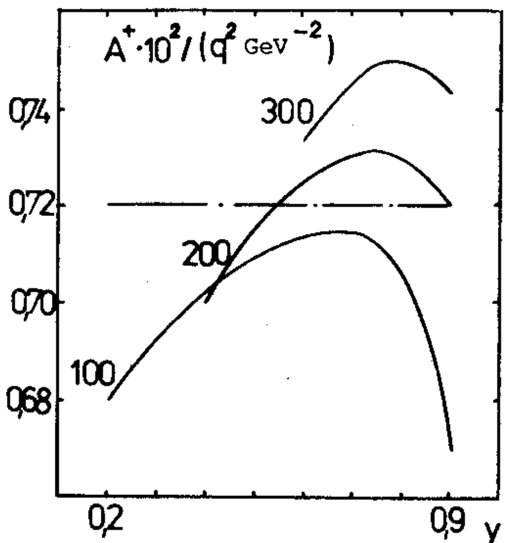
$A^{+}\cdot 10^{2}/(q^{2}\ \mathrm{GeV}^{-2})$
0,74
0,72
0,70
0,68
300
200
100
0,2
0,9
y

Fig. 3

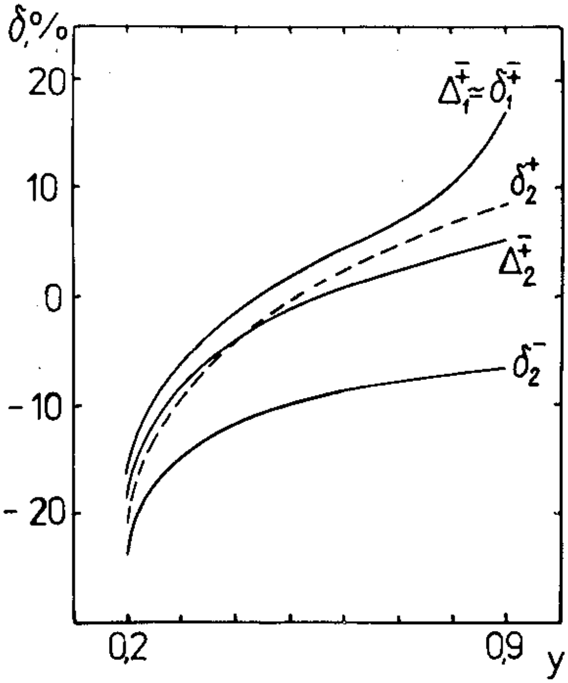

Fig. 4

(one half or more) of this difference is due to $Z\gamma$-mixing diagrams. To illustrate this point, we calculate two new factors $\Lambda^{\mp}_{1,2}$ purging $Z\gamma$ -mixing diagrams from the restricted set of diagrams. From fig. 4 it is seen that $\Lambda^{\mp}_1 \simeq \delta^{\mp}_1$ and $\Lambda^-_2 \simeq \Lambda^+_2$ and the latter are essentially smaller than δ^-_2. An analysis of simple formulae for RC to A^+ from the restricted set of diagrams, shows that for $\ell^- N$ -scattering the contribution of $Z\gamma$ -diagrams is kinematically enhanced by a factor 2-3 and is summed with the other diagram contributions. But for $\ell^+ N$ -scattering such a kinematical enhancement is absent and, moreover, the contribution of $Z\gamma$ -diagrams tends to cancel other diagram contributions. Approximate equalities $\Delta^{\mp}_1 \simeq \delta^{\mp}_1$ and $\Lambda^+_2 \simeq \Delta^-_2$ mean that the sum of asymmetries $A^+ + A^-$ is sensitive in principle to the contribution of $Z\gamma$ -mixing diagrams. Of course, to gain some information about $Z\gamma$-mixing it is necessary to measure A^+ and A^- with 2-3% accuracy. This is a very hard experimental task.

From fig. 4 it is possible to draw also the conclusion that even without $Z\gamma$ -mixing RC do generate asymmetry which reaches 10% at $y \geq 0.9$. At high values of y it is due to hard-photon emission, which gives rise to a nonfactorized $(\Delta_1^{\mp} \neq \Delta_2^{\mp})$ RC to the cross section (26). Even if bremsstrahlung contributions are ignored, then the usual vacuum polarization generates 2% RC to A_0^+.

In the calculation of beam conjugation asymmetry B, except of the restricted set of diagrams it is necessary to take into account also diagrams of types 38 and 39 of fig. 1 with the 2γ-exchange and also interference of diagrams 44-45 with 46-47. Two latter contributions to B were calculated in /16/. They are of order α but are not suppressed by the factor q^2/M_W^2. For this reason their contribution may be very large relative to B_0. For example, at the considered q^2 and E it reaches 50%. This effect in B and the method of its measurement were discussed in detail in ref. /16/. A new point is the consideration of the restricted set of one-loop diagrams, also being of α order relative to B_0. The analysis of numerical results shows that RC to B from the latter set of diagrams behaves itself similar to RC to A^+: at large y they reach 10%

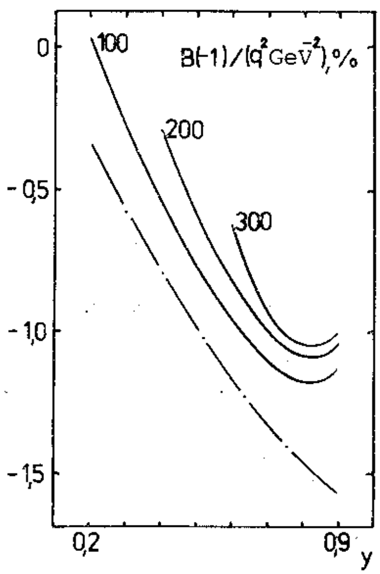

Fig. 5

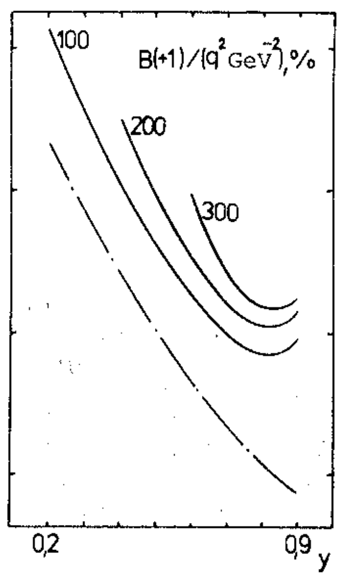

Fig. 6

for B(−1) and 15% for B(+1) (this difference is also due to $Z\gamma$-mixing diagrams) and in both cases they are summed with the RC discussed in ref.[16].

In figs. 5 and 6 we present asymmetries $\vec{B}_l(-1)$ and $\vec{B}_l(+1)$ for the case of deep inelastic scattering of longitudinally polarized muons at $E = 280$ GeV for three fixed $q^2 = 100$, 200 and 300 GeV^2 and at $\sin^2\Theta_W^F = 1/4$. The dash-dotted line shows prediction (3). We note that all other diagrams of fig. 1 change asymmetry B_l within 5%.

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REFERENCES

1. Барков Л.М., Золотарев М.С.Письма в ЖЭТФ,1978,27,с.379.
2. Prescott C.Y.et al. Phys.Lett., 1978, 77B, p.347; SLAC-PUB-2319, May, 1979.
3. Николаев Н.Н., Шифман М.А., Шматиков М.Ж. Письма в ЖЭТФ, 1979, 18, с.70.
4. Derman B. Phys.Rev., 1973, D7, p.2755.
5. Shifman M.A., Shmatikov M.Zh. Lett. Nuovo Cim., 1973, 8, p.201.
6. Berman S.M., Primack J.R. Phys.Rev., 1974, D9, p.2171.
7. Wilson W.J. Phys.Rev., 1974, D10, p.218.
8. Klein M., Riemann T. Phys.Lett., 1978, 76B, p.79.
9. Marciano W.J., Sanda A.I. Phys.Rev., 1978, D18, p.4341.
10. Rizzo T.G. Preprint BNL-25837, Upton, New York, 1979.
11. Weinberg S. Phys.Rev.Lett., 1967, 19, p.1264. Salam A. In: Elementary Particle Theory: Relativistic Groups and Analyticity (Nobel Symposium, No.8), p.367.
12. Holder M. et al. Phys.Lett., 1977, 72B, p.254. Bosetti P.C. et al. BEBC-Collaboration, preprint, 1978.
13. Clifft R. et al. CERN (SPSC), 74-78,P18, 1974. Krienen F. et al. CERN (SPSC) 74-79, P19, 1974.
14. Биленький С.М. ЯФ, 1979, 29, с.982.
15. Klein M. Preprint CERN Seminar held at the XX International School of Elementary Particle Physics, Kupari (Yugoslavia), 16-38 September, 1979.
16. Бардин Д.Ю., Шумейко Н.М. ЯФ, 1979, 29, с.969. ОИЯИ, Р2-10872, Дубна, 1977. Бардин Д.Ю., Федоренко О.М., Шумейко Н.М. ОИЯИ, Р2-10114, Дубна, 1976.

17. Бардин Д.Ю., Федоренко О.М. ОИЯИ, Р2-11413, Р2-11414, Дубна, 1978.
18. Bardin D.Yu., Fedorenko O.M., Shumeiko N.M. JINR, E2-12564, Dubna, 1979.
19. t'Hooft G., Veltman M. Nucl.Phys., 1972, B44, p.189.
20. Salomonson P., Ueda Y. Phys.Rev., 1975, D8, p.3612.
21. Бардин Д.Ю., Федоренко О.М. ЯФ, 1979, 30, с.811. JINR, E2-12085, Dubna, 1979.
22. Bardin D.Yu., Shumeiko N.M. Nucl.Phys., 1977, B127, p.242.
23. Barger V., Phillips P.J.M. Nucl.Phys., 1974, B73, p.268.
24. Strubbe H.S. Comp.Phys.Comm., 1974, 8, p.1.

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