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GERASIMOV-DRELL-HEARN SUM RULE AND THE BEHAVIOUR OF NUCLEON POLARIZED STRUCTURE FUNCTION AT SMALL Q^2

30 - 21 Ереван

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ԳԵՐԱՍԻՄՈՎ-ԴՐԵԼԼ-ՀԵՐՆԻ ԳՈՒՄԱՐԻ ԿԱՆՈՆՆԵՐԸ ԵՎ ՆՈՒԿԼՈՆԻ ԲԵՎԵՌԱՑՄԱՆ ԿԱՌՈՒՑՎԱԾՔԱՅԻՆ ՖՈՒՆԿՑԻԱՅԻ ՎԱՐՔԸ ՓՈՔՐ Q^2 ԴԵՊՔՈՒՄ։

Ի.Գ.ԱԶՆԱՈՒՐՅԱՆ

Օգտագործելով Գերասիմով-Դրելլ-Հերնի գումարների կանոնը ցույց է տրված, որ նեյտրոնի բևեռացման կառուցվածքային ֆունկցիան փոքր $Q=2$ԳէՎ^2 դեպքում դուրս է գալիս ասիմպտոտիկ արժեքի վրա։ Պրոտոնային բևեռացման կառուցվածքային ֆունկցիաների համար ցույց է տրված, որ սկսած 1.5ԳէՎ^2 նրա շեղումը ասիմպտոտիկ արժեքից չի գերազանցում 15-20%։ Եղած տվյալների հիման վրա, $Q^2<3$ԳէՎ^2 դեպքում էներգիաների ռեզոնանսային տիրույթում ստացված են նուկլոնի բևեռացման կառուցվածքային ֆունկցիայի ինտեգրալների արժեքները $X=0.45-1$ սահմանում, ուր բացակայում են փորձարարական տվյալները։ Պարզվել է, որ $Q^2=2-3$ԳէՎ^2 դեպքում այդ ինտեգրալները ունեն սկեյլինգյան վարք, իսկ նրանց մեծությունները համաձայնեցվում են փորձարարական աշխատանքներում արված էկստրապոլյացիաների հետ, մեծ X-ի տիրույթում։

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GERASIMOV-DRELL-HEARN SUM RULE AND THE BEHAVIOUR OF NUCLEON POLARIZED STRUCTURE FUNCTION AT SMALL Q^2

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Abstract

Using Gerasimov-Drell-Hearn sum rule it is shown that neutron polarized structure function achieves the asymptotic value at $Q^2 = 2\text{Gev}^2$. For proton polarized structure function it is shown that starting from 1.5 Gev^2 its deviation from the asymptotic value does not exceed 15-20%. The integrals over nucleon polarized structure functions are obtained in the interval of $x = 0.45 \div 1$ on the basis of available data in the resonance energy region at $Q^2 < 3\text{Gev}^2$.It appears that at $Q^2 = 2 \div 3\text{Gev}^2$ these integrals have scaling behaviour, and their values agree with the extrapolations to the region of large x made in experimental works.

Recently the Gerasimov-Drell-Hern sum rule (GDH) [1, 2] has drawn attention from the point of view to obtain using it an information on the possible scenaria of transition to the asymptotics of the nucleon polarized structure function $g_1(x, Q^2)$ [3]-[5]. When comparing with the Ellis-Jaffe [6] and Bjorken [7] sum rules this sum rule dictates strong change of the integral over nucleon polarised structure function under variation of Q^2 from 0 to ∞:

$$I_N(Q^2) \equiv \frac{m^2}{2\pi e^2}\int\limits_{Q^2/2m}^{\infty}\frac{d\nu}{\nu}\left[\sigma_{1/2}(Q^2)-\sigma_{3/2}(Q^2)\right]_{\overline{\overline{Q^2=0}}\atop Q^2\to\infty}$$

$$= m\int\limits_{Q^2/2m}^{\infty} g_1^N(\nu, Q^2)\frac{d\nu}{\nu^2} = \qquad (1)$$

$$= \begin{cases} -\frac{k_N^2}{4} \quad \text{for} \quad Q^2 = 0 \quad \text{(GDH sum rule [1, 2])}, & (1a) \\ \frac{2m^2}{Q^2}\Gamma_N(Q^2) \equiv \frac{2m^2}{Q^2}\int\limits_0^1 g_1^N(x)dx \quad \text{for} \quad Q^2 \to \infty, & (1b) \end{cases}$$

where $\sigma_{1/2}$ and $\sigma_{3/2}$ are total absorption cross sections of transverse photons by nucleons with parallel and antiparallel spins, m and k are the nucleon mass and anomalous magnetic moments, and in the asymptotics according to the Ellis-Jaffe [6] and Bjorken [7] sum rules we have:

$$\Gamma_p(Q^2 \to \infty) = \frac{1}{12}\left[\frac{g_A}{g_V} + \frac{5}{3}(3F - D)\right] = 0.188 \pm 0.014, \tag{2}$$

$$(\Gamma_p - \Gamma_n)(Q^2 \to \infty) = \frac{1}{6}\frac{g_A}{g_V} = 0.209 \pm 0.001. \tag{3}$$

In this connection an assumption was made [8], that the significant deviation of the measured at $Q^2 = 10.7\text{Gev}^2$ value $\Gamma_p = 0.126 \pm 0.010 \pm 0.015$ [9]-[11] from the asymptotic one (2) is connected with the large corrections which can be estimated using the GDH sum rule. However, the investigation of the resonance contributions to the Q^2 - evolution of the integral $I_p(Q^2)$ has shown [4],[11] that the strong change of this integral with increasing Q^2 is connected mainly with the Δ -isobar contribution, and after extraction of this contribution it appeared that at $Q^2 = 10.7\text{Gev}^2$ the corrections are not large.

In this work we will use the GDH sum rule in the framework of the approach developed in [4] to investigate the behaviour of the nucleon polarized structure function at small $Q^2 < 3\text{Gev}^2$. Such consideration is of interest as the recent measurement of the neutron polarized structure function at $Q^2 = 2\text{Gev}^2$ [12] has revealed that $\Gamma_n(Q^2)$ achieves its asymptotic value at small Q^2. At the same time according to the results of the Ref [4] at small Q^2 $\Gamma_p(Q^2)$ deviates significantly from its asymptotic value. We will draw special attention to the account of the resonance contributions which are important at small Q^2 and which can not be described by simple extrapolation of the integral $I_N(Q^2)$ from its value at $Q^2 = 0$ to the asymptotic value given by relations (1-3).

Let us devide the integrals in (1) into integrals over resonance energy region and over high energies:

$$I_N(Q^2) = I_N^{Res}Q^2 + I_N^{HE}(Q^2). \qquad (4)$$

The analyses made in Refs.[12, 14, 15] show that at $W > 1.8$Gev ($W^2 = 2m\nu - Q^2$) the resonance contributions to $I_N(Q^2)$ are negligible, and in $I_N^{Res}(Q^2)$ it is reasonable to be restricted by the energy region with $W < 1.8$Gev. This energy region includes the I-resonance region- the resonance $P_{33}(1232)$, the II-resonance region-the resonances $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$ and the III-resonance region - the resonances $S_{31}(1620)$, $S_{11}(1650)$, $D_{15}(1675)$, $F_{15}(1680)$, $D_{13}(1700)$, $D_{33}(1700)$ and $P_{13}(1720)$

The integrals $I_N^{Res}(Q^2)$ can be quite reliable estimated at $(Q^2) < 3\text{Gev}^2$ as the main contributions wich come from the resonances $P_{33}(1232), D_{13}(1520), S_{11}(1535)$ and $F_{15}(1680)$ are well known from the experiments o. the proton [15] - [21], and other contributions (and contributions for the neutron) can be obtained using the analysis made in [21]. In this work on the basis of available experimental data on the proton for the members of multiplets $[70, 1^-]$ – $D_{13}(1520), S_{11}(1535)$ and $[56, 2^+]$ – $F_{15}(1680)$ and of selection rules wich follow from Melosh transformation [22], the amplitudes for other members of these multiplets are obtained. So, amplitudes for remained resonances are also known. These are amplitudes on the neutron for $D_{13}(1520), S_{11}(1535)$ and $F_{15}(1680)$ and the amplitudes for $S_{31}(1620), S_{11}(1650), D_{15}(1675), D_{13}(1700), D_{33}(1700)$ - members of the multiplet $[70, 1^-]$, and for $P_{13}(1720)$ - member of the multiplet $[56, 2^+]$.

To calculate resonance contributions to $I_N^{Res}(Q^2)$ it is convenient to explore the narrow resonance approximation which gives:

$$I_N^{Res}(Q^2) = \sum_{a=I,II,III} I_a^N(Q^2), \quad I_a(Q^2) = \frac{2m^3}{e^2}\sum_{i=Res}\frac{(A_{1/2}^i)^2 - (A_{3/2}^i)^2}{M_i^2 - m^2 + Q^2} \qquad (5)$$

where we have represented $I_N^{Res}(Q^2)$ as a sum of contributions from the above defined three resonance regions, the amplitudes are normalised according to the condition

$$\sigma_\lambda^i = \frac{4m}{M_i\Gamma_i}(A_\lambda^i)^2,$$

and M_i and Γ_i are mass and total width of the resonance i. In the numerical calculations we have used the parametrisations of the amplitudes A_λ^i obtained in Refs.[11],[21] Let us note that in the I-resonance region we have also taken into account the contribution of the region near threshold. This contribution is determined mainly by the one-pion-exchange in the pion photoproduction on nucleons. It is quite large at $Q^2 = 0$ due to smallness of the denominator in the integral $I_n(Q^2)$ (1) near threshold. With increasing Q^2 this contribution falls rapidly.

Summary resonance contributions in three resonance regions are given on fig.1. These contributions are characterised by the large and negative contribution of the resonance $P_{33}(1232)$ (which is decisive at $Q^2 = 0$), and beginning with 1 GeV^2 by large and positive contribution of II-and III-resonance regions into integral for proton $I_n(Q^2)$. These contributions are determined mainly by the resonances $D_{13}(1520)$, $S_{11}(1535)$ and $F_{15}(1680)$ and are characterized by unusually slow decreasing of the amplitudes $A^p_{1/2}$ with increasing Q^2. For the resonances $D_{13}(1520)$ and $F_{15}(1680)$ this slow decreasing of the amplitudes $A_p^{1/2}$ results in the early (up to 1 Gev^2) change of the sign of the asymmetry $A = (A^2_{1/2} - A^2_{3/2})/(A^2_{1/2} + A^2_{3/2})$ for proton, which is observed in many experiments [23]. The neutron amplitudes have not such behaviour, by this reason the contributions of the II- and III- resonance regions into the integral for the neutron $I_n(Q^2)$ are significantly smaller. As a result the integral over $g_1(x, Q^2)$ over resonance energy region:

$$\Gamma_N^{Res}(Q^2) \equiv \Gamma_N(x_{Res}, Q^2) = \int\limits_{x_{Res}}^{1} g_1^N(x, Q^2)dx, \tag{6}$$

($x_{Res} = Q^2/[(W^{max}_{Res})^2 - m^2 + Q^2]$, in our consideration $W^{max}_{Res} = 1.8$ Gev) at $Q^2 = 2 \div 3$Gev^2 for the proton is larger than for the neutron, namely:

$$\begin{aligned} &\Gamma_p(0.46, \quad 2\text{Gev}^2) = 0.02, \quad \Gamma_p(0.56, \quad 3\text{Gev}^2) = 0.018, \\ &\Gamma_n(0.46, \quad 2\text{Gev}^2) = -0.003, \quad \Gamma_n(0.56, \quad 3\text{Gev}^2) = 0.003. \end{aligned} \tag{7}$$

These results agree well with the extrapolations made in [8, 9, 12] into the region of large x, where experimental data are absent:

$$\Gamma_p(0.45, \quad Q^2 = 10.7\text{Gev}^2) = 0.017^{[8,\ 9]}, \tag{8}$$

$$\Gamma_n(0.6, \quad Q^2 = 2\text{Gev}^2) = 0.003^{[12]}. \tag{9}$$

So, we obtain that at $Q^2 = 2 \div 3\,\text{Gev}^2$ the contribution of the resonance energy region into $\Gamma_N(Q^2)$ has scaling behaviour and agrees with estimations made in the experimental works.

Let us consider now the integrals over high energy region with $W > 1.8\,\text{Gev}$ and suppose, as it is made in Refs.[3, 4] that their Q^2-evolution is determined by vector dominance:

$$I_N^{\text{HE}}(Q^2) = a_N \frac{\mu^2}{\mu^2 + Q^2} + b_N \frac{\mu^4}{(\mu^2 + Q^2)^2}, \tag{10}$$

where μ-is the mass of ρ-meson. With this in asymptotics we have:

$$I_N^{\text{Res}}(Q^2) \to 0, \quad I_N^{HE}(Q^2) \to \frac{2m^2}{Q^2}\,\Gamma_N(Q^2) \quad \text{at} \quad Q^2 \to \infty, \tag{11}$$

and from asymptotic sum rules (1b), (2) and (3) it follows:

$$a_p = 0.56, \quad a_n = -0.062. \tag{12}$$

At $Q^2 = 0$ using GDH sum rule (1a) and the values of $I_N^{\text{Res}}(0)$ (fig.1) we obtain

$$I_p^{HE}(0) = a_p + b_p = 0.200, \quad I_n^{HE}(0) = a_n + b_n = -0.205. \tag{13}$$

So, both parts in the integrals $I_N(Q^2)$ (4) are determined, and we can turn to the final results for $\Gamma_N(Q^2)$ which are presented on fig.2.

Our results for the proton at large Q^2 coincide with the results of [4] which are also presented on fig.2. However at $Q^2 = 1.5 \div 3\text{Gev}^2$ our results are more close to the asymptotic value of $\Gamma_p(Q^2)$ than in [4]. This is connected with the fact that in addition to the resonance $P_{33}(1232)$, which is taken into account in [4], we have taken into account the contributions of the II-and III-resonance regions which are quite large due to slow decreasing of the amplitudes $A^p_{1/2}$ for the resonances $D_{13}(1520)$, $S_{11}(1535)$ and $F_{15}(1680)$.

For the neutron the integrals over resonance energy region at $Q^2 = 2 \div 3\text{Gev}^2$ turned out to be negligible. Beginning with $Q^2 = 2\text{Gev}^2$ the resonance contributions do not reflect final results, where the integrals over the region with $W > 1.8\text{Gev}$ we have obtained by simple extrapolation from the value at $Q^2 = 0$ which follows from the GDH sum rule to the asymptotic value given by the Bjorken and Ellis-Jaffe sum rules. With this the value of the integral over the neutron polarized structure function turned out to be close to the asymptotic value beginning with 2Gev^2.

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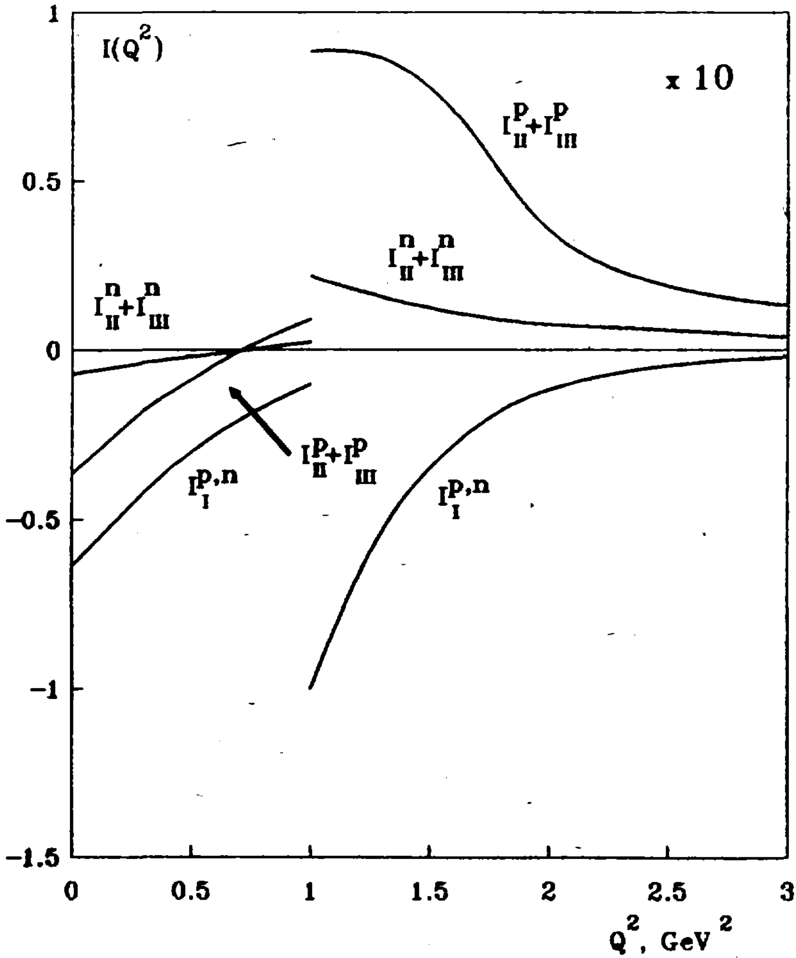

I(Q^2)
x 10
I^p_II+I^p_III
I^n_II+I^n_III
I^n_II+I^n_III
I^p,n_I
I^p_II+I^p_III
I^p,n_I
1
0.5
0
−0.5
−1
−1.5
0
0.5
1
1.5
2
2.5
3
Q^2, GeV^2

Fig. 1

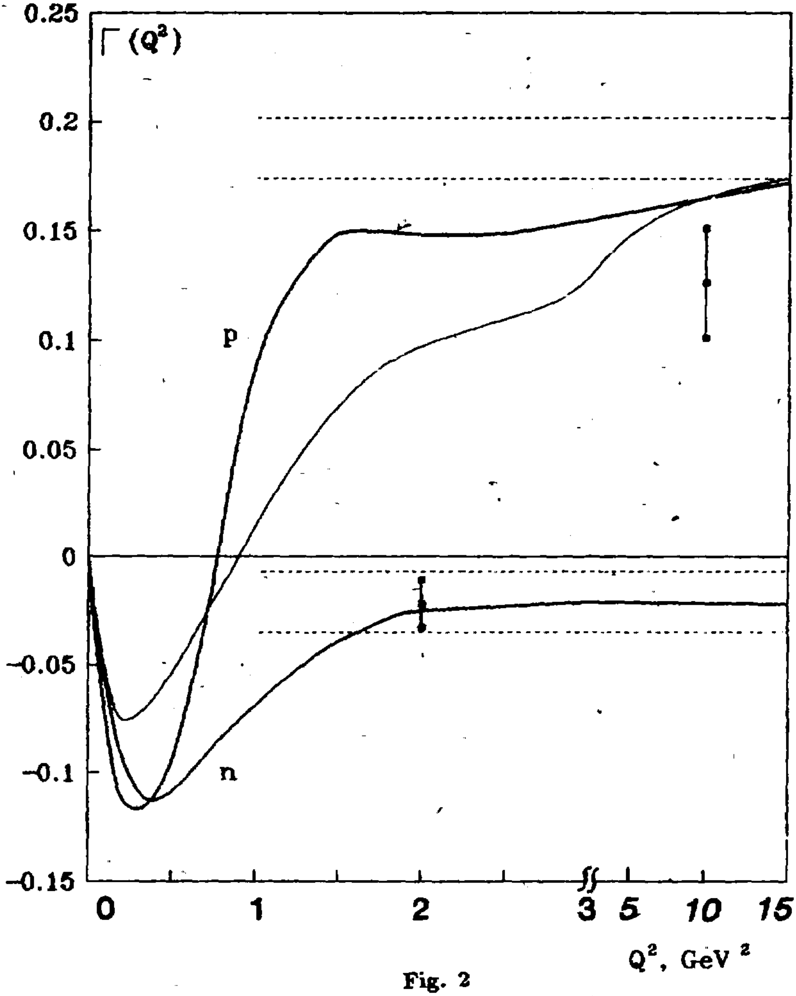

Fig. 2

Figure caption

Fig 1. *The first resonance energy region contribution* and the *summary contribution* of the II- and III- resonance energy regions into integral $I_N(Q^2)$ (1). At $Q^2 > 1\mathrm{Gev}^2$ the scale is changed tenfold.

Fig 2. Theory predictions for $\Gamma_N(Q^2)$ (1b) and experimental data. Bold curves represent our results, thin curves are results of [4], dashed curves are limits given by the Ellis-Jaffe [6] and Bjorken [7] asymptotic sum rules (2,3). Experimental data are taken from Refs.[8, 9, 12]

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И. Г. АЗНАУРЯН

ПРАВИЛО СУММ ГЕРАСИМОВА-ДРЕЛЛА-ХЕРНА И ПОВЕДЕНИЕ ПОЛЯРИЗАЦИОННОЙ СТРУКТУРНОЙ ФУНКЦИИ НУКЛОНА ПРИ МАЛЫХ Q^2

Используя правило сумм Герасимова-Дрелла-Херна, показано, что поляризационная структурная функция нейтрона выходит на асимптотическое значение при Q^2=2Гэв^2. Для протонной поляризационной структурной функции показано, что, начиная с 1.5 Гэв^2, ее отклонение от асимптотического значения не превышает 15-20%. На основании имеющихся данных в резонансной области энергий при Q^2 < 3 Гэв^2 получены значения интегралов от поляризационной структурной функции нуклона в интервале x=0.45-1, где отсутствуют эксперимментальные данные. Оказалось, что при Q^2= 2-3 Гэв эти интегралы имеют скейлинговое поведение, а их величины согласуются со сделанными в экспериментальных работах экстраполяциями в область больших x.

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Правило сумм Герасимова-Дрелла-Херна и поведение поляризационной структурной функции нуклона при малых Q^2

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