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# ARGONNE EFFECT - EVIDENCE FOR THE SHELL STRUCTURE OF PROTON

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## Abstract

A strong spin effect in $p_\uparrow p_\uparrow$ scattering at $p_\perp^2 \gtrsim 4(\mathrm{GeV}/c)^2$ (Argonne effect) is explained by the presence of Fock configuration $(q_\uparrow q_\uparrow c\bar{c}q_\downarrow)$ in proton which has the structure of p-shell. An analogous effect in the region $p_\perp^2 \gtrsim 25(\mathrm{GeV}/c)^2$ associated with the configuration $(qqb\bar{b}q)$ is predicted.

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*) The report on the workshop "Studies of spin effects in high energy physics", IHEP, Serpukhov, November 23-26,1982.

The results of measurements of differential cross section of the polarized proton elastic scattering on a polarized proton target under 90°cms at parallel ( $\uparrow\uparrow$ ) and antiparallel ( $\downarrow\uparrow$ ) spin orientation relative to the normal of the reaction plane have been presented in the works by the Argonne group [1] . Fig.1a, b shows the dependences of $d\sigma/dt\uparrow\uparrow(90^\circ)$ and $d\sigma/dt\downarrow\uparrow(90^\circ)$ on the scattered proton momentum $p_\perp^2$ at the incident proton momentum variation. The main question of how to explain the sharp relative increase of the ratio $\frac{d\sigma}{dt}(\uparrow\uparrow)/\frac{d\sigma}{dt}(\uparrow\downarrow)$ in the hard region $p_\perp^2 \gtrsim 4(\mathrm{GeV}/c)^2$ where spin effects, according to perturbative QCD, are suppressed - remains open [1,2] .

As will be shown, this effect can be naturally explained if one takes into account that besides the Fock configurations corresponding to valent quarks (uud), proton has an internal nonperturbative pair $Q\bar{Q}$ resulting in the configurations of the type $(qqQ\bar{Q}q)$ [5], for instance, $(udd\bar{d}u)$; $(uds\bar{s}u)$; $(udc\bar{c}u)$ ... with a probability decreasing in the given sequence.

The initial point of our argumentation is that because of the symmetry properties of pp-scattering at the parallel spin orientation (triplet) and at 90°cms, of five matrix elements entering the pp-scattering amplitude

$$M = A + C(\sigma_{1n} + \sigma_{2n}) + B\sigma_{1n}\sigma_{2n} + G(\sigma_{1p}\sigma_{2p} + \sigma_{1q}\sigma_{2q}) + \\ + H(\sigma_{1p}\sigma_{2p} - \sigma_{1q}\sigma_{2q}) \qquad (1)$$

only two terms C and H *) are nonzero. For the following it is convenient to choose the spin quantization axis z towards the normal of the reaction plane n . Then

$$M(\uparrow\uparrow)90^\circ = C(\sigma_{1z}+\sigma_{2z}) + H(\sigma_{1x}\sigma_{2x}-\sigma_{1y}\sigma_{2y}), \qquad (2)$$
$$d\sigma/dt\,(\uparrow\uparrow)90^\circ = |C|^2+|H|^2$$

In this representation $C=C_{11}$ and $H=H_{-11}$ can be defined as spin-orbital amplitudes without spin flip ($C_{11}$) and with it ($H_{11}$).

The antiparallel spin state is not pure; $d\sigma/dt(\uparrow\downarrow) > |A_{ss}|^2$ where $A_{ss}$ is the scattering amplitude from the singlet state. Thus, the effect will be even more dramatic when comparing differential cross sections in the pure triplet and singlet states.

The amplitudes $A_{ss}$, C and H expressed via the partial amplitudes have at $\theta_{c.m.s.}=90^\circ$ the form [3] **)

$$A_{ss}(\theta)=\sum_{\text{even } l} P_l(\theta) f_0(l) \qquad (3)$$

$$C(90^\circ)=\sum_{\text{odd } l} P_l'(90^\circ)\left\{f_1(l,l+1)-f_1(l,l-1)+O\left(\tfrac{1}{l}\right)\right\} \qquad (4)$$

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*) For the triplet state of two protons $M(\theta)=-M(\pi-\theta)$ . At replacing $\theta\to\pi-\theta$: $\vec{n}\to-\vec{n}$ $\vec{p}\rightleftarrows\vec{q}$ . The vectors $\vec{n}$, $\vec{p}$, $\vec{q}$ are $\vec{k}_i\times\vec{k}_f$ , $\vec{k}_i+\vec{k}_f$ , $\vec{k}_i-\vec{k}_f$ respectively, where k is the proton momentum in cms.

**) At 90° cms the matrix elements $M$ of ref. [3] are associated with $C_{11}$, $H_{-11}$ and $A_{ss}$; $C_{11}=\frac{\sqrt{2}}{4}i(M_{10}-M_{01})$; $H_{-11}=\frac{\sqrt{2}}{4}i(M_{10}+M_{01})$; $A_{ss}=M_{ss}$

$$H(90^\circ)=\sum_{\text{odd } l} \mathcal{P}_l'(90^\circ)\left\{f_2(l+1)-f_2(l-1)+O\left(\frac{1}{l}\right)\right\} \tag{5}$$

where $f_1(l, l\pm 1)$ depends on the phase shifts in the state $l$, $J=l\pm 1$ while $f_2(l\pm 1)$ on the phase shifts and mixing parameters in the states $J=l\pm 1$. If initial spin is oriented along the normal to the reaction plane ( $S_z=+1$ ), then in terms of the impact parameter $b=l/k$ the partial amplitudes in the r.h.s of eqs.(4),(5) takes the simple form [4]

$$f(+b)-f(-b)+O\left(\frac{1}{kb}\right)$$

where $f(+b)-f(-b)$ are the amplitude differences at the flight of a probe particle (polarized proton) from the right and from the left of the polarized proton of the target (fig.2); the scale of $1/kb$ in the Argonne experiment $\lesssim$ 0.2..

Thus, the proton scattering with parallel spins under 90° cms is mainly determined by the amplitude differences at the flight from the right and from the left of the polarized proton. Since the density of the quark-gluon matter of nucleon is only radius dependent, the difference can be explained by rotation of the polarized proton [4]. Such a rotation of a system of three point-like quarks in s-state is very difficult to understand *).

Another situation takes place at additional account of $Q\bar{Q}$ pair. Such a pair is in the $^3P_0$ state as owing to negative internal parity of $Q\bar{Q}$ such a state corresponds to quantum num-

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*) The spin-orbital interaction in usual hard processes is suppressed [2] $C/A \simeq m_q^2/P_\perp^2$ .

bers of vacuum $0^+$ . With account of internal $Q\bar{Q}$ pairs, the polarized proton can be represented as a loop in which the upper pairs $\bar{Q}q$ and lower triples $qqQ$ can be considered as a virtual p-wave state of proton dissociated into "bare baryon" + "meson" in p-state (fig.3). It can be thought that just these nonperturbative "p" nucleon states are a genetic reason of a strong spin-spin and spin-orbital interaction. A common-known example - the nucleon pion shell whose account enables one to quantitatively describe polarization effects in $\pi p$ scattering [6] at small t. In the singlet state the interaction of p-shells of colliding protons is absent since the amplitude depends only on the absolute value of the impact parameter. Thus, the comparison of $d\sigma/dt\ (90^\circ)$ in the singlet state with $d\sigma/dt\ (90^\circ)\uparrow\uparrow$ gives information on the contribution of pp-interaction associated with the shells. The Argonne effect means that at 90° cms and $p_\perp^2 \gtrsim 3.5(\text{GeV/c})^2$ the shell interaction in pp-scattering is dominant.

When $p_\perp^2$ rises, the shells associated with heavy quarks come into play. In the region $p_\perp^2 \gtrsim 3.5(\text{GeV/c})^2$ the amplitude in the triplet state $\propto \sqrt{\frac{d\sigma}{dt}(\uparrow\uparrow)90^\circ} \approx \exp(-0{,}75\,p_\perp^2)$ (fig.1a). Hence we obtain for the characteristic mass of the exponent factor $M = \sqrt{\frac{\text{Гэв}^2}{0{,}75}} = 1{,}15\ \text{Гэв} \simeq m_c$ . This corresponds to the effective impact parameter $\sigma \simeq 2/m_c$ as it must be the case at collision of two identical configurations with $z \simeq 1/m_c$ . Therefore, it can be supposed that the Argonne effect at $p_\perp^2 \gtrsim 4(\text{GeV/c})^2$ is associated with configurations of the type $(qqc\bar{c}q)$ . The contribution of configurations $(qqc\bar{c}q)$ into the total cross section $\sigma^t_{pp}$ can be very roughly estimated as follows. The total cross section $\sigma^t_{pp}$ is equal to the sum of the total cross sections of the incident proton on all (i) configurations of the target proton

$$\sigma^t_{pp} = \sum_i \sigma^t_{pi} \simeq \frac{1}{2} 4\sqrt{\pi} \sum_i \left(\frac{d\sigma_{pi}}{dt}\right)^{1/2}_{t=0} \quad {}^{*)} \qquad (6)$$

Suppose that $\sqrt{\frac{d\sigma}{dt}(pp)90^\circ} \approx \exp(-0{,}75\, p_\perp^2)$ characterizes the $p_\perp^2$ - dependence of the proton scattering amplitude on configurations $(qqc\bar{c}q)$ at $P_{lab} \simeq 12$ GeV/c (see fig.1b). Extrapolating $\exp(-1{,}5\, p_\perp^2)$ in fig.1a onto point $p_\perp^2 = 0$ we get for

$$\sigma^t_{p,(qqc\bar{c}q)} \simeq 2\sqrt{\pi}\left(\frac{d\sigma_{p,(qqc\bar{c}q)}}{dt}\right)^{1/2}_{t=0} = 0{,}55\cdot 10^{-28}\ cm^2$$

and $\sigma_{p,(qqc\bar{c}q)} / \sigma^t_{pp} \simeq 10^{-2}$ at $P_{lab} = 12$ GeV/c. This value is consistent with probability estimates of configurations $(qqc\bar{c}q)$ in proton made in ref. [7] on the basis of the bag theory and in [5] from the data on charmed hadron production in diffraction processes. The account of the shell structure of proton makes it possible to predict that the enhancement of $d\sigma/dt\,(pp)90^\circ$ should be also expected in the region $p_\perp^2 \gtrsim 25\,(\mathrm{GeV/c})^2$, the exponent factor being characterized by the b quark mass. It may be also expected that $\sigma^t_{p,(qqc\bar{c}q)} / \sigma^t_{p,(qqc\bar{c}q)}$ will be $\simeq m_c^2/m_b^2 \simeq 0{,}1$ in accord with the estimates of ref. [5].

In conclusion, let us make some remarks on the properties of nucleon shells. The number of p-shells in the nucleon is $N = n_f - 1$ where $n_f$ is the number of flavours, since u and d-quarks are associated with one shell structure ($SU_2$ degeneration). The nucleon shells are complicated formations. In particular, the direction of "rotation" in the shell may be different depending on the spin of the system qqQ (cf.

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*) The coefficient 1/2 takes into account proton identity (pointed out by L.B.Okun).

loops N, $\Delta$ [4] ). Information on the shell structure can be obtained from the polarization data [4]. The radius of the shells associated with light quarks is determined by the inverse value of meson masses according with the uncertainty relation. The radius of the shells associated with heavy quarks is determined rather by inverse values of their masses.

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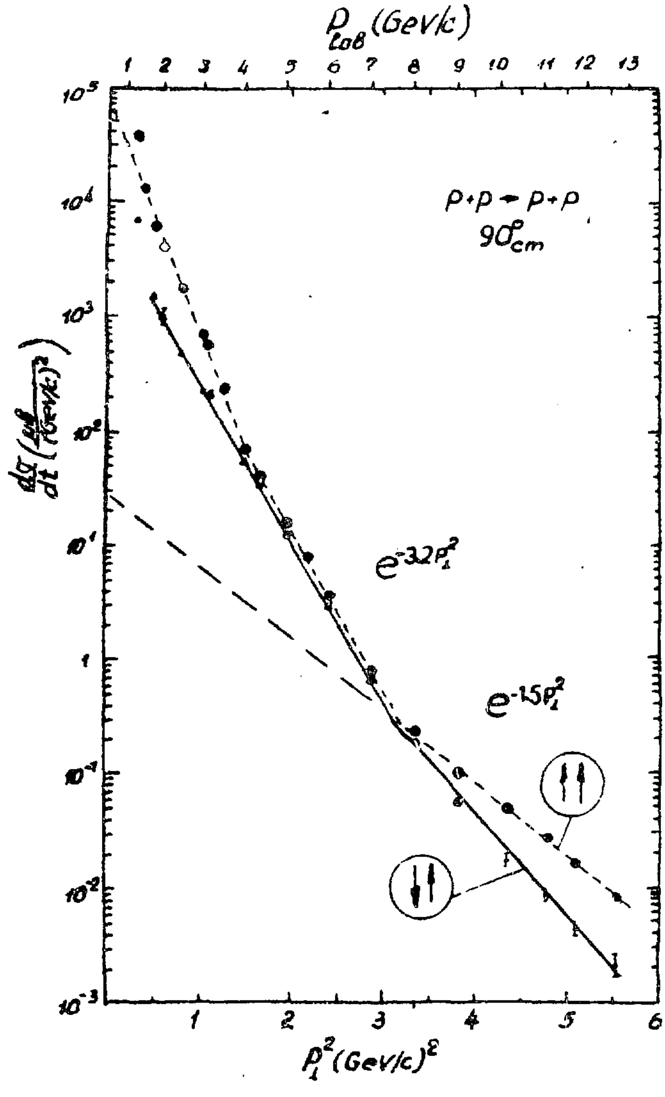

Fig.1a. Proton-proton differential elastic cross section at initial states ↑↑ and ↓↑ depending on $p^2$ at 90° cms [1].

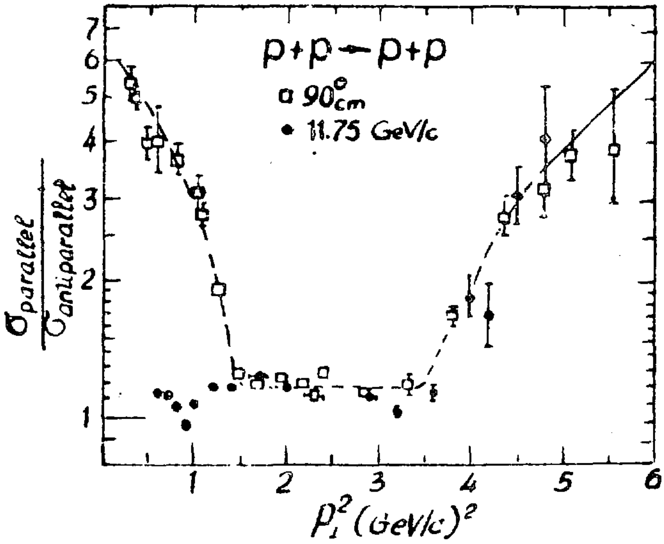

Fig.1b. The ratio $\frac{d\sigma}{dt}(\uparrow\uparrow)/\frac{d\sigma}{dt}(\uparrow\downarrow)$ depending on $p_\perp^2$ for elastic pp-scattering. The data for the fixed angle 90° cms and for the fixed energy 11.75 GeV are compared [1].

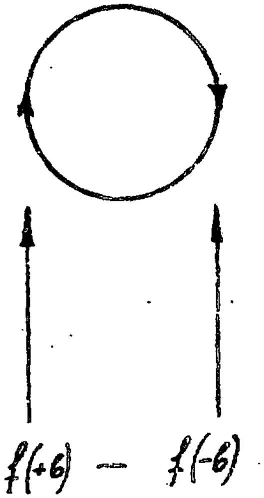

Fig. 2. Spin-orbital amplitudes C and H in the impact parameter representation (b).

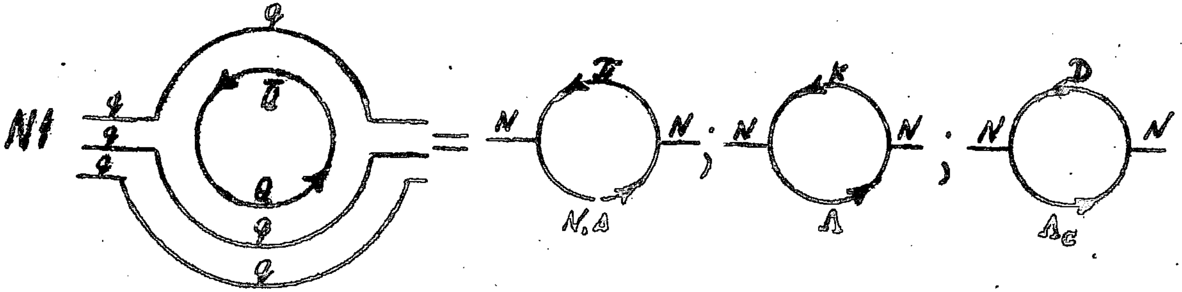

Fig.3. Nucleon p-shells.

## References

1. G.Crabb et al., Phys.Rev.Lett. 111, 1257 (1978); A.D.Krisch, Lecture at VI Seminar on High Energy Physics Problems, JINR, Dubna, Sept.1982.
2. S.J.Brodsky, T.Huang, G.P.Lepage, SLAC-PUB-2868, January,1982, p.55.
3. H.P.Stapp, T.J.Ypsilantis, N.Metropolis, Phys.Rev. 105, 302 (1957).
4. I.I.Levintov, Preprint ITEP-36, M.,1973; Pisma v ZhETF 22 249-252 (1975); "Elementarnye chastitzy/ the 3-d ITEP Winter School of Physics, is.2, p.75, Moscow, Atomizdat 1975; Preprint ITEP-144, 1978; "Elementarnye chastitzy, the 6-th ITEP School of Physics, M.,1979. p.25, is.1.
5. S.J.Brodsky, C.Peterson, N.Sakai, Phys.Rev. D23, 2745 (1981).
6. K.G.Boreskov, G.V.Grigorian, A.B.Kaidalov, I.I.Levintov. Yad.Fiz. 27, 813 (1978).
7. J.F.Donoghue, E.Golowich, Phys.Rev. D15, 3421 (1977).

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