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ON "THE TRANSVERSE SIZE" OF A FASTMOVING NUCLEON

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According to modern ideas, the basic features of strong interactions are described by quantum chromodynamics. At the same time this theory certainly includes the previous results explaining, for example, short-range nuclear forces. As is known, the Yukawa idea[1] played an important role in due course. According to this idea, nucleons interact between themselves with the help of pion exchange. The Yukawa potential (stationary meson field, i.e., in the c.m.s. S* for the nucleon) takes the form

$$\phi^*_\pi = - g_\pi \frac{\exp(-\mu R^*)}{R^*} . \qquad (1)$$

Here g_π denotes the interaction constant similar to electron charge in electrodynamics, μ is the pion mass and $\hbar = c = 1$. Just Yukawa's exponent in the function ϕ^*_π leads to the fact that the "action radius" of nuclear forces, μ^{-1} (~1 fm), is smaller than the one of electrostatic forces described by the Coulomb potential. Further on exchange by heavier mesons has been taken into account to explain the strong interaction behaviour at small ranges. Along with (1), for example, we have

$$\phi^*_V = -g_V \frac{\exp(-\mu_V R^*)}{R^*} , \qquad (2)$$

where μ_V are the vector (ρ and ω) meson masses.

On the other hand, supposing, for example, $\mu_V = 0$, in the last expression we return evidently to the Coulomb potential type. Applying to the gluon fields, this potential named a colour one is written in the form

$$\phi^*_g = - \frac{\alpha_S}{R^*} , \qquad (3)$$

where α_S is a moving constant. This result can be obtained in another way for exponent expansion in a series at small values of $\mu_V R^*$. It is evident that the first term will present expression (3). As already noted since free gluons and quarks are not observed in nature, the colour potential must be "broken" on the bound where nuclear forces end and hadronization

of the quark-gluon field takes place. Apparently, in any case this role is qualitatively taken just by Yukawa's exponent.

In order to answer the question of our interest concerning the nuclear field behaviour of the relativistic nucleon, it is necessary to go to a moving system (see Appendix). Strictly speaking, we must have corresponding relativistic - covariant expression. On the basis of analogy between, the gluon and Coulomb potentials and based on the transition from the Coulomb to the Lienard - Wiechert potential for the 4-vector of the gluon potential, we find

$$\phi^i_g = - \frac{\alpha_S u^i}{u^i R_i} , \qquad (4)$$

where u^i is the nucleon 4-velocity; R_i, the 4-vector of a retarding distanse, i, k = 0, 1, 2, 3. In fact, on the basis of this result for the relativistic expression corresponding to (1) and (2), we have[2]

$$\phi_\pi = -g_\pi \frac{\exp(-\mu \cdot u^i \cdot R_i)}{u^i \cdot R_i} , \qquad (5)$$

$$\phi^i_V = - \sum_{\phi,\omega} g_V \frac{u^i \cdot \exp(-\mu_V \cdot u^i \cdot R_i)}{u^i \cdot R_i} , \qquad (6)$$

$$\phi^{ik}_T = - \sum_{A_2, f} g_T \frac{u^i u^k \exp(-\mu_T u^i R_i)}{u^i R_i} . \qquad (7)$$

Here we have also written down the formula for tensor potential that, as is seen, describes the virtual meson field with spin 2.

Taking into account that the masses of $\rho(A_2)$ - and $\omega(f)$ - mesons are close, one can, in a good approximation, move off the exponent from under the summation mark. Then we shall evidently have simply the sum of the corresponding interaction constants. On the basis of (5), it has been previously shown[3] that the equipotential surfaces for the pionic field of the moving nucleon have the shape of a rotating ellipsoid. This ellipsoid is stretched in the direction of motion. The degree of "stretching" is determined by the value of u^0 (or by the Lorentz-factor). Besides, it has been found that the vector field contribution due to u^i in the numerator increases and becomes dominating at $u^\circ \gtrsim 10^2$. But, may be, the most important result is the transverse size growth for the nucleon due to the vector field. This increase is sufficiently well described by the function $(\ln\gamma)^{0.8}$. The observed growth of the nucleon interaction cross section at $\gamma \gtrsim 10^2$ is apparently due to the indicated increase of the transverse size of the nucleon.

Below we present more precise data for the vector meson field behaviour and also for the A_2 - , f-meson and the gluon field.

On the basis of[4] for the interaction constants the following precise values have been obtained: $(g_\rho + g_\omega)\cdot g_\pi^{-1} = 0.96 \pm$ $\pm\ 0.08$ and $g_f \cdot g_\pi^{-1} = 0.47 \pm 0.03$.

These values were used in calculations. The results of calculations are given in the table where $R_\perp$ denotes the maximum transverse size and $R_\parallel^f$ is in fact the longitudinal size for the corresponding field. For the gluon field α_s is assumed to be $g\cdot e^{-1}$.

Table

γ	π		ρ,ω		A_2, f			gluon	
	$R_\perp, \mu^{-1}$	$R_\parallel^f$	$R_\perp$	$R_\parallel^f$	$R_\perp$	$\ln\gamma/\ln 81$	$R_\parallel^f$	$R_\perp$	$R_\parallel^f$
1	1	1	0.36	0.36	0.21		0.21	1	1
1,5	1	2.6	0.41	1.1	0.27		0.70	1.5	3.9
5	1	9.9	0.57	5.6	0.47		4.7	5	4.9
10	1	20	0.66	13	0.60		12	10	$2\cdot10^2$
50	1	10^2	0.90	90	0.90		90	50	$5\cdot10^3$
10^2	1	$2\cdot10^2$	1.0	$2.0\cdot10^2$	1.0	1.0	$2.0\cdot10^2$	10^2	$2\cdot10^4$
10^3	1	$2\cdot10^3$	1.4	$2.7\cdot10^3$	1.5	1.5	$3.0\cdot10^3$	10^3	$2\cdot10^6$
10^4	1	$2\cdot10^4$	1.7	$3.5\cdot10^4$	2.0	2.0	$4.0\cdot10^4$	10^4	$2\cdot10^8$
10^5	1	$2\cdot10^5$	2.1	$4.2\cdot10^5$	2.5	2.5	$4.9\cdot10^5$	10^5	$2\cdot10^{10}$

As one can conclude from the table, the field size of spin 2 mesons grows faster (in comparison with the vector field). At the same time transverse size behaviour is described by the function $\ln\gamma$. Certainly, as is seen, the free gluon field "swells" more significantly. But the behaviour of the nucleon size must be effectively determined just by the meson field due to hadronization processes on the nucleon "bounds".

So, the nucleon cross section will grow proportionaly to $(\ln\gamma)^{1.6} \div (\ln\gamma)^2$ with increasing its energy. The basic contribution will obviously give rise to meson fields with higher spins due to a faster growth.

APPENDIX

We pass from the rest system S^* to the S-system, where the nucleon moves (with velocity $v_x = \beta$), in order to get an expression for the Yukawa potential of a moving nucleon. For this we should make the Lorentz transformation of distance R^* in formulae (1) and (2). As a result, we have

$$R^* = \sqrt{y^{*2} + x^{*2}} \simeq \sqrt{y^2 + (x - \beta t)^2\gamma^2}, \tag{A.1}$$

here γ is the Lorentz-factor. Passing to polar coordinates and assuming that the propagation velocity of strong interaction is equal to the light one, i.e., $t = R$, we find

$$\begin{aligned} R^* &= \sqrt{R^2(1 - \cos^2\theta) + R^2\cos^2\theta\gamma^2 - 2\beta\cos\theta R^2\gamma^2 + \beta^2R^2\gamma^2} = \\ &= R\sqrt{(1 + \beta^2\gamma^2) - (1 - \gamma^2)\cos^2\theta - 2\beta\cos\theta\gamma^2} = R(1 - \beta\cos\theta)\gamma. \end{aligned} \tag{A.2}$$

Just the last expression was used to calculate the equipotential surfaces of nucleon meson fields.

With the help of 4-velocity u^i it can be presented (A.2) in an explicitly relativistic invariant form:

$$\gamma t - \beta\gamma x = u^\circ R_\circ + u^1 R_1. \tag{A.3}$$

In such a form it figures in formulae (5)-(7). As to the relativization of Yukawa's potential, for example, for vector mesons, the condition $\mu_V \to 0$ in the transformation to the Lienard - Wiechert potential should be additionaly taken into account. This means that in fact the right part of formula (5) should be simply multiplied by 4-velocity.

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