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ON RELATIVISTIC FORM FACTORS OF MANY-BODY SYSTEMS

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О релятивистских формфакторах многочастичных систем

Получены выражения для релятивистских формфакторов многочастичных систем в рамках квазипотенциального подхода в переменных "светового фронта".

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On Relativistic Form Factors of Many-Body Systems

The "light-front" form of the quasipotential approach in quantum field theory is applied for constructing the relativistic form factors of namy-body composite systems.

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1. Introduction

In refs. /1-5/ a problem of constructing form factors of composite particles has been considered. The consideration was based on the Logunov-Tavkhelidze quasipotential approach in quantum field theory /6/. Expressions for the form factors in the case of two constituents have been obtained in terms of the relativistically covariant quasipotential quantities /7/. In ref. /5/ the two-particle quasipotential formalism has been developed in terms of the "light-front" variables /8/ and a method for calculating form factors has been outlined.

In the present paper following methods of refs. /1-5/ we consider the case of many-body systems.

Let us recall some aspects of the method of refs. /1-5/ for completeness. Wave functions, in terms of which the form factors of composite particles are expressed, depend on values of the Bethe-Salpeter amplitudes $\chi_{P,a}(x_\mu)$ on definite hyperplanes. In the case of the "light-front" variables quasipotential wave functions $\Phi_{P,a}(x, \vec{p}_\perp)$ /5/ depend on values of the Bethe-Salpeter amplitude on the hyperplane

$$x_0 + x_3 = 0 \qquad (1.1)$$

and obey the following equation:

$$[P^2 - \frac{(\vec{p}_\perp + (1/2-x)\vec{P}_\perp)^2 + m_1^2}{x} - \frac{(\vec{p}_\perp + (1/2-x)\vec{P}_\perp)^2 + m_2^2}{1-x}]\Phi_{P,\alpha}(x,\vec{p}_\perp) =$$

$$= \int_0^1 \frac{dx'}{x'(1-x')} \int d\vec{p}'_\perp V(P;x,\vec{p}_\perp;x',\vec{p}'_\perp)\Phi_{P,\alpha}(x',\vec{p}'_\perp). \qquad (1.2)$$

Here

$$\Phi_{P,\alpha}(x,\vec{p}_\perp) = P_+ x(1-x)\Psi_{P,\alpha}(p_+,\vec{p}_\perp) \qquad (1.3a)$$

$$\Psi_{P,\alpha}(p_+,\vec{p}_\perp) = \frac{1}{(2\pi)^3}\int d^4x\,\delta(x_+)\,e^{i(p_+x_- - \vec{p}_\perp\vec{x}_\perp)} X_{P,\alpha}(x_\mu) \qquad (1.3b)$$

P and p are total and relative momentum of the two-body system, respectively. The variable x is introduced in the following way:

$$x = \frac{1}{2} + \frac{p_+}{P_+} = \frac{1}{2} + \frac{p_0 + p_3}{P_0 + P_3}. \qquad (1.4)$$

2. Equation of the Quasipotential Type for N Interacting Particles

We define the Fourier transform of the N-particle Bethe-Salpeter amplitude as

$$\delta^{(4)}(P - \sum_{i=1}^N p^{(i)})X_{P,\alpha}([p^{(i)}]) =$$
$$= \int \prod_{i=1}^N d^4x^{(i)}\, e^{i\sum_{i=1}^N (p^{(i)}x^{(i)})} X_{P,\alpha}([x_\mu^{(i)}]). \qquad (2.1)$$

Here

$$[p^{(i)}] = p^{(1)},\ldots,p^{(N)}\ ;\ [x_\mu^{(i)}] = x_\mu^{(1)},\ldots,x_\mu^{(N)}. \qquad (2.2)$$

Introducing the "light-front" variables

$$P_\pm = P_0 \pm P_3\ ;\ p_\pm^{(i)} = p_0^{(i)} \pm p_3^{(i)};\ x_\pm^{(i)} = \frac{x_0^{(i)} + x_3^{(i)}}{2} \qquad (2.3)$$

and integrating (2.1) over $\prod_{i=1}^N dp_-^{(i)}$ we obtain

$$2\delta(P_+ - \sum_{i=1}^N p_+^{(i)})\delta^{(2)}(\vec{P}_\perp - \sum_{i=1}^N \vec{p}_\perp^{(i)})\Psi_{P,\alpha}([p_+^{(i)},\vec{p}_\perp^{(i)}]) = \qquad (2.4)$$
$$= (2\pi)^N \int \prod_{i=1}^N d^4x^{(i)}\,\delta(x_+^{(i)})\,e^{i\sum(p_+^{(i)}x_-^{(i)} - \vec{p}_\perp^{(i)}x_\perp^{(i)})} X_{P,\alpha}([x_\mu^{(i)}]).$$

The function $\Psi_{P,\alpha}([p_+^{(i)},\vec{p}_\perp^{(i)}])$ is related to the Bethe-Salpeter amplitude in the following manner:

$$\Psi_{P,\alpha}([p_+^{(i)},\vec{p}_\perp^{(i)}]) = \int_{-\infty}^{\infty}\prod_{i=1}^N dp_-^{(i)}\,\delta(P_- - \sum_{i=1}^N p_-^{(i)})X_{P,\alpha}([p^{(i)}]). \qquad (2.5)$$

Let us introduce the Fourier transform of the "two-time" Green function

$$\bar{G}(P;[p_+^{(i)},\vec{p}_\perp^{(i)}],[p_+^{(i)\prime},\vec{p}_\perp^{(i)\prime}]) = \qquad (2.6)$$
$$= \int_{-\infty}^{\infty}\prod_{i=1}^N dp_-^{(i)}\,dp_-^{(i)\prime}\,\delta(P_- - \sum_{i=1}^N p_-^{(i)})G(P;[p^{(i)}],[p^{(i)\prime}])$$

$G(P;[p^{(i)}],[p^{(i)\prime}])$ is defined by the relation

$$G([x_\mu^{(i)}],[x_\mu^{(i)\prime}]) = \langle 0|T(\phi_1(x_\mu^{(1)})\ldots\phi_N(x_\mu^{(N)})\phi_1(x_\mu^{(1)\prime})\ldots$$
$$\phi_N(x_\mu^{(N)\prime}))|0\rangle =$$

$$= \frac{1}{(2\pi)^{4N}} \int \prod_{i=1}^{N} d^4p^{(i)} d^4p^{(i)\prime} e^{-i\sum_{i=1}^{N}(p^{(i)}x^{(i)} - p^{(i)\prime}x^{(i)\prime})} \times \tag{2.7}$$

$$\times G(P;[p^{(i)}],[p^{(i)\prime}]).$$

For the case of free particles we have

$$G^{(0)}(P;[p^{(i)}],[p^{(i)\prime}]) = \frac{i^N \prod_{i=1}^{N} \delta^{(4)}(p^{(i)} - p^{(i)\prime})}{\prod_{i=1}^{N}(p^{(i)2} - m^{(i)2} + i\epsilon)}. \tag{2.8}$$

Integrating both sides of eq. (2.8) according to the definition (2.6), we get

$$\tilde{G}^{(0)}(P;[p_+^{(i)},\vec{p}_\perp^{(i)}],[p_+^{(i)\prime},\vec{p}_\perp^{(i)\prime}]) = \tag{2.9}$$

$$= \prod_{i=1}^{N} \theta(x^{(i)})\theta(1-x^{(i)})\tilde{G}^{(0)}(P;[p_+^{(i)},\vec{p}_\perp^{(i)}],[p_+^{(i)\prime},\vec{p}_\perp^{(i)\prime}]),$$

where

$$\tilde{G}^{(0)}(P;[p_+^{(i)},\vec{p}_\perp^{(i)}],[p_+^{(i)\prime},\vec{p}_\perp^{(i)\prime}]) =$$

$$= \frac{(2i)^N(2\pi i)^{N-1}\prod_{i=1}^{N}\delta(p_+^{(i)} - p_+^{(i)\prime})\delta^{(2)}(\vec{p}_\perp^{(i)} - \vec{p}_\perp^{(i)\prime})}{P_+^{N-1}\prod_{i=1}^{N}x^{(i)}\left[P^2 - \sum_{i=1}^{N}\frac{(\vec{p}_\perp^{(i)} - x^{(i)}\vec{P}_\perp)^2 + m^{(i)2}}{x^{(i)}}\right]} \equiv \tag{2.10}$$

$$\equiv \tilde{G}^{(0)}(P;[p_+^{(i)},\vec{p}_\perp^{(i)}])\prod_{i=1}^{N}\delta(p_+^{(i)} - p_+^{(i)\prime})\delta^{(2)}(\vec{p}_\perp^{(i)} - \vec{p}_\perp^{(i)\prime}).$$

The variables $x^{(i)}$ are defined by the following formula

$$x^{(i)} = \frac{p_+^{(i)}}{P_+}. \tag{2.11}$$

Thus, the function $\tilde{G}^{(0)}(P;[p_+^{(i)},\vec{p}_\perp^{(i)}])$ is defined under the conditions

$$\sum_{i=1}^{N} x^{(i)} = 1; \quad 0 < x^{(i)} < 1; \quad \sum_{i=1}^{N}\vec{p}_\perp^{(i)} = \vec{P}_\perp. \tag{2.12}$$

Let us introduce now the inverse operator $\tilde{G}^{-1}$ by means of the relation

$$\int_0^{P_+}\prod_{i=1}^{N} dp_+^{(i)\prime\prime}\int\prod_{i=1}^{N} d\vec{p}_\perp^{(i)\prime\prime}\,\tilde{G}^{-1}(P;[p_+^{(i)},\vec{p}_\perp^{(i)}],[p_+^{(i)\prime\prime},\vec{p}_\perp^{(i)\prime\prime}])\times$$

$$\times\tilde{G}(P;[p_+^{(i)\prime\prime},\vec{p}_\perp^{(i)\prime\prime}],[p_+^{(i)\prime},\vec{p}_\perp^{(i)\prime}]) = \prod_{i=1}^{N}\delta(p_+^{(i)} - p_+^{(i)\prime})\times \tag{2.13}$$

$$\times\delta^{(2)}(\vec{p}_\perp^{(i)} - \vec{p}_\perp^{(i)\prime})$$

and define the quasipotential V:

$$\tilde{G}^{-1}(P;[p_+^{(i)},\vec{p}_\perp^{(i)}],[p_+^{(i)\prime},\vec{p}_\perp^{(i)\prime}]) =$$

$$= \tilde{G}^{(0)-1}(P;[p_+^{(i)},\vec{p}_\perp^{(i)}],[p_+^{(i)\prime},\vec{p}_\perp^{(i)\prime}]) - \tag{2.14}$$

$$- \frac{\delta(P_+ - \sum_{i=1}^{N}p_+^{(i)})\delta^{(2)}(\vec{P}_\perp - \sum_{i=1}^{N}\vec{p}_\perp^{(i)})}{(2i)^N(2\pi i)^{N-1}}V(P;[p_+^{(i)},p_\perp^{(i)}],[p_+^{(i)\prime},p_\perp^{(i)\prime}]).$$

The equation for the wave function

$$\Phi_{P,\alpha}([x^{(i)},\vec{p}_\perp^{(i)}]) = P_+^{N-1}\prod_{i=1}^{N}x^{(i)}\,\Psi_{P,\alpha}([p_+^{(i)},\vec{p}_\perp^{(i)}]) \tag{2.15}$$

looks as follows

$$\left[P^2 - \sum_{i=1}^{N}\frac{(\vec{p}_\perp^{(i)} - x^{(i)}\vec{P}_\perp)^2 + m^{(i)2}}{x^{(i)}}\right]\Phi_{P,\alpha}([x^{(i)},\vec{p}_\perp^{(i)}]) =$$

$$= \int_0^1 \frac{\prod_{i=1}^{N} dx^{(i)'} \delta(1-\sum_{i=1}^{N} x^{(i)'})}{\prod_{i=1}^{N} x^{(i)'}} \int \prod_{i=1}^{N} dp_\perp^{(i)'} \delta^{(2)}(\vec{P}_\perp - \sum_{i=1}^{N} \vec{p}_\perp^{(i)'}) \times \tag{2.16}$$

$$\times V(P; [x^{(i)}, \vec{p}_\perp^{(i)}], [x^{(i)'}, \vec{p}_\perp^{(i)'}]) \Phi_{P,\alpha}([x^{(i)'}, \vec{p}_\perp^{(i)'}]).$$

In the next section a formalism developed here is applied for constructing the relativistic form factors of many-body systems. An analysis of the equation obtained and some of its applications will be given elsewhere.

3. Form Factors of Composite Particles

In the present section we develop a method for constructing relativistic form factors of composite particles in terms of the quasipotential wave functions (2.5), (2.15).

Consider the quantity R, which is defined by the vacuum expectation value of the chronologically ordered product of the Heisenberg field operators $\phi_i(x_\mu^{(i)})$ and a local current $J(x)$

$$R([x_\mu^{(i)}], [y_\mu^{(i)}]) = \langle 0 | T(\phi_1(x_\mu^{(1)}) \dots \phi_N(x_\mu^{(N)}) \; J(0) \times$$

$$\times \phi_1^+(y_\mu^{(1)}) \dots \phi_N^+(y_\mu^{(N)})) | 0 \rangle =$$

$$= \frac{1}{(2\pi)^{4N}} \int \prod_{i=1}^{N} d^4 p^{(i)} d^4 q^{(i)} e^{-i \sum_{i=1}^{N} (p^{(i)} x^{(i)} - q^{(i)} y^{(i)})} \times \tag{3.1}$$

$$\times R([p^{(i)}], [q^{(i)}]).$$

The quantity R can be presented in the form [9]

$$R = G \Gamma G, \tag{3.2}$$

where G is the Green function of the fields $\phi_i(x_\mu^{(i)})$

$$G([x_\mu^{(i)}], [y_\mu^{(i)}]) = \langle 0 | T(\phi_1(x_\mu^{(1)}) \dots \phi_N(x_\mu^{(N)}) \times$$

$$\times \phi_1^+(y_\mu^{(1)}) \dots \phi_N^+(y_\mu^{(N)})) | 0 \rangle \tag{3.3}$$

and the vertex function Γ is defined by the sum of the irreducible diagrams for the $(2N+1)$ -point function (3.1) (Fig. 1)

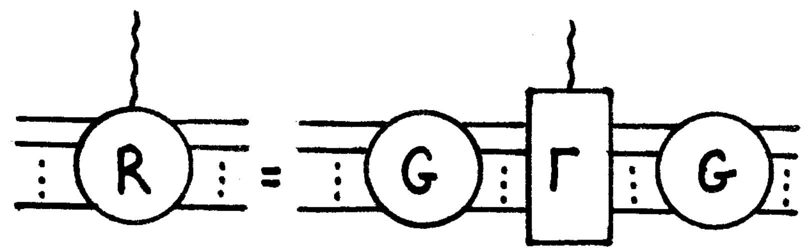

Fig. 1

Proceedings now to the quasipotential description we introduce the quantity $\tilde{R}([p_+^{(i)}, \vec{p}_\perp^{(i)}], [q_+^{(i)}, \vec{q}_\perp^{(i)}])$ by the relation

$$\tilde{R}([p_+^{(i)}, \vec{p}_\perp^{(i)}], [q_+^{(i)}, \vec{q}_\perp^{(i)}]) =$$

$$= \int_{-\infty}^{\infty} \prod_{i=1}^{N} dp_-^{(i)} dq_-^{(i)} \delta(P_- - \sum_{i=1}^{N} p_-^{(i)}) \delta(Q_- - \sum_{i=1}^{N} q_-^{(i)}) \times \tag{3.4}$$

$$\times R([p^{(i)}], [q^{(i)}])$$

and write it in the form

$$\tilde{R} = \tilde{G}\,\tilde{\Gamma}\,\tilde{G}. \qquad (3.5)$$

Multiplication in formula (3.5) has to be understood in the operator sense:

$$\tilde{A}\tilde{B} = \int \prod_{i=1}^{N} dq_{+}^{(i)\prime}\, dq_{\perp}^{(i)\prime}\, \delta(Q_{+} - \sum_{i=1}^{N} q_{+}^{(i)\prime})\,\delta^{(2)}(\vec{Q}_{\perp} - \sum_{i=1}^{N} \vec{q}_{\perp}^{(i)\prime}) \times$$
$$\times \tilde{A}([p_{+}^{(i)}, \vec{p}_{\perp}^{(i)}],[q_{+}^{(i)\prime}, \vec{q}_{\perp}^{(i)\prime}])\,\tilde{B}([q_{+}^{(i)\prime}, \vec{q}_{\perp}^{(i)\prime}],[q_{+}^{(i)}, \vec{q}_{\perp}^{(i)}]). \qquad (3.6)$$

From the spectral properties of the function R it follows that $\tilde{R}$ possesses the double pole singularities

$$\tilde{R}([p_{+}^{(i)}, \vec{p}_{\perp}^{(i)}],[q_{+}^{(i)}, \vec{q}_{\perp}^{(i)}]) \simeq \qquad (3.7)$$
$$P^2 \to M_{\alpha}^2,\ Q^2 \to M_{\beta}^2$$

$$\simeq [i(2\pi)^4]^2 \frac{\Psi_{P,\alpha}([p_{+}^{(i)}, \vec{p}_{\perp}^{(i)}]) \langle P,\alpha | J(0) | Q,\beta \rangle \Psi^{+}_{Q,\beta}([q_{+}^{(i)}, \vec{q}_{\perp}^{(i)}])}{(P^2 - M_{\alpha}^2)(Q^2 - M_{\beta}^2)}$$

in the vicinity of the points, where N -particle system forms bound states with masses M_{α} and M_{β} and a set of other quantum numbers α and β, respectively.

On the other hand knowing the pole singularities of the Green function

$$\tilde{G}([p_{+}^{(i)}, \vec{p}_{\perp}^{(i)}],[q_{+}^{(i)}, \vec{q}_{\perp}^{(i)}]) \simeq \qquad (3.8)$$

$$\simeq i(2\pi)^4 \frac{\Psi_{P,\alpha}([p_{+}^{(i)}, \vec{p}_{\perp}^{(i)}])\Psi^{+}_{P,\alpha}([q_{+}^{(i)}, \vec{q}_{\perp}^{(i)}])}{P^2 - M_{\alpha}^2}$$

one can cast formula (3.5) into the form

$$\tilde{R}([p_{+}^{(i)}, \vec{p}_{\perp}^{(i)}],[q_{+}^{(i)}, \vec{q}_{\perp}^{(i)}]) \simeq$$

$$\simeq [i(2\pi)^4]^2 \frac{\Psi_{P,\alpha}([p_{+}^{(i)}, \vec{p}_{\perp}^{(i)}])\Psi_{Q,\beta}([q_{+}^{(i)}, \vec{q}_{\perp}^{(i)}])}{(P^2 - M_{\alpha}^2)(Q^2 - M_{\beta}^2)} \times$$
$$\times \int \prod_{i=1}^{N} dp_{+}^{(i)}\, dp_{\perp}^{(i)}\, \delta(P_{+} - \sum_{i=1}^{N} p_{+}^{(i)})\,\delta^{(2)}(\vec{P}_{\perp} - \sum_{i=1}^{N} \vec{p}_{\perp}^{(i)}) \times \qquad (3.9)$$
$$\times \int \prod_{i=1}^{N} dq_{+}^{(i)}\, d\vec{q}_{\perp}^{(i)}\, \delta(Q_{+} - \sum_{i=1}^{N} q_{+}^{(i)})\,\delta^{(2)}(\vec{Q}_{\perp} - \sum_{i=1}^{N} \vec{q}_{\perp}^{(i)}) \times$$
$$\times \Psi^{+}_{P,\alpha}([p_{+}^{(i)}, \vec{p}_{\perp}^{(i)}])\,\tilde{\Gamma}_{\alpha\beta}([p_{+}^{(i)}, \vec{p}_{\perp}^{(i)}],[q_{+}^{(i)}, \vec{q}_{\perp}^{(i)}]) \times$$
$$\times \Psi_{Q,\beta}([q_{+}^{(i)}, \vec{q}_{\perp}^{(i)}]).$$

Here

$$\tilde{\Gamma}_{\alpha\beta}([p_{+}^{(i)}, \vec{p}_{\perp}^{(i)}],[q_{+}^{(i)}, \vec{q}_{\perp}^{(i)}]) =$$

$$= \lim_{P^2 \to M_{\alpha}^2,\, Q^2 \to M_{\beta}^2} \int \prod_{i=1}^{N} dp_{+}^{(i)\prime}\, d\vec{p}_{\perp}^{(i)\prime}\, \delta(P_{+} - \sum_{i=1}^{N} p_{+}^{(i)\prime})\,\delta^{(2)}(\vec{P}_{\perp} - \sum_{i=1}^{N} \vec{p}_{\perp}^{(i)\prime}) \times$$
$$\times \prod_{i=1}^{N} dp_{+}^{(i)\prime\prime}\, d\vec{p}_{\perp}^{(i)\prime\prime}\, \delta(Q_{+} - \sum_{i=1}^{N} p_{+}^{(i)\prime\prime})\,\delta^{(2)}(\vec{Q}_{\perp} - \sum_{i=1}^{N} \vec{p}_{\perp}^{(i)\prime\prime}) \times$$
$$\times \tilde{G}^{-1}([p_{+}^{(i)}, \vec{p}_{\perp}^{(i)}],[p_{+}^{(i)\prime}, \vec{p}_{\perp}^{(i)\prime}]) \times \qquad (3.10)$$
$$\times G\,\Gamma\,G([p_{+}^{(i)\prime}, \vec{p}_{\perp}^{(i)\prime}],[p_{+}^{(i)\prime\prime}, \vec{p}_{\perp}^{(i)\prime\prime}]) \times$$
$$\times \tilde{G}^{-1}([p_{+}^{(i)\prime\prime}, \vec{p}_{\perp}^{(i)\prime\prime}],[q_{+}^{(i)}, \vec{q}_{\perp}^{(i)}]).$$

Comparing (3.7) with the (3.9) we arrive at the following expression for the matrix element of the bound state current:

$$\langle P,\alpha | J(0) | Q,\beta\rangle = \int \prod_{i=1}^{N} dp_+^{(i)}\, d\vec{p}_\perp^{(i)}\, \delta\Big(P_+ - \sum_{i=1}^{N} p_+^{(i)}\Big) \times$$

$$\times\, \delta^{(2)}\Big(\vec{P}_\perp - \sum_{i=1}^{N} \vec{p}_\perp^{(i)}\Big) \times$$

$$\times \prod_{i=1}^{N} dq_+^{(i)}\, d\vec{q}_\perp^{(i)}\, \delta\Big(Q_+ - \sum_{i=1}^{N} q_+^{(i)}\Big)\, \delta^{(2)}\Big(\vec{Q}_\perp - \sum_{i=1}^{N} \vec{q}_\perp^{(i)}\Big) \times \tag{3.11}$$

$$\times\, \Psi^+_{P,\alpha}([p_+^{(i)}, \vec{p}_\perp^{(i)}])\, \tilde{\Gamma}_{\alpha\beta}([p_+^{(i)}, \vec{p}_\perp^{(i)}], [q_+^{(i)}, \vec{q}_\perp^{(i)}]) \times$$

$$\times\, \Psi_{Q,\beta}([q_+^{(i)}, \vec{q}_\perp^{(i)}]).$$

The vertex operator $\tilde{\Gamma}_{\alpha\beta}$ can be constructed, using, for instance, perturbation theory methods of quantum field theory. Here we consider the so-called "impulse approximation" (Fig. 2)

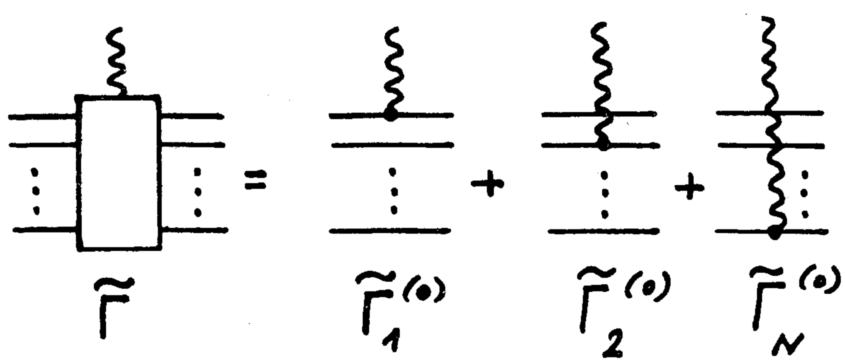

Fig. 2

In this case

$$\tilde{\Gamma}_\mu = \sum_{k=1}^{N} (\tilde{\Gamma}_\mu^{(0)})_k \tag{3.12a}$$

$$(\tilde{\Gamma}_\mu^{(0)})_k = [\tilde{G}^{(0)}]^{-1}\, [G^{(0)} (\Gamma_\mu^{(0)})_k\, G^{(0)}]\, [\tilde{G}^{(0)}]^{-1} \tag{3.12b}$$

Here

$$(\tilde{\Gamma}_\mu^{(0)})_k = (2\pi)^4 Z_k (p^{(k)} + q^{(k)})_\mu \prod_{\substack{j=1 \\ j\neq k}}^{N} \delta(p^{(j)} - q^{(j)}) \times [G^{(0)}(q^{(j)})]^{-1} \tag{3.13a}$$

$$G^{(0)}([p^{(i)}]) = i^N \prod_{i=1}^{N} (p^{(i)2} - m^{(i)2} + i\epsilon)^{-1} \tag{3.13b}$$

$$G^{(0)}([q^{(i)}]) = i^N \prod_{i=1}^{N} (q^{(i)2} - m^{(i)2} + i\epsilon)^{-1} \tag{3.13c}$$

Z_k is the charge of k -th particle.

Performing integration in formula (3.12b) according to the definition (3.4), proceeding to the reference frame, where

$$P_+ = Q_+,\ \vec{Q}_\perp = 0,\ (P - Q)^2 = \Delta^2 = -\vec{\Delta}_\perp^2 \tag{3.14}$$

and using the transformation properties of wave functions

$$\Psi_{P,\alpha}([x^{(i)}, \vec{p}_\perp^{(i)}]) = \Psi_{\vec{P}_\perp = 0,\alpha}([x^{(i)}, \vec{p}_\perp^{(i)} - x^{(i)} \vec{P}_\perp]) \tag{3.15}$$

we obtain

$$\langle P,\alpha | J_\mu(0) | Q,\beta\rangle = \sum_{k=1}^{N} \langle P,\alpha | J_\mu(0) | Q,\beta\rangle_k\ , \tag{3.16}$$

where, for instance

$$\langle P,\alpha | J_+(0) | Q,\beta\rangle_k = (P_+ + Q_+) F_k(-\vec{\Delta}_\perp^2) =$$

$$= \frac{-(2\pi)^4 Z_k (P_+ + Q_+)}{(2i)^{N+1} (2\pi i)^{N-1}} \int_0^1 \frac{\prod_{i=1}^{N} dx^{(i)}\, \delta\big(1 - \sum_{i=1}^{N} x^{(i)}\big)}{\prod_{i=1}^{N} x^{(i)}} \times$$

$$\times \int \prod_{i=1}^{N} d\vec{p}_{1}^{(i)} \, \delta^{(2)}\left(\sum_{i=1}^{N} \vec{p}_{\perp}^{(i)}\right) \times$$

$$\times \Phi^{+}_{\vec{P}_{\perp}=0,\alpha}\left([x^{(i)}, \vec{p}_{\perp}^{(i)} - x^{(i)}\vec{\Delta}_{\perp}]_{i\neq k}, x_k, \vec{p}_{\perp}^{(k)} + (1-x)\vec{\Delta}_{\perp}\right) \Phi_{\vec{P}_{\perp}=0,\beta}([x^{(i)}, p_{\perp}^{(i)}]). \tag{3.17}$$

The wave functions $\Phi_{\vec{P}_{\perp}=0,\alpha}([x^{(i)}, \vec{p}_{\perp}^{(i)}])$ are defined by the formula (2.15).

Taking into account the normalization condition for the wave functions

$$i(2\pi)^4 \int \prod_{i=1}^{N} dp_{+}^{(i)} d\vec{p}_{\perp}^{(i)} \, \delta(P_{+} - \sum_{i=1}^{N} p_{+}^{(i)}) \delta^{(2)}(\vec{P}_{\perp} - \sum_{i=1}^{N} p_{\perp}^{(i)}) \times$$

$$\times \prod_{i=1}^{N} dq_{\perp}^{(i)} d\vec{q}_{\perp}^{(i)} \, \delta(Q_{+} - \sum_{i=1}^{N} q_{+}^{(i)}) \delta^{(2)}(\vec{Q}_{\perp} - \sum_{i=1}^{N} \vec{q}_{\perp}^{(i)}) \times$$

$$\times \Psi^{+}_{P,\alpha}([p_{+}^{(i)}, \vec{p}_{\perp}^{(i)}]) \frac{\partial \tilde{G}^{-1}(P; [p_{+}^{(i)}, \vec{p}_{\perp}^{(i)}], [q_{+}^{(i)}, \vec{q}_{\perp}^{(i)}])}{\partial P^2} \times$$

$$\times \Psi_{Q,\beta}([q_{+}^{(i)}, \vec{q}_{\perp}^{(i)}]) = 1 \tag{3.18}$$

for $\vec{\Delta}_{\perp} = 0$ we get

$$F(\Delta^2 = 0) = \frac{1}{2} \sum_{k=1}^{N} Z_k . \tag{3.19}$$

Thus formulas (3.16); (3.17) define the form factors of a many-body system in terms of the quasipotential wave functions

$$\Phi_{\vec{P}_{\perp}=0,\alpha}([x^{(i)}, \vec{p}_{\perp}^{(i)}]) .$$

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