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A Renormalized, Ghost-Free Lee Model.

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Summary. — A dispersion relation model is constructed so as to reproduce the results of a Lee model. This allows to compute explicitly the boson form factor; with it the renormalization constants can be shown to be incorrectly defined, even though the model can be regularized. A new method of solution is proposed with well-defined renormalization constants and free from ghost states.

1. – Introduction.

The field model proposed by Lee (1) has the advantage over other models of being exactly soluble, in the sense that the cross-section for a given process can be computed, given the masses of the particles and the coupling constant. It is a nonlocal model however, needing to postulate a form factor describing the region where the interaction takes place. Besides, as is well known, it leads to ghost states appearing in the theory, for which the scattering amplitude presents a pole outside the physically possible region. Rasche and Straumann (2) have proposed a method to eliminate the effect of the ghost state and to obtain the renormalization constants of the model, by subtracting the residue at the pole belonging to the ghost state from the expressions where it appears. However, the position of the pole, the residue itself and the renormalization constants remain unknown, because the form factor is undetermined.

(1) T. D. Lee: *Phys. Rev.*, **95**, 1329 (1954).
(2) G. Rasche and N. Straumann: *Nuovo Cimento*, **26**, 772 (1962).

In the present paper we propose a dispersion relation model which reproduces the results of the Lee model with an explicitly known form factor. When the renormalization constants are computed, it turns out that the coupling constant renormalization is outside its expected range, namely between zero and one, and the mass renormalization diverges.

A new method of solution is proposed, closely related to the one used by ZACHARIASEN in his model (3), but then, even when his parameter λ is chosen to be negative so as to get rid of the ghost states, the renormalization constants turn out to be outside their expected range.

A redefinition of the usually accepted relationship between the vertex function and the scattering amplitude is found to be necessary. This redefinition is made in terms of the general solution found by OMNÈS (4) for integral equations of the same form as the one satisfied by the vertex function. This general solution is modified however, because it is seen that a more general class of functions are solutions of the equation proposed.

The renormalization constants are then found to be in their expected ranges, that is in the ranges consistent with their definitions, and a new limitation for the range of values of λ appears as a consequence of imposing the condition $\delta m < 0$.

In Sect. **2** previous results are presented together with the proposed dispersion relation model, very much like Zachariasen's model. In Sect. **3** the form factor is found and the renormalization constants computed. Finally in Sect. **4** the redifined vertex function is introduced and using it, the renormalization constants are recalculated.

2. – The Lee model and the regularization of Rasche and Straumann.

The Lee model deals with a system of three particles, two fermions N and V and a boson θ. The allowed reactions among the particles are

$$V \rightleftarrows N + \theta \, .$$

Given a system of an N and a θ particle, we introduce the center-of-mass energy

$$m = \sqrt{p^2 + m_N^2} + \sqrt{p^2 + \mu^2} = p_N^0 + \omega \, .$$

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(3) F. ZACHARIASEN: *Phys. Rev.*, **121**, 1851 (1961).

(4) R. OMNÈS: *Nuovo Cimento*, **8**, 316 (1958).

In the nonrelativistic limit used in the Lee model this means

$$\begin{cases} m = m_N + \omega\,, \\ p = \varrho(m) = \sqrt{(m-m_N)^2-\mu^2}\,. \end{cases} \tag{2.1}$$

The scattering amplitude for these particles is known to be

$$R_{N'\theta',N\theta} = \frac{g^2}{(2\pi)^3}\,\frac{|f(\omega)|^2}{2\omega}\,\delta^3(\boldsymbol{p}-\boldsymbol{p}')\,\frac{1}{m-m_V}\cdot \cdot\left[1+\frac{g^2}{(2\pi)^2}(m-m_V)\int_a^\infty \frac{\varrho(m')\,|f(\omega')|^2}{(m'-m_V)^2}\,\frac{\mathrm{d}m'}{m'-m-i\varepsilon}\right]^{-1}, \tag{2.2}$$

where $a=m_N+\mu$, g is the renormalized coupling constant and $\boldsymbol{p}$ and $\boldsymbol{p}'$ the relative moments before and after the interaction; $f(\omega)$ is the boson form factor, undetermined except for $f(\mu)=1$.

Introducing

$$\varphi(m) = 1+\frac{g^2}{(2\pi)^2}(m-m_V)\int_a^\infty \frac{\varrho(m')\,|f(\omega')|^2}{(m'-m_V)^2}\,\frac{\mathrm{d}m'}{m'-m-i\varepsilon}, \tag{2.3}$$

Equation (2.2) then reads

$$R_{N'\theta',N\theta} = \frac{g^2}{(2\pi)^3}\,\frac{|f(\omega)|^2}{2\omega}\,\delta^3(\boldsymbol{p}-\boldsymbol{p}')\,\frac{1}{m-m_V}\,\varphi(m)^{-1}\,, \tag{2.4}$$

and writing eq. (2.3) as

$$\varphi(m) = 1-\frac{g^2}{g_c^2}+\frac{g^2}{(2\pi)^2}\int_a^\infty \frac{\varrho(m')\,|\Gamma(m')|^2}{(m'-m_V)}\,\frac{\mathrm{d}m'}{m'-m-i\varepsilon}, \tag{2.5}$$

where

$$g_c^2 = (2\pi)^2\left[\int_a^\infty \frac{\varrho(m)\,|\Gamma(m)|^2}{(m-m_V)^2}\,\mathrm{d}m\right]^{-1} \qquad \text{and} \qquad \Gamma(m) = f(m-m_N)\,,$$

one observes that being $\varphi(m_V)=1$ and $\lim_{m\to\infty}\varphi(m)=1-g^2/g_c^2$ ghost states can appear for $g>g_c$.

Rasche and Straumann subtract the effect of these poles by analytically continuing the model in g, thus obtaining from the expression of the physical propagator for a V particle, for instance,

$$S'_V(m) = \frac{1}{m-m_V+i\varepsilon}-\frac{g^2}{(2\pi)^2}\int_a^\infty \frac{\varrho(m')\,|\Gamma(m')|^2}{(m'-m_V)^2\,|\varphi(m')|^2}\,\frac{\mathrm{d}m'}{m'-m-i\varepsilon}, \tag{2.6}$$

the regularized propagator

$$S'_{V_c}(m) = \frac{1}{m - m_V + i\varepsilon}\,\frac{1}{\varphi(m)} - \frac{R}{m - K + i\varepsilon}, \tag{2.7}$$

where K is the spurious zero of $\varphi(m)$ and R proportional to the propagator in that point

$$R = \frac{1}{K - m_V}\,\frac{1}{\mathrm{d}\varphi(m)/\mathrm{d}m|_{m=K}}\,. \tag{2.7a}$$

R and K cannot be determined unless the function $\Gamma(m)$ be known.

In the next Section we will try to define $\Gamma(m)$ from a Lee model satisfying dispersion relations. This model will again represent a system of three particles that can interact among themselves as described in the first paragraph of this Section and besides, will satisfy the conditions of the Zachariasen model. That is, the theory is supposed to be describable in terms of an S-matrix given by

$$S_{ij} = \delta_{ij} - i(2\pi)^4\delta^4(p_i - p_j)\,\frac{T_{ij}}{N_i N_j} \tag{2.8}$$

with $N_i = \prod_{k \text{ in } i} (2E_k)^{\frac{1}{2}}$. The T_{ij}, functions of m are supposed to satisfy dispersion relations

$$T_{ij}(m) = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{\operatorname{Im} T_{ij}(m')}{m' - m - i\varepsilon}\,\mathrm{d}m'\,, \tag{2.9}$$

where $\operatorname{Im} T_{ij}$ is given by unitarity

$$\operatorname{Im} T_{ij}(m) = -\frac{1}{2}\sum_n \frac{T_{in} T^*_{jn}}{N_n^2}\,(2\pi)^4\delta^4(p_i - p_n) \tag{2.10}$$

in the physical range for m and eventually in the position of virtual particles, and zero outside these regions. This means that for i and j representing states of an N and θ particle

$$\operatorname{Im} T(m) = -\pi g^2\,\delta(m - m_V) - \frac{1}{8\pi}\,\frac{\varrho(m)}{m}\,|T(m)|^2\,. \tag{2.11}$$

3. – Determination of the boson form factor and the renormalization constants.

Equation (2.9) can be solved by setting $T(m) = g^2/(m - m_V)D(m)$, where $D(m)$ has no zeros but the poles of T; then if T has no zeros and a single pole at m_V as is well known,

$$D(m) = 1 + g^2 \frac{m - m_V}{(2\pi)^2} \int_a^\infty \frac{\varrho(m')}{2m'(m' - m_V)^2} \frac{\mathrm{d}m'}{m' - m - i\varepsilon}, \tag{3.1}$$

that is

$$T(m) = \frac{g^2}{m - m_V} \left[1 + g^2 \frac{m - m_V}{(2\pi)^2} \int_a^\infty \frac{\varrho(m')}{2m'(m' - m_V)^2} \frac{\mathrm{d}m'}{m' - m - i\varepsilon}\right]^{-1}. \tag{3.2}$$

Now, if (3.2) and (2.4) describe the same physical process, the integrands in both expressions must coincide meaning that $|\Gamma(m)|^2 = 1/2m$ except for a normalization constant that can be absorbed in the coupling constant. Of course the numerators must also coincide. If we write the reduced scattering amplitude for the Lee model as ([5])

$$f(m) = \frac{1}{\varrho(m)} \cdot \exp[i\delta(m)] \cdot \sin\delta(m) = -\frac{g^2}{4\pi} \frac{|\Gamma(m)|^2}{m - m_V} \cdot \frac{1}{\varphi(m)} \quad (^*), \tag{3.3}$$

as T in our model will be proportional to f,

$$\operatorname{Im} T(m) = \operatorname{Im}[\alpha f(m)] = \frac{\alpha}{\varrho(m)} \sin^2\delta(m) = \frac{\varrho(m)}{\alpha} |T(m)|^2,$$

from where $\alpha = -8\pi m$ and therefore

$$f(m) = -\frac{g^2}{8\pi m} \frac{1}{(m - m_V)\varphi(m)};$$

from this equation and (3.3) we obtain again $|\Gamma(m)|^2 = 1/2m$.

The form factor being known it is then possible to compute R and K in the regularization of RASCHE and STRAUMANN.

If we compute for instance the coupling constant renormalization from ([6])

$$Z_V^{-1} = 1 + \int_a^\infty \sigma(m^2)\,\mathrm{d}m \tag{3.4}$$

([5]) See for instance S. S. SCHWEBER: *Relativistic Quantum Field Theory* (New York, 1961), chap. 12, p. 363.

(*) f is used for different functions when no confusion is possible.

([6]) H. LEHMANN: *Nuovo Cimento*, **11**, 342 (1954).

with in our case

$$\sigma(m^2) = \frac{1}{(2\pi)^2} \frac{\varrho(m)}{2m(m-m_V)^2} |F(m)|^2 \qquad \text{(see Appendix)}, \tag{3.5}$$

where $|F(m)|^2 = |T_{N\theta,V}|^2/2m_V$. Taking $F(m) = g/D(m)$, that fulfills the condition $F(m_V) = g$, one obtains

$$Z_V^{-1} = 1 + \frac{g^2}{(2\pi)^2} \int_a^\infty \frac{\varrho(m)}{2m(m-m_V)^2} \frac{\mathrm{d}m}{|D(m)|^2}. \tag{3.6}$$

Using the fact that $\lim\limits_{m\to\infty} D(m) = 1 - g^2/g_c^2$, this expression can be calculated by residues giving

$$Z_V = 1 - g^2/g_c^2, \tag{3.7}$$

which is outside the expected range for Z_V when $g > g_c$.

In the same way the mass renormalization is

$$\delta m_V = \int_a^\infty (m_V - m)\sigma(m^2)\,\mathrm{d}m = -\frac{g^2}{(2\pi)^2} \int_a^\infty \frac{\varrho(m)}{2m(m-m_V)} \frac{\mathrm{d}m}{|D(m)|^2}, \tag{3.8}$$

which diverges logarithmically.

Therefore to obtain a model free from spurious ghosts and at the same time with renormalization constants finite and in their expected range it is necessary to modify the form of solution of the model; this is best done by introducing a new parameter, following ZACHARIASEN, in

$$T(m) = \frac{\lambda + g^2/(m-m_V)}{D_c(m)}, \tag{3.9}$$

where, now, $D_c(m)$ can have a zero at $m_0 = m_V - g^2/\lambda$ and where λ must be negative so that if $T(m_0) = 0$ it be $m_0 > m_V$ (*), and so as to eliminate the spurious pole in T. With this form of solution

$$D_c(m) = 1 + \lambda \frac{m - m_V}{(2\pi)^2} \int_a^\infty \frac{(m'-m_0)\varrho(m')}{2m'(m'-m_V)^2} \frac{\mathrm{d}m'}{m'-m-i\varepsilon}, \tag{3.10}$$

which satisfies $D_c(m_V) = 1$ and $\lim\limits_{|m|\to\infty} D_c(m) = -\lambda \ln|m|$.

If λ is negative and large enough, the spurious pole is eliminated; we can

(*) As required by (2.9) and (2.11).

proceed then to recalculate the renormalization constants. If the usual hypothesis $F(m)=g/D_c(m)$ is maintained, we obtain for Z_V^{-1} again expression (3.6), with $D(m)$ replaced by $D_c(m)$; using

$$\operatorname{Im} D_c(m)^{-1} = -\lambda \frac{\varrho(m)}{8\pi m} \cdot \frac{m-m_0}{m-m_V} \cdot \frac{1}{|D_c(m)|^2},$$

it can be rewritten as

$$Z_{V_c}^{-1} = 1 - \frac{g^2/\lambda}{\pi} \int_a^{\infty} \frac{\operatorname{Im} D_c(m)^{-1}}{(m-m_0)(m-m_V)} \, dm \,. \tag{3.11}$$

Computing this integral by residues we obtain $Z_{V_c}=1-g^2/g_c^2$ for $m_0<a$. This value is outside the expected range for Z_V, for $g>g_c$.

4. – The renormalization of the ghost-free model.

The assumed relation between $F(m)$ and $T(m)$ is not the most general expression of the equation connecting these two functions; it is rather a very particular case.

$F(m)$ satisfies by (2.9) a dispersion relation of the form

$$F(m) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{\operatorname{Im} F(m')}{m'-m-i\varepsilon} \, dm', \tag{4.1}$$

where by (2.10)

$$\operatorname{Im} F(m) = -\frac{1}{2} \sum_n \frac{(2\pi)^4}{N_n^2} T_{N\theta,n} T^*_{V,n} \delta^4(p_i - p_n) = \tag{4.2}$$

$$= -\frac{\varrho(m)}{8\pi m} T(m) F^*(m) = F^*(m) \exp[i\delta(m)] \sin\delta(m) \,,$$

where, as usual, we have set $T(m) = -\big(8\pi m/\varrho(m)\big) \exp[i\,\delta(m)] \sin\delta(m)$.

Therefore $F(m)$ satisfies the integral equation

$$F(m) = \frac{1}{\pi} \int_a^{\infty} \frac{\sin\delta(m') \cdot \exp[i\delta(m')] F^*(m')}{m'-m-i\varepsilon} \, dm' \,. \tag{4.3}$$

The most general solution of this equation is [4]

$$F(m) = f(m) \frac{P(m)}{(m-a)^n} \exp[\chi(m) + i\delta(m)] \tag{4.4}$$

if

$$\chi(m) = \frac{1}{\pi} P \int_a^\infty \frac{\delta(m')}{m' - m} \, \mathrm{d}m'$$

converges.

In this expression, $P(m)$ is an arbitrary polynomial, n an arbitrary integer; $f(m)$, not appearing in Omnès solutions, is an analytic function of m in the whole complex plane except for poles that are located at the zeros of the arbitrary polynomial. In our problem, $\chi(m)$ converges because $\lim_{m\to\infty} \delta(m) \sim \sim 1/\ln|m|$. Now, if F satisfies a dispersion relation, as it does, the maximum order of the polynomial may be n, and in this case $\lim_{m\to\infty} f(m) = 0$ because $\lim_{m\to\infty} \exp[\chi(m)] = 1$.

On the other hand, from unitarity,

$$\operatorname{Im} T(m) = \operatorname{Re} T(m) \operatorname{tg} \delta(m) = T^*(m) \exp[i\,\delta(m)] \sin \delta(m) ,$$

$$\operatorname{Im} F(m) = \operatorname{Re} F(m) \operatorname{tg} \delta(m) = F^*(m) \exp[i\,\delta(m)] \sin \delta(m) ,$$

that is $F(m) = A(m)\, T(m)$ where $A(m)$ is a real arbitrary function of m; this last expression can also be written as $F(m) = a(m) \sin\delta(m) \exp[i\,\delta(m)]$. Therefore, as $T(m)$ has a pole in m_V, $f(m)$ must contain it, and $a(m)$ must contain the pole of $F(m)$ in a; therefore $f(m) \sim \sin\delta$ and $P(m) = (m - m_V) P_1(m)$.

Imposing the condition that $F(m_V) = g$, and choosing the smallest possible n for $F(m)$ to satisfy a dispersion relation of the form (4.3) (unsubtracted), we obtain

$$F(m) = \frac{1}{g} \frac{(m - m_V)(m_V - a)}{(m - a)} T(m) . \tag{4.5}$$

Therefore, from (3.5)

$$\sigma(m^2) = \frac{1}{(2\pi)^2} \frac{\lambda^2}{g^2} \frac{(m - m_0)^2 \varrho(m)}{2m(m - m_V)^2} \left(\frac{m_V - a}{m - a}\right)^2 \frac{1}{|D_c(m)|^2} , \tag{4.6}$$

from where one immediately obtains

$$Z_{V_c}^{-1} = 1 + \frac{\lambda^2}{(2\pi g)^2} \int_a^\infty \frac{(m - m_0)^2 \varrho(m)}{2m(m - m_V)^2} \left(\frac{m_V - \alpha}{m - a}\right)^2 \frac{\mathrm{d}m}{|D_c(m)|^2} . \tag{4.7}$$

In this integral, the point $m = a$ must be excluded to obtain real values of Z_{V_c}, that is, we take as physically meaningful the regular part of the integral. Then, after an integration by residues

$$Z_{\mathrm{V}_c}^{-1}=\frac{1}{D_c(a)}-\frac{\lambda}{g^2}(a-m_{\mathrm{V}})(a-m_0)\left[\frac{d}{\mathrm{d}m}\frac{1}{D(m)}\right]_a, \tag{4.8}$$

which, as can be readily verified is larger than 1 as expected, as long as λ is kept negative, for $m_0 \lessgtr a$.

In a similar way we obtain for the mass renormalization

$$\delta m_{\mathrm{V}}=\frac{\lambda}{g^2}(m_{\mathrm{V}}-a)^2\left\{\frac{1}{D_c(a)}+(a-m_0)\left[\frac{\mathrm{d}}{\mathrm{d}m}\frac{1}{D_c(m)}\right]_a\right\} \tag{4.9}$$

and for the physical propagator of the V particle

$$S'_{\mathrm{V}_c}=\frac{1}{m-m_{\mathrm{V}}}-\frac{1}{m-m_{\mathrm{V}}}\cdot \tag{4.10}$$

$$\cdot\left\{1-\frac{\lambda}{g^2}\left(\frac{m_{\mathrm{V}}-a}{m-a}\right)^2\left[\frac{m-m_0}{D_c(m)}\Theta(a-m)-\frac{a-m_0}{a-m_{\mathrm{V}}}\frac{m-m_{\mathrm{V}}}{D_c(a)}\right]-Z_{\mathrm{V}_c}^{-1}\frac{m-m_{\mathrm{V}}}{m-a}\right\},$$

which satisfies the condition $\lim\limits_{m\to\infty} S'_{\mathrm{V}_c}=Z_{\mathrm{V}_c}^{-1}$ and which has a pole of unitary residue at $m=m_{\mathrm{V}}$, as expected; this again as a consequence of taking the regular part of integral (4.7).

If we analyse the expression for δm_{V}, that can be written

$$\delta m_{\mathrm{V}}=\frac{\lambda}{g^2}(m_{\mathrm{V}}-a)^2\cdot \tag{4.11}$$

$$\cdot\left\{1-\frac{\lambda}{(2\pi)^2}\int_a^\infty\frac{\varrho(m)}{2m(m-m_{\mathrm{V}})}\frac{m-m_0}{m-a}\left[\frac{a-m_{\mathrm{V}}}{m-m_{\mathrm{V}}}+\frac{a-m_0}{m'-a}\right]\frac{\mathrm{d}m}{|D_c(m)|^2}\right\},$$

it can again be shown that if $m_0<a$, that is, $\lambda<-g^2/\mu$, $\delta m_{\mathrm{V}}<0$.

If $\lambda>-g^2/\mu$, δm_{V} is negative when $\lambda<-g^2/2\mu$ (supposing $m_{\mathrm{N}}=m_{\mathrm{V}}$); otherwise the sign of δm_{V} is undetermined, depending on the relative values of the constants of the problem.

The particular case for which m_0 coincieds with $a=m_{\mathrm{N}}+\mu$, leads from (4.5) to

$$F(m)=g/D_c(m)\,. \tag{4.12}$$

In this case, according to the prescription given after eq. (4.7), m_0 must be considered excluded from the integral; then $Z_{\mathrm{V}_c}^{-1}$ is effectively given by $Z_{\mathrm{V}_c}=1-g^2/g_c^2$. Just as for any value of $m_0\leqslant a$, the theory will be valid only if $g < g_c$, otherwise $D(m)$ will present zeros that are not poles of $T(m)$, for we started from the hypothesis that no bound states appear in the model. Therefore when $g > g_c$, λ must be chosen in such way that $m_0 > a$, that is $\lambda > -g^2/\mu$; then an upper limit is given by the condition $\delta m_V < 0$, another by the condition of exclusion of ghost states.

It is always possible then to construct a Lee model without ghost states and renormalization constants within their expected range, by constructing a Zachariasen model reproducing the results of the Lee model; however the relationship between $F(m)$ and $T(m)$ must be of the form (4.5) when a minimum condition for the existence of the dispersion relation model is imposed. Other solutions are possible when the order of the pole in a is taken larger than one; these solutions will introduce $(n-1)$ arbitrary parameters, coefficients of the arbitrary polynomial (or position of its zeros).

APPENDIX

To obtain equation (3.5) we consider the reduction formula for fermions:

$$\begin{aligned}(\text{A.1})\qquad {}_{+}\langle N(\boldsymbol{q})\theta(\boldsymbol{k})\,|\,V(\boldsymbol{p})\rangle &= \\ &= -\,i\int \mathrm{d}^4y\,{}_{+}\langle N(\boldsymbol{q})\theta(\boldsymbol{k})\,|\,\bar{\psi}_V(y)\,|\,0\rangle\,(\overleftarrow{-\,i\gamma\cdot\partial_y - m_V})\,\frac{u(p)}{\sqrt{2p^0}}\exp[-\,ipy] = \\ &= -\,i(2\pi)^4\,{}_{+}\langle N(\boldsymbol{q})\theta(\boldsymbol{k})\,|\,\bar{\psi}_V(0)\,|\,0\rangle(\gamma\cdot p_n - m_V)\,\frac{u(p)}{\sqrt{2p^0}}\,\delta(p_n - p)\,,\end{aligned}$$

where $p_n^0 = m_N + \omega = m$ and $\boldsymbol{p}_n = 0$. Specializing to positive energy solutions, in the nonrelativistic limit this reduces to

$$(\text{A.2})\qquad {}_{+}\langle N(\boldsymbol{p})\theta(\boldsymbol{k})\,|\,V(\boldsymbol{p})\rangle = -\,i(2\pi)^4\,{}_{+}\langle N(\boldsymbol{q})\theta(\boldsymbol{k})\,|\,\psi_V^*(0)\,|\,0\rangle\,(m - m_V)\,\delta(p_n - p)\,.$$

On the other hand we know that

$$(\text{A.3})\qquad {}_{+}\langle N(\boldsymbol{q})\theta(\boldsymbol{k})\,|\,V(\boldsymbol{p})\rangle = -\,i(2\pi)^4\,\frac{T_{N\theta,V}}{N_{N\theta}N_V}\,\delta(p_n - p)\,.$$

Therefore for $p_n = p$, that is, outside the mass shell for the V particle

$$(\text{A.4})\qquad (m - m_V)\,{}_{+}\langle N(\boldsymbol{q})\theta(\boldsymbol{k})\,|\,\psi_V^*(0)\,|\,0\rangle = \frac{T_{N\theta,V}}{(2m_N 2\omega 2m_V)^{\frac{1}{2}}}\,,$$

from which (3.5) is obtained with

$$\sigma(m^2) = (2\pi)^3 \sum_{|N\theta\rangle_+} \langle 0 | \psi_V(0) | N\theta\rangle_{++}\langle N\theta | \psi_V^*(0) | 0\rangle = \tag{A.5}$$

$$= (2\pi)^3 \int \frac{d^3q}{(2\pi)^3} \int \frac{d^3k}{(2\pi)^3} \frac{1}{(m-m_V)^2} \frac{|T_{N\theta,V}|^2}{2m_N 2\omega 2m_V} \delta(p_N + p_\theta - p) =$$

$$= \frac{1}{(2\pi)^2} \frac{\varrho(m)}{2m} \frac{|F(m)|^2}{(m-m_V)^2} .$$

RIASSUNTO (*)

Si costruisce un modello di relazioni di dispersione che riproduca i risultati di un modello di Lee. Ciò permette di calcolare esplicitamente il fattore di forma del bosone; con esso si può dimostrare che le costanti di rinormalizzazione sono definite scorrettamente, anche se il modello può essere regolarizzato. Si propone un nuovo metodo di soluzione con ben definite costanti di rinormalizzazione e libero da stati fantasma.

(*) *Traduzione a cura della Redazione.*