A NON LOCAL MODEL FOR THE HIGH ENERGY p-p ELASTIC COLLISION

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ABSTRACT: A calculation of the differential cross section for the p-p elastic collision is made, taking into account the contribution of a scalar, vectorial, or tensorial intermediate meson. We have calculated the second order of the perturbative approach, using the Feynmann diagrams techniques; the well-known divergence of this series is cutoffed supposing that the interaction among hadrons is non local.

DEFINITION AND CALCULATION OF THE FORM FACTOR

In this work we study the high energy p-p elastic scattering using a non-local interaction model, proposed by G. Wataghin[1, 2, 3].

In this theory, it is supposed that the well known divergences, found in the field theory of strong interactions, arise from considering the nucleons as point-particles, which assumes that the interaction is perfectly localized in space and time. We avoid such hypothesis assuming that, due to the extension of the particles, the interaction takes place in a finite-4-dimensional domain D_l with a lineal extension l comparable to the Compton wavelength of the nucleon. As a consequence of this assumption, the momenta and the energies of the particles resulting from the collision are strongly cutoffed. It can be demonstrated that, in this way, we introduce in the S-matrix a form factor preserving the usual properties of the S-matrix, such as relativistic covariance and unitarity. This form factor is chosen in such a way that the macrocausality condition is also fulfilled.

Following the prescription of reference[3], the cutoff invariants in momentum space, defined in the vertex frames of in-going and out-going particles, are:

$$G^{\pm} = G_s G_t^{\pm} \tag{1}$$

with

$$G_t^{\pm} = (1 + iI_t)^{-1} \quad ; \quad G_s = (1 + I_s^2)^{-1} \tag{2}$$

$$I_t = lk_{\mu} u^{\mu} \quad ; \quad I_s = (I_t - l^2 k_{\mu} u^{\mu})^{1/2} \tag{3}$$

where k_{μ} is the four-momentum of the in-going and out-going particles, and u_{μ} is a four-vector parallel to the total momentum in the vertex frame (see also[4]).

The form factor $G^{\pm}$ must be applied in any vertex and in any line of the Feynmann diagrams of the problem. The "time" cutoff G_t^+ is associated with the creation operators, and G_t^- with the destruction operators; they act in a different way on the created and on the absorbed particles in order not to mix in-going with out-going waves, ensuring that one obtains only out-going waves for future times, and only in-going waves arising from the past at points of D_l.

The "space" cutoff G_s modifies the statistical weight of each non-degenerate eigenstate of the momentum of the particles; it follows immediately, from the behavior of G_s as function of p, that the higher momenta are less probable than the lower ones.

In our case the form factor which multiplies the matrix element is

$$G = G^-(p_1^{\mu})\ G^+(p_{1'}^{\mu})\ G\ (p_1^{\mu} + p_{1'}^{\mu})\ G^-(p_1^{\mu} + p_{1'}^{\mu})\ G^-(p_2^{\mu})\ G^+(p_{2'}^{\mu}) \tag{4}$$

where the four-vectors p_1^{μ}, $p_{1'}^{\mu}$, p_2^{μ}, $p_{2'}^{\mu}$, are defined in fig. 1.

THE DIFFERENTIAL CROSS SECTION

Since the cutoff operators are applied to each line and vertex of the Feynmann diagrams, we can assume that the higher order diagrams are strongly cutoffed, so that the perturbative series may be convergent. For this reason, we have only calculated the second order diagrams, arising from the interchange of only one meson. Since protons are no distinguishable particles, in order to satisfy Pauli principle, we take also into account the diagrams with the final state interchanged. We have considered the exchange of scalar, vector and tensor mesons.

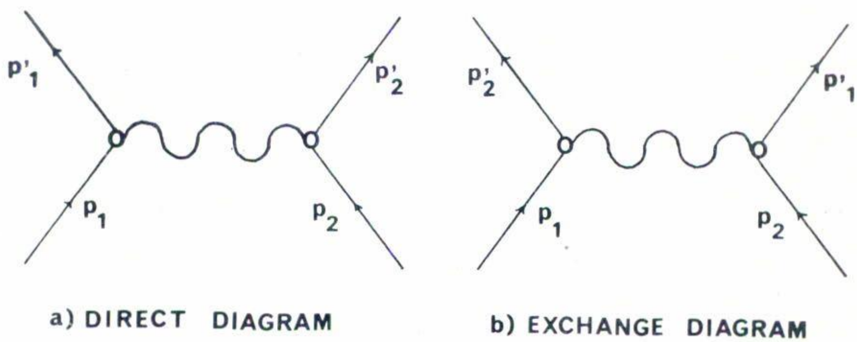

FIG. 1

The case of scalar and vector intermediate mesons, (π^0 and ρ^0), has been studied in ref. (5) obtaining a good agreement with the experimental data, specially at large momentum transfers.

The good results obtained in the treatment of p-p annihilation with tensor bosons as intermediate states[6], suggest us that it will be interesting to study the exchange of such mesons in p-p elastic scattering. We assume that the interaction lagrangian between tensor field and spinor field is[7]

$$L = - \frac{g}{2m_p} (\psi \gamma_\mu \partial_\nu \overline{\psi} - \partial_\nu \overline{\psi} \gamma_\mu \psi) \phi_{\mu\nu} \tag{5}$$

where $\phi_{\mu\nu}$ is the field function of the tensorial field. After a simple, but rather long algebra, using the usual trace theorems, we have calculated the differential cross section[8]; its dominant term can be written as

$$\frac{d\sigma}{d\Omega} \sim - \frac{1}{32s} \frac{u}{(t - M^2)^2} \frac{(t - s)^4}{m_p^6} , \tag{6}$$

where t, s and u are the Mandelstam invariants, M is the tensor meson mass[6] and m_p is the proton mass.

It can be demonstrated that the form factors, independently from the nature of intermediate particles which multiply the direct, exchange and mixing terms in the differential cross sections, are respectively:

$$G^2(t) = (1+l^2t')^{-8}[1+l^2(t'+m_p^2)]^{-4}[1+l^2(t+4m_p^2)]^{-2} \tag{7}$$

$$G^2(u) = (1+l^2u')^{-8}[1+l^2(u'+m_p^2)]^{-4}[1+l^2(u+4m_p^2)]^{-2} \tag{8}$$

$$G(t)\,G(u) = (1+l^2t')^{-4}[1+l^2(t'+m_p^2)]^{-2}[1+l^2(t+4m_p^2)]^{-1}$$

$$\times(1+l^2u')^{-4}[1+l^2(u'+m_p^2)]^{-2}[1+l^2(u+4m_p^2)]^{-1} \tag{9}$$

where $t' = t/4$ and $u' = u/4$.

This differential cross section reproduces the experimental data at very high energies only if we use a strong cutoff, choosing $l^{-1} \sim m_p$; but the value of $(d\sigma/dt)_{t=0}$, even cutoffed, increases with s, in contrast with the experimental data; furthermore, if we plot

$$\left(\frac{d\sigma}{dt}\right)/\left(\frac{d\sigma}{dt}\right)_{t=0}$$

given by π^0, ρ^0 and ω exchange against t, we obtain a good agreement with the experimental data, taking $l^{-1} = 2.5m_p$ in the cutoff (this value of l is almost the same as used in references (4)(5)(6)). For these reasons we think that the vector meson exchange is the right hypothesis. The expression for this differential cross section is analogous to the formula calculated in Ref (5), except for the new contribution of the ω meson and the interference between π^0, ρ^0 and ω. For example, we can write the direct term as follows

$$\left(\frac{d\sigma}{d\Omega}\right)_{\rm dir} = \frac{G^2(t)}{4s}\left[\left\{\left(\frac{g^2_{\rho p}}{4\pi}\right)\frac{16}{(t-m_\rho^2)^2} + \left(\frac{g^2_{\omega p}}{4\pi}\right)^2\frac{16}{(t-m_\omega^2)^2} + \frac{g^2_{\rho p}\,g^2_{\omega p}}{\pi^2}\,\frac{2}{(t-m_\rho^2)(t-m_\omega^2)}\right\}\right.$$

$$\left\{(s-2m_p^2)^2 + t\left(s+\frac{t}{2}\right)\right\} + \frac{16m_p^2\,t}{t-m_\pi^2}\left\{g^2_{\pi p}\left(\frac{{}^{\circ}\rho p}{m_\rho^2} + \frac{g^2_{\omega p}}{m_\omega^2}\right)\right\}$$

$$\left. + \left(\frac{g^2_{\pi p}}{4\pi}\right)^2\frac{t^2}{(t-m_\pi^2)^2}\right] \tag{10}$$

The numerical values of this differential cross-section have been plotted against t for three momenta of the incident proton (3, 4 and 10 gev/c in the laboratory system).

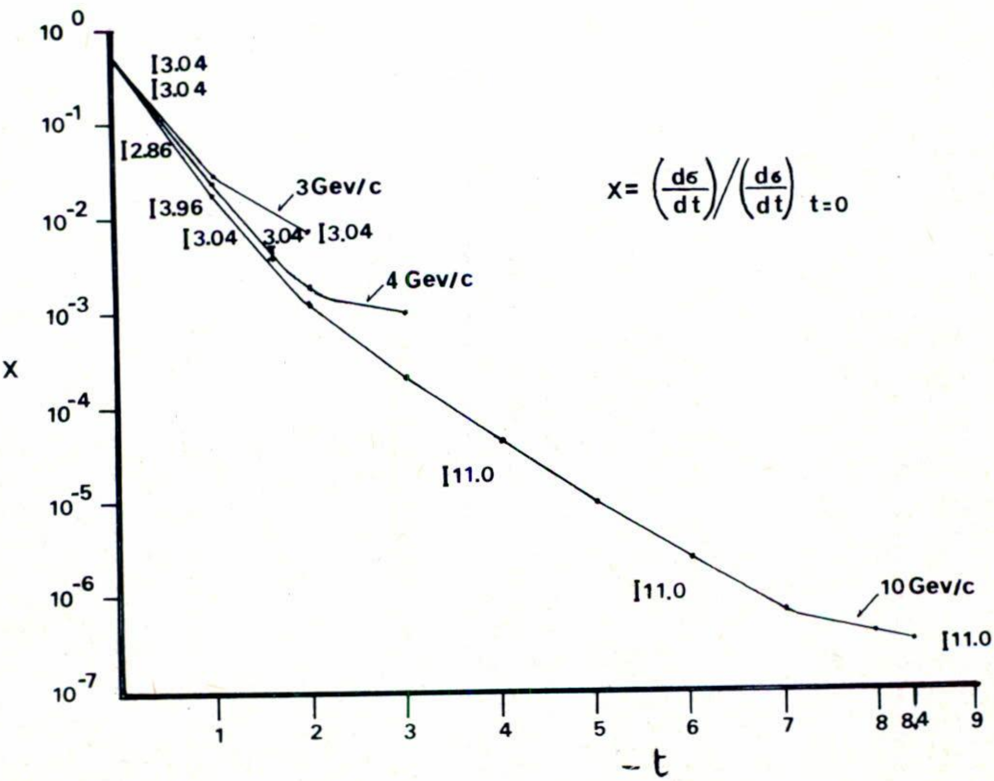

FIG. 2

The experimental points are taken from ref. (10). Curves at higher energies, with only π^0 and ρ^0 in the intermediate state, are showed in the ref. (5).

The theoretical values, as the experimental ones, have been normalized by $(d\sigma/dt)_{t=0}$ where the forward scattering cross section is obtained from the experimental total cross section, with the aid of the optical theorem; since the theoretical differential cross sections for $t = 0$ have the same s-dependence as the experimental ones, all the curves arise from the same point.

CONCLUSIONS

Comparing the contribution to the differential cross section of the p–p elastic collision, arising from the exchange of scalar, vector and tensor mesons, we can conclude that the vector mesons reproduce the most important qualitative features of the experimental data, if we use the form factor defined in the first section.

The quantitative agreement is not completely satisfactory, because we are neglecting the contribution of infinitely many intermediate processes to the p–p elastic collision, mainly the diffraction effect which is dominant near zero-momentum transfer.

Nevertheless, the purpose of this work was to show that, even if we take into account only the processes included in the easiest calculation, in the frame of the perturbative approach, we can reproduce quite well the experimental data, assuming the non-locality of the interaction among hadrons, and using almost the same value of l (the only arbitrary parameter in this model) as it has been done in the calculation of several other processes[4, 5, 6].

This non-local interaction model will be tested also in $\bar{p}$–p elastic scattering; the results will be published elsewhere.

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RESUMEN

Se calcula la sección de choque diferencial para la colisión elástica protón-protón, tomando en cuenta la contribución de un mesón intermedio escalar, vectorial o tensorial. El cálculo se lleva a cabo hasta el segundo orden perturbativo, mediante las técnicas de los diagramas de Feynman. La divergencia de la serie se corrige introduciendo un factor de forma definida mediante la suposición de no localidad de la intersección entre hadrones.