The parameters β, $\overline{\beta}$ and λ_1 are quite insensitive to small (10%) variations in χ^2 except λ_2, which changes drastically.

In the $^3S_1$ state, there is also the tensor force. This was investigated by many authors with the ansatz of Yamaguchi[3]. But these ansatz gives no polarization in N—N scattering[4]. One way to get out of this trouble is to use again a rank two potential of the form:

$$V(p', p) = \lambda_1 g_1(p') g_1(p) + \lambda_2 g_2(p') S(\hat{\vec{p}}') g_2(p) S(\hat{\vec{p}})$$

where the form factors g_1 and g_2 are given before and S is the usual tensor-operator. The parameters of this potential will also be fitted.

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4.10. Analysis of the off mass shell-behaviour of the hadronic scattering matrix as constructed by means of an effective Lagrangian model*

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Abstract: Starting from an effective Lagrangian model relativistic covariant and gauge invariant scattering amplitudes for certain hadronic interactions with an additional emitted or absorbed photon are constructed, which allow one to examine the validity of this Lagrangian model for off mass shell-hadrons.

Lagrange function for some hadrons and introduction of the photon. In this work a dynamical model for some hadrons is developed, which is based on an interaction Lagrangian for the pion nucleon system[1]. This Lagrange function includes the relativistic fields of the mesons σ ($J = 0^+$, $I = 0$), π and ϱ, the nucleons n and p and the baryon resonance $\Delta(1238)$

$$(J = {}^3/_2{}^+,\ I = {}^3/_2):$$

$$L_{int}(x) = g_{\sigma\pi\pi}\, \sigma(x) \frac{\vec{\pi}^2(x)}{2} + g_{\sigma NN}\, \overline{N}(x)\, N(x)\, \sigma(x) + g_{\rho\pi\pi}\, \vec{\varrho}^{\,\mu}(x) \left[\pi(x) \times \partial_\mu \vec{\pi}(x)\right] +$$

$$+ g_{\rho NN}\, \overline{N}(x)\, \gamma_\mu \frac{\vec{\tau}}{2} N(x)\, \vec{\varrho}^{\,\mu}(x) + g_{NN\pi}\, \overline{N}(x)\, \gamma_\mu\, \gamma^5 \vec{\tau}\, N(x)\, \partial^\mu \vec{\pi}(x) +$$

$$+ g_{\Delta N\pi} \overline{N}(x)\, \vec{\tau}\, N_\mu(x)\, \partial^\mu \vec{\pi}(x).$$

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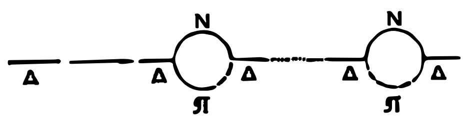
Now the principle of minimal electromagnetic coupling is used to introduce the relativistic photon field.

Scattering amplitude. The Lagrange function as developed above enables one to construct a relativistic covariant and completely gauge invariant scattering amplitude for certain hadronic processes with an additional absorbed or emitted photon. This electromagnetic interaction is regarded only to first order.

Of course the arising scattering amplitude contains the original purely hadronic scattering amplitude as kernel, but not all the hadrons, which this kernel is consisting of, are lying on the mass shell. This fact allows one to examine the validity of the underlying dynamical hadron model for off mass shell-handrons.

The resonance $\Delta(1238)$ is described in this model by a Feynman propagator which has a pole at the resonance position $S = M_\Delta^2$, where S is the squared four momentum of the Δ resonance. Therefore an imaginary part must be added to the resonance mass M_Δ in order to get finite cross sections. This can be done by the following standard method of field theory: the line of the internal Δ is replaced by the following Feynman graph



The corresponding scattering amplitude shows the right threshold behaviour too.

Special examples, parameters and results. To examine this Lagrangian model numerically two special scattering processes, which are connected by the crossing principle, are calculated explicitely:

radiative pion-nucleon scattering $\pi^+ p \to \pi^+ p \gamma$

double-pion photoproduction $\gamma p \to p \pi^+ \pi^-$.

In these computations the following numerical values of the masses, coupling constants and corresponding decay widths of the involved particles are used:

$$m_\pi = 139.6 \text{ MeV}, \ M = 938.6 \text{ MeV},$$

$$M_\Delta = 1238 \text{ MeV}, \ m_\rho = m_\sigma = 765 \text{ MeV};$$

$$\frac{g^2_{\sigma\pi\pi}}{4\pi} = 67.4\, m_\pi^2 \, (\Gamma_{\rho\to\pi\pi} = 400 \text{ MeV}), \frac{g^2_{\sigma NN}}{4\pi} = 0.06,$$

$$\frac{g^2_{\rho\pi\pi}}{4\pi} = \frac{g^2_{\rho NN}}{4\pi} = 2.5 \ (\Gamma_{\rho\to\pi\pi} = 130 \text{ MeV}),$$

$$\frac{g^2_{pn\pi}}{4\pi} = \frac{0.08}{m_\pi^2},$$

$$\frac{g^2_{\Delta^{++}p\pi}}{4\pi} = 18.6 \, (\Gamma_{\Delta^{++}\to p\pi^+} = 120 \text{ MeV}).$$

With the above value of the coupling constant $g_{\sigma NN}$ the S-wave scattering length of elastic pion-nucleon scattering agrees with the experimental value

$$a_s^{(+)} = -0.009\, m_\pi^{-1} \text{ [2]}.$$

For radiative pion-nucleon scattering the only experimental value so far known is[3]:

$$\sigma_{tot}\,(p\pi^+ \to p\pi^+\gamma) = 0.22 \pm 0.05 \text{ mb}$$

$$\text{at } E_{KIN}^{LAB}(\pi^+) = 300 \pm 70 \text{ MeV}.$$

In this case the results of the Lagrangian model[4] are lying too high, for example

$$\sigma_{tot}\,(p\pi^+ \to p\pi^+\gamma) = 0.55 \text{ mb} \qquad \text{at } E_{KIN}^{LAB}(\pi^+) = 300 \text{ MeV}.$$

But for the photoproduction $\gamma p \to p\pi^+\pi^-$ the predictions of the Lagrangian model[5] agree rather well with experimental data[6,7,8] for photon laboratory energies up to about 650 MeV.

Some remarks on the application of the Low-theorem on radiative pion-nucleon scattering. One very interesting feature of processes as for example radiative pion-nucleon scattering, which could be proved numerically by this work, is the following: The dependence of differential cross sections on the photon energy, as calculated by means of the Lagrangian model under discussion, shows explicitely, that it is not reasonable to analyse radiative processes, which are dominated by resonances as the $\Delta(1238)$, by means of the Low-theorem for soft photons, as done for example in[9], because the presence of such a strongly marked resonance as $\Delta(1238)$ disturbs the $1/K$ behaviour of cross sections (photon energy K)[10].

General conclusions. Up to now it is not clear, if the discrepancy between experimental data and the predictions of this Lagrangian model for pion-nucleon bremsstrahlung stems from the neglect of any possible momentum dependence of the coupling constants, or if this one experimental value is too small and should be corrected.

But for all the scattering processes, which have been discussed in this short survey, there are characteristic differences between the results of this non-unitary Lagrangian model and experimental data, which have their deeper reason in the fact, that there exists up to now no satisfactory relativistic quantum theory of unstable particles as for example the resonances of strong interaction.

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