СООБЩЕНИЯ
ОБЪЕДИНЕННОГО
ИНСТИТУТА
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
Дубна

E2 - 4370

M.A.Markov

FORM FACTORS AND TOTAL CROSS SECTIONS OF WEAK AND ELECTROMAGNETIC INTERACTIONS

ЛАБОРАТОРИЯ ТЕОРЕТИЧЕСКОЙ ФИЗИКИ

1969

E2 - 4370

M.A.Markov

FORM FACTORS AND TOTAL CROSS SECTIONS OF WEAK AND ELECTROMAGNETIC INTERACTIONS*

* The report was presented at the CERN-JINR Seminar on the perspectives in high energy physics, in Riga (June, 1967).

In my report I would like to touch upon possible effects of the form factors, arising as a result of strong interactions, on the total cross sections of weak and electromagnetic processes. In particular, I shall speak about the effects of inelastic reactions of the type

$$\nu_\mu + n \to p' + \mu^- + \ldots$$

$$e^- + e^+ \to p + \tilde{\tilde{p}} + \ldots.$$

$$\gamma + p \to p + \Omega^- + \tilde{\tilde{\Omega}}^- + \ldots.$$

$$e + p \to e' + p' + \ldots.$$

$$\nu_\mu + z \to z' + \mu^+ + \mu^- + \nu_\mu' + \ldots. \qquad \text{etc.}$$

At the same time, I would like to use this occasion to make some general statements (however not grounded theoretically, as yet) concerning the total cross sections of such reactions induced by weak and electromagnetic interactions. As is known, at high energies the form factors of strong interactions weaken the energy dependence of elastic and quasielastic weak and electromagnetic processes as compared with the calculated cross sections in which the form factors are not taken into account, i.e. as compared with the cross sections of "point" particles. At the same time the strong interactions, which give rise to form factors, at extremely high energies lead to the appearance of an infinite number of new reaction channels. Decreasing the cross sections of elastic weak and electromagnetic processes the strong interactions tend as if to compensate this decrease at the expense of the total cross sections.

The question arises as to to what extent these total cross sections in their magnitude and energy dependence may approach the corresponding cross sections for weak and electromagnetic processes calculated in the approximation of point particles. It seems to me that there must exist certain general theorems and I would like to formulate a working hypothesis of the intuitive character concerning such theorems.

We denote the cross section of a given weak or electromagnetic interaction of point particles by σ_0. Here we imply the processes of the type

$$\nu_\mu + n \to p + \mu^- ; \quad p + e \to p' + e' ; \quad p + \tilde{\tilde{p}} \to e^+ + e^-$$

$$\gamma + p \to p + w^+ + w^- \quad ; \quad \gamma + p \to p + q + \tilde{\tilde{q}}$$

etc.

The total cross sections for given initial states, taking into account the form factors and the hadron production, are denoted by σ_{tot}^{form}. Now the hypothesis which I would like to formulate is represented by the relation

$$\sigma_{tot}^{form} \underset{E_0 \to \infty}{\gtrsim} \sigma_0 \; . \qquad (1)$$

May be such a general theorem does not exist and this intuition is of a purely subjective character. As a matter of fact, these considerations were made several years ago/1/ and after that some experimental facts/2/ and theoretical arguments /3/ appeared which are capable of giving a certain support to the hypothesis about the existence of such a theorem.

It is known that the cross section σ_0 calculated for the process

$$n + \nu_\mu \to p + \mu^- \quad (2)$$

increases linearly with energy in the Lab. system.

According to the CERN experiments the elastic cross section (2) becomes constant at $E_\nu \approx 1$ GeV. Yet, it is also known, according to the CERN data, that the total cross section for the process

$$n + \nu_\mu \to p + \mu^- + \dots \quad (3)$$

at least, increasing again linearly with energy

$$\sigma_{tot}^{form} \geq \approx E_\nu .$$

Underground experiments with neutrino flux in cosmic rays have shown that the cross section continues to increase with energy at least, up to 10^{11} eV.

An interesting result in this sense was obtained in a recent theoretical paper of J.D.Bjorken/3/ on the total cross section for the annihilation of an electron-positron pair into hadrons at high energies. A rather trivial example may be given when σ_{tot}^{form} is beforehand known to be larger than σ_0 .

In the electron-neutron scattering there arises a direct electric interaction of particles, only if the strong interactions are taken into account. Processes of the type

$$n + e \to p + \pi^- + e' \quad (5)$$

which are due to the strong interaction, contribute also to the corresponding total cross section.

A certain primitive model of the form factors in question is the electron cloud of a hydrogen atom.

It is known that if one considers the interaction of a bound electron (i.e. the electronic cloud) with photons and calculates the self energy of the electron using only the functions of the bound state, then for the electron self energy one obtains a finite (nondivergent) value. (Blokhintsev /4/).

If the intermediate states include also the states of the continuous spectrum (i.e. all the "inelastic" processes are taken into account), then there arises the same divergence as in the case of the point electron.

At present we are trying to find more general theoretical arguments which would give grounds for the above point of view on the inelastic interactions. For the time being we make the statement formulated as a working hypothesis and consider some its consequences.

From the point of view of this hypothesis of most interest are the reactions with large momentum transfer, when there is a strong energy dependence of the cross section, if the interaction is assumed to be a point one.

For instance, if the hyperon Ω^- has really spin 3/2 then the cross section for pair production $\Omega^- + \tilde{\Omega}^-$ by gamma quanta on a point Coulomb centre of charge z has (as was shown by A.Komar /5/), the form

$$\sigma \approx z^2 r_0^2 \alpha \left(\frac{E_\gamma}{m_\Omega}\right)^6 10^{-2} \; ; \; r_0 = \frac{e^2}{m_\Omega c^2} .$$

The account of the nuclear form factor change strongly the energy dependence

$$\sigma \approx z^2 r_0^2 \alpha \left(\frac{E_\gamma}{m_\Omega}\right)^3 \left(\frac{q_{max}}{M_\Omega}\right)^3 .$$

If

$$m_\Omega \cong 2 M_p , \qquad r_0 \approx 10^{-16} \text{cm}$$

then

$$\sigma_{\gamma p \Omega} : \quad \gamma + p \to p + \Omega^- + \tilde{\Omega}^-$$

in the Lab. system

$$\sigma_{\gamma p \Omega} \approx 10^{-2} \alpha r_0^2 \left(\frac{E_\gamma}{m_\Omega}\right)^3 \left(\frac{M_p}{2 m_\Omega}\right)^3$$

at

$$E_\gamma = 20 M_p \; ; \; \sigma^0_{\gamma p \Omega} \approx 0.3 \cdot 10^{-33} \text{ cm}^2 .$$

If $E_{\gamma} \approx 20 M_p$ is high enough for the "total" inelastic process

$$\gamma + p \to p + \Omega^- + \tilde{\tilde{\Omega}}^- + \ldots .$$

then

$$\sigma^{\text{form}}_{\text{tot}} \geq 10^{-33} \text{ cm}^2 .$$

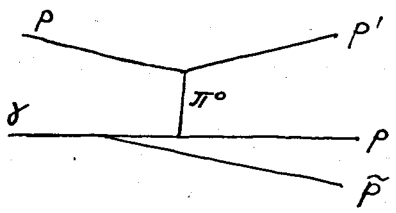
We may remind that for purely electromagnetic process $\gamma + p \to p + \tilde{\tilde{p}} + p$

$$\sigma_0 \approx 10^{-33} \text{ cm}^2.$$

According to the DESY data

$$\sigma_0 \approx 10^{-31} \text{ cm}^2.$$

This may be interpreted as follows: in the diagram



the momentum is transferred to the proton by means of π^0 . In other words, due to the action of the strong interactions in the intermediate state, the electromagnetic effect of nucleon pair production increases by two orders.

If Ω^- has spin 3/2 then for photoproduction of $\Omega^- + \tilde{\tilde{\Omega}}^-$ the cross section may be expected to be about 10^{-31} cm in the region $E_{\gamma} \approx 20 M_p$.

At higher gamma quantum energies (e.g. $E_{\gamma} \approx 40 M_p$) the cross section for $\Omega^- + \tilde{\tilde{\Omega}}^-$ pair production may turn out to be larger than that for nucleon-antinucleon pair production.

I have pointed to this reaction since it is also of interest independently of the philosophy presented above. This large increase of the cross section for production of high-spin particles, is of a special interest, in itself.

The strong energy dependence facilitates the search for pairs of such particles by means of high energy beams.

It is possible that the search for high spin hyperons (e.g. 5/2 and 7/2) may be of interest in cosmic-ray physics.

Returning to our hypothesis concerning inelastic processes we may note that the above considerations might be extended to the production of quarks

$$\gamma + p \to p + q + \tilde{\tilde{q}} + \ldots$$

The cross section of this process in high energy limit might approach or be even larger than the electromagnetic one

$$\gamma + p \to p + q + \tilde{\tilde{q}}$$

calculated for point particles. The same may be valid for the production of intermediate boson pairs.

Analogously we may expect a certain increase of the cross section of noncoherent production of $\mu^+\mu^-$ pairs on nucleons

$$\nu_\mu + z \to z' + \mu^+ + \mu^- + \nu_\mu + \ldots .$$

The noncoherent production may give even larger contribution than the coherent one, for example on lead. Even in this case it is doubtful that the cross section for $E_\nu \approx 10$ GeV on lead would essentially exceed 10^{-40} cm^2. Apparently, a corresponding experiment will require that the proton beam intensity be larger than 5.10^{12} proton/sec. This effect is of interest of principle since it answers the question whether the direct interaction $(\nu\mu)(\nu\mu)$ exists or not.

To my mind the investigation of the process

$$\nu_\mu + p \to p + e^+ + e^- + \nu_\mu$$

is of the same interest as the search for the process $\nu_\mu p \to \nu_\mu' p'$ which relates to the existence of the so-called neutral currents in weak interactions.

The search for $(\nu_\mu e)(\nu_\mu e)$ interaction has some advantage since in this case the cross sections may be larger by two orders.

References

1. M.A.Markov. "Neutrino", Preprint P-1269, p.54, Dubna (1963).
2. M.A.Markov. "Neutrino" , Publishing House "Nauka",Moscow, p.81 (1964).
3. J.D.Bjorken. Phys. Rev., 148, 1987 (1966).
4. D.I.Blokhintsev. Report on the Seminar in the Lebedev Physical Institute of the Academy of Science of the USSR, 1938, Published in "Collected Scientific papers", vol. 2, p.333. P 252 , Dubna, 1958.
5. A.Komar. Nuclear Physics, 9, 56 (1958).

Received by Publishing Department
on March 21 , 1969.