SOVIET PHYSICS JETP VOLUME 15, NUMBER 5 NOVEMBER, 1962

THE ROLE OF THE BIPION IN SINGLE PION PRODUCTION IN NUCLEON-NUCLEON COLLISIONS

L. L. NEMENOV, L. D. SOLOV'EV, and D. I. KHOMSKIĬ

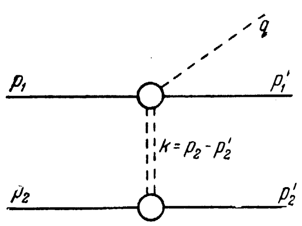
Joint Institute for Nuclear Research

Submitted to JETP editor December 9, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **42**, 1283-1284 (May, 1962)

The contribution of the "bipion" diagram to the differential cross sections for the process $N + N \to \pi + N + N$ is calculated. It is found that, for energies up to 1.5 BeV, the contribution of the "bipion" diagram to the differential cross sections is less than 10% of the contribution due to the single meson diagram.

HITHERTO only single meson diagrams have been considered in calculations of pion production in NN collisions.[1] A determination of the contribution of the two meson diagram (see the figure) to this process is of interest.



We limit ourselves to energies of the nucleons in flight from 600 to 1500 MeV. Then the energy of the nucleon and meson in the final state is close to the energy of the (3, 3) resonance, and it is sufficient to consider their interaction only in the resonance state. It follows, from conservation of isotopic spin at both vertices of the diagram, that the particles in the intermediate state must here have isotopic spin $T = 1$. At an energy close to 4.7μ (μ denotes the mass of the π meson) there is resonance interaction between two mesons in the state with $T = J = 1$, and it is possible to assume that the resonance state plays an essential role in two meson exchange for the energies under consideration. We therefore consider the exchange of two mesons that are in resonance interaction (bipion exchange).

In this connection, we have to deal with a narrow resonance; therefore the term corresponding to the lower vertex of the diagram reduces to a constant, and that corresponding to the upper vertex reduces to a four-particle amplitude. With respect to isotopic and transformation properties, the vertices with a bipion are equivalent to the isotopic-vector parts of vertices with a virtual photon. Therefore the following expression ($\hbar = c = \mu = 1$) corresponds to the lower vertex of the diagram:

$$\bar{u}(p_2')\,\tau_\alpha\,\{\mathscr{E}\gamma^n + \mathfrak{M}\tfrac{1}{2}[\gamma^n,\ \gamma k]\}\,u(p_2) \qquad (1)$$

($\mathscr{E}$ and $\mathfrak{M}$ act as the isotopic-vector charge and magnetic moment of the nucleon), and the virtual photoproduction amplitude (for an isotopic-vector transition), the expression for which is known[2] for the energies under consideration, corresponds to the upper vertex. Considering (in the virtual photoproduction amplitude) only the magnetic dipole transition into the (3, 3) state (and making the substitution $F_e^V\tau_3 \to \mathscr{E}\tau_\alpha$, $F_\mu^V\tau_3 \to \mathfrak{M}\tau_\alpha$, where the $F_{e,\mu}^V$ are isotopic-vector nucleon form factors), we obtain an expression for the upper vertex of the diagram:

$$(\delta_{q\alpha} - \tfrac{1}{3}\tau_q\tau_\alpha)\,\chi^+(p_1')\,\{i(\sigma\mathbf{k})\,\mathbf{q} - i(\mathbf{kq})\,\sigma - 2\,[\mathbf{qk}]\}\,\chi(p_1)$$
$$\times\sqrt{\pi}\,(\mathscr{E} + 2M\,\mathfrak{M})\,\omega e^{i\delta_{33}}\sin\delta_{33}/fM^2q^3 \qquad (2)^*$$

(we are using the coordinate system for which $\mathbf{p}_1' + \mathbf{q} = 0$, $\omega = p_1'^0 + q^0$; M is the nucleon mass, the χ are two-component spinors, $f^2 = 0.08$). $(m_B^2 - k^2)^{-1}$ corresponds to the bipion line in the diagram, where m_B is the mass of the bipion (the energy of the 2π resonance).

The scheme under consideration is equivalent to a resonance approximation in dispersion relations in k^2. It is possible to determine the constants $\mathscr{E}$ and $\mathfrak{M}$ by applying the same scheme to elastic πN scattering and to the nucleon form factors and by utilizing the experimental data for these processes.[3,4]

The reaction $p + p \to \pi^+ + p + n$ was specifically considered, and the differential cross sections for fast protons scattered through small angles

---

*$(\sigma\mathbf{k}) = \boldsymbol{\sigma}\cdot\mathbf{k}$, $[\mathbf{qk}] = \mathbf{q}\times\mathbf{k}$.

were calculated. In these cross sections the single diagram [1] gives the major contribution when p_1 is the momentum of the proton in flight, p_2 is the momentum of the target proton, p_1', p_2', and q denote the momenta of the final proton, neutron, and π^+ meson, respectively. Considering the essential terms in (1), we obtain an expression for the bipion contribution to the indicated process:

$$
\begin{aligned}
&[\sqrt{2\pi}\,(\mathcal{E} + 2M\mathfrak{M})^2\,\omega e^{i\delta_{33}}\sin\delta_{33}/fM^2q^3] \\
&\quad\times|[(p_2^0 + M)(p_2'^0 + M)/4M^2]^{1/2} \\
&\quad\times\chi^+(p_1')\{2\,[\mathbf{qk}] + i\,(\mathbf{kq})\,\sigma - i\,(\sigma\mathbf{k})\,\mathbf{q}\}\,\chi(p_1) \\
&\quad\times\chi^+(p_2')\,\sigma\left(\frac{\sigma\mathbf{p}_2}{p_2^0 + M} + \frac{\sigma\mathbf{p}_2'}{p_2'^0 + M}\right)\chi(p_2)\,(m_B^2 - k^2)^{-1}. \qquad (3)
\end{aligned}
$$

The values [3] $(\mathcal{E} + 2M\mathfrak{M})^2 = 466$, $m_B^2 = 22.4$ were used for the constants; we used Höhler's formulas [5] for the δ_{33} phase shift.

The cross sections calculated with the aid of (3) were compared with the contribution due to the corresponding single meson exchange diagram (interference between the bipion and one meson diagrams vanishes for unpolarized nucleons).

It was found that the relative contribution of the bipion diagram increases monotonically with increase of initial energy; however, in the region up to 2 BeV, it does not exceed 9 to 10% of the contribution due to the single meson exchange diagram. The bipion exchange calculation does not introduce any characteristic features into the angular and energy distributions of the scattered protons. Therefore a systematic calculation of the contribution of one meson diagrams and its comparison with experiment is of interest.

In conclusion, we express our gratitude to L. M. Soroko for useful discussions, to L. I. Lapidus for his interest in the work, and to Kim Ze Phen for carrying out the numerical computations.

[1] J. Iizuka and A. Klein, Phys. Rev. **123**, 669 (1961).

[2] L. D. Solov'ev and G. N. Tentyukova, Preprint, Joint Inst. Nuc. Res., R-384, 1961.

[3] L. D. Solov'ev and Ch'en Tsun-mo, JETP **42**, 526 (1962), Soviet Phys. JETP **15**, 369 (1962).

[4] Bowcock, Cottingham, and Lurie, Nuovo cimento **16**, 918 (1960); **19**, 142 (1961).

[5] G. Höhler, Nuvo cimento **16**, 585 (1960).

Translated by H. H. Nickle
211