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DISTINCTION BETWEEN THE MODEL OF VECTOR DOMINANCE AND THE MODEL OF OF OSCILLATIONS

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Различие между моделью векторной доминантности
и моделью осцилляций

На примере $\gamma \to \rho^0$ рассматривается различие между моделью векторной доминантности и моделью осцилляций. Показано, что вероятности переходов в этих случаях различаются на фактор 2. Также обсуждается причина возникновения этих схем переходов.

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Distinction between the Model of Vector Dominance
and the Model of Oscillations

The distinction between the model of vector dominance and the model of oscillations is considered on the example of $\gamma \to \rho^0$ transitions. It is shown that transition probabilities in these cases differ by a factor of 2. The physical reason of these transition schemes is also discussed.

The investigation has been performed at the Veksler and Baldin Laboratory of High Energy Physics, JINR.

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INTRODUCTION

Usually it is supposed that in the model of vector dominance [1, 2] there is mixing between gamma quanta and rho meson (i.e., mixings of vector fields of these particles). Since masses of gamma quanta (m_γ) and rho meson (m_ρ) significantly differ, this mixing (transition) in vacuum can be only virtual. To see these mixings (transitions), it is necessary to carry out a transition of the corresponding particle on mass shell via quasi-elastic interaction of γ quanta. Work [2] has shown that there are other models of vector dominance: $\gamma - Z^0$, $\rho^0 - Z^0$.

In principle, this process can be accompanied by oscillations as in the neutrino case [3, 4] (see also references in [3]). This work considers possible schemes of mixings and oscillations of γ quanta and ρ^0 meson and the physical motivation of these schemes.

1. $\gamma \leftrightarrow \rho^0$ MIXINGS AND VECTOR DOMINANCE MODEL

The Lagrangian of the interaction, for example, of proton p with gamma, can be written down in the following form:

$$\mathcal{L} = \begin{pmatrix} \bar{p} & \bar{p} \end{pmatrix} \gamma^\alpha V \begin{pmatrix} p \\ p \end{pmatrix}, \tag{1}$$

$$V = \begin{pmatrix} eA_\mu & 0 \\ 0 & G\rho^0_\mu \end{pmatrix}. \tag{2}$$

If we expand this expression, then we have

$$\mathcal{L} = \bar{p}\gamma^\alpha p \left(eA_\mu + G\rho^0_\mu\right), \tag{3}$$

where e is a coupling constant of electromagnetic interactions and G is a coupling constant of strong interactions.

Let us consider mixings which appear in the vector dominance model [1]. This model takes into account the mixing between vector field V_μ of strong interacting ρ_μ^0 meson and vector field A_μ of electromagnetic interactions. When the strong and electromagnetic interactions are switched on, primary fields

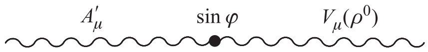
$$\begin{pmatrix} V_\mu \\ A_\mu \end{pmatrix} \tag{4}$$

are mixed [2] and we get

$$\begin{pmatrix} V'_\mu \\ A'_\mu \end{pmatrix} = U \begin{pmatrix} V_\mu \\ A_\mu \end{pmatrix} \equiv \begin{pmatrix} \cos\varphi & -\sin\varphi \\ \sin\varphi & \cos\varphi \end{pmatrix} \begin{pmatrix} V_\mu \\ A_\mu \end{pmatrix}, \tag{5}$$

$$\begin{aligned} A'_\mu &= \cos\varphi A_\mu - \sin\varphi V_\mu, \\ V'_\mu &= \cos\varphi V_\mu + \sin\varphi A_\mu. \end{aligned} \tag{5'}$$

The first term of the expression (5) can be represented in the form of the following diagram:



At the inverse transformation of (5) we obtain

$$\begin{aligned} A_\mu &= \cos\varphi A'_\mu + \sin\varphi V'_\mu, \\ V_\mu &= \cos\varphi V'_\mu - \sin\varphi A'_\mu. \end{aligned} \tag{6}$$

It is obvious that the coupling constant of A'_μ or V'_μ must be the same, then substituting the expression (6) for the expression (3), we get

$$e\cos\varphi = G\sin\varphi, \tag{7}$$

or

$$\sin\varphi = \frac{e}{\sqrt{e^2+G^2}}, \quad \cos\varphi = \frac{G}{\sqrt{e^2+G^2}}. \tag{8}$$

ρ^0 meson consists of u and d quarks: $\rho^0 = \frac{1}{\sqrt{2}}(\bar{u}u - \bar{d}d)$, which have electric charges; therefore, this state will participate in electromagnetic interactions. Besides, at transition of γ quanta to ρ meson in vacuum the mass shell cannot change $m_\gamma^2 = m_\rho^2 = 0$, then there is no violation of gauge invariance. As stressed above, γ-to-ρ^0 transition must be virtual. So, transition of γ gamma into ρ^0 meson will be realized via the interaction vertex.

Probability P of transition of γ quanta into ρ^0 meson state is as follows:

$$P(\gamma \to \rho^0) = \sin^2 \varphi, \tag{9}$$

$$P(\gamma \to \rho^0) \simeq \frac{e^2}{G^2}, \quad G \gg e, \tag{9'}$$

and probability P' that γ quanta will remain on its eigenstate is

$$P'(\gamma \to \rho^0) = 1 - P(\gamma \to \rho^0), \tag{10}$$

In order to carry out the real transition of $\gamma \to \rho^0$, the γ quanta must participate in a quasi-elastic process for its transition on mass shell of ρ^0 meson [1, 2, 5].

2. HOW CAN $\gamma \leftrightarrow \rho^0$ MIXINGS APPEAR WITH SUBSEQUENT OSCILLATIONS?

At present it is supposed that neutrino oscillations have been observed [3]. Let us consider an analogous mechanism for γ and ρ^0 transitions, i.e., γ and ρ^0 oscillations. Then we will come to a comparison of the obtained transition probability and the transition probability obtained in the vector dominance model.

To solve this issue, we have to introduce $\gamma(A_\mu), \rho^0(V_\mu)$ states dependent on time. For this aim we rewrite the expression (6) in the following form, introducing the time dependence:

$$\begin{aligned} A_\mu(t) &= \cos\varphi A'_\mu(t) + \sin\varphi V'_\mu(t), \\ V_\mu(t) &= \cos\varphi V'_\mu(t) - \sin\varphi A'_\mu(t), \end{aligned} \tag{10}$$

or

$$\begin{pmatrix} A_\mu(t) \\ V_\mu(t) \end{pmatrix} = \begin{pmatrix} \cos\varphi & +\sin\varphi \\ -\sin\varphi & \cos\varphi \end{pmatrix} \begin{pmatrix} A'_\mu(t) \\ V'_\mu(t) \end{pmatrix}. \tag{10'}$$

Then taking into account that this process proceeds in vacuum, we can write the following:

$$A'_\mu(t) = A'_\mu(0) \exp(-iE_1 t), \quad V'_\mu(t) = V'_\mu(0) \exp(-iE_2 t). \tag{11}$$

Now we have to stress one peculiarity which distinguishes the above mechanism from the mechanism being considered now. In the above scheme the mass matrix had the following form:

$$\begin{pmatrix} m_A^2 & \mu^2 \\ \mu^2 & m_V^2 \end{pmatrix} = \begin{pmatrix} 0 & 0 \\ 0 & m_\rho^2 \end{pmatrix}, \tag{12}$$

where non-diagonal terms of the mass matrix are equal to zero. In this scheme it is supposed that the mass matrix is non-diagonal:

$$\left(\begin{array}{cc} m_A^2 & \mu^2 \\ \mu^2 & m_V^2 \end{array}\right) = \left(\begin{array}{cc} 0 & m_{12} \\ m_{21} & m_\rho^2 \end{array}\right) = U^{-1}\left(\begin{array}{cc} m_{A'}^2 & 0 \\ 0 & m_{V'}^2 \end{array}\right) U, \qquad (13)$$

and after diagonalization we obtain the following mass matrix:

$$\left(\begin{array}{cc} m_{A'}^2 & 0 \\ 0 & m_{V'}^2 \end{array}\right). \qquad (14)$$

These states are new mass eigenstates after mixings (i.e., new mass states appear). This is a fundamental distinction between these schemes.

Substituting (11) into (10), we obtain

$$\begin{aligned} A_\mu(t) &= \cos\varphi A'_\mu(0)\exp(-iE_1 t) + \sin\varphi V'_\mu(0)\exp(-iE_2 t), \\ V_\mu(t) &= \cos\varphi V'_\mu(0)\exp(-iE_2 t) - \sin\varphi A'_\mu(0)\exp(-iE_1 t). \end{aligned} \qquad (15)$$

Then using

$$\begin{aligned} A'_\mu(0) &= -\sin\varphi V_\mu(0) + \cos\varphi A_\mu(0), \\ V'_\mu(0) &= \cos\varphi V_\mu(0) + \sin\varphi A_\mu(0), \end{aligned}$$

we can rewrite the expression (15) in the following form:

$$\begin{aligned} A_\mu(t) &= \left[e^{-iE_1 t}\cos^2\varphi + e^{-iE_2 t}\sin^2\varphi\right] A_\mu(0) + \\ &\qquad + \left[e^{-iE_1 t} - e^{-iE_2 t}\right]\sin\varphi\cos\varphi V_\mu(0), \\ V_\mu(t) &= \left[e^{-iE_1 t}\sin^2\varphi + e^{-iE_2 t}\cos^2\varphi\right] V_\mu(0) + \\ &\qquad + \left[e^{-iE_1 t} - e^{-iE_2 t}\right]\sin\varphi\cos\varphi A_\mu(0). \end{aligned} \qquad (16)$$

The probability that state $A_\mu(0)$ produced at the time $t = 0$ within time t will be transformed into state $V_\mu(t)$ is given by the following expression:

$$\begin{aligned} P(A_\mu(t) \to V_\mu(0)) &= \left|(V_\mu(0) \cdot A_\mu(t))\right|^2 = \\ &= \frac{1}{2}\sin^2 2\varphi\left[1 - \cos(E_1 - E_2)t)\right] = \\ &= \sin^2 2\varphi \sin^2((E_1 - E_2)t/2), \end{aligned} \qquad (17)$$

$$\begin{aligned} P(V_\mu(t) \to A_\mu(0)) &= \left|(A_\mu(0) \cdot V_\mu(t))\right|^2 = \\ &= 1 - \frac{1}{2}\sin^2 2\varphi\left[1 - \cos(E_1 - E_2)t)\right] = \\ &= 1 - \sin^2 2\varphi\, \sin^2((E_1 - E_2)t/2), \end{aligned} \qquad (18)$$

where the expression (16) is used.

If we average the expression $\overline{\sin^2((E_1 - E_2)t/2)} = 1/2$ over time, then we obtain the following:

$$\bar{P}(A_\mu(t) \to V_\mu(0)) = \frac{1}{2}\sin^2(2\varphi), \tag{19}$$

$$\bar{P}(V_\mu(t) \to A_\mu(0)) = 1 - \frac{1}{2}\sin^2(2\varphi). \tag{20}$$

Then using the expression (8), we obtain

$$\bar{P}(A_\mu(t) \to V_\mu(0)) = \frac{1}{2}4\left(\frac{eG}{e^2 + G^2}\right)^2 = 2\frac{e^2G^2}{(e^2 + G^2)^2}. \tag{21}$$

If $G \gg e$, then we arrive at the following expression:

$$\bar{P}(A_\mu(t) \to V_\mu(0)) \simeq 2\frac{e^2}{G^2}. \tag{22}$$

The value obtained in this case is twice as large as that obtained in the vector dominance model where direct $\gamma(A_\mu) \leftrightarrow \rho^0(V_\mu)$ transitions are realized without intermediate A'_μ, V'_μ states.

CONCLUSION

Thus, by using the example of $\gamma \to \rho^0$ transitions, the distinction between the above models, of vector dominance and of oscillations, has been considered. It has been shown that the transition probabilities in these cases differ by a factor of 2. The physical reasons for these mixings (oscillations) schemes have also been discussed.

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