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The methods of determining the intrinsic parities of particles in reactions $e^+ e^- \to a_1 + a_2$ are discussed. The methods are based on invariance with respect to rotations and reflections and on conservation of helicity of ultrarelativistic electrons.

1. One of the main problems in high energy physics in the experiment to determine intrinsic parities (e.g. [1-3]). A significant progress has recently been made in experiments on colliding electron-positron beams. In this connection it is interesting to consider the methods of determining the intrinsic parity in the reactions of the form

$$e^+ e^- \to a_1 + a_2 \qquad (1)$$

A case of polarized initial particles is worth considering since radiation on prolonged motion in the storage ring magnetic field may produce a transversal polarization of the electron (counter-field) and the positron (along-field) [4,5]. Only general requirements of invariance with respect to rotations and reflections, and conservation of helicity of ultrarelativistic electrons are to be used [6-8].

Let $E, \vec{P}$ be the energy and the momentum of the initial electron $(E \gg mc)$; $\vec{q}$ the momentum of the particle a_1 in cms; $\vec{\zeta}^{(1)}, \vec{\zeta}^{(2)}$ the polarization vectors of electron and positron; $J_i; I_i$ the spin and intrinsic parity of the particle a_i. The direction of the momentum $\vec{P}$ is chosen as the axis z. The axis x is directed along the normal to the reaction plane (the plane formed by the vectors $\vec{P}$ and $\vec{q}$).

We will confined ourselves to considering the cases where the summation is performed over the polarizations of the final particles or where the final particles have certain spin projections on the direction of the normal to the reaction plane. The expression for the reaction differential cros-sections (1) σ (accurate to the terms $\sim m_e/E$) on arbitrary polarization of the initial particles will be written in the form

$$\sigma = a(\theta)\left[1+\zeta_3^{(1)}\zeta_3^{(2)}\right]+b(\theta)\left(\zeta_1^{(1)}\zeta_1^{(2)}-\zeta_2^{(1)}\zeta_2^{(2)}\right) \qquad (2)$$

where

$$a(\theta)=\frac{1}{2}\left|<\vec{q},f|S|(+),(+)\vec{P}>\right|^2$$
$$b(\theta)=\frac{1}{2}<\vec{q}\,f|S|(+),(+)\vec{P}><\vec{q},f|S|(-),(-),\vec{P}>^* \qquad (3)$$

In (3) the value $<\vec{q},f|S|(+),(+)\vec{P}>(<\vec{q},f|S|(-),(-)\vec{P}>)$ is the matrix element of process (1) with a proper normalization for the case where both initial particles are polarized along the axis Z (counter the axis Z)

When deriving (2) and (3) the conservation of helicity of ultrarelativistic electrons and invariance with respect to reflection in the reaction plane are used.

2. Let us consider process (1) in a one-photon channel for the case $J_1 = J$, $J_2 = 0$ It should be noted that, if $J_1 = J_2 = 0$, process (1) takes place in the one-photon channel in the case only where the value $I = I_1 I_2$ is positive; the respective expression for the process crosssection is found in ref.[9]. The methods of determining the parity for the case, where in the final state there are n particles with a 0 spin whose momenta are in the reaction plane are found in [8]. In virtue of the one-photon nature of approximation the spin projection of the particle a_1 on the direction of its momentum can assume the values $M = \pm 1, 0$ only. According to the results of refs. [9-11] the relationships

$$a(\theta) = 2G_1 - G_2 \sin^2\theta$$
$$b(\theta) = -G_2 \sin^2\theta \qquad (4)$$

may be obtained for the differential cross-section summed up

over the particle a_1 polarizations. In (4) $\cos\theta = \frac{\vec{P}\vec{q}}{|\vec{P}||\vec{q}|}$ and G_1, G_2 are the functions of form-factors of the final particles.1)

Using (3,4), the one-photon nature of the channel and the invariance with respect to reflection of the axes y and z we obtain

$$G_2 = -\frac{1}{4}[1+\eta]F_1 + F_2$$
$$2G_1 - G_2 = \frac{1}{4}[1+\eta]F_1 + F_2 \qquad (5)$$

where

$$F_1 = |<\vec{q}, J, 0|S|(+),(-),\vec{P}>|^2 \quad (M=0,\ \theta=\frac{\pi}{2})$$
$$F_2 = |<\vec{q}, J, 1|S|(+),(+),\vec{P}>|^2 \quad (M=1,\ \theta=\frac{\pi}{2}) \qquad (6)$$
$$\eta = I(-1)^J$$

At

$$\eta = -1,$$
$$G_1 = G_2 = F_2, \qquad (7)$$

and the expression for the differential cross-section is of the form

$$\sigma = F_2\left[(1+\cos^2\theta)(1+\zeta_3^{(1)}\zeta_3^{(2)})-\sin^2\theta\left(\zeta_1^{(1)}\zeta_1^{(2)}-\zeta_2^{(1)}\zeta_2^{(2)}\right)\right] \qquad (8)$$

The check-up of the fulfilment of relationship (8), when examining the differential cross-section of the reaction, may be used as a method of determining the sign of the value η.

3. Let the particle a_1 be a photon, and $J_2 = 0$. In this case $M \neq 0$, $F_1 = 0$ and (8) takes place regardless the sign of the value I_2. For determining the value I_2 the final photon polarization should be measured in this case.

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1) The values G_1 and G_2 are in a simple manner related to the functions [illegible] and [illegible] in refs [9,11].

Making use of (2,3) and the invariance with respect to reflections in the reaction plane, the expression for the parameter ξ, determining the degree of linear polarization of the final photon, is obtained

$$\xi\bar{\sigma} = R(\theta)(1+\zeta_3^{(1)}\zeta_3^{(2)}) - I_2\sigma_0(\zeta_1^{(1)}\zeta_1^{(2)} - \zeta_2^{(1)}\zeta_2^{(2)})$$
$$\bar{\sigma} = \sigma_0(1+\zeta_3^{(1)}\zeta_3^{(2)}) - I_2 R(\theta)(\zeta_1^{(1)}\zeta_1^{(2)} - \zeta_2^{(1)}\zeta_2^{(2)}) \qquad (9)$$

where σ_0 is the reaction cross-section with nonpolarized particles, $\bar{\sigma}$ is the cross-section with polarized initial particles. The value $R(\theta)$ is determined by the dynamics of the process and is readily found from (3)[2]. By means of formulas (9) one easily obtains various relationships between the values observed, enabling one to determine I_2. Thus, for a particular case of colliding beams with transversal antiparallel polarizations of initial particles the value I_2 can be found, say, from the relationship

$$\frac{\xi_\perp\bar{\sigma}_\perp - \xi_\parallel\bar{\sigma}_\parallel}{\bar{\sigma}_\perp + \bar{\sigma}_\parallel} = I_2 \, |\vec{\zeta}^{(1)}||\vec{\zeta}^{(2)}| \qquad (10)$$

where $\xi_\perp$ ($\xi_\parallel$) is the degree of linear polarization of final photon for the case $\zeta_1^{(1)} = \pm|\vec{\zeta}^{(1)}|$, $\zeta_1^{(2)} = \mp|\vec{\zeta}^{(2)}|$ (for the case $\zeta_2^{(1)} = \pm|\vec{\zeta}^{(1)}|$, $\zeta_2^{(2)} = \pm|\vec{\zeta}^{(2)}|$), $\bar{\sigma}_\perp$, $\bar{\sigma}_\parallel$ are the reaction cross-sections with the same polarizations of initial particles.

4. Let us consider the case $J_1 = \frac{1}{2}$, $J_2 = \frac{1}{2}$

It will be shown that the expressions for the polarization vector projections of the particles a_1 and a_2 on the direction of the normal (P^1, P^2) are of the form

2) In the one-phton channel

$$I_2 R(\theta)/\sigma_0 = \sin^2\theta/(1+\cos^2\theta)$$

$$P^{1,2}\bar{\sigma} = N_{1,2}(\theta)(1+\zeta_3^{(1)}\zeta_3^{(2)}) - I N_{2,1}(\theta)(\zeta_1^{(1)}\zeta_1^{(2)} - \zeta_2^{(1)}\zeta_2^{(2)}),$$
$$\bar{\sigma} = \sigma_0(1+\zeta_3^{(1)}\zeta_3^{(1)}) - I K(\theta)(\zeta_1^{(1)}\zeta_1^{(2)} - \zeta_2^{(2)}\zeta_2^{(1)}). \qquad (11)$$

Here $I = I_1 I_2$; $N_{1,2}(\theta)$, $K(\theta)$ are determined by the dynamics of the process and are readily obtained from(3). The sense of the values σ_0, $\bar{\sigma}$ is the same as in item 3.

By means of (11) one easily obtains various relationships between the values observed, enabling one to determine I. For the case of cross antiparallel polarizations of initial particles, as in item 3, the value I can be found, say, from the relationship

$$\frac{(P^1)_\perp\bar{\sigma}_\perp - (P^1)_\parallel\bar{\sigma}_\parallel}{(P^2)_\perp\bar{\sigma}_\perp + (P^2)_\parallel\bar{\sigma}_\parallel} = I\,|\vec{\zeta}^{(1)}||\vec{\zeta}^{(2)}| \qquad (12)$$

If $|\vec{\zeta}^{(1)}| = |\vec{\zeta}^{(2)}| = 1$ then

$$(P^1)_\perp = I(P^2)_\perp \qquad (13)$$
$$(P^1)_\parallel = -I(P^2)_\parallel$$

If a_2 is an antiparticle with respect to a_1, then in this case invirtue of the CP invariance of the theory

$$N_1(\theta) = N_2(\theta); \qquad P^1 = P^2 \qquad (14)$$

If a_1, a_2 are a muon pair, then in virtue of conservation of helicity $N_{1,2}(\theta) \sim \mu/E$ where μ is the muon mass.

The intrinsic parity of particles in process (1) can also be found from the behaviour of the process cross-section at the threshold [12.]

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