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ЛАБОРАТОРИЯ ТЕОРЕТИЧЕСКОЙ ФИЗИКИ

Z.Kunszt, R.M. Muradyan, V.M. Ter-Atonyan

RESONANT SCATTERING OF LIGHT BY LIGHT

1970

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Резонансное рассеяние света на свете

Рассмотрено резонансное рассеяние света на свете за счет обмена C -четных π^0 и η мезонов. Полное сечение процесса $\gamma\gamma$ -рассеяния в резонансной точке $s = m_\pi^2$ равно $\sigma^\pi = \frac{16\pi}{m_\pi^2} \approx 1{,}1 \cdot 10^{-24}$ см^2. Предполагая 2% разрешение по энергии получим для сечения величину порядка $10^{-30} \approx 10^{-31}$ см^2. Показано, что сечение для реакции $\gamma\gamma \to \pi^+\pi^-$ около f(1260)-резонанса имеет величину 10^{-29} см^2.

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Resonant Scattering of Light by Light

Resonant scattering of light by light due to exchange of C -even mesons, such as π^0 and η, is considered. The total cross section for $\gamma\gamma$ -scattering at resonance point $s = m_\pi^2$ has the value $\sigma^\pi = \frac{16\pi}{m_\pi^2} \approx 1.1 \times 10^{-24}$ cm^2. Assuming 2% energy resolution, the cross section has the magnitude $10^{-30} \approx 10^{-31}$ cm^2. It is shown, that the cross section for the reaction $\gamma\gamma \to \pi^+\pi^-$ near f(1260) -resonance has the value 10^{-29} cm^2.

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Z.Kunszt, R.M. Muradyan, V.M. Ter-Atonyan

RESONANT SCATTERING OF LIGHT BY LIGHT

The fundamental process of $\gamma\gamma$ scattering was first considered by Vavilov/1/, but it has not been observed till now. Some years ago Harutynian et al./2/ have pointed out that using intense pulsed ruby laser with 1.78 eV photons and 6 GeV γ quanta from electron accelerator ($E_{om} \approx 7.7 \cdot 10^{-2}$ MeV) it may be feasible to observe the elastic scattering of γ -quanta by photons near forward direction if the value of the cross section for the reaction is in the region $\gtrsim 10^{-36} \frac{cm^2}{sterad}$ given by calculations using Q.E.D. Other types of experiments have been suggested in/3,4/ for both low and high energies. Further related non-linear quantum electrodynamic effects are discussed in the review article/5/. In all these papers the interest is first devoted to low c.m. energies ($E_{cm} < 1$ MeV) where the elastic scattering can be described taking into account only the electron-positron vacuum polarization and where these contributions have a maximum.

We notice that although the positronium exchange gives large resonant effect, the feasible bad energy resolution reduces its importance completely. At the top of the resonance peak the cross section is $\sigma \approx 2 \cdot 10^{-20} cm^2$, but assuming energy resolution 2% the average value turns out to be $\overline{\frac{d\sigma}{d\Omega}} \approx 6 \cdot 10^{-31} \frac{cm^2}{sterad}$. Compare it with the contributions coming from the electron loop $\left(\frac{d\sigma}{d\Omega}\right)^{loop} =$

$$(E = 0.5 \text{ MeV}, \theta = \frac{\pi}{2}) \approx 1.7 \cdot 10^{-32} \frac{cm^2}{sterad} .$$

In this paper we discuss the possibility of the resonant photon-photon scattering due to hadronic vacuum polarization. We want to stress that the exchange of the C -even pseudoscalar mesons π^0 and η

$$\gamma + \gamma \to \pi^0 \to \gamma + \gamma \tag{1}$$

$$\gamma + \gamma \to \eta \to \gamma + \gamma \tag{2}$$

can enhance the cross section considerably at the c.m. energies, where the photon-photon scattering takes place due to the real production of the intermediate mesons. Using Breit-Wigner resonance formula, the differential cross section (1) and (2) will be isotropic and exhibits the usual form

$$\frac{d\sigma}{d\Omega} = \frac{s^3}{64 \cdot 16\pi^2} \frac{|G(s)|^2}{(s-m)^2 + m^2\Gamma^2}, \tag{3}$$

where for the reaction (1) the formfactor $G_\pi(s)$ is connected with the width of π^0 at $s = m_\pi^2$ as

$$\Gamma_{\pi \to 2\gamma} = \frac{m_\pi^3}{64\pi} | G_\pi (m_\pi^2)|^2. \tag{4}$$

The differential and the total cross sections at the resonance energies are

$$\left(\frac{d\sigma}{d\Omega}\right)^\pi_{res} = \frac{4}{m_\pi^2} = 0{,}9 \cdot 10^{-25} \frac{cm^2}{sterad}; \quad \sigma^\pi_{res} = \frac{16\pi}{m_\pi^2} = 1{,}1 \cdot 10^{-24} cm^2 \tag{5a}$$

$$\left(\frac{d\sigma}{d\Omega}\right)^\eta_{res} = \frac{4}{m_\eta^2} = 0{,}52 \cdot 10^{-26} \frac{cm^2}{sterad}; \quad \sigma^\eta_{res} = \frac{16\pi}{m_\eta^2} = 0{,}7 \cdot 10^{-25} cm^2. \tag{5b}$$

The average cross section near the resonance, for the energy resolution $\Delta\Gamma \ll \Delta \ll m$, is

$$\overline{\frac{d\sigma}{d\Omega}} = \frac{1}{4m\Delta}\int_{m^2-2m\Delta}^{m^2+2m\Delta}\frac{d\sigma}{d\Omega}\,ds \approx \frac{\pi}{4}\,\frac{\Gamma}{\Delta}\left(\frac{d\sigma}{d\Omega}\right)_{res}. \qquad (6)$$

Assuming 2% energy resolution, we obtain

$$\left(\overline{\frac{d\sigma}{d\Omega}}\right)^{\pi} \approx 0{,}37\cdot 10^{-30}\ \frac{cm^2}{sterad} \qquad (7a)$$

$$\left(\overline{\frac{d\sigma}{d\Omega}}\right)^{\eta} \approx 0{,}78\cdot 10^{-30}\ \frac{cm^2}{sterad}\ . \qquad (7\,b)$$

Compare the contribution of the electron-positron vacuum polarization at $s=m_\pi^2$, $\left[\left(\frac{d\sigma}{d\Omega}\right)^{loop}_{\theta=\frac{\pi}{2},\ s=m_\pi^2} = 4{,}2\cdot 10^{-31}\left(\frac{2m_e}{m_\pi}\right)^2 \approx 0.46\cdot 10^{-36}\frac{cm^2}{sterad}\right.$ which is by six order smaller than (7).

In a real experiment with energy resolution better than 2% one needs at least $10^{30}\ cm^{-1}h^{-1}$ luminosity for the clashing γ-beams which is well inside the borderline of the region where $\gamma\gamma$ scattering experiments can be feasible/4/.

It is well known that the resonant effects play important role in the experiments where e^+e^- colliding beams are used to study the vector meson resonances. More likely the observation of the process

$$\gamma + \gamma \rightarrow \text{hadrons}^{x/} \qquad (8)$$

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x/The crossed reaction is discussed in/6/ and/7/.

will provide us a very clean way to investigate the C -even meson resonances such like ϵ , f , f′ etc. The simplest process is the 2π production. Near the f(1260) resonance x/ e.q. ($E_{cm} \approx 630$ MeV), the cross section has the usual Breit-Wigner form

$$\frac{d\sigma}{d\Omega} = \frac{75}{16\, m_f^2} \, \frac{\Gamma_{f \to 2\gamma} \; \Gamma_{f \to \pi^+\pi^-}}{(2E-m)^2 + \frac{1}{4}\Gamma^2_{tot}} \sin^4\theta \tag{9}$$

$$\sigma(E) = \frac{10\pi}{m_f^2} \, \frac{\Gamma_{f \to 2\gamma} \; \Gamma_{f \to \pi^+\pi^-}}{(2E-m)^2 + \frac{1}{4}\Gamma^2_{tot}} , \tag{10}$$

$\Gamma_{f\to 2\pi}$ is known from experiment ($\approx$ 150 MeV); $\Gamma_{f\to 2\gamma}$ can be estimated using 2^+-meson dominance and universality hypothesis for the energy-momentum tensor and vector meson dominance for the photons. Interaction Lagrangian for the $f\gamma\gamma$ and $f\pi\pi$ vertices reads:

$$L_{int}(x) = \frac{g}{m_f} G_{\mu\nu} F^{\mu\lambda} F^{\nu}_{\lambda} + \frac{g'}{m_f^3} G_{\mu\nu} \partial^{\rho} F^{\mu\lambda} \partial_{\rho} F^{\nu}_{\lambda} + \\ + \frac{f}{m_f} G_{\mu\nu} \partial^{\mu} \vec{\pi} \, \partial^{\nu} \vec{\pi} , \tag{11}$$

where $G_{\mu\nu}$ is the 2-spin field operator, $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$ is the electromagnetic field, and $\vec{\pi}$ is the pion field. The universality hypothesis requires the hadrons to be coupled to the symmetric energy-momentum tensor with the same strength

$$\Theta_{\mu\nu} = \frac{f}{m_f} (\partial_\mu \vec{\pi} \; \partial_\nu \vec{\pi} + \vec{V}_{\mu\lambda} \vec{V}^{\lambda}_{\nu} + \dots), \tag{12}$$

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x/ The role of the f -meson in the process $e^+e^- \to \pi^+\pi^-$ is investigated by Gatto/8/.

where $\vec{V}_{\mu\lambda} = \partial_\mu \vec{V}_\lambda - \partial_\lambda \vec{V}_\mu$ and $\vec{V}_\mu$ is the ρ -meson field. Adding to these the assumption of ρ meson dominance we obtain the following relations

$$g = a \frac{4\pi}{\gamma_\rho^2} \frac{f}{4} \approx \frac{a f}{2} \quad \text{and} \quad g' = 0, \tag{13}$$

where a is the hyperfine constant, and γ_ρ is the conventional $\gamma - \rho$ coupling constant ($\frac{\gamma_\rho^2}{4\pi} = 0,5$). Using the experimental value for $\Gamma_{\to 2\pi}$ we obtain

$$\Gamma_{f \to 2\gamma} = \frac{g^2}{4\pi} \frac{m}{40} \approx 1,13 a^2 \Gamma \approx 8 \text{ KeV} . \tag{14}$$

We mention that from dispersion relations and using pole dominance hypothesis the author of Ref./9/ obtained a value $\Gamma_{f \to 2\gamma} \approx$ $\approx$ 40 keV.

The cross section (10) at the top of the resonance peak is

$$\sigma \approx 3 \cdot 10^{-29} \text{ cm}^2 . \tag{15}$$

It is expected that the cross section near the f -resonance has the magnitude $\approx 10^{-29} cm^2$ (Having a broad resonance the finite energy resolution does not modify these values).

If meson factories at high energies work, the experimental study of the reaction $\gamma + \gamma \to f \to \pi^+ + \pi^-$ will be possible/4/.

Indirect methods, however, seem to be more reliable. The observation of the $e^- e^- \to e^- e^- \pi^+ \pi^-$ process e.g. will be feasible in the next future and near c.m. energies of 600-700 MeV it gives the best way to measure the resonant cross section (10) (see Ref./6,10/).

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