The Resonant Breit-Wheeler Process in a Strong Electromagnetic Field

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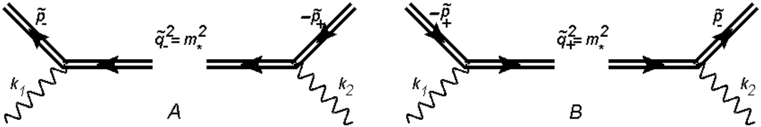
Pioneer works

- **Volkov** (1935,1937). Solution of Dirac's equation for an electron in the field of plane electromagnetic wave.
- **Schwinger** (1951), **Brown** and **Kibblie** (1964). Green's function for an electron in the field of plane electromagnetic wave.
- **Oleinik** (1967). Resonant processes.
- **McDonald** et al. (1996). A study of strong-field QED, experiment E-144, is underway at the SLAC in which the picosecond pulse from a TW laser collides with 50-GeV electrons.

Describing of the resonant process

- The main parameter of the field is the classical relativistic invariant parameter
$$\eta = \frac{eF\lambda\!\!\!^{-}}{mc^2}, \tag{1}$$
numerically equal to the ratio of the field work at the wavelength to the rest energy of the electron.
- Feynman diagrams of the resonant Breit-Wheeler Process



Under resonance conditions, the intermediate virtual electron (positron) in the external field comes on the mass shell.

The resonant kinematics

- The initial process of the second order in the fine structure constant effectively reduces into two successive processes of the first order: the external field-stimulated Breit–Wheeler process and the external field-stimulated Compton effect.
- The energies of the initial and final particles are ultrarelativistic and their momenta lie in a narrow cone of angles

$$\omega_{1,2} \gg m_*, \quad E_\pm \gg m_*, \quad m_* = m\sqrt{1+\eta^2}; \tag{2}$$

$$\theta_{j\pm} \equiv \angle(\mathbf{k}_j, \mathbf{p}_\pm) \ll 1, \quad j = 1,2; \quad \theta \equiv \angle(\mathbf{k}_{1,2}, \mathbf{k}) \sim 1. \tag{3}$$

Defining the variables and parameters

- Energies of final particles in units of the total energy of the initial gamma-quanta

$$x_{\pm\eta} = \frac{E_\pm}{\omega_i}, \quad \omega_i = \omega_1 + \omega_2. \tag{4}$$

- Characteristic numbers of absorbed photons of the external wave

$$r_\eta = \frac{(2m_*)^2}{4\omega\omega_2 \sin^2\frac{\theta}{2}}, \quad r'_\eta = \frac{m_*^2}{4\omega\omega_1 \sin^2\frac{\theta}{2}}. \tag{5}$$

- Ultrarelativistic parameters

$$\delta_{2+} \equiv \frac{\omega_i}{2m_*}\theta_{2+}, \quad \delta_{1-} \equiv \frac{\omega_i}{m_*}\theta_{1-}. \tag{6}$$

Consideration of the vertex with pair production

- Solutions for energy of the final positron (stimulated Breit–Wheeler process)

$$x_{+\eta(r)} = \frac{\omega_2}{2\omega_i(\varkappa_{\eta(r)} + \delta_{2+}^2)}\left[\varkappa_{\eta(r)} \pm \sqrt{\varkappa_{\eta(r)}(\varkappa_{\eta(r)} - 1) - \delta_{2+}^2}\right], \quad (7)$$

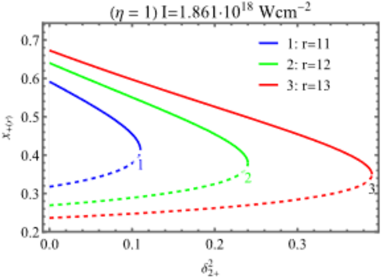
$$\varkappa_{\eta(r)} = \frac{r}{r_\eta} \geq 1. \quad (8)$$

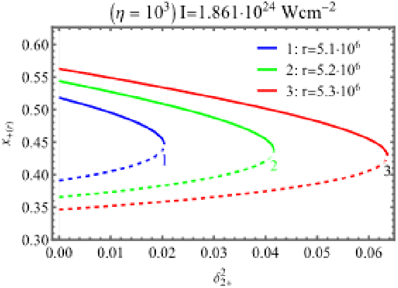
- Restriction for the outgoing angle of the final positron

$$0 \leq \delta_{2+}^2 \leq \varkappa_{\eta(r)}(\varkappa_{\eta(r)} - 1). \quad (9)$$

- For the oncoming motion of the gamma-quanta and the laser wave $\theta = \pi, \omega = 1eV$ and the energy of the initial gamma quantum $\omega_2 = 50GeV$ can be obtained $r_\eta \approx 5(1 + \eta^2)$.

Energies





The dependence of the resonant positron energy (in units of the total energy of the initial gamma-quanta) on its outgoing angle for a different number of absorbed wave photons for two laser intensities. Solid lines correspond to the solution with the "plus" sign, dotted lines – with the "minus" sign. The initial parameters are equal to:

$\omega_1 = 5GeV, \omega_2 = 50GeV, \omega = 1eV$

Consideration of the vertex with Compton effect

- Solution for the energy of the final electron (stimulated Compton effect)

$$x_{-\eta(r')} = \frac{\omega_1}{2\omega_i(\varkappa'_{\eta(r')} - \delta^2_{1-})}[\varkappa'_{\eta(r')} + \sqrt{\varkappa'^2_{\eta(r')} + 4(\varkappa'_{\eta(r')} - \delta^2_{1-})}], \tag{10}$$

$$\varkappa'_{\eta(r')} = \frac{r'}{r'_\eta} \gtrsim 1. \tag{11}$$

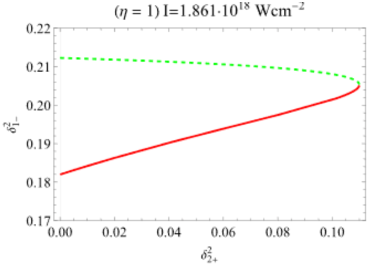
- Restriction for the outgoing angle of the final electron

$$0 \leq \delta^2_{1-} < \varkappa'_{\eta(r')}(1 - \frac{\omega_1}{\omega_i}) - \frac{\omega_1^2}{\omega_i^2}. \tag{12}$$

An agreement of solutions

The energy conversation law

$$x_{-\eta(r')} = 1 - x_{+\eta(r)}. \tag{13}$$



The dependence of the outgoing angles of the electron on the outgoing angle of the positron, at which the law of the energy conservation is fulfilled.

The resonant cross section

- The maximum resonant cross section for channel A

$$\frac{d\sigma^{max}_{\eta(r,r')}}{d\delta^2_{2+}} = r_e^2 \frac{m^2}{\omega_1\omega_2}\left(\frac{32}{\alpha}\right)^2 P(u_{2+}, \varkappa_{\eta(r)}) \frac{f_\eta}{P^2(r_\eta)} K(u_{1-}, \varkappa'_{\eta(r')}), \tag{14}$$

- Functions from BW-process

$$P(u, \varkappa_{\eta(r)}) = J_r^2(\gamma) + \eta^2(2u-1)\left[\left(\frac{r^2}{\gamma^2} - 1\right)J_r^2 + J_r'^2\right]; \tag{15}$$

$$P(r_\eta) = \sum_{r=r_{\eta min}}^{\infty} \int_1^{\varkappa_{\eta(r)}} \frac{du}{u\sqrt{u(u-1)}} P(u_{2+}, \varkappa_{\eta(r)}); \tag{16}$$

$$\gamma = 2r\frac{\eta}{\sqrt{1+\eta^2}} \sqrt{u\varkappa_{\eta(r)}(1 - u\varkappa_{\eta(r)})}. \tag{17}$$

The resonant cross section

- Functions from Compton effect

$$K(u, \varkappa'_{\eta(r')}) = -4J^2_{r'}(\gamma') + \eta^2 \left(2 + \frac{u^2}{1+u}\right)(J^2_{r'-1} + J^2_{r'+1} - 2J^2_{r'}), \quad (18)$$

$$\gamma' = 2r' \frac{\eta}{\sqrt{1+\eta^2}} \sqrt{u\varkappa'_{\eta(r')}(1 - u\varkappa'_{\eta(r')})}. \quad (19)$$

- Ultrarelativistic invariants

$$u_{2+} = \frac{\omega_2}{4x_+\omega_i(1 - x_+\omega_i/\omega_2)}, \quad u_{1-} = \frac{\omega_1}{\omega_i x_-}. \quad (20)$$

- Estimation for $\eta = 1$

$$d\sigma^{max}_{\eta(r,r')} \approx 2 * 10^7 d\sigma_{BW}. \quad (21)$$