PRODUCTION OF TWO ELECTRON-POSITRON PAIRS IN COLLISIONS OF FAST PARTICLES

V.G. Serbo
Novosibirsk State University
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Recently Balakin, Budnev, and Ginzburg [1] proposed a new mechanism for the investigation of the reaction $\gamma\gamma \to$ hadrons at high energy. Assuming that the cross section of this reaction is constant and is of the order of $\sim(\alpha/m_\pi)^2 \sim 10^{-30}$ cm^2, they estimated the inelastic process of hadron production by colliding electron beams (Fig. a). The total cross section increases like the fourth power of the logarithm of the energy, and for the soon to be attained experimental beam energies $\sqrt{s} = 2E = 7$ GeV this cross section should be no less than 10^{-33} cm^2 [1].

We wish to point out in this paper a similar purely electrodynamic process, namely the production of two $e\bar{e}$ pairs in collision of fast particles.

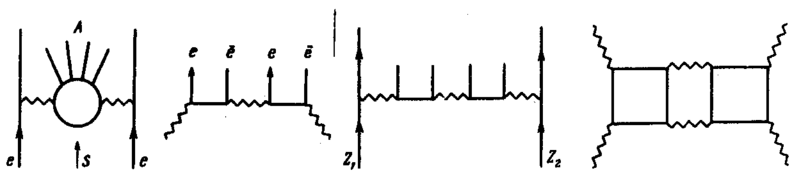
It is known that the cross section for the production of one $e\bar{e}$ pair by two photons decreases with increasing energy, and when $s \gg m^2$ the cross section is $\sigma(\gamma\gamma \to e\bar{e}) = 4\pi(\alpha^2/s)\ln(s/m^2)$. The cross section for the production of one pair in the collision of fast particles with charges Z_1e and Z_2e, obtained by Landau and Lifshitz [2, 3], to the contrary, increases logarithmically

$$\sigma(Z_1Z_2 \to Z_1Z_2 + e\bar{e}) = \frac{28}{27\pi}\left(\frac{\alpha^2}{m} Z_1Z_2\right)^2 \ln^3\gamma , \tag{1}$$

where $\tilde{\gamma} = 1/\sqrt{1 - v^2}$ and v is the relative velocity of the colliding particles, m is the electron mass, and $\alpha = 1/137$.

The cross section for the production of two $e\bar{e}$ pairs (Fib. b) by two photons was obtained by Lipatov and Frolov [4]; it is constant at high energy

$$\sigma(\gamma\gamma \to 2e\bar{e}) = \sigma_2 = \frac{\alpha^4}{9\pi m^2}\left[50\ln 2 - \frac{25\pi^2}{12} - \frac{19}{2}\right] = 0{,}67\cdot 10^{-30}\,\text{cm}^2. \tag{2}$$



a b c d

Using the value (2) for σ_2, we can easily find by the method of equivalent photons also the cross section $\sigma(Z_1Z_2 \to Z_1Z_2 + 2ee)$. The calculations here are similar to those used to determine (1) (see [3]). To this end, we find first the cross section for the production of two pairs in the field of the nucleus Ze by a photon of frequency $\omega \gg m$

$$\sigma(\gamma Z \to Z + 2e\bar{e}) = \sigma_2 Z^2 \frac{\alpha}{\pi} \ln^2 \frac{\omega}{m} . \tag{3}$$

Further, using (3), we find the cross section for the production of two pairs in the collision of two fast particles (Fig. c)

$$\sigma(Z_1Z_2 \to Z_1Z_2 + 2ee) = \sigma_2 \frac{1}{6}\left(Z_1Z_2\frac{\alpha}{\pi}\right)^2 \ln^4 \gamma . \qquad (4)$$

For colliding electron beams with $E = 3.5$ GeV ($\gamma = 2E^2/m^2 = 0.94 \times 10^8$) this cross section is equal to 0.7×10^{-31} cm^2.

We note in conclusion that the cross section for the production of two muon pairs is suppressed compared with (2) by a factor $(m/\mu)^2$, $\sigma(\gamma\gamma \to 2\mu\bar{\mu}) \sim 2.3 \times 10^{-5}\,\sigma_2$ ($\mu \simeq 206m$ is the muon mass). At the same time the cross section for the production of one $e\bar{e}$ pair and one $\mu\bar{\mu}$ pair can be higher by two orders of magnitude. In fact, using the result of Cheng and Wu [5] for elastic zero-angle $\gamma\gamma$ scattering (Fig. d) and replacing m by μ in one of the photon impact factors, we obtain for the amplitude (cf. (2))

$$M^{\gamma\gamma}_{++,\,++}(s, t = 0) = i s \frac{\alpha^4}{9\pi\mu^2}\left[\frac{112}{3}\ln^2\frac{\mu}{m}\right]$$

(recognizing that $\mu \gg m$, we have retained here only the higher powers of $\ln\mu/m$). It is then easy to obtain from the optical theorem that $\sigma(\gamma\gamma \to e\bar{e} + \mu\bar{\mu}) \sim 5 \times 10^{-3}\sigma_2$.

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Supplement

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In the article the author uses the constant $\sigma_2 = 0.67\mu b$, obtained in [1]. As reported by the authors of [1], an error was made in the calculation of σ_2. The correct value of this cross section is larger by almost one order of magnitude

$$\sigma_2 \equiv \sigma(\gamma\gamma \to 2e\bar{e}) = \frac{a^4}{36\pi m^2}\,[175\,\xi(3) - 38\,] = 6.44\ \mu b$$

($\xi(3) = 1.202$ is the Reimann Zeta function).

When this is taken into account, the numerical estimates and relations derived in the article must be altered. For colliding beams with energy $2E = 7$ GeV, the cross section is $\sigma(ee \to ee + 2e\bar{e}) = 0.66\ \mu b$. The constant cross section at high energy (obtained by numerical integration) is

$$\sigma(\gamma\gamma \to e\bar{\bar{e}} + \mu\mu) = 5.7\cdot 10^{-33}\ \mathrm{cm}^2 = 0.88\cdot 10^{-3}\sigma_2 = 38\,\sigma(\gamma\gamma \to 2\mu\bar{\mu}).$$

On the other hand, the formulas obtained in the article remain unchanged.

Reference

[1] L.N. Lipatov and G.V. Frolov, ZhETF Pis. Red. 10, 399 (1969) [JETP Lett. 10, 254 (1969)].