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P. Costa and A. F. Grillo: LOW'S PARTICLE: A REVIEW OF EXPERIMENTAL AND THEORETICAL DATA AND A PROPOSAL FOR AN $e^+e^- \rightarrow \gamma\gamma$ ADONE EXPERIMENT.

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1. -

The starting point of this work is Low's proposal[1] to explain possible violations of Q. E. D. by introducing new particles and interactions.

In view of the growing interest in the exploration of electrodynamics at high energies, we have calculated the cross section of the reaction (soon to be studied in Adone)

$$e^+ e^- \rightarrow \gamma\,\gamma \qquad (1)$$

supposing the existence of a particle ($L^{\pm}$) with mass greater than the mass of the electron and the same quantum numbers.

The interaction of the L-particle with the electrons is described by a non-minimal Hamiltonian[(x)]

(x) - Recently Barut et al.[2] have given arguments for assuming the existence of such a particle with mass M = 882 MeV and coupled to the electron by (2).

(2) $$H_I = \frac{\lambda e}{M} \bar{\psi}_L(x)\, \sigma_{\mu\nu} \psi(x)\; F_{\mu\nu}(x) + \text{H. C.}$$

(M is the L mass)

We first examine the limitations imposed on the parameters λ and M of the Low particle; from these we shall derive some conditions for the possibility of measuring its contribution to a reaction like (1) in colliding beam experiments.

These limitations are:

a) Measurements of protonic recoil in experiments like[3÷6]:

$$ep \rightarrow Lp$$
$$\hookrightarrow e\gamma$$

The parameter region forbidden by these experiments is shown in Fig. 3.

b) No $L \rightarrow e\gamma$ decay has been observed by visual methods, so that we can conclude that the L mean-like (against e. m. disintegration) must be $\leqslant 10^{-14}$ sec. This lifetime can be calculated, it is:

(3) $$\tau_L = \frac{2\pi}{e^2} \frac{1}{\lambda^2 M}$$

If we impose that $\tau_L \leqslant 10^{-14}$ sec. $= \bar{\tau}$ we have the relation[x]

$$(\lambda e)^2 \geqslant \frac{2\pi}{M\bar{\tau}}$$

c) No $K \rightarrow L\nu$ (or $K \rightarrow e\nu\gamma$) decay has been observed; we must therefore have[1] $M \geqslant 493.82$ MeV.

d) The correction to the electron g-2 owing to the L interaction has been calculated by H. Terzawa[7]; he found (note that H_I implies a non renormalizable theory)

(4) $$\Delta\mu = \frac{1}{2\pi^2}\left(\frac{\lambda e}{M}\Lambda\right)^2 + 0\left(\log\frac{\Lambda^2}{M^2}\right)$$

(Λ is a cut-off parameter); the lower limit for Λ ($\Lambda = M$) corresponds to the lower limit on $\Delta\mu$, $\Delta\mu \geqslant (\lambda e)^2/2\pi^2$.

(x) - (3) is expressed in natural units $c=\hbar=1$. If we take τ_L in sec. and M in MeV we have $\tau_L = (4.10^{-20})/\lambda^2 M$.

Taking for $\Delta\mu$ the value[8] $\Delta\mu = (60 \pm 30)10^{-9}$ we have the upper limit on λ^2:

(5) $$\lambda^2 \lesssim 1.29 \times 10^{-5}$$

As we see, this limitation is very strong[(x)].

e) Since L has the same quantum numbers as the electron, the (weak) decay $L \to e\, \nu_e \bar{\nu}_e$ is theoretically permitted; its mean-life is

(6) $$\tau_L^W = \frac{192\,\pi^3}{G^2 M^5}$$

By requiring that $\tau_L^W > \tau_L$ we have

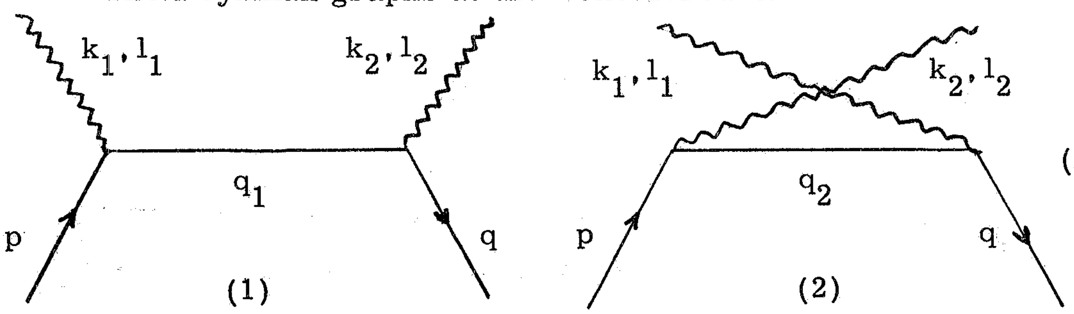
$$(\lambda e)^2 > \frac{G^2 M^2}{96\,\pi^2}$$

If we assume for λ^2 the value given under D), we have $M \gtrsim 12\, M_n$ where M_n is the nucleon mass. It must, however, be pointed out that recently Pontecorvo[9] has suggested that it may be a small violation of leptonic charge conservation.

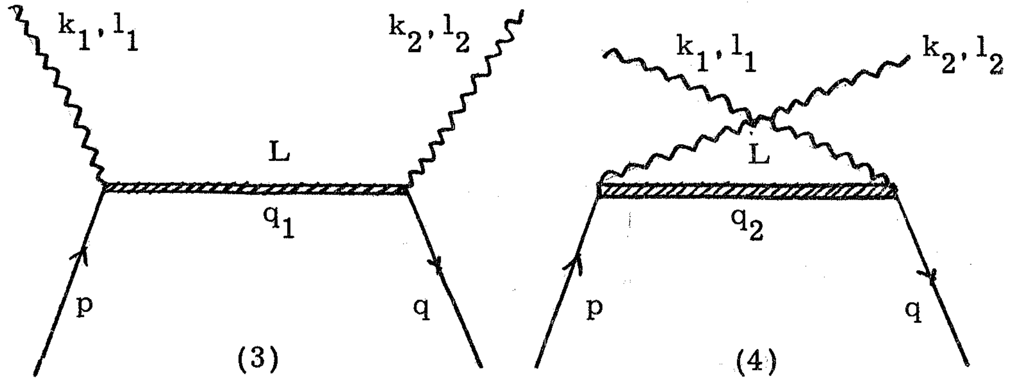
In this scheme we could think that Low's particle is the muon; but if we calculate the Branching-ratio $R(\mu \to e\gamma)/R(\mu \to e\nu\bar{\nu})$ we obtain the following limitation on λ^2: $\lambda^2 \lesssim 10^{-21}$ (note that in this case the C) limitation does not hold at all, since the $K \to \mu\nu$ is the dominanating decay of the kaon).

2. - CALCULATION OF $d\sigma/d\Omega\ (e^+e^- \to \gamma\gamma)$. -

The Feynman graphs at the considered order are the following



(x) - We must in anycase point out that in Ref. (3) is reported a limitation due to Blackmon (Ph. D. thesis, unpublished) that is in complete disagreement with Terazawa calculations both in numerical value and in functional dependence of λ^2 from M.



(3) (4) (x)

where k_1, e_1 are the momentum and polarization of the photon, p and q the e^-, e^+ momenta.

We obtain then, for the reactions (x) (in the ultrarelativistic limit ($\gamma = E/m \gg 1$) and for $\theta \gg 1/\gamma$, where θ is defined in C.M. by $\theta = (|\vec{p}||\vec{k}_1|)^{-1}\, \vec{p}\cdot\vec{k}_1$)

(7) $$\frac{d\sigma_L}{d\Omega} = \frac{d\sigma_o}{d\Omega} + \lambda^2 \frac{d\sigma_1}{d\Omega} + \lambda^4 \frac{d\sigma_2}{d\Omega}$$

where

$$\frac{d\sigma_o}{d\Omega} = \frac{r_o}{2\gamma^2} \; \frac{\mathrm{sen}^4\theta/2 + \cos^4\theta/2}{\mathrm{sen}^2\theta}$$

is the usual $e^+e^- \to \gamma\gamma$ cross section ($r_o = e^2/m^2$)

$$\frac{d\sigma_1}{d\Omega} = \frac{26\, r_o}{\gamma^2} \left(\frac{E}{M}\right)^4 \left[\frac{\mathrm{sen}^4\theta/2}{1+4\frac{E^2}{M^2}\mathrm{sen}^2\theta/2} + \frac{\cos^4\theta/2}{1+4\frac{E^2}{M^2}\cos^2\theta/2} \right]$$

is the sum of $(1,2) \leftrightarrow (3,4)$ interference terms and

$$\frac{d\sigma_2}{d\Omega} = 128\, \frac{r_o}{\gamma^2} \left(\frac{E}{M}\right)^6 \left\{ \left[\frac{\mathrm{sen}^2\theta/2}{(1+4\frac{E^2}{M^2}\mathrm{sen}^2\theta/2)^2} + \frac{\cos^2\theta/2}{(1+4\frac{E^2}{M^2}\cos^2\theta/2)^2} \right]^2 + \right.$$

$$\left. + 4\frac{E^2}{M^2}\cos^2\theta/2\,\mathrm{sen}^2\theta/2 \left[\frac{\cos^4\theta/2}{(1+4\frac{E^2}{M^2}\mathrm{sen}^2\theta/2)^2} + \frac{\mathrm{sen}^4\theta/2}{(1+4\frac{E^2}{M^2}\cos^2\theta/2)^2} \right] \right\}$$

We can see that, at the energies considered and for the allowed values of λ^2, M, we have $\lambda^2(d\sigma_1/d\Omega) \gg \lambda^4(d\sigma_2/d\Omega)$ for all θ, so that the λ^4 term will be neglected.

(7) can be written again in a more handy form

$$\frac{d\sigma_L}{d\Omega} = \frac{r_o}{2\gamma^2} \frac{F_1(q_1q_2)\mathrm{sen}^4\theta/2 + F_2(q_1q_2)\cos^4\theta/2}{\mathrm{sen}^2\theta}$$

where

$$F_1(q_1q_2) = 1 + \frac{8\lambda^2}{M^2}\frac{q_1^2 q_2^2}{M^2+q_1^2} \qquad q_1^2 = 4E^2\,\mathrm{sen}^2\theta/2$$

$$F_2(q_1q_2) = 1 + \frac{8\lambda^2}{M^2}\frac{q_1^2 q_2^2}{M^2+q_2^2} \qquad q_2^2 = 4E^2\cos^2\theta/2$$

A more expressive way to examine the results is to consider the quantity

$$(R-1) = \left[\frac{d\sigma_L}{d\Omega}\bigg/\frac{d\sigma_o}{d\Omega}\right] - 1 = 32\,\lambda^2\,\frac{E^2}{M^2}\,x$$

$$x\,\frac{\mathrm{sen}^4\theta/2\Big/(1+4E^2/M^2\mathrm{sen}^2\theta/2) + \cos^4\theta/2\Big/(1+4E^2/M^2\cos^2\theta/2)}{(\mathrm{sen}^4\theta/2+\cos^4\theta/2)\Big/\mathrm{sen}^2\theta}$$

that represents the per cent correction due to Low's particle.

In Fig. 1 we plot (R-1) as function of θ at $\lambda = 5\mathrm{x}10^{-3}$ and at various values of E/M.

We can seen from Fig. 1 that (R-1) has a maximum at $\theta = \pi/2$.

For $\theta = \pi/2$ and E=1500 MeV, (R-1) has been calculated as function of M and at various values of λ^2 (see Fig. 2).

We now consider the possibility to reveal experimentally the contribution of the L-particle to the reaction (1) in an ADONE experiment at maximum energy (E=1.5 GeV); the "optimum" conditions for this experiment are at $\theta = \pi/2$, as we can see in Fig. 1.

In this case we have

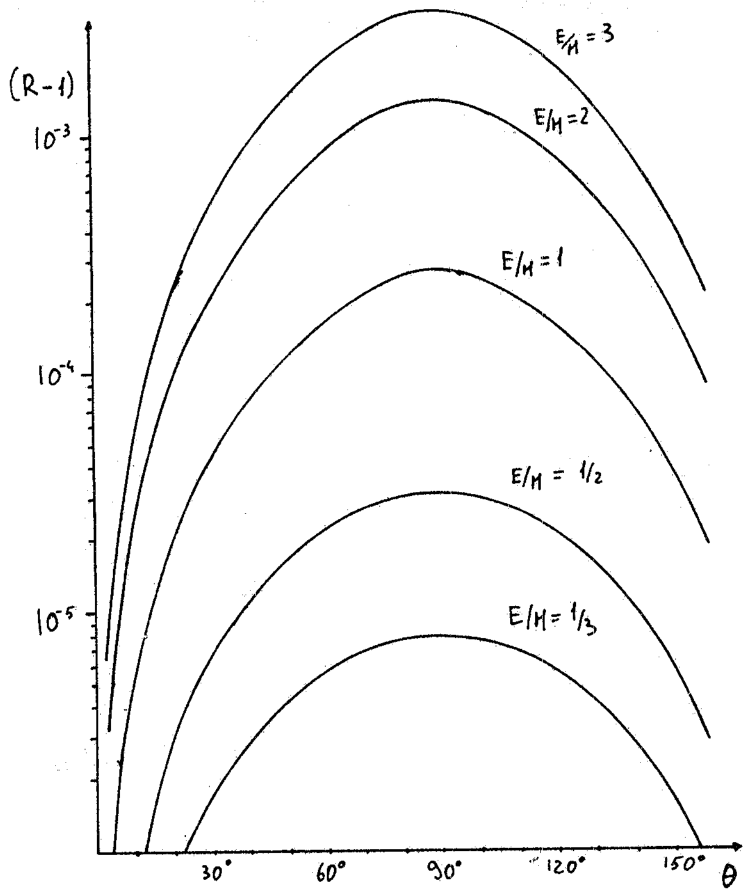


FIG. 1 - Angular dependence of (R-1) ($\lambda = 5 \times 10^{-3}$)

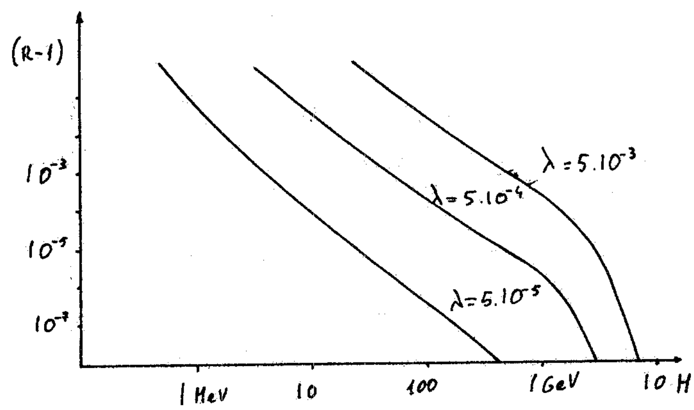


FIG. 2 - (R-1) as function of λ and M at $\theta = \pi/2$ and E=1.5 GeV.

$$(R-1) = 32 \left(\frac{E}{M}\right)^4 \frac{\lambda^2}{1+2\left(\frac{E}{M}\right)^2}$$

If P is the precision of the experiment, we must have $P \leq (R-1)$; so that, if we fix P, this defines a curve in the Low's parameter space that gives a lower limit on λ^2 as function of M.

These curves are shown in Figures 3, 4 with the limitation discussed in section 1.

3. - CONCLUSIONS. -

It is obvious that the main obstacle in the way of measuring the contribution of L-particle to (1) is the anomalous magnetic moment of the electron.

If we follow Terazawa, we must conclude that no experiment, at least at energies now attainable, can show a contribution of L (see Fig. 3); if we follow Blackmon, there is a region where an experiment $e^+e^- \to \gamma\gamma$ at $\theta = \pi/2$ can show a contribution of L. (Fig. 4 - in this figure we have extrapoled the Blackmon curve, since we don't know the details of his calculation).

Independently of the limitations imposed by anomalous magnetic moment, we see that the strong dependence of (R-1) on the energy make such an experiment possible at energies above 3-4 GeV.

We are grateful to Prof. B. Touschek for useful suggestions and discussions.

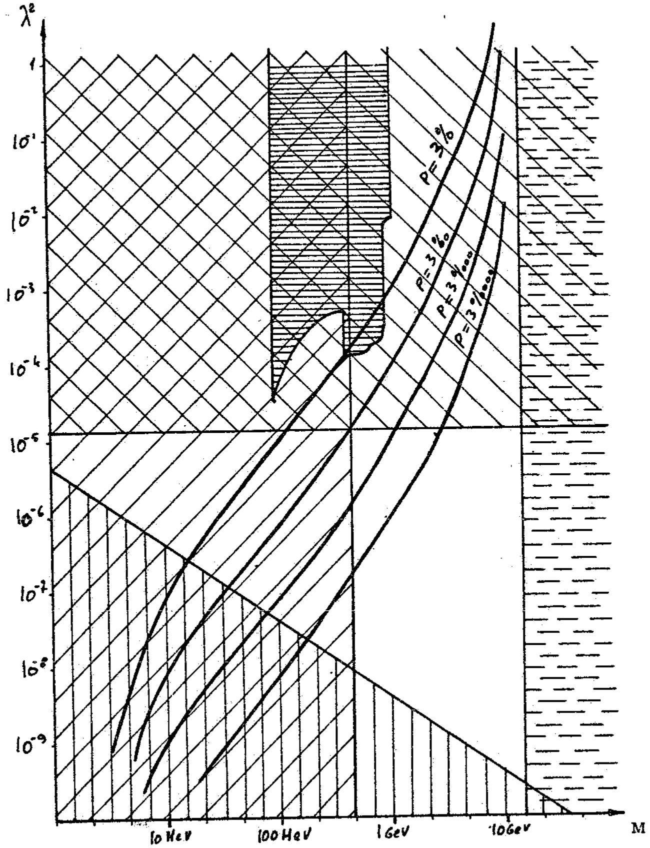


FIG. 3

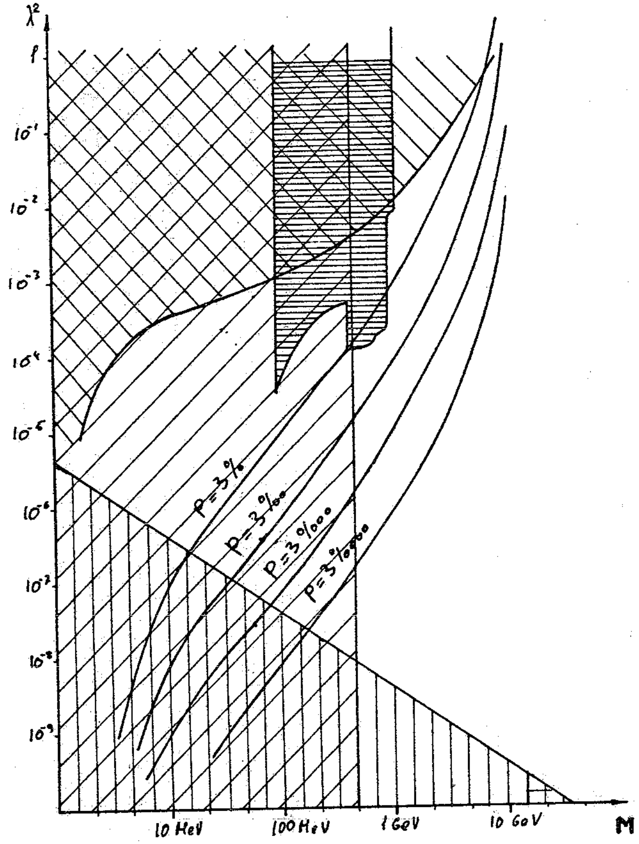


FIG. 4

Low's parameter region allowed for experiments at various. P.

Region forbidden by experimental limitations

Mean life limitation

Region forbidden by the anomalous magnetic moment of the electron (Fig. 3 - Terazawa; Fig. 4 - Blackmon).

Region forbidden by the K decay

Region forbidden by the weak decay of L

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