Production of heavy leptons in colliding e^+e^- beams followed by the decay $L \to \mu(e) + \nu + \nu_L$

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It is shown that the singularities of the energy spectrum of the muons or electrons from leptonic decays of heavy leptons produced in the process $e^+e^- \to L^+L^-$ make it possible to distinguish this process from others and to determine the mass of the heavy leptons from the position of the maximum of the spectrum.

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The observation of μ^+e^- pairs in experiments with colliding e^+e^- beams[1] has attracted attention to the problem of the existence of the heavy lepton $L^\pm$, since one of the simplest mechanisms whereby μe pairs can be produced at the observed probability level is the process

$$e^+ + e^- \to L^+ + L^-, \quad L^- \to e^- + \bar{\nu}_e + \nu_L, \quad L^+ \to \mu^+ + \nu_\mu + \bar{\nu}_L \qquad (\ldots$$

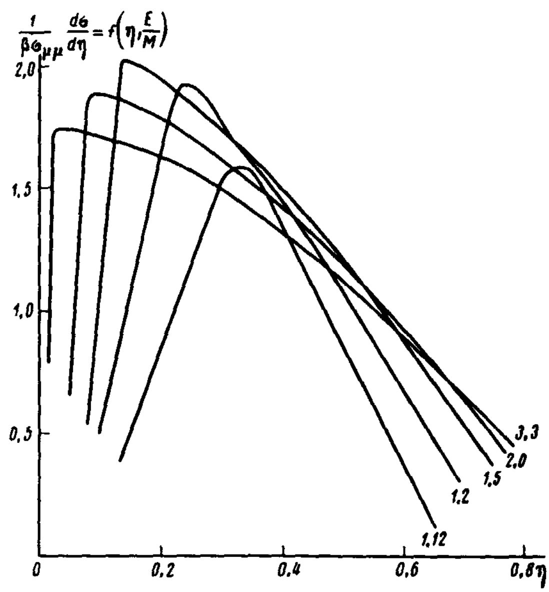
he existence of such processes explains the experiment, if the L^+ mass is $\bar{} = 1.7$—2.3 GeV at a relative fraction $\beta \sim 0.1$—0.25 of the decay of the heavy ›ptons via lepton modes.[2]

Many various theoretical weak-interaction models have been discussed in the terature, as well as unified models of weak, electromagnetic, and strong ıteractions, in which heavy leptons are introduced. It is clear *a priori* that the xistence of such particles should be experimentally proved by all the possible ıethods in a wide range of proposed $L^\pm$ masses (from 1 to 10—15 GeV).

A study of the reaction (1) can give a relatively simple kinematic method of roving the existence of $L^\pm$ by measuring the energy spectra of the leptons from ıe $L^\pm$ decay period.

Calculation of the differential cross section $d\sigma/d\omega$ of the process (1), where is the energy of the one of the leptons from the decay of L^+ (or L^-) can be ırried through to conclusion in analytic form. We have considered two cases: the $L^\pm$ are "ordinary" heavy leptons, that is, particles analogous to $\mu^\pm$ and , so that the structure of the weak current responsible for the leptonic decay $L^\pm$ is analogous to the leptonic part of the ordinary $V-A$ current; 2) the eorgi-Glashow model, in which the particles are assumed to be (μ^-, e^-, L^+), ith corresponding change of the weak-current structure.

If we neglect the mass μ of the final lepton, then the quantity $(1/\beta\sigma_{\mu\mu})(d\sigma/d\eta)$, ıere β is the relative fraction of the decays in the channel $L \to \mu(e)\,\nu\nu_L$ and $_{\mu} = \pi\alpha^2/3E^2$ is the total cross section of the process $e^+e^- \to \mu^+\mu^-$, depends only $\eta = \omega/E$ and on the ratio E/M (E is the energy of the electrons in the initial ›am, M is the mass of the heavy lepton). The figure shows this quantity as a nction of η for different values of the ratio E/M and for "ordinary" heavy ptons.



We note that the difference between calculations by the model of "ordinary" heavy leptons and by the Georgi-Glashow model consists only of a certain increase (~ 20%) of the amplitude of the maxima of the $d\sigma/d\eta$ spectrum, but with an unchanged position of the maximum relative to η, and in a more abrupt decrease of the spectrum past the maximum. The total cross sections are the same in both cases.

For purely kinematic reasons connected with the three-particle character of the $L^{\pm}$ decay, formulas for the quantity $(1/\beta\sigma_{\mu\mu})(d\sigma/d\eta)$ are different in the regions $\eta < \eta_0$ and $\eta > \eta_0$, where

$$\eta_0 = \frac{1}{2}\left[\frac{(M/E)^2}{1+\sqrt{1-(M/E)^2}} + \left(\frac{\mu}{M}\right)^2\left(1+\sqrt{1-(M/E)^2}\right)\right]. \quad (2)$$

Direct calculations show that the energy spectrum rises at $\eta < \eta_0$ and drops $\eta > \eta_0$. Thus, the position of the maximum in the spectrum for different E and M is close to the value of η_0.

This general property of the spectrum is preserved at values of E and M satisfying the inequality $E/M \lesssim \sqrt{M/4\mu}$. Allowance for the mass of the final lepton results in small corrections $\sim (\mu/M)^2$ and $(\mu/E)^2$ to the form of the spectrum. Thus, calculations show that when the L^+L^- pair is produced in the process (1), a certain qualitative effect, essentially of kinematic origin, should appear. This effect should permit, in principle, the identification of the reaction (1) with the aid of the shapes of the spectra of the leptons from the decays of L^+ and L^-, and the determination of the mass of the heavy lepton from the position of the maxima of the energy spectra of the leptons $\mu^{\pm}$ and $e^{\pm}$ (or $\mu^+\mu^-$ and e^+e^-).

We note also that leptonic decays of $L^{\pm}$ of the type (1), proceeding via a neutral current of the mixed V and A type, do not change to any significant extent the position of the maximum of the spectrum with respect to η. Semileptonic modes of the decay $L \to \nu_L(\bar{\nu}_L)$ + hadrons, which proceed via interaction of charged currents, do not make any contribution whatever to the spectrum of μ or e. The decays $L \to \mu^{\pm}(e^{\pm})$ + hadrons, proceeding via neutral V and A currents, can be easily shown within the framework of the quark parton model[3] to have likewise little effect on the shape of the spectrum with respect to η and on the position of the maximum, since the minimum possible effective mass of the quark-antiquark pair is small in comparison with the mass of $L^{\pm}(m_{q\bar{q}} \sim m_{\pi})$. This question, however, calls for an additional thorough study of the concrete modes of the semileptonic decays of $L^{\pm}$ and their relative probabilities.

If there can exist in nature, for some profound reasons, only diagonal neutral leptonic currents of the type $(\bar{\nu}\nu)$, $(\bar{e}e)$, $(\bar{\mu}\mu)$, and $(\bar{L}L)$, then leptonic and semileptonic decay of $L^{\pm}$ will be utterly forbidden, and the only $L^{\pm}$ decay modes with production of μ or e will be the processes (1).

Recent papers[4,5] discuss the angular correlations of the final leptons in the process (1), and in[5] they calculate also the energy spectra of single leptons. The calculations were performed only for an energy value $E = 2.4$ GeV in connection with experiments[1] on the observation of μe pairs. The authors reach the conclusion that the available statistics do not permit a unique interpretation of the results of these experiments. However, the singularities noted by us above in the behavior of the energy spectra of the leptons at different values of E and M were not noted in[5], although we regard this effect as worthy of the attention of experimenters searching for heavy leptons in colliding e^+e^- beams.

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