Role of heavy leptons in the reaction $e^+e^- \rightarrow$ hadrons

Ya. I. Azimov, L. L. Frankfurt, and V. A. Khoze

B. P. Konstantinov Institute of Nuclear Physics, USSR Academy of Sciences

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We discuss the expected properties of heavy leptons (with mass $M_L \sim 1.8$ GeV) and their manifestation in the reaction $e^+e^- \rightarrow$ hadrons.

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1. It appears that the reaction $e^+e^- \rightarrow$ hadrons can be described within the framework of a two-component scheme (e.g., a quark-parton component is produced namely, at $\sqrt{s} \gtrsim 2$ GeV, and at $\sqrt{s} \gtrsim 3.6$ GeV there are produced also new particles—heavy hadrons with new quarks (HH) and heavy leptons (HL). The contribution of the HL might explain (albeit in part) the growth of $R = \sigma(e^+e^- \rightarrow \text{hadrons})/\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ at $\sqrt{s} \gtrsim 3.6$ GeV,[1,6,7] the hadron jets, and the behavior of the inclusive spectra of the hadrons.[5] It is also hoped that the HL will explain the decrease of the energy fraction $\epsilon(s) = \langle E_{ch} \rangle / \sqrt{s}$ carried away by the charge particles with increasing $\sqrt{s}$ at $\sqrt{s} > 3.6$ GeV.[6,7]

Data on the anomalous μe pairs in e^+e^- annihilation [8] provide weighty indications that an HL pair L^+L^- with $M_L \sim 1.8$ GeV/c is actually produced, and possibly with a new lepton number (in this case L is connected with a new neutrino ν_L). Anomalous production of muons in e^+e^- annihilation,[9] which apparently is also due to the L^+L^- pair, was recently observed.

We show in this article that the data of [9] agree with the expected properties of the HL, but one pair of HL cannot be fully responsible for the observed behavior of $\epsilon(s)$.[10] We discuss also briefly the possible contributions of L^+L^- to R under actual experimental conditions.[10,11]

2. The properties of HL with universal weak interaction constant have been discussed in a number of papers (e.g., [12,5,7]). The decays

$$L^- \begin{array}{l} \nearrow \nu_L + e^- + \bar{\nu}_e, \qquad \nu_L + \mu^- + \bar{\nu}_\mu \\ \searrow \nu_L + \pi(K), \qquad \nu_L + \rho \end{array} , \tag{1}$$

are calculated in standard fashion (see [12,7]). The ratio of the sum of the widths of the decays (1) to

$$\Gamma_l \equiv \Gamma_{L^- \to \nu_L + e^- + \bar{\nu}_e}$$

is equal to ~ 3.8 at $m_{\nu_L} = 0$ and increases with increasing m_{ν_L}. It follows from the data of [8] that for $L^\pm$ we have $\Gamma_{\mathrm{tot}}/\Gamma_e \approx 6 \pm 1$, i.e., the reliably described decays (1) play the principal role. The properties of the multiparticle decay

$$L^- \to \nu_L + \text{hadr. continuum} \tag{2}$$

are less clear. In the case under discussion, when $\langle M_{\mathrm{cont}} \rangle \sim 2/3 M_L \sim 1.2$ GeV, there are no well-founded theoretical arguments for the contribution of the axial current. For estimates it is customary to resort [12] to the CVC, asymptotic chiral symmetry, and SU_3 hypotheses. The contribution of A_1 is taken into account separately, while the spectral functions of the vector and axial current $\rho^{VV}(s)$ and $\rho^{AA}(s)$ are assumed to be equal at $\sqrt{s} \gtrsim 1$ GeV. As a result we expect $\Gamma_{\mathrm{tot}}/\Gamma_e \approx 5.2$ at $m_{\nu_L} = 0$.[7] But this method is not quite reliable. It appears that $\rho^{VV}(s)$ at $\sqrt{s} \approx 0.9$–1.3 GeV, as follows from e^+e^- annihilation, can be described by the contribution of $\omega\pi$ with πA_1 admixture.[13] The contribution of 5π to $\rho^{AA}(s)$ is probably small, while the contribution of 3π is in the main apparently connected with A_1. It is therefore possible that without A_1 we have $\rho^{AA}(s) \ll \rho^{VV}(s)$ in this region.

The values of ϵ for the decays (1) and $L^- \to \nu_L A_1^-$ are calculated in standard fashion.[12,7] The usual assumptions for (2) without A_1 [12,7] yield $\epsilon_{\mathrm{h.c.}} = 0.44$. However, when the indicated uncertainties are taken into account at $\rho^{AA}/\rho^{VV} = 0$–1 and $m_{\nu_L} = 0$ we obtain $\epsilon_{\mathrm{h.c.}} \approx 0.55$–$0.44$.

Typically, mainly one charge particle (one track) in the L decay is produced. If $\Gamma(n)$ is the width of the decay with formation of n tracks, then at $m_{\nu_L} = 0$ we have

$$\frac{\Gamma(\gtrsim 3)}{\Gamma(1)} = 0.18 - 0.3; \quad \delta_1 = \frac{\Gamma(1)}{\Gamma_{tot}} = 0.85 - 0.77; \quad \frac{\Gamma_e}{\Gamma(1)} \lesssim 0.25. \tag{3}$$

This agrees well with the data of [9]

$$\left(\frac{\Gamma(\gtrsim 3)}{\Gamma(1)}\right)_{\exp} < 1/3; \left(\frac{\Gamma_e}{\Gamma(1)}\right)_{\exp} < 1/3,$$

thus indicating that in [9] they have indeed observed HL and not HH (for which the expected ratio is $\Gamma(\geq 3)/\Gamma(1) > 1$ [3,5]).[1)]

3. The behavior of $\epsilon(s)$, which was experimentally investigated for events with $n_{ch} \geq 3$,[10] is determined by the formulas

$$\epsilon(s) = \epsilon_h(s) + (\epsilon_L - \epsilon_h(s)) \frac{\bar{R}_L(s)}{\bar{R}_h(s) + \bar{R}_L(s)},$$

$$\bar{R}_L(s) = \frac{1}{2} V(3 - V^2) \bar{B}_L, \tag{4}$$

where $V^2 = 1 - 4M_L^2/s$, $\bar{R}_h(s)$ and $\epsilon_h(s)$ are the contributions of pure hadronic events with $n_{ch} \geq 3$, while $\bar{R}_L(s)$ and ϵ_L are the contribution of events with production of L^+L^- and with $n_{ch} \geq 3$. Since $\epsilon_L < \epsilon_h$, it follows that $\epsilon(s)$ decreases starting with the L^+L^- production threshold. It is usually assumed that $\epsilon_L \approx 0.4$.[4,7] As noted above, however, ϵ_L can be also larger, thus decreasing the expected effect. Even more importantly, the selection of events with $n_{ch} \geq 3$ [10] yields $\bar{B}_L \lesssim (1 - \delta_1^2) \leq 0.2$—$0.4$. Thus, the standard statements [7] notwithstanding, the HL cannot describe fully the decrease of $\epsilon(s)$ even at $\sqrt{s} \lesssim 6$ GeV, and it is apparently necessary to take the influence of the HH into account here. This remark pertains also to the inclusive spectra of hadrons and to hadrons jets, where events with $n_{ch} \geq 3$ are also used.[10]

The contribution of the HL to $R_{\exp}$ is less clear. It is similar to the contribution of $\bar{R}_L$, but with a weight $B_L(\sqrt{s})$ corresponding to the actual conditions of the registration.[11] The condition $\theta_{\text{copl}} > 20°$ imposed on the coplanarity angle decreases the fraction of events with $n_{ch} = 2$, and with increasing $\sqrt{s}$ this limitation becomes stronger. Rough estimates show that under the experimental conditions [11] at $\sqrt{s} \approx 7.4$ GeV one can expect the fraction of the two-track events to decrease by $\approx 30\%$. If we exclude in addition two-track events with a single electron, then $B_L(7.4 \text{ GeV}) \lesssim 0.65$. Of course, this rough estimate is given only for illustration. It is actually necessary to have a more detailed allowance for the registration conditions.

Allowance for the measurement conditions is important also for an experimental verification of the theoretical sum rules that connect the inclusive spectra of the hadrons with other quantities $(R(s), \epsilon(s), \langle n_{ch} \rangle)$.

An analysis of the properties of HL shows that they are quite different from the properties of HA. Therefore it is possible, by varying the registration conditions, to enhance or to weaken the relative role of the HL and HH. For example, in events with $n_{ch} = 2$ the relative contribution of the HL is stronger, since $\langle n_{ch} \rangle_L \approx 2.5$—$3$. Consequently it becomes meaningful already to speak not of two components in the reaction $e^+e^- \to$ hadrons, but of three components.

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1)After completing this work we learned that Snow [14] reached a similar conclusion.

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