Laboratori Nazionali di Frascati

LNF-74/11(P)

S. Orito, R. Visentin, F. Ceradini, M. Conversi,
S. D'Angelo, L. Paoluzi and R. Santonico :

A SEARCH FOR HEAVY LEPTONS WITH e^+e^- COLLIDING BEAMS

Phys. Letters 48B, 165 (1974)

A SEARCH FOR HEAVY LEPTONS WITH e^+e^- COLLIDING BEAMS☆

S. ORITO, R. VISENTIN
Laboratori Nazionali del CNEN, Frascati (Roma), Italy

and

F. CERADINI, M. CONVERSI, S. d'ANGELO, L. PAOLUZI and R. SANTONICO
Istituto di Fisica dell'Università di Roma and INFN Sezione di Roma, Italy

Received 15 October 1973
Revised manuscript received 19 November 1973

A search for heavy leptons has been carried out with the Frascati e^+e^- storage ring by looking for (μe) pairs. A lower mass limit of 1.15 GeV, with 95% confidence level, is obtained for various types of heavy leptons.

The puzzling question of the muon-electron universality has stimulated the idea that a sequence of leptons heavier than the muon may exist with their own neutrino partners. Some of the recent attempts to develop a unified renormalizable theory of weak and electromagnetic interactions [1] have also introduced heavy leptons, $E^\pm$ and $M^\pm$, which have the same lepton number as $e^\mp$ and $\mu^\mp$, respectively. A lower mass limit of 490 MeV is claimed for these hypothetical particles, based on the fact that they have never been observed in K-meson decay. Various experiments have been performed to improve this lower limit [2, 3].

In this paper we report a search for heavy leptons performed with the Frascati e^+e^- storage ring, Adone.

We consider the production process

$$e^+e^- \to H^+H^-$$

through the one photon channel, where $H^\pm$ represent the heavy leptons in general. The final states searched for are generally non-collinear (μe) pairs coming from the following H-decay modes;

$$H^+ \to \bar{\nu}_H e^+ \nu_e \quad \text{or} \quad \bar{\nu}_H \mu^+ \nu_\mu$$
$$H^- \to \nu_H e^- \bar{\nu}_e \quad \text{or} \quad \nu_H \mu^- \bar{\nu}_\mu . \qquad (1)$$

Fig. 1 shows the experimental setup, which is an improved version of the one previously described [4] and consists of two movable counter-spark-chamber telescopes (total weight 80 tons) placed on opposite sides of Adone's vacuum chamber. The thin-foil spark chambers C_1 closest to the beam line are used for the precise reconstruction of particle trajectories. Typical accuracy is ± 2 mm in space and ± 20 mrad in angle. The other track chambers are thick plate chambers, in which high energy electrons develop clearly observable electromagnetic showers and muons are identified by their penetration and by the absence of nuclear interactions. The perpendicular thickness is 125 g cm^{-2} (9.2 radiation lengths mainly in iron) from the beam line to the end of spark chamber C_5, and 290 g cm^{-2} in iron to the scintillation counter S_6 or to the spark chamber C_6. The angular acceptance of the telescope is $\theta = 90° \pm 40°$ and $\phi = 90° \pm 40°$, where θ is the angle from the incident beam, and ϕ the azimuthal angle around the beam ($\phi = 0$ at the normal to the beam orbit plane).

The colliding section was also equipped with a forward-electron tagging system [6] by which we could reject a potential source of background from the photon-photon process $e^+e^- \to e^+e^-\mu^+\mu^-$, by detecting the forward-scattered e^+ or e^-.

Data were taken at incident $e^\pm$ energies of 1.5, 1.4 and 1.3 GeV/beam with integrated luminosities of 342, 160 and 166 nb^{-1}, respectively. The luminosity was measured with a 5% accuracy by means of the small angle Bhabha scattering monitoring system [7].

Two physicists independently scanned all the

☆An earlier version of the present paper was presented to the International Symposium on Electron and photon interactions at high energies, Bonn 1973.

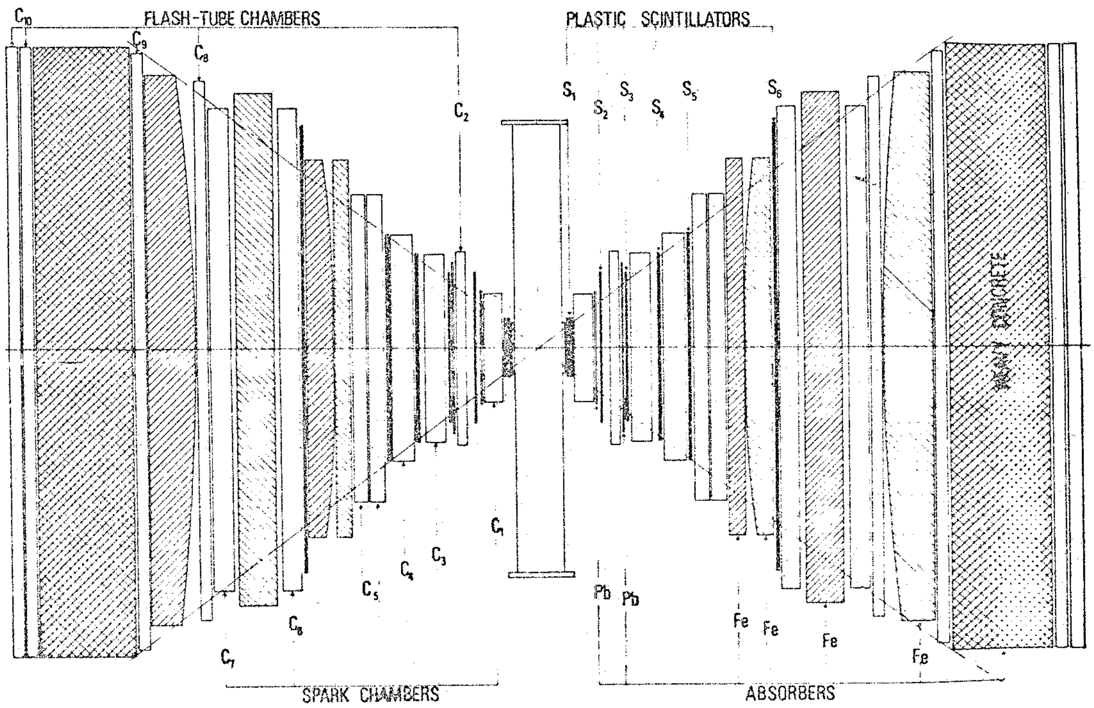

Fig. 1. Horizontal cross-sectional view of the main apparatus, C_2, C_8, C_9 and C_{10} are bigap hodoscope chambers [5]. The end chambers C_9 and C_{10} (of 8 m^2 sensitive area, filled with ~ 2.500 neon flash tubes 2 m long, of 1.8 cm diameter) were employed to observe muon stops from $e^+e^- \to \mu^+\mu^-$ at the highest machine energies. Additional equipment, not shown in the figure, was used to record the machine luminosity and to tag the $e^{\pm}$'s emitted forward in processes of the type $e^+e^- \to e^+e^-$ (see text and ref. [6]).

events twice each. No (μe) candidate was found satisfying all of the following criteria:

1) The event must contain two tracks, one in each of the two telescopes;

2) Both tracks are extrapolated into the intersection region. A non-convergence up to 15 cm at the beam position is allowed between the tracks in order to maintain a relatively high detection efficiency even for heavy leptons having considerable flight lengths before their decay†. If the two tracks meet at the e^+e^- interaction region, then the acoplanarity angle must be greater than 5°. The acoplanarity angle is defined as the angle between the two planes each of which contains one of the tracks and the beam axis.

3) One of the tracks must develop an electromagnetic shower in the thick plate chambers (electron identification).

4) The other tracks must be "μ like", which we define by the absence of visible nuclear interactions and penetration of at least 290 g cm^{-1} of iron (up to C_6 or S_6).

The following measurements were made to obtain the precise detection efficiency for (μe) pairs. The electron detection efficiency of each telescope was measured to be higher than 90% at energies greater than 600 MeV, by using wide angle Bhabha scattering. For lower energy electrons, the efficiency was determined by putting electron beams from the Frascati Synchrotron into an identical telescope. Below 600 MeV, the efficiency slowly decreases to about 50% at 300 MeV [4]. The electron detection efficien-

†Typical calculated decay lengths are 5 cm for M_H = 0.8 GeV at E_b = 1.5 GeV and 1 mm for M_H = 1.1 GeV at E_b = 1.5 GeV, where M_H is the mass of the heavy lepton, and E_b the beam energy.

cy was taken into account in calculating the expected event rates.

The apparatus was continuously monitored during the runs with e^+e^- and $\mu^+\mu^-$ pairs from the e^+e^- collision. The detection efficiency for the muons was always higher than 96%. The correct counting rate of the process $e^+e^- \rightarrow \mu^+\mu^-$ [8], measured simultaneously, shows that there is no important effect due to possible beam polarization [e.g. 9].

To set a lower limit on the mass of the heavy lepton the expected event rate was calculated for the above defined (μe) events by means of a Monte Carlo simulation. In this Monte Carlo calculation, four possible independent helicity states of the heavy leptons were generated from e^+e^- collisions through the one-photon channel [10]. Then each heavy lepton was allowed to decay into "μ" or "e" or "hadronic" decay modes. The branching ratios, as well as the decay parameters [11] for muonic or electronic decays depend on the assumed lepton model. The following three kinds of heavy leptons were considered.

A) The heavy lepton $H^\pm$ with its own lepton number, different from that of e or μ: in this case the decay parameters are

$$\rho = \delta = \tfrac{3}{4}, \qquad \eta = 0, \qquad \text{and} \qquad \xi = 1. \qquad [10]$$

The branching ratios were taken from the paper of Tsai [10]. The ambiguity in the branching ratio due to the multihadronic decay mode is negligible for the heavy lepton mass range invested here [10].

Table 1
Expected event rates.

M_H in GeV	Type of heavy lepton		
	H	E	M
0.6	5.8	5.8	6.0
0.7	7.7	7.6	8.0
0.8	8.2	8.1	8.5
0.9	6.1	6.0	6.2
1.0	4.5	4.6	4.7
1.1	3.4	3.4	3.4
1.2	2.7	2.5	2.5
1.3	1.6	1.4	1.4
1.4	0.7	0.6	0.6

M_H represents the heavy lepton mass. Heavy leptons $H^\pm$, $E^\pm$ and $M^\pm$ are assumed to have, respectively, a new lepton number, the same lepton number as $e^\mp$, and the same lepton number as $\mu^\mp$.

B) The heavy lepton $E^\pm$ with the same lepton number as $e^\mp$: in this case $\nu_H(\overline{\nu}_H)$ in eq. (1) stands for $\overline{\nu}_e$ (ν_e), and the decay parameters are

$$\rho = \delta = \eta = 0 \qquad \text{and} \qquad \xi = 3.$$

The branching ratios were taken from the work of Bjorken and Llewellyn Smith [12].

C) The heavy lepton $M^\pm$ with the same lepton number as $\mu^\mp$: then in eq. (1) $\nu_H(\overline{\nu}_H)$ represents $\overline{\nu}_\mu(\nu_\mu)$, and the decay parameters are the same as in (B). The branching ratios were deduced from the results of ref. [11].

Electrons and muons thus generated were followed in the detectors to see whether the (μe) criteria defined above were satisfied. In the Monte Carlo program, all the important experimental conditions such as the spatial distribution of the interaction points and the electron detection efficiency of the telescopes [4] were taken into account. The maximum possible systematic error is less than 10%. A typical statistical error of the Monte Carlo calculation is ± 2%.

The resulting expected numbers of events are summarized in table 1. Very similar expected event rates are obtained for the three types of heavy leptons. The muonic (electronic) branching ratio for M(E) is expected to be larger than that for H by a factor 2. This factor happens to be cancelled, however, by the smaller detection efficiency for M(E) lepton events due to the less sharp angular and energy distribution of the decay muons (electrons).

Taking three expected events to define the upper limit at 95% confidence level for no observed event, we conclude that, if the heavy lepton exists its mass must be larger than 1.15 GeV for all three types of heavy leptons considered here.

After the present paper was completed, new mass limits of 2.4 GeV and 2.0 GeV were reported for the heavy lepton M, as obtained by neutrino experiments at CERN [13] and NAL [14], respectively. Our limit of 1.15 GeV is still relevant, however, for the heavy leptons E and H defined above.

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