Hamburg talk

BNL-23513

OG 379

Conf-770883--2

Experimental Limits on Heavy Lepton Production by Neutrinos

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Abstract

We have searched for heavy charged leptons decaying semileptonically into $e^{\pm}$ in a neutrino exposure of the Fermilab 15' bubble chamber filled with a heavy-neon hydrogen mixture. If the heavy lepton couples to ν_μ with full (V-A) strength, then its mass must be greater than 7.5 GeV if negative and 9.0 GeV, if positive. If the 1.9 GeV τ-meson does couple to ν_μ, then the ν_μ-τ coupling strength must be less than 2.5% of the ν_μ-μ coupling.

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DISCLAIMER

At this conference many groups have reported on the existence of anomalous μ,e events in e^+-e^- colliding beam experiments which are inconsistent with charm production. As discussed by M. Perl in his review talk, these events are consistent with the production and leptonic decay of a heavy lepton (τ) with mass $\sim$ 1.9 GeV and leptonic branching ratio $\sim$ 20%. One open question is the lepton number of the τ. If it has the same lepton number as the muon then it should be produced in muon-neutrino interactions and it should decay into $e^\pm\nu\bar{\nu}$ as shown in Fig. 1.

We have searched for heavy lepton production and decay via the process in Fig. 1 in an experiment using the Fermilab 15' bubble chamber filled with a heavy neon-hydrogen mixture (64 atomic percent neon) exposed to the two-horn focused wideband neutrino beam produced by an average of 0.8×10^{13} 400 GeV/c protons per pulse. The neutrino spectrum extends from a few GeV up to $\sim$ 200 GeV and peaks near 25 GeV. The heavy neon mixture has a radiation length of 40 cms (the chamber is $\sim$ 10 radiation lengths across), and has an interaction length of 125 cms.

The results presented here are based on the analysis of 46,000 pictures in which 27,600 charged current ν_μ interactions were found.

The film was scanned for events with an e^+ or an e^- in the final state. Events in which the $e^\pm$ were part of a Dalitz pair or the e^- was a δ-ray or Compton electron near the vertex were rejected. The $e^\pm$ were identified on the scanning table by the following signatures:

a) a charge track which curls up with minimum ionization.

b) a charge track which radiates, followed by conversion into a visible e^+e^- pair.

Events where the $e^{\pm}$ was identified by at least two signatures and had a momentum greater than 1 GeV/c were selected. A sample of 187 events with an e^- and 80 events with an e^+ was obtained.

A substantial number of the e^+ events have a μ^- track[1] and these presumably come from charm production and its semileptonic decay.[2] From the observed multiplicity distribution of the 22 e^+ events with no μ^- and the known interaction length in neon, we calculate that 6 e^+ events have a fake μ^- track. The number of events with an e^+ but no μ^- is, therefore, 28.

Few of the e^- events are expected to have a μ^- track and the number of leaving negative tracks is consistent with the expected number of noninteracting negative hadrons. Consequently, in calculating the upper limit for a heavy lepton decaying to an e^-, it will be assumed that there are no events with μ^- tracks in the e^- sample.

The most likely interpretation for these events is that they are ν_e and $\bar{\nu}_e$ interactions.

$\nu_e + Ne \rightarrow e^- + ---$	187±14 events
$\bar{\nu}_e + Ne \rightarrow e^+ + ---$	28±6 events

From the calculated ν_e/ν_μ and $\bar{\nu}_e/\nu_\mu$ flux ratios of (1.3±0.4)% and (0.14±0.04)%, respectively we expect 215±60 ν_e and 23±8 $\bar{\nu}_e$ interactions in this sample.[3] Therefore there is no significant excess to be interpreted as a signal for heavy lepton production. Subtracting the calculated number of events from the observed number we obtain the 90% confidence upper limits of 52 e^- and 18 e^+ events which could be ascribed to heavy lepton production. Several corrections must be applied: a) From a double scan of the film, the scanning efficiency was determined to be 0.9±0.05; b) For $e^{\pm}$ tracks with momentum $\geq$ 1 GeV/c, the two signature efficiency is 0.95±0.05; c) Backgrounds of 3%(4%) in the $e^+(e^-)$

sample due to asymmetric Dalitz pairs and Compton electrons; d) 14% losses in each sample. The corrected data samples are to be compared to the 27,600 charged current events, 79% of which are in the reduced fiducial volume of the $e^{\pm}$ events, to obtain the limits:

$$\frac{\nu_\mu + Ne \rightarrow L^- + X \rightarrow e^- + X}{\nu_\mu + Ne \rightarrow \mu^- + X} \leq 3 \times 10^{-3} \qquad 90\% \text{ confidence}$$

$$\frac{\nu_\mu + Ne \rightarrow L^+ + X \rightarrow e^+ + X}{\nu_\mu + Ne \rightarrow \mu^- + X} \leq 1 \times 10^{-3} \qquad 90\% \text{ confidence}$$

The number of heavy leptons relative to the total number of charged current interactions expected in this experiment has been calculated(4) as a function of the mass $M_L^{\pm}$ as shown in Fig. 2. Also shown in Fig. 2 are the reduced ratios reflecting the $L^{\pm} \rightarrow e^{\pm}\nu\bar{\nu}$ branching ratio. The width of the line represents the uncertainties in the branching ratio calculations.(5)

From a comparison of our limits with the calculations displayed in Fig. 2, we conclude:

a) If the τ meson (mass 1.9 GeV) has the same lepton number as the μ^- and is coupled with full strength to ν_μ, its production is 60% of the charged current events. Using the measured 20% branching ratio of τ^- into e^-, we would expect $\sim$ 12% e^- events whereas our limit is 0.3%. Thus the coupling strength of ν_μ to τ must be less than 2.5% of the coupling strength of the ν_μ to μ. Alternatively, if the τ meson is not a member of the same multiplet as the μ, there can still be mixing between the μ and the τ. Our results then imply a limit on the mixing angle: $\tan^2 \theta \leq 0.025$.

b) A heavy muon-type lepton, which couples to the standard quarks with full V-A interaction, must be heavier than 7.5 GeV for L^- and 9.0 GeV for L^+.

We wish to acknowledge the help given us by the Neutrino Department and staff of the 15' bubble chamber at Fermilab and thank the scanning and measuring personnel at Columbia and Brookhaven. We thank C.H. Albright for making available to us the heavy lepton production cross-sections and for many interesting and useful discussions. We also thank Byron Roe for helpful discussions on the neutrino flux calculations.

Research supported by the U.S. DOE under contract No. EY76-C-02-0016, and the National Science Foundation.

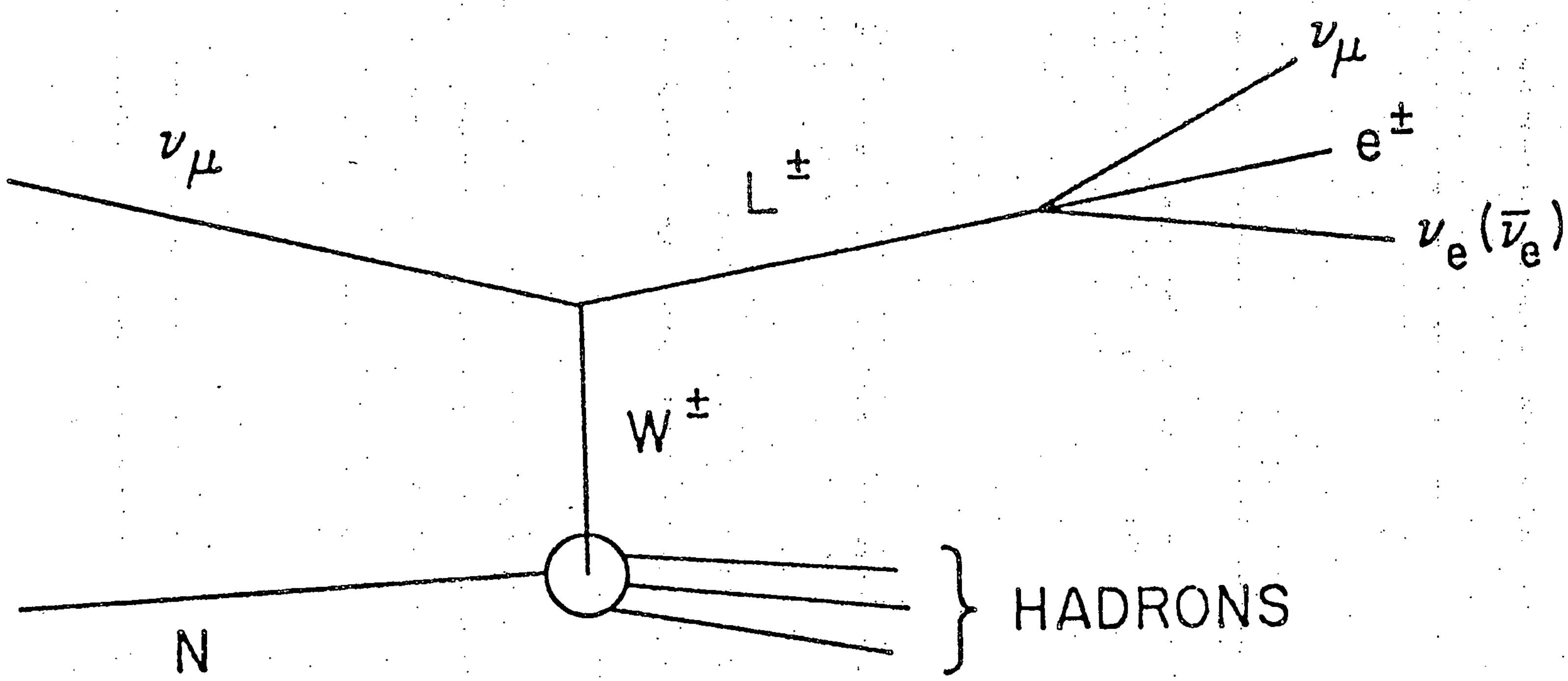
References

1. A μ^- candidate is defined as the fastest leaving negative track in an event. The π^- punch through is calculated from the observed number and momentum distribution of the interacting negative tracks and the measured hadron interaction length in the liquid.
2. C. Baltay, et al. Phys. Rev. Lett. 39 (1977) 62.
3. The main uncertainty in the ν_e/ν_μ and $\bar{\nu}_e/\nu_\mu$ flux ratio calculations come from the uncertainties on the K/π ratios, since absolute normalizations etc. cancel out in the flux ratios. We used the K/π ratios from the measurements of Baker, et al., Phys. Lett. 51B, (1974) 303, B. Aubert, et al., Le Physique Neutrino de Haute Energie, Ecole Polytechnique, Paris, p. 385 (1975), and the CalTech-Fermilab experiment (O. Fackler, private communication).
4. C.H. Albright, J. Smith and J.A.M. Vermaseren, Stony Brook Preprint ITP-SB-77-43. For the calculation, full strength V-A coupling to the light quarks is assumed and the resulting cross-sections integrated over the calculated experimental ν_μ spectrum. We have checked that in this model, the experimental momentum cut of 1 GeV/c has little effect on $e^\pm$ originating from heavy lepton decays.
5. C.H. Albright, C. Jarlskog, Nuclear Physics B84, (1975) 467.

Figure Captions

Fig. 1. Heavy lepton production by muon neutrinos.

Fig. 2. Heavy lepton production by muon neutrinos relative to normal charged current production for the Fermilab horn-focused neutrino beam.



ν_μ
$L^\pm$
ν_μ
$e^\pm$
$\nu_e(\bar{\nu}_e)$
$W^\pm$
N
HADRONS

HEAVY LEPTON PRODUCTION-FRACTION OF σ_{tot}(CC)