SEARCH FOR CLOSE-MASS LEPTON PAIRS (L^-, L^0) *

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We report preliminary results of a search in $207\,pb^{-1}$ of MARK II PEP data at $\sqrt{s} = 29\,GeV$ for lepton pairs (L^-, L^0) where the L^0 mass can be close to, but not exceed, the L^- mass. The numbers of $e - \mu$, and 3 or more charged hadrons versus isolated e or μ, events are compared to Monte Carlo predictions for $e^+e^- \rightarrow \tau^+\tau^-$, $e^+e^- \rightarrow q\bar{q}$, and two-virtual-photon processes. Possible residual signals for (L^-, L^0) pairs are compared to Monte Carlo simulations and 2σ confidence level limits on the L^- and L^0 masses are presented.

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We report preliminary results of a search in MARK II PEP data for lepton pairs (L^-, L^0) where the L^0 mass, m_0, can be close to the L^- mass, m_-, but not exceed m_-. It is convenient to define the mass difference as

$$\delta = m_- - m_0 \qquad (1)$$

We assume an $L^+ L^-$ production cross section

$$\sigma = 136\beta(3 - \beta^2)/2 \ pb \qquad (2)$$

at $\sqrt{s} = 29 \, GeV$ via

$$e^+ + e^- \rightarrow \gamma_{virtual} \rightarrow L^+ + L^- \qquad (3)$$

and L^- decay to a stable L^0 through the conventional $V - A$ weak interaction

$$L^- \rightarrow L^0 + W^-_{virtual} \qquad (4)$$

As one of us[1] first pointed out, searches for heavy sequential charged leptons which assume massless neutrinos lack sensitivity in the small δ region. In addition, possible lepton pairs with small δ may be missed in total cross section measurements because of the small visible energy in such events.

Recently Raby and West[2] have proposed that lepton pairs with $m_0 \approx 5 - 20 \, GeV$ and δ of up to a few GeV may provide solutions to both the solar neutrino problem and the dark matter problem.

The preliminary search reported here uses $207 \, pb^{-1}$ of data taken by the original MARK II detector at PEP during 1982 to 1984. Our analysis uses two event types : (i) $e - \mu$ pairs, and (ii) an isolated e or μ versus three or more charged non-leptonic particles plus photons. The event type requirements were (i) $e - \mu$ events consisted of only one e and one μ of opposite charge and with momenta $p > 0.5 \, GeV/c$; (ii) isolated lepton events consisted of an e or μ with momentum $1.25 \, GeV/c < p < 14.5 \, GeV/c$ isolated by $> 90°$ from each of the three or more charged tracks, which were required not to be identified leptons, and from any photons. If any pair of tracks were possibly, but not necessarily, an e^+ and e^- and were consistent with being an $e^+ e^-$ pair from γ conversion or π^0 Dalitz decay the charged track count was reduced by two. Charged

tracks were required to have $p > 0.1\,GeV/c$ and to satisfy loose vertex and track quality cuts. Photons were required to have $E_\gamma > 0.2\,GeV$ and to be well isolated from charged tracks. Events with a lepton versus three charged tracks were required to have zero total charge. The event types were subdivided into (i) $e - \mu$ acolinearity angle $\theta_{acol} < 25°$ and $\theta_{acol} > 25°$, and (ii) isolated e and isolated μ, 3 and ≥ 4 charged non-leptonic tracks, and non-leptonic invariant mass $m_{inv} < 2.5\,GeV/c^2$ and $m_{inv} > 2.5\,GeV/c^2$. The numbers of events in these 10 subtypes are given in Table 1.

Contributions from conventional processes were studied in Monte Carlo simulations with the indicated integrated luminosities: $e^+e^- \rightarrow \tau^+\tau^-$ $817\,pb^{-1}$; $e^+e^- \rightarrow q\bar{q}$ $972\,pb^{-1}$; $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$ $414\,pb^{-1}$; $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$ $1256\,pb^{-1}$; $e^+e^- \rightarrow e^+e^-u\bar{u}$ $385\,pb^{-1}$; $e^+e^- \rightarrow e^+e^-d\bar{d}$ $428\,pb^{-1}$; $e^+e^- \rightarrow e^+e^-s\bar{s}$ $658\,pb^{-1}$; and $e^+e^- \rightarrow e^+e^-c\bar{c}$ $1356\,pb^{-1}$. The numbers of events expected from these processes, normalized to the data integrated luminosity of $207\,pb^{-1}$, are given in Table 1. World average τ branching fractions[8] were assumed: $\tau^- \rightarrow e^-\nu_\tau\overline{\nu_e}$ 17.9%, $\tau^- \rightarrow \mu^-\nu_\tau\overline{\nu_\mu}$ 17.4%, and $\tau^- \rightarrow 3\ charged\ particles$ 13.1%. Subtraction of the predicted conventional events from the observed number of events yields an excess in 9 of the 10 categories in Table 1. This excess is very sensitive to the parameters used to simulate the performance and efficiencies of the detector and to assumptions about the conventional sources of background events. For example, the excess $e - \mu$ and isolated lepton versus 3 charged track events would vanish if the τ branching fractions were $B_e = 18.8\%$, $B_\mu = 18.2\%$, and $B_3 = 15.1\%$. Hence, although care was taken to include small corrections for differences in tracking efficiency and e, μ, and π identification efficiencies between the data and Monte Carlo, we cannot tell if there is actually an excess of events in any category.

Table 2 shows the expected numbers of events from close-mass lepton pairs of the indicated masses. The L^- branching fractions were calculated with finite L^0 mass effects included.[4] Constraints are provided by the τ branching fractions and by the requirement that $B(L^- \rightarrow L^0\bar{u}d) = 3 \times B(L^- \rightarrow L^0e^-\overline{\nu_e})$ etc. for $m_- = \infty$ and $m_0 = 0$.

The hatched areas of the plots in Figure 1 indicate the regions in (m_-, δ) space for which the expected number of close-mass lepton pair events (Table 2) exceeds the possible signal (Table 1, bottom line) by more than two standard deviations. We conclude that our preliminary study excludes close-mass lepton pairs with conventional couplings from the hatched region at the 2σ confidence level.

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3. P. R. Burchat, Proc. 2nd Conf. Intersections between Particle and Nuclear Physics (Lake Louise, Canada 1986)

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TABLE 1. Events in data, and expected from conventional sources.

	$e - \mu$ $< 25°$	$e - \mu$ $> 25°$	e vs 3 $m < 2.5$	e vs 3 $m > 2.5$	μ vs 3 $m < 2.5$	μ vs 3 $m > 2.5$	e vs > 3 $m < 2.5$	e vs > 3 $m > 2.5$	μ vs > 3 $m < 2.5$	μ vs > 3 $m > 2.5$
$e^+e^- \rightarrow$ Data	241 ±15.5	59 ±7.7	277 ±16.6	31 ±5.6	176 ±13.3	9 ±3.0	18 ±4.2	37 ±6.1	3 ±1.7	5 ±2.2
$e^+e^- \rightarrow$ $\tau^+\tau^-$	237.2 ±11.1	19.8 ±2.1	243.0 ±10.6	5.8 ±1.2	149.9 ±8.1	3.5 ±0.9	0.9 ±0.5	0.2 ±0.2	1.2 ±0.5	0.2 ±0.2
$e^+e^- \rightarrow$ $q\bar{q}$	0	0	0.2 ±0.2	0.6 ±0.4	0	0	0.2 ±0.2	1.3 ±0.5	0	0.6 ±0.4
$e^+e^- \rightarrow$ $ee\mu\mu$	4.2 ±1.4	13.6 ±2.5	0	0	0	0	0	0	0	0
$e^+e^- \rightarrow$ $ee\tau\tau$	0	0.8 ±0.3	1.3 ±0.5	0.2 ±0.2	0	0	0	0.8 ±0.4	0	0
$e^+e^- \rightarrow$ $e^+e^-u\bar{u}$	0	0	2.2 ±1.1	0.5 ±0.5	0	0	1.6 ±0.9	9.7 ±2.3	0	0
$e^+e^- \rightarrow$ $e^+e^-d\bar{d}$	0	0	0	0	0	0	1.0 ±0.7	0.5 ±0.5	0	0
$e^+e^- \rightarrow$ $e^+e^-s\bar{s}$	0	0	0.3 ±0.3	0	0	0	0.3 ±0.3	1.6 ±0.7	0	0
$e^+e^- \rightarrow$ $e^+e^-c\bar{c}$	0	0	1.1 ±0.4	0.6 ±0.3	0	0	0.9 ±0.4	4.9 ±0.9	0	0
Excess Events	−0.4 ±19.1	24.8 ±8.4	28.9 ±19.7	23.3 ±5.8	26.1 ±15.6	5.5 ±3.1	13.1 ±4.4	18.0 ±6.7	1.8 ±1.8	4.2 ±2.2

TABLE 2. Events expected from (L^-, L^0) pairs with masses m_- and $m_0 = m_- - \delta$.

| m_-, δ (GeV/c^2)	$e-\mu$ $< 25°$	$e-\mu$ $> 25°$	e vs 3 $m < 2.5$	e vs 3 $m > 2.5$	μ vs 3 $m < 2.5$	μ vs 3 $m > 2.5$	e vs > 3 $m < 2.5$	e vs > 3 $m > 2.5$	μ vs > 3 $m < 2.5$	μ vs > 3 $m > 2.5$
2, 0.5	85 ±19	4 ±4	0	0	0	0	0	0	0	0
4, 0.5	22 ±10	0	0	0	0	0	0	0	0	0
2, 1	188 ±29	13 ±8	34 ±13	0	24 ±11	0	0	0	0	0
4, 1	106 ±22	28 ±11	54 ±16	0	30 ±12	0	0	0	0	0
10, 1	4 ±4	4 ±4	9 ±7	0	0	0	0	0	0	0
3, 1.8	252 ±41	73 ±22	264 ±43	0	313 ±48	0	7 ±7	0	0	0
6, 1.8	86 ±24	133 ±30	265 ±44	14 ±10	219 ±40	0	7 ±7	0	0	0
10, 1.8	26 ±13	46 ±17	161 ±34	0	63 ±21	0	0	0	0	0
12, 1.8	12 ±7	41 ±13	52 ±15	0	27 ±11	0	4 ±4	0	0	0
13, 1.8	3 ±3	10 ±6	26 ±10	0	15 ±8	0	0	0	0	0
2.5, 2.5	210 ±27	61 ±14	505 ±56	6 ±6	336 ±46	18 ±10	6 ±6	0	6 ±6	0
5, 2.5	138 ±22	80 ±17	541 ±55	17 ±10	366 ±46	6 ±6	39 ±15	0	28 ±13	0
10, 2.5	19 ±8	106 ±18	252 ±35	0	96 ±22	0	5 ±5	0	25 ±11	0
13, 2.5	7 ±3	41 ±8	70 ±14	0	24 ±8	0	13 ±6	0	3 ±3	0
4, 4	128 ±15	72 ±11	481 ±43	61 ±15	354 ±37	47 ±14	122 ±22	72 ±17	54 ±15	70 ±16
9, 4	49 ±11	105 ±16	268 ±36	73 ±19	199 ±32	30 ±12	102 ±22	50 ±16	73 ±19	70 ±19
13, 4	17 ±5	79 ±10	91 ±16	8 ±5	53 ±12	6 ±4	22 ±8	6 ±4	22 ±8	6 ±4
7, 7	46 ±9	92 ±13	176 ±29	120 ±24	180 ±29	52 ±16	120 ±24	260 ±35	66 ±18	184 ±30
12, 7	5 ±3	99 ±13	60 ±16	48 ±14	53 ±15	37 ±12	52 ±14	116 ±22	16 ±8	45 ±14
14, 7	2 ±1	52 ±6	25 ±6	12 ±4	15 ±4	12 ±4	12 ±4	24 ±6	10 ±4	16 ±5
10, 10	19 ±5	109 ±12	116 ±20	92 ±18	63 ±15	70 ±16	65 ±15	177 ±25	35 ±11	143 ±22
14, 10	4 ±2	40 ±6	26 ±7	13 ±5	6 ±4	15 ±6	8 ±4	13 ±5	2 ±2	15 ±6
14, 14	3 ±1	52 ±6	9 ±4	11 ±4	10 ±4	10 ±4	11 ±4	25 ±6	6 ±3	16 ±5
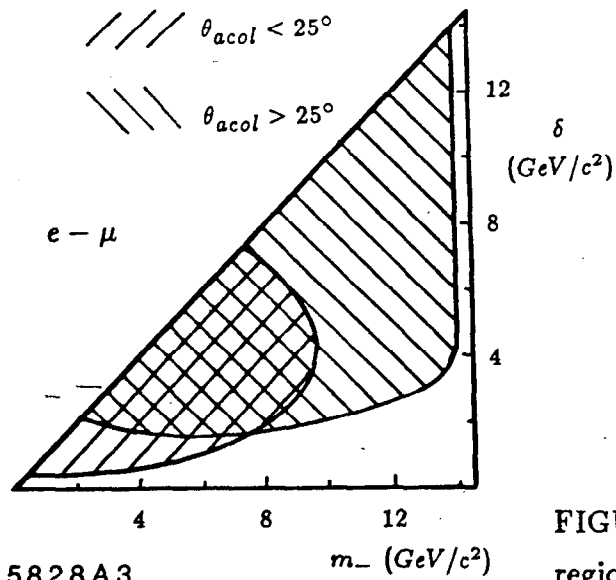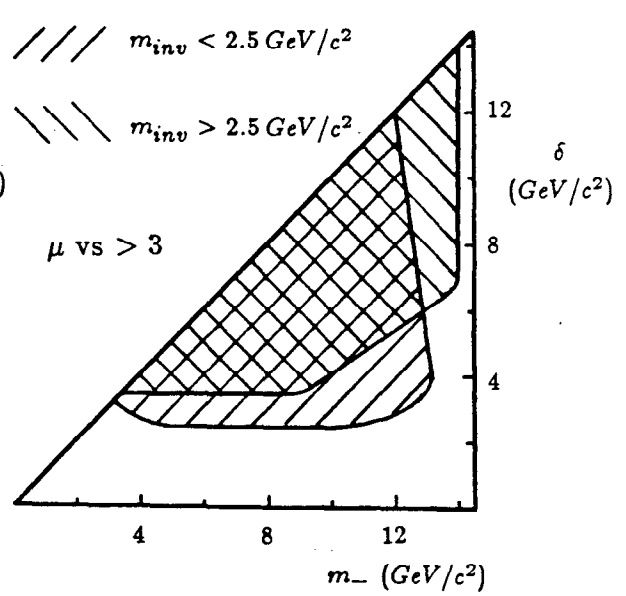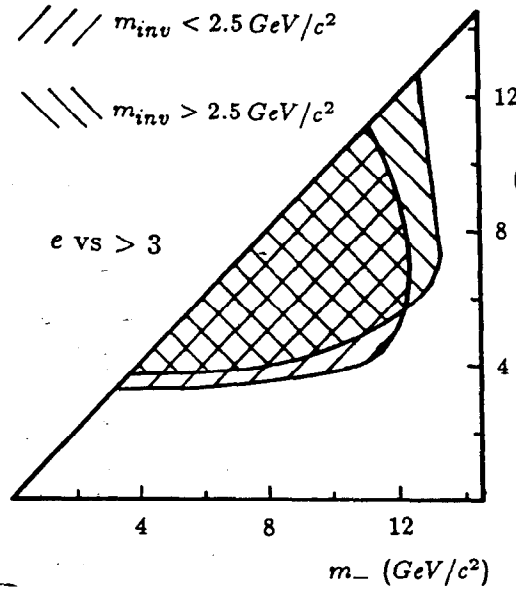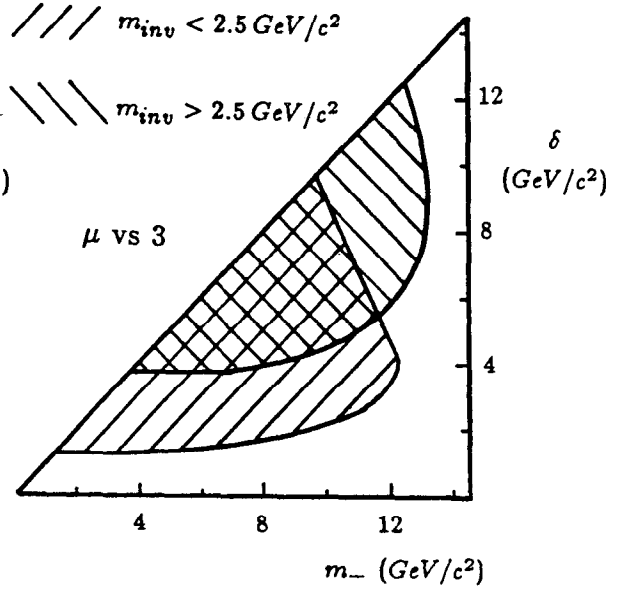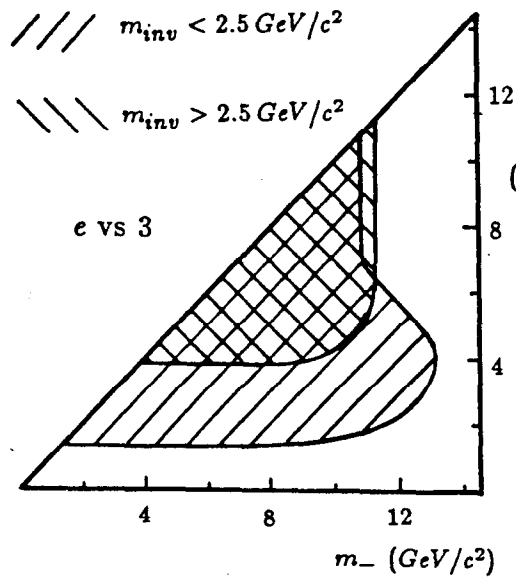
FIGURE 1. (L^-, L^0) pairs within the hatched region are excluded with $> 2\sigma$ confidence.

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