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Search for Lepton-Pair Decays of Mesonic Resonances*

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In this letter we report a search for lepton pairs originating from mesonic resonances in the reaction $K^- + p \rightarrow \Lambda + 2$ prongs. The motivations for the experiment were (a) a test for Ne'eman's proposal for a new vector field possibly associated with the ϕ meson,[1] (b) a test for the quantum electrodynamic description of the muon,[2] (c) a systematic search for undiscovered meson resonances with a major decay mode into lepton pairs. No unambiguous evidence is obtained in this experiment for lepton pairs, enabling us thereby to exclude the ϕ as a candidate for Ne'eman's field and also extend the quantum-electrodynamic description of the muon to another class of experiments.

The experiment was performed with 2.45-, 2.6-, and 2.7-BeV/c K^- in the Lawrence Radiation Laboratory's 72-in. hydrogen bubble chamber. In a measured sample of 23,500 V 2-prong events, 17,800 of the V's were found to fit $\Lambda \rightarrow p\pi^-$. In bubble-chamber kinematic analyses, one usually assumes that the charged tracks at the interaction vertex are pions or kaons, and indeed of these, 2160 fitted $\Lambda\pi^+\pi^-$ with $\chi^2 < 24$ for this 4-constraint fit. Most of the remainder fitted either $\Lambda\pi^+\pi^-\pi^0$, $\Lambda\pi^+\pi^-$MM (where MM, the missing mass, is greater than π^0), or ΛK^+K^-. However 1510 events fitted none of these reactions. Among this last group, one would expect to find candidates for the reaction $K^- + p \rightarrow \Lambda + \ell^+ + \ell^-$ where ℓ is a lepton, i.e., either a muon or electron.

Events fitting $\Lambda\pi^+\pi^-$ and the 1510 events that did not fit any reaction were subjected again to a computer fit assuming that the two tracks at the production vertex were muons or electrons. The results were: (a) Some events that had previously fitted $\Lambda\pi^+\pi^-$ now also fitted $\Lambda\ell^+\ell^-$. We considered them as lepton-pair candidates if the confidence level of the fit to $\Lambda\ell^+\ell^-$ was three times greater than for $\Lambda\pi^+\pi^-$.[3] (b) For those events with no previous fit, some now fitted $\Lambda\ell^+\ell^-$ with $\chi^2 < 24$. Table I summarizes the results of these fits. For those events fitting both $\Lambda\mu^+\mu^-$ and Λe^+e^- we have chosen the hypothesis with the higher confidence level. After the first measurement we are left with 75 candidates for $\Lambda\mu^+\mu^-$ and 24 for Λe^+e^-. In this manner, starting from 17,800 events, we obtain an enriched sample of possible lepton pairs upon which we perform other studies.

Let us first investigate the χ^2 distribution for the fits to $\Lambda\ell^+\ell^-$ for type (a) events, that also fit $\Lambda\pi^+\pi^-$. This is shown in Fig. 1a for $\Lambda\mu^+\mu^-$ and in 1b for Λe^+e^-, where we plot χ^2 for $\Lambda\pi^+\pi^-$ vs χ^2 for $\Lambda\ell^+\ell^-$. The solid curves represent different ratios of confidence level based on the fit to the two hypotheses. The lined areas in the projections refer to events that did not fit $\Lambda\ell^+\ell^-$ with $\chi^2 < 24$; the shaded area in the other axes refers to events with $C_{\ell^+\ell^-} > 3C_{\pi^+\pi^-}$. It is clear from the distribution of points that the intrinsic uncertainties on each event are such that there can be no clean separation of lepton pairs. The events with $C_{\ell^+\ell^-} > 3C_{\pi^+\pi^-}$ are entirely consistent with the expected χ^2 distribution for a 4-constraint fit. This condition merely permits us to deal with an enriched sample of possible candidates for lepton pairs.

The condition $C_{\ell^+\ell^-} > 3C_{\pi^+\pi^-}$ also rejects possible lepton-pair events for which we must apply a correction for later evaluation of branching ratios.

We can estimate this correction by assuming the χ^2 distribution for the true $\Lambda \ell^+ \ell^-$ events to be the same as for true $\Lambda \pi^+ \pi^-$ where we have an experimental value, and that the distribution for the wrong hypothesis is the same in either case. This estimate indicates that 65% of the $\Lambda \mu^+ \mu^-$ and 82% of the $\Lambda e^+ e^-$ are examined under the imposed conditions. This fraction f is reported in the last column of Table I. From Fig. 1 it is evident that had we set a higher ratio for the confidence levels, f would be smaller.

To test the validity of this selection criteria we made a Monte Carlo calculation, using the program FAKE[4] to generate events in the 72-in. bubble chamber. A sample of fictitious $\Lambda \pi^+ \pi^-$ events was generated taking into account the known production rates and angular distributions of ρ^0 and $\Sigma_\delta^\pm(1385)$ in this final state at these momenta.[5] These events were then fitted to $\Lambda \ell^+ \ell^-$. Furthermore, to evaluate our detection efficiency for ω or ϕ decaying in lepton pairs, we generated samples of $\Lambda \ell^+ \ell^-$ events with the known production angular distribution for these resonances[5,6] and then fitted them to $\Lambda \pi^+ \pi^-$. The results are in Table II.

The agreement between the Monte Carlo-generated events and our measured $\Lambda \pi \pi$ events is quite good, indicating that the number of lepton pairs in our sample is very small, if not zero.[7] On the other hand, the same Monte Carlo calculations (b), (c), (d), and (e) show that for the known resonances in this mass region, our method allows us to select from 65%, in the worst case, to 98% of the lepton pairs produced.

We studied candidate events further, in an attempt to isolate lepton pairs from the background. All 99 events were remeasured to see if the previously poor fits to $\Lambda \pi^+ \pi^-$ could result from measurement error. After remeasurements 24 events are left, indicating that poor measurements, more than ambiguous kinematical conditions, led to the selection of so many $\Lambda \pi^+ \pi^-$ events as $\Lambda \ell^+ \ell^-$.

We have inspected the 48 tracks associated with the candidates for lepton pairs for the following properties:

1. Ionization. Only one track had a momentum sufficiently low (< 140MeV/c) to distinguish pions from leptons by ionization. It was consistent with being a pion.

2. Interactions. Two interactions were observed in 16 meters of path length, where we would expect 1.9 for pions of this momentum spectrum in hydrogen.

3. δ rays. Among the 24 candidates, only 10 had δ rays on one or both possible leptons. None of these δ rays had an energy and angle that would allow separation between pions and leptons.

In Fig. 2a and b we plot the effective masses of the 15 possible muon pairs and nine possible electron pairs respectively. Neither distribution shows peaking at any particular mass. Instead they roughly approximate the $\pi\pi$ mass spectrum for the reaction $K^-+p\rightarrow\Lambda+\pi^++\pi^-$. In particular, for the ϕ there is one candidate among the muon-pair events with a mass M = 1036± 13 MeV. For the ω there is a possible $\mu^+\mu^-$ event (M = 799± 9 MeV) and a possible e^+e^- event (M = 795± 10 MeV). These three events fit the $\Lambda\pi^+\pi^-$ hypothesis with a probability of 5%, < 0.5%, and < 0.5%, respectively.

We conclude that in the sample examined, there is no clear evidence for lepton-pair production. We can calculate only upper limits for the leptonic decay rate of ω and ϕ knowing the number of ω's produced at these energies in the $K^-+p\rightarrow\Lambda+\pi^++\pi^-+\pi^0$ channel and ϕ produced in the $K^-+p\rightarrow\Lambda+K+\overline{K}$ channel. Table III summarizes the results. The upper limit for $\omega\rightarrow e^+e^-$ decay does not disagree with the previously published results of Murray et al.[8] which gave < 0.01, and Barmin et al.[9] which gave < 0.0039±.0015 and Bezaguet et al.[10], which gave $(\omega\rightarrow e^+e^-)/(\omega\rightarrow\pi^+\pi^-\pi^0) < 2.8\times10^{-3}$.

Finally we make some remarks about the theoretical predictions concerning this experiment.

1. The suggested fifth interaction of Ne'eman is similar to electromagnetism, but some ten times stronger. The associated vector field χ is coupled to the strangeness current, and in connection with SU3 would provide symmetry-breaking effects in the correct direction to require all masses to obey the first-order mass formula. It was further suggested that if the χ was a massive particle, it could also explain the muon's mass. Ne'eman suggested that $\phi(1020, 1^-)$ was a good candidate for the χ field. Its connection with the muon can be checked by measuring the ratio $(\phi \rightarrow \mu^+\mu^-)/(\phi \rightarrow K\bar{K})$. Beder et al. find that if the ϕ is the χ field and if it is responsible for the muon mass, then the ratio should be about 10.[11] Our upper limit of 0.005 for this ratio is more than three orders of magnitude lower than the calculated ratio of Beder et al., leading to the conclusion that even if the ϕ is the vector field χ, it cannot be made responsible for the mass of the muon.

2. In the past few years many experiments have been performed to check the validity of the quantum electrodynamic description of the muon. So far no difference between muon- and electron-pair production has been observed. A different approach for checking electrodynamics over small distances consists in comparing the branching ratios of strongly interacting vector mesons (ω, ϕ) decaying into an electron pair or into a muon pair. Under certain circumstances the latter decay may be expected to be greatly enhanced.[12] Although our branching ratios are only upper limits, we see no evidence for an anomalous interaction of the muon.

3. In the ω, ϕ mixing model the ratios of rates $(\omega \rightarrow e^+e^-)/(\phi \rightarrow e^+e^-)$ and of $(\omega \rightarrow \mu^+\mu^-)/(\phi \rightarrow \mu^+\mu^-)$ are predictable, since only the unitary octet component of the

physical states ω and ϕ is coupled to electromagnetism. Using the physical masses of ω, ϕ, K^*, and ρ,[13] and the experimental widths of ω and ϕ, one finds $[(\omega \rightarrow \ell^+\ell^-)/(\text{total } \omega)]/[(\phi \rightarrow \ell^+\ell^-)/(\phi \rightarrow K\bar{K})] < 0.2$. This is not in contradiction to the experimental upper limits reported here.

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FOOTNOTES AND REFERENCES

*Work sponsored by the U. S. Atomic Energy Commission.

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6. Private communication from James S. Lindsey, Lawrence Radiation Laboratory, Berkeley.

7. We have plotted the fictitious events in a scatter plot like Fig. 1 and obtain similar two-dimensional distributions and projections as well.

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12. E. D. Zhizhin and V. V. Solov'ev, in Proceedings of the 1962 International Conference on High Energy Physics at CERN (CERN, Geneva 1962), p. 493 and Soviet Phys. JETP 43, 268 (1962).

13. R. H. Dalitz, in Proceedings of the Sienna International Conference on Elementary Particles (Societa Italiana de Fisica, Bologna, Italy, 1963), Vol. 2, p. 171.

Table I. Summary of events fitted to $\Lambda\mu^+\mu^-$ and Λe^+e^-.

Type of fit	Number of events	Fitted reaction	Good fits		$C_{\ell^+\ell^-} > 3C_{\pi^+\pi^-}$, M=1*		$C_{\ell^+\ell^-} > 3C_{\pi^+\pi^-}$, M>1*		f†
			Events	%	Events	%	Events	%	(%)
(a) Fit $\Lambda\pi^+\pi^-$	2160	$\Lambda\mu^+\mu^-$	1280	59.0	43	2.0	90	0.4	65.2
		Λe^+e^-	52	2.4	17	0.7	4	0.2	82.0
(b) No previous fit	1510	$\Lambda\mu^+\mu^-$	32		32		6		
		Λe^+e^-	8		8		5		

*$C_{\ell^+\ell^-}$ is the confidence level for the fit $\Lambda\ell^+\ell^-$, where ℓ^+ is a lepton. M =1 means events measured only once, M > 1 means events measured two or three times.

†f is the fraction of $\Lambda\ell^+\ell^-$ events examined under our criteria.

Table II. Summary of Monte Carlo generated events.

Type generated	Number generated	Fitted reaction	Good fits Events	Good fits %	$C_{\ell^+\ell^-} > 3C_{\pi^+\pi^-}$ Events	$C_{\ell^+\ell^-} > 3C_{\pi^+\pi^-}$ %	f (%)
(a) $\Lambda\pi^+\pi^-$ *	4200	$\Lambda\mu^+\mu^-$	2680	64.0	110	2.6	65
	2700	Λe^+e^-	43	1.6	12	0.5	85
(b) $\Lambda\mu^+\mu^-(M_{\mu^+\mu^-} = M_\omega)$	900	$\Lambda\pi\pi$	365	40.5	777	86	86
(c) $\Lambda e^+e^-(M_{e^+e^-} = M_\omega)$	870	$\Lambda\pi\pi$	57	6.6	848	98	98
(d) $\Lambda\mu^+\mu^-(M_{\mu^+\mu^-} = M_\phi)$	970	$\Lambda\pi\pi$	775	80.0	630	65	65
(e) Λe^+e^- $(M_{e^+e^-} \doteq M_\phi$	980	$\Lambda\pi\pi$	138	14.1	950	97	97

*This sample has 50% phase space, 22% ρ^0, 19% Y^{*+}, 9% Y^{*-}.

Table III. Branching ratios for lepton pair decays of ω and ϕ.

	$\mu^+\mu^-$	e^+e^-	Total[a]	Corrected total[b] μ	Corrected total[b] e	Branching ratios	
ω	1?	1?	980 ± 50	840	960	$\frac{\omega \to \mu^+\mu^-}{\text{total } \omega} < 0.0012$	$\frac{\omega \to e^+e^-}{\text{total } \omega} < 0.0010$
ϕ	1?	0	290 ± 30	188	280	$\frac{\phi \to \mu^+\mu^-}{\phi \to K\bar{K}} < 0.0052$	$\frac{\phi \to e^+e^-}{\phi \to K\bar{K}} < 0.0036$

a. Total number of ω and ϕ found in the same path length and same topology as examined here, corrected for neutral decays.

b. Here we use the factors f calculated in Table II.

FIGURE CAPTIONS

Fig. 1. χ^2 for $\Lambda 2\pi$ fit ($\chi^2_{2\pi}$) versus χ^2 for $\Lambda 2\ell$ fit ($\chi^2_{2\ell}$). In (a) the leptons are $\mu^+\mu^-$; in (b) the leptons are e^+e^-. On the right is the χ^2 distribution for the $\Lambda 2\pi$ fit; lined areas refer to events that did not fit $\Lambda\ell^+\ell^-$. On the horizontal axes is reported the χ^2 distribution for events that fitted $\Lambda\ell^+\ell^-$; the shaded area refer to events with $C_{\ell^+\ell^-} > 3C_{\pi^+\pi^-}$.

Fig. 2. (a) Invariant mass distribution of the ($\mu^+\mu^-$) system for the 15 candidates for $\Lambda\mu^+\mu^-$. (b) Invariant mass distribution of the (e^+e^-) system for the nine candidates for Λe^+e^-. (c) Momentum distribution of charged secondaries of the above 24 events.

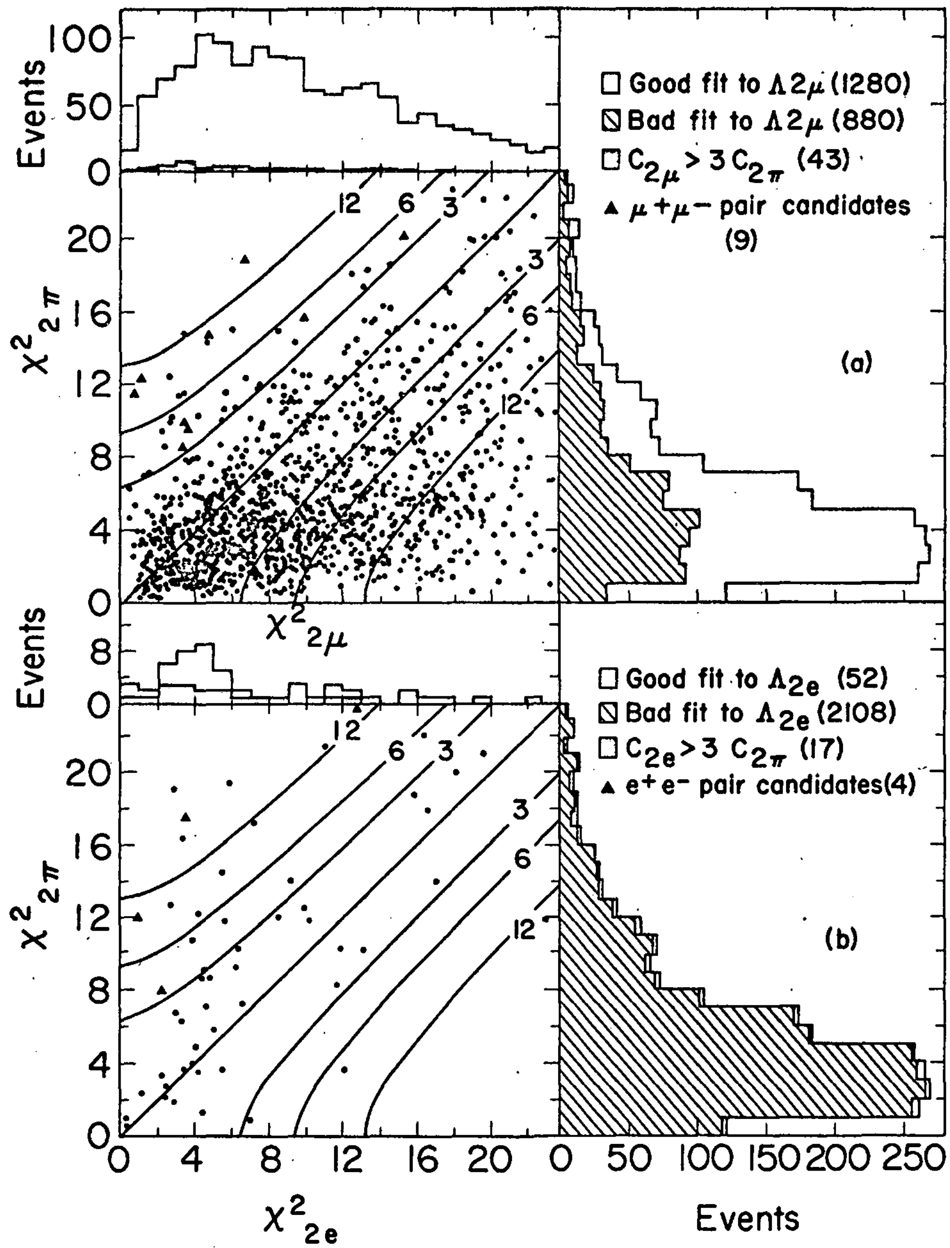
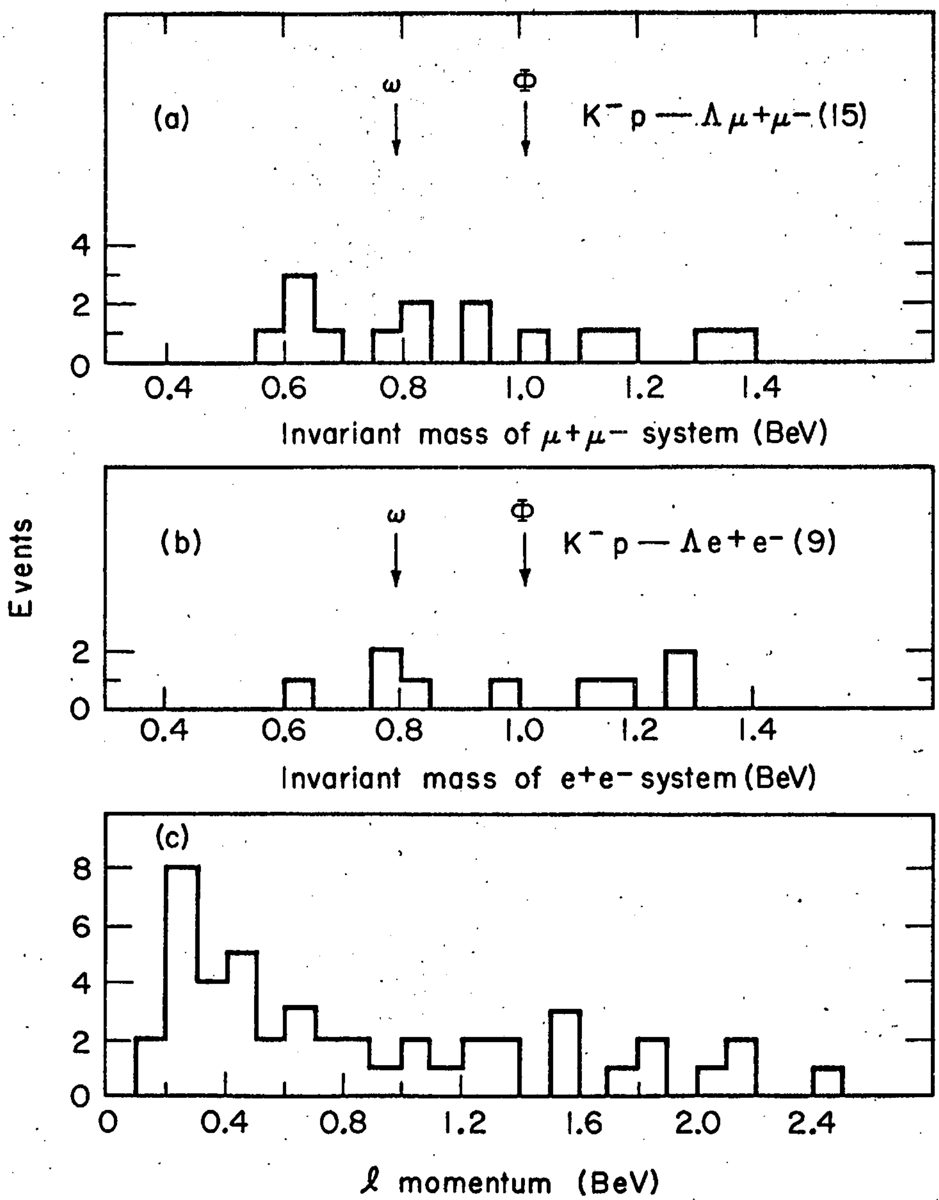

Events
100
50
0
Good fit to Λ2μ (1280)
Bad fit to Λ2μ (880)
C2μ > 3 C2π (43)
▲ μ+μ− pair candidates (9)
χ²2π
(a)
χ²2μ
Events
8
Good fit to Λ2e (52)
Bad fit to Λ2e (2108)
C2e > 3 C2π (17)
▲ e+e− pair candidates (4)
χ²2π
(b)
0 4 8 12 16 20
χ²2e
0 50 100 150 200 250
Events
MUB-5060

Fig. 1.



MUB-5059

Fig. 2.