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SEARCH FOR $\Phi \rightarrow \mu^+\mu^-$

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Angela Barbaro-Galtieri and Robert D. Tripp

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(Presented by Ronald R. Ross)

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Recently Ne'eman suggested the existence of a fifth interaction, similar to electromagnetism but some ten times stronger, mediated by a vector field or particle χ, coupled to the strangeness current S = Y-B.[1] In connection with SU_3 this interaction would provide symmetry-breaking effects in the correct direction to require all masses to obey the first-order mass formula.[2] Furthermore, if the χ is a massive particle, it could also explain the muon's mass. A mass $m_\chi > m_{2\pi}$ seems consistent with most experimental results, and Ne'eman suggests that the Φ (1020, 1^-) is a good candidate to be the χ field. Its connection with the muon can be checked by measuring the $\Phi \to \mu^+\mu^-$ decay rate and comparing it with the $\Phi \to e^+e^-$ decay mode. Beder et al. find that if the Φ is the χ field and it is responsible for the muon mass, it should decay via a muon pair ten times more rapidly than via a $K\bar{K}$ pair.[3] That is, $R[(\Phi \to \mu^+\mu^-)/(\Phi \to K\bar{K})]$ would be approximately 10, the calculated width for $\Phi \to \mu^+\mu^-$ being 30 MeV, about ten times the experimental width $\Gamma_\Phi = 3.1 \pm 0.6$ MeV.[4] We report in this paper an experiment performed to check the validity of this theory. In particular, we have investigated the decay modes $\Phi \to \mu^+\mu^-$ and $\Phi \to e^+e^-$. In an experiment performed with the Lawrence Radiation Laboratory 72-inch hydrogen bubble chamber while making a general study of K^-p interactions at 2.4-and 2.7-BeV/c incident K^- momentum,[5] we have investigated the reactions

$$K^- p \rightarrow \Lambda \mu^+ \mu^- \quad (1)$$

and

$$K^- p \rightarrow \Lambda e^+ e^- \quad (2)$$

Approximately 18 000 events with the V 2-prong topology have been measured. In about 8000 events the V fitted a Λ, 70 events fitted the reaction $K^- p \rightarrow \Lambda \Phi$ with $\Phi \rightarrow K^+ K^-$, and 1250 events passed the criteria for fitting $K^- p \rightarrow \Lambda \pi^+ \pi^-$. A cutoff in the four-constraint fit to this reaction has been set at $\chi^2 = 24$. The χ^2 distribution is reported in Fig. 1. Since the momentum distribution of muons and electrons is expected to be peaked above 200 MeV/c, we do not expect to separate muons and electrons from pions on the basis of ionization measurement. A sample of events has been selected with the following criteria: (a) events that did fit Λ for the V, but did not fit any of the usual reactions involving a Λ: (b) events that had a fit for $\Lambda \pi^+ \pi^-$ but for which the χ^2 was larger than 5. In our sample 435 events are of type a and 487 of type b.

These selected 922 events have been fitted again, with the assumption that the two tracks at the production vertex are muons or electrons. Table I summarizes the results of these fits.

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

Events	Fitted reaction	Good fit	$CL > CL_{2\pi}$ (a)	$CL > 5CL_{2\pi}$
Type a, 435	$\Lambda \mu^+ \mu^-$	13		13
	$\Lambda e^+ e^-$	9		9
Type b, 487	$\Lambda \mu^+ \mu^-$	326	63	19
	$\Lambda e^+ e^-$	128	24	8

(a) CL = confidence level for the fit

Few events of type a have a good fit, because badly measured events fall in this category. The last two columns report the number of events whose fit is better for the μ and e hypothesis than for the π hypothesis. We consider as candidates for Reactions (1) and (2) only events for which $CL > 5\,CL_{2\pi}$.

In Fig. 1, we plot χ^2 for $\Lambda 2\pi$ fit versus χ^2 for $\Lambda 2\mu$ fit. The solid curves represent different ratios of confidence level (CL). Figure 2 represents a similar scatter diagram for the e^+e^- hypothesis. On each axis the histogram represents the χ^2 distribution for that hypothesis; the shaded area refers to events that did not fit the other hypothesis for the particle masses. Some of the events fit $\mu^+\mu^-$ as well as e^+e^-; in this case the hypothesis with the higher CL has been chosen. We are left with 22 candidates for $\mu^+\mu^-$ and 11 for e^+e^-.

In Fig. 3a we plot the invariant mass $M(\mu^+\mu^-)$ of the system $\mu^+\mu^-$ of Reaction (1), and in Fig. 3b, $M(e^+e^-)$. Neither distribution shows any peaking at any particular mass, but they are similar to a $\pi\pi$ mass spectrum for the reaction $K^-p \rightarrow \Lambda\pi^+\pi^-$. Of the known resonances, only the ω shows two possible candidates in the $\mu^+\mu^-$ system. In Fig. 3c we plot the p distribution of the secondary tracks of the 33 candidates. The total length of these tracks is L = 24 m. We observe three interactions along the tracks, while we expect none for muons or electrons. Were these tracks all π^+, or π^-, from the known cross sections at their momenta ($\sigma_{av} \approx 30$ mb) we would expect 2.7 interactions in this path length, which is consistent with what we observe.

In conclusion, in the examined sample there are two possible candidates for $\omega \rightarrow \mu^+\mu^-$; however, all events are consistent with being $\pi\pi$ productions. At this stage of the experiment, we can calculate only upper limits for

lepton-pair decays of the ω and ϕ mesons, which we produce in other channels. Table II summarizes the results.

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

	$\mu^+\mu^-$	e^+e^-	Total[(a)]	$2/3 \times$ total[(b)]	Branching ratios	
ω	2?	0	540	360	$\frac{\omega\to\mu^+\mu^-}{\text{total } \omega} < 0.005$	$\frac{\omega\to e^+e^-}{\text{total } \omega} < 0.003$
ϕ	0	0	111	74	$\frac{\phi\to\mu^+\mu^-}{\Phi(K\bar{K})} < 0.013$	$\frac{\phi\to e^+e^-}{\Phi(K\bar{K})} < 0.013$

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

(b) This factor 2/3 takes into account the fact that we examine only events for which $CL_{2\mu}$ (or CL_{2e}) $> 5\ CL_{2\pi}$.

The upper limit for $\omega \to e^+e^-$ decay is not in disagreement with the previously published result of Murray et al. ($R < 0.01$) and of Barmin et al. ($R < 0.0039$).[6]

The upper limit for $R[(\Phi \to \mu^+\mu^-)/(\Phi \to K\bar{K})]$ turns out to be 0.013 which is three orders of magnitude lower than the value $R = 10$ calculated by Beder et al.[3] This result rules out the suggestive speculation that the Φ meson interacts with the muon and produces its mass, leading to the conclusion that even it the Φ meson is the vector field χ of Ne'eman's fifth interaction,[7] it cannot be responsible for the mass of the muon.

We wish to acknowledge the support and cooperation of the Bevatron and bubble chamber crews and of the scanning and measuring staff, as well as of the many other physicists involved in this K^- experiment. We especially thank Professor Luis W. Alvarez for his stimulation and encouragement throughout the experiment. This work was done under the auspices of the Atomic Energy Commission.

FOOTNOTES AND REFERENCES

1. Y. Ne'eman, Phys. Rev. 134, B1355 (1964).

2. M. Gell-Mann, California Institute of Technology Synchrotron Laboratory Report TSL-20, 1961 (unpublished); S. Okubo, Progr. Theoret. Phys. (Kyoto) 27, 949 (1962).

3. D. Beder, R. Dashen, and S. Frautshi, California Institute of Technology, private communications, July 1964. We are indebted to Dr. S. Frautschi for communicating to us this result prior to publication.

4. Weighted average from the values of P. L. Connelly et al., in Proceedings of the Sienna International Conference on Elementary Particles, 1963 (Societa Italiana di Fisica, Bologna, Italy, 1963), Vol. 1, p. 130; N. Gelfand et al., Phys. Rev. Letters 11, 438 (1963); R. Armenteros et al., quoted by A. Berthalot in Proceedings of the Sienna International Conference on Elementary Particles, 1963 (Societa Italiana di Fisica, Bologna, Italy, 1963), Vol. 2, p. 70.

5. J. J. Murray, J. Button-Shafer, F. T. Shively, G. H. Trilling, J. A. Kadyk, A. Rittenberg, D. M. Siegel, J. S. Lindsey and D. W. Merrill, Lawrence Radiation Laboratory Report UCRL-11426, May 1964, to be presented at the 1964 International Conference on High Energy Physics, Dubna, USSR, Aug. 1964.

6. J. J. Murray, Jr., M. Ferro-Luzzi, D. O. Huwe, J. B. Shafer, F. T. Solmitz, and M. L. Stevenson, Phys. Letters 7, 358 (1963); V. V. Barmin, A. G. Dolgolenko, Yu S. Krestnikov, A. G. Meshkovsky, and V. A. Shebanov, in Proceedings of the Sienna International Conf. on Elementary Particles, 1963, Vol. 1, p. 207.

7. It should be pointed out that this experiment cannot prove whether the Φ is or is not the postulated vector field, χ, of the fifth interaction.

Figure Captions

Fig. 1. χ^2 for $\Lambda 2\pi$ fit ($\chi^2_{2\pi}$) versus χ^2 for $\Lambda 2\mu$ fit ($\chi^2_{2\mu}$). On the right is the χ^2 distribution for $\Lambda 2\pi$. On the X axes is reported the χ^2 distribution for only those events satisfying $CL_{2\mu} > 5\, CL_{2\pi}$. The solid lines represent different ratios of confidence level for $\Lambda 2\mu/\Lambda 2\pi$ hypotheses.

Fig. 2. χ^2 for $\Lambda 2e$ fit (χ^2_{2e}) versus χ^2 for $\Lambda 2\pi$ fit ($\chi^2_{2\mu}$). On the right is the $\chi^2_{\Lambda\pi^+\pi^-}$ distribution for $\Lambda\pi^+\pi^-$. On the X axis is reported the χ^2 distribution for only those events satisfying $CL_{2\mu} > 5\, CL_{2\pi}$. The solid lines represent different ratios of confidence levels for $\Lambda 2e/\Lambda 2\pi$ hypothesis.

Fig. 3(a). Invariant mass distribution of the ($\mu^+\mu^-$) system for 22 events satisfying the criteria (see text) for fitting $K^-p \rightarrow \Lambda\mu^+\mu^-$. (b) Invariant mass distribution of the (e^+e^-) system for 11 events fitting $K^-p \rightarrow \Lambda e^+e^-$. (c Momentum distribution of μ or e tracks of the above 33 events.

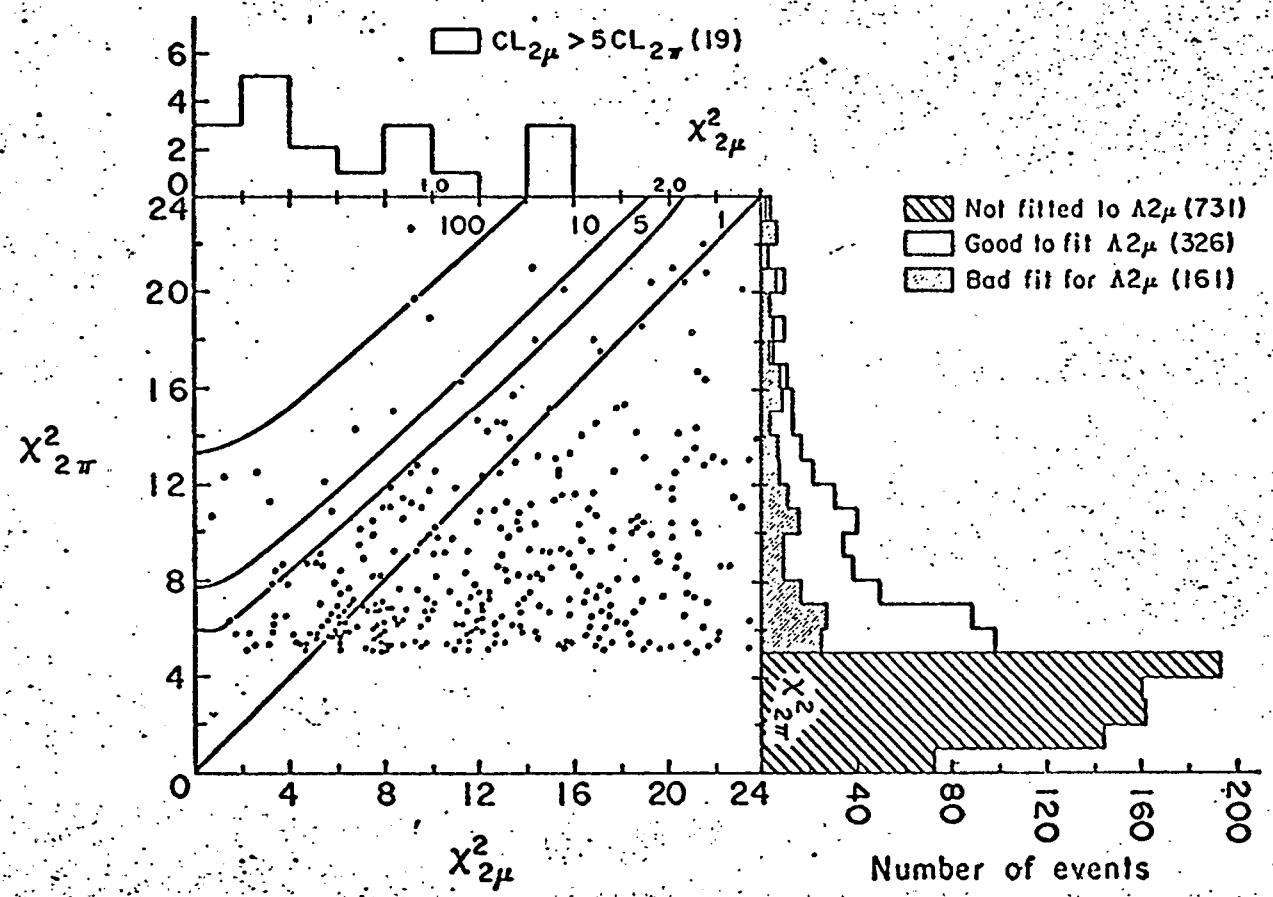

$CL_{2\mu} > 5CL_{2\pi}$ (19)
$\chi^2_{2\mu}$
$\chi^2_{2\pi}$
Not fitted to $\Lambda 2\mu$ (731)
Good to fit $\Lambda 2\mu$ (326)
Bad fit for $\Lambda 2\mu$ (161)
Number of events
MUB-3418

Fig. 1.

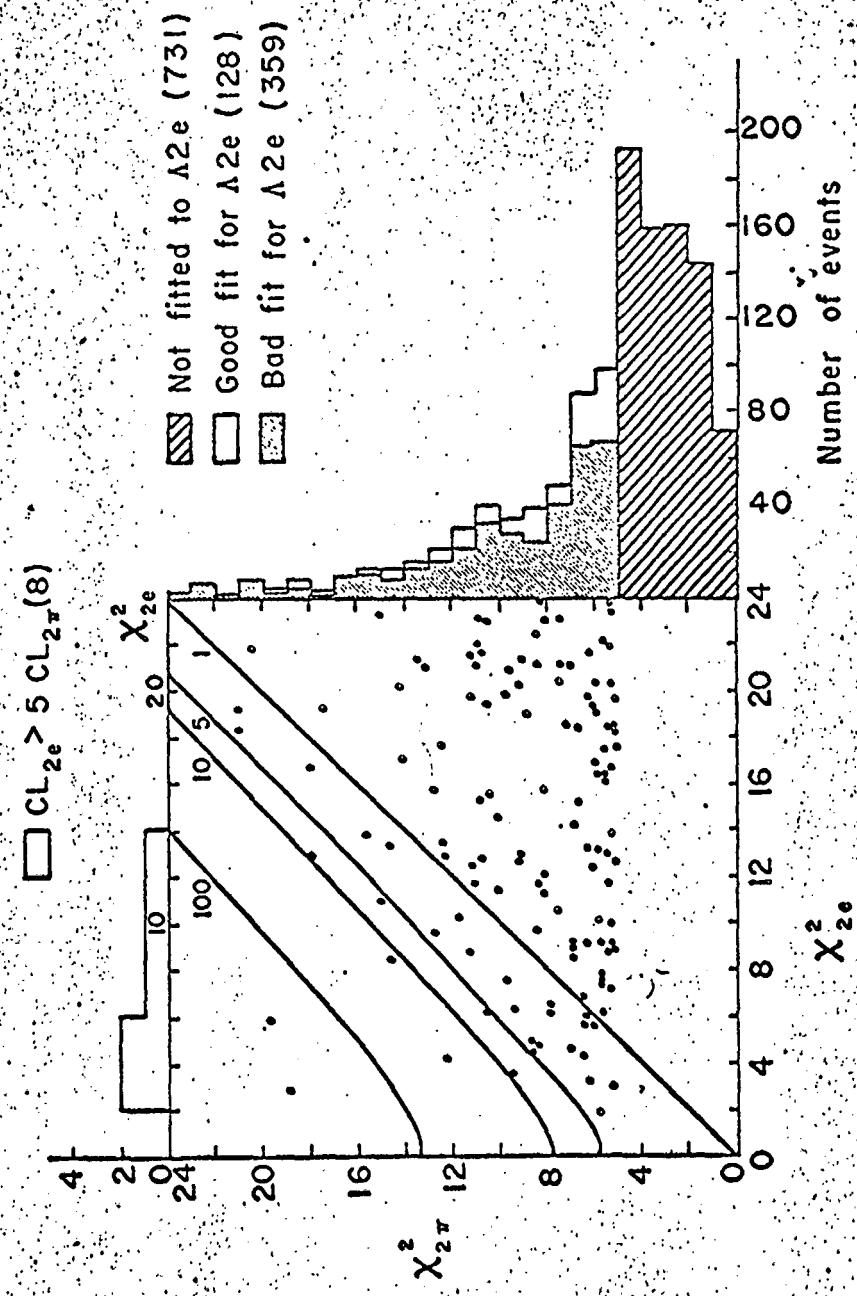
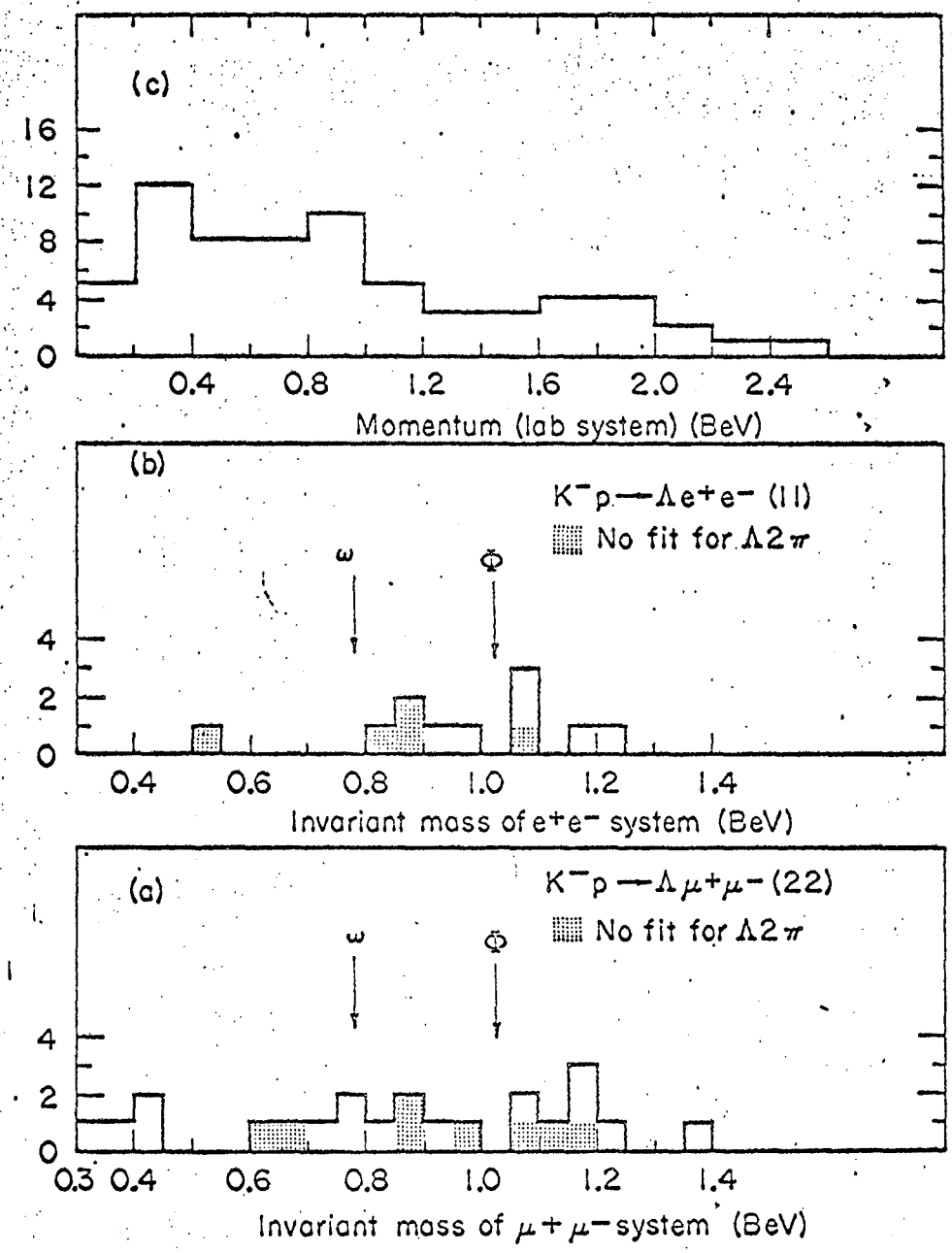

Not fitted to Λ2e (731)
Good fit for Λ2e (128)
Bad fit for Λ2e (359)
CL2e > 5 CL2π(8)
χ²2e
χ²2π
Number of events
MUB-3419

Fig. 2.



MUB-3420

Fig. 3(a), (b), and (c).

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