Title
A SEARCH FOR A NEW VECTOR MESON

Author
Clark, Alan R.

Publication Date
1972-04-04

Submitted to Nuovo Cimento Letters

LBL-947
Preprint

A SEARCH FOR A NEW VECTOR MESON

Alan R. Clark, R. C. Field, W. R. Holley,
Rolland P. Johnson, Leroy T. Kerth, R. C. Sah,
G. Shen, W. A. Wenzel, and A. R. Zingher

April 4, 1972

AEC Contract No. W-7405-eng-48

LBL-947

DISCLAIMER

LBL-947

A SEARCH FOR A NEW VECTOR MESON*

Alan R. Clark, R.C. Field, W.R. Holley, Rolland P. Johnson**
Leroy T. Kerth, R.C. Sah, G. Shen, W.A. Wenzel, A.R. Zingher

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

April 4, 1972

ABSTRACT

A two arm spectrometer system has been used at the Bevatron to search for a new vector meson, the χ^0, which has been suggested as an explanation of the low experimental limit on the $K^0_L \rightarrow \mu^+\mu^-$ rate. The branching ratio limit determined by this experiment,

$$\frac{\Gamma(K^0_L \rightarrow \gamma\, \chi^0 \rightarrow \gamma ee;\ 350 < m_{\chi^0} < 425\ \mathrm{MeV}/c^2)}{\Gamma(K^0_L \rightarrow \mathrm{all})} < 6.6 \times 10^{-5}\ (90\%\ \mathrm{C.L.})$$

is incompatible with the theoretical prediction.

Most attempts to explain the low experimental limit on the $K^0_L \to \mu\mu$ branching ratio[1] have been based on the presumption that some intermediate state (or states) destructively interferes with the expected two photon intermediate state. Since the decay $K^0_L \to \gamma\gamma$ actually occurs it gives a contribution "on the mass shell" to the imaginary part of the decay matrix element for $K^0_L \to \mu\mu$. A term interfering with this contribution must also come from a state on the mass shell.

Various theories have considered intermediate states that include a pair of as yet unobserved, uncharged leptons[2] (note that lepton number conservation and angular momentum conservation imply that a $\nu\bar{\nu}$ state is impossible), a $\pi^{\pm}\mu^{\mp}$ resonance[3] reported by Ramm[4], as well as the 3π and $\pi\pi\gamma$ modes. The 3π and $\pi\pi\gamma$ states have been examined in some detail with the conclusion that the necessary coupling strengths to two muons would have to be unreasonably large[5].

Another possible intermediate state suggested by Alles and Pati[6] requires the existence of a new vector meson, for which the search described here was conducted. The Alles-Pati mechanism requires that the K^0_L decay into a photon and a new meson (χ^0) with spin-parity $J^P = 1^-$ and mass between 350 and 425 MeV/c^2. To make the $K^0_L \to \chi^0\gamma$ decay sufficiently strong for plausible coupling strengths an upper limit on the χ^0 mass is set by phase space consideration. The lower limit on the mass is set by considering (i) the absence of the $K^+ \to \pi^+ + \chi^0$ decay mode, (ii) the anomalous magnetic moment of the muon, and (iii) the limits on the branching ratios of η and $\eta' \to \chi^0 + \gamma$ decays.

To suppress the unobserved decay of the χ^0 into dipion final states the G parity must be negative. The χ^0 is then a low mass ω meson. The predominant decay mode is expected to be $\chi^0 \rightarrow \pi^0\gamma$. It is estimated by Alles and Pati that $\frac{\Gamma(\chi^0 \rightarrow ee \text{ or } \mu\mu)}{\Gamma(\chi^0 \rightarrow \text{all})} > 5\%$, and that the width of the χ^0 is less than 0.1 MeV/c^2.

In order to account for the observed suppression of the $K^0_L \rightarrow \mu^+\mu^-$ mode[1], Alles and Pati require

$$\frac{\Gamma(K^0_L \rightarrow \chi^0\gamma)}{\Gamma(K^0_L \rightarrow \text{all})} \geq 1.2 \times 10^{-2}$$

Thus there is the necessary condition that

$$\frac{\Gamma(K^0_L \rightarrow \gamma\chi^0 \rightarrow \gamma\, ee \text{ or } \gamma\mu\mu)}{\Gamma(K^0_L \rightarrow \text{all})} > 6 \times 10^{-4}.$$

A search for dielectron and dimuon decays in the suggested invariant mass interval was made using a double-arm, spark chamber spectrometer located in a neutral beam at the Bevatron. The apparatus has been described before[1] and is shown schematically in Fig. 1. The spectrometer magnetic fields were set to enhance the detection efficiency in the desired dilepton invariant mass interval.

The trigger logic required a particle to count in the H array in one spectrometer arm and a coincident particle to register as a "lepton" in the other arm. For the trigger, a "lepton" was defined as a particle which was parallel to the neutral beam line within ± 45 mr (as determined by the hodoscopes F and R), and which was identified either as an electron by counting in the Cherenkov counter (Freon-12 at 1 atm) or as a possible muon by penetrating beyond the second of the 17 counters in the range box (corresponding to a minimum muon momentum of 550 MeV/c). This triggering scheme was used in order to collect a sample of $K_{\ell 3}$ decays necessary for normalization and background studies along with the possible $K \rightarrow \gamma \ell\ell$ decays.

The reconstructed events were required to pass cuts on trajectory continuity on each side, vertex reconstruction, and kinematic consistency with the assumed decay. In addition, range cuts were applied to the possible $K_{\mu 3}$, K_{e3} and $K \rightarrow \gamma\mu\mu$ events to insure that the secondary particles were properly identified. That is, a muon had to stop within 20% of its expected range and a pion had to stop more than 30% short of the expected range of a muon of the same momentum. Thus all $K_{\ell 3}$ events had a pion which was clearly identified because it either interacted in the absorber or decayed in flight. Events which were consistent with $K^0_L \rightarrow \pi^+\pi^-$ decay were eliminated from the $K_{\mu 3}$ spectrum.

Figure 2A shows the πe invariant mass spectrum from K_{e3} decays in the data sample. Fig. 2B is the spectrum of dielectron invariant mass from the same K_{e3} events where the π has deliberately been mis-identified as an electron. Figure 2C is the spectrum of dielectron events where both secondaries actually counted in a Cherenkov counter. The Cherenkov counters were measured to be more than 99% efficient for electrons and to count other particles as electrons less than 1% of the time. Note that the scale of the spectrum of Figure 2C has been multiplied by 100 relative to that of 2A and 2B.

To estimate the limit on an e^+e^- signal, a smooth background curve was drawn through the observed distribution. Since the resolution was measured from the $K^0_L \rightarrow \pi^+\pi^-$ peak to be 4 MeV/c^2 (FWHM), the possible enhancement was expected to be visible in bin widths of less than 6 MeV/c^2. Peaks of this width were therefore ignored for the purposes of defining the background. A limit on the size of the possible signal was taken to be the difference between the observed number of events in a given mass range and the background curve, plus twice the statistical uncertainty on the total number of events in the range. This was considered to be a conservative estimate of the 90% confidence level upper limit.

It has been assumed for the purposes of normalization that the detection efficiency at a given invariant mass m_{ee} for $K^0_L \to \gamma\chi^0 \to \gamma e^+e^-$ is the same as that for the $K^0_L \to \pi^\pm e^\mp \nu$ events in Fig. 2B at the same value of m_{ee}. The Dalitz plot distributions of the $K_{\ell 3}$ data indicate that the apparatus would in fact have been somewhat more efficient for the detection of a vector χ^0 decaying into two fermions than for the charged secondaries from $K_{\ell 3}$. Consequently the upper limits obtained are rather conservative on these grounds also.

With these considerations, for $\Gamma_{ee} < 6$ MeV/c^2 the worst case in the range $350 < m_{ee} < 425$ MeV/c^2 gives the limit

$$\frac{\Gamma(K^0_L \to \gamma\chi^0 \to \gamma e^+e^-)}{\Gamma(K^0_L \to \text{all})} < 6.6 \times 10^{-5} \quad (90\%\,\text{C. L.})$$

Below 350 MeV/c^2 our sensitivity deteriorates. However, even at 320 MeV/c^2, somewhat beyond the range of interest of Alles and Pati, the limit is 1.7×10^{-4} at 90% confidence.

If the analysis were carried out as above but without background subtraction, the corresponding limits would be 9.3×10^{-5}, $350 < m_{ee} < 425$ MeV/c^2, and 2.5×10^{-4} at 320 MeV/c^2.

Although the limits are expected to be less precise for the dimuon mode than for the dielectron mode, a similar analysis has been made with the $\mu\mu$ spectrum. The analogous spectra to those in Fig. 2 are shown in Fig. 3 for the $K_{\mu 3}$ data. Note that the greater background in the assumed $\mu\mu$ sample shown in Figure 3C precludes a definitive confrontation of the theory. Such background is expected because $K_{\mu 3}$ decays with π decay in flight are a source of real dimuon events and because the range devices are not as good at distinguishing muons from pions as the Cherenkov counters are at distinguishing electrons from other particles.

For the dimuons of Fig. 3C, for $\Gamma_{\mu\mu} < 6$ MeV/c^2 and $370 < m_{\mu\mu} < 450$ MeV/c^2, the limit is

$$\frac{\Gamma(K_L^0 \to \gamma\chi^0 \to \gamma\mu^+\mu^-)}{\Gamma(K_L^0 \to \text{all})} < 2 \times 10^{-4} \ (90\% \text{ C.L.})$$

Again the limit is less rigorous at lower masses and a statistically insignificant peak at 360 MeV/c^2 gives a limit of 8×10^{-4} at 90% confidence.

Thus although the dimuon limit is not quite inconsistent with the theory at the lowest range of the mass of interest, the dielectron limit definitely contradicts the predictions of Alles and Pati. Unless there is some new reason for a strong suppression of the dielectron decay mode relative to the dimuon mode, we conclude that the χ^0 does not exist.

Since the completion of this work a report has appeared of an experiment which sought the $\pi^0\gamma$ and e^+e^- decay modes of the χ^0[7].

The result obtained is expressed as

$$\frac{\Gamma(K^0_L \to \chi^0 \gamma)}{\Gamma(K^0_L \to \text{all})} < 2.4 \times 10^{-4} \text{ (90\% C. L.)},$$

a factor of 50 below the theoretical lower limit.

FOOTNOTE AND REFERENCES

*Work done under the auspices of the United States Atomic Energy Commission.

**Present address: High-Energy Physics Institute, Serpukhov, Moscow District, USSR.

1. A.R. Clark, T. Elioff, R.C. Field, H.J. Frisch, R.P. Johnson, L.T. Kerth, and W.A. Wenzel, Phys. Rev. Letters 26, 1667 (1971). For a complete description of the apparatus, see H.J. Frisch, Doctoral thesis, UCRL-20264, March 24, 1971, (unpublished).

2. L.M. Sehgal, Phys. Rev. D5, 744 (1972).

3. S. Barshay, A Suggestion Concerning the Present Anomaly in Rate $(K_L \to \mu\mu)$/Rate $(K_L \to 2\gamma)$, Niels Bohr Institute preprint (1971). Note that this explanation is found unlikely by S.C. Chhajlany and S. Pakvasa, Some Implications of a Possible $\pi\mu$ Resonance, Univ. of Hawaii preprint UH-511-101-71 (May 1971).

4. C.A. Ramm, Nature 277, 1323 (1970). For evidence against such a resonance see A.R. Clark, T. Elioff, R.C. Field, H.J. Frisch, R.P. Johnson, L.T. Kerth, G. Shen, and W.A. Wenzel, Nature 237, 388 (1972).

5. B.R. Martin, E. deRafael, and J. Smith, Phys, Rev. D2, 179 (1970). S. L. Adler, G.R. Farrar and S.B. Treiman, Phys. Rev. D5, 770 (1972).

   S. Barshay, Physics Letters 37B, 397 (1971).

   R. Aviv and R.F. Sawyer, The Three Pion Intermediate State and the $K^0_L \to \mu^+\mu^-$ Puzzle, UCSB preprint (1971).

   M.K. Gaillard, Phys. Lett. 35B, 431 (1971).

6. W. Alles and J.C. Pati, <u>Tests for a Possible Class of C.P. Invariant Solutions to the $K^0_L \to \mu\bar{\mu}$ Problem.</u> CERN preprint TH-1429 (November 1971).

7. V.V. Barmin, G.V. Davidenko, V.S. Demidov, A.G. Dolgolenko, V.A. Matveev, A.G. Meshkovsky, G.S. Mirosidi, T.A. Chistyakova, I.V. Chuvilo and V.A. Shebanov, <u>Search for Neutral Vector Meson in K_L – Decays</u>. ITEP preprint 906 (1972).

FIGURE CAPTIONS

1) Plan view of the apparatus. F and R are counter hodoscopes. H is a six-counter array. T is a fast-timing counter.

2A) The πe invariant mass spectrum from K_{e3} events.

2B) The ee invariant mass spectrum obtained from the events in Figure 2A by deliberately misidentifying the π as an e.

2C) The actual ee invariant mass spectrum. Note that the ordinate has been expanded by a factor of 100 compared to Figures 2A and 2B. The smooth curve indicates the subtracted background.

3A) The $\pi\mu$ invariant mass spectrum from $K_{\mu 3}$ events.

3B) The $\mu\mu$ invariant mass spectrum obtained from the events in Figure 3A by deliberately misidentifying the π as a μ.

3C) The actual $\mu\mu$ invariant mass spectrum. Note that the ordinate has been expanded by a factor of 10 compared to Figures 3A and 3B. The smooth curve indicates the subtracted background.

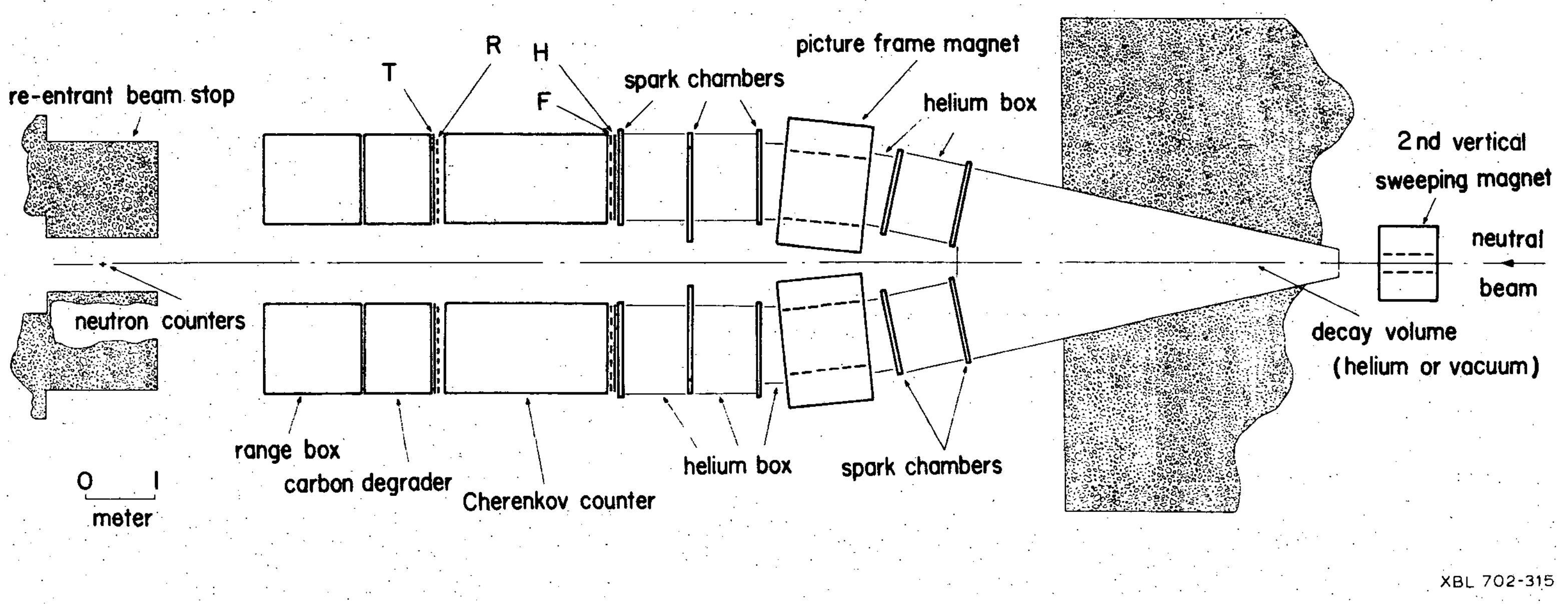
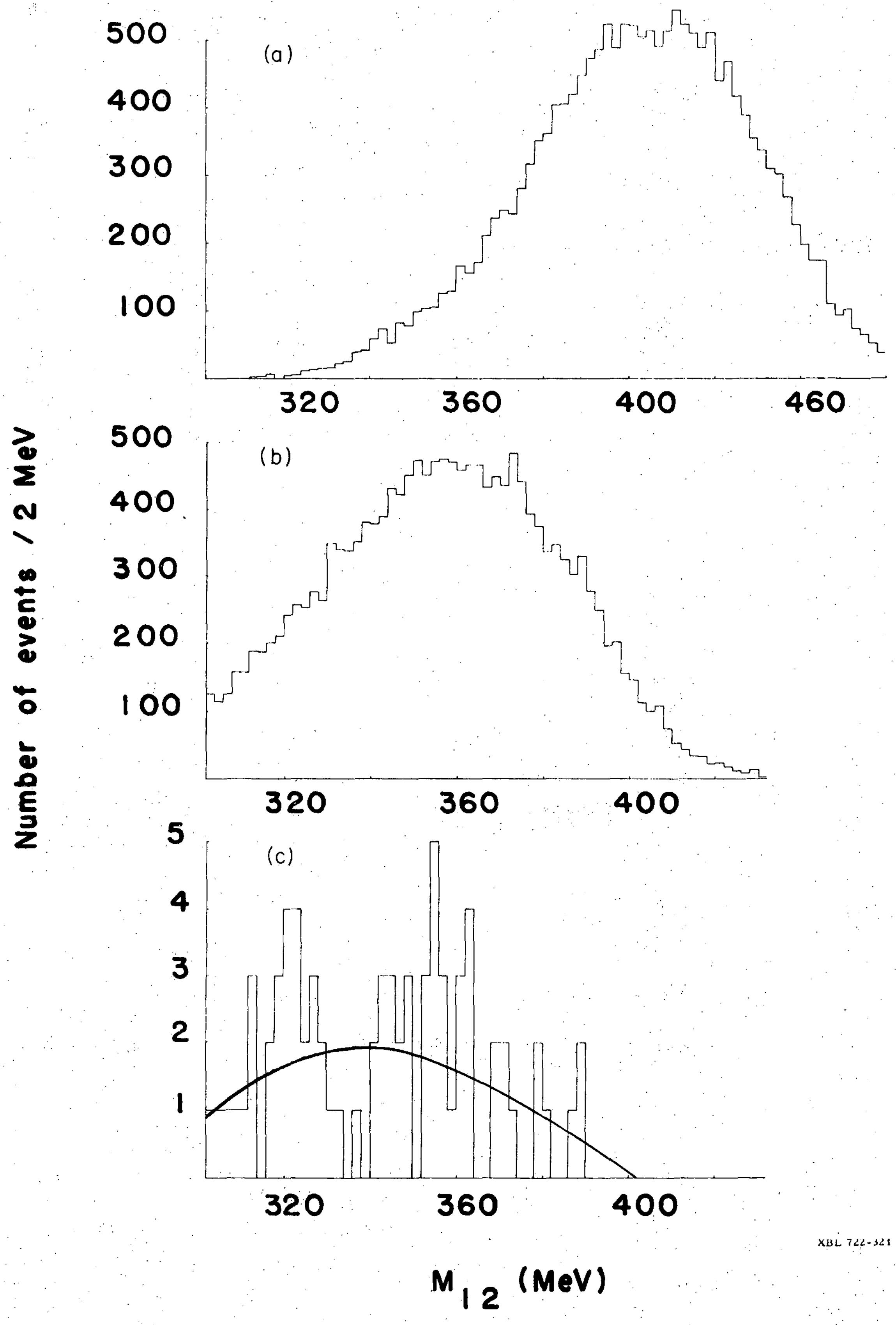
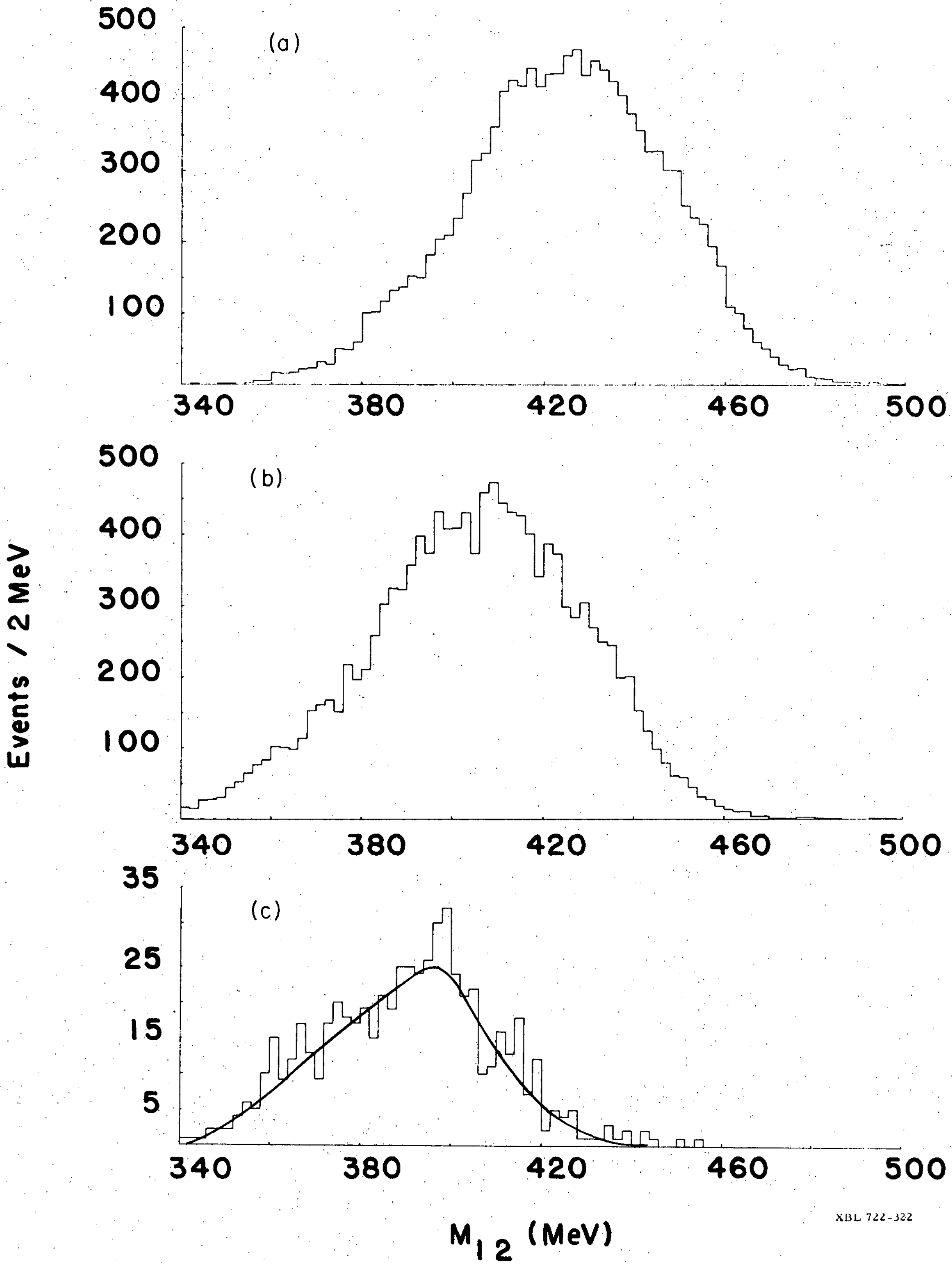

re-entrant beam stop
T
R
H
F
spark chambers
picture frame magnet
helium box
2nd vertical
sweeping magnet
neutral
beam
neutron counters
decay volume
(helium or vacuum)
range box
carbon degrader
Cherenkov counter
helium box
spark chambers
O
I
meter
XBL 702-315

Fig. 1



Number of events / 2 MeV
(a)
500
400
300
200
100
320
360
400
460
(b)
500
400
300
200
100
320
360
400
(c)
5
4
3
2
1
320
360
400
XBL 722-321
M_{12} (MeV)

Fig. 2



500
400
300
200
100
(a)
340
380
420
460
500
500
400
300
200
100
(b)
340
380
420
460
500
35
25
15
5
(c)
340
380
420
460
500
Events / 2 MeV
M_{12} (MeV)
XBL 722-322

Fig. 3

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720