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SEARCH FOR FINE STRUCTURE IN THE $K^o_{\ell 3}$ FINAL STATES*.

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ABSTRACT

A double armed magnetic spectrometer in a Bevatron neutral beam has been used to study the decays $K^o_L \to \pi^{\pm}\mu^{\mp}\nu$ and $K^o_L \to \pi^{\pm}e^{\mp}\nu$. Over three hundred thousand events have been analyzed and compared to the V—A predictions. No deviations from the expected spectra are seen. In particular, no evidence is seen for the structure in the $\pi^{\pm}\mu^{\mp}$ invariant mass spectrum near $m_{\pi\mu} \approx 429$ MeV which has been reported in the final states of $\nu p \to \mu\pi p$ interactions and $K^o_L \to \pi^{\pm}\mu^{\mp}\nu$ decays.[1]

Interest in leptonic resonances has been generated recently by both experimental and theoretical investigations.[1,2] Anomalies in bubble chamber data have indicated a possible $\pi^{\pm}\mu^{\mp}$ resonance of mass ≈ 429 MeV and width < 15 MeV in the final state of both $\nu p \to \pi\mu p$ interactions and $K^o_L \to \pi\mu\nu$ decays.[1] Theoretical estimates of the effects of such a resonance have been made[3], and it has been suggested[4] that the low measured limit on the $K^o_L \to \mu^+\mu^-$ rate[5] could be a consequence of an interfering $\pi\mu$ intermediate state. Studies of finite quantum field theory with an indefinite metric by E.C.G. Sudarshan[6] suggest that leptonic resonances if they exist could manifest themselves in γe, πe, $\pi\mu$ and $\pi\nu$ channels.

The data reported here consist of more than 100,000 analyzed $K_{\mu 3}$ events and 200,000 K_{e3} events. A plan view of the detection apparatus is shown in Fig. 1. The spectrometer was originally designed to search for K_L^o decays into lepton pairs and has been described elsewhere[5]. The region of the Dalitz plot examined in this data sample was determined by setting the field integral of the spectrometer magnets to correspond to a transverse momentum of 180 MeV/c.

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 counter in the range box (corresponding to a minimum muon momentum of 550 MeV/c). The spark chamber and counter information was checked with an on-line PDP-9 computer and stored on magnetic tape for later analysis on a CDC 6600 computer. The experimental conditions were such that the data reported here were accumulated in less than 24 hours.

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 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 $K_L^o \to \pi^+\pi^-$ decay were eliminated from the $K_{\mu 3}$ spectra.

The histograms of Figures 2, 3 and 4 show the final $\pi\ell$, $\pi\nu$ and $\ell\nu$ mass spectra for the $K_{\mu 3}$ and K_{e3} data. Because the charged secondary particle momenta and directions were measured, the $m_{\pi e}$ spectrum from K_{e3} and the $m_{\pi\mu}$ spectrum from $K_{\mu 3}$ decays are computed directly. However, because the kaon momentum is not known, only its direction, each event has two kinematically acceptable solutions for the neutrino vector momentum. Thus each event is plotted twice for the $m_{\pi\nu}$ and $m_{\mu\nu}$ spectra from $K_{\mu 3}$ events, and for the $m_{\pi\mu}$ and $m_{e\nu}$ spectra from K_{e3} events. The resolution of the apparatus and the absolute invariant mass calibration were determined from an analysis of $K_L^o \to \pi^+\pi^-$ events taken simultaneously with the $K_{\mu 3}$ and K_{e3} events. The resolution (FWHM) is less than 4 MeV for the $m_{\pi\mu}$ and $m_{\pi e}$ distributions.

The smooth curves in Figs. 2–4 are the predictions of the V–A theory folded with the calculated acceptance of our equipment; the factors assumed were $\xi(0) = -0.8$, $\lambda_+ = 0.04$ and $\lambda_- = 0$. For reasons of economy, the efficiency calculations were done with variables appropriate to the $\pi\mu$ and πe mass spectra, and it was necessary to smooth the curves shown with the $\pi\nu$, $e\nu$ and $\mu\nu$ data. Accordingly, the curves shown in Figs. 3 and 4 were not used to check for deviations from the V–A theory; nevertheless the computed predictions agree quite well with the data.

In order to estimate the contributions from a $\pi\mu$ resonance as reported in Reference 1, we have compared the measured $m_{\pi\mu}$ spectrum to the V–A spectrum plus a Breit–Wigner enhancement of width 15 MeV. We see no evidence for an enhancement in our data, with an upper limit on the branching ratio

$$\frac{\Gamma(K_L^o \to \mu^*(429) + \nu \to \pi^\pm + \mu^\mp + \nu)}{\Gamma(K_L^o \to \text{all})} < 3 \times 10^{-4} \quad (90\% \text{ C.L.}) .$$

This limit is two orders of magnitude lower than the branching ratio estimate given in Reference 1 for the $K^o_{\mu 3}$ data. If the structure is assumed to be something other than a final state resonance, it seems unlikely that the effect would be seen in the bubble chamber data and not in this experimental search which has better resolution, positive particle identification, and 30 times the data in the region of interest.

It was suggested in Reference 1 that the observed anomalies may be correlated with the angle $\theta_{\mu\nu}$ between the muon and the neutrino as measured in the $\pi\mu$ center of mass. The $\theta_{\mu\nu}$ distributions (not shown) for the $K_{\mu 3}$ data shown in Fig. 2 have been compared to the Monte Carlo calculations. In all cases the $\theta_{\mu\nu}$ distributions vary smoothly as the $m_{\pi\nu}$ interval changes and agree well with the V-A predictions. Also the relative detection efficiency as a function of $\theta_{\mu\nu}$ for any $m_{\pi\mu}$ near the reported enhancement does not vary by more than ± 30%; thus the contradiction between the bubble chamber results and those reported here cannot be attributed to a difference in detection efficiencies.

In addition to the test described above on the $\pi\mu$ data, each spectrum was tested for smoothness. For bin widths of 10, 6 and 2 MeV, deviations of each bin from a curve through 6 neighboring bins have been examined for all the spectra. In addition, the $\pi\mu$ and πe spectra were treated in 20 MeV wide bins to check for the effect reported in Ref. 1 (The analysis was done twice, with the bins offset by 10 MeV). In all, 600 bins have been examined, and only four have been found to deviate from a smooth curve by more than three standard deviations, the largest deviation being 3.7 standard deviations. From this analysis there is no statistically significant evidence for structure narrower than 10 MeV in any of the mass spectra, or 20 MeV in the $\pi\mu$ and πe spectra.

We wish to thank the Lawrence Berkeley Laboratory engineers, the Bevatron staff, and our technicians for their interest and effort which made the experiment possible. Discussions of the data with C. A. Ramm were most stimulating.

FOOTNOTES AND REFERENCES

* Work performed under the auspices of the U. S. Atomic Energy Commission

** On leave from LBL to the U. S. Atomic Energy Commission, Washington, D.C.

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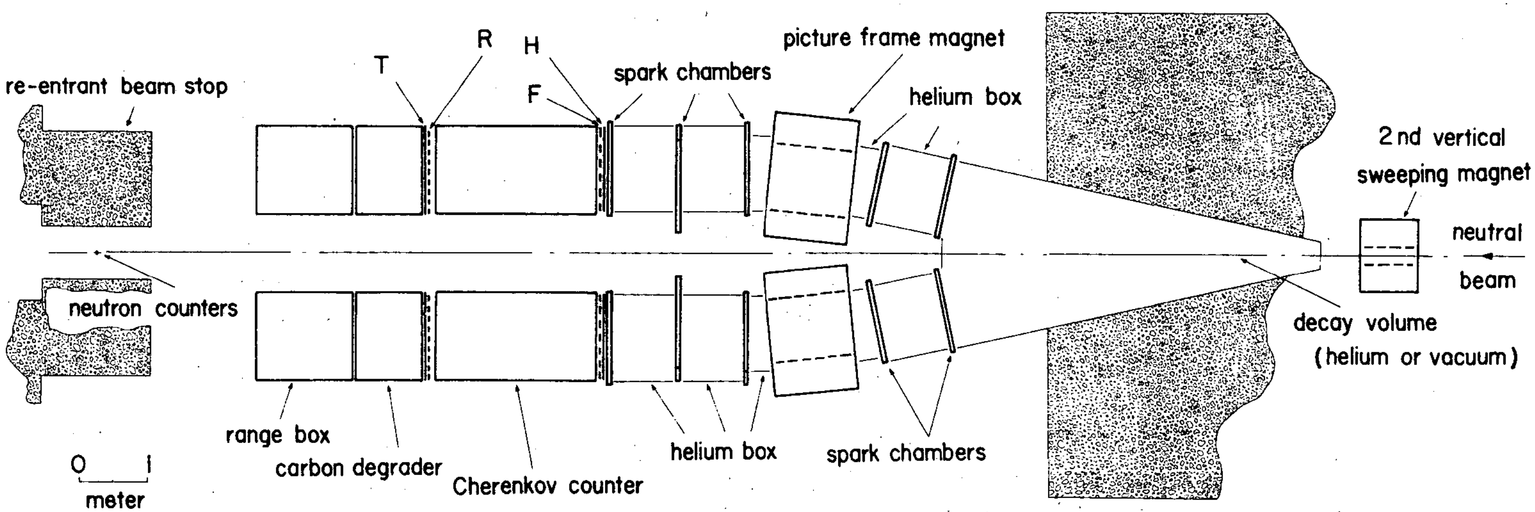
FIGURE CAPTIONS

1) Plan view of the apparatus. The apparatus is symmetric about the neutral beam center line. F and R are scintillation counter hodoscopes. H is a six-counter array. T is a fast-timing counter.

2) a) The $\pi\mu$ invariant mass spectrum from the $K_L^0 \to \pi + \mu + \nu$ data.
b) The πe invariant mass spectrum from the $K_L^0 \to \pi + e + \nu$ data.
The smooth curves are from V-A theory (see text).

3) Invariant mass spectra for the decay $K_L^0 \to \pi + \mu + \nu$:
a) $\pi\nu$ mass spectrum; b) $\mu\nu$ mass spectrum.
The smooth curves are from V-A theory (see text). Each event is plotted twice in each figure.

4) Invariant mass spectra for the decay $K_L^0 \to \pi + e + \nu$:
a) $\pi\nu$ mass spectrum; b) $e\nu$ mass spectrum.
The smooth curves are from V-A theory (see text). Each event is plotted twice in each figure.



XBL 702-315

Fig. 1

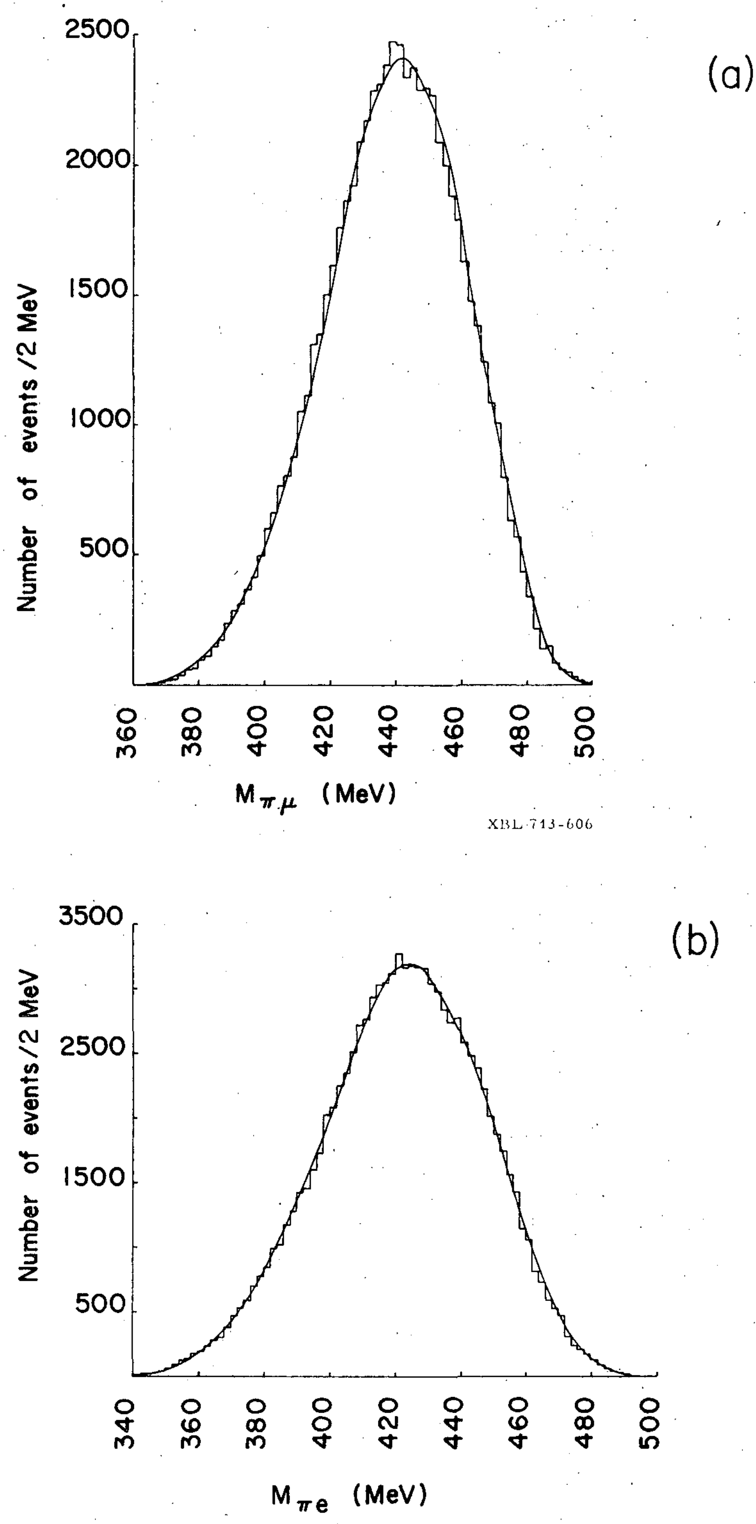
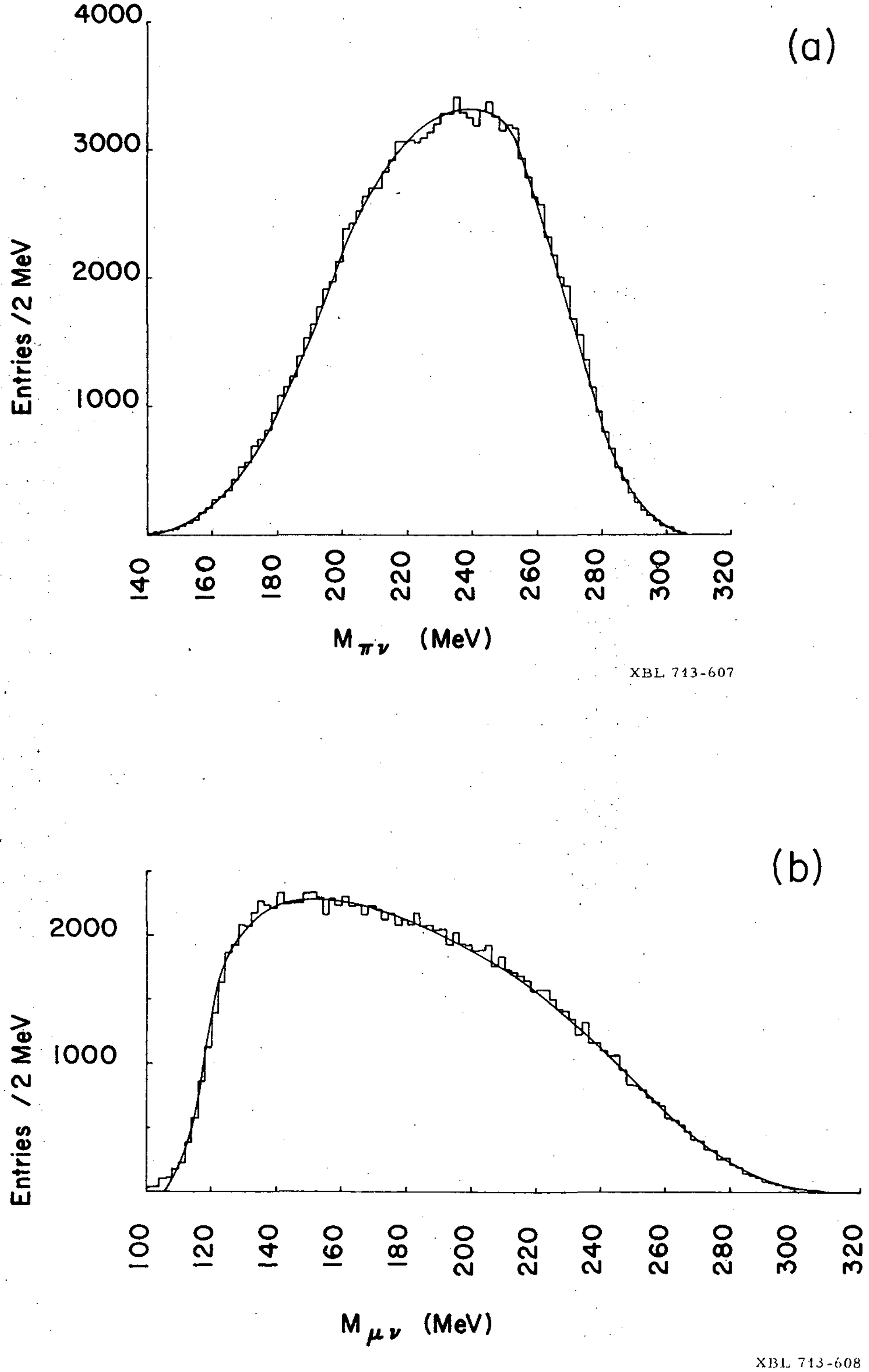

2500
2000
1500
1000
500
Number of events /2 MeV
360
380
400
420
440
460
480
500
$M_{\pi\mu}$ (MeV)
(a)
XBL 713-606
3500
2500
1500
500
Number of events /2 MeV
340
360
380
400
420
440
460
480
500
$M_{\pi e}$ (MeV)
(b)
XBL 713-609

Fig. 2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3000
2000
1000
Entries /2 MeV
(a)
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160
180
200
220
240
260
280
300
320
M πν (MeV)
XBL 713-607
(b)
2000
1000
Entries /2 MeV
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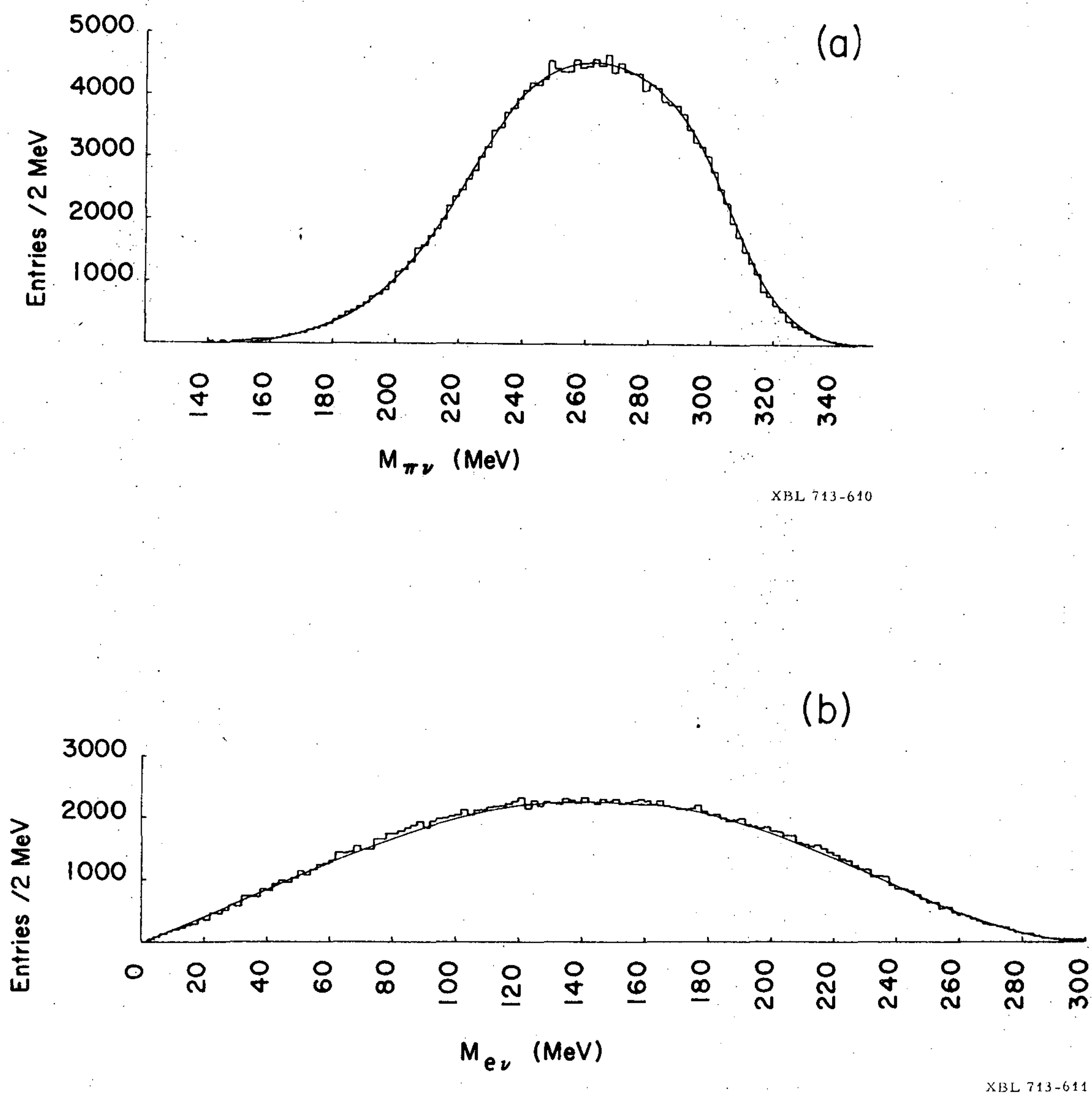
120
140
160
180
200
220
240
260
280
300
320
M μν (MeV)
XBL 713-608

Fig. 3


(a)
5000
4000
3000
2000
1000
Entries /2 MeV
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160
180
200
220
240
260
280
300
320
340
M_πν (MeV)
XBL 713-610
(b)
3000
2000
1000
Entries /2 MeV
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
M_eν (MeV)
XBL 713-611

Fig. 4

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