Submitted to Physical Review Letters August 1976

Observation of a Narrow Anti-Baryon State at 2.26 GeV/c^2 *

B. KNAPP[†], W. LEE, P. LEUNG, S.D. SMITH, A. WIJANGCO

Columbia University, New York, N.Y. 10027

J. KNAUER, D. YOUNT

University of Hawaii, Honolulu, Hi. 96822

J. BRONSTEIN, R. COLEMAN, G. GLADDING, M. GOODMAN, M. GORMLEY[‡], R. MESSNER, T. O'HALLORAN, J. SARRACINO, A. WATTENBERG

University of Illinois, Urbana, Ill. 61801

M. BINKLEY, I. GAINES, J. PEOPLES

Fermi National Accelerator Laboratory, Batavia, Ill. 60510

* Research supported in part by the National Science Foundation and the U. S. Energy Research and Development Administration.

† Alfred P. Sloan Foundation Fellow.

‡ Present address: Fermilab, Batavia, Ill. 60510

ABSTRACT

We report evidence, from a study of multihadron final states produced in the wide-band photon beam at Fermilab, for the production of a new antibaryon state which decays into $\bar{\Lambda}\pi^-\pi^-\pi^+$. The mass of the state is 2.26 $\pm$ 0.01 GeV/c^2 and the decay width is < 75 MeV/c^2. We also report evidence of a higher mass state (~ 2.5 GeV/c^2) which decays into the 2.26 GeV/c^2 state.

This paper is based on the study of multihadron final states produced in the wide-band photon beam at Fermilab. We report on the observation of a narrow peak near 2.26 GeV/c^2 in the invariant mass spectrum of the $\bar{\Lambda}\pi^-\pi^-\pi^+$ final state. We do not observe a significant peak near 2.26 GeV/c^2 in the $\bar{\Lambda}\pi^+\pi^+\pi^-$ final state. We also observe evidence that there exists a state of higher mass near 2.5 GeV/c^2 which then decays into $\bar{\Lambda}\pi^-\pi^-\pi^+$ (2.26 GeV) + π^+.

Our results are based on studies of multihadron data taken during September - December of 1975 in the wide-band photon beam at Fermilab.[1] The results of similar studies with data taken earlier have been previously reported.[2] A description of the detector can be found in Refs. 1 and 2.

All pairs of oppositely charged tracks which verticize more than 27 in. downstream of the production target are potential candidates for $K_S \to \pi^+\pi^-$, $\Lambda(\bar{\Lambda}) \to p(\bar{p})\pi^-(\pi^+)$, or new long-lived objects. For events considered in this paper, we further require that there be a vertex within the production target with more than two charged tracks, and that the V^o intersect this vertex. If the invariant mass of the V^o is the mass of K_S (498 $\pm$ 15 MeV/c^2), it is not considered as a candidate for Λ or $\bar{\Lambda}$. (We lose ~ 10% of Λ due to K_S/Λ mass ambiguity.) For the remaining V^o's, we plot the invariant mass assuming tracks are $\pi^-p(\pi^+\bar{p})$ and they are shown in Figs. 1a and 1b. We make a mass cut of 1116 $\pm$ 2 MeV/c^2. The background to the $\Lambda(\bar{\Lambda})$ signal is a few percent.

We have studied the invariant mass distribution of $\bar{\Lambda} n\pi^{\pm}$ (n = 1,2,3,4) in all charge states. In this paper, we will discuss n = 3 and n = 4 states only. In order to be included in our studies, events must pass the following selection criteria: 1) The total energy of the charged tracks of an event is less than 200 GeV. 2) The total number of reconstructed tracks is less than nine. These cuts reduce neutron-induced events.

In Figs. 2a and 2b, the invariant mass distributions of all combinations of $\bar{\Lambda}\pi^-\pi^-\pi^+$ and $\bar{\Lambda}\pi^+\pi^+\pi^-$ are shown. We observe a clear peak near 2.26 GeV/c^2 in $\bar{\Lambda}\pi^-\pi^-\pi^+$, but not in $\bar{\Lambda}\pi^+\pi^+\pi^-$ final states. The statistical significance of the peak is ~ 7 standard deviations. We estimate the mass of the peak to be 2.26 ± 0.01 GeV/c^2 and the measured width to be 40 ± 20 MeV/c^2 (FWHM). The measured width is consistent with our experimental mass resolution (~ 30 MeV/c^2) for a zero-width state.

We have also studied the invariant mass distributions of the states $\Lambda\pi^+\pi^+\pi^-$ and $\Lambda\pi^-\pi^-\pi^+$. At present, we neither observe nor rule out a similar signal near 2.26 GeV in either state. The number of $\Lambda 3\pi^{\pm}$ combinations in the vicinity of the mass of 2.26 GeV is about three times larger than that of $\bar{\Lambda}3\pi^{\pm}$, a result, no doubt, of the excess of baryons over antibaryons in the neutral beam and the production target.

The first question of interest is whether this is a well-known hadron or a new member of a well-known hadron family. There exists in the literature a particle, $\Sigma(2.25\ \mathrm{GeV/c^2})$, with a full width of 100-230 MeV/c.[2,3] The upper limit of our measured width is substantially smaller than the quoted width. We also believe that if this were an ordinary hadron, we should have observed a peak in $\bar{\Lambda}\pi^+\pi^+\pi^-$.

One of the attractive features of the $\bar{\Lambda}$ final state is that, by studying the longitudinal polarization of $\bar{\Lambda}$, it is possible to determine whether or not parity is violated. We studied, in the $\bar{\Lambda}3\pi$ rest system, the forward/backward asymmetry in the angular distribution of the $\bar{p}$ with respect to the $\bar{\Lambda}$ direction. Although we do not observe a statistically significant asymmetry, we do find that the $\bar{p}$ favors the forward direction. The effect is $\sim 2\ \sigma$. We also look at the energy distribution of the π^+ and the π^- in the $\bar{\Lambda}\pi^-\pi^-\pi^+$ state. On the average, the energy of the π^+ is higher than that of the π^-.

We also observe evidence of a cascade $\bar{\Lambda}(4\pi)^0$ ($\sim 2.5\ \mathrm{GeV/c^2}$) $\rightarrow \bar{\Lambda}(3\pi)^{-1}$ (2.26) $+ \pi^+$, which we illustrate in Fig. 3. Invariant masses for all combinations of $\bar{\Lambda}(4\pi)^0$ are shown in Fig. 3a. For each of these entries, we then plot the masses of both $\bar{\Lambda}(3\pi)^-$ combinations in Fig. 3b. In Fig. 3c, we plot the mass difference between the $\bar{\Lambda}(4\pi)^0$ and

$\bar{\Lambda}(3\pi)^-$, separately for $\bar{\Lambda}(3\pi)^-$ mass within the 2.26 peak (2.25-2.275) and immediately outside (dashed). A clear peak for mass difference $\sim$ 200 MeV/c^2 is visible only in association with the $\bar{\Lambda}(3\pi)^-$ peak at 2.26 GeV/c^2.

In summary, we observe a clear peak near 2.26 GeV in the $\bar{\Lambda}\pi^-\pi^-\pi^+$ final state, though not in the $\bar{\Lambda}\pi^+\pi^+\pi^-$ final state. The measured width of this state is consistent with the experimental mass resolution of a zero width state. We also observe evidence of the cascade process $\bar{\Lambda}\pi^+\pi^-\pi^+\pi^-$ ($\sim$ 2.5 GeV/c^2) $\rightarrow$ $\bar{\Lambda}\pi^-\pi^-\pi^+$ (2.26 GeV/c^2) + π^+. It is also noted that one neutrino event reported by Cazzoli et al has the same mass as the $\bar{\Lambda}\pi^-\pi^-\pi^+$ state and shows the similar cascade process.[4]

Our results are consistent with predictions of a lowest mass charmed baryon (C_0^+/Λ_c^+) near 2.26 GeV/c^2 and two next higher states (C_1/Σ_c, C_1^*/Y_c^*) near 2.42 and 2.48 GeV/c^2, which cascade to $C_0^+/\Lambda_c + \pi$.[5] Together with the narrow mesonic states recently observed by the SLAC-LBL group,[6] and one unusual neutrino event observed at BNL,[4] our observation lends further evidence for the existence of a new quantum number, charm.[7,8]

It is a pleasure to acknowledge the assistance of the staff of the Fermi National Accelerator Laboratory, especially that of the proton Department. We would also like to thank Prof. T. D. Lee and B. W. Lee and N. Samios for valuable discussions.

[1] B. Knapp et al, Phys. Rev. Lett. 34, 1040 (1975).

[2] W. Lee, Proceedings of the 1975 International Symposium, Stanford, Calif., p. 213.

[3] N. Samios et al, "Hadrons and SU 3", BNL Preprint.
R. Cool et al, Phys. Rev. D1, 1887 (1970).

[4] E.G. Cazzoli et al, Phys. Rev. Lett. 34, 1125 (1975).

[5] A. DeRujula, H. Georgi, S.L. Glashow, Harvard Preprint.

[6] G. Goldhaber et al, Phys. Rev. Lett. 37, 255 (1976).
I. Peruzzi et al, to be published.

[7] B.J. Bjorken, S.L. Glashow, Phys. Lett. 11, 255 (1964); S.L. Glashow, J. Iliopoulos, L. Maiani, Phys. Rev. D1, 1285 (1970); M.K. Gaillard, B.W. Lee, J.L. Rosner, Rev. Mod. Phys. 47, 277 (1975); A. DeRujula, H. Georgi, S.L. Glashow, Phys. Rev. D12, 147 (1975).

[8] Other indications of possible charm particle production have come from neutrino induced dilepton experiments. See, for example, A. Benvenuti et al, Phys. Rev. Lett. 34, 419 (1975); J. Bleitschau et al, Phys. Lett. 60B, 207 (1976); J. von Krogh et al, Phys. Rev. Lett. 36, 710 (1976); B.C. Barish et al, Phys. Rev. Lett. 36, 939 (1976); W. Lee et al and C. Baltay et al, in Proceedings of the Aachen Neutrino Conference (1976), to be published.

Fig. 1 Invariant mass distributions for V^0's, assuming:

(a) $p\pi^-$; (b) $\bar{p}\pi^+$.

Fig. 2 Invariant mass distributions for $\bar{\Lambda}3\pi$ combinations, separated by total charge: (a) $\bar{\Lambda}\pi^+\pi^-\pi^-$;

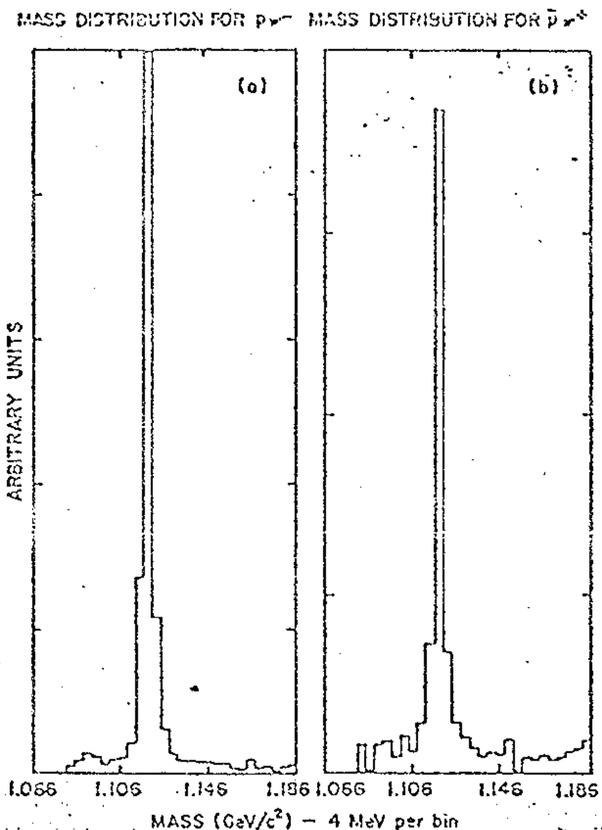
(b) $\bar{\Lambda}\pi^+\pi^+\pi^-$.

Fig. 3 Study of cascade $\bar{\Lambda}(4\pi)^0 \rightarrow \bar{\Lambda}(3\pi)^- + \pi^+$:

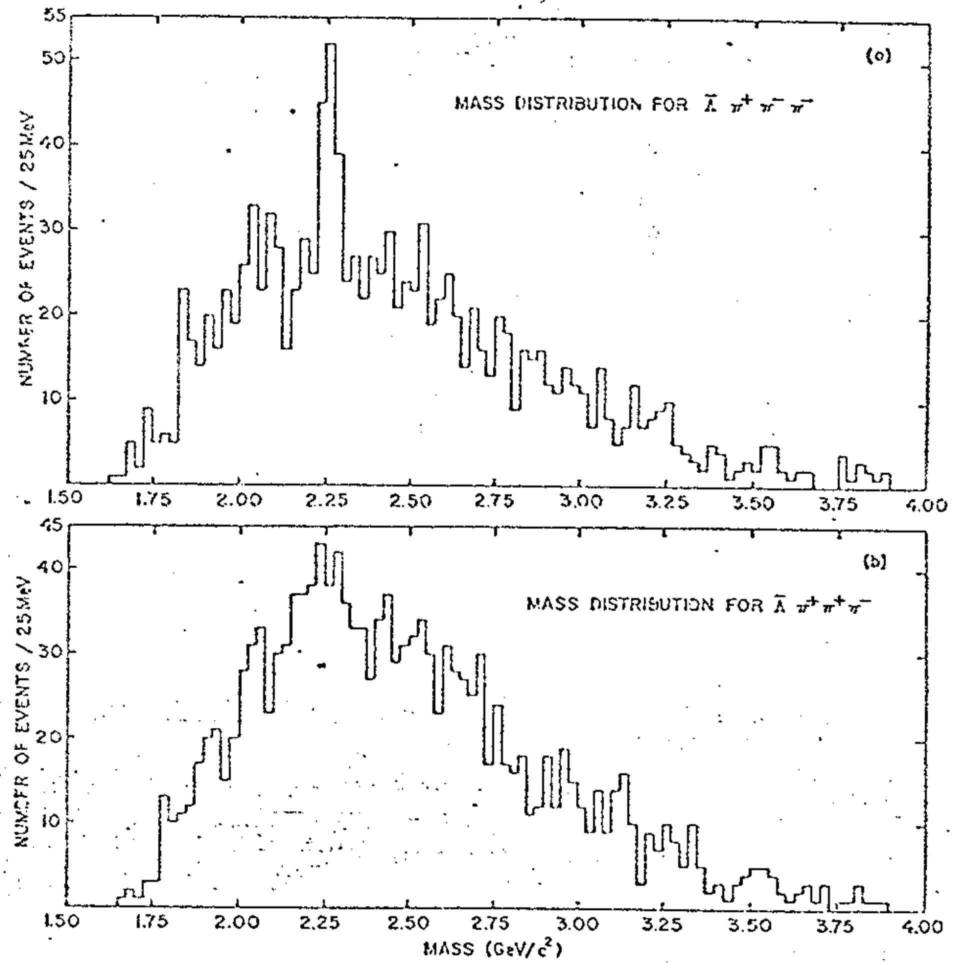
(a) Invariant mass of all $\bar{\Lambda}(4\pi)^0$ combinations;

(b) Invariant mass of all $\bar{\Lambda}(3\pi)^-$ combinations from $\bar{\Lambda}(4\pi)^0$;

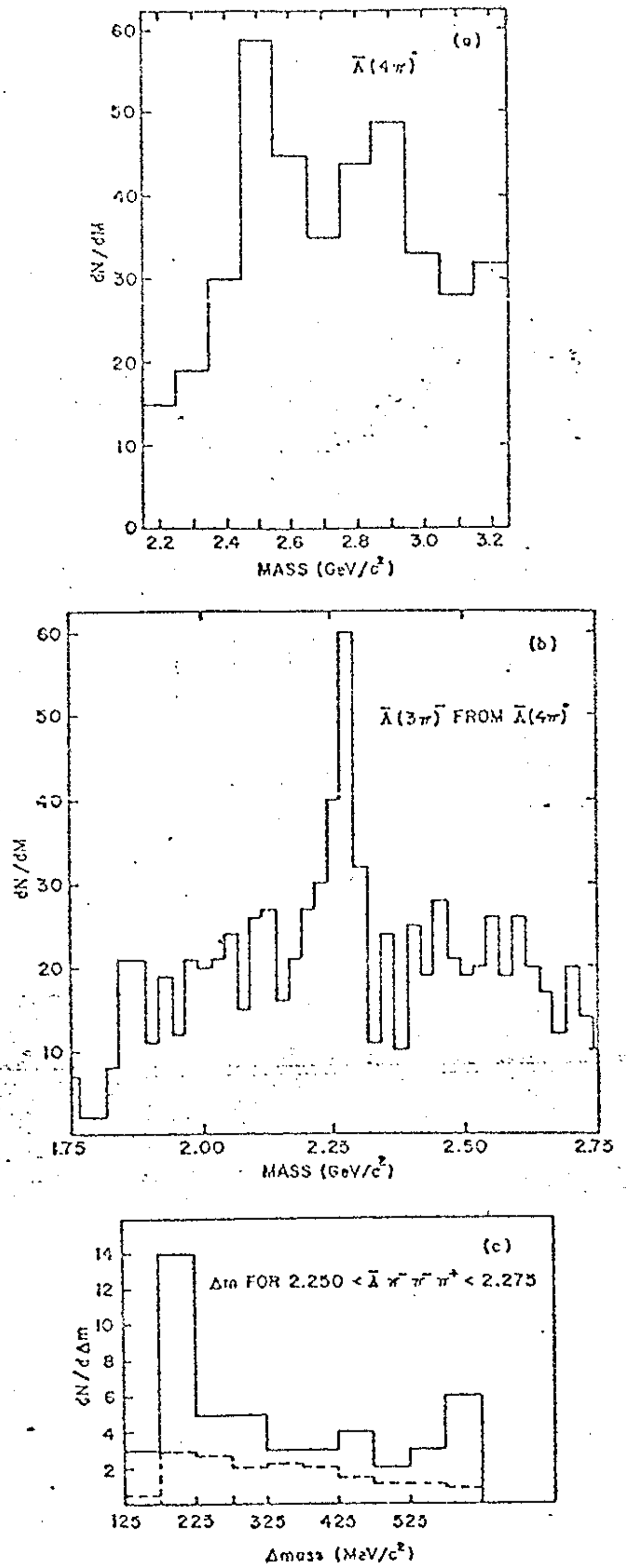
(c) Mass difference between $\bar{\Lambda}(4\pi)^0$ and $\bar{\Lambda}(3\pi)^-$, separately for $\bar{\Lambda}(3\pi)^-$ within 2.26 peak and immediately outside the peak (dashed curve).

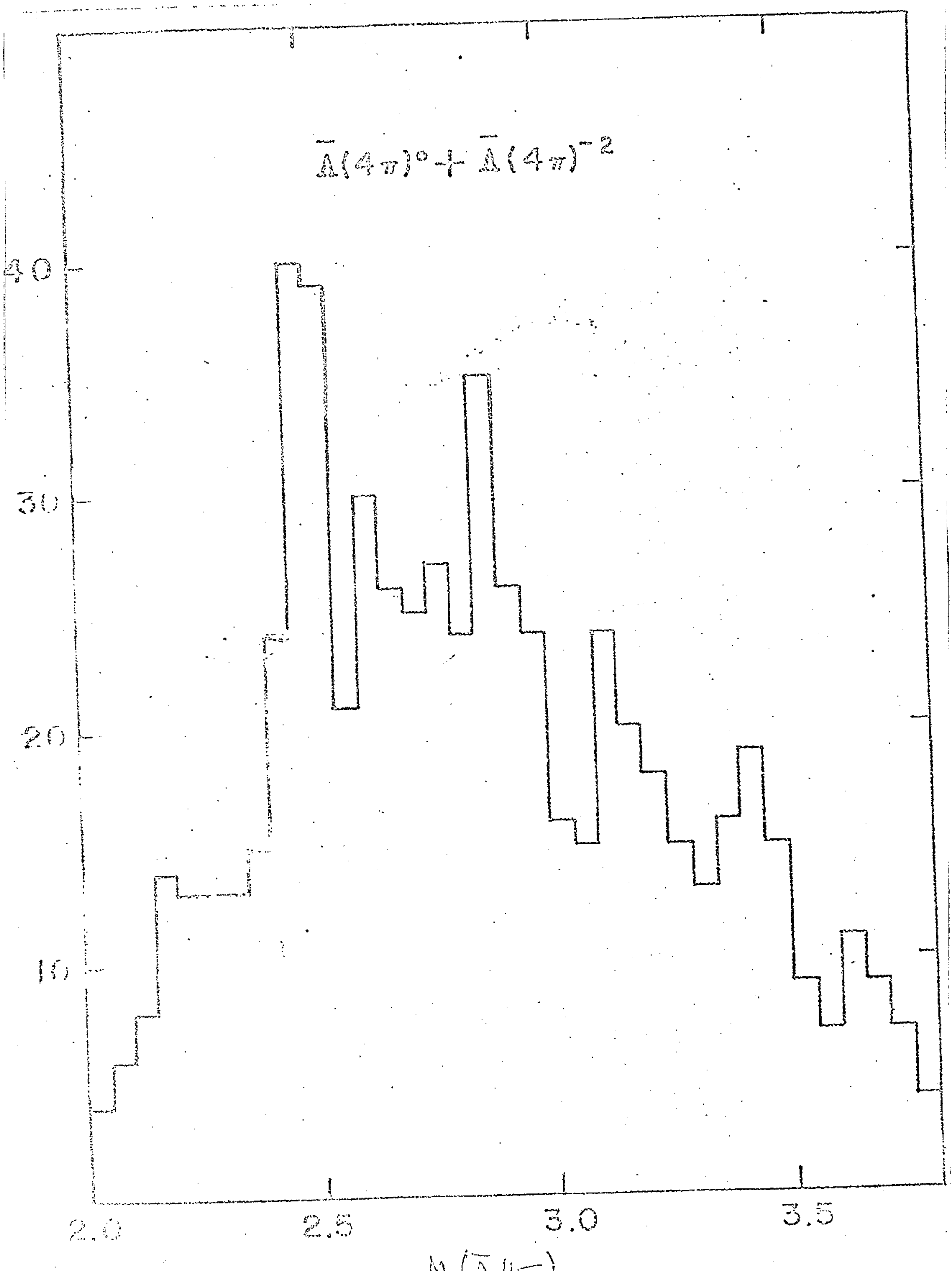


MASS DISTRIBUTION FOR $p\pi^-$
MASS DISTRIBUTION FOR $\bar{p}\pi^+$
(a)
(b)
ARBITRARY UNITS
1.066
1.106
1.146
1.186
1.066
1.106
1.146
1.186
MASS (GeV/c^2) — 4 MeV per bin



(a)
MASS DISTRIBUTION FOR $\bar{\Lambda}\pi^+\pi^-\pi^-$
NUMBER OF EVENTS / 25 MeV
55
50
40
30
20
10
1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
(b)
MASS DISTRIBUTION FOR $\bar{\Lambda}\pi^+\pi^+\pi^-$
NUMBER OF EVENTS / 25 MeV
45
40
30
20
10
MASS (GeV/c^2)


(a)
Λ̄(4π)
dN/dM
60
50
40
30
20
10
0
2.2
2.4
2.6
2.8
3.0
3.2
MASS (GeV/c²)
(b)
Λ̄(3π)⁻ FROM Λ̄(4π)
dN/dM
60
50
40
30
20
10
1.75
2.00
2.25
2.50
2.75
MASS (GeV/c²)
(c)
Δm FOR 2.250 < Λ̄ π⁻ π⁻ π⁺ < 2.275
dN/dΔm
14
12
10
8
6
4
2
125
225
325
425
525
Δmass (MeV/c²)



$\bar{\Lambda}(4\pi)^0 + \bar{\Lambda}(4\pi)^{-2}$
40
30
20
10
2.0
2.5
3.0
3.5
$M(\bar{\Lambda}4\pi)$