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(Presented by S.D. Protopopescu)

## ABSTRACT

We have carried out a sensitive ($\gtrsim$5 events/nb) search for narrow $\bar{p}p$ states at the BNL Multiparticle Spectrometer. We found no evidence of narrow $\bar{p}p$ states at 2020 and 2200 MeV in the reaction $\pi^- p \to p\pi^- \bar{p}p$ at 16 GeV/c. We quote 2 $\sigma$ upper limits of $\lesssim$ 3 nb for these states in our data. Based on the cross sections of the CERN $\Omega$ experiment at 12 GeV/c and assuming baryon-exchange processes for the production, we should have seen $\gtrsim$5 $\sigma$ signals at 2020 and 2200 MeV.

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In recent years narrow $N\bar{N}$ states have attracted much interest from both theorists and experimentalists. They represented prime candidates for being four-quark exotic states, often referred to as baryonium. Several $\bar{p}p$ states with narrow widths ($\lesssim$ 24 MeV), have been reported. Of these, the two states with mass 2020 and 2200 MeV have been seen with good statistical significance in only one experiment. This was a production experiment with $\pi^- p$ interactions at 9 and 12 GeV/C carried out in 1977 at the CERN $\Omega$ by Benkheiri et al.[1] A number of experiments have since looked for these states in both formation as well as other production processes, all with negative results.[2,3,4]

Our experiment is the first to search for these states in the same reaction as the $\Omega$ -spectrometer experiment using similar trigger techniques and acceptance.[1] The reaction studied is

$$\pi^- p \rightarrow (p_f \pi^-) \ (\bar{p}p)_s \tag{1}$$

where the subscript f(s) refers to a fast (slow) system in the laboratory. Our experiment was performed at the BNL Multiparticle Spectrometer (MPS) with a $\pi^-$ beam at 16 GeV/c impinging on a 60 cm long $LH_2$ target (see Fig. 1). The trigger required a fast forward proton with good acceptance for a baryon-exchanged, fast $p\pi^-$ system going downstream of the target. The slow-recoil $\bar{p}p$ system was then kinematically identified with the aid of spark-chamber modules on both sides as well as downstream of the target. The trigger elements included two planar PWC's, $T_1$ and $T_2$, and two scintillation counter hodoscopes, $H_5$ and $H_7$, which were used to select on-line positive tracks with momenta between 8 and 12 GeV/c, and two Čerenkov counters, $C_6$ and $C_7$, with $\gamma$ thresholds of 20 and 13, respectively. For proton identification the trigger utilized two sets of three dimensional coincidence-matrix logic systems implemented via two random access memories, RAM1 and RAM2. The elements in the logic system were (T1, T2, H5.$\bar{C}$6) in RAM1 and (T1, T2, H7.$\bar{C}$7) in RAM2. With these systems the efficiency for rejecting fast forward $\pi^+$ and $K^+$ was better than 99%. In addition, a multiplicity trigger around the target was required to select events with charged tracks $\geq$ 3. A total of 3.4 x $10^6$ proton triggers were recorded, and $\sim$80% of the sample have been analyzed to date, corresponding to a total path length of 62 $nb^{-1}$.

Events have been processed in two stages. The first stage consisted of a pattern-recognition and a crude vertex-fitting program. One can already glean at this stage much of the physics information contained in our data, as is demonstrated by a plot of $M(\pi^- p)$ for $V^o$ events (see Fig. 2). Note that a clean $\Lambda^o$ peak is seen with mass (1115.1 $\pm$ 0.2) MeV and $\sigma$ = 3.5 MeV. From a total 450K 4-prong events collected at this stage, we have selected 40K 4C candidates by requiring missing momenta to be small ($|\Delta P_x| <$ 300 MeV, $|\Delta P_y| <$ 200 MeV and $|\Delta P_z| <$ 1 GeV), and processed them through a more elaborate fitting program.

The second stage of our data reduction chain consists of a fitting program designed to perform iterative fits to spark-chamber measurements and beam parameters simultaneously, where the parameters in the fit are the vertex position and the momentum of each track at the vertex plus kinematic constraints (if any). The 40K sample has been processed through this program, first without the kinematic constraints (OC-fits), and then with the 4C kinematic constraints for the hypothesis corresponding to Reaction (1). Figs. 3a-c show the distributions in missing momenta $\Delta P_x$, $\Delta P_y$ and $\Delta P_z$ after the OC-fit. Fig. 3d shows the difference in CM energy, $\Delta\sqrt{s} = \sqrt{s}$ (initial) $-\sqrt{s}$ (final), after making cuts on the OC missing momenta ($|\Delta P_x| < 75$ MeV/c, $|\Delta P_y| < 60$ MeV/c and $\Delta P_z < 300$ MeV). It is seen that a clean peak in $\Delta\sqrt{s}$ emerges with practically no non-4C background. From this we estimate that non-4C background in our final sample is at most a few percent of the events in the sample. A total of ~7K events survive the 4C-fit for Reaction (1) with acceptable $\chi^2$. The surviving events are shown as shaded histograms in Figs. 3a-d for comparison with the OC events.

In Fig. 4 we present $M(p_f\pi^-)$ from our final ~7K sample, where $p_f$ is the fast-forward triggered proton. Although the background is substantial, $\Delta^0(1238)$, $N^0(1520)$ are clearly produced in our data. Fig. 5 shows the effective mass of the recoil system, $M(\bar{p}p_s)$, where $p_s$ is the slow proton not associated with the triggered particle. There is no evidence for the production of 2020 and 2200 MeV states in our data. We have attempted to enhance the baryon-exchanged $N^0$ or $\Delta^0$ production by making cuts on $M(p_f\pi^-)$, on the corresponding $t'$, and on the Jackson angle for the $\bar{p}p_s$ system. None of the cuts significantly improved the signal of the two claimed $\bar{p}p$ states.

Our resolution for the $\bar{p}p_s$ system has been estimated from Monte-Carlo (MC) events generated according to the observed resolution and efficiency of the MPS spark chambers, PWC's and hodoscopes. By examining the spread in mass after the MC events generated at a given $M(\bar{p}p_s)$ have been processed through our data-reduction programs, we conclude that the mass resolution is less than that shown in Fig. 6a. Thus, our resolution at 2020 (2200) MeV is less than 7(11) MeV, sufficient for us to have seen narrow states, had they been produced in our data. As a check of our mass resolution calculation we have calculated the four known masses of the final state $p_f\pi^-\bar{p}p_s$ for each particle from the remaining three plus the beam and the target for the OC fits from the data and from the MC events, and found very good agreement.

Our acceptance from finite geometry and program inefficiency as a function of $M(\bar{p}p_s)$ has been estimated using again the same MC events. The results are shown in Fig. 6b at two different values of $M(p_f\pi^-)$ corresponding to $\Delta^0(1238)$ and $N^0(1520)$, respectively. It is seen that our acceptance for $M(\bar{p}p_s)$ at 2.02 (2.20) GeV is 23% (16%) with $M(p_f\pi^-)$ at $\Delta^0(1238)$.[5] Our estimate for the additional loss due to inefficiencies in the trigger components, $\chi^2$ cut, etc., is ~44%. Thus, the overall visible sensitivity for our present data is

| $M(\bar{p}p_s)$ | $\Delta^0(1238)$ | $N^0(1520)$ |
|---|---|---|
| 2.02 GeV | 8.0 evts/nb | 7.0 evts/nb |
| 2.20 GeV | 6.0 evts/nb | 5.0 evts/nb |

to be compared with the original CERN data with sensitivities in the 1-2 evts/nb range.

Since the CERN experiment saw their $\bar{p}p$ states most clearly with $M(p_f\pi^-)$ and Jackson angle cuts, we display in Figs. 7a-c the $M(\bar{p}p_s)$ spectra selecting for $\Delta^o(1238)$, $N^o(1520)$ and with $\cos\theta_J < 0$. Again we see no evidence for the 2020 and 2200 MeV states. The dotted histograms show our estimate of the peaks we should have seen, had they been produced with the cross sections quoted in reference (1) but reduced via $\sim P_{lab}^{-2.5}$, a typical behavior of baryon-exchange processes. The absence of the $\bar{p}p$ states in our data corresponds to $\gtrsim 7\sigma$ and $\gtrsim 5\sigma$ discrepancies at 2020 and 2200 MeV, respectively. We show in Fig. 8, $2\sigma$ upper limit cross sections of 3.0 nb for 2.02 state (obtained by combining $\Delta^o$ and $N^o$ events) and 2.0 nb for 2.20 state (for $\Delta^o$ events alone), along with the quoted cross sections of the CERN data.

We must point out, however, that we do see a marginal signal at 2.02 GeV, if our $\sim$7K sample is enlarged by relaxing the $\chi^2$ cut. This effect is demonstrated in Fig. 9a, where the $M(\bar{p}p_s)$ spectrum is shown with $\cos\theta_J < 0$ and with two different $\chi^2$ cuts. This signal is closely associated with $\rho^o$ events from the reaction

$$\pi^- p \to (p_f\pi^-)\ (\pi^+\pi^-)X^o \qquad (2)$$

Note that, if $X^o$ is slow in the laboratory and has mass $\sim$500 MeV, the events resulting from this reaction would be impossible to distinguish from the events of Reaction (1). If we take the $\bar{p}p_s$ system to be a $\pi^+\pi^-$ system and plot the resulting effective mass (see Fig. 9b), we see a broad enhancement in the $\rho^o$ vicinity. If we take those events within the 2020 region (dotted lines in Fig. 9a), we find that they are indeed associated with the $\rho^o$ peak (shaded area in Fig. 9b). The effect is even more noticeable if we take events which fail the 4C fit for Reaction (1) and satisfy Reaction (2) with $X^o$ mass $< 800$ MeV.

The effect of a $\rho^o$ contamination can be further illustrated with MC events, shown in Fig. 10. Potential sources for difficulties with the $\rho^o$ events are twofold. First, the apparent width of the $\rho^o$ is reduced by a factor of $\sim$2 if the $\pi^+\pi^-$ system is taken to be a $\bar{p}p$ system. Second, if the $\rho^o$ happens to be on a steeply rising background (dashed curve in Fig. 10a), one is tempted to overestimate the background with the resultant apparent decrease in width of the resonance. Again, the 2020 MeV region is associated with the $\rho^o$ events: the shaded area in Fig. 10b, peaked at the $\rho^o$ region, corresponds to the 2020 MeV region (dotted lines in Fig. 10a).

We wish to emphasize, therefore, that it is very important to demonstrate that, if one observes a signal in $\bar{p}p$ at 2020 MeV, it is not due to $\rho^o$ contamination.

In summary, we do not observe the 2020 and 2200 MeV $\bar{p}p$ states in our $\pi^-p$ data at 16 GeV/c. We find that the 2 $\sigma$ upper limits for these states are less than 3 nb. From the cross sections of the 12 GeV/c CERN data and the assumption of nucleon exchange, we should have seen $\gtrsim 5\ \sigma$ signals at 2020 and 2200 MeV in our data. We conclude, therefore, that our experiment contradicts the results of the CERN data. In order for our data and the CERN data to agree, one will have to invent a precipitous energy dependence, unlike that encountered so far in the studies of exclusive exchange processes.

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## REFERENCES AND FOOTNOTES

1. P. Benkheiri et al., Phys. Lett. 68B, 483 (1977); Phys. Lett. 81B, 380 (1979). A marginal signal was also seen in $e^-p$ interactions by Gibbard et al., Phys. Rev. Lett. 42, 1593 (1979).

2. Several $\bar{p}N$ formation experiments do cover the 2020 MeV region, but find little evidence for the peak: W. Bruckner et al., Phys. Lett. 67B, 222 (1977); M. Alston-Garnjost, Phys. Rev. Lett. 43, 1901 (1979); R.P. Hamilton et al., Phys. Rev. Lett. 44, 1179 (1980); Phys. Rev. Lett. 44, 1182 (1980).

3. Several $\bar{p}p$ backward production experiments report no evidence of either 2020 or 2200 MeV states: C. Cline et al., Phys. Rev. Lett. 43, 1771 (1979); R.M. Bionta et al., Phys. Rev. Lett. 44, 909 (1980); A.S. Carroll et al., BNL preprint BNL 27492.

4. Peripherally produced $\bar{p}p$ systems have also been examined, with equally negative results: T.A. Armstrong et al., Phys. Lett. 85B, 304 (1979); W.E. Cleland, Phys. Lett. 86B, 409 (1979): C. Daum et al., Phys. Lett. 90B, 475 (1980).

5. Quoted acceptances include absorption effects in the $LH_2$ target. All other losses due, for example, to equipment inefficiency, etc., have been lumped together separately and commented on elsewhere in the text.

## FIGURE CAPTIONS

Figure 1. Floor plan of the experiment. $T_1$ and $T_2$ are the planar PWC's; $H_4$, $H_5$, and $H_7$ are the scintillation counter hodoscopes; $C_3$, $C_6$ and $C_7$ are the Cerenkov counters.

Figure 2. $M(\pi^-p)$ in the $\Lambda$ region.

Figure 3. (a-d) Missing momentum and energy for Reaction (1). Shaded histograms are for those events satisfying the 4-C fits.

Figure 4. $M(p_f\pi^-)$ for the events of Reaction (1).

Figure 5. $M(\bar{p}p_s)$ for the events of Reaction (1).

Figure 6. (a) Mass resolution for the $\bar{p}p_s$ system.
(b) Acceptance as a function of $M(\bar{p}p_s)$ with the recoil system in the region of $\Delta^0(1238)$ or $N^0(1520)$.

Figure 7. (a-c) $M(\bar{p}p_s)$ for the events in the region of $\Delta^o(1238)$, $N^o(1520)$, and $\Delta^o$ plus $N^o$ with $\cos\theta_J < 0$. Dotted bins delineate the 2020 and 2200 peaks expected from the CERN data.

Figure 8. 2 $\sigma$ upper limits for the 2200 and 2020 states in our data, along with the cross sections quoted in the CERN paper.

Figure 9. (a) $M(\bar{p}p_s)$ for the events with $\cos\theta_J < 0$ and $\chi^2$ (per degree-of-freedom) < 5 [this is the cut adopted for Reaction (1) throughout this paper], and also for those with $\cos\theta_J < 0$ and $\chi^2$ (per degree-of-freedom) < 10.

(b) Mass spectrum for the events with the larger $\chi^2$ cut in (a), under the hypothesis that the $\bar{p}p$ system is a $\pi^-\pi^+$ system. The shaded histogram corresponds to those events in the 2020-MeV region [dotted lines in a)].

Figure 10. Monte Carlo events generated with a $\rho^o$ on a smooth, rising background. (a) and (b) are similar to those of Figure 9.

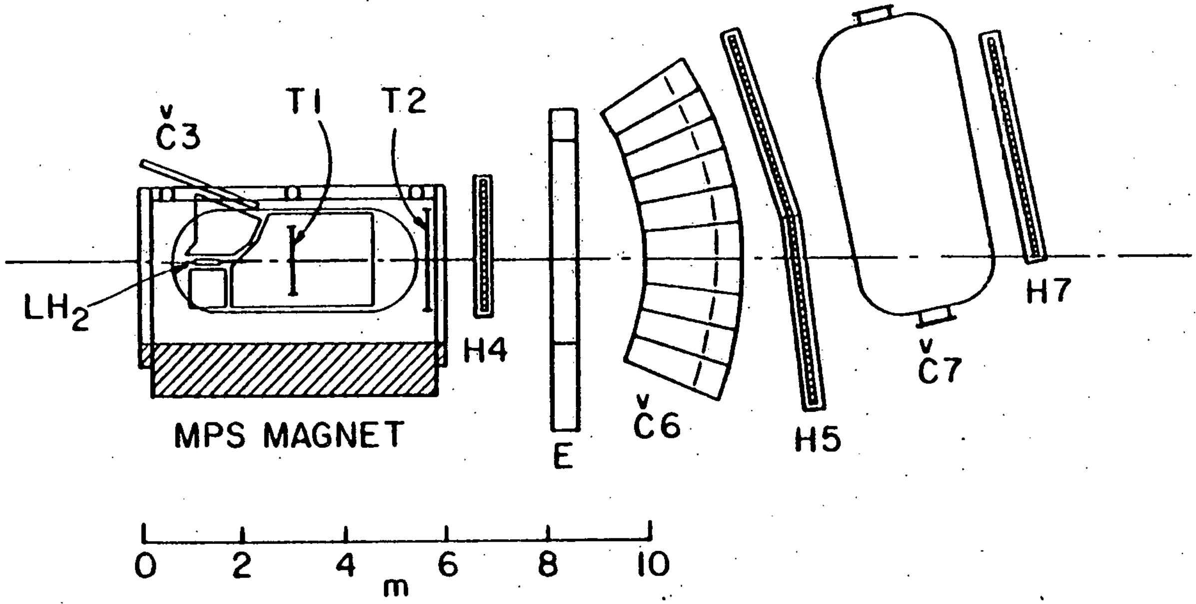



Fig. 1

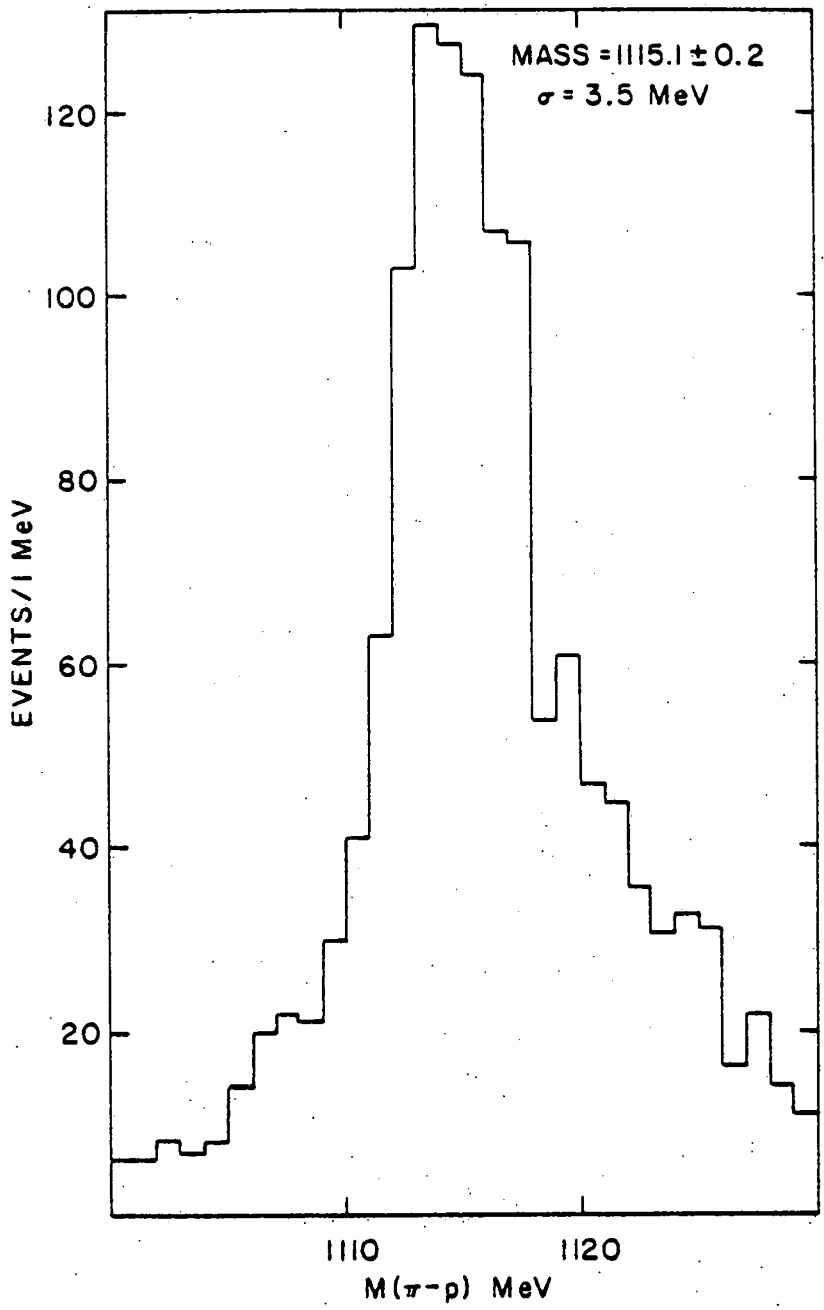

MASS = 1115.1 ± 0.2
σ = 3.5 MeV
EVENTS/1 MeV
120
100
80
60
40
20
1110
1120
M(π−p) MeV

Fig. 2

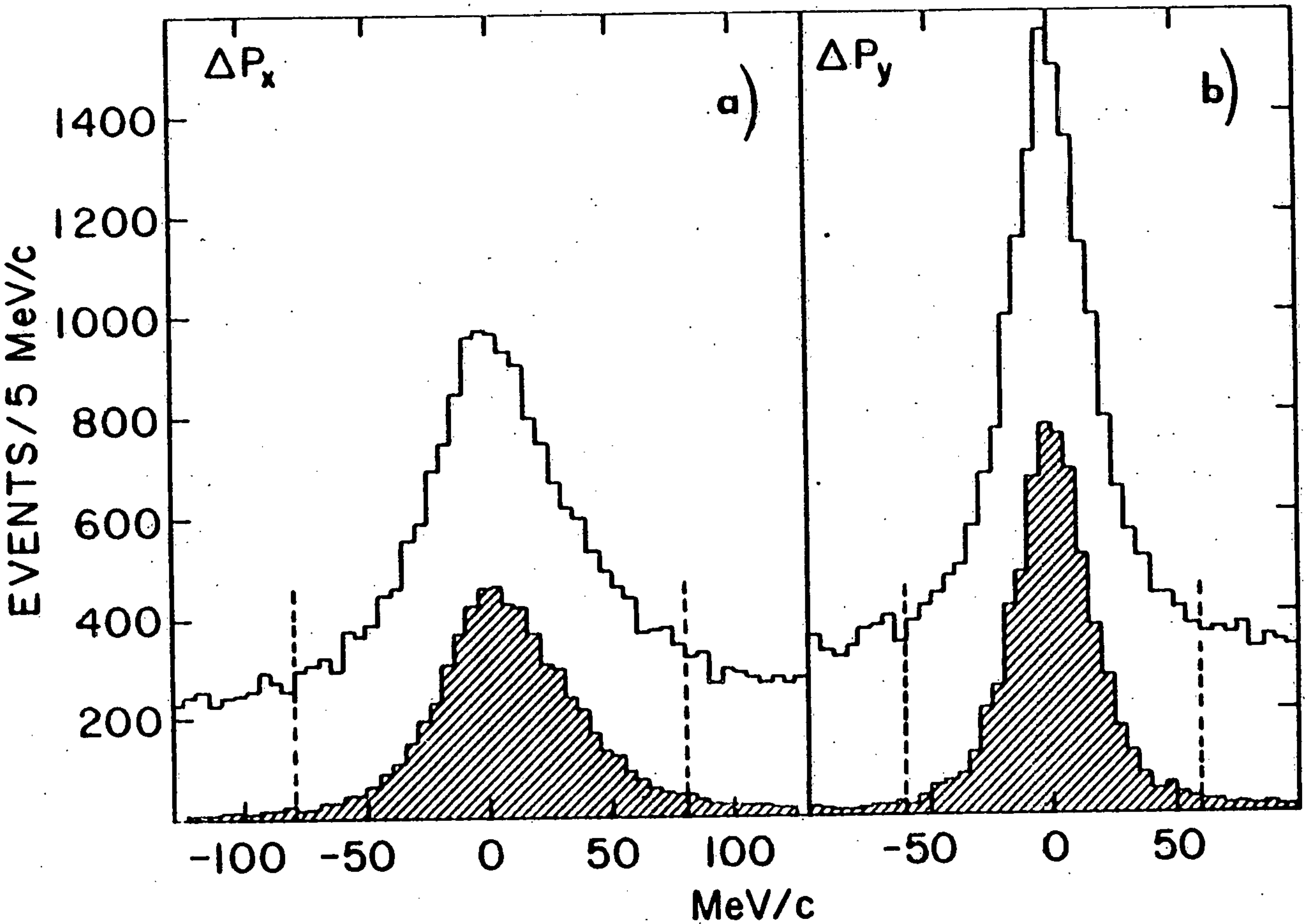

ΔPx
a)
ΔPy
b)
EVENTS/5 MeV/c
1400
1200
1000
800
600
400
200
-100
-50
0
50
100
-50
0
50
MeV/c

Fig. 3 (a,b)

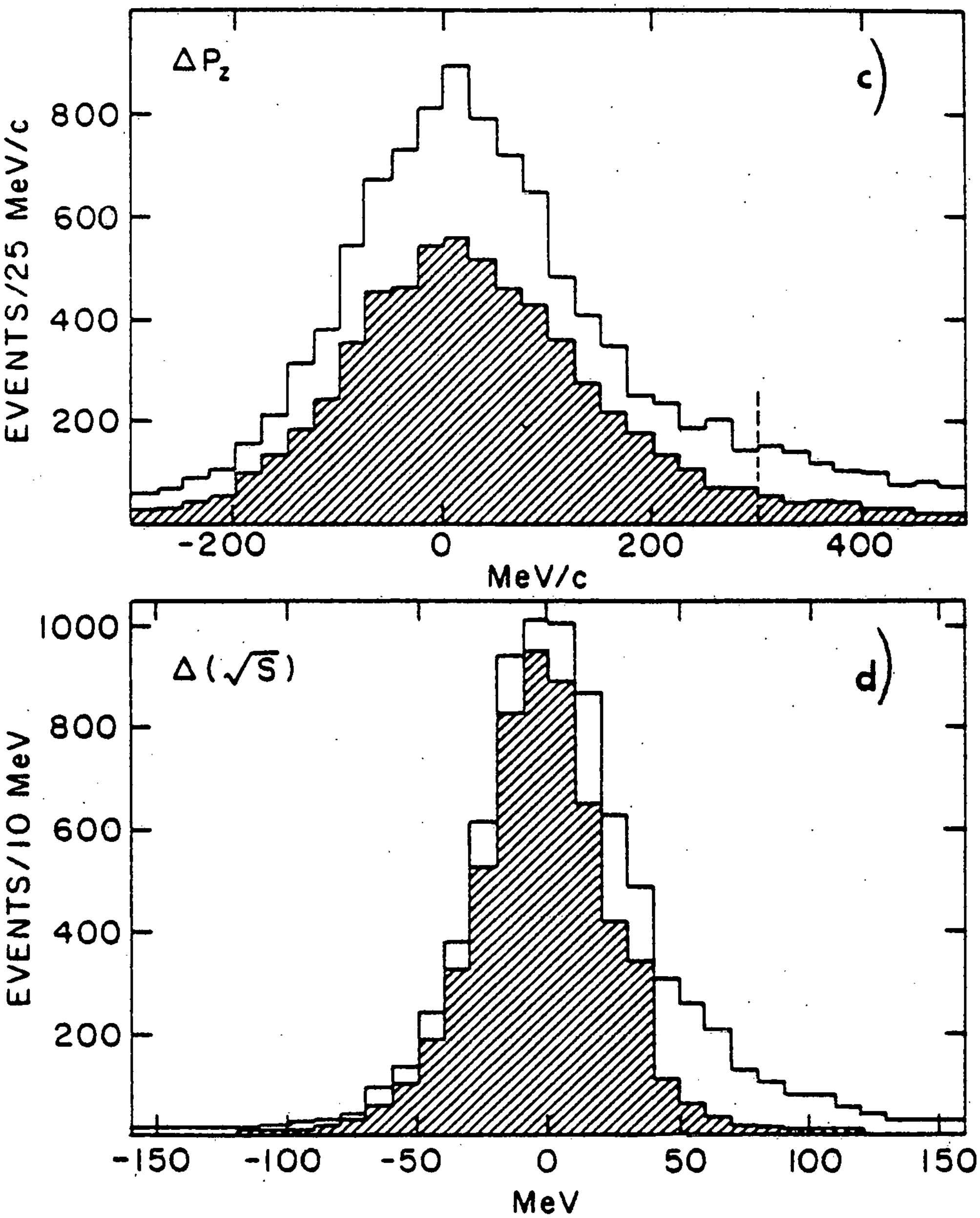

ΔP_z
c)
EVENTS/25 MeV/c
800
600
400
200
-200
0
200
400
MeV/c
Δ(√S)
d)
EVENTS/10 MeV
1000
800
600
400
200
-150
-100
-50
0
50
100
150
MeV

Fig. 3 (c,d)

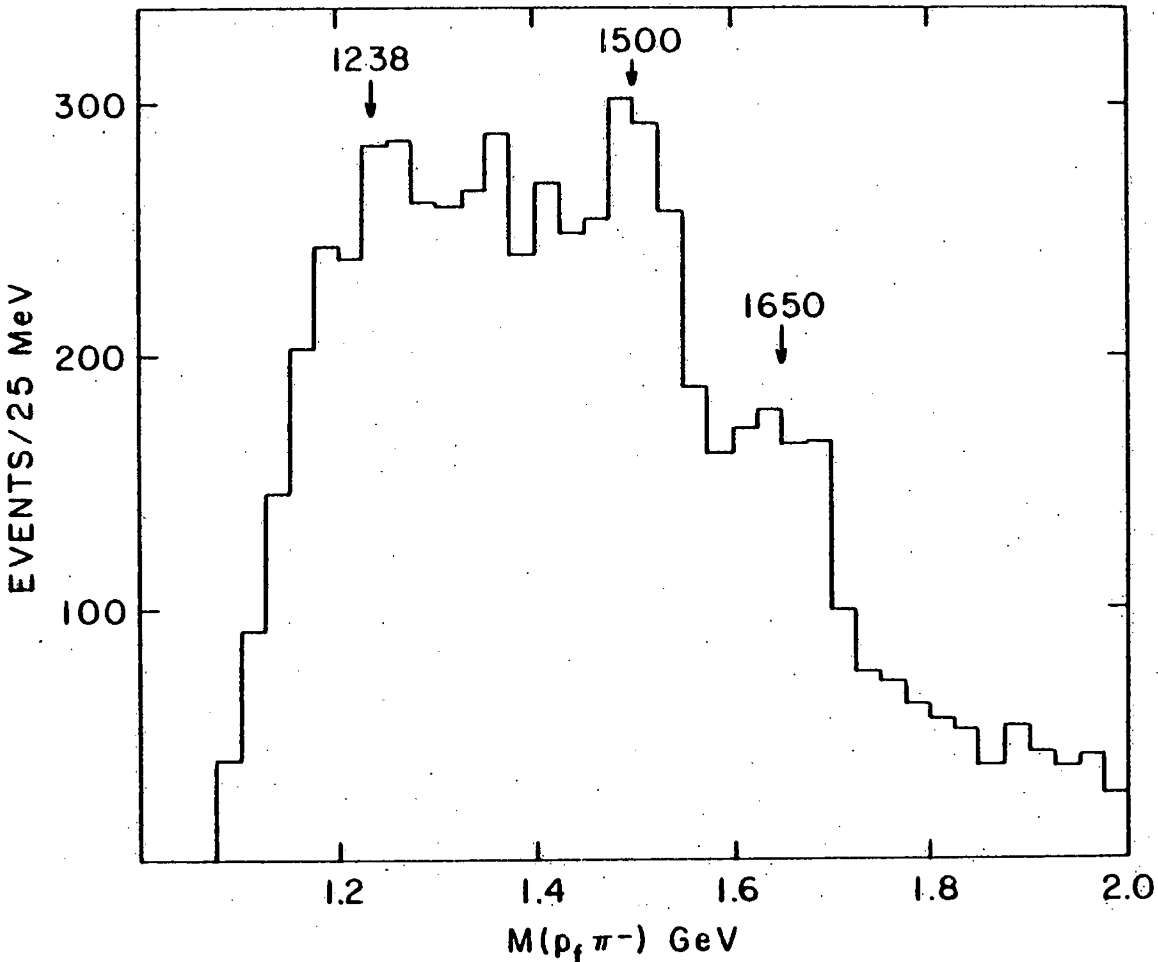

1238
1500
1650
300
200
100
EVENTS/25 MeV
1.2
1.4
1.6
1.8
2.0
M($\rho_f\pi^-$) GeV

Fig. 4

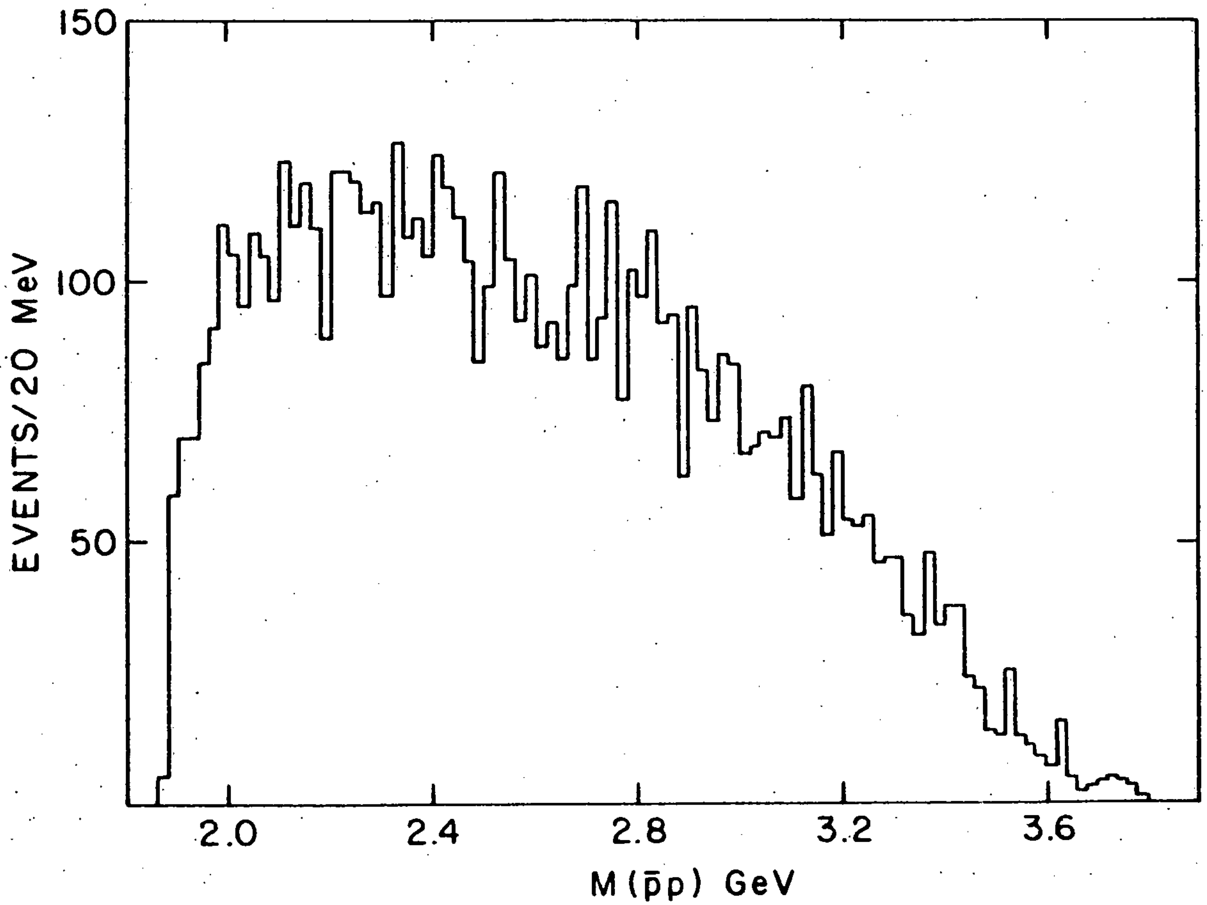



Fig. 5

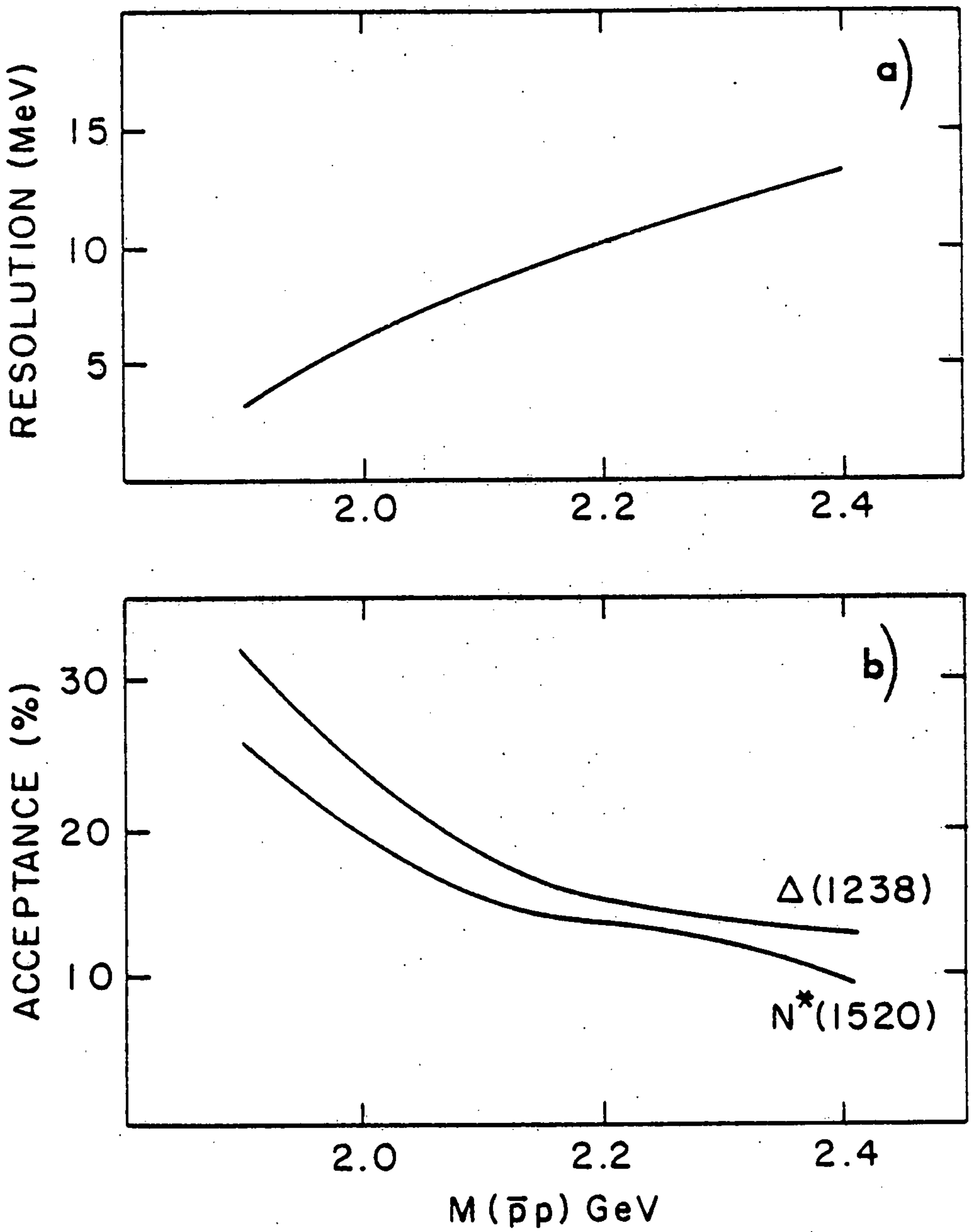
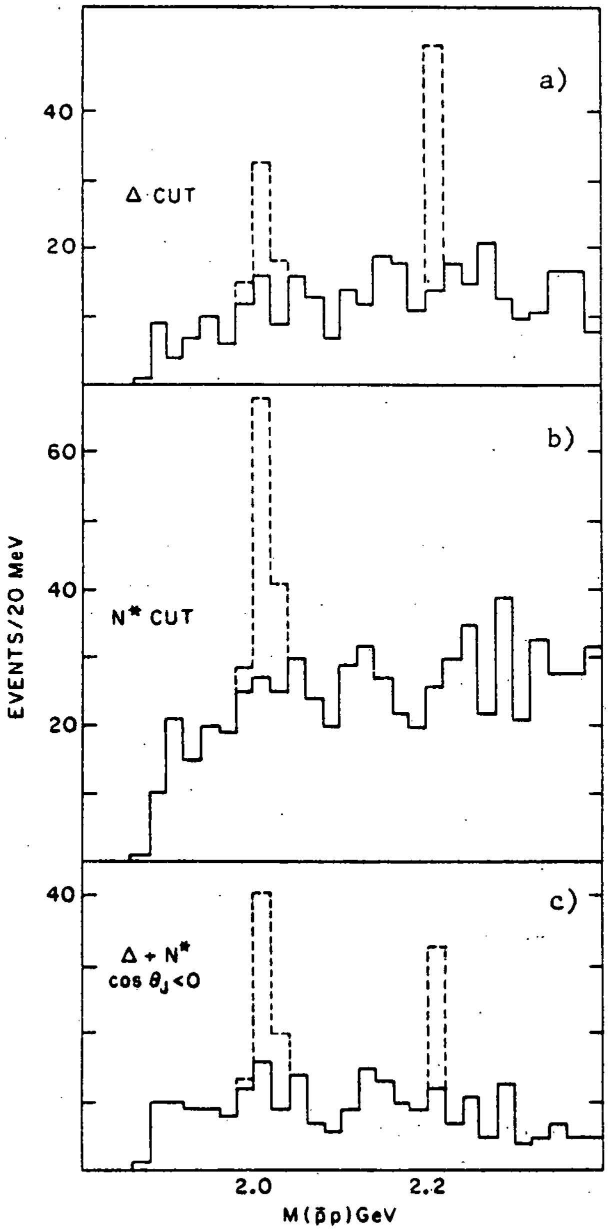
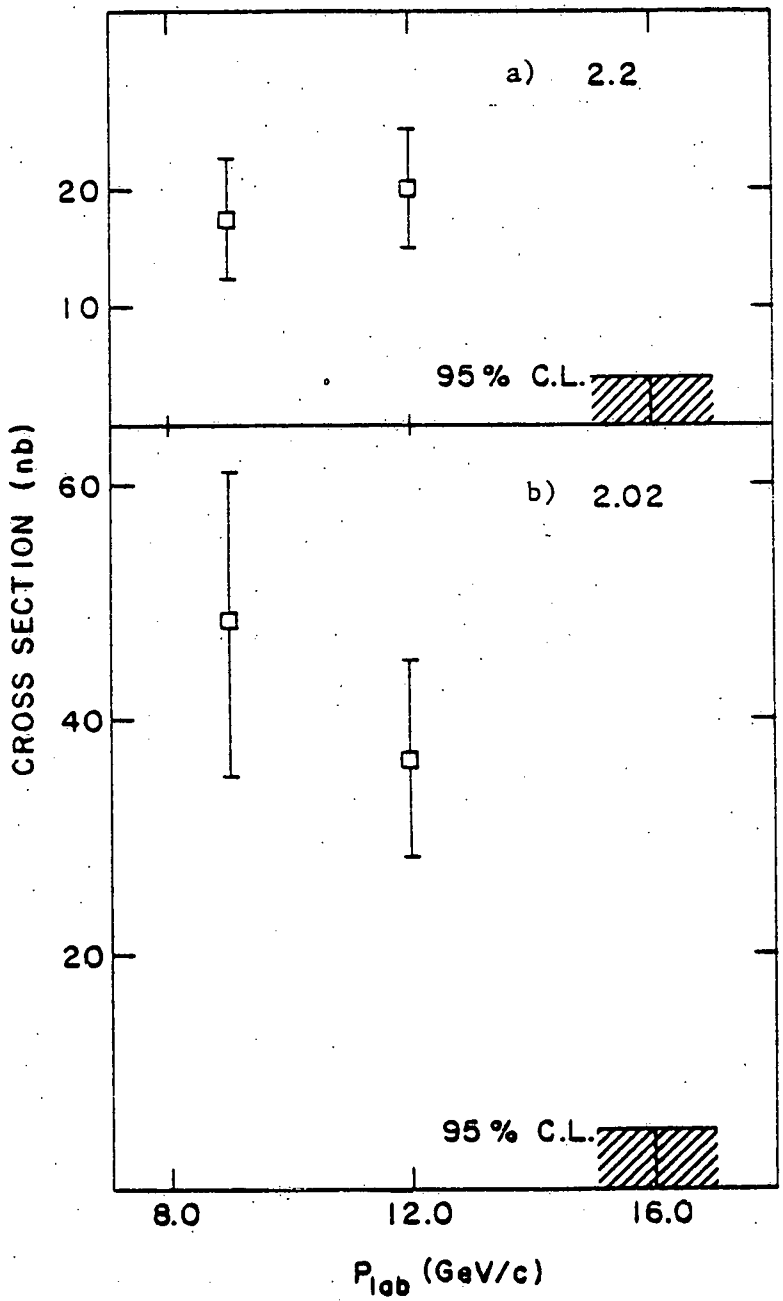

a)
RESOLUTION (MeV)
15
10
5
2.0
2.2
2.4
b)
ACCEPTANCE (%)
30
20
10
Δ(1238)
N*(1520)
2.0
2.2
2.4
M (p̄p) GeV

Fig. 6



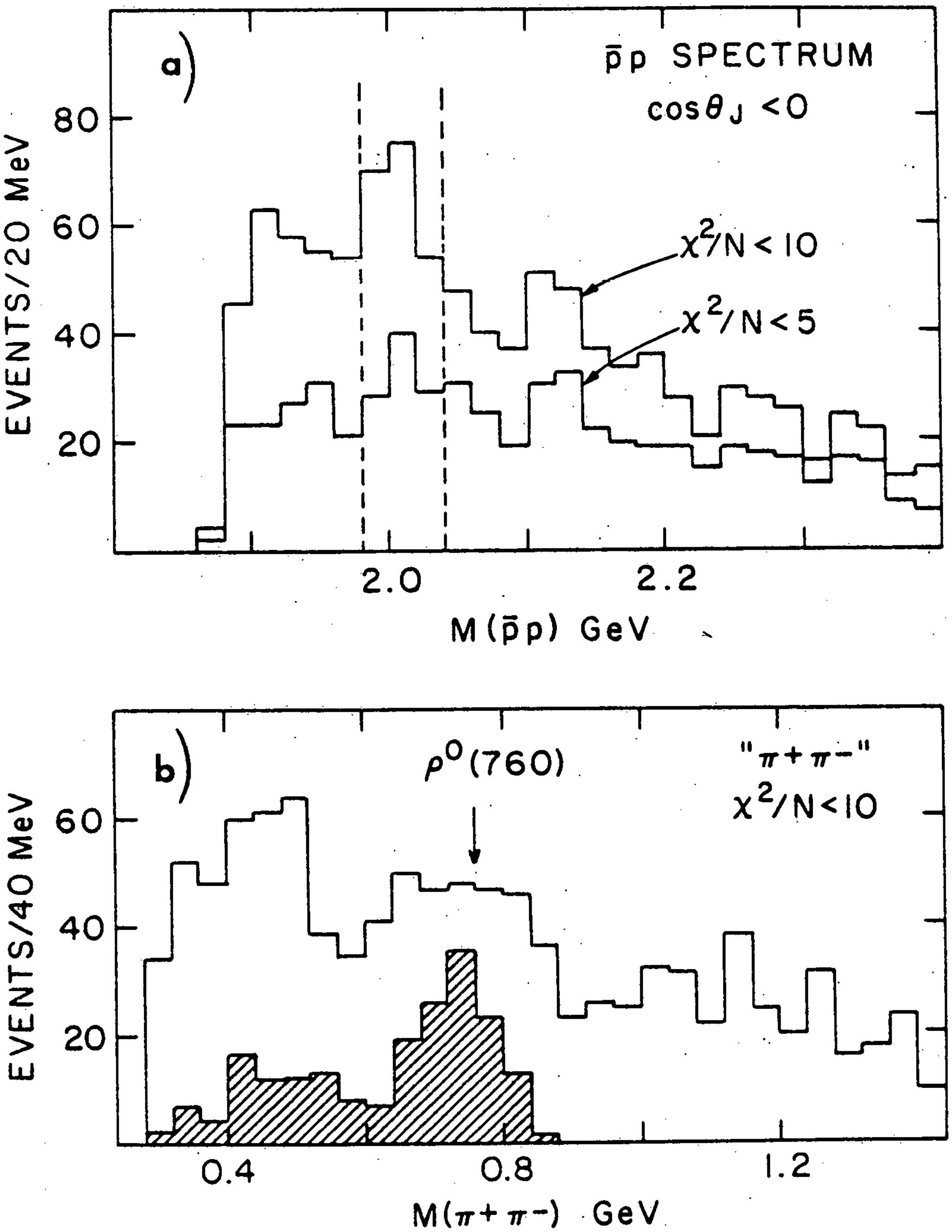
a)
40
20
Δ·CUT
b)
60
40
20
N* CUT
EVENTS/20 MeV
c)
40
Δ + N*
cos θ_J<0
2.0
2.2
M(p̄p)GeV


Fig. 7



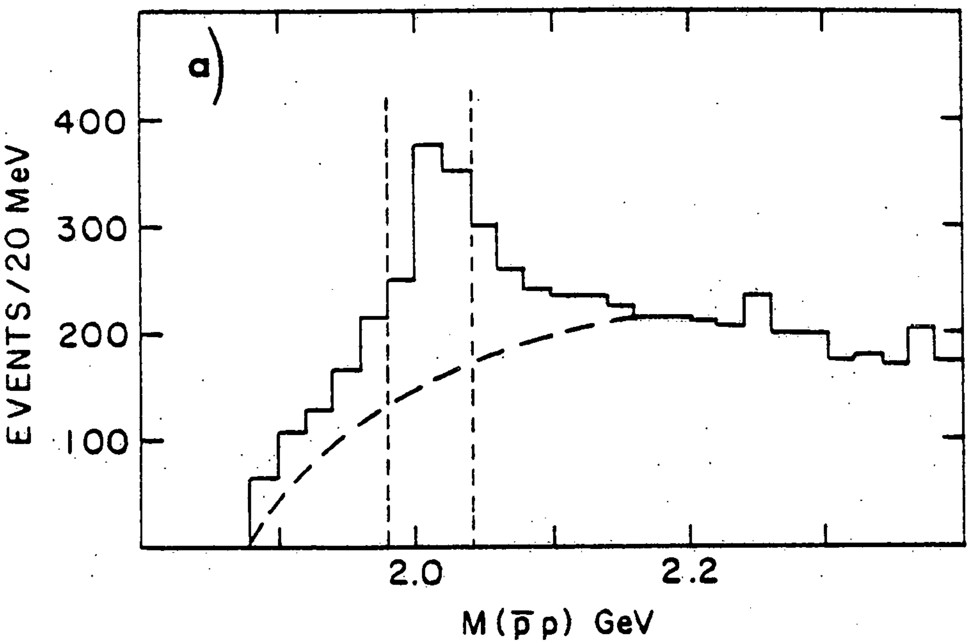
a) 2.2
b) 2.02
95 % C.L.
95 % C.L.
CROSS SECTION (nb)
20
10
60
40
20
8.0
12.0
16.0
$P_{lab}$ (GeV/c)


Fig. 8



a)
p̄p SPECTRUM
cosθ_J <0
χ²/N < 10
χ²/N < 5
80
60
40
20
EVENTS/20 MeV
2.0
2.2
M(p̄p) GeV
b)
ρ⁰(760)
"π+π−"
χ²/N<10
60
40
20
EVENTS/40 MeV
0.4
0.8
1.2
M(π+π−) GeV


Fig. 9


a)
400
300
200
100
EVENTS/20 MeV
2.0
2.2
M(p̄p) GeV

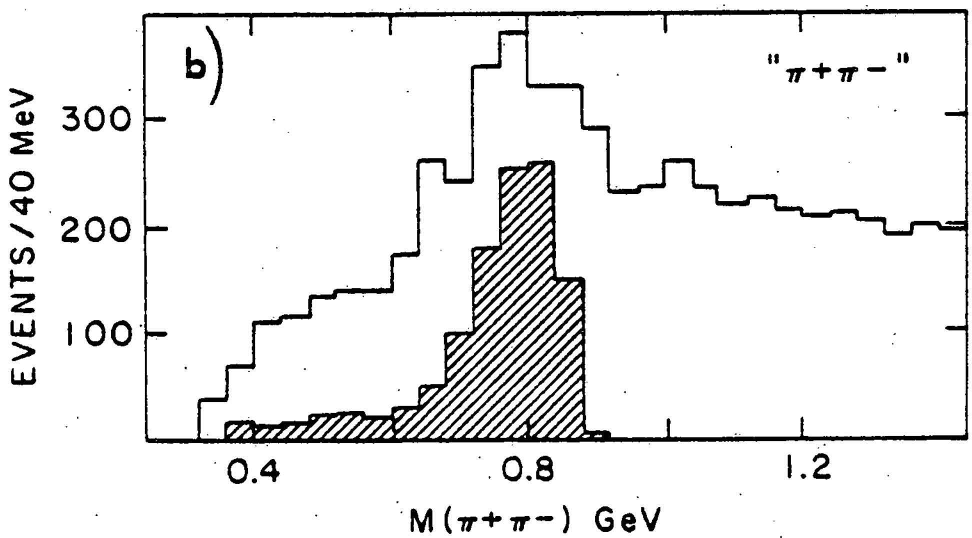

b)
"π+π−"
300
200
100
EVENTS/40 MeV
0.4
0.8
1.2
M(π+π−) GeV

Fig. 10