of the width, $\simeq 10$ MeV, as found in our data. It is quite possible that a more rigorous, relativistic calculation of the two-step process, which incorporates the off-mass-shell effects properly, would move the kinematical peak to lower energies, to fit our observed enhancement.

On the other hand, in view of the position of the peak and asymmetry of our mass distribution, we cannot invoke a simple resonance model, as has been done by Cline *et al.*[1] It may, however, be seen from Fig. 3 that a possible interpretation of our data is in terms of a resonance having mass $= 2125-2129$ MeV and width ≈ 10 MeV, together with a kinematical enhancement of the type calculated by Alexander having a peak at 2139 MeV with width 25–30 MeV.

A more direct search for a Λp resonance should be possible in experiments on Λp scattering. This has so far proved to be inconclusive[4] because of the poor statistics involved.

We are indebted to the operating crews of the NIMROD and the Saclay bubble chamber, and to the scanning and measuring teams in our laboratories for their diligent efforts.

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Production of $B(1235)$ and ρ (1710) 4π Enhancements in 16-GeV/c $\pi^{\pm}p$ Collisions*

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Production of $B(1235)$ and $\rho(1710)$ mesons is observed in the four-pion decay modes $\pi^{\pm}\pi^{+}\pi^{-}\pi^{0}$ in 16-GeV/c $\pi^{\pm}p$ collisions. Decay distributions and branching fractions into various modes are presented. Absence of the two-pion mode $\pi^{-}\pi^{0}$ for the $\rho(1710)$ is noted.

We report on data from two exposures in the Brookhaven National Laboratory 80-in. hydrogen bubble chamber. Both used an incident beam momentum of 16 GeV/c. In the first exposure 60000 pictures were taken in a negative (unseparated) pion beam and subsequently all two- and four-prong events were measured. The second exposure of 50000 pictures used an rf-separated π^+ beam, and all four prongs were measured.

From the two-prong data we obtained a sample of 446 events constraining to the reaction

$$\pi^- p \to p\pi^-\pi^0 . \qquad (1)$$

Selection of these events was similar to that described in Ref. 1: All events with a four-constraint (4c) fit were removed from the sample, and missing-mass and confidence-level cuts were applied to the remaining fits to separate the final states $\pi^+\pi^- n$, $p\bar{p}n$, $K^+K^- n$ from reaction (1). The reaction cross section was measured by two methods as described in Ref. 1, one where the normalization was set by the measured two-prong topological cross section and the other normalizing to the elastic 4c events corrected for losses at low t by comparison with the published elastic scattering data.[2] The result for reaction (1) is 0.43 ± 0.08 mb, as shown in Table I.

The four-prong events were treated in a similar manner. After removal of the 4c events, only fits with greater than 1% confidence were considered, the missing mass squared was chosen in the interval ± 0.11 GeV^2 about the π^0 mass and finally the error on the missing mass squared was required to be less than 0.18 GeV^2. We found 1192 events pass-

TABLE I. $\pi^{\pm}p$ cross sections at 16 GeV/c.

Reaction	σ (mb) π^-p	σ (mb) π^+p
$\pi^{\pm}p \to$ 2 prongs	8.7 ±0.6	7.6 ±0.6
$\pi^-p \to p\pi^-\pi^0$	0.43 ±0.08	...
$\pi^{\pm}p \to$ 4 prongs	8.8 ±0.7	8.6 ±0.6
$\pi^{\pm}p \to p\pi^{\pm}\pi^+\pi^-\pi^0$	1.24 ±0.15	1.28 ±0.17
$\pi^{\pm}p \to pB^{\pm}$, $B^{\pm} \to \pi^{\pm}\pi^+\pi^-\pi^0$	0.040±0.015	0.030±0.010
$\pi^{\pm}p \to p\rho^{\pm}(1710)$, $\rho^{\pm}(1710) \to \pi^{\pm}\pi^+\pi^-\pi^0$	0.040±0.015	0.025±0.010

ing these criteria for the reaction

$$\pi^-p \to p\pi^-\pi^+\pi^-\pi^0 \quad (2)$$

and 951 events for reaction

$$\pi^+p \to p\pi^+\pi^-\pi^+\pi^0. \quad (3)$$

The reaction cross sections for (2) and (3), along with the four-prong topological cross sections from which they were obtained, are listed in Table I.

We first discuss the mass spectra for the 4π states. Figure 1(a) shows the four-pion mass spectrum for reaction (2). Two enhancements are easily visible in the uncut spectrum, one at ~ 1.25 GeV, which we associate with the B meson,[3-10] and the other at ~ 1.70 GeV, which we associate with the $\rho(1710)$.[10-14] The shaded spectrum shows those events which have a $\pi^+\pi^-\pi^0$ combination in the ω^0 (here taken to be 0.78 ± 0.06 GeV). The B-meson signal is seen to be dominantly from the $\omega^0\pi^-$ events, while the $\rho(1710)$ branches only weakly (< 30% at the 90% confidence level) into this mode. In Fig. 1(b) we see the same spectrum for events with a $\pi^+\pi^-$ combination in the ρ^0 band (taken to be 0.76±0.08 GeV). The $\rho(1710)$ appears strongly in the data while there is no evidence of a B signal.

Figures 2(a) and 2(b) show the corresponding spectra for reaction (3). They closely resemble the data of Fig. 1. As might be expected, the Δ^{++} is stronger in reaction (3) and has a greater overlap with the $\rho(1710)$ than for reaction (1) [about 25% of the data are removed from the $\rho(1710)$ region when Δ^{++} is excluded in Fig. 2(a) versus 10% in Fig. 1(a)]. The B spectrum appears very much the same in both samples.

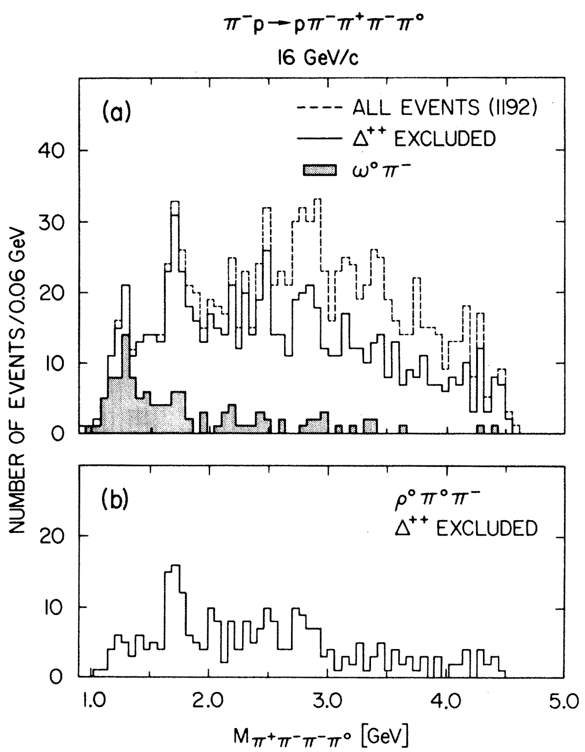

FIG. 1. Four-pion invariant mass spectra for the process $\pi^-p \to p\pi^-\pi^+\pi^-\pi^0$ at 16 GeV/c. (a) The dashed curve shows all events; the solid curve excludes events in the Δ^{++}; the shaded histogram contains events with an ω^0, and excludes Δ^{++}. (b) Histogram of events containing an associated ρ^0.

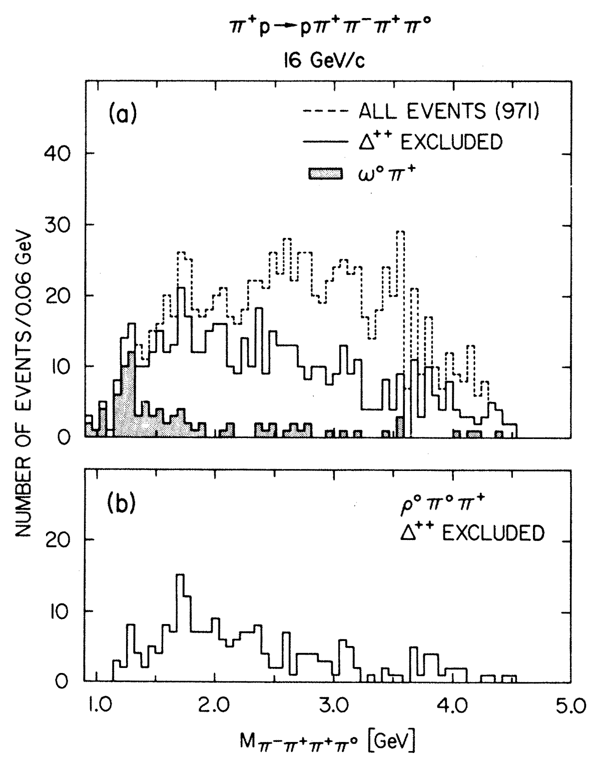

FIG. 2. Four-pion invariant mass spectra for the process $\pi^+p \to p\pi^+\pi^-\pi^+\pi^0$ at 16 GeV/c. (a) The dashed curve shows all events; the solid curve excludes events in the Δ^{++}; the shaded histogram contains events with an ω^0, and excludes Δ^{++}. (b) Histogram of events containing an associated ρ^0.

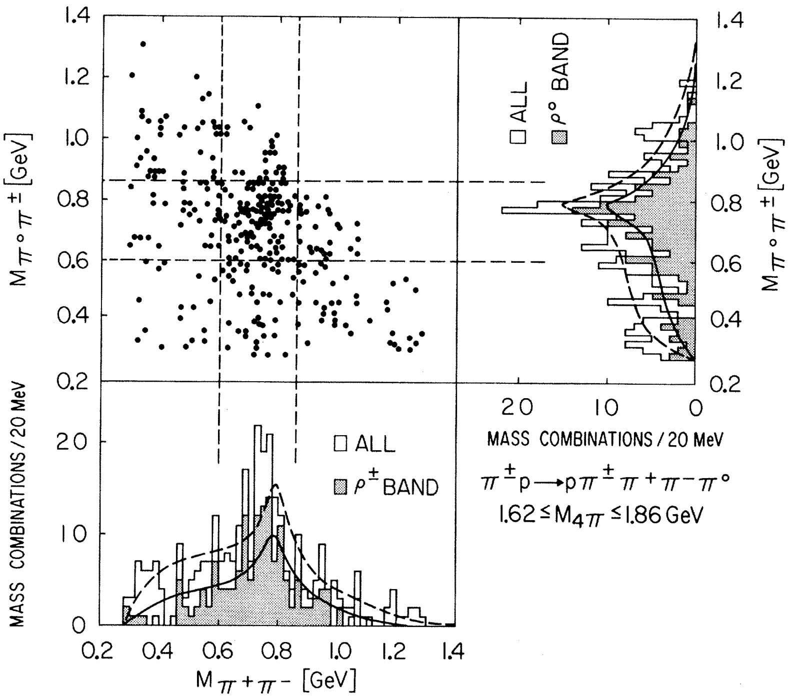

FIG. 3. Scatter plot of $M(\pi^+\pi^-)$ versus $M(\pi^{\mp}\pi^0)$ for events in the $\rho(1710)$ region for $\pi^{\pm}p \rightarrow p\pi^{\pm}\pi^+\pi^-\pi^0$ with their associated mass projections. The shaded histogram shows mass projections for events with an associated ρ in the conjugate pair. The fitted curves are explained in the text.

Table I includes the production cross sections found for both enhancements in their two charge states decaying into the four-pion modes observed here. These are obtained using a simple Breit-Wigner resonance form over a hand-drawn background to describe the resonances. Although the cross sections for the two charges agree within statistics, those for reaction (3) tend to be systematically lower. This is most likely due [at least for the $\rho(1710)$] to difficulties in estimating cross sections in the heavier Δ^{++} background of reaction (3). In addition, the presence of two $p\pi^+$ combinations in reaction (3) doubles the probability of erroneous losses of good events when the Δ^{++} is excluded.

An investigation of the most likely decay modes of the 1710-MeV enhancement is hampered by the limited statistics, the large (~ 50%) background, and the "false combination" of four particles taken in pairs or triplets. At first sight there seems to be evidence of a large $\rho^0\rho^-$ decay mode, as is indicated in Fig. 3 where $\pi^+\pi^-$ pair invariant masses are plotted against $\pi^{\pm}\pi^0$ masses. The overlap region of ρ^0 and $\rho^{\pm}$ is preferentially populated, indicating strong ρ^0 and $\rho^{\pm}$ decay modes. To distinguish a $\rho\rho$ mode from a $\rho 2\pi$ mode, the data were divided into 3 regions of $m(4\pi)$: 1.06 to 1.62 GeV, 1.62 to 1.86 GeV (the region shown in Fig. 3), and 1.86 to 2.0 GeV. In addition, each of these regions was divided into the dashed areas shown in the $\pi^+\pi^- - \pi^{\pm}\pi^0$ mass scatter plot, illustrated in Fig. 3. The background was characterized by a smooth curve and a phase-space distribution of $\pi\pi$ masses.

The solid curves in Fig. 3 show the expected mass projection for $\rho(1710) \rightarrow \rho\rho$. The dashed curve shows the expected mass projections for the subsample of events associated with a ρ in the conjugate pair. The resulting fit favored slightly $\rho\rho$ decays over $\rho\pi\pi$, though both are acceptable.

Other possible decay modes of the $\rho(1710)$ are $A_1\pi$ or $A_2\pi$. Invariance of the decay under isospin rotation requires equal fractions of $A^{\pm}\pi^0$ and $A^0\pi^{\pm}$ for an $I=1$ or 2 parent state, and hence, equal amounts of $\rho^{\pm}\pi^0\pi^0$, $\rho^0\pi^{\pm}\pi^0$, $\rho^{\pm}\pi^-\pi^+$, $\rho^{\mp}\pi^+\pi^+$. The lat-

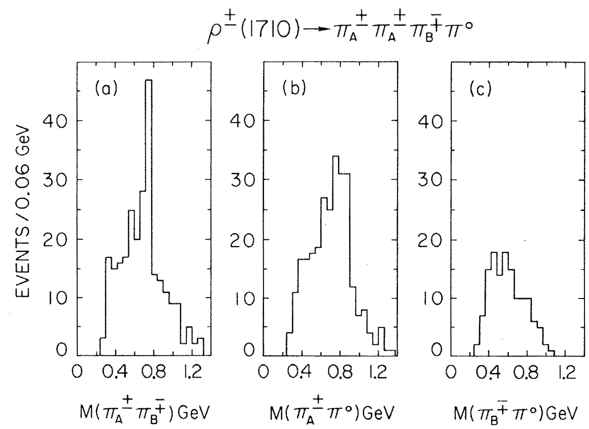

FIG. 4. Invariant mass plots of $\pi\pi$ systems for events in the $\rho^{\pm}(1710)$ region of the combined sample of reactions (2) and (3). (a) Mass $(\pi^+\pi^-)$. (b) Mass $(\pi^{\pm}\pi^0)$ having the same charge as the incident beam [$\pi^-\pi^0$ from reaction (2) + $\pi^+\pi^0$ from reaction (3)]. (c) Mass $(\pi^{\mp}\pi^0)$ with a charge opposite the beam charge [$\pi^+\pi^0$ from reaction (2) + $\pi^-\pi^0$ from reaction (3)].

ter three modes are observable in reactions (2) and (3) and give rise to equal populations of ρ^0, ρ^+, and ρ^- in the data. For events in the $\rho(1710)$ we find a strong ρ^0 signal in both reactions (2) and (3) as seen in Fig. 4(a); there is an equally strong signal for ρ's having the same charge as the incident beam [ρ^- for reaction (2), ρ^+ for reaction (3)] shown in Fig. 4(b); and *no* apparent signal for ρ's of charge opposite to the beam [Fig. 4(a)]. Hence an $A\pi$ decay mode is not required in our data.

In summary we find the 4π decay modes of the $\rho(1710)$ to divide in the following way:

$$\frac{\Gamma(\rho\pi\pi)}{\Gamma(\text{all } 4\pi)} = 0.88 \pm 0.15 \text{ (indistinguishable from } \rho\rho),$$

$$\frac{\Gamma(\omega^0\pi)}{\Gamma(\text{all } 4\pi)} = 0.12 \pm 0.07,$$

$$\frac{\Gamma(A\pi)}{\Gamma(\text{all } 4\pi)} < 0.4 \text{ (90\% confidence limit).}$$

Finally, we looked for evidence of a 2π mode for the $\rho(1710)$ resonance. In Fig. 5 we show the $\pi^0\pi^-$ mass plot for events from reaction (1). The mass resolution in the vicinity of the $\rho(1710)$ is calculated to be only slightly worse[15] (±21 MeV compared to ±19 MeV, well within the binning selected) for the $\pi^-\pi^0$ spectrum than in the corresponding four-pion case of Fig. 1. A weak ρ signal is observed, but there is no evidence of the $\rho(1710)$ decay into 2π. Previous observations of this decay mode in a π^-p experiment[12] at 7 GeV/c, and a π^+p experiment[16] at 8 GeV/c reported the $2\pi/4\pi$ branching ratio as 0.7 ± 0.18 and 0.8 ± 0.15, respectively. Such a branching ratio would require a signal of ≈ 30 events in 2π mass spectrum in the $\rho(1710)$ region, which is clearly not supported by the data. The best estimate of the branching ratio at 16 GeV/c is then $< 12\%$, at the 90% confidence level.

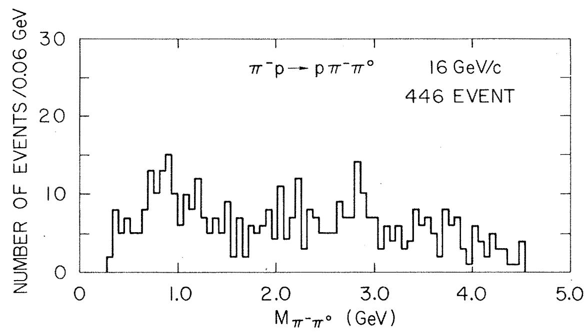

FIG. 5. Invariant mass of the $\pi^-\pi^0$ system for the process $\pi^-p \to p\pi^-\pi^0$ at 16 GeV/c.

In conclusion, we find that the B and $\rho(1710)$ mesons are produced in 16-GeV/c πp collisions, decaying into 4π but only weakly into 2π. We take this as rather clear evidence that the $\rho_{4\pi}(1710)$ and $g_{2\pi}(1640)$ are indeed different states.

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[15]Calculation of the mass resolution was done using the error matrix from kinematic fitting. The resolution function was assumed to be Gaussian $\{f(m)=N\exp[-(m-\bar{m})^2/2\sigma^2]\}$ and the widths quoted above are the values found from ideograms of events in the mass region 1.5 to 2.0 GeV. As a check on the validity of this calculation, the resolution of events from reaction (2) in the $\pi^+\pi^-\pi^0$ spectrum near the ω was obtained by the same procedure and compared with a maximum-likelihood fit to the data, which assumed a linear background with a Gaussian for the ω. The calculated value of ±21.8 MeV agrees quite well with the fitted value of $\pm(20.9 \pm 3.0)$ MeV.

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