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4π MASS ENHANCEMENTS IN 16 GeV/c $\pi^- p$ INTERACTIONS*

J. Ballam, A. D. Brody, G. B. Chadwick, Z. G. T. Guiragossián,
W. B. Johnson, D. W. G. S. Leith and E. Pickup

Stanford Linear Accelerator Center
Stanford University, Stanford, California

ABSTRACT

In a 16 GeV/c $\pi^- p$ experiment we have observed production of two 4π resonances at 1250 and 1700 MeV, whose predominant decay modes are $\omega^o \pi^-$ and $\rho^o \rho^-$ respectively.

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In this paper we report the observation of two resonances produced in 16 GeV/c $\pi^- p$ collisions which decay into $\pi^+\pi^-\pi^-\pi^o$. The first resonance, with mass $\sim$1250 MeV, can probably be identified with the B meson observed at lower energies[1-8] while the second, with mass $\sim$1700 MeV, can probably be identified with the similar $(4\pi)^-$ enhancement reported also at lower energies.[8-10] The possibility of identifying this resonance with the g meson reported to decay into two pions[10-12] is discussed.

The data come from a study of 60,000 photographs of the BNL 80" hydrogen bubble chamber. Using the procedures described in the previous paper, we have obtained 1192 examples of the reaction

$$\pi^- p \longrightarrow p\pi^+\pi^-\pi^-\pi^o$$

after the four body events had been removed from 15,000 four prong measurements. The events were examined for compatibility of track ionization with the fits and accepted only if no other fit had confidence level within a factor 10 of the chosen hypothesis. In addition, the missing mass squared had to be within ± 0.11 GeV^2 of the π^o mass and its error less than 0.18 GeV^2. After correction for these cuts we find the cross section for this reaction to be 1.24 ± 0.2 mb.

These events show strong Δ^{++}, ρ^o and ω^o signals. In addition, two enhancements at $\sim$1250 and 1700 MeV in the negatively charged four pion invariant mass spectrum are evident, as is shown in Fig. 1a. These enhancements are evident without requiring mass cuts in the data. However, if events associated with ω^o are plotted (shaded histogram) it can be seen in Fig. 1a that the 1250 MeV enhancement (henceforth referred to as "B") shows a strong $\omega^o\pi^-$ correlation, while the 1700 MeV enhancement (here called g' after Biswas et al.[9]) has

only a weak correlation. There is no evidence of a peak in the B region for the non-ω^o events. If events associated with Δ^{++} are excluded the g' enhancement is even more striking (Fig. 1a, unbroken histogram). In fact there is negligible overlap of these resonances with either Δ^{++} or Δ^o.

We now discuss the two resonances in detail. The resonance parameters estimated are shown in Table I, along with data from experiments at other energies for which cross sections are reported. In addition, our values for the mass and width of the B, higher than reported for $\pi^{\pm}p$ below 5 GeV/c, agree well with those of the ABC collaboration[5] (8 GeV/c π^+p) and with Ascoli et al.[7] (6 GeV/c π^-p).

The helicity angular distribution of the ω^o from our sample in the B region is consistent with transverse ω^o polarization (with 10% probability of fitting isotropy). Evidence for such polarization has been reported by Ascoli, et al.,[7] and by Chung, et al.[4] We can draw little additional information from our distribution (owing to its statistical significance) other than the indication that our enhancement can be identified with the B meson found in $\pi^{\pm}p$ interactions between 3 and 11 GeV/c. We remark, however, that the decay of a 1^+ particle into $\omega^o\pi^-$ through pure s-wave would have an isotropic ω^o-helicity distribution, so that s and d waves are required to explain the decay distribution. This fact makes the 1^+ assignment of spin to the B very insecure, since more than one partial wave amplitude can be made to interfere in such a way to fit the data for almost any assumed spin and parity. The ω^o polarization is in contrast with that of the ρ^o from our A_1, as reported in the previous paper, where s and d wave decays seem to result in longitudinal polarization.

The production cross section inferred for the B meson is dependent upon the form of background. We have assumed a shape approximating that used at

lower energies for consistency in the Table: if normal phase space is assumed (and the rise at 1700 MeV attributed to the g' as described later) the upper limit obtains.

It appears that a simple one pion exchange production mechanism may be excluded since the energy dependence of the cross section is far from proportional to s^{-2}, where s is the square of the total CMS energy. The data could be considered consistent with an s^{-1} behavior (vector exchange) except that no striking evidence of vector exchange occurs in the Treiman-Yang angular distribution. Since the masses and widths found in the lowest energy data seem inconsistent with that found at high energies, and since we cannot exclude a constant cross section from 8 to 16 GeV/c, a kinematic origin for the enhancement discussed here is still possible.

We now describe the features of the 4π resonance at 1700 MeV. Figure 1b shows the 4π mass spectrum for events with ω^o and Δ^{++} excluded, and in addition having a $\pi^+\pi^-$ mass combination in the ρ^o region. It can be seen that the g' enhancement is almost entirely accounted for by ρ^o and ω^o associated events. To observe a possible $A\pi$ or $\omega\pi$ decay mode we have plotted all 3π mass combinations for events in the g' region in Fig. 2a. Although the number of ω^o combinations above background is not significantly higher than in the neighbouring regions, the spectrum of Fig. 1a would not be inconsistent with the 25% branching ratio reported by Johnston et al.[10] At higher 3π masses no significant A^- signal is apparent if the $\pi^-\pi^-\pi^o$ and $\pi^+\pi^-\pi^o$ distributions are used to estimate the shape of a mass distribution without resonances. The latter combination is predominantly $\rho^o\pi^o$, a forbidden mode for an $I = 1$, $I_3 = 0$ particle. In addition, no ρ^+ signal is evident independently for events in this region, arguing against an $A^o\pi^-$ decay mode for the g'.

We find a strong indication that the g' decay proceeds predominantly into $\rho^o\rho^-$ pairs. Figures 2d and e show the mass spectra of the $\pi^-\pi^o$ combinations recoiling against $\pi^+\pi^-$ when the latter are respectively in the ρ^o mass region and below the ρ^o mass region. Figures 2f and g show the inverse: the $\pi^+\pi^-$ mass recoiling respectively against ρ^- masses and masses below 650 MeV. The smooth curves are phase space predictions normalized in each case to the numbers of events with $\pi\pi$ mass below 650 MeV, combined with a Breit-Wigner resonance with the known ρ parameters. The number of ρ^o combinations unassociated with ρ^- is consistent with that found in the 4π mass regions on either side of the g'. We find 33 ± 9 $\rho^o\rho^-$ associated events, after correcting for the mass cuts used to select ρ mesons. Since the total enhancement in $(4\pi)^-$ is 40 ± 12 events, we conclude

$$\frac{g' \longrightarrow \rho^o\rho^-}{g' \longrightarrow (\text{all } 4\pi)} = 0.83 \pm 0.3$$

The remaining branching fraction can be accounted for by the $\omega^o\pi^-$ mode,[10] the $A\pi$ mode not being required: it is zero within the above error.[13]

The production cross section determination for the g' meson is subject to less uncertainty than the B since it is reasonably far from threshold and the background extrapolates smoothly under it. For production by 8, 11 and 16 GeV/c π^-, the cross section times branching ratio of g' into 4π, fits an energy dependence s^{-1} very well (see Table I). The 7 GeV/c data point[10] may be low owing to the assumption that the 4π enhancement has narrower width found for the 2π peak.

The only connection between the possible 2π and 4π modes of g' meson decay is from the 7 GeV/c data,[10] where the branching ratio is reported to be near unity. At 8 GeV/c the 2π mode was not observed in a π^-p experiment,[9] however some evidence has been reported for π^+p at 8 GeV/c.[11] Therefore,

it is difficult to reach a conclusion that the 2π and 4π enhancements are alternate modes of a single resonance.

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TABLE I

Resonance Parameters for B and "g" Mesons for this Experiment and Reported Values for Other Experiments

REFERENCE	REACTION	BEAM MOM. GeV/c "B" MESON	M MeV	Γ MeV	$\sigma \times$Branching Ratio μb $B \to \omega^0 \pi^-$
Abolins[1]	$\pi^+ p$	3.5	1220	100±20	115±30
Goldhaber[2]	$\pi^+ p$	3.65	1220	80	85±25[(a)]
Chung[4]	$\pi^- p$	3.2	1220±20	150±20	108±30
	$\pi^- p$	4.2			67±20
ABC[5]	$\pi^+ p$	8.0	1259±27	204±75	28±9
Caso[8]	$\pi^- p$	11.0	1250	-	~30
This exp.	$\pi^- p$	16.0	1250±35	200±50	25^{+20}_{-10}
Baltay[6]	$p\bar{p}$	rest	1200±20	100±50	-

		CHARGED "g" MESON			$g^- \to \pi^- \pi^0$ μb	$g^- \to \rho^- \rho^0$ μb
Crennell[12]	$\pi^- p$	6.0	1630	200[(b)]	40±20[(b)]	No Data
Johnston[10]	$\pi^- p$	7.0	1675±10	90±20	35[(c)]	33[(c)]
Biswas[9]	$\pi^- p$	8.0	1710±23	162^{+58}_{-40}	<18	60±20
Caso[8]	$\pi^- p$	11.0	~1670 - 1720[(d)]	~100-120[(d)]	No Data	40 - 60
This exp.	$\pi^- p$	16.0	1700±35	180±50	No Data	30±10

[(a)] Private communication from B. C. Shen.

[(b)] Private communication from K. W. Lai.

[(c)] The ratio $(g^- \to \pi^- \pi^0)/(g^- \to \rho^- \rho^0)$ is given by the authors. We have estimated the magnitude by comparison with ρ production.

[(d)] The range of masses represent values for non-peripheral and peripheral events.

FIGURE CAPTIONS

1. (a) Mass of $\pi^+\pi^-\pi^-\pi^0$ in the reaction $\pi^- p \rightarrow p\pi^+\pi^-\pi^-\pi^0$. The broken line histogram shows all events, the solid line has events with Δ^{++} excluded. The shaded histogram shows $M(\omega^0\pi^-)$, Δ^{++} also excluded. The Δ^{++} exclusion requires $M(p\pi^+) > 1.4$ GeV, while ω^0 and ρ^0 selection require $0.72 < M(\pi^+\pi^-\pi^0) < 0.84$ GeV and $0.68 < M(\pi\pi) < 0.84$ GeV.

   (b) Mass of 4π system for ρ^0 associated events, Δ^{++} excluded.

2. (a) $M(\pi^+\pi^-\pi^0)$, two combinations per event, for 4π mass events in the g' region (1.62 - 1.86 GeV).

   (b) $M(\pi^+\pi^-\pi^-)$ for g'.

   (c) $M(\pi^-\pi^-\pi^0)$ for g'.

   (d) $M(\pi_a^-\pi^0)$ for events with 4π mass in the g' and $M(\pi_b^-\pi^+)$ in the ρ^0 region, π_a and π_b being distinct.

   (e) Same with $M(\pi_b^-\pi^+) < 0.65$ GeV.

   (f) $M(\pi_a^-\pi^+)$ against ρ_b^- .

   (g) $M(\pi_a^-\pi^+)$ against $M(\pi_b^-\pi^0) < 0.65$ GeV.

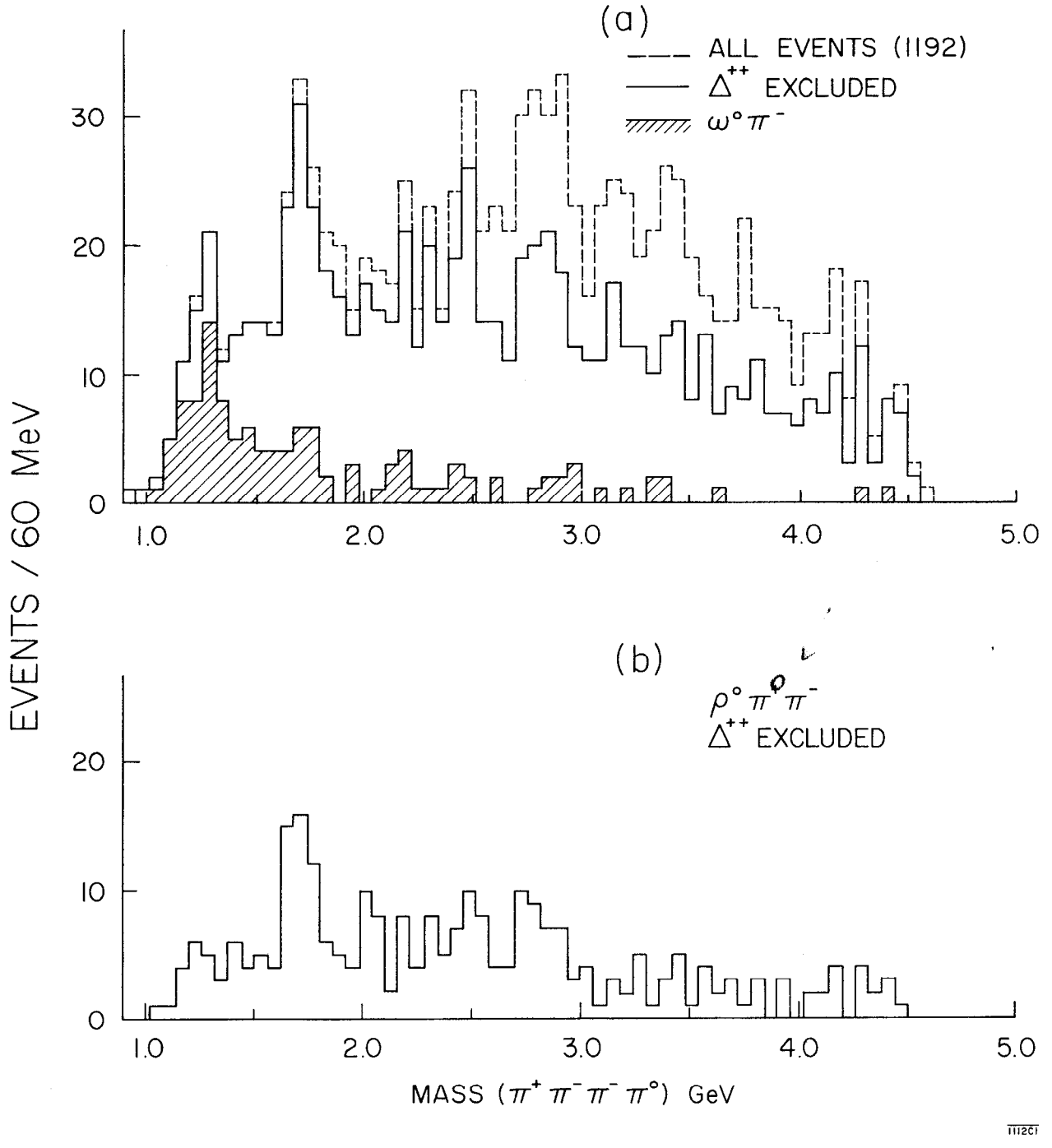
(a)
ALL EVENTS (1192)
Δ++ EXCLUDED
ω°π⁻
EVENTS / 60 MeV
30
20
10
0
1.0
2.0
3.0
4.0
5.0
(b)
ρ°π°π⁻
Δ++ EXCLUDED
20
10
0
1.0
2.0
3.0
4.0
5.0
MASS (π⁺π⁻π⁻π°) GeV
111261

Fig. 1

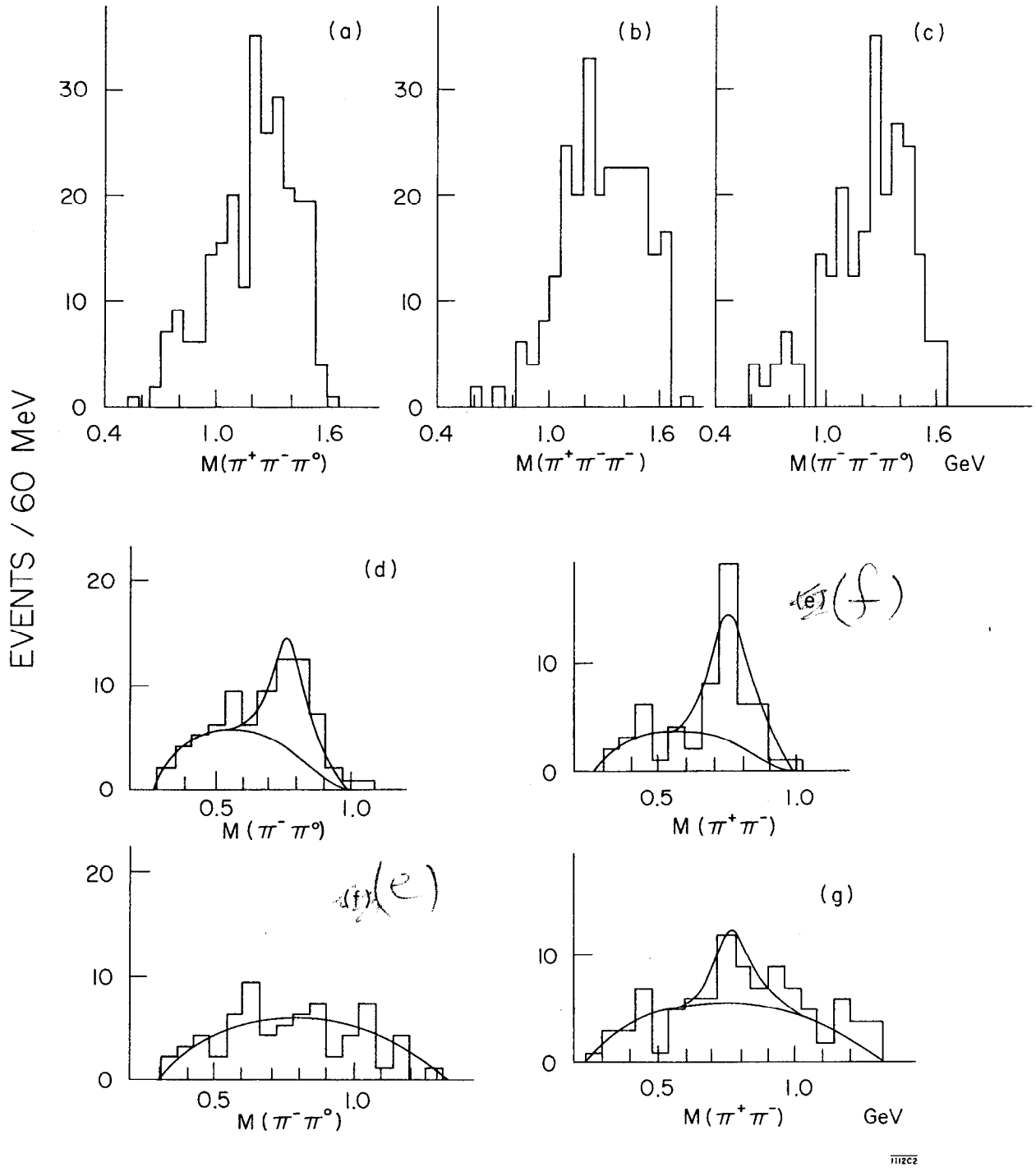
EVENTS / 60 MeV
(a)
(b)
(c)
30
20
10
0
0.4
1.0
1.6
M(π⁺π⁻π°)
M(π⁺π⁻π⁻)
M(π⁻π⁻π°)
GeV
(d)
(e)
(f)
(g)
0.5
M(π⁻π°)
M(π⁺π⁻)

Fig. 2