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RESONANCE SEARCH WITH $\bar{p}p$

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Narrow resonances in $\bar{p}p$ reactions have been reported for some time. They have a curious, now-you-see-it-now-you-don't character: the one at 2.02 GeV, for example, being alternately discovered, disproved and rediscovered several times (see Appendix). Here we pursue the hypothesis that such resonances are real and reflect underlying mesonic states of the main sequence, that their narrowness is peculiar to the $\bar{p}p$ channel and may vary with the conditions of observation, and that this selective narrowness may make $\bar{p}p$ interaction useful to explore meson sequences up to $m \sim 4$ GeV: that is, up to incident $\bar{p}$ momenta of 7-8 GeV/c.

1. Review of $\bar{p}p$ resonance information.

It is perhaps not generally appreciated how substantial a contribution $\bar{N}N$ studies have already made to meson spectroscopy. In the region $m > 2$ GeV information about meson sequences comes mainly from two sources: two-body decays with special signatures like $\pi^0\pi^0$ or $\bar{K}K$, and reactions involving $\bar{N}N$.

The first category has provided evidence on the leading trajectory with $J = L + 1$ on the $\bar{q}q$ model: $J^P = 4^+$ (1,2), 5^- (3), 6^+ (4), 7^- (5). These states define a good straight line of m^2 vs. J, with $dm^2/dJ \sim 1.14$ GeV^2 and an intercept of $J \sim 1/2$ at $m^2 = 0$.

Although one of these states, the h(2040), has been seen in the $\bar{N}N$ channel from $\pi^- p$ at 18 GeV (6), the great majority of resonances inferred from $\bar{N}N$ studies seem to lie on other trajectories, most notably the fundamental $J = L - 1$ sequence. If we define this sequence as starting with the $\rho'(1600)$ and the X(1850) for $J^P = 1^-, 2^+$, the states in Table I define a good straight line with $dm^2/dJ = 0.97$ GeV^2 and an $m^2 = 0$ intercept around $J = -3/2$.

Table I. Candidates for J = L - 1 Trajectory

J^P	M(GeV)	Reference
1^-	1.55	2
2^+	1.83	7
3^-	2.11	6,8,9
4^+	2.36	6,8,9,10
5^-	2.48	6,8
6^+	2.71	4

The values in Table I are plotted in Fig. 1 along with the leading J = L + 1 trajectory. If the linearity persists to higher values, the trajectories will extrapolate to cross at $J \sim 12$. If the difference in slope is ascribed to spin-orbit coupling $\delta m^2 = C_1(\underset{\sim}{\Sigma}\cdot\underset{\sim}{L})$, then $C_1 \sim 8.5 \times 10^{-2}$ GeV^2.

2. Possible higher resonances.

Such evidence as exists regarding higher resonances comes entirely from involvement of $\bar{N}N$ channels. The reaction $\bar{p}p \to 6$ prongs at 6.4 GeV(11) indicates a meson at 3.04 GeV and $\Gamma \sim 200$ MeV, and another candidate at 3.42 GeV that might be narrower. The reaction $\bar{p}n \to X\pi^-$ from $\bar{p}d$ at 5.5 GeV(12) indicated narrow resonances at $m_X = 2.85$ and 3.05 GeV. And in $\pi^-p \to \bar{p}p\pi^-X$ at 16 GeV(13) a resonance was perceived at 2.95 GeV at a width compatible with the experimental resolution of order 20 MeV. Less outstanding but also visible in the same data summary graph, reproduced as Fig. 2, are peaks at 3.16 and 3.45 GeV. As with the 2.02 GeV example we assume the later obliteration of these effects[14] to result from changes in the experimental setup.

A schematic summary of this information is as follows: possible states at $(2.90)^2$, $(3.04)^2$, 3.16 and $(3.44)^2$ GeV, where $(\quad)^2$ indicates presence in two separate experiments. Comparison with Fig. 1 suggests possible correspondences as in Table II.

Table II. Trajectory Assignments for Higher States

m(GeV)	J=L+L	J=L-1
2.90	8^+	7^-
3.04	---	8^+
3.16	9^-	9^-
3.44	11^-	11^-

Of course this is highly speculative but indicates that mesonic states of very high spin may already have been detected.

3. Narrowness of $\bar{N}N$ States.

Some understanding of the narrowness of $\bar{N}N$ resonances is desirable if they are to be relied on when searching for meson states. Presumably this has to do with the existence of $\bar{N}N$ systems as definable entities not the same as $\bar{q}q$ systems but strongly related to them. A $\bar{q}q$ state of given J^{PC} may be connected with a number of different $\bar{N}N$ configurations, which serve as doorway states. Although reactions proceed mainly through the $\bar{q}q$ core, they also have direct contributions from the $\bar{N}N$ states. The interference effects between these two reaction routes may depend sensitively on the particular channel being observed - or in some cases even the angular range of the detector because of different t dependence of the interfering amplitudes.

If the level density of related $\bar{N}N$ states were 10^2-10^3 times that of the $\bar{q}q$ state in question, the situation would resemble $n\gamma$ capture on heavy nuclei. The particle widths of the many individual states form an envelope, the strength function, which is characteristic of a single particle in an optical potential: the present analogy nominating $\bar{N}N$ as the individual states and $\bar{q}q$ as the single-particle system. The difference is that there the level density of $\bar{N}N$ states is probably only ~10x that for $\bar{q}q$, so that the "envelope" exhibits granularity.

Qualitatively, this picture can explain the $\bar{N}N$ observations. In an occasional experimental setup the reaction through a mesonic state will be dominated by one or a few $\bar{N}N$ channels, producing a peak with characteristic width of order (a few) x 10 MeV. Because this effect depends sensitively on interference, it will not be seen equally under different conditions; it may sometimes be entirely washed out, or in an extreme case might shift position slightly by moving to a different constitutent $\bar{N}N$ state.

In this way we can perhaps understand why a narrow state at 2.02 GeV should appear[15] in $\pi^- p \rightarrow p\bar{p}p\pi^-$ but not[16] in $\pi^- p \rightarrow p\bar{n}p$ nor[17] in $\pi^+ p \rightarrow \Delta^{++}\bar{p}p$ and re-appear[18] in $\bar{p}p \rightarrow \bar{p}n\ \pi^+\pi^+\pi^-$ and $\bar{n}p\pi^+\pi^-\pi^-$ and also[19] in $\gamma p \rightarrow p\bar{p}p$. All of these observations had selection criteria based on fast particles in the final state. Of particular interest by comparison was $\pi^+ n \rightarrow \bar{p}pp$ at 10 GeV[20] where a sufficiently comprehensive measurement was made to determine $J^P = 4^+$. In such a complete observation one would expect a more or less unselected sum over all $\bar{N}N$ channels; and indeed the resonance appears to have $\Gamma \gtrsim 100$ MeV, appropriate to the h(2040).

Parenthetically one may remark that in all cases where a narrow state at 2.02 GeV was seen, the data with sufficient statistics[15,18] showed the presence of similar states at ~1.93 and ~2.18 GeV, although they were not always claimed. According to the general arguments given here, these also represent mesonic states.

Of course the model of $\bar{N}N$ interference with $\bar{q}q$ states should be articulated further for specific instances. Even in this qualitative form, however, it may serve to encourage reliance on narrow $\bar{N}N$ states as a search mechanism for locating mesonic states of high mass. Candidates so surveyed could then be examined more thoroughly, perhaps with other channels, to arrive at J^{PC} assignments.

Appendix

The chronology of the narrow 2.02 GeV state shows an amusing oscillation, displayed below:

Pub. Date	Result	Reaction	Ref.
July '77	+	$\pi^- p \to p\bar{p}p\pi^- X$	15
Feb. '79	−	$\pi^- p \to p\bar{p}n$	16
June '79	+	$ep \to ep\bar{p}p$	21
Apr. '80	−	$\pi^+ p \to \Delta^{++}\bar{p}p$	17
Nov. '80	−	$\pi^- p \to p\bar{p}p\pi^-$	22
Mar. '83	+	$\bar{p}p \to (\bar{p}n\pi^+/p\bar{n}\pi^-)\pi^+\pi^-$	18
Dec. '83	+	$\gamma p \to p\bar{p}p$	19

In this account we have omitted two measurements that were ambiguous: one that could claim with low statistics to see no effect(23), but which had a suggestive accumulation of events at 2.02 GeV; and one that saw the peak(20) in $\bar{p}p$ at 2.02 GeV and measured $J^P = 4^+$ but did not find it narrow. Also omitted are the negative experiments that were sufficiently "dirty" to permit the objection that they might have washed out any narrow resonances - one because if its beam(24) and one because of its target (25).

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Figure Captions

Figure 1 - Plots of m^2 vs. J for postulated leading trajectories $J = L + L$ and $J = L - 1$.

Figure 2 - Reproduction of Fig. 3 from Ref. 13 on $\pi^- p$ at 16 GeV/c.

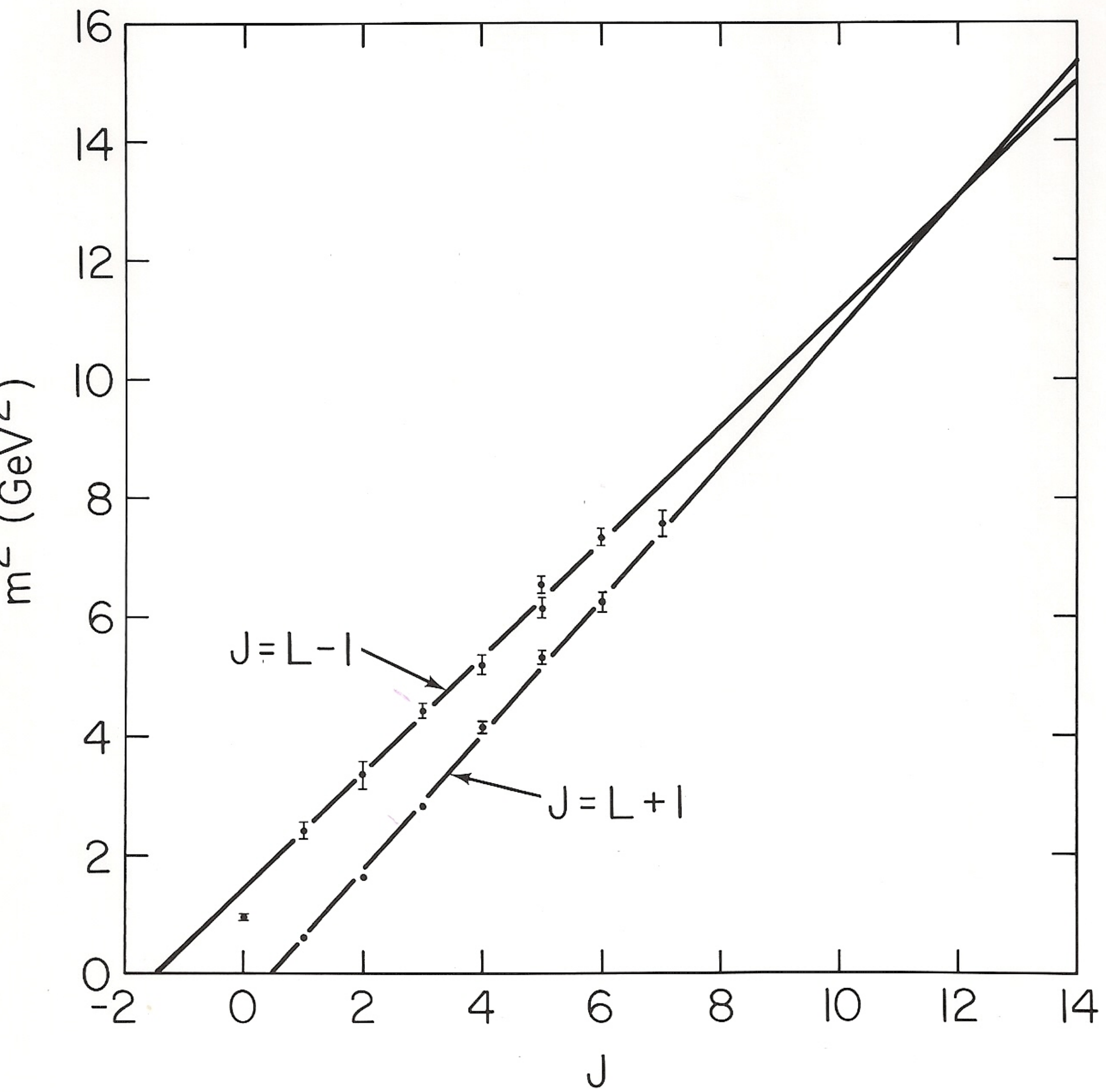

Fig. 1

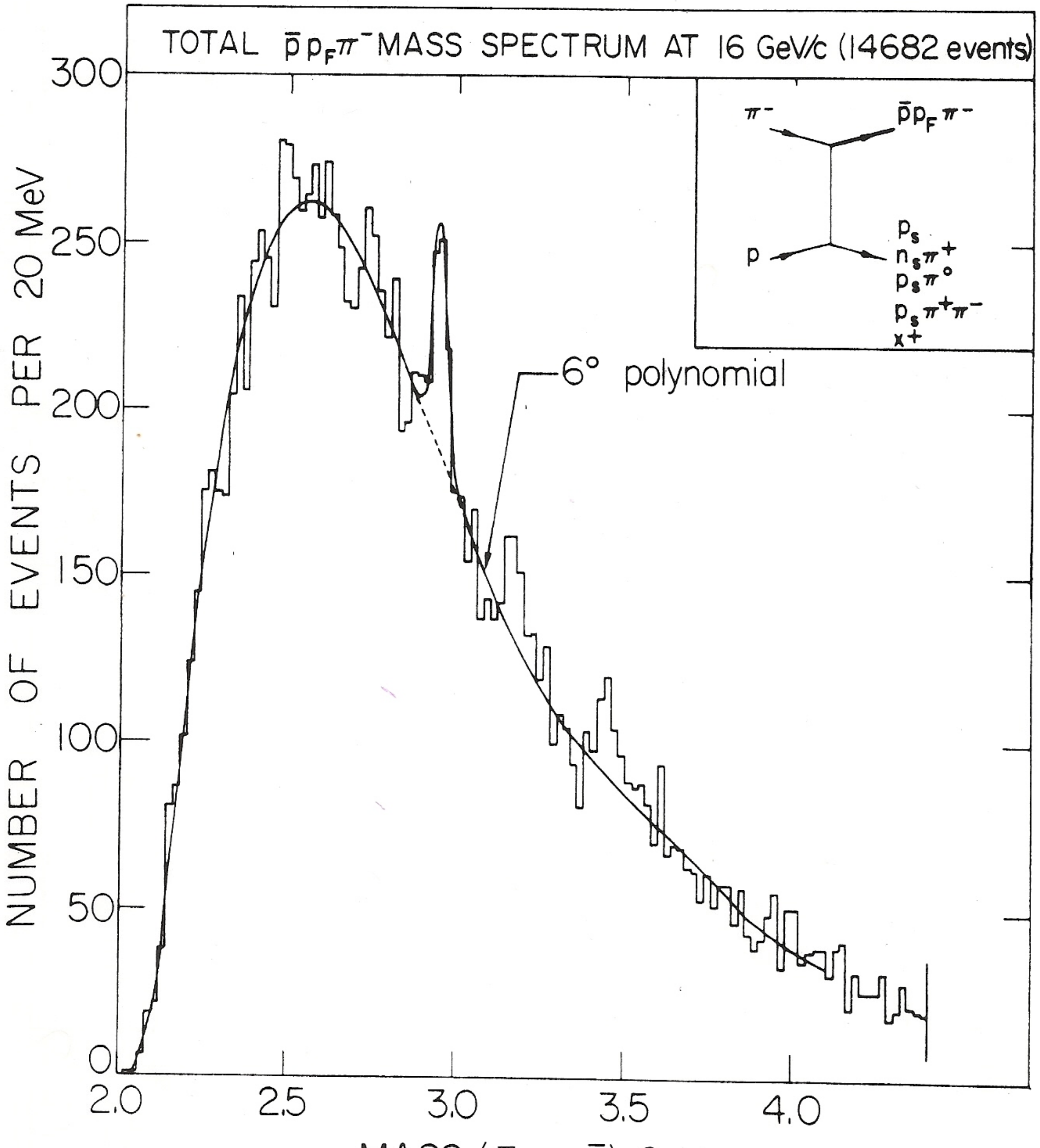
TOTAL $\bar{p}p_F\pi^-$ MASS SPECTRUM AT 16 GeV/c (14682 events)
NUMBER OF EVENTS PER 20 MeV
300
250
200
150
100
50
0
2.0
2.5
3.0
3.5
4.0
MASS ($\bar{p}p_F\pi^-$) GeV
6° polynomial
π^-
$\bar{p}p_F\pi^-$
p
p_s
$n_s\pi^+$
$p_s\pi^0$
$p_s\pi^+\pi^-$
x+

Fig. 2