OBSERVATION OF A NARROW $\bar{p}p$ ENHANCEMENT AT 1940 MeV

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ABSTRACT

A narrow enhancement is observed in $\bar{p}p$ states produced inclusively in proton-proton interactions at 93 GeV. The mass (1940 ± 1 MeV) is consistent with that of the S(1936).

1. INTRODUCTION

Evidence for narrow structures in the $\bar{p}p$ system has been given by several experiments [1-6]. The narrow widths of these high-mass enhancements and their strong coupling to $\bar{p}p$ suggests that they cannot be interpreted as simple meson resonances. It has been speculated that they are narrow bound states of the $\bar{N}N$ system [7,8], or that they are the first evidence for the existence of exotic mesons, i.e. multiquark states composed of a diquark and an antidiquark [9,10].

The experimental situation concerning these narrow "baryonium" states is, however, still confusing. From the observed structures, only the S(1936) is seen in more than one experiment. But, even for the S(1936), the resonance status is not undisputed. A structure near 1940 MeV is seen in several formation experiments in $\bar{p}p$ and $\bar{p}d$ total cross-sections, and $\bar{p}p$ elastic and annihilation cross-sections. However, a similar effect is not seen in the charge exchange cross-section, in contrast to what should be expected for a pure isospin state [11,12]. Also in backward $\bar{p}p$ elastic scattering the cross-section does not show a clear enhancement at this mass [13]. Complicated interference effects have to be invoked in order to explain these observations [14,15].

Some disagreement exists on the width of the observed structures. Most experiments agree on a narrow width -- 10 MeV or less. In a recent experiment, however, the width is found to be larger -- (22 ± 6) MeV [5].

Given this rather confused situation it is important to corroborate the evidence by observing the S(1936) in production experiments. Preliminary results from the WA4 photon experiment indicate a narrow structure at about 1930 MeV in inclusive $\bar{p}p$ production [16]. In this letter we give results of inclusive $\bar{p}p$ production in proton-induced interactions, showing a narrow peak in the $\bar{p}p$ invariant mass distribution at 1940 MeV.

2. EXPERIMENT AND DATA

The data were obtained in experiment WA3 in the West Area of the CERN Super Proton Synchrotron (SPS). A schematic plan of the apparatus is shown in Fig. 1.

A hadron beam of 93 GeV impinges on a 50 cm liquid-hydrogen target. The charged reaction products are momentum-analysed by a two-magnet spectrometer with a total bending power of 2.9 T·m and with 80 magnetostrictive spark chamber planes for track detection. The incident beam particles are identified by one threshold and two differential Čerenkov counters. Two large-aperture Čerenkov hodoscopes $\check{C}_1$ and $\check{C}_2$ are used to identify particles in the final state. The results presented in this letter come from a data sample which in the first place is used to study inclusive ϕ -production. The main elements in the trigger are $\check{C}_1$ and two scintillation counter hodoscopes P_6 and P_4 . The P_6 array is located immediately behind $\check{C}_1$ and has elements matching the dimensions of the $\check{C}_1$ mirrors. The trigger requires at least two particles in opposite halves of the bending plane, giving a hit in a P_6 array element but no signal in the corresponding Čerenkov cell. The scintillation counter array P_4 is used to impose a very crude momentum window on tracks satisfying the $(P_6 \cdot \overline{\check{C}_1})$ coincidence.

The π , K, and proton thresholds of $\check{C}_1$, using freon-22 as gas filling, are 3.7, 13, and 24 GeV, respectively. The trigger therefore selects pairs of particles which are either π mesons below 3.7 GeV, K mesons below 13 GeV, or protons with momentum less than 24 GeV. The (anti) protons are thus uniquely identified in the momentum range 13-24 GeV, apart from inefficiencies of $\check{C}_1$ at the level of about 2% per track. In order to reduce computing time, a further event selection is made in the off-line processing. The program requires that at least two trajectories reconstructed in Arm III of the spectrometer (see Fig. 1) satisfy the criteria for a low-mass K^-K^+ or $\bar{p}p$ pair before a full event reconstruction is done. This software selection affects events with a $\bar{p}p$ invariant mass above about 2000 MeV and, with the geometric acceptance, produces a fall-off of the invariant mass spectra with increasing mass.

3. RESULTS

In Fig. 2 we show the $\bar{p}p$ invariant mass distributions for incident protons, π^+ 's, and π^- 's, for those events where the (anti) proton assignment is unique,

i.e. the momentum is in the range $13 < p < 24$ GeV. The background curves drawn in Fig. 2 are obtained by calculating the invariant mass of uncorrelated $\bar{p}p$ pairs. For this purpose two particles are taken from different events and are required to satisfy all experimental cuts. The background is normalized to the total number of events in the plot.

For the π -induced data the background distributions follow smoothly the observed mass spectra. This is also the case for the proton-induced data, except for an enhancement at 1940 MeV. It has been checked that this enhancement is not a reflection of $\phi \rightarrow K^-K^+$ or $\Lambda(1520) \rightarrow K^-p$ decays, because of K mesons misidentified as protons. When, instead of the proton mass, the K-meson mass is assigned to the relevant particles, neither the K^+K^- nor the K^-p invariant mass distribution shows any enhancement at the ϕ or $\Lambda(1520)$ mass. It has also been checked that Λ and $\Delta(1232)$ cannot produce the observed effect by a wrong mass assignment.

The inset in Fig. 2 shows the mass distribution in the peak region after background subtraction. The events in the peak amount to 36 ± 9 .

The width is consistent with our resolution, which, using the measured resolution of the inclusive ϕ -data, is estimated to have a $\sigma = 3$ MeV. A more accurate determination of the width of the signal is not feasible because of the uncertainty in the background subtraction.

The central mass value of the peak is (1940 ± 1) MeV. In Fig. 3 we show the distribution in Feynman x ($x_F = 2p_L^{\text{cm}}/\sqrt{s}$) and p_T^2 for events in the peak ($1935 < m_{\bar{p}p} < 1945$ MeV) and for events in control regions ($1930 < m_{\bar{p}p} < 1935$ MeV and $1945 < m_{\bar{p}p} < 1950$ MeV). The full line gives the acceptance as a function of x_F . It is calculated assuming an isotropic decay angular distribution and an exponential p_T^2 distribution with slope 1; however, the dependence on the slope value is weak. Figure 3 suggests that in the range $0.2 < x_F < 0.48$ the cross-section has no strong x_F dependence. With an average acceptance of $(30 \pm 5)\%$ and a flat x_F distribution in this interval, we calculate a cross-section of (1.1 ± 0.3) μb .

The K^+K^- mass distribution for events where the two triggering particles have momenta between 3.7 and 13 GeV is dominated by the ϕ -peak [17]. If we assign the

proton mass to these particles instead of the K-meson mass, the reflection of the ϕ signal is seen in the $\bar{p}p$ mass distribution as a bump centred at 1900 MeV with a width of about 15 MeV. It gives a small but smooth contribution in the mass interval 1935-1945 MeV. The number of events above background in this interval amount to 62 ± 35 events. This corresponds, for an average acceptance of 55%, to an integrated cross-section of $(1 \pm 0.6) \mu\text{b}$ in the range $-0.1 < x_F < 0.2$. We conclude that our observations are incompatible with a predominantly central production of the S meson. This together with the fact that the enhancement is seen in proton interactions only, seems to indicate that the S meson is produced in the proton fragmentation region. Since in our spectrometer the acceptance for S mesons produced in the target fragmentation region is negligibly small, incident protons are required to make the particle observable. The observed production characteristics seem to confirm the exotic nature of the S meson. In particular, if interpreted as a diquark-antidiquark state, the quark content of the proton would favour its production in the proton fragmentation region. In this framework one may expect the additional proton, which is required to conserve baryon number, to be produced at smaller x_F than the $\bar{p}p$ system. Indeed the signal-to-noise ratio improves if we eliminate from our sample those events in which an additional proton is detected with momentum greater than 24 GeV, using $\tilde{C}_2$ to identify this proton. With this selection our S-meson signal corresponds to 34 ± 8 events. Unfortunately, the small number of events prevents the measurement of the decay angular distribution. We observe, however, that the enhancement is associated almost solely with events in which the proton is the faster particle, indicating a strongly asymmetric distribution of the decay angle in the $\bar{p}p$ rest frame. This is demonstrated by Fig. 4 in which we show the $\bar{p}p$ invariant mass distribution for events with no additional fast ($p_p > 24 \text{ GeV}$) proton, and for which the momentum of the proton is greater than that of the antiproton. The number of events in the peak after these cuts is 30 ± 7 . The observation of an asymmetric decay angular distribution is in disagreement with the assumption of a single non-interfering resonance. We note, however, that a similar effect seems to occur in $\bar{p}p$ elastic scattering. An enhancement at 1939 MeV is seen in the forward elastic cross-section but not in the backward one [13].

We conclude that we observe a 4 standard deviation enhancement in $\bar{p}p$ states produced inclusively in 93 GeV proton interactions while there is no enhancement in the pion-induced reactions. The mass and narrow width suggest that this enhancement can be ascribed to the S(1936). Its production characteristics seem to be consistent with the observations made in $\bar{p}p$ formation experiments. No other statistically significant enhancement is observed. In particular our data do not show evidence for a resonant state at 2020 MeV.

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Figure captions

Fig. 1 : Schematic plan of the spectrometer:

H_2 : H_2 target;

P_1 : proportional chamber;

$P_{2/3}$, P_6 , P_4 : scintillation counter hodoscopes;

$\check{C}_1$, $\check{C}_2$: Čerenkov counter hodoscopes;

spark chambers in arm I (A); arm II (B); arm III (C).

Fig. 2 : $\bar{p}p$ invariant mass distribution for a) incident p , b) incident π^+ and c) incident π^- at 93 GeV. The (anti)protons have momenta between 13 and 24 GeV. The background curves are obtained by pairing a proton and an antiproton from two different events and are normalized to the total number of events in the plot. The inset in Fig. 2a is an enlarged view of the background-subtracted mass distribution around 1940 MeV.

Fig. 3 : Feynman x ($x_F = 2p_L^{cm}/\sqrt{s}$) and p_T^2 distributions of $\bar{p}p$ pairs produced in 93 GeV proton interactions in the mass range $1.935 < m_{\bar{p}p} < 1.945$ GeV. The dotted distributions are those of the neighbouring control regions $1.930 < m_{\bar{p}p} < 1.935$ GeV and $1.945 < m_{\bar{p}p} < 1.950$ GeV. The full line in the x_F distribution indicates the acceptance of our experiment.

Fig. 4 : Invariant mass distribution of $\bar{p}p$ pairs produced inclusively in 93 GeV proton interactions. Events satisfy the following conditions:

- a) the momentum of the proton is larger than that of the antiproton;
- b) no additional proton of momentum greater than 24 GeV is detected.

Fig. 1

Fig. 2

Fig. 3

Fig. 4