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SEARCH FOR NARROW DIQUONIUM STATES IN π^-p INTERACTIONS AT 10 GeV/c

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ABSTRACT

Narrow diquonium production in the reactions $\pi^- p \rightarrow \bar{p} \pi^- pp$, $\bar{p} \pi^- p \pi^+ n$ and $\bar{p} \pi^- pp \pi^0$ is investigated in a 5.3 ev/nb experiment performed at the Omega Spectrometer. The computed upper limits are compared with the predictions of the Chan-Høgaasen model.

1. INTRODUCTION

Recently, experimental evidence has been found for various narrow and broad structures coupled to the baryon-antibaryon system. Ref. [1] gives a compilation of the reported evidence. These observations are of considerable interest since a possible interpretation is that they are candidates for the long sought exotic mesons. In the quark model these mesons are considered to be formed of two quarks and two antiquarks. The particular configurations in which the two quarks are in an s wave state (diquark) and separated from the two antiquarks (also in an s wave state) by a high angular momentum barrier ($L \geq 2$) are expected to be strongly coupled to the baryon-antibaryon system [2,3]. According to these models, states in which the diquark (antidiquark) is in a $\bar{3}(3)$ colour representation are expected to decay into a baryon-antibaryon pair with a width of a few hundred MeV and to be easily produced in $\bar{p}p$ formation experiments. These states are currently referred to as T diquonium. On the other hand, states in which the diquark (antidiquark) is in a $6(\bar{6})$ colour representation are expected to have narrower widths ($\Gamma \lesssim 10$ MeV) and decay preferentially by cascade decays into narrow states coupled to $\bar{B}B$. These mesons can be produced in the forward direction by P or Regge meson exchange mechanisms [3] and are normally called M diquonium.

In the present paper we present results on a search for the production of M diquonium in the systems $\bar{p}N m \pi$ ($m = 0, 1, 2$), peripherally produced in the following reactions at 10 GeV/c

$$\pi^- p \rightarrow \bar{p} \pi^- pp \quad (1)$$

$$\rightarrow \bar{p} \pi^- \pi^+ p n \quad (2)$$

$$\rightarrow \bar{p} \pi^- pp \pi^0 . \quad (3)$$

At present information exists on reaction (1) with $\pi^\pm$ incident from bubble chamber experiments [4,5] with sensitivities of a few events/ μb and from an experiment at the SLAC 40" hybrid bubble chamber facility [6] with a sensitivity of 250 events/ μb . Studies of reactions (1)-(3) were performed in two experiments at 16 GeV/c with the Omega spectrometer at sensitivities of 2 events/nb and 30 events/nb respectively [7,8].

General information on the trigger and the experiment is given in sect. 2. In sect. 3 and 4 diquonium production in the reactions (1)-(3) is discussed. The general properties of reaction (1) are also discussed in sect. 3. Finally, in sect. 5 comparison between present upper limits for M diquonium production in the $\bar{p}p\pi^-$, $\bar{p}p\pi^-\pi^0$, $\bar{p}n\pi^+\pi^-$ systems and the predictions of the Chan-Høgaaasen model is presented.

2. APPARATUS, TRIGGER AND DATA HANDLING

The experiment has been performed using the Omega spectrometer at CERN [9], exposed to an unseparated pion beam of 10 GeV/c. The total beam flux corresponds to 5.3 ev/nb. The layout of the CERN Omega spectrometer facility as used in the present experiment has been described in a previous publication [10] and is shown in fig. 1. In this section we will summarize the main characteristics of the trigger and of the data processing. The selection of the events by the trigger required:

- (a) No hit in the beam veto counter A, a hit in the scintillation counter placed around the hydrogen target (TS) or at least two hits in MWPCI.
- (b) At least one hit in MWPCIII.
- (c) A hit in the scintillation hodoscope H1 correlated to a hit in the scintillation hodoscope H2.
- (d) No light for a negative track in the atmospheric pressure Cerenkov counter (C) which was filled with isobutane and had π^- , K^- and $\bar{p}$ thresholds of 2.8, 9.8 and 18.8 GeV/c respectively.

MWPCIII and IV and the lead in front of it played no part in this particular investigation. The trigger thus accepted those interactions in the hydrogen target creating a K^- or a $\bar{p}$ of momentum greater than 2.8 GeV/c.

The 1.1 million triggers obtained were processed in a modified version of the Omega pattern recognition and geometry program ROMEO [11]. Events with the main vertex in the hydrogen target and a good triggering track were then processed by the kinematic fitting program KOMEGA [12].

The four-prong charge conserving events have been fitted to reactions (1), (2), (3) and to

$$\pi^- p \rightarrow K^- \pi^- p K^+ \quad (4)$$

$$\rightarrow K^- \pi^- K^+ \pi^+ (n) \quad (5)$$

$$\rightarrow K^- \pi^- p K^+ (\pi^0). \quad (6)$$

Events with a slow particle in the laboratory system can be detected by the spectrometer as three-prong events. When originating from the four-body reactions (1) and (4), these events can be fitted as one-constraint hypotheses:

$$\pi^- p \rightarrow \bar{p} \pi^- p(p) \quad (7)$$

$$\rightarrow K^- \pi^- K^+(p) \quad (8)$$

$$\rightarrow K^- \pi^- p(K^+) \quad (9)$$

$$\rightarrow \bar{p} p p(\pi^-) \quad (10)$$

$$\rightarrow K^- K^+ p(\pi^-). \quad (11)$$

The criteria used to select events of interest in the present analysis are discussed in the following sections. A weight was applied to each event to take into account the geometrical acceptance of the trigger and the probability of secondary interactions.

3. STUDY OF THE REACTION $\pi^- p \rightarrow \bar{p} \pi^- p p$

3.1 Selection of the sample

Reaction (1) is selected from the sample of four-prong events using the results of the kinematic fit and from the sample of three-prong events by means of the kinematic fit and an analysis of the missing mass to the charged outgoing tracks. Fig. 2 shows the probability distribution of

events fitting reaction (1). Table 1 shows the number of events fitting reaction (1) and the relative ambiguities with other possible fitted reactions. After a 10% cut in probability, kinematic ambiguities between reaction (1) and reaction (6) are resolved by assigning the events to the more constrained reaction (1) (4C vs 1C). To verify that this assignment is correct we interpreted the ambiguous events as events of reaction (6) $\pi^- p \rightarrow K^- \pi^- K^+ p \pi^0$ and plotted the effective masses of the $K^+ \pi^0$, $K^+ \pi^-$ systems. No indication of $K^*(890)$ was found in any of the above mass combinations; this indicates that few of the ambiguous events could be due to reaction (6). On the contrary the same events, when interpreted as events of reaction (1) show a large signal in the $\bar{p} \pi^-$ effective mass corresponding to the $\bar{\Delta}^{++}$ (1232). The above criteria select a sample of 3469 events.

When a slow proton is not detected by the spectrometer, events of reaction (1) are identified from the three-prong sample as events fitting hypothesis (7). However, as is apparent from the large background present under the proton peak (fig. 3) in the missing mass squared to the three outgoing charged particles ($MM^2(\bar{p} \pi^- p)$), this sample is highly contaminated by reactions involving the production of kaons and one or more neutral particles. Due to this contamination, these events have not been included in the study of reaction (1), but have been considered in the computation of the cross section. A fit to the $MM^2(\bar{p} \pi^- p)$ by a gaussian and a linear background evaluates the number of events present in the proton peak to be 13% of the four-prong sample.

A similar study has been made for hypothesis (10). Figs 4(a), (b) and (c) show the $MM^2(\bar{p} p p)$ for the total sample, the sample with the strong π^- peak of reaction (11) selected ($-0.1 \leq MM^2(K^- K^+ p) \leq 0.075 \text{ GeV}^2$) and antiselected respectively. Once the strong reflection due to reaction (11) is absent, the missing π^- of reaction (10) is visible (fig. 4(c)). The background under the pion peak (fig. 4(c)) is reduced further by requiring the missing momentum to be lower than 500 MeV/c (fig. 4(d)). The above selection criteria and a fit probability to hypothesis (10) greater

than 10% select 1331 events. This sample represents 80% of the sample of hypothesis (10) and contains a 30% background from other reactions.

In conclusion from the study of the four- and three-prong events we select a sample of 4800 events of reaction (1). These events represent 75% of the sample accepted by the trigger and include 8% contamination from other reactions.

3.2 General properties of the reaction and Longitudinal Phase Space (LPS) analysis

Since the antiproton is selected by the trigger to have a momentum greater than 2.8 GeV/c the $x(\bar{p})$ (where $x = 2p_L^*/\Sigma|p_L^*|$ and p_L^* is the longitudinal momentum in the c.m.s.) is always positive and the slower of the two protons has always a negative $x(p_s)$, the longitudinal phase space of reaction (1) studied by the present experiment can be described by the scatter diagram $x(\pi^-)$ vs $x(p_F)$, where p_F indicates the faster of the two protons. Fig. 5 shows this diagram for the events of reaction (1) unweighted and weighted by geometrical acceptance. For orientation the type of peripheral two vertex exchange diagram which populates each quadrant of the plot is shown. From fig. 5 it is evident that the most populated sector is the one corresponding to forward three-body ($\bar{p}\pi^-p_F$) production. The sectors which correspond to baryon exchange are less populated.

3.2.1 Sector A: $\pi^-p \rightarrow (\bar{p}p_F\pi^-)p_s$

The mass spectra relevant to this sector are shown in fig. 6. The $\bar{p}p_F\pi^-$ spectrum is characterized by a broad structure peaking ~ 300 MeV above threshold. This shape is similar to the 3π , $K\bar{K}\pi$ and $K\pi\pi$ mass spectra obtained in diffractive reactions [13]. The two-body effective masses (fig. 6(d), (e) and (f)) show a large $\bar{\Delta}^{++}(1232)$ and no particular structure in the $\bar{p}p$ system. The observation that the $\bar{\Delta}^{++}(1232)$ is more

abundantly produced than the $\Delta^0(1232)$ is consistent with the $\bar{p}\pi^-$ system being in a $I = 1$ state ($\overline{\Delta^{++}}/\Delta^0 = 9$) and not in a $I = 2$ state ($\overline{\Delta^{++}}/\Delta^0 = 1$). These characteristics indicate that diffraction dissociation is the possible dominant production mechanism in this sector. Since the trigger required the antiproton of reaction (1) to have a momentum greater than 2.8 GeV/c there are zero acceptance regions in the space of the angular decay variables for the $\bar{p}_F\pi^-$ system (holes). Due to the complexity of the $\bar{p}_F\pi^-$ system, the loss of events due to the "holes" cannot be computed in a model independent way and a detailed study of the differential cross section of the $\bar{p}_F\pi^-$ system cannot be performed in the present experiment.

3.2.2 Sector B: $\pi^- p \rightarrow (\bar{p}p_F)\pi^-$

This sector is expected to be populated dominantly by the forward production of $\bar{p}p$ pairs recoiling against a low mass $p\pi^-$ system. In the reaction in which the $\bar{p}p$ pair is produced backward by baryon exchange, evidence has been presented for the existence of two narrow $\bar{p}p$ states at 2.02 and 2.2 GeV [14]. Fig. 7 shows the relevant mass spectra from this sector. No evidence for the production of narrow $\bar{p}p$ systems is found either in the total $\bar{p}p$ mass spectrum or in the $\bar{p}p$ associated with the $\Delta^0(1232)$ or $N^{*0}(1470)/N^{*0}(1520)$ present in the $p_s\pi^-$ system.

3.2.3 Sector C: $\pi^- p \rightarrow \bar{p}(\pi^- pp)$ and Sector D: $\pi^- p \rightarrow (\bar{p}\pi^-)pp$

These sectors represent reactions in which a $\bar{p}/p\pi^-$ system is produced forward by baryon exchange against a two-nucleon system $pp\pi^-/pp$. The particular case in which two backward nucleons are bound together to form a deuteron has been previously studied in the same experiment [10]. In this case however it is difficult to differentiate between the baryon exchange reaction and the decay of a large mass $\bar{p}p\pi^-$ or $\bar{p}p$ system produced according to the mechanism of sectors A or B. Figs 8 and 9 show for completeness the relevant mass spectra.

3.3 Cross section and upper limits on diquonium production

From the events selected in sect. 3.1, corrected for kinematic cuts and loss of slow protons and weighted for geometrical acceptance, we compute a detected cross section for reaction (1) of $\sigma_{\text{vis}} \sim 3 \mu\text{b}$. As discussed in sect. 3.2.1 the correction due to the presence of "holes" in the $\bar{p}p\pi^-$ decay variable space cannot be performed in a model independent way. In the following the number of events in the "holes" has been computed for various $\bar{p}p\pi^-$ masses and four momentum transfer squared t/p_s assuming an isotropic three-body decay. It produces a correction of the order of 37%, weakly dependent on $M(\bar{p}p\pi^-)$ and t/p_s and gives for the cross section of reaction (1) an estimate of $\sigma \sim 5 \mu\text{b}$. Baryonium can be produced in reaction (1) in the $\bar{p}p\pi^-$ and $\bar{p}p$ systems. Figs 10(a) and (c) show these effective masses, once the slowest proton has been interpreted as the recoiling nucleon. As can be seen in figs 10(b) and (d) no significant deviations (≥ 4 s.d.) from the fitted smooth polynomial curves are detected either in the $\bar{p}p\pi^-$ or in the $\bar{p}p$ system. Evidence for a narrow $\bar{p}p\pi^-$ structure at 2.95 GeV was presented in a similar experiment at 16 GeV/c [7]. However, this observation has not been substantiated by the collection of new data [8]. We notice from fig. 10(b) that fluctuations are present in the $\bar{p}p\pi^-$ mass spectra around 3 GeV. The statistical significances of these fluctuations vary from 2 s.d. to 4 s.d. depending on the binning and alone are not sufficient to claim a physical effect. From the spectra of fig. 10 and assuming the above correction factor for the presence of "holes" we have computed 99.8% (3 s.d.) confidence level upper limits for the production of narrow baryonium states (Γ less than the experimental resolution) in the $\bar{p}p$ and $\bar{p}p\pi^-$ systems. The experimental resolution varies linearly between 4 (8) MeV and 14 (18) MeV for $\bar{p}p_F$ ($\bar{p}p_F\pi^-$) effective masses going from threshold to 3 GeV. The computed upper limits are given in table 2 and will be discussed in sect. 5.

4. SEARCH FOR DIQUONIUM PRODUCTION IN THE REACTIONS $\pi^- p \rightarrow \bar{p}\pi^- p\pi^+ n$ AND

$$\pi^- p \rightarrow \bar{p}\pi^- pp\pi^0$$

Reactions (2) and (3) can be a rich source of diquonium states produced directly against a nucleon (or nucleon plus pions) and which can generate

other diquonium states by cascade decay via pion emission. As a consequence, a search for diquonium can be made in any $\bar{p}N\pi\pi$ ($m = 0,1,2$) mass combinations.

4.1 Channel selection

Fig. 11(a) shows the $MM^2(\bar{p}\pi^-\pi\pi^+)$. A neutron peak indicating the presence of reaction (2) is visible on a background due to multineutral reactions. Due to this background the sample selected by the kinematic fit to reaction (2) is strongly contaminated and will not be used to select reaction (2). The ratio signal to background is improved by requiring the missing momentum to be greater than 1.75 GeV/c (fig. 11(b)). In the following analysis events are assigned to reaction (2) if $0.78 \leq MM^2(\bar{p}\pi^-\pi\pi^+) \leq 0.98 \text{ GeV}^2$ and the missing momentum $\geq 1.75 \text{ GeV/c}$. In the study of the effective masses, the background under the neutron peak is taken into account by subtracting the spectra of events with the $MM^2(\bar{p}\pi^-\pi\pi^+)$ in two bands on either side of the neutron peak (dotted lines fig. 11(b)). As a consequence of the above selection criteria and of the trigger condition ($\bar{p}$ momentum $\geq 2.8 \text{ GeV/c}$), the study of reaction (2) will be limited to production mechanisms in which the $\bar{p}$ and the n are produced predominantly in the forward direction in the c.m.s.

Reaction (3) is identified by the presence of a peak in the $MM^2(\bar{p}\pi^-\pi\pi^0)$ at the π^0 position. This signal is clearly visible when events fitting the reaction $\pi^-\bar{p} \rightarrow K^-\pi^-\pi^+\pi^0$ are antiselected (fig. 12(a)). The sample of the antiselected events does not show evidence for the presence of reaction (3) (fig. 12(b)). Events are assigned to reaction (3) if $-0.02 \leq MM^2(\bar{p}\pi^-\pi\pi^0) \leq 0.05 \text{ GeV}^2$ and $|MM^2(K^-\pi^-\pi^+\pi^0) - m_{\pi^0}^2| \geq 0.06 \text{ GeV}^2$. As in the case of the study of reaction (2) the fit results have not been used and the background under the π^0 peak is dealt with by subtracting from the mass spectra events with $MM^2(\bar{p}\pi^-\pi\pi^0)$ in the two bands on either sides of the π^0 peak.

4.2 Effective mass spectra and upper limits for diquonium production

Figs 13 and 14 show the various $\bar{p}N\pi\pi$ ($m = 0,1,2$) mass spectra, where diquonium may be produced directly or by cascade decay. The recoiling nucleon is the proton in the case of reaction (2) and the slower of the two protons in reaction (3). The full histograms show the mass spectra corresponding to the events in the n/π^0 peak. Shaded histograms show the corresponding spectra once the events lying in the guard bands have been subtracted. The curves superimposed on these spectra represent polynomial functions which adequately describe the general shape of the mass spectra. Differences between fitted curves and experimental values are shown at the bottom of each spectrum. Since these differences are less than two standard deviations we conclude that no significant narrow structure is observed. All spectra shown in figs 13 and 14 are unweighted by geometrical acceptance, but a similar study performed on the weighted mass spectra leads to the same negative conclusions.

For completeness figs 15 and 16 show various two-body mass combinations. Accumulations in the region of $\Delta(\bar{\Delta})$ are visible. Isobars are also detected in association with the recoiling proton, particularly in the case of the $p\pi^+$ system of reaction (2). Selection or antiselection of the isobar does not show any relevant structure in the $\bar{p}n\pi^-$ spectrum. Upper limits for diquonium production have been computed on the weighted mass spectra taking into account the errors introduced by the subtraction of the background under the n/π^0 peak. Since in the present work we are principally concerned with the upper limit of diquonium production recoiling against a single nucleon, we have evaluated the correction due to the presence of "holes" by a Monte-Carlo method assuming peripheral production and isotropic decay of a four-body system. However, the fraction of events in the zero acceptance regions is weakly dependent on the number of pions present at each vertex and is a maximum for the above assumed mechanism. As a consequence the upper limit computed with the above assumptions are meaningful also in the case of different production mechanisms (with the antiproton at the top vertex). The loss due to the

requirement in reaction (2) of a fast neutron (momentum ≥ 1.75 GeV/c) has been computed by similar methods and results in a small additive correction factor for all graphs with a forward $\bar{p}n$ pair. The mean correction factor due to the existence of "holes" and selection criteria is 2.5 for reaction (2) and for reaction (3). A further correction has to be applied to take into account the loss of slow tracks in the spectrometer. Since in the case of the one-constraint channels this loss cannot be evaluated from the data, we have assumed in the evaluation of the upper limits the same correction factor (1.4) as that deduced from the three-prong events attributed to reaction (1).

The resolution on the effective masses containing a neutral particle is considerably worse than in the case of the charged particle combination and is of the order of 30 MeV for the fast neutron and 60 MeV for the π^0 channel respectively. Table 2 gives the computed upper limit (99.8% c.l.) after applying the above corrections for the experimental biases. The significance of these upper limits in the light of the Chan-Høgaasen model is discussed in the next section.

5. COMPARISON BETWEEN EXPERIMENTAL UPPER LIMITS AND THE CHAN-HØGAASEN MODEL

In this section we will compare the experimental upper limits for the systems $\bar{p}p\pi^-$, $\bar{p}n\pi^+\pi^-$, $\bar{p}p\pi^-\pi^0$ produced in reactions (1), (2) and (3), respectively, with the predictions of the Chan-Høgaasen model for the production and decay of $I = 1$ M diquonium states. This model [3] predicts abundant production of M diquonium in peripheral interactions due to mixing between $q\bar{q}$ and $qq\bar{q}\bar{q}$ trajectories. According to this picture, the production cross section σ_E of an exotic state is related to the production cross section σ_M of a $q\bar{q}$ meson of the same mass by

$$\sigma_E \approx \sigma_M \cdot \sin^2 \theta_R, \quad (12)$$

where θ_R is the mixing angle between the exchanged Regge and diquonium trajectories. This mixing angle is computed in the frame work of the Dual

Unitarization theory [15], and gives a reduction factor of ~ 25 in the case of both $\mathbb{P}$ and ρ - A_2 exchange, but only ~ 2 in the case of ω exchange.

The mixing angle of the π trajectory cannot be calculated within the Dual Unitarization theory. We have used the estimate $\sin^2 \theta_\pi = 0.1$ given in ref. [16].

We have estimated by extrapolation of the available experimental information the cross sections for high mass ($2.0 \leq M \leq 3.0$ GeV) ordinary mesons produced opposite a proton by a $\mathbb{P}$, π and ω exchange. This extrapolation is based on and justified by FMSR relations [17]. The cross section for meson production by $\mathbb{P}$ exchange is estimated from those for A_1 and A_3 [18,19] applying corrections for the Chew-Low boundary limits. As expected from FMSR relations these cross sections are consistent with an M^{-2} dependence.

In contrast with a $\mathbb{P}$ exchange process FMSR predict in the case of meson exchange (π , ρ , ω ...) a production cross section increasing with mass. This prediction has been tested in the case of π exchange up to the g meson mass region for the reaction $\pi^- p \rightarrow X^0 n$ [17]. Extrapolating the ρ^0 , f^0 and g^0 cross sections to the (2.0 - 3.0) GeV mass range we find, after application of isospin and Chew-Low boundary correction factors, a production cross section decreasing from 85 μb to 35 μb . Using the cross sections measured for 2.0 and 2.2 GeV mass mesons in the channel $K^+ K^- n$ [20] the above predictions imply a branching ratio for these mesons into $K\bar{K}$ of $\sim 0.5\%$ (to be compared with a value of 1.3% for the g meson).

Hoyer et al. [17] have shown that the ratio between meson production cross sections by π and ω exchange increases linearly with the square of the meson mass. Using this prediction and the production cross sections evaluated above for π exchange, we compute in the (2.0 - 3.0) GeV mass range a production cross section for ω exchange decreasing from 36 μb to 7 μb .

The M diquonium states with $I = 1$, are predicted from the model to lie on two Regge trajectories labelled $\{1, 18\}$ and $\{0, 36\}$ respectively. The two indices represent the total quark spin and the dimension of the SU3 flavour representation. The states lying on the trajectory $\{1, 18\}$ are predicted to decay significantly into an $I = 0$ $N\bar{N}$ narrow state by emitting a pion. Consequently these should be observable in the $\bar{p}p\pi^-$ final state. As for the $I = 1$ states lying on the $\{0, 36\}$ trajectory, they are predicted to decay into an $I = 0$ $N\bar{N}$ state via two successive pion emissions and should as a consequence be observable in the $\bar{p}p\pi^-\pi^0$ final state. We explicitly note that no significant decays are expected into the final state $\bar{p}n\pi^-\pi^+$, since the nucleon and the antinucleon in this case are in an $I = 1$ state.

A detailed study of the decay properties of diquonia with an orbital angular momentum $L = 1$, has been made by M. Fukugita and T.H. Hansson [21]. From their study we assume a mean branching ratio of $1/3$ for the cascade decay of a $I = 1$ diquonium by pion emission and a mean branching ratio of $1/2$ for the decay of the $I = 0$ diquonium into $N\bar{N}$. From these assumptions we estimate a branching ratio into the $\bar{p}p\pi^-$ system of the order of 8% and into the $\bar{p}p\pi^-\pi^0$ of the order of 3%.

Fig. 17 shows the predicted production cross sections for $I = 1$ M-diquonium in the systems $\bar{p}p\pi^-$ and $\bar{p}p\pi^-\pi^0$, together with our experimental upper limits. From this we observe that the Chan-Høgaasen predictions for M-diquonium production by Pomeron exchange are compatible with the experimental data. Predictions for M diquonium production by π and ω exceed the experimental upper limits by one order of magnitude for the $\bar{p}p\pi^-$ system and are compatible for the $\bar{p}p\pi^-\pi^0$ system.

The simplest reason for this disagreement is an overestimate of the θ_π and θ_ω mixing angles. A recent study of the difference of inclusive cross sections [22] constrains the ω -baryonium mixing angle in the range 0° to 15° . The assumption of $\theta_\omega = 15^\circ$ ($\sin^2\theta_\omega = 0.07$) makes the model

prediction and the experimental data compatible. Furthermore we point out that the value of $\sin^2 \theta_\pi = 0.1$ used in relation (12) is an order of magnitude estimate [16] and does not come from the Dual Unitarisation theory [15].

6. CONCLUSIONS

From the study of the $\bar{p}N\pi\pi$ ($m = 0,1,2$) effective mass combinations produced in the reactions $\pi^- p \rightarrow \bar{p}\pi^- pp$, $\bar{p}\pi^- p\pi^+ n$ and $\bar{p}\pi^- pp\pi^0$ at 10 GeV/c no evidence is found for narrow structures which could be interpreted as M-diquonium states. Comparison of the data with the Chan-Høgaasen model for M-diquonium production opposite a proton has been made and disagreement between experimental upper limits and model predictions has been found for ω and π exchange mechanisms, if $\sin^2 \theta_\omega = 0.5$ and $\sin^2 \theta_\pi = 0.1$ are assumed.

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TABLE CAPTIONS

Table 1 Number of events fitting reaction (1) and relative ambiguities with other possible fitted reactions with and without a 10% probability cut.

Table 2 Upper limits in nb for narrow M diquonium production as a function of mass for various $\bar{p}N\pi\pi$ systems ($m = 0,1,2$).

TABLE 1

Reaction	Constr.	No. of events	%	No. of events (10%) cut	%
(1) $\bar{p}\pi^-p$	4C	4094	100	3469	100
(2) $\bar{p}\pi^-p\pi^+(n)$	1C	112	3	28	0.8
(3) $\bar{p}\pi^-p\pi^0$	1C	29	0.7	-	-
(4) $K^-\pi^-pK^+$	4C	221	5	33	0.9
(5) $K^-\pi^-K^+\pi^+(n)$	1C	724	18	213	6
(6) $K^-\pi^-pK^+(\pi^0)$	1C	3713	91	2940	85

TABLE 2

Reaction	System M(GeV)	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	
(1)	$\bar{p}p$	25	40	45	40	35	30	30	25	20	15	-	-	-	-	-	-
	$\bar{p}p\pi^-$	-	-	-	30	40	50	50	55	55	55	55	55	50	50	-	-
(2)	$\bar{p}p\pi^+\pi^-$	-	-	-	-	-	55	95	115	140	170	195	225	260	315	345	395
	$\bar{p}p\pi^-$	-	-	160	235	280	290	310	290	265	220	180	145	105	80	20	-
	$\bar{p}p\pi^+$	-	-	135	195	260	285	290	290	280	255	215	175	140	90	20	-
	$\bar{p}n$	205	440	380	295	235	195	160	120	105	90	50	35	-	-	-	-
(3)	$\bar{p}p\pi^-\pi^0$	-	-	-	-	30	65	80	130	160	185	205	230	250	275	285	225
	$\bar{p}p\pi^0$	-	-	115	185	235	270	275	260	235	210	180	140	100	65	30	-
	$\bar{p}p\pi^-$	-	-	65	95	120	130	135	120	100	80	70	55	40	25	15	-
	$\bar{p}p$	100	100	90	65	50	45	35	25	20	15	15	15	-	-	-	-

FIGURE CAPTIONS

- Fig. 1 Layout of the Omega spectrometer as used in the present experiment.
- Fig. 2 Probability distribution for the events fitting reaction (1).
- Fig. 3 $MM^2(p\pi^-p)$ for the three-prong ($--+$) events. The arrow indicates the missing proton corresponding to hypothesis (7). The peaks at $MM^2 \approx 0.6 \text{ GeV}^2$ and $\approx 0.2 \text{ GeV}^2$ correspond to the missing p and K^+ of hypotheses (8) and (9).
- Fig. 4 $MM^2(\bar{p}pp)$ for the three-prong ($++-$) events for (a) the total sample; (b) the sample with the missing π^- of reaction (1) selected ($-0.1 \leq MM^2(pK^+K^-) \leq 0.075 \text{ GeV}^2$); (c) antiselected; (d) as (c) and requiring the missing momentum $\leq 0.5 \text{ GeV}/c$.
- Fig. 5 Longitudinal phase space distribution for the events of reaction (1). The slanting bars are proportional to the cross section in bins of $x^2 = (0.1)^2$ unweighted (left) and weighted (right) by geometrical acceptance. Note the difference of a factor 2 between the scale for the unweighted and weighted bars.
- Fig. 6 Effective mass spectra for events corresponding to sector A weighted and unweighted (shaded histograms) for geometrical acceptance.
- Fig. 7 Effective mass spectra for events corresponding to sector B weighted and unweighted (shaded histograms) for the geometrical acceptance. The dotted bands indicate the $p\pi^-$ mass intervals used to define the Δ^0 and N^{*0} regions.
- Fig. 8 Effective mass spectra for events corresponding to sector C weighted and unweighted (shaded histograms) for the geometrical acceptance.

FIGURE CAPTIONS (Cont'd)

- Fig. 9 Effective mass spectra for events corresponding to sector D weighted and unweighted (shaded histograms) for the geometrical acceptance.
- Fig. 10 (a) $\bar{p}\pi^-p_F$ effective mass distributions weighted and unweighted (shaded histogram) for events assigned to reaction (1). The curve represents a fitted polynomial. (b) Difference between the fitted polynomial and the experimental values. (c) $\bar{p}p_F$ effective mass distributions weighted and unweighted (shaded histogram) for events assigned to reaction (1). The curve represents a fitted polynomial. (d) Difference between the fitted polynomial and the experimental values.
- Fig. 11 (a) $MM^2(\bar{p}\pi^-p\pi^+)$ for four-prong events not fitting reaction (1) or (4). The arrow indicates the position of the neutron corresponding to hypothesis (2). The large peak at lower values is due to reactions (3), (5) and (6). (b) $MM^2(\bar{p}\pi^-p\pi^+)$ requiring a missing momentum greater than 1.75 GeV/c. The dashed lines indicate the missing mass intervals used as guard bands to take into account the background under the n peak.
- Fig. 12 $MM^2(\bar{p}\pi^-pp)$ (a) antiselecting and (b) selecting the π^0 peak corresponding to hypothesis (6) ($-0.04 \leq MM^2(K^-\pi^-pK^+) \leq 0.1 \text{ GeV}^2$). The dashed lines indicate the missing mass intervals used as guard bands to take into account the background under the π^0 peak.
- Fig. 13 Effective masses for the systems $\bar{p}n\pi\pi$ ($m = 0,1,2$) for the events having the $MM^2(\bar{p}\pi^-p\pi^+)$ in the neutron peak ($0.78 \leq MM^2(\bar{p}\pi^-p\pi^+) \leq 0.98 \text{ GeV}^2$) with (shaded histograms) and without guard band subtraction. The curves represent fitted polynomial functions on the guard band subtracted spectra. The diagrams below each spectrum represent the differences between experimental values and the fitted curves as a function of the effective mass.

FIGURE CAPTIONS (Cont'd)

- Fig. 14 Effective masses for the systems $\bar{p}p_F m\pi$ ($m = 0,1,2$) for events having $MM^2(\bar{p}\pi^-pp)$ in the π^0 peak and antiselection of the π^0 peak of reaction (6) with (shaded histograms) and without guard band subtraction. The diagrams below each spectrum represent the differences between the experimental value and the fitted curves as a function of the effective mass.
- Fig. 15 Two-body effective masses for events assigned to reaction (2) with (shaded histograms) and without guard band subtraction.
- Fig. 16 Two-body effective masses for events assigned to reaction (3) with (shaded histograms) and without guard band subtraction.
- Fig. 17 Predicted $I = 1$ M-diquonium production cross sections as a function of the diquonium mass for (a) the $\bar{p}\pi^-\pi^-$ system produced in reaction (1), (b) the $\bar{p}p\pi^-\pi^0$ system produced in reaction (2). Dotted lines represent the experimental upper limits.

Fig.1

Fig. 2

Fig. 4

Fig. 5

Fig.6

Sector B

Fig.7

Sector C

Fig. 8

Sector D

Fig. 9

Fig.10

Fig.11

Fig.12

Fig.13

Fig.14

Fig.15

Fig.16

Fig.17