Search for narrow $\bar{p}p$ resonances in the reaction $\bar{p}p \to \bar{p}p\pi^+\pi^-$

The JETSET Collaboration

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(22 April 1997)

The reaction $\bar{p}p \to \bar{p}p\pi^+\pi^-$ has been studied with high statistics at CERN-LEAR with incident $\bar{p}$ momenta from 1.65 to 2.0 GeV/c by the JETSET (PS202) experiment. The aim of this paper is to search for narrow resonances decaying to $\bar{p}p$. No evidence for such structures is found. In particular, an upper limit for the production of a 2.02 GeV state with a width of $\Gamma = 20$ MeV, having been seen in other hadroproduction experiments, is established. Our results restrict the cross section for such a peak to be below 200 nb at the 95% confidence level.

The search for narrow ($\Gamma \approx 10$ MeV) baryonium resonances decaying to $N\bar{N}$, has been an exciting field for several years, when structures decaying to $\bar{p}p$ and $\bar{p}p\pi$ have been reported in some hadron induced reactions. In particular, evidence for two narrow states, at 2.02 and 2.2 GeV, was observed in baryon exchange π^-p interactions at 9 and 12 GeV/c in the reaction $\pi^-p \to p_f\pi^-(\bar{p}p)^*$ at the CERN Ω spectrometer [?]. These states were interpreted as coming from backward production of baryonium, a suggested $\bar{q}q\bar{q}q$ system of quarks and antiquarks, in association with a fast forward N^* baryon.

A search for these narrow resonances started soon in several hadroproduction experiments, in π^- [?] [?], K^- [?] and $\bar{p}$ [?] induced reactions, all with negative results. In particular, these states were not observed in the high-statistics experiment WA56 at the CERN Ω spectrometer, which studied the reactions $\pi^-p \to p_f\pi^-(\bar{p}p_s)$ at 12 GeV/c and $\pi^+p \to p_f\pi^+(\bar{p}p_s)$ at 20 GeV/c [?]. Also, no evidence for such states was seen in central production experiments which studied the reactions $(\pi^+/p)p \to (\pi^+/p)_f(\bar{p}p)p_s$ at 85 GeV/c [?]. Searches for baryonium resonances below the $\bar{p}p$ threshold have been conducted at LEAR with negative results [?]. However, a recent reanalysis of $\bar{p}d \to p_s5\pi$ data [?] reports evidence for a narrow (10 MeV) state at 1.870 GeV.

A similar history took place with another narrow state, at a mass of 2.95 GeV and decaying to $\bar{p}p\pi^-$, which was reported in the reaction $\pi^-p \to \bar{p}p_f\pi^-p_s$, again at the CERN Ω spectrometer [?]. Here also a later high-statistics experiment failed to confirm the existence of such a state [?].

These experimental results severely dampened the interest in further searches for baryonium resonances. Recently however the question of existence of baryonium has been reopened owing to a reanalysis of the WA56 data. Using a different event selection procedure designed to enhance the central production of the $\bar{p}p$ system, the authors of ref. [?] find evidence, in three different reactions, for a structure at a mass of 2.02 GeV having the narrow width between 10 and 20 MeV. These data suffer from a relatively high background due to the fact that all of the analyzed channels are only partially reconstructed since there is always one missing particle in the final state. Nevertheless, the significance of the peaks is quoted to be between 5 and 7 standard deviations. This new information motivated us to search for this narrow resonance in a high statistics experiment using in-flight $\bar{p}p$ annihilations.

The main focus of the Jetset (PS202) experiment at CERN-LEAR is the study of the cross section and spin observables in the reaction $\bar{p}p \to \phi\phi \to 4K^{\pm}$. The motivation for this work is the search for structures in the observables which are indicative of hadronic resonances. The experimental apparatus has been described in more detail in a previous publication [?]. The essential ele-

*the subscripts f or s indicate a relatively fast or slow particle respectively ments which concern the present study are the following. The stored $\bar{p}$ beam interacts with an internal hydrogen gas jet target in one of the straight sections of LEAR. The interaction point is surrounded by a non-magnetic detector which includes charged-particle tracking chambers, trigger scintillators, particle-identification detectors (PID), and electromagnetic calorimetry. The PID system includes silicon dE/dx pads, freon or water "threshold" Čerenkov counters, and a ring-imaging Čerenkov counter (RICH) [?], the latter of which was introduced after the intial data-taking. The entire detector is symmetric in azimuth but is subdivided into a forward ($\approx 10^0 < \theta < 45^0$) and a barrel ($45^0 < \theta < 135^0$) sector, where θ is the laboratory polar angle defined with respect to the incident antiproton direction. The detector is open in the backward direction. Antiproton momenta in the range from 1.12 to 2.0 GeV/c were utilized.

The trigger was designed to select a sample of four-charged-particle events with the kinematics commensurate with the reaction $\bar{p}p \to 4K^{\pm}$. This led to a global restriction imposed by the segmented trigger scintillator system that the emitted particles were all forward of $\theta = 65^0$ and that at least three of them had $\theta \leq 45^0$. A restriction on the β of the particles was imposed such that at least one, and sometimes two, of the particles would have passed through the threshold Čerenkov counters without registering a hit. Events having γ's in the barrel calorimeter were rejected by use of a hardware trigger or by cuts in the data analysis while those events with γ's in the forward region were identified and removed only in the analysis phase.

One of the background channels, satisfying the trigger conditions and falling inside the acceptance of the apparatus, is the reaction:

$$\bar{p}p \to \bar{p}p\pi^+\pi^- \quad (1)$$

This reaction can be fully reconstructed with little background contamination and it has been used extensively as a known source of particles for the detector calibration and the study of systematic errors. However it is the aim of this study to make a more detailed analysis of reaction (1) and to search for narrow resonances decaying to $\bar{p}p$ in the kinematic region covered by the experiment.

Since the charged-particle tracks were measured in the absence of a magnetic field, only the directions are known. The momenta are thus computed using the energy-momentum conservation equations given an assumption on the masses of the four particles. The three equations obtained from the 3-momentum conservation can be used to express the momentum of the particles as linear functions of one parameter, which we call μ (the momentum of one of the four outgoing particles). The sum of the inferred energies of the particles can be expressed in terms of this parameter as $E_{final}(\mu)$. Defining $f(\mu) = E_{final}(\mu) - E_{initial}$ this function has a single minimum which we call ΔE and the energy conservation equation $f(\mu) = 0$ has two solutions, of which the ones having a negative momentum for some of the particles were discarded. The remaining solutions were then tested for compatibility with the PID system.

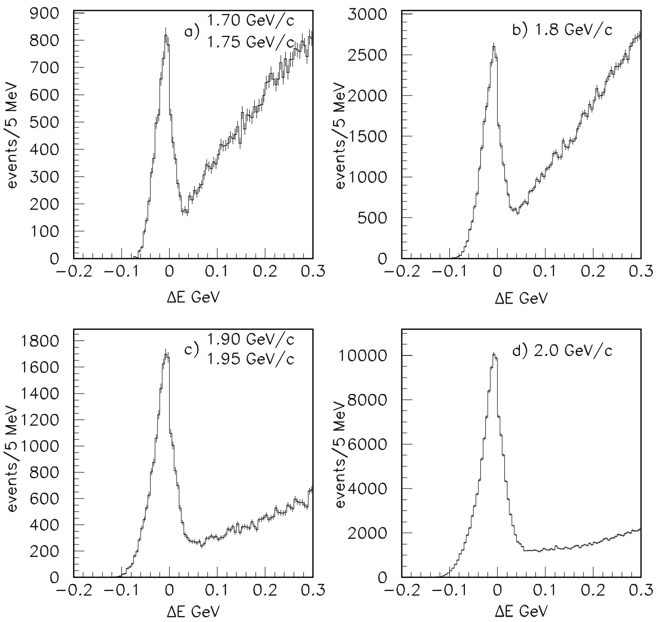

FIG. 1. ΔE (see text) distributions for reaction $\bar{p}p \to \bar{p}p\pi^+\pi^-$ for different $\bar{p}$ incident momenta.

Each of the six possible mass combinations in reaction (1) was tested for compatibility with the kinematics and PID. If at least one of the solutions from a given mass combination satisfies these tests, then the corresponding ΔE value is plotted. Distributions of ΔE for such solutions at different incident antiproton momenta are shown in fig. 1. We observe a dominant peak near $\Delta E = 0$ with little background. This is a conclusive signature for reaction (1). A selection of events with $\Delta E \leq 40$ MeV defines the final event sample.

In order to derive the cross section for this reaction, the ΔE distributions were fit using a second order polynomial to describe the background, and a peak shape derived from Monte-Carlo simulations. The Monte Carlo is based upon GEANT [?] and contains a detailed description of the apparatus. Events so produced were subjected to the same reconstruction procedure and selection criteria used for the real data. The acceptance of the apparatus for reaction (1) was determined from this study.

Due to the limitations imposed mainly by the trigger, the acceptance function was limited and therefore information on the dynamics of the reaction cannot be gained from our data only. We therefore used in the Monte-Carlo simulation a model which assumed that reaction (1) proceeds entirely through $\bar{p}p \to \Delta^{--}\Delta^{++}$ and

TABLE I. Summary results for the study of the reaction $\bar{p}p \to \bar{p}p\pi^+\pi^-$. The factor $N_{\bar{\Lambda}\Lambda}$ represents the estimated number of $\bar{p}p\pi^+\pi^-$ events coming from the reaction $\bar{p}p \to \bar{\Lambda}\Lambda$. The errors on the final cross section are statistical only; they do not reflect the uncertainties in acceptance owing to different trigger and detector configurations.

p (GeV/c)	Lum. (nb^{-1})	Acceptance (‰)	$N_{\bar{p}p\pi^+\pi^-}$	$N_{\bar{\Lambda}\Lambda}$	σ (μb)
1.65	13.7	2.5	934	278	18.9 ± 1.9
1.70	17.9	2.8	2559	471	41.8 ± 2.1
1.75	14.5	3.2	3212	448	59.3 ± 2.2
1.80	22.3	3.6	11049	800	128.7 ± 2.3
1.90	7.8	4.7	8003	312	211.6 ± 3.6
1.95	7.7	5.3	7843	323	184.6 ± 3.4
2.0	14.5	6.4	24417	676	255.8 ± 2.1
2.0	38.5	6.0	78542	1795	331.1 ± 1.7

a four momentum t-distribution from the incident $\bar{p}$ to the Δ^{--} obtained from the study of the same reaction at 3.2 GeV/c [?]. Uncertainties on the validity of this assumption introduce a systematic error in the determination of the cross section of approximately 5%.

One background reaction which survives the selection criteria used to isolate reaction (1) comes from the process:

$$\bar{p}p \to \Lambda\bar{\Lambda} \to (\bar{p}\pi^+)(p\pi^-) \quad (2)$$

where the two Λ's have a decay close to the interaction vertex and are therefore merged into a four pronged event. The cross section for this reaction is well known [?] and a Monte-Carlo simulation of reaction (2) has been performed in order to obtain the overall acceptance for this process. The estimated contamination is then subtracted from the data in the computation of the final cross section for reaction (1).

We obtained, finally, the cross section for reaction (1) which is listed in table 1 along with the integrated luminosities, and the estimated contamination from reaction (2). The data are also shown in fig. 2 where a comparison with previous measurements [?] [?]is given. The errors on the final cross section values which are listed in the table are statistical only. Inspection of the two distinct runs at 2.0 GeV/c where the final cross sections differ by approximately 25% in two data sets having different detector and trigger conditions is indicative of the largest systematic uncertainty which remains in the scale of the final cross sections. We conclude, therefore that an overall systematic uncertainty of 25% should be applied to all the cross sections measured in the present experiment.

The main aim of this study is the analysis of the $\bar{p}p$ effective mass distributions for which a precise knowledge of the total cross section is not important. The $\bar{p}p$ mass experimental resolution, $\sigma_{m(\bar{p}p)}$, has been computed using the Monte-Carlo simulation. At an invariant mass of 2 GeV, $\sigma_{m(\bar{p}p)} = 9$ MeV. The resulting effective mass

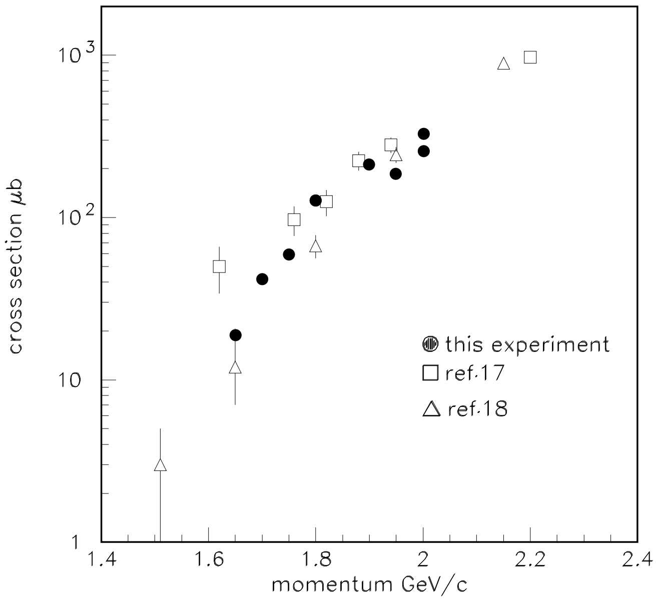

FIG. 2. The total cross section for the reaction $\bar{p}p \to \bar{p}p\pi^+\pi^-$ as measured in this experiment (solid circles) and in previous measurements from [?] (open squares) and [?] (open triangles).

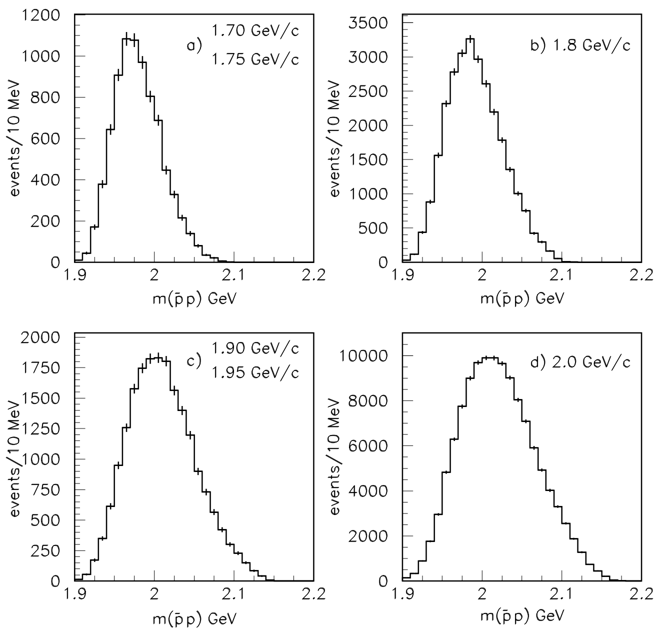

FIG. 3. $\bar{p}p$ effective mass distributions derived from events from the reaction $\bar{p}p \to \bar{p}p\pi^+\pi^-$ for different incident antiproton momenta.

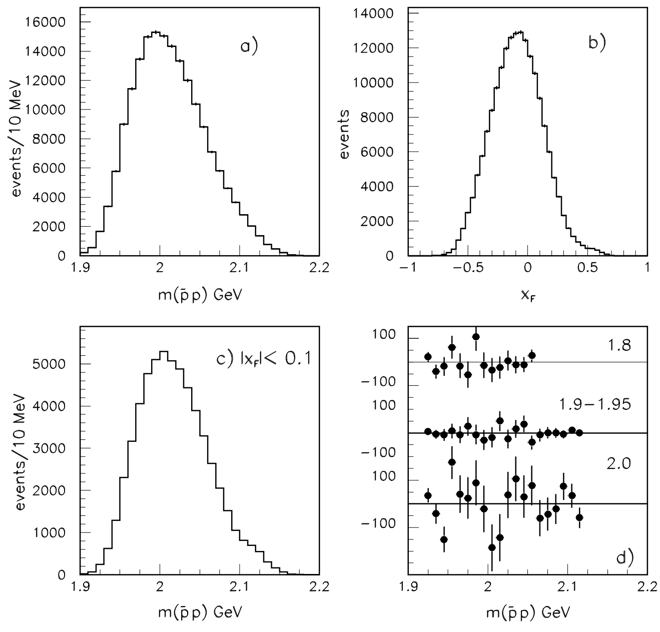

FIG. 4. a) $m_{\bar{p}p}$ distribution for all of the data; b) Feynman x_F distribution for the $\bar{p}p$ system; c) $m_{\bar{p}p}$ distribution when $|x_F| \leq 0.1$; d) Residuals from the fits for different $\bar{p}$ incident momenta.

distributions, binned in 10 MeV increments, are shown in fig. 3 for four groupings of the incident antiproton momenta. All of the distributions are smooth and none show striking evidence for resonant structures.

Low energy $\bar{p}p$ annihilations cannot be described by peripheral models, therefore "central production" of a given system has no meaning. In order to enhance possible contributions from a kinematic region where the $\bar{p}p$ system is "central", we have combined the distributions (fig. 4a) and have plotted (fig. 4b) the Feynman x_F distribution ($x_F = p^*_L/p^*_{Lmax}$) for all of the data. Here p^*_L is the longitudinal centre of mass momentum of the $\bar{p}p$ system with respect to the beam direction. Requiring $|x_F| \leq 0.1$ yields the $m_{\bar{p}p}$ distribution shown in fig. 4c where, again, no structure is visible.

The $\bar{p}p$ effective mass distributions were then fitted using a smooth shape of the form $(m-m_{th})^{a+bm}e^{-cm-dm^2}$ where a, b, c, d and m_{th} are free parameters. The residuals distribution for different $\bar{p}$ incident momenta are shown in fig. 4d) and do not show evidence for resonance structure in the 2.02 GeV region. Attempts to include a Gaussian function describing the presence of a possible narrow resonant state in the 2.02 GeV mass region having a width between 10 and 20 MeV failed. An upper limit for the production of a 20 MeV wide resonance at 2.02 GeV is determined to be

$$\sigma < 200 \text{ nb at } 95\% \text{ c.l.}$$

In conclusion, we have studied the reaction $\bar{p}p \rightarrow \bar{p}p\pi^+\pi^-$ with the Jetset experiment at LEAR for a variety of incident antiproton momenta from 1.65 to 2.0 GeV/c. In addition to a determination of the cross section, a search was made in the $\bar{p}p$ effective mass distribution for possible resonant behavior. Even with a selection of events which enhanced the centrality of the $\bar{p}p$ system, no structure was observed. In particular, an upper limit of $\sigma < 200$ nb at 95% c.l. is established for the production of a 20 MeV wide resonance at 2.02 GeV decaying to $\bar{p}p$. Such a state has been reported to be centrally produced by baryon exchange. The reaction studied in this paper, in the "central" selection described above, just selects a baryon exchange mechanism, but no signal is observed.

This work has been supported in part by CERN, the German Bundesminister fuer Bildung, Wissenschaft, Forschung und Technologie (BMBF), the Italian Istituto Nazionale di Fisica Nucleare, the Swedish Natural Science Research Council, the Norwegian Natural Science Research Council, and the United States National Science Foundation, under contract NSF PHY 94-20787.

We acknowledge useful discussions with A. A. Grigoryan.

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