Limits on baryonium production in $\bar{p}p$ interactions at 8.3 and 13.0 GeV/c

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Results are presented from a search for the production of narrow $\bar{p}p$ states in antiproton interactions at 8.3 and 13.0 GeV/c. Cross-section upper limits have been established for four candidate baryonium states. The upper limits (95% probability level) range from 0.21 to 1.29 μb for inclusive forward production, and from 0.11 to 0.89 μb for backward production in the final state $\omega_f^0(\bar{p}p)$.

Many conflicting results have been presented concerning the existence of narrow meson resonances which decay predominantly into final states with a baryon-antibaryon pair ("baryonium"). As of 1980, the S(1936) was considered the best established of the baryonium candidates. It had been observed, with slight variations in mass and width, in four separate $\bar{p}p$ formation experiments.[1] Two other states, with masses of 2020 and 2200 MeV/c^2, were also regarded as strong baryonium candidates. They were observed in an experiment which used the CERN Ω spectrometer for a high-statistics study[2] of the baryon-exchange reactions $\pi^- p \to N_f^*(1520)(\bar{p}p)$ and $\pi^- p \to \Delta_f^0(1232)(\bar{p}p)$ at 9.0 and 12.0 GeV/c. Evidence for baryonium was also reported in production experiments involving interactions ranging from γp and ep to $\pi^+ p$ and pp.[3] However, a number of experiments performed recently to investigate the properties of baryonium have failed to find any evidence for its existence.[4]

We report the results of a baryonium search performed using the Large-aperture solenoid spectrometer (LASS) at SLAC with antiproton beams of 8.3 and 13.0 GeV/c. The apparatus is shown in Fig. 1. LASS provided nearly 4π acceptance and good momentum resolution over a wide range of p_L and p_T. Two Čerenkov counters, $\check{C}_1$ and $\check{C}_2$, a time-of-flight hodoscope, and a neutral-hadron

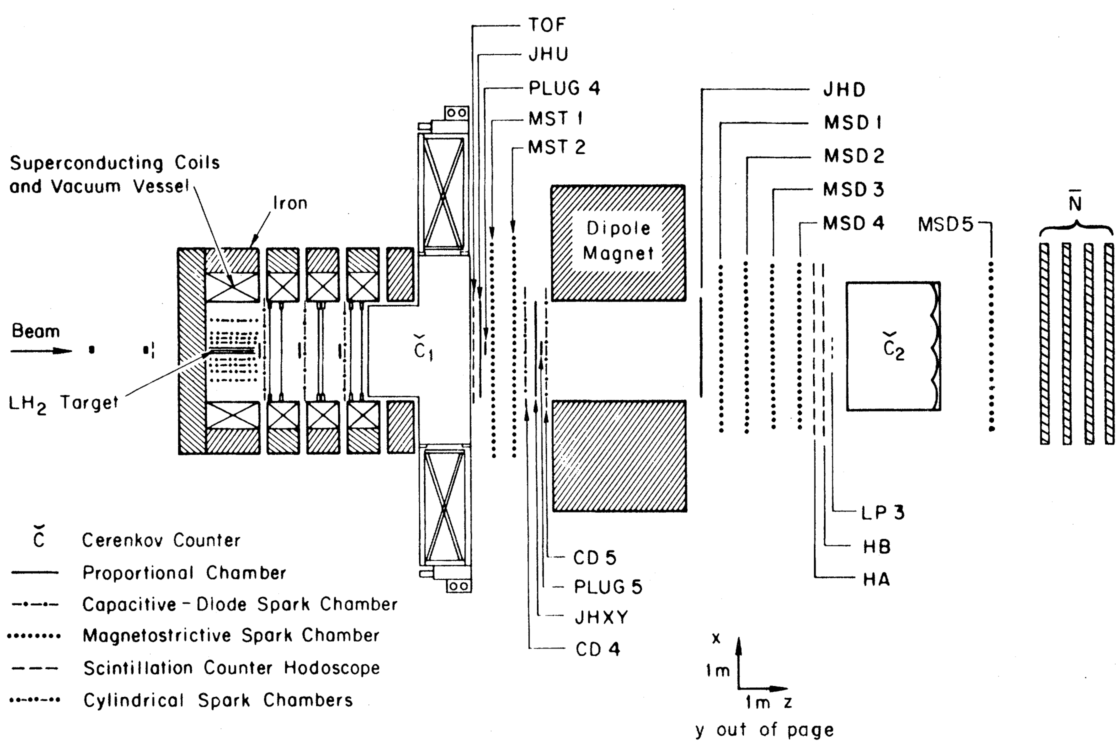

FIG. 1. The large-aperture solenoid spectrometer.

detector facilitated particle identification. $\check{C}_1$ and $\check{C}_2$ had pion thresholds of 2.7 and 1.8 GeV/c, kaon thresholds of 9.6 and 6.3 GeV/c, and proton thresholds of 18.0 and 12.0 GeV/c, respectively. The time-of-flight resolution of 1.2 nsec [full width at half maximum (FWHM)] provided p/π separation to $\sim$2.0 GeV/c.

The search for baryonium in $\bar{p}p$ interactions was motivated by the possibility that the production cross section might be much larger than in analogous $\pi^- p$ interactions. This could be the case if baryonium were produced in a baryon-exchange process, as indicated by the CERN Ω spectrometer result. Baryon-exchange reactions have been successfully parametrized by $d\sigma/dt = Ae^{bt}$, with typical values[5] of b ranging from 4 to 10. Regge theory suggests that this differential cross section, at a fixed t and center-of-mass energy, would be smaller by about a factor of 2 in $\bar{p}p$ as opposed to $\pi^- p$ interactions.[6,7] However, since the maximum possible value of t is always greater in a given $\bar{p}p$ reaction than in the analogous $\pi^- p$ reaction, a kinematic enhancement of baryonium production in $\bar{p}p$ interactions might result, the size of which would be determined by the slope parameter b and the kinematic limits on t. For example, if b were 7, the reaction $\bar{p}p \to \omega^0 B(2020)$ at 8.3 GeV/c would be favored over the reaction $\pi^- p \to N^*(1520)B(2020)$ at 9.0 GeV/c by a factor of 200 due to kinematics.

One other experimental result suggested that the cross section for baryonium production might be much larger in baryon-antibaryon interactions than in $\pi^- p$. In 1976, Braun *et al.*[8] reported a 5.1-standard-deviation enhancement in the X^0 mass spectrum at 2850 MeV/c^2 in the reaction $\bar{p}n \to \pi^- X^0$ at 5.55 GeV/c where the X^0 consisted of a $(\bar{p}p)$, $(\bar{p}p\pi^0)$, $(\bar{p}n\pi^+)$, or $(\bar{n}p\pi^-)$. The extremely large production cross section, 83 ± 16 μb, quoted for this enhancement did not contradict any existing experimental result. The present experiment is the first high-statistics $\bar{p}p$ study published with a large acceptance for $\bar{p}p$ pairs with effective masses as high as 2850 MeV/c^2.

Two data samples were chosen for this study. In the first, events were selected in which a positively charged particle with momentum greater than 2.7 GeV/c traversed both Čerenkov counters without radiating light in either. These events were searched for the decay into a $\bar{p}p$ pair of a forward baryonium, recoiling against any combination of particles. The second sample consisted of events produced by the 8.3-GeV/c $\bar{p}$ beam which contained a fast forward pion (as identified by one or both Čerenkov counters). The four-prong events from this data sample were subjected to a kinematically constrained fit to isolate the final state $\bar{p}p\pi^+\pi^-\pi^0$. Those

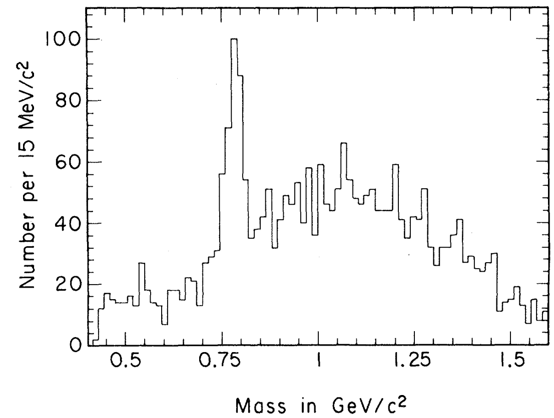

FIG. 2. $\pi^+\pi^-\pi^0$ effective-mass distribution for events fit to $\bar{p}p \to \bar{p}p\pi^+\pi^-\pi^0$, with the requirement $|t| < 1.0$ (GeV/c)^2.

events which included an ω^0 meson were selected, and the $\bar{p}p$ pair recoiling against the ω^0 was examined for evidence of baryonium production. In order to isolate peripheral events in both data samples, the square of the four-momentum transfer from the beam $\bar{p}$ to the forward system was required to satisfy $|t| < 1.0$ (GeV/c)^2.

These channels were selected because the backgrounds were expected to be very small. Mechanisms which could yield a forward proton are baryon exchange, double baryon exchange, exchange of an exotic (baryon number=2) particle, and production in the $\bar{p}p$ annihilation fireball. All of these mechan-

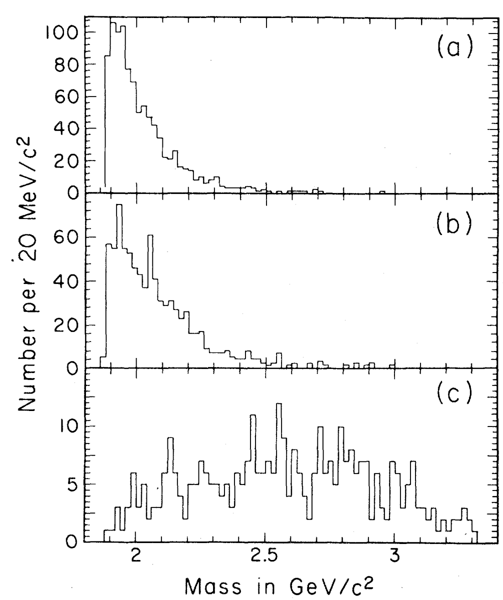

FIG. 3. $\bar{p}p$ effective-mass distributions for the reactions: (a) $\bar{p}p \to (p_f\bar{p})X$ at 8.3 GeV/c^2, (b) $\bar{p}p \to (p_f\bar{p})X$ at 13.0 GeV/c^2, and (c) $\bar{p}p \to \omega_f^0(\bar{p}p)$.

TABLE I. Trigger acceptance for baryonium production.

Mass in MeV/c^2	$\bar{p}p \to (p_f\bar{p})X$ at 13.0 GeV/c^2	$\bar{p}p \to (p_f\bar{p})X$ at 8.3 GeV/c^2	$\bar{p}p \to \omega_f^0(\bar{p}p)$ at 8.3 GeV/c^2
1936	59%	27%	47%
2020	43%	20%	45%
2200	26%	9%	40%
2850	10%	4%	10%

isms except baryon exchange are heavily suppressed. The $\omega_f^0(\bar{p}p)$ final state was attractive because the ω^0, unlike the ρ^0 or the f^0, is a narrow resonance and appears over a small background (Fig. 2).

The $\bar{p}p$ effective-mass spectra are shown in Fig. 3. No narrow $\bar{p}p$ enhancements were observed, and cross-section upper limits were computed for four candidate baryonium states: $B(1936)$, $B(2020)$, $B(2200)$, and $B(2850)$.

The two-particle effective-mass resolution of LASS was determined from the covariance matrices associated with the tracks forming $\bar{p}p$ pairs. The resolution (one standard deviation) was determined to be 3.5 MeV/c^2 near threshold, 4.5 MeV/c^2 at 2200 MeV/c^2, and 8.0 MeV/c^2 at 2850 MeV/c^2. The resolution for $\bar{p}p$ pairs near threshold and at high effective mass was verified by comparing the computed mass error with the observed FWHM of the $\bar{\Lambda}$ and K^0, respectively. All cross-section upper limits were made assuming a resonance width less than the appropriate calculated mass resolution.

The sensitivity is the production of raw sensitivity, event-reconstruction efficiency, and trigger acceptance. The raw sensitivity was 81.5 events/μb for the 13.0-GeV/c p_f-filtered event sample, 96 events/μb for the 8.3-GeV/c π_f-filtered sample, and 155 events/μb for the 8.3-GeV/c p_f-filtered sample. The event-reconstruction efficiency was determined to be 88% for p_f-filtered events and 73% for π_f-filtered events.

The acceptance of the hardware triggers and software filters was computed using a Monte Carlo program which simulated the response of LASS to individual events. Tracks were generated using a two-body baryon-exchange model with the differential cross section parametrized as $d\sigma/dt \propto e^{bt}$. Values of b from 3 to 7 yielded similar acceptances; $b=3$ was used in the cross-section calculations.[9] The acceptance for $\bar{p}p \to (p_f\bar{p})X$ was sensitive to the baryonium decay angular distribution, since this affects the transverse momentum of the decay proton. The degree to which the acceptance depended on this angular distribution varied from a very small dependence for $\bar{p}p$ pairs of mass 1936 MeV/c^2 to an overwhelming dependence for high-mass pairs. This was not the case for the exclusive reaction $\bar{p}p \to \omega_f^0(\bar{p}p)$, since neither of the baryonium decay products was included in the trigger. All cross sections were calculated assuming isotropic baryonium decay. The trigger acceptances used are shown in Table I. The cross-section upper limits obtained from this analysis are listed in Table II.

Two other high-statistics searches for baryonium in $\bar{p}p$ interactions have been reported recently. One of these was performd at the CERN Ω spectrometer with a 12.0-GeV/c $\bar{p}$ beam[10] and the other was done using a 5.0-GeV/c $\bar{p}$ beam at the Brookhaven multiparticle spectrometer.[11] Both groups triggered on a fast forward proton and isolated the final state $(p_f\bar{p})\pi^0$. They then searched for narrow enhancements in the mass spectrum of $\bar{p}p$ pairs produced forward in the laboratory. The Brookhaven group also studied the final state $(p_f\bar{p})\rho^0/\omega^0$. No evidence for the production of baryonium was reported by either group. The upper limits established for various low-mass baryonium candidates ranged from 0.04–0.12 μb for the $(p_f\bar{p})\pi^0$ final state and 0.20–0.22 μb for the $(p_f\bar{p})\rho^0/\omega^0$ final state.

The results of the present experiment on backward as well as forward production of baryonium,

TABLE II. 95%-probability upper limits on the production of baryonium in $\bar{p}p$ interactions.

Mass in MeV/c^2	8.3 GeV/c $(p_f\bar{p})X$	13.0 GeV/c $(p_f\bar{p})X$	8.3 GeV/c $\omega_f^0(\bar{p}p)$
1936	0.54 μb	0.33 μb	0.12 μb
2020	0.21 μb	0.27 μb	0.14 μb
2200	1.29 μb	0.56 μb	0.11 μb
2850	0.54 μb	0.80 μb	0.89 μb

together with the two null results on forward production,[10,11] are in clear disagreement with the $\pi^- p$ results which inspired all three experiments,[2] given reasonable assumptions concerning the baryon-exchange production mechanism. The present experiment alone clearly rules out copious production in $\bar{p}p$ interaction of a baryonium state with mass near 2850 MeV/c^2.

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