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Brief Reports

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Search for exclusive J/ψ production

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We have searched for exclusive hadronic J/ψ production by looking for narrow resonances in the e^+e^- mass spectrum of the reaction $\pi^-p \rightarrow e^+e^-n$. No events were observed in the region around 3.1 GeV/c^2. The cross section for the reaction $\pi^-p \rightarrow J/\psi n$ at 13 GeV/c is no more than 103 pb at the 90% confidence level.

The cross sections for $\pi^-p \rightarrow \eta' n$ (exclusive η' production) and $\pi^-p \rightarrow \phi n$ (exclusive ϕ production) give us insight as to the internal structure of the η' and the ϕ mesons; they indicate the percentage of light valence quarks in these hidden-strangeness mesons.[1] Similar insight would be obtained about mesons with hidden charm if the exclusive production rates of the η_c and J/ψ could be measured. We have looked for η_c's and J/ψ's in the reactions $\pi^-p \rightarrow \gamma\gamma n$ and $\pi^-p \rightarrow e^+e^-n$. In the $\gamma\gamma$ mass spectrum we saw no narrow resonance, and reported an upper limit of 44 pb for the η_c production cross section times branching ratio.[2] In this paper we describe the portion of the experiment that searched for exclusive J/ψ production.

The experiment was performed at the Brookhaven Alternating Gradient Synchrotron. A 13-GeV/c pion beam interacted in a 30.5-cm-long segmented plastic-scintillator target. Final-state electrons and photons were analyzed in two electromagnetic-shower spectrometers each consisting of two lead-glass-block arrays preceded by a 4-radiation-length-thick active converter as shown in Fig. 1. Any charged particle, or photon of more than 50-MeV energy, that did not strike the spectrometers was detected in an extensive array of veto counters surrounding the target and the spectrometers. The final-state neutrons were not detected.

During special calibration runs the energy resolution of the spectrometers was measured to be $14\%/\sqrt{E\text{ (GeV)}}$. The x-y scintillation hodoscopes between the converter and the lead-glass arrays measured the particles' positions to ±6 mm. The two-shower resolution of the spectrometers was sufficient to distinguish both photons from a

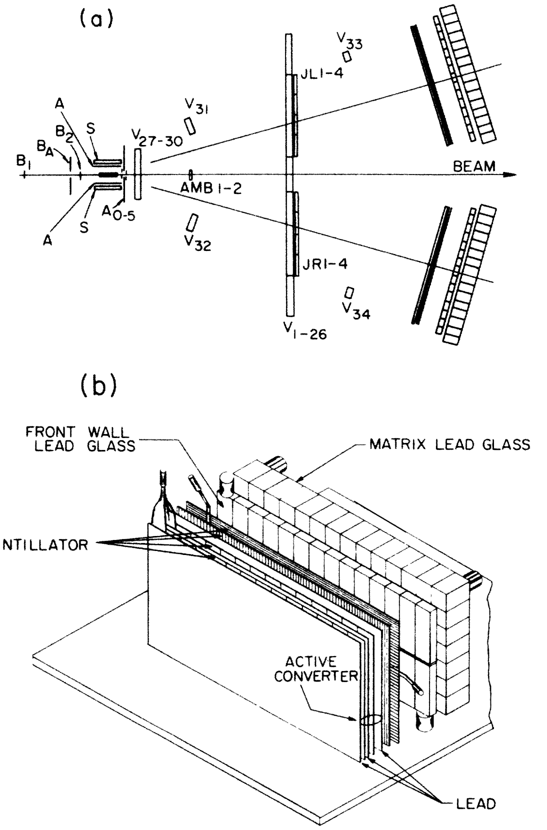

FIG. 1. (a) Plan view of the apparatus used for the η_c and J/ψ searches, (b) one of the electromagnetic-shower spectrometers.

minimum-opening-angle π^0 decay.

Data for the reactions $\pi^- p \rightarrow \gamma\gamma n$ and $\pi^- p \rightarrow e^+e^- n$ were recorded concurrently, using different triggers. In $\gamma\gamma$ triggers no charged particles were allowed to emerge from the target; counters A_0–A_5 vetoed forward-going charged particles. Additional details of the $\gamma\gamma$ experiment can be found in Refs. 2 and 3. For the e^+e^- triggers the noninteracting beam particles were vetoed with two small counters: *AMB*1 and *AMB*2. Charged particles that struck the spectrometers were tagged with counters A_0–A_5 and in a second set of paddle counters, *JR*1–*JR*4 and *JL*1–*JL*4. The trigger required that a minimum of 2 GeV of energy be deposited in each spectrometer and that the sum of the energy in both spectrometers be at least 10 GeV. A slower second-stage trigger required that a charged particle detected in the *J* counters line up with a shower in the converter section of the spectrometer. A total of 1.4×10^6 events were recorded with the e^+e^- trigger in an exposure of 4.5×10^{12} incident π^-'s.

The preliminary analysis of the e^+e^--trigger data proceeded much as that of the $\gamma\gamma$ triggers. We discarded events in which the veto system indicated the presence of an additional photon or charged particle, or in which there was more than one shower in either spectrometer. Figure 2(a) shows the spectrum of the sum of the two electromagnetic-shower energies in the remaining events. The peak at ~10.5-GeV energy is an artifact of the minimum-energy requirement in the trigger. The shower-energy spectrum of identified $\pi^0\pi^0$ pairs (collected with the $\gamma\gamma$ trigger) is plotted for comparison in Fig. 2(b). The lower average energy of the e^+e^- triggers indicates that this sample is largely due to background processes with undetected energy. Events which remain in the e^+e^--trigger sample after the cuts described above came primarily from two sources: (1) $\pi^+\pi^-$ events in which both pions interacted in the spectrometers, and (2) $\pi^0\pi^0$ events in which both π^0's decayed asymmetrically, each giving one low-energy photon that escaped detection and one high-energy photon that converted into an e^+e^- pair before leaving the target region.

The charged-pion background was reduced by making cuts on the longitudinal development of the showers in the spectrometers. The energy deposited by an electron was greatest in the first bank of lead-glass blocks (radiation lengths 5–7 of the spectrometer), while the energy deposition due to a pion peaked in the rear-wall-array blocks (radiation lengths 8–16). With these shower characteristics in mind, we defined a detected "electron" as a charged particle that deposited more than 16% but less then 70% of its observed energy in the rear-wall blocks, and more than 4% in the converter counters. To eliminate $\pi^+\pi^-$ events we required an "electron" signature in both spectrometers, and that at least one of the two charged particles deposit a "large" amount of its observed energy in the converter counters. We determined that more than 85% of the e^+e^- events should have satisfied these cuts by making calibration runs in which beams of 2, 4, 6, 8, and 10 GeV/*c* electrons impinged on a spectrometer. The observed shower-energy distribution of the events remaining after the "electron" cuts is shown in Fig. 2(c).

To satisfy our trigger requirements, one photon from each π^0 in a $\pi^0\pi^0$ event had to convert to an e^+e^- pair before leaving the target region. To eliminate these events we had to identify at least one of the e^+e^- pairs. True e^+e^- events had only one charged particle incident on each spectrometer, and therefore had smaller pulse heights in the corresponding *A* and *J* counters than did the $\pi^0\pi^0$ events. We defined a shower as coming from a "single charged particle" if it was associated with one and only one *J* counter, and with at least one but no more than two adjacent *A* counters, and that the pulse heights in the *A* and *J* counters were consistent with those of a minimum-ionizing particle. A good e^+e^- event was then required to have a "single charged particle" in each spectrometer. To test the efficiency of the "single-charged-particle" cut we used $\pi^+\pi^-$ events that were clearly identified by very low pulse heights in the front-wall lead-glass blocks, and high

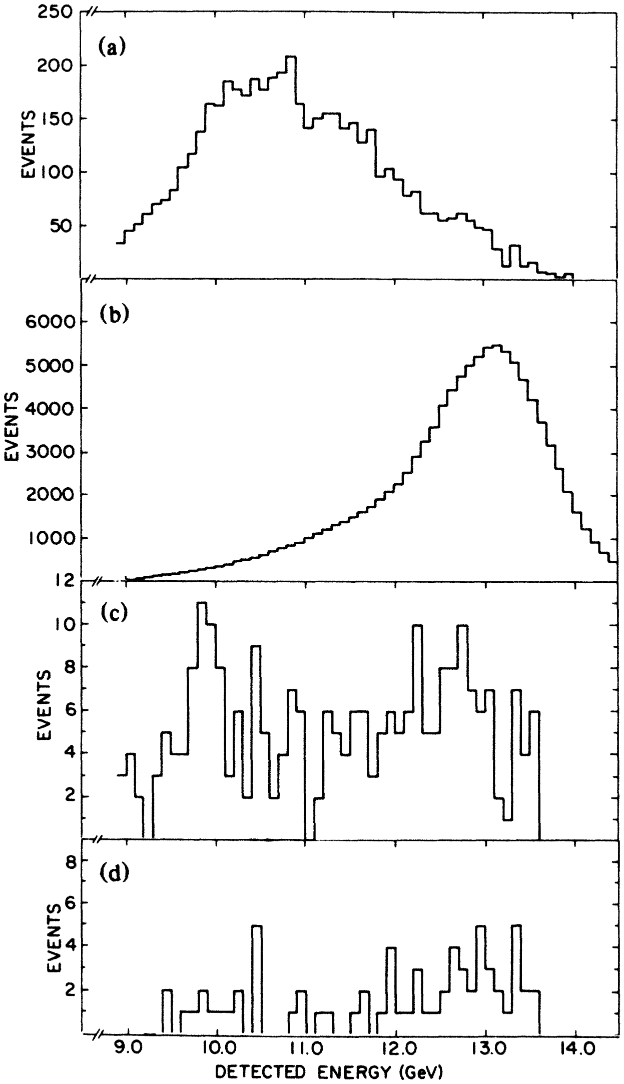

FIG. 2. Observed shower-energy spectrum of (a) all events that satisfied the hardware e^+e^--trigger requirements and had one and only one shower in each spectrometer, (b) $\pi^0\pi^0$ events, (c) events that satisfied the "electron" cuts, and (d) events that satisfied both the "electron" and the "single-charged-particle" cuts.

pulse heights in the rear-wall blocks. We determined that 75% of the true e^+e^- events would pass the "single-charged-particle" requirements, and, hence, 65% would pass both the "electron" cuts and the "single-charged-particle" cuts. The spectrum of events that satisfied both of these sets of cuts is shown in Fig. 2(d).

The events passing the above cuts were fit to the hypothesis of $\pi^- p \rightarrow e^+e^- X$, where the missing mass X was desired to be a neutron. We required the square of the missing mass to be less than 1.9 GeV^2/c^{-1}; about 85% of the neutron events would survive this cut. As $M_X{}^2$ is approximately linearly dependent on the observed shower energy, the missing-mass cut is roughly equivalent to discarding all events in Fig. 2(d) with energy below 12.4 GeV. The e^+e^- invariant-mass distribution for those events consistent with a neutron missing mass is shown in Fig. 3. There is no indication of any narrow e^+e^- state within our acceptance, and there are no events at all in the J/ψ region. The mass resolution for $J/\psi \rightarrow e^+e^-$ events was estimated to be 130 MeV/c^2 (full width at half maximum) with the aid of a Monte Carlo simulation of the experiment. One event in Fig. 3 corresponds to 3.3 pb of cross section. Therefore we set an upper limit at the 90% confidence level for the exclusive J/ψ production cross section times branching ratio into e^+e^- of 7.6 pb. A branching ratio into e^+e^- of 7.4% (Ref. 4) implies an upper limit on J/ψ exclusive production of 103 pb.

The limit of 103 pb is based on the assumption that there are only 3.3 effective protons in the carbon nuclei of our scintillator target. This derives from the observation of an $A^{0.67}$ dependence on target atomic weight for exclusive π^0 and η production.[5] If the dependence of exclusive J/ψ production on target atomic weight were actually A^1, then our limit should be reduced by a factor of 0.62, and would be 64 pb.

J/ψ events have never been observed in exclusive hadron-production reactions. Upper limits have been set at lower[6] and higher[7] beam momenta. When these limits are extrapolated to 13 GeV/c using a p^{-1} power law, our limit is eight times more stringent. A rough upper limit on exclusive J/ψ production can also be extracted from a measurement of large-x_F inclusive J/ψ production in π^-Cu interactions at 16 GeV/c.[8] The cross section was found to be 400 ± 200 pb (per nucleon) in the interval $0.8 < x_F < 1$ and assuming an A^1 dependence on target atomic weight, while the result would be 1400 ± 700 pb if one assumes an $A^{0.67}$ dependence. The fraction of this result which can be attributed to exclusive J/ψ production is of course unclear.

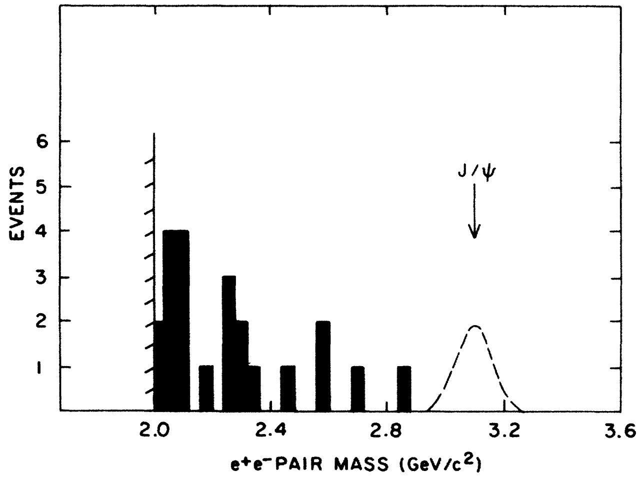

FIG. 3. The observed electron-positron invariant-mass spectrum. The curve shows the spectrometer resolution at the J/ψ mass. Pairs with mass less than 2 GeV/c^2 had low detection efficiency, and are not plotted.

Theoretical expectations for J/ψ exclusive production are very model dependent. Bolzan *et al.*,[9] using a duality-violating model, and Kodaira and Sasaki,[10] using a Veneziano model, predict a cross section of only a few picobarns. Pham and Mau,[11] on the other hand, use a Regge model and predict cross sections of about 80 pb. Berger and Sorensen[12] expect a threshold enhancement, analogous to that observed in exclusive ϕ production, to yield an even larger cross section for a 13-GeV/c beam. While our result is not precise enough to rule out any of the first three models, the large Regge-cut threshold enhancement of Berger and Sorenson appears inconsistent with the present results on exclusive J/ψ production.

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