obtained in (p, π) calculations by Miller[1] and others[14] using the static approximation are trustworthy. We note that recent DWBA calculations of (p, π^+) on a large series of targets give good (generally within a factor of ~2 in absolute magnitude) systematic agreement with present measurements,[12] and the remaining discrepancies are easily accounted for by reasonable wave functions so that the goal of using (p, π^+) reactions as a nuclear-structure probe at high momentum seems much more attainable than it did just a few years ago.

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Search for Heavy Narrow Resonances Produced by Photons with Energies up to 11.8 GeV*

G. Theodosiou, B. Gittelman,† K. M. Hanson,‡ D. Larson, E. Loh,§ and A. Silverman
Laboratory of Nuclear Studies, Cornell University, Ithaca, New York 14853
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A search has been made for photoproduced bosons or leptons of mass between 1.2 and 3.5 GeV that decay into either an electron-positron pair, two photons, or an electron and a photon. Within the sensitivity of the experiment no evidence for any new narrow resonance was found. An upper limit is given for the cross section per nucleon times the branching ratio.

Stimulated by the discovery of the $\psi(3.1)$ meson[1] and the conjectured existence of the related pseudoscalar state, an experiment was undertaken at the Wilson Synchrotron Laboratory to search for photoproduction of narrow heavy resonances. In particular, it would be of considerable importance to observe the decay into two photons of the η_c, a $J^p = 0^-$ meson with mass around 3.0 GeV, predicted by the recent theories with charm.[2] The detection system was the same as the one used in

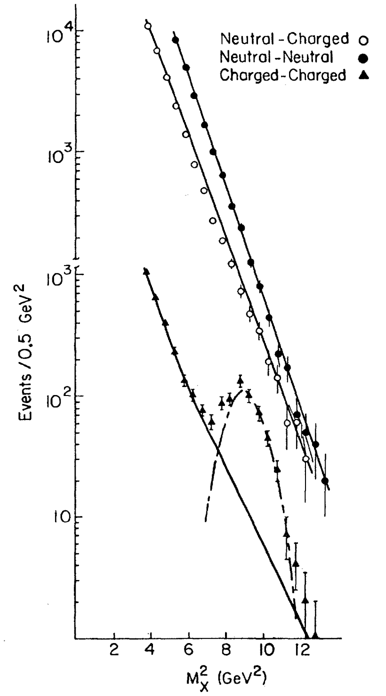

FIG. 1. nn, nc, and cc spectra for data set 1 in which the ψ (3.1) boson was observed.

our earlier measurement of the photoproduction cross section of the $\psi(3.1)$ and is described by Gittelman *et al.*[3] A collimated photon beam passed through a 2.93-g/cm² beryllium target. Electrons and photons produced in the target were detected in a pair of lead-glass hodoscopes. An event trigger was generated by a coincidence between two hodoscope signals in which each signal corresponded to an energy greater than a prescribed minimum, E_{single}, and their sum was greater than E_{sum}. An array of scintillation counters located in front of the lead-glass hodoscopes was used to distinguish electrons from photons. In this way each event was classified as charged-charged (cc), neutral-neutral (nn), or neutral-charged (nc), according to the charge of the detected particles.

Data were recorded for two distinct configurations. In the first, one hodoscope was placed below the beam line and the other symmetrically above in order to detect the decay products of particles produced near 0°. The sensitive mass range was varied by changing the bremsstrahlung endpoint energy. The mass-squared distributions for data accumulated with an 11.8-GeV endpoint energy are illustrated in Fig. 1. One sees a bump at the ψ mass in the cc distribution but no similar evidence of any other enhancement.

In the second configuration, the detector was moved about 48 cm to the right of the beam line to detect particles produced away from 0°. This was motivated by the possibility that one might miss observing a spin-0 particle because of an unusually strong suppression of the cross section near 0°. In this configuration the synchrotron energy was kept fixed at 11.5 GeV and the sensitive mass range was varied by changing the distance of the target from the detector. In Table I the conditions of each run are summarized.

The width of a bump in the mass-squared spec-

TABLE I. Experimental configurations.

Data set	Machine energy (GeV)	Distance[a] to the target (in.)	Mean[b] mass M_0 (GeV)	E_{single} (GeV)	E_{sum} (GeV)	Equivalent quanta
On axis						
1	11.8	60.0	3.03	2.50	7.7	3.28×10^{15}
2	9.8	60.0	2.51	1.80	7.0	7.4×10^{14}
3	8.2	60.0	2.10	1.75	6.5	4.5×10^{14}
4	6.8	60.0	1.74	1.25	5.4	6.6×10^{14}
5	5.7	60.0	1.46	1.00	4.5	3.5×10^{14}
Off axis						
7	11.5	145.0	1.17	2.23	8.7	3.6×10^{14}
8	11.5	127.0	1.44	2.23	8.7	5.9×10^{14}
9	11.5	107.0	1.70	2.50	8.7	5.8×10^{14}
10	11.5	92.4	1.95	2.50	8.7	5.3×10^{14}

[a]The distance between hodoscope centers was fixed at 38 in. for all data sets except No. 7, for which it was 35.4 in.

[b]The mass acceptance of the detector changes by less than a factor of 2 for mass values within ±10% of the mean mass m_0.

trum is a combination of the intrinsic particle width and the detector resolution. For this experiment the latter is given by $\Delta m^2/m^2 = 0.32/\sqrt{E}$ rms, where E is the laboratory energy of the decaying resonance in GeV. This relation was checked experimentally using the measured $\psi(3.1) \to e^+e^-$ spectrum ($E \simeq 11.0$ GeV) and in a separate run using the $\eta^0 \to \gamma\gamma$ spectrum ($E \simeq 6.5$ GeV). Restricting the investigation to narrow resonances, we have the constraint that an observed mass enhancement must have a width given by the detector resolution if it is to be considered as evidence of a resonance. With this in mind each mass-squared spectrum was analyzed as follows. First, the whole sensitive mass range was fitted with the function $A\exp(-bm^2)$ where A and b were varied. Then the spectrum was refitted for each mass value m_0, in the range of interest, with the function

$$A_1\exp(-bm^2) + A_2\exp\{-\tfrac{1}{2}[(m^2 - m_0{}^2)/\Delta m_0{}^2]^2\}. \quad (1)$$

Here the parameters A_1 and A_2 are varied, but b is held fixed at its previously determined value. The first term is background. The second term measures the yield from a resonance of mass m_0. $\Delta m_0{}^2$ is the known detector resolution. Using this procedure, we searched the sensitive mass range of each data set. No statistically significant enhancements were found. The limits quoted in this paper are based on the number of events that one would have detected for a 4-standard-deviation signal on top of the background. The significance of this criterion is illustrated in Fig. 2. To give an upper limit for the production cross section times the decay branching ratio, B_r, we assumed an isotropic angular distribution $d\sigma(t)/dt = A_0$ and with use of a Monte Carlo routine we calculated the value of A_0B_r that produced the number of observed events. For the decay angular distribution in the c.m. system we assumed $1+\cos^2\theta$ for the cc mode and an isotropic one for the nn and nc modes. The calculated limits are shown in Fig. 3 for on-axis (solid lines) and off-axis (dashed lines) data. In this calculation the $t - t_{\rm min}$ acceptance of the detector and the incident photon energy spectrum were taken into account. Assuming $d\sigma/dt = Ae^{bt}$ we also calculated the upper limit on AB_r for $b = 1$, 3, and 5 GeV^2. The results for the nn data are shown in Table II. Approximate limits for various functional forms of $d\sigma/dt$ may be calculated from

$$\int_{t_{\rm min}}^{t_{\rm max}} (d\sigma/dt)dt = A_0(t_{\rm max} - t_{\rm min}), \quad (2)$$

where $(t_{\rm max} - t_{\rm min})$ is the $t - t_{\rm min}$ acceptance given in Table II, $t_{\rm min}$ may be calculated from the typi-

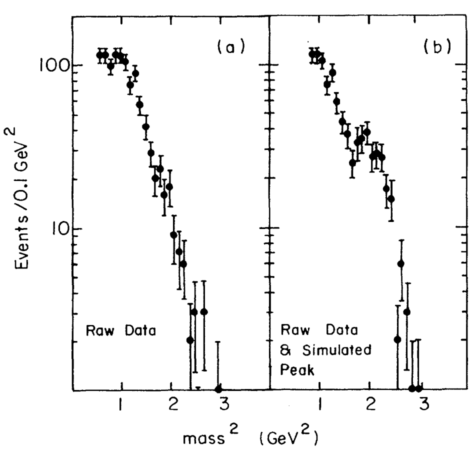

FIG. 2. In (a) the measured e^+e^- mass-squared spectrum for data set 4 is shown. In (b) a 4-standard-deviation bump is generated by adding to the measured spectrum 160 events from the decay of a resonance of $m_0{}^2 = 2.15$ GeV^2 with $\Delta m_0{}^2 = 0.29$ GeV^2.

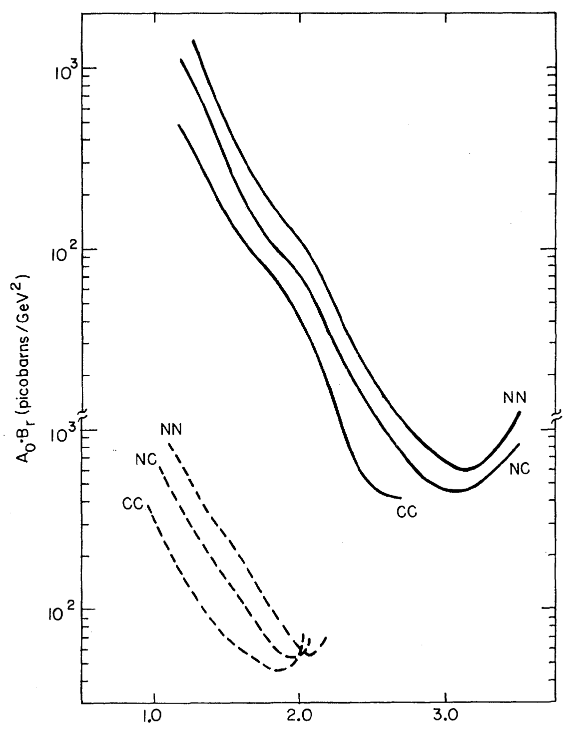

FIG. 3. The upper limits on A_0B_r per nucleon (B_r is the branching ratio, $A_0 = d\sigma/dt$ for an isotropic angular distribution). Dashed lines correspond to off-axis and solid lines to on-axis data. See text and Table II to convert these limits to other assumed cross sections.

TABLE II. Incident photon energy and $(t-t_{min})$ range contributing at various masses.

Mass (GeV)	Photon energy range (GeV)	$(t-t_{min})^a$ acceptance (GeV^2)	Upper limit on nn events AB_r (pb/GeV^2) $b=0$	1	3	5
On-axis data						
1.6	4.8–5.7	0.4	455	645	1152	1852
2.0	5.4–6.8	0.4	119	190	417	809
2.2	7.0–9.8	1.1	74	197	521	1235
2.4	7.7–11.8	1.6	28	75	257	600
2.8	7.7–11.8	1.4	10	30	128	376
3.2	8.7–11.8	1.0	6.7	24	153	682
Off-axis data						
1.1	8.7–11.5	0.8	833	1494	3822	7229
1.5	8.7–11.5	1.4	251	699	2975	5192
2.0	8.7–11.5	1.7	64	281	1257	4795

[a] Value at which the $(t-t_{min})$ acceptance falls to half of its maximum.

cal photon energy, and A_0B_r can be read off Fig. 3. For example, $d\sigma/dt=Ae^{bt}$ may be integrated to obtain the limit on AB_r

$$AB_r \simeq \frac{b(t_{max}-t_{min})A_0B_r}{\exp(bt_{min})\{1-\exp[b(t_{max}-t_{min})]\}}. \qquad (3)$$

Comparison of the Monte-Carlo results with numbers calculated from Eq. (3) showed that the formula tends to underestimate AB_r by 20 to 30%.

A singlet-s bound state of charmed quark and antiquark, having a mass $m \leq 3.1$ GeV, has been postulated in the charm theories of the ψ and ψ' resonances. This state, η_c, if it exists, should decay into photon pairs with a branching ratio[3] of about 10^{-3}. Assuming the photoproduction cross section of the η_c is similar to that of the $\eta^0(0.55)$, one expects the falloff in momentum transfer to be described by $b \simeq 3$ GeV^2. Using Table II and the estimated ratio $B_r = 10^{-3}$, we find the limit on the cross section to be $d\sigma/dt < 130e^{3t}$ nb/GeV^2. This limit is comparable with the $\eta^0(0.55)$ photoproduction cross section[4] $d\sigma/dt \simeq 150e^{3t}$ nb/GeV^2 at 11-GeV incident photon energy but much higher than the $\psi(3.1)$ cross section $d\sigma/dt \simeq 1.0e^{1.3t}$ nb/GeV^2 found in our ψ photoproduction measurement.[2]

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†Present address: Deutsches Elektronen-Synchrotron, 2 Hamburg 52, West Germany. On sabbatical leave from Cornell University, Ithaca, N. Y. 14853.

‡Permanent address: Meson Physics Division, Los Alamos Scientific Laboratory, Los Alamos, N. Mex. 87545.

§Permanent address: University of Utah, Salt Lake City, Utah 84112.

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