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MUON PAIR PHOTOPRODUCTION AT 20.5 GeV

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ABSTRACT

We have studied the production of muon pairs with invariant masses from 1 to 4 GeV by 20.5 GeV bremsstrahlung radiation. The invariant mass distribution has a large deviation from the expected Bethe-Heitler shape which we attribute to the ψ(3.1 GeV). We determine the ψ(3.1 GeV) photoproduction cross section to be $3.7^{+2.2}_{-1.5}$ nb at an average photon energy of 18 GeV.

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We have studied the photoproduction of high invariant mass muon pairs by a 20.5 GeV bremsstrahlung beam striking a Be target. The experiment was designed to search for deviations from Bethe-Heitler behavior, and to measure the cross section for photoproducing the $\psi(3.1\text{ GeV})$.(1,2) The method is similar to that in a less sensitive search previously reported.(3)

The experimental apparatus is shown schematically in Fig. 1. A 20.5 GeV electron beam from the Stanford Linear Accelerator Center (SLAC) strikes an 18.5 gm/cm^2 Be target. The incident beam contains 1.5×10^5 electrons in each 1.3μ sec SLAC pulse. Muon pairs are produced in the target through two successive steps. First the incident electron radiates, then the radiation photoproduces the muon pair. The intermediate radiation is primarily real bremsstrahlung, with only a 10% contribution from the virtual photons associated with electroproduction.

The spectrometer, consisting of a magnet and a multi-wire proportional chamber (MWPC) array, has been described earlier.(3) A superconducting beam pipe provides forward-produced radiation from the target with a field-free path through the magnet. To enter the MWPC array a particle from the target must typically pass through first, 50 gm/cm^2 of Cu in the superconducting beam pipe wall; second, a 280 gm/cm^2 concrete absorber; and third, 11 kG-meters of transverse magnetic field.

The trigger which initiates readout of the MWPC array comes from two scintillation hodoscopes. The first is immediately behind the final MWPC. The second is further downstream, behind a 787 gm/cm^2 Fe absorber. We require in coincidence a signal from each side of the front hodoscope and a signal from each side of the rear hodoscope.

Muons were defined to be straight tracks in the MWPC array which pointed back to the target, had measured momenta greater than 2 GeV/c, and passed through hodoscope elements which were latched for the event. A sample of 605 events having 2 muons whose arrival times at the rear scintillation hodoscope differed by less than 4 nsec were retained for further consideration. Of these events 110 contained same-signed (++ or --) muon pairs, and 495 contained opposite-signed (+-) muon pairs. In the 5% of these events which had more than 2 muons, opposite-signed pairs and higher-momentum muons were preferentially chosen.

Kinematics were calculated for each event assuming the reaction

$$\gamma N \rightarrow \mu \mu N \tag{1}$$

where N is either a proton or a neutron initially at rest. We computed M, the invariant mass of the muon pair, E, the incident photon energy, and $t' = t - t_{MIN}$. Here t is the momentum transfer squared to the nucleon N, and t_{MIN} is the t whose absolute value is the smallest kinematically allowed at the computed value of E. The r.m.s. resolution in M was computed to change linearly with M from 0.05 GeV at $M = 1$ GeV to 0.13 GeV at $M = 4$ GeV. Events with $t' < -2.0\ (\mathrm{GeV}/c)^2$ and $M < 1.0$ GeV were excluded to restrict the analysis to a region of relatively uniform acceptance. The acceptance was 0 for $M > 4$ GeV.

The primary background in the data comes from accidental coincidences between unassociated muon-like tracks. The size of this background was estimated by studying the ++ and -- events, which appeared to be entirely of this accidental nature. Unlike the +- events, these events did not have a sharp coincident peak in the digitized time-of-flight difference between left and right muons, and did not have the sharp peak in t' at $t' = 0$ which for the +- events was characteristic of the Bethe-Heitler mechanism.

The M distribution of the muon pair events is shown in Fig. 2. Here only the +- events are included, and the estimated (20%) contribution from accidentals has been subtracted.

The M distribution expected from the Bethe-Heitler photoproduction of muon pairs is also shown in Fig. 2. This curve comes from a Monte Carlo integration of the cross sections[4] and acceptances for the three dominant Bethe-Heitler mechanisms - elastic scattering from Be, quasi elastic scattering from nucleons, and pion production. The curve shown is normalized absolutely using independent information about the beam flux, counter and MWPC efficiencies, etc. The estimated overall systematic uncertainty in this normalization is $\pm$ 15%. For $M < 2.7$ GeV we find no major deviation from the expected Bethe-Heitler behavior, although we are continuing to investigate the small possible excess of events between 1.7 and 2.3 GeV.

In the M range above 2.7 GeV we find 5 events. We expect fewer than 1 from the Bethe-Heitler process or from the accidental background. The kinematic parameters of these 5 events are listed in Table I. These events have an average mass of 3.09 GeV, with an r.m.s. deviation of 0.15 GeV. We associate these events with ψ(3.1 GeV) photoproduction

$$\gamma N \rightarrow \psi N \ , \tag{2a}$$

followed by the decay

$$\psi \rightarrow \mu^+ \mu^- . \tag{2b}$$

If the t' dependence of the cross section for (2a) is simply $e^{bt'}$ then the last 4 events in Table I suggest that $b \approx 4(\text{GeV/c})^{-2}$, and the first event is a highly unlikely event.

We calculate from these 5 events that the cross section for (2a) is

$$\sigma_{\gamma N \rightarrow \psi N} = 3.7 {}^{+2.2}_{-1.5} \text{ nb.}$$

at an everage photon energy of 18 GeV. We assume in this calculation

(1) that the contribution to our 5 events from coherent ψ photoproduction off the Be nucleus is negligible,

(2) that the cross section for (2a) is constant over the range $13.5 < E < 20.5$ GeV,

(3) that the cross section varies with t' as $e^{bt'}$ where $b > 3(\mathrm{GeV}/c)^{-2}$,

(4) that the ψ decays to a muon pair 7% of the time[1], and

(5) that the ψ decay angular distribution is $1 + \cos^2\theta$ where θ is the angle between the lab direction and the positive muon direction in the ψ c.m. frame.

Using the vector meson dominance model one can relate the differential cross section at t = 0 reaction (2a) to the total ψN cross section. Using the procedure outlined earlier[3] we have done this assuming $b = 4\ (\mathrm{GeV}/c)^{-2}$ and computed

$$\sigma_{\psi N(TOT)} = 1.0 \pm 0.3 \text{ mb}$$

at an average γ energy of 18 GeV. This is considerably smaller than the equivalent cross sections determined for the other vector mesons.[3]

We note that experimenters at FNAL[5] have measured a similar value for $\sigma_{\psi N}$ at a considerably larger value of E_γ($\sim$1 mb at $\sim$ 120 GeV/c). Experimenters at Cornell[6] operating close to threshold for reaction 2a have shown that the ψ photoproduction cross section there is less than 1.3 nb, and extracted an upper limit of 1.2 mb for $\sigma_{\psi N}$.

In addition to measuring the ψ photoproduction cross section we can set limits on the photoproduction cross sections for other (unknown) vector meson states with masses in the range $1 < M_V < 2.7$ GeV.[7] The 90% confidence level upper limit on the product of the photoproduction cross section and the branching ratio for any such narrow state is 0.16 nb. Assumptions here are identical to those made in computing the ψ(3.1 GeV) photoproduction cross section. In addition, we see no evidence for ψ(3.7 GeV) photoproduction, and determine this cross section to be less than 72 nb with 90% confidence. We assume the branching ratio for ψ(3.7 GeV) to muons to be 0.5×10^{-2}. [1]

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TABLE I

$\psi(3.1)$ EVENTS

No.	M	t'	E
1	3.05	-1.45	18.1
2	2.97	-0.34	13.9
3	3.35	-0.08	18.9
4	3.04	-0.54	19.2
5	3.06	-0.20	16.4

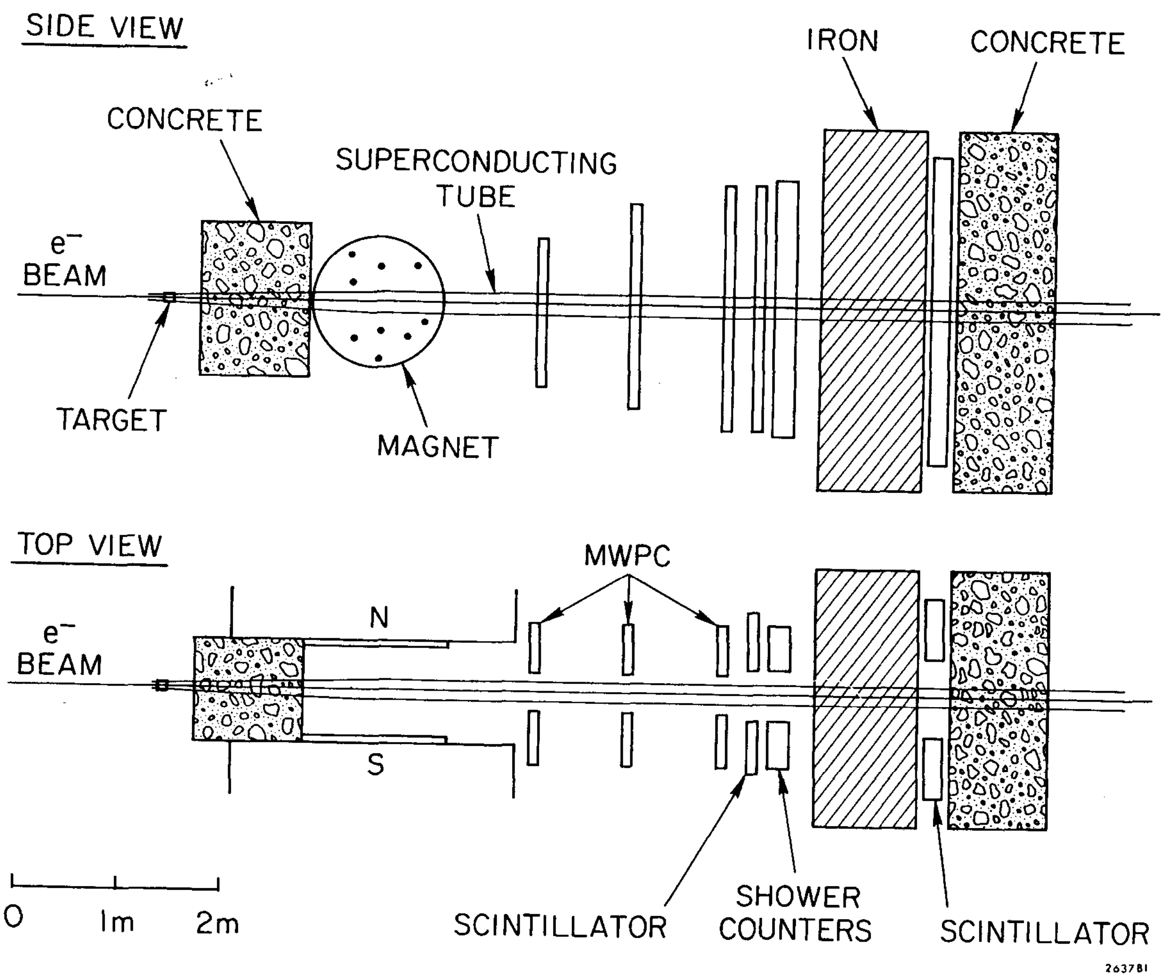

Fig. 1

Schematic drawing of the apparatus.

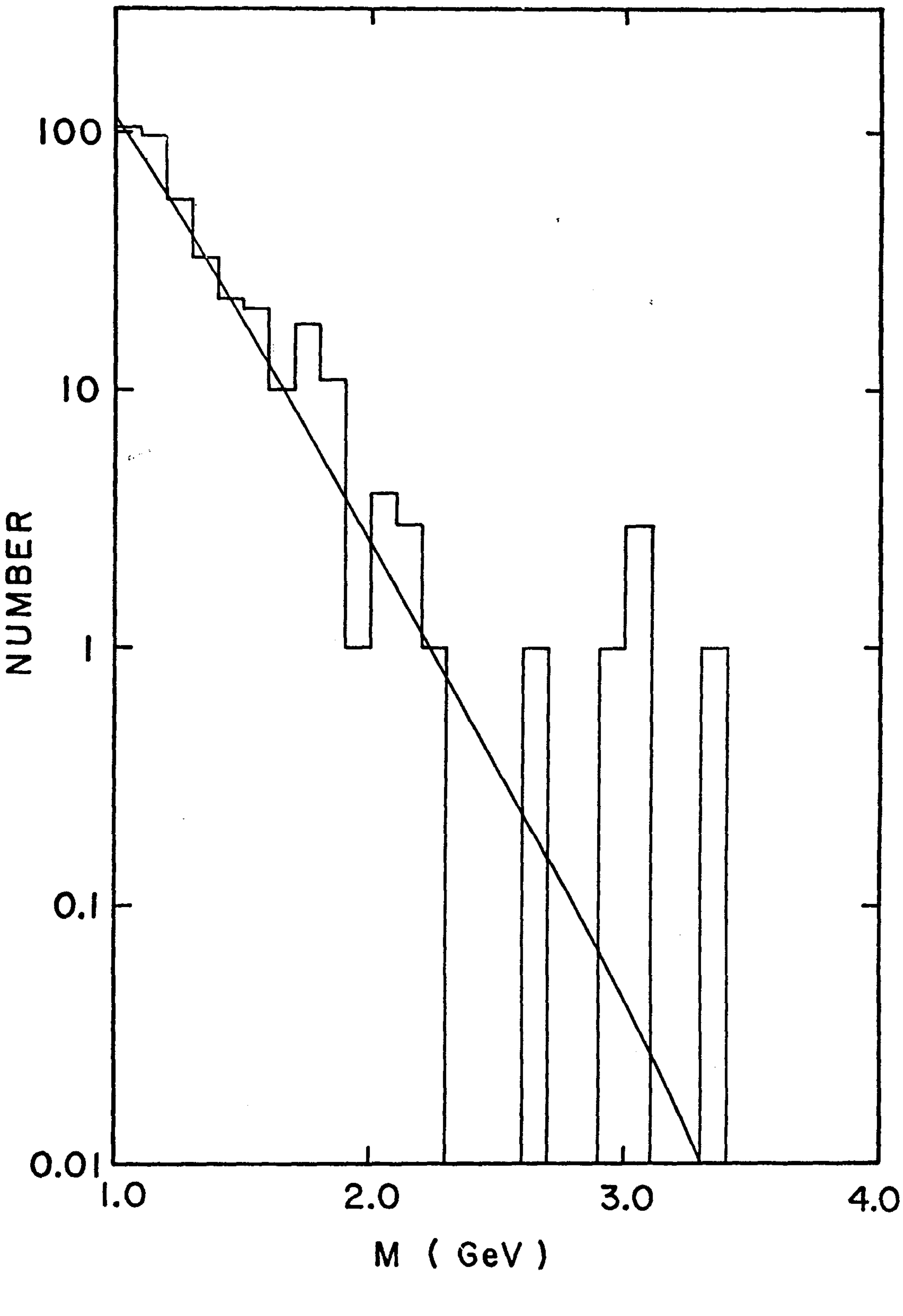

Fig. 2

Histogram of the invariant masses of detected muon pairs. The curve shows the expected yield from the Bethe-Heitler mechanism.