Experimental Observation of a Heavy Particle J†

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We report the observation of a heavy particle J, with mass $m = 3.1$ GeV and width approximately zero. The observation was made from the reaction $p + \mathrm{Be} \rightarrow e^+ + e^- + x$ by measuring the $e^+ e^-$ mass spectrum with a precise pair spectrometer at the Brookhaven National Laboratory's 30-GeV alternating-gradient synchrotron.

This experiment is part of a large program to study the behavior of timelike photons in $p + p \rightarrow e^+ + e^- + x$ reactions[1] and to search for new particles which decay into $e^+ e^-$ and $\mu^+ \mu^-$ pairs.

We use a slow extracted beam from the Brookhaven National Laboratory's alternating-gradient synchrotron. The beam intensity varies from 10^{10} to 2×10^{12} p/pulse. The beam is guided onto an extended target, normally nine pieces of 70-mil Be, to enable us to reject the pair accidentals by requiring the two tracks to come from the same origin. The beam intensity is monitored with a secondary emission counter, calibrated

daily with a thin Al foil. The beam spot size is 3×6 mm^2, and is monitored with closed-circuit television. Figure 1(a) shows the simplified side view of one arm of the spectrometer. The two arms are placed at 14.6° with respect to the incident beam; bending (by $M1$, $M2$) is done vertically to decouple the angle (θ) and the momentum (p) of the particle.

The Cherenkov counter C_0 is filled with one atmosphere and C_e with 0.8 atmosphere of H_2. The counters C_0 and C_e are decoupled by magnets $M1$ and $M2$. This enables us to reject knock-on electrons from C_0. Extensive and repeated calibra-
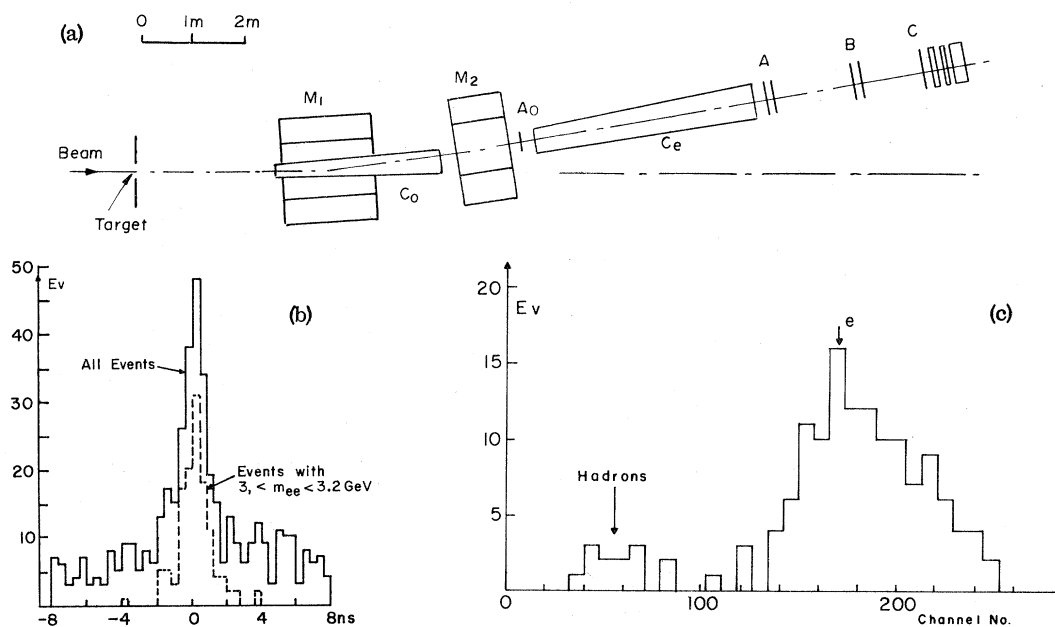

FIG. 1. (a) Simplified side view of one of the spectrometer arms. (b) Time-of-flight spectrum of $e^+ e^-$ pairs and of those events with $3.0 < m < 3.2$ GeV. (c) Pulse-height spectrum of e^- (same for e^+) of the $e^+ e^-$ pair.

tion of all the counters is done with approximate-
ly 6-GeV electrons produced with a lead convert-
er target. There are eleven planes $(2 \times A_0, \ 3 \times A,$
$3 \times B, \ 3 \times C)$ of proportional chambers rotated ap-
proximately 20° with respect to each other to re-
duce multitrack confusion. To further reduce the
problem of operating the chambers at high rate,
eight vertical and eight horizontal hodoscope
counters are placed behind chambers A and B.
Behind the largest chamber C (1 m × 1 m) there
are two banks of 25 lead glass counters of 3 ra-
diation lengths each, followed by one bank of
lead-Lucite counters to further reject hadrons
from electrons and to improve track identifica-
tion. During the experiment all the counters are
monitored with a PDP 11-45 computer and all
high voltages are checked every 30 min.

The magnets were measured with a three-di-
mensional Hall probe. A total of 10^5 points were
mapped at various current settings. The accep-
tance of the spectrometer is $\Delta\theta = \pm 1°$, $\Delta\varphi = \pm 2°$,
$\Delta m = 2$ GeV. Thus the spectrometer enables us
to map the e^+e^- mass region from 1 to 5 GeV in
three overlapping settings.

Figure 1(b) shows the time-of-flight spectrum
between the e^+ and e^- arms in the mass region
$2.5 < m < 3.5$ GeV. A clear peak of 1.5-nsec width
is observed. This enables us to reject the acci-
dentals easily. Track reconstruction between the
two arms was made and again we have a clear-
cut distinction between real pairs and accidentals.
Figure 1(c) shows the shower and lead-glass
pulse height spectrum for the events in the mass
region $3.0 < m < 3.2$ GeV. They are again in agree-
ment with the calibration made by the e beam.

Typical data are shown in Fig. 2. There is a
clear sharp enhancement at $m = 3.1$ GeV. Without
folding in the 10^5 mapped magnetic points and
the radiative corrections, we estimate a mass
resolution of 20 MeV. As seen from Fig. 2 the
width of the particle is consistent with zero.

To ensure that the observed peak is indeed a
real particle $(J \rightarrow e^+e^-)$ many experimental checks
were made. We list seven examples:

(1) When we decreased the magnet currents by
10%, the peak remained fixed at 3.1 GeV (see
Fig. 2).

(2) To check second-order effects on the target,
we increased the target thickness by a factor of
2. The yield increased by a factor of 2, not by 4.

(3) To check the pileup in the lead glass and
shower counters, different runs with different
voltage settings on the counters were made. No
effect was observed on the yield of J.
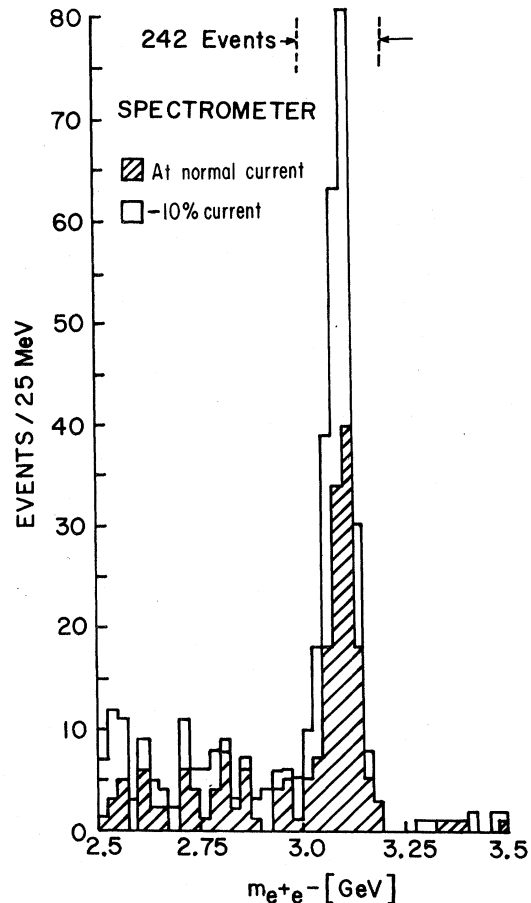

FIG. 2. Mass spectrum showing the existence of J.
Results from two spectrometer settings are plotted
showing that the peak is independent of spectrometer
currents. The run at reduced current was taken two
months later than the normal run.

(4) To ensure that the peak is not due to scatter-
ing from the sides of magnets, cuts were made
in the data to reduce the effective aperture. No
significant reduction in the J yield was found.

(5) To check the read-out system of the cham-
bers and the triggering system of the hodoscopes,
runs were made with a few planes of chambers
deleted and with sections of the hodoscopes omit-
ted from the trigger. No effect was observed on
the J yield.

(6) Runs with different beam intensity were
made and the yield did not change.

(7) To avoid systematic errors, half of the data
were taken at each spectrometer polarity.

These and many other checks convinced us that
we have observed a real massive particle $J \rightarrow ee$.

If we assume a production mechanism for J to
be $d\sigma/dp_\perp \propto \exp(-6p_\perp)$ we obtain a yield of J of ap-

proximately 10^{-34} cm^2.

The most striking feature of J is the possibility that it may be one of the theoretically suggested charmed particles[2] or a's[3] or Z_0's,[4] etc. In order to study the real nature of J,[5] measurements are now underway on the various decay modes, e.g., an $e\pi\nu$ mode would imply that J is weakly interacting in nature.

It is also important to note the absence of an e^+e^- continuum, which contradicts the predictions of parton models.[6]

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[1]The first work on $p + p \rightarrow \mu^+ + \mu^- + x$ was done by L. M. Lederman et al., Phys. Rev. Lett. 25, 1523 (1970).

[2]S. L. Glashow, private communication.

[3]T. D. Lee, Phys. Rev. Lett. 26, 801 (1971).

[4]S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967), and 27, 1688 (1971), and Phys. Rev. D 5, 1412, 1962 (1972).

[5]After completion of this paper, we learned of a similar result from SPEAR. B. Richter and W. Panofsky, private communication; J.-E. Augustin et al., following Letter [Phys. Rev. Lett. 33, 1404 (1974)].

[6]S. D. Drell and T. M. Yan, Phys. Rev. Lett. 25, 316 (1970). An improved version of the theory is not in contradiction with the data.

Discovery of a Narrow Resonance in $e^+ e^-$ Annihilation*

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We have observed a very sharp peak in the cross section for $e^+e^- \rightarrow$ hadrons, e^+e^-, and possibly $\mu^+\mu^-$ at a center-of-mass energy of 3.105 ± 0.003 GeV. The upper limit to the full width at half-maximum is 1.3 MeV.

We have observed a very sharp peak in the cross section for $e^+e^- \rightarrow$ hadrons, e^+e^-, and possibly $\mu^+\mu^-$ in the Stanford Linear Accelerator Center (SLAC)–Lawrence Berkeley Laboratory magnetic detector[1] at the SLAC electron-positron storage ring SPEAR. The resonance has the parameters

$$E = 3.105 \pm 0.003 \text{ GeV},$$

$$\Gamma \leq 1.3 \text{ MeV}$$

(full width at half-maximum), where the uncertainty in the energy of the resonance reflects the uncertainty in the absolute energy calibration of the storage ring. [We suggest naming this structure $\psi(3105)$.] The cross section for hadron production at the peak of the resonance is ≥ 2300 nb, an enhancement of about 100 times the cross section outside the resonance. The large mass, large cross section, and narrow width of this structure are entirely unexpected.

Our attention was first drawn to the possibility of structure in the $e^+e^- \rightarrow$ hadron cross section during a scan of the cross section carried out in 200-MeV steps. A 30% (6 nb) enhancement was