

Experimental Observation of a Heavy Particle J^\dagger

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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 $p + \text{Be} \rightarrow e^+ + e^- + x$ 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 $p + p \rightarrow e^+ + e^- + x$ reactions¹ 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 mm², 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 M_1 , M_2) 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 M_1 and M_2 . This enables us to reject knock-on electrons from C_0 . Extensive and repeated calibra-

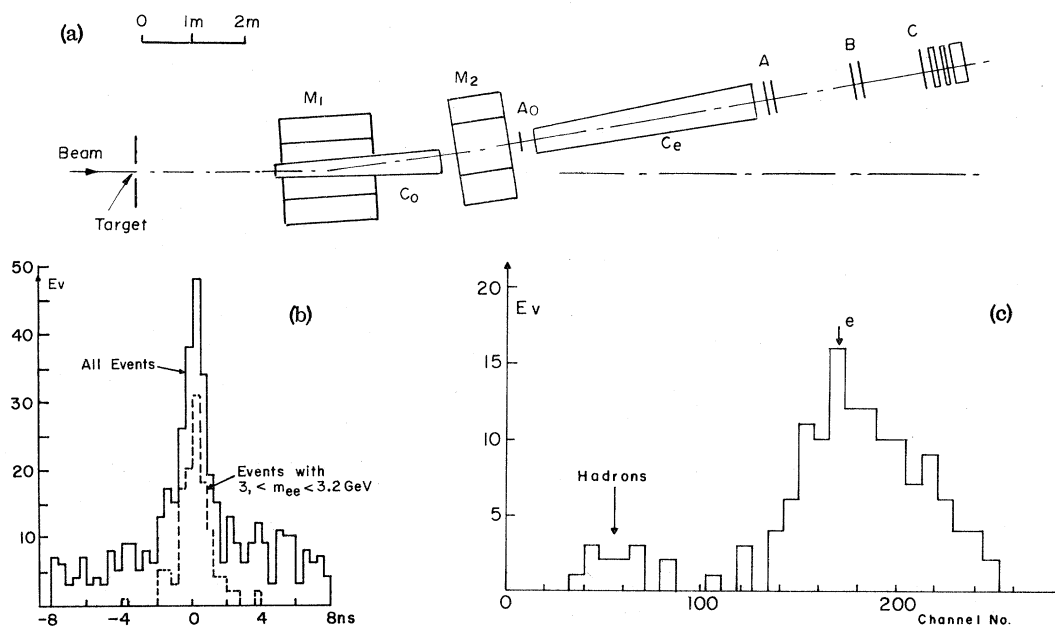


FIG. 1. (a) Simplified side view of one of the spectrometer arms. (b) Time-of-flight spectrum of e^+e^- pairs and of those events with $3.0 < m < 3.2$ GeV. (c) Pulse-height spectrum of e^- (same for e^+) of the e^+e^- pair.

tion of all the counters is done with approximately 6-GeV electrons produced with a lead converter target. There are eleven planes ($2 \times A_0$, $3 \times A$, $3 \times B$, $3 \times C$) of proportional chambers rotated approximately 20° with respect to each other to reduce 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* ($1 \text{ m} \times 1 \text{ m}$) there are two banks of 25 lead glass counters of 3 radiation lengths each, followed by one bank of lead-Lucite counters to further reject hadrons from electrons and to improve track identification. 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-dimensional Hall probe. A total of 10^5 points were mapped at various current settings. The acceptance of the spectrometer is $\Delta\theta = \pm 1^\circ$, $\Delta\varphi = \pm 2^\circ$, $\Delta m = 2 \text{ GeV}$. 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 $2.5 < m < 3.5 \text{ GeV}$. A clear peak of 1.5-nsec width is observed. This enables us to reject the accidentals 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 $3.0 < m < 3.2 \text{ GeV}$. They are again in agreement with the calibration made by the e beam.

Typical data are shown in Fig. 2. There is a clear sharp enhancement at $m = 3.1 \text{ GeV}$. 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 .

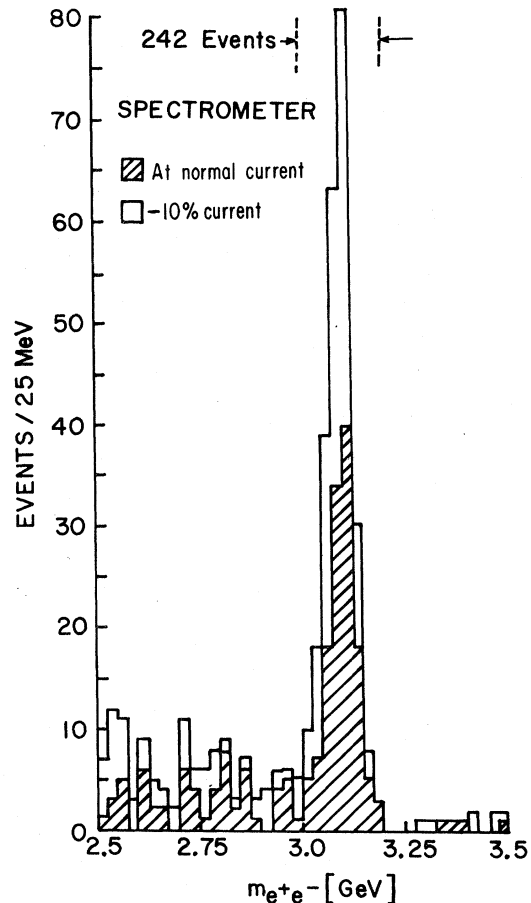


FIG. 2. Mass spectrum showing the existence of J . Results from two spectrometer settings are plotted showing that the peak is independent of spectrometer currents. The run at reduced current was taken two months later than the normal run.

(4) To ensure that the peak is not due to scattering 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 chambers and the triggering system of the hodoscopes, runs were made with a few planes of chambers deleted and with sections of the hodoscopes omitted 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 $d\sigma/dp_\perp \propto \exp(-\delta p_\perp)$ we obtain a yield of J of ap-

proximately 10^{-34} cm².

The most striking feature of J is the possibility that it may be one of the theoretically suggested charmed particles² or a 's³ 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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¹The first work on $p + p \rightarrow \mu^+ + \mu^- + x$ was done by L. M. Lederman *et al.*, Phys. Rev. Lett. **25**, 1523 (1970).

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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 detector¹ 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