

## 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  $p + p \rightarrow e^+ + e^- + x$  reactions<sup>1</sup> 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  $2 \times 10^{12}$   $p$ /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  $3 \times 6$  mm<sup>2</sup>, 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  $14.6^\circ$  with respect to the incident beam; bending (by  $M_1$ ,  $M_2$ ) is done vertically to decouple the angle ( $\theta$ ) 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  $\text{H}_2$ . 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-

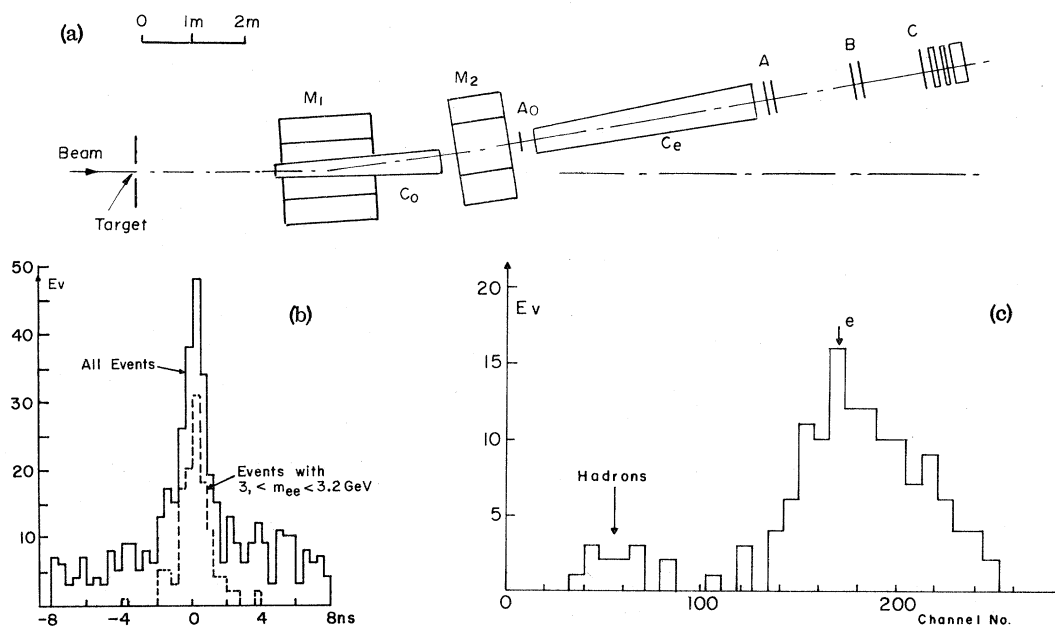


FIG. 1. (a) Simplified side view of one of the spectrometer arms. (b) Time-of-flight spectrum of  $e^+e^-$  pairs and of those events with  $3.0 < m < 3.2$  GeV. (c) Pulse-height spectrum of  $e^-$  (same for  $e^+$ ) of the  $e^+e^-$  pair.

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  $20^\circ$  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  $\Delta\theta = \pm 1^\circ$ ,  $\Delta\phi = \pm 2^\circ$ ,  $\Delta m = 2 \text{ GeV}$ . 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  $J$ .

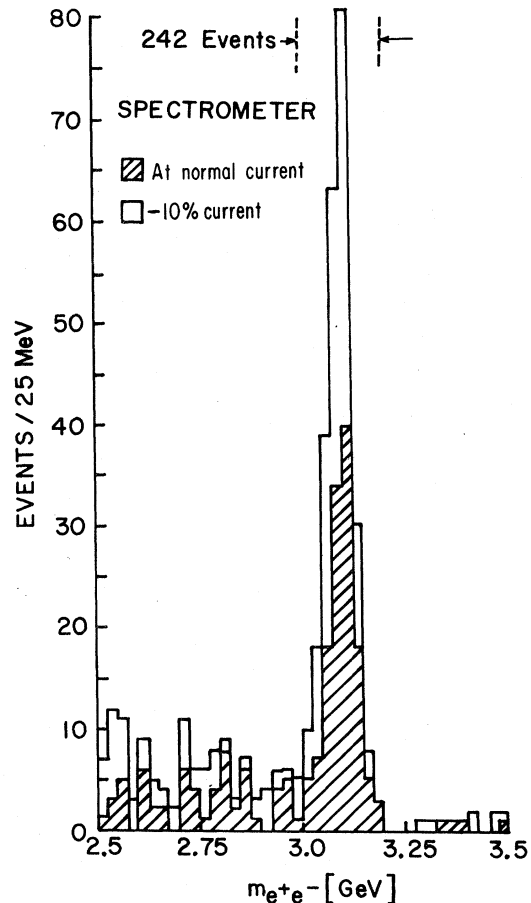


FIG. 2. Mass spectrum showing the existence of  $J$ . Results from two spectrometer settings are plotted showing that the peak is independent of spectrometer currents. The run at reduced current was taken two months later than the normal run.

(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  $10^{-34}$  cm<sup>2</sup>.

The most striking feature of  $J$  is the possibility that it may be one of the theoretically suggested charmed particles<sup>2</sup> or  $a$ 's<sup>3</sup> or  $Z_0$ 's,<sup>4</sup> etc. In order to study the real nature of  $J$ ,<sup>5</sup> 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.<sup>6</sup>

We wish to thank Dr. R. R. Rau and the alternating-gradient synchrotron staff who have done an outstanding job in setting up and maintaining this experiment. We thank especially Dr. F. Epling, B. M. Bailey, and the staff of the Laboratory for Nuclear Science for their help and encouragement. We thank also Ms. I. Schulz, Ms. H. Feind, N. Feind, D. Osborne, G. Krey, J. Donahue, and

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

<sup>2</sup>S. L. Glashow, private communication.

<sup>3</sup>T. D. Lee, Phys. Rev. Lett. **26**, 801 (1971).

<sup>4</sup>S. Weinberg, Phys. Rev. Lett. **19**, 1264 (1967), and **27**, 1688 (1971), and Phys. Rev. D **5**, 1412, 1962 (1972).

<sup>5</sup>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)].

<sup>6</sup>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  $3.105 \pm 0.003$  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<sup>1</sup> 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  $\geq 2300$  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

observed at a c.m. energy of 3.2 GeV. Subsequently, we repeated the measurement at 3.2 GeV and also made measurements at 3.1 and 3.3 GeV. The 3.2-GeV results reproduced, the 3.3-GeV measurement showed no enhancement, but the 3.1-GeV measurements were internally inconsistent—six out of eight runs giving a low cross section and two runs giving a factor of 3 to 5 higher cross section. This pattern could have been caused by a very narrow resonance at an energy slightly larger than the nominal 3.1-GeV setting of the storage ring, the inconsistent 3.1-GeV cross sections then being caused by setting errors in the ring energy. The 3.2-GeV enhancement would arise from radiative corrections which give a high-energy tail to the structure.

We have now repeated the measurements using much finer energy steps and using a nuclear magnetic resonance magnetometer to monitor the ring energy. The magnetometer, coupled with measurements of the circulating beam position in the storage ring made at sixteen points around the orbit, allowed the relative energy to be determined to 1 part in  $10^4$ . The determination of the absolute energy setting of the ring requires the knowledge of  $\int B dl$  around the orbit and is accurate to  $\pm 0.1\%$ .

The data are shown in Fig. 1. All cross sections are normalized to Bhabha scattering at 20 mrad. The cross section for the production of hadrons is shown in Fig. 1(a). Hadronic events are required to have in the final state either  $\geq 3$  detected charged particles or 2 charged particles noncoplanar by  $> 20^\circ$ .<sup>2</sup> The observed cross section rises sharply from a level of about 25 nb to a value of  $2300 \pm 200$  nb at the peak<sup>3</sup> and then exhibits the long high-energy tail characteristic of radiative corrections in  $e^+e^-$  reactions. The detection efficiency for hadronic events is 45% over the region shown. The error quoted above includes both the statistical error and a 7% contribution from uncertainty in the detection efficiency.

Our mass resolution is determined by the energy spread in the colliding beams which arises from quantum fluctuations in the synchrotron radiation emitted by the beams. The expected Gaussian c.m. energy distribution ( $\sigma = 0.56$  MeV), folded with the radiative processes,<sup>4</sup> is shown as the dashed curve in Fig. 1(a). The width of the resonance must be smaller than this spread; thus an upper limit to the full width at half-maximum is 1.3 MeV.

Figure 1(b) shows the cross section for  $e^+e^-$  final states. Outside the peak this cross section

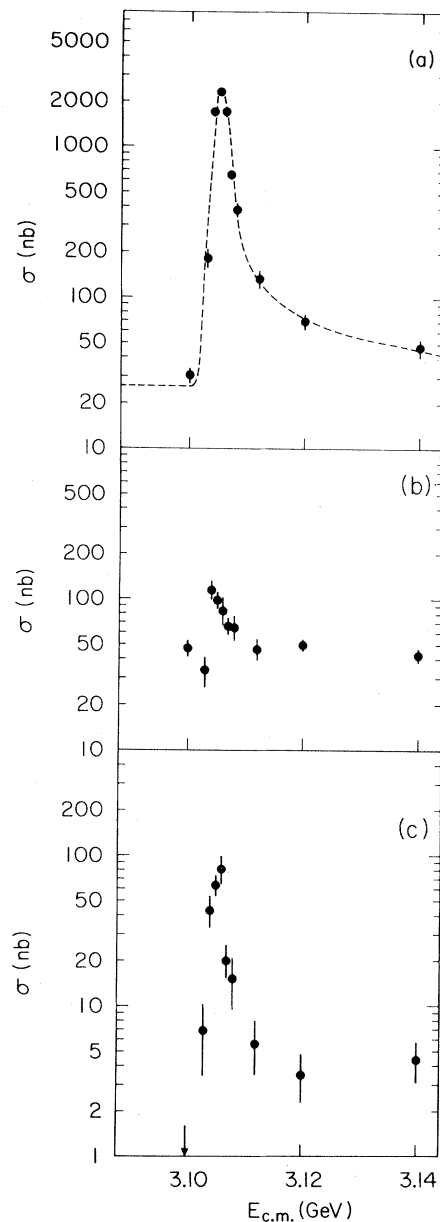


FIG. 1. Cross section versus energy for (a) multi-hadron final states, (b)  $e^+e^-$  final states, and (c)  $\mu^+\mu^-$ ,  $\pi^+\pi^-$ , and  $K^+K^-$  final states. The curve in (a) is the expected shape of a  $\delta$ -function resonance folded with the Gaussian energy spread of the beams and including radiative processes. The cross sections shown in (b) and (c) are integrated over the detector acceptance. The total hadron cross section, (a), has been corrected for detection efficiency.

is equal to the Bhabha cross section integrated over the acceptance of the apparatus.<sup>1</sup>

Figure 1(c) shows the cross section for the production of collinear pairs of particles, excluding electrons. At present, our muon identi-

fications system is not functioning and we therefore cannot separate muons from strongly interacting particles. However, outside the peak the data are consistent with our previously measured  $\mu$ -pair cross section. Since a large  $\pi\pi$  or  $KK$  branching ratio would be unexpected for a resonance this massive, the two-body enhancement observed is *probably* but not *conclusively* in the  $\mu$ -pair channel.

The  $e^+e^- \rightarrow$  hadron cross section is presumed to go through the one-photon intermediate state with angular momentum, parity, and charge conjugation quantum numbers  $J^{PC} = 1^{--}$ . It is difficult to understand how, without involving new quantum numbers or selection rules, a resonance in this state which decays to hadrons could be so narrow.

We wish to thank the SPEAR operations staff for providing the stable conditions of machine performance necessary for this experiment. Special monitoring and control techniques were developed on very short notice and performed ex-

cellently.

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<sup>1</sup>The apparatus is described by J.-E. Augustin *et al.*, to be published.

<sup>2</sup>The detection-efficiency determination will be described in a future publication.

<sup>3</sup>While preparing this manuscript we were informed that the Massachusetts Institute of Technology group studying the reaction  $pp \rightarrow e^+e^- + x$  at Brookhaven National Laboratory has observed an enhancement in the  $e^+e^-$  mass distribution at about 3100 MeV. J. J. Aubert *et al.*, preceding Letter [Phys. Rev. Lett. **33**, 1402 (1974)].

<sup>4</sup>G. Bonneau and F. Martin, Nucl. Phys. **B27**, 381 (1971).

### Preliminary Result of Frascati (ADONE) on the Nature of a New 3.1-GeV Particle Produced in $e^+e^-$ Annihilation\*

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We report on the results at ADONE to study the properties of the newly found 3.1-BeV particle.

Soon after the news that a particle of 3.1 GeV with a width consistent with zero had been observed at Brookhaven National Laboratory by the Massachusetts Institute of Technology group,<sup>1</sup> it was immediately decided to push ADONE beyond its nominal limit of energy ( $2 \times 1.5$  GeV) to look

for this particle. On the following day the information had reached us that this particle had also been observed at SPEAR at the energy of exactly 3.10 GeV with a narrow width,  $< 1.3$  MeV.<sup>2</sup>

Three experiments<sup>3</sup> [the Gamma-Gamma Group, the Magnet Experimental Group for ADONE