DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 86-005
January 1986

LEPTON PAIR PRODUCTION IN DOUBLE TAGGED TWO-PHOTON INTERACTIONS

by

JADE Collaboration

ISSN 0418-9833

NOTKESTRASSE 85 · 2 HAMBURG 52

DESY 86-005
January 1986
ISSN 0418-9833

Lepton Pair Production In Double Tagged Two-Photon Interactions

JADE Collaboration

W. Bartel, L. Becker, D. Cords[1], R. Felst, D. Haidt, G. Knies, H. Krehbiel, P. Laurikainen[2], N. Magnussen[3], R. Meinke, B. Naroska, J. Olsson, D. Schmidt[3], P. Steffen
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

G. Dietrich, J. Hagemann, G. Heinzelmann, H. Kado, K. Kawagoe[4], C. Kleinwort, M. Kuhlen, A. Petersen[1], R. Ramcke U. Schneekloth, G. Weber
II. Institut für Experimentalphysik der Universität Hamburg, Germany

K. Ambrus, S. Bethke, A. Dieckmann, E. Elsen, J. Heintze, K.H.Hellenbrand, S. Komamiya, J. von Krogh, P. Lennert, H. Matsumura, H. Rieseberg, J. Spitzer, A. Wagner
Physikalisches Institut der Universität Heidelberg, Germany

C. Bowdery, A. Finch, F. Foster, G. Hughes, J. Nye
University of Lancaster, England

J. Allison, A.H. Ball[5], R.J. Barlow, J. Chrin, I.P. Duerdoth, T. Greenshaw, P. Hill, F.K. Loebinger, A.A. Macbeth, H.E. Mills, P.G. Murphy, K. Stephens, P. Warming
University of Manchester, England

R.G. Glasser, J.A.J. Skard, S.R. Wagner[6], G.T. Zorn
University of Maryland, Maryland, USA

S.L. Cartwright, D. Clarke, R. Marshall, R.P. Middleton
Rutherford Appleton Laboratory, Chilton, England

T. Kawamoto, T. Kobayashi, M. Minowa, H. Takeda, T. Takeshita, S. Yamada
ICEPP University of Tokyo, Japan

[1]Now at SLAC, California, USA
[2]University Helsinki, Helsinki, Finland
[3]Universität-Gesamthochschule Wuppertal, Germany
[4]DAAD fellow
[5]Now at University of Marland, USA
[6]Now at University of Colorado, USA

ABSTRACT

Lepton pair production by two-photon processes has been studied using the JADE detector at PETRA. The study probed QED to α^4 in the highest Q^2 region. Both electrons and positrons were tagged by the endcap or barrel shower counters. The observed events consist of two produced leptons as well as two tagged electrons. These events show good agreement with QED to order α^4.

Introduction

Lepton pair production by the two-photon processes,

$$e^+e^- \to e^+e^-\mu^+\mu^- \qquad (1)$$

and

$$e^+e^- \to e^+e^-e^+e^- \qquad (2),$$

is described by higher order QED reactions. Studies of these processes provide tests of QED to α^4 at large momentum transfers (Q^2). These measurements complement the two conventional ways to test QED. One type of test is the measurement of the anomalous magnetic moment (g-2) of electrons and muons, which provide very precise tests of higher order QED at small Q^2. The other type of test is the measurement of QED reactions at very large Q^2, such as Bhabha scattering and muon-pair production from e^+e^- colliding experiments at high energy, which test QED to order α^2 and α^3 at small distances.

The two-photon process $e^+e^- \to e^+e^- l^+l^-$ has a large total cross section at high energy. Because of the bremsstrahlung nature of the process, the small Q^2 region of the reaction dominates the cross section. Therefore most of the reaction products, as well as the scattered electrons and positrons, go into the beam directions. For this reason, almost all experimental analyses reported from e^+e^- experiments investigated the produced leptons under "no tag" or "single tag" conditions [Ref. 1, 2 and 3]. In the "no tag"("single tag") experiments, none(one) of the scattered electrons/positrons is detected by special tagging devices at small angles.

In this paper, we present results from a "double tag" experiment in which both of the scattered beam particles were detected at large angles with respect to the beam axis. The produced lepton pairs were also detected. This exclusive measurement has the advantage of identifying the reactions with small backgrounds. This study probes QED to order α^4 in the highest Q^2 region tested so far.

Event Selection

The data were collected using the JADE detector at the PETRA e^+e^- storage ring. A detailed description of the apparatus can be found elsewhere [Ref. 4]. The total integrated luminosity was 95 pb^{-1}; the centre of mass energy varied from 28.8 to 46.8 GeV, with a weighted average of 36.5 GeV.

We required two high energy showering particles detected at large angle ("tagged electrons"), and two additional charged particles ("lepton candidates"). Each tagged electron was required to satisfy the following criteria:

A) The measured shower energy had to exceed $\sqrt{s}/6$.

B) The polar angle ϑ (with respect to the beam axis) of the electromagnetic shower was required to be either $|\cos\vartheta|<0.76$ or $0.91<|\cos\vartheta|<0.955$. The polar angle cuts correspond to the fiducial regions of the barrel and endcap lead glass arrays respectively. Together with condition A), the Q^2 region is defined to be between -9.2 and -1200 GeV^2 for each tagged electron.

C) At least one acceptable charged track was required to lie within a 5 ° cone around the direction of the electromagnetic shower. The track was required to come from the collision volume which was a cylinder of r = 30 mm, |z| = 300 mm along the beam direction at the interaction point. The sum of the momenta of the tracks associated with the shower was required to be at least 1/10 of the measured electromagnetic shower energy.

In addition, the acollinearity angle between the two tagged electrons had to be larger than 10° to avoid Bhabha events, and smaller than 170° to ensure a clear separation of the electromagnetic showers.

The conditions for the lepton candidate tracks were as follows:

A) Only two charged tracks were allowed (in addition to those associated with the tagged electrons).

B) Each track had to originate from the collision volume and had to have a polar angle > 15°.

C) The higher momentum track was required to have a momentum > 1 GeV/c. The lower momentum track had to have a momentum greater than 0.05 GeV/c.

D) Each track had to be at least 10 ° away from all other tracks. This requirement removed $ee\gamma$ events where a photon converted in the beam pipe or the pressure vessel of the jet chamber. The condition C) together with D) corresponded to a minimum mass of two leptons to be 0.04 GeV/c^2.

A lepton candidate was identified as an electron if it had more than 2 GeV of associated electromagnetic shower energy, and as a muon if it had a momentum > 2 GeV/c in addition to having associated hits in more than three layers of muon chambers. Since the detection efficiency of leptons was estimated to be about 98%, no correction was applied.

The selected sample contains $e^+e^-e^+e^-$, $e^+e^-\mu^+\mu^-$ and a few $e^+e^-h^+h^-$ events, where h represents a hadron. Events in which one lepton candidate was identified as an electron were accepted as $e^+e^-e^+e^-$. Events with one identified muon were classified as $e^+e^-\mu^+\mu^-$. After the above cuts, there remained 9 $e^+e^-\mu^+\mu^-$ and 20 $e^+e^-e^+e^-$ candidates. No event satisfied both lepton identifications $e^+e^- \to e^+e^-e^+\mu^-$ or $e^+e^-e^-\mu^+$ which could come from τ decay. The number of events from τ decay are 2 ± 0.5 events as predicted by a Monte Carlo calculation described below.

Since all the final state particles were detected, a four-constraint kinematical fit was made in order to eliminate backgrounds. Events which contained missing particles such as neutrinos or radiated photons were rejected. There were 8 and 13 events which gave a good fit for reactions (1) and (2), respectively.

Background Estimation

For each process (1) and (2), two kinds of background are expected.

These are

$$e^+e^- \to e^+e^-\tau^+\tau^- \quad (3)$$

and

$$e^+e^- \to e^+e^-h^+h^- \quad (4).$$

For reaction (2), additional background sources are

$$e^+e^- \to \tau^+\tau^- \quad (5)$$

and

$$e^+e^- \to e^+e^-\gamma\gamma \quad (6).$$

Events from reaction (3) might be contained in the sample, if both τ's decay into one charged particle plus neutrinos, one being an electron or a muon. This process was studied by a Monte Carlo (MC) calculation described in the next section. The kinematical fit, however, discriminated well against such events and the background from this source was found to be < 1%.

For reaction (4) we used the measured ratio |Ref.5| of the cross section for hadron pair and muon pair production as an upper limit. We estimate that this process contributes < 0.5% and < 1% to the muon and electron sample respectively, taking into account the probability for a hadron to be misidentified as a lepton (3% for μ and 11% for e under the very generous cuts used in this analysis).

The background from reaction (5) contributes when one τ decays into an electron plus neutrinos and the other τ decays into charged and neutral pions plus a neutrino, where the pions simulate electrons. This background is greatly reduced by the kinematical fit and estimated to be < 1%.

Higher order radiative Bhabha events, reaction (6), can be included if the radiated photons convert in the beam pipe or the pressure vessel of the jet chamber and simulate electrons. No calculation for this process is available. These events were rejected by eye scanning, and the contamination from reaction (6) is expected to be negligible.

Since the contributions from these background processes were found to be small compared to the statistical errors, no background subtraction was made.

Comparison with QED and Discussion

QED calculations were made using two independent programs. One was by Vermaseren (V) |Ref.6| and the other one by Berends, Daverveldt and Kleiss (BDK) |Ref.7|. Both programs calculate absolute cross sections under certain requirements for the final states, and generate events by the MC method. Vermaseren's calculation takes into account the multiperipheral and bremsstrahlung diagrams shown in Fig. 1-a and b. BDK includes not only these diagrams but also the conversion and annihilation diagrams shown in Figs. 1-c and d. All interference effects are taken into account and found to be smaller than 10%. The contributions from the conversion and annihilation diagrams were calculated to be about 13 % and 2 % for reaction (1) and (2) in BDK, respectively, when we required all four final particles to be emitted at $\vartheta > 10°$. Within statistics, both MC calculations were in agreement. Since the BDK program was optimized to produce events under "no tag" or "single tag" conditions, applying this program to "double tag" events was inefficient. For this technical reason, the QED MC events were generated by the V-generator without radiative corrections.

Since invariant mass requirements between the two produced leptons were very small in the event selection, we set the minimum mass allowed to be 0.3 GeV in the MC calculation.

The generated events were first passed through a full detector simulation, which included the effects of electrons showering in the material inside the coil and various inefficiencies. The events were then analysed by the same programs as the real data.

The total number of events expected from MC calculation was 8.6 ± 0.5 and 12.0 ± 0.6 events for reactions (1) and (2), respectively, while we observed 8 and 13 events. In the observed sample, we had 0 and 1 event which contained an additional photon ($E\gamma > 1.0$ GeV) from reaction (1) and (2), respectively. The errors attached to the MC values take into account uncertainties of the luminosity (1.5%) as well as the statistical error (typically 4%). Within the limited statistics, the agreement between the observed events and the QED calculation is excellent.

Various distributions are shown for the final samples and compared with QED calculations. Figures 2 and 3 show the energy and angular distributions of electrons for reactions (1) and (2). In the case of reaction (2), there is no separation between tagged and produced electrons, four entries per event are included, as against two entries per event for reaction (1). Figures 4-a and b show momentum and angular distributions for muons. There is good agreement between QED and the data within statistics. We have also calculated the minimum mass distribution of two leptons. We took the smaller invariant mass of the e^+e^- or $\mu^+\mu^-$ combinations for reaction (1) and the smallest mass of all four possible combinations (e^+e^-) for reaction (2). The invariant mass distribution is shown in Figure 5, and the agreement is good. The bremsstrahlung diagram is the dominant contribution (about 75 % according to the MC). The relative contribution of the multiperipheral diagrams is increased from 25% to 40% for reaction (1), if we restrict the minimum invariant mass to be greater than 1 GeV as done in a similar investigation by the CELLO-Collaboration |Ref.8|. In this case we have 4 events for reaction (1) and 11 events for reaction (2), while the MC calculation predicts 5.8 ± 0.6 and 8.9 ± 0.7 events from reactions (1) and (2), respectively. The distributions of the minimum invariant mass agree well with the QED predictions and don't confirm the indication for an excess of events with large invariant masses observed in Ref. 8.

Conclusion

We have measured four-lepton final states in double tagged two photon processes. QED expectations describe the data well for both the $e^+e^- \rightarrow e^+e^-e^+e^-$ and $e^+e^-\mu^+\mu^-$reactions for the Q^2 range between -9.2 and -1200 GeV^2. The absolute rate and various kinematical distributions show good agreement with QED to order α^4.

We are indebted to the PETRA machine group and the DESY computer center for their excellent service during the experiment. We gratefully acknowledge the effort of all the engineers and technicians who have participated in the construction and maintenance of the apparatus. This experiment was supported by the Bundesministerium für Forschung und Technologie, by the Japanese Ministry of Education, Science and Culture, by the UK Science and Engineering Research Council through the Rutherford Appleton Laboratory and by the Department of Energy U.S.A. The visiting groups wish to thank the DESY directorate for the hospitality extended to them.

References

1) A.Courau, Proc. of the Intern. Workshop on $\gamma\gamma$ Collisions, Amiens, 1980.
M.Pohl, Proc. of the Intern. Workshop on $\gamma\gamma$ Collisions, Aachen, 1983.
2) PLUTO Collab.-Ch.Berger et al., Phys. Lett. 94B(1980)254.
MARK-J Collab.-B.Adeva et al., Phys. Rev. Lett. 48(1982)721.
MAC Collab.-E.Fernandez et al., Phys. Rev. D28(1983)2721.
CELLO Collab.-H.J.Behrend et al., Phys. Lett. 120B(1983)384.
PEP-9 Collab.-M.PCain et al., Phys. Lett. 147B(1984)232
3) C.J.Biddick et al., Phys. Lett. 97B(1980)320
4) JADE Collab.-W.Bartel et al., Phys. Lett. 88B(1979)171;
Phys. Lett. 92B(1980)206 ; Phys. Lett. 99B(1981)277
5) PLUTO Collab.-Ch.Berger et al., Phys. Lett. 137B(1984)267
TASSO Collab.-M.Althoff et al., Z. Phys. C10(1981)117
6) J.A.M. Vermaseren, Proc. of the Intern. Workshop on $\gamma\gamma$ collisions, Amiens, 1980.
7) F.A.Berends, P.H.Daverveldt, R.Kleiss, Nucl. Phys. B253(1985)441
8) CELLO Collab.-H.J.Behrend et al., DESY 1984-103

Figure Captions

Fig. 1 : Feynman diagrams for lepton pair production in two photon interactions:
(a) the multiperipheral term,
(b) the bremsstrahlung term,
(c) the conversion term and
(d) the annihilation term.

Fig. 2 : Energy distribution of electrons for the reaction $e^+e^- \to e^+e^-\mu^+\mu^-$(a) and $e^+e^- \to e^+e^-e^+e^-$(b).
The histogram is the QED prediction described in the text.

Fig. 3 : Polar angle distribution of the electrons for the $e^+e^-\mu^+\mu^-$ (a) and $e^+e^-e^+e^-$ (b) final states and the QED prediction.

Fig. 4 : Momentum distribution of the muons in the $e^+e^-\mu^+\mu^-$ (a) final state and polar angle distribution of the muons in the $e^+e^-\mu^+\mu^-$ (b) final state.

Fig. 5 : The smaller of the e^+e^- or $\mu^+\mu^-$ invariant mass for the reaction $e^+e^- \to e^+e^-\mu^+\mu^-$ (a) and the smallest invariant mass of possible 4 combinations for the reaction $e^+e^- \to e^+e^-e^+e^-$ (b), together with the QED order α^4 calculation.

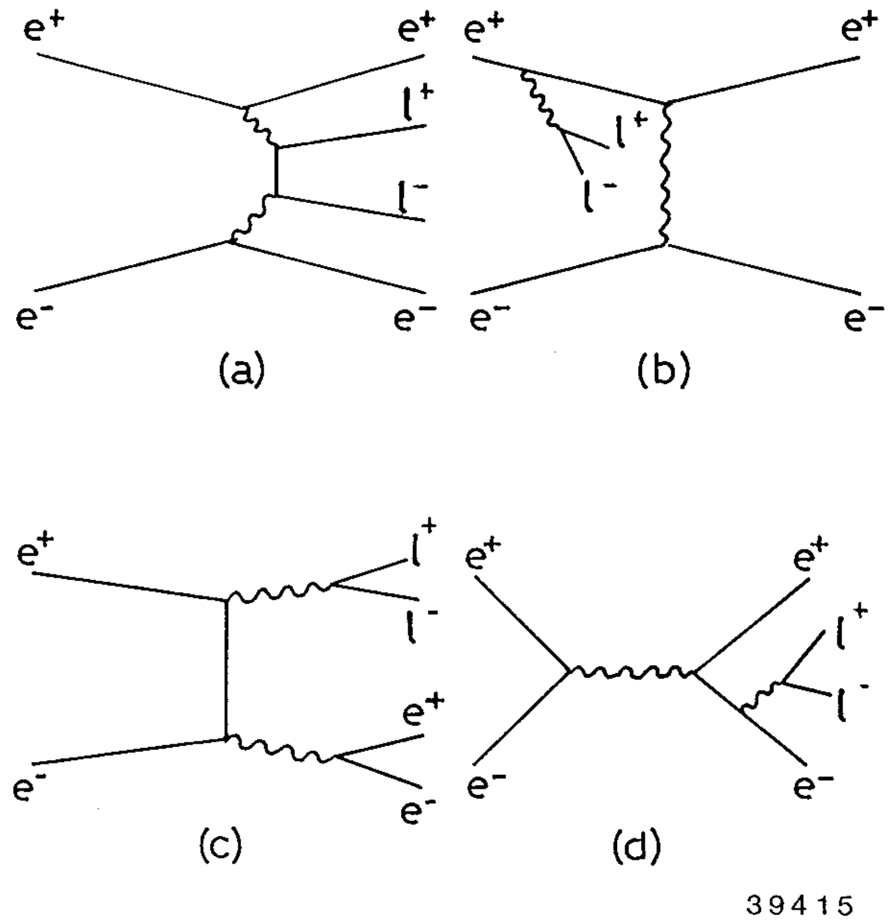

Fig. 1

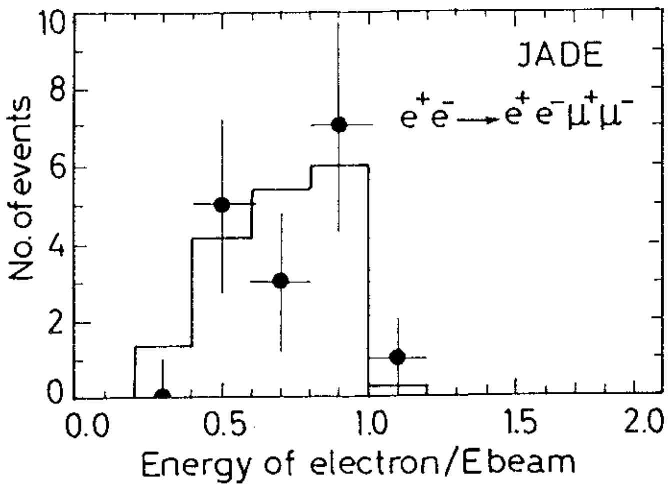

Fig. 2a

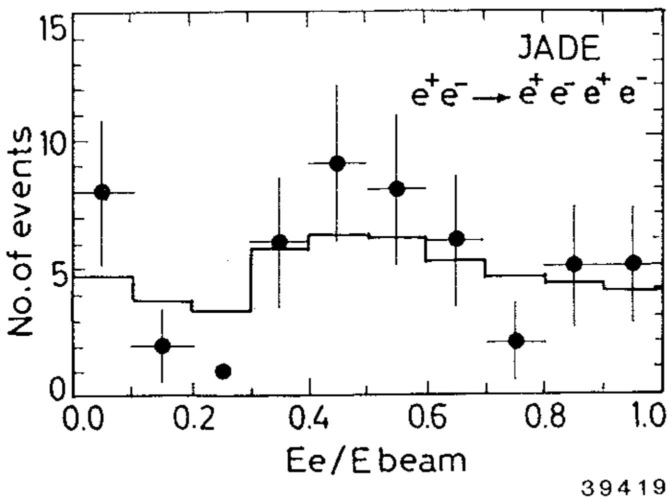

Fig. 2b

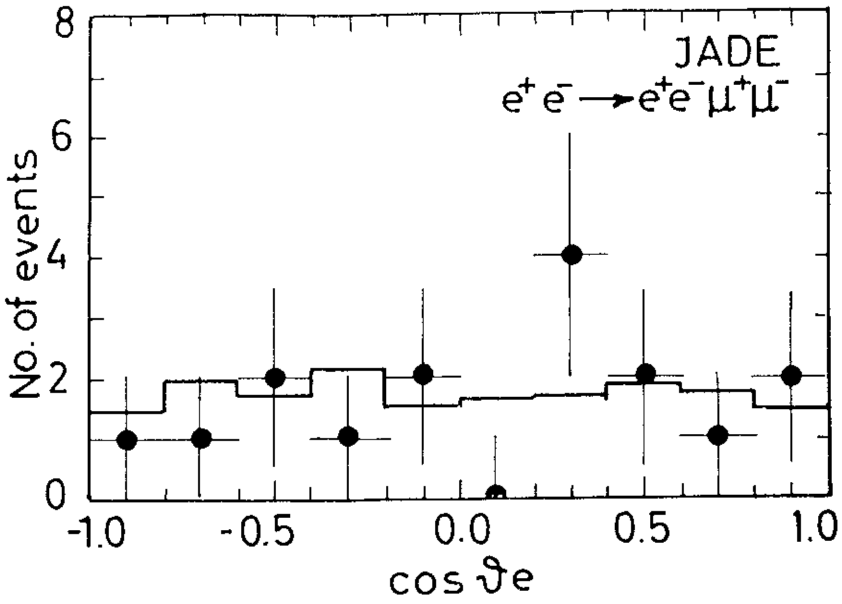

Fig. 3a

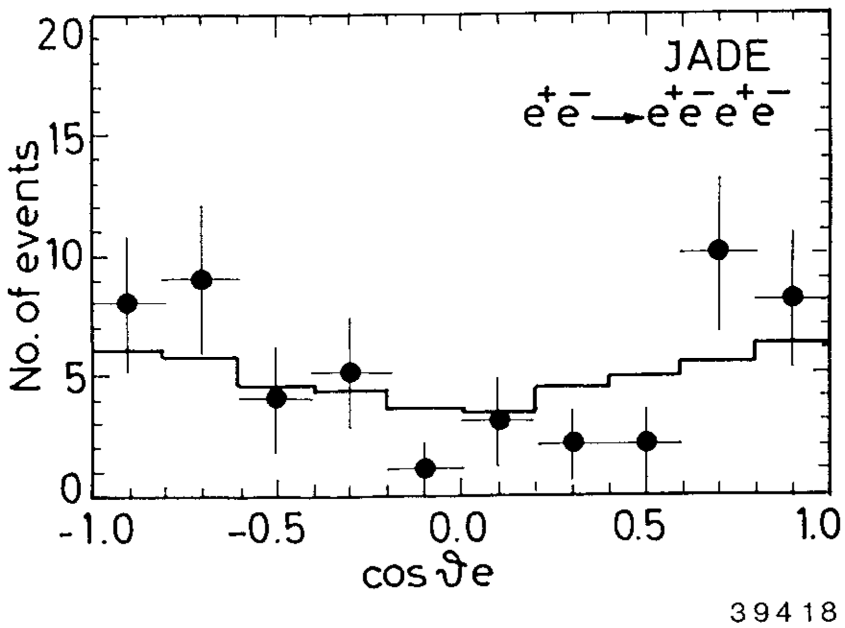

Fig. 3b

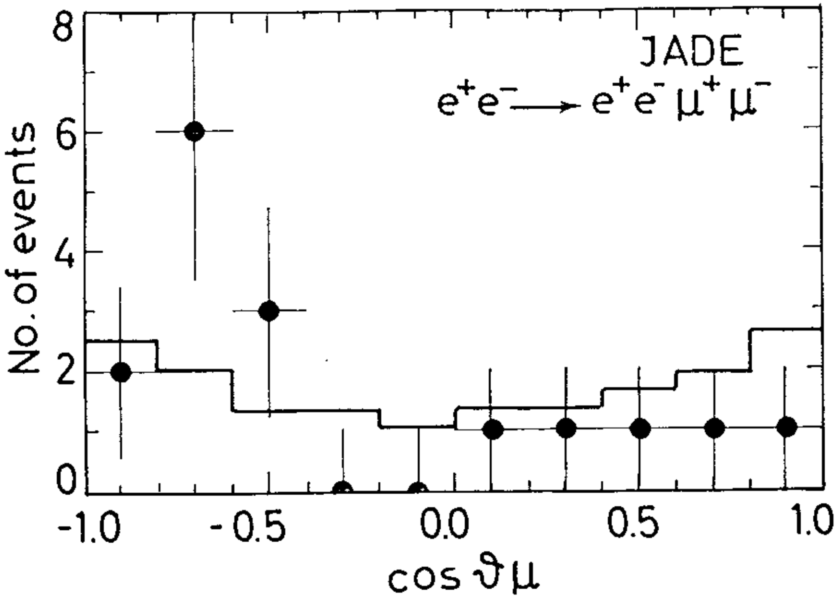

Fig. 4a

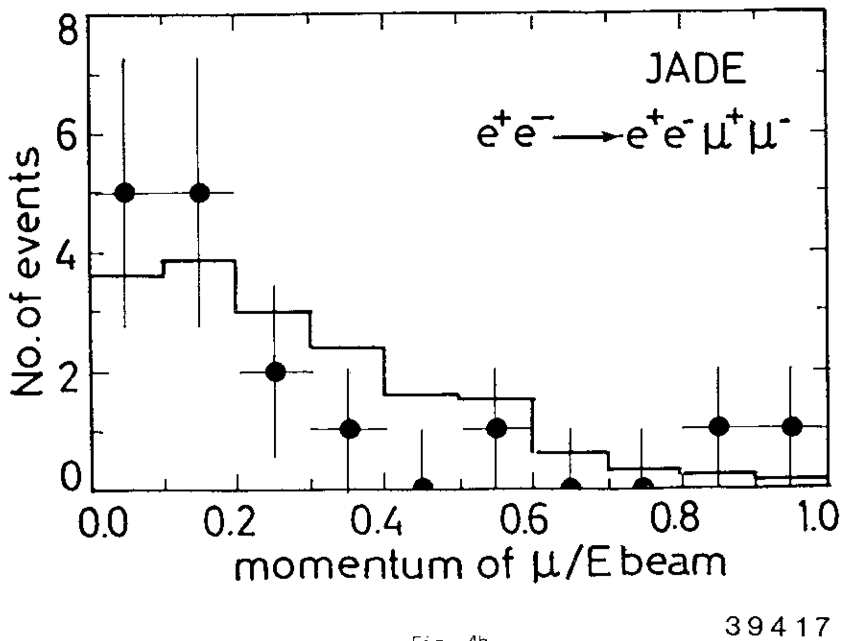

Fig. 4b

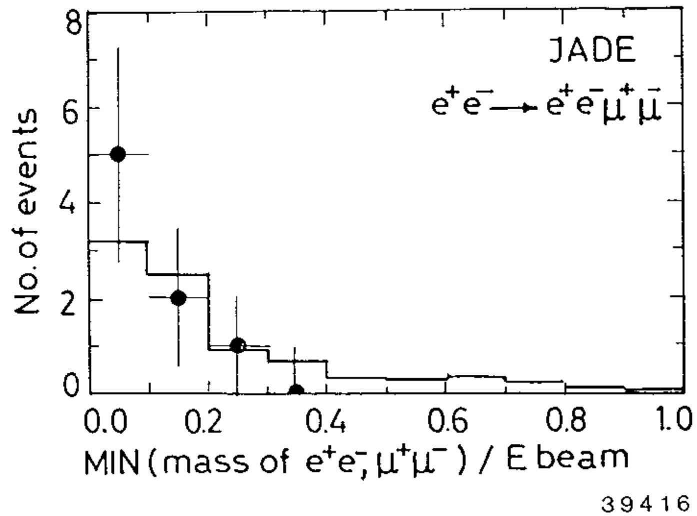

Fig. 5a

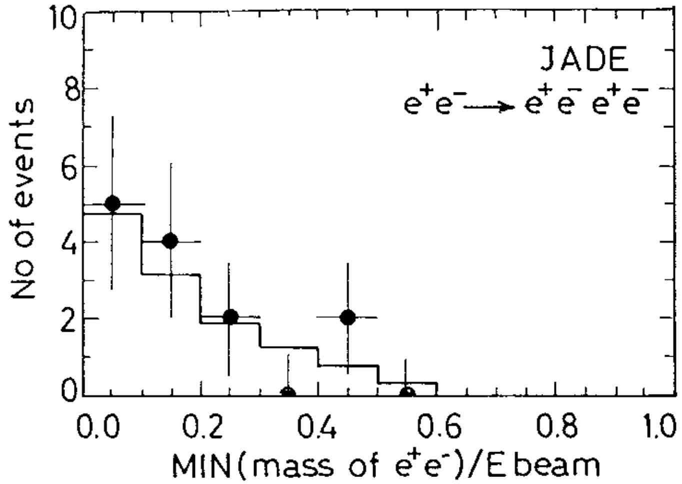

Fig. 5b