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NOTKESTRASSE 85 · 2 HAMBURG 52

OBSERVATION OF AN EXCESS OF EVENTS IN e^+e^- ANNIHILATIONS INTO NEUTRAL FINAL-STATES LEADING TO THREE ELECTROMAGNETIC SHOWERS AT 10 GeV†

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ABSTRACT

During the Υ investigation at DORIS, we observed six events in the e^+e^- annihilation into three electromagnetic showers in a particular kinematical configuration where QED predicted 1.0 ± 0.4 events for the three-photon final-state. The excess events were not related to the Υ resonance. A cross-section of approximately 70 pb has been determined.

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In this letter we present results of the analysis of data on e^+e^- annihilation into neutral final states detected via electromagnetic showers. These showers were due to single photons or possibly to unresolved photon pairs from high energy π^0 decays. At c.m.s. energies of approximately 10 GeV, the two- and three-photon QED processes were expected to dominate the neutral channel. However, we observed an excess of events with three showers which cannot be explained by the QED process for the three-photon final-state. The data was obtained with the DESY-Heidelberg detector at the e^+e^- storage ring DORIS at DESY during the summer of 1978. The measurements were performed during the Τ measurement for c.m.s. energies between 9.41 and 9.51 GeV with an integrated luminosity of 173 nb^{-1}, and during the Τ' search for energies between 9.98 and 10.1 GeV with 120 nb^{-1} [1].

The DESY-Heidelberg detector was well-suited to investigate neutral and QED channels. The apparatus has been described in detail by Bartel et al. [2] and is shown in Fig. 1. The inner detector consisted of two scintillator hodoscopes for triggering purposes, and three cylindrical drift chambers to measure the direction of charged tracks. It was surrounded by an outer detector consisting of NaI and lead-glass blocks to measure electromagnetic showers. The detector covered 86% of 4π, allowing the observation of photons between 33 and 147 degrees with respect to the beam axis. The energy resolutions of the shower counters was approximately $12\%/\sqrt{E}$, where E is in GeV. Coordinates of photons were measured by their conversion in a lead converter (1 radiation length) between the second and third cylindrical chamber, or by their conversion in 1.8 radiation lengths of active NaI converters which in turn were followed by drift chambers. The direction of the converted photons was measured to a precision of $\Delta\phi = \Delta\theta = \pm 80$ mrad. Coordinates of photons that converted in the outer detector were determined from the position of the shower counters and the energy sharing between them, but with a resolution varying between ±30 and ±200 mrad. Two photons could safely be resolved if the difference in either the azimuthal or polar angles was greater than 600 mrad.

The sample of neutral events was found with a special trigger requiring at least one photon converted in the lead or the active converter and at least 1 GeV of energy deposited in the apparatus. Off-line selection required no tracks in the innermost hodoscope and the inner two cylindrical drift chambers. Figure 2 shows a plot of the observed total energy versus the sum of the measured momenta for these events. The momentum of a photon was determined from its measured energy and direction. In this plot, neutral final-states of e^+e^- annihilations were distinguished from other channels such as beam-gas interactions or cosmic-ray events by requiring that the apparatus measured approximately the total c.m.s. energy but found the sum of the momenta of the final-state particles to be substantially smaller. This cut is indicated as a dotted line in Fig. 2. No background from beam-gas interactions or cosmic-rays was expected to exceed this cut. The observed spread in total measured energy and momentum of the accepted events was due to shower leakage at the edges of the apparatus and has been verified by studies of Bhabha scattering events. The remaining sample of events was dominated by two-photon events. From QED calculations, we expected 271 photon-pairs and 244 were observed. Their angular distribution also agreed with the QED prediction. In order to select a clean sample of events with more than two showers, we also required that the angles between showers was greater than 600 mrad, and the lowest shower energy exceed 100 MeV, well above the noise limit of the phototubes.

We found 16(7) three-shower events in the c.m.s. energy range from 9.41 to 9.51 (9.98 to 10.1) GeV. There were no events found with more than three showers. We are confident that none of our three-shower events could have been caused by reactions with charged tracks. First of all, the classification of charged tracks as neutral showers required a complete inefficiency of the innermost two-cylindrical drift chambers and the inner hodoscope. The performance of the chambers and the hodoscope was checked by scanning triggers before and after the three-shower events and the detectors were found to be operating normally. Secondly, if such events would have contributed to the three-shower channel, we should have observed a large number of events with two showers and one charged track. We found only two candidates which could be explained by beam-pipe conversion. Therefore we believe that our sample of three-shower events are clean and free of background.

In order to compare the three-shower events with QED predictions, the kinematic reconstruction program assumed the showers were due to photon conversions. The position of the showers and the total c.m.s energy are sufficient to completely reconstruct the event including the reaction vertex, the inclination of the reaction plane, and the energies of all three photons. For the three-photon events, the reconstructed interaction vertex peaked well in the region of e^+e^- bunch crossing. The calculated energy of the photons agreed with the observed energy within their resolutions, considering the shower leakage problem mentioned above. Because of this energy leakage problem the measured energies were not used in the reconstruction.

In calculating the the invariant mass of a two-photon system from three photons, there are three mass combinations of which only two are independent. Figure 3a shows a Dalitz plot of the highest mass squared solution versus the lowest mass squared solution for events recorded during the T measurement (c.m.s. energies 9.41 to 9.51 GeV). The numbers, n_{QED}, attached to the delineated regions A, B, C, and D of the plot indicate the number of events expected in these areas from QED. The prediction of the QED process e^+e^- into three photons was calculated using the differential cross-section formula of Geshkenbein and Terentev [3] which is a high energy approximation (photon energy) >> 0.5 MeV) of the exact cross-section given by Berends and Gastmans [4]. The differential cross-section was integrated for the four regions of the Dalitz plot with a Monte Carlo method, taking into account the geometrical acceptance, the conversion probabilities of the detector elements, and the various cuts for the events selection. The predicted numbers are based on an integrated luminosity of 173 nb^{-1}. In addition, the variation of the integrated cross-section as influenced by the cut in the minimum photon energy as well as the uncertainty in the photon direction were carefully studied. The errors quoted above, together with the expected number of events, were derived from these studies.

Three-photon events from the radiative two-photon process with the characteristic one low energy photon were found in the lower-right region A of the Dalitz plot (Fig. 3a). The rate of these events was slightly higher than the QED estimate for this process. However, the number of events in region A depended very critically on the energy cut of 100 MeV, while this cut does not affect the other regions B, C, and D. In region B of the Dalitz plot we found six events where only 1.0 ± 0.4 were expected. The probability of observing six or more events where we expected 1.0 was calculated to be 0.06%. When we included the positive error in the expectation value, the probability increased to 0.3%.

As an important cross check of the estimates of the QED process, we studied radiative Bhabha events. Except for the two charged tracks in the inner cylindrical drift chambers, these events behave very similarly to the QED three-photon process. Their differential cross-section also has a similar structure. We evaluated the radiative Bhabha events by neglecting the track information of the inner two chambers and using the identical cuts as for the three-photon events. The observed events are shown in the Dalitz plot in Fig. 3c. The QED estimates are from a Monte Carlo integration of the differential cross-section for this process given by Swanson [5]. We observe excellent agreement between the experimental data and the theoretical prediction, giving us confidence that the various cuts for the event selection and the Monte Carlo integration of the QED cross-section for the three-photon process have been taken into account correctly.

Of the six events in Fig. 3a region B, two came from c.m.s. energies below the T resonance, two at the resonance, and two above. Thus we conclude that these events are not connected with the T resonance but with the continuum. We checked that these events were not correlated with any particular geometric region of the apparatus.

In general, we were not able to differentiate between a photon and a π^0 of energy greater than 500 MeV due to our finite spatial resolution for electromagnetic showers. However, the unresolved photon pair should have been converted more often in the lead or active converter than a single photon. The low statistics of the six events does not exclude the possibility that some photon showers were from π^0's. In our sample of six events, we observed three events with three photons converted, two with two photons converted, and one with one photon converted.

All six events (region B, Fig. 3a) had a similar topology of two photons with about 4 GeV and one with about 1.4 GeV. The angle between the two high energy photons peaked around 160 degrees, while the low energy photon had an angle of approximately 100 degrees to both high energy photons. One of these events is illustrated in Fig. 1. If these events in region B are interpreted in terms of resonance production, the higher mass solution gives a mass of 7.9 GeV and the lower solution a mass of 3.4 GeV. The estimated mass resolution is about 0.5 GeV.

We determined a production cross-section of 70 pb ± 40 pb for five events (six observed events minus one expected from QED) calculated from a luminosity of 173 nb^{-1} and the experimental efficiency of 40 %. The luminosity was determined from Bhabha scattering with a precision of 10%. The efficiency calculation included experimental cuts, conversion probabilities from the beam pipe and the inner converter, and geometric losses calculated from random rotations around the beam axis and the normal to the production plane.

Figure 3b shows data obtained during the T' search (c.m.s. energies 9.98 to 10.1 GeV) where we had a luminosity of 120 nb^{-1}. Five more events in the QED corner of the Dalitz plot were observed where theory predicted $3.6^{+2.0}_{-1.4}$ events, and two events in region B where we expected 0.7 ± 0.3 events. The number of events in region B agreed with the observation of an excess of events in the energy range $9.41 \leq \sqrt{s} \leq 9.51$ GeV but could also be explained by QED.

It is difficult to interpret the excess of events by any known process, particularly in light of their very high production cross-section of approximately 10% of the rate for $e^+e^- \rightarrow \mu^+\mu^-$. Therefore we must conclude that we have observed some new phenomenon or a large statistical fluctuation of over three standard deviations.

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Figure captions

Fig. 1 : Layout of the NaI lead-glass detector showing cross-section view perpendicular to the e^+e^- beam direction. A three-photon event is illustrated. Hodoscope hits are represented by heavy lines, drift chamber hits by black dots, and deposited energy (in MeV) by numbers in shower counters.

Fig. 2 : Plot of the measured total energy versus the sum of the momenta of all events with no charged tracks in the inner detector for $9.41 \leq \sqrt{s} \leq 9.51$ GeV. Squares indicate the positions of the six events from region B of the Dalitz plot Fig. 3a.

Fig. 3 : Dalitz plot of highest mass squared combination versus lowest mass squared combination. QED predictions, n_{QED}, are indicated for the delineated regions.

(a) observed three-photon events for $9.41 \leq \sqrt{s} \leq 9.51$ GeV.

(b) observed three-photon events for $9.98 \leq \sqrt{s} \leq 10.1$ GeV.

(c) observed radiative Bhabha scattering events for $9.41 \leq \sqrt{s} \leq 9.51$ GeV (there are 49 events in region A, 15 in region B, 17 in region C, and 15 in region D).

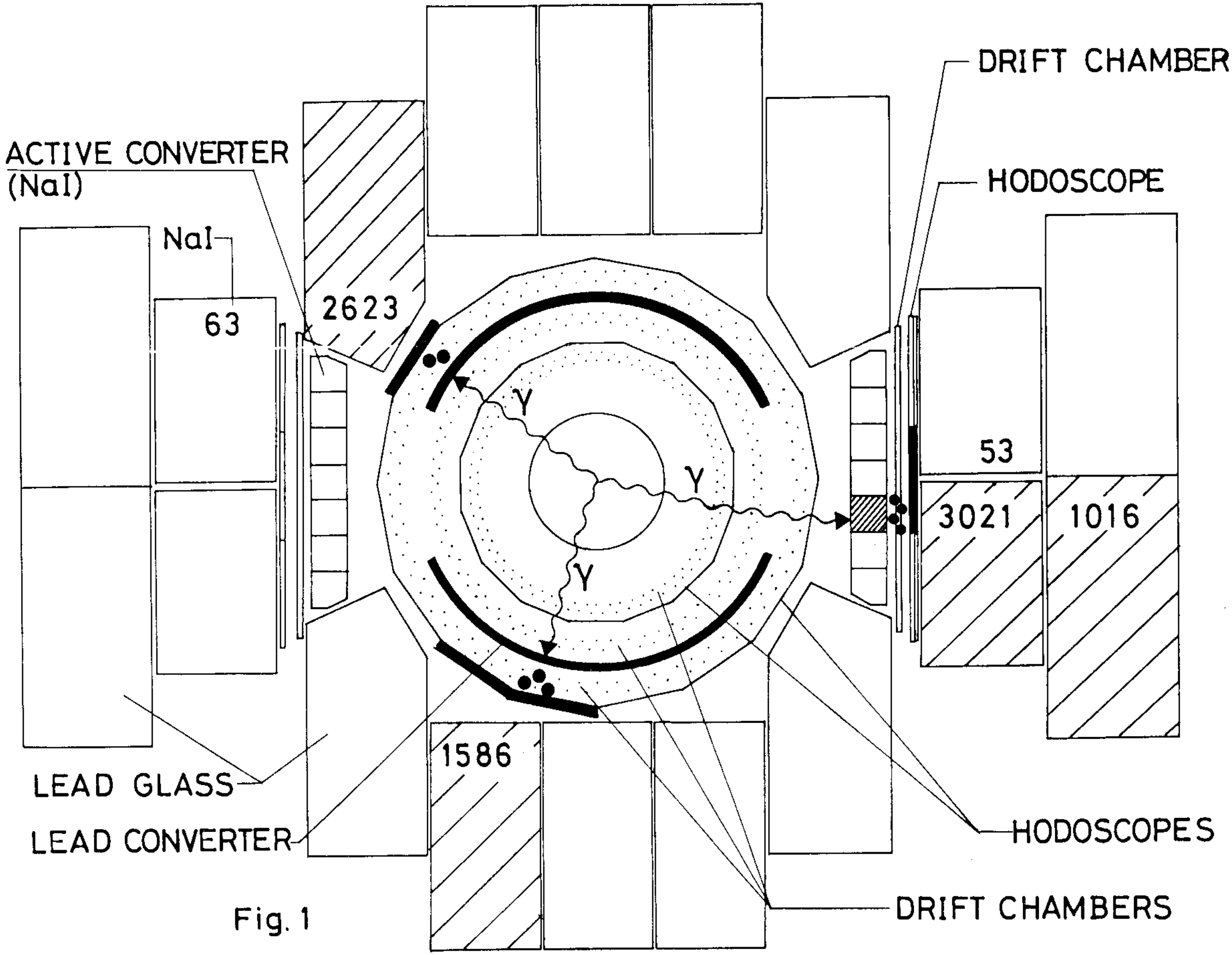

ACTIVE CONVERTER
(NaI)
NaI
63
2623
γ
γ
γ
53
3021
1016
1586
DRIFT CHAMBER
HODOSCOPE
LEAD GLASS
LEAD CONVERTER
HODOSCOPES
DRIFT CHAMBERS

Fig. 1

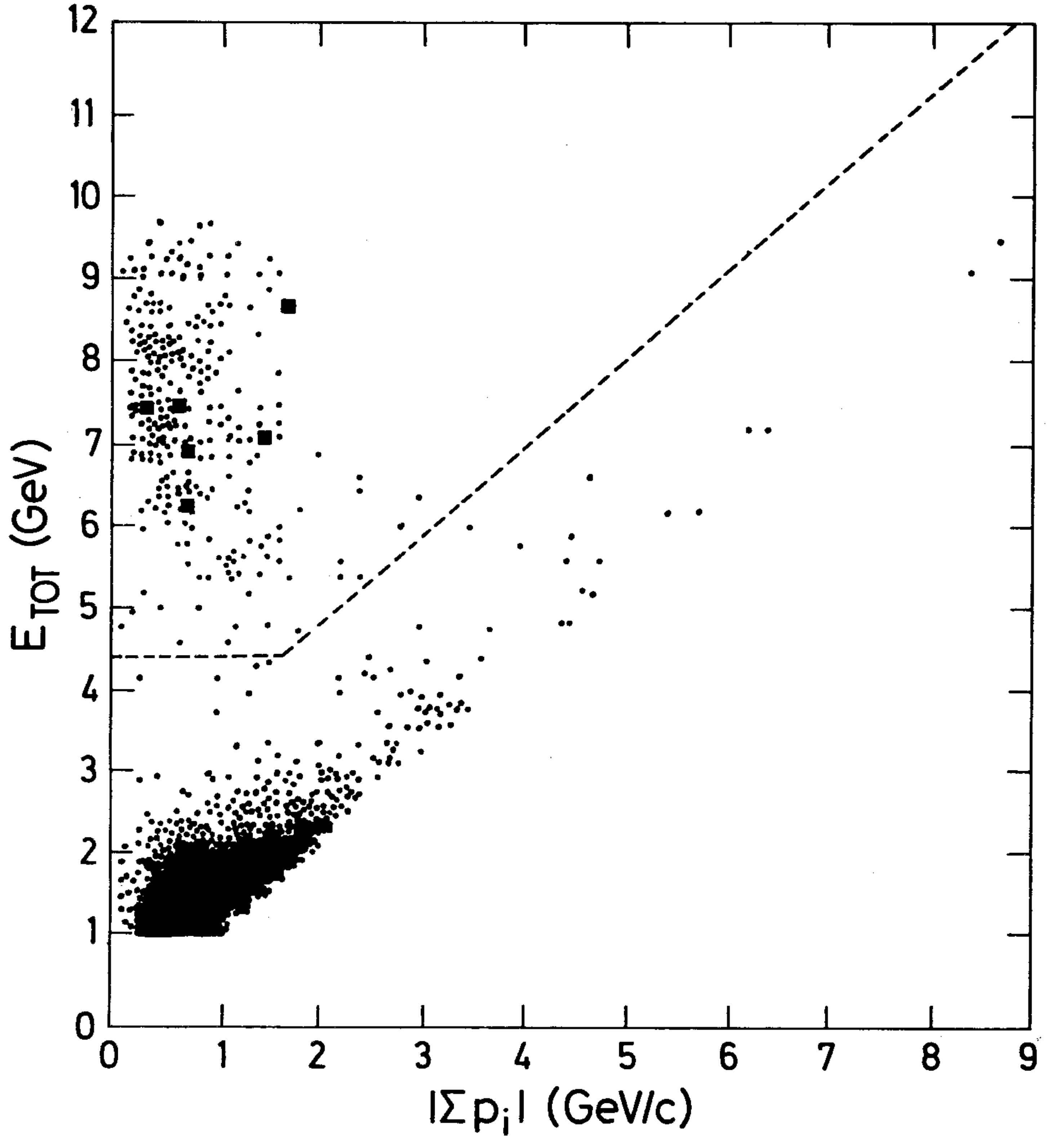
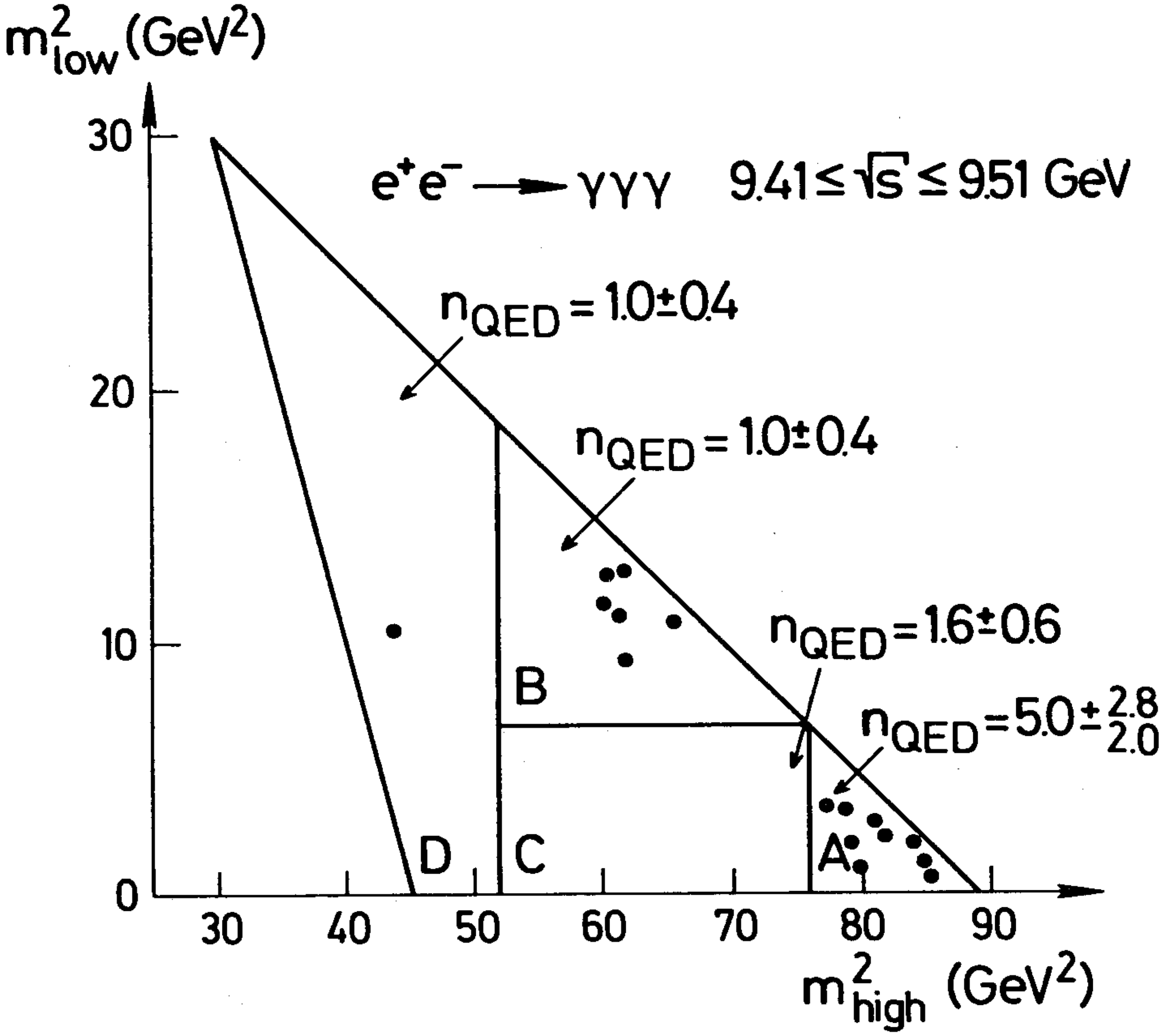
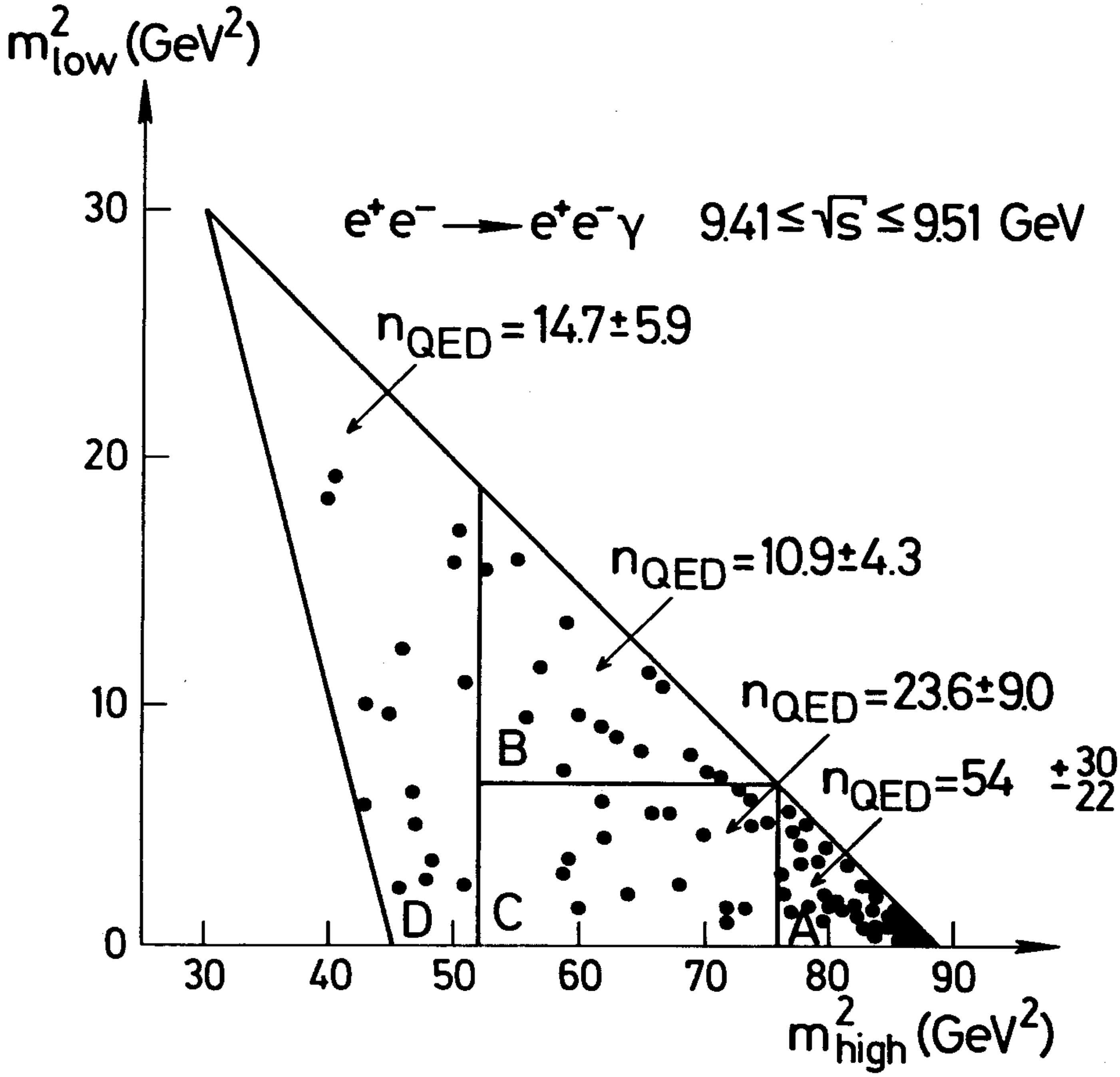


Fig. 2



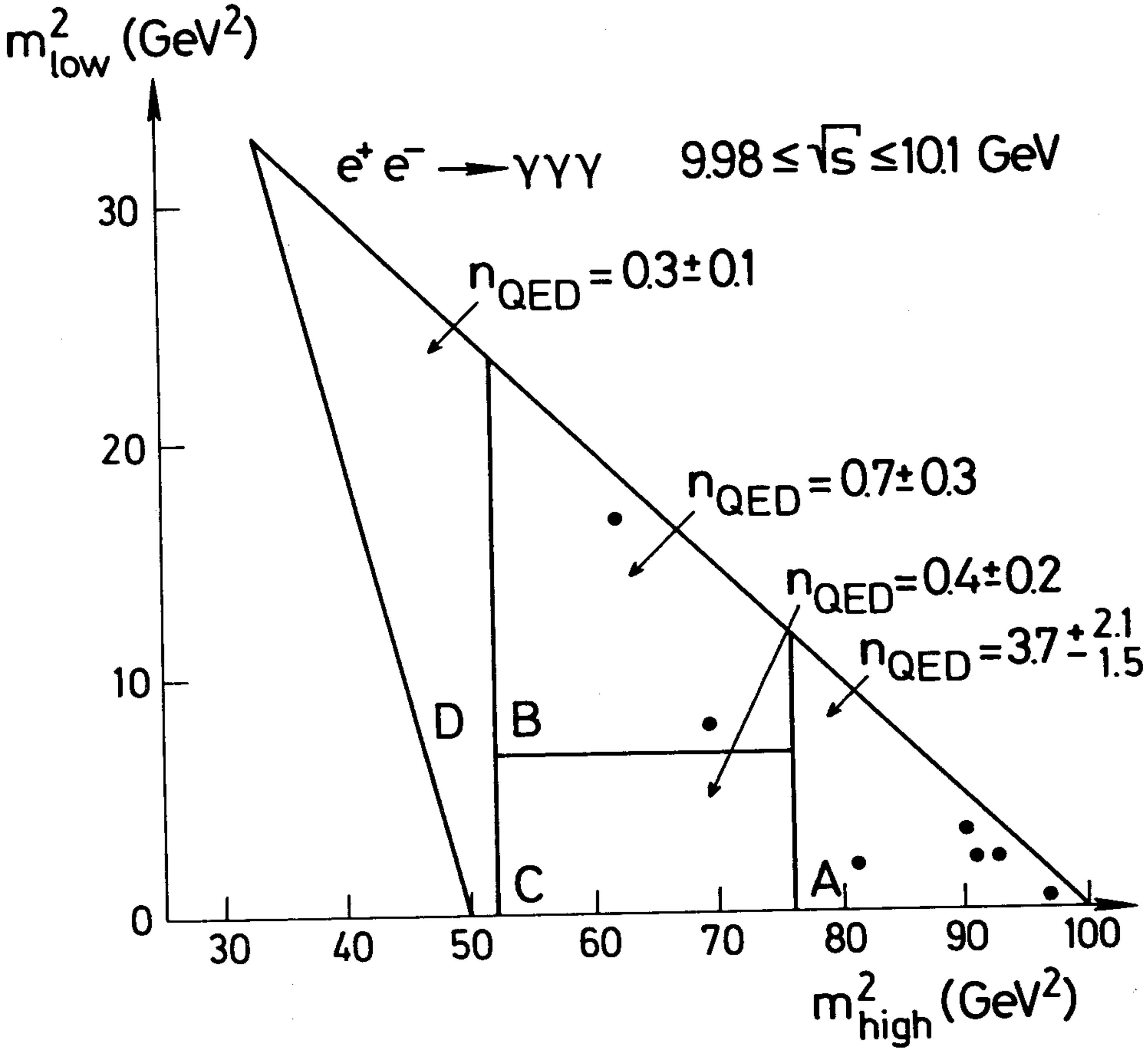
m^2_{low} (GeV^2)
30
20
10
0
$e^+e^- \longrightarrow \gamma\gamma\gamma$ $9.41 \leq \sqrt{s} \leq 9.51$ GeV
$n_{QED} = 1.0 \pm 0.4$
$n_{QED} = 1.0 \pm 0.4$
$n_{QED} = 1.6 \pm 0.6$
$n_{QED} = 5.0^{+2.8}_{-2.0}$
B
A
D
C
30
40
50
60
70
80
90
m^2_{high} (GeV^2)

Fig. 3a



m^2_{low} (GeV^2)
30
20
10
0
$e^+e^- \rightarrow e^+e^-\gamma$ $9.41 \leq \sqrt{s} \leq 9.51$ GeV
$n_{QED} = 14.7 \pm 5.9$
$n_{QED} = 10.9 \pm 4.3$
$n_{QED} = 23.6 \pm 9.0$
$n_{QED} = 54 \; ^{+30}_{-22}$
B
C
D
A
30
40
50
60
70
80
90
m^2_{high} (GeV^2)

Fig. 3b



m^2_{low} (GeV^2)
$e^+e^- \rightarrow \gamma\gamma\gamma$
$9.98 \leq \sqrt{s} \leq 10.1$ GeV
$n_{QED} = 0.3 \pm 0.1$
$n_{QED} = 0.7 \pm 0.3$
$n_{QED} = 0.4 \pm 0.2$
$n_{QED} = 3.7^{+2.1}_{-1.5}$
30
20
10
0
D
B
C
A
30
40
50
60
70
80
90
100
m^2_{high} (GeV^2)

Fig. 3c