DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 74/62
December 1974

A Measurement of Collinear and Nearly Collinear Photon Pairs Produced by e^+e^- Annihilation at the 3100 MeV Resonance

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Abstract

We have measured collinear and nearly collinear photon pairs from e^+e^- annihilation at total energies covering the resonance at 3100 MeV. The observed cross section is in good agreement with the $e^+e^- \to \gamma\gamma$ cross section expected from quantum electrodynamics. Upper limits for the decay modes (3100) $\to \gamma\gamma$, $\pi^0\gamma$ and other modes are derived.

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We have studied the recently discovered 3100 MeV resonance (1) for final states involving two or more photons. The experiment was performed at the DESY e^+e^- colliding beam facility DORIS using a nonmagnetic spectrometer. The same apparatus was used concurrently for the measurement of large angle Bhabha scattering previously reported (2). The relative luminosity was monitored by observing Bhabha scattering at small angles.

The apparatus shown in Fig. 1 is part of the Double Arm Spectrometer (DASP) and consists of two identical detectors mounted above and below the beams. Photons produced at angles θ between 35^0 and 145^0 were detected in a total solid angle of 1.4 sterad. The basic unit of each detector consists of a scintillation counter hodoscope, a sheet of lead 5mm thick, and a proportional tube chamber (3). A particle produced in the interaction region passes through a layer of scintillation counters surrounding the beam pipe, then through four of the units just described, and finally through a lead-scintillator shower counter, 8 radiation lengths thick. Note that a particle must pass through two scintillation counters before reaching the first lead converter.

The trigger in each detector required a coincidence between the shower counter and one of the two immediately preceding scintillation counters (see Fig.1). The energy loss threshold was well below the measured energy for a 1.5 GeV photon shower in the detector. The event trigger was a coincidence between the two detectors.

If one of the photons converts too far back in the hodoscope, the event will fail to trigger the apparatus. Both hodoscopes were calibrated for conversion depth in a tagged photon beam. Another much smaller source of inefficiency is the conversion of both photons at the beam pipe, so that an e^+e^- event is simulated.This probability was estimated from the amount of material in the path, and is consistent with the observed probability that one of the photons converts in the beam pipe. Including both effects the detection efficiency varied between o.79 at 90^0 and o.91 at 45^0.

Data were collected at total energies E between 3081 and 3099 MeV covering the region in which the resonance was observed at DORIS (2,4). The total luminosity integrated over the duration of the experiment was 5×10^{34} cm^{-2}. We used the following criteria to seperate the photon events from the much more numerous large angle e^+e^- scattering events and the background from cosmic rays and beam-gas interactions.

1) Of the two upper and two lower layers of scintillation counters between the interaction point and the two first lead converters no more than two counters should fire. This allows for the possibility of one of the two photons to convert.

2) The energy deposited in each detector should be at least 100 MeV, and the total energy should be more than 1200 MeV for both detectors.

3) At least 20 proportional tubes should be set. At 3 GeV 80 tubes were set on the average.

4) The time difference between pulses from the two detectors should be less than 3.5 nsec.

5) The photons should be collinear within $\pm 25^0$ in θ and $\pm 15^0$ in ϕ.

Note that only criterion 1) discriminates against Bhabha events. The criteria are set deliberately loose so that no wanted photon event would be lost.

The 169 events satisfying the above criteria were scanned by physicists. All events which did not originate at the interaction point or which were accompanied by charged particles in the proportional tubes surrounding the beam pipe were rejected. This reduced the sample to 125 events. To ensure uniform detection efficiency the limits on the production angles θ and ϕ, measured in the upper detector, were chosen to be 40^{0} to 140^{0} and $\pm 12^{0}$, respectively. A total of 101 events remained.

We consider first the $\gamma\gamma$ final state by requiring the two photons to be collinear to within 6^{0}. Of the 101 events 77 are in this collinear class. Fig. 2a shows the measured cross section as a function of the total energy E of the two beams. The absolute scale is determined by taking account of the photon detection efficiency, the detection aperture in ϕ, and the luminosity obtained by normalizing the total number of $e^{+}e^{-}$ scattering events outside the peak at E = 3081 and 3099 MeV to the prediction of quantum electrodynamics (2). The cross section is consistent over the entire energy range with the theoretical cross section obtained from lowest oder quantum electrodynamics with radiative corrections (5). There is no evidence for a statistically significant enhancement in the region of E = 3090 MeV, where a resonance was observed in the same apparatus during the same data runs. Fitting with the nonresonant background plus a Gaussian peak of the same shape and energy as observed in the $e^{+}e^{-}$ scattering data (2), we derive an upper limit on the energy integral of the cross section for production and $\gamma\gamma$ decay of the 3100 MeV resonance:

$$\int \sigma_{\gamma\gamma} (E)\, dE \ < \ 28 \text{ nb-MeV} \quad (90\% \text{ confidence})$$

A cross section value of this amount is shown by the dotted curve in Fig. 2. Comparing with our value for the corresponding integral in the scattering case, we conclude that the ratio of decay rates is limited by

$$\Gamma_{\gamma\gamma}/\Gamma_{ee} < \ 0.050 \ (90\% \text{ confidence}).$$

The angular distribution of collinear photon pairs, summed over all energies E, is given in Fig. 3. The shape is consistent with the prediction of quantum electrodynamics. The decay of a spin-1 particle into two photons is forbidden by gauge invariance and Bose-Einstein statistics, regardless of the C-parity of the particle. For other spins it is allowed, provided that C is even or not conserved.

Nearly collinear photons can arise from the decay chain

$$(3100) \rightarrow x^0\gamma$$
$$x^0 \rightarrow \gamma\gamma$$

provided that either (a) $m_x << m_{3100}$, in which case the two photons from the decay of the meson x^0 come off with small opening angle and collinear with the other photon, or (b) m_x close to 3100 MeV, in which case the pair of photons from the x^0 are almost collinear and share most of the original 3100 MeV energy. Condition (a) is satisfied by the decay $(3100) \rightarrow \pi^0\gamma$; the noncollinearity angle between the single photon and one of the two photons from the π^0 is always less than 5^0 ($2m_\pi$/3100 MeV). Case (b) would require a C = +1 meson x^0 of mass slightly lower than 3100 MeV.

In Fig.2b we plot the energy dependence of the cross section corresponding to all the 101 two-photon events,without the 6^0 collinearity requirement. If we attribute any deviation from a flat cross section to the production of the 3100 MeV particle and its decay into $\pi^0\gamma$, we can derive an upper limit for the energy integral of the cross section:

$$\int \sigma_{\pi^0\gamma}(E)\ dE \ < \ 73 \text{ nb-MeV (90\% confidence)}.$$

This implies that

$$\Gamma_{\pi 0\gamma} / \Gamma_{ee} \ < \ 0.13 \quad \text{(90\% confidence)}$$

for the 3100 MeV particle. For comparison,the corresponding ratio for the $\phi(1020)$ meson decay is (6) 7.8 ± 3.8.

The upper limit for nearly collinear photons from case (b) depends on the assumed mass of the meson x^0 and its branching ratio into two photons. If the mass is less than about 2600 MeV, it will be emitted with momentum high enough to cause a noncollinearity of greater than 20^{o} in its decay photons. This reduces considerably its probability of detection in our experiment. However, for masses m_x above 2600 MeV we can derive the upper limit

$$\frac{\Gamma(3100\to x^{o}\gamma)\ \dfrac{\Gamma(x^{o}\to\gamma\gamma)}{\Gamma(x^{o}\to \mathrm{all})}}{\Gamma(3100\to e^{+}e^{-})} < 0.2 \quad (90\%\ \text{confidence}).$$

Acknowledgements

We thank all engineers and technicians who have participated in the construction and building of DASP. We are also indebted to the DORIS machine group for their excellent support during the experiment. We thank T.Walsh for many helpful discussions. The members of the groups from RWTH Aachen, Max-Planck-Institut für Physik und Astrophysik, München, and University of Tokyo wish to thank the DESY Direktorium for the kind hospitality at DESY.

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3) To be submitted to Nuclear Instruments and Methods.

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Figure Captions

Fig 1 A sketch of the experimental apparatus.

Fig 2 (a) The energy dependence of the observed cross section for production of collinear (within 6^{o}) photon pairs between $\theta=40^{o}$ and 140^{o}. The dashed line indicates the prediction of quantum electrodynamics. The dotted curve shows the enhancement that would result from a $\gamma\gamma$ decay of the resonance at the rate corresponding to our 90% confidence upper limit.
(b) The energy dependence of all two-photon events without collinearity requirement.

Fig 3 The angular distribution of collinear two-photon events folded about 90^{o}. The curve represents the prediction of quantum electrodynamics for the reaction $e^+e^- \rightarrow \gamma\gamma$.

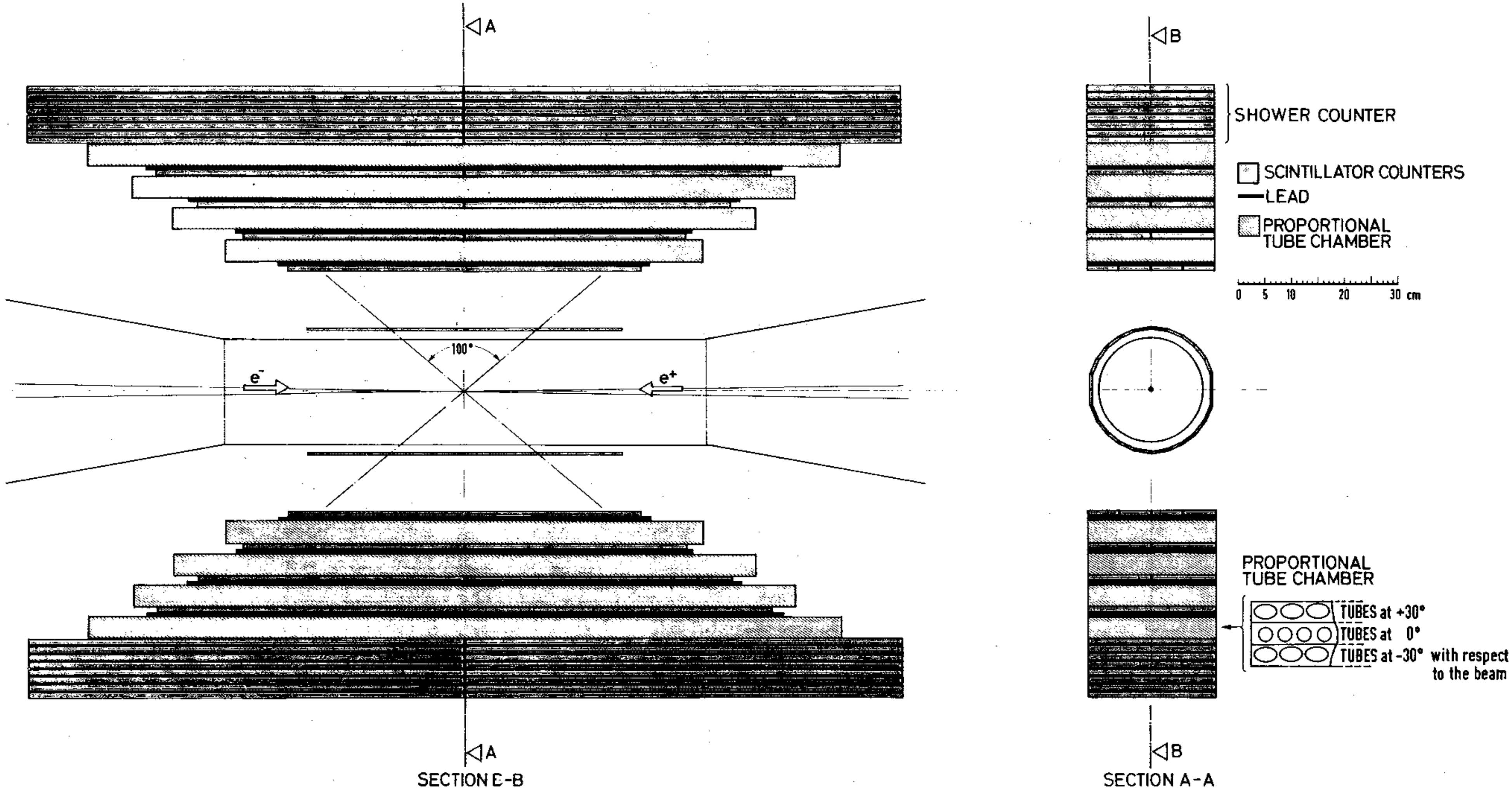
A
B
SHOWER COUNTER
SCINTILLATOR COUNTERS
LEAD
PROPORTIONAL TUBE CHAMBER
0 5 10 20 30 cm
100°
e⁻
e⁺
PROPORTIONAL TUBE CHAMBER
TUBES at +30°
TUBES at 0°
TUBES at -30° with respect to the beam
SECTION B-B
SECTION A-A

Fig. 1

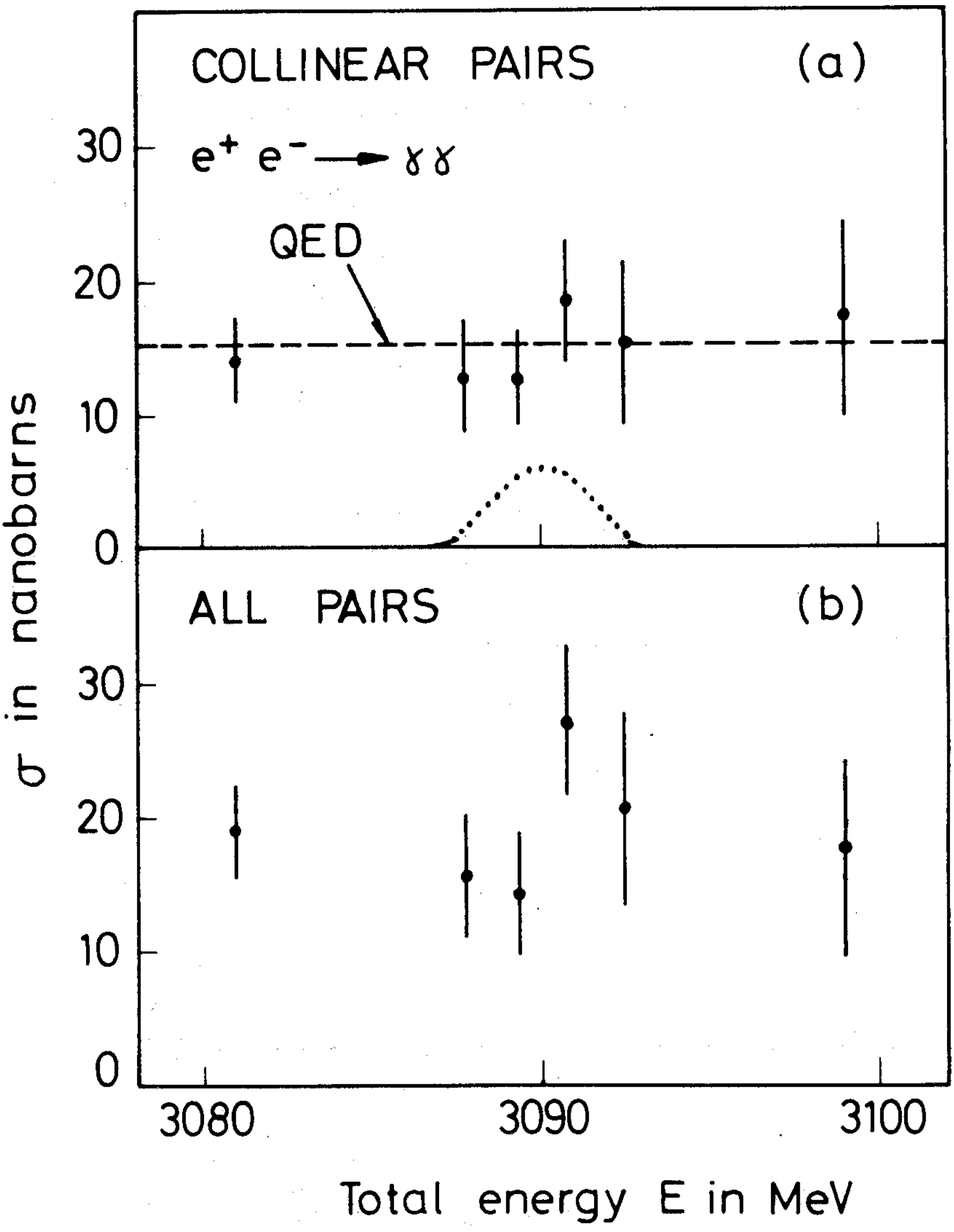
COLLINEAR PAIRS
(a)
e+ e- → γγ
QED
ALL PAIRS
(b)
σ in nanobarns
0
10
20
30
3080
3090
3100
Total energy E in MeV

Fig. 2

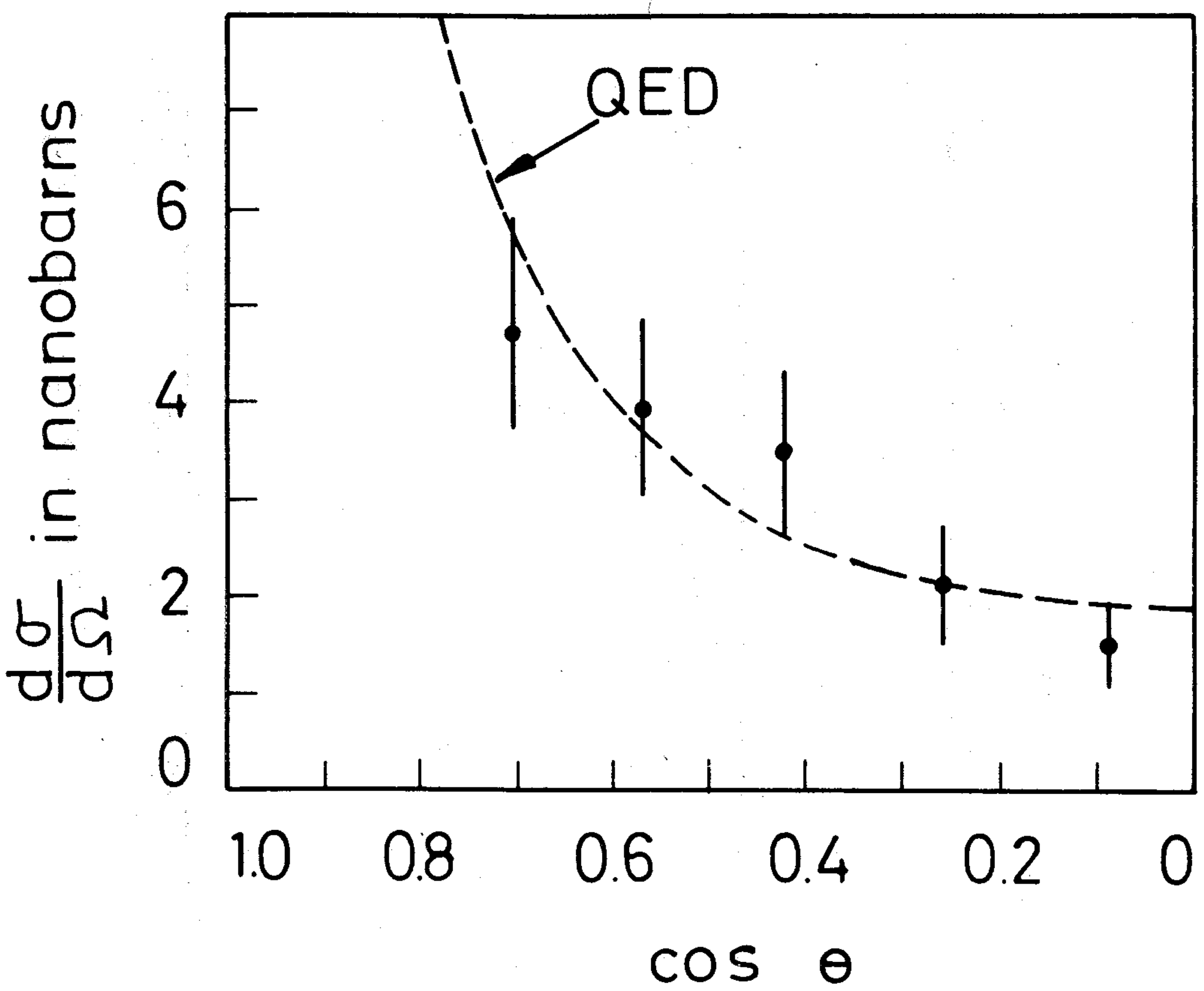

Fig. 3