EXCLUSIVE PROTON–ANTIPROTON PRODUCTION IN TWO-PHOTON COLLISIONS

TASSO Collaboration

R. BRANDELIK, W. BRAUNSCHWEIG, K. GATHER, F.J. KIRSCHFINK, K. LÜBELSMEYER, H.-U. MARTYN, G. PEISE, J. RIMKUS, H.G. SANDER, D. SCHMITZ, A. SCHULTZ von DRATZIG, D. TRINES and W. WALLRAFF

I. Physikalisches Institut der RWTH Aachen, Germany [8]

H. BOERNER, H.M. FISCHER, H. HARTMANN, E. HILGER, W. HILLEN, G. KNOP, L. KÖPKE, H. KOLANOSKI, P. LEU, R. WEDEMEYER, N. WERMES and M. WOLLSTADT

Physikalisches Institut der Universität Bonn, Germany [8]

H. BURKHARDT, S. COOPER, D. HEYLAND, H. HULTSCHIG, P. JOOS, W. KOCH, U. KÖTZ, H. KOWALSKI [1], A. LADAGE, D. LÜKE, H.L. LYNCH [2], P. MÄTTIG, K.H. MESS [3], D. NOTZ, J. PYRLIK, D.R. QUARRIE [4], R. RIETHMÜLLER, A. SHAPIRA [5], P. SÖDING, B.H. WIIK and G. WOLF

Deutsches Elektronen-Synchrotron, DESY, Hamburg, Germany

R. FOHRMANN, M. HOLDER, H.L. KRASEMANN, G. POELZ, O. RÖMER and P. SCHMÜSER

II. Institut für Experimentalphysik der Universität Hamburg, Germany [8]

I. AL-AGIL, R. BEUSELINCK, D.M. BINNIE, A.J. CAMPBELL, P.J. DORNAN, D.A. GARBUTT, T.D. JONES, W.G. JONES, S.L. LLOYD, D. PANDOULAS, J.K. SEDGEBEER, R.A. STERN and S. YARKER

Department of Physics, Imperial College London, England [9]

M.G. BOWLER, I.C. BROCK, R.J. CASHMORE, R. DEVENISH, P. GROSSMANN, J. ILLINGWORTH, M. OGG, G.L. SALMON, J. THOMAS, T.R. WYATT and C. YOUNGMAN

Department of Nuclear Physics, Oxford University, England [9]

K.W. BELL, B. FOSTER, J.C. HART, J. PROUDFOOT, D.H. SAXON and P.L. WOODWORTH

Rutherford Appleton Laboratory, Chilton, England [9]

E. DUCHOVNI, Y. EISENBERG, U. KARSHON, G. MIKENBERG, D. REVEL and E. RONAT

Weizmann Institute, Rehovot, Israel [10]

T. BARKLOW, J. FREEMAN [6], T. MEYER [7], G. RUDOLPH, E. WICKLUND, S.L. WU and G. ZOBERNIG

Department of Physics, University of Wisconsin, Madison, WI, USA [11]

Received 18 September 1981

[1] Now at CERN, Geneva, Switzerland.
[2] On leave at UC Santa Barbara, USA.
[3] On leave from CERN, Geneva, Switzerland.
[4] On leave from Rutherford Appleton Laboratory, England.
[5] Minerva Fellow, on leave from Weizmann Institute, Rehovot, Israel.
[6] Now at FNAL, Batavia, USA.
[7] Now at A & M University, TX, USA.

[8] Supported by the Deutsches Bundesministerium für Forschung und Technologie.
[9] Supported by the UK Science and Engineering Research Council.
[10] Supported by the Minerva Gesellschaft für die Forschung mbH.
[11] Supported in part by the US department of Energy contract WY-76-C-02.

0 031-9163/82/0000–0000/$ 02.75 © 1982 North-Holland

Production of proton–antiproton pairs by two-photon scattering has been observed at the electron–position storage ring PETRA. A total of eight proton–antiproton pairs have been identified using the time-of-flight technique. We have measured a total cross section of 4.5 ± 0.8 nb in the photon–photon c.m. energy range 2.0–2.6 GeV.

In recent years experiments at high-energy storage rings have started to explore the field of two-photon ($\gamma\gamma$) scattering. In particular the $\gamma\gamma$ production of lepton and meson pairs has been studied [1–6]. In this letter we present the first result on baryon pair production by two photons. We have measured the reaction

$$e^+e^- \to e^+e^- + \gamma\gamma \to e^+e^- + p\bar{p},$$

where the protons and antiprotons have been identified by means of time-of-flight (TOF) measurements. The cross section for the reaction $\gamma\gamma \to p\bar{p}$ has been determined for invariant masses of the $\gamma\gamma$ system ($W_{\gamma\gamma}$) between 2.0 and 2.6 GeV.

The experiment has been performed with the TASSO detector at the DESY storage ring PETRA. A description of the detector can be found elsewhere [7]. Our data sample corresponds to an integrated luminosity of 19 685 nb^{-1} at beam energies between 15.0 and 18.3 GeV.

The data have been taken with the trigger designed for events with two charged tracks (two-prong events) coplanar with the beam axis (topology trigger). The trigger covered 2π in azimuth and polar angles of $|\cos\theta| \leqslant 0.82$. Its efficiency was dependent on the momentum transverse to the beams (p_T), with a threshold at about 0.3 GeV/c, and rising to about 90% at 0.5 GeV/c. For part of the data we had a two-prong trigger which had no coplanarity requirement. This trigger (MONIKA trigger) used the fast on-line track-finder MONIKA [8]. While we have not used these data in the cross section calculation they allowed us to check the angular correlation of the two-prong events without a bias from the coplanarity requirement of the topology trigger. The scattered electrons (positrons) were not detected.

Candidates for two-photon produced two-prong events were selected requiring two oppositely charged tracks in the central detector with $|\cos\theta| \leqslant 0.8$ and $p_T \geqslant 0.3$ GeV/c and coplanar with the beam axis within 15°. In order to reject lepton pairs from one-photon annihilation (1γ) the two tracks had to be noncollinear by more than 5° and the sum of their momenta had to be less than 40% of the beam energy. The collinearity cut also removed all cosmic ray events.

For the identification of $p\bar{p}$ pairs we have used TOF measurements from the 48 scintillation counters surrounding the cylindrical drift chamber at a radius of 1.32 m. The counters covered 82% of 4π. Within this solid angle the efficiency of the TOF measurement for tracks coming from the vertex was 91% and the resolution was 465 ps, both averaged over the full data taking period. In order to achieve a separation of 3 standard deviations between protons and kaons we restricted our analysis to events with track momenta between 0.4 and 0.9 GeV/c.

For the remaining 9017 events the square of the mass of the particle (m^2_{TOF}) has been calculated from the measured track length, momentum and TOF. In fig. 1 we plot m^2_{TOF} of the negative particle versus m^2_{TOF} of the positive. The bulk of events cluster around zero. They are mostly due to electron, muon and pion pairs. In this analysis we do not distinguish these three particle types and will henceforth refer to them all as "pions". In addition, we observe two distinct clusters of proton–"pion" and proton–antiproton events. A study of the vertex distributions showed that most of the proton–"pion" events are due to

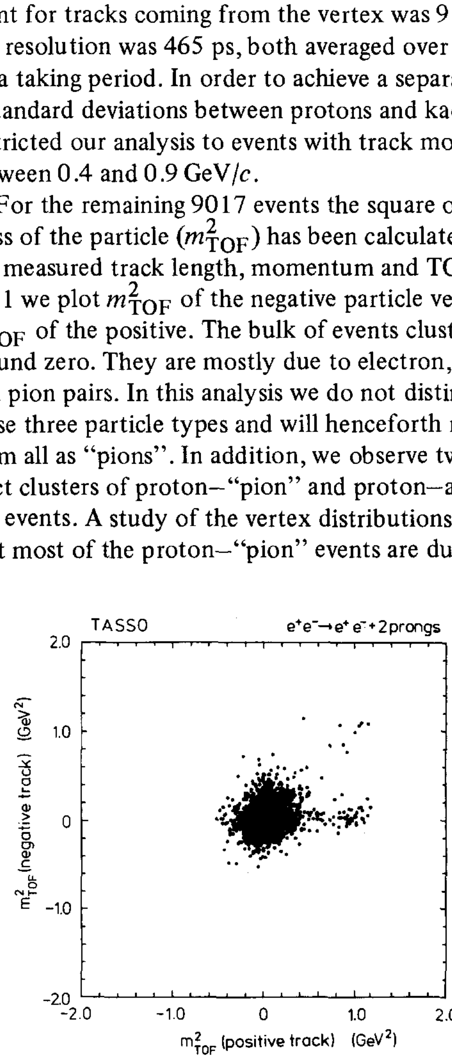

Fig. 1. Scatter plot of m^2_{TOF} of the negative versus m^2_{TOF} of the positive particle.

beam–gas interactions. The proton–antiproton cluster contains 8 events. There is one event near to the $p\bar{p}$ cluster, which fits the pK hypothesis. The probability that this event is $p\bar{p}$ is less than 0.3%. Studies of the tails of the pion and kaon clusters showed that the probability for one of the 8 identified $p\bar{p}$ events to be in fact a $\pi^+-\pi^-$, K^+-K^-, p–π or p–K event is less than 1.0%. All 8 $p\bar{p}$ events come from the interaction region indicating that beam–gas scattering does not contribute. The energy deposited by the tracks of the 8 events in the scintillation counters as well as in the dE/dx strips of the liquid-argon barrel counters [9] was checked and found to be consistent with the expected energy loss for protons.

To demonstrate that we have observed exclusive $p\bar{p}$ events we plot for each event the sum of the transverse momenta $|\boldsymbol{p}_{T1} + \boldsymbol{p}_{T2}|$ of the two tracks (fig. 2). The distribution peaks at zero, as expected for $\gamma\gamma$ events with no missing particles, since the transverse momentum of the $\gamma\gamma$ system is small with respect to the beam axis.

To check that the preference for small values of $|\boldsymbol{p}_{T1} + \boldsymbol{p}_{T2}|$ is not due to the topology trigger we have analysed two-prong events taken with the MONIKA trigger. We found that the contamination from non-exclusive $p\bar{p}$ production is small. A possible contribution from $p\bar{p}$ production by 1γ annihilation with a hard photon radiated from the initial state is excluded by the requirements on the angles of the two tracks.

For the determination of the cross section we have simulated the reaction $e^+e^- \to e^+e^- + p\bar{p}$ in the detector with a Monte Carlo program. Events were generated according to

$$d\,\sigma(W_{\gamma\gamma})/d\cos\theta^* = F(W_{\gamma\gamma})\,d\,\sigma_{\gamma\gamma\to p\bar{p}}(W_{\gamma\gamma})/d\cos\theta^*,$$

where θ^* is the angle between photon and proton in the $\gamma\gamma$ center of mass system; $F(W_{\gamma\gamma})$ is the integrated flux of transverse photons [10]. The cross section for $\gamma\gamma \to p\bar{p}$ was set to be independent of $W_{\gamma\gamma}$ and was generated with a flat distribution in $\cos\theta^*$. The average Q^2 of the photons was found to be about 0.002 GeV^2. We used a ρ form factor to extrapolate to zero-photon mass. The simulation of the TASSO detector included energy loss, multiple scattering and nuclear interactions. The loss of events due to nuclear absorption was found to be 22%.

The distribution of $|\boldsymbol{p}_{T1} + \boldsymbol{p}_{T2}|$ expected for $p\bar{p}$ production is shown by the curve in fig. 2. It agrees well with the data.

The cross section for the reaction $\gamma\gamma \to p\bar{p}$ averaged over a $W_{\gamma\gamma}$ range from 2.0 to 2.6 GeV was found to be

$$\sigma_{\gamma\gamma\to p\bar{p}} = 4.5 \pm 1.6(\text{stat.}) \pm 0.8(\text{syst.})\ \text{nb}.$$

To check the model dependence of our efficiency, we also generated events according to the Born diagrams for $\gamma\gamma \to p\bar{p}$ where protons and antiprotons were treated as pointlike spin 1/2 particles with a pure QED coupling (Dirac protons) [11]. This model results in a detection efficiency 13% lower than the one determined with the isotropic model.

The cross section expected from the Born model (43 nb averaged over the accepted $W_{\gamma\gamma}$ range) is about an order of magnitude larger than the measured one. However, due to the fact that the exchanged proton is far off the mass shell, the strong interaction may suppress the cross section strongly. We also used the vector dominance model to calculate the expectation for $\sigma_{\gamma\gamma\to p\bar{p}}$ from measured data for the inverse reactions $p\bar{p} \to \rho\rho$ and $p\bar{p} \to \rho\omega$ [12]. This gives an averaged cross section of about 0.2–1.0 nb for the accepted $W_{\gamma\gamma}$ range. An earlier experiment [13] reported two candidate events for the inverse reaction $p\bar{p} \to \gamma\gamma$ at $W = 2.26$ GeV. The cross section deduced from these two events is roughly 2 orders of magnitude larger than computed from our result by detailed balance.

To summarize, in the sample of two-prong events originating from two-photon collisions we have identified 8 proton–antiproton pairs with particle momenta between 0.4 and 0.9 GeV/c corresponding to an invari-

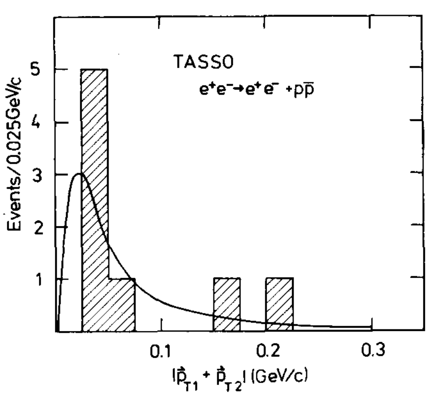

Fig. 2. Distribution of the sum of the transverse momenta for the 8 candidate $\gamma\gamma \to p\bar{p}$ events. The full line is the prediction of the Monte Carlo simulation normalized to the data.

ant mass range between 2.0 and 2.6 GeV. The data are consistent with the exclusive process $\gamma\gamma \to p\bar{p}$ leading to a cross section of $\sigma_{\gamma\gamma \to p\bar{p}} = 4.5 \pm 1.6 \pm 0.8$ nb.

We gratefully acknowledge the support by the DESY directorate and the tremendous efforts of the PETRA machine group, in particular Drs. Steffen and Degèle, for successfully increasing the luminosity with the new minibeta insertions. We wish to thank the technical service groups at DESY and all the engineers and technicians at the collaborating institutions for their invaluable help. Those of us from outside DESY wish to thank the DESY directorate for the hospitality extended to us while working at DESY. We thank Professor Renard for discussions on $\gamma\gamma \to p\bar{p}$.

References

[1] PLUTO Collab., Ch. Berger et al., Phys. Lett. 94B (1980) 254.
[2] A. Courau et al., Phys. Lett. 96B (1980) 402.
[3] C.J. Biddick et al., Phys. Lett. 97B (1980) 320.
[4] TASSO Collab., R. Brandelik et al., DESY 81/026 (June 1980), to be published in Z. Phys.
[5] Mark II Collab., A. Roussarie et al., SLAC-PUB-2734 (1981).
[6] TASSO Collab., R. Brandelik et al., Phys. Lett. 97B (1980) 448.
[7] TASSO Collab., R. Brandelik et al., Z. Phys. C4 (1980) 87; Phys. Lett. 83B (1979) 621.
[8] P. Schildt, H.-J. Stuckenberg and N. Wermes, Nucl. Instrum. Methods 178 (1980) 571.
[9] TASSO Collab., R. Brandelik et al., to be published.
[10] J.H. Field, Nucl. Phys. B168 (1980) 477 (and Erratum).
[11] J. Smith, J.A.M. Vermaseren and G. Grammer, Phys. Rev. D15 (1977) 3280.
[12] CERN-HERA 79-03 data compilation.
[13] D.L. Hartill et al., Phys. Rev. 184 (1969) 1415.