FIRST OBSERVATION OF HADRON PRODUCTION IN e^+e^- COLLISIONS AT 13 AND 17 GeV CMS ENERGY WITH THE PLUTO DETECTOR AT PETRA

PLUTO Collaboration

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First results from the magnetic detector PLUTO at the new e^+e^- storage ring PETRA are shown. The ratio R of the cross section for hadron production to that for μ-pair production has been measured to be $R = 5.0 \pm 0.5$ at 13 GeV and 4.3 ± 0.5 at 17 GeV. Both values have an additional systematic error of 20%. The events show a typical 2-jet structure. The mean transverse momentum approaches a constant value with increasing energy implying a shrinkage of the jet opening angle

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In this letter we report first results obtained with the PLUTO detector operating at the new e^+e^--storage ring PETRA at DESY in Hamburg. With the start of PETRA the energy range in e^+e^- physics has been extended considerably. At present, center of mass energies of 17 GeV have been obtained. With the data sample taken up to the end of January 1979 we check the $1/s$-dependence of the hadronic annihilation cross section and the topology of hadronic events which has been shown to be increasingly jetlike [1] up to 9.4 GeV. Deviations from the expected behaviour should indicate interesting changes in the process of e^+e^- annihilation, for the new energy region between 9.4 and 17 GeV. In addition to annihilation events we also observed events which give evidence for hadron production by two-photon interaction,

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

The e^+e^--storage ring PETRA (Positron Electron Tandem Ring Accelerator) came into operation in summer 1978. A detailed description of this machine is given in ref. [2]. Until the end of January 79 about 25 days runtime were made available to experiments. During this period with colliding electrons and positrons PETRA operated at 6.5 and 8.5 GeV per beam. With beam currents up to 2 mA per bunch typical luminosities measured were 5×10^{29} cm^{-2}s^{-1}.

The magnetic detector PLUTO which was recently used for experiments at the DORIS e^+e^--storage ring in the $\Upsilon(9.46)$ energy region [1,3] was moved to the North East interaction region of PETRA. The central part of the detector, which remained unchanged, uses a superconducting solenoid providing a field of 1.65 T. Its inner volume is filled with 13 cylindrical proportional wire chambers for tracking and momentum measurement. A set of shower counters measures photon and electron energies. The flux return yoke is used as a hadron absorber of an average thickness of about 70 cm iron equivalent and is covered by proportional tube chambers for identification of muons.

For experiments at PETRA the detector was extended by several new components (fig. 1). The flux return yoke has been surrounded by an "iron house", covered by planar drift chambers, to increase the total thickness of the hadron absorber to about 1 m of iron equivalent. In both beam directions the detector has been equipped with forward spectrometers in order to measure photons and electrons produced at small angles. Each arm of the forward spectrometer consists of a "large angle tagger" (LAT) and a "small angle tagger" (SAT). The LAT covers the polar angle region between 70 and 260 mrad. The energy of elec-

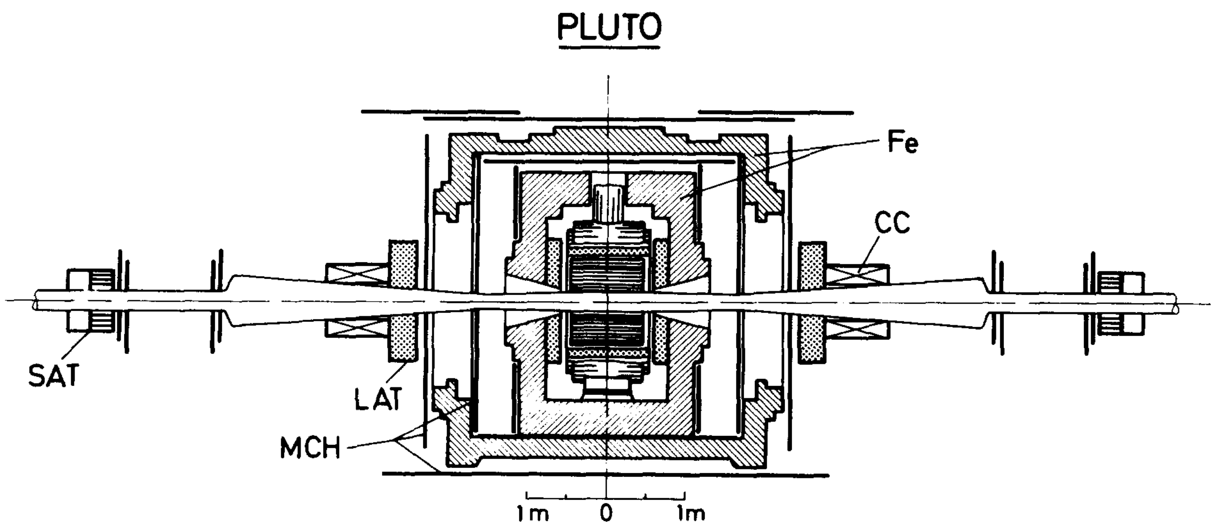

Fig. 1. Cross-sectional view of the PLUTO detector along the beam line (SAT = small angle tagger, LAT = large angle tagger, Fe = hadron absorber consisting of iron yoke and "iron house", MCH = chambers for muon detection, CC = compensation coils).

trons and photons is determined with a lead scintillator shower counter of 14.5 radiation lengths thickness. The position of charged particles is determined by four planes of proportional tube chambers with a wire spacing of 1 cm. The SAT covers the angular region between 23 and 70 mrad. Energy information of electrons and photons is obtained by a lead glass shower counter matrix. It consists of 96 lead glass blocks (each with a front area of $6.6 \times 6.6\ \mathrm{cm}^2$) in a concentric arrangement around the beam pipe. The thickness of this counter is 12.5 radiation lengths. Tracking of charged particles can be done by a set of four planar proportional wire chambers (wire distance 0.3 cm). In a test beam the energy resolution of the LAT was measured to be $11\%/\sqrt{E}$ (rms) and of the SAT $8.5\%/\sqrt{E}$ (rms), E in GeV.

The detector was triggered by one of the following conditions:

(i) two coplanar or three arbitrary tracks found by the wire logic of the central detector,

(ii) an energy of more than 3 GeV deposited in the inner shower counters,

(iii) more than 3 GeV in both forward spectrometers,

(iv) a coincidence requiring 2×0.5 GeV or 1×3 GeV in the forward spectrometers, together with either 1 GeV shower energy or one track in the central detector.

The trigger was gated by a bunch crossing signal. The rate was about 5 triggers per second, out of which ~20% are due to cosmic rays.

The luminosity was determined by measuring events from Bhabha scattering in the small angle tagger. We required an energy deposit of more than 3 GeV in both small angle monitors. In addition we only accepted events with a collinearity angle of less than 21 mrad. From the distribution of the energy and the collinearity angle we estimated the background in the remaining sample. This background was highest (~10%) just after the beams had been brought to collision; on average, however, it was less than 2%.

After applying radiative corrections [4], we get an integrated luminosity for the data samples at 17 and 13 GeV center of mass energies of $88.3\ \mathrm{nb}^{-1}$ and $42.6\ \mathrm{nb}^{-1}$, respectively.

Using the LAT and the central shower counters we are able to check our luminosity measurement by two completely independent devices. Comparing detector acceptances the Bhabha rates in the LAT are expected to be lower by a factor of 9.5 with respect to the SAT. Applying similar cuts in energy and collinearity to the LAT events we find for a subsample of runs that the two measured luminosities agree within ±8%. For a measured luminosity of $18.6\ \mathrm{nb}^{-1}$ in the SAT we expected 170 Bhabha events in the inner shower detector, using only the polar angle region between 30.5° and 149.5°, while we observed 173 events. From both comparisons we estimate the systematic error of our luminosity measurement to be 10%.

The wide angle Bhabha scatters recorded with the central detector have been used to determine the interaction point. Fig. 2a shows the distribution of the reconstructed vertices along the beam line. From a gaussian fit we derive the bunch length to be $\sigma_b = 11.8 \pm 0.5$ mm being in good agreement with the value of $\sigma_b = 11.4$ mm obtained by machine studies.

To select hadronic e^+e^--annihilation events we applied the following criteria:

(i) number of charged prongs ≥ 2,

(ii) difference in azimuthal angle for 2-prongs $\Delta\phi < 150°$,

(iii) detected neutral energy $\geq 0.3 \times E_{cm}$.

These cuts are similar to those used in our previous analyses of hadronic events [1,3].

Background from beam gas interactions was estimated by measuring the distribution of reconstructed event vertices along the beam line and was found to be small (fig. 2b). Radiative Bhabha scatters were removed by excluding any 2- or 3-prong events in which a track had an associated shower with an energy of more than $0.3 \times E_{beam}$.

A further background to the annihilation process may arise from two-photon interactions. Using the standard model calculations for the cross section $\sigma_{\gamma\gamma \to \mathrm{hadrons}}$ [5], we expect from a Monte Carlo study, introducing the same cuts as described above, a visible cross section of 0.15 nb and thus 13 events in our 17 GeV sample, and 6 events in the 13 GeV sample.

Our final sample contains 96 events at 13 GeV and 108 events at 17 GeV. To obtain the total cross section these numbers have been corrected for acceptance losses (28%), radiative effects (−10%), and for the estimated contamination of two-photon events. Table 1 shows the resulting values for $R = \sigma(e^+e^- \to \mathrm{hadrons})/\sigma_{\mu\mu}$ at 13 and 17 GeV together with PLUTO

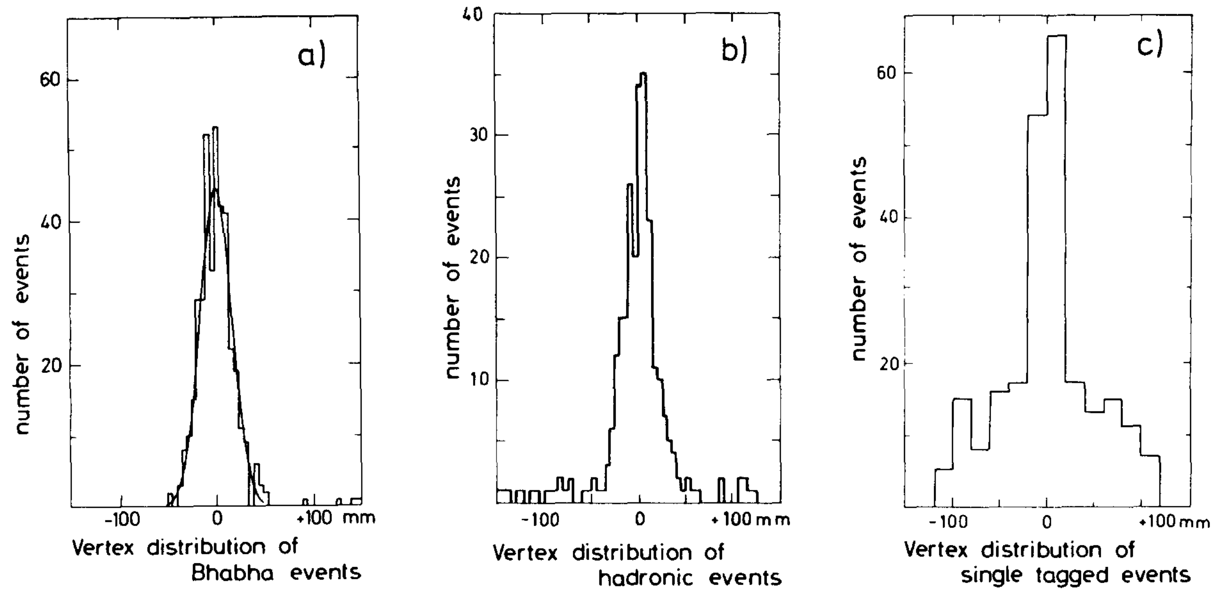

Fig. 2. Distributions of the reconstructed event vertices along the beam line, (a) and (b) are given for a subsample of the data (22.6 nb^{-1}). (a) Bhabha scattering events recorded with the central detector; the solid line is a gaussian fit to the data. (b) Hadronic events of the e^+e^- annihilation. (c) Events with at least one tag in the forward spectrometer and ⩾2 prongs in the central detector ("2-γ" candidates).

Table 1
Ratio R of the total hadronic cross section divided by $\sigma_{\mu\mu}$ for 13 and 17 GeV, and some selected energies measured with PLUTO at lower E_{cm}. The contribution from $e^+e^- \to \tau^+\tau^-$ has been subtracted.

E_{cm} (GeV)	R	
3.6	2.08	0.03
4.03	4.49	0.09
5.0	3.82	0.04
7.7	3.92	0.26
9.4	3.70	0.30
13.0	5.0	0.5
17.0	4.3	0.5

measurements at lower energies [6,3]. Contributions to R from τ-pair production have been removed at all energies [‡1]. The errors in table 1 do not include systematic errors which have been estimated to be 15% below 10 GeV and 20% above 10 GeV. These systematic errors account for uncertainties in the model used for the acceptance calculation, in the monitoring and in the contamination from two-photon interactions. Our data are consistent within errors with R being constant over the large energy range from 5 to 17 GeV.

For the investigation of event topologies we required in addition to the criteria given above a minimum of 4 charged tracks per event. This cut removes 19% and 13% of the events at 13 and 17 GeV respectively. We determined for each of the events sphericity and thrust [‡2] as well as the mean transverse and parallel momentum with respect to the jet axis, using the charged tracks observed. These topological quantities are compared with a 2-jet Monte Carlo prediction [7] which, however, only includes jet production from the u, d and s quarks. The data presented here are not corrected for acceptance and cuts. We take account of this by imposing identical cuts on the Monte Carlo events.

The mean observed sphericity for energies between

[‡1] Note that the values for R given in refs. [3] and [6] include the τ-contribution.

[‡2] We used sphericity and thrust as defined in ref. [1].

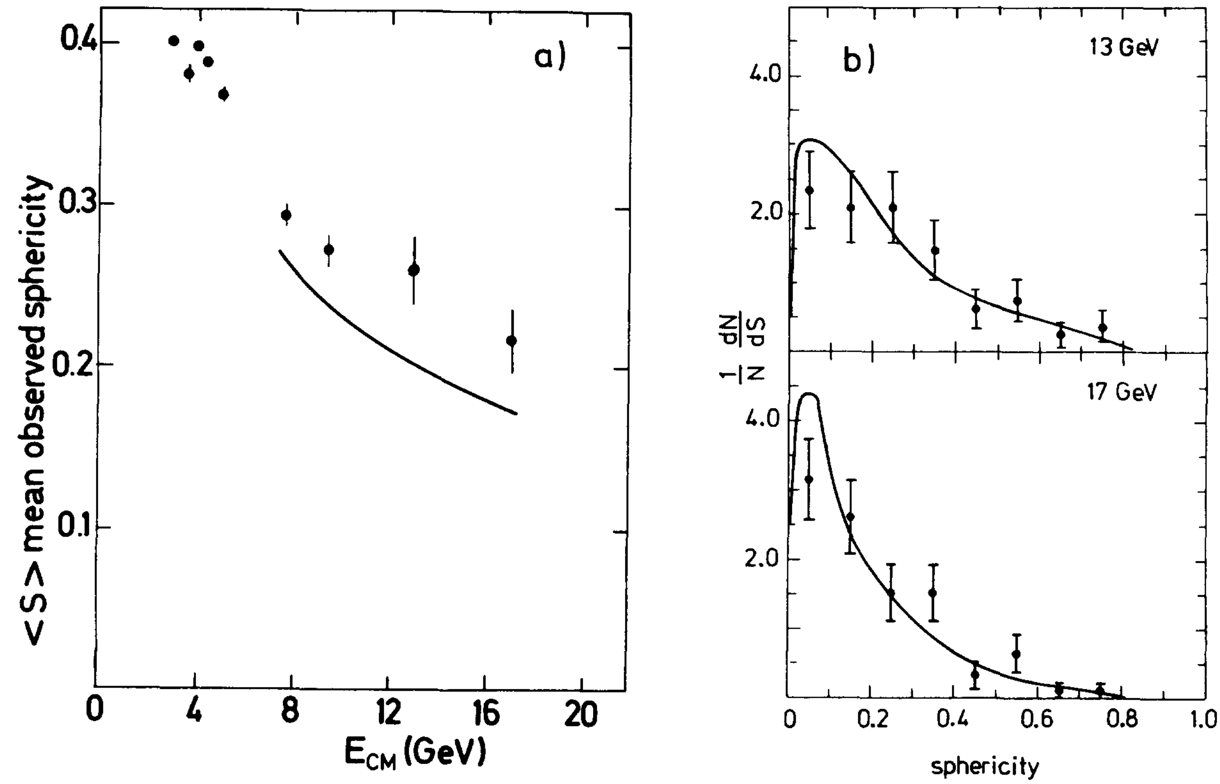

Fig. 3. (a) Mean observed sphericity for ⩾ 4 prongs versus center of mass energy. The solid line is the prediction of the 2-jet Monte Carlo calculation. (b) Distribution of sphericity for 13 and 17 GeV.

4 and 17 GeV is plotted in fig. 3a. The distribution of sphericity is shown in fig. 3b for the events at 13 and 17 GeV. We also determined the thrust variable, which shows features rather similar to sphericity. The values for the average thrust (sphericity) are 0.82 ± 0.01 (0.26 ± 0.02) at 13 GeV and 0.84 ± 0.01 (0.22 ± 0.02) at 17 GeV. The 2-jet Monte Carlo describes well the observed trend of sphericity to decrease with energy (fig. 3a, full line). The difference in absolute value may be attributed to the fact that the model does not include heavy quarks.

A characteristic feature of hadronic jets is the limitation of the mean momentum transverse to the jet axis $\langle p_t \rangle$, whereas the mean parallel momentum $\langle p_\parallel \rangle$ should grow with increasing energy. These quantities are plotted in fig. 4. To suppress the non-scaling part of the single-particle distribution we have plotted $\langle p_\parallel \rangle$ with a cut $x_\parallel = 2p_\parallel/E_{cm} > 0.1$, which shows almost a linear rise with energy as expected from scaling. The transverse momentum shows almost no change at higher energies and has a value of about 350 MeV/c. Both features imply that the jet opening angle up to 17 GeV continues to shrink with increasing energy.

With the extended PLUTO detector we are able to detect events resulting from two-photon interactions by requiring the outgoing electron (positron) to be tagged in the forward spectrometers. In fig. 2c we show for a subsample of our data (22.6 nb^{-1}) the distribution of the event vertices along the beam line for all events with at least 1 GeV deposited in the forward spectrometers and with two or more prongs in the central detector. The distribution shows a clear peak at the interaction point on top of a constant background. The peak contains 85 events. For 10 of the

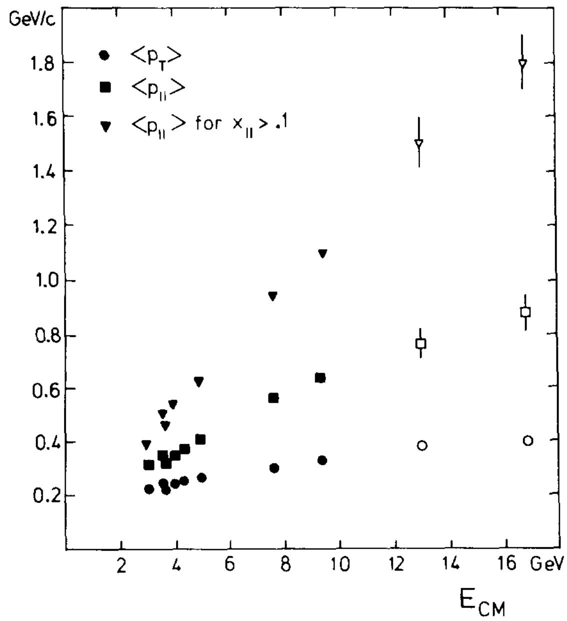

Fig. 4. Mean observed parallel and transverse momentum with respect to the jet axis. The triangle data points are obtained for $\langle p_{\parallel}\rangle$ with $x_{\parallel} = 2p_{\parallel}/E_{cm} > 0.1$.

events both electrons are tagged in the SAT, with all tracks in the central detector coming from the interaction point. Two of them have 4 non-showering tracks in the central detector, and at least these must be due to hadron production by two photons. For accidental coincidences between the small angle tagger and the central detector we estimate an upper limit of 0.6%, based on the observation that only 1 of the 173 Bhabha events seen in the central detector is accompanied by a single tag in the SAT. Thus we expect only 0.3 accidental double tag events in our sample [‡3].

[‡3] Experimental details of the two-photon interactions observed are subject to a forthcoming paper.

In conclusion, R is fairly constant over the large energy range from 5 to 17 GeV. Our data do, however, allow for the small step and the structure expected from the b quark threshold. The event topology behaves as expected from a 2-jet model, with $\langle p_t\rangle$ approaching a constant value. There is clear evidence for hadronic two-photon events.

The outstanding efforts of the PETRA machine group which opened a new energy region to physics made this experiment possible. We congratulate and thank our colleagues working at PETRA for this remarkable achievement. We are also indebted to the technicians of the service groups who supported the experiment, namely, our cryogenic group, the computer center, the gas supply group and the vacuum group. We thank the Hallendienst, in particular Mr. H. Gosau, for all the efforts during the installation time of the detector. We are grateful to our technicians for construction and maintenance of the PLUTO detector. The non-DESY members want to thank the DESY directorate for support and hospitality extended to them.

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