Study of Electron-Positron Collisions at Center-of-Mass Energies of 27.4 and 27.7 GeV at PETRA

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This paper reports on the first results of the study of e^+e^- collisions at $\sqrt{s} = 27.4$ GeV and $\sqrt{s} = 27.7$ GeV at PETRA, using the 4π-sr electromagnetic and calorimetric detector MARK-J. We obtain an average $R = \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-) = 3.8 \pm 0.3$ (statistical) ± 0.6 (systematic) and a relative $R = 1.0 \pm 0.2$ between the two energies. The R values, the measured thrust distribution, and average spherocity show no evidence for the production of new quark flavors.

We have taken data with the MARK-J detector[1,2] at the high-energy electron-positron colliding-beam accelerator (PETRA) at center-of-mass energies $\sqrt{s} = 27.4$ and $\sqrt{s} = 27.7$ GeV with a peak luminosity of 1.5×10^{30} cm^{-2}/sec, and have obtained new results on hadron production by e^+e^- annihilation.

The MARK-J detector distinguishes charged and neutral hadrons, electrons, photons, and muons. It covers a solid angle of $\varphi = 2\pi$ and $\theta = 9°$ to $171°$ (θ is the polar and φ is the azimuthal angle). It surrounds the intersection region with Lucite Cherenkov counters followed by two layers (A and B) of three radiation lengths each of lead-scintillator shower counters, with one fast photomultiplier tube at each end. The counters A and B enable us to locate shower maxima in various θ and φ directions. They are followed by the sixteen C counters, consisting of twelve layers (twelve radiation lengths) of lead scintillator sandwich also with one tube at each end. Surrounding the electromagnetic shower counters are drift chambers which measure tracks from hadron showers and measure the incident muon angle. The next layers are hadron calorimeters consisting of magnetized iron scintillator sandwiches. The last layer of calorimeter, the D counters, is used for triggering on muons and for rejecting cosmic rays. The magnetic field in the iron is toroidal and its value is 17 kG. Finally, in the outermost layer we have drift chambers which are used to measure single- and double-muon exit angles and thus momenta.

The total energy of each interaction and the direction of a particle or group of particles is computed from the time and pulse-height information of the shower counters and calorimeter counters. The azimuthal position is determined by the finely segmented shower counters. This method enables us to determine the θ and φ angles to an accuracy of $<5°$ for e or γ and $<15°$ for μ or hadrons.

Events from the single-photon reaction $e^+e^- \to$ hadrons are selected as previously described.[1] The crucial criterion used to eliminate background from other processes is a total-energy cut. We require that the sum of measured energy in each event be greater than 50% of the center-of-mass energy, thus greatly reducing the contamination from two-photon processes which yield e^+e^- and hadrons.

A Monte Carlo program was used to compute the acceptance for

$$e^+e^- \to \text{hadrons} \tag{1}$$

and to determine the contribution to our hadron event sample from the two-photon process

$$e^+e^- \to \text{hadrons} + e^+e^- \tag{2}$$

and

$$e^+e^- \to \tau^+\tau^-. \qquad (3)$$

The Monte Carlo program described in our previous paper[1] has been improved. The program generates two jets for Reaction (1) according to the Feynman-Field *Ansatz*,[3] which includes not only u, d, and s quarks but also the contributions of c (charmed), b (bottom), and t (top) quarks. The branching ratios for the decays of the D and F mesons rely either on available experimental data or otherwise on the isospin-statistical models of Gaillard, Lee, and Rosner.[4] The branching ratios for the decay modes of B mesons (from $\bar{b}b$) and T mesons, which are yet to be observed, are based largely on the work of Ali and co-workers.[5,6] in the framework of the Kobayashi-Maskawa six-quark model.[7] The probability of producing each quark flavor is taken to be proportional to the square of the quark charge q, with $q_c = \frac{2}{3}$ and $q_b = \frac{1}{3}$.

Acceptances for Reaction (1) were computed using u, d, s, c, and b quarks only, with the masses of the B mesons taken to be in the range of 5–6 GeV, expected if the Υ is a $b\bar{b}$ bound state. The production of t-quark pairs was only considered in connection with the jet analysis of the events which will be described later. Above this threshold the $t\bar{t}$ production probability was assumed to be $\frac{4}{15}$ of the total cross section, i.e., proportional to the square of the quark charges so that threshold effects were ignored. To improve the accuracy of the model computations for Reaction (1) we incorporated initial-state radiative effects[8,9] in the computer program.

The generation of events for Reaction (2) was performed in the equivalent-photon approximation with multipions only in the final state.[10] Simulated events for Reaction (3) were produced according to the "standard model," where the τ is considered as a sequential heavy lepton,[11] as indicated by available data.[12]

The acceptance after cuts is 80% for Reaction (1), 0.2% for Reaction (2), and 25% for Reaction (3). Consequently, contributions to the final value of R from Reactions (2) and (3) are 0.11 and 0.3, respectively. Systematic errors due to model uncertainties for the acceptance of Reaction (1) are 10% and the uncertainties in evaluating Reactions (2) and (3) are limited by the lack of experimental data on high-energy, high-multiplicity states.

At $\sqrt{s} = 27.4$ GeV we had an integrated luminosity of 260.3 nb^{-1} and 113 hadronic events and at $\sqrt{s} = 27.7$ GeV we had an integrated luminosity of 174.5 nb^{-1} and 77 events. The result of our measurement of the average relative hadron cross section is $R = 3.8 \pm 0.3$ (statistical) $\pm$ 0.6 (systematic). The relative R between the two energies is 1.0 $\pm$ 0.2. The corrections for the two-photon processes (2), τ production (3), and initial-state radiative corrections have been applied. This value of R is not significantly different from our result at $\sqrt{s} = 13$ and 17 GeV. The lower-energy R values were analyzed slightly differently[1] than in the present work. We had obtained values of $R = 4.6 \pm 0.5$ (statistical) $\pm$ 0.7 (systematic) at $\sqrt{s} = 13$ GeV and $R = 4.9 \pm 0.6$ (statistical) $\pm$ 0.7 (systematic).

A jet analysis of the hadronic events was performed with use of the spatial distribution of the energy deposited in the detector. For each counter hit a vector $\vec{p}_i$ is constructed, whose direction is given by the position of the signal in the counter, and magnitude by the corresponding deposited energy. The thrust parameter T and the spherocity parameter S' are then defined as

$$T = \max(\sum |p_{\parallel}{}^i| / \sum p^i),$$

$$S' = (4/\pi)^2 \min(\sum |p_{\perp}{}^i| / \sum p^i)^2,$$

where $p_{\parallel}{}^i$ ($p_{\perp}{}^i$) is the parallel (perpendicular) component of $\vec{p}_i$ along a given axis, and the maximum (minimum) is found by varying the direction of this axis. The sums are taken over all counter hits.

The normalized thrust distributions $N^{-1} dN/dT$ for 13-, 17-, and the average of 27.4- and 27.7-GeV data (labeled 27 GeV combined) are shown in Fig. 1 along with the Monte Carlo predictions. The individual distributions at 27.4 and 27.7 GeV are in agreement with each other.

As expected for production of final states with two jets of particles, the distribution peaks at high T. The average T increases with c.m. energy, which is also expected if the outgoing particles have a limited transverse momentum with respect to the jet axis. The data are consistent with the Monte Carlo distributions which include u, d, s, c, and b quarks. The present data are also compared to a Monte Carlo distribution including a charge-$\frac{2}{3}$ (with mass 9–13 GeV) t quark produced as described above. The secondary peak in Fig. 1(c) moves by 0.05 units when we vary the mass of the t quark from 9 to 12 GeV. The data are inconsistent with productions of t quarks. The spherocity distributions yield the same conclusions.

The average thrust $\langle T \rangle$ and spherocity $\langle S' \rangle$ val-

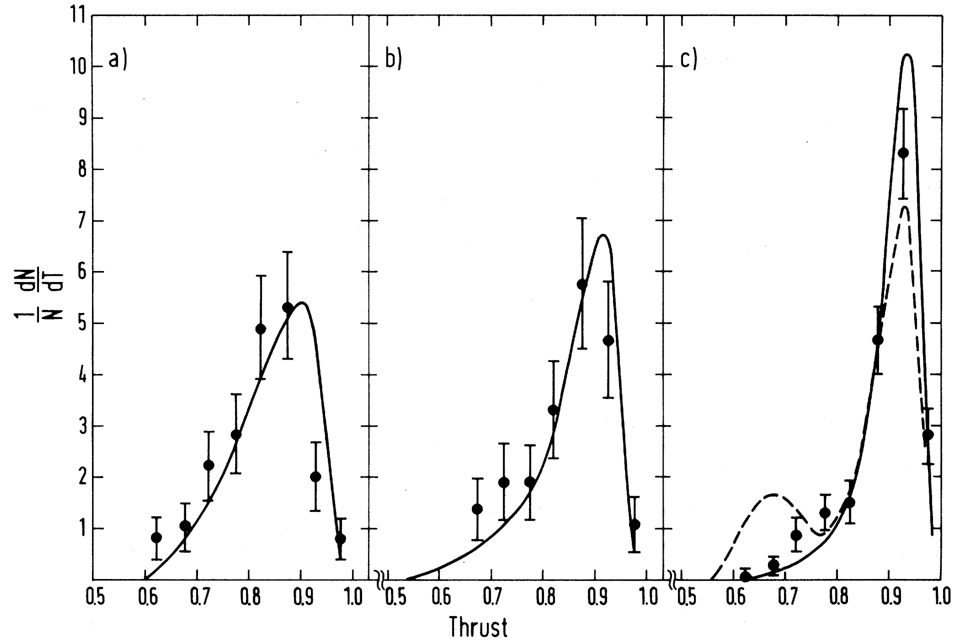

FIG. 1. The thrust distribution $N^{-1}dN/dT$ at (a) $\sqrt{s}=13$ GeV, (b) $\sqrt{s}=17$ GeV, and (c) $\sqrt{s}=27$ GeV combined. The solid curve is the Monte Carlo prediction based on u, d, s, c, and b quarks and the dashed curve in (c) has included the t-quark contribution. The data are in agreement with the prediction without t-quark contribution.

ues at the $\sqrt{s}$ value of 13, 17, and 27 GeV (combined) are, respectively, $(\langle T\rangle, \langle S'\rangle) = (0.82\pm0.01, 0.32\pm0.03)$, $(0.85\pm0.01, 0.24\pm0.03)$, $(0.88\pm0.01, 0.18\pm0.03)$.

Thus, within the limits of the model described earlier, our measurements of R, T, and S' all indicate that the production of a new charge-$\frac{2}{3}$ quark at this energy is unlikely.

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