A MEASUREMENT OF $e^+e^- \longrightarrow$ hadrons at $\sqrt{s} = 27.4$ GeV

D. Barber, U. Becker, H. Benda, A. Böhm, J. Branson, J. Bron, D. Buikman, J. Burger, C.C. Chang, M. Chen, D.P. Cheng, Y.S. Chu, P. Duinker, H. Fesefeldt, D. Fong, M. Fukushima, M.C. Ho, H.K. Hsu, R. Kadel, D. Luckey, C.M. Ma, G. Massaro, T. Matsuda, H. Newman, J.P. Revol, M. Rohda, H. Rykaczewski, T.T. Shui, H.W. Tang, S.C.C. Ting, K.L. Tung, F. Vannucci, M. White, T.W. Wu, P.C. Yang.

Aachen-Annecy-DESY-M.I.T.-NIKHEF-Peking Collaboration

Presented by James G. Branson, DESY, Hamburg, W. Germany.

ABSTRACT

During the initial running of PETRA at 27.4 GeV, we have measured the reaction $e^+e^- \longrightarrow$ hadrons using the MARK J detector. We find a value of R of 4.1 ± .5 (statistical) ± .7 (systematic). Events are analyzed in terms of thrust and sperocity. Overall, we find no evidence for a new threshold in hadron production up to the present energy.

During April and May, PETRA has been running with a beam energy of 13.7 GeV. Up to the present time, we have detected 101 hadronic events mainly from the process $e^+e^- \longrightarrow$ hadrons using the MARK J detector. Since PETRA has opened up a large new energy region, between 10 GeV and 27 GeV, it is most interesting to determine if a threshold for production of new hadronic particles has been crossed. The most mundane new particles would be those with the quantum number "top". They would contain a t quark which is thought to belong in a doublet with the b quark, a component of an upsilon. The t quark should have charge 2/3. Of course it is also quite possible that a charge 1/3 quark could have a lower mass than the t quark or that there is a new color degree of freedom at high energy. There may be a threshold for some particles that we know nothing about.

The data on $e^+e^- \longrightarrow$ hadrons taken so far is consistent with a simple model in which the electron and positron annihilate, producing a timelike photon. The photon then decays to a quark antiquark pair. The quark and antiquark each produce a hadron jet by pulling more $q\bar{q}$ pairs out of the sea. These final state interactions between the quarks do not alter the cross section very much. The cross section is also only slightly modified by radiative corrections. This allows a simple comparison to the process for $e^+e^- \longrightarrow \mu^+\mu^-$ which proceeds by the same process. The ratio is simply

$$R = \frac{\sigma(e^+e^- \longrightarrow \text{hadrons})}{\sigma(e^+e^- \longrightarrow \mu^+\mu^-)} = \sum_{\substack{\text{flavors}\\ \text{colors}}} (q_i)^2$$

When we have crossed a threshold for production of a new kind of quark, the sum is then extended and the ratio R increases.

Another signal for production of a new particle is a change in the jet behavior of the events. In the simple model, the $q\bar{q}$ pair decay to hadrons with limited momentum transverse to the direction of the initial quark or antiquark. This transverse momentum is independent of energy except for relatively small possible effects of gluon emission. Then, as the center of mass energy increases, the initial quark has more momentum and the events become more and more jetlike.

However, if a very massive quark is produced near threshold, its momentum is rather small. The massive particle containing this quark should then decay with the daughter particles randomly distributed in direction. This type of event would be very spherical and such behavior would persist quite far above threshold if the mass of the particle is large. Thus production of spherical events is simply a kinematical property of the production of a massive quark near enough to threshold. The result is that we would expect to see a class of very spherical events, from the new particles, mixed with the jetlike events. This is a statistically more powerful way of looking for new flavor production.

To study the hadronic events, we used the MARK J detector which has been previously described[1]. It consists of an electromagnetic shower counter followed by a hadron calorimeter. These both cover a solid angle of nearly 4π steradians. In addition, muons are identified and momentum analyzed in a drift chamber iron magnet system. To identify hadronic events, we require that at least 65% of the center of mass energy be deposited in the detector. Our overall energy resolution is less than 20% σ because a very large fraction of the energy is deposited in the shower counter.

To calculate the acceptance of the detector and to compare data to the expectations from the quark parton model we use a detailed Monte Carlo program. This generates events by producing $q\bar{q}$ pairs, the relative flavor productions being determined by the square of the quark charges. In general, we use u, d, s, c and b quarks; however, to test for the existence of a new flavor, we generate events with t quarks of charge 2/3 and mass 12 GeV. The initial quarks then fragment, producing hadrons according to the Feynman-Field Monte Carlo method. For the results I will show, we have used fragmentation functions

$$D(z) \propto (1 - z)^2$$

for all flavors. We have tried a constant D(z) for charmed, bottom and top quarks and found that this does not significantly effect our conclusions. The average $p_\perp$ of the primary mesons is 323 MeV.

The unstable mesons are then allowed to decay, with branching ratios taken whenever possible from the data. For the bottom and top particles, we have used the expectations of Ali et al.[2] which include 30% semileptonic decays. The final particles are traced through the detector depositing energy in the counters and causing hits in the drift chambers. From this information, counter ADCs and TDCs are generated as well as drift wire TDCs. All of this information is then passed on to the same analysis program used for normal data. The same cuts are applied and the acceptance is found to be .785.

Other processes are also generated by the Monte Carlo to measure our sensitivity to them. We find that $e^+e^- \longrightarrow \tau^+\tau^-$ contributes 0.3 to R. Also, $e^+e^- \longrightarrow e^+e^-$ + hadrons contributes 0.1.

Up to the time I left Hamburg, we had analyzed 101 hadronic events at 27.4 GeV. Of these, 12 have tracks that penetrate more than one meter of iron. This fraction is up substantially from the 13 and 17 GeV data and is insensitive to punchthrough. From these 101 events, we compute the value of R shown in Table 1 along with our previously reported values at 13 and 17 GeV.

Table 1

$\sqrt{s}$ (GeV)	13	17	27.4
R	4.5 ± .5 ± .7	4.9 ± .6 ± .7	4.1 ± .5 ± .7

The contamination from τ pair production and two photon processes has been subtracted. If the effects of initial state radiation are corrected for, the value of 4.1 changes to 3.7. The data at the three energies are in agreement with a constant value of R but of course this must be checked more thoroughly by taking data at intermediate energies. At any rate there is no evidence for an increase in R which would signal the production of new particles.

We have analyzed the jet behavior of the data in terms of the quantities, thrust and spherocity, defined below.

$$T = \max \left[\frac{\Sigma\, p_{\parallel}}{\Sigma\, p}\right] \qquad \text{and} \qquad S' = (4/\pi) \min \left[\frac{\Sigma\, p_{\perp}}{\Sigma\, p}\right]^2$$

These are parameters of each event that are maximized or minimized by choosing a single jet axis with respect to which $p_{\parallel}$ and $p_{\perp}$ are calculated.

Since we have a calorimetric detector, we do not measure the momenta of individual particles in a jet. We do however measure the energy flow for an event. Thrust and spherocity are defined in terms of particle momenta but, in fact, for these, only the energy flow is needed. We are therefore able to test the jet behavior by a method we call pseudotracks. A track is defined for each hit counter. The direction of the track is determined from the position of the hit and the magnitude from the energy depositied. Using this method, we reproduce the jet axis with either thrust or spherocity with an RMS error of less than 10 degrees.

Thrust distributions for energies of 13, 17 and 27.4 GeV are shown in figures 1a), 1b) and 1c). The solid lines are Monte Carlo calculations with u, d, s, c and b quarks and the dashed line in figure 1c) is with the addition of a t quark. At 13 and 17 GeV, the data and Monte Carlo agree quite well. At 27.4 GeV, the data are in reasonable agreement with the Monte Carlo although they may tend to be less strongly peaked. The data do not agree with the curve including top. In the region from .5 to .7, we would expect 12 events if top were being produced and we see zero. This is statistically quite powerful but perhaps model dependent. For instance, if the top quark were stable, we would not see a signal in the low thrust region from it.

Finally, we have calculated average values of thrust and spherocity, corrected for detector smearing, which are shown in Table 2. These are in good agreement with the Monte Carlo expectations.

Table 2

Corrected Average Thrust and Spherosity

$\sqrt{s}$	13	17	27.5
<T>	.82 ± .01	.85 ± .01	.87 ± .01
<S'>	.32 ± .03	.24 ± .03	.17 ± .03

In conclusion, we have studied hadron production for 27.4 GeV electron positron collisions and found no evidence for a new threshold in either the value of R or in the thrust distribution. In particular, a new charge 2/3 quark seems to be ruled out. We do not yet have enough information to comment of new leptons although we do recognize a probable τ signal in the data in the μ hadron mode.

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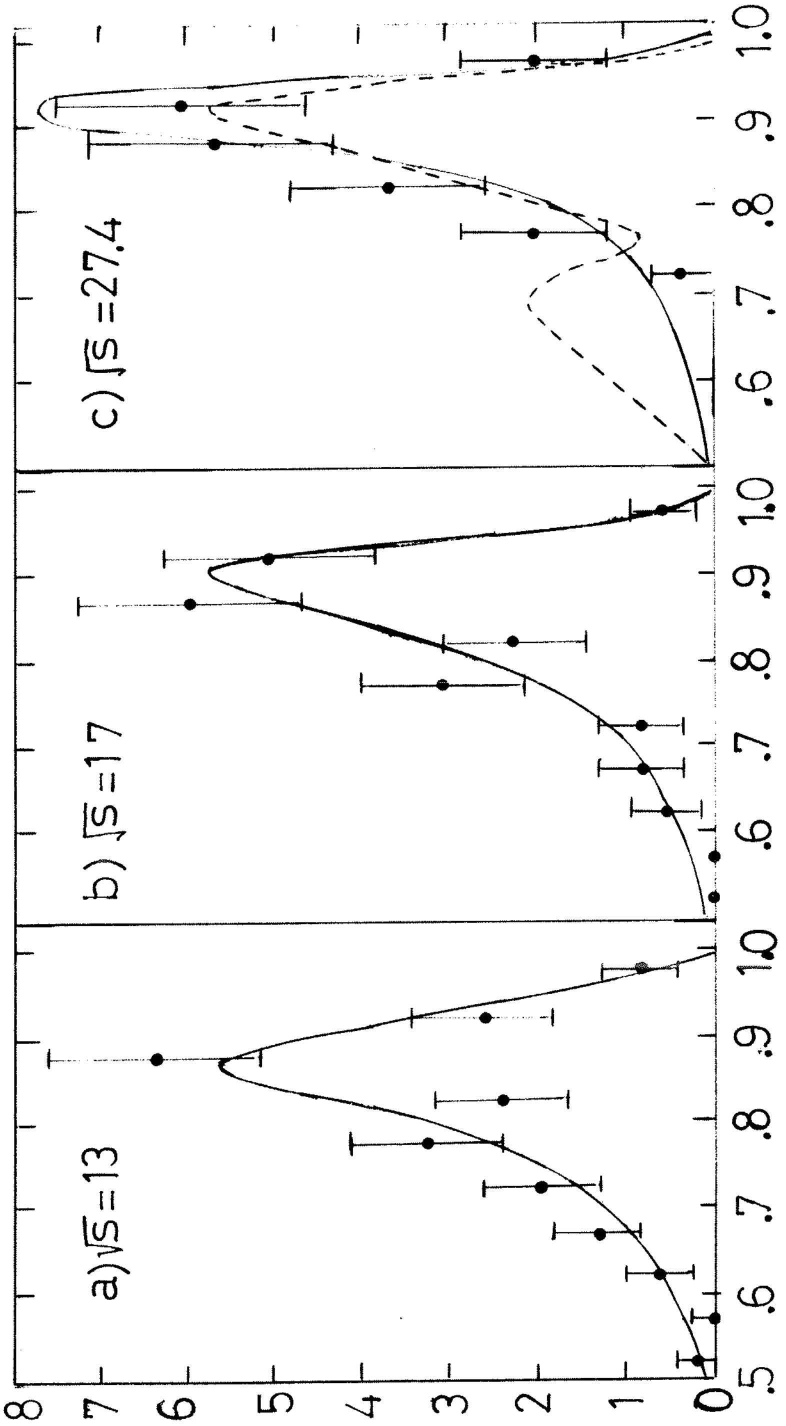

fig. 1