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THE HADRONIC FINAL STATE IN e^+e^- ANNIHILATION AT C.M. ENERGIES OF 13, 17 AND 27.4 GeV

by

TASSO Collaboration

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THE HADRONIC FINAL STATE IN e^+e^- ANNIHILATION AT C.M. ENERGIES OF 13, 17 AND 27.4 GeV

TASSO Collaboration*

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ABSTRACT

Results on the hadronic final state in e^+e^- annihilation at 13, 17 and 27.4 GeV are presented. There is no compelling evidence for the existence of the t quark in these data, which are in general agreement with a simple quark parton model. Some tentative indications of QCD effects are observed in the p_T^2 distributions.

1. THE TASSO DETECTOR AND EXPERIMENT

The TASSO detector is sited at one of the intersection points at the PETRA e^+e^- storage ring at DESY and has been described in detail previously[1]. The data described here have been obtained with only a part of the final detector. This consists of a large magnetic solenoid, 440 cms in length and with a radius of 135 cms producing a field of 0.5 Tesla parallel to the beam axis. The solenoid is filled with tracking chambers to allow measurement of the charged particles produced in the interactions. A luminosity monitor, which measures small angle Bhabha scattering, consists of eight counter telescopes mounted symmetrically with respect to the beam line and interaction point.

A particle emerging from the interaction point traverses the beam pipe and one of 4 scintillation counters which form a cylinder around the beam pipe, before entering a low mass cylindrical proportional chamber, a drift chamber and a set of time of flight counters. The proportional chamber has four gaps each containing anode wires parallel to the beam axis. The efficiency of the anode wires was 97%. The drift chamber contains 15 layers, 9 with sense wires parallel to the axis (zero-degree layers) and 6 with the sense wires oriented at approximately $\pm 4^{\circ}$ to the axis (stereo layers). The efficiency of each layer was found to be 96% together with a resolution of approximately 0.3 mm. Finally there are 48 time of flight counters (TOF) mounted between the drift chamber and the coil.

The 27.4 GeV data were obtained with the following trigger (which differs slightly from that used at 13 GeV and 17 GeV[1]): A coincidence between beam pick up signal, any beam pipe counter and any TOF counter gated information from 6 of the 9 zero degree layers of the drift chamber into a hardwired logic unit. This unit searched for tracks and determined their transverse momentum. Simultaneously the hits in the proportional chamber were gated into a separate processor which searched for track segments. A track was finally defined as the coincidence between a track from the drift chamber processor, a track segment from the proportional chamber processor and a TOF counter which was set. The trigger demanded either two tracks coplanar with the beam axis or at least four tracks. The transverse momentum of these tracks with respect to the beam axis was required to exceed 320 MeV/c. The resulting trigger rate was in the range of 1.0-2.0 Hz.

The luminosity was determined from measurements of the Bhabha cross-section at small angles. Large angle Bhabha scattering observed in the central detector was found to be consistent with these values within the statistical and systematic errors.

The resulting data samples and integrated luminosity are summarized in Table 1.

Table 1

Data samples and integrated luminosities

Energy	13	17	27.4
$\int Ldt$ (nb^{-1})	31.0	39.2	99.2
Triggers (K)	∿350	∿300	∿300

2. THE SELECTION OF MULTIHADRON EVENTS AND THE MEASUREMENT OF R

In this section the criteria applied to select multihadron events from the 27.4 GeV data are described (these again differ slightly from those employed at 13 and 17 GeV[1]). Two steps were used to select the multihadron events:

At least 3 tracks were required in the projected r-ϕ plane (perpendicular to the beam axis) with at least 2 fully reconstructed in three dimensions. The three tracks have d < 2.5 cms and $|z| < 10$ cms, where d is the distance of closest approach in the r-ϕ plane and z is the z coordinate of the point of closest approach to the z axis (the beam axis). Furthermore at least one charged track must be in each of the two hemispheres oriented along the beam direction and the sum of the absolute values of the momenta should exceed 1 GeV. Approximately 120 events remained after applying these criteria.

An excess of events at low W (invariant mass) was apparent which we ascribed to beam gas and $\gamma\gamma$ interactions[2]. By considering events with $10 < |z| < 30$ cms we have been able to study beam gas effects. Requiring the sum of the absolute value of the momenta to exceed 9 GeV in an event ($\sum_i p_i \geq 9$ GeV) effectively removes all such events. The $\gamma\gamma$ interactions mainly populate low W also and thus this cut removes essentially all the $\gamma\gamma$ background too. That the $\gamma\gamma$ process was present can be deduced from our observation of

(i) events with one tagged electron

(ii) $\gamma\gamma \to \mu^+\mu^-$ and e^+e^- in the central detector

and we have checked that these events are consistent with the expected energy dependence of the $\gamma\gamma$ process.

In the second step to obtain multihadron events we applied the following criteria

(i) $\sum_i p_i \geq 9$ GeV (45 events remain)

(ii) events with one charged track in one hemisphere recoiling against the remaining tracks in the opposite hemisphere were removed. This is designed to remove heavy lepton contamination[3] (2 events are removed).

The remaining events, 43 in total, constituted the multihadron sample at 27.4 GeV and contains essentially no background.

In order to measure the total cross-section (and R) we have calculated the detection efficiency for events to trigger the apparatus and satisfy our selection criteria, using a 2 jet Monte Carlo program[4]. The detection efficiency was found to be 0.75 at 27.4 GeV and fairly stable to changes in the input to the 2-jet Monte Carlo. The resulting value for R was 5.0 ± 0.8 which after radiative corrections led to a value of

$$R = 4.6 \pm 0.8 \pm 0.9$$

where the two contributions to the error are our estimates of the statistical and systematic errors respectively.

The values of R that we have measured are summarized in Table 2.

Table 2

The value of $R = \sigma_{hadrons}/\sigma_{\mu\mu}$

Energy (GeV)	13	17	27.4
R	$5.6 \pm 0.7 \pm 1.1$	$4.0 \pm 0.7 \pm 0.8$	$4.6 \pm 0.8 \pm 0.9$

Our expectations for R within the quark model are

u d s c b $\qquad$ $R = 11/3$

u d s c b + t $\qquad$ $R = 5$

From our results on R it is clear that we have no evidence for or against the existence of a new charge 2/3 or 1/3 quark or a charge 1 lepton.

3. INCLUSIVE PROPERTIES OF THE HADRONIC FINAL STATE

(i) Single particle inclusive spectra

Within the simple quark parton model the inclusive cross-section $\left(\frac{S}{\beta}\right) \frac{d\sigma}{dx_E}$ should scale with C.M. energy[5]. β is the particle velocity, $x_E = \frac{2E_h}{W}$ and $S = W^2$. At present we do not determine the particle type and hence we have used the quantity $S\frac{d\sigma}{dx}$ with $x = P/P_{beam}$. The resulting inclusive distributions are shown in Fig. 1. It is clear that scaling exists for $x \geq 0.2$. Only with greater statistics will we be able to look for the expected scaling violations in these distributions. It is also worth noting that the inclusive distribution at low x in the 13 GeV data exceeds that at the other energies which when taken with the larger value of R might indicate large production of $b\bar{b}$ states at this energy.

(ii) Multiplicities and rapidity distributions

The mean charged multiplicities we observe are in excess of simple extrapolations of the form[6]

$$\langle n \rangle = 2.1 + 0.7 \ln s$$

from lower energies. Thus the increase in $\langle n \rangle$ is not due solely to a lengthening of the rapidity plateau, it must rise as well.

4. JET PROPERTIES OF THE HADRONIC FINAL STATE

In the simplest quark parton model we expect the final hadronic system to be obtained from an initial $q\bar{q}$ system, resulting in jets of particles surrounding the original quark

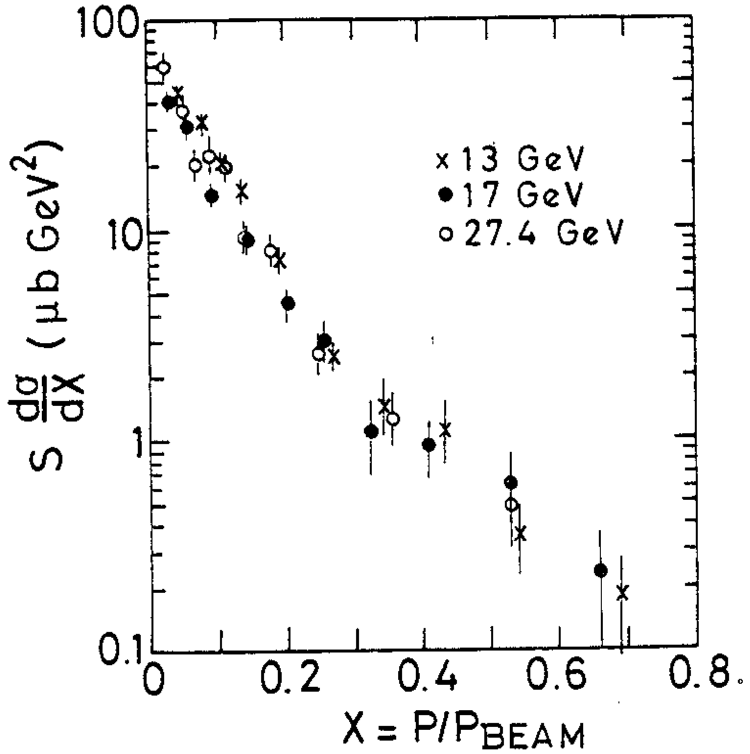

Fig. 1 The Inclusive Hadron Spectrum

direction having 'smallish' transverse momentum with respect to this direction. Within QCD modifications of this picture are expected where the quarks radiate gluons[7,8].

In order to study these jets we have defined the jet axis by minimizing the sphericity[9])

$$S = \frac{3}{2} \min \frac{\sum_i (p_T^i)^2}{\sum_i (p^i)^2}$$

where p^i is the momentum of a particle and p_T^i is its transverse component with respect to the axis. Studies using theoretically more desirable quantities e.g. thrust[8] lead to similar conclusions[10]. With the jet defined in this way we have studied

(a) sphericity distributions

(b) p_T^2 distributions

(c) jet axis angular distribution .

Our current low statistics (∿150 events at all energies) make the determination of the jet axis distribution (c) difficult. However the sum of all 3 energy samples is consistent with the expected form

$$\frac{d\sigma}{d\Omega} \propto 1 + \cos^2\theta$$

To study (a) and (b) we need to compare the data to a model. We have used the quark jet model described by Field and Feynman[4] with extensions to include c and b quark production[11]. The main assumptions are listed below

(i) quarks are produced according to the square of their charges

$$u\bar{u} : d\bar{d} : s\bar{s} : c\bar{c} : b\bar{b} = 4 : 1 : 1 : 4 : 1$$

(ii) quarks pairs are created in the fragmentation in the ratios

$$u\bar{u} : d\bar{d} : s\bar{s} = 2 : 2 : 1$$

(iii) the fragmentation function $f(\eta)$ is given by

$$f(\eta) = 1 - a + 3a\eta^2$$

with $a = 0.77$ $\eta = 1-z$ $z = E/Eq$

(iv) pseudoscalar mesons are produced as frequently as vector mesons

(v) the input mean p_T in the quark fragmentation is

$$\langle p_T^q \rangle = 0.250 \text{ GeV}$$

(vi) a statistical model is used for the decays of mesons containing c and b quarks

(vii) the masses of mesons containing b quarks are in the range $5.5 \rightarrow 6$ GeV

It is against this background that we have searched for the existence of the t-quark or QCD gluon effects.

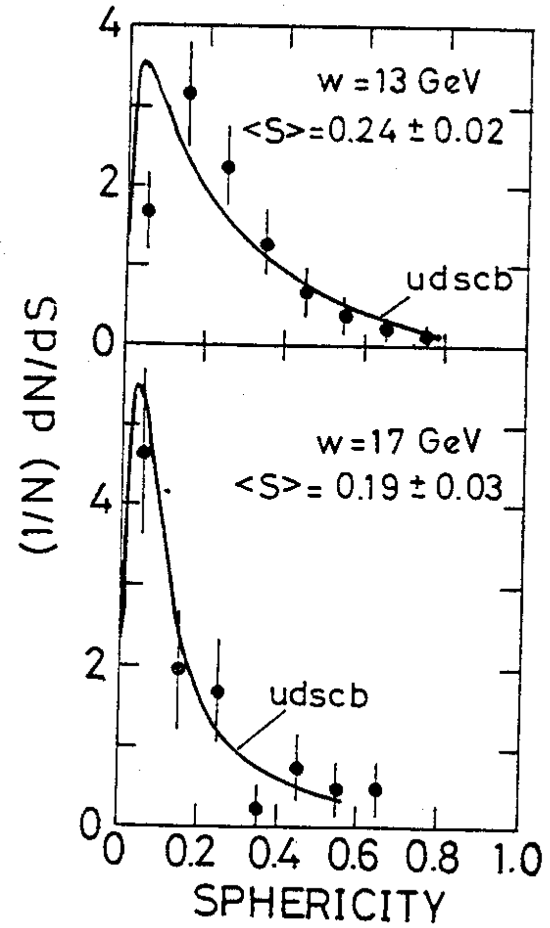

Fig. 2a Sphericity distributions at 13 and 17 GeV. The curves are from the two jet Monte Carlo with u,d,s,c,b quarks.

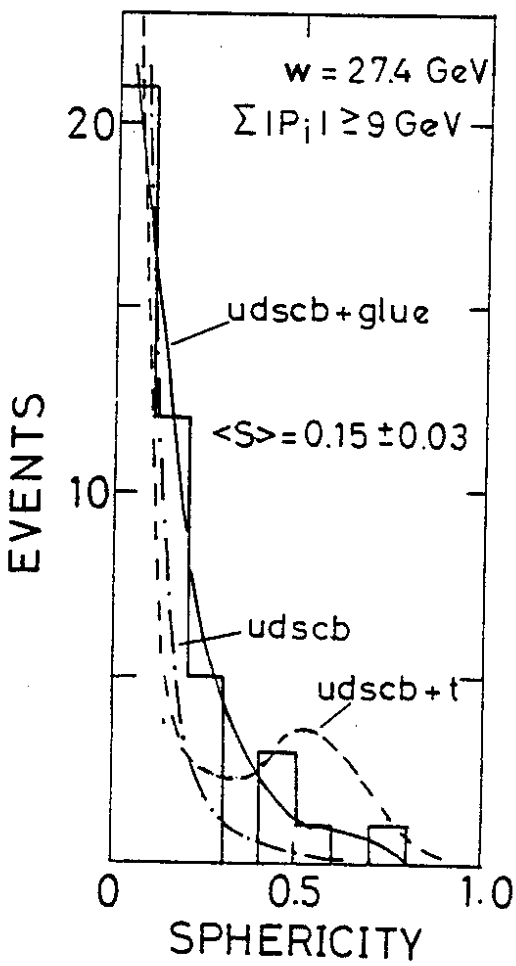

Fig. 2 b Sphericity distribution at 27.4 GeV together with different model predictions.

(a) Sphericity distributions

In Fig. 2a the sphericity distributions at 13 and 17 GeV are shown. The model, containing u,d,s,c and b quarks, clearly fits the data well. However at 27.4 GeV (Fig. 2b) the predicted distribution is clearly too narrow and the data contain some high sphericity events. To understand this distribution we have considered three modifications:

(i) inclusion of a t quark: the model distribution is still too narrow at low sphericity and predicts more events (7.5) at sphericities greater than 0.5 than are observed (2.0). Thus it is unlikely that production of a new quark is responsible.

(ii) a wider p_T distribution in the model: if we use $\langle p_T^q \rangle = 0.500$ GeV good agreement with the data is obtained (not shown). However there is little physical motivation for following this course.

(iii) include QCD effects: if QCD effects are included in the udscb quark jet model[12] good agreement with the data is obtained as indicated in Fig. 2b.

Thus we conclude that it is unlikely that new charge 2/3 quarks are produced at these energies. The explanation probably lies in (ii) or (iii). To investigate this we have studied the p_T distributions with respect to the jet axis.

(b) P_T distributions

We have observed that the $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ are increasing with energy as indicated in Table 3.

Table 3

$\langle p_T \rangle$ and $\langle p_T^2 \rangle$ as a function of energy

Energy GeV	13	17	27.4
$\langle p_T \rangle$ GeV	0.313 ± 0.009	0.344 ± 0.012	0.393 ± 0.016
$\langle p_T^2 \rangle$ GeV^2	0.145 ± 0.010	0.175 ± 0.014	0.276 ± 0.029

The broadening p_T distribution with C.M. energy is clearly demonstrated in Fig. 3.

Changing $\langle p_T^q \rangle$ in the jet model to a value of 0.500 GeV reproduces $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ but the resulting fit to the distribution is poor indicating that the correct explanation probably does not lie in a steady broadening of both jets.

Within QCD we expect one jet to broaden (by gluon emission) more frequently than both and we have searched for such indications within the data. In each event we have classified the two jets as a 'low $\langle p_T \rangle$' jet and a 'high $\langle p_T \rangle$' jet according to their values of $\langle p_T \rangle$. We have then evaluated $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ for each of these categories, the results for the latter quantity being summarized in Table 4.

A bias is clearly introduced in the selection of the jets. However the difference is not constant with energy but increases in a manner qualitatively consistent with the predictions of QCD.

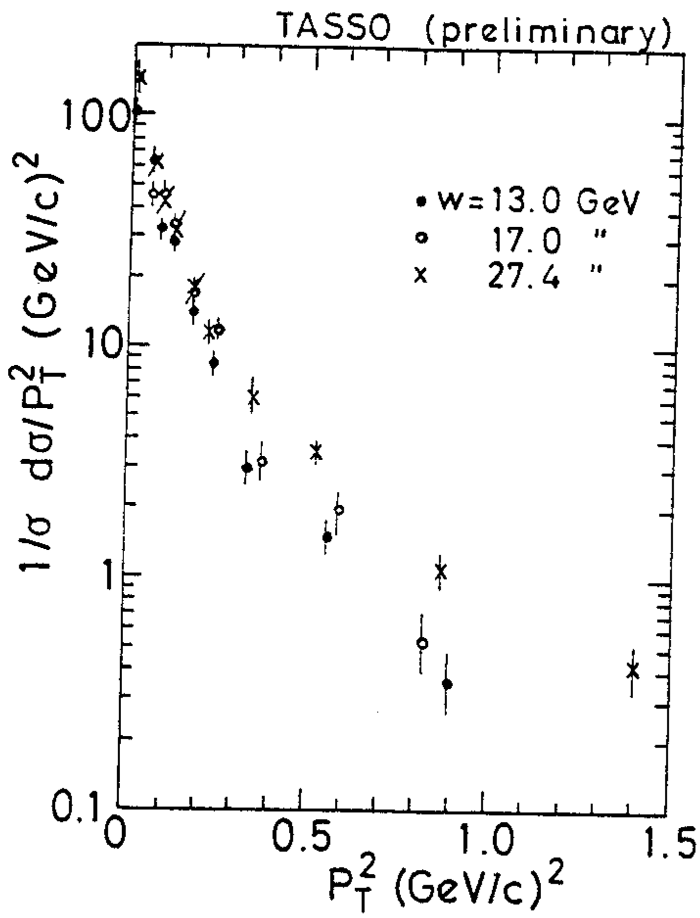

Fig. 3 The p_T^2 distribution measured relative to the spehericity axis.

Table 4

$<p_T^2>$ of 'low' and 'high' $<p_T>$ jets

Energy GeV	13	17	27.4
$<p_T^2>_{low}$ GeV²	0.105 ± 0.01	0.11 ± 0.01	0.18 ± 0.02
$<p_T^2>_{high}$ GeV²	0.21 ± 0.02	0.24 ± 0.03	0.43 ± 0.05

Thus we conclude that the data are not represented by a two jet model but are qualitatively closer to a QCD interpretation. However the current statistical accuracy of the data precludes any quantitative proof of the QCD model. Finally we have some evidence for 3 jet events within our data[10].

5. CONCLUSIONS

The data (R, $s\frac{d\sigma}{dx}$) demonstrate general consistency with the simple quark model ideas without any compelling evidence for the existence of a new quark. The naive models of quark fragmentation leading to jets do not reproduce the data at 27.4 GeV, the predicted sphericity and p_T^2 distributions being too narrow. However merely increasing $<p_T^q>$ in the model is not the solution, the data being more in qualitative agreement with QCD. Before any quantitative conclusions on QCD can be drawn a much larger data sample is required together with a more detailed analysis of the events.

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