RECENT RESULTS FROM PETRA: SEARCH FOR NEW PARTICLES

Jochen Bürger
Deutsches Elektronen Synchrotron DESY
Notkestr.85, D 2000 Hamburg 52, Fed. Rep. Germany

ABSTRACT

Recent results on the search for new particles, new thresholds and on properties of B-mesons are reported. No new particle has been observed. More stringent limits on production cross sections have been obtained.

1.0 INTRODUCTION

During the last year the collaborations working at PETRA have performed many searches for new particles. Since the energy of PETRA has not been increased during this time, there was no chance to find the top quark (or any other quark) which is still one of the main issues of this storage ring. But due to better statistics and refined analyses, the limits on production cross sections of several hypothetical particles could be lowered considerably.

In the rich spectrum of particles proposed by theories a special class becomes an issue of its own: the scalar particles. If the existence of scalar particles were shown experimentally, this could most probably could help to provide an understanding of the masses of known particles /1/. Thus I will start my talk by reporting on searches for these and some other particles, called together "exotic objects". The following sections are devoted to particles which have a different kind of reality in the understanding of the physics of today: quarks. In Sec. 3 an experiment searching for free quarks is discussed, in Sec. 4 an update of the search for a top or any further quark is given. In the last section measurements of properties of hadrons containing a b-quark are reported.

Some general remarks on the experiments and the performance of the PETRA storage ring can be found in the talk of R.Felst /2/. The bosons mediating interactions like gluons and Z^0 are not discussed in this talk. Experimental results on these particles are presented in the talks of W.Braunschweig /3/ and J.Branson /4/.

2.0 SEARCH FOR EXOTIC OBJECTS

2.1 SUPERSYMMETRIC PARTICLES

In supersymmetric theories as a further symmetry of fundamental particles a direct correspondence between fermions and bosons is postulated /5/. In the framework of these theories every particle of spin J has a partner of spin $J\pm{}^1/_2$. Besides the aesthetic attraction of introducing a higher degree of symmetry into our description of nature, supersymmetric theories have two main advantages: (i) perturbation series converge faster and (ii) generalisations by including general relativity are possible thereby avoiding the well known difficulties related to the quantisation of gravity /6/.

Unfortunately there is no experimental indication of supersymmetry in the spectrum of particles and interactions observed to date. Thus the masses of the supersymmetric partners of the known particles must have masses larger than a few GeV /7/. Although the scale at which supersymmetry becomes apparent, if ever, is completely unknown, there is a possibility that the breaking of supersymmetry may have a scale of ≤100 GeV the same as that of the weak interactions. Thus in a search for supersymmetric particles even PETRA energies can provide significant constraints for such theories.

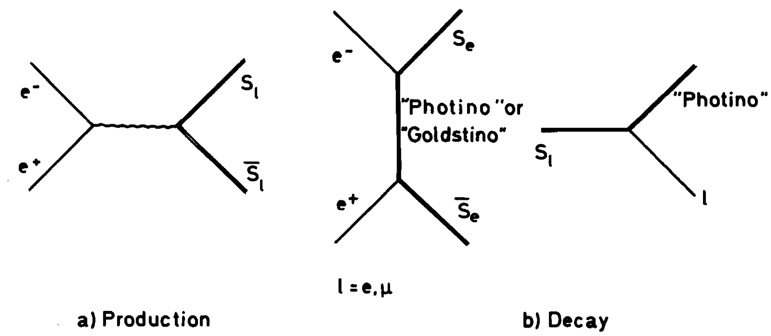

Figure 1. Production and decay of scalar leptons

In the simplest supersymmetric models the leptons have spin 0 partners (actually each lepton has two partners, one for each helicity state) S_l and T_l (l = e, μ, τ). These scalar leptons can be produced via a virtual photon in the s channel or in the t channel by the exchange of a photino (the fermion partner of the photon) or by a goldstino (the Goldstone spinor associated with the breaking of symmetry) (Fig. 1a). The scalar leptons are assumed to decay after a very short lifetime into a photino (which behaves neutrino-like) and into an ordinary lepton (Fig. 1b). Thus the event signature in e^+e^--annihilation is

$$e^+e^- \rightarrow 2 \text{ (acoplanar) leptons + non interacting particles.}$$

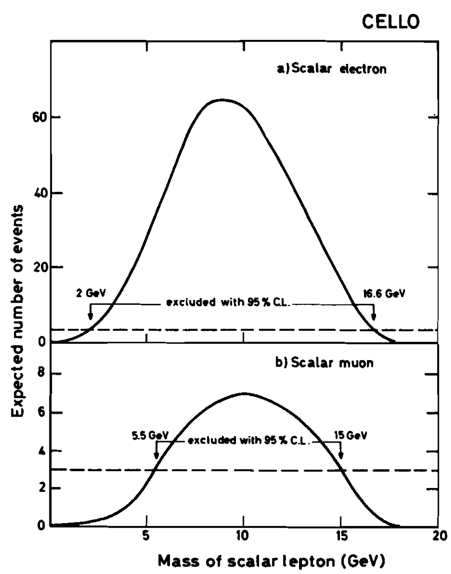

Figure 2. Expected number of scalar leptons: (a) electron (b) muon. The horizontal line indicates the 95% confidence level for the observation of no event.

Possible background sources are QED reactions with one undetected photon (e.g. $e^+e^- \rightarrow e^+e^-+\gamma$) and QED final states from the two photon channel where both scattered electrons are in the beam pipe (e.g. $e^+e^- \rightarrow \mu^+\mu^- + e^+e^-$).

The CELLO Collaboration searched for both scalar electrons and muons using a sample of events which corresponds to an integrated luminosity of 3240 nb^{-1} at an average beam energy of 17.3 GeV. They selected 2-prongs pointing into the inner detector (35° < Θ < 145°) with an aplanarity of ≧ 30°. Applying some cuts against QED reactions they found only lepton pairs with additional energy in the shower counters. Fig. 2 shows the expected rate for scalar leptons as obtained from Monte Carlo simulations assuming the cross section of a spin 0 particle. The absence of any candidate event allows the exclusion of scalar leptons in mass range as shown in Fig.2, improving earlier results of other PETRA experiments, which are all listed in Tab. 1.

Experiment	Mass of scalar Electron	lepton (GeV) Muon	year /Ref./
JADE	> 16		1980 /8/
MARK J		> 15	1980 /9/
PLUTO	> 13		1980 /10/
CELLO	> 15	> 16.6	1981

Table 1. Lower limits on scalar lepton masses.

2.2 TECHNICOLOUR PARTICLES

It has been proposed that the conventional Higgs fields should be replaced by bound states of new types of quarks and leptons with superstrong interactions /11/, called technicolour or hypercolour. The scale parameter Λ_{TC}, defined in analogy with the conventional QCD scale parameter Λ_{colour} should be of the order of 1 TeV. Thus a rich spectrum of technicolour particles (technirho, techni...) with masses of O(1 TeV) is expected in such theories.

However, in the simplest scenarios as a consequence of spontaneous symmetry breaking, a triplet of Goldstone bosons is created which are absorbed by the weak bosons, W^+, W^- and Z^0, to give mass to these particles. In order to give mass also to the "fundamental fermions", it is necessary to extend the basic technicolour interactions. In one such minimally extended technicolour scheme /12/ one is left with the conventional colour singlets and octets and a quartet of 0^- colour singlet Goldstone bosons (P^0, $P^{0\prime}$, P^+, P^-). These Goldstone bosons are called technipions and are supposed to have masses of the order of 10 to 20 GeV. Thus they could be produced at PETRA energies in the reaction

$$e^+e^- \rightarrow P^+ P^-.$$

The charged technipions subsequently decay predominantly into heavy quarks or leptons . It should be mentioned that conventional charged Higgs bosons are expected to have the same production and decay mechanism though details could be quite different /13/.

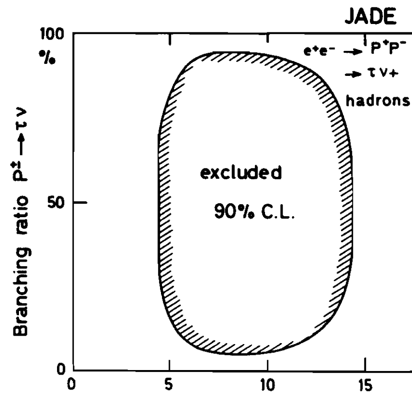

Figure 3. Production of charged techni-(hyper)pions: the 90% confidence level contour (shaded area) is given as a function of the branching ratio into τ leptons and the mass of the technipion

The JADE Collaboration searched for light charged technipions, which are assumed to decay either into cs quark pairs or into $\tau\nu$ lepton pairs. The event signature used for the search is

$$e^+e^- \rightarrow P^+ P^- \rightarrow \tau + \nu + \text{hadrons} \qquad (1)$$

where one of the technipions decays into hadrons while the other decays into a τ lepton and its neutrino.

The general signature of such events are two jets which are not back to back. To select events of reaction (1) the following cuts have been applied to remove background from ordinary hadronic two jet final states and from τ pair production:
(i) The thrust axis has to point into the full acceptance (i.e. the angle Θ of the thrust axis with respect to the beam line has to fulfill $|\cos\Theta| < 0.7$) to assure good event reconstruction.
(ii) By means of a plane normal to the thrust axis, the event can be divided into two hemispheres. The energy in the hemisphere containing the bigger fraction of measured energy has to be > 0.63 of the beam energy.
(iii) The opposite hemisphere has to contain at least one charged particle. Further charged particles have to have an angle > 70° with respect to the thrust axis.
(iv) The thrust axes, determined individually for each hemisphere, have to have an acoplanarity angle of > 20°.
After these cuts only one event remained in a sample representing an integrated luminosity of $\sim$10000 nb^{-1}. Using a Monte Carlo simulation of production and decay of technipions limits on the mass could be determined as a function of the branching ratio $P \rightarrow \tau\nu$ as shown in Fig.3. Thus the production of light technipions with masses of 5 to 15 GeV is excluded at 90% confidence level for reasonable branching ratios $P \rightarrow \tau\nu$.

2.3 HEAVY NEUTRAL ELECTRON

The existence of heavy leptons which belong to the normal lepton families has been discussed in the context of electroweak theories a long time ago/14/. Although the standard electroweak theory SU(2)×U(1) does not require such particles it is of at least phenomenological interest to search for such particles. Production and decay of such heavy leptons have been studied by several authors in some detail /15,16/.

One of these heavy leptons is the neutral heavy electron E^0, which has the same lepton numbers as the electron. A possible production mechanism is via charged current (Fig. 4a). The coupling of the E^0 could be V+A or V-A. Subsequentely the E^0 decays into a (virtual) W boson and an electron (Fig. 4b). In principle E^0 production and decay is also possible via neutral currents, but this possibility is not discussed here.

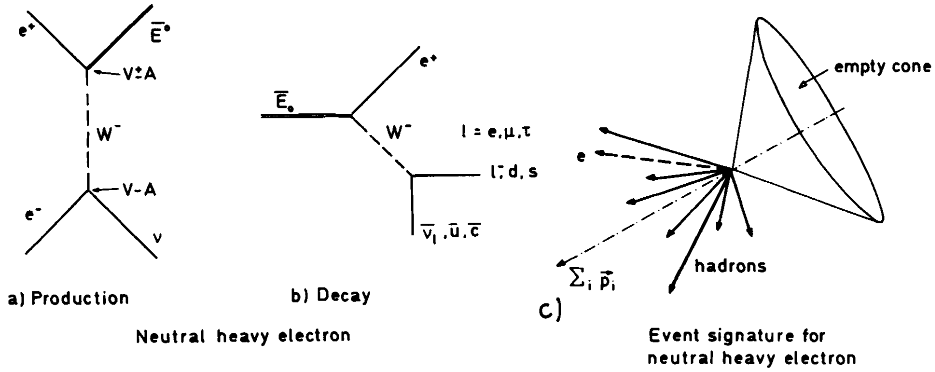

Figure 4. Production (a), decay (b) of the E^0 and the event signature used for the search (c)

The JADE Collaboration searched for such neutral heavy electrons. Since the decay products of the initial two body reaction are back to back and the neutrino does not give any signal in the detector, the signature of such reactions are highly unbalanced events. Assuming simple flavour counting the W couples with a branching ratio of ~70% to a quark pair. The JADE Collaboration selected events of the following type: the charged particles (including at least one electron) are constrained to a hemisphere opposite to a cone of half opening angle of 50° which does not contain charged particles or shower energy (Fig. 4c). No event of this type was observed.

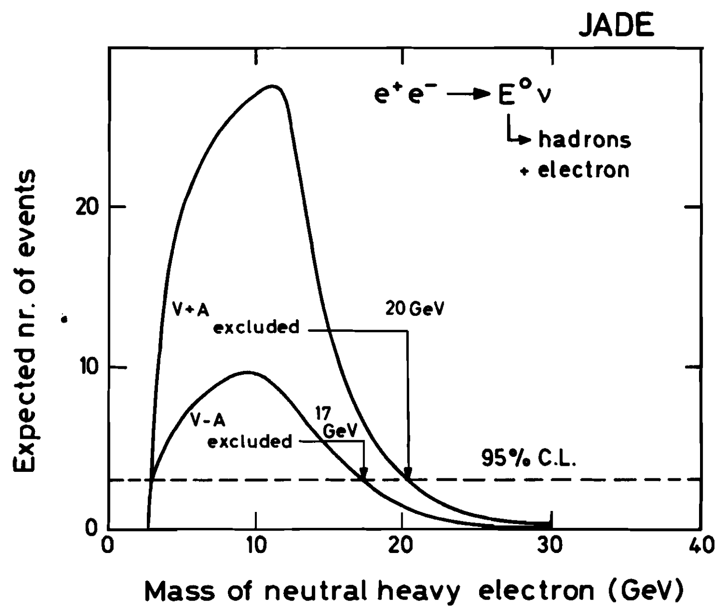

Figure 5. Expected number of events from E^0 production: the horizontal line indicates the 95% confidence level for the observation of no event

Using the calculations of Ref./16/ for the (charged current) production cross section of a heavy neutral electron in a Monte Carlo simulation the following 95% confidence level lower bounds on the E^0 mass were found (Fig. 5): $m(E^0) < 20$ GeV (V+A coupling) and $m(E^0) < 17$ GeV (V-A coupling).

2.4 EXCITED STATES OF LEPTONS

The existence of excited states of the leptons would indicate a structure of the leptons which is pointlike down to distances of 10^{-16}cm /17/. In addition this would cause serious deviations from QED, which has been derived on the basis of pointlike particles.

2.4.1 Excited Electrons

The existence of an excited state of the electron e^* would manifest itself as a modification of the QED reaction $e^+e^- \to \gamma\gamma$. To the pure QED cross section (graph in Fig.6a)

$$d\sigma_{QED}/d\Omega = (\alpha/s)\cdot(1+\cos^2\Theta)/\sin^2\Theta$$

the e^* would contribute a further term (Fig.6b):

$$d\sigma(e^+e^-\to\gamma\gamma)/d\Omega = d\sigma_{QED}/d\Omega\cdot[1+(s^2/2\Lambda^4)\cdot\sin^2\Theta]$$

where $\Lambda = m(e^*)\cdot\sqrt{(\alpha/\alpha^*)}$, $m(e^*)$ denotes the mass and α^* the coupling of the e^*. In principle α^* is unknown, but in the following it is assumed that it couples like the normal electron (i.e. $\alpha=\alpha^*$).

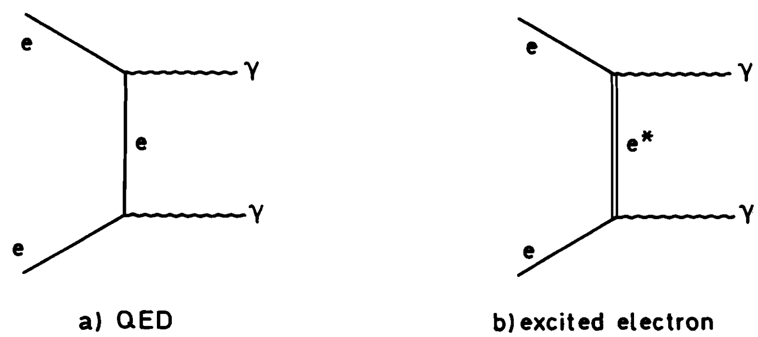

Figure 6. Graphs for the reaction $e^+e^- \to \gamma\gamma$: pure QED (a) and the e^* contribution (b)

In Fig. 7 measurements from all five PETRA experiments of the cross section of the reaction $e^+e^- \to \gamma\gamma$ are plotted in units of the pure QED cross section as a function of $\cos\Theta$. No significant deviation from the pure QED prediction is observed. Including latest data from the MARK J experiment leads to lower limits on the mass of the excited electron of ~50 GeV (Tab. 2).

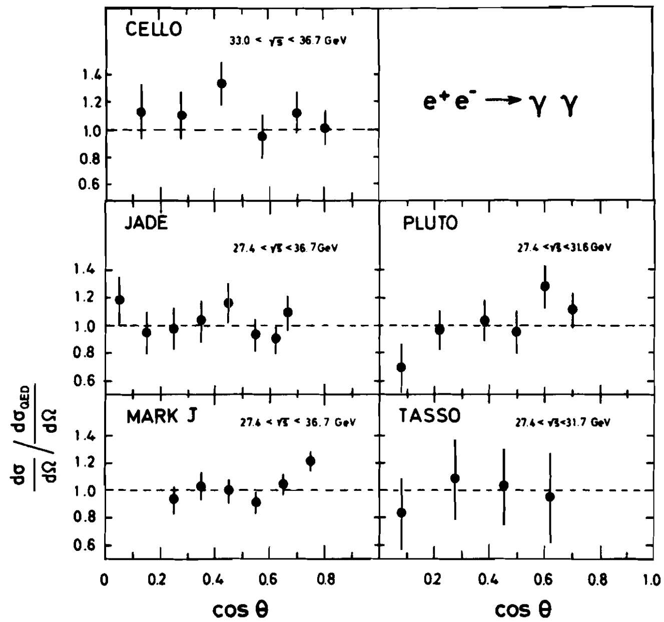

Figure 7. Cross section of the reaction $e^+e^- \to \gamma\gamma$ (from Ref /17/)

Experiment	lower limit m(e*) GeV (95% C.L)	centre of mass energy GeV
CELLO *)	43	35
JADE *)	47	35
MARK J	58	35
PLUTO *)	46	31
TASSO *)	34	35

Table 2. Lower limits on the mass of an excited electron e* (results marked by *) are taken from Ref./17/).

2.4.2 Excited Muons

Excited states of muons could be produced either in pairs or in combination with "normal" muons:

$$e^+e^- \to \mu^*\mu^* \qquad (2a)$$

$$e^+e^- \to \mu^*\mu \qquad (2b)$$

The excited muon μ^* decays into a muon and a photon.

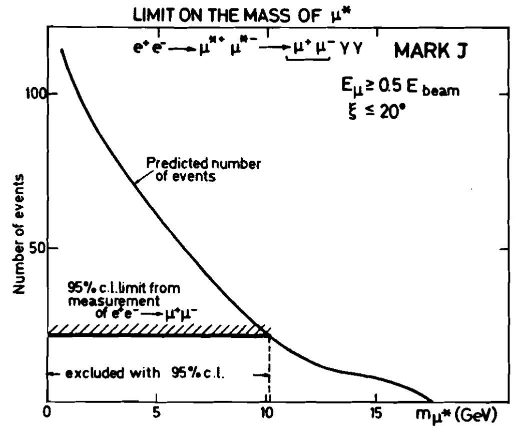

Figure 8. Expected number of events from the reaction $e^+e^- \to \mu^*\mu^*$

The MARK J Collaboration searched for μ^* pair production (reaction 2a) using events with final states of the type $e^+e^- \to \mu\mu\,\gamma\gamma$. The energy of each muon was required to be 50% of the beam energy and the acoplanarity angle had to be $\leq 20°$. From the number of observed events of this signature and the number of expected events from a QED Monte Carlo simulation /18/ they derive an upper limit on the number of events of reaction (2a) as a function of the mass of the μ^* (Fig. 8). A mass of the excited muon of < 10 GeV is ruled out at 95% confidence level.

The production cross section of reaction (2b) is /19/:

$$d\sigma/d\Omega = (\alpha^2\lambda^2/s^3)\cdot(s+m(\mu^*)^2)^2 \cdot [s + m(\mu^*)^2 - (s-m(\mu^*)^2)\cdot\cos^2\Theta]$$

where the coupling of the μ^* is denoted by $\alpha\lambda$. Integration over the solid angle yields:

$$\sigma(e^+e^-\to\mu\mu^*) = \lambda^2\cdot(8\pi\alpha^2)/(3s^3) \cdot [(s-m(\mu^*)^2)^2\cdot(s+2m(\mu^*)^2)] \qquad (3)$$

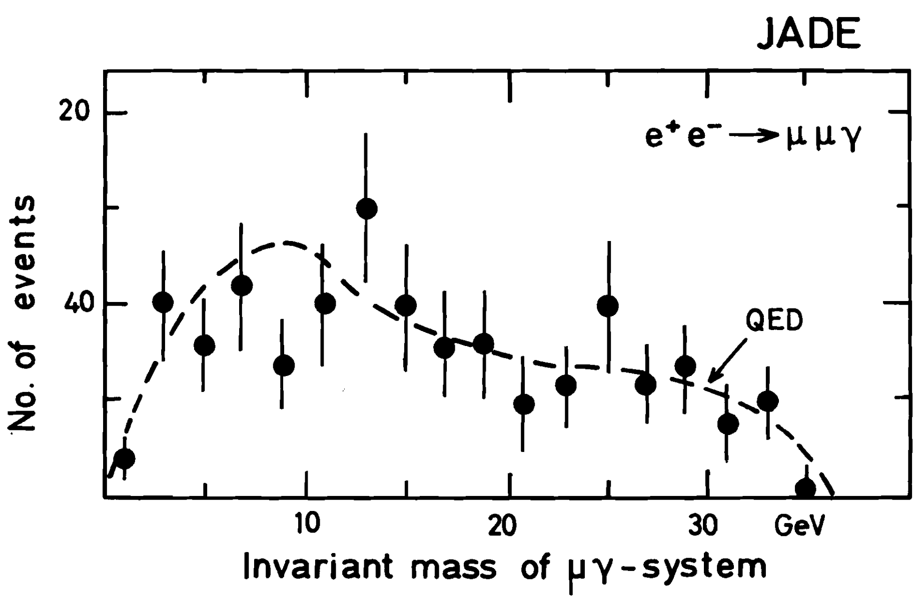

Figure 9. Invariant mass distribution of the $(\mu\gamma)$-system

The JADE Collaboration analysed a sample of events with an integrated luminosity of 10620 nb^{-1} at centre of mass energies of $22 \leqq \sqrt{s} \leqq 37$ GeV. They selected events of the type $e^+e^- \rightarrow \mu\mu\gamma$ fulfilling the following criteria: (i) the energy of the photon has to be $\geqq 1$ GeV, (ii) the angle between the photon and the muon has to be $\geqq 15°$, (iii) the invariant mass of the $\mu\mu$-system has to be > 1 GeV and (iv) the events have to be planar, i.e. the sum of the three angles between the three particles has to be $> 350°$. With these cuts they selected 66 events. In Fig. 9 the invariant mass distribution of the $\mu\gamma$-system is plotted (2 entries per event). In the same plot also the QED prediction from a Monte Carlo simulation (broken line) is plotted. The quantitative agreement with the data is very good indeed: 68 events are expected from a QED calculation /20/. For each bin an upper limit of events of reaction (2b) can be determined as a function of the mass of the μ^*. Since the cross section (Eq. 3) is a function both of λ^2 and $m(\mu^*)$ in Fig. 10 the resulting upper limit of the coupling constant λ^2 is plotted as function of $m(\mu^*)$. If one fixes the mass of the excited muon to, for example, 16 GeV, the cross section (Eq. 3) in units of the QED μ-pair cross section is $\sigma/\sigma_{\mu\mu} < 0.0075$ (90 % confidence level).

The MARK J Collaboration performed a similar analysis without measuring the invariant masses of the $\mu\gamma$-system. They analysed an event sample of 12300 nb^{-1} at centre of mass energies of $27.4 \leqq \sqrt{s} \leqq 36.7$ GeV, requiring a minimal angle of 20° between the photon (with an energy of at least 20% of the beam energy) and the muon. They selected 11 events, while they expected 12 events from a QED calculation. The resulting upper limit (95% confidence level) of the coupling constant λ^2 is also plotted in Fig. 10. For a fixed mass of 16 GeV for the excited muon this experiment yields for the production cross section $\sigma/\sigma_{\mu\mu} < 0.0375$ (95% confidence level).

Thus from both measurements the existence of an excited state of the muon with mass smaller than ~ 20 GeV is excluded.

2.5 FURTHER SEQUENTIAL HEAVY LEPTON

Further sequential heavy leptons would open a new lepton family in contrast to the heavy leptons discussed in Sec. 2.3. In e^+e^- interactions they would be produced in pairs like the

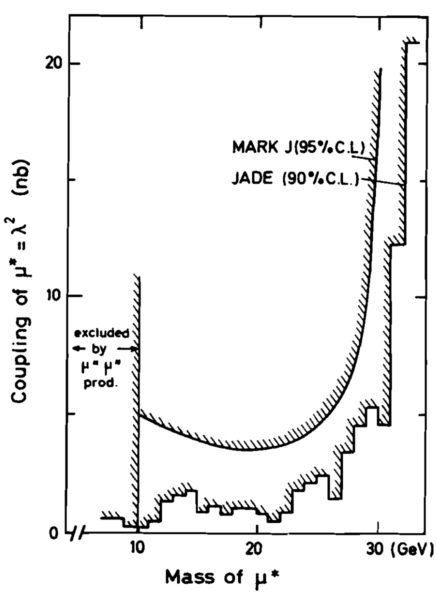

Figure 10. Upper limits of the coupling λ^2 of the μ^* as a function of its mass

muon or τ lepton. Their branching ratios can be calculated in analogy with the τ decays. Since the reaction $e^+e^- \to L^+ L^- \to e\ \mu$ + missing energy, which has the cleanest signature for such a further heavy lepton L, has a very small cross section, the search for this particle was performed by exploiting the hadronic decay modes for at least one of the produced heavy leptons L. Due to the higher energies available it is expected that their decay into hadrons and a neutrino results in a final state jet. The escape of neutrinos leads to events unbalanced in detected energy and momentum. In Tab. 3 lower limits of the mass of a further heavy lepton are listed as obtained by the different experiments.

Experiment	lower limit m(L) GeV (95% C.L)	event signature	Ref.
MARK J	16	single muon recoiling against many hadrons	/9/
PLUTO	14.5	single muon recoiling against many hadrons	/21/
TASSO	15.5	single charged part. recoiling against many hadr.	/22/
JADE	18.1	two acolinear jets	

Table 3. Lower limits on the mass of a further sequential heavy lepton L

3.0 SEARCH FOR FREE QUARKS

Hadrons are believed to be made out of quarks. For the time being there is no direct evidence for these objects. However, during the past years an increasing number of experimental results confirms the reality of quarks indirectly, e.g. deep inelastic scattering, charmonium spectroscopy or the 2-jet structure of the events in e^+e^- annihilation. On the basis of these results it is generally accepted that quarks are fractionally charged point-like spin $^1/_2$ objects which may be either relatively light (m(u,d,s-quark) << 1 GeV) or heavy (m(c,b,(t)) > 1 GeV). Although the production mechanism and the properties of free quarks are not well known, several searches for free quarks have been performed using cosmic rays, stable matter or accelerators /23/.

The JADE Collaboration searched for stable heavy particles with fractional charge, which have the properties of quarks in the simple standard model. It is assumed that quarks are produced in pairs either in exclusive $e^+e^- \to q\bar{q}$ or in inclusive $e^+e^- \to q\bar{q}\ X$ reactions.

The JADE detector is able to perform such a search by means of its track detector,the so called jet chamber /24/. This chamber not only measures the apparent momentum p/Q (Q = charge of the particle) but also the energy loss due to ionisation, dE/dx. The latter is sampled up to 48 times for a single track. Due to improved electronics and refined analysis it is now possible to search for charge $^1/_3$ objects, which was not possible at the time of an earlier publication /25/.

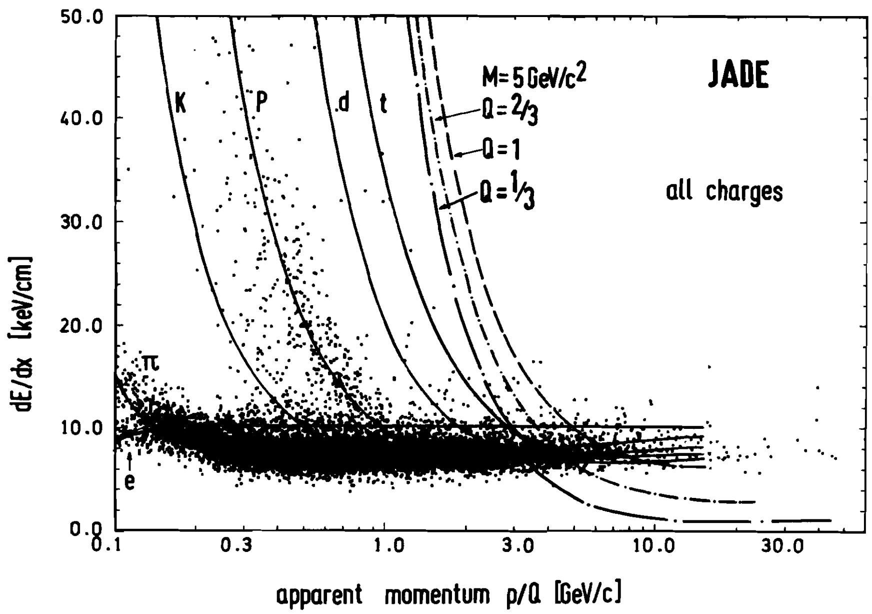

Figure 11. Apparent momentum p/Q as function of energy loss: the ionisation curves of the existing particles and of hypothetical particles with 5 GeV mass and $Q={}^1/_3$, ${}^2/_3$ and 1 are also shown.

In Fig.11 the mean energy loss dE/dx is plotted versus the apparent momentum p/Q for a subsample of tracks. Almost all entries lie on the ionisation curves of the known particles e, π, K, p, d, and t. The production of d and t is explained by backgound events from beam gas interactions remaining in the sample. Indeed, if one uses only particles with negative charge, the d and t band in Fig.11 vanishes. Thus this detector is sensitive in certain momentum ranges to abnormally ionising particles.

The overall efficiency to detect a quark in a jet depends on the charge, on the efficiency of pattern recognition, on the solid angle covered by the detector and, since the total momentum range is not available, on the mass of the quark. For charge ${}^2/_3$ (${}^1/_3$) quarks the total detection efficiency is 0.15 - 0.36 (0.11 - 0.27) depending on the quark mass.

For the exclusive channel collinear two prong events were used. The trigger is fully efficient for charge ${}^2/_3$ quarks, while charge ${}^1/_3$ quark pairs do not trigger the device.

Analysing an event sample of ~12000 nb^{-1} for the charge ${}^2/_3$ quark search and ~4500 nb^{-1} for the charge ${}^1/_3$ quark search the JADE Collaboration did not find any quark candidate either in inclusive or exclusive reactions. This zero result can be transformed into upper limits on the the quark production cross section as a function of the quark mass. Details of these calculations are described in Ref. /25/. For the inclusive channel the upper limit depends on the momentum spectrum of the quarks used to extrapolate the data into the full momentum range. Two different models for the differential momentum distribution have been used:

$$E(d^3\sigma/dp^3) = \sigma(qq)\cdot f_i(p) \qquad (i= I,II)$$

with $f_I(p) \propto \exp(-3.5\ E)$ and $f_{II}(p) \propto$ constant.

Fig. 12 shows the upper limit of the quark production cross section, in units of the QED μ-pair cross section $\sigma_{\mu\mu}$, of the inclusive channel (a) and of the exclusive channel (b). In addition the cross sections of free pointlike colourless objects of charge ${}^1/_3$ and ${}^2/_3$ are plotted. The

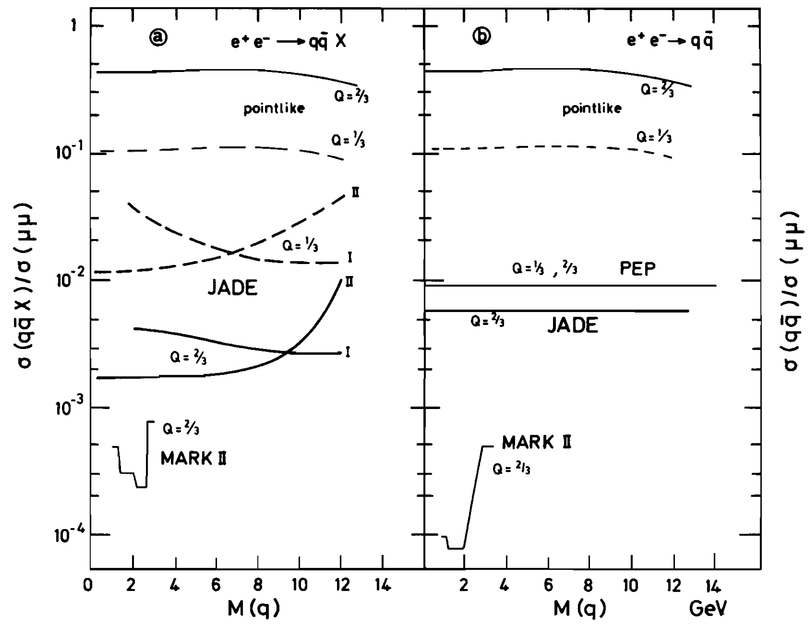

Figure 12. Results of quark search experiments in the inclusive (a) and exclusive (b) channel : the upper limit of the production cross section (90% confidence level) is plotted versus the quark mass.

results of the MARK II experiment at lower centre of mass energies /26/ and of the PEP quark search experiment of the exclusive channel /27/ are also shown in this figure.

4.0 SEARCH FOR THE TOP QUARK

After the ϒ-resonance was discovered and interpreted as a $q\bar{q}$ bound state of a new quark b, the existence of a sixth quark, generally called t (for 'top' or sometimes 'truth'), was postulated immediately to restore the hadron lepton symmetry. Thus the t-quark should have charge $^2/_3$. The search for the t-quark (or for any further quark with charge $^1/_3$) became an important issue of the physics at PETRA since it started running.

To search for a new quark in e^+e^- interactions at least two different approaches are possible, either the search of a bound state of a $t\bar{t}$ pair (hidden top) or the search for a threshold of open t flavour production. Both searches have been performed by all PETRA experiments.

4.1 SEARCH FOR HIDDEN TOP

Both the J/Ψ and the ϒ resonances have masses somewhat smaller than the threshold for the open flavour production and their widths are very small. Applying this picture to a possible $t\bar{t}$-state, one expects such a resonance below the threshold. This state should have a width which is much smaller than the energy resolution of PETRA (~ 20 MeV at $\sqrt{s}$ = 30 GeV). During the last years two scans have been performed. Using steps of ~20 MeV the energy ranges of (i) 27 < $\sqrt{s}$ < 31.6 GeV (1979) and (ii) 33 < $\sqrt{s}$ < 37 GeV (1980/81) have been scanned completely.

For each energy point $R=\sigma_{tot}/\sigma_{\mu\mu}$ has been determined. To get an upper limit on the width of such a bound $q\bar{q}$-state, each measured point of the cross section as fitted to a Gaussian with radiative corrections plus a constant background term. The width of the Gaussian is determined by the energy resolution of the storage ring. The integral of the Gaussian curve is related to the parameters of the resonance by

$$\int \sigma_{tot}(\sqrt{s})\ d(\sqrt{s}) = 6\pi^2/m_{res}^2 \cdot \Gamma_{ee}B_{had},$$

where m_{res} is the mass of the assumed resonance, Γ_{ee} is the partial width for the decay into electrons and B_{had} is hadronic branching ratio.

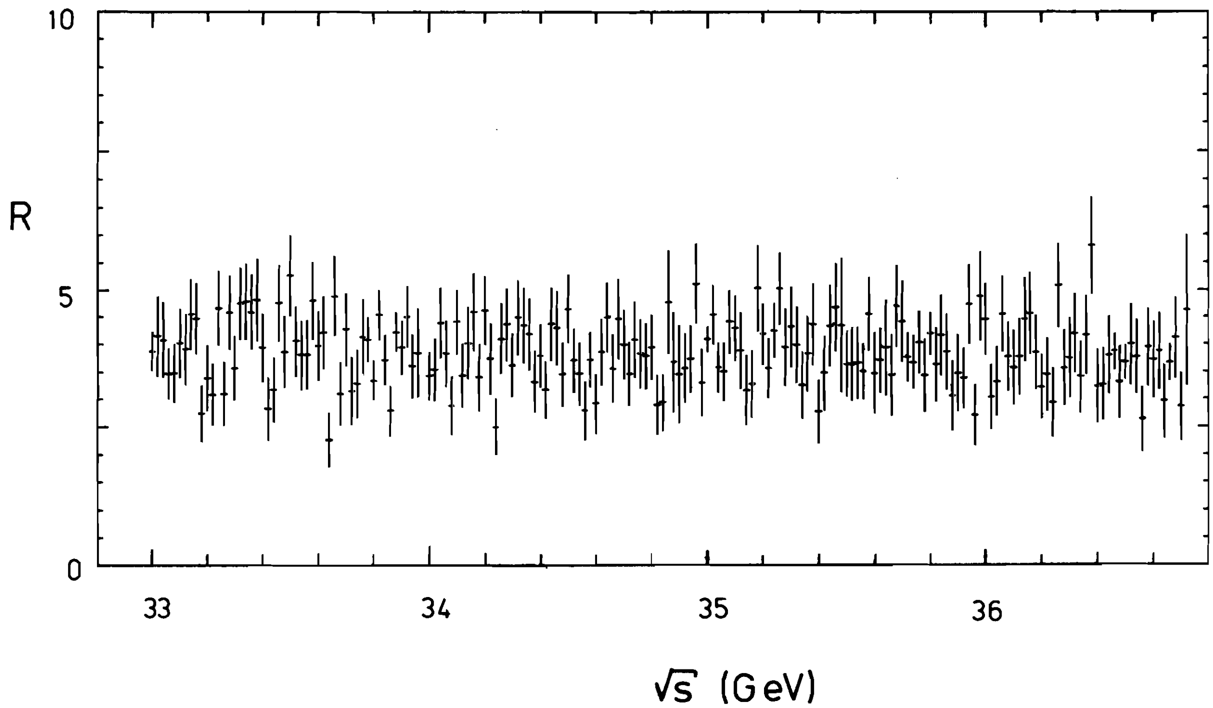

Figure 13. Total hadronic cross section of the scan region: the data of all experiments (CELLO, JADE, MARK J, and TASSO) are combined.

The results of the scan (i) have been reported at the Madison Conference /8/. Thus here only the results of the scan (ii) are presented. Fig. 13 shows the measurement of R combining the data of all PETRA experiments. Table 4 lists values of m_{res} where the fit yields a maximal $\Gamma_{ee}B_{had}$ for each individual experiment. For the combined data this fit yields $\Gamma_{ee}B_{had} \leqq 0.61$ keV (90% confidence level) at $m_{res} = 33.34$ GeV.

All $q\bar{q}$-resonances (ρ, ω, Φ, J/Ψ, Υ) have as a common feature an almost constant ratio $\Gamma_{ee}/Q^2 \sim 10$ keV, where Q is the charge of the quark q. Assuming $B_{had} \geqq 0.7$ one expects $\Gamma_{ee}B_{had} \geqq 0.77$ keV ($\geqq$ 3.08 keV) for a further resonance of $^1/_3$ ($^2/_3$) charged quarks respectively. Thus the existence of a $t\bar{t}$-resonance (charge $^2/_3$ quarks) is ruled out in the mass range up to ~37 GeV.

Experiment	mass of the assumed resonance GeV	upper limit of electronic width x BR(hadrons) keV (90% C.L.)
CELLO	33.52	1.79
JADE	33.34	1.22
MARK J	35.12	0.97
TASSO	33.34	1.33
all experiments	33.34	< 0.61

Table 4. Results of the $t\bar{t}$-resonance search

4.2 SEARCH FOR A TOP THRESHOLD

The most direct evidence for the existence of a sixth quark is to search for a step in the total hadronic cross section, which in the simple quark parton model is given by

$$R = \sigma_{tot}/\sigma_{\mu\mu} = 3\ \Sigma_i\ Q_i^2$$

where Q_i are the quark charges and the summation extends over all flavours i. A new quark would add 1.33 (0.33) units in R for $^2/_3$ ($^1/_3$) charge to the value of R = 3.67 for five flavours. The relative changes are 36% (9%) of R respectively. Keeping in mind that the systematic error of the R measurements is still of the order of 10% /2/, it is impossible to rule out a charge $^1/_3$ quark by this method.

Averaging over the centre of mass energy range from 12 to 37.6 GeV a value $\langle R \rangle = 3.84 \pm 0.04$ (statistical error only) is obtained. Including QCD corrections (up to 2nd order /28/) one expects R = 3.88 for five flavours, R = 5.31 and 4.25 for $^2/_3$ and $^1/_3$ charged top quarks. Thus a top quark is ruled out by the data.

To rule out a charge $^1/_3$ quark with a threshold accessible to PETRA one has to apply refined analysis methods. The most commonly used techniques are event shape analyses and the measurement of the inclusive muon rate.

4.2.1 Event Shape Analysis

If particles with a new flavour are created near threshold, they are almost at rest and they decay more or less isotropically. This fact should show up as significant deviation from the planar structure of the events produced by quarks of much lower mass. The effect decreases as the centre of mass energy increases above the threshold energy.

The CELLO and TASSO Collaborations performed an event shape analysis. Using only aplanar events with $A \geq 0.15$ where the aplanarity $A = {}^3/_2 \cdot Q_1$ is defined using the normalized eigenvectors of the sphericity tensor. In Tab. 5 the number of events found is compared with the number of events expected for different models. This clearly rules out a $^1/_3$ charged quark threshold at the level of more than four standard deviations.

	CELLO	TASSO
Mass of further quark	16 GeV	15 GeV
No. events found	9	12
No. events expected: udscb + QCD	5.2 +/- 1.4	11 +/- 1
+ top	96.3 +/- 4.2	138
+ Q=2/3	31.3 +/- 1.4	43

Table 5. Expected number of events form events with A ≧ 0.15

For quarks with masses of ≦ 16 GeV the number of expected aplanar events becomes smaller. The CELLO Collaboration excludes at 95% confidence level the production of charge $^1/_3$ ($^2/_3$) quarks with masses < 9 GeV (< 6 GeV) respectively.

4.2.2 Inclusive Muon Rate

In the Kobayashi-Maskawa model /29/ the top quark is expected to decay predominantly into the b-quark, which subsequently decays into a c-quark etc. In this cascade there is an appreciable probability of ~10% that each of these decays is semi-muonic. So top quark production should be a rich source of prompt muons if the top lifetime is not too long (i.e. less than ~ 10^{-10} sec).

The MARK J Collaboration measured the muon yield at different centre of mass energies. In Fig. 14 the relative production rate of hadronic events containig a muon is shown. The data fit nicely with the expectation of a five flavour Monte Carlo simulation /30/, however, the production of a top quark cannot be ruled out completely.

A much more sensitive result is obtained if the event shape analysis is performed using only events with a muon. The MARK J Collaboration analysed with the thrust method 352 events having at least one muon. In Fig. 15 the thrust distribution and also the expected rates from different models are plotted. The data are in excellent agreement with the prediction of the Monte Carlo model with five flavours udscb. Both for charge $^1/_3$ and $^2/_3$ quark production a bump in the distributions is expected at low thrust values which is not observed in the data. Quantitatively, comparing the observed number of events with thrust T ≦ 0.75 (14 events) with the predicted number of events from the udscb-model (13.8 events) the agreement is very good. The expectation from models with further quarks are 60 (163) events for charge $^1/_3$ ($^2/_3$) quarks respectively and thus these models are clearly ruled out.

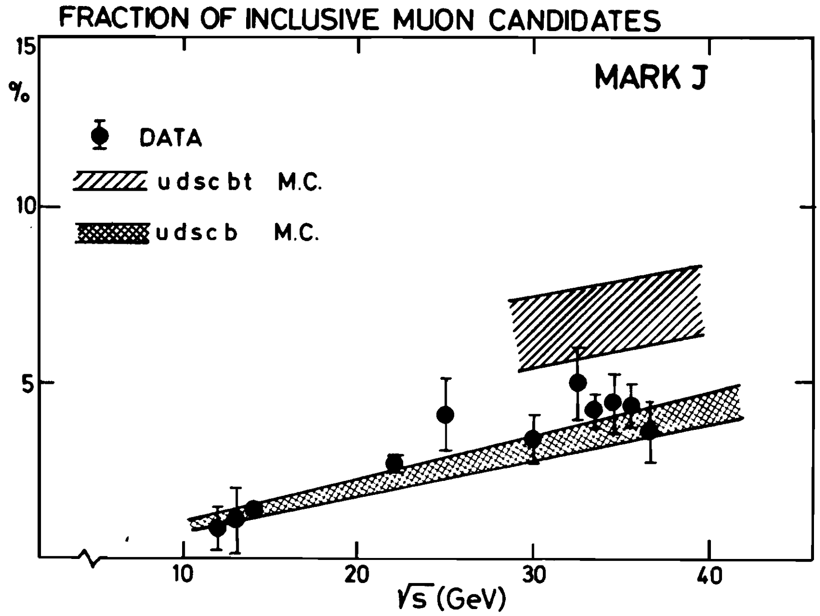

Figure 14. Fraction of events containing a muon as function of the centre of mass energy

The JADE Collaboration performed a similar analysis using events in the centre of mass energy range of $33 < \sqrt{s} < 36.7$ GeV. They found 494 single and 27 double muon candidates. To make a special selection for top events, they required events with high sphericity ($S \geq 0.5$) and a transverse momentum of the muon with respect to the thrust axis of $p_t > 2$ GeV. They observed one event of this type, while they expected 104 (35) events for a charge $^2/_3$ ($^2/_3$) top quark. This result can be transformed into an upper limit of a production cross section of a pair of heavy quarks q of mass m(q) = 16 GeV and charge $^1/_3$:

$$\sigma \cdot BR(e^+e^- \to q\bar{q}) \leq 0.002 \cdot \sigma_{\mu\mu} \quad (90\% \text{ confidence level}).$$

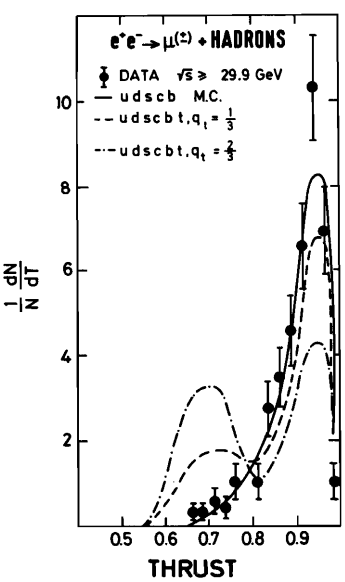

Figure 15. Thrust distribution of inclusive muon events (MARK J)

5.0 PROPERTIES OF BOTTOM PARTICLES

Since the events containing a muon are not due to the production of top quarks, as shown in the previous section, they are a good trigger to enhance considerably the fraction of events with a primary b-quark pair. This fact has been used by the JADE and MARK J collaborations to measure the branching ratios B → μ+X (Sec. 5.1) and B → $\mu^+\mu^-$+X (Sec. 5.2) and to determine an upper limit for the lifetime of hadrons containing a b-quark(Sec. 5.3).

5.1 MEASUREMENT OF THE BRANCHING RATIO B → μ+X

Due to the production kinematics of the relatively heavy B-particles the average transverse momentum of the muons with respect to the jet axis should be greater than the transverse momentum of the other particles in the same jet and especially also greater than the transverse momentum of muons of other sources (charm, K, π decay)/31/.

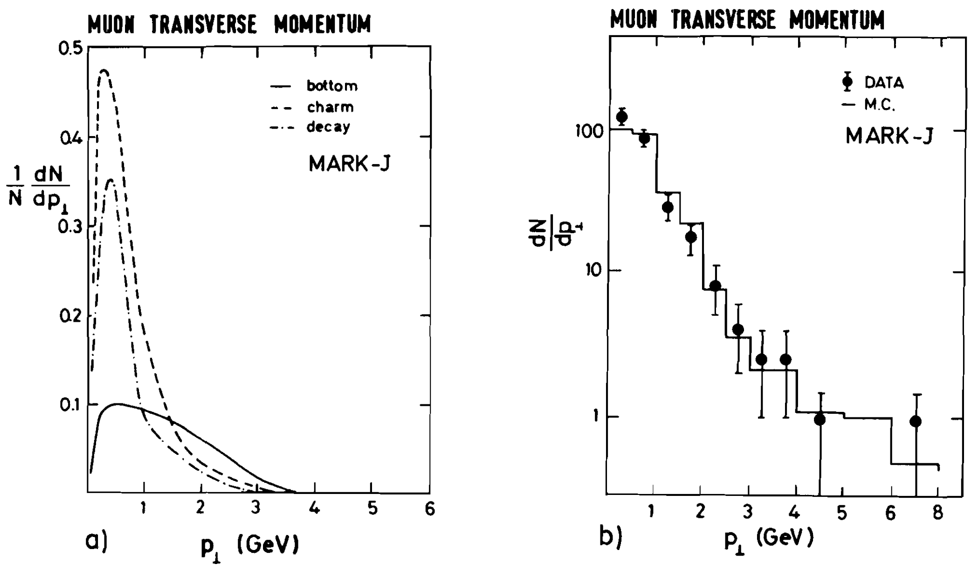

Figure 16. Muon transverse momentum distribution: (a) decomposed into three classes by a Monte Carlo study and (b) experimental result (MARK J) (points) compared with the Monte Carlo prediction (full histogram).

If the total inclusive muon rate is decomposed by a Monte Carlo simulation /30/ into three classes (bottom, charm production and decay) as performed by the MARK J Collaboration (Fig.16a), it is found that (i) all muons show p_t-distributions much different from those of the hadrons which have an $<p_t> \sim$ 300 MeV and (ii) the muons from B decay are enhanced in the tail of the distribution over the muons from other sources.

In Fig. 16b the measured muon transverse momentum distribution is shown in comparison with the Monte Carlo prediction. After subtracting the rates from (i) decay (~ 35%) and (ii) charm using the known branching ratios into muons for the different charmed particles, a branching ratio B → μ+X is fitted to the number of observed events with p_t > 1.2 GeV. The MARK J Collaboration obtained (preliminary)

$$BR(B \rightarrow \mu + X) = 8\% \pm 2.7\% \text{ (statistical)} \pm 2\% \text{ (systematic error)}.$$

This result is in agreement with measurements of CESR /32/.

5.2 MEASUREMENT OF THE BRANCHING RATIO $B \rightarrow \mu^+\mu^- + X$

The decay of the B-particles into a lepton pair is forbidden in standard models in which all quarks are contained in left handed doublets under SU(2). But this decay mode is of particular interest in models in which the b-quark is assumed to form a SU(2) singlet or where it has a special quantum number which forbids mixing with u- and d-quarks, i.e in models which do not require the existence of a sixth quark. In these models this decay mode is possible via flavour changing neutral currents. It has been pointed out /33/, if non leptonic b decays exist and if $B \rightarrow \mu^+\mu^- + X$ is suppressed to a few percent, then the b-quark is part of a SU(2) doublet and the t-quark must exist. Thus in the framework of "topless" theories it is important to look for this dimuon decay of the B-particles.

The JADE Collaboration studied events with two muons of opposite charge in the final state. Both muons were required to be in the same jet. They found 8 candidates. All of them have an invariant mass of the μ-pair system being less than the mass of the b-quark (~ 5.2 GeV). They expect 6.9 events from the standard charged current decays of b- and c-quarks plus background (K, π decay, misidentified muons from punch through of hadrons etc.), which gives an upper limit of

$$BR(B \rightarrow \mu^+\mu^- + X) < 3\ \% \quad (90\% \text{ confidence level})$$

ruling out most of the models in which the b-quark is assigned to a singlet. This result is in agreement with measurements at the $\Upsilon(4S)$ resonance /32/.

5.3 LIFETIME OF THE B-PARTICLES

The generalized Cabbibo angles ϑ, β, γ describe the coupling between the three quark doublets. While the coupling $s \rightarrow u$ quarks is described by $\sin\vartheta$, the sine of the conventional Cabbibo angle ϑ, the coupling $b \rightarrow u$ is described by $\sin\beta$ and $b \rightarrow c$ by $\sin\gamma \cdot \cos\beta$. The angles are related to the lifetime of the B-particles by

$$1/\tau_b = (2.74 \sin\gamma + 7.7 \sin^2\beta)/(10^{-14} \text{ sec}).$$

Thus a limit for the lifetime of the B-particles imposes constraints on these angles.

The JADE Collaboration has determined an upper limit of the B-particles using their dE/dx measurements of $\tau_b < 2 \cdot 10^{-9}$ sec /25/. To improve this result they used events with inclusive muons and determined the closest distance of approach of the muon to the vertex in a plane normal to the beam. From a sample of 210 candidates containing a muon, they selected 43 events with an enhanced fraction of events with a primary b quark pair and with almost no background. In particular the requirement that the sum of the transverse momenta (with respect to the event plane) has to exceed ~10% of the visible energy of the event enhances the b fraction by a factor of ~ 3. Thus in the final sample there are ~27% of the events from b-quark pairs, ~53% from c-quark pairs and ~20% from u,d,s production.

For each of these events they reconstructed the event vertex and measured the closest distance of approach to the vertex χ_μ in units of the standard deviation width of the vertex distribution σ (σ=0.6mm). The vertex distribution is shown in Fig. 17. The dashed line in this figure represents the number of events expected from b and c production. All tracks with $\chi_\mu >$

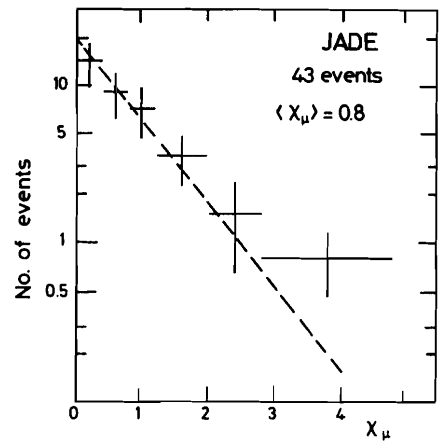

Figure 17. Vertex distribution: the dashed line is the expectation from bottom and charm production.

2 can be explained by the expected number of K decays. From the non observation of an excess of events at high χ_μ-values an upper limit of the lifetime of the B-particles can be derived:

$$\tau_b < 5\cdot 10^{-12} \text{ sec} \quad (90\% \text{ confidence level})$$

This imposes further constraints on the weak mixing angles as shown in Fig. 18, where the lower left hand region in the $\sin\beta$-$|\sin\gamma|$-plane is excluded by these measurements. The upper bound $\sin\beta < 0.8$ has been determined from the universality of the weak coupling /34/. From the K_L-K_S mass difference a restriction of $\sin^2\gamma$ can be derived in terms of the ratio of the charm and the top mass $\eta = (m_c/m_t)^2$ /35/:

$$\sin^2\gamma < \eta\cdot\ln\eta + \sqrt{(\eta\cdot\ln\eta)^2+\eta} \quad .$$

Using the current lower limit on the top mass (cf. Sec. 4.2), this angle is restricted to $\sin^2\gamma < 0.7$.

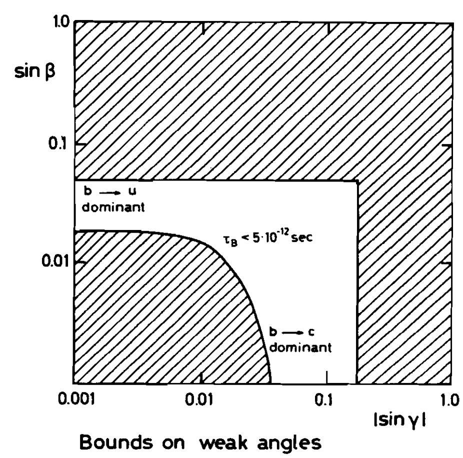

Figure 18. Bounds on weak angles: the excluded areas are hatched, the lower left hand region is excluded by the measurement of the upper limit of the B-lifetime.

SUMMARY

During the last year no new particle has been observed at PETRA up to beam energies of ~18.5 GeV. In particular:

- No scalar particle (electron, muon) or charged techni-(hyper-)pion has been found with mass less than 15 GeV.
- No further lepton, either excited, or sequential or neutral has been observed.
- No free quark has been observed in inclusive and exclusive production at a level of 1% and 0.1% of the muon pair cross section for $^1/_3$ and $^2/_3$ charged quarks respectively.
- No evidence for the existence of the top quark in the energy range covered by PETRA has been found. No narrow $t\bar{t}$-resonance and no threshold for free top production has been observed. As far as the threshold of a further quark is considered this holds also for a charge $^1/_3$ quark.

The inclusive muon events have been used to study properties of B-particles. Two branching ratios have been determined:

$$\mathrm{BR}(B \to \mu + X) = 8\% \pm 2.7\% \text{ (statistical)} \pm 2\% \text{ (systematic error)}$$

$$\mathrm{BR}(B \to \mu^+\mu^- + X) < 3\ \% \quad \text{(90\% confidence level)}.$$

From the latter result it is concluded with high confidence that the b-quark exists in a doublet under SU(2), i.e. that a sixth quark must exist. A measurement of the upper limit of the lifetime of the B-particles

$$\tau_b < 5 \cdot 10^{-12} \text{ sec} \quad \text{(90\% confidence level)}$$

gives further bounds for the weak mixing angles.

Acknowledgments

I wish to thank my colleagues of the CELLO, JADE, MARK J, PLUTO and TASSO Collaborations for providing their latest results and for many discussions, A.Ali for theoretical discussions and D.Lüke for compiling the scan data of all collaborations. I gratefully acknowledge the work of my scientific secretaries K.Derikum and M.Wollstadt. Finally I wish to thank the organizers of the conference whose outstanding efforts and warm hospitality made our stay in Bonn most enjoyable.

REFERENCES

1. Okun, L.B., these proceedings.

2. Felst, R., these proceedings.

3. Braunschweig, W., these proceedings.

4. Branson, J., these proceedings.

5. Gol'fan, Yu.A, E.P.Likhtman, JETP Letters 13 (1971) 323;
   Wess, J. and B.Zumino, Nucl.Phys. B70 (1974) 39.

6. for a review see e.g.:
   Fayet, P. and S.Ferrara, Phys.Rep. 32C (1977) 249;
   Fayet, P., Proceedings Orbis Scientiae Conf. (Coral Gabels,Florida,USA) "New Frontiers in High Energy Physics", Plenum Press, New York, 1978, p.413;
   Farrar, G., Proc. Int. School of Subnuclear Physics (Erice,Italy), 1978.

7. Barbiellini, G. et al.(ECFA LEP-Study Group), DESY report 79/67 (1979).

8. Cords, D., Proc. Int. Conf. High Energy Physics 1980, Madison (USA), AIP Conf. Proceedings No. 68, New York, 1981, Vol.1, p.590.

9. MARK J collaboration, D.P. Barber et.al, MIT report LNS 113 (1980).

10. Spitzer, H., Proceedings of the 15th Rencontre de Moriond, Les Arcs (France) 1980, Vol.II, p.157 and DESY report 80/43 (1980).

11. Susskind, L., Phys. Rev. D20 (1979) 2619;
    Weinberg, S., Phys. Rev. D19 (1979) 1277;
    Eichten, E. and K.Lane, Phys. Lett. 90B (1980) 125;
    Dimopulos, S., Nucl. Phys. B168 (1980) 69.

12. Peskin, E.M., Saclay report DPh-T/80/46 (1980).

13. Ali, A. and M.Beg, DESY report 80/98 (1980);
    Ellis, J., CERN preprint TH 2910 - CERN (1980).

14. Bjorken, J.D. and C.Llewellyn-Smith, Phys.Rev. D7 (1973) 887.

15. Ali, A., Phys.Rev. D10 (1974) 2801;
    Gourdin, M. and X.Y.Pham, Nucl.Phys. B164 (1980) 387 and 389.

16. Bletzacker, F. and H.T.Nieh, Phys.Rev. D16 (1977) 2115.

17. for a recent review of QED tests see e.g.:
    Dittmann, P. and V.Hepp, DESY report 81/030 (1980) to be published in Z.Phys. C.

18. Berends, F.A. and R.Kleiss, Nucl.Phys. B178 (1981) 141.

19. Litke, A., Havard University, Ph.D thesis (1970), unpublished;
the JADE Collaboration used a similar calculation performed by:
Terazawa, H., M.Yassue, K.Akama and M.Hayashi (private communication).

20. Berends, F.A. et al., Nucl.Phys. B57 (1973) 381.

21. TASSO Collaboration, R.Brandelik et al., Phys.Lett. 99B (1981) 163.

22. PLUTO Collaboration, Ch.Berger et al., Phys.Lett. 99B (1981) 489.

23. for a listing of different quark search experiments see
Barbiellini,G. et al. (ECFA LEP Study Group), DESY report 80/42 (1980).

24. Drumm, H. et al., Nucl. Inst. and Meth., 176 (1980) 333.

25. JADE Collaboration., W.Bartel et al., Z.Phys. C6 (1980) 295.

26. Weiss, J.M. et al., SLAC report, SLAC-Pub-2671 (1981).

27. Mariani, A. et al.,"A Search for Fractionally Charged Particle at PEP",paper No. 78, submitted to this conference;
Litke, A.M., these proceedings.

28. Dine, M. and J.Sapirstein, Phys.Rev.Lett. 43 (1979) 668;
Chetyrkin, K.G. et al., Phys.Lett. 85B (1979) 277;
Celmaster, W. and R.J.Gonsalves, Phys.Rev.Lett. 44 (1980) 560.

29. Kobayashi, M. and K.Maskawa, Progr.Theor.Phys. 49 (1973) 652.

30. Ali, A. et al., Phys.Lett. 93B (1980) 155 and DESY report 79/86 (1979).

31. see e.g.:
Puhala, M.J. et al.,"B-meson Trigger at High Energies in e^+e^--Annihilation", paper No.55 submitted to this conference and "High Transverse Momentum Leptons from B-Mesons (...)", paper No.56 submitted to this conference.

32. Silverman, A., these proceedings.

33. see e.g.:
Georgi, H. and S.L.Glashow, Nucl.Phys. B167 (1980) 173;
Kane, G.L., University of Michigan preprint, UM HE 80-18 (1980).

34. Ellis, J. et al., Nucl.Phys. B109 (1976) 213.

35. Ellis, J. et al., Nucl.Phys. B131 (1977) 285.

DISCUSSION

J. Kirkby, SLAC:
For the b semileptonic branching ratio from the single μ data there is a possibility of a large systematic error because the subtraction of the charm background may be quite difficult. The D^0 semileptonic branching ratio is probably ~ 5% and the D^+ is about 20%. You have to measure the D^0 and the D^+ content of the data before you do the subtraction properly.

H. Newman (MARK J Collaboration), DESY:
We tried to put into the Monte Carlo as best as possible the D^0 and charged D production rates and branching ratios. The point is, however, that the overall inclusive leptonic branching ratio from D is measured very well, it is (8 ± 1)%. As long as we keep that, the systematic errors are as we quoted.

J. Kirkby:
The old fashioned number of (8 ± 1)% is based on measurements that were done at SPEAR and DORIS which assumed equal branching ratios. In the DELCO case, where the detection efficiencies were very different for those decay modes, the average semileptonic branching ratio is certainly not 8%. The individual branching ratio are close to 20% and 5%. You really have to be careful about that subtraction.

H. Newman:
The detection efficiencies are very sensitive at low energies.

J. Rohlf, Havard:
Is charm production from vacuum included in the Monte Carlo?

J. Bürger:
Yes.

J. Rohlf:
You said there were 48 events after having made the p_t-cut. From the statistical error on the (8 ± 2.7)%, the background subtraction must have been about half of that. Is the signal to background ratio really 2:1? It did not look so good from the curves you showed.

J. Bürger:
The quoted error is well compatible with the signal to background ratio of 1:1.