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SEARCH FOR NEW PARTICLES

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SEARCH FOR NEW PARTICLES

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INTRODUCTION

Recent experiments on new particle searches are reviewed. Here new particles mean those which have not been found yet. The conclusion of this report will all be negative. However, since the last Symposium at Bonn[1], limits on various masses and production cross sections have been improved considerably.

At present the gauge model, SU(3) x $SU(2)_L$ x U(1), looks very successful . By the discovery of the weak bosons[2,3] the electroweak theory[4] has been further confirmed. Let us first survey which particles are still missing in the standard model or expected beyond the standard model.

The SU(3) part has coloured quarks and gluons as its building stuff. Although these particles are indirectly seen as jet of hadrons[5], they have not been observed as free particles. The study of CP conservation of strong interaction implies the existence of an axion.

The origin of symmetry breaking in the electroweak theory is not experimentally verified. The standard model does not contain a right handed charged weak current. Is it really absent? As for the third generation, the top quark is still missing. Are there heavier sequential heavy leptons? It is an interesting question to investigate how many generations of quarks and leptons exist. There may be also exotic heavy leptons.

In the grand unified theory one expects that nucleons decay and there might remain heavy monopoles from the big bang. Supersymmetry predicts a lot of new particles as partners of the known particles. Some of them may be light enough to be produced in the energy range of the running experiments. In the composite models of quarks and leptons there are preons as fundamental building bricks. Even if they may be too heavy to be produced by the presently available energy, the effect of compositeness of the quarks and leptons may be already observable.

The following topics are discussed briefly.

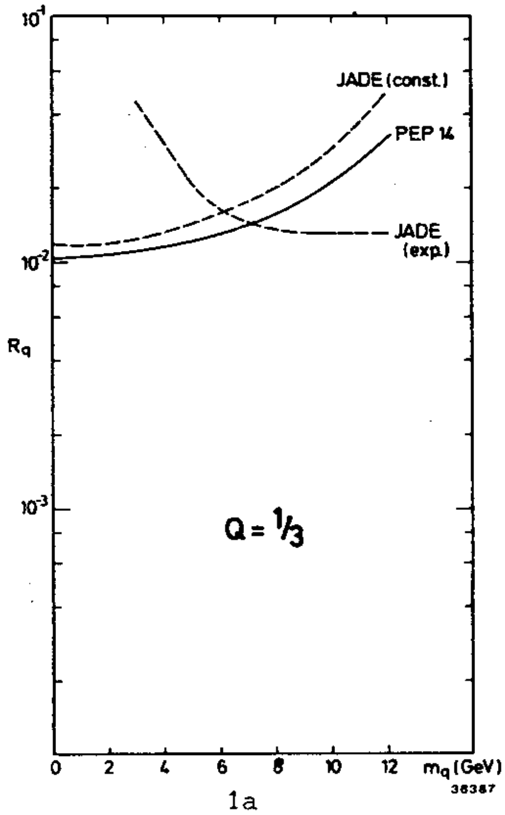
Free quarks
Axions
Right-handed charged weak currents
Higgs particles
Top quarks
Generations
-- sequential heavy leptons
-- exotic heavy leptons
-- neutrino counting
-- familons
Supersymmetric particles
Composite leptons
Magnetic monopoles

The experiments which are reviewed here employ two different methods. One way is to study a known process very precisely. Another way is to plan an experiment or choose analysis parameters in accordance with the predicted characteristics of the particle in order to remove the background. Usually the latter method is sensitive to a few events, but the former can lead to an unexpected surprise. Since details of individual experiments cannot be included, refer to the original papers for them.

FREE QUARKS OR FRACTIONALLY CHARGED PARTICLES

Free quarks have been hunted for many years by different methods[6]. In high energy physics, whenever higher energy became available, searches for fractionally charged particles were done. Since the Bonn conference new results have been added from e^+e^-, $\bar{p}p$ and μBe collisions. There was a new experiment to look for slowly moving fractionally charged particles in cosmic rays. In these experiments, the ionization loss of charged particles was measured by means of plastic scintillators or gas filled track detectors. No evidence for fractionally charged particles are found, and limits on the production cross section are obtained.

Fig. 1a,b and c show the results of the recent PEP experiments[7] together with the SPEAR and PETRA data[8]. The ratio of the inclusive quark production cross section to the muon pair cross section is plotted as a function of the quark mass. Fig. 1a and 1b are for $Q = 1/3$ and $2/3$, respectively. Fig. 1c is for the $Q = 4/3$ particle or diquark. Since ionization measurements provide unique charge identification only in the limited momentum range, the total cross section is obtained by extrapolation. JADE and TPC group assumed both flat and exponential distributions for the quark inclusive spectrum. In order to estimate the total acceptance PEP14 used a jet Monte Carlo calculation, in which one



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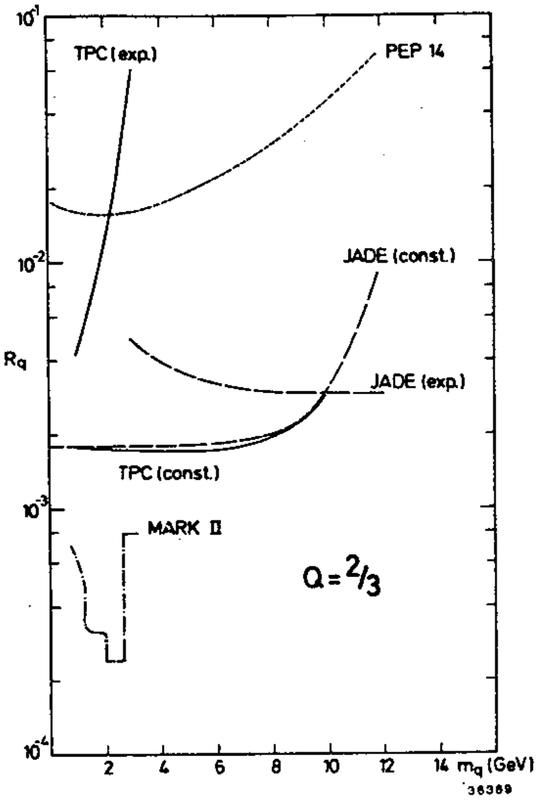

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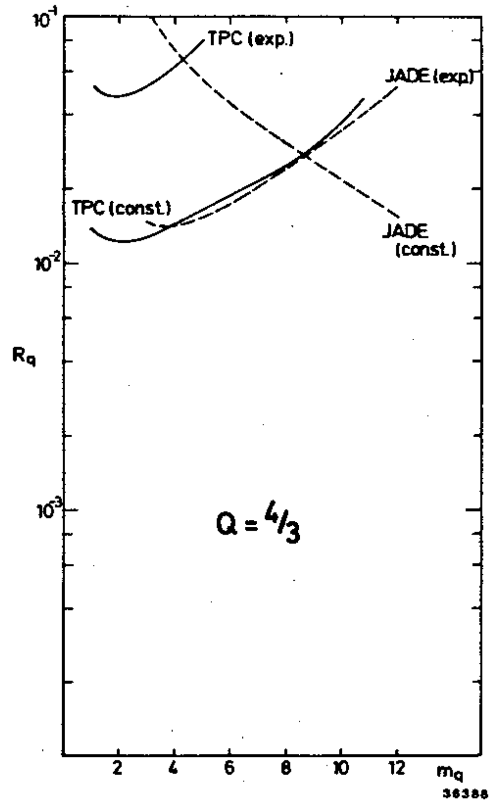

1c

Fig. 1: 95% CL limits on the ratios of the cross sections of the fractionally charged particle production to that of muon pair in the e^+e^- annihilation. a, b and c are for Q = 1/3, 2/3 and 4/3, respectively. The exponentioal distribution assumes

$E \frac{d^3\sigma}{dp^3} \propto \exp(-3.5E)$. The constant distribution assumes

$E \frac{d^3\sigma}{dp^3} = \text{const.}$

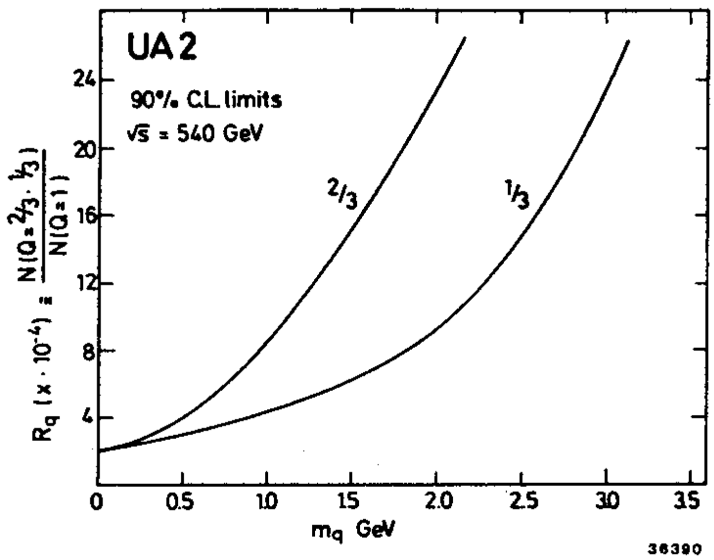

Fig. 2: 90% CL upper limit of the ratio of the fractionally charged particle production cross section to charge 1 particle production cross section measured at $\overline{p}p$ collider by UA2[9].

pion was replaced by one quark in each event.

Fractionally charged particles were searched for by the UA2 group at the $\overline{p}p$ collider[9]. They put six layers of scintillators at $\eta=4$, where η is the pseudorapidity. The acceptance was $\Delta\eta=0.4$. No candidate was found at $\sqrt{s}=540$ GeV. Fig. 2 shows the 90% C.L. limit on the ratio of the production cross section of the Q=2/3, 1/3 particles to that of Q=1 particles.

The EMC group[10] put six pairs of scintillators 360 meters behind the target to detect fractionally charged particles coming from the μ-Be collisions. The gate time was set in such a way that up to 9 (15) GeV heavy Q=2/3 (1/3) particles were detected if they live longer than 10^{-8} seconds. There was no event which had less than $0.75x(dE/dx)_{min}$ in more than one layer. The limits on the cross section are listed in Table I

Q	2/3	1/3	-2/3	-1/3	-2/3	-1/3
p ± Δp (GeV)	167±17	83±8	167±17	83±8	33±3	17±2
$\sigma(10^{-36}cm^2)$/nucleon	1.20	1.5	3.5	4.5	11.8	16

Table I: Upper limits obtained by the EMC collaboration[10] on the production cross section of fractionally charged particles in μBe collisions in each momentum setting of the spectrometer.

for different momentum settings of the spectrometer. The ratio of the cross section limit to the total muon-hadron production cross section is of the order 10^{-6}.

Recently a search for fractionally charged particles in slowly moving cosmic ray particles was reported[11]. Six layers of scintillators were set 250 m underground to measure dE/dx and the time of flight. In Fig. 3 the energy loss is plotted versus $1/\beta$, where β is the velocity of the particle. In the figure, negative velocities mean upward going

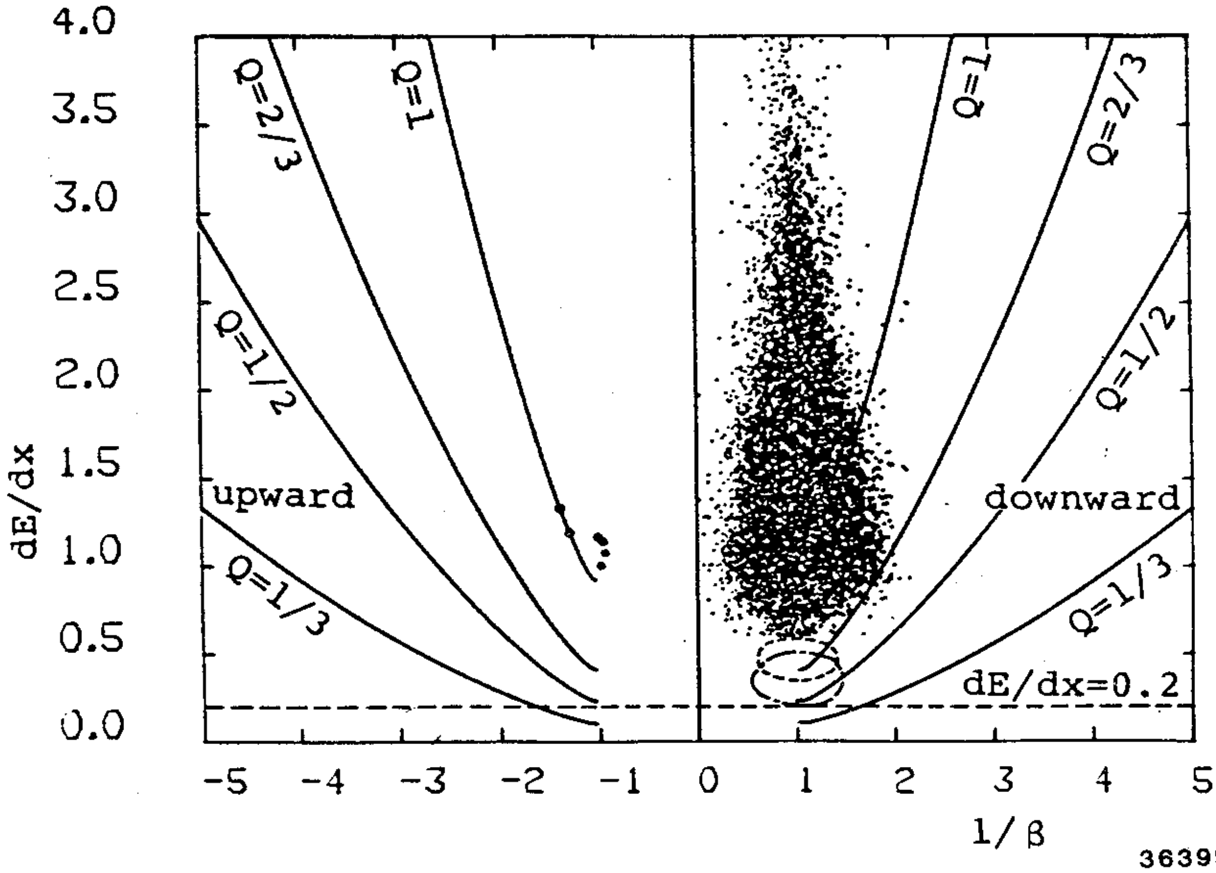

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Fig. 3: The correlation of the ionization loss and $1/\beta$ of underground cosmic rays . Expected curves for different charges are shown.

particles. There were no hits observed except a large number of cosmic ray muons. It gives a 90% C.L. limit of $1.5 \times 10^{-12} cm^{-2} sec^{-1} str^{-1}$ on the flux of fractionally charged cosmic ray particles. The accepted velocity range varies for different charges. They are determined by the trigger threshold of $0.25 \times (dE/dx)_{min}$. For charge 1, 2/3, 1/2 and 1/3, the velocity ranges are $3.5 \times 10^{-4}<\beta<0.4$, $4 \times 10^{-}<\beta<0.4$, $4.5 \times 10^{-4}<\beta<0.4$

and 6 x $10^{-4}<\beta<0.4$, respectively.

In all these experiments it is assumed that the fractionally charged particles do not interact so strongly that they are absorbed before arriving at the detector.

AXIONS

The axion(A)[12,13] is expected as a Nambu-Goldstone boson[14] of the Peccei-Quinn symmetry[15] which is introduced to explain the CP conservation of the strong interaction. In the standard axion model, $SU(2) \times U(1) \times U(1)_{P.Q.}$, which has two Higgs fields, the axion appears as a long living, very light particle. Its main decay proceeds like $A \rightarrow \gamma\gamma$. The existence of such a particle was tested by the radiative decays of heavy quarkonia, the decay of unstable nuclei and the coherent muon pair production in the ν-experiments.

The radiative decay branching ratio of J/ψ and Υ into A are expressed as[13]

$$B(J/\psi \rightarrow A\gamma) = B(J/\psi \rightarrow \mu\mu) \frac{G_F}{\sqrt{2}\pi\alpha} m_c^2 \chi^2, \quad (1)$$

$$B(\Upsilon \rightarrow A\gamma) = B(\Upsilon \rightarrow \mu\mu) \frac{G_F}{\sqrt{2}\pi\alpha} m_b^2 \frac{1}{\chi^2}, \quad (2)$$

where χ is the unknown ratio of the vacuum expectation values of the two Higgs fields. Since its contribution for $Q = 2/3$ quarkonium and $Q = -1/3$ quarkonium is reversed, it is eliminated when the two branching ratios are multiplied. Using the measured leptonic branching ratios, the expected value of the product is estimated as

$$B(J/\psi \rightarrow A\gamma) \times B(\Upsilon \rightarrow A\gamma) = B(J/\psi \rightarrow \mu\mu) \times B(\Upsilon \rightarrow \mu\mu) \times \frac{G_F^2}{2\pi^2\alpha^2} m_c^2 m_b^2 \quad (3)$$

$$= (16 \pm 3) \times 10^{-9} \quad (4)$$

Studies were made at SPEAR[16], CESR[17] and DORIS[18]. The experimental signal for the long living axion is the decay of narrow resonances emitting a monochromatic single gamma ray.

$$e^+e^- \rightarrow J/\psi \text{ or } \Upsilon \rightarrow \gamma + (\text{long living A}) \quad (5)$$

The recoil energy of the gamma ray is almost the beam energy for light axions. Evidence for such a decay was not observed. Upper limits on the branching ratio from various experiments are listed in Table II. Combination of the J/ψ and $\Upsilon(1S)$ ($\Upsilon(3S)$) data gives an upper limit on the product of 4.2×10^{-9} (0.6×10^{-9}), which is significantly smaller than the expected value. Thus the long living axion is excluded.

There are reports on searches of reactor experiments for nucleus decays which emit axions. They also give negative results[19].

	Crystal ball	CLEO	CUSB		LENA
	J/ψ	$\Upsilon(1S)$	$\Upsilon(1S)$	$\Upsilon(3S)$	$\Upsilon(1S)$
limit on $B_{A\gamma}$	1.4×10^{-5}	3×10^{-4}	3.5×10^{-4}	1.2×10^{-4}	9×10^{-4}

Table II: 90% C.L. upper limits on the branching ratio of the heavy quarkonium into a single monochromatic gamma ray

CHARM collaboration studied coherent production of muon pairs[20] in the context of axion reactions. Based on two candidate events, they concluded the following limits on the axion production cross section.

$\frac{1}{\chi^2}\sigma$ (PN $\rightarrow$ AX) < 330 pb/nucleon for the same A-dependence as π production and

$\frac{1}{\chi^2}\sigma$ (PN $\rightarrow$ AX) < 250pb/nucleon for the linear A-dependence.

After these negative results, invisible axions[21] have attracted more interest, and discussions have been made on their cosmological implications[22]. There is a contribution which proposes how to observe the invisible axion[23].

RIGHT HANDED WEAK INTERACTIONS

The Berkeley-Northwestern-TRIUMF group[24] has contributed for this question. They measured the electron spectrum of the muon decay very precisely in different directions with respect to the muon spin orientation. In V-A theory, it is forbidden for e^+ to carry the highest kinematically possible momentum when it is emitted exactly backwards with respect to the muon spin orientation. If there is a right-handed weak boson (W_R), as expected in the left-right symmetric models[25], and if the right-handed neutrino mass is lighter than 10 MeV, there can be a finite yield at the spectrum end point. The height of the step depends on the mass of W_R and the mixing angle between W_L and W_R. The experiment was done at TRIUMF using highly polarized muons which were stopped in metal foils. Fig. 4 shows the electron spectrum near the endpoint in the backward direction. After careful corrections, including the finite acceptance, a limit on the W_R mass, is estimated as $M > 380$ GeV for any mixing angle.

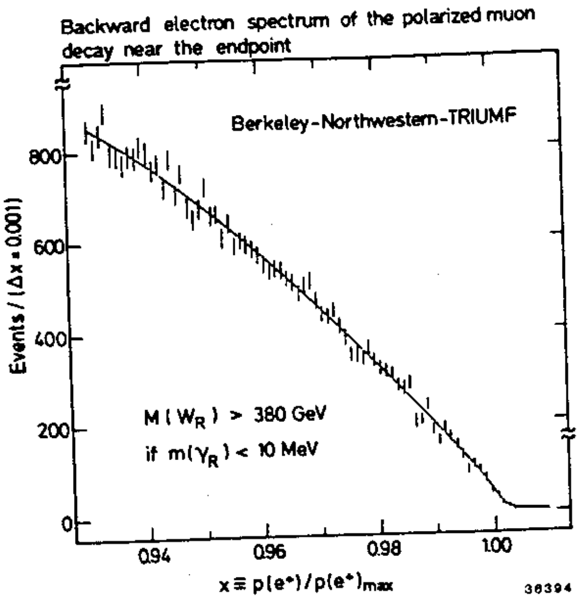


Fig. 4:

The electron spectrum of the polarized muon decay in the backward direction near the end point, measured by the Berkeley-Northwestern-TRIUMF collaboration[24].

HIGGS PARTICLES

The Higgs particle[26] plays an important role for spontaneous symmetry breaking of the electroweak theory. In the minimal standard model there is one neutral Higgs particle, H^o, and in other models more Higgs particles are expected including charged ones H^+ and H^-[27]. When gauge symmetry breaking is done dynamically, like technicolor[28], there appear scalar particles as Nambu-Goldstone bosons, which behave like Higgs particles. The coupling of these particles to fermions is proportional to the fermion mass. Such scalars are still missing in the particle table. The first experimental search for them was reported from JADE at the 1981 Bonn conference[1]. In the concluding talk of the conference, Okun[29] urged experimentalists to look for them, too. Much work has been done since then.

The standard Higgs particles can be produced in the radiative decay of heavy quarkonia like

$$Q\bar{Q} \to \gamma H^o, \tag{6}$$

which gives a monochromatic gamma ray. The branching ratio is[13]

$$B(Q\bar{Q} \to \gamma H^o) = \frac{G_F\, M^2_{Q\bar{Q}}}{4\sqrt{2}\alpha\pi}\, B(Q\bar{Q} \to \mu\mu)\ \left(1 - \frac{M^2_{H^o}}{M^2_{Q\bar{Q}}}\right) \tag{7}$$

For J/ψ and Υ the expected branching ratios are

$$B(J/\psi \to \gamma H^o) = 6 \times 10^{-5} \quad \text{and} \tag{8}$$

$$B(\Upsilon \to \gamma H^o) = 2.5 \times 10^{-4}, \tag{9}$$

if the kinematical factor is taken to be 1.0. The heavier the quarkonium, the more pronounced the signal is. For that reason, toponium will be the best place to look for it.

The photon inclusive spectrum was studied by the CUSB group on the Υ[30]. There was not any monochromatic peak found in the photon spectrum and 90% C.L. limits on the $\Upsilon \to \gamma H^o$ branching ratio were obtained for different H^o masses, as shown in Fig. 5. The experimental constraint is still much larger than the theoretical predictions.

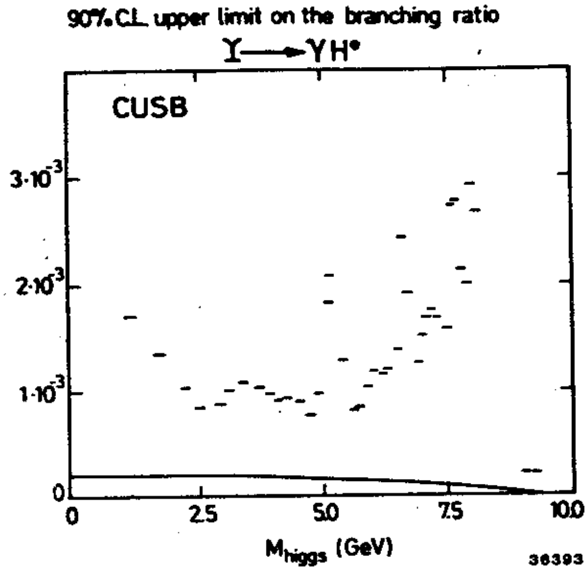


Fig. 5:

90% C.L. upper limit on the branching ratio $\Upsilon \to \gamma H^o$, plotted as a function of the Higgs mass obtained by the CUSB collaboration[30]. The curve is the expected branching ratio.

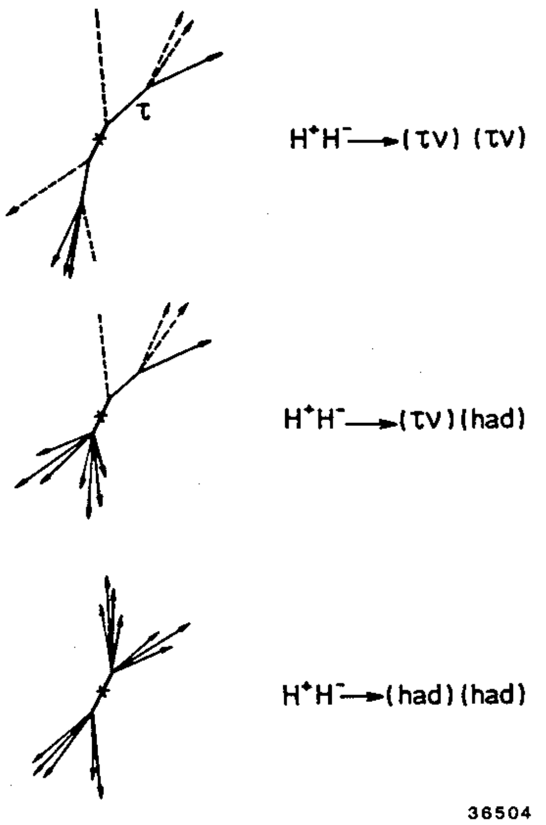
Extensive searches for charged Higgs or technipions($P^{\pm}$) were done mainly in e^+e^- reactions, in which they are pair produced as pointlike particles according to the cross section

$$\frac{d\sigma}{d\Omega}\,(e^+e^- \to H^+H^-) = \frac{\alpha^2}{8s}\,\beta^3 \sin^2\theta \qquad (10)$$

where β is the velocity of $H^{\pm}$. $H^{\pm}$ couples to the weak quark or lepton doublet like $W^{\pm}$. The coupling is, however, proportional to the fermion mass, and the heaviest doublet of quarks or leptons makes the dominant decay mode. The ratio between hadronic decay and leptonic decay is unknown as

$$\frac{B(H^{\pm}\to \text{had})}{B(H^{\pm}\to \tau\nu)} = \frac{M_c^2}{M_\tau^2}\,x, \qquad (11)$$

where x is a model dependent parameter. Since the hadronic and leptonic decays look very different from an experimental point of view, searches for Higgs scalars were done separately for different x regions. Typical expected event shapes are illustrated in Fig. 6.



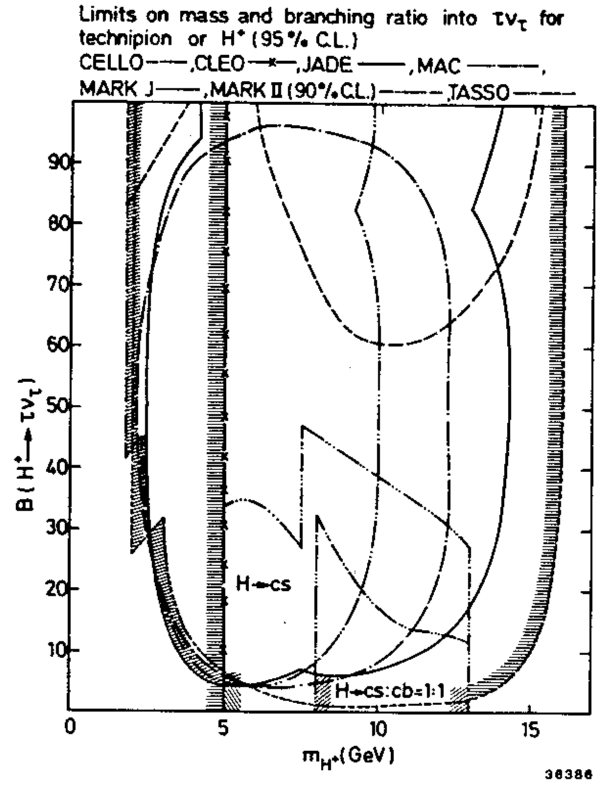


Fig. 6:

Expected event patterns for $e^+e^- \to H^+H^-$ reaction for different decay modes of $H^\pm$. For details see text.

Fig. 7:

The combined limit on the mass of charged Higgs or technipions as a function of its branching ratio into $\tau\nu$, obtained by e^+e^- experiments.

For $x \ll 1$, $H^+ \to \tau^+\nu$ is the dominant mode and the probability of $H^+H^- \to (\tau^+\nu)(\tau^-\nu)$ is high. When the mass of H^+ is high, the event produces an acoplanar τ-pair because of the energy carried away by neutrinos. When the H^+ mass is not so large, the event will give an excess in τ-pair production over the QED yield. This mode has been studied by CELLO[31], JADE[32], MARK II[33], MARK J[34] and MAC[35].

When x is about one, the probability of mixed decays $H^+H^- \to (\tau\nu)$(hadrons) is the highest. In this case there will be such multihadron events where the neutrinos carry a substantial fraction of energy so that the observed total energy is lower than the available energy and the total momentum is unbalanced in P_t, giving an acoplanar event. For the light mass $H^\pm$, a significant characteristic is that a single lepton from the τ decay is emitted against a hadron jet. These cases were studied by JADE[32], MAC[35], MARK II[33] and MARK J[34].

If $x' >> 1$, the dominant decay gives a hadronic final state. TASSO[36] has made a study of the 4-jet events which are expected from $H^+H^- \to (q\bar{q})(q\bar{q})$, where $(q\bar{q})$'s are $(c\bar{b})/(b\bar{c})$ or $(c\bar{s})/(s\bar{c})$.

There was no event candidate found for $H^\pm/P^\pm$ in those investigations. The results are summarized in Fig. 7, which shows the excluded area in the $(m_H{}^+, B(H^+ \to \tau\nu))$ plane.

Light charged Higgs were searched for by the CLEO group by studying the b-decay[37]. When the $H^\pm$'s are lighter than B-mesons, b quark decay $(b \to uH^-)$ will occur predominantly since there is only one weak coupling involved. In this case the $ue\nu$ final state is suppressed since H^- decays preferentially into heavier leptons. The observed electron yields and the charged track multiplicity was compared with the Higgs predictions by changing the relative branching ratios of $H \to \mu\nu$, $\tau\nu$ and cs. It was found that any value of the relative ratio cannot reproduce the observation, and thus the existence of a light charged Higgs is excluded.

Combining all data we can conclude that charged Higgs particles (or technipions) do not exist below 16 GeV.

TOP QUARK

Since the discovery of the Υ-mesons[38], the partner of the bottom in the context of the standard model doublet, the top quark, has been looked for[39]. Despite the large effort, the top quark is not found yet.

In e^+e^- experiments, where the search has been intensively made, there are several ways to hunt for it. There will be several narrow toponia toponia bolow the open top production threshold. They might decay more into planar events than 2 jet events due to the decay via three gluons. When an open top pair is produced, the R value, the ratio of the total cross section to the muon pair production cross section, will increase by 4/3, although the detailed threshold behaviour is unknown. The top events will be characterized by a spherical event shape, and, when the top decays semileptonically, by the presence of high P_t leptons among the final state particles.

The highest energy was scanned recently at PETRA. The PETRA energy has been increased to 43 GeV since Spring 1983. An energy scanning of R was finished between 39.94 GeV and 43.15 GeV one week before the conference. Preliminary results from the four running experiments, CELLO, JADE, MARK J and TASSO, are compiled and shown in Fig. 8[40]. The energy step for the scanning was 30 MeV in total energy, which is compatible with the machine energy spread. At each energy, every group accumulated an average of 50 nb^{-1} integrated luminosity. The R values are consistent with being flat. Their average is 3.94 ± 0.06. A possible Gaussian peak with the given width was searched for in the data[40]. The highest enhancement is also shown in the figure. The fit gives

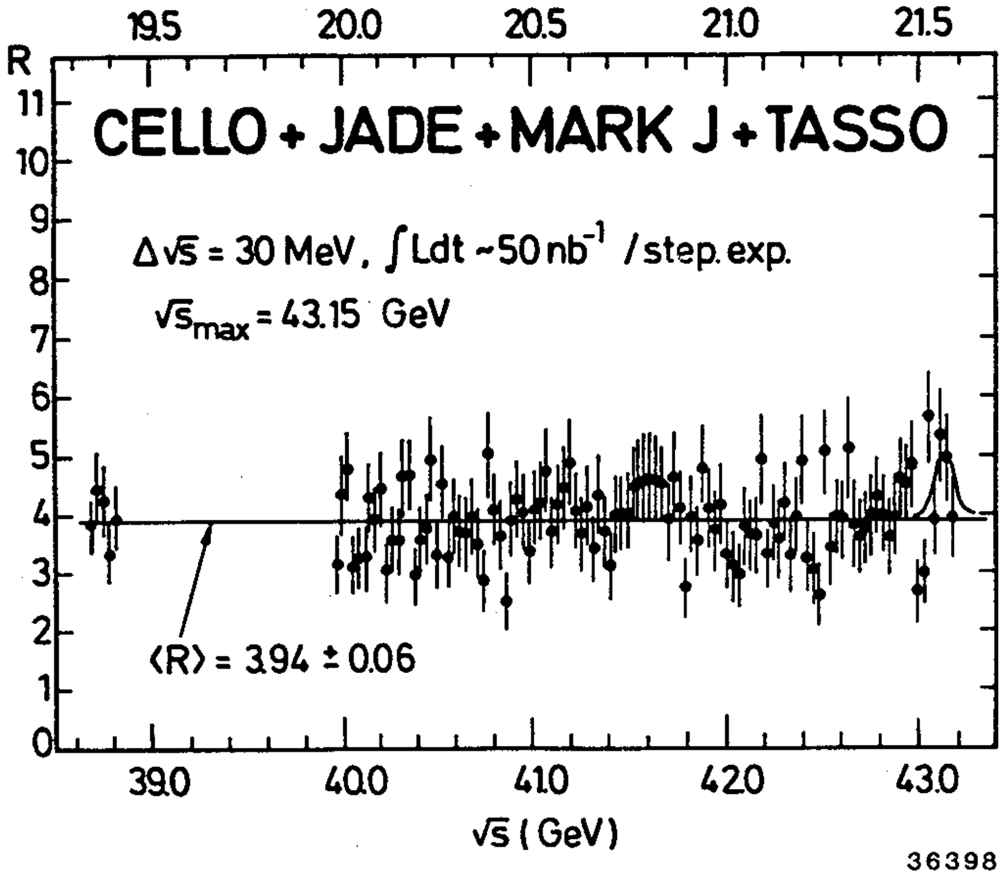


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Fig. 8: The combined R value of the fine energy scanning by the PETRA experiments.

$$M = 43.09 \text{ GeV}, \qquad \Gamma_{ee}B_{had} = (0.61 \pm 0.25) \text{ keV} \tag{12}$$

It leads to a 95% C.L. limit on the $\Gamma_{ee}B_{had}$ of the narrow resonance of 1 keV. It should be compared with the expected $\Gamma_{ee}B_{had}$ of the Q = 2/3 toponium, 4 keV. Thus the existence of such a toponium is excluded in the scanned region.

Multihadron events due to open top quark are also examined by measuring the yield of aplanar or inclusive muon events. The thrust distribution for muon containing events was measured by MARK J[41] and is shown in Fig. 9. The data is consistent with the expectation obtained without a top quark contribution. A similar result was obtained by JADE[41], too. In Fig. 10, the fraction of aplanar events, which were measured by TASSO[41], is compared with a threshold behaviour of pointlike heavy particles with Q = 2/3 and 1/3. If the top quark cross

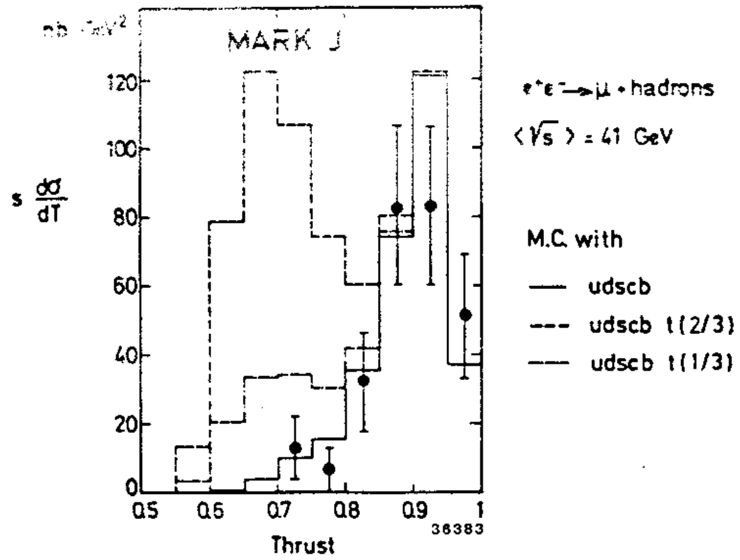

Fig. 9: The thrust distribution of the muon inclusive events at 41 GeV measured by MARK J.

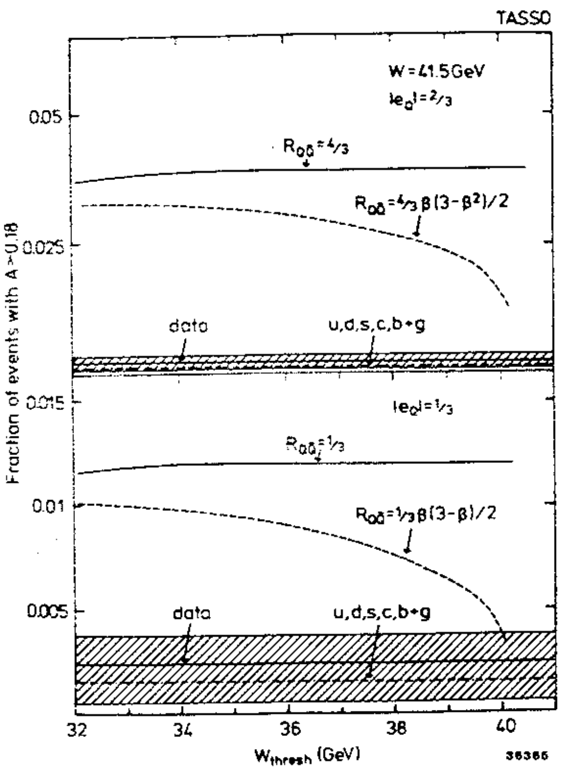

Fig. 10:

The fraction of aplanar events as a function of the W threshold. The region above the shaded band is excluded at the 95% C.L. by TASSO. The dotted curves are expectations for Q = 2/3 and 1/3 pointlike particles.

section increases like the curves, they give 95% C.L. mass limits on the Q = 2/3 and Q = 1/3 quarks to be 20.7 and 19.8 GeV, respectively.

Dilepton decay of the b quark has been studied by CLEO[42], JADE[43], MARK II[44] and MARK J[45]. Such a decay is expected to occur in models[46] without top, where the bottom is a right handed singlet. The expected branching ratio for $b \rightarrow \mu\mu X$ is above 1%. These experiments have observed no evidence for the dimuon decay and obtained limits on the branching ratio of less than 0.7%. From the absence of the flavour changing neutral current decay, one can conclude that the top is expected to be somewhere.

GENERATIONS

Heavy Leptons

The standard model does not tell how many generations of fermions exist. The question must be answered experimentally. One method is to look for heavy leptons. Historically it happened that the charged lepton was always the first to be found for each generation. Searches for a sequential heavy lepton (L) have been performed in e^+e^- interactions up to 43 GeV. Pair production of a spin 1/2 pointlike particle is described as

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4s} \beta_L \{1 + \cos^2\theta + (1 - \beta_L^2) \sin^2\theta\} \qquad (13)$$

In the standard model, L decays into its own neutrino by emitting a virtual W, which then couples to fermion doublets as shown in Fig. 11[47]. If L is heavy compared to the charm quark or τ-particle, the pure leptonic and semi-hadronic branching ratios are expected to be

$$B(L \rightarrow l\nu\nu) = 11\% \text{ (for } e, \mu, \tau)$$
$$B(L \rightarrow \text{had} + \nu) = 67\%. \qquad (14)$$

Although purely leptonic events, such as anomalous acoplanar $e\mu$ events, are not copious, there will be a fair amount of lepton + hadron events or momentum unbalanced multihadron events due to high energy missing neutrinos. So far there is no evidence found for such particles, which follow the above threshold behaviour. The limits from CELLO[48], JADE[49], MAC[50], MARK J[51], MARK II[52], PLUTO[53] and TASSO[54] are summarized in Table III.

CELLO	JADE	MAC	MARK J	MARK II	PLUTO	TASSO
16.3	20.6	14.0	20.5	13.8	14.5	15.5

Table III: 95% C.L. lower limits on the sequential heavy lepton mass (GeV).

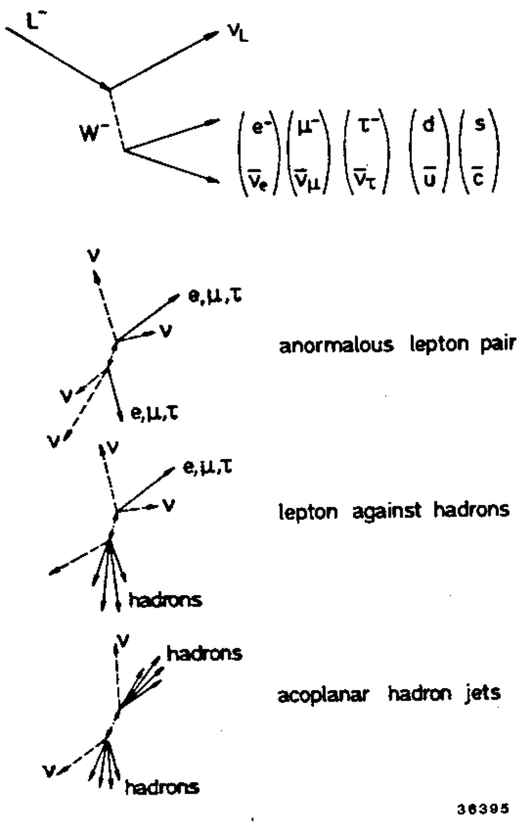

Fig. 11:

The decay process of a heavy lepton in the standard model and the expected event topologies for a new heavy lepton pair.

If the neutral partner of the new lepton doublet is heavier than the charged one, the new charged lepton may be stable or very long lived. Pair production of such a stable lepton was studied by JADE[55] and MARK J[56]. JADE used dE/dx, time of flight and momentum information to look for heavy ionizing, slow particle pairs, which otherwise satisfy muon pair selection criteria. No event was found. The 95% C.L. limit on the mass was obtained to be 18.4 GeV. MARK J investigated the possible excess in the absolute muon pair cross section due to an extra contribution and obtained a limit on the stable lepton mass of 14 GeV.

A massive electron type neutral heavy lepton is postulated in some models[57]. Such a heavy lepton (E^o) forms a doublet with the electron and can be produced in e^+e^- annihilation via W-exchange. Since the associated particle is a neutrino, a very massive E^o can be produced (see Fig. 12). In the standard model, the decay of E^o is similar to that of the sequential heavy lepton. The difference is that an electron is emitted instead of a neutrino, as shown in Fig. 12.

JADE[49] applied the heavy lepton analysis to the E^o case and obtained limits (95% C.L.) on the E^o mass of 24 GeV (V-A) and 26.5 GeV (V+A), where the coupling type indicates the E^oe coupling to the W.

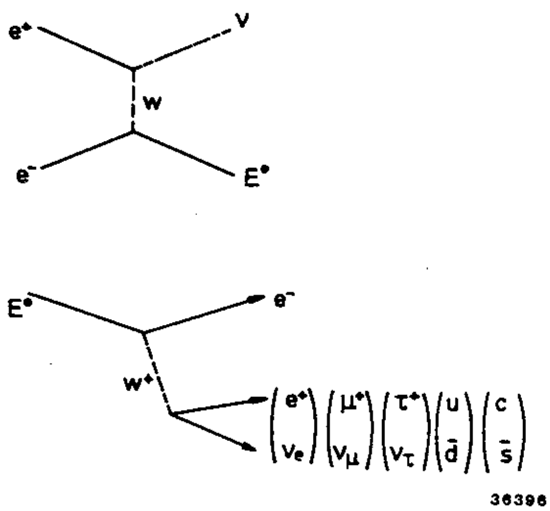

Fig. 12:

Production and decay of an electron type neutral heavy lepton E^o.

MAC[58] searched for high energy electrons emitted at large angles with respect to the hadron jet axis and obtained a limit (95% C.L.) on the mass of 23 GeV for V-A coupling.

Neutrino Counting

It can well happen that neutrinos remain light for higher generations, of which the charged leptons are very heavy. Neutrino counting is then an effective way of estimating the number of such generations. Since the Z^o has been discovered, this can be done by measuring the Z^o width. The UA1 and UA2 groups reported the following limits on the width ,

$$\begin{aligned} \Gamma &< 8.5 \text{ GeV} \quad (\text{UA1})^{2} \\ \Gamma &< 11 \text{ GeV} \quad (\text{UA2})^{3} \end{aligned} \tag{15}$$

which corresponds to limits on the number of neutrino of 34 (UA1) and 47 (UA2). The UA1 group estimated the number of neutrinos from the lower limit of the branching ratio of the observed decay $Z^o \to e^+e^-$ to be 18 (90% C.L.).

In e^+e^- reaction, the radiative process $e^+e^- \to \gamma\nu\bar{\nu}$ via the virtual Z^o can be used to estimate the number of light neutrinos[59]. MAC[60] measured single photon events with the conditions $|\cos\theta| < 0.8$ and $P_{t,\gamma} > 4.3$ GeV. There was no accepted event and they obtained 90% C.L. limit on the neutrino number to be 103.

These numbers are substantially reduced and less model dependent than the previously achieved estimates from laboratory experiments[61]. The limits obtained from the Z^o width includes also massive neutrinos, which contribute in the Z^o decay.

Familons

There is an idea of symmetry between generations[62]. The Berkeley-Northwestern-TRIUMF group analysed their electron endpoint spectrum from the muon decay looking for the effect of familons. The familon (f) is a massless Nambu-Goldstone boson associated with the breaking of family symmetries[63]. If it exists, the muon can decay like $\mu \to ef$, due to the interaction

$$L_{int} = \frac{1}{F_{\mu e}} \bar{\mu} \gamma_\rho e \, \partial_\rho f_{\mu e} \qquad (16)$$

The branching ratio can be written in terms of $F_{\mu e}$ as $B(\mu \to ef) = B(\mu \to e\nu\bar{\nu}) \times 2.5 \times 10^{14}\ \mathrm{GeV}^2/F_{\mu e}$. The two body decay makes a peak at the endpoint of the electron spectrum. From the absence of such an enhancement, a limit on the branching ratio was obtained to be $B(\mu{\to}ef)<6\times10^{-6}$.

SUPERSYMMETRIC PARTICLES

Supersymmetry (SUSY)[64] attracts much interest, both theoretically and experimentally. For the theoretical aspects, refer to the talk by J. Ellis at this conference. The symmetry is apparently broken at low energy since there is no fermion-boson pair which have the same property except spin. There are many models about how to realize the symmetry breaking. Some are global and the others are local. Experimental searches for SUSY partners are done for the N = 1 model, which has one to one correspondence between the SUSY multiplets as shown in Table IV.

spin 1	spin 1/2	spin 0
	q_l, q_R	$\tilde{q}_l, \tilde{q}_R$ (squark)
	l_l, l_R	$\tilde{l}_l, \tilde{l}_R$ (sleptron)
g (gluon)	$\tilde{g}$ (gluino)	
γ	$\tilde{\gamma}$ (photino)	
W, Z	$\tilde{W}, \tilde{Z}$ (wino, zino)	
	$\tilde{h}_l, \tilde{h}_R$ (shiggs)	H_L, H_R
	G (Goldstino)	

Table IV: Supersymmetric multiplets

Some remarks follow. For leptons and quarks, there will be two SUSY scalars corresponding to the left-handed and right-handed components. In SUSY, there are two Higgs multiplets. The Goldstino disappears in the local symmetry breaking models, in which it turns into a component of massive gravitino. The SUSY current is assumed to be conserved. Hence a SUSY particle is produced by normal particles in associate production. When decaying, it decays into another SUSY particle. The lightest one is stable. Different symmetry breaking models predict different mass relations of SUSY particles. It must be noted that since experimental works are dependent on certain models, they can be applied only to the corresponding models. In what follows recent searches for each SUSY particle are described.

Massive Photino

If the photino exists, e^+e^- annihilate into two photinos by scalar electron exchange as shown in Fig. 13. The cross section is

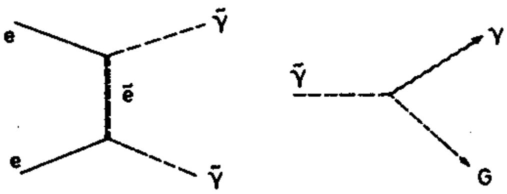

Fig. 13:

Production of a photino pair in the e^+e^- reaction and decay of the massive photino into a photon and a Goldstino.

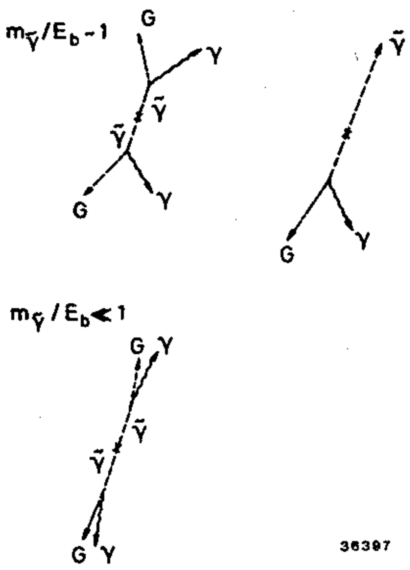

Fig. 14:

Expected event topologies for the heavy and/or light massive photinos.

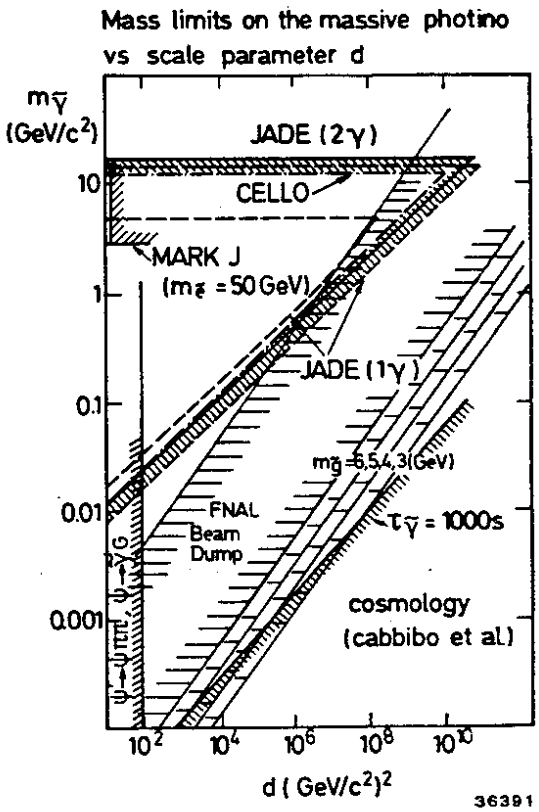

Fig. 15:

95% C.L. limits on the mass of the massive photino as a function of the scale parameter, d, obtained from the e^+e^- reaction[67,68,69], the beam dump experiment[70] and other studies as cited in ref. 67. CELLO and JADE assumed $m_{\tilde{e}}$ = 40 GeV and MARK J assumed $m_{\tilde{e}}$ = 50 GeV.

given for the case $m_{\tilde{e}_R} << m_{\tilde{e}L}$ and $s/m^2_{\tilde{e}_R} << 1$ by[65]

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 s \beta^3_{\tilde{\gamma}}}{8} \cdot \frac{1}{m^4_{\tilde{e}_R}} (1 + \cos^2\theta_{\tilde{\gamma}}) \tag{17}$$

Further, if the photino is massive and if it decays into a photon and a massless Goldstino, the lifetime can be determined by its mass and the scale parameter, d, as[66]

$$\tau_{\gamma} = \frac{8\pi d^2}{m^5_{\tilde{\gamma}}} \tag{18}$$

This case was first studied by CELLO[67] by analysing $e^+e^- \to \gamma\gamma$. When the mass of the photino is large, decay photons are emitted as aco-planar photon pair because of the large P_t carried away by Goldstinos. When the mass is small, the decay photons will be collinear but their energies will be substantially reduced from the beam energy. An expected event pattern is illustrated in Fig. 14. A similar analysis was done by JADE[68] and MARK J[69]. JADE also analysed single photon events which may occur when the photino lifetime is long and only one of the photinos decays in the detector. There was no evidence for such particles and limits on the photino mass were obtained as a function of the scale parameter. The excluded regions from these experiments are shown in Fig. 15. If the mass of the selectron is larger, the forbidden area in Fig. 15 is reduced.

Massive photinos were also searched for by the FNAL beam dump experiment (E613)[70]. In the analysis, three processes are assumed. First, a gluino pair is produced in the proton-nucleus reaction by gluon fusion. Second, the gluino decays into $\tilde{\gamma}+q\bar{q}$ and these photinos then hit the neutrino detector after travelling 60 meters. Third, the photinos then decay into photons and Goldstinos. If the decay occurs in the detector, a purely electromagnetic shower can be observed. There was no excess of muonless neutrino interaction with $E_{vis} > 20$ GeV and a 90% C.L. limit on the $\tau_{\tilde{\gamma}}/m_{\tilde{\gamma}}$ was obtained for different gluino masses. The results are summarised in Table V and shown in Fig. 15.

$m_{\tilde{g}}$(GeV)	excluded for $\tau_{\tilde{\gamma}}/m_{\tilde{\gamma}}$(sec/GeV)
3	$8.0 \times 10^{-11} \sim 7.6$
4	$8.3 \times 10^{-11} \sim 0.63$
5	$1 \times 10^{-10} \sim 6.8 \times 10^{-2}$
6	$1.2 \times 10^{-10} \sim 7.8 \times 10^{-3}$

Table V: 90% C.L. limits on $\tau_{\tilde{\gamma}}/m_{\tilde{\gamma}}$ for different gluino masses obtained by the FNAL beam dump exp.[70].

Smuon, $\tilde{\mu}$

Smuons are produced in e^+e^- annihilation as pointlike scalars following the formula (10). If $\tilde{\mu}_L$ and $\tilde{\mu}_R$ are degenerate, the cross section can be multiplied by factor 2. Except for some groups, however, this assumption is not taken. The smuon decays into $\mu+\tilde{\gamma}$ with a short lifetime if the photino mass is not too close to the smuon mass[71].

The two experimental methods are used to detect smuons. One way (a) is to examine the QED process precisely. The absolute measurement of $\sigma_{\mu\mu}$ is sensitive to the low mass smuon. The acoplanarity and/or acollinearity distribution of μ-pairs will deviate from the QED predictions when such particles are mixed in the data. This method was used by JADE[68], MAC[72] and TASSO[73]. No clear deviation from the QED prediction has been observed. Another way (b) is to look for acoplanar μ-pairs accompanied by no other particles. When a detector has a large acceptance both for charged and neutral particles, QED events like $e^+e^- \to \mu\mu\gamma$ or $ee\mu\mu$ can be removed. By this method, even a few events can be detected. It was used by CELLO[74], JADE[68], MAC[35] and MARK J[75]. No events were found which satisfied the cuts introduced by each group. The current mass limit on the smuon from each experiment is listed in Table VI together with the selection criteria. The listed results are

	method	momentum cut	acoplanarity cut	excluded mass
CELLO	b	$P_1, P_2 > \frac{1}{5} E_b$	$\alpha > 30^\circ$	$3.3 \sim 16.0$
JADE	a	$P_1+P_2 > \frac{2}{3} E_b$	$15^\circ > \alpha > 2^\circ$	$m_\mu \sim 17.0$
	b	$P_1 > 3.5$ GeV $P_2 > 0.2$ GeV $\Sigma P_t > 3.5$ GeV	$\alpha > 20^\circ$	
MAC	a	$P_1, P_2 > 1.5$ GeV	$\Delta\psi > 30^\circ$	$m_\tau \sim 13.8$
MARK J	b	$P_1 P_2 > \frac{1}{5} E_b$	$\alpha > 20^\circ$	$3 \sim 18$
TASSO	a	$P_1, P_2 > \frac{1}{5} E_b$ $P_1+P_2 > 0.7\ E_b$	$\alpha < 90^\circ$	$m_\mu \sim 16.4$

Table VI: Limits on the smuon mass (95% C.L.). For a description of methods a and b see text. P_1 and P_2 are the momenta of the two muons. $\Delta\psi$ is defined as $|90^\circ - \cos^{-1}(\hat{z}\cdot(\vec{P}_1 \times \vec{P}_2)/|\vec{P}_1 \times \vec{P}_2|)|$, $\hat{z}$ // beam .

based on the assumption that the photino is a massless or very light stable particle. If the photino mass is not negligibly light, the muon momentum in the final state will be reduced and may not satisfy the selection criteria. Furthermore, if there is a massless Goldstino and the $\tilde{\gamma}$ decays like γ+G, the second method mentioned above will reject most candidates since the final state will be $\mu\mu\gamma\gamma$ + missing energy. JADE investigated these cases by lowering the momentum cut and also allowing $\mu\mu\gamma\gamma$-events. The excluded regions in the ($m_{\tilde{\mu}}$, $m_{\tilde{\gamma}}$) plane are shown in Fig. 16 for the stable and unstable photino cases.

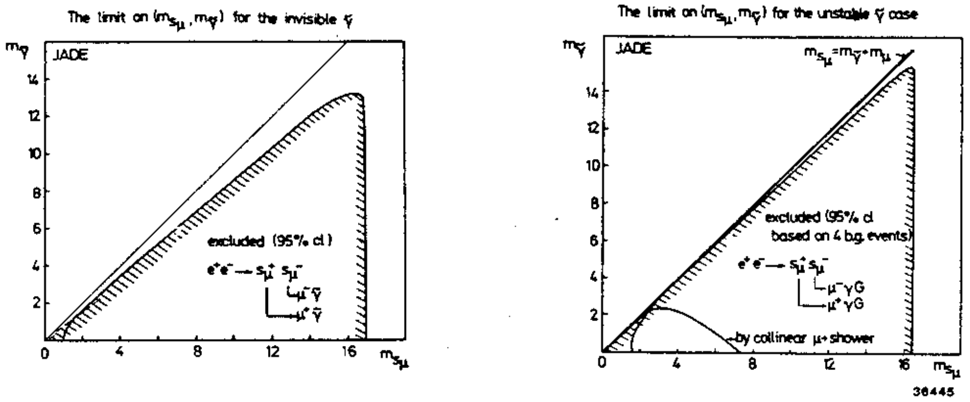

Fig. 16: 95% C.L. limits on the smuon mass (in GeV) versus the photino mass (in GeV) for the stable and unstable photinos.

If the photino is heavier than the smuon, the smuon may be stable. JADE[68] applied the stable heavy charged particle search, which was described earlier, to this scalar particle. It leads to a 95% C.L. limit of 16.6 GeV on the mass of the stable smuon.

Scalar τ, $\tilde{\tau}$

The scalar τ search is exactly the same as the $H^\pm$ search with a 100% branching ratio into τ if the photino mass is light. The present limits from various experiments are listed in table VII.

CELLO	JADE	MAC	MARK II	MARK J
15.3	14	13	9.9	16.5

Table VII: Limits on the $\tilde{\tau}$ mass in Gev. (95% C.L. except for MARK II which gave 90% C.L. limit)

Selectrons, $\tilde{e}$

There are three e^+e^- processes which are studied in search of selectrons. They are pair production of $\tilde{e}^+\tilde{e}^-$, single $\tilde{e}$ production and radiative annihilation into $\tilde{\gamma}\tilde{\gamma}$. The simplest way is to look for events originated by the process shown in Fig. 17a. The cross section is given by the following formula[76]

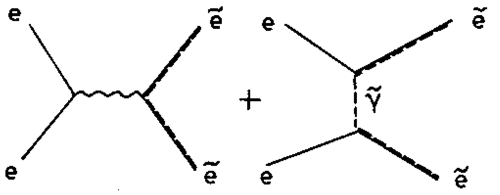

Fig. 17a:

Pair production of selectrons in e^+e^- annihilation.

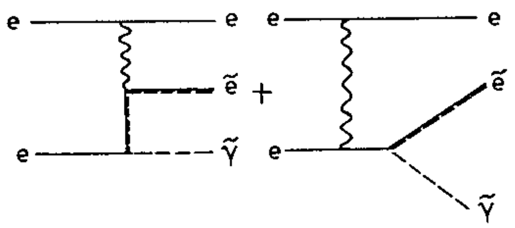

Fig. 17b:

Single production of $\tilde{e}$.

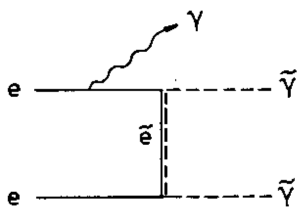

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Fig. 17c:

Radiative annihilation of e^+e^- into $\tilde{\gamma}\tilde{\gamma}$ by $\tilde{e}$ exchange.

$$\frac{d\sigma(e^+e^- \to \tilde{e}_L^+\tilde{e}_L^- \text{ or } \tilde{e}_R^+\tilde{e}_R^-)}{d\Omega} = \frac{\alpha^2\beta^3\sin^2\theta}{16s}\left\{1 + \left[1 - \frac{4k}{1-2\beta\cos\theta+\beta^2}\right]^2\right\} \quad (19)$$

If Goldstino exchange is neglected, $k = 1.0$. Experimental conditions are similar to smuons, where muons are replaced by electrons. This reaction was first studied by JADE[77] at high energies, and extensive investigations have since been done by many groups.[68,73,74,94]

A single selectron production process was suggested[78] by which one can produce massive selectrons heavier than the beam energy. The process is illustrated in Fig. 17b. When q^2 is small, the cross section is reasonably high. The recoil electron in such cases, however, is emitted in the very forward direction and escapes detection. The observed signal is a single electron coming from the decay selectron.

Experimentally this process requires a careful investigation of the background due to other QED processes, like eeγ. Electron acceptance must be restricted in such a region where QED background cannot contribute. The method was studied by MAC[79] and MARK II[80].

The indirect method is based on the radiative annihilation $e^+e^- \to \gamma\tilde{\gamma}\tilde{\gamma}$, which occurs via $\tilde{e}$ exchange[81] (Fig. 17c). The cross section depends on the $\tilde{e}$ mass as

$$\frac{d\sigma}{dxdy} = \frac{2\alpha^3 s(1-x)}{3x(1-y^2)} \left[(1-\frac{x}{2})^2 + \frac{x^2y^2}{4}\right]\left[\frac{1}{m_{\tilde{e}_L}^4} + \frac{1}{m_{\tilde{e}_R}^4}\right], \tag{20}$$

where $x = E_\gamma/E_{beam}$ and $y = \cos\theta_\gamma$. The experimental signal is a single gamma ray event, like the neutrino counting experiment. MAC[79] analysed the single gamma ray events in terms of the $\tilde{e}$ mass and obtained a 95% C.L. limit on the mass to be 24 GeV. The present limits from various experiments are summarized in Table VIII.

	method	limits on $m_{\tilde{e}}$ (GeV)
CELLO[74]	acoplanar e^+e^- pair + nothing	16.8
HRS[94]	acoplanar e^+e^- pair + nothing	14.2
JADE[68]	acoplanar e^+e^- pair + nothing	17.8
MAC[79]	single e^+/e^- single γ	21 24
MARK II[80]	single e^+/e^-	22.4
TASSO[73]	acoplanar e^+e^-	16.6

Table VIII: 95% C.L. limits on the selectron mass ($m_{\tilde{\gamma}} = 0$).

JADE[82] studied the selectron mass limits for the case of massive photinos. Both stable and unstable photinos were considered. The excluded region for ($m_{\tilde{e}}$, $m_{\tilde{\gamma}}$) is shown in Fig. 18. For the massive photino, the $\tilde{e}^+\tilde{e}^-$ production cross section changes by more than factor of two, if one assumes that $m_{\tilde{e}_L} = m_{\tilde{e}_R}$.[83]

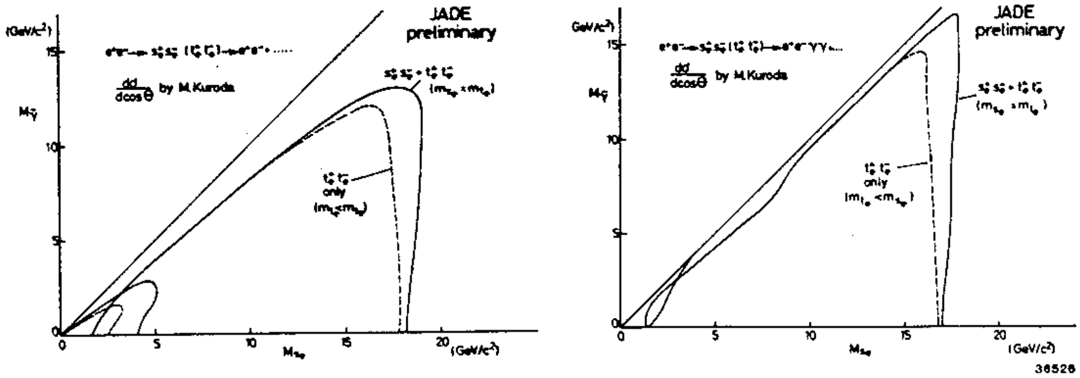

Fig. 18: 95% C.L. limits on the selectron mass versus photino mass for the stable and unstable photinos.

Gluino, $\tilde{g}$

Gluinos were searched for in beam dump experiments at CERN[84] and FNAL[69] . The study assumes the following processes which are similar to those described in the photino search. First, gluino pairs are produced by gluon fusion in the proton-nucleus collision. The gluinos decay into $\tilde{\gamma}q\bar{q}$, where the photino mass is negligibly small compared to the gluino mass. The photino beam is put into the neutrino detector where photinos interact like $\tilde{\gamma}q \to \tilde{g}q$, which looks like a neutral current interaction. In these analyses, photinos are assumed to be stable or suffiently long living. The CERN experiment dumped the 400 GeV proton beam onto a copper target and muonless reactions were searched for in the CHARM detector. The FNAL experiment (E613) dumped 400 GeV protons onto a tungsten or beryllium target. In these experiments, there was no excess of muonless events with $E_{vis} > 20$ GeV. The lower limits on the gluino mass are estimated for different squark masses. The results of the experiments are shown in Fig. 19. Under the assumed

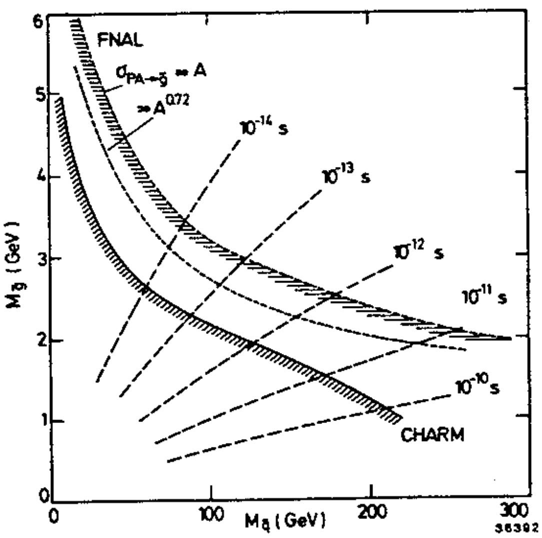

Fig. 19:

90% C.L. limits on the gluino mass as a function of the squark mass obtained by beam dump experiments. CHARM assumed $\sigma_{PA \to \tilde{g}} \propto A$. Broken lines are gluino lifetime constraints for the CHARM experiment.

conditions, the gluino mass is larger than 3 GeV, if $M_{\tilde{q}}$ < 100 GeV.

Squark

The preliminary result of a stable squark search was reported by the JADE group[85] . In the analysis the following assumptions were made. The squarks are pair produced like the smuons with the cross section modified by the squark charge and the colour factor 3. They fragment like normal heavy quarks, where the emission of the gluino is assumed to be absent. For the squark fragmentation the formula of Peterson et al.[86] is used as

$$f(z) = \frac{1}{z(1-\frac{1}{z} - \frac{\varepsilon}{1-z})^2}, \quad \text{where} \quad \varepsilon = \varepsilon_{charm} \cdot \left(\frac{m_c}{m_{\tilde{q}}}\right)^2 \tag{21}$$

Two types of analyses were made to detect the squark signal. One was the search for heavy stable particles in the multihadron events, which is relevant if a charged squark-meson is formed. The other was the search for missing P_t hadronic events, which may be caused by long living neutral squark-meson or by the decay of squarks into unobserved particles like $\tilde{q} \to \tilde{\gamma}q$.

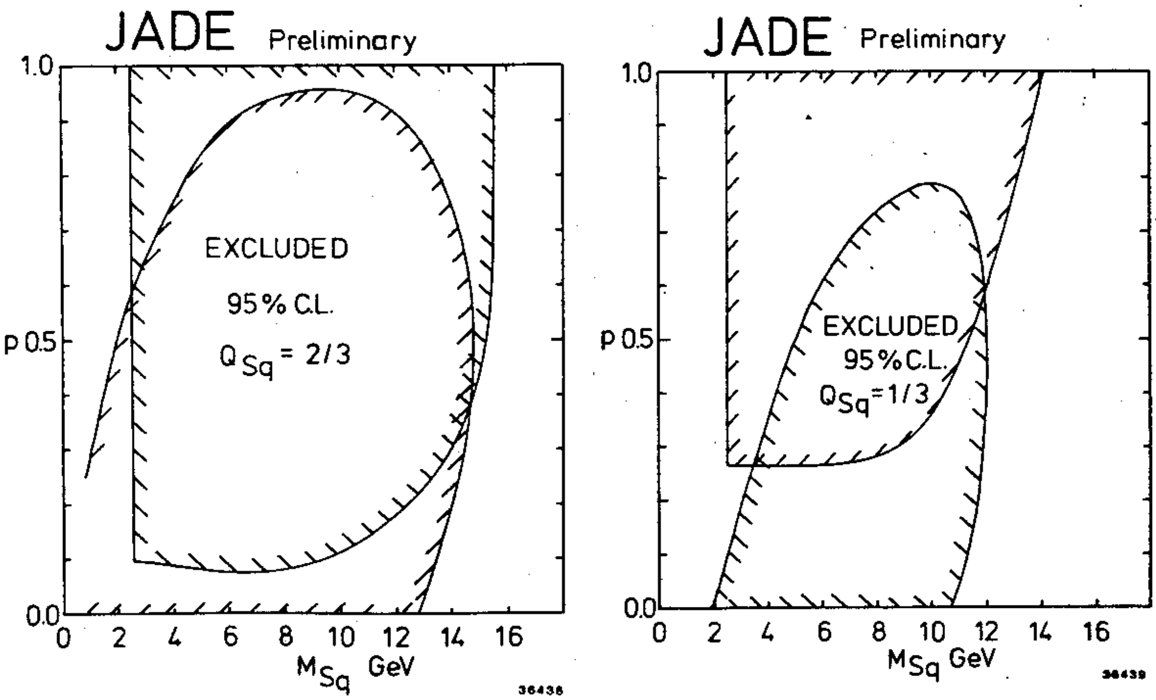

Fig. 20: 95% C.L. limits on the squark mass for different probabilities of squark-mesons being charged. Results of the heavy particle search and the unbalanced P_t event search are combined for Q = 1/3 and 2/3 squarks.

Using the dE/dx measurements, there were 7 events found which contained heavy particle candidates with the mass larger than 2.5 GeV. These events were compatible with the background. The missing P_t events were looked for among the low visible energy multihadron events, $0.5 < E_{vis}/W < 1.0$. After the cut $P_t > 9$ GeV, there were 6 events left which could be the tail of the normal events. Based on these observations, limits on the mass of squarks were obtained as a function of the charged smeson production probability,as shown in Fig.20.

COMPOSITE LEPTONS

There are models[87] for composite leptons and quarks and suggestions have been made on how to observe the effect of compositeness at present energies[88-89]. One way is to look for excited leptons and the other is to reexamine the QED cutoff parameters in the context of the composite picture.

Excited Lepton

If excited electrons exist, there is the $e^*e\gamma$ coupling as

$$L_{int} = \frac{\lambda e}{2M_{e^*}} \bar{\Psi}_{e^*}\sigma_{\mu\nu}\Psi_e F^{\mu\nu} + h.c. \qquad (22)$$

where λ is the measure of the coupling strength relative to the electric charge. Then $e^+e^- \to \gamma\gamma$ can occur by e^* exchange. The extra contribution modifies the QED cross section as follows[88],

$$\frac{d\sigma}{d\Omega}(e^+e^- \to \gamma\gamma) = \frac{\alpha^2}{s} \cdot \frac{1+x^2}{1-x^2}\left[1 + \frac{s^2}{2\Lambda^4}(1-x^2)\right] \qquad (23)$$

where $x = \cos\theta$ and Λ is related to λ and M_{e^*} as

$$\Lambda^2 = M_{e^*}^2/\lambda. \qquad (24)$$

The experimental results of the $\gamma\gamma$ annihilation process were consistent with the QED predictions and limits on the cutoff parameter Λ were obtained as summarized in Table IX. If $\lambda = 1.0$, they correspond

	CELLO[74]	JADE[90]	MAC[96]	MARK J[56]	MARK II[1]
Λ(GeV)	59	61	55	58	50

Table IX: 95% C.L. limits on the cutoff parameter Λ for the reaction $e^+e^- \to \gamma\gamma$ obtained by recent measurements.

to a limit on the e* mass of about 60 GeV.

Direct production of e* via ($e^+e^- \rightarrow e^{*+}e^-$) can occur by the interaction (22) as[88,89]

$$\frac{d\sigma}{dt} = -\frac{2\pi\alpha^2\lambda^2}{M_{e^*}^2 S^2}\left[\frac{t^2 + (t - M_{e^*}^2)^2}{S} + \frac{S^2 + (S - M_{e^*}^2)^2}{t}\right] \qquad (25)$$

where t is the four momentum transfer squared between e^+ and e^{*+}.

The e* then decays into e+γ. A search for a peak in the eγ mass distribution in the eeγ-events is much sensitive to small λ's. The recent result from JADE[90] is shown in Fig. 21. The eγ mass distribution is consistent with the QED prediction. The limit on λ is shown in Fig. 22 for different e* masses.

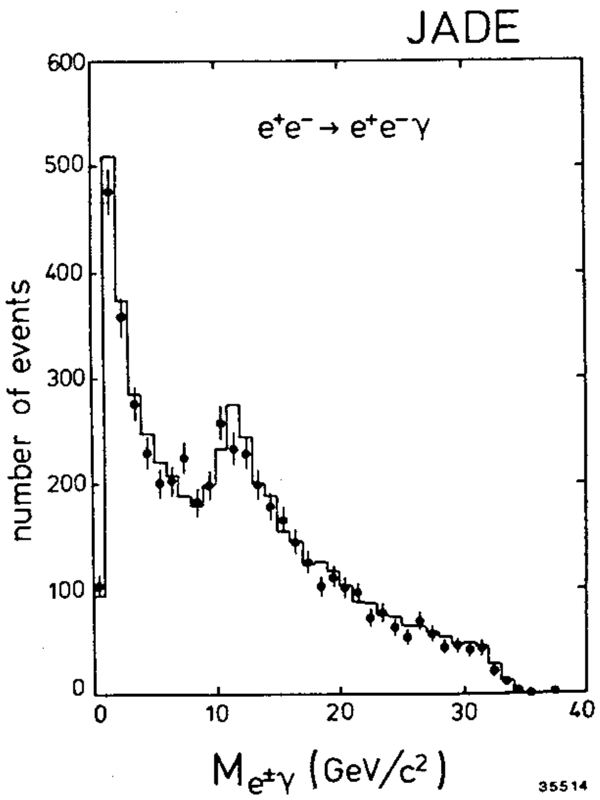

Fig. 21:

The mass distribution of $e^{\pm}\gamma$ in the reaction $e^+e^- \rightarrow e^+e^-\gamma$ measured by JADE[90]. The histogram shows the expectation of α^3 QED.

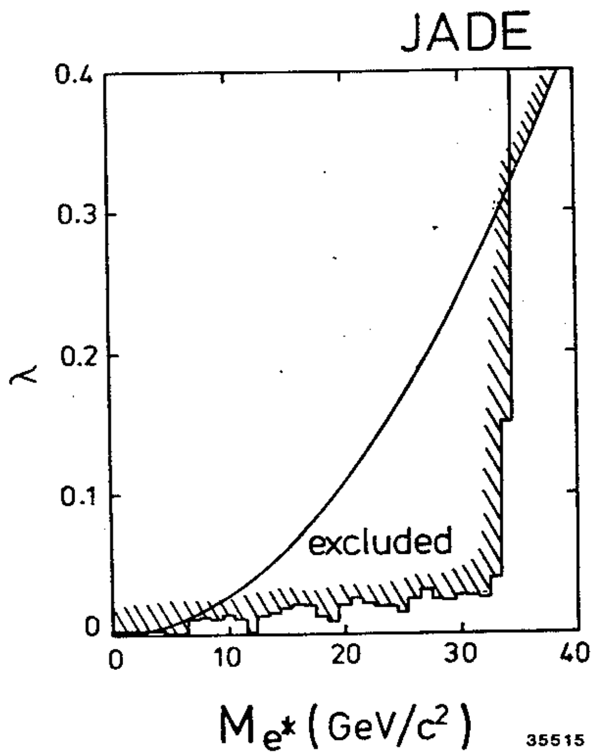

Fig. 22:

The limits on the e*eγ coupling constant λ. The histogram is the result of the e* search in the $e^{\pm}\gamma$ mass distribution. The curve is obtained from the cutoff parameter for the reaction $e^+e^- \rightarrow \gamma\gamma$.

The excited muons can be produced by a similar interaction. The cross section is given by[88,89]

$$\frac{d\sigma}{d\Omega}(e^+e^- \rightarrow \mu^+\mu^{*-} + \mu^{*+}\mu^-) = \frac{\alpha^2\lambda^2}{2M^2_{\mu^*}} \left(1 - \frac{M^2_{\mu^*}}{s}\right)^2 \left[\frac{2M^2_{\mu^*}}{s} + \left(1 - \frac{M^2_{\mu^*}}{s}\right)\sin^2\theta \right] \quad (26)$$

Studies of $\mu\mu\gamma$ final states were done by JADE[91], MAC[92] and MARK J[56] looking for a peak in $\mu\gamma$ mass distributions. There was no evidence for a μ^* by these experiments. The 95% C.L. limits on the λ's are shown in Fig. 23.

If the μ^* is lighter than the beam energy, they can be pair created as pointlike particles and produce the $\mu\mu\gamma\gamma$ final state. Investigation of the $\mu\mu\gamma\gamma$ events were done by the above three groups, looking for the same mass ($\mu\gamma$)-pairs. There were 4, 3 and 0 candidates found by JADE, MAC and MARK J, respectively. These candidates did not cluster at a specific mass and were consistent with the higher order QED expectation. For the spin 1/2 μ^*, the upper limit on the mass are obtained to be 17.9, 14.0 and 14.0 GeV by JADE[91], MAC[92] and MARK J[56], respectively.

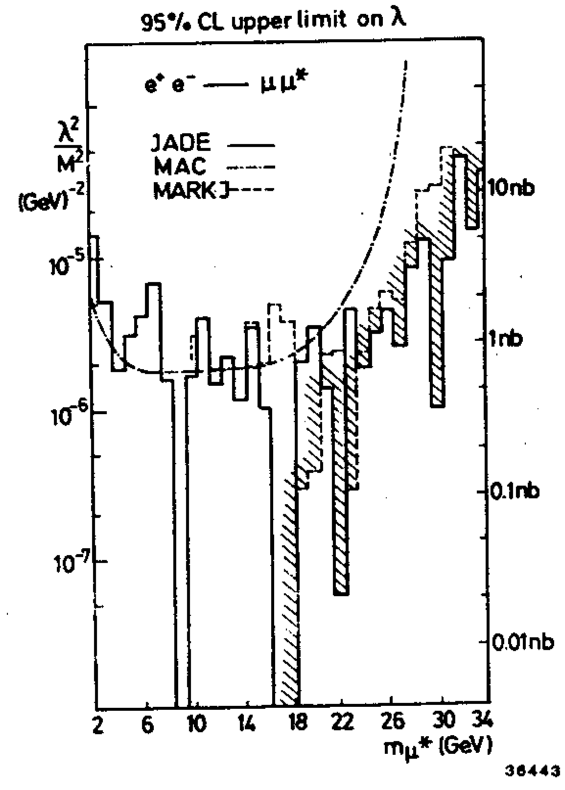

Fig. 23:

95% C.L. limits on the $\mu^*\mu\gamma$ coupling constant λ from various experiments. For definitions see equations (22) and (26). The hatch indicates the combined limit including the results of $\mu^*\mu^*$ searches.

Preon Mass Scales

A new way of testing QED was suggested by Eichten et al.[93] in order to investigate the compositeness of fermions. If fermions are composite particles, there are contact interactions of the fundamental preons like

$$L_{\psi\psi} = \frac{g^2}{2\Lambda^2}\Big[\eta_{LL}\,\overline{\psi}_L\gamma_\mu\psi_L\overline{\psi}_L\gamma^\mu\psi_L + \eta_{RR}\overline{\psi}_R\gamma_\mu\psi_R\overline{\psi}_R\gamma^\mu\psi_R + 2\eta_{RL}\overline{\psi}_R\gamma_\mu\psi_R\overline{\psi}_L\gamma^\mu\psi_L\Big] \tag{27}$$

where Λ is the mass scale of the preons, g is the coupling constant of the preons and η_{LL}/η_{RR} are parameters which describe which chiral components of the fermion are composite. If one takes $g^2/4\pi = 1.0$, for example, the Bhabha scattering cross section is modified in the presence of the Z^0 and the contact interaction as follows.

$$\begin{aligned}
\frac{d\sigma}{dx} &= \frac{\pi\alpha^2}{4s}\left[4A_0 + A_-\,(1-x)^2 + A_+\,(1+x)^2\right] \\
x &= \cos\theta \\
A_0 &= \left(\frac{s}{t}\right)^2\left|1 + \frac{g_R g_L}{e^2}\,\frac{t}{t_z} + \frac{\eta_{RL}t}{\alpha\Lambda^2}\right|^2 \\
A_- &= \left|1 + \frac{g_R g_L}{e^2}\,\frac{s}{s_z} + \frac{\eta_{RL}s}{\alpha\Lambda^2}\right|^2 \\
A_+ &= \frac{1}{2}\left|1 + \frac{s}{t} + \frac{g_R^2}{e^2}\left(\frac{s}{s_z} + \frac{t}{t_z}\right) + \frac{2\eta_{RR}s}{\alpha\Lambda^2}\right|^2 \\
&\quad + \frac{1}{2}\left|1 + \frac{s}{t} + \frac{g_L^2}{e^2}\left(\frac{s}{s_z} + \frac{t}{t_z}\right) + \frac{2\eta_{LL}s}{\alpha\Lambda^2}\right|^2
\end{aligned} \tag{28}$$

In (28), $g_R = e \cdot \tan\theta_w$, $g_L = -e\cdot\cot 2\theta_w$, $s_z = s - m_Z^2 + im_Z\Gamma_Z$ and

$t_z = t - m_Z^2 + im_Z\Gamma_Z$.

HRS[94], JADE[95] and MAC[96] have analysed their Bhabha scattering data in this context. They have obtained the limits on the mass scale Λ for various cases of η's. The results are listed in Table X.

cut off parameter	conditions			HRS	JADE	MAC
	η_{LL}	η_{RR}	η_{RL}			
Λ^{+}_{LL}	1	0	0	638	675	1200
Λ^{+}_{RR}	0	1	0	638	675	1200
Λ^{+}_{AA}	1	1	-1	810	1900	1300
Λ^{+}_{VV}	1	1	1	1419	2200	2500
Λ^{+}_{LL}	-1	0	0	509	1300	
Λ^{-}_{RR}	0	-1	0	509	1300	
Λ^{-}_{AA}	-1	-1	1	1061	2700	
Λ^{-}_{VV}	-1	-1	-1	1375	2400	

Table X: 95% C.L. limits on the cutoff parameters in GeV in the context of the composite model. For definitions, see the text.

A similar analysis was done by the Berkeley-Northwestern-TRIUMF group[97] using muon decays. The contact interaction relevant to the muon decay can be written as

$$\begin{aligned} L_{int} = \frac{g^2}{\Lambda^2} \{ & \eta_1(\bar{\nu}_{\mu L}\gamma^{\mu}\mu_L)(\bar{e}_L\gamma_{\mu}\nu_{eL}) + \eta_2(\bar{\nu}_{\mu R}\gamma^{\mu}\mu_R)(\bar{e}_R\gamma_{\mu}\nu_{eR}) \\ & +\eta_3(\bar{\nu}_{\mu L}\gamma^{\mu}\nu_{eL})(\bar{e}_R\gamma_{\mu}\mu_R) + \eta_4(\bar{e}_L\gamma^{\mu}\mu_L)(\bar{\nu}_{\mu R}\gamma_{\mu}\nu_{eR}) \\ & +\eta_5(\bar{\nu}_{\mu L}\mu_R)(\bar{e}_L\nu_{eR}) + \eta_6(\bar{\nu}_{\mu L}\nu_{eR})(\bar{e}_L\mu_R) \\ & +\eta_7(\bar{\nu}_{\mu R}\mu_L)(\bar{e}_R\nu_{eL}) + \eta_8(\bar{\nu}_{\mu R}\nu_{eL})(\bar{e}_R\mu_L)\} \end{aligned} \tag{29}$$

For concrete studies one has to assume different cases. For instance, if only the left-handed leptons are composite, only η_1 is nonzero. If the right-handed ν is missing or it is heavy, then only η_1 and η_3 are nonzero. Including the contact interaction, the backward electron spectrum near the endpoint is expressed as

$$\frac{d\Gamma}{x^2 dx d\cos\vartheta} = 2\left(\frac{620\ \text{GeV}}{\Lambda}\right)^4 \left(\frac{g^2}{4\pi}\right)\left(\eta_2^2 + \eta_3^2 + \frac{1}{4}\eta_5^2\right) \qquad (30)$$

$$< 0.0041.$$

They assumed that $g^2/4\pi = 2.1$, η's > 0.2, and obtained $\Lambda > 2300$ GeV from their upper limit on the yield.

Although these analyses contain the unknown coupling constant, the limits can be easily scaled for other models which assume different coupling constants. It should be noted that very precise measurements may enable to survey of very high energy structures in the TeV region, even at present energies.

MONOPOLES

Many experiments have been done[98] to search for the magnetic monopoles which have the quantized magnetic charge like

$$eg = n\hbar c/2. \qquad (31)$$

For n = 1, $g \sim 70e$. There are two types of monopoles anticipated; the Dirac monopole and the GUT monopole. The mass of the Dirac monopole is not predicted by the theory but that of the GUT monopole is expected to be as heavy as the unification mass, $O(10^{15})$ GeV. Hence the Dirac monopole has been searched for whenever a higher energy has become available by a new accelerator and the GUT monopoles are hunted for by the cosmic ray experiments since the big bang is considered to be the only occasion where such heavy particles could be produced and the relic monopoles might still remain.

New searches for the Dirac monopoles were reported from the e^+e^- and the $\bar{p}p$ collisions recently. These experiments used the plastic foils to detect the heavily ionizing particles coming from the reactions. A Lexan sheet and a CR39 sheet were put out of the vacuum pipe of PEP[99] and seven layers of kapton foil were put inside the PETRA vacuum pile[100]. At the $\bar{p}p$ collider, two layers of kapton were put in the beam pipe and the third layer was placed outside the pipe[101]. After the exposures and etchings, these foils were scanned and no evidence was found for monopole-like particles. 95% C.L. limits on the monopole production cross section are obtained in the e^+e^- experiments for the shaded mass region in Fig. 24. They are $8.5 \times 10^{-37}\text{cm}^2$ and $4 \times 10^{-38}\text{cm}^2$ from the PEP and the PETRA experiments, respectively. The 90% C.L. limits on the monopole production cross section in the $\bar{p}p$ interaction are shown in Fig. 25 for n = 1 and 3.

The monopoles have such large charges that they might emit many photons and, loosing their energy immediately, might annihilate before they reach the detectors. Then the observed final state would be only

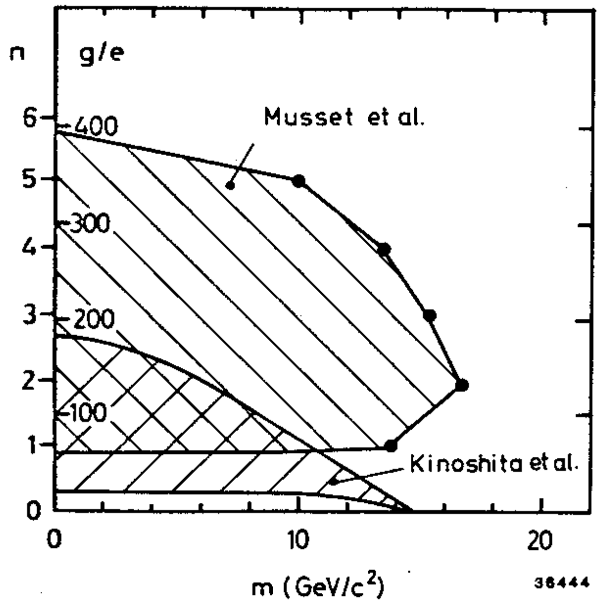

Fig. 24:

The monopole mass, for which the PEP and PETRA experiments were sensitive, is shown for various magnetic charges. For n, see the text.

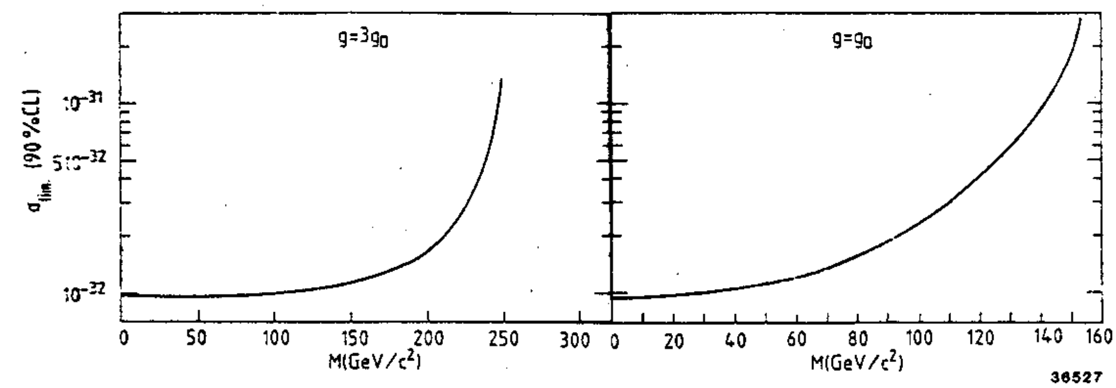

Fig. 25: 90% C.L. limits on the production cross section of heavily ionizing magnetic monopoles in the $\bar{p}p$ collisions.

many photons. The process can happen below the monopole pair production threshold via a virtual monopole loop. Searches for many gamma events have been done in proton-nucleus collisions[102]. In the e^+e^- reactions JADE[103] searched for many gamma events using its lead glass array. The selection conditions were that the sum of the shower energy was larger than the E_{beam}, the number of the shower energy cluster was larger than 20(8) for E_{sh} > 45(300) MeV and there were no charged tracks except for converted e^+e^- pairs. There were no events found. A 95% C.L. limit on the cross section is obtained to be 1.2 x $10^{-37}cm^2$ for $N\gamma$ = (10--300) if the gamma rays are isotropically distributed.

GUT monopole searches have been done also by looking for heavily ionizing slow particles in cosmic rays. However, careful studies are needed to estimate monopole energy loss in the different materials . On GUT monopole searches, there was a detailed discussion by V. Rubakov at this conference. The summary of the recent experiments are shown in Fig. 26, which shows the limits on the

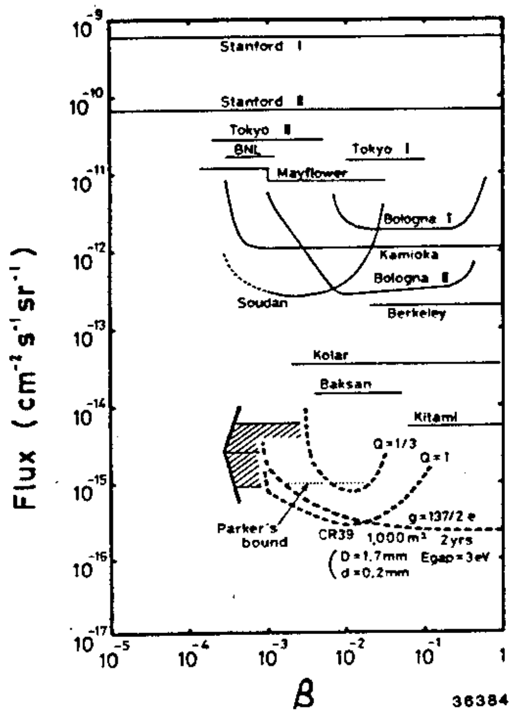

Fig. 26:

Upper limits on the flux of GUT monopole-like particles in cosmic rays obtained by various experiments. The figure was taken from the contribution c-104 to this conference. The hatched band indicates a level of sensitivity expected by the experiment after two years operation.

flux as a function of the particle velocity, taken from ref. 104. There are contributions from two groups which are planning to build large detectors for high sensitivity. One group[104] uses plastic detectors intending to reach the Parker bound, and the other[105] uses a superconducting magnetometer which can detect the entire velocity range down to the flux of $0(10^{-12})$ $cm^{-2}sec^{-2}str^{-1}$ in one year's operation.

CONCLUSIONS

The present status of new particle searches has been reviewed. Many experiments have been done recently looking for those particles which are expected by the standard gauge theory or by the theories beyond the standard one. Except for the $W^{\pm}$ and Z^{0}, no new particles have been found. The upper limits on the production cross section and/or the lower limits on the masses of these particles have been given.

It should be noted at the end that many of the anticipated new particles will manifest themselves in the same or similar way. For instance in the e^+e^- interactions, charged Higgs, heavy lepton, shiggs and squarks may look alike. Therefore, when candidates are found, one will need to study the threshold behaviour, the angle distribution, the various decay modes and so forth in order to identify the candidates with the specific new particle. Before that happens, experimental efforts as described here will be continued further. An unexpected surprise could also come from careful experiments some of which were not covered here.

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