KfK 3758
Juni 1984

Search for New Particles at PETRA

G. Flügge
Institut für Kernphysik

Kernforschungszentrum Karlsruhe

KERNFORSCHUNGSZENTRUM KARLSRUHE

Institut für Kernphysik

KfK 3758

SEARCH FOR NEW PARTICLES AT PETRA

G. Flügge

Kernforschungszentrum Karlsruhe GmbH, Karlsruhe

Kernforschungszentrum Karlsruhe GmbH
ISSN 0303-4003

SEARCH FOR NEW PARTICLES AT PETRA

ABSTRACT:

Latest results from PETRA since autumn last year are presented. New experimental limits on narrow resonances, composite bosons and supersymmetric particles are discussed. A peculiar hadronic event with two isolated muons and high invariant leptonic and hadronic masses is shown.

SUCHE NACH NEUEN TEILCHEN BEI PETRA

ZUSAMMENFASSUNG:

Neue Ergebnisse von PETRA seit Herbst letzten Jahres werden vorgestellt. Neue experimentelle Grenzen für schmale Resonanzen, zusammengesetzte Bosonen und supersymmetrische Teilchen werden diskutiert. Ein seltsames hadronisches Ereignis mit zwei isolierten Müonen und großen invarianten Massen der Leptonen und der Hadronen wird gezeigt.

Invited Talk at the "XIXth Rencontre de Moriond"; February 26 - March 4, 1984

1. INTRODUCTION

Only few particles are still missing in the standard model - the top quark, the Higgs and maybe for sceptics direct evidence for the τ neutrino. We have however a long list of further suggestions from our theoreticians, where emphasis changes with time and fashion. At PETRA, many of these ideas have been pursued in the last few years. I will not attempt to review all these results but rather concentrate on what is new since about autumn last year. Otherwise I refer to previous reviews, e.g. by S. Yamada in Cornell and here in Moriond last year[1].

2. SEARCH FOR NARROW RESONANCES IN $e^+e^- \to$ HADRONS

During 1983 a search for narrow resonances in the total hadronic cross section

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

has been performed in the high energy regime 39.8 GeV $\leq \sqrt{s} <$ 45.2 GeV at PETRA. The detectors CELLO, JADE, MARK J[2] and TASSO[3] scanned this energy range in steps of $\Delta(\sqrt{s})$ = 30 MeV, i.e. well within the natural energy spread of the machine of 35 to 45 MeV. The experiments accumulated on average 50 (since September 60) nb^{-1} per point and experiment. The scan was continued in 1984. A maximum energy of 46.78 GeV was reached in April.

Fig. 1 shows the combined data of all four experiments[4]. It contains on average 45 hadronic events per point. The ratio $R = \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$ is desplayed as a function of CM energy $\sqrt{s}$.

The mean value of R integrated over the energy range of Fig. 1 for the different experiments is

R = 3.85	± 0.11	± 0.31	CELLO	(preliminary)
R = 4.12	± 0.09		JADE	(preliminary)
R = 4.08	± 0.08	± 0.24	MARK J	(preliminary)
R = 4.10	± 0.10	± 0.20	TASSO	

All experiments are in good agreement with the expectation for five quarks (udscb) of R = 4.07 including weak ($\sin^2\theta$ = 0.23) and QCD (α_s = 0.17) correc-

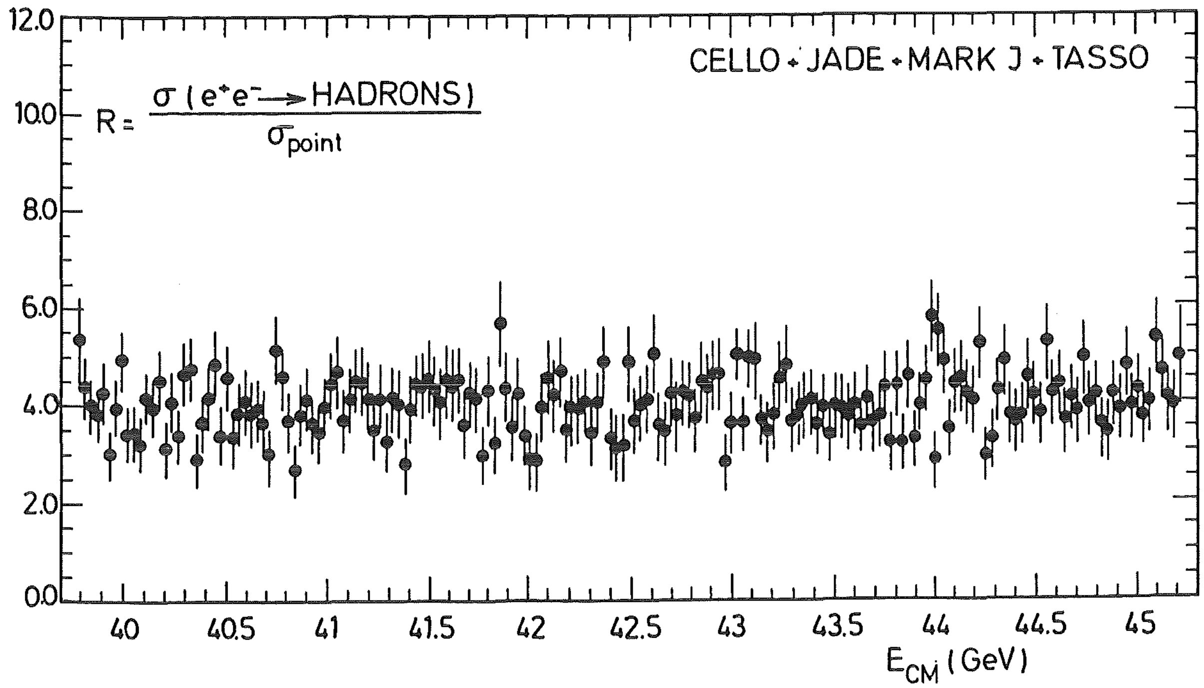


Fig. 1: Ratio R of the total hadronic cross section normalized to the point cross section as a function of cm energy $\sqrt{s}$. Combined data of CELLO, JADE, MARK J, TASSO.

tions. An additional quark of charge 2/3 would yield R = 5.5 which can be excluded by each single experiment. Given the systematic uncertainties, an additional charge 1/3 quark yielding R = 4.4 cannot be ruled out by the R measurement alone. Taking into account the event topology as well, the TASSO group has derived 95% C.L. lower limits on the continuum production of new flavours[3]. Their result is a lower limit of 22 GeV for top quarks and of 21 GeV for new charge 1/3 quarks.

Neither the individual data of all four experiments nor the combined data of Fig. 1 show any obvious resonance structure. Fitting possible Breit-Wigner resonances to the individual data the following 95% C.L. upper limits on the product of the decay width Γ_{ee} of a narrow vector resonance into e^+e^- and its hadronic branching ratio B_{had} are obtained

$\Gamma_{ee} \cdot B_{had}$	$<$ 2.7 keV at $\sqrt{s}$ =	43.15 GeV	CELLO	(preliminary)
$\Gamma_{ee} \cdot B_{had}$	$<$ 2.3 keV	42.49 GeV	JADE	(preliminary)
$\Gamma_{ee} \cdot B_{had}$	$<$ 2.9 keV	44.00 GeV	MARK J [2]	
$\Gamma_{ee} \cdot B_{had}$	$<$ 2.4 keV	42.64 GeV	TASSO [3]	

Extrapolating the empirical observation that $\Gamma_{ee}/Q_q^2 \simeq 10$ keV for all known vector meson ground states and assuming B_{had} = 80% one would expect $B_{had} \cdot \Gamma_{ee}$

= 3.6 keV for Q_q = 2/3 and 0.9 keV for Q_q = - 1/3. Only the first case can again be excluded by each single experiment.

The largest value for a limit on $\Gamma_{ee} \cdot B_{had}$ in the combined data is obtained near $\sqrt{s}$ = 44 GeV. It is of the order of 1 keV and would even be higher without the remeasured low point at $\sqrt{s}$ = 44 GeV (see Fig. 1). A rescan of this region is planned after the Easter shutdown.

3. SEARCH FOR COMPOSITE BOSONS

The observation of two events in the UA1 and UA2 experiments[5] which could be interpreted as decays $Z^0 \rightarrow e^+e^-\gamma$ has lead to various speculations about their origin[6-11]. Taking the 2 radiative events out of 12 Z^0 decays at face value, a radiative width $\Gamma_r \equiv \Gamma(Z^0 \rightarrow e^+e^-\gamma) \simeq 20$ MeV can be estimated. It has been suggested, that either excited leptons decaying into $e\gamma$ [11] or new composite bosons coupling to e^+e^- [6-10] could be responsible for the seemingly strong enhancement of $Z^0 \rightarrow e^+e^-\gamma$. Since the mass expected for such composite bosons is between 40 and 50 GeV from the collider data, such particles would be within the reach of present PETRA experiments.

Possible explanations of the radiative Z^0 events in composite models were presented by Schildknecht and Renard[12] at this meeting. The basic idea discussed here is to postulate a composite (pseudo-) scalar partner X of the Z^0 which by analogy to the VDM of light vector mesons is related to Z^0 and γ via the relative coupling strength sin θ_W between γ and Z^0 (see Fig. 2). VDM which is the minimal assumption to mimik the standard model is necessary to relate $\Gamma_{ee} \equiv \Gamma(X \rightarrow e^+e^-)$ which may be accessible in e^+e^- annihilation with $\Gamma_r \equiv \Gamma(Z^0 \rightarrow e^+e^-\gamma)$ estimated from the collider data.

The relation thus otained by Hollik, Schrempp's[13] and Peccei[19] reads

$$\varepsilon\, \Gamma_{ee} \cdot BR(X \rightarrow \gamma\gamma) = \rho_{VDM}\, \Gamma_r \qquad (1)$$

with

$$\rho_{VDM} = \frac{\Gamma(X\rightarrow\gamma\gamma)}{\Gamma(Z\rightarrow X\gamma)} = \sin^2\theta_W\, \frac{3}{2}\left(\frac{M_x M_z}{M_z^2 - M_x^2}\right)^3 \qquad (2)$$

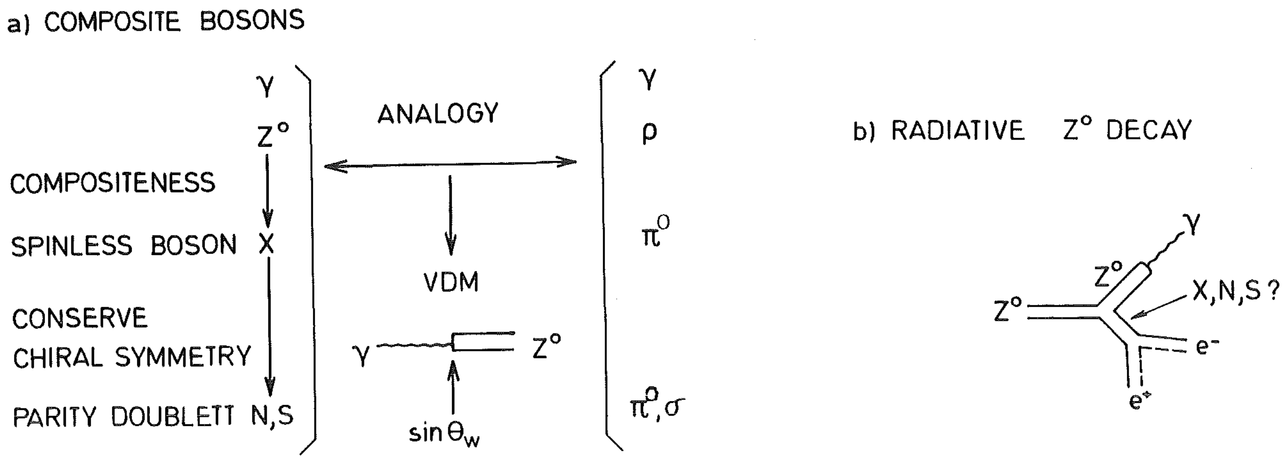


Fig. 2: Z^0 decay into $e^+e^-\gamma$ in a composite model with vector dominance.
a) composite bosons, b) radiative Z^0 decay

where $\varepsilon = 1$ for a single scalar or pseudoscalar boson,

$\varepsilon = 2$ for a parity doublet (scalar and pseudoscalar)

contributing to the process under study.

In particular since $BR(X\to\gamma\gamma) < 1$ we obtain

$$\varepsilon\,\Gamma_{ee} > \rho_{VDM}\,\Gamma_r \simeq 2\text{ MeV} \quad \text{at } M_x = 45\text{ GeV} \tag{3}$$

The consequences of such a new particle in e^+e^- reactions have been studied by various groups[9,13,14,15]. The main characteristics are

a) no interference and thus a simple additional Breit Wigner term in the reactions $e^+e^- \to \mu^+\mu^-$, $\tau^+\tau^-$, $\gamma\gamma$, hadrons

$$\sim \frac{\Gamma_{ee}\;\Gamma_{\mu\mu,\tau\tau,\gamma\gamma,hadr.}}{(s-M_x^2)^2 + M_x^2\,\Gamma_x^2} \tag{4}$$

b) an interference term between the t channel γ and s channel x exchange in the reaction $e^+e^- \to e^+e^-$ [13,15])

$$\frac{s-M_x^2}{1-\cos\theta}\;\frac{\alpha\,\Gamma_{ee}\,/\,M_x}{(s-M_x^2)^2 + M_x^2\,\Gamma_x^2} \tag{5}$$

Whereas a) would give a very clear resonance signal in the scan region $M_x < \sqrt{s}$ (Max), b) would be the most sensitive reaction for $M_x > \sqrt{s}$ (Max), since the interference term decreases more slowly (like $(M_x^2-s)^{-1}$ than the Breit-Wigner term of reactions a).

a) $M_x < \sqrt{s}$ (Max)

All four experiments have searched for resonances of type a). Fig. 3 shows an example for the most sensitive case $e^+e^- \to \gamma\gamma$. No resonances have been found. The results of the CELLO[16] and MARK J[2] collaboration on a search for narrow resonances are summarized in Table 1. In particular the limit on $\varepsilon\ \Gamma_{ee}\ B_{\gamma\gamma}$ is in clear conflict with Γ_r by three orders of magnitude. The Table also contains a determination of Γ_{ee} by summing up all channels as suggested by the MARK J group.

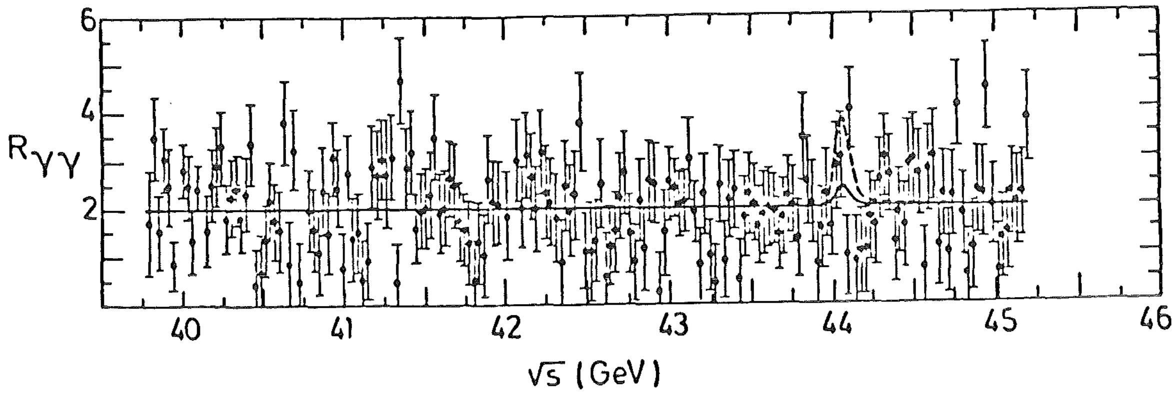


Fig. 3: Ratio $R_{\gamma\gamma}$ of the cross section $e^+e^- \to \gamma+\gamma^-$ integrated over $|\cos\theta| < 0.8$ normalized to the point cross section as a function of cm energy $\sqrt{s}$. The curves show the best fit (—) and the 95% C.L. upper limit (--) for a hypothetical resonance.

95% C.L.	CELLO[16]	MARK J[2]
$\varepsilon\ \Gamma_{ee}\ B_{ee} <$	9.9 keV	
$\varepsilon\ \Gamma_{ee}\ B_{\mu\mu} <$	5.6 keV	4.5 keV
$\varepsilon\ \Gamma_{ee}\ B_{\tau\tau} <$	7.0 keV	
$\varepsilon\ \Gamma_{ee}\ B_{had} <$	8.1 (prel.)	8.7 keV
$\varepsilon\ \Gamma_{ee}\ B_{\gamma\gamma} <$	2.6 keV	3.7 keV
$\varepsilon\ \Gamma_{ee}\ B_{\gamma\gamma} \approx 2$ MeV ($Z^0 \to ee\gamma$, VDM)		
$\varepsilon\ \Gamma_{ee}\ (B_{had}+B_{\gamma\gamma}+6B_{\mu\mu})$	(prel.)	
↓ $\varepsilon\ \Gamma_{ee}$	< 44 keV	< 39 keV

Table 1:
95% C.L. limits on the product $\varepsilon\ \Gamma_{ee} \cdot B_{ii}$ for ii = ee, $\mu\mu$, $\tau\tau$, hadrons and $\gamma\gamma$ for the production of narrow resonances.

The case of a broad resonance was also studied by the CELLO group[16]. Again, the result in the $\gamma\gamma$ channel (Γ_x = total width of X)

$$\varepsilon\ \Gamma_{ee}\ \Gamma_{\gamma\gamma}\ /\ \Gamma_x^2\ <\ 2.2\cdot10^{-6}$$

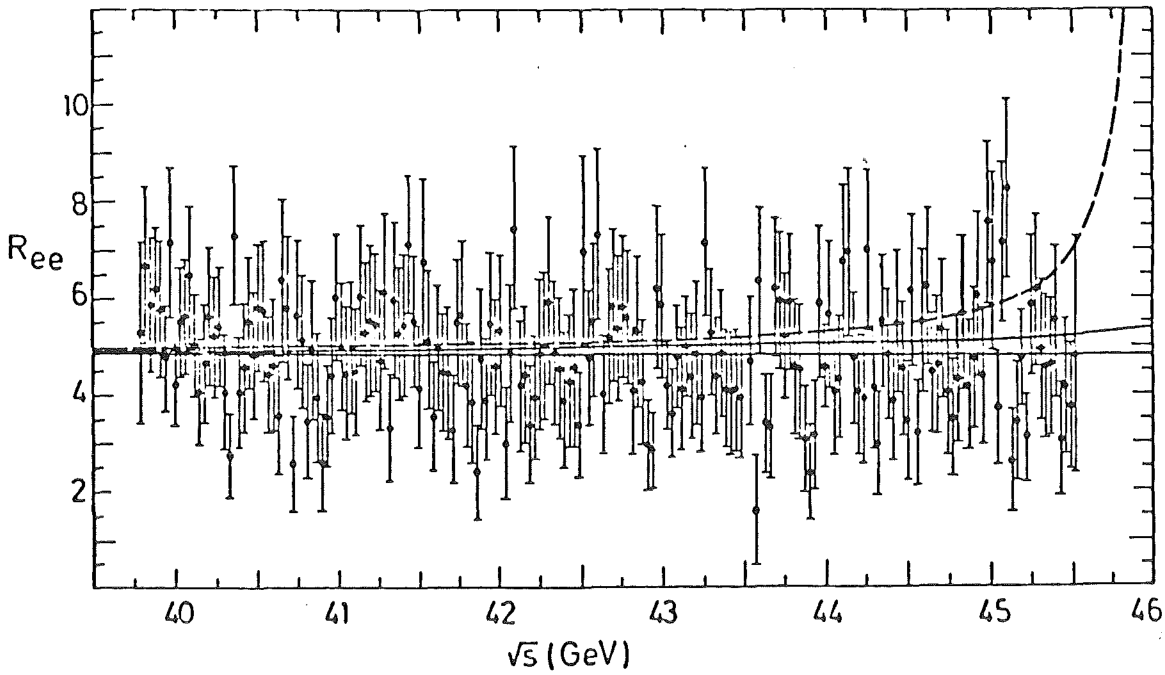


Fig. 4: Ratio R_{ee} of the Bhabha cross section integrated over $\cos\theta$ 0.5 normalized to the point cross section as a function of cm energy $\sqrt{s}$. The curves[13] show the effect of a hypothetical scalar particle of mass 46 (--) and 47.8 (—) GeV assuming $\varepsilon\Gamma_{ee}$ = 4 MeV (twice the minimum)

is the most sensitive and clearly contradicts (3) for reasonable $\Gamma_x < M_x$.

b) $M_x \gtrsim \sqrt{s}$ (Max)

As stated above, the reaction $e^+e^- \to e^+e^-$ is the most suitable one to search for any effects of a possible composite boson with mass above the scan region. But even in this reaction the sensitivity decreases rapidly (c.f. equ. (5)) with mass as illustrated in Fig. 4. Fig. 5 shows the lower limits on $\Gamma_{ee} \cdot \Gamma_{ee,\mu\mu,\tau\tau,\gamma\gamma}$ as a function of M_x [16]. For comparison, the upper limit deduced from equ. (3) with Γ_r = 15 MeV is also indicated. It is clear, that both limits are compatible with each other.

Contribution to the differentical cross-section

One could try to get more stringent limits on the production of scalar bosons by studying differential cross sections. As illustrated in Fig. 6 [17], a scalar boson would add a constant term to the differential cross section of $e^+e^- \to \gamma\gamma$. The minimum effect expected from the collider data (equ. (3)) is however much (about 8x) smaller than indicated in Fig. 6. Following the suggestion of the Siegen group[14] the CELLO collaboration[16] has analysed its differential $\gamma\gamma$ cross section under the additional assumption of a universal

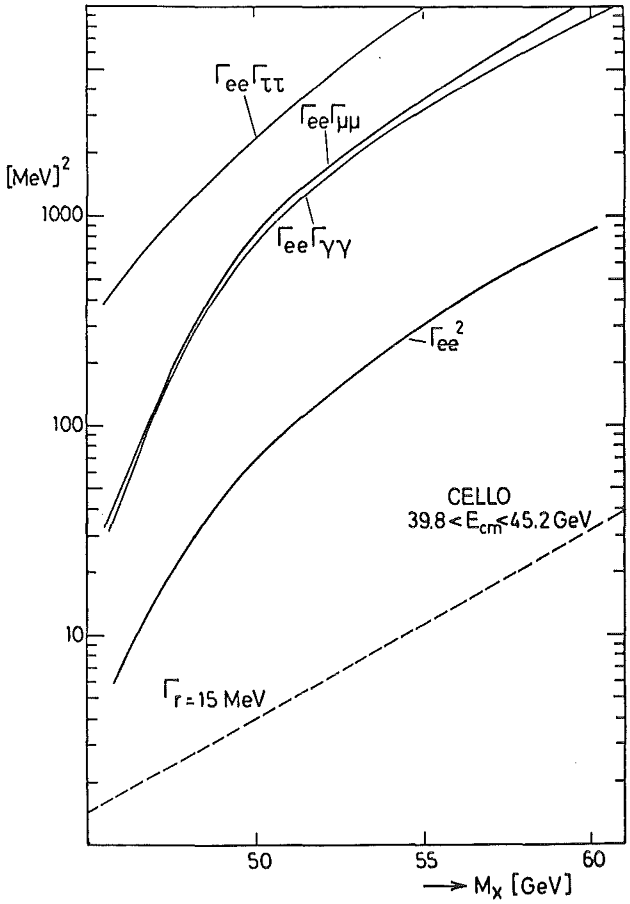


Fig. 5:
95% C.L. upper limits for the product of the coupling constants $\varepsilon^2\ \Gamma^2_{ee}$ and $\varepsilon\ \Gamma_{ee}\ \Gamma_{ii}$. with ii = $\gamma\gamma$, $\mu\mu$ and $\tau\tau$ as a function of the mass M_X of the (pseudo-) scalar boson X. The dashed line indicates the lower limit deduced from Γ_r = 15 MeV.

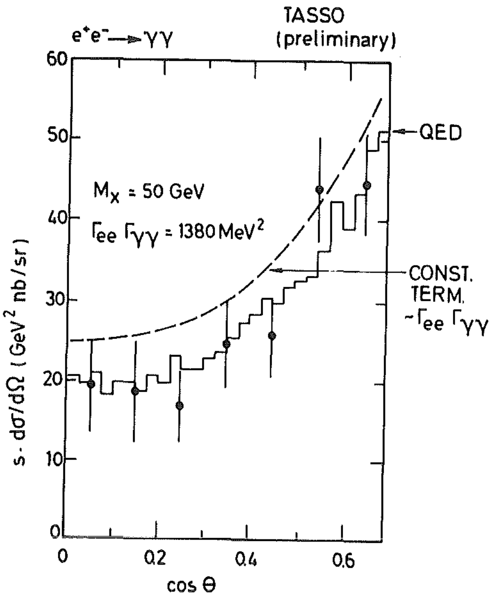


Fig. 6:
Differential cross section of the reaction $e^+e^- \rightarrow \gamma\gamma$ as a function of cos θ. The dashed line shows the effect of a hypothetical scalar boson of mass M_X = 50 GeV and a coupling $\varepsilon\ \Gamma_{ee}\ \Gamma_{\gamma\gamma}$ = 1380 MeV^2 (~ 8 × minimum).

scalar boson-fermion coupling. Thus one is left with three variables only: $\alpha_h = 2\Gamma_{ee}/M_X$, M_X and Γ_r. Fig. 7 shows a contour plot of allowed values of Γ_r. Taking into account the additional limit, obtained from the differential $e^+e^- \rightarrow e^+e^-$ cross section, only the small banana shaped region above ~ 47 GeV stays allowed for Γ_r = 15 MeV. In Fig. 7, the pessimistic case of ε = 1 is assumed. In a recent paper Aguila et al[18] argue, that only ε = 2 is compatible with the anomalous magnetic moment of leptons. Assuming ε = 2 the contours in Fig. 7 have to be rescaled by a factor of 2 and the allowed region

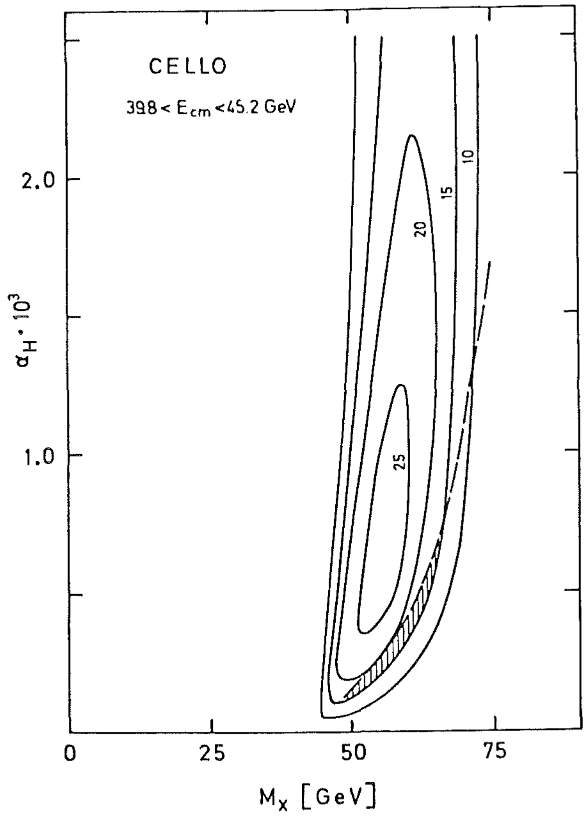


Fig. 7:

95% C.L. limits on the universal coupling constant $\alpha_h = 2\Gamma_{ee}/M_X$ as a function of the mass M_X of the spinless boson from fits to the differential cross section of $e^+e^- \to e^+e^-$ (--) and $e^+e^- \to \gamma\gamma$ (—), the latter for different values of Γ_r in MeV. $\varepsilon = 1$ is assumed. The allowed area for Γ_r = 15 MeV is shaded.

would disappear. However, one should keep in mind, that this result is only obtained assuming a universal fermion-boson coupling, which is only justified by simplicity.

4. SEARCH FOR SUPERSYMMETRIC PARTICLES

Supersymmetry (SUSY)[18,19] relates fermions and bosons by the symmetry operation J±1/2. Thus, each standard particle has its SUSY partner with spin J±1/2. Table 2 summarizes the minimal SUSY extension of the standard model[19]. Note that two Higgs doubletts are necessary to preserve the one to one correspondence between Higgs and Shiggs. The SUSY partners of the vector boson and Higgs sector can mix to form neutralinos and charginos. In the following I will concentrate on new results on sleptons, photinos, neutralinos and charginos and again refer to previous talks for earlier results[1].

Search for photinos

Many SUSY models assume the photino $\tilde{\gamma}$ to be the lightest SUSY particle. The search for such stable and thus 'invisible' (neutrinolike) photinos was covered in the previous talk by H. Band[20]. I will concentrate on the alternative,

Table 2: Supersymmetric Particles

Standard particles			$J \pm 1/2$	Supersymmetric sparticles		
	$J = 1/2$				$J = 0$	
Quark	q_L q_R	q=u,d...		Squark	$\tilde{q}_L$ $\tilde{q}_R$	q=u,d...
Lepton	ℓ_L ℓ_R	$\ell=e\mu\tau$		Slepton	$\tilde{\ell}_L$ $\tilde{\ell}_R$	$\ell=e\mu\tau$
Neutrino	ν_e ν_μ ν_τ			Sneutrino	$\tilde{\nu}_e$ $\tilde{\nu}_\mu$ $\tilde{\nu}_\tau$	
	$J = 1$				$J = 1/2$	
Gluon	g			Gluino	$\tilde{g}$	
W-Boson	$W^\pm$			Wino		$\tilde{W}^\pm$ (Charge-inos)
Z-Boson Photon	Z^o,γ			Zino Photino	$\tilde{Z}^o$ $\tilde{\gamma}$ (Neutra-linos)	
	$J = 0$					
Higgs	H_1^+ H_2^o H_1^o H_2^-			Shiggs	$\tilde{H}_1^o$ $\tilde{H}_2^o$ (Neutra-linos)	$\tilde{H}_1^+$ $\tilde{H}_2^-$ (Charge-inos)

that $\tilde{\gamma}$ is unstable and decays into a photon and a goldstino (or gravitino) G (c.f. Fig. 8). The photino lifetime is then given by $\tau_{\tilde{\gamma}} = 8\pi d^2/M_{\tilde{\gamma}}^5$, where d is a scale parameter of SUSY breaking[21]. The experimental signatures are illustrated in Fig. 8 a,b) and c). Two relatively heavy photinos decaying in the detector give rise to two acoplanar photons (c) whereas relatively light photinos would reveal themselves by large missing energy of the two decay photons (a). Both cases were first studied by the CELLO group[22] and later by the JADE[23] and MARK J[24] collaboration. The JADE group also investigated case (b) where only one photino decays in the detector, whereas the other one escapes, thus leaving a single photon in the detector[23]. The results of all three experiments are summarized[1] in Fig. 9. The triangles show the area excluded by the JADE and CELLO experiments. The upper bound is determined by the available beam energy and the experimental cuts, the diagonal limit is given by the detector size (escape probability of the photino). Together with bounds[1] from cosmology, ψ decay and beam dump experiments nearly the whole area of $M_{\tilde{\gamma}} \sim 15$ GeV seems to be excluded. This has however to be taken with some caution, in particular since the beam dump result, depends strongly on the $\tilde{g}$ mass, as indicated in the Figure.

Search for Neutralinos

As mentioned above, photinos, zinos, and shiggs may mix to form neutralinos[20]. In particular, J.M. Frère[25] discussed the case, where a light $\tilde{\gamma}_1$ and an unstable $\tilde{\gamma}_2$ may result from such a mixing[20]. $\tilde{\gamma}_1$ and $\tilde{\gamma}_2$ could be produced

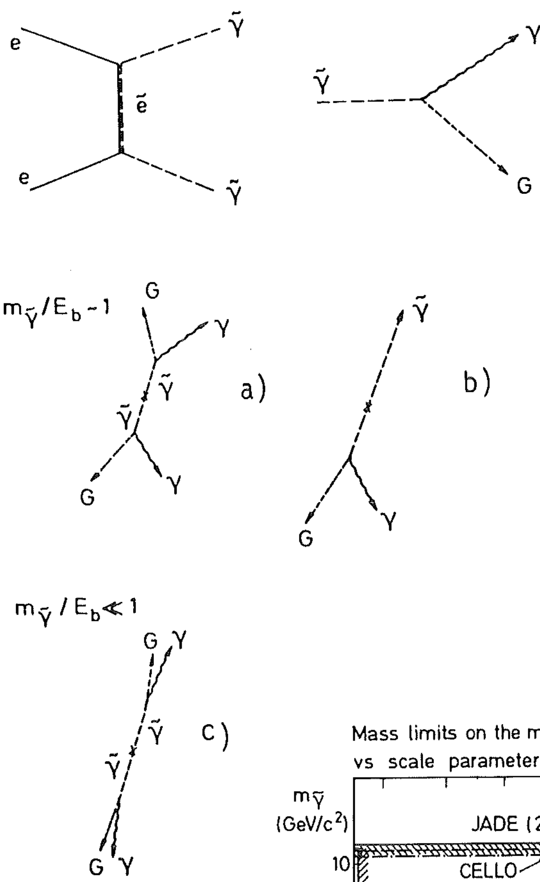


Fig. 8
Production and decay of photinos in e^+e^- annihilation and expected event topologies (G = Goldstino)[1].

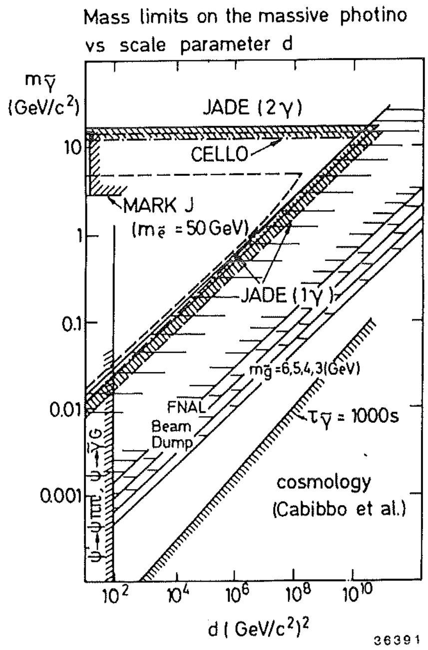


Fig. 9
95% C.L. limits on the mass of the photino as a function of the SUSY scale parameter d. CELLO and JADE assume $m_{\tilde{e}}$ = 40 GeV, MARK J $m_{\tilde{e}}$ = 50 GeV.

in pairs where $\tilde{\gamma}_2$ would decay into an e^+e^- pair and a $\tilde{\gamma}_1$ (Fig. 10). The resulting signature would be an acoplanar pair of electrons (c.f. search for electrons). The CELLO group[26)] looked into this process and for the experimental cuts of $|\cos\,\Theta| \leq .85$, $p_1 > 2.5$ GeV, $p_2 > 6$ GeV (θ, p_1, p_2 are the production angle with respect to the beam axis and the momenta of the two electrons) and an acoplanarity of more than 30^0 they find no events. This can be turned into a limit on the production cross secion of

$$\sigma(e^+e^- \to \tilde{\gamma}_1\, \tilde{\gamma}_2 \to \tilde{\gamma}_1\, \tilde{\gamma}_1\, e^+e^-) < 1 \text{ pb} \qquad (95\%\ \text{C.L.})$$

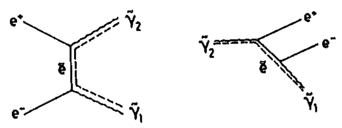


Fig. 10: Production and decay of neutralinos in e^+e^- annihilation.

Search for SUSY Leptons

In e^+e^- annihilation, sleptons would be pairproduced and decay (electromagnetically) into normal leptons and photinos. Depending on the photino mass, different cases have to be considered.

a) $\tilde{\gamma}$ is stable (invisible):

For light sleptons this would show up as an increase in the lepton pair cross section, for larger masses it would lead to acoplanar lepton pairs with missing energy.

b) $\tilde{\gamma}$ is unstable as discussed above:

The final state would consist of a lepton pair and two photons; it has to be distinguished from the QED background by missing energy.

c) $\tilde{\gamma}$ is heavier than $\tilde{e}$:

The slepton would be stable (longlived) and behave like a heavy charged particle.

All three types of scalar leptons have been searched for by the PETRA experiments[1]. In the following I will give examples of new results on smuons, selectrons, staus and also charginos which fit into the same experimental signature.

Scalar Muon

Fig. 11 shows the result on a scalar muon search by the JADE collaboration[27]. The areas excluded for the different cases listed above are given in a diagram of photino vs. smuon mass. The triangle above the diagonal of equal masses is excluded by the absence of heavy charged particles pairproduced in e^+e^- annihilation.

Scalar Electron

The results on a search for scalar electrons by the CELLO[26] and JADE[30] groups are given in Figs. 12 and 13. e^+e^- annihilation is more sensitive to selectron than to other slepton production due to the additional exchange of a photino in the t channel[28]. In case the two selectrons $\tilde{e}_L$ and $\tilde{e}_R$ are degenerate in mass, an additional s-wave term increases the sensitivity even more (full line in Fig. 12)[29].

In addition to the pairproduction the JADE collaboration[30] has also studied the processes

$$e^+e^- \rightarrow \gamma\tilde{\gamma}\tilde{\gamma}$$

and

$$e^+e^- \rightarrow \tilde{e}\,\tilde{\gamma} \rightarrow e\, e\, \tilde{\gamma}\tilde{\gamma}$$

$\quad$ ↳ beam pipe

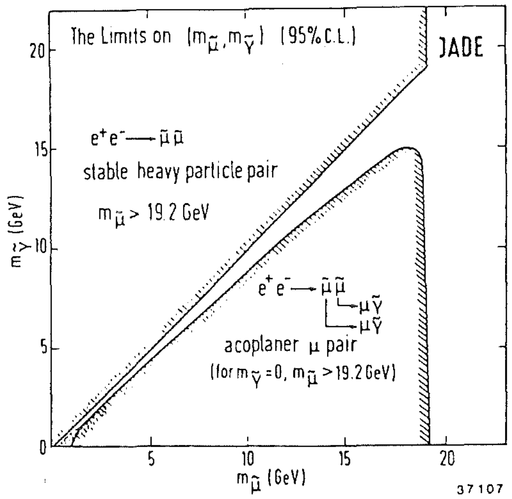


Fig. 11:
95% C.L. limits on the mass of scalar muons as a function of the photino mass (both in GeV) for stable and unstable photinos.

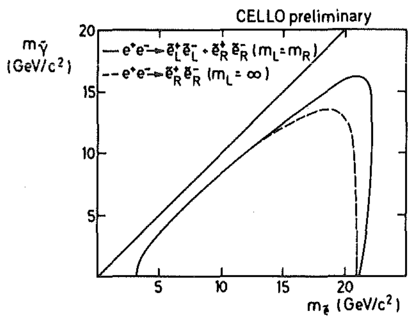
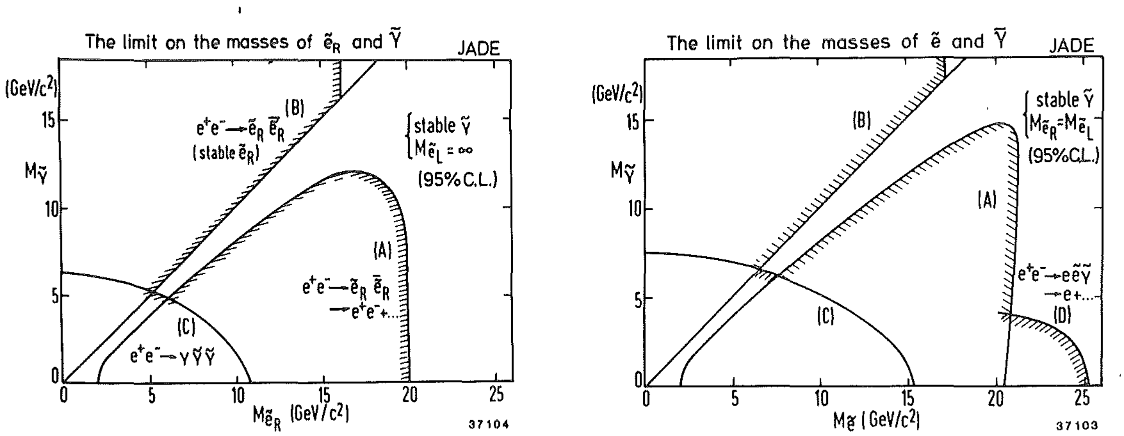


Fig. 12:
95% C.L. limits on the mass of the scalar boson as a function of the photino mass for stable photinos and $M_{\tilde{e}_L} = \infty$ (--) or $M_{\tilde{e}_L} = M_{\tilde{e}_R}$ (—).

These processes are discussed in detail in H. Band's talk[20]. Briefly, the first reaction leads to a single visible photon in the detector, whereas in the second process one electron stays in the beampipe and only a single electron is detected. In both cases missing energy will discriminate the process from QED reactions. As can be seen in Fig. 13, the single electron reaction considerably increases the sensitivity for high selectron masses.



(a) (b)

Fig. 13:
95% C.L. limits on the mass of scalar electron as a function of the photino mass for stable photinos and $M_{\tilde{e}_L} = \infty$ (a) or $M_{\tilde{e}_L} = M_{\tilde{e}_R}$ (b).

Scalar Tau

As an example of a recent result on scalar taus the MARK J results[24] are shown in Fig. 14. Only the case of a stable (invisible) photino is considered here. The signature of a single μ acoplanar with a hadronic or electromagnetic shower is used.

Table 3 summarizes the present limits from PETRA on scalar lepton.

	$\tilde{e}$ acopl. e^+e^-	$\tilde{e}$ single e	$\tilde{\mu}$	$\tilde{\tau}$	Ref.
CELLO	< 21.3		3 - 16	6 - 15.5	26,31
JADE	< 20.3	< 25.2	< 19.3	4 - 14	27,30
MARK J			3 - 18	3 - 16.5	24
TASSO	< 16.6		< 16.4		1,32

Table 3:
Summary of scalar lepton masses excluded at the 95% C.L. in GeV for $m_{\tilde{\gamma}} = 0$.

Search for Charginos

The absence of events of the signature used in Fig. 14 can also be used to determine limits on chargino production. Charginos are mixtures of winos and shiggs[19] and are supposed to decay weakly into a light neutral higgsino or photino with coupling to the conventional weak charged current as indicated in Fig. 15. Thus the same signature as for the scalar tau or heavy lepton search can be used. The result of the MARK J group[24] is given in Fig. 15.

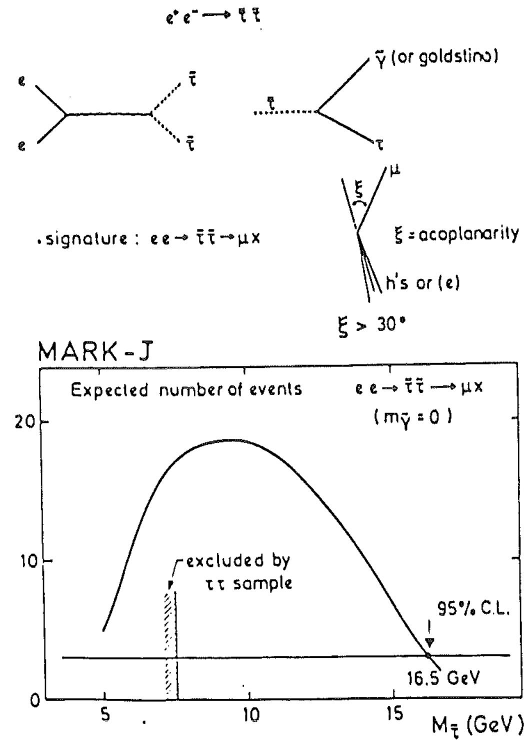


Fig. 14:
Production and decay of scalar taus in e^+e^- annihilation and expected event signature. Expected number of events from scalar tau production as a function of the $\tilde{\tau}$ mass. The lower mass region is excluded by the measured $\tilde{\tau}$ pair production cross section.

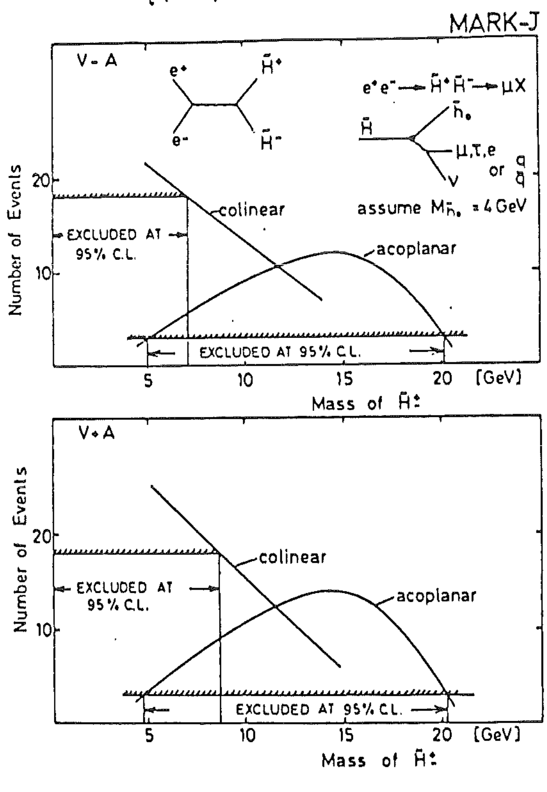


Fig. 15:
Expected number of events for pairproduction of charginos as a function of chargino mass assuming V-A or V+A coupling to the charged weak current. The mass of the shiggs $\tilde{h}_0$ is assumed to be 4 GeV.

5. A PECULIAR EVENT IN SEARCH FOR ISOLATED MUONS AT CELLO

In a search for isolated muons in hadronic e^+e^- annihilation the CELLO collaboration found an event with two isolated muons of opposite sign.[33] The event is shown in Fig. 16. The muons are clearly identified and have large transverse momenta of $p_\perp(\mu^+) = 7.2$ GeV and $p_\perp(\mu^-) = 4.2$ GeV with respect to the event thrust axis. Fig. 17 shows a momentum plot of the event in the plane of the two muons. The hadrons are clustered in two jets. The event is remarkably planar: the mean transverse momentum out of the μ plane is only 270 MeV, like the average transverse momentum in normal hadronic jets.

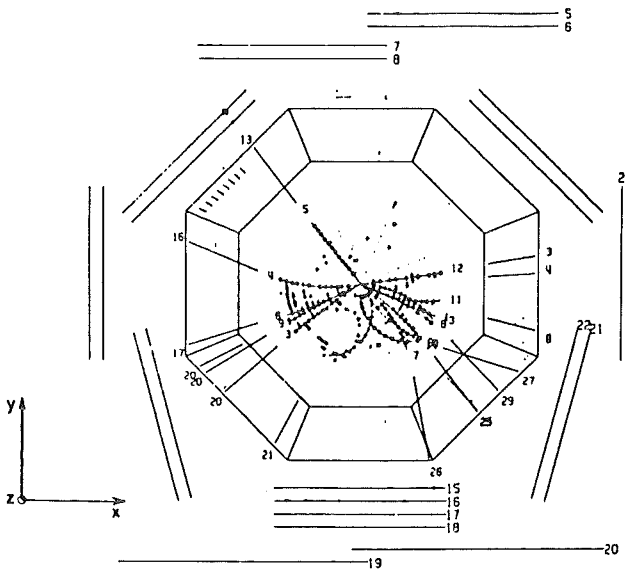


Fig. 16: Hadronic dimuon event with large transverse momenta of the two muons with respect to the event thrust axis observed at the CELLO detector.

Assuming the four-particle structure suggested by Fig. 17 the four-vectors of the two muons and two jets are listed in Table 4a. Note that within the error of a few GeV the total measured energy in the event is compatible with the e^+e^- energy of $\sqrt{s} = 43.45$ GeV at which the event was found.

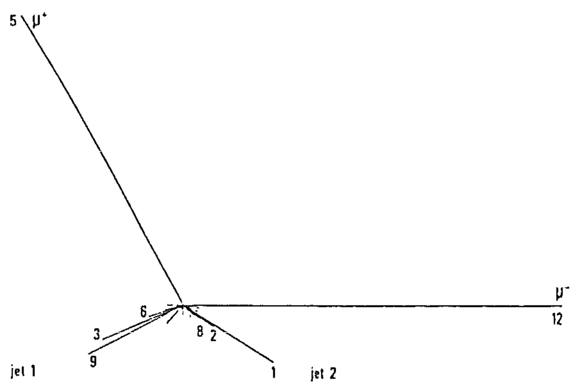


Fig. 17: Momentum diagram of the dimuon event in the $\mu^+\mu^-$ plane.

Table 4b shows the invariant masses of all pairs of muons and jets. All masses are high, in particular the $\mu^+\mu^-$ and jet 1 - jet 2 masses are of the order of 20 GeV. If one would try to interpret the event in terms of pair production the most suitable solution would be the combinations μ^+-jet 2 and μ^--jet 1, which have equal masses within the errors.

Table 4: Kinematics of the dimuon event

(GeV)	E	p_x	p_y	p_z	M
μ^+	11.0	-7.0	8.5	0.5	0.105
μ^-	12.6	11.0	1.3	-6.1	0.105
JET 1	10.1	-7.4	-4.2	4.8	2.4±0.1
JET 2	9.1	6.7	-3.5	-2.0	4.7±0.1

a) muon and jet 4-vectors

(GeV)	μ^+	μ^-	JET 1
JET 2	19.4±1.3	9.5±0.5	17.3±0.3
JET 1	14.1±1.0	22.2±1.6	
μ^-	20.4±1.1		

b) invariant masses of muon and jet pairs.

Estimate of Conventional Sources

Two conventional sources for this event have been considered.

a) Heavy quark decay

The effect of heavy (c or b) quark production in $e^+e^- \to q\bar{q}(g)$ and decay into muons and hadrons has been studied by MC methods taking into account hadron punchthrough and decay. The simulation has been checked to reproduce correctly the lepton momentum spectrum, the hadron multiplicity and momenta, the distribution of angles between high transverse momentum particles and their closest charged particle and the punchthrough probability.

The simulation shows that less than $8 \cdot 10^{-4}$ events of the observed type are expected from this source. The limit is determined by the available statistics of the simulation. It is probably even much lower than the number given.

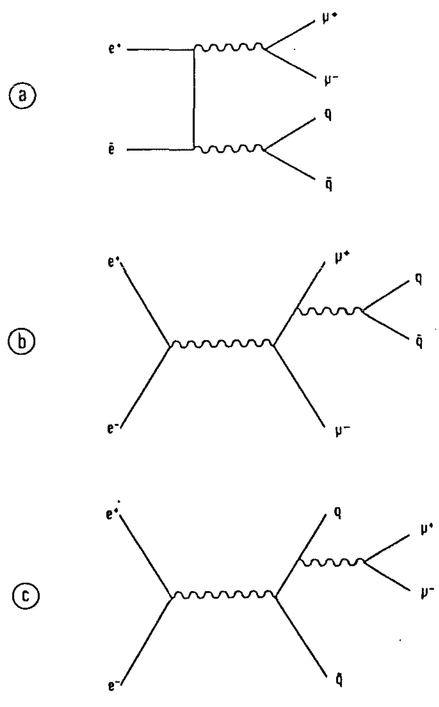


Fig. 18: Feynman graphs for $e^+e^- \to q\bar{q}\mu^+\mu^-$ to order α^4.

b) QED processes

Three diagrams shown in Fig. 18 could give rise to the observed event. The CELLO group has calculated diagram a) using a factorized form of the differential cross section. The result is in good agreement with a full QED calculation of all three diagrams preformed by Kleiss[34]. This confirms the conjecture, that the contributions from b) and c) are small. The result is that less than $8 \cdot 10^{-4}$ events of the observed type are expected from QED.

6. SUMMARY

A search for new particles at PETRA has led to the following new results:

- The production of narrow resonances or opening of new thresholds resulting from charge 2/3 (top) quarks is excluded for $\sqrt{s} > 45$ GeV.

- No narrow resonances have been found in the QED channels e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$, $\gamma\gamma$. This excludes (pseudo-)scalar bosons X proposed to explain the radiative Z^0 decays in the mass range 39.8 GeV > M_X > 45.2 GeV. Tighter limits can be quoted if a universal X-fermion coupling is assumed.

- Improved mass limits can be given for unstable photinos, scalar electrons, scalar muons, scalar taus, and charginos.

- A peculiar hadronic event with two energetic isolated high transverse momentum muons and high invariant masses (~ 20 GeV) of the $\mu^+\mu^-$ and the hadrons has been observed at CELLO. From conventional sources, less than 10^{-3} events of this type are expected.

Acknowledgement

I am indebted to A. Böhm, B. and F. Schrempp, J. Wess, G. Wolf, S. Yamada and my colleagues from CELLO for many discussions and comments.

REFERENCES

1) S. Yamada, DESY-Report 83-100 (November 1983) and Proc. of the Int. Conf. on Lepton and Photon Interactions at High Energies, Cornell (1983), p. 525

2) MARK J Collaboration, B. Adeva et al., MIT Technical Report, Number 134 (February 1984)

3) TASSO Collaboration, DESY Report 84-001 (January 1984)

4) I am indebted to O. Achterberg, P. Kuijer, D. Lüke, M. Minowa and H. Rykaczewski for this compilation; data from CELLO and JADE are preliminary

5) UA2 Collaboration, G. Arnison et al., Phys.Lett. 129B (1983) 130
UA1 Collaboration, P. Bagnaia et al., Phys.Lett. 135B (1984) 250

6) G. Gounaris, R. Kögerler, and D. Schildknecht, Univ. Bielefeld preprint BI-TP 83/17 (Oct. 1983)

7) M.J. Duncan and M. Veltman, Univ. of Michigan preprint UMHE 84-1

8) U. Baur, H. Fritzsch and H. Faissner, Phys.Lett. 135B (1984) 313

9) R.D. Peccei, Phys.Lett. 136B (1984) 121

10) F.M. Renard, Preprint PM/83/11 (1983)

11) N. Cabibbo, L. Maiani, and Y. Srivastava, INFN preprint (1983)

12) D. Schildknecht, this conference
F.M. Renard, this conference

13) W. Hollik, B. Schrempp and F. Schrempp, DESY Report 84-011 (Jan. 1984)

14) F.W. Bopp et al., Univ. of Siegen preprint SI-83-24 (1983)

15) F.W. Bopp et al., Univ. of Siegen preprint SI-84-3 (March 1984)

16) CELLO Collaboration, H.-H. Behrend et al., DESY Report 84-020 (Febr. 84)

17) TASSO Collaboration, private communication

18) F. del Águila, A. Méndez and R. Pascual, Univ. of Barcelona preprint UAB-FT-105 (March 84)

19) Y.A. Gol'fand and E.P. Likhtman, Pis'ma Zh. Eksp. Teor. Fiz. 13 (1971) 323
D. Volkov and V.P. Akulov, Phys.Lett. 46B (1973) 109
J. Wess and B. Zumino, Nucl.Phys. B70l (1974) 39
G. Altarelli, this conference
G.L. Kane, Fourth Workshop on Grand Unification, Philadelphia (1983)

20) H. Band, this conference

21) N. Cabibbo, G.R. Farrar, and L. Maiani, Phys.Lett. 105B (1981) 155

22) CELLO Collaboration, H.-J. Behrend et al., Phys.Lett. 123B (1983) 127

23) JADE Collaboration, W. Bartel et al., DESY Report 84-016 (Febr. 84)

24) MARK J Collaboration, MIT Report Number 131 (Dec. 1983)

25) J.M. Frère, this conference

26) CELLO Collaboration, H. Küster, private communication

27) JADE Collaboration, (see Ref. 1),
S. Yamada, private communication

28) G.R. Farrar and P. Fayet, Phys.Lett. 89B (1980) 191

29) M. Glück and E. Reya, Univ. of Dortmund preprint DO-TH 83/13 (1983)

30) JADE Collaboration, T. Kobayashi, private communication

31) CELLO Collaboration, H.-J. Behrend et al., Phys.Lett. 114B (1982) 287

32) TASSO Collaboration, P. Brandelik et al., Phys.Lett. 117B (1982) 365

33) CELLO Collaboration, H.-J. Behrend et al., DESY Report 84-024 (Febr. 84)

34) R. Kleiss, Institute Lorentz preprint, Leiden (1984) and private communication