SEARCH FOR SCALAR PARTICLES AND EXCITED LEPTONS AT PETRA*

By Y. Ducros

Departement de Physique des Particules Élémentaires, Saclay**

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A search for scalar leptons, charged Higgs and excited leptons has been done with the five experiments installed at PETRA (CELLO-JADE-MARK J-PLUTO-TASSO). No scalar lepton or Higgs particles with conventional decay are created in e^+e^- annihilation. The highest value of the mass for such particles is close to the beam energy (17 GeV/c). Direct production of excited lepton gives also a negative result up to a mass value equal to 30 GeV/c^2. Comparison with QED for reaction $e^+e^- \to \gamma\gamma$ gives a limit of 59 GeV/c^2 for the e* mass.

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Introduction

Electron-positron annihilation is a simple and powerful reaction to search for new heavy, and charged particles. Most of the experiments at PETRA have given limits on production of scalar leptons (CELLO–MARK J–TASSO) and Higgs particles (CELLO–JADE–MARK J). Excited leptons μ^* and e* have also been searched in e^+e^- annihilations at PETRA.

1. Scalar lepton search

1.1. Scalar electrons and scalar muons

Scalar leptons are predicted by supersymmetry theories [1]. Two scalar leptons are associated to each lepton, one per helicity state: s_l and t_l. These charged particles can be pair-produced in e^+e^- annihilation.

$$e^+e^- \to s_l^+ + s_l^-, \quad s_l^- \to l^- + \bar{\lambda}, \quad s_l^+ \to l^+ + \lambda$$

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** Address: D.Ph.P.E., Saclay, BP No 2, Gif-sur-Yvette 91190, France.

where λ corresponds to the photino (goldstino), the partner of the photon (Goldstone boson) in the supersymmetry theories, and l is the associated lepton. Scalar muons and scalar taus are produced by annihilation, whereas the scalar electron can also be produced via the photino exchange. The cross-section is shown in Fig. 1a, for both types of leptons. Behaviour of the cross-section for point like scalar particles is given by the following formula:

$$d\sigma/d\cos\theta = \pi\alpha^2\beta^3\sin^2\theta/4s \ .$$

where s is the total c.m. energy squared, α the fine structure constant, and β the velocity of the final particles s_l.

Two leptons of the same kind are detected in the final state. They should exhibit large acolinearity and acoplanarity, and a total energy corresponding to roughly half the energy of the reaction. No other particles are seen in the detector (except for scalar taus). All experiments at PETRA [2–6] have reported limits on production of scalar electron and scalar muon.

A possible background is from QED reaction with an additional undetected photon. No candidate has been found in any of the experiments. The limits on the mass of the scalar electron (s_e) and scalar muon (s_μ) are given in Table I. Low mass scalar electrons

TABLE I

Limits on the mass of scalar lepton obtained from the PETRA experiments. The masses are in GeV/c^2

	CELLO	JADE	MARK J	PLUTO	TASSO
Scalar electron	$M < 2$ $M > 16.8$	$M > 16$		$M > 13$	$M > 16.6$
Scalar muon	$M < 3.3$ $M > 16.$		$M < 3$ $M > 15$		$M > 16.4$

(or scalar muons) are ruled out after comparison of the number of Bhabhas or muon pairs with the QED prediction. For high mass ($M > 3$–4 GeV) no candidate was found with the applied cuts.

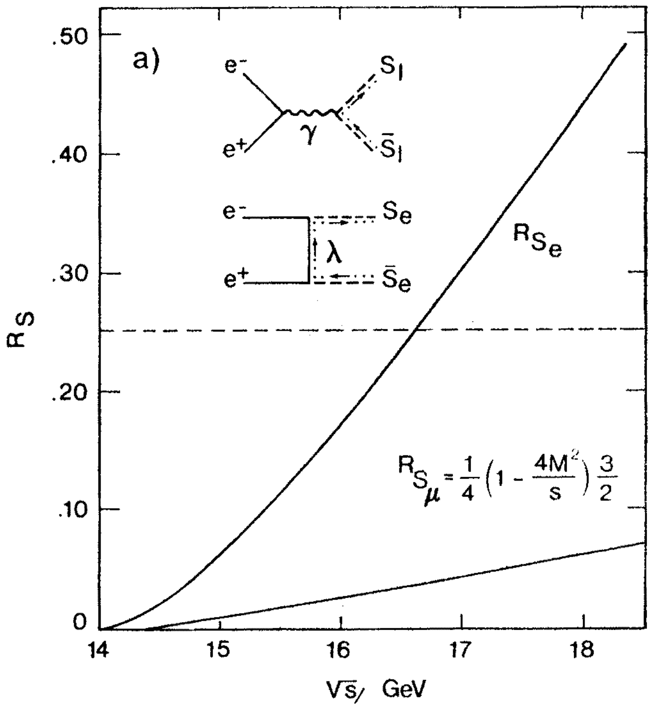
In conclusion no scalar electron is detected for $M < 16.8$ GeV/c^2 and no scalar muon for $M < 16.4$ GeV/c^2. Fig. 1b–c shows CELLO results concerning scalar electron and scalar muon for masses larger than 2–3 GeV/c^2.

1.2. Scalar tau

Scalar tau production goes through the same mechanism compared to s_e or s_μ

$$e^+e^- \rightarrow s_\tau^+ + s_\tau^-$$
$$s_\tau^- \rightarrow \tau^-\bar{\lambda}$$
$$s_\tau^+ \rightarrow \tau^+\lambda$$

The tau decay leads to two or more charged prongs with a total energy of about the quarter of the center of mass energy.



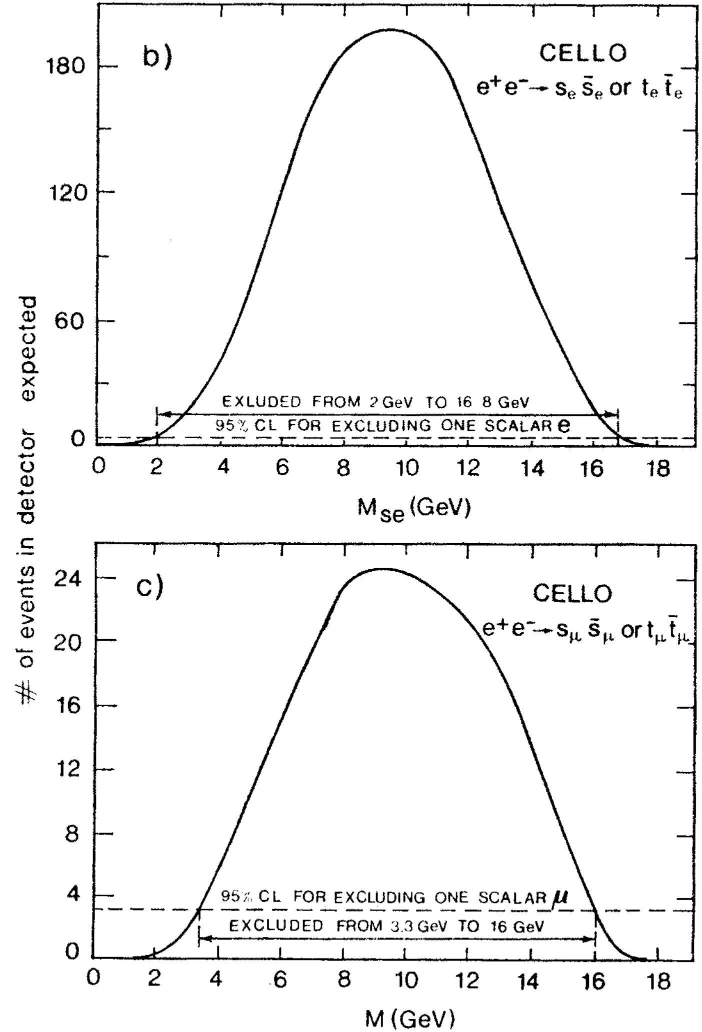


Fig. 1. a) Behaviour of cross-section for the process $e^+e^- \to s_l\bar{s}_l$ and $e^+e^- \to s_\mu\bar{s}_\mu$, function of the beam energy for a scalar lepton mass of 14 GeV and in units of μ pair production cross-section. Insert: diagrams contributing to these crossection in lowest order in e^2. b) Expected number of events in the CELLO detector as a function of the scalar electron mass for the process $e^+e^- \to s_e\bar{s}_e$. None is seen, excluding the given mass interval at the 95% C.L. (3 events). c) Expected number of events in the CELLO detector as a function of the scalar muon mass, for the process $e^+e^- \to s_\mu\bar{s}_\mu$. None is seen, excluding the given mass interval at the 95% C.L.

Three experiments have published limits on the production of scalar taus [3–5].

CELLO [3] considers the τ decay in one prong only, and can exclude the mass range between 6 GeV and 15.3 GeV at 95 per cent of confidence level. At low mass the scalar tau production leads to an excess of tau pairs. Then adding the statistical and systematic uncertainties to the observed number of $\tau^+\tau^-$ events, a mass range between the tau mass and 3.8 GeV can be excluded (with a data sample corresponding to 11.1 pb^{-1}).

A similar analysis has been done by MARK J using 40 inverse pb [4]. A search for two acoplanar taus has been done, one of them decaying in $\mu\nu_\mu\nu_\tau$, the second one in hadrons plus ν_τ.

This analysis leads to the exclusion of scalar tau production for masses between 6 and 14 GeV. On the other hand, a comparison of the number of τ pairs with QED prediction is not compatible with a scalar tau with a mass between the tau mass and 7 GeV (Fig. 2).

In summary, PETRA experiments exclude a scalar tau with a mass between τ value and 15.3 GeV.

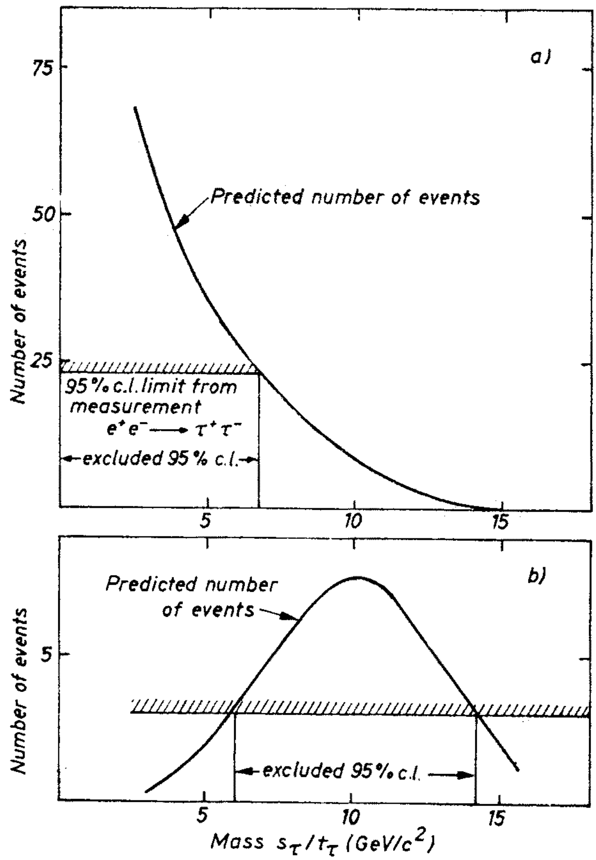


Fig. 2. Results from MARK J for the scalar tau production limits. a) Corresponds to the comparison with QED tau pairs production. b) No events is seen with acoplanar muon-hadron. The 95% C.L. limit is indicated

2. Search for charged Higgs or technipions

The mass generation in the Gauge Theories are well explained by the existence of point like scalar particles (Higgs) or composite particles (technipions). In both cases, Higgs particles or technipions couple preferentially to heavy quarks or fermions. Consequently, experimentalists search for Higgs and technipions decaying in τν or in hadrons (cb, cs).

2.1. (τν)-hadrons mode

JADE [6] and MARK J [4] have given limits on the production of charged scalars going into a lepton pair (τ, ν) and hadrons (cb) and (cs). Reaction:

$$e^+e^- \to H^+H^-$$
$$\quad \llcorner\!\!\to \text{Hadrons}$$
$$\llcorner\!\!\to (\tau, \nu)$$

has been studied by both experiments: MARK J identifies the τ by its decay in $\mu\nu\bar{\nu}$, and JADE by its decay in one or three prongs.

Selection of events is made by applying cuts to eliminate background from the one photon annihilation channel and from the two photon mechanism, mainly to remove muons from hadronic decays, and tau production in the two photon reaction.

MARK J gives an upper limit of the branching ratio H → τν equal to 24% for masses between 5 and 13 GeV/c^2.

The results of the JADE analysis are shown in Fig. 3. The limits on the mass of the Higgs and the branching ratio $B_{\tau\nu} \cdot B_{had}$ are given by curves A_1 and A_2.

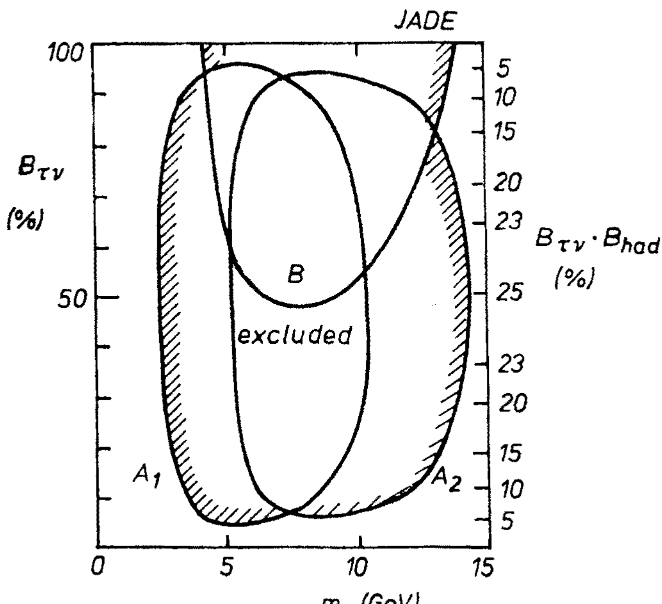


Fig. 3. Results from JADE. Limits on the branching ratio of Higgs, decay as a function of mass. Curves A_1, A_2 correspond to the decay in (τ, ν) and hadrons. Curve B corresponds to the (τ, ν) (τ, ν) decay. All the curves correspond to 95% C.L.

2.2. (τν) (τν) mode

CELLO [3], JADE [6] and MARK J [4] have reported limits on the reaction:

$$e^+e^- \to H^+H^- \quad H^- \to \tau^-\bar{\nu}, \quad H^+ \to \tau^+\nu$$

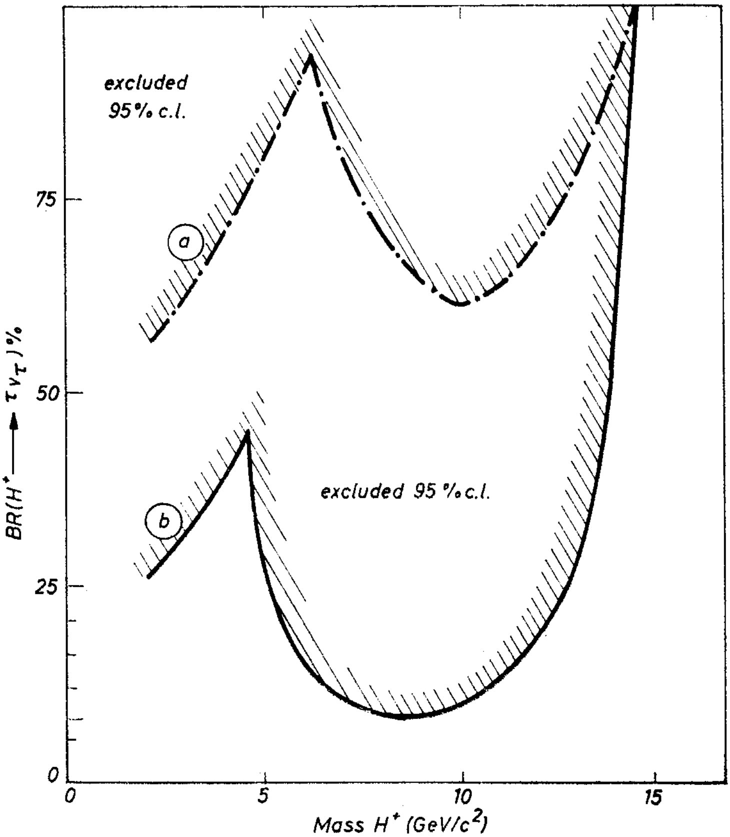


Fig. 4. Results from MARK J. Curve *a* corresponds to the reaction $e^+e^- \to H^+H^- \to \tau^+\nu, \tau^-\nu$. Curve *b* is obtained in using the previous reaction and the reaction $e^+e^- \to H^+H^- \to (c\tau)\tau^-\nu$

The kinematics are the same compared to the scalar tau production. The absence of candidates within the applied cuts gives a limit to the branching ratio H → τν as a function of the mass of the Higgs.

A mass region between the τ mass and 15.3 GeV can be eliminated for a branching ratio varying betwen 100% and 50%. The 50% branching ratio corresponds to masses around 10 GeV (curve *a* Fig. 4, curve *B* Fig. 3).

Thus no charged Higgs with conventional decay in lepton and hadrons has been found in e^+e^- reactions in the mass range between the tau mass and 15.3 GeV/c^2.

3. *Excited leptons*

The existence of excited leptons e* or μ* decaying in lepton plus one photon is connected to the composite nature of quarks and leptons. Limits on the mass of such new particles put important constiaints on the models.

3.1. Limits on e* mass

The analysis of the reaction $e^+e^- \to \gamma\gamma$ gives a lower limit on the e* mass [7], assuming the e*eγ coupling equal to the electron charge. The limit is given by the deviation of the $e^+e^- \to \gamma\gamma$ cross section, from the QED prediction. The results obtained by all experiments at PETRA are in agreement with QED. The limits obtained correspond to an e* mass around 50 GeV/c^2 (Table II).

TABLE II

Lower limit of the e* mass, with $\lambda' = 1$. The masses are in GeV/c^2. The CELLO value corresponds to all the statistics, compared to [8]

	CELLO	JADE	MARK J	PLUTO	TASSO
e* mass	59	47	58	46	34

MARK J shows the variation of the limit on the mass, as a function of the coupling constant λ' (Fig. 5), assuming an effective Lagrangian as: $L_{\text{eff}} = \frac{\lambda' e}{2M_{e^*}} \bar{\psi}_e \sigma_{\mu\nu} \psi_e F^{\mu\nu} + h.c.$

3.2. Search for μ* production

Direct production of excited muons has been investigated by CELLO, JADE and MARK J [9–10]. The reaction $e^+e^- \to \mu^*\mu^*$ corresponds to a conventional reaction with two identical spin 1/2 particles. The total cross-section is:

$$\sigma = \frac{2\pi\alpha^2}{3s}\beta(3-\beta^2).$$

The maximum of the μ* mass is equal to the beam energy. This limit can be pushed up to 30 GeV if we consider the production of one μ* associated with one muon. This cross--section depends on a scale parameter λ, and is given by the following expression:

$$\sigma = 8\pi\alpha^2 \frac{\lambda^2}{3}\left(1-\frac{M_{\mu^*}^2}{s}\right)\left(1+\frac{2M_{\mu^*}^2}{s}\right).$$

The absence of a μ* signal in μγ and the comparison with QED exclude the existence of a μ* with mass lower than 16.9 GeV. At higher energy the experiments give a limit on the parameter λ^2 (Fig. 6). Values of λ^2 greater than 5 nb are excluded for $M_{\mu^*} < 30$ GeV/c^2.

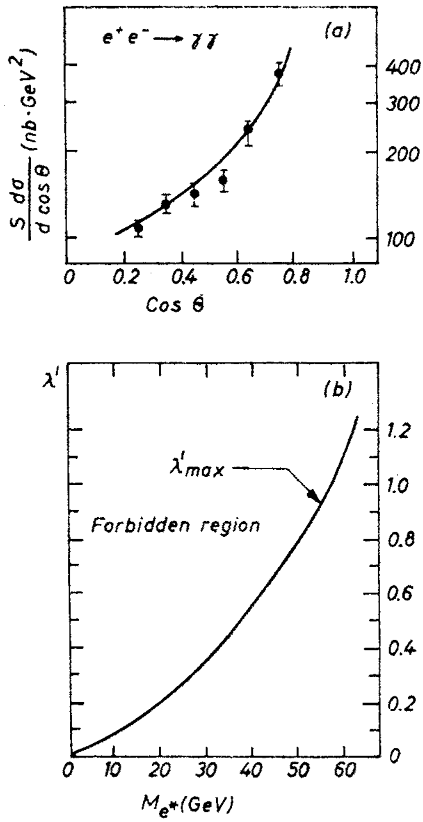


Fig. 5. 95% confidence level upper limit on the coupling λ' as a function of the mass of e*. Result from MARK J

MARK J experiment gives a maximum λ^2 value of 1 nb for masses between 17 GeV and 27 GeV. We have to notice that the measurement of the anomalous magnetic moment of the muon gives a better limit on λ^2 for masses greater than 30 GeV/c^2.

PETRA experiments have put a limit of 59 GeV/c^2 on the mass of an hypothetic e*, from $e^+e^- \to \gamma\gamma$ reactions. Direct search for μ* allows us to put a limit on the μ* mass which corresponds to 16.9 GeV/c^2 with conventional current, and 30 GeV/c^2 for non conventional current, in this last case the scale parameter λ is 0.7 10^{-16} cm.

4. *Conclusion*

Searches for scalar leptons, Higgs particles and excited electron or positron have been done at PETRA. All experiments agree to put lower limits on Higgs and scalar leptons equal to the beam energy (17 GeV/c^2). For excited leptons the limits can be somewhat extented: e* is excluded for masses lower than 59 GeV/c^2 and μ* for masses lower than 30 GeV/c^2 and λ^2 greater than 1 nb.

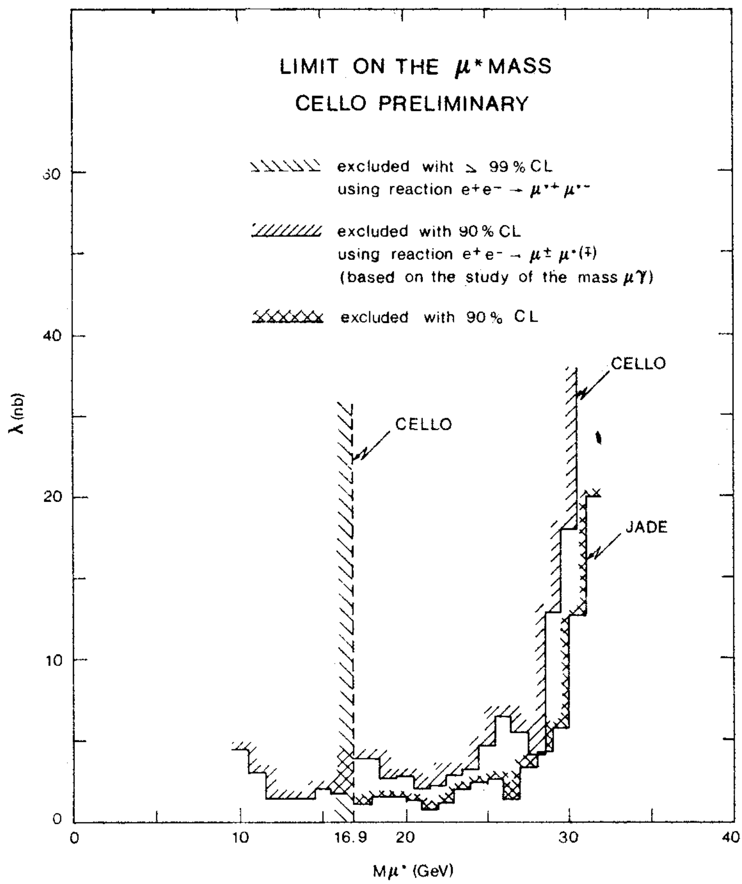


Fig. 6. Limits on the μ^* mass given by CELLO and JADE

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