SCALAR LEPTON SEARCH WITH THE CELLO DETECTOR AT PETRA

CELLO Collaboration

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We report on the search for "supersymmetric" scalar leptons conducted with the CELLO detector, at the PETRA e^+e^- storage ring. 11.1 pb^{-1} of high energy data were analysed (33 GeV $< \sqrt{s} <$ 36.72 GeV). At a 95% c.l., the existence of a scalar e is ruled out for masses between 2 GeV and 16.8 GeV; correspondingly, a scalar μ is excluded between 3.3 GeV and 16 GeV, and a scalar τ between 6 GeV and 15.3 GeV, as well as between the τ mass and 3.8 GeV.

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"Supersymmetry" is the concept of a (spontaneously broken) symmetry of the particle world that very attractively brings together its fermion and boson contents. Details as to how specific theories achieve this, and complete discussions of their consequences – reaching as far as quantum gravity – can be found in ref. [1].

The relevant features for this work are:

(i) Fermion and boson degrees of freedom are associated within representations of the supersymmetry group; thus to a lepton, say e^-, there correspond 2 scalar charged particles, say s_e and t_e, one for each helicity state of the spin $\frac{1}{2}$ lepton.

(ii) After being pair-produced in e^+e^- collisions, these s_ℓ and t_ℓ, where ℓ stands for e, μ, τ, ..., should decay quickly and only via

$$s_\ell \text{ (or } t_\ell) \to \ell + \lambda ,$$

where the photino λ is a neutrino-like carrier of some conserved quantum number associated with supersymmetry (just like ν conserves the traditional lepton number in e.g. $\pi^- \to \ell^- + \nu_\ell$). This means that the observable final state comprises only a $\ell^+\ell^-$ pair or its decay products for $\ell \equiv \tau$, since λ escapes undetected.

(iii) Production cross section via the first diagram of fig. 1 goes like $\frac{1}{4}\beta^3 = R_{s\mu}$ with $\beta = (1 - M_s^2/E^2)^{1/2}$ for a pointlike scalar μ or τ of mass M_s, at a beam energy E

For s_e (t_e), the additional t-channel diagram dramatically changes the energy (or mass) dependence (ref. [2]). Fig. 1 illustrates these behaviours of σ_{tot} versus beam energy, for M_s = 14 GeV.

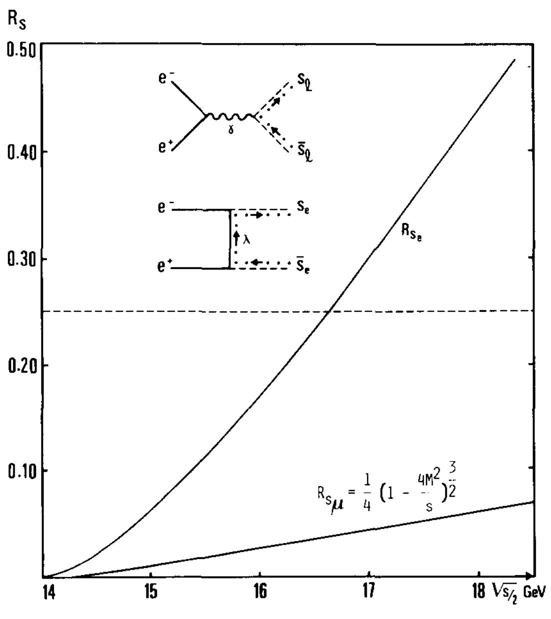

Fig. 1. Behaviour of cross sections for the processes $e^+e^- \to s_e\bar{s}_e$ (or $t_e\bar{t}_e$) and $e^+e^- \to s_\mu\bar{s}_\mu$ (or $t_\mu\bar{t}_\mu$), as functions of the beam energy, for a scalar lepton mass of 14 GeV and in units of the μ pair production cross section. Insert: diagrams contributing to these cross sections in lowest order in e^2. Arrows indicate the flow of a new conserved quantum number.

Therefore a search for a scalar e or μ means looking for events with $\ell^+\ell^-$ pairs, where on average half the energy is missing (because of the unseen λ's and the two leptons are not back to back (because of the limited boost along the scalar lepton direction). Of course, one should also require that no other particle is seen inside the detector acceptance. For a scalar τ the corresponding prescriptions are described further down.

The data used in this analysis correspond to a total integrated luminosity of 11.1 pb^{-1}, taken at c.m. energies between 33.0 and 36.7 GeV. A description of the CELLO detector can be found in ref. [3].

Acceptance cuts were performed to avoid edge effects and possible reconstruction problems:

(i) events were required to have less than 8 charged track candidates (defined at the level of the charged particle trigger), but at least 2 of them eventually reconstructed with $p_T > 800$ MeV and with angles to the beam direction between 35° and 145°. This covers 82% of the 4π solid angle;

(ii) to eliminate lowest order QED events, an acoplanarity angle [‡1] of more than 30° was required between any two such tracks. For 7.8 pb^{-1}, this minimum angle was raised to 40° due to alterations of the fast on-line filtering program.

All totally reconstructed events were then visually scanned.

(a) Case of e and μ scalars only. Because of an important background from $\gamma\gamma$ processes, further energy cuts were necessary: for e scalars, $E_{e^+} + E_{e^-} > 5$ GeV, as measured in the central part of the LA (liquid argon) calorimeter; for μ scalars $|p_{\mu^\pm}| > 0.2\, E_{beam}$.

Also, to eliminate higher order QED events such as $ee\gamma$, $\mu\mu\gamma$, etc., no additional neutral shower was to be found in the LA detector (end caps and central part).

Within these cuts, no candidate was found. From figs. 2a and 2b, which show the expected numbers of

[‡1] I.e. in the plane transverse to the beam direction. Lowest order QED gives events with acoplanarity equal to 0°.

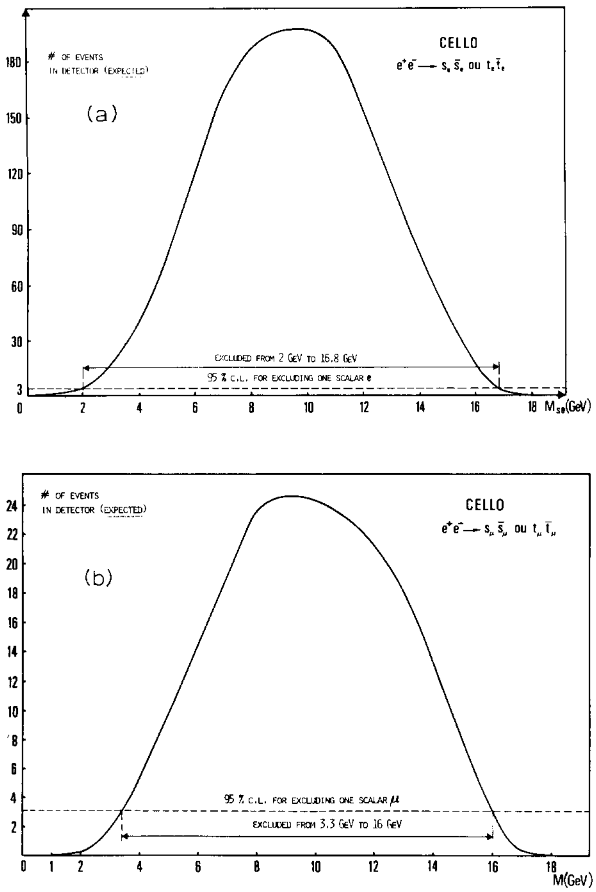

Fig. 2. (a) Expected number of events in the detector as a function of the scalar electron mass, for the process $e^+e^- \to s_e\bar{s}_e$ (or $t_e\bar{t}_e$). None is seen, excluding the given mass interval at the 95% c.l. (b) Expected number of events in the detector as a function of the scalar muon mass, for the process $e^+e^- \to s_\mu\bar{s}_\mu$ (or $t_\mu\bar{t}_\mu$). None is seen, excluding the given mass interval at the 95% c.l.

events plotted against the scalar lepton mass, one can *exclude* the existence of:

– A scalar e in the mass range 2 GeV to 16.8 GeV.

– A scalar μ in the mass range 3.3 GeV to 16 GeV.

at the 95% c.l.

These figures take into account the overall detection and reconstruction efficiency, determined by a complete Monte Carlo simulation.

(b) Case of τ scalars. The final states used here include all two charged prong $\tau^+\tau^-$ decays. This cuts the rate with respect to μ scalars by a factor (ref. [4])

$$[\mathrm{BR}(\tau \to 1\ \mathrm{prong})]^2 \simeq 0.71\ .$$

Moreover, these final states possess less energy, on average, than in case (a):

if $s_\tau \to \tau + \lambda$, $\tau \to \pi\nu$ for example, then $\langle E_\pi \rangle \simeq E_{\mathrm{beam}}/4$, whereas the same figure for case (a) was $\langle E_\ell \rangle = E_{\mathrm{beam}}/2$. Leptonic and multihadronic final states are even mor affected.

Therefore, the energy or momentum cut of case (a) was replaced by the condition: $p_T(\mathrm{pair}) = |p_T(1) + p_T(2)| > 2.5$ GeV (1.6 GeV if the decay of the τ's produced at least one photon above 500 MeV) [‡2]. A Monte Carlo simulation of $\gamma\gamma$ events showed that <1 event was expected in that region, given all the other cuts, for the processes:

$$\mathrm{ee} \to (\mathrm{ee})\,\mu^+\mu^-\ , \quad \mathrm{ee} \to (\mathrm{ee})\,\mathrm{e}^+\mathrm{e}^-\ , \quad \mathrm{ee} \to (\mathrm{ee})\,\tau^+\tau^-$$

into 2 charged prongs.

A scalar τ is then excluded at the 95% c.l. in the mas range 6 GeV $< M_s <$ 15.3 GeV, since no event is seen inside the cuts. This is indicated on the line BR = 100% which corresponds to the case of a scalar τ, in fig. 3.

We tried to improve on the lower limit by requiring that a possible scalar τ contribution to the observed $\tau-\tau$ events should not spoil their agreement with the

‡2 Also, neutral showers are tolerated here, given that they construct no invariant mass with a charged track above 2 GeV (i.e. they should really come from a τ decay).

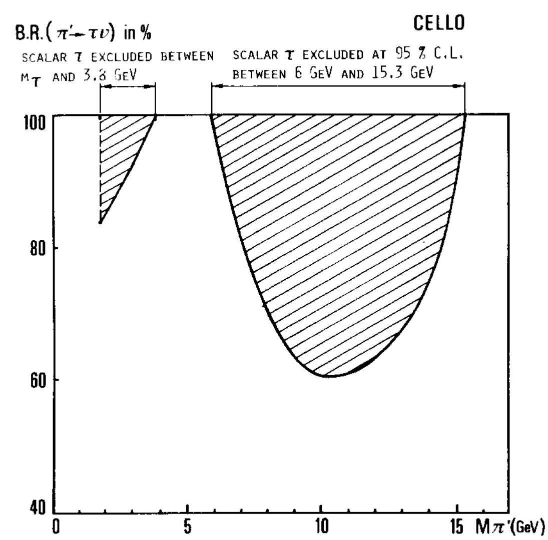

Fig. 3. Excluded domain at the 95% c.l. of mass versus branching ratio into $\tau\nu$, for a hyper-pion. The line BR = 100% corresponds to the case of a scalar τ.

predicted cross section for the process $e^+e^- \to \tau^+\tau^-$, as obtained in ref. [4]. Adding the statistical and systematic uncertainties to the observed number of $\tau-\tau$ events, we obtained the maximum excess (95% c.l.) over QED allowed by our measurement of the $\tau-\tau$ cross section. The expected scalar τ contribution turned out rather close to this maximum excess, pair production of scalars being at least a factor of 4 down compared to the $\tau-\tau$ cross section. We could still rule out a scalar τ with a mass between the τ mass and 3.8 GeV (95% c.l.) Combining both models *excludes*:

$$6\ \mathrm{GeV} < M_s < 15.3\ \mathrm{GeV}\,, \quad M_\tau < M_s < 3.8\ \mathrm{GeV}\,.$$

One can look for other particles with properties similar to those of the scalar τ, namely "techni-" or "hyperpions". These are expected within the dynamical symmetry breaking scheme known as extended technicolor (ref. [5]), and should be relatively light on the "techni-" mass scale of 1 TeV (for the same reasons that the usual pion is light with respect to the hadronic mass scale).

Moreover, these hyper-pions π' should couple preferentially to the heaviest fermions, as ref. [6] discusses. A decay $\pi' \to \tau\nu$, after pair production of $\pi'^+\pi'^-$, would have the same kinematical characteristics as $s_\tau \to \tau\lambda$. From the scalar τ study, one can therefore derive limits on the mass of a hyperpion with a given value of branching ratio into $\tau\nu$, which is an additional free parameter in that case. Fig. 3 shows the excluded (95% c.l.) domain in the plot of $M_{\pi'}$ versus $\mathrm{BR}(\pi' \to \tau\nu)$.

Consistency checks of the analysis were performed with higher order QED processes of similar topology, such as $e^+e^- \to e^+e^-\gamma$ (ref. [7]) and $e^+e^- \to \mu^+\mu^-\gamma$ (ref. [8]), which will be studied in greater detail in a forthcoming paper. Using a Monte Carlo program by Berends and Kleiss, the total number of $ee\gamma$ events with acoplanarity greater than 30°, detector and reconstruction inefficiencies included, was predicted to be 68 ± 7 (± 4 syst.). With the selection criteria of the scalar e search, but allowing for an additional neutral shower in the LA calorimeter, we found 59 such $ee\gamma$ events. The corresponding figures for $\mu\mu\gamma$ are 13.9 ± 1.0 expected events for 11 observed events.

In conclusion, we have set limits on all scalar lepton masses, *excluding them* at the 95% c.l. in the intervals:

$2\ \mathrm{GeV} < M < 16.8\ \mathrm{GeV}$ for a scalar electron ,

$3.3\ \mathrm{GeV} < M < 16\ \mathrm{GeV}$ for a scalar muon ,

$M_\tau < M < 3.8\ \mathrm{GeV}$ and $6\ \mathrm{GeV} < M < 15.3\ \mathrm{GeV}$ for a scalar tau .

These figures improve on previous results (refs. [9–11] [3]). From the scalar τ search, we were also able to exclude the existence of a hyper-pion with given values of mass and BR to $\tau\nu$.

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[3] Ref. [9] excluded $M_{s_e} < 13$ GeV (95% c.l.), ref. [10] excluded $M_{s_e} < 16$ GeV, ref. [11] excluded 3 GeV $< M_{s_\mu} < 15$ GeV (95% c.l.).

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