NEW PARTICLE SEARCHES IN ALEPH (part II)

by the ALEPH Collaboration

presented by

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ABSTRACT

This report is the second part of the ALEPH search report. It covers the search for supersymmetric particles (Higgs, charginos and neutralinos) within the framework of the Minimal Supersymmmetric Standard Model and the search for composit charged leptons and neutrinos. Lower limits of masses of such new particles are given. Most of them are very close to the LEP I kenematical limit.

This report follows a presentation on the search for the standard Higgs boson in ALEPH made at this conference [1]. It covers the search for supersymmetric particles (Higgs, charginos and neutralinos) within the framework of the Minimal Supersymmetric Standard Model and the search for composit charged leptons and neutrinos. Lack of space does not allow to give updates of the search for other supersymmetric particles and for new quarks and leptons. For the same reason the experimental selections are only briefly recalled because they are described in referenced previous publications.

SEARCH FOR SUPERSYMMETRIC HIGGS BOSONS

The Minimal Supersymmetric Standard Model (MSSM) is a model with two Higgs doublets coupled respectively to down and up-type quarks only. This very constrained model requires 5 physical Higgs states : 2 mixed scalar neutral h^o and A^o (mixing angle α), 1 pseudoscalar neutral A^o and 2 charged Higgs $H^{\pm}$. Masses and couplings depend only on two parameters M_h and $\beta = A \tan\ (v_2/v_1)$(where v_1 and v_2 are the vacuum expectation values of the 2 Higgs doublets). In particular according to the relation :

$$M_h \leq M_Z|\cos 2\beta| \qquad (1)$$

the h boson has to be lighter than the Z^o. The model relates the $Z \to hZ^*$ and $Z \to hA$ coupling constants :

$$g_{hZZ} = g\ \sin(\beta - \alpha), \qquad g_{ZhA} = g\ \cos\ (\beta - \alpha) \quad (2)$$

to the weak coupling constant g. When $\mathrm{tg}\,\beta$ is very different from unity the $Z \to hA$ decay dominates. Otherwise it is the $Z \to hZ^*$ decay. The search for signatures of these two decays are complementary for exploring the $\mathrm{tg}\,\beta$, M_h plane of MSSM Higgs bosons.

The search for charged Higgs bosons described elsewhere [1] has not been updated for this report. We will restrict ourselves to the neutral Higgs search.

I - Search for $Z \to h^o Z^*$

The Z partial width expected for the mode $Z \to h^o Z^*$ in MSSM is, compared to its standard model value, reduced by a factor $\sin^2(\beta - \alpha)$ (eqn.2). For $M_h > 2M_\mu$, the search which rely on the observation of the Z^*, is identical to the standard model Higgs boson search. The Aleph limit, $M_H \geq 41.6$ GeV 95% C.L., reported at this conference [3], can be converted in the exclusion of a domain in the $\mathrm{tg}\,\beta, M_h$ plane (curve A in figure 1). In this figure, the curve labelled T, limits the domain theoretically excluded by equation 1. From these two excluded domains, we get bounds on $\mathrm{tg}\,\beta$.

$$\mathrm{tg}\,\beta > 1.60 \quad \text{or} \quad \mathrm{tg}\,\beta < 0.63, \quad 95\%\ \text{C.L.}$$

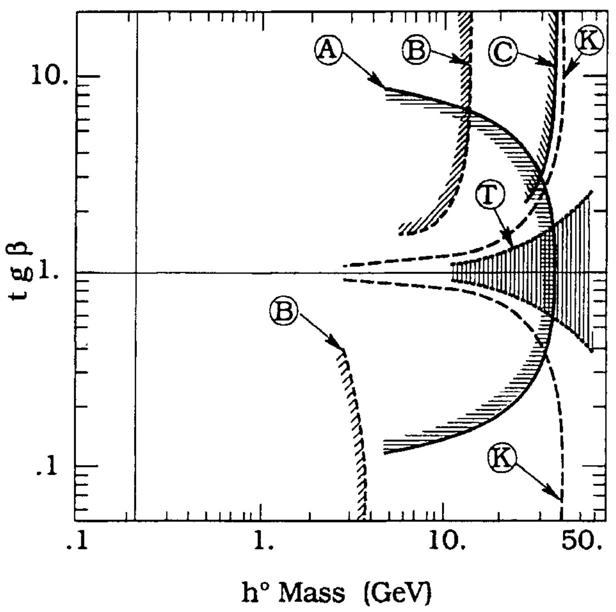

Fig.1 : Excluded domains in the $M_h, \text{tg}\,\beta$ plane for heavy Higgs. Altogether Aleph and theory exclude the hatched region (see text).

In the low M_h region ($M_h < 2\ M_\mu$) where the only decay modes are $h \to e^+e^-$ and $\gamma\gamma$, the h boson lifetime starts to exceed tens of picoseconds. The standard Higgs search described above is therefore limited to the exclusion of the domain inside curve 1 of figure 2.

Special additional searches, described in detail in [3] are therefore needed .

i) Very light Higgs are so stable that they escape detection. Only the Z^*decay is visible. Lepton pair decays associated to missing energy are searched for. No event are detected [2]. The domain inside curve 2 of fig.2 is 95% C.L. excluded.

ii) Intermediate mass light Higgs decays inside the Aleph tracking chamber system resulting in a detached vertex. Lepton pair decays of the h are looked for, whatever is the Z^* decay. No events are found excluding the domain inside curve 3 of fig. 2.

iii) In order to reach the high $\text{tg}\,\beta$ region, it is necessary to search for $Z \to hA$ decays. In the very light Higgs region under consideration, either the quasi-stable Higgs escapes detection or its decay products ($e^+e^-, \gamma\gamma$ pair) fail the $Z \to$ hadrons selection. The Aleph measurement of the Z invisible width can be converted in the exclusion of the domain outside curve 4 of fig.2.

From these four negative searches displayed in figure 2, we can exclude (95% C.L.) any minimal supersymmetric light Higgs ($M_h < 2M_\mu$).

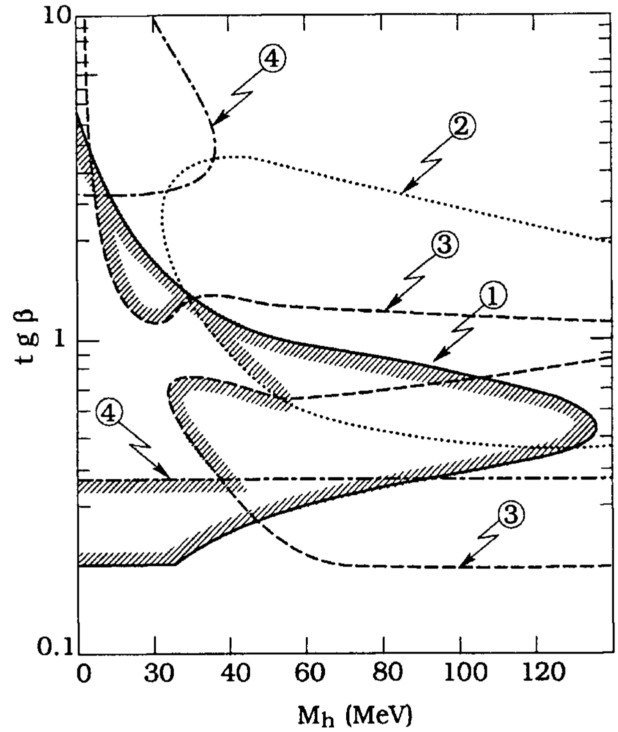

Fig.2 : Excluded domains in the $M_h, \text{tg}\,\beta$ plane for $M_h < 2M_\mu$ (see text) : the overall region is excluded.

II - Search for $Z \to h^\circ A^\circ$

According to equation 2, the $Z \to hA$ decay width is, compared to the $Z \to$ leptons width, reduced by a factor $\cos^2(\beta - \alpha)$ which is sizable when $\text{tg}\,\beta$ differs appreciably from unity. h and A Higgs boson decay, depending on their mass, to the heaviest possible pair of identical flavours :

- g, μ, s, τ and b pairs for $\text{tg}\,\beta \gg 1$
- g and c pairs for $\text{tg}\,\beta \ll 1$.

Therefore different types of selection are needed to search for MSSM Higgs depending on their masses and $\text{tg}\,\beta$. They are precisely detailled in reference 4. We just recall the various search principles :

1) Low multiplicity states :

Each event is divided into two hemispheres with respect to the sphericity axis. The total charge of each hemisphere is required to be 0. The hemisphere charged track topology is selected to be 2 + 2 or 2 + 4. For 18600 hadronic Z decays we found [4] only 1 event. Hundred are expected from MSSM in the region B of the $\mathrm{tg}\,\beta, M_h$ plane ploted in figure 1, which is 95% C.L. excluded.

2) $\tau\tau$ jet jet states :

Events with 2 "one track" jets of opposite charge (called "τ jets") and 2 additional jets are kept [4]. The energy of these 4 jets are rescaled to ensure energy-momentum conservation, allowing to look for the $Z \to hA$ signal in a "τ-τ" and "jet-jet" masses 2-dimentional histogram. For 101000 Z only one event ($M_h = 36$, $M_A = 51$) is found allowing to exclude the region C of figure 2 where $hA \to \tau\tau\ bb$ dominates.

3) 4 jets states :

This selection [4] which suffers a very high $Z \to q\bar{q}\ gg$background appears to be not more efficient than the previous one. It results in the exclusion of region D of figure 2.

On figure 2, together with the various excluded domains (labelled A to C) curve K gives the LEP I kinematical limits $(M_h + M_A = M_Z)$. For $\mathrm{tg}\,\beta > 1$, which is theoretically favoured, almost all the kinematically allowed region (inside curve K) is excluded. For $\mathrm{tg}\,\beta > 1$, the same limits are displayed in figure 3 in the M_A, M_h plane. We can set the 95% C.L. bounds

$$M_h > 33.2 \text{ GeV} \qquad \text{and} \qquad M_A > 42.1 \text{ GeV}.$$

SEARCH FOR CHARGINOS AND NEUTRALINOS

In the Minimal Supersymmetric Standard Model (MSSM) the 6 superpartners of the gauge bosons and Higgs have to be looked for. They are :

* the $W^{\pm}$ and $H^{\pm}$ partners who mix to form 2 charginos: $\chi^{\pm}$ is the lightest.

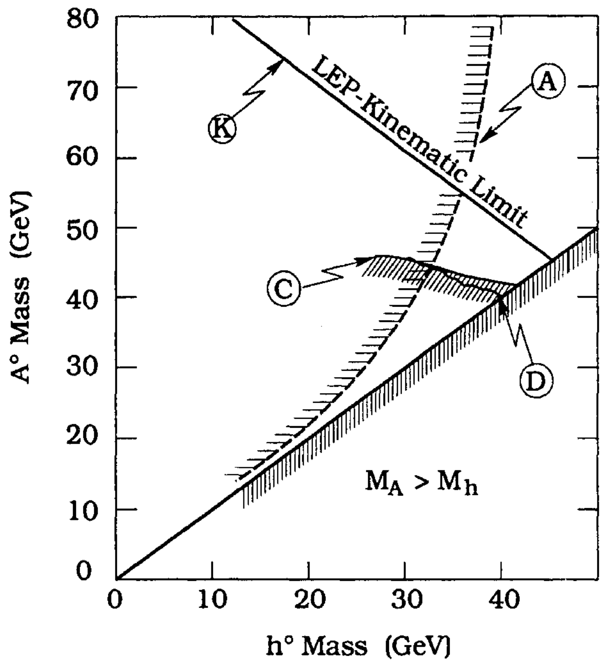

Fig.3 : Excluded domains in the M_h, M_A plane for $\mathrm{tg}\,\beta > 1$ (see text).

* the Z^o and neutral Higgs partners who mix to form 4 neutralinos : χ is the lightest and χ' anyother one. The lightest of χ and $\chi^{\pm}$ has to be stable. Only two additional parameters M , and μ are needed to describe this sector.

I - Search for charginos ($\mathbf{M}_{\chi^{\pm}} > \mathbf{M}_{\chi}$)

Charginos are pair produced in the reaction $e^+e^- \to Z \to \chi^+\chi^-$. We search for their semi-leptonic decay into the lightest stable neutralino : $\chi^{\pm} \to \ell^{\pm}\chi\nu$ (branching fraction $\sim 10\%$). The selection requires the observation of an acoplanar lepton pair associated with missing energy [5]. For 72000 hadronic Z decays this set a 95% lower limit on $M_{\chi^{\pm}}$ which ranges from 45.0 to 46.9 GeV (for $M_{\chi} < 20$ GeV) depending upon the chargino mix-

II - Search for neutralinos

Neutralinos are pair produced through the decays $Z \to \chi\chi'$ and $\chi'\chi'$. If χ is the lightest superpartner it is stable, while two χ' decay possibilities are considered as described in ref.6 :

• $\chi' \rightarrow \chi f \bar{f}$: the selection looks for a lepton or jet acoplanar pair with missing energy or, in order to cover the case where χ and χ' are both lights, it searchs for monojet events.

• $\chi' \rightarrow \chi\gamma$: the selection requires one or two acoplanar γ. The lower branching ratio expected for this mode is compensated by the advantage of a much cleaner selection.

No events are selected for 101000 hadronic Z decays.

Additional constraints [6] on the neutralino masses can be pull out from the Z line shape measurements. Decays like $Z \rightarrow \chi\chi$ should contribute to the invisible width while $Z \rightarrow \chi\chi', \chi'\chi', \chi^+\chi^-$ may be visible, depending on the masses but independently of the $\chi, \chi', \chi^\pm$ decay mode. In particular we can also exclude cases where $\chi^\pm$ is the lightest superpartner.

The direct search and the line shape constraints set a 95% C.L. limit in the MSSM parameter plane M, μ given in reference 7. Unfortunatly we have no space to reproduce it in this written report. The result is given in the "naturality" domain ($|M|$ and $|\mu| < 2\ M_Z$) where theory expect these parameters to lie. The part of this domain kinematically accessible to LEP I $\left(M_\chi + M'_\chi \leq M_Z\right)$is completly excluded for $\mathrm{tg}\,\beta \geq 2$.There is only room for a future improvement at LEP I, in the region $1.6 \leq \mathrm{tg}\,\beta \leq 2$. The excluded domain corresponds to the 95% C.L. limit $M_\chi > 30$ GeV.

SEARCH FOR COMPOSITNESS

Composite leptons ℓ^* have been looked for in Aleph, through their decay into a lepton-photon pair. Pair and single productions are studied. The search has been made for excited charged leptons and excited neutrinos.

Pair production : $\mathbf{Z \rightarrow \ell^*\ell^*}$

* Excited charged leptons : the selection requires to detect an acoplanar lepton pair with two energetic γ emitted away from both leptons [7]. No candidate is found. The standard model coupling is taken for the $Z^o \rightarrow \ell^*\ell^*$ coupling and the excited lepton is assumed to decay only into $\ell^*\gamma$. One can exclude (95% C.L.) excited electrons, muons and taus respectively below 45.6, 45.6 and 45.4 GeV.

* Excited neutrinos : events in which we observe only two acoplanar γ with missing energy are kept [8]. No candidate is found. The mass limit we can derive depends on f :

$$f = \frac{g\ (Z \rightarrow \nu^*\nu)}{g\ (Z \rightarrow \nu\nu)} \times BR\,(\nu^* \rightarrow \nu\gamma)\,.$$

Depending on the excited neutrino type (Dirac, Majorana) and on the structure of the composite object, f is a priori unknown ($f \leq 1$). The expected rate depends also on the number of such neutrinos, light enough to be produced. Excited neutrinos with masses below 40 GeV are excluded (95% C.L.) if f exceeds 4.7% for 1 neutrino and 2.7% for 3 mass-degenerated neutrinos.

Another limit on excited neutrinos can be derived from their contribution to the Z total width measured from the Z line shape. Such a limit is independent on the neutrino decay mode. 95% C.L. lower limit on the excited neutrino mass are derived. For one such neutrino (resp. 3 mass-degenerated neutrinos) the limit is 35.7 GeV (resp. 44.3) for a Dirac type and 26.9 GeV (resp. 37.7) for a Majorana type.

Single production of charged leptons : $\mathbf{Z \rightarrow \ell\ell^*}$

The selection requires to detect an acoplanar lepton pair with one energetic photon emitted away from both leptons [7]. Events of that kind are found which originate from the radiative production $e^+e^- \rightarrow \ell^+\ell^-\gamma$. For any mass of each $\ell\gamma$ pair, the level of observed events is compared to the sum background + expected number of excited leptons.

The branching ratio $BR\,(Z \rightarrow \ell\ell^*)$ depend on the ratio of the magnetic coupling constant λ (introduced through a phenomenological lagrangian) to the lepton mass $m_\ell*$. For values of λ/m_{ℓ^*} exceeding 2 10^{-3} one can exclude (95% C.L.) excited electrons, muons and taus respectively below 84, 84 and 78 GeV.

Search for excited electrons can also be performed by looking to their production through the quasi-real compton scattering ; $\gamma e \rightarrow e^* \rightarrow \gamma e$ where the incident γ is a hard initial-state bremsstrahlung photon.$e\gamma$ events satisfying the kinematic of this process are selected. As before, for values of $\lambda/m_e{}^*$ exceeding 2 10^{-3}, one can exclude (90% C.L.) excited electron below 90 GeV.

CONCLUSION

From a sample of 100 000 hadronic Z decays, Aleph has made negative searches for the following particles.

In the framework of the Minimal Supersymmetric Standard Model we have derived the limit :

$$\mathrm{tg}\,\beta > 1.60 \quad \text{or} \quad \mathrm{tg}\,\beta < 0.63$$

For $\mathrm{tg}\,\beta > 1$ we set limits on the neutral Higgs masses :

$$M_h > 33.2 \text{ GeV} \quad \text{and} \quad M_A > 42.1 \text{ GeV}$$

Most of the kinematically accessible domain of LEP I is excluded with respect to the production of charginos ($M_{\chi^\pm} > 45$ GeV), neutralinos ($M_\chi > 30$ GeV) and composit charged leptons and neutrinos.

References

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