5) due to the role of RC, as previously discussed. In a tree-level calculation $\Omega_\chi h^2$ at the representative point of fig. 5 would look as shown in fig. 8; here one notices that above the threshold for $\chi\chi \to hA$ the values of $\Omega_\chi h^2$ are about one order of magnitude smaller than in fig. 5.

We note that in those figures $\Omega_\chi h^2 < 1$ almost everywhere. More generally, in the region of M_2, μ explored in this paper, overclosure occurs only for small m_χ, mainly in regions already excluded by present LEP experimental searches.

For the computations of the event rates relevant to direct and indirect searches we need to determine the local (solar neighbourhood) value of the neutralino density ρ_χ. In those regions of the explored range of m_χ where the value of $\Omega_\chi h^2$ is $\gtrsim 0.05$, and then consistent with the value of the local density ρ_l, we take $\rho_\chi = \rho_l$.

Otherwise, when $\Omega_\chi h^2 < 0.05$, one cannot maintain that the neutralino constitutes the entire DM; ρ_χ must then be rescaled with respect to ρ_l [5,16]. Thus here, whenever $\Omega_\chi h^2 < 0.05$, we rescale as follows:

$$\rho_\chi = \frac{\Omega_\chi h^2}{0.05}\rho_l. \tag{3.6}$$

Note that in the regions where rescaling occ one has

$$\rho_\chi \propto \Omega_\chi h^2 \propto \langle \sigma_{\rm ann} v \rangle_{\rm int}^{-1}. \tag{3}$$

As we shall see, this proportionality has markable implications on the theoretical pred tions for direct and indirect detection.

4. Direct detection

The direct search for the neutralino DM based on the measurement of the effects induc in appropriate detectors by the neutralin nucleus elastic scattering.

The event rate per nucleus is given by

$$R = \frac{v_\chi \rho_\chi \sigma}{m_\chi}, \tag{4.}$$

where σ is the elastic cross-section and v_χ is t neutralino average velocity.

In order to evaluate σ the following process have to be considered: (1) Z-exchange: this pr vides a spin-dependent cross-section for higgsin (the coherent part is missing due to the Majora character of the neutralino); (2) squark-exchang

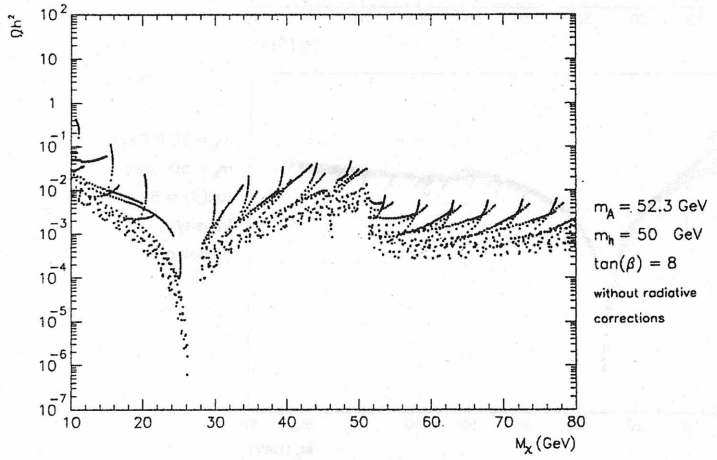

Fig. 8. An example of $\Omega_\chi h^2$ as a function of the neutralino mass m_χ computed at tree level. Here $\tan\beta = 8$, $m_h = 50$ Ge $m_A = 52.3$ GeV (to be compared with fig. 5 where RC are included).

this gives a coherent contribution for $\tilde{Z}$-higgsino mixture as well as an incoherent cross-section mainly for gauginos; (3) Higgs boson-exchange: this term gives a coherent cross-section for $\tilde{Z}$-higgsino mixture.

For the nuclei used in present detectors (Ge, NaI, Si) the coherent scattering is by far dominant. The squark-exchange contribution can be safely neglected compared to the Higgs-exchange one if we take for both the Higgs and the squark masses values close to the present experimental lower bounds, $m_h = 50$ GeV, $m_{\tilde{q}} = 150$ GeV; indeed, corrections due to inclusion of squark-exchange diagram are $(m_h/m_{\tilde{q}})^2 \approx 0.1$ in this case.

As far as the Higgs-nucleon coupling is concerned, we employ here the values reported in ref. [17]. These values differ somewhat from those given by other authors. The effects of this theoretical uncertainty on the event rate are discussed in ref. [3].

As for the spin-dependent cross-sections, the sole Z-exchange contribution may be retained, due to the above lower limit on $m_{\tilde{q}}$.

By way of example the rate for χ–Ge scattering is given for the two cases of non – rescaled (fig. 9a) and rescaled (fig. 9b) ρ_χ. By comparing the two yields one notices two main features in the rescaled case: (i) the spread at a given value of m_χ shrinks greatly and, (ii) the overall value of the yield is dramatically reduced.

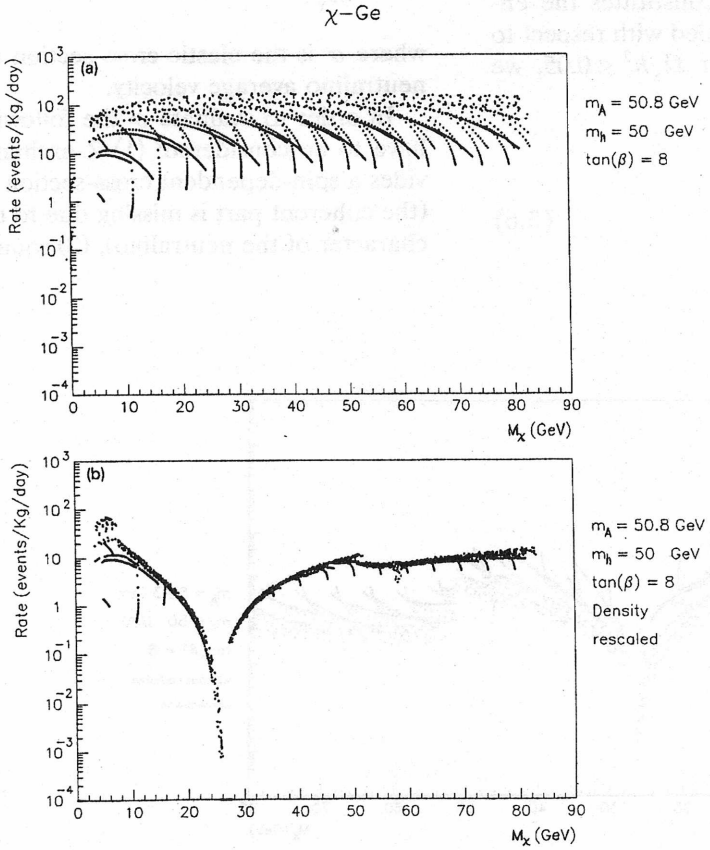

Fig. 9. Rate for χ–Ge scattering events/(Kg day) for $\tan\beta = 8$, $m_h = 50$ GeV, $m_A = 50.8$ GeV. (a) $\rho_\chi = \rho_l$; (b) ρ_χ has been rescaled.

The reason for (i) is that, because of the rescaling, the rate is proportional to $\sigma/\langle\sigma_{\rm ann}\rangle_{\rm int}$ (see eq.(3.7)). At low m_χ, when only the $f\bar{f}$ annihilation channel is open, the cross-section $\sigma_{\rm ann}$ is dominated by exchange of the pseudoscalar A whereas σ is dominated by the h-exchange diagram. Now, the amplitude for $\chi\chi \to A \to q\bar{q}$ depends on the parameters M_2 and μ only through m_χ and the factor

$$F_A \equiv a_2(-a_3 \sin\beta + a_4 \cos\beta) \times \begin{cases} 1/\tan\beta, & \text{for up-type quarks,} \\ \tan\beta, & \text{for down-type quarks,} \end{cases} \tag{4.2}$$

whereas the amplitude for $\chi q \to \chi q$ (with an exchanged h in t channel) has a dependence through m_χ and

$$F_h \equiv a_2(a_3 \sin\alpha + a_4 \cos\alpha) \times \begin{cases} \cos\alpha/\sin\beta, & \text{for up-type quarks,} \\ -\sin\alpha/\cos\beta, & \text{for down-type quarks.} \end{cases} \tag{4.3}$$

Since, by including RC to Higgs masses, one has, for $\tan\beta \gtrsim 2$–3, $\alpha \simeq -\beta$, it also follows that

$$F_A \simeq F_h, \tag{4.4}$$

except for very small values of $\tan\beta$. If we further notice that in this $f\bar{f}$ annihilation $q\bar{q}$ (with heavy q) final states dominate, we can conclude that the dependence of $\sigma/\langle\sigma_{\rm ann}v\rangle_{\rm int}$ on M_2 and μ is strongly attenuated. We wish to stress that the property for the rate of being largely independent on M_2 and μ follows from the combined effects of the rescaling and of the inclusion of RC to Higgs masses. When the process $\chi\chi \to hA$ opens the effect becomes less pronounced.

The theoretical prediction at point(ii) shows that a rather high sensitivity is needed in the experimental search. Detailed quantitative comparisons between theory and data have been presented in [3,18] where it is seen that the sensitivity in the present direct measurements is not yet sufficient to place constraints over the neutralino parameters. In ref. [18] the outlooks and perspectives of direct neutralino search are also d cussed.

5. Indirect detection: results and conclusions

Relic neutralinos with local density ρ_χ crossi the Sun or the Earth may loose energy by elas scattering on the nuclei of the celestial body a become gravitationally trapped. So the Sun a the Earth keep accumulating neutralinos; th density grows with time, and also the rate for χ annihilation increases until it matches the ca ture rate. The subsequent pair annihilation of t accumulated neutralinos may generate a stea flux of neutrinos from the celestial bodies.

The most accurate study of the capture ra has been performed by Gould [19]. A compa formula for the capture rate is [5,20]

$$C = \frac{\rho_\chi}{v_\chi} \sum_i \frac{\sigma_i}{m_\chi m_i} (M_B f_i) \langle v_{\rm esc}^2 \rangle_i X_i, \tag{5.1}$$

where σ_i is elastic χ cross-section off nucleus i, is the mass fraction of the element i in t macroscopic body of mass M_B, $\langle v_{\rm esc}^2\rangle_i$ is t square escape velocity averaged over the distrib tion of the element i, X_i is a factor which tak into account further neutralino–nucleus kinema ical effects.

The slowing down of χ by elastic scattering most efficient when m_χ is equal to the mass some scatterer nucleus inside the celestial bod The presence of heavy nuclei in the Earth mak it very efficient in capturing χ's in our m_χ rang

For capture when $m_\chi \gg m_W$ the Earth loos efficiency while the Sun, in spite of the smalle nuclei mass, is still effective because of its muc larger escape velocity. (For a discussion of indirect detection in this high m_χ regime see re [21]).

In the region of parameters in which we ar interested here one can assume that both in th Sun and in the Earth equilibrium between cap ture and annihilation rates has been reached; thi is certainly true for the Sun and marginally s also for the Earth.

So at equilibrium $\Gamma_{\rm ann} = \frac{1}{2}C$ and the flux of neutrinos at a distance d from the annihilation region is given by

$$\frac{dN_\nu}{dE_\nu} = \frac{\Gamma_{\rm ann}}{4\pi d^2} \sum_f B_f \frac{dN_{f,\nu}}{dE_\nu} \qquad (5.2)$$

Here $dN_{f,\nu}/dE_\nu$ denotes the differential distribution of the neutrinos generated by the semileptonic decays of the fermions produced by $\chi\chi$ annihilations; B_f are the relevant branching ratios. The ν_μ's may then convert into muons into the Earth and thus generate a signal of muons which would cross a neutrino telescope upwardly.

From (5.2) the estimate of the final upgoing muon flux can be obtained by well established computations (see, for instance, ref. [22] and ref. [3]).

We summarize in some figures a sample of our computations for the upgoing muon yield in the case of the Earth and of the Sun. The representative points are selected as before. The neutralino local density is rescaled as explained when $\Omega_\chi h^2 < 0.05$. Events are referred to a detector of area $\times$ time of 10^5 m^2 year; the muon threshold energy has been set at 2 GeV.

For the Earth a half aperture of 30° has been used. The background of upgoing muons due to

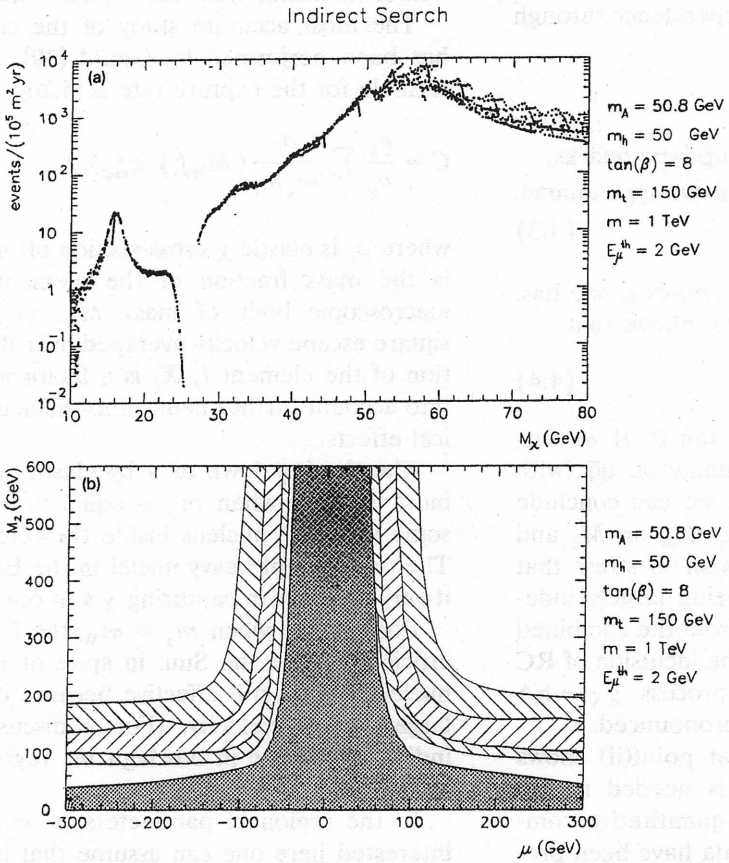

Fig. 10. Indirect detection of neutralinos ($\chi\chi$ annihilation in the Earth): rates of upgoing muons in a detector of area 10^5 m^2. Half aperture is 30°. ρ_χ is rescaled. Parameters are: $\tan\beta = 8$, $m_{\rm h} = 50$ GeV, $m_{\rm A} = 50.8$ GeV. The threshold for muons is 2 GeV. (a) Upgoing-muon rate per year as a function of m_χ; (b) the upper-left to lower-right dashed plus the inner lower-left to upper right dashed regions represent the domain in the parameter space that can be covered at 4σ in 3 years. The inner dashed area is the region presently excluded by the upper limit [24]. The dotted domain denotes the area excluded by LEP-CDF.

atmospheric neutrinos is $\Phi = 2.5 \times 10^{-13}$ cm^{-2} s^{-1} sr^{-1} [23], which translates into about 6500 events/year in a 10^5 m^2 detector.

Figure 10a shows the event rate for the Earth as a function of m_χ at $m_h = 50$ GeV and tan $\beta = 8$. The yield follows the general trend of $\Omega_\chi h^2$, in particular the dip in the intensity of the signal is the direct consequence of the enhancement in the annihilation when $m_\chi = \frac{1}{2} m_A$ and of the ensuing depletion of $\Omega_\chi h^2$. In this scatter plot the reduced spread, which is particularly pronounced below the threshold for hA channel in annihilation, is due to the properties already discussed in connection with the direct measurements.

In fig. 10b we represent the region in parameter space that can be covered at 4σ in a period 3 years in a detector of 10^5 m^2. We stress th this search could cover virtually all of the parar eter space below the kinematical limit $m_\chi < M$ (notice that the central dotted region is exclud by accelerator searches). The inner dashed ar shows the region presently excluded by the upp limit established at Kamiokande [24] $\Phi \leq 4.0$ 10^{-14} cm^2 s^{-1} (90% C.L.).

Figure 11a shows the yield from the Ear when $m_h = 80$ GeV and tan $\beta = 8$. The regic that can be explored at 4σ over the backgrour is shown in fig. 11b.

It is remarkable that in both cases shown abo the region that can be explored in 3 years

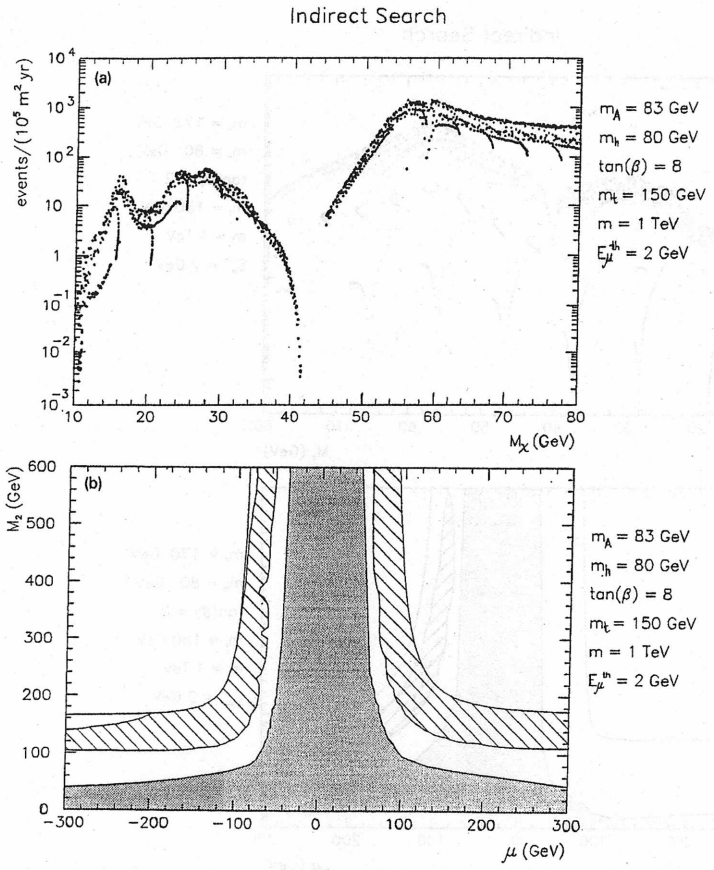

Figure 11b

Fig. 11. Same as in fig. 10 with tan $\beta = 8$, $m_h = 80$ GeV, $m_A = 83$ GeV. (a) upgoing-muon rate per year as a function of m_χ; (b) th dashed region is the domain in the parameter space that can be covered at 4σ in 3 years.

complementary to present accelerator searches and includes domains that will not be reached by future searches at LEP II.

The case $m_h = 80$ GeV and $\tan\beta = 2$ is less favourable, essentially due to the low value of $\tan\beta$. We see an ample spread of the yield as function of the parameters in fig. 12a. The lower overall level of the rate entails a reduced possibility for exploring a region at 4σ over the backgroud, as pictured in fig. 12b.

Let us now discuss the yield from the Sun. The signal and the background have been computed for a half aperture of 25° and an efficiency factor of 0.15. The background is 670 events/10^5 m^2/year. The yields are reproduced in fig. 13. Again typically for a given m_χ the yield shows a weak dependence on M_2 and μ for $\tan\beta = 8$, while the dependence on these parameters is strong for $\tan\beta = 2$.

The Kamiokande upper limit for the flux from the Sun is [24] $\Phi < 6.6 \times 10^{-14}$ cm^{-2} s^{-1} (90% C.L.). This limit corresponds to a yield of about 310 muons/year in 10^5 m^2; the fluxes shown in fig. 13 are too low for providing constraints from this experimental bound.

We see from our results that, in the m_χ range considered here, the detection of the signal from the Sun (which is otherwise important for its signature over the background) would require a detector of an area larger than 10^5 m^2, while the signal from the Earth can be well detected in a few years of operation with a neutrino telescope of area 10^5 m^2 in large regions of parameters if $m_h < 100$ GeV.

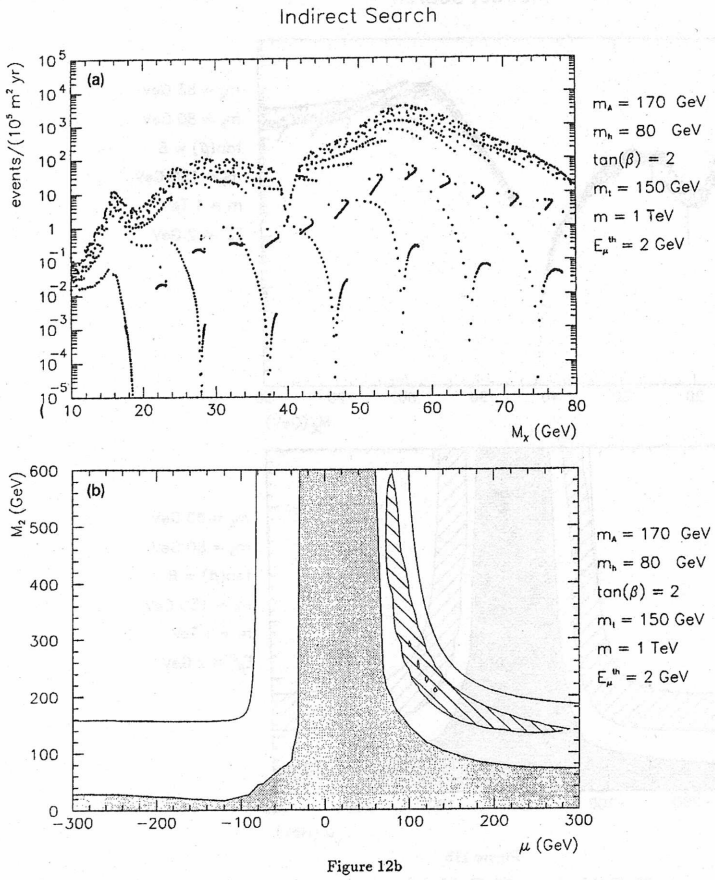

Figure 12b

Fig. 12. Same as in fig. 11 with $\tan\beta = 2$, $m_\chi = 80$ GeV, $m_A = 170$ GeV.

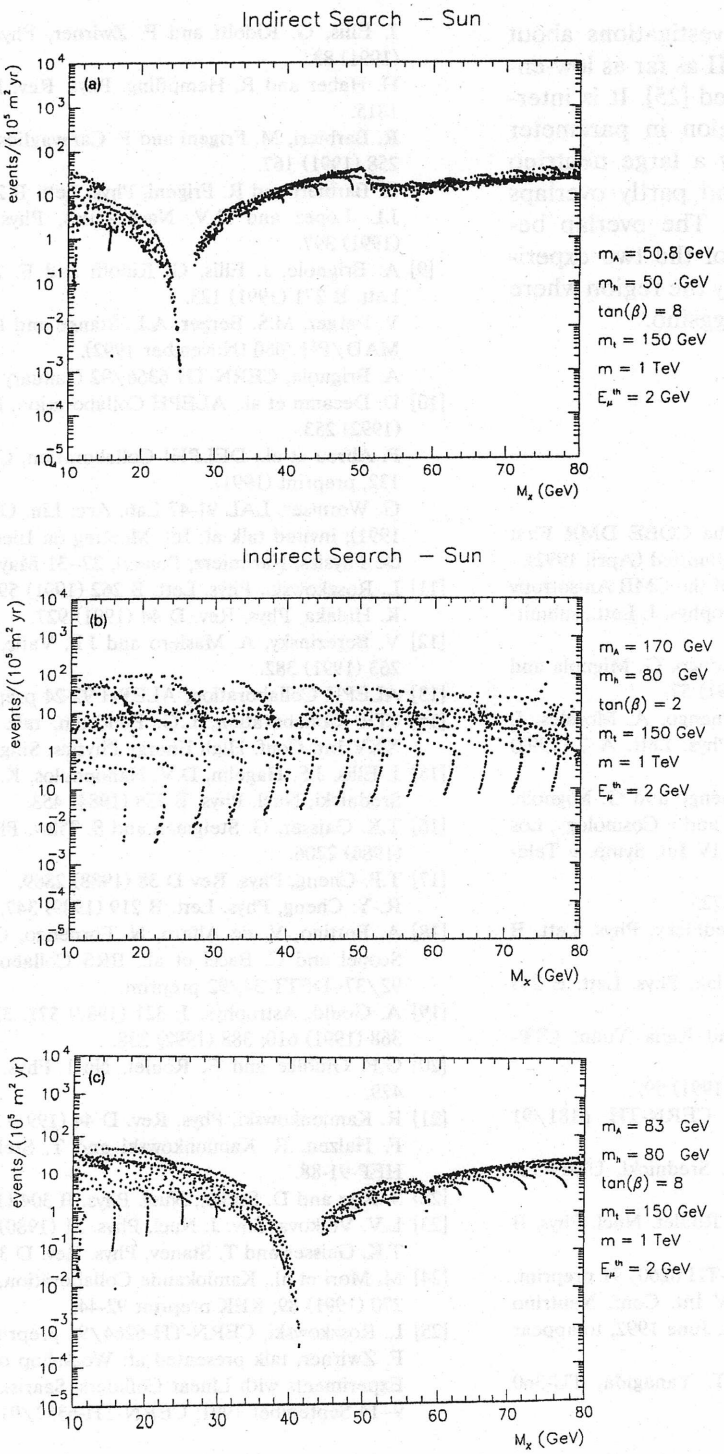

Fig. 13. Indirect detection of neutralinos ($\chi\chi$ annihilation in the Sun): rates of upgoing muons per year in a detector of area 10^5 m as a function of m_χ. Half aperture is taken 25°. ρ_χ is rescaled. The threshold for muons is 2 GeV. (a) tan $\beta = 8$, $m_h = 50$ Ge $m_A = 50.8$ GeV; (b) tan $\beta = 2$, $m_h = 80$ GeV, $m_A = 170$ GeV; (c) tan $\beta = 8$, $m_h = 80$ GeV, $m_A = 83$ GeV.

There have been recent investigations about the discovery potential at LEP II as far as low-energy supersymmetry is concerned [25]. It is interesting to remark that the region in parameter space that can be explored by a large neutrino telescope is complementary and partly overlaps the one accessible at LEP II. The overlap between the sensitivity domains of the two experimental searches concerns mainly the region where the neutralino is dominantly higgsino.

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