FLUX LIMITS FOR HIGH ENERGY COSMIC PHOTINOS FROM UNDERGROUND EXPERIMENTS

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ABSTRACT

Underground experiments, which detect the interactions of atmospheric neutrinos, could also be sensitive to photinos. Using data from the Fréjus and Kamiokande detectors we give upper limits on the possible flux of high-energy relativistic photinos incident on Earth, as functions of the squark or selectron masses. These limits improve considerably existing ones, by four to nine orders of magnitude or more, especially for very energetic photinos. Although not yet very constraining, they may be used to eliminate the possibility that high-energy cosmic photinos could contribute significantly to the energy density of the Universe.

Supersymmetric theories of particles predict that ordinary particles should be associated with new superpartners. The superpartner of the photon is a neutral spin -1/2 fermion, which cannot be identified with any of the known neutrinos, and has been named the photino [1].

Neutrinos have weak interactions with matter, resulting from the exchanges of heavy $W^{\pm}$ or Z bosons. In a somewhat similar way, photinos can have elastic or inelastic scatterings on nucleons and electrons, as an effect of the exchanges of heavy squarks and selectrons, simulating effective neutral current interactions. The values of the photino cross-sections depend crucially on the squark and selectron masses. For relativistic photinos these cross-sections are roughly similar to neutrino weak interaction cross-sections, if squarks and selectrons have masses of the order of 100 GeV/c^2 [1,2].

Underground experiments are now sensitive to "atmospheric neutrinos" resulting from the decays of pions and kaons produced by primary cosmic rays striking the atmosphere [3,4]. If there is also a flux of photinos arriving on Earth, these photinos would induce effective-neutral-current interactions in a detector, similar to neutrino interactions. The results of underground experiments may be used to derive upper limits on the flux of cosmic photinos, as functions of their energy, and of the squark or selectron masses. The present paper summarizes the results of an analysis published in Ref. [5].

Photinos can have elastic scatterings on electrons,

$$\tilde{\gamma}\, e \rightarrow \tilde{\gamma}\, e \tag{1}$$

induced by selectron exchanges, or, also, elastic or inelastic scatterings on nucleons, resulting from the processes

$$\tilde{\gamma}\ \overset{(-)}{q} \rightarrow \tilde{\gamma}\ \overset{(-)}{q}\ , \qquad \tilde{\gamma}\ \overset{(-)}{q} \rightarrow \tilde{g}\ \overset{(-)}{q}\ , \tag{2}$$

induced by squark exchanges. (The excitation of gluinos $\tilde{g}$ can occur only if they are sufficiently light, or, alternately, at very high energies, typically $\gtrsim m_{\tilde{g}}^2/m_{Nucleon}$; gluinos are then expected to decay, normally into $q\,\bar{q}\,\tilde{\gamma}$, giving back photinos in the final state.)

The high-energy scattering cross-section of relativistic photinos on electrons reads, in the local limit approximation [2,5]:

$$\sigma\,(\tilde{\gamma}\, e \rightarrow \tilde{\gamma}\, e) \simeq \frac{16\,\pi\,\alpha^2}{3\,m_{\tilde{e}}^4}\, m_e\, E_{\tilde{\gamma}}$$

$$\simeq 1.8\ 10^{-42}\ cm^2\ \frac{E_{\tilde{\gamma}}\ (GeV)}{(m_{\tilde{e}}/100\ GeV/c^2)^4} \tag{3}$$

Similarly, we have, for the scatterings of high-energy photinos on nucleons,

$$\sigma(\tilde{\gamma}\, N \rightarrow \tilde{\gamma}\, X) \simeq 1.7\, 10^{-40}\, cm^2 \, \frac{E_{\tilde{\gamma}}\ (GeV)}{(m_{\tilde{q}}/100\ GeV/c^2)^4} \qquad (4)$$

$$\sigma(\tilde{\gamma}\, N \rightarrow \tilde{g}\, X) \underset{\text{above threshold}}{\simeq} 1.2\, 10^{-38}\, cm^2 \, \frac{E_{\tilde{\gamma}}\ (GeV)}{(m_{\tilde{q}}/100\ GeV/c^2)^4} \qquad (5)$$

in which $\alpha_s \simeq .15$ has been used in the latter formula.

This leads to the following estimates for the "expected numbers" of photino scattering events, which depend on the squark mass $m_{\tilde{q}}$ (or selectron mass $m_{\tilde{e}}$) and photino flux $\phi_{\tilde{\gamma}}$:

$$N(\tilde{\gamma} + \text{nucleon} \rightarrow \tilde{\gamma} + X) \simeq 3.2\ \text{event/kt yr} \ \frac{E_{\tilde{\gamma}}(GeV)\ \phi_{\tilde{\gamma}}(cm^{-2}s^{-1})}{(m_{\tilde{q}}/100\ GeV/c^2)^4}\ K(y_0) \qquad (6)$$

$$N(\tilde{\gamma}\, e \rightarrow \tilde{\gamma}\, e) \simeq .016\ \text{event/kt yr iron}\ (\text{or } .019\ \text{event/kt yr water}) \ \frac{E_{\tilde{\gamma}}(GeV)\ \phi_{\tilde{\gamma}}(cm^{-2}\ s^{-1})}{(m_{\tilde{e}}/100\ GeV/c^2)^4}\ K(y_0) \qquad (7)$$

$K(y_0) \leqslant 1$, defined in Ref. [5], takes the effects of the energy cuts in the final state into account. From there we derive upper limits on cosmic photino fluxes. Since we ignore the shape of the incoming photino spectrum to be considered we assume it is monochromatic, for simplicity, and express limits on $\phi_{\tilde{\gamma}}$ as functions of the incoming photino energy, $E_{\tilde{\gamma}}$, and of $m_{\tilde{q}}$ or $m_{\tilde{e}}$.

The details of the analysis are given in ref. [5]. $\tilde{\gamma}$-nucleon scattering events have no visible charged lepton in the final state, and would therefore be classified experimentally as "Neutral Current" events. Upper limits on the possible numbers of $\tilde{\gamma}$-nucleon scattering events have been derived by comparing the numbers of events observed in the Fréjus experiment [4] with those expected from atmospheric neutrino interactions. The resulting upper limits on the photino flux $\phi_{\tilde{\gamma}}$ (limits which depend on both $m_{\tilde{q}}$ and the photino energy $E_{\tilde{\gamma}}$) are shown in Fig.1.

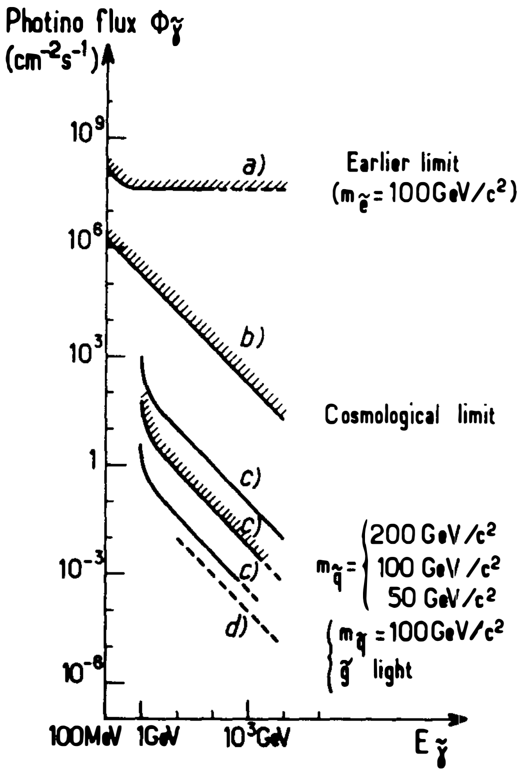

Fig. 1 : Upper limits on the flux $\phi_{\tilde{\gamma}}$ of relativistic photinos, as functions of their energy [5]. The limits c), derived from $\tilde{\gamma}$ + nucleon $\rightarrow$ $\tilde{\gamma}$ + X scatterings, correspond to various squark masses $m_{\tilde{q}}$ = 50, 100 or 200 GeV/c^2. A more constraining limit d) could be obtained if gluinos were sufficiently light to be excited by photino scatterings. Also shown are the approximate cosmological limit b) (for which high energy relativistic photinos would be responsible for the closure of the Universe), and the earlier limit a) derived from possible $\tilde{\gamma}$ e $\rightarrow$ $\tilde{\gamma}$ e scatterings.

$\tilde{\gamma}$ e $\rightarrow$ $\tilde{\gamma}$ e scattering events, on the other hand, have a single electron and no other particle visible in the final state, and would therefore be classified experimentally as (single track) "Charged Current" electron events (like ν_e nucleon $\rightarrow$ e^- + X events). Upper limits on the possible numbers of $\tilde{\gamma}$ electron scattering events - and, subsequently, on the photino flux $\phi_{\tilde{\gamma}}$ - have been derived from the results of the Kamiokande experiment [3] at lower energies ($E_{\tilde{\gamma}} \lesssim$ 1 GeV), and from those of the Fréjus experiment [4], at higher energies. The resulting upper limits on the photino flux are shown in Fig. 2.

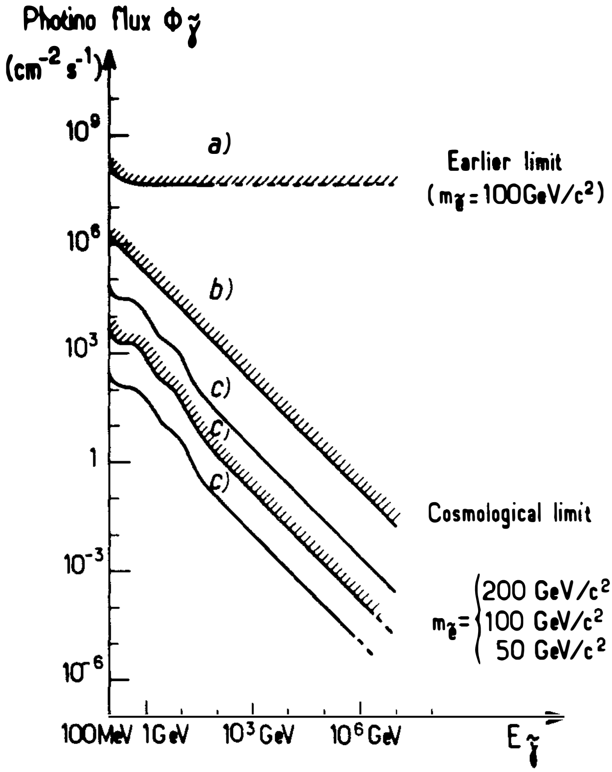

Fig. 2 : Upper limits on the flux $\phi_{\tilde{\gamma}}$ of relativistic photinos, derived from searches for $\tilde{\gamma}\, e \rightarrow \tilde{\gamma}\, e$ scattering events [5]. These limits c) are shown for various selectron masses $m_{\tilde{e}}$ = 50, 100 or 200 GeV/c^2. Also shown are the approximate cosmological upper limit b), and the earlier limit a) derived from the HPW experiment [6].

Above 1 GeV the limits derived from possible $\tilde{\gamma}$ e scatterings are in general less constraining than the limits derived from $\tilde{\gamma}$ nucleon scatterings, unless selectrons are relatively light compared with squarks, i.e. $m_{\tilde{e}} < (.3$ to $.5)\, m_{\tilde{q}}$. These limits, however, extend to lower photino energies, down to about 100 MeV.

The results obtained improve by four to nine orders of magnitude or more - depending on the photino energy $E_{\tilde{\gamma}}$ - an earlier limit established using preliminary results obtained with the HPW detector [6]. Despite this spectacular improvement, however, the flux limitswe have derived are not yet very constraining. Nevertheless they allow us to discuss the possibility that high energy cosmic photinos could contribute significantly to the energy density of the

Universe. (This may of course a priori appear unlikely, since the total energy density associated with ordinary cosmic rays is essentially negligible, especially for high energies.)

A very crude upper limit on the photino flux may be derived from cosmology, if this flux is assumed to be approximately homogeneous in the Universe. If this flux were very large, the photino contribution to the energy density could be too high. A homogeneous distribution of relativistic photinos of energy $E_{\tilde{\gamma}}$ would lead to $\Omega = \rho / \rho_{critical} \simeq 1$, if the photino flux were as large as

$$\phi_{\tilde{\gamma}}^{Cos.} \simeq \frac{1.8\ 10^5\ cm^{-2}\ s^{-1}}{E_{\tilde{\gamma}}\ (GeV)} \qquad (8)$$

The approximate flux limits corresponding to $\Omega = 1$ (i.e., relativistic photinos responsible for the Universe having the critical energy density, with a typical value of the reduced Hubble constant $h_0 \simeq .75$) are shown in Figs. 1, 2.

Under the assumptions made, the limits we derived from underground experiments imply that (at least for $m_{\tilde{e}}$ and $m_{\tilde{q}} \lesssim 100$ GeV/c^2, and photino energies between 100 MeV and 10^6 GeV) relativistic cosmic photinos can provide, at most, only a very small fraction of the critical energy density required to close the Universe. Although we expressed our flux limits in terms of the energy of monochromatic photinos, this conclusion does not depend on the actual shape of the photino energy spectrum, since photino cross-sections increase approximately linearly with the energy.

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