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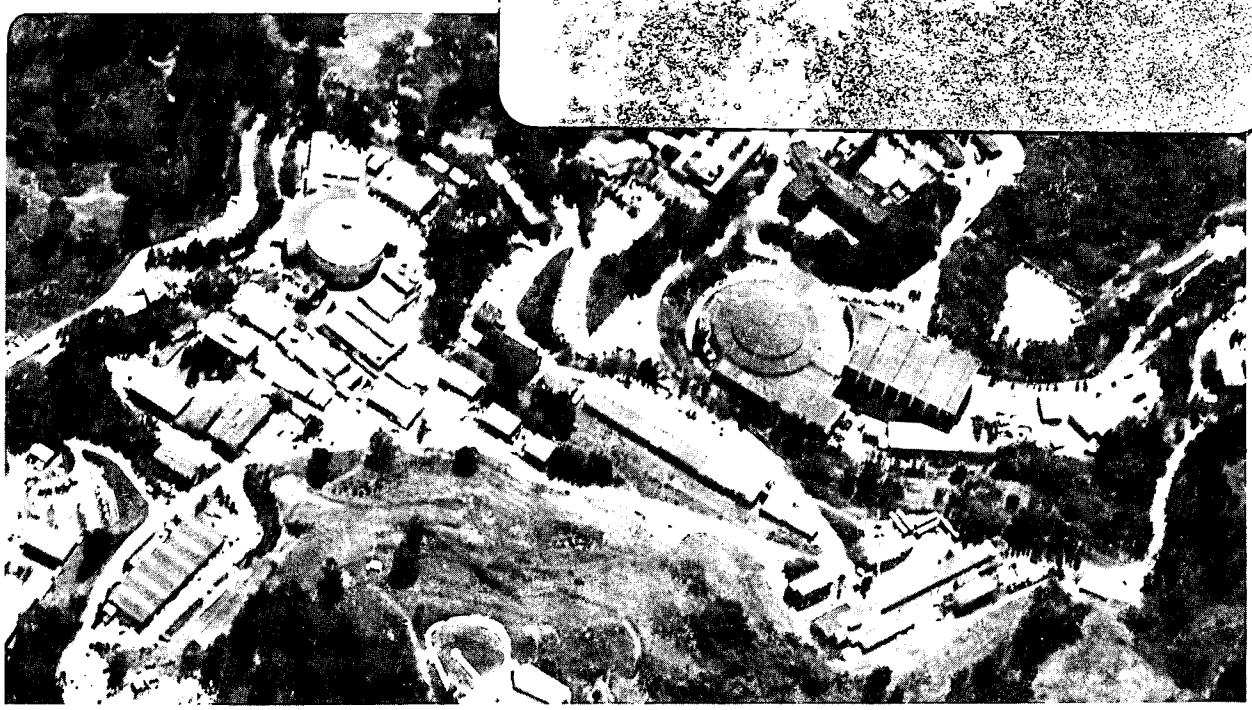

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ABSTRACT

We discuss the rates,signatures and backgrounds likely to be encountered by experiments attempting to detect dark matter particles by elastic scattering.

1. GENERAL CONCEPTUAL FRAMEWORK.

In the following, we will assume that dark matter indeed exists, nearly closes the universe ($\Omega \approx 1$) and is non baryonic [1]. The hypothesis we would like to test, is that it is made out of heavy particles that we will call δ, not to call them heavy neutrinos[2], photinos[3], higgsinos[4], scalar neutrinos[5], cosmions[6], WIMPS[7] etc...., which would limit the generality of our remarks.

Can we say anything about the interaction rates of the δ's (which are presumably concentrated in the halo of our galaxy) with an ordinary matter target? It is clear that this is possible in specific models [3],[4]. We claim [8] that a general argument can be constructed in the case where the δ's have been in thermodynamical equilibrium in the early universe, with quarks and leptons, presumably through the annihilation channel

$$\delta \ \bar{\delta} \rightarrow q\,\bar{q},\ e^+e^-, \nu\ \bar{\nu} \ldots.$$

This excludes the axion from our considerations. Combining the Lee-Weinberg argument [2] relating the present density and the annihilation rate at freeze out, with crossing, it is possible to conclude in a rather model independent way that

$$\sigma_{el}(\delta N \rightarrow \delta N) \geq 10^{-38} cm^2 / (\Omega_\delta h^2) \text{ for } m_\delta \geq 1 GeV/c^2,$$

where Ω_δ is the current ratio of the δ average density to the critical density, h is the Hubble constant in units of 100km/s/Mpc and N stands for p or n. It can be also shown that accelerator data bound the δ mass from below around a few GeV, (although another allowable region exists around 1 electron-volt, that we will not discuss here).

2. RATES.

Let us first remark that although fairly model independent, the above arguments contain loopholes and it is possible to have a zero elastic cross section at low energy, for instance in the case of pure p-wave scattering (e.g. for AV or VA couplings), or of no coupling to the up and down quarks. This is however unlikely and does not occur in existing models.

Let us secondly assume that there is no initial asymmetry getween the number of δ and $\bar{\delta}$. In that case, $10^{-38} cm^2 / (\Omega_\delta h^2)$ is not a lower limit but the approximate value of the cross section on p or n.

For heavier targets, we should take into accounts coherence effects[9]. For certain couplings, (axial vector as for the photinos) the additive quantum number is the spin and the coherence factor is $\lambda^2 S(S+1)$, which at most of order unity (it is zero for a spinless target). For favorable targets (e.g. Boron), the event rate would be of the order given [8] by Fig 1_a. We assumed $\Omega_\delta h^2 = 1/4$, a mean root square velocity of 300km/s and a halo density of 0.7 10^{-24} g/cm^3.Note that because σ_{el} is roughly constant, the rate goes down as $1/m_\delta$ if m_δ is comparable to the mass of the target.

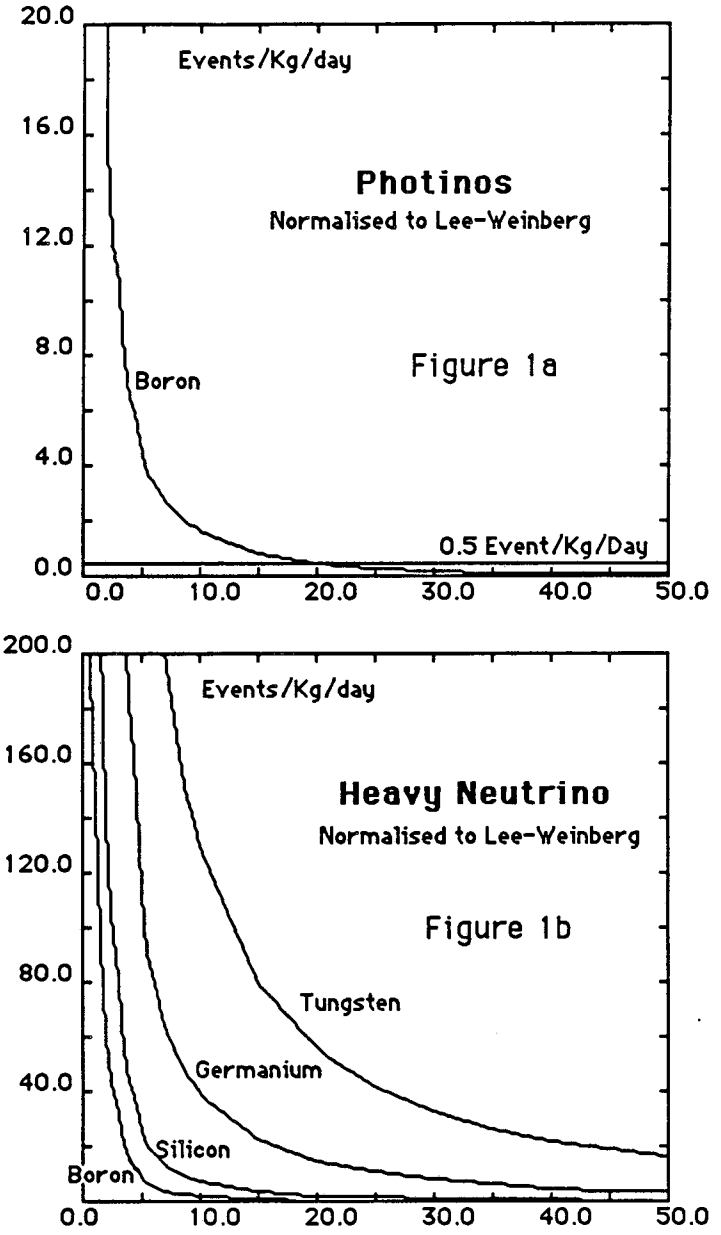

Figure 1: Interaction rates on various targets for two archetypes of dark matter models without initial asymmetry.

A third case, which is more favorable, is that of an additive quantum number proportional to A, or the number of protons or neutrons(as for heavy neutrinos). The rate is much bigger (Fig 1_b) but still decreasing as $1/m_\delta$.
As a last archetype of what could happen, we should consider an initial asymmetry between the number of δ and $\bar{\delta}$. The annihilation cross-section can be much bigger than the Lee-Weinberg limit. Fig 2 gives the example of a heavy neutrino coupling with the full Z^0 strength. The rates are much bigger and already double β experiments put limits on such models of dark matter[10].

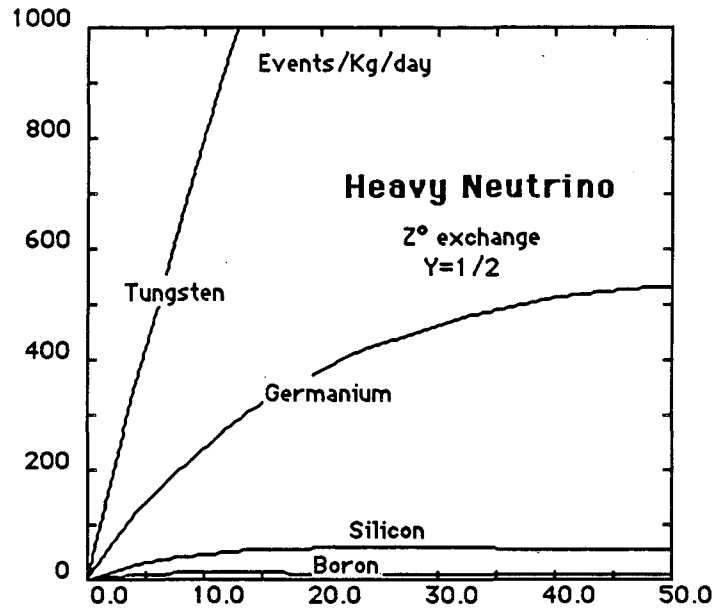

Figure 2: Interaction rates on various targets for an archetype of models with initial asymmetry between δ and δ.

Because the scattering occurs at low energy in the s-wave, the energy deposition spectrum is essentially independent of the considered model. In a scattering of a δ particle at an angle θ* in the center of mass

$$E_d = \frac{m_\delta^2 M v^2 (1-\cos\theta^*)}{(m_\delta + M)^2}$$

where M is the mass of the target nucleus. Assuming a Maxwell distribution of the δ in the halo, we get typically energy deposition distribution as that shown in Fig 3 (m_δ=5 GeV/c^2 incident on germanium). It is clear that in order to cover the full mass range

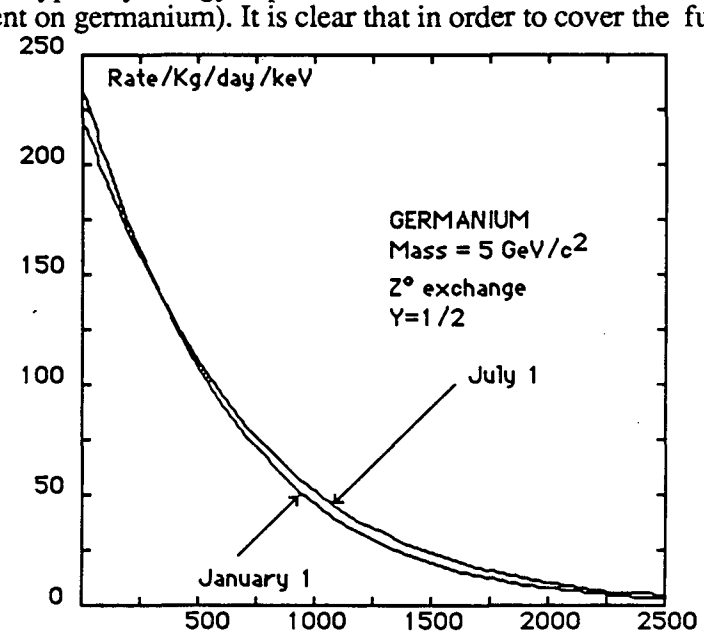

Figure 3: Example of energy deposition spectrum. The 2 curves refer to specific dates during the year.

not excluded by accelerators, threshold as low as 100 eV are needed. This is a strong motivation for the development of cryogenic detectors [11-13].

3. SIGNATURES.

Let us assume that a detector with such a low threshold indeed sees a potential signal at low energy. How could we be sure that it is due to dark matter particles from the halo of our galaxy?

The most convincing signature would be the annual modulation demonstrated in Fig 2. The halo has not collapsed significantly and is believed to have very small overall angular velocity. On the other hand, the sun goes around the galaxy and therefore through the halo at 200km/s and the earth is adding(substracting) half of its velocity to the sun velocity in the summer (winter). Both the mean energy deposition and the rate should vary by about ±7%. In order to observe such an effect at 5σ, we would need about 5000 events. Therefore large mass detectors ($\approx$ 10kg) would have to be built!

Other important signatures include the shape of the energy distribution, which is expected to be different from X ray lines or Compton scattering (which is flat). The dependence of the energy deposition on the material used as a target might allow a measurement of the mass of the δ. The use of a mix of materials, may then allow to exclude the possibility that the incident particle is a γ or a neutron from the surrounding.

Finally, all the quantities used to discriminate against the radioactive background (e.g. distance from edges, ratio of heat to ionisation etc....),should have the distributions expected for dark matter. In principle, it is always possible to increase the radioactivity in the detector by a large amount, in order to show that the low-energy peak is not due to a feed-down from high energy contamination.

4. BACKGROUNDS.

The main background is from the residual radioactivity in the detector elements and in tits surrounding.

4.1 The **state of the art** is encouraging. The double β decay experiments of LBL/UCSB[12] and PNL/USC[10] get background rates of the order of 0.5 to 1 event/kg/keV/day at 20 keV. The rise observed below are related to specific instrumental problems which can be cured, and both groups are currently attempting to decrease their thresholds . This effort will bring new experimental information within the next year.

4.2 This level of radioactivity is quite compatible with attempts to **predict *a priori* background**[13].

a) Cosmic rays can be vetoed. Their indirect effects, spalliation and neutron production by muon capture, are more annoying and may require working underground.

b) Internal radioactivity of the detectors are expected to be negligible if crystals as Ge, Si, and may be B are used. On the other hand, spallation products such as ^3H [14] may quite disturbing, and it may be necessary to displace this tritium by hydrogen.

c) The main source of background will presumably come from the surrounding (refrigerator, dewar, shield).α's and β's can be eliminated completely in a position sensitive detector by imposing a fiducial region. Fast neutron from U and Th decays or μ capture, are potentially dangerous but can be thermalised easily with 40cm of water. Slow neutrons which may create γ rays can be absorbed by a borated shield.

By far the most difficult background to deal with are the γ rays from lines, nγ reactions and β bremstrahlung. Their main detrimental effect is a <u>flat</u> Compton background, which may be quite difficult to decrease appreciably with an active veto, because of the

high energy of the parent γ. Typical computed levels [13] are compatible with the spectra observed by double β decay experiments.

4.3 **Scaling Laws.** If it is true that the observed background is flat in energy, experiments searching for dark matter particles, may run into signal to noise problems, if the interesting mass range is pushed up, for instance by new results of accelerators. If there is no initial asymmetry,the rate is proportional to

$$\frac{M}{(m_\delta + M)^2 m_\delta}$$

while the noise, if the background is flat, will be proportional to

$$\frac{m_\delta^2 \quad M}{(m_\delta + M)^2}$$

Thus, the signal to noise goes down exactly as $1/m_\delta^3$ and the statistical accuracy roughly as $1/m_\delta^2$ at large masses!

A solution would be of course to improve dramatically the background rejection, by combining measurement of the heat deposited and of ionisation. The dark matter elastic scattering will give a nucleus recoil depositing comparitively little energy in ionisation, while ordinary radioactive background (except the neutrons which are easy to slow down) will deposit a much larger fraction in ionisation[15]. This method which has been suggested several times but not yet shown to be feasible, is presumably the only hope to detect dark matter if it is very heavy.

5. CONCLUSION

As a conclusion, we could list the necessary characteristics of a reasonnably complete detector for dark matter search, geared at the small mass region (≤ 20 GeV/c^2):10 kg detector,threshold 100-200 eV; measurement of the energy spectrum; mix of many materials, some with nuclear spins; localisation; very low radioactive background.

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