

A Proposal on Cryogenic Detection of Neutrino Magnetic Moment at a Level Better Than $10^{-11} \mu_B$ (Bohr Magneton)

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A thermal detection of recoil electrons caused by (anti)neutrino scattering is considered in viewpoint of non-zero neutrino magnetic moment. A compact, low-background tritium-based antineutrino source providing a flux of $2 \cdot 10^{15} \text{cm}^{-2} \text{s}^{-1}$ is proposed. An upper limit of $2 \cdot 10^{-12} \mu_B$ is expected for germanium 1L volume calorimetric detector.

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1. INTRODUCTION

The possible existence of a neutrino magnetic moment μ is of stable interest for a long time. Up to now the most reliable proposal on experimental verification is a measurement of a μ -induced addition to a standard electroweak neutrino-electron scattering. An upper limit on μ obtained so far with a fission reactor antineutrino source is $2,4 \cdot 10^{-11} \mu_B$ [1], while a limit of $3 \cdot 10^{-12} \mu_B$ is derived from astrophysical data [2]. Therefore, a direct μ measurement at the latter level would be very desirable. Another strong motivation is that the moment of $10^{-11} \mu_B$ can explain solar neutrinos deficit [3]. As is seen from Fig.1, the total cross section for weak scattering rapidly drops to zero with the neutrino energy E decrease, following E^2 -dependence at $E \ll m_e c^2$, while for magnetic one it is nearly independent of E . Thus, the only way to make the magnetic scattering dominating, and hence, to improve the μ -limit considerably, is to lower the neutrino energy compared with the already performed measurements. This gives a decisive advantage to a β -decay neutrino sources over fission reactors or accelerators. Other advantages are also of great importance:

- i) a much higher antineutrino flux is possible;
- ii) absence of a correlated background, including inverse β -decay, for at least low-energy β -emitters;
- iii) small size, permitting underground operation and an easy flux modulation to subtract uncorrelated background;
- iv) the uncertainty of the neutrino energy spectra is small.

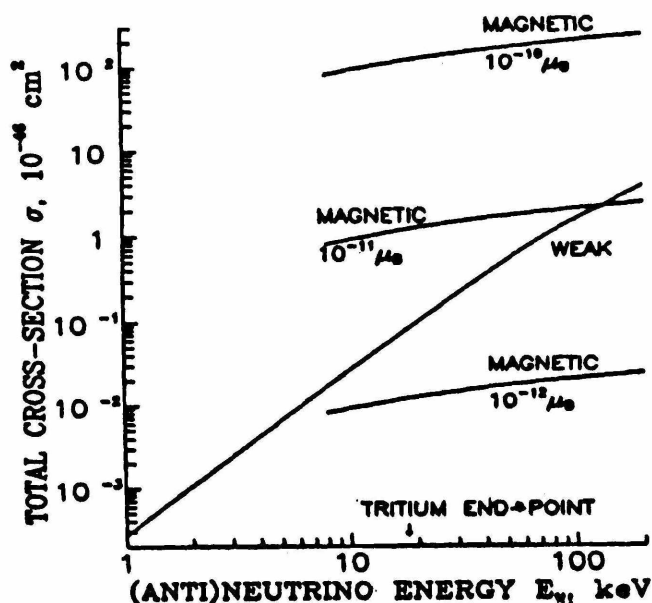


Fig.1 Cross section versus neutrino energy. Lower cut-off energy for magnetic scattering is taken to be 0.01 keV

Indeed, proposals on using of ^{90}Sr and ^{54}Mn high activity sources with Borexino detector at Gran-Sasso have been made recently [4]. For expected μ value at a level of $10^{-12} \mu_B$, however, and tacking into account other limitations, possible β -emitters are restricted to tritium, producing antineutrinos with maximum energy 18.6keV. The corresponding spectrum of recoil electrons is limited with 1.3keV, mainly beyond a threshold of conventional detectors. Cryogenic detection was proposed to bypass this problem [5], offering the second possible application of ultralow temperature calorimetry in nuclear physics [6], after $2\beta(0\nu)$ -decay [7].

2. TRITIUM SOURCE

Tritium may provide a compact source of high-intensity steril antineutrino flux. Both betas and bremsstrahlung can easily be avoided. This β -emitter is relatively available and inexpensive, and, what is most important, obeys reliable technologies for production, storage and maintenance, developed in atomic and nuclear weapon industries. It is well known, that tritium, chemically bounded with some transition metals, has an atomic concentration higher than in condensed phases. Antineutrino source in a form of spherical layer with the inner and outer diameters of 14 and 30 cm respectively, filled with tritium saturated titanium, yields the following parameters:

- active volume of 14 liters;
- netto mass of 56kg;
- tritium atomic concentration of $9 \cdot 10^{22} \text{ cm}^{-3}$;
- activity of 60MCi;

- thermal power of 7kW;
- antineutrino flux at the center of $1.3 \cdot 10^{15} \text{ cm}^{-2}\text{s}^{-1}$;
- flux at the inner wall of $1.7 \cdot 10^{15} \text{ cm}^{-2}\text{s}^{-1}$;

Therefore, within the existing technologies, the flux can be enlarged nearly two orders with respect to reactors. Total cross-sections for free ν -e scattering from tritium ν 's are presented in Fig.2, depending on lower cut-off energy of a detector. For magnetic scattering a moment of $2 \cdot 10^{-12} \mu_B$ is taken.

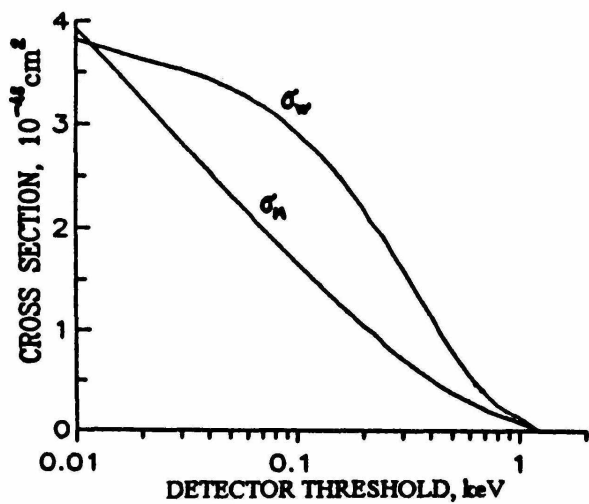


Fig.2 Free ν -e scattering cross-section for tritium ν 's with $\mu=2 \cdot 10^{-12} \mu_B$ versus detecting threshold

3.THERMAL DETECTOR

An expected magnetic and weak reduced spectra $g(T)=N(T)/N$ for free electrons scattering, are shown in Fig.3.

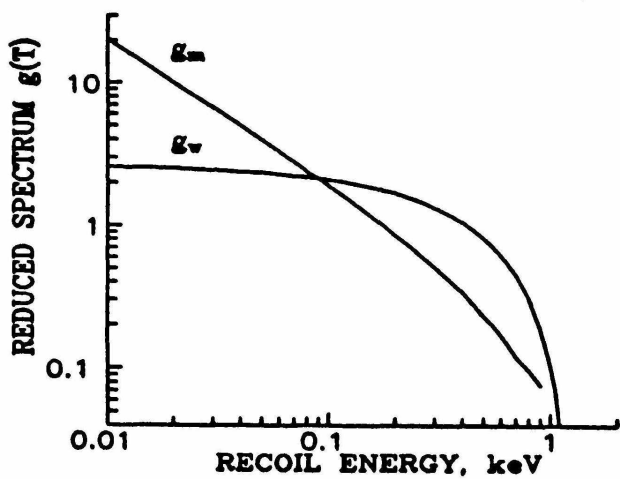


Fig.3 Free electrons recoil reduced spectra averaged over tritium ν 's

Evidently, the reduction of a detector threshold is of crucial importance. The estimations of a counting rate were made for a 1L-volume Ge cryogenic detector, placed at the center of the source. The respective ionization potentials for all electronic shells in Ge atom were taken into account. The resulting counting rate per day in the case of $\mu = 10^{-11} \mu_B$ and the flux $10^{15} \text{ cm}^{-2}\text{s}^{-1}$ is 0.42 (weak channel) and 9.4 (magnetic channel) with an average energy loss per event of 400 and 150eV respectively. The detector, operating at 10mK, with a resistance thermometer, offering a sensitivity $R^{-1} (dR/dT)$ of 10^3 K^{-1} [8], and a registration bandwidth 1kHz, is estimated to have a calorimetric energy threshold approximately 600eV, too high for a major part of the recoil spectrum. Hence a T^{-1} - dependence of the spectrum, which is the strong signature of magnetic scattering can not be resolved. This can be improved with replacing of Ge by Si and reducing of the volume with subsequent counting rate decrease. But the radical method to lower the threshold without loss in statistics, is to use the ionization-into-heat conversion effect [9], which allows to obtain few keV of heat release per one charge carrier, arising in cooled semiconductor under irradiation. An enhancement of thermal response of silicon detectors up to 300 times for ^{60}Co gammas, and 2000 times for visible light, have been demonstrated [10]. As can be seen from the above mentioned values, the recoil electrons have still enough energy to produce secondary ionization. Therefore, the threshold as low as few eV is expected in principle.

4.BACKGROUND

An operation in a low energy region is drastically complicated with a background increase. The problem is very similar to DM detection, complicated with the need to detect recoil electrons, not nuclei. Therefore, the single background Compton electrons can not be discriminated in principle, except some part rejected by coincidences. To overcome this additional difficulties, a specific $1/T$ shape of the magnetic recoil spectra and a modulation of the neutrino flux should be used for verification. Obviously, all the other methods to reduce the background, which are proposed and developed for DM observation, are also necessary to use in considered experiment.

5.CONCLUSIONS

The ν -e scattering remains the most reliable proposal for direct measurement of neutrino magnetic moment. To lower the upper limit on μ , neutrino energy should be decreased, followed by a cross-section drop, low recoil energy, background increase. Therefore, a combination of high-intensity neutrino source, low-threshold detector, and refined technique for background reduction, is strongly desired to battle these problems. From this point of view, β -emitters are much superior over fission reactors, which have been used

so far, while cryogenic detectors may provide eV-range threshold, much lower than conventional detectors. The existing progress in cryogenic detection and tritium technologies makes it possible to perform a full experiment on neutrino magnetic moment limitation at a level of $2 \cdot 10^{-12} \mu_B$ with calorimetric detector and modulated (anti)neutrino flux from tritium-based source.

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