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On Implementation of the SATURNE Project

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Abstract—We report on the current state of implementation of the Sarov tritium neutrino experiment at the National Center for Physics and Mathematics. The experiment will involve a high-intensity tritium neutrino source and three different detection systems sensitive to very low energy depositions. As an outcome, it is expected to observe for the first time coherent elastic neutrino-atom scattering and achieve a record-high sensitivity to the neutrino magnetic moment.

Keywords: SATURNE, neutrino magnetic moment, tritium, coherent elastic neutrino-atom scattering, liquid He-4 detector, Si crystal detector, CsI scintillation detector, SrI_2(Eu) scintillation detector, low-background neutrino laboratory

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1. INTRODUCTION

Electromagnetic properties of neutrinos and, in particular, the magnetic moments of neutrinos are one of the basic unsolved problems in neutrino physics. Figure 1 shows the historical progress of the experimentally achieved upper limits [1–12] on the neutrino magnetic moment μ_ν. The projected μ_ν sensitivity [13–15] of the Sarov tritium neutrino experiment (SATURNE [15–17]) is also presented. If the latter neutrino property is discovered, a window to new physics will be opened (for an overview, see [18]).

Currently, thanks to the Russian GEMMA experiment for detecting reactor antineutrinos at the Kalinin Nuclear Power Plant, an upper limit on the neutrino magnetic moment has been determined to equal to $2.9 \times 10^{-11}\mu_B$. This results for upper bounds on the neutrino magnetic moment are the best in the world for reactor antineutrinos and are included by the Particle Data Group Collaboration in the "Review of Elementary Particle Physics" [19].

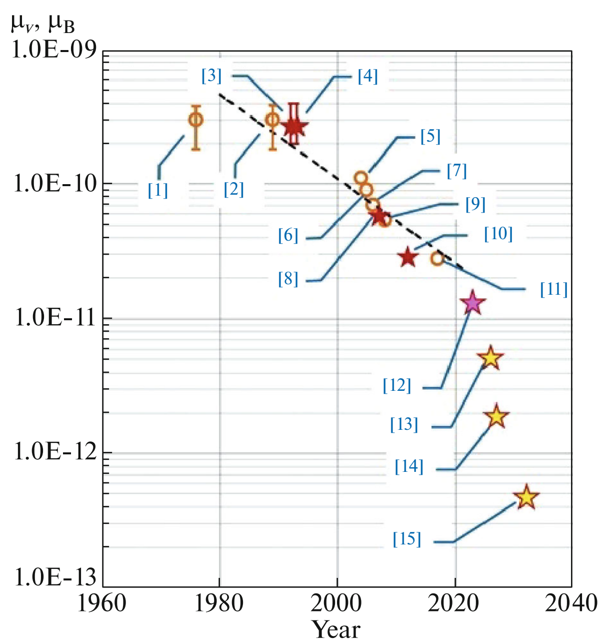

Fig. 1. Progress in measuring the laboratory limitation on the magnetic moment of neutrinos.

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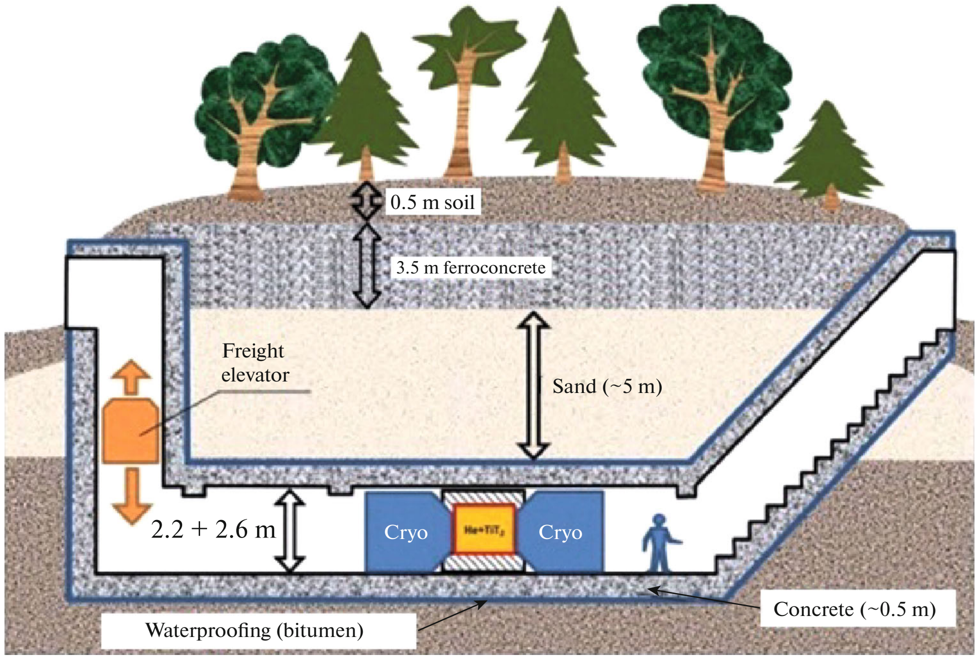

Fig. 2. Sectional drawing of the laboratory building.

It is worth highlighting the recently published results of the international collaboration XENON (USA) on the search for the effects of new physics when measuring the low-energy part of the spectrum of recoil electrons in the XENON1T detector [20]. One of the possible explanations of the experimental data obtained was the presence of a solar neutrino magnetic moment from 1.4×10^{-11} to $2.9 \times 10^{-11} \mu_B$.

Within the framework of the SATURNE project, it is proposed to prepare and implement a series of experiments to search for the magnetic moment of neutrinos using three types of detectors which have different registration thresholds for the energy deposited in the detector by the neutrino:

a) a low-temperature (from −60 to −40°C) scintillation (CsI(pure) or SrI_2(Eu), respectively) detector with a registration threshold of 100 eV [13];

b) a cryogenic (from 10 to 50 mK) silicon detector with internal gain [21] providing a registration threshold from 1 to 3 eV [14];

c) a cryogenic (from 40 to 60 mK) helium detector with a registration threshold of about 0.01 eV [15].

Among the proposed experiments, the most ambitious is the experiment described in the work [22]. In that paper, for the first time, a fundamentally new experimental scheme is put forward for observing coherent elastic neutrino—atom scattering (CEνAS) using a liquid helium target and electron antineutrinos from tritium decay. As a result of the analysis of the sensitivity of the proposed experimental setup to the possible magnetic moment of the electron neutrino, it is shown that it is possible to set an upper limit for the magnetic moment at the level of $(2-4) \times 10^{-13} \mu_B$ [15, 17], which is two orders of magnitude stronger than the constraints obtained in the GEMMA and Borexino experiments, and almost an order of magnitude better than the current world leading experimental limits obtained on the basis of astrophysical observations (see [19] and references therein).

2. TRITIUM NEUTRINO SOURCE

The basic design scheme of a tritium neutrino source (TNS) has been worked out in [23]. TNS is a set of tritium elements in which tritium is in a chemically bound state on titanium (Fig. 3).

Titanium powder in bulk is placed in the tritium element. Then the titanium powder is thermally activated and saturated with tritium, afterwards the tritium element is sealed.

In [23], the mass of tritium in the tubular tritium element is 50 g (0.5 MCi). For a specific detecting system, the geometry of the tritium element should be optimized by considering the following aspects: the efficiency of using the neutrino source, ensuring the convenience of production and operation of the tritium element, ensuring the safety of work with the

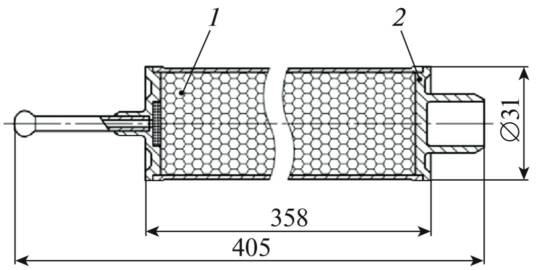

Fig. 3. Construction of a tubular tritium element. *1*— titanium tritide; *2* — body.

tritium element and the experimental installation as a whole.

3. LOW-BACKGROUND NEUTRINO LABORATORY

To conduct the experiment, it will be necessary to create a low-background neutrino laboratory (LBNL), which provides conditions for minimizing the contribution of the hard component of cosmic radiation, which will affect the background characteristics of the detecting system.

It is estimated that a 10 m depth underground or the presence of a powerful concrete floor with a thickness of about 4 m is sufficient. Figure 2 shows a cross-sectional diagram of the building available at VNIIEF. As can be seen from the presented scheme, there are 4 m of reinforced concrete above the LBNL working rooms, made before the "nuclear" era and in this respect pure in elements of the uranium series, 5 m of sand and more than 0.5 m of soil. Therefore, it is expected that the background conditions will be acceptable for the work.

4. CONCLUSIONS

The use of an intensive tritium source in combination with the aforementioned detection systems in the LBNL will drastically improve the world leading experimental limits on the neutrino magnetic moment. This will set a new benchmark in this field for years to come, and in the case of discovering the neutrino magnetic moment, it will open a direct portal to new physics beyond the Standard Model.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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