Conference Paper

Project of NNbar experiment at the WWR-M reactor

A K Fomin, A P Serebrov, O M Zherebtsov, M E Chaikovskii, A N Murashkin, E N Leonova, O P Fedorova, V G Ivochkin, V A Lyamkin, D V Prudnikov, and A V Chechkin

Petersburg Nuclear Physics Institute NRC KI, Gatchina, Leningrad region, 188300, Russia

Corresponding Author:
A K Fomin
fomin_ak@pnpi.nrcki.ru

Received: 25 December 2017
Accepted: 2 February 2018
Published: 9 April 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICPPA Conference Committee.

Abstract

Supersource of ultracold neutrons on the basis of superfluid helium is under construction in PNPI NRC KI. It must provide UCN density 2-3 orders of magnitude higher than existing sources. For the new source we propose an experiment on search for neutron–antineutron oscillations based on the storage of ultracold neutrons in a material trap. The sensitivity of the experiment mostly depends on the trap size and the amount of UCN in it. The results of simulations of the designed experimental scheme show that the sensitivity can be increased by ∼ 10–40 times compared to sensitivity of previous experiment depending on the model of neutron reflection from walls.

1. Introduction

We plan the experiment of searching for oscillation of free neutron into antineutron using the ultracold neutrons (UCN) stored in a material trap. $n-\bar{n}$ oscillation is a hypothetical process in which free neutron transforms into antineutron. Neutrons and antineutrons are electrically neutral particles, therefore only conservation of baryon number forbids the $n-\bar{n}$ oscillation. According to A. Sakharov, baryon number violation is one of the conditions, which needed to explain observed matter-antimatter or baryon number asymmetry of the Universe [1]. Hence the search for processes violating the baryon number is very important for researches of the origin of matter in the Universe.

Previously proton decay was in focus of both theoretical and experimental search for baryon nonconservation process. The discovery of neutrino oscillations renewed interest in search for $n-\bar{n}$oscillations. The seesaw mechanism is the widely spread idea to explain the smallness of neutrino mass and it requires the B-L symmetry to be broken. Dominant proton decay modes of interest respects B-L symmetry, while $n-\bar{n}$ oscillations breaks the B-L by two units. For more detailed review of theoretical and experimental status of search for $n-\bar{n}$ oscillations see [2, 3].

How to cite this article: A K Fomin, A P Serebrov, O M Zherebtsov, M E Chaikovskii, A N Murashkin, E N Leonova, O P Fedorova, V G Ivochkin, V A Lyamkin, D V Prudnikov, and A V Chechkin, (2018), "Project of NNbar experiment at the WWR-M reactor" in *The 3rd International Conference on Particle Physics and Astrophysics*, KnE Energy & Physics, pages 109–114. DOI 10.18502/ken.v3i1.1731

Experiment on search for neutron-antineutron oscillations was realized in beam experiment at Institute Laue-Langevin (ILL) [4]. In this experiment current limit on period of neutron-antineutron oscillations of 8.6·10^7 s was obtained. Sensitivity of experiment depends on so called discovery potential $N\,t^2$, where N is number of neutrons reaching the target per second and t is time of neutron flight to the target. Discovery potential of ILL experiment was 1.5·10^9 n s.

In the case of experiment with UCN stored in a material trap the walls of UCN trap play the role of annihilation target. The sensitivity of experiment with UCN mostly depends on the trap size and number of UCN in it. Increase in sensitivity is possible only with creation of a powerful source of ultracold neutrons.

2. UCN source at the WWR-M reactor

On the basis of the research WWR-M reactor at PNPI there is being built a highly intensive source of ultracold neutrons [5]. Ultracold neutrons are “produced” in superfluid helium from cold neutrons with a wavelength of 9 Å or with energy of 12 K, which is just equal to the phonon energy; i.e., a cold neutron excites a phonon and this neutron almost stops, becoming ultracold. The cold neutrons penetrate through the wall of the source chamber, while the UCNs are reflected; therefore, the effect of UCN accumulation up to the density determined by the time of storage in the chamber with helium is feasible. The ultracold neutrons move through the neutron guide to the experimental setups. The source will allow us to obtain UCN density of 10^4 cm^{-3} [6, 7], which approximately 2-3 orders of magnitude exceeds the available density of ultracold neutron at existing UCN sources. UCN production by the source will be about 10^8 n/s. The full-scale source model, including all required cryogenic and vacuum equipment, the cryostat, and the ultracold neutron source model has been created and successfully tested [8]. Experimental program is developed. Complex of installations of UCN source at the WWR-M reactor is shown in figure 1.

3. Sensitivity of experiment

In our works [9-11] we estimated possible sensitivity of experiment on search for $n-\bar{n}$ oscillations at the new UCN source. According to available area we accepted UCN trap in form of horizontal cylinder with diameter of 2 m and length of 4 m. The calculations show that the sensitivity can be increased by ~ 10–40 times compared to sensitivity of ILL experiment depending on the model of neutron reflection from walls. We used two models of neutron reflection from trap walls: with partial accumulation of the

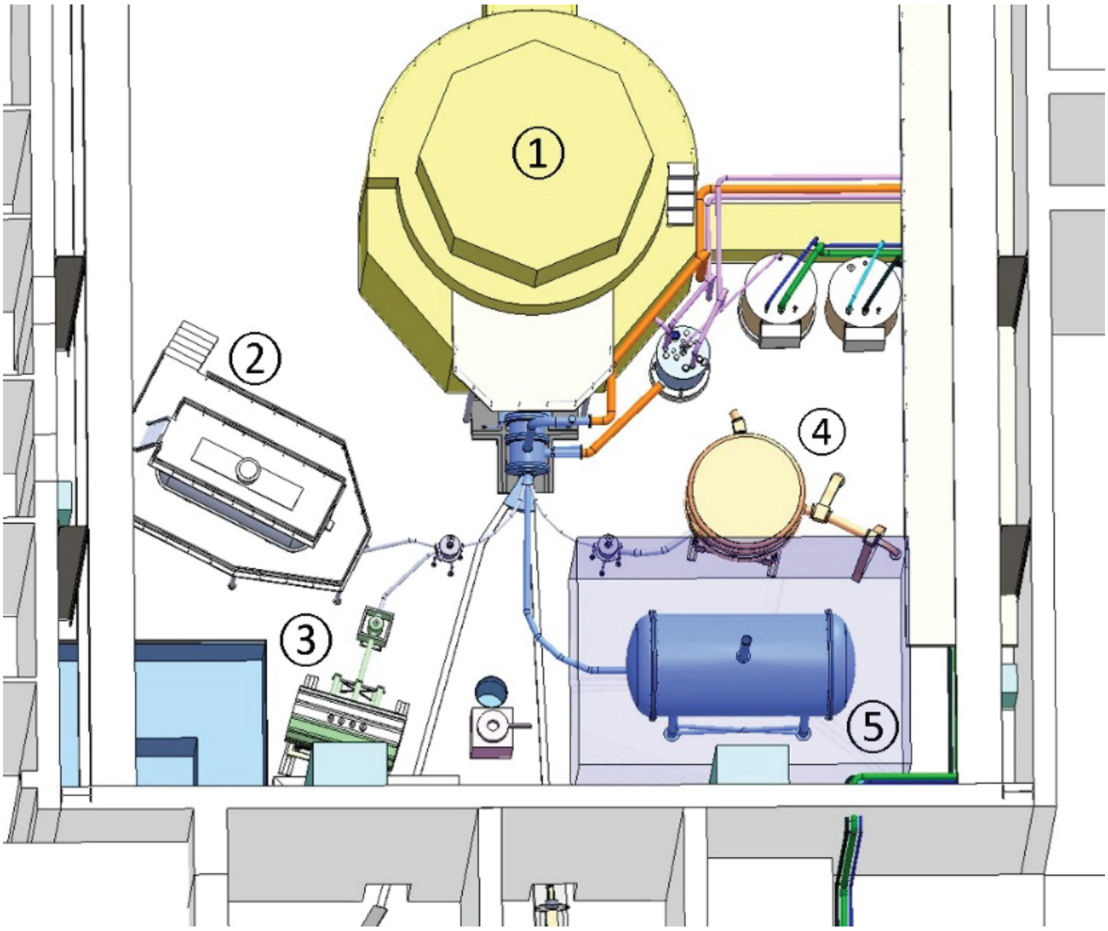

Figure 1: Complex of experimental installations of UCN source at the WWR-M reactor: 1 - WWR-M reactor, 2 - gravitational trap for measurement of neutron lifetime, 3 – experiment on search for mirror dark matter, 4 – spectrometer for measurement of neutron electric dipole moment, 5 - setup for neutron-antineutron oscillations search.

antineutron phase and without it. Real parts of the reflection potential are close or coinciding for the first case. For the second case - real part of the reflection potential for antineutron is close to zero. In the first case, one expects antineutrons to reflect from walls and the antineutron phase to be accumulated in contrast to the second case, in which no such accumulation can take place because the antineutrons immediately annihilate upon entering the matter. However, the coefficient of antineutron reflection in the first case cannot be sufficiently high because of a large imaginary part of the reflection potential for antineutron due to a large annihilation cross section. Dependence of sensitivity on length of UCN trap is shown in Figure 2.

4. Detector efficiency

If a neutron in the trap oscillate to an antineutron then the antineutron will annihilate into the interaction with trap wall and create a multi-pion signal with total energy of

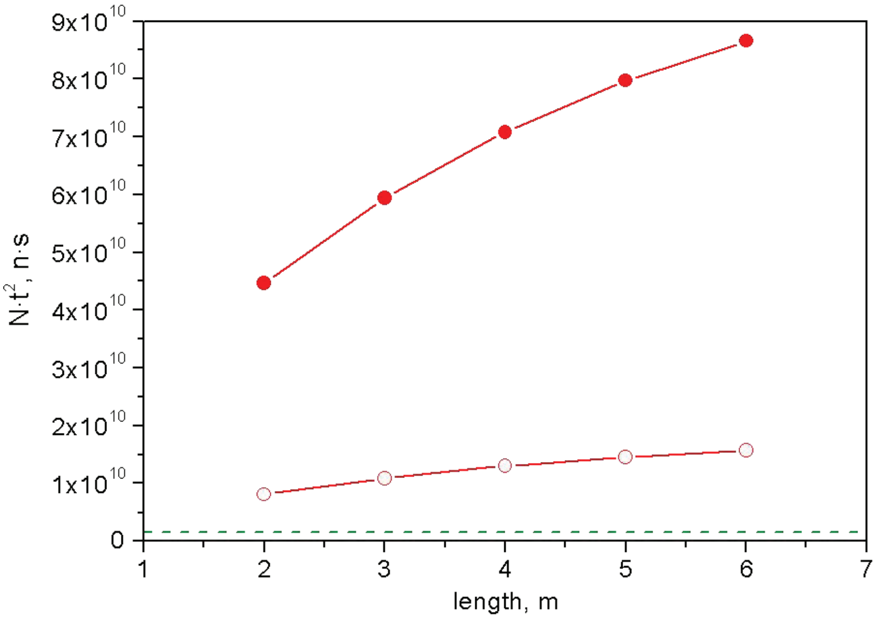

Figure 2: Sensitivity of experiment depending on length of UCN trap. Filled signs correspond to the case with partial accumulation of the antineutron phase. Empty signs correspond to the case without accumulation of the antineutron phase. Dashed horizontal line corresponds to sensitivity of the ILL experiment.

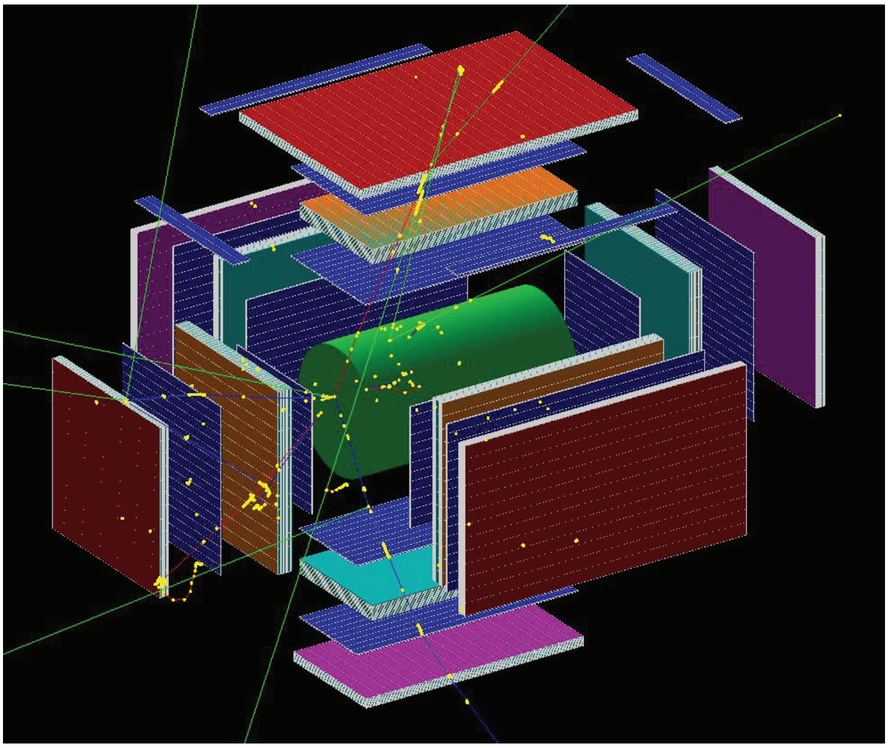

Figure 3: GEANT4 model of the experiment. The ranges between the parts are increased for better illustration.

about 2 GeV [12-14]. This fact determines the way to search for the oscillation process. One need a detector system which can observe simultaneous production of several neutral and charged pions, can be used to reconstruct tracks of the particles and the total energy of the interaction.

The event of neutron-antineutron oscillation is considered very rare, hence the detector system has to be very effective to observing the results of the annihilation. On the other hand, the background has to be suppressed by trigger system. To calculate the efficiency of the detector we are performing the Monte-Carlo simulation using GEANT4 toolkit.

In our experiment all the neutrons are stored in the trap and hence are localized within a few cubic meters volume. That means we can surround the trap by detector system providing almost 4π covering of the trap. In comparison, in beam experiments the covered solid angle is limited by the direction of initial beam and the beam dump [4]. This fact leads to significant advantage in detector efficiency of trap measurements.

The efficiency of the detector is a product of trigger efficiency and event reconstruction efficiency. The trigger criteria has to be good enough to exclude most background events, but also to keep as many useful events as possible. Only the signals, which meets the trigger criteria, would be recorded. The signals, which passed the trigger system are processed by energy and track reconstruction program. This program aims to reconstruct the initial energy of the event, particle tracks and initial event point. If the reconstructed properties of the event fit the annihilation hypothesis than the event can be considered as counted. The ratio of counted events to all simulated events forms the detector efficiency.

In Figure 3 the illustration of GEANT4 model of the detector and charged particles tracks specific to annihilation process are presented. The ranges between the parts are increased for better illustration. The green cylinder in the center is a magnetic screen and there is no sensitive parts under this screen so all particles have to pass the screen to reach the sensitive parts. UCN storage trap should has shielding from the Earth's magnetic field because it suppresses amplitude of $n-\bar{n}$ oscillations. We plan to have a two layer passive shielding from mu-metal and external active compensation coils. Thickness of mu-metal plates is 1.5 mm. Distance between layers is 100 mm. Blue plates are plastic scintillator blocks of the hodoscope system. The hodoscope system consists of inner and outer row of blocks at each side and aims to measure the time of flight for the particles. Between the hodoscope blocks is the tracker. The tracker has 10 sensitive layers bound by aluminum honeycomb fastening system. The farthest from the trap part is the calorimeter. It consists of the sensitive layers separated by aluminum and lead layers. Calorimeter measures the energies of the particles produced in annihilation event. Another goal of MC simulation is to calibrate the calorimeter.

Acknowledgments

This work was supported by the Russian Foundation for Basic Research, grant no. 16-02-00778-a.

References

[1] Sakharov A D 1967 *JETP Lett.* **5** 24

[2] Phillips II D G, Snow W M, Babu K *et al.* 2016 *Physics Reports* **612** 1

[3] Mohapatra R N 2009 *J. Phys. G: Nucl. Part. Phys.* **36** 104006

[4] Baldo-Ceolin M, Benetti P, Bitter T *et al.* 1994 *Z. Phys. C* **63** 409

[5] Serebrov A P 2011 *Crystallogr. Rep.* **56** 1230

[6] Serebrov A P, Fomin A K 2015 *Tech. Phys.* **85** 136

[7] Onegin M S, Serebrov A P, Fomin A K *et al.* 2017 *Tech. Phys.* **62** 633

[8] Serebrov A P, Lyamkin V A, Prudnikov D V *et al.* 2017 *Tech. Phys.* **62** 329

[9] Serebrov A P, Fomin A K, Kamyshkov Yu A 2016 *Tech. Phys. Lett.* **42** 99

[10] Fomin A K, Serebrov A P, Zherebtsov O M *et al.* 2017 *J. Phys.: Conf. Ser.* **798** 012115

[11] Fomin A 2017 *PoS* (INPC2016) 189

[12] Armenteros R and French B 1969 *Antinucleon-Nucleon Interactions, High Energy Phisics* vol 4 (New York: Academic) p 237

[13] Pavlopoulos P *et al.* 1978 *AIP Conf. Proc.* **41** 340

[14] Backenstoss A et al. 1983 *Nucl. Phys. B* **228** 424