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Investigation of coherent neutrino scattering at the Spallation Neutron Source

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Abstract

We propose to observe and to study neutrino coherent scattering reaction at Spallation Neutron Source accelerator facility of the Oak Ridge National Laboratory (U.S.A.) using two-phase liquid xenon emission detector. We present expected detector rates for different experimental conditions.

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*Keywords:*coherent scattering, neutrino; two-phase emission detector; liquid xenon, scintillation; electroluminescence

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1. Introduction

Coherent neutrino elastic scattering off nuclei is predicted and well described by the Standard Model (SM), but never been observed. The reaction is important for understanding processes in supernovae. The reaction study can provide the sensitive SM tests and search of nonstandard neutrino interaction.

2. Neutrino coherent scattering

The process of neutrino coherent elastic interaction with atomic nuclei attracted attention long time ago [1]. The differential cross section can be presented in zero spin approximation and for energy below ~50 MeV as:

$$\frac{d\sigma}{dE_r} = \frac{G_F^2}{4\pi} Q_W^2 M \left(1 - \frac{ME_r}{2E_\nu^2}\right) F^2(Q^2) \qquad (1)$$

where G_F is the Fermi constant, $F(Q^2)$ is the form factor at four-momentum Q and $Q_W = N - (1 - 4\sin^2(\theta_W))Z$ is the weak charge for a nucleus with N neutrons and Z protons, θ_W is the weak mixing angle.

The total cross section has the largest for neutrino reactions value due to coherent enhancement factor ~N^2 for heavy enough nuclei and can be parameterized as:

$$\sigma \approx 0.4 \cdot 10^{-44} N^2 (E_\nu)^2 cm^2 \qquad (2)$$

The reaction has never been observed because of the very low energy (up to several tenth of keV) of recoil nuclei.

3. Detector RED100

We propose to use two-phase emission detector for neutrino scattering event. The emission method of particle detection was invented about 40 years ago [2]. Particles interact with the condensed target medium, exciting and ionizing atoms, generating prompt signal in form of scintillation. Ionization electrons drift to the free liquid surface under influence of electric field. In the gas phase drifting electrons generate electroluminescent signal (secondary scintillation). An array of photomultipliers is used to detect both scintillation signals. The two-dimensional distribution of detected scintillation photons can be used to determine the coordinates of the original events in plane. Since the secondary scintillation is delayed from the primary one by the electron drift time, the third coordinate of the interaction can be reconstructed from the delay time analyses.

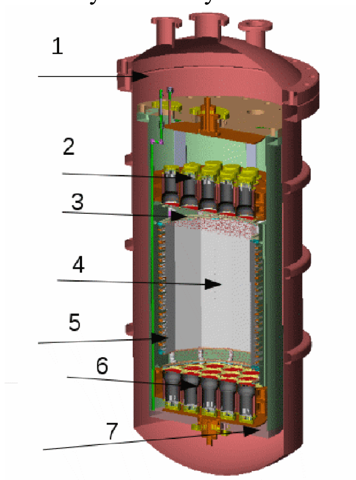

Fig. 1. RED100. 1-titanium warm vessel; 2- top PMT array; 3-Xenon gas gap; 4- liquid Xenon; 5-teflon reflector;6-bottom PMT array; 7-titanium cold vessel.

RED100 (Russian Emission Detector) is under commissioning now. The design of the detector is presented at Fig. 1. A cryostat of the detector is made of low radioactivity titanium. The target volume of 400 mm diameter is filled with liquid Xenon and is viewed by two arrays of nineteen 3”-diameter photomultipliers of Hamamatsu R11410-20. The distance between the PMT arrays is 750 mm. The internal vessel of the cryostat is cooled down and kept at the constant temperature using the thermosyphon technology. The total mass of liquid Xenon is 200 kg. The data will be taken from the central fiducial volume of 100 kg mass.

4. Spallation Neutron Source

We consider Spallation Neutron Source (SNS) accelerator facility of the Oak Ridge National Laboratory in U.S.A. as the most promising intensive pulsed source of neutrino. At Spallation Neutron Source neutrinos are produced as a result of decays of pions and muons after interaction of protons with a massive-nucleus target. The SNS is a 1MW 1 GeV proton accelerator producing neutrons by spallation in a bulk mercury target. Every proton interacting with the target also gives 0.098 π^+ and 0.061 μ^+ in average. The negative pions are quickly stopped and captured by atomic nuclei with little chance to decay. On the contrary, the stopped π^+ and μ^+ decay at rest and create three neutrino species - muon neutrino and anti-neutrino, electron neutrino. The proton beam at the SNS hits the target with 600-ns bunches at 60 Hz frequency. Due to the short beam spill the neutrinos at SNS have specific time distributions: muon neutrinos from the pion decays are produced during a beam spill but muon anti-neutrinos and electron neutrinos have time distribution with a muon life time of 2.2 μs that provides unambiguous signature of neutrino scattering signals [3].

5. Detection of coherent neutrino scattering

The RED100 response to neutrino scattering and background events was simulated in computational model based on Geant4 [4], [5], with aim of package NEST [6], describing interaction of charged particles in noble gases based detectors.

The signature of useful event is pair of primary scintillating signal and electroluminescent signal. Not all of coherent scattering events produce primary scintillation signal, but to completely realize the benefits of SNS neutrinos time structure only double events should be taken into account, providing possibility to get precise time correlation with pulsed beam.

The result of the detector RED100 response simulation, corresponding to such double signals is presented at the Fig. 2. The distance from the SNS target corresponds to 30 m.

The time structure of the SNS beam gives the opportunity to select neutrino scattering events corresponding to delayed portion of neutrino flux only, originating from μ^+ decay. Sorting out events arriving 1 μs after beam pulse reduces available neutrino flux by factor 0.78. The result of the detector RED100 response simulation, corresponding to such delayed signals is presented at the Fig. 3.

The detailed treatment of background sources was performed. The list consists of:

- natural radioactivity from detector components, including PMT
- natural radioactivity from surrounding construction materials
- cosmic muons
- neutrons, induced by cosmic muon interaction with surrounding construction materials

The time structure of the SNS beam will greatly reduce background rates since all neutrinos will arrive within several microseconds after the beam pulses [3]. As a result, all background events will be suppressed by a factor ~1000-2000 by ignoring events too late after a beam pulse.

The most dangerous background source is the beam-induced high energy neutrons flux, but it can be suppressed by appropriate siting and shielding. The measurements with 1 μs time cut will reduce much this background source too, because emission of such neutrons occur within this time window mainly.

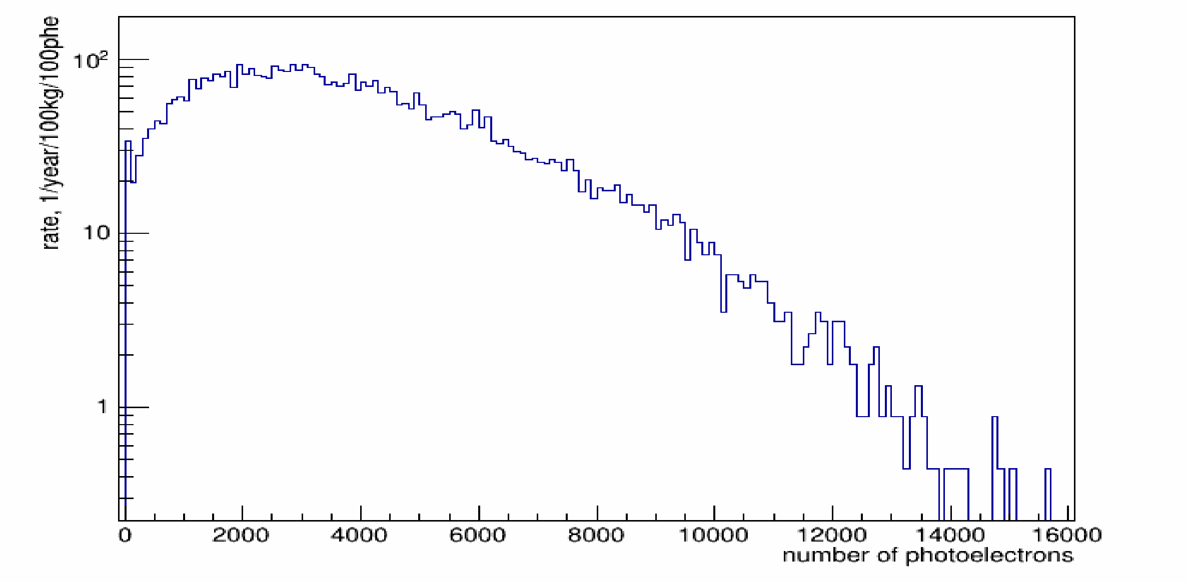

Fig. 2. Simulated counting rate in RED100 detector at 30 m from SNS target.

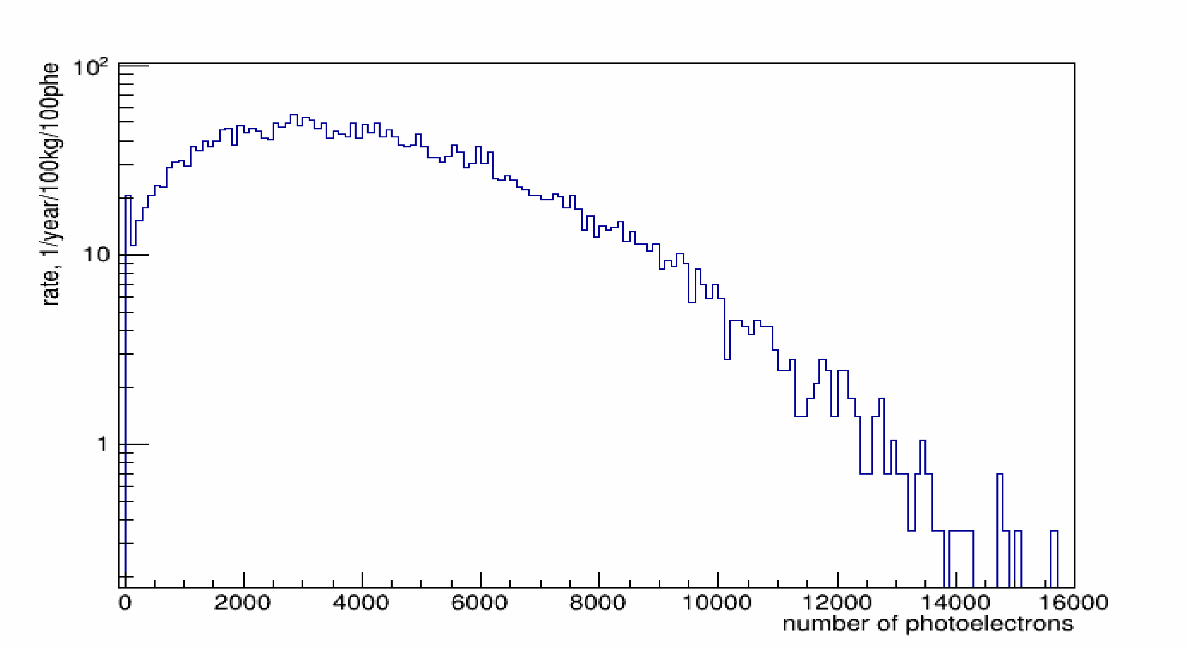

Fig. 3. Simulated counting rate in RED100 detector at 30 m from SNS target with 1 μs time cut.

6. Conclusion

We investigated the possibility to detect and to study the reaction of neutrino coherent scattering on nuclei in neutrino flux, emitting by Spallation Neutron Source of the Oak Ridge National Laboratory in U.S.A. The evaluated experimental conditions promise good opportunity to register this reaction.

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