Gaseous Detector of Ionizing Eradiation in Search for Coherent Neutrino-Nucleus Scattering

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Abstract

We propose to search for coherent neutrino-nucleus scattering (CNNS) by means of a triple-sectioned low background proportional counter. As a working medium we plan to use argon and xenon at about 1 MPa. We have shown using bench-scale assembly, that pulse-shape discrimination enables to effectively suppress noise pulses from electromagnetic disturbances and microphonic effect in the energy region where one expects signal from CNNS (from 20 eV to 100 eV) with a factor of about $10^3$. The calculation has been done of the background from neutrons, generated by muons of cosmic rays. The experimental setup has been proposed.

At small recoil energies when neutrino does not “see” nucleons constituting a nucleus but rather scatters as a wave on a grid, the neutrino-nucleus elastic scattering by means of exchange of $Z_0$-bozon is coherent over the nucleons in the nucleus. Due to the coherence the cross section is proportional to the square of the number of neutrons in a given nucleus (the contribution of protons is given in the expression for the cross section with the weight of approximately 0.08) and it can reach so big value that even for a mass of a target of about 1 kg and a flux of antineutrinos from a reactor of $2 \cdot 10^{13} \text{nu/cm}^2/\text{s}$ the count rate may reach the value of several events per day. This process has been described in 1970th of last century [1, 2], has been often discussed later on [3–7] but has never been observed because of extremely small (less than 600 eV for reactor antineutrinos) kinetic energy of the recoiling nucleus and only small portion of this energy (about 15%) is transferred into the one of ionizing eradiation. The discovery of this process would be the great
achievement of the modern physics and this explains the current interest of experimentalists to this task. By choosing the gaseous proportional counter as a detector of CNNS the emphasis is done on the following advantages of this technique:

1. Very high factor of the gas amplification ($>10^4$).

2. Possibility to use gas at relatively high pressure about 1 MPa to obtain the mass sufficient for count rate of about 1 events per day.

3. Good signature of the events by a pulse shape (very characteristic front and tail of the pulses).

4. The possibility to discriminate noise from electromagnetic disturbances and microphonic effect.

5. Availability of the efficient methods of gas purification.

6. Detector can be fabricated only from very pure materials without PMTs as a possible source of ionizing eradication etc.

7. The possibility easily change the working gas (argon – xenon) not changing the configuration, what is important to perform the comparative measurements at the same site.

We performed the measurements of the energy spectra of the pulses in argon using a small bench scale assembly. The calibration has been done using $^{55}Fe$ as a source of X-ray eradiation of 5.9 keV. Proportional counter had 37 mm, the central wire of 20 mm in diameter and it was filled by argon and methane (10%) mixture by 100 and 300 kPa. The shapes of the pulses from output of charge sensitive preamplifier of the sensitivity of about 0.4 V/pC have been recorded by 8-bit digitizer. The shapes recorded during certain time were analysed in off-line. The aim was to see how efficient could be the pulse shape discrimination of the noise pulses from electromagnetic disturbances and microphonic effect in the region below 100 eV, i.e. where the main effect is expected from CNNS of reactor antineutrinos. In Fig.1 we show the pulses observed during time interval 400$\mu$s where one can see “true” pulse with correct signature from ionization process and “wrong” pulse from electromagnetic disturbances.
Figure 1: The pulses on the output of charge sensitive preamplifier: The point ionization (red) and from electromagnetic disturbances (blue). The sensitivity of electronic channel 1 mV/10 eV

Electromagnetic disturbances have usually non regular shape, the pulses from “microphonic effect” have typically response in the audible range with the shapes close to sinusoidal. The pulses from the point ionization in gas have typically a relatively short front edge (a few microseconds) corresponding to the time drift of positive ions to cathode and long (hundreds of microseconds) tail corresponding to the time of the base line restoration of the charge sensitive preamplifier. These events might be produced in our detector by internal radioactivity of the materials of the counter, by electronic emission from the walls of the counter and also by ionizing particles produced by cosmic rays. The amplitude of these events may be even smaller then an average energy to produce a single electron pulse because of the relatively broad energy distribution in this case (Polia distribution). Using two peaks from $^{55}Fe$ calibration source (5.9 keV and 2.85 keV escape peak in argon) we observed relatively good linearity of the conversion energy – amplitude and rather high $4 \cdot 10^4$ gas amplification. In the range from 20 eV to 100 eV, where main effect from coherent scattering of reactor antineutrinos should be observed, the pulse shape discrimination enabled to reduce the noise by a factor of about $10^3$. Thus we show that this range can be effectively used.
for counting of the events from CNNS. The similar problem of counting the
events from very small energy release has been solved in a number of exper-
iments with cryogenic detectors. In 1997 we together with the staff of the
laboratory of Professor Sandro Vitale in University of Genoa in Italy were
first who succeeded in counting the pulses from peaks 57 eV and 112 eV from
the decay of $^7\text{Be}$ $^8$. The energy threshold in this work was 40 eV. This was
achieved thanks to effective pulse shape discrimination of the noise pulses
from electromagnetic disturbances and “microphonic effect”. The count rate
from CNNS of reactor antineutrinos is calculated to be a few events per day
per kg of argon in the energy range from 20 eV to 100 eV. To collect a mass
of argon of about 1 kg the detector should have the volume of about 50 liters
even at the pressure 1 MPa. But to get the gas amplification higher $10^4$ at
High Voltage 3 kV the diameter of the cathode should be 40 mm, not more.
To reconcile these conflicting demands we should use an array of counters
and each counter should have a central, avalanche region with a small diam-
eter of the cathode and external, drift region, separated from avalanche region
by a grid. The diameter of the drift region is taken to be 140 mm. Apart
from this, there should be external cylindrical layer of counters working as an
active shielding and also as a passive one of the fluorescence from the walls
of the counter. All assembly is placed in a cylindrical body made of titanium
as a relatively pure on $^{226}\text{Ra}$ material, as our previous measurements have
shown. In Fig.2 we show the general view of this counter.

We plan to use an array of 16 similar counters, each working on separate
charge sensitive preamplifier and digitizing board. The counters will be as-
sembled in 4 planes, each one having 4 counters. The size of the assembly
will be approximately 100x100x100 cm. To reduce the background from cos-
mic rays, neutrons and gamma-rays the assembly will be placed in the box
made of slabs of iron 30 cm thick, internal surfaces will be lined by borated
polyethylene 20 cm thick. To shield from fast neutrons from the reactor we
plan to use additional external layer of water 50 cm thick and on the outside
– plastic scintillator as an active veto shield from ionizing particles of cosmic
rays penetrating to the depth of about 16 m of water equivalent. The water
shield reduces the background from fast neutrons by an order of magnitude,
thus, it will be possible by comparing the data collected with and without
water to determine how large will be the contribution of reactor neutrons
to the effect observed. All this assembly will be placed in a hermetically
sealed housing filled by argon purified of radon. We select this design of
shielding to reduce at most the background from gamma-quanta from ex-
ternal radioactivity and from neutrons, generated in iron by cosmic rays. Borated polyethylene 20 cm thick decreases approximately 10-fold the flux of fast neutrons from iron. The slabs of iron 30 cm thick effectively absorb gamma-radiation from the walls. In Fig.3 we show the calculated effect from CNNS and the background from neutrons, generated at 16 meters of water equivalent for argon and xenon as a working medium of the detector.

The energy spectrum of nuclear recoils presented on Fig.3 was taken from [9]. In the calculation of the background from scattering of neutrons, generated by muons of cosmic rays, we used the data on the energy spectrum of neutrons from [10]. For precise interpretation of the effect from CNNS one needs an accurate, with the uncertainty of a few percents, measurement of the quenching factor in gaseous xenon and argon which is expected to be approximately 10-15% at the energy of the recoiling nucleus lower than 500 eV [11]. Further development of the technique described in this paper is needed to accomplish the task within approximately 5 years to obtain some significant physical result.

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Figure 3: The energy spectrum of nuclear recoils from CNNS of reactor antineutrinos (1 – xenon, 2 – argon) and from scattering of neutrons, generated by muons of cosmic rays (3 – xenon, 4 – argon)

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