

## COHERENT Experiment: current status

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**Abstract.** The COHERENT Collaboration is realizing a long term neutrino physics research program. The main goals of the program are to detect and study elastic neutrino-nucleus



scattering (CE $\nu$ NS). This process is predicted by Standard Model but it has never been observed experimentally because of the very low energy of the recoil nucleus. COHERENT is using different detector technologies: CsI[Na] and NaI scintillator crystals, a single-phase liquid Ar and a Ge detectors. The placement of all the detector setups is in the basement of the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL). The current status of the COHERENT experimental program is presented.

## 1. Introduction

### 1.1. Coherent Elastic Neutrino-Nucleus Scattering

Coherent elastic neutrino-nuclei scattering (CE $\nu$ NS) is a fundamental process predicted by D.Z. Freedman in 1974 [1] but has never been observed because of the extremely low energies of the resulting nuclear recoils. The CE $\nu$ NS cross-section can be described with the formula [2]:

$$\sigma_{tot} = \frac{G_F}{4\pi} E_\nu [Z(4 \sin^2 \theta_W - 1) + N]^2, \quad (1)$$

where  $G_F$  is the Fermi constant,  $E_\nu$  is the energy of the neutrino,  $\theta_W$  is the Weinberg angle,  $Z$  is the number of protons and  $N$  is the numbers of neutrons in the target nucleus. Since  $\sin^2 \theta_W \approx 0.22$ ,  $\sigma_{tot}$  depends on the square of the number of neutrons in the nucleus.

Since CE $\nu$ NS is cleanly predicted by the Standard Model, it could be a very sensitive probe of the Standard Model [3, 4]. Observation of CE $\nu$ NS is also important for sterile neutrino searches [5], supernova studies [6, 7] and direct dark matter searches [8, 9]. Since  $\sigma_{tot}$  depends on  $\theta_W$ , measurement of the CE $\nu$ NS cross section is an additional independent method to clarify the weak mixing angle value [10].

The COHERENT Collaboration, established in 2014 [11], aims to search for CE $\nu$ NS, to measure its  $N^2$  cross-section dependence and to search for physics beyond the Standard Model using several detector technologies at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory, Tennessee.

### 1.2. Spallation Neutron Source

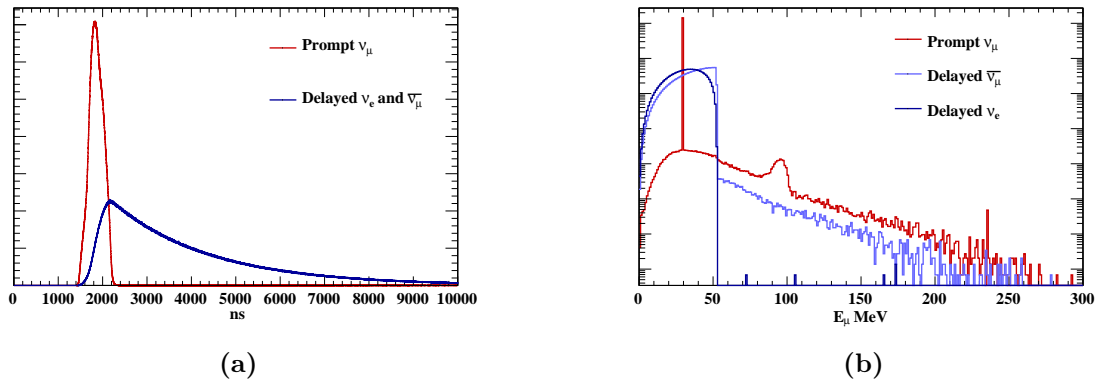
The SNS is a facility that produces the most intense pulsed neutron beams in the world [11]. At an energy level of 1 GeV per proton and a frequency of 60 Hz, proton bunches strike a liquid mercury target and produce neutrons and pi mesons. Pions stop inside the target volume and decay producing neutrinos of different flavors ( $\nu_\mu$ ,  $\nu_e$ ,  $\bar{\nu}_\mu$ ). Energy spectra of these neutrinos are shown in figure 1(b). SNS provides a neutrino flux of  $\sim 4 \times 10^7$  per cm per second at distance of 20 m from the target. The neutrino flux consists of two components: a prompt  $\nu_\mu$  component and a delayed one including  $\nu_e$  and  $\bar{\nu}_\mu$  with lifetimes of 2.2  $\mu$ sec and up to 10  $\mu$ sec correspondingly(see figure 1(a)).

Neutrinos arrive in a few microseconds. Time correlations between the proton beam and registered events provide suppression of cosmic rays by a factor of  $\sim 2 \times 10^3$ .

### 1.3. Neutron Background

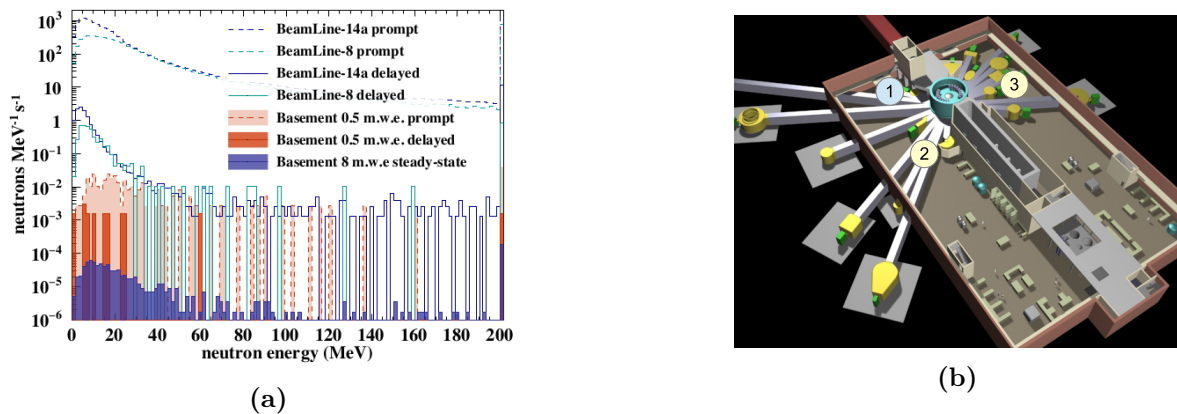
Understanding and reducing background sources are very important for the COHERENT research program. The SNS duty cycle allows to reduce cosmic background component and radioactivity. These backgrounds can be measured using events outside the SNS beam window [11].

Beam-related neutron background is the most dangerous background for a CE $\nu$ NS search. Neutrons passing through the shielding can interact in the target volume of the detector and produce the same signal as CE $\nu$ NS does.



**Figure 1:** (a): time structure for prompt (red) and delayed (blue) components of neutrino flux. (b):  $\nu$  spectrum for flux  $4.3 \times 10^7 \text{ cm}^{-2}\text{s}^{-1}$  at 20 m from the target in arbitrary units at the SNS.

A series of background measurements in several possible detector positions carried out since 2013 using a single portable 5-liter liquid scintillator detector and a two-plane neutron scatter camera [12] have shown that the most neutron-quiet location is the basement of SNS (figure 2).



**Figure 2:** (a): fluxes of background neutrons measured at SNS. Locations where these fluxes have been measured can be found in figure (b): 1 is the selected basement location, 2 is Beamline 8 and 3 corresponds to the Beamline 14.

Other possible sources of neutron background are neutrino induced neutrons (NINs) [13]. The detector shielding uses several tons of lead. The charged ( $^{208}\text{Pb}(\nu_e, e)^{208}\text{Bi}$ ) and neutral ( $^{208}\text{Pb}(\nu_x, \nu'_x)^{208}\text{Pb}$ ) current interactions of high energy neutrinos from pion decay with passive lead shielding of any detector may be a source of background neutrons appearing at the same time as the beam-related prompt  $\nu_\mu$  component arrives. That could be the cause of fake CE $\nu$ NS signal. Accurate measurement of the NIN production cross section is very important for background predictions.

There are three detectors, named Neutrino Cubes, proposed to study NIN production from different materials usually used in shielding: iron, copper and lead [11]. The lead monitoring Neutrino Cube is already collecting data, and the other two are under deployment. Each Neutrino Cube is a liquid scintillator detector surrounded by the shielding material under consideration, plus water and muon veto.

## 2. Detector Subsystems

The COHERENT Collaboration uses several detector technologies as detector subsystems with different target media. Energy resolutions of all of the detector subsystems are sufficient to allow to detection of the prompt  $\nu_\mu$  neutrino component. At the moment, the Collaboration has all the detector technologies available: CsI[Na] has been deployed in 2015, NaI[Tl] and CENNS-10 are under deployment now and the Ge detector is also available and will be deployed in early 2017.

### 2.1. CsI[Na] Scintillator detector

CsI[Na] scintillator crystals present properties suitable for a CEvNS measurement. The combination of large neutron numbers ( $N = 74, 78$ ) and sufficiently low threshold provides a possibility to observe this process at the SNS. CsI[Na] has a high light yield of about 64 photons/keV and matches well to the sensitivity of bialkali photomultipliers. Another advantage of using CsI[Na] as a target in the low-energy experiments is lack of the excessive afterglow that is characteristic of CsI[Tl] [14].

The measurement of the quenching factor (QF) for nuclear recoils in CsI[Na] over the energy region of interest performed in [14] using the methods described in [15] allows to expect a realistic threshold of about 5 keV<sub>nr</sub> for such a detector. Additional QF measurements were performed by COHERENT at the D(D,n) source at TUNL to minimize the related systematic uncertainties. At the time of this writing the analysis of new QF data continues.

The single 14.5 kg CsI[Na] crystal with a 5 inch Hamamatsu R877-100 PMT and shielding was deployed at the SNS in June 2015. The shielding consists of 7.5 cm high-density polyethylene inner neutron moderator, 15 cm of lead (the innermost 5 cm selected for low  $^{210}\text{Pb}$  content), a 99.6% efficient 5 cm thick muon veto and a 10 cm outer neutron moderator and absorber built out of thin wall aluminum tanks filled with water. A calibration using  $^{241}\text{Am}$  was performed to measure the light yield for gamma rays of energy 59.54 keV. Data containing low-energy forward Compton scattering events from a collimated  $^{133}\text{Ba}$  source were used to train the analysis procedure. At the time of this writing the analysis of calibration data continues.

The CsI[Na] detector took “beam on” data at the SNS starting from October 8<sup>th</sup>, 2015. At the moment of this writing approximately 9 months of SNS “beam on” data have been recorded. Approximately 500 CEvNS events are expected in the detector above threshold, per year.

### 2.2. CENNS-10 single-phase liquid Ar detector

Argon is a very promising target material because it has light yield ( $\sim 40$  photons per keV) and two energy states with different populations, due to different time constants of singlet and triplet molecular decay channels. The last property makes possible to use pulse shape discrimination to distinguish nuclear recoil signals from electron background. A disadvantage of a LAr detector is  $^{39}\text{Ar}$  which produced by cosmic rays. The decay rate of  $^{39}\text{Ar}$  is  $\sim 1$  kBq/ton.

CENNS-10 is single-phase liquid Ar detector with 36 kg fiducial volume. The liquid Ar volume is viewed from top and bottom with two Hamamatsu R5912-MOD2 PMT immersed into the liquid. To provide light collection efficiency, the detector fiducial volume is surrounded by tetraphenylbutadiene (TPB) covered acrylic surfaces.

Detector shielding consists of a 4 inch lead layer, a 0.25 inch copper layer and 12 inches of water. Lead is used for gamma protection, copper provides lead-induced neutron protection and water serves as a major neutron moderator and absorber. Detector active shielding is provided by muon veto panels. It is expected that about 340 CEvNS events will be produced in the fiducial volume of CENNS-10 detector per year. CENNS-10 has already been shipped to ORNL and is under deployment now.

### 2.3. NaI[Tl] Scintillator detector

An array of NaI[Tl] scintillator detector modules have become available. These detectors can be used to observe and study CE $\nu$ NS as well as charged current neutrino interactions on  $^{127}\text{I}$  [15]. Every detector module contains a 7.7 kg NaI[Tl] crystal hermetically sealed into an aluminum container. This is required due to high hygroscopicity of NaI. While studies of detector characteristics were done, a first phase setup containing 185 kg of NaI has already been deployed at ORNL.

### 2.4. P-type Point Contact Germanium Detectors

P-type point-contact (PPC) High Purity Germanium detectors (HPGe) have moderate and sufficiently large atomic number ( $72 \leq A \leq 76$ ), low thresholds, high energy resolution, a suitable and well-measured quenching factor and low internal backgrounds [16, 11]. Thus this detector technology is well matched to the CE $\nu$ NS search and study tasks.

High purity PPC HPGe detectors with total mass of 10 kg are placed into vacuum cryostat. The cryostat is cooled with liquid nitrogen ( $\text{LN}_2$ ) driven thermosyphon system. The shield of the setup will consist of 18 cm thick polyethylene for slow neutrons absorption, 5 cm plastic scintillator muon veto and 15 cm lead gamma-ray shield. An additional 7.5 cm of polyethylene and 12.5 mm of copper shields will be placed into the lead shielding to reduce NIN and  $^{210}\text{Pb}$  decay background components correspondingly.

There are approximately 220 CE $\nu$ NS events per year expected for the delayed  $\bar{\nu}_\mu$  component from SNS target source. The Ge detector subsystem is undergoing operational tests. The expected time of deployment at the SNS is early 2017.

## 3. Summary

The COHERENT Collaboration is realizing a long term neutrino physics research program at the SNS. The main goals of these studies are to observe and measure CE $\nu$ NS. Background measurement studies started in 2013 showed that the SNS basement is the most neutron quiet place available to deploy detector setups. Two detector subsystems, CsI[Na] and NaI[Tl], are already deployed and liquid argon is under deployment. The Ge detector subsystem will also be deployed. To estimate the NIN component of the CE $\nu$ NS signal the Collaboration is attempting to measure the cross section of NINs on iron, lead and copper using independent scintillator detectors named Neutrino Cubes. The neutrino cube with lead target is already operating, and other two are under deployment. Future evolution of the detector setups for the COHERENT research program includes increasing mass of the existing detector targets and possibly other detectors.

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