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Nuclear Physics B (Proc. Suppl.) 138 (2005) 221–223
NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS
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MOON (Mo Observatory Of Neutrinos) for double beta decay

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The MOON (Molybdenum Observatory Of Neutrinos) project aims at studies of double beta decays with a high sensitivity of $< m_\nu >\sim 0.03$ eV and real-time studies of low-energy solar neutrinos. Two β rays from ^{100}Mo are measured in coincidence for the $0\nu\beta\beta$ studies. The inverse β rays from solar neutrino captures of ^{100}Mo are measured in delayed coincidence with the following β decay of ^{100}Tc. Measurements with good energy resolution and good position resolution enable one to select true signals. A prototype MOON detector (MOON 1) is now under development. The present report describes briefly the outline of the MOON project and the status of MOON 1.

1. INTRODUCTION

The recent experimental data and theoretical studies for ν oscillation experiments suggest that the effective mass to be studied by neutrino-less double beta decays($0\nu\beta\beta$) is of the order of 0.1 $\sim$ 0.01 eV if the neutrino is a Majorana particle and the mass spectrum is with inverted hierarchy. Thus it is of great interest to measure $\beta\beta$ decays with that sensitivity. Real-time studies of

*A part of this work is supported by a Grant-in-Aid of Scientific Research and Ministry of Education, Science and Culture, Japan.

0920-5632/$ – see front matter
doi:10.1016/j.nuclphysbps.2004.11.053

solar neutrinos have been made of the high-energy component of ^{8}B neutrinos. It is now important to make real-time studies of the low-energy solar neutrinos, which are the major component of the solar neutrino flux.

^{100}Mo is shown to have large responses for both the $\beta\beta$ decays and the low-energy solar neutrinos [1,2]. The MOON (Molybdenum Observatory Of Neutrinos) project is a hybrid $\beta\beta$ and solar ν experiment with $\sim$ 1 ton of ^{100}Mo. It aims at high-sensitivity studies of the neutrino-less $\beta\beta$ decays with sensitivity to Majorana mass of the order of $< m_\nu >\sim$0.03 eV and the measurements of low-energy solar neutrinos [2]. This paper describes the MOON project, the prototype detector MOON 1 and its R&D studies. Some of them have been partially presented at the recent conference [3].

2. MOON DETECTOR

^{100}Mo is one of promising $\beta\beta$ nuclei. The large Q value of $Q_{\beta\beta}$=3.034 MeV gives a large phase-space factor $G^{0\nu}$ to enhance the $0\nu\beta\beta$ rate and a large energy sum of $E_1 + E_2 = Q_{\beta\beta}$ to place the $0\nu\beta\beta$ energy signal well above most backgrounds.

The MOON detector is based on the recent $\beta\beta$ studies of ^{100}Mo by ELEGANT V [4]. It is a tracking-calorimeter detector. Measurements with good energy resolution and good position resolution enable one to select true events. Position detectors, between which an enriched ^{100}Mo foil is interleaved, define the vertex point of the two β rays. Calorimeters for energy measurements are placed behind the position detectors.

One of the unique features of MOON is the tracking-calorimeter structure repeating many times. Calorimeters work as an active shield to another calorimeter. It makes MOON possible to be a compact detector with high sensitivity. Most background events have successive gamma decay. Calorimeters surrounding the decay point are very efficient active shields.

Many of the background events are due to natural and cosmogenic radioactive isotopes. They are mostly associated with pre- and/or post-decay particles, such as $\beta\alpha$ or γ rays. They decay and emit the other energetic particles at the same position. Those delayed activities indicate they are not the double beta decay events, since true $\beta\beta$ signals are not associated with other $\beta\gamma$ or α rays.

To distinguish neutrino-less double beta decays ($0\nu\beta\beta$) from two-neutrino double beta decays ($2\nu\beta\beta$), good energy resolution is required. The simulation has been performed in case of 0.02 g/cm^2 thick of the Mo foil. The sum energy spectrum of two beta rays is shown in Fig. 1. It is the case for $2\nu\beta\beta$ to $0\nu\beta\beta$ ratio of 10^6, which corresponds to about $< m_\nu >= 0.2\sim0.7$ eV [5,6]. The energy difference between $0\nu\beta\beta$ and $2\nu\beta\beta$ is less than 200 keV. It requires very good energy resolution, better than 7% for 3MeV sum energy, to distinguish $0\nu\beta\beta$ events from $2\nu\beta\beta$ events.

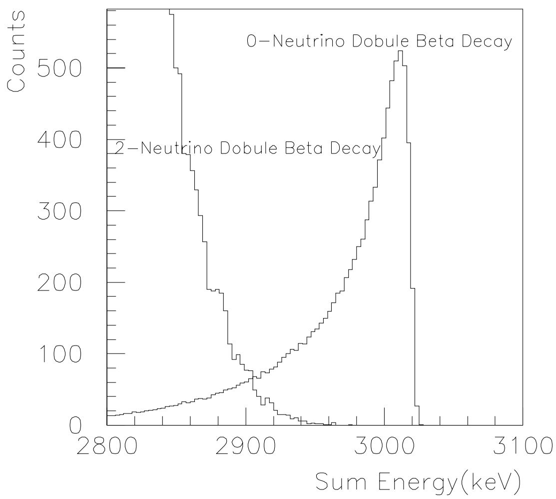

Figure 1. Simulated sum energy spectrum of $\beta\beta$ events with the Mo foils with a thickness of 0.02 g/cm^2. $2\nu\beta\beta$ to $0\nu\beta\beta$ ratio of 10^6 is assumed

3. MOON PHASE-1 DETECTOR

The aim of MOON phase-1 is to study double beta decay with about 1 kg of ^{100}Mo. It will study the sub-eV mass region (0.2$\sim$0.7 eV on the basis of the recent QRPA matrix elements). It is the first step to a large detector system. Background study and improvement of energy resolution are under progress.

There are some options for energy measurements and position measurements. Calorimeters for energy measurement are plastic scintillator plates, and scintillating fibers measure position. One module consists of a 50 cm by 50 cm square plate plastic scintillator and two sets of x-y fiber scintillator planes, between which a thin ^{100}Mo film is interleaved. MOON phase 1 is 4∼10 layers of the module. The fiber scintillators enable one to get the position resolution of a few mm. A part of the cross-section is shown in Fig. 2.

Good energy resolution is a key to distinguishing $0\nu\beta\beta$ from $2\nu\beta\beta$. In order to improve the energy resolution, R&D for improving the photon collection efficiency is in progress. The preliminary test suggests that the improvement of photon collection efficiency is promising, just by increasing PMT's area coverage. Usually PMTs are placed at both ends of the scintillator bar, as in ELEGANT V [7]. We put PMTs at four sides of the scintillator plate to increase PMT coverage. This configuration also reduces the length of light-path and the number of reflections. We are expecting improvement of factor $2 \sim 3$ to conventional plastic scintillator bar with PMTs at both ends. Consequently, energy resolution (FWHM) of better than $12\%/\sqrt{E(MeV)}$ are expected.

MOON 1 uses the copper shields and lead shields of the ELEGANT V detector.

4. SUMMARY

The MOON (Molybdenum Observatory Of Neutrinos) project is a hybrid $\beta\beta$ and solar ν experiment with ^{100}Mo. It aims at high-sensitivity studies of $\beta\beta$ decays with a sensitivity of $< m_\nu > \sim 0.03$ eV and real-time measurements of low-energy solar neutrinos. Increasing the coverage of PMTs is expected to improve the energy resolution, which is the most crucial requirement for $0\nu\beta\beta$ measurements.

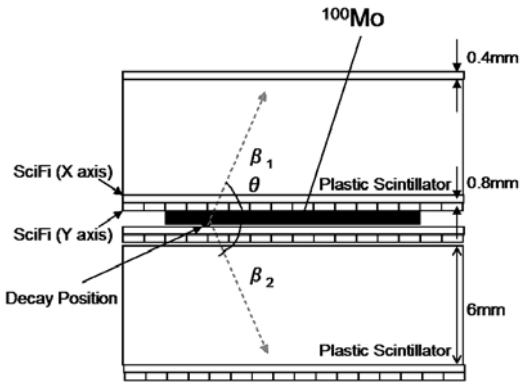

Figure 2. A part of cross-section of MOON-1 detector.

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