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Spectroscopy of low energy solar neutrinos by MOON -Mo Observatory Of Neutrinos-

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The MOON (Molybdenum Observatory Of Neutrinos) project aims at high sensitive studies of the double beta ($\beta\beta$) decays with sensitivity to Majorana ν mass of the order of $< m_{\nu} > \sim 0.03$ eV and the charged-current (CC) neutrino spectroscopy of the major components of the *pp* and ^{7}Be solar ν's. The present status of MOON for the low energy solar ν experiment is briefly discussed. The inverse β rays from solar-ν captures of ^{100}Mo are measured in delayed coincidence with the subsequent β decay of ^{100}Tc. MOON's exclusive CC value by ^{7}Be solar ν, together with the GNO CC data, will provide the *pp* solar ν flux with good accuracy.

1. INTRODUCTION

Realtime studies of the high-energy component of ^{8}B ν's which are only a fraction (less than 10^{-4}) of the total solar ν flux have been made. Realtime studies of individual low-energy solar ν fluxes will be emphasized herein, not only because they are major components of the total ν flux, but also because their contribution has been more precisely determined than that of the high-energy ^{8}B solar ν flux [1].

^{100}Mo is shown to have large responses for both

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the $\beta\beta$ decays and the low-energy solar ν's [2, 3]. The MOON (Molybdenum Observatory Of Neutrinos) project is a "hybrid" $\beta\beta$ and solar ν experiment with $\sim$ 1 ton of ^{100}Mo.

The unique features of MOON for low-energy solar ν's are as follows.

1. The intermediate ^{100}Tc nucleus is only 168 keV above ^{100}Mo with a 1^+ ground state and a very large matrix element for inverse beta decay. That makes good sensitivity for low-energy solar neutrinos such as *pp* and ^{7}Be possible. The *pp* and ^{7}Be ν's are captured only into the ground state of ^{100}Tc and the rate ratio of *pp* and ^{7}Be ν's is independent of the $B(GT)$ value. This is important in terms of the measurement of their ratio, which can exclude exotic solutions to the solar ν problem experimentally [4].

2. The CC ν capture rates for individual solar ν sources are derived from the $B(GT)$ values measured by the (^{3}He,t) reaction [5]. The raw count rates for the *pp* and ^{7}Be ν's are expected to be 121 and 39, respectively, without ν oscillations, and around 70 and 20 with the LMA oscillation. As the transition is ground state to ground state, direct experimental measurements of the transition matrix element can be made by studying the electron-capture decay of ^{100}Tc, and such measurements have been reported [6], and a more accurate measurement is in progress at the IGISOL facility by Garcia and collaborators [7].

3. Because ^{100}Tc decays to ^{100}Ru with a half-life of 16 s, the occurrence of a solar-neutrino interaction can be tagged with the subsequent beta decay, which has a high endpoint energy of 3.034 MeV.

4. The measurement of two β-rays (charged particles) enables one to localize in space the decay-vertex positions for both the $0\nu\beta\beta$ and solar-ν studies. The tightly localized event in space, together with the appropriate time and energy window, are key points for selecting signals and for reducing various kinds of backgrounds, and thus for building large detectors with materials with realistic purities around 0.01$\sim$0.001 Bq/ton. This purity level has been achieved for Ni and other materials for the Sudbury Neutrino Observatory. The same carbonyl process appears to be applicable to the purification of Mo as has been so successful for Ni, and exploratory tests are beginning.

5. MOON is based on the recent $\beta\beta$ studies of ^{100}Mo by ELEGANT V [8] and the solar ν studies by SNO [9].

2. MOON 1 DETECTOR AND R&D

MOON is required to have a large amount ($\sim$ one ton) of enriched ^{100}Mo isotope and good energy ($\sim$12 % for 1 MeV) and position (Δx $\sim$ mm) resolutions. Most natural and cosmogenic RI BG's are accompanied by γ rays and/or pre-(post-)β/α decays. They are removed by SSSC (signal selection by spatial correlation) and SSTC(signal selection by time correlation). The good position resolution and the time correlation are crucial to reduce the accidental coincident $2\nu\beta\beta$ rate, which is the major background. The fact that the transitions are all beta decays means they are well localized. The detector readout scheme is designed to provide the subdivision.

R&D for solid and liquid scintillators are under progress. A possible option for the solid scintillator is a supermodule of hybrid plate and fiber scintillators. One module consists of a plate scintillator and two sets of x-y fiber scintillator planes, between which a thin ^{100}Mo film is interleaved. The hybrid plate and fiber scintillators can be used for energy read-out and position read-out, respectively. The energy resolution of plate scintillator has been tested by using both γ-ray's Compton edge from a radioactive source, such as ^{137}Cs [10] and single-photon counting from the light of LED coupled with optical fiber. The preliminary test suggests that the improvement of photon collection is promising just by increasing the area covered by the PMT's. The PMT readout is maximized by viewing not only at the ends, but in all directions except for the vertical. Since there are only a few photons expected from the thin fiber scintillators, a digital readout using Avalanche Photo-Diodes, in addition to conventional multi-channel readouts of multi-anode PMT's, will be used. A prototype detector, MOON 1, which will be 4$\sim$10 layers of supermodule; each module may consist of 2 layers of plate scintillator with (x,y,z)=(50 cm,50 cm,0.6

cm) and two sets of x-y fiber scintillator with 0.4 mm square, is going to be constructed. MOON 1 uses the same Cu and Pb shielding as was used in the ELEGANT V detector.

The low-energy solar neutrino efficiencies are dominated by losses in the Mo foils, especially for the *pp* solar ν case. The realistic GEANT simulation has been performed for the MOON 1 detector with the above-mentioned dimensions using a Mo foil of thickness 0.02 g/cm^2. Upon folding in the energy resolution for both plate and fiber scintillator, the expected inverse β spectrum for ^{7}Be ν is shown in Fig. 1. With a threshold of 60 keV the efficiency is expected to be more than 60%. In order to obtain the overall efficiency, one must multiply the efficiency at 60 keV by the efficiency resulting from the delayed tagging of beta. Multiple scattering is exemplified especially for this low-energy beta by this simulation.

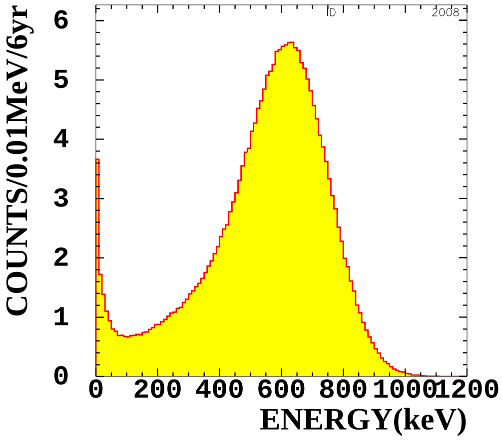

Figure 1. Simulated energy spectrum of inverse β by ^{7}Be ν for a planned MOON 1 detector (see text) with the Mo foils with thickness of 0.02 g/cm^2.

MOON with 6 year-ton data taking capability is expected to yield a ^{7}Be solar ν CC flux with $\sigma \sim$ 10 % statistics, which corresponds to 2 SNU in σ for 10% of LMA. This CC value, together with the GNO CC data [11], will provide the *pp* solar ν flux with $\sigma \sim 3$ % statistics ($\sim$2 SNU in σ), which is shown in Fig. 2. MOON is complementary to BOREXINO with electron scattering and LENS, using a different experimental procedure which employs a different isotope.

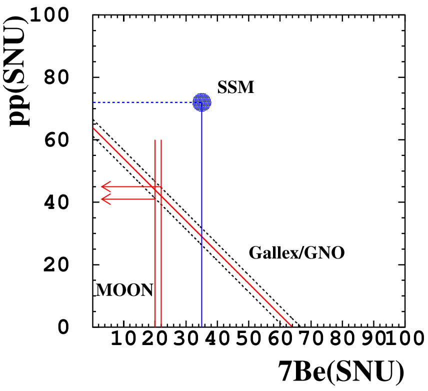

Figure 2. Flux of *pp* solar neutrino vs the flux of ^{7}Be solar neutrino, as deduced from the GNO and the expected MOON's ^{7}Be data. The shaded circle shows the SSM value. The dashed lines represent the $\pm 1\sigma$ errors.

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