MOON: A Next Generation Double Beta Decay and Solar Neutrino Experiment

J.A. Formaggio (*Center for Experimental Nuclear Physics and Astrophysics, University of Washington*) for the MOON Collaboration

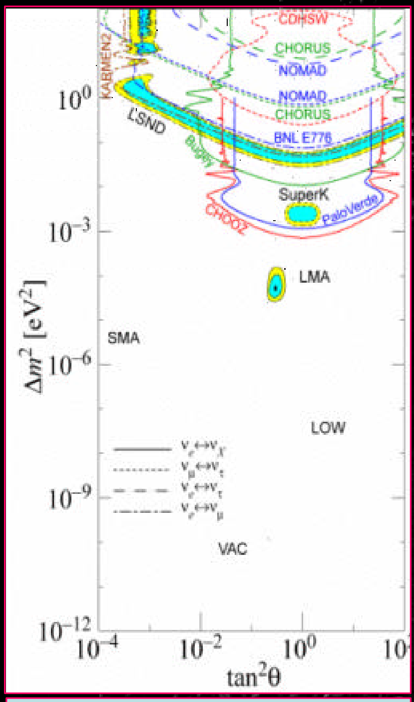
1. Motivation

Over the past thirty years, experimental evidence has pointed scientists to the fact that neutrinos, once considered massless particles, exhibit a phenomenon known as neutrino oscillations, which implies that they possess non-zero masses. This realization comes from not one single observation, but a body of evidence gathered from solar, atmospheric, and reactor neutrino experiments. The goal of the next generation of neutrino experiments is to probe deeper into understanding the very nature of neutrino masses and mixings.

One of the goals for future experiments is to address the nature of the neutrino mass. It is possible that neutrinos are what are called Marojana particles, where the neutrino and anti-neutrino are the same particle. Such an observation will have a great impact on our theoretical understanding of neutrinos.

A second goal for future experiments to address is the absolute mass of the neutrino. Although oscillation experiments can measure neutrino mass differences, they cannot tell us the absolute scale. Knowing the neutrino mass scale has significant impact on astrophysics and cosmology.

Finally, a third goal for future experiments is to gain greater precision on the neutrino oscillation parameters. Knowing more precisely how neutrinos mix will shed new light on the nature of the weak force and on physics beyond the Standard Model.



Summary of neutrino masses and mixings from solar, reactor, atmospheric, and accelerator experiments. Filled regions illustrate positive signals (from Murayama).

2. Three Experiments in One

The MOON experiment (**Mo**lybdenum **O**bservatory **o**f **N**eutrinos) is a next generation neutrino experiment with the capability of addressing multiple physics questions within a single detector.

The MOON experiment uses ^{100}Mo as an active target that is sensitive to low energy neutrino processes. Firstly, the ^{100}Mo target provides an ideal setting to studying double beta and neutrinoless double beta decay. The experiment is sensitive to neutrinoless double beta decay via the ^{100}Mo decay to the ground and excited state of ^{100}Ru.

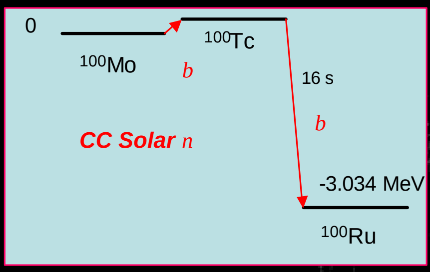
Secondly, MOON is sensitive to low energy solar neutrinos above the ^{100}Mo β-decay threshold of 168 keV. Unlike radio-chemical experiments, MOON provides real time sensitivity to charged current neutrino reactions.

Finally, because of its low energy threshold, MOON can also serve as monitor for neutrinos emitted during a supernova explosion.

3. Solar Neutrinos

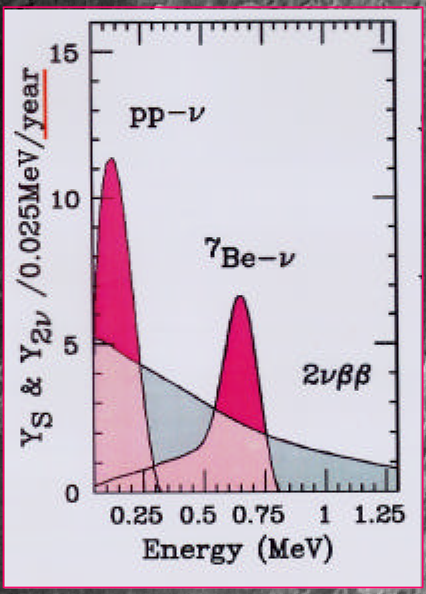
The MOON experiment can be sensitive to low energy solar neutrinos via the charged current reaction:

$$\nu_e + {}^{100}\text{Mo} \longrightarrow {}^{100}\text{Tc} + e^-$$



This reaction has a threshold of 168 keV and can be tagged via the subsequent decay to ^{100}Ru. The low threshold allows one to measure both the ^{7}Be and pp solar flux in real time. Ability to distinguish signal from background requires good energy and spatial resolution.

Reaction	Rate/yr/ton^{100}Mo
pp	120
^{7}Be	40
pep	2.5
^{8}B	5.1
^{13}N	4.2
^{15}O	6.1

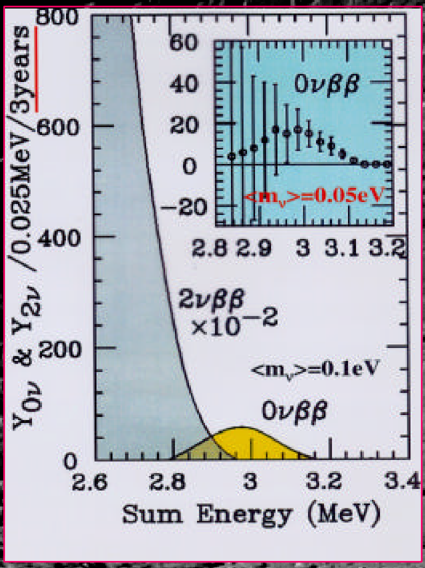


Expected solar neutrino energy spectrum in a 3-ton MOON detector. Irreducible background from 2νββ is also shown.

4. Double Beta Decay

In addition to solar neutrinos, the ^{100}Mo target has an allowed transition to the 2νββ and 0νββ decay to ^{100}Ru. It is the latter reaction that is of importance to neutrino physics, since it can only occur if the neutrino and anti-neutrino are the same particle. In which case, the reaction is proportional to the Majorana mass term of the neutrino:

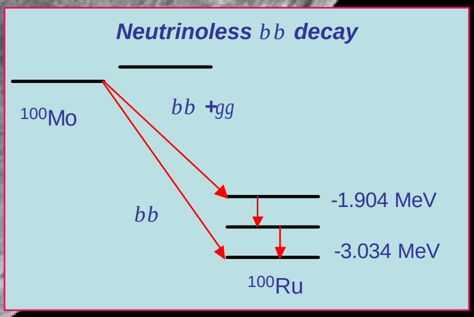
$$\langle m_{bb} \rangle = \sum_{i=1}^{3} |U_{ei}|^2 m_i e_i$$



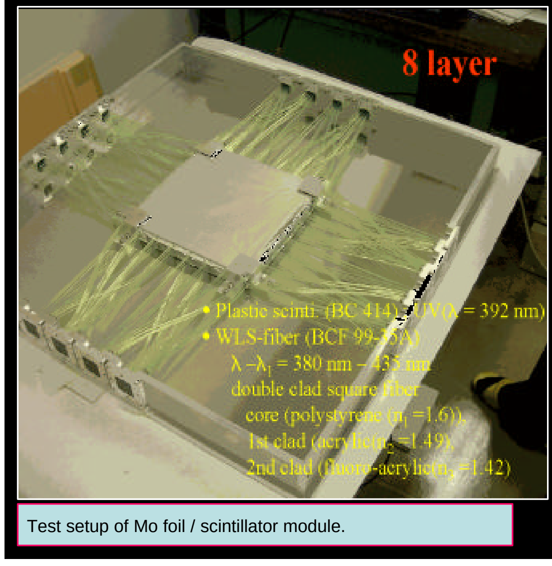
Spectrum of 2νββ and 0νββ assuming a Majorana neutrino mass of 0.1 eV

MOON has two unique channels to study this reaction. It can study the 0νββ decay to the ground state, which emits two electrons with a combined energy of 3.034 MeV. Alternatively, ^{100}Mo can transition to the 0^+_1 state, which releases two photons with 596 and 540 keV of energy. The latter reaction, though suppressed by a factor of 40, provides a 4-fold coincidence signature, making it essentially background-free.

The 0νββ measurement requires high isotopic purity and good energy resolution.



5. Scintillator Technology



Test setup of Mo foil / scintillator module.

One technological approach in constructing the MOON detector is to use plastic scintillator to measure the position and energy of electrons produced from the solar and 0νββ decay signals. This technology takes advantage of the spatial-time correlation to separate signal from background.

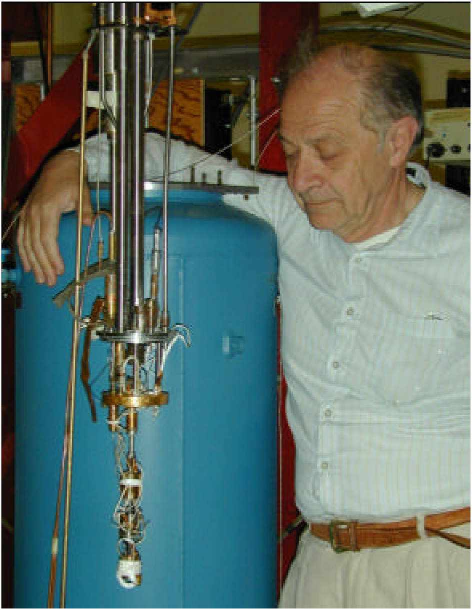
Under this configuration, the detector would consist of thin molybdenum foils sandwiched between scintillating fibers (which would measure the vertex of the event) and plastic scintillator plates (which would measure the energy of the event). The fibers would measure 2 mm x 2 mm x 0.5 mm, while the plastic scintillator plates would measure 2 m x 2 m x 6 mm. Tests with ELEGANT V show that by using avalanche type sensors can yield a final energy resolution of 1.5% at 3 MeV (4.4% with the Mo plate). R&D is ongoing at Osaka University.

6. Bolometry

Another technological approach that is currently understudy is using cryogenic detectors. Such an approach is especially suited for 0νββ measurements, where good energy resolution is essential in separating the signal from the irreducible 2νββ background.

As molybdenum is a superconductor with T_c= 0.92 K and H_c = 19 G, it is a good candidate to be used as an active cryogenic detector. Equilibration between broken pairs and lattice, however, are very slow. Therefore, non-metallic compounds such as $MoSi_2$ might be better suited so as to achieve faster response times.

Current R&D is ongoing at both the University of Washington on the superconducting capabilities of molybdenum. Previous studies with CUORICINO have shown cryogenic techniques using ^{130}Te have achieved energy resolutions of order 0.2-0.6%.



Oscar Vilches and his dilution refrigerator.