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Recent Developments in Neutrino Science: A Whole Lot About Almost Nothing

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Recent Developments in Neutrino Science: A Whole Lot About Almost Nothing

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Results from Super-K[1,2], SNO[3,4], and KamLAND[5,6] provide strong evidence that neutrinos undergo flavor-changing oscillations and therefore have non-zero mass. The ν-disappearance observations by KamLAND, assuming CPT conservation, point to matter enhanced (MSW) oscillations with large mixing angles as the solution to the solar neutrino problem – a result consistent with the MSW parameters recently defined by these experiments. This requires that the observed neutrino flavors (e, μ, and tau) are not mass eigenstates, but are linear combinations of the mass eigenstates of the neutrino. However, such oscillation experiments can only determine the differences in the masses of the neutrinos, not the absolute scale of neutrino mass. What can be inferred from these experiments is that at least one species of neutrino has a mass greater than 55 meV. In fact, the WMAP[7,8,9] observations of large-scale structure point to a sum-neutrino mass of ~ 0.7 eV (roughly 0.25 eV/species assuming democracy between the flavors). Furthermore, there is still the important issue of whether the neutrino and anti-neutrino are distinct particles (i.e. Dirac type) or not (Majorana type). The only way to answer both of these questions is through neutrinoless double beta decay (DBD) experiments.

CUORE (Cryogenic Underground Observatory for Rare Events) is a proposed next generation experiment designed to search for the neutrinoless DBD of ^{130}Te using a bolometric technique. The source/detector will be composed of 988 5x5x5-cm single crystals of TeO_2 all housed in a common dilution refrigerator and operated at a temperature of 8-10 mK. The total mass of ^{130}Te contained in CUORE will be approximately 203 kg. Attached to each crystal will be one or more neutron-transmutation doped (NTD) germanium thermistors that will measure the small temperature rise produced in a crystal when radiation is absorbed. A schematic illustration of the CUORE detector is shown in Figure 1. Details about the TeO_2 cryogenic detector are contained in a NIM A paper[10] and the physics potential of CUORE is described in a recent article in Astroparticle Physics.[11] A complete description of the CUORE project is also available online.[12] The estimated sensitivity of CUORE illustrated in Figure 2 is sufficient to cover essentially all of the so-called inverted mass hierarchy region deduced from the oscillation experiments.

There are several compelling reasons to study ^{130}Te DBD. The $\beta\beta$ decay of ^{130}Te has been observed in geo-chemical experiments. Thus, a direct laboratory measurement of the 2ν $\beta\beta$ decay rate will provide an excellent calibration for 0ν-DBD. Second, because of its large decay energy and large expected nuclear matrix element, the half-life of ^{130}Te is predicted to be shorter than that of a number of other candidate isotopes. Third, based on the sensitivity needed to reach the mass scales inferred from the above-mentioned oscillation experiments, the ^{130}Te experiment can be done utilizing the natural abundance of ^{130}Te (34%), without the time and expense of obtaining separated isotopes. Of all the proposed next generation DBD experiments, only CUORE can reach the needed sensitivity without isotopic enrichment.

Array of 988 crystals:
19 towers of 52 crystals/tower.
M = 0.78 ton of TeO_2

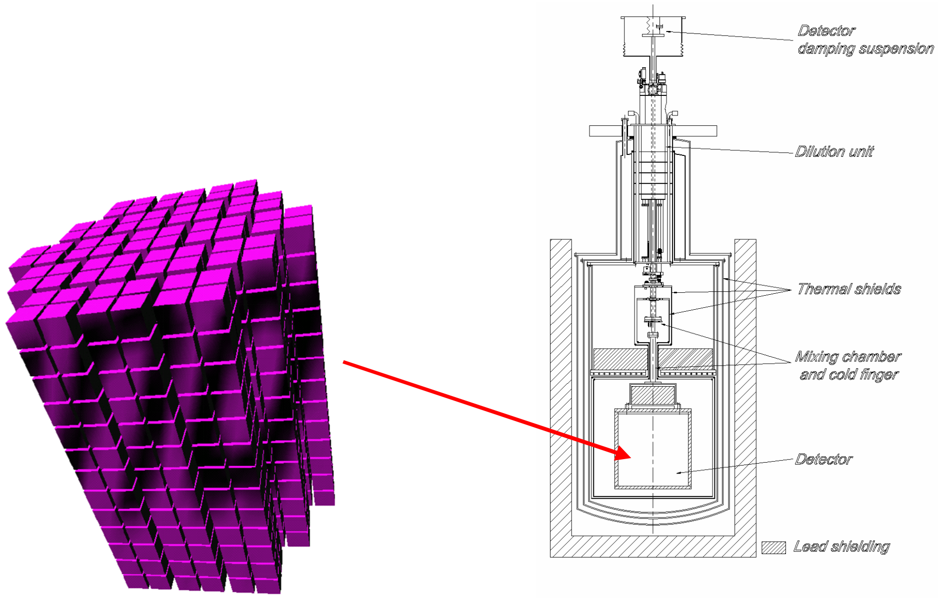

Figure 1. Schematic drawing of the CUORE detector.

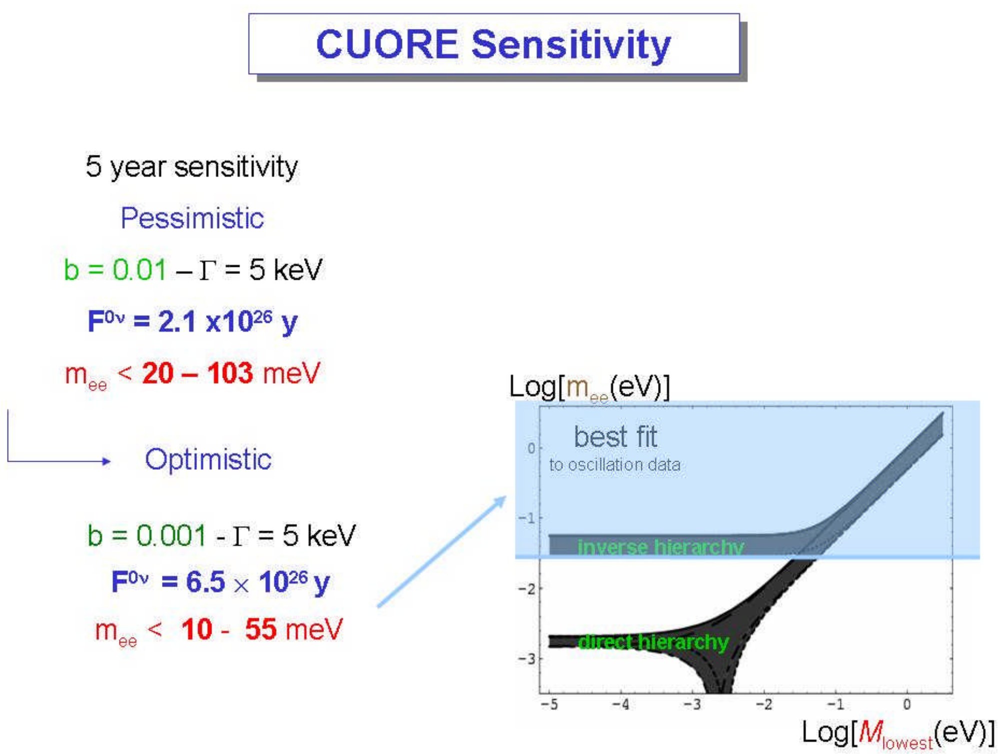

Figure 2. Estimated sensitivity of CUORE from 5 years of running.

In addition to being ideal for double beta decay searches, CUORE will also be a powerful detector for cold dark matter and solar axion searches. One of the great strengths of CUORE is its modular nature and the fact that many isotopes can be incorporated in a bolometer. Once CUORE is constructed, one could remove a number of crystals from the center of the array and replace them with crystals containing other materials of interest. The rest of CUORE could then be used as an anti-coincidence shield, which would provide the lowest background environment in the world in which to search for rare events. Exquisitely sensitive searches could be made for rare nuclear decays or for exotic processes such as the decay of the electron.

CUORE has been approved by the Scientific Committee of the Gran Sasso National Underground Laboratory (LNGS) in Italy and has already been assigned space in this world-class facility. A prototype experiment, CUORICINO, which consists of 62 TeO_2 crystals, is now running at the LNGS. CUORICINO is presently the largest operating double beta decay experiment in the world and has recently published its first physics result[13] – a limit on neutrino mass only slightly less stringent than that obtained from previous ^{76}Ge experiments.

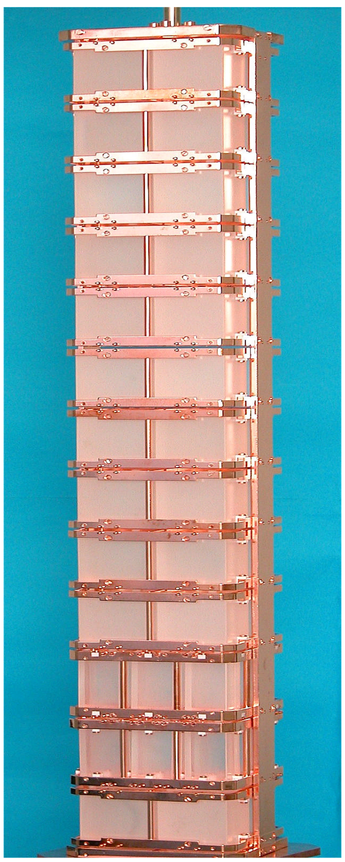

Figure 3. The CUORICINO array of 62 TeO_2 crystals that is currently operating at the LNGS.

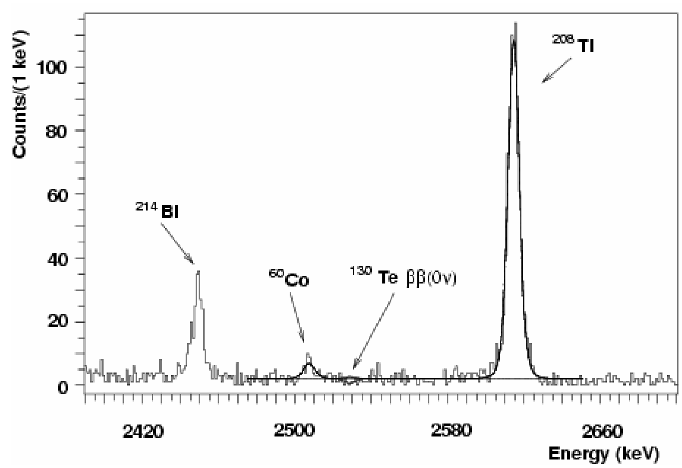

Figure 4. Background spectrum obtained from CUORICINO in an exposure of 10.85 kg-y. The energy resolution measured at 2615 keV = 9.2 $\pm$ 0.5 keV (FWHM). The background in the $0\nu\beta\beta$ region = 0.18$\pm$0.01 counts/(keV/kg/y. No peak is observed at the expected position of $0\nu\beta\beta$ and a limit of $t_{0\nu 1/2} > 1.8 \times 10^{24}$ y at 90% C.Lhas been obtained. The inferred limit on neutrino mass derived from this results is: $m_\nu < 0.2 – 1.1$ eV.

Figure 5 illustrates the growth in the mass of TeO_2 detector systems that have been assembled and operated by members of the CUORE collaboration as a function of time. From this plot one can see that CUORE is a very natural and reachable extension based upon what we have already demonstrated.

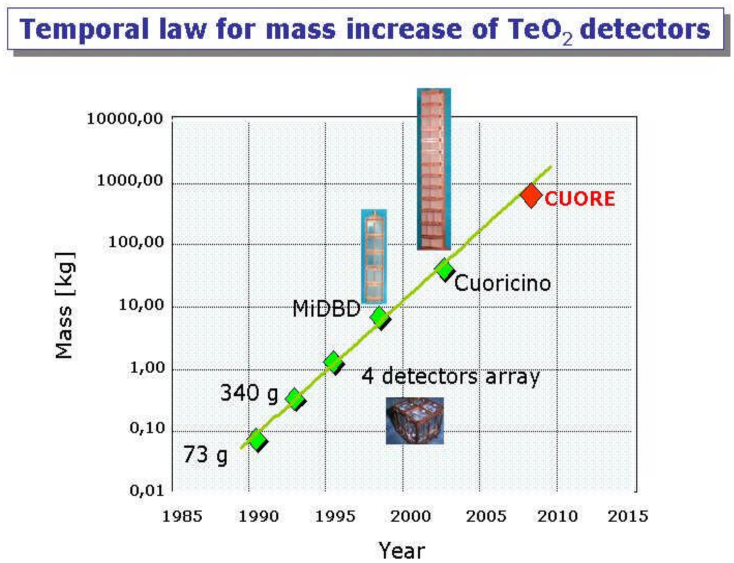

Figure 5. The mass of TeO_2 detector systems that have been assembled and operated by members of the CUORE collaboration as a function of time.

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