LENS, MINILENS –Status and Outlook

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Abstract

The current status of development of the LENS detector for measuring the luminosity of the sun in neutrinos is outlined. Plans for testing the technology and concepts of background control of LENS via a 250 liter prototype—MiniLENS- are described.

The low-energy solar \(\nu\) spectrum offers unique access to specific low-energy evidence for the MSW-LMA \(\nu\) model and new scenarios of non-standard particle physics and astrophysics. A crucial test is the fundamental equality of the \(L_{\nu}\), the solar luminosity inferred from \(\nu\) fluxes and the photon luminosity \(L\). Any inequality \(L_{\nu}/L \neq 1.00\) that survives at high precision, implies new discovery in astrophysics or \(\nu\) physics. A precision measurement of the \(\nu\) luminosity implies the measurement of the complete set of pp, \(^7\)Be, pep, & CNO \(\nu\) fluxes, which together, make up >99.99% of the \(\nu\) luminosity. The \(L_{\nu}=L\) test requires the individual fluxes of specific energies so that they can be reverse-engineered to pre-conversion fluxes (needed to derive \(L_{\nu}\)) using a \(\nu\) model. Energy specific, real-time \(\nu\) detection is thus essential. The needed technology is available in LENS (Low-Energy Neutrino Spectroscopy), the only charged-current (CC) based real-time detector developed up to now for low energy solar \(\nu\)'s. The neutrino target in LENS is the 96% isotope \(^{115}\)In. The recent success of Borexino in detecting \(^7\)Be solar neutrinos (and possibly other low energy neutrinos in the future) provides a major new impetus. Borexino uses \(\nu\)-electron scattering based on both CC and NC interactions. The combination of Borexino and LENS data for the same neutrino source eliminates the need for determining the absorption nuclear matrix element for the In reaction. A separate LENS experiment for this purpose with a MCi radioactive source (planned earlier), may no longer be needed.

Neutrino detection in In-LENS is based on the charged current (CC) tagged \(\nu_e\) capture in \(^{115}\)In: \(\nu_e + ^{115}\text{In} \rightarrow e^- + (\tau =4.76 \mu s) 2 \gamma + ^{115}\text{Sn}\). The detection medium is an organic liquid scintillator containing 8-10wt% of indium (InLS). This reaction is unique because: 1) It provides a prompt \(e^-\) signal with the energy \(E(e^-) = E(\nu) - Q\) that uniquely specifies the incident \(\nu\) energy and thus its spectrum. The \(Q\) value is only 114 keV, the lowest known for CC solar \(\nu\) capture. The reaction is thus sensitive to \(\sim 95.5\%\) of the pp \(\nu\) continuum (0-420 keV). 2) The prompt electron is followed by a tag of 2 \(\gamma\)'s after a mean delay of \(\tau = 4.76 \mu s\). This central feature allows on-line tagging of \(\nu\) events and powerful discrimination against background.

R&D of the In based LENS has achieved major results in the last few years. The main aspects are, a) Monte Carlo simulations that have revealed new analysis tools to discriminate against the random coincidence background from the decay of the In target. b) Development of In-loaded scintillators with properties suitable for LENS. c) A new type of detector design—the scintillation lattice—that allows digital 3-D location of nuclear events an order of magnitude more precisely than the analog TOF methods of the usual array of longitudinal detector modules.

Background Suppression: The major background arises from the natural beta-activity of \(^{115}\)In. The MINILENS R&D focuses on this problem. Fig. 1 shows the topologies of the In-neutrino tag and the random coincidence background due to the Indium decay. Extensive GEANT4 monte carlo simulations that examine the topology of events. Fig. 1 shows the signal/background ratios
and detection efficiencies achievable by the various cuts. The results indicate that the overall In decay background can be suppressed by a factor $6 \times 10^{11}$ at the cost of a signal loss by factor of 1.6, leading to a S/N ratio of $\sim 3$, sufficient for achieving the physics objectives of LENS.

**Indium loaded Liquid Scintillator (InLS):** The choice of InLS as the basic technology for LENS was clear early in the historical development of LENS. Thus a viable InLS technology has been the focus if LENS R&D programs for more than a decade. The LENS demands on the InLS are extraordinarily stringent and unprecedented. These have been achieved for the first time in our work in the last 2 years. The following typical figures of merit are observed using the LS solvent pseudocumene (PC).

- **Indium loading**: $\sim 8$ wt%
- **Scintillation light efficiency relative to pure PC**: $Y \sim 8000$ hv/MeV
- **$(1/e)$ Light attenuation length $L_e$ for 430 nm scintillation light**: $L_{1/e} \sim 800$ cm
- **Chemical and Optical Stability (from time history of $L_e$)**: $> 8$ months

Recently we have studied the suitability of a new solvent Linear Alkylbenzene (LAB). The flash point of this solvent is high ($\sim 100^\circ C$ vs $45^\circ C$ for PC) thus more compatible with underground operations. It is also considerably less expensive. All the figures of merit above for PC (Indium loading, scintillation yield, attenuation length, long term stability) have been reproduced with somewhat less favorable figures of merit. The work so far shows that LAB may be suitable as the solvent of choice for LENS and will be field tested in the prototype project MINILENS.
**Scintillation Lattice Detector Design:** We have developed a new detector technology: the 3-D scintillation lattice chamber (Fig. 2). The basic idea extends the 1-D light piping property of the long module to 3-dimensions using a close packed 3-D assembly of InLS filled cubic cells with air gaps surrounding each cell. In such a device, scintillation light generated in a cell travels only in channels along the 3 coordinate axes intersecting the vertex cell. If the cubic array faces are optically coupled with PMT’s, the light triggers only the 6 PMT’s viewing the channels specific to the event cell. This is seen in a laboratory model (Fig. 2) consisting of a cubic array of acrylic cubes that simulate the optical segmentation. A plastic scintillator somewhere in the array (= a nuclear event) is fluoresced by UV light. The fluorescence light triggers only the PMT’s at the end of the channels (the bright squares on the faces) that lead back along the channels to the original event. Event location is thus digital. Important progress has been made in applying this concept to real detector configurations of optical segmentation using plastic foils in a solvent.

![Fig. 2 Concept of a scintillation lattice](image)

![Fig. 3 Schematic Design of MINILENS](image)

**MINILENS:** The roadmap to the stage of readiness for the full-scale LENS calls for a practical demonstration of the essential elements of LENS. We see two phases in this roadmap. In phase I, the R&D will continue to address the next essential questions. In phase II we plan to globally test all the R&D conclusions, design plans and strategies in a modest, scalable detector –MINILENS that will demonstrate the essential control of background as well as field testing the technology, e.g., large scale InLS production and handling and construction and operation of the scintillation lattice. We propose to construct MINILENS with In mass of ~20-40 kg in the lattice design as a 6x6x6 array of cubic cells 125 mm on the side (see Fig. 3 for a schematic design. The outer array in Fig. 3 would be filled with non-In LS as an active buffer and the inner volume with ~250 L of InLS containing a minimum of 8% In). The PMT’s cover the faces (6 or 3 with mirrors on the other 3 faces), sufficient for full 3D event localization. Passive shielding will be added as needed. MINILENS thus contains all the basic elements of our design for LENS and is scalable to the full experiment. The In singles rate in such a detector will be at least 5 kHz, sufficient to critically test the trigger design, DAQ and the background suppression concepts. MINILENS will be located at the recently commissioned Kimballton Underground Research Facility at a depth of ~1400 mwe, near the VT campus. Thus we can make a direct test of the operability of LENS at these depths.

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