

Low energy neutrino astronomy with the large liquid-scintillation detector LENA

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Abstract. The detection of low energy neutrinos in a large liquid scintillation detector may provide further important information on astrophysical processes as supernova physics, solar physics and elementary particle physics as well as geophysics. In this contribution, a new project for **Low Energy Neutrino Astronomy** (LENA) consisting of a 50 kt scintillation detector is presented.

1. Introduction

In the recent years, low energy neutrino research was particularly successful in neutrino astronomy and neutrino elementary particle physics. This led to the first observation of a supernova explosion via neutrino detection [1, 2], the measurement of the solar neutrino spectrum [3] and the discovery of neutrino oscillations [4, 5, 6]. In this paper, we investigate the potential for new discoveries if low energy neutrinos can be detected in a large scintillation device with a total mass of 50 kt using the low background technology developed for the BOREXINO detector [7]. These investigations focus on the following topics: solar neutrino spectroscopy, neutrino detection from a nearby supernova explosion, detection of relic neutrinos from previous supernova explosions, detection of neutrinos emitted from the Earth and search for proton decay.

2. The LENA detector design

The **Low Energy Neutrino Astronomy** (LENA) detector [8, 9], is assumed to be constructed as a double-walled cylinder with a diameter of 30 m and a length of approximately 100 m. As indicated in figure 1, the inner volume is instrumented at the walls with photomultiplier tubes providing a surface coverage of 30% photo-sensitive cathode area and filled with 50 kt of liquid scintillator consisting of PXE as solvent and ~ 2 g/l of pTP and 20 mg/l of bisMSB serving as wavelength shifters. This scintillator was developed as an option for the BOREXINO detector [7]. The scintillator has a density of 0.99 g/cm³ and with a light attenuation length of $\lambda = 12$ m [10], a photoelectron efficiency of ~ 120 pe/MeV is expected. In the outer section

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of the cylinder, 2 m of water provide shielding against external radioactivity, as well as a water Cherenkov detector serving as a muon veto.

The detector is aimed at a detection threshold of 250 keV, yielding 30 photoelectrons at threshold, and should be constructed at an underground site placed at a depth of more than 4000 m water equivalent to provide a sufficient muon background reduction. In Europe, two favourable sites satisfy these requirements. One is in the south of Greece, at the Nestor deep underwater laboratory where the detector might be placed at a depth of 4000-5000 m water in the Mediterranean sea. A second suitable place might be at the Center of Underground Physics in Pyhäsalmi (CUPP) [11] in a mine covered by 1400 m rock. Both laboratories are situated far from nuclear power plants which limit the electron antineutrino background.

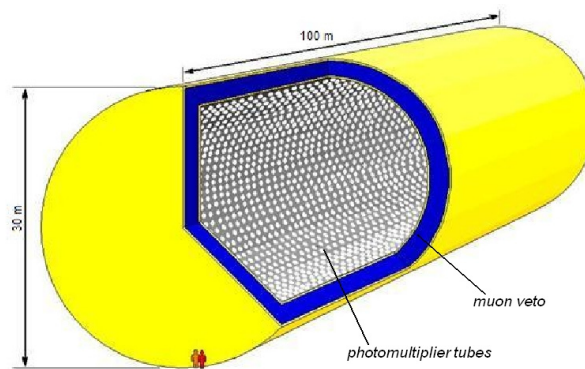


Figure 1. Illustration of the LENA detector. The inner part of about 13 m radius will contain approximately 50 kt of liquid scintillator. The outer part (13 – 15 m radius) will be filled with water acting as muon veto.

3. Detection of solar neutrinos

The detector LENA would be able to detect solar ${}^7\text{Be}$ neutrinos via neutrino electron scattering with a rate of ~ 5400 events/day. Depending on the signal-to-background ratio, this would provide a sensitivity for time variations in the ${}^7\text{Be}$ neutrino flux of $\sim 0.5\%$ during one month of measuring time. Such a sensitivity may give information at a unique level on helioseismology (pressure or temperature fluctuations) and on a possible magnetic moment interaction with a timely varying solar magnetic field.

The additional detection of pep neutrinos with a rate of ~ 210 events/day could provide information on neutrino oscillation which is expected to show a transition from matter-induced oscillation to vacuum oscillation in the energy range between 1–2 MeV. The ratio of the neutrino flux from the reactions of pep fusion and pp fusion is theoretically determined with an accuracy $\leq 1\%$. Thus the measurement of the pep neutrino flux is effectively as well determining the pp solar neutrino flux. In addition, information on the contribution of the CNO cycle to the energy production in the Sun can be obtained with LENA.

With a liquid scintillator, ${}^{13}\text{C}$ atoms naturally contained in it can be used as target for ${}^8\text{B}$ neutrinos [12] as the energy threshold for the charge current reaction is 2.2 MeV. Around 360 events of this type per year can be expected for LENA. A deformation due to the MSW-effect should be observable in the low-energy regime of the ${}^8\text{B}$ neutrino spectrum after a couple of years of measurements.

4. Supernova neutrinos

A $8 M_{\odot}$ supernova exploding in the centre of the milky way (10 kpc distance) typically will induce a signal rate of $\sim 20\,000$ events. A discrimination between electron neutrinos and electron antineutrinos would be possible by charge current reactions: the interaction of antineutrinos via inverse beta decay and neutrino interaction at ^{12}C . In this way, LENA will deliver information on ν_e and $\bar{\nu}_e$ fluxes and spectra. The neutral current reactions will be sensitive to all neutrino flavours and thus determine the total flux [8].

Due to the high statistics of the neutrino detection a time-resolved neutrino-flux rate for different neutrino interactions could be measured which would give new results on the dynamics of supernova explosions and would be complementary to the information accessible in large water-Cherenkov detectors or in a large liquid-Argon detector.

5. Supernova relic neutrinos

The neutrino background generated by supernova explosions throughout the Universe (supernova relic neutrinos, SRN) provides valuable information on supernova explosion mechanisms as well as on the star formation rate (SFR). Unlike observational astronomy that can be impeded by light extinction due to dust, SRN-detection with LENA would allow for more precise determination of the SFR. The current best limit on the SRN-flux comes from the SuperKamiokande experiment, giving an upper limit of $1.2 \text{ cm}^{-2}\text{s}^{-1}$ for $\bar{\nu}_e$ with an energy threshold of 19.3 MeV [13]. As the inverse beta decay is used as detection reaction for $\bar{\nu}_e$, LENA will lower this threshold to ~ 10 MeV by means of its improved background rejection. This lower threshold is given by the background from nuclear power reactors and is therefore strongly dependent on the detector position.

6. Terrestrial neutrinos

Unique information on the interior of the Earth can be obtained by the detection of electron antineutrinos from the Earth. Present technology permits drilling of holes down to a depth of approximately 10 km, compared to the Earth radius of ~ 6300 km. It is known that the emitted heat from the Earth exceeds the energy flow from the Sun by around ~ 40 TW. This excess is generally attributed to heat emitted by natural radioactivity of material inside the Earth [14]. However, estimations of the Earth's interior composition account only for half of the radioactivity required. Part of the missing energy may be covered by latent heat emitted in geochemical processes [15]. A measurement of the electron antineutrino flux of the Earth could provide valuable information to solve this question.

These so-called geoneutrinos have recently been measured for the first time by the liquid-scintillator detector KamLAND [16]. Neutrinos from ^{40}K being below the energy threshold of the inverse beta decay reaction can not be detected. However, with a good energy resolution (high statistics), neutrinos from the ^{238}U and ^{232}Th decay chains can be discriminated.

In addition, if directional information on the antineutrino flux can be obtained, a spatial distribution of the natural radioactivity in the interior of the Earth could be derived. Scaling the experimental result from KamLAND to LENA yields an event rate in the range between $4 \cdot 10^2$ and $4 \cdot 10^3 \text{ y}^{-1}$ for the location in Pyhäsalmi (continental crust). In first calculations, we overestimated LENA's directional sensitivity based on the n-displacement after inverse beta decay of the proton due to the neutrino momentum. These calculations are currently being revised.

A natural nuclear reactor has been suggested to reside in the centre of the Earth thus providing a further explanation for the missing energy source in the Earth [17]. The existence of such a nuclear reactor (for example of ~ 10 TW) could be tested with LENA.

7. Proton decay

A large scintillation detector guarantees unique sensitivity to the proton decay channel $p \rightarrow K^+\bar{\nu}$. This decay mode is favoured in many Supersymmetry theories and may be expected with a lifetime τ below 10^{35} y. Based on Monte Carlo calculations for this decay mode, a lower limit of $\tau > 4 \cdot 10^{34}$ y at 90% C.L. has been derived [9]. More detailed information on this result is given in a contribution to this conference by T. Marrodán Undagoitia.

8. Summary

A large liquid-scintillation detector with a total detector mass of 50 kt may provides a unique tool for neutrino astronomy, geophysics and elementary particle physics. The use of a scintillator as a neutrino target and detector medium has a variety of advantages due to the very high light output. A more detailed design study will be performed in the near future.

This detector would be largely complementary to a megaton water Cherenkov detector being discussed for different locations in Europe, USA and Japan. Due to the competence and expertise present in Europe, especially for scintillation detectors with extremely low background at low energies, a LENA-type detector may be of particular interest to be investigated in Europe.

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