Reconstruction of GeV Neutrino Events in LENA

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Abstract. LENA (**L**ow **E**nergy **N**eutrino **A**stronomy) is a proposed next generation liquid-scintillator detector with about 50 kt target mass. Besides the detection of solar neutrinos, geoneutrinos, supernova neutrinos and the search for the proton decay, LENA could also be used as the far detector of a next generation neutrino beam. The present contribution outlines the status of the Monte Carlo studies towards the reconstruction of GeV neutrinos in LENA. Both the tracking capabilities at a few hundred MeV, most interesting for a beta beam, and above 1 GeV for a superbeam experiment are presented.

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INTRODUCTION

LENA (**L**ow **E**nergy **N**eutrino **A**stronomy) has been proposed as a next generation large volume liquid-scintillator detector [1]. With about 50 kt target mass it will be considerable larger than the present liquid-scintillator neutrino detectors Borexino (300 t) and Kamland (1000 t).

About 50 kt of organic liquid scintillator (see Figure 1) are contained in a cylindrical nylon vessel of 96 m height and 26 m in diameter. Scintillation light will be detected by $\sim$ 45000 eight-inch photomultiplier tubes (PMTs) equipped with light concentrators (corresponding to 30% optical coverage), mounted to a scaffolding in 2 m distance from the nylon cylinder. Additional 2 m of non-scintillating buffer liquid will shield the target volume against γ rays emitted by the PMTs and the surrounding steel tank of 30 m diameter. Outside the steel tank at least 2 m of water will serve as an active muon veto and as a shield against fast neutrons produced by cosmic muons in the surrounding rock. On top of the steel tank plastic scintillator panels are mounted, which serve as an additional active muon veto.

Amongst the physics goals are the detection of solar neutrinos, galactic and relic supernova neutrinos, geoneutrinos and the search for the proton decay. But LENA could also be used as the far detector of a next generation neutrino beam. Two European sites are deep enough (more than 4000 m.w.e. of rock shielding against cosmic rays) to host the LENA detector: Frejus (France, 130 km distance to CERN) and Pyhäsalmi (Finland, 2300 km distance to CERN), resulting in a 1^{st} oscillation maximum at $E_\nu = 0.26$ GeV and $E_\nu = 4.65$ GeV, respectively.

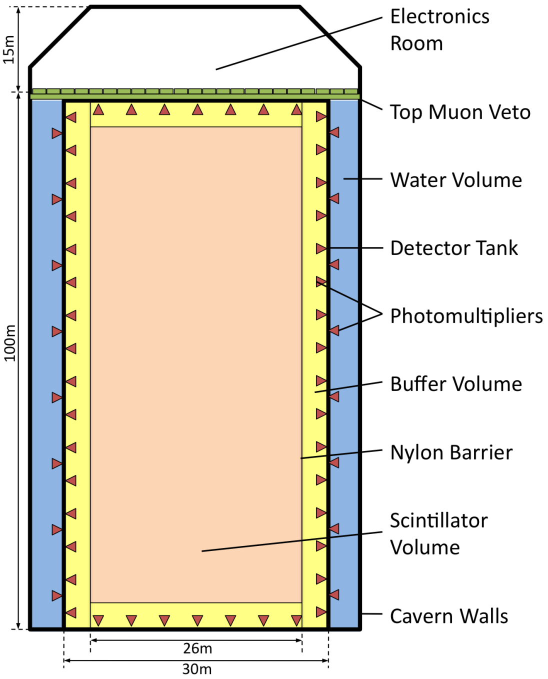

FIGURE 1. Schematical view of the LENA detector.

RECONSTRUCTION OF NEUTRINO EVENTS IN LENA

Reconstruction of Particle Tracks in Liquid Scintillator

Contrary to a water-Čerenkov detector, the light in a liquid-scintillator detector is emitted isotropically.

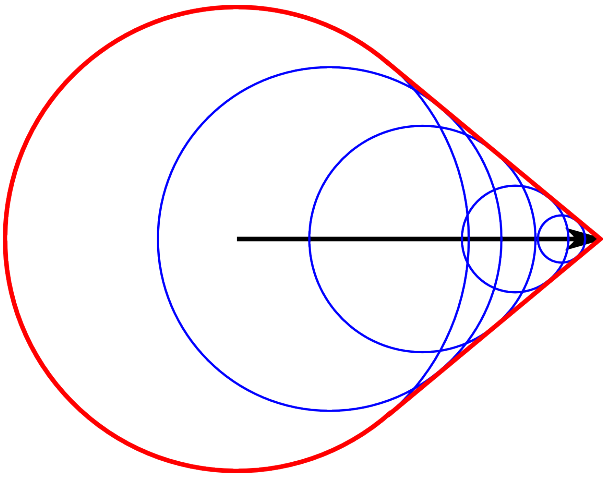

FIGURE 2. Light emission of a particle track in a liquid scintillator. The superposition of the spherical waves leads to the first photon cone. The shape of the cone contains information about the track direction.

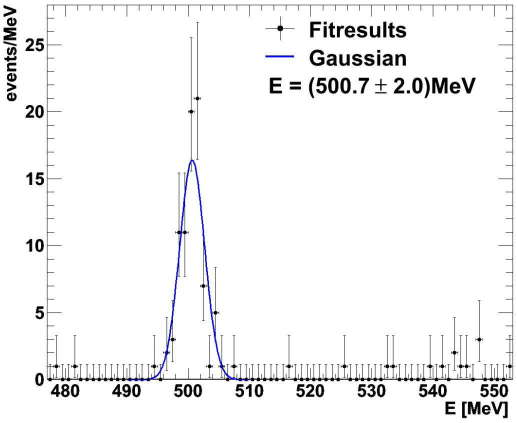

FIGURE 3. Reconstructed energy of 300 MeV muons. Excluding the high-energy outliers, that are caused by not identified muon decays, the energy resolution is $\sim 0.5\%$.

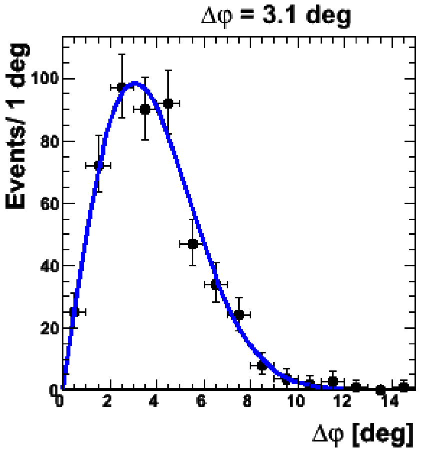

FIGURE 4. Angular deviation of the reconstructed track from the simulated track for 300 MeV muons. The resulting angular resolution is 3.1°.

Therefore there is no directional information for point-like events. But if the particle creates a track that is longer than the position resolution of the detector ($\sim 10\,\mathrm{cm}$) it is possible to reconstruct the track from the superposition of the spherical light waves along the track [2] (see Figure 2).

Low Energy Neutrino Events (0.2 GeV-1 GeV)

Below 1 GeV quasi-elastic (QEL) charged current (CC) scattering is the dominant detection channel:

$$\nu_{e/\mu} + \mathrm{n} \rightarrow e^-/\mu^- + \mathrm{p} \tag{1}$$

The ν flavour can be identified by the measurement of the lepton flavour. Muons can be discriminated from electrons by the muon decay, which is visible in about 85% of all muon events, and the different typical pulse shapes. Though more than 95% of all CC neutrino events in this energy range are QEL events, there is still a small contribution from resonance pion production (RES) and deep inelastic scattering (DIS) events. Pions produced in RES and DIS events can lead to a misidentification of the neutrino flavour, as π^0s can be reconstructed as electrons and $\pi^{\pm}$s as muons. A possible means of pion identification is currently being investigated.

For the reconstruction of the lepton track, which is based on the photon arrival time pattern at the PMTs, the probability density function (PDF) $P\left(\vec{p},\vec{S}\right)$, that an event with the parameters $\vec{p}$ creates the signal $\vec{S}$, is calculated. Assuming that each PMT signal (consisting of a multitude of photons) is a function of the PMT position $\vec{r_i}$ and the orientation $\vec{n_i}$, the most probable track can be obtained by minimizing the log-likelyhood function

$$\mathcal{L} = -\sum_{i=1}^{N_{PMT}} \ln\left[P_s\left(\vec{p},\vec{S_i},\vec{r_i},\vec{n_i}\right)\right] \tag{2}$$

where $P_s\left(\vec{p},\vec{S_i},\vec{r_i},\vec{n_i}\right)$ is the PDF for each individual PMT.

Figure 3 shows the reconstructed energy for 300 MeV muon events, generated with a full detector Monte-Carlo simulation based on GEANT4 [3]. As the signal of the muon decay needs to be subtracted, the events where the muon decay could not be separated are reconstructed at too high an energy. Not including these events, the energy resolution is $\sim 0.5\%$. The track start point was determined with about 2 cm-3 cm uncertainty and the angular resolution is 3.1° (see Figure 4). Due to the higher statistical fluctuations of the electron tracks, the angular resolution as well as the start point positional resolution are slightly worse. Muon tracks with a kinetic energy below 100 MeV and electron tracks below 250 MeV could not be fitted successfully. Therefore the angular information will be lost for these events, but the energy can still be measured.

The neutrino energy resolution will be worse than the lepton energy resolution due to nuclear effects and the quenching of the scattered proton (or neutron) in the scintillator. Further Monte Carlo studies are neccessary.

High Energy Neutrino Events (1 GeV-5 GeV)

Above 1 GeV neutrino energy, the contribution from resonance pion production and deep-inelastic scattering events can not be neglected anymore. Therefore it is necessary to reconstruct multiple tracks in one event. The following results were obtained using a different approach, relying on a simplified Monte Carlo simulation and alternate reconstruction strategies [4]. The available data samples are small due to the associated computing times. Single lepton tracks can be reconstructed precisely with a positional accuracy of 10 cm or better. For muon tracks the angular resolution is better than 1°. In case of electron tracks, the angular resolution is slightly worse (a few degrees), due to the shorter track lengths and the emission of bremsstrahlung. Muon and electrons can be distinguished by the track length difference. So far, for none of about hundred simulated events was a wrong lepton flavour determined, thus the discrimination between electron and muon tracks can be considered as practically absolute.

Two sufficiently long tracks in one event ($> \mathcal{O}(50\,\mathrm{cm})$) can be reconstructed, if they are clearly angularly separated. Events consisting of 3 tracks can only be reconstructed if all tracks are longer than 1 m and clearly angularly separated. If 4 or more tracks are present in one event, it is usually not possible to reconstuct the tracks. The energy resolution depends on the event signature and ranges from 1% for QEL events to 5% for DIS events.

As it is possible to reconstruct multiple particle tracks in one event, π^0 and $\pi^\pm$ produced in addition to the lepton in CC reactions can be easily identified. Therefore, only single pions produced in neutral current reactions provide a background. Methods for rejecting these background events are currently being investigated.

CONCLUSION

While originally designed for the detection of low energy neutrinos and the search for the proton decay, LENA will also be capable of measuring neutrinos in the GeV range. Thus LENA can be used as the far detector of a next generation neutrino beam, offering two possible baselines, CERN-Frejus (130 km) and CERN-Pyhäsalmi (2300 km). At 300 MeV, muon and electron tracks can be reconstructed with an angular resolution of about 3° and $\sim 0.5\%$ energy resolution. An identification of the neutrino flavour is possible by either detecting the muon decay, or by the different typical pulse shapes of electrons and muons. Above 1 GeV, the neutrino energy can be reconstructed with 1% to 5% accuracy, depending on the event type. Up to 3 tracks in one event can be reconstructed, if they are longer than 1 m and clearly angularly separated. The angular resolution is a few degrees or better, depending on the event type. Muon tracks can be distinguished from electron tracks by the track lengths difference.

The backgrounds due to pion production by NC reactions (and CC reactions in case of neutrino energies below 1 GeV) are currently investigated.

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