Liquid Scintillation Neutrino Detectors

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Scintillation Principle

- Scintillator – materials which exhibits property of luminescence when excited by ionizing radiation.
- Liquid scintillator – A scintillator material in liquid form. (mixture of several organic liquids).

Available liquid scintillation Neutrino detectors

- KamLAND (Kamioka Liquid Scintillator Antineutrino Detector)
- BOREXINO (BORon Experiment)
- NOVA (NuMI Off-Axis νe Appearance)
- LENA (Low energy neutrino astrophysics)
- CLEAN (Cryogenic Low-Energy Astrophysics with Neon)

- LENS (Low Energy Neutrino Spectroscopy)
- Double chooz (Double Chooz Reactor Neutrino Experiment)
- DAYA BAY (Daya Bay Reactor Neutrino Experiment)

KamLAND

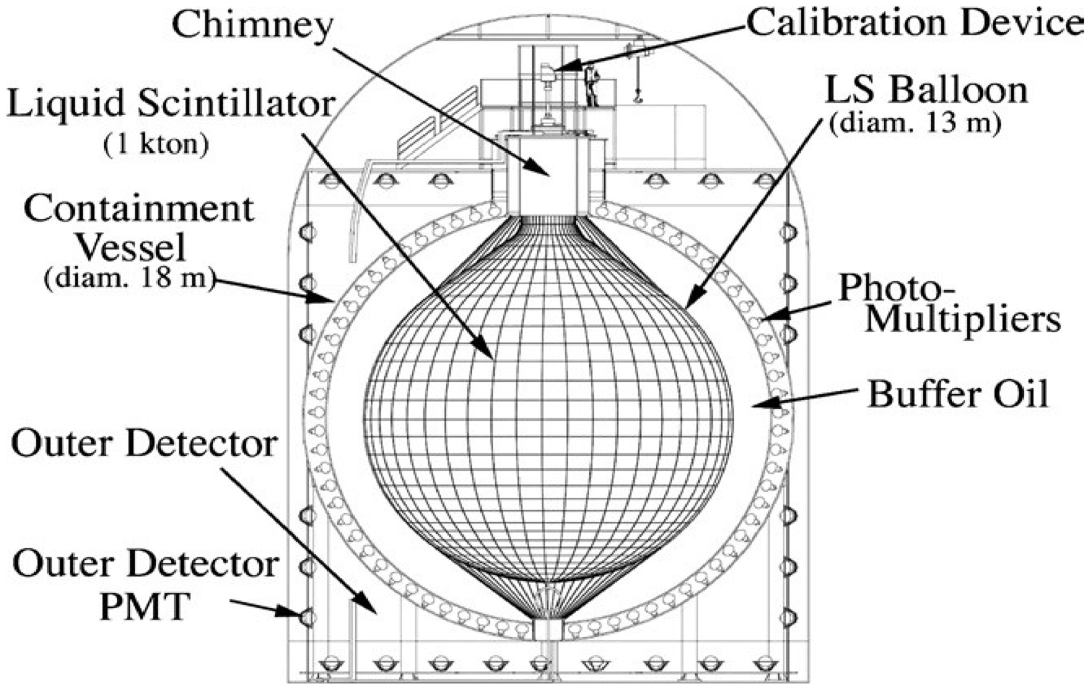
Kamioka Liquid-scintillator Anti-Neutrino Detector

- Uses Liquid organic scintillator as active neutrino target.
- The baseline from reactor is 180 Km.
- Determines a precise value for the neutrino oscillation parameter,

$$\Delta m^2_{21} = 6.9 \times 10^{-5}\ eV^2.$$

$$\sin^2\theta_{12} = 1.$$

View of kamLAND detector



Detector Description

- 1-kiloton liquid scintillator.

  80V% of normal-dodecane+20v% of pseudocumene+1.52g/liter of PPO.

  PPO is 2,5-Diphenyloxazole.

  Pseudocumene is 1,2,4 trimethylbenzene (gives high light output).

  Normal-dodecane is immune to oxidization.
- Base line is 180 Km.
- Contains two detector, outer and inner.
- The experiment is sensitive to antineutrinos from nuclear reactors that exceed the threshold energy of 1.8 MeV.

Detection of anti-neutrinos

- Detects the anti neutrino (electron) from distant reactor.
- Expected event rate is 2/day for the whole scintillator volume in absence of oscillation.
- Anti neutrino performs charged current interactions as below

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

- This positron produces scintillation light on passing through detector.
- Neutron thermalises by colliding with protons to produce 2.2MeV γ ray. $n + p \rightarrow d + \gamma \; (2.2 MeV)$
- This γ ray emission will take place after 200 μs after positron emission.
- By requiring coincidence between γ ray and positron scintillation light backgrounds can be eliminated.

Results

- Finds a large deficit of reactor neutrinos for the first time.
- Determines a precise value for the neutrino oscillation parameter,

$$\Delta m^2_{21} = 6.9 \times 10^{-5}\ eV^2.$$

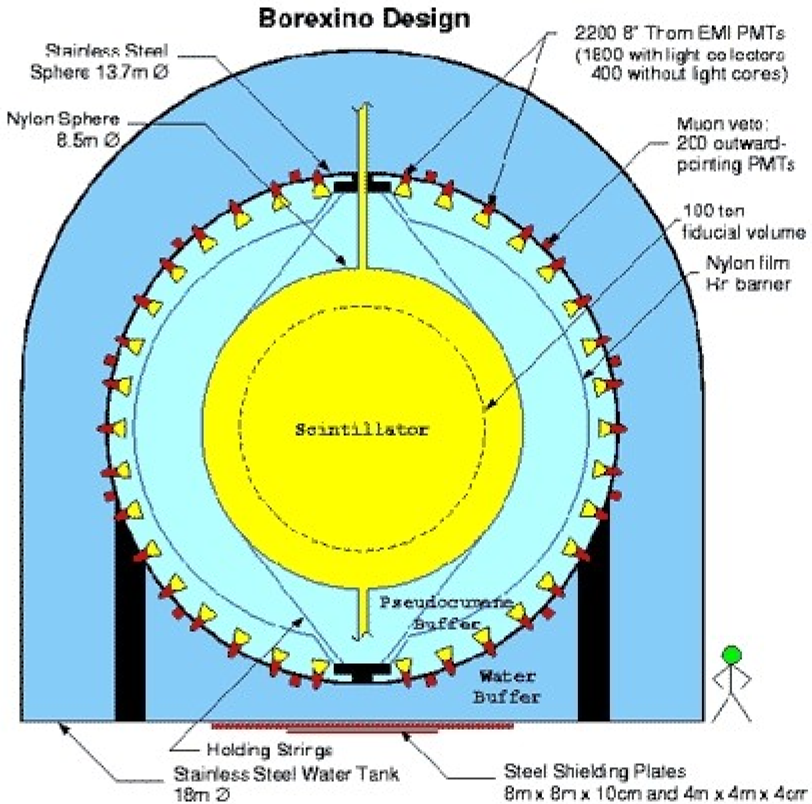
$$\sin^2\theta_{12} = 1.$$

BOREXINO Detector

(BORon Experiment)

- Solar neutrino detector operational in hall C of LNGS(operational since may-2007).
- Detects the ^{7}Be solar neutrinos.
- It's the experiment to detect low energy solar neutrinos (sub-MeV).
- Aimed at detection of 0.862 MeV ^{7}Be solar neutrino. Minimum Threshold of 250 keV.

View of BOREXINO Detector



Detector Description

- Unsegmented spherical detector made of 300 tones of shielded ultra pure liquid scintillator.

  pseudocumene (also called 1,2,4-trimethylbenzene),

  1.5 grams/liter of 2,5-diphenyloxazole, a fluor.

- Contains 2200 photo multipliers.
- Core is transparent sphere -nylon (100 μm thick) 8.5 m of diameter.
- External shielding is provided by 2400 tonnes of pure water acting as muon veto.

Detection of neutrinos

- Solar neutrinos are detected via elastic scattering off electrons: $\nu_x + e^- \rightarrow \nu_x + e^-$
- Low energy neutrinos of all flavours are detected by means of elastic scattering of electrons.
- Anti ν_e are detected by inverse beta decay on protons or carbon nuclei.
- The electron (Positron) recoil energy is converted into scintillation light which is collected by PMT.

Goals

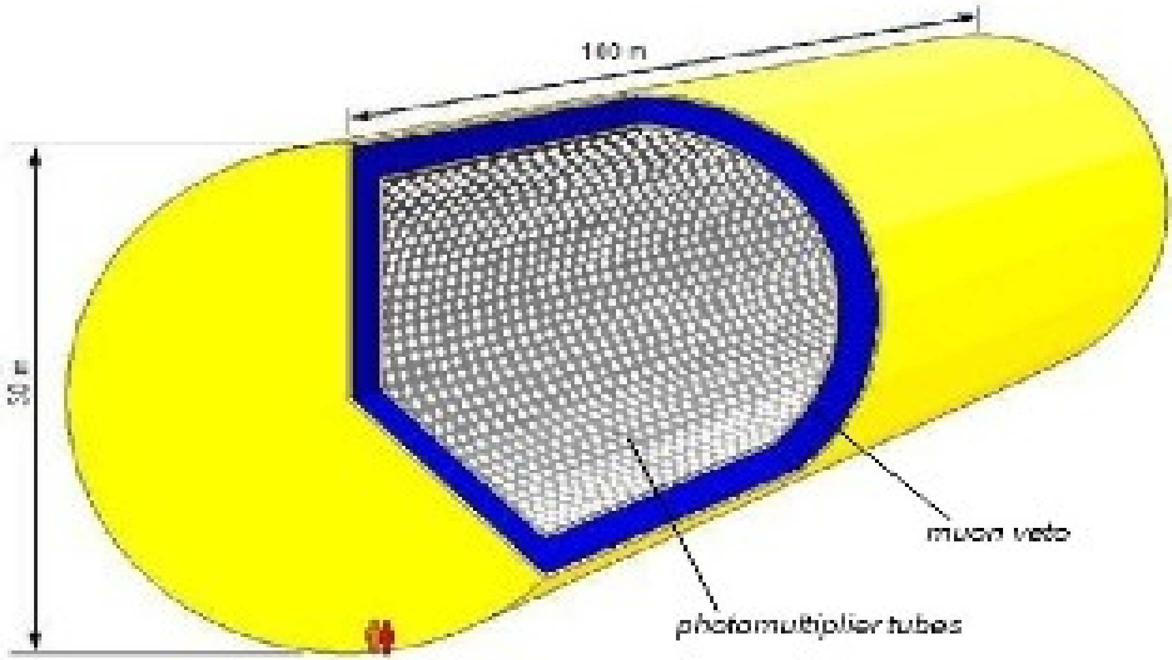
- To make precise measurement of the Beryllium-7 neutrino flux from the sun.
- This allows to understand the sun further and also helps to determine properties of neutrino propagation (MSW effect).
- Other goals are to detect Boron-8, pp, pep and CNO solar neutrinos as well as antineutrinos from the Earth and nuclear power plants.

LENA Detector

(Low energy neutrino astrophysics)

- Large volume Detector (50 kilo ton).
- Uses liquid scintillation principles.
- Provides high count rate even for rare events because of largest target mass of ~50 k tons.
- Organic liquid scintillator provides high energy resolution and background discrimination.

View of LENA Detector



Detector Description

- Double-walled cylinder with diameter of 30m and length 100m.
- Inner Volume is filled with 50 k ton liquid scintillator material and contains photo multiplier tubes.

  uses PXE (Phenyl-o-xylylethane $c_{12}H_{26}$) as scintillator solvent

  ~2g/l of pTP and 20mg/l of bisMSB as wavelength shifters.

- Outer part filled with water acts as muon veto.

- Water in outer part also shields the detector against external radioactivity.
- Proposed site is Pyhäsalmi in Finland.
- The detector will be placed in deep mine or deep underwater (~4000 meters of water equivalent).
- Alternative scintillator mixture of PXE and dodecane or on pure linear alkylbenzene can optimize characteristics.

Detection of neutrinos

- Enables precision measurements of neutrinos produced from,
  1) ν_e from the Sun.
  2) Anti ν_e from the Earth's crust and mantle.
  3) Neutrinos emitted by galactic supernovae and artificial nuclear reactors.
  4) The decay of the proton.

Expected Results

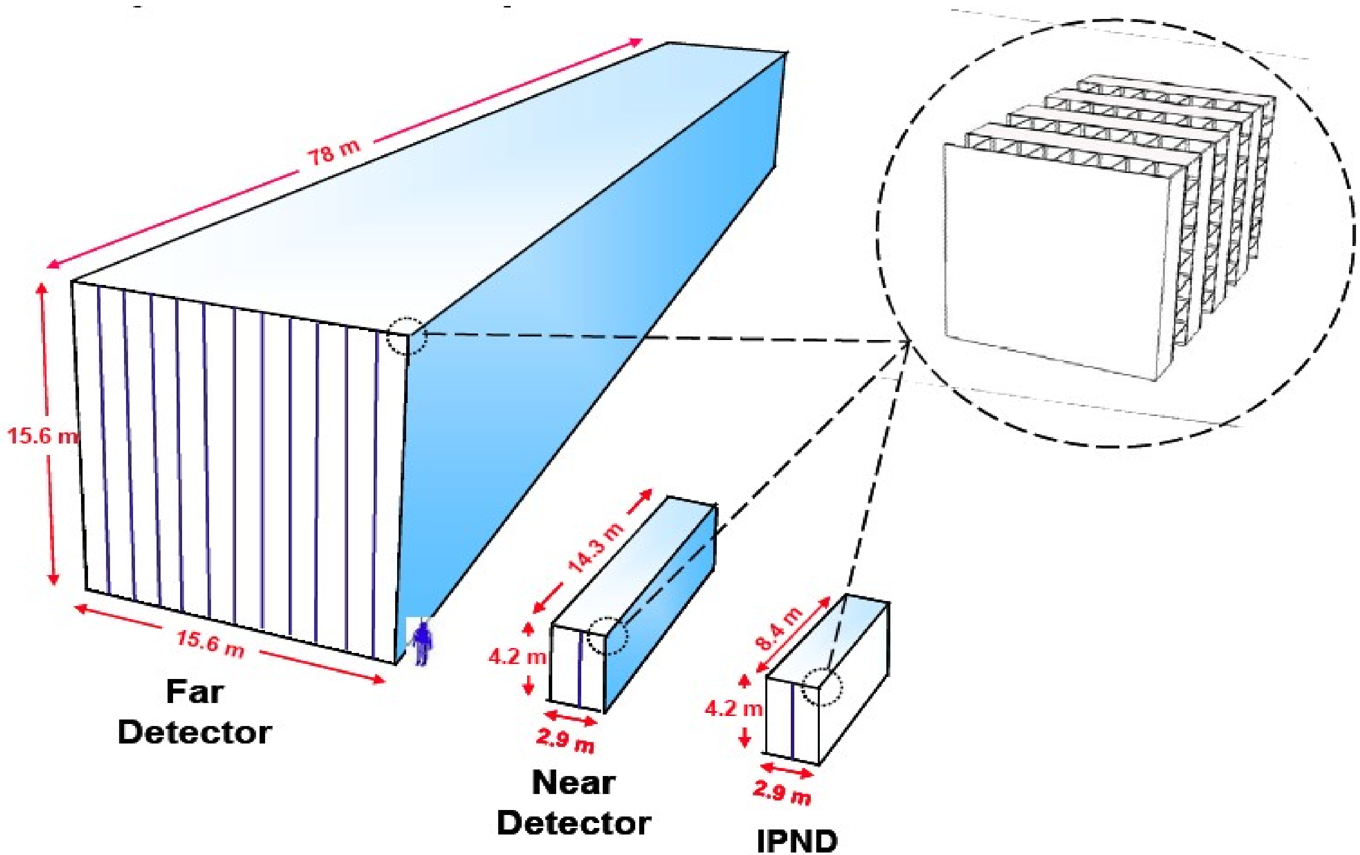
- By detection of geo-neutrinos (~10^3/year) the upper limit of 2TW can be achieved on thermal power of geo reactor.
- By detecting anti ν_e from nuclear reactor precise solar mixing angle and Δm^2_{21} can be found out.
- LENA can be used in long base line beta beam experiment to correctly identify muon neutrino at 90% level, suppressing ν_e background.

NOVA Detector

(A neutrino appearance experiment)

- Detects $\nu_\mu \rightarrow \nu_e$ oscillations in existing ν_μ beam.
- uses 15 kiloton liquid scintillator detector .
- The NOνA Experiment is based in Fermilab E929.
- The primary goal is to search for evidence of muon to electron neutrino oscillations.

View of NOVA Detector



Detector Description

- Uses two detector (Near and far).
- The near detector (222 metric ton) is placed in underground carven near to Fermilab site. (2.9 m x 4.2 m x 14.3 m)
- The far detector (15 metric kiloton) is placed in new facility near ash river (Near to U.S-Canada border). (15.6 m x 15.6 m x 78 m)

- Contains 385,000 cells of extruded PVC plastic Loaded with titanium oxide to enhance reflectivity.
- Each cell is 3.9 cm wide by 6.0 cm deep and is 15.5 meters long.
- The cells are filled with 3.3 million gallons of liquid scintillator.
- The Base line is 810 km from Fermilab at an off-axis of 12 Km from center of neutrino beam.

- The charged particles produced by the neutrino interaction inside the detector cause the liquid scintillator to produce light.
- Scintillation light is collected by 0.7mm diameter wave length shifter fibres along with APD (Avalanche photo diode) for Data collection.
- The threshold neutrino energy in this detector ~GeV.

Detection of neutrinos

- Detects the ν_e produced from ν_μ by comparing the ν_e flux with the near and the far detector.
- For a ν_e appearance experiment, the dominant background is neutral current π^0 production in the detector.
- For a fixed neutrino energy(Using off- axis strategy), the π^0 s from neutral current interactions will have a lower average energy than the electrons from the quasi-elastic process.

Expected results

- Tells about the oscillation of muon neutrinos to electron neutrinos.
- Tells about the ordering of neutrino masses.
- Answers the question of symmetry between neutrinos and antineutrinos.
- provides a measurement of the last unknown mixing angle, θ_{13}.