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Determination of Supernovae Direction with Reconstructed Positron Information

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Liquid Scintillator (LS) detectors feature low energy threshold and good energy resolution. Since scintillation light is isotropic, we cannot tell the track information. While cerenkov light is highly directional, we can derive the track info of the particles travelling in it. The direction reconstruction performance by using cerenkov light in scintillator detector is discussed in this manuscript. One potential usage of the direction information in LS detector is discussed. We can see improvements in determination of supernovae direction with reconstructed positron direction information.

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1. Introduction

Cerenkov light has unique polarization and directional properties. Neutrino observatory, such as Super-kamiokande, exploits cerenkov light to observe the direction of electrons produced in neutrino elastic scattering interactions,directly demonstrated that the sun was a source of neutrinos. Liquid scintillator neutrino observatory, such as Daya Bay, mostly exploit scintillation light. This kind of detector features low energy threshold for neutrinos interaction and high energy resolution. Scintillation light is isotropic, therefore no direction information can be derived based on scintillator light. It's feasible both theoretically and technically to pick up a large fraction of cerenkov light in a sea of scintillation photons [1, 2]. Here we study this separation power in JUNO detector and relevant elements that affect this power. Besides, a new Concept Scintillator Detector named WBLS [3] also tries to take advantage of both cerenkov light and scintillation light. It's really the trend.

2. lepton track in Liquid scintillator detector

The Jiangmen Underground Neutrino Observatory (JUNO) is a multi-purpose neutrino experiment.It consists of a central detector, a water Cherenkov detector and a muon tracker.The central detector is a LS detector of 20 kton fiducial mass and $3\%/\sqrt{E(MeV)}$energy resolution.The PMT photocathode coverage is $\geq$ 75%.The PMT photocathode quantum efficiency is $\geq$ 35%.The attenuation length of the liquid scintillator needs $\geq$ 20m at 430 nm. one possible way to distinguish cerenkov light and scintillating light is by their hittime difference[2]. we expect PMT detect cerenkov light earlier than scintillation light. First of all, all Liquid scintillator has fast and slow components, in the case of JUNO, this is 4.93*ns (79.9%) and 20.6*ns respectively. Therefore, there is a delay of several nanoseconds between the photon emission and the energy deposit. Opposed to scintillation, cerenkov radiation produced from very small displacements by a very large number of electrons ,occurs immediately after the particle has passed since electrons would return to their normal positions instantaneously[4]. Secondly, cerenkov radiation spectrum is continuousčňit has more long wavelength photons ratio than scintillation light.Long wavelength photon moves faster and has less absorption and remission chance in the transportation process in Liquid scintillator. Both makes cerenkov photon keeps ahead.

3. reconstruction of lepton track

There are two steps to reconstruct lepton track. Firstly, vertex reconstruction algorithm, Push and Pull method adopted from Kamland [6],should be executed. Then, pick up early hits on time of flight subtracted hittime pdf. If the electron momentum is 3.0 MeV and originated from the detector center, shooting straightly upwards, then by selecting hits whose hittime is less than 98.8 ns ,almost 50% of the hits are generated from cerenkov photons which contains electron direction information Fig. 1. Electron direction determination is by taking the centroid of all vectors pointing from the vertex to the hits on the photon detector.Due to scintillation light is isotropic, falsely picked up scintillation photons will not affect the direction determination.

Absolute cerenkov over scintillation fraction prediction in MC is difficult because of uncertainty in remission probability. Fortunately uncertainty in remission probability at wavelength $>$

300nm does not significantly affect Cerenkov fraction. The separation of cerenkov light and scintillation light relies on the recorded hittime from electronics readout system. Therefore PMT TTS can greatly diminish the power of separation. Besides, the separation power should be energy depended. For a higher energy,the ratio between direct cerenkov light and remitted scintillation light is increasing.Here in Geant 4 simulation, the input Birk's constant is $6.5\times10^{-3} g/cm^2$/MeV and the photon yield is 10400P.e. MeV.

Better track reconstruction performance is ascribed to higher cerenkov fraction in higher electron kinetic energy.In total,10 energy points are simulated.These energy are related to the energy of prompt signal from inverse beta decay of reactor antielectron neutrinos. The other two energy points are provided for future accelerator neutrino experiments. In Table 1, the 1σ error is defined as 68% reconstructed directions contained in a cone centered by the true direction within this angle.

kinetic energy/MeV	1/MeV	2/MeV	3/MeV	4/MeV	5/MeV
1 σ error	95.1°	78.4°	61.1°	50.7°	44.8°
kinetic energy/MeV	6/MeV	7/MeV	8/MeV	40/MeV	300/MeV
1 σ error	39.9°	34.1°	30.6°	10.2°	2.4°

Table 1: reconstruction performance.

4. supernovae direction determination

The supernovae is assumed as the explosion in the final stage of the stellar evolution, one of the most violent and spectacular events in the Universe. A core collapse supernovae (SN) may be not optically visible at all due to dust obscuration or because some collapsing stars may never blow up into supernovae. However, neutrino signal emerging from the core provides a way to determine supernovae direction. JUNO detector can detect about 5000 neutrino events from a 10 kpc supernovae. Neutrino fluxes spectral form are approximately parameterized by Eq. (4.1):Ref[5].

$$\phi(E_\nu) = N\left(\frac{E_\nu}{\langle E_\nu\rangle}\right)^{\alpha} exp\left[-(\alpha+1)\frac{E_\nu}{\langle E_\nu\rangle}\right] \tag{4.1}$$

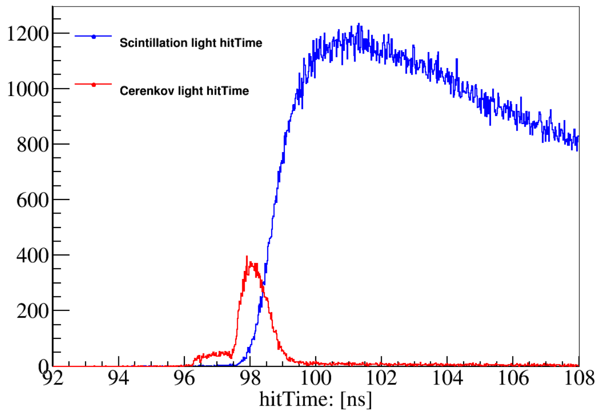

Figure 1: Hittime difference.

In simulation, α was taken to be 3 and mean neutrino energy $\langle E_\nu \rangle$ was 12.0 MeV.The expected supernova antielectron neutrino spectra is shown in Fig. 2.

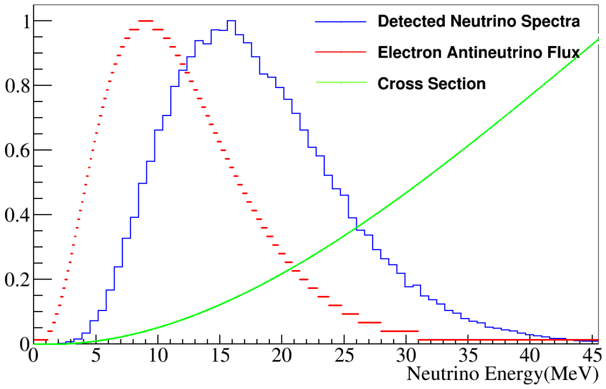

Figure 2: expected supernova spectra .

Positron direction information can be reconstructed from above procedures , here 1ns PMT tts is supposed. Neutrino direction can be calculated on a per event basis using conservation of momentum and energy. Two difference methods are applied to estimate SN direction. One is the same as [7], SN direction is estimated based on statistically averaged vector pointing from positron vertex to neutron vertex. SN direction uncertainty is 11.21°. The other method takes the statistically averaged anti-electron neutrino direction as SN direction, and the SN direction uncertainty is 8.17°. Thus, it helps supernovae direction determination if additive positron direction information is used.

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