PROCEEDINGS OF SCIENCE

PoS(EPS-HEP2019)417

Testing The MSW Effect in Supernova Explosion with Neutrino Event Rates

---

Shao-Hsuan Chiu[1], **Kwang-Chang Lai**[1], **Chun Sing Jason Leung**[*2] **and Guey-Lin Lin**[2]
[1]*Center for General Education, Chang Gung University, Kwei-Shan, Taoyuan, 333, Taiwan*
[2]*Institute of Physics, National Chiao Tung University, Hsinchu, 300, Taiwan*
E-mail: `jasonleung.py04g@g2.nctu.edu.tw`

The flavor transition mechanisms of supernova neutrinos as they propagate outward from the deep inside of a supernova are yet to be determined. We study the time-evolution patterns of different neutrino flavors in various flavor transition scenarios. With simulation data of supernova neutrinos, we calculate the neutrino event rates at different kinds of detectors for different flavor transition scenarios. Using the calculated event rates of IBD and ν_eAr in corresponding liquid scintillation detectors and liquid argon detectors, we calculate the ratios of two cumulative time distribution up to $t = 100$ ms in Nakazato's supernova models with 13, 20, and 30 $M_\odot$ progenitor mass. We show that the time evolutions of cumulative ratios are effective in determining whether MSW oscillations really occur

European Physical Society Conference on High Energy Physics - EPS-HEP2019 -
10-17 July, 2019
Ghent, Belgium

---

[*] Speaker.

I. Introduction

Flavor transitions of SN neutrinos have been an attractive field of research and motivated numerous efforts (See [2][1] for a review) on flavor changing during the gravitational core collapse of a massive star. Originating from deep inside the SN core, neutrinos are expected to experience significant flavor transitions as propagating outward to the terrestrial detectors. On account of MSW effects ν_e and $\bar{\nu}_e$ fluxes will swap with ν_x fully or partially when the neutrino vacuum oscillation frequency $\omega = \Delta m^2/2E$ is of the order of the matter potential, $\lambda = \sqrt{2}G_F n_e$. Here Δm^2 denotes one of the mass-squared differences, E the neutrino energy, and n_e the net electron density. For typical SN post-bounce matter profiles, this MSW-induced flavor conversions occur at distances of $\sim \mathscr{O}(10^3)$ km from the SN core where $\omega \simeq \lambda$. [1].

Flavor transitions are expected to change flavor compositions of primary SN neutrino fluxes and, hence, to leave imprints in neutrino events measured in terrestrial detectors. This motivates our study of probing flavor transitions with measurements of galactic SN neutrinos at the Earth. Unlike the status of MSW effects, consensus on collective flavor transitions has not yet been reached so studies of collective flavor transition effects on terrestrial SN neutrino fluxes are few. Meanwhile, the study of fast flavor conversions has just developed in recent years and is still far from a thorough understanding. Therefore, we focus on MSW effects in SN neutrinos. Based on the understanding that MSW effects are sensitive to neutrino mass hierarchy, lots of studies are inspired to probe NMH by using SN neutrino events detected at the Earth. These studies all assume the occurrence of MSW effects. In this work, we, instead, investigate the capability to probe whether MSW effects occur in SN neutrinos or not. Based on the simulated SN neutrino emissions, we calculate the event rates of ν_eAr interaction in liquid argon detector and inverse beta decay in liquid scintillation detector. By comparing the two event rates in the neutronization era, we show that their cumulative ratio is effective in determining the occurrence of MSW effects for SN neutrinos.

II. Supernova Neutrino Events and Occurrence of MSW Effects

A SN neutrino burst lasts for $\Delta t \approx 10$s, during which the neutronization burst happens at $t_{pb} \sim 10-15$ms. Here, t_{pb} denotes the post-bounce time. In our calculation, we extract the primary neutrino fluxes from the SN simulation [6] for progenitor masses of 13, 20, and 30 $M_{\odot}$, accounting for SNe with iron core. With these neutrino fluxes, we calculate event rates of SN neutrinos for all flavors, ν_e, $\bar{\nu}_e$, and ν_x, whether no oscillations occur to modify the flavor contents or they are changed by MSW effects as SN neutrinos propagate outward from the core. In the latter case, both normal and inverted hierarchies are taken into consideration. To encmopass the whole duration of the neutronization burst, we perform our analysis for a time period of $\Delta t = 0.1$ s from the start. The event rates and quantities induced from these rates are displayed in numbers per bin with a 5 ms bin width throughout this article.

Assuming a SN at a distance of 5 kpc, the event rates of ν_eAr [8] in DUNE [7] and those of IBD [3] in JUNO [4] are shown in Fig. 1. To account for the sharp rise of ν_e flux during the neutronization burst, we define cumulative time distributions of the SN neutrino signals for the

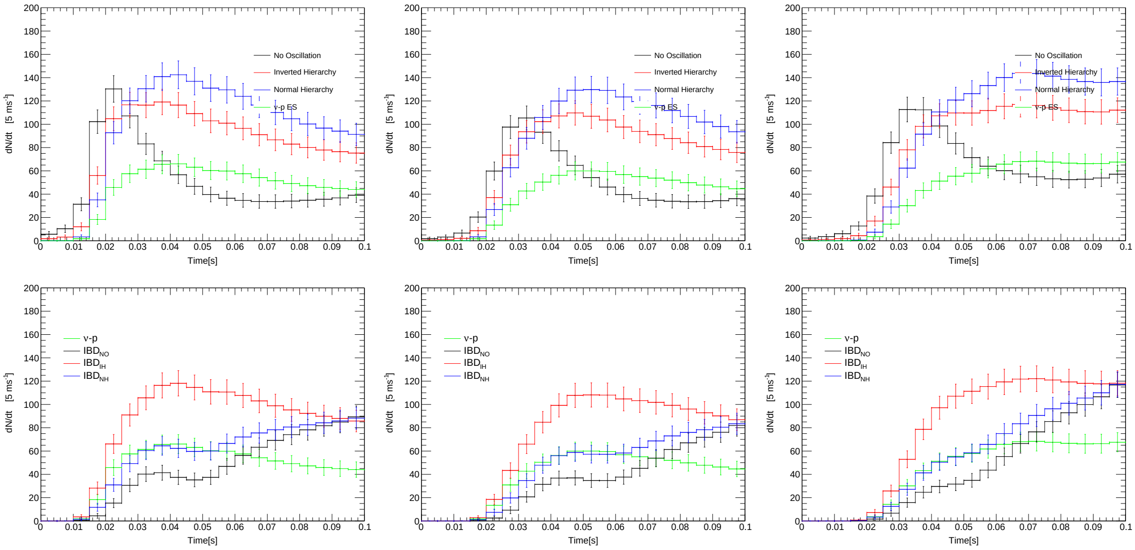

Figure 1: Event rates of ν_eAr and IBD in different flavor transition are shown on the upper and lower panels, respectively, with event rates of pES as a reference. These event rates are obtained with progenitor masses of 13, 20, and 30 M$_\odot$, from left to right.

time interval of interest $t = 0 - 0.1$s as in [5]

$$K(t) = \frac{\int_0^t \frac{dN}{dt} dt}{\int_0^{0.1\text{s}} \frac{dN}{dt} dt} \tag{II.1}$$

In Fig. 2, we show K_{Ar} and K_{IBD}, the cumulative distributions of ν_eAr and IBD event rates, on the upper and lower panels, respectively, in non-oscillation scenario and NH and IH MSW scenarios. To illustrate that non-oscillation scenario can be distinguished from MSW scenarios, a ratio between the cumulative signals, K_{Ar} and K_{IBD}, is defined as

$$K_r(t) \equiv \frac{K_{\text{Ar}}(t)}{1 + K_{\text{IBD}}(t)} \tag{II.2}$$

As shown in Fig. 3, K_r's in non-oscillation are larger than in MSW scenarios. In non-oscillation scenario, the ratio K_r grows faster to a maximum of ~ 0.55 around $t \gtrsim 50$ ms and then slowly decreases to 0.5 at $t = 0.1$ s. Meanwhile, K_r in MSW scenarios increases monotonically to 0.5 at $t = 0.1$ s, with a slower pace. It is clearly seen that the black curve, the time evolution of K_r for the non-oscillation scenario, can be distinguished from the colored curves, the time evolutions for MSW scenarios.

III. Summary and Conclusions

We have proposed a method to testify the occurrence of MSW effects in SN neutrinos by measuring the of SN neutrino event rates during the neutronization burst in liquid argon and scintillation detectors. $\nu_e Ar$ events in liquid argon detectors and IBD events in scintillation detectors

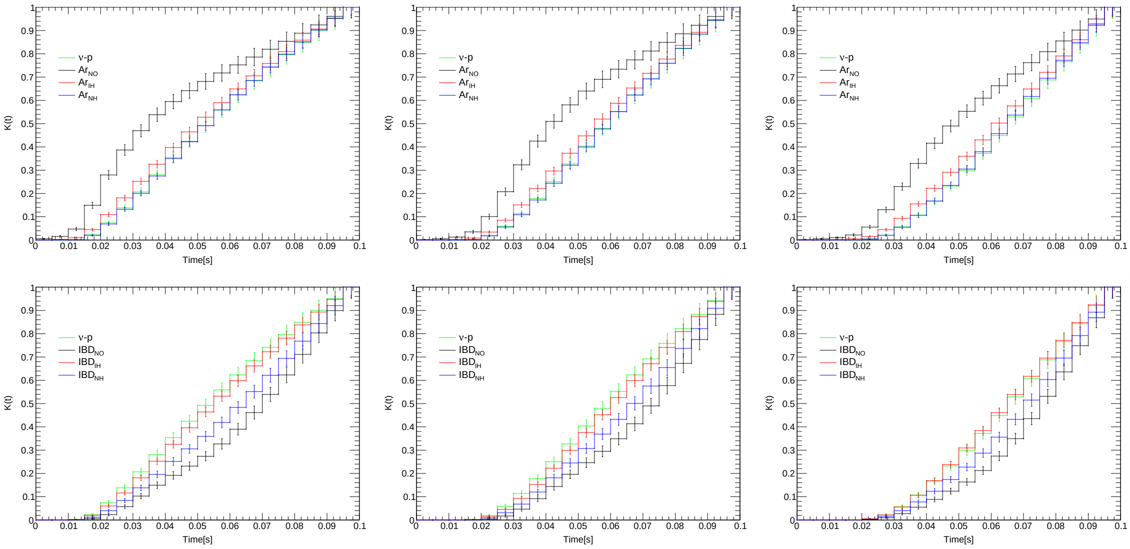

Figure 2: Cumulative distribution of ν_eAr signals, on the upper panel, and of IBD signals, on the lower panel, for the time period of 0.1s.

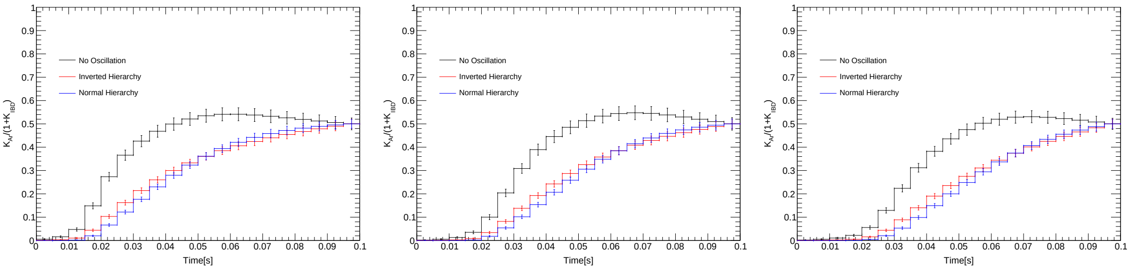

Figure 3: Ratio between cumulative distribution of ν_eAr and of IBD for the time period of 0.1s for progenitor masses of 13, 20, and 30 $M_\odot$, from left to right.

are taken to define a cumulative event ratio K_r. The ratios are calculated with SN neutrino emissions extracted from SN simulation data for progenitor masses of 13, 20, and 30 $M_\odot$, which covers most of the mass range of iron-core SNe. With this ratio, we have shown whether MSW effects occur for SN neutrinos or not can be probed by comparing the time evolutions of ν_eAr event rates in liquid argon detectors and IBD event rates in liquid scintillation detectors.

References

[1] L. Wolfenstein, Phys. Rev. D **17**, 2369 (1978).

[2] A. S. Dighe and A. Y. Smirnov, Phys. Rev. D **62**, 033007 (2000), arXiv:hep-ph/9907423.

[3] A. Strumia and F. Vissani, Phys. Lett. B **564** (2003) 42-54, astro-ph/0302055.

[4] F. An *et al.* [JUNO Collaboration], J. Phys. G **43**, no. 3, 030401 (2016), arXiv:1507.05613.

[5] Tobias Fischer, Lorenz Hudepohl et al., “Probing the neutrino mass hierarchy with the rise time of supernova burst", Phys.Rev. D85 085031

[6] K. Nakazato et al., “Supernova Neutrino Light Curves and Spectra for Various Progenitor Stars: From Core Collapse to Proto-neutron Star Cooling", Astrophys.J.Supp.205:2,2013

[7] DUNE Conceptual Design Report, arXiv:1512.06148v2 [physics.ins-det]

[8] I. Gil-Botella, A. Rubbia, “Oscillation effects on supernova neutrino rates and spectra and detection of the shock breakout in a liquid Argon TPC", JCAP0310:009,2003