shock wave propagation, which is in reasonable agreement with 56.7 % decrease as shown by their calculations. We thus conclude that their theoretical calculations and ours of the neutrino event rates agree with each other despite several essential differences: We solved in Eq. (1) both flavor conversion of neutrinos and supernova density profile numerically in our method described in Sec. 1, while Fogli et al. [27] applied an artificial model of density profile of shock wave propagation without solving dynamical supernova explosion.

For further comparison, let us analytically estimate the decrease in the neutrino events in the non-adiabatic case (with shock) compared with the adiabatic case (without shock). In the non-adiabatic case, we define the survival probability of $\bar{\nu}_e$ as $\bar{P} = 0.7$ in our model, and we use the result of $\bar{\nu}_e$ in the case of normal hierarchy in Fogli's model. We set $\bar{P} = 0$ in the adiabatic case. Thus estimated analytical results show 62.3 % and 63.0 % decrease in the neutrino events from adiabatic to non-adiabatic cases in our model and their model, respectively. These values are close enough to each other, and $\sim 60\%$ are not very different from $\sim 55.0\%$ which was inferred from numerical calculations as discussed in the previous paragraph. This fact justifies that our treatment of analytical estimates are reasonable. Therefore, regardless of all possible differences between the two models, the supernova neutrinos provide a powerful tool to indicate the shock wave propagation inside supernova if $\sin^2 2\theta_{13}$ is large in the inverted hierarchy.

We assumed that CP violating phase is zero and $\sin^2 2\theta_{23} = 1$ throughout this study. However, CP-phase is unknown and there is an uncertainty in the mixing angle θ_{23}. Here we discuss the dependence of the shock effect on neutrino flavor transitions on CP-phase and θ_{23}. Transition probabilities of neutrinos in arbitrary density profile have been studied theoretically in [65], where it was found that the transition probabilities of $\nu_e \to \nu_e$ and $\bar{\nu}_e \to \bar{\nu}_e$ do not depend on CP-phase and mixing angle θ_{23} at all. Furthermore, one can show from their formula in [65] that the sum of the transition probabilities of $\nu_\mu \to \nu_e$ and $\nu_\tau \to \nu_e$ ($\bar{\nu}_\mu \to \bar{\nu}_e$ and $\bar{\nu}_\tau \to \bar{\nu}_e$) are totally free from CP-phase and θ_{23}. Since the spectra of ν_μ and ν_τ ($\bar{\nu}_\mu$ and $\bar{\nu}_\tau$) are the same at the neutrino sphere, the transition probability from ν_μ or ν_τ ($\bar{\nu}_\mu$ or $\bar{\nu}_\tau$) to ν_e ($\bar{\nu}_e$) can be written as a half of the sum of the transition probabilities of $\nu_\mu \to \nu_e$ and $\nu_\tau \to \nu_e$ ($\bar{\nu}_\mu \to \bar{\nu}_e$ and $\bar{\nu}_\tau \to \bar{\nu}_e$). The transition probability from ν_μ or ν_τ ($\bar{\nu}_\mu$ or $\bar{\nu}_\tau$) to ν_e ($\bar{\nu}_e$) does not depend on CP-phase and θ_{23}. We thus conclude that there is no effect of CP-phase and mixing angle θ_{23} on the supernova neutrino spectra.

If the influence of the shock wave is seen very early ($t \leq 1s$) in the observation of the