Electron Neutrino Mass Measurement by Supernova Neutrino Bursts and Implications for Hot Dark Matter

戸谷 友則

(Tomonori Totani)

Univ. of Tokyo, Dept. Phys.

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Introduction

- Future Galactic Supernova would produce huge number of neutrino events in underground detectors such as the SK
- We can constrain the neutrino masses by observing the arrival time delay of ν's, at least down to ~100 eV.
- Present upper limits on ν masses (PDG1996):
  - ν_e : < 10-15 eV
  - ν_μ : < 170 keV (90% C.L.)
  - ν_τ : <24 MeV (95% C.L.)
- Neutrino events in the Super-K are dominated by electron anti-neutrinos (~5000 events for a SN at D=10 kpc)
- We propose a new method to constrain the electron neutrino mass which is sensitive to ~3 eV.

Implications on Hot Dark Matter:

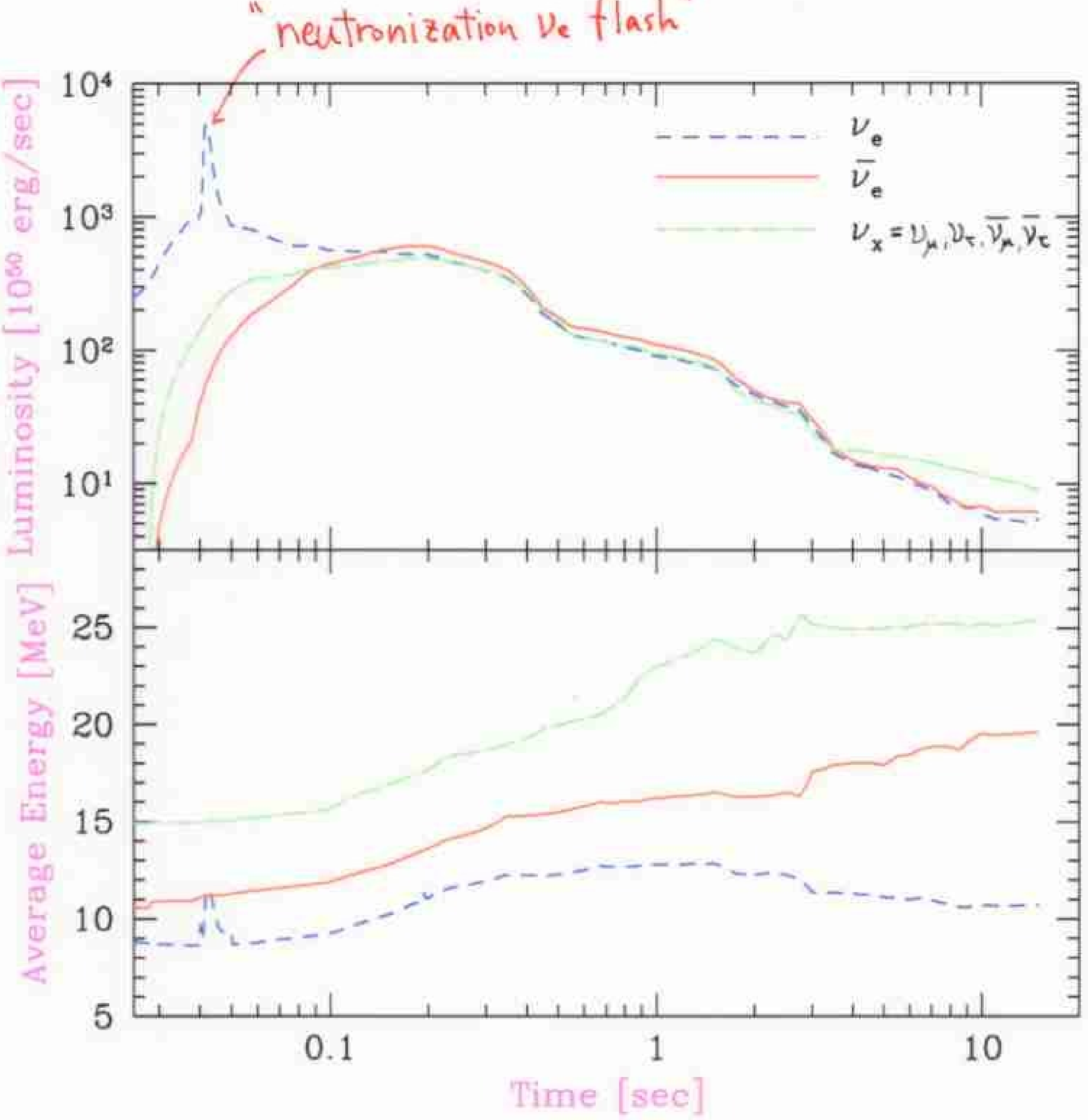
- Solar Neutrino Problem:
  - » MSW between $\nu_e \leftrightarrow \nu_\mu$,
    $\Delta m^2 \sim 10^{-5}$ eV^2
- Atmospheric Neutrino Problem:
  - » Vacuum osc. between $\nu_\mu \leftrightarrow \nu_\tau$,
    $\Delta m^2 \sim 10^{-2}$ eV^2
- Density Fluctuation in the Universe
  - Standard CDM..... ×
  - » cold+hot dark matter with $\Omega_\nu \sim 0.3$?

- Solution: Nearly Degenerate Mass Hierarchy with

$$m_\nu = 4.6 \left(\frac{H_0}{70 \text{ km / s / Mpc}} \right)^2 \left(\frac{\Omega_\nu}{0.3} \right) \text{ [eV]}$$

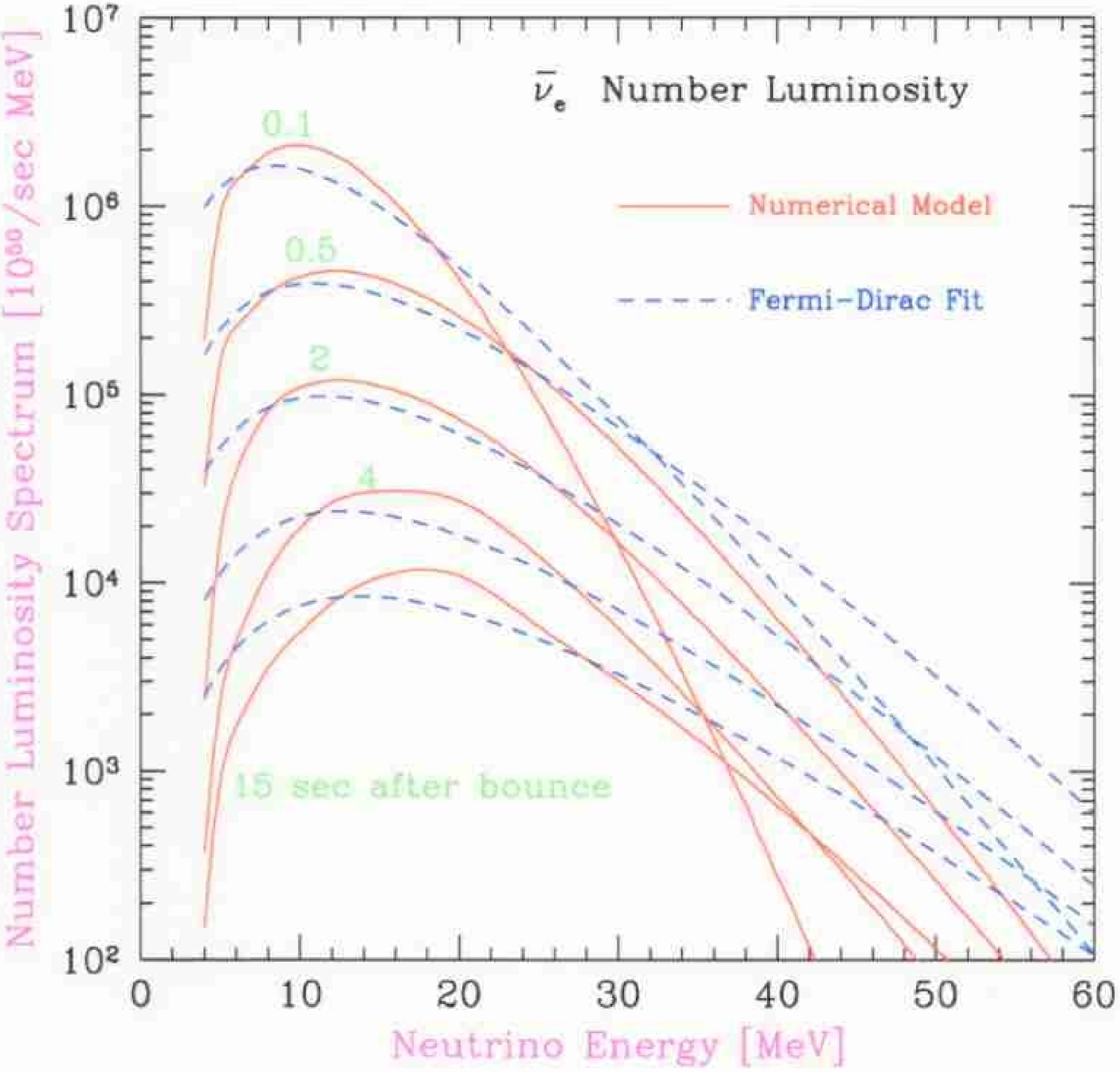
  - Caldwell & Mohapatra 1993
  - Petcov & Smirnov 1994
  - Joshipura, 1994

- Detectable by this method!



Totani, Sato, Dalhed, & Wilson 1998

ApJ 496 216



Totani et al. (1998) ApJ 496 216

Monte-Carlo Simulations of the SK detection of Supernova Neutrino Bursts

- Source Neutrino Flux:
  - result of an one-dimensional simulation by Wilson, Mayle, & Dalhed (1997)
  - includes all six types of ν without assumption of the Fermi-Dirac spectrum
- MC simulation of the Super-K detection (Totani et al. 1998)
  - taking account of the four reactions of

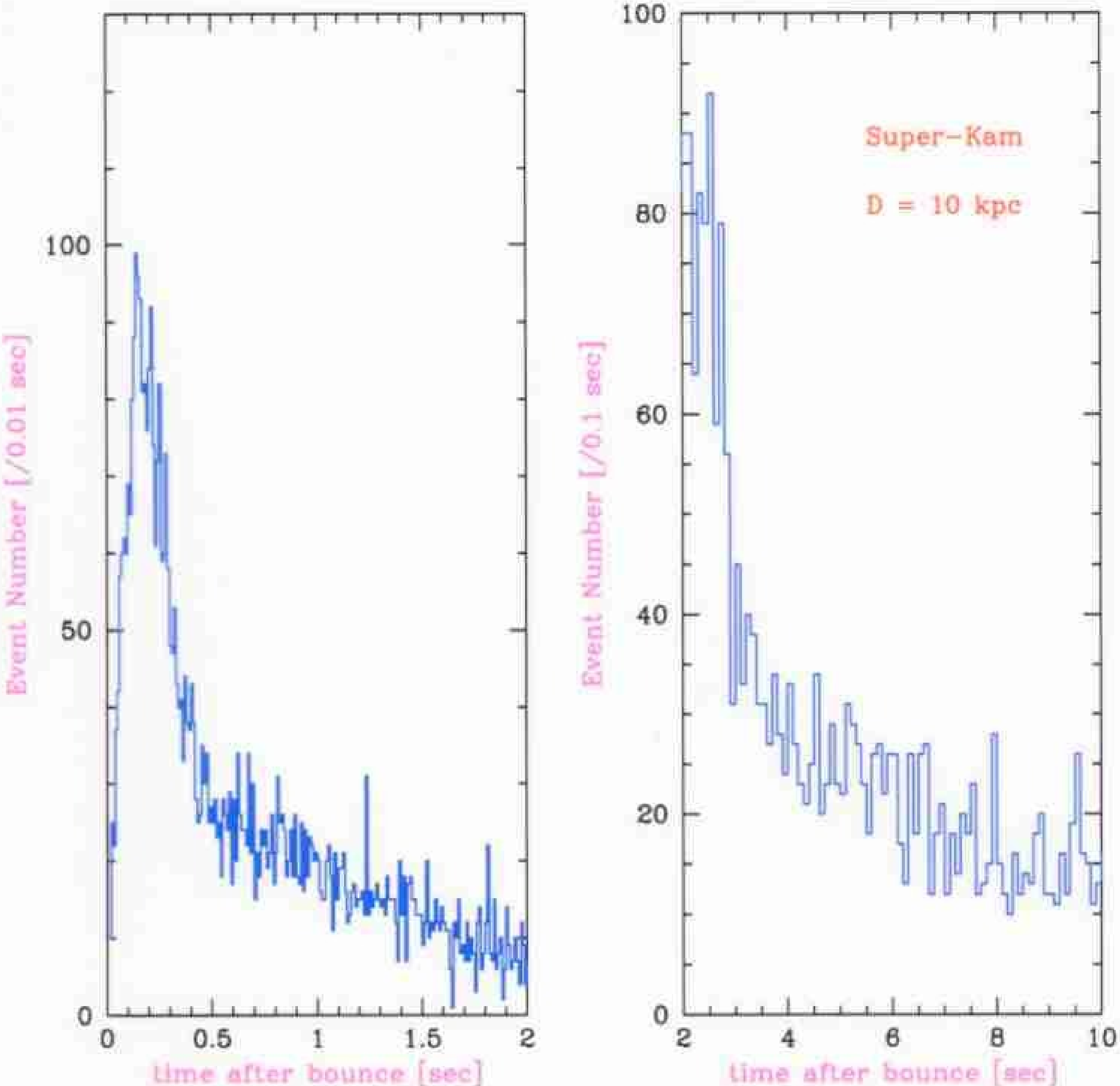
$$\bar{\nu}_e + p \rightarrow n + e^+ \quad \sim 8000 \text{ events}$$

$$\nu + e^- \rightarrow \nu + e^- \quad \sim 200$$

$$\left.\begin{array}{l} \nu_e + {}^{16}\mathrm{O} \rightarrow e^- + {}^{16}\mathrm{F} \\ \bar{\nu}_e + {}^{16}\mathrm{O} \rightarrow e^+ + {}^{16}\mathrm{N} \end{array}\right\} \sim 100$$

if D = 10 kpc

  - Energy resolution and detection efficienty are appropriately taken into account.
- This MC simulation is used to check the reliability of the proposed strategy.



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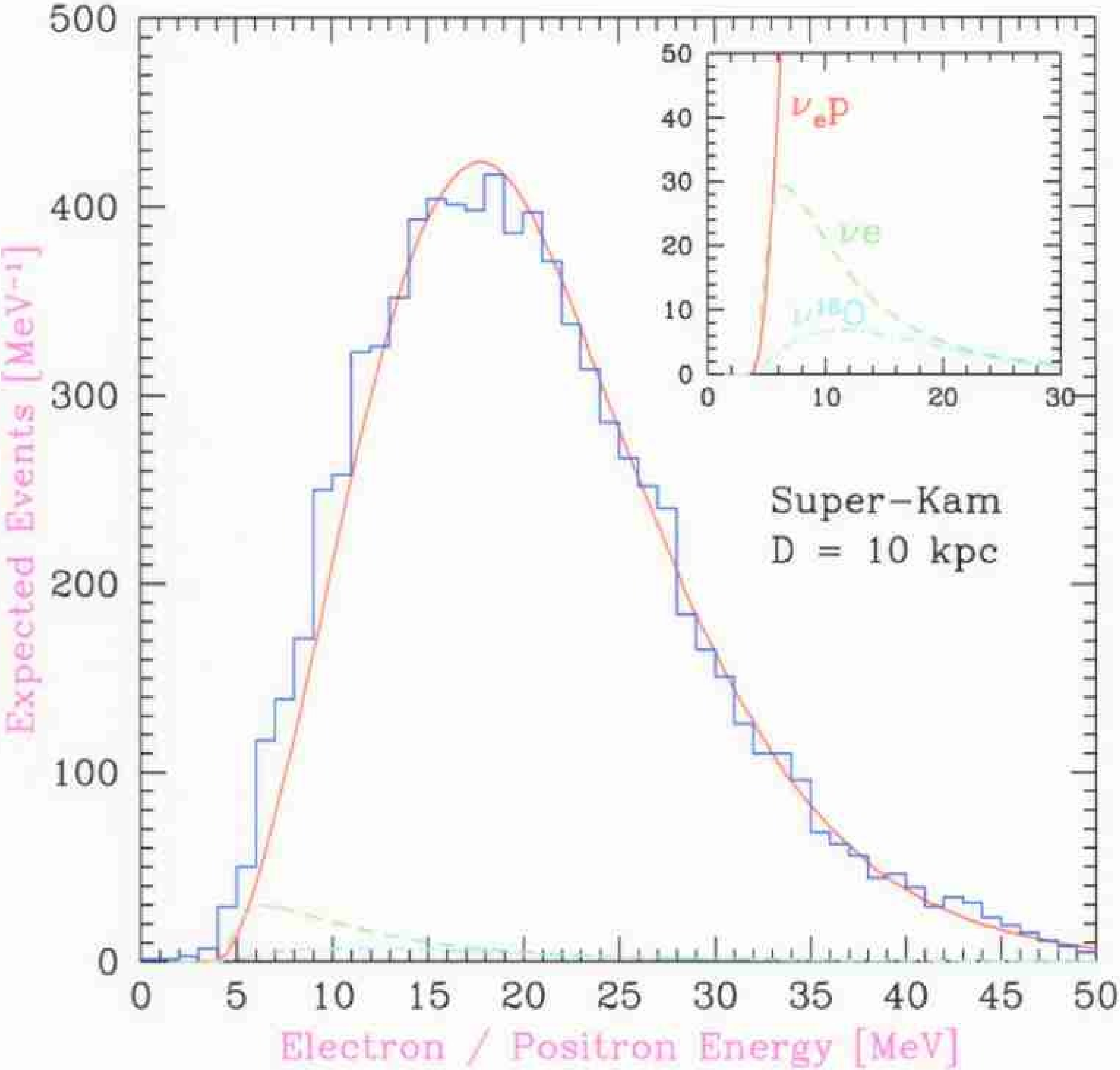
1998, ApJ, 496 216



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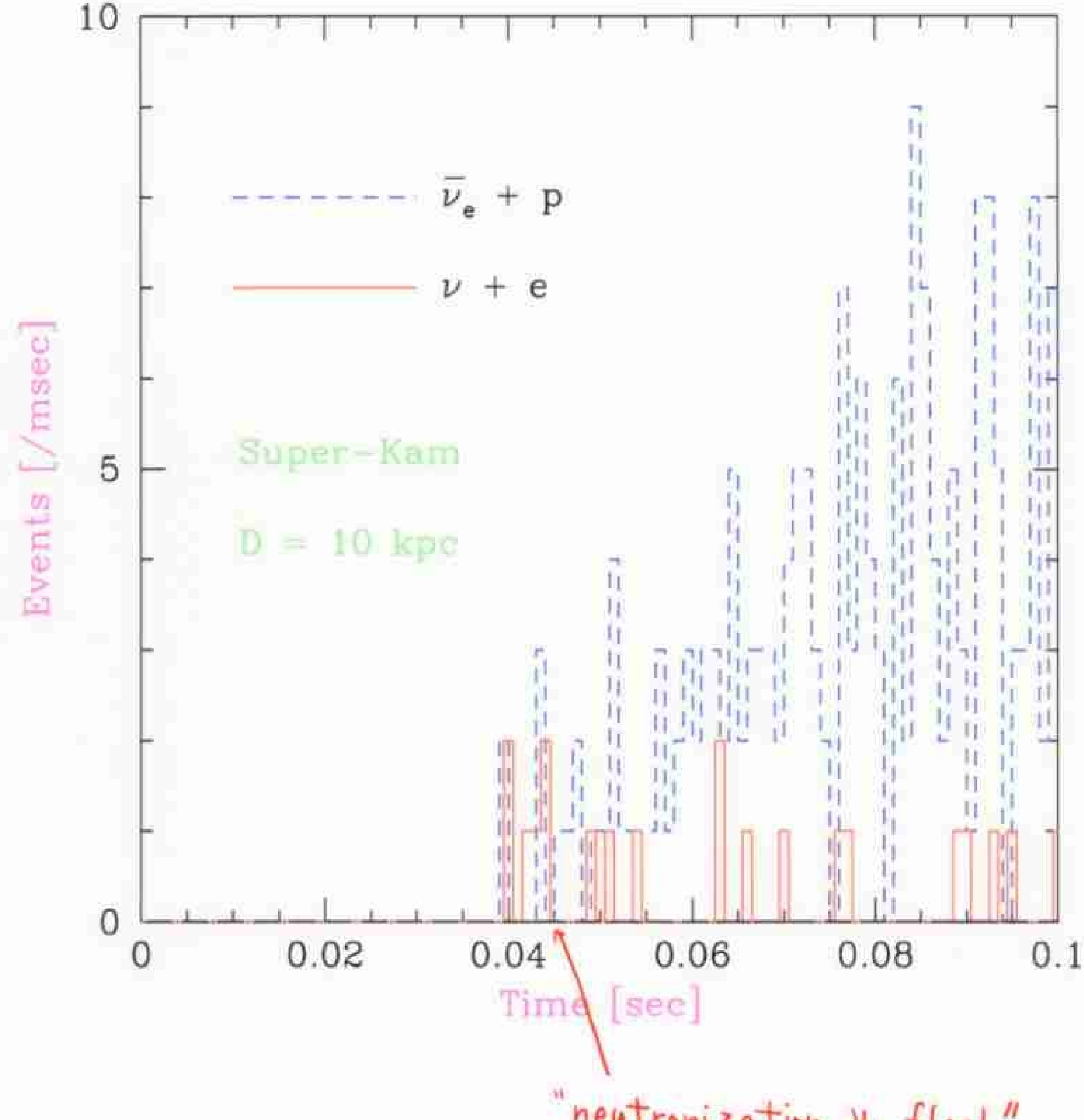


"neutronization ν_e flash"

~ a few events if D=10 kpc

Probing ν_e Mass by Supernova Neutinos

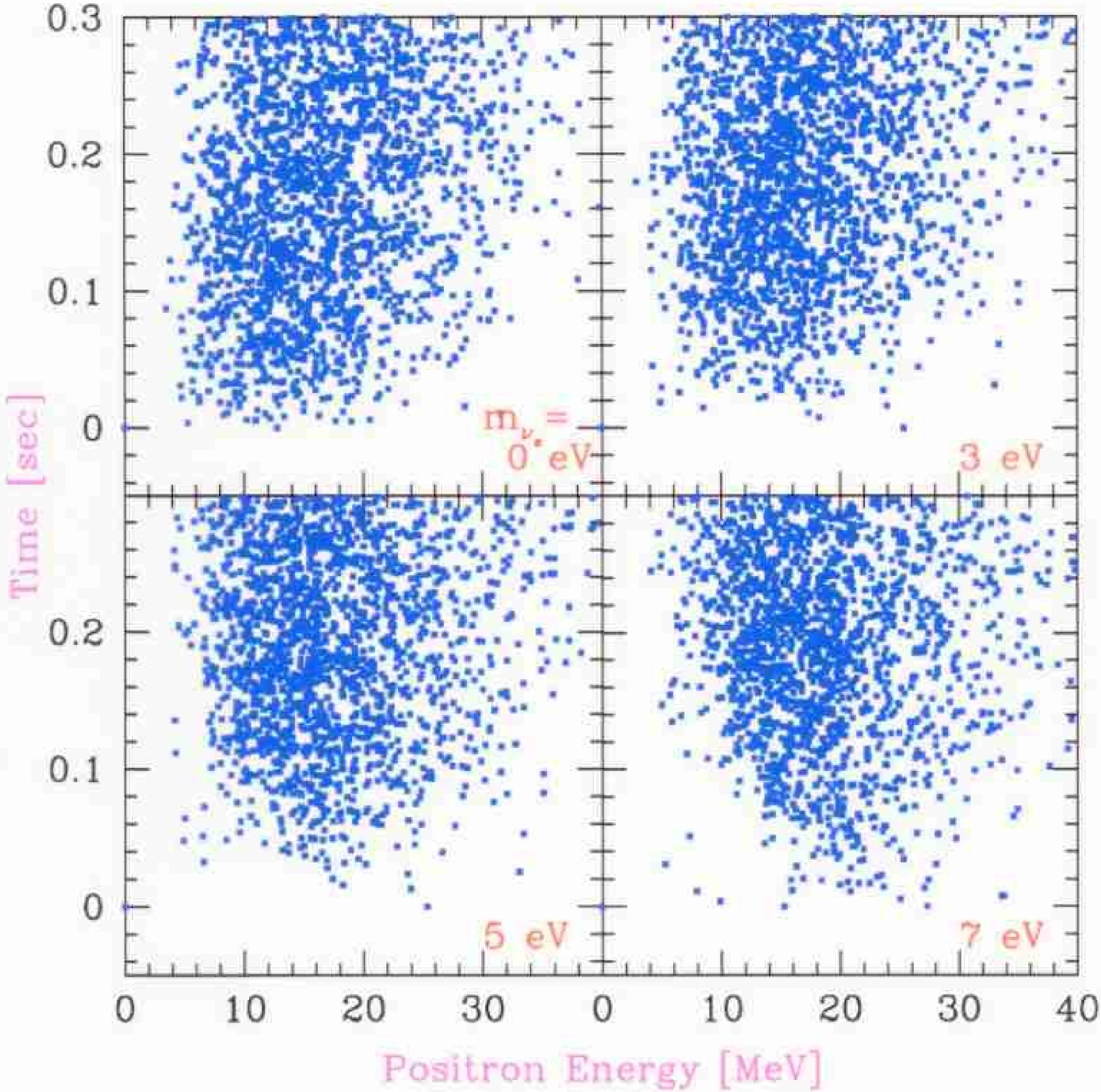
- Time Delay:

$$\Delta t = 5.15 \left(\frac{D}{10\ \mathrm{kpc}} \right) \left(\frac{m_\nu}{1\ \mathrm{eV}} \right)^2 \left(\frac{\varepsilon_\nu}{10\ \mathrm{MeV}} \right)^{-2} \mathrm{msec}$$

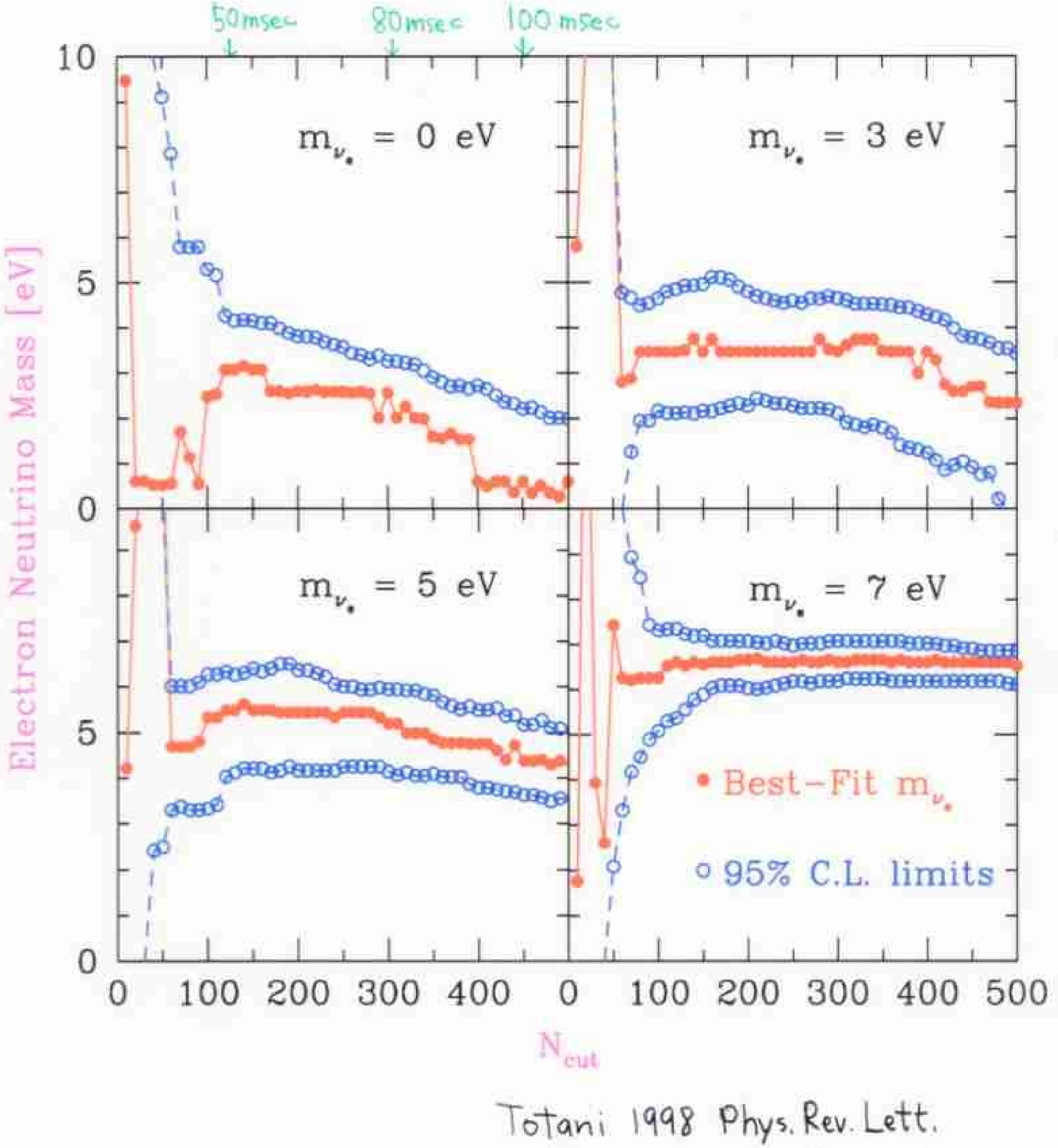
- Time Scale in ν Luminosity Evolution
  - late cooling phase ~1-10 sec

    → ν_e mass ~ 30 eV
  - initial rise of ν Luminosity ~1-10msec

    → ν_e mass ~ 1 eV
- The late cooling phase was used for SN1987A because of shortage of events, but we can use the initial rise in the next Galactic supernova.
- The characteristic of our method is the use of this initial rise of ν luminosity.



Time [sec]
Positron Energy [MeV]
m_ν = 0 eV
3 eV
5 eV
7 eV
0
0.1
0.2
0.3
0
10
20
30
40



Totani 1998 Phys. Rev. Lett. 80, 2039

- Neutrino Oscillation?
  - (almost) complete conversion between $\bar{\nu}_e \leftrightarrow \bar{\nu}_\mu$ or $\bar{\nu}_\tau$
    - MSW under inverse mass hierarchy
    - magnetic moment ($\sim 10^{-12} \mu_B$?)

    We can measure the mass of ν_μ or ν_τ

  - mixture of $\bar{\nu}_e$ and $\bar{\nu}_\mu$ or $\bar{\nu}_\tau$
    - vacuum oscillation with large mixing

  - if $m_{\nu_e} \ll m_{\nu_\mu} \ll m_{\nu_\tau}$:

    this method is not applicable.

  - if $m_{\nu_e} \simeq m_{\nu_\mu} \simeq m_{\nu_\tau}$:

    this method is still applicable.

- Dependence on the distance to SN
  - two competing effects:
    - event number ↗ with D ↘
    - time delay ↘ with D ↘
  - The sensitivity (~ 3eV) is almost constant for a SN in our Galaxy

Summary

- We have proposed a new method to constraint the electron neutrino mass by future detection of a Galactic SN by the Super-Kamiokande.
- We need not assume or specify any SN ν model parameters.
- The only assumption is constant spectrum of neutrinos during the first 100 msec, which seems a good approximation from recent supernova calculations.
- The reliability of this method is checked by a test using realistic Monte-Calro simulations of the SK detection.
- The method is sensitive to a mass of $\sim$3 eV, which is as low as the prediction of the cold+hot dark matter universe with nearly degenerate mass hierarchy.