Detection of supernova ν_e in Gd loaded Super-Kamiokande

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Motivation

- Supernova νs carry ~99% of total energy --- need to detect all flavors in adequate numbers
- Neutrino flavors that can be detected easily at present

  (i) $\bar{\nu}_e$ via inverse beta (IB) interaction $\boxed{\bar{\nu}_e + p \to e^+ + n}$

  (ii) $\nu_x = (\nu_\mu + \nu_\tau)$ & antiparticles via elastic scattering on protons in liquid scintillator detectors $\boxed{\nu + p \to \nu + p}$
- Presently NO good way to measure ν_e in large numbers
- Largest number of ν_e signal interactions is in Super-Kamiokande via $\boxed{\nu_e + e^- \to \nu_e + e^-}$
- $\boxed{\nu_e + {}^{16}\mathrm{O} \to e^- + {}^{16}\mathrm{F}^*}$ gives comparable number of events when the average energy of ν_e is high
- Efficient way to detect these ν_e in Gd loaded Super-K

Assumptions

- Energy carried by Galactic (~ 10 kpc) supernova = 3 × 10^{53} erg --- equally divided between all neutrino species
- Different cases of neutrino average energies:

(a) $\langle E_{\nu_e}\rangle = 12\,\mathrm{MeV}, \langle E_{\bar{\nu}_e}\rangle = 15\,\mathrm{MeV}$ & $\langle E_{\nu_x}\rangle = 18\,\mathrm{MeV}$

(b) $\langle E_{\nu_e}\rangle = 18\,\mathrm{MeV}, \langle E_{\bar{\nu}_e}\rangle = 15\,\mathrm{MeV}$ & one of the ν_x has an average energy of 12 MeV and the others have 18 MeV ➔ $\nu_e \leftrightarrow \nu_x$

(c) $\langle E_{\nu_e}\rangle \approx 11\,\mathrm{MeV}$ & $\langle E_{\bar{\nu}_e}\rangle \approx \langle E_{\nu_x}\rangle \approx 15\,\mathrm{MeV}$

- $$\frac{dN}{dE_\nu} = \frac{128}{3}\frac{E_\nu^3}{\langle E_\nu\rangle^4}\exp\left(-\frac{4E_\nu}{\langle E_\nu\rangle}\right)$$
- Galactic supernova is detected in a water Cherenkov detector loaded with gadolinium --- we take the example of Super-Kamiokande (32 kton)

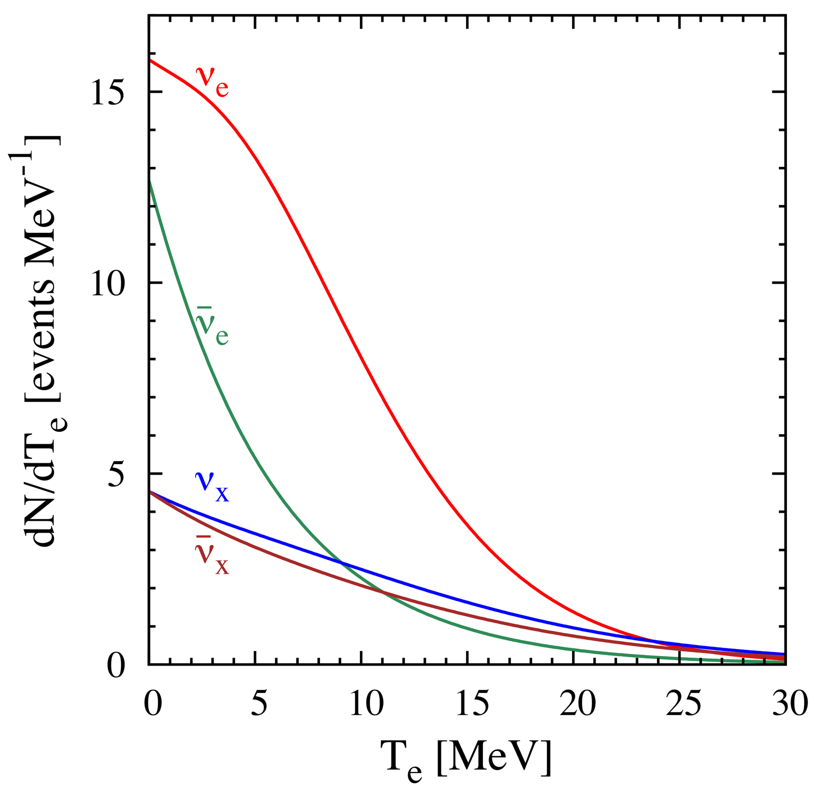
Detection strategy

- Use angular cut to isolate the electrons from $\nu_e + e^- \to \nu_e + e^-$ --- inverse beta backgrounds still too large
- Gadolinium in Super-K ➔identify neutrons ➔ remove inverse beta events individually with high efficiency
- Remove the remaining smaller backgrounds statistically
- When $\langle E_{\nu_e}\rangle$ is high ➔ ^{16}O is important ➔ detect electrons in the "backward" cone ➔ Gd helps in removing the enormous background

Detection channel	12 MeV	15 MeV	18 MeV
$\nu_e + e^- \to \nu_e + e^-$	188	203	212
$\bar{\nu}_e + e^- \to \bar{\nu}_e + e^-$	56	64	70
$\nu_x + e^- \to \nu_x + e^-$	60	64	68
$\bar{\nu}_x + e^- \to \bar{\nu}_x + e^-$	48	54	56
$\nu_e + {}^{16}\mathrm{O} \to e^- + {}^{16}\mathrm{F}^*$	16	70	202
$\bar{\nu}_e + p \to e^+ + n$	5662	7071	8345

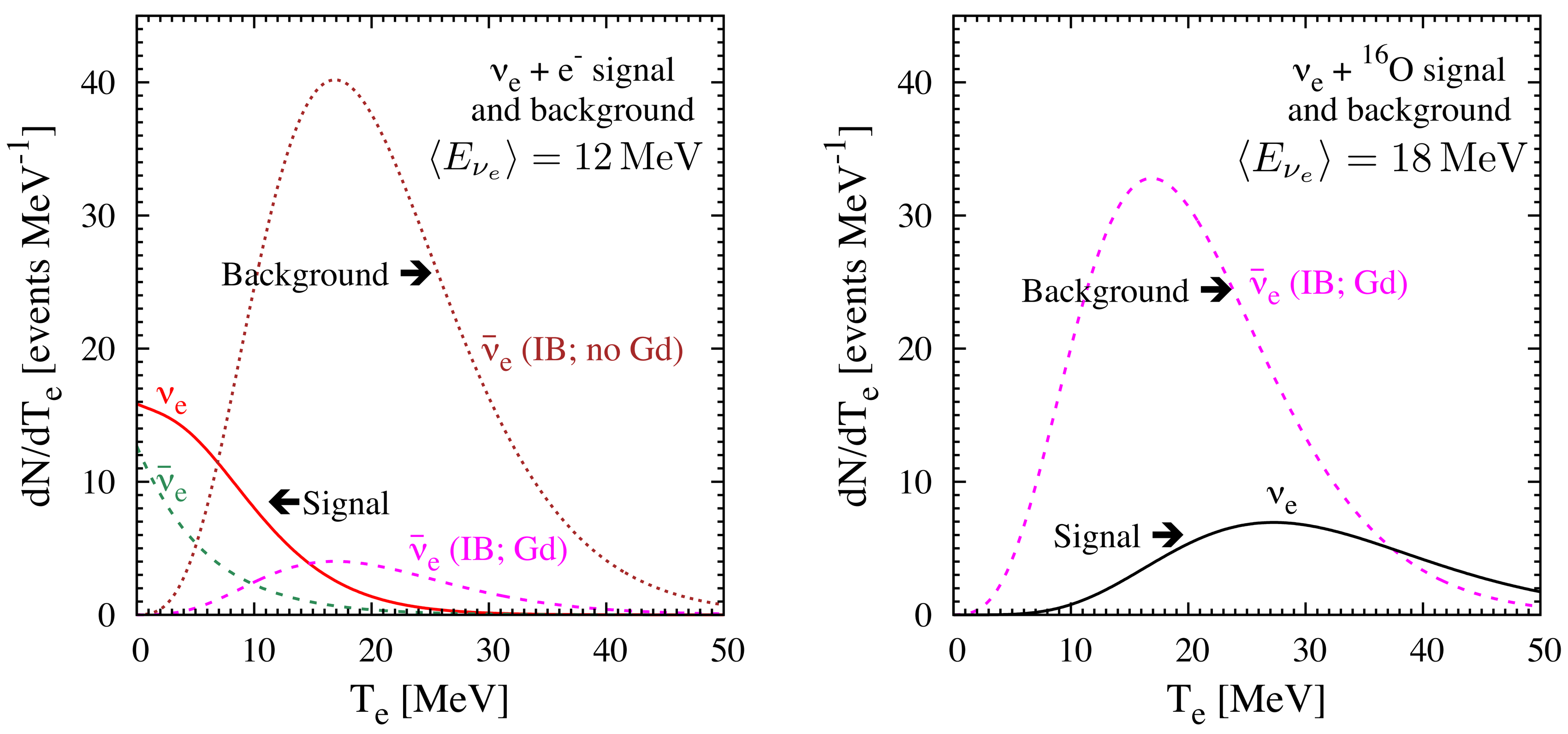
Results

- Elastic scattering on electrons is very weakly dependent on $\langle E_\nu\rangle$
- Scattering on ^{16}O is extremely sensitive on the $\langle E_\nu\rangle$
- Gd improves the fit from electron scattering by a lot
- Impact of Gd on fits from oxygen interaction is modest
- Possible to know the ν_e spectral properties to $\boxed{\sim 20\%}$
- Help distinguish various scenarios

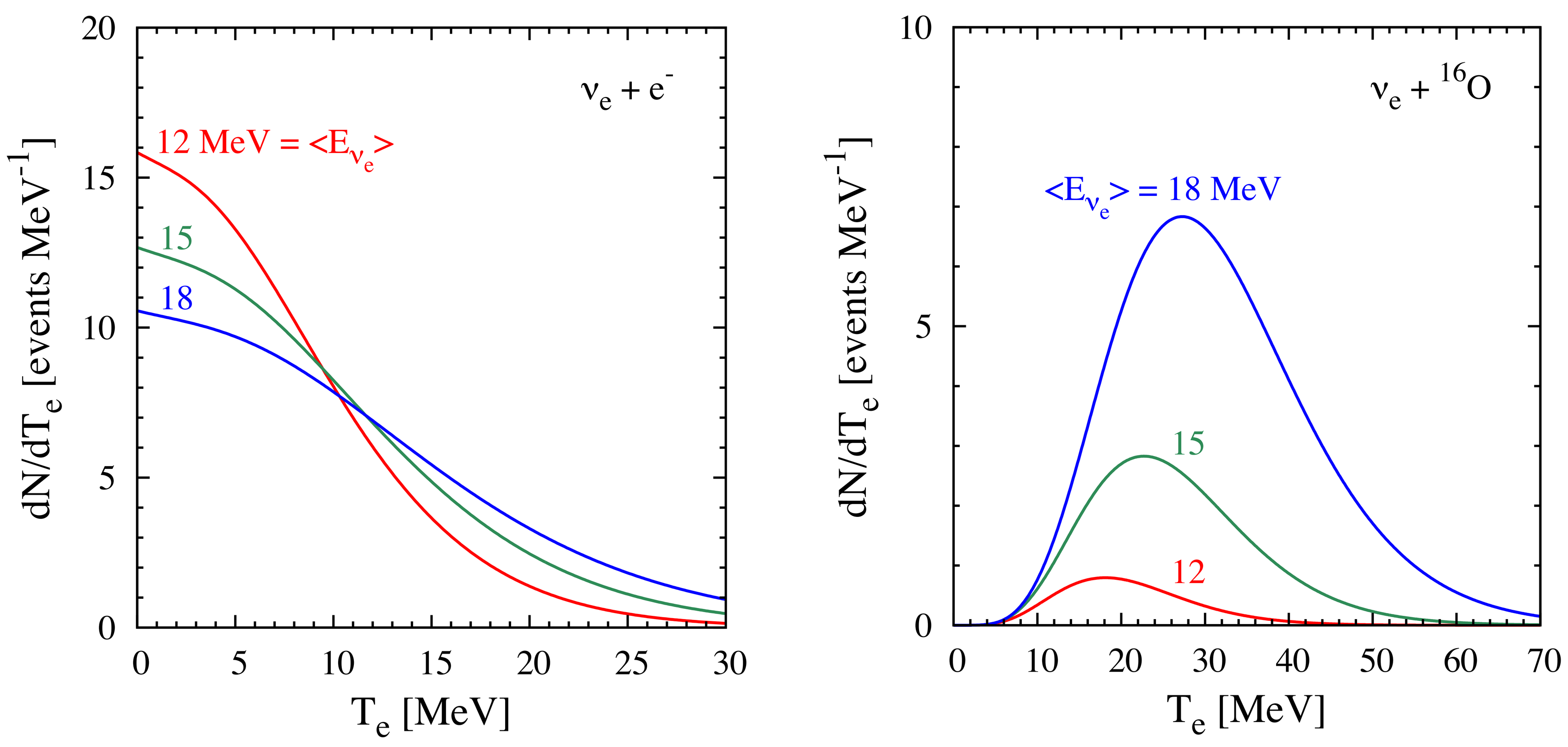


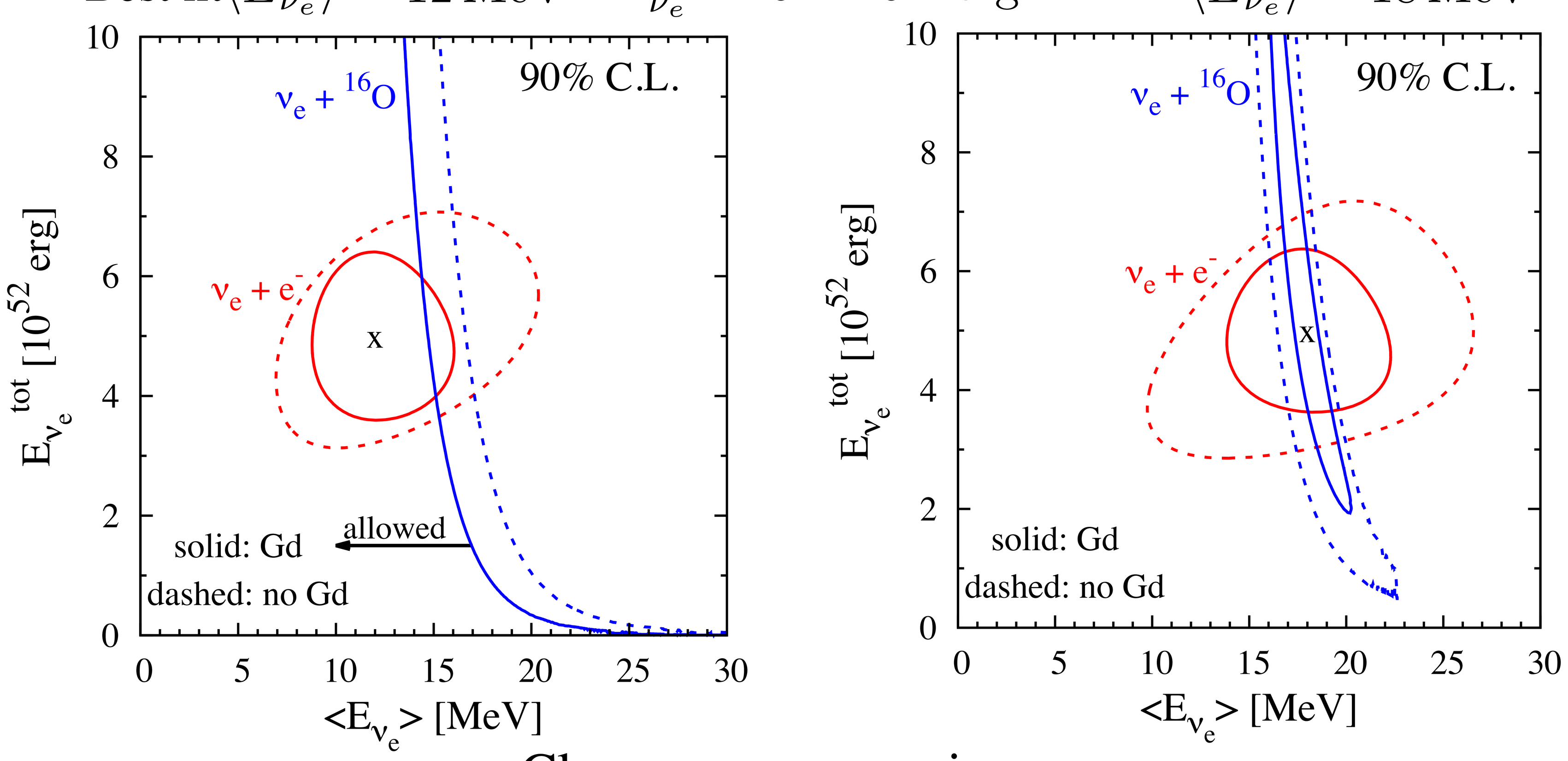
Electron spectra in the forward 40° for the $\nu_e + e^- \to \nu_e + e^-$ detection channels for a supernova in Super-K. The average energies are $\langle E_{\nu_e}\rangle = 12\,\mathrm{MeV}$ $\langle E_{\bar{\nu}_e}\rangle = 15\,\mathrm{MeV}$ $\langle E_{\nu_x}\rangle = 18\,\mathrm{MeV}$ $E_\nu^{\mathrm{tot}} = 5 \times 10^{52}\,\mathrm{erg}$

Impact of Gd – dramatic reduction of background

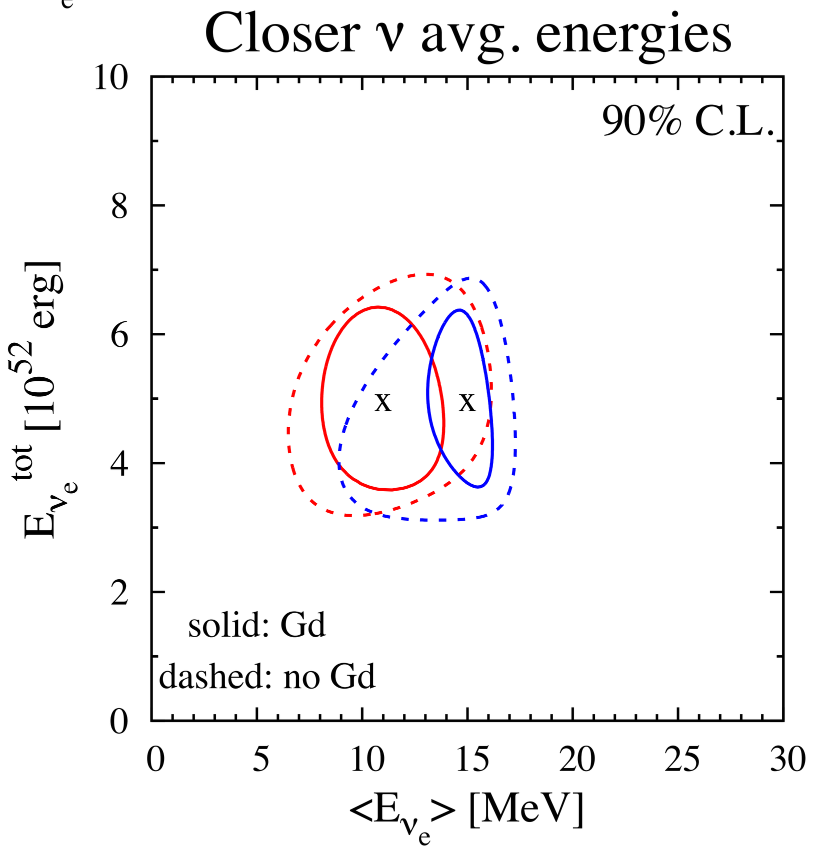


Impact of neutrino average energy





Closer ν avg. energies



Best fit $E_{\nu_e}^{\mathrm{tot}} = 5 \times 10^{52}\,\mathrm{erg}$ $\langle E_{\nu_e}\rangle = 11\,\mathrm{MeV}$ $\langle E_{\nu_e}\rangle = 15\,\mathrm{MeV}$

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