Detection of supernova ν_e in Super-K Gd and large LS detector

Ranjan Laha[1]

[1]PRISMA Cluster of Excellence and Mainz Institute for Theoretical Physics, Johannes Gutenberg-Universität Mainz ranjalah@uni-mainz.de

R.L. & John F. Beacom arXiv: 1311.6407 PRD 89 063007 (2014)

R.L., John F. Beacom & Sanjib K. Agarwalla arXiv:1412.8425 and A. Niktant, R.L. & S. Horiuchi arXiv: 1711.00008 PRD 97 no.2 023019 (2018)

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
- Near-future large liquid scintillator detector can also detect supernova ν_e via $\boxed{\nu_e + {}^{12}\mathrm{C} \to {}^{12}\mathrm{N}_{\mathrm{g.s.}} + e^-}$
- The ${}^{12}\mathrm{N}_{\mathrm{g.s.}}$ decays with the half-life of 11 ms $\boxed{{}^{12}\mathrm{N}_{\mathrm{g.s.}} \to {}^{12}\mathrm{C} + e^+ + \nu_e}$
- The double coincidence signature of this interaction can very efficiently detect the supernova

Detection strategy (Super-K Gd)

- 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

Detection strategy (large liquid scintillator detector – JUNO, RENO-50, LENA)

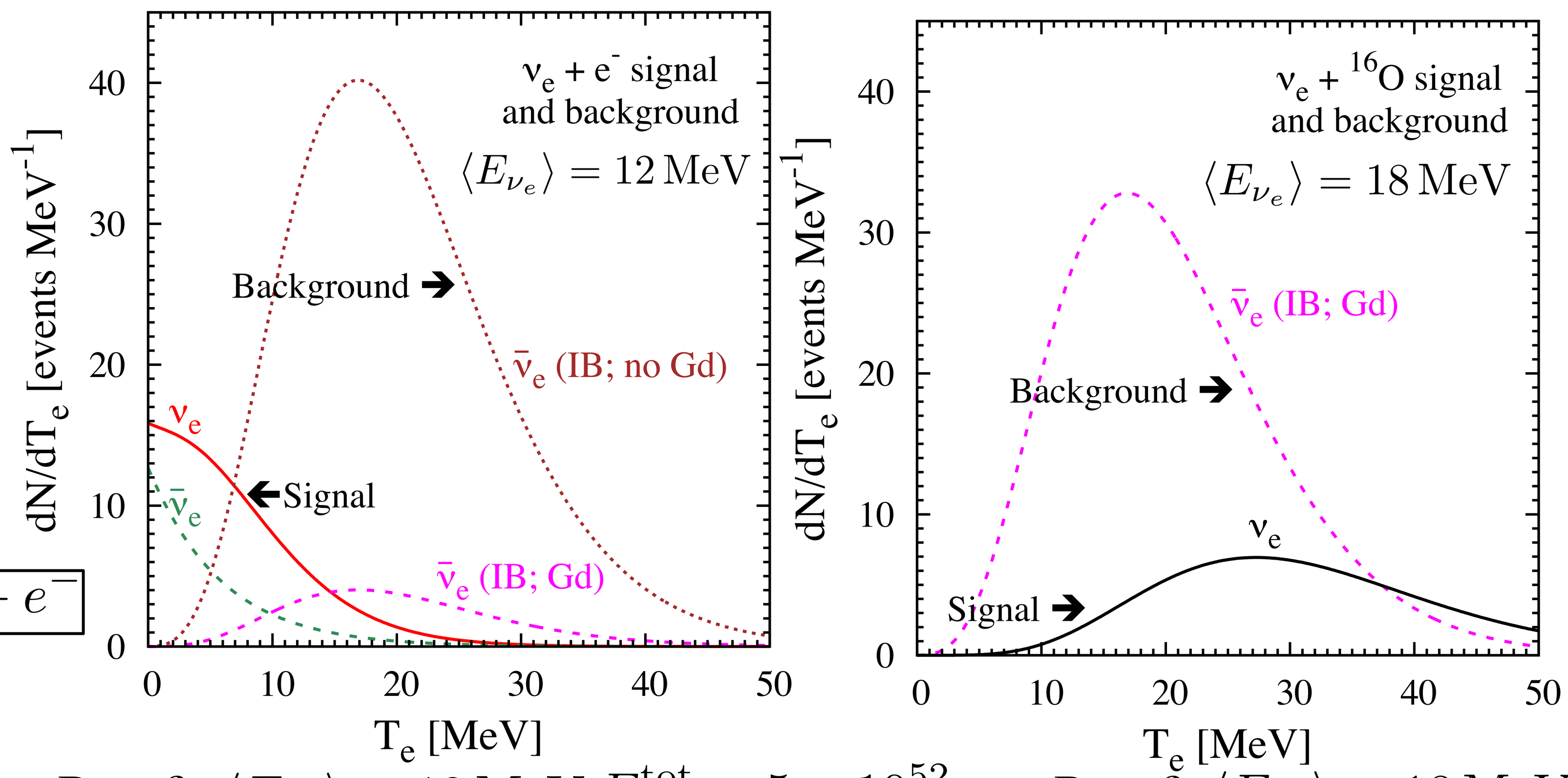
- No Gadolinium in these detectors ➔ detect neutrons from inverse beta interactions via capture on hydrogen and carbon
- Detect electrons from $\nu_e + e^- \to \nu_e + e^-$ --- no angular information --- efficiency determined by neutron capture efficiency
- Detect the electron and positron from the double coinicidence signature in the interaction $\nu_e + {}^{12}\mathrm{C} \to {}^{12}\mathrm{N}_{\mathrm{g.s.}} + e^-$--- backgrounds due to $\bar{\nu}_e + {}^{12}\mathrm{C}$ ➔ important to distinguish electrons and positrons in liquid scintillator detectors via pulse shape discrimination and different lifetime of the excited nucleus

Detection channel	12 MeV	15 MeV	18 MeV
$\bar{\nu}_e + p \to e^+ + n$	3898	4857	5727
$\nu + p \to \nu + p$	50	129	236
$\bar{\nu} + p \to \bar{\nu} + p$	50	129	236
$\nu_e + e^- \to \nu_e + e^-$	159	160	160
$\bar{\nu}_e + e^- \to \bar{\nu}_e + e^-$	65	66	67
$\nu_x + e^- \to \nu_x + e^-$	26	27	27
$\bar{\nu}_x + e^- \to \bar{\nu}_x + e^-$	23	23	23
$\nu_e + {}^{12}\mathrm{C} \to e^- + {}^{12}\mathrm{N}_{\mathrm{g.s.}}$	44	114	214
$\bar{\nu}_e + {}^{12}\mathrm{C} \to e^+ + {}^{12}\mathrm{B}_{\mathrm{g.s.}}$	49	107	177
$\nu + {}^{12}\mathrm{C} \to \nu' + {}^{12}\mathrm{C}^*$ (15.11)	26	60	104
$\bar{\nu} + {}^{12}\mathrm{C} \to \bar{\nu}' + {}^{12}\mathrm{C}^*$ (15.11)	24	56	95

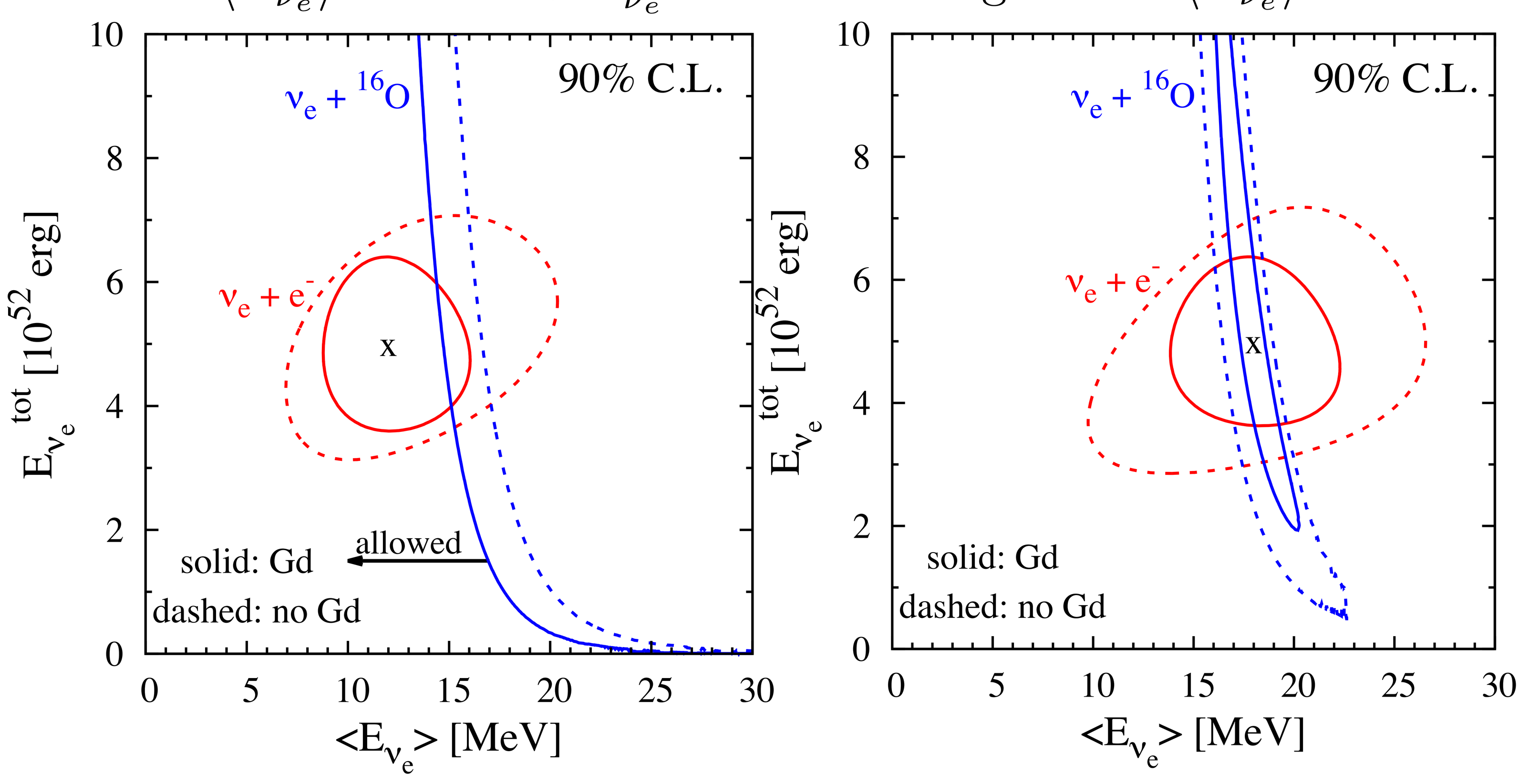
Results

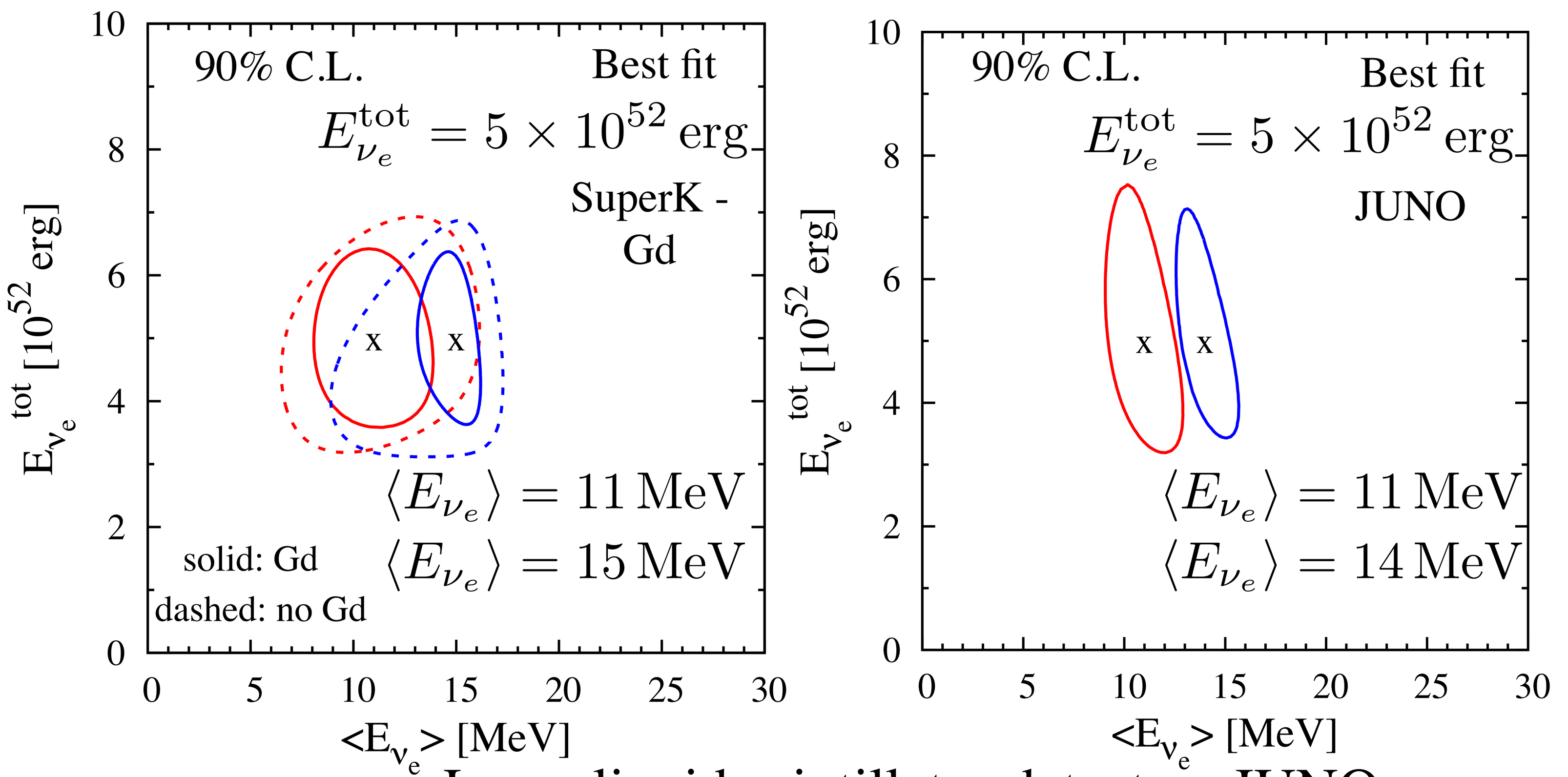
- Important to detect supernova ν_e in as many detectors as possible
- Super-K Gd and near future large liquid scintillator detectors (JUNO, RENO-50 and LENA) have excellent sensitivity to supernova ν_e

Impact of Gd – dramatic reduction of background

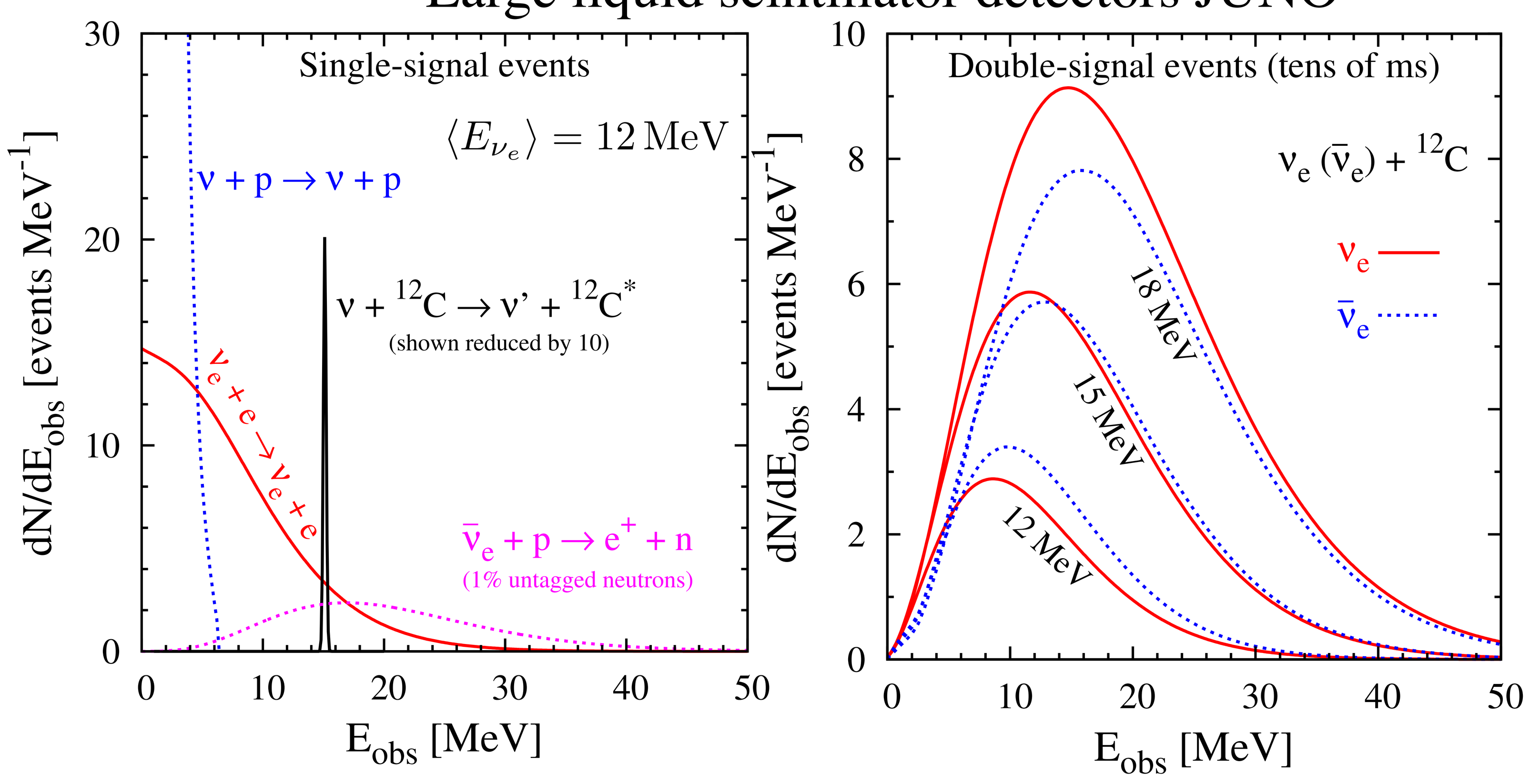


Best fit $\langle E_{\nu_e} \rangle = 12$ MeV $E^{\mathrm{tot}}_{\nu_e} = 5 \times 10^{52}$ erg Best fit $\langle E_{\nu_e} \rangle = 18$ MeV

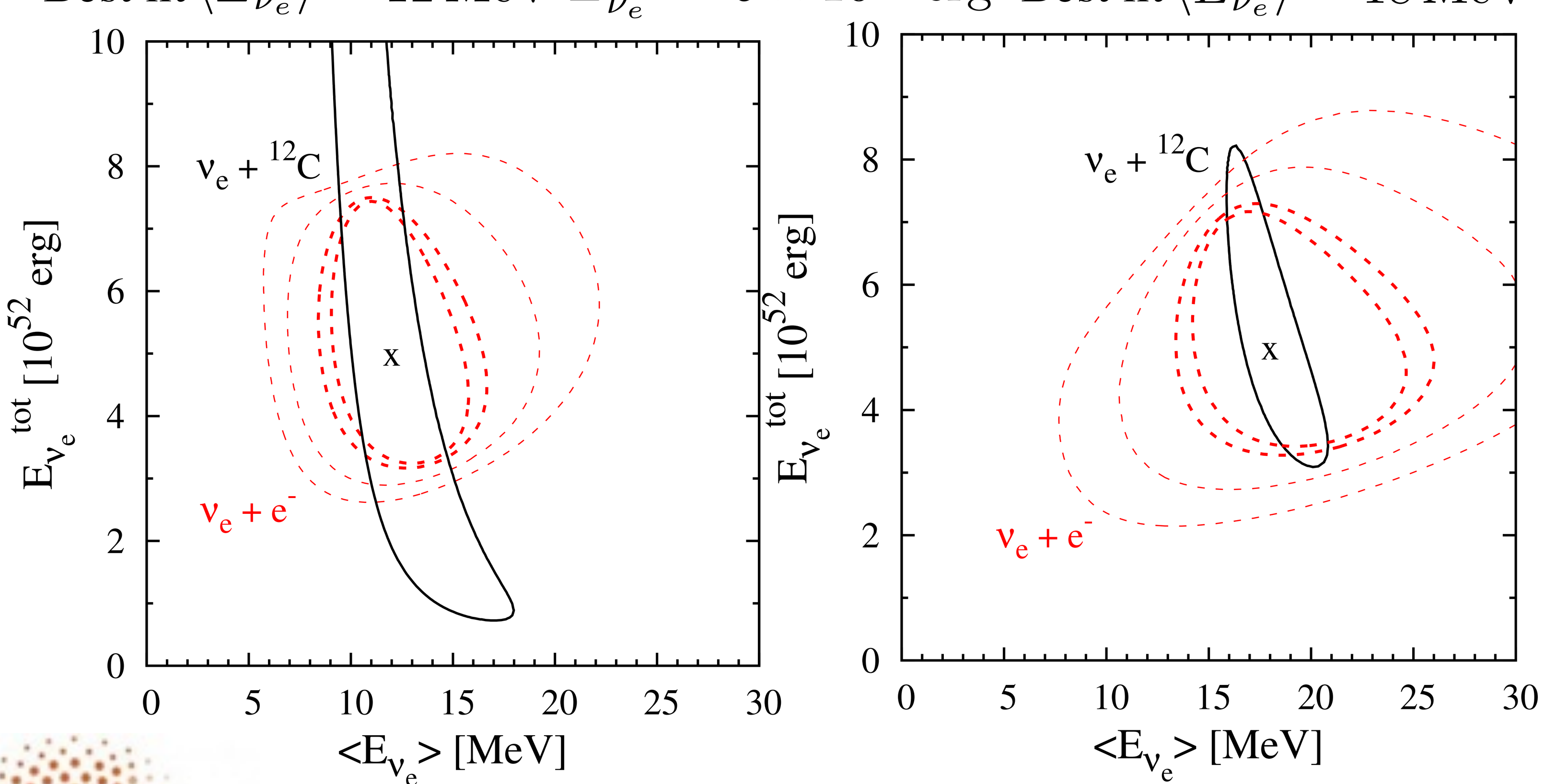




Large liquid scintillator detectors JUNO



Best fit $\langle E_{\nu_e} \rangle = 12$ MeV $E^{\mathrm{tot}}_{\nu_e} = 5 \times 10^{52}$ erg Best fit $\langle E_{\nu_e} \rangle = 18$ MeV



Cluster of Excellence PRISMA Precision Physics, Fundamental Interactions and Structure of Matter
European Research Council Established by the European Commission
JOHANNES GUTENBERG UNIVERSITÄT MAINZ