Observing Supernova Neutrinos to Late Times

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SLAC

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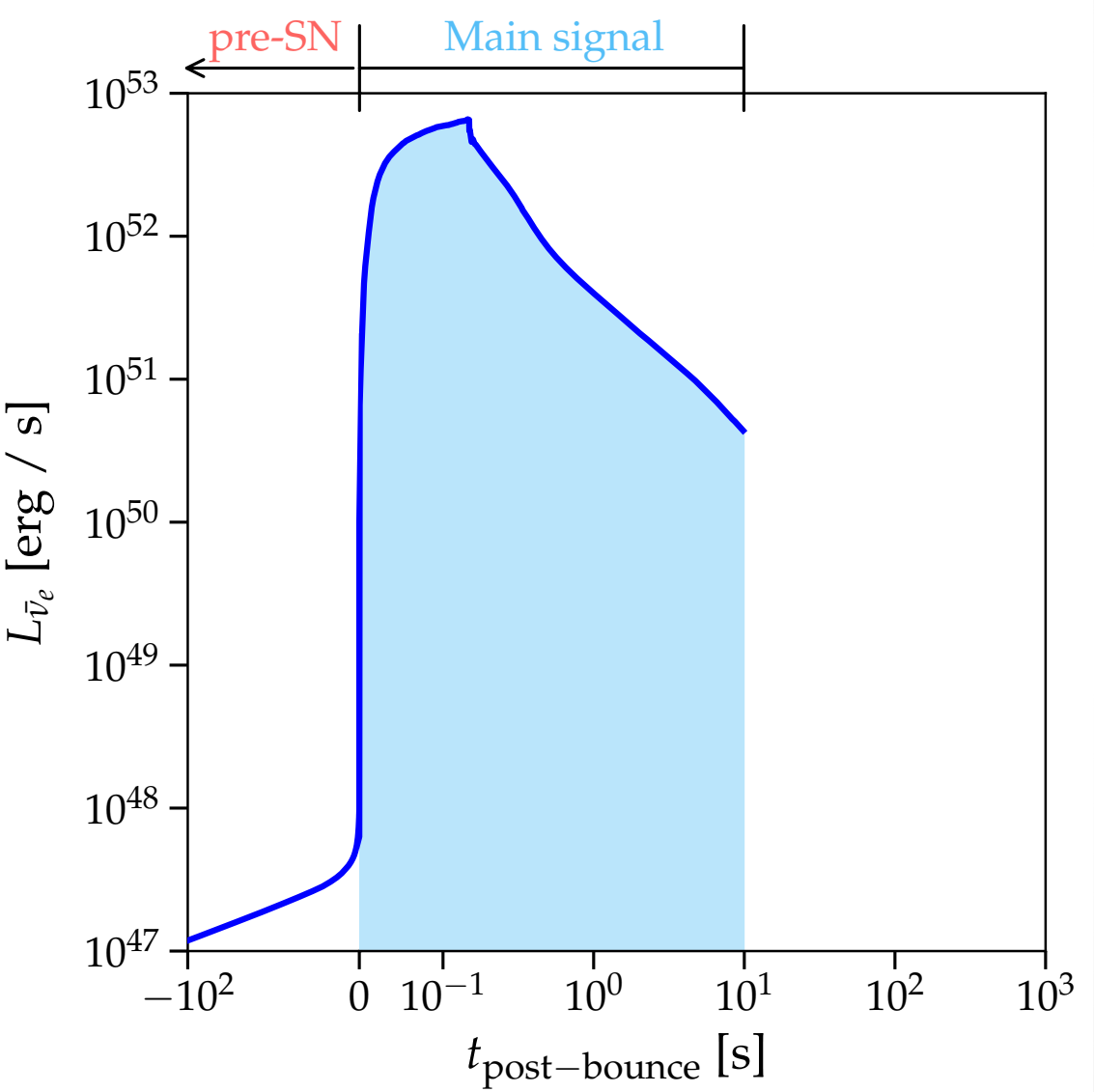
Timescale of a SN



Timescale of a SN

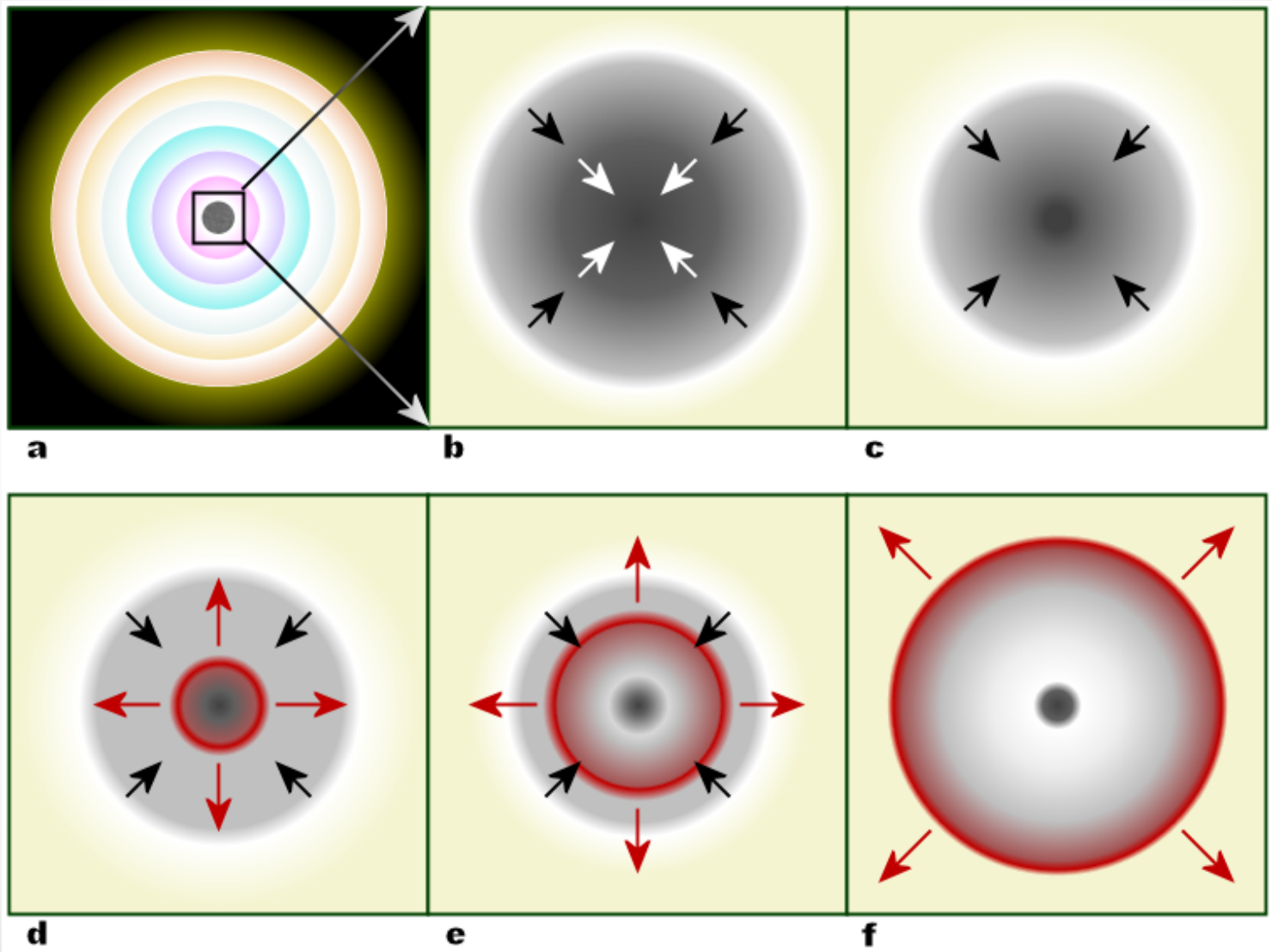


Figure credit: R.J. Hall

Timescale of a SN

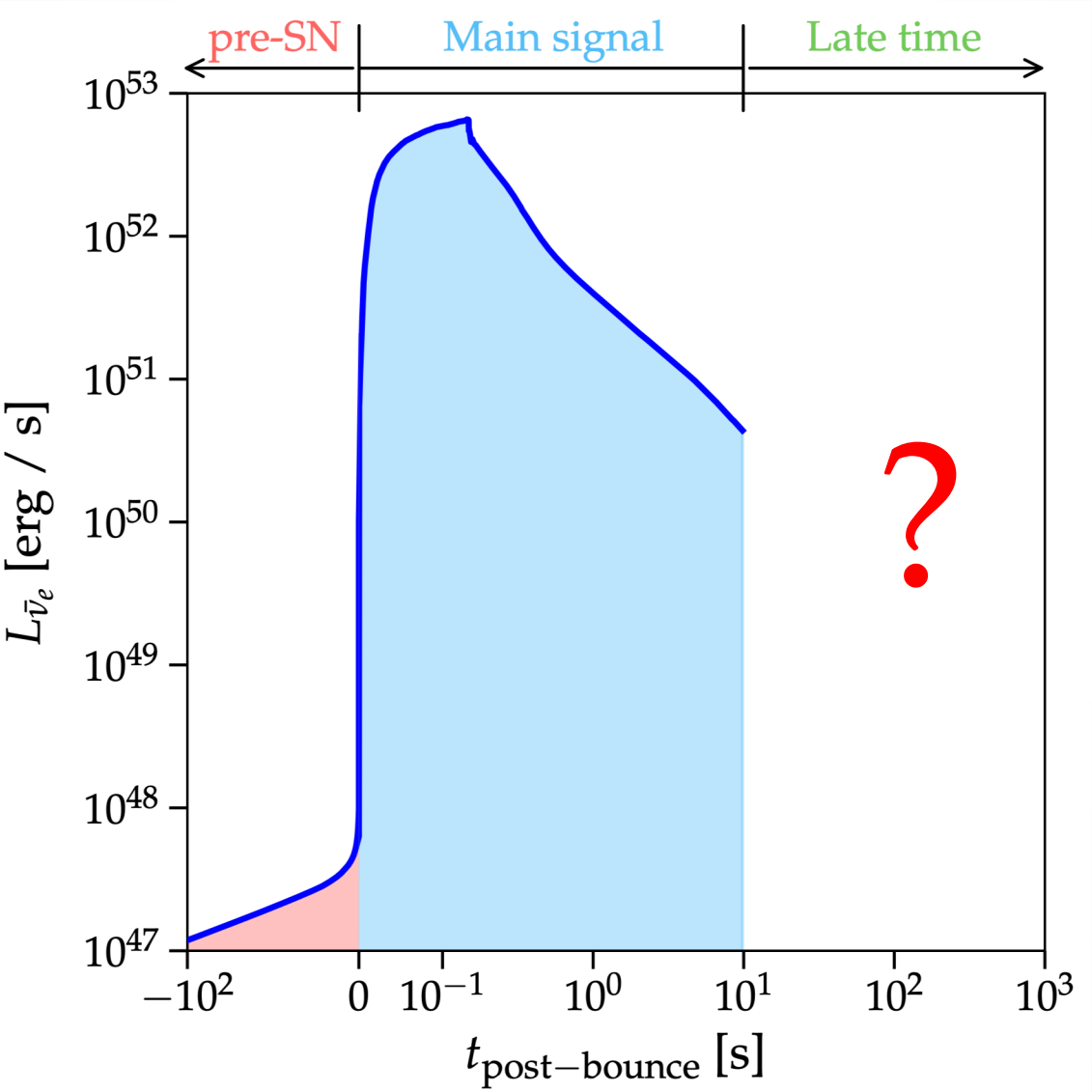


Figure credit: R.J. Hall

Timescale of a SN

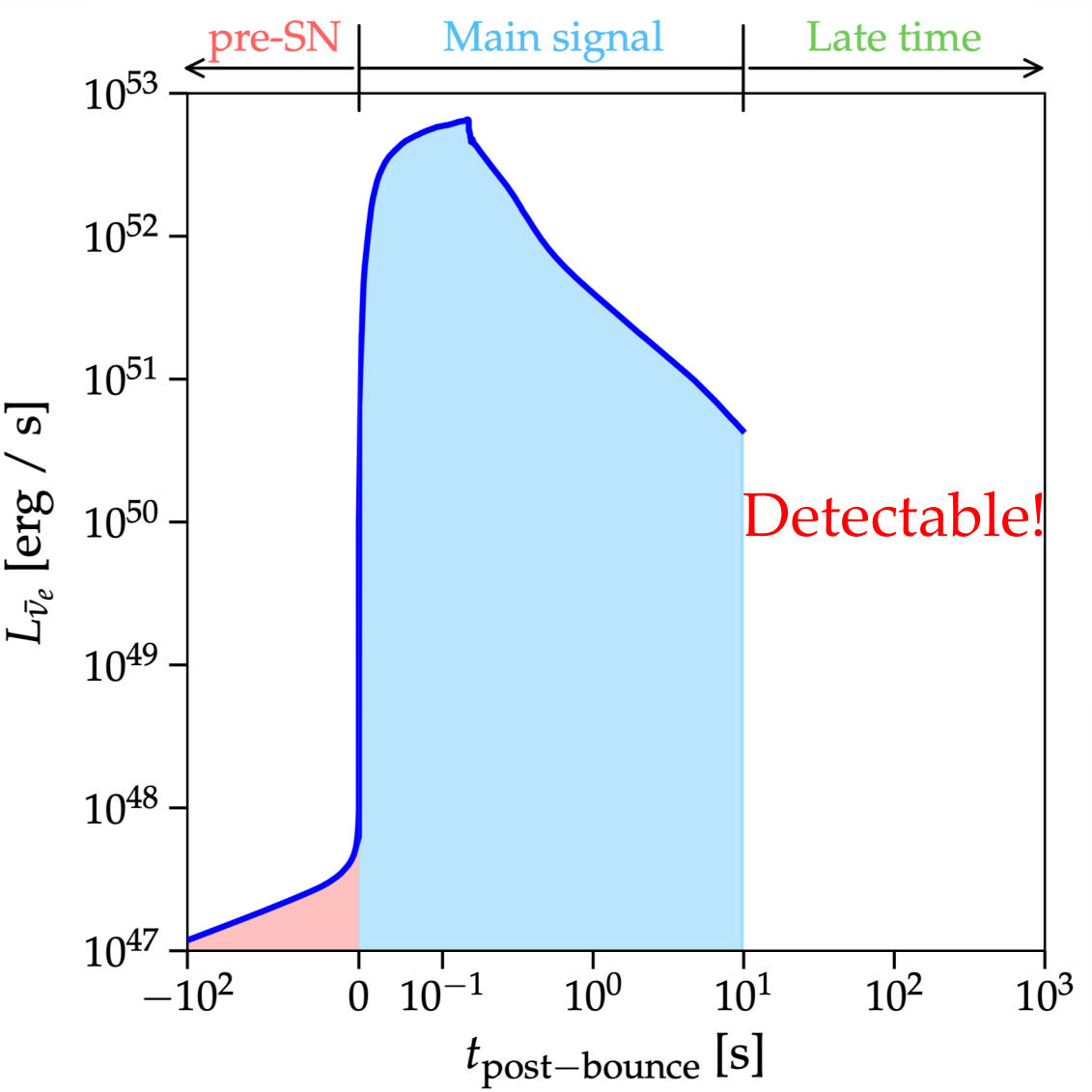
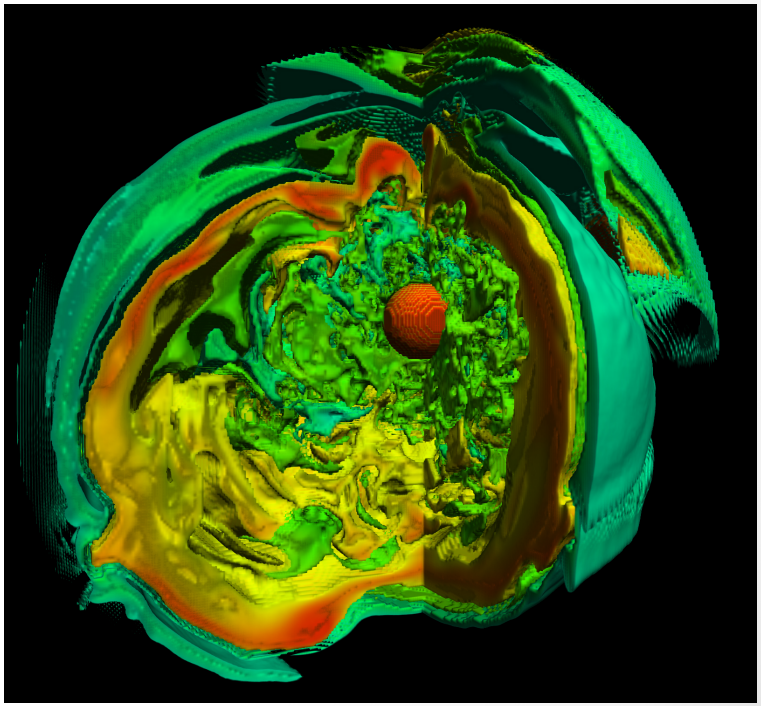


Figure credit: R.J. Hall

First input -- simulation

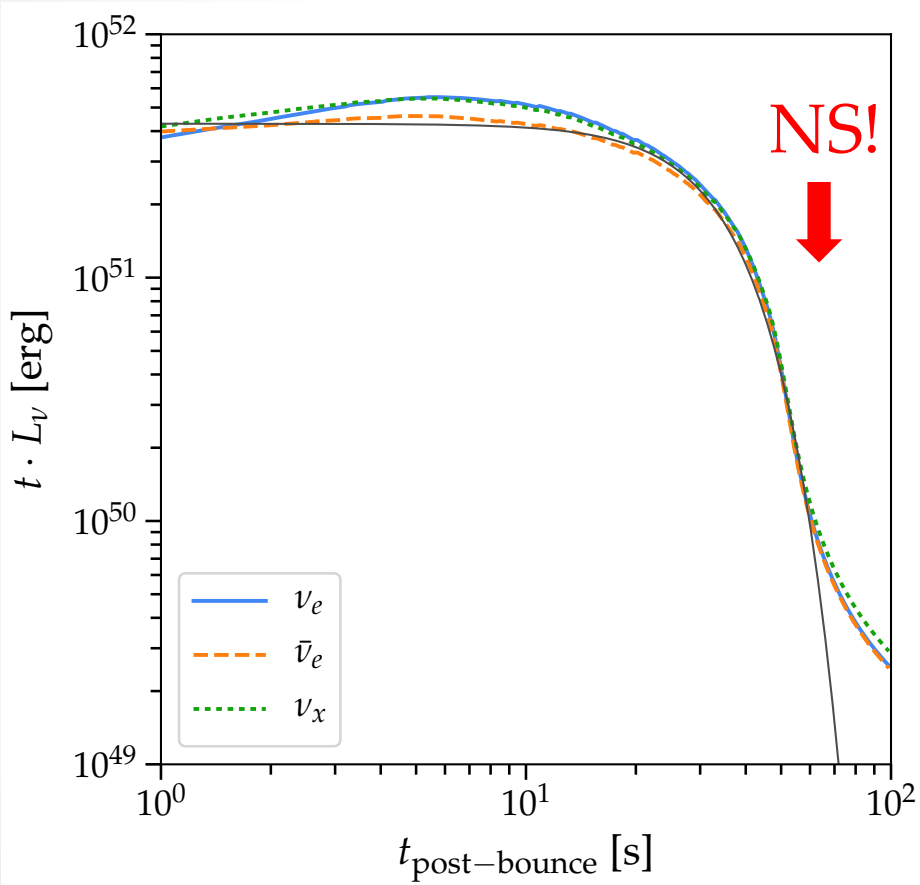
Luke Roberts



Blondin et al., 2003

Late-time neutrinos

Neutrino luminosity and energy



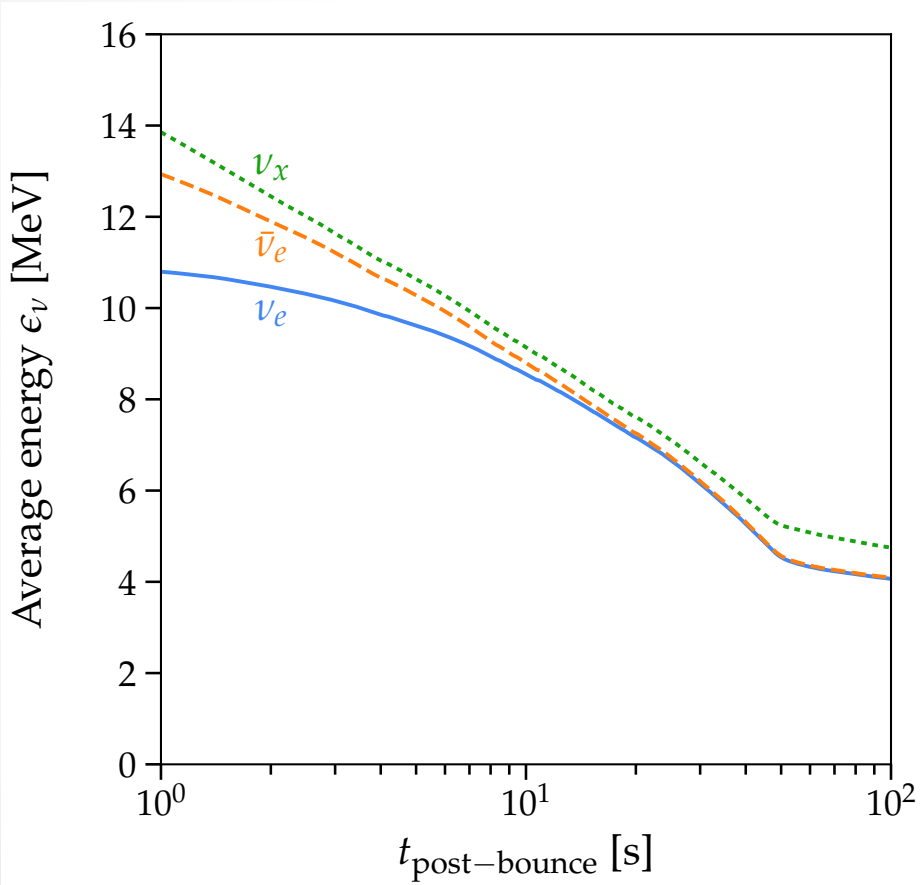
- 1/t behavior surprising
- Connects SN and NS
- Moderate mixing effect

Li, Roberts & Beacom, in prep

Late-time neutrinos are interesting & robust!

Late-time neutrinos

Neutrino luminosity and energy



- 1/t behavior surprising
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Li, Roberts & Beacom, in prep

Late-time neutrinos are interesting & robust!

Supernova neutrino detection

Large cross sections	Multi-10 kton
$\bar{\nu}_e + p \rightarrow e^+ + n$	Super-K
$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$	DUNE
$\nu_x + p \rightarrow \nu_x + p$	JUNO

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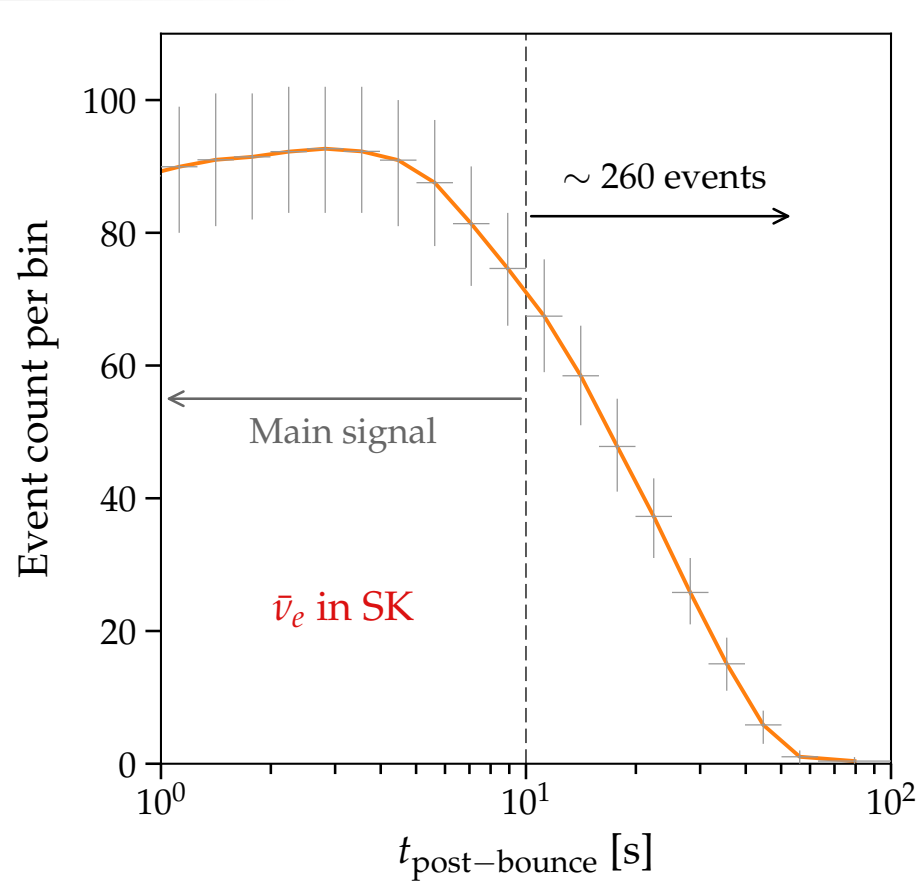
$\bar{\nu}_e$ signal rate

$$\bar{\nu}_e + p \rightarrow e^+ + n$$



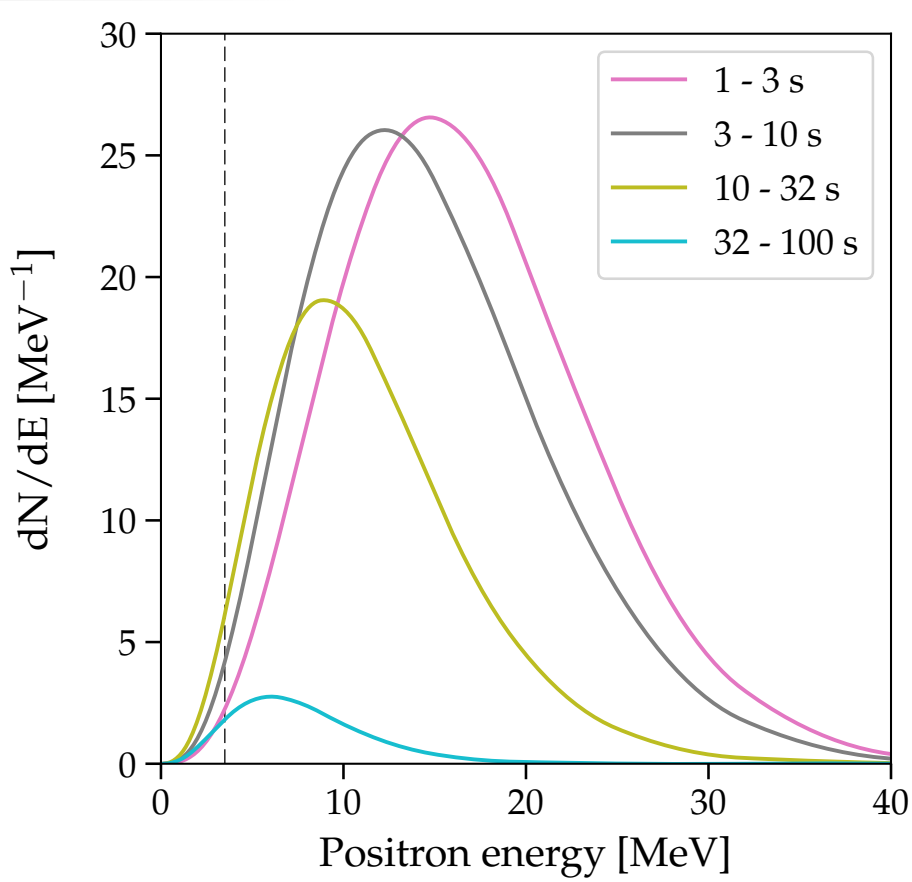
- Inputs:
  - 10 kpc SN
  - 22.5 kton
  - 3.5 MeV threshold

Li, Roberts & Beacom, in prep

Plenty of events in Super-K!

$\bar{\nu}_e$ energy spectrum

$$\bar{\nu}_e + p \rightarrow e^+ + n$$



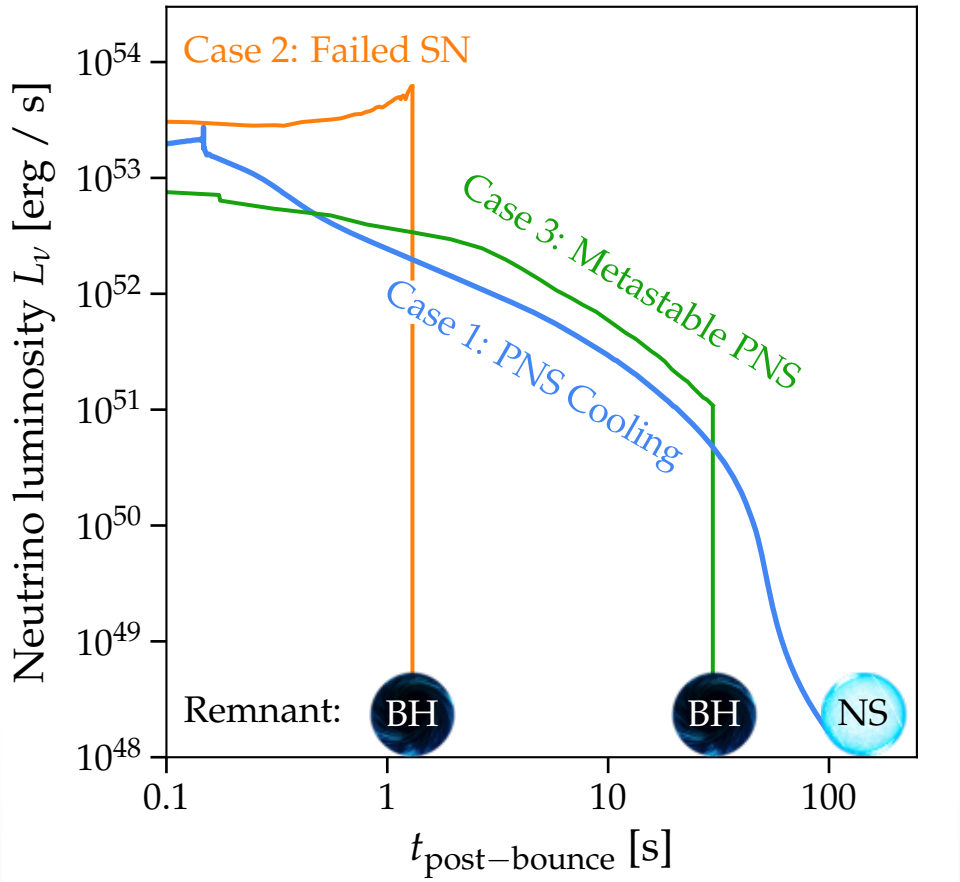
- $E_{e^+} = E_{\bar{\nu}_e} - 1.3$ MeV
- --- known detection threshold

Li, Roberts & Beacom, in prep

Easily reconstruct neutrino spectrum

Alternative outcome -- BH

Different mechanisms for BH formation

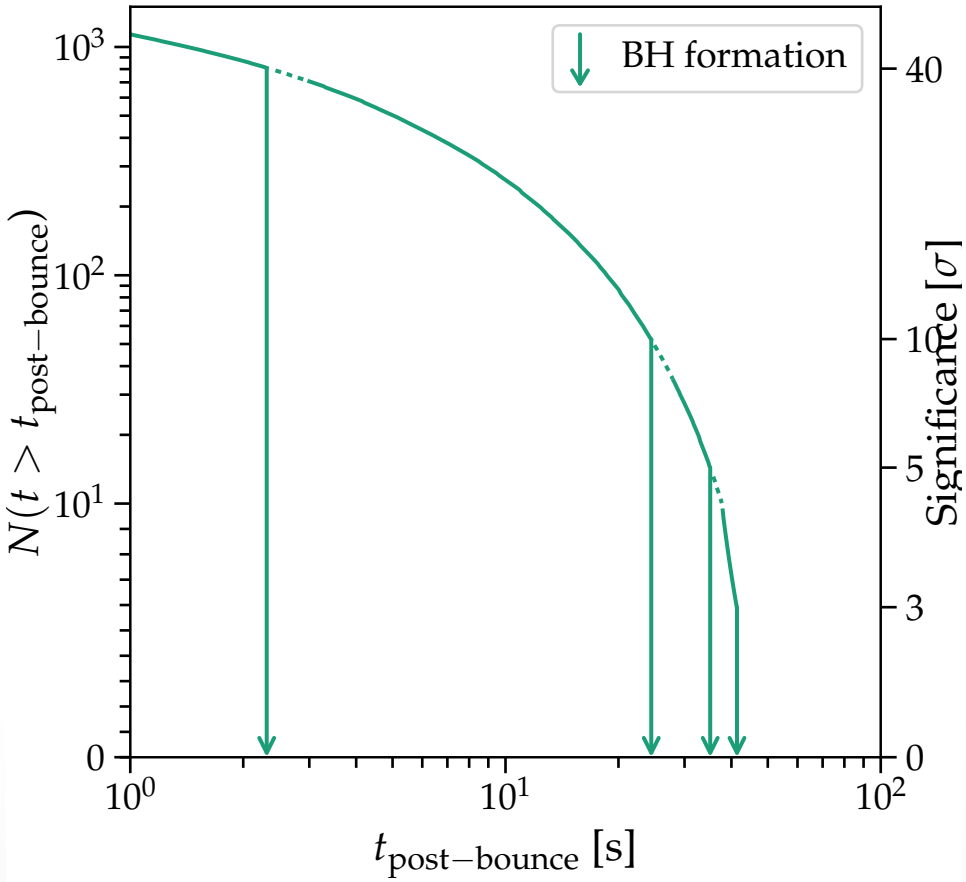


Li, Roberts & Beacom, in prep

BH may form at late times

Detecting BH formation

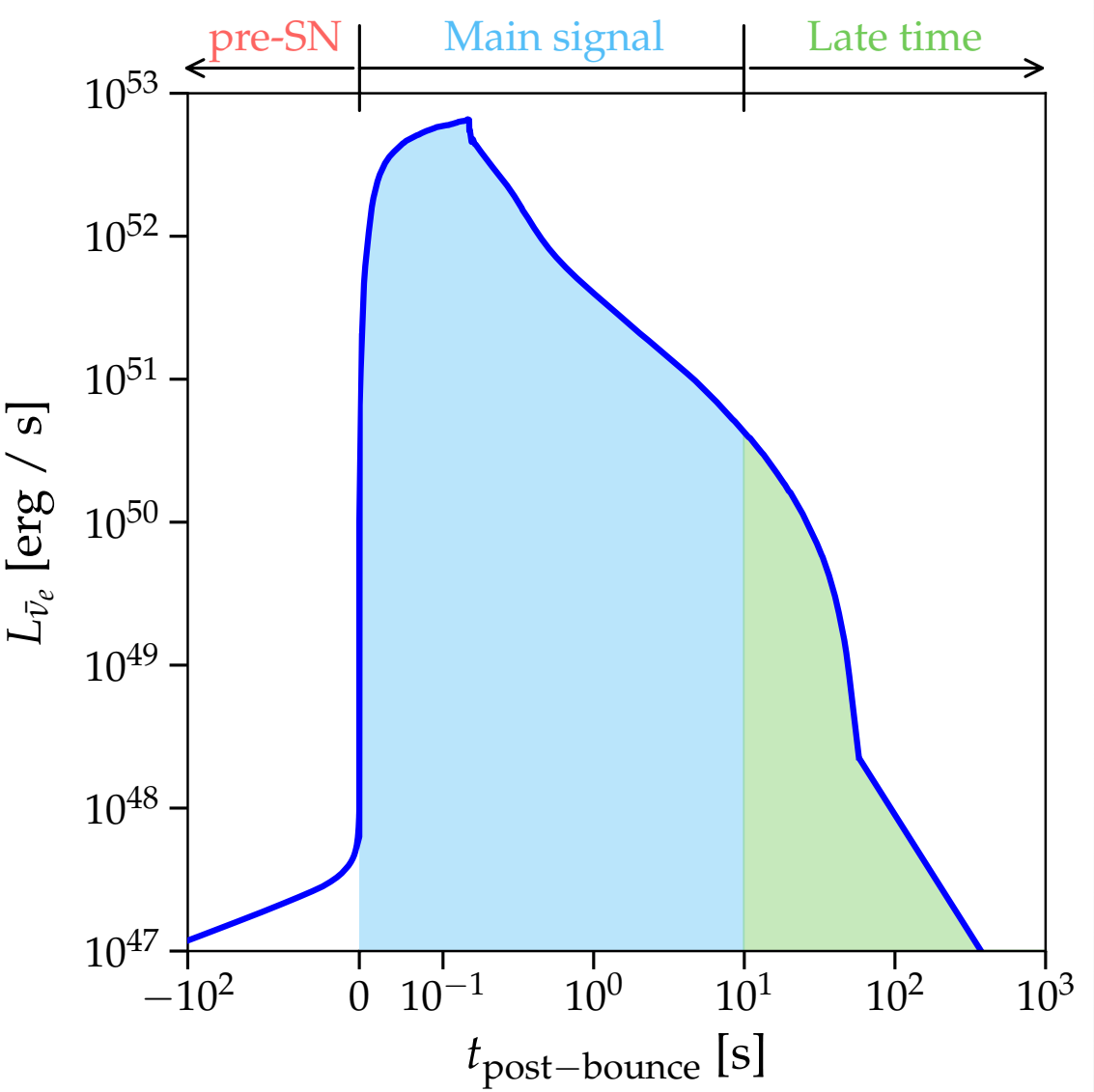
Detection significance of BH formation



Li, Roberts & Beacom, in prep

We can detect BH formation at late times

Conclusions

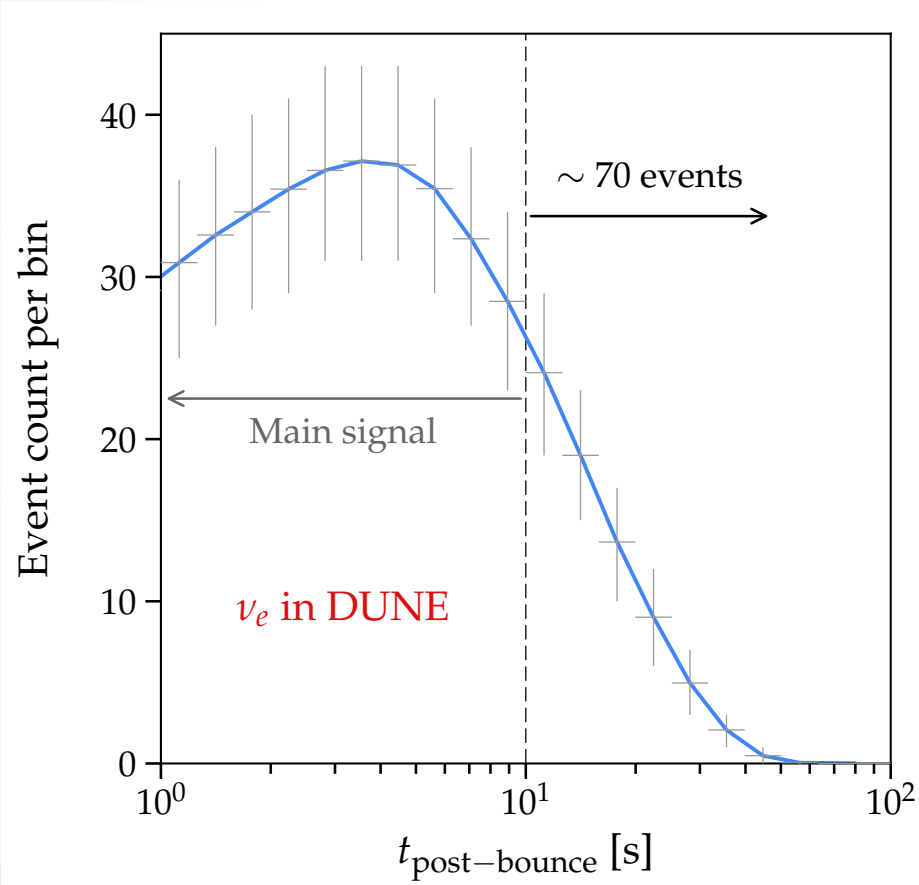


Thank you!

Back up

ν_e signal rate

$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$



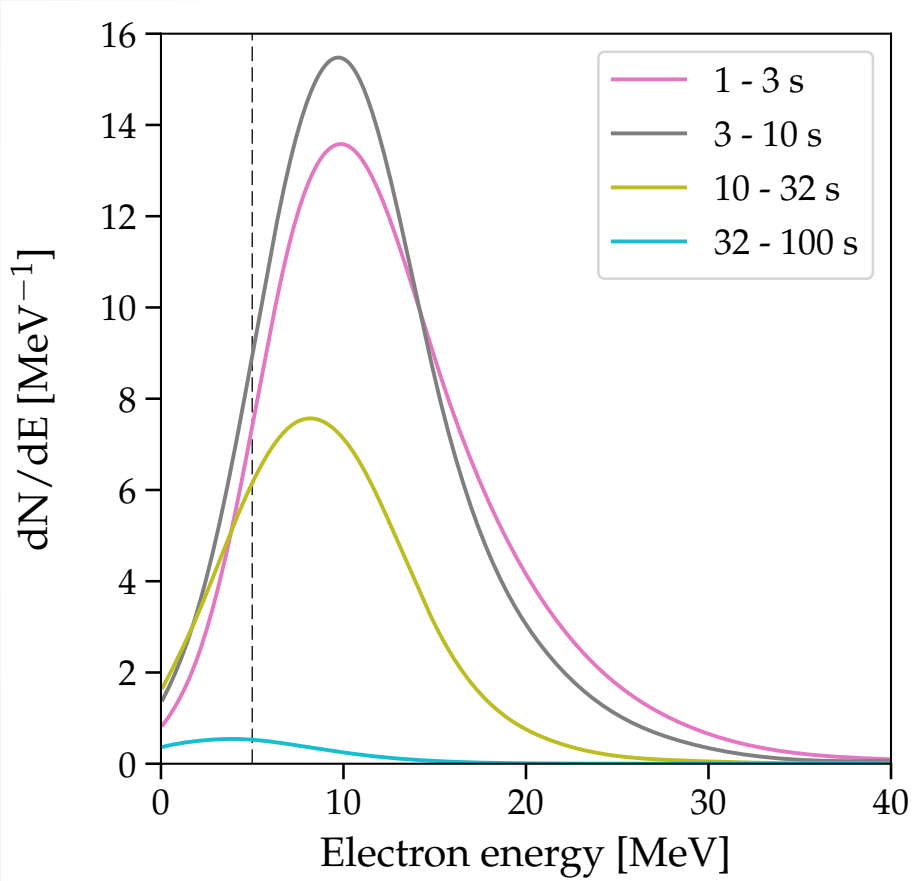
- Inputs:
  - 10 kpc SN
  - 40 kton
  - 5 MeV threshold

Li, Roberts & Beacom, in prep

Plenty of events to late time in DUNE!

ν_e energy spectrum

$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$



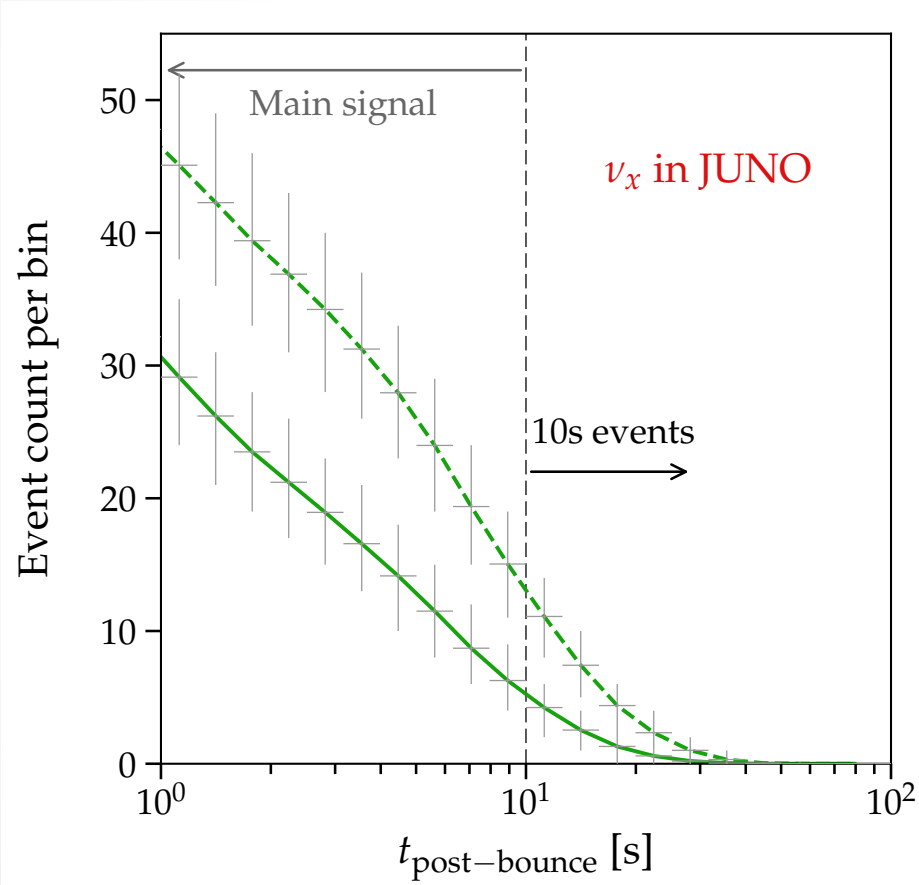
- $E_e = E_{\nu_e} - 5.8$ MeV
- --- unknown detection threshold

Li, Roberts & Beacom, in prep

Detection threshold needs to reach ~ 5 MeV

ν_x signal rate

$$\nu_x + p \rightarrow \nu_x + p$$



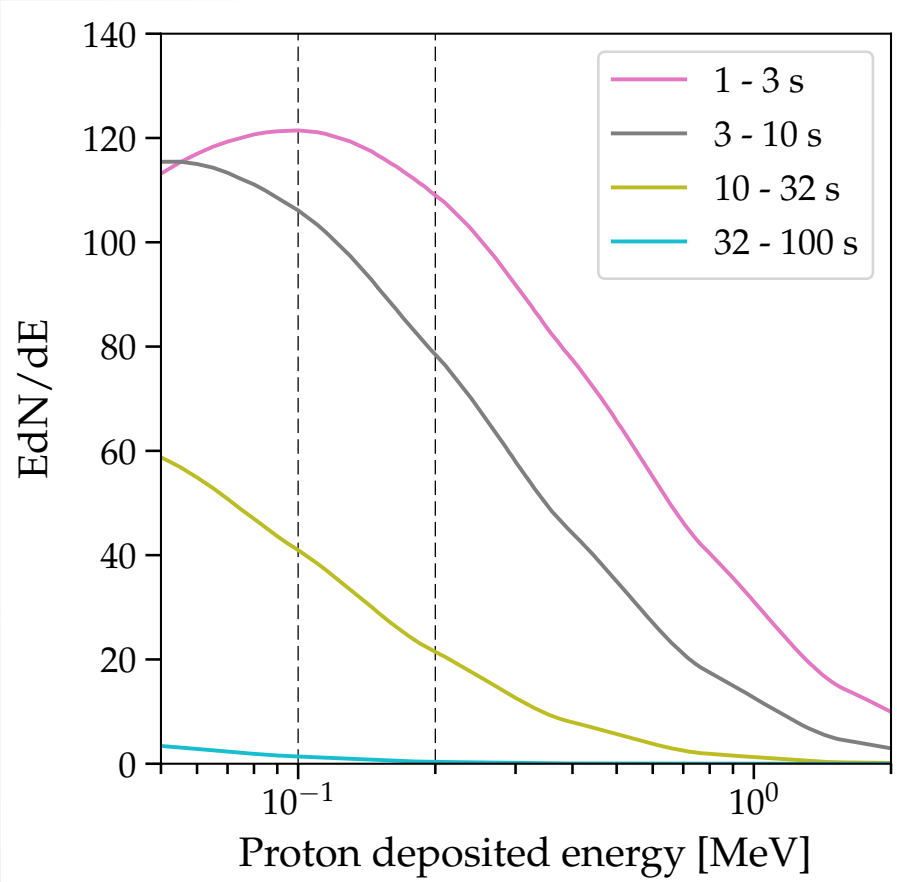
- Inputs:
  - 10 kpc SN
  - 22.5 kton
  - 0.1, 0.2 MeV threshold

Li, Roberts & Beacom, in prep

Non-negligible events at late time

ν_x energy spectrum

$$\nu_x + p \rightarrow \nu_x + p$$



- $E_{\text{det}} \ll E_{\nu_x}$
- --- unknown detection threshold

Li, Roberts & Beacom, in prep

Detection threshold is crucial