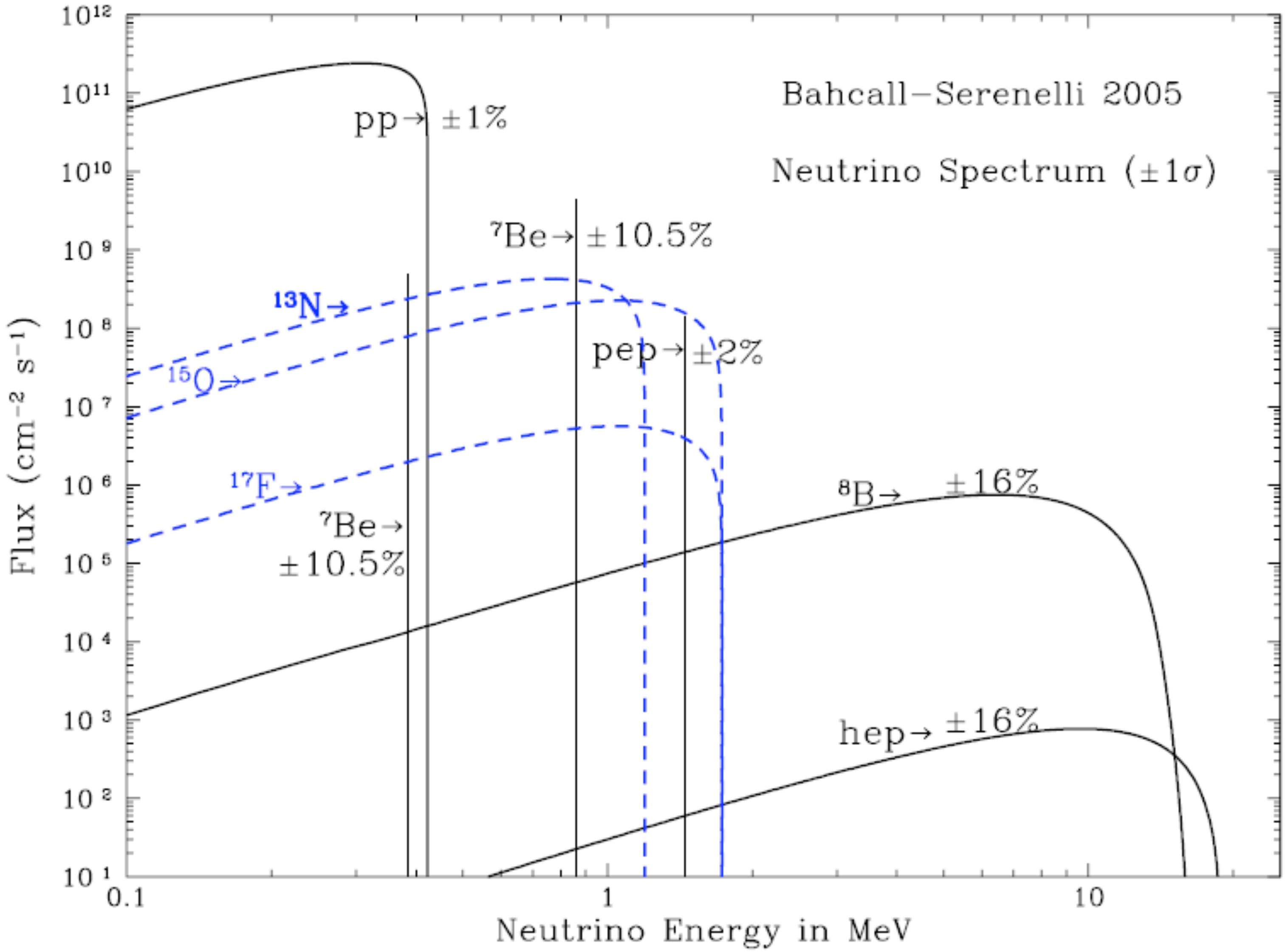
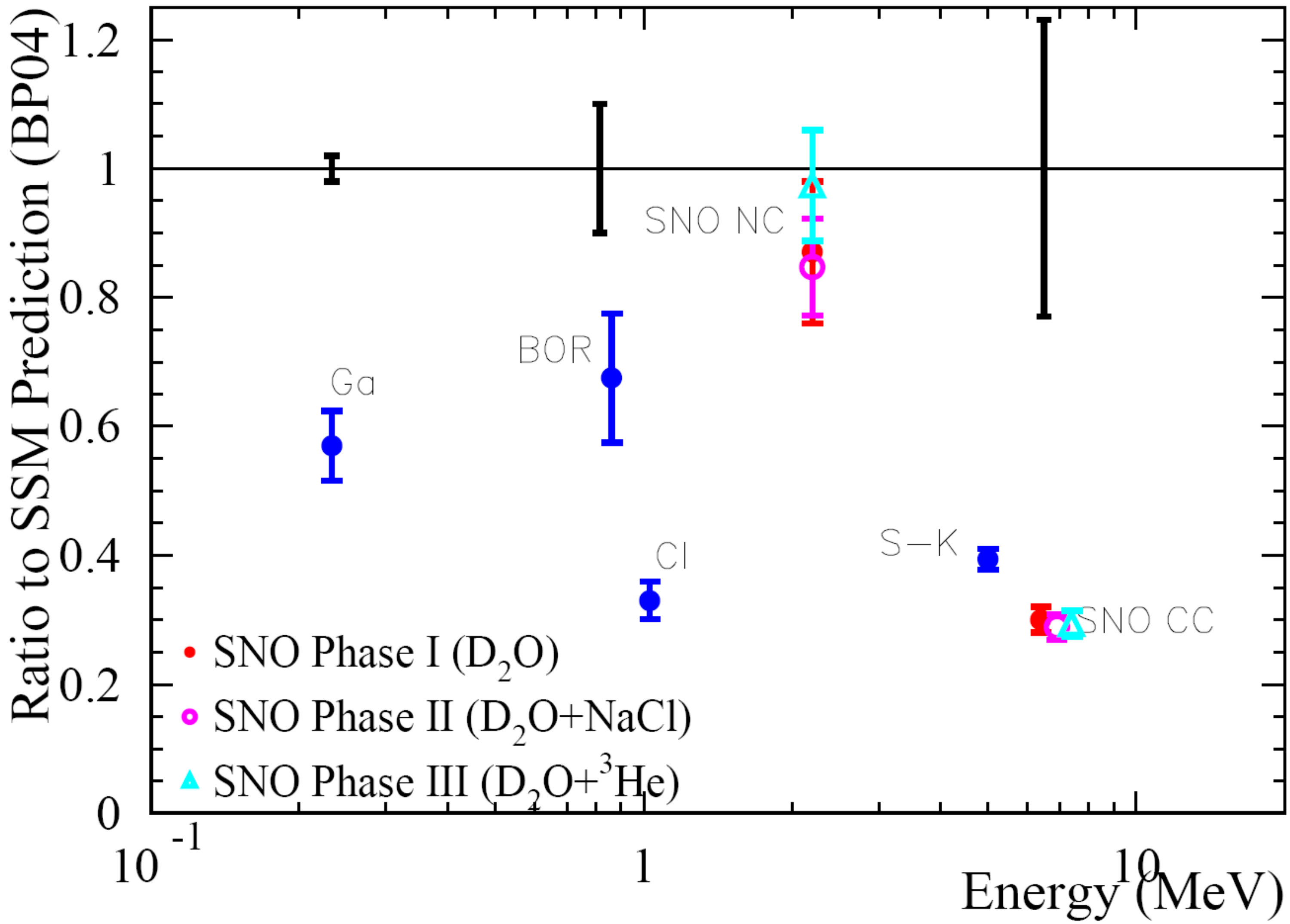
Solar and Supernova νs in VL H_2O Cherenkov and Liquid Argon Detectors

- Is there any new solar ν physics to do?
- Supernova bursts
- Relic Supernova νs

Solar ν Predictions

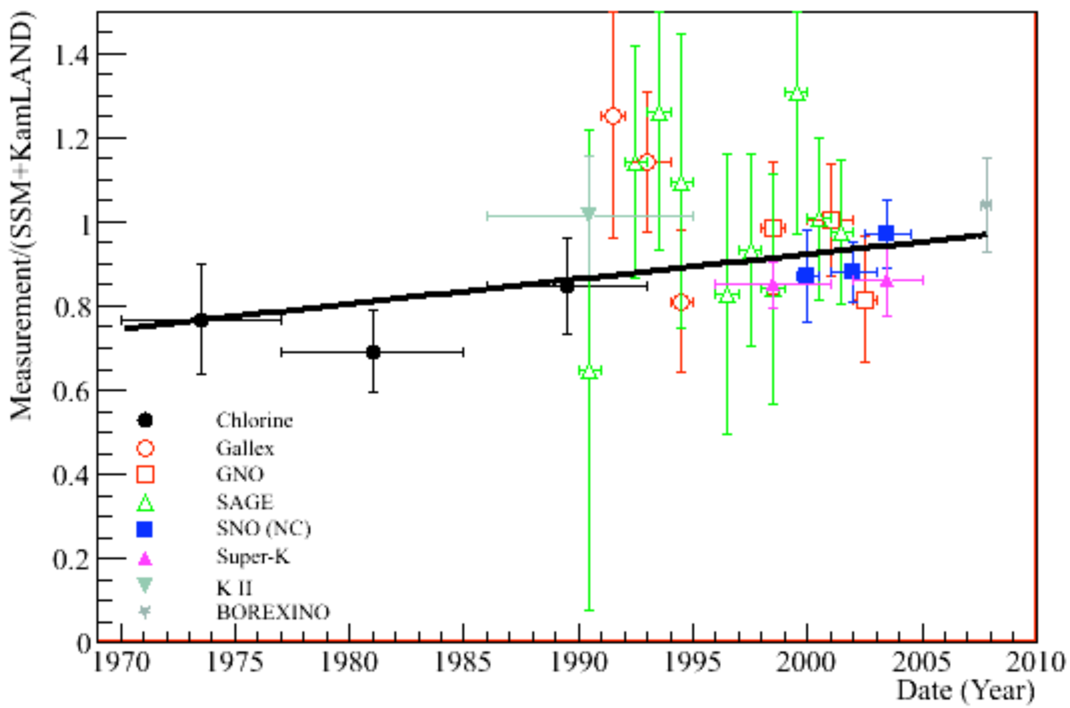


Solar ν Measurements



Forty Years of Monitoring the Core

Using KamLAND mixing+Standard Solar Model



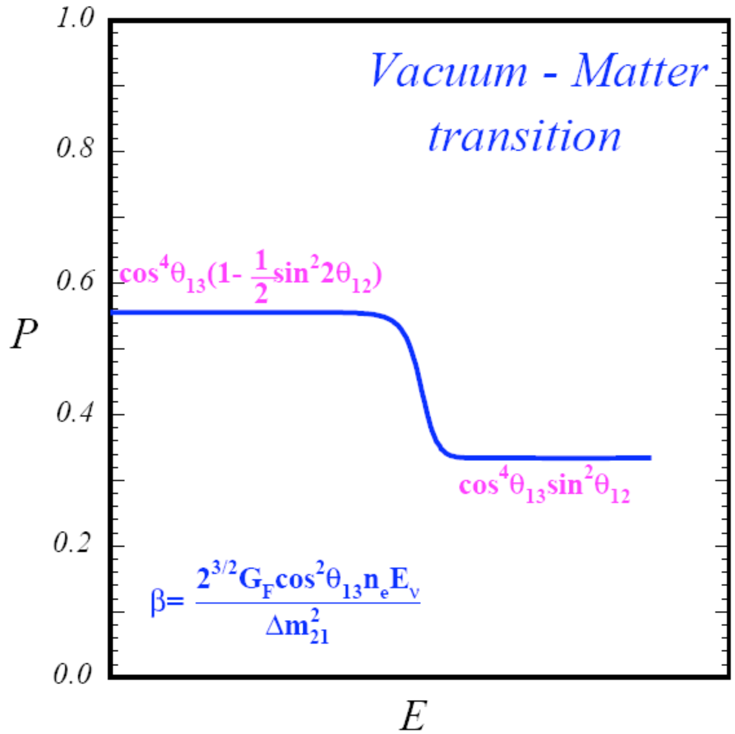
(SSM uncertainties *not* included)

Thanks to O. Simard and SNO

Goals of the Future Solar ν Program

- Test the model of massive neutrino mixing
    - Can we observe MSW-specific signatures?

Vacuum/Matter Transition

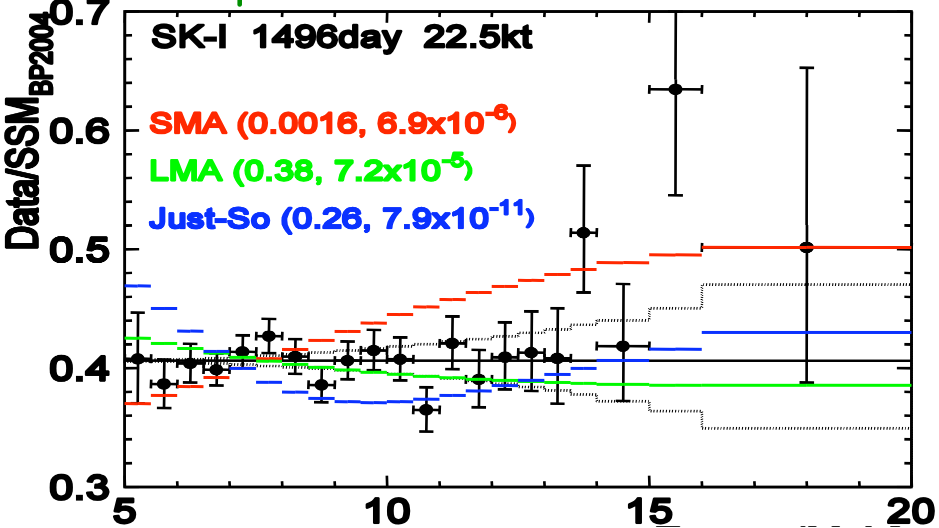


Day/Night ν_e Asymmetry

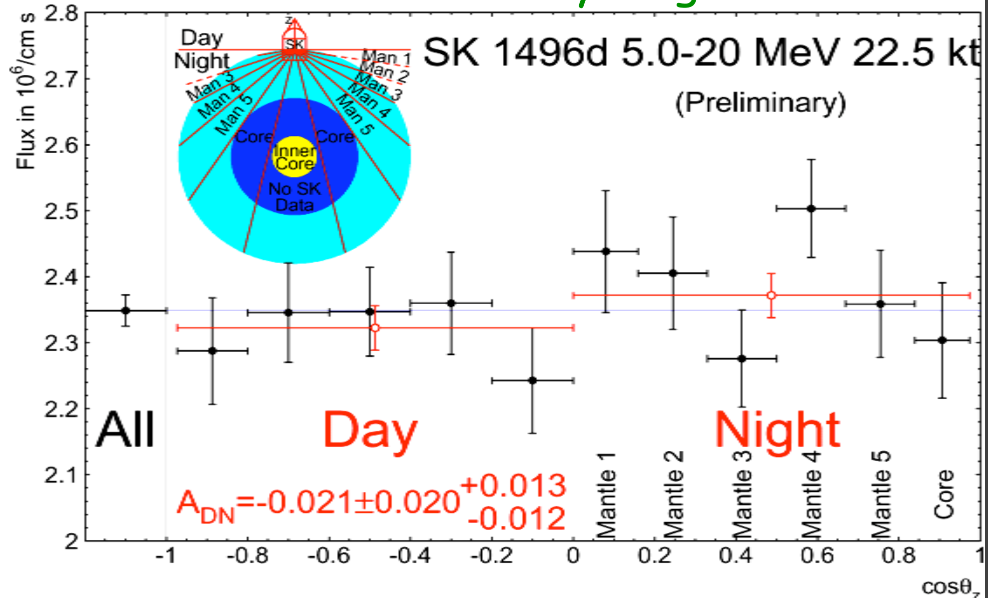
Goals of the Future Solar ν Program

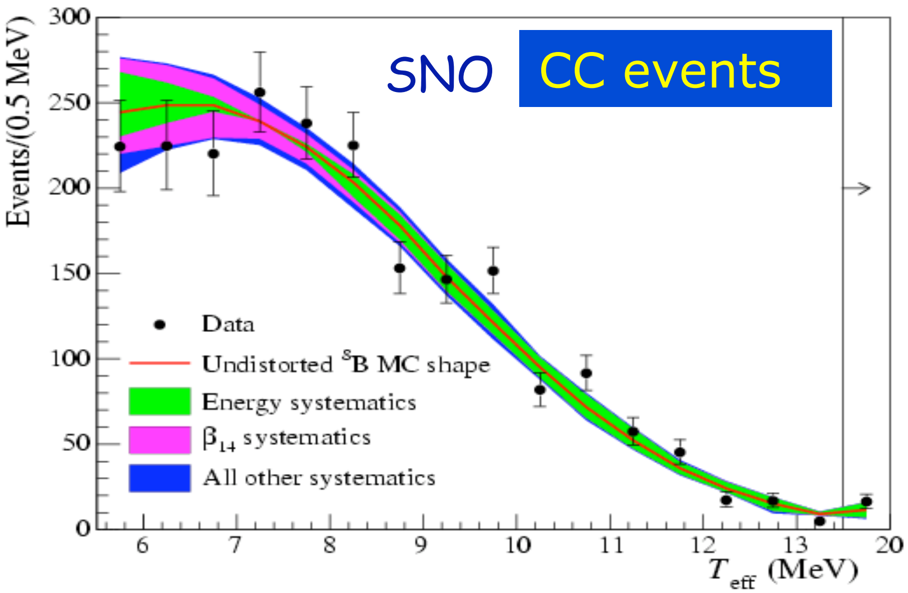
`Unlucky' Parameters so far…

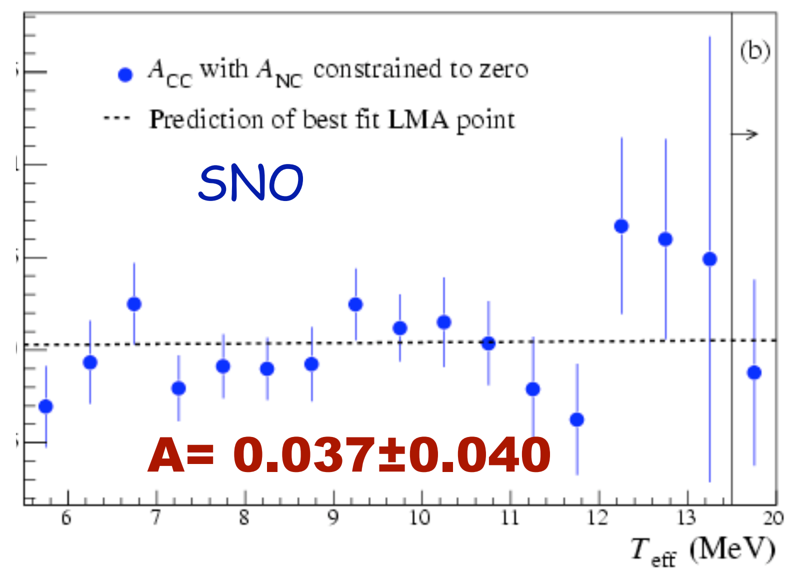
Spectrum



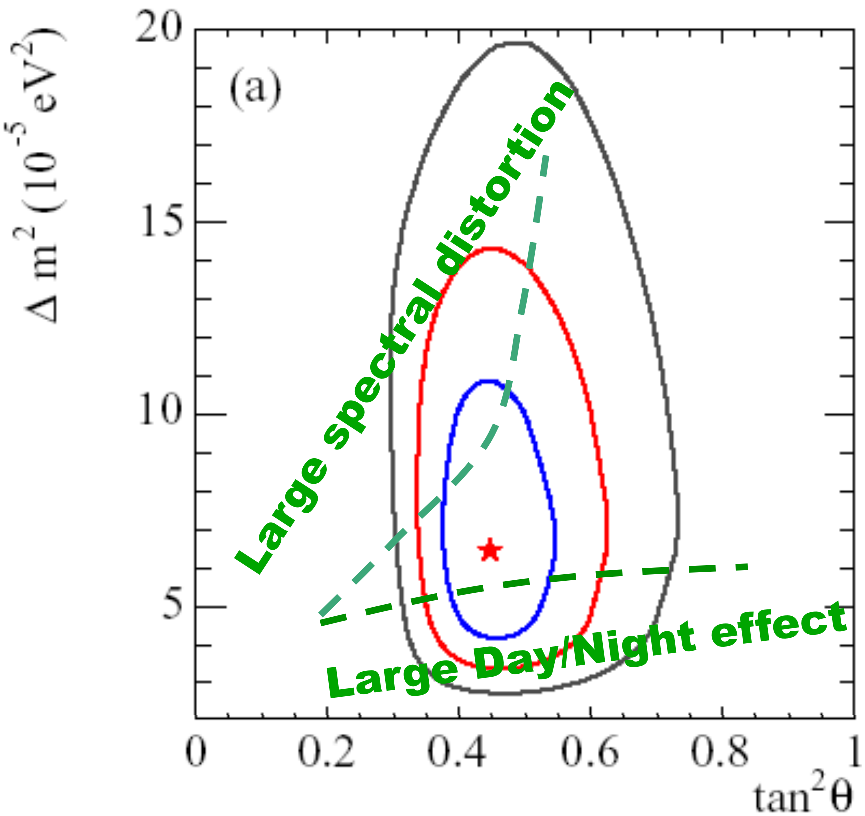
Day/Night







Unlucky Parameters

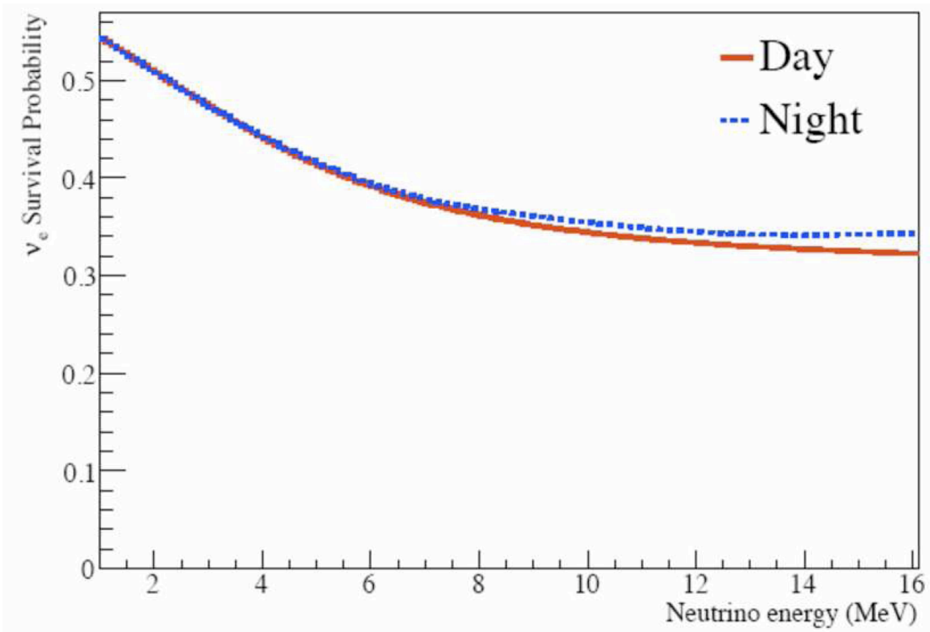


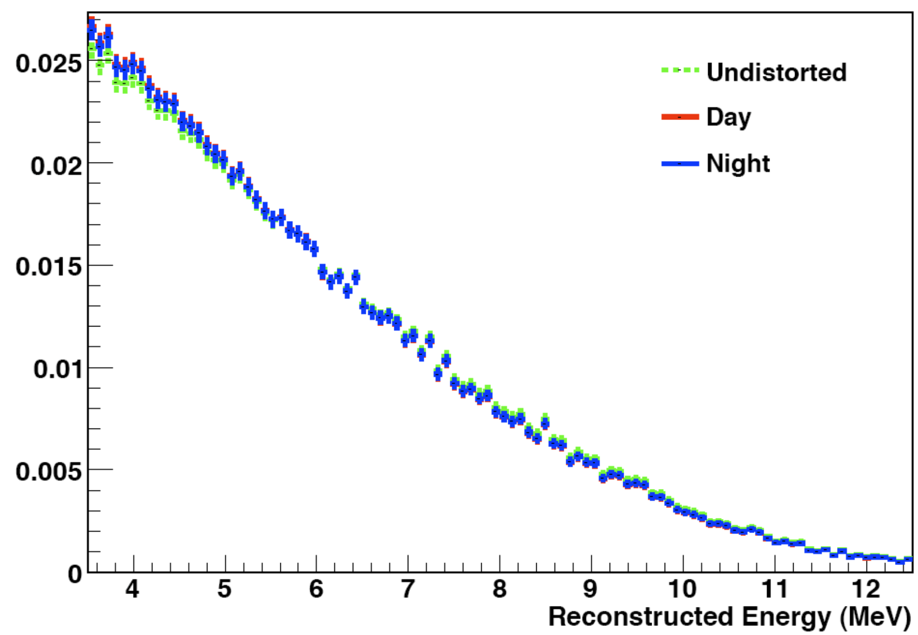
So far, it seems that Nature has picked out one of the few regions where we'd miss a direct MSW signature—

`unlucky' parameters

Day/Night Effect

➢ Energy Dependence





S. Seibert

$$A = \frac{2(\phi_{\nu_e}^{night} - \phi_{\nu_e}^{day})}{\phi_{\nu_e}^{night} + \phi_{\nu_e}^{day}}$$

Statistics on integral asymmetry good enough for ~0.5% measurement, expect 2% asymmetry

Day/Night Effect

- Integral Asymmetry

$$A = \frac{2(\phi_{\nu_e}^{night} - \phi_{\nu_e}^{day})}{\phi_{\nu_e}^{night} + \phi_{\nu_e}^{day}}$$

Statistics for 300kTon on integral asymmetry good enough for ~0.7% measurement, expect 2% asymmetry

Spectral information could play bigger role for LAr…

…and can we see CC interactions on Ar? If yes, even better

Day/Night Effect

➢ Spallation Backgrounds (H_2O)

Cosmic rate ~0.2 Hz, so cut on Δt>0.5 s and E> 7 MeV

Nucleus	Mode	Br. Ratio	Max β γ Energy (MeV)	$T_{1/2}$(sec)
$^{11}_{4}$Be	β^-	55%	11.5	13.8
$^{11}_{4}$Be	$\beta^-\gamma$	42%	9.4(β)+8(γ)	13.8
$^{16}_{7}$N	β^-	28%	10.4	7.13
$^{16}_{7}$N	$\beta^-\gamma$	66%	4.3(β)+6.1(γ)	7.13

$$\mu^- + ^{16}_{8}O \rightarrow ^{16}_{7}N + \nu_\mu$$

A. Marino

~1.7% of cosmics lead to spallation products, ^{11}Be is 5×10^{-5} of these and ^{16}N is 1.4×10^{-3}

→ Leads to ~150 spallation events/year before any additional cuts

Day/Night Effect

➢ Other Systematics

$$A = \frac{2(\phi_{\nu_e}^{night} - \phi_{\nu_e}^{day})}{\phi_{\nu_e}^{night} + \phi_{\nu_e}^{day}}$$

Ratio makes up for a lot of sins…

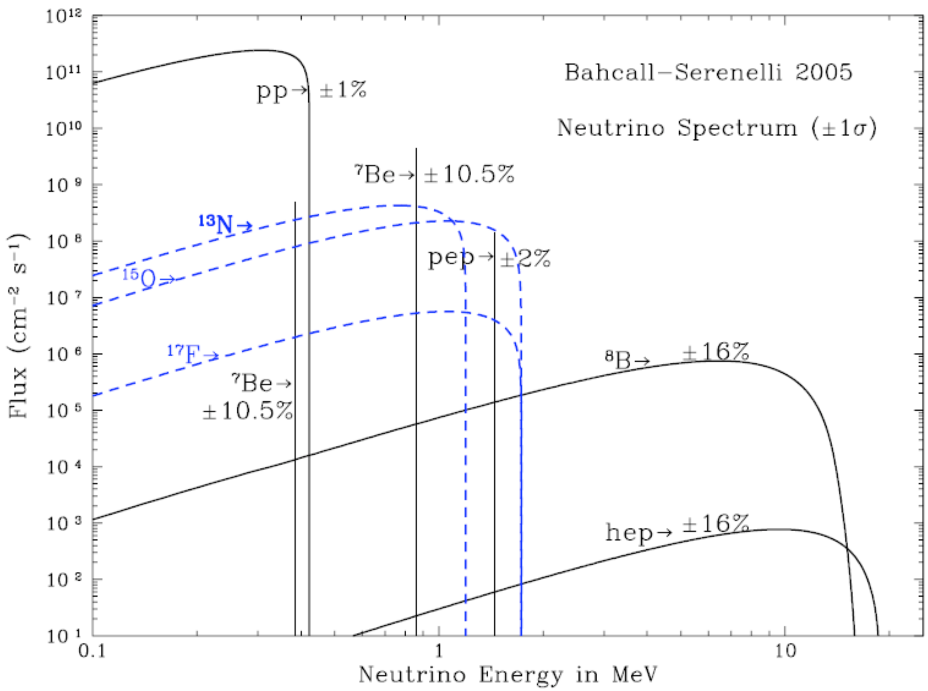
…but top/down detector asymmetries
or time variations can `alias' into fake D/N asymmetry

Day/Night Effect

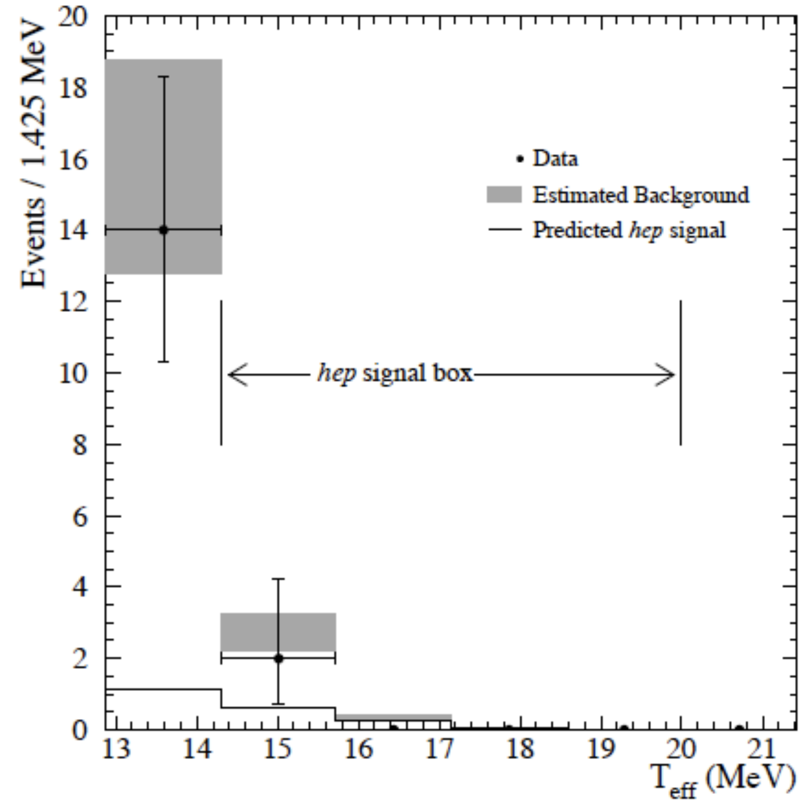
➢ Summary

- Smoking gun matter effect
- Need reasonably low (~7 MeV) threshold
  - What are backgrounds in `segmented' LAr?
- Need to be deep for H_2O—4850 ft good enough
- CC might just make up for smaller LAr mass (?)
- Need reasonably good E resolution for H_2O
  - so PMT coverage at least >20%?
- Need continuous calibration system to remove time variations
- Need calibration system to illuminate full detector

hep neutrinos



SNO Limits

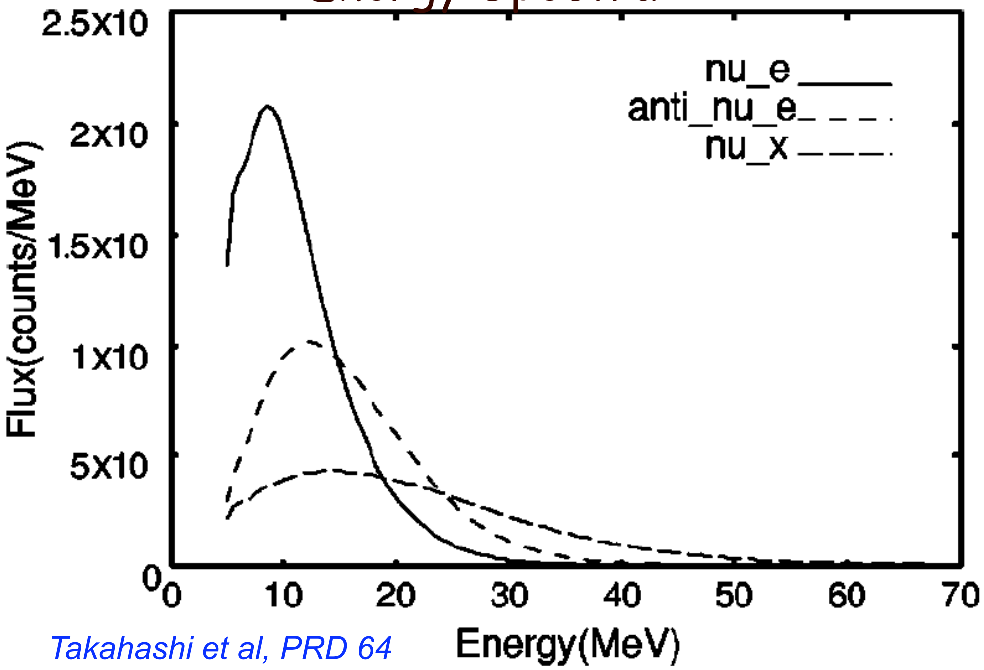


Tough to do with ES and with poorer energy resolution, but lots of events---fit ^{8}B shape?

LAr might do very well especially with CC

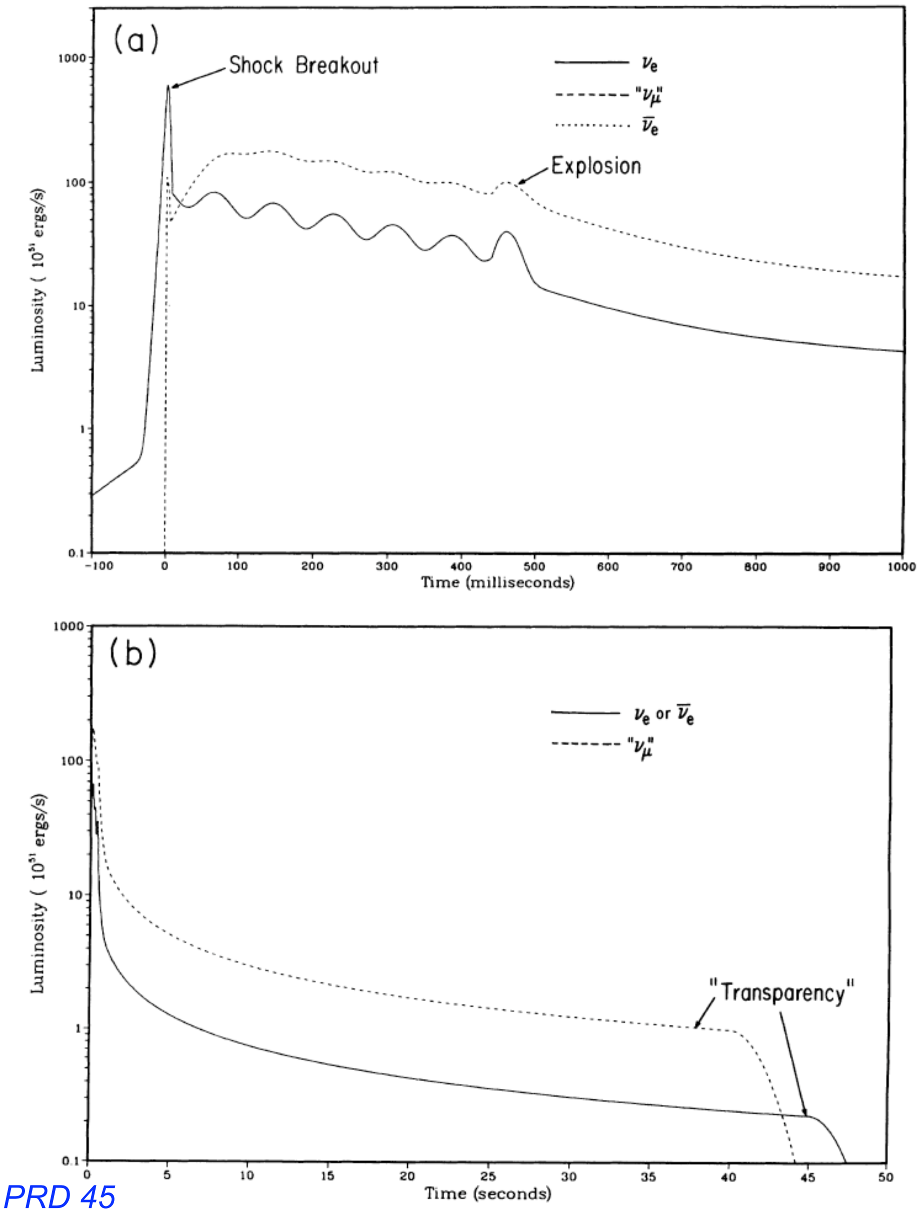
Supernova νs

Energy Spectra



Takahashi et al, PRD 64

Time Evolution



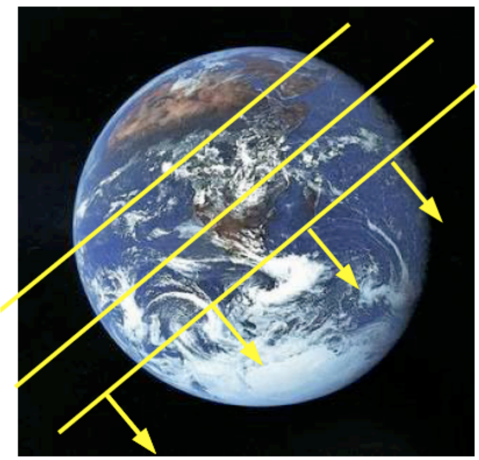
Burrows, Klein, and Gandhi, PRD 45

Models differ in details, but ν_e `breakout burst' and energy region are generically the same (and they fit SN1987A)

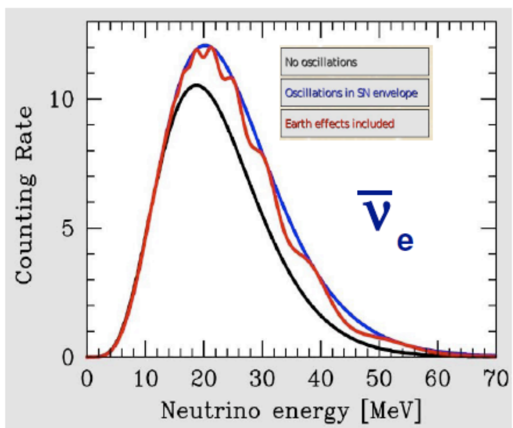
Supernova vs

➢ Physics

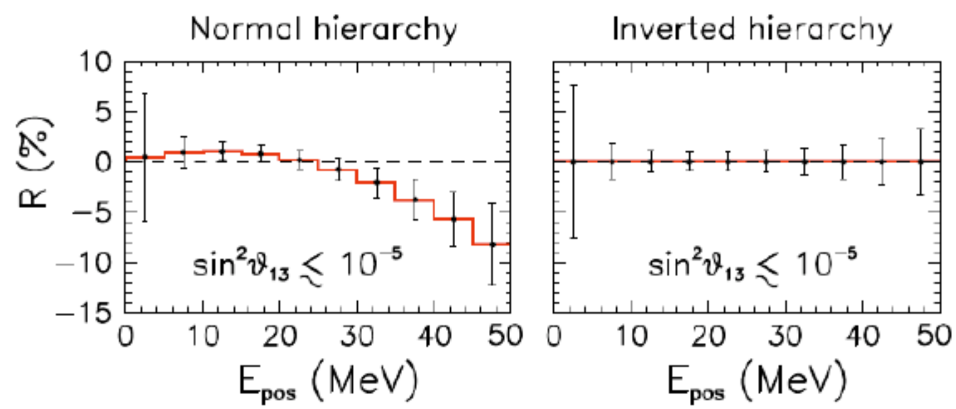
- Supernova core collapse
- Neutrino oscillation: MSW in supernova shock
- θ_{13}
- MSW Effect and Mass Hierarchy



Kachelreiss, Raffelt et al.



K. Scholberg



B.Dasgupta, AD, A. Mirizzi, arXiv:0802.1481

Supernova vs

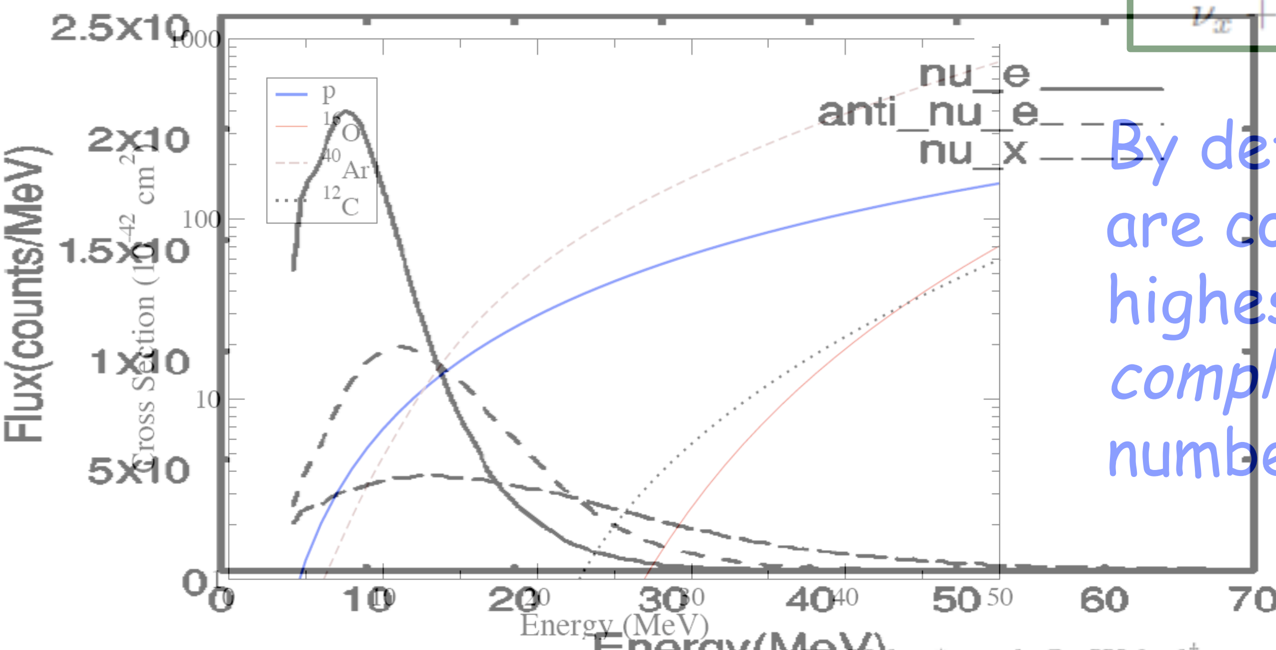
➢Reactions

H_2O

$$\overline{\nu}_e + p \rightarrow n + e^+ \quad (88\%/89\%)\,,$$
$$\nu_e + e^- \rightarrow \nu_e + e^- \quad (1.5\%/1.5\%)\,,$$
$$\overline{\nu}_e + e^- \rightarrow \overline{\nu}_e + e^- \quad (<1\%/<1\%)$$
$$\nu_x + e^- \rightarrow \nu_x + e^- \quad (1\%/1\%)\,,$$
$$\nu_e +^{16} O \rightarrow e^- +^{16} F \quad (2.5\%/<1\%)$$
$$\overline{\nu}_e +^{16} O \rightarrow e^+ +^{16} N \quad (1.5\%/1\%)\,, an$$
$$\nu_x +^{16} O \rightarrow \nu_x + O^*/N^* + \gamma \quad (5\%/6\%)\,,$$

LAr

$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow {}^{40}\mathrm{K}^* + e^-$$
$$\bar{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow {}^{40}\mathrm{Cl}^* + e^+$$
$$\nu_\alpha + {}^{40}\mathrm{Ar} \rightarrow {}^{40}\mathrm{Ar}^* + \nu_\alpha$$
$$\hookrightarrow {}^{40}\mathrm{Ar} + \gamma_1 + \ldots \gamma_n$$
$$\nu_e + e^- \rightarrow \nu_e + e^-$$
$$\overline{\nu}_e + e^- \rightarrow \overline{\nu}_e + e^-$$
$$\nu_x + e^- \rightarrow \nu_x + e^-$$



C. Volpe* and J. Welzel†

By definition, H_2O and LAr are complementary here: highest cross sections have *complementary* lepton numbers

Supernova vs

Event Rates

100 kt of LAr, SN @ 10 kpc

Interaction	Rates ($\times 10^4$)
ν_e CC (^{40}Ar, ^{40}K*)	2.5
ν_x NC (^{40}Ar*)	3.0
ν_x ES	0.1
anti–ν_e CC (^{40}Ar, ^{40}Cl*)	0.054

A. Bueno NP2008, via K.Scholberg

100 kt H_2O, SN@10 kpc

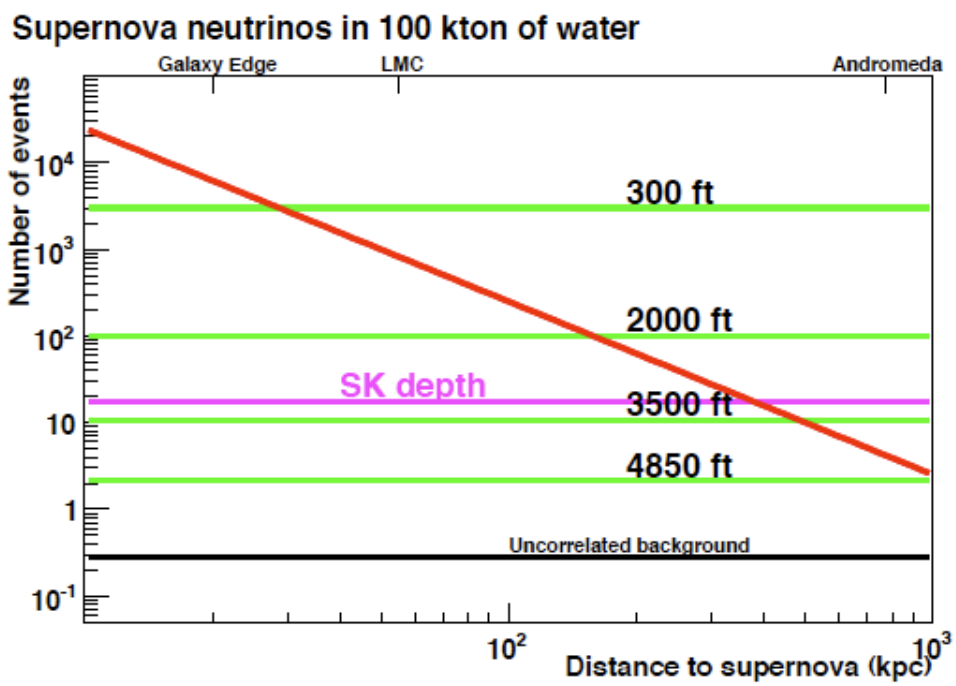
Interaction	Rates ($x10^4$)
$\bar{\nu}_e + p \to n + e^+$	2.3
$\nu + e \to \nu + e$	0.1
$\nu_x + {}^{16}O \to {}^{16}O + \nu_x$	0.05
$\nu_x + {}^{16}O \to {}^{16}F + e$	0.2

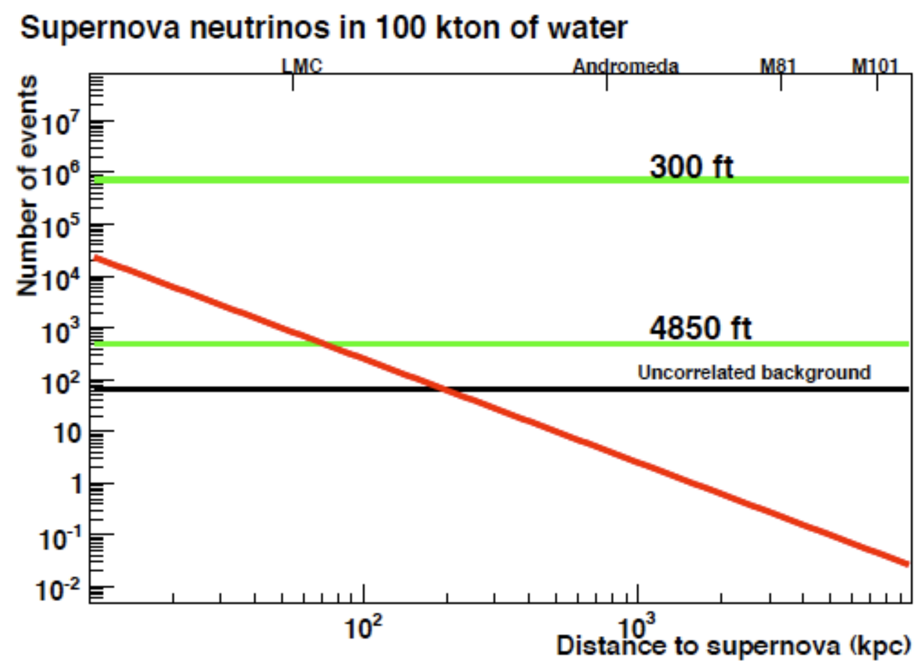
For Andromeda, multiply by $2x10^{-4}$

Supernova vs

➢ Event Rates vs. Distance

K. Scholberg





Δt<30 s

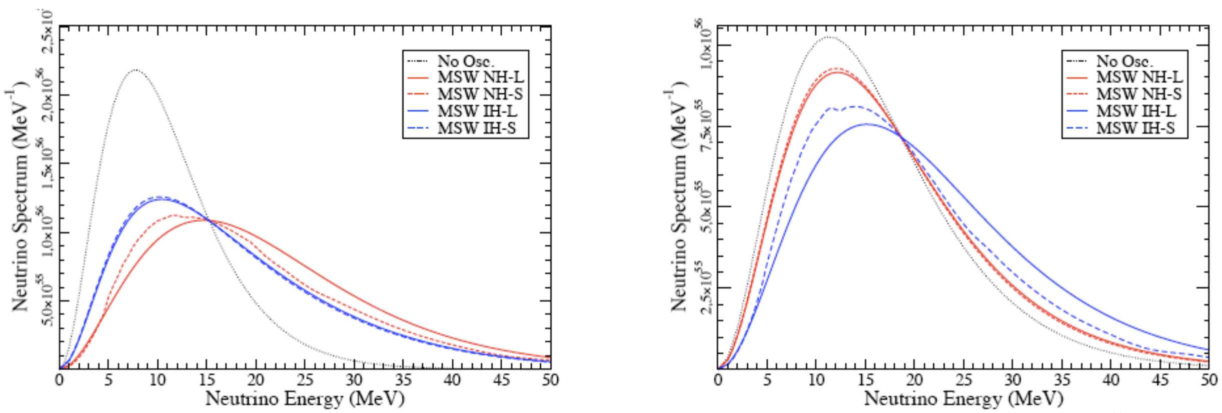
Δt<1 hour

+optical coincidence

Diffuse Supernova ν Background

Physics:

- Cosmological star formation rate
- Spectrum gives information about supernova details
- Spectrum also influenced by MSW within supernova



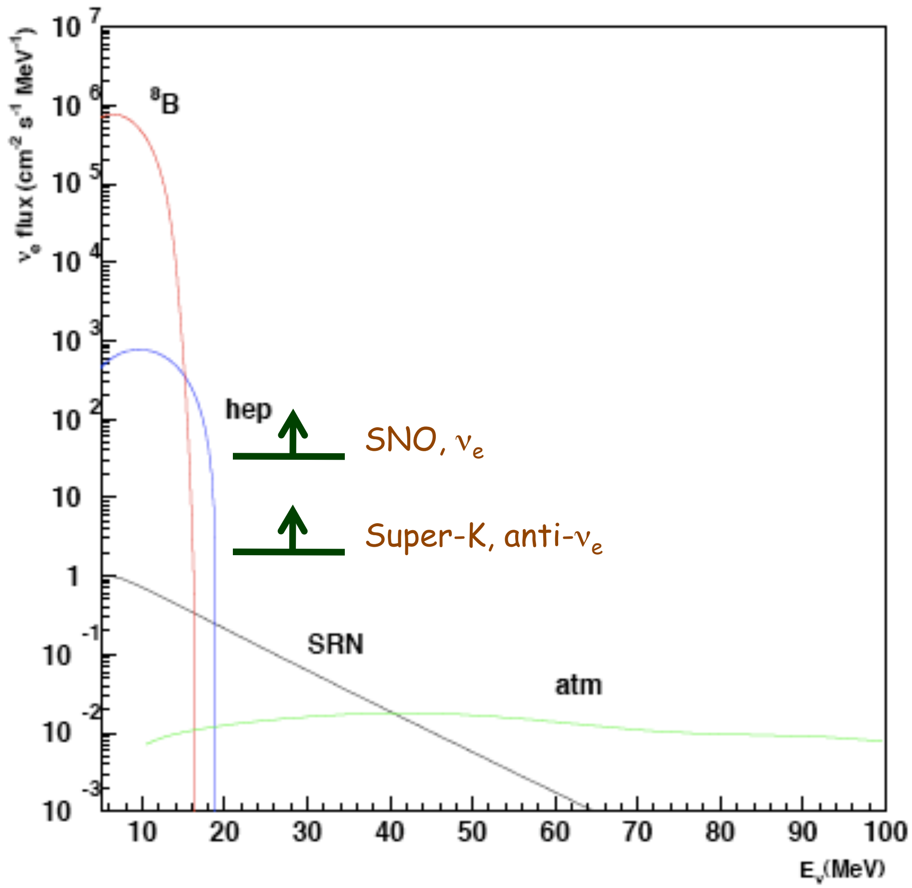
Cocco et al, hep-ph/0408031v2

FIG. 3: Electron neutrino (left) and anti-neutrino (right) spectra after propagation in a core-collapse supernova, Eqs. (1-2) with $B = 0$, for the normal hierarchy with $\sin^2 2\theta_{13} = 0.19$ (NH-L) or $\sin^2 2\theta_{13} = 10^{-4}$ (NH-S) (thin solid and dashed lines) and the inverted hierarchy with $\sin^2 2\theta_{13} = 0.19$ (IH-L) or $\sin^2 2\theta_{13} = 10^{-4}$ (IH-S) (thick solid and dashed lines). The Fermi-Dirac distribution is also shown for comparison (dotted line).

- Potential `continuum' source of supernova νs to study

Diffuse Supernova ν Background

Current best limits:

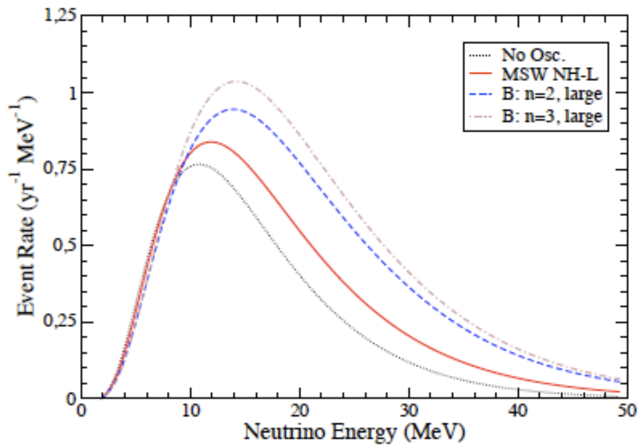


Cocco et al, hep-ph/0408031v2

Diffuse Supernova ν Background

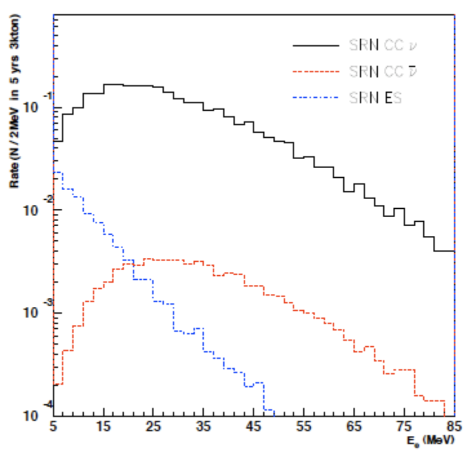
Expected rates:

H_2O: 20 events/year/100kTon



Volpe and Welzel, astro-ph/0711.3237

LAr: 10 events/year/100kTon



Cocco et al, hep-ph/0408031v2