Low Energy Neutrino Experiment Overview

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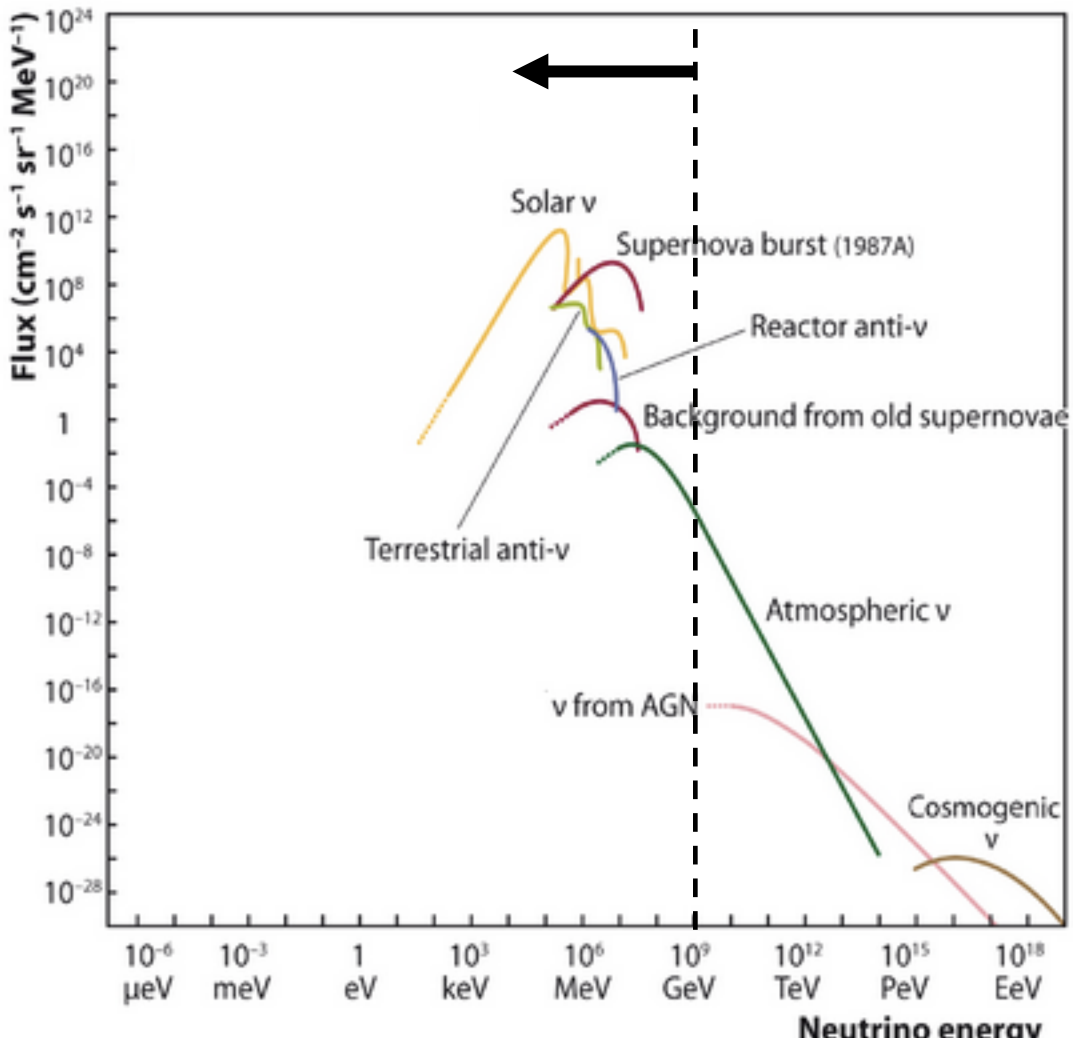
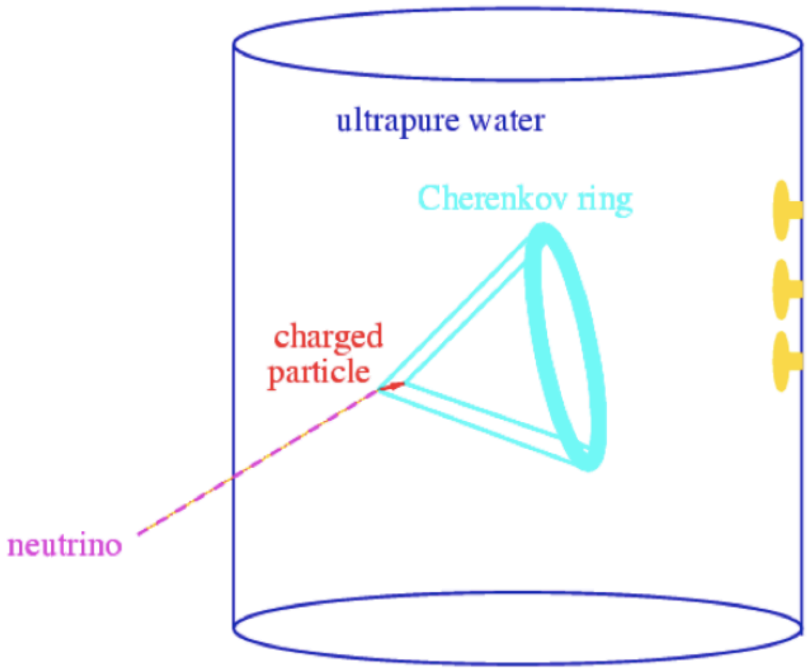
Low energy experiments: less than GeV



Water Cherenkov Experiments



Important reactions

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

$$\nu + e^- \rightarrow \nu + e^-$$

Also some interactions on ^{16}O

$$\nu_e + {}^{16}O \rightarrow e^- + {}^{16}F^{(*)}$$

$$\bar{\nu}_e + {}^{16}O \rightarrow e^+ + {}^{16}N^{(*)}$$

$$\nu_x + {}^{16}O \rightarrow \nu_x + {}^{16}O^*$$

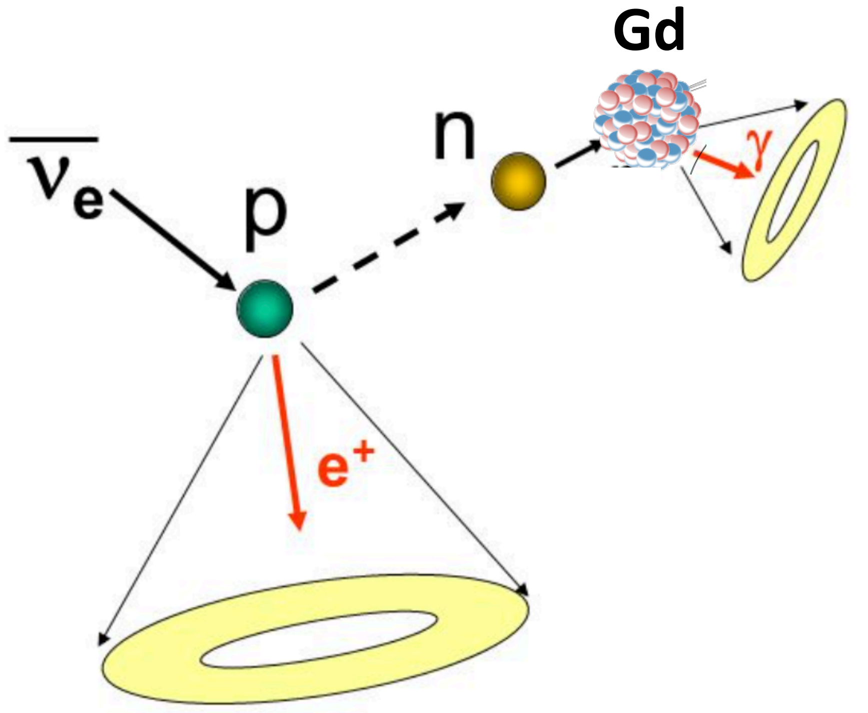
Advantages:

- water is cheap!

- directional info in the ES channel

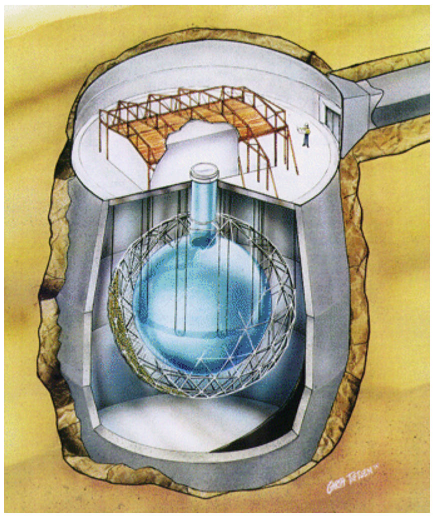
Water Cherenkov Experiments (with Gd)

Increase neutron tagging capability by adding Gd – look for delayed coincidence!



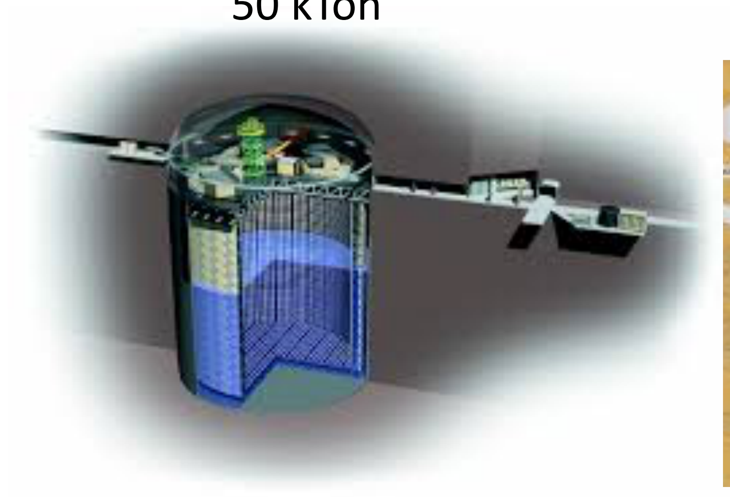
Examples of water Cherenkov experiments

1 kTon



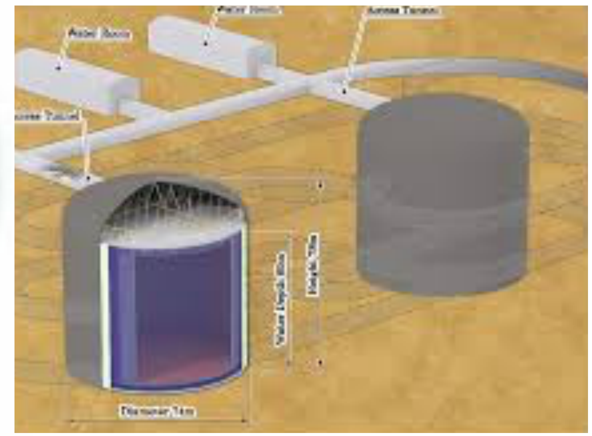
Sudbury Neutrino Observatory (past)

50 kTon



Super-Kamiokande (current)

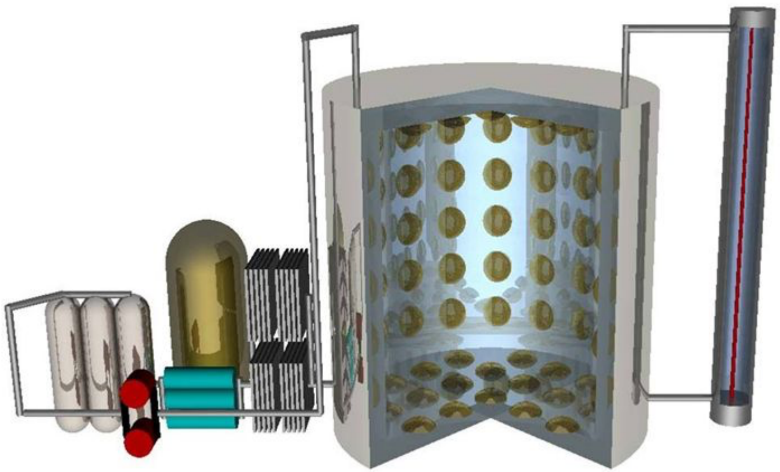
516 kTon



Hyper-Kamiokande (future)

Examples of water Cherenkov experiments with Gd

200 Ton

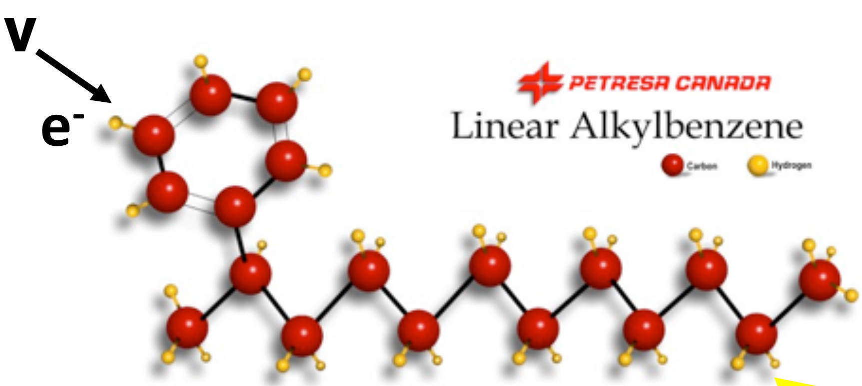


EGADS (currently running)

50 kTon

SK-Gd (near term)
Add Gd to the SK detector

Liquid Scintillator Experiments



Important reactions

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

$$\nu + e^- \rightarrow \nu + e^-$$

Also some interactions on ^{12}C

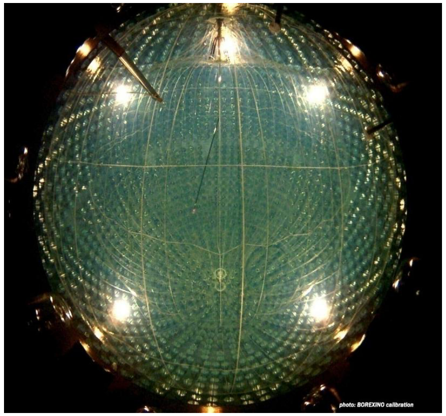
$$\nu + {}^{12}C \rightarrow \nu + {}^{12}C^*$$

Advantages:

-lots of photons = low energy measurements

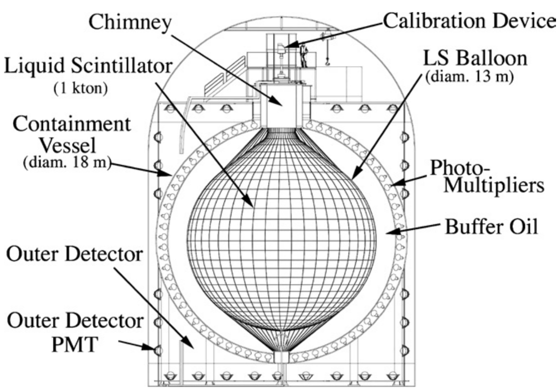
Examples of liquid scintillator experiments

0.3 kTon



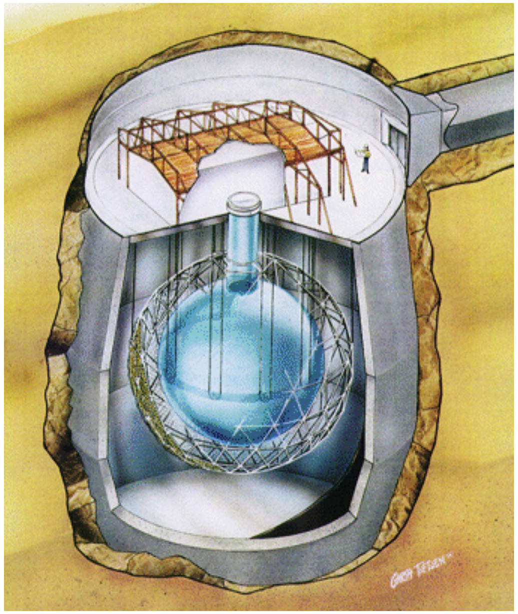
BOREXINO (current)

1 kTon



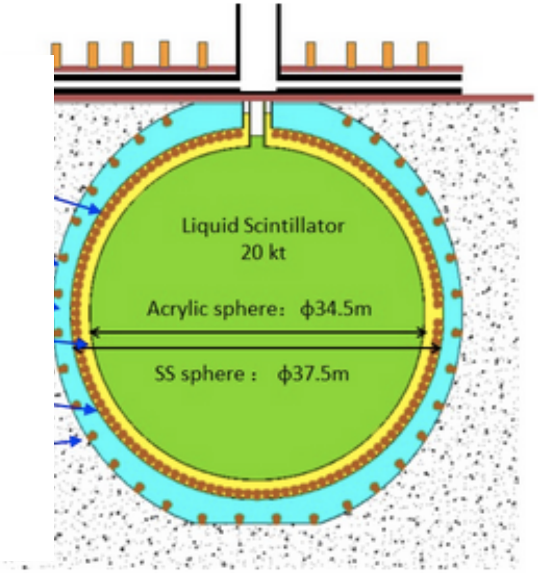
KAMLAND (current)

0.8 kTon



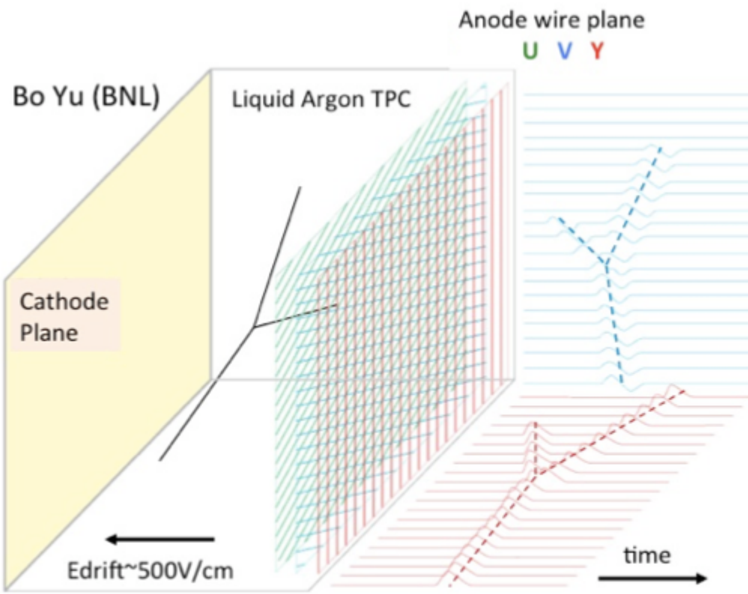
SNO+ (near-term)

20 kTon



JUNO (future)

Liquid Argon Experiments



Important Reactions

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

$$\nu + e^- \rightarrow \nu + e^-$$

$$\overline{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow e^+ + {}^{40}\mathrm{Cl}^*$$

Advantages:

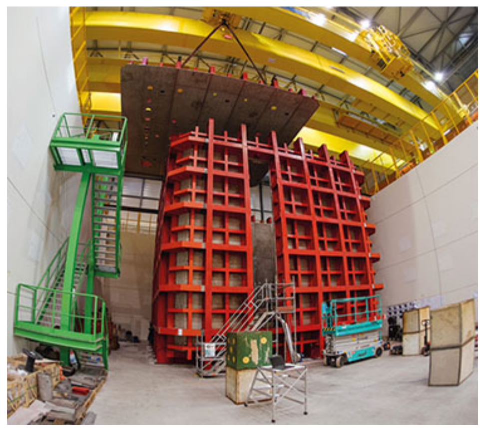
- Using a time-projection chamber = good particle identification

Examples of liquid argon experiments

0.75 ton

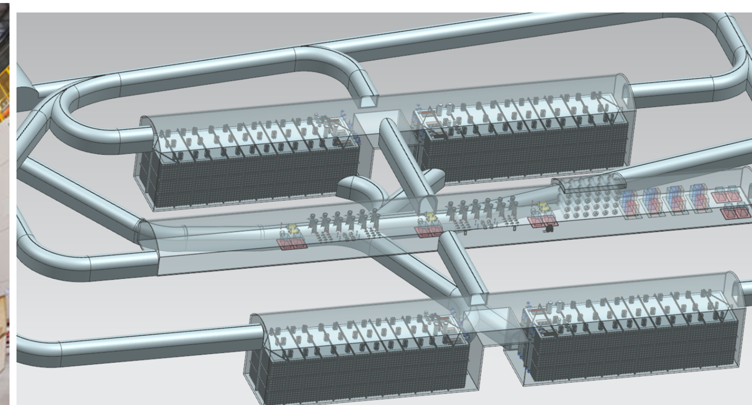
Argoneut/LArIAT (past)

770 ton



ProtoDUNE (near-term)

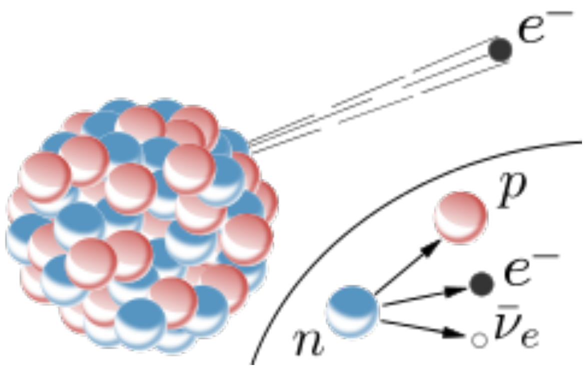
40 kton



DUNE (future)

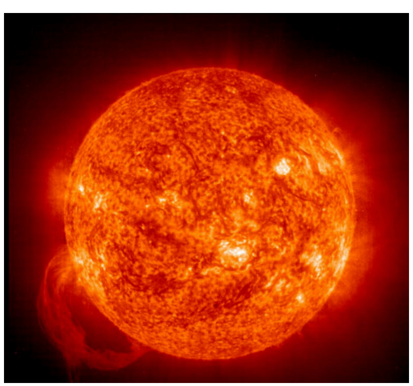
Low energy experiments have many different sources

Reactor neutrinos

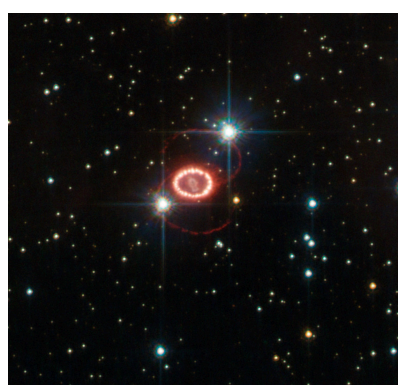


Geoneutrinos

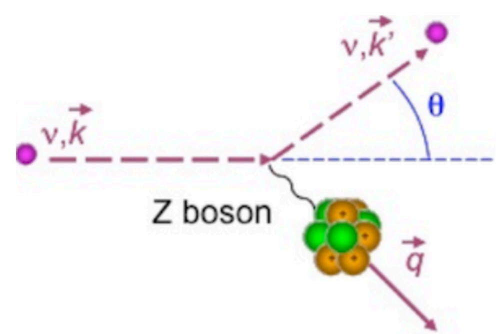
Solar neutrinos



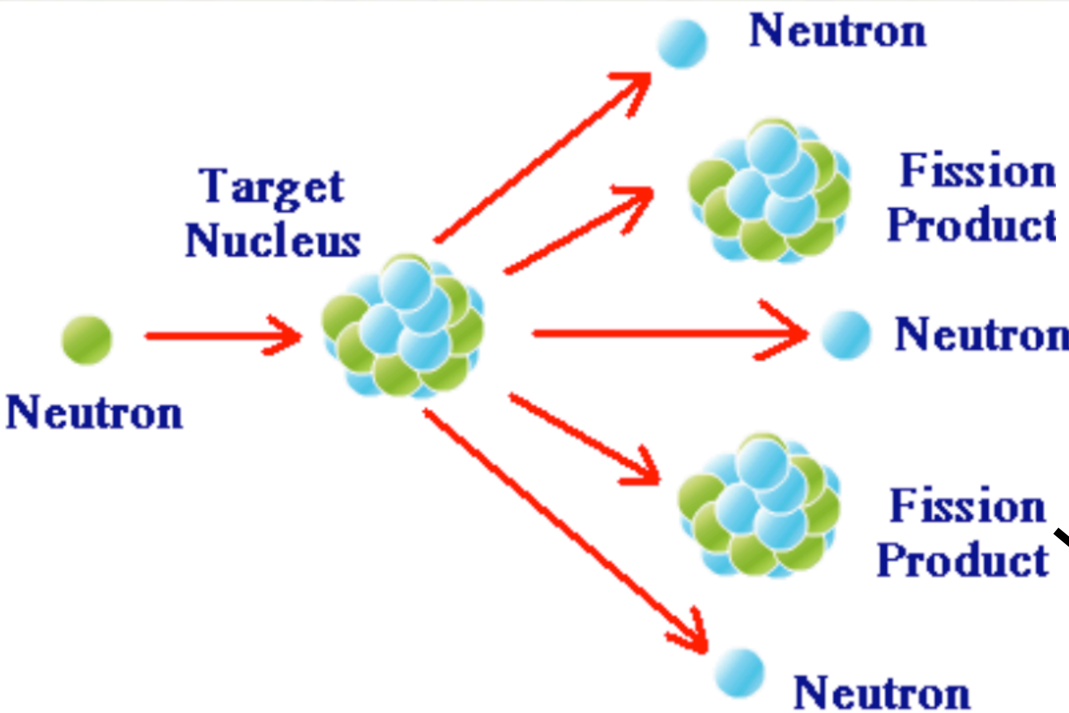
Supernova neutrinos

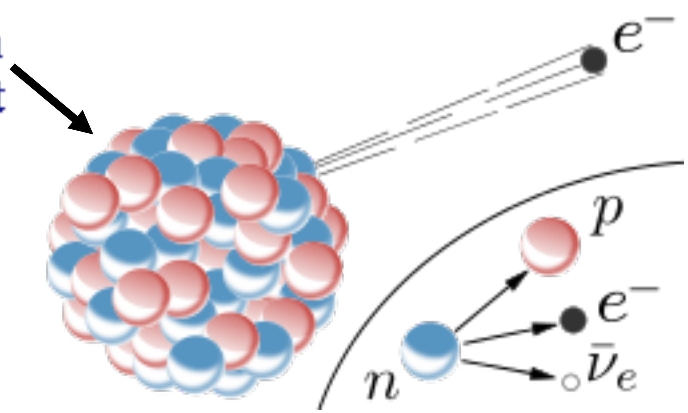


Coherent scattering

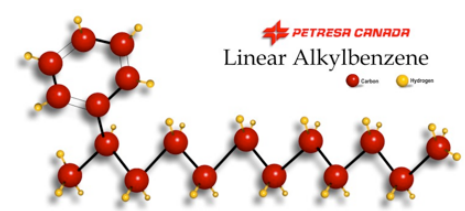


Reactor neutrinos: Created from fission products in reactors





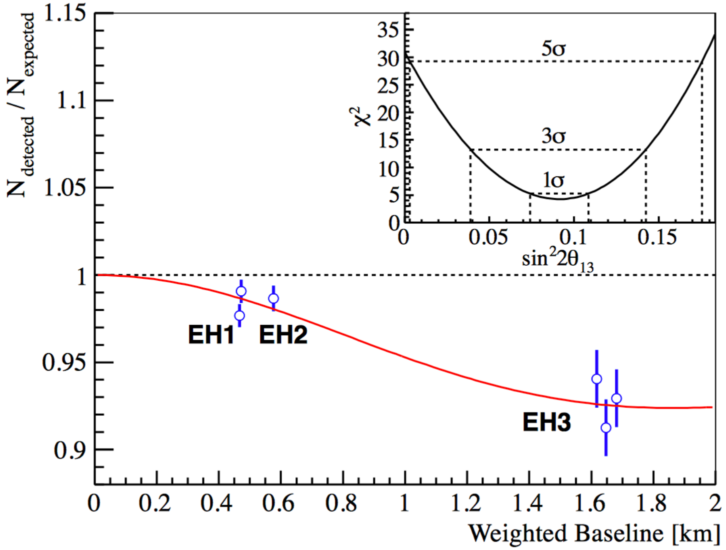
Liquid scintillator



What have we learned from reactor neutrino experiments?

First (anti)neutrino measurement

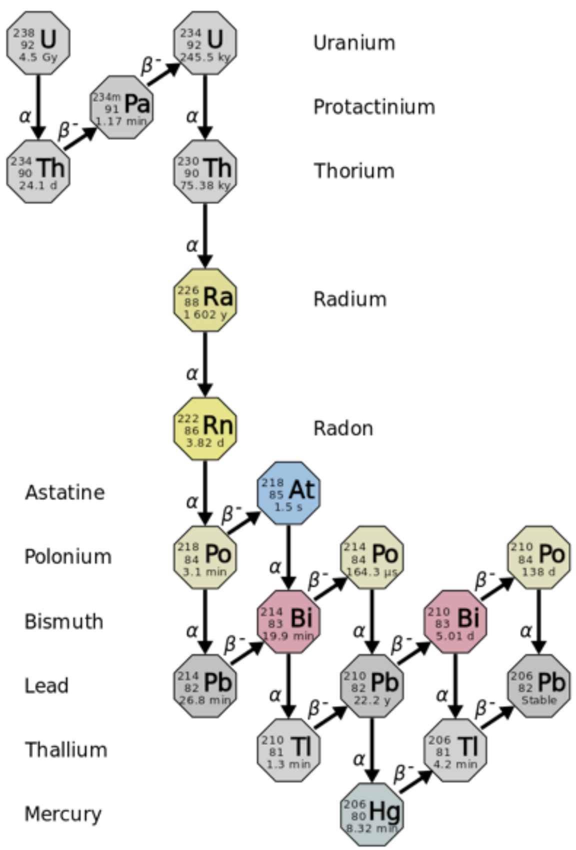
Measurement of θ_{13} oscillation parameter



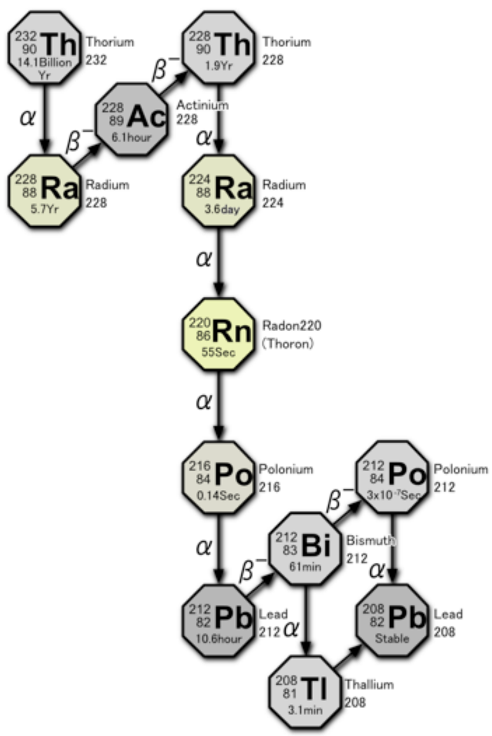
An et al. 2012

Geoneutrinos: Created via U and Th chain decays in the Earth

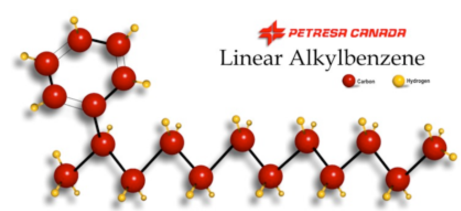
Uranium chain



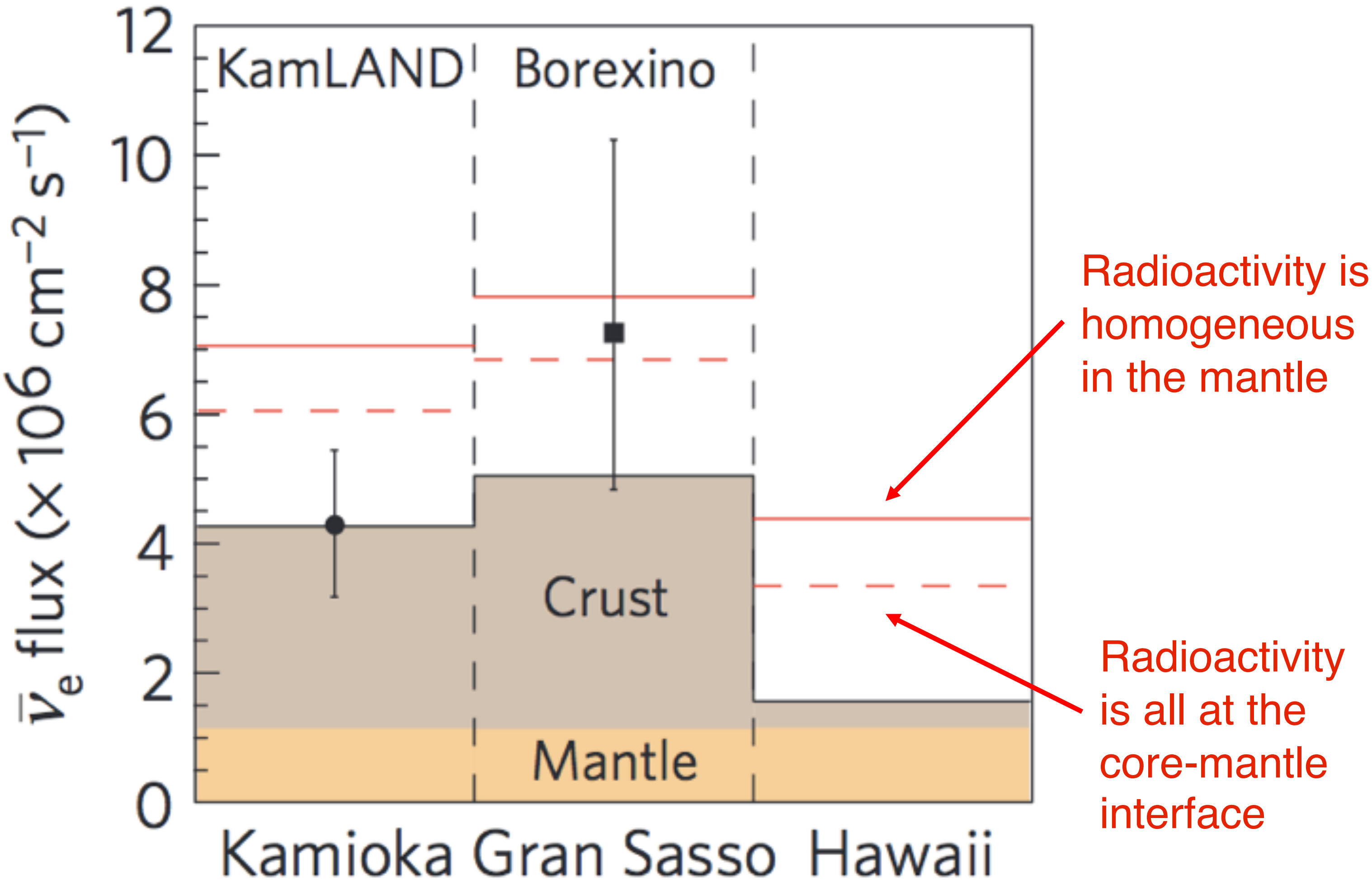
Thorium chain



Liquid scintillator



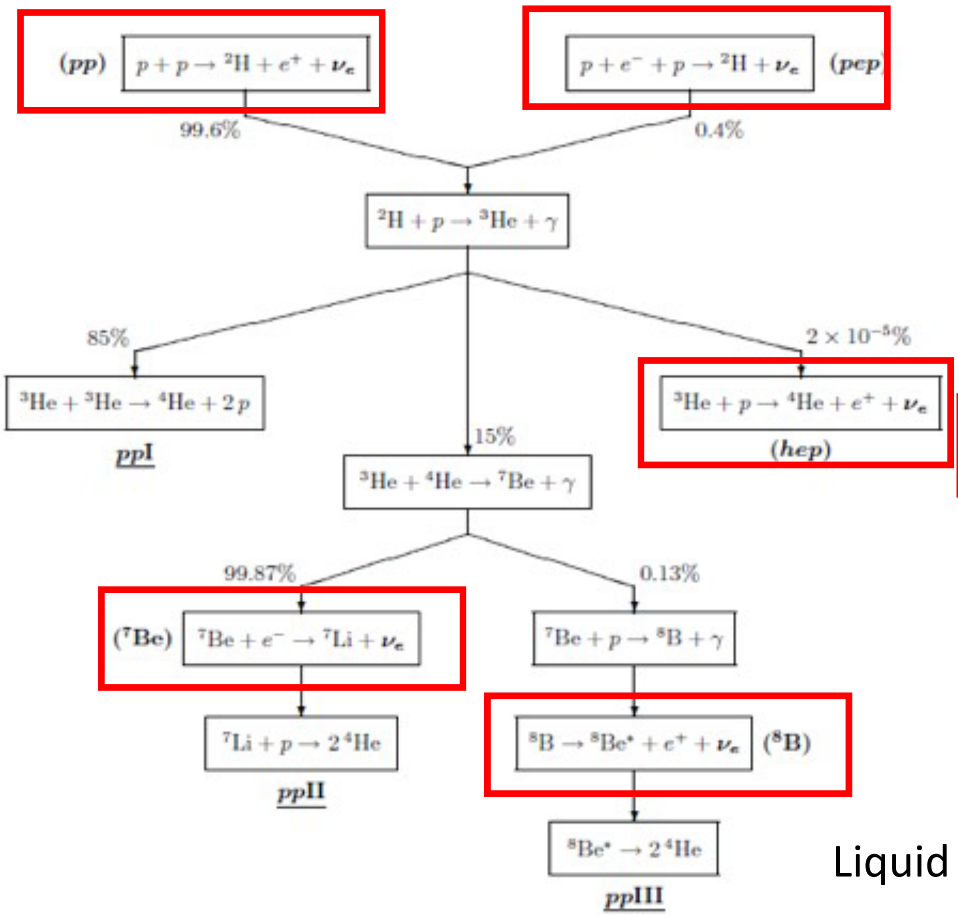
Geoneutrinos: Probing the composition of the Earth



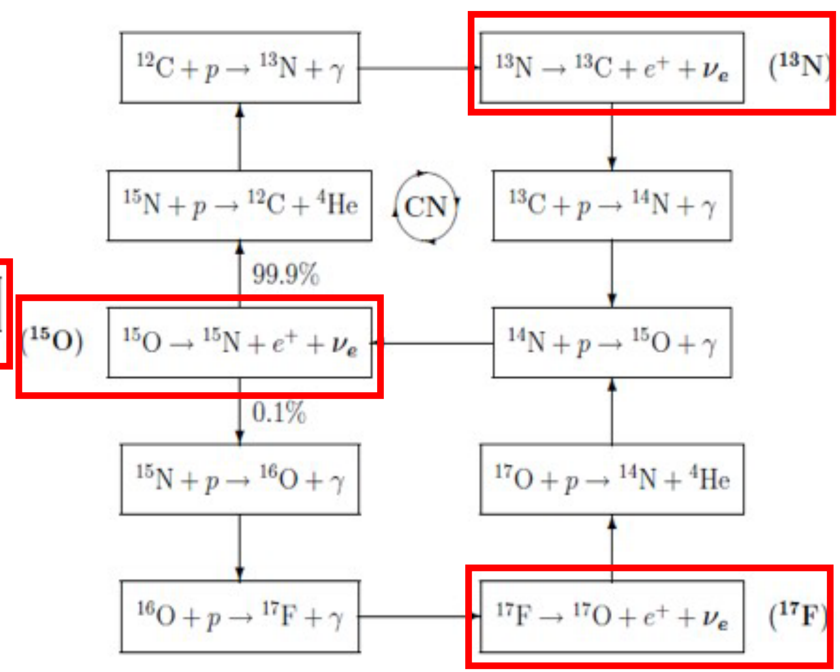
Modified from Nature Geoscience 4, 647–651 (2011)

Reactions in the thermal cycle of the Sun produce neutrinos

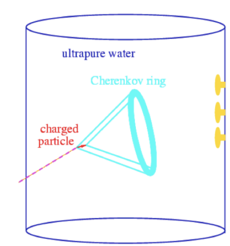
pp chain

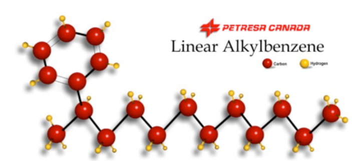


CNO cycle

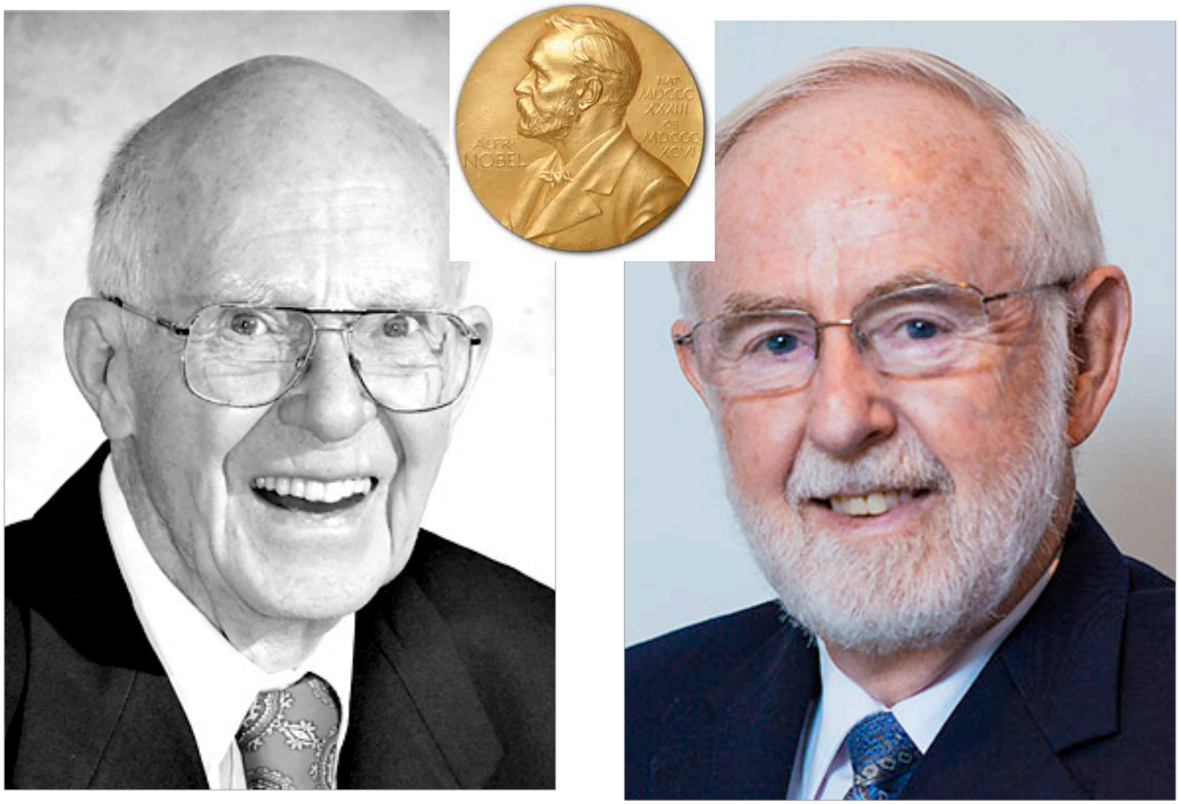


Liquid scintillator
Water





What have we learned from solar neutrino experiments?



First Detection

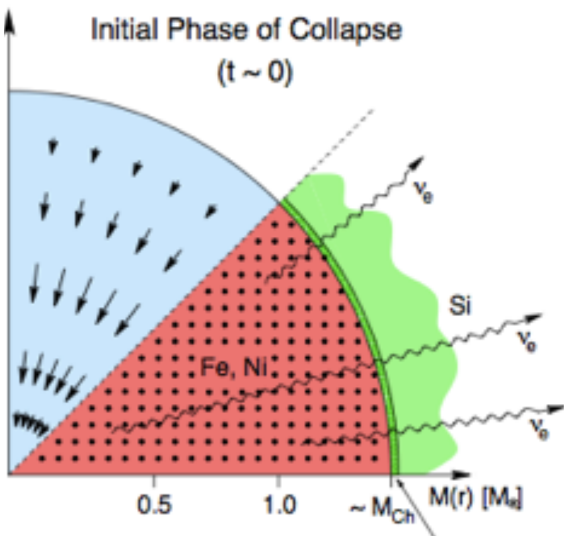
Ray Davis Jr. 2002
"for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos"

Art McDonald 2015
"for the discovery of neutrino oscillations, which shows that neutrinos have mass"

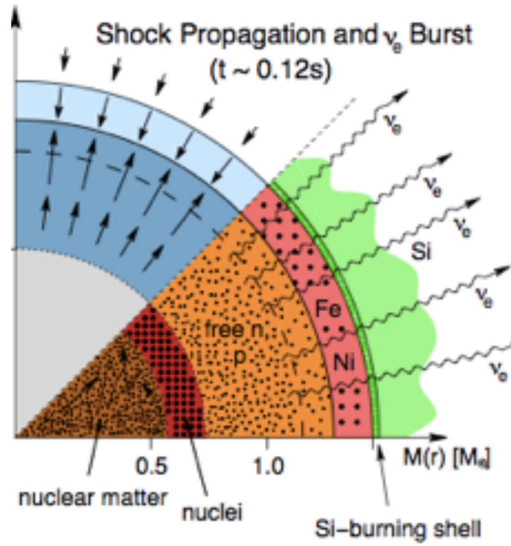
Discovery of neutrino oscillations

Supernova neutrinos: Produced in various phases of explosion

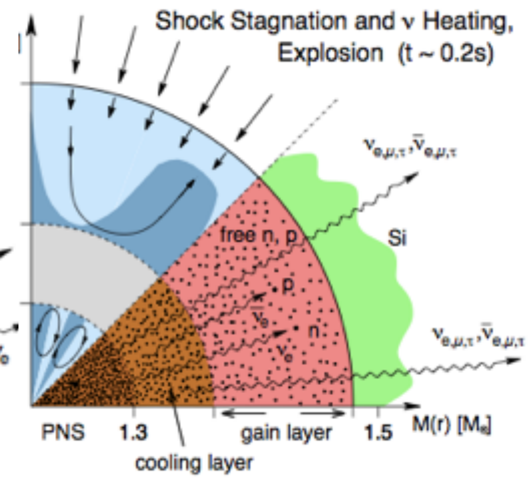
Infall



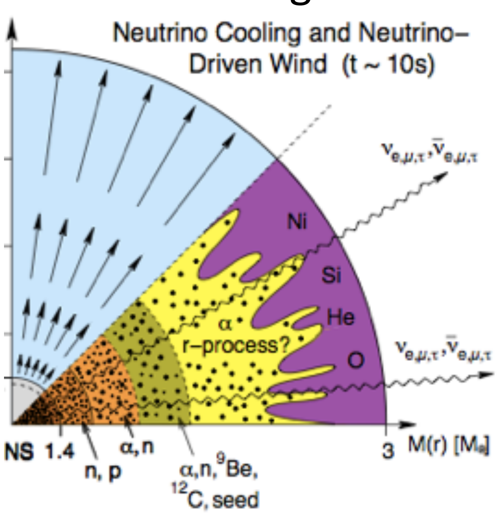
Neutronization burst



Accretion

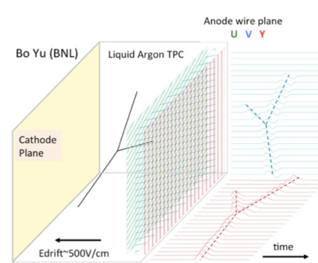


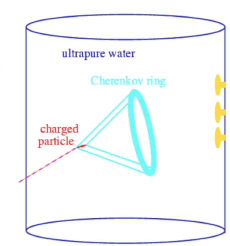
Cooling

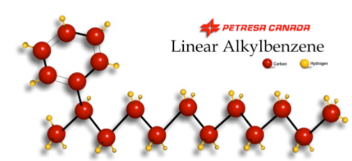


Modified from Janka et al 2007 (arXiv:astro-ph/0612072)

Liquid scintillator
Water
Argon





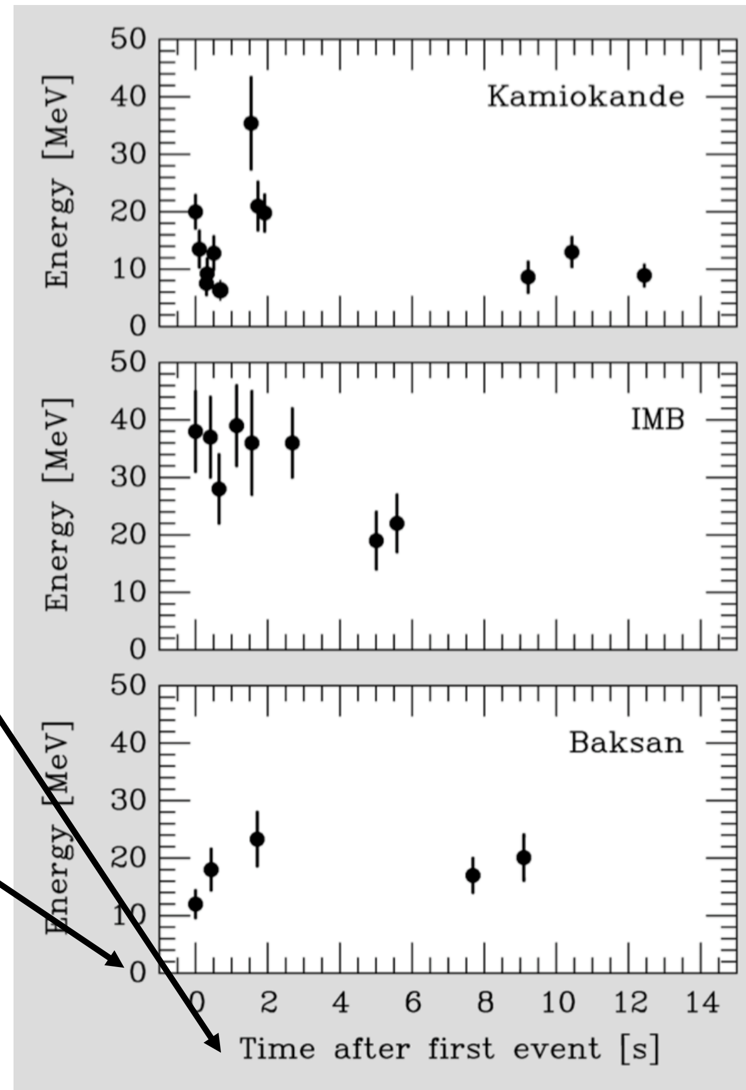


What have we learned from supernova neutrino measurements?

From only a handful of neutrinos measured from SN1987a, we learned:

Neutrinos arrive in a time window of about 10 s

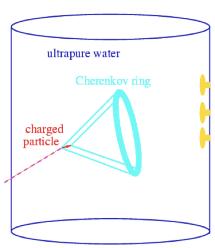
Neutrinos have energies of tens of MeVs



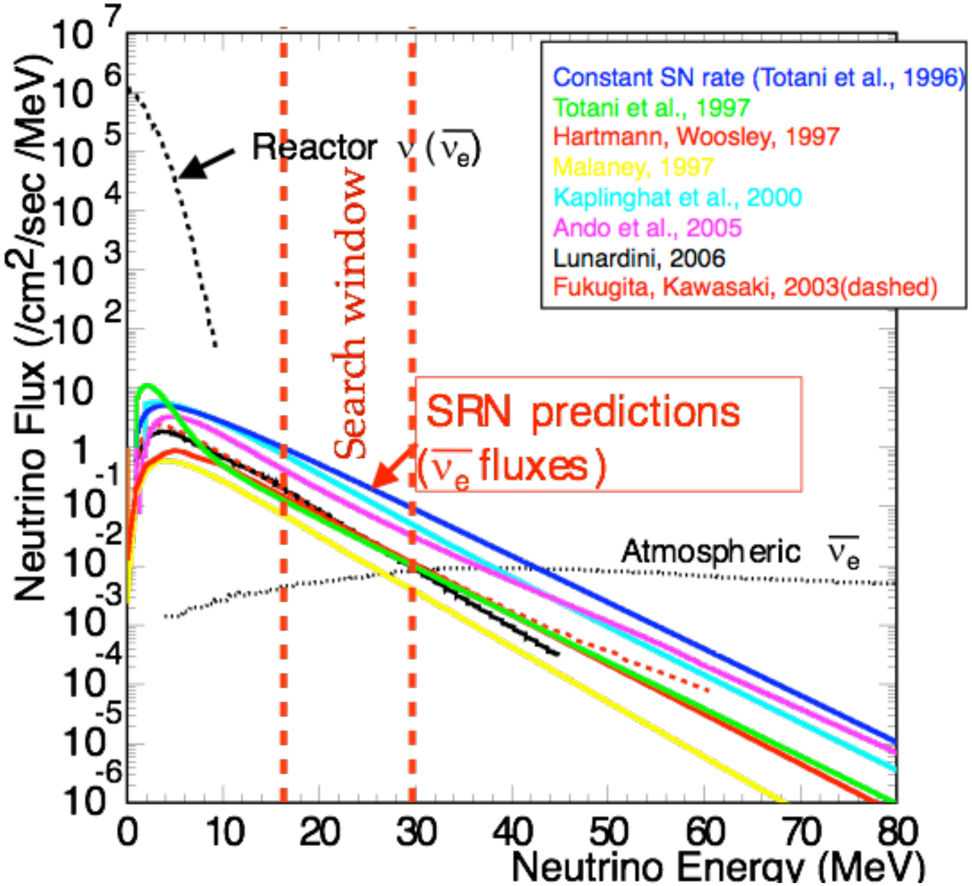
Diffuse Supernova Neutrino Background

Mainly search using inverse beta decay:

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



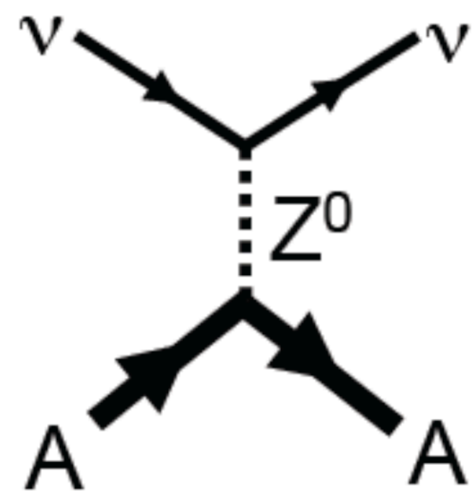
Water



Big advantage when you tag the neutron (by adding Gd, for example)

Coherent neutral current neutrino-nucleus elastic scattering (or, coherent scattering for short)

$\nu + A \rightarrow \nu + A$



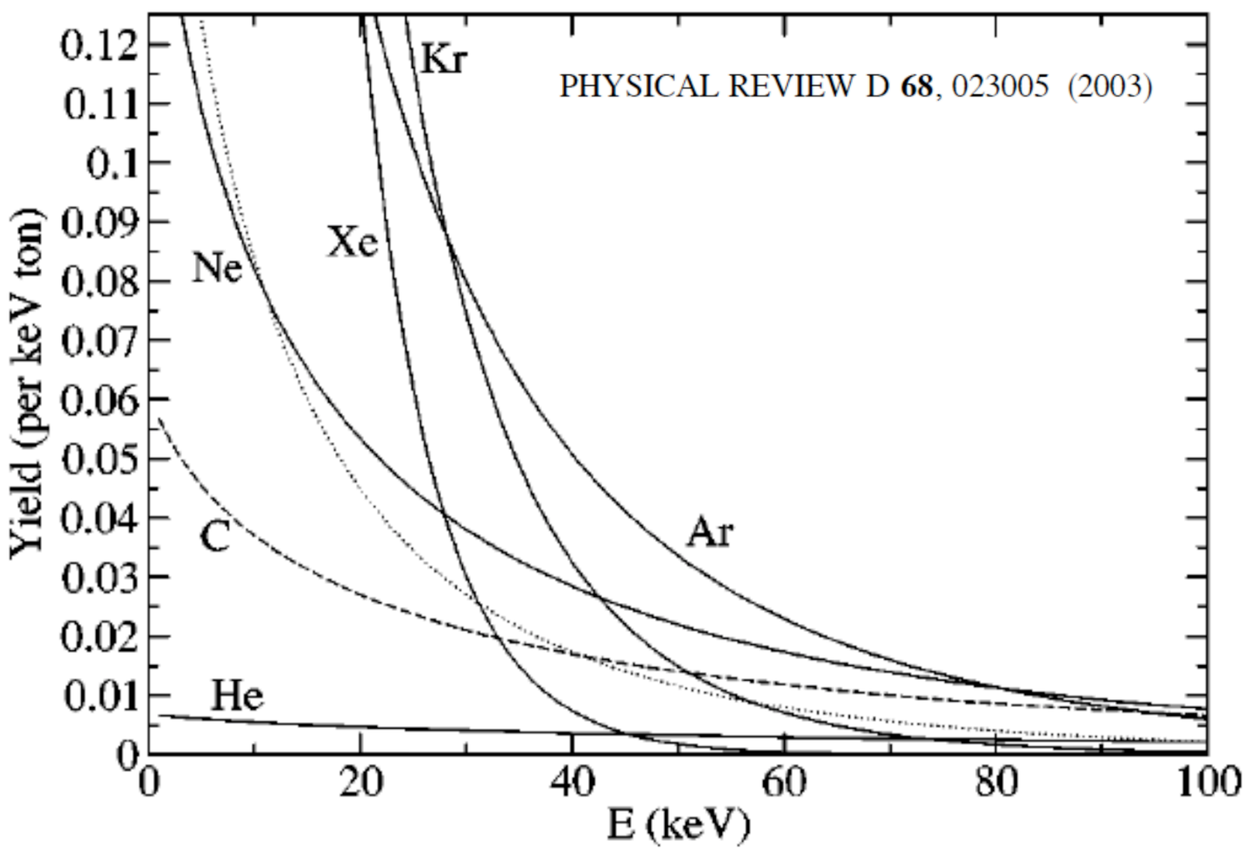
Neutrino scatters off the nucleus, causing a nuclear recoil

What have we learned from coherent scattering experiments?

No measurement yet…

What have we learned from coherent scattering experiments?

No measurement yet…



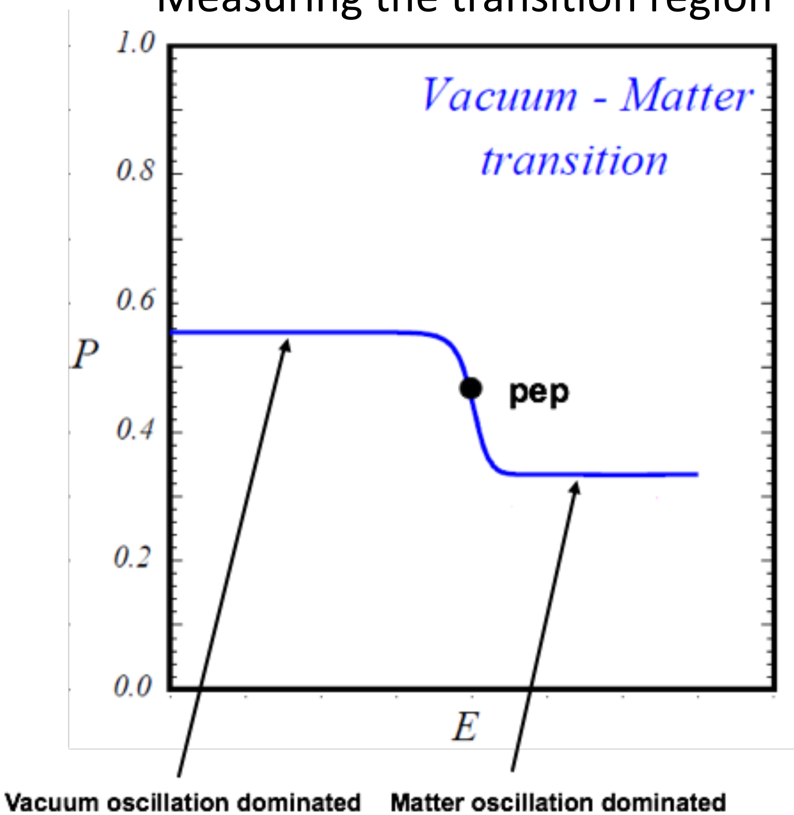
Recoils from a 5 MeV neutrino.

The nuclear recoil is very low in energy!

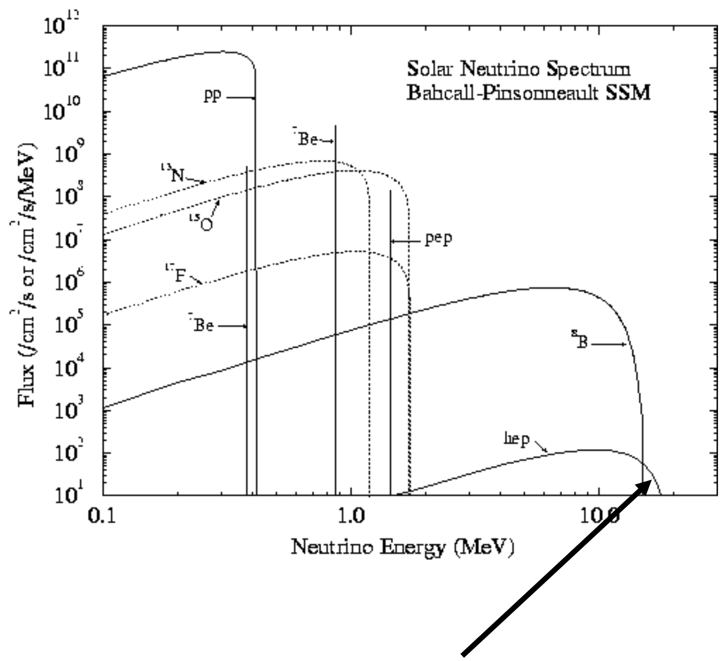
So what’s next?

Future directions for solar neutrino experiments

Measuring the transition region



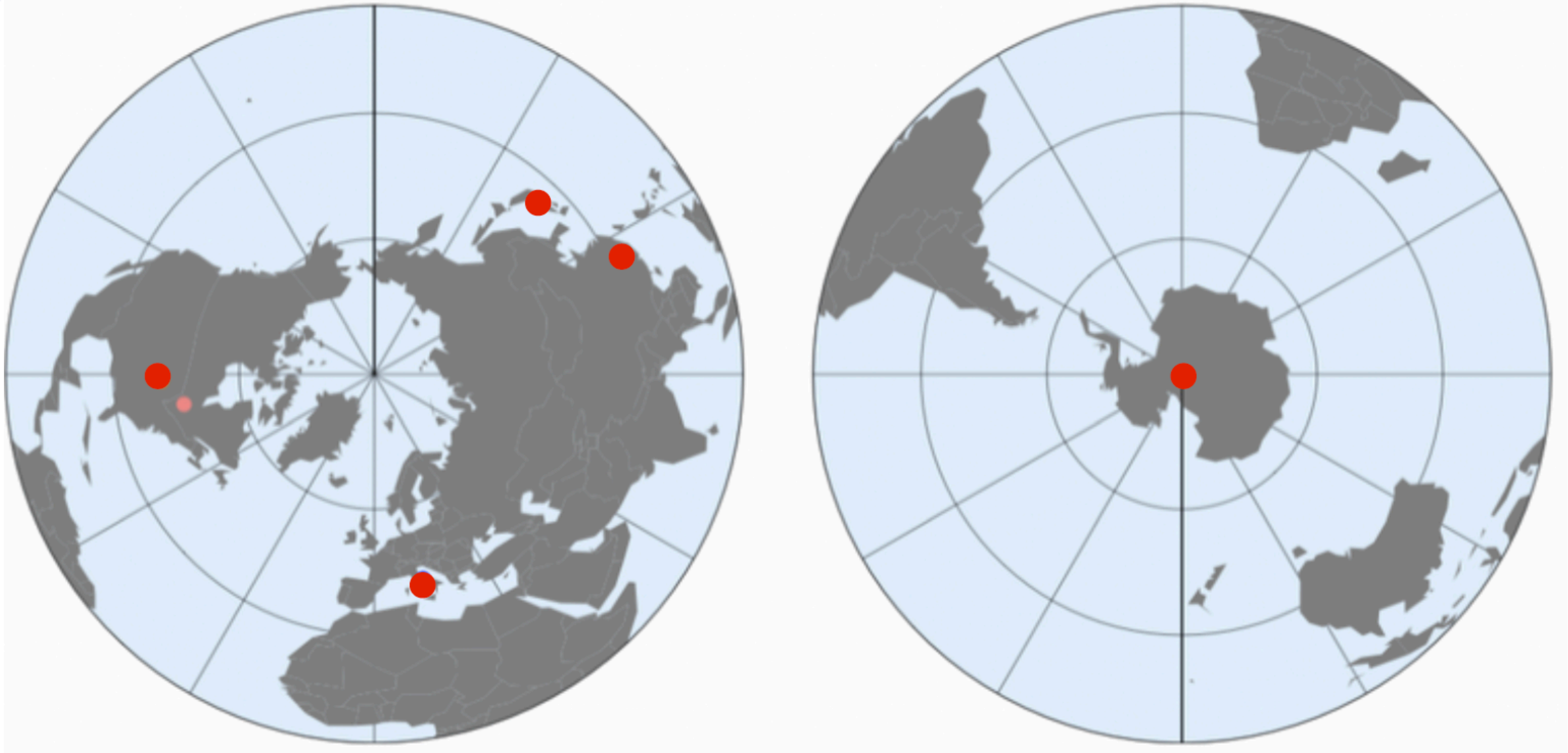
Measuring the hep neutrino



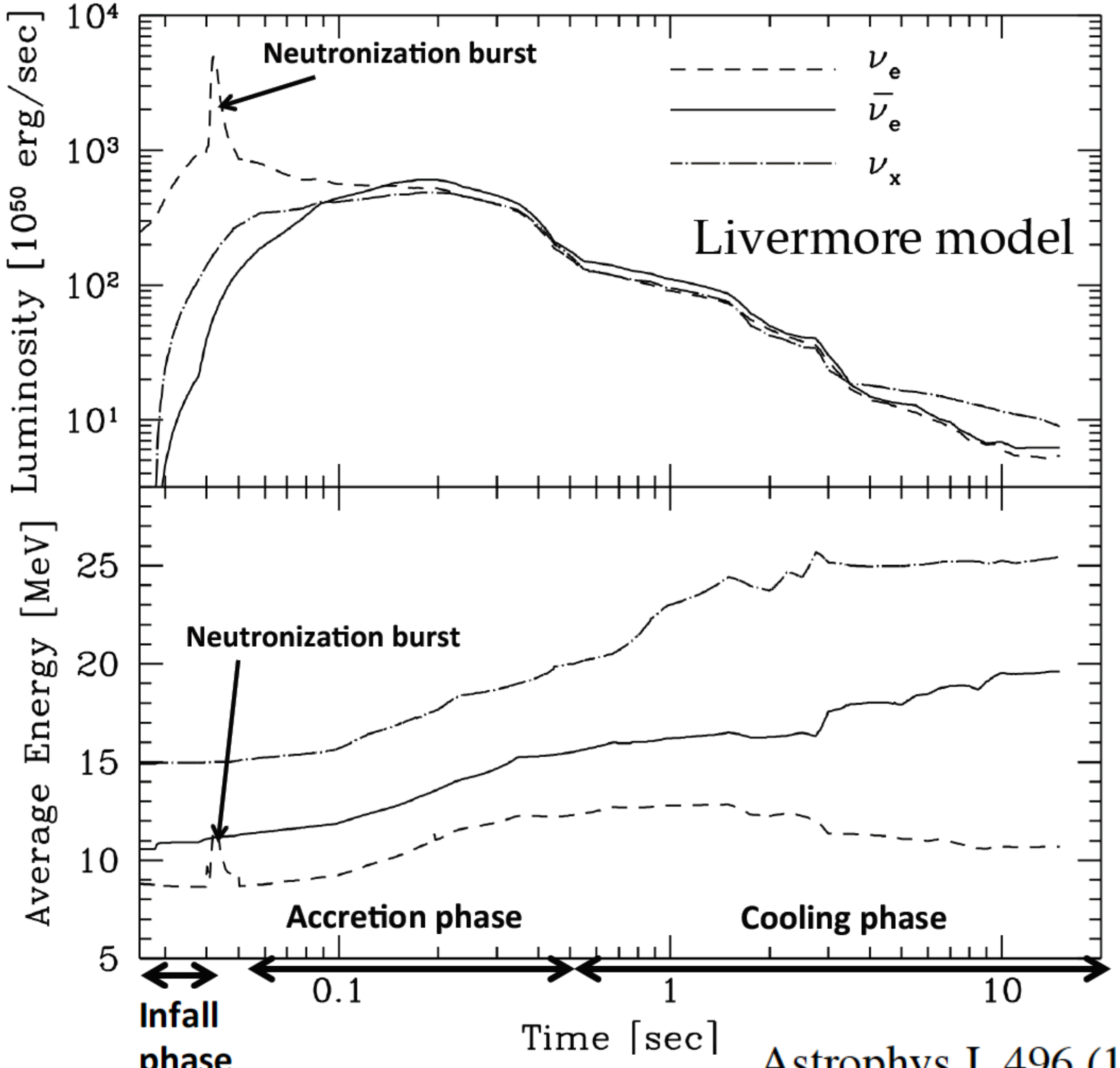
Small energy region above ^{8}B neutrinos

Supernova Early Warning System: Ready for the next Galactic Supernova

Neutrino detectors connected to the SNEWS system



High statistics supernova neutrino measurements expected for a galactic supernova



Astrophys.J. 496 (1998) 216-225

Coherent neutrino scattering experiments

Conclusions

- Low energy neutrino physics is a rich and varied field
- Similar interactions, similar challenges, different technologies
- Exciting results to come!