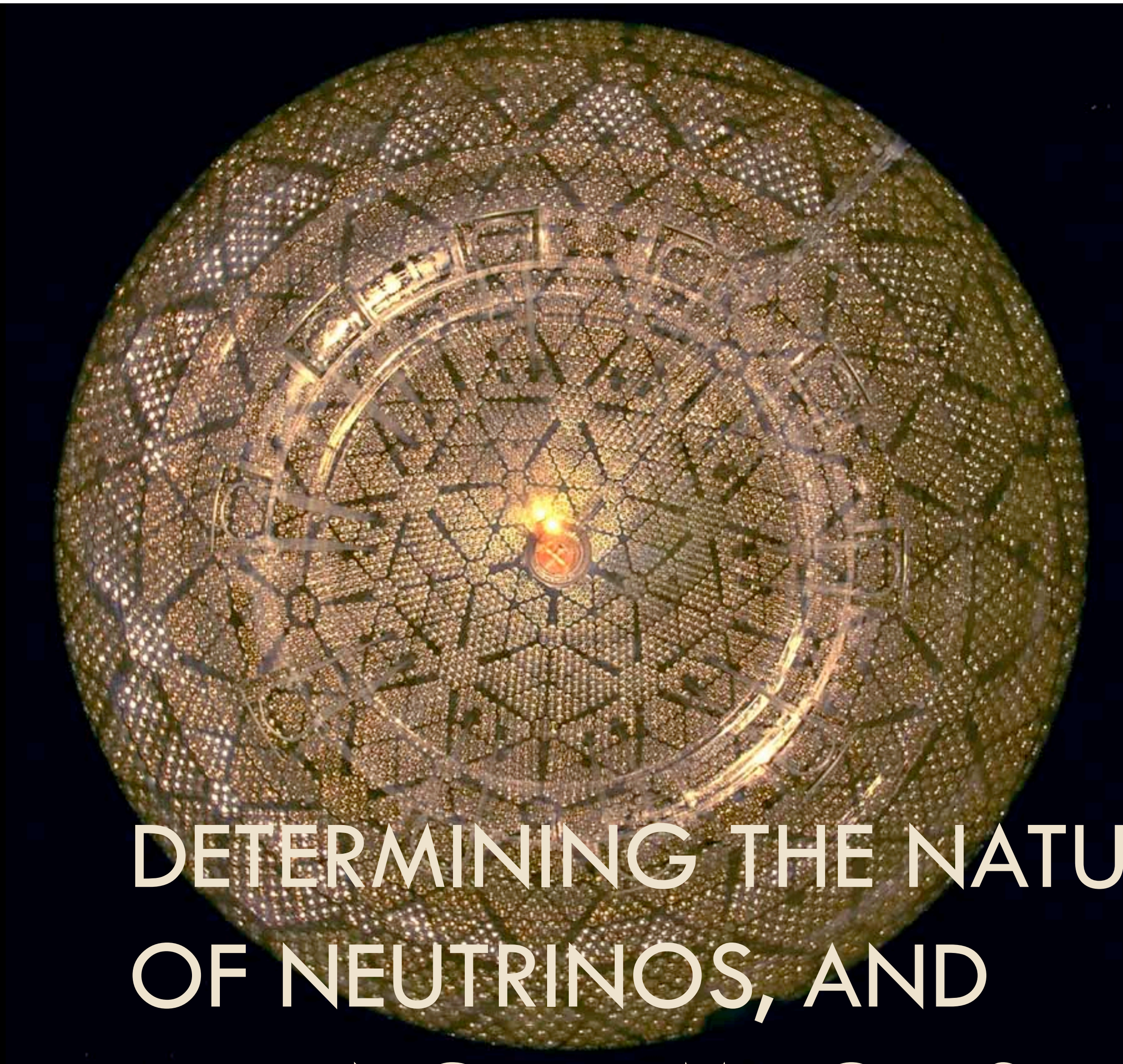


DETERMINING THE NATURE OF NEUTRINOS, AND PUTTING THEM TO USE

Nikolai Tolich

Outline

- Science
  - Double-beta-decay
  - Geoneutrinos
- SNO+

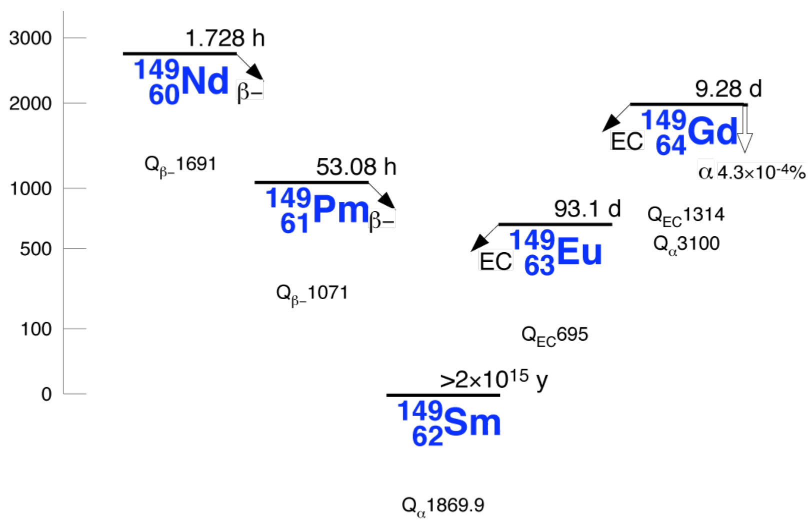
Beta-decay

- β^--decay is the conversion of a bound neutron into a proton with the emission of an electron and an electron anti-neutrino
  $${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + e^- + \overline{\nu}_e$$

- β^+-decay is the conversion of a bound proton into a neutron with the emission of a positron and an electron neutrino
  $${}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + e^+ + \nu_e$$

- Electron-capture is similar to β^+-decay but instead of producing a positron, an electron is captured
  $${}^{A}_{Z}X + e^- \rightarrow {}^{A}_{Z-1}Y + \nu_e$$

Conservation of energy

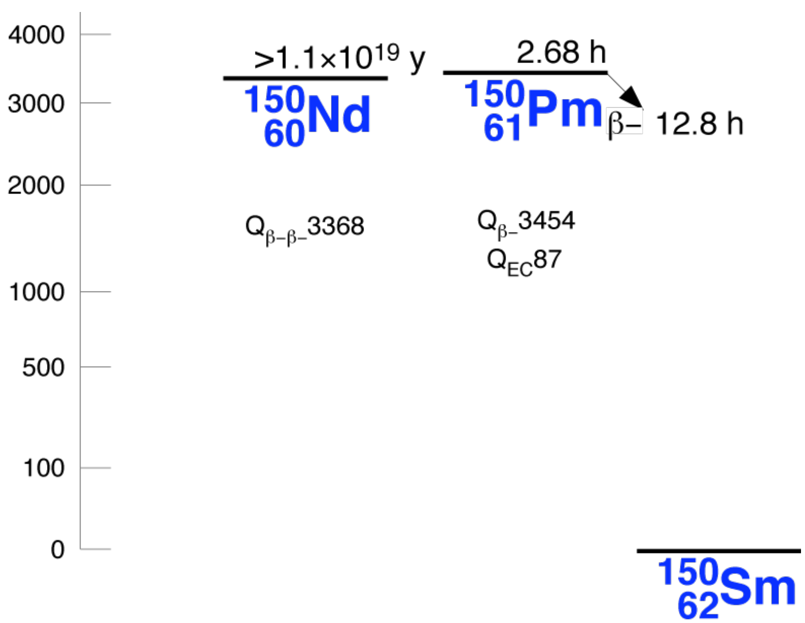


- Conservation of energy tells us that for
  - β-decay:

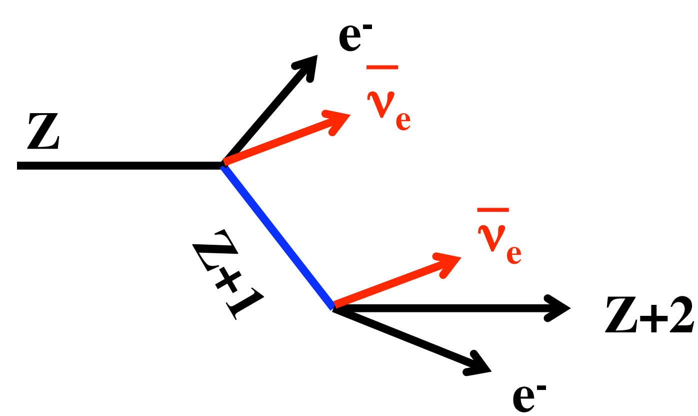
    mass of the X is greater than the sum of the mass of Y, the electron, and neutrino
  - Electron-capture:

    mass of the X plus electron is greater than the mass of Y plus the neutrino
- Nuclear physicists often draw energy level diagrams for a particular atomic mass, like that on the left

Double-beta-decay

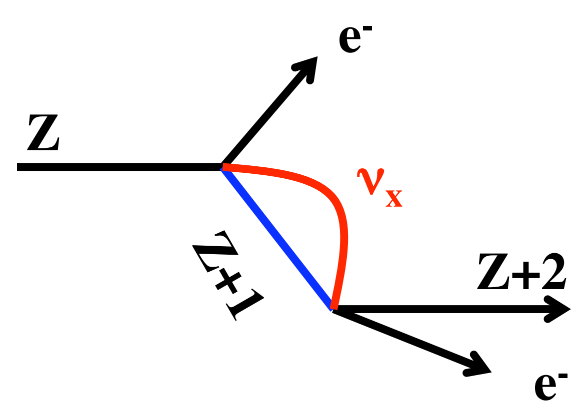


- Double-beta-decay occurs when the single beta-decay is energetically forbidden.
- It is an extremely rare process, but has been observed in numerous isotopes.



Neutrinoless double-beta-decay

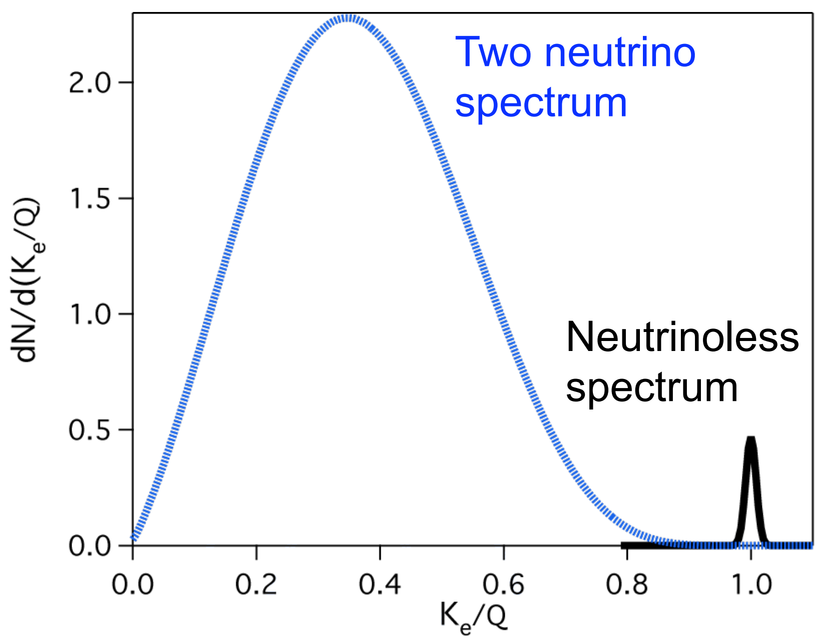
- If neutrinos are Majorana particles (an anti-neutrino is equivalent to a neutrino) then we do not need to emit any neutrinos in a double-beta-decay.
- Neutrinoless double-beta-decay is the best probe we have to test if neutrinos are Majorana particles.



Majorana neutrinos?

- So-called “seesaw” models, which explain the lightness of the neutrino, require the neutrino to be a Majorana particle.
- Leptogenesis, which could explain the apparent matter dominance of the universe also requires neutrinos to be a Majorana particle.
- **All other particles are Dirac particles.**

Observing neutrinoless double-beta-decay

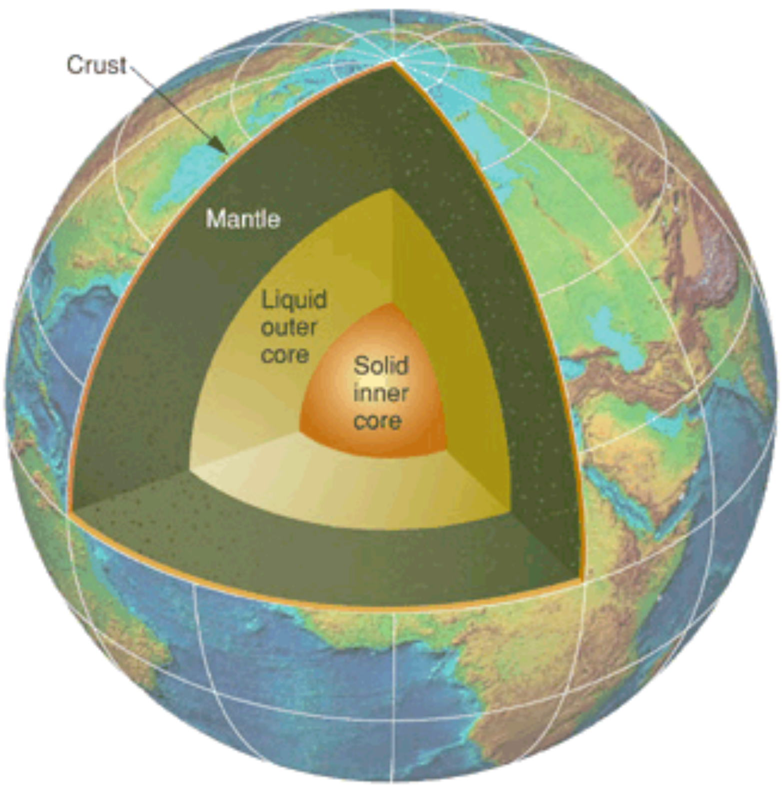


arXiv:hep-ph/0611243

- Because there are no neutrinos to take away energy, the total electron energy in neutrinoless double-beta-decay is equal to the decay energy.
- We can recognize neutrinoless double-beta-decay by observing a peak at the end of the total electron energy spectrum.

Geoneutrinos

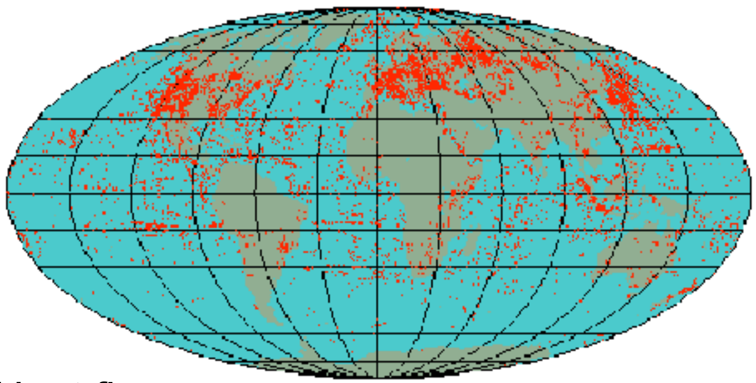
Structure of the Earth



- Seismic data splits Earth into 5 basic regions: inner core, outer core, mantle, oceanic crust, and continental crust.
- All these regions are solid except the outer core.
- The mantle convects even though it is solid.
- It is responsible for the plate tectonics and earthquakes.
- Oceanic crust is being renewed at mid-ocean ridges and recycled at trenches.

Heat flow from the Earth

Bore-hole measurements



Heat flow

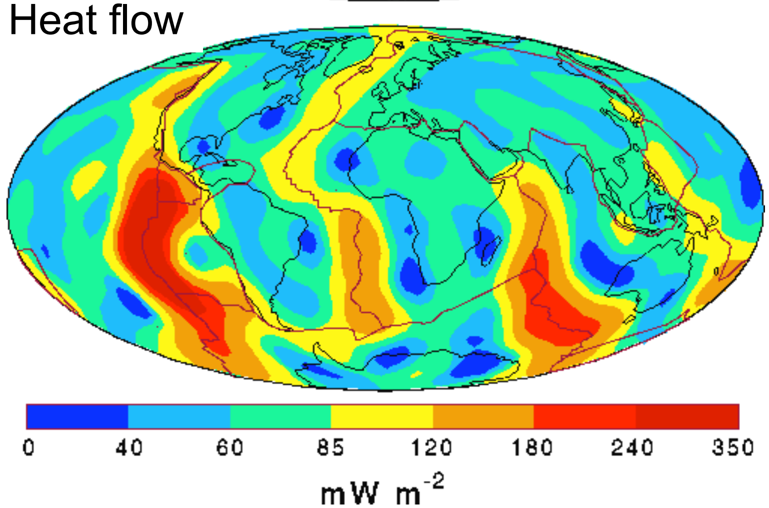


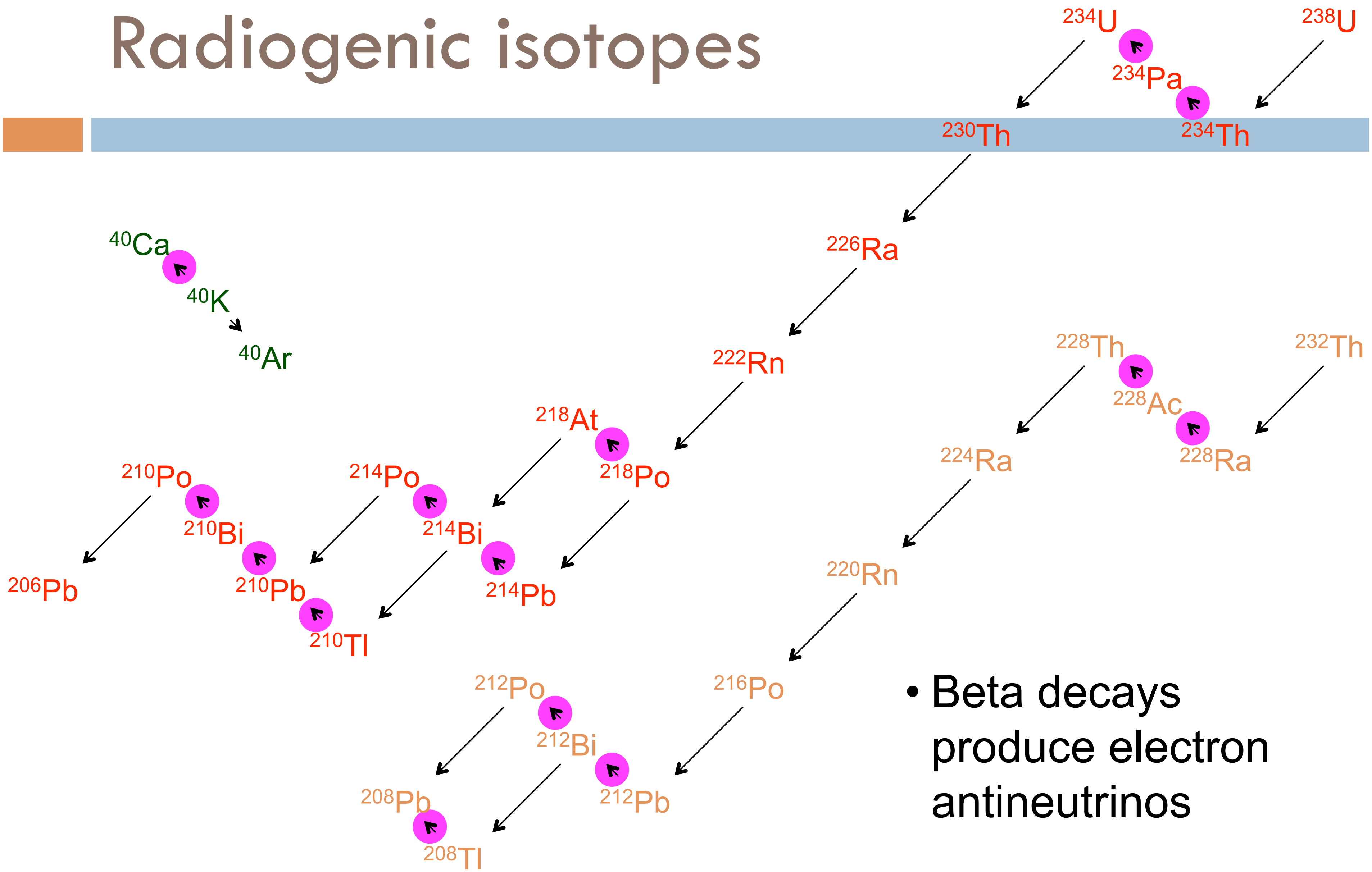
Image: Pollack *et. al*

- Conductive heat flow measured from bore-hole temperature gradient and conductivity
- Total heat flow 44.2±1.0TW (87mW/m^2), or 31±1TW (61mW/m^2) according to more recent evaluation of same data despite the small quoted errors.
- Based on chondritic meteorites the heat production from U, Th, and K are 8TW, 8TW, and 3TW, respectively.

Discrepancy?

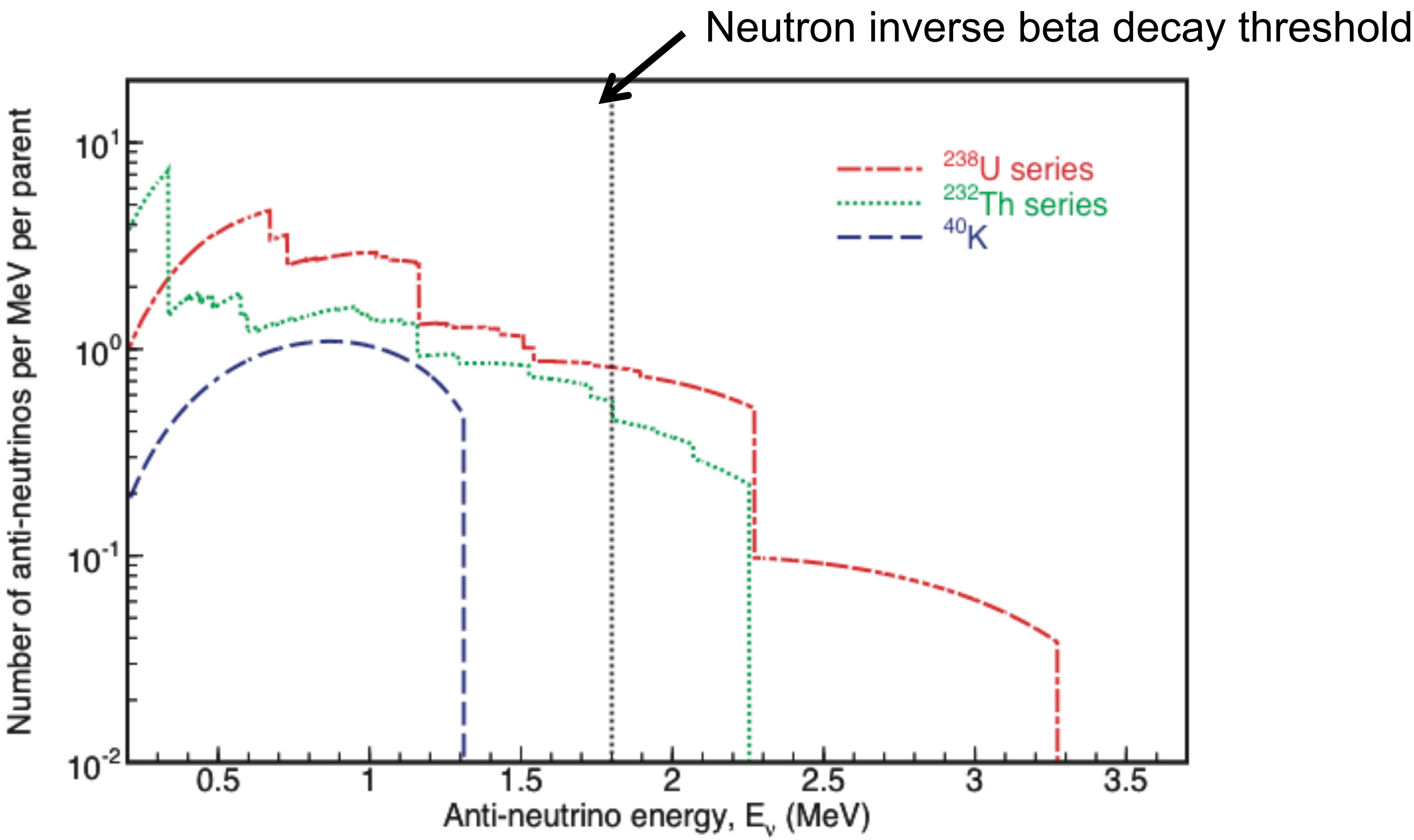
- The measured total heat flow is 44 or 31 TW.
- The estimated radiogenic heat produced is 19 TW.
- Models of mantle convection suggest that the radiogenic heat production rate should be a large fraction of the measured heat flow.
- Problem with
  - Mantle convection model?
  - Total heat flow measured?
  - Estimated amount of radiogenic heat production rate?
- Geoneutrinos can serve as a cross-check of the radiogenic heat production.

Radiogenic isotopes



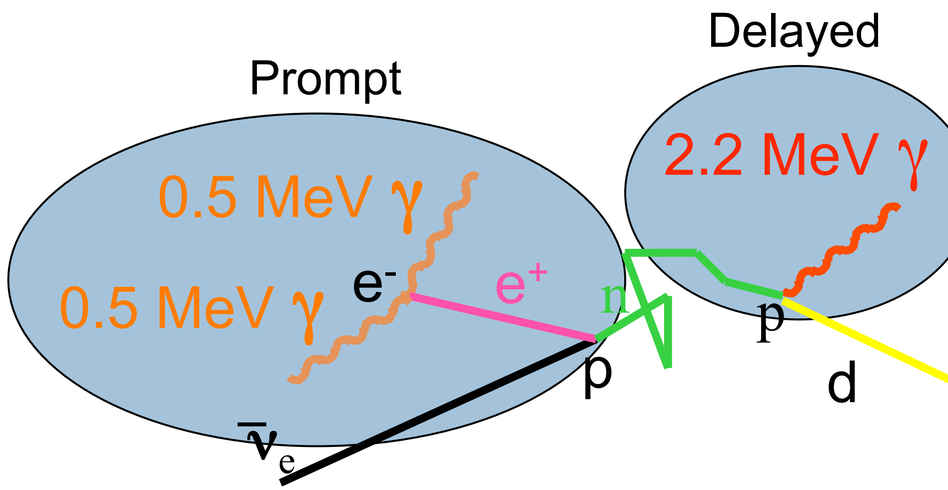
- Beta decays produce electron antineutrinos

Geoneutrino signal

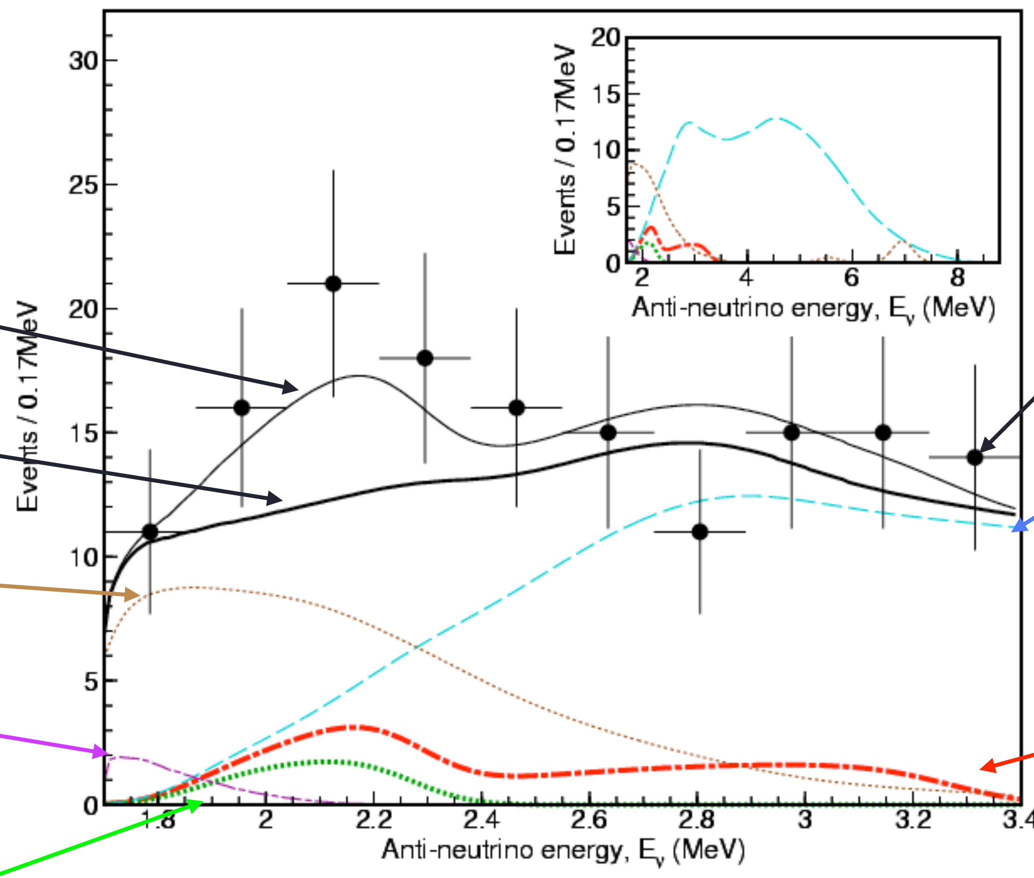


Neutron inverse-beta-decay

- $\overline{\nu}_e + p \rightarrow e^+ + n$
  The positron energy is related to the neutrino energy.
- The positron loses its energy then annihilates with an electron.
- The neutron first thermalizes then is captured by a proton with a mean capture time of ~200ms.



Results from KamLAND



Expected total

Expected total Background
127±13 events

(α,n)

Random

Expected Th
3.9 ± 0.2

Candidates
152 events

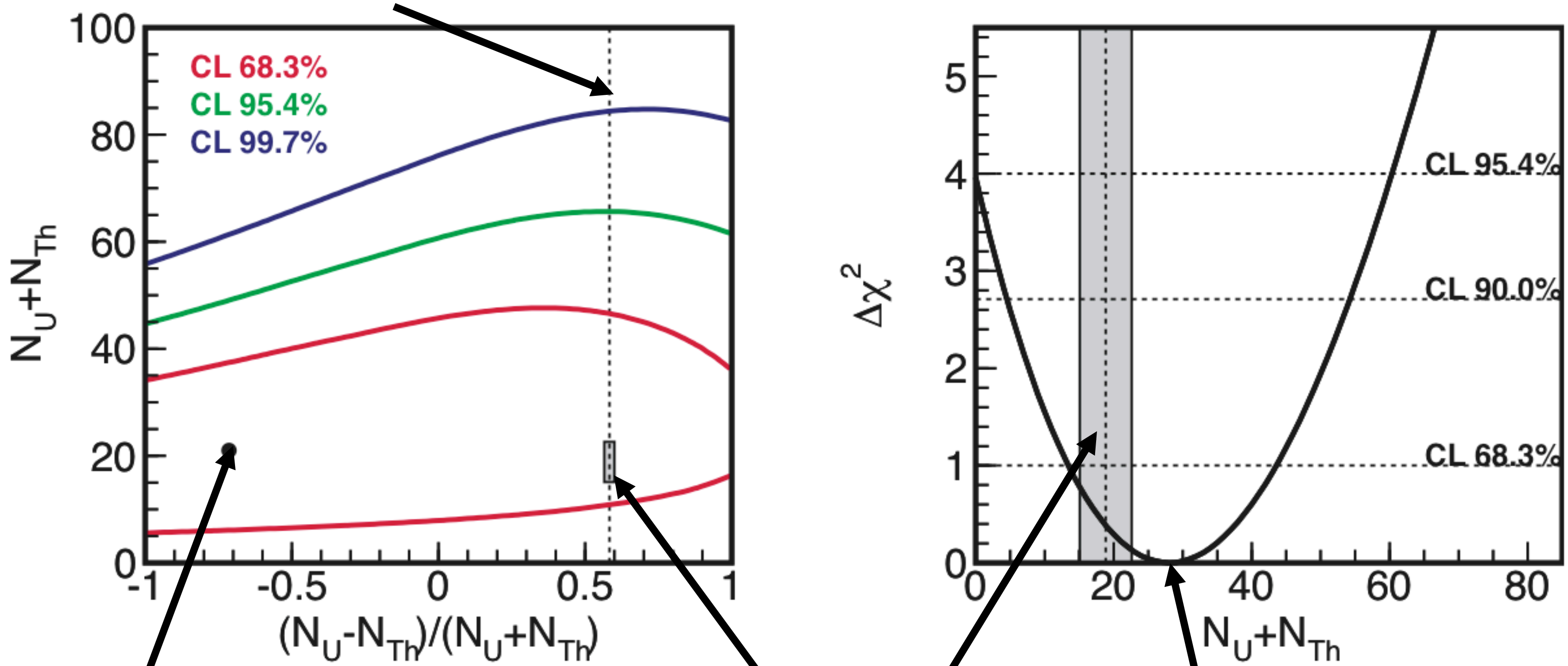
Expected reactor

Expected U
14.8 ± 0.7

Nature **436**, 499-503 (28 July 2005)

How many geoneutrinos?

Expected ratio from chondritic meteorites

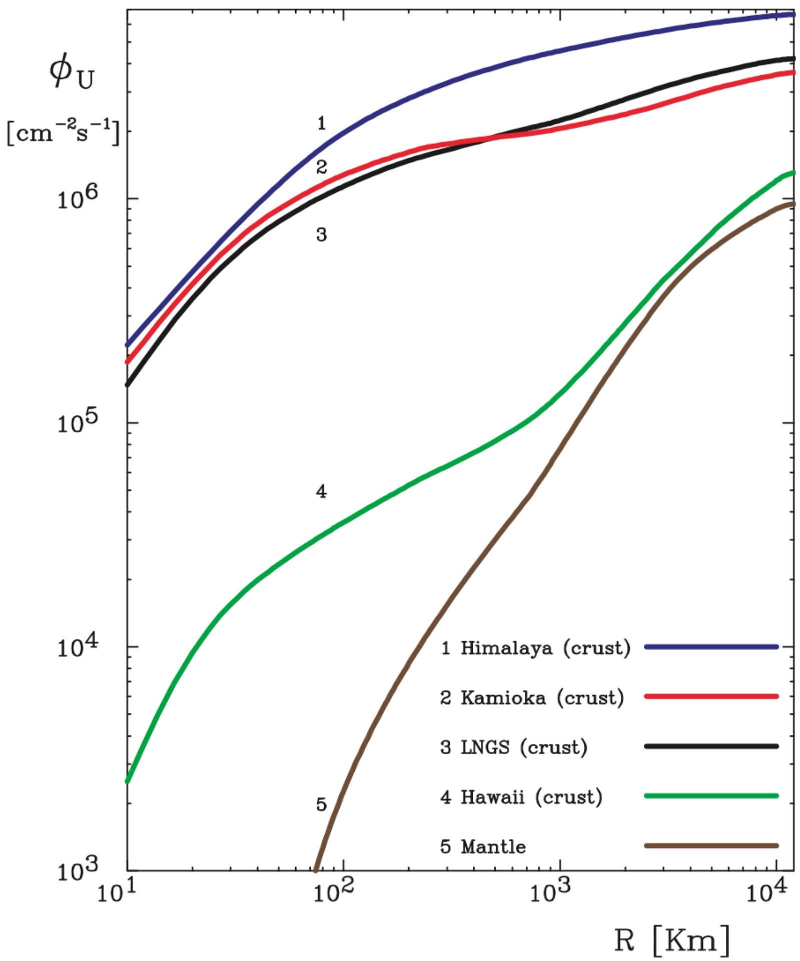


Best fit
3 U geoneutrinos
18 Th geoneutrinos

Expected result from reference Earth model

Central value 28

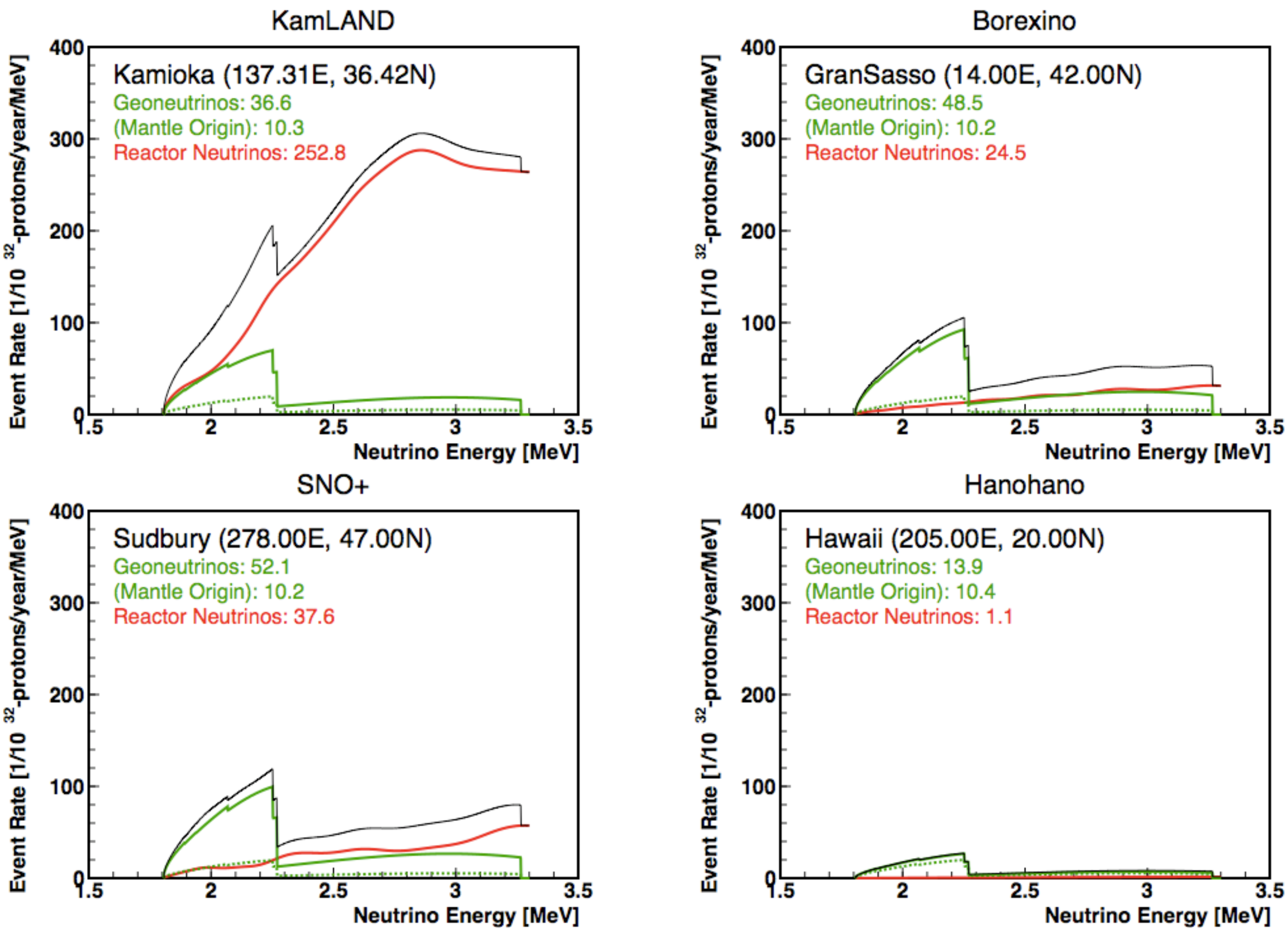
Source of geoneutrinos



Mantovani F. *et. al* Phys Rev D **69** (2004) 013001

- U and Th are thought to be absent from the core and present in the mantle and crust.
  - The core is mainly Fe-Ni alloy.
  - U and Th are lithophile (rock-loving), and not siderophile (metal-loving) elements.
- U and Th concentrations are highest in the continental crust.
- On continental crust approximately
  - 50% of the flux comes from the surrounding 500km.
  - 25% of the flux comes from the mantle

Expected signals



Images: S. Enomoto

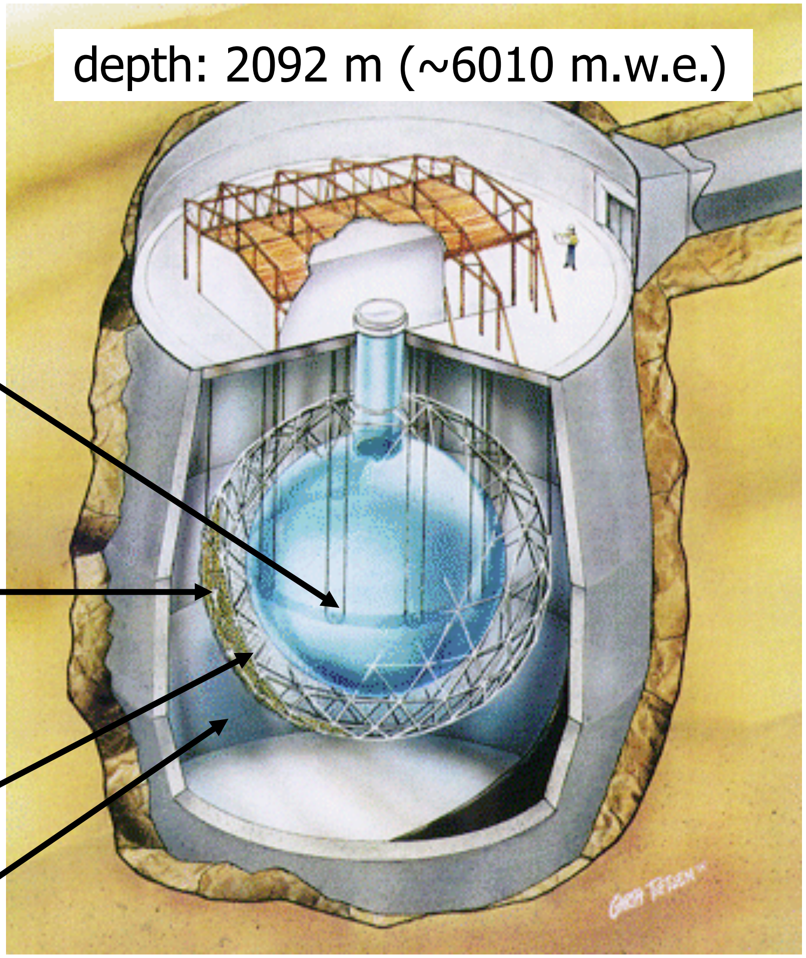
SNO+

Introduction

- Plan to use the now unused SNO detector to search for neutrinoless double-beta-decay in ^{150}Nd
- Can also measure:
  - geoneutrinos
  - reactor neutrinos
  - solar neutrinos (without Nd loading)
  - supernova neutrinos
- Ready for data in 2011 (2012)

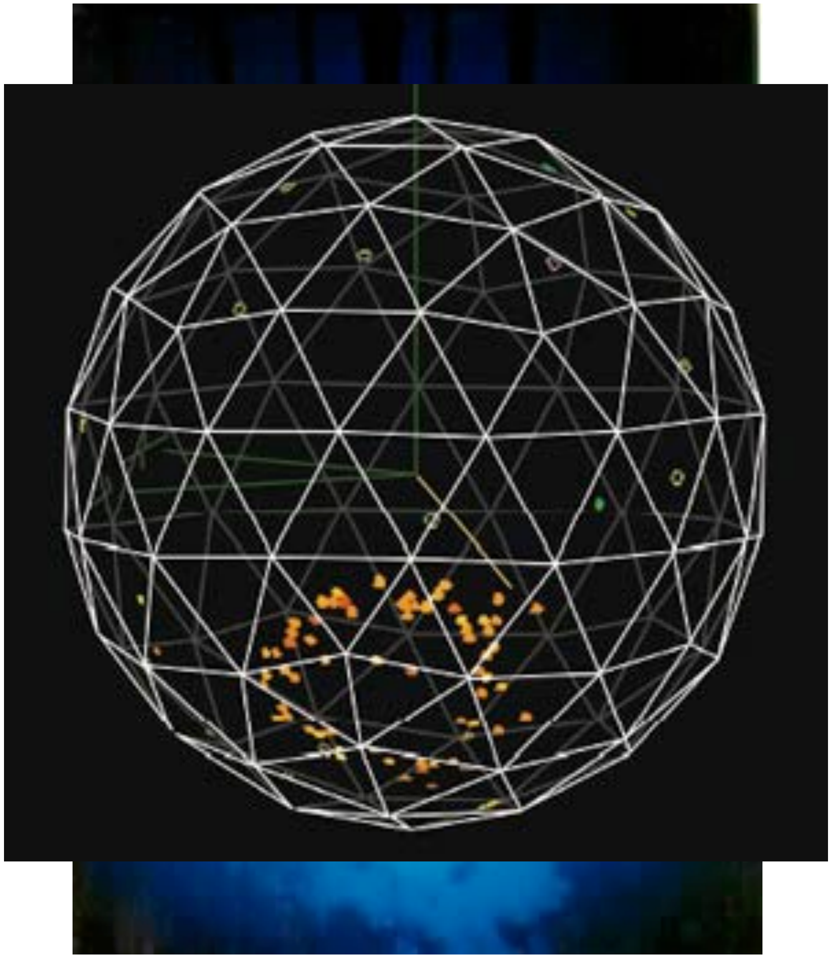
SNO (SNO+) detector

- Located in the Vale Inco Ltd. Creighton Mine near Sudbury, Canada
  - 1 kton D_2O held in 12 m diameter acrylic vessel, **to be replaced with Nd doped liquid scintillator**
  - 18 m diameter support structure holds 9500 PMTs (~60% photocathode coverage)
  - 1.7 kton inner shielding H_2O
  - 5.3 ktons outer shielding H_2O



Cerenkov detectors

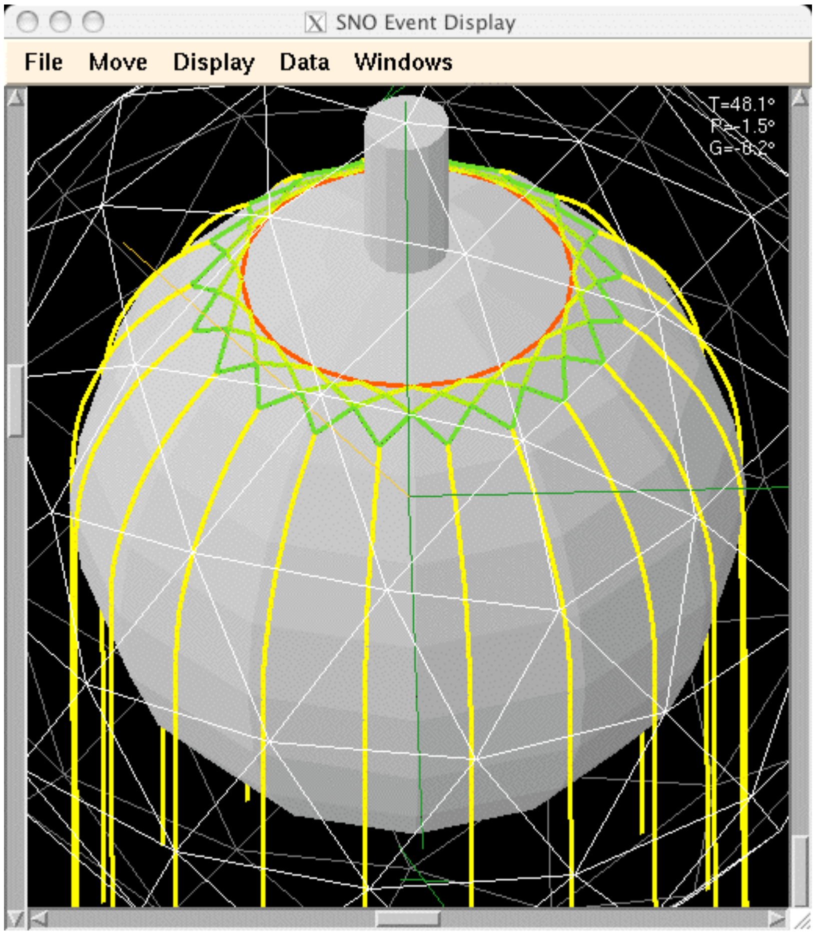
- When a charged particle moves faster than the speed of light in that medium it emits Cerenkov radiation.
- This radiation is emitted in a cone along the direction the particle is traveling.



Liquid scintillator detectors

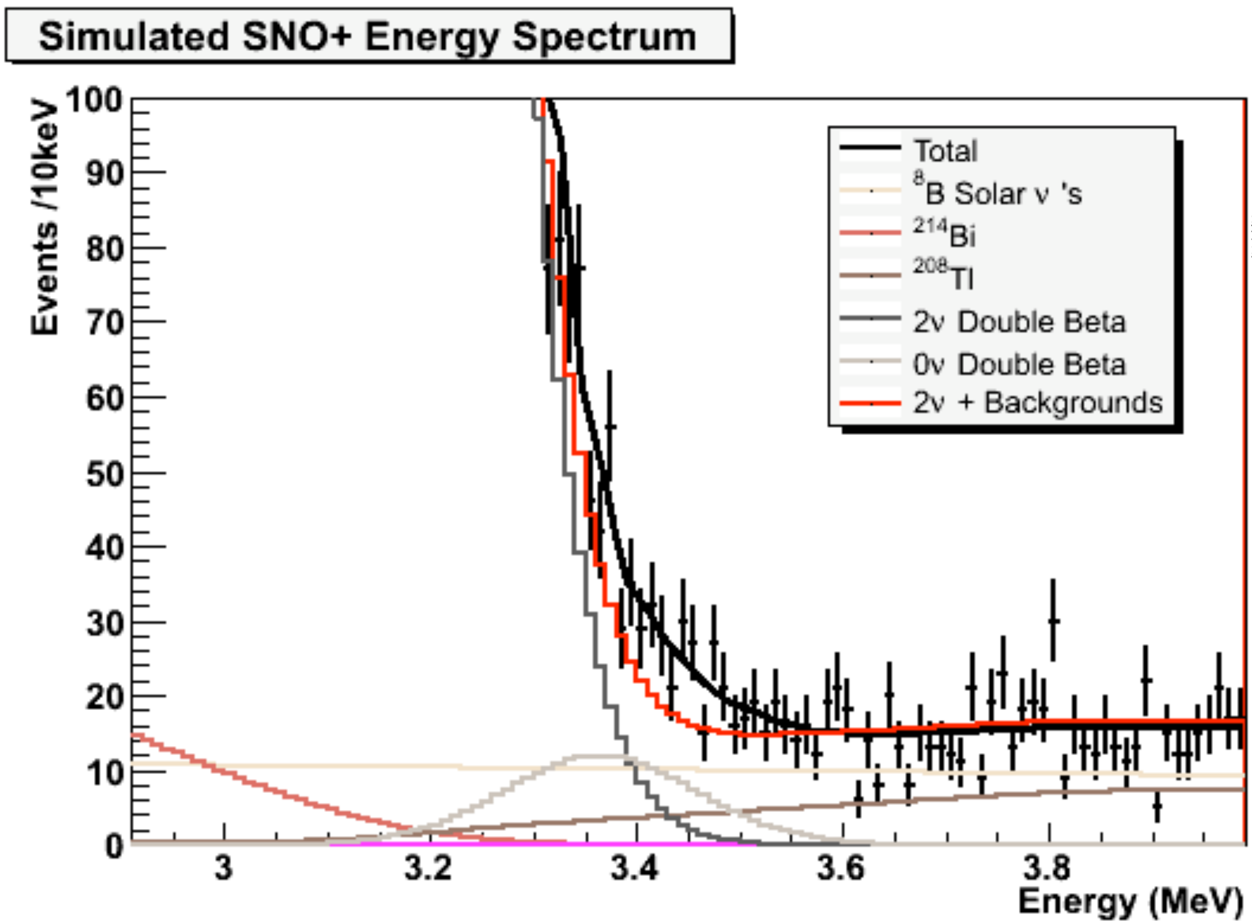
- When a charged particle moves through matter it can excite the molecules.
- The de-excitation of these molecules results in the isotropic emission of photons.
- The number of photons detected is directly related the kinetic energy of the charged particle.
- Unlike a Cerenkov detector there is no cone so we cannot determine the direction of the charged particle, but the total amount of light is significantly higher so the accuracy with which we can determine the kinetic energy is better.
- Based on the time the light reaches the Photomultiplier Tubes we can determine the location of the charged particle.

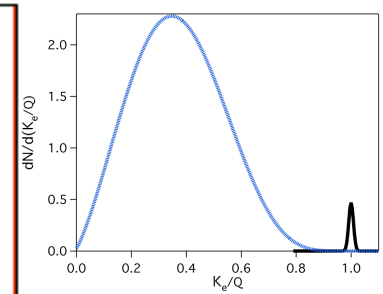
Hold down net



- D_2O is denser than H_2O, liquid scintillator is less dense, therefore instead of supporting the acrlyic vessel from the top, we will have to hold it down.

Expected energy spectrum



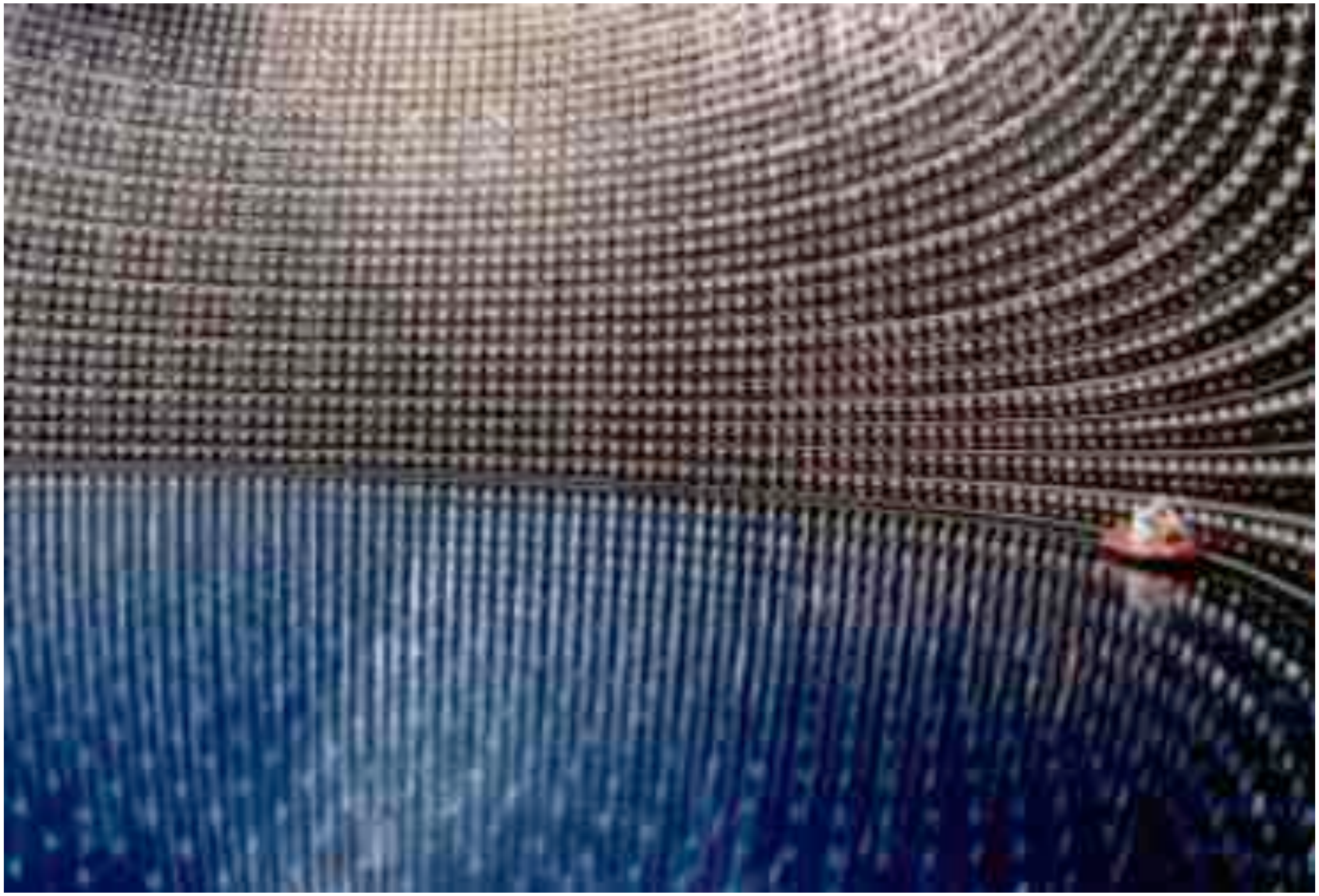


56 kg of ^{150}Nd and $<m_{\nu}>$ = 100 meV

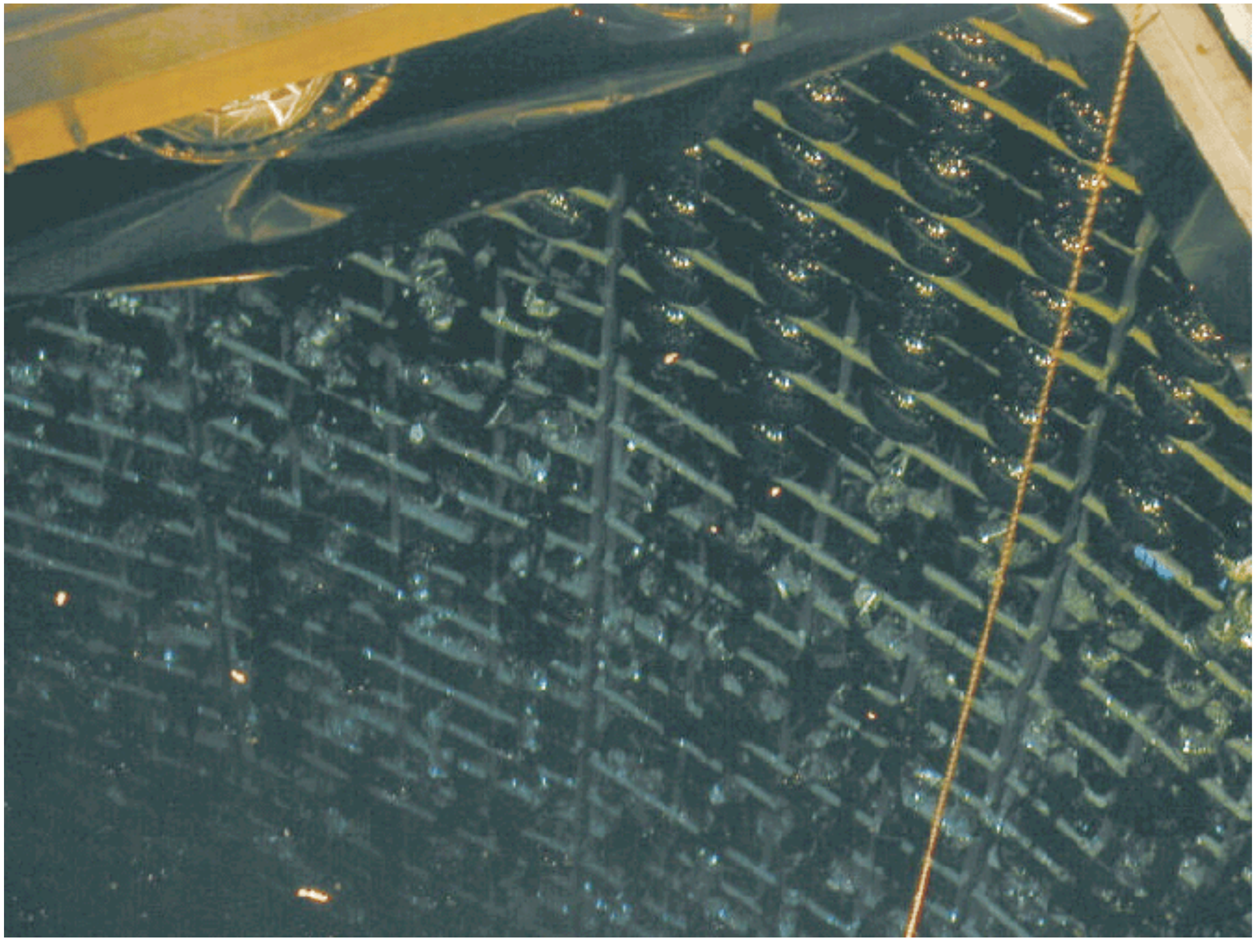
Pretending to be miners

Very clean miners

Super-K cleaning



Boating in Super-K, not likely again



Questions?