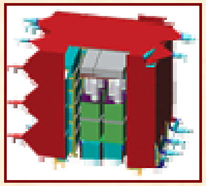
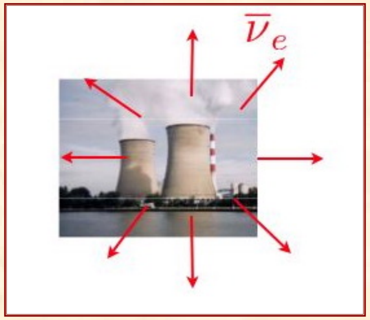
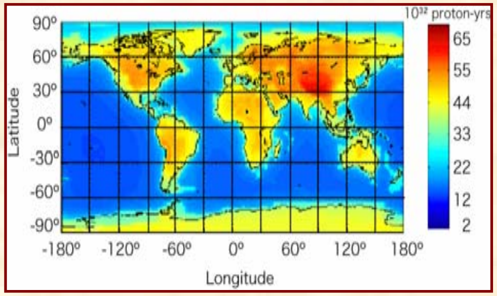
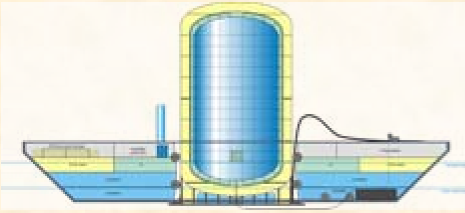








Applied Anti-neutrino Workshop Introduction

Time to make nus work for us

John Learned and Steve Dye

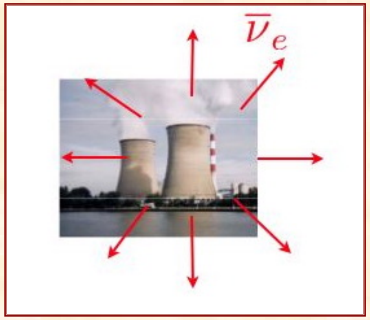
University of Hawaii

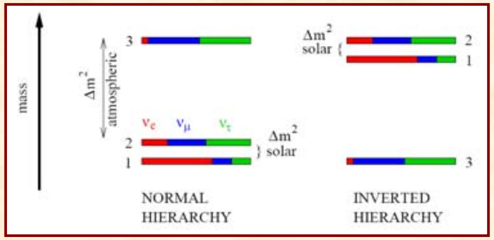
With much help from friends

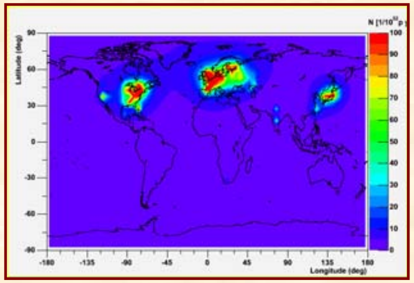
With particular thanks to Gene Guillian, Hitoshi Murayama, Bob Svoboda, Georg Raffelt, and many others for graphics.

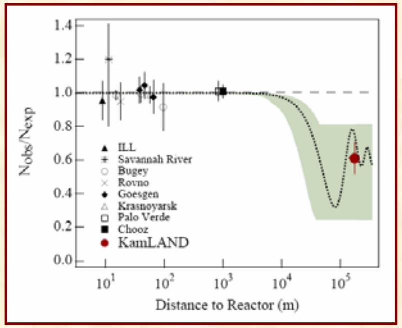
Outline

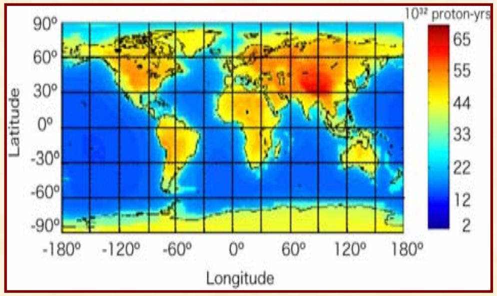
- Whazza Nu?
- Where you get 'em
- How do we "see" them?
- Neutrino Tricks – shape shifters
- Who needs 'em?
- Useful for nuclear security?
- What's cooking down there?
- Other cool science we can do.
- Studies needed and gadgets we hope to build.

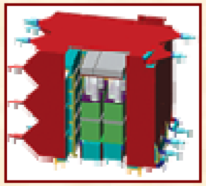


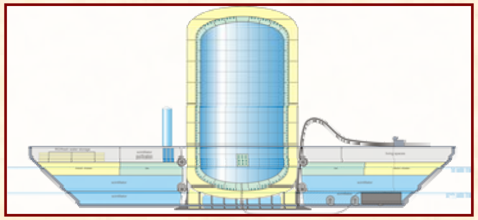


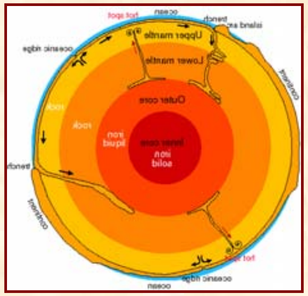












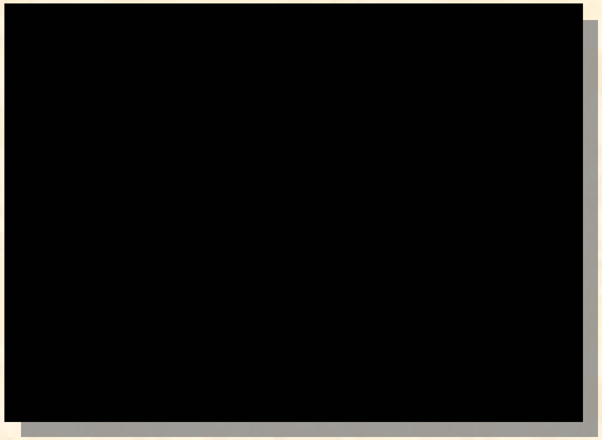
Named for a subatomic particle with almost zero mass …

Greek letter Nu

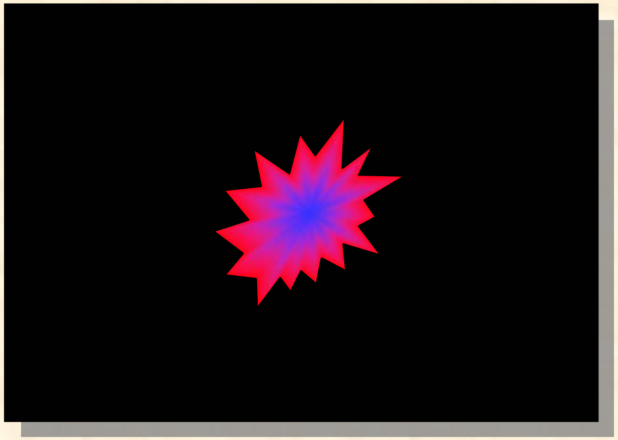

DISNEY PRESENTS A PIXAR FILM
THE IνCREDIBLES
NOW PLAYING
ν_τ
ν_s?
ν_μ
ν_e
© Disney Enterprises, Inc./Pixar Animation Studios. All Rights Reserved.

So, what IS a Neutrino?

This is a Neutrino

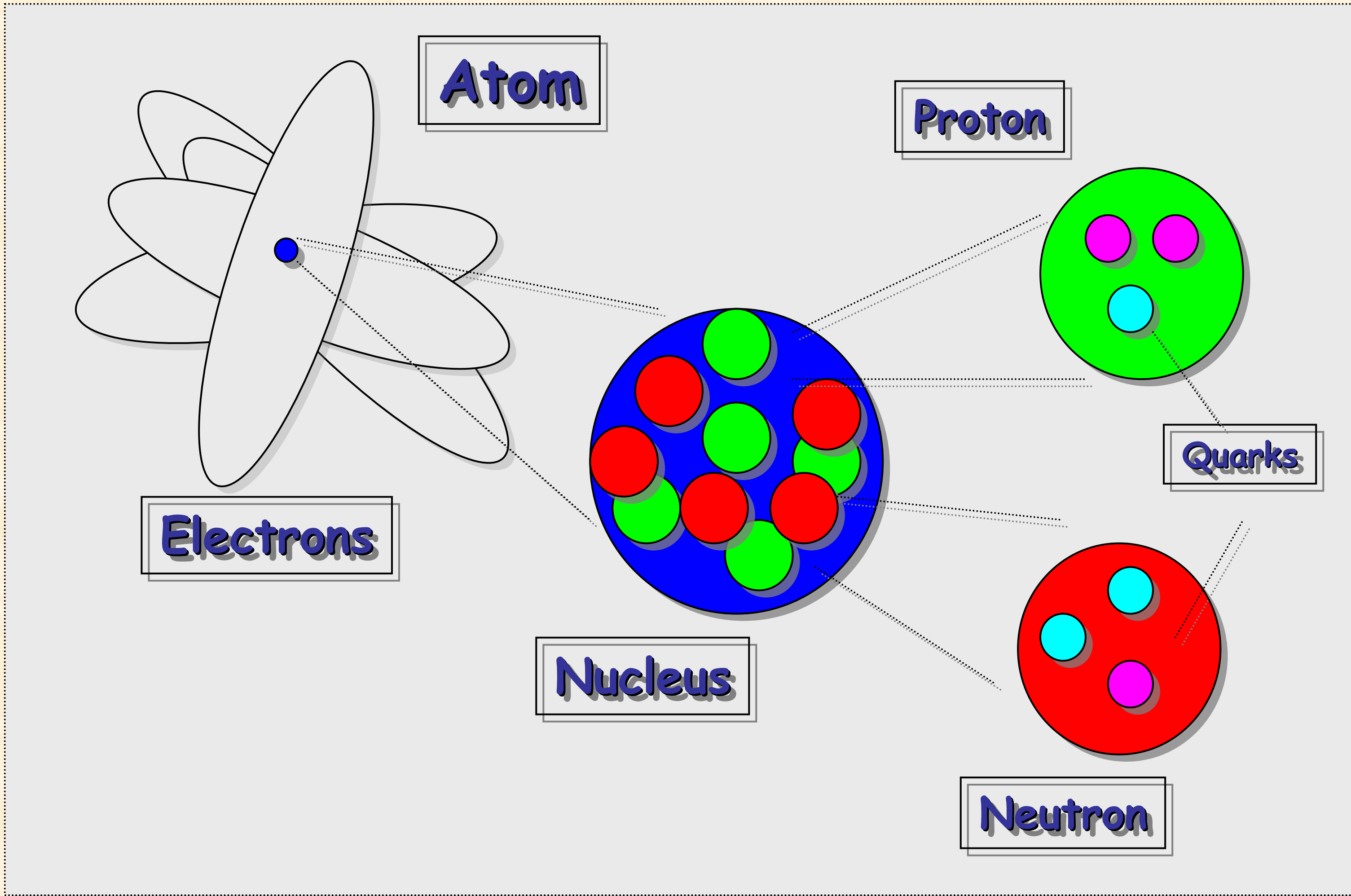


This was a Neutrino



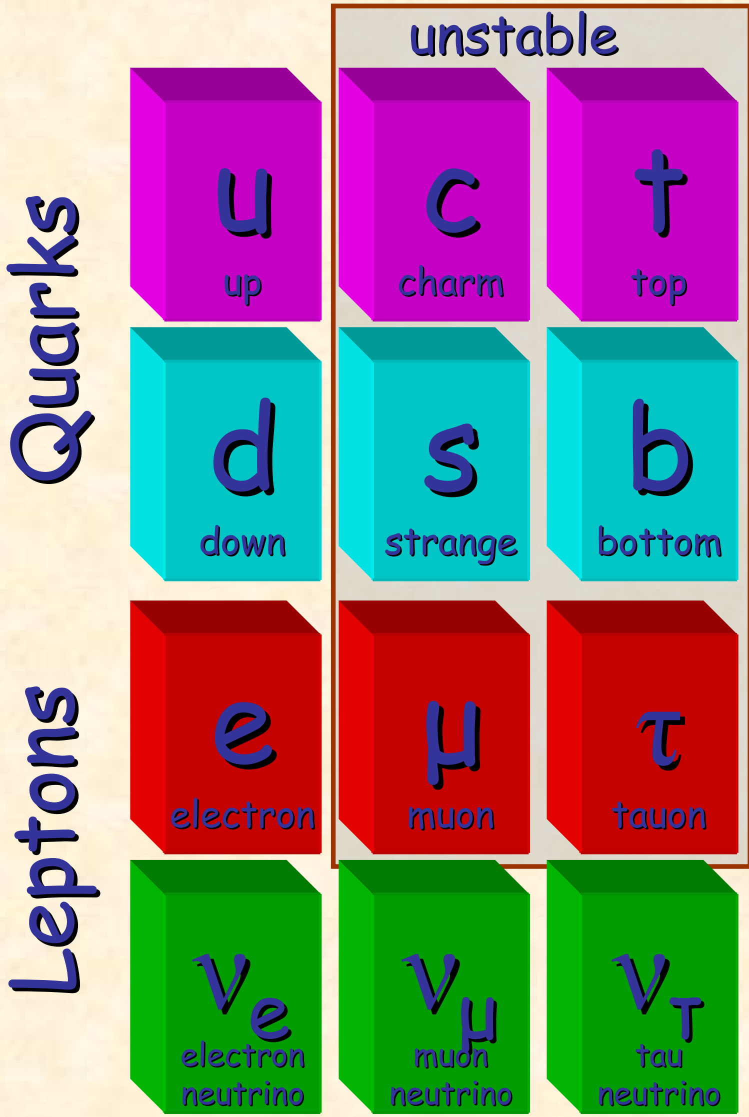
Stable Elementary Particle – 3 of 6 constituents of matter
No electric charge – cannot see it
Very little interaction with matter – goes through the earth unscathed
Has very little mass – less than 1 millionth of electron
Lots of them though – 100 million in your body any time!

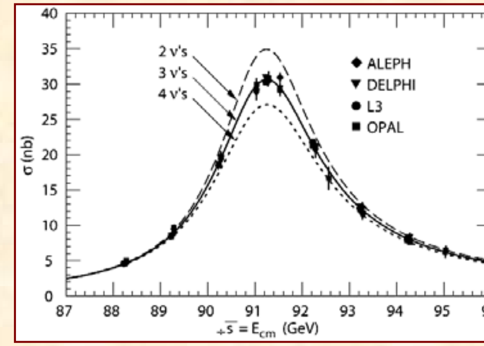
Subatomic Structure



Seen one, you've seen 'em all! Complexity from Legos.

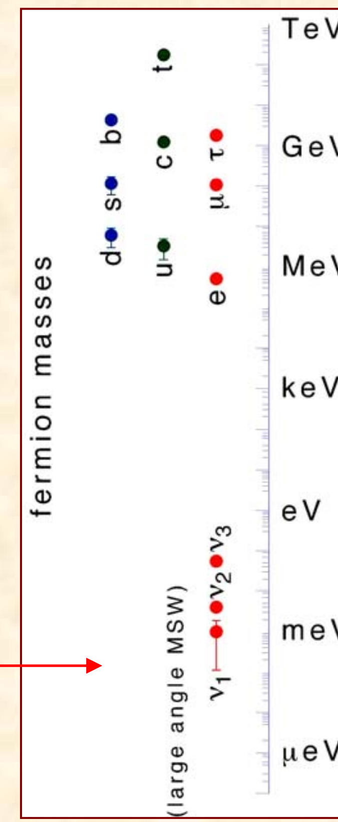
Nature's building blocks





Three flavors or generations, and no more, and we do not know why.

Some mass, but curiously little.



Where do Neutrinos come from?

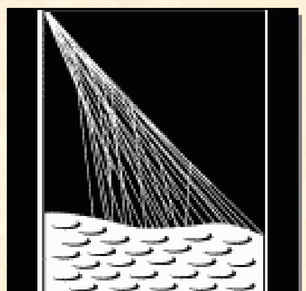
✓ Nuclear Reactors (power stations, ships)

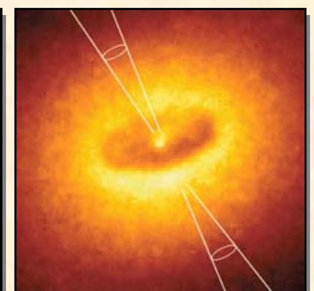
Sun ✓

✓ Particle Accelerator

Supernovae (star collapse)
SN 1987A ✓

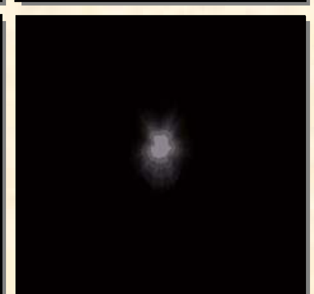
✓ Earth's Atmosphere (Cosmic Rays)





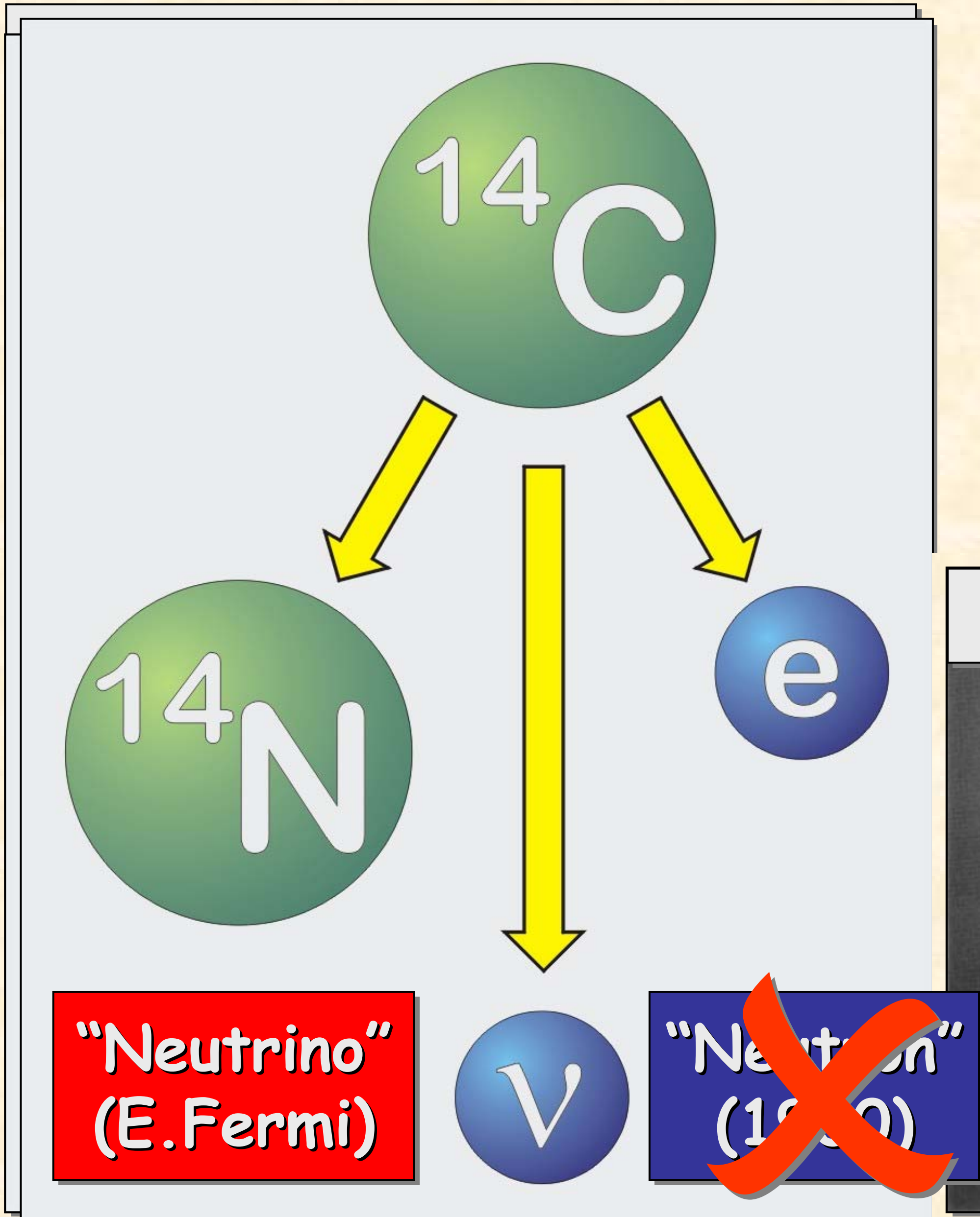
Astrophysical Accelerators
Soon ?

✓ Earth's Crust (Natural Radioactivity)



Big Bang (here 330 ν/cm^3)
Indirect Evidence

Why did we "need" neutrinos ?



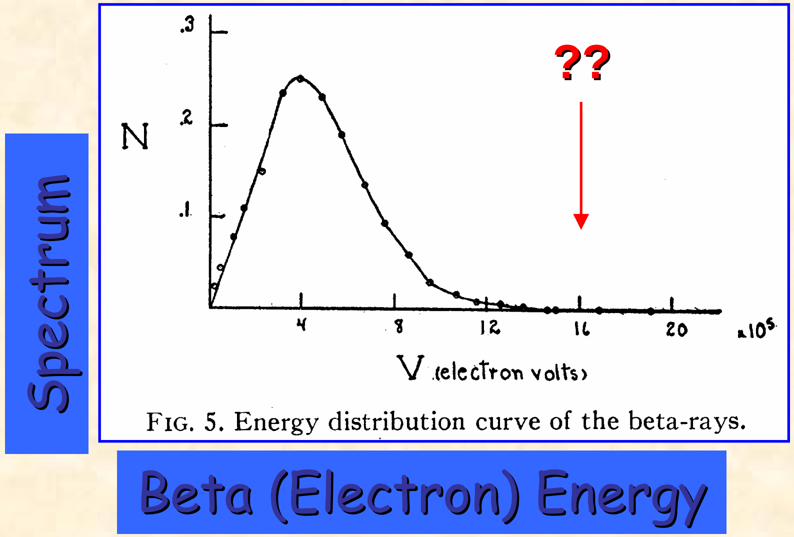


FIG. 5. Energy distribution curve of the beta-rays.

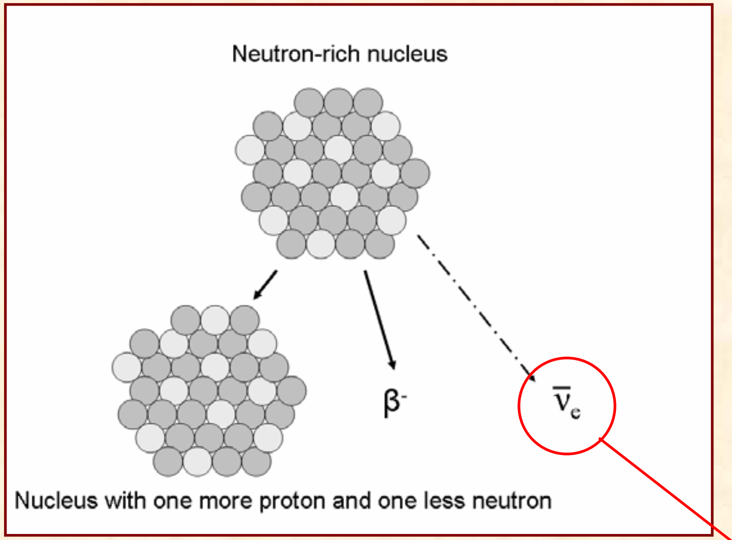
Radioactive Beta Decay

Wolfgang Pauli
(1900-1958)
Nobel Prize 1945

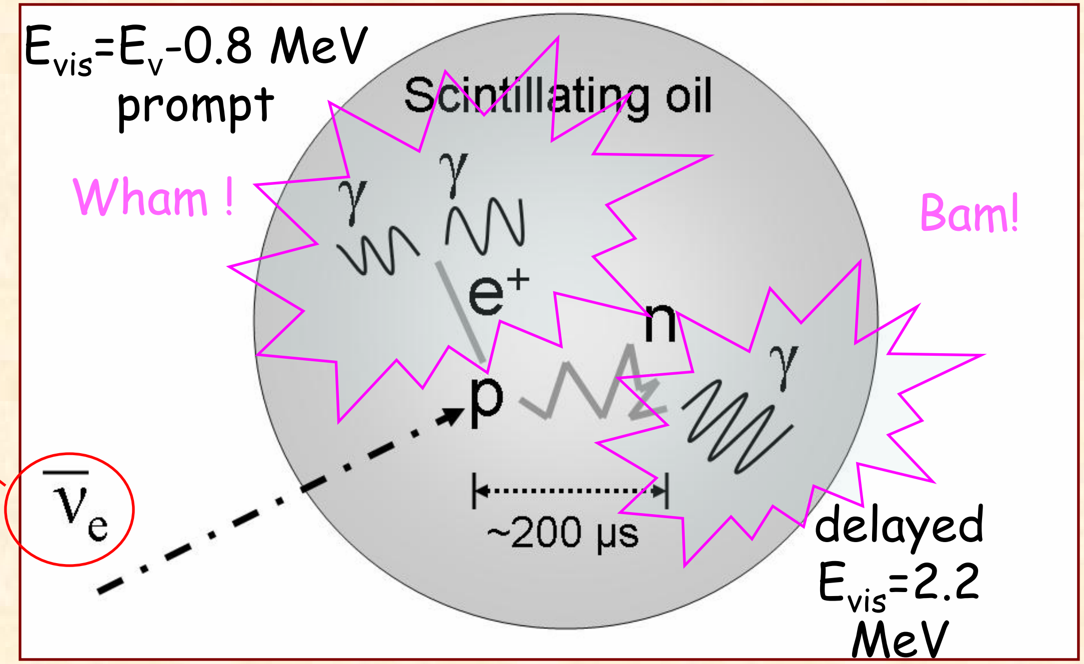
MeV-Scale Electron Anti-Neutrino Detection

Production in reactors and natural decays

Key: 2 flashes, close in space and time, 2^{nd} of known energy, **eliminate background**



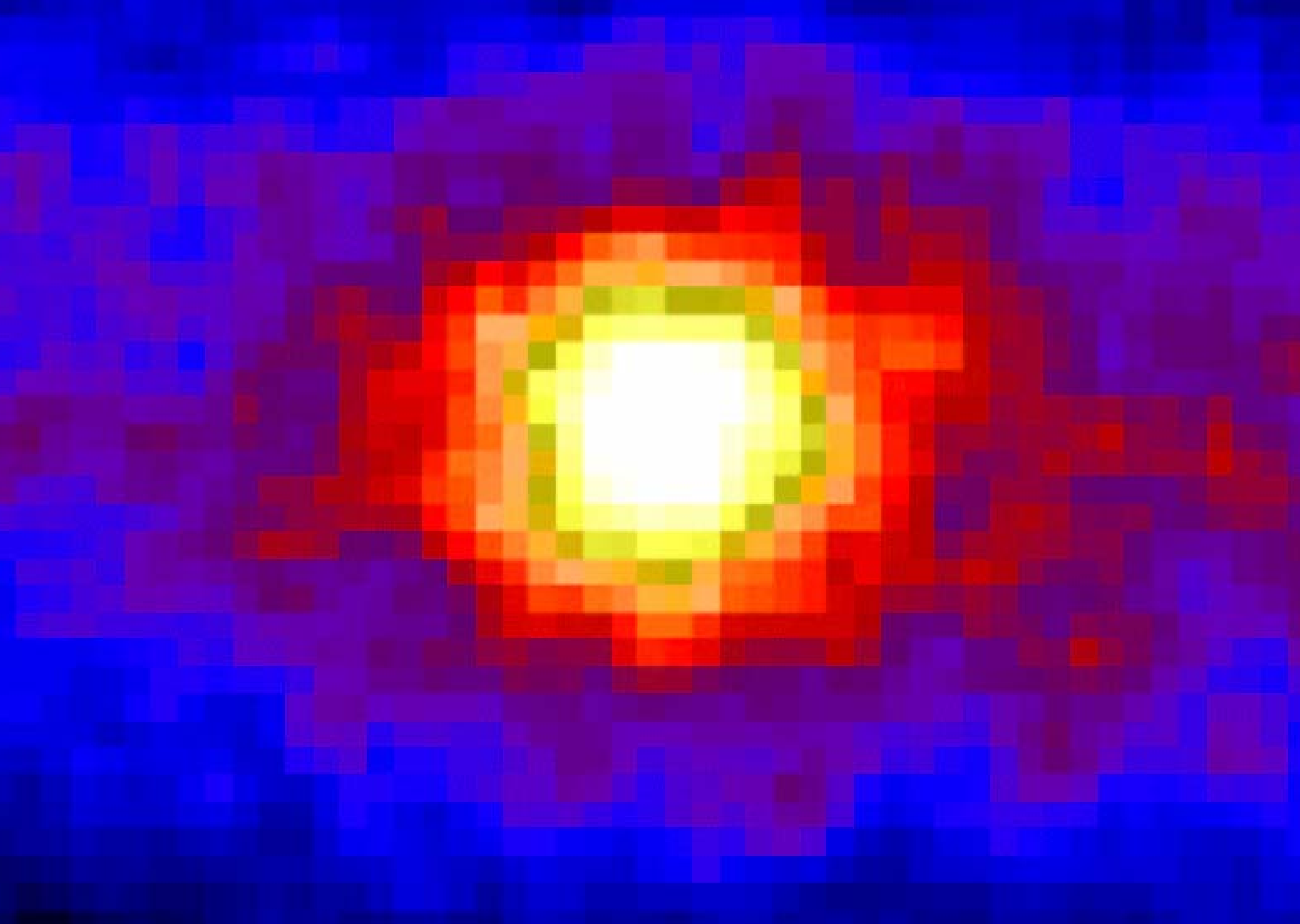
Detection



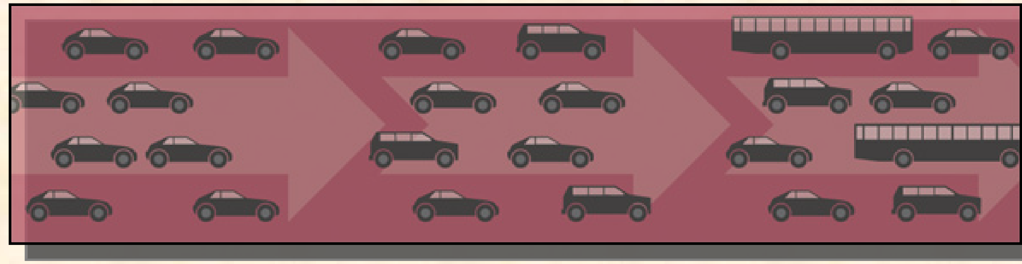
Reines & Cowan, 1955

- Standard "inverse β-decay" coincidence
- E_ν > 1.8 MeV
- Rate and spectrum only - no direction

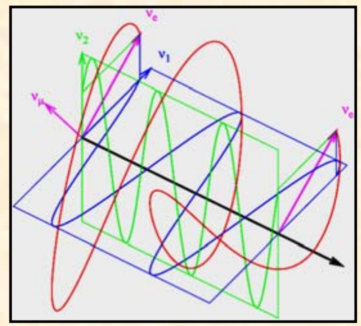
Neutrinos from the core of the sun!

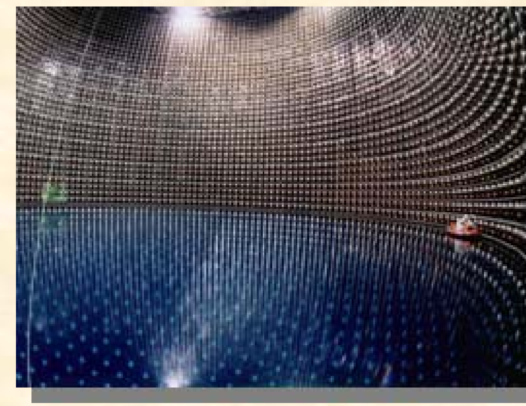


Neutrinos are “shapeshifters”

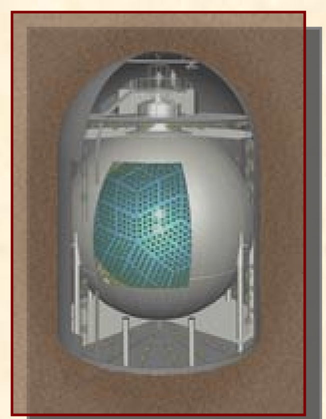


- First strong evidence at SuperKamiokande experiment in 1998.

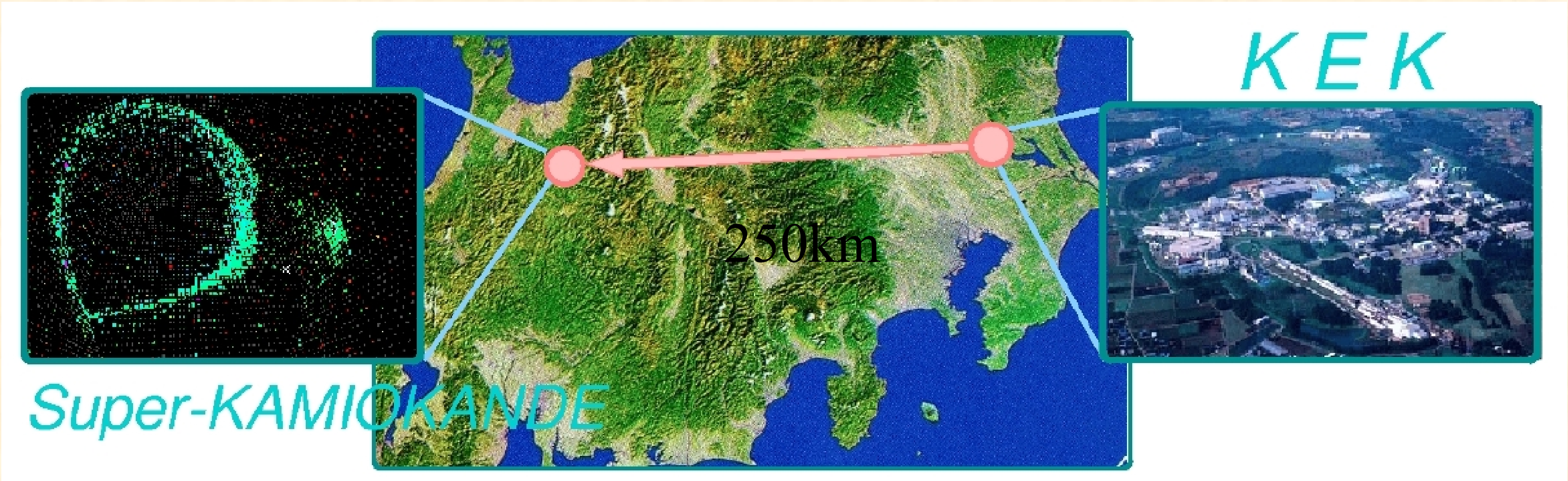




- Now much more evidence, including new work from KamLAND which clinch case.
- Oscillation from one flavor to another implies finite, though small, mass. Formerly thought to be mass-less.
- No predictions from theory… mixing much larger than anticipated.
- **experimentalists game, and a strange one too.**



Confirmation with man-made neutrino beams



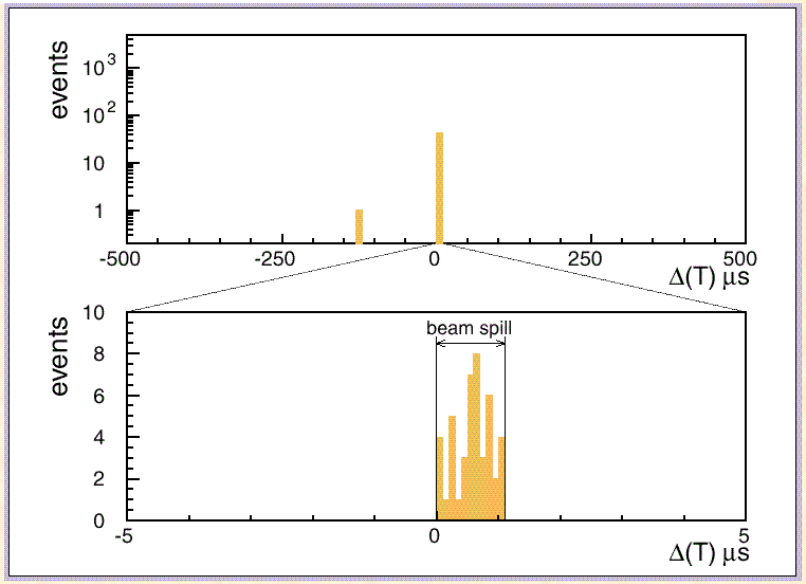
K2K experiment report in 2006:

158±9 events if no oscillation

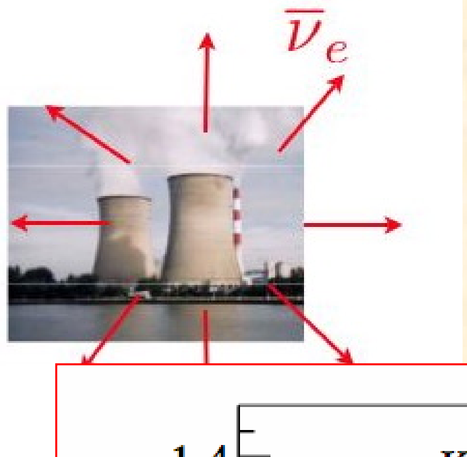
112 events observed

Deficit at 4.3 sigma level

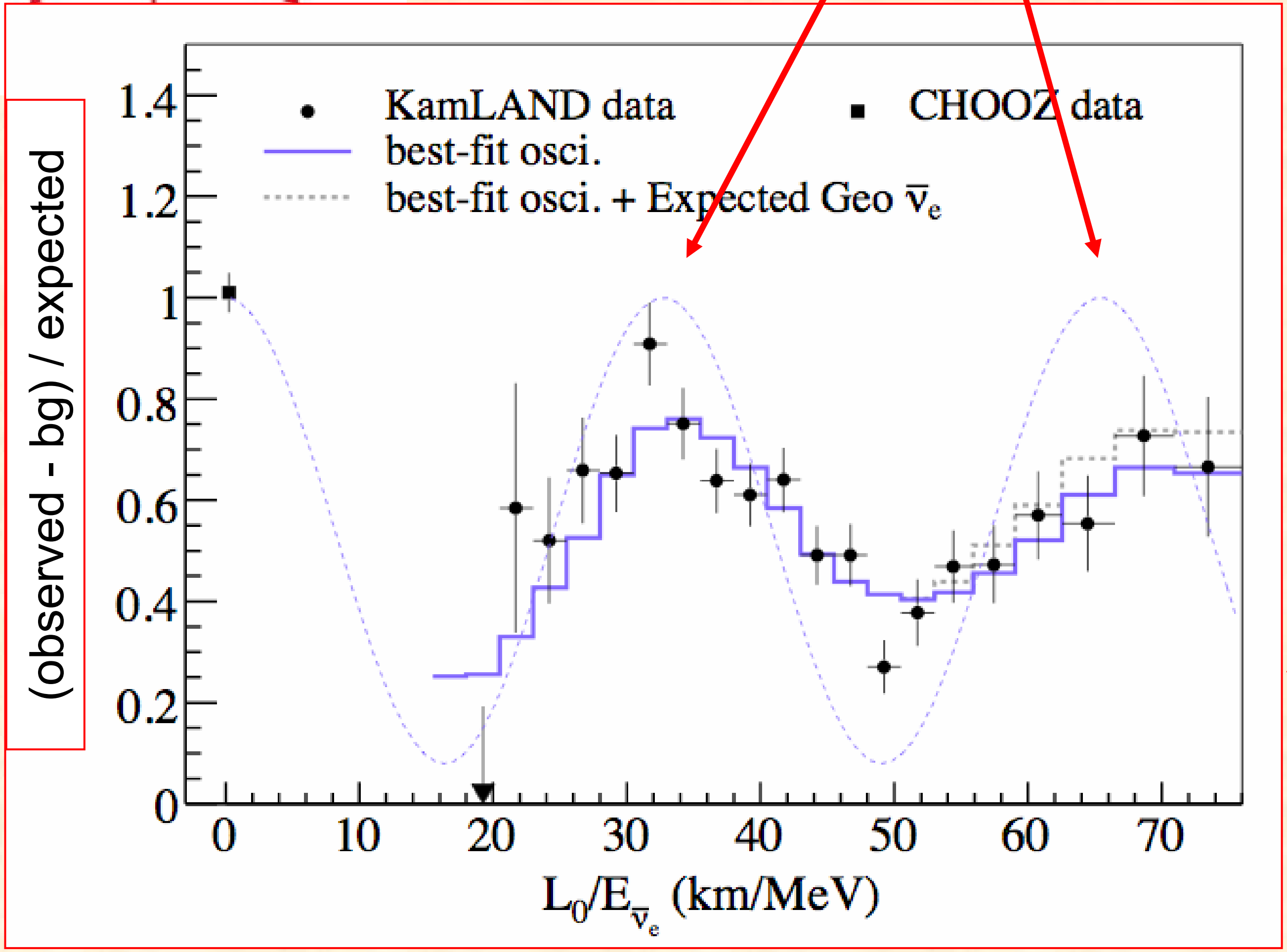
Now confirmed with 2 more experiments in US and Europe



ν Survival Probability: L/E Variation

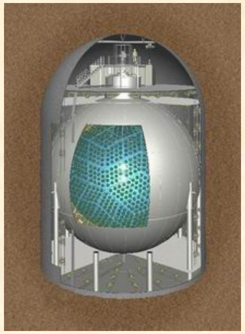


Oscillations: 1st and 2nd reappearance!

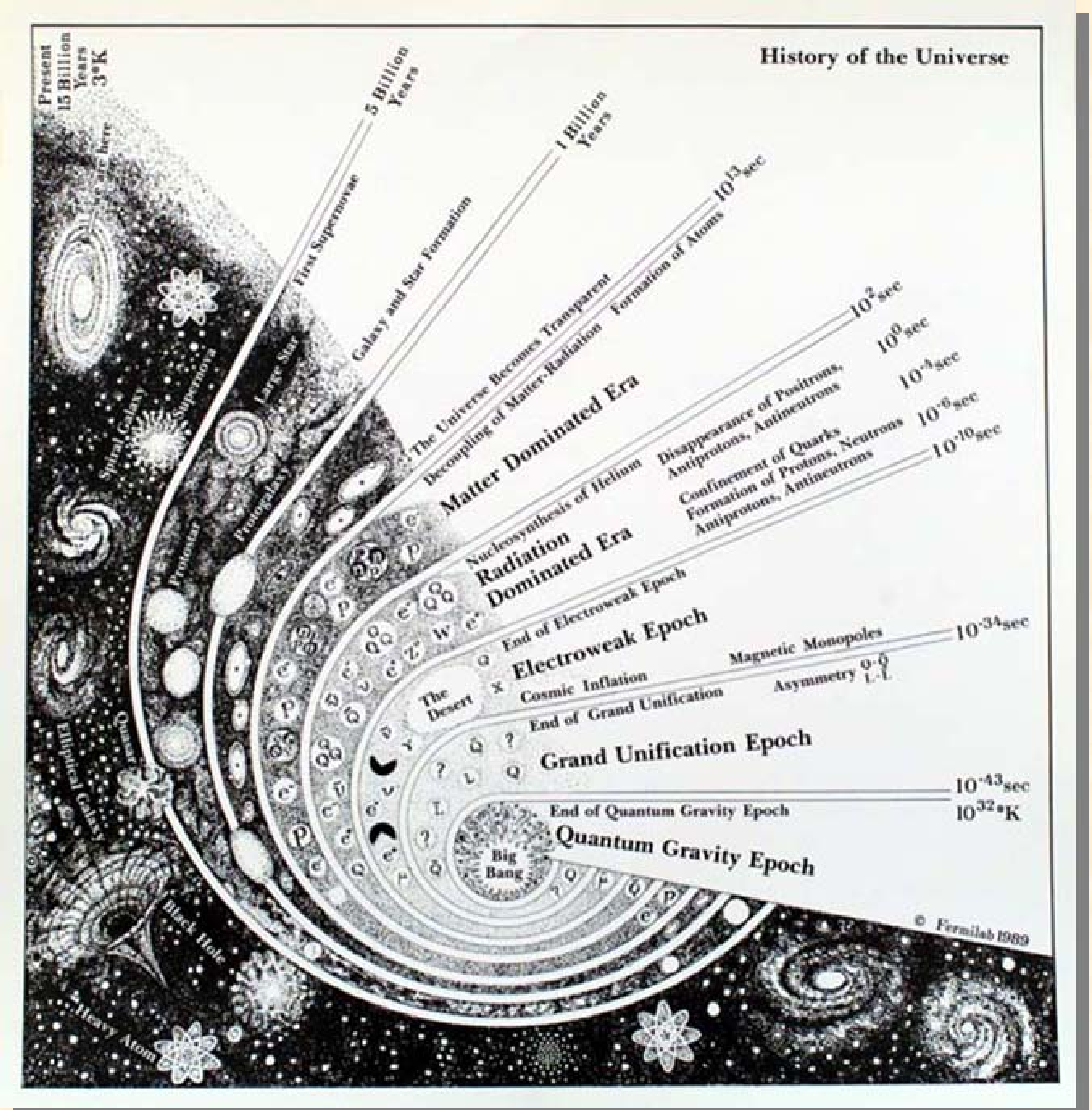


Expected neutrino survival probablity for point source at 180km baseline

Kamland Detector



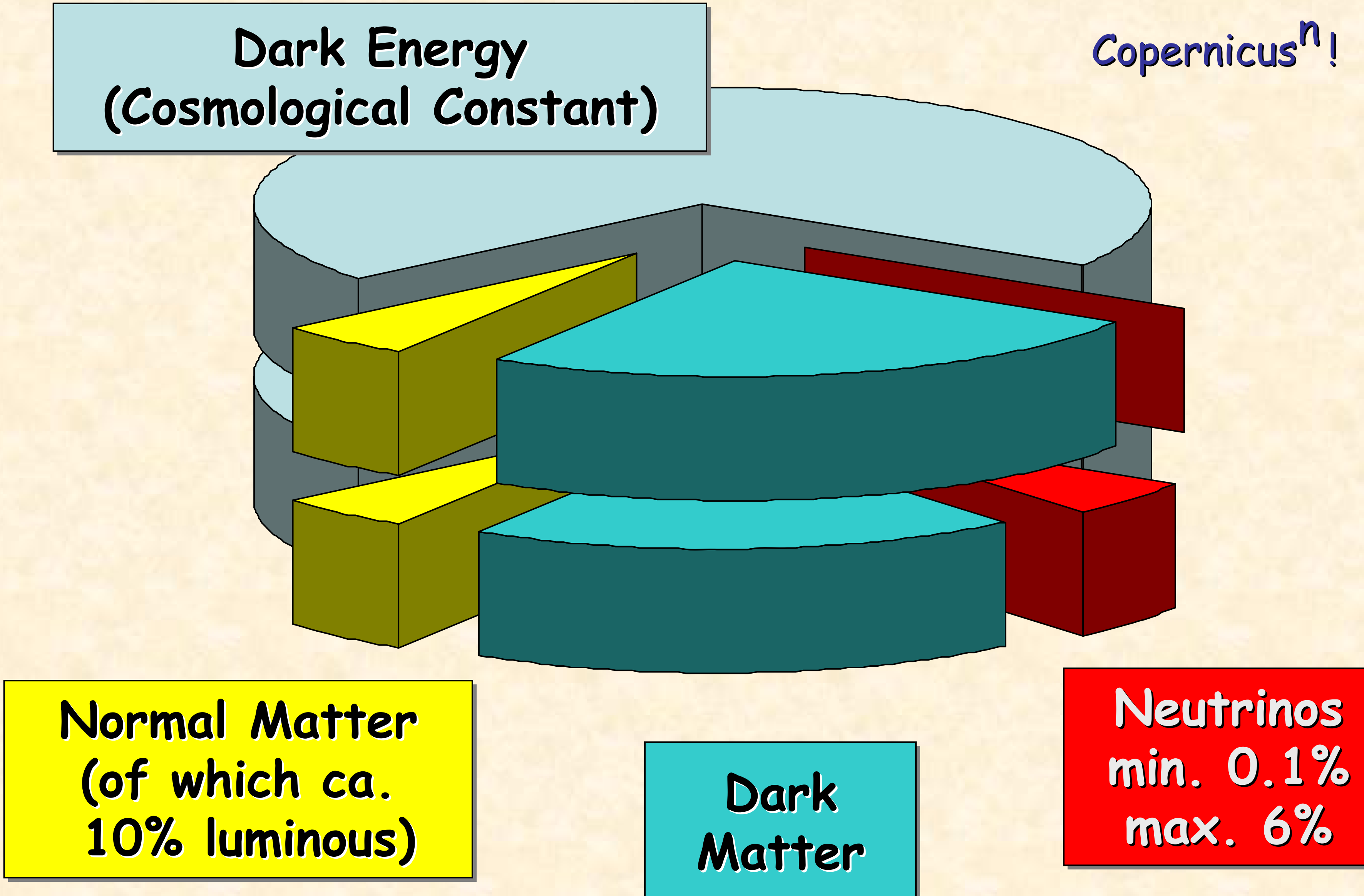
L_0 = 180km flux-weighted average reactor distance

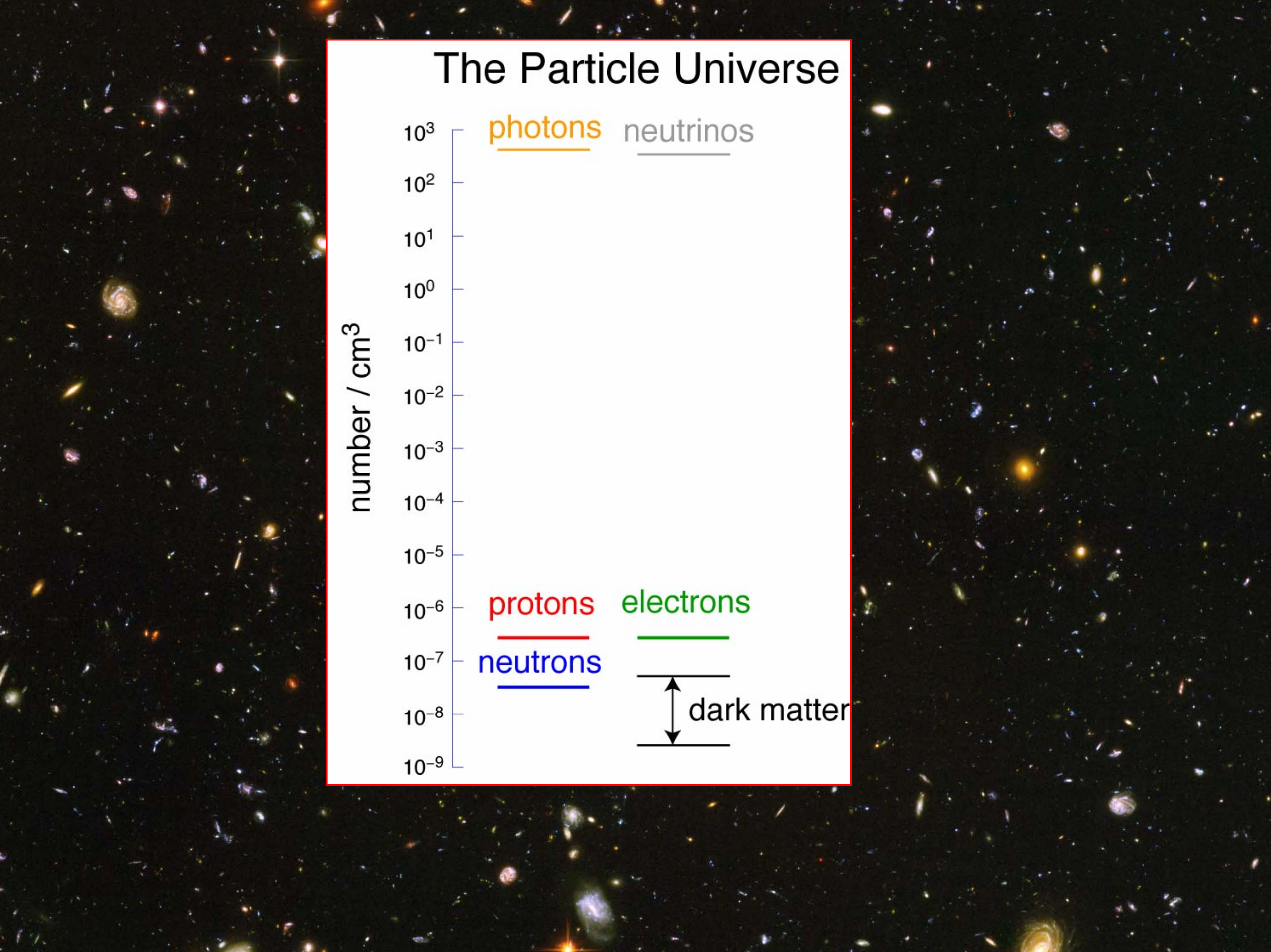


Neutrinos may play crucial role in the genesis of **excess matter over anti-matter** in the universe.

Mass-Energy Inventory of the Universe

Copernicus^n!





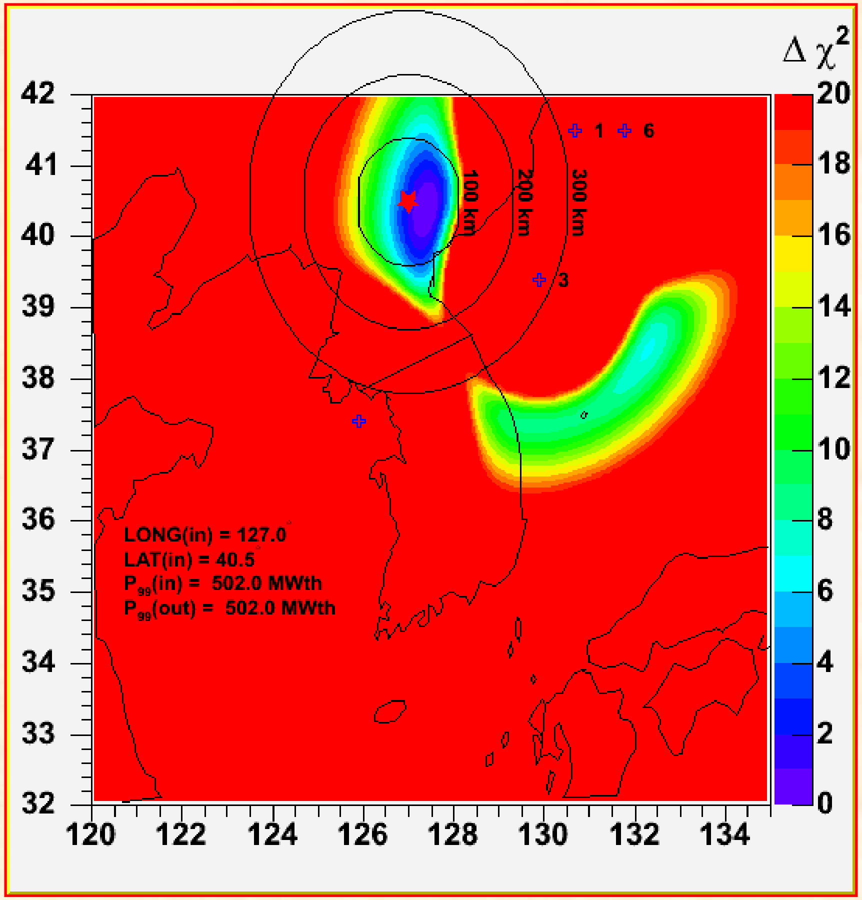
The Particle Universe
number / cm3
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
photons
neutrinos
protons
electrons
neutrons
dark matter

Neutrino Conclusions

- Neutrinos do indeed exist and are
  weird **shapeshifters**
- **Small but finite neutrino mass:**
  Need drastic new ideas to understand it
- ***Neutrino mass may be responsible for our existence (or even the universe itself)***
- A lot more to learn in the next few years
- In any event they now appear to be useful here on earth, for **geology**, **security** and other future applications.

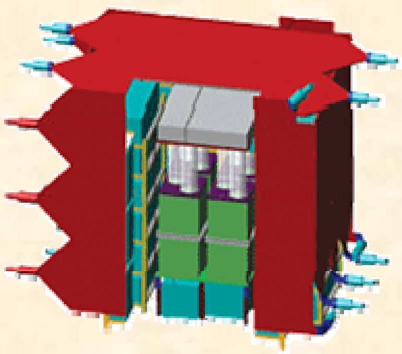
Practical Application: Monitoring Reactors

- Expected proliferation of reactors in near future as oil runs out.
- Need to keep track of “special materials”.
- Close-up (10-100m), intermediate range (1-10 km) and remote (100-1000 km) monitoring of nuclear reactors is possible.
- Giant neutrino detector network will help.



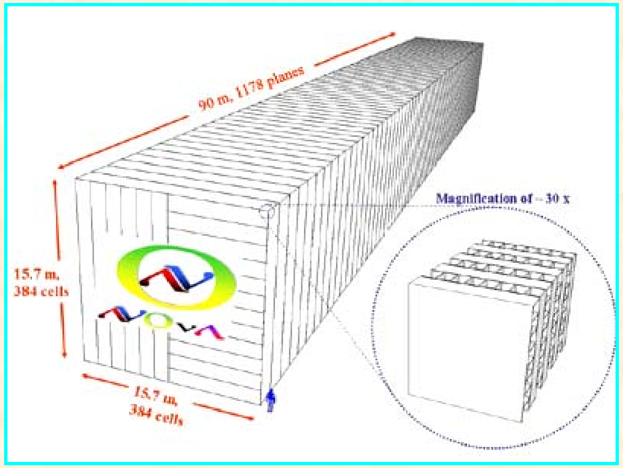
Near and Intermediate Distance Monitoring

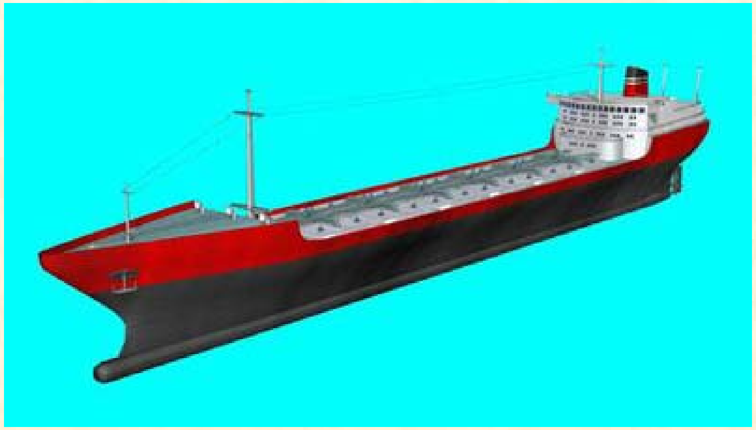
SONGS



- Close-in
- 10 – 100 m
- 1-100 Tons
- Measure details
- Technology: LS or water
- In operation San Onofre
- Much study with Double Chooz and Daya Bay experiments.

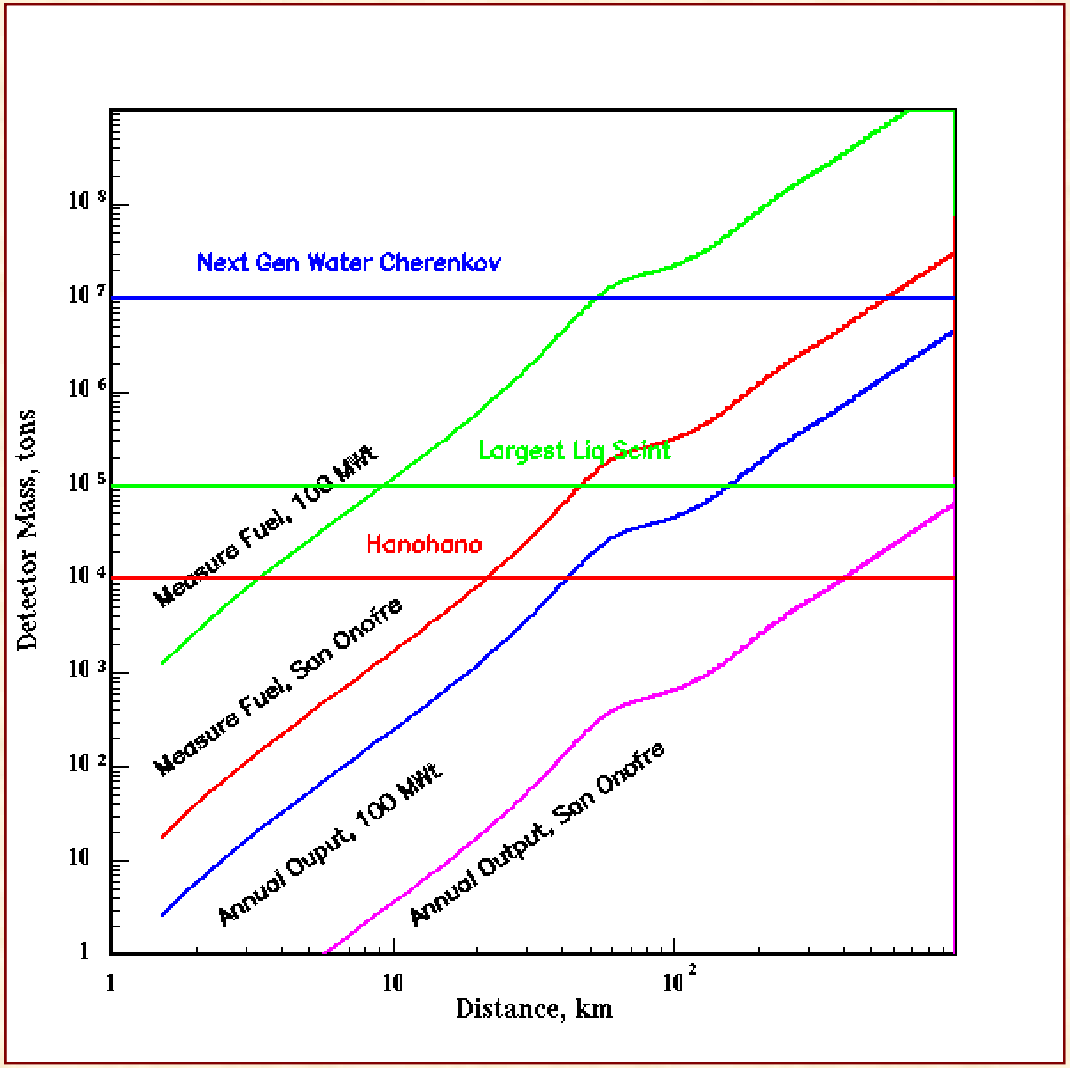
- Intermediate Range
- 1 – 10 km
- 1 10 kT
- Measure details
- Technology: LS
- **Segmentation needed**
- Directionality possible
- Study needed





Reactor Monitoring from Afar

Lines are for San Onofre and a generic 100 MWt reactor required mass versus distance for two extreme purposes:
- the larger gets one 4000 events per month from that source to measure fuel mix;
- the smaller gets one 100 events per year, 10% measure of total power and hence production.

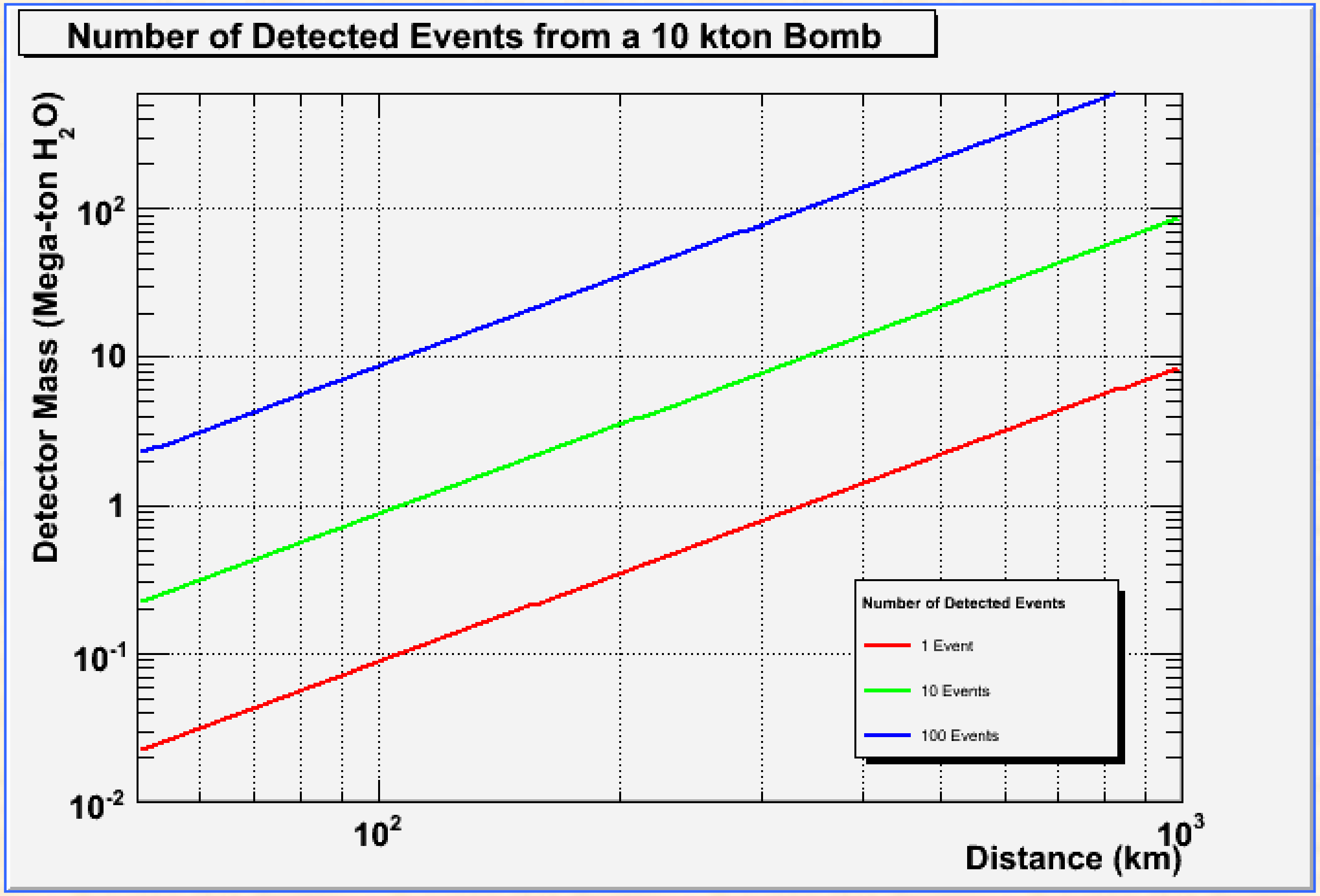


Fuel mix measurement is not and will not be practical for small reactors beyond 100km, even in the fairly far term.

A Hanohano (10KT) scale device can accomplish annual production monitoring out to 40km from a small reactor, and reach to 400 km for a large reactor complex.

A next generation 10 MT detector can monitor Small reactor production out to >1000 km.

Detection of Clandestine Bomb Testing



Neutrino Application: Answer some Big Picture Questions in Earth Sciences

What drives **plate tectonics**?

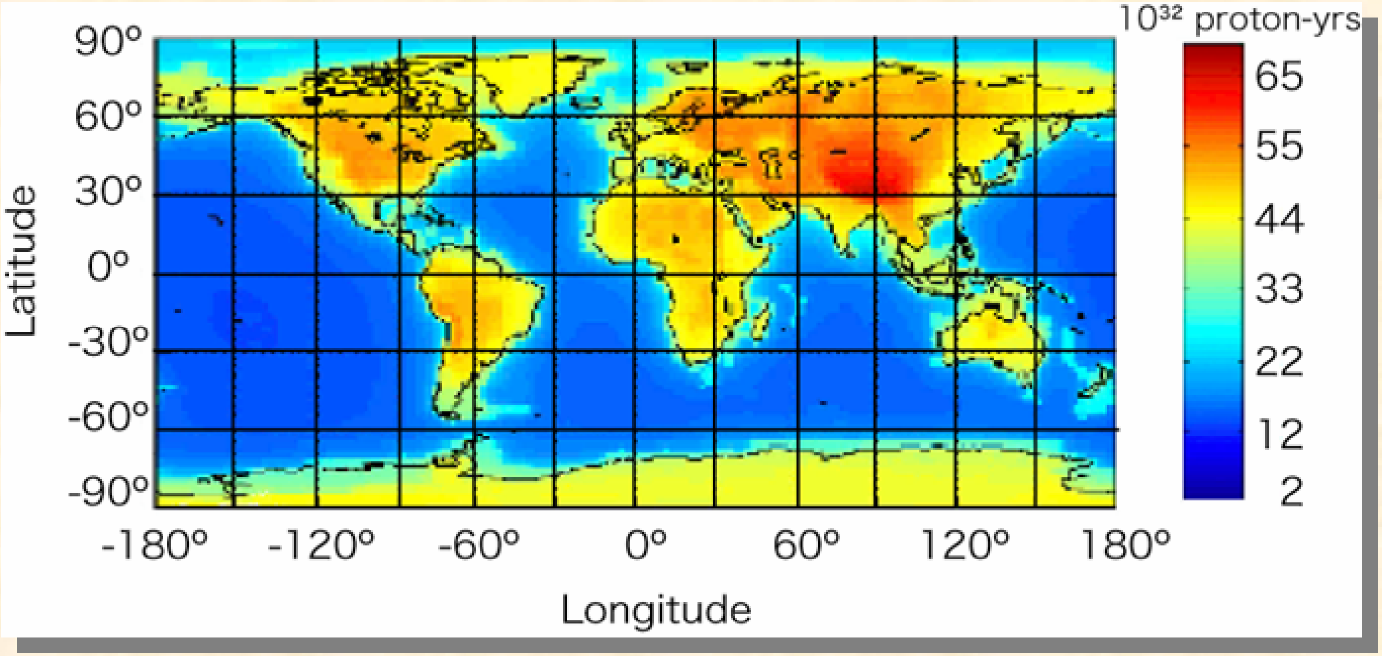
What is the Earth's **energy budget**?

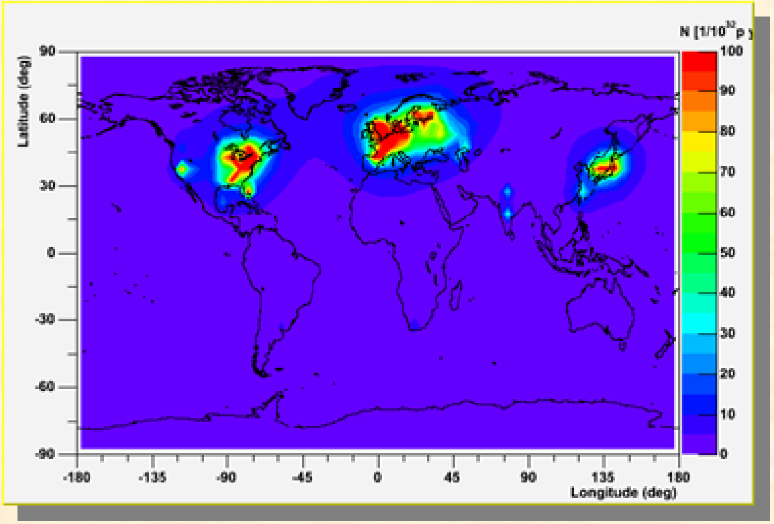
What is the **Th & U conc**. of the Earth?

Energy source driving the **Geodynamo**?

Via measurement of anti-neutrinos from earths mantle and core.

Predicted Geoneutrino Flux





Reactor Flux - irreducible background

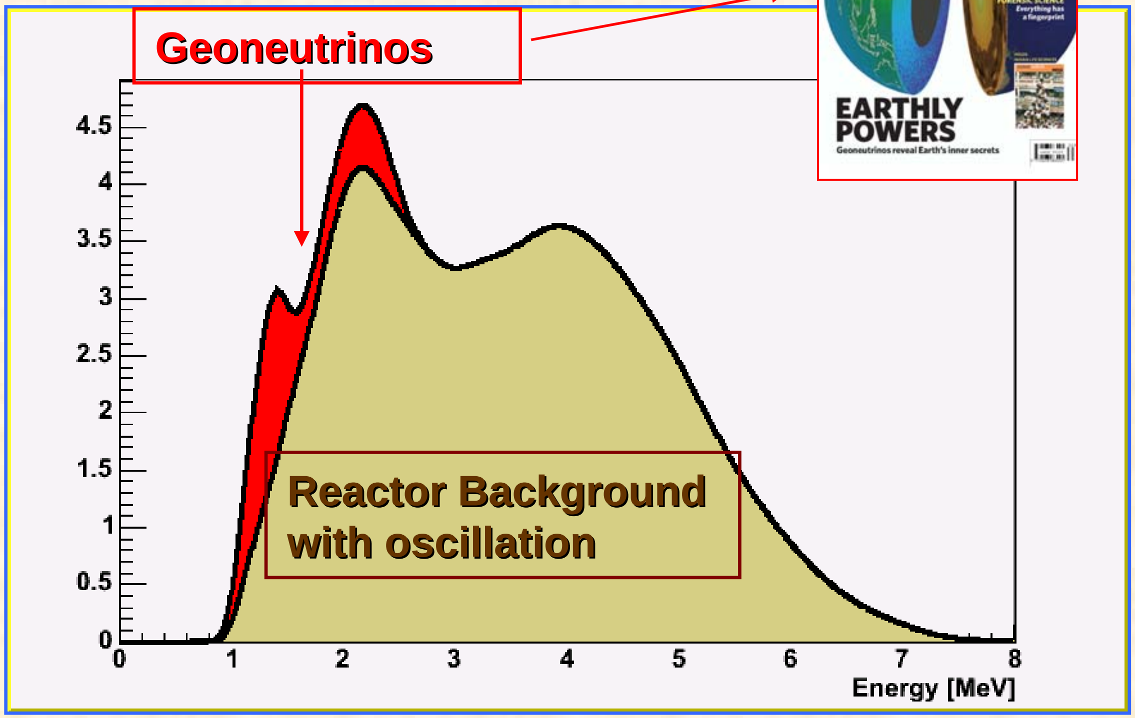
Geoneutrino flux determinations

-continental (KamLAND, SNO+, LENA? DUSEL?)

-oceanic (Hanohano)

synergistic measurements

Reactor "Background"



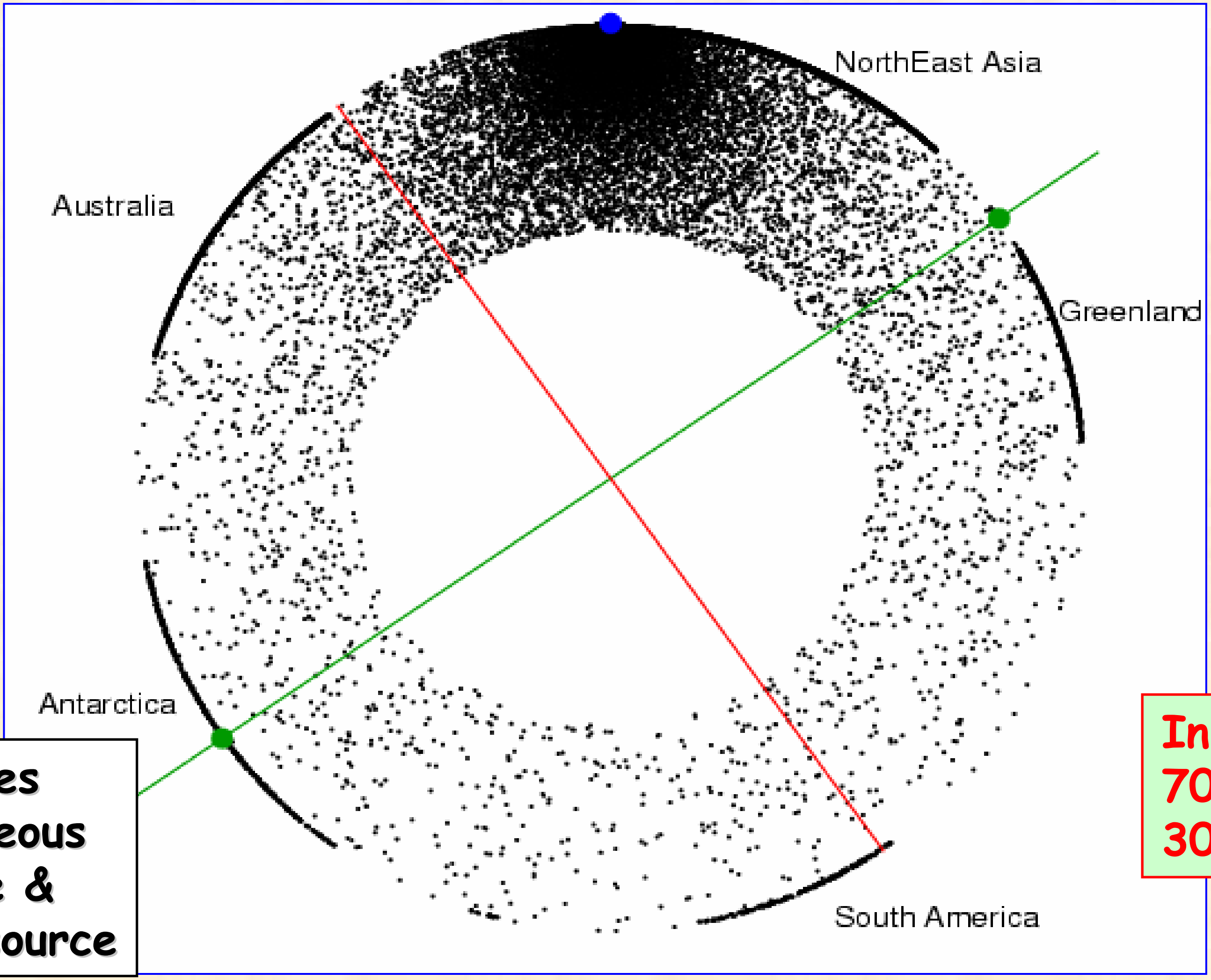
- KamLAND was designed to measure reactor antineutrinos.
- Reactor antineutrinos are the most significant background in Japan region.

Go to deep ocean to measure mantle/core geonus.

Simulated Geoneutrino Origination Points

KamLAND

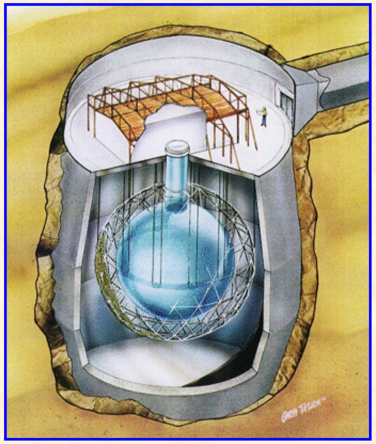
50% within 500km
25% from Mantle



Assumes homogeneous mantle & no core source

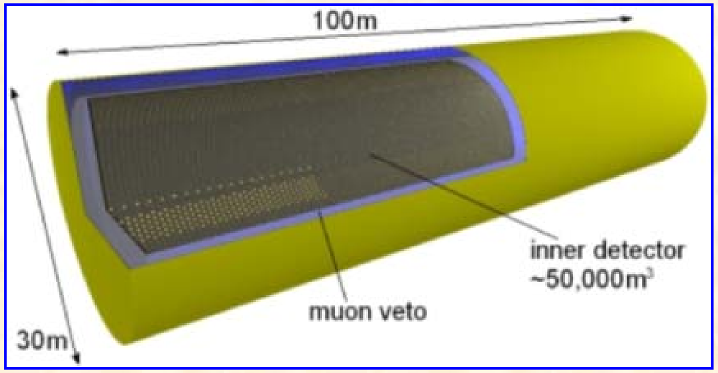
In Mid-Ocean
70% Mantle
30% Other

KamLAND, SNO+, LENA and Others will measure neutrinos from crust



1 kT SNO+ Sudbury Canada

- KamLAND will continue for years
- SNO+ nearly approved
- LENA proposed as part of MEMPHYS
- Dutch proposal EARTH for Curasao
- DUSEL in US may have KamLAND-like detector



50 kT LENA perhaps in Finland

- All of these will be useful to determine the crustal U/TH content.
- Together with at least one deep ocean detector we can start to learn where the U/Th in the earth resides

Hawaii Anti-Neutrino Observatory

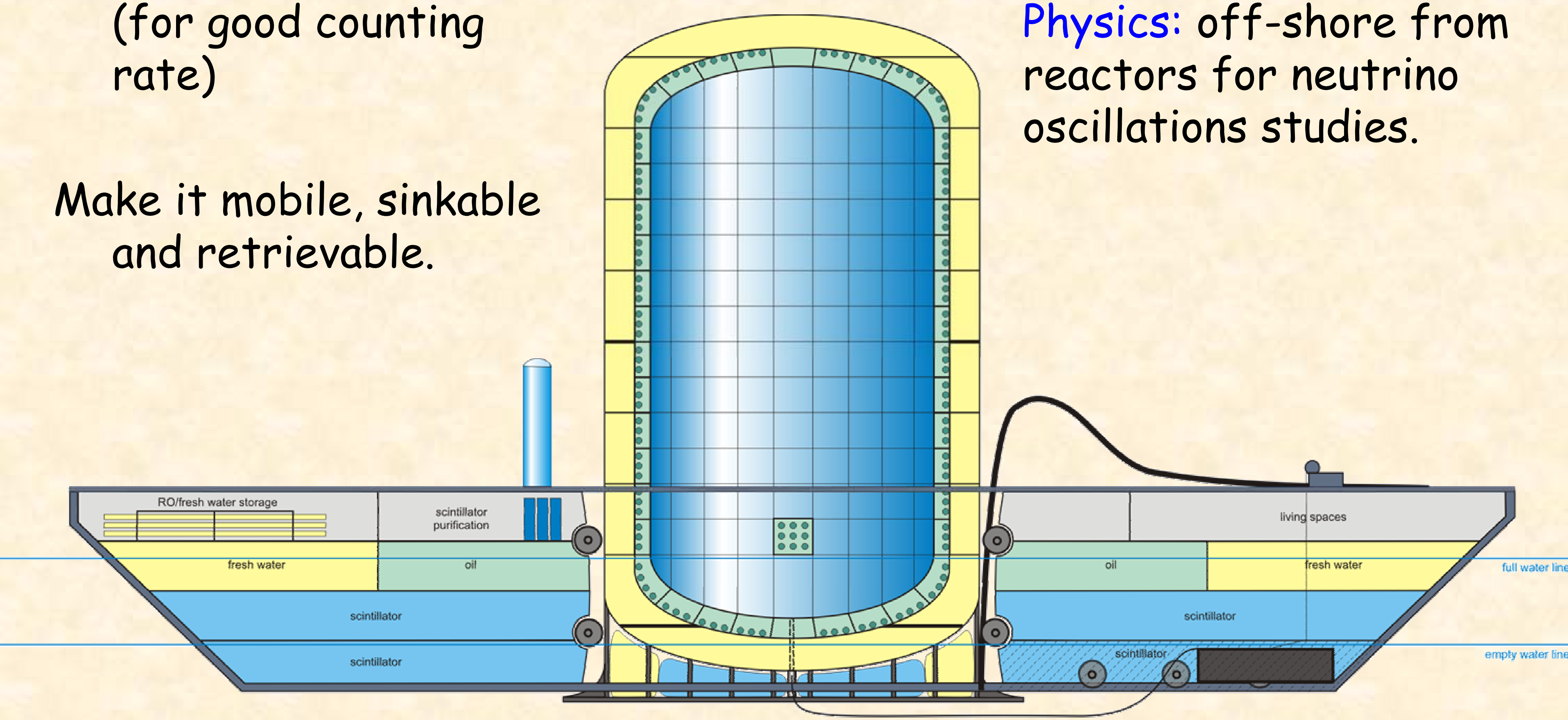
Hanohano

Idea: detector based on KamLAND technology adapted for deep ocean, but >10KT larger (for good counting rate)

Make it mobile, sinkable and retrievable.

Geology: mid-Pacific and elsewhere for geo-neutrinos from mantle.

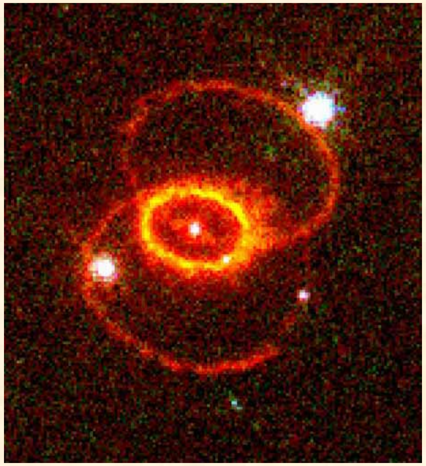
Physics: off-shore from reactors for neutrino oscillations studies.

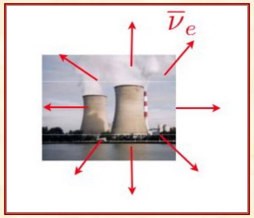


Additional Physics/Astrophysics

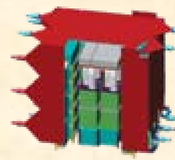
Big low-energy neutrino detectors can do much excellent science.

- Nucleon Decay: SUSY-favored kaon modes
- Supernova Detection: special ν_e ability
- Relic SN Neutrinos
- GRBs and other rare impulsive sources
- Exotic objects (monopoles, quark nuggets, etc.)
- Long list of ancillary, non-interfering science, with strong discovery potential





Summary



- Neutrino detectors can play important societal roles in the future, monitoring nuclear reactors, checking on bomb testing, and further in future, tomography and even weapons control.

- Initial prototype detectors can accomplish transformational geophysics, geochemistry, particle physics and astrophysics: answers to key, big questions in multiple disciplines. Enormous discovery potential. Build strong community of interest and experience.

- Key techology issues are development of new photodetectors, better target materials, full understanding of backgrounds, exploration of direction sensing, lower thresholds (K40), and radically new detection means (coherent).

- Future, much science and many applications for low energy neutrino detection with huge instruments.

- It is a very exciting time in the neutrino business as you will see and hear in the following talks.