HANOHANO

- Hawaii Anti-Neutrino Observatory
- “distinctive”, “glorious”
- 10 kton, liquid scintillator
- 1 MeV energy scale
- 3-5 km ocean depth
Geo-Neutrinos

- Radioactive decay ν's, 3.3 MeV or less
- Radiogenic heating contributes to plate tectonics and geomagnetic field
- Won't speak to $^{40}$K content

\[ ^{238}U \rightarrow ^{206}Pb + 8^4He + 6e^- + 6\bar{\nu}_e \]
\[ ^{232}Th \rightarrow ^{208}Pb + 6^4He + 4e^- + 4\bar{\nu}_e \]
\[ ^{40}K \rightarrow ^{40}Ca + e^- + \bar{\nu}_e \]
What's going on inside our planet?

- Seismic data gives density: inner/outer mantle, inner/outer core
- Fractional U/Th in the crust is thought to be 100x that in the mantle, while the mass of the mantle is 100x the mass of the crust.
- Geo-reactor?
- Continental vs Oceanic
Where?

Neutrino flow

Cumulative Geoneutrino Flux (U+Th)

(a)

Cumulative Flux [$10^{2}$ cm$^{-2}$sec$^{-1}$]

Percentage of total (%) [100]

Distance from Detector [km]

(b)

Cumulative Flux [$10^{6}$ cm$^{-2}$sec$^{-1}$]

Percentage of total at Kamioka (%) [100]

Distance from Detector [km]
Reactor Neutrino Background

- When trying to see geoneutrinos from the mantle (and/or core) reactors become background
HANOHANO Applications

- Geoneutrinos – mapping the Uranium and Thorium content of the mantle (and core?)
- Reactor monitoring
- Measurements of mixing parameters:
  - Mass Hierarchy
  - Mixing angles
- Long baseline experiments
Liquid Scintillator Studies

- How will the scintillator perform at the ocean floor?
- LAB, PPO & BisMSB
- Bicron (proprietary)
- Depth of 4km:
  - 4 °C
  - 6000 PSI

Figure 4.1: Stainless Steel Test Assembly
Fermat's Principle

“The path taken between two points by a ray of light is the path that can be traversed in the least time.”

- As muon travels through liquid scintillator, photons are emitted isotropically.
- A “Fermat Surface” (Cerenkov and spheres) is defined by the wavefronts of first hit times.
- Huge statistics determining this surface.

Approx. 5m long muon track centered in a 40m x 40m right cylinder detector
Electron and muon events are distinguishable by differences between equi-charge and equi-time surfaces.

Opens up the study of high energy (~1 GeV) neutrino interactions with LS detectors.

Potential for long baseline experiments.

Does not interfere with lower energy (MeV) physics (e.g. reactors, geonuses, supernovae, etc.).
Time and Charge Fits

Conclusions:
- Charge point fit to middle of track works well
- Time point fit to near start of muon track works well
Simple Point Fits (Q and T) Give Center of Track and point Near Origin

Muon angular resolution to <1 Degree

10 sigma better fit to line than shower profiles

Chisquare/DOF Equivalent

Vertex location to few cm with first point fit.
Further: Much Information in Time Distribution of Hits (PMT Waveform)

Sample PMT hit time distributions from top of detector

1 GeV Muon

1 GeV e Shower
First Results on Tomographic Reconstruction

before contrast cuts

x-z projection  y-z projection  x-y projection
Applications

- Long Baseline with accelerators ~ 1 GeV
  - Hanohano with Tokai Beam?
  - LENA with CERN beam?
  - New DUSEL Experiment with Fermilab Beam?
- Nucleon Decay (high free proton content)
  - See details of decays such as Kaon modes
- Particle Astrophysics (low mass WIMPS, ...)
- All the Low Energy Physics (geonius, reactor studies, monitoring, solar neutrinos.....) unimpeded!
Outlook

- Hanohano will give unique insights in geology and neutrino physics
- Development of Hanohano technologies is key to geoneutrino and reactor studies
- Large LS detectors are capable of detailed neutrino physics.
- “Fermat Surface” technique opens new avenues for neutrino physics with LS detectors.
Mahalo!