Applied Antineutrino Physics Workshop

An Alternative Design based on Inverse Beta Detection

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• History
• The immediate future
• The 2-3 yr. time frame
• The beehive
• Summary

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History

• Our first generation detector
  – Conservative design
  – It works!
  – Inefficient
  – Big
Immediate Future

• The next generation detector
  – To be deployed quickly (mid 2007)
  – More efficient
  – A straightforward extension of existing work
  – Much better electronics
  – Probably a Gd loaded scintillator with better optics and more hermetic muon veto
Intermediate future (2 to 3 yr.)

– My pitch!
– A relatively advanced inverse beta design
– Smaller!
– More efficient!
Proposed Design for 2 to 3 yr. Timeframe
“The Beehive”

- Liquid scintillator (~1 m³)
- Honeycomb partition immersed in liquid scintillator
- Thin acrylic honeycomb coated with $^6\text{LiF}:\text{ZnS(Ag)}$ scintillator
- Read out with ~100 PMTs
ZnS(Ag) scintillator with 6Li loading

Proposed Design

Liquid organic scintillator with pulse shape discrimination
A neutrino hit in the proposed design

- Neutrino interaction signature
  - Positron
    - one cell (discounting annihilation photons)
    - Electron-like event in liquid scintillator (fast pulse decay)
  - Neutron
    - Bright ZnS pulse in two adjacent cells about ~10 µs after positron

\[ \bar{\nu}_e + p \rightarrow e^+ + n \]
Background events
Fast neutron enters detector

Existing Detector
• Mimics antineutrino capture
  – Pulse from n-p scatter
  – Followed by n-capture on Gd

Proposed Detector
• Cut because:
  – n-p scatter distinguishable from pulse shape
Background events
fast neutron into detector

Neutrino-like event

Background event (fast neutron capture)
Background events
slow neutron into detector coincident with gamma ray

Existing Detector
• Mimics antineutrino capture
  – Pulse from n-p scatter
  – Followed by n-capture on Gd

Proposed Detector
• Cut because:
  Gamma event very unlikely to be in same cell as neutron event

\[ \bar{\nu}_e + p \rightarrow e^+ + n \]

\[ \nu + e^-; \ n + ^6Li \]
Background events
two chance gamma-rays within time window

Existing Detector
• Mimics antineutrino capture

Proposed Detector
• Cut because:
  No signal from ZnS scintillator
  gammas do not deposit enough energy in ZnS and light from neutron on Li is very large = \( Q = 4.8 \text{ MeV} \)
  Light pulses from more than one cell
Beehive Detector

- More efficient than existing detector
  - Due to \( \sim 100\% \) efficiency of neutron capture reaction in \( ^{6}\text{LiF}:\text{ZnS(Ag)} \) scintillator

- Greater background rejection
  - Phase space of signal cuts is much richer; easier to classify events
    - Spatial, pulse shape, and two types of scintillator

\( \bar{\nu}_e + p \rightarrow e^+ + n \)
But Wait, There’s More!
Some directionality!

ZnS(Ag) scintillator with $^6\text{Li}$ loading

$\bar{\nu}_e \rightarrow \text{n}$

$\nu_e \rightarrow \text{n}$
But Wait, There’s More!
Some directionality!

- Although neutron diffusion is a random walk, a slowing neutron preserves a memory (if sloppy) of its original momentum.
- This property has been observed and exploited in neutrino detection before.

![Graph showing neutron properties](image)

**FIG. 5.** The shift (solid line) $\langle x \rangle$ and width (long-dashed line) $\sigma_x = \sqrt{\langle x^2 \rangle - \langle x \rangle^2}$ for monoenergetic neutrons (initial kinetic energy $T_n$) emitted from the origin, moving initially along the $x$-axis. Note $\langle y \rangle = \langle z \rangle = 0$, and $\sigma_x = \sigma_y = \sigma_z$. We used a $\text{(CH}_2)_n$ liquid of density $0.80 \text{ g/cm}^3$, with or without $0.1\%$ Gd doping by mass.
A recent experiment

![Graph showing experimental data and exponential fits]

- Start-stop time interval [µs]: 0 2 4 6 8 10
- Frequency of occurrence [counts]: 100 1000
- Experimental data:
  - 1.5 µs exponential fit
  - 13 µs exponential fit

![Diagram showing PMT and Scintillator]

- PMT
- LiF/ZnS(Ag) Scintillator
- Trans-Stilbene 2” single crystal
Summary and Acknowledgements

• A highly segmented detector with $^6\text{LiF:ZnS(Ag)}$ scintillator partitions looks very attractive for monitoring of reactor antineutrinos.

• We want to do some design experiments!

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