Detecting Antineutrinos Using the SNO+ Detector

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Antineutrinos - $\bar{\nu}_e$

Produced in very large fluxes from nuclear reactors

Travel large distances unimpeded

Very small fraction will interact and a signal may be observed
Antineutrino Oscillation
Antineutrino Oscillation

\[ \bar{\nu}_e \quad 100's \ of \ km \quad \text{Energy} \]

![Graph showing energy distribution](image)
Antineutrino Oscillation

\[ \bar{\nu}_e \rightarrow 100's \text{ of km} \rightarrow ? \]

Energy

Graph showing counts vs. energy [MeV].
Antineutrino Oscillation

\[ \bar{\nu}_e \rightarrow \text{100's of km} \rightarrow ? \]

\[ \bar{\nu}_e \rightarrow \bar{\nu}_\mu \]

Energy

![Energy Distribution Graph]

Counts

0 5000 10000 15000 20000 25000 30000 35000 40000 45000

Energy [MeV] 0 2 4 6 8 10
Antineutrino Oscillation

Before oscillation

After oscillation

Energy
Antineutrino Interaction

Expecting:
110 interactions per year

Sensitivity to $\Delta m^2_{12}$ of $0.2 \times 10^{-5}$ eV$^2$

Before oscillation
After oscillation

Stacked contribution from:
Bruce
Pickering + Darlington
All other reactors
Added motivation

KamLAND (2011)

$\Delta m_{12}^2$ [10^{-5} eV^2]

$10^{-5}$
Added motivation

KamLAND
(2011)
Super-Kamiokande
(2016)

\[ \Delta m^2_{12} \left[ 10^{-5} \text{ eV}^2 \right] \]

Added motivation

KamLAND (2011)
Super-Kamiokande (2016)

$\Delta m^2_{12}$ [10$^{-5}$ eV$^2$]

10

0

SNO+ will be able to add an independent measurement
SNO+ Detector

Consists of:

12 m diameter acrylic sphere

9300 photomultiplier tubes (PMTs)

7000 tonnes of surrounding water

Will be filled with 780 tonnes of liquid scintillator

- Also 3.9 tonnes of natural tellurium
Currently...

Filled with water

Now collecting physics data
Inverse Beta Decay

Antineutrinos may interact in the SNO+ detector via the inverse beta decay (IBD) reaction:

\[
\bar{\nu}_e + p \rightarrow e^+ + n
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$t = 0$

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$t \approx O[\text{ns}]$
Inverse Beta Decay

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- $t = 0$ (initial state)
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- $t \approx O[\text{ns}]$
- $t \approx O[100 \mu\text{s}]$
Inverse Beta Decay
IBD Signal in SNO+ *while the detector is filled with water
IBD Signal in SNO+
IBD Signal in SNO+

*while the detector is filled with water

O[100µs] later
Backgrounds in SNO+

... but we also have naturally occurring radioactive backgrounds...
Backgrounds in SNO+

... but we also have naturally occurring radioactive backgrounds...
Could two background events that occur within a short time of each other and mimic this signal?

How can we distinguish the signal from antineutrinos?
Simulation – Antineutrino Search

Two Monte Carlo simulations:

IBD signal only

... with statistics corresponding to...

5000 years of data taking

All expected backgrounds

60 minutes of data taking

- $^{212}\text{Po}$
- $^{214}\text{Bi}$
- $^{208}\text{Bi}$
- $^{208}\text{Tl}$
- $^{40}\text{K}$

Selection Criteria

First **remove** events that occur near or past the surface of the spherical vessel (more radioactivity here)

- Impose a fiducial volume cut (FV)
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Radius $r < 5.5\ m$
Selection Criteria – Cont’d

See that these signal events have correlations between them
Selection Criteria

Next, keep only event pairs that occur within a specific **time interval** of each other

- Coincident events
Selection Criteria

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- Coincident events

**Time difference**
\[ \Delta t < 500 \mu s \]
Selection Criteria

Third, **keep** only coincident events that occur within a short **distance** from each other.

Reconstructed distance between coincident event pairs **IBD Events**

Background Events
Selection Criteria

Third, keep only coincident events that occur within a short distance from each other

Position difference $d < 2 \text{ m}$
Implications

Imposing this criteria:

- Reduces signals from IBD events
- But **greatly reduces** signals from radioactive backgrounds

Realistically, only expect to have approx. **1 IBD decay event** left in our data set after these cuts are applied
  - Assuming current data collection in water for **6 months**

More than likely, there will be many more background coincidences, drowning the signal
Conclusions

*But...*

By looking at this in Monte Carlo and in ‘water phase’ data:

- We can **develop** the tools needed to search for IBD signals
- Begin **optimizing** the techniques that pull out the signal from the data collected
- Better **understand** the backgrounds that mimic this signal

*We are set up well for a measurement of antineutrinos when ‘scintillator phase’ begins* *(scheduled: Late 2017)*
Back-up Slides
Neutrino Oscillation

\[
P_{\nu_\alpha \rightarrow \nu_\beta} = \sin^2(2\Theta) \sin^2(1.27 \Delta m^2 [eV^2] \frac{L [km]}{E [GeV]})
\]