AmBe Source Calibrations in Measuring Reactor Antineutrinos in SNO+ Water Phase

Introduction

SNOLAB is an international particle astrophysics laboratory located 6800ft below the surface in Creighton Mine in Sudbury, Ontario Canada. The laboratory is a class 2000 clean-lab, meaning there are less than 2000 particles per cubic feet that are great than 0.5 μm in size.

Why go to such great lengths?

The 2km thick layer of rock helps to block millions of muons coming from the sun and cosmos. The combination of rock shielding and ultra-low background environment in SNOLAB helps to reduce background particle noise and allows for the existence of extremely sensitive detectors.

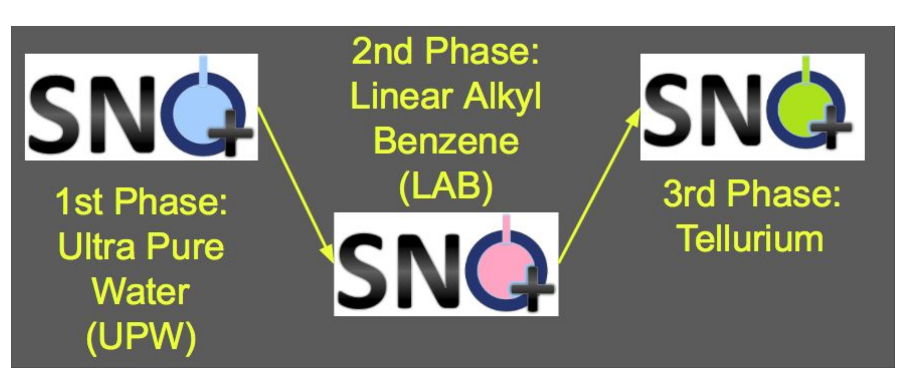
SNO+

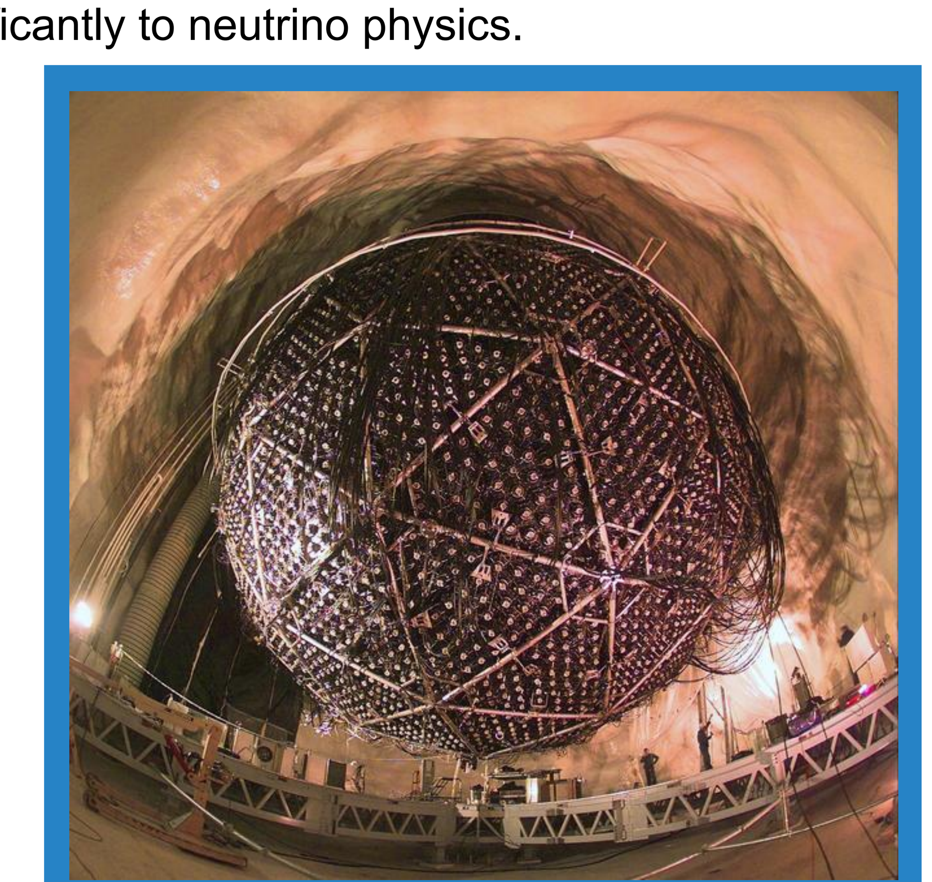
SNO+ is one of the detectors located in SNOLAB. The detector is the largest in SNOLAB. It's 6m acrylic vessel and 9m stainless steel structure (PSUP) supports ~9800 photomultiplier tubes (PMTs) located in an ~85ft by ~72ft cavern. The low background environment of SNOLAB and the size of the SNO+ detector makes it extremely sensitive.
It is the successor of the SNO experiment whose contributions won the 2015 Nobel Physics prize for demonstrating that neutrinos have mass. SNO+ hopes to continue to contribute significantly to neutrino physics.

Physics goals and Phases of SNO+

SNO+ is a multphase multi-purpose experiment

- Neutrinoless double beta decay ($0\nu\beta\beta$)
  - Main physics goal of the experiment.
- Geo- and Reactor Antineutrinos
- Solar neutrinos
- Supernova neutrinos
- Nucleon Decay





AmBe Source and Reactor Antineutrino

In order to measure the reactor antineutrinos the detector must be calibrated to make accurate measurements and estimate how many antineutrino signals are detected and where they occur.

The Americium-Beryllium (AmBe) neutron source was selected to mimic the antineutrino signal. The AmBe source was deployed in 23 different positions in the detector over a 3 day period.

Analysis Goals:

- **Measure Neutron Capture Efficiency and Capture Time**
- **Calibrate energy and position reconstruction (future work)**

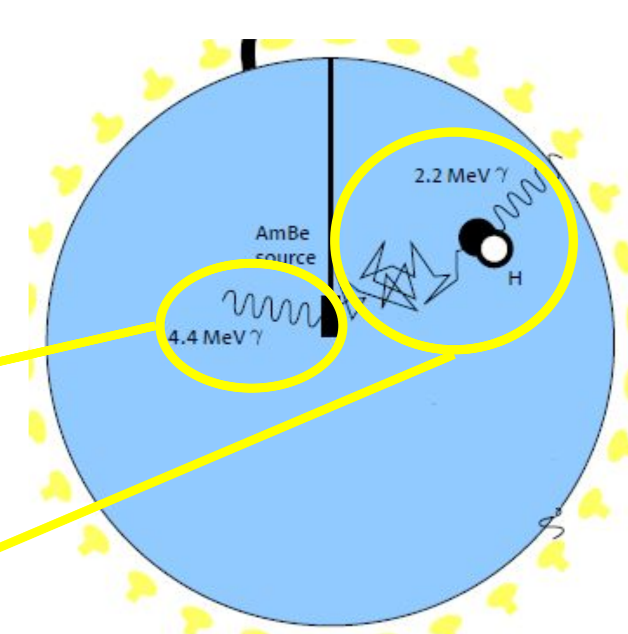
AmBe Signal

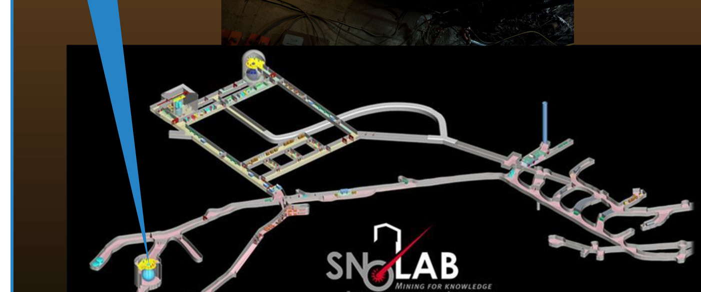
Primary Signal

Initial neutron from AmBe scatters of a hydrogen atom which produces a 4.4 MeV gamma

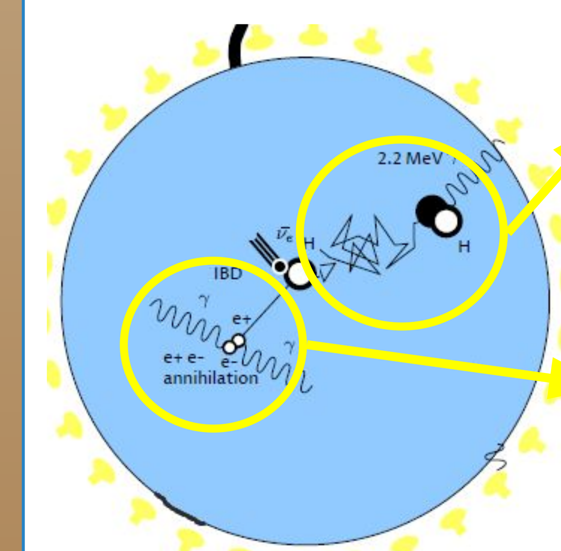
Secondary Signal

Neutron is then captured in the UPW which produces a secondary 2.2 MeV gamma





Reactor Antineutrino signal



Primary Signal

Reactor antineutrino collides with hydrogen atom and undergoes an inverse beta decay.

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

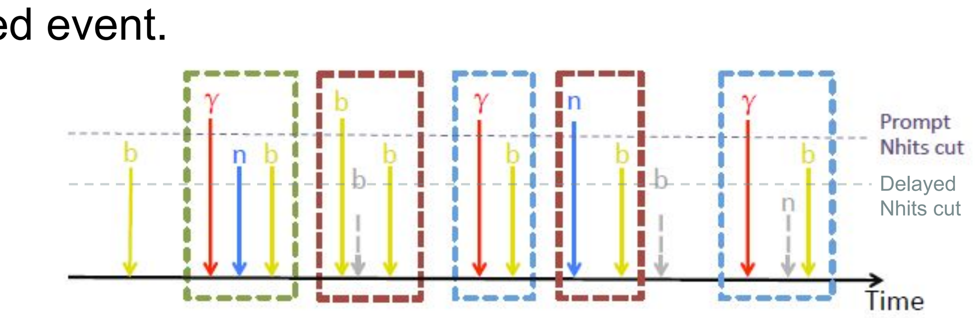
Secondary Signal

Neutron is then captured and produces secondary 2.2 MeV gamma.

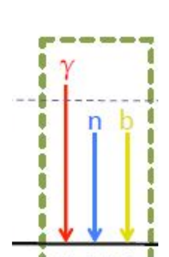
Identifying AmBe events

We use two quantities to identify and tag AmBe events

I. Nhit Cut
  - Number of PMTs hit in the detector
  - Related to the energy
2. Time Window Cut (Δt)
  - Time after the prompt event in which we look for a candidate delayed event.



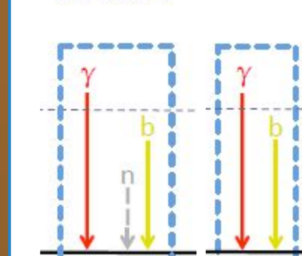
Events are iterated through. When an event passes the prompt nhit cut, events within a coincident time period are investigated for potential candidate delayed events.
We plot the Δt between events and fit it using the following function.



True-True

$$P \cdot E \cdot \lambda e^{-(\lambda+R_2)t}$$

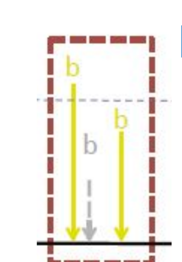
Prompt event is the 4.4 MeV ɣ
Delayed event is the 2.2 MeV ɣ



True-Fake

$$P \cdot E \cdot R_2 e^{-(R_2+\lambda)t}$$

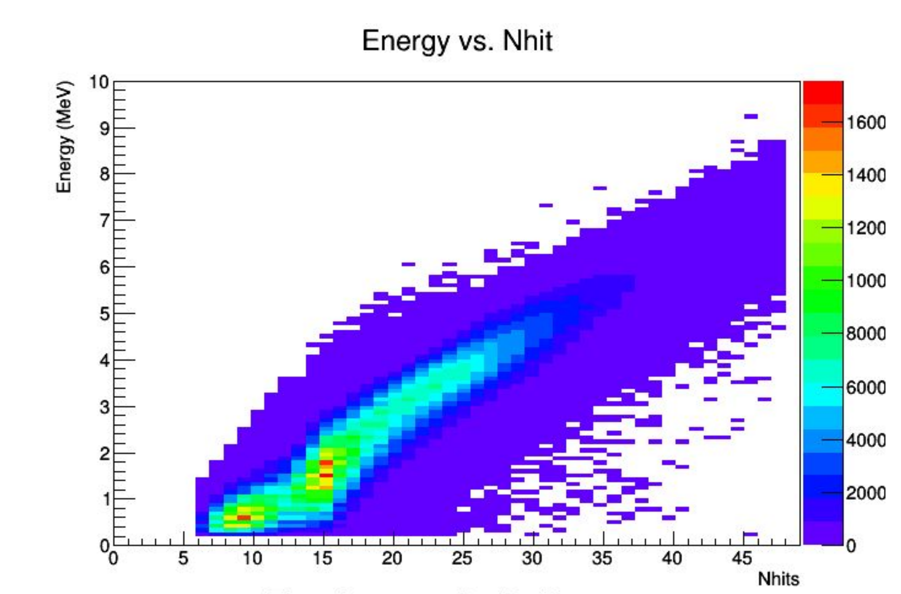
Prompt event is the 4.4 MeV ɣ
Delayed event is background

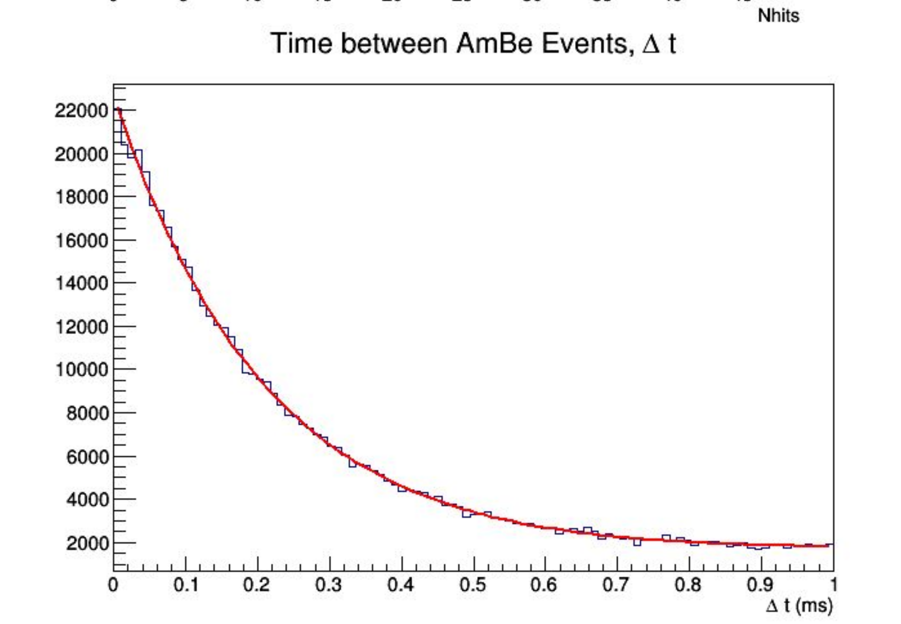


Fake-Fake

$$(1 - P \cdot E) \cdot R_2 e^{-R_2 t}$$

Prompt event is background
Delayed event is background





$$F(t) = N \cdot R_1(P \cdot E \cdot (\lambda + R_2)e^{-(\lambda+R_2)t} + (1 - P \cdot E) \cdot R_2 e^{-R_2 t})$$

- N : Normalization (run time x histogram binning)
- R_1 : Rate of candidate prompt events
- P : Probability of selecting a true 4.4 MeV ɣ
- E : Neutron (2.2 MeV ɣ) detection efficiency
- $P \cdot E$: Neutron Capture Efficiency analysis goal!
- λ : Neutron capture time analysis goal!
- R_2 : Rate of candidate delayed events

Neutron Capture Efficiency and Capture Time

Using the fit function to solve for the neutron capture time (λ) and efficiency ($P \cdot E$). We can plot the values over all runs.

~45% Neutron Capture

** highest observed neutron capture efficiency among reactor antineutrino detectors

207 μs Neutron Capture Time

** This preliminary results are in agreement with other SNO+ analysis.