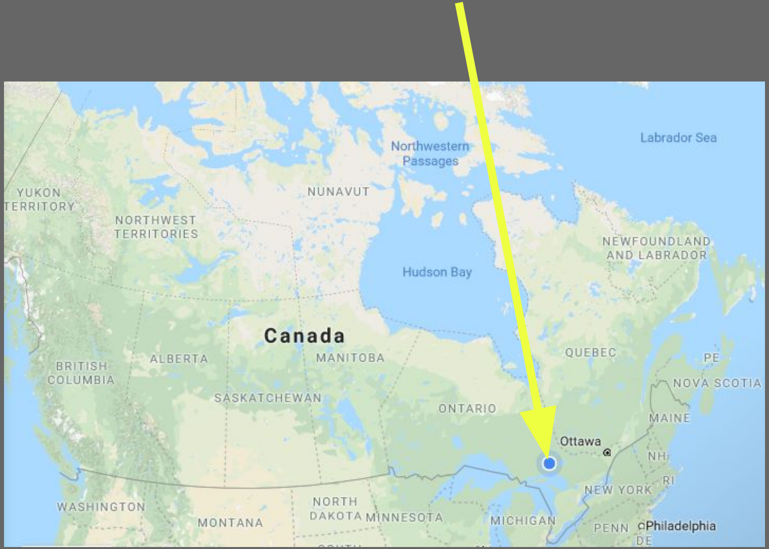
AmBe Source Calibrations in Measuring Reactor Antineutrinos in SNO+ Water Phase

Jamie Grove

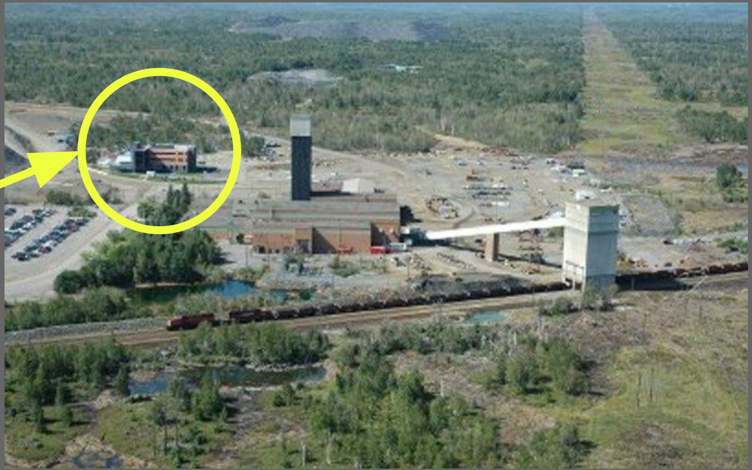
SNOLAB

- A physics laboratory located in Sudbury, Ontario



SNOLAB

- Located 2 km underground in an active mine called Creighton Mine, owned by Vale



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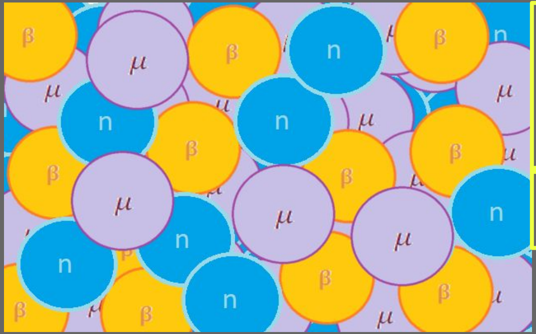
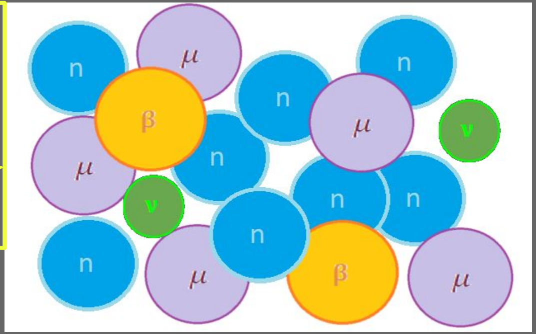


2km of rock to shield from background particles



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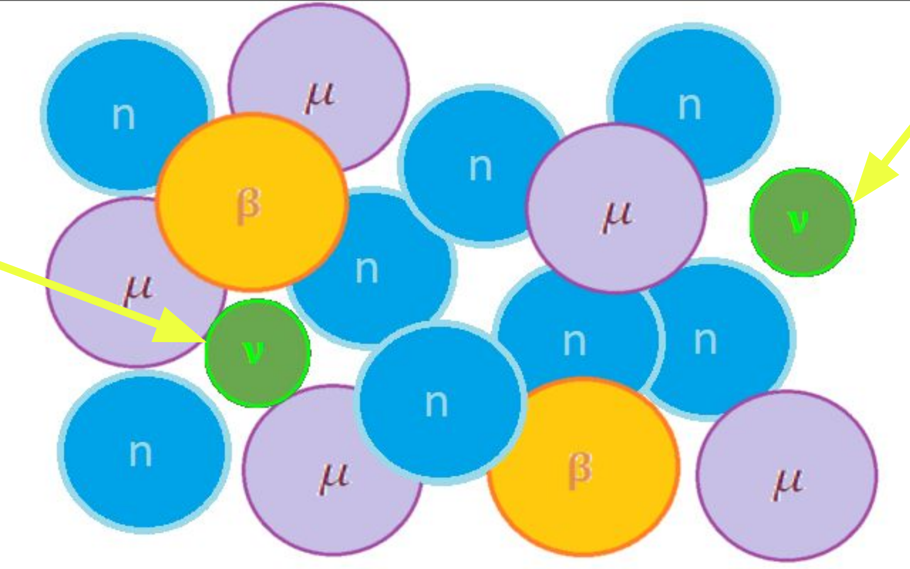
    - We are studying very small particles and need an ultra low background environment.

SNOLAB is a CLASS 2000 lab meaning less than
2000 particles > 0.5 μm in size per cubic ft.

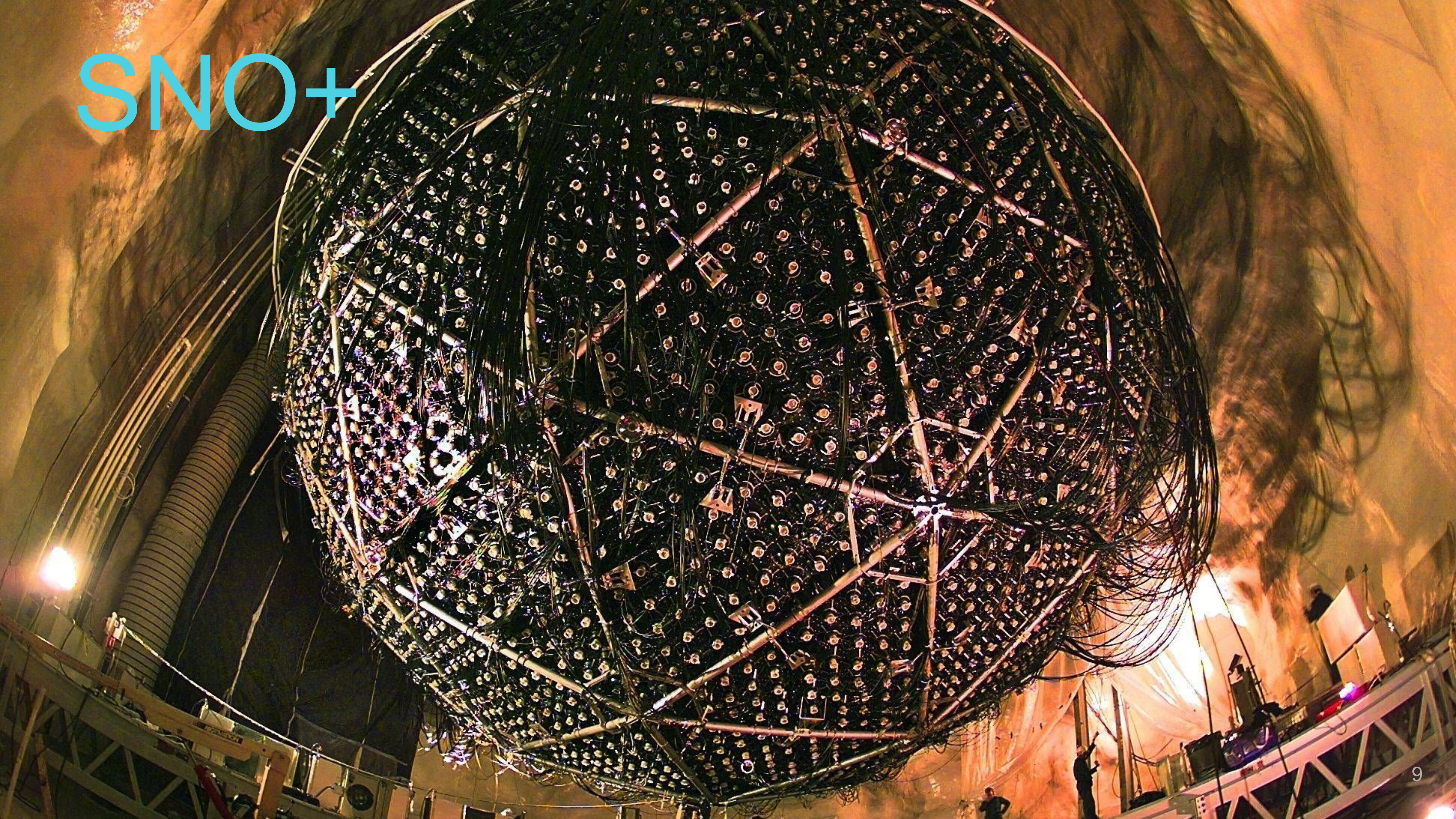
Why?

Neutrino!



Neutrino!

SNO+



SNO+

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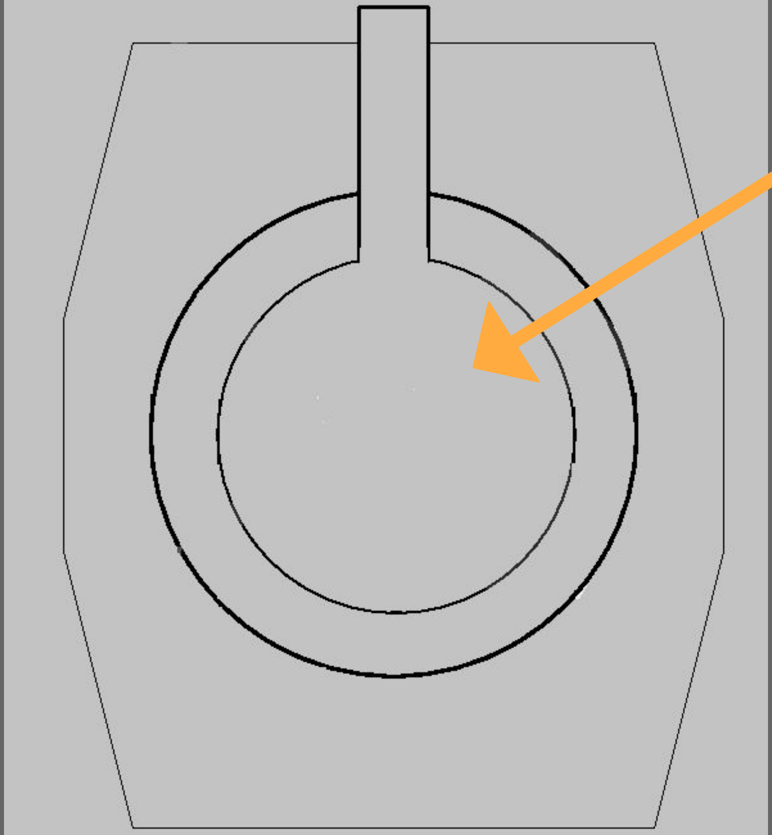
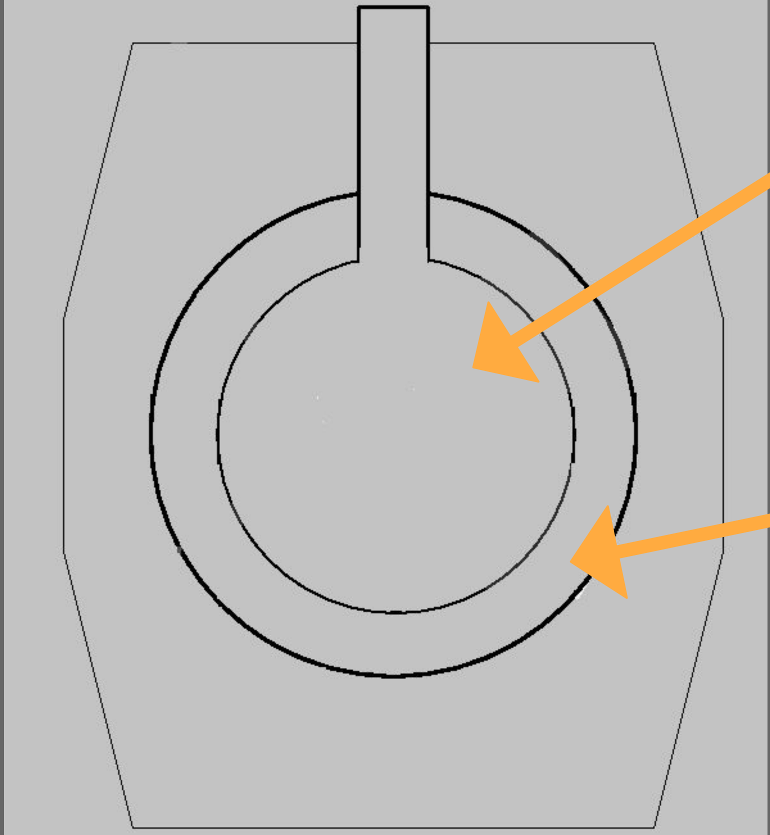


6m radius Acrylic Vessel (AV)

SNO+

- It's BIG!



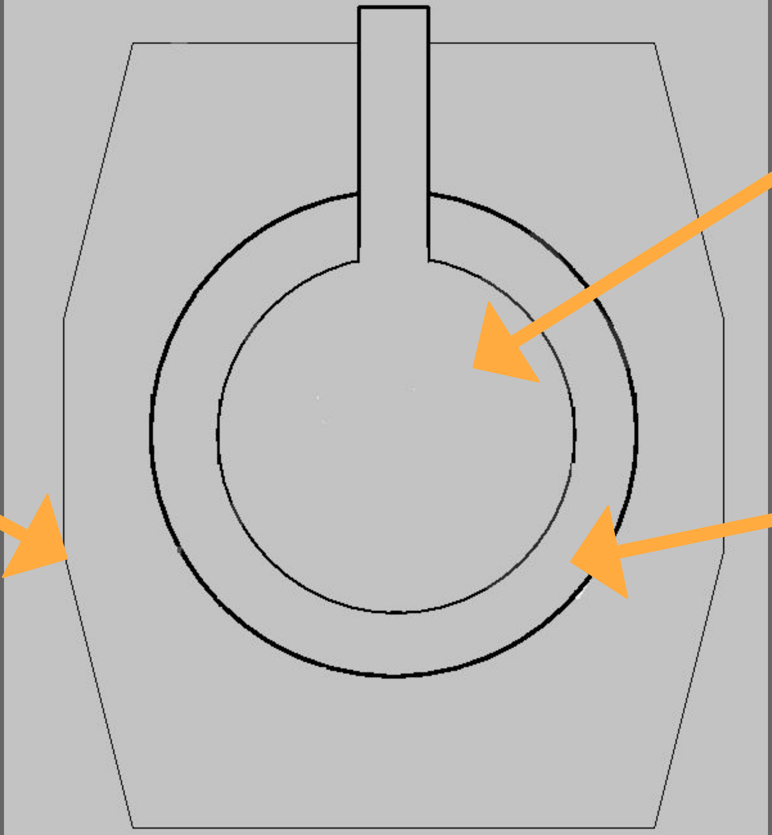
6m radius Acrylic Vessel (AV)

9m radius stainless steel structure (PSUP) Supports ~9600 Photomultiplier tubes (PMTs)

SNO+

- It’s BIG!

85 ft high and 72 ft length cavern



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Supports ~9600 PMTs!

SNO+ Phases and Physics Goals

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1st Phase:
Ultra Pure
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3rd Phase:
Tellurium

SNO+ Phases and Physics Goals

- Neutrinoless Double Beta Decay
- Solar Neutrinos
- Reactor Antineutrinos
- Geo-Neutrinos
- Supernova neutrinos
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Reactor Antineutrino Goals

- Goal: Measure Neutron capture efficiency and time
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↓

Goal: Measure antineutrino signal in SNO+

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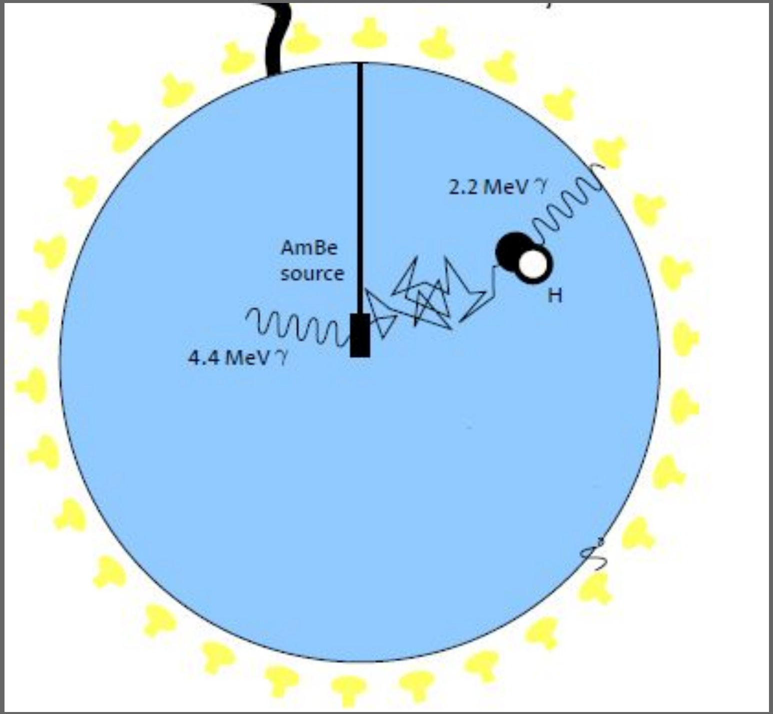
- Goal: Measure Neutron capture efficiency and time
- Goal: Calibrate energy and position reconstruction

To Measure these we used an Americium-Beryllium (AmBe) neutron source

AmBe Source

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



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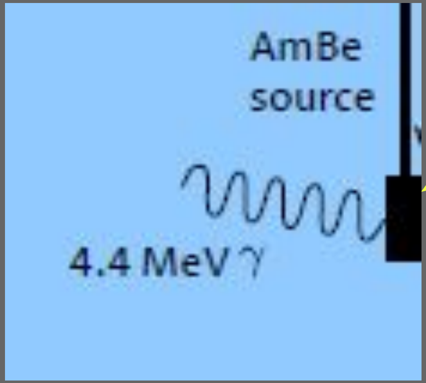
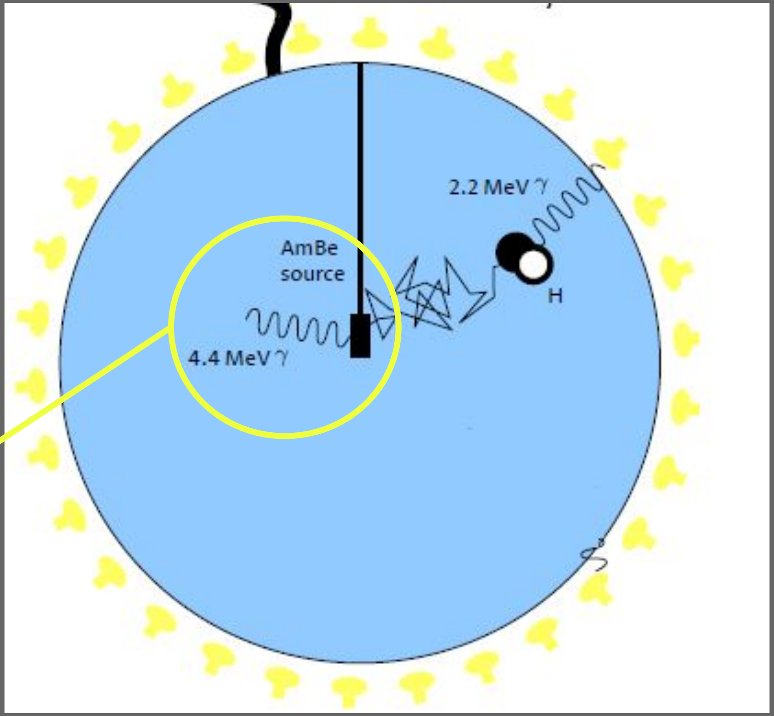
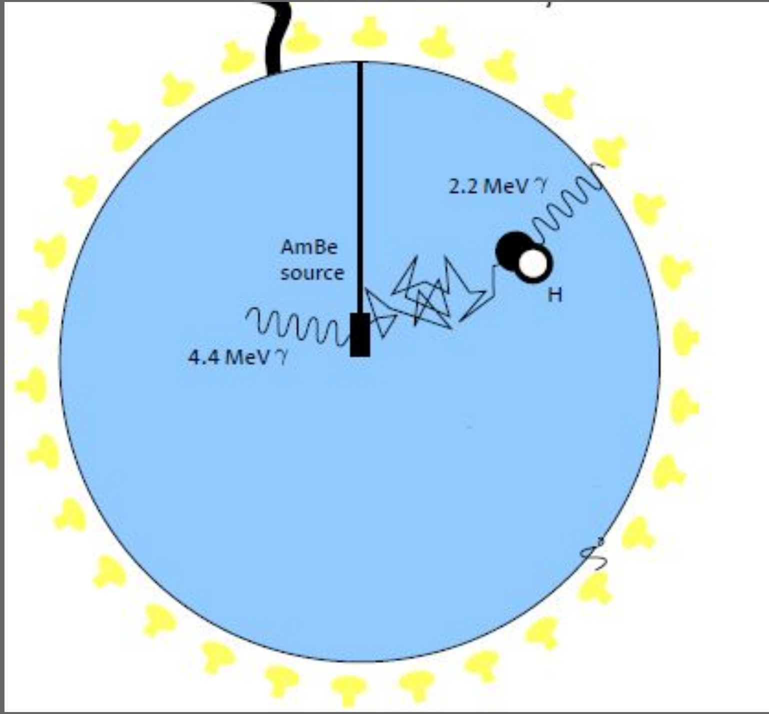




AmBe Source

- Initial neutron from AmBe scatters of a hydrogen atom which produces a 4.4 MeV gamma
- Neutron is then captured in the UPW which produces a secondary 2.2 MeV gamma



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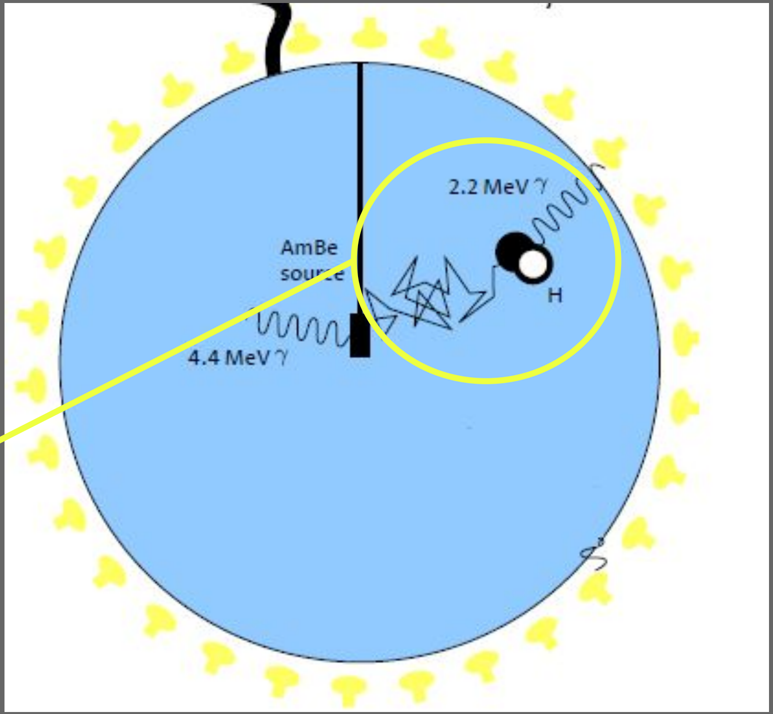

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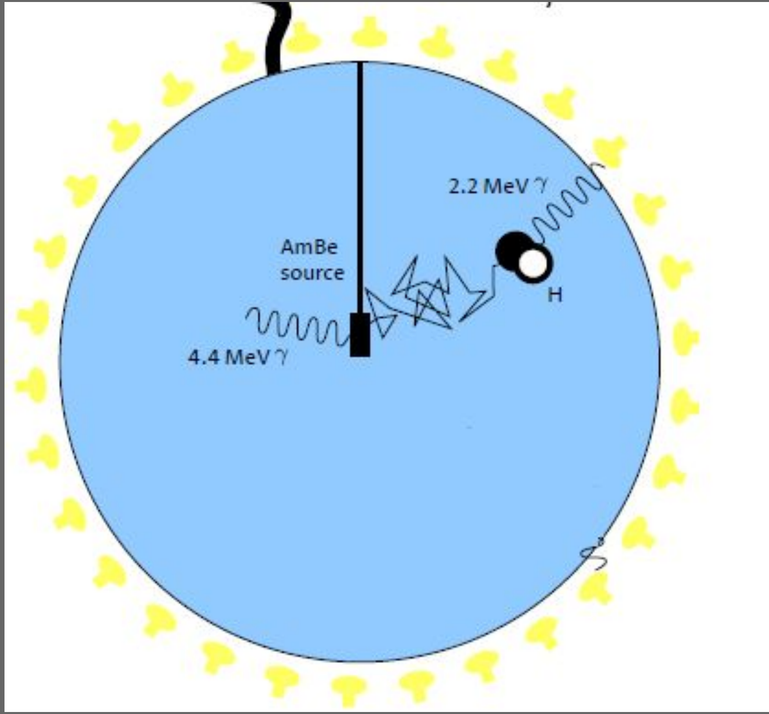

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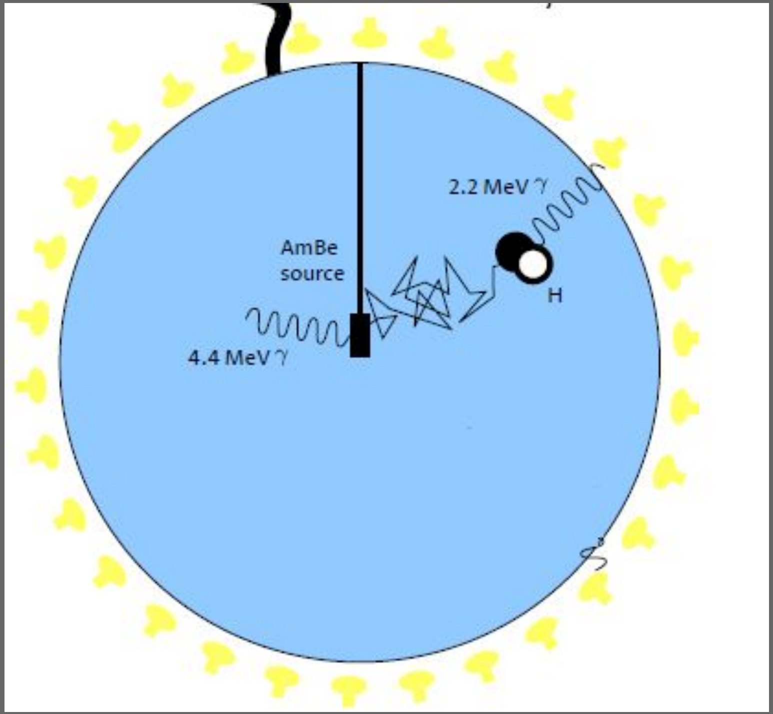
How does this help with our physics goals?

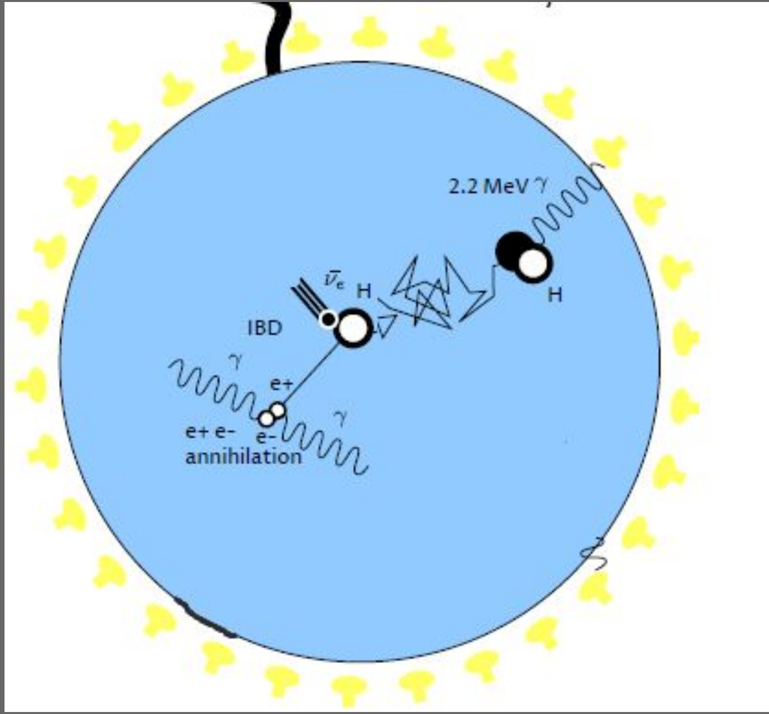


Antineutrino Signal in SNO+

- Measure antineutrino signal

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

- Electron (reactor) antineutrino collides with hydrogen atom and undergoes an inverse beta decay



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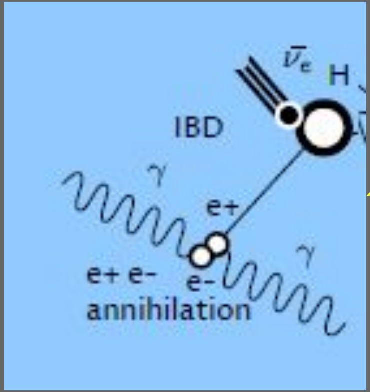

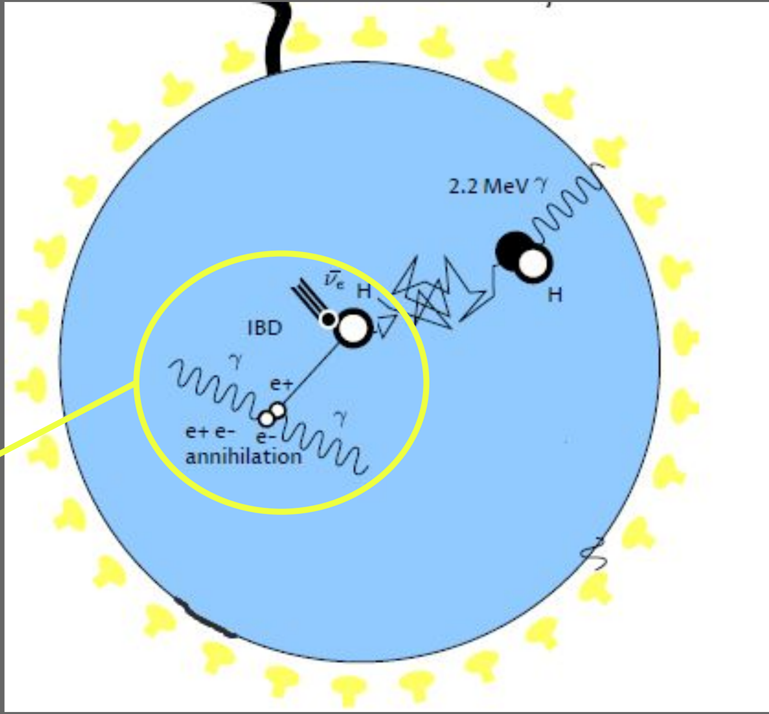

Antineutrino Signal in SNO+

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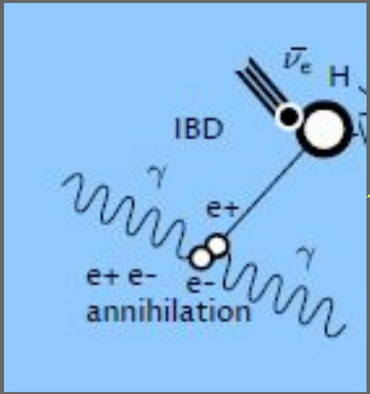
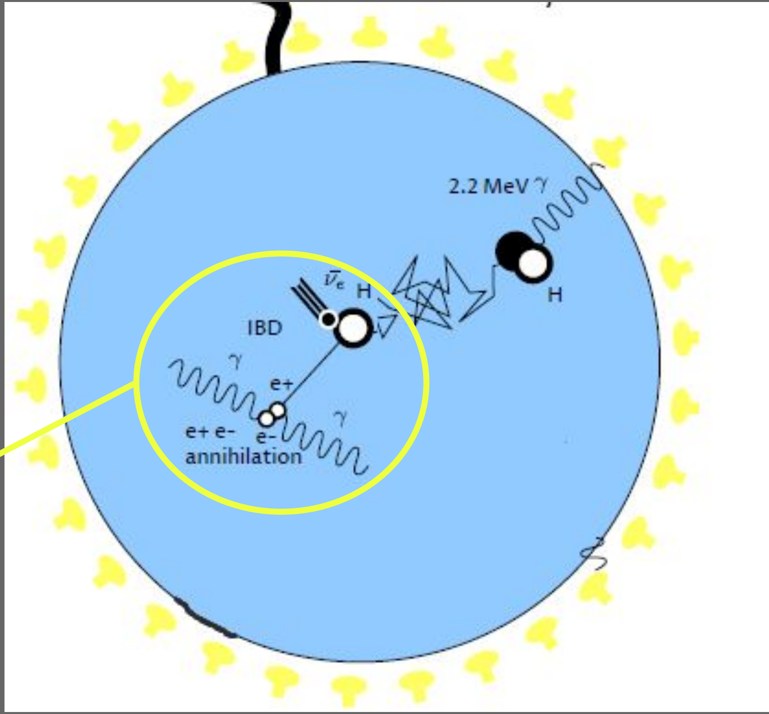
  - Electron (reactor) antineutrino collides with hydrogen atom and undergoes an inverse beta decay

Similar to the prompt event from AmBe!





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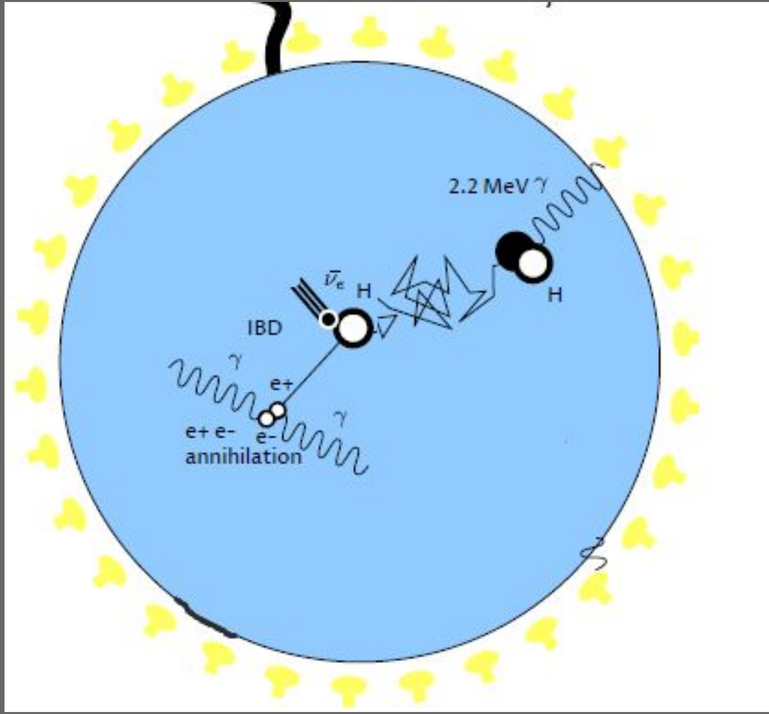

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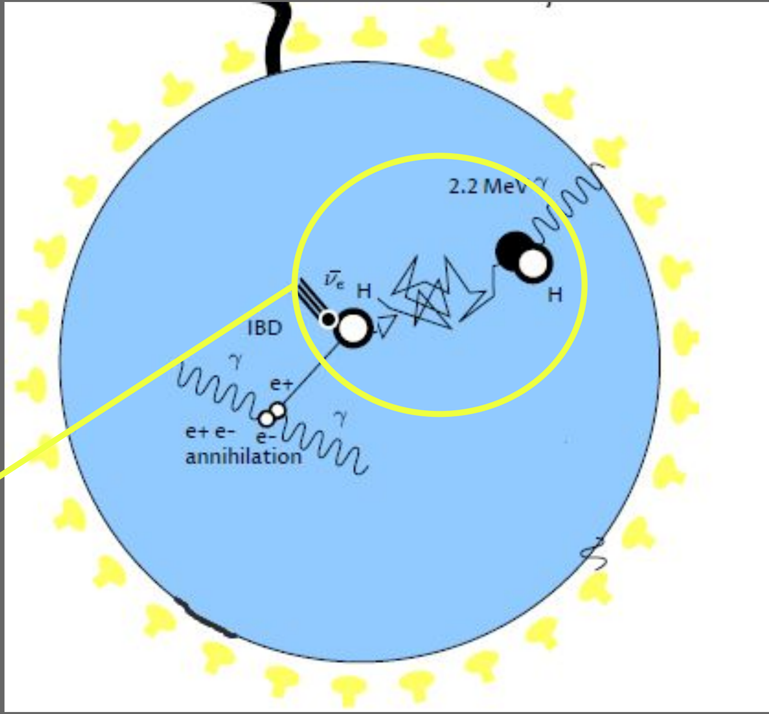

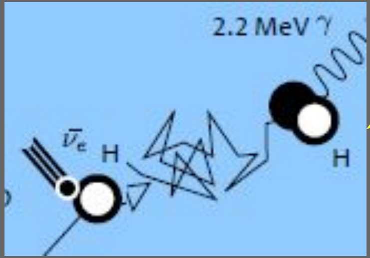

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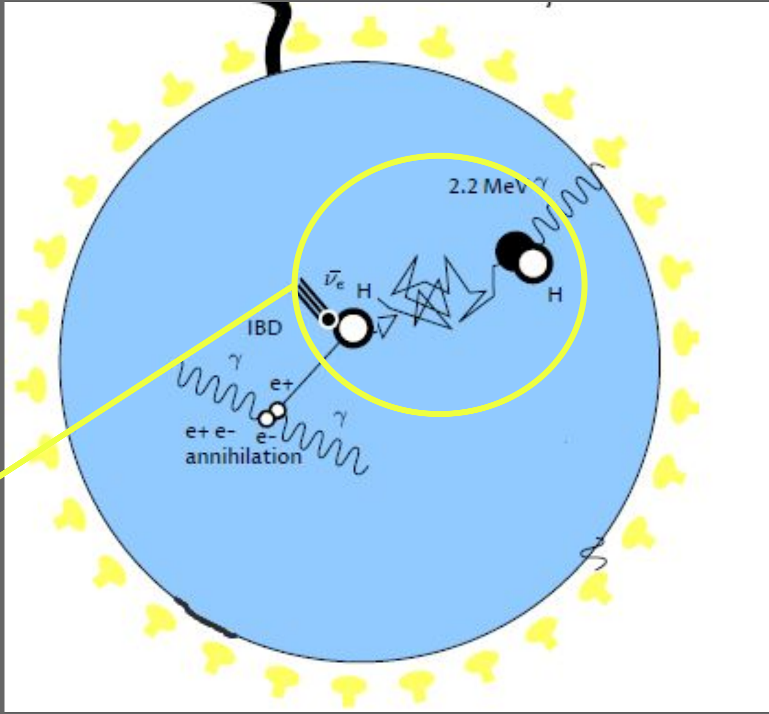
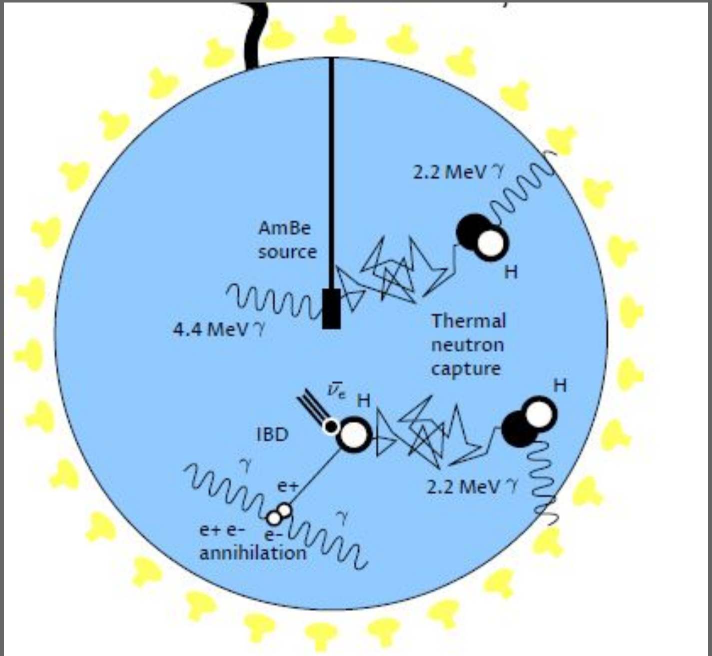


Similar to delayed event from AmBe!

AmBe Source to Measure Antineutrino Signal in SNO+



Identifying AmBe Events

We use two quantities to identify and tag AmBe events:

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Use this to determine 2.2 MeV ɣ or 4.4 MeV ɣ

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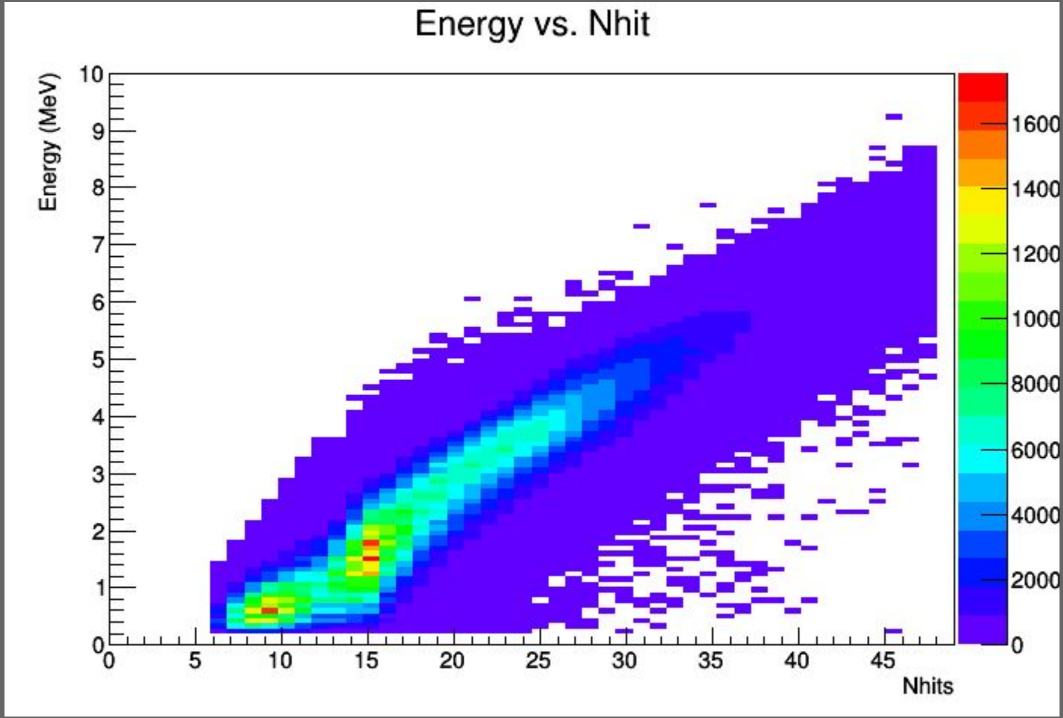

Identifying AmBe Events

We use two quantities to identify and tag AmBe events:

1. Nhit cut
    - ➢ Number of PMTs hit in the detector
    - ➢ Related to the energy
2. Time window cut
    - ➢ Time after the prompt event in which we look for a candidate delayed event

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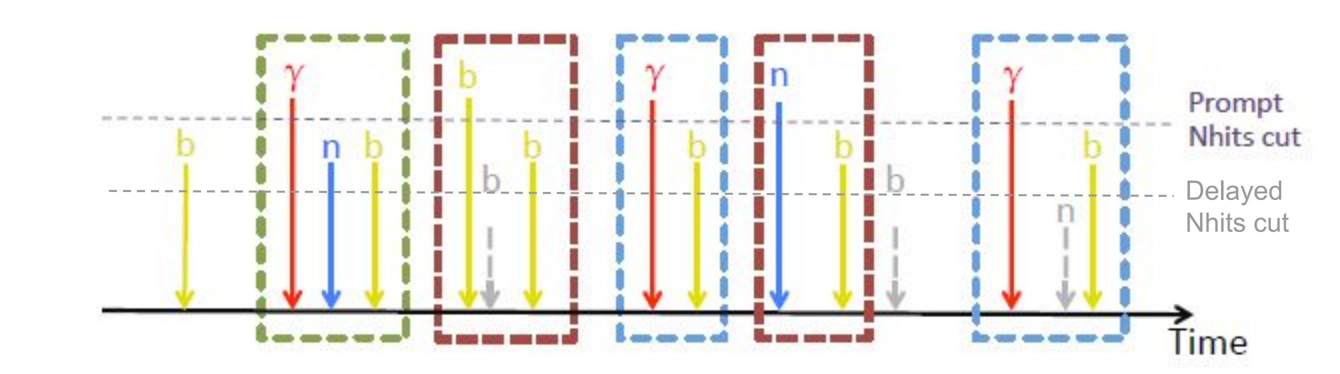
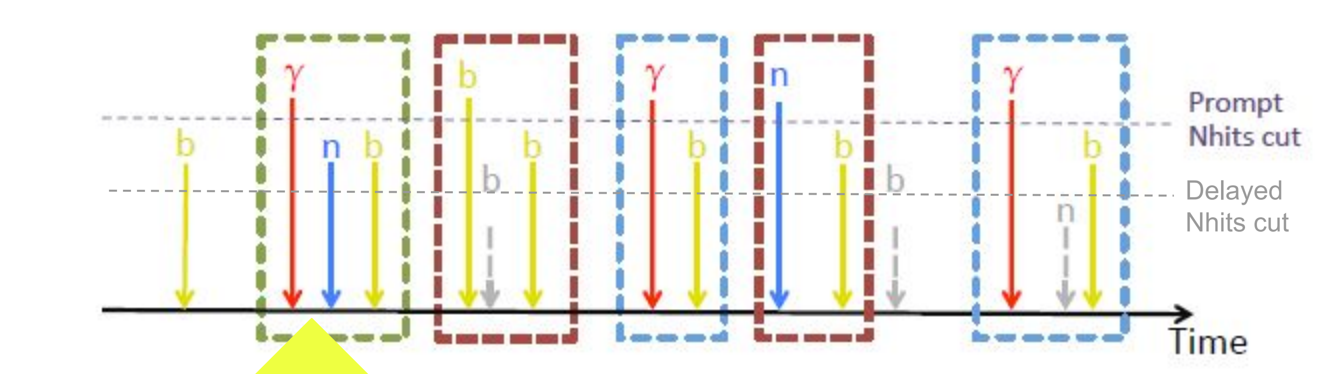
Use this to determine coincident events
This quantity is called Δt

Identifying AmBe Events



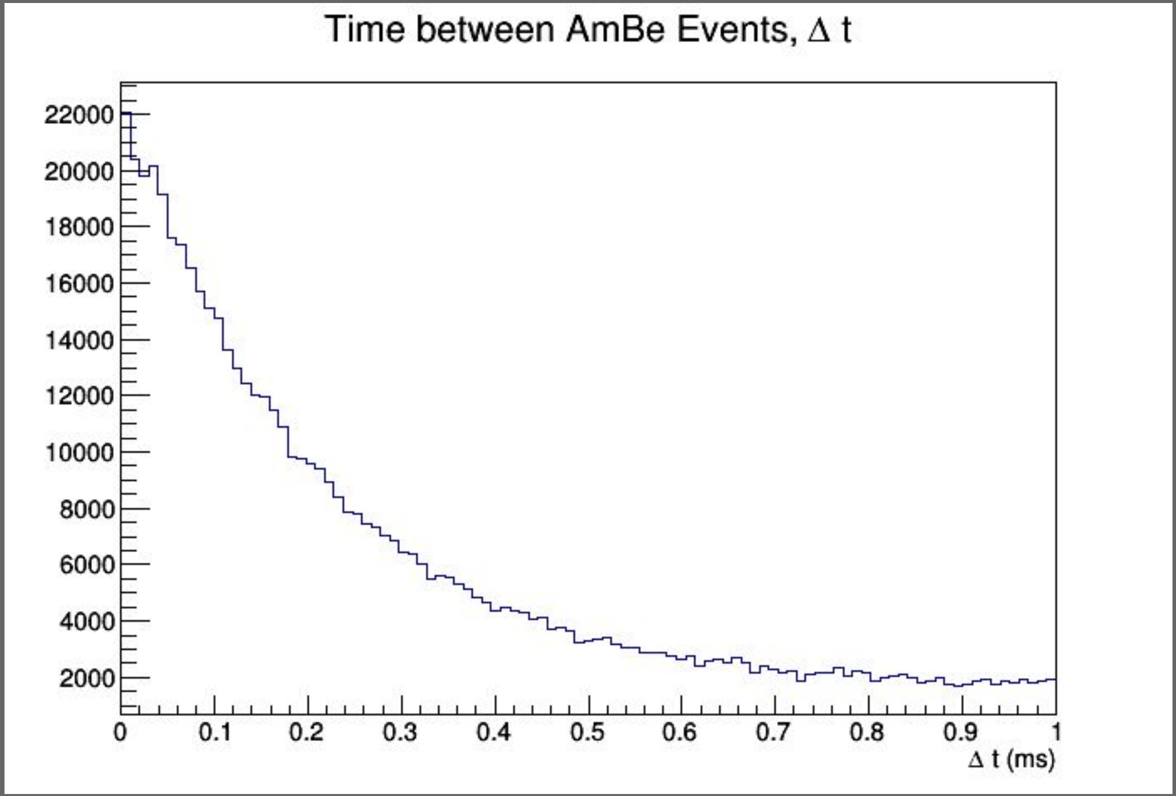
- Events are iterated through. When an event passes the prompt nhit cut, events within a coincident time period are investigated for potential candidate delayed events.

Identifying AmBe Events

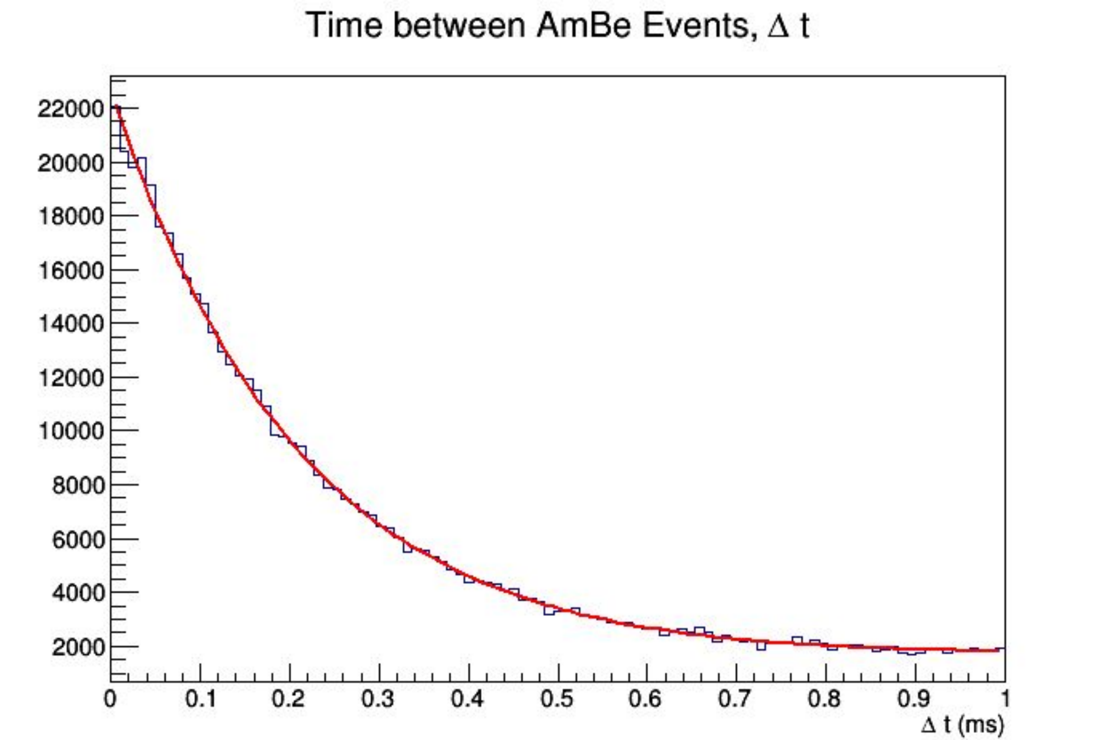


We can plot the time difference between events, Δt

Time between Events Δt



Time between Events Δt

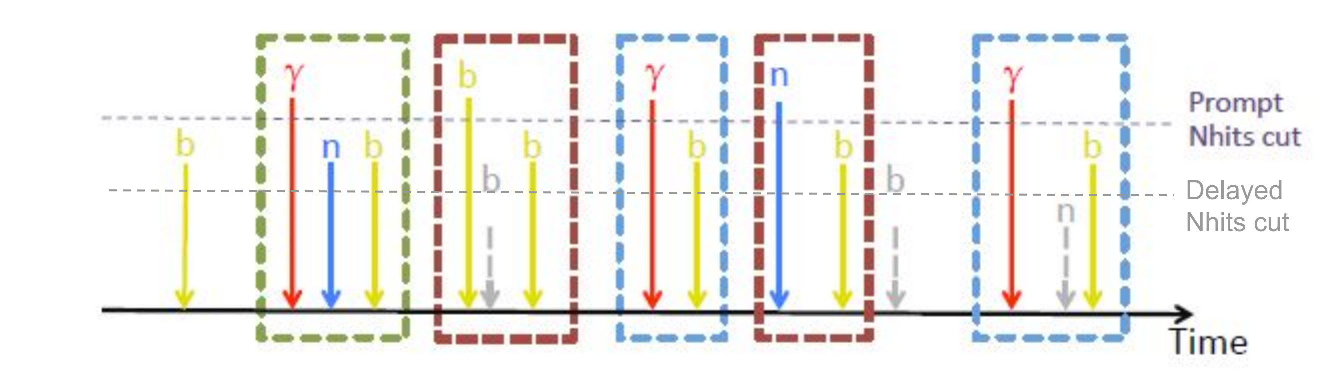


$$F(\mathrm{t}) = N \cdot R_1 (P \cdot E \cdot (\lambda + R_2) e^{-(\lambda + R_2)\mathrm{t}} + (1 - P \cdot E) \cdot R_2 e^{-R_2 \mathrm{t}})$$

Fitting AmBe Events

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

- Each component of the function represents different event scenarios



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N: Normalization (run time x histogram binning)

Fitting AmBe Events

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R1: Rate of single candidate prompt events

Fitting AmBe Events

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P: Probability of selecting a true 4.4 MeV ɣ

E: Neutron (2.2 MeV ɣ) detection efficiency

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P*E (Neutron capture efficiency)
One of our physics goals!

Fitting AmBe Events

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λ: Neutron capture time

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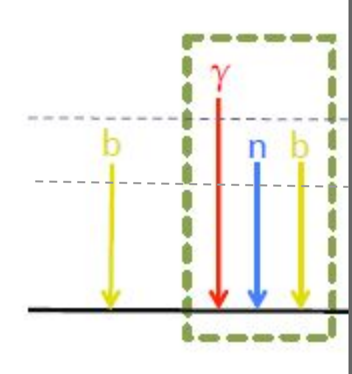
R2: Rate of single candidate delayed events

Fitting AmBe Events



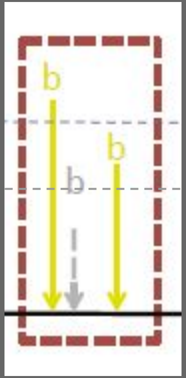
True-True Event:

- The prompt event is the 4.4 MeV ɣ
- The delayed event is the 2.2 MeV ɣ

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

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

Fitting AmBe Events



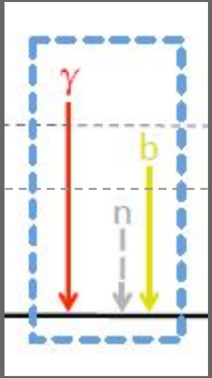
Fake-Fake Event:

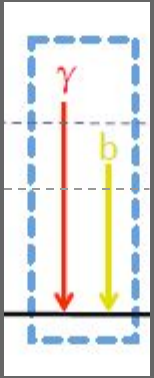
- The prompt event is background
- The delayed event is background

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

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

Fitting AmBe Events





True-Fake Event:

- The prompt event is the 4.4 MeV γ
- The delayed event is background

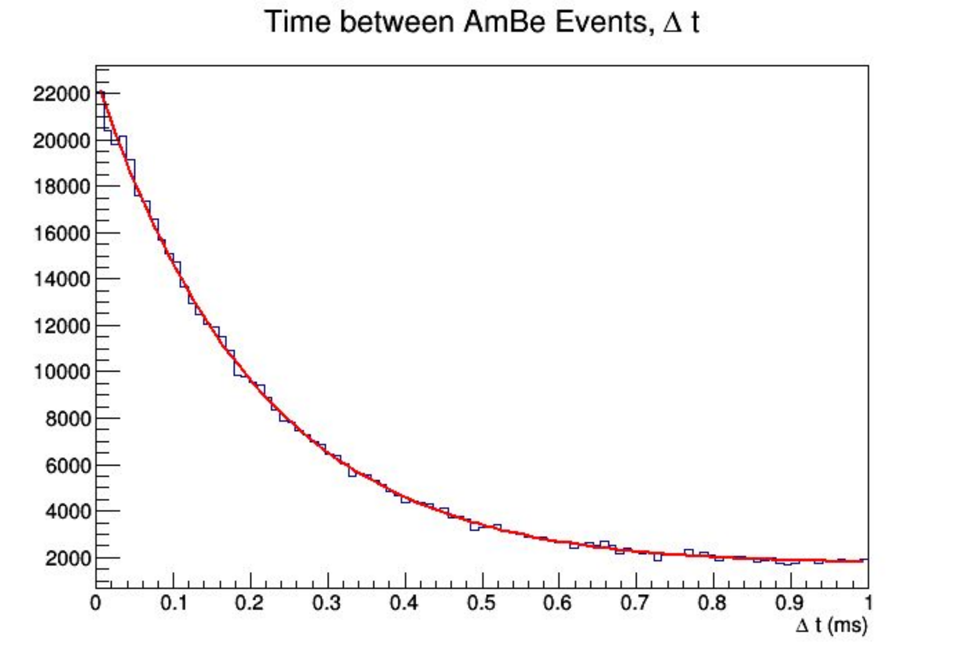
$$P \cdot E \cdot R_2 e^{-(R_2+\lambda)\mathrm{t}}$$

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

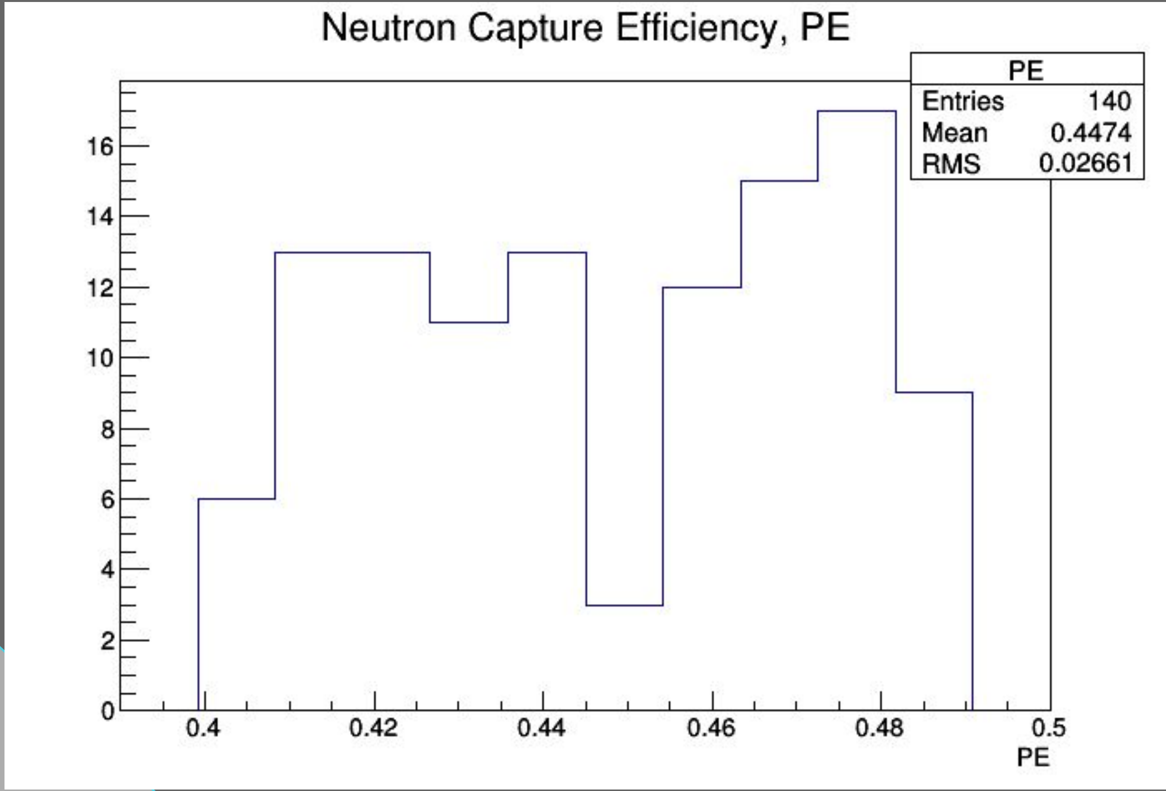
Neutron Capture Efficiency

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

- We use the fit function to solve for the P*E

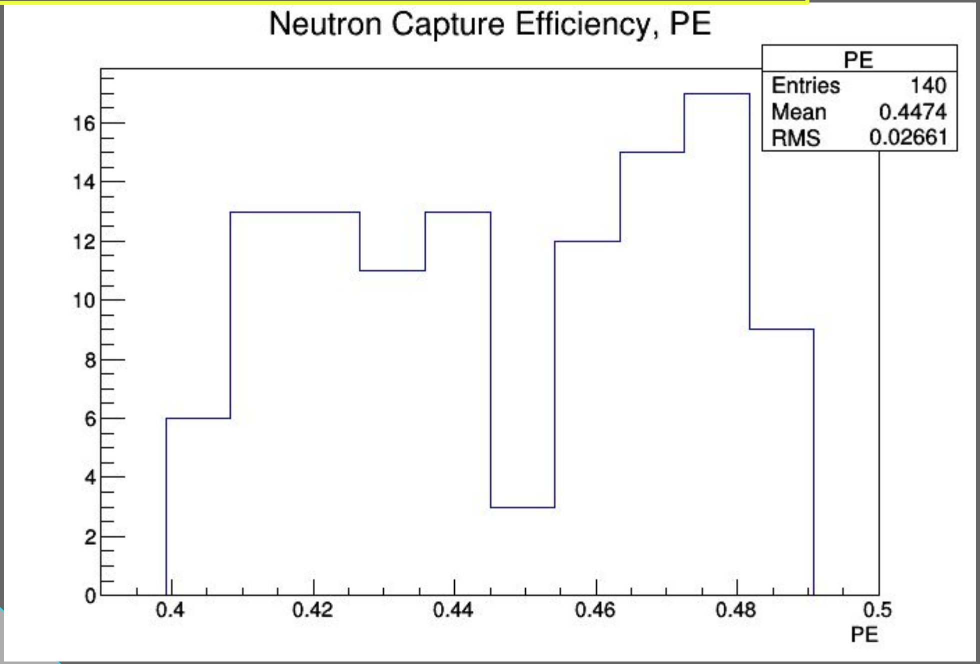


Neutron Capture Efficiency



Neutron Capture Efficiency

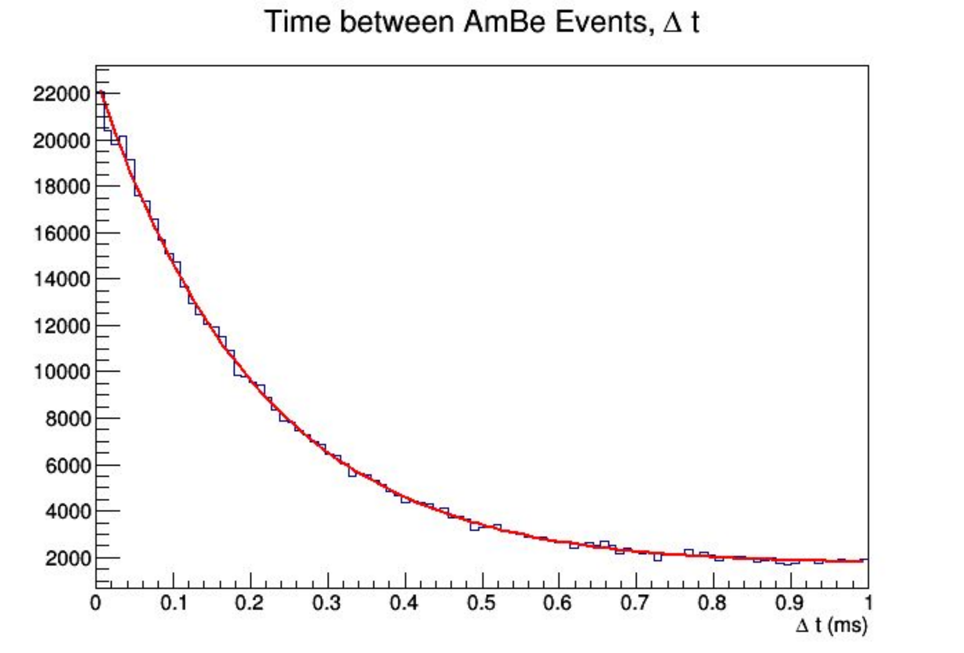
~45% Neutron Capture Efficiency



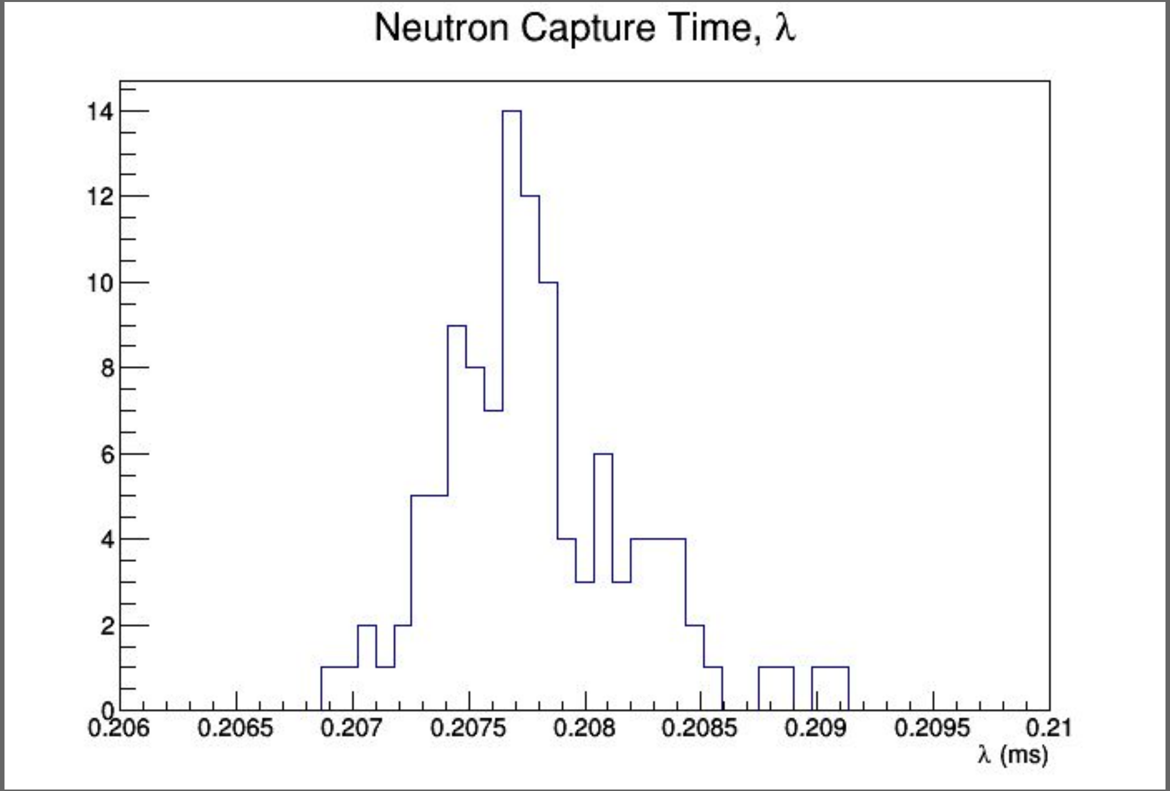
Neutron Capture Time

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

- We use the fit function to solve for the λ (neutron capture time)

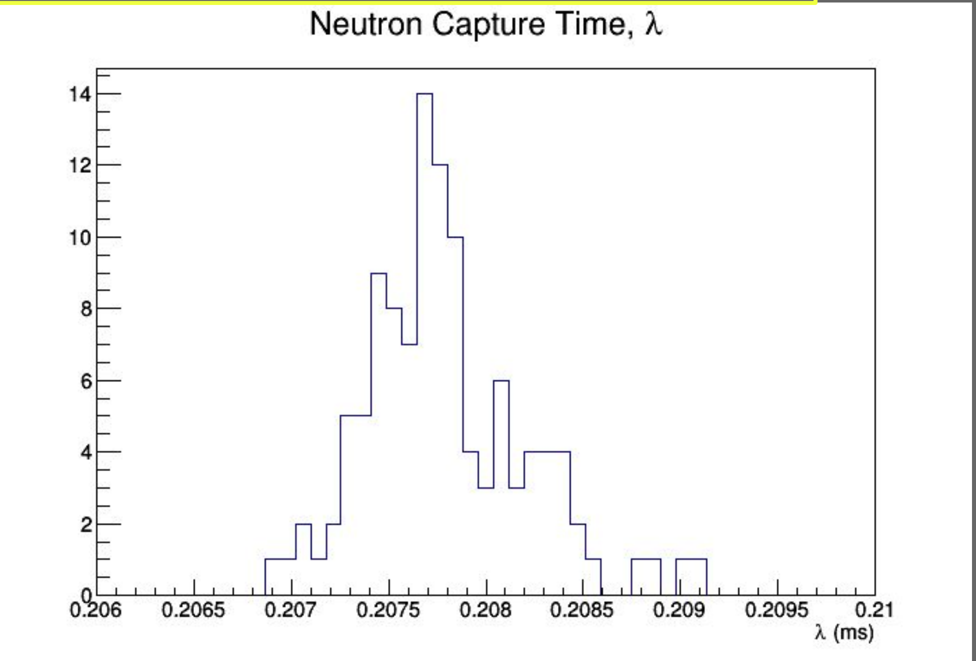


Neutron Capture Time, λ



Neutron Capture Time, λ

~207.8 μs Neutron Capture Time



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Currently working towards this analysis

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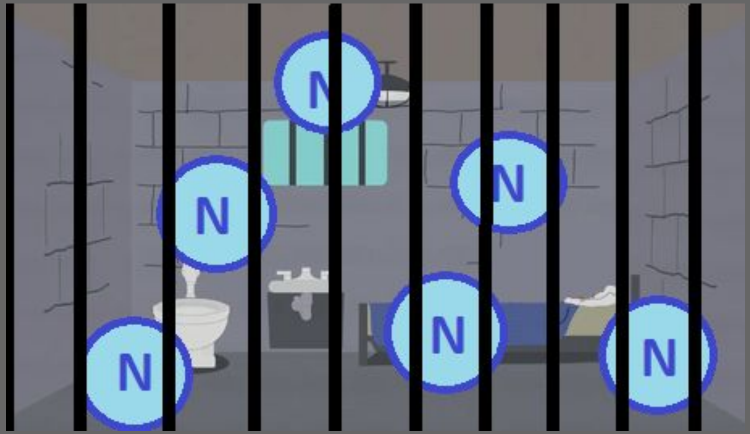
Goal: Measure antineutrino signal in SNO+

Conclusion

- Able to use AmBe source to measure neutron capture efficiency and time

Conclusion

~45% Neutron Capture Efficiency



- Achieved the highest neutron capture efficiency in a pure water Cherenkov detector
- Able to trigger on low energy events thanks to the size and sensitivity of SNO+

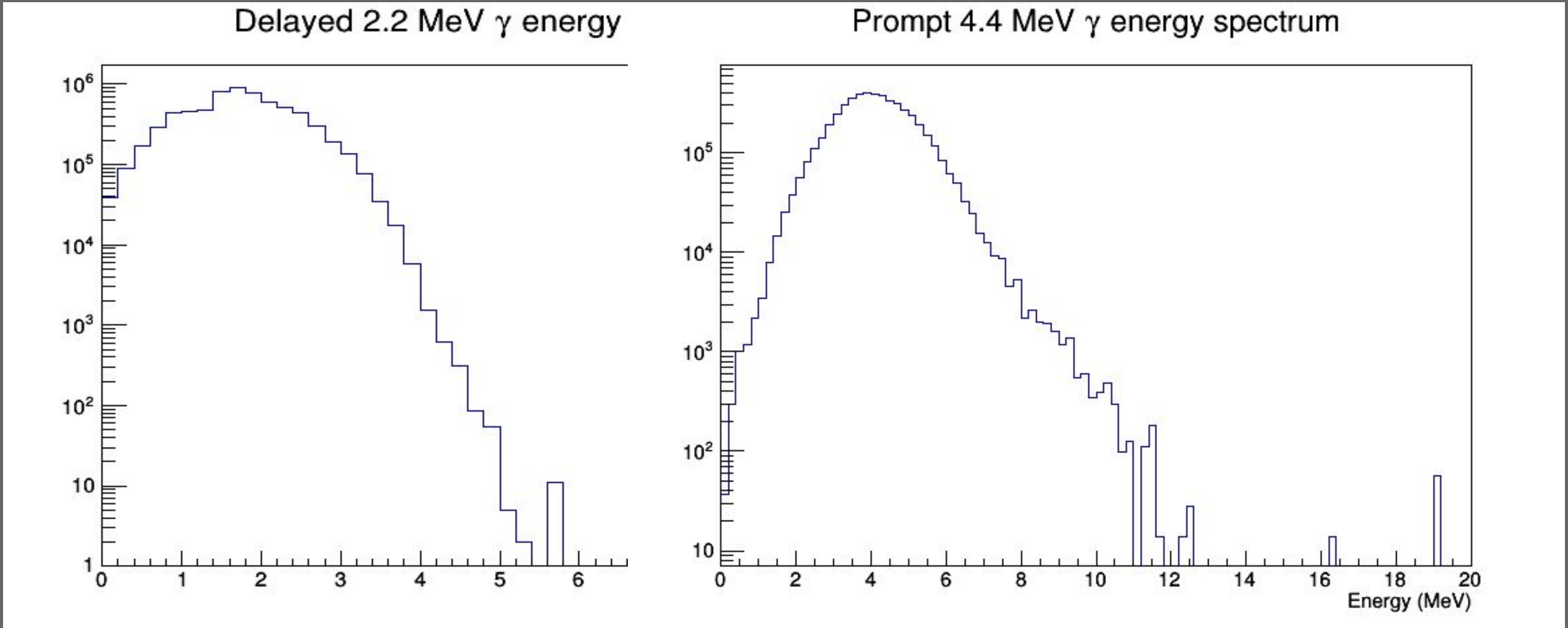
Thank you!

- Come check out my poster and say hi!

Additional Slides

- Goal: Calibrate energy and position reconstruction

Energy Distribution



Position Reconstruction