# BACKGROUND CHARACTERISATION FOR WATER AND SCINTILLATOR PHASES OF SNO+


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# INTRODUCTION

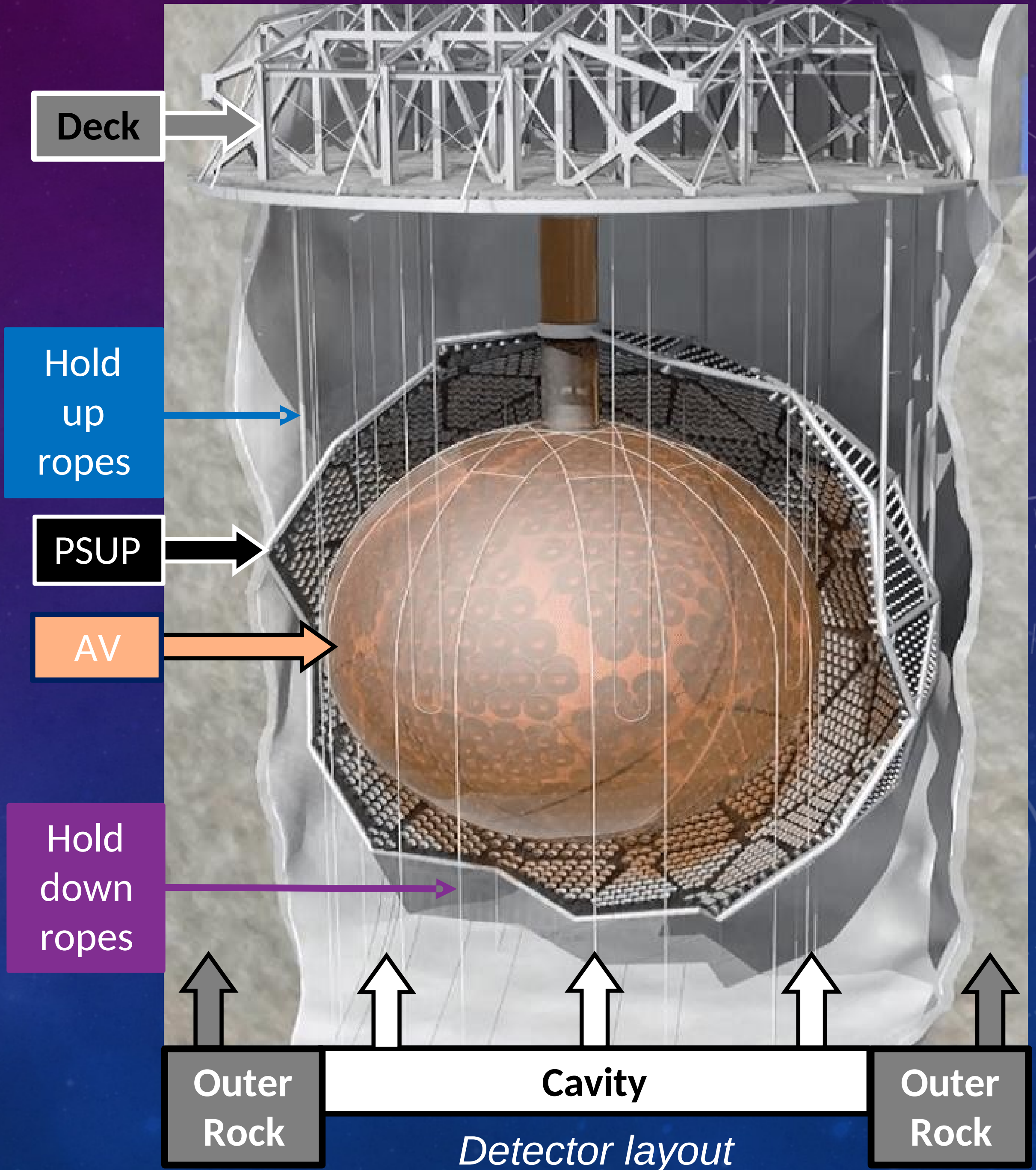
During this talk, I will cover:

- SNO+ general overview
- Analysis timeline
- Water phase analysis
- Scintillator phase analysis

*Dawning of the day at SNOLAB*

# SNO+ OVERVIEW

- SNO+ is a neutrino detector based 2km underground
  - Low backgrounds ~65 muons each day
- Upgraded from SNO (Nobel prize winning) experiment
- Main scientific goal:
  - **Neutrinoless double beta decay (0νββ)**
- Several scientific goals, including:
  - Supernova & Solar neutrino observations
  - Invisible nucleon decay (ND) studies
  - Antineutrino studies
- Three phases to SNO+:
  - Water Cherenkov – 900 tonnes of Ultra Pure Water (UPW)
    ~ 2 years of data taken (May 2017 – July 2019)
  - Pure Liquid Scintillator – 780 tonnes of LAB + Fluor PPO (LS)
    Detector currently almost half full (364 tonnes of LS)
  - Tellurium Doped Liquid Scintillator – additional 3.9 tonnes of $^{130}$Te
    5 years of predicted data taking




*Detector layout*

# PHD TIMELINE

**Year 1**
*Day-by-day monitoring of Radon levels within the detector*

*Development of tools for Radon monitoring*

**Year 2 (Current)**
*Reanalysis of Radon levels with reprocessed data (i.e. improved water and acrylic optics)*

*Analysis of AlphaN in scintillator during filling*

*Development of AlphaN analysis code*

*Extrapolate data analysis cuts for application during Pure Liquid Scintillator stage*

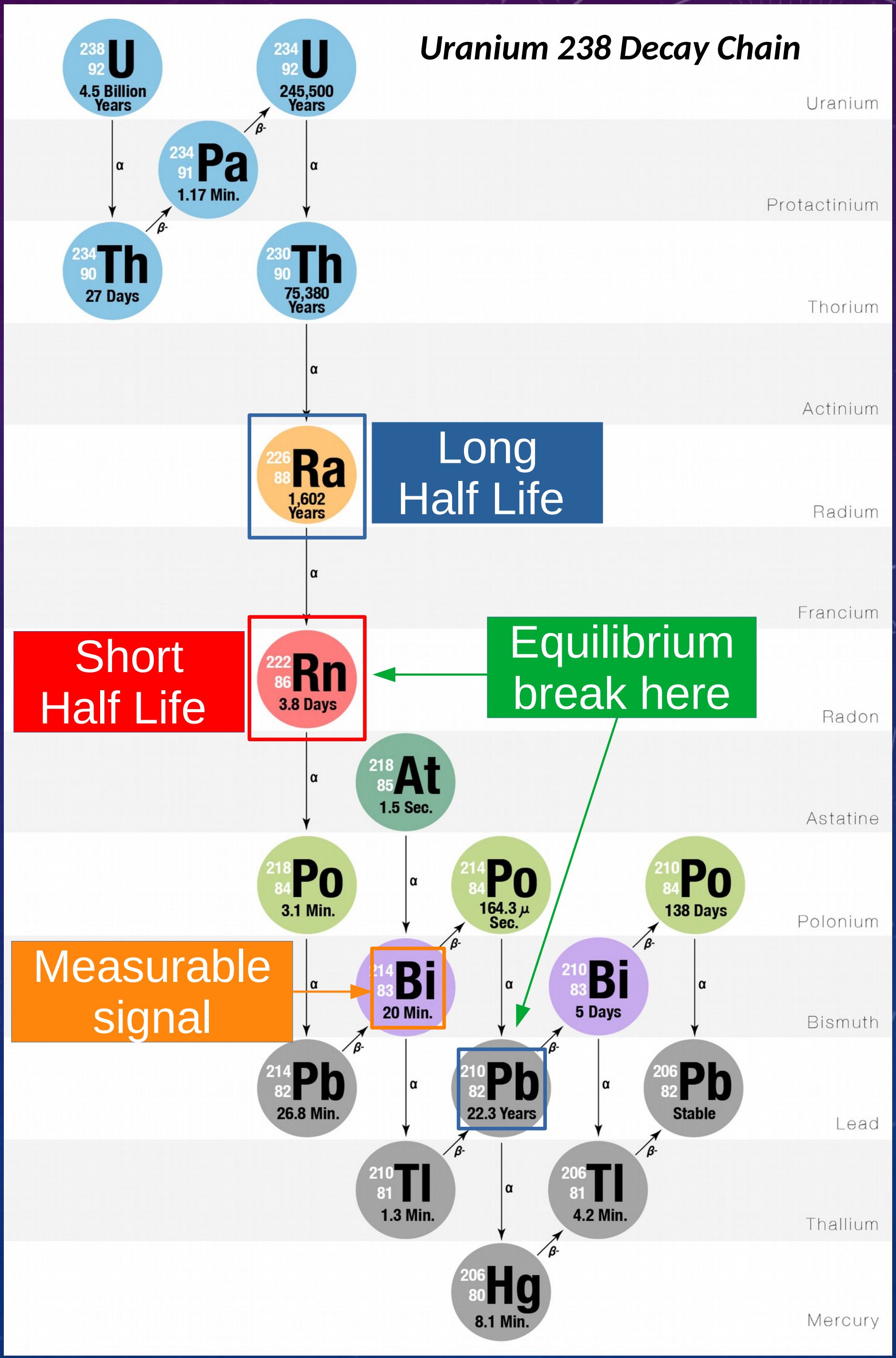
**Year 3**
*Continued AlphaN analysis for Pure Liquid Scintillator*

*AlphaN analysis during Tellurium Loaded stage*

*Neutrino signal analysis for Pure Liquid Scintillator and Tellurium Loaded stages*

# RADON ANALYSIS CONTEXT

- Natural Radon gas present in mine air (130 Bq/m$^3$ at SNOLAB)
- Ingress breaks the secular equilibrium of Thorium 232 & Uranium 238 decay chains ($^{238}$U is more significant)
- Radon 222's daughters are a background for Nucleon Decay and Solar Neutrino studies
  - Cherenkov detectors not sensitive to α radiation
  - Beta radiation of Bismuth 214 is a dominant background
- Bismuth 214 used as a proxy to calculate Radon levels in detector



# DAY BY DAY RADON MONITORING TECHNIQUE

***Algorithm Analysis***

Data cleaning cuts applied:
exclude instrumental noises

Energy and position values used
to reconstruct events

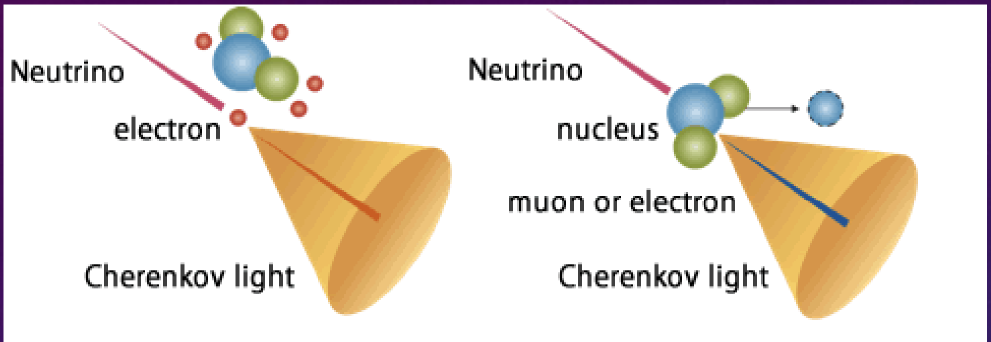
Isotropy cut applied:
Cherenkov signal is anisotropic

ITR cuts applied:
$\hat{U}.\hat{R}$
Exclude events with broad timing
distributions

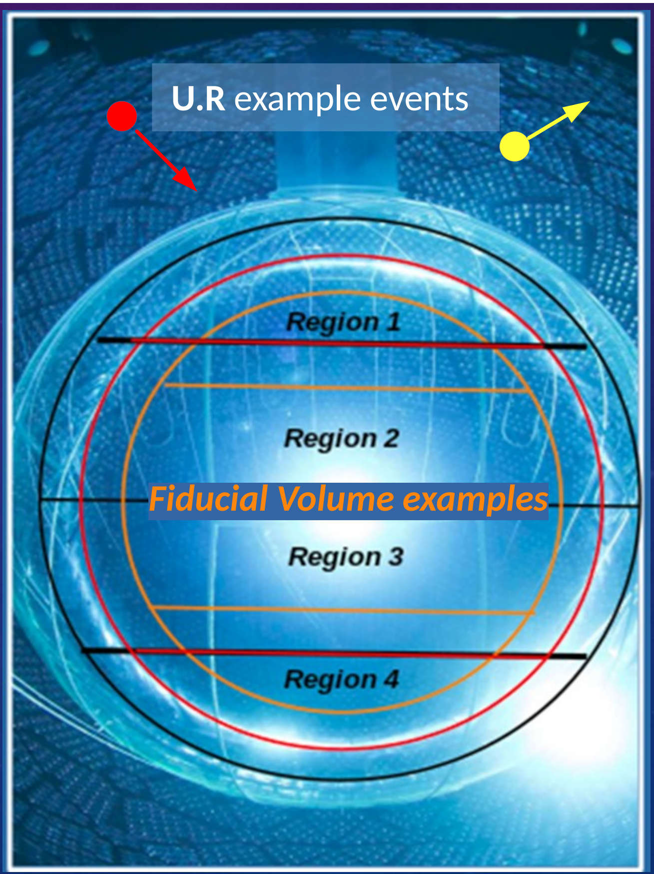
Energy cuts applied:
Exclude events below 3.5 MeV

Fiducial Volume cuts applied:
Reduce backgrounds from regions
other than analysed volume

**U.R** cuts applied:
[External data only]
Red Rejected, Yellow Accepted




*Anisotropy of Cherenkov Radiation*




***Post Algorithm Analysis***

Compared data with
Monte Carlo
simulations for
Bismuth 214 in water

Data plotted
as concentration
(g/g)
[or event density/s]
against time

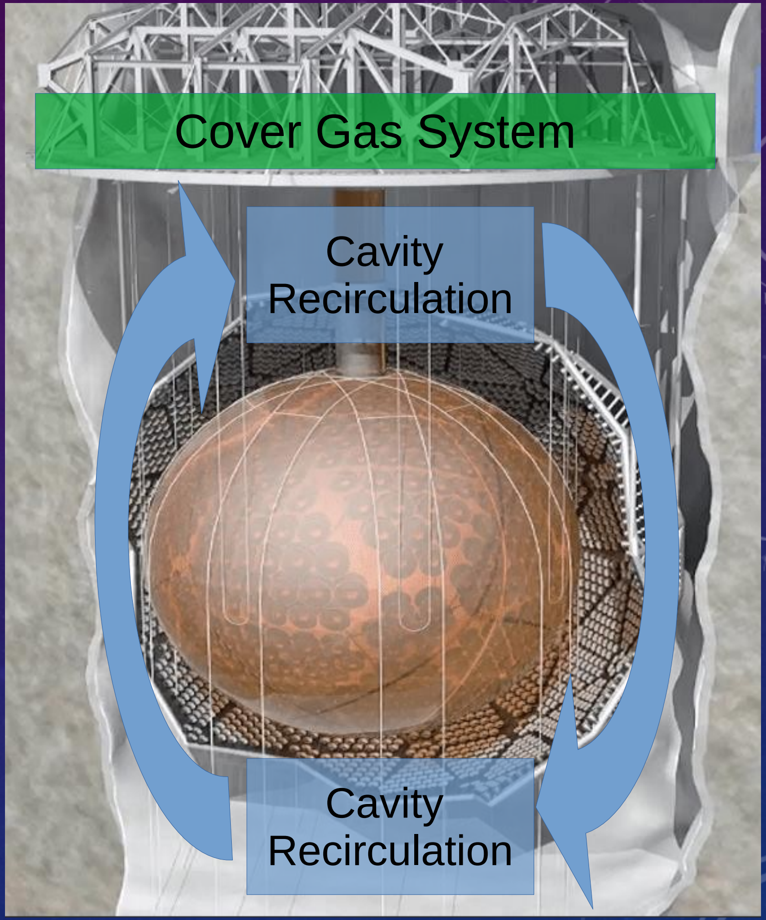
Cross checked levels
with local Radon
monitor

Report data weekly
(or immediately if
any significant
deviations occurred)

# RADON INGRESS PREVENTION

- Prevention systems implemented:
  - Cavity Circulation (external water)
  - Cover Gas System (above detector neck)
  - Day by day monitoring (**My previous work**)

- SNO+ detector was initially open to air
  - Nitrogen Cover Gas (CG) system installed (October 2018)
  - Approximately 190 days of UPW data
  - Concentration of Bismuth ~10 times lower on average after cover gas installed
- Day by day monitoring of Bismuth 214 concentration
  - Real time results –> quick corrective action




| | $gU/gH_2O$ | $gTh/gH_2O$ |
|---|---|---|
| Dataset I | $(3.6 \pm 0.9^{+1.0}_{-0.7}) \times 10^{-14}$ | $< 1.3 \times 10^{-14}$(95%CL) |
| Dataset II | $(3.2 \pm 0.7^{+1.1}_{-0.9}) \times 10^{-15}$ | $< 1.1 \times 10^{-15}$(95%CL) |

*Comparison between the BEST portion of **dataset I**, and the entirety of **dataset II**.*

"Nucleon Decay Neutrino Poster", Morgan Askins [Neutrino 2020 conference, 22/06/20 - 02/07/20]

# ALPHA-N PROCESSES

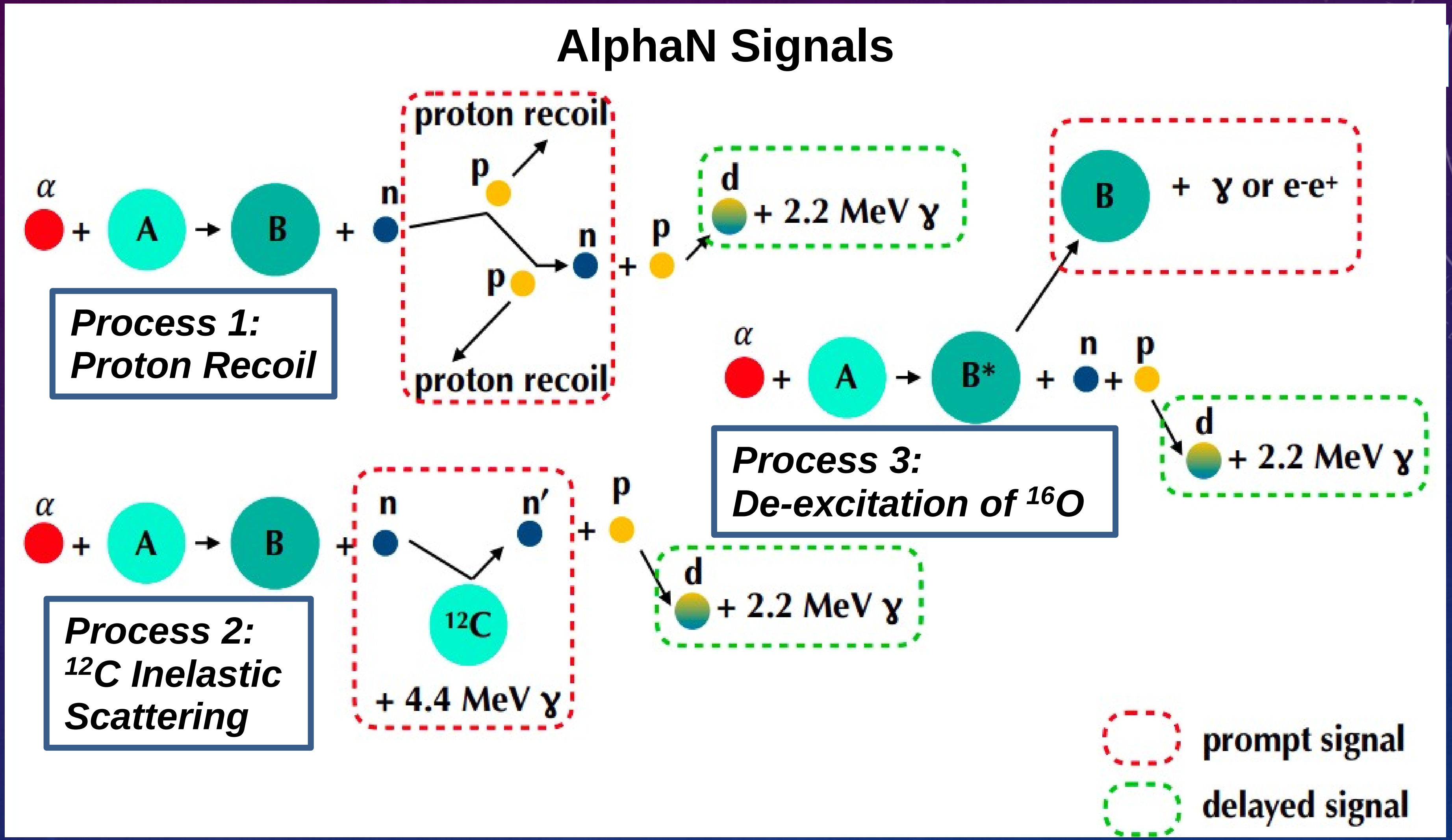
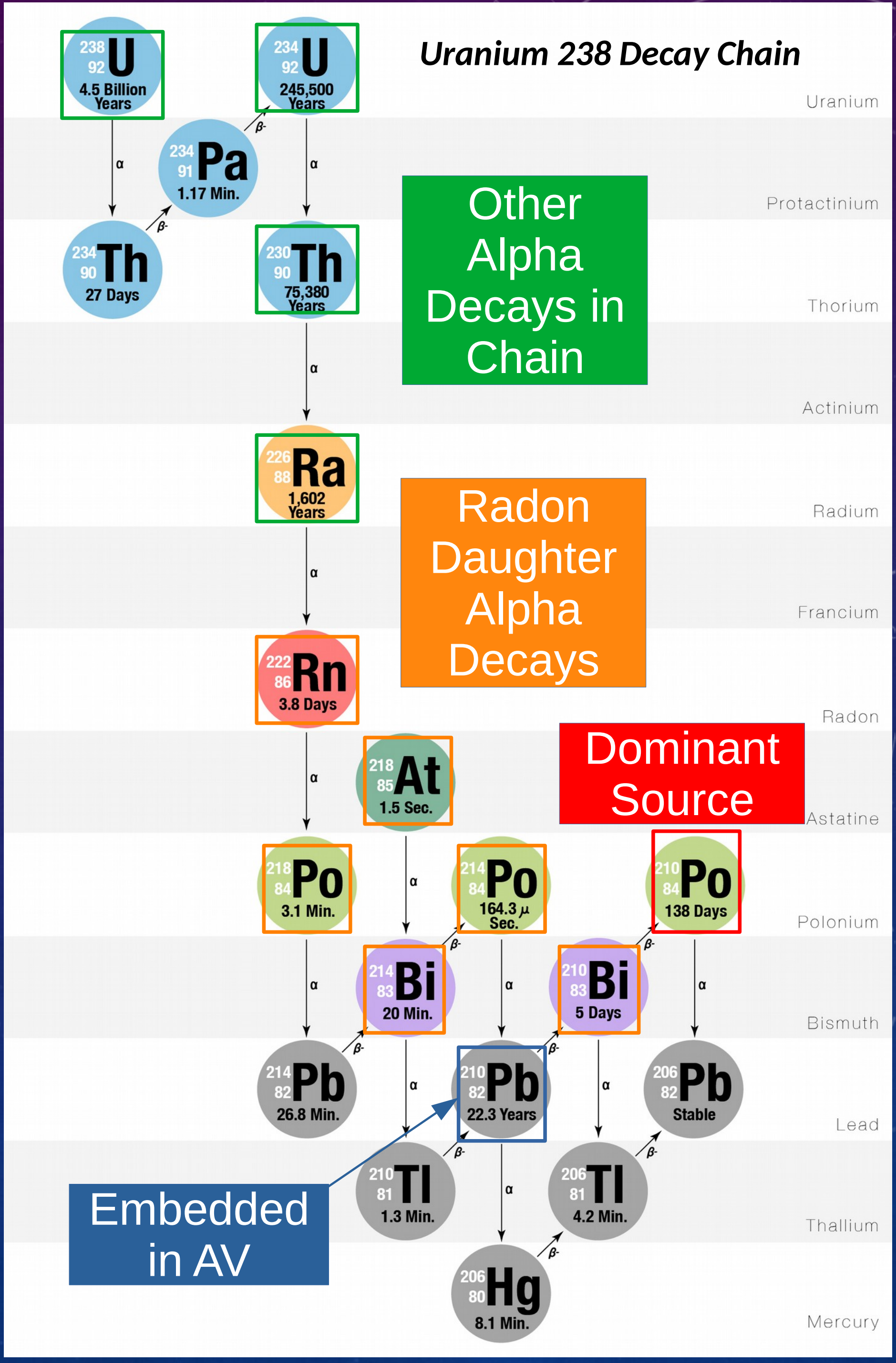



Figure adapted from Dr Valentina Lozza's "($\alpha$,n) events in SNO+" talk
[($\alpha$,n) yield in low backgrounds conference, 21-22 /11/19]

# ALPHAN DECAY SOURCES

- All Alpha decays in detector contribute to AlphaN background
- Radon Daughters are a more prominent source of alpha particles in LAB
  - Particularly Polonium 210
- Alpha sources:
  - Inherent in scintillator and introduced during filling
  - Introduced through Radon ingress
  - Radon daughters in the AV
- Lead 210 embedded within the AV's surface when detector was open/exposed for maintenance
  - A source of AlphaN events on AV surface



# ALPHA-N AS A BACKGROUND

- AlphaN reactions act as a background for multiple SNO+ studies:

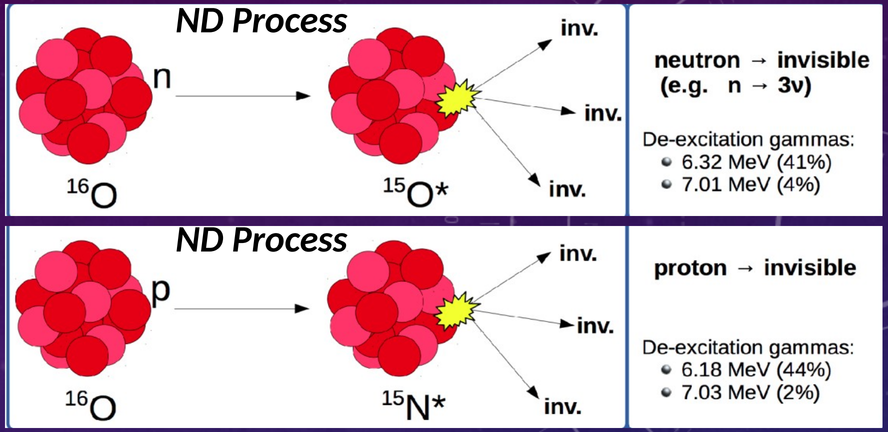
  Invisible Nucleon Decay (ND) analysis -
  - High energy gammas from $^{16}O$ de-excitation can fall into Regions of Interest (ROI) for $^{15}O^*$ and $^{15}N^*$ decay modes

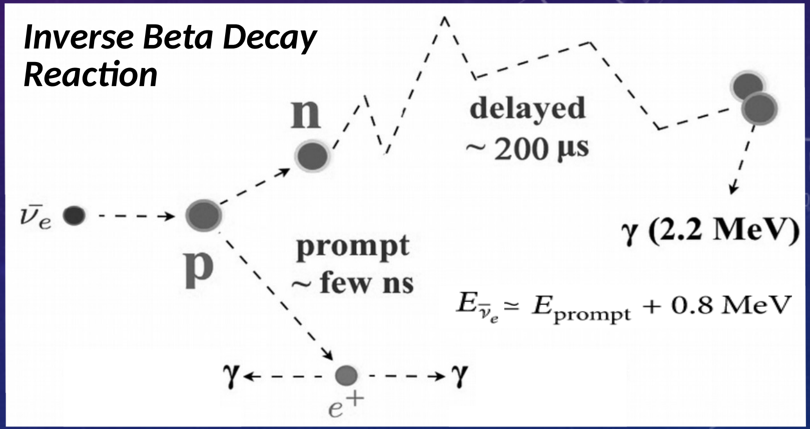
- Antineutrino analysis -
  - Reactor and geoneutrinos produce Inverse Beta Decay (IBD) signals
  - AlphaN signals replicate prompt – delay IBD signals

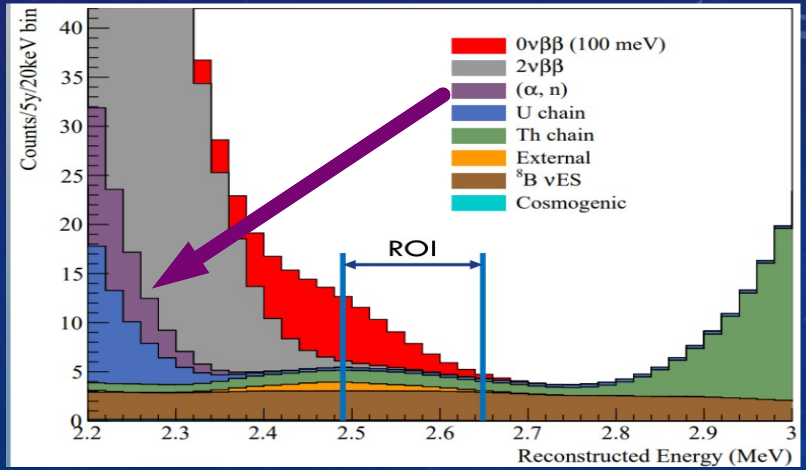
- Neutrinoless double beta decay analysis -
  - Proton recoil and neutron capture signals can fall within the ROI for 0νββ

→ ***Essential to tag and discriminate against this background***

*V. Fisher, CIPANP 2018 - Phys. Rev. C 48, 1442*




*Predicted neutrinoless double beta decay and background signals**

**AlphaN rejection already applied to plot*

# ALPHAN EXPECTATION VALUE WITHIN DETECTOR BULK

- An expectation value of AlphaN events can be calculated using the following equation:

$$N_{all}^{\alpha,n} = R_{Po210} \cdot A_{\alpha,n} \cdot t$$

*Where: $R_{Po210}$ is the rate of Polonium 210 within the scintillator*

*Po210 has a clear and measurable signal with detector*

*$A_{\alpha,n}$ is the thick target neutron yield (in medium)*

*t is the total period of analysed data*

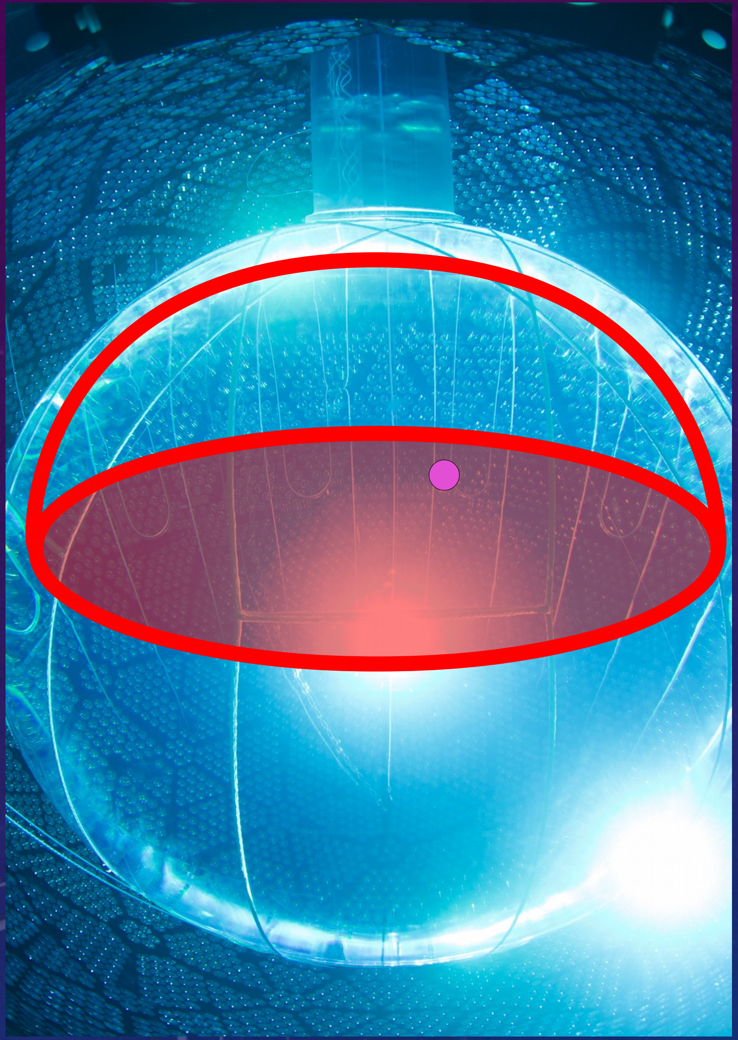
- This expectation value can then be compared with the observed coincidence values
- A number of potential AlphaN events have been observed in the current analysis
  - ➢ Need to identify whether these are potential background, antineutrino or true AlphaN signals
- A sideband background study was performed:
  - ➢ No events observed in study suggesting exclusion of potential backgrounds
- AlphaN studies will soon be expanded to investigate AV surface event

# AlphaN Coincidence Tagging Technique

**Delay Event**

**Fiducial volume cut**

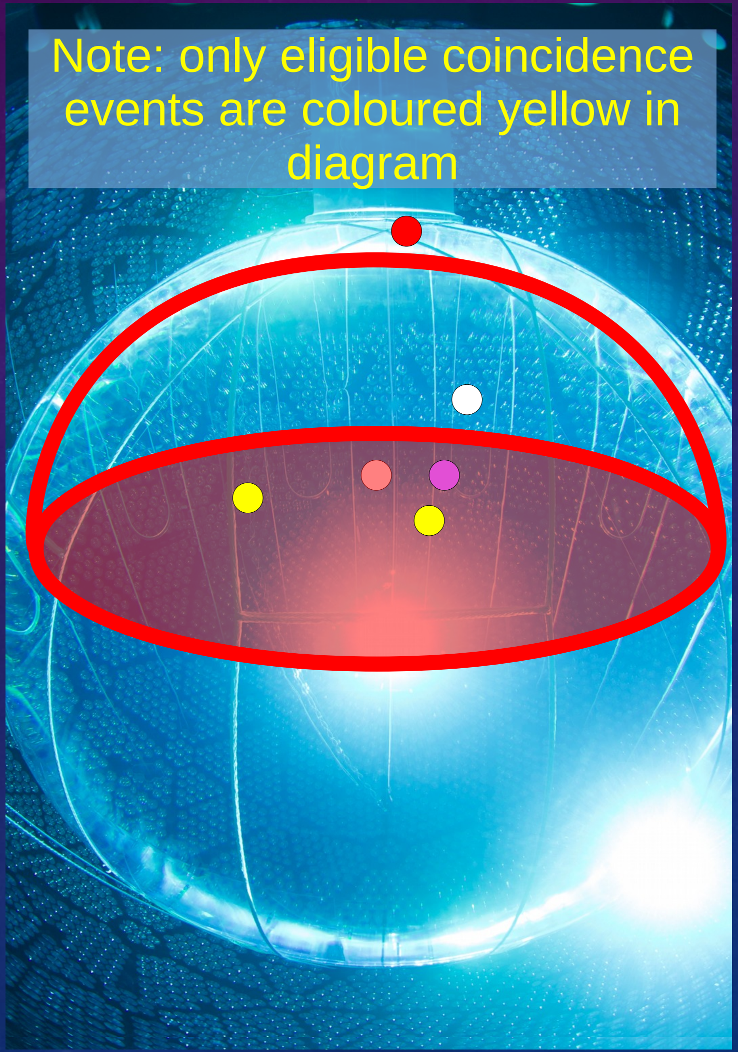
**Energy cut**



**Prompt Event**

**Fiducial volume cut**

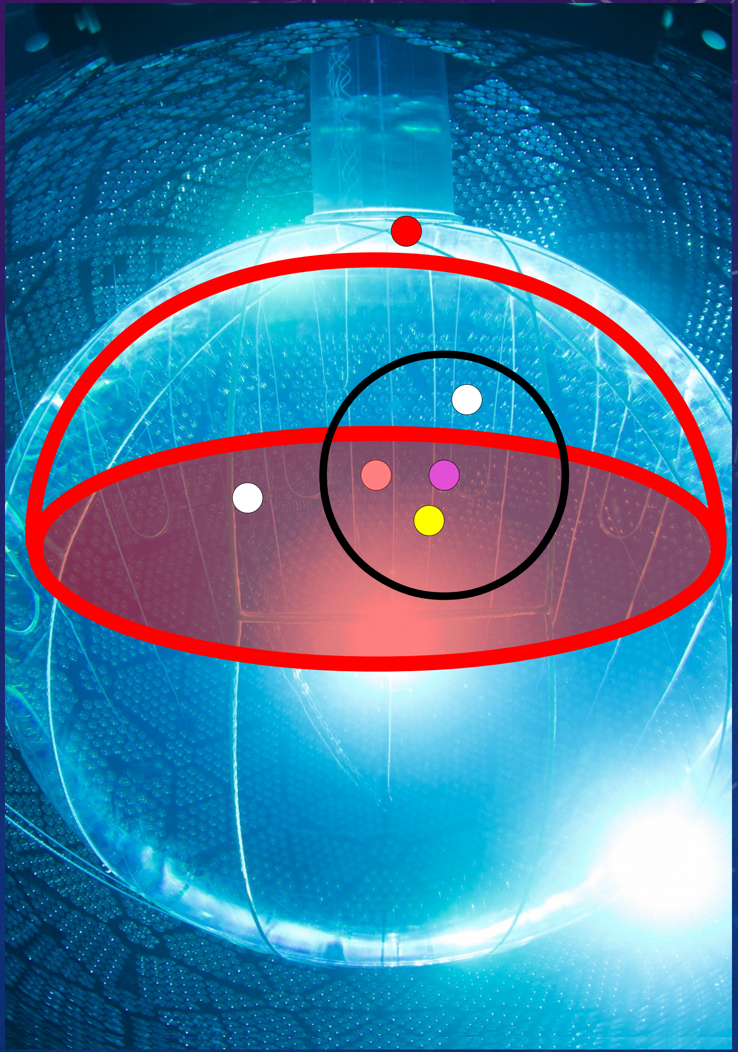
**Energy cut**




**Coincidence**

**Radial distance cut**

**Timing window cut**



# ALPHAN MONTE CARLO (MC) ANALYSIS – PMT HITS

- Monte Carlo simulations were used to determine data analysis cuts for the scintillator bulk
- An FV cut selected at a radius < 5.8m and Z > 85cm (20cm from AV; 10cm above water-scintillator interface)
  - Overall FV cut efficiency = 86%
- Energy cuts were set using a conversion rate of ~ 270 PMT hits per MeV for MC

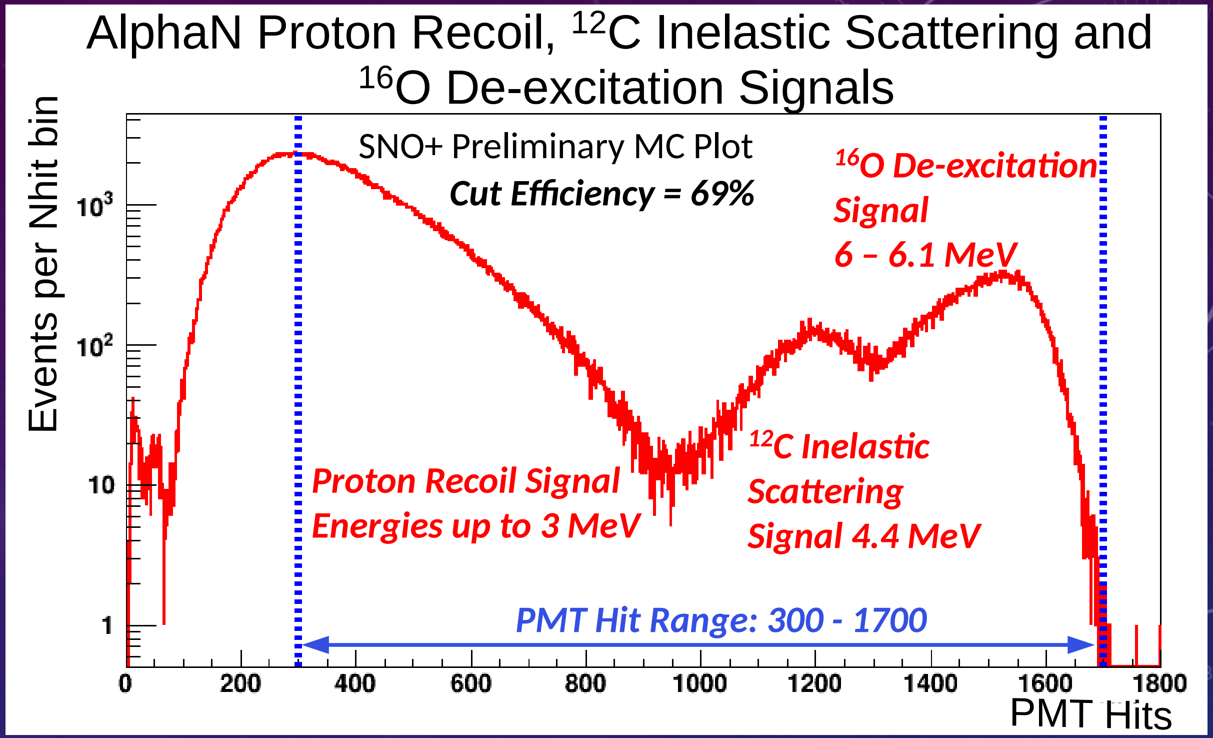
***Prompt Signal***

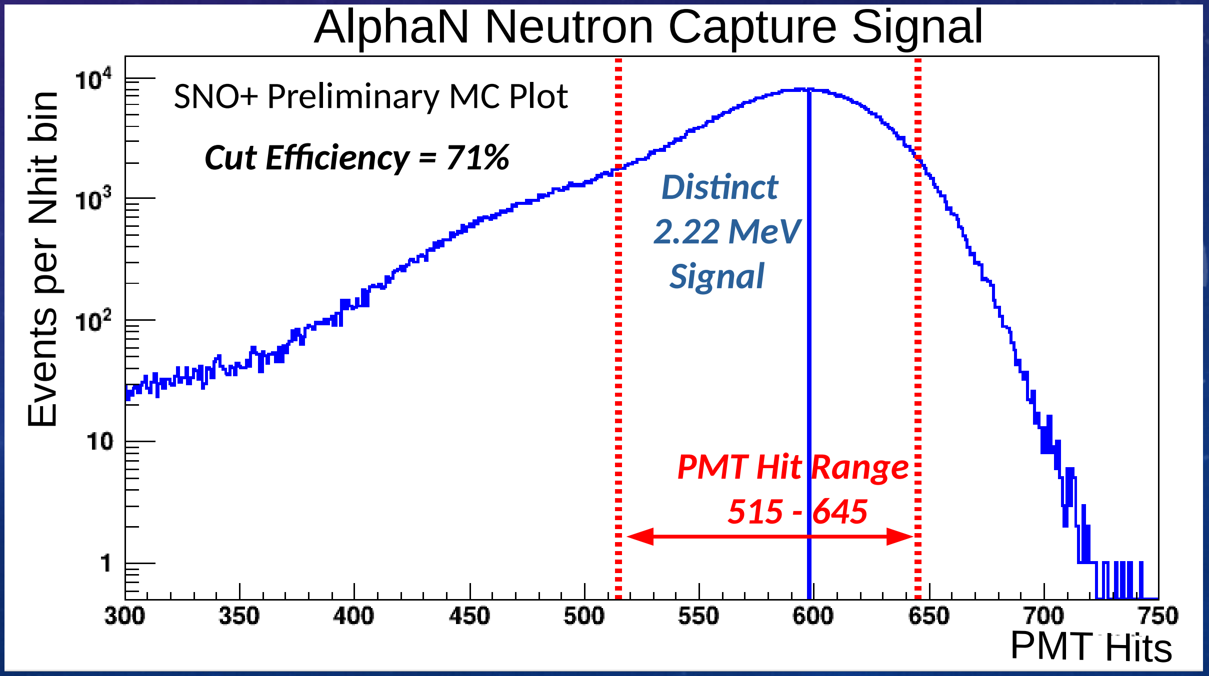
- PMT hit cut range (for Data): 300 – 1700
- Cutting a significant percentage of the proton recoil signal to exclude various backgrounds

***Delay Signal***

- PMT hit cut range (for Data): 515 – 645
- Tight cut made around know 2.22 MeV peak to further exclude backgrounds

- To account for true detector conditions, cuts applied to data were scaled by a factor of 1.12



# ALPHAN MONTE CARLO COINCIDENCE CUTS (DELTA-T & DELTA-R)

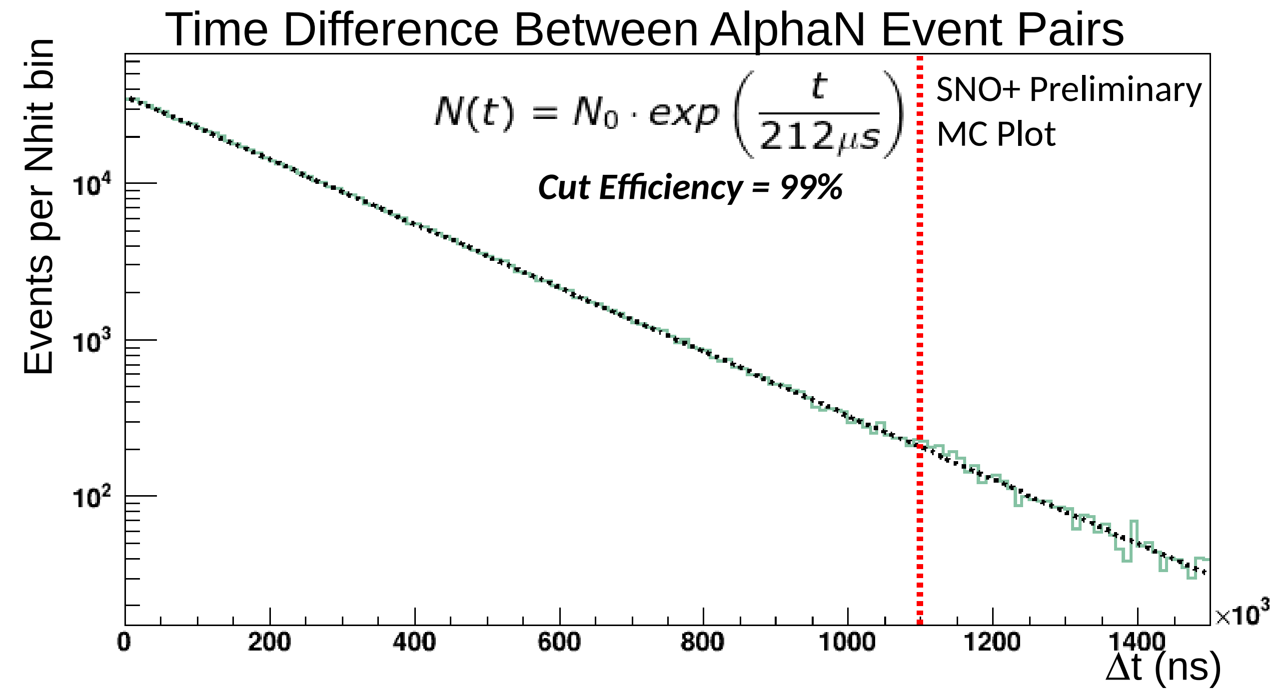
- The remaining number of isotopes follows an exponential decay law:

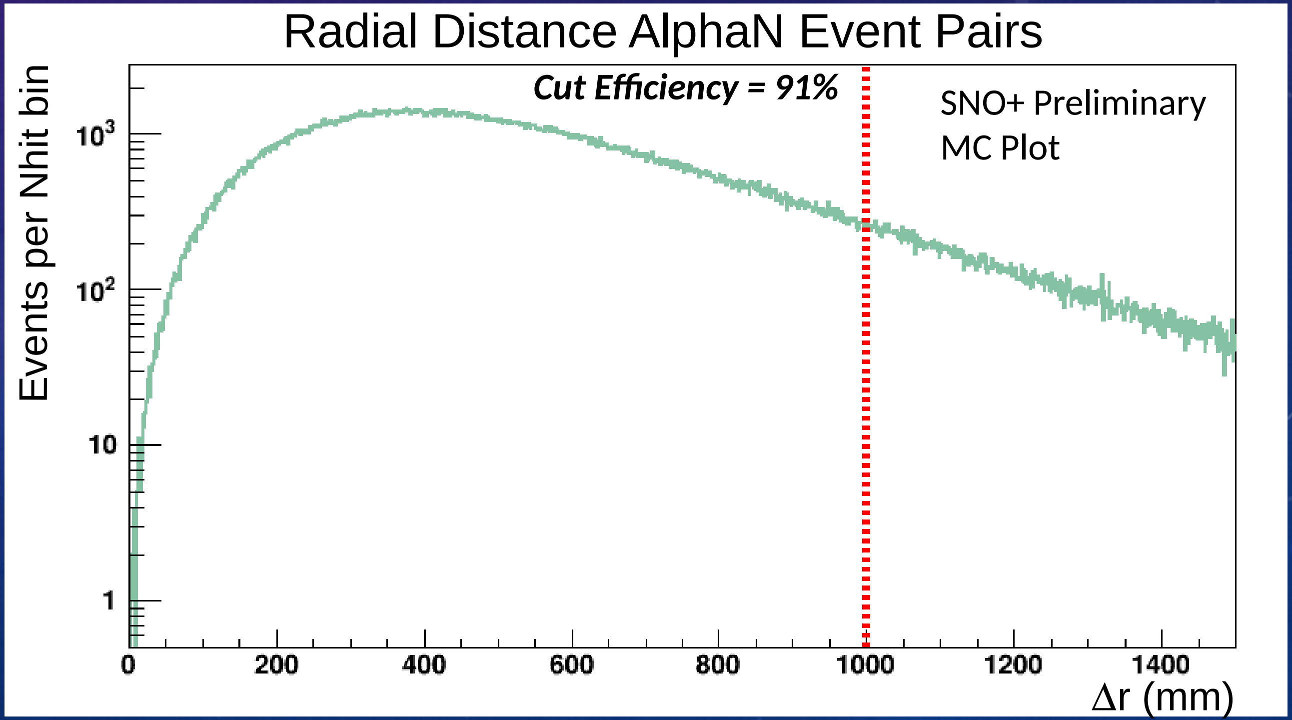
$$N(t) = N_0 \cdot exp\left(\frac{t}{\tau}\right)$$

- Fitting exponential function to MC data yields

  ***mean lifetime $\tau$ = 212$\mu$s***

- Timing window of 400ns – 1.1ms selected
  - Lower limit set to exclude pile-up events (signal from sum of multiple events in short time)
  - Upper limit set at ~5 times mean lifetime
- 1m radial distance cut selected
  - Preserves 91% of events
- ***Combined cut efficiency = 27%***



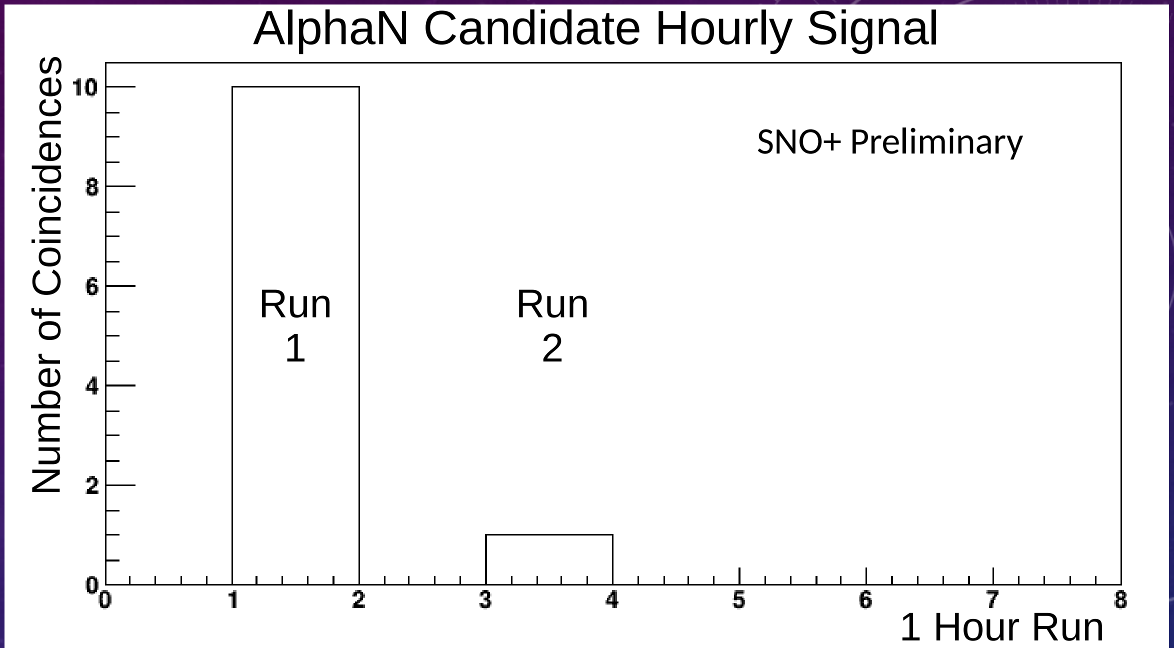
# ALPHAN ANALYSIS – DATA CLEANING & MUONS

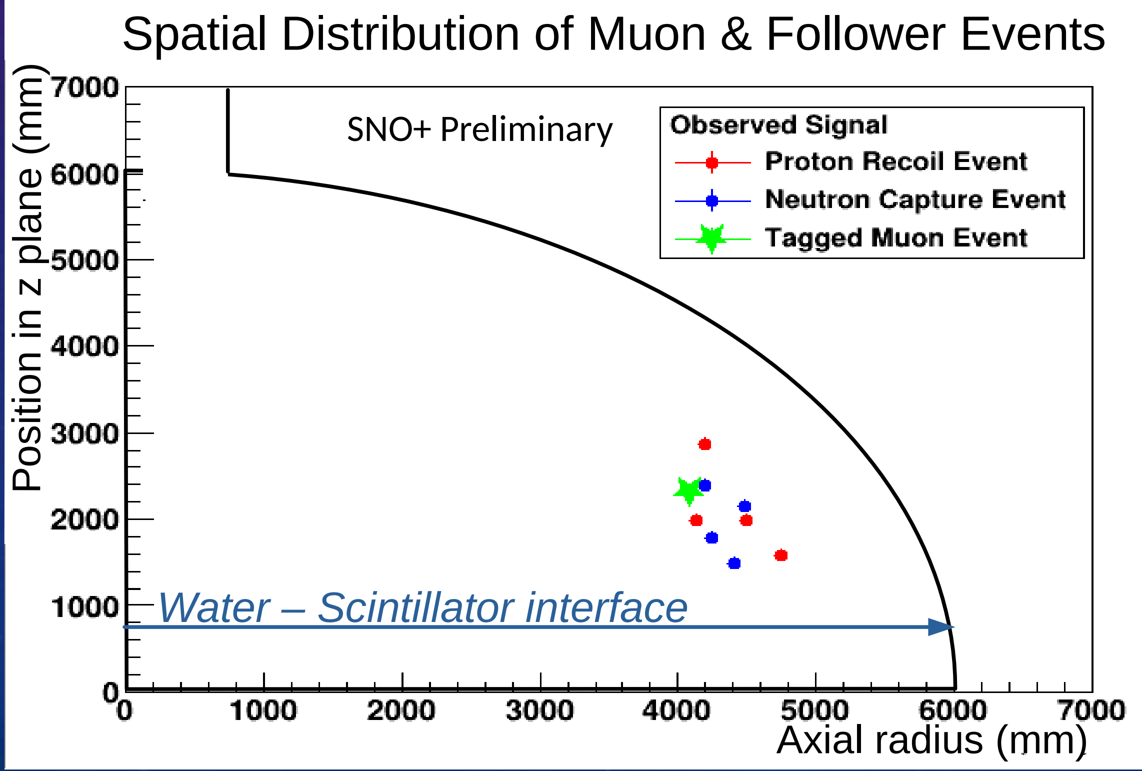
***Data Cleaning***

- Research was performed to find data sacrifice for implemented cleaning cuts
- Similar coincidence signals used for study (i.e. decay from Bismuth 214 to Polonium 214)

***Muon Investigation***

- Some observations of multiple coincidences in a single run
  - Typically, 0 - 1 coincidence events observed (in a run)
- Examined runs with multiple 'events' present
  - 'Events' found to be localised spatially around a known muon signal
  - 'Events' also fall within 400μs of the tagged muon
- Evidence these 'events' are caused by muon follower neutrons and not an AlphaN candidate



# SUMMARY

**Past**

- Radon levels monitored on a daily basis during SNO+’s water phase
  - Vitally important to minimise internal detector backgrounds

**Present**

- Tools developed for Radon analysis during UPW phase
  - Ongoing analysis of low background data (with improved optics)

- Tools developed to identify potential AlphaN candidates within scintillator
  - Analysis being refined during partial fill phase
  - Important to identify as a dominant background for antineutrino studies
  - Important to identify for neutrinoless double beta decay studies

- AlphaN studies will soon be expanded to investigate AV surface events

- **Future**
- Refined AlphaN analysis will be performed for pure and Tellurium doped scintillator stages of detector lifetime

- Analysis of antineutrino signal in scintillator

# VOILA! QUESTIONS?

*Me at SNOLAB*