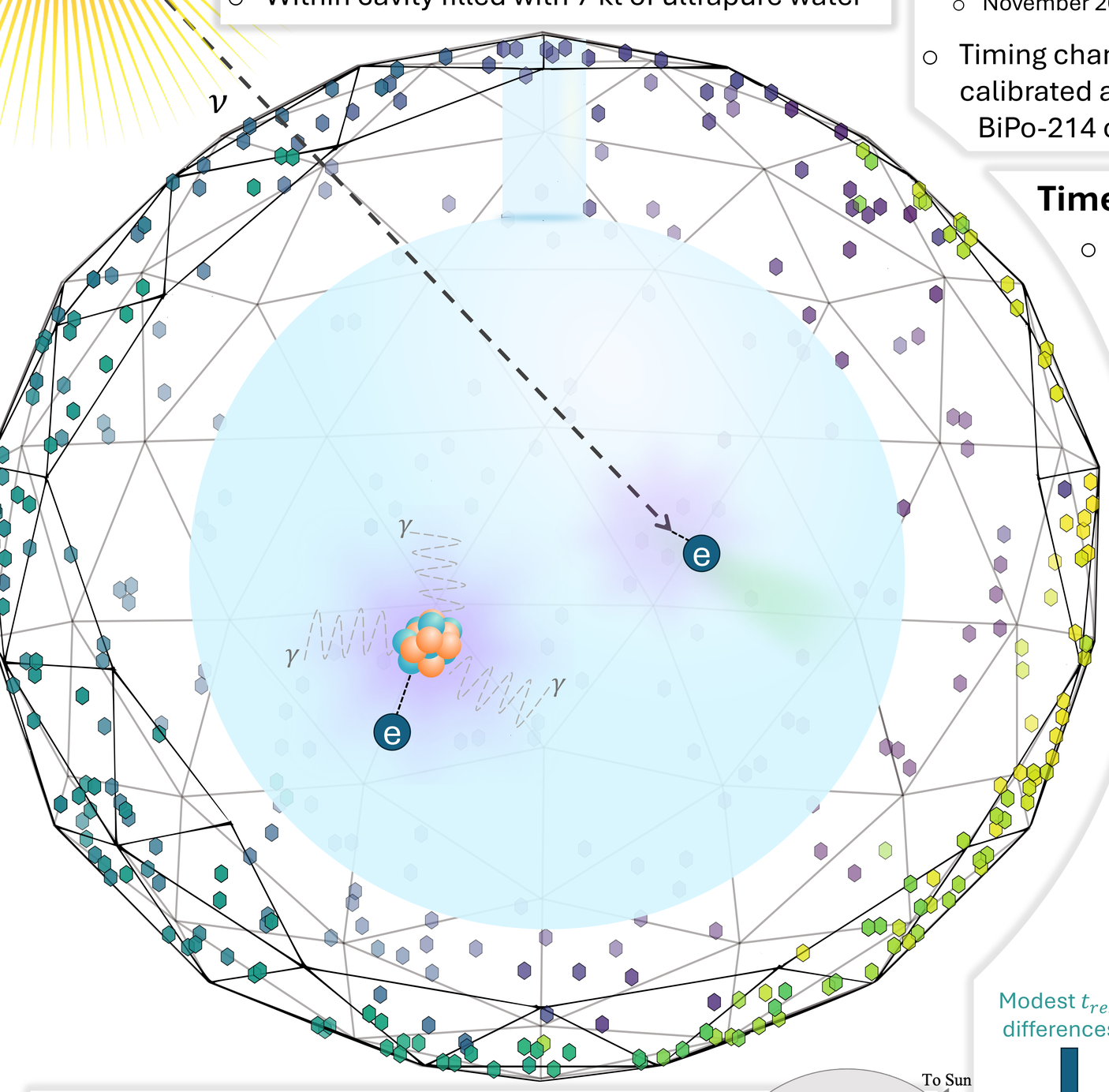
Time-based event discrimination methods for solar neutrino analyses in the SNO+ liquid scintillator phase

R. Hunt-Stokes[i,*] and **A. S. Inácio**[ii,**], for the SNO+ collaboration

[i] rafael.hunt-stokes@stcatz.ox.ac.uk , [ii] ana.carpinteiroinacio@physics.ox.ac.uk

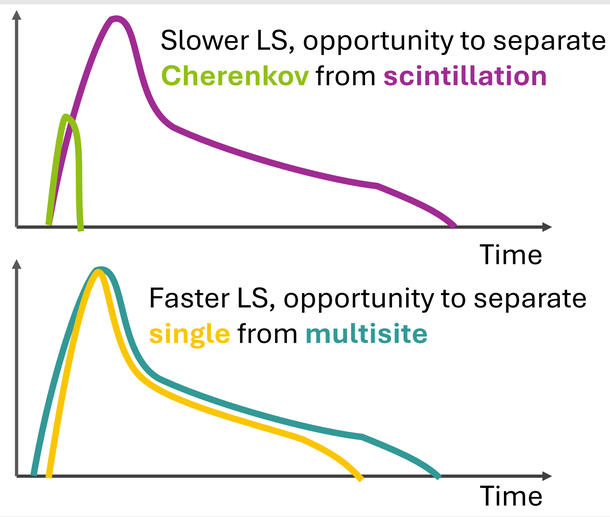
The SNO+ Experiment

- Multipurpose neutrino detector at SNOLAB
  - 2 km (~6000 m.w.e) underground
- 6-m radius acrylic vessel (AV)
- 9362 PMTs in 9-m radius support structure
- Within cavity filled with 7 kt of ultrapure water



SNO+ Liquid Scintillator

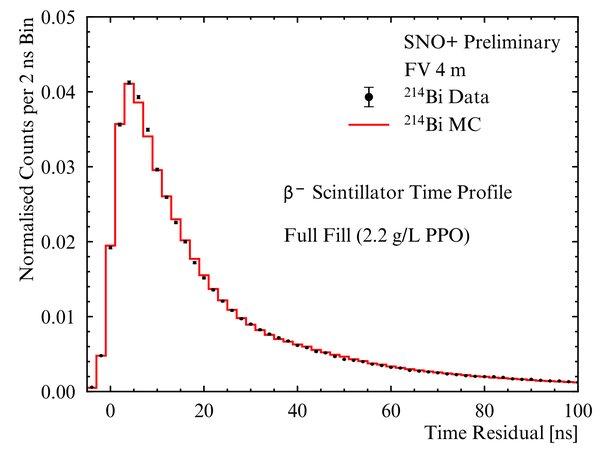
- 365 t of LAB + 0.6 g/L PPO
  - April – October 2020
- 780 t of LAB + 2.2 g/L PPO
  - April 2022 – June 2023
- 780 t of LAB + 2.2 g/L PPO + bisMSB
  - November 2023, on-going
- Timing changes with target composition calibrated and monitored using in-situ BiPo-214 coincidences



Time Residuals

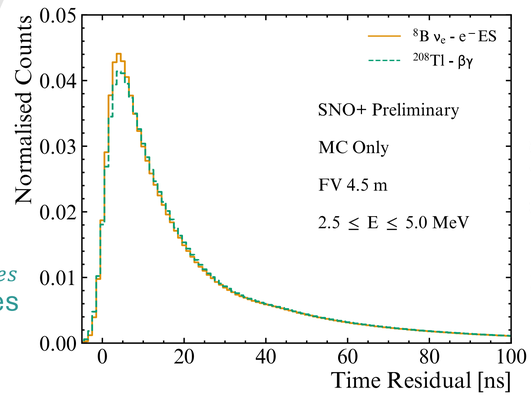
- PMT hit times are the physical observables in SNO+ events
  - Hit times are converted into position-independent time residuals:

$$t_{res} = t_{hit} - t_{tof} - t_{ev}$$



Multisite Event Discrimination of ^{8}B Solar Neutrinos from ^{208}Tl

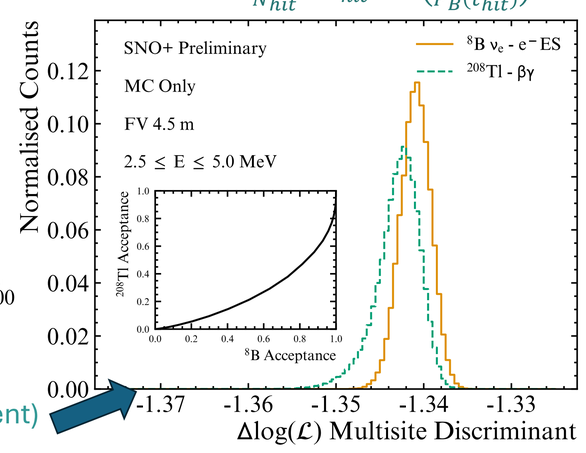
- Analysis of 2.2 g/L PPO data, focus on 2.5 < E < 5 MeV ROI
- Exploits differences in t_{res} between single-site ^{8}B ν_e - e$^-$ ES and dominant multisite ^{208}Tl β - γ decays



Modest t_{res} differences

But PDFs are well determined (large statistics + calibrated time profiles + large sample rate per event)

$$\Delta\log(\mathcal{L}) = \frac{1}{N_{hit}} \sum N_{hit} \log\left(\frac{P_S(t_{hit})}{P_B(t_{hit})}\right)$$



Event-by-event Direction Reconstruction

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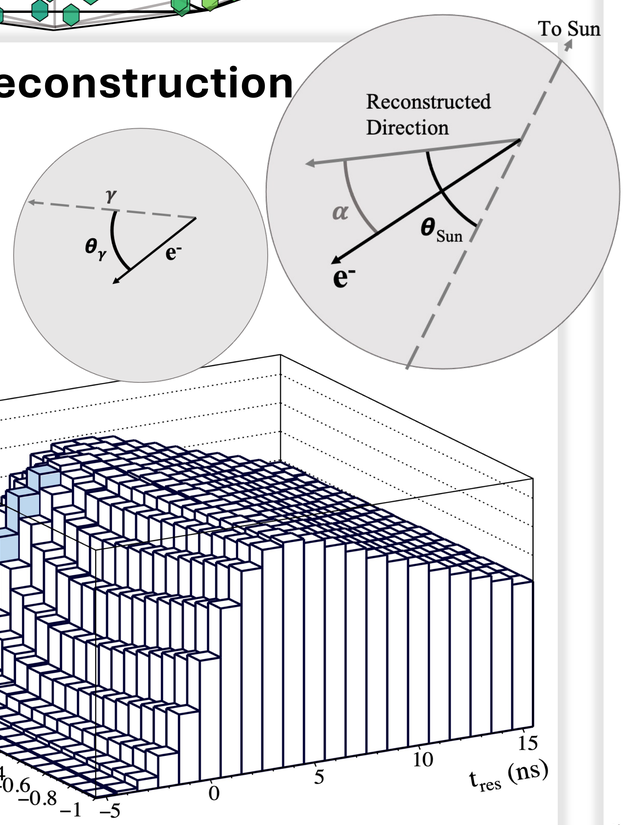
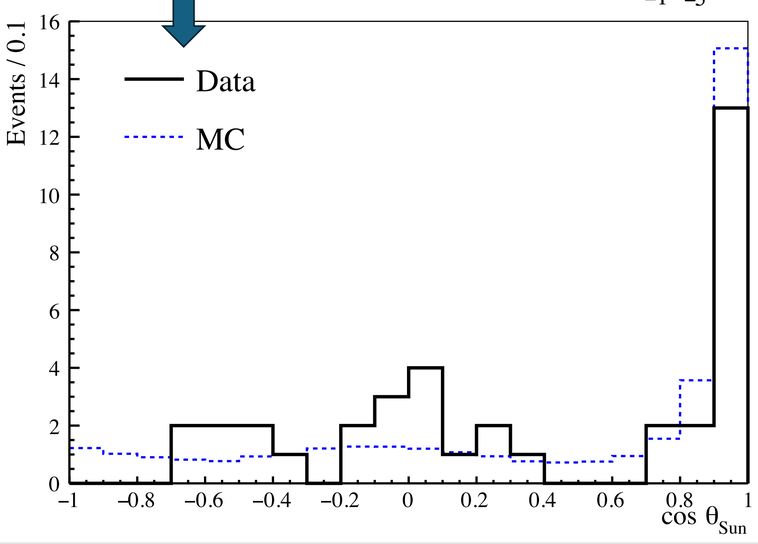
- Analysis of 0.6 g/L PPO data
- Selection of ^{8}B ν_e - e$^-$ ES signals
  - 5 < E < 15 MeV region
- Maximum likelihood reconstruction method
  - Using 2D PDF of $\cos\theta_\gamma$ and t_{res}



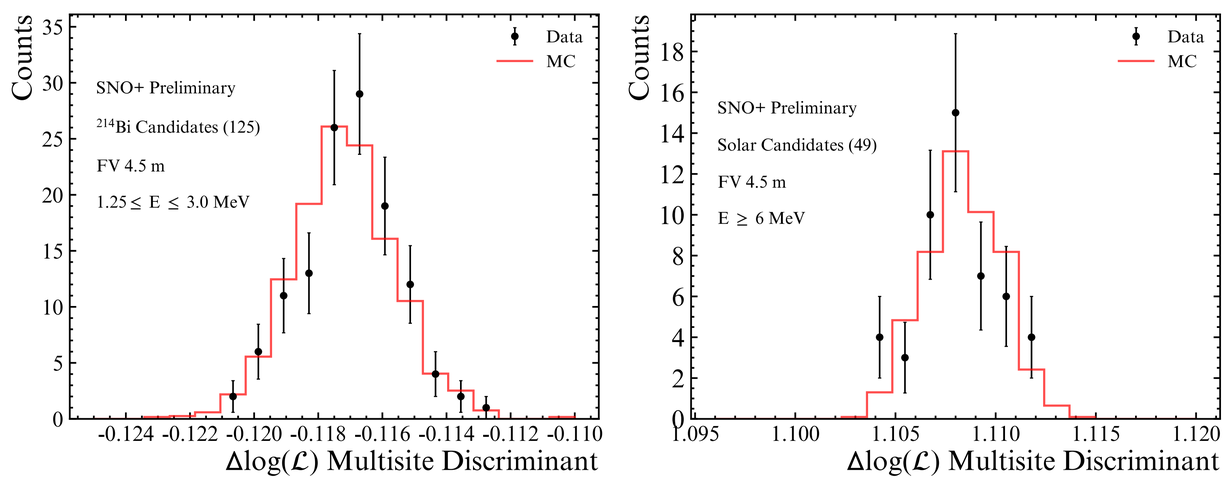
Angular Cherenkov peak at early times

- Applied to 37 candidate events



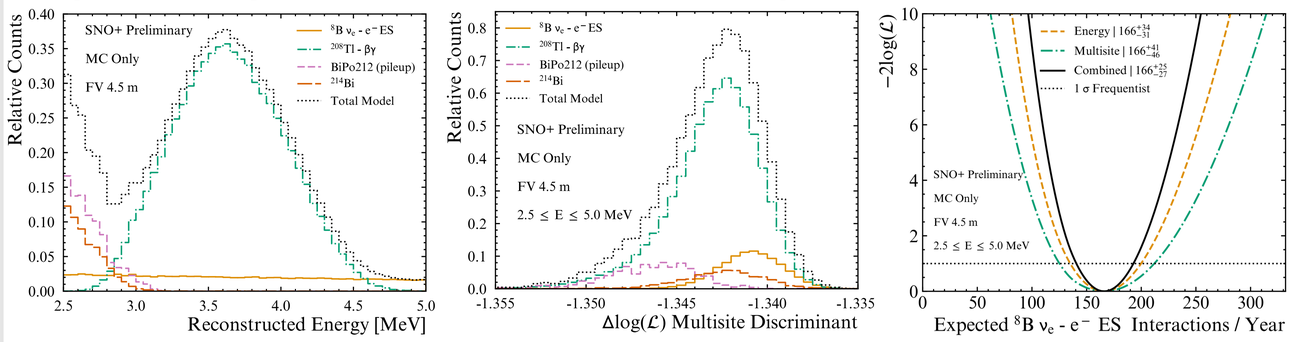
- On-going work with 2.2 g/L PPO data
- Also exploring Machine Learning methods for the direction reconstruction

Validation of Multisite Discriminant



Good agreement between data and MC in two distinct sidebands!

Expected impact on ^{8}B Solar Neutrino Analysis



- PDFs constructed from MC in both energy and multisite discriminant
- Multisite encodes comparable information to energy shape information
- Combination of energy and multisite leads to improved sensitivity!

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