First Demonstration of Event-by-Event Directional Reconstruction in the SNO+ Scintillator Phase

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Motivation

- Directional information can be a very powerful tool for background rejection in neutrino experiments
  - Solar studies can benefit greatly from event selection based on direction
  - This information is often obtained through Cherenkov cone identification
- Scintillator experiments benefit from high light yield
  - This leads to high precision energy and position reconstruction
  - However, scintillator light is isotropic and gives no directional information
- If Cherenkov light can be isolated from the scintillation signal, directional reconstruction in scintillator could be possible
  - Slow scintillators have shown promise on a bench-top scale (Nucl. Instrum. Meth. A 972, 164106)

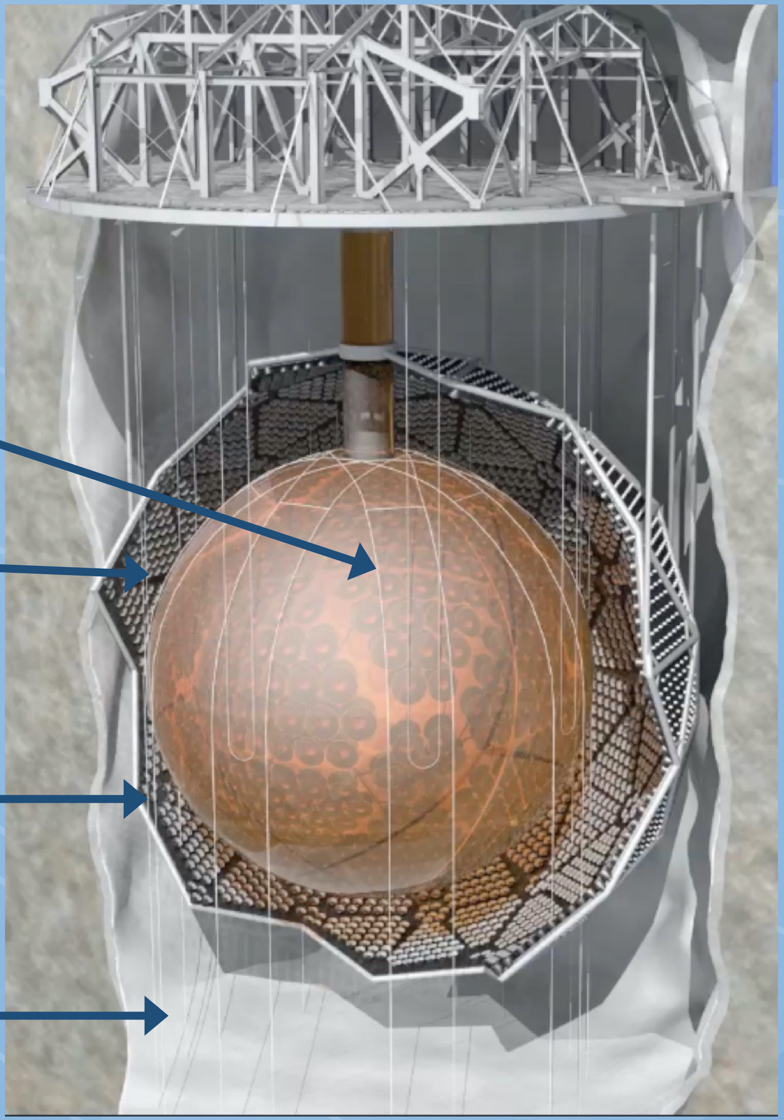
The SNO+ Detector

12 m diameter Acrylic Vessel (AV), filled with 780 T of liquid scintillator

9,300 inward facing PMTs for ~50% effective coverage

PMT Support Structure (PSUP)

Water shielding
1700 T inside PSUP
5300 T outside PSUP

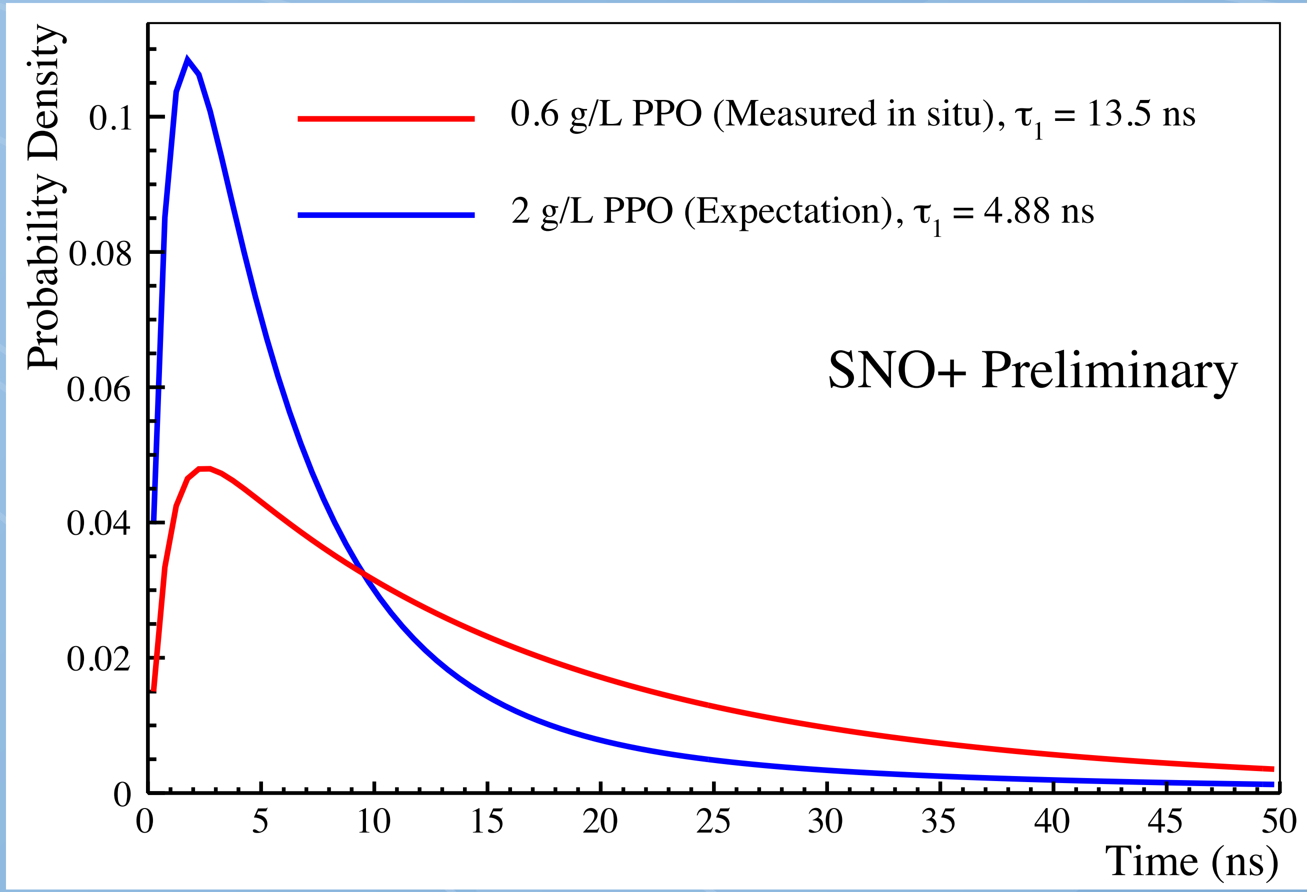


The SNO+ Experiment
2021 JINST 16 P08059

Timing Separation

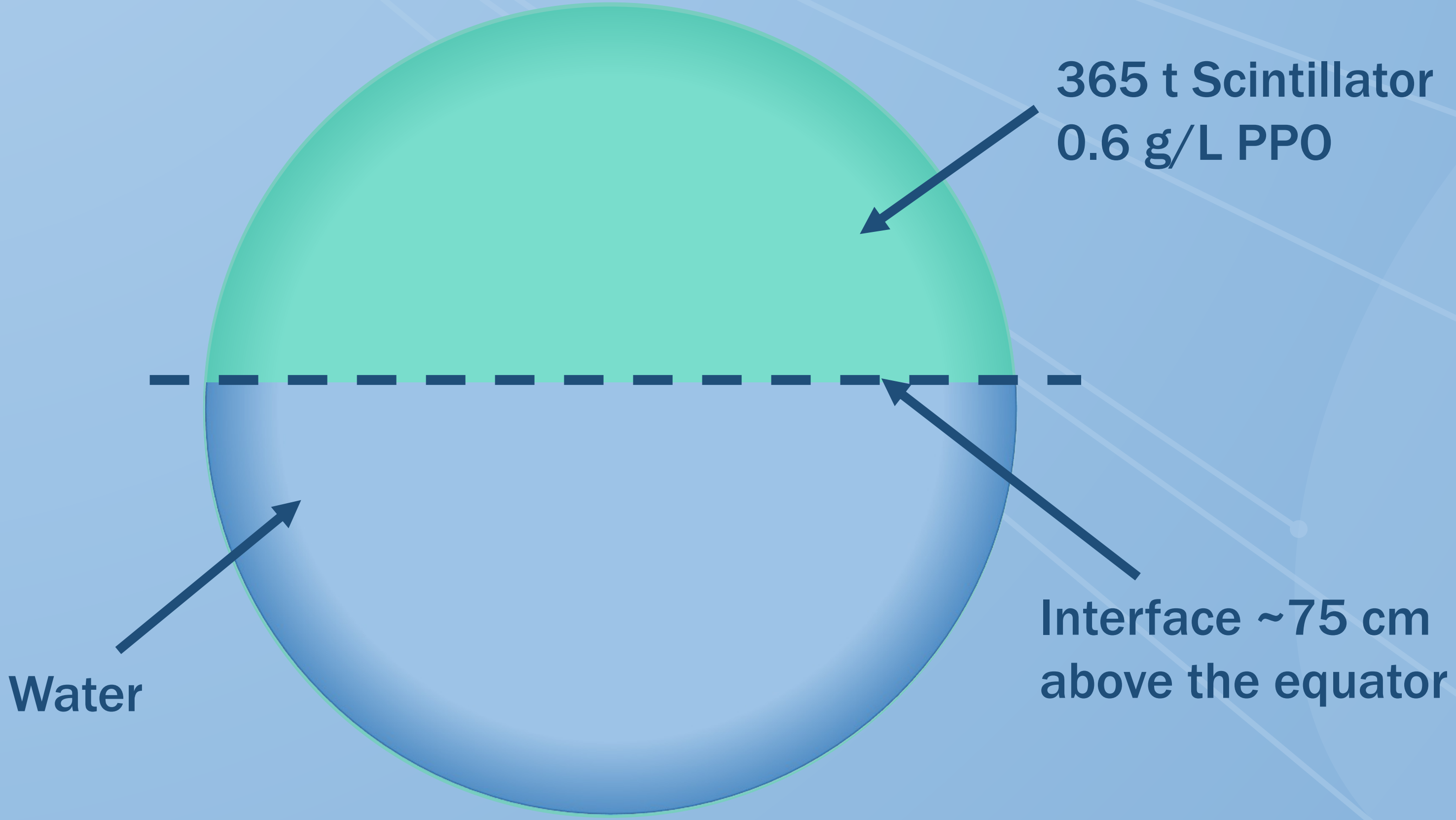
- SNO+ uses 2,5-diphenyloxazole (PPO) as a primary fluor in linear alkylbenzene (LAB)

- Lower concentration leads to a slower scintillator
- Easier separation of instantaneous Cherenkov light



SNO+ Partial Fill Phase

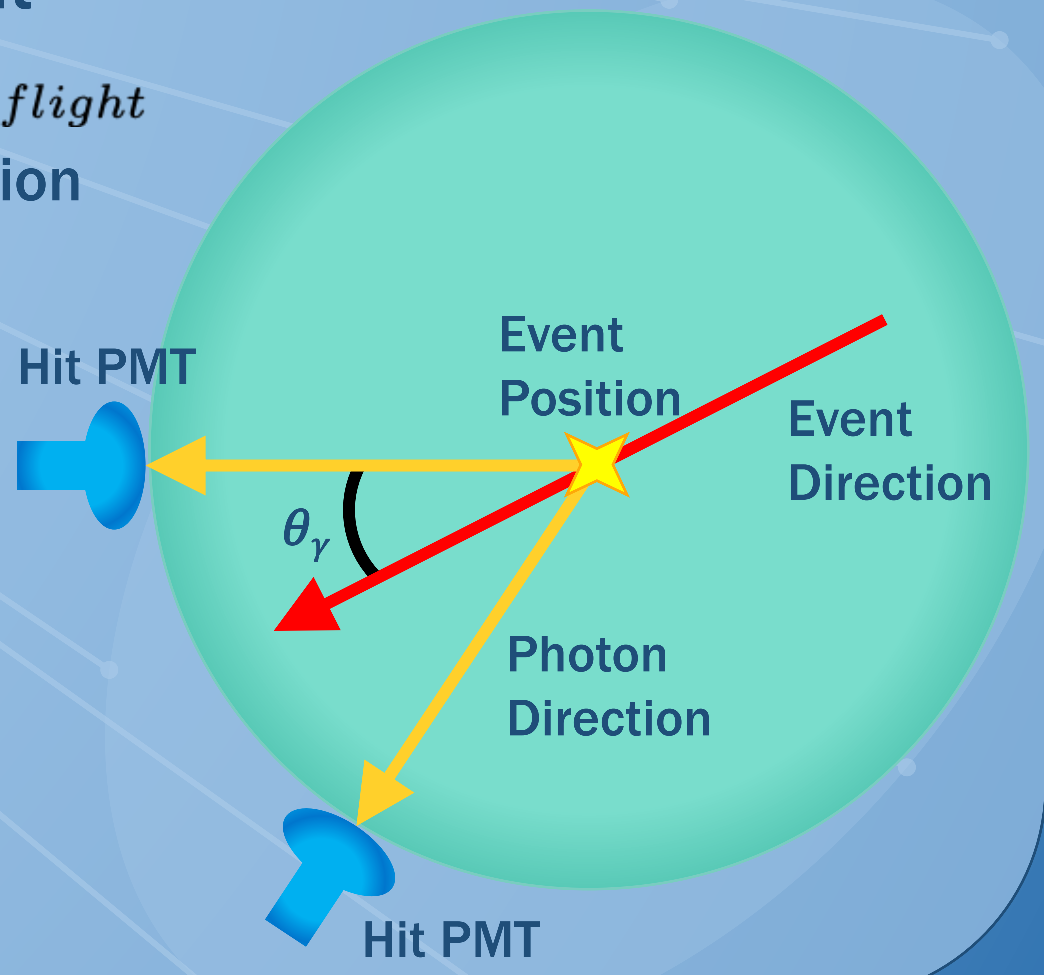
- A "Partial Fill" stage of SNO+ contained 0.6 g/L PPO
  - 5th April - 24th October 2020



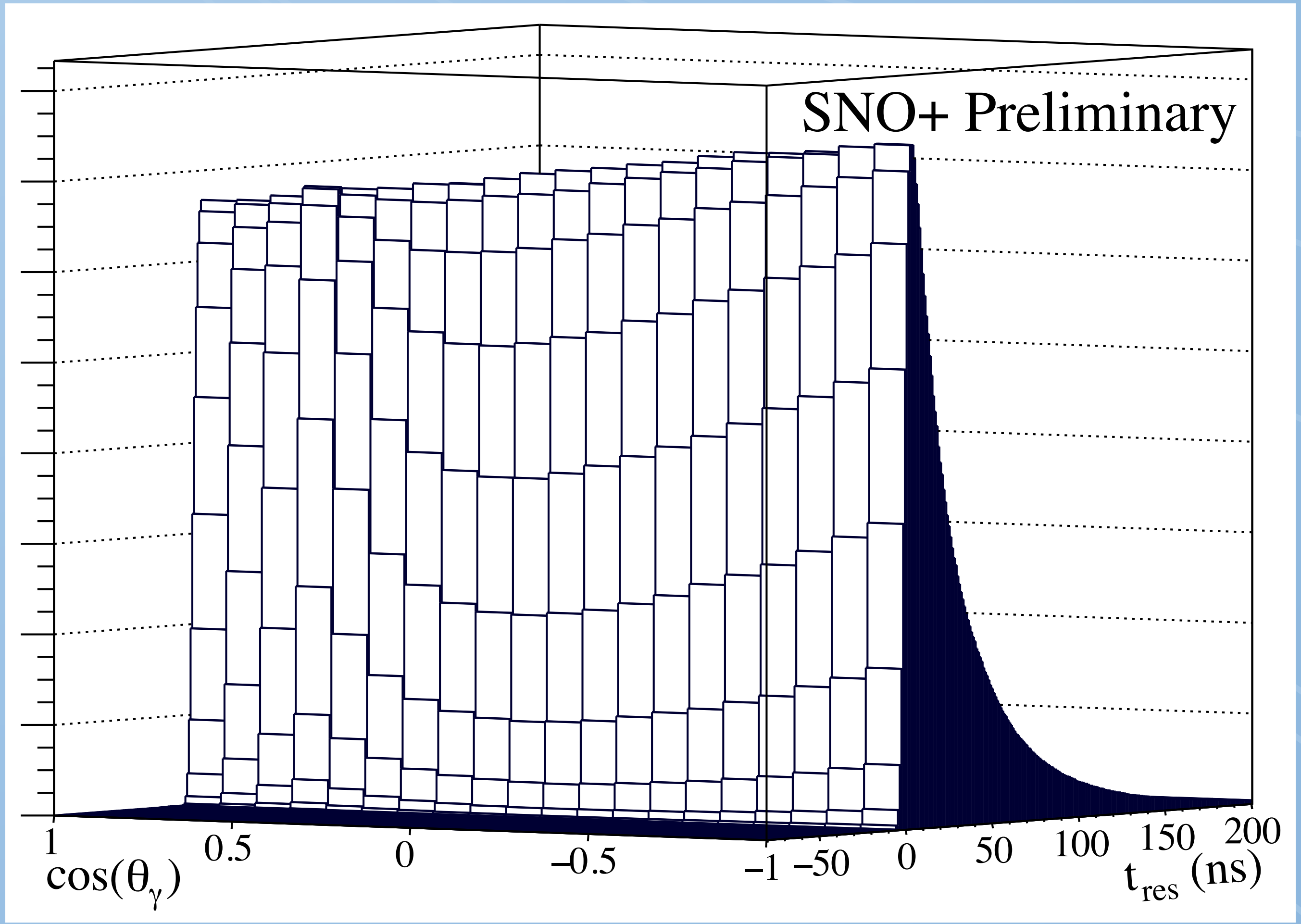
Perfect for testing directionality!

Cherenkov Peak Isolation

- Two ways to separate Cherenkov light
- Time Residual $t_{res} = t_{hit} - t_{event} - t_{flight}$
  - Cherenkov will be earlier than scintillation
- Photon Angle:
  - Cherenkov will have a peak in θ_γ
- Cherenkov peak can be isolated by plotting the detected light using these parameters



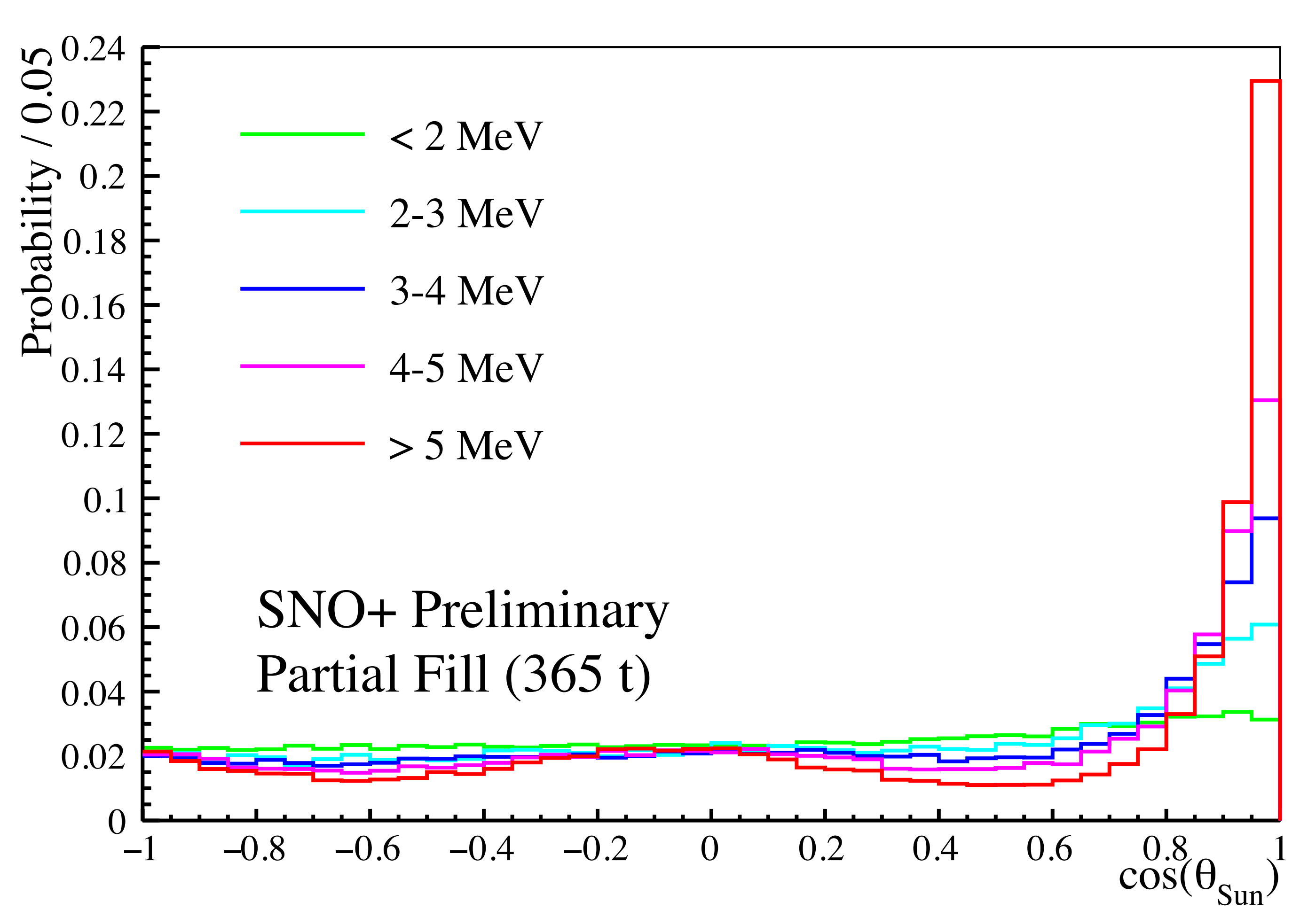
2D Plot - Simulation



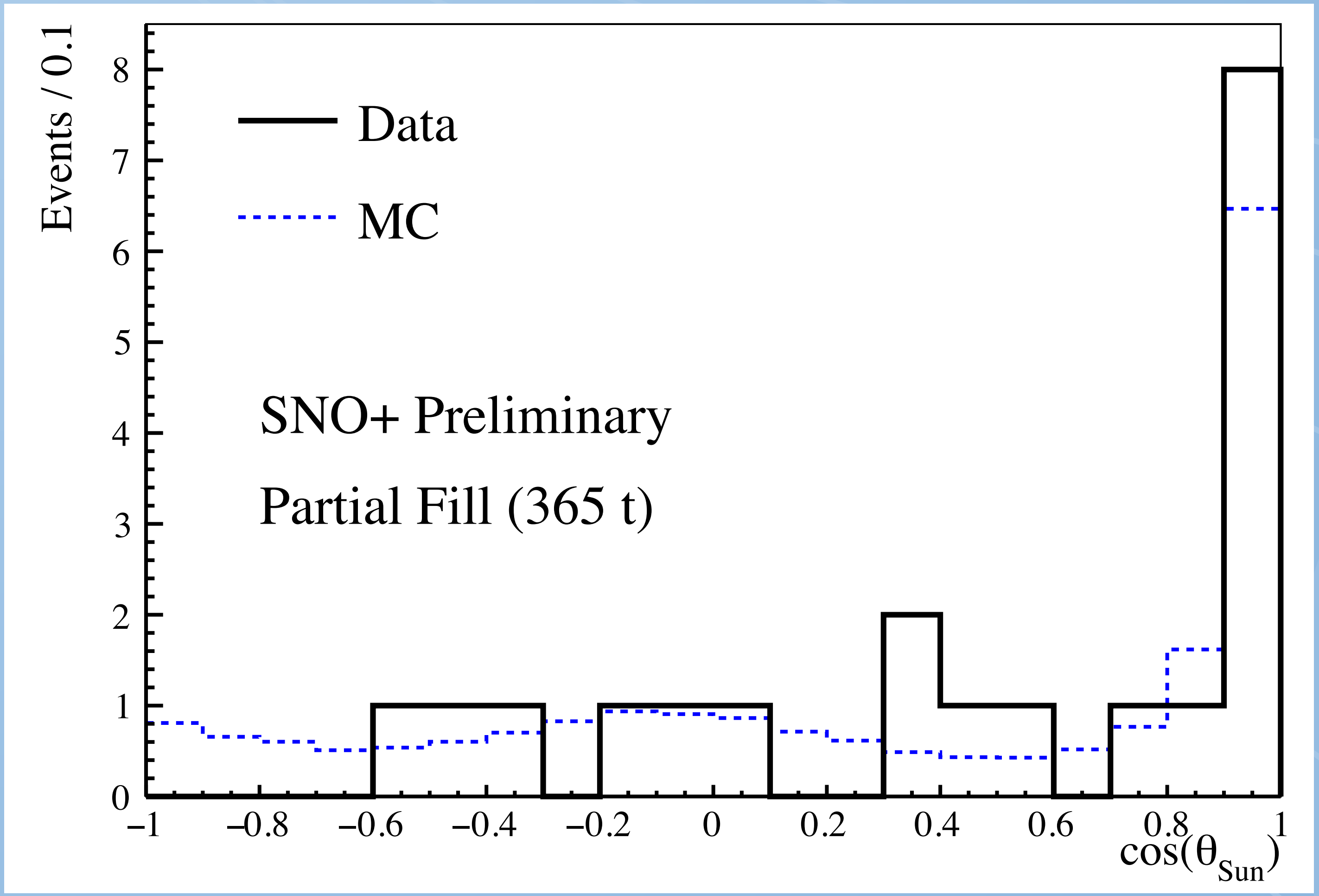
- 6 MeV electrons simulated
  - Perfect-state full-fill detector
  - Full volume, isotropic directions
  - 0.6 g/L PPO scintillator
- Clear Cherenkov peak seen
- "Backwards" peak also seen
  - Caused by bias in positional reconstruction
- Can be used as a PDF for a directional likelihood fitter

MC Predictions

- ^{8}B solar ν_e MC
  - Run conditions of the Partial Fill detector
  - Cuts: z > 1 m above equator, r < 5.5 m from centre of AV
- Grid search likelihood fitter
- cos(θ_{Sun}) - angle between reconstructed and solar direction



Data Results

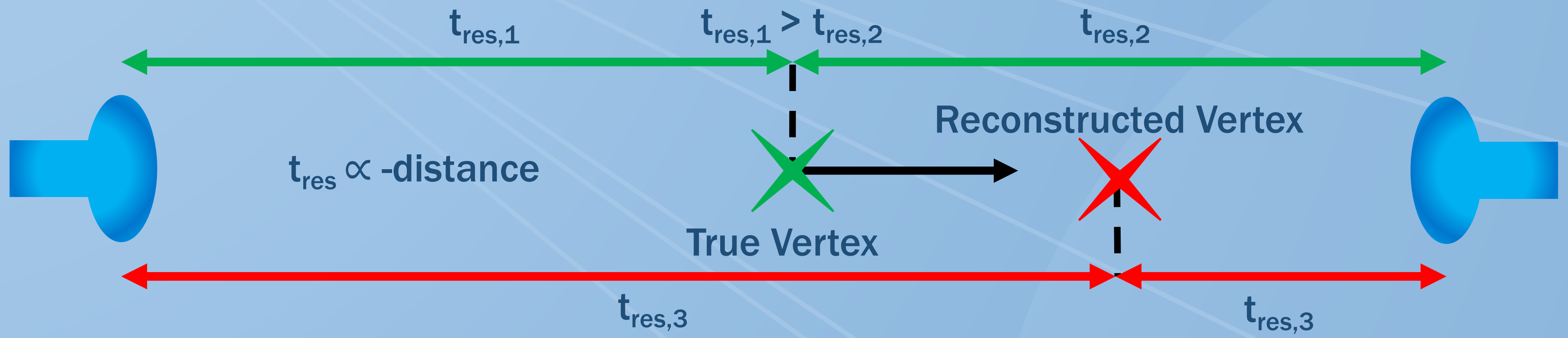


- Data taken from the Partial Fill Phase
  - Livetime of 92 days
  - PMT Hit cut of >1500 used
    - ~ 5 MeV
  - 20 events extracted
  - Equivalent MC plot included
- 20 ^{8}B events extracted
- First event-by-event directional reconstruction < 10 MeV in a large scale liquid scintillator experiment!

Potential Positional Improvement

- There is a noticeable directional bias in the position

$$t_{res} = t_{hit} - t_{event} - t_{flight}$$



- Interdependent effects
  - By reconstructing direction, it may be possible to correct for drive
  - By correcting for drive, we could more accurately reconstruct direction
- Work is ongoing for improvements to this reconstruction

Summary

- First demonstration of event-by-event* direction reconstruction < 10 MeV** in a liquid scintillator detector!
  - Also the first demonstration in a high yield scintillator**
  - Direction has been reconstructed for Solar events > 5 MeV in the SNO+ Partial Fill Phase
- Even more improvements to come!

- *Statistical separation of solar directionality has been shown by Borexino using ~20,000 events [1]
- ** LSND[2] MiniBooNE[3] have previously used directional reconstruction at higher energy scales using lower yield scintillators.

Thank you for listening

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References

1. Borexino Collaboration. Correlated and Integrated Directionality for sub-MeV solar neutrinos in Borexino. arXiv:2109.04770 [hep-ex], 2021.
2. C Athanassopoulos et al. The liquid scintillator neutrino detector and LAMPF neutrino source. Nucl. Instrum. Meth. A, 388(1):149–172, 1997.
3. R.B. Patterson and E.M. Laird and Y. Liu and P.D. Meyers and I. Stancu and H.A. Tanaka. The extended-track event reconstruction for MiniBooNE. Nucl. Instrum. Meth. A, 608(1):206–224, 2009.