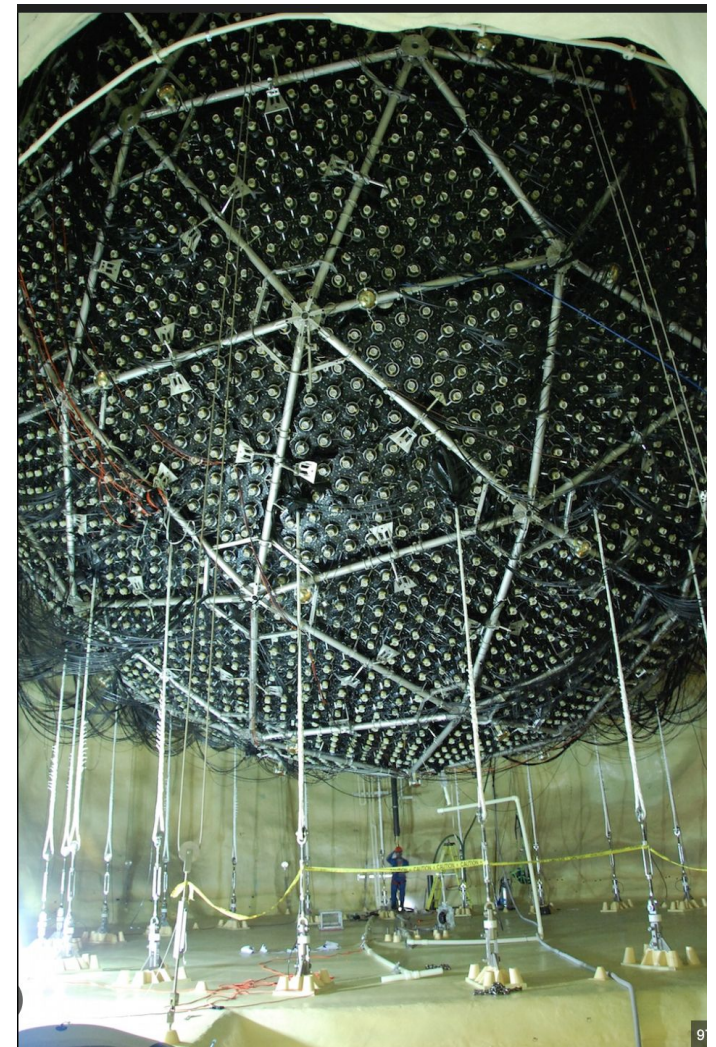


# Calculate the SNO+'s Liquid Scintillator's Index of Refraction

April 17th 2026  
Supervised by Szymon Manecki  
Zeming Dai

# Outline

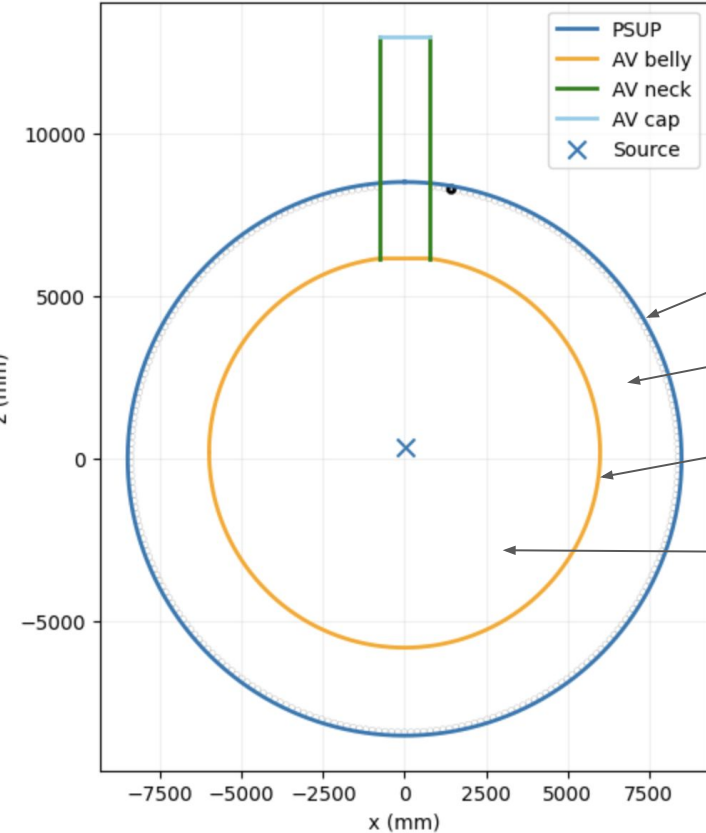
- Introduce background
  - Geometry of AV
  - Calibration source
  - Composition of Scintillator
- Method
  - Identify and select data
- Results
- Discussion
- Conclusion



# Introduction - SNO+

... liquid scintillator detector for excellent for detecting neutrino

2D geometry



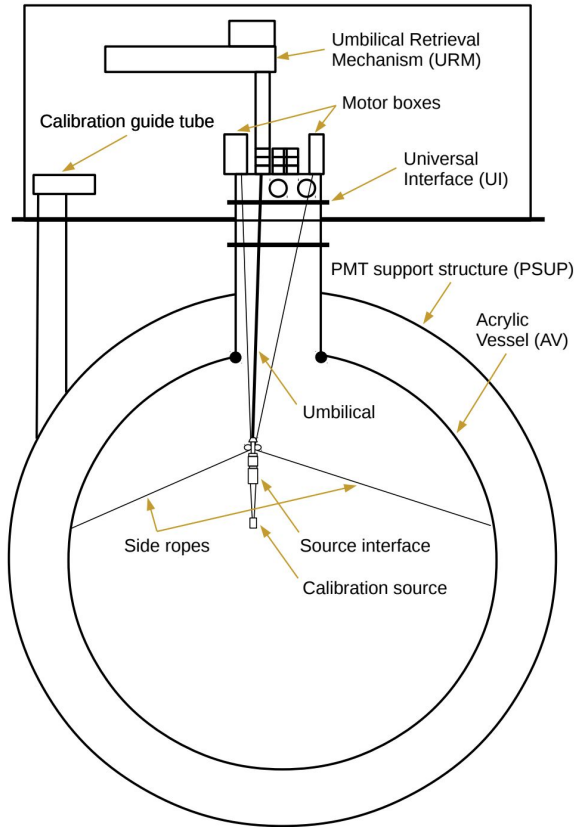
PMT Support Structure (PSUP) 8500 mm inner radius

UPW

Acrylic Vessel (AV), 6000 mm radius

Linear AlkylBenzene (LAB) Scintillator

# Introduction: Laser Ball Source



## Laser Ball: Light Diffuser:

- lights injected via fibre optic cable.
- acting as point light source (acceptably)

## Data used:

- 1 hour duration
- Laserball center of AV
- 500 nm
- 40 Hz, 500 detected photons per pulse

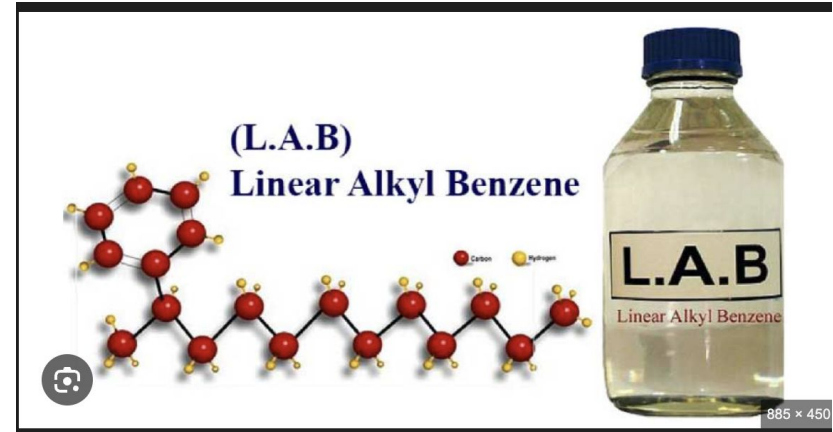
# Introduction: Linear Alkyl Benzene (LAB)

## LAB:

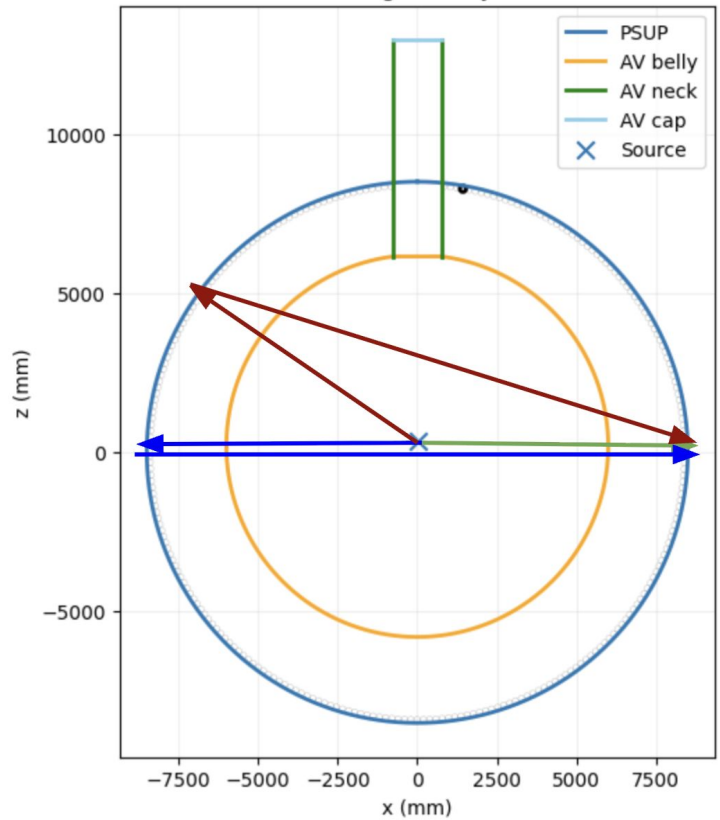
- Excellent optical transparency ( $\approx 20$  m),
- high light yield
- low inherent radioactive impurity

## HIGHLY SENSITIVE

- Speed of light differs by temperature
- *Ex situ* measurement exist
- Better have *in situ* condition.

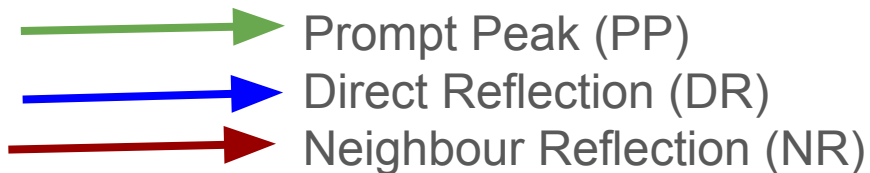


2D geometry



# Method

- Measuring Index of Refraction (IoR)
- Use Time of Flight (ToF) across detector
- For single PMT;
  - Determine ToF Difference of predicted paths



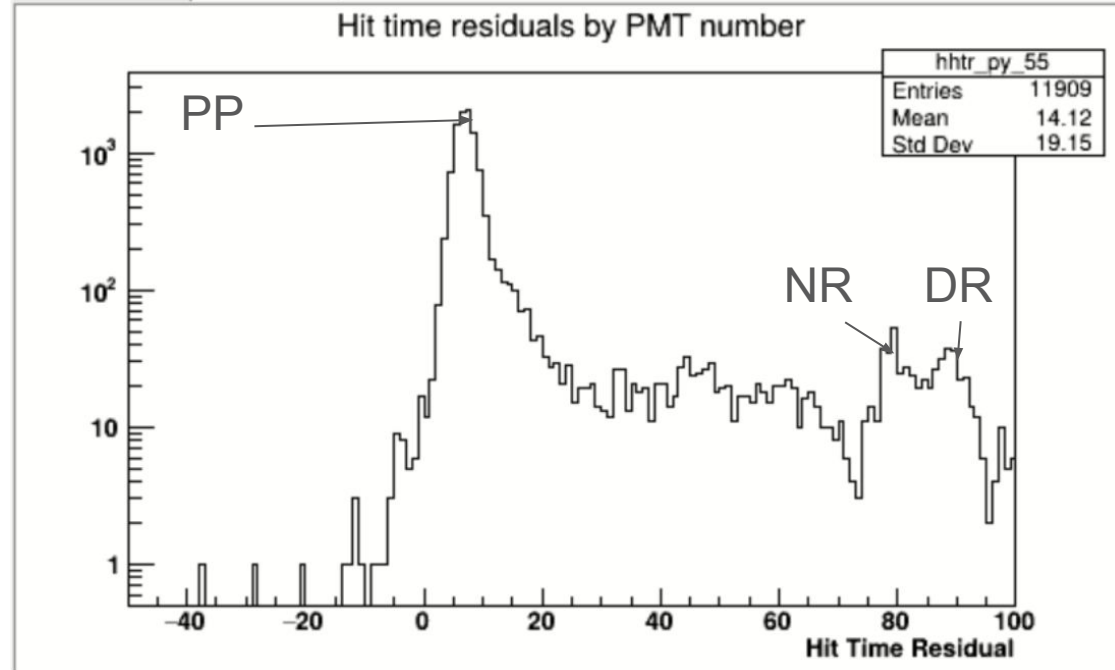
# Hit Time Residuals

A measurement of hit registered relative to event time.

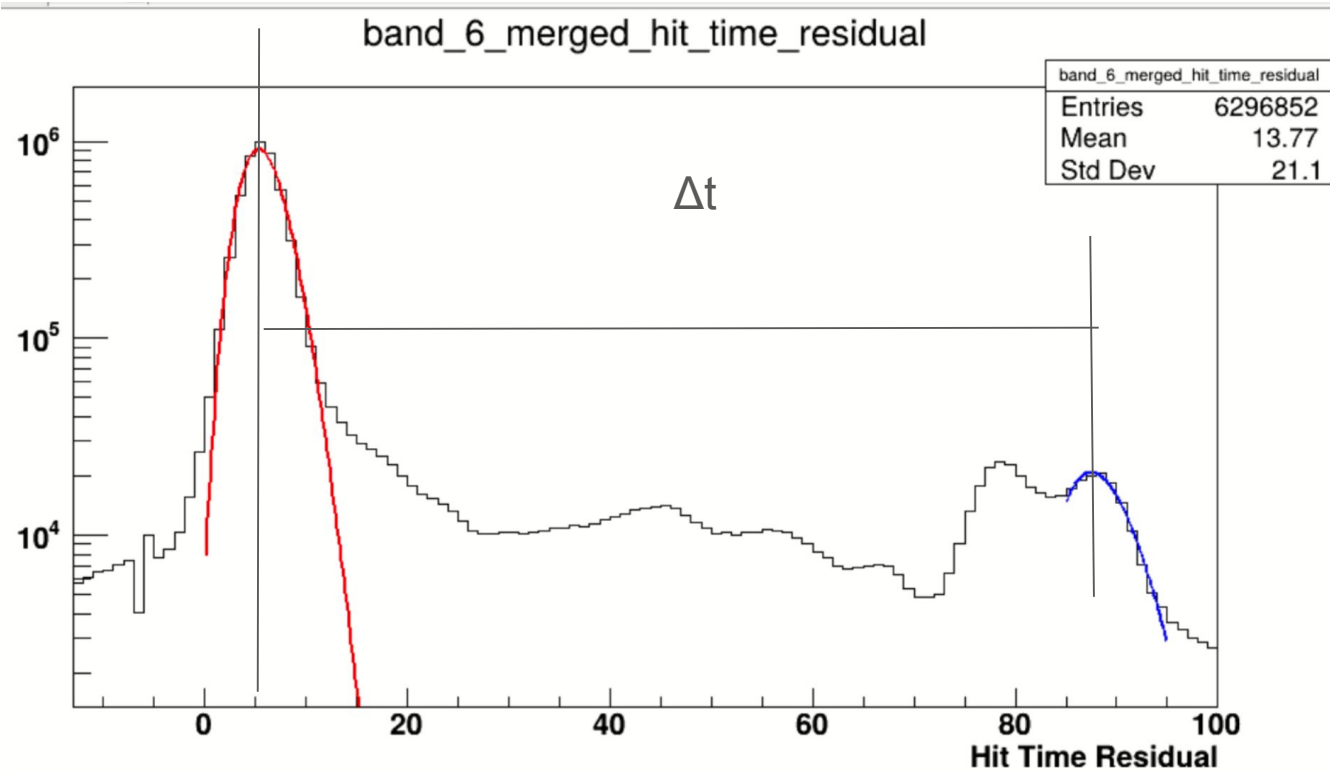
Compiled on PMT/PMT basis

DR-PP  $\propto$  distance

traversed through scintillator in  
AV + distance traversed  
through opposite end water

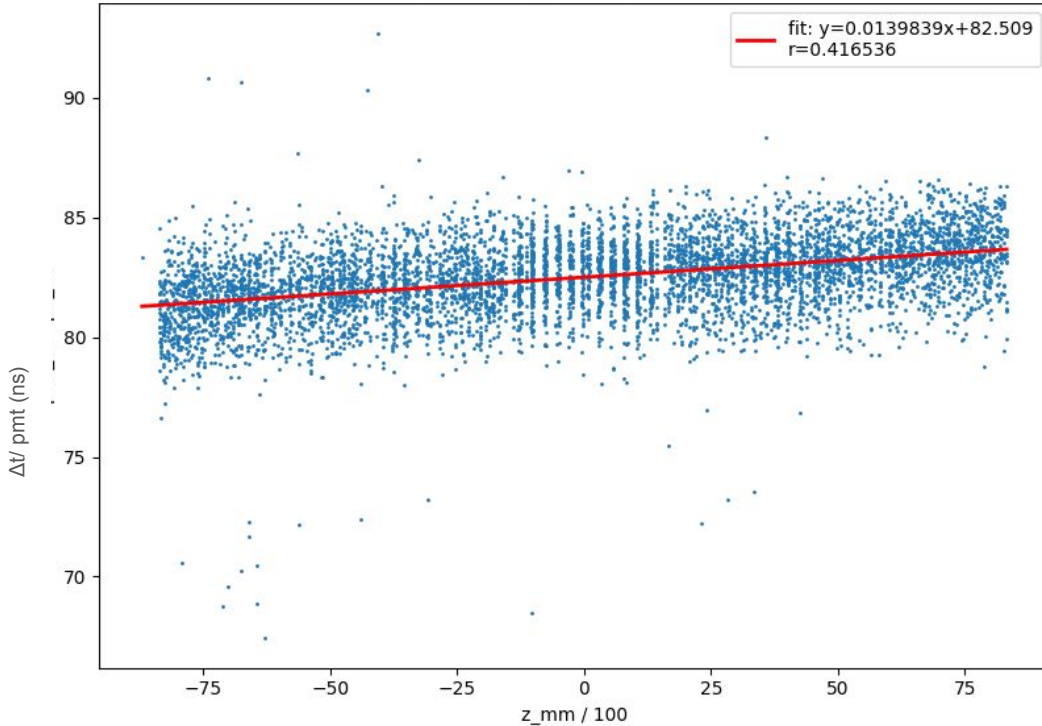


# Data selection, Methodes



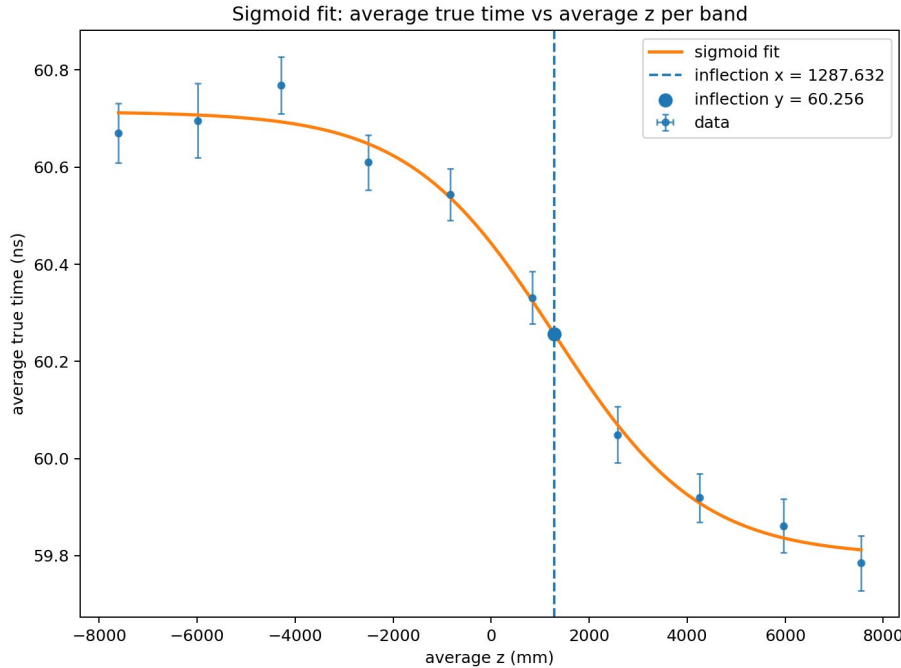
# Select Data, Results:

$\Delta t / \text{pmt}$  (ns) vs  $z / \text{PMT}$ (mm)



1. 6540 valid PMT data points
2. Linear Regression reflects
  - a. 20 cm offset
  - b. Dominated by Time water
3. Raw data of peaks
  - a. Time in water need to be removed
    - i. Per PMT
    - ii. Per Distance
  - b. Group to Band by Z

# Results:



Subtracting time difference in far water

- Time dominated per PMT- AV distance

Use inflection time as mean time

- $60.256 \pm 0.066$  ns

Get:

$$n_{\text{LAB}} = 1.505 \pm 0.034$$

Assumption: light straight line

# Discussion: fit

Input measured IoR for LAB into simulation

- account for reflection and refraction:
- For  $z = 1.29 \pm 0.27$  m
  - Gives 60.140 ns effective time

60.140 ns and 60.256 ns differs by 0.116 ns

Consider other systematical errors:

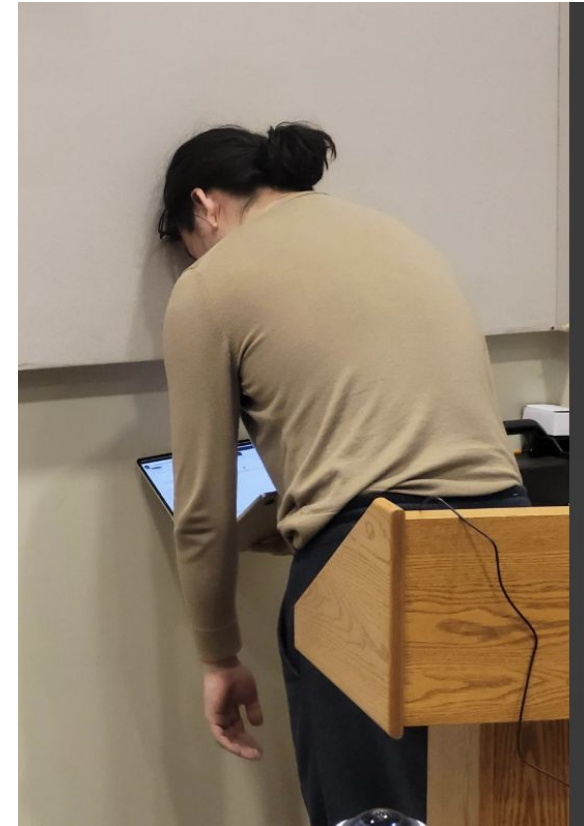
- Position bias and it's uncertainty

Results in order of 0.5 ns, well bounded



# Conclusion

1. Successfully measured light time propagation in SNO+ AV
  - a. using data from Laserball collection
2. Measure index of refraction of  $1.505 \pm 0.034$
3. Next step : Investigate systematical errors
4. Further Refinements



The me exhausted



# THE SNO+ EXPERIMENT

*Probing the nature of neutrinos*

Ryan Bayes! Szymon Manecki! Christine kraus! Aleksandra Bialek! Cody O'neill !

**Credits! Yay : D**

And all the SNO+ collaborators!

# Citations

Charles Drummond Ellis, W. A. Wooster; The average energy of disintegration of radium E. *Proc. A* 1 December 1927; 117 (776): 109–123.

<https://doi.org/10.1098/rspa.1927.0168>

Advanced information. NobelPrize.org. Nobel Prize Outreach 2026. Tue. 7 Apr 2026. <<https://www.nobelprize.org/prizes/physics/1995/advanced-information/>>

Pauli, Wolfgang. *Dear Radioactive Ladies and Gentlemen*. 4 Dec. 1930. Letter.

Ellis, C. D. (1927). The average energy of disintegration of radium E. *Proceedings of the Royal Society of London. Series A*, 117(776), 109–123.

<https://doi.org/10.1098/rspa.1927.0168>

Singh, M. & Karmakar, Shuvadeep & Wong, H & Singh, Damini & Singh, Venktesh. (2020). Recent Advancements in Detector Technology to Reduce the Background for  $0\nu\beta\beta$  decay.

Agostini, Matteo; Benato, Giovanni; Detwiler, Jason A.; Menéndez, Javier; Vissani, Francesco (30 May 2023). "Toward the discovery of matter creation with neutrinoless  $\beta\beta$  decay". *Reviews of Modern Physics*. 95 (2) 025002. [arXiv:2202.01787](https://arxiv.org/abs/2202.01787). [Bibcode:2023RvMP...95b5002A. doi:10.1103/RevModPhys.95.025002](https://doi.org/10.1103/RevModPhys.95.025002).

Zhang, H. S., Beretta, M., Cialdi, S., Yang, C. X., Huang, J. H., Ferraro, F., Cao, G. F., Reina, G., Deng, Z. Y., Suerra, E., Altília, S., Antonelli, V., Basilico, D., Brigatti, A., Caccianiga, B., Giammarchi, M. G., Landini, C., Lombardi, P., Miramonti, L., ... Votano, L. (2024). *Refractive index in the JUNO liquid scintillator. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 1068, 169730.

<https://doi.org/10.1016/j.nima.2024.169730>

SNO collaboration, J. Boger et al., The Sudbury Neutrino Observatory, *Nucl. Instrum. Meth. A*449 (2000) 172–207, [nucl-ex/9910016].