The MAD-CHANDLER 650 Reactor Anti-neutrino Detector

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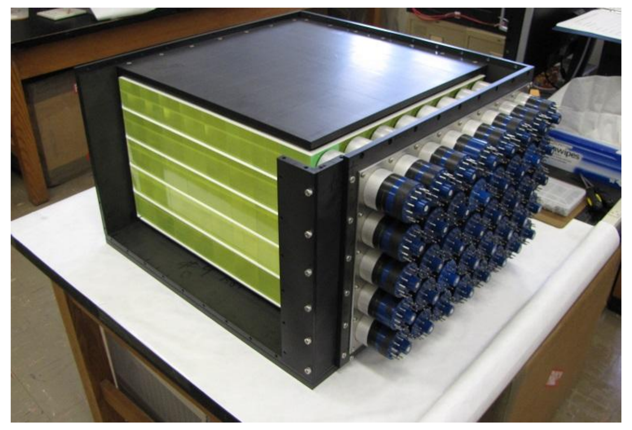
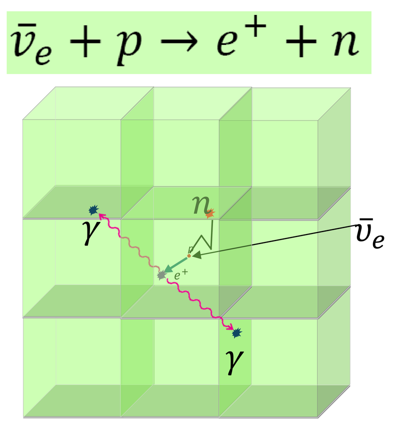
THE CHANDLER TECHNOLOGY

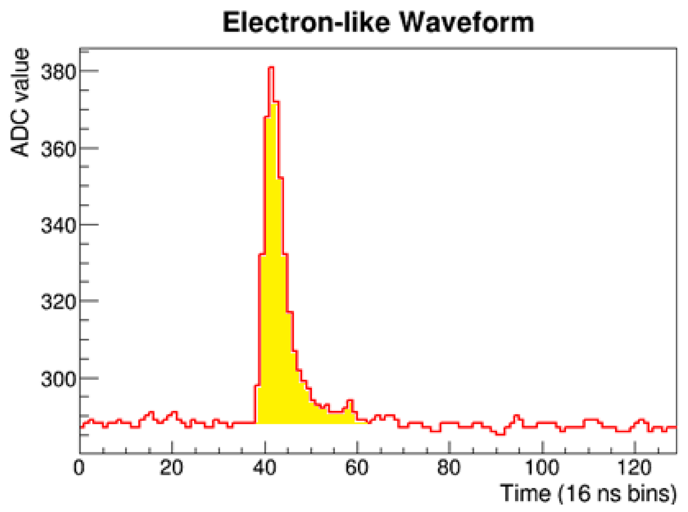
The CHANDLER technology employs a highly-segmented grid of wavelength shifting plastic scintillating cubes for positron detection sandwiched between ^{6}Li loaded ZnS sheets for neutron capture and tagging. The detector identifies the prompt and delayed components of inverse beta decay events with high spatial granularity. This configuration of optically connected cubes is known as the Raghavan Optical Lattice.

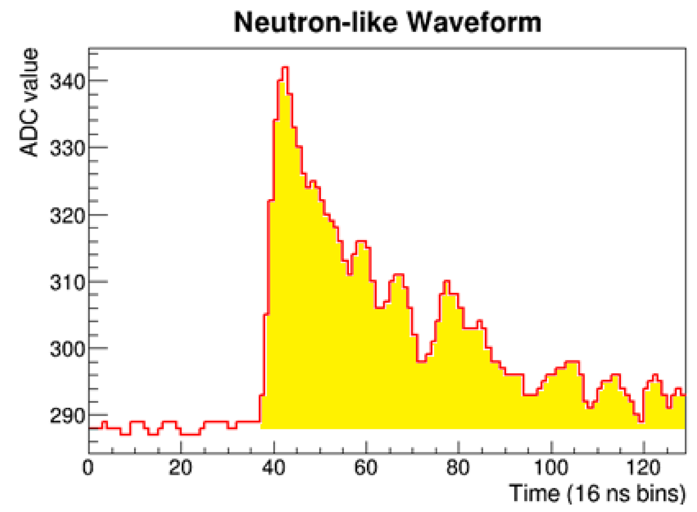




Light from the sheets is collected and transported to the edges with the cubes through total internal reflection. The Raghavan Optical Lattice allows us to achieve unprecedented spatial resolution over a large, unbroken detector mass.

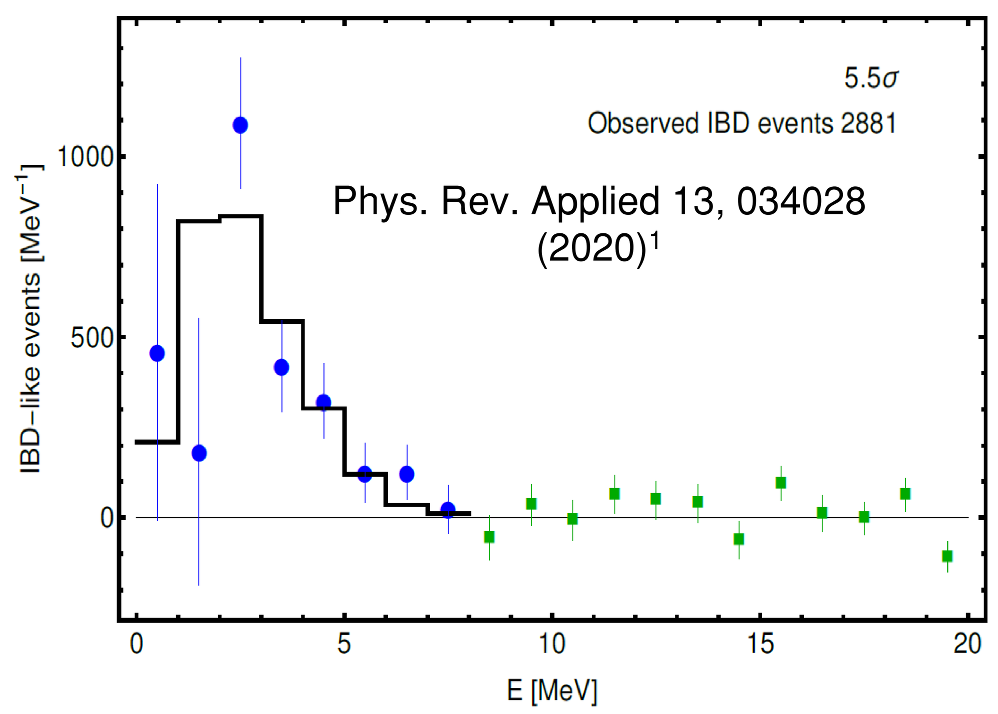
Neutron capture in **CHANDLER** has a **distinct signature**: the ZnS scintillator releases its light over a longer time scale (~200 ns) than the cubes (~10 ns)





MiniCHANDLER

MiniCHANDLER is an 80kg system consisting of an 8 x 8 x 5 grid of cubes viewed by 80 PMTs on two sides. There are 6 neutron sheets total.

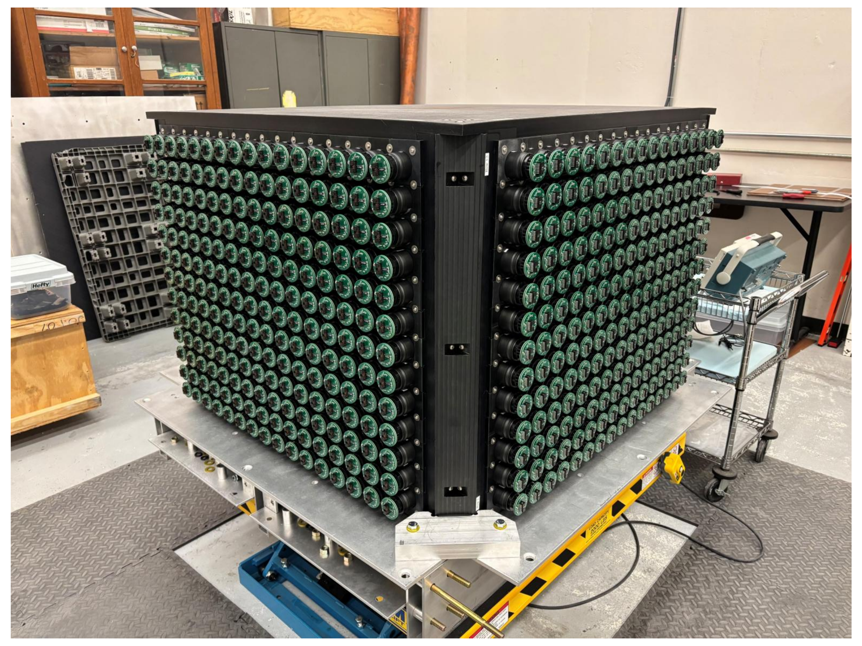


MiniCHANDLER was installed in the Mobile Neutrino Lab and deployed at the North Anna generating station, for 4 months, including 1 month of reactor off in 2017

The MiniCHANDLER reactor campaign observed 2881 IBD events

MAD-CHANDLER-650

MAD-CHANDLER-650 is one of two reactor antineutrino detectors part of the Mobile Antineutrino Demonstrator project (See posters **492**, N. Bowden and **493**, S. Ghosh). MAD-CHANDLER-650 is a larger 3D detector based on the CHANDLER technology consisting of 25 layers of a 16 x 16 grid of plastic scintillating half-cubes. It has an active mass of 650 kg and uses 832 PMT's.

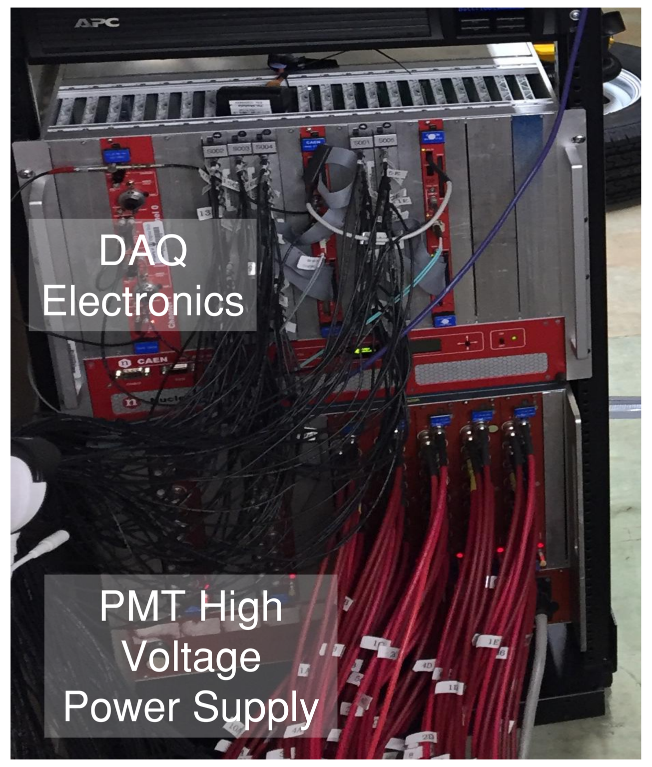


UPGRADES

After the MiniCHANDLER reactor campaign at North Anna, several upgrades were developed to improve performance beyond the original prototype configuration and have been incorporated into the MAD-CHANDLER-650 design. They include:

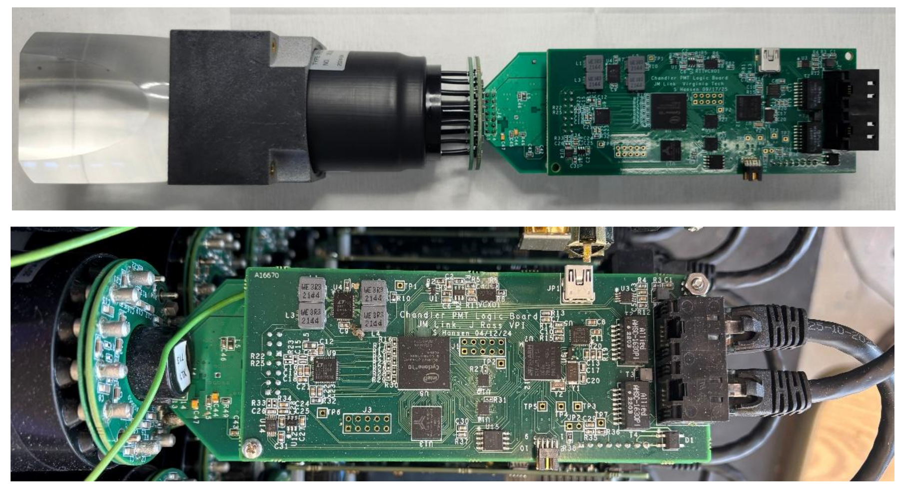
- **New Electronics* (All-in-One Base):** The upgraded all-in-one PMT base integrates high-voltage control and signal readout into a compact electronics package. This reduces cable clutter and power usage while improving system stability. The high voltage is generated and controlled through the board-level electronics and can be adjusted remotely using an Ethernet-based controller.

Old Electronics



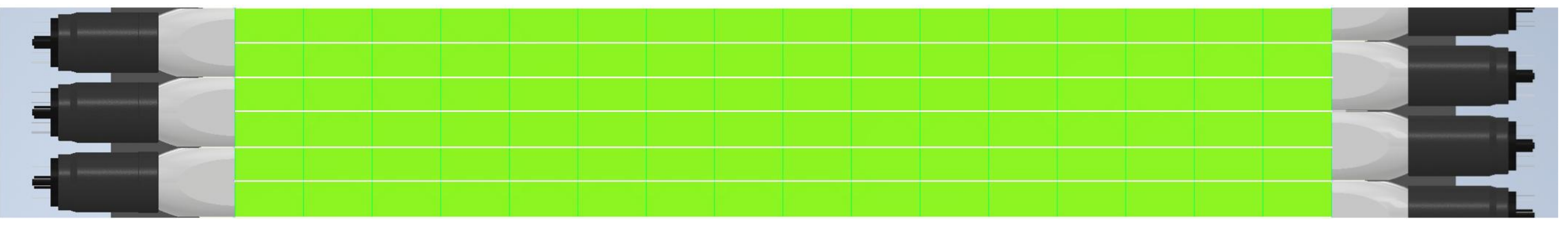
New Electronics

All-in-One Base

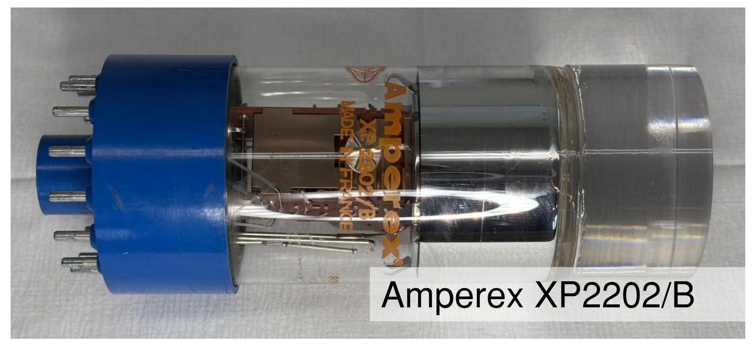


- Onboard HV generator, analog-to-digital converter (ADC) and FPGA for signal processing
- Replaces bulky rack-mounted electronics with compact PMT-base readout boards
- Reduces electronics footprint from 16U to 2U of rack space in MiniCHANDLER
- Reduces cable clutter, power usage, and eliminates channel-to-channel cross-talk

- **Half cubes*:** By using half cubes, allowing for extra neutron sheets show a 35% increase in neutron capture, 65% decrease in random coincidences and only a 12% increase in cost.

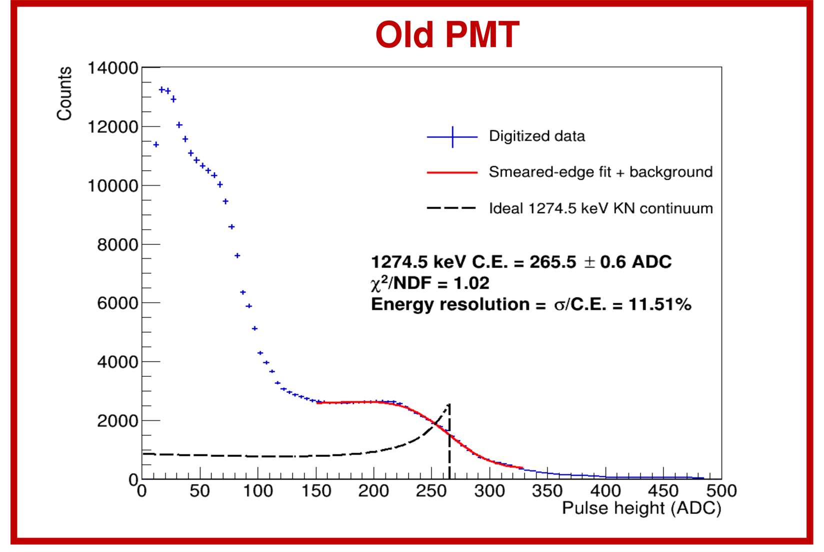


- **Improved Optics*:** New PMTs (Hamamatsu R6231-100) and parabolic light guides to focus photons from a cube face onto the cathode's circular face

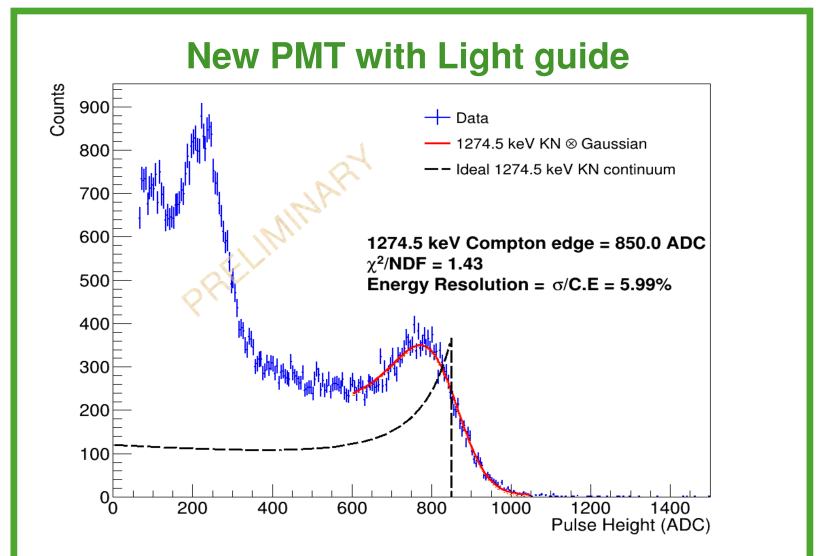


In a gamma study, we studied the detector resolution with a Na-22 source. In the fit, a Klein-Nishina Compton-scattering model convolved with a Gaussian is used to extract the 1274.5 keV Compton edge energy resolution.

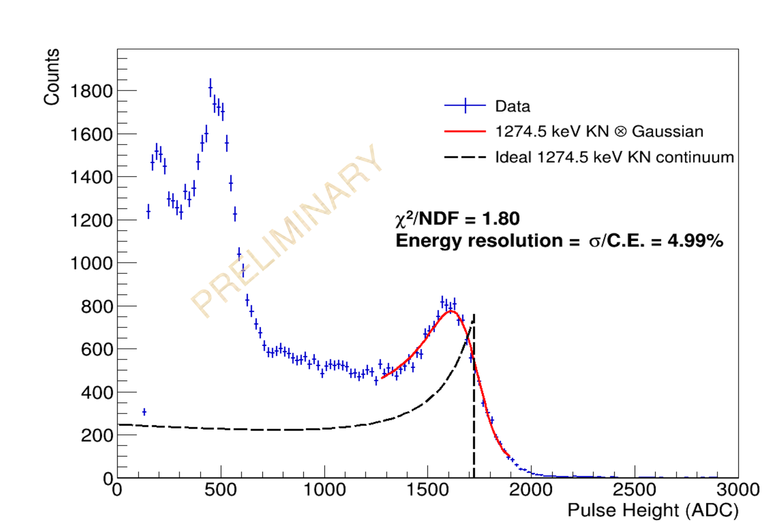
Old PMT



New PMT with Light guide



- Sharper 1274.5 keV Compton edge response
- Single PMT measured energy resolution improves from **11.5%** to **6.0%**

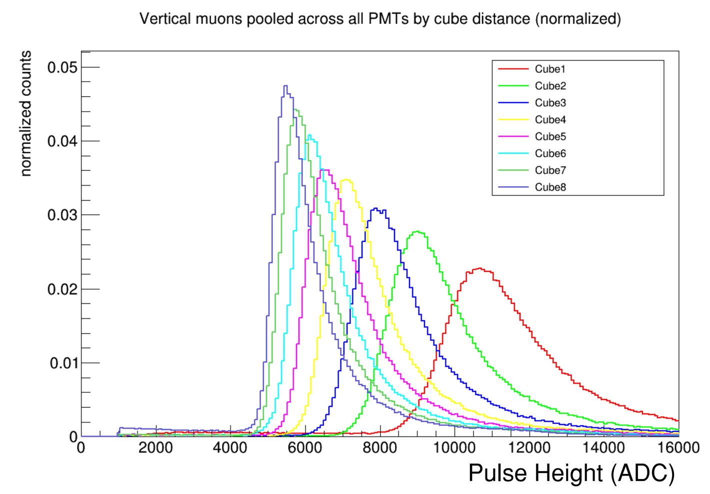


- Improved energy resolution when combining the two PMTs viewing the source cube (**5.0%**)

- **PMT's on all sides:** This help us readout a 16 x 16 array and narrows down signal location efficiently
- **Low Z Shielding:** 0.5 m of shielding is added to reduce fast neutron backgrounds

Conclusion/Summary

- MiniCHANDLER has been upgraded with new PMTs, light guides, and compact all-in-one electronics.
- Vertical muons are used to calibrate and measure light attenuation across cube distance.
- Na-22 calibration measurements demonstrate improved energy resolution with the upgraded optics.
- These upgrades are being tested in MiniCHANDLER ahead of a new reactor campaign and have been incorporated into the completed MAD-C-650 detector.



REFERENCES

1. Haghighat et al., 2020, **"Observation of Reactor Antineutrinos with a Rapidly-Deployable Surface-Level Detector"**, https://doi.org/10.48550/arXiv.1812.02163

*Currently being tested on MiniCHANDLER

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