The CHANDLER Reactor Neutrino Detector

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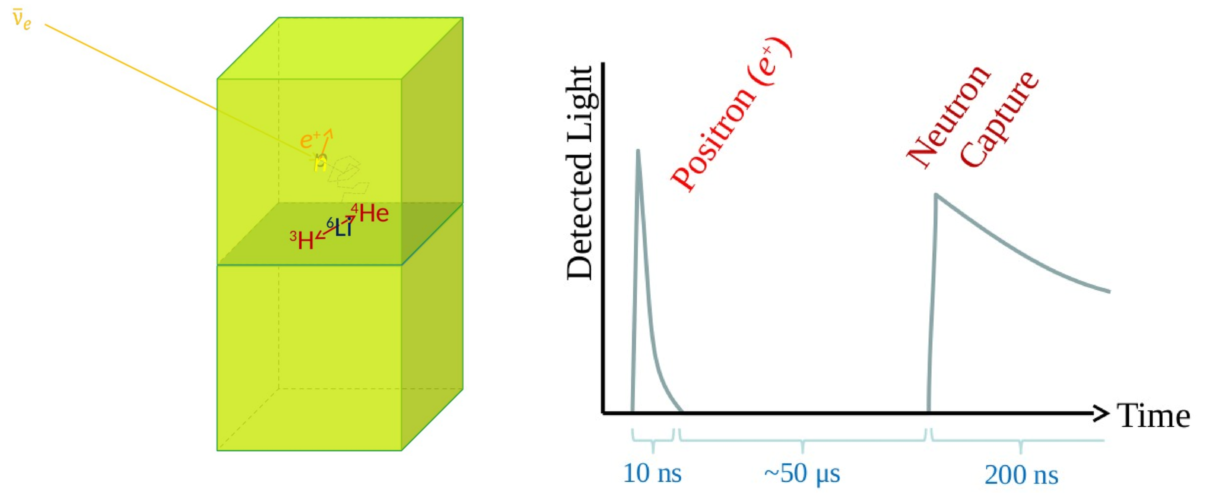
Introduction

CHANDLER is composed of layers of wavelength shifting plastic scintillating cubes separated by the sheets of ^{6}Li loaded zinc sulfide (ZnS) scintillator.

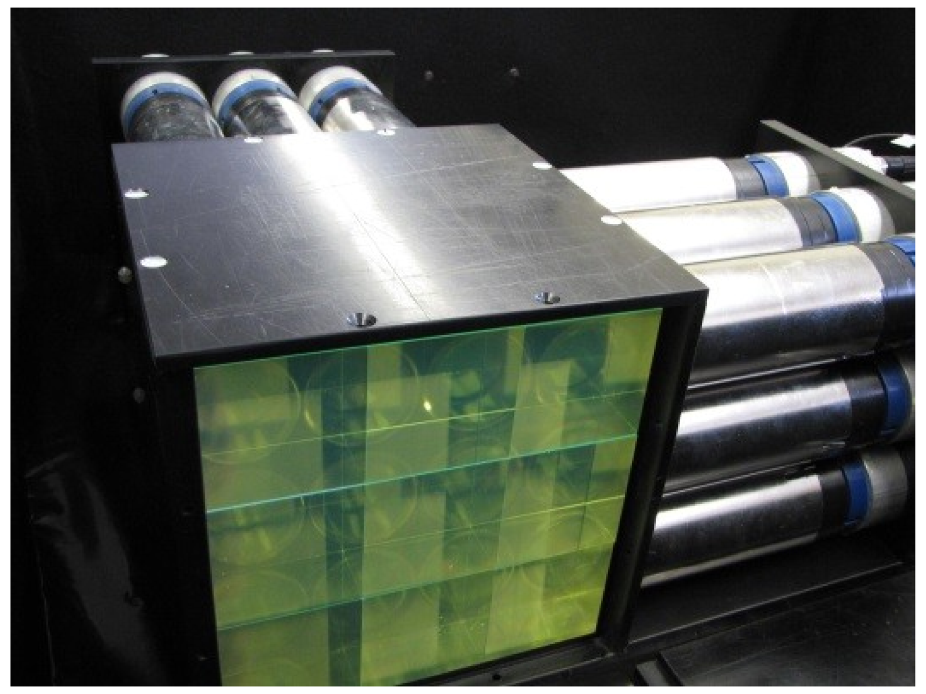


Neutrino interaction in a cube (left) and positron and neutron pulse in time (right)

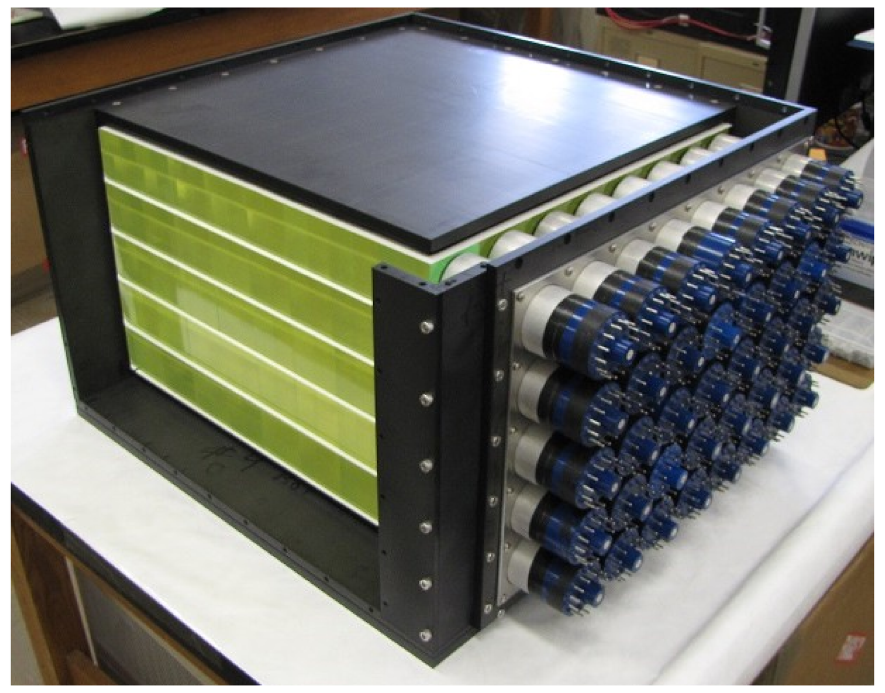
Positrons from inverse beta decay (IBD) deposit energy in the cubes giving a prompt signal, which is followed by the neutron capture on ^{6}Li in the sheets, which forms a delayed signal. Light produced by charged particle in a cube is transmitted to the detector's surface by total internal reflection where it is collected by PMTs. The ZnS light is absorbed by the wavelength shifter in the cubes and retransmitted.

Detector R&D

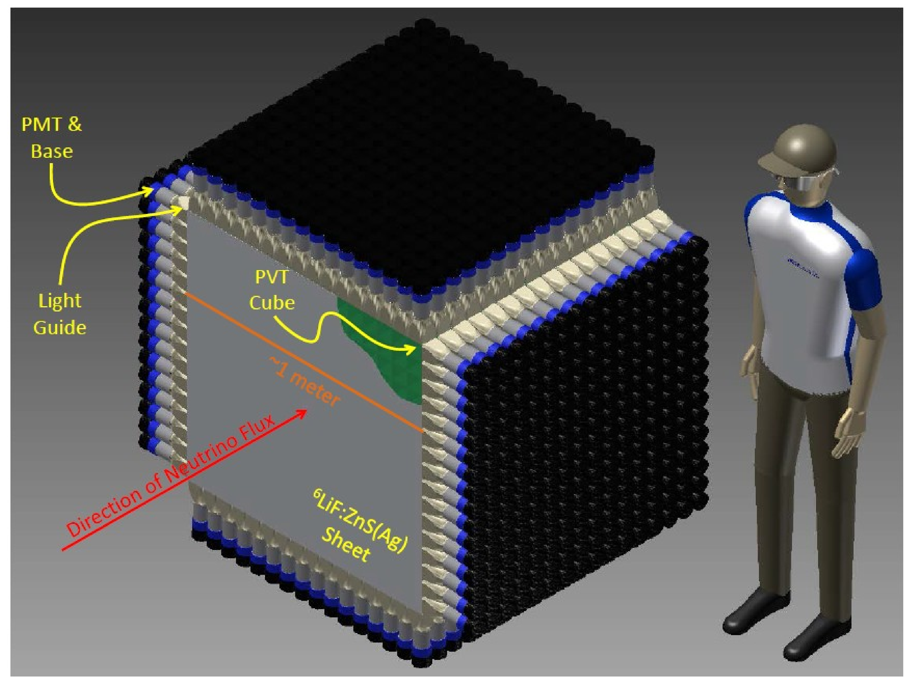
The program consists of three stages.



MicroCHANDLER
A 3×3×3 prototype used to study neutron capture, data acquisition and background rates.



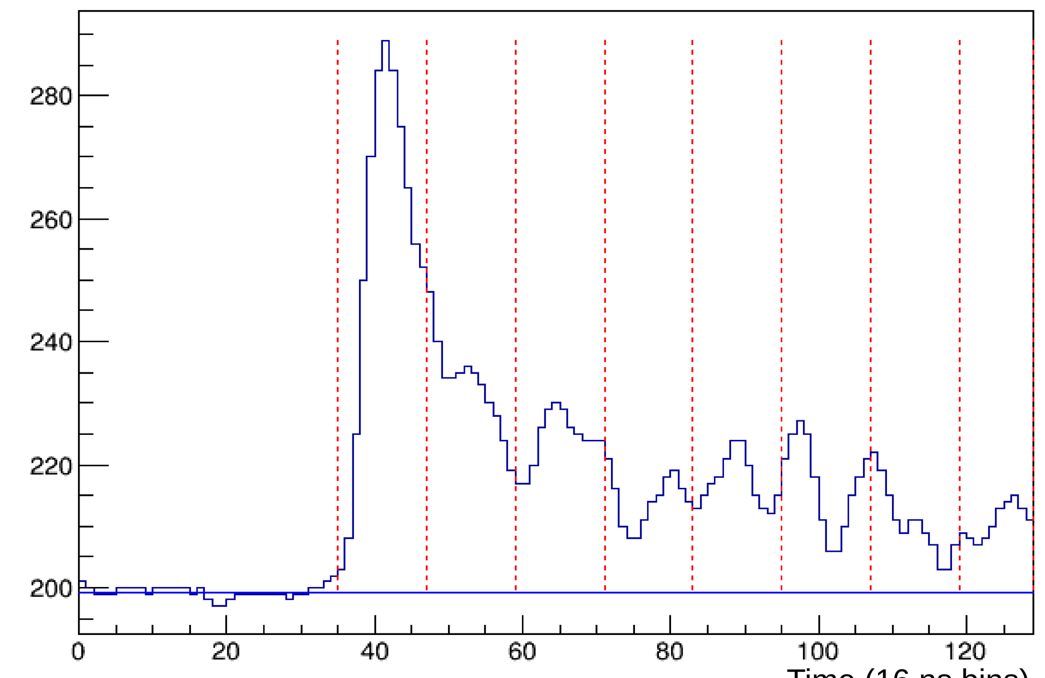
MiniCHANDLER
An 8×8×5 Prototype for an overall system test and optimization.



CHANDLER
The full scale detector is 16×16×16 cubes with a mass of 1 ton for sterile neutrino search and nuclear non-proliferation.

Neutron Identification

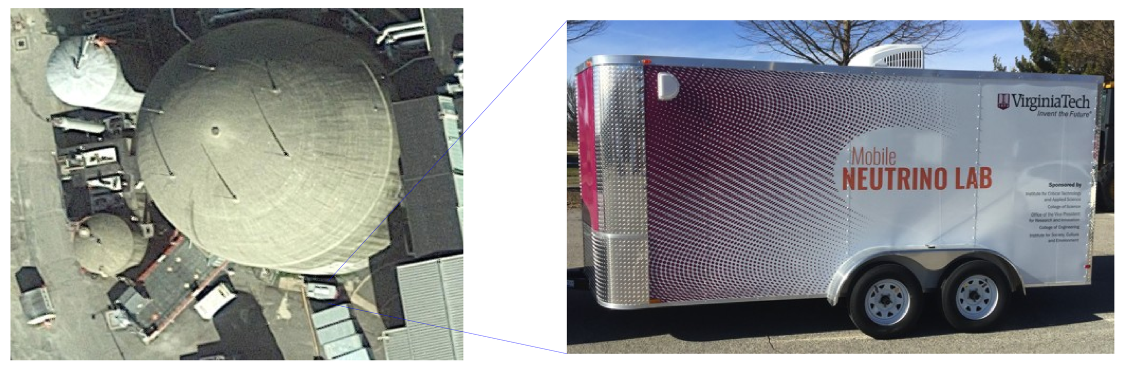
To identify neutrons captured on ^{6}Li, we divide the waveform into eight time-segments and find the normalized area in each segment. The area values are then compared with the standard neutron and gamma template for pulse shape discrimination.



A neutron waveform

Deployment

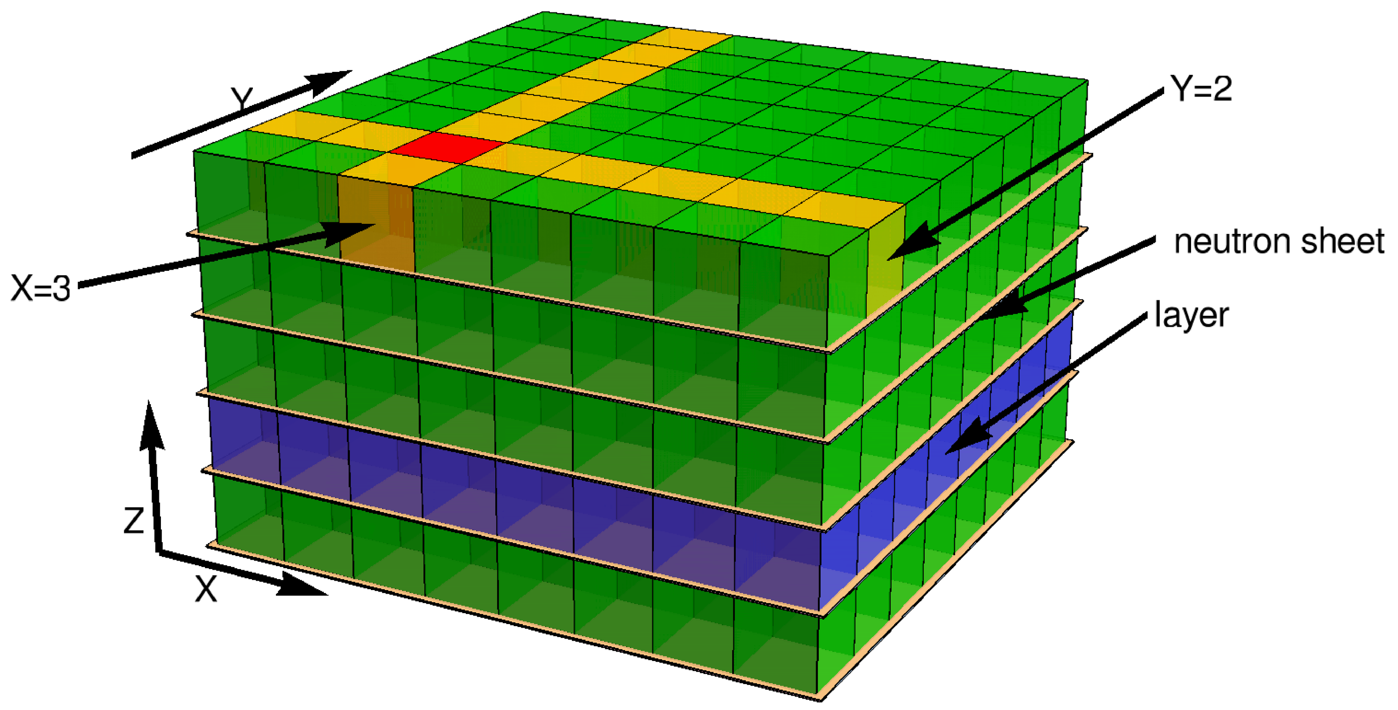
We installed MiniCHANDLER inside a trailer, deployed it at North Anna Nuclear Power Plant and took data for four months, including both reactor on and reactor off periods.



North Anna Nuclear Power Plant and the trailer

Prompt Energy Reconstruction

The position of an event is determined from the PMT signals along x and y-directions. Vertical muons are used for energy calibration, which is further cross-checked with ^{22}Na source Compton edges.

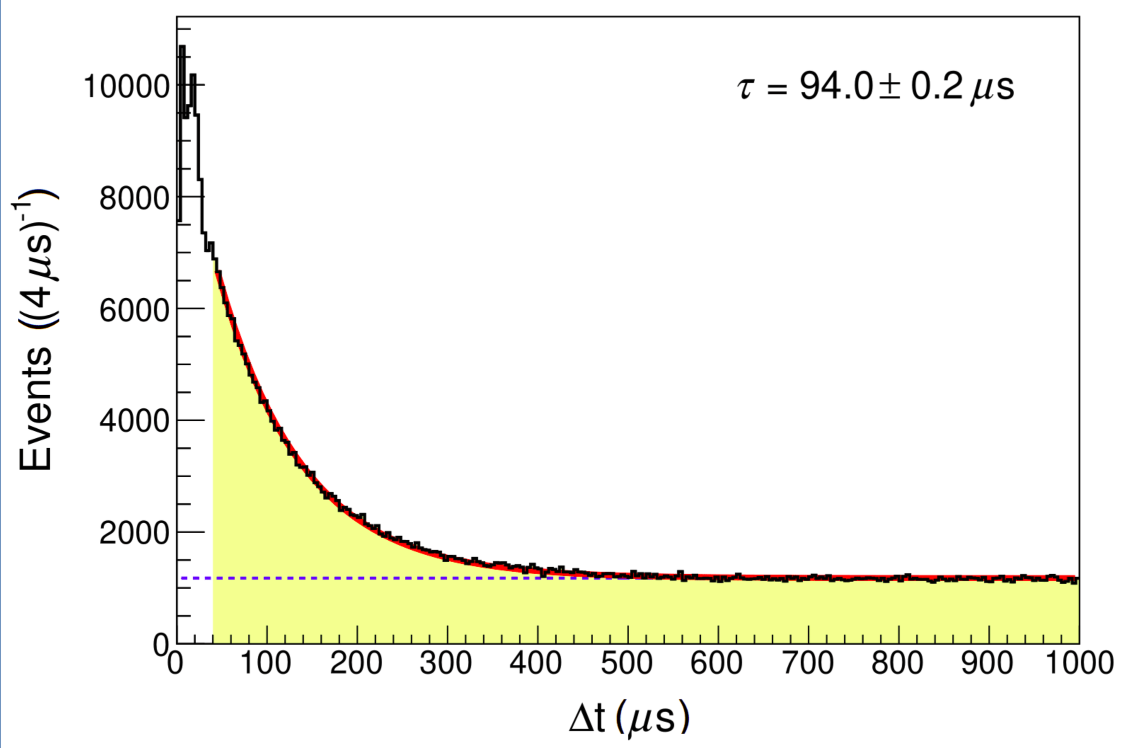


MiniCHANDLER schematic

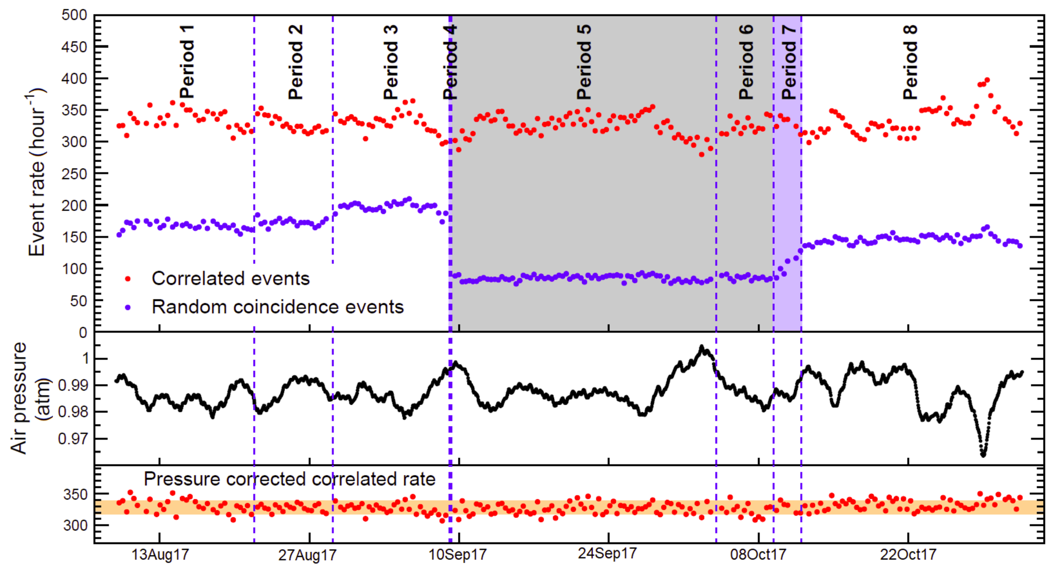
IBD Analysis

Event Selection

- Require prompt and neutron to be within neighboring cubes
- Fit Δt histogram with exponential plus constant parts.
- The flat part gives the random coincidence events, and the exponential part represents correlated events (cosmic ray fast neutrons and IBD events).
- The correlated events are stable over the reactor periods.



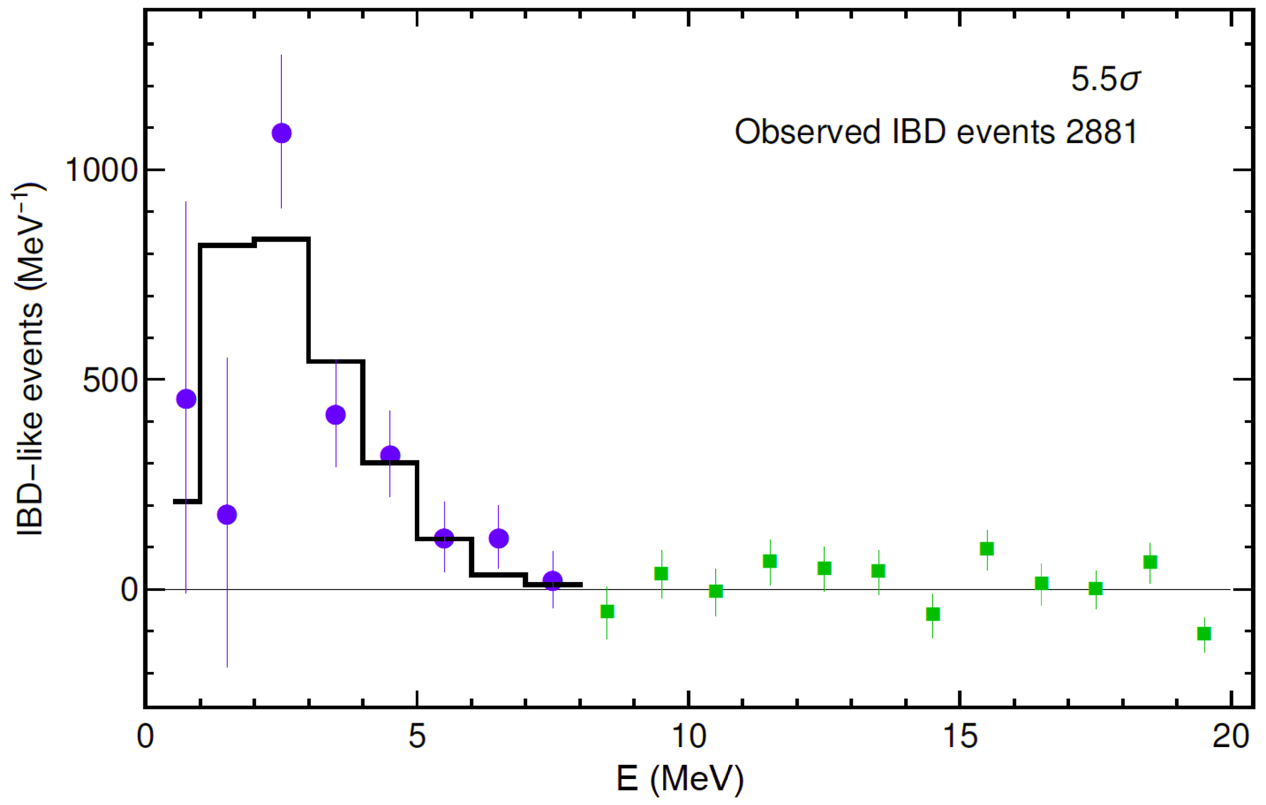
Prompt neutron Δt histogram



Event rate stability

Result

- Measure the number of correlated events in 1 MeV energy bins.
- Scale the reactor-off events using the energy bins beyond 8 MeV to match the reactor-on rate.
- Since the correlated event rate is stable over different periods, subtract reactor-off rates from reactor-on to get the IBD spectrum.



IBD spectrum

Conclusion

MiniCHANDLER detected the reactor antineutrino signal from a commercial nuclear reactor at 5.5σ significance with no overburden and minimal shielding. This demonstrates a novel surface-level neutrino detection concept with a mobile neutrino detector.

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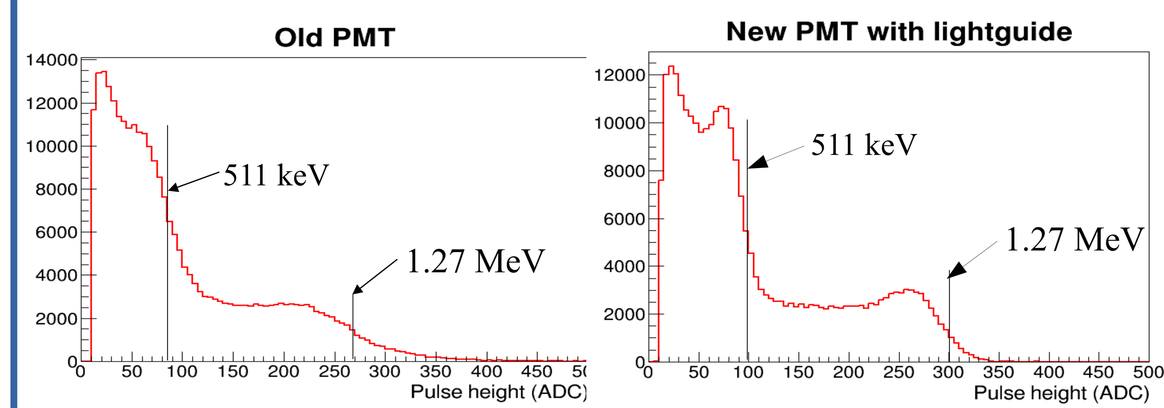
MiniCHANDLER Upgrade

We envisioned a number of improvements in MiniCHANDLER from this deployment.

- The combination of new PMTs and light guides will improve the energy resolution by a factor of two.



Compton Edge of ^{22}Na using (left) Old PMT and (right) new PMTs with light guides

- Adding a neutron sheet in the middle of each layer would increase the neutron capture efficiency by 35%.
- Adding a meter of water shielding would reduce the fast neutron background by order of magnitude.
- The use of custom electronics will increase the dynamic range by a factor of four, fix the overshoot/undershoot issue of current electronics, and eliminates the electronics cross-talk.

The upgraded MiniCHANDLER is under development and will be deployed soon at the same power plant.

Haghighat, A., Huber, P., Li, S., Link, J. M., Mariani, C., Park, J., & Subedi, T. (2020). Observation of Reactor Antineutrinos with a Rapidly Deployable Surface-Level Detector. Physical Review Applied, 13(3), 034028