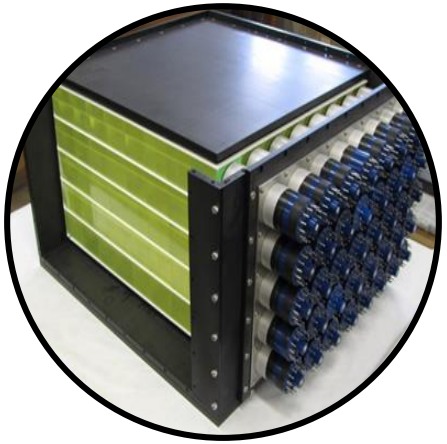


MiniCHANDLER Result

Jaewon Park

Center for Neutrino Physics, Virginia Tech

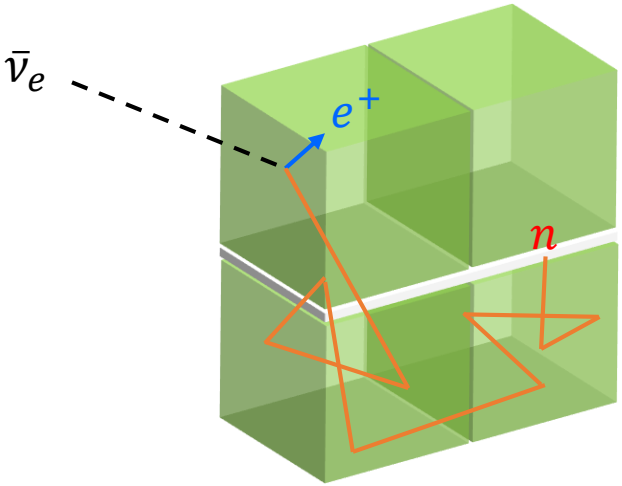
AAP 2018

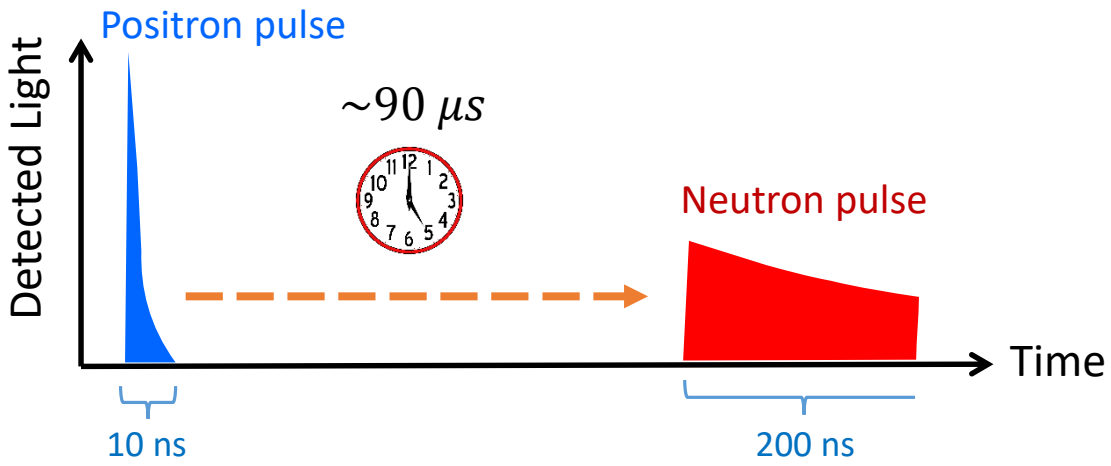
Lawrence Livermore National Laboratory, Oct 10-11, 2018

How It Works

Inverse beta decay (IBD)

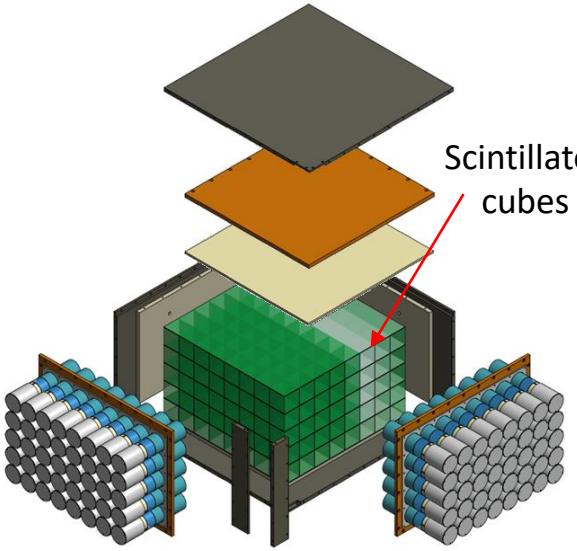
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

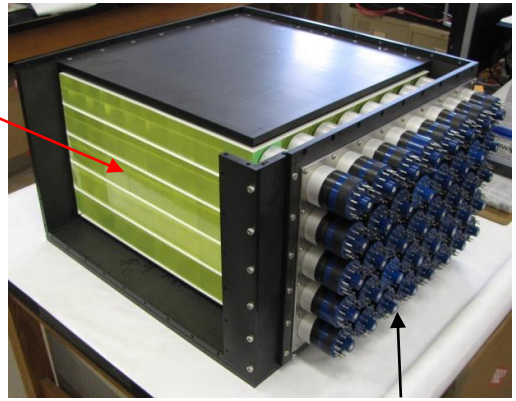


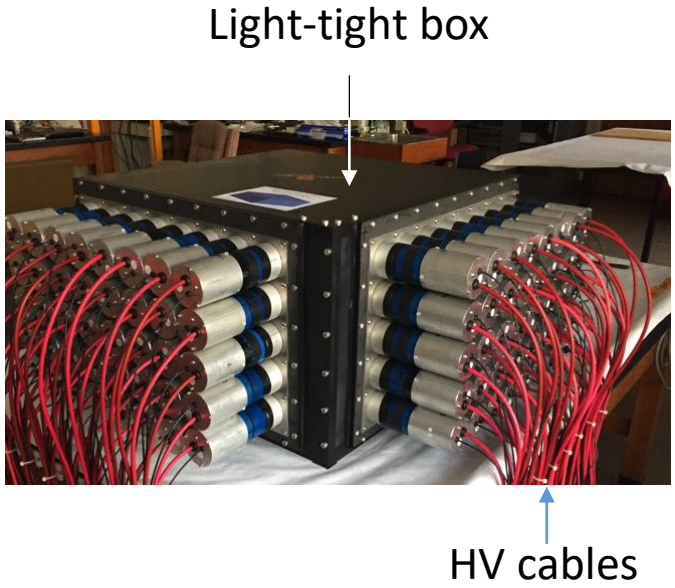


- Most positron stops in a single cube
- Neutron capture time: $\sim 90\ \mu s$
- Neutron capture on ^{6}Li-loaded ZnS sheet
- Long scintillator decay time of ZnS gives pulse shape discrimination (PSD)
- Cube design
  - Prompt-delay spatial correlation
  - Topological event selection utilizing 511 keV gamma

MiniCHANDLER Detector



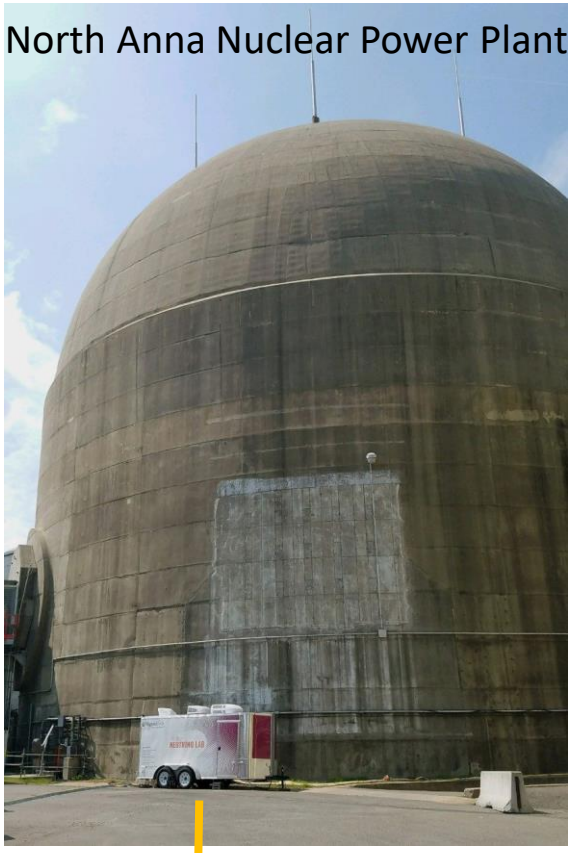




- 62 x 62 x 62 mm^3 wavelength-shifting scintillator cube
- Light read out by total internal reflection in X and Y directions
- 8 x 8 x 5 cubes (320 cubes)
- ^{6}Li-loaded ZnS neutron sheet between layers and top/bottom
- 80 2-inch PMTs
- PMT pulse → preamp + shaper (25 ns shaping time) → 16 ns waveform digitizer

Mobile Neutrino Lab

- Mobility + fast deployment
- Reactor monitor for nuclear nonproliferation
- Data taking: June 15, 2017 – November 2, 2017 at North Anna Nuclear Power Plant
  - 48 days reactor-on, 24 days reactor-off



Inside the trailer

PMT fan

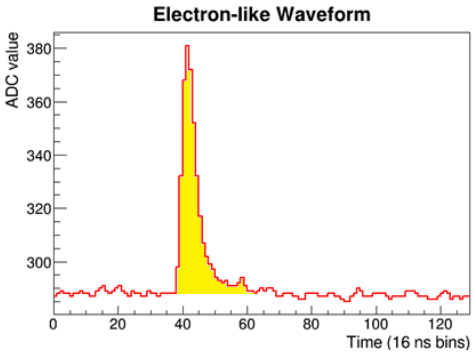
Boron-loaded plastic panel (light purple)

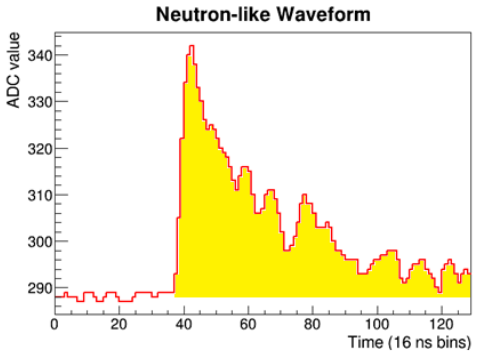
Electronics rack

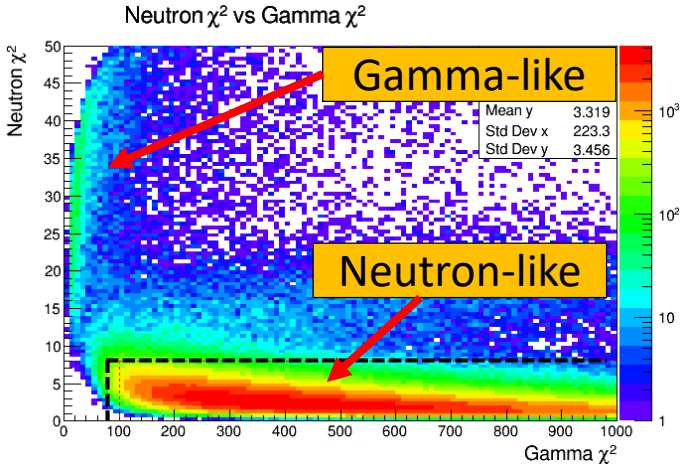
MiniCHANDLER detector

Mobile Neutrino Lab (trailer)

Neutron Tagging

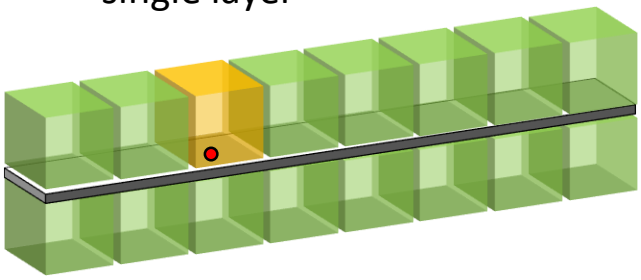




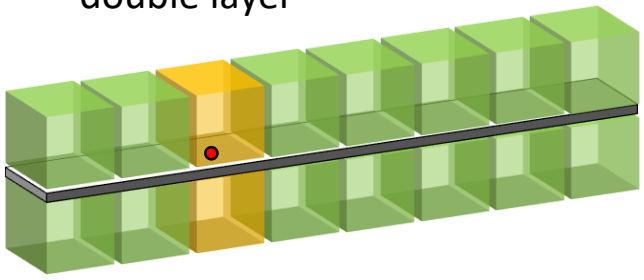


- Neutron PID = (area under pulse) / (pulse height)
- PMT flasher can mimic high value of neutron PID
- Use two χ^2s based on electron-like and neutron-like pulse shape templates to reject PMT flasher
- Neutron can be observed as single or double layer

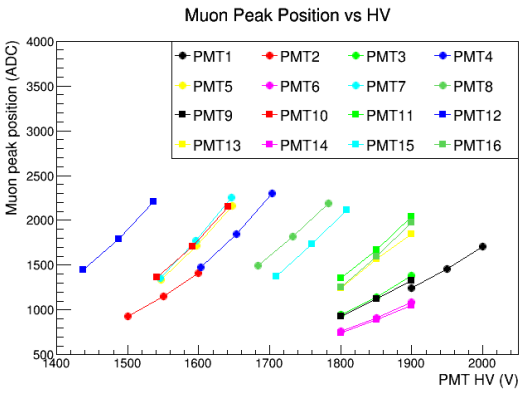
single layer



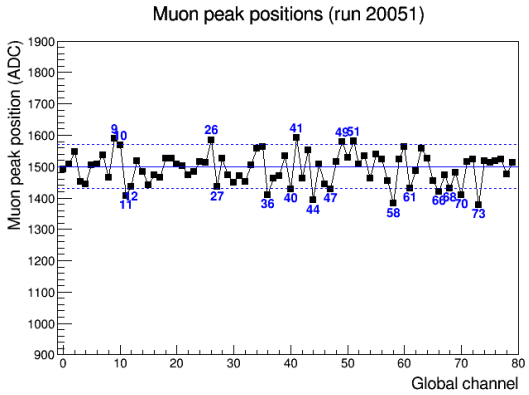
double layer



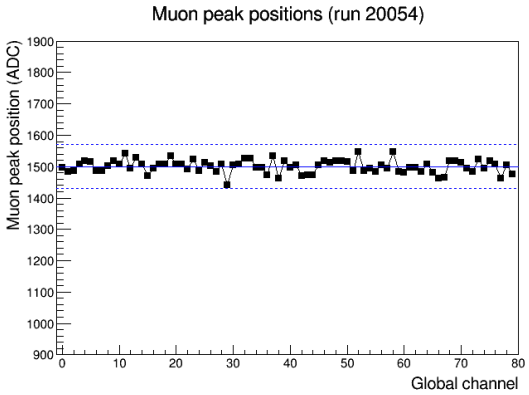
Gain Calibration



Before HV tuning

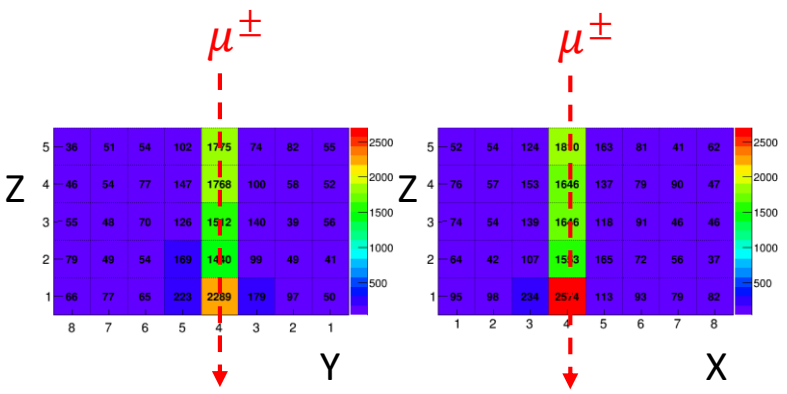


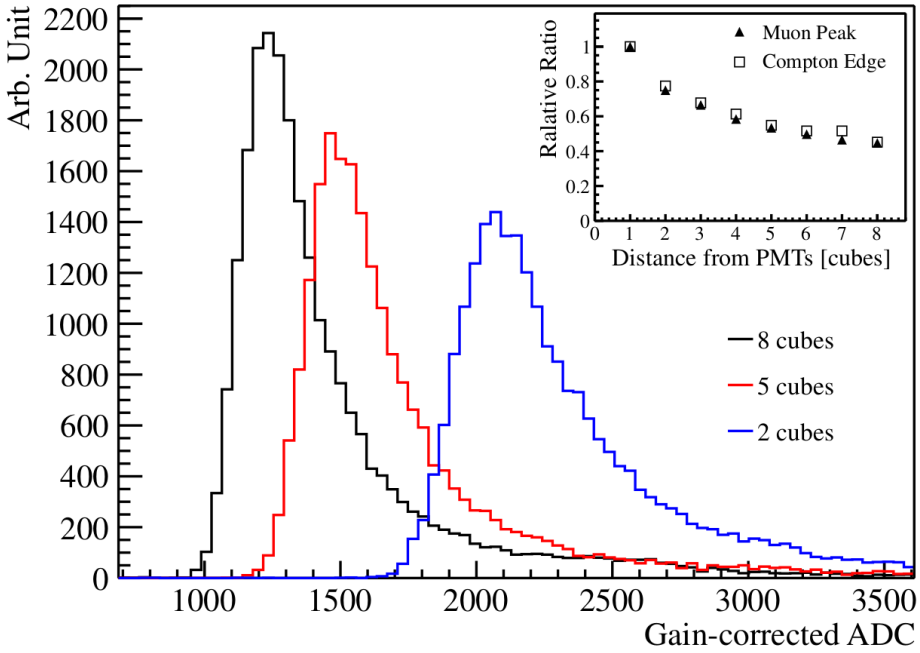
After HV tuning



- PMT HVs were tuned to equalize the light-to-ADC response
- Remaining small gain variation per PMT channel per run is applied on offline data

Vertical Muon

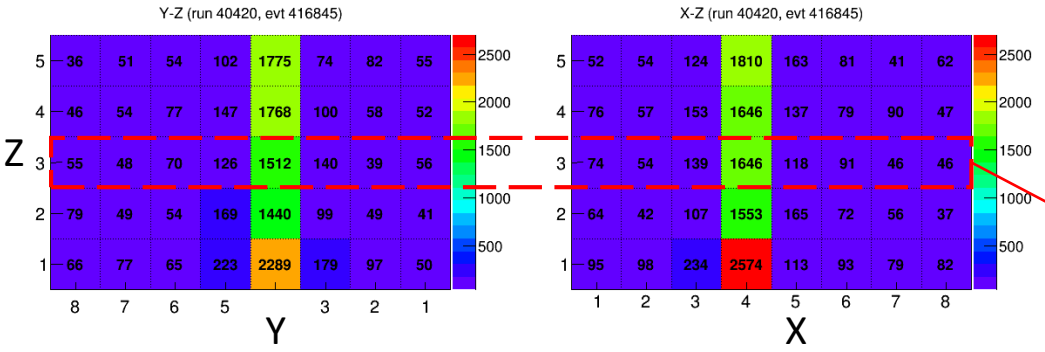




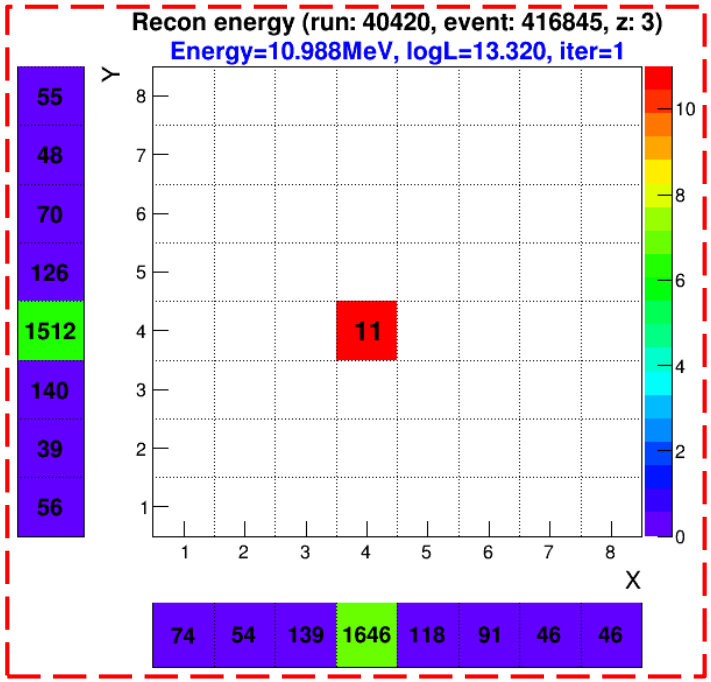
- Use cosmic muon to obtain attenuation curve
- Vertical muon provides a clean dE/dx distribution
- Peak of dE/dx as a function of distance from PMT → attenuation curve
- Muon attenuation curve is consistent with one from sodium source Compton edge

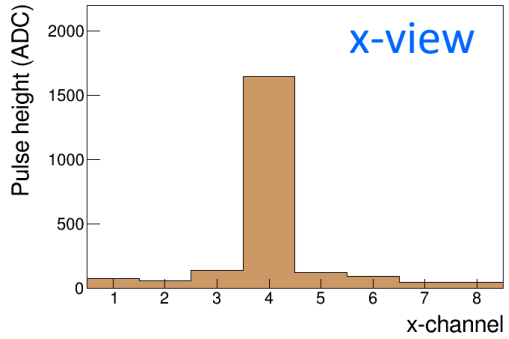
Unchanneled Light

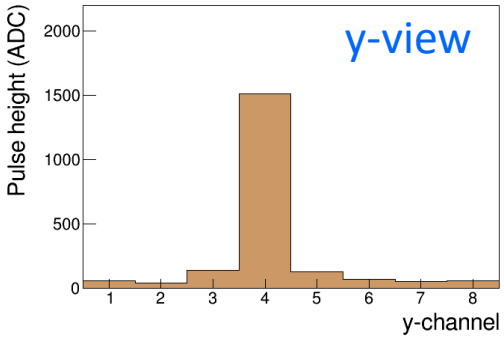
Side-view



Top-view



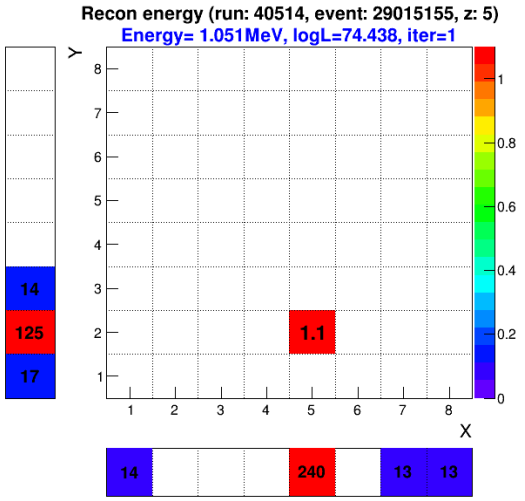




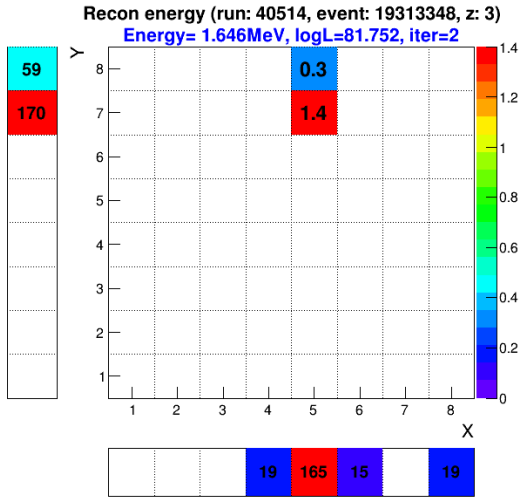
- Unchanneld light profile for 64 cube location using vertical muon
- It is used for reconstruction and simulating unchanneled light in MC

Energy Reconstruction

1-cube event

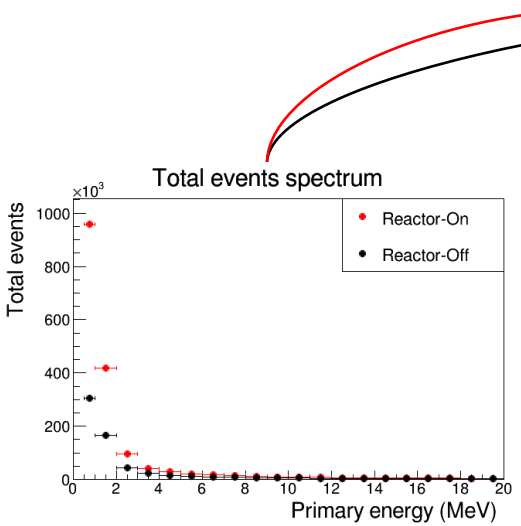


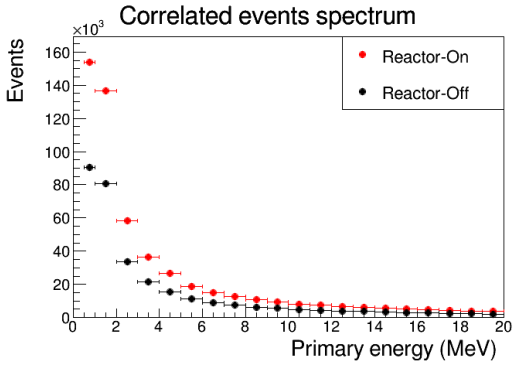
2-cube event

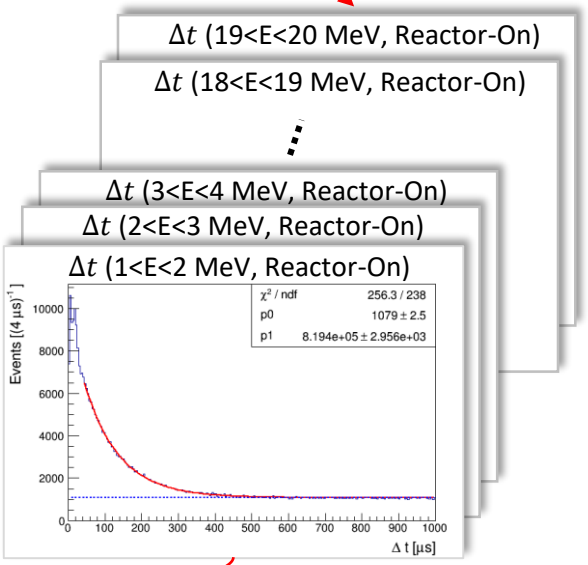


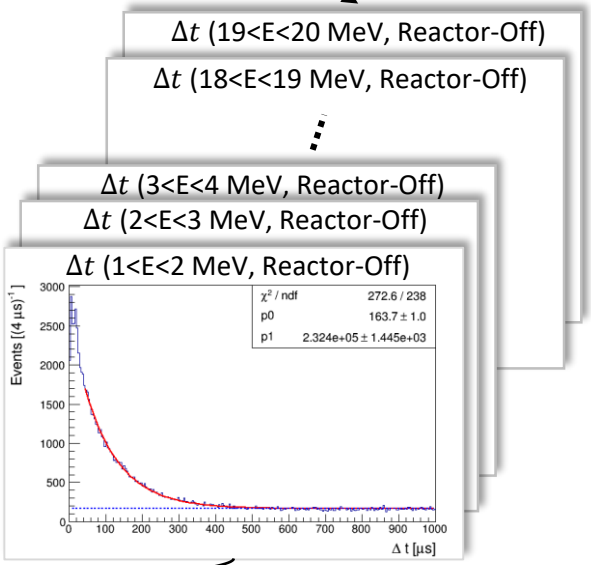
- New energy reconstruction algorithm developed since AAP 2017
- Old reconstruction didn't work well for finding 511 keV gamma
- IBD simulation study indicates that cube multiplicity is not high
- It starts with one cube and then keep trying more cubes up to 4 cubes
- MC IBD study shows high efficiency of energy reconstruction

IBD Analysis: Δt Fit In Each Energy Bin





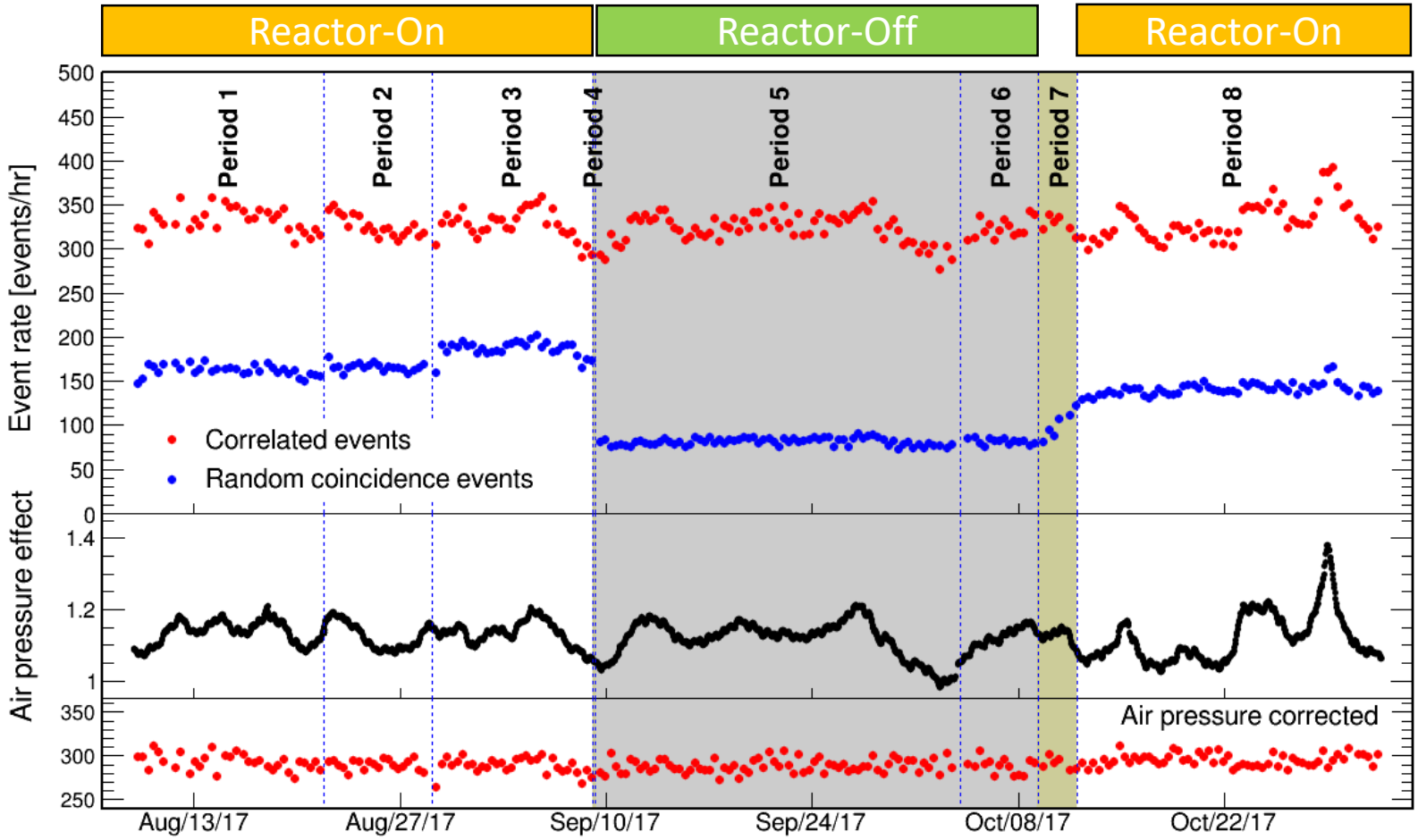




After subtracting random coincidence events

- Δt fit is performed in each 1 MeV primary energy bin to subtract random coincidence events
- $\Delta t < 40\ \mu s$ is excluded on correlated event counting due to electronics effect
- Reactor-On and Off data are normalized based on 9-20 MeV tail where no IBD events exist
- (IBD spectrum) = (Reactor-On) – (Reactor-Off)

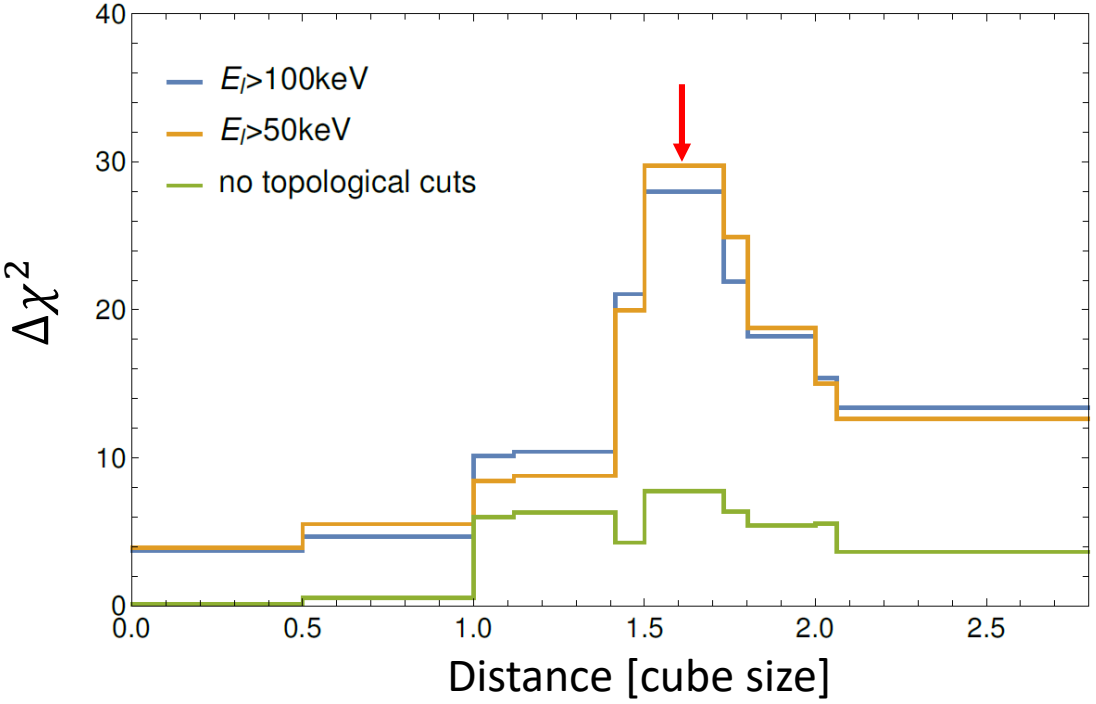
Event Rate Stability



Event Selection

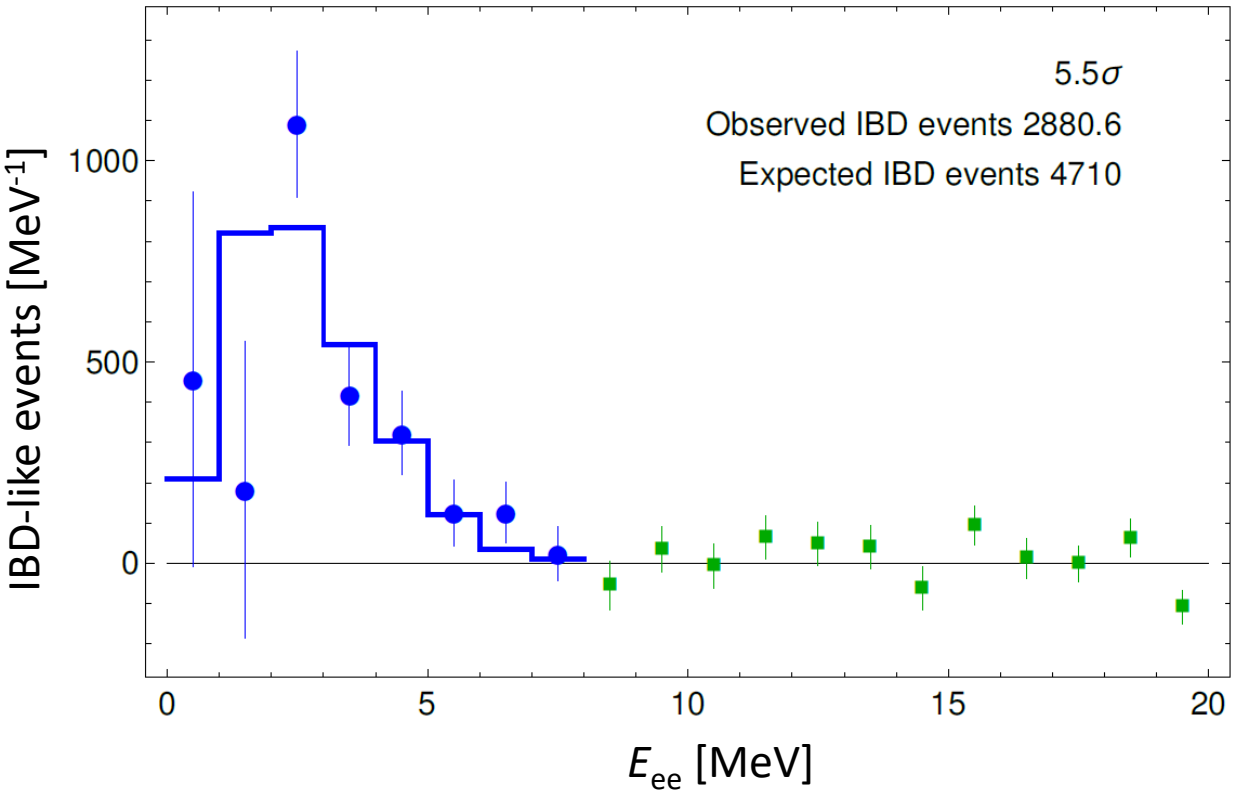
- Energy reconstruction quality cut
- Prompt-delay spatial cut: spherical distance cut
- Topological event selection to look for Compton scattering energy from two 511 keV gammas
  - At least one cube with energy = [0.05, 0.511] MeV
  - Total energy outside primary cubes is less than 2×0.511 MeV

Significance vs Distance Cut



- Optimized primary-delay distance cut for best signal significance
- Also shows the advantage of topological event selection
  - Topological event selection improved S/B by factor 4

IBD Result



- 5.5 σ IBD signal has been observed
- S:B = 1:60
- Prompt-delay distance cut + 511 keV gamma topological event selection played major role to reduce the background

Summary

- MiniCHANDLER has successfully measured > 5σ IBD signal from North Anna Nuclear Power Plant
- It demonstrated the fast-deployable antineutrino detector technology for possible nuclear nonproliferation application
- MiniCHANDLER gives useful feedbacks on improving potential full CHANDLER

Thanks you!