# ALARM

## Array of Lattice for Antineutrino Reactor Monitoring

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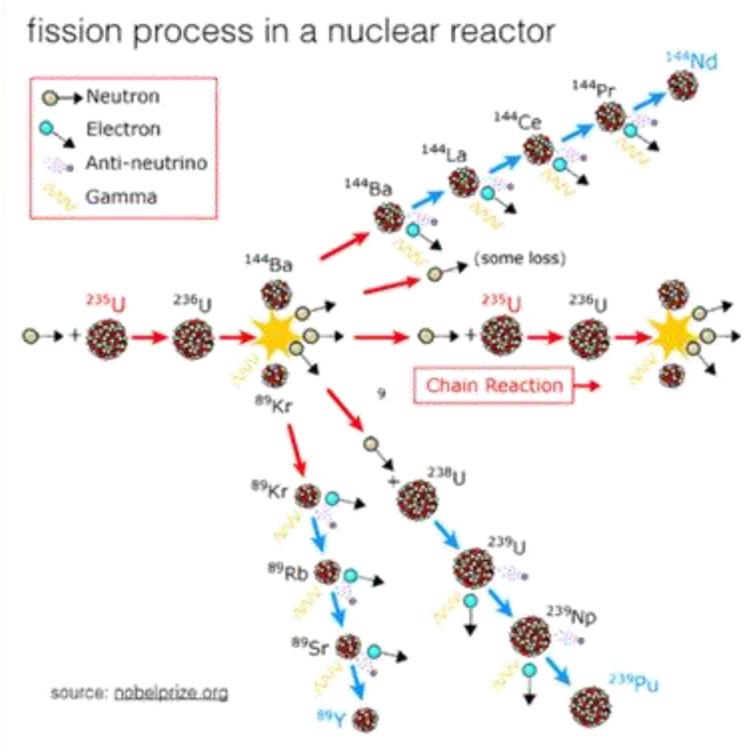
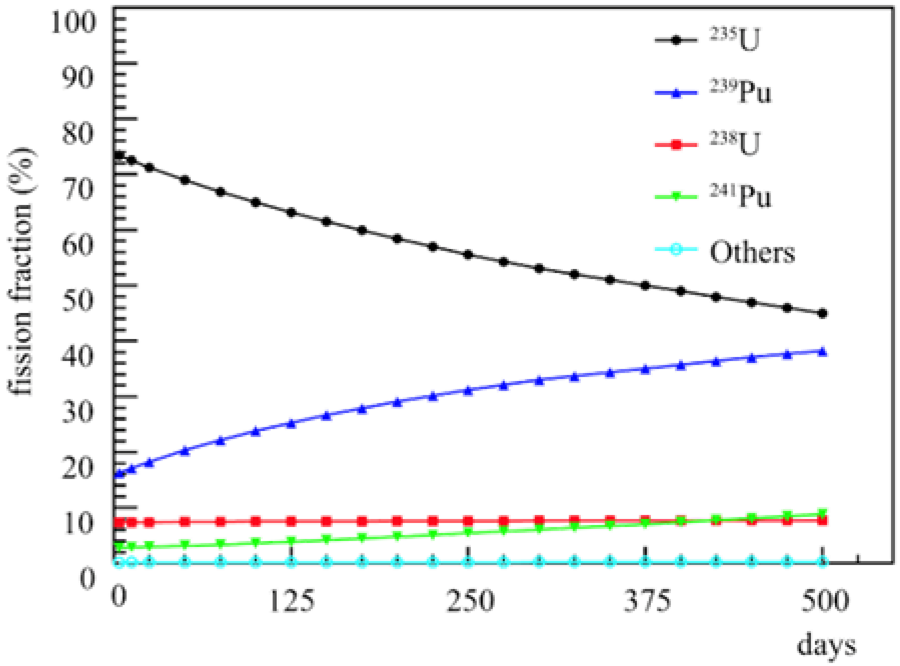
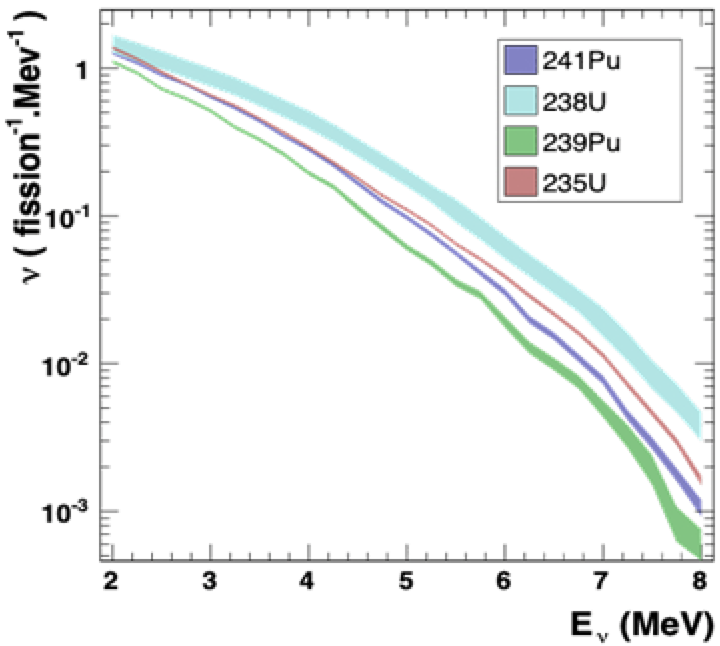
Sun Yat-sen University
April 9, 2025

# Reactor as antineutrino source




~6 $\bar{\nu}_e$ /fission

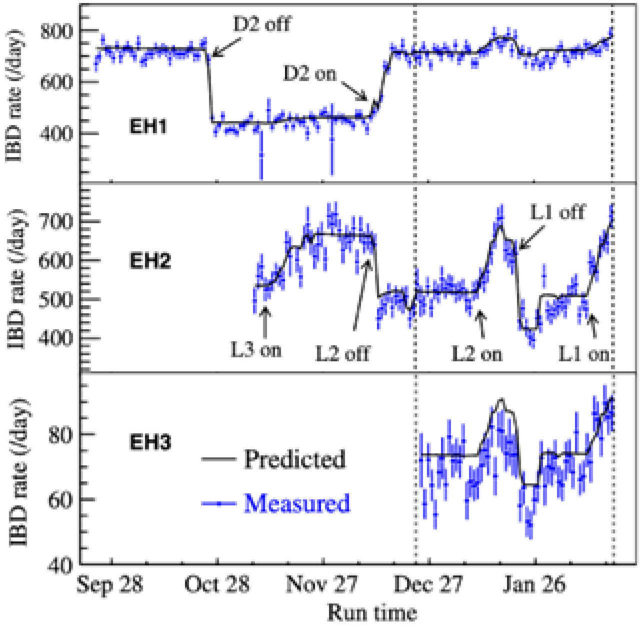
fission fraction evolution in 1 cycle

fissile isotope neutrino spectrum
Huber-Muller model

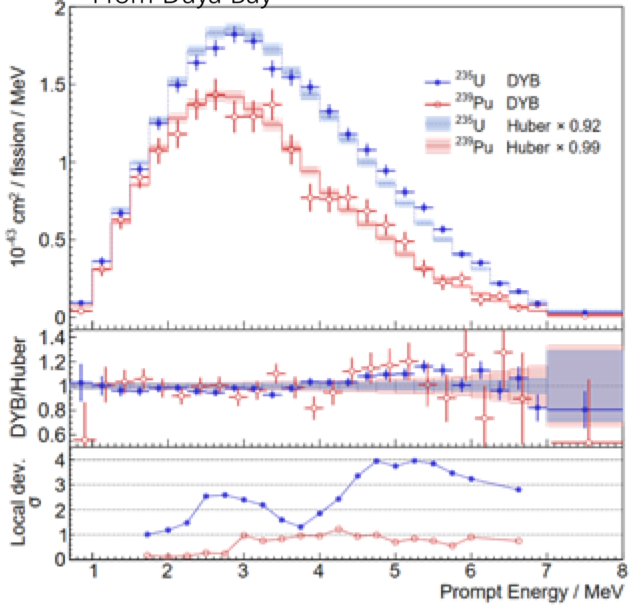
# Neutrinos as Effective Probes for Reactors

- Neutrino flux is proportional to reactor thermal power
- Energy spectrum shape contains reactor evolution information
- Neutrinos penetrate matter easily, enabling non-invasive monitoring

From Daya Bay




From Daya Bay



# Neutrino Reactor Monitoring Applications

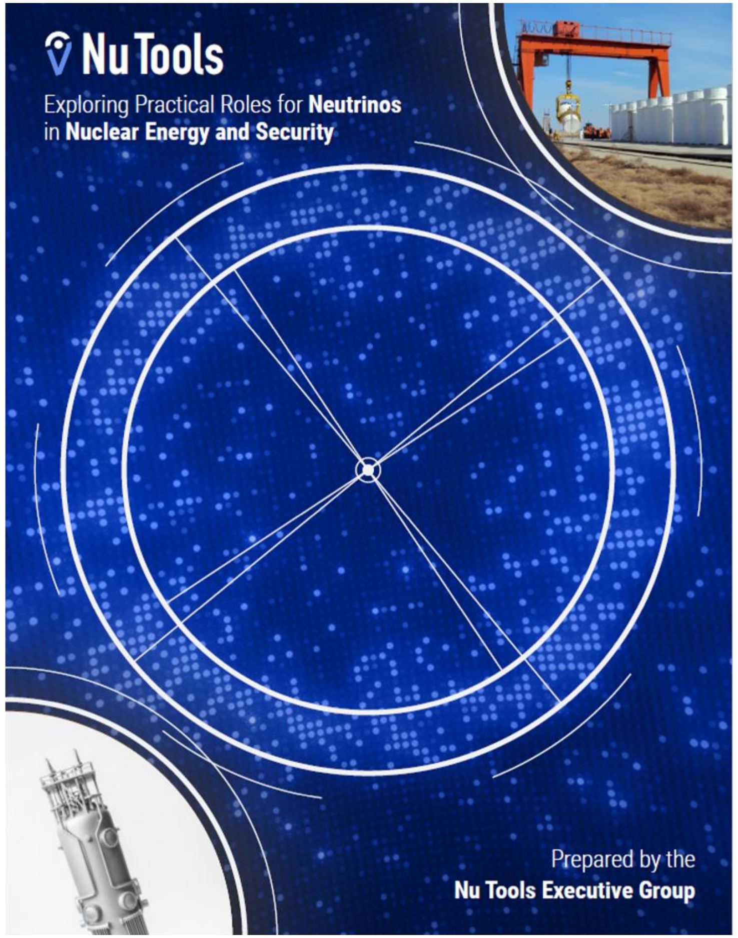
**Nuclear Nonproliferation Monitoring**

- Monitor reactor operational status changes
  reactor startup/shutdown, power operation

- Potential to identify plutonium breeding activities

**Reactor Safety Monitoring**

- Monitor power peaking factors
- Support advanced reactor R&D
(e.g., lead-based fast reactors)



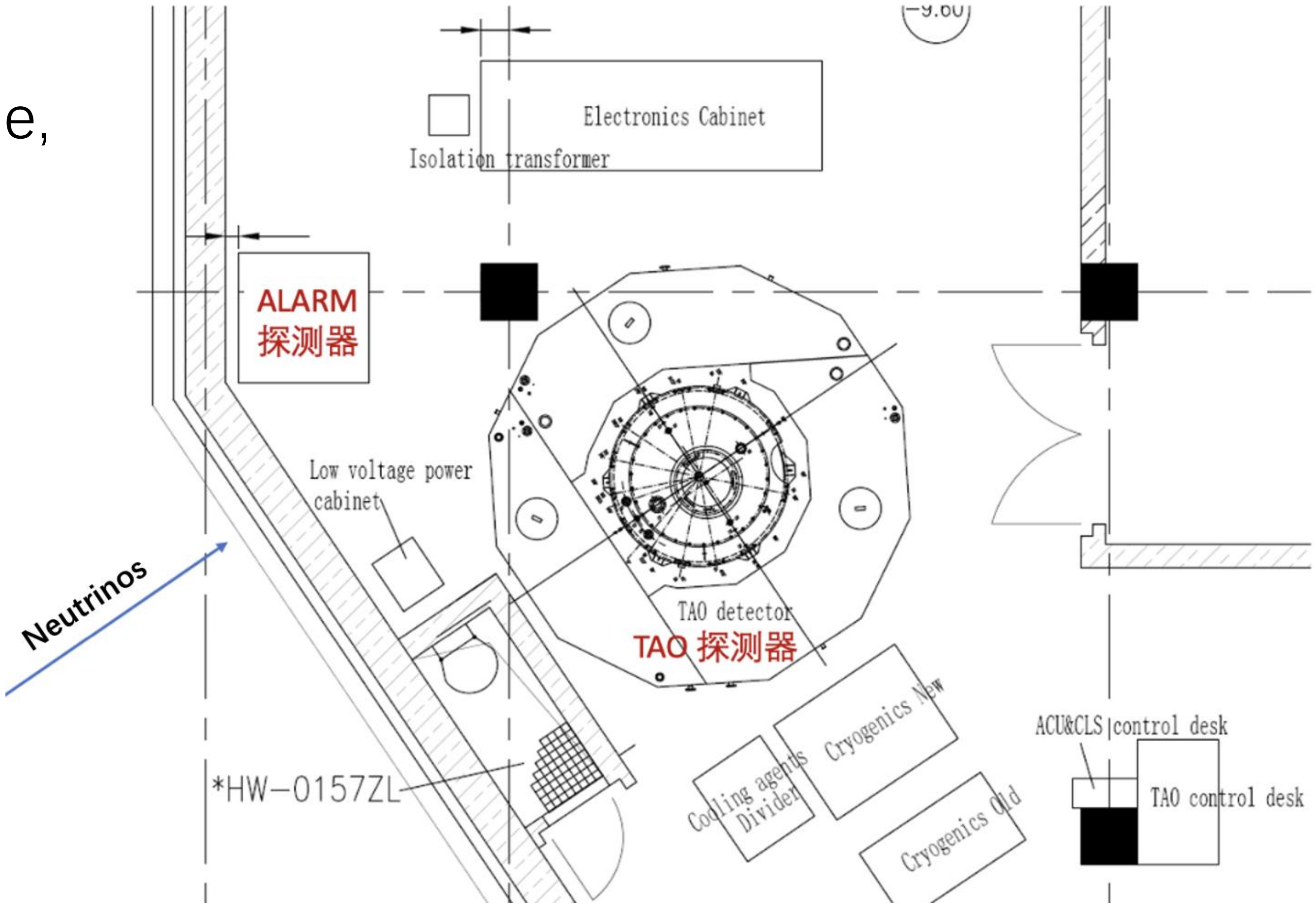
# ALARM- Array of Lattice for Antineutrino Reactor Monitoring

**Physics Goals**

- Reactor power monitoring using simple, compact, low-cost detector
- Validate neutrino monitoring application technologies

**Layout**

- Taishan nuclear power power plant, side by side with JUNO-TAO
- Share electronics room with TAO
- Under ground 9.6m, baseline: 42 m
- Reactor thermal power: 4.6GW

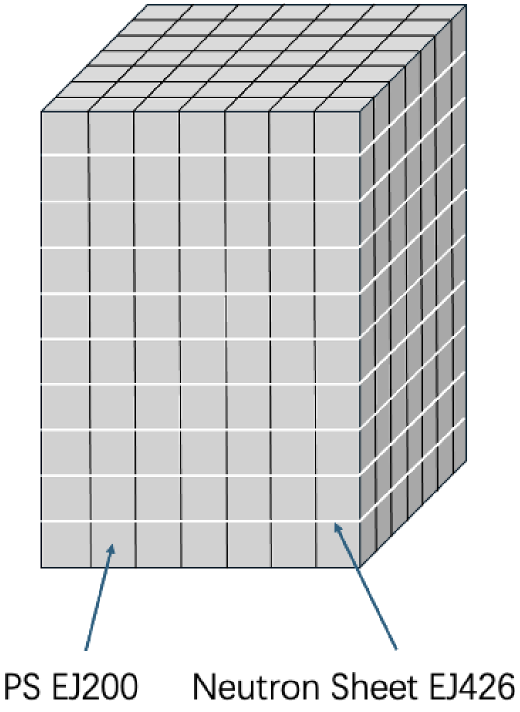


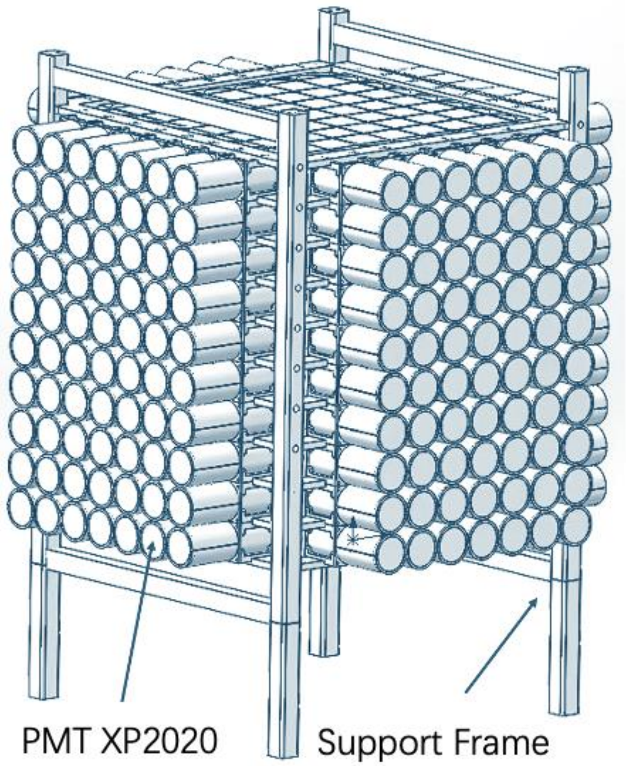
# Detector Design

Inverse beta decay: $\bar{\nu}_e + p \rightarrow e^+ + n$

- Shares the same detector design from CHANDLER experiment
- Modular plastic scintillator array
- 7×7×10 PS array modules + 11 neutron sheet

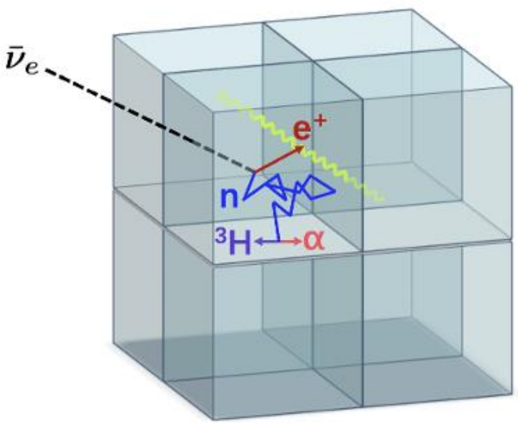
PS total weight:
108.27kg

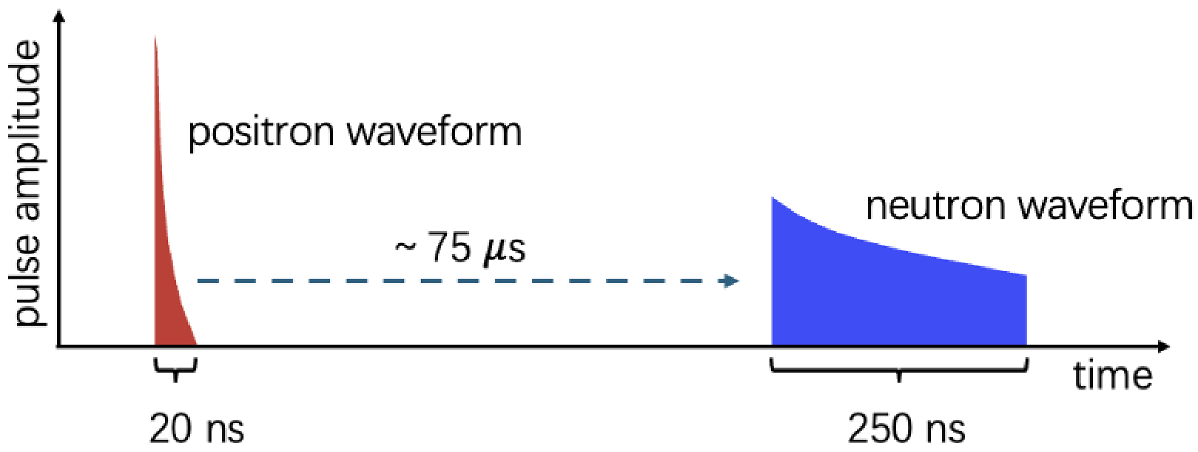


# Neutrino Signal Characteristics

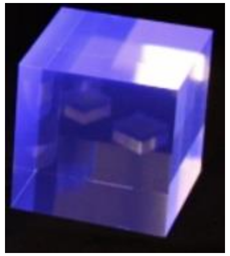
$$\bar{\nu}_e + p \rightarrow e^+ + n$$




## Gamma detection: plastic scintillator

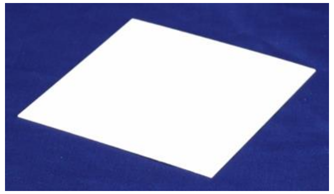
EJ-200



- Short scintillation time
- Long decay length

## Neutron detection: neutron sheet

EJ-426

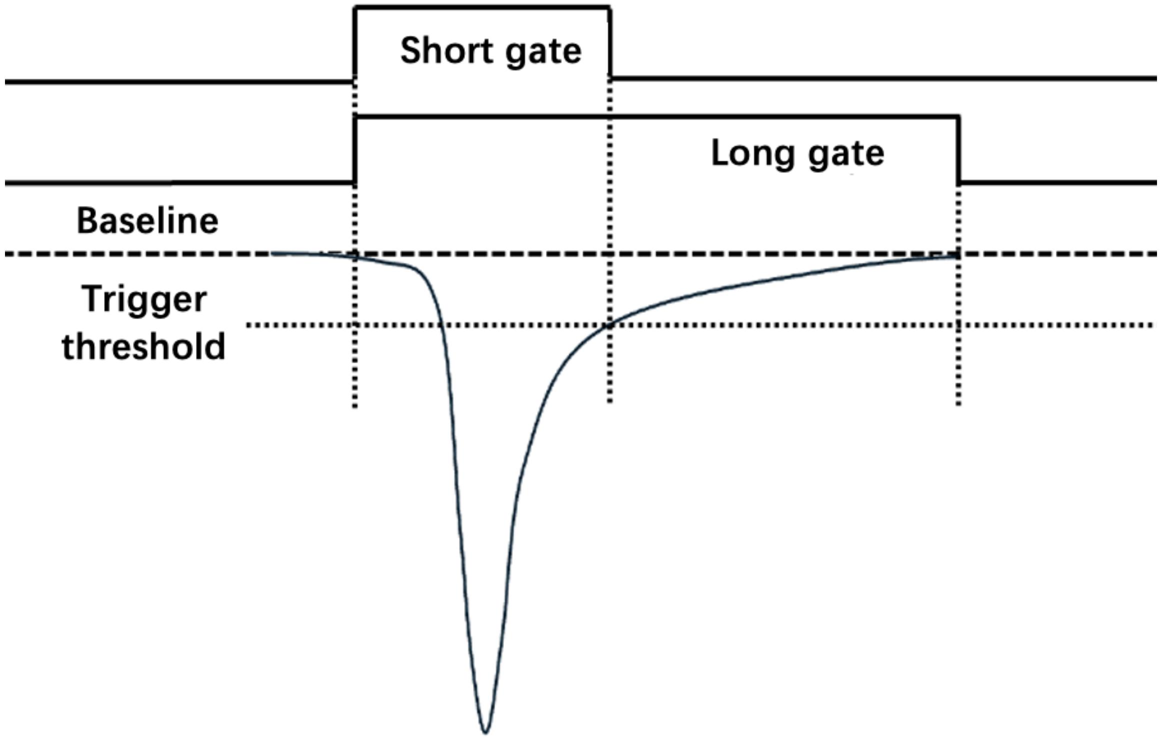


- High neutron detection efficiency
- Low sensitivity to gamma
- Long scintillation time

**$^6$LiF:ZnS(Ag)**

$$^6Li + ^1n \rightarrow ^3H + ^4He + 4.78MeV$$

# Pulse Shape Discrimination

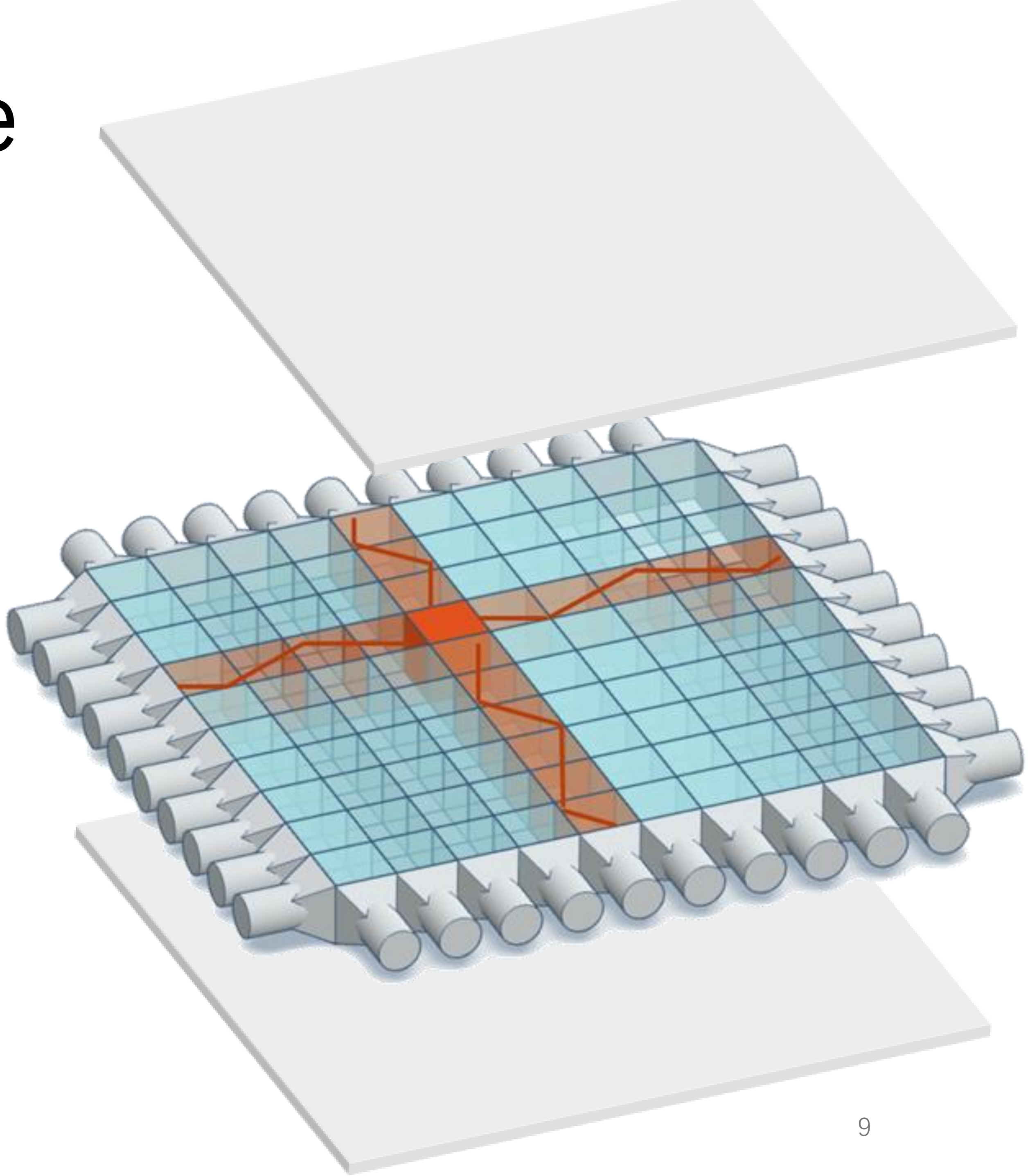

$$PSD = \frac{Q_{short}}{Q_{long}}$$

**Mesytec MDPP-32QDC**

output: $Q_{short}$, $Q_{long}$, Time stamp

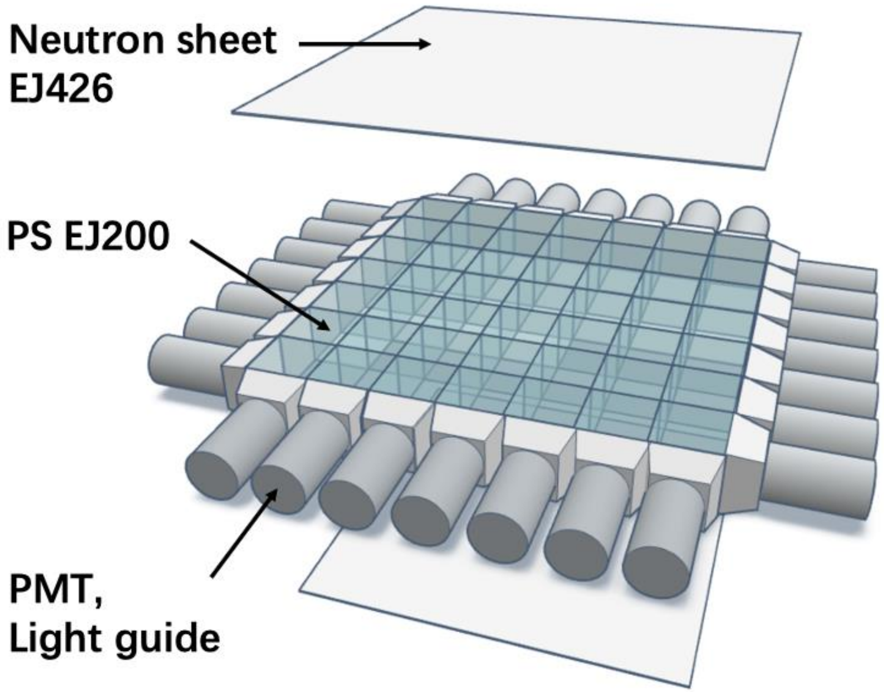
# Raghavan Optical Lattice

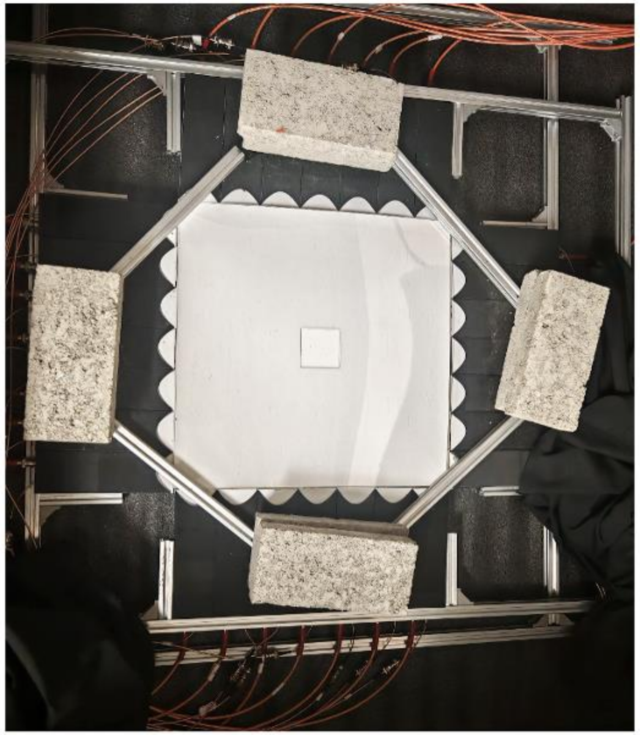
- Compact PS array to form the light total reflection channels, X-Y position
- Non-transparent neutron sheet in between PS array: Z position
- Natural 3D resolution



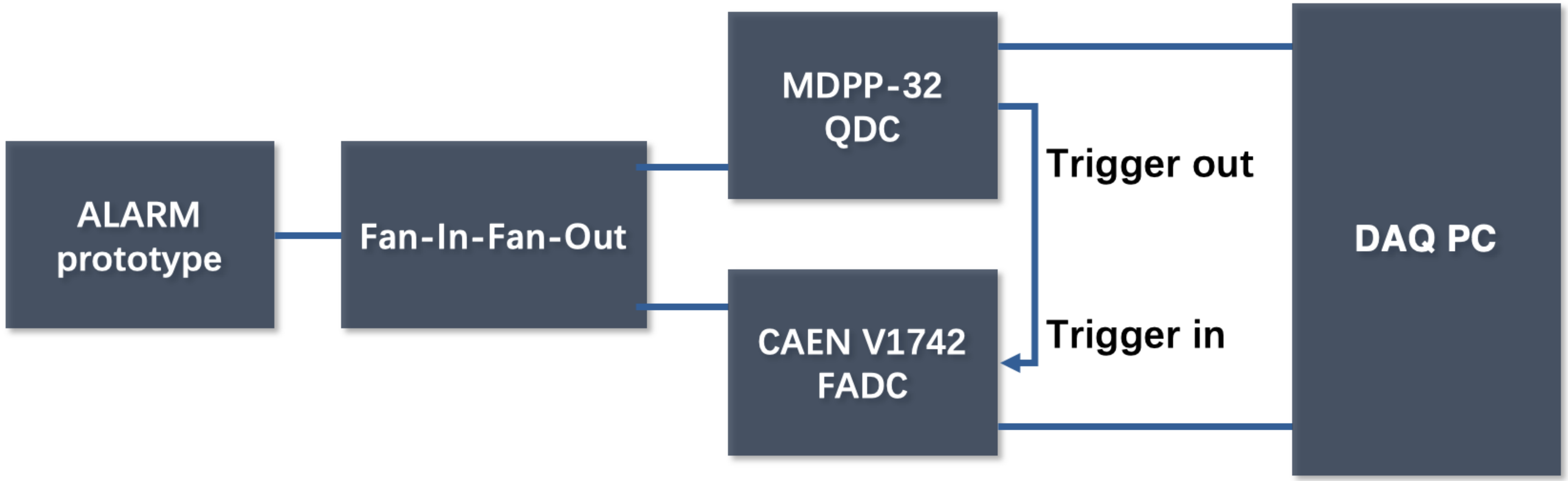
# 1 layer prototype in SYSU lab

7 x 7 PS array + 2 layers neutron sheet



# 1 layer prototype in SYSU lab

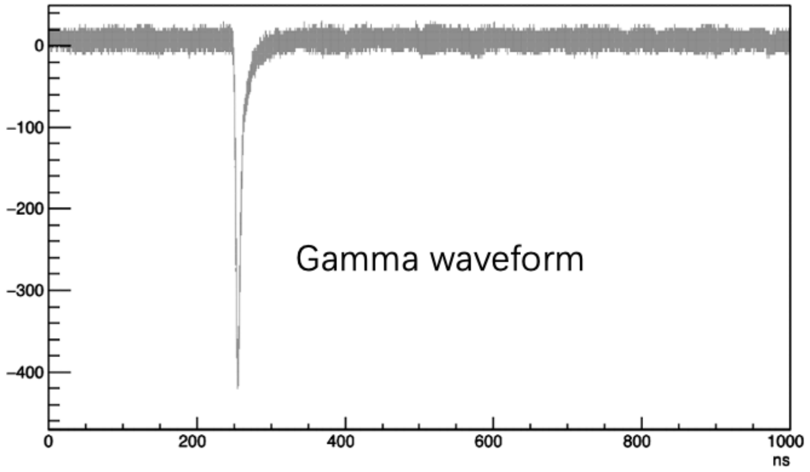


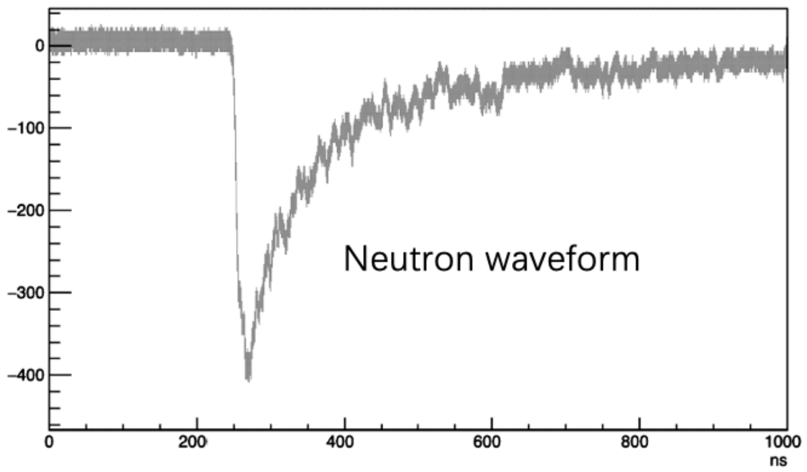

Prototype detector:

Extra CAEN V1742 FADC to get gamma and neutron waveforms samples to optimize the MDPP-32 QDC integration time setup.

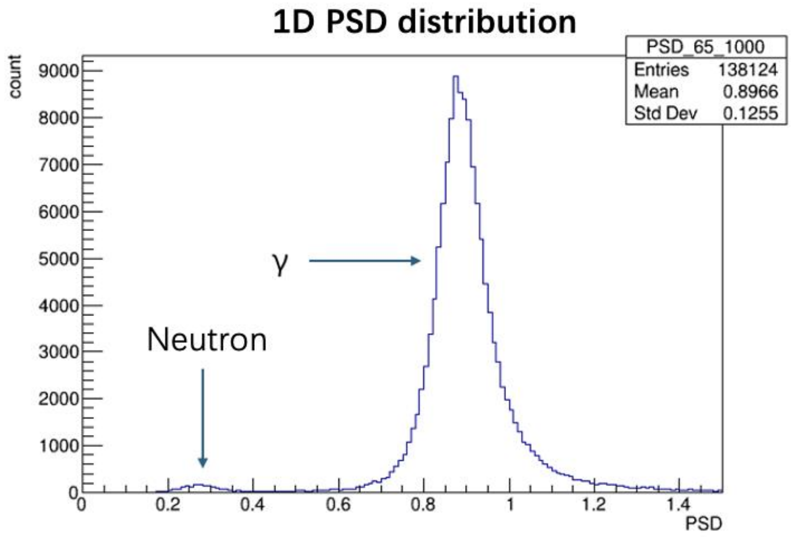
# Preliminary PSD result in prototype with radioactive source

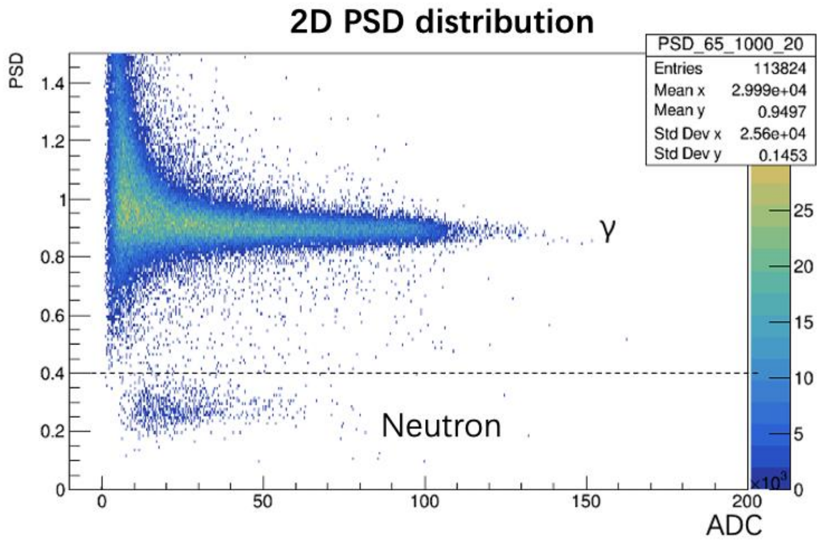
Typical waveforms:




PSD distributions:



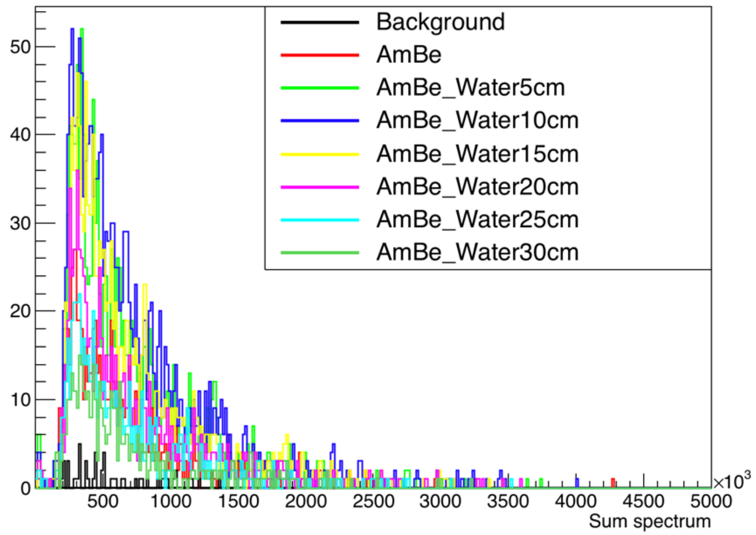




$$PSD = \frac{Q_{short}}{Q_{long}}$$

# Shielding test with porotype detector

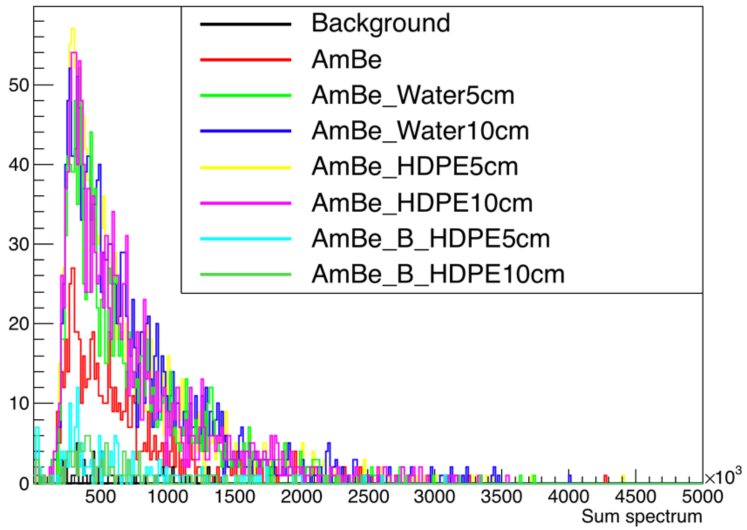
**Neutron shielding:**
Boron doped HDPE

prototype test for HDPE



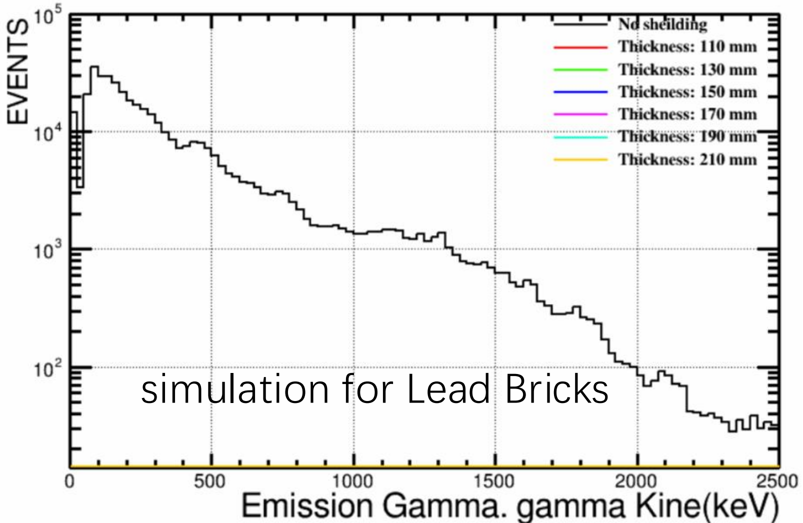

25cm HDPE reduce 80% fast neutron

prototype test for B-HDPE




Boron doped HDPE reduce >90% thermal neutron

**Gamma shielding:**
Lead bricks

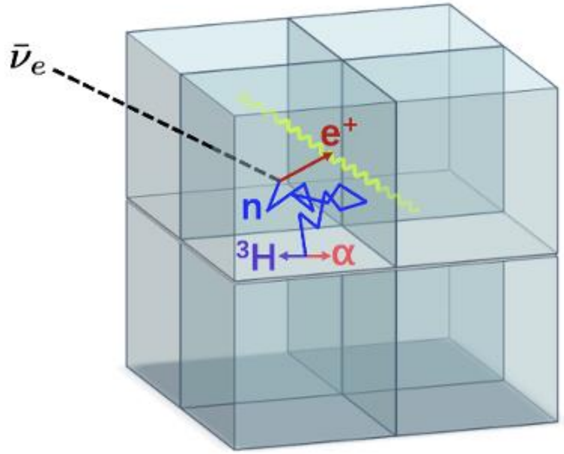


# Neutrino signal and backgrounds

**IBD selection:**

- Neutron candidate coincides with gamma like event
- Multiple IBD selections:
  4-ch PMT coincidence trigger, μ veto, prompt-delay time coincidence, energy selections, space selections, space-energy topology selection

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




**IBD rate:** 70 events. /day

- Baseline: 42m
- Reactor thermal power: 4.6GW
- Target protons: $5.47\times10^{27}$
- Detection efficiency: ~40%

# Neutrino signal and backgrounds

Main backgrounds：

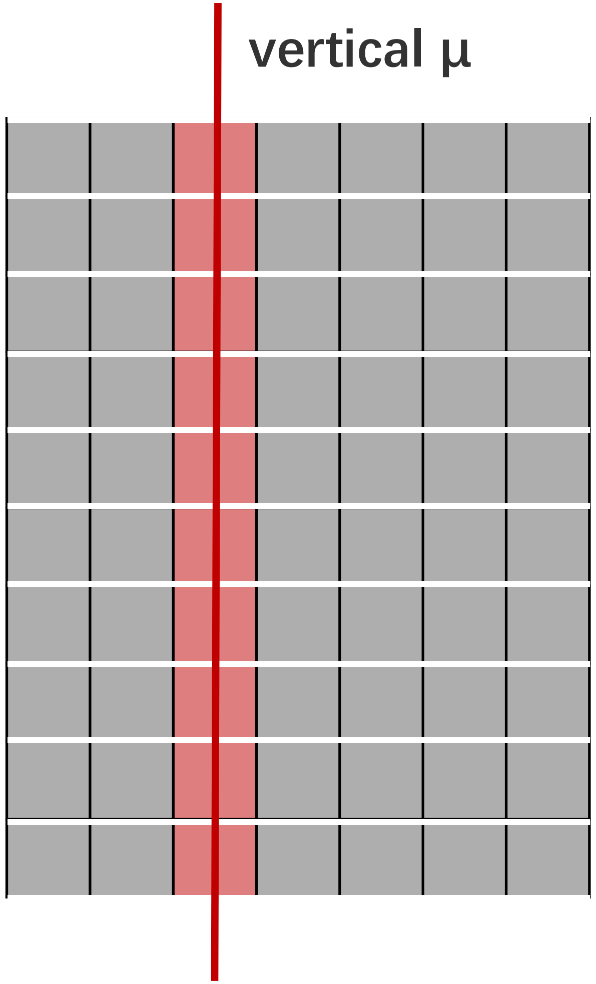
- **Fast neutron:** a prompt signal from the proton recoil and a delayed signal from the neutron capture on neutron sheet after thermalization.
- **Accidental backgrounds:** signals correlated accidentally with the delayed signal(neutron candidate) to form a IBD like event.
- **$^8$He/$^9$Li:** Cosmic muon induced spallation reactions generate isotopes like $^8$He/$^9$Li, their β-neutron decays form IBD like events.

Rough preliminary estimation:

| | |
|---|---|
| IBD | 70/day |
| Fast neutron | 8/day |
| Accidental | 4/day |
| $^8$He/$^9$Li | 2/day |

# Detector calibration

- Vertical muon as a calibration source:
  - 6cm thick PS cube, ~12MeV/cube
  - optical response monitor




- Radioactive sources:

| source | $^{137}Cs$ | $^{60}Co$ | $^{152}Eu$ | $^{239}Pu$ | $^{241}Am$ |
|---|---|---|---|---|---|
| decay | γ | γ | γ | α | α |
| Energy (keV) | 662 | 1173, 1333 | 344、778、964、1085、1112、1408 | 5156 | 5486 |

For PS cube ($^{137}Cs$, $^{60}Co$, $^{152}Eu$)

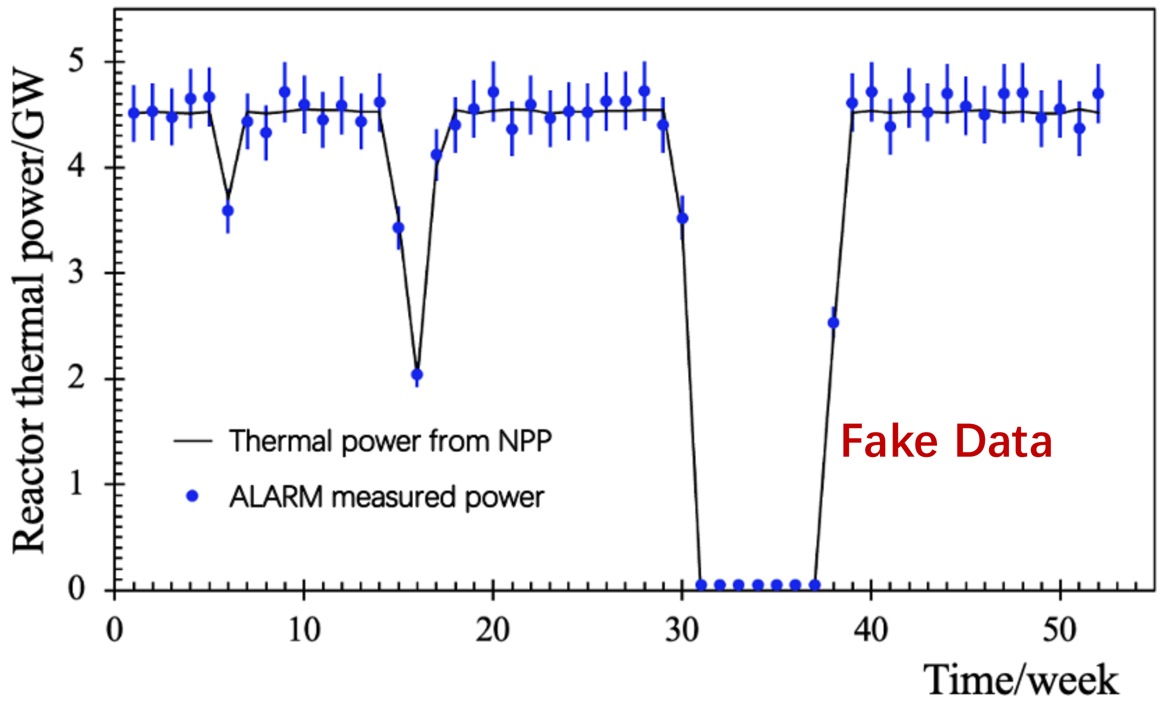
For neutron sheet ($^{239}Pu$, $^{241}Am$)

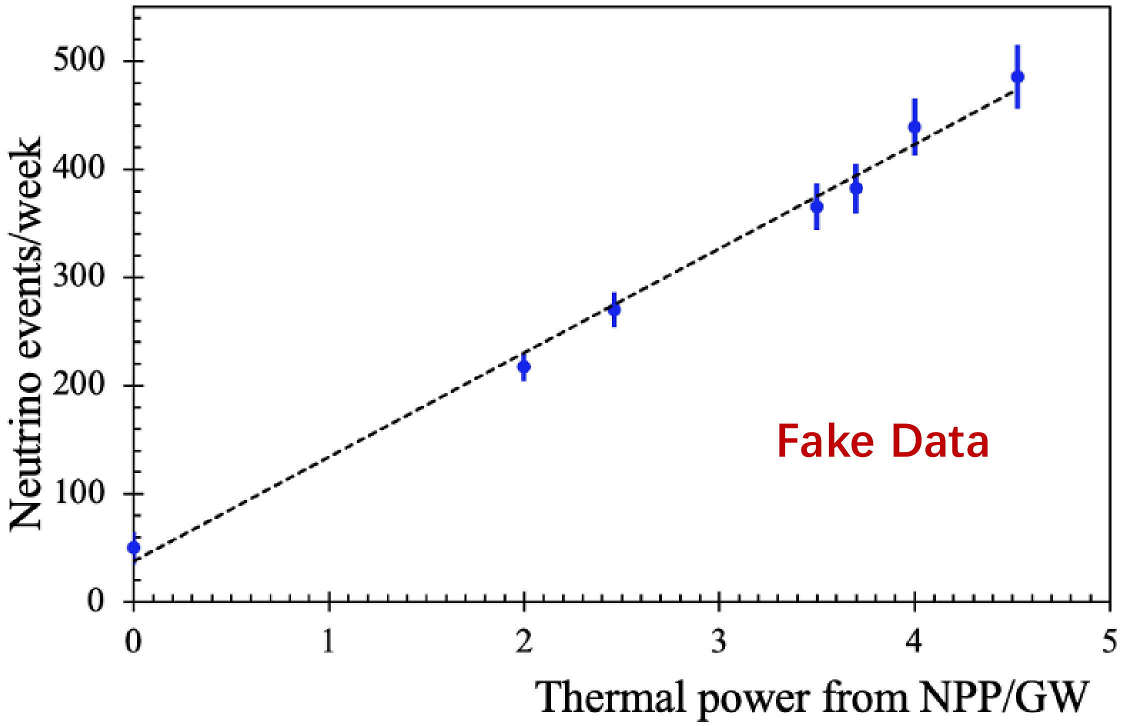
- LED array on top layer to monitor optical response

# Possible joint analysis with TAO

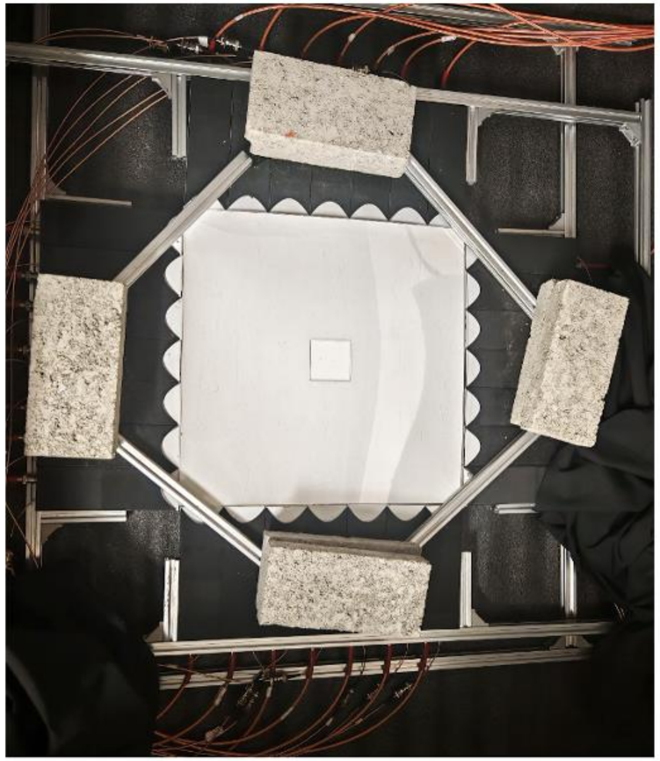
- Same lab, same reactor
  - Common environmental backgrounds, muon flux
  - Observing the same source at the same time
- Joint analysis： $\chi^2 = \chi^2_{TAO} + \chi^2_{ALARM}$
- TAO as a neutrino flux calibration detector for ALARM

# Expectations



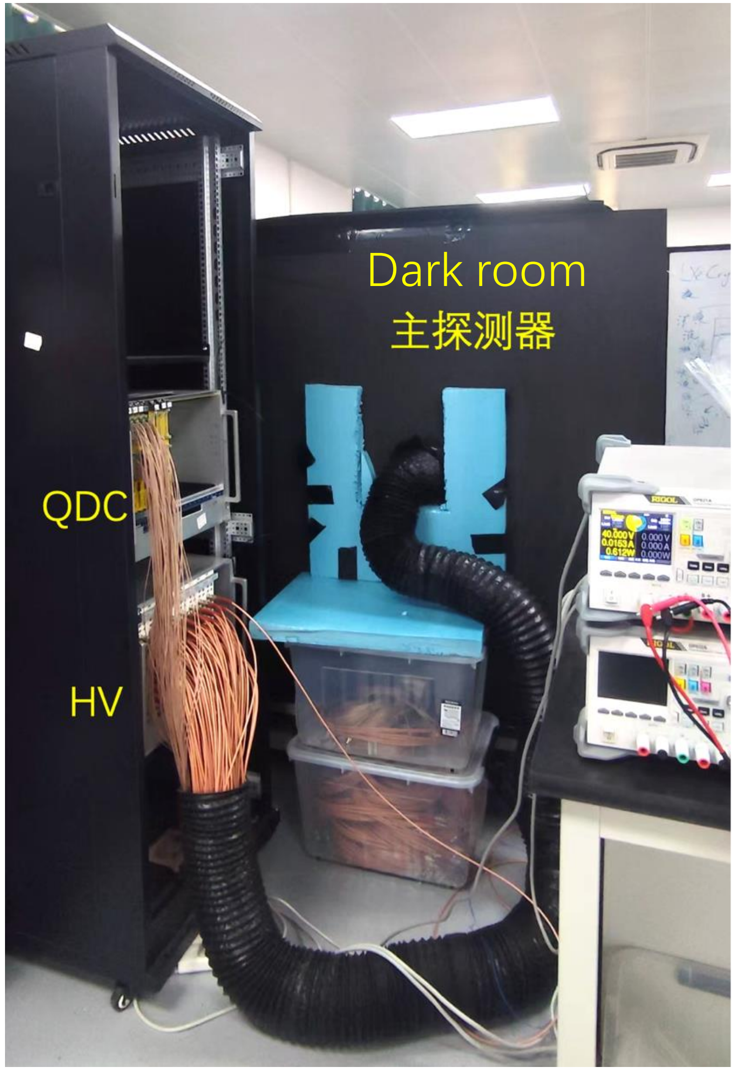



# Recent progress



1 layer prototype


installation test




Integration in dark room

# Installation and data taking plan

Aug. 2025: Assembly in SYSU Lab

Nov. 2025: Transportation to Taishan Lab for installation and commissioning

Jan. 2026： Data taking

# Summary

- Main Physical Goals of ALARM: Reactor power monitoring using a simple, compact, and cost-effective detector design.

- Technical validation for reactor neutrino monitoring applications.

- Potential joint analysis and cross-verification with the TAO detector.

# Thanks！