Honeycomb cell detector with Epoxy resin based scintillator

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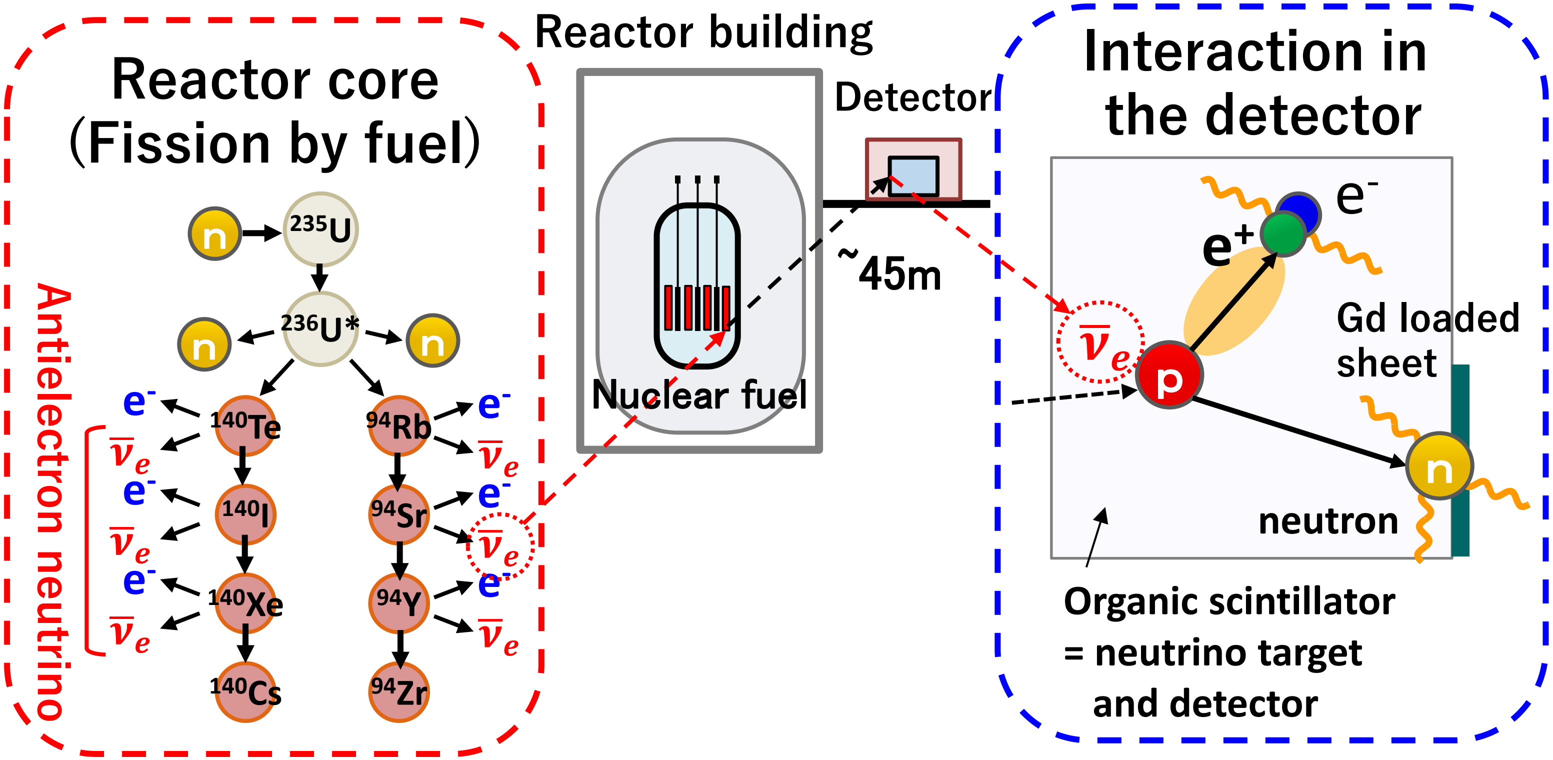
Introduction

Portable reactor neutrino detection

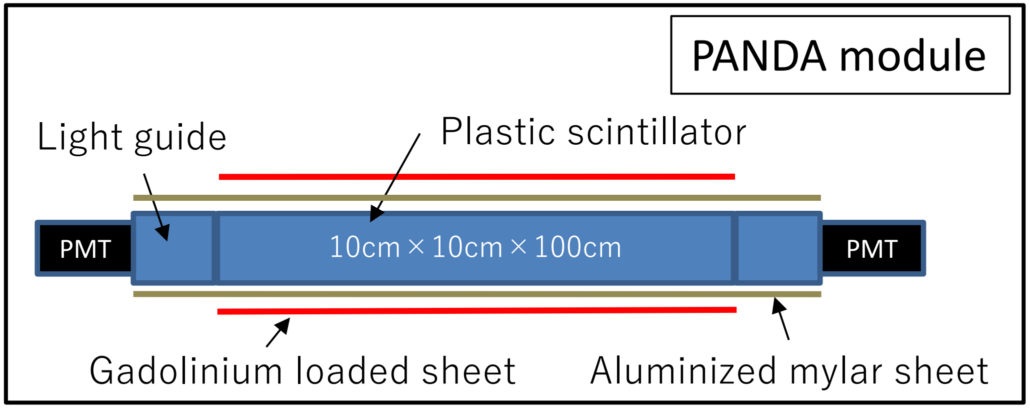


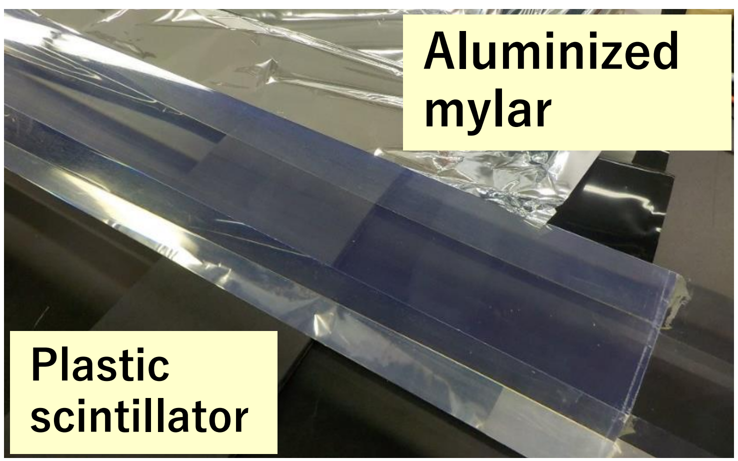
Reactor＝Powerful source of reactor neutrino

- Neutrinos / fission：$6\text{x}10^{20}\ \nu$ /s (3GWth)
- Observable in outside of building (~45m)

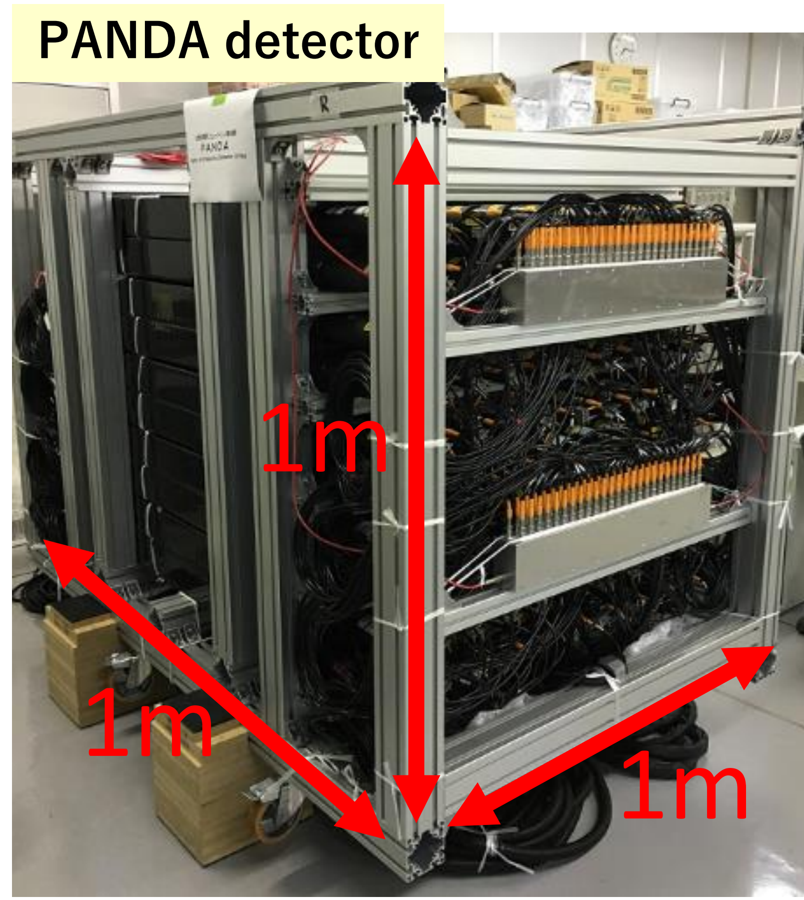
→ Realtime and remote reactor monitoring is possible

Plastic Anti-Neutrino Detector Array (PANDA)





Combined 10 x 10 = 100 modules



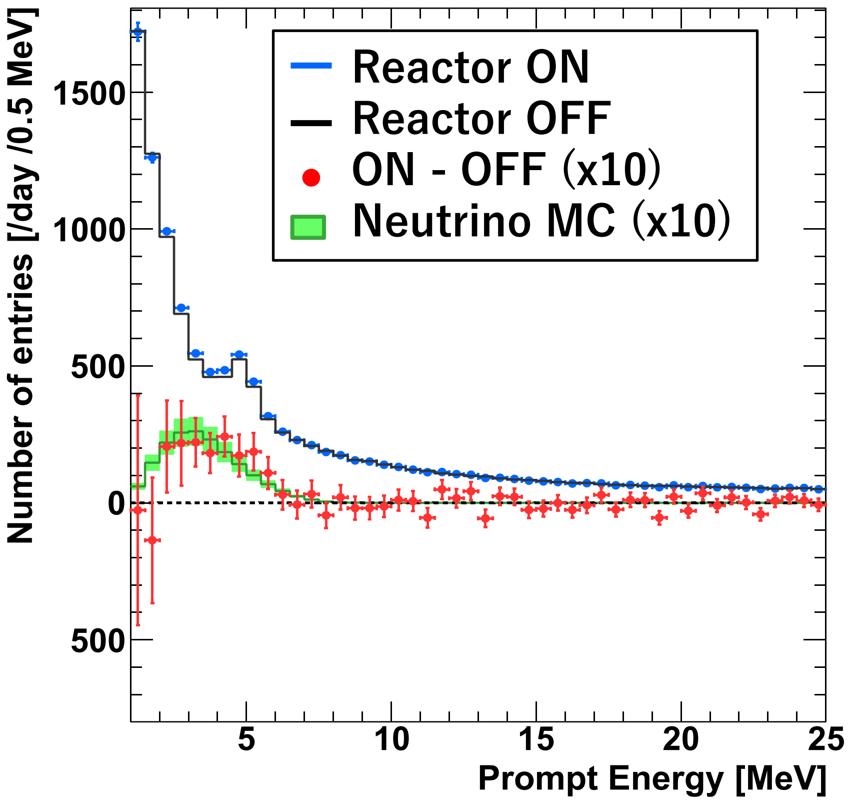
- 1 ton volume : 1 x 1 x 1m^3
- Neutron is detected by Gd

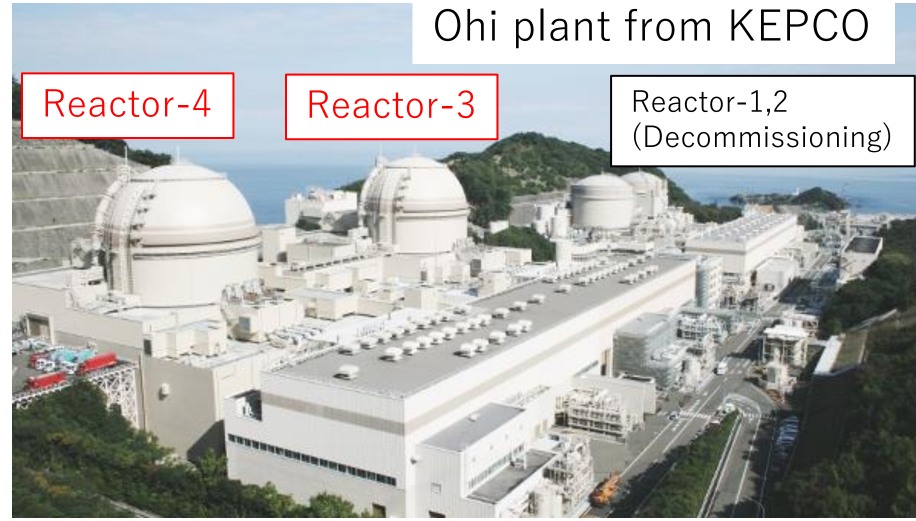
$$n + \mathrm{Gd}^{155/7} \rightarrow \mathrm{Gd}^{156/8} + \gamma\mathrm{s}$$

Portable on the truck

Measurement at Ohi reactor (2019)

Spectra of IBD candidates





The detector located at parking area of the reactor-4.

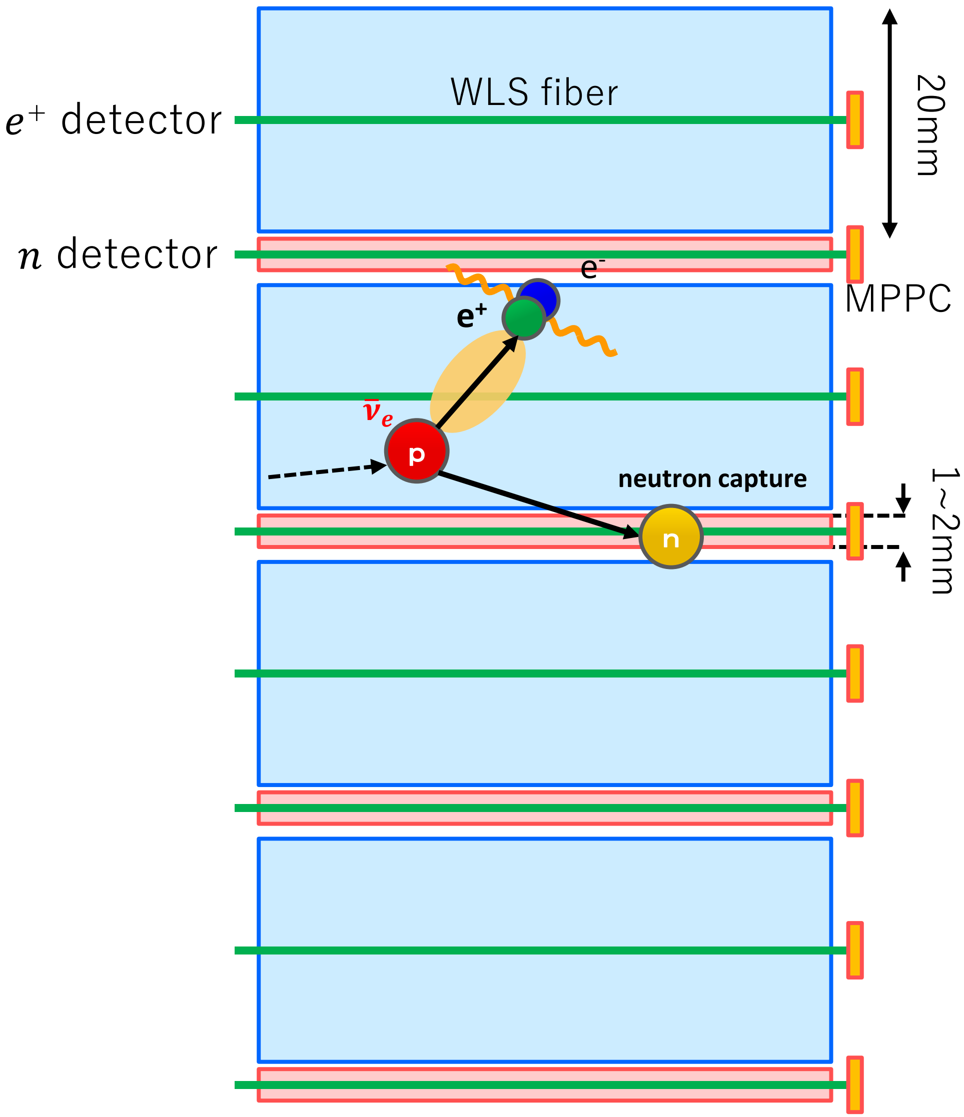
- Comparison with 20days for ON and 30 days for OFF

=> : $175.8 \pm 34.4 [\mathrm{day}^{-1}]$

Need to reduce backgrounds from environment γs and ns

Development of Honeycomb cell detector

Multi plane layers for e^+ and n

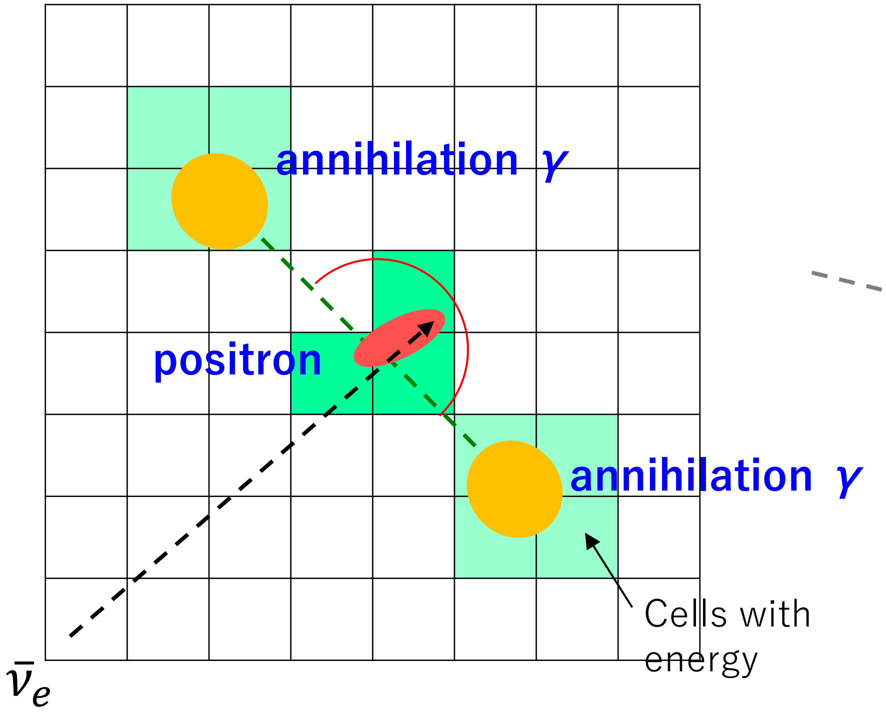


- Detector volume is divided into Optically separated planes of e^+ and n detectors.
- Plastic scintillator plane with 20mm thick is for neutrino target and e^+ calorimeter
- Another thin plane is for neutron detection
- Both layers are read out via WLS fiber and MPPC
- Sub-meter scale detector is under development
  - 40 e^+ detection planes

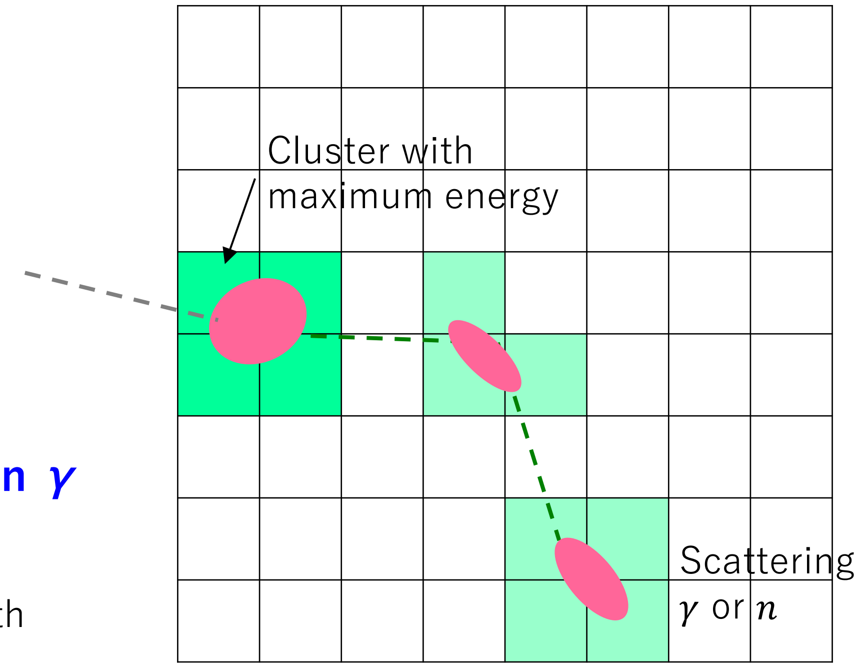
Event topology based PID for e^+

- IBD Prompt signal has e+ leading annihilation γs
  - 511keV γs will go in back-to-back direction
  - Relative position of the cluster with maximum energy should be different between IBD and backgrounds

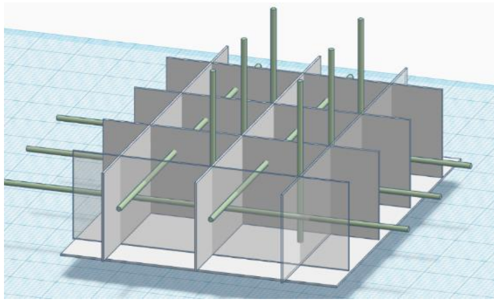
Signal = positron + annihilation γs



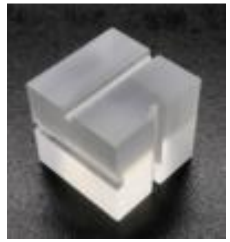
Background = scattering of γ or n



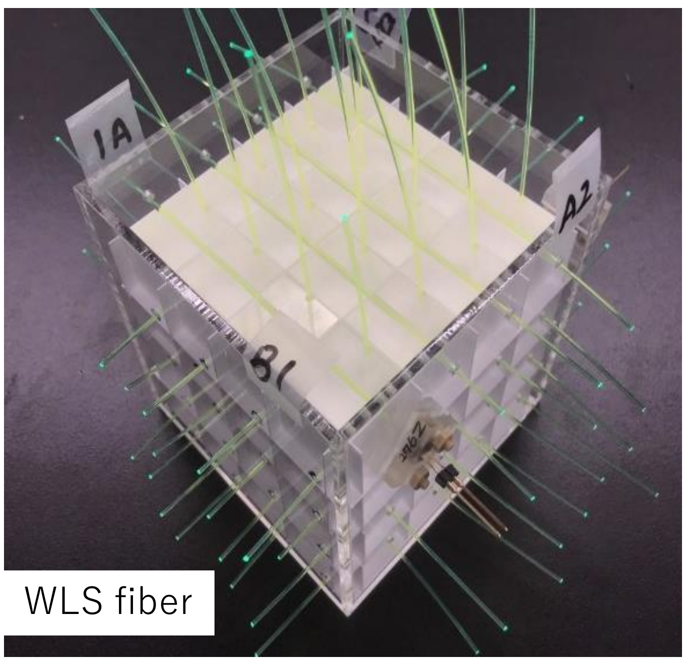
Cell structure with scintillator cubes



Drawing assembly of WLS fiber and partition

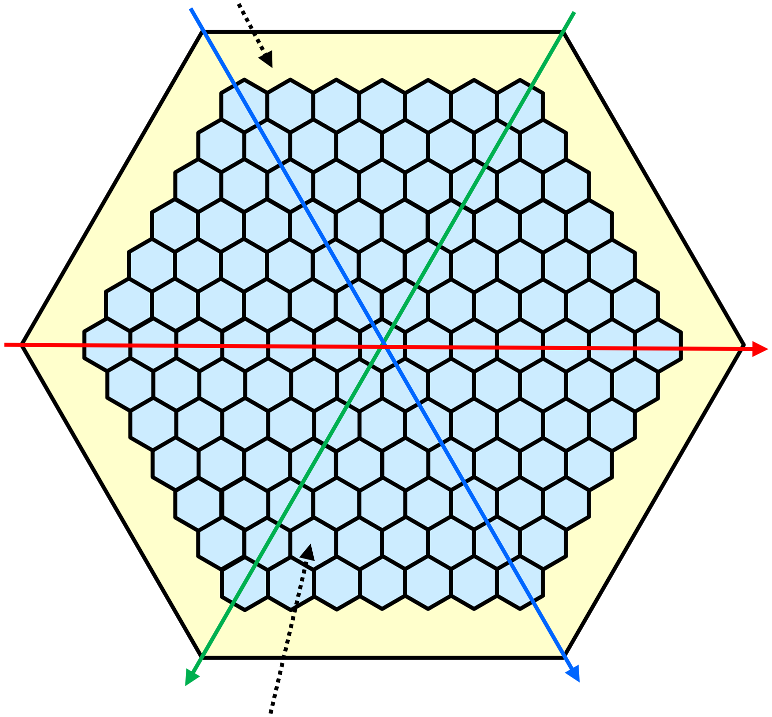


Scintillator cube



- Original idea of the cell structure is to assemble plastic scintillator cubes
- WLS fibers are assembled in XYZ directions.
  - 10 cm scale test type is developed
- Enlarging the detector volume is very difficult to assemble
- Next idea is to pile up independent planes with Honeycomb structure

Honeycomb cell structure for e^+

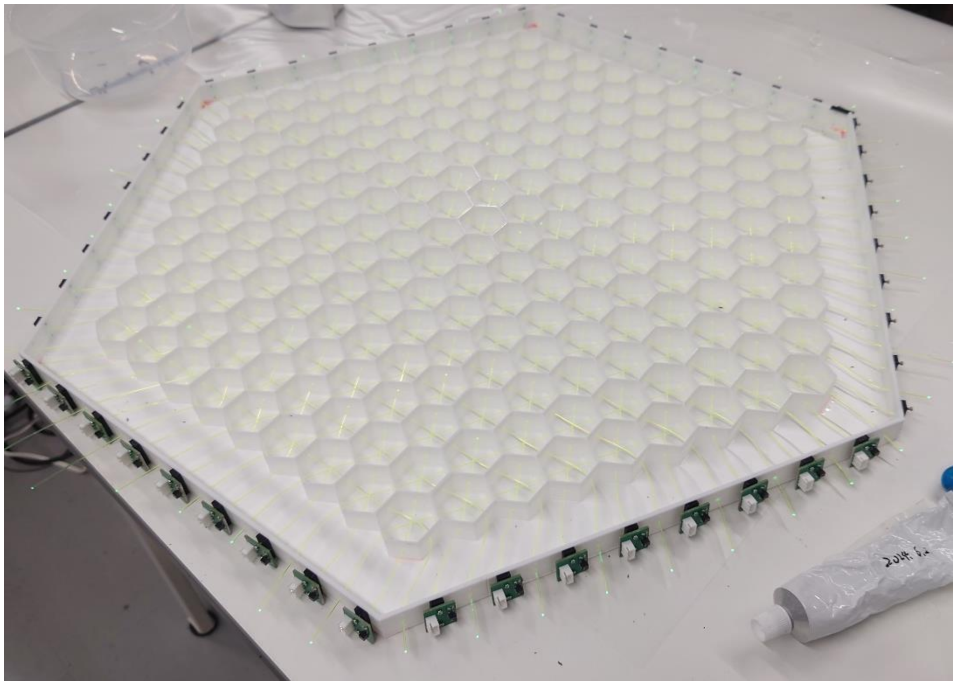


Example drawing for 13 cells in 1 row

Honeycomb cells by hexagonal with a side length of 2 cm

- Read via WLS fibers
  - 3 direction in a plane
  - 1 MPPC per fiber is attached
- Planes are optically separated
  - Easy to increase the volume
- Plane for test production has 17 cells in a maximum row
  - 60 cm in the long side
  - 20 planes will be produced.

Production of Honeycomb cell plane



Test production just started
in the middle of October.

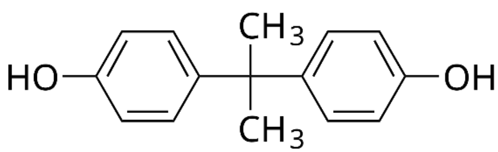
Next problem is
"How should we fill
scintillator in the cells ?"

- Honeycomb structure is produced by 3D printer
  - White PETG filament
  - 2days per plane including outer walls
- Attached on PET reflector with 1mm thickness
- Integrated WLS fibers for three directions
- 51 MPPCs are attached
- 20 planes will be produced for test detector

Epoxy based plastic scintillator

- Bisphenol A epoxy based resin is possible to work as plastic scintillator
- Use a commercial epoxy resin
- PPO and Bis-MSB are mixed in the base resin
  - PPO = 1.05g / Bis-MSB = 0.45g per 100 g resin
- ~76% light yield compared to plastic scintillator

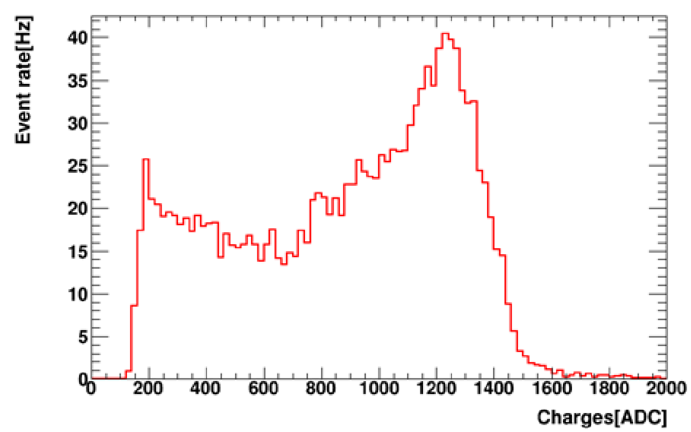
Bisphenol A (BPA)



Mixing PPO and Bis-MSB in epoxy resin

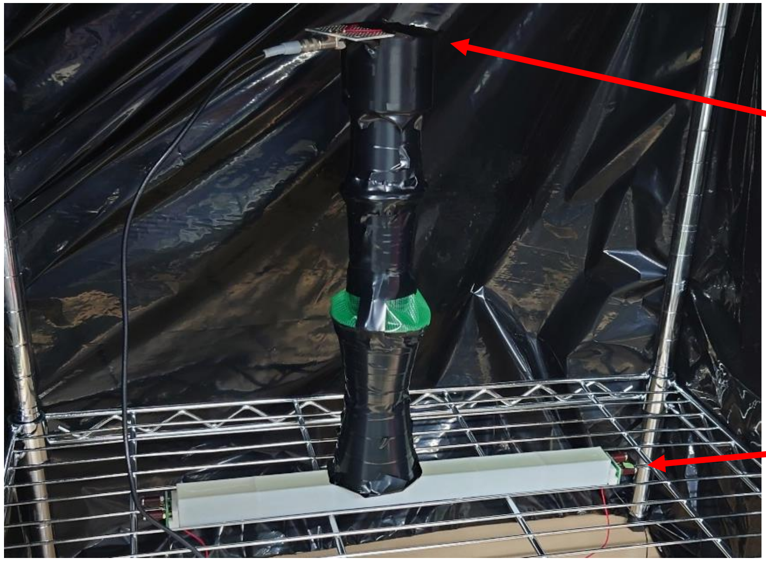
Filled in a container made by 3D printer

Light yield with 60Co



Attenuation in WSL fiber in Epoxy

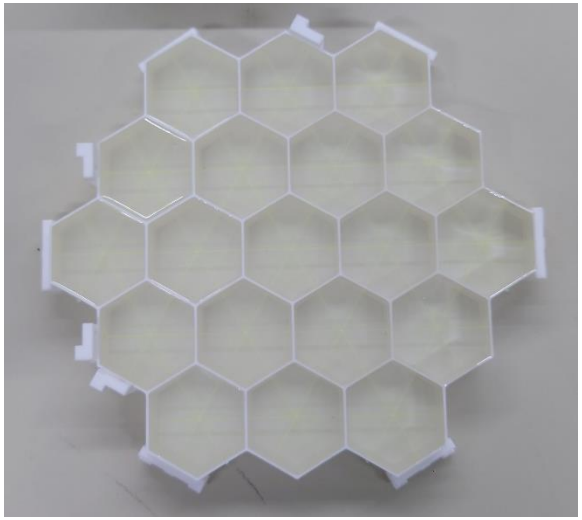
- Attenuation length of Kurare Y-11 is > 3.5 m
- The attenuation length might shorten due to light leak
  - Refraction index of epoxy resin is larger than fiber
- Tested with 30cm WSL fiber in epoxy scintillator
- Light yields decreased by 30% in 30cm distance
  - Estimated attenuation length is ~190cm
  - Acceptable but need more study to stretch the length



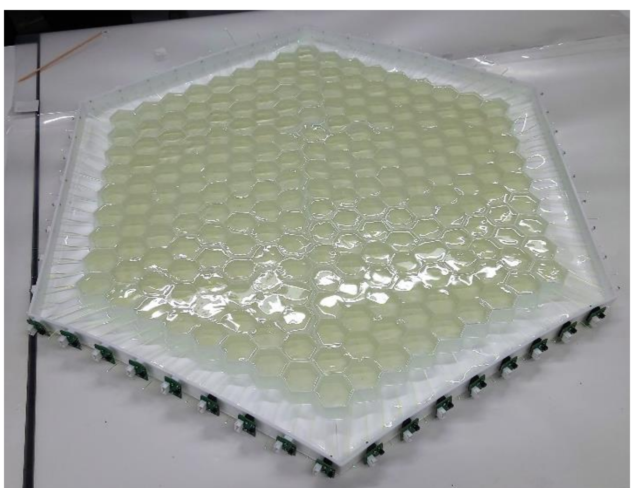
LED flasher

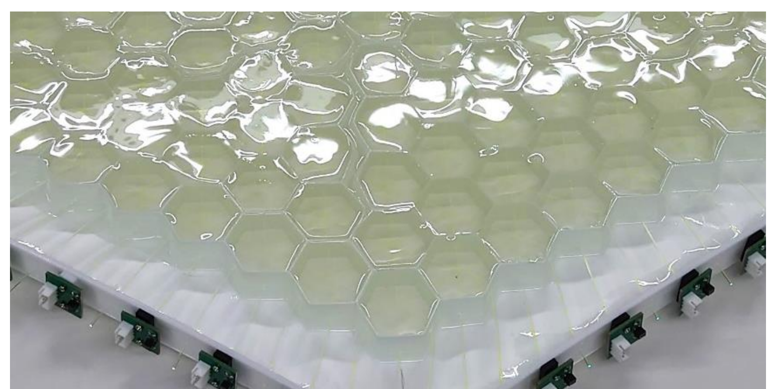
Epoxy scintillator attached by MPPCs

Filling epoxy scintillator to the cells



- Test filling of the epoxy scintillator to a small cell cluster was done well.
- Filling the resin to the test plane
  - 3.6kg base resin + 1.4kg hardening
  - Filled all resin at once
  - Formed in a night
- The cell structure deformed due to shrinkage of the resin
- → Need to fill the resin in sections



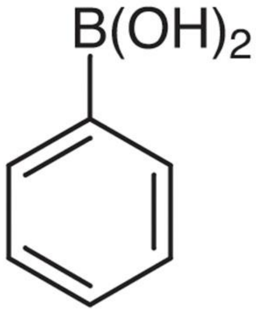


Neutron detection with α emittion

- α emitting neutron capture is very powerful to localize interactions after capturing compared to Gd-γ rays
- Two candidates are considered to mix in epoxy scintillator
- LiF (lithium fluoride) : $n + {}^{6}\mathrm{Li} \rightarrow \alpha + {}^{3}\mathrm{T}$
  - White powder with good reflection
  - Can not dissolve in the epoxy
  - ^{6}Li has 7 % of natural isotope ratio

Right : Epoxy scintillator
Left : +1w% LiF

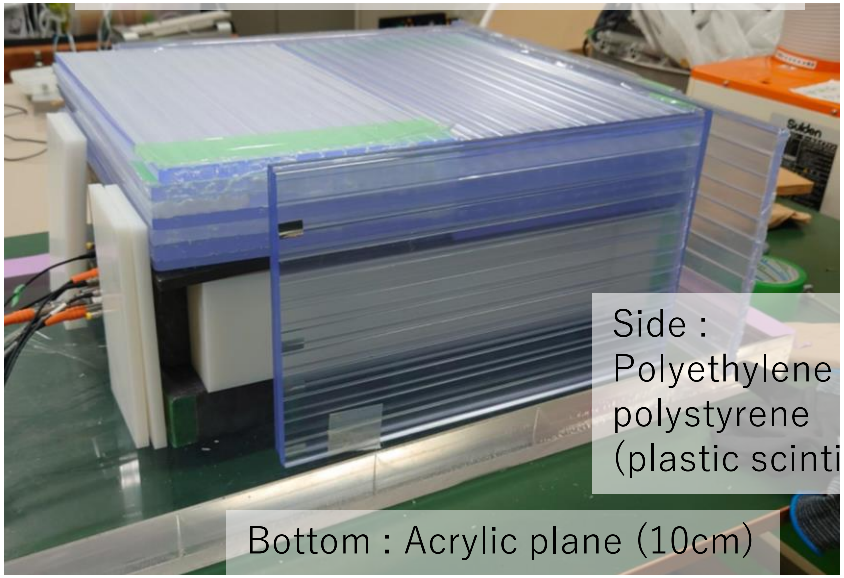
- $PhB(OH)_2$ (Phenylboronic Acid) : $n + {}^{10}\mathrm{B} \rightarrow \alpha + {}^{7}\mathrm{Li}$
  - Easy to dissolve into epoxy resin
  - ^{10}B has 20 % of natural isotope ratio

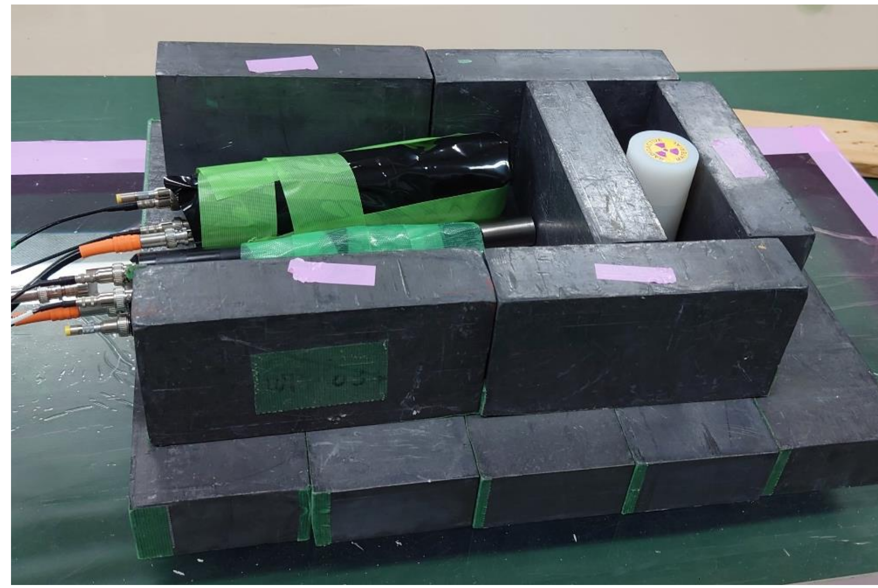


Right : Epoxy scintillator
Left : +10w% $PhB(OH)_2$

Neutron irradiation test with ^{252}Cf

Top : polystyrene (plastic scintillator)

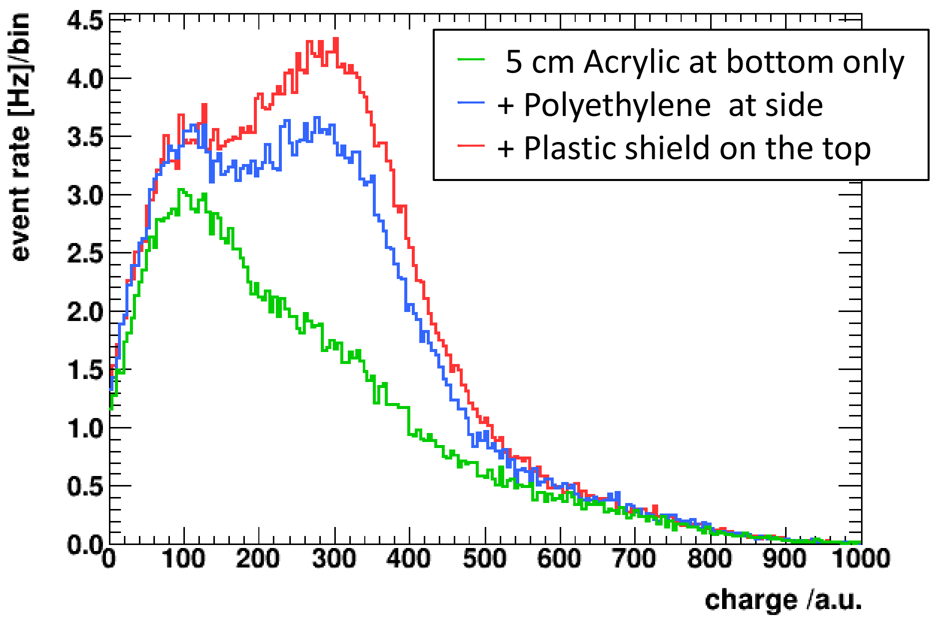




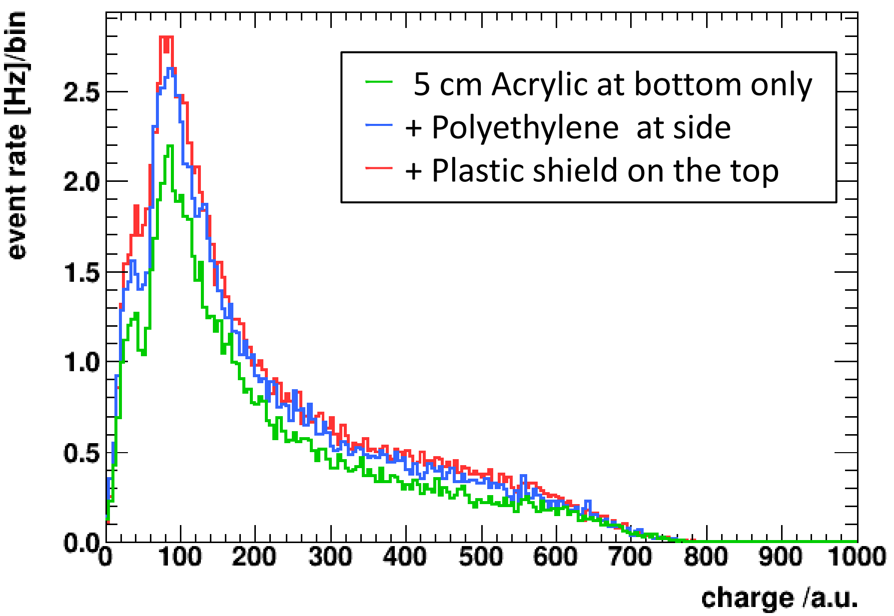
- ^{252}Cf with 1MBq is used to produce thermal neutrons
  - Detector and Source are surrounded by plastic materials
  - Lead blocks to shield gamma rays
- Thermal neutron rate is also monitored by ^{3}He chamber

Results of the test with ^{252}Cf

Charge distribution w/ 10w% $PhB(OH)_2$



Charge distribution w/o $PhB(OH)_2$



- Sample with $PhB(OH)_2$ has excess by neutron capture
  - Possible to add more $PhB(OH)_2$
- Sample with LiF has no excess du to small mass ratio of ^6Li
  - Need to increase percentage of ^6Li
    - Enrich ^6Li or Mix more LiF to 10~20%

Summary and next plan

- New technologies to reduce environment backgrounds is a challenge to reactor neutrino monitor
- Honeycomb cell plane is designed to separate positron and annihilation gamma rays in the prompt signal.
  - Reduction of backgrounds by event topology PID
- Epoxy resin is possible to work as plastic scintillator
- α emitting neutron capture can be integrated
  - Phenylboronic Acid has good performance in the epoxy resin scintillator

Next plan

- 20 e^+ detection planes will be produced in this year.
- neutron detection with WLS fiber will be tested
- Background measurement in the research reactor JRR-3