Measurement of Reactor Anti-neutrinos with ISMRAN detector array

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Outline

- Motivation and Introduction to the ISMRAN experiment for antineutrino detection in Dhruva reactor.
- Characteristic studies of plastic scintillator bar with radioactive sources in a non-reactor environment.
- Different kind of backgrounds for ISMRAN experiment.
- Performance of detectors at different reactor conditions.
- Conclusion & Outlook.

Motivation

Fig 1

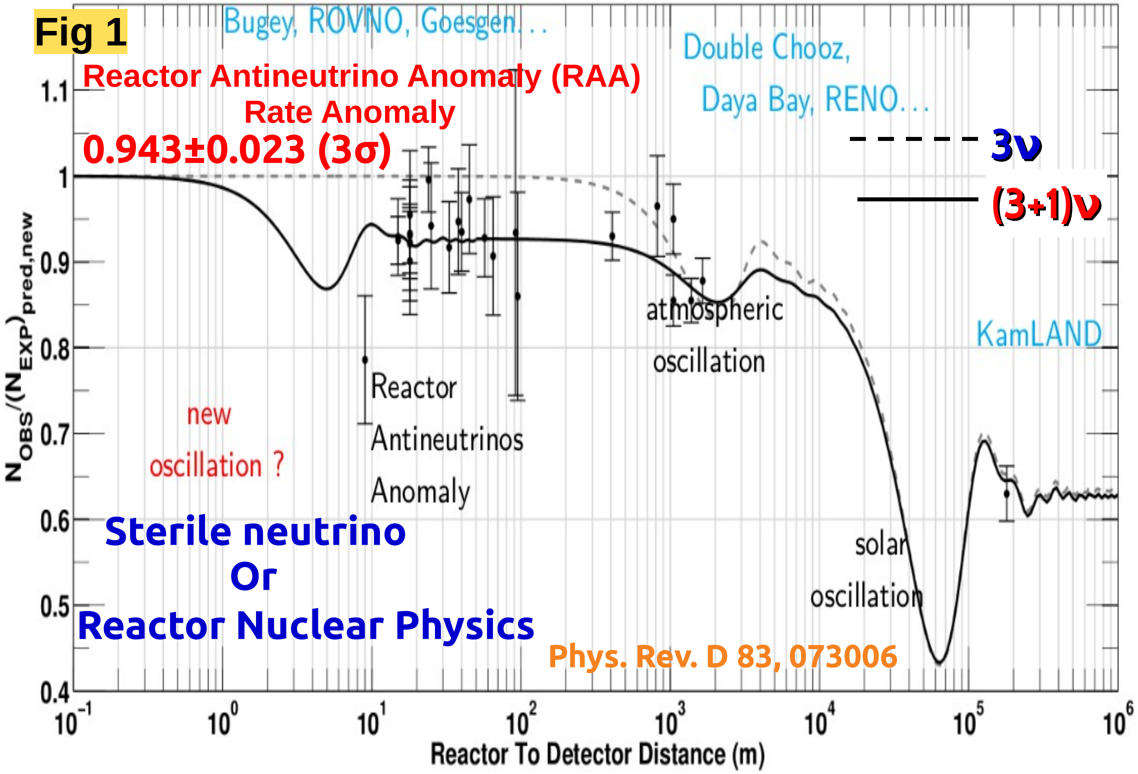


Fig 2

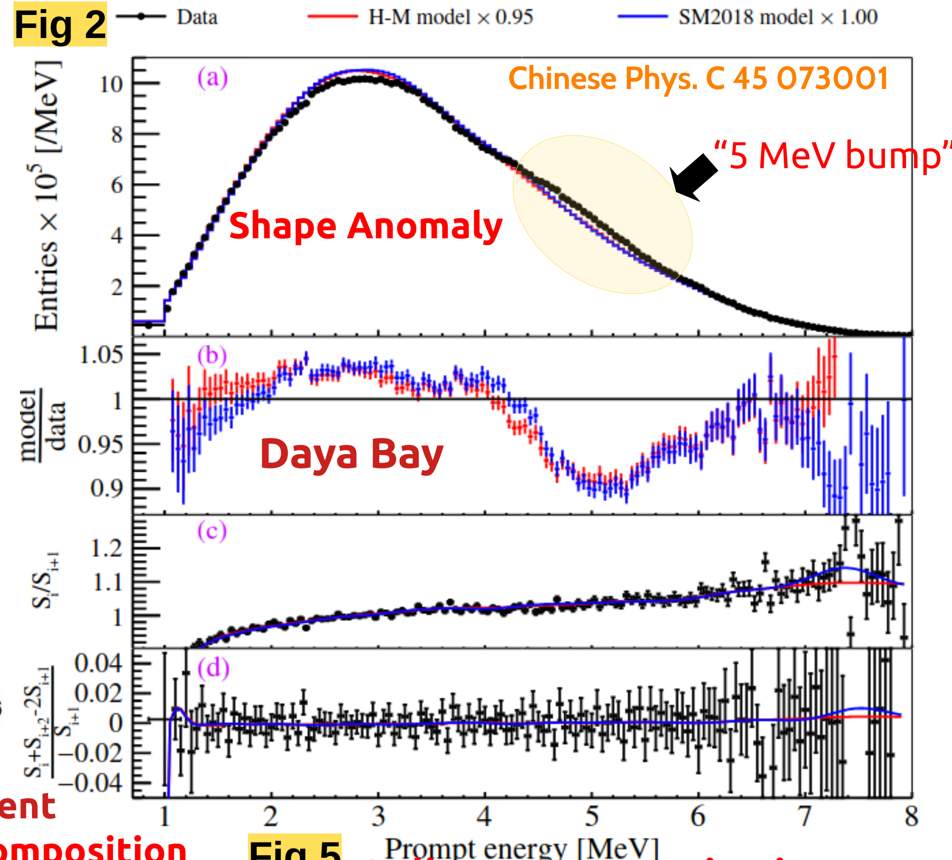


Fig 3

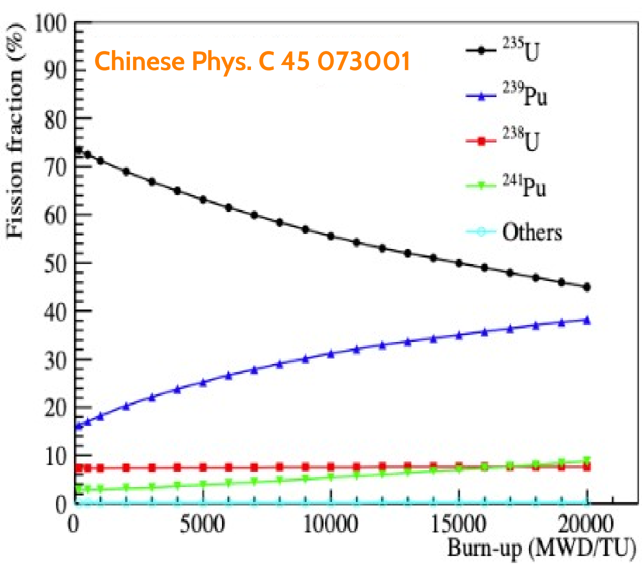


Fig 4

SONGS experiment

Evolution of core composition

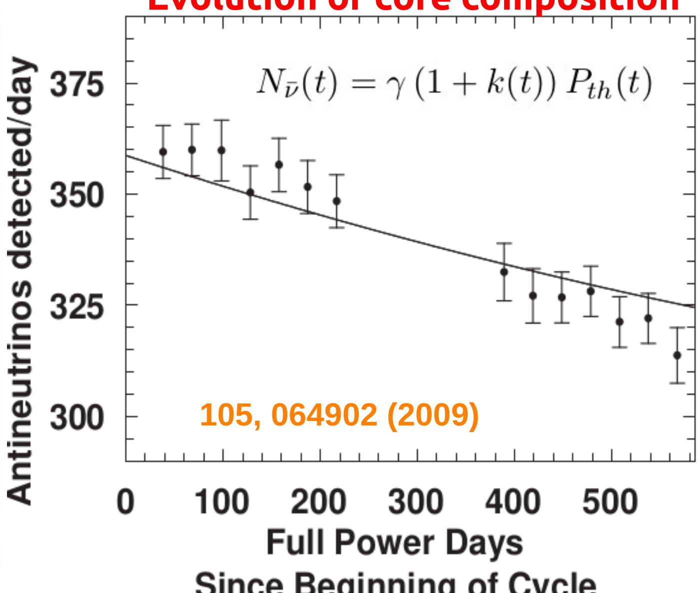
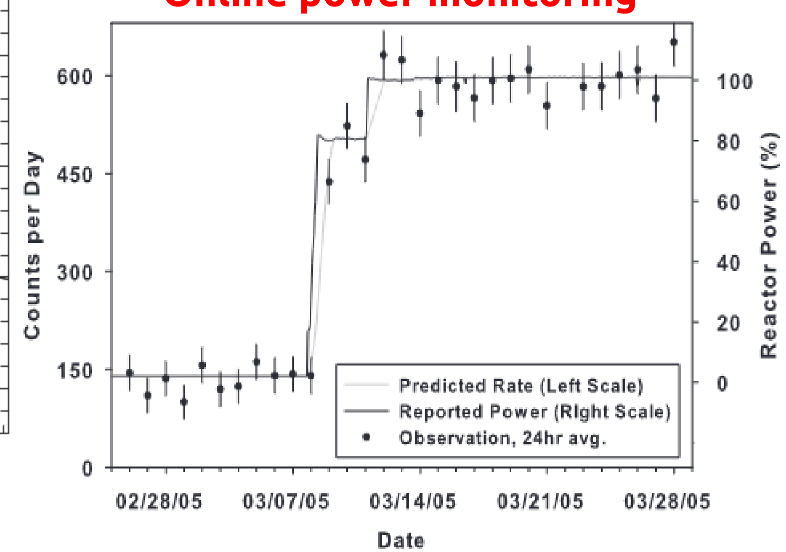


Fig 5

Online power monitoring



Introduction

- ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu are targeted with neutrons.

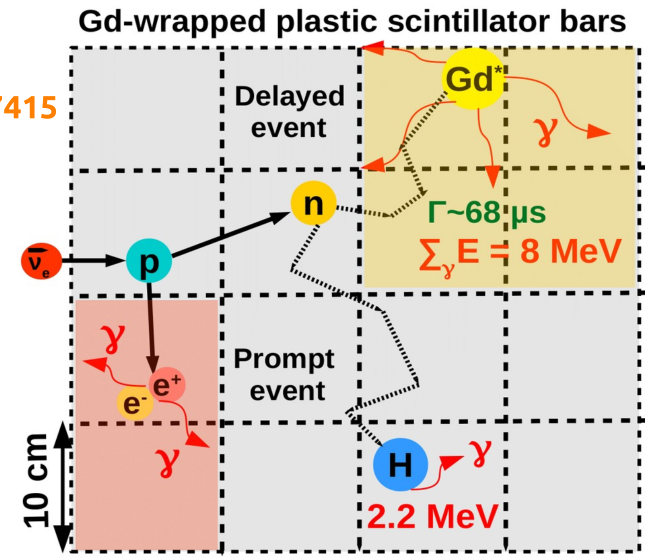
- The basic principle of detection for anti-neutrino: inverse beta decay (IBD):

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

6 $\overline{\nu}_e$ are produced per fission.

2×10^{20} $\overline{\nu}_e$ per sec. per GW_{th} thermal power are emitted.

NIMA, 1042, 167415



- Segmented geometry : 9 x 10 array of 90 PS bars. 0.9 ton by weight. 10 cm thick Lead (Pb) : Gamma shielding; 10 cm thick Borated polyethylene(BP) : thermal neutron shielding.

$$N_{\overline{\nu}e} = \frac{N_p\, \eta\, t\, P_{th}\, \overline{\sigma}_f}{4\,\Pi\, D^2\, E_f\, 1.6\text{x}10^{-19}}$$

$N_p = 5.23 \times 10^{28} / m^3$; $\eta = 15\%$; $t = 86400s$; $D = 13\ m$; $P_{th} = 100\ MW_{th}$; $\sigma_f = 5.91 \times 10^{-43}\ cm^2$

The expected neutrino rate (ISMRAN) is ~ 60 day^{-1}

- The obtained anti-neutrino like events in mini-ISMRAN at RON (128 days) are 218 ± 50 (stat) ± 37 (sys)[Theoretical estimation 214 ± 32].

[NIMA, 1024, 166126 (2021)]

Fig 1

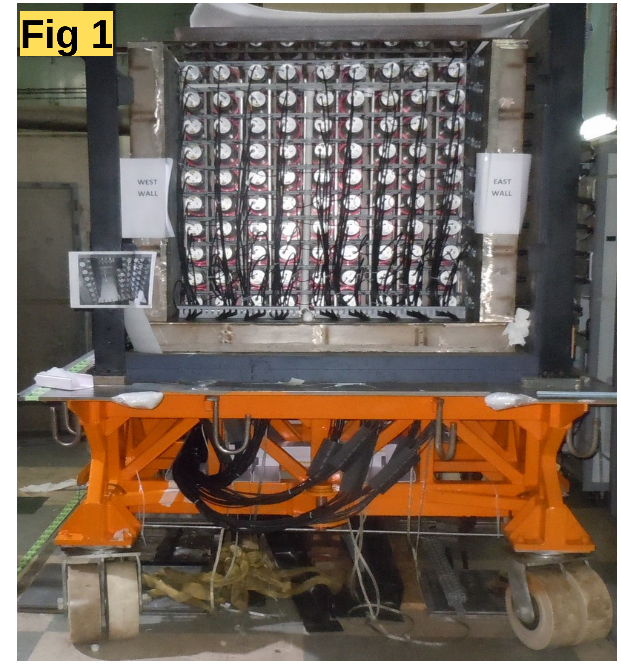


Fig 2

Characterisation of Plastic Scintillator Bar

Fig 1

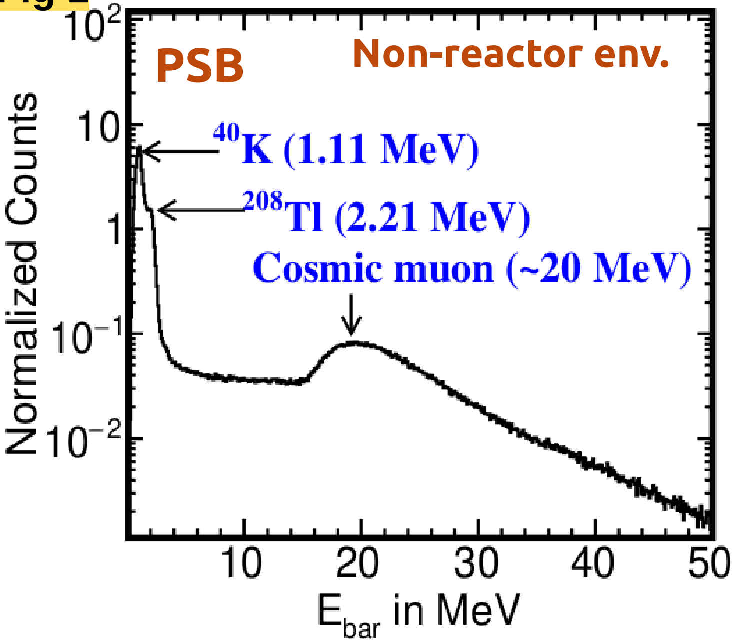


Fig 2

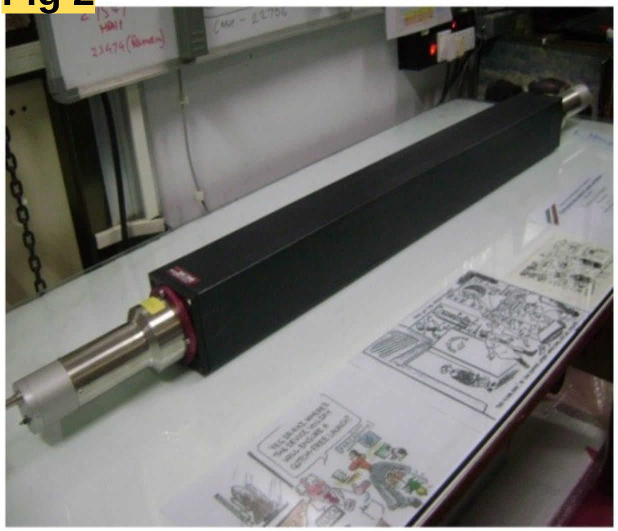
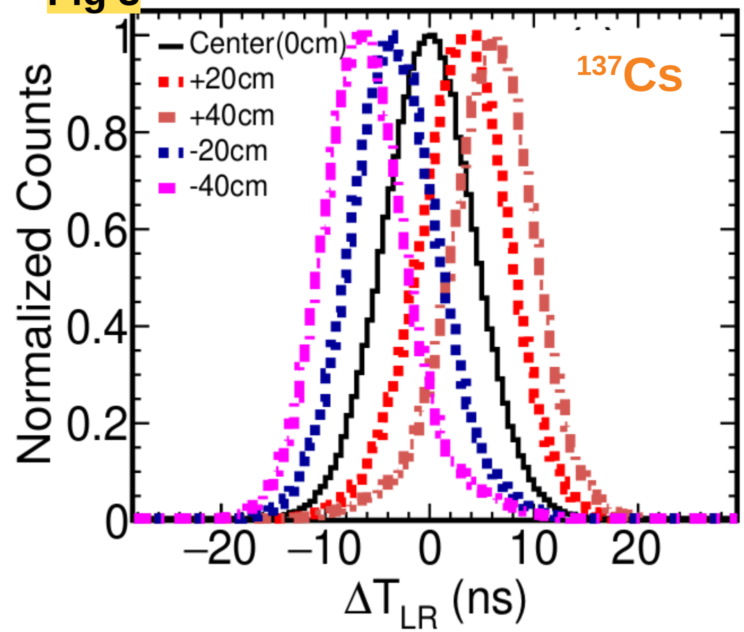


Fig 3



- Reconstruction of ΔT_{LR} for parameterizing an approximate position (Z_{pos}) using ^{137}Cs source.

Fig 4

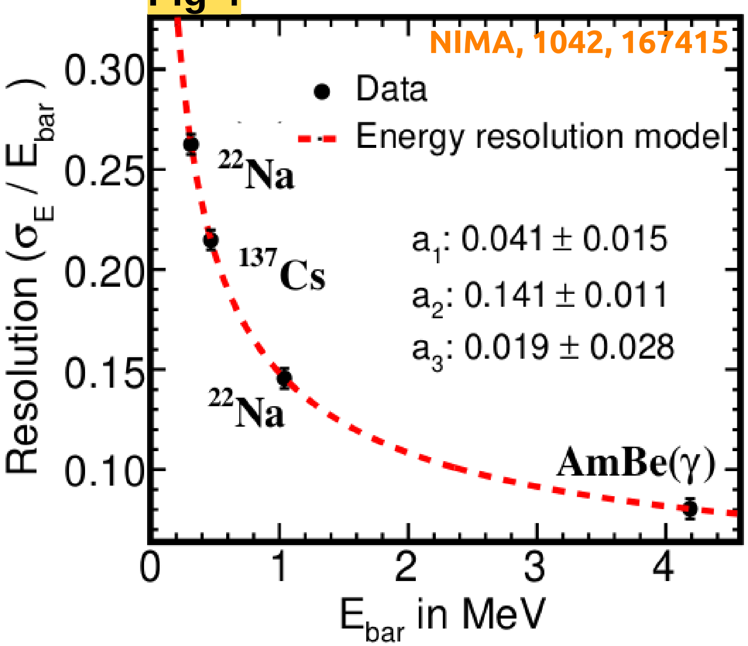
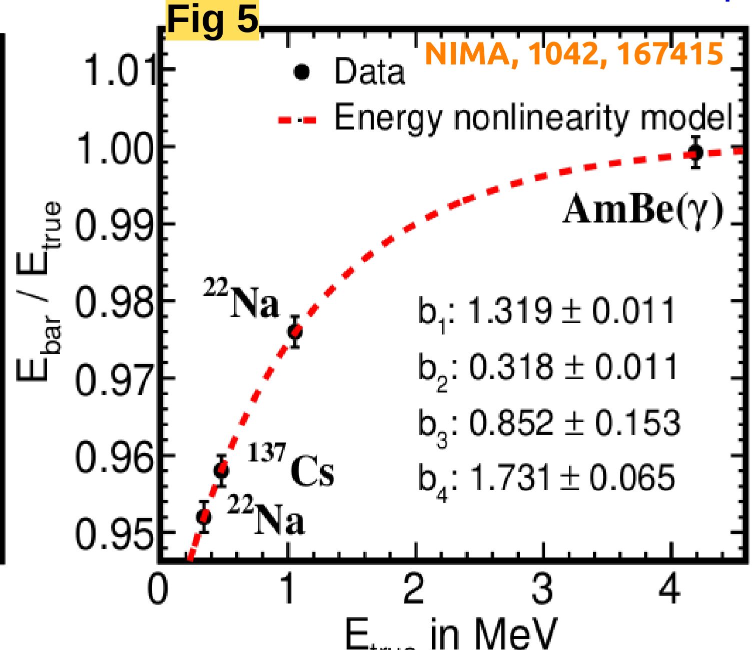


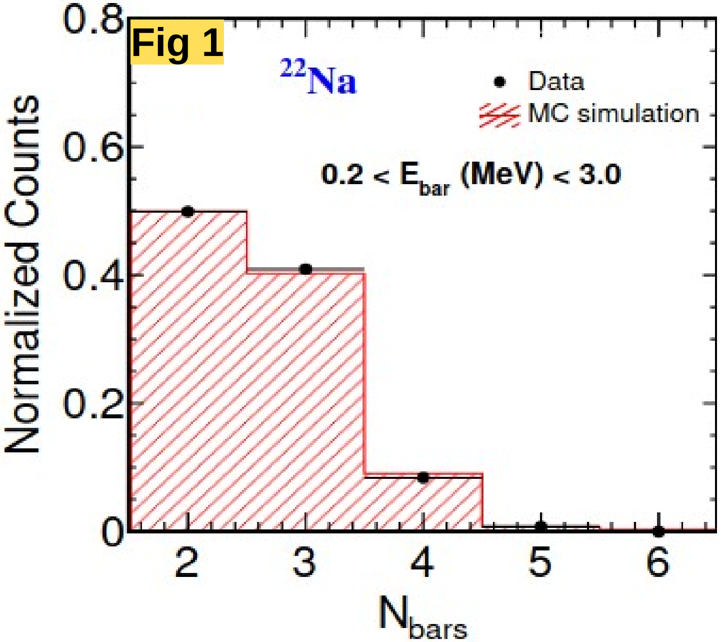
Fig 5

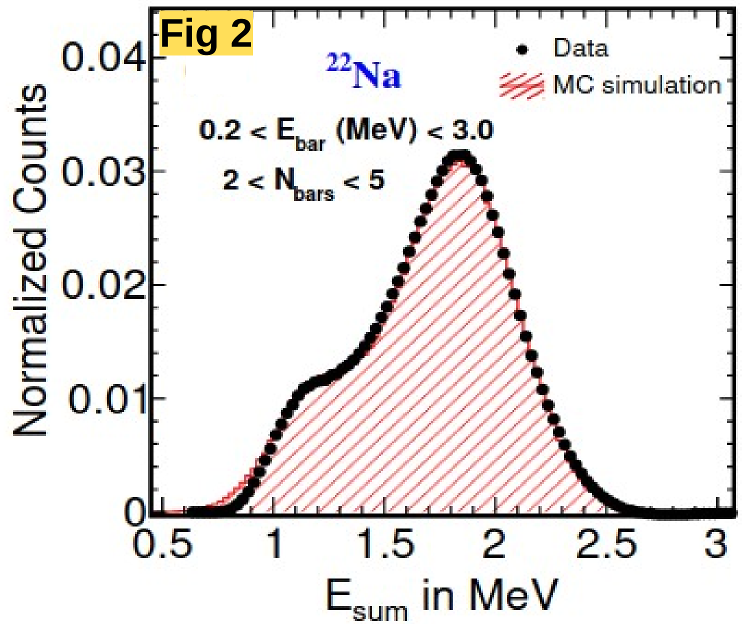


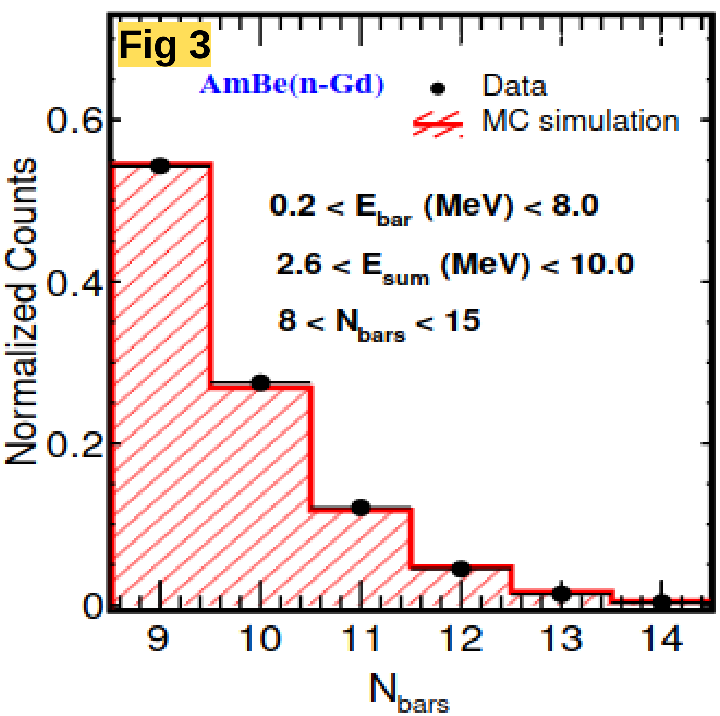
- Energy dependent resolution(σ_E / E_{bar}) = 14% / √E
- Energy non-linearity model of PSB:

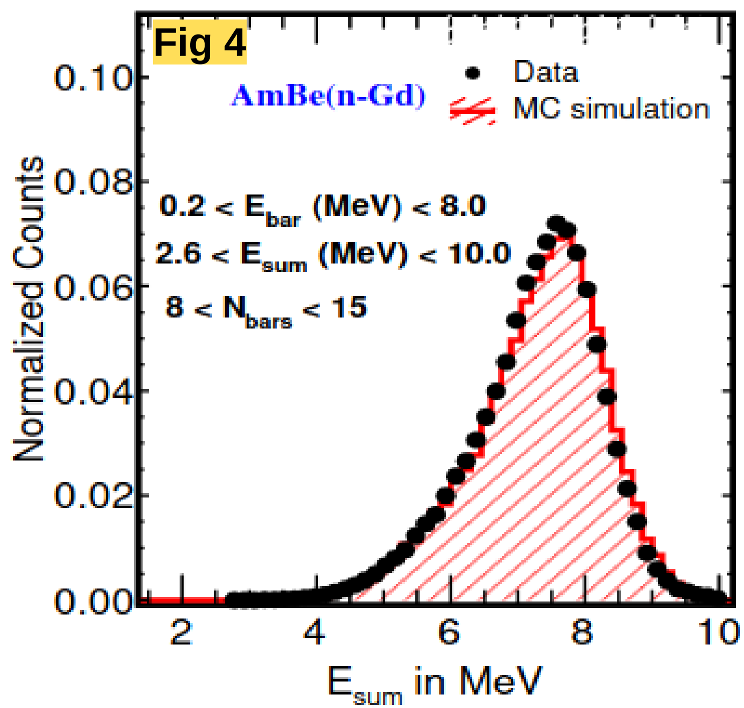
$$E_{bar} / E_{true} = b_1 - b_2/[1 - e^{b_3 E_{true} + b_4}]$$

Reconstruction of sum energy and bar multiplicity

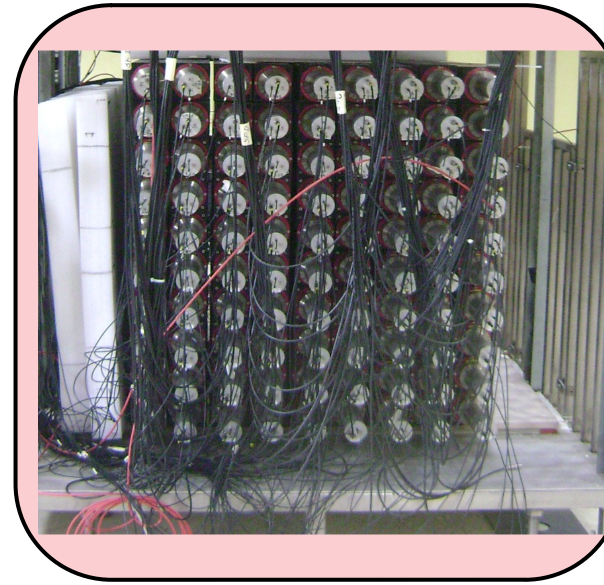








- Measured data and MC simulated E_{sum} and N_{bars} distributions for ^{22}Na positron + γ source.



- Measured data and MC simulated E_{sum} and N_{bars} distributions for n-Gd capture cascade γ-rays.

Backgrounds inside the Dhruva reactor hall

Fig 1

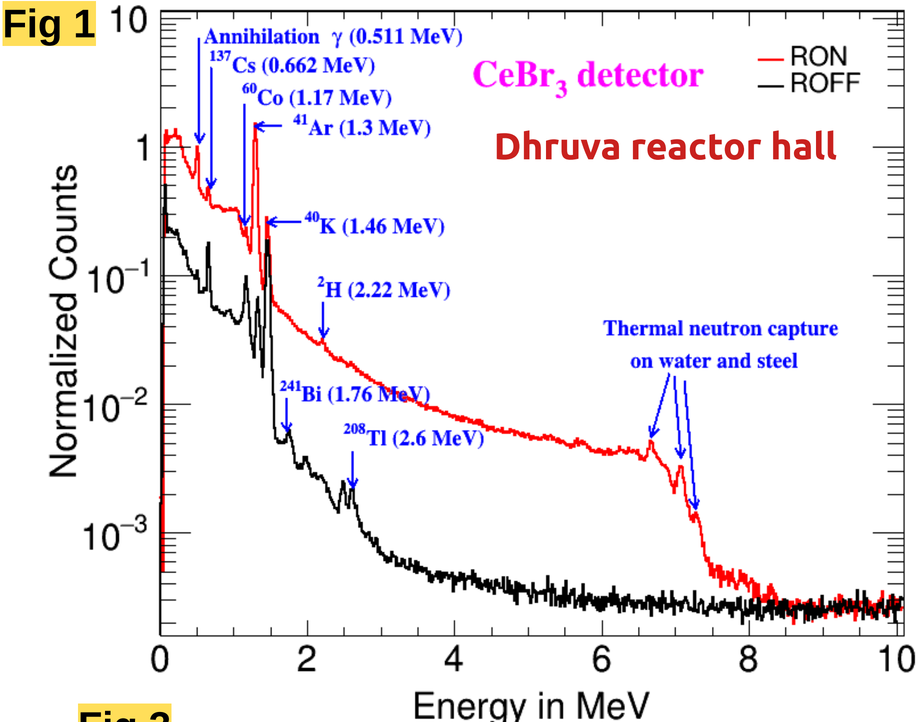


Fig 2

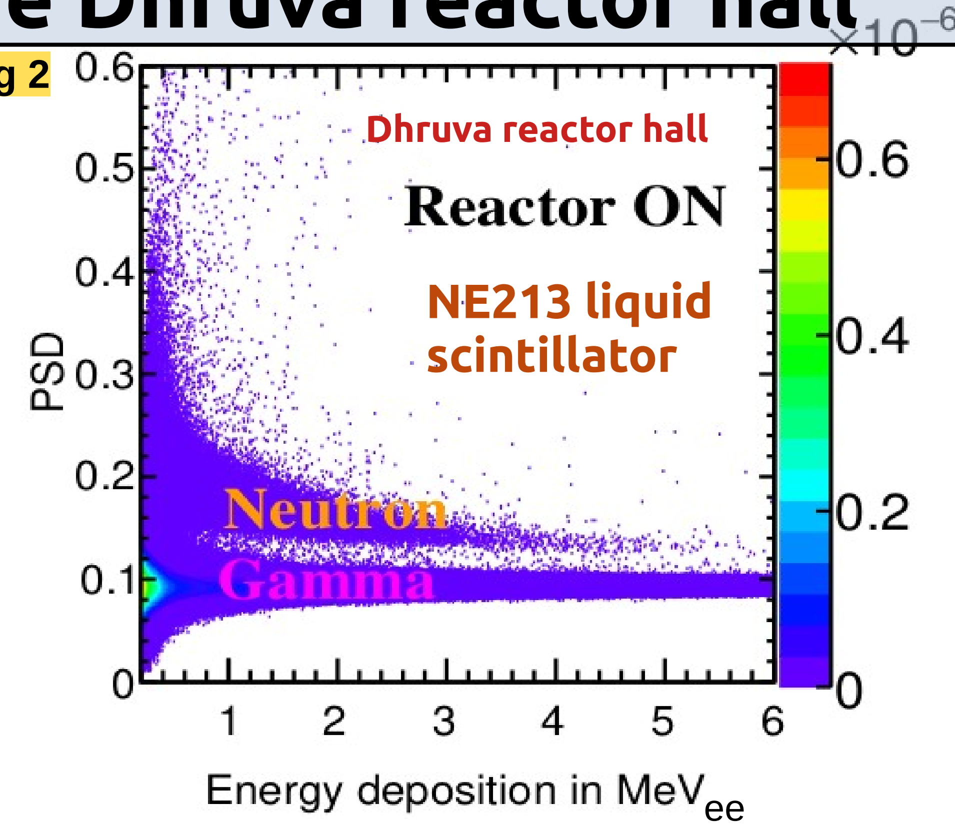
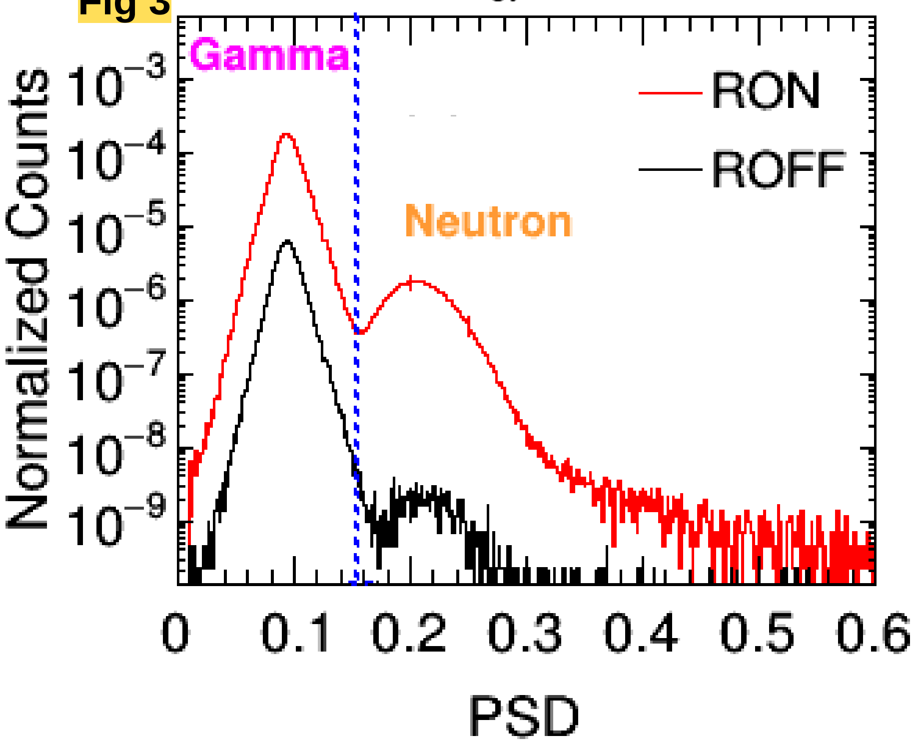


Fig 3



- Higher reactor-correlated background rates are encountered at ISMRAN site.
- High energy γ-rays from neutron interactions on water, steel, or other structural materials.
- PSD parameter distribution of γ-rays and fast neutrons using NE213 liquid scintillator at reactor ON and OFF conditions.

Detector response and In-situ energy calibration

Fig 1

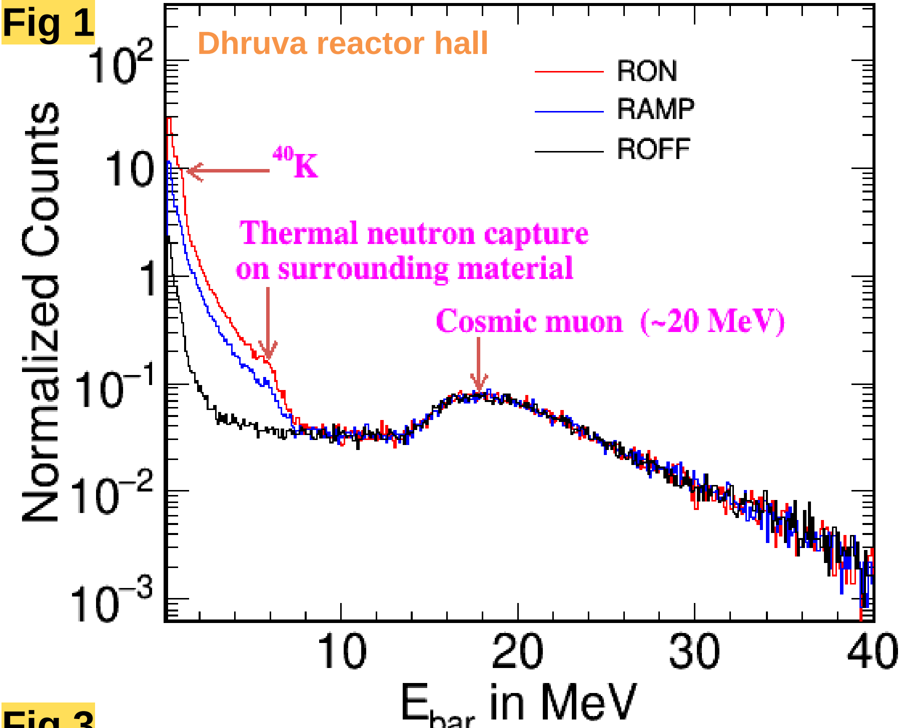


Fig 2

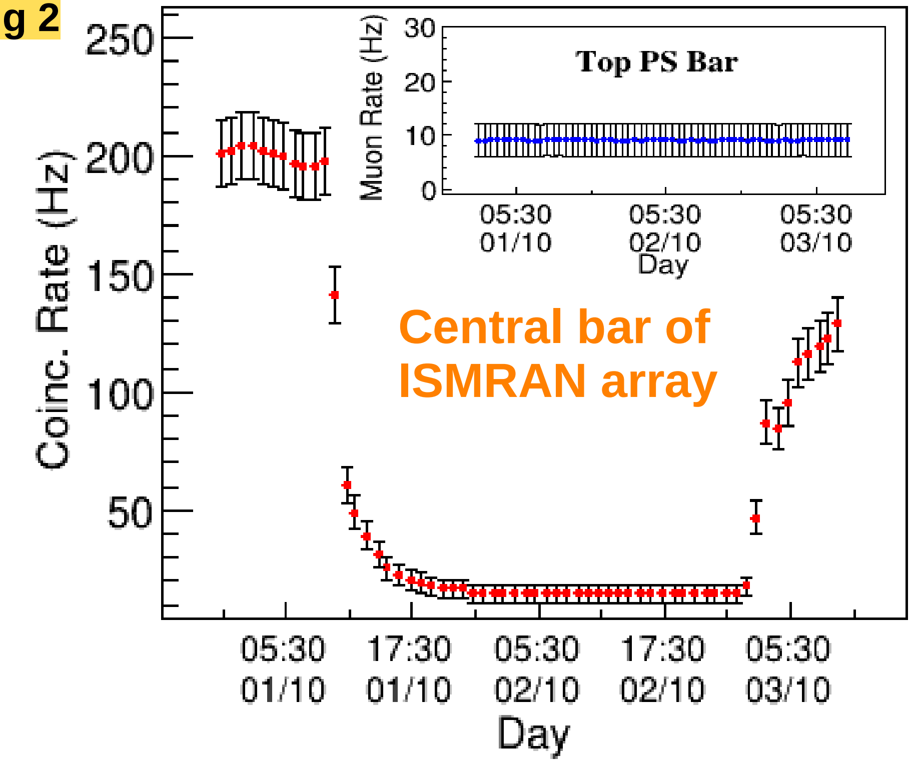
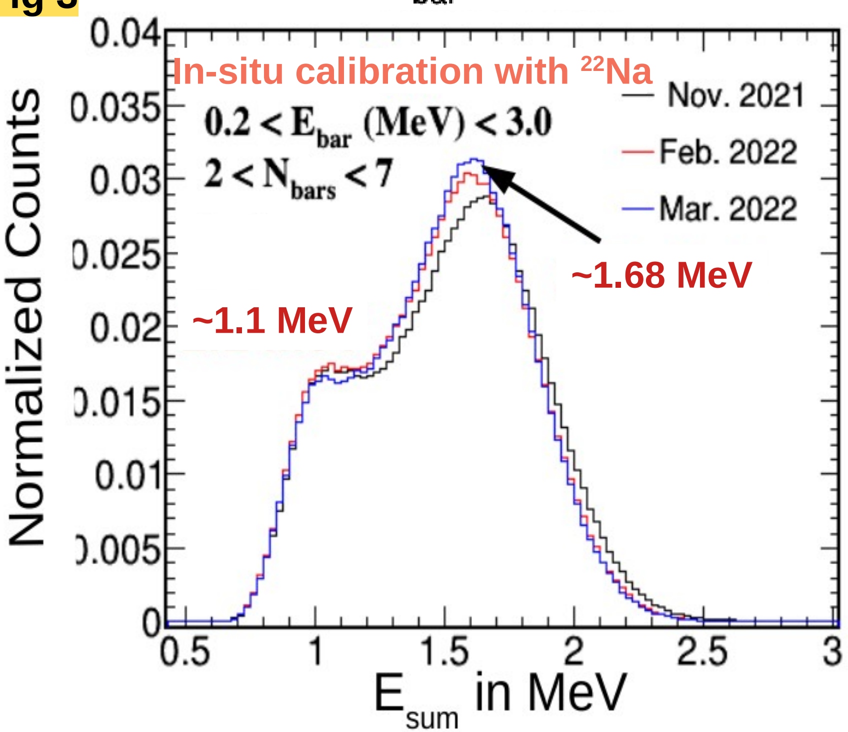


Fig 3



- Comparisons of single bar energy deposition in the center bar of ISMRAN array at different reactor conditions.
- Coincidence rate of the center bar and muon rate at the top most bar of ISMRAN array at reactor ON condition.
- Reconstructed sum energy distributions of ^{22}Na source, placed at the center of ISMRAN array.

Reconstruction of Prompt & Delay event

Fig 1

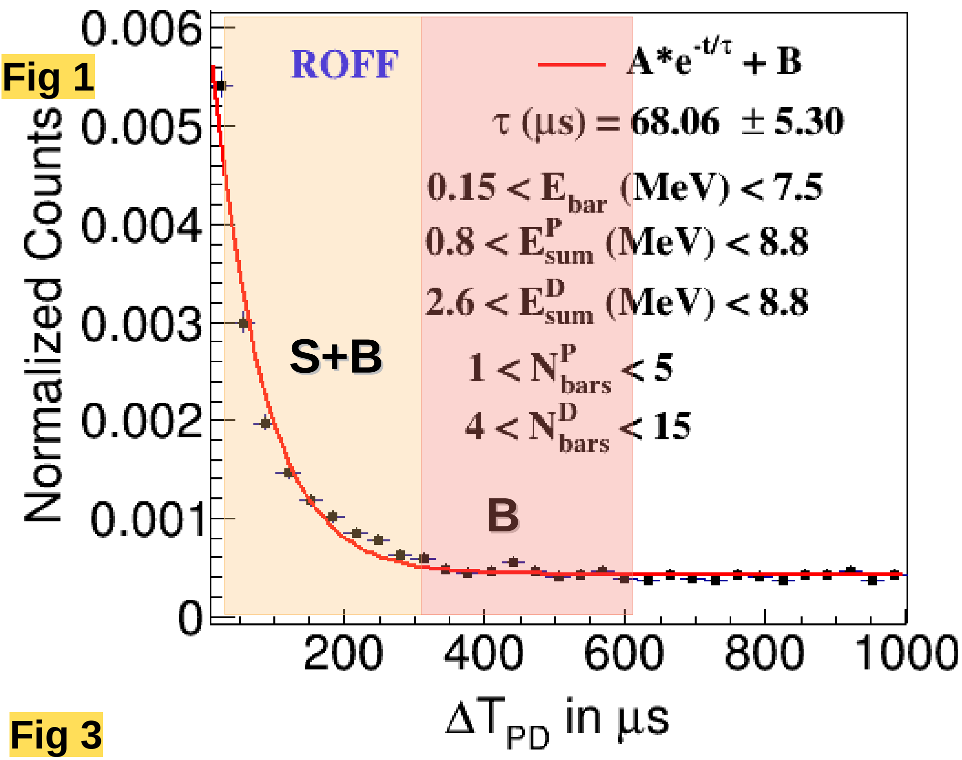


Fig 2

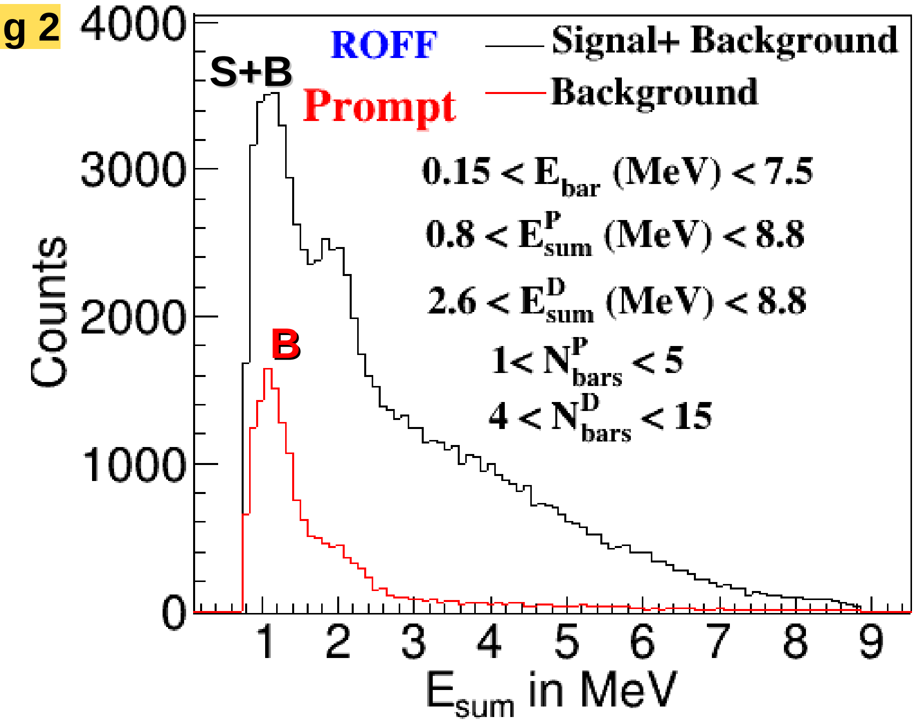
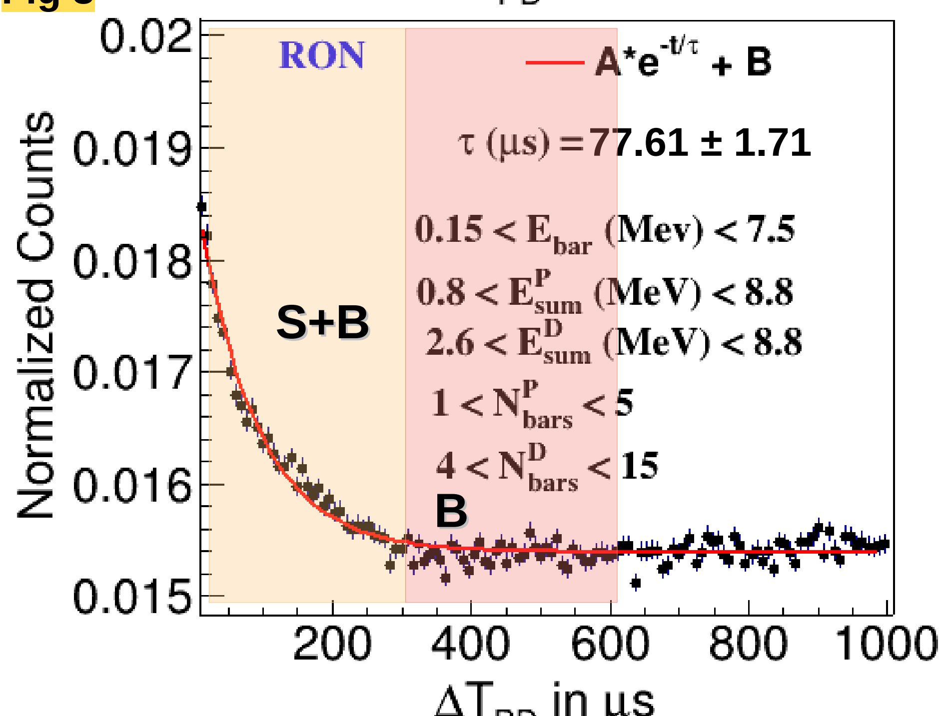


Fig 3



- **Distribution of time difference (ΔT_{PD}) between prompt and delayed event pairs for reactor OFF condition.**
- **Signal region: $10 < \Delta T_{PD}$ (μs) < 310 ; Background region: $310 < \Delta T_{PD}$ (μs) < 610.**
- **Sum energy distribution for prompt events at reactor OFF condition at different ΔT_{PD} regions within a 20 ns coincidence time window.**

Conclusion and Outlook

- ✍ We have performed the comparative study of response of PSB in RON, ROFF and RAMP conditions in terms of single bar energy deposition.

- ✍ We have also studied the uniformity of detector response (in-situ energy calibration) by reconstructing sum energy for ^{22}Na source when it is kept at the center of the ISMRAN array and it is observed that the reconstructed peaks are constant over the period of time.

- ✍ We have discussed about the ongoing efforts on the measurements of the anti-neutrino events from the full scale ISMRAN detector setup at Dhruva reactor hall.

- ✡ Full scale ISMRAN had been installed and commissioned in Dhruva reactor hall in November 2021 and acquiring data in the round the clock mode. Data Analysis for obtaining the reactor anti-neutrino energy spectra is in full swing.

- ✡ Machine learning technique has been tested for discriminating non-reducible fast neutron background to separate the IBD events in reactor ON condition.

References:

1. R. Dey et al.: NIMA, 1042, 167415 (2022), doi: 10.1016/j.nima.2022.167415.

2. P.K. Netrakanti et al.: NIMA, 1024, 166126 (2021), doi:10.1016/j.nima.2021.166126.

3. S.P. Behera & D.K. Mishra et al. : Phys. Rev. D 102, 013002 (2020), doi:10.1103/PhysRevD.102.013002.

Acknowledgement

Nuclear Physics Division

Centre for Design and Manufacture

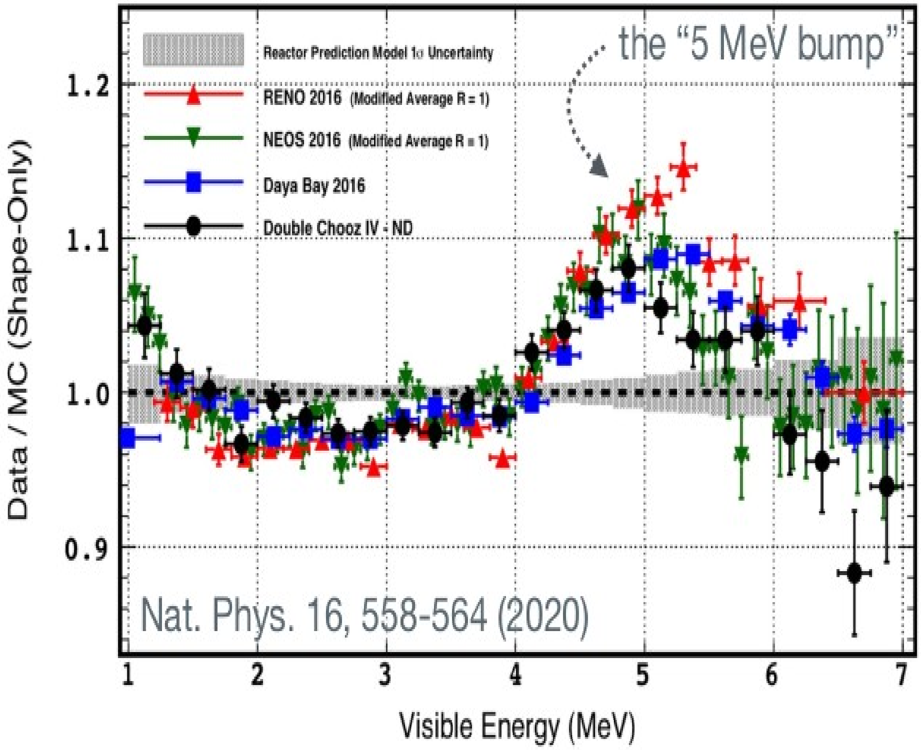
Research Reactor Services Division

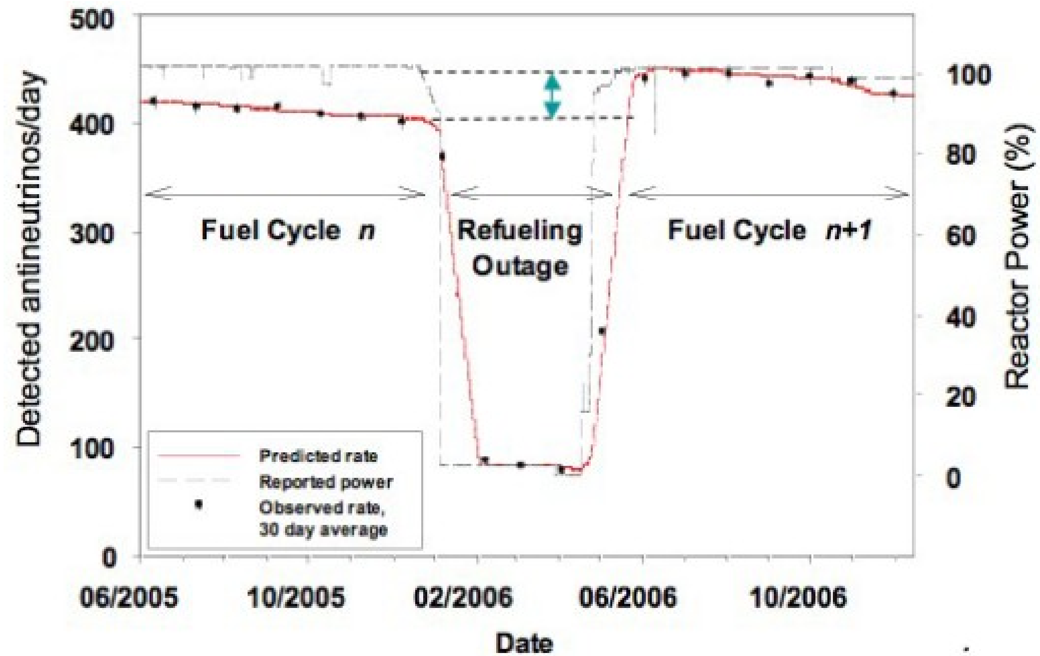
Reactor Operations Division

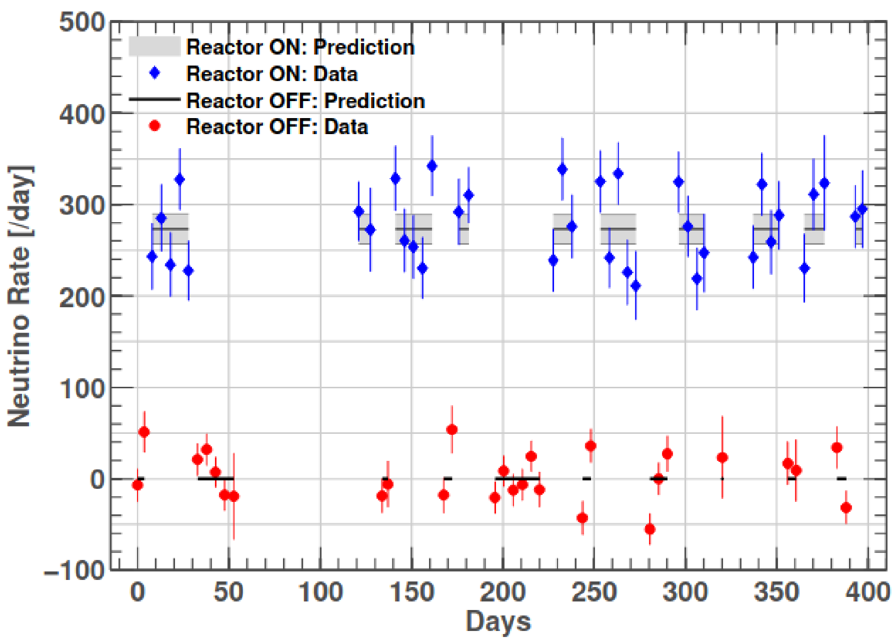
Reactor Safety Division

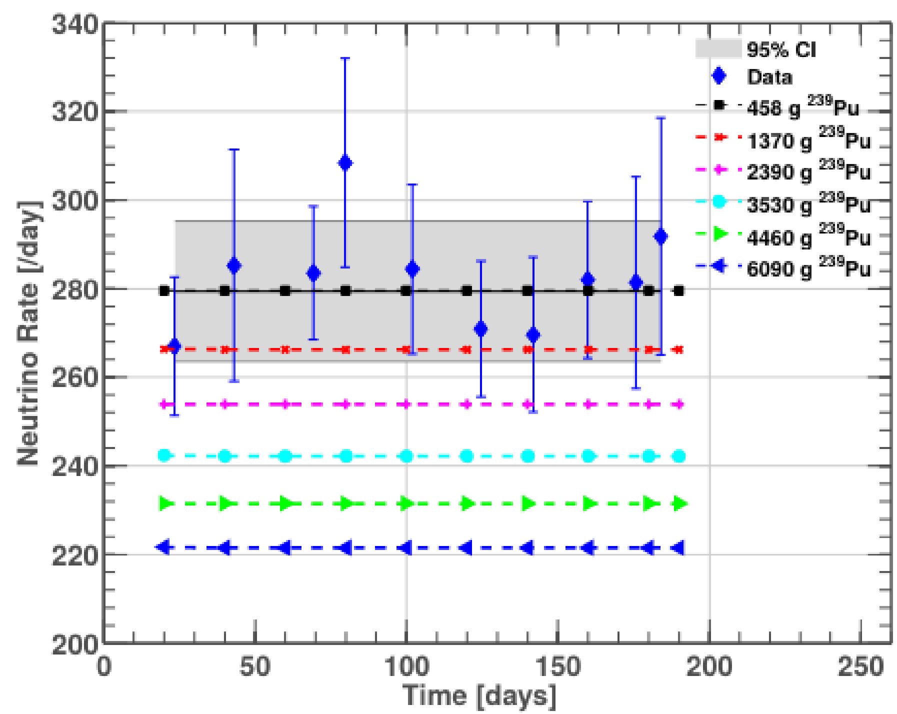
Thanks for your attention!!

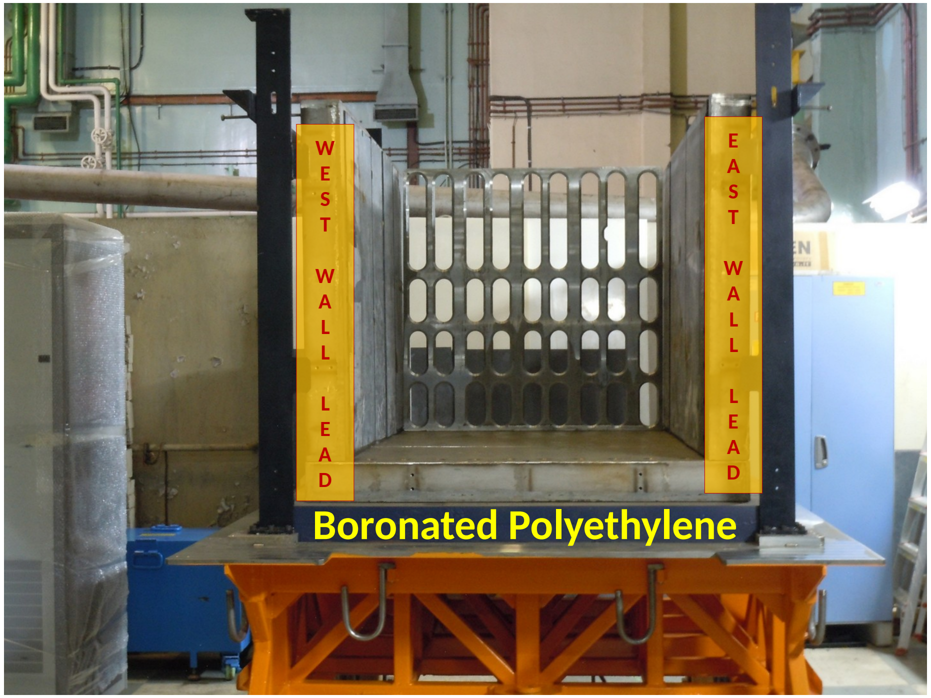
Backup slides

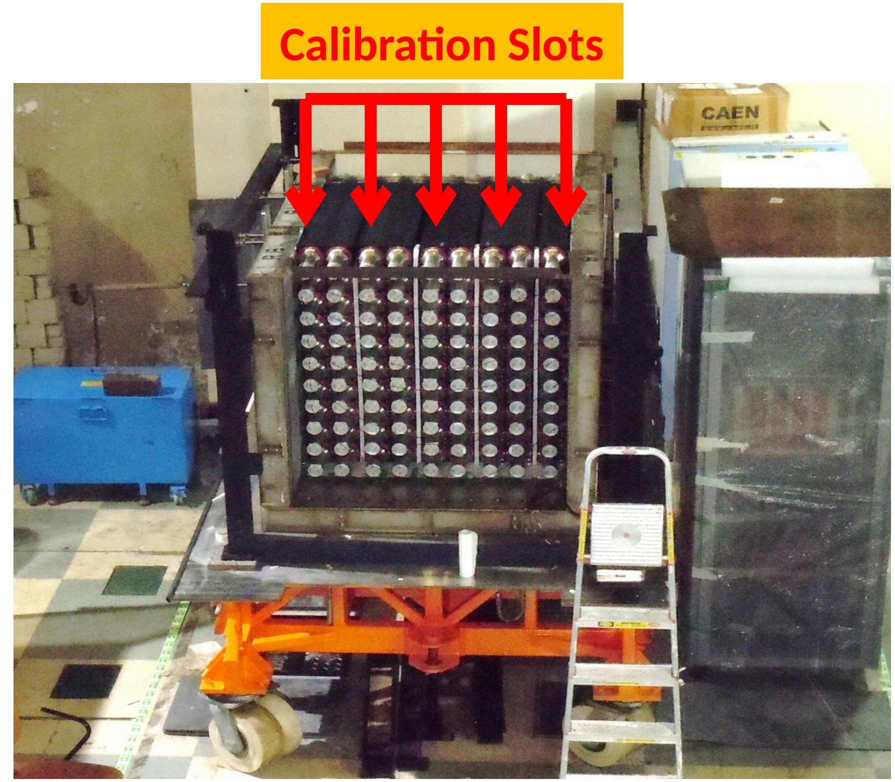

Reactor Prediction Model 1σ Uncertainty
RENO 2016 (Modified Average R = 1)
NEOS 2016 (Modified Average R = 1)
Daya Bay 2016
Double Chooz IV - ND
the "5 MeV bump"
Nat. Phys. 16, 558-564 (2020)
Data / MC (Shape-Only)
Visible Energy (MeV)

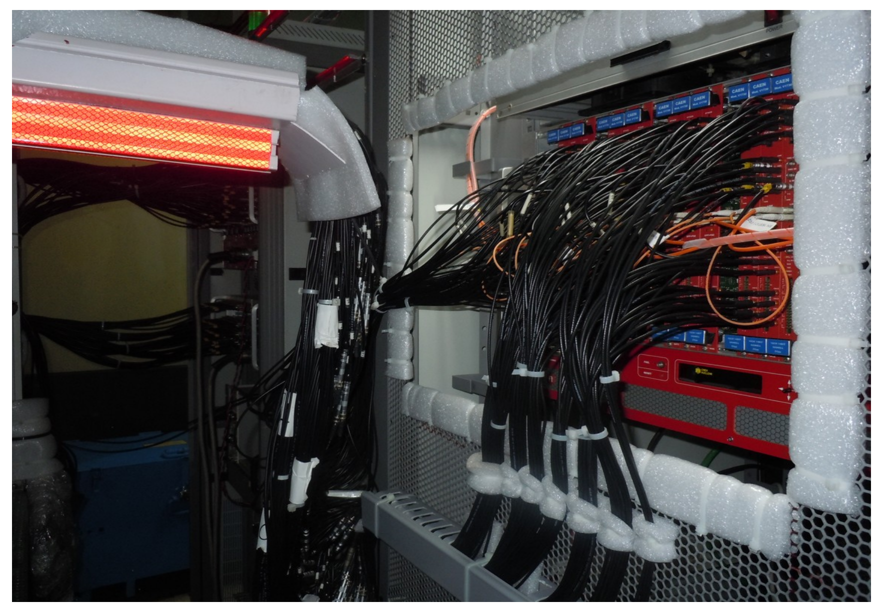

Fuel Cycle n
Refueling Outage
Fuel Cycle n+1
Predicted rate
Reported power
Observed rate, 30 day average
Detected antineutrinos/day
Reactor Power (%)
Date
06/2005
10/2005
02/2006
06/2006
10/2006


Reactor ON: Prediction
Reactor ON: Data
Reactor OFF: Prediction
Reactor OFF: Data
Neutrino Rate [/day]
Days


95% CI
Data
458 g 239Pu
1370 g 239Pu
2390 g 239Pu
3530 g 239Pu
4460 g 239Pu
6090 g 239Pu
Neutrino Rate [/day]
Time [days]







$$N^{I}_{\bar{\nu}_e}\ (IBD) = [\ (\ N^{R}_{RON}\ (S + B) - N^{R}_{RON}\ (B)\ ) - K\ (\ N^{R}_{ROFF}\ (S + B) - N^{R}_{ROFF}\ (B)\ )\ ],$$

$$N^{II}_{\bar{\nu}_e}\ (IBD) = [\ (\ N^{R}_{RON}\ (S + B) - N^{M}_{RON}\ (S + B)\ ) - K\ (\ N^{R}_{ROFF}\ (S + B) - N^{M}_{ROFF}\ (S + B)\ )\ ],$$

$$\text{Resolution}\left(\frac{\sigma_E}{E_{bar}}\right) = \sqrt{A^2 + \frac{B^2}{E_{bar}} + \frac{C^2}{E_{bar}^2}}, \tag{4}$$