Indian Scintillator Matrix for Reactor Anti-Neutrino detection

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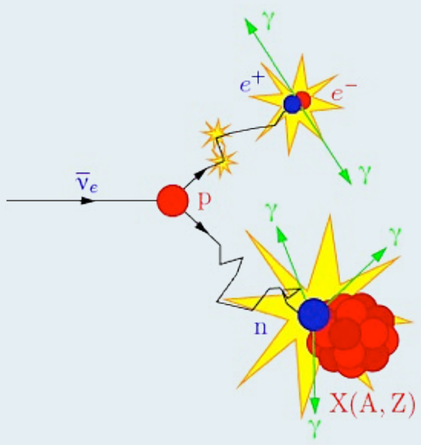
Poster based on references [1] and [2]

Reactor anti-neutrinos and their detection mechanism:

Anti-neutrinos from reactors are excellent probes for monitoring reactor power and its core composition as well as for sterile oscillation searches.



Inverse Beta Decay

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

Prompt e^+ signal: Energy loss+Annihilation

$e^+ + e^- \rightarrow 2\,\gamma$

Delayed neutron signal: Capture on Gd

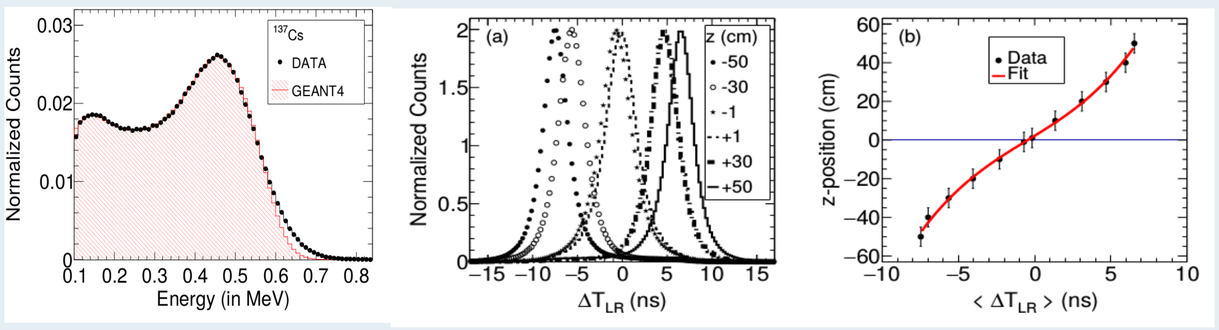
$n + {}^{155}Gd \rightarrow {}^{156}Gd^* \rightarrow {}^{156}Gd + \gamma's$

$n + {}^{157}Gd \rightarrow {}^{158}Gd^* \rightarrow {}^{158}Gd + \gamma's$

$\overline{\nu}_e$ is detected predominantly through Inverse Beta Decay (IBD) reaction with a two-fold prompt and delayed signature.

ISMRAN plastic scintillator bar characterization studies

Geometric mean of signal from the two PMTs used for energy calibration.
Time difference between timestamps of the two PMT signals related to the position along the PS bar.

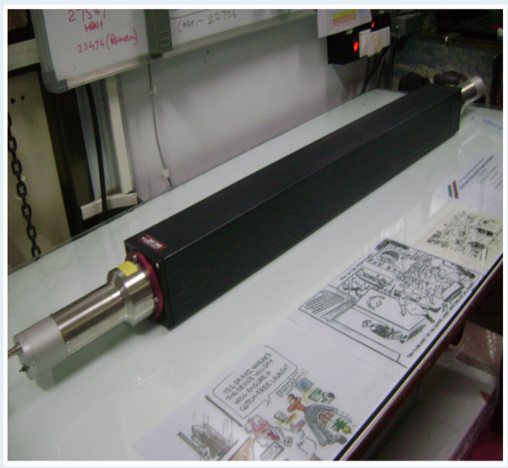


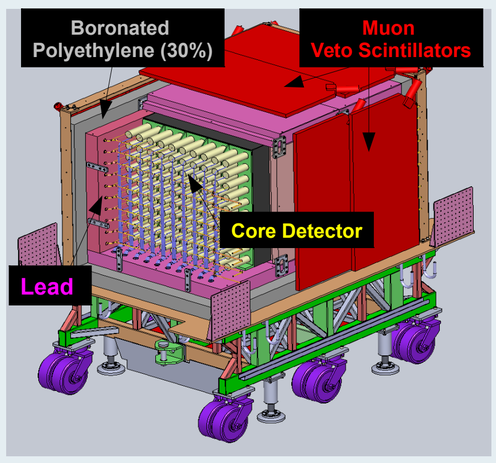
Left : Calibrated data vs simulation for ^{137}Cs in PS bar. **Right:** Time difference between end PMT signals at different positions and their relation.

Comparing the data and simulation for known γ-ray source data gives energy resolution function as ~20%/√E

ISMRAN detector and its prototype mini-ISMRAN

Segmented geometry : 10 cm x 10 cm x 100 cm plastic scintillator (PS) bars directly coupled to 3" PMTs at both ends and wrapped with Gd coated mylar.





Left: ISMRAN Plastic Scintillator(PS) bar **Right:** Proposed ISMRAN detector with shielding

ISMRAN: 100 PS bars in 10 x 10 matrix. Volume: 1m3; Weight: 1 ton. High sampling rate (500 MS/s) digitizers to read the 200 PMT channels. Shielding of 10 cm Lead (Pb) and 10 cm Borated Polyethylene (BP) and with muon veto scintillators to allow for above ground operation.

About 60 IBD interactions per day are expected at 13m distance from the 100 MW_{th} reactor core for a realistic efficiency of ~16%.

mini-ISMRAN: 16 PS bars in 4 x 4 matrix Shielding same as for ISMRAN. No veto.

More than 3 months of reactor ON and OFF data collected.

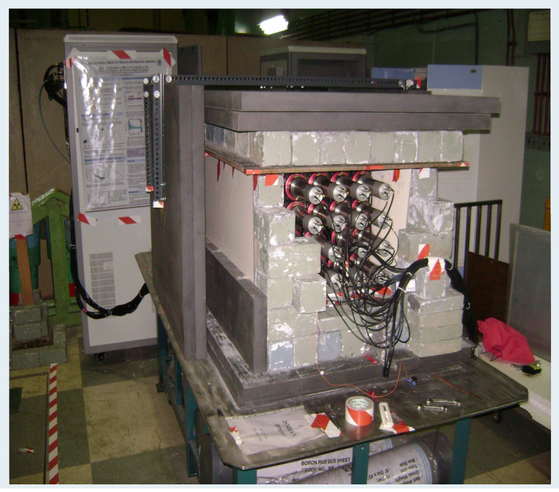
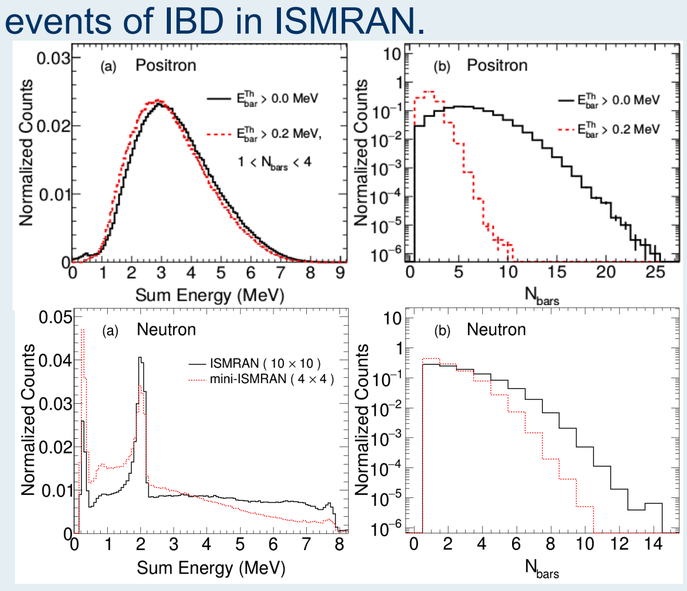


Fig on the Right: Prototype mini-ISMRAN detector setup with full shielding in reactor hall. Snapshot taken while halfway through the installation and shows the 16 bars and cables routed back to DAQ

ISMRAN detector simulations and estimated detection efficiency

Sum of energy deposits (E_{prompt} & $E_{delayed}$) and Number of bars with energy deposit ($N_{bars\ prompt}$ & $N_{bars\ delayed}$) used to define and identify prompt and delay events of IBD in ISMRAN.

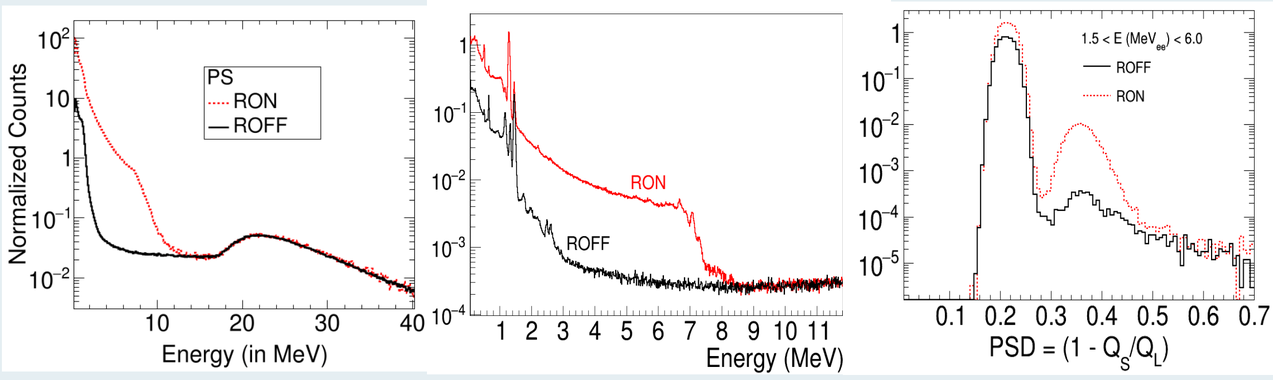


Selection 1 (Relaxed cuts)	η(%)
1.8 < E_{prompt} (MeV) < 8.0, 1 < $N_{bars\ prompt}$ < 4 0.8 < $E_{delayed}$ (MeV) < 8.0, $N_{bars\ delayed}$ > 3	20
1.8 < E_{prompt} (MeV) < 8.0, 1 < $N_{bars\ prompt}$ < 4 0.8 < $E_{delayed}$ (MeV) < 8.0, $N_{bars\ delayed}$ > 3 4.0 < ΔT (μs) < 200.0	19

Selection 2 (Tighter cuts)	η(%)
2.2 < E_{prompt} (MeV) < 8.0, 1 < $N_{bars\ prompt}$ < 4 3.0 < $E_{delayed}$ (MeV) < 8.0, $N_{bars\ delayed}$ > 3	18
2.2 < E_{prompt} (MeV) < 8.0, 1 < $N_{bars\ prompt}$ < 4 3.0 < $E_{delayed}$ (MeV) < 8.0, $N_{bars\ delayed}$ > 3 8.0 < ΔT (μs) < 200.0	16

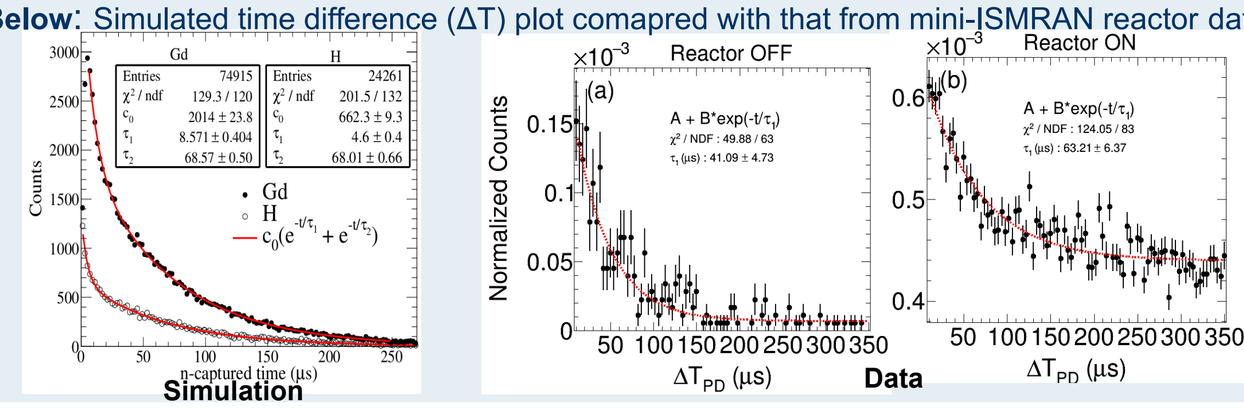
Left: Typical sum energy and N_{bars} spectra for IBD prompt events (top) and delayed events (bottom) as seen in simulations.
Right: Detection efficiencies calculated for two selection scenarios based on these simulations

Background measurements @ Dhruva & filtered IBD like events



Above: Reactor γ-ray and neutron backgound spectra in PS bar, CeBr3 and liquid scintillators

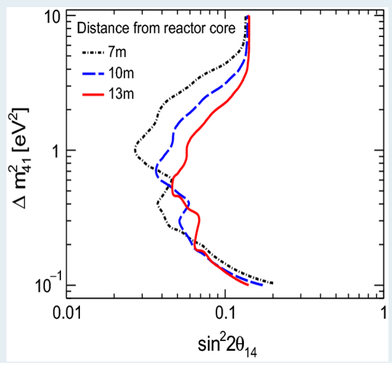
Below: Simulated time difference (ΔT) plot comapred with that from mini-ISMRAN reactor data



Sterile neutrino sensitivity studies for ISMRAN

The study on active-sterile (3+1 scenario) neutrino mixing sensitivity is performed at an exposure of 1 ton-year for ISMRAN at 13 m from DHRUVA core.

Sensitivity seen for $\sin^2 2\theta_{14} \geq 0.064$ at $\Delta m^2_{41} = 1.0\ eV^2$. and improves by twice when distance reduced to 7 m as seen in figure alongside.



Reactor Data analysis results from mini-ISMRAN

Data from mini-ISMRAN analysed for 2 reactor ON and OFF cycles with signal events discriminated from background based on ΔT between prompt and delayed events.

Reasonable agreement between rates estimated from power calculations; but correlated background contribution not considered in analysis.

Data Sets	DATA (mini-ISMRAN)	Prediction
March **ROFF : ~22 days**	**7.0 ± 2.8(stat)**	**------**
June **RON : ~28 days** **ROFF : ~ 2 days**	**54.2 ± 28.9(stat)** **1.0 ± 0.4(stat)**	**56.8**
November **RON : ~27 days** **ROFF : ~ 3 days**	**55.5 ± 30.2(stat)** **2.0 ± 0.8(stat)**	**57.9**

Conclusions and Outlook :

The data from prototype detector shows promising results for using ISMRAN as a reactor monitoring setup. Also, simulation results predict sterile oscillation sensitivity covering sufficient parameter space to verify sterile neutrino hypothesis in the 3+1 scenario.

The final 1 ton ISMRAN setup is expected to be comissioned by spring next year. Meanwhile, detailed quantification of various correlated backgrounds and improvements on event filtering techniques are underway to achieve better signal to background ratio.

References :

[1] D. Mulmule et. al. NIM A 911 (2018) 104–114

[2] Behera, S.P., Mishra, D.K. & Pant, L.M. Eur. Phys. J. C (2019) 79: 86.

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