National Superconducting Cyclotron Lab.
at Michigan State University

Neutron Detection with Plastic Scintillators Coupled to Solid-state Photomultiplier Detectors

- DE-SC0011280

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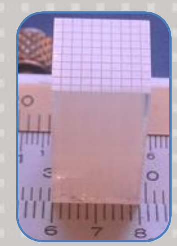
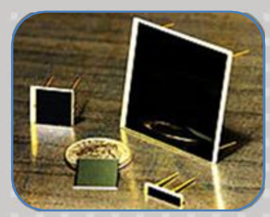
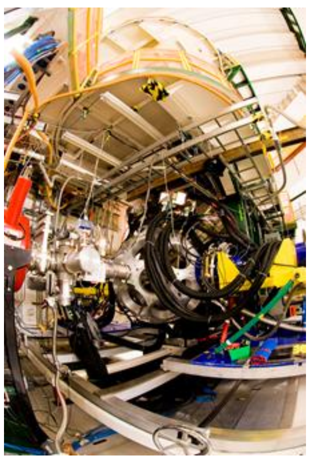


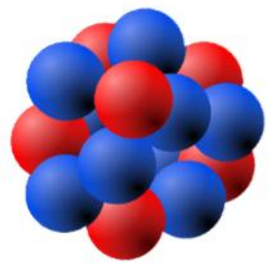


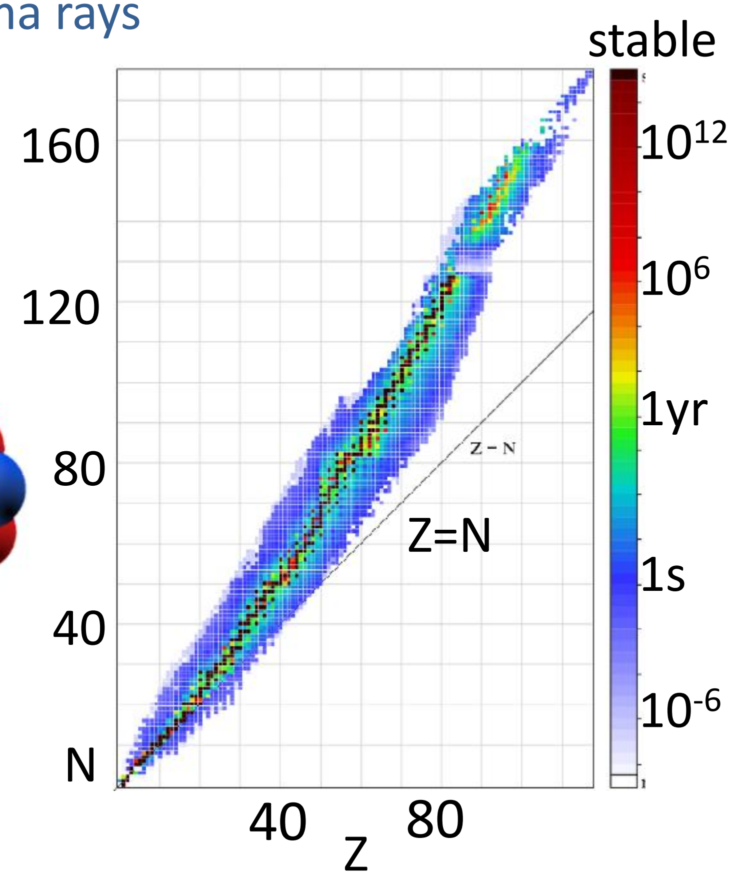
Program Goals

Enable experiments to explore very exotic nuclei systems, in particular with very large neutron excesses.

- Better discrimination for neutrons and gamma rays
- Improved spectroscopy for neutrons
- Ability to operate in magnetic field







- Construct “large-volume” detector with SiPMs

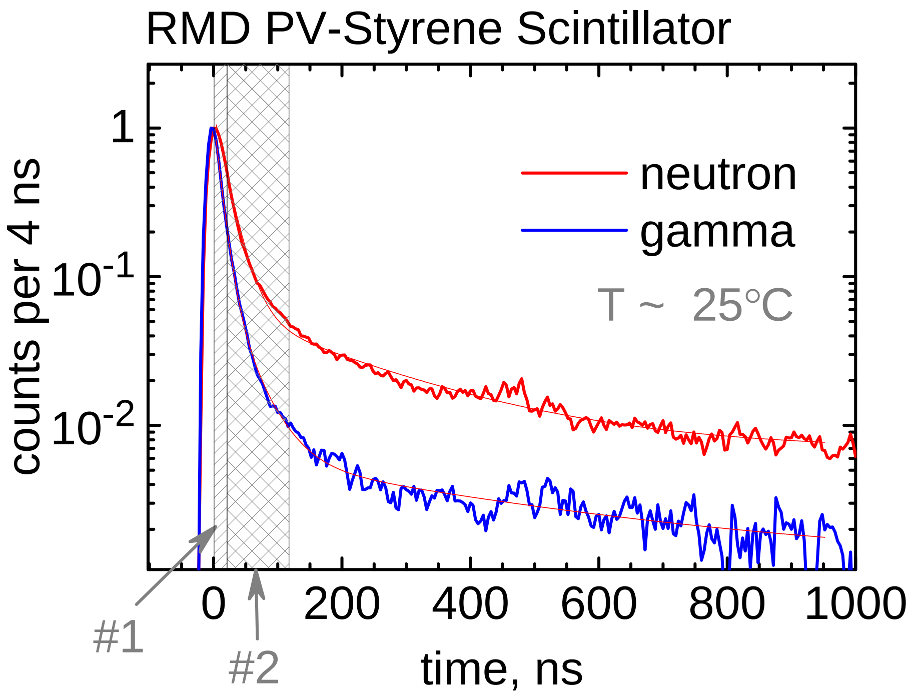
Plastic scintillation material comparison

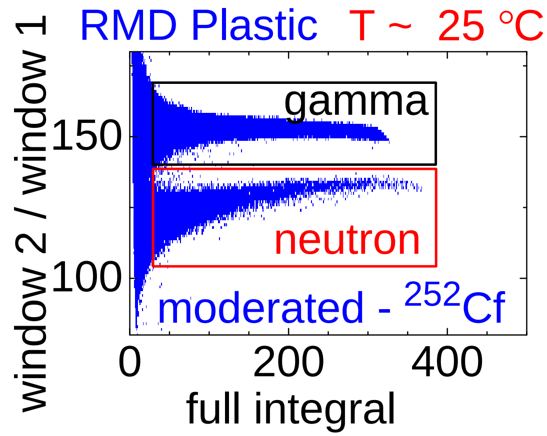
Table: Properties of fast neutron scintillators

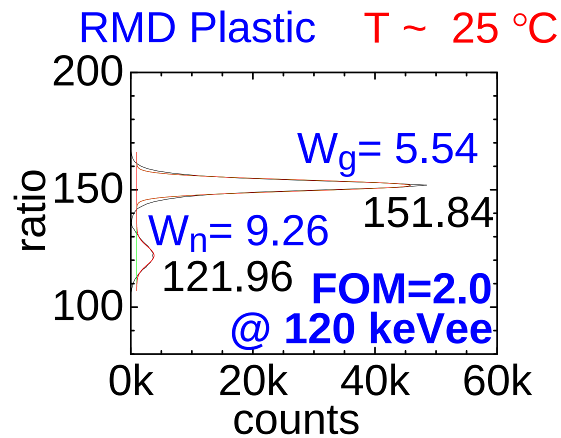
Scintillator	λ (nm)	Light yield (ph/MeV)	Decay time (ns)	Pulse shape discrimination
BC-408 plastic	425	12,800	2.1	poor
BC-501A liquid	425	15,600	3.2	Very good
Anthracene	445	20,000	30	poor
Stilbene	380	14,000	3.5	good
FR001-BBQ	480	~13,000	18	Very good
FR002-POPOP	440	13,900	1.8	Very good
DPA	468	15,000	12	Very good
Phenylcarbizol	445	25,000	9-10	Very good

- Emerging organic PSD materials exceeding Anthracene's Light Yield
- Plastic scintillation materials with emission-wavelength discrimination
- LENDA bar uses BC-408

PSD distinguishes between gamma (loLET) and neutron (hiLET) events



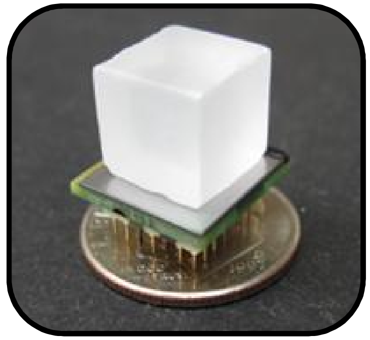


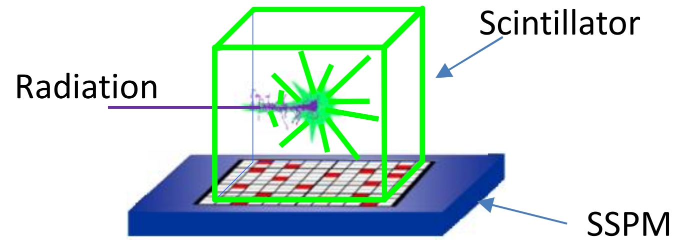


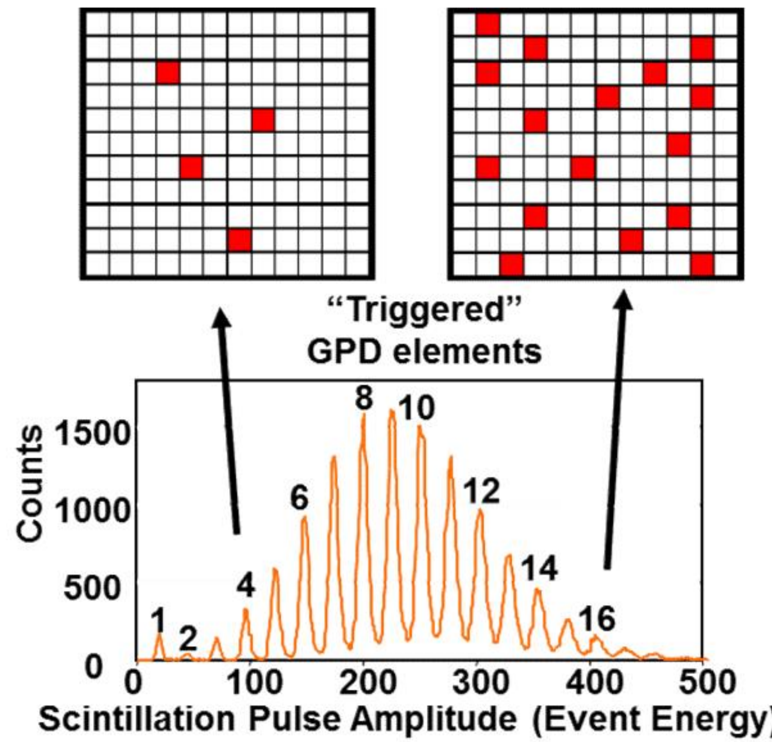
Pulse shape discrimination (PSD): Collection of excited states depends on LET

- Performance specifications: Light yield, **FOM**, and PSD threshold (depends on detector noise)

SSPM Introduction: Array of Geiger Photodiode Elements







- SSPMs (SiPM – SSPM in Silicon)
  - Gain >1,000,000
  - Very low noise
  - Robust
  - Digital (photon counting)
  - High DE
- Dark count rate has improved from a few MHz/mm^2 for early MRS devices to ~30 kHz/mm^2

Selected Si-SSPM Devices

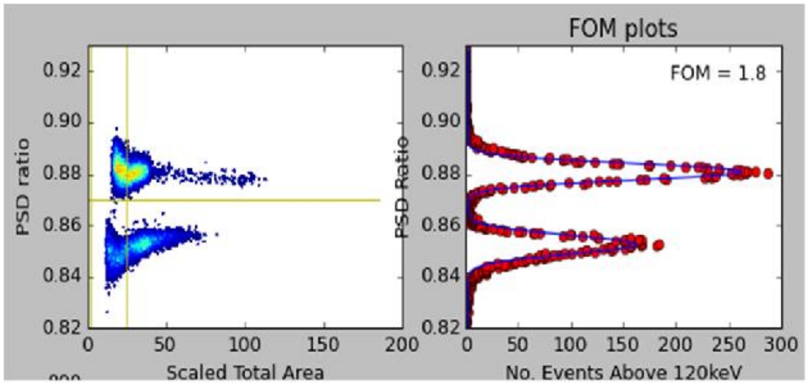
Manufacturer	Device	Total Area (mm^2)	Peak DE l (nm)	Peak DE (%)	DCR @ rT (kHz/mm^2)
SensL	c-series, 60035	7×7	425	30-41	33
	Arrayj-60035-4P-DVB	12.3×12.3	420	38-51	45
Hamamatsu	S13360-6050VE	6.4×6.4	450	40	55
	S13361-3050AE-04	13×13	450	40	55
Ketek	PM6650-EB	6.5×6.5	425	38	250
AdvanSiD	ASD-NUV4S-P	4.5×4.5	420	43	<100
RMD CMOS	TSMC Rambler	5.1×5.1	420	25	350

- SensL and Hamamatsu provide excellent room Temperature (rT) DCR performance
- SensL shortest lead time

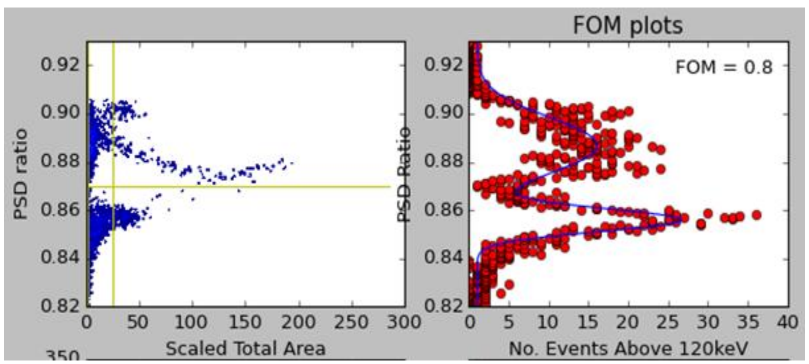
P1: Scintillator Composition and SiPM Mfgr.

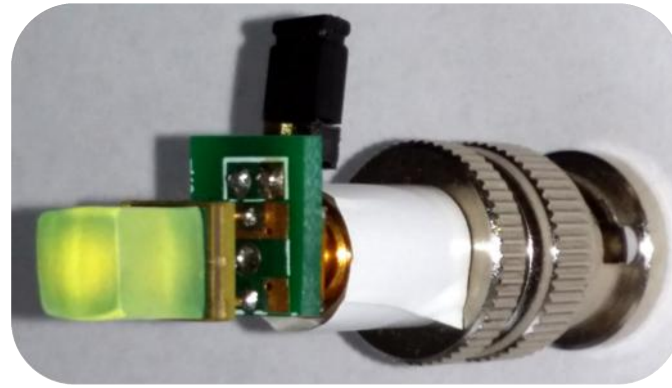
University of Kentucky Neutron Beam

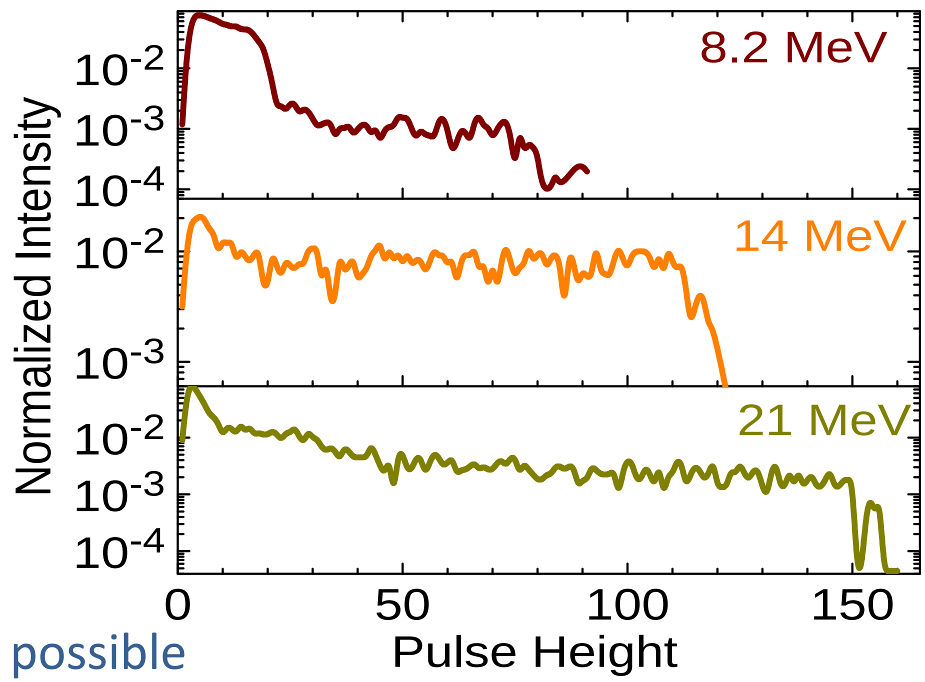
- 8.3 MeV neutrons: FR001



- 20.8 MeV neutrons: FR001







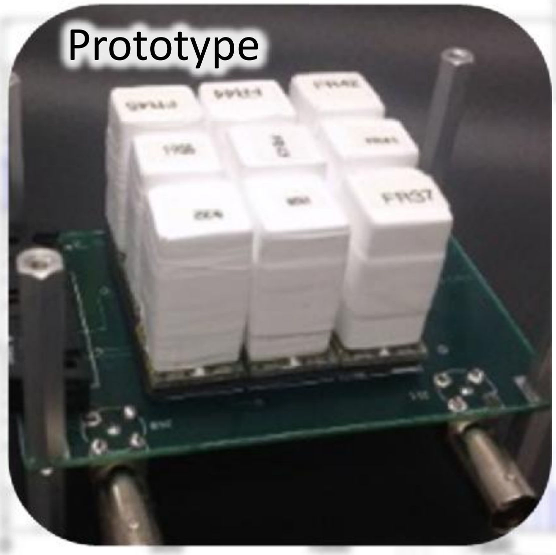
- Peak neutron energy determination is possible

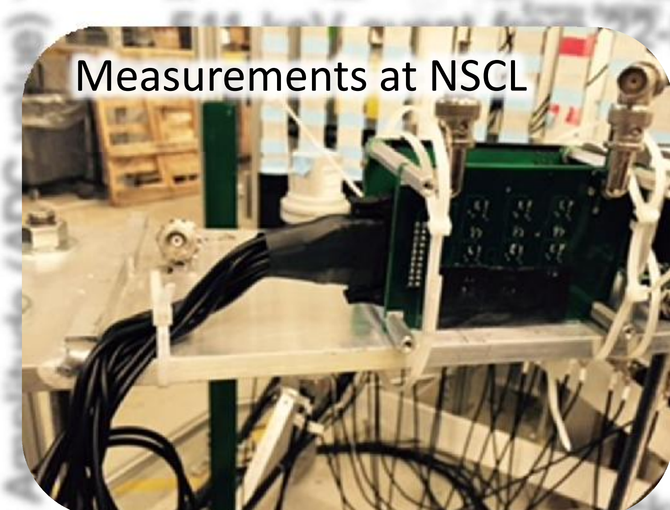
Phase-2 Schedule

	Year 1					Year 2			
Work plan	Q1	Q2	Q3	Q4		Q1	Q2	Q3	Q4
1. Kickoff meeting									
2. Finalize scintillator properties									
Fine tune wavelength shift and establish optimal fluor concentration									
Determine cross-linker fraction for material handling and rigidity									
Scale to large volume materials									
3. Select optical detector unit and test small scintillation samples									
Optimize detector module geometry									
Build tiled array and measure response									
Quantify cooling effect on neutron energy threshold									
Design and build cooled module									
4. Design review									
5. Build processing electronics									
6. Design and build test module									
Travel to NSCL for test									
Analyze results and design improved modules.									
7. Build expanded module for field use experiments									
Send modules to NSCL for test									
Study effect of neutron damage									
Measure neutron response and absolute efficiency in high energy neutron beams									

Program successfully completed

Phase-2 Year 1 Summary





- Scale up to large sizes of at least 3 cm × 5 cm × 5 cm.
- Characterized at NSCL (compared to PMT-based LENDA detector modules).

Performance Summary

Noise floor ~57 keVee

SNR (wrt LENDA): 56%

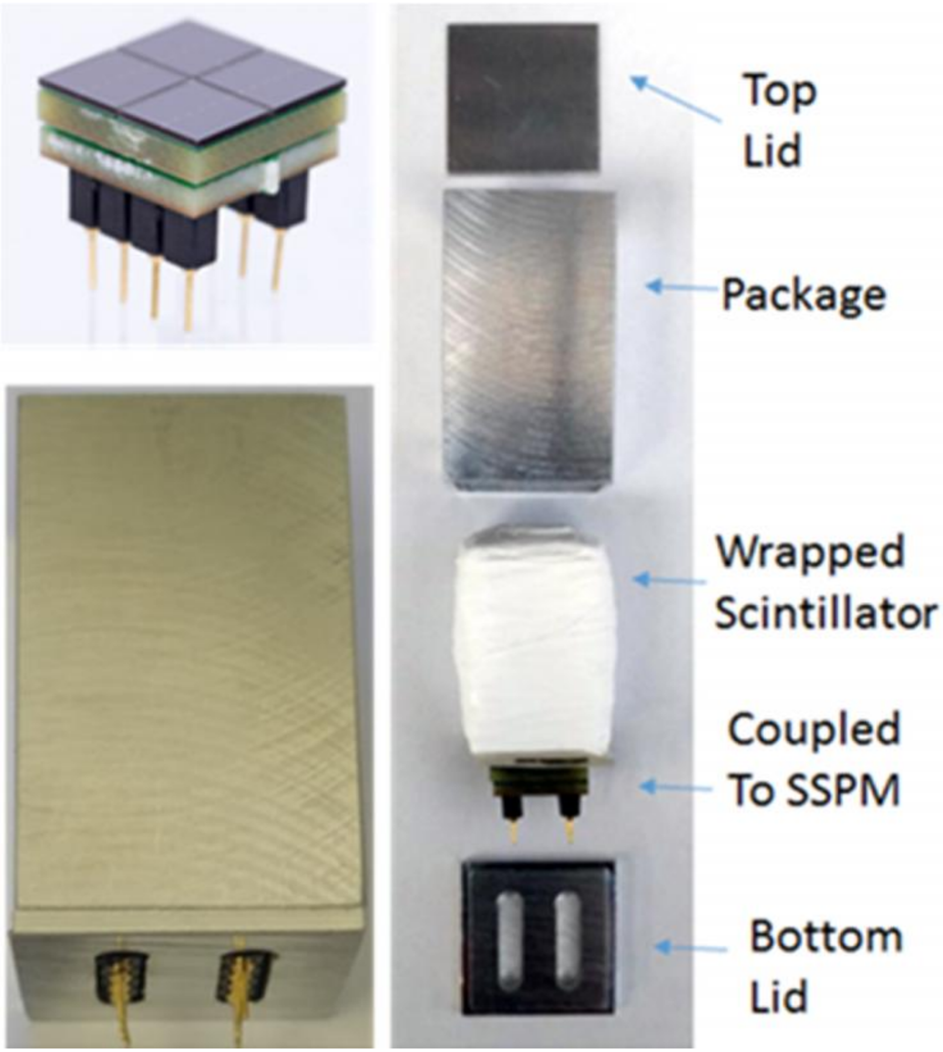
Timing: 2.5 ns (>300 keV)

PSD FOM: 0.87 (>400 keV)

Needs to be improved

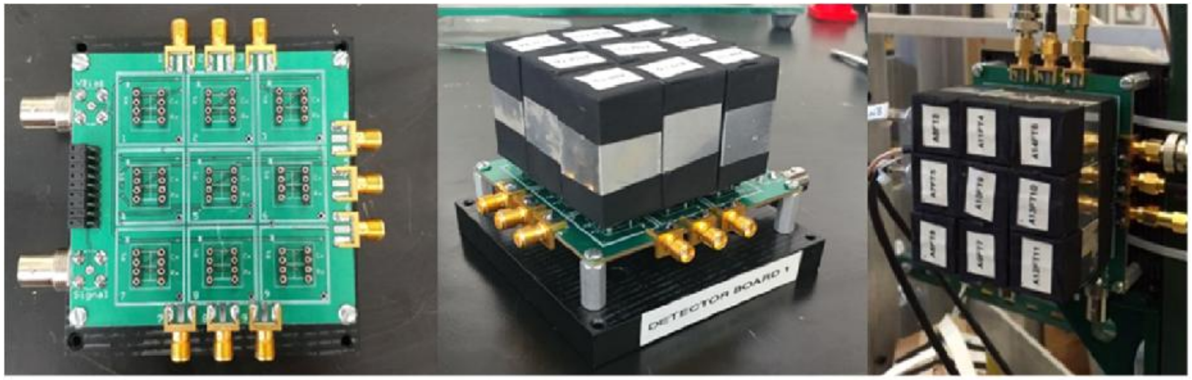
1.6 × 1.6 × 3 cc

Year 2: Second Prototype

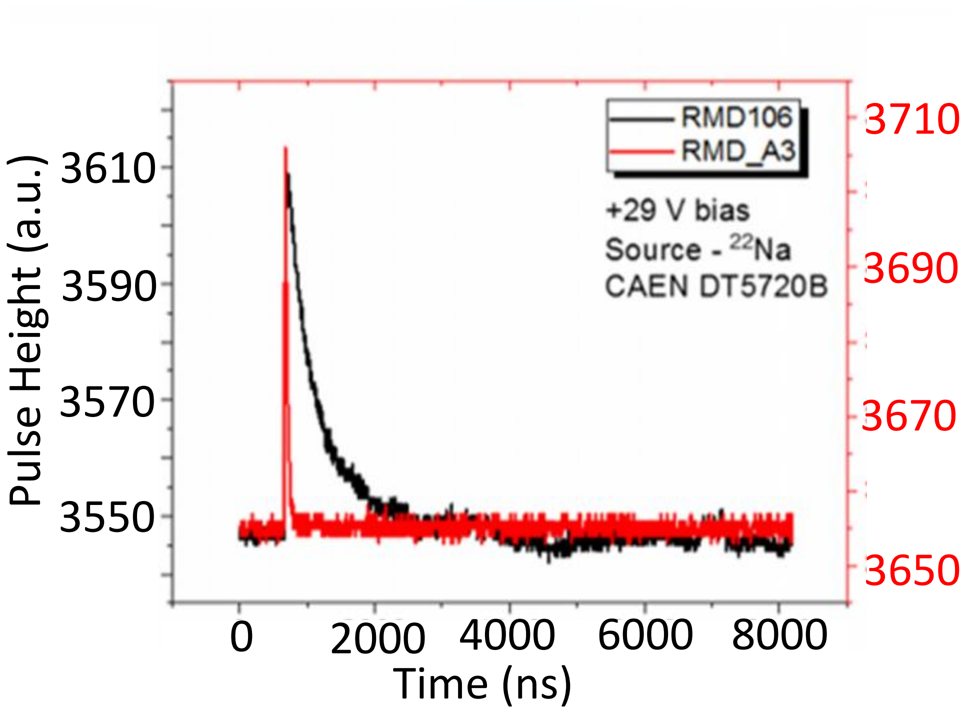


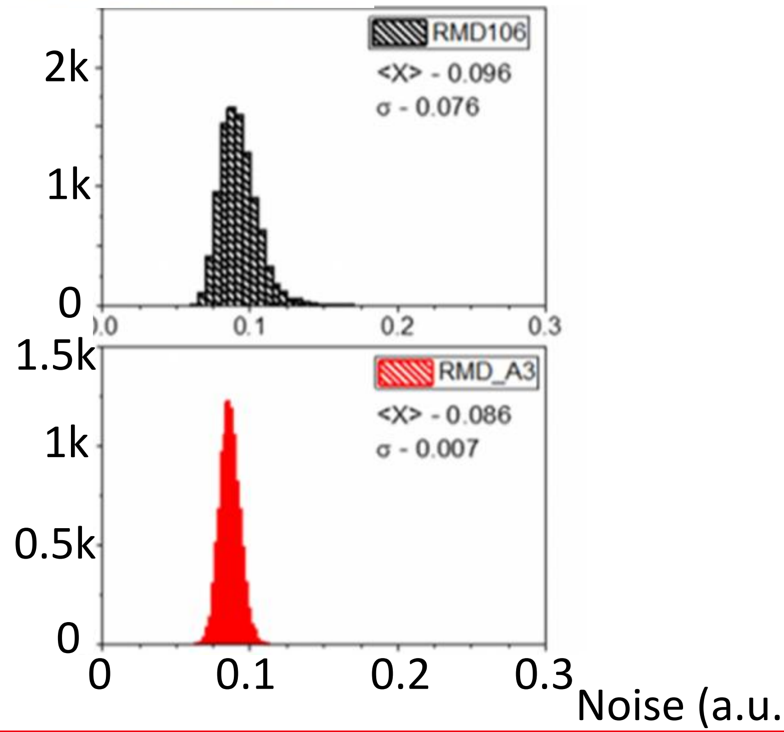
- SensL J-Series SiPMs boast improved QE, PDE, pixel count, rise time, pulse width, and significantly reduced noise.
- OEM 2x2 arrays used to minimize noise (solder, flux, etc.).
- 2x2's have common bias on interposer and individual anode pin-out.
- Modules are self-contained in custom Al housing.
- Single bias filter is now placed on carrier board.
- Scintillator coupled via silicone interface.
- Separate SMA headers for unit readout.

P2 Year 2: Testing at NSCL



Prototype



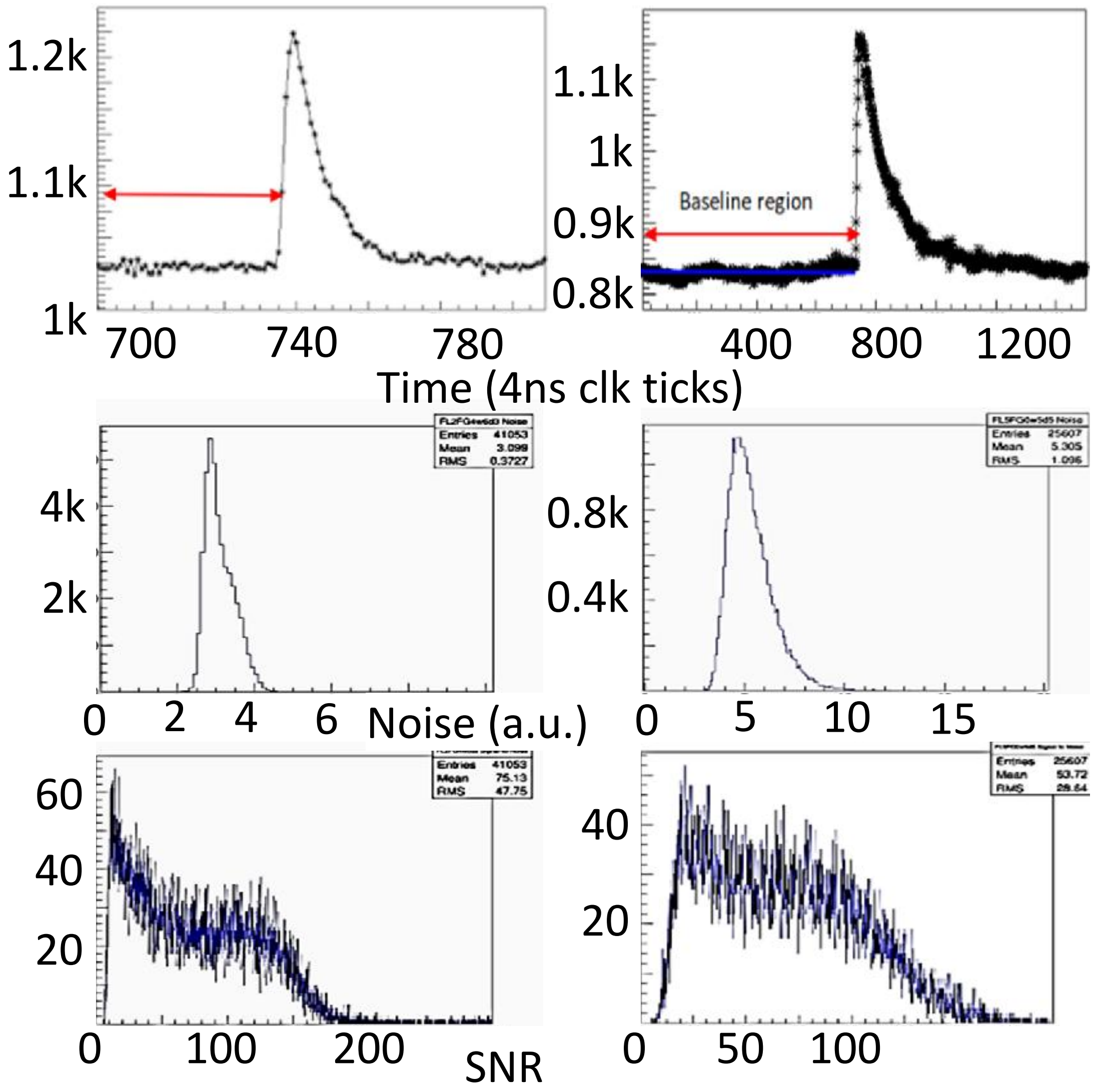


RMD A Dynasil Company

NSCL

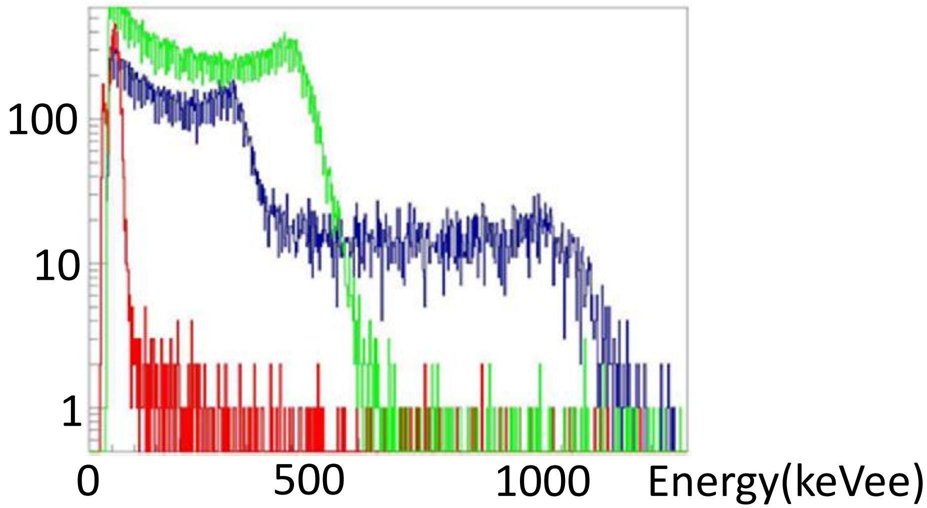
Business Sensitive

Comparison to Year 1



- A complete 2nd generation detector prototype was tested under similar conditions at NSCL.
- Initial pulse trace analysis showed marked improvement over the 1st generation detector modules.
- The J-Series-based modules were found to bring the average noise value down to 3.01 from 5.31, similar to the LENDA detector.
- Average SNR saw an improvement of almost 25%, which translates to other key properties for the proposed neutron detector.

Energy Calibration and Threshold: compared to year 1



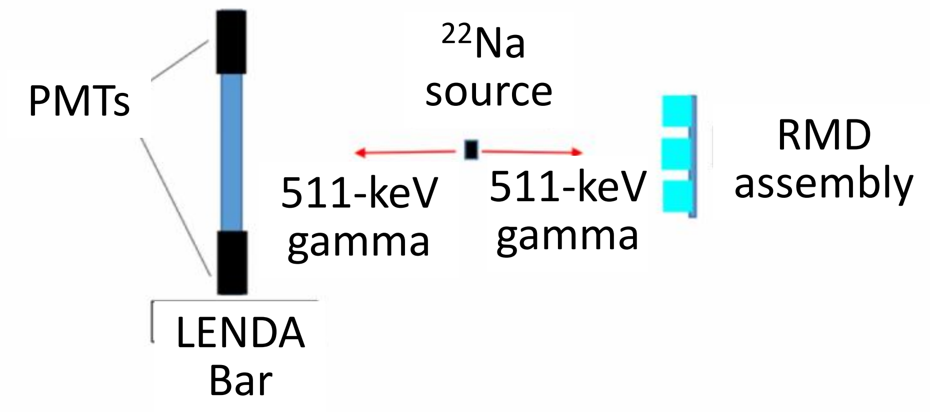
RMD Det. ID	Energy Thresh (keVee)	RMD Det. ID	Energy Thresh (keVee)	RMD Det. ID	Energy Thresh (keVee)
101	45	104	45	107	55
102	64	105	75	108	65
103	45	106	65	109	55

RMD Det. ID	Energy Thresh (keVee)	RMD Det. ID	Energy Thresh (keVee)	RMD Det. ID	Energy Thresh (keVee)
201	29.9	204	24.6	207	28.0
202	25.7	205	27.3	208	29.1
203	26.3	206	31.2	209	25.3

- Energy calibration and lower bound were found in the same manner for the 2nd generation prototype.
- An immediately noticeable characteristic of the new modules is the clear resolution of the 60 keV photopeak from Am-241.
- Lower energy bound was found by dropping DDAS threshold to average noise, but also used 26 keV photopeak from Am-241 as a guide to determine where noise peak began overlap.
- New prototypes outperform old by factor of ~2

$\langle E_{th} \rangle = 27.5$ keVee ($\sigma = 2.2$ keVee)

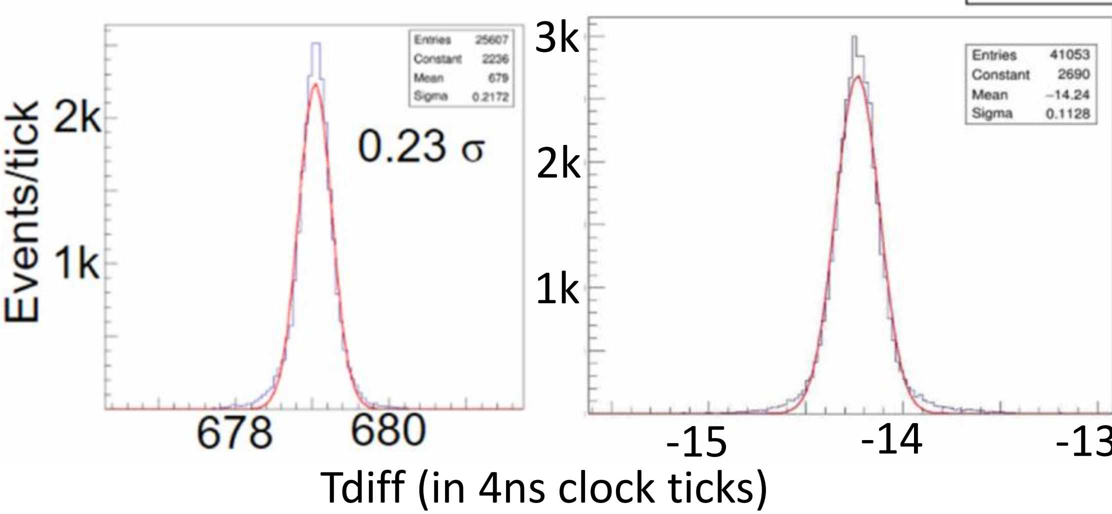
Timing Resolution: compared to year 1

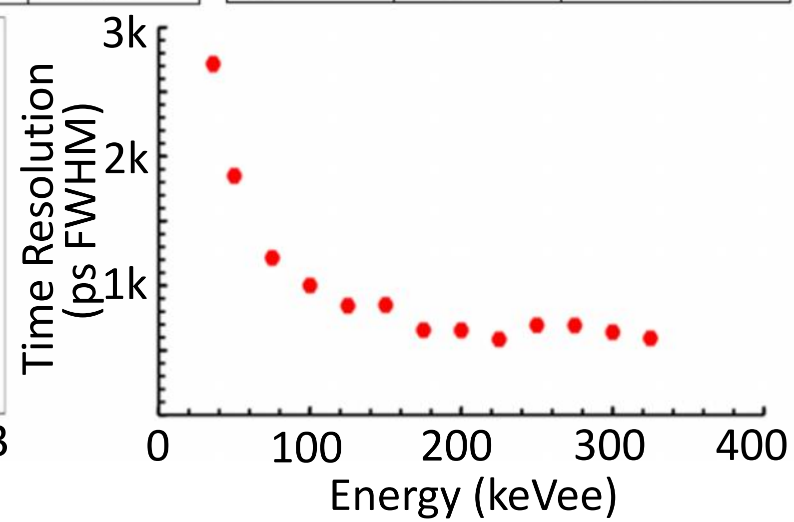


>300 keV

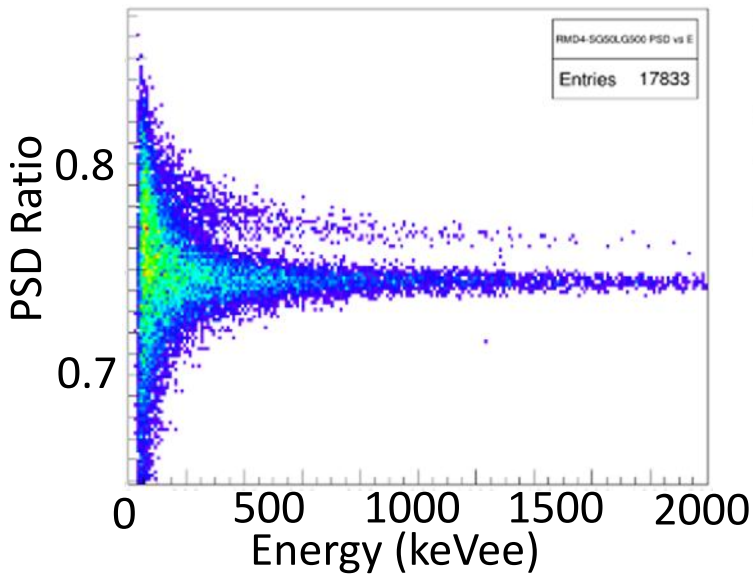
RMD Det. Id.	Timing Res. (ns)
101	2.05
102	2.50
103	2.91
104	1.98
105	2.33
106	3.02
107	2.06
108	2.29
109	3.29

RMD Det. ID.	Timing Resolution (ps)	
	All Events	>200 keVee Events
201	1255	981
202	1423	1094
203	1519	1022
204	935	659
205	886	631
206	986	682
207	988	680
208	934	671
209	1086	735



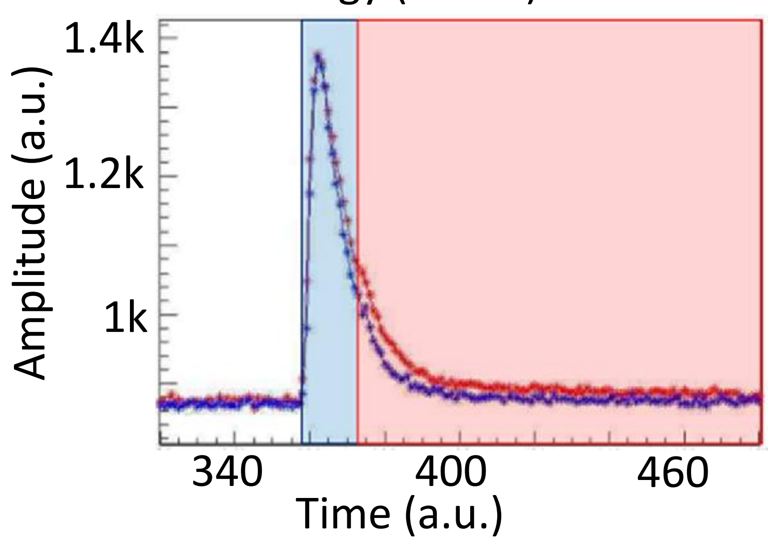


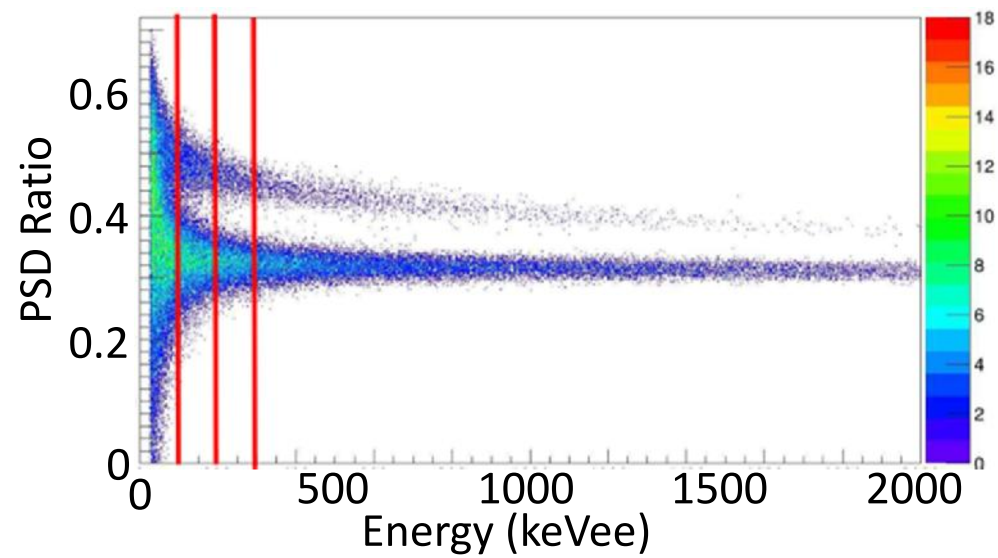
PSD Performance: ^{252}Cf



RMD Det. ID	PSD FOM	RMD Det. ID	PSD FOM	RMD Det. ID	PSD FOM
101	0.89	104	1.03	107	0.93
102	0.51	105	0.83	108	0.71
103	1.22	106	1.02	109	0.73

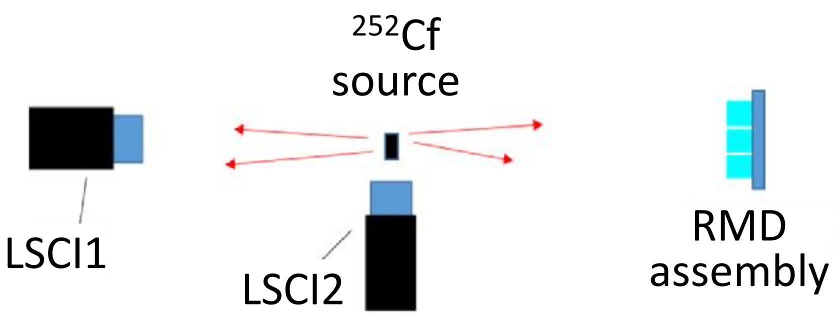
RMD Det. ID	PSD FOM	RMD Det. ID	PSD FOM	RMD Det. ID	PSD FOM
201	1.34	204	1.36	207	1.35
202	1.30	205	1.39	208	1.36
203	1.37	206	1.31	209	1.43

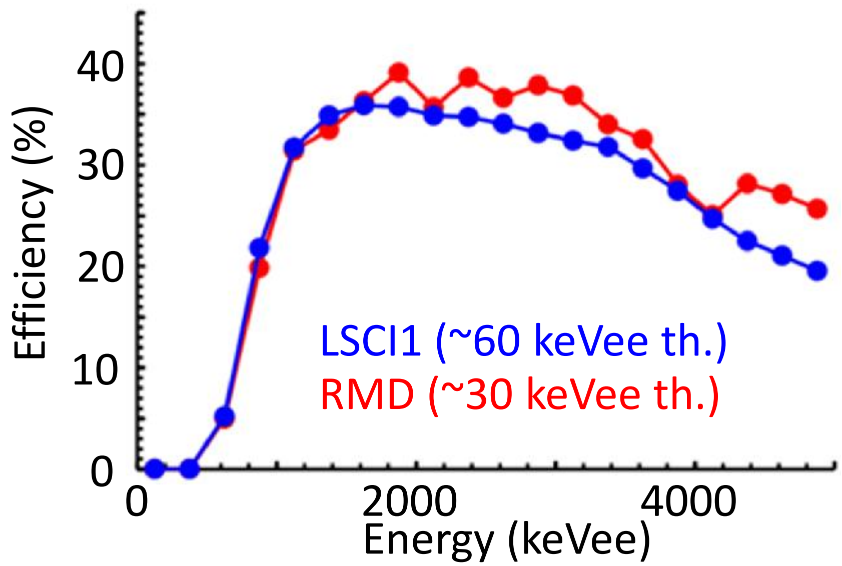




Neutron Detection Efficiency

- A liquid scintillator detectors were used to determine neutron detection efficiency.
- The Cf-252 source was placed on LSCI2 and used to measure the T_{diff} distribution of gammas/neutrons in LSCI1 and the RMD detector.
- PSD from LSCI2 used to select gamma/neutron event in coincidence with events in other detectors.
- Neutron count in LSCI1 used to calculate RMD efficiency.
- Tdiff values converted to neutron KE, $K_n = m_n c^2(\gamma^2-1)$





Performance summary

Differences Between Y1 and Y2

- RMD FR001-BBQ versus RMD FR002-POPOP;
- Size of the scintillation detector, 14 mm × 14 mm × 26 mm vs. 17 mm × 17 mm × 28 mm;
- SiSSPM c-series versus j-series 2×2;
- Use of grease versus a gel pad for optical coupling, respectively;
- Connectors interfacing the signals to the data acquisition system.

LENDA bar

Noise floor ~10 keVee
SNR: 100%
Timing: 0.5 ns
PSD FOM: N/A

Year 1 Prototype

Noise floor ~57 keVee
SNR: 56%
Timing: 2.5 ns (>300 keV)
PSD FOM: 0.87 (>400 keV)

Year 2 Prototype

Noise floor ~27 keVee
SNR: 96%
Timing: 0.78 ns (>200 keV)
PSD FOM: 1.4 (>300 keV)

Acknowledgements

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Instrument Research and Development Group at RMD

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Questions ?

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