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Sandia National Laboratories

Optically Segmented Single Volume Scatter Camera for Neutron Imaging: Interaction Position Calibration

PRESENTED BY

Kevin Keefe on behalf of the SVSC Collaboration

U.S. DEPARTMENT OF ENERGY | NNSA

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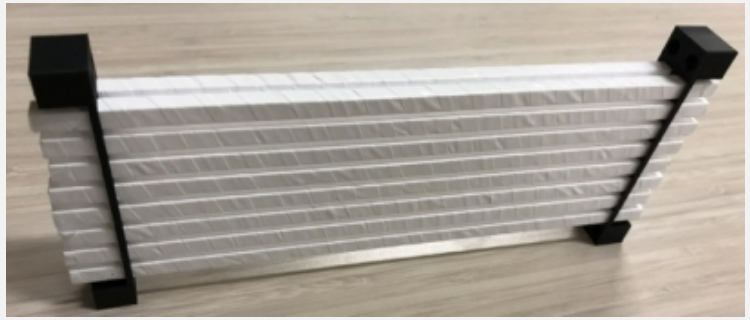
Agenda

1. Introduction
2. OS2 - Detector Design / Electronics
3. OS2- Detector Calibration Results
4. Future Goals of OS detectors

Optically Segmented Module **(OSMO)** Prototype enclosure, both assembled and disassembled.



Introduction – Single Volume Scatter Camera (SVSC)

Single Volume Scatter Camera

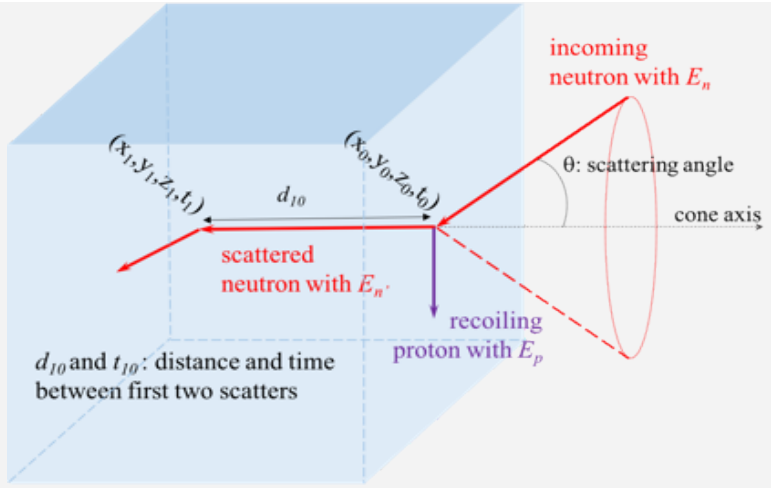
- Fast scintillators and silicon photomultipliers (SiPMs) based approach
- Measures Neutron Double Scatter interaction
- General Procedure:
  - Measure energy deposited in first interaction
  - Measure time of flight and interaction positions
  - Reconstruct cone
  - Repeat

Optically Segmented (OS) Approach

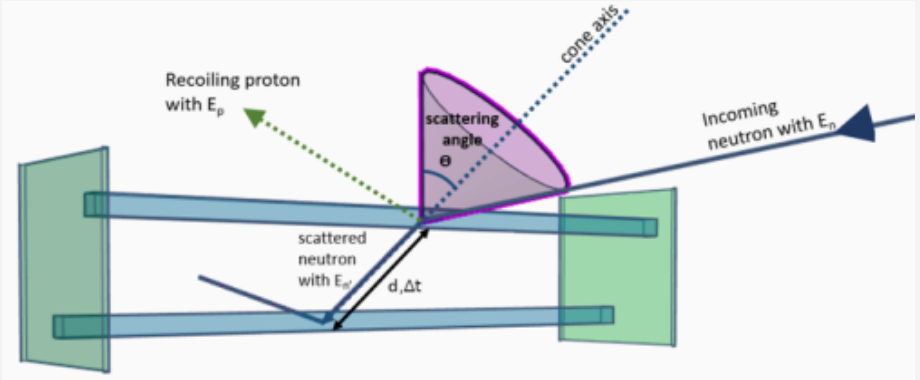
- Array of bars gives two positions of interaction for “free”

However,

- Additional surfaces to optically couple
- Additional bars to wrap in Teflon



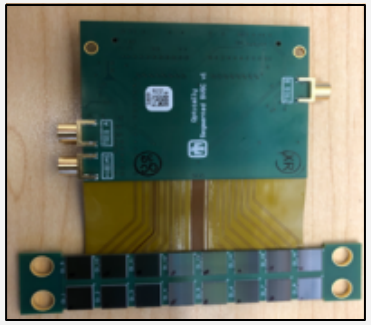
SVSC Double Scatter Reconstruction

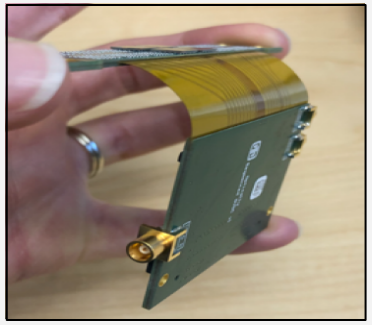


Optically Segmented Double Scatter, with two bars of interest [1]

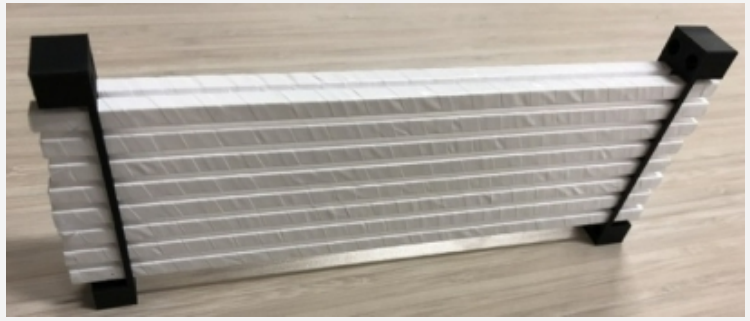
The Second Prototype (OS2) – Detector Design

SCEMA-B





Flex-card Interposer



2x8 EJ204 Array

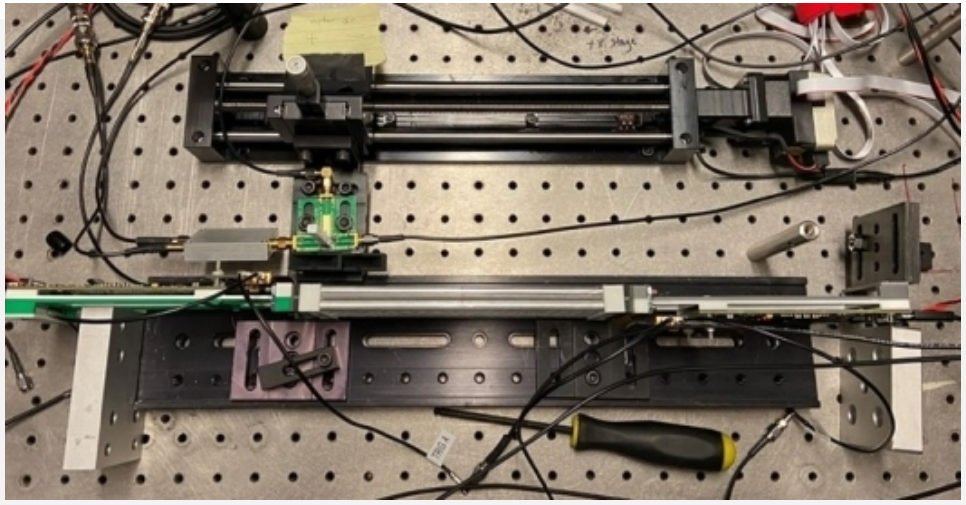
Design Goals:

- Reduce electrical crosstalk
- Allow particle source calibration access to all bars
- Improve modularity

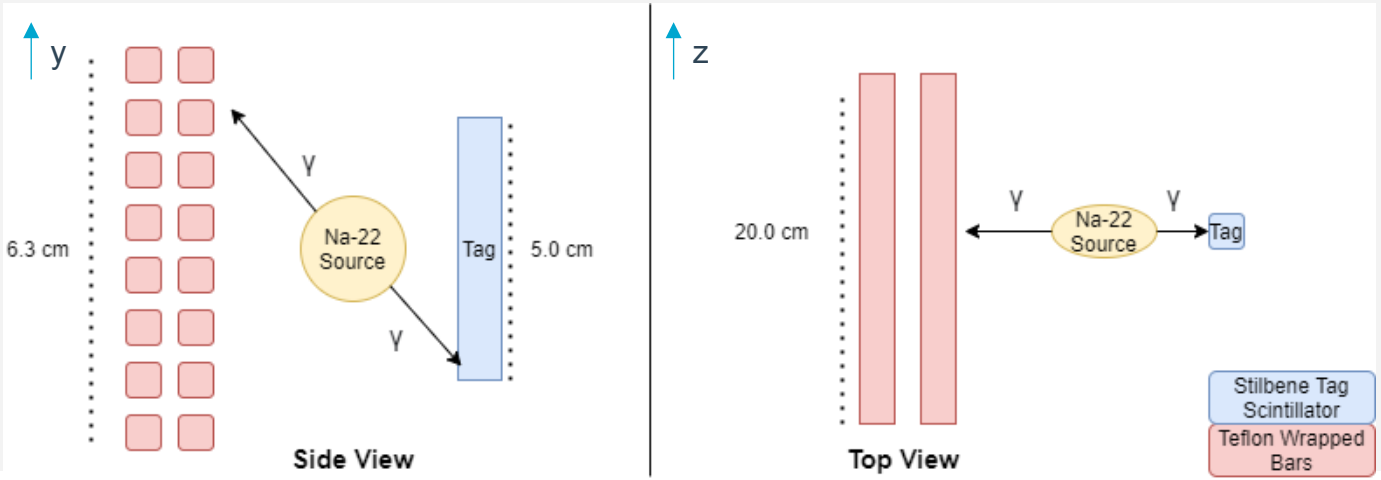
OS2 Current Optically Segmented Module (OSMO) Design:

- 2x8 Modular Design of 16 Teflon wrapped 5mm x 5mm x 20cm ej204 scintillating bars
- SCEMA-B (Sandia Laboratories Compact Electronics for Modular Acquisition, rev B) design based on [5].
  - Each SCEMA-B has 16+2 channel digitization by using 2 PSI-DRS4's sampling at ~5gsps
- "Flex-card" interposer connects 16 (2x8) SensL j-series 6.13mm SiPMs to SCEMA-B digitization boards.
  - Flex-card uses "sum trigger" circuit which reads common cathode line of all 16 SiPMs for self-triggering

The Second Prototype (OS2) – Detector Calibration Procedure



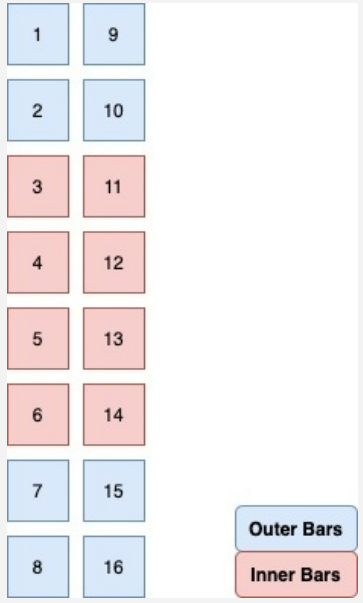
Na22 Scan setup. Single SensL eval SiPM board holds tag, and motor moves source along OSMO face



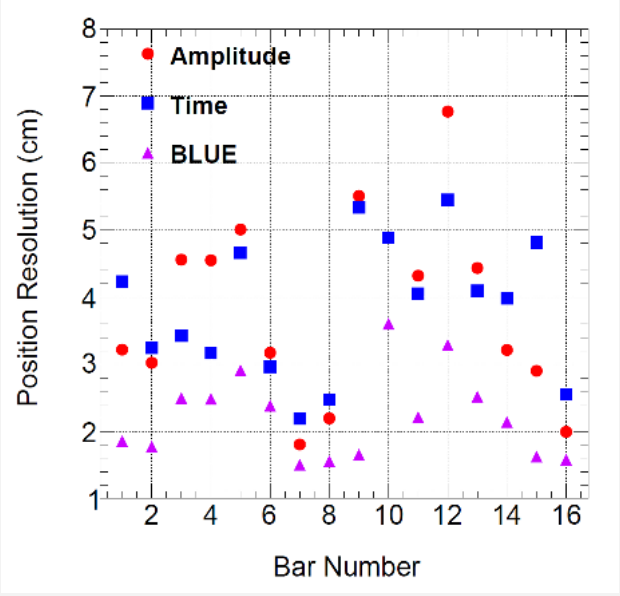
- Electrical Calibrations involve a Na-22 scan along bar lengths with a ”tag” source as described in [4]
- SensL Eval Board Fast output uses 10x gain amplifier sent to DG535 to issue synchronous digital trigger to SCEMA-B’s in OSMO
- 8 bar calibration simultaneous calibration uses a 5cm tall Stilbene crystal as a tag.
  - Magnification of source is used match OSMO width but this effect also magnifies position uncertainty in direction of interest along bar length.
- Two sets of calibrations are repeated with different optical coupling:.
  - EJ-550 Optical Grease
  - Ej-560 Silicone Pads

Calibration Results: Optical Coupling

- Z-position reconstruction is obtained through pulse rise-time and pulse amplitude.
- Time and Amplitude resolutions are combined through Best Linear Unbiased Estimator (BLUE)
- “Outer bars” show poorer overall position resolution in optical pad configuration

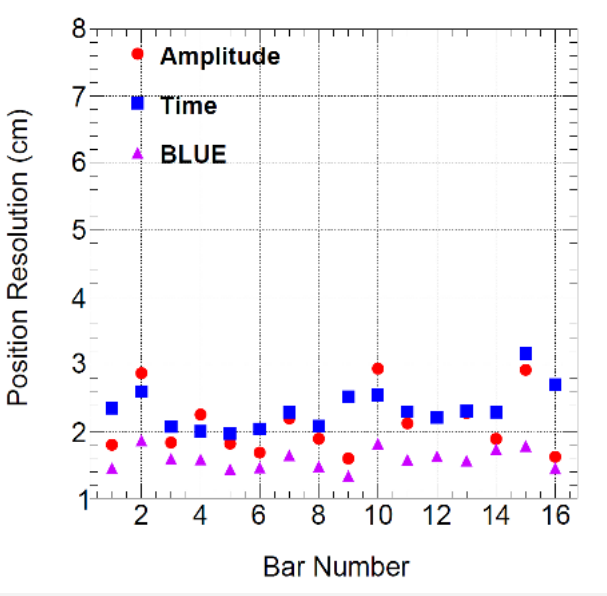


EJ-560 Optical Pads



$= 2.22 \pm 0.66$

EJ-550 Optical Grease

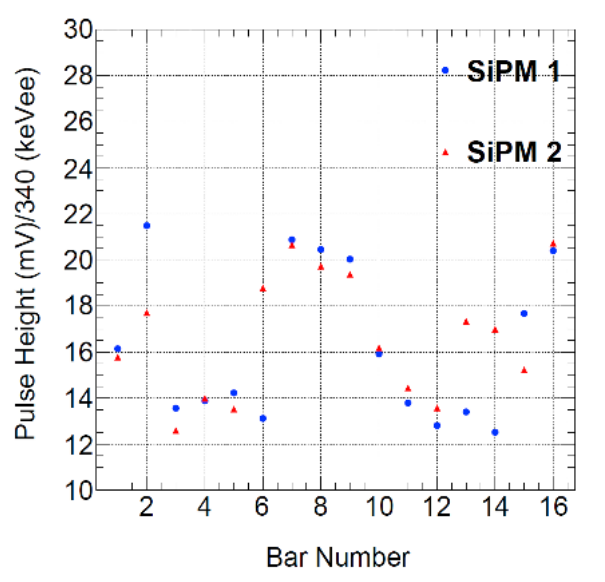


$= 1.59 \pm 0.15$

Calibration Results: Optical Coupling and light collection

- Overall resolution can be traced back to light collected at the end of each SiPM
- Energy calibrations are performed for each bar end to find a conversion from mV to keVee, and the bars with poorer light collection have overall poorer position resolution.

EJ-560 Optical Pads

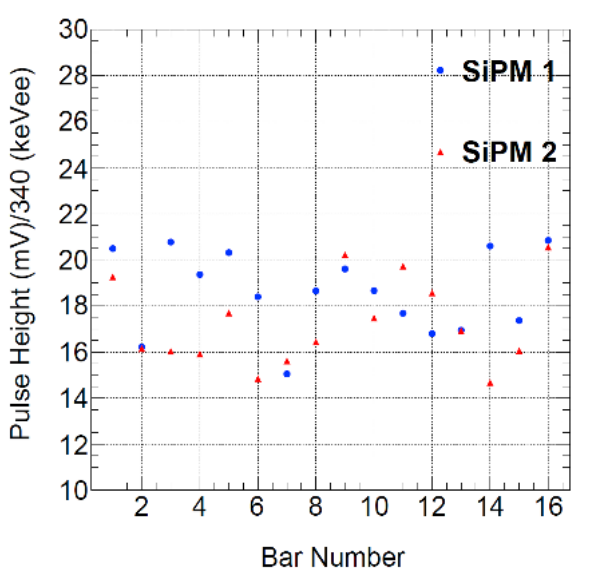


$$SiPM_1 = 16.27 \pm 3.23$$
$$SiPM_2 = 16.66 \pm 2.58$$

"inner bar" collection

$$SiPM_1 = 13.41 \pm 0.54$$
$$SiPM_2 = 15.15 \pm 2.09$$

EJ-550 Optical Grease

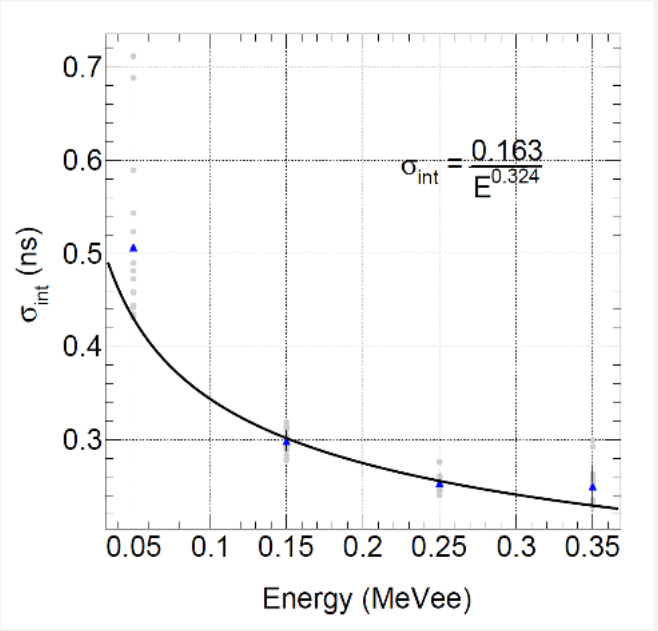


$$SiPM_1 = 18.54 \pm 1.79$$
$$SiPM_2 = 17.35 \pm 1.95$$

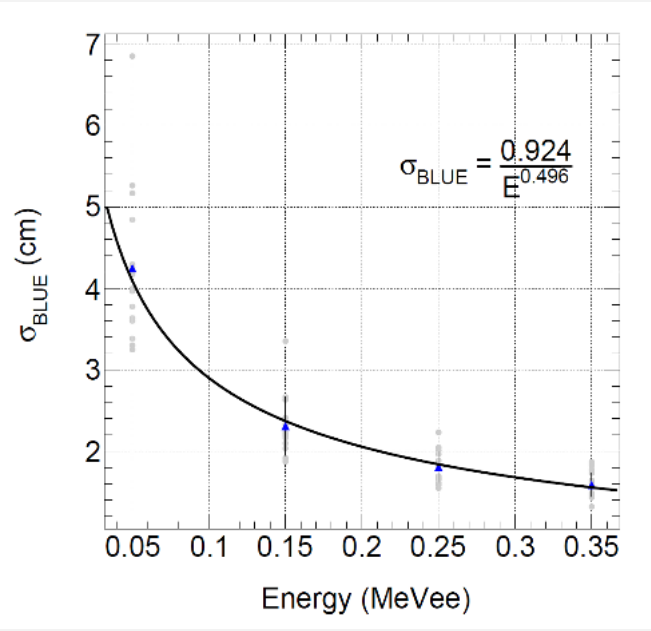
Calibration Results: Energy Response

- Events are reconstructed after calibrations and grouped into 0.100 MeVee bins to measure interaction time and z-position reconstruction
- Interaction time is ~250ps in the 0.3 – 0.4 MeVee range, which is ~2x improvement from first OS prototype developed at UH [1].
- Position resolution in 0.3-0.4 MeVee range ~1.6cm, which is still worse than ~1 cm ”single bar” results [4].

Interaction Time Response



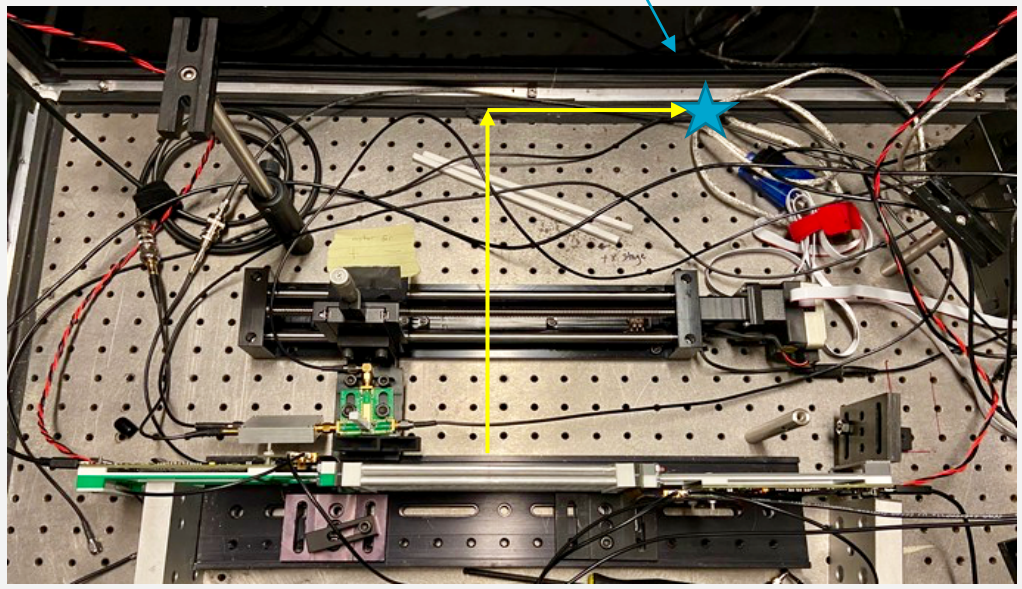
Position Resolution Response



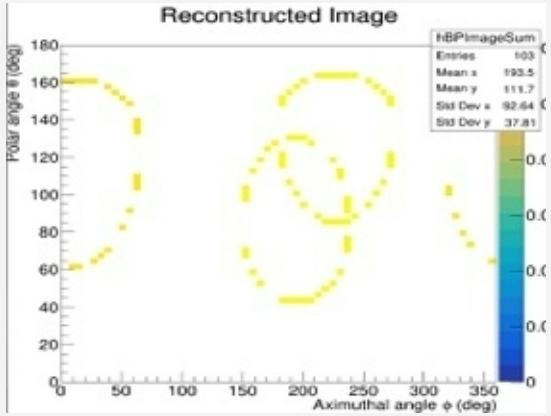
Current Status, and OS-SVSC Future

- Next steps:
  - Calibrate more modules
  - Imaging
- Current OSMO has no internal triggering mechanism, so we use a tagged AmBe source
- LaBr3 as the tag triggers on gammas
- More Data!

AmBe Source, ~49cm total from center



- 14 inches, +y direction
- 13 inches, +x direction



OS2 Summary:

- Overall best z-position Resolution for bars is 1.59 cm +/- 0.15 cm
  - Position resolution varies widely with optical coupling
  - Overall position resolution is correlated with energy resolution
- Timing Resolution appears to have suffered the most when scaling:
  - 150 ps single bar
  - 500 ps interaction time OS1
  - 250 +/- 21 ps interaction time OS2
- Electrical crosstalk is greatly reduced compared to first prototype
  - Reduced from -10% to 0.71%
- Processing imaging data to reconstruct improved images
- Modified sum trigger
  - Will work as desired in full 4 – OSMO configuration
- Improvements to OS2's overall resolution would come from timing and improved light collection
  - "Concentrator" PCB to combine modules and distribute, power, trigger, and clock.

The SVSC Team

@Sandia National Laboratories (Lead Laboratory)

- Erik Brubaker (PI)
- Jon Balajthy (post-doc)
- Belkis Cabrera-Palmer
- Kevin Keefe
- Patrick Feng
- Paul Maggi (post-doc)
- Peter Marleau
- John Steele
- Melinda Sweany

@Argonne National Laboratory

- Jeff Elam (PI)
- Anil Mane

@Oak Ridge National Laboratory

- Paul Hausladen (PI)
- Micah Folsom (grad)
- Jason Nattress (post-doc)
- Klaus Ziock

References:

[1] A. Galindo-Tellez *et al.* arXiv:2102.02951 (Accepted at JINST)

[2] J. Braverman *et al.* arXiv:1802.05261 [physics.ins-det] (2018).

[3] K. Weinfurther, *et al. Nucl. Inst. And Meth. A* **883** (2018) 115-135

[4] M. Sweany *et al. Nucl. Inst. And Meth. A* **927** (2019) 451-462

[5] J. Steele et al. *Journal of Instrumentation* **14** (2019) P02031.


Questions?