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The Single Volume Scatter Camera: Optically Segmented Effort

M. Sweany for the SVSC Collaboration

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Portable, efficient kinematic neutron imaging:

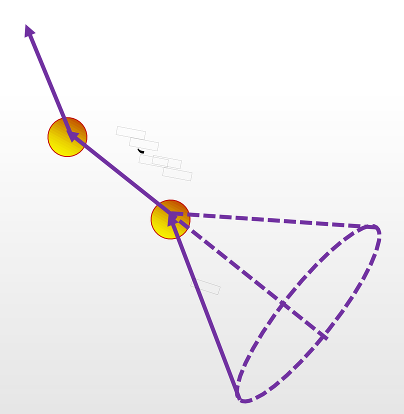

Fig. 1: A double-scatter event in which the neutron has originated from an angle $\cos\theta = \sqrt{E_n'/E_n}$ in relation to the axis defined by the two scatters, where E_n is the incoming neutron energy and $E_n' = (1/2)\,m(\Delta d/\Delta t)^2$ is the neutron energy after the first interaction

The Single Volume Scatter Camera (SVSC) can improve the efficiency of traditional neutron double scatter imagers by a factor of ten, even with a reduction in volume[1]:

- efficiency improvements are largely a result of improved geometrical efficiency
- requires position, time and energy measurements of neutron scatters off of hydrogen within a single volume of organic scintillator
- aiming for O(1cm/1ns) position and timing resolution of both neutron interactions in the same scintillator volume

[1]J. Braverman, J. Brennan, E. Brubaker, B. Cabrera-Palmer, S. Czyz, P. Marleau, J. Mattingly, A. Nowack, J. Steele, M. Sweany, K. Weinfurther and E. Woods, "Single-Volume Neutron Scatter Camera for High-Efficiency Neutron Imaging and Spectroscopy" *arXiv: 1802.05261* (2018)

One option: optically segmented along one axis

The optically-segmented SVSC (SVSC-OS) simplifies event reconstruction by isolating light in long scintillator bars which are readout on each end by Silicon Photo-multipliers (SiPM)[2]:

- (x, y) determined simply by the SiPM location
- reconstruction in z along bar of length L is determined by two linear relationships:
  - $\log\frac{A_1}{A_2} = \frac{L}{\lambda} - \frac{2z}{\lambda}$
  - $t_1 - t_2 = \frac{2z}{v} - \frac{L}{v}$
- $A_{1,2}$ is pulse amplitude: ratio sensitive to reflectivity losses and bulk attenuation (λ)
- $t_{1,2}$ is pulse arrival time: difference sensitive to propagation speed (v) along bar

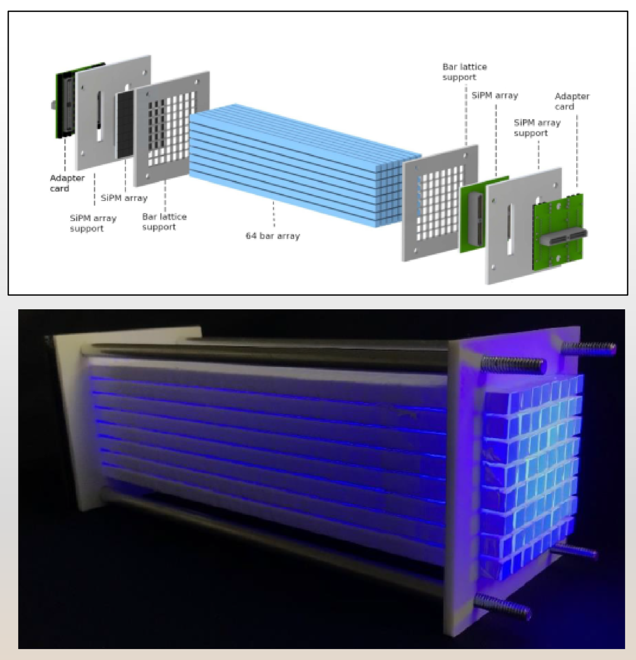

Fig. 2: A rendering of the first SVSC-OS prototype with all components shown, and the physical device without SiPMs or readout electronics.

[2]K. Weinfurther, J. Mattingly, E. Brubaker and J. Steele, "Model-based Design Evaluation of a Compact, High-Efficiency Neutron Scatter Camera" *Nucl. Inst. and Meth. in Phys. A* **883** (2018) 115-135

First OS Prototype @UH

Recently accepted publication[4] of first OS prototype calibration shows decreased performance compared to single bar results[5]. Several possibilities may account for this:

- different electronics, sampling at 1 GHz rather than 5 GHz
- silicone coupling pads between scintillator/SiPM rather than optical grease
- electronic cross talk in J-series array
- non-uniform bar spacing/Teflon-wetting due to mechanical instability

In addition, position/timing calibration for inner bars of array required time intensive cosmic muon method due to scattering of gammas from

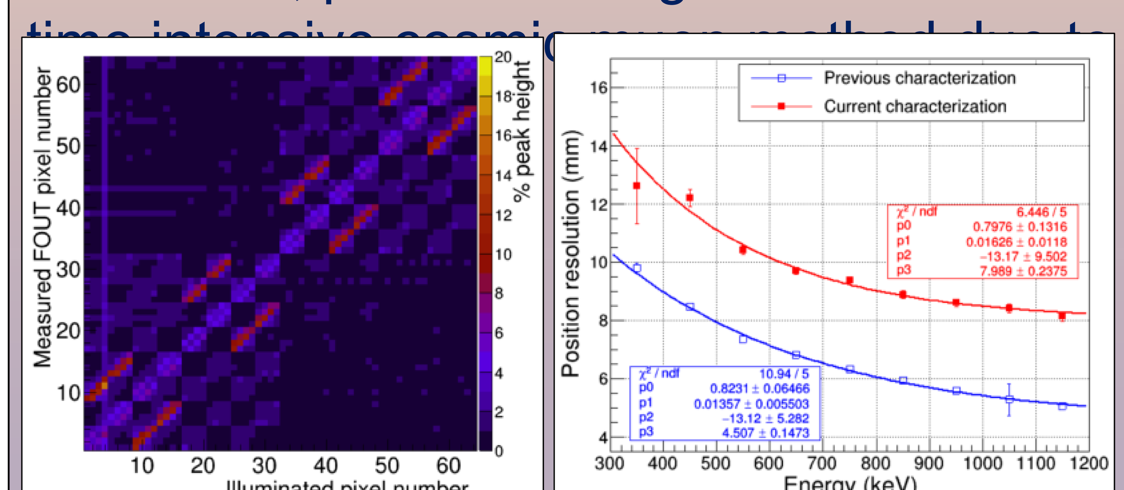

Fig. 3: (left) electronic cross talk in the acquisition path, attributed to several connectors, including J-series array (center) A comparison of the BLUE position resolution as a function of energy for single bar data (blue) and the first prototype (red).

[4]A. Galindo-Tellez, K. Keefe, *et al. arXiv:2102.02951* (2021)
[5]M. Sweany, *et al. Nucl. Inst. and Meth. in Phys. A* **927** (2019) 451-462

Second OS Prototype @SNL

A modular design solves many if not all of the issues of the 1st prototype:

- 2x8 array allows access to each bar for ^{22}Na calibration scans
- custom 2x8 SiPM array couples to SNL developed 16-channel SCEMA electronics utilizing 5 GHz DRS4 digitizers used in single bar scans[6]
- improved mechanical stability reduces potential for mis-alignment and non-uniform Teflon wetting
- final system will consist of 4 modules, for a comp

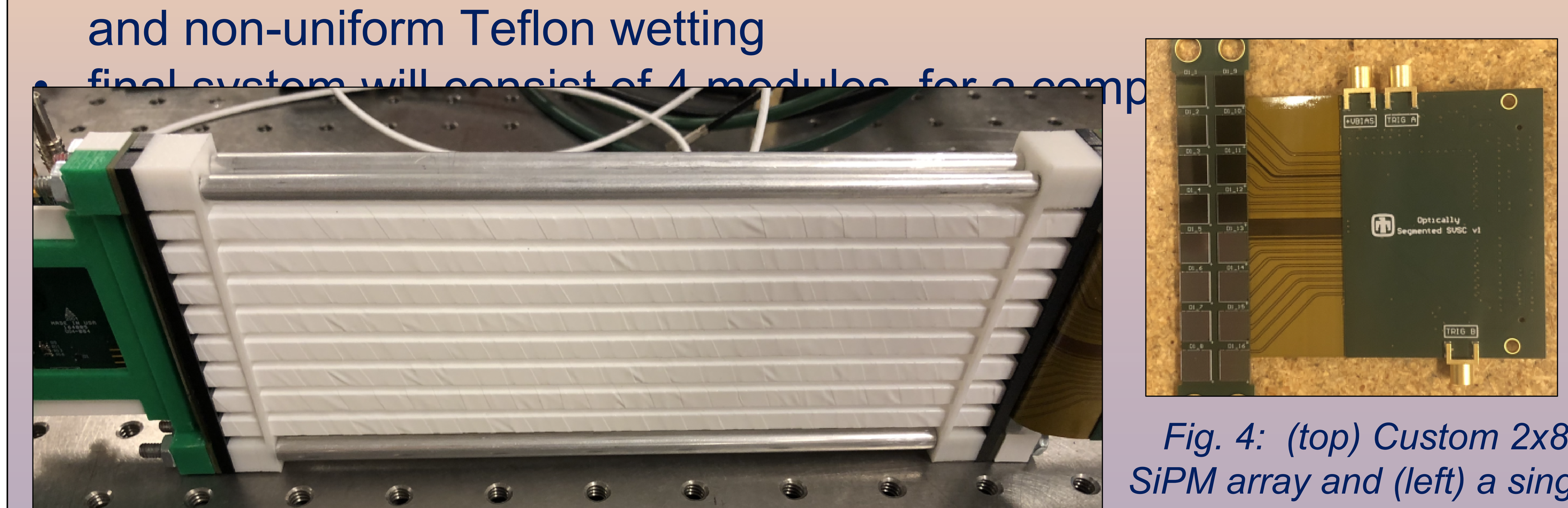

Fig. 4: (top) Custom 2x8 SiPM array and (left) a single optically segmented module with 2x8 array of Teflon-wrapped EJ-204 bars

[6]J. Steele, J.A. Brown, E. Brubaker and K. Nishimura *Journal of Instrumentation* **14** (2019) P02031

Electronic Cross talk in second OS Prototype

A laser setup is used to characterize the electronic cross talk in the custom SiPM array and SCEMA acquisition board

- laser pulse is aimed at each pixel in 2x8 array
- all other channels acquired in coincidence
- peak finding algorithm searches for pulses

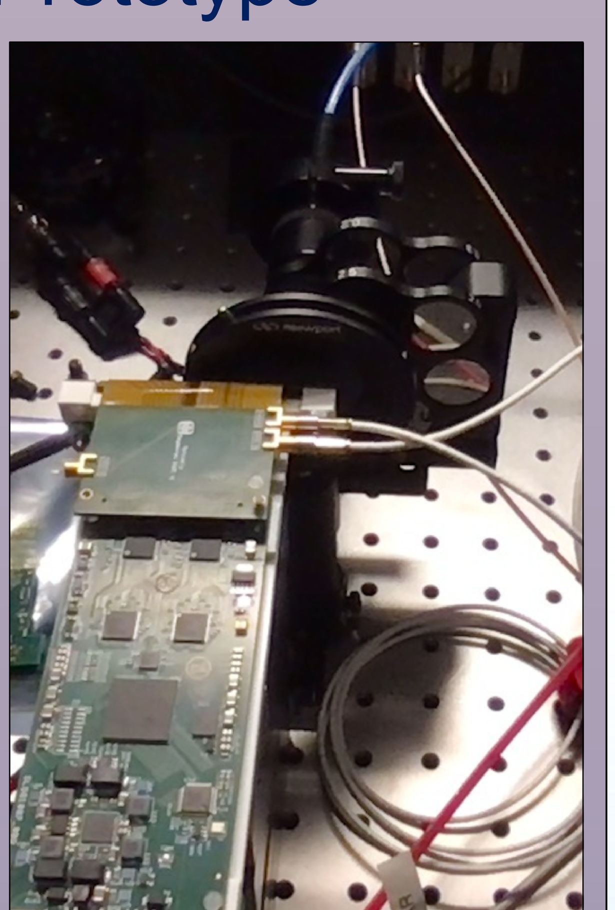

Fig. 5: The laser setup to test electronic cross talk of custom 2x8 SiPM board, readout by SCEMA.

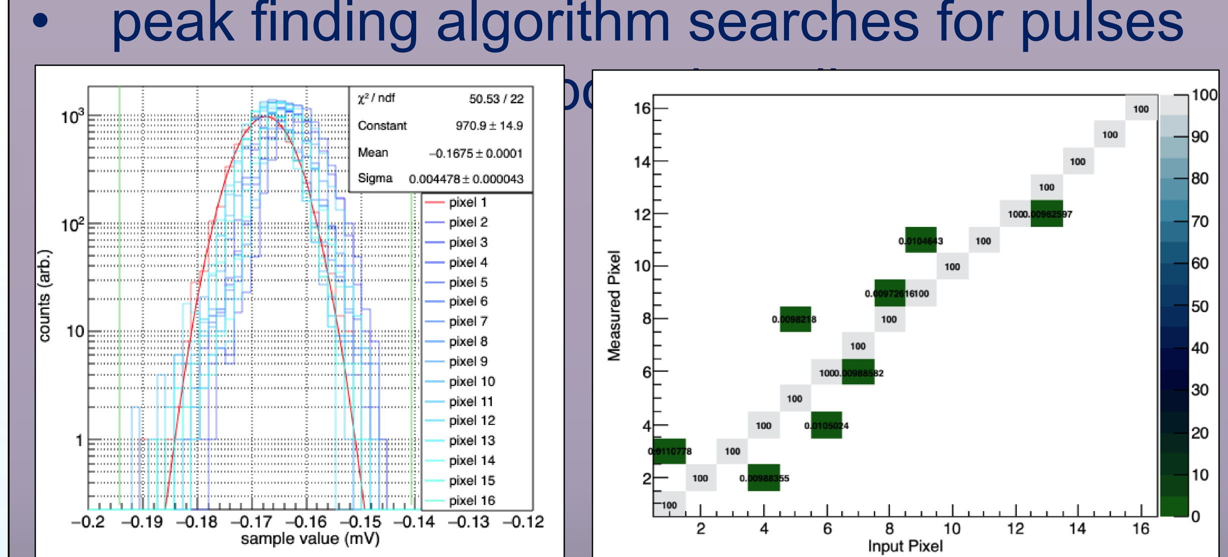

Fig. 6: (left) The sample values in the baseline region, with $\pm 6\sigma$ lines in green (SiPM 1). (right) The percentage of the input pixel pulse height, indicating nearly non-existent electronic cross talk compared to ~10% with prior electronics.

Calibrations of second OS Prototyp

Interaction reconstructions are calibrated with a ^{22}Na source and tag scintillator on a moving stage. Events which are triggered by an interaction in the tag scintillator are expected to be at the known z-position of the stage due to the back-to-back 511 keV γ pair emitted from the source.

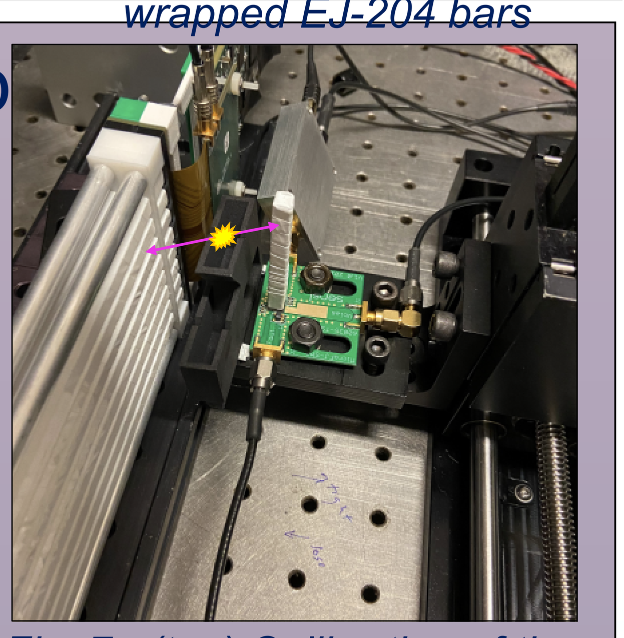

Fig. 7: (top) Calibration of the optically segmented module with back-to-back 511 keV γ (pink lines) from a ^{22}Na source (yellow).

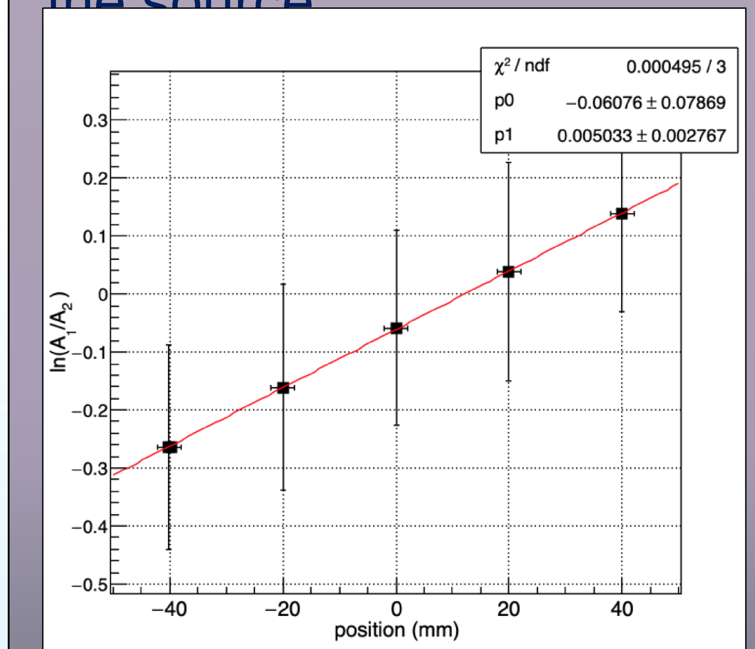

Fig. 8: (left) Preliminary results indicate the position resolution using the log-ratio of amplitudes, measured at 3.5 cm in the 100-600 keVee energy range, is degraded compared to single bar tests, which measured 2.4 cm using the log-ratio of amplitudes alone.

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