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Position and Timing Resolution Measurements of Organic-Glass scintillator bars for the Optically Segmented Single-Volume Scatter Camera

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Portable, efficient kinematic neutron imaging:

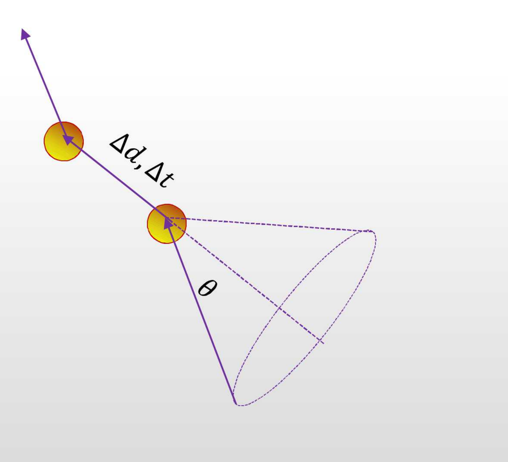

Fig. 1: A double-scatter event in which the neutron has originated from an angle $\cos\theta = \sqrt{E_n'/E_n}$ in relation to the axis defined by the two scatters, where E_n is the incoming neutron energy and $E_n' = (1/2)\, m(\Delta d/\Delta t)^2$ is the neutron energy after the first interaction

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

- efficiency improvements are largely 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 reconstruction of both 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 reconstruction problem by isolating light in long bars readout on each end by SiPMs[2]:

- (x, y) determined simply by the SiPM hit
- reconstruction in z (along bar of length L) 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 is pulse arrival time: difference sensitive to propagation speed (v) along bar

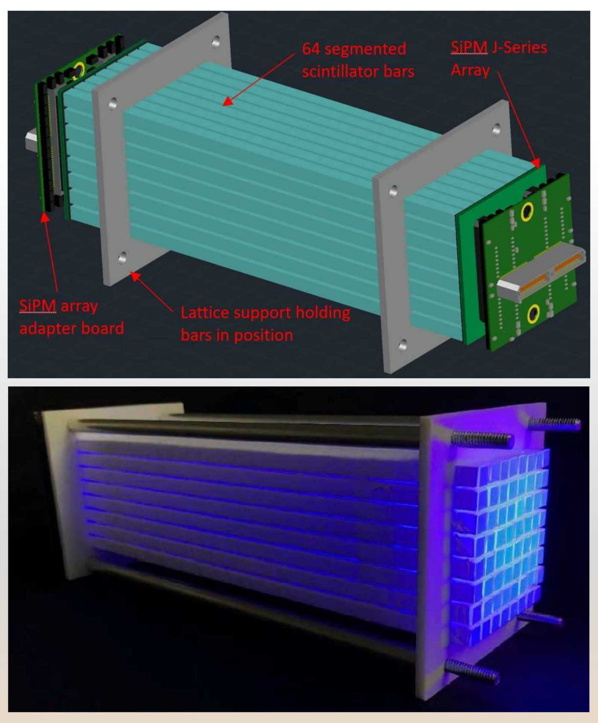

Fig. 2: A rendering of the first SVSC-OS prototype with all components shown, and the physical device without SiPMs or readout electronics.

[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

Single bar characterizations

The position, event time, and and energy of a variety of scintillators and reflector materials were characterized with two independent measurement setups

- collimated ^{90}Sr scan @UH provided position measurements over broad energy
- tagged ^{22}Na measurement provided position, time, and energy measurements for the Compton edge of 511 keV annihilation gammas
- combined measurement provided high-quality systematic error estimation
- Full results reported in NIM A[3]

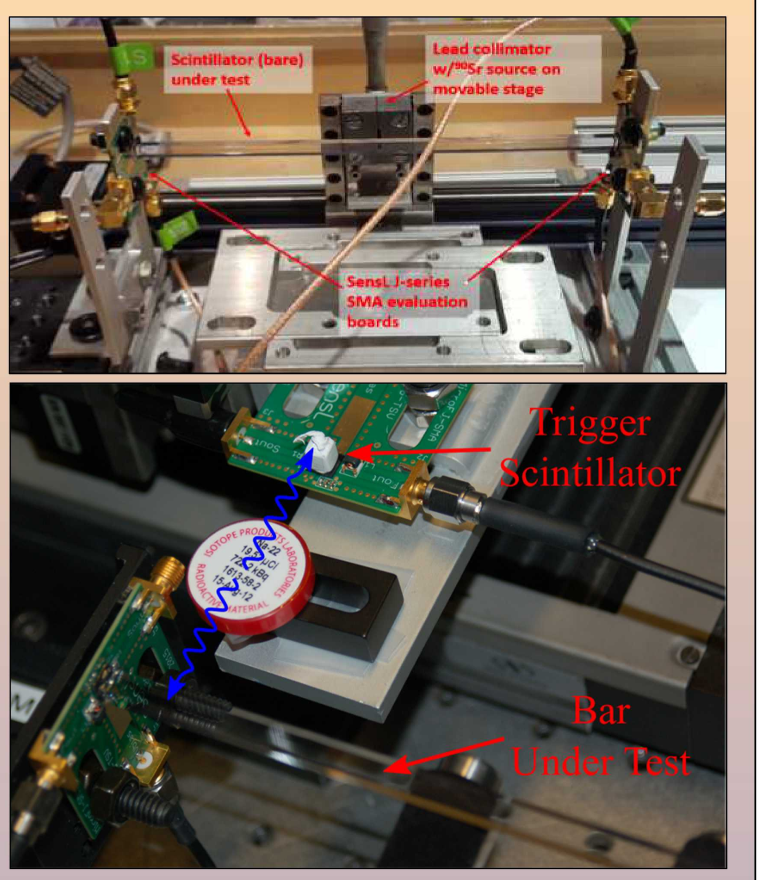

Fig. 3: (top) collimated ^{90}Sr setup and (bottom) ^{22}Na setup

[3]M. Sweany, A. Galindo-Tellez, J. Brown, E. Brubaker, R. Dorrill, A. Druetzler, N. Kaneshige, J. Learned, K. Nishimura and W. Bae, "Interaction position, time, and energy resolution in organic scintillator bars with dual-ended readout" *Nucl. Inst. and Meth. in Phys. A* **927** (2019) 451-462

Measurement methods

For each scan position in z, the response for the relations above and the event time $(t_0 = (t_1 + t_2)/2)$ are fit with Gaussian:

- mean (μ) as a function of z is fit to 1st-order polynomial
- sigma (σ) as a function of z is fit to 0th-order polynomial
- resolution defined as the constant of the σ fit divided by slope of μ fit
- measurements combined to form best linear unbiased estimate (z_{BLUE})
- z_{BLUE} on the order of 8.06±0.73 (sys) cm measured with the ^{22}Na scan on EJ-204+Teflon wrapping[3]

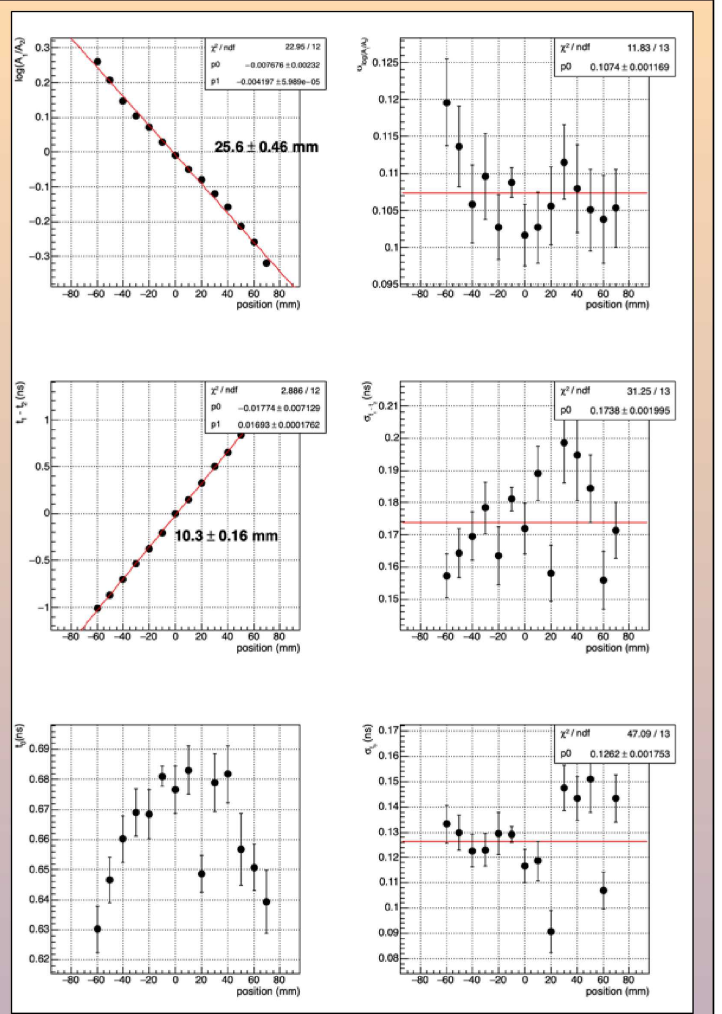

Fig. 4: Example ^{22}Na scan results showing the μ and σ of Gaussian fits to $\log(A_1/A_2)$, $t_1 - t_2$, and t_0. Configuration 5: 20 cm sample with 20% P2, coated.

PSD and improved light output with organic glass

Recently, a new scintillator material called organic glass as shown improved pulse-shape discrimination and light output compared to commercial alternatives[4]

- PSD FoM close to Stilbene: 2.3@487 keV
- light output comparable to Stilbene
- compound crystalized by optical grease: coat with PVT
- Both of these properties could improve the response of the SVSC-OS
- Challenge is to manufacture the long aspect ratio of our application

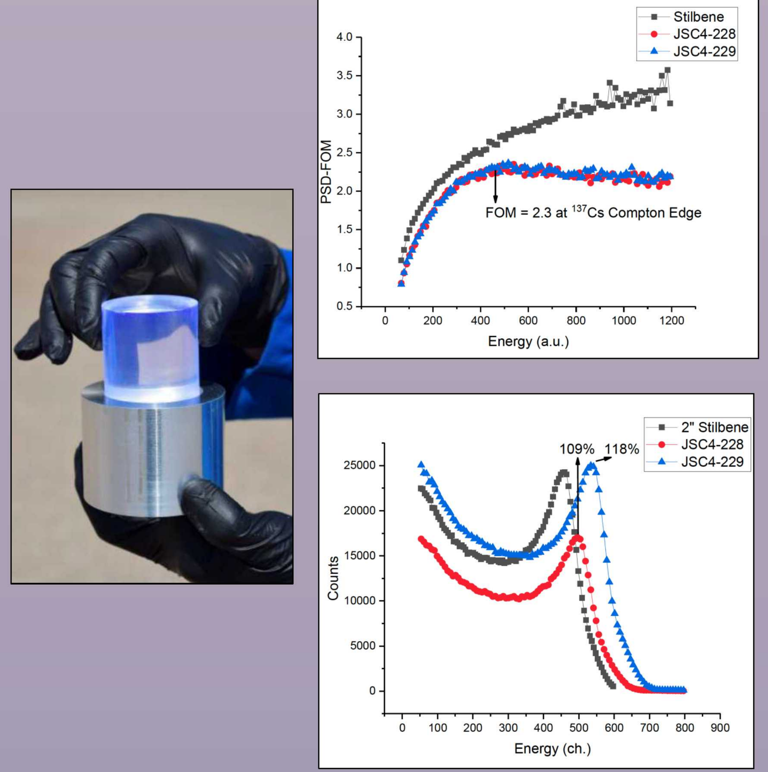

Fig. 5: The PSD FoM and Cs-137 response for a 2" stilbene crystal and two different formulations with the organic glass (P2) compound.

[4]J. Carlson and P. Feng. *Nucl. Inst. And Meth. A* **832** (2016) 152-157

Results with organic glass scintillator

In order to manufacture bars of high aspect ratio, the P2 compound is combined with plastic for stability

- PVT coating (config. 2 vs. 3) may improve surface properties, light propagation (worse z_a)
- results indicate comparable timing, detected photons (N_d) to EJ-204, higher N_d than EJ-230
- bulk attenuation may be shorter with P2, roughly comparable to EJ-230 (better z_a)

Configuration	σ_z (mm)			σ_{t0} (ps)	N_d
	σ_{zA}	σ_{zt}	σ_{BLUE}		
1. EJ-230, 19 cm	18.2±0.1	11.3±0.1	9.6±0.1	140±2	182±14
2. EJ-204, 20 cm	26.4±0.5	11.9±0.2	10.9±0.1	125±2	301±17
3. EJ-204, 20 cm, coated	37.3±0.7	11.0±0.2	10.5±0.1	136±2	326±18
4. 50% P2, 18 cm, coated	13.6±0.5	10.8±0.2	8.5±0.1	124±2	281±17
5. 20% P2, 20 cm, coated	25.6±0.5	10.3±0.2	9.5±0.1	126±2	332±18
Systematic Error	1.64	0.59	0.73	7	-

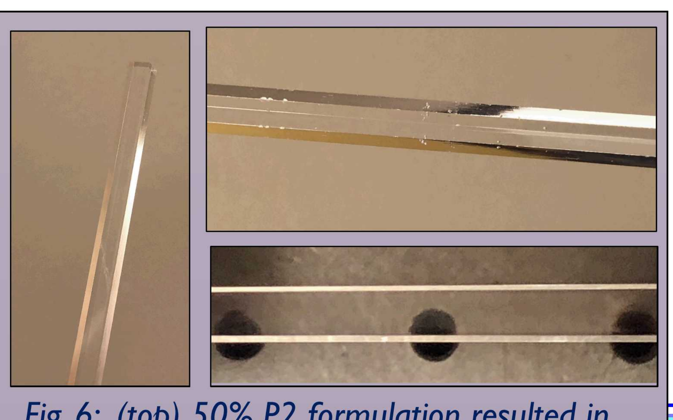

Fig. 6: (top) 50% P2 formulation resulted in high bubble fraction compared to EJ-204 (left), interfering with light propagation. 20% P2 composition (bottom) has no bubbles.

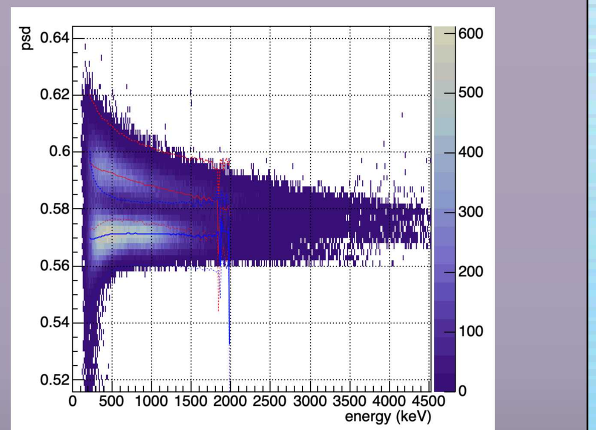

Fig. 7: preliminary PSD studies show worse n/γ separation than expected: due to limited trace length of digitizer or formulation?

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