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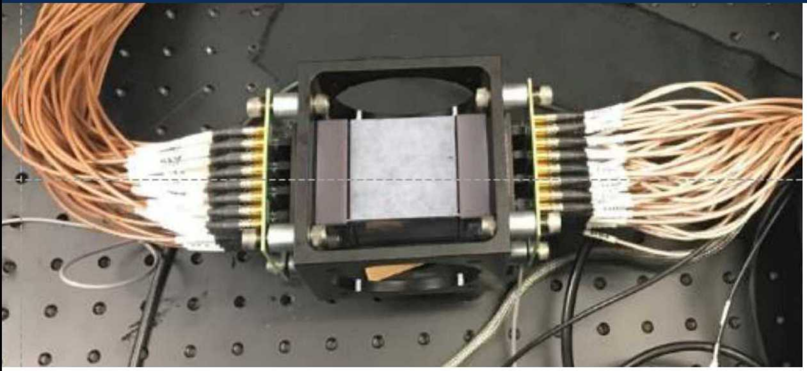

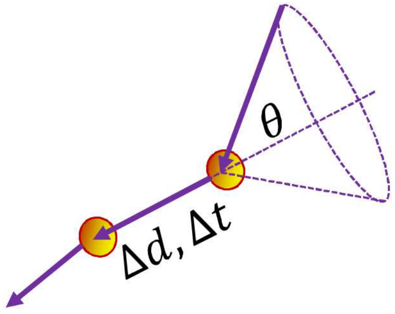

The Single-Volume Scatter Camera Project

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July 15th, 2019

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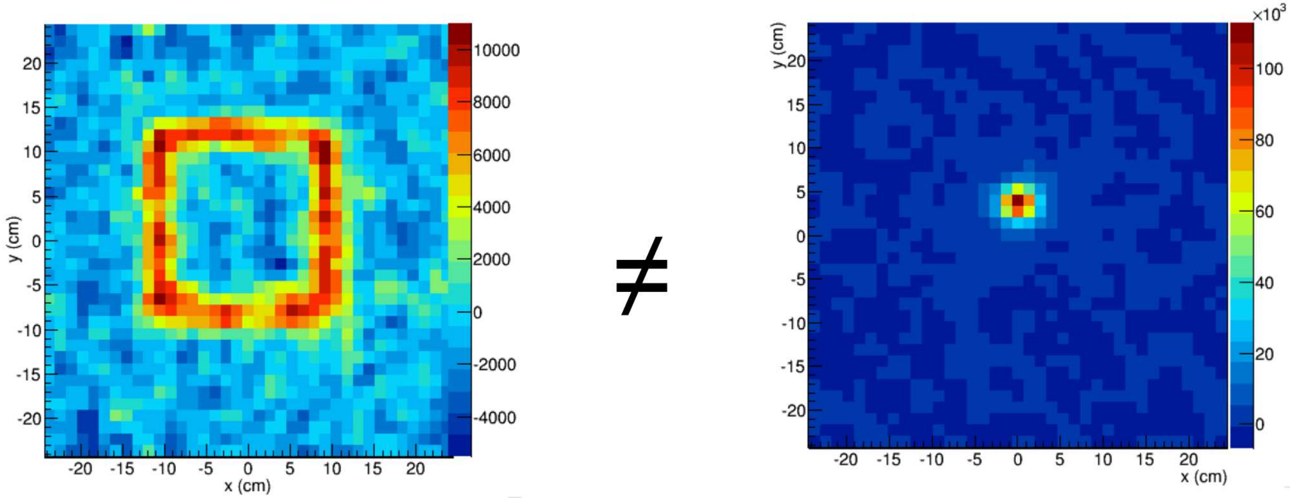
Why neutron imaging?

Enables localization, characterization of SNM

- In an unknown radiation environment, imaging improves signal to noise compared to radiation counter
- For neutrons, less background sources compared to gammas
- Characterizes spatial distribution of plutonium or other neutron emitting materials



Two imaging methods for fission-energy neutrons:

- Kinematic neutron imaging and ~~coded aperture~~

How kinematic imaging works

Exploits neutron scatters off of hydrogen:

- The first neutron scatter losses energy proportional to proton recoil energy:

$$E_p$$

- The remaining energy is measured through non-relativistic time-of-flight:

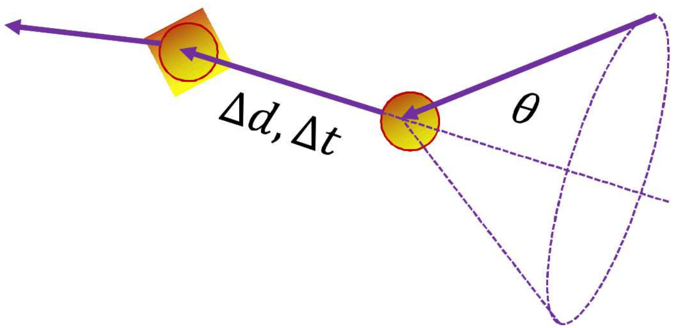
$$E'_n = \frac{1}{2} m_n \left(\frac{\Delta d}{\Delta t}\right)^2$$

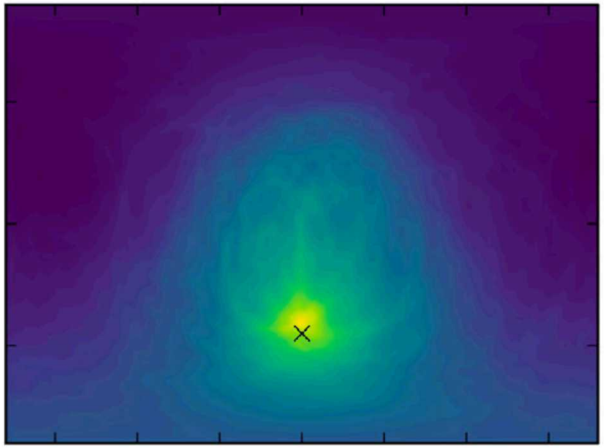
- The total incoming neutron energy is:

$$E_n = E'_n + E_p$$

- Kinematic reconstruction of both recoils also restricts in-coming trajectory of neutron:

$$\theta = \cos^{-1}\left(\sqrt{\frac{E'_n}{E_n}}\right)$$





Why not neutron imaging?

Typically large (poor SWaP), and inefficient detection systems

- Requires two neutron scatters
- Distributed scintillator volumes have poor geometrical acceptance
- High channel count, power requirements

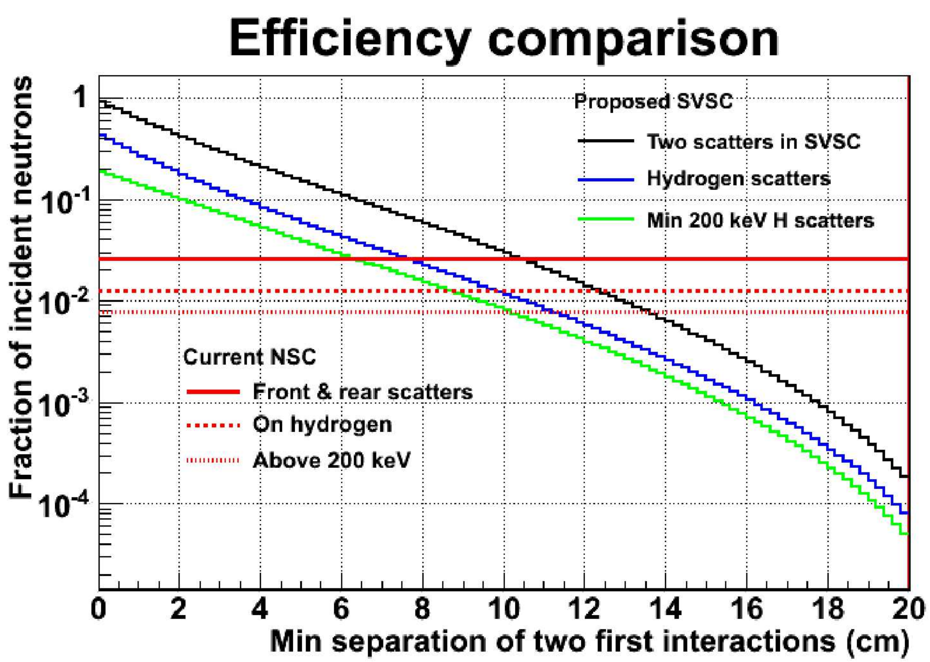
SNL's first neutron scatter camera system:

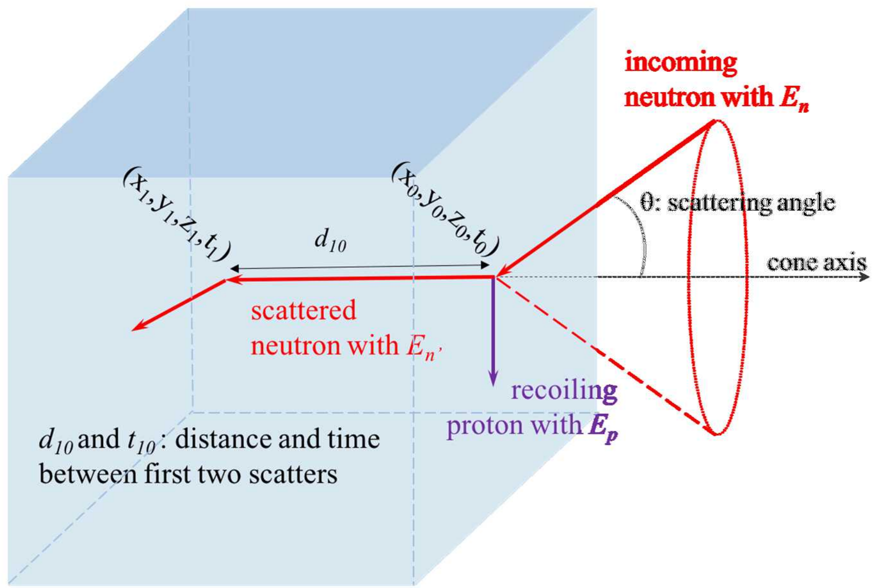
SNL's MINER system with improved SWaP

Why Single-Volume Scatter Camera?

Portability, combined with improved geometrical acceptance

- Potentially a factor of 10 improvement in overall efficiency compared to NSC
- Requires ability to detect two neutron scatters *O(1cm)/O(1ns)* apart
- Recent advances in fast photodetectors and electronics may enable this!





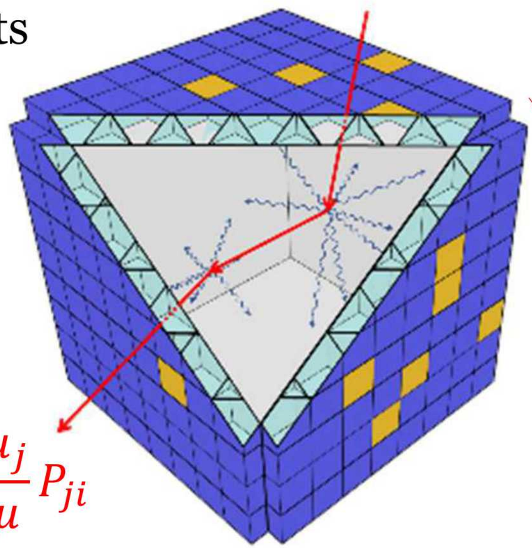
Our two-pronged approach

Two prototype paths: monolithic vs. optically segmented

- Surround a cube of scintillator with photodetectors: 64*6 = 384 channels
- Use the individual photon time/position hits in a complex likelihood function to reconstruct events

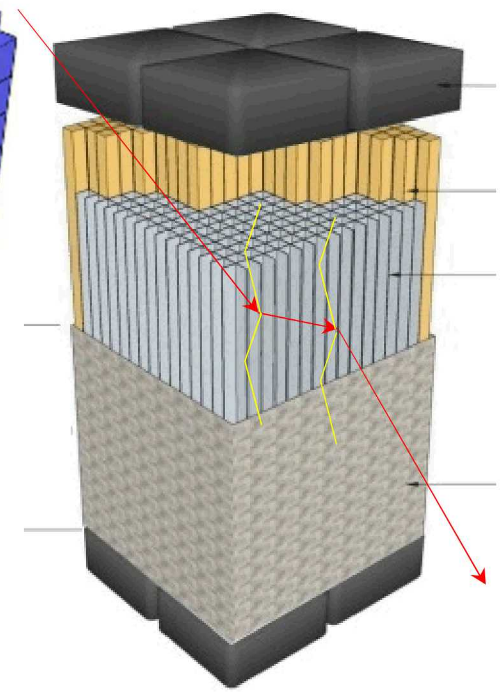
- Optically segment into scintillator bars with photodetectors on the ends
- Reduce channel count to 64*2 = 128
- Simplify reconstruction to linear relations in one dimension

Easy detector, complicated reconstruction



$$\mathcal{L} = \frac{e^{-\mu}\mu^n}{n!}\prod_{i=1}^{n}\sum_{j=1}^{N}\frac{\mu_j}{\mu}P_{ji}$$

$$P_{ji} = \frac{\Omega_{jk(i)}Q_{k(i)}e^{\frac{-d_{jk(i)}}{\lambda}}}{4\pi\sum_k\frac{\Omega_{jk}}{4\pi}Q_k e^{\frac{-d_{jk}}{\lambda}}}f(t_i - t_j - \frac{d_{jk(i)}n}{c})$$



$$\ln\frac{A_1}{A_2} = \frac{L}{\lambda} - \frac{2z}{\lambda}$$

$$t_1 - t_2 = \frac{2z}{v} - \frac{L}{v}$$

Complicated detector, easy reconstruction

Multiple, modular components

Both systems depend on four main components

- We are exploring improvements in all four that can be incorporated into existing prototypes:

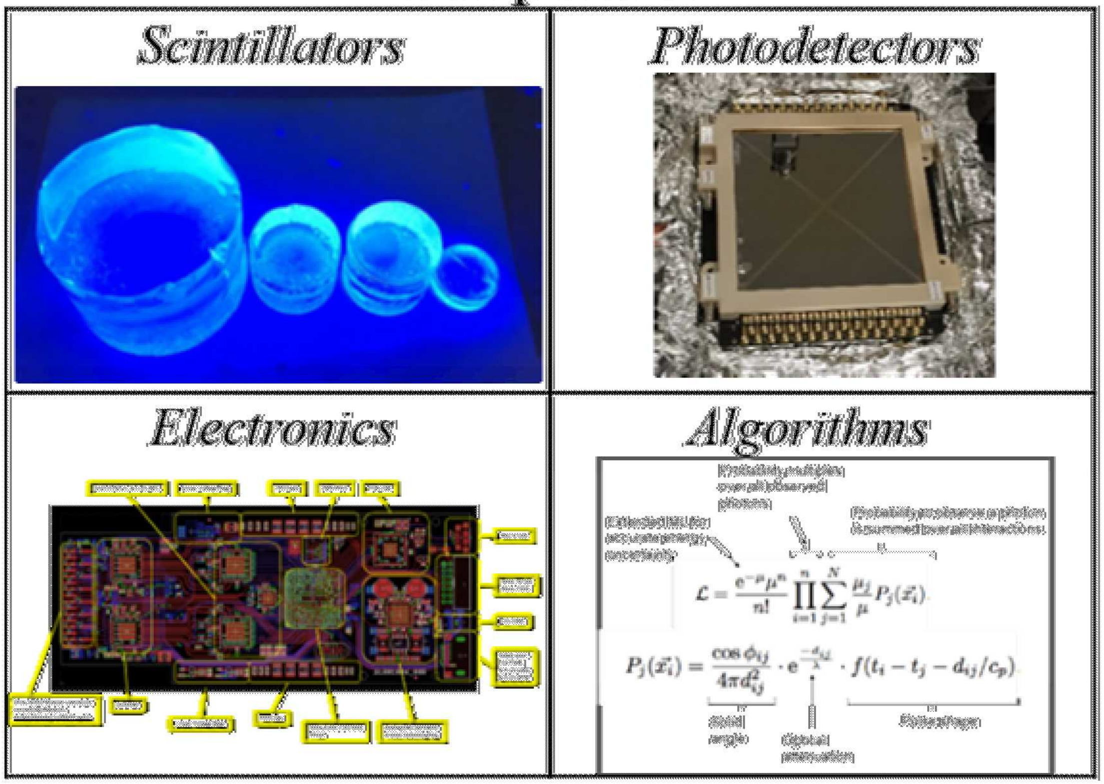
Fast, bright organics, pref. with PSD

Fast, high PDE, scaleable

Fast, scaleable

O(1cm/1ns)

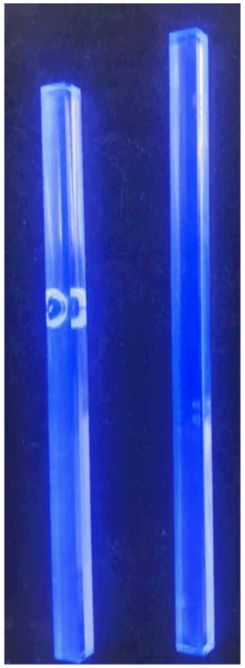
Components

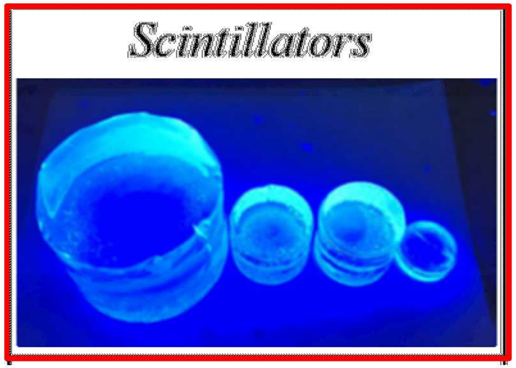


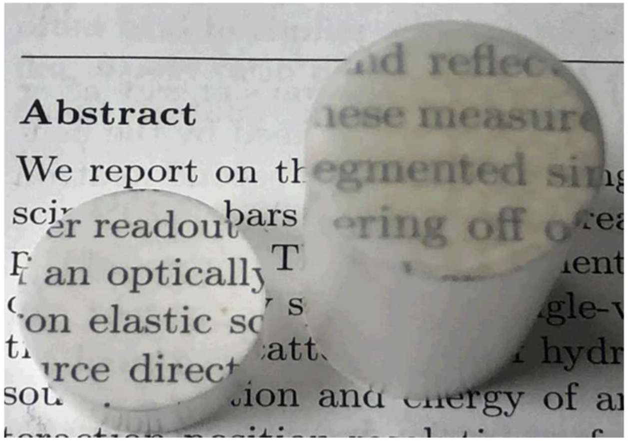
Multiple, modular components

Scintillators

- Bright organic with fast rise, preferably with pulse-shape discrimination
- Need to know neutron light output, pulse shape
    - High-fidelity scintillator characterizations on-going @LBL/UCB/SNL:
        - *J. Brown et al. "Proton light yield in organic scintillators using a double time-of-flight technique" Journal of Applied Physics* ***124*** *(2018) 045101.*
        - *T. Laplace et al. "Low energy light yield of fast plastic scintillators" Nuclear Instruments and Methods in Physics A, in press doi:10.1016/j.nima.2018.10.112.*
    - Improved timing, light output with glass-based scintillator @SNL:
        - *J. Carlson and P. Feng. "Melt-cast organic glasses as high-efficiency fast neutron scintillators" Nuclear Instruments and Methods in Physics A* ***832*** *(2016) 152-157.*
    - Scintillating Nanoguide from Paradigm/Incom: loss-less light propagation through transverse Anderson Localization?



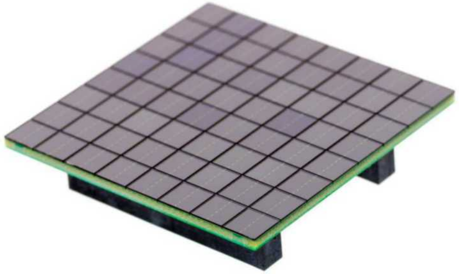




Multiple, modular components

Photodetectors

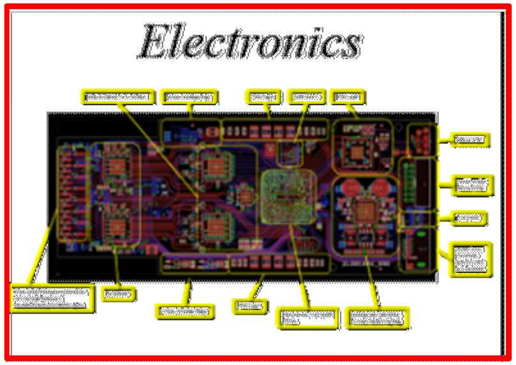
- O(10-100) ps timing response
- High particle detection efficiency
- Need to know cross-talk, dark count rate:
  - Characterizations of the LAPPD (large area pico-second photo-detector) @SNL/UCB:
    - *publication pending*
  - Atomic layer deposition studies for improved MCP-PMT gain/lifetime @ANL
  - On-going SiPM/MCP-PMT characterizations @ORNL/SNL/UH
    - Hamamatsu MPPC
    - J-series SiPM from SensL
    - Planacon MCP-PMT
    - Hamamatsu MCP-PMT



Multiple, modular components

Electronics

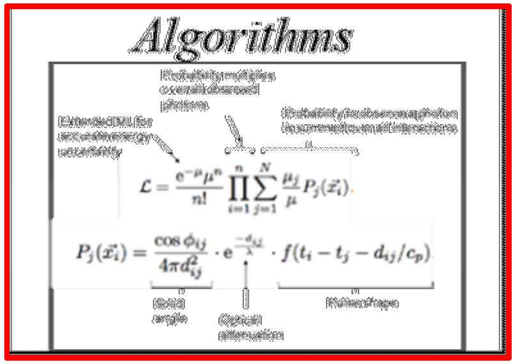
- GS/s digitization for first prototype
- Fast analog could be used for later prototypes:
  - Characterization of drs4-based commercial digitizers @SNL/UH/ORNL
  - Development of 16-channel drs4-based readout @SNL/UH:
    - *J. Steele et al. "SCEMA: a high channel density electronics module for fast waveform capture" Journal of Instrumentation* ***14*** *(2019) P02031.*
  - Frequency domain multiplexing research @NCSU
    - *M. Mishra et al. "Frequency domain multiplexing of pulse mode radiation detectors" Nucl. Instr. And Meth. A 902 (2018) 117-122*
  - Characterization of analog ASIC @SNL: *upcoming*
    - PETSys Electronics' TOFPET2 ASIC

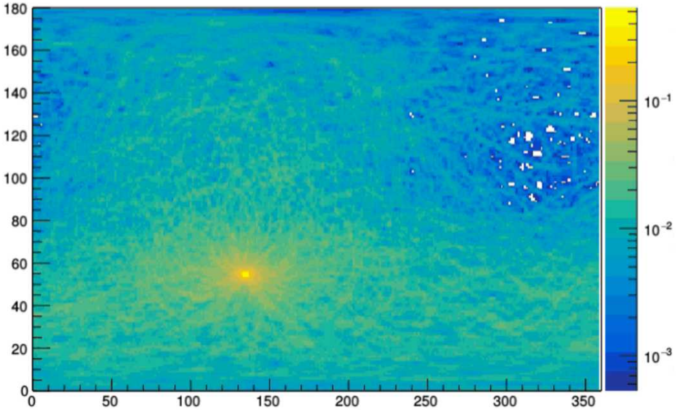


Multiple, modular components

Algorithms

- Need to reconstruct first recoil energy, and position/time of proton recoil pairs with O(1 cm/1 ns) resolution:
  - Study of monolithic likelihood performance in Geant4 simulation @SNL:
    - *J. Braverman, et al. "Single-volume neutron scatter camera for high-efficiency neutron imaging and spectroscopy" arXiv:1802.05261 (2018)*
    - *on-going improvements*
  - Single bar characterizations of OS reconstruction in simulation (@SNL/NCSU) and experiment (@SNL/UH):
    - *K. Weinfurther et al. "Model-based design evaluation of a compact, high-efficiency neutron scatter camera" Nucl. Instr. And Meth. A 883 (2018) 115-135*
    - *M. Sweany et al. "Interaction position, time, and energy resolution in organic scintillator bars with dual-ended readout" Nucl. Instr. And Meth. A 927 (2019) 451-462*
  - On-going: How will reconstruction parameters effect imaging metrics (@SNL/UCB)?
- Also imaging algorithms!

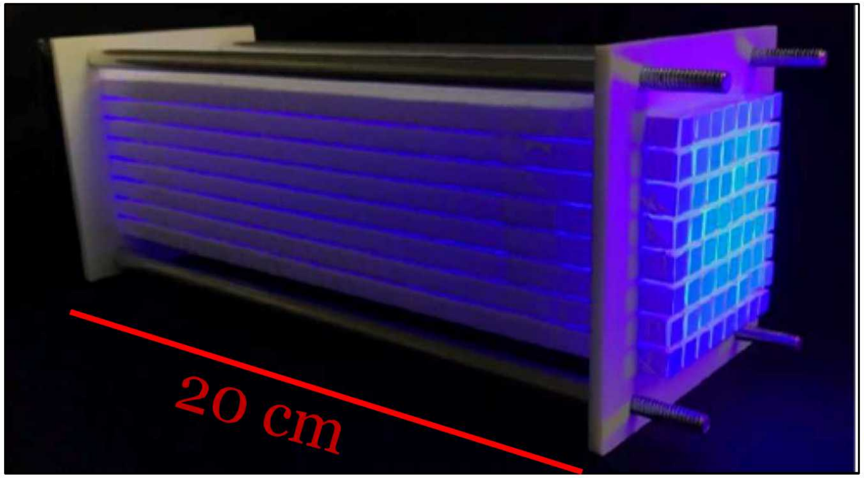


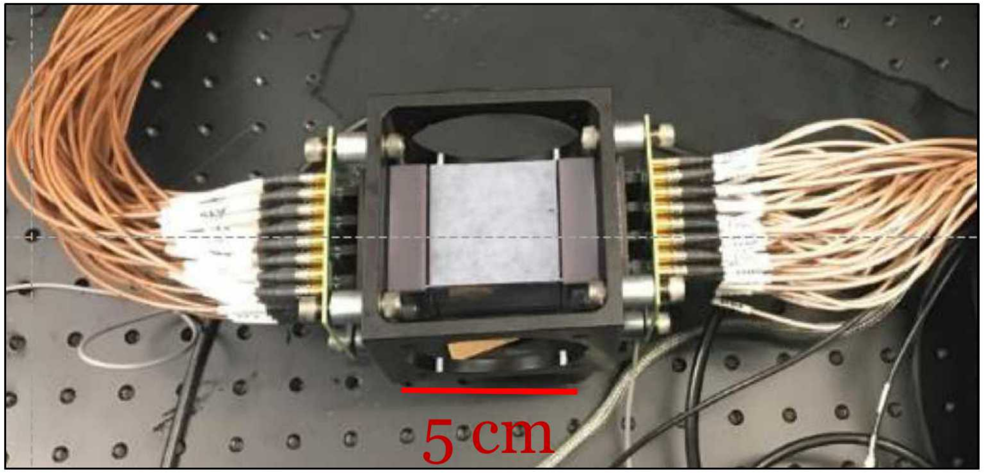


Current status

Both prototypes are built and undergoing characterizations

- Assembly completed late CY2018
- Physics measurements pending electronics characterizations and calibrations
- Upgrade path being pursued for both based on component improvements
- Upgrades planned for late CY2019





Summary

- Neutron kinematic imaging can provide improved radiological localization capabilities in unknown background environments, and provide spatial characterization of SNM
- The Single Volume Scatter Camera promises to address the SWaP and detection efficiency drawbacks of current neutron kinematic imaging systems
- Required technical capabilities of detector components has recently be achieved
- We are conducting detailed characterizations of components, implementing into two prototype systems
- The two systems have been recently assembled, undergoing further system-wide characterizations

Thank you!

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Questions?