Defense Nuclear Nonproliferation Research & Development

Nuclear Security Applications Research & Development Portfolio Review

NSARD 2018

Single-Volume Neutron Scatter Camera Development

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Project data

- Title: "Single-Volume Scatter Camera Development"
- Participants: Six institutions
  - SNL/CA (lead): E. Brubaker, M. Sweany, J. Brown, J. Steele, B. Cabrera-Palmer, et al.
  - ORNL: P. Hausladen, K. Ziock, M. Febbraro, M. Folsom, et al.
  - ANL: J. Elam, A. Mane
  - U Hawaii: K. Nishimura, J. Learned, A. Druetzler, et al.
  - UC Berkeley/LBL: B. Goldblum, T. Laplace
  - NCSU: J. Mattingly, K. Weinfurther, M. Mishra

What are we trying to do?

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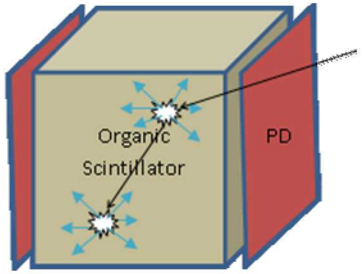
- **Why neutron emission imaging?**
  - **1) Improves detection of weak SNM sources, enables localization.**
  - **2) Characterizes the spatial distribution of plutonium or other neutron emitters.**
- **A compact imager is easy to transport and deploy, has high efficiency, and can be placed near an item to increase sensitivity & spatial resolution.**
- **For passive neutron imaging to be useful for nuclear security, we need to improve on existing systems by making them smaller *and* more efficient.**
  - **Size: ~2 m^3 (NSC) → ~0.2 m^3 (MINER) → ~0.05 m^3 (SVSC)**
  - **Order of magnitude efficiency improvement over NSC/MINER**
- **How? Detect and resolve 2+ neutron scatters in a single active region.**
  - **Monolithic approach: Detect each individual photon propagating isotropically.**
  - **Optically segmented approach: Guide light to ends of bars.**
- **Outcomes/deliverables: Prototypes, performance studies; Improved photodetectors, electronics, scintillators; Papers, theses, human capital**



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How is n emission imaging done today?

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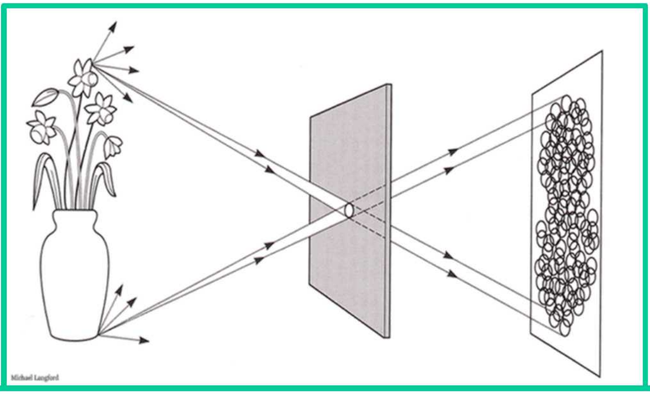
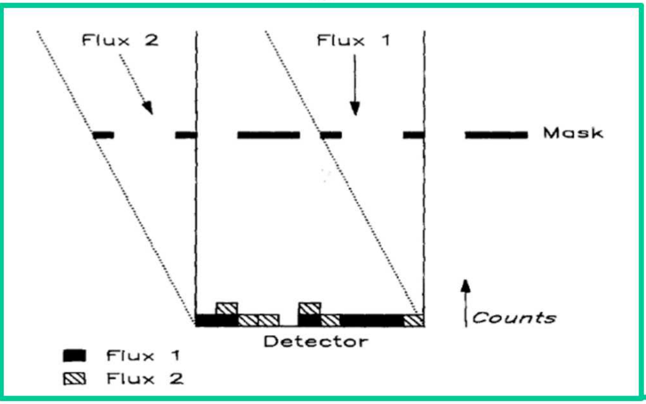
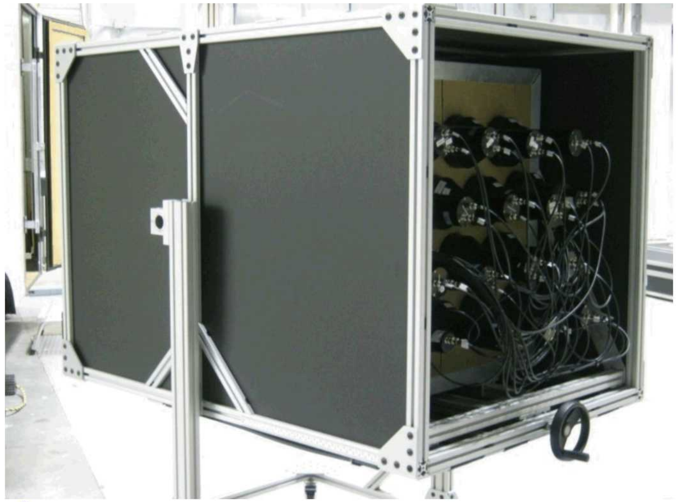
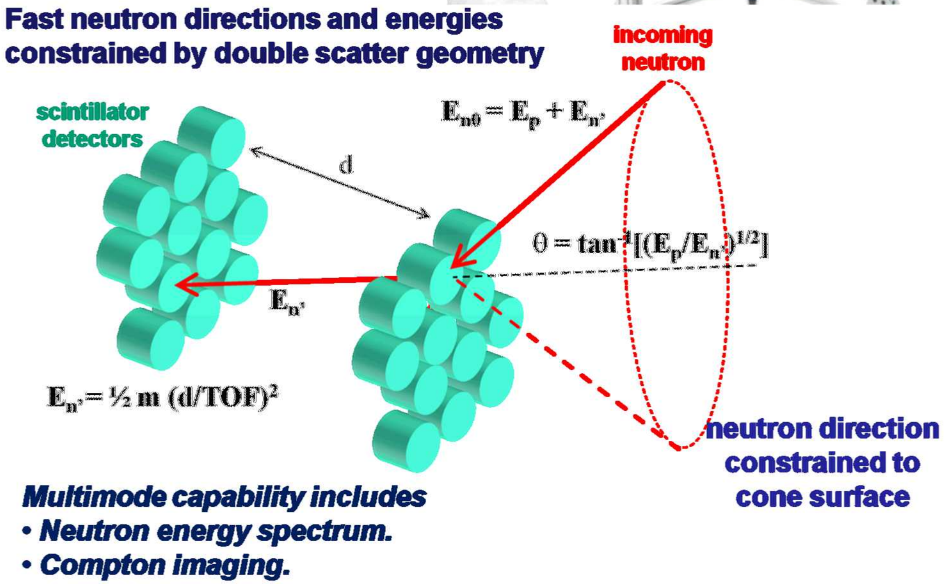


Pinhole: High Resolution, Low Throughput



Coded aperture: High Resolution, High Throughput





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What is our new approach?

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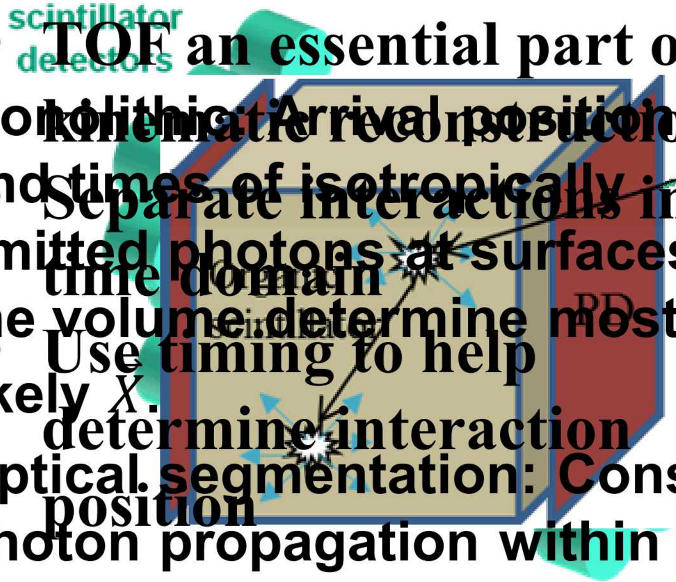
- **Cell-based → single volume**
- **Two configurations:**
  - **Monolithic scintillator**
  - **Optically segmented scintillator**
- **Both rely on excellent time resolution:**
  - **TOF an essential part of kinematic reconstruction**
  - **Separate interactions in time domain**
  - **Use timing to help determine interaction position**

Prototyping

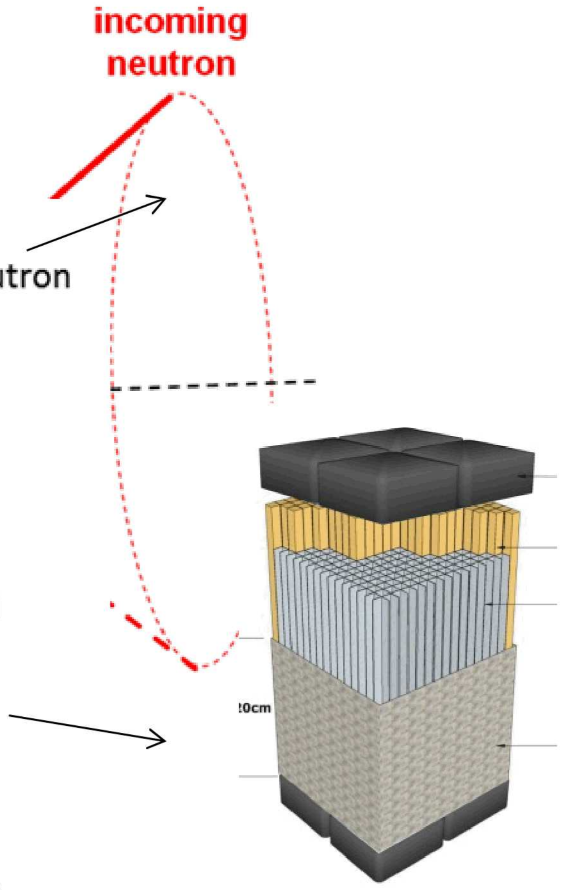
Monolithic | Opt. Segmented

Concept requires a method of determining *two* (or more) event locations within a bulk scintillator to sub-cm precision. $\vec{X} = (x, y, z, t)$



- TOF an essential part of kinematic reconstruction
- Separate interactions in time domain
- Use timing to help determine interaction position

1. **Monolithic: Arrival positions and times of isotropically emitted photons at surfaces of the volume determine most likely** $\vec{X}$.
2. **Optical segmentation: Constrain photon propagation within bulk to associate specific PD channels with** $\vec{X}$.

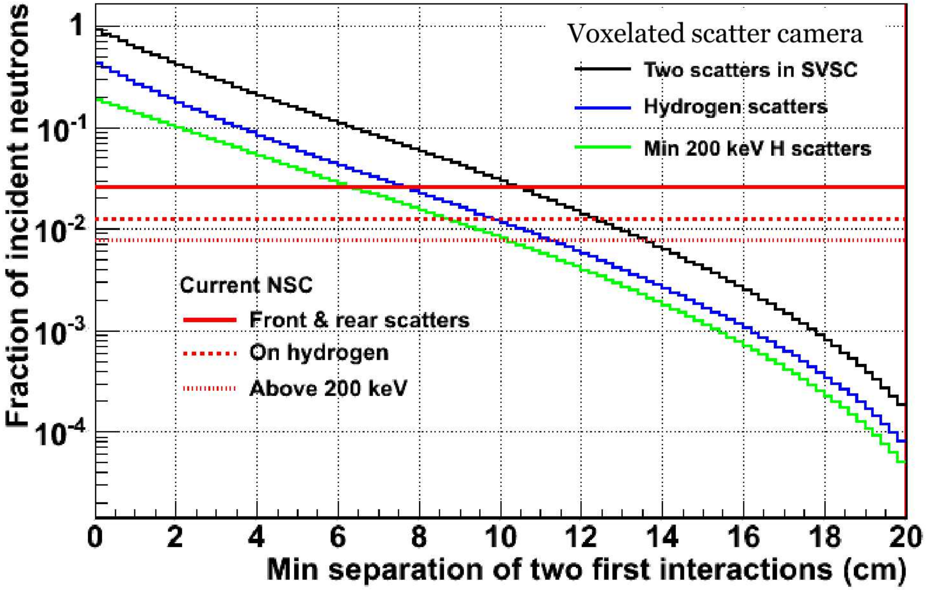


Who cares? What difference will it make?

Compact high-efficiency neutron imager:

- High efficiency reduces measurement time to acquire given information.
- Compact form factor allows easy transport, deployment in tight spaces, close approach to threat sources.
- Application spaces:
  - SNM search/standoff detection
  - Cargo screening
  - Arms control
  - Emergency response

Efficiency comparison



Technology development:

- Fast pixelated photodetector/readout enables other improved systems: coded aperture, transmission neutron imaging, etc.
- Advances in scintillators & characterization methods, photodetectors, electronics feed other fields: medical imaging, basic science, etc.

If successful:

- Spectroscopic capability
- Good per-event angular resolution
- High efficiency
- Compact form factor

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What are the risks & challenges?

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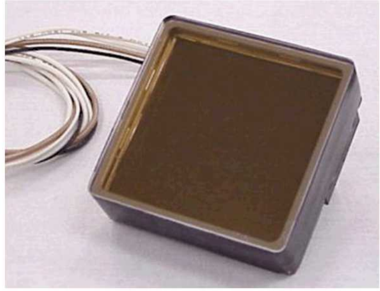
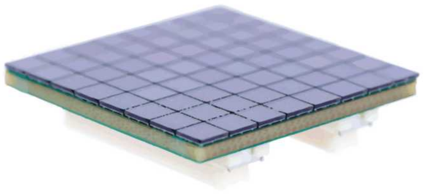
- **In an organic scintillator, the mean free path of a 1 MeV neutron is 3 cm, which takes 2 ns.**
- **The concept only works with:**
  - **Fast & bright organic scintillators**
  - **Fast, efficient photodetectors**
  - **Fast, scalable electronics**
  - **Sophisticated algorithms**
- **We have demonstrated feasibility in simulation—information content is there.**
- **Technical achievability is not guaranteed—need to integrate multiple cutting-edge technologies.**

Example challenge #1: Photodetector choice



Photonis Planacon



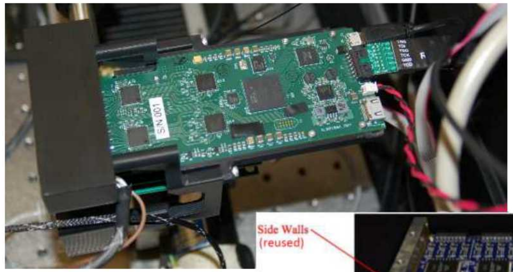
MCP-PMT: Fast! 30-100 ps tts Less mature, niche product	SiPM: High PDE, cheaper, low V Slower, need amp, temp dep

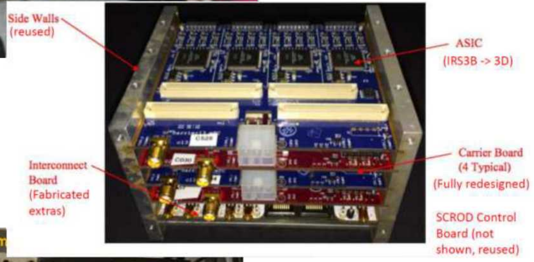
Example challenge #2: Scalability of electronics

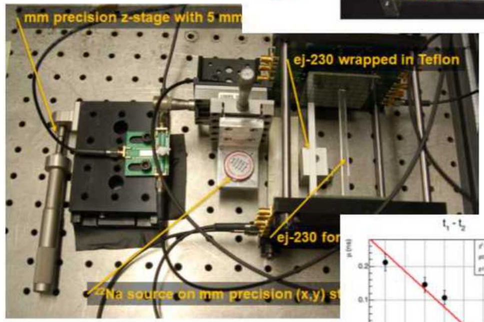
DRS4 eval bd: Works well Can't scale	Caen V1742 (DRS4): Num channels scales Too big	Home-grown: Scalable, compact Hard!

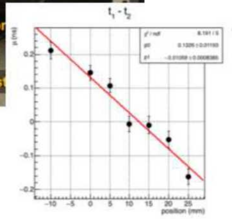
Progress to date

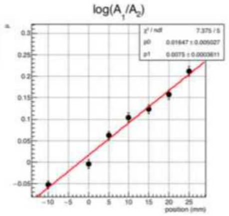
- Operationalized home-grown electronics: compact 16-channel DRS4-based board & SCROD stack.
- Evaluated timing performance of Planacon MCP-PMT & several SiPMs, developed amplification scheme.
- Evaluated single-bar position resolution, proceeding to compare multiple scintillators, reflective treatments.
- Measured light yield of ~8 scintillators—down to 50 keV!—at LBL 88” cyclotron.
- Developing new scintillator concepts, improved ALD process, freq. domain multiplexing, optical coded ap simulations, pulse shape measurements, etc.
- Worked with Incom as “early adopter” to acquire 1 of 2 first production LAPPDs.
- Submitted 1 journal article, a few conference abstracts.



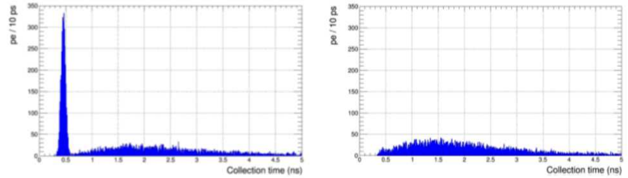








GRIN, 7.5 cm from PD   No-GRIN



Future work

- **Project is in some ways still ramping up**
  - **Hiring postdocs, attracting grad students**
- **Work is proceeding on multiple fronts:**
  - **Short-term develop, prototype, evaluate, iterate:**
    - **Monolithic concept**
    - **Optically segmented concept**
  - **Longer-term efforts, incorporate outcomes in 1-3 yrs**
    - **Component test & evaluation**
      - **Scintillator characterization, LAPPD, Tranloc**
    - **Technology development**
      - **Scintillators, LAPPD, electronics, algorithms**
- **Downselect approach when technical feasibility clear.**
- **Work toward hardware demonstrations, peer-reviewed publications, and conference presentations.**