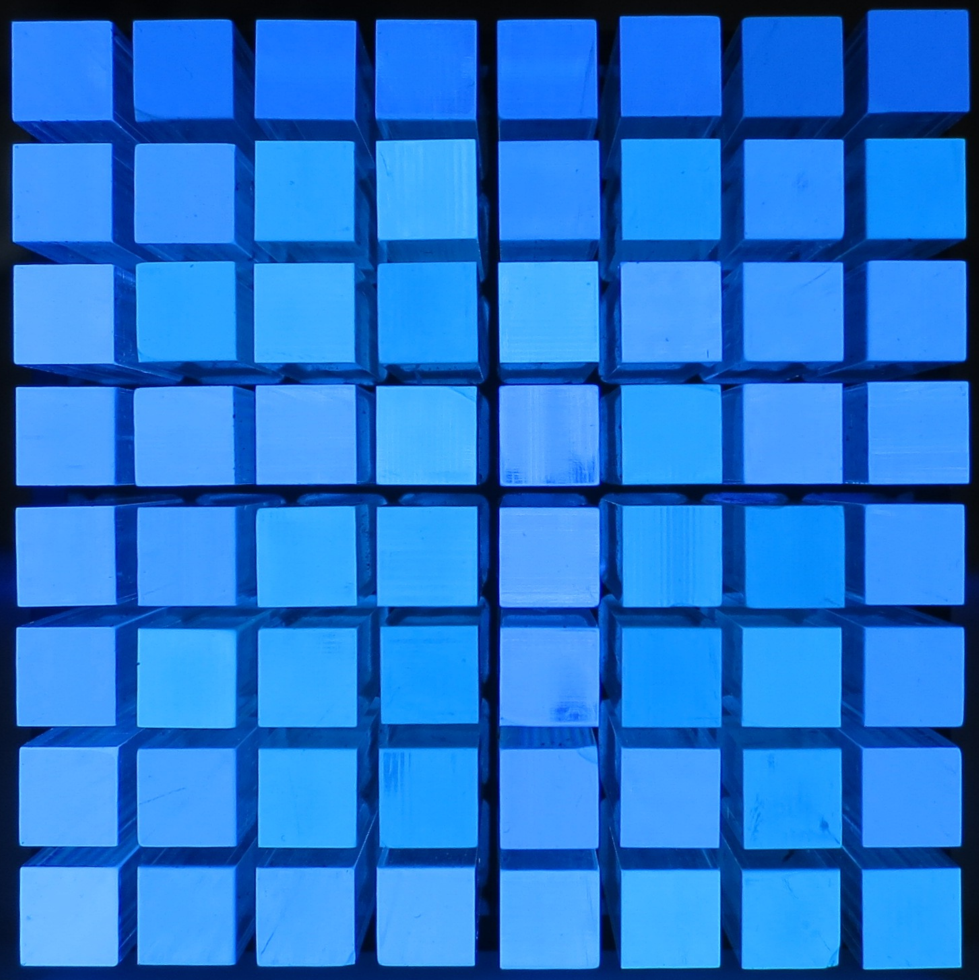
Towards scalable fast-neutron and reactor-antineutrino detectors based on ^{6}Li-doped PSD plastic scintillators and SiPM arrays



Collaboration:

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Lawrence Livermore National Laboratory

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Desired detector characteristics

High fidelity resolution of:

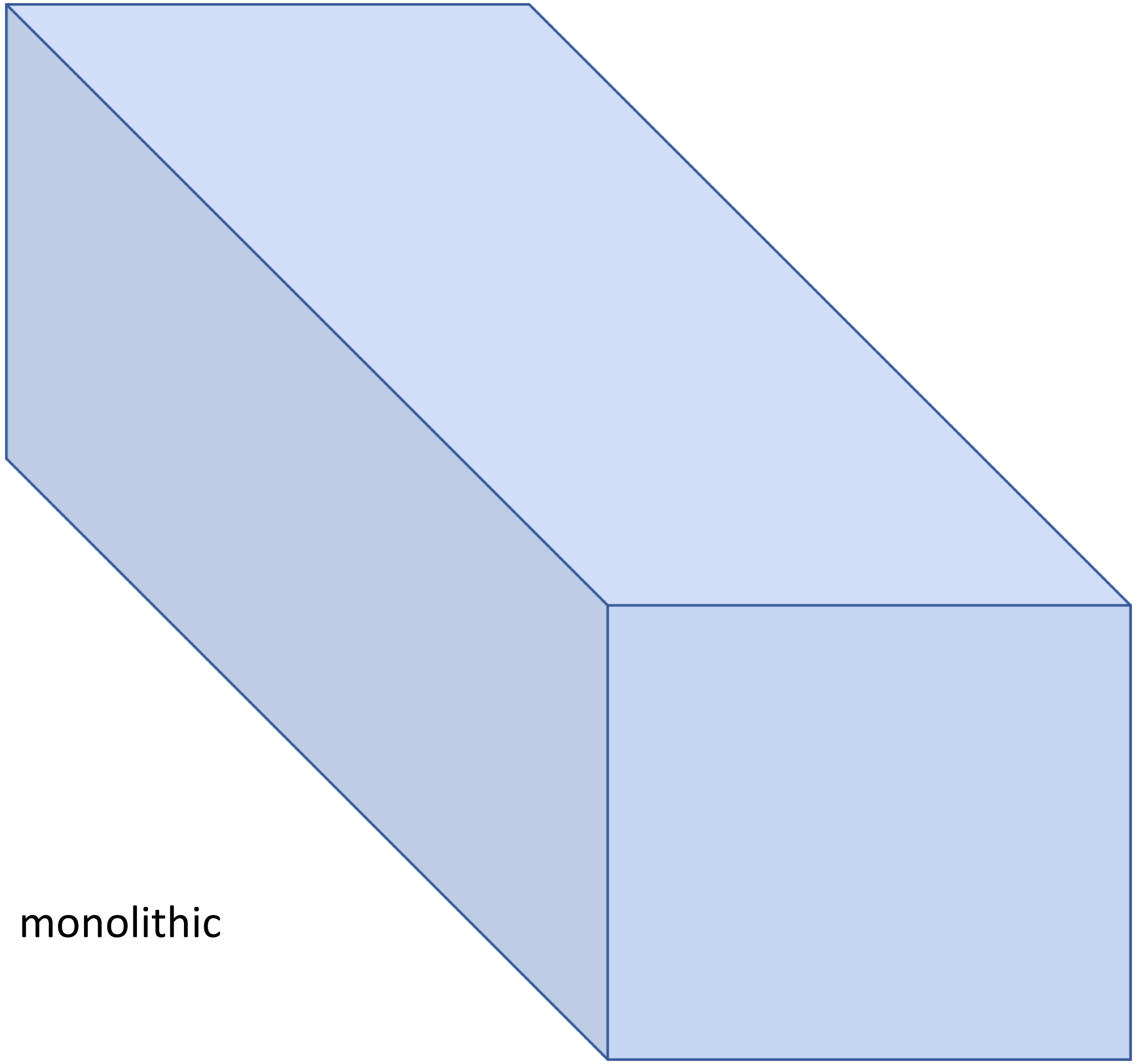
- ✓ Timing
- ✓ Energy
- ✓ Position

For IBD reactor-antineutrino detectors:
to get antineutrino directionality
and to reduce backgrounds.

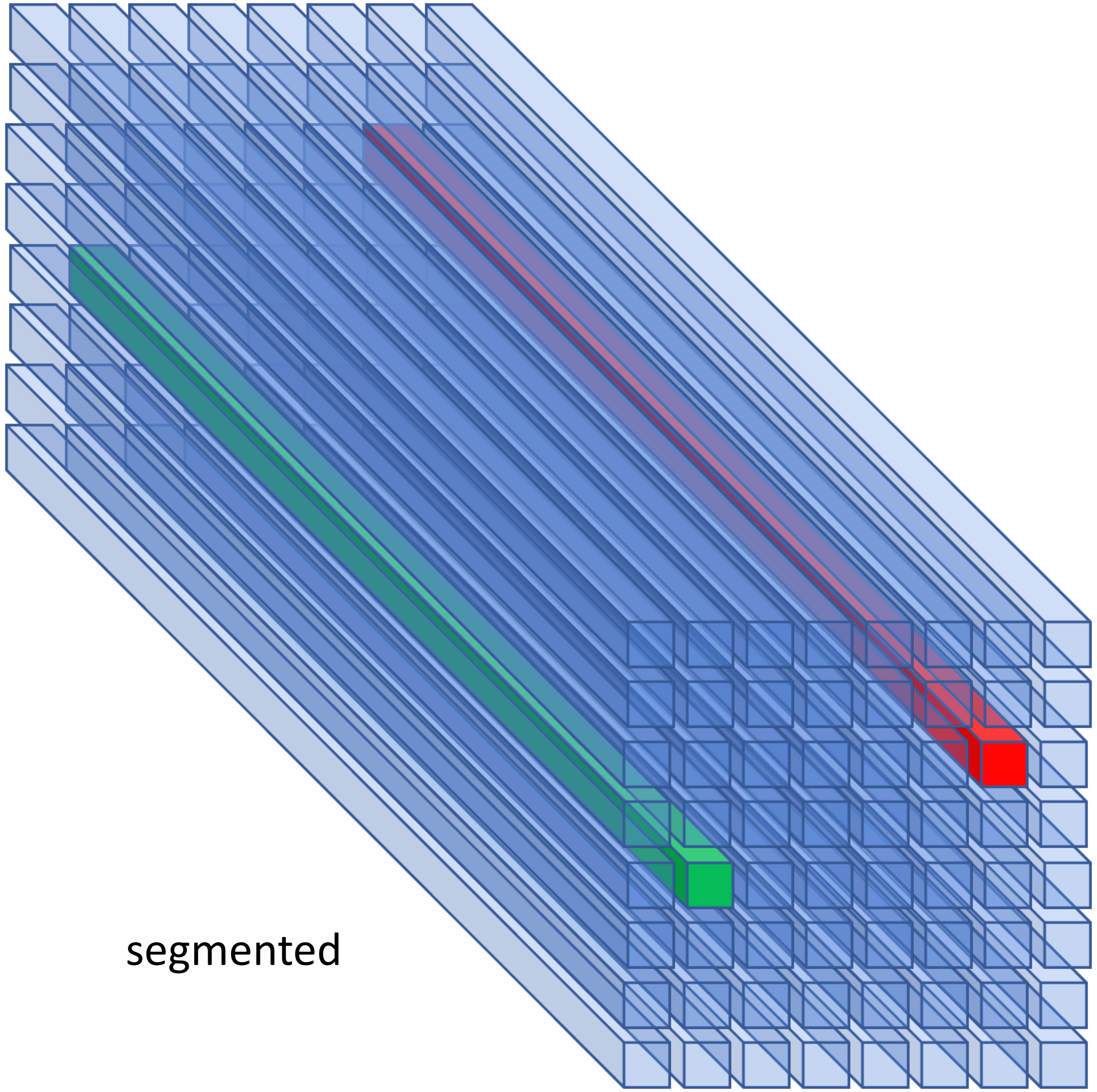
For double-scatter neutron cameras:
to reconstruct direction of incoming neutrons.

Organic scintillator is a requirement for IBD interactions and neutron-scatter cameras.

Finer segmentation ➡ better kinematic details



monolithic



segmented

Example of the importance of **position, energy, and timing** resolution

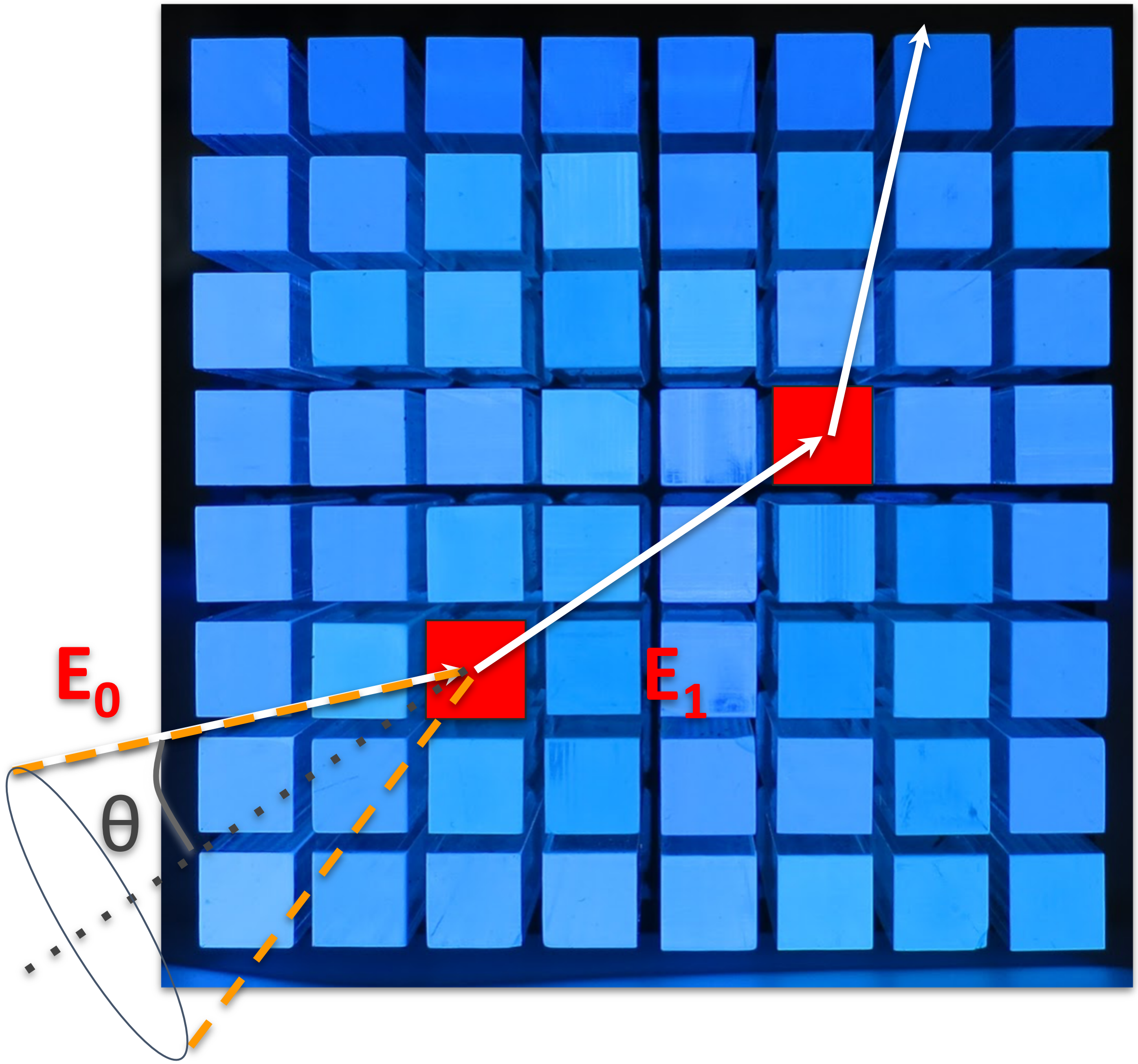
$\sin\theta = \sqrt{(E_0 - E_1)/E_0}$

$(E_0 - E_1)$ — energy deposited in the first rod

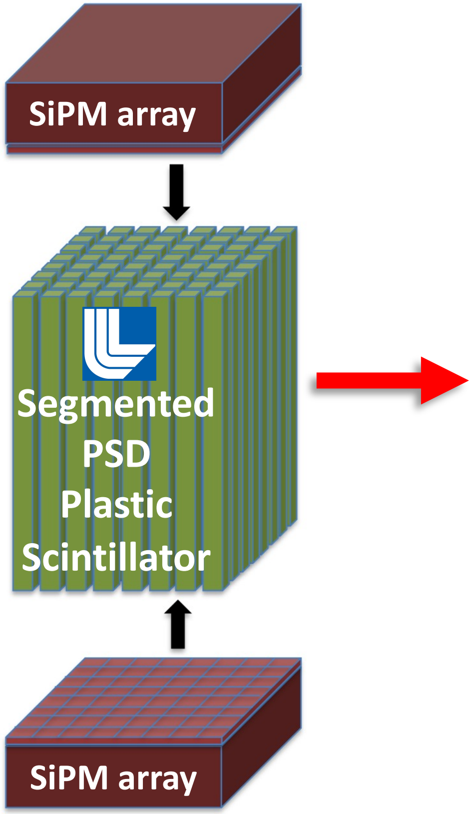
MeV neutron — 10 cm in 7 ns

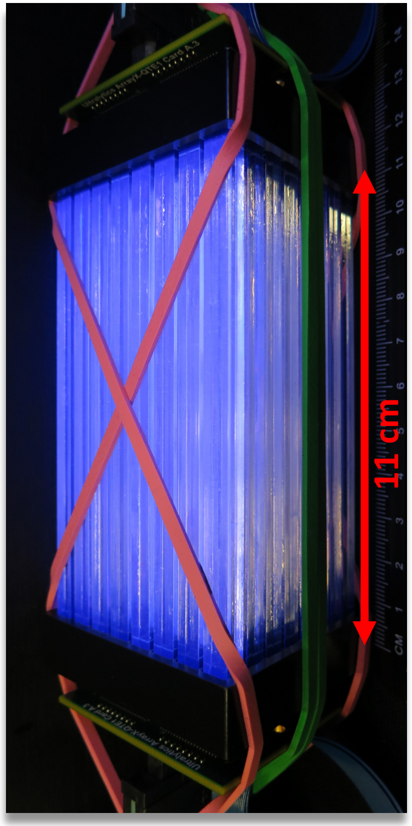
Gamma — 10 cm in 0.3 ns

True Neutron-source position



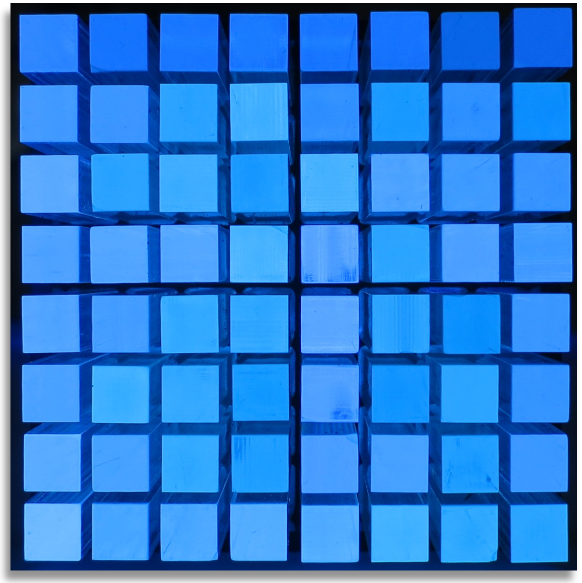
First prototype (undoped PSD plastic)





The dual-ended readout allows for coincidence trigger and position reconstruction along the rods.

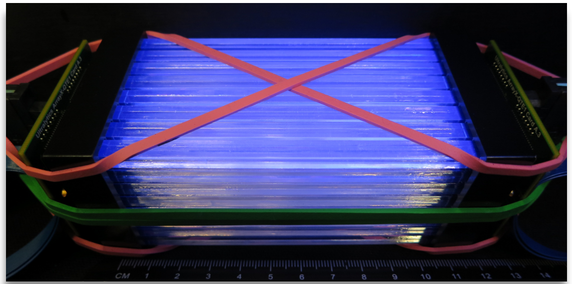
Each rod is viewed by two SiPM pixels.



The light propagates along each segment via Total Internal Reflection (TIR). Segments are separated by air.

Li et al., NIM A942, 162334 (2019).

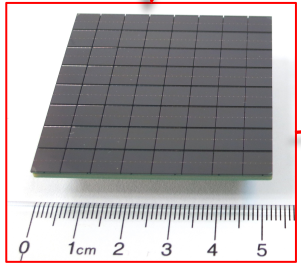
Full-waveform data acquisition (DAQ) system



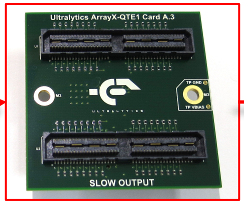
light-tight enclosure

64 LLNL-made PSD plastic (undoped) scintillator rods

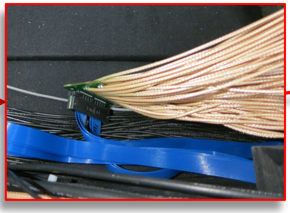
2x



SensL J-series 8x8 SiPM array 5 mm x 5 mm pixel



Ultralytics custom interconnect board (slow output)



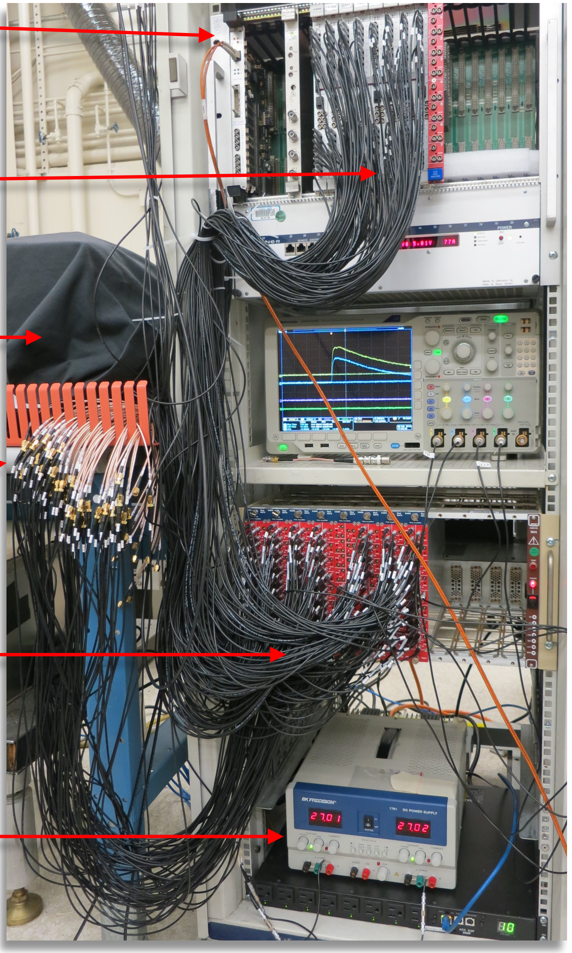
SAMTEC ribbon -> SMA coax interconnect board

Optical link to storage/analysis

DAQ VME Struck 3316 digitizers (250 MHz)

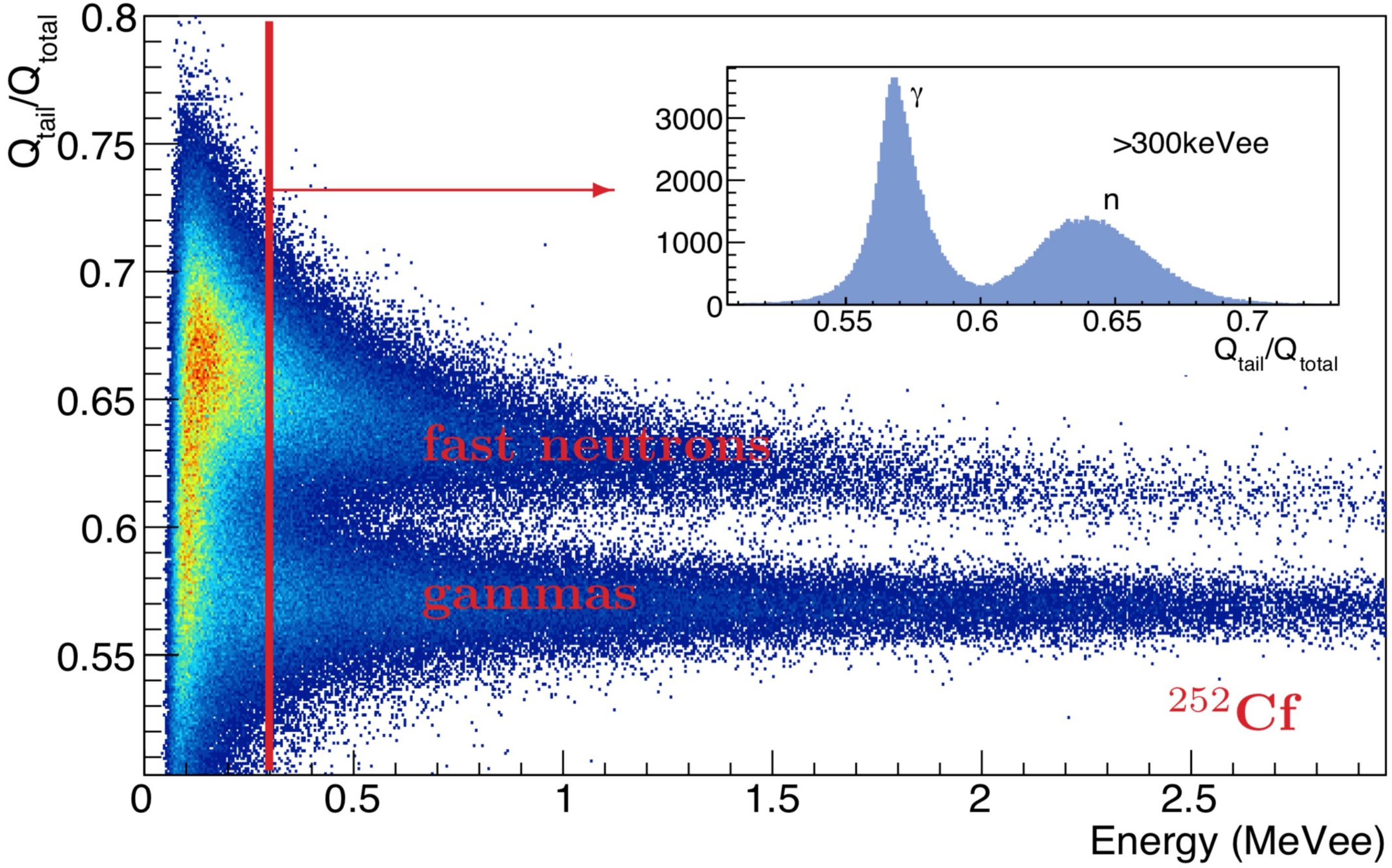
128-channel 10x amps

SiPM power supply (27V)



Li et al., NIM A942, 162334 (2019).

Pulse-Shape Discrimination

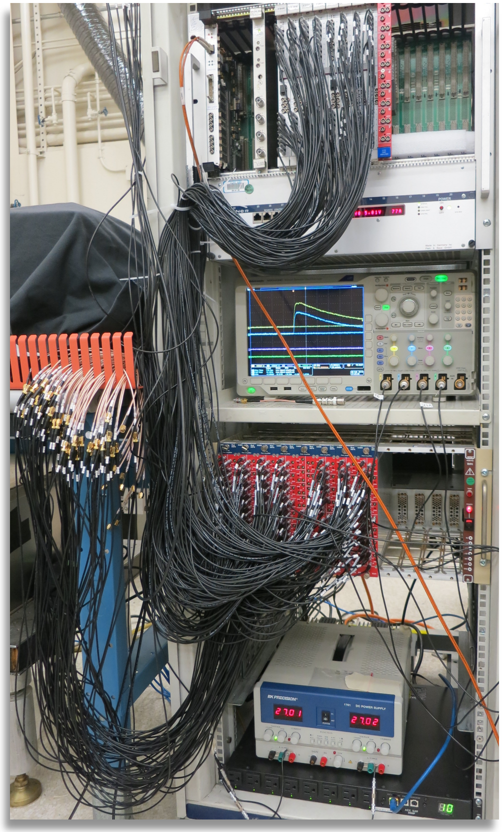


11-cm long bars undoped

Sutanto et al., NIM A, submitted (2021).

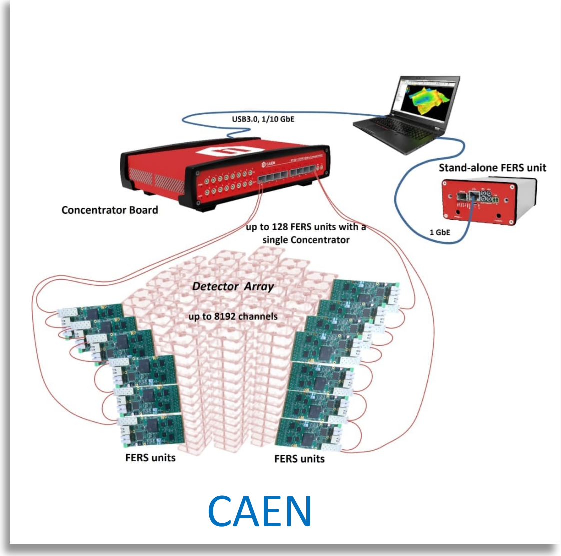
Electronics is a limiting factor to make detector **compact** and **scalable**

PRESENT

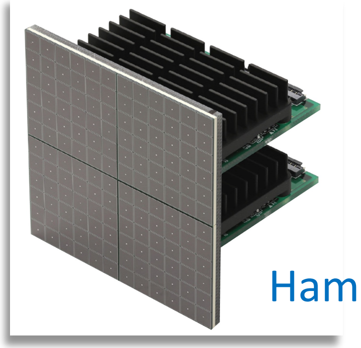


FUTURE


PETsys



CAEN

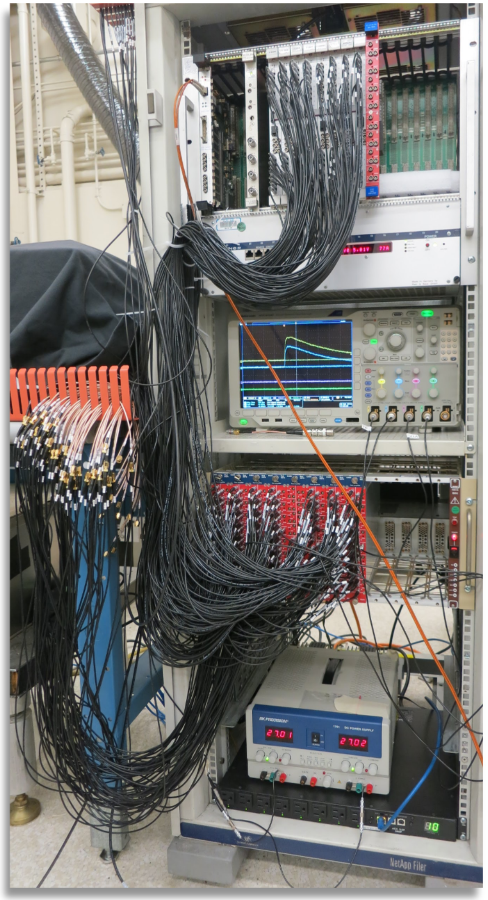

Hamamatsu

Future multi-channel detectors would require low-power, low-cost, fast-timing electronics

Off-the-shelf SiPM-readout options
(expandable beyond 1,000 channels)

Reducing the electronics footprint

128 channels

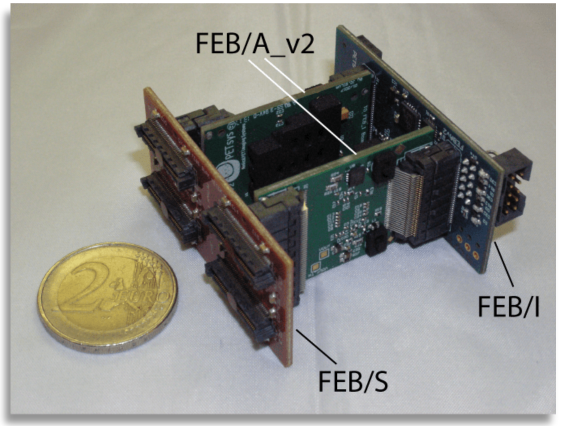


full-waveform

(per channel)	Power	Cost	Data/event	Timing resolution
current readout	10.00 W	$1,000.00	~1000 Bytes	4.0 ns
PET	**0.01 W**	**$10.00**	**~4 Bytes**	**0.1 ns**

Lack of waveforms makes it challenging to troubleshoot and utilize PSD.

128 channels



PET

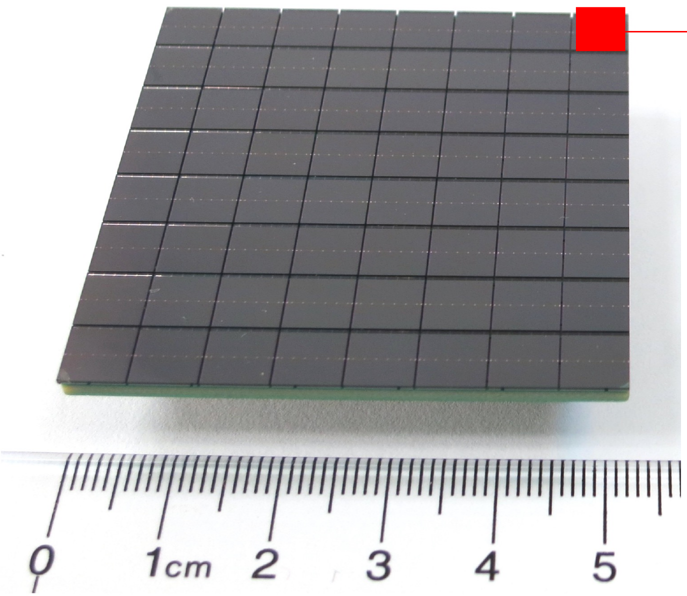
Can state-of-the-art compact low-power electronics from medical PET scanners be used for double-scatter fast-neutron imaging?

V. Li et al. SANDD prototype, NIM A 942 (2019)

Signal splitting for Pulse-Shape Discrimination (PSD)

x64 pixels (per SiPM array)

individual pixel

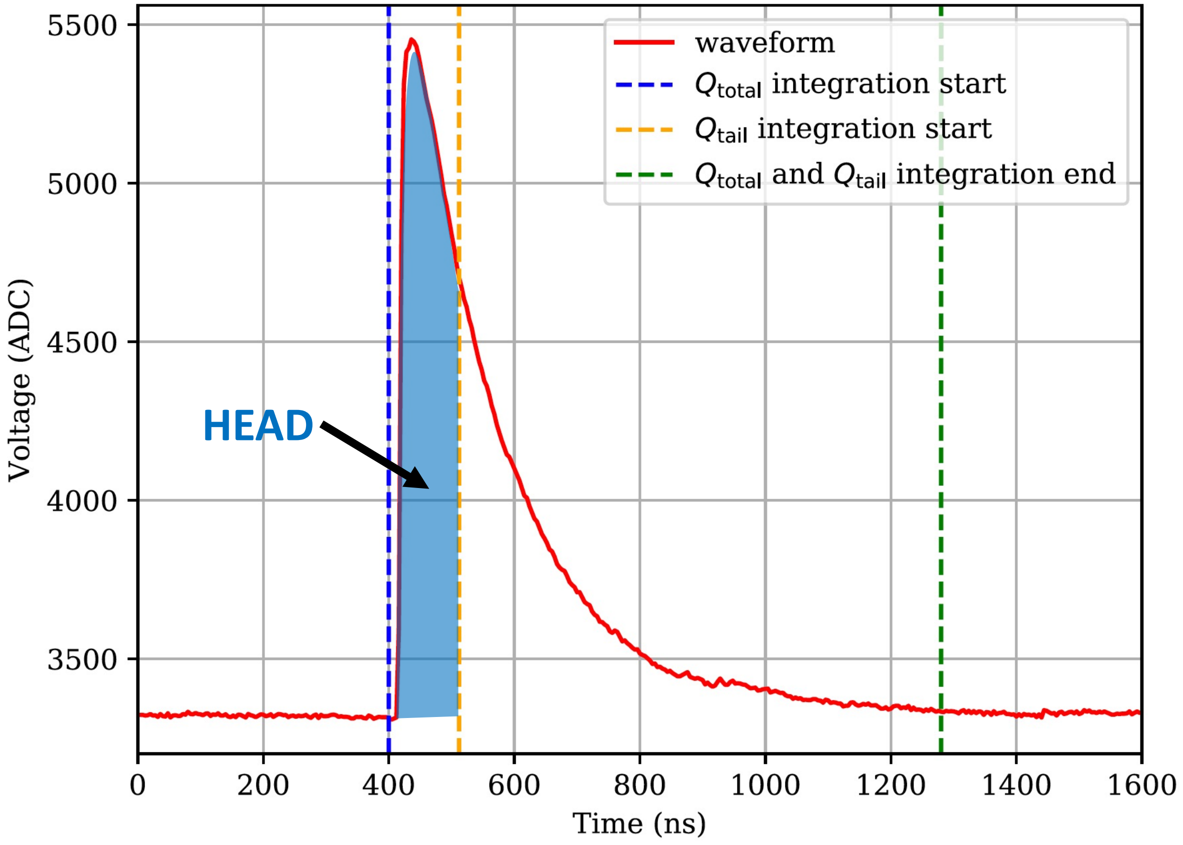


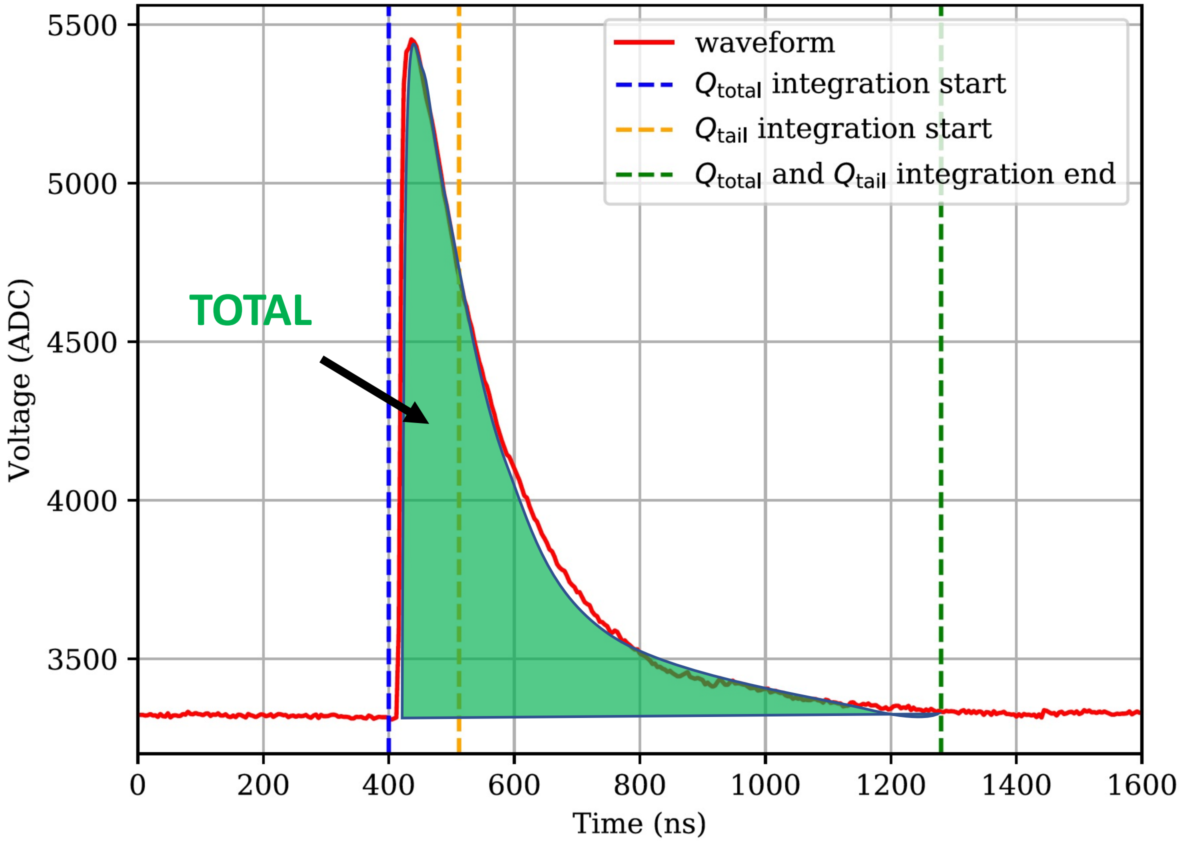
HEAD ~100-ns integration time

TOTAL ~800-ns integration time

PSD measurement results from comparison between these two signals.

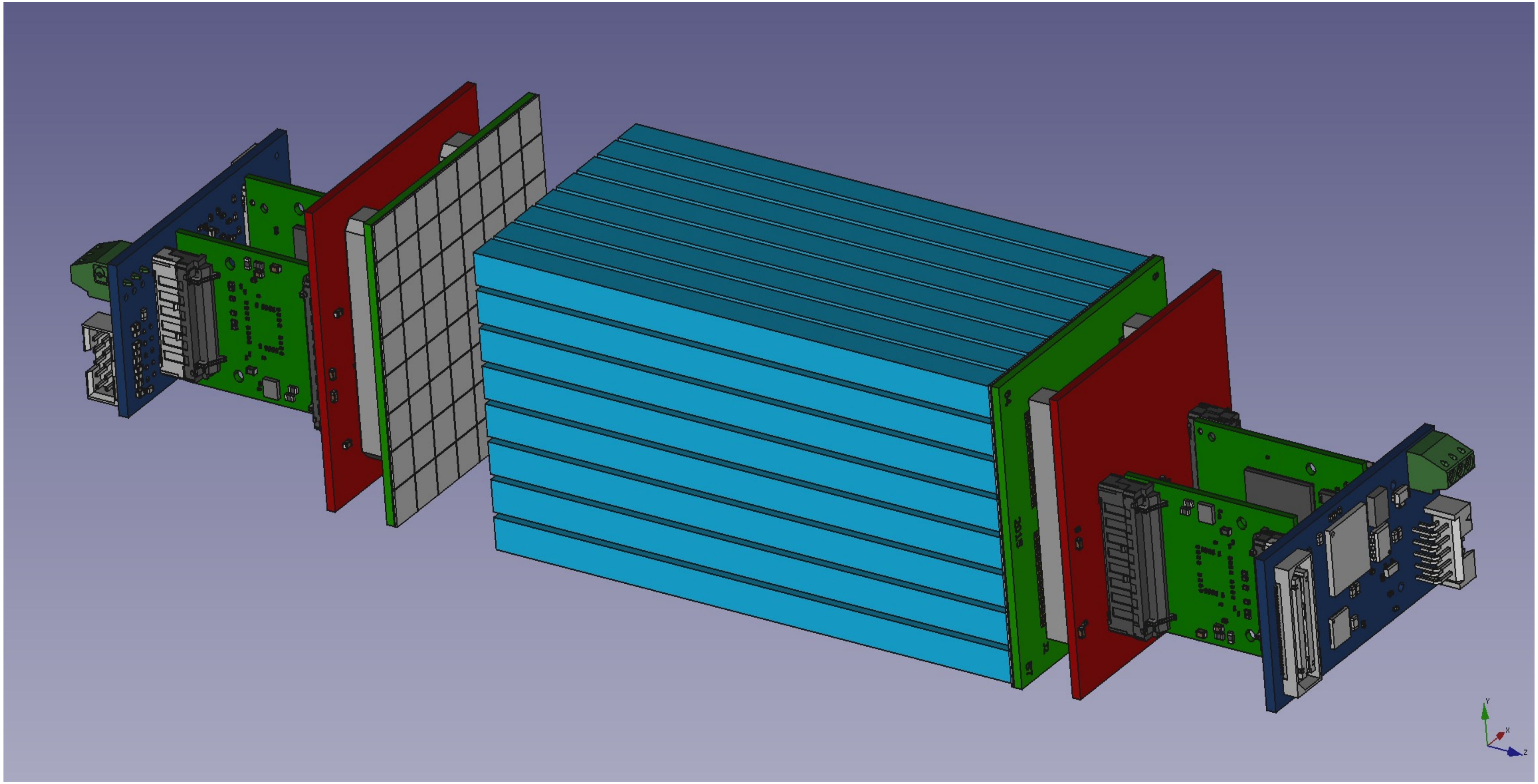
PSD determination — Head and Total



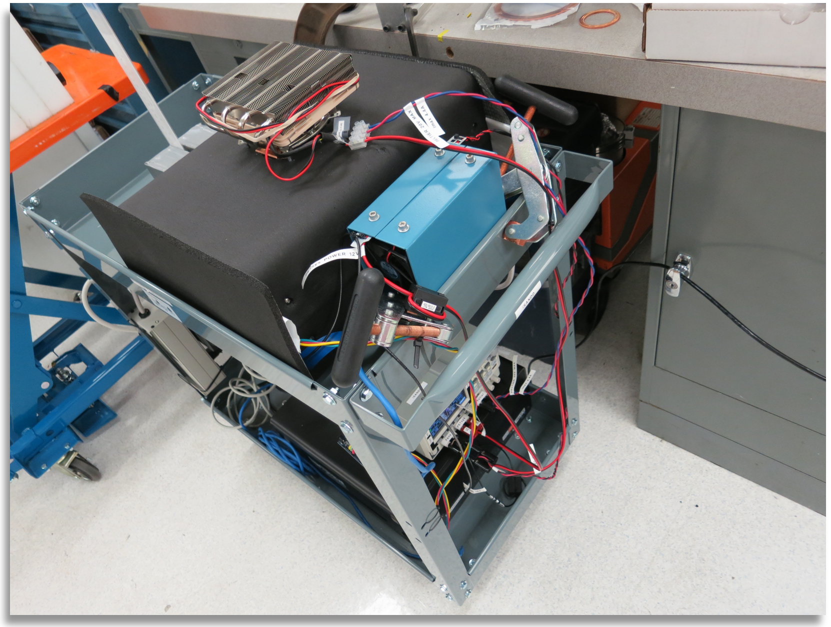


$$Q_{tail} = Q_{total} - Q_{head}$$

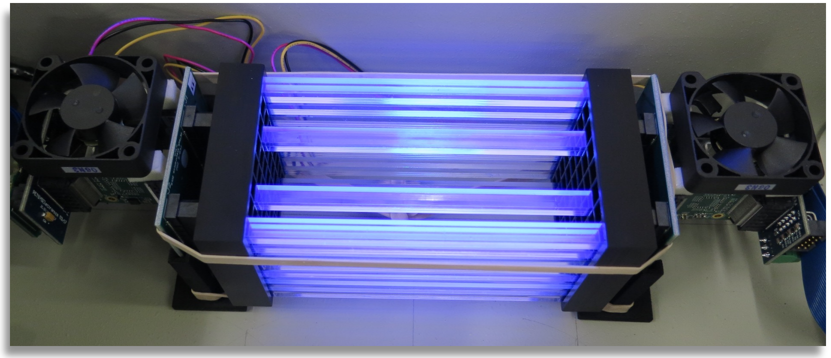
Detector Concept



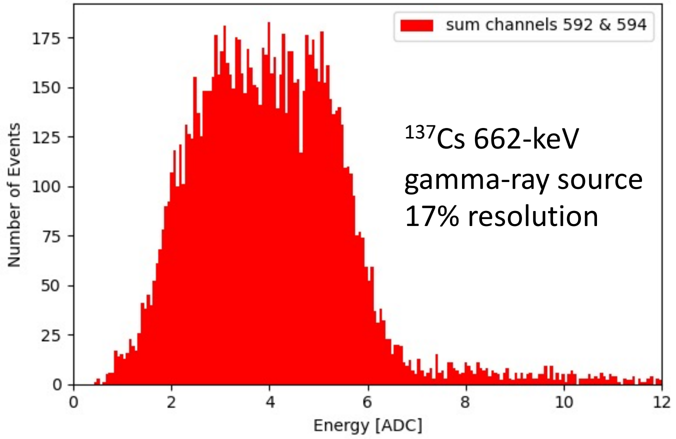
Preliminary Results



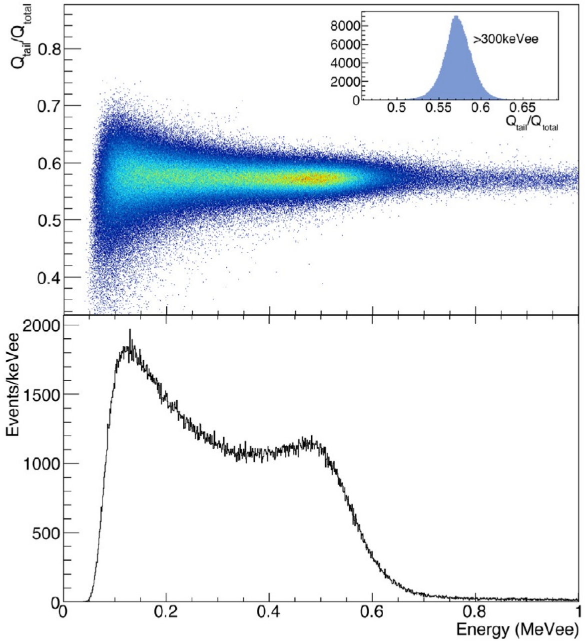
LLNL ^{6}Li-doped PSD scintillator rods
11cm X 0.5cm X 0.5cm



PETsys



Full waveform

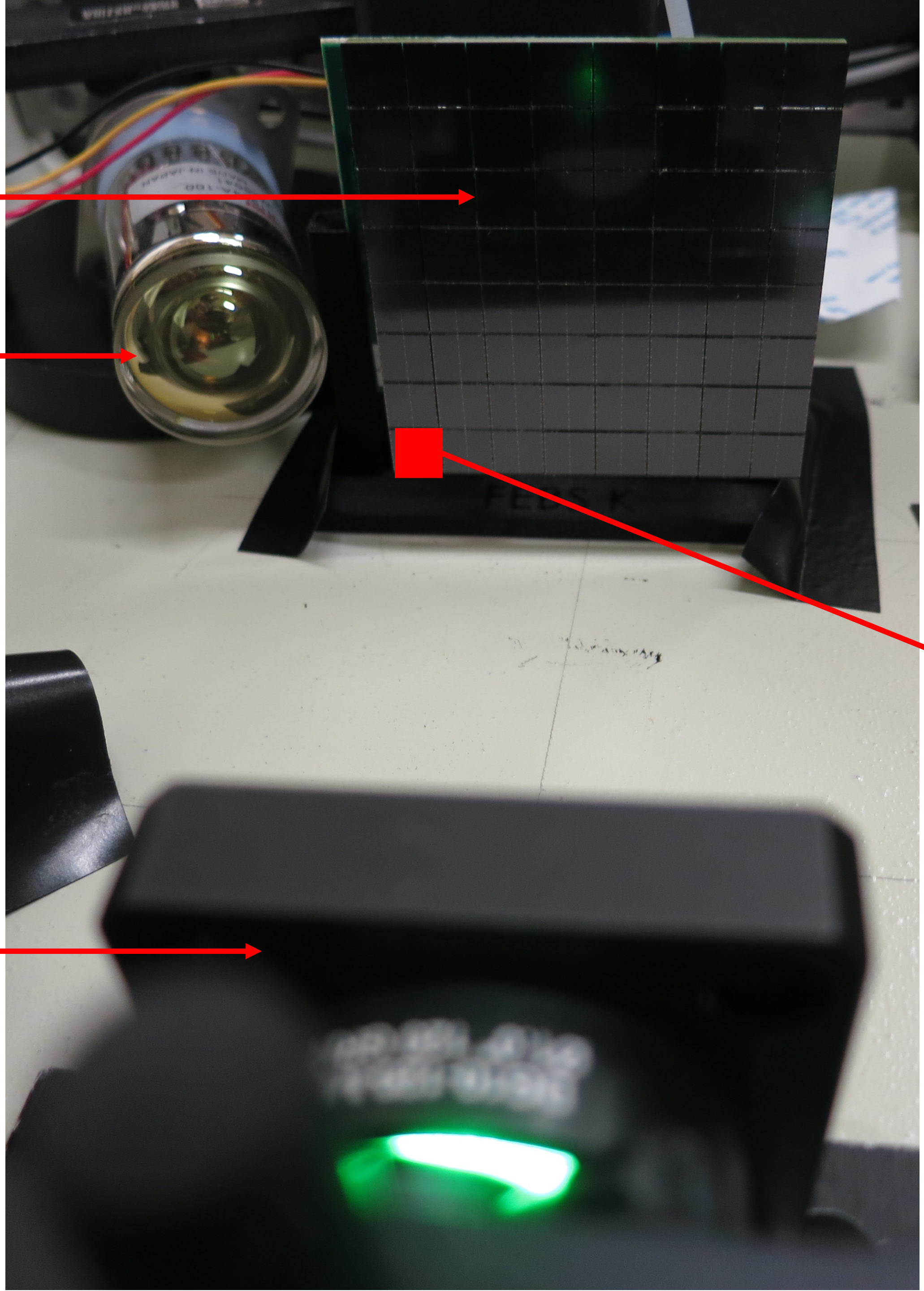


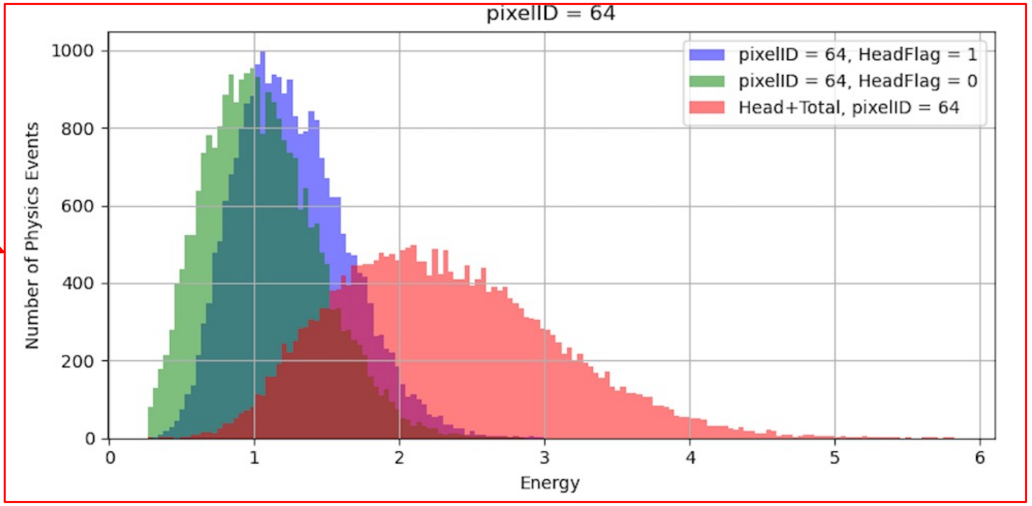
- Timing resolution <100 ps
- Energy resolution ~17% (Cs Compton edge) as good as with the full-waveform digitizers.
- Sensitivity to position along the bars (~1cm, using timing)
- Different response to Cs (gamma) vs Cf (gamma/neutron)
- Low power (6W per 256 channels)

SiPM+PETsys

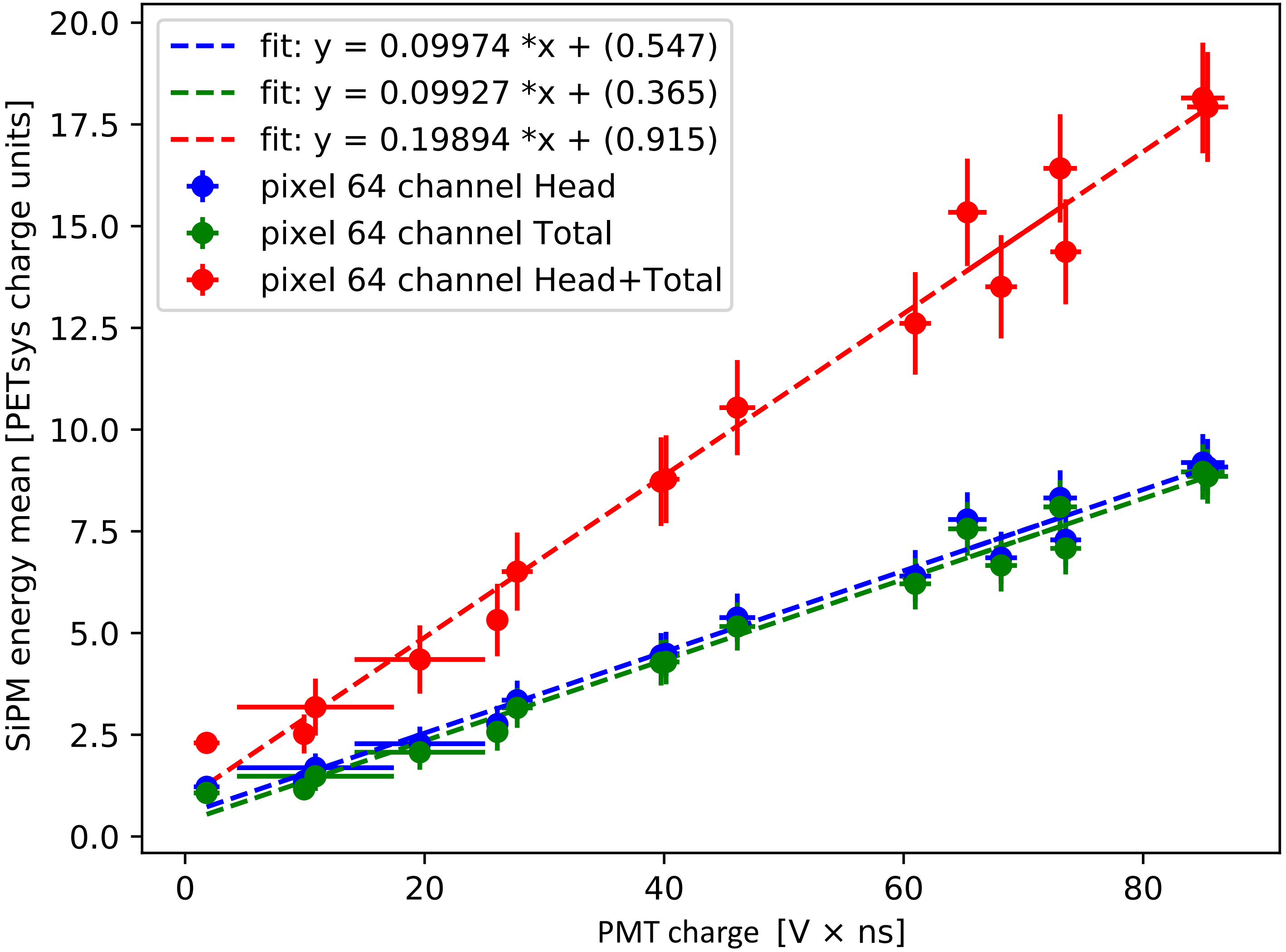
1” PMT

Diffused LED





Linear behavior of SiPM+PETsys



Summary

- **An antineutrino detector and neutron-imager are both under construction using segmented ^{6}Li-doped PSD plastic scintillators.**
- **PSD (using 8x8 scintillator array) works well with the full-waveform digitizer system.**
- **Energy resolution PETsys and full-waveform digitizer are comparable.**
- **Timing resolution is <100ps.**
- **Calibrations are ongoing. We hope to test PSD in the near future.**

Thank You!