A Compact Real Time Segmented Double-Scatter Neutron Imager

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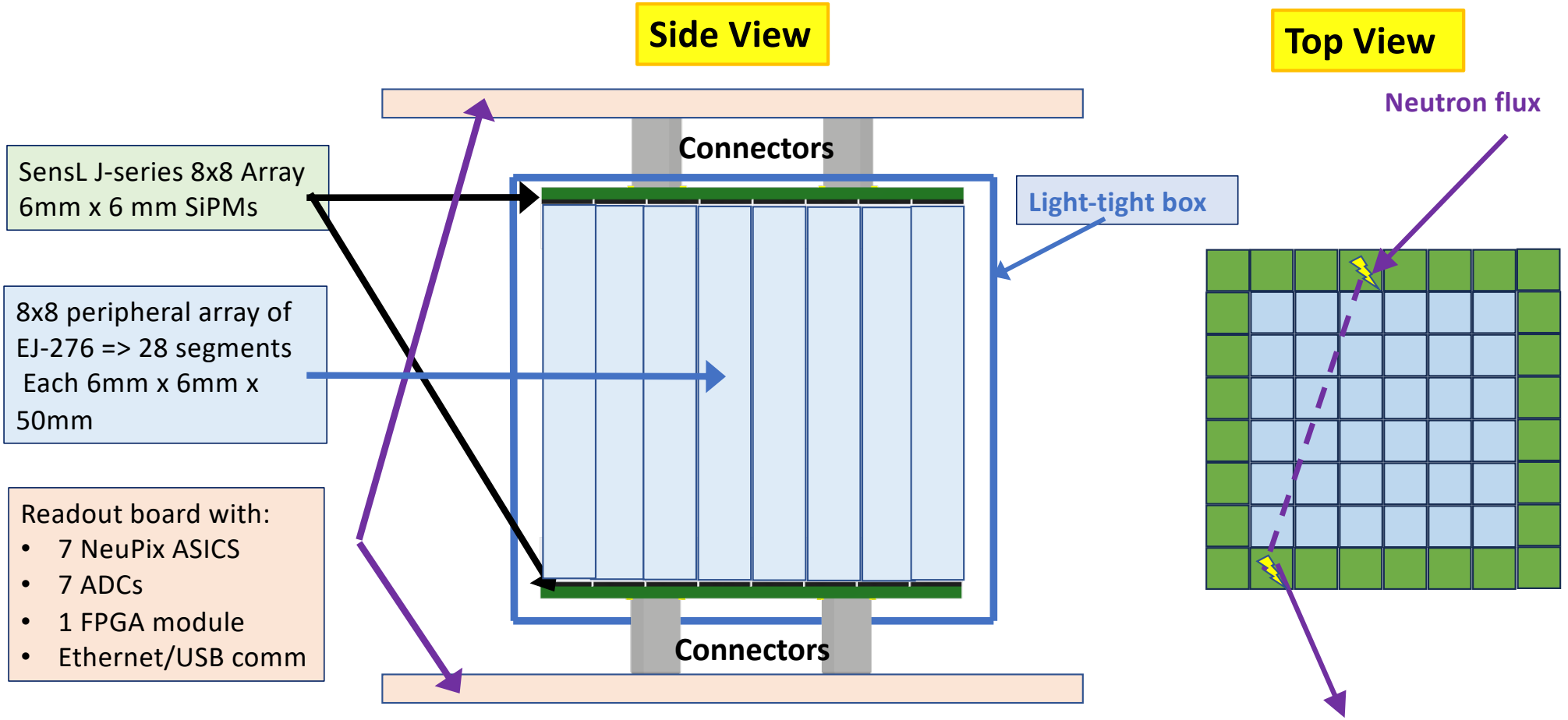
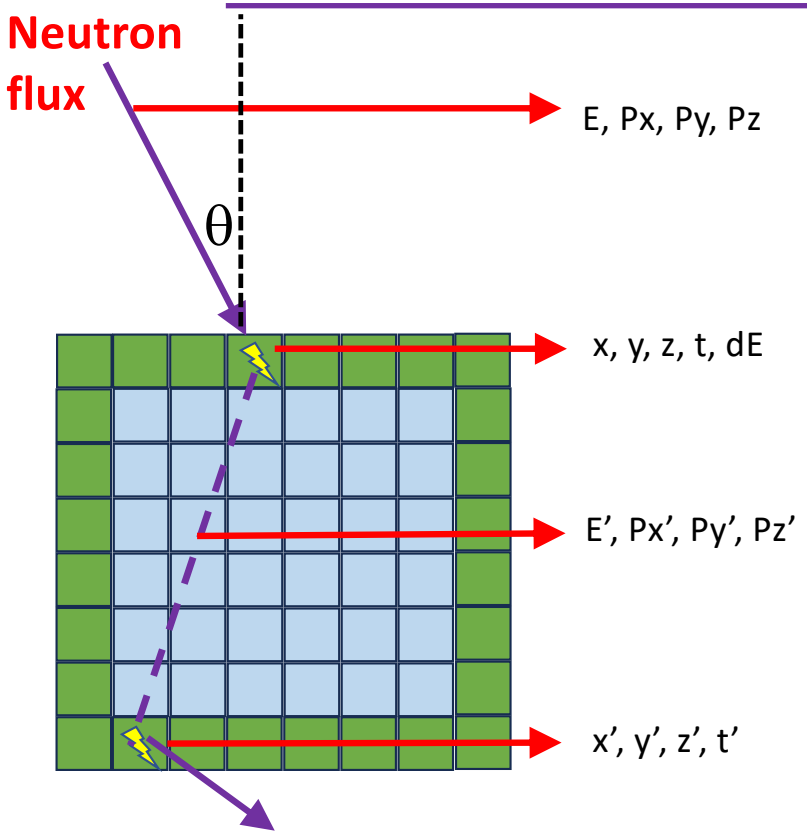
Project Goals

- Develop a compact, low-power (=> portable) neutron imaging camera using solid state devices. This design utilizes the proven double-scatter concept.
- Device should be capable of battery or solar panel powered operation for remote deployment.
- Components of this design are EJ-276 scintillator blocks, SensL (OnSemi) SiPM arrays, NeuPix ASICs, and commercial ADCs and FPGAs.
- Demonstrate capabilities in a neutron beam and/or a high intensity neutron source.
- Relevance to LIDINE: Applications requiring neutron scattering based calibrations of prototype dark matter detectors and imaging of background neutron/gamma sources.

Conceptual Camera Design



Measurement Technique and Errors in Resolution



$\theta = \tan^{-1}[\mathrm{sqrt}(dE/E')]$

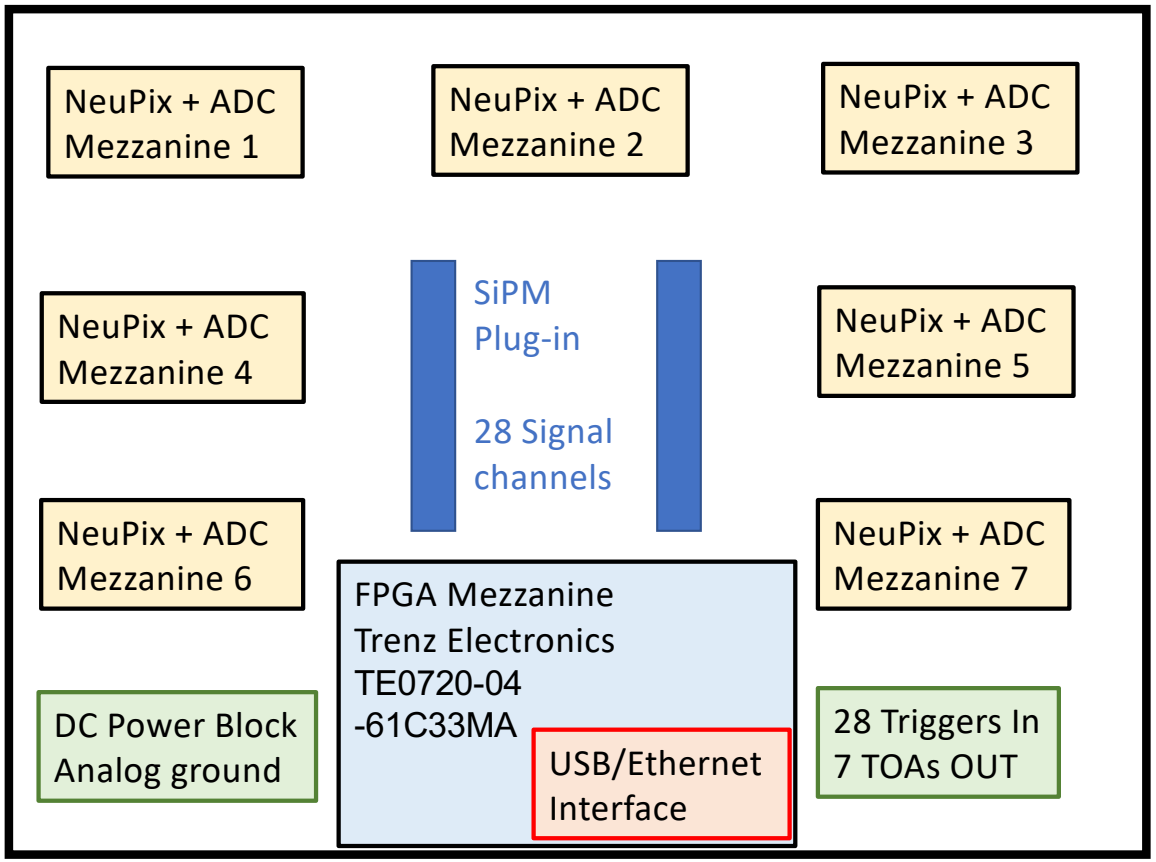
$E' = m/2\,[d/\Delta t]^2$

Measured Quantity	Feature	Method	Error
x, y, x', y'	6mm x 6 mm cells	1/sqrt(12)	~2 mm
dE = (E - E')	Light yield	dE ~ c + k/sqrt(E)	k ~ 200%
z, z'	5 cm tall cell	Top-bottom asymmetry	~2 mm
t, t'	SiPM risetime	1 Gsps digitizer	~ 1 ns
Derived Quantity	**Feature**	**Method**	**Error**
d	Un-correlated errors	Quadrature	~ 3.5 mm
$\Delta t = t' - t$	Un-correlated errors	Quadrature	~ 1.4 ns

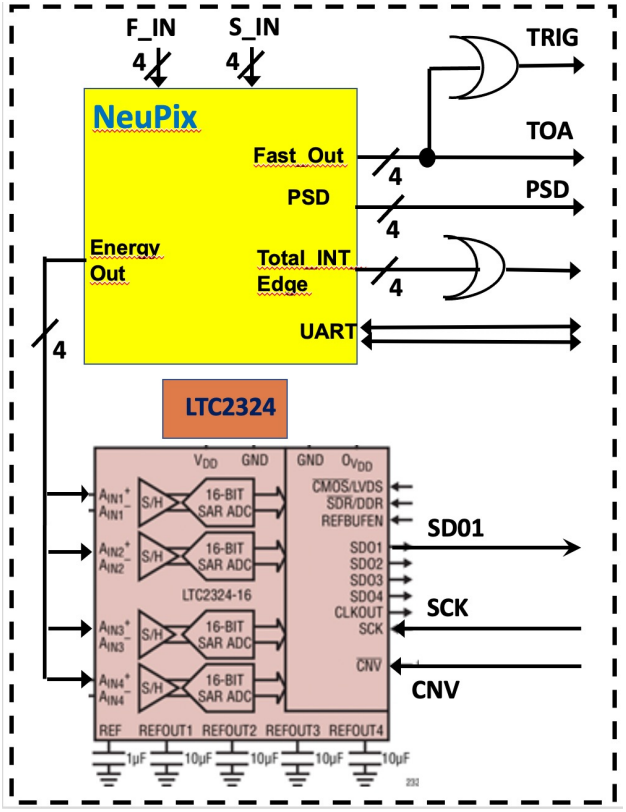
- These error estimates are for a proof-of-concept device.
- The error in d can be reduced by employing smaller SiPMs and also by enlarging the geometry.
- The fundamental error in Δt is difficult to improve, but enlarging the device reduces the relative error.

Camera Readout Board under development

- SiPM cells will be read out by 7 NeuPix ASICs. A 6-layer board with 2 each power & ground planes.
- No need for fast digitization of analog pulses. NeuPix integrates the area and a slow ADC captures the level.

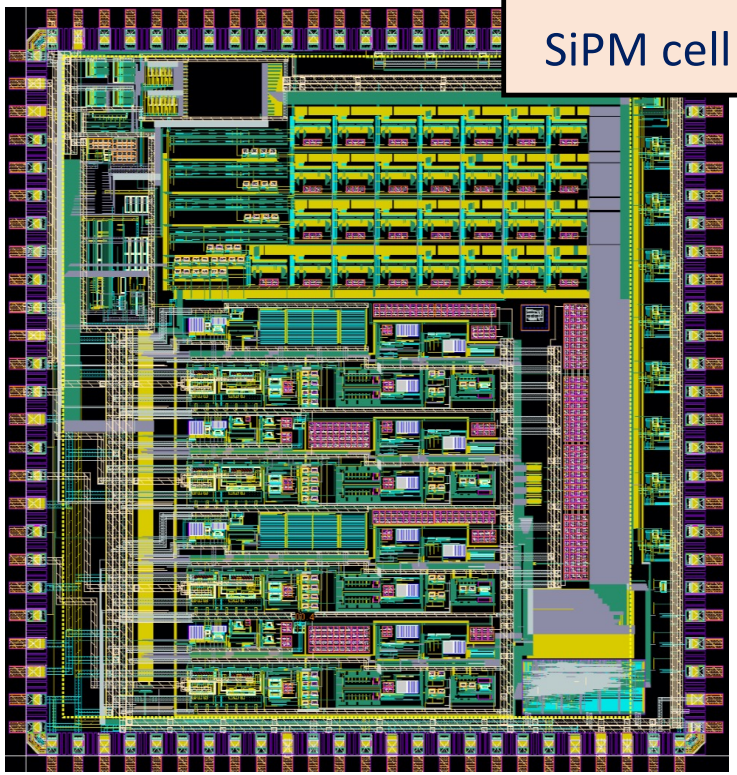


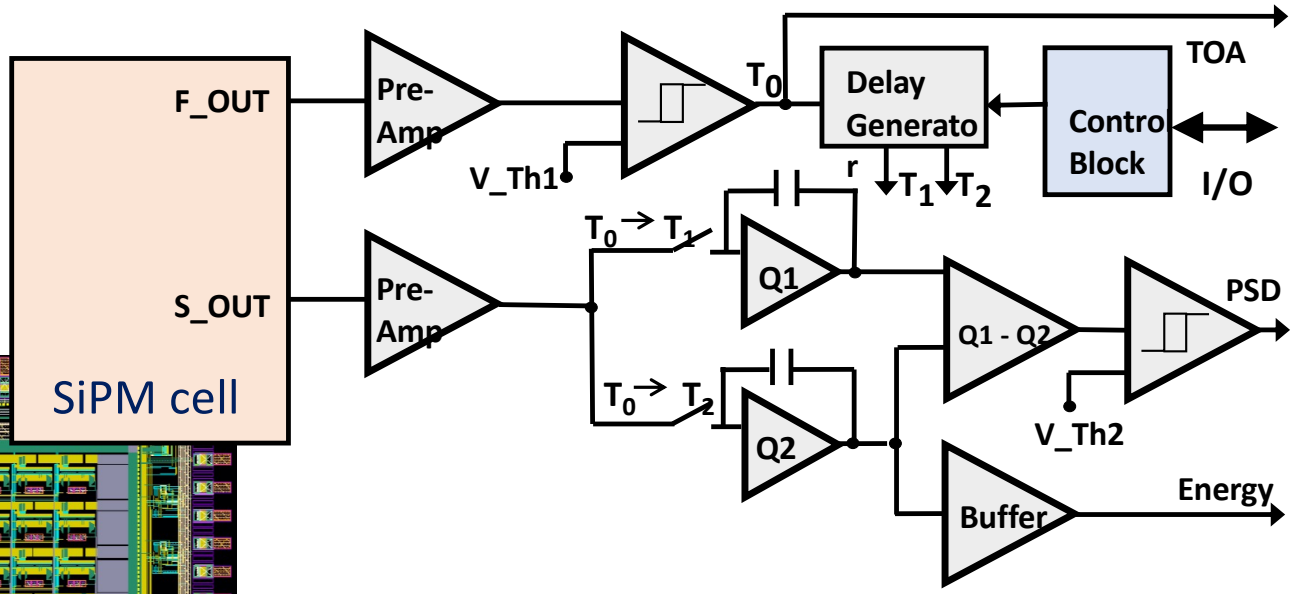
NeuPix + ADC Mezzanine Board



NeuPix ASIC

Conceptual One Channel Diagram



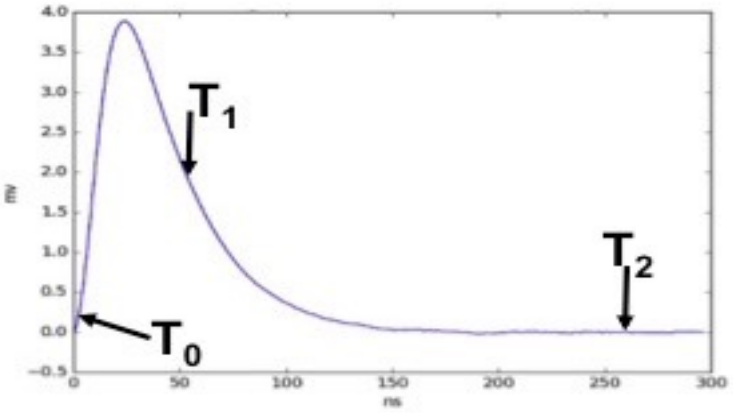


Outputs:

a) Time of arrival

b) PSD bit

c) Total energy

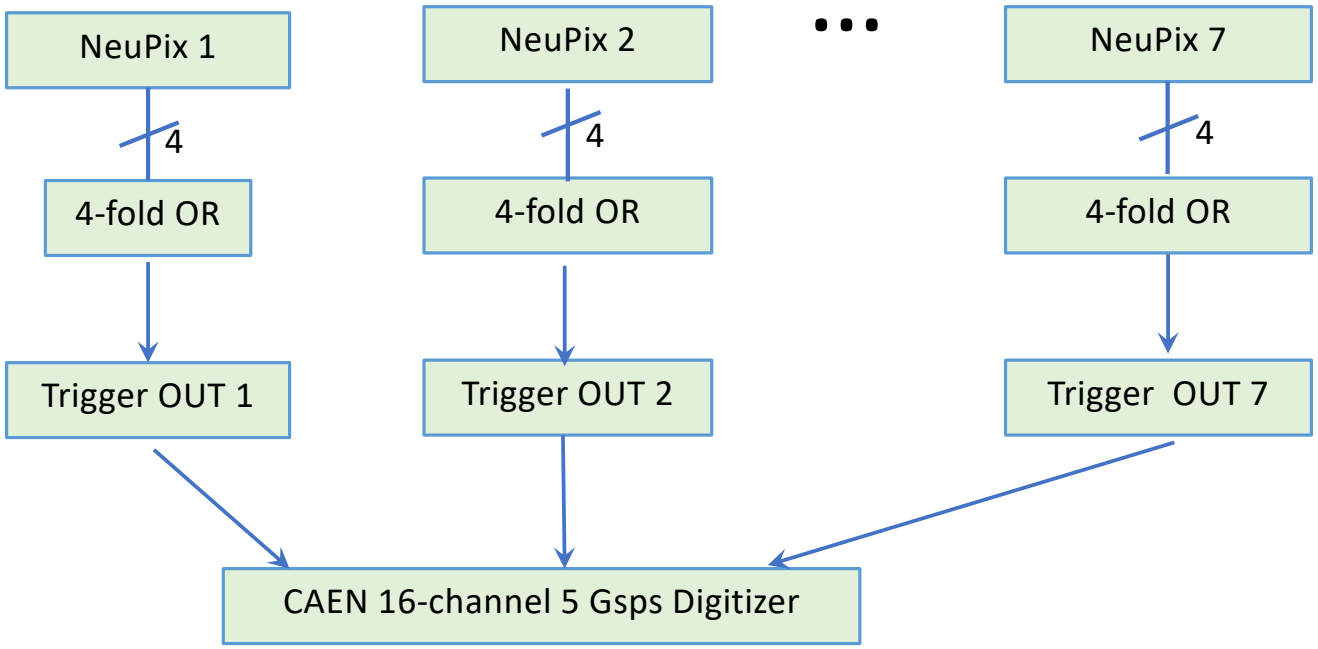


SensL SiPMs provide:

- A capacitively coupled fast output (FOUT)
- A resistively coupled standard output (SOUT)

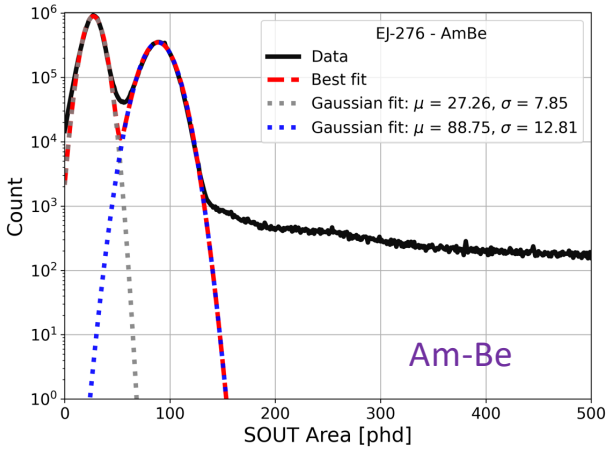
Time of Arrival Capture

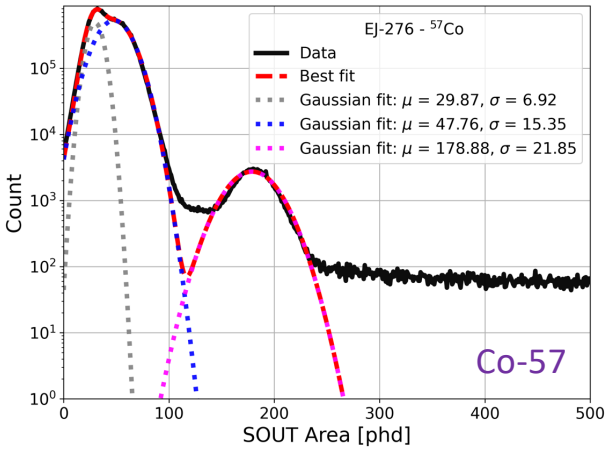
The TOA outputs of each NeuPix are ganged into a single output. The two scatters are required to be far apart in camera geometry, so there is no loss of information if neighboring groups of 4-channels are combined into one.

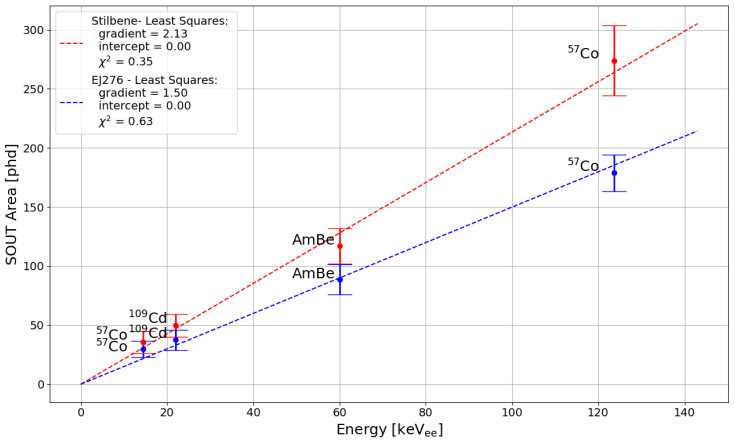


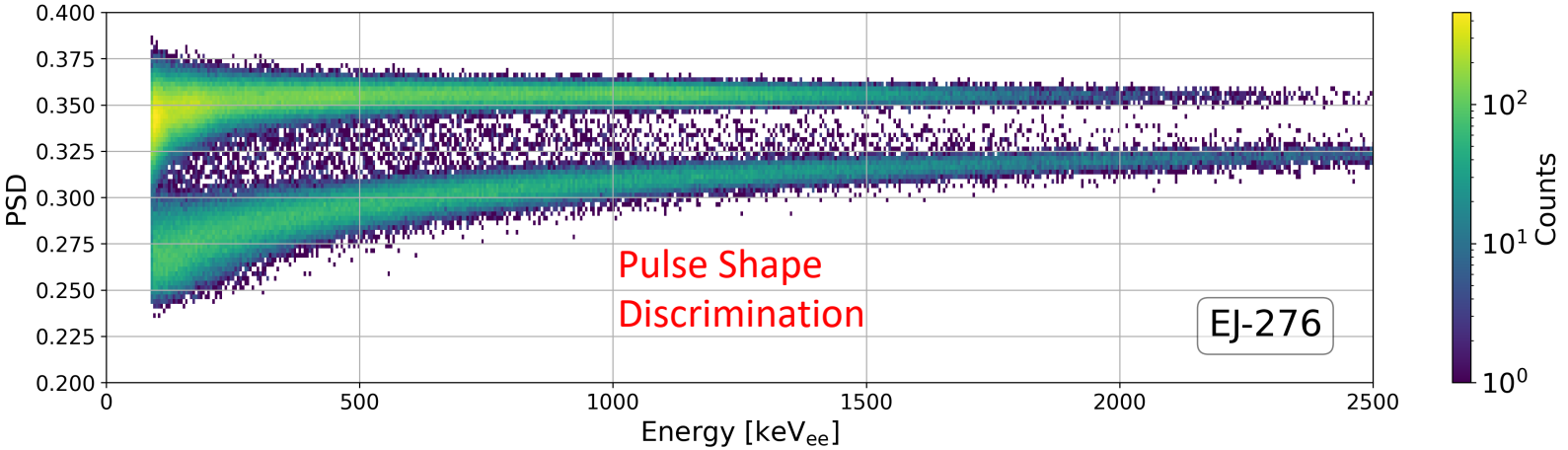
A total of 14 TOA outputs is well accommodated in a 16-channel CAEN digitizer.

Energy Calibrations for EJ-276 (Details presented in LIDINE 2022)



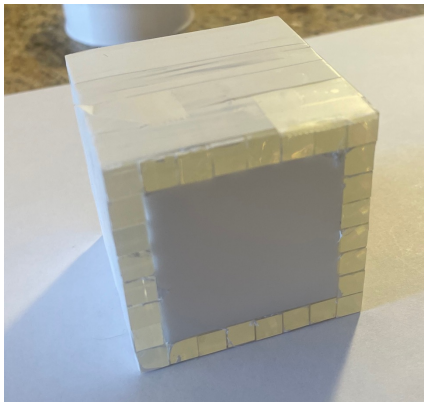


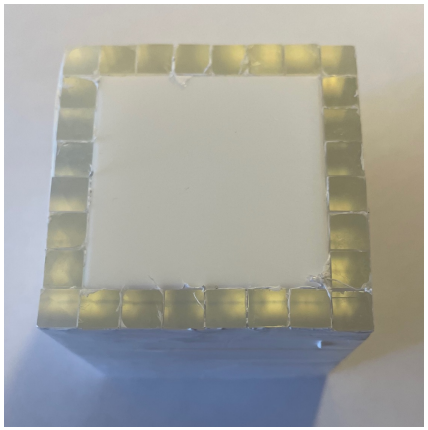




EJ-276 is an effective lower-cost solution for this device.

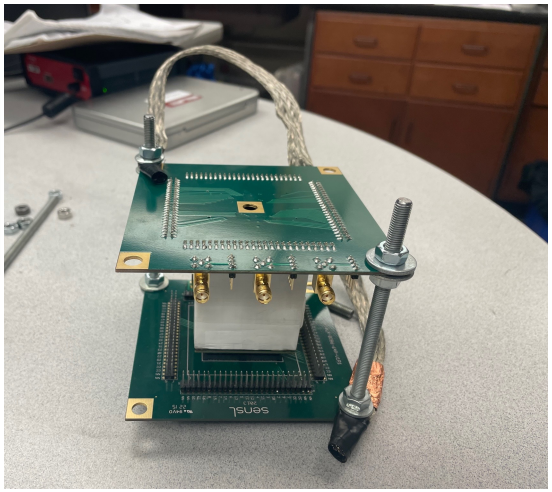
Construction/Assembly of the prototype



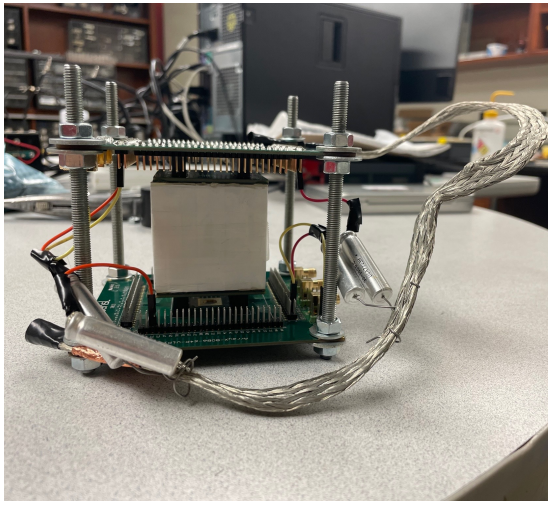


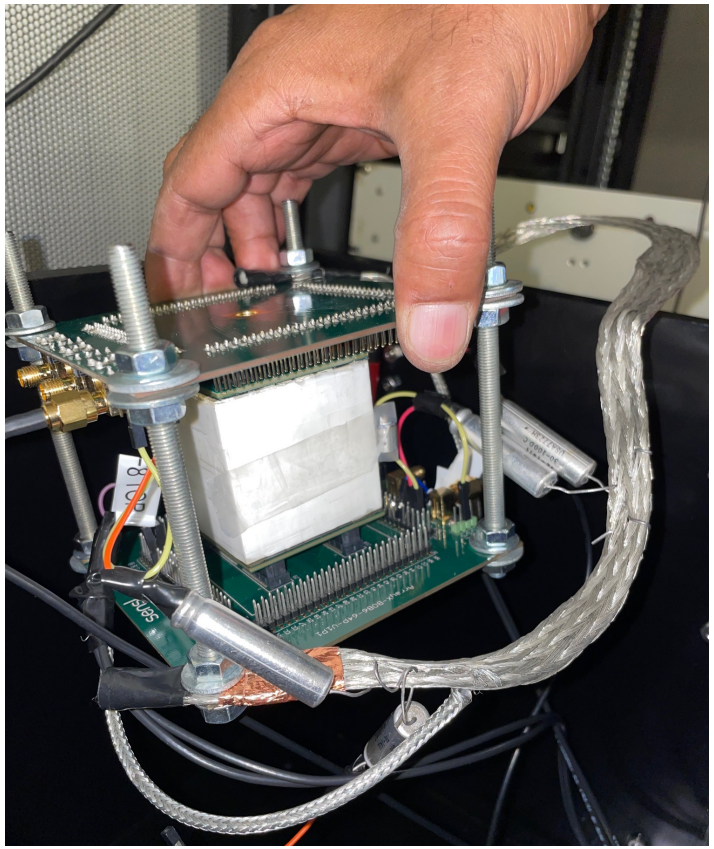
28 elements wrapped in Teflon and mounted on a PTFE cube.

Cube sandwiched between two SiPM arrays.



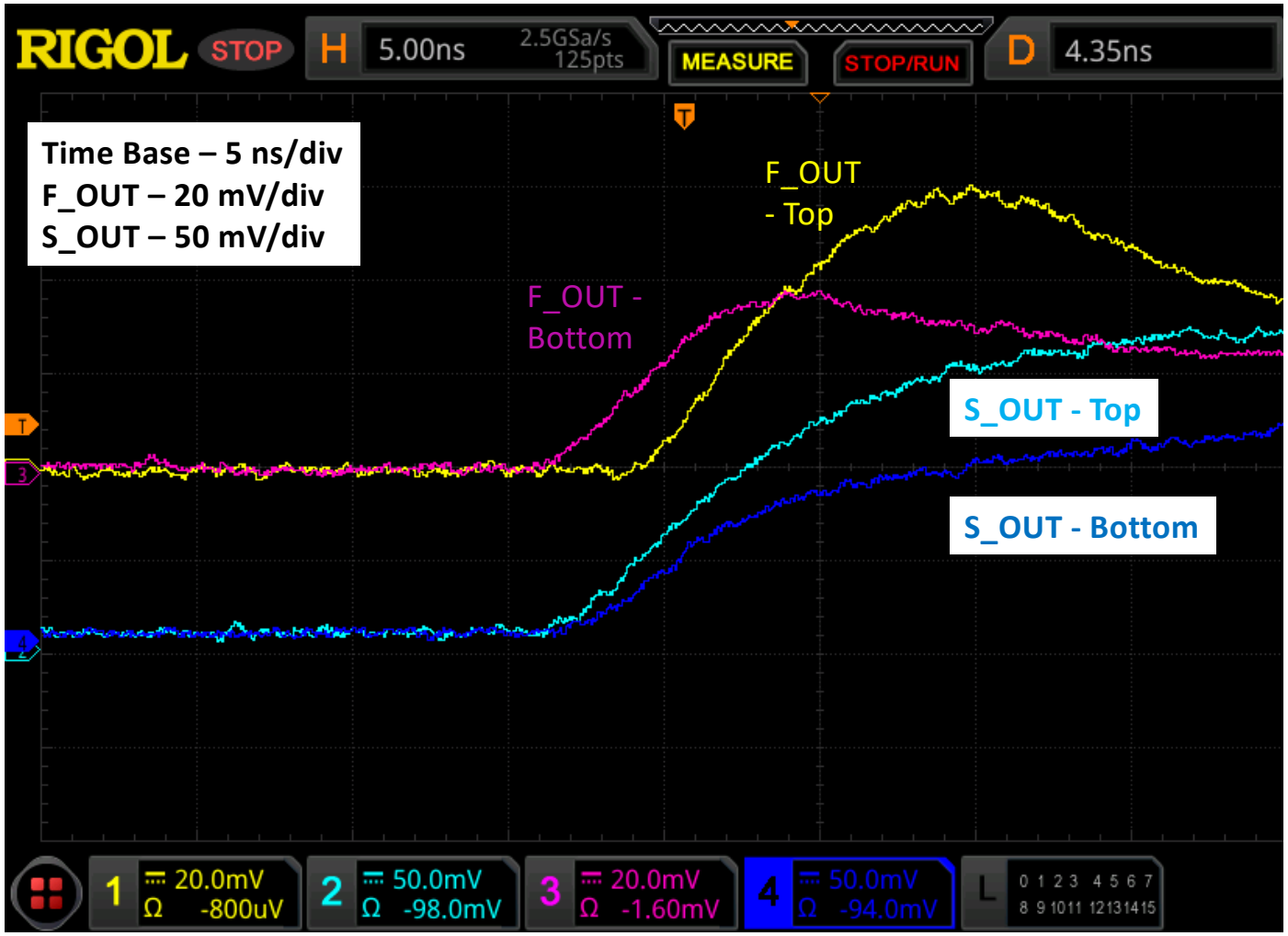
Grounding braids and bypass capacitors installed.

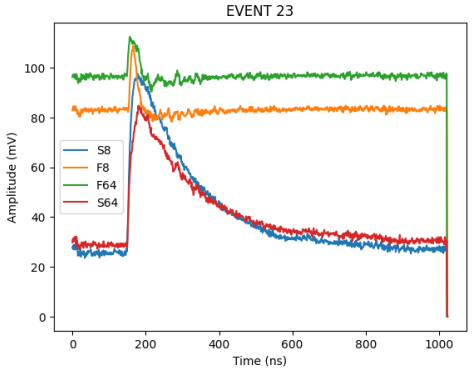




Complete assembly with signal cables plugged in. Ready to be housed in the dark box.

First Measurement: Scope Traces from a typical event





- F_OUT risetimes will allow for ~1 ns timing. Top trace (yellow) has been deliberately delayed by a few ns for clarity.
- S_OUT areas from top and bottom readouts enable z-position estimation from asymmetry.

Conclusions

- A prototype camera geometry has been designed and assembled.
- Preliminary bench tests using an AmBe source show promising results.
- A readout board using NeuPix ASICs, Analog Devices LTC2324-12 ADCs, and Trenz Electronics module based on AMD/Xilinx Zynq FPGAs is being developed.
- Beam tests using a fast neutron beam at the Crocker cyclotron at UC Davis are being planned.

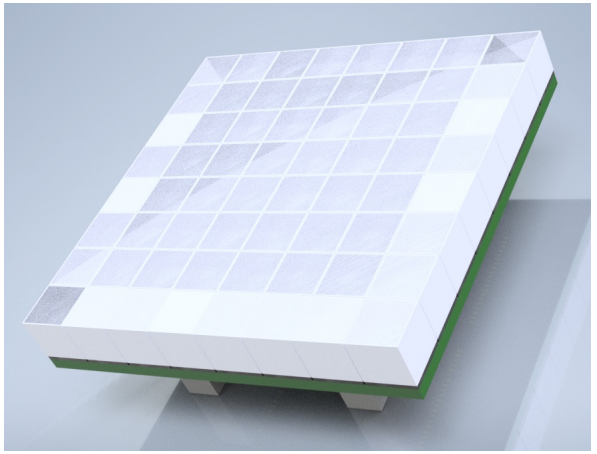
Future:

- Remove segmentation of camera scintillator walls. Light sharing among cells along the length of the wall improves resolution in that dimension.
- Investigate feasibility as a gamma imager. Δt is not useful in this case, so one can assume incoming gamma energy and scan over known emission lines.
- Enlarge camera dimensions (provided resources can also be enlarged).

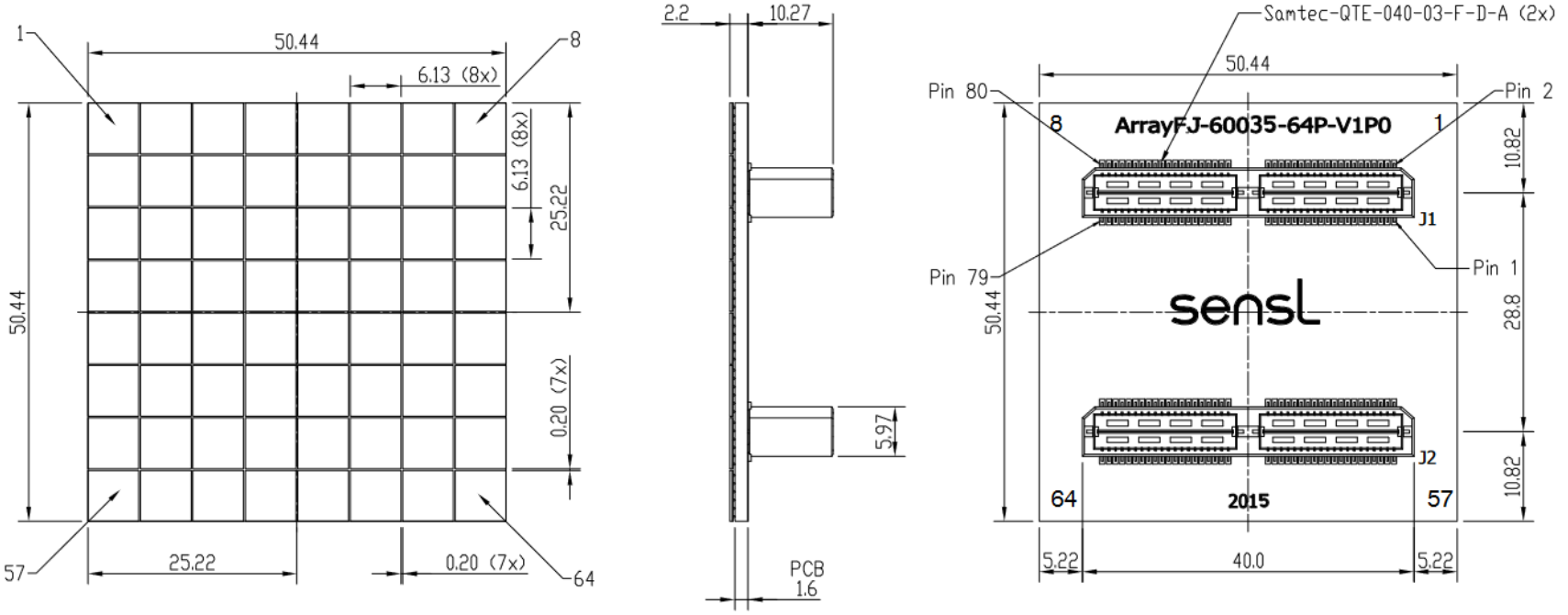
Extra Slides

SiPM Array dimensions

https://eu.mouser.com/datasheet/2/308/ARRAYJ-SERIES-D-1489628.pdf

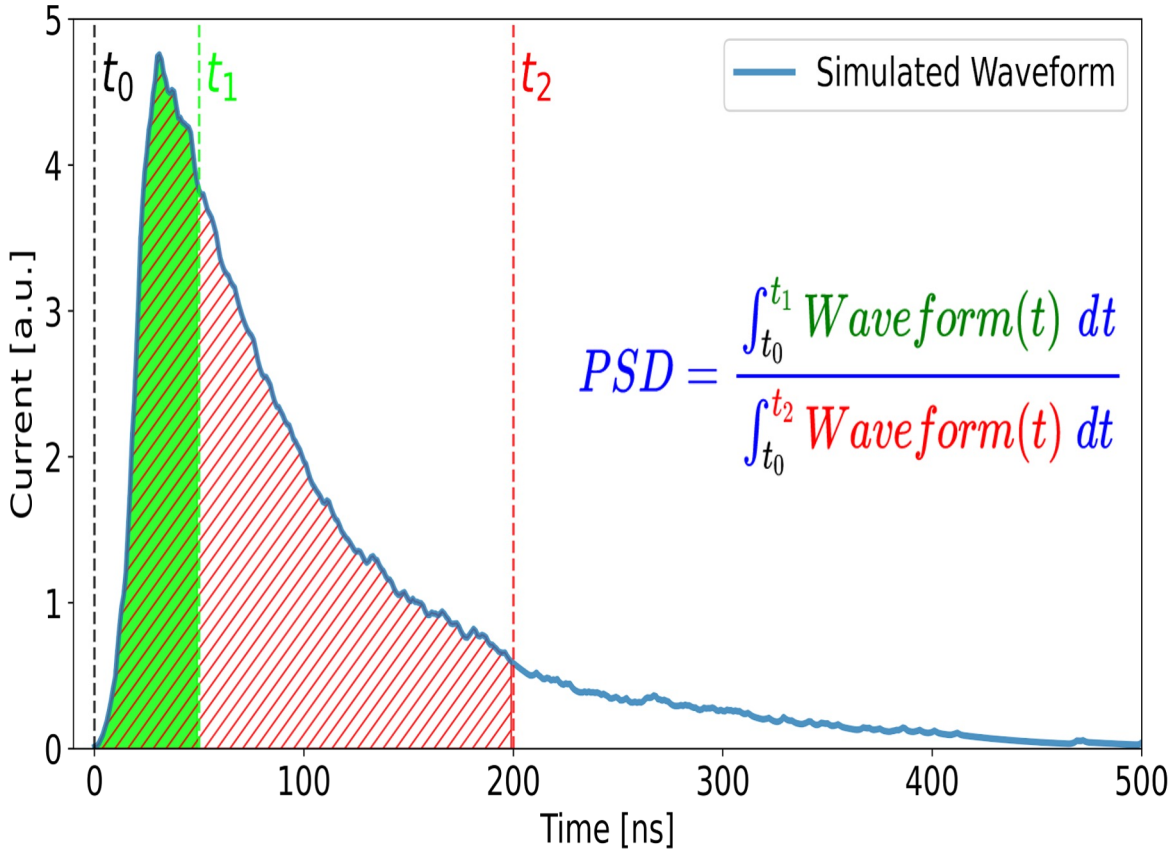


ARRAYJ-60035-64P Board Drawing



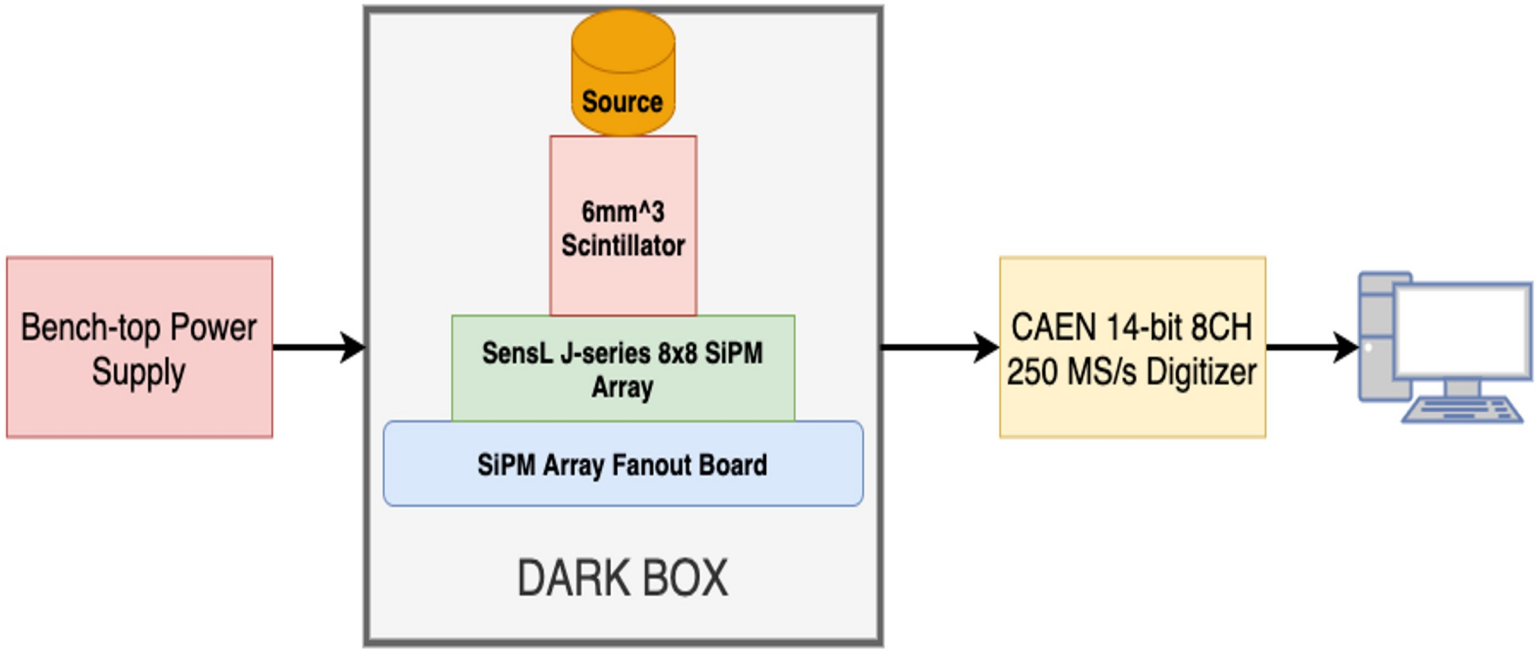
Pulse Shape Discrimination

- Emission spectra can be dependent on the type of interacting particle, especially due to differential excitations of various excited states, which subsequently decay with distinct decay constants.
- The resultant electronic signal pulse has these characteristics encoded in its temporal profile.



We are defining and implementing an electronic version of this concept on a custom chip (NeuPix) that discriminates between neutrons and gammas based on the quantity PSD.

SiPM + Scintillator Characterization Test Bed



- A 6x6x6 mm^3 block of scintillator is coupled to a 6x6 mm^2 SensL J-Series SiPM.
- Both SOUT and FOUT outputs are recorded by a CAEN digitizer (250 Msps)
- Two types of scintillators used: Stilbene and EJ-276.