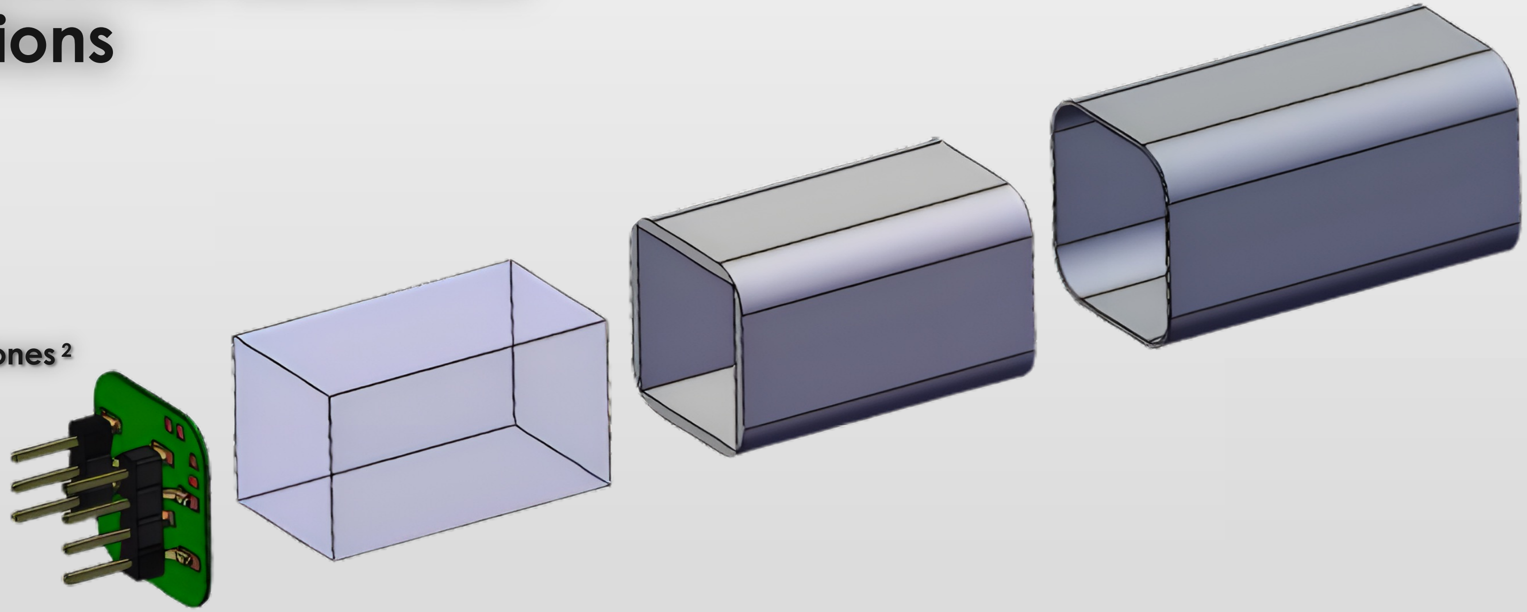
Characterization and Performance Evaluation of SiPM-Based Gamma and Neutron Detectors for Nuclear Science Applications



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NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences

DEPARTMENT OF PHYSICS UNIVERSITY OF CAPE TOWN IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

MeASURe Metrological and Applied Sciences University Research Unit

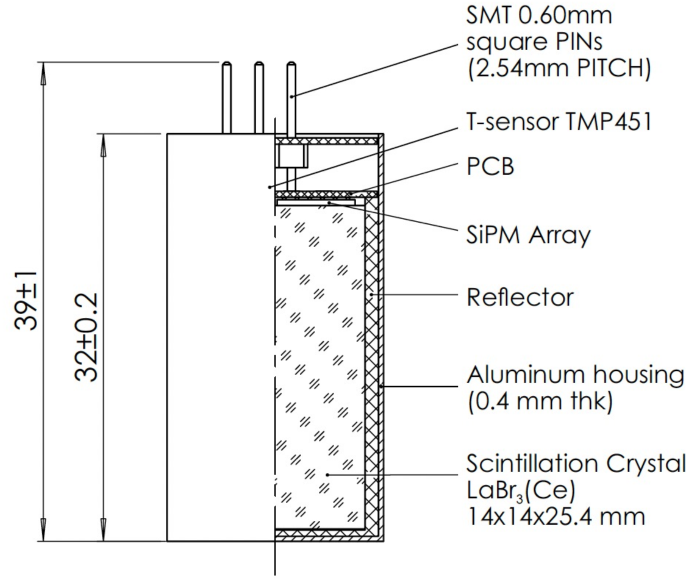
PGI CAPE TOWN

Detector Assemblies

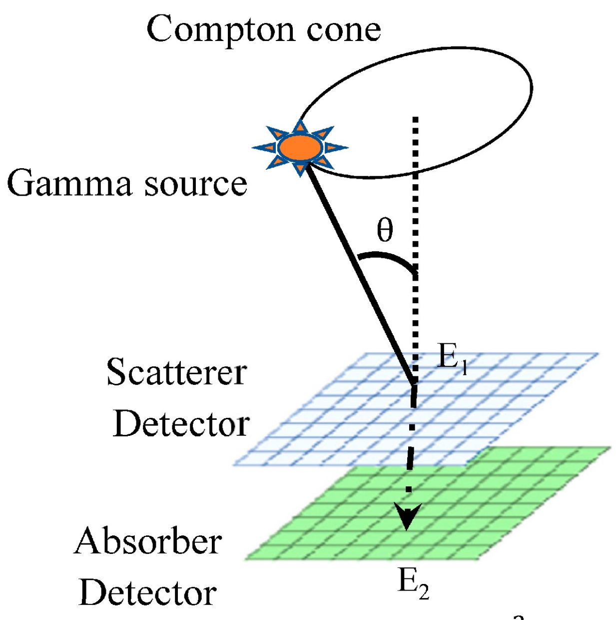
Two of each detector type in the cuboid (14 x 14 x 25.4 mm^3) aluminum housing geometry, coupled to a 2x2 MicroFJ-60035-TSV SiPM array and TMP451 temperature sensor packed in an Al canister. Obtained from CapeScint (MA,USA).

Detector Assembly	Typical Resolution
$LaBr_3$:Ce - SiPM	3.0% at 662 keV
SrI_2:Eu - SiPM	3.0% at 662 keV
Cs_2LiYCl_6 - SiPM	4.5% at 662 keV

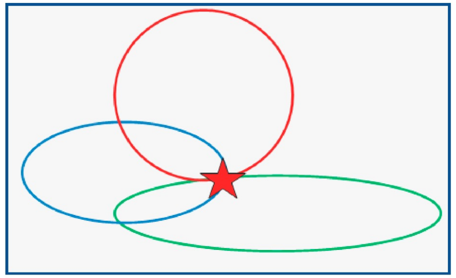
SiPM: Microcell size: 35 µm
Total number: 18980 microcells



Compton Camera



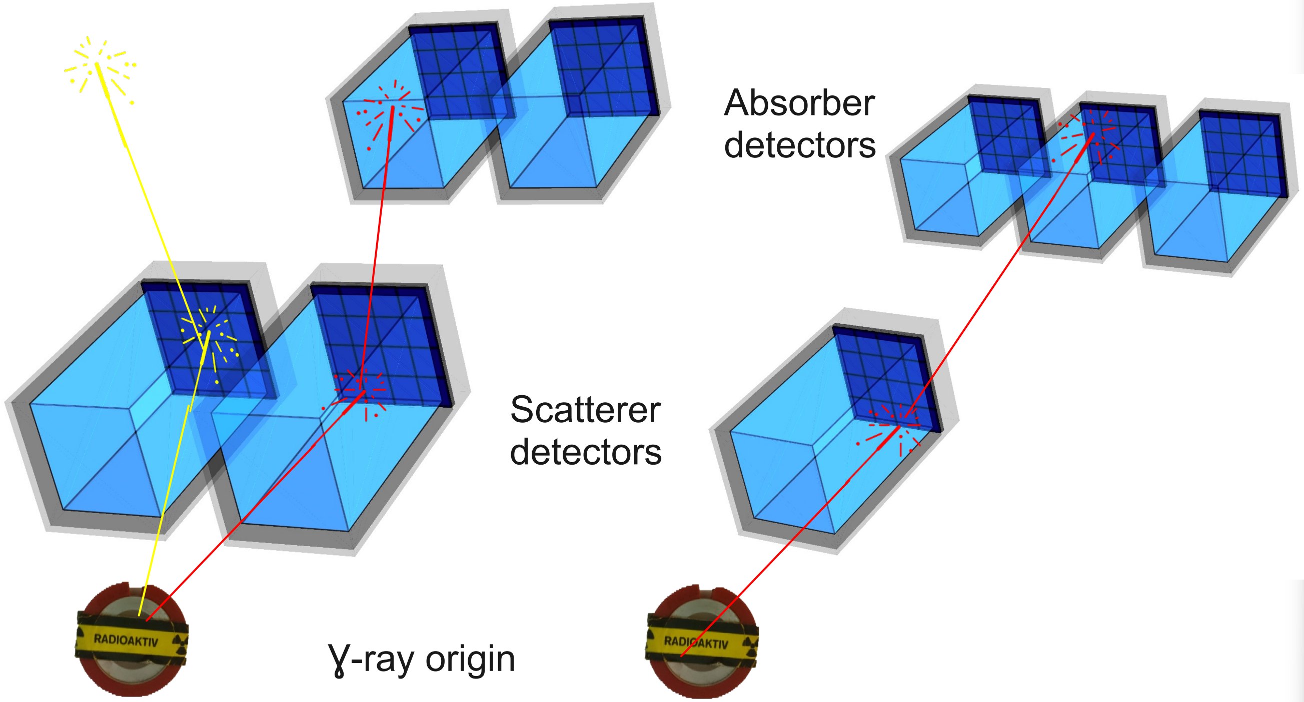
Imaging Plane



Compton cones superimpose to estimate gamma source

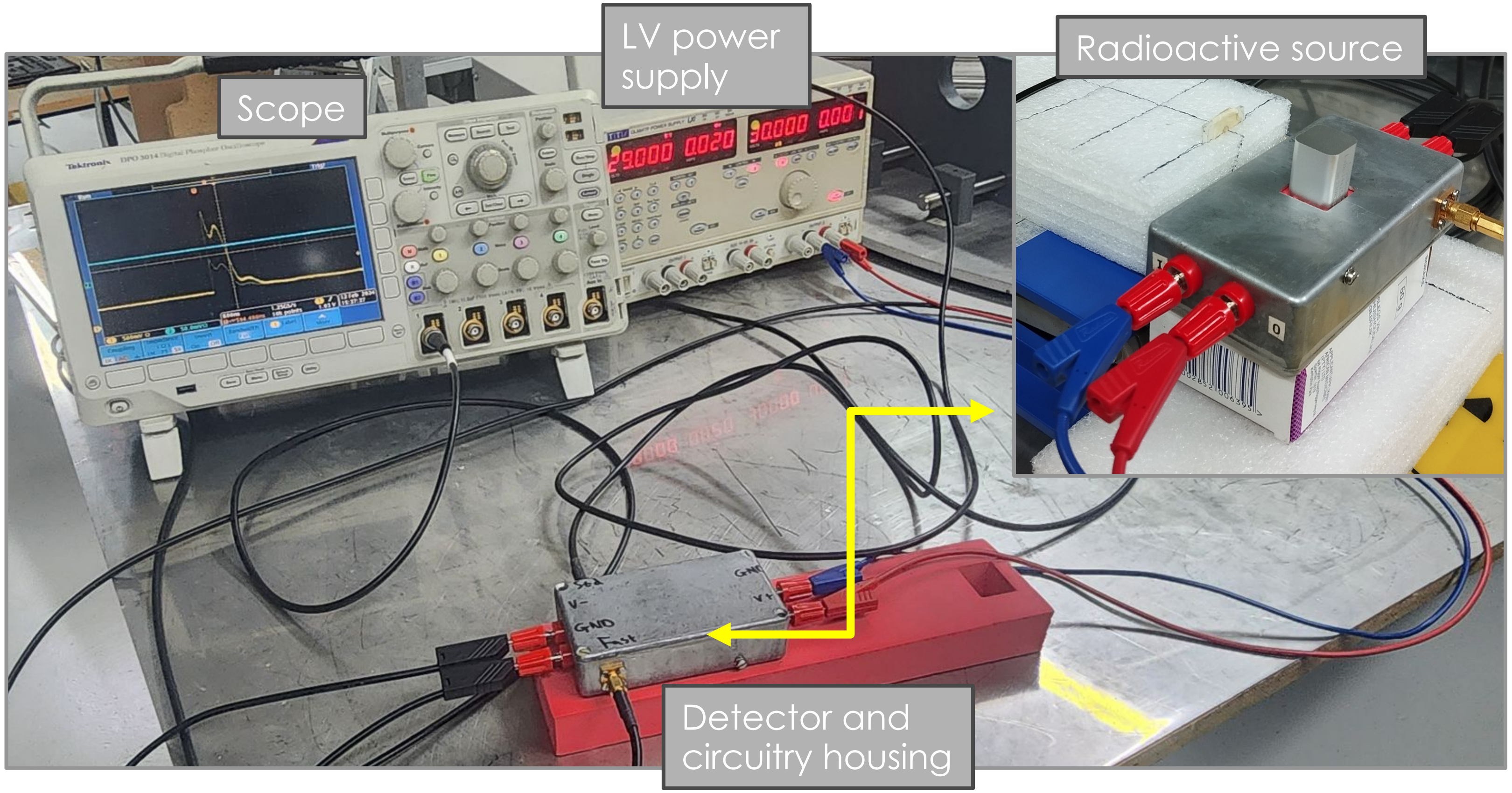
$$\cos\theta = 1 - \frac{m_e c^2 E_1}{E_2(E_1+E_2)}$$

Image taken from: Parajuli, R.K. et al. (2022). Development and Applications of Compton Camera—A Review. Sensors (Basel, Switzerland), 22.

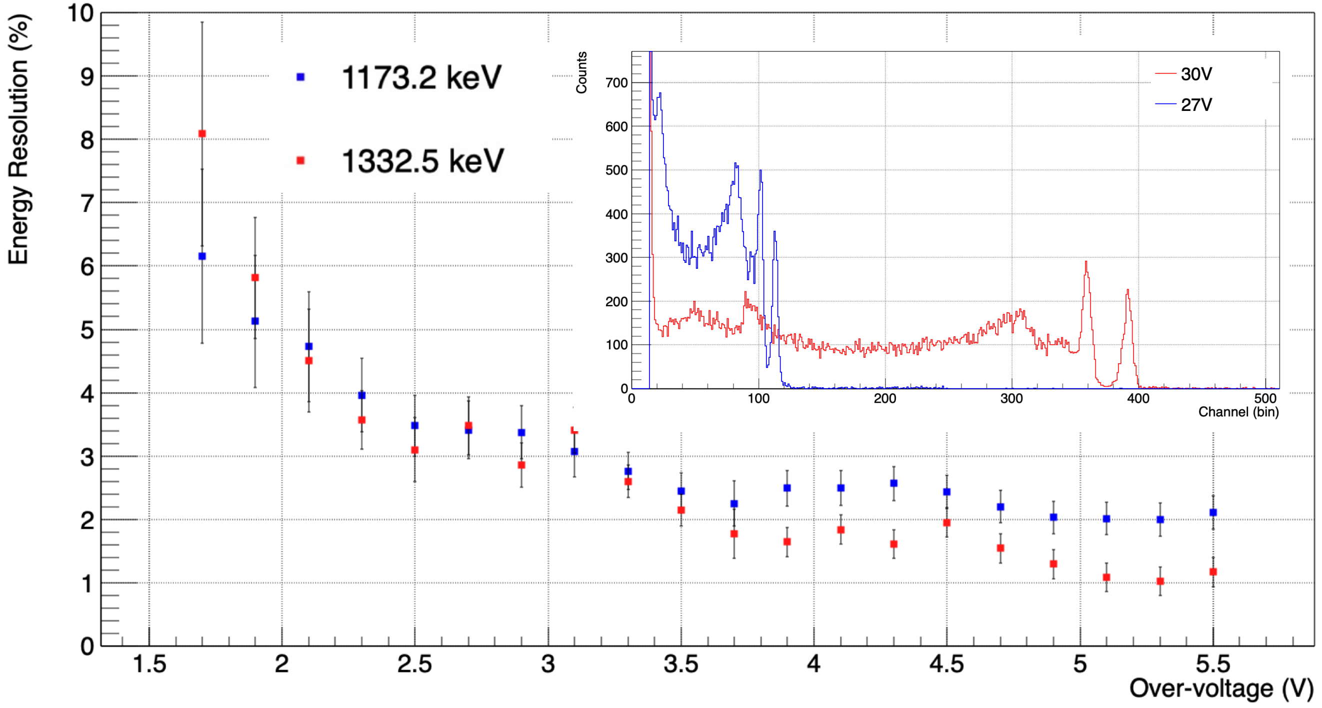


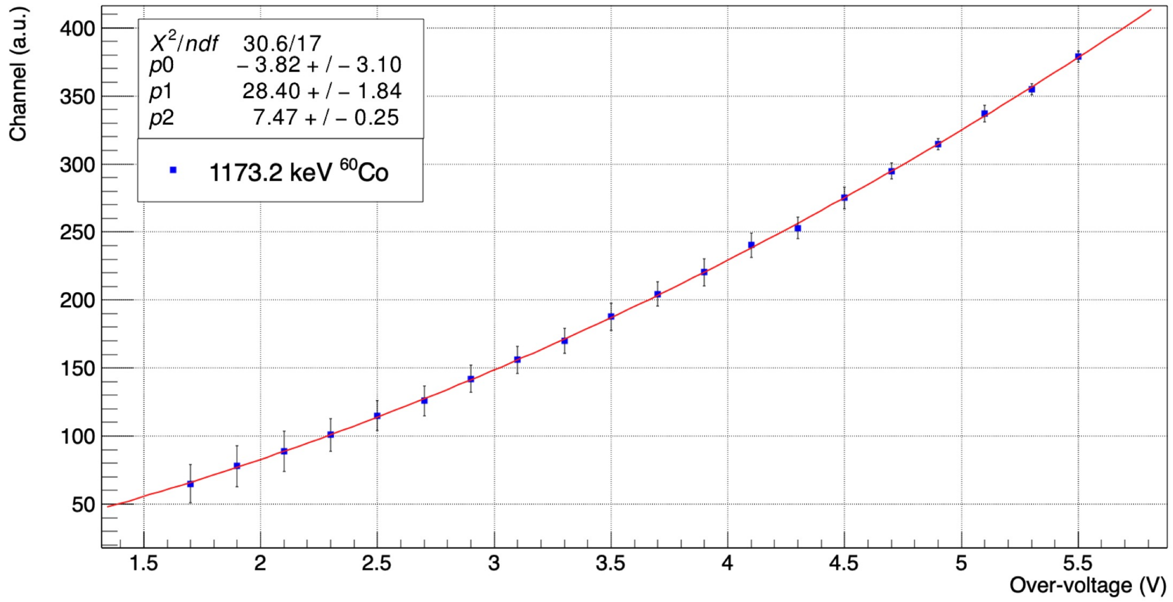
Goal:

- Determine the optimum operational voltage of SiPM.
- Characterize the new portable gamma and neutron detectors coupled to SiPM.
- Investigate the new detectors for use as a Compton camera.



SiPM Operational Voltage

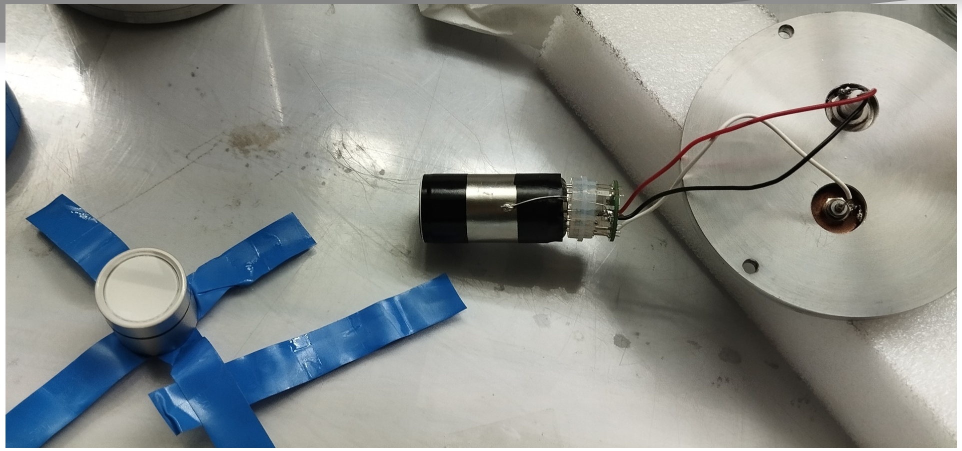




Manufacturer suggested voltage: 26 – 32 V

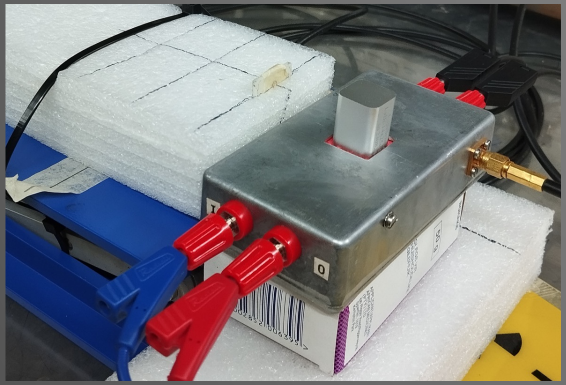
Detector crystals

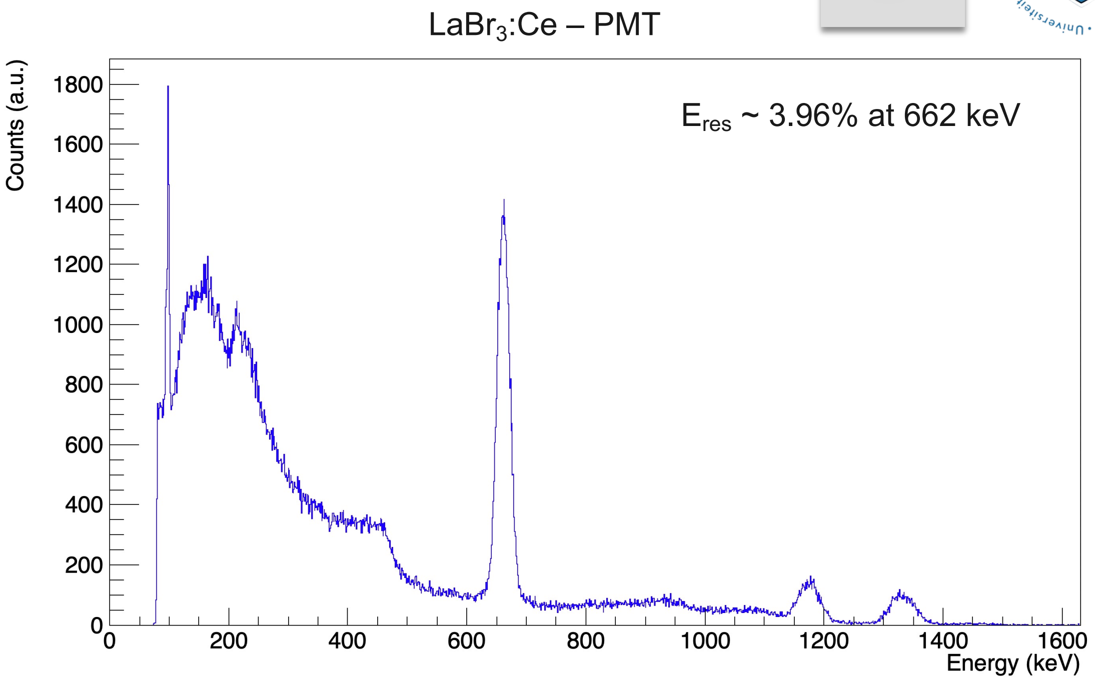
- Two 1” x 1” $LaBr_3$:Ce detectors manufactured by CapeScint
- Energy resolutions of 2.23% and 2.36% at 662 keV as determined by manufacturer.
- Coupled to Hamamatsu R3998-02 Photomultiplier Tube
- Used to benchmark SiPM performance

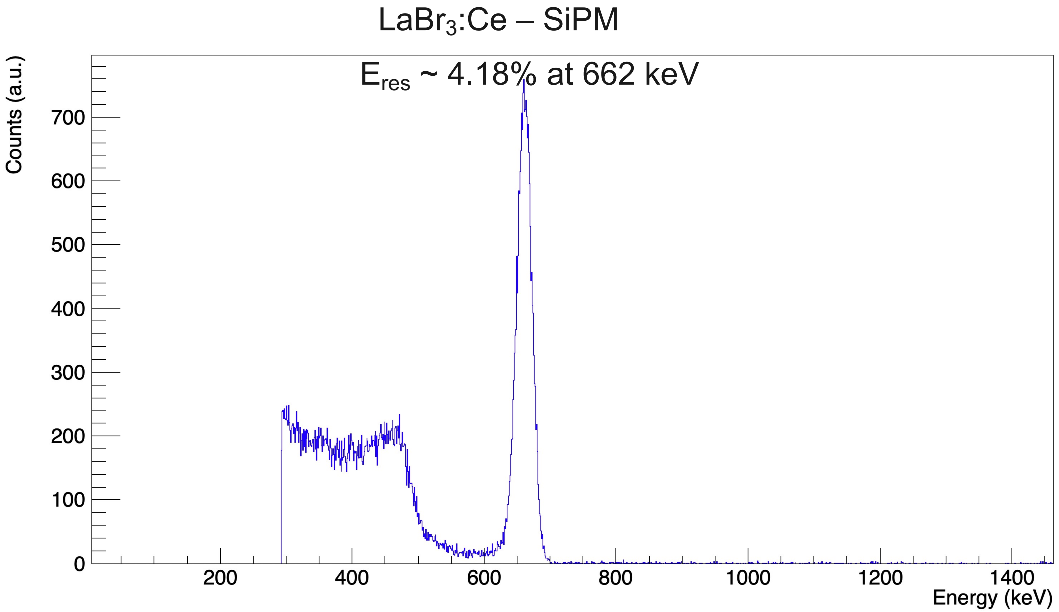


Why $LaBr_3$:Ce-SiPM?

- Measurements taken with the triggerless XIA PIXIE-16 500MHz data acquisition system.
- SiPM is compact and operates at 30 V.
- PMT less compact and operates at 1000 V.
- Measurements taken using ^{137}Cs source 3cm from the detector side.



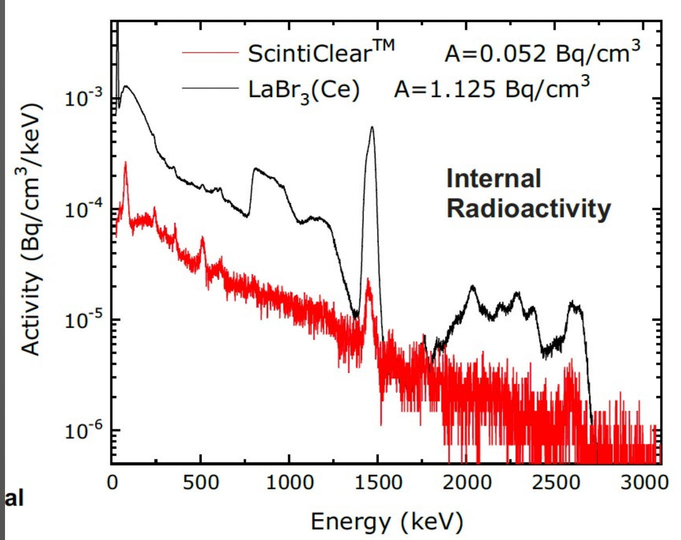


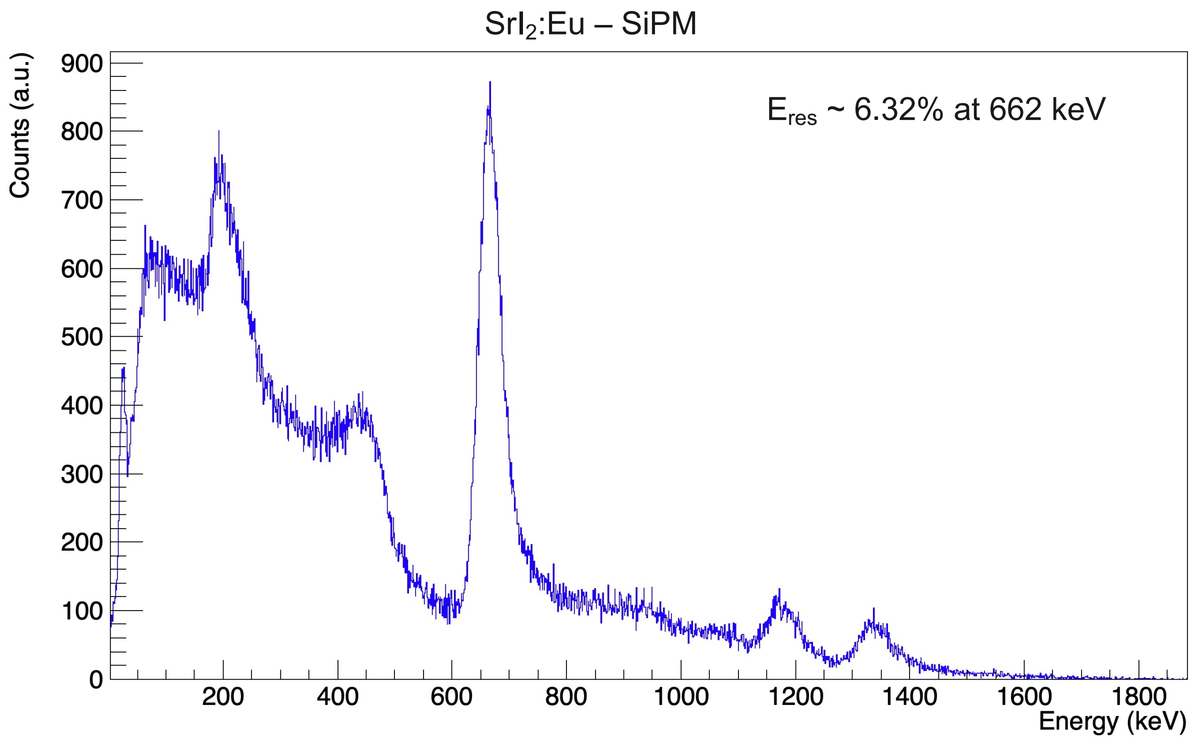


Why $SrI_2:Eu$?

- Low intrinsic internal activity - about 40 times lower than that of $LaBr_3:Ce$

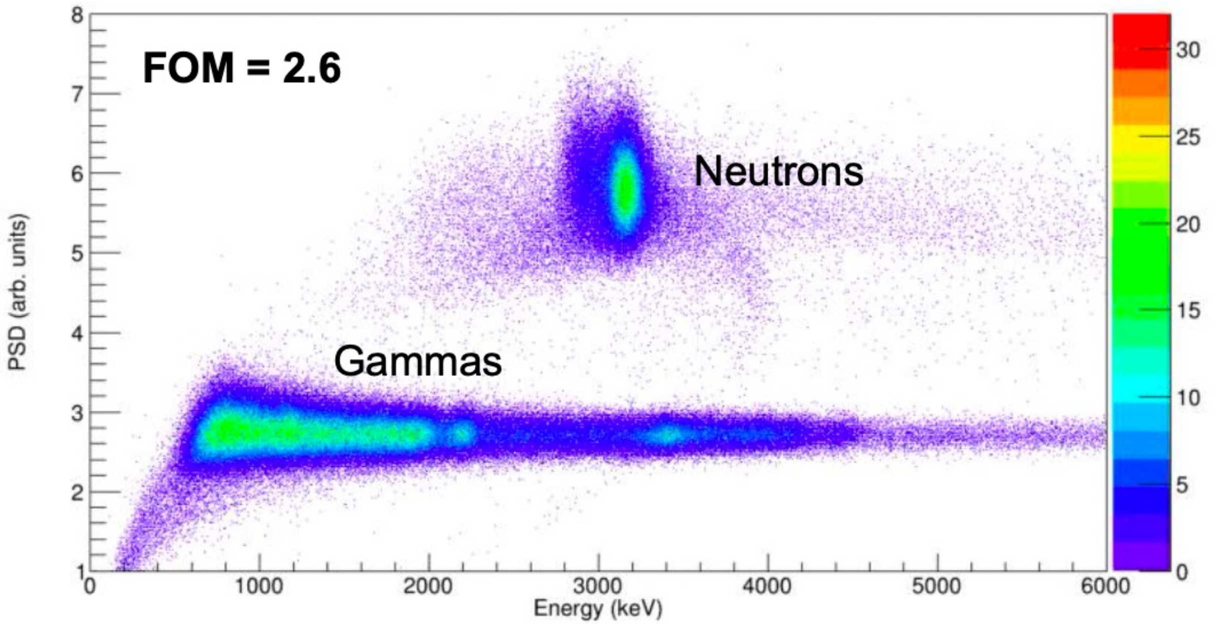
- Excellent energy resolution (~3% at 662 keV)





Why Cs_2LiYCl_6:Ce (CLYC) – SiPM?

- Allows us to discriminate between neutron/gamma radiation
- nEL crystals incorporate 7% 6-Li permitting thermal neutron detection, while Cl-35 enables fast neutron detection.
- Potential application for experimental measurement of the thermal *neutron* flux, fast *neutron* component and gamma ray dose rate for treatment planning verification in Proton Therapy.



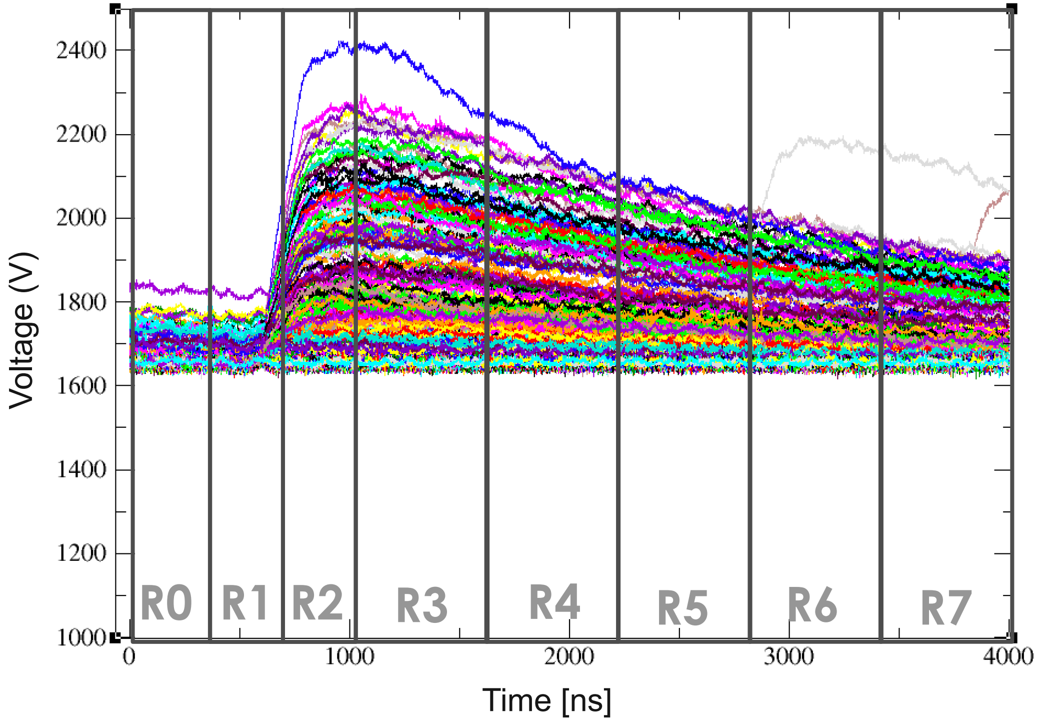
A figure of merit (FOM) value of 2.6 was achieved by the manufacturer (CapeScint) using a Pu/Be neutron source.

Pulse shape Discrimination using CLYC

To cleanly separate **gamma-ray** and **neutron** interactions, pulse amplitude traces are used to perform pulse shape discrimination (PSD) using the MIDAS software and XIA Pixie-16 14-bit 500 MHz DAQ module.

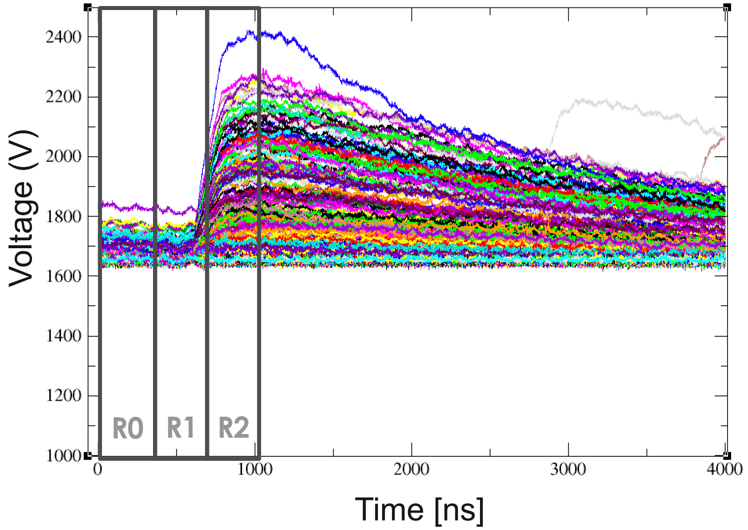
The current incoming pulse is integrated onto capacitor C, with continuous reset provided by resistor R.

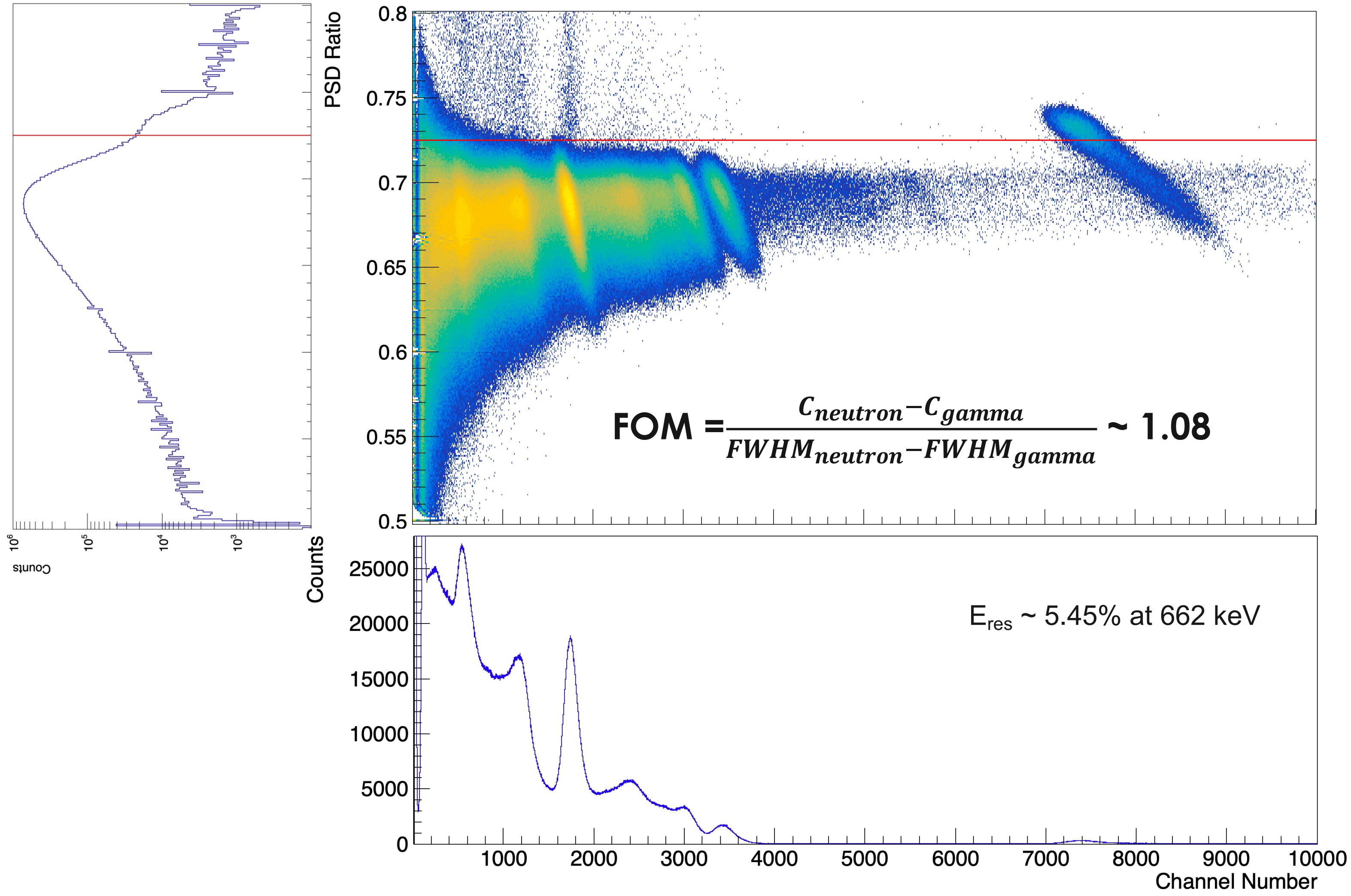
The analog-to-digital converter (ADC) samples the integrated voltage in sets of 600 ns and 1200 ns intervals after the initial trigger.



CLYC PSD Results

- Measurements taken using ^{137}Cs, 60Co gamma ray sources, as well as an AmBe neutron source.





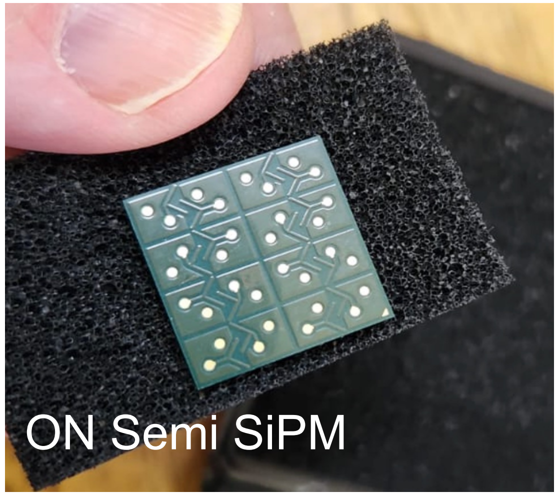
$$\text{FOM} = \frac{C_{neutron} - C_{gamma}}{FWHM_{neutron} - FWHM_{gamma}} \sim 1.08$$

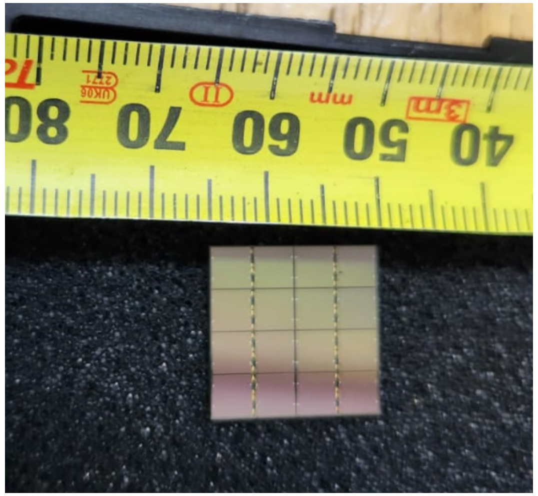
Next steps

- Characterize the fast-timing capabilities of the SrI2:Eu and LaBr3:Ce detectors.

- Investigate the optimum detector configuration/s for use as a Compton Camera (CC) - may involve coupling the ON Semi AFBR-S4N44P163 4×4-pixel NUV SiPM.

- Simulate the characterized detectors in Geant4 for the CC investigation





Conclusion

- We have instrumented and characterized a set of pre-assembled SiPM readout detectors.
- We have begun to clearly distinguish between the neutron and gamma contributions in the CLYC detector using PSD.
- We can now begin to investigate Compton camera geometries.

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Thank you for your attention.