Comparison of Pulse-Shape Discrimination (PSD) Performance Using the Pixelated Stilbene and Plastic Scintillator (EJ-276) Arrays for the Hand-Held Dual-Particle Imager

Jihwan Boo, Seoryeong Park, and Manhee Jeong

Dept. of Nuclear and Energy Engineering, Jeju National University

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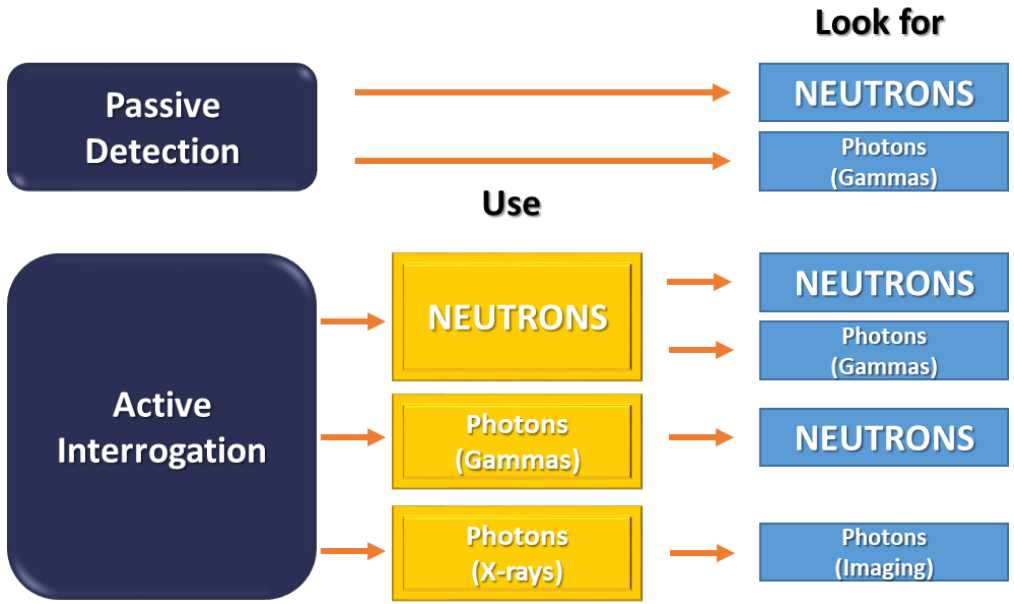
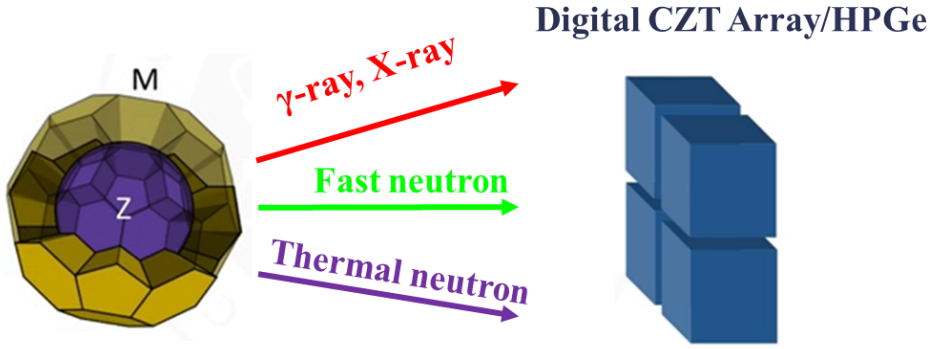
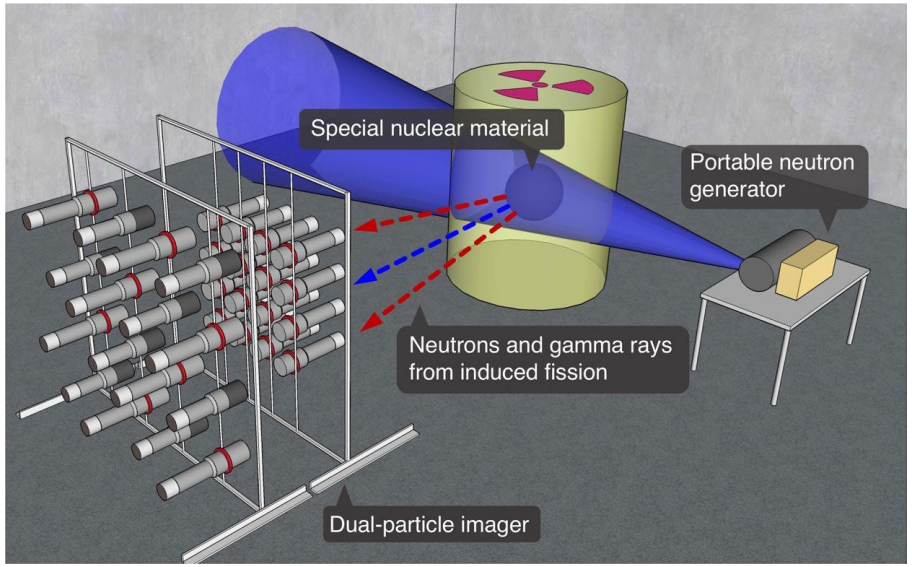
Introduction

Special Nuclear Material Detection Methods



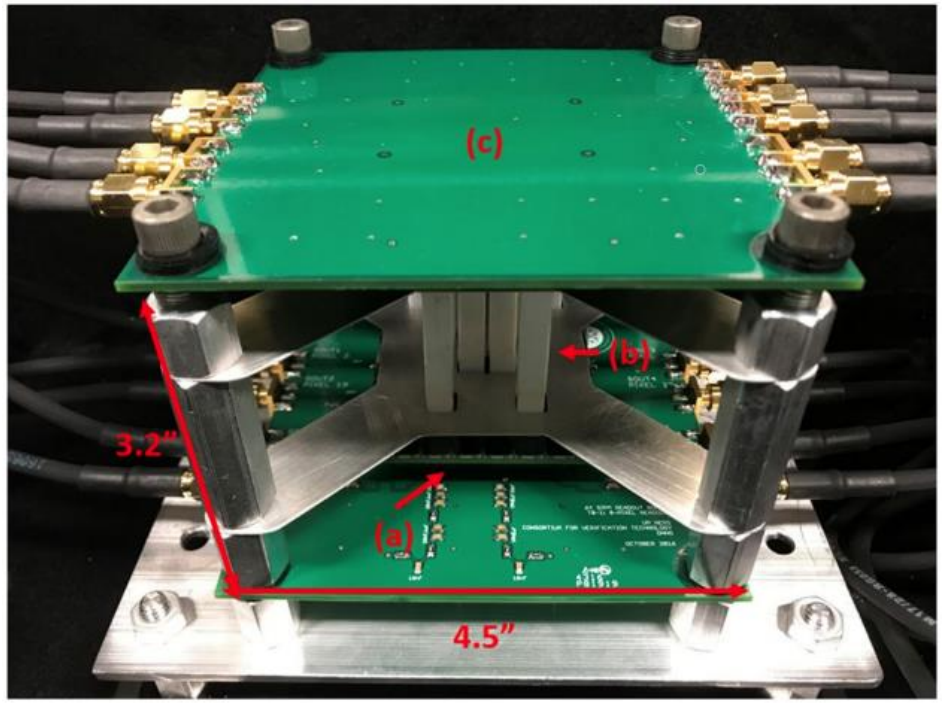
	Usability	Performance
Passive modes	simple and safe	rather ineffective against shielded SNM (in particular, HEU)
Active modes	cannot be used in many circumstances (e.g. dose to humans)	able to trigger charac-teristic response by SNM (e.g. fission)





Introduction

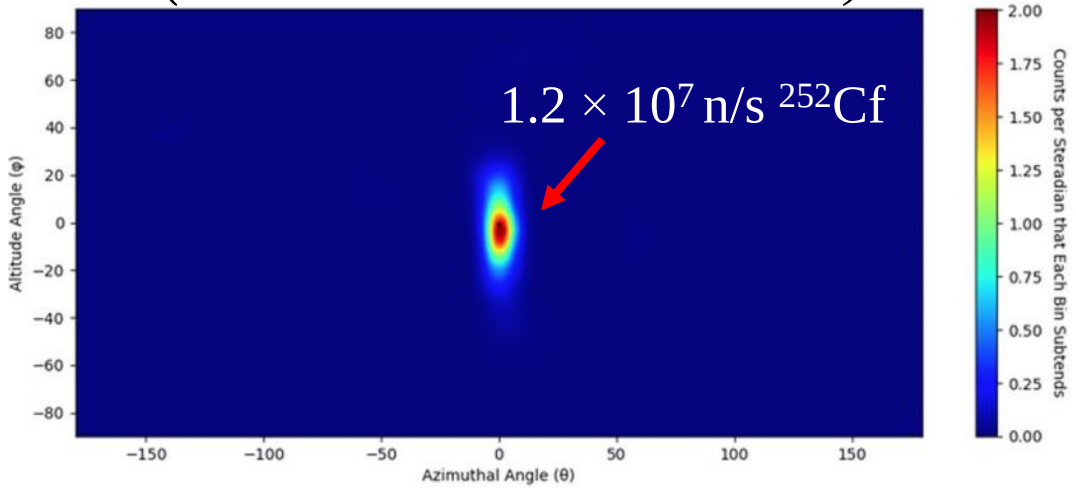
Scatter Camera



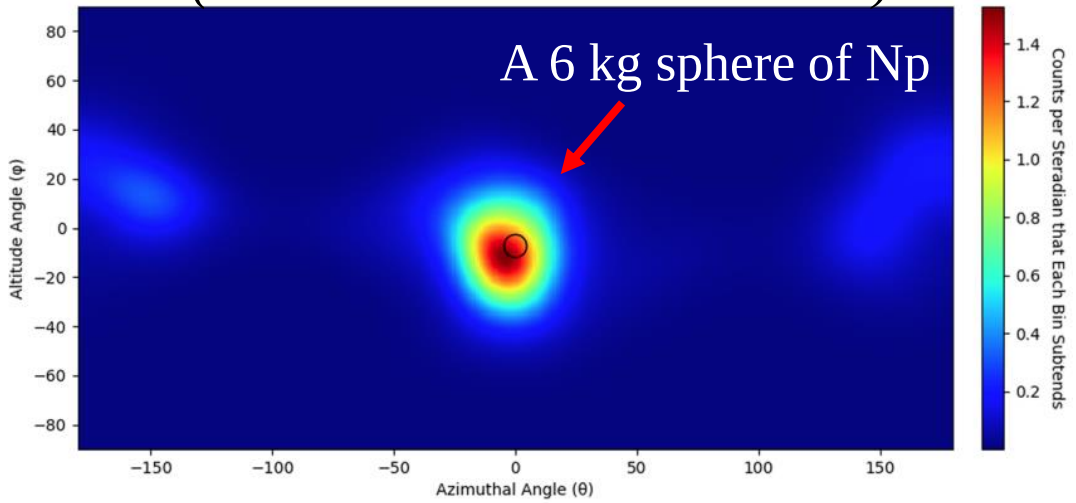
Eight bars of stilbene
with $6 \times 6 \times 50$ mm^3 each

V1730 CAEN 14-bit
500-MS/s digitizer

Neutron image
(~30 minutes at 58 cm distance)



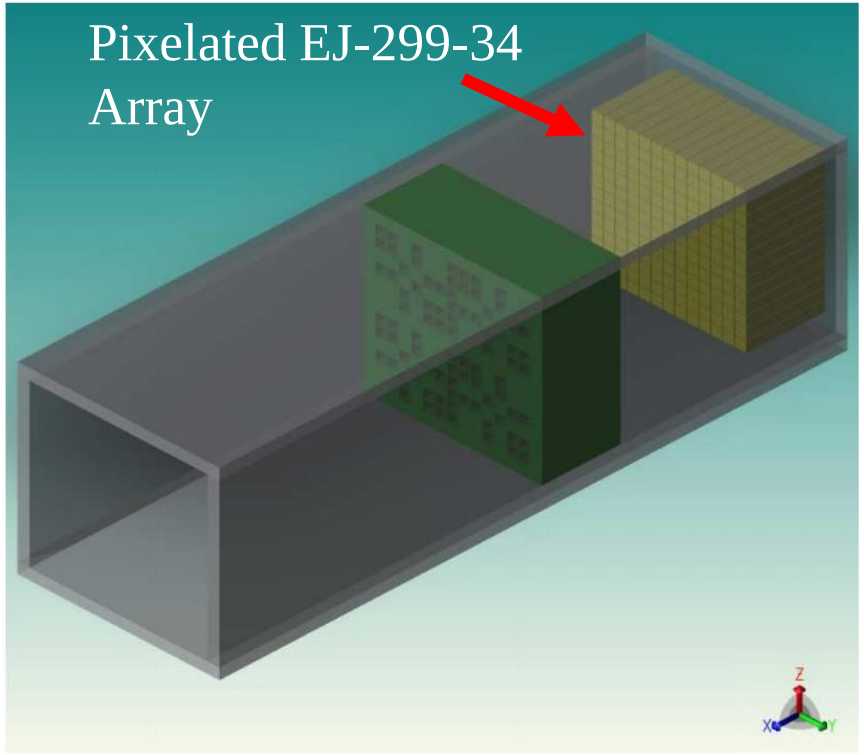
Gamma-ray image
(~45 minutes at 55 cm distance)



(William M. Steinberger et. al., Scientific Reports volume 10, Article number: 1855 (2020))

Introduction

Spatial Coded Aperture

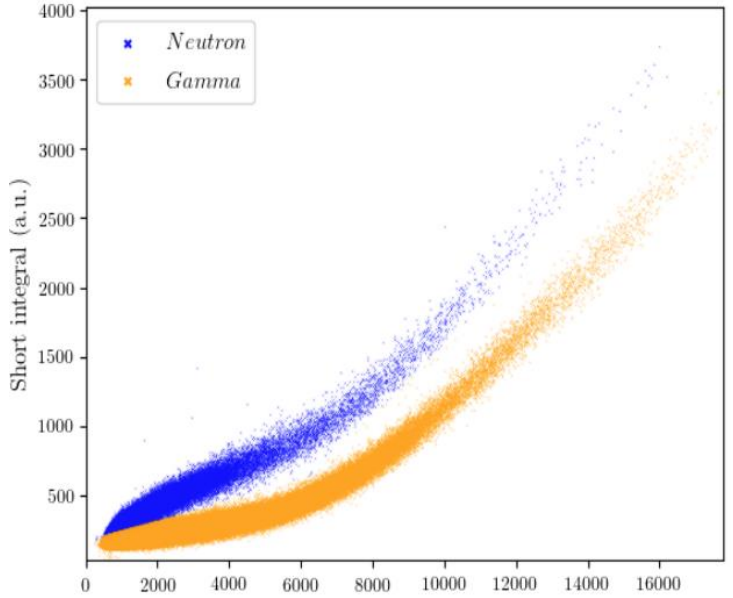


13 × 13 pixels with
2.8 × 2.8 × 15 mm each

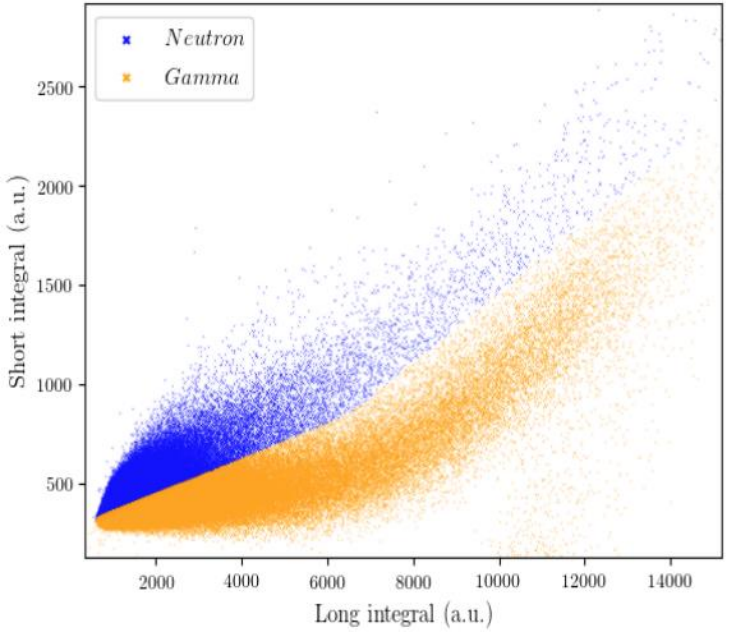
ET Enterprises 9107B
PMT (a single channel)

[Single crystal]

(Ø 25 mm, 25 mm_t)



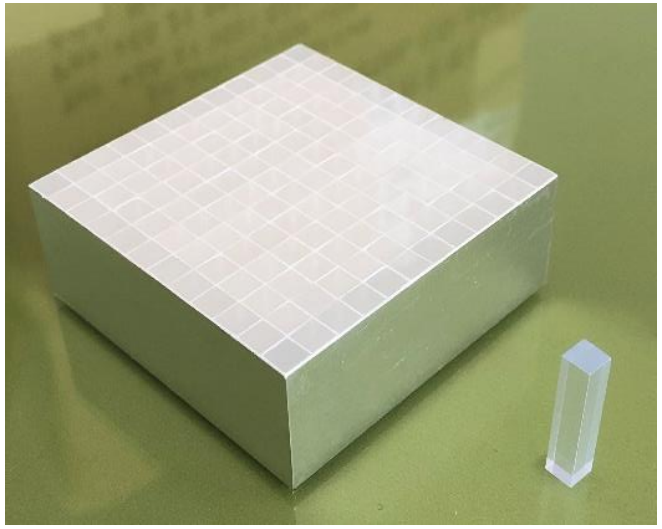
[169 Pixels]



(M. J. Cieślak et al., Journal of Instrumentation volume 14, Page: 07017 (2019))

Methods

EJ-276 plastic scintillator (Eljen Technology)



Stilbene (Inrad Optics)

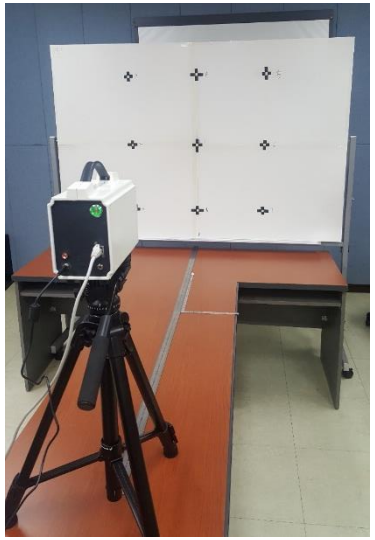
- Pixel size : 4 × 4 × 20 mm_t
- Pixel pitch : 4.2 mm
- Gap material: $BaSO_4$ (Plastic) and PTFE (Stilbene) 0.2 mm_t

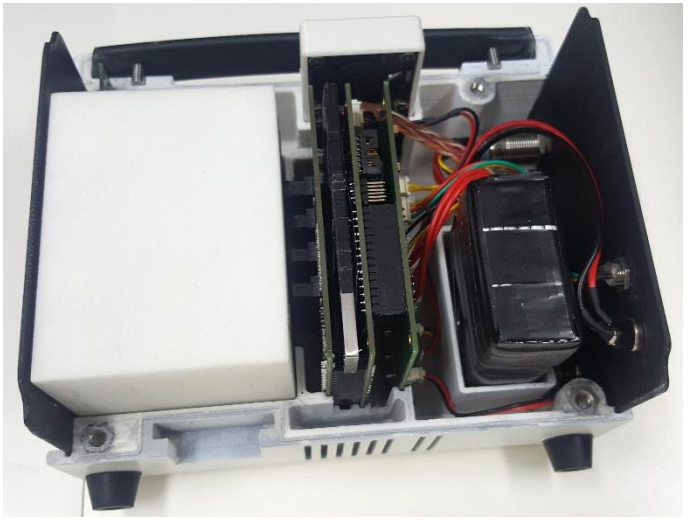
	Plastic scintillator (EJ-276)	Stilbene
Density (g/cm^3)	1.096	1.15
Peak Emission (nm)	425	390
Decay Time (ns)	γ (13, 35, 270) n (13, 59, 460)	3.5 ~ 4.5
Light Yield (photons/MeV)	8,600	γ (14,000) n (10,700)
No. of H atoms / No. of C atoms	0.927	0.858

Methods

EPSILON-D

(**E**nergetic **P**article **S**ensor for the **I**dentification and **L**ocalization of **O**riginating **N**uclei)



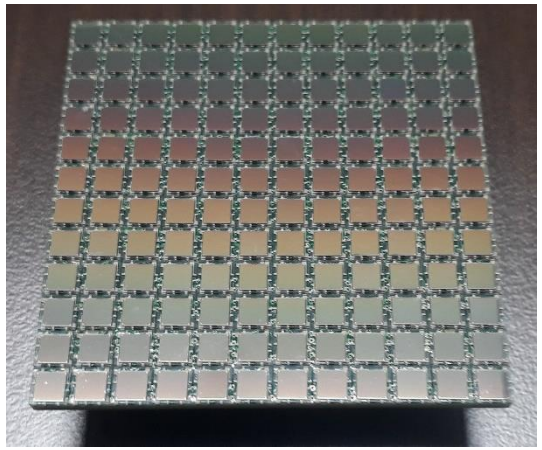


➢ Specification

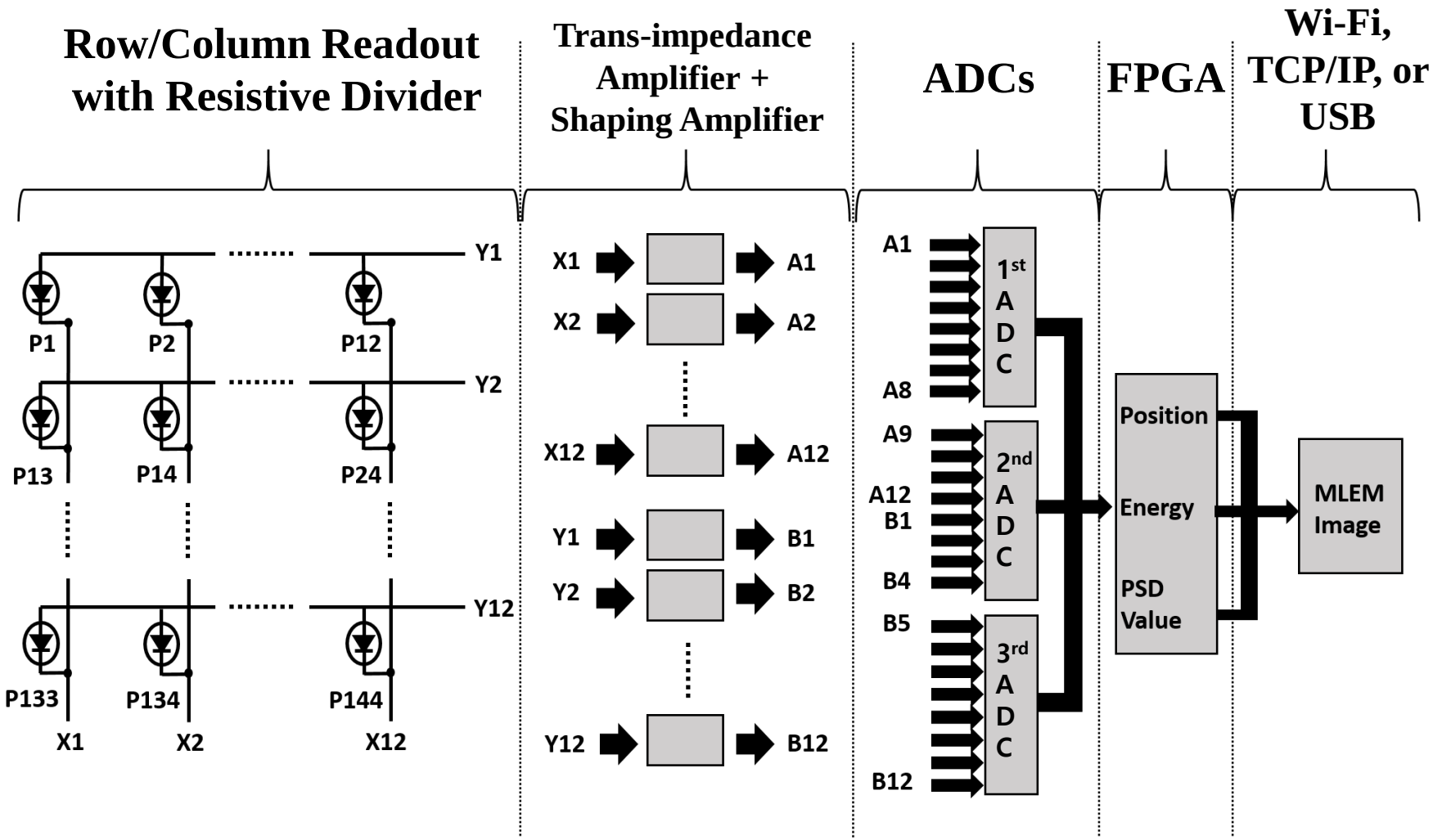
- Technology: Coded-aperture imaging
- Mask: 11 rank of MURA with 2 cm_t **W**
- FOV: 50°
- Angular resolution: 6.8°
- Sensitivity: < 70 sec. for 6.4 μSv/h of ^{137}**Cs**
  < 6 min. for 3.5 × 10^5 n/s ^{252}**Cf**
- Max. count rate: 100k cps
- Size (weight): 104 × 144 × 197 mm (4.1 kg)
- Image Reconstruction method: MELM

Methods

SiPM C-series (SensL)



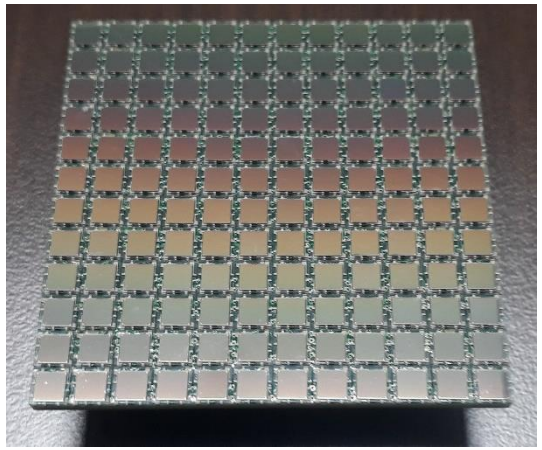
- Pixel size : 3 × 3 mm^2
- Pixel pitch : 4.2 mm



Methods

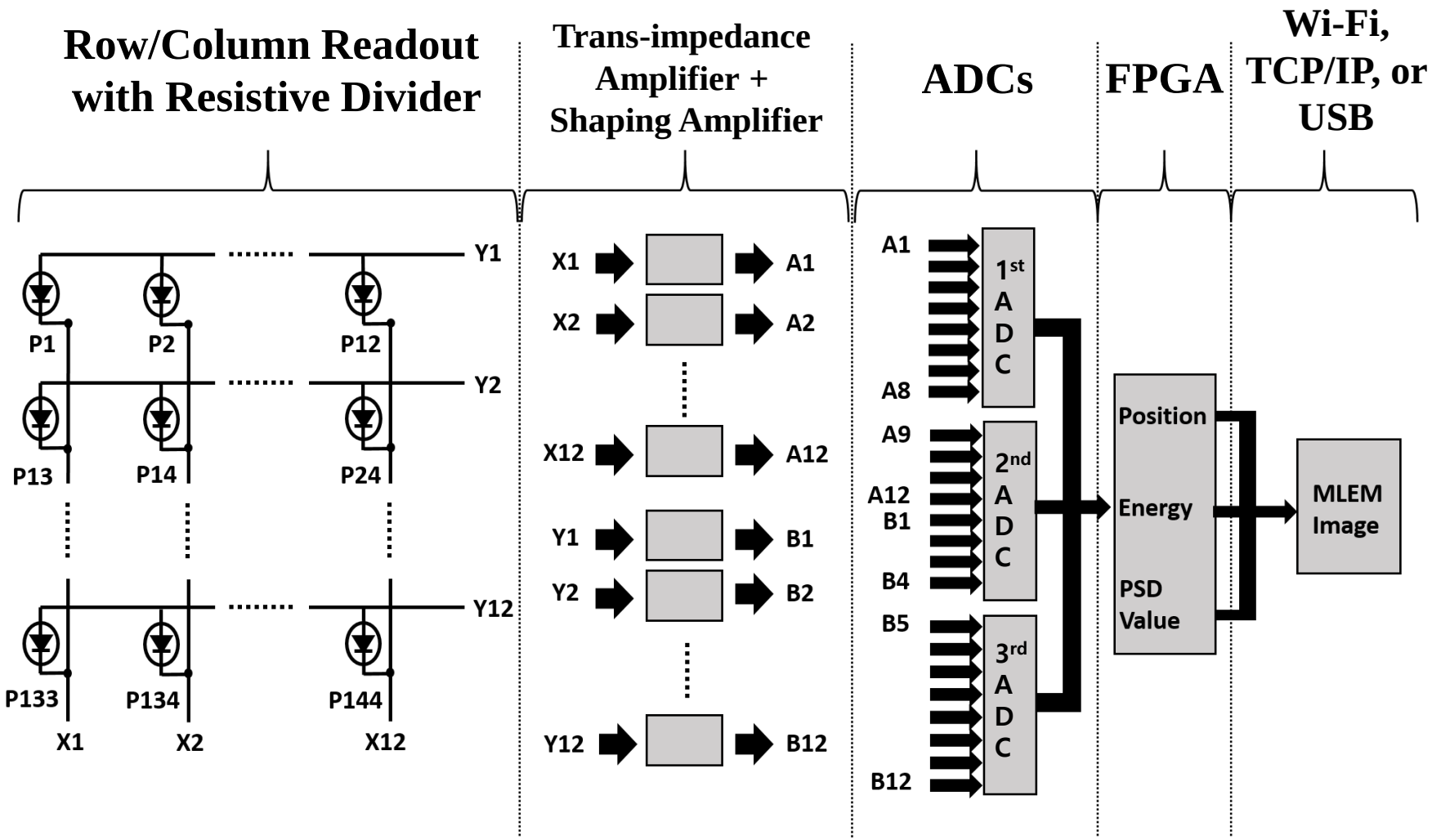
Operation Voltage:
26, 27, 28, 29, or 30 V

SiPM C-series (SensL)



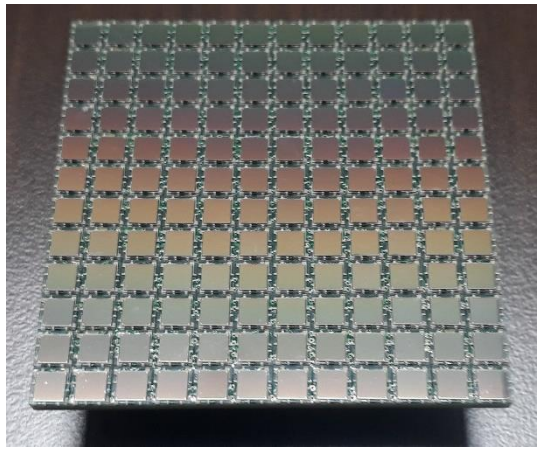
- Pixel size : 3 × 3 mm^2
- Pixel pitch : 4.2 mm

(ArrayC-30035-16P-PCB A)



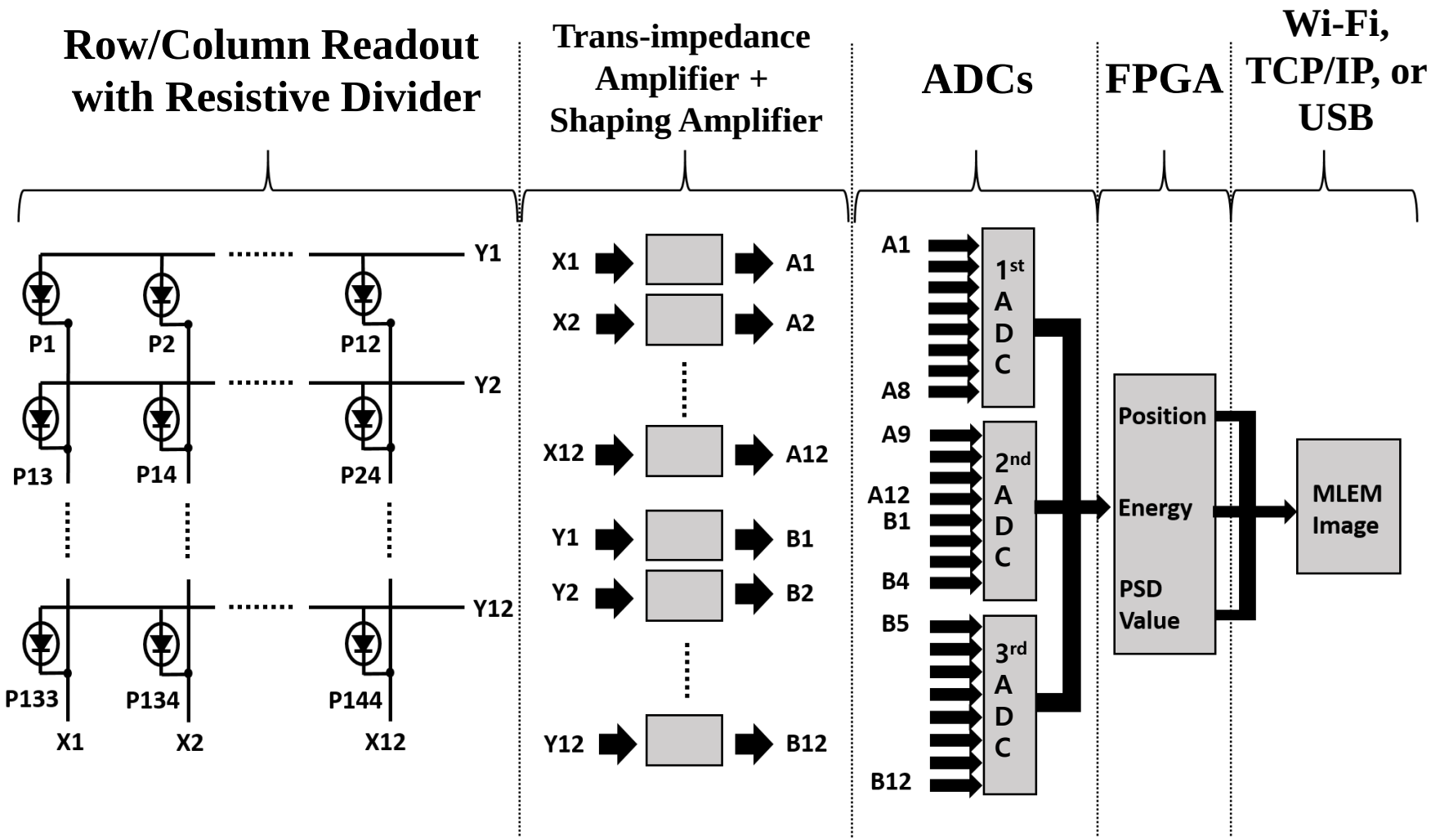
Methods

SiPM C-series (SensL)



- Pixel size : 3 × 3 mm^2
- Pixel pitch : 4.2 mm

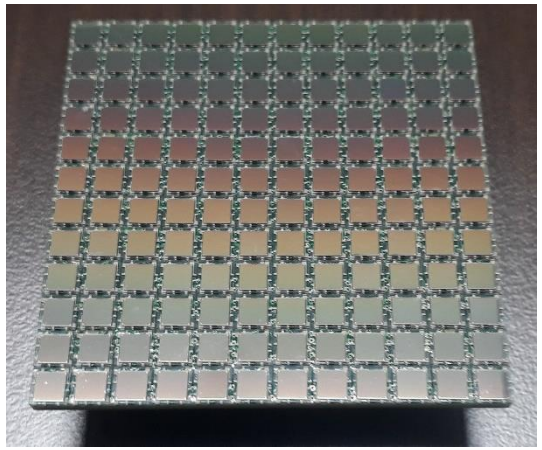
The feedback resistance (R_f)
of TIA: 30, 100, or 300 Ω



(TIA: LMH6723, Texas Instruments)

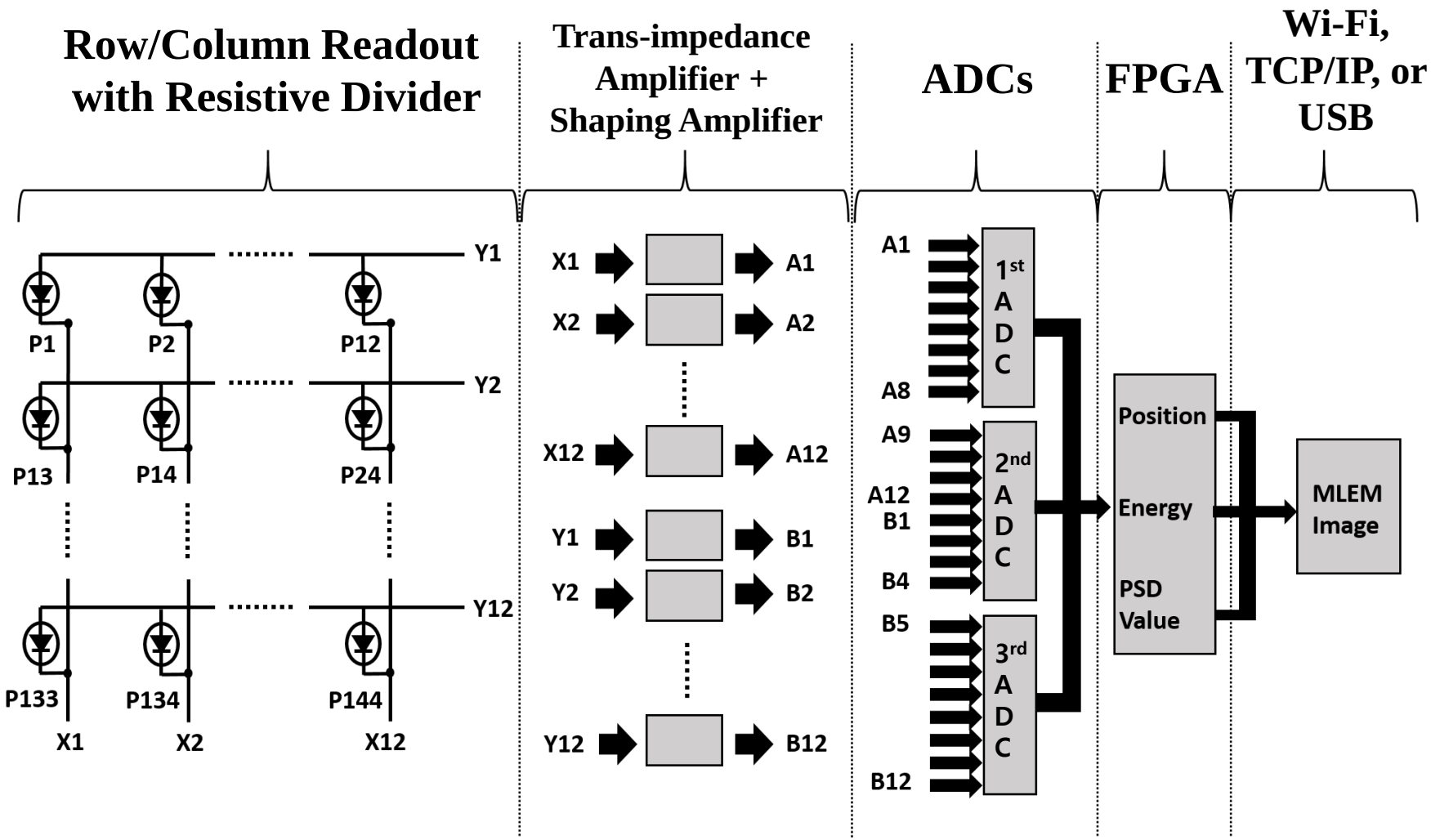
Methods

SiPM C-series (SensL)



- Pixel size : 3 × 3 mm^2
- Pixel pitch : 4.2 mm

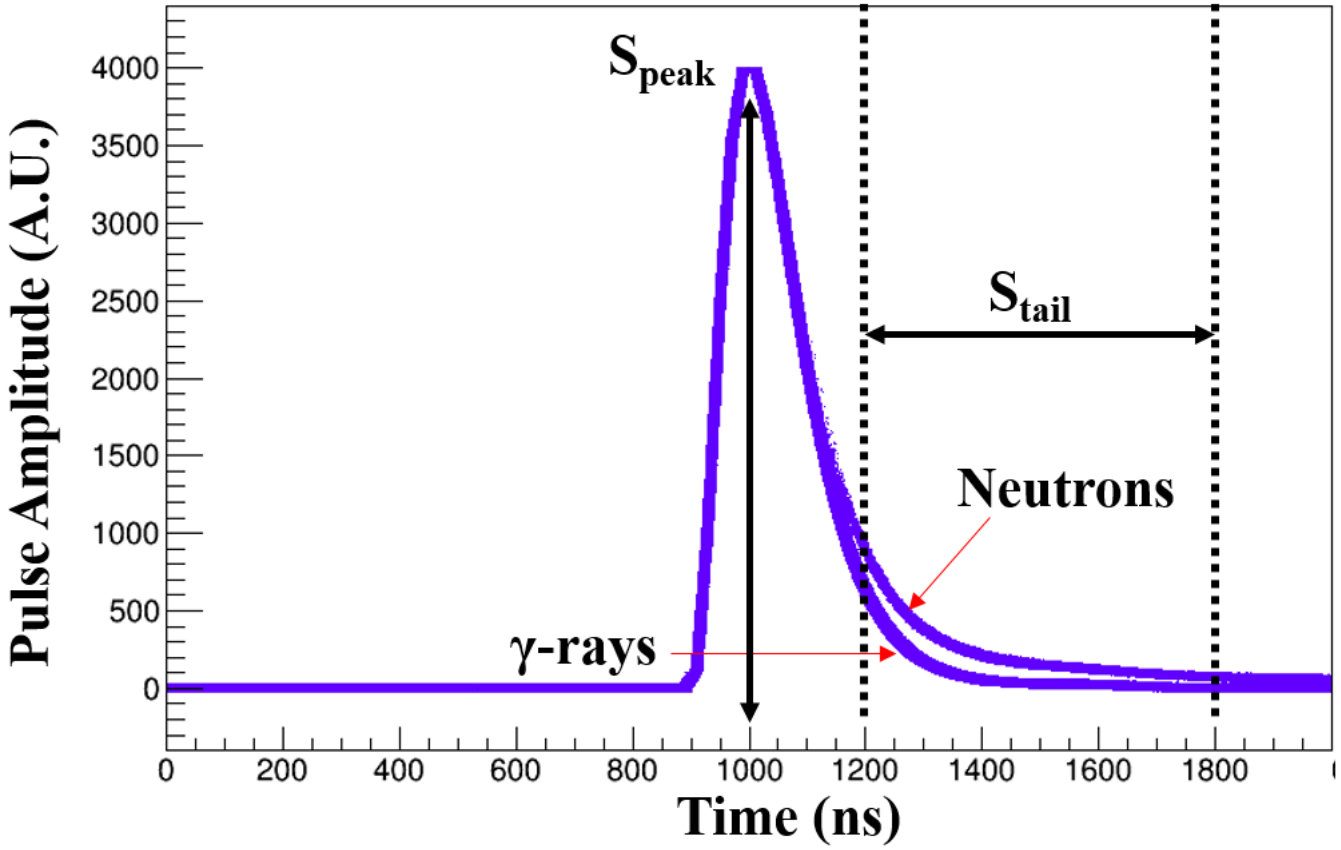
ADCs : 12-bit, 50 MHz

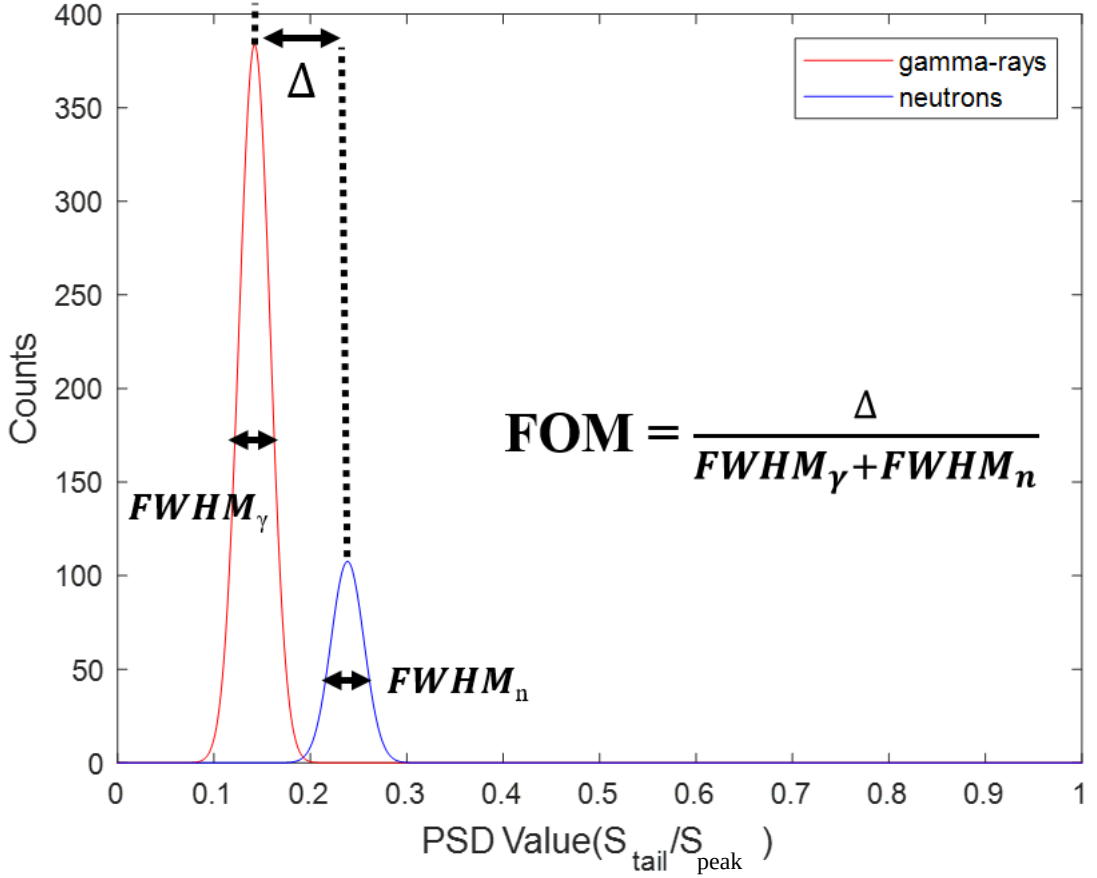


ADS5281 (Texas Instruments)

Methods

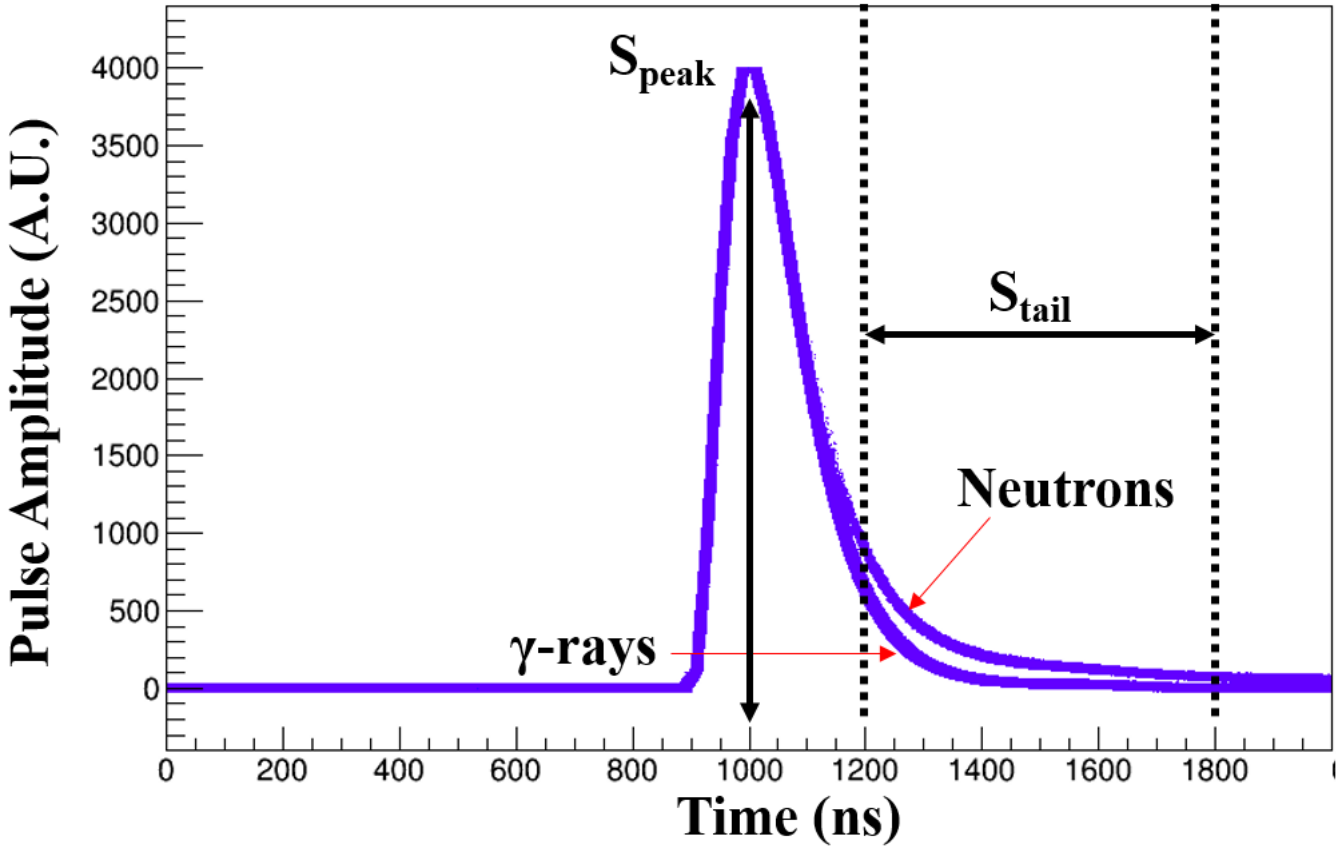
Pulse Shape Discrimination (PSD)- Simplified Charge Comparison Method (SCCM)

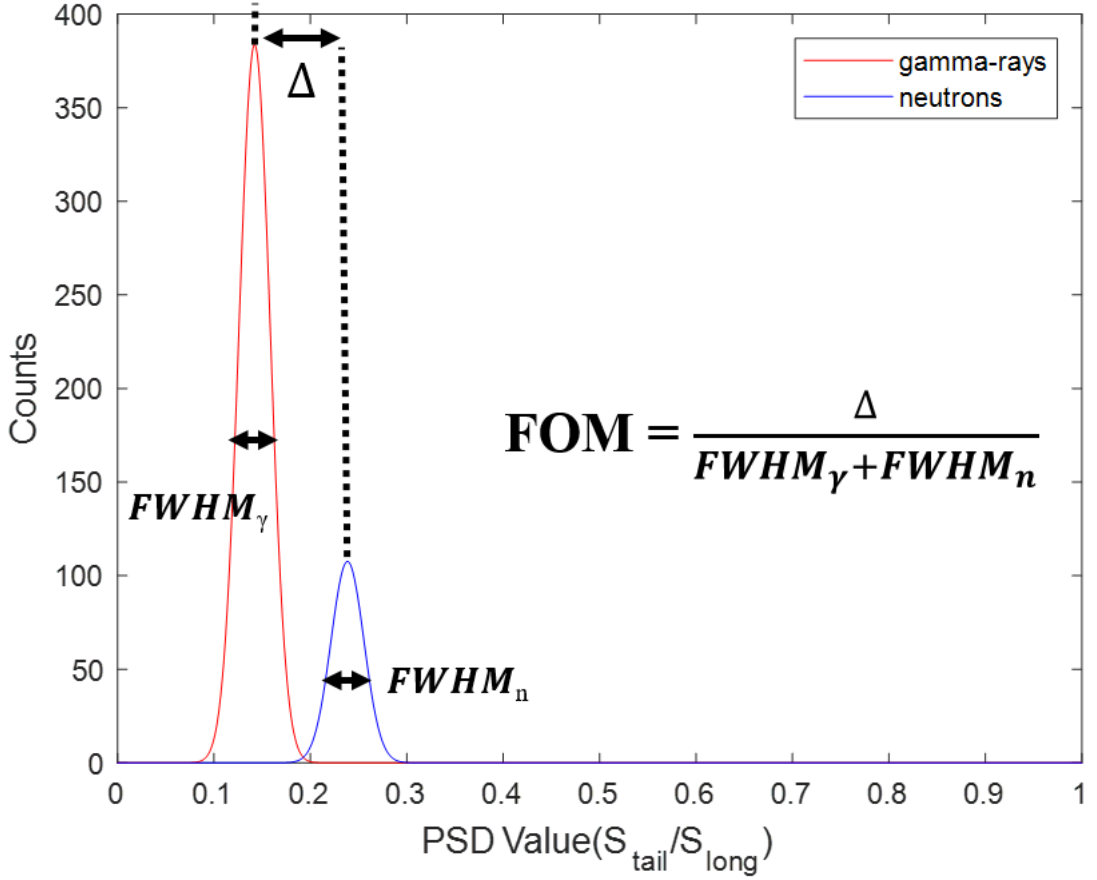




Methods

Pulse Shape Discrimination (PSD)- Simplified Charge Comparison Method (SCCM)





✓ Neutron & gamma-ray source: Cf-252 (3.5×10^5 n/s) & Cs-137 (20 μCi)

Results & Discussion

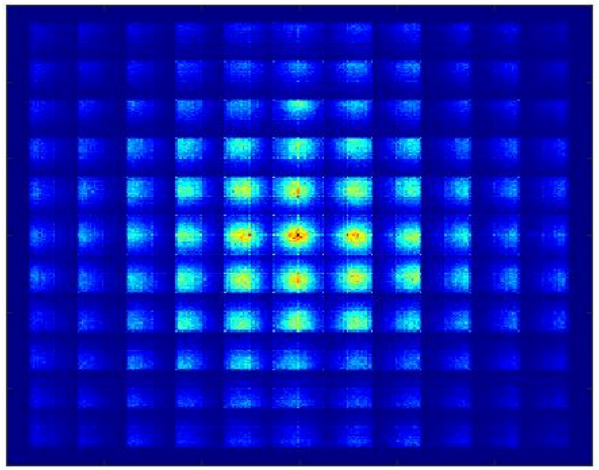
2D flood map for ^{137}Cs

[Plastic array]

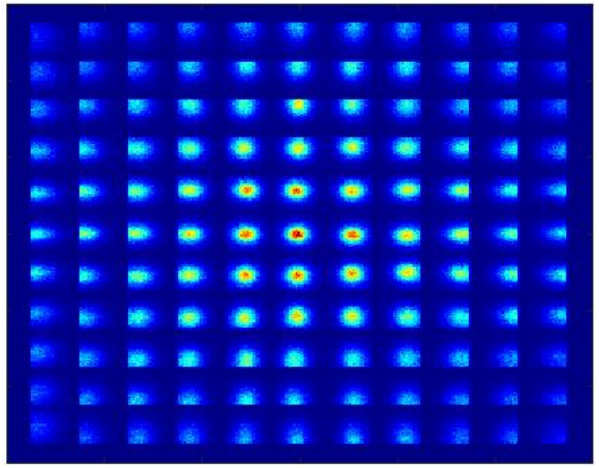
R_f	ADCs
low (30 Ω)	12 bit

[Stilbene array]

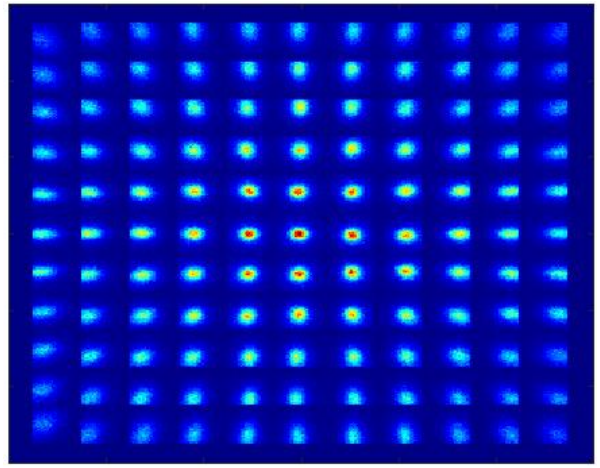
Flood map at 26 V



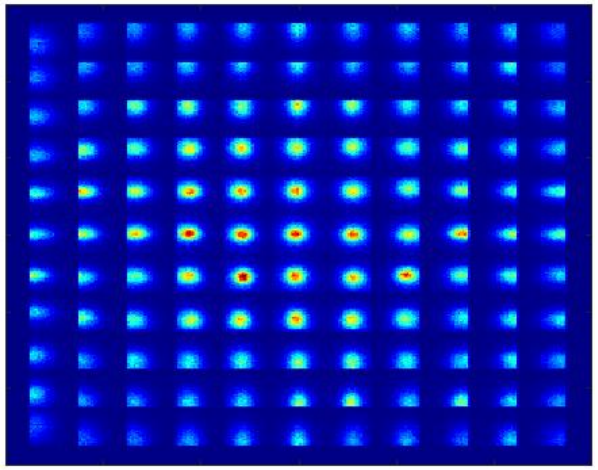
Flood map at 27 V



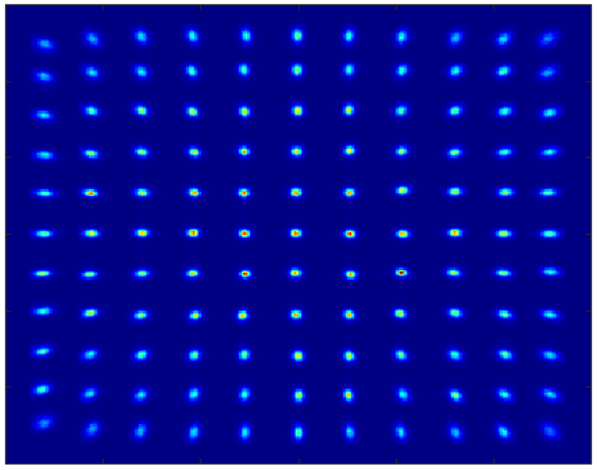
Flood map at 28 V



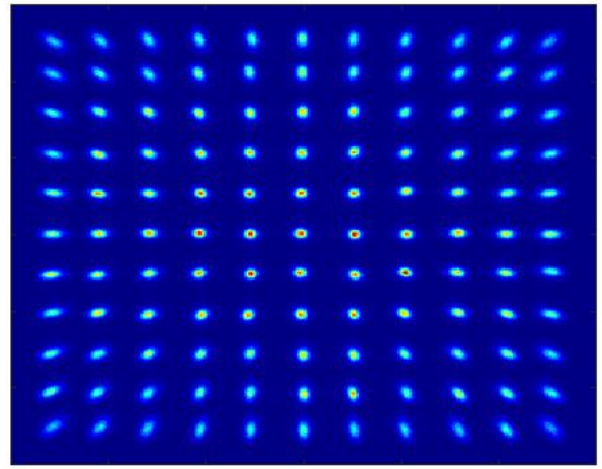
Flood map at 26 V



Flood map at 28 V



Flood map at 30 V



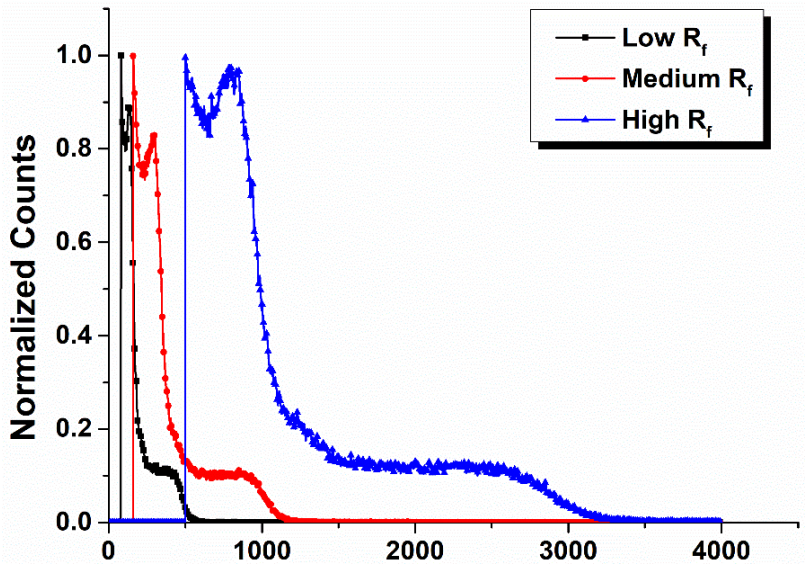
Results & Discussion

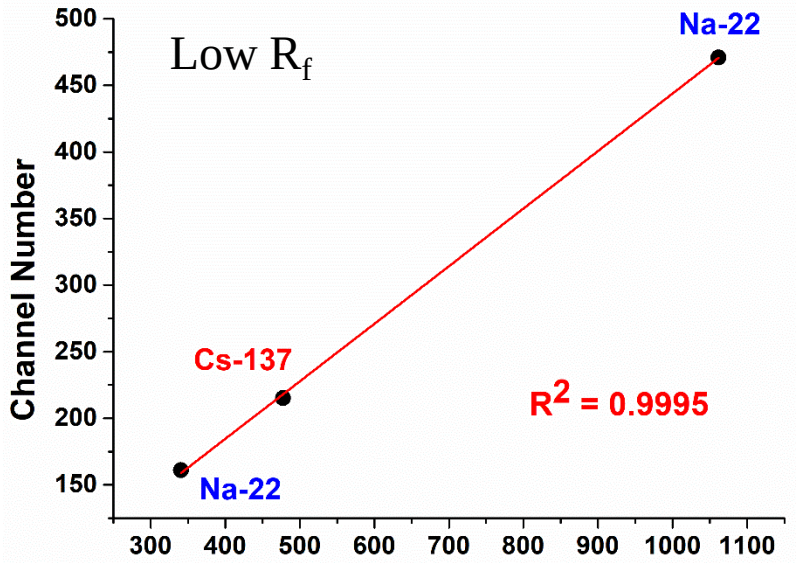
Gamma-ray spectra & system linearity

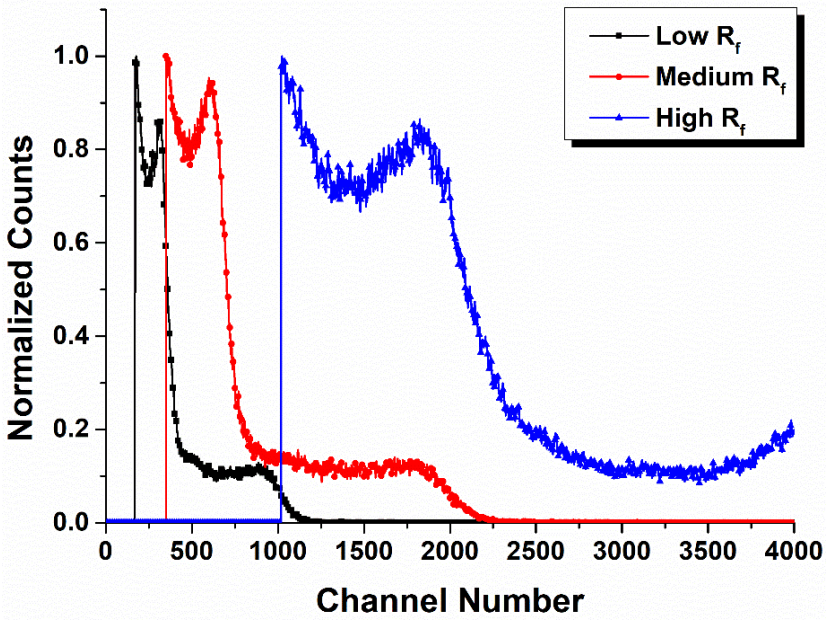
[Plastic array]

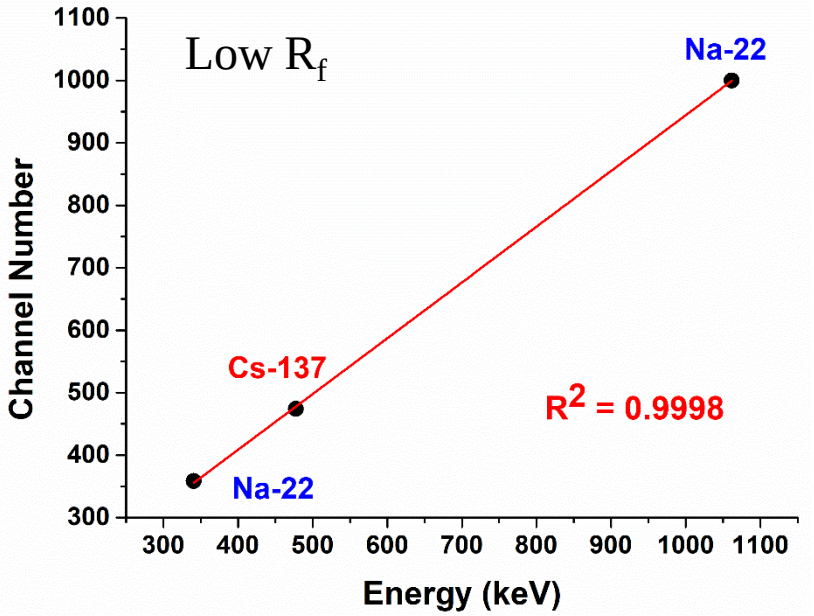
Bias voltage (V)	ADCs
28	12 bit

[Stilbene array]









Results & Discussion

PSD performance for the arrays

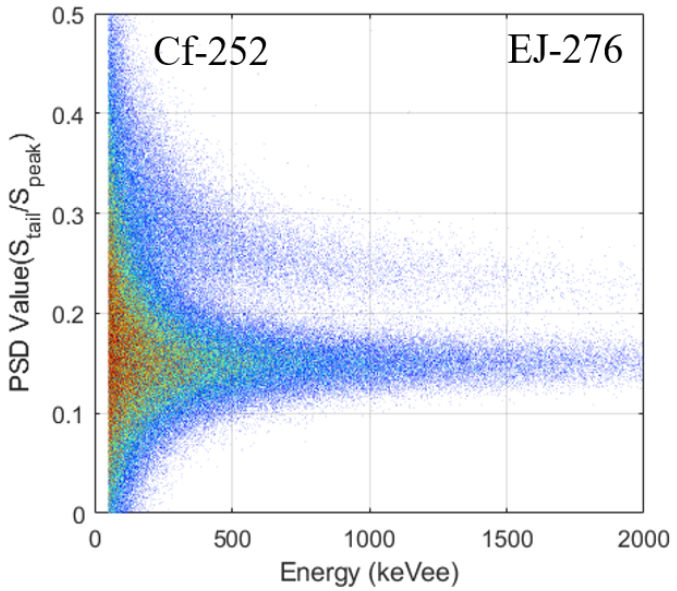
S_{tail}: 180 ns – 800 ns

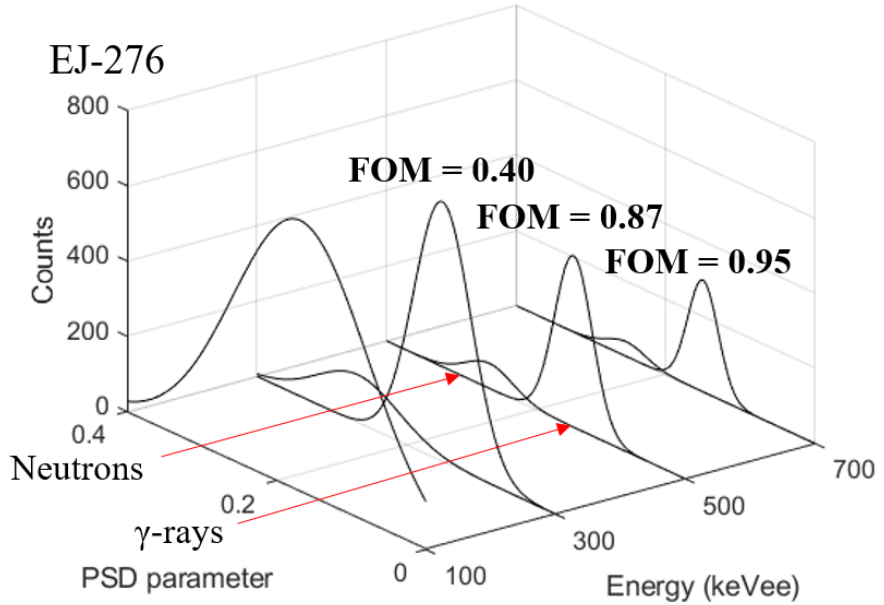
[Plastic Overall pixel]

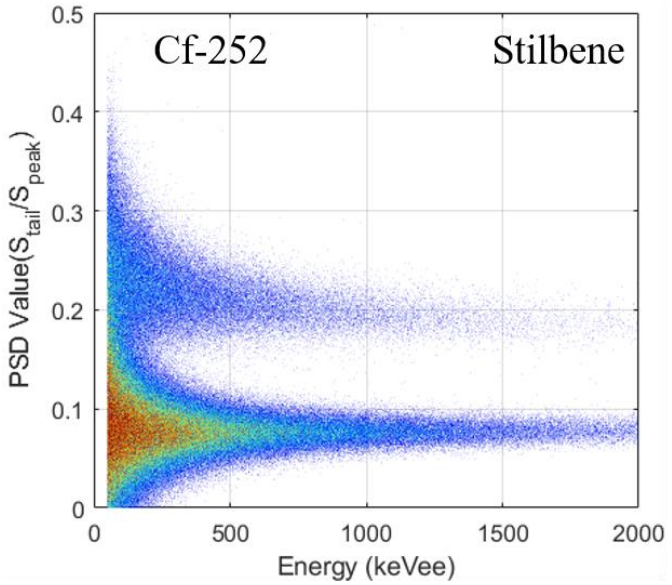
Bias voltage (V)	R_f	ADCs
28	Mid (100 Ω)	12 bit

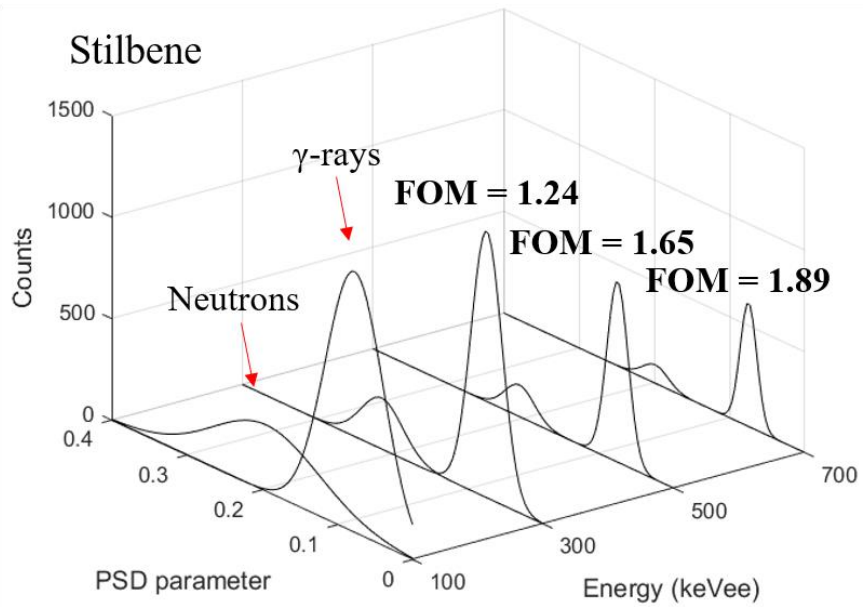
[Stilbene Overall pixel]

S_{tail}: 180 ns – 600 ns









Results & Discussion

PSD performance for single pixels

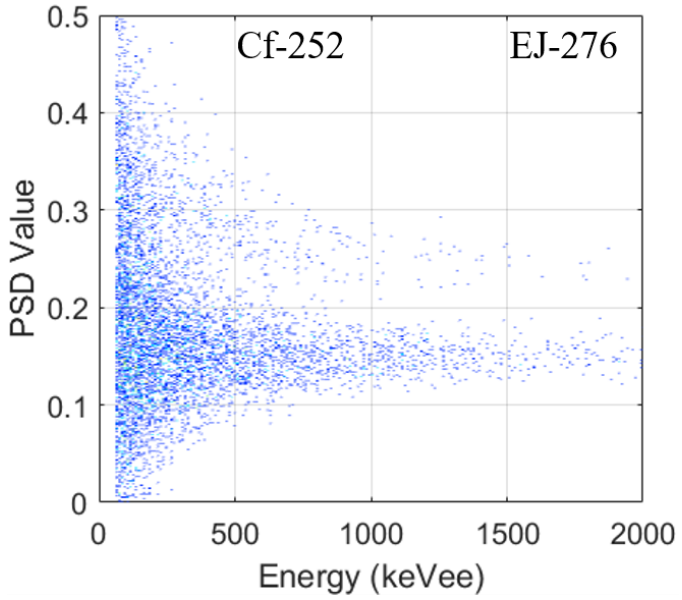
S_{tail}: 180 ns – 800 ns

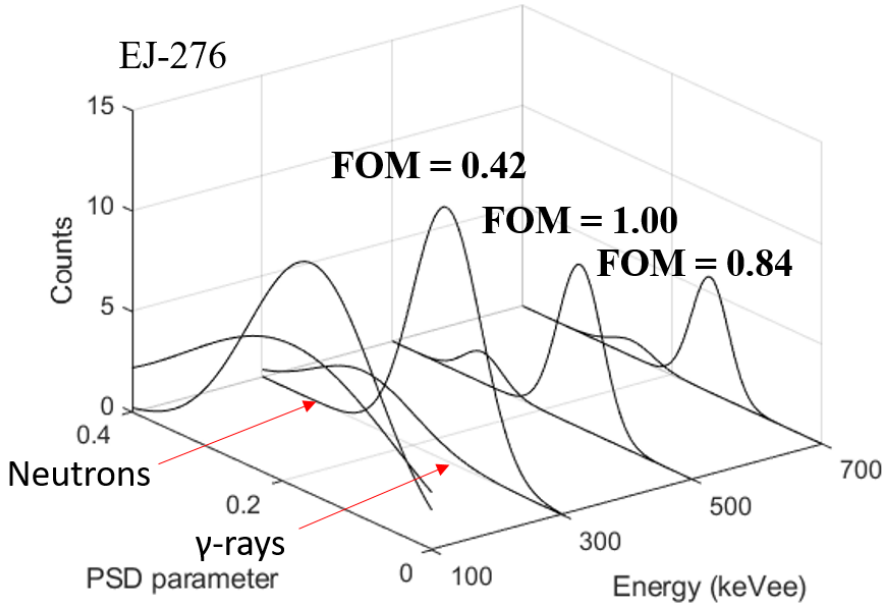
[One of the Plastic pixels]

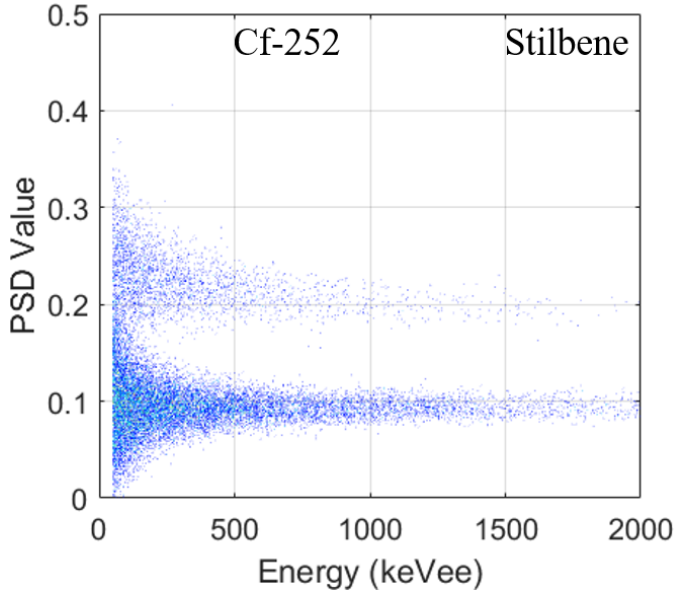
Bias voltage (V)	R_f	ADCs
28	Mid (100 Ω)	12 bit

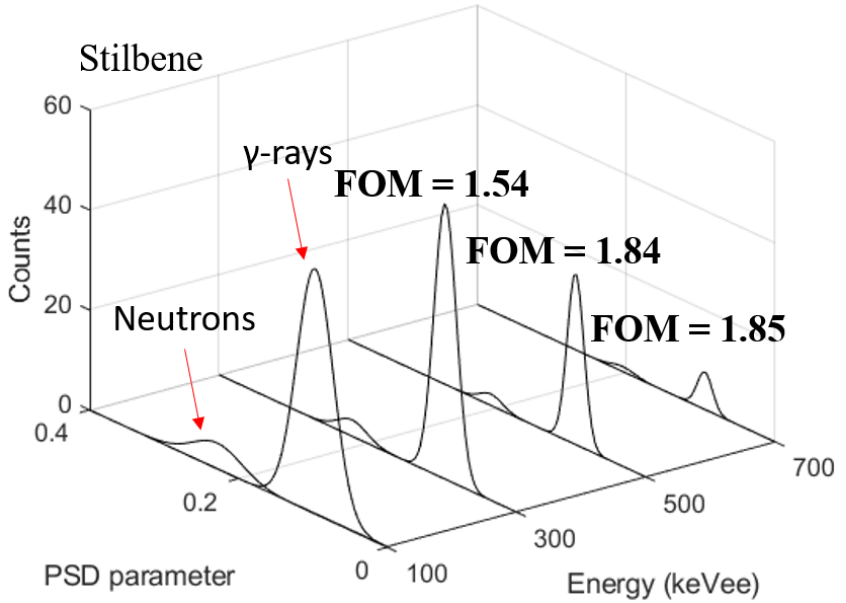
[One of the Stilbene pixels]

S_{tail}: 180 ns – 600 ns









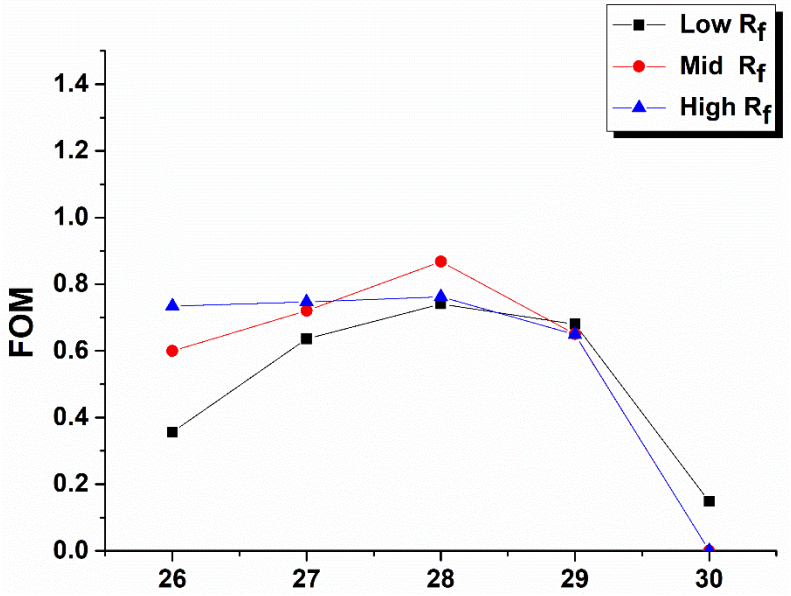
Results & Discussion

Comparison of PSD performance

[Plastic Overall pixel]

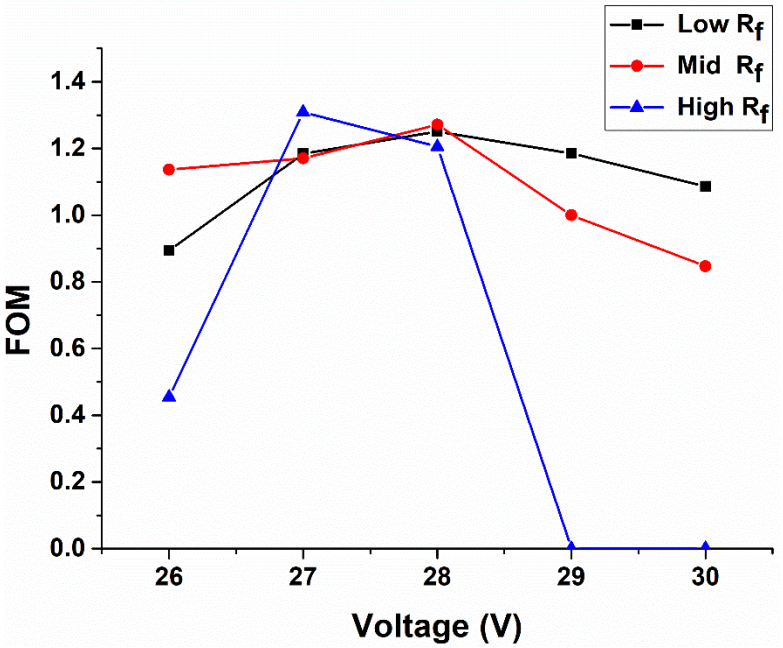
ADCs

12 bit



✓ FOM (500 ± 100 keVee)

[Stilbene Overall pixel]

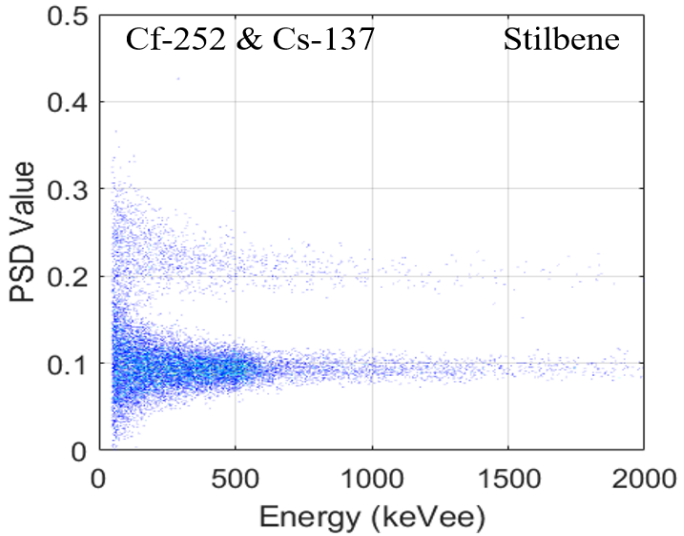


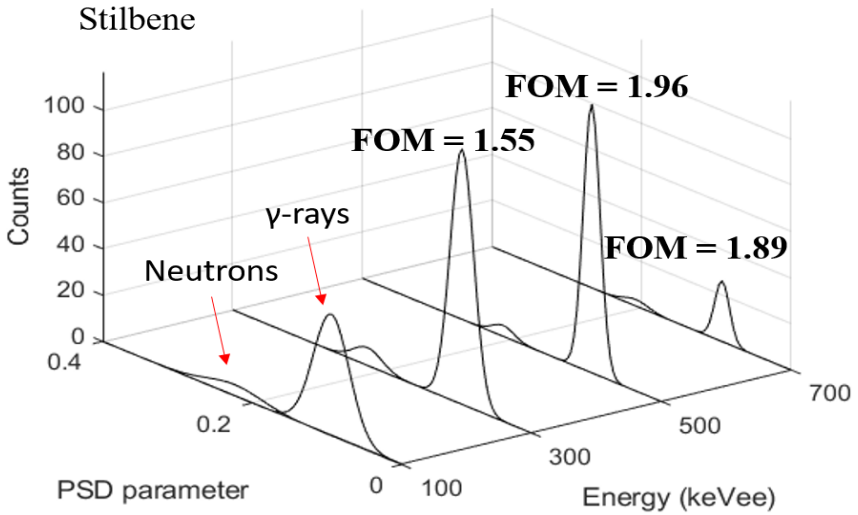
✓ FOM (300 ± 100 keVee)

Results & Discussion

Comparison of PSD performance

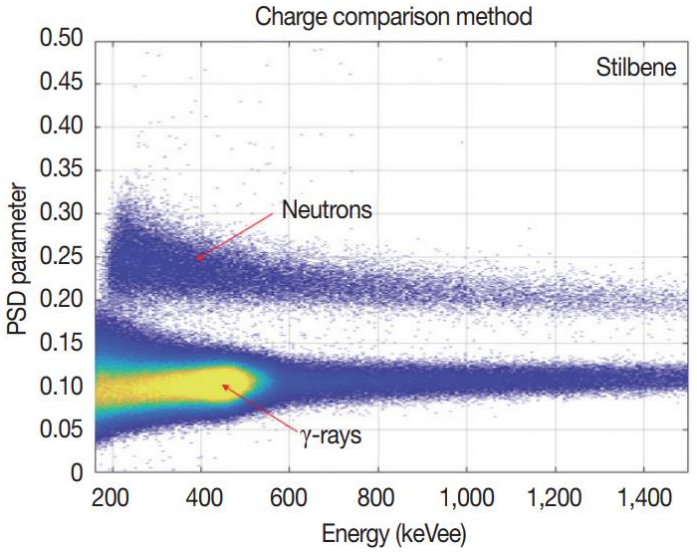
[One of the Stilbene pixels]

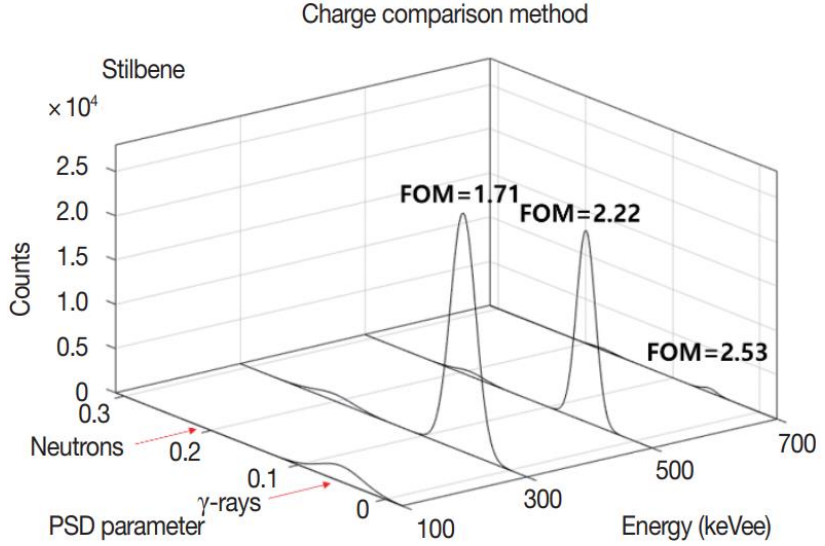




(Ø 5 cm, 5 cm_t)

[Stilbene cylinder crystal]



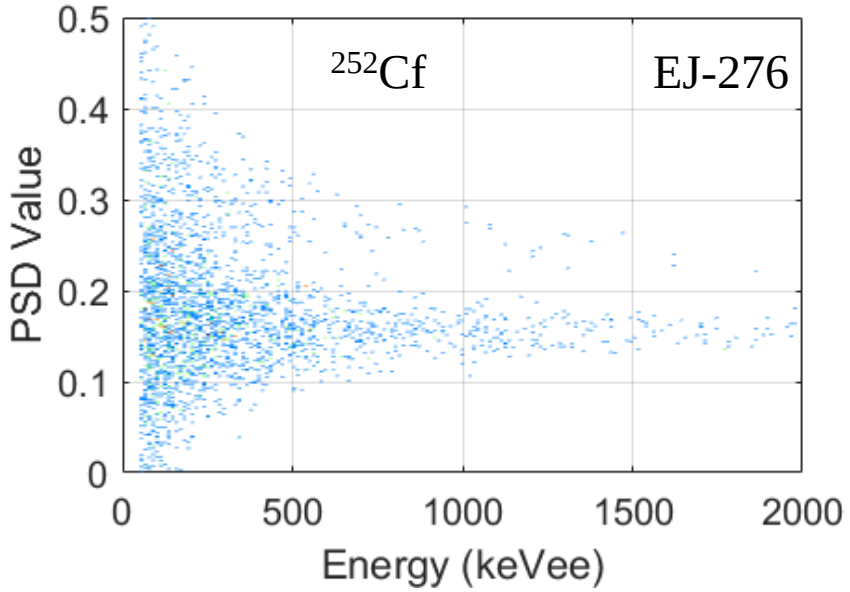


(Kim, C. et. al., J. Radiat. Prot. Res. Vol. 44, Page: 53 (2019))

Results & Discussion

Comparison of PSD performance

[One of the Plastic pixels]

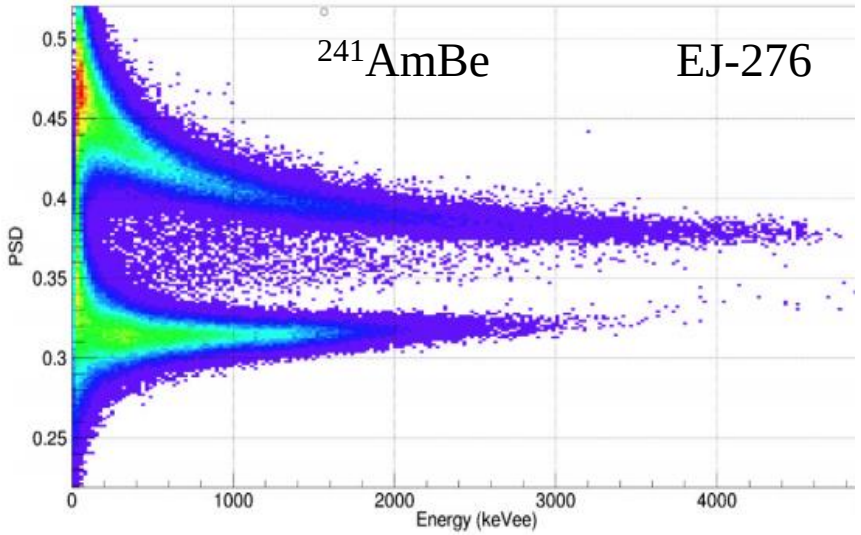


Sensor \ FOM	0.5-0.6 MeVee	1–1.1 MeVee	1.5-1.6 MeVee
C-series	1.02	1.67	N/A

(ADCs: 12-bit, 50 MS/s)

(6 mm × 6 mm × 6mm)

[Plastic cube crystal]



Sensor \ FOM	0.5-0.6 MeVee	1–1.1 MeVee	1.5-1.6 MeVee
J-series	2.39	2.84	3.03

(ADC: 14-bit, 500 MS/s)

(Taggart, M. P. et. al., Nucl. Instrum. Meth. A, Vol. 908, Page: 148 (2018))

Conclusion & Future Works

- Comparison performance between Stilbene and Plastic scintillator arrays (EJ-276) for DPI application
- PSD performance heavily dependent on its light yield when a pixelated array is needed

- Pulse Shape Discrimination (PSD) optimization
  - Change the ADCs resolutions from 12 bits to 14 when maintaining the sampling rate
  - Apply a light guide to match the active area of SiPM to the crystal size

Comparison of Pulse-Shape Discrimination (PSD) Performance Using the Pixelated Stilbene and Plastic Scintillator (EJ-276) Arrays for the Hand-Held Dual-Particle Imager

Thank you for your attention

Presenter: Mr. Jihwan Boo
Email: wlghks5648@jejunu.ac.kr

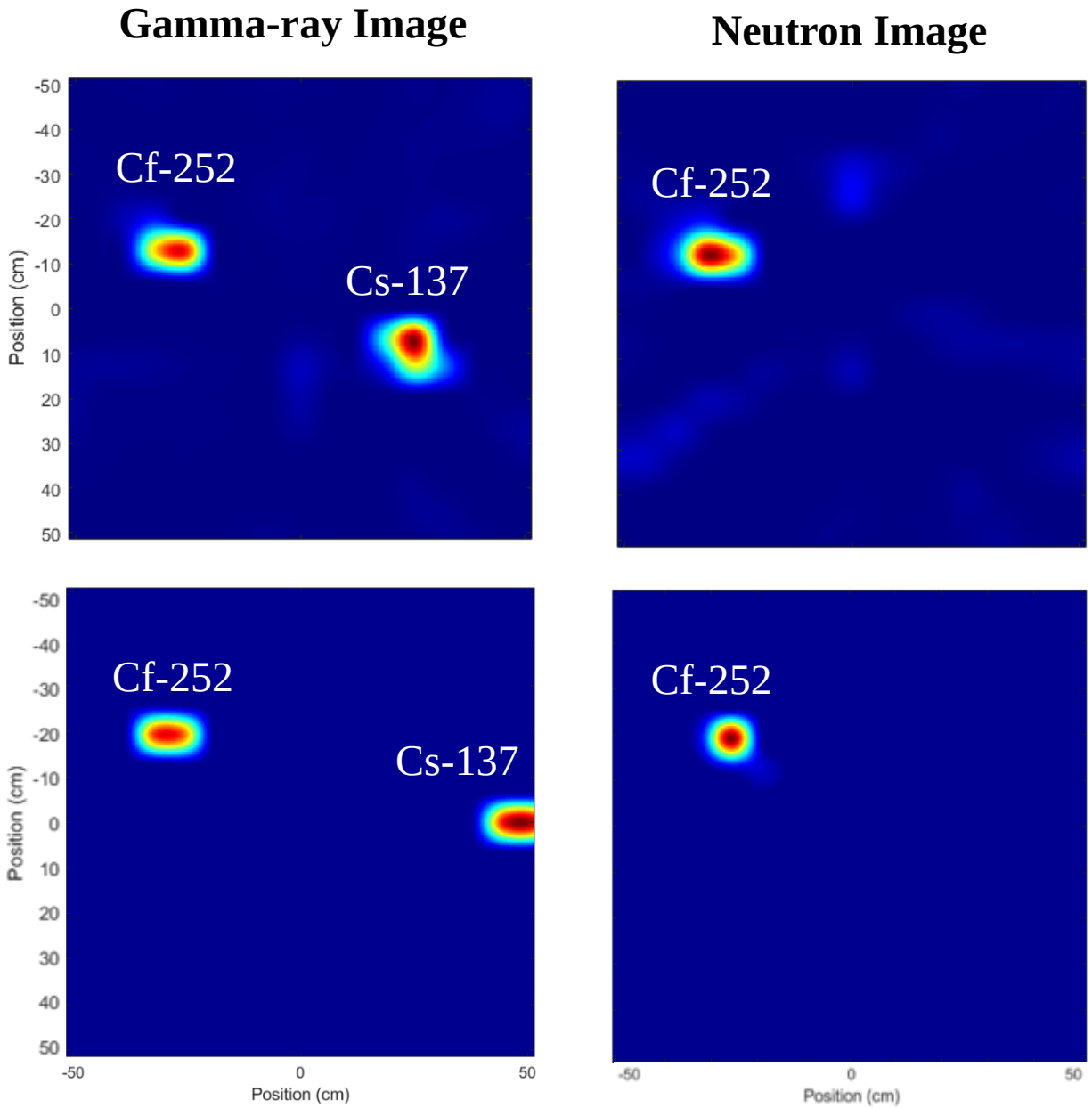
Appendix

Comparison of the reconstructed MLEM image

[Plastic array]

Bias voltage (V)	R_f	ADCs
28	Mid (100 Ω)	12 bit

[Stilbene array]



Measurement time: 5 min

Appendix

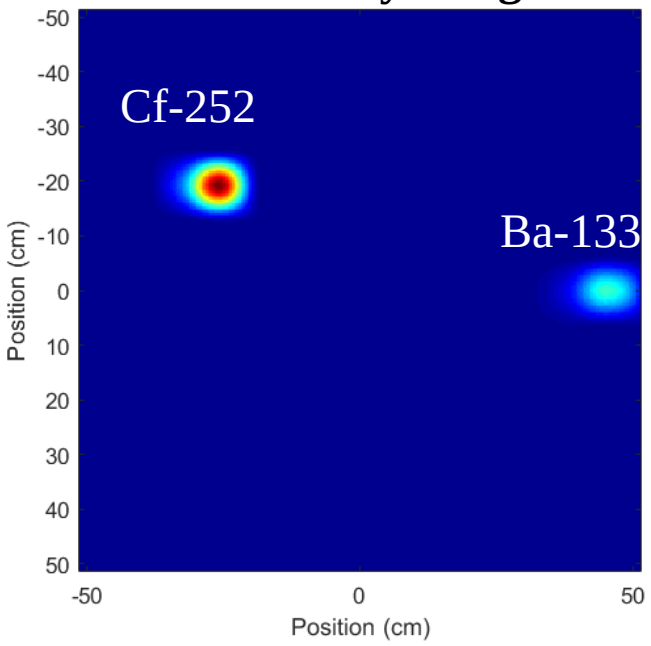
Comparison of the reconstructed MLEM image

[Plastic array]

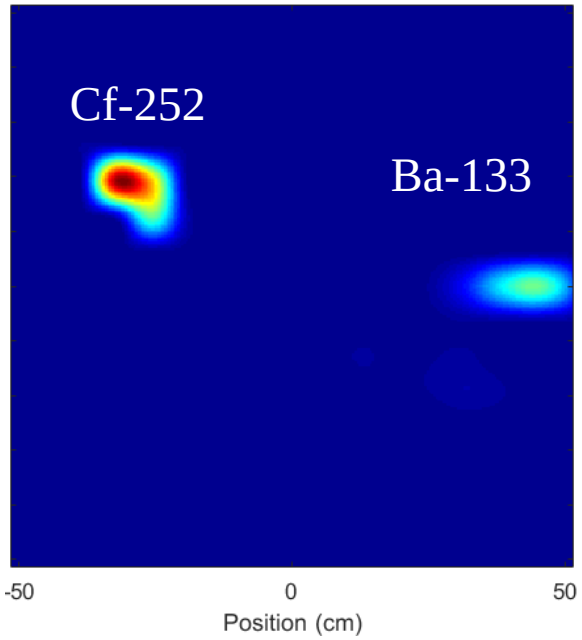
Bias voltage (V)	R_f	ADCs
28	Mid (100 Ω)	12 bit

[Stilbene array]

Gamma-ray Image



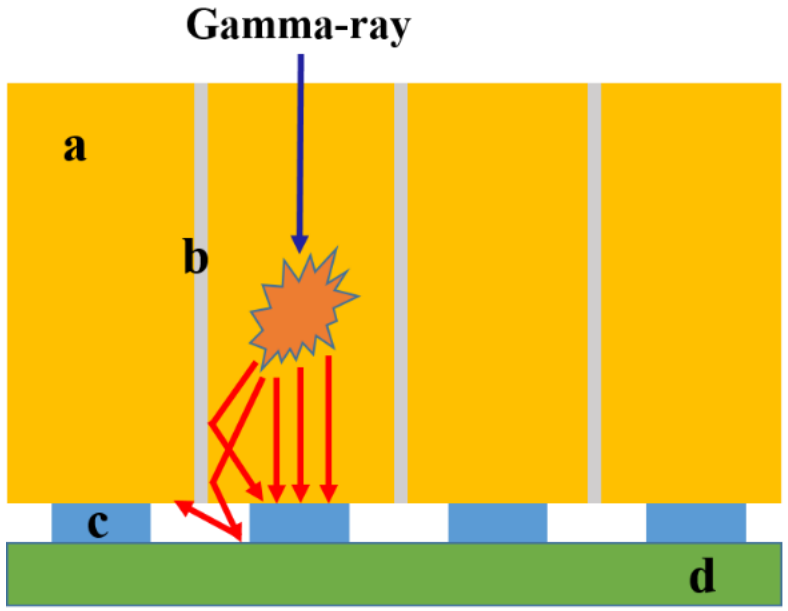
Neutron Image



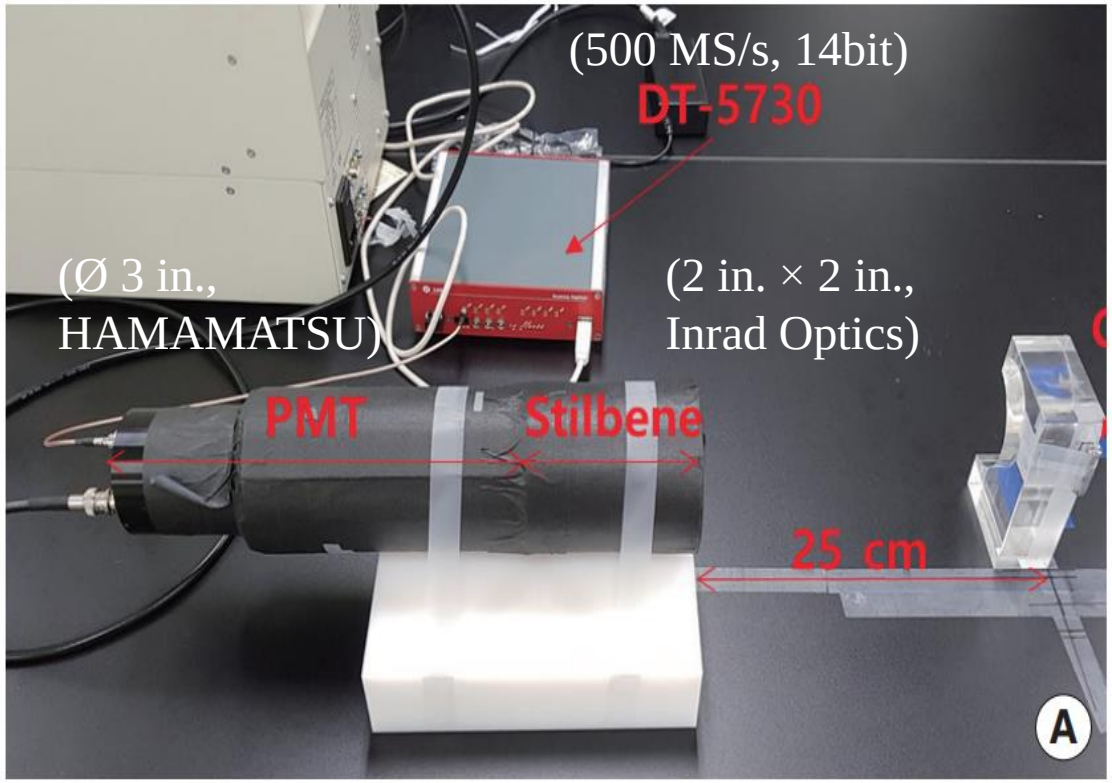
Measurement time: 6 min

Appendix

Comparison of PSD performance



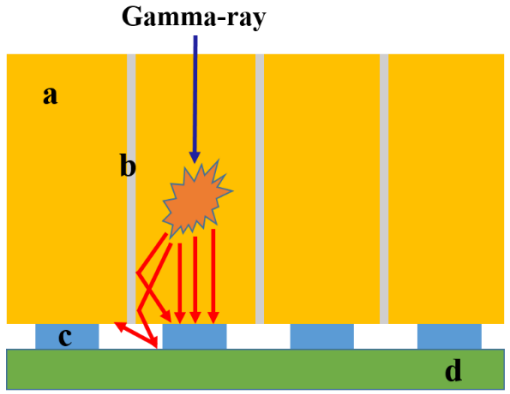
a: Stilbene, 4 × 4 × 20 mm^3
b: Reflector (PTFE, 0.2 mm_t)
c: SiPM, 3 × 3 mm^2
a: PCB



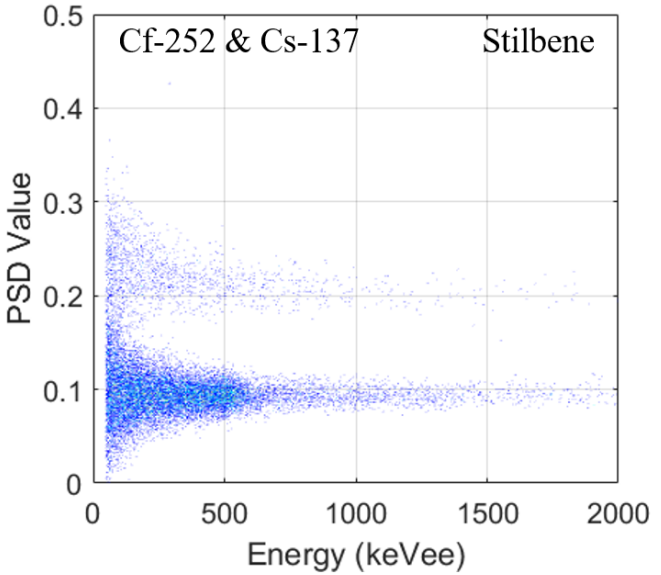
(Kim, C. et. al., J. Radiat. Prot. Res. Vol. 44, Page: 53 (2019))

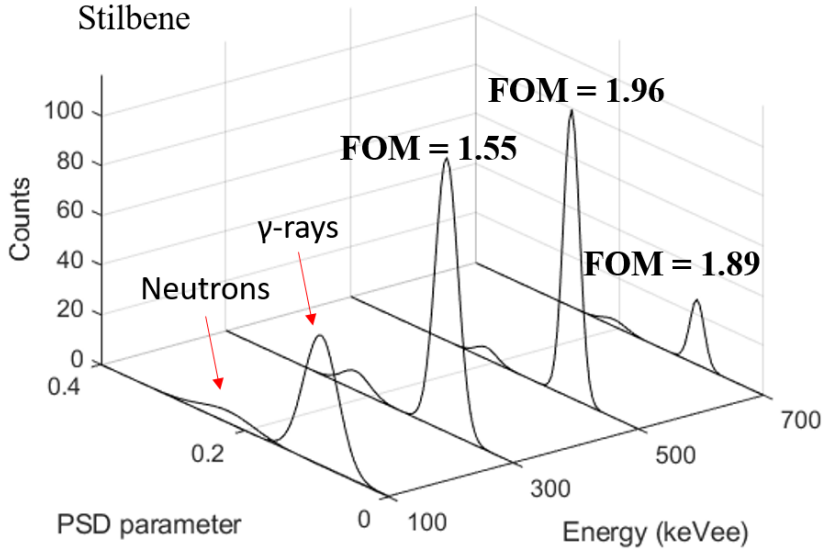
Appendix

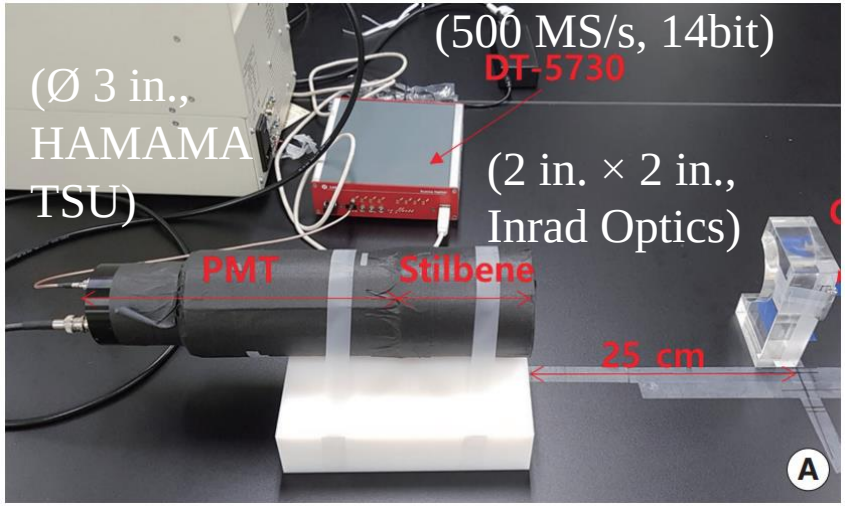
Comparison of PSD performance

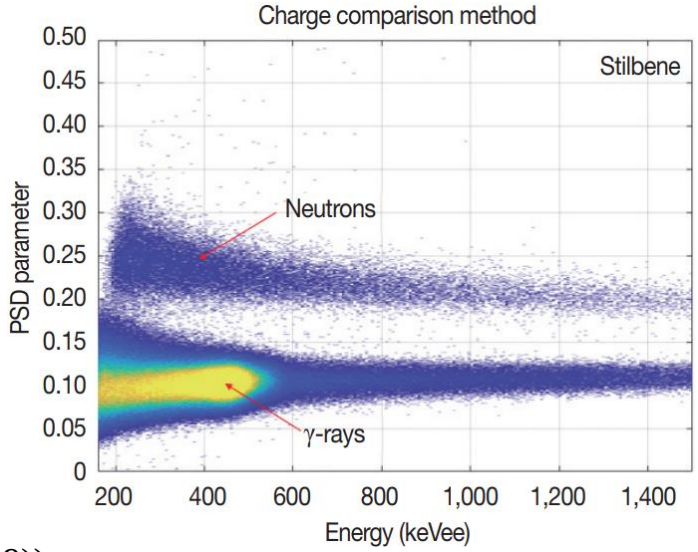


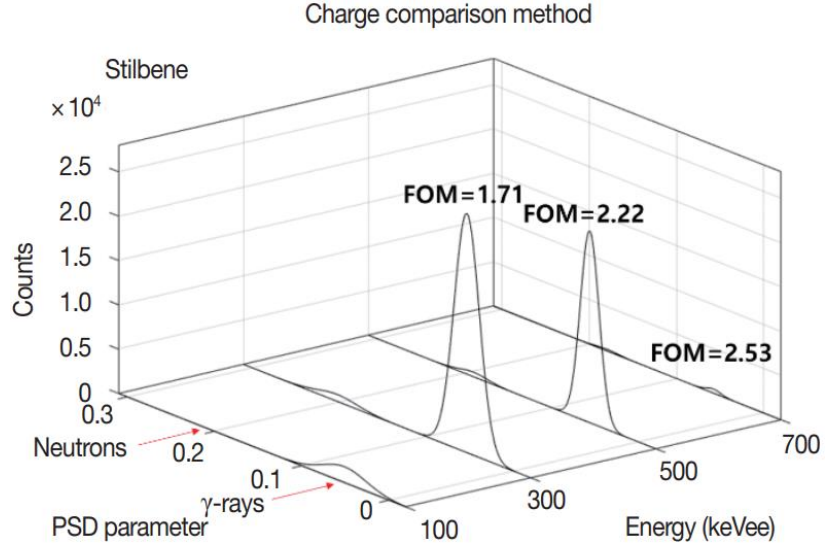
a: Stilbene, 4 × 4 × 20 mm³
b: Reflector (PTFE, 0.2 mm_t)
c: SiPM, 3 × 3 mm²
a: PCB











(Kim, C. et. al., J. Radiat. Prot. Res. Vol. 44, Page: 53 (2019))

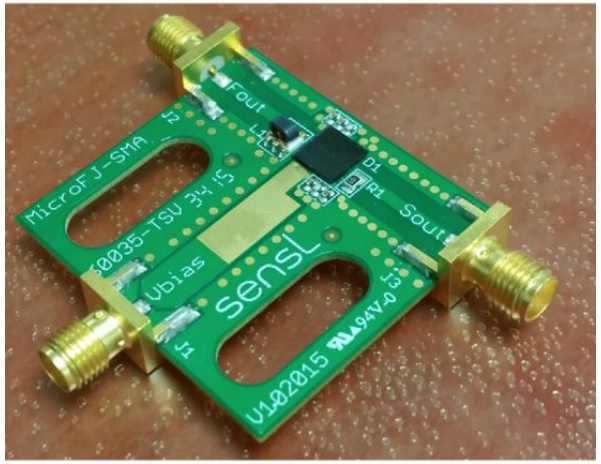
Appendix

Comparison of PSD performance

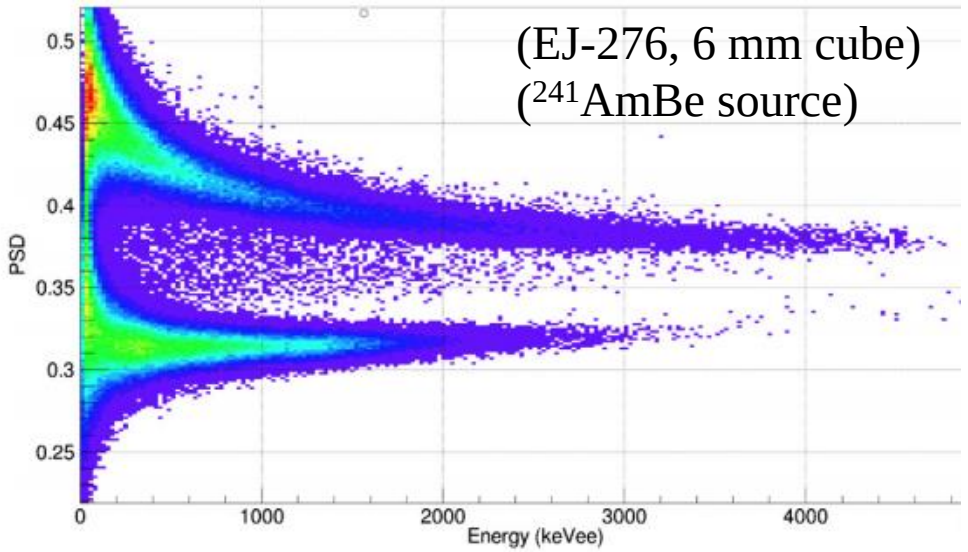
Some example SiPM characteristics for the SensL C- and J-series.

SiPM	λ_{min} (nm)	λ_{max} (nm)	No. of microcells	Fill factor
C	300	950	18,980	64%
J	200	900	22,292	75%

SensL MicroFJ-SMA



(500 MS/s, 14bit)



(EJ-276, 6 mm cube)
(^{241}AmBe source)

(Taggart, M. P. et. al., Nucl. Instrum. Meth. A, Vol. 908, Page: 148 (2018))