Characterization of monolithic GAGG:Ce for gamma imaging in Nuclear Medicine

SAPIENZA
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Summary

Equipment innovation:

- Scintillation Crystal: Size recently available of monolithic GaGG:Ce
- Readout electronics: new technology SiPM

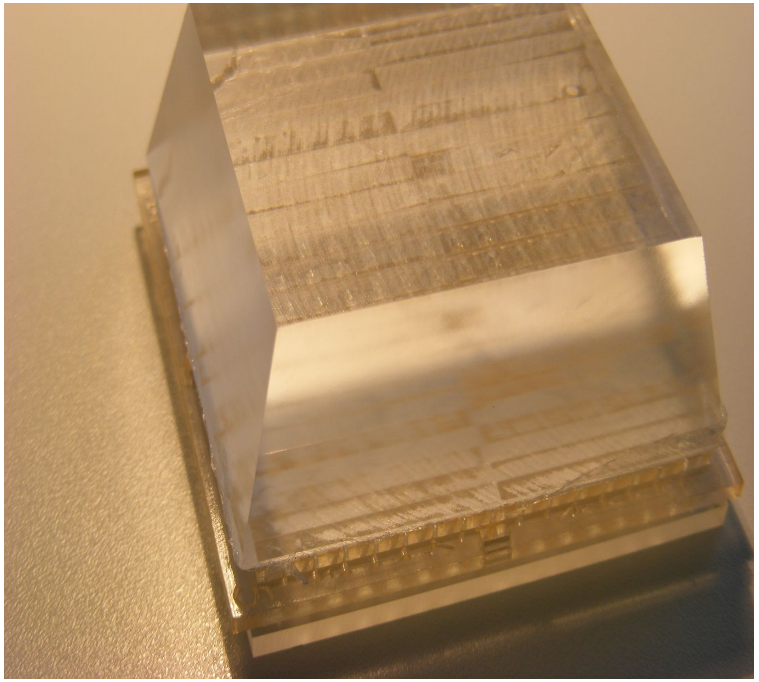
Experimental measurements:

monolithic GaGG:Ce coupled to PS-SiPM { Energy Resolution (SR) / Spatial Resolution (SR)

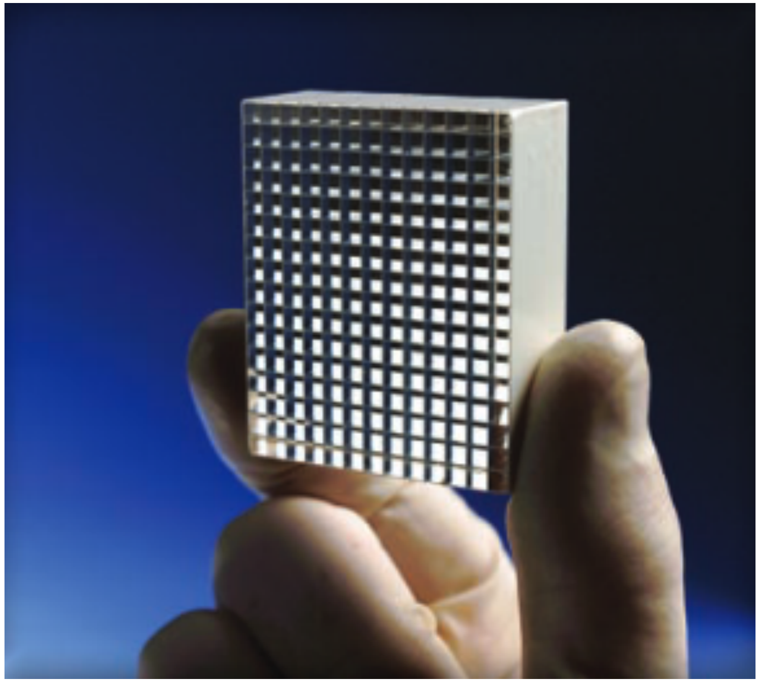
Scintillation Crystal

2 possible configurations
scintillation imager dilemma

Monolithic Crystal



Pixelated Crystal



Scintillation Crystal

2 possible configurations
scintillation imager dilemma

Monolithic Crystal

Pros
Excellent light output
Good energy resolution
No limit to the spatial resolution
Costs of production

Cons
Poor position linearity
Harder imaging reconstruction
Depth-dependent spatial resolution

Pixelated Crystal

Pros
Excellent position linearity
Good spatial resolution
Easier image reconstruction
Depth-independent spatial resolution

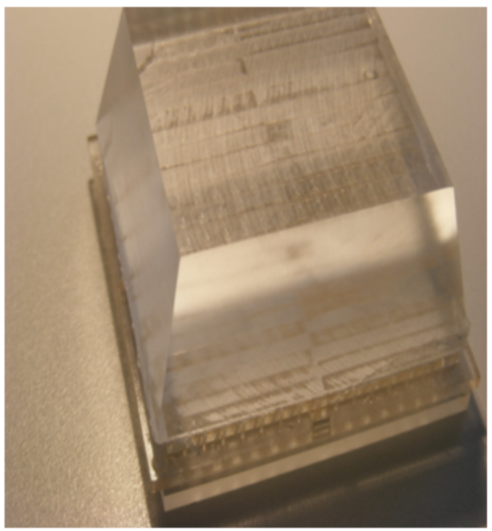
Cons
Poor light output
Limited spatial resolution
Poor energy resolution
Costs of production

The main problem related to monolithic crystals is represented by a linearity compression that can be reduced through proper reconstruction algorithms (bad Centre-of-Gravity)

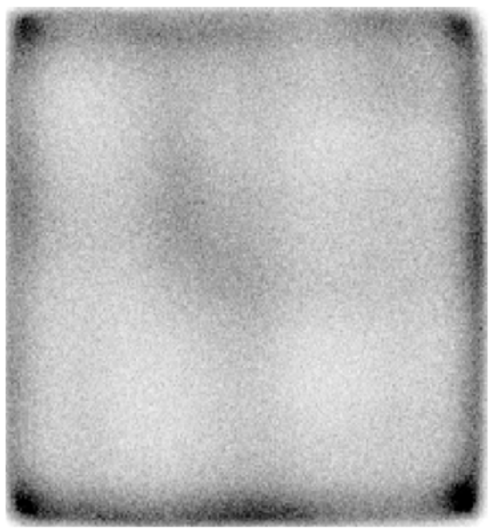
Scintillation Crystal

2 possible configurations
scintillation imager dilemma

Monolithic Crystal

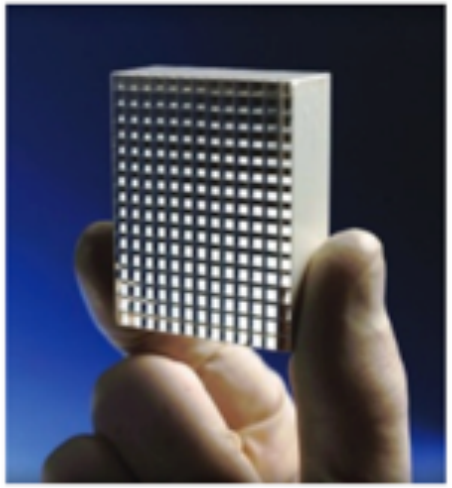


(a) A monolithic crystal

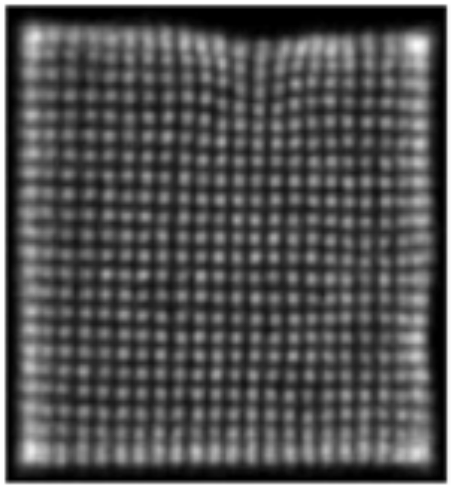


(b) Image from a flood-field

Pixelated Crystal



(a) Array of pixelated crystals



(b) Image from a flood-field

Scintillation Crystal

	CRY-018	CRY-019	LaBr3:Ce	NaI:Tl	GAGG:Ce	LYSO
Density (g/cm3)	4.54	7.1	5.0	3.67	6.6	7.2
Attenuation coefficient (cm-1) @511 keV	0.36	0.83	0.47	0.33	0.62	0.86
Attenuation coefficient (cm-1) @140 keV	1.3	6.3	2.7	2.5	4.8	6.4
Decay time (ns)	45	46	16	230	88	30-35
Index of refraction	1.79	1.81	1.88	1.85	1.9	1.81
ER % @661 keV	7.0	8.0	2.9	6.8	6.7	7.6-8.7
Wavelength of max. emission (nm)	425	420	358	415	540	420
Hygroscopicity	No	No	Yes	Yes	No	No
Light yield (kph/Mev)	30	15-28	63	38	50	30-32

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Choice for SPECT/PET

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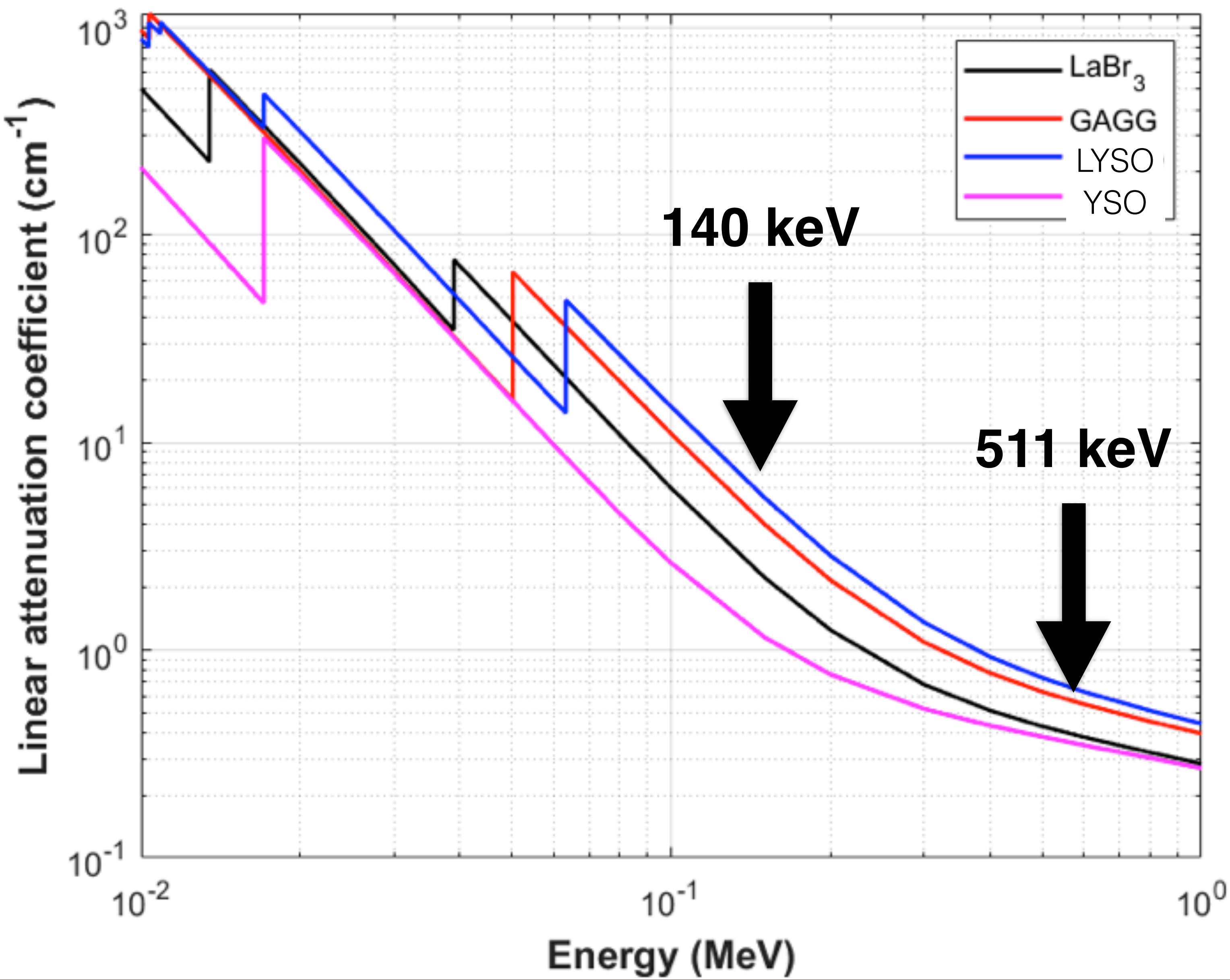
Drawback?

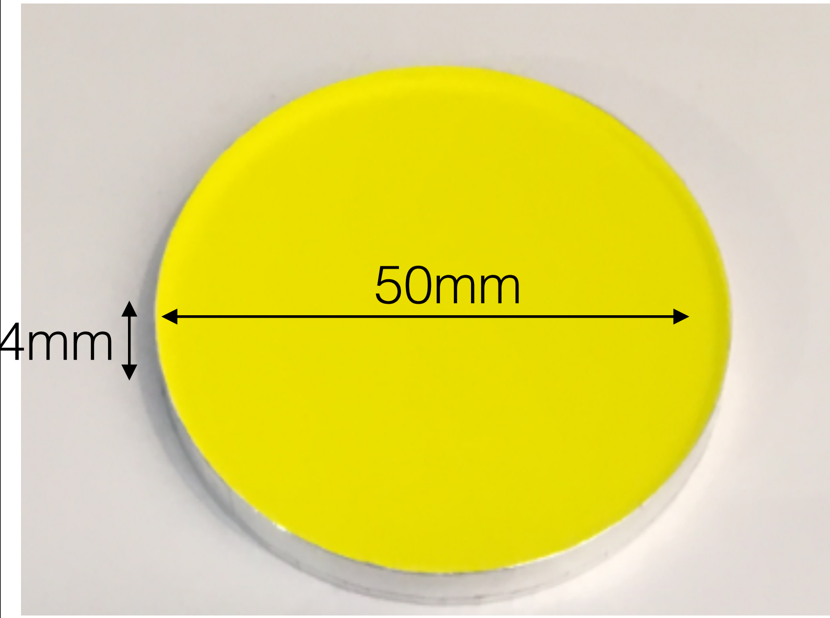
Choice for SPECT/PET

Scintillation Crystal



Scintillation Crystal

Circular monolithic Cerium doped $Gd_3Al_2Ga_3O_{12}$ (GAGG:Ce)
Size recently available! [EPIC Crystal (China)]



Best light output with crystal surface coating of 0.2 mm white paint of BaSO4

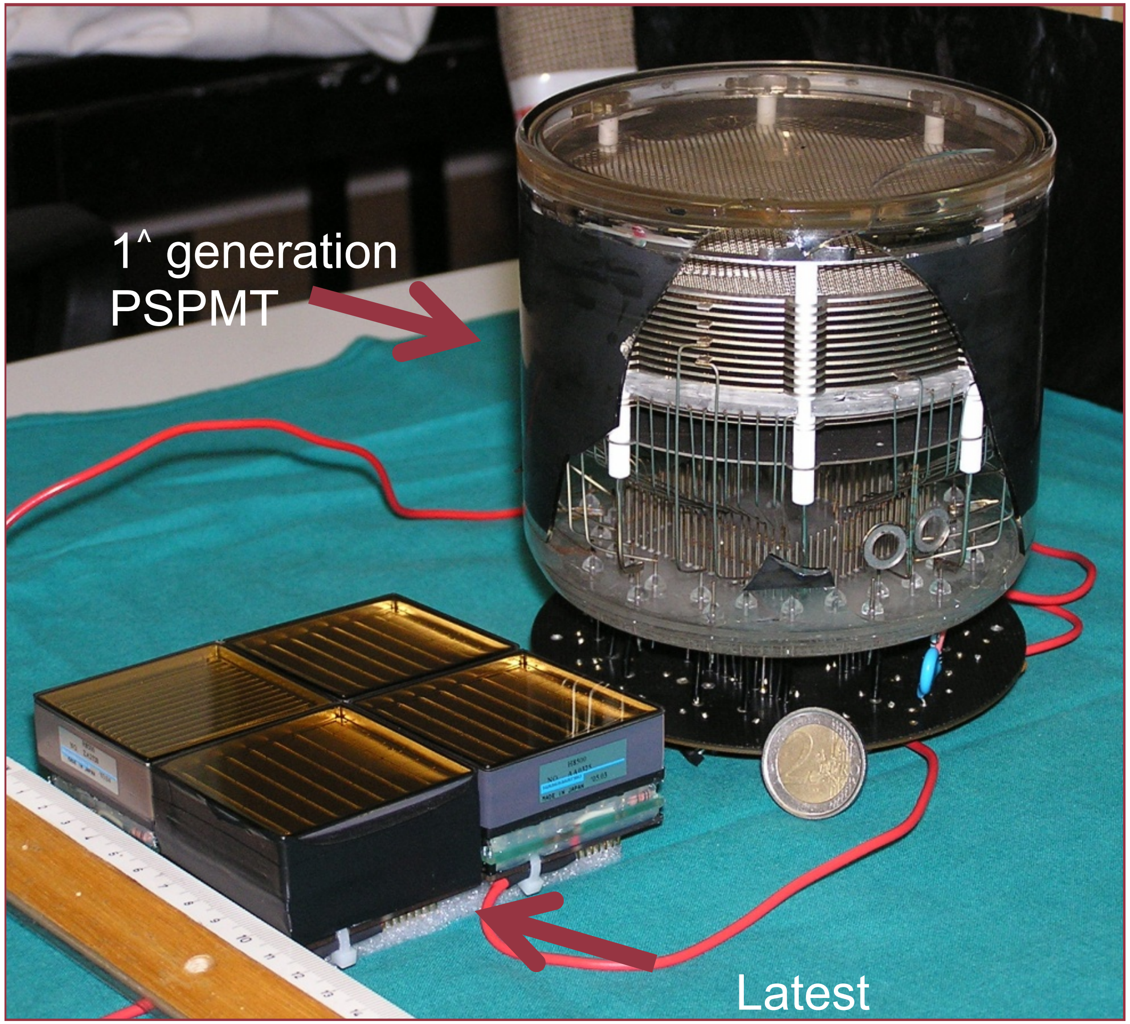
↓

increase of light collection, Expected best Energy Resolution, since the best uniform response in PHA

Behaviour close to spectrometric scintilllation crystal

PS-PMT: 1st generation

Photodetector: Position sensitive Flat Panel PMT H8500 Hamamatsu



PMT and MA-PMT ER

From a work of our group presented in this conference[1]: comparison of PMT and MA-PMT ER

Monolithic crystals (CRY18 and CRY19) with full reflective coating + Hamamatsu PS-PMT

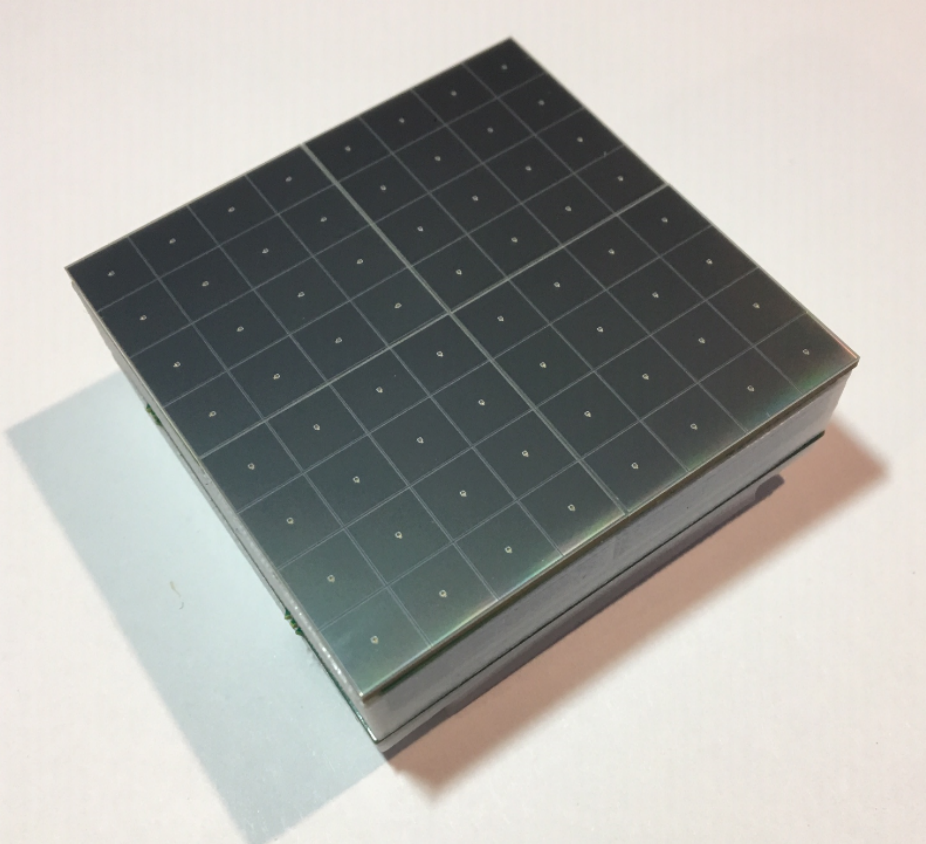
ER(%)=FWHM(%)													
Energy (keV)	PMT		Single Spot min		Single Spot max		64 Spots Sum		Anodic gain correction		Flood	
	CRY18	CRY19	CRY18	CRY19	CRY18	CRY19	CRY18	CRY19	CRY18	CRY19	CRY18	CRY19
31	13.0	23.0	24.3	/	37.6	/	27.8	/	/	/		
81	13.5	16.2	19.0	/	25.3	/	20.1	/	/	/		
122	12.7	15.3	15.9	20.7	17.5	23.7	17.3	22.5	16.5	21.5	17.1	21.0
356	8.5	10.07	8.0	/	12.4	/	12.0	/	/	/		
662	6.5	7.6	/	9.4	/	12.6	/	12.5	/	/	10.5*	15.1*

Example of ER degradation due to variability of single anodes gain

[1] Pellegrini et al., Imaging performance dependence on crystal absorption properties: the CRY018 and CRY019 comparison, poster @IPRD2019

State of the art SiPM

PS-SiPM: HAMAMATSU MPPC S14160 Series

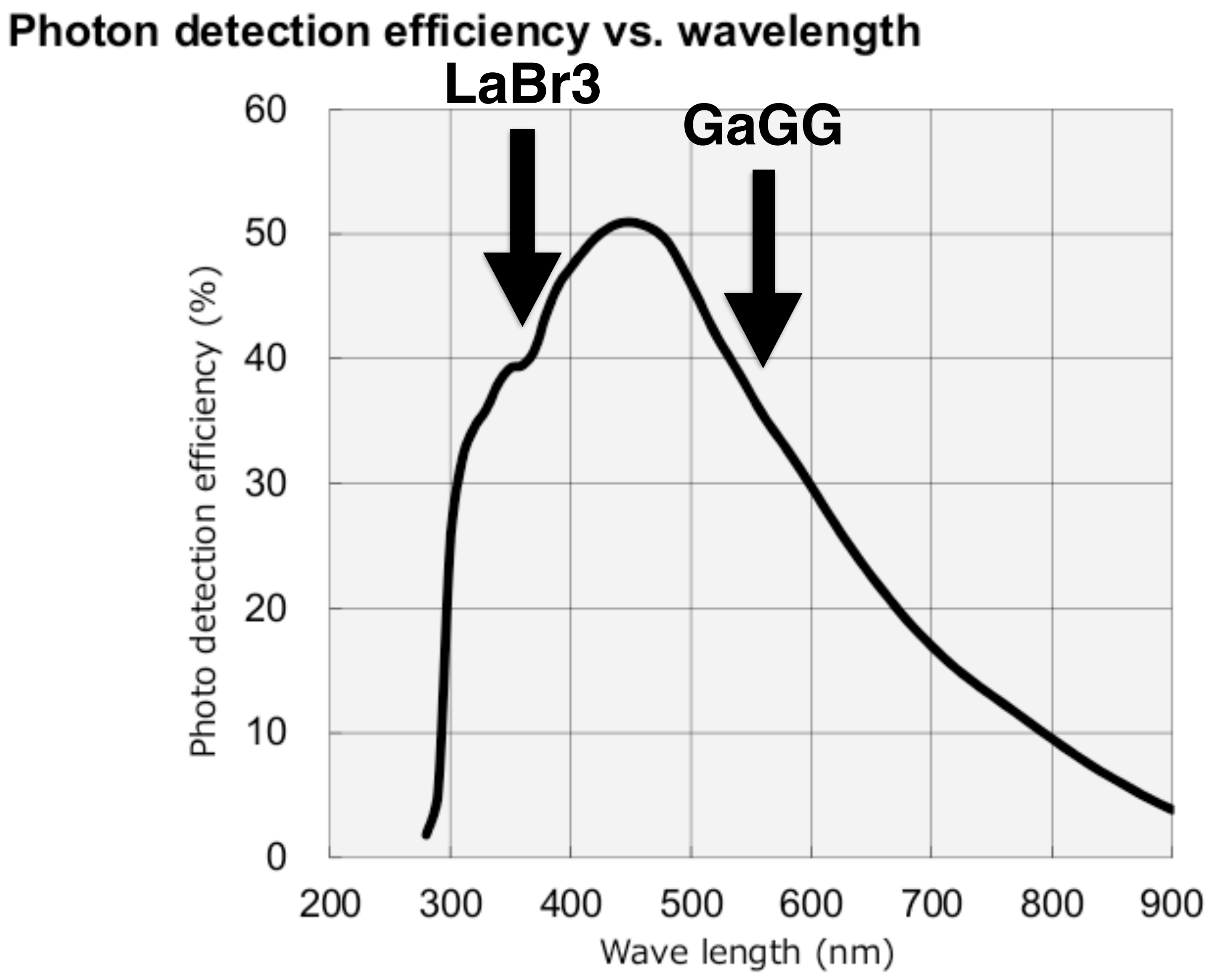


50x50mm2 Photodetector assembly – 64 independent chains

- HWB (Hole Wire Bonding) tecnology
- **geometrical fill factor: 74%**
- temperature range: da -40 a +85 °C
- peak sensitivity: 450 nm
- **PDE: 50% (25% improved)**
- operating voltage: 40V
- Gain : 2.5 x 10^6 (47% improved)
- Temperature coefficient: 34mV/°C
- Cost : about 600 Euro

SiPM allows calibration for each anodes, as usual gamma cameras → with proper calibration reduced the inter-anode gain variability (about 2%) → improvement of ER(%) / Uniform positioning response

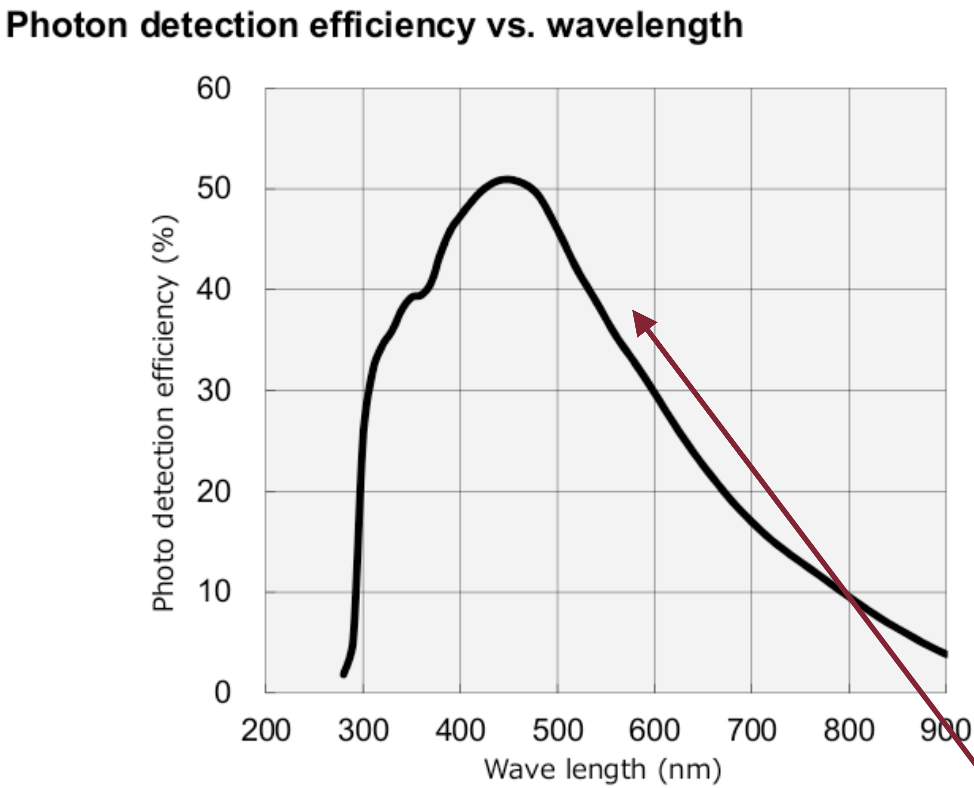
PS-SiPM PDE



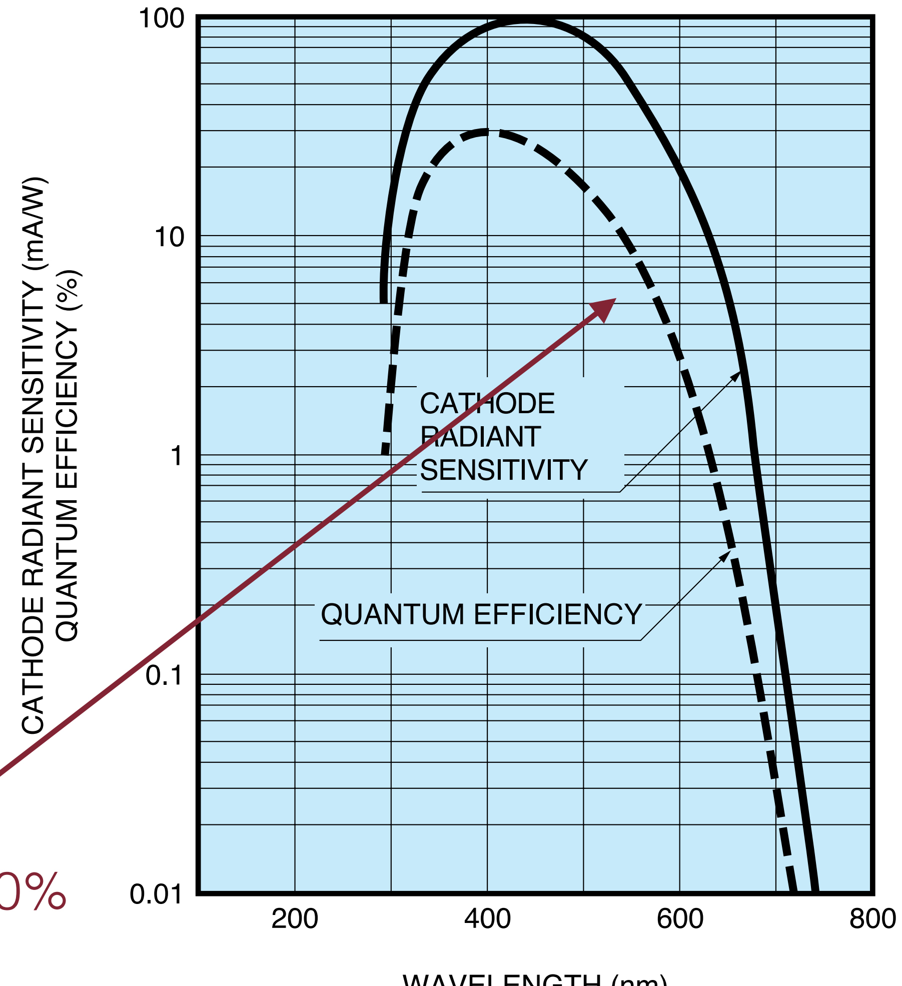
Photon detection efficiency vs. wavelength
LaBr3
GaGG
60
50
40
30
20
10
0
Photo detection efficiency (%)
200
300
400
500
600
700
800
900
Wave length (nm)

Comparison MA-PMT / SiPM

SiPM



PMT [2]

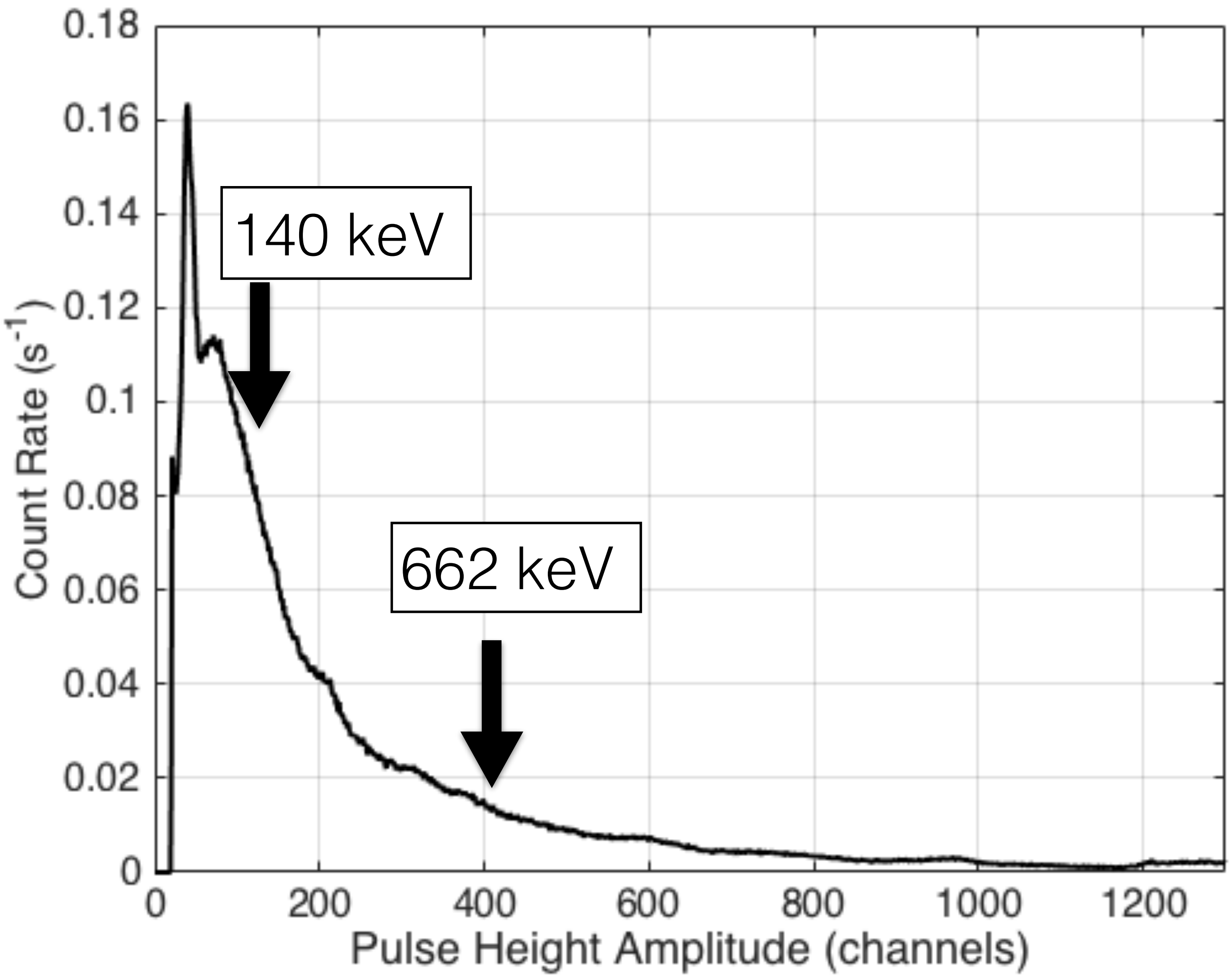


@540 nm: 38% vs <10%

[2] Hamamatsu, Photomultiplier Tubes: Construction and Operating Characteristics Connections to External Circuits

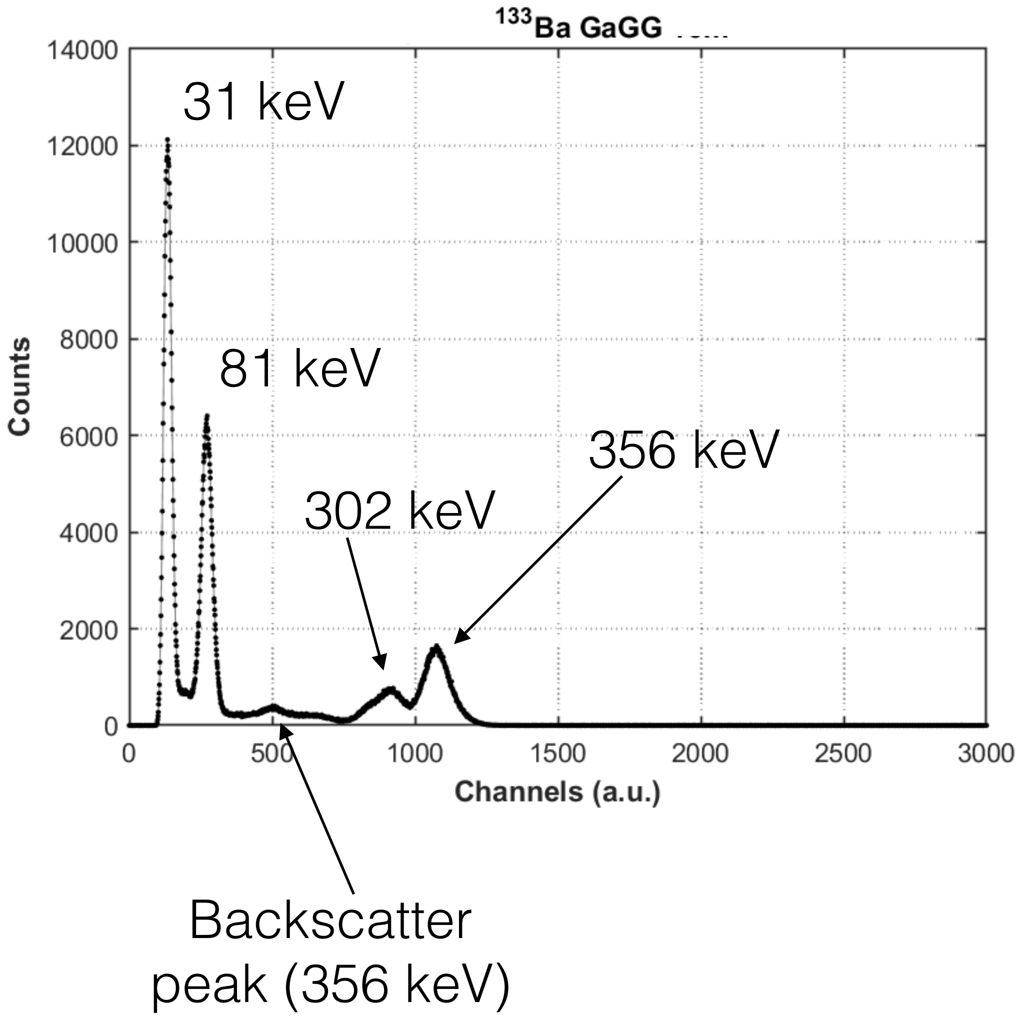
GaGG:Ce Background activity

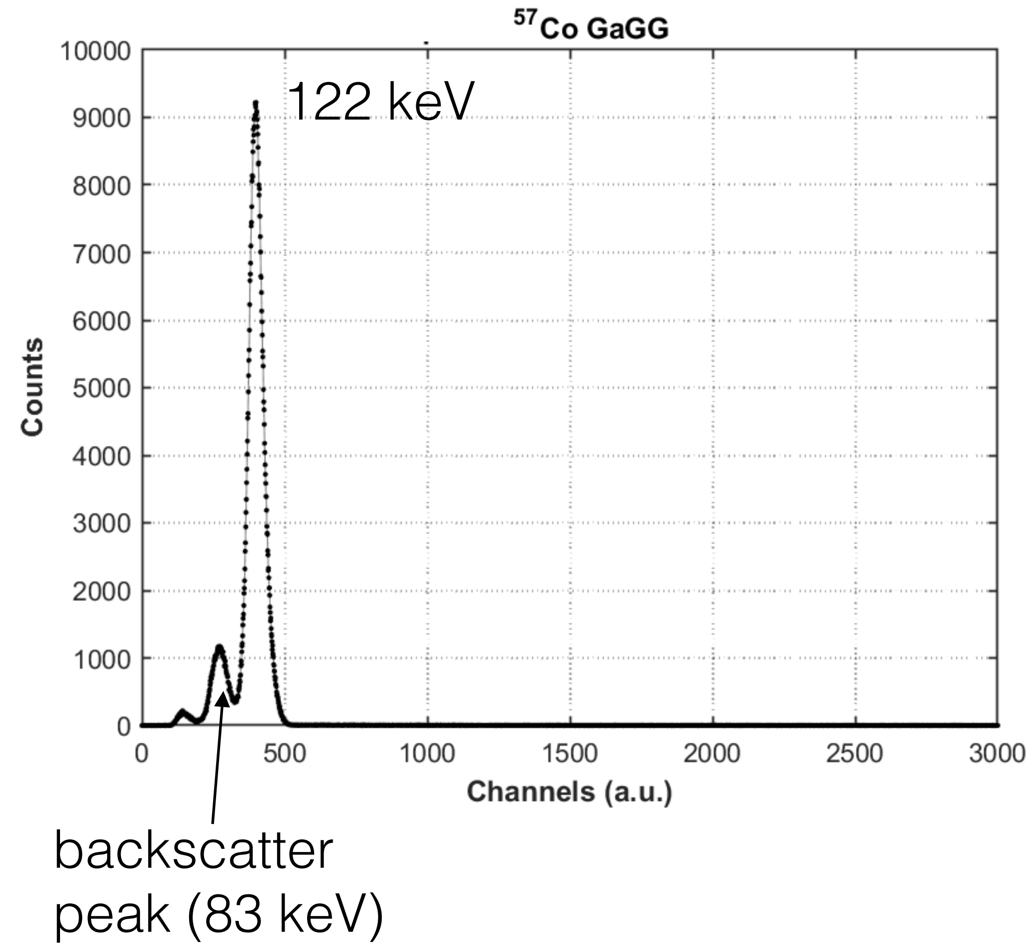
Background Radioactivity measure (>24h)



GaGG Spectra

monolithic GaGG:Ce with full reflective coating coupled to PS-SiPM





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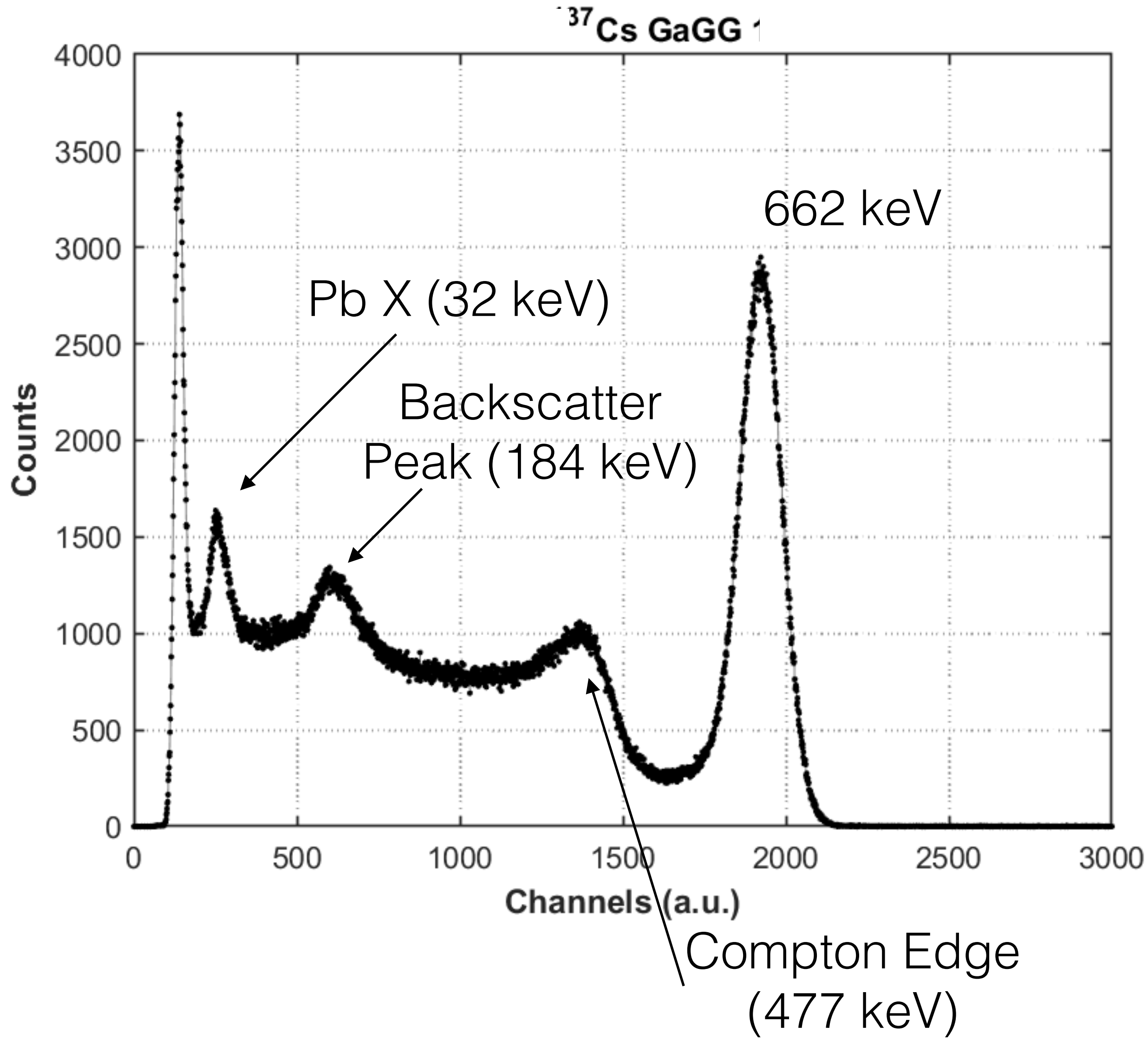
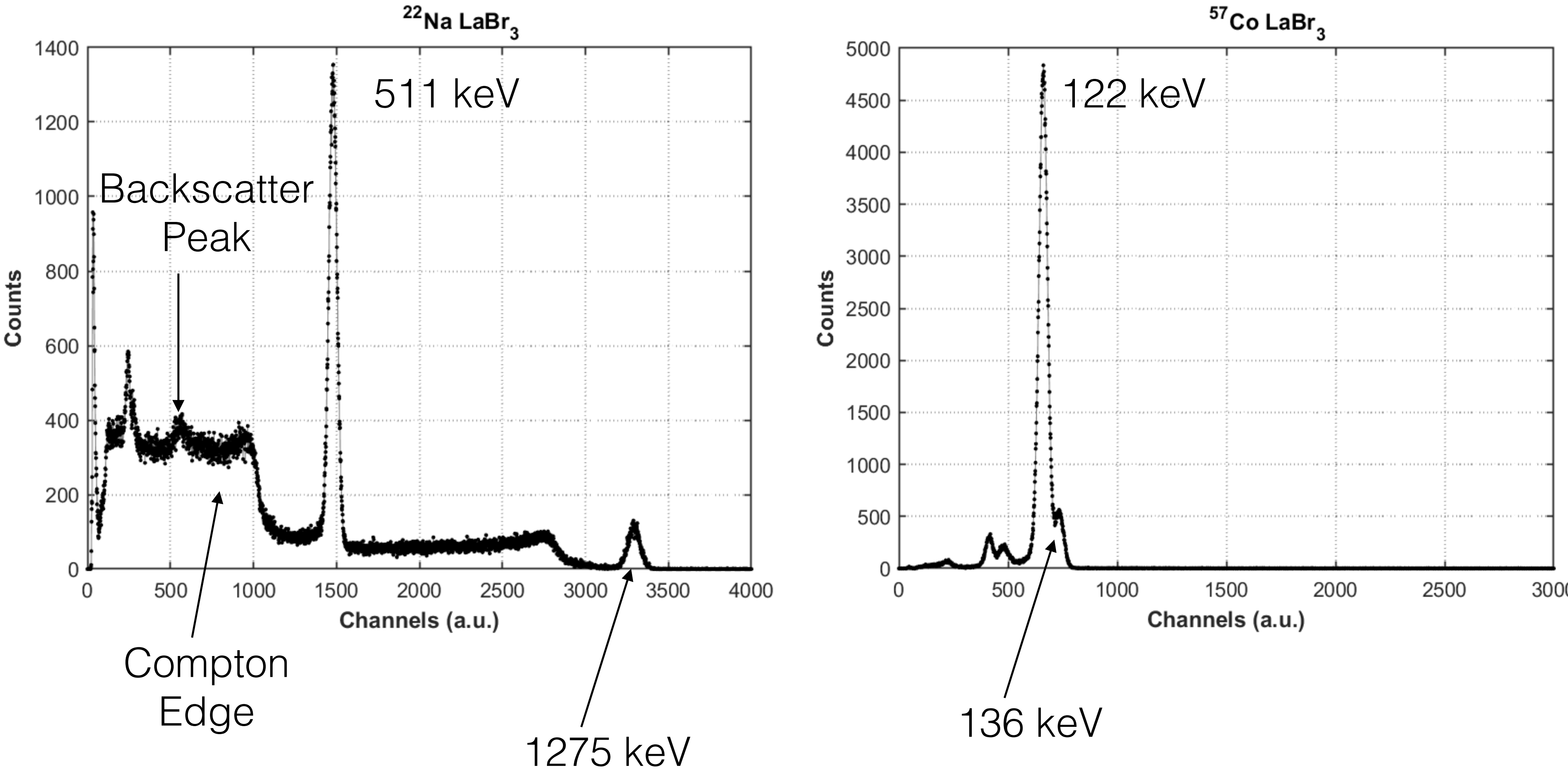


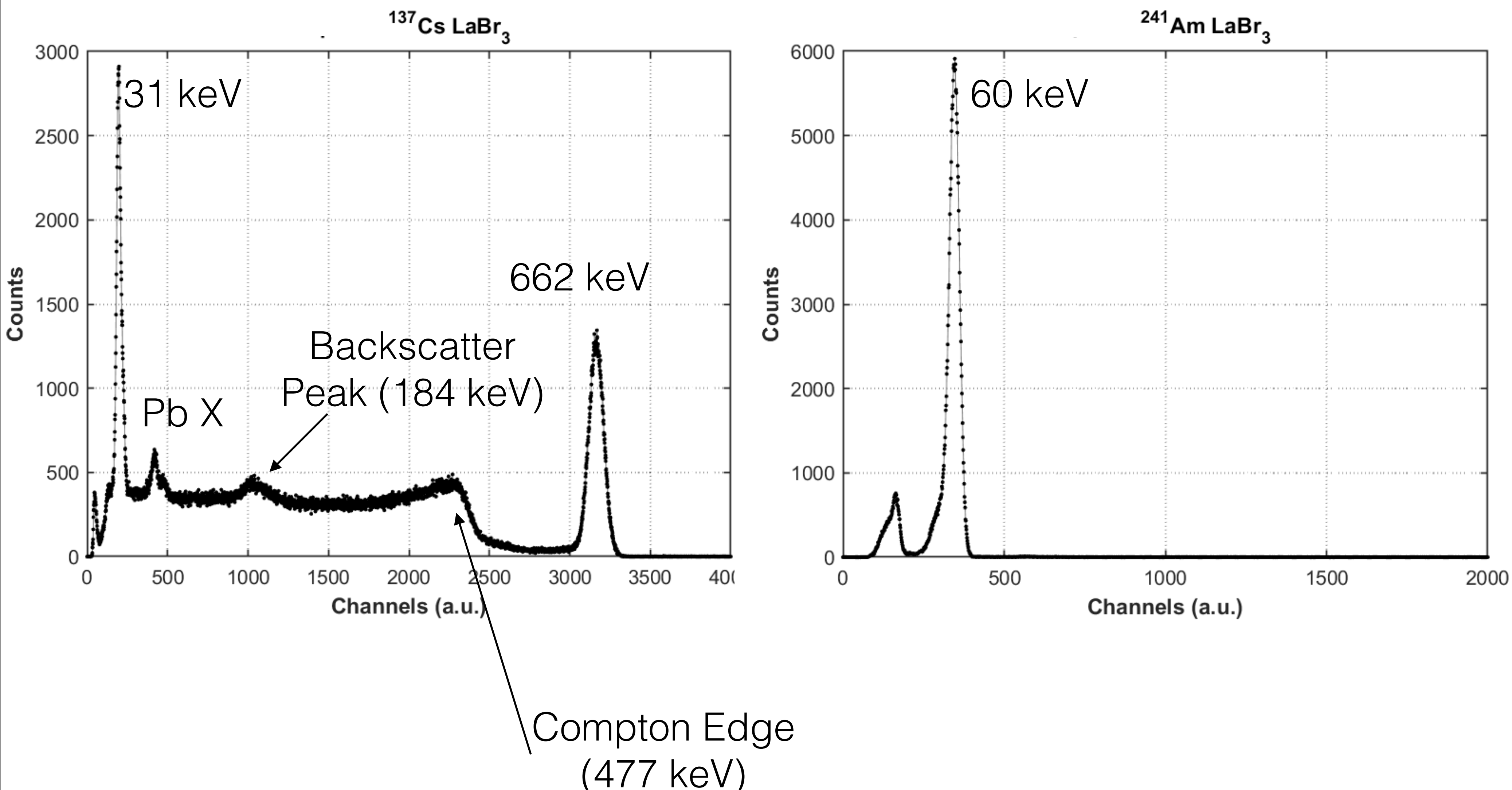
LaBr3:Ce Spectra

monolithic LaBr3:Ce with full reflective coating coupled to PS-SiPM



LaBr3:Ce Spectra

monolithic LaBr3:Ce with full reflective coating coupled to PS-SiPM



GaGG:Ce ER

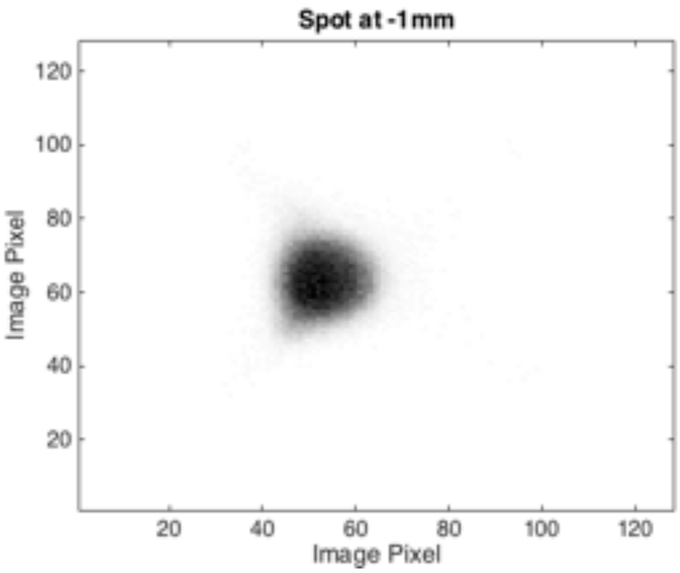
Energy (keV)	ER (%) GaGG:Ce+PS:SiPM	ER(%) PMT+GaGG:Ce
31	30	-
81	18	-
122	13	15
662	6.7	7.6

Imaging

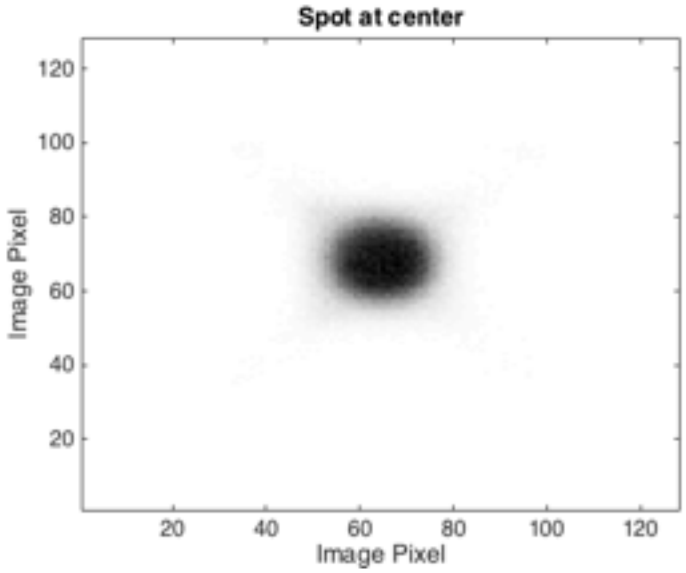
monolithic GaGG:Ce with full reflective coating coupled to PS-SiPM

Three spots with 1mm collimated ^{99m}Tc source

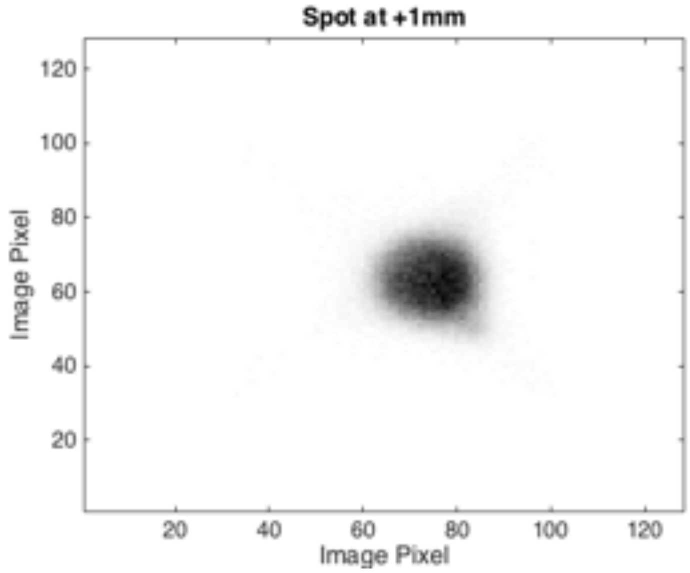
Crystal center-1mm (24mm)



Crystal center



Crystal center+1mm (26mm)

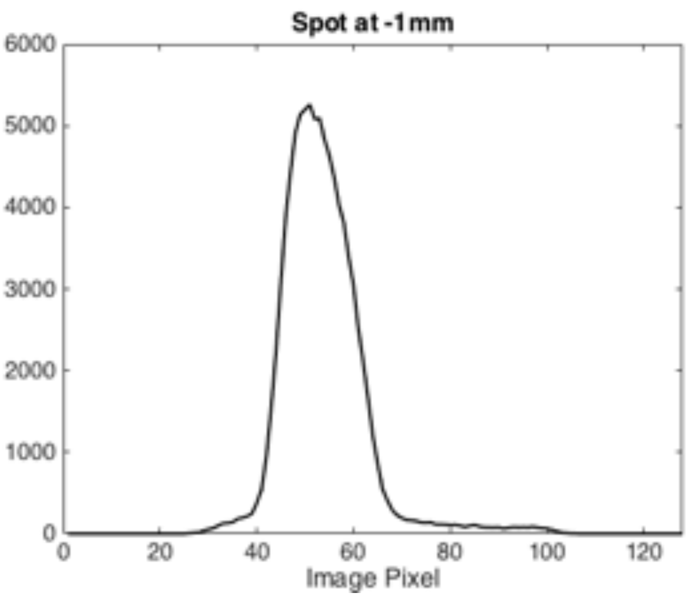


Imaging

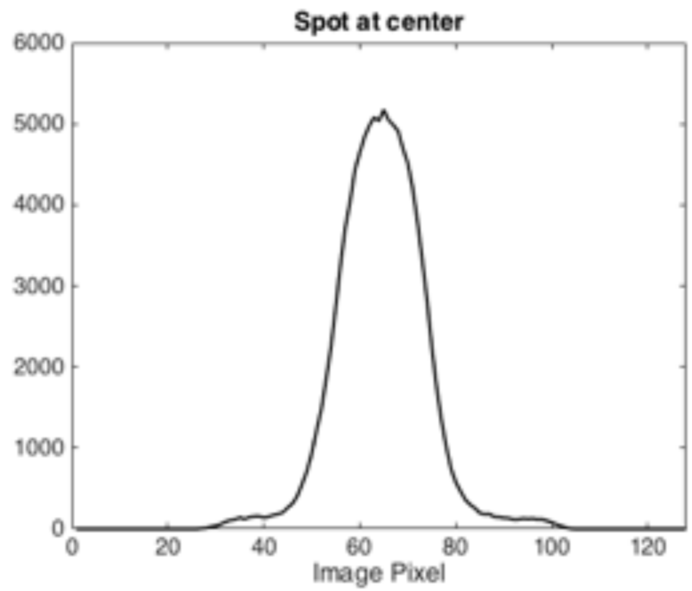
monolithic GaGG:Ce with full reflective coating coupled to PS-SiPM

Three spots with 1mm collimated ^{99m}Tc source

Crystal center-1mm (24mm)



Crystal center



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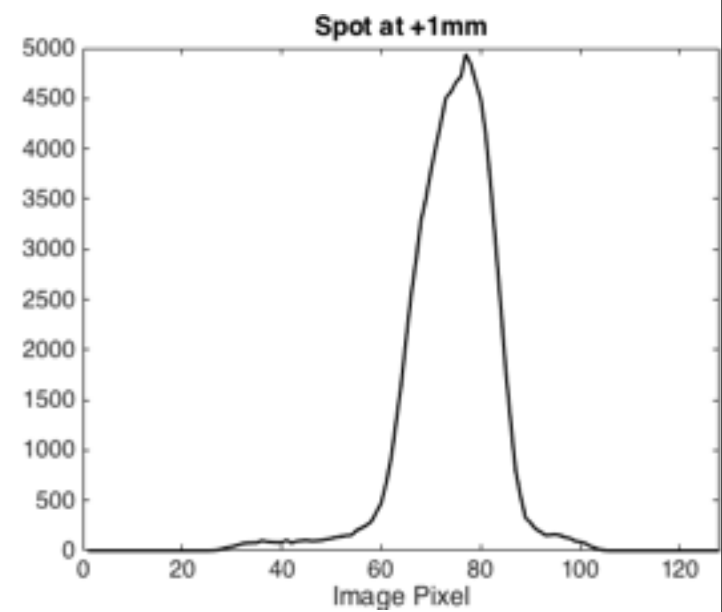


FWHM = 1.4mm

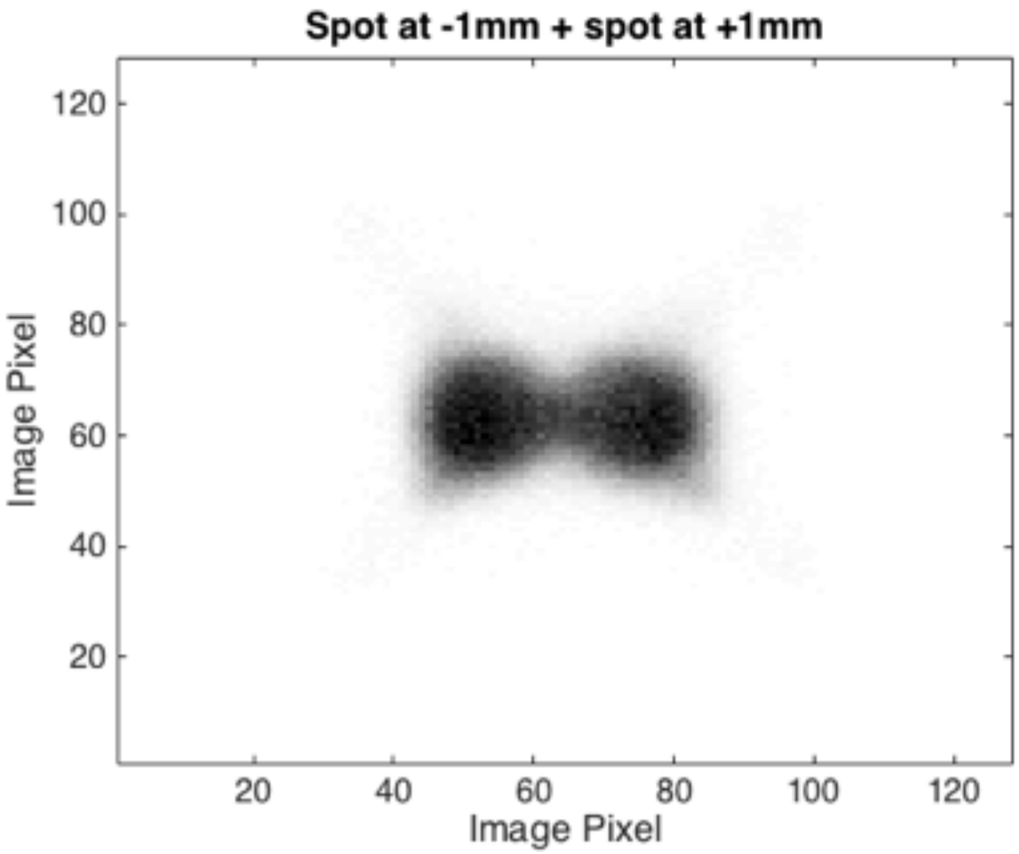
$$iSR = \sqrt{SR_{TOT}^2 - SR_{COLL}^2}$$

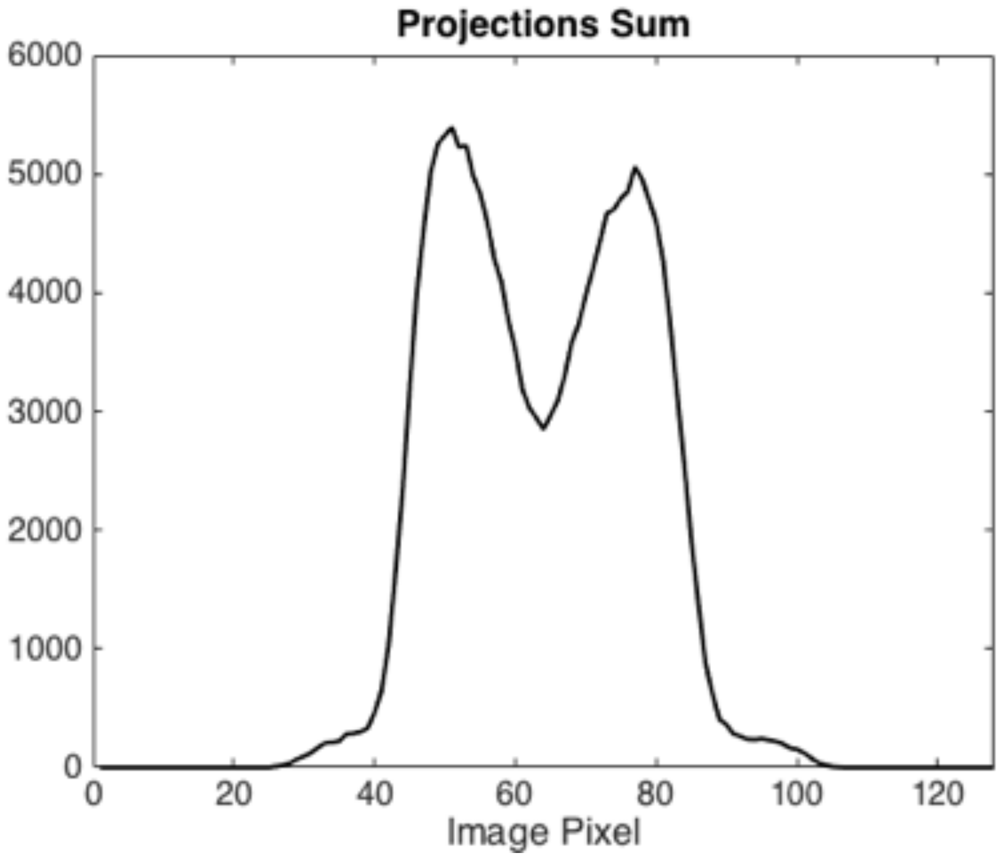
iSR < 1mm

Imaging

monolithic GaGG:Ce with full reflective coating coupled to PS-SiPM

Sum of spot -1mm and spot+1mm





Conclusion

Scintillation Crystal: recently available GaGG:Ce advantage

- high density (i.e. high efficiency)
- low decay time (low dead time, pet application and SiPM match)
- high light yield, best ER with full reflective coating (similar to LYSO, but no self-act)
- no self-activity
- no hygroscopic
- Maximum Emission Wavelength (nm) close to SiPM max PDE (guardare forma emissione luce GaGG)

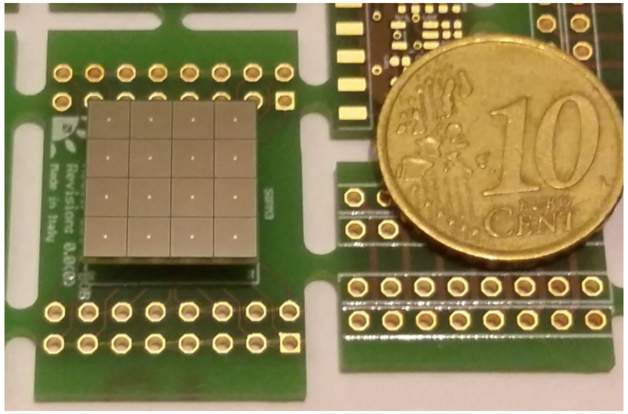
Photodetection System: last PS-SiPM generation advantages

- high PDE (50%)
- no optical guide (only 0.2 mm window)
- geometrical fill factor (74%)
- as for gamma cameras, possibility of single anode calibration (gain variability reduction->high ER)

GaGG:Ce coupled to PS-SiPM -> high performance measured (efficiency, ER, SR) spatial resolution better than 1mm, good PHA uniformity response

Backup

PS-SiPM



Hamamatsu SiPM:
Active area for channel: 3 mm
50 m pitch
35 PDE
Spectral range 320 ÷900 nm
Gain: 1.2 *106

SiPM does not need intrinsic light guide since SiPM have a very small dead area

Energy Resolution

The detection process of γ-rays in scintillation detectors can be described by a chain of subsequent processes which introduce uncertainty in the measured energy as a result of γ-rays absorbed in the detector. These processes can be identified as

1) **γ-ray absorption and light generation in the crystal**
2) **photoelectron production at the photo-cathode (PDE)**
3) **photoelectron collection at the first dynode**
4) multiplication by the PMT dynodes

$$(\Delta E/E)^2 = (\delta_{sc})^2 + (\delta_p)^2 + (\delta_{st})^2 + (\delta_n)^2$$

- $(\delta_{sc})^2$: crystal intrinsic resolution
- $(\delta_p)^2$: transfer resolution
- $(\delta_{st})^2$: statistical contribution
- $(\delta_n)^2$: dark noise (detector's current and electronics noise)

$$\delta_{st} = 2.35 \times 1/N^{1/2} \times (1+\varepsilon)^{1/2}$$

N=photoelectrons number, **ε** variance of gain

PS-PMT

The collection efficiency of the first dynode about 95% for PMT, which decreases to 60-70% for MAPMT

[fonte?]

reason: loss of electron collection, and therefore RE poorer

SiPM fotorivelatore offre RE uguale o superiori a PMT standard per spettrometria

Col GaGG possiamo realizzare gamma camera con risposta spettrometrica confrontabile con lo standard PMT [zone morte ridotte al minimo]

controllo guadagni equalizza anche risposte in posizione