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CeBr₃ scintillator for imaging application: comparison between MAPMT and SiPMs array

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Introduction: In this work we compare the imaging properties of a CeBr₃ crystal when optically coupled to a multi anode PMT (MAPMT) and to a SiPMs array, in comparison with a LaBr₃:Ce with similar shape and optical properties. CeBr₃ is a very promising candidate for gamma imaging applications representing an effective alternative to LaBr₃:Ce. As a matter of fact, it not only provides detection properties (light yield, stopping power, decay time and maximum wavelength of emission) comparable to that of LaBr₃:Ce, at a considerably reduced production cost, but the absence of Lanthanum avoids self activity from the crystal.

The tested scintillators and photodetectors

The crystals

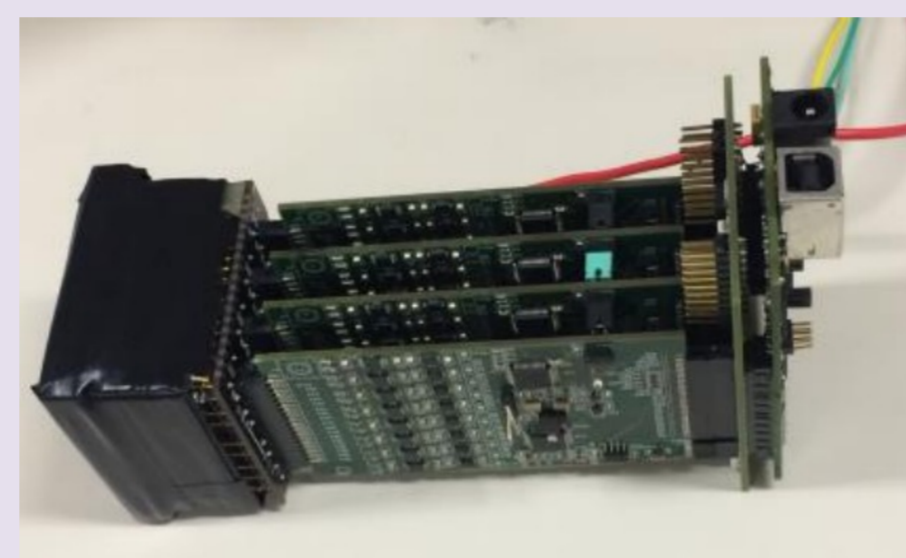
- CeBr₃ 51mm x 51mm x 6mm by Scionix. Diffusive/reflective edges and back plane
- LaBr₃:Ce 51mm x 51mm x 6mm by Saint Gobain. Diffusive/reflective back plane and absorbent edges

Scintillators are sealed in an aluminum housing equipped with quartz windows (2-mm thick for the CeBr₃ and 1-mm thick for the LaBr₃:Ce)

	LaBr ₃ :Ce	CeBr ₃
Light Yield (ph/MeV)	63 000	60 000
Decay Constant (ns)	16	19
Wavelength of emission (nm)	380	380
ΔE/E @ 662 keV (%)	2.9	3.8
Proportionality	Good	Good

The MAPMT

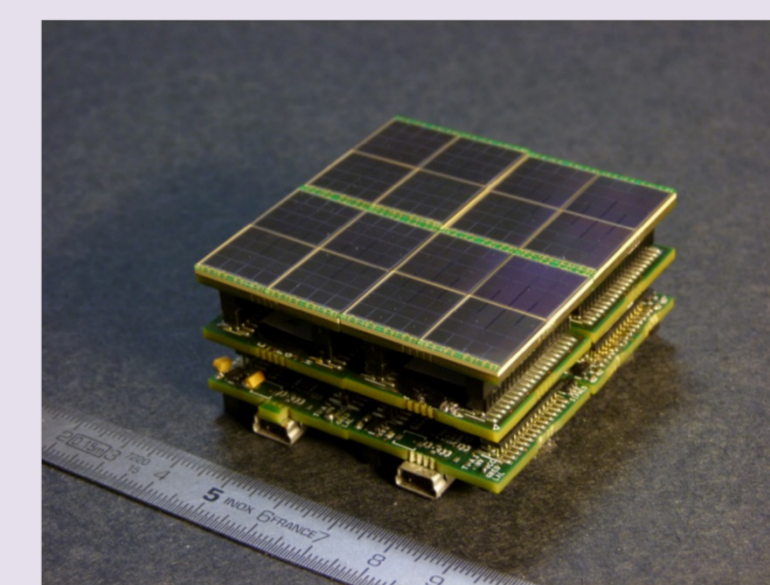
- Hamamatsu 10966-100: 51mm x 51mm entrance window (49mm x 49mm active area), Q.E. ~ 34% @ 380 nm, 8-stages, 8x8 multianode (5.8mm x 5.8mm anode size)



- The electronic readout reads all 64 channels simultaneously.
- Free-run acquisition at a fixed frequency of 100 kHz
- Event-by-event energy selection applied by the digital control implemented in the FPGA
- Threshold is pre-settable by the control software and it is also used to exclude those sampling intervals where no event detection has occurred

The SiPMs array

- 256 SiPM matrix made of 16 Hamamatsu S11828-3344M monolithic arrays, 3mm x 3mm SiPMs, 50μm x 50μm cell size



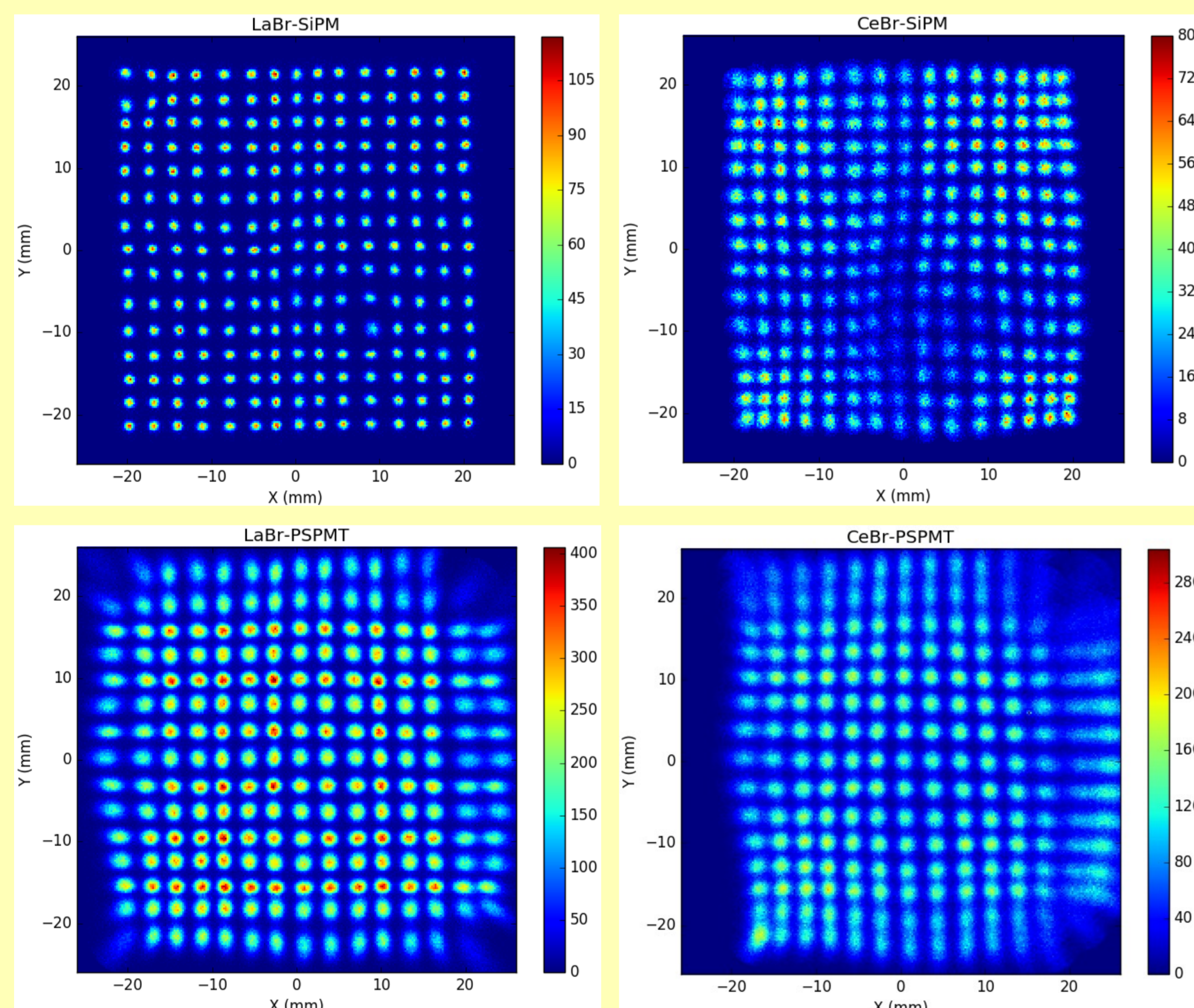
The electronic contains two 32 channels EASIROC ASICs with fully analogical front end electronics dedicated to gain trimming and readout of the SiPMs

- The analog data are digitized by an external two-channel ADC (12 bits and 2Msamples/s)
- The four modules are mounted on two 256 channels motherboards combining an FPGA, an USB interface and the power supplies
- The 0-4.5V range 8-bit input DAC embedded at the ASIC input allows to adjust individually the SiPM bias voltage

Imaging properties and spatial resolution

We used a collimated ⁵⁷Co gamma-ray source in order to evaluate the imaging properties of the CeBr₃ and LaBr₃:Ce based gamma cameras. The source was fixed on a platform that can be moved along the x- and the y-axes via stepper motors. We performed a 3 mm step-scanning with a 0.5 mm (SiPM) or 1 mm (PSPMT) hole collimator to evaluate the detector linearity and spatial resolution on the whole field of view.

Images were reconstructed with two methods : center of gravity of the charge distribution raised to the power two and an iterative fitting method based on an analytical model of the light distribution (Scrimger Becker).



Iterative fitting method	Spatial Resolution (mm)	STD (mm)	BIAS (mm)	STD (mm)
PSPMT- CeBr	1.59	0.51	0.46	0.43
PSPMT- LaBr ₃	1.25	0.43	0.35	0.42
SiPM- CeBr	1.55	0.34	0.52	0.57
SiPM- LaBr	0.84	0.09	0.41	0.33

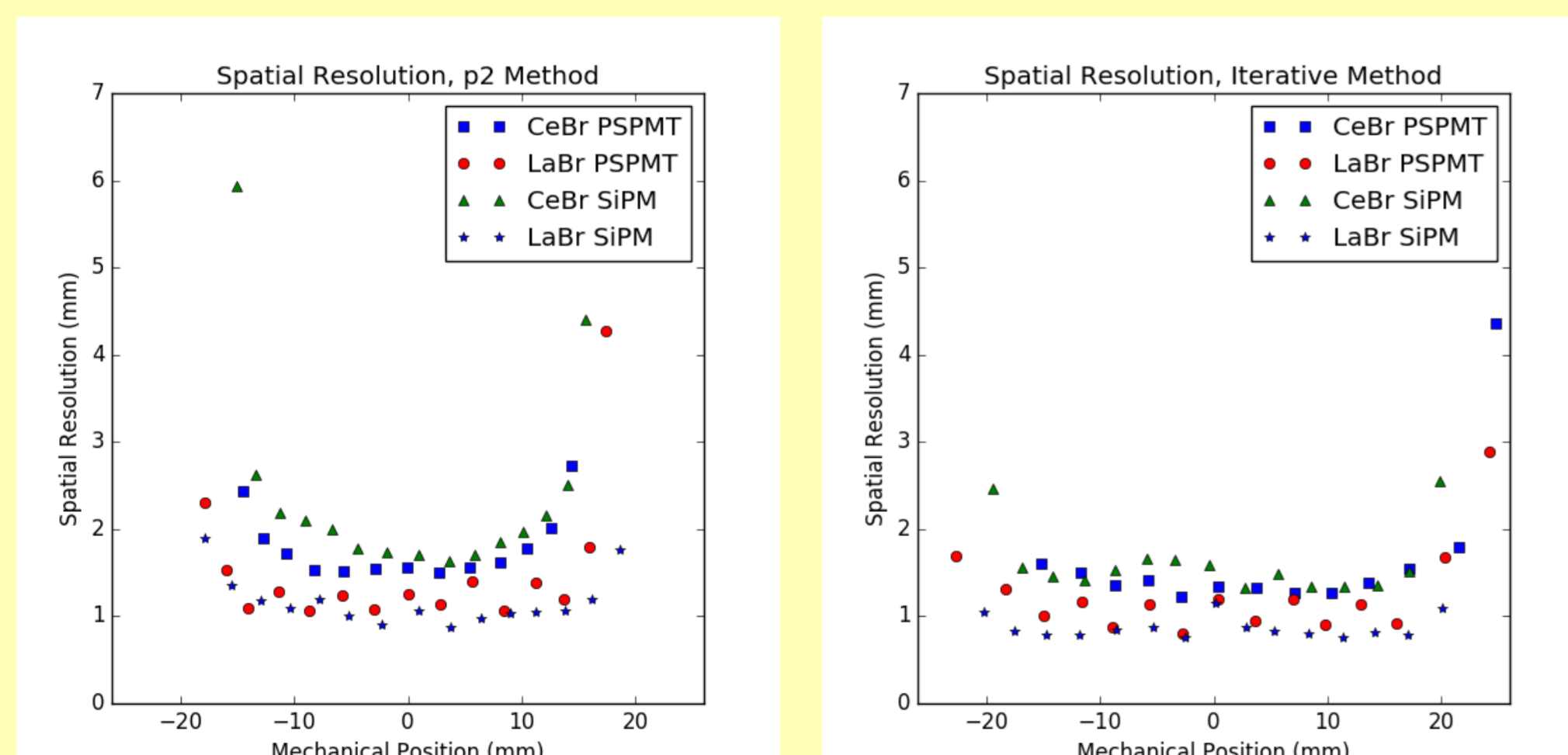
Images of the scan obtained by using the iterative fitting methods

Mean SR values were obtained in the central area of the detectors after correction of the local bias and deconvolution of the size of the collimator. The mean bias is given for the whole FoV

Power 2 CoG	Spatial resolution (mm)	STD (mm)	BIAS (mm)	STD (mm)
PSPMT+ CeBr	1.77	0.48	0.90	1.36
PSPMT+ LaBr	1.29	0.30	0.94	1.47
SiPM+ CeBr	2.14	0.33	0.79	1.12
SiPM+ LaBr	1.14	0.12	0.45	0.61

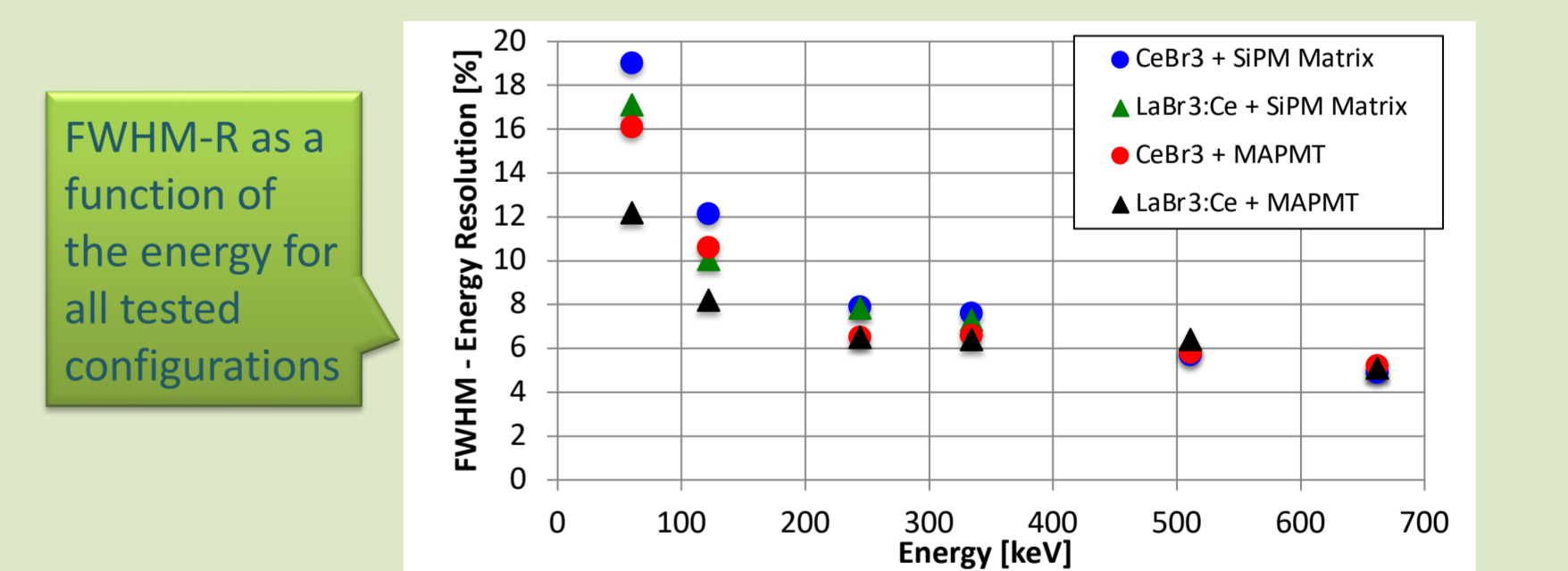
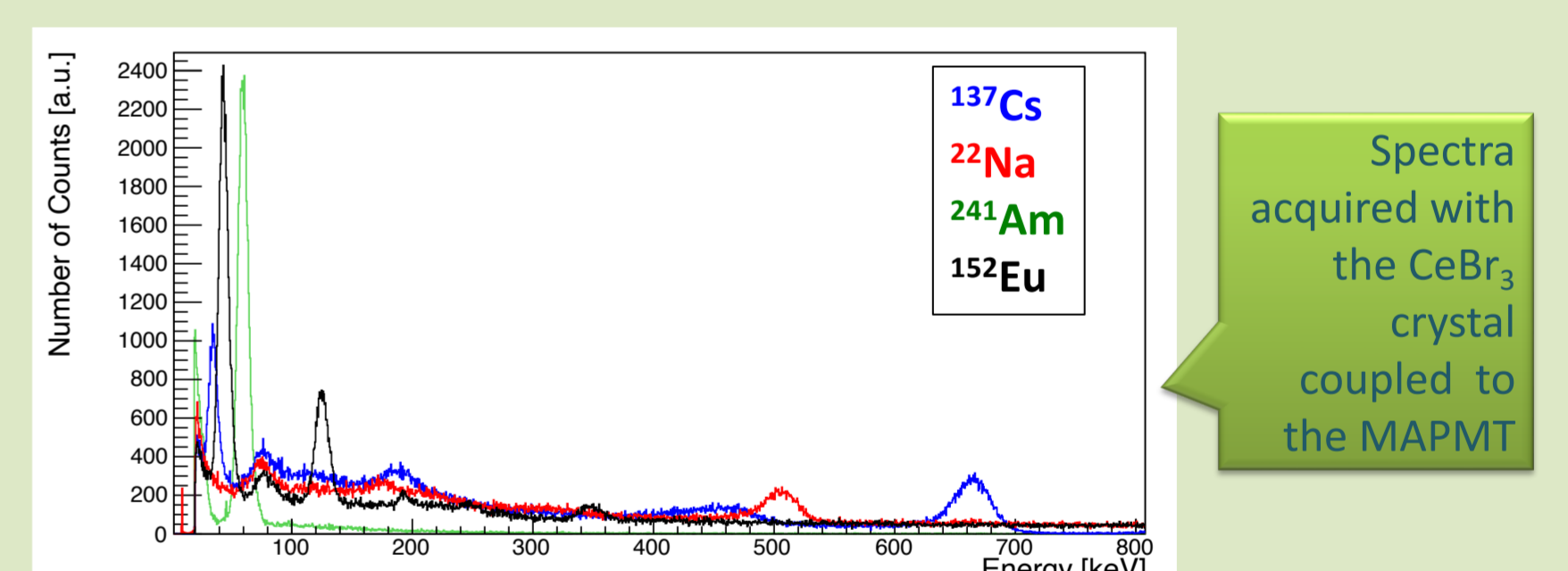
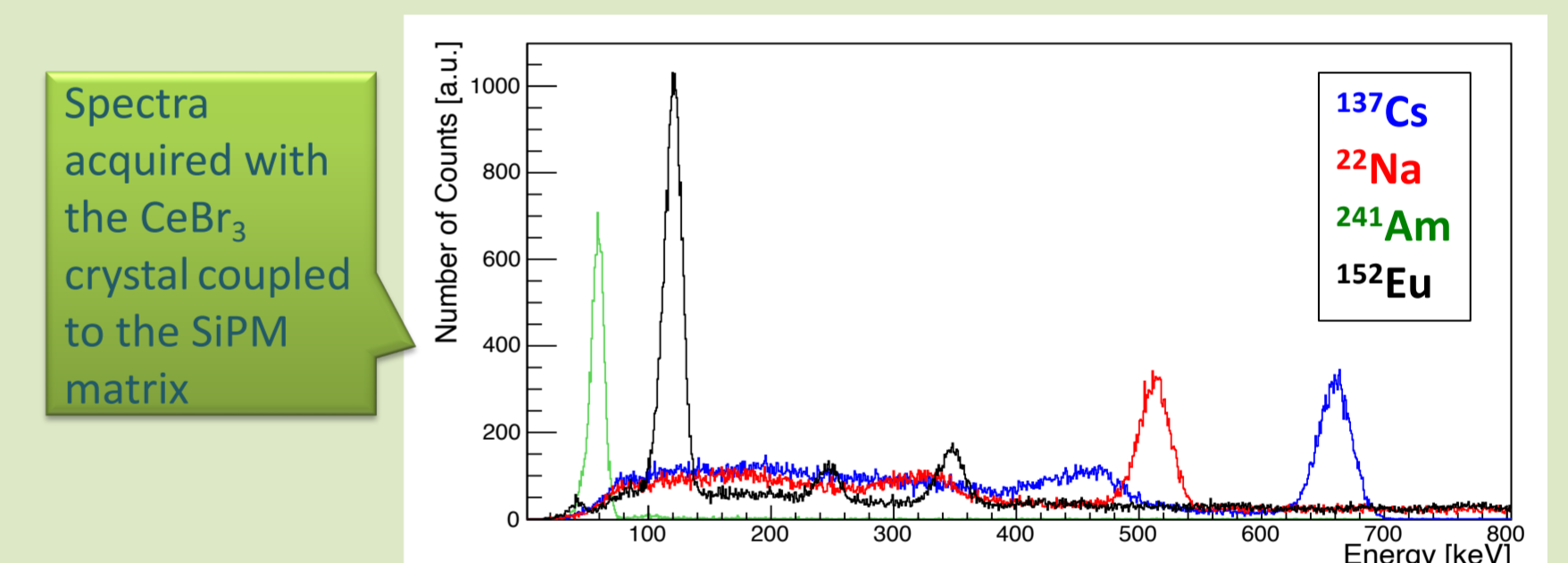
As expected, the high light yield of LaBr₃:Ce provides better spatial resolution for both photodetection systems. However, the impact is more significant with the SiPMs array. The huge difference between spatial resolution achieved with SiPM-CeBr and SiPM-LaBr shows that a large amount of light is needed to take advantage of the smallest pixel size of the SiPMs arrays. The distortion is only slightly affected by the nature of the crystal.

The iterative fitting method improves both spatial resolution and distortion compared to the center of gravity for all tested configurations, but the impact is low for the PSPMT. This demonstrates that the fitting method is strongly dependent on the accuracy of the measurement of the charge distribution and, thus on the size/number of the photodetection pixels.



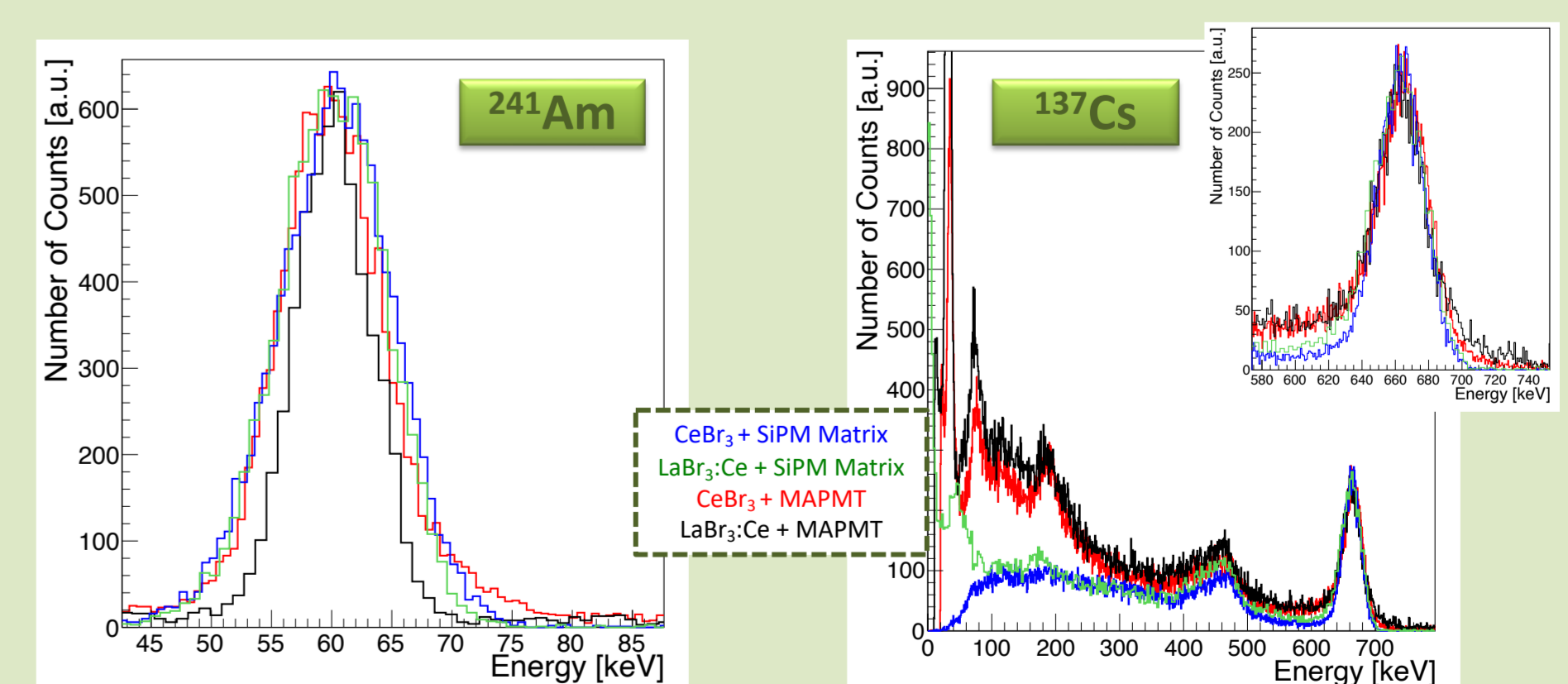
Gamma spectroscopy

The detectors energy resolution was evaluated using gamma-rays emitting sources in the energy range between 60 and 662 keV



At 662keV all different detector's configurations provide very similar energy resolution, close to 5%, but at lower energies the spread increases: the MAPMT-based detectors provide better resolution and the LaBr₃:Ce crystal is confirmed to feature improved resolution with respect to the CeBr₃

	R [%] @ 60 keV	R [%] @ 662 keV
CeBr ₃ + SiPM Matrix	19.0 ± 0.2	4.9 ± 0.1
LaBr ₃ :Ce + SiPM Matrix	17.1 ± 0.2	5.1 ± 0.1
CeBr ₃ + MAPMT	16.1 ± 0.2	5.2 ± 0.1
LaBr ₃ :Ce + MAPMT	12.2 ± 0.2	5.1 ± 0.1



Conclusions

We tested the imaging/detection properties of a CeBr₃ crystal, in comparison with a LaBr₃:Ce one, when optically coupled to a MAPMT and a SiPM matrix

- ★ LaBr₃(Ce) provides better spatial resolution with respect to CeBr₃ for all detectors
- ★ The smallest pixel size of the SiPMs array allows to achieved submillimetric spatial resolution when the amount of collected light is high, as is the case with LaBr₃(Ce)
- ★ At low energy values the LaBr₃:Ce crystal provides, as expected, better energy resolution with respect to CeBr₃. At 662 keV, the measured resolutions result comparable for all detectors due to differences in the light collection efficiencies for the tested configurations.
- ★ The lower electronics noise level and the bigger pixels size of the MAPMT lead to a better energy resolution with respect to the SiPM matrix for energies lower than 344 keV.

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