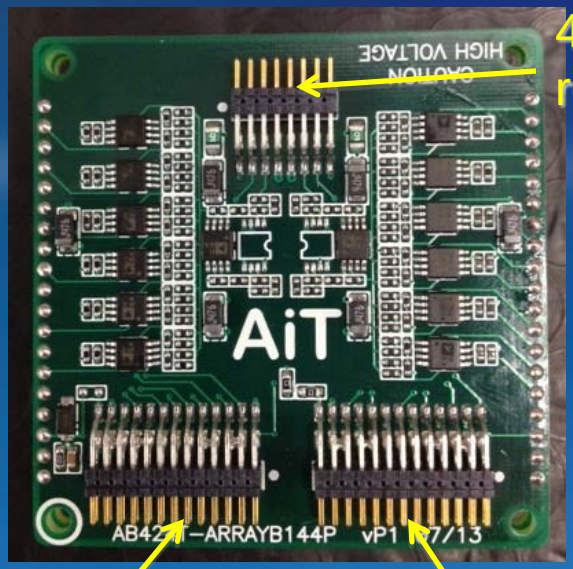
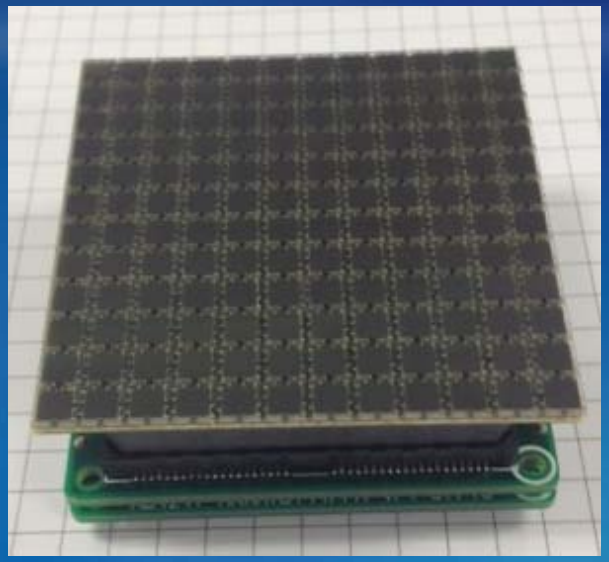
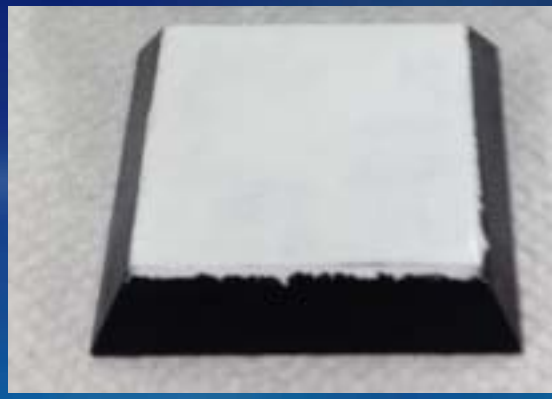
Studies with the SensL 144 3mm SiPMs B array ArrayB-30035-144P-PCB

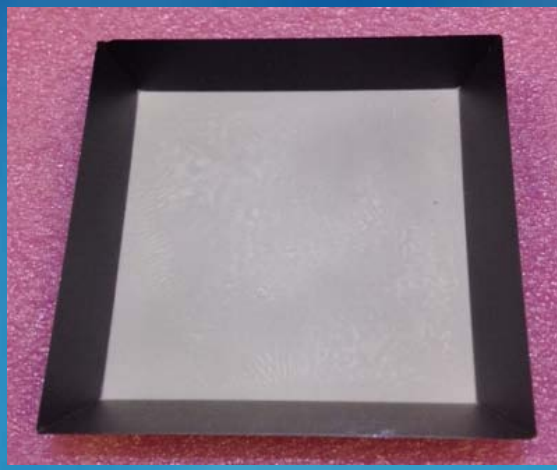
24-Channel Row & Column Readout

Studies with the ArrayB-30035-144P-PCB





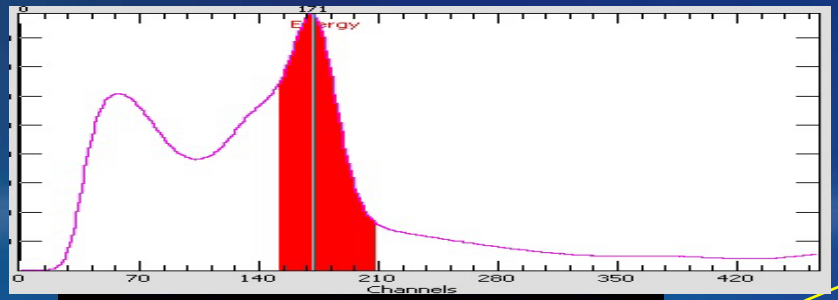


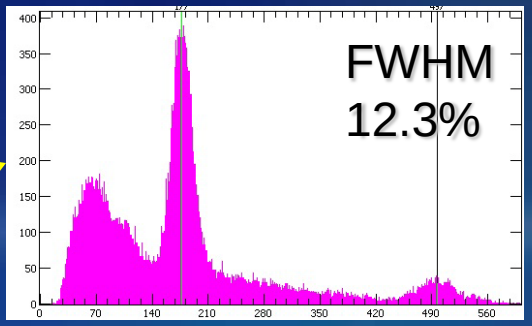


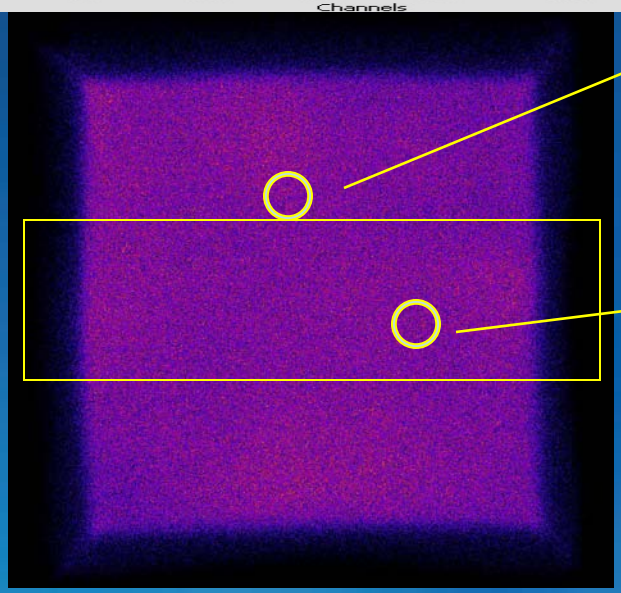
Hybrid readout board from AiT Instruments with the row-and-column cable (top connector) used top provide bias voltage.

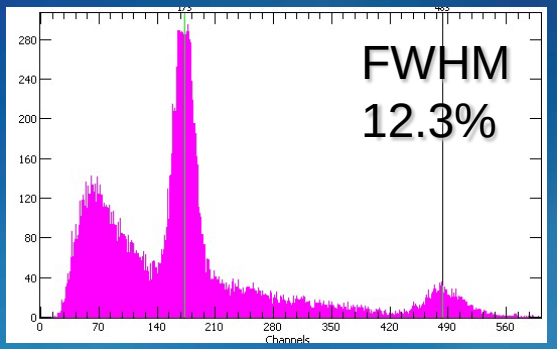
10mm thick trapezoidally shaped monolithic plate was first studied with the original black top (and black sides) and then the top paint was replaced by a BC-620 reflective paint from Saint Gobain. Between the scintillator and the SiPM array 4.5mm thick UV acrylic plate was inserted to allow for proper light sharing between the individual 3mm SiPM sensors. Silicone optical compound Visilox V-788 was used between all optical surfaces.

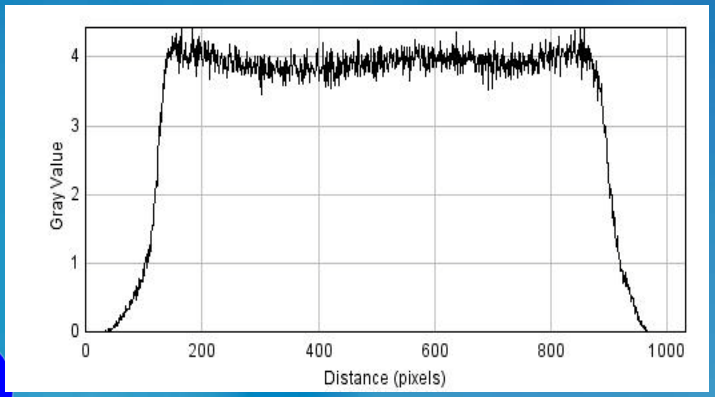
Studies with the ArrayB-30035-144P-PCB





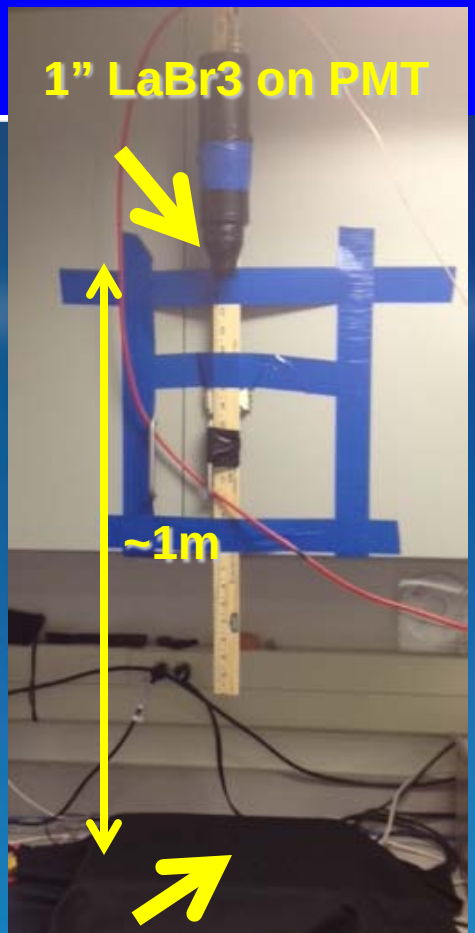


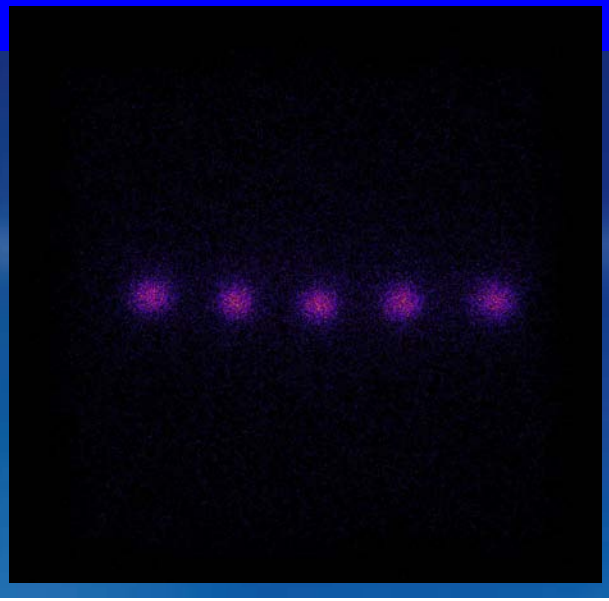


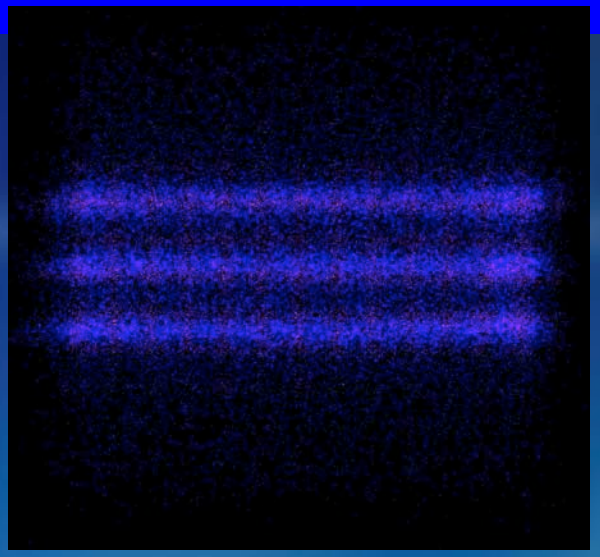


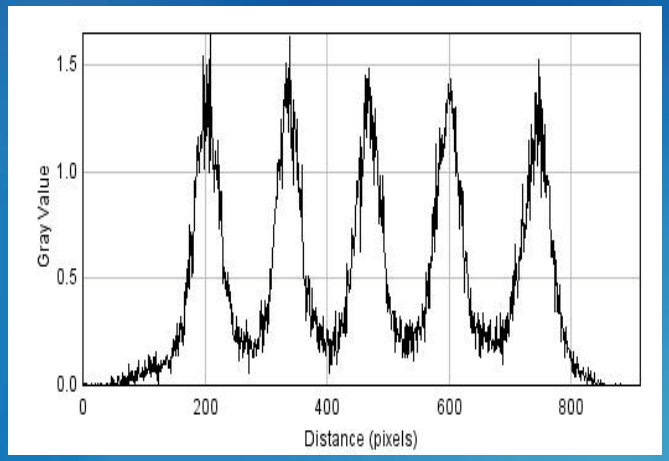
Combination of white top, optimized spreader window, quadratic COG algorithm and energy cut eliminating lower amplitudes originating in the edge regions, produces uniform response across the active surface with energy resolution in the range 12-14 % @511 keV.

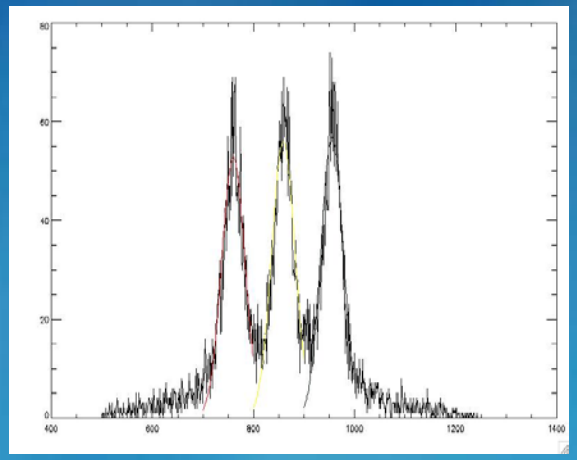
Studies with the ArrayB-30035-144P-PCB







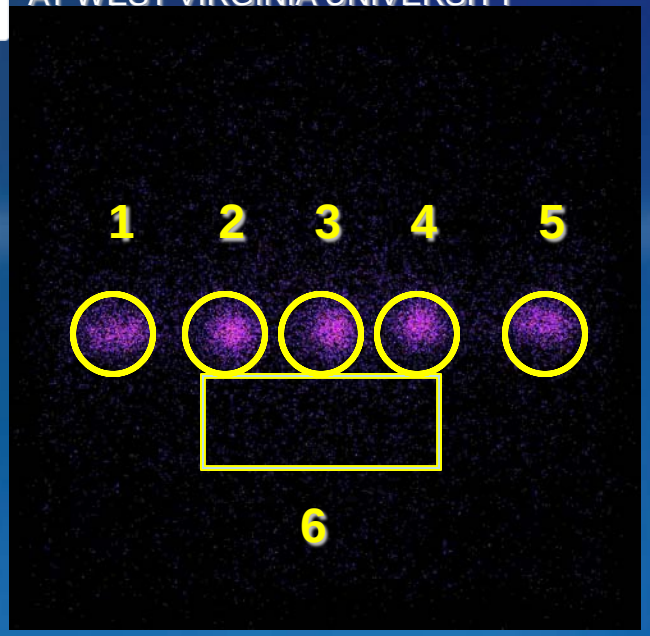




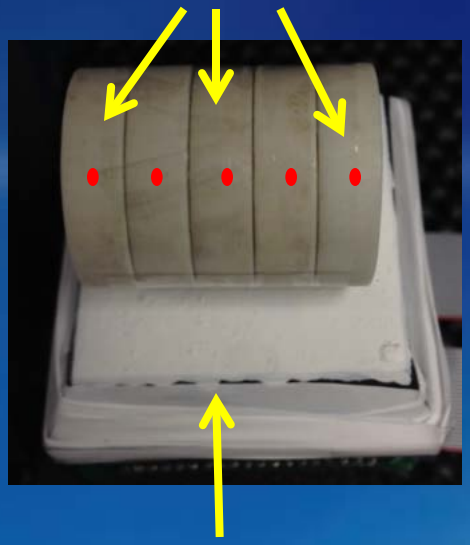
Point sources

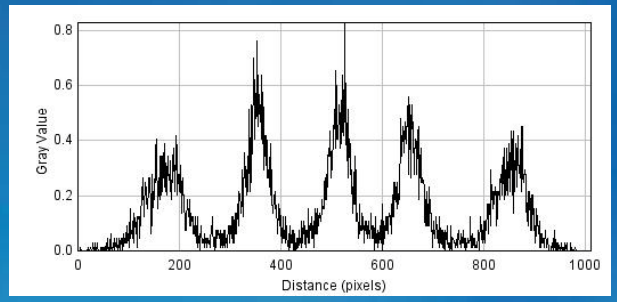
Plate LYSO

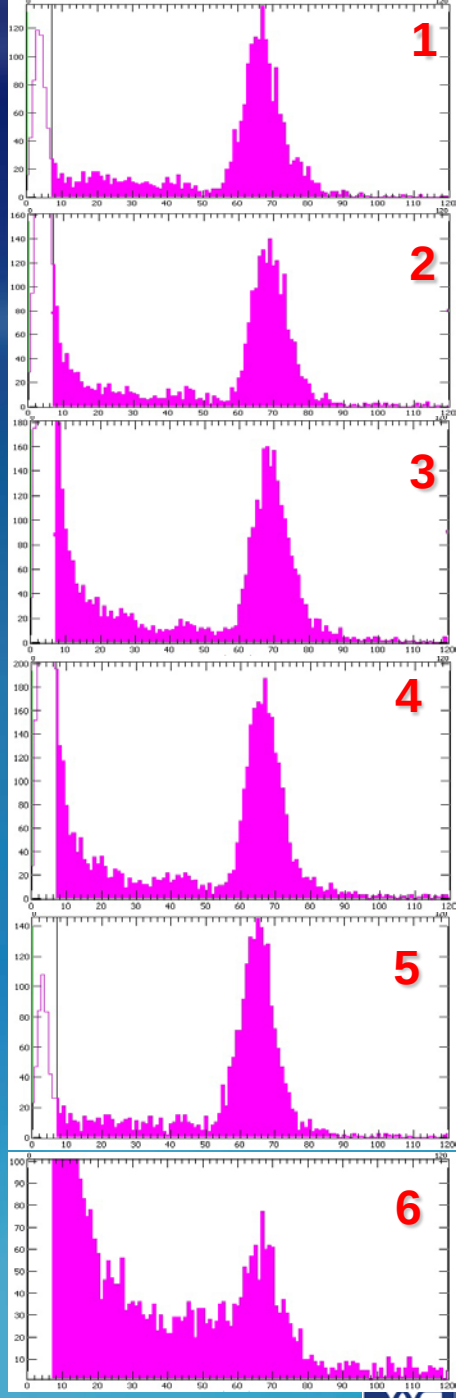
Spatial resolution measurements with electronically collimated 511 keV beams. Left: five <1mm Na22 sources placed at 6.5mm pitch. Right: three 0.5mm capillaries with F18 solution placed at 5mm spacing. The best results show uniform spatial response with about 1.8-2.0mm FWHM. As experimentally confirmed, this limit in resolution is not due to geometry or source size.



Point Na22 sources in plastic capsules

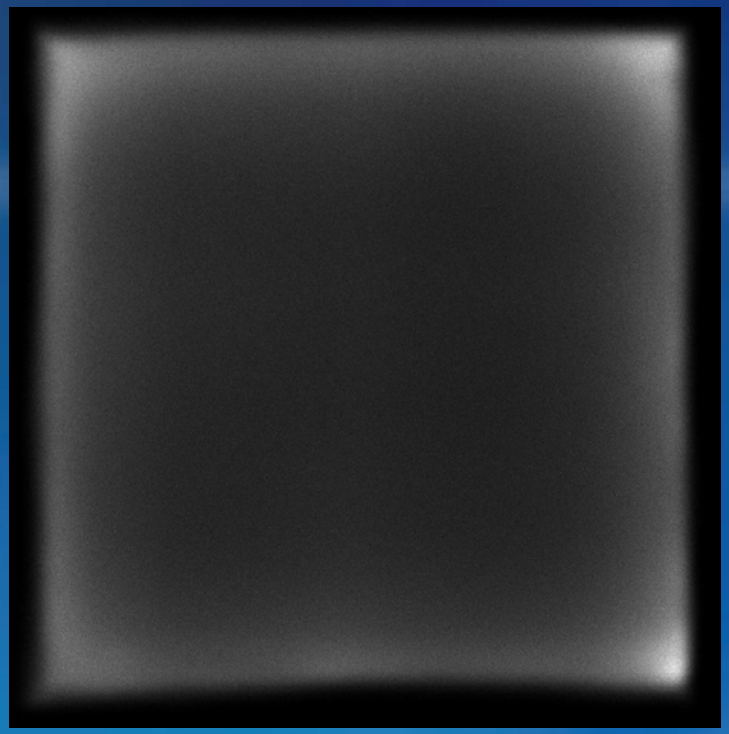


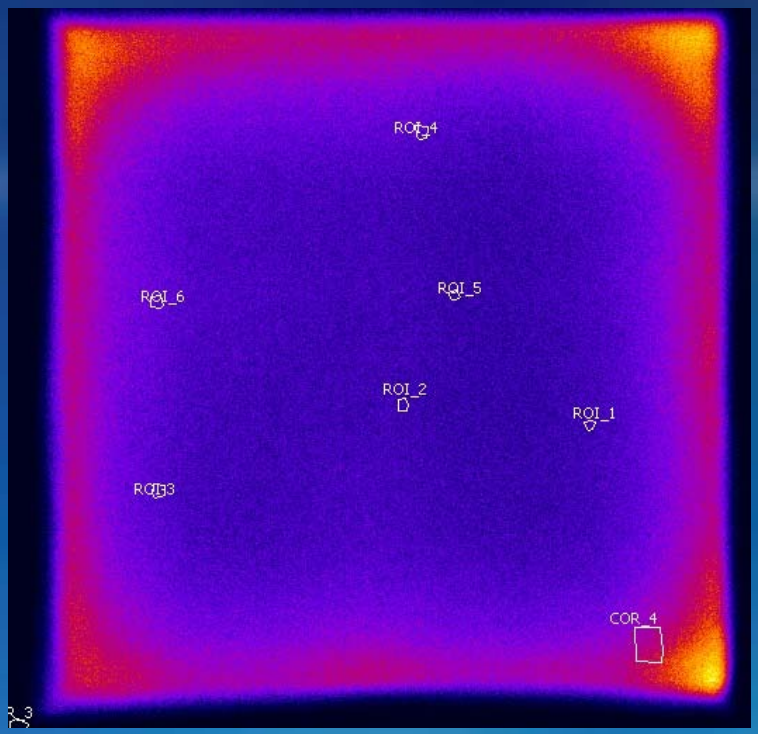


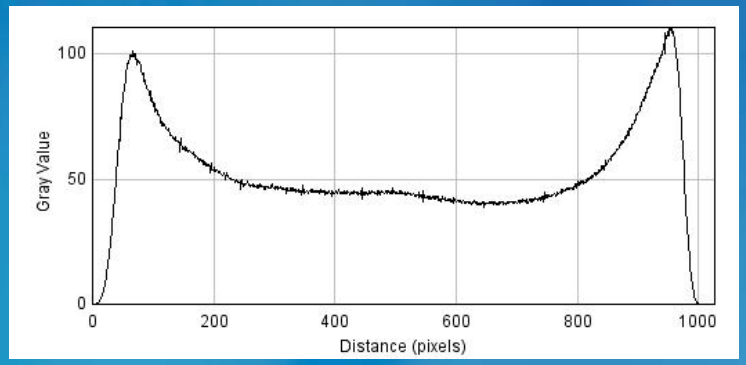


For comparison, linear COG algorithm was also implemented in the measurement with five Na22 point sources. The result was (as expected) with the loss of response linearity at the edges of the module leading to worsening of spatial resolution above 2mm FWHM. The energy spectra for the six selected ROI regions are shown. FWHM energy resolutions are in the range 12.5-14.5 % (zero energy is not at zero scale due to the effect of the diode circuitry)

Studies with the ArrayB-30035-144P-PCB

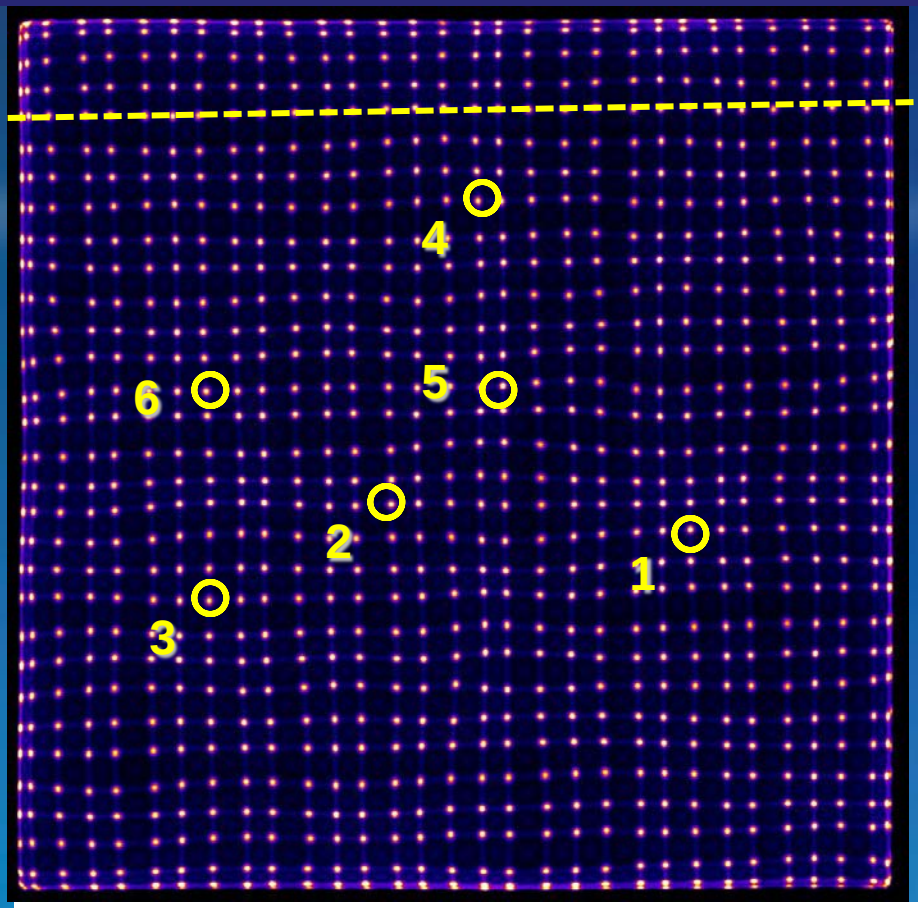


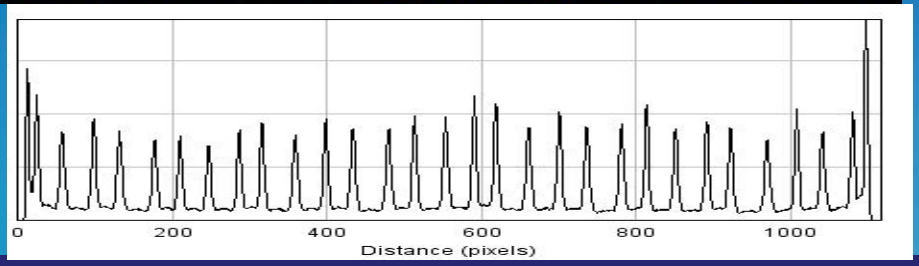


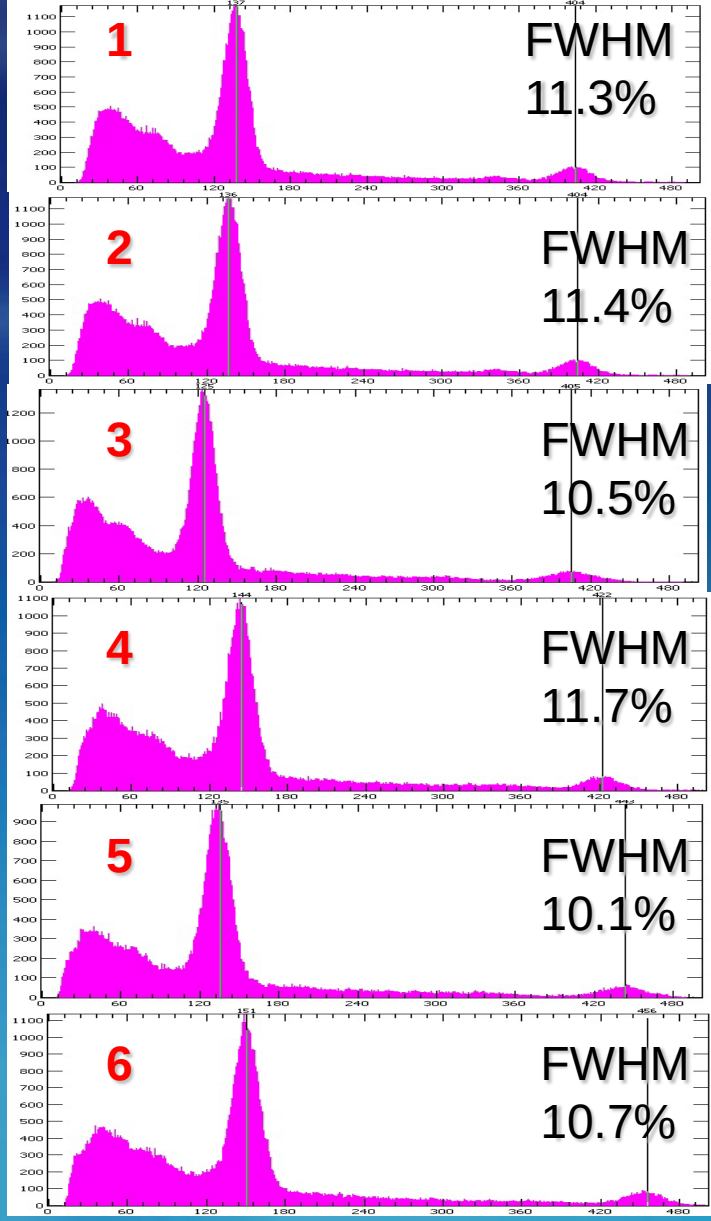


For comparison, measurements with the WVU 1cm thick by 5 cm x 5 cm LYSO crystal from Proteus with all sides polished, and standard straight black-painted side walls and white top shows serious response non-linearity with heavy edge effects.

ArrayB-30035-144P-PCB

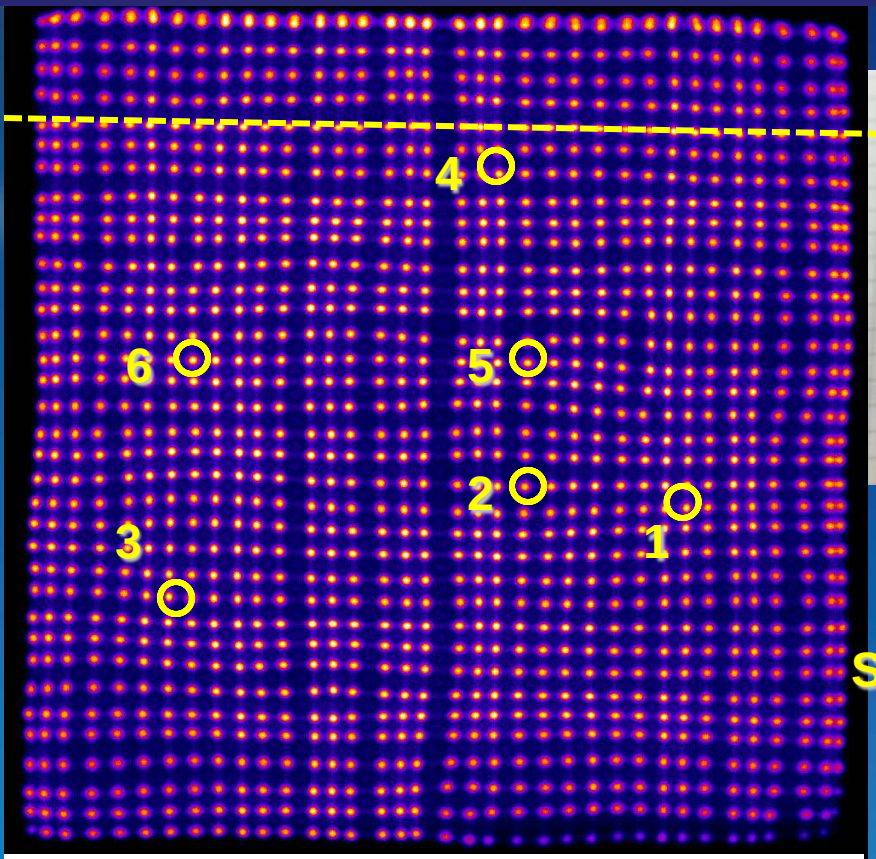


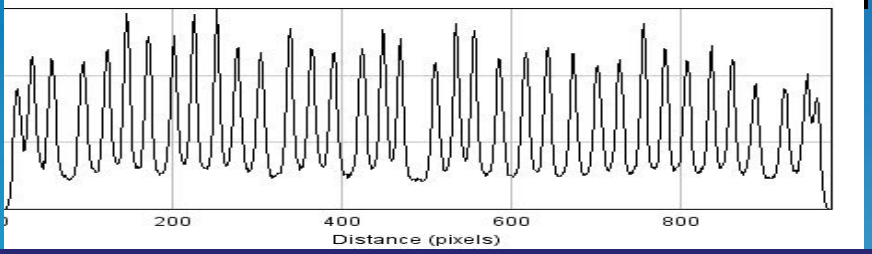


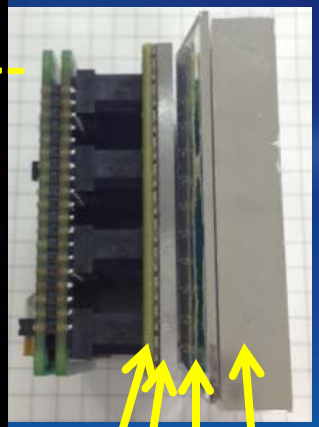


For comparison, measurements with the 1.57mm pixel size 10mm thick and 57x57 mm transversal size LYSO array. 2.1mm thick spreader window was used between LYSO array and SiPM array to produce more uniform spatial response. Bias voltage 28.4V.

ArrayB-30035-144P-PCB





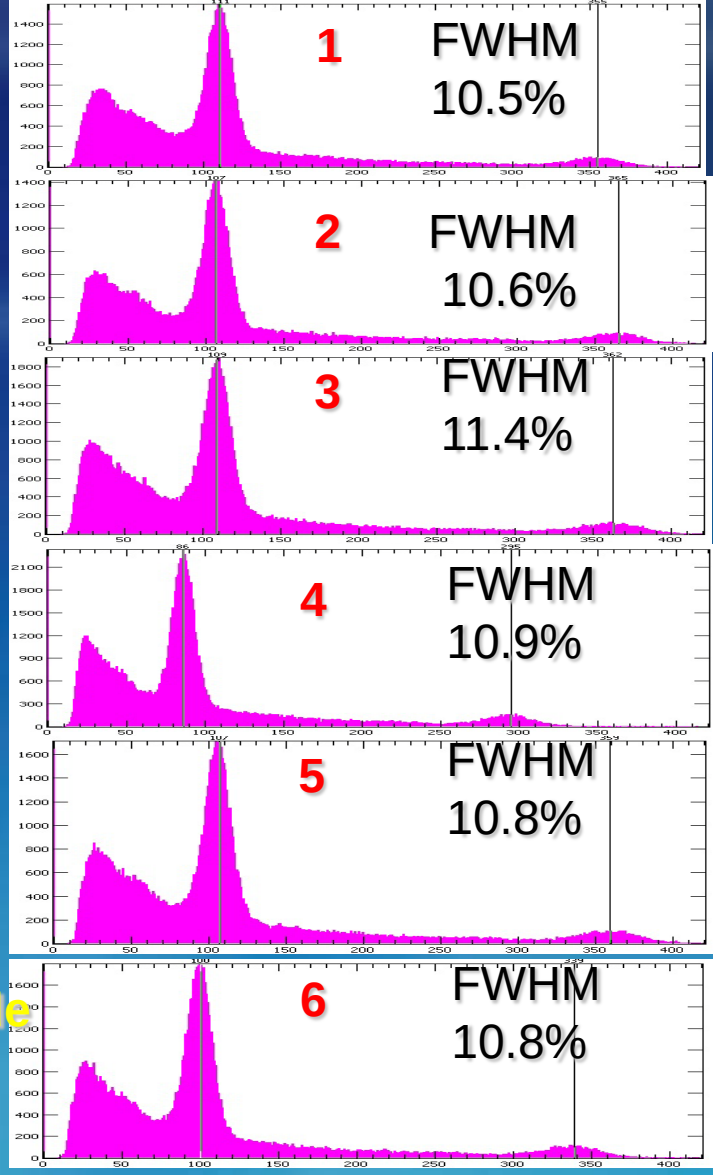


SiPMs

LYSO array

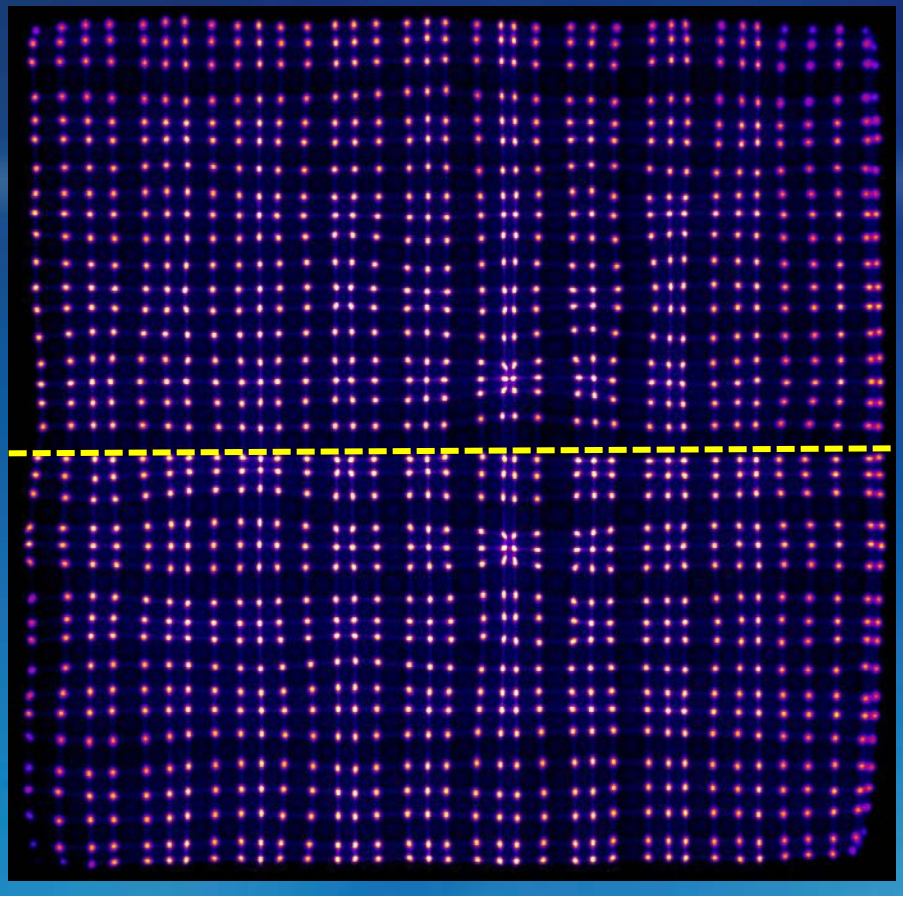
Tapered Light guide

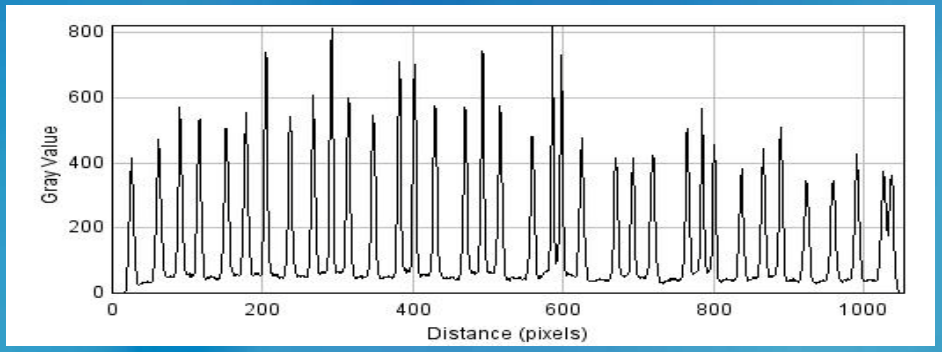
2.3mm window



Measurements with the 1.57mm pixellated 10mm thick and 57mmx 57mm on a side LYSO array and the tapered light guide (matching the SiPM array size) from Agile. An additional 2.3mm spreader window is used to produce more uniform spatial response. Bias voltage 28.7 V. 145 ns gate to ADC, truncation factor 0.05. Energies corrected for energy cut due to diode circuitry.

ArrayB-30035-144P-PCB

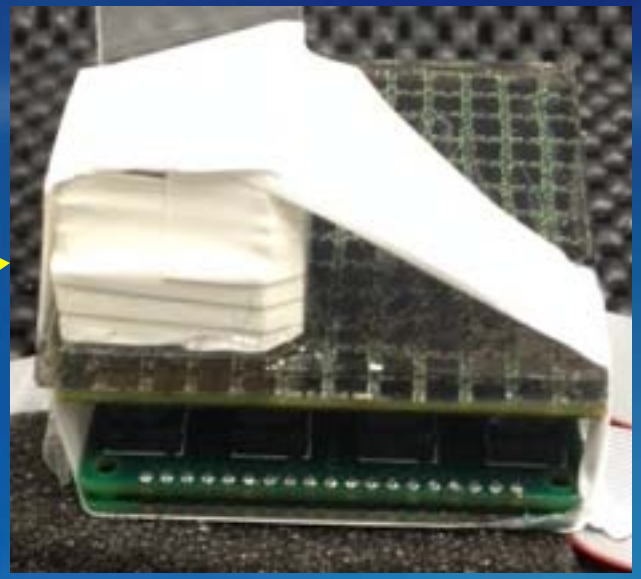




Measurements with the 1.57mm pitch pixellated 10mm thick and 57mm x 57mm LYSO array with the tapered light guide (matching the SiPM array size) from Agile. No spreader window. Bias voltage 29.5 V. 145 ns gate to ADC, truncation factor 0.05.

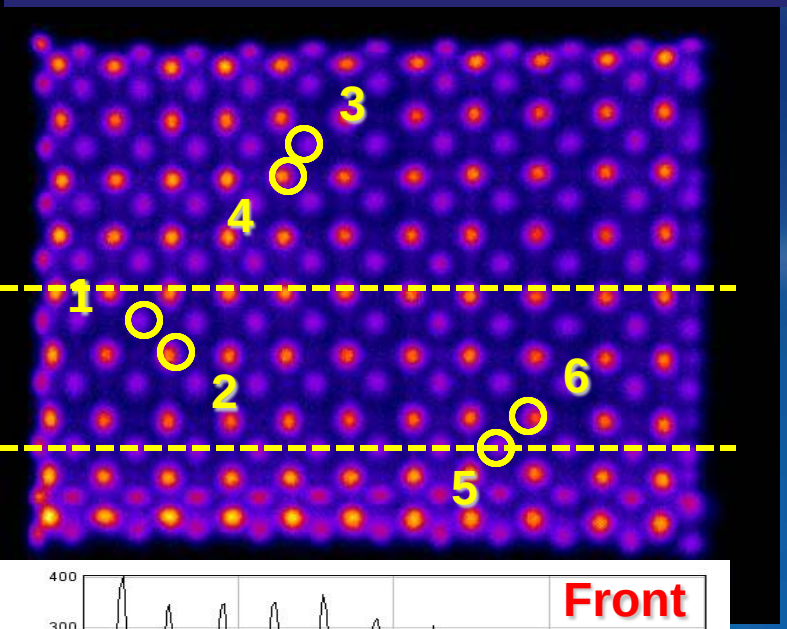
ArrayB-30035-144P-PCB

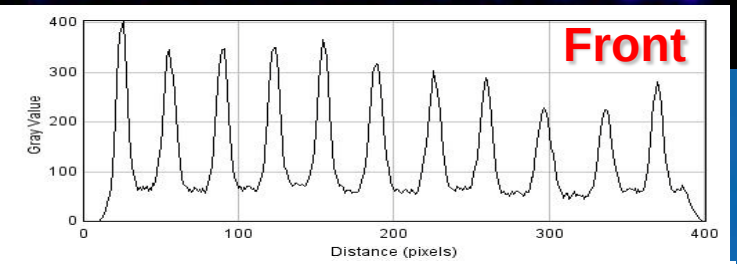
Sample of stacked/shifted 1.5mm pitch LYSO arrays placed in the corner of the B array

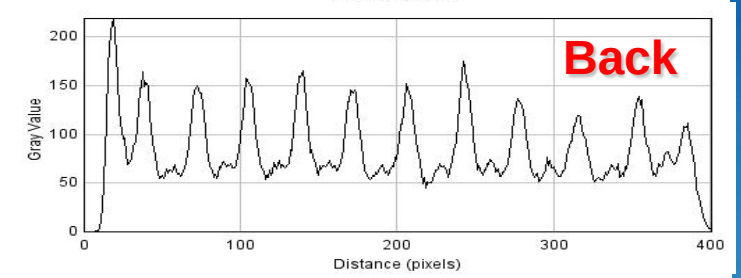


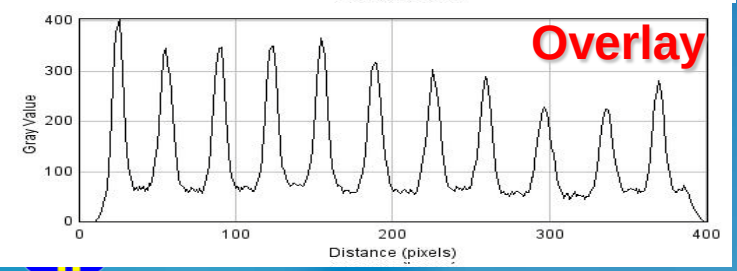
Measurements with two stacked/shifted 1.5mm pitch pixellated 10mm thick LYSO arrays and 2.3mm spreader window.

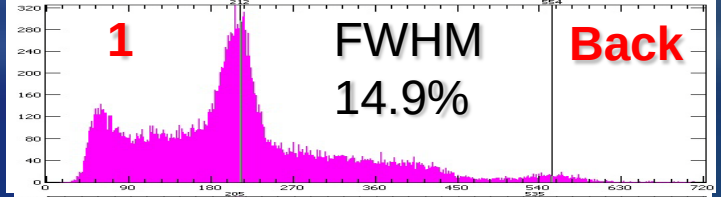
Direct coupling through a 2.3mm spreader window.

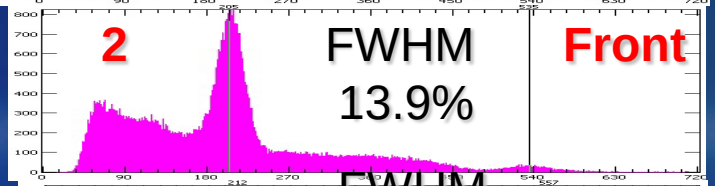


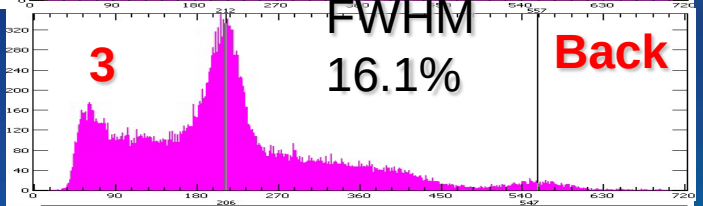


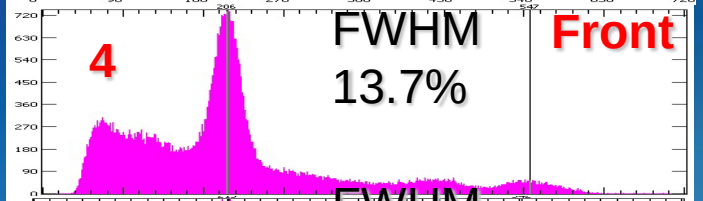


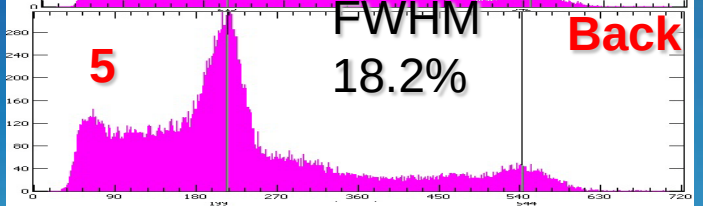


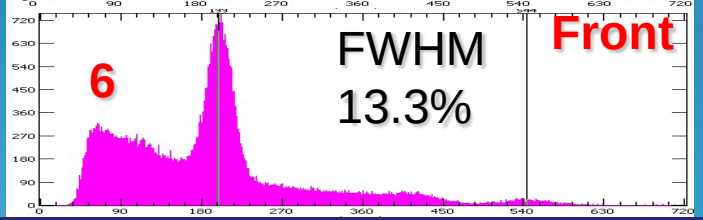






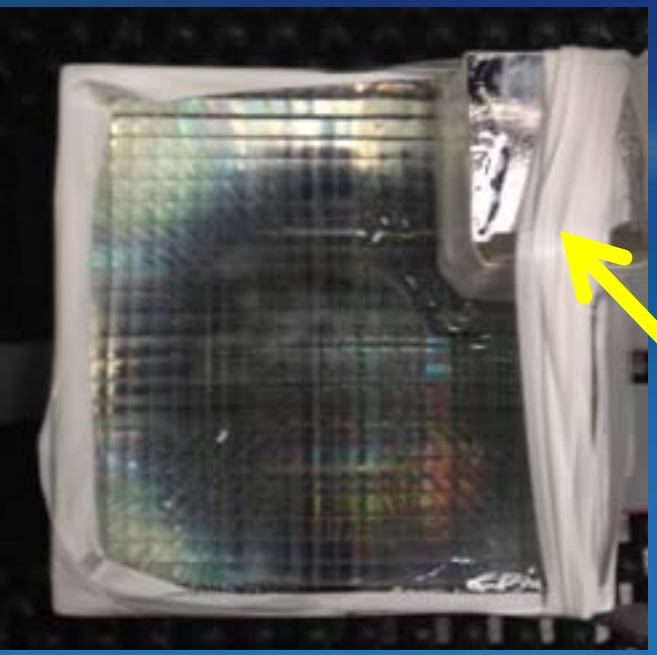




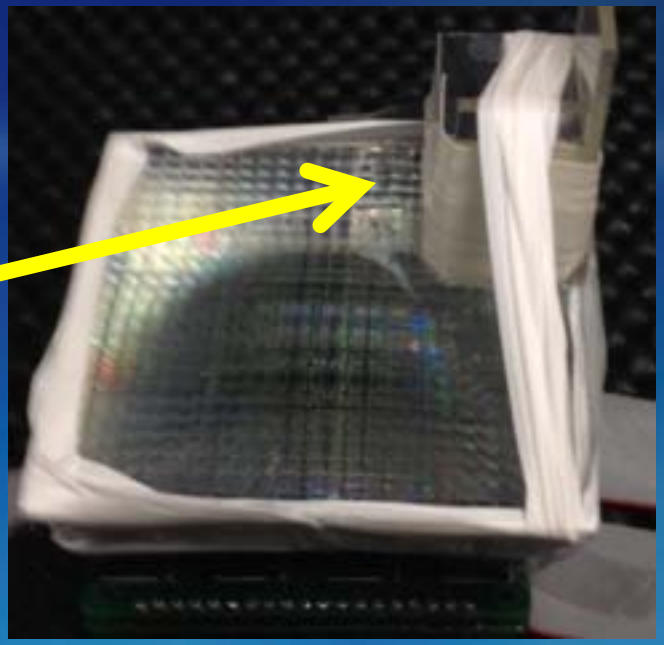


Measurements with two stacked/shifted 1.5mm pitch pixellated 10mm thick LYSO arrays and 2.3mm spreader window. Bias voltage 30.1 V. 145 ns signal integration gate in ADC, truncation factor 0.05. Energies corrected for thresholding effect due to the diode circuitry.

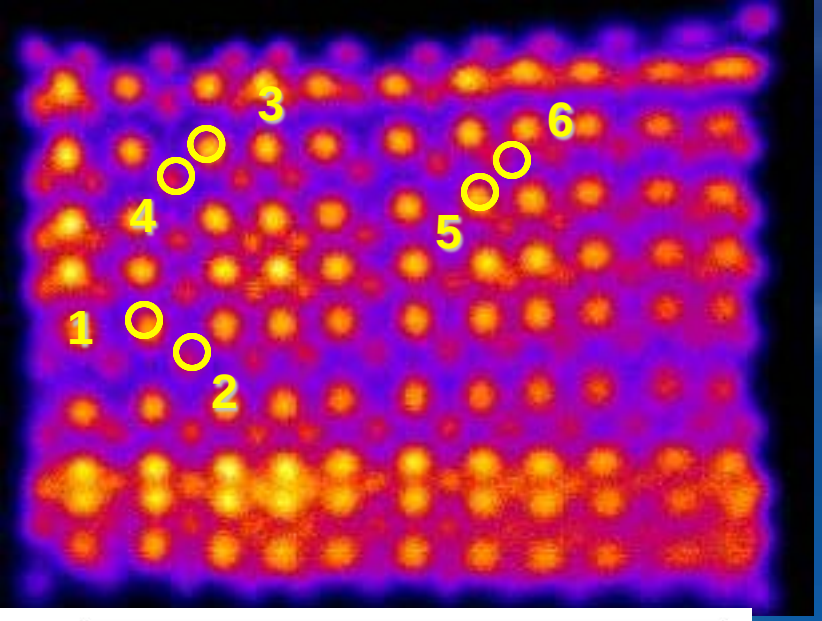
ArrayB-30035-144P-PCB

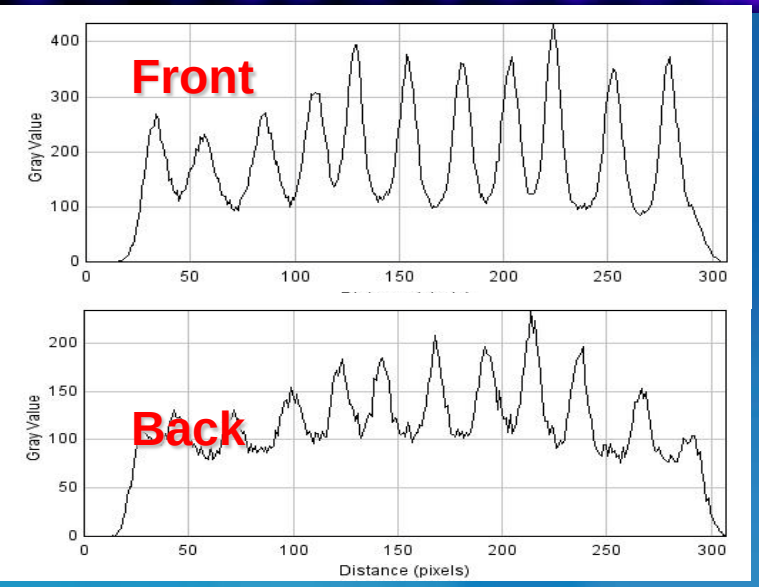


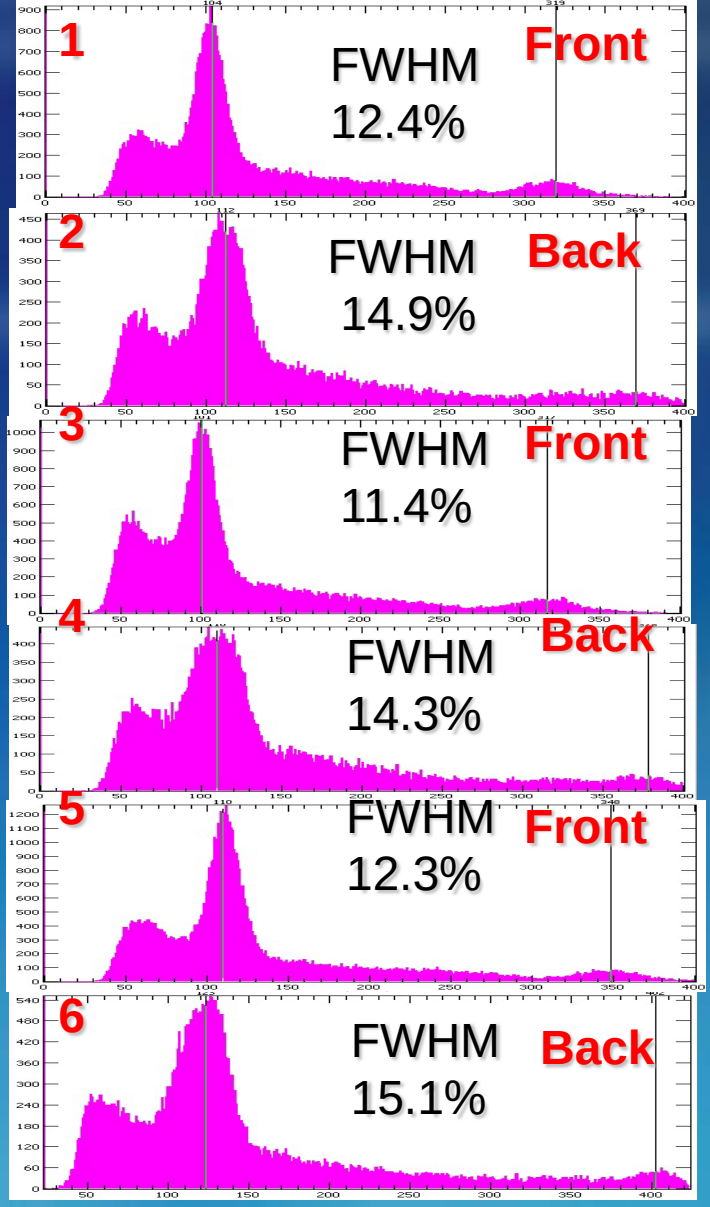
Sample of stacked/shifted 1.5mm pitch LYSO arrays placed in the corner of the tapered Agile light guide placed over the B array.



Measurements with two stacked/shifted 1.5mm pitch pixellated 10mm thick LYSO arrays and tapered light guide with several spreader windows.

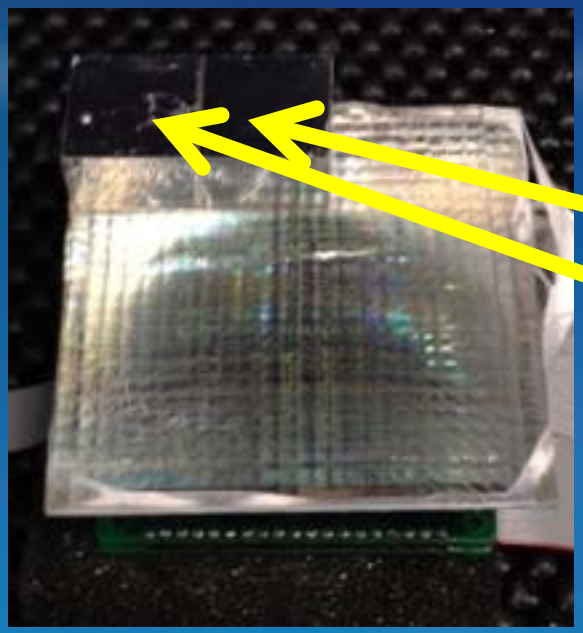




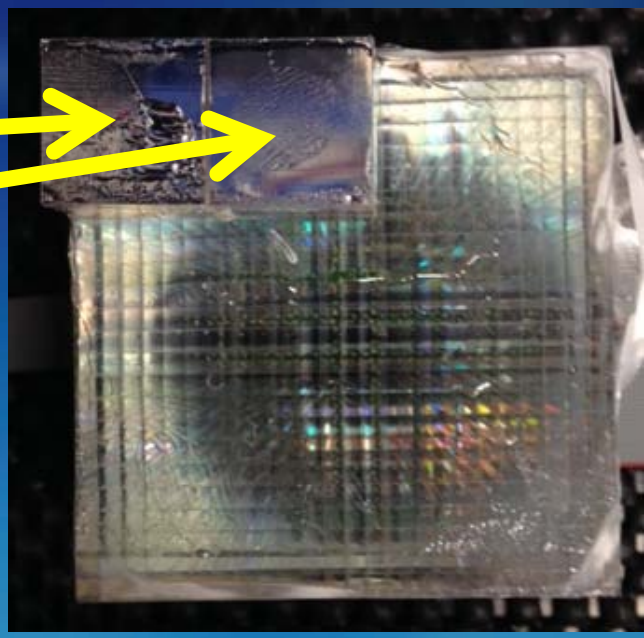


Measurements with two stacked/shifted 1.5mm pitch pixellated 10mm thick LYSO arrays with a tapered light guide and a 1.6mm spreader window placed between scintillator and tapered light guide. Bias voltage 30.1 V. 145 ns signal integration gate in ADC, truncation factor 0.075. Energies corrected for thresholding effect due to the diode circuitry.

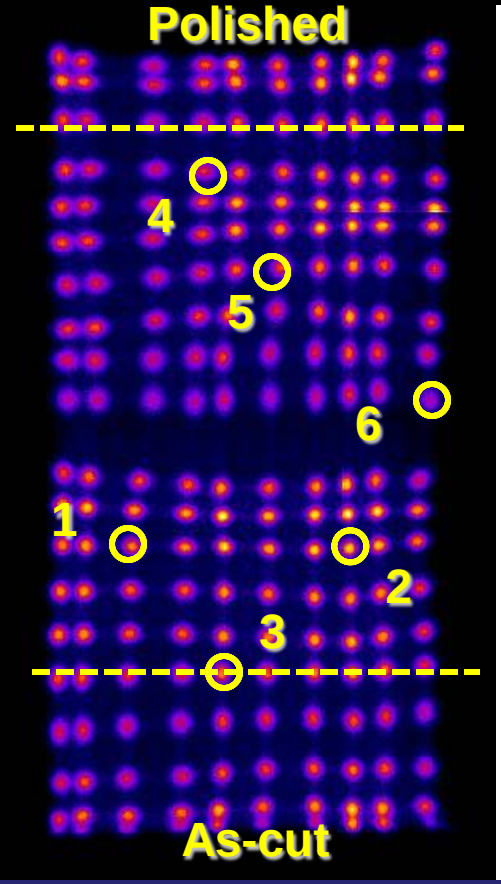
ArrayB-30035-144P-PCB

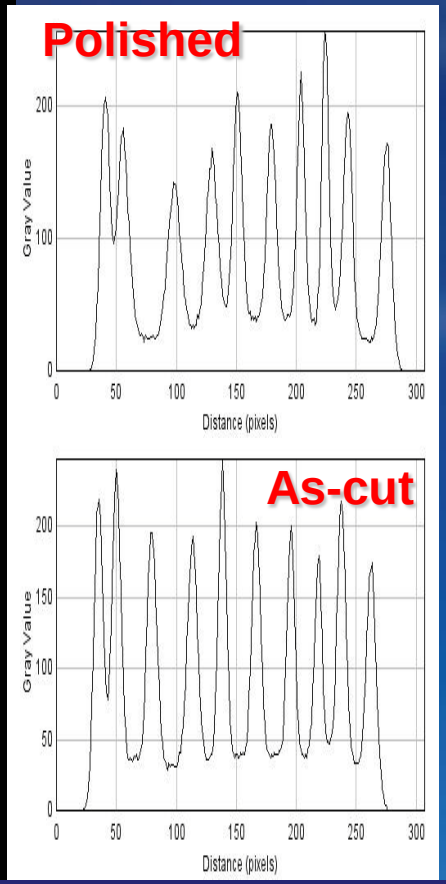


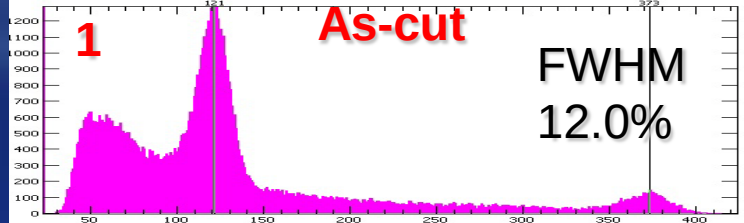
Two samples of 1.5mm pitch LYSO arrays placed in the corner of the tapered Agile light guide placed over the B array.

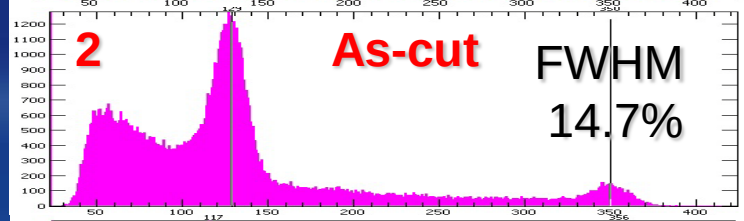


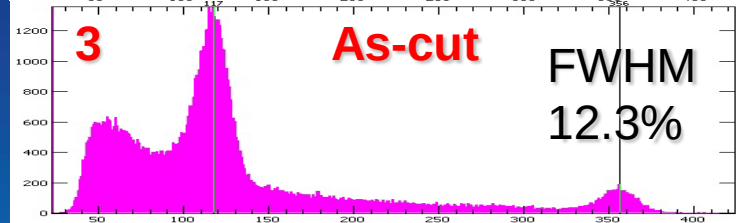
Measurements with two 1.5mm pitch 10mm thick LYSO array samples from Proteus/Agile. One of the samples had all sides polished while the second had side surfaces "as cut". Additional 1.6mm spreader window light guide placed between the arrays and the tapered light guide.

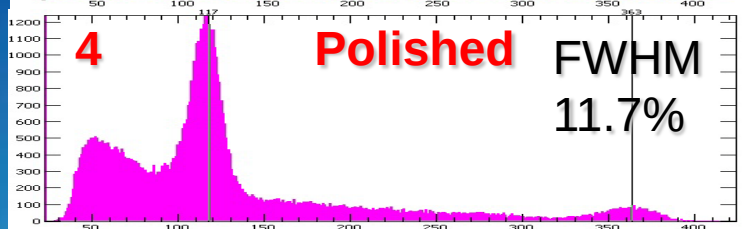


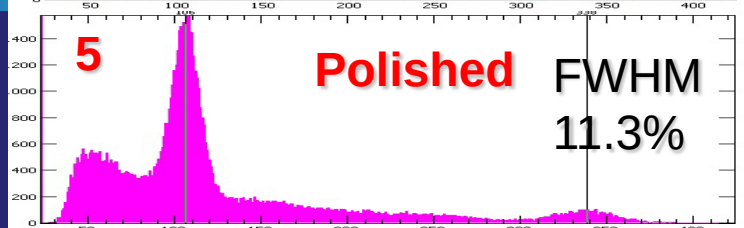


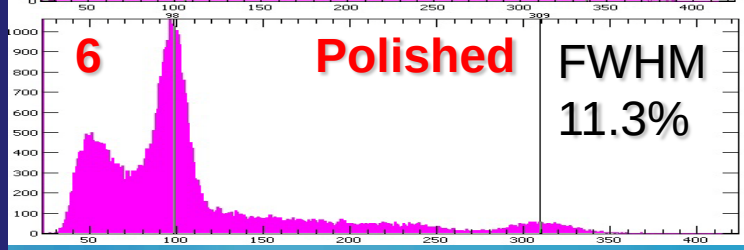






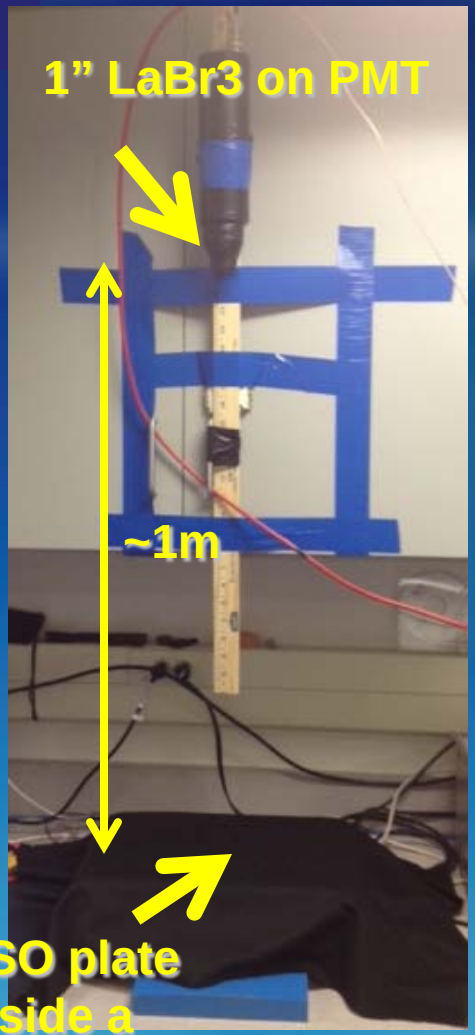






Measurements with two 1.5mm pitch 10mm thick LYSO array samples from Proteus/Agile. One of the samples had all sides polished while the second had side surfaces "as cut". Additional 1.6mm spreader window light guide placed between the arrays and the tapered Agile light guide. Bias voltage 29.5V. 145 ns integration gate at the ADCs. Truncation factor 0.1. Pulse heights corrected for signal tresholding with the diode circuitry. Polished sample amplitudes are lower on average but have higher energy resolution. Spatial uniformity is better for as-cut.

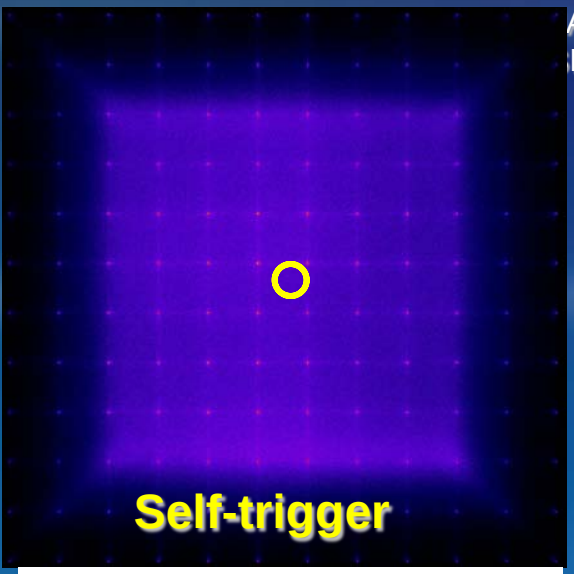
ArrayB-30035-144P-PCB

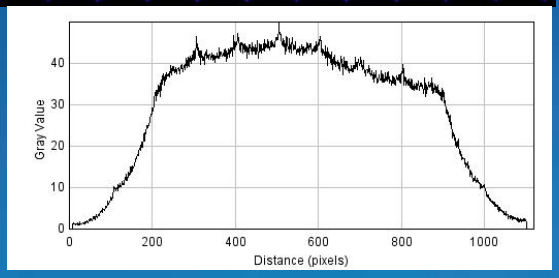


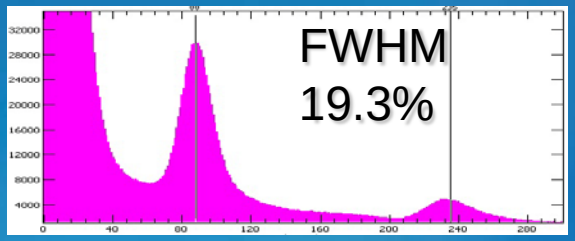
SiPMT with LYSO plate and sources inside a mini-dark box

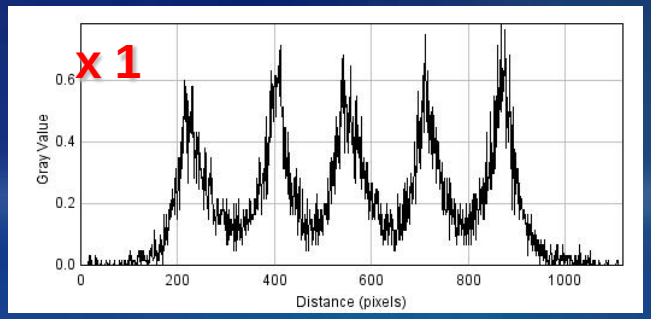
Measurements with the 21mm thick LYSO module. The module was placed either directly on the B array or coupled via several light guides.

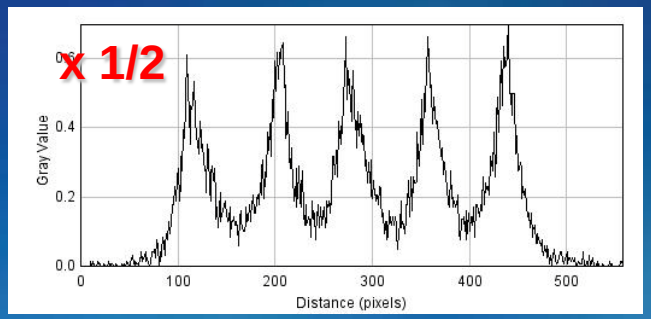
ArrayB-30035-144P-PCB

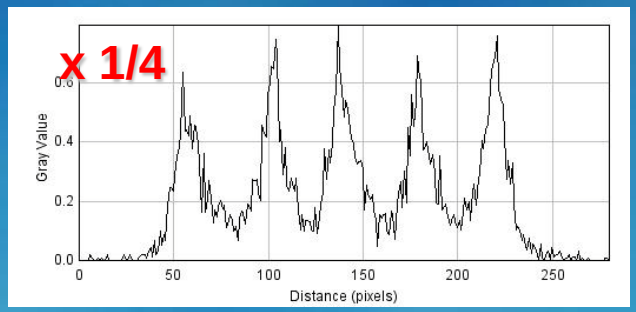












Measurements with the 21mm thick LYSO module. The module was placed directly on the B array. Five Na22 sources placed at a 6,5mm pitch. Quadratic algorithm (R. Pani). Truncation factor (-)0.025. Bias voltage 31.7V. 145 ns wide ADC gate. The coincident profile plot was also compressed 2 and 4 times for better visualization. Estimated spatial resolution ~ 2mm FWHM. Some artifacts seen in the flood image at left primarily due to LYSO radioactive background.

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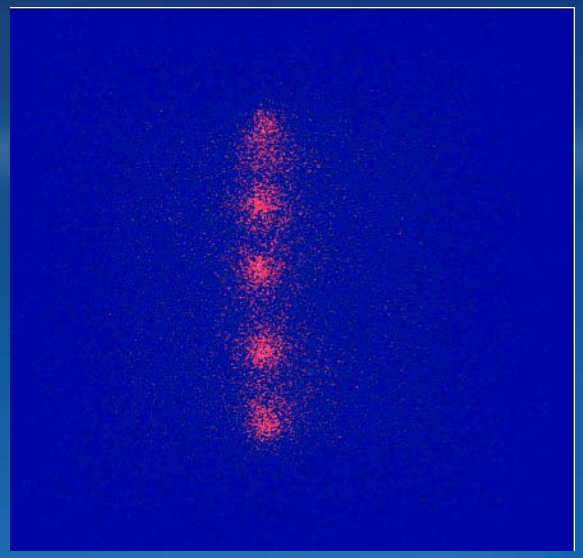
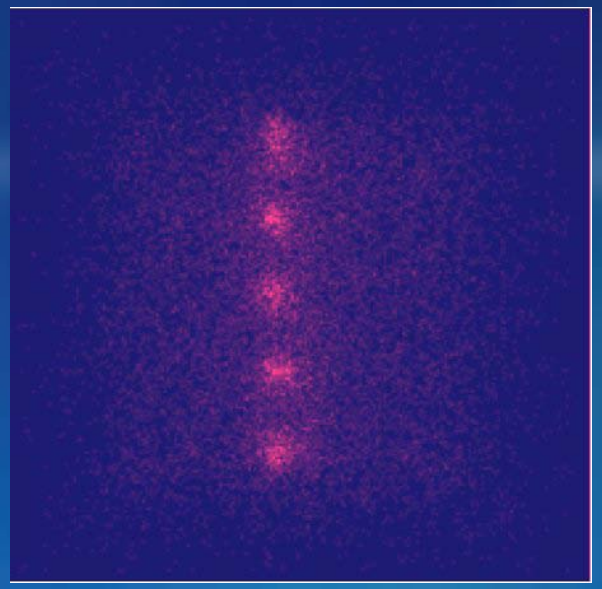
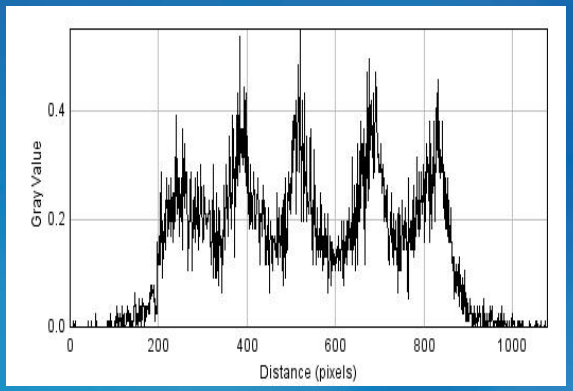
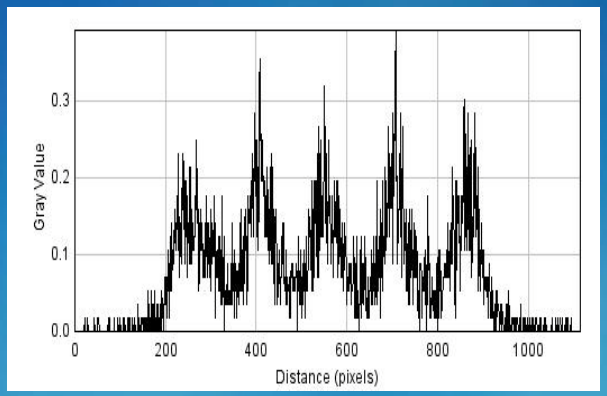
ArrayB-30035-144P-PCB







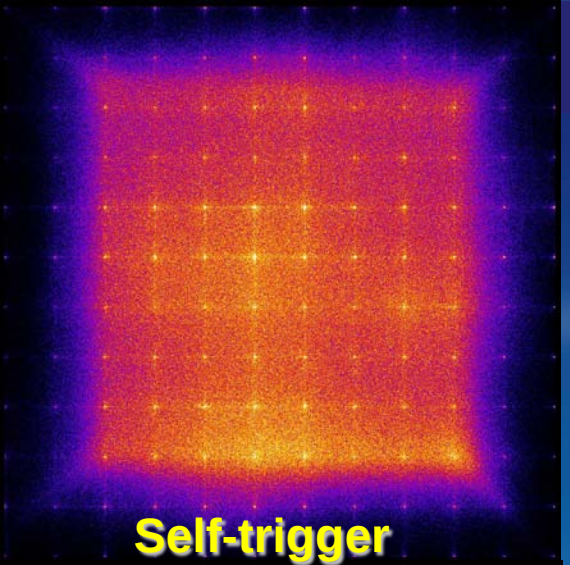


Measurements with 5 sources placed at 6.5mm pitch with the 21mm thick LYSO module. Light guides were placed between the scintillator and the B array. Left: fiberoptic with 1mm square elements, from Agile. Right: thin fiberoptic. In both cases amplitude dropped by about 15-20% compared to the direct coupling. Quadratic algorithm. Truncation factor (-)0.025. Bias voltage 31.7V. 145 ns wide ADC gate. No improvement in resolution.

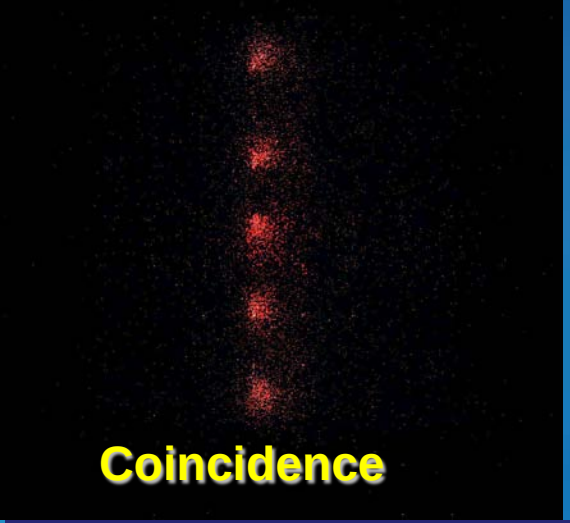
ArrayB-30035-144P-PCB

24ch readout

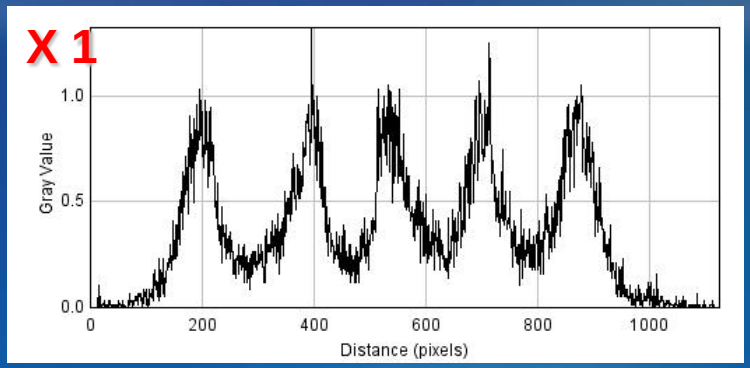
10 deg C

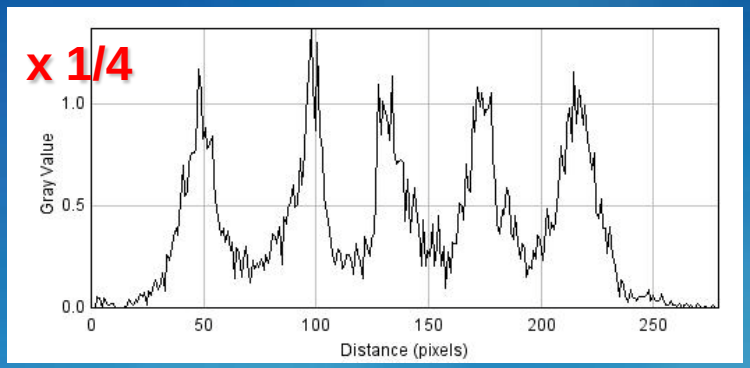


Self-trigger



Coincidence





Measurements with the 21mm thick LYSO module at 10 deg C. The module was placed directly on the B array. Five Na22 sources placed at a 6,5mm pitch. Quadratic algorithm (R. Pani). Truncation factor 0.0. Bias voltage 30.8V. 145 ns wide ADC gate. The coincident profile plot was also compressed 4 times for better visualization. Estimated spatial resolution ~ 2.5mm FWHM. Some artifacts seen in the flood image at top left primarily due to radioactive background in the LYSO scintillator.

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Studies with the SensL 144 3mm SiPMs B array ArrayB-30035-144P-PCB

4-Channel Readout

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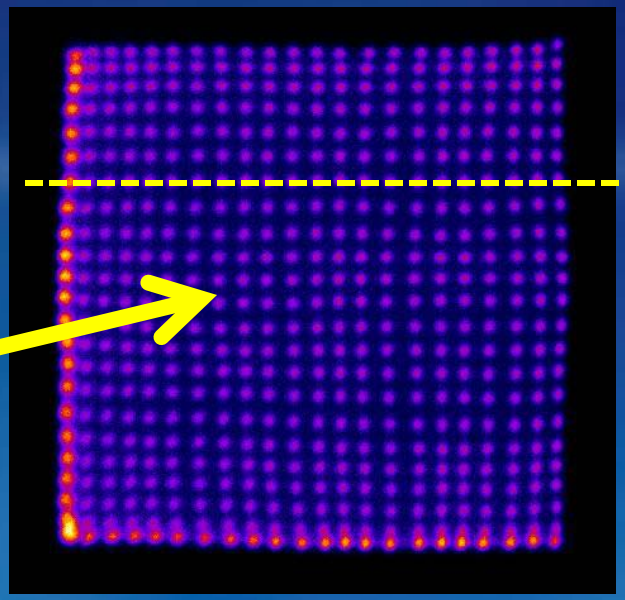
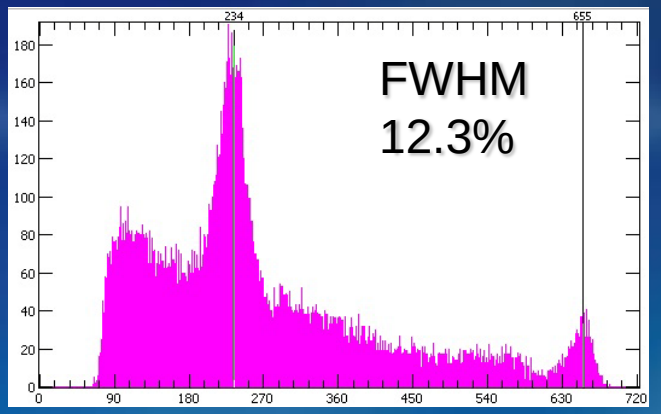
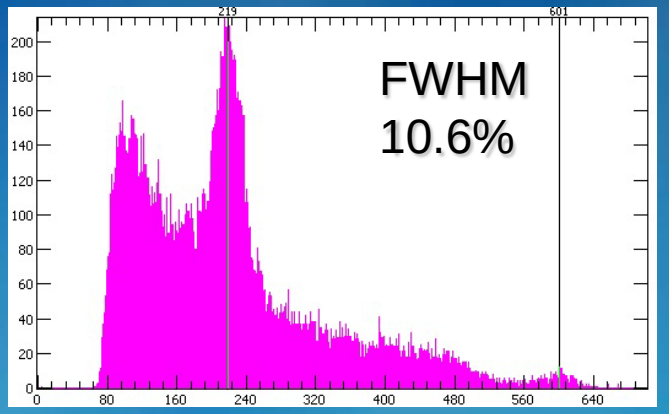
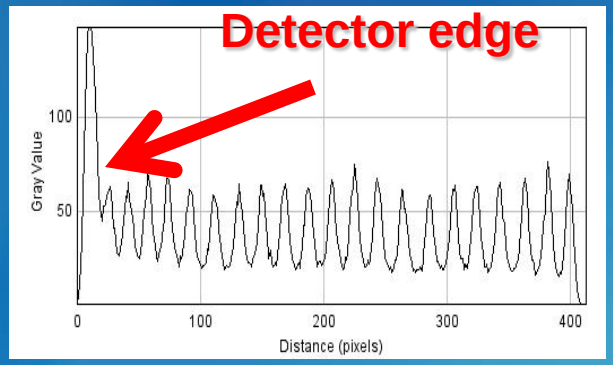
ArrayB-30035-144P-PCB
4ch readout - 10 deg C





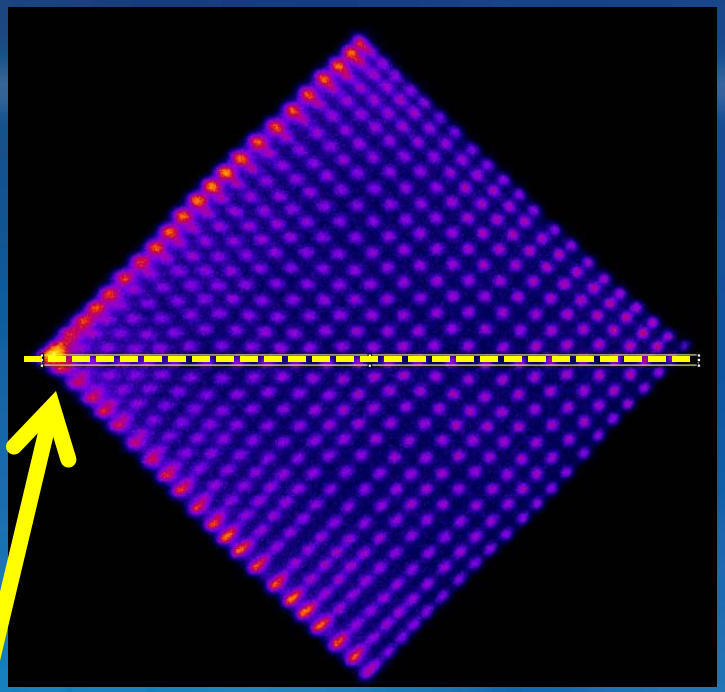


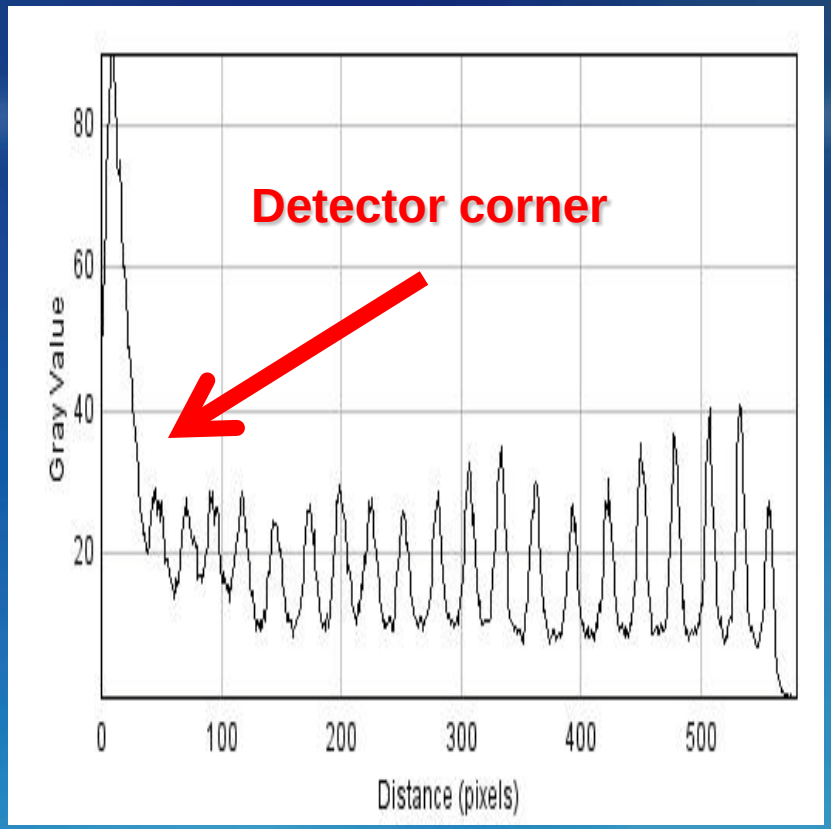
1mm pitch LYSO array from Proteus placed by the corner of the SiPM array



Measurements with a 1mm pitch 10mm thick LYSO array (24x24 pixels). 2.75mm thick UV acrylic light spreader window placed between the array and the SiPM module. Linear algorithm. Truncation factor 0.05. Bias voltage 29.5V. 145 ns wide ADC gate. Two examples of single LYSO pixel energy spectra. Energy peaks corrected for the thresholding effect due to diode charge division circuitry. Slight saturation seen in the 1274 keV peak (from Na22 source)

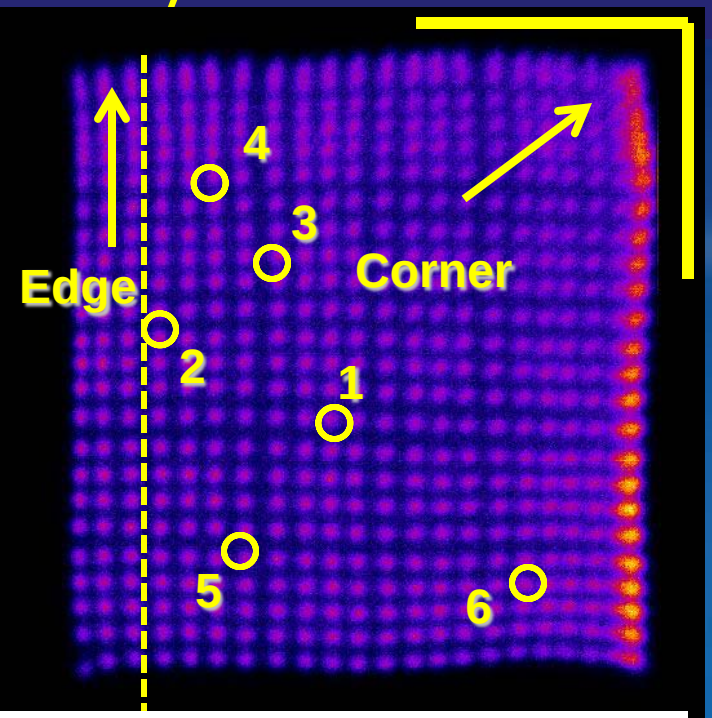
ArrayB-30035-144P-PCB
4ch readout - 10 deg C

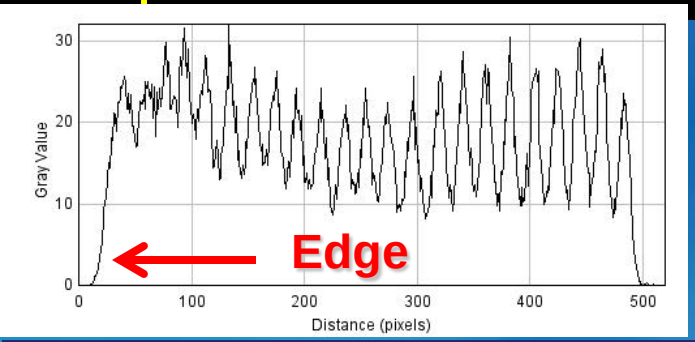


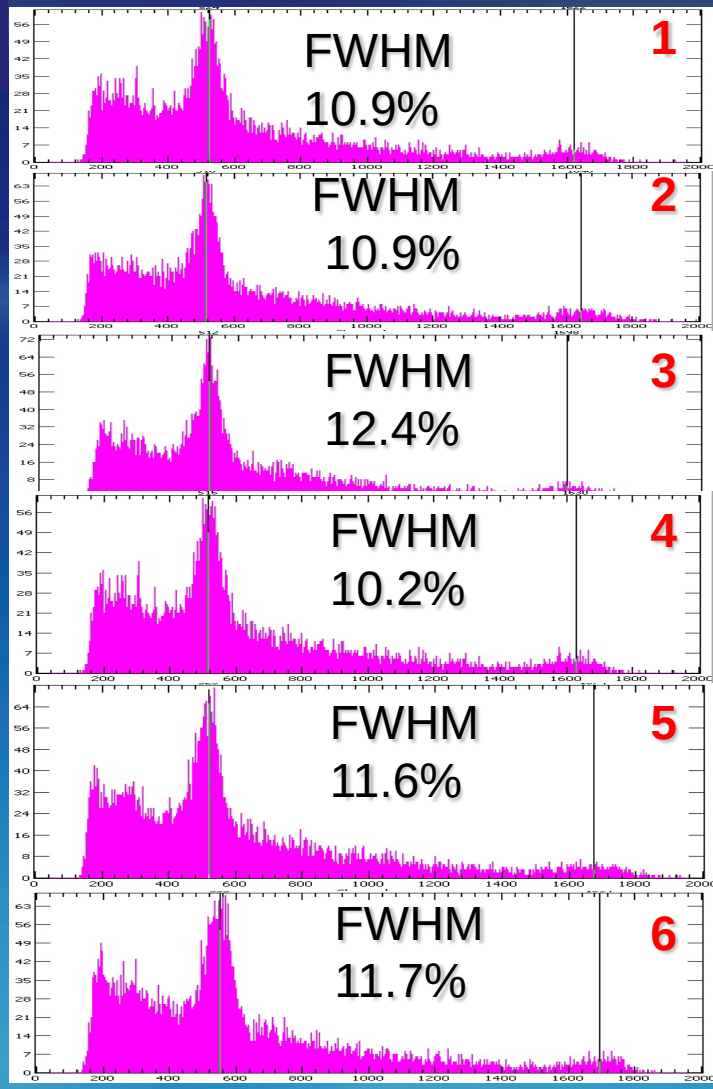


Cont'd. Bias 30.0V. Even in the corner region (worst case) pixel separation is adequate.

ArrayB-30035-144P-PCB; 4ch readout; 22 deg C



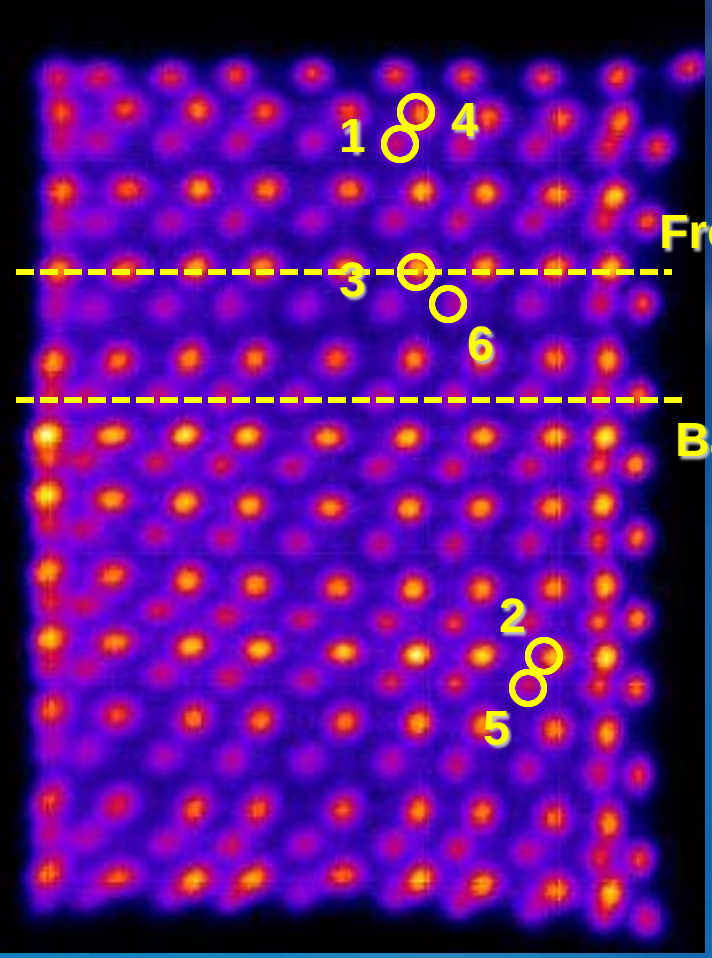




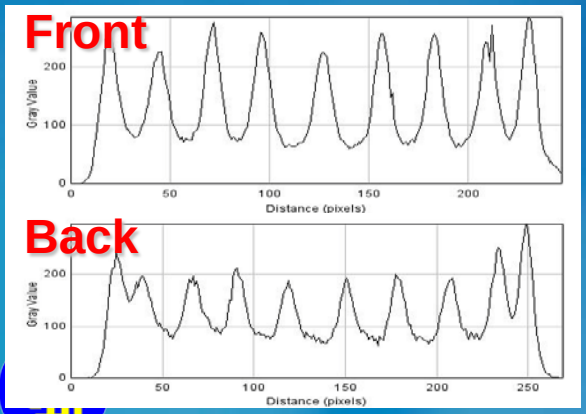
1.0 mm pixel size 10 cm thick Agile/Proteus LYSO array coupled to the SiPM array via 2.75mm spreader window. LYSO array was placed in the corner of the SiPM array. Bias voltage 28.4 V. COG truncation factor 0.075. Examples of a profile and six energy spectra for 1.0mm LYSO pixels. The peak positions were corrected for zero energy shift (thresholding) effect produced by the diode circuitry. Image blurring effects at the edges observed due to higher noise level (higher temperature).

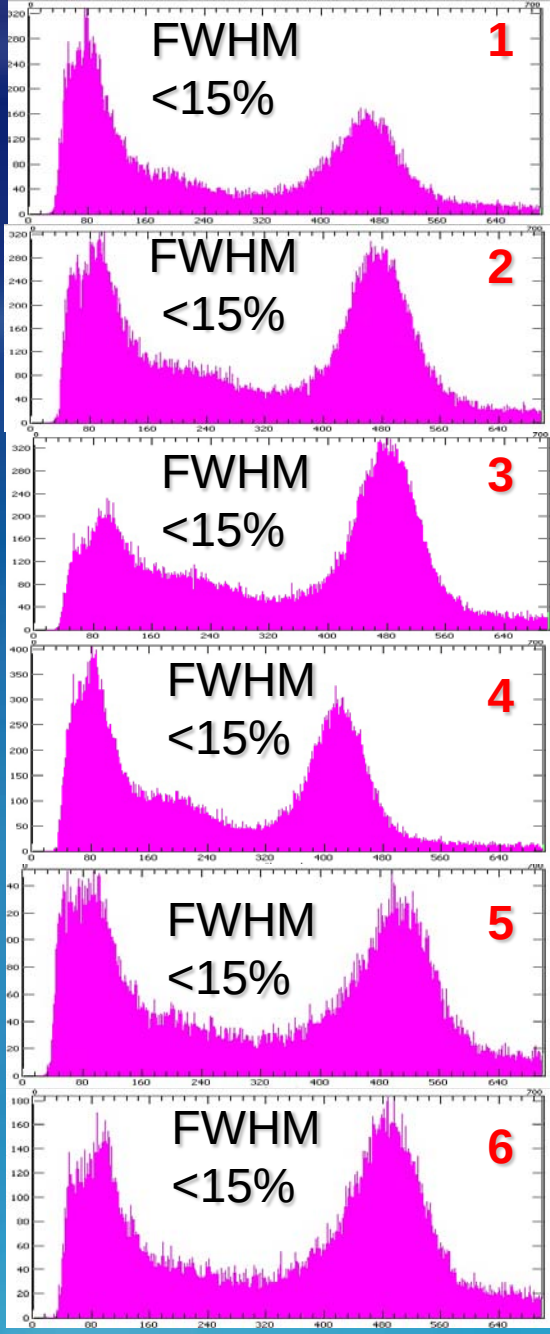
ArrayB-30035-144P-PCB

4ch readout
10 deg C

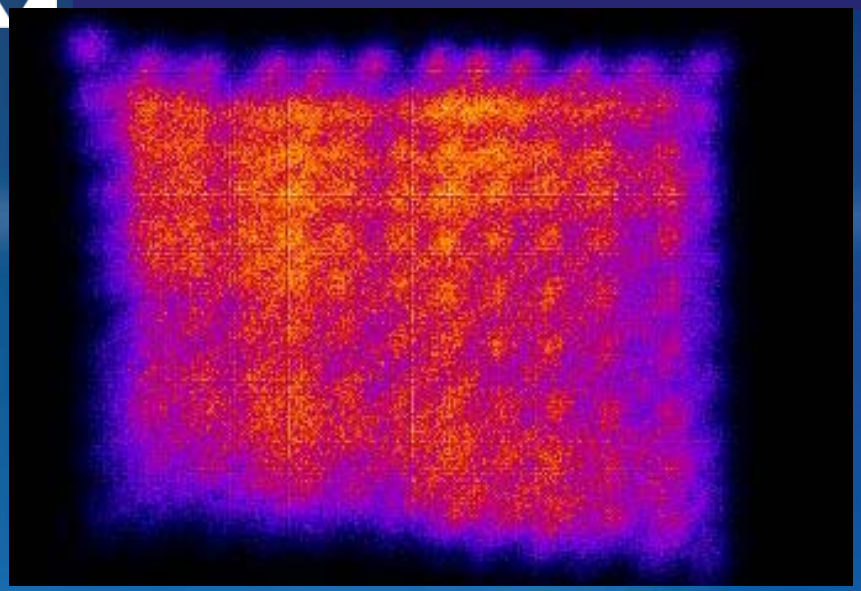


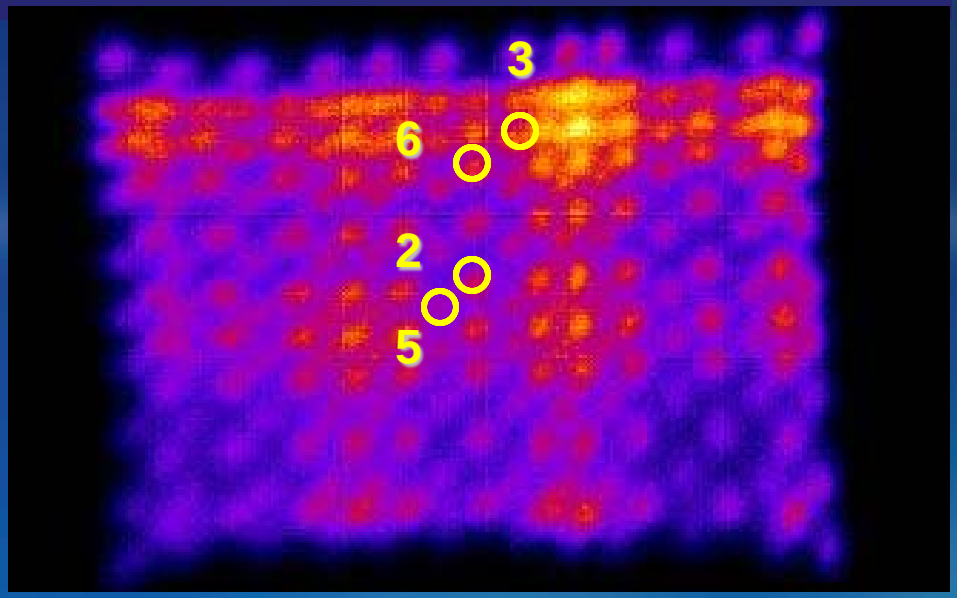
Measurements with a small sample of two stacked and shifted 10mm thick arrays of 1.5mm LYSO pixels. The stack was placed in the SiPM corner. 2.75mm thick UV acrylic light spreader window placed between the array and the SiPM module. Linear algorithm. Truncation factor 0.05. Bias voltage 28.8.V. 145 ns wide ADC gate. F18 source. Energies not corrected for the thresholding diode effect. Estimated corrected resolution is less than 15% FWHM.

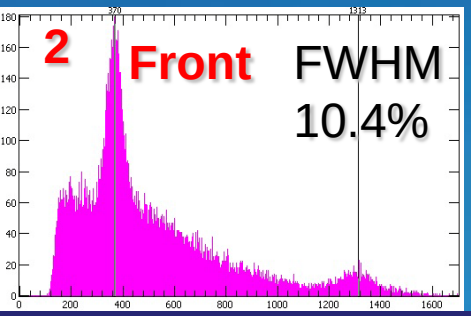


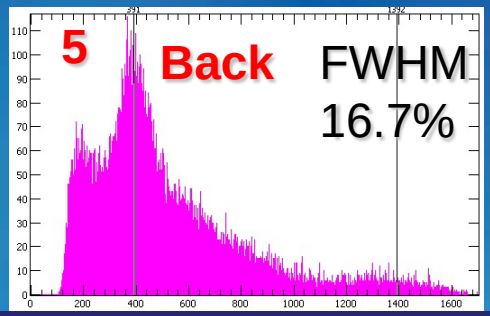


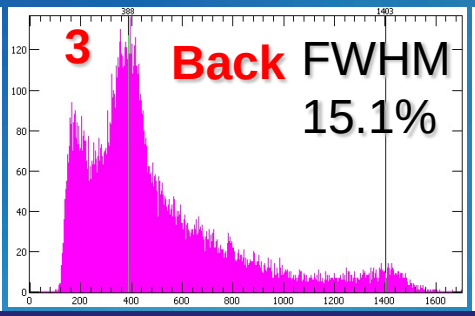
ArrayB-30035-144P-PCB; 4ch readout; 10 deg C

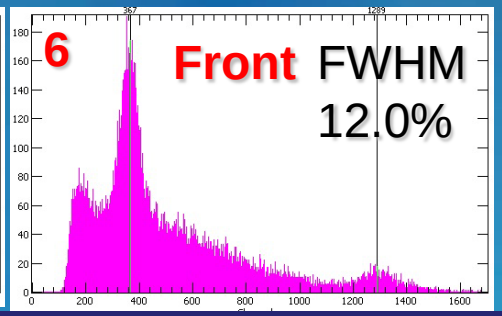












Two stacked 1.5mm LYSO arrays coupled to the corner of the SiPM array via the tapered Agile light guide. Bias voltage 29.4 V. *COG* truncation factor 0.05. Top left: additional 2.75mm spreader window placed between the tapered light guide and the SiPM array. Top right: 1.6mm spreader window placed between the LYSO arrays and the tapered light guide. No window between the tapered light guide and the SiPM array. Insufficient pixel separation Examples of four energy spectra for 1.5mm LYSO pixels from both arrays of the stack. The energies were corrected for thresholding effect produced by the diode circuitry.

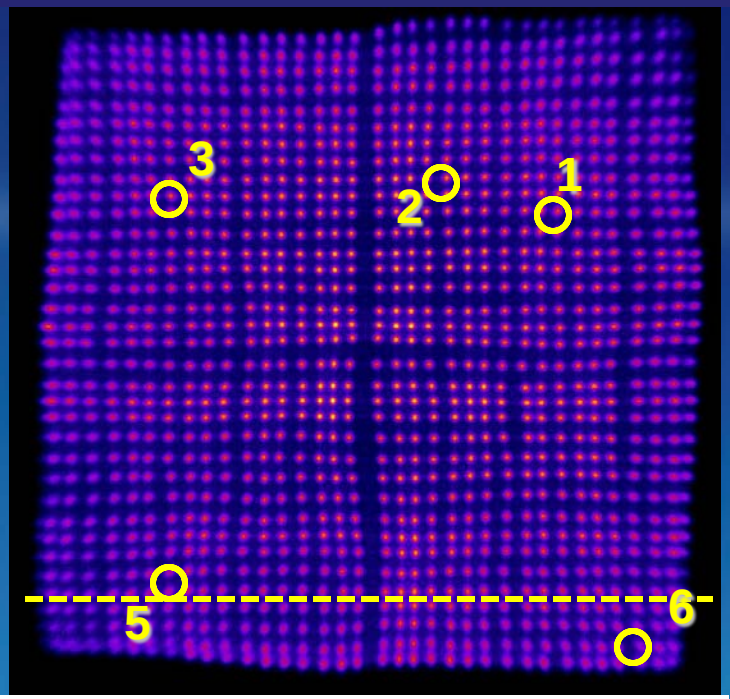
ArrayB-30035-144P-PCB; 4ch readout; 10 deg C

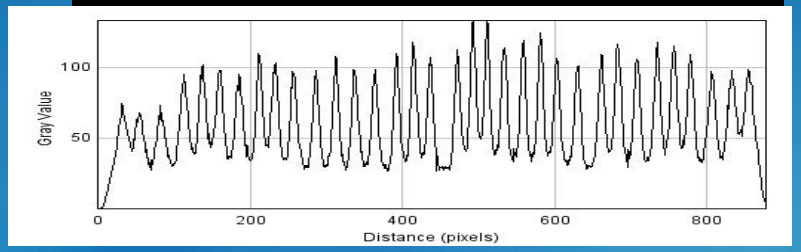
SiPMs

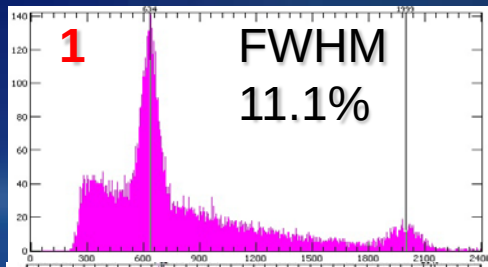
Tapered Light guide

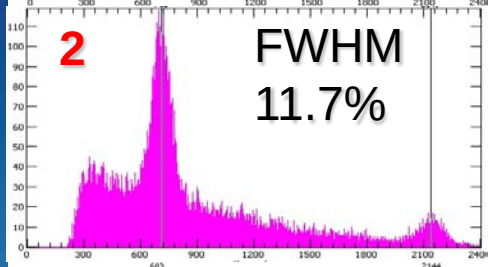
2.1mm window

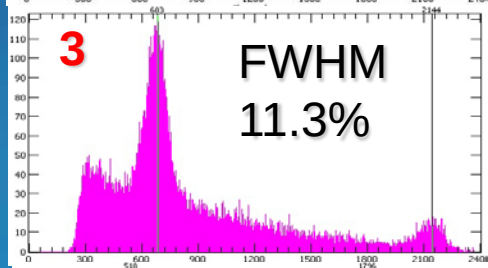
1.57mm LYSO array

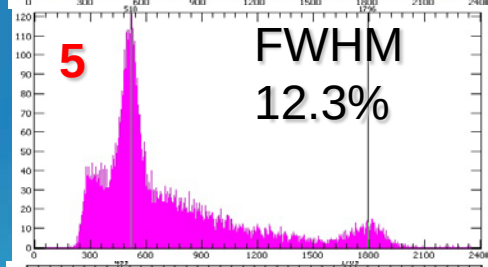


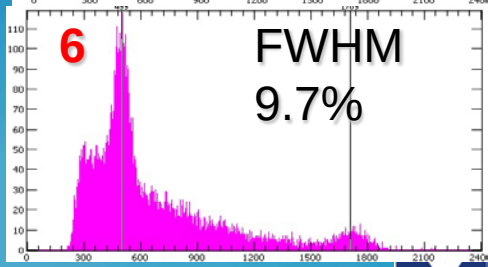






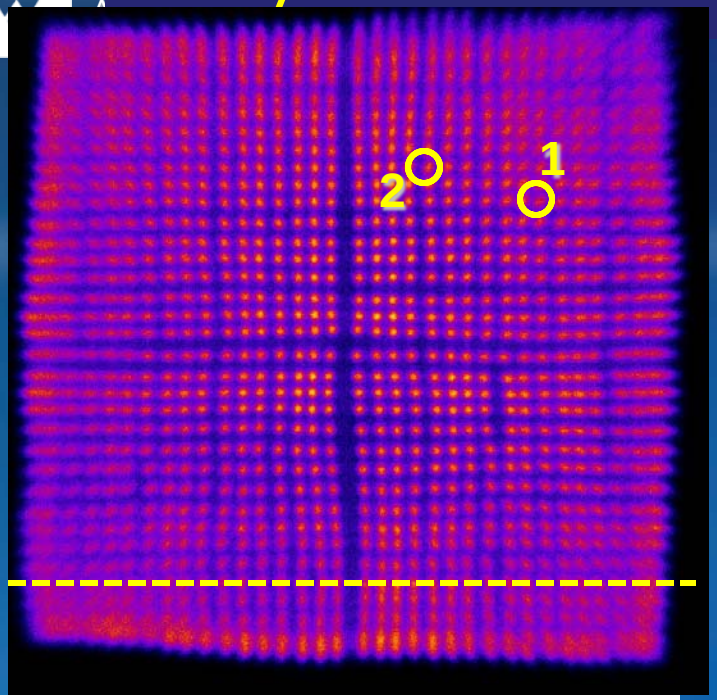


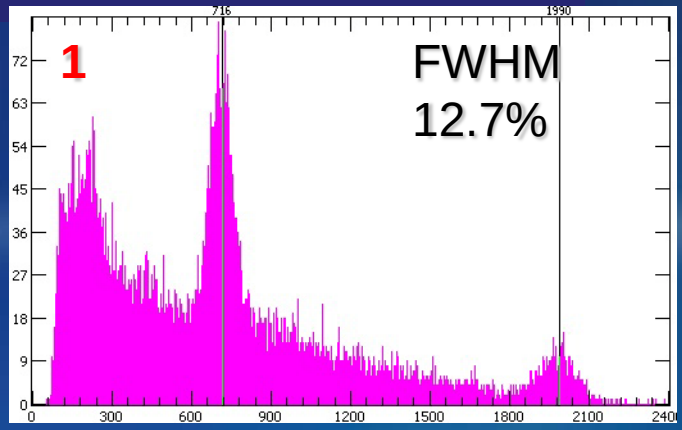


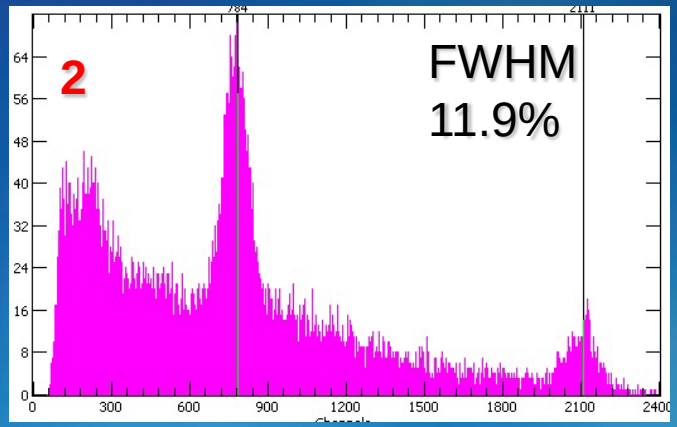


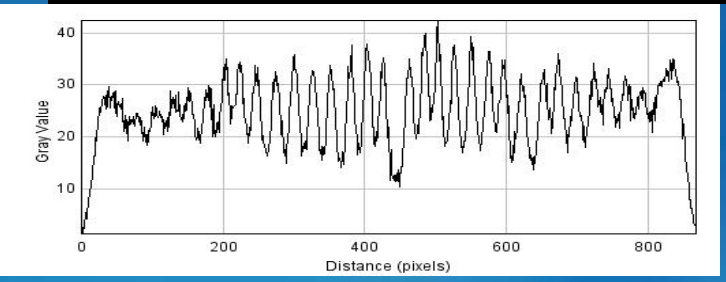
1.57mm pixel size 10 cm thick Agile/Proteus LYSO array coupled to the SiPM array via the tapered Agile light guide. Bias voltage 29.4 V. COG truncation factor 0.075. 2.1mm spreader window placed between the LYSO array and the tapered light guide. No window between the tapered light guide and the SiPM array. Examples of energy spectra for five 1.57mm LYSO pixels. The peak positions were corrected for thresholding effect produced by the diode circuitry.

ArrayB-30035-144P-PCB; 4ch readout; 22 deg C









1.57mm pixel size 10 cm thick Agile/Proteus LYSO array coupled to the SiPM array via the tapered Agile light guide. Bias voltage 29.4 V. COG truncation factor 0.075. 2.1mm spreader window placed between the LYSO array and the tapered light guide. No window between the tapered light guide and the SiPM array. Examples of energy spectra for two 1.57mm LYSO pixels. The peak positions were corrected for thresholding effect produced by the diode circuitry. Image blurring effects observed due to higher noise level (higher temperature).

Summary: Current conclusions

- (A) The best performance attained with the continuous crystals using limited spatial algorithms available at WVU - ~ 2.0 mm FWHM.
- (B). Quadratic center of gravity (COG) from Roberto Pani offers best performance for the plate option.
- (C). Cooling down to 10 deg C does not improve spatial resolution obtained with the 21mm thick plate scintillator. Limit is then in the statistical variations in scintillation signal distribution.
- (D) The stacked/shifted operation for two 1.5mm LYSO arrays is shown to satisfy the 1.5mm intrinsic resolution requirement, also with a tapered Agile light guide to obtain two DOI layers variant.
- (E). Phoswich concept (not tested this time) should be able to provide four DOI structure with four DOI layers, two of each scintillation type.
- (F). 4-channel readout variant provides satisfactory performance with the single 1mm LYSO array and the stacked 1.5mm array when used without tapered light guide and when cooled down.
- (G). Tapered light guide requires row-and-column 24ch readout for the stacked/shifted 1.5mm arrays as well as for a single 1.5mm array.