Performance of monolithic BGO crystals as gamma detectors using a Neural-Network event decoding algorithm

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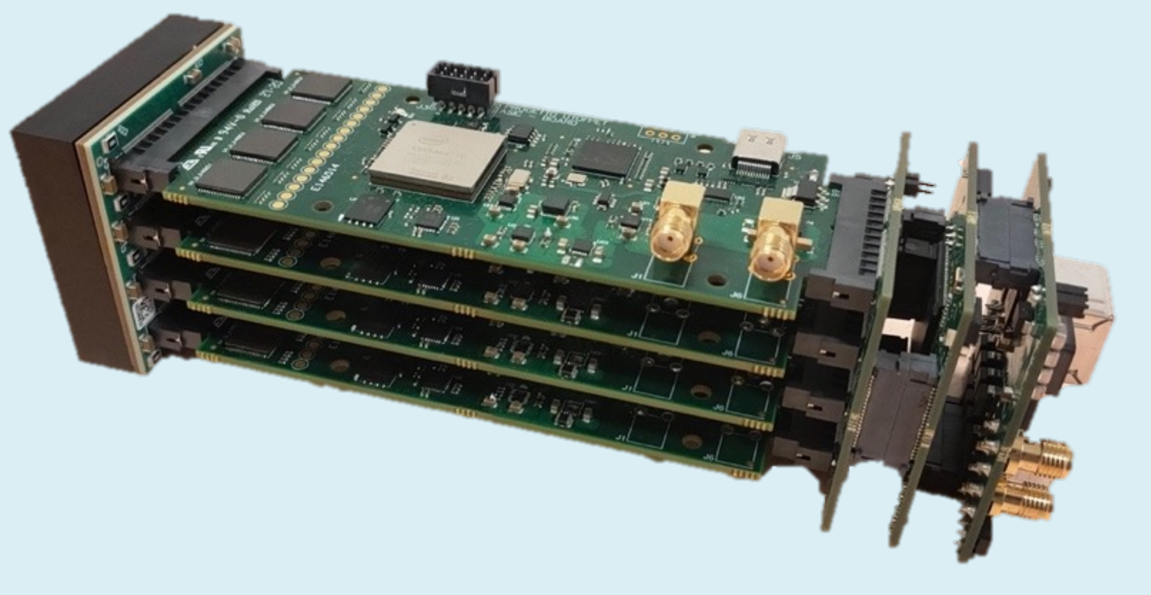
1. Aim

We compare experimentally and in simulation the performance of monolithic BGO crystals with that of LYSO when coupled to MPPC arrays of two different size. LYSO is the gold standard in time-of-flight (ToF) applications such as Positron Emission Tomography (PET) and is considered the best choice for ToF-PET scanners. BGO has been used only in non-ToF applications, due to its long scintillation decay time and low light yield [1]. We aim at showing that BGO can comply with ToF requirements by using a recently developed neural network (NN) event decoding algorithm [2], while keeping its other advantages with respect to LYSO such as its smaller attenuation length, lack of intrinsic radiation and lower cost.

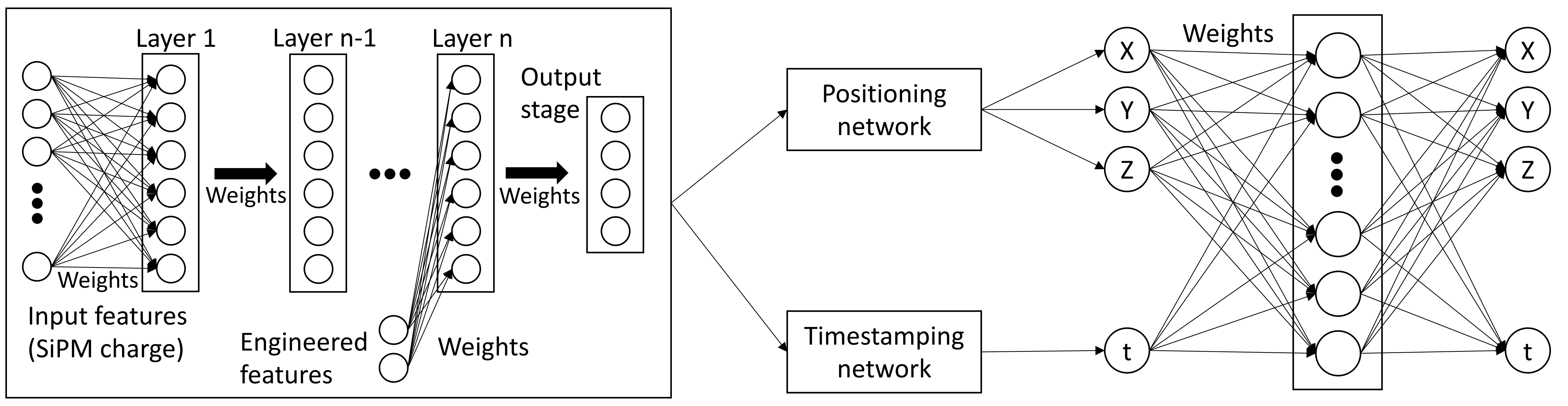
2. The UTOFPET DAQ



The UTOFPET DAQ system has been used to acquire data [3]. The DAQ hosts up to 256 SiPMs read by 16 HRFlexToT ASICs mounted on 4 ASIC boards, each containing a control FPGA with 64 embedded TDCs (25 ps bin) for timing and ToT charge measurement. Events from the 4 ASIC boards are processed either off-line or in real-time by the SoC-FPGA on the back of the DAQ.

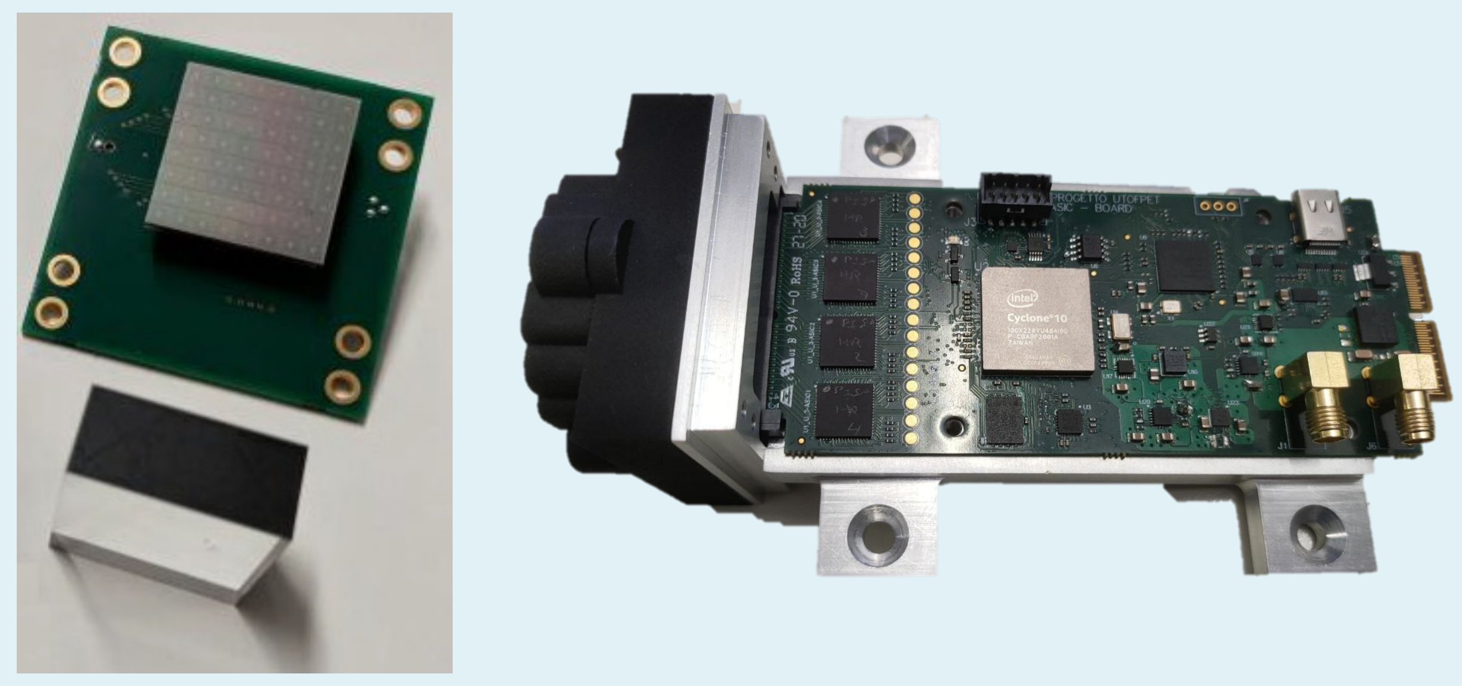
3. Neural Network architecture

The NN is designed to limit the number of parameters for FPGA implementation. Time and positioning are evaluated on two NNs and integrated on a third one. The number of MPPC that read more than 5% of the total charge and the charge variance are added as engineered features to facilitate DOI estimation.



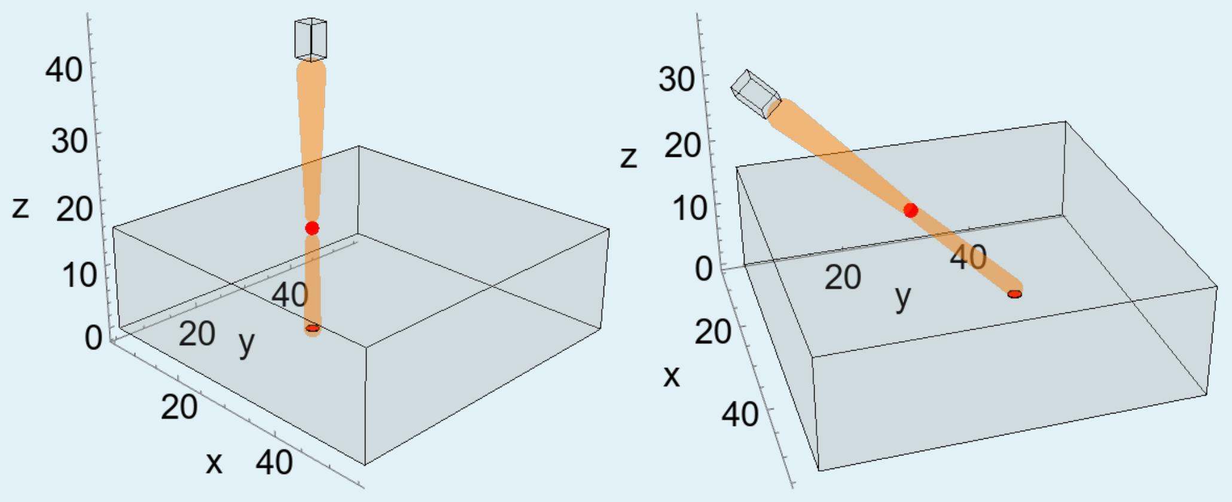
4. Experimental setup

The detector under test is composed of a 25.9 mm x 25.9 mm x 12 mm scintillating crystal (either LYSO or BGO) coupled to a Hamamatsu array of 64 MPPCs. Two MPPC sizes are used and compared, i.e., models S14160-3050 (3.2 mm pitch) and S14160-6050 (6.2 mm pitch), the latter only in simulation using a custom developed simulation framework [4]. The lateral sides of the scintillator are painted black while the top side is covered with a specular reflective film. The detector was placed facing a small LYSO crystal of 3 mm x 3 mm x 10 mm which served as reference for time and position.



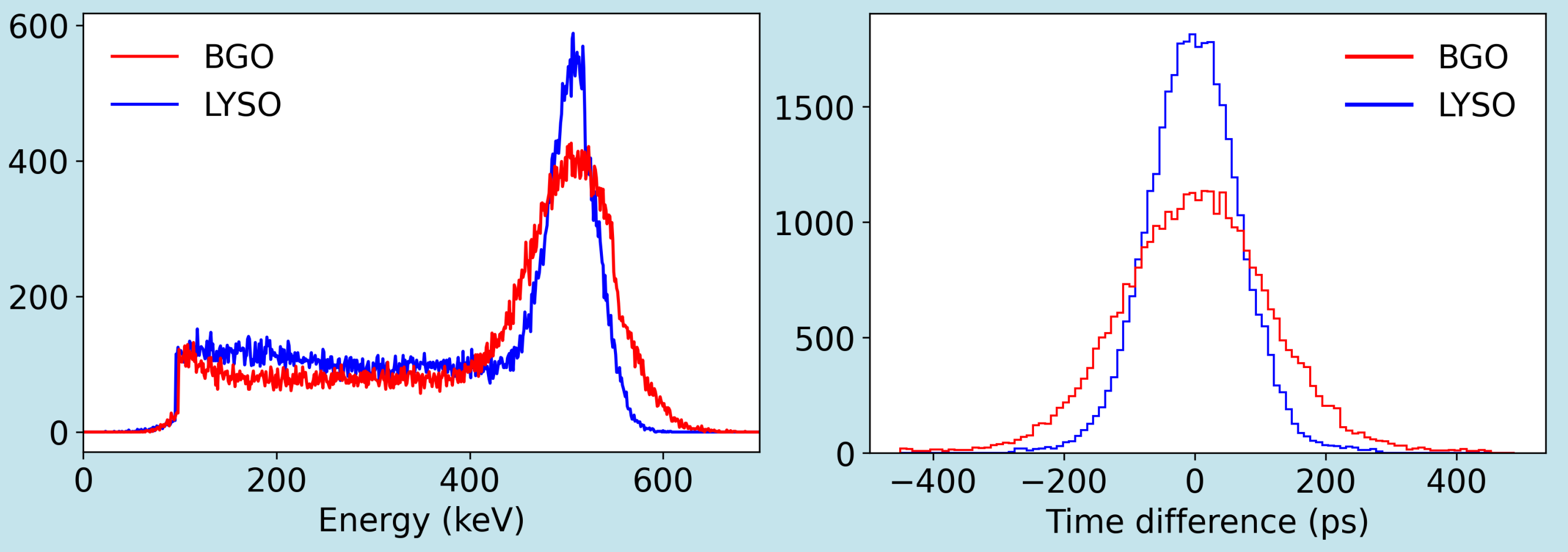
A ^{22}Na point source (0.5 mm diameter) was placed between the two detectors at a distance of 1 cm from the monolithic crystal and at a distance of 40 cm from the reference detector. The measured coincidence time resolution (CTR) was evaluated by subtracting the contribution of the reference detector and by multiplying by the square root of 2.

A perpendicular collimation setup was used for measuring the intrinsic spatial resolution along the *x* and *y* axes. This configuration was used also to train the NN to estimate *x* and *y* coordinates. Then, an oblique collimation was used to correlate the *z* with the estimated *y* coordinate, in order to be able to have a reference DOI. The experimental setup is replicated in simulation for validating the results with 3.2 mm MPPC and to improve NN training.

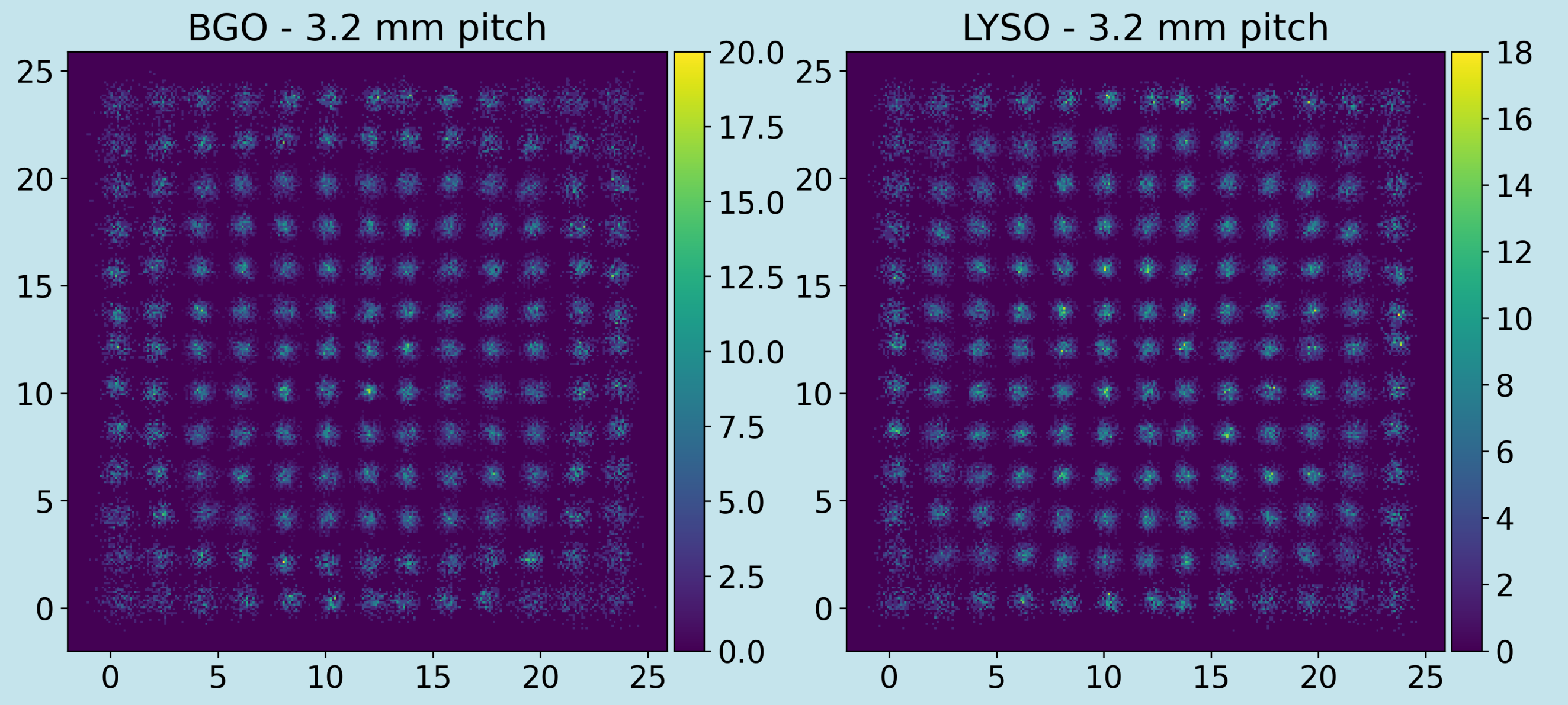


5. Results

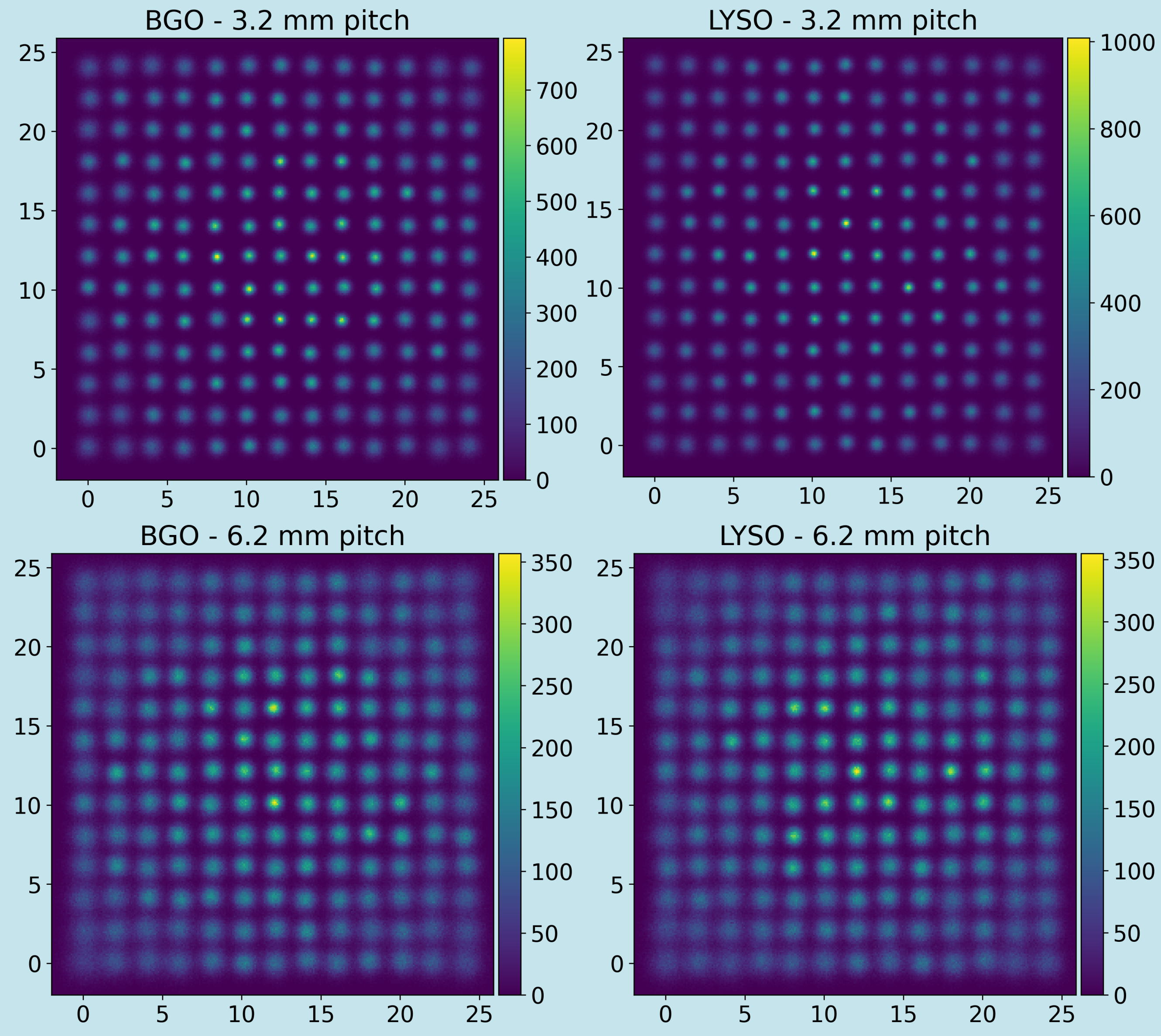
Experimental results obtained using the monolithic BGO and LYSO detectors in coincidence with the reference detector. Left: energy spectra. Right: coincidence time difference.



Flood maps obtained experimentally by irradiating the detectors with 3.2 mm pitch MPPCs on a 13 x 13, 2 mm step grid with a total of approximately 70 thousand events.



Flood maps obtained in simulation by irradiating the detectors in the different configurations on a 13 x 13, 2 mm step grid with a total of approximately 3 million events.



Experimental and simulated detector performance

EXPERIMENTAL	CTR (ps)	SR (mm)	Energy Res. (%)
3.2 mm LYSO	160	0.8	12.7
3.2 mm BGO	320	0.8	20.2

SIMULATED		CTR (ps)	SR (mm)	DOI (mm)
6.2 mm	LYSO	301	0.99	1.7
	BGO	320	1.10	1.8
3.2 mm	LYSO	129	0.65	1.3
	BGO	280	0.70	1.5

6. Conclusions

The time-position estimation based on neural networks can improve significantly the performance of monolithic scintillators for gamma detection. The performance gap between BGO and the more performant LYSO in terms of CTR can be reduced significantly to the level that BGO becomes a valid alternative for time-of-flight PET applications.

7. References

[1] S. Vandenberghe et al., 2016, EJNMMI Physics.
[2] P. Carra et al., 2021 IEEE NSS-MIC.
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[4] P. Carra PhD Thesis, University of Pisa, 2021.

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