Spatial resolution of large monolithic detector: performance evaluation with two positioning algorithms

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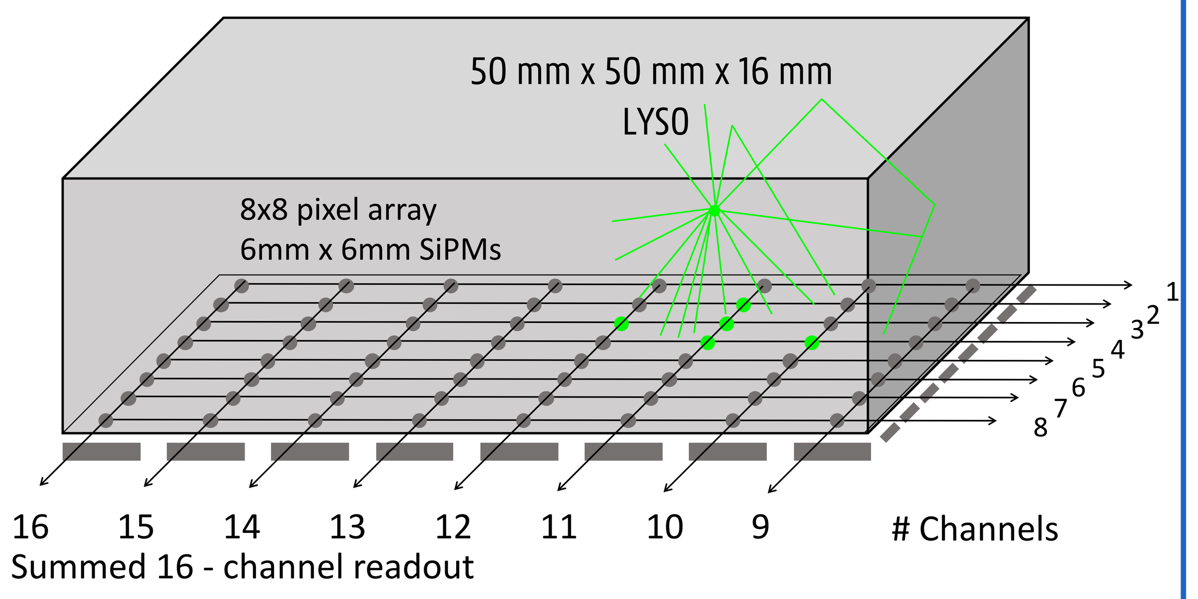
Background

- Monolithic detectors offer a high-resolution alternative to the segmented detector design [1]
- Economically more attractive for detector resolution of <2 mm → high cost of manufacturing segmented scintillator arrays
- Trend towards total body (TB) PET imaging requires a large increase of detectors (x10)
- Systems with smaller or adaptive bore could favour from intrinsic resolutions of as good as 0.9 mm [2] [3]



Objective

i. Design high-resolution detector hardware and software

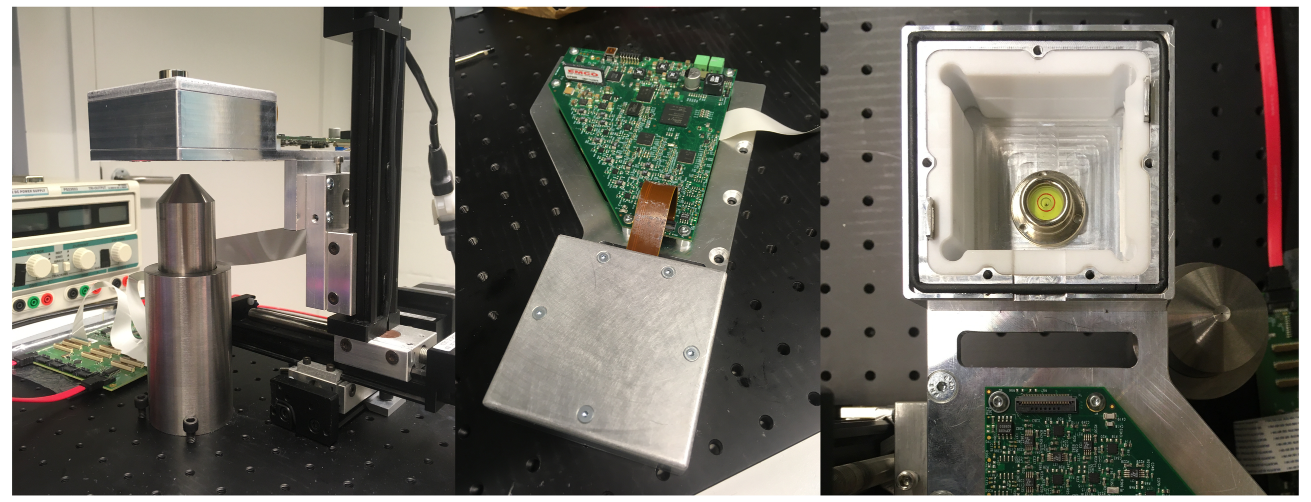
ii. Optimization of spatial resolution.

iii. Evaluation with 2 positioning algorithms
  i. **k- nearest neighbor** (kNN) algorithm
  ii. neural network based **deep learning** (DL) algorithm

Materials and Methods

Hardware

- 50×50×16 mm³ LYSO (Epic Crystal)
- 8x8 array of SiPMs (SemiON MicroFJ-60035-TSV)
- Summed row and column readout → 16 channels
- Surfaces finish: rough black painted finishing on crystal sides; specular reflector + polished crystal top



Calibration

- ^{68}Ge calibration source (69 MBq)
- 1 mm calibration grid (49x49) a 70s per position
- Calibration data extraction: Anger positioning + ROI selection

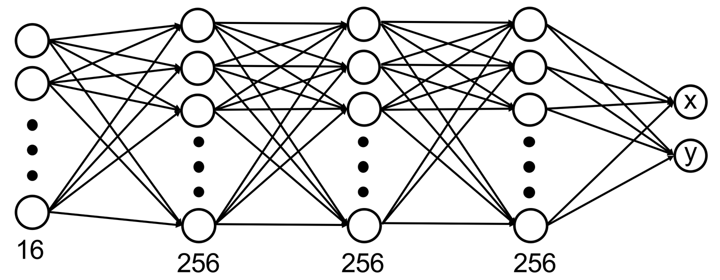
Positioning algorithms

kNN positioning algorithm

- ~7000 events/position
- calibration data six depth-dependent groups according to the signal std. dev.
- For each group a mean signal is calculated and interpolated to a calibration grid step size of 0.25
- Mean reference light distribution are saved to LUTs
- kNN: exhaustive neighbour search
- More details in [4]

Deep learning positioning algorithm

- 1000 events/position
- Leaky ReLU activation
- Adam optimisation
- Learning rate = 10^{-3}
- Batchsize = 256
- L1 loss
- Early stopping based on validation loss
- PyTorch /11 GB NVIDIA RTX 2080Ti GPU
- Overfitting: network is validated after every epoch on data acquired in 0.5mm steps

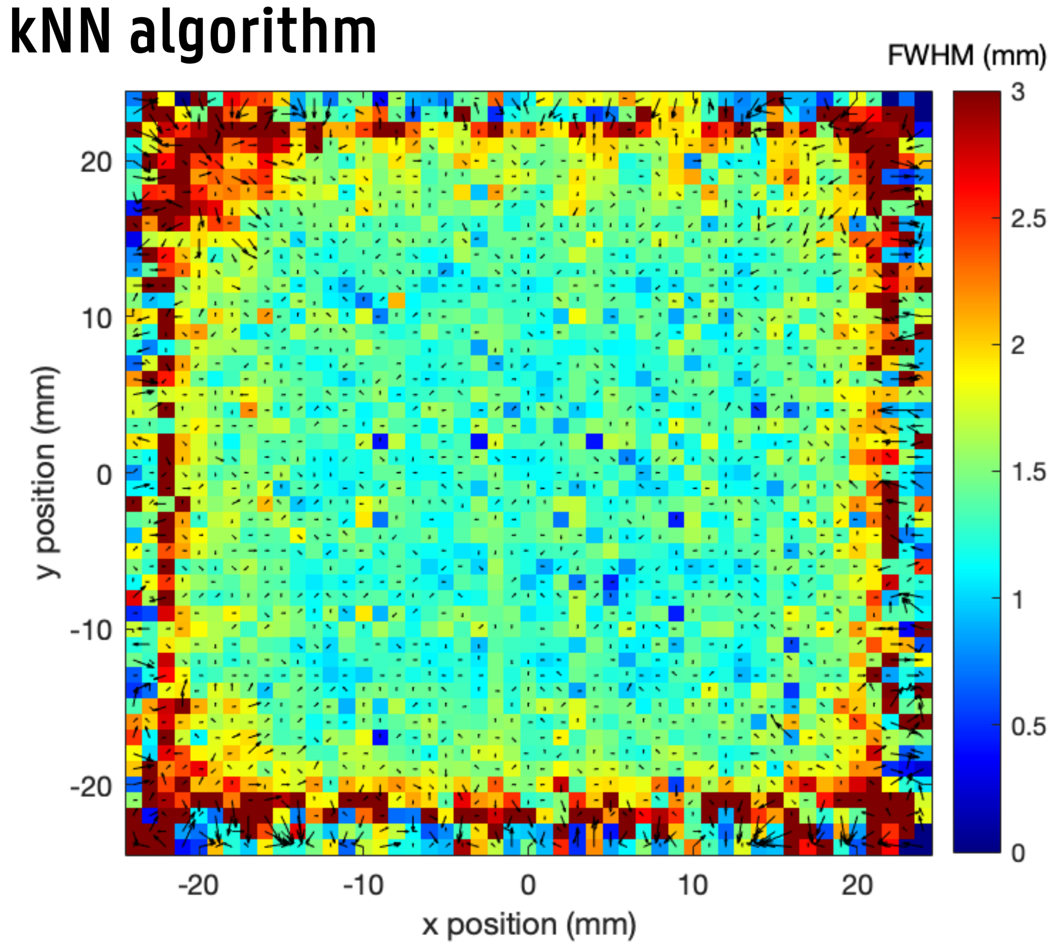


Evaluation

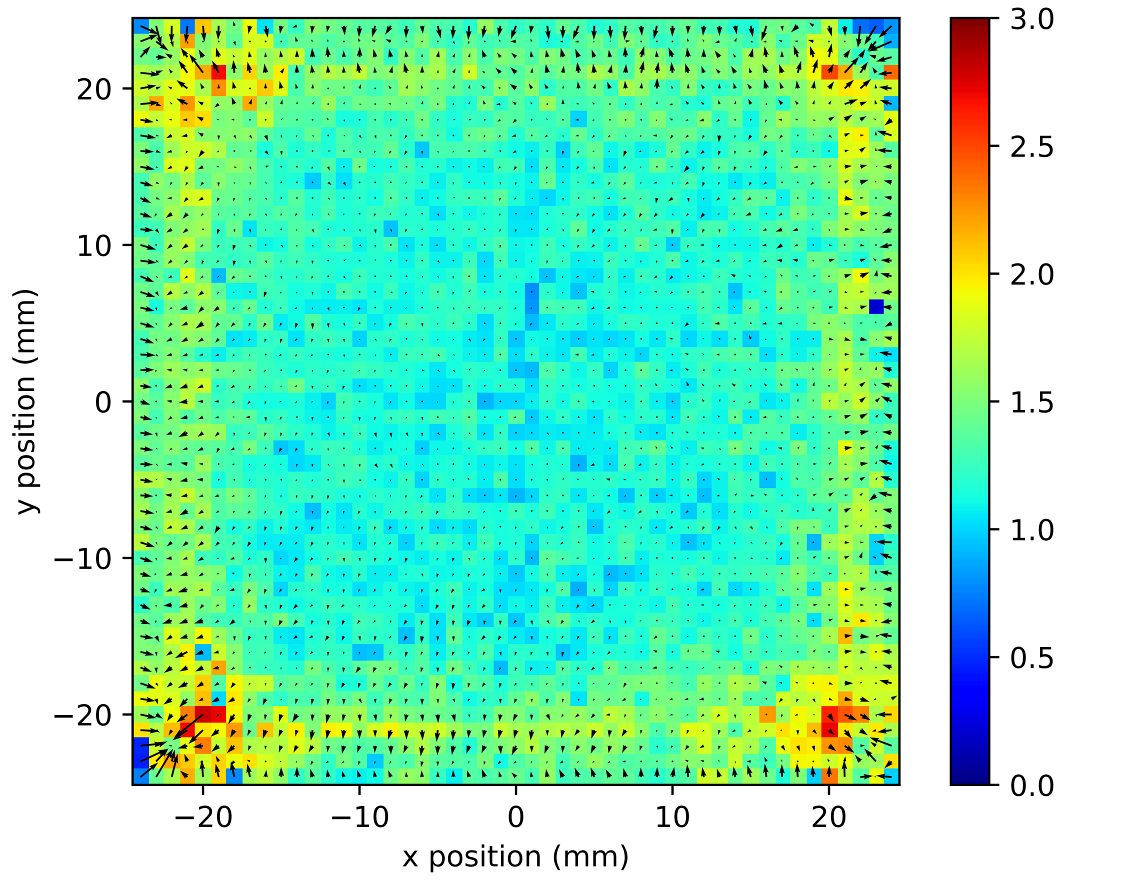
- 20000 events/position
- FWHM: Gaussian fit to horizontal and vertical line profile of PSF in the 2D histogram.
- Positioning bias: Euclidean distance between peak of the PSF and calibration position

Results and Discussion

kNN algorithm



DL algorithm



	Full detector 5x5 cm²		Center region 3x3 cm²	
	kNN	DL	kNN	DL
FWHM mean	1.69	1.34	1.31	1.16
FWHM median	1.42	1.26	1.29	1.17
Bias mean	0.35	0.18	0.19	0.10
Bias median	0.25	0.12	0.25	0.09

- DL algorithm achieves improvement of the mean FWHM of 21% for the full detector and 11.5% for the detector center
- mean positioning bias is decreased by almost 50%

- Results are in line with simulations that have previously been presented [5]
- DL algorithm trained on individual events ↔ kNN database trained on mean of multiple signals
  → mean signal acts like a filter for signals from scattered events
  → positioning of scattered events might be improved with the DL algorithm

Conclusion

- The superior algorithm is the DL algorithm with an overall mean FWHM of 1.34 mm and 1.17 mm in the centre
- To the authors knowledge there is no comparable detector with this good spatial resolution
- A potential application for this detector is any conventional clinical PET system, but especially, due to its cost advantages when high resolution is desired, a TB-PET system with an adaptive system bore
- On a system level this leads to a spatial resolution of ~2 mm for large bore diameters and improves further for smaller bore diameters.

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REFERENCES

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[2] W. W. Moses, "Fundamental limits of spatial resolution in PET," Nucl Instrum Methods Phys Res A. 2011, vol. 648, pp. 236–240, 2011.
[3] S. Vandenberghe, E. Mikhaylova, B. Brans, R. van Holen, D. R. Schaart, J. S. Karp, "PET 20.0: A cost efficient, 2.00mm resolution total body MONOLITHIC PET WITH VERY HIGH SENSITIVITY and an adaptive axial FOV up to 2.00m," in EANM conference, 2017.
[4] Stockhoff M, Van Holen R, Vandenberghe S. Optical simulation study on the spatial resolution of a thick monolithic PET detector. Phys Med Biol. 2019;64(19):195003. doi:10.1088/1361-6560/ab3b83
[5] M. Decuyper, M. Stockhoff, and R. Van Holen, "Deep Learning for Positioning of Gamma Interactions in Monolithic PET Detectors," in IEEE MIC Poster, 2019.

Related research

'Mitigating the adverse effect of Compton scatter on the positioning of gamma interactions in large monolithic PET detectors', Poster M-15-027 #1714 Milan Decuyper