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Investigation of monolithic and pixelated detectors and two-layer geometry for hemispheric PET systems: a simulation study

Knuth Scheiff* and Christoph Hoeschen   Otto-von-Guericke-University Magdeburg, Institute of Medical Engineering, Chair of Medical Systems Technology

Introduction

Positron Emission Tomography (PET) is used for diagnostic and research on many different brain diseases e.g. tumors, epilepsy, and dementia. These applications require to improve the resolution down to 1 mm. Since resolution of PET is highly depended on the systems radius, brain dedicated geometries have been proposed and prototyped during the recent years. [1] Several of these brain dedicated PET systems use a spherical or hemispherical geometries so as to keep the radius of the scanner to the minimum possible. [2] As most PET systems, most brain dedicated geometries rely on detectors with highly pixelated crystals. Depending on crystal width and coating thickness, crystal pitch reduces the volume fraction of the crystals volume fraction and thereby the detection efficiency significantly. During the last 10 years, detectors using monolithic crystals achieved intrinsic resolutions comparable to pixelated ones. Usage of monolithic crystals might allow to increase the detection efficiency at same detector size and similar resolution. [3] Since the intrinsic resolution of monolithic crystal is related to thickness, a second layer of detectors might be used to reach the same total crystal depth as used in pixelated detectors and close gaps in the positioning of the first one. In this simulation study detectors with similar intrinsic resolution of different materials and in different arrangements were investigated.

Materials and Methods

The simulations were conducted using Gate, a medical application toolkit for GEANT4. The system as the "mothervolume" in Gate is "PETscanner" (predefined in Gate). Hemispheric geometries with one and two layers consisting of monolithic detectors, pixelated detectors and a combination of both detector types were conducted. The chosen crystal materials were BGO, LSO and LYSO. Deadtimes 200 ns non-paralysable and 400 ns paralysable were considered. An additional chin detector array was added. As radiation source was placed 5 cm on x- and y-axis off the centre.

Geometry:

- Hemisphere of an inner diameter of 25 cm, fitting the human head
- Detectors have a 44x44 mm² surface and an additional 4 mm for the housing
- Electronics: 44x44x10 mm³ (1 layer) and 44x44x20 mm³ (2 layer) block of silicon respectively
- 1 layer
  - ➢ Pixelated detector: 40x40 crystals of 1x1x20 mm³, 1 mm pitch
- 2 layer
  - ➢ Both layers are either pixelated or monolithic or inner layer is pixelated and outer layer monolithic (pixelated-monolithic)
  - ➢ Detectors: pixelated: 40x40 crystals of 1x1x10 mm³, 1mm pitch ; monolithic: 44x44x10 mm³ monolithic crystal

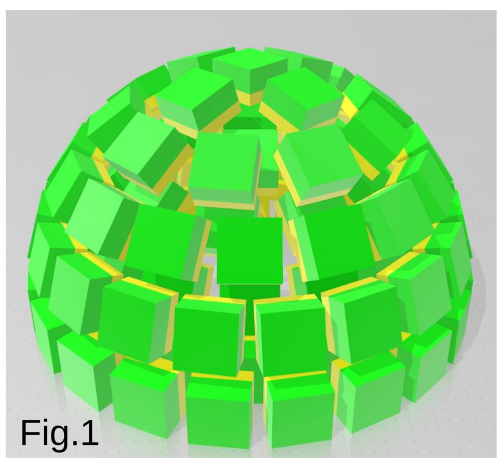


Fig.1

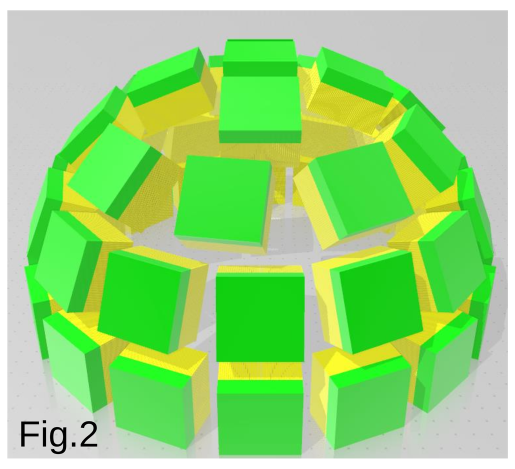


Fig.2

- Fig.1 double layer arrangement
- Fig.2 single layer arrangement
- Fig.3 & Fig.4 double layer arrangement with chin array

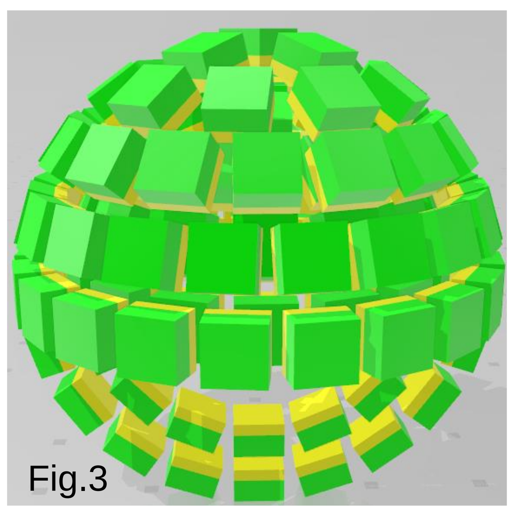


Fig.3

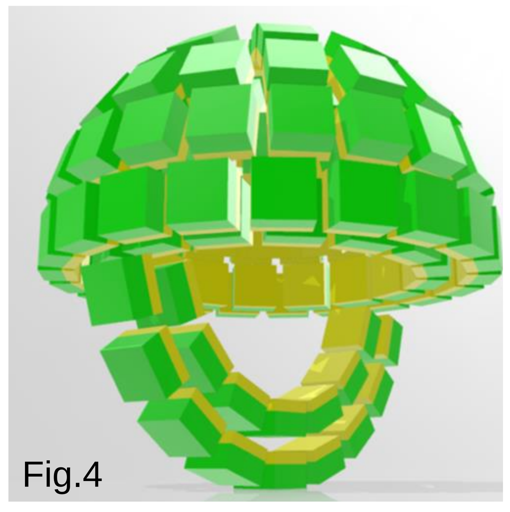
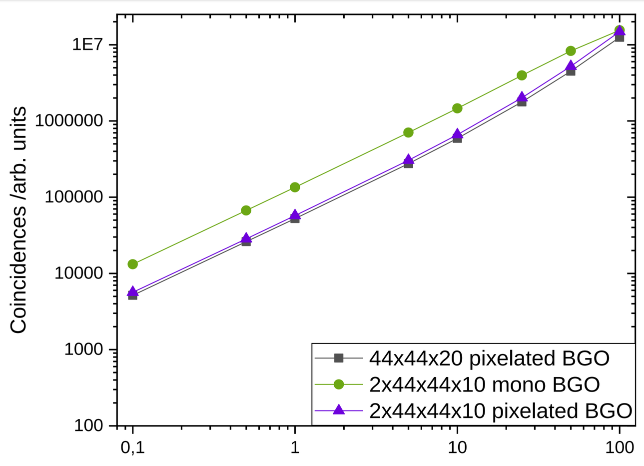


Fig.4

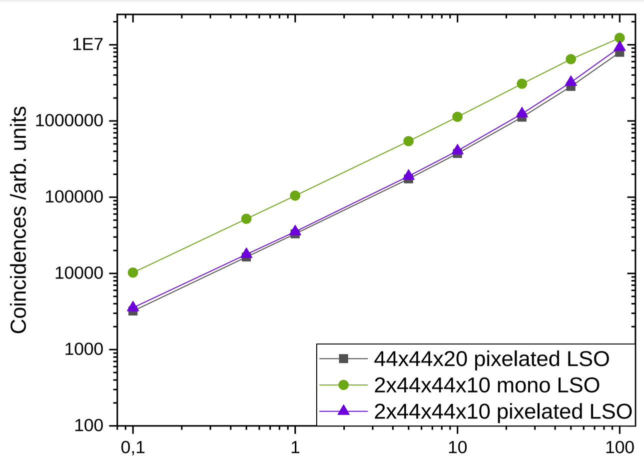
Results

BGO | LSO | LYSO

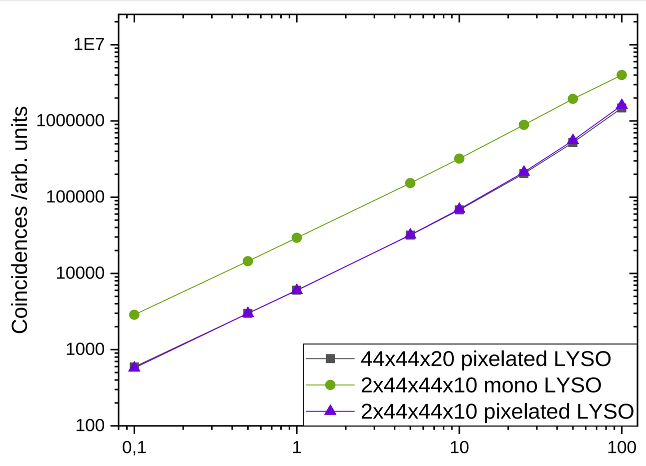
1 layer vs. 2 layers



Tab. 1.1



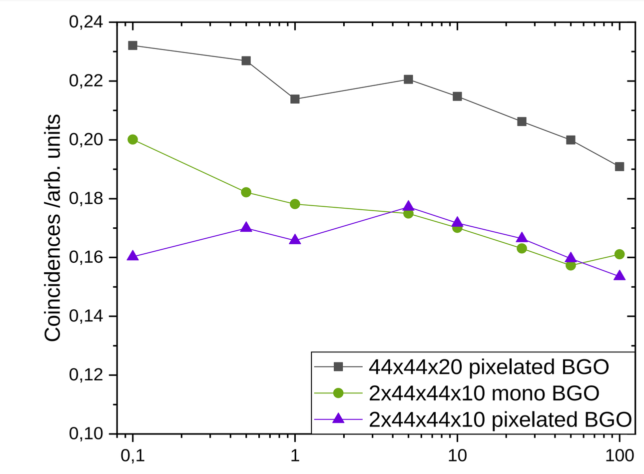
Tab. 1.2



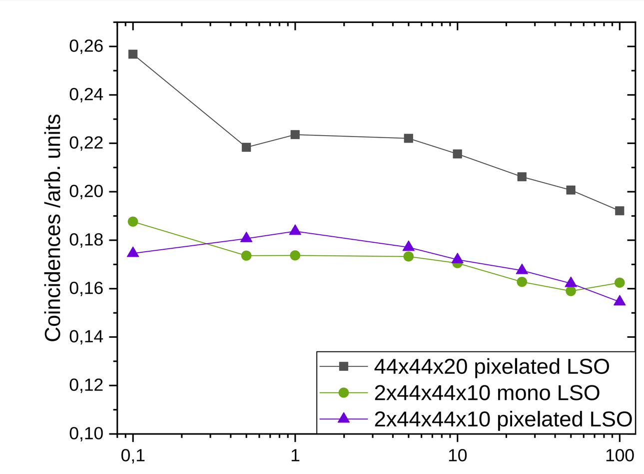
Tab. 1.3

- 2 layers design presents superior to one layer
- Monolithic arrangement superior to pixelated detector at lower activities
- At high activities pixelated detectors catch up
- Performance order of the crystals in terms of count rate: BGO, LSO, LYSO
- For LYSO monolithic detectors shows the highest superiority to pixelated

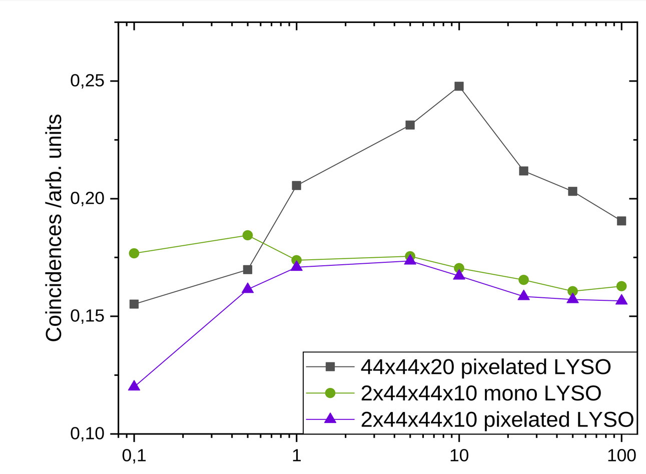
Improvement by chin detectors



Tab. 2.1



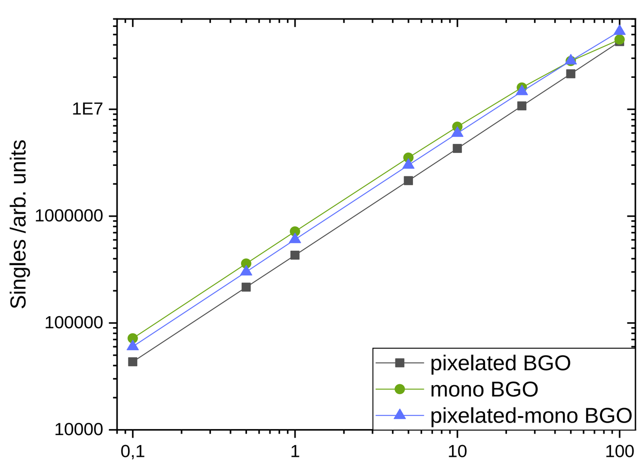
Tab. 2.2



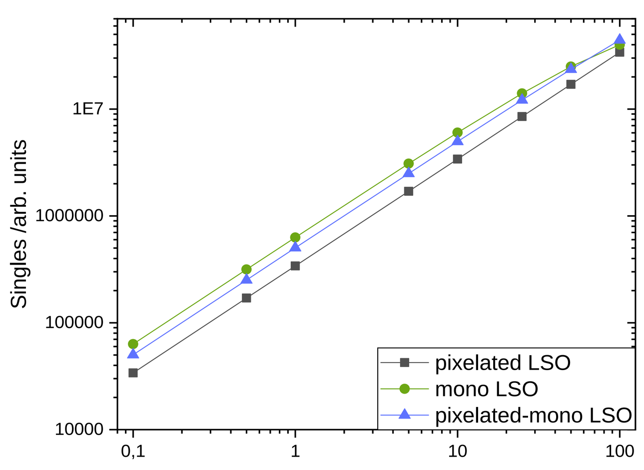
Tab. 2.3

- Chin detector improves sensitivity
- Improvement between ca. 12% to 26%
- Similar to results presented by *Hideaki Tashima et. al 2015* [4] on hemispheric PET prototype

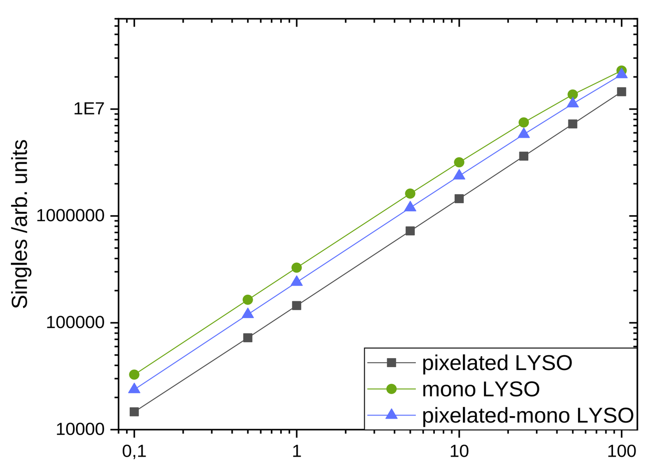
2 layers pixelated vs. 2 layers monolithic vs. 2 layers pixelated-monolithic



Tab. 3.1



Tab. 3.2



Tab. 3.3

- Since gate does not allow counting of coincidences on the pixelated-monolithic arrangement → confinement on singles
- Pixelated-monolithic superior to pixelated
- Surpassing monolithic at high activities

Discusion

Since monolithic detectors present the highest sensitivity in terms of count rate in most parts of the investigated range of activity, all materials indicate a loss of sensitivity at higher activities. This might turn out to be a disadvantage of monolithic detectors. The simulation indicates, that the combination of pixelated and monolithic detectors can compensate this disadvantage. This might also enable the System to combine time of flight and depth of interaction abilities. Also LYSO seems to be the least preferable material due to its relatively low count rates. Since this study does not take material characteristics, such as decay time, into account.

Further work

1. Optimization on pile up and blurring
2. Further determination of dead time
3. Programming a reconstruction algorithm
4. Finalizing simulation for phantom testing
5. Construction and characterization of a demonstrator system

Literature

[1] Ciprian Catana, "Development of Dedicated Brain PET Imaging Devices: Recent Advances and Future Perspectives", J. Nucl. Med. 2019 Aug.; 60(8):1044–1052.
[2] Hideaki Tashima et al 2019, „First prototyping of a dedicated PET system with the hemisphere detector arrangement", 2019 Phys. Med. Biol. 64 065004
[3] Andrea Gonzalez-Montoro et al, „Evolution of PET Detectors and Event Positioning Algorithms Using Monolithic Scintillation Crystals", IEEE Transactiom on radiation and plasma medical sciences, Vol. 5, No. 3, May 2021
[4] Hideaki Tashima et. al 2015, „Development of the Helmet-Chin PET Prototype", 2015 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), 2015, pp. 1-3

Acknowledgements

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* corresponding author: knuth.scheiff@ovgu.de, Tel.: +49-391-67-59363