Nuclear medicine application in the GAMUS project: Gamma-ray detection system for breast cancer biopsy

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Introduction

A paradigm shift in the diagnosis of breast cancer is emerging from the team of researchers from the Gamma and Neutron Spectroscopy Group at the Institute of Corpuscular Physics (IFIC). This is a joint centre of the Consejo Superior de Investigaciones Científicas (CSIC) and the Universitat de València, a project led by the scientist Luis Caballero, who has patented a novel device for carrying out guided biopsies in vivo that could improve the prognosis of patients. Its main objective is to obtain a sample in the biopsy of a tumor in the breast that can be representative of the heterogeneity that could present this tumour in order to make an image reconstruction in situ. Project in which I have participated in the gamma-ray detectors individual and full system performance characterisation as well as in the system configuration optimization through Monte Carlo simulations, comparing simulated and experimental data trying to maximise their detection efficiency and spatial resolution.

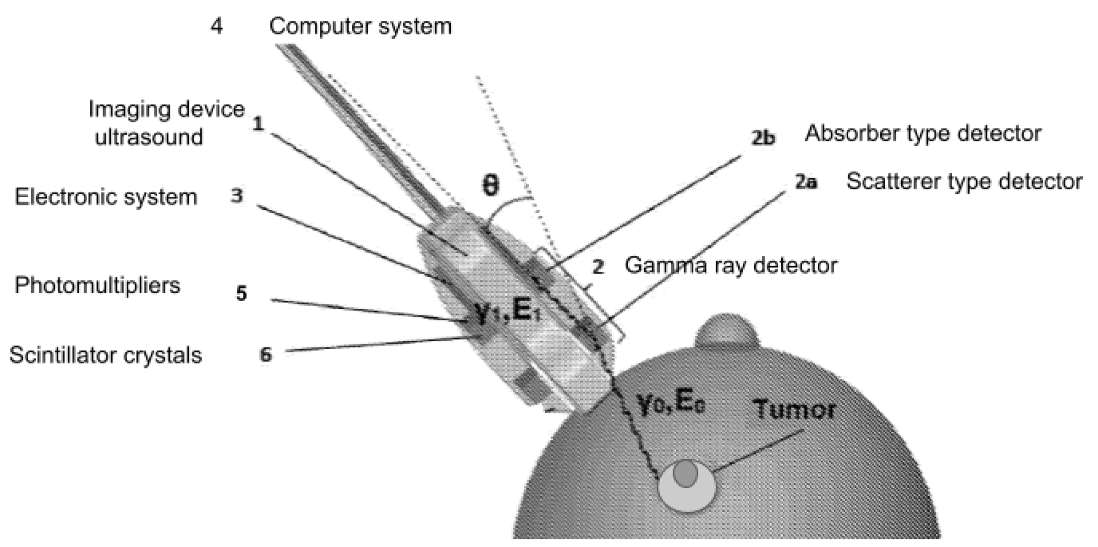

Figure 1:Basic schematic of the hybrid ultrasound and Compton camera device for biopsy guidance of a breast biopsy

This project arises from the need to obtain a light, easy-to-use and to have a mobile instrument capable of obtaining anatomical and functional information. This objective is achieved thanks to the application of a hybrid system consisting of a centred ultrasound device surrounded by detection modules with scintillation detectors. The only way to obtain metabolic information in medical imaging is by injecting patients with a radiotracer, whit is a substance containing radioisotopes which decay and emit gamma radiation. The fluorodeoxyglucose molecule ^{18}FDG is the most widely used drug in the PET technique.

$$^{18}_{9}F \longrightarrow^{18}_{8} O + e^{+} + \upsilon \qquad (1)$$

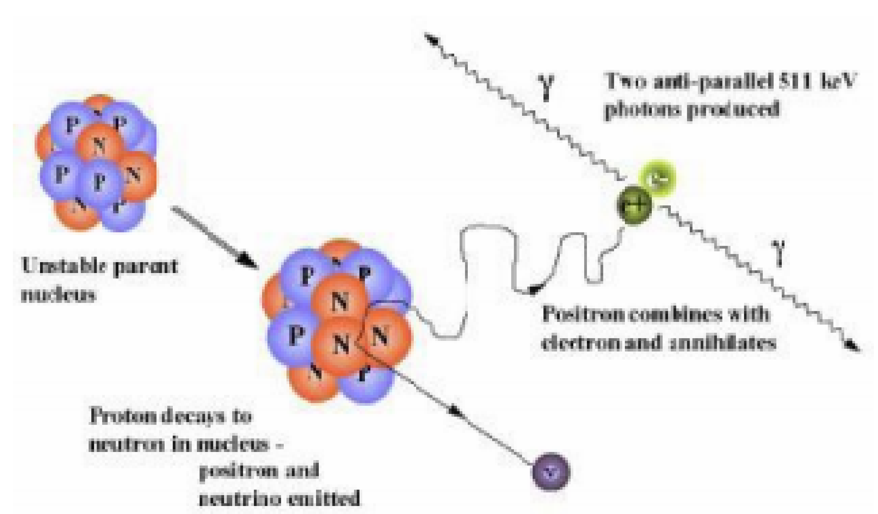

Figure 2:Disintegration scheme $\beta+$

Simulation and experimental set-up

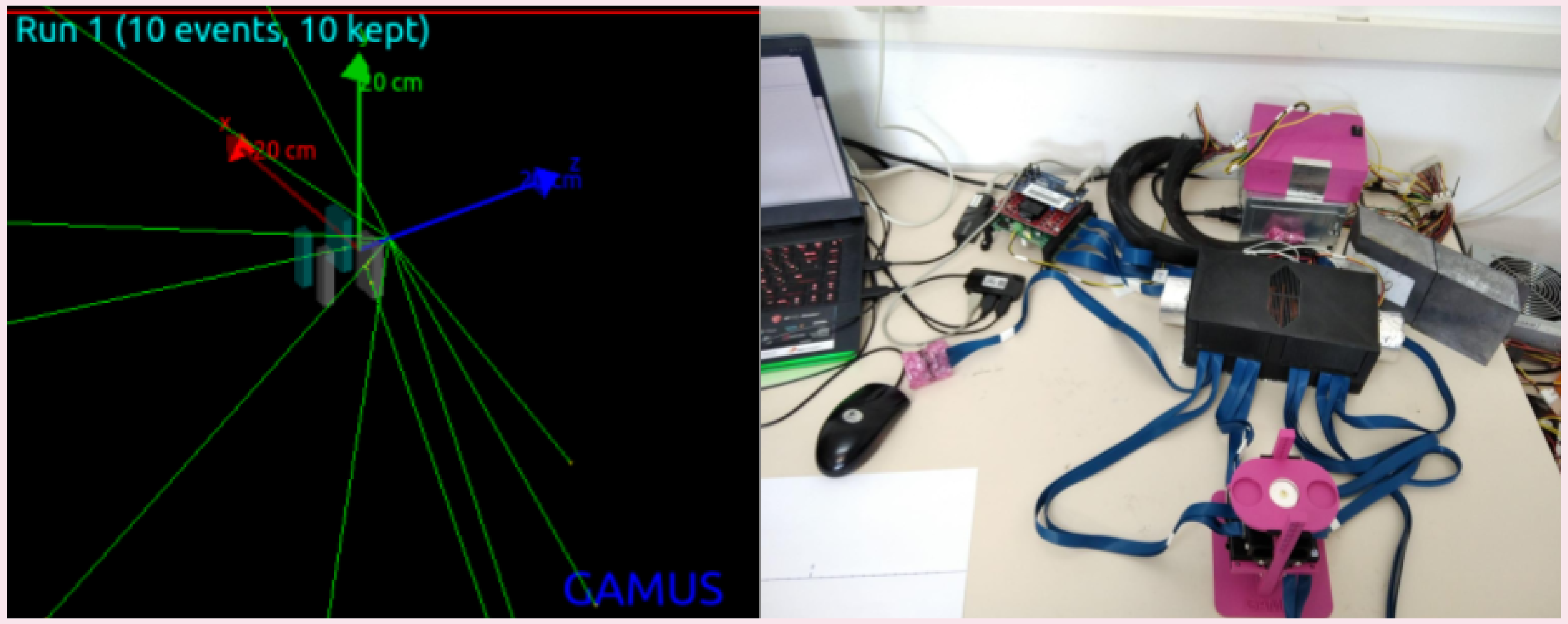

Figure 3:On the left, there is the simulation of a Compton camera in GEANT4. On the right, there is the experimental setup with all the necessary electronics

Methodology

A Compton camera consists of two detector modules working in coincidence, formed by two Scatterer and two Absorber detectors. Compton scattering occurs first in the *Scatterer* detector, followed by the detection of the residual energy in the second detector *Absorber*. The sum of the energy released in both detectors defines the initial gamma-ray energy. With the Compton angle and the impact positions in both the scatterer and absorber, a cone where the gamma emission point should be can be reconstructed from the ratio of the Compton angle and the energy deposited in the detector *Scatterer*:

$$cos\theta = 1 - mc^2[\frac{1}{E_\gamma - E_{Scatt}} - \frac{1}{E_\gamma}] \qquad (2)$$

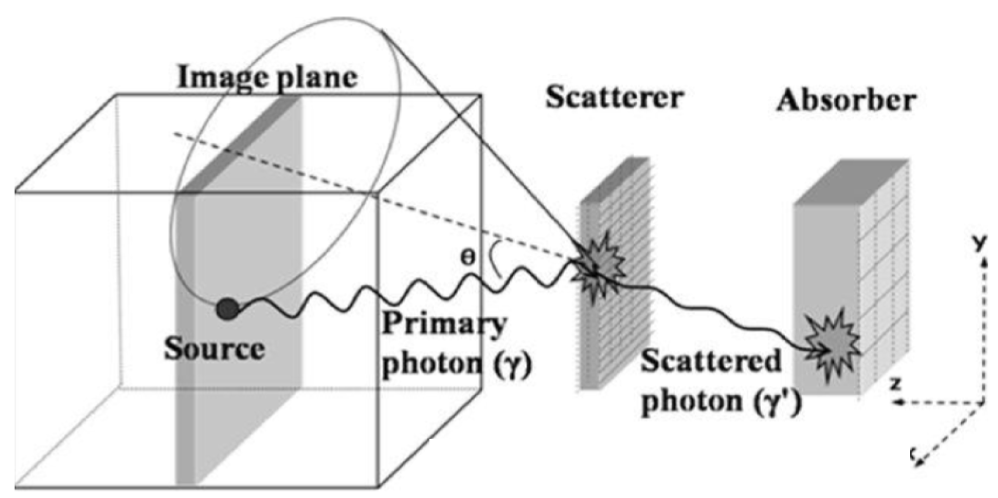

Figure 4:Basic configuration of a Compton camera

Results

It characteristics of the scintillator crystals and SiPMs together with their geometrical position will determine the resolution of the energy and positions of the recorded events, as well as their arrangement and overall efficiency. More than 300 simulations are performed in GEANT4 to obtain it, and later be able to compare these results with those obtained experimentally. The absolute efficiency is therefore the fraction of detected events out of all events emitted by a source, it depends on the sensitive detector material, as well as on the detector volume and the measurement geometry.

$$\epsilon = \frac{P.detected}{P.source} = \epsilon_{intr} \cdot f_{geom} \qquad (3)$$

Scintillation detector material: GAGG(Ce)							
Dimension Scatterer -Absorber : $(13x52)mm^2$ $(26x5)mm^2$							
Photopeak 1275KeV							
Multiplicity 2	S1-A1	S1-S2	S1-A2	A1-A2	A1-S2	S2-A2	Total
	25.3 %	21.2 %	11.1 %	7.1 %	10.3 %	25 %	98 %
Multiplicity 3		S1-S2-A1	S1-A1-A2	S2-A1-A2	S2-A2-S1		Total
		0.59 %	0.41 %	0.38 %	0.58 %		2 %
Total efficiency hits 0.022 %							
Photopeak 511KeV							
Multiplicity 2	S1-A1	S1-S2	S1-A2	A1-A2	A1-S2	S2-A2	Total
	26.5 %	18.2 %	11.8 %	5.4 %	11.7 %	26.5 %	99 %
Multiplicity 3		S1-S2-A1	S1-A1-A2	S2-A1-A2	S2-A2-S1		Total
		0.26 %	0.21 %	0.2 %	0.29 %		1 %
Total efficiency hits 0.08 %							

Figure 5:Efficiencies obtained in the simulations

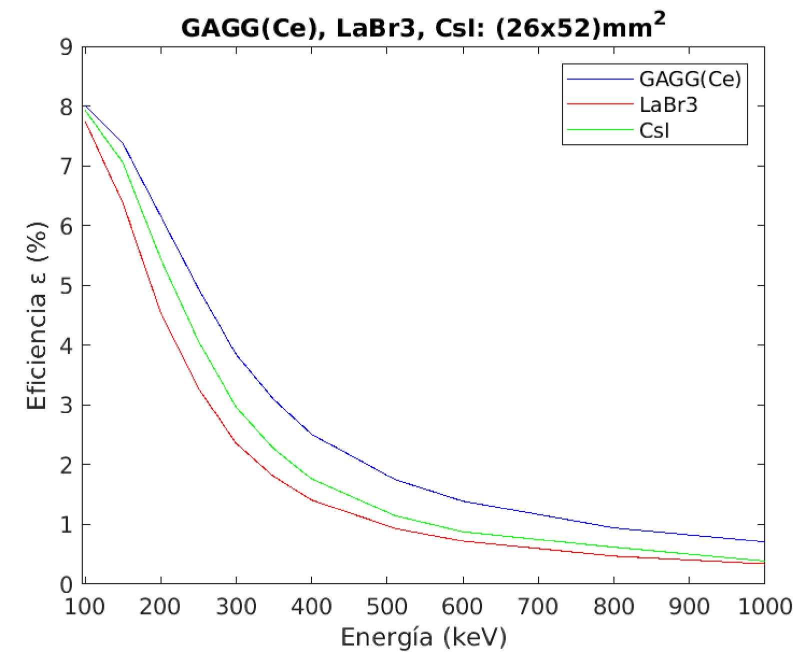

Figure 6:Comparison of efficiencies from 100keV to 1MeV, between the different materials for 10mm thickness

Discussion

After simulating and experimentally assembling the device, it can be concluded that it may be feasible to reconstruct images with dual anatomical and functional information in a short time with good resolution. The production of a compact and practical Compton camera with real-time imaging capability for medical applications still requires a number of technical challenges and the use of some technical improvements that are under development. Compton imaging as a visualisation technique has significant advantages for these applications.

Main References:

[1] L Caballero.
Study of the feasibility of a compact gamma camera for real-time cancer assessment.
arXiv preprint arXiv:1802.05150, 2018.

[2] Luis Caballero Ontanaya, César DOMINGO PARDO, and Francisco Javier Albiol Colomer.
Dual image system suitable for oncological diagnoses and real time guided biopsies, April 2 2020.
US Patent App. 16/622,744.

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