Abstract—The interest of small animal imaging has been primarily due to the recent advances in genetics with the need to perform longitudinal studies on mice or rat. Recent work has shown that single photon emission computed tomography (SPECT) imaging of small animals can provide high spatial resolution with a high sensitivity where the addition of an X-ray CT system provides the lack of anatomical structures. In our group, we are developing a multi modality system combining X-ray, SPECT and PET imaging system. In this paper, we discuss the development of the SPECT component. The key features of the system are i) four individual cameras arranged around the animal, ii) one pinhole aperture and 5 detector modules per camera, iii) a 28 mm focal length, and iii) pixellated scintillator arrays of 2.3 x 2.3 x 28 mm$^3$ YAP:Ce pixels coupled to 8 x 8 multi anode PMT. With the pinhole configuration, the axial field of view strongly depends on the axial size of the PMT which is 18.4 mm. In order to increase this field of view, an hybrid collimator made of parallel strip of tungsten is designed. This collimator leads to parallel collimation in the axial direction and pinhole collimation in the transverse direction. The intrinsic resolution of the system is measured to be 1.5 mm in both directions leading to a 1 mm spatial resolution in the center of the field of view using a 0.5 mm diameter pinhole aperture. The predicted absolute detection efficiency of the system is 34.9 cps/MBq and 12.9 cps/MBq for the pinhole and the hybrid collimation. As a conclusion, we propose a modular SPECT system with high spatial resolution combined with high sensitivity.

I. INTRODUCTION

Amongst the recent progress in the development of nuclear imaging devices, one of them was motivated to use this technique with small animal imaging. This interest has been primarily due to recent advances in genetics with the need to perform longitudinal in vivo studies on mice or rat. The main challenge is to scale down the instrument to obtain appropriate performances according to the animal size. Several groups already demonstrated the interest of combining two different imaging modalities in order to obtain complementary information [1]. For example, an X-ray computed tomography (CT) system provides the lack of anatomical structure in the radioactive distribution map given by a single photon emission computed tomography (SPECT) system. In the same way, at the subatomic research institute (IReS, Strasbourg, France), we are developing a multimodality imaging platform combining X-ray CT, SPECT and PET systems for mice and rat imaging. In this paper we will discuss the design and the development of the micro SPECT component.

II. SYSTEM DESCRIPTION

The small animal SPECT component of the platform is based on a modular concept where four individual cameras are arranged in ring geometry to cover the entire transverse field of view. The axial field of view can be increased by the use of additional rings to cover the whole body of the animal as illustrated in Fig. 1.

![Fig. 1. (a) Drawing of the SPECT system defined by four individual cameras positioned around the animal support. (b) Additional rings increasing the axial field of view.](image)

The rings are mounted on a gantry allowing the cameras to rotate around the animal.

A. Description of the camera

Each camera consists of 5 individual modules arranged around a ring of 58 mm diameter and centered on the pinhole as illustrated in Fig. 2. Each module is comprised of 8 x 8 array of 2.3 x 2.3 x 28 mm$^3$ of YAP:Ce crystals (Crytur, Turnov, CZ) optically glued to a 64 multi-anode...
photomultiplier tube (PMT) (Hamamatsu Corp., Japan). Each PMT anode corresponds to one crystal.

The signals coming from each PMT are fed into a data acquisition system developed in our group. The collimation is performed using a pinhole aperture with a keel-edge shape. The pinhole collimator has a 28 mm focal length and several interchangeable tungsten pinhole apertures ranging in diameter from 0.5 mm to 1.5 mm depending on the specific imaging situation. This geometrical configuration leads to a magnifying factor of 2.1 (pinhole-detector distance / pinhole-object distance). The circular transverse field of view and the axial field of view are equal to 40 mm and 9.5 mm respectively. The small axial field of view is due to the limited axial size of the PMT equal to 18.4 mm.

B. Description of the hybrid collimator

In order to increase the axial field of view for whole body imaging purposes, we design an hybrid collimator. In the transverse field of view, the selection of photon is performed by pinhole collimation whereas in the axial direction, it is performed by parallel collimation. This axial geometry leads to an 18.4 mm axial field of view. The collimator is made of thirty one parallel tungsten strips positioned perpendicular to the axial direction. The parallel strips are 0.1 mm thick and spaced by 0.5 mm to cover the 18.4 mm of the PMT as illustrated in Fig. 3. Each strip has a circular shape where the pinhole represents the center of the circle with a radius of 55 mm. The different parameters of the parallel collimation such as the size of the septa (strip thickness), the size of the hole (distance between two parallel strips) and the height of the strip are chosen to optimized the spatial resolution and the detection efficiency in the axial direction.

C. The data acquisition system

The signal processing electronics is composed of a front end board to connect the PMT and two identical daughter boards vertically plugged into a rectangular mother board. Each daughter board is used to process half of the PMT channel. This electronics takes place in a metallic case in order to avoid devastating electronics discharges.

A scintillation event produces a charge distribution on the 64 PMT anodes. The charge of each anode is first amplified and sampled using a dedicated ASIC originally developed for the OPERA collaboration [2]. The signal is then digitized to 12-bits. The setup of the ASIC is controlled by an FPGA. On the mother board, a DSP communicates with the two FPGA by sending the setup parameters and then receiving the acquisition data from the 64 channels.

The data of each PMT channel is sent using a USB bus to a dedicated software developed on a PC. The energy and the spatial position of each scintillation event are then calculated and stored in a list mode format.

D. Gantry of the multimodality platform

The main support of the platform is built in an aluminum framework providing the stability of the gantry. Each modality structure is composed of two parallel aluminum plates allowing the system to be plugged on the main support as shown in Fig. 4. The continuous motion of the animal support is provided by a motorized translation stage.

The rotation of each device is performed by an annular rotation stage (RV160, Newport) with an angular resolution of 7.5x10^-5 degrees and a maximum angular speed of 20 degrees per second.

III. PRELIMINARY RESULTS

A. Spatial resolution and energy resolution

The intrinsic resolution of the YAP:Ce matrix coupled with the multi anode PMT was measured using a collimated 57Co radioactive source. The mean number of PMT fired channels is equal to 7. The position of the scintillation is calculated using an Anger logic.
Due to a non-zero size of the photon beam, the intersection of the 122 keV collimated photons with the front side of the matrix is not a point but a disk where its diameter partly depends on the size of the collimator hole. We measured the full width at half maximum (FWHM) of the detector response for two different diameters of the collimator hole. A linear fit is performed on the two values. The intrinsic spatial resolution is calculated as the intersection of the line with the ordinate axis and equal to 1.4 mm in both x and y directions.

The reconstructed spatial resolution using a diameter of 0.5 mm for the pinhole aperture is then estimated to be 1 mm in the center of the field of view.

For the hybrid collimation, the reconstructed spatial resolution in the axial direction is estimated to be equal to 1.8 mm in the center of the field of view.

The energy resolution of the system was measured using the same collimated $^{57}$Co radioactive source. The energy resolution (FWHM) is 30% at 122 keV.

### A. Detection efficiency

A Monte Carlo simulation package (Gate [3]) is used to evaluate the detection efficiency of one camera based on five modules. Two different collimations are simulated:

i) The pinhole collimation is performed by a keel-edge shape made of tungsten where the channel height is equal to 0.5 mm, the diameter of the aperture is 0.5 mm and the acceptance angle is 90 degrees.

ii) The hybrid collimation is performed by thirty one parallel tungsten strips of 0.1 mm thick and 55 mm height. The distance between the strips is 0.5 mm.

The first experiment consists of generating $4.32 \times 10^8$ photons of 140 keV in all directions from a point source located in the center of the field of view. No attenuated media are used.

Fig. 5-a represents the projection of the point source obtained with the pinhole collimation. A profile along the radial direction for z=0 is plotted on Fig. 5-b.

The total number of counts detected by the camera using the pinhole collimation is equal to 15065 events where 39.5% are primary counts, 60% are scattered in the crystal and 0.5% are scattered inside the pinhole. The total number of photons detected by the camera leads to a detection efficiency of 34.9 cps/MBq.

Fig. 6-a represents the projection of the point source obtained with the hybrid collimation. A profile along the radial direction for z=0 is plotted on Fig. 6-b.

The second experiment consists of generating $2.6 \times 10^{10}$ photons of 140 keV in all directions from a line source inserted in a uniform cylinder filled with water. The diameter of the cylinder is equal to 40 mm with a length of 50 mm matching in average the size of a mouse.

Fig. 7-a represents the projection of the line source obtained with the pinhole collimation. A profile along the radial direction through the center of the field of view is plotted on Fig. 7-b.
The total number of counts detected by the camera using the pinhole collimation is equal to 134419 events where 33% are primary counts, 19% are scattered in the cylinder, 46.5% are scattered in the crystal and 1.5% are scattered inside the pinhole. The total number of photons detected by the camera leads to a detection efficiency of 5.2 cps/MBq.

Fig. 8-a represents the projection of the line source obtained with the hybrid collimation. A profile along the radial direction through the center of the field of view is plotted on Fig. 8-b.

The total number of counts detected by the camera using the hybrid collimation is equal to 147034 events where 32% are primary counts, 22% are scattered in the cylinder, 45% are scattered in the crystal and 1% are scattered inside the parallel strips. The total number of photons detected by the camera leads to a detection efficiency of 5.7 cps/MBq.

II. DISCUSSION AND CONCLUSION

We presented a new design of a single photon emission computed tomography dedicated to small animal imaging included in the multi modality imaging platform developed at the subatomic research institute. The system is based on modular cameras arranged around the animal to optimize the detection efficiency keeping a spatial resolution less than one millimeter. This sub-millimeter spatial resolution can be achieved for a 28 mm radius of rotation. This will limit the transverse field of view to a radius of 20 mm which is appropriate for studying mouse. However, the combination of a limited PMT axial size and the use of pinhole collimation lead to a reduced axial field of view. To overcome this limitation, we introduce an hybrid collimator where the main purpose is to increase the axial field of view using parallel collimation. The thickness of the tungsten strips is chosen to be small enough compared to the axial spatial resolution but thick enough to provide a rigid structure.

We can observe that the use of hybrid collimation compared to the pinhole collimation reduced the absolute detection efficiency by a factor of 2.7 due to the restricted solid angle of the parallel collimation. In fact, a complete ring comprising four cameras leads to an absolute detection efficiency of 140 cps/MBq for the pinhole collimation compared to 52 cps/MBq for the hybrid collimation.

We also observe that in both collimations, ~20% of the detected photons are events already scattered inside the cylinder (simulated mouse). In this case, the detection efficiency of the system using the hybrid collimation is quiet similar to the one using a pinhole aperture with an axial field of view extended by a factor of 2. A complete ring comprising four cameras leads to a detection efficiency of 21 cps/MBq for the pinhole collimation compared to 22.8 cps/MBq for the hybrid collimation. However, to increase the detection efficiency, the axial spatial resolution must be sacrificed.

As a conclusion, we propose a modular SPECT system with high spatial resolution combined with high sensitivity dedicated to small animal.

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IV. REFERENCES