Towards Very High Resolution RPC-PET for Small Animals

Paulo Martins, Alberto Blanco, Paulo Crespo, M. Fátima Ferreira Marques, Rui Ferreira Marques, Paulo M. Gordo, Marcin Kajetanowicz, Grzegorz Korcyl, Luis Lopes, Jan Michel, Marek Palka, Michael Traxler and Paulo Fonte

a LIP - Laboratório de Instrumentação e Física Experimental de Partículas
Rua Larga, 3004-516 Portugal
E-mail: paulo.martins@coimbra.lip.pt
b Physics Department, University of Coimbra
3004-516 Coimbra, Portugal
c Polytechnic Institute of Coimbra, ISEC
Rua Pedro Nunes, 3030-199 Coimbra, Portugal
d Nowoczesna Elektronika
ul. Bolesłwa Prusa 15/10, 30-109 Cracow, Poland
e Jagiellonian University
ul. Gołebia 24, 31-007 Cracow, Poland
f Institut für Kernphysik, Goethe-Universität
Max-von-Laue-Str. 1, 60438 Frankfurt am Main, Germany
g GSI Helmholtz Centre for Heavy Ion Research
Planckstraße 1, 64291 Darmstadt, Germany

ABSTRACT: We present imaging results of needle-like and planar $^{22}$Na sources obtained with a prototype of a high-acceptance small-animal positron emission tomograph based on resistive plate chambers (RPC-PET). The maximum-likelihood expectation-maximization (MLEM) reconstruction of the acquired data yielded an excellent and stable resolution of 0.4 mm FWHM.

KEYWORDS: small-animal; PET; RPC.

* Corresponding author.
1. Introduction

A small-animal positron emission tomograph (PET) based on resistive plate chamber detectors (RPC-PET) has been proposed for high-resolution imaging of small animals required by pharmaceutical research [1]. RPC-based detectors offer simple and economic construction, reliability of operation, and extremely good time and intrinsic position resolutions (300 ps full width at half maximum, FWHM, for the coincidence [1], and 38 µm σ measured with cosmic muons [2], respectively). The depth-of-interaction (DOI) can also be accurately measured [3], rendering RPC-PET essentially parallax-free.

In here we report a world-class image resolution of 0.4 mm FWHM in realistic, but prototypal, conditions. A depiction of the full scanner under development can be seen in Figure 1.

![Figure 1 – Representation of the small animal RPC-PET scanner under development and its relation to the present work.](image)
2. Experimental setup and methods

We imaged two radioactive sources made with the $^{22}$Na radioisotope. In one source the radioactive material was contained inside a stainless steel needle with 125 μm wall thickness and 250 μm internal diameter, while in the other source the radioactive material was squeezed between Al flat disks. The activities were, respectively, 44 μCi and 5 μCi. The needle-like source was mounted on a movable platform, allowing its translation in the axial direction (see Figure 2).

The outgoing photons were detected by RPCs, in the arrangement shown in Figure 2. The sources were placed close to the centre of the field-of-view, allowing lines-of-response (LORs) to be acquired in a pyramidal-like solid angle, subtending approximately ±56° relative to the transaxial direction.

The detectors’ internal structure and signal readout method have been described in [2] and we will not elaborate further here.

For image reconstruction from the collected LORs we used a reconstruction method based on the maximum-likelihood expectation-maximization (MLEM) algorithm, operating on the list-mode data with a ray-driven approach for navigation in the image space [4]. Before imaging the actual data the algorithm was trained on synthetic data of similar geometry to assure that no significant distortions were introduced, with the result shown in Figure 3.

![Figure 2 – Mechanical arrangement of the experimental setup, showing both the $^{22}$Na radioactive sources used and the detectors. The axial direction is perpendicular to the plane of the figure.](image-url)
3. Results

Images were reconstructed from the collected LORs considering all LOR angles (“full 3D mode”), all gas gaps (see [2]) and the full pulse-height spectrum.

The needle-like source was imaged in two different positions physically separated by 1 mm in the axial direction. The planar source was imaged in a single position, but half of the LORs were mathematically displaced by 1 mm in the same direction. The datasets thus generated were jointly reconstructed and the results are shown in Figure 4 for both sources.

As the present prototype has incomplete solid angle coverage, the resolution was determined only in the axial direction, perpendicular to both the needle axis and to the plane of the disk-like source. A fit by the sum of three gaussian functions to the reconstructed activity profile along a line crossing the most active pixels in each source position (see upper left panel in Figure 4 a)) yielded resolutions of the order of, respectively, 0.4 mm and 0.5 mm FWHM for the needle-like and planar sources, plus some diffuse background (Figure 5). Note that the physical dimensions of the source were not deconvoluted from these figures.
Figure 4 – a) Reconstructed images obtained from the needle-like source in two different positions physically separated by 1 mm and jointly reconstructed. The activity profile mentioned in Figure 5, left panel, was taken along the black line shown in the upper left panel. b) Reconstructed images obtained from the planar source in a single position but having half of the LORs mathematically displaced by 1 mm and then jointly reconstructed. For both a) and b) the axial coordinate is labelled Y and the source plane (see Figure 2) is XZ. The colourwash maps represent the relative reconstructed activity along the 3 perpendicular planes crossing the most active voxel, while the green volumes are delimited by the 50% isoactivity surface.
Figure 5 - Activity profiles along the axial coordinate and through the maximum intensity voxels as exemplified in Figure 4 a), upper left panel. A fit with the sum of three Gaussian functions to the signal (blue), yields a background (magenta) and point-spread function profiles (green) exhibiting a 0.4 and 0.5 FWHM spatial resolution for the needle-like (left panel) and planar (right panel) sources, respectively.

4. Conclusion

Maximum-likelihood (MLEM) image reconstruction of PET data obtained on a realistic prototype of an RPC-PET small-animal imager demonstrated world-class resolutions close to, respectively, 0.4 mm and 0.5 mm FWHM for needle-like and planar $^{22}$Na radioactive sources.

Acknowledgments

This work was supported by the EU, FEDER, POCI, QREN, COMPETE, POFC, PORC, MaisCentro and by the Portuguese Government through Foundation for Science and Technology (FCT) and Comissão de Coordenação da Região Centro (CCRC), under the contracts CERN/FP/123605/2011 and CENTRO-07-ST24-FEDER-002007, co-funded by the European Social Fund and by POPH - Programa Operacional Potencial Humano. P. Martins acknowledge FCT grant number SFRH/BD/45040/2008.

References