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Very high position resolution gamma imaging with resistive plate chambers

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Abstract

In this study we present experimental results from a first prototype of a positron emission tomography system based on the resistive plate chamber (RPC) technology. The system is composed of two counting heads, each one containing 16 single-gap RPC detectors capable of detecting the photon interaction point in the transaxial plane. Uniformity studies were performed for image resolution and sensitivity, yielding a rather uniform image resolution close to 0.3 mm FWHM across the field of view. The contribution of the photons noncolinearity effect to the intrinsic spatial resolution was also studied, causing a variation from 0.52 to 0.63 mm when the system diameter ranges from 60 to 120 mm, in agreement with calculations.

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Keywords: Gaseous detectors; Photodetectors; RPC; PET

1. Introduction

Positron emission tomography (PET) is one of the in vivo imaging modalities largely developed in the last decades.

One of the PET applications is the small-animal tomography, applied in the development of new drugs, human disease studies and validation of gene therapies. In this modality, small animals, like transgenic mice and rats, are used as experimental models owing to their genetic similitude with humans, short reproductive cycle and simple breeding. Due to the small dimensions of these animals dedicated high spatial resolution instruments are often required.

The present work aims at validating previous simulation-based expectations [1], that a system built with resistive plate chambers (RPCs) may deliver sub-millimetre spatial resolution free of parallax error, which could be useful for the imaging of small animals.

2. System description

The system [2] is composed of two detecting heads (see Fig. 1), each one built with 16 stacked-timing RPCs [3]. Each RPC is made from a metallic cathode and a resistive glass anode under which 32 signal pickup strips, 1 mm wide, sense the avalanche position information in the neighboring gas-filled gap.

Each of the heads is able to detect the photon interaction point in the transaxial plane, measuring the radial

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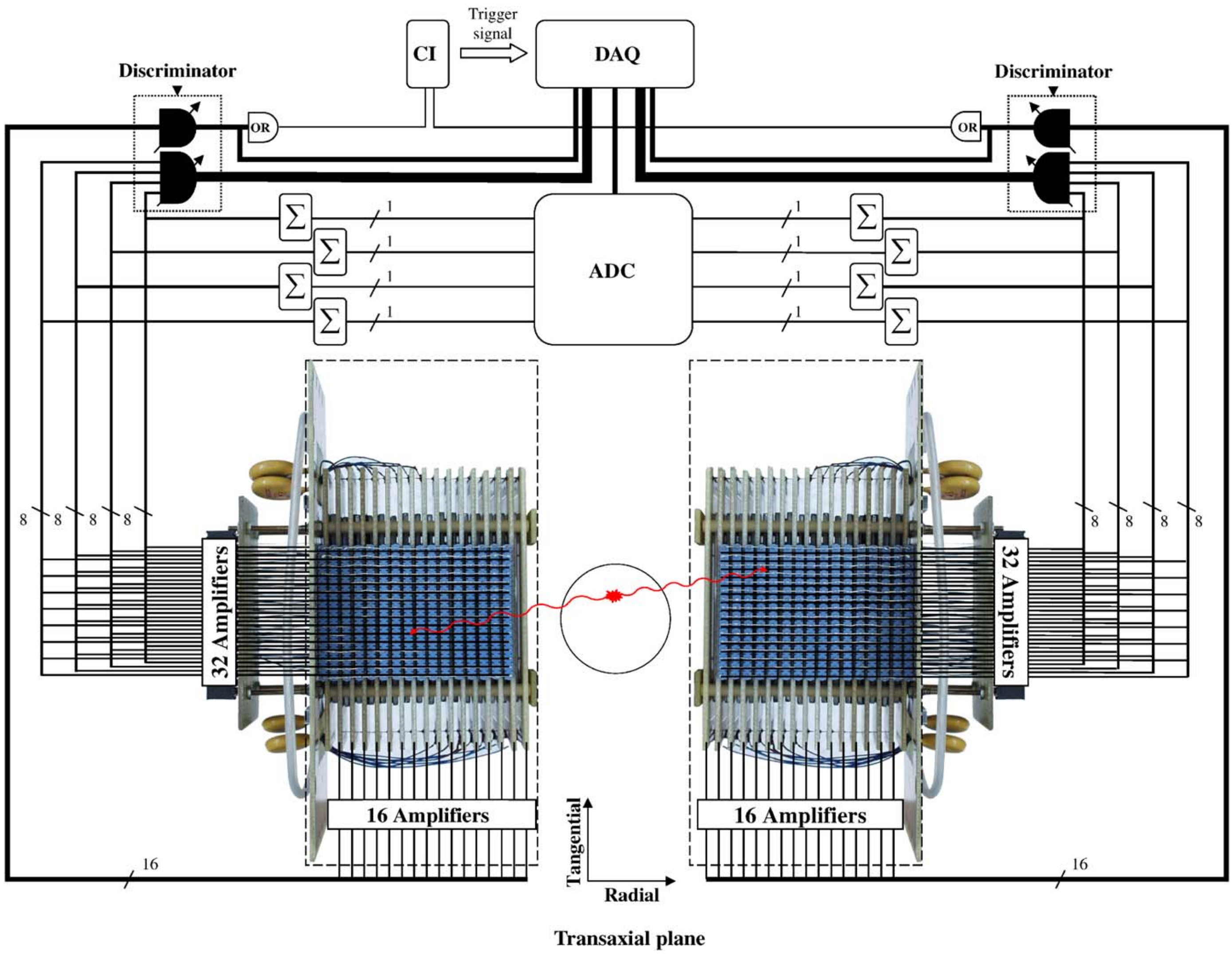

Fig. 1. Readout scheme of the two detecting heads. All signals are discriminated to obtain the coarse avalanche position and a trigger signal to the data acquisition system. The charge signals from the pickup strips, used to obtain the fine tangential coordinate, are summed in four groups and sent to a charge-integrating ADC.

coordinate (or depth of interaction—DOI) and the tangential coordinate.

The charge induced in each cathode, readout by a charge-sensitive amplifier (*Analog Devices OP467*), is discriminated to identify the gap where the interaction takes place and therefore the radial coordinate. A trigger signal is provided to the data acquisition system as the coincidence (from CI unit) of the *ORs* of the 16 cathode signals from each detecting head.

The charge induced in the pickup strips, connected together in columns, is sensed by 32 preamplifiers in each head and discriminated to obtain the coarse tangential coordinate of the photon interaction point. These charges are summed in four groups, corresponding to strips separated by three, (see Fig. 1) and digitized. The fine tangential coordinate is obtained by comparison between the measured group of charges and an electrostatic model of the charge induction process.

3. Homogeneity of response

3.1. Image spatial resolution

To determine the spatial resolution of the system a point-like ^{22}Na source was mounted in a micrometric screw and positioned in the transaxial plane at four different places along the tangential direction: −8, −1, 0 and 1 mm from the center of the field of view (FOV).

Data from the four source positions was merged and reconstructed together using a ML-EM type algorithm [4], resulting in an image with a homogeneous spatial resolution close to 0.3 mm FWHM and 0.8 mm FWTM (Fig. 2).

3.2. Sensitivity

The count distribution in a detecting head as a function of the fine tangential coordinate for a source placed in the

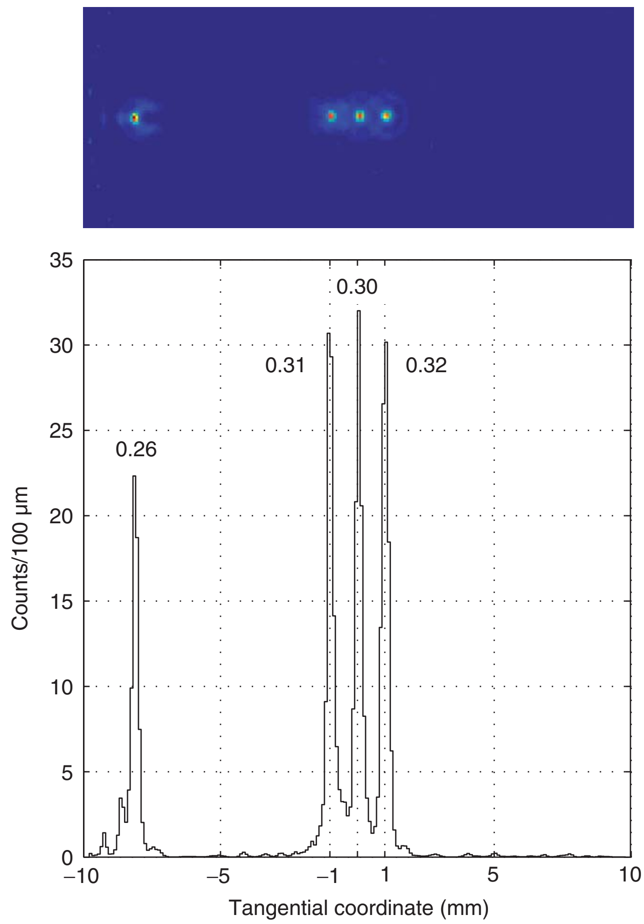

Fig. 2. Image reconstruction of a point-like source placed in four positions along the tangential direction. The histogram corresponds to the image profile taken along the tangential (horizontal) coordinate. The figures close to the peaks indicate the respective FWHM in mm, evidencing a rather homogeneous spatial resolution close to 0.3 mm FWHM.

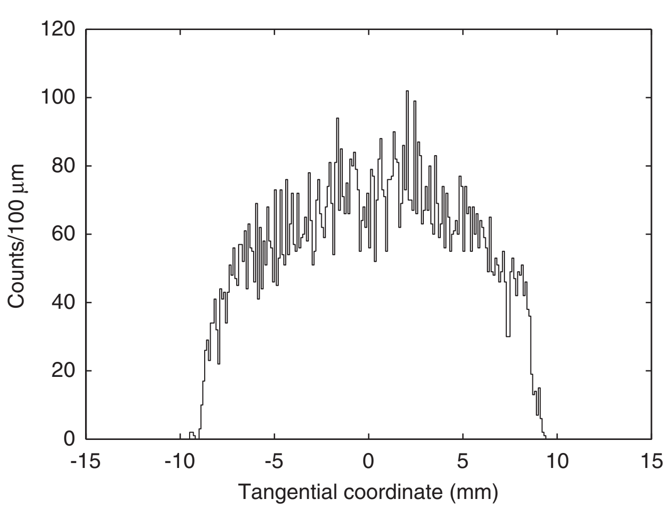

Fig. 3. Count distribution in a detecting head as a function of the tangential coordinate, showing a sensitivity modulation across the entire head compatible with the subtended solid angle. The residual irregularities are compatible with the statistics available.

center of the FOV (Fig. 3), shows an overall triangular-like shape determined by the subtended solid angle (the abrupt ends at ± 9 mm correspond to a cut in the data analysis) and a rather homogeneous sensitivity across the entire head. The residual irregularities are compatible with the statistics available.

4. Intrinsic spatial resolution vs. system diameter

To determine the intrinsic spatial resolution and to identify the different contributions to it, the projected point spread function (essentially the width of the sinogram band for a point source) was fitted with a function, $R(x)$, that convolutes all the instrumental and physical contributions: annihilation photon noncolinearity, positron range, detector response, source size and scatter background, as described in Ref. [6].

At our level, the spatial resolution becomes largely influenced by physical effects like photon noncolinearity and positron range [5–7]. The former effect can be experimentally observed in this prototype by analyzing datasets taken at different depths into the detecting heads.

Fig. 4 shows the resulting intrinsic spatial resolution as a function of the system diameter. The solid and dashed lines represent, respectively, the calculated FWHM and FWTM using the function $R(x)$ [6], in which the system diameter was varied while keeping the other parameters fixed at the values obtained for the front part of the detecting heads (60 mm point). The crosses and open circles represent, respectively, the measured FWHM and FWTM for datasets corresponding to system diameters of 60, 88 and 120 mm. There is clearly a good agreement between the measured and calculated FWHM, showing an intrinsic resolution of 0.52 mm for a system diameter of 60 mm and a ~20% degradation when the system diameter increases up to 120 mm.

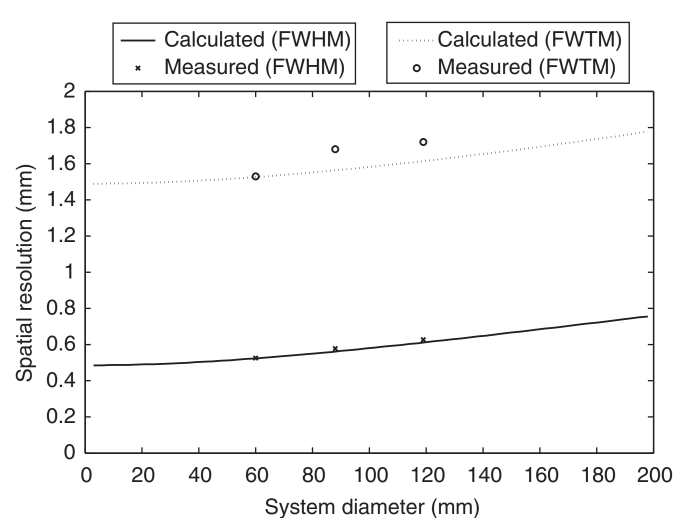

Fig. 4. Calculated and experimental intrinsic spatial resolution as a function of the system diameter.

The measured FWTM for 88 and 120 mm shows a discrepancy, because the calculated spatial resolution does not reflect the increase of the scatter background at the deeper layers in the head, which worsens the distribution tails.

5. Conclusions

We have presented results from a first prototype of a small PET system based on the RPC technology.

The uniformity of response of the system was studied both in terms of resolution and of sensitivity.

Image resolutions around 0.3 mm FWHM were obtained at different positions, along the tangential coordinate in the field of view, demonstrating the parallax-free imaging capability of the system [1].

A sensitivity profile compatible with solid angle effects was observed along the transaxial direction.

The contribution of the photon noncolinearity effect to the intrinsic spatial resolution was studied experimental and analytically. A degradation of 20% was observed when the system diameter varies from 60 to 120 mm, corresponding to intrinsic resolutions ranging from 0.52 to 0.63 mm FWHM.

This technology seems to be very appropriate for small-animal PET studies, providing a very high spatial resolution free of parallax error.

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