RPC-PET: status and perspectives[1]

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***Resumo* – O estado da tecnologia RPC-PET para pequenos animais é brevemente revisto e as características de sensibilidade deste método para PET humano são estudadas por meio de simulações Monte-Carlo. O custo reduzido destes detectores e a sua boa precisão temporal abrem a possibilidade de construção de sistemas TOF-PET com campo de visão muito longo. As simulações sugerem que a sensibilidade destes sistemas para exames de corpo inteiro poderão, debaixo de hipóteses razoáveis, exceder por um factor 20 aquela dos sistemas PET actuais, baseados em cristais.**

***Abstract* - The status of the RPC-PET technology for small animals is briefly reviewed and its sensitivity performance for human PET studied through Monte-Carlo simulations. The cost-effectiveness of these detectors and their very good timing characteristics open the possibility to build affordable TOF-PET systems with very large fields of view. Simulations suggest that the sensitivity of such systems for human whole-body screening, under reasonable assumptions, may exceed the present crystal based PET technology by a factor up to 20.**

I. INTRODUCTION

The Resistive Plate Chamber (RPC) TOF-PET concept [1] is based on the converter-plate principle [2] and takes advantage of the naturally layered structure of RPCs, of its simple and economic construction, excellent time resolution (300 ps FWHM for 511 keV photon pairs [1]) and very good intrinsic position accuracy (50 μm in digital readout mode [3]).

These characteristics may be of interest for the detailed imaging of small animals and for high-sensitivity whole-body human PET.

In this article we briefly review the work done so far on RPC-PET for small animals and describe a preliminary simulation study of the application of RPCs to human PET [1]. The simulations are done in GEANT4 and closely follow the norm NEMA NU-2 1994 (NU94) [4], which is extended to accommodate a larger axial fields of view (AFOV) and the Time-of-Flight (TOF) capability.

II. RPC-PET FOR SMALL ANIMALS

A first prototype [5], aimed at verifying the expectation of an extremely good position resolution for the imaging of small animals, yielded an intrinsic spatial resolution of 0.52 mm FWHM for a system diameter of 60 mm, imaging a small 22Na positron source in the transaxial plane. A corresponding image spatial resolution of 0.51 mm FWHM was obtained using the standard algorithm of filtered back projection and 0.31 mm FWHM after reconstruction by an ML-EM type algorithm with resolution modelling [6]. The parallax-free imaging capability was confirmed by imaging source positions considerably off-axis without discernible loss of resolution [7].

As the system resolution is largely limited by the physical limitations of the PET technique, positron range and photon non-colinearity, a direct measurement of the long component of the positron range in acrylic plastic could be made [5], validating experimentally simulations done by other authors [8].

A system optimized for mice was simulated to evaluate the expected sensitivity and system count rate performance, suggesting a central point absolute sensitivity up to 21 cps/kBq and a NECR figure up to 320 kcps at an activity of around 2.3 MBq/cm3 for a mouse-sized phantom (38 cm3) [5].

III. SENSITIVITY ASSESSMENT OF HUMAN RPC-PET

While the foreseeable detection efficiency of RPCs for 511 keV photons is certainly lower than the traditional crystal scintillators used in PET, this handicap may be offset by two favourable factors: the very good time resolution and the possibility to increase the AFOV to human-sized dimensions, which seems technically and

[1] Submitted to Nuclear Instruments and Methods in Physics Research.

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economically feasible within this technology, conceived for enormous High Energy Physics experiments [9].

An excellent time resolution of Δt=300 ps FWHM [1] allows the TOF-PET technique to be considered. Among other advantages [10], it is to be expected an improvement of the system sensitivity by a factor

$$g = \frac{L}{(c/2)\Delta t} = \frac{200mm}{45mm} = 4.4 \qquad (1)$$

where L is the typical object size (we adopted the phantom size used in the simulations) and c is the speed of light.

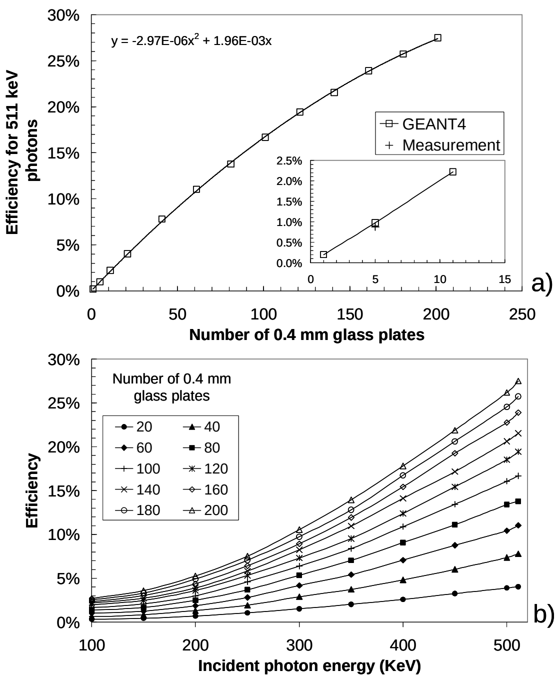

Figure 1 – a) Efficiency of a stack of 0.4 mm glass plates for the detection of 511 keV photons as a function of the number of plates. The points were fitted to a quadratic curve and the inset shows a comparison between the simulation and a measurement. b) Energy sensitivity of the efficiency – an important feature for the rejection of object-scattered photons in PET.

The RPC sensitivity handicap maybe compensated also if the AFOV is much extended, allowing very considerable solid-angle gains. Indeed, the system sensitivity was reported to depend over-linearly on the AFOV up to 60 cm [11], promising considerable gains in sensitivity as the AFOV is further enlarged [12]. Systems with enlarged AFOV (68.5 cm) have already been deployed and are now under evaluation [13].

As a first step to assess the feasibility of the RPC-PET system, it is important to compare the expected sensitivity performance with existing commercial PET/CT systems.

A. Efficiency of glass-RPCs for gamma photons

The GEANT simulations on the efficiency of RPCs for the detection of gamma photons already described in [1] (Fig.2) were repeated for a stack of 0.4 mm thick glass plates. Although not optimal in terms of gamma efficiency, these are readily available and may be used for RPC construction without any further R&D.

The probability that a 511 keV photon will eject an electron from a plate of the stack (efficiency) is shown in Figure 1 a). The inset shows a recent measurement made on a 5-gap detector, in good agreement with the simulations. The energy sensitivity of the stack, an important feature for scatter rejection in PET, is shown in Figure 1 b).

B. Sensitivity assessment of human RPC-PET

Two situations were considered: 60 and 120 glass plates with efficiencies for 511 keV photons of, respectively, 11.0% and 19.4% (see Figure 1). Other situations may be easily calculated as the behavior of the sensitivity is exactly quadratic with the efficiency. The TOF capabilities of the RPC were taken into account by multiplying the sensitivity results by the factor of 4.4 calculated in (1.1).

The results are shown in Figure 2, for several values of the acceptance on the axial angle of the Lines of Response (LORs). It is clear that acceptances of 30º or above are mandatory for optimal sensitivity. For comparison, the sensitivity values measured for the GE ADVANCE tomograph [15] are presented along with the corresponding values calculated within the present simulation, which show a satisfactory agreement.

It is clear that large sensitivity gains are to be expected, up to a factor close to 20.

5. CONCLUSION

A first prototype of an RPC-PET system for small animals has shown a parallax-free reconstructed image resolution of 0.51 mm FWHM using the standard algorithm of filtered back projection and 0.31 mm FWHM after reconstruction by an ML-EM type algorithm with resolution modelling.

Simulations suggest that large RPC-based TOF PET systems aimed at human whole-body screening will show a sensitivity advantage by a factor up to 20 when compared with the present crystal-based PET systems. The comparison for smaller regions of interest is less clear-cut and will be addressed in the future.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the technical contributions of N.Carolino, A.Pereira, J.Silva and the ISEC-GTIA.

This work was financed by “Fundação para a Ciência e Tecnologia” and FEDER under contracts POCI/FP/63411/2005, POCI/SAU OBS/61642/2004 and by “Instituto de Investigação Interdisciplinar da Universidade de Coimbra”.

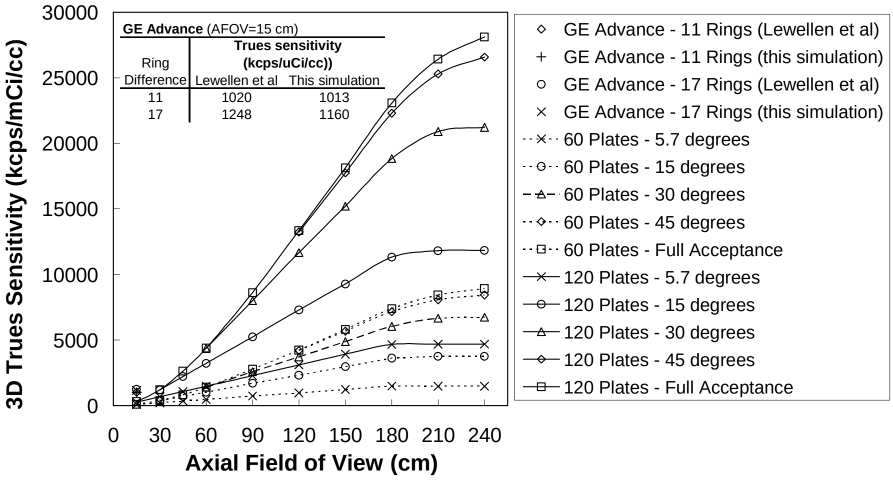

Figure 2 – Absolute trues sensitivity as function of the axial field of view (AFOV) of the tomograph for several values of the acceptance on the axial angle of the Lines of Response, considering RPCs made with 60 or 120 glass plates and the gain sensitivity owed to TOF (1.1).

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