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PET CAMERA USING BAF_2 AND PHOTOSENSITIVE MULTIWIRE PROPORTIONAL CHAMBER

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Abstract

Barium Fluoride scintillator coupled to a low pressure multiwire proportional chamber (MWPC) has previously been investigated and found applications in High Energy Physics. At present a BaF_2/ NWPC detector is being developed for use in a PET medical imaging system. We present technical results obtained with a prototype detector. It is shown that the impact point of the gamma ray can be determined with a precision of a few mm and that the detection efficiency is 60% with a time resolution of 10nm (FWHM). A scanner based on the new principle is described and its anticipated performance discussed.

Keywords: Barium Fluoride, MWPC, PET, SSPC.

Introduction

In pet systems, one of the needs is the improvement of the spatial resolution to the intrinsic limit of 2-3 mm. This has led to the development of complicated (and costly) ring systems containing thousands of scintillation crystals and photo multipliers. To minimize the scatter fraction, ring type PET scanners, which subtend a small solid angle have been developed. This brings us to the second need in PET: an increased sensitivity, which can only be attained by constructing devices subtaining a larger detection solid angle than that of ring systems. Thirdly, the present PET cameras suffer from serious dead time loses at count rates of the order of 10 per second caused by the rather long decay time of the scintillators.

In order to overcome these problems and also to limit the cost, several wire chamber designs have been applied to PET. These (e.g. HIDAC, HISPET MUP-PET) (Jeavons and Parkman,1983; Conti *et al*, 1987 and Bateman *et al*, 1988). were based on using high density lead as a converter. The 511keV radiation was absorbed in the lead producing photo or compton electrons. These could be drifted into MWPC and amplified.

These systems could produce large-area detectors more cost effectively than the conventional ring systems. However, their principal limitation was the very poor efficiency (≤10%) which limits their clinical application.

In order to overcome the limitation in sensitivity, the solid scintillator proportional counter (SSPC) has been proposed by (Mine *et al*, 1997) as a highly efficient position-sensitive detector suitable for use in PET.

BaF_2 is a high Z scintillator with a high absorption efficiency for 511keV annihilation radiation and a relatively high photo fraction. Since in a SSPC only the fast scintillation component is detected (Mine *et al*, 1988) dead time losses caused by the scintillator can be neglected. On the other hand, the application of low pressure MWPCs enables a good time resolution and high count rates.

In principle, the SSPC is an uncomplicated (relatively inexpensive) detector for the position sensitive detection of annihilation radiation. A certain insensitivity to scattered radiation is also present. Recent results on photocathodes show an increased detection efficiency of SSPC (Garty *et al*, 1999). We report on tests of this idea and show how the principle could be used to build a scanner with several attractive features.

Experimental arrangement

We used a square matrix of 36 BaF_2 crystals, each 5x5x50 mm^3, followed by a multiwire proportional chamber (MWPC) (Fig.1). The crystals are optically separated and covered with reflective aluminium foil. On the side facing the MWPC, they are in contact with a transparent grid, kept at a fixed potential. The 511keV gamma rays are absorbed in the BaF_2, and produce scintillation light with a fast and slow component. The fast component has a maximum intensity at 220nm and a decay time constant of 0.6ns. The slow component has a maximum intensity at 310nm, but the TMAE is not sensitive to light of this wavelength. Only the fast component photoionizes the TMAE vapour. The wire chamber consists of a series of grids and wire planes which define a succession of gaps. Next to the crystals is 2mm conversion gap in which the UV photons ionize the organic vapour. The field across the gap is 100V, sufficient to collect the charge but insufficient to produce a large amplification. In the next gap there is a potential difference of 300V over 3.6 mm. The electric field in this gap causes electron amplification by avalanche formation. The amplification in this gap is of the order of 1000. Next the electrons are transferred to the final amplification gap which consists of two crossed layers of cathode wires 6mm apart bisected by an anode plane at ground potential. The final amplification occurs mainly in the neighbourhood of the fine anode wires, since the field is strongest close to the wires. The total amplification is of the order of 10^6, which is sufficient to allow the detection of single photoelectrons with standard electronic techniques. The cathode planes are made of 100μm diameter wires, 1mm apart grouped into 5mm strips in such a way that a strip faces a row of crystals. These strips provide the X and Y coordinate of the hit crystal. The anode plane uses 14μm thick wires, and provides the timing signal. The wire chamber has a sensitive area of 15x15 cm^2 and is mounted in an aluminum enclosure sealed with viton o-rings and connected to a vacuum pump and a supply of TMAE vapour. Because of the low vapour pressure of TMAE at room temperature the supply of TMAE is kept at about 55°C to avoid condensation. For some of the measurements a few mbar of isobutane gas was added. If the chamber is filled and closed we observe a deterioration in performance over a period of 24h. for this reason we used a continuous gas supply system as shown in Fig. 2. With this system we have been able to operate the apparatus continuously for three months without observable degradation.

Results

The diction efficiency for 511keV gamma rays was measured with a ^{22}Na point source of known activity. The source was placed between the chamber and a 20x20x50mm^3 BaF_2 crystal mounted directly against the window of a philips XP2O2OQ quartz window photomultiplier tube. The coincidence rate between the anode of the wire chamber and the signal from the photomultiplier was recorded and compared to the coincidence rate which is obtained with the same setup, but with the chamber replaced by a 110x110ϕmm^3 NaI crystal on a 5" phototube. The two methods gave compatible results. Fig. 3 shows the measured detection efficiency as a function of the anode voltage. Above 310V a detection efficiency of 69% is obtained. This can further be improved by using a high efficiency photocathode (Singh *et al*, 2000).

The time resolution was measured by recording the arrival time of the anode signal from the chamber relative to the start signal provided by the XP2020Q photomultiplier.

We observed that the time resolution of the chamber depended more or less linearly on the thickness of the conversion gap. This can easily be understood, since the drift velocity of the electrons in this gap is of the order of $100\mu m/ns$. The fluctuations in drift time therefore dominate the time jitter of the chamber signal. On the other hand, the detection efficiency of the chamber also depends strongly on the thickness of this conversion gap. A gap thickness of 2mm seems a reasonable compromise and yields a detection efficiency of 60% and a time resolution of 10ns FWHM. Under these conditions each 511keV gamma ray interacting in the crystal gives rise to only a few photoelectrons. As a result the chamber has almost no energy resolution. The detection efficiency increases approximately linearly with the gamma energy for gammas between 0 and 511keV (Schotanus, 1987), thus there is, nevertheless, a significant suppression of scattered events. To measure the position resolution, the same setup was used with the ^{22}Na source at 12cm from the crystals in the chamber.

The impact point of the gamma rays was defined by a $5x5mm^2$ BaF_2 crystals, viewed by a XP2020Q photomultiplier and placed 68cm from the source, opposite the chamber. The position resolution was measured by moving the source parallel to the surface of the crystal matrix. For each coincidence between the photomultiplier and the chamber anode signal, the amplitude of the signals on all the cathode strips facing the crystals was recorded. The cathode strip with the largest signal was taken as the measured impact point of the gamma ray. Fig. 4 represents the result. The spatial resolution is approximately equal to the size of the crystals.

The set of the measurement presented above shows that it is possible to detect 511keV gamma rays with an efficiency and a time resolution which is comparable to that achieved by commercial PET systems, while at the same time allowing the use of a very large number of small scintillators.

Geometry for a scanner based on the results and conclusion.

The geometry which we propose is represented schematically in Fig. 5. The sensitive part of the detector will be a cylinder with diameter of about 90 cm, 15 cm high, made up of 16800 BaF_2 crystals, each measuring $5x5x50mm^3$. The dead space between the crystals will be kept at a minimum. Preliminary studies indicate that the introduction of thin separations in tungsten between the crystals would slightly improve the resolution, by suppressing cross talk due to compton scattering. The cylindrical scanner will be subdivided electronically into 8 sectors. To define events of interest the anode plane from each sector will be placed in coincidence with three sectors on the opposite side of the ring. For each trigger the amplitudes of the signals on the 70X and 30 Y strips in each of the two sectors concerned will be digitized and recorded in order to localize the impact point of the gamma rays. The system will be equipped with removable septa. It can be used either with the septa in place as a 30 ring scanner, with coincidences only between the same or adjacent rings, or without the septa, taking all inter-ring coincidences. The second mode of operation is illustrated in Fig.5. In this case the useful height of the image is 10cm. Close to the edge the sensitivity is too low to compensate for the degradation resulting from the increased scatter fraction. The average sensitivity of the scanner over the useful image height is 330Hz/μCi/cm^3, and the resolution in the centre expected to be 4.3 mm in all 3 space directions. Compared to commercial systems there is a significant gain in axial resolution and in sensitivity, and it will be possible to image many organs in one data taking run due to the large visible volume.

We propose a fairly large diameter for the ring (90 cm), since the scatter fraction decreases R-2 , the results of Townsend *et al.* (1987) show that the scatter fraction will be of the order of 50%. For applications where this is not acceptable the instrument will be used with septa. This will not affect the resolution, but will reduce the sensitivity.

We estimate that the scanner proposed here, if commercially produced, would be comparable in price to systems based on photomultipliers with a few rings.

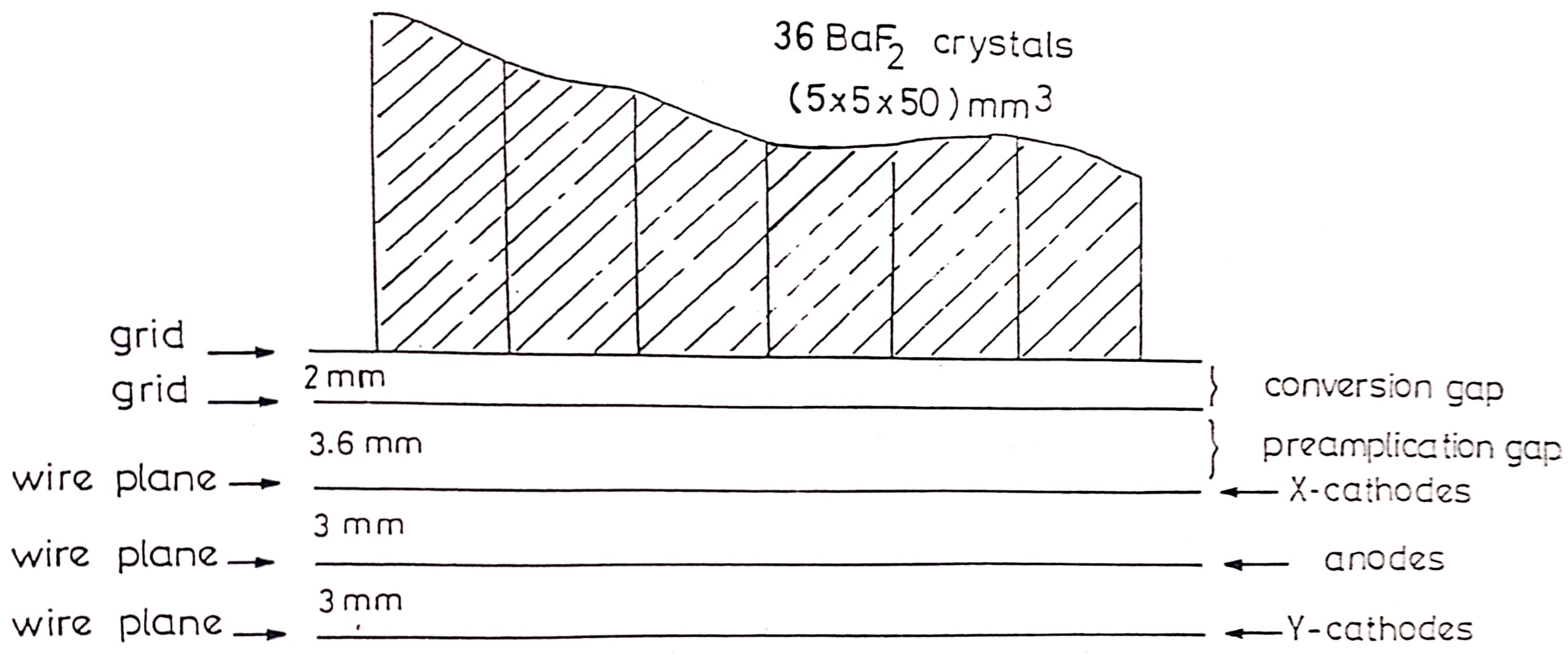

Fig. 1. Active part of the test setup. All grids and wire planes are soldered to printed circuit board frames.

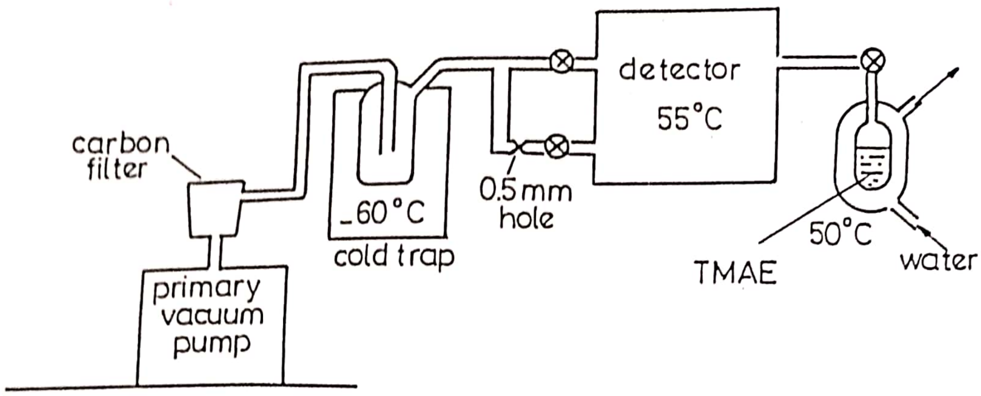

Fig.2. Schematic representation of the gas supply system used in many of the tests.

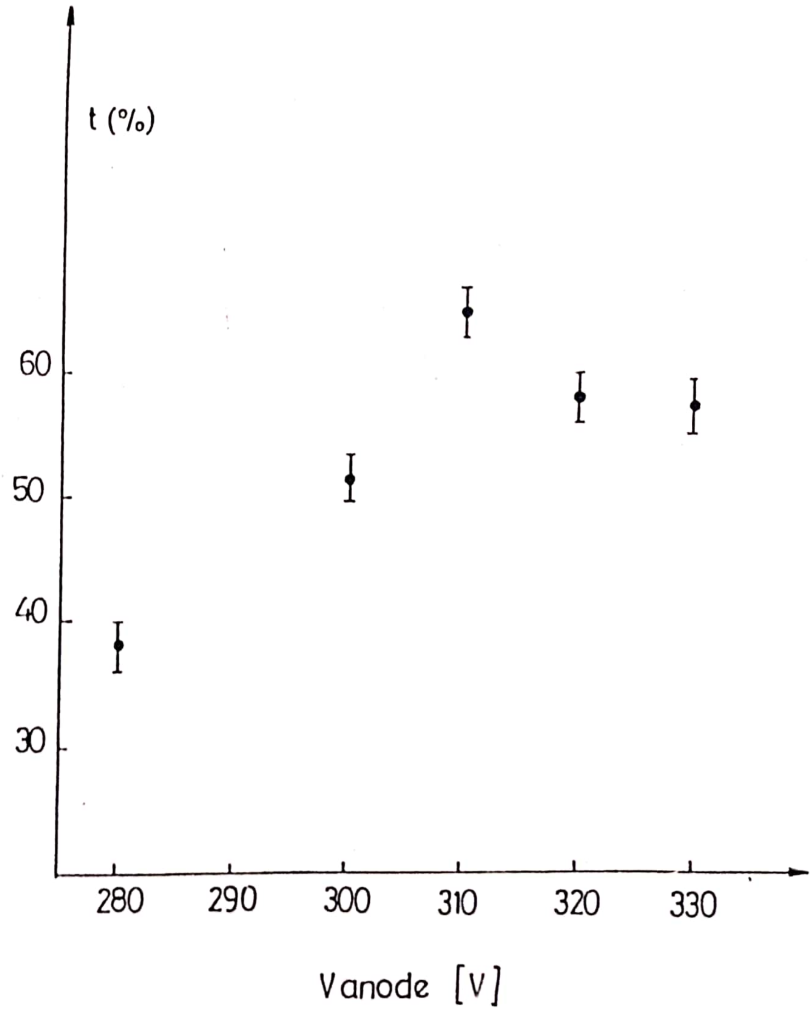

Fig.3. Detection efficiency for 511 keV gamma rays as a function of the anode voltage.

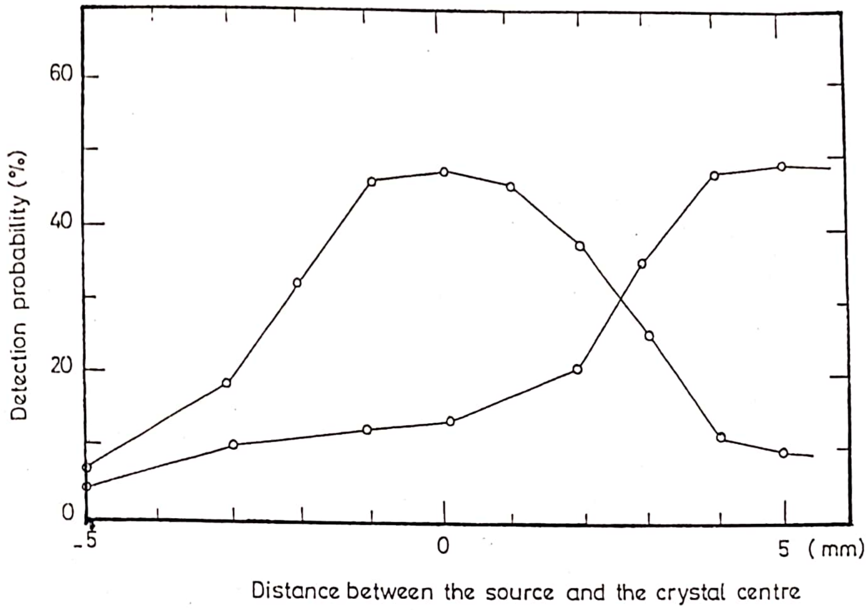

Fig.4. Probability that the wire chamber localizes a gamma ray in a given crystal as a function of the distance of the true impact point from the centre of the crystal.

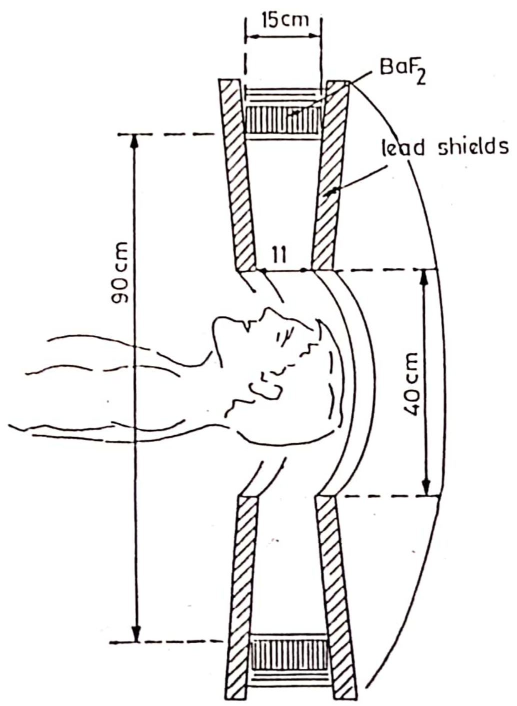

Fig.5. Schematic diagram of a hypothetical scanner based on the gamma ray detection principle described in this work.

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