CONF-851009 - BNL--37343

DE86 005690

PROPERTIES OF A BARIUM FLUORIDE-TMAE-MULTIWIRE PROPORTIONAL CHAMBER DETECTOR USING A LARGE SINGLE CRYSTAL

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ABSTRACT

The properties of a detector consisting of a large barium fluoride crystal and a multiwire proportional chamber operating at low pressure with TMAE have been studied. Measurements of the time resolution, pulse width, energy resolution, photoelectron yield and the effective energy threshold were carried out in a test beam using minimum ionizing particles. Although the detector is sensitive to signals originating from an adsorbed layer of TMAE from the crystal surface, no indication of such a signal was observed.

Introduction

The technique of using tetrakis(dimethylamino) ethylene, commonly known as TMAE, as a photosensitive agent to detect the fast scintillation light from barium fluoride was originally developed by Anderson[1]. This technique offers many attractive features for an electromagnetic shower detector over conventional sampling calorimetry or other types of scintillating crystals read out using phototubes. The advantages of this method are its high rate capability, the ease of having a highly segmented readout, good low energy detection efficiency, and the ability to work inside a magnetic field. An experiment to study rare kaon decays[2] at the AGS at Brookhaven proposes to use such a device as a veto detector for photons in the 20-200 MeV energy range in order to achieve a sensitivity for the decay $K^+ \to \pi^+\nu\bar{\nu}$ at a level approaching that of the standard model. A series of tests were carried out in a test beam at the AGS to study the properties of a prototype detector to determine whether a device of this kind could meet the requirements dictated by the experiment. The results show that these requirements can be met and effort is now underway to build and test a larger scale system.

The Detector

The detector used a single 4.7 cm (flat-to-flat) × 10.4 cm long hexagonal BaF_2 crystal supplied by the BDH Chemical Company, Ltd., Poole, England, a division of Merck, Inc. The light output for the fast (0.6 ns) and slow (620 ns) emission components was measured using XP2020Q photomultiplier coupled to the crystal using Viscasil 100,000 cps silicon grease. For these measurements, as well as all subsequent measurements with the TMAE detector, the crystal was wrapped on all sides except the readout end with white teflon tape to improve the light collection efficiency. We obtained a photoelectron yield of 21 p.e./MeV for the fast component and 246 p.e./MeV for the slow. This is considerably less than has been measured for small crystals[3] and is due to a combination of poorer light collection efficiency, higher uv absorption and, possibly, lower intrinsic light output. However this crystal was an early sample with greater self absorption than is possible for crystals of this size. The attenuation length measured at 210 nm was 80 cm. More recently, we have obtained samples up to 15 cm in length with considerably improved uv transmission and higher light output in the fast component.

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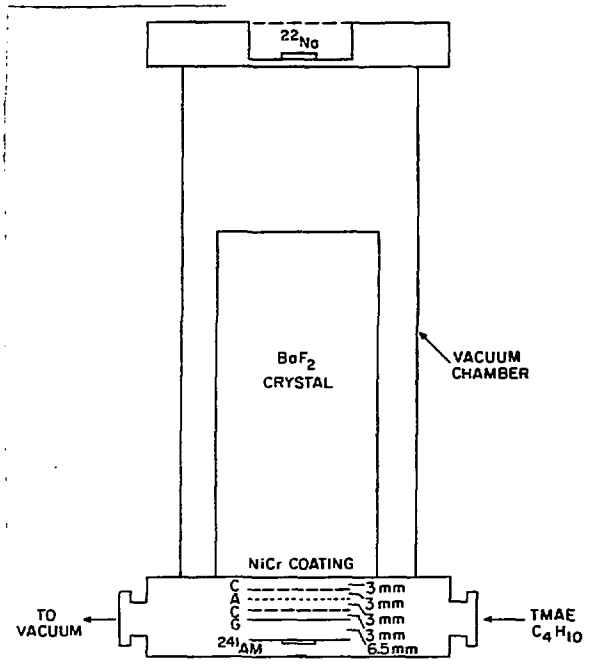

Fig. 1. The BaF_2-TMAE-MWPC Detector. C = cathode, A = anode, G = ground electrode.

The detector consisted of the crystal and a multiwire proportional chamber (MWPC) enclosed in a common stainless steel vacuum chamber as shown in Fig. 1. The readout end of the crystal was coated with a thin 15 Å layer of nichrome over the entire face and served as a ground electrode. This was overcoated with a thick (≈ 1000 Å) layer of gold ≈ 2 mm wide around the outside edge to form an electrical contact. The MWPC was located just below the readout end of the crystal. It consisted of two wire cathodes made of 50 μm diameter Be-Cu wire with 0.5 mm spacing, and a wire anode made of 12 μm diameter gold plated tungsten wire with 1 mm spacing. Another wire plane identical to the anode was located below the lower cathode which served as a second ground electrode. The spacing between all electrodes was 3 mm. For this series of tests, the active area of the MWPC was only about one-third of the area of the crystal.

Before each set of measurements, the chamber was evacuated and then filled with ≈ 0.35 Torr of TMAE (T ≈ 20°C). Isobutane was added by bubbling through liquid TMAE to reach the final operating pressure. The detector was kept at a slightly elevated temperature (≈ 30°C) to prevent the TMAE from condensing on the proportional chamber wires. For the beam tests, the chamber was filled, sealed off and removed from the gas system while in the beam. No gas circulation was provided and chamber lifetimes of up to 13 hrs were achieved with no degradation in efficiency or increased noise. (It is unlikely, however, that such a sealed system

would work for a large detector). Measurements were made at 5, 10 and 253 Torr, although most of the data was taken at a pressure of 10 Torr. Additional tests were carried out in the laboratory with pressures ranging from 2 Torr to one atmosphere. All parts of the detector were exposed to TMAE during normal operation and none of the materials were adversely affected after more than 6 months of use.

Readout

Photoelectrons are produced in the TMAE vapor by the fast scintillation uv photons emitted by the crystal. It has also been reported[4] that an additional signal is produced by an adsorbed layer of TMAE on the nichrome coating as well as from the surfaces of other electrodes of the MWPC. We utilized two methods of biasing to attempt to observe and distinguish between the origin of these sources. In the positive bias mode, a small positive voltage was applied to the cathodes. In this mode, electrons produced in the gas collection regions between the cathodes and the ground electrodes, as well as any photoelectrons originating from the crystal surface, drift towards the cathode and are subsequently amplified in the anode-cathode gap. In the negative bias mode, a small negative voltage was applied to the cathodes, whereby only electrons produced inside the anode-cathode gap were collected.

The anode signal was capacitively coupled to a fast common base charge sensitive preamplifier followed by a fast shaping amplifier utilizing a pole-zero cancellation network[5]. This electronics was used in order to effectively utilize the fast decay time of the BaF_2 and the fast response of the low pressure wire chamber. The rise time of the preamplifier was < 2 ns and the shaping amplifier provided delay line clipping to give a short decay time. The pole zero cancellation network was used to cancel the tail of the pulse from the chamber due to the positive ion collection time. The impulse response of the preamplifier and shaping amplifier combination using a 4 ns clipping delay line could be characterized by a pulse which has a rise time ≈ 12 ns and a baseline width of ≈ 25 ns. The slower rise time was due to a combination of external factors which included the added capacitance of protection diodes on the input to the preamp, the integration time of the shaping amplifier, and a linear fanout of the shaping amplifier output signal. Narrower pulses can be obtained with this system under more ideal conditions.

The cathode signal was taken from the two cathodes tied together and capacitively coupled to a slower charge sensitive preamplifier. The output was fed into an Ortec 472 spectroscopy amplifier with a 1 μs shaping time. The cathode signal was used to collect more of the available avalanche charge and better determine the gain of the chamber for use in calibration. Calibration was achieved by using a ^{241}Am source located inside the chamber which produced a known amount of ionization in the gas[6]. This was particularly useful at low pressures where the signal produced by minimum ionizing particles in the gas resulted in charge levels which were too low to measure. At higher pressures, an ^{55}Fe source was also used to monitor the gas gain. This provided a convenient cross check against the ^{241}Am calibration at intermediate pressures (≈ 25 Torr) where both methods could be used.

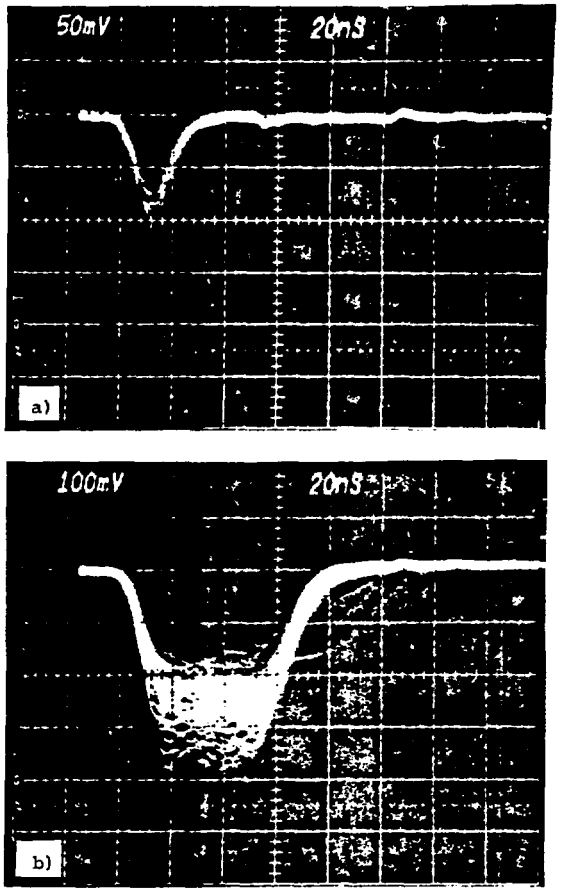

Fig. 2. Anode shaping amplifier output pulses showing ≈ 100 minimum ionizing particles. Pressure = 10 Torr isobutane + TMAE. Clipping delay line = 4 ns.
a) Negative bias, V_{anode} = 560V, $V_{cathode}$=-100V.
b) Positive bias, V_{anode} = 760V, $V_{cathode}$=+100V.

Results

Figure 2a shows the anode shaping amplifier output signal with negative bias for one AGS spill containing ≈ 100 minimum ionizing particles (10 GeV negative pions) traversing the 10.4 cm length of the crystal. The pulse width is dominated by the response time of the preamplifier and shaping amplifier combination and gives a full width of ≈ 30 ns at the baseline. Figure 2b shows the same signal for positive bias with the same anode to cathode voltage difference. The pulse is much wider and is dominated by the drift time for the electrons in the outer collection regions. The width of the plateau can be used to estimate a drift velocity in the collection regions of ≈ 15 ns/mm. A signal originating at the crystal surface would show up as a peak on the trailing edge of the plateau. We clearly see no indication of an enhancement of this type. We have also done studies of the pulse shape in the laboratory using a slightly different electrode configuration. In this case, the crystal surface was 6 mm from the upper cathode and the lower electrode was 11.5 mm from the lower cathode. Figure 3 shows the arrival time of photoelectrons produced by 511 keV gamma rays for this configura-

tion. The time distribution is still quite flat. We conclude that under our conditions we do not observe a signal due to an adsorbed layer of TMAE on any of the surfaces in our detector.

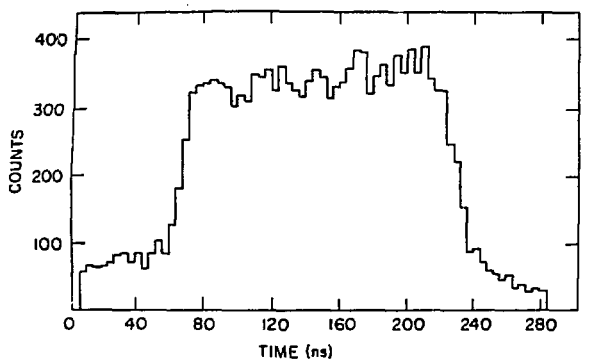

Fig. 3. Arrival time distribution of anode signals for 511 keV photons. Positive bias, P = 25 Torr.

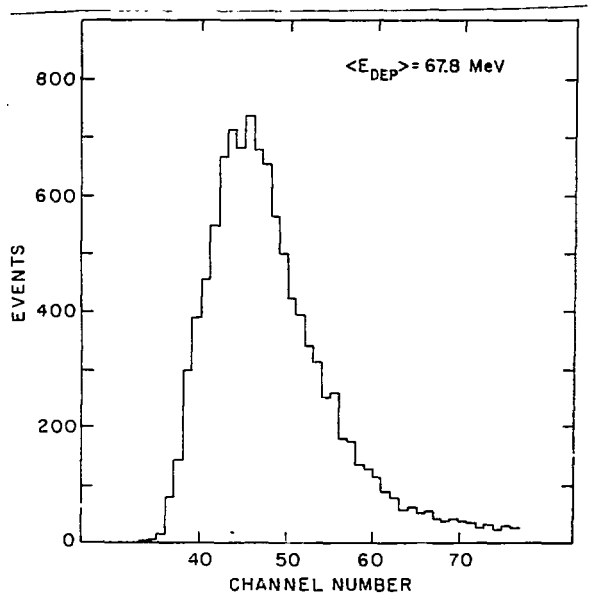

Fig. 4. Anode pulse height distribution for minimum ionizing particles traversing the 10.4 cm length of the crystal. Negative bias, P = 10 Torr.

Figure 4 shows the pulse height distribution for the anode signal with negative bias. We observe a characteristic Landau-like distribution which has a FWHM = .53 and corresponds to an average energy deposit in the crystal (based on dE/dx) of 67.8 MeV. The energy resolution, after unfolding the contribution due to photoelectron statistics, can be characterized by .05 $E^{-1/2}$ (GeV). The corresponding value for positive bias, measured using the cathode signal, was .035 $E^{-1/2}$. This can be compared with a value of .025 $E^{-1/2}$ predicted from measurements made with a sampling device[7] operated similarly to our positive bias mode using 100-200 MeV electrons. Our results have not been corrected for any systematic effects.

Figure 5 shows the time distribution for negative bias obtained with the anode signal using a simple leading edge discriminator. The distribution

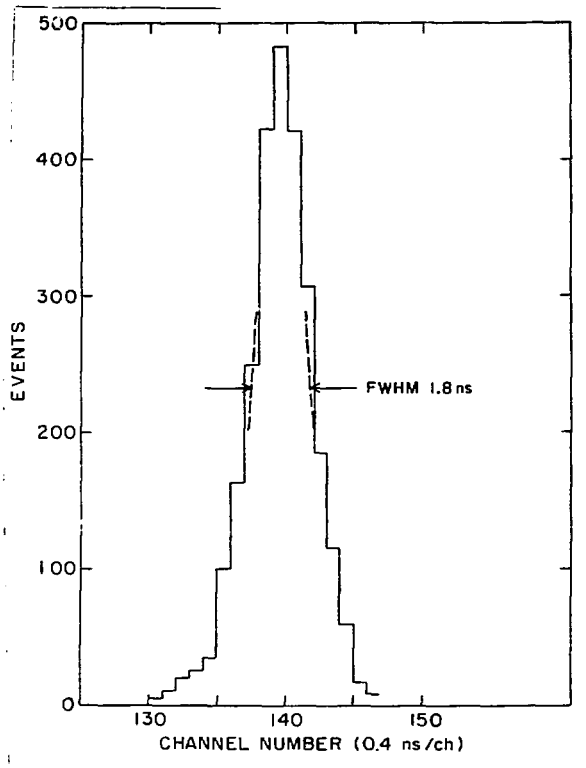

Fig. 5. Leading edge time distribution for anode signals relative to beam scintillators for minimum ionizing particles. Negative bias, P = 10 Torr.

gives the arrival time of the anode pulse relative to a set of scintillation counters in the beam. No correction was made for the time resolution of the beam counters, although their contribution to the width is small. The distribution has a FWHM = 1.8 ns. The time resolution could certainly be improved by correcting for pulse height slewing or by the use of a constant fraction discriminator.

Figure 6 shows the effective trigger threshold for negative bias as a function of the applied anode voltage. The trigger threshold was set at three times the rms electronic noise. A value of 1.8 MeV was obtained for the highest voltage setting. This corresponds to a real threshold of ≈ 0.6 MeV allowing for the limited area coverage of the MWPC. This low threshold is a very attractive feature for a detector of this type which is to be used as an efficient veto for low energy photons.

The photoelectron yield can be expressed as the number of photoelectrons produced per millimeter of gas in which the uv absorption occurs, assuming there is no signal from any surface. This was computed by first taking the difference between the total anode charge obtained for positive bias and negative bias for the same anode to cathode voltage difference. The ^{241}Am source was used to measure the gas gain, which was typically 1.3×10^4 for a pressure of 10 Torr. This then gives the number of primary photoelectrons produced in the collection regions. We obtain a value of 2.7 photoelectrons/mm per MeV deposited in the crystal, after correcting for the area factor. We estimate that the

contribution to the photoelectron yield due to Cherenkov light produced by the minimum ionizing particle in the crystal is less than 10%.

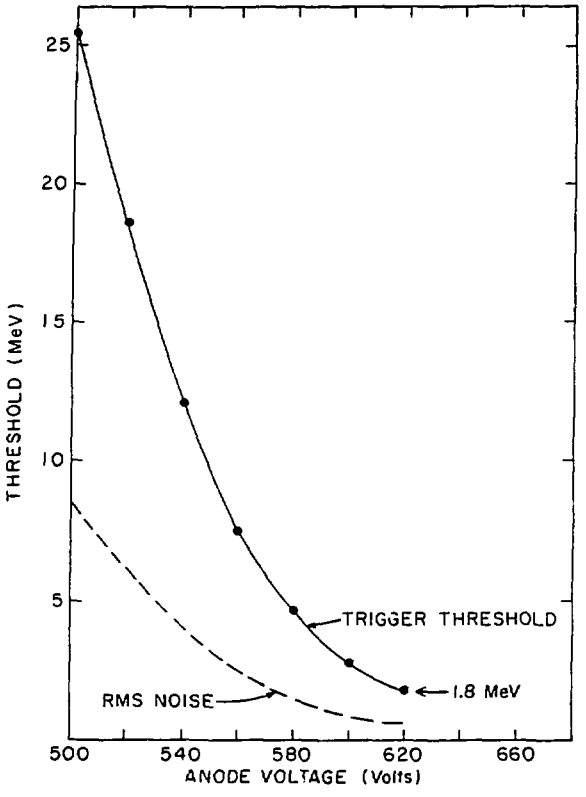

Fig. 6. Effective trigger threshold vs anode voltage, cathode voltage = - 100V, P = 10 Torr.

The flux of uv photons from the crystal was estimated using the photoelectron yield measured with the photomultiplier and correcting for the phototube quantum efficiency and the emission spectrum of the BaF_2 fast component. Using this we can estimate the TMAE quantum efficiency in the gas phase at a pressure of 0.35 Torr of ≈ 2% per millimeter integrated over the BaF_2 fast component emission spectrum. Comparing this with the average uv absorption of ≈ 3.2% per millimeter over the short distances within our detector, we estimate that the probability of photoelectron emission by a TMAE molecule after absorption of a uv photon from the BaF_2 is ≈ 0.6.

The uv absorption and hence the photoelectron yield can be increased by heating the TMAE to higher temperatures, being careful to keep the detector slightly warmer than the TMAE reservoir to prevent condensation. We also hope that better quality crystals will improve the photoelectron yield.

Conclusion

The properties of a BaF_2-TMAE-MWPC detector have been studied with the goal of determining whether a system of this type could be used as a photon veto in a large scale high energy physics experiment. The basic properties of the detector seem adequate to achieve the necessary detection efficiency, time resolution and energy resolution required by the experiment. We have not observed a surface effect from the TMAE as previously reported, but the photoelectron yield is high enough and the time response fast enough to obtain a usable signal from the gas alone. It must now be demonstrated that these parameters can be achieved on a large scale system.

Acknowledgments

We gratefully acknowledge useful consultations with D. Anderson and S. Majewski, as well as D. Stephani concerning the electronic readout and E. Mathieson for theoretical discussions. We also acknowledge W. Frieze for his help during the initial design of the system. We thank T. Kycia and the E787 collaboration for their continuing support of this work. This research was supported by the U.S. Department of Energy under Contract No. DE-AC02-76CH00016.

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