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THE EXPERIMENT 787 HIGH EFFICIENCY PHOTON VETO DETECTOR IN THE 20 – 300 MEV RANGE

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Abstract

Experiment E787 is searching for the rare decay $K \to \pi\nu\bar{\nu}$ at the Brookhaven Alternating Gradient Synchrotron (AGS). To suppress the background from the dominant $K \to \pi\pi^0$ branch, a fast lead scintillator sandwich veto assembly system was used. An inefficiency level of $\sim 1 \times 10^{-6}$ has been achieved for detecting π^0. The limitations are in part geometrical in part due to photonuclear interactions. Our present understanding of these limitations will be presented together with our upgrading plans using pure CsI crystals.

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An experiment aiming at the measurement of the rare branch $K^+ \to \pi^+\nu\bar{\nu}$ is currently underway at the Alternating Gradient Synchrotron (AGS) of the Brookhaven National Laboratory (BNL) by a BNL-Princeton-TRIUMF collaboration.[1] The standard model makes a branching ratio prediction for this second order weak branch[2] in the range of 2 – 6 10^{-10}, the uncertainty coming mainly from the unknown top quark mass, the poor determination of the mixing matrix element V_{td} and the phase responsible for CP violation.

The experiment is carried out with stopped kaons and the signature for the decay $K^+ \to \pi^+\nu\bar{\nu}$ is the presence of a positive pion in the final state with momentum between 0 and 227 MeV/c. However, several more copious decay branches can also emit pions ($K \to \pi^+\pi^0$, $K \to \pi^+\pi^+\pi^-$) or muons ($K \to \mu\nu_\mu$, $K \to \mu\nu\gamma$) which, if mistaken for a pion, would create confusion . These background modes must be suppressed to a level of 10^{-10} sensitivity. For $K \to \pi\pi^0$ (branching ratio (BR) = 0.21) and $K \to \mu\nu_\mu\gamma$ (BR $\simeq 0.6 \times 10^{-2}$) one relies on the detection of accompanying photons to identify these processes as background.

The detector[3] shown in Fig. 1 includes the following characteristics:

- high rate capability
- totally active medium for π^+ identification via total energy measurement, momentum and range determination. This is accomplished by using a scintillating fiber target assembly, a low mass drift chamber in a 10 kG magnetic field and a 38 cm layered scintillation stack with a range resolution of $\sigma \sim 1$ cm.
- detection of the $\pi \to \mu\, e$ sequence in the plastic scintillation counters in which the pion stopped. This is accomplished by using pulse shape information via 500 MHz transient digitizers.[4]

A hermetic photon detection system is made of a barrel veto assembly constituted of lead-scintillator stacks 14 radiation lengths deep and 2 m long readout through acrylic light guides penetrating the magnet pole pieces, and two end-cap plugs also made of 12.4 radiation lengths of fast scintillator-lead sandwiches. The operating conditions of these two end caps

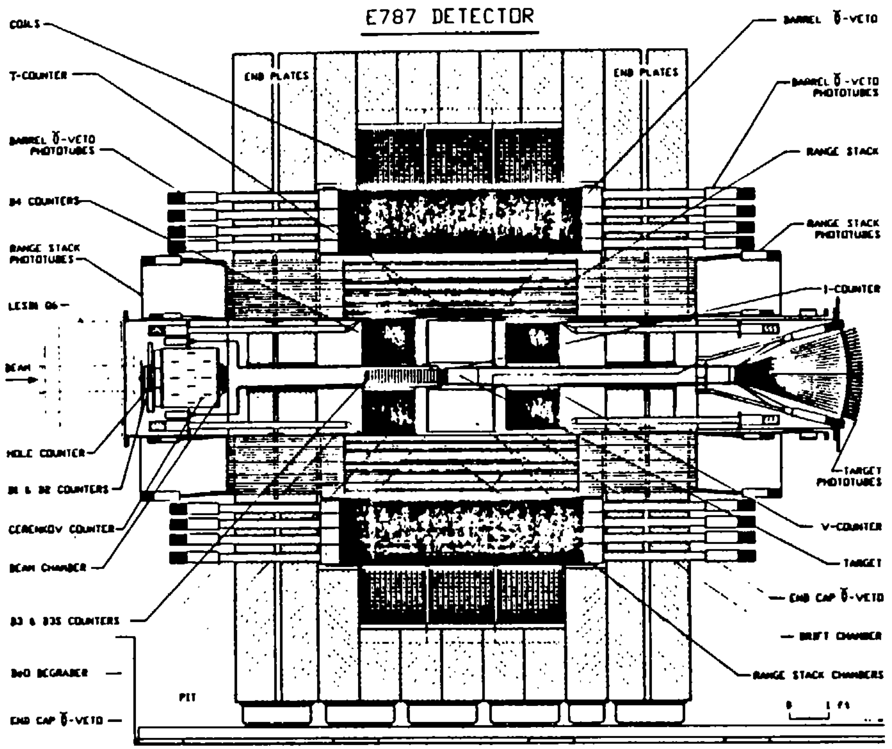

Fig. 1. General lay-out of the Experiment 787 detector.

are the most demanding and have led to a proposal to upgrade them by replacing their lead-scintillator-wavelength shifter technology with CsI crystals read-out by high field phototubes mounted directly on them.

The goal of this paper is to present some of the performances achieved by the present system and the parameters of the new CsI based assemblies.

Performance requirements of the γ-veto system

The system must be highly efficient at detecting photons in the range 0 - 300 MeV. The system must be fast, deadtime less and it must operate in a 10 kG axial magnetic

field. Typical counting rates encountered so far in the endcap assemblies were 20 MHz per 3.10^5 K^+/sec stopping in the target. For the future data taking periods, the stopping rate is expected to increase by an order of magnitude while the pion contamination in the beam will be reduced by a factor 6, leading to an expected total rate of some 60 MHz. To maintain the accidental veto rate to a reasonable level a pulse pair resolution of 10 nsec will be required. Let us review the present capability of the lead-scintillator sandwich assemblies. Because of its more demanding specification, only the end cap detectors[5] will be described.

Figure 2 shows a detail view of a module which makes 1/24 of an end cap assembly.

66 layers of 1 mm thick Pb sheets and 5 mm thick fast scintillator sheets are wrapped together and read-out via a flat wavelength shifter bar running along the wide edge of the module. A good match was found by selecting a NE104* (405 nm peak emission) scintillator and BBOT based acrylic wavelength shifter bars of 6 mm thickness. A 0.3 mm air gap separates the scintillator edges and the BBOT bar. The shifted light (425 nm) is piped down 1.5 m long UVT plexiglass rods to phototubes located outside the magnet.

6 photoelectrons/MeV deposited energy are observed. However, only 29% of the energy deposited appears as visible light and some photonuclear events are lost in the lead plates

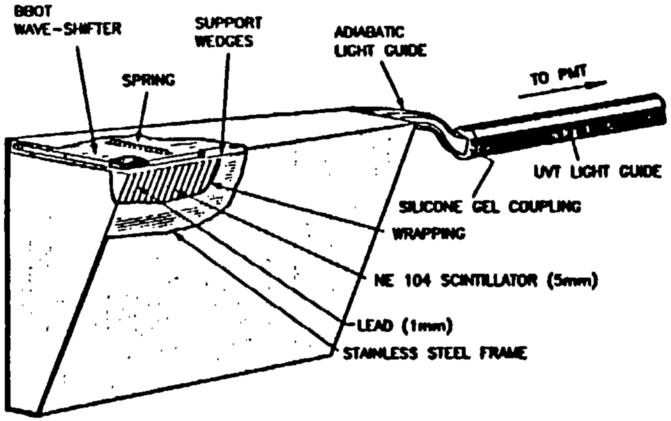

Fig. 2. Details of an end-cap photon veto module.

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limiting the ultimate efficiency. Fairly narrow pulses are observed even after 50 meters of cable to the discriminator (2.5 nsec rise time and 15 – 20 nsec fall time) leading to a pulse full width of half max of 10 nsec.

A total inefficiency for the detector of $\sim 10^{-6}$ was measured for 205 MeV/c π° from $K \rightarrow \pi\pi^\circ$ decays.[6] This inefficiency is caused in part by geometrical gaps (entrance beam hole and exiting target read-out fibres) and by photonuclear events where a nuclear product is absorbed in the dead layers of lead or when a photo-produced neutron escapes detection. So far our simulation shows that the photonuclear effects limit our detection efficiency for high energy gamma rays while geometrical consideration dominates the low energy part of the photon spectrum (see Fig. 3).

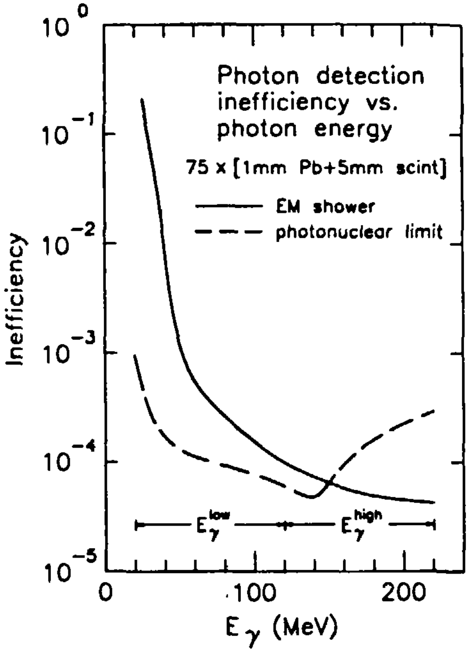

Fig. 3. Monte Carlo simulation of single photon detection inefficiency for lead-scintillator assembly similar to the one used in the experiment.

CsI upgrade

Since only 29% of the deposited energy produces light in a lead-sinctillator sandwich, one can get back more light per MeV by going to totally active scintillators. As well some of the photonuclear reactions could also lead to visible light from decaying nuclear excitation or charged particle emission. This effect is much harder to quantify. However, the requirement of operation in a very high counting rate environment limits the possibilities and so far the best choice is intrinsic CsI which can be produced in large blocks (13 radiation lengths) with most of the emitted light in a 10 – 30 nsec decay time component.

To study the parameters which affect the final pulse shape of CsI blocks, tests are being conducted by the collaboration with two sections of the present end caps replaced by CsI assemblies.

The readout method selected makes use of the recent development in phototube technology towards compact grid structures which allow operation in high axial magnetic fields (Hamamatsu). These phototubes are glued directly on the CsI blocks.

To meet the pulse pair resolution requirements for the experiment, we intend to a) minimize the intrinsic pulse width of the light collection system and b) to digitize the pulse over a 125 nsec period around the time of an event, allowing for a software deconvolution of possible pile up effects.

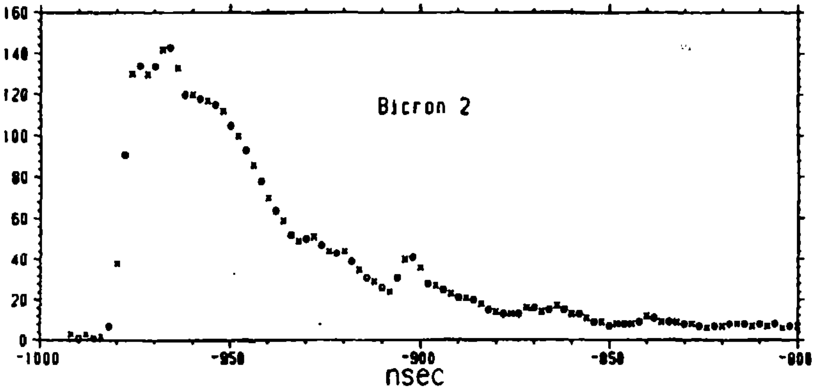

Fig. 4. Digitized pulse shape using 500 MHz transient digitizers, this pulse is from a CsI block replacing an endcap module.

The recent production of fast CCDs based on GaAs technology[7] allowed us to produce 500 MHz transient digitizers at affordable costs. We intend to equip each CsI block with such a device. Figure 4 shows such a digitized pulse which exhibits a secondary pulse (15 p.e.) riding on the tail of a large primary pulse (450 p.e.). With an expectation of a final sensitivity of 100 p.e./MeV, it means that threshold as low as 150 keV could be envisaged.

Summary

E787 requires fast, efficient photon detectors in the range of 0 – 250 MeV. Intrinsic CsI blocks of 13 RL seem to satisfy our expectation of producing up to 100 p.e./MeV with pulses of 50 nsec or less in width. When instrumented with 500 MHz digitizers, an effective threshold of a few hundred keV can be expected.

We are in the process of acquiring enough CsI crystals to completely rebuild the two end caps. This requires 0.26 m^3 of CsI blocks (25 cm long) and should be available by the summer of 1993 for a long data taking run which is aimed at achieving a sensitivity for seeing the $K^+ \rightarrow \pi^+\nu\overline{\nu}$ branch in the region predicted by the standard model estimates (2 – 10 10^{-10}).

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