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MONTE CARLO SIMULATION OF A LEAD-SCINTILLATING FIBERS CALORIMETER

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Monte Carlo Simulation of a Lead-Scintillating Fibers Calorimeter

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Abstract

In this paper a detailed GEANT simulation of an electromagnetic calorimeter based on the use of scintillating fibers is briefly described. Some preliminary results on the efficiency for low energy photons are presented and compared with similar results obtained with EGS4.

Introduction

A measurement of the ratio ε'/ε at a Φ-factory can be performed by identifying the CP-violating decay $K_L^o \rightarrow \pi^o\pi^o$ among the non CP-violating decay $K_L^o \rightarrow \pi^o\pi^o\pi^o$ background. The photons emerging from the neutral decays can have an energy as low as $\sim 20MeV$, which puts some very stringent requirements on the design of an electromagnetic calorimeter for a detector at DAΦNE [1]. In particular such a detector will have to provide a very high detection efficiency for low energy photons, together with good spatial resolution to measure the photons conversion point, and good resolution to measure the energy.

There are several possible designs that meet these requirements, some of them are based on the use of scintillating fibers embedded in lead. Several prototypes are under constructions or have already been constructed at Frascati and other laboratories [2, 3, 4] , which will allow the study of the performances of this type of technique on a test beam. At Frascati these studies can be performed using the LADON tagged photon beam, but while the measurements of the energy and spatial resolutions could be done immediately, the presently available test set-up will need some modifications to measure the detection efficiency.

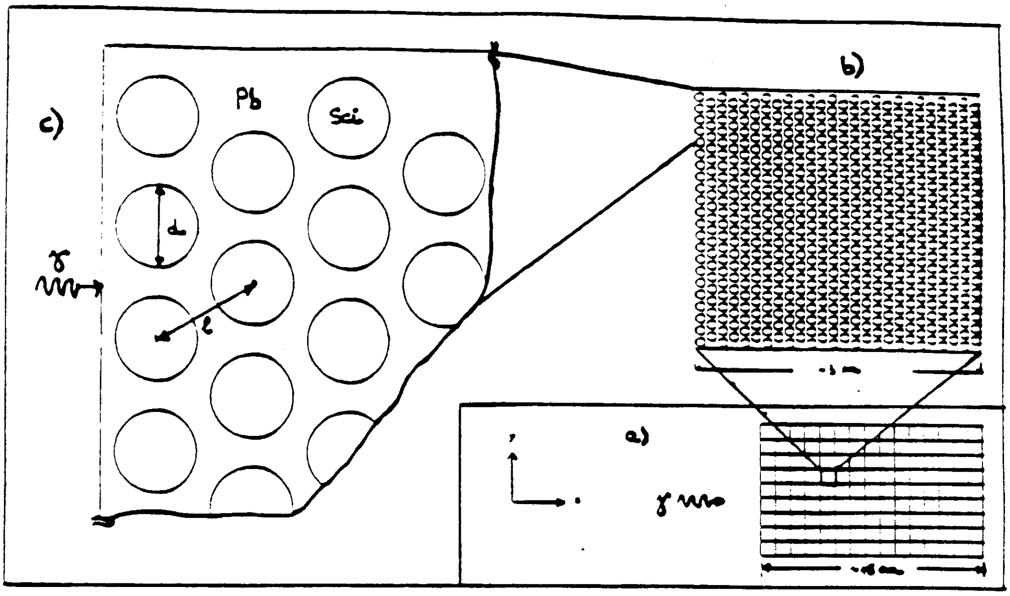


Figure 1: Cross section of the simulated detector. a) the array of phototubes; b) One block of fibers; c) enlarged view of the block strucuture showing the geometry details.

The Monte Carlo Simulation

To get a preliminary idea on what this efficiency will be, we wrote a Monte Carlo simulation of such a device using the GEANT 3.14 program [5]. Table 1 shows the list of GEANT parameters that were changed from the default values for this simulation; all the others had their default values.

Table 1: GEANT runcards used in the simulation

parameter	value	parameter	value
CUTGAM	10 KeV	CUTELE	10 KeV
PHOT	1	COMP	1
PAIR	1	BREM	1
DRAY	0	ANNI	1

The geometry of the apparatus is shown in Fig.1; we have taken three different configurations: detectors A, B and C characterized by different sampling fractions and whose dimensions are summarised in Table 2; in both cases the length of the fibers was 200cm. The scintillator $X_0 = 42.4\ cm$ and $\varrho = 1.032\ g/cm^3$ were taken from the Particle Data Book.

The fibers are grouped in blocks (3 x 3 cm^2) that correspond to single phototubes, and the whole detector is made out of a number of layers of adjacent blocks.

The simulation of the response of the fibers is accomplished in the following way: the energy deposited in each fiber is converted to a number N_γ° of photons ($100 eV/\gamma$), these are then 'propagated' to the end of the fiber where the number of photons is given by

$$N_\gamma = N_\gamma^\circ \frac{1}{2}\frac{1}{4}\varepsilon_c e^{-z/\lambda_{att}}$$

where λ_{att} is the light attenuation length (typically $200 - 300cm$) [6], ε_c is the light collection efficiency that takes into account the light escaping through the fiber's lateral surface, the factor $\frac{1}{2}$ is due to the fact that the light is collected at only one end of the fiber, and the factor $\frac{1}{4}$ accounts on the fact that only a fraction of the photons are transmitted through the core of the fiber, the rest of them being transmitted through the cladding. This last component dies away much more rapidly than the core's [6], and becomes neglegible after a metre or so. Since the incident photons were made to enter the calorimeter always at the center of the fibers, that is at $1m$ from the end, then most of the photons reaching the photomultiplier were from the core light. A more accurate simulation should take into account both these components with a sum of two exponentials with different λ_{att} , but for the present work this should not make any substantial difference.

The photons coming from the fibers belonging to a block read out by the same phototube are summed and then a number of photoelectrons is calculated, which is the number predicted by the Poisson statistics for the given quantum efficiency (ε_Q).

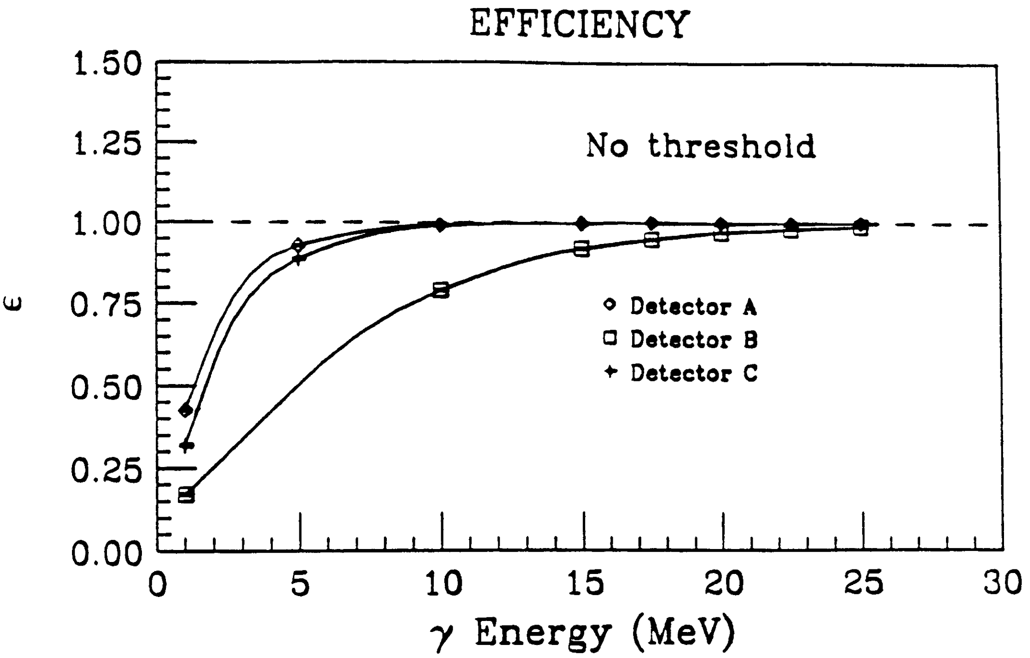
The final photoelectron yield has been tuned by varying ε_c until an average of $\approx 5\ p.e./mm$ @ $1m$ was obtained, which is a typical yield measured with minimum ionizing particles [4]. This tuning was done with $1GeV$ muons impinging on the centre of $5mm$ circular fibers. Table 2 summarises the choice of various quantities used in the simulation.

Table 2

Parameter	Detector A	Detector B	Detector C
d	$1.00mm$	$2.00mm$	$2.00mm$
l	$1.35mm$	$3.00mm$	$2.35mm$
fibers/block	572	120	224
λ_{att}	$200cm$		
ε_c	0.169		
ε_Q	0.20		

Results

Once we defined the geometries of the three detectors, we generated events in which a single photon of a given energy entered the calorimeter always at its center along z and between two fibers. We made runs of 10^4 events each at several different energies, between 1 and $25MeV$, and for each run we counted the number of events that had at least one hit in the calorimeter. A hit was defined as at least N_{th} photoelectrons



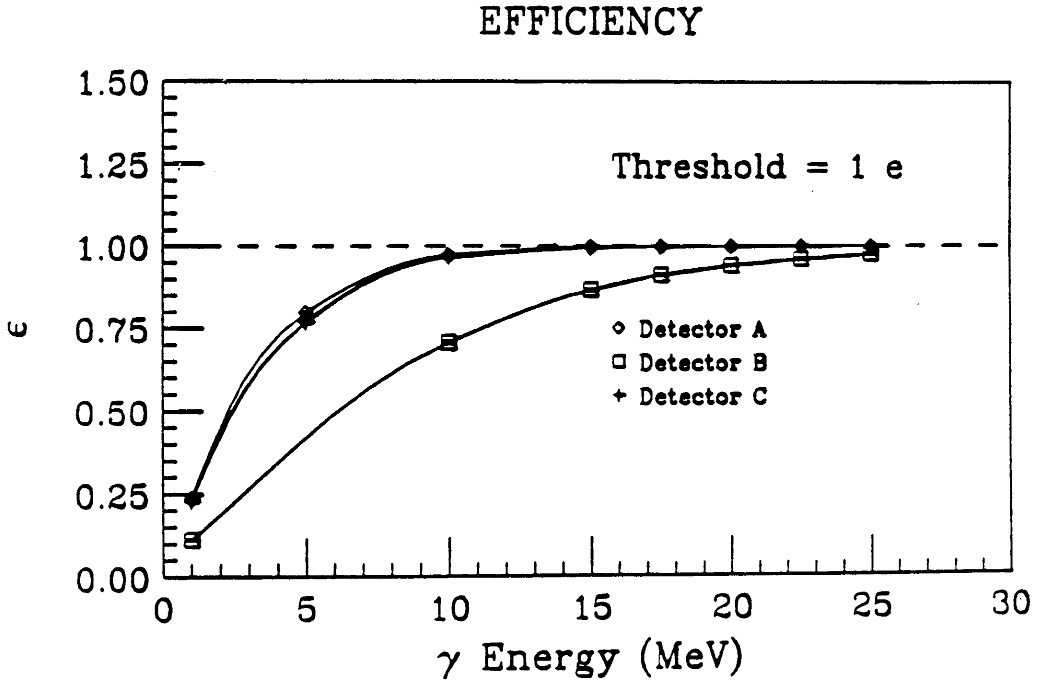


Figure 2: Efficiency as a function of energy

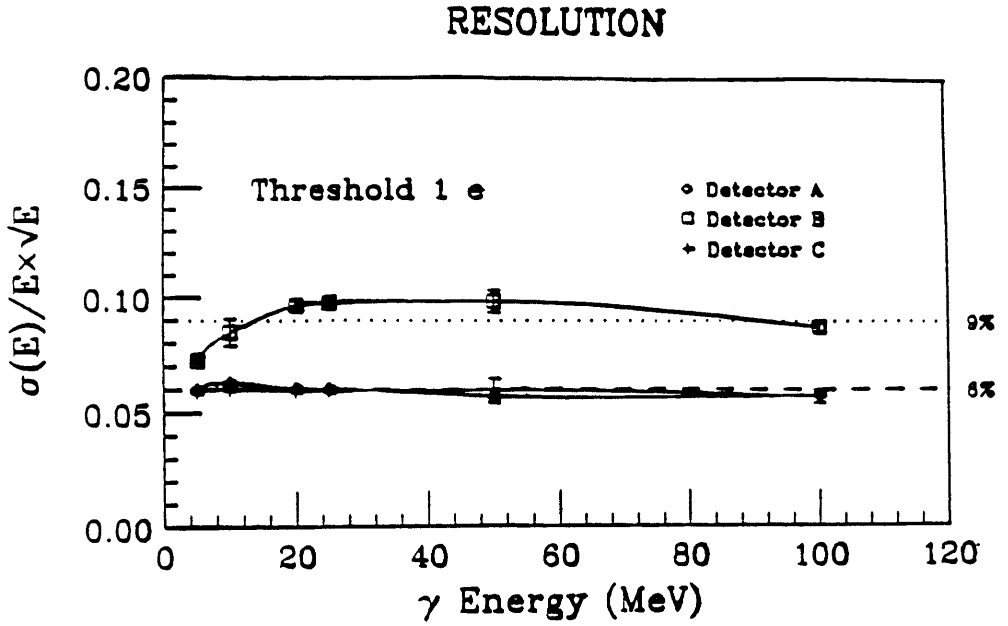


Figure 3: Energy resolution for the simulated detectors.

in any one of the photomultipliers. The results are given in Fig.2 ; the curves with no threshold were obtained by calling a hit any amount of energy > 0 in any individual fiber, and represent therefore the pure effect of the sampling fluctuations.

We can see that detectors A and C give very similar results and already reach $\approx$ 99.9% efficiency at an energy of $\geq 15MeV$ for $N_{th} = 1$, whereas B is only 94% efficient still at $20MeV$ with the same threshold. Solution B for the geometry is already limited by the sampling fluctuations: even with zero threshold it doesn't reach 100% efficiency.

The three configurations give an energy resolution that scales $\approx 1/\sqrt{E}$ between 20 and 100 MeV and that corresponds to ~ 6% @ 1 GeV for A and C, and ~ 9.5% @ 1 GeV for B, as shown in Fig. 3.

In the absence of real data we decided to get a preliminary check of these results, albeit not at all conclusive, from a comparison of GEANT with a different Monte Carlo, EGS4 [7]. This program has been already used and tested at low energies [8] and is therefore a good starting point. The comparison has been carried out for a slightly different (simpler) setup, in which the calorimeter was made of alternating planes of lead ($0.5mm$) and scintillator ($1mm$), and with the same choice of corresponding parameters for the two programs. The results on the efficiency show a very good agreement between them with no threshold. A $\approx 5 \div 10\%$ difference is observed, with GEANT giving a higher value, when we introduce an energy threshold of $50KeV/layer$ (that roughly corresponds to $N_{th} = 1$), which is due to a difference in the shape of the low energy end of the energy per layer distribution.

Conclusions

We have written a GEANT program to simulate in some detail the response of a lead-scintillating fiber sampling calorimeter with which we have checked the low energy photon detection efficiency and energy resolution for three different samplings. The results disfavour the solution with coarser segmentation (B). The other solutions are found to have close to 100% efficiency down to $\approx 20 MeV$ together with a good $6\%/\sqrt{E}$ energy resolution. The results have been found to agree to within 10% with those obtained with the EGS4 program.

The dependence of both efficiency and energy resolution on incidence angle has not been studied but will be the subject of future developments.

Acknowledgements

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