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A Pb - SCI.FI CALORIMETER FOR DAΦNE

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A Pb - SCLFI. Calorimeter for DAFNE

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ABSTRACT

The requirements of a calorimeter for DAFNE experiments are discussed. An idea based on a sampling calorimeter, with very fine absorbing medium and excellent timing properties, is presented, along with the design parameters and simulation studies of a prototype currently under construction. Preliminary results on timing properties of the active medium (i.e. scintillating fibers) are also given.

1. INTRODUCTION

DAFNE, the recently approved project of an e^+e^- storage ring, with very high luminosity ($L = 10^{32} \rightarrow 10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$) at the Φ meson, opens a wealth of physics opportunities, which have been thoroughly discussed during this workshop [1],[2],[3]. The $K_S^0 K_L^0$ system, in particular,

is suited to measure the ratio ϵ'/ϵ of the CP violation parameters to an unprecedented degree of precision. Taking the double ratio method [4] as a benchmark:

$$\frac{N(K_L^0 \rightarrow \pi^0 \pi^0) \times N(K_S^0 \rightarrow \pi^+ \pi^-)}{N(K_L^0 \rightarrow \pi^+ \pi^-) \times N(K_S^0 \rightarrow \pi^0 \pi^0)} = 1 - 6 \Re\left(\frac{\epsilon'}{\epsilon}\right),$$

the statistical error on $\mathcal{R}\left(\frac{\epsilon'}{\epsilon}\right)$ is determined by the less abundant decay mode, $K_L^0 \rightarrow \pi^0 \pi^0$, and

can be expressed as:

$$\delta\left(\mathcal{R}\left(\frac{\epsilon'}{\epsilon}\right)\right) = \frac{1}{6\sqrt{\frac{2}{3} N(K_L^0 \rightarrow \pi^0 \pi^0)}}$$

A $\delta\left(\mathcal{R}\left(\frac{\epsilon'}{\epsilon}\right)\right) = 10^{-4}$ will therefore need $\approx 5 \times 10^6$ $K_L^0 \rightarrow \pi^0 \pi^0$, which could be readily collected

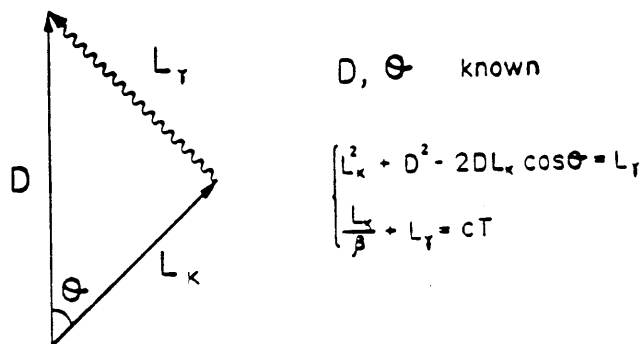
in 100 days of running at a luminosity $L = 3 \times 10^{32}$, by a detector of suitable radius (~ 2 m).

As a consequence, in order not to spoil the statistical significance of the measurement, systematic errors are to be held below 5×10^{-5} , by keeping under control detection efficiency, geometric acceptance (fiducial volume) and background subtraction. In particular, the determination of the fiducial volume for the decay $K_L^0 \rightarrow \pi^0 \pi^0$, translates into the requirement for the calorimeter to be capable of locating the decay vertex with a $\sigma \leq 1$ cm., a formidable task, considering the softness of the energy spectrum of the γ 's ($20 \text{ MeV} < E_\gamma < 300 \text{ MeV}$), (which does not allow to determine the γ direction from the shower profile) and the fact that the K_L^0 decays are almost evenly distributed in the whole detector volume. The only viable method to find the K vertex was based on a global fit technique [5], assuming an "imaging" calorimeter, capable of determining the photon conversion point with a precision of a few millimeters and with a fairly good energy resolution ($\Delta E/E \leq 5\% \sqrt{E[\text{GeV}]}$).

2. THE T.O.F. OPTION

An additional method to determine the decay vertex, which exploits the low speed of the K_L^0 ($\beta \approx .22$), is based on the measurement of the arrival time of the photons on the calorimeter, at known locations. Since the K_L^0 flight direction is determined by the tagging of the K_S^0 charged decay, a single photon is sufficient to determine the K_L^0 decay point (fig. 1)

FIG 1



A detailed study of the method has been presented at this workshop [6]. In summary, it proves

that a calorimeter with fair to good energy and spatial resolution ($7\%/\sqrt{E}$ (GeV) and $1 \times 1 \times 5$ cm³ respectively) and excellent time resolution (300 psec at 20 Mev, scaling with a $1/\sqrt{E}$ law) is capable of determining the K decay vertex with a $\sigma \simeq .75$ cm. If the timing resolution is assumed to be 300 psec, independent of photon energy, the vertex resolution is worsened by $\sim 30\%$, still within the requirements. Another important feature of the method is given by its ability to reconstruct the K vertex, without any appreciable resolution loss, also in the case in which one photon escapes detection. The kinematical variables of the undetected photon (energy, direction) can be determined as well with good resolution.

3. A LEAD-SCINTILLATING FIBER CALORIMETER FOR DAFNE

The above results revive sampling calorimetry, based on a fast active medium, as an attractive option for DAFNE experiments.

The other necessary requirements can be fulfilled by a careful design: efficiency for low energy γ 's and energy resolution can be obtained by a very thin absorber thickness ($\leq .1 X_0$), hermeticity and homogeneity by proper engineering (preliminary studies, using finite element analysis on a barrel of 2 mt. radius and 4 mt. long, indicate that an almost self-supporting structure can be build with a minimal dead space [7]). Moreover, such a technique has a number of features, which are of relevant importance for DAFNE experimentation, like speed (the calorimeter is a critical component in the trigger), compactness (will limit the dimension of the external magnet), number of channels (as presented in this workshop [8][9], the very high rate of good events will require a DAQ bandwidth at least one order of magnitude bigger than the present state-of-the-art) and eventually cost. The choice of the active medium, scintillating fibers, is dictated mostly by the timing performance requirement. Plastic scintillating fibers have undergone a massive development in the last few years and are commercially available at high quality standards and reasonable cost. They exhibit long attenuation lengths (> 3 mt. for "blue", > 5 m. for "green" fibers), due mainly to the quality of the core-cladding interface as a result of the construction technique, they can be doped with a number of different shifters (the matrix, polystyrene, is an intrinsic scintillator), allowing to exploit different characteristics (speed, light output, radiation hardness, etc...) and, above all, they have remarkable timing performances. In a recent paper [10], two counters $2 \times 3 \times 200$ cm, one built by layers of fibers and the other built with a piece of bulk scintillator, identical to the one used in the fiber core, are compared in their timing properties. It is seen that at short distances from the photomultiplier the bulk counter has better timing resolution, but, as soon as the distance grows, the fiber counter rapidly overcomes the bulk counter performances. At a distance of 200 cm. from the p.m., the fiber counter still retains a $\sigma \simeq 210$ psec., while the bulk counter has a resolution a factor 2 worse. This difference in behavior is largely ascribed to the fact that pathlength dispersion for the transmitted light is considerably reduced in the fibers, due to the smaller trapping angle.

In order to test a "minimal" scheme for the barrel calorimeter, we are building two prototype modules using .38 mm lead plates, grooved with a 1.35 mm. pitch, which accommodate 1 mm. diameter blue fibers (fig 2a). The ratio of lead to fibers is 35 : 50 (the rest is glue), resulting in a 15% sampling fraction and an average X_0 of 1.6 cm. Each prototype has front dimensions of $10 \times 200 \text{ cm}^2$ and is $15 X_0$ deep (24 cm.). The fibers are read on both ends, grouping them into the photomultipliers with the scheme sketched in fig 2b): a first part of square elements $3.3 \times 3.3 \text{ cm}^2$, and a second part (tail catcher) with a coarser ($5 \times 5 \text{ cm}^2$) granularity. This should give a transverse resolution $dxdy \approx 1 \text{ cm}^2$, while we intend to reconstruct the coordinate along the beam direction with arrival time difference. The prototype goals are a percent energy resolution of 6% at 1 Gev and a timing resolution of 300 psec for a 20 MeV incident photon.

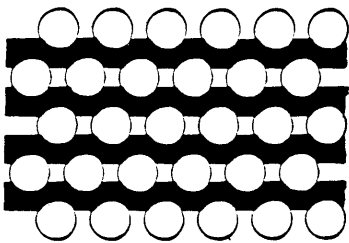


FIG 2a)

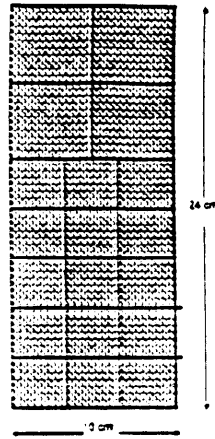


FIG 2b)

A full simulation of the prototype has been performed, using GEANT 3.14 with properly tuned cutoff parameters. As an example, the obtained normalized energy resolution is shown in fig. 3, together with the experimental data obtained by other groups on a calorimeter of similar composition, used in the head-on configuration [11][12]. The agreement is quite good, even at low energies.

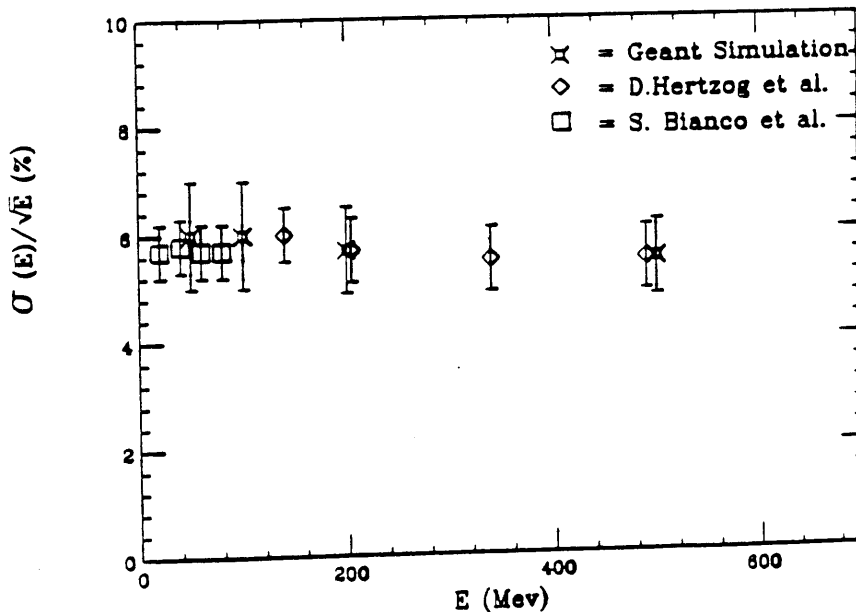


FIG 3

In order to corroborate our intended goal for time resolution, we have also fabricated a set of counters built by layers of fibers and we have studied their timing properties with minimum ionizing particles. Fig 4a) shows the uncorrected timing distribution of a 50 cm. long counter built by 19 layers of 1 mm. blue fibers, stacked to obtain maximum filling. Once that the start jitter is removed, we get a $\sigma \approx 250$ psec, a satisfactory result, considering that no particular optimization has been sought after (we used fiber with rather poor light yield, standard p.m. and electronics). A 200 cm. long counter of similar construction, but only 9 layers thick, yields a $\sigma \approx 390$ psec, confirming a $1/\sqrt{E}$ behavior (fig 4 b).

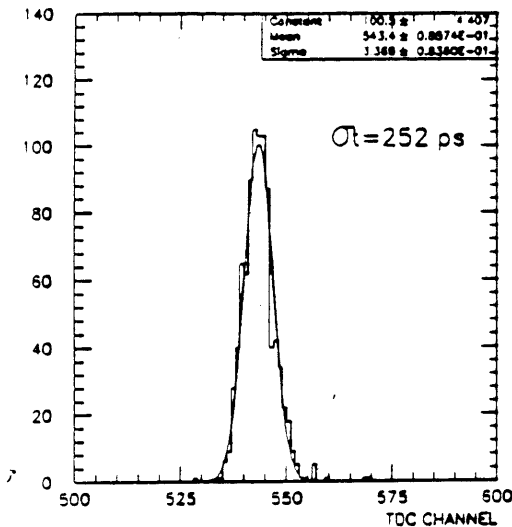


FIG 4a)

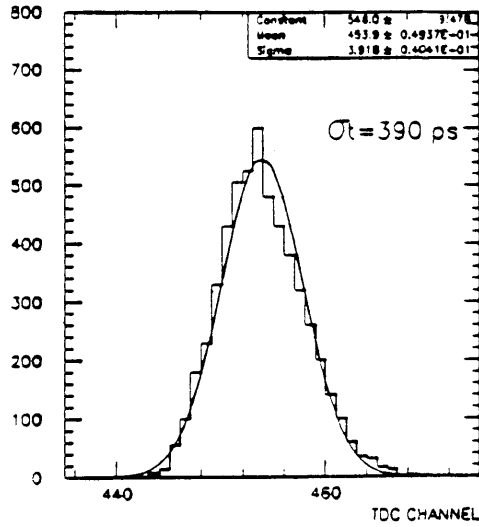


FIG 4b)

It should be noted that the energy released in the 19 layer counter by a minimum ionizing particle (≈ 2.6 MeV) compares quite well with the average energy deposited in the calorimeter active medium by a 20 MeV photon (recalling that the sampling fraction is 15%) and therefore similar timing performances could in principle be expected. A rather ample margin for improvement is still available (fibers with faster decay time and higher light output, more sophisticated electronics) and it is actively being pursued.

4. CONCLUSIONS

A sampling calorimeter using scintillating fiber layered between thin Pb plates seems to match well with the requirements of DAFNE experimentation. Simulation studies and preliminary measurements indicate that energy and timing resolutions of 6% (at 1 GeV) and of 300 psec (at 20 MeV photon energy) can be attained. If the "minimal" scheme, adopted in the prototype construction, is proven to work, a rugged and relatively simple solution will be available for the realization of a large volume calorimeter for DAFNE.

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