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Feasibility study of an active target for the MEG experiment

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Abstract

We consider the possibility to have an active target for the upgrade of the MEG experiment (MEG II). The active target should work as (1) a beam monitoring, to continuously measure the muon stopping rate and therefore provide a direct evaluation of the detector acceptance (or an absolute normalization of the stopped muon); and as (2) an auxiliary device for the spectrometer, to improve the determination of the muon decay vertex and consequently to achieve a better positron momentum and angular resolutions, detecting the positron from the muon decay. In this work we studied the feasibility of detecting minimum ionizing particle with a single layer of 250 μm fiber and the capability to discriminate between the signal induced by either a muon or a positron.

Keywords: Scintillating fiber, silicon photomultiplier, beam monitoring, position measurements

1. Introduction

One of the most interesting fields in particle physics is the search for evidence of new physics beyond the Standard Model (SM). The most promising sector is the charged Lepton Flavor Violation (cLFV), which is very clean from SM backgrounds. The MEG experiment has recently set the most stringent upper limit on the branching ratio $\mathcal{B}$ of the $\mu^+ \to e^+\gamma$ decay, $\mathcal{B} < 5.7 \times 10^{-13}$ at 90% confidence level [1]. An upgrade of the experiment is going on to explore the 10^{-14} sensitivity region [2].

In the framework of MEG II an active target is considered: (1) to continuously measure the muon stopping rate and therefore provide a direct evaluation of the detector acceptance (or an absolute normalization of muon data); (2) to improve the determination of the muon decay vertex and consequently to achieve a better positron momentum and angular resolutions, detecting the positron from the muon decay [3].

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High granularity and fast detector time response are mandatory requirements to sustain the most intense continuous muon beam (up few $\times 10^8$ particles/s).

The target thickness is kept at 250 μm by the thinnest available multi-cladding scintillating fibers to minimize positron multiple scattering and γ background from positron annihilation in the target material. Only a 30 keV mean energy deposit is expected from minimum ionizing particle into such a thin scintillating material making the positron detection a challenging measurement.

Each fiber will be coupled to a single Silicon Photomultiplier (SiPM), which guarantees a sensitivity to the single photoelectron, a fast time response to sustain high rate and able to work in a magnetic field environment. Finally the small dimensions and the low bias voltage of SiPM strongly simplify the mechanical and electronic implementation.

For the minimal active target configuration a single layer of 240 fibers is considered, readout only on one side. On the other side of the fiber an aluminum Al deposit is foreseen to increase the light collection and the detection efficiency.

In this work we report some preliminary measurements and Monte Carlo simulations to investigate the feasibility of this device.

2. Experimental set-up

A set of measurements of a single fiber (square 250×250 μm multi-cladding Saint-Gobain BCF12) coupled to a SiPM (Hamamatsu S10362-11-50C) was done. A Sr^{90} source provides electrons with an endpoint energy of 2.28 MeV. A plastic collimator mounted in front of the source ensured that a fraction of electrons goes through the fiber first and then is stopped in a thick plastic scintillator (BC400 - diameter 20 mm x length 20 mm), coupled to a photomultiplier (Hamamatsu R5900U). The plastic scintillator signal provides the trigger and suppresses the SiPM dark current background. To select the endpoint of the spectrum corresponding to a m.i.p. in the fiber an energy threshold of the external trigger was set at level of 1.5 MeV.

A smart low-noise (<10mV peak-to-peak) front-end board developed for the μSR experiment at PSI is used to amplify the signal. Both input attenuation and output shaping are tunable. The same board provides the bias to the detector.

The signal is digitized using the DRS4 evaluation board, with a sampling speed up to 5 Gs/s [4]. Excellent time and amplitude performances are reached. A custom waveform analysis was implemented.

Based on the Midas Slow Control Bus system [5], an accurate and cheap low power supply is used and remotely controlled.

3. Results

Fig. 1 shows the measured charge spectrum using a fiber in which on the free end an Al 50 nm thickness film was deposit. The timing waveform integration to extract the charge is fixed and equal to 15 ns. We measured a collected light mean of 5 photoelectrons and a detection efficiency of $\epsilon \sim 80\%$. In order to have an optimized mirror effect associated with the Al deposit the fiber was first polished with a diamond head. A comparison between polished and unpolished fiber ends is shown in the picture taken at the microscope (Fig. 2). We get similar results by either painting or sputtering the Al deposit. Although the sputtering method is time consuming it has the advantage that a known, controlled and uniform thickness deposit can be done, in a range of 10-1000 nm. A comparison between a fiber with and without Al deposit showed that an increasing of the light collection of about a factor 1.5 was obtained. This factor is a bit less than what we measured comparing the effect of the Al deposit on square 1 mm multi-cladding BCF12 fiber, equal to 1.7 [6].

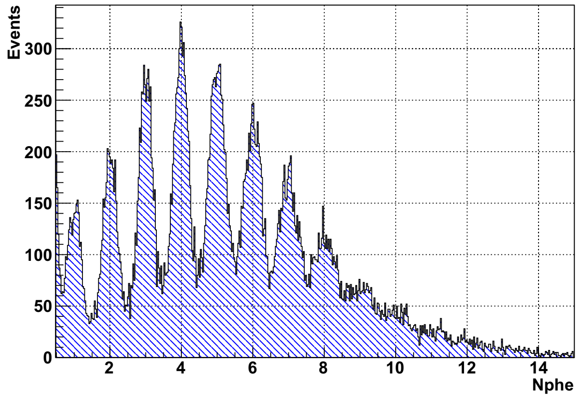

Figure 1: Charge spectrum induced by minimum ionizing electrons in a painted Al square multi-cladding 250 μm scintillating fiber coupled to a SiPM Hamamatsu S10362-11-100C.

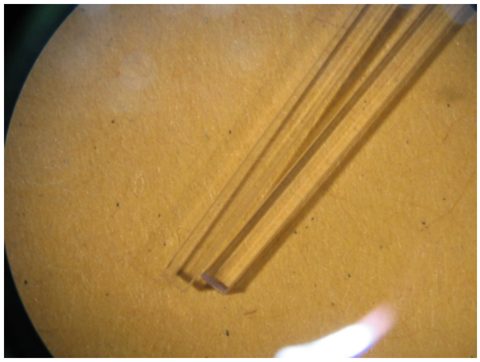

Figure 2: Saint-Gobain square 250μm multi-cladding fiber BCF12 at the microscope. Polished fiber end (left) and unpolished fiber end (right).

A simplified Monte-Carlo simulation based on GEANT4 was performed showing a general good agreement with the data. Fig. 3 shows the transmitted photons at the end of the fiber for a fiber without Al deposit (black) and with Al deposit (red). This Monte Carlo simulation does not include the electrical SiPM response. The SiPM response takes into account for instance the optical matching between the scintillator and the photodetector, the photon detection efficiency PDE [1], etc. The simulated number of photoelectron

[1] $PDE = p \cdot ff \cdot QE$, defined as the product of the pixel geiger

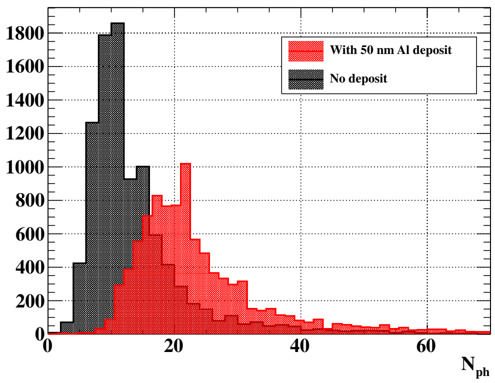

Figure 3: GEANT4 Monte-Carlo simulation: transmitted photons at one end of the fiber, without Al deposit (black) and with Al deposit (red) on the opposite free end of the fiber.

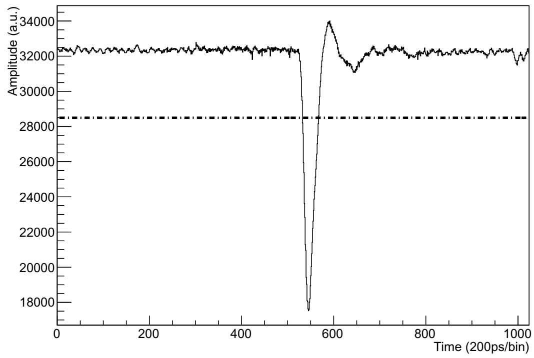

Figure 4: A typical waveform induced by stopped muons of 28 MeV/c into a Saint-Gobain square 250 μm multi-cladding BCF12 fiber coupled to SiPM.

needs to be rescaled by the SiPM response in order to have a direct comparison with the data. The measured collected light is about a 25% less than expected.

As we mentioned at the beginning the active target has to work also as a muon beam monitoring. Some preliminary results with a thicker fiber were discussed in the past [6]. Muon detection is still straightforward even with such a small thickness of the fiber, because muons are stopped in it depositing a large amount of energy. Fig. 4 shows a typical muon waveform when muons of 28 MeV/c are slowed down and stopped into a 250 μm fiber. The dashed black line in the figure provides a reference about the typical positron amplitude waveform, showing the capability to distinguish between the two particles.

4. Prospects

Several prototypes were produced to finalize the results shown here and to be able to address some mechanical issue that we expect to have in experiment: (1) a single fiber double readout to provide an experimental reference about the maximum light collection and efficiency; (2) a single fiber single readout with an Al coating around the fiber to get a light tight device and to optically separate the fibers when an array is done; (3) a multi-fiber array as a first in scale prototype of the final target.

An implementation of the SiPM response based on a statistical approach is going on to finalize the Monte-Carlo simulation.

5. Conclusion

We are studying the possibility to have an active target for the upgraded MEG experiment. The active target should work as a beam monitoring of the most intense continuous muon beam and as an auxiliary device to complement the new proposed spectrometer. These preliminary results are promising stimulating us to fully exploit the feasibility of this project.

Acknowledgments

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discharge p, the geometrical fill factor ff and the quantum efficiency)