PROCEEDINGS OF SCIENCE

Position, timing and particle ID with scintillating fibers read-out by SiPM

Angela Papa[*]
Paul Scherrer Institut, 5232 Villigen-PSI, Switzerland
E-mail: `angela.papa@psi.ch`

Aldo Antognini
Institute for Particle Physics, ETH Zurich, 8093 Zurich, Switzerland
E-mail: `aldo@phys.ethz.ch`

Gianluca Cavoto
Istituto Nazionale Fisica Nucleare, P.le Aldo Moro, 00185 Roma, Italy
E-mail: `gianluca.cavoto@roma1.infn.it`

Emanuele Ripiccini
Istituto Nazionale Fisica Nucleare, P.le Aldo Moro, 00185 Roma, Italy
E-mail: `emanuele.ripiccini@roma1.infn.it`

An active target for the MEG experiment based on thin scintillating fibers read-out by SiPM is proposed here. It should provide a precise measurement of the muon decay vertex and timing, resulting in an improved resolutions of positron absolute momentum and angular variables. Because of its fast time response it can be operated in a high rate environment. Thus this detector can be used also to measure muon beam rates and intensity profiles even at the strongest muon beam in the world. Additionally particle ID (muons versus electrons) can be achieved.

International Workshop on New Photon-detectors,
June 13-15, 2012
LAL Orsay, France

---

[*]Speaker.

PoS(PhotoDet 2012)045

1. Introduction

The MEG experiment searches for the lepton flavor violating $\mu^+ \rightarrow e^+\gamma$ decay. Based on the 2009 and 2010 data samples a new upper limit on the branching ratio (BR) of this process was set: BR($\mu^+ \rightarrow e^+\gamma$) $\leq 2.4 \times 10^{-12}$ at the 90% C.L. [1]. During 2011, the MEG experiment collected a data sample comparable to the 2009+2010 statistics. Data-taking is continuing with the intent of reaching a branching ratio sensitivity of a few times 10^{-13} in the next few years, which corresponds to the designed MEG sensitivity.

A MEG experiment upgrade is now under discussion with the ambition to push down the experimental sensitivity to a few times 10^{-14} in a relatively short time. A new positron spectrometer and a liquid Xenon calorimeter upgrade should provide better positron and photon momenta and time resolutions. Moreover an increased detection efficiency is expected. The upgraded detector should be able to sustain the maximum muon beam intensity available at the Paul Scherrer Institute (PSI), that is few times $10^8\mu/s$.

2. Active target concept

We consider in this section the possibility to complement an active target to the new proposed MEG spectrometer [2]. The active target is used to improve the determination of the muon decay vertex and consequently to achieve better positron momentum and angular resolutions. This measurement is challenging because of the stringent requirements to minimize positron multiple scattering and γ background from positron annihilation in material. In order to meet these severe demands the target must have minimal thickness and low-Z materials. It must have a fast response time to sustain the high rates and must operate in a high magnetic field environment (1.3 T). Silicon wafers and scintillating fibers have the potential to fullfill these requirements. Here we consider only the latter.

The position of the muon decay vertex can be determined by detecting the stopping muon or the emerging positron, using 250 μm fast scintillating fibers coupled to SiPM.

- Muon detection. In this case a spacial correlation should be used to connect the muon signal, detected by the target, with the positron track, measured by the spectrometer. The reconstructed positron track is extrapolated back to the target plane so a small area is selected on it. Only one fiber is expected to be fired in this area, which provides the muon position. This process is however rate limited to $\approx 10^7$ particles/s, above which, muon multiplicities become larger than one and the efficiency of the method rapidly vanishes.

- Positron detection. In this case the positron detected by the target is timing correlated with the reconstructed track in the spectrometer, where the positron time is provided by fast scintillators. This timing correlation can be used to have an external trigger on the target signal, which is fundamental to extract the expected weak positron signal as explained below.

The detection of the muon, without requiring any correlation with positrons, is also foreseen. It provides a continuous measurement of the muon stopping rate. This would be an independent

Target/ Spectrometer	thickness (μm)/ angle (deg)	σ_p (keV)	σ_ϕ (mrad)	σ_θ (mrad)	comment
Passive/old	205/ 20.5	320	11.7	9.8	measured
Passive/new	205/ 20.5	110	6.3	5.3	simulated
Passive/new	140/ 15	110	5.3	4.8	simulated
Active/new	250/ 20.5	90	4.7	5.1	simulated

Table 1: Measured positron momentum and angular resolutions with the present spectrometer (first row) . Monte Carlo simulation results for different target options coupled to the new spectrometer in $\mu^+ \to e^+\gamma$ events are then reported.

determination of the number of stopped muons, or, alternatively, a direct evaluation of the detector acceptance, which is needed to normalize the signal yield measurement. The muon and positron signals can be distinguished referring to the large difference of energy deposit into the detector, as we describe in section 4.

With the proposed target a position resolution of $\sigma_y < 100$ μm is achievable and a timing resolution $\sigma_t < 500$ psec is expected with a photo-electron statistics of about 10. A detection efficiency larger than 80% is desired.

3. Monte-Carlo simulations

In the current MEG experimental set-up there is no direct measurement of the muon decay vertex. Muons are stopped in a passive target (target thickness = 205 μm, slant angle 20.5 deg relative to the beam direction) and the positrons from muon decay are detected, after traversing ~ 40 cm He gas (at 1 atm pressure and room temperature). The muon decay vertex is determined by back-projecting the reconstructed positron track to the target plane. The measured performances of the present spectrometer coupled with a passive target are given in Tab. 1.

If an active target is used in a minimal configuration with only one single layer of horizontally mounted fibers, the measurement of the Y-coordinate can be performed and it strongly constrains the positron momentum reconstruction. Figure 1 shows typical positron momentum (left) and ϕ angle (right) resolution distributions. The improved resolutions are summarized in Tab. 1.

4. Experimental set-up for R & D studies

The active target will be made by an array of 240 (0.25×0.25 mm^2) multi-clad BCF12 (from Saint-Gobain) square fibers, with a peak emission at 435 nm, a light yield of about 8000 ph/MeV, a trapping efficiency of $\approx 7\%$, an attenuation length of 2.7 m and a decay time of 3.2 ns. Each fiber will be coupled to a single SiPM (Hamamatsu S10362-11-100C). The detector efficiency was optimized by using the SiPM with a detection efficiency (PDE) of 65% and a gain of 2.4×10^6 (dark rate = 600 kHz at 0.5 phe).

Positron detection. The main challenge is to detect minimum ionizing particles (m.i.p.) with high efficiency using 0.25×0.25 mm^2 fibers (average energy deposit of ~ 40keV). A set of measurements of a single fiber (BCF12) coupled to a SiPM (Hamamatsu S10362-11-50C) were done. A

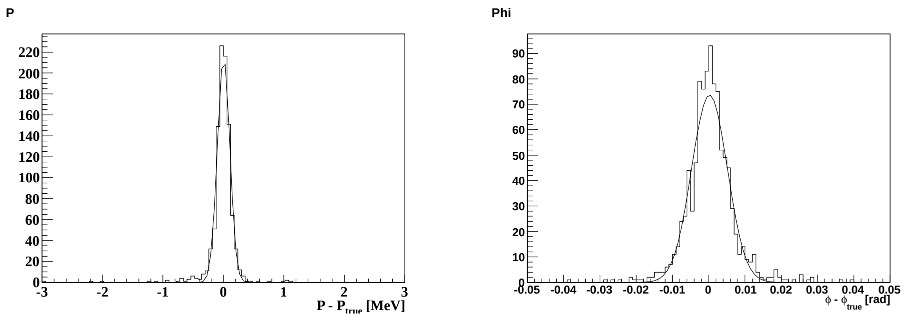

Figure 1: Monte Carlo simulation of positron momentum $\sigma_p = 90$ keV/c (left) and phi angle $\sigma_\phi = 4.7$ mrad (right) resolutions in $\mu^+ \to e^+\gamma$ events using an active target coupled with the new spectrometer.

Sr^{90} source provides electrons with an end-point 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), read by a photomultiplier (Hamamatsu R5900U). The plastic scintillator signal provides the trigger and suppresses the SiPM dark current background. An energy threshold at level of 1.5 MeV was set to select only minimum ionizing particles.

Several fiber thicknesses (1×1, 0.5×0.5 and 0.25×0.25 mm^2) were tested. The measured number of photoelectrons scales, as expected, with the deposited energy, in all cases except for the 0.25 mm fiber, where slightly less light was collected due to a non-optimized mechanical and optical coupling. The signal from the SiPM was amplified by a factor 10 using a low-noise ($<$ 10 mV peak-to-peak) front-end preamplifier board (PSI made). The same board delivers the 70 V bias voltage to the detector. The data was acquired using a LeCroy WaveRunner 640Zi, 4 GHz Oscilloscope, with up to 40 GS/s.

Figure 2 shows the charge spectrum obtained as a result of a waveform integration in a fixed time window (15 ns). A mean of 3.5 photoelectrons is measured to be compared with the expected 5. A lower limit on the m.i.p detection efficiency was also measured to be $\varepsilon > 60\%$. We believe there is room for improve such result. The light collection, for instance, can be enhanced by depositing an aluminum reflector on the opposite end of the fiber. For 1×1 mm^2 fibers an increasing of light collection of about 70% was obtained. Figure 3 shows the comparison between fiber without (left) and with (right) aluminum deposit, where a mean of 19 and 32 photo-electrons are measured respectively.

Muon detection. The muon detection study was performed using a layer of 4 rounded fibers (BCF-12, diameter 0.5mm) coupled to SiPM (Hamamatsu S10362-33-50C) at the PSI πE1 beam line, tuned to positive muons of 28 MeV/c (the same as used in MEG). The muon intensity was about 2×10^6 μ/s. The signal was digitized using the DRS4 evaluation board developed at PSI [3], with a sampling speed up to 5 GS/s. This allows a custom waveform analysis to be easily implemented (pile-up rejection, template, after-pulse tagging etc.). Based on the Midas Slow Control Bus system [4] an accurate and cheap low power supply is used and remotely controlled. A typical waveform amplitude distribution is shown in Figure 4. A scan of the collected light as a function of the muon momentum was performed inserting 50 μm thick mylar foils in front of the fibers

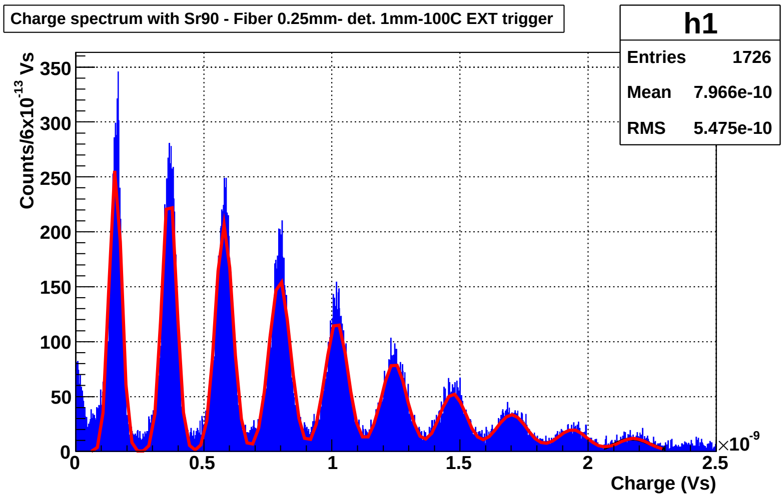

Figure 2: Charge spectrum induced by minimum ionizing electrons in a $0.25 \times 0.25\,\text{mm}^2$ scintillating fiber coupled to a SiPM Hamamatsu S10362-11-100C.

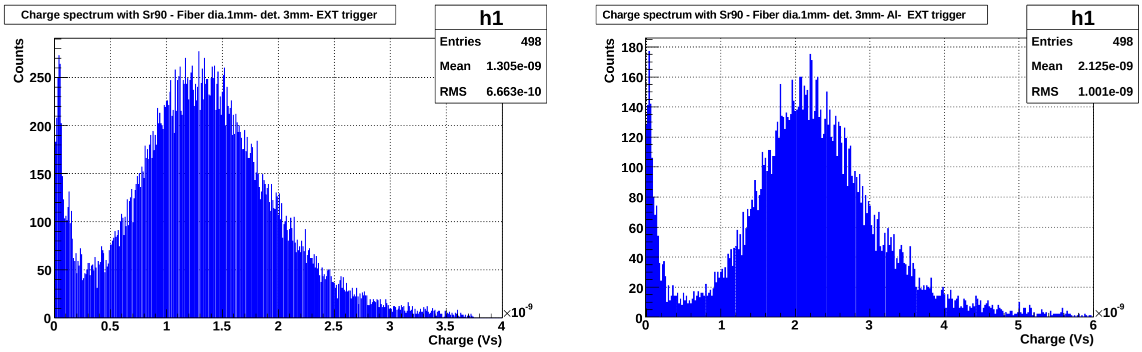

Figure 3: Charge spectrum induced by minimum ionizing electrons in a $1 \times 1\,\text{mm}^2$ scintillating fiber coupled to a SiPM Hamamatsu S10362-33-50C to one fiber end, without (left) and with (right) aluminum deposit on the other end.

until the muons are stopped into it. The muon signal is clearly visible for all the different energy deposits.

4.1 Event selection

Positron selection. For 10^8 muon stopped per second a rate of $2 \cdot 10^6$ event/s per fiber of $0.25 \times 0.25\ \text{mm}^2$ is expected. Two are the main background sources for positron signal selection: the thermal noise and the muons. The first is present since the positron signal is expected to be at a level of few photo-electrons and therefore at the same level of the thermal noise, with a rate of few hundred KHz (in the best case). The second since the higher muon signal could overlap the positron one. This muon signal can come from uncorrelated muon hitting the same fiber fired by the positron or from the stopping muon from which the positron originates. Both can be rejected using the Timing Counter detector as an external trigger (MEG trigger) in a time window of 20 ns.

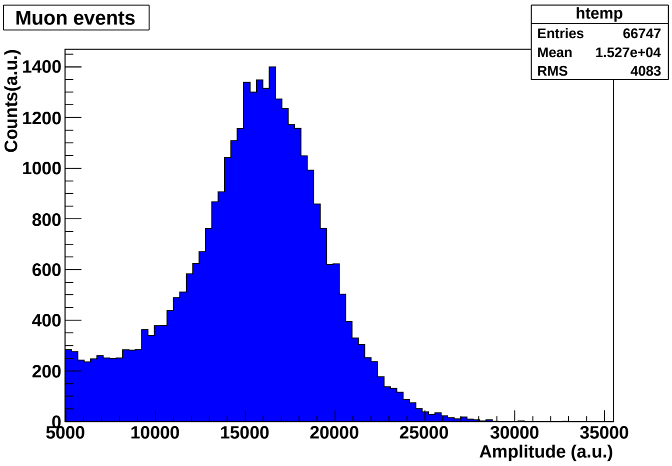

Figure 4: Waveform amplitude spectrum induced by muons of 28 MeV/c in a 0.5 mm (diameter) scintillating fiber coupled to a SiPM Hamamatsu S10362-33-50C.

All the listed backgrounds are reduced at a contamination level of few percent. In conclusion the positron selection efficiency based on an external trigger is expected to be $\geq 95\%$.

Muon selection. The muon rate can be measured setting a relatively high amplitude threshold, which removes completely the positron and thermal noise contributions.

5. Conclusion

In conclusion, preliminary tests have shown that minimum ionizing particles can be detected with 250 μm scintillating fibers coupled to SiPM. The positron signal is clearly detected rejecting the thermal noise with an external trigger. No cooling system for the SiPM is needed. The large pulse-height difference between positron and muon allows to distinguish between the two particles. A prototype is under-construction in order to finalize the project.

Acknowledgments

The authors thank PSI for the technical support; Claude Petitjean for generous assistance during the test beam activities; Alexey Stoykov and MEG colleagues for the very useful discussion. This work was supported by INFN and PSI.

References

[1] J. Adam, et al., *New Limit on the Lepton-Flavor-Violating Decay* $\mu^+ \rightarrow e^+\gamma$, *Phys. Rev. Lett.* **107** (2011) 171801-1.

[2] A. Papa, et al., *Development of an active target for* $\mu \rightarrow e\gamma$ *search*, in proceedings of *12th Pisa Meeting on Advanced Detectors*, *Nucl. Instum. Meth.* **A** - special issue (2012).

[3] S. Ritt, *Electronics for the* $\mu \rightarrow e\gamma$ *experiment*, *Nucl. Instrum. Meth.* **A494** (2002) 520.

[4] P. Amaudruz, et al., *http://midas.psi.ch/htmldoc/index.html*.