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Measurement of the detection efficiency of a 100 µm thin plastic scintillator for muons with $p = 28$ MeV/c

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Abstract: In the muEDM experiment, a gate detector is used to trigger the storage mechanism when a muon enters the experimental apparatus. This detector should operate at full efficiency and low thermal noise contamination. Furthermore, it should have a very low material budget to minimize the deflection of the muon trajectory by multiple coulomb scattering. A first prototype of this detector is a 100 µm thick plastic scintillator, connected to eight silicon photomultipliers reading out the scintillation light. In a dedicated beamtime at the πE1 beamline at the Paul Scherrer Institute, we measured the detection efficiency of this scintillator with 28 MeV/c muons.

Keywords: Scintillators and scintillating fibres and light guides; Trigger detectors; Scintillators, scintillation and light emission processes (solid, gas and liquid scintillators)

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Contents

1 Gate detector for the muEDM experiment

The muEDM experiment, currently in preparation at the Paul Scherrer Institute (PSI), will enable a search for the electric dipole moment (EDM) of the muon and aims to improve the limit on the muon EDM down to $|d_\mu| \leq 6 \cdot 10^{-23}$ e·cm [1], whereas the detection of a non-zero EDM would be a direct hint of CP violation. The idea of the experiment is to store muons in an electromagnetic field tuned so that the only source of spin precession is the EDM while the $g-2$ precession is cancelled (frozen spin technique [2]). A gate detector is used to detect the arrival of a muon and to trigger the storage mechanism. This gate detector should operate at high efficiency and low thermal noise contamination. Furthermore, it should only minimally deflect the muon since a precise control of the particle trajectory is crucial to achieve a high storage efficiency. These requirements suggest the use of a very thin plastic scintillator as a gate detector. The characterization of such a thin scintillator with a muon beam is described in this article.

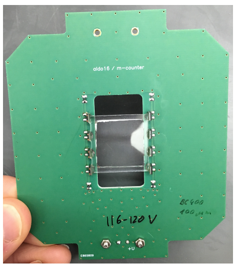

Figure 1. The BC-400 gate scintillator, having a thickness of 100 µm and an area of $20 \times 20\,\text{mm}^2$.

2 Beam tests of a first gate detector prototype

The first prototype of the gate detector is depicted in figure 1 and consists of a very thin BC-400 [3] plastic scintillator with 100 µm thickness to keep the path deflection due to multiple coulomb scattering at a minimum. The scintillation light is read out by eight Hamamatsu silicon photomultipliers (SiPMs) with an effective photosensitive area of $1.3 \times 1.3\,\text{mm}^2$ [4]. The output

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signals of the eight SiPMs are combined into a single readout channel by an electronic board. To also perform other measurements, the gate detector was equipped with several additional detectors mounted on a telescope as shown in figure 2. In addition to the gate scintillator (1), a veto detector (3) was used to collimate the beam onto the gate scintillator and a long rectangular channel made of plastic scintillators (2) was used to measure the fraction of muons able to be injected into the experiment. At the end of the telescope, a 200 µm BC-400 plastic scintillator (4) was used as exit detector to detect muons leaving the channel.

In the following, we report about tests of the thin gate detector performed with a 28 MeV/c muon beam at the πE1 beamline of PSI. The main goal of the beam tests was to measure the muon detection efficiency of this very thin 100 µm scintillator. This is an important quantity when deciding for a trigger threshold, because in this case we need to find a compromise between the desired detection efficiency and an acceptable thermal noise contamination.

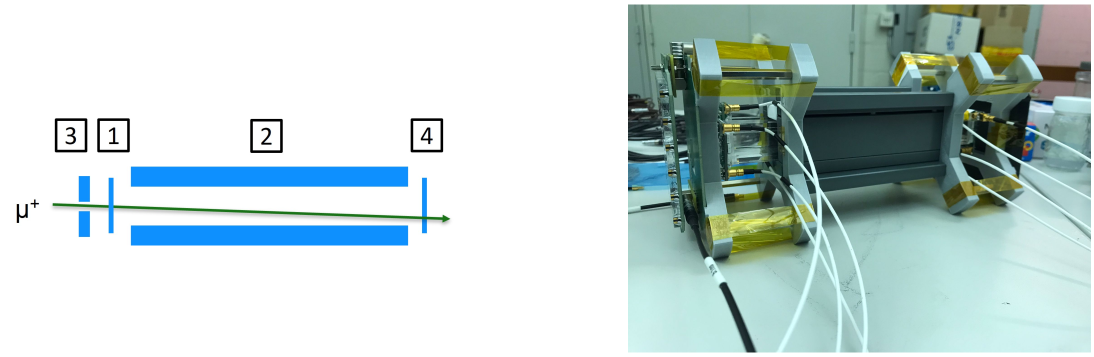

Figure 2. Left: scheme of the telescope used for the measurements of the gate scintillator. [1] Gate detector. [2] Scintillating channel. [3] Veto. [4] Exit detector. Right: image of the assembled telescope with all detectors.

3 Gate scintillator detection efficiency

To measure the muon detection efficiency of the gate detector, we triggered on muon hits in the exit detector and recorded the waveforms in the gate detector. This method allows to observe the full amplitude distribution of the muons in the gate detector and by counting the number of waveforms above threshold the detection efficiency can be deduced. When counting the waveforms above threshold in the gate, we only want to take into account waveforms due to muon hits but not due to thermal noise pulses in the triggered time window. Since the scintillator is very thin, the muons leave signals with an amplitude comparable to the thermal noise, and consequently the muon signals cannot be distinguished from thermal noise using only the amplitude information. To further separate thermal noise pulses from muon waveforms, we exploited the fact that the muon hits occur at a fixed time with respect to the exit trigger signal. For muons, this time difference is given by the time of flight from the gate to the exit, whereas thermal noise pulses occur randomly in time with respect to the exit trigger. In figure 3, the time difference of the hit in the gate and the exit detector is plotted against the amplitude of the waveform in the gate detector. The time difference was corrected by a fixed cable delay (35 ns) and the expected time of flight of the muons (2.8 ns), so that the most probable value for 28 MeV/c muons is a time difference of zero. The events occurring at larger times

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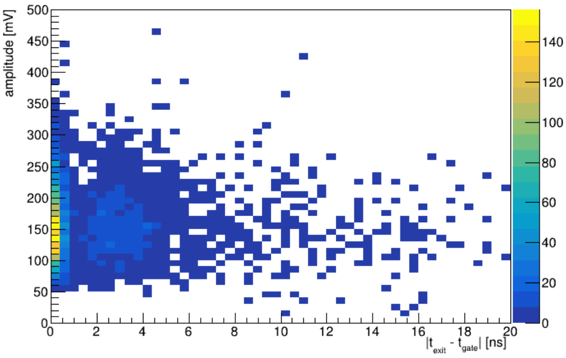
than expected for muons are most probably thermal noise pulses in the recorded waveform. The detection efficiency can then be deduced by counting the number of waveforms in the gate detector above a certain threshold which arrive within a certain time difference with respect to the exit trigger signal. In figure 3, the detection efficiency values are given for a time window of 10 ns centered at the trigger time of the exit. We also applied a small (< 1 ‰) correction accounting for thermal noise pulses which occur accidentally in the time window expected for the muons by estimating the number of recorded thermal noise pulses in a sideband at large time differences (≥ 10 ns).



Threshold [mV]	ϵ [%]	t.n. rate [kHz]
−50	87.1	150
−100	77.8	7.2
−150	47.6	0.6
−200	18.8	0.04
−250	6.2	0.005

Figure 3. Left: the waveform amplitude in the gate detector plotted against the time difference between the hits in the gate and the exit (corrected by the time of flight). A total of 3998 events were recorded at a trigger rate of about 60 kHz. Right: the measured detection efficiencies of the 100 µm gate scintillator with 28 MeV/c muons, and the corresponding thermal noise (t.n.) rate of the gate detector.

4 Conclusion

We measured the detection efficiency of a 100 µm thick plastic scintillator for muons with a momentum of 28 MeV/c. To choose a trigger threshold in the experiment, these efficiency values have to be compared to the thermal noise rate of the detector. From the table in figure 3 it is clear that this detector can not be operated at high detection efficiency and low thermal noise contamination at the same time. A possible solution to operate such a thin scintillator would be to use a multi-channel readout of the SiPMs instead of combining them into a single readout channel. The scintillation light due to a muon hit would be visible in all channels of a multi-channel readout, whereas the thermal noise is uncorrelated between the channels. The coincidence of two or more channels would therefore help to reject thermal noise pulses and to operate the detector at low threshold and high efficiency.

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