Pre-Proposal for Master thesis

Decay Reconstruction Software for Muonium Detector in the MAGE Antimatter Gravity Experiment

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1 Introduction

The *equivalence principle of general relativity* states that objects with the same inertial mass behave identically under the influence of gravity. While most physicists expect this to apply to antimatter, it has never been satisfyingly verified in a direct measurement [1]. Newton's famous apple is known to fall to the ground, but an anti-apple could potentially fly up – we simply do not know [2]. Therefore, the MAGE experiment at PSI seeks to measure the acceleration of antimatter in Earth's gravitational field. For this purpose, muonium atoms ($\bar{\mu} + e$) are used, which makes MAGE the first experiment to measure the gravity of a second-generation particle ($\bar{\mu}$) [3].

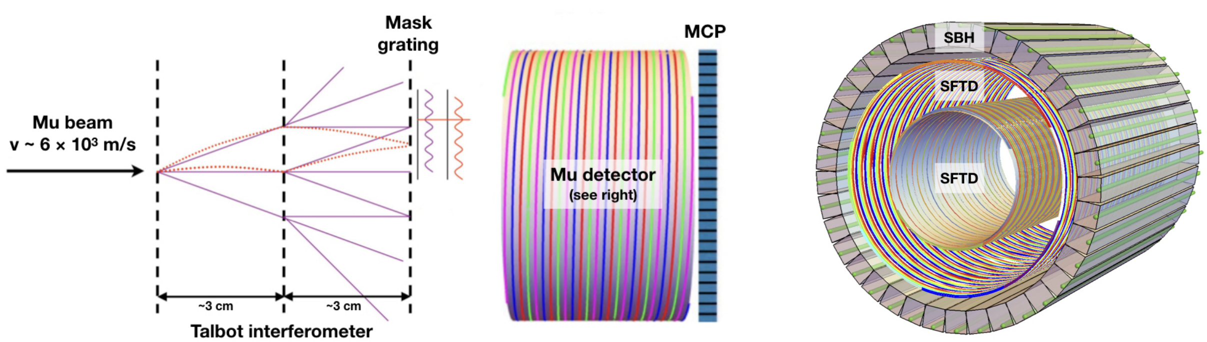


Figure 1: Basic setup of the MAGE experiment (from [1], edited).

As described in [1], a Mach-Zehnder type interferometer is used to measure the deflection of muonium atoms in Earth's gravitational field. A muonium detector measures the beam intensity after the interferometer by counting the number of decays (1) per time.

$$\underbrace{\bar{\mu} + e}_{\text{Mu}} \longrightarrow \bar{e} + \nu_e + \bar{\nu}_\mu + e \tag{1}$$

The generated positrons are measured in the two helix-shaped scintillating-fiber tracking detectors (SFTD) and the surrounding scintillating-bar hodoscope (SBH). The slow electrons are accelerated in an electric field and measured using a microchannel plate (MCP). Only if the measurement of a positron coincides with the measurement of an electron are they attributed to a muonium decay, thereby suppressing the background noise.

2 Objectives

The goal of the project is to develop a muonium decay reconstruction software that allows for the reconstruction of the positron tracks (RP), the reconstruction of the electron tracks (RE) and the verification of coincidences (VC).

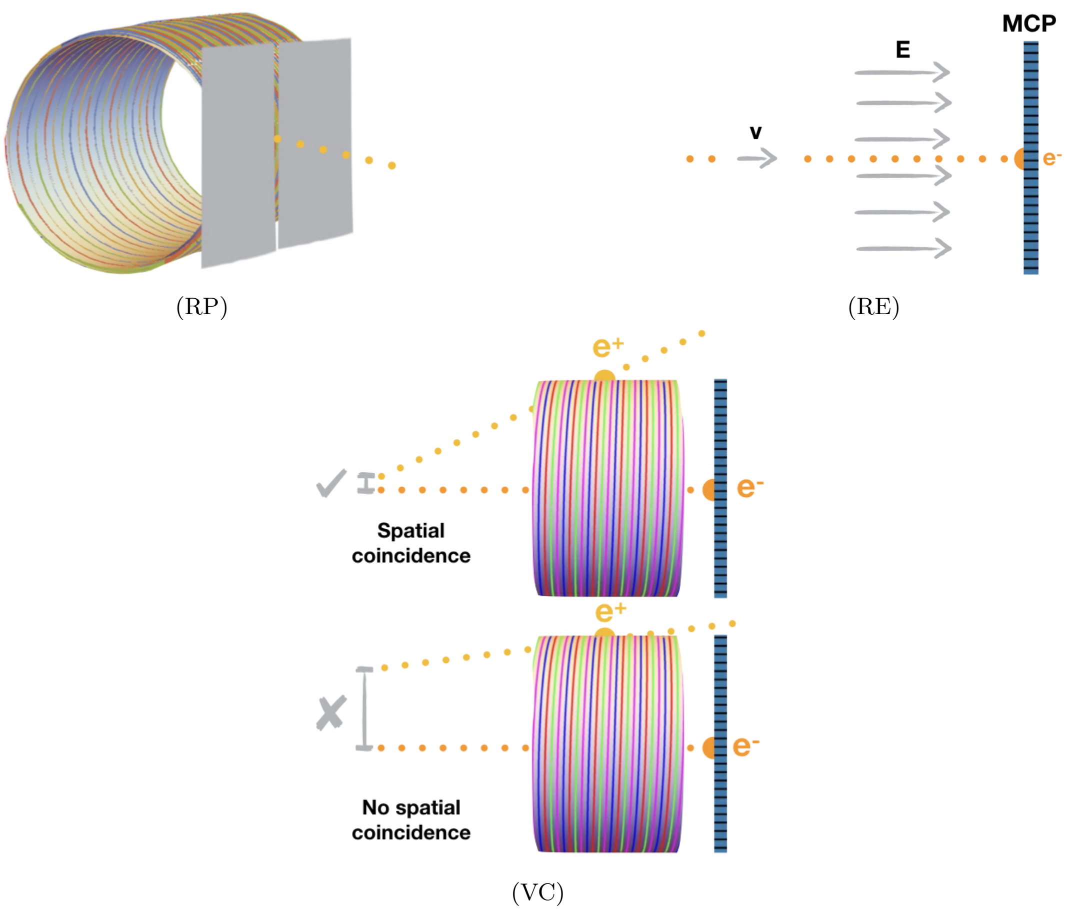
3 Methods

(RP) Method proposed in [1]: Both SFTDs have photo-detectors attached at both ends of the helix. The turns of the helices penetrated by the positron can be determined via the differences in amplitude and time between the measurements at both ends. By including the SBH mesurements, the positron track can be reconstructed.

This method could be improved by employing machine learning (ML) algorithms. The necessary training data can be obtained experimentally by shooting a beam of charged particles perpendicularly at the SFTDs having all but one helix turn shielded ($\sim$10 cm lead should suffice for the shielding [4, 5]).

(RE) Method proposed in [3]: The electron tracks can be reconstructed knowing the applied electric field and the spot on the MCP where they hit.

(VC) The coincidence technique implemented electronically could be verified by checking whether the electron and positron tracks intersect. The spatial coincidence window could be determined via ML tools. The training could be carried out by incentivizing coincidence detections in data taken *with* electric field applied (coincidences mainly true-positives), while penalizing coincidence detections in data taken *without* electric field (false-positives).



(RP) (RE) (VC)

Figure 2: Methods (parts from [1]).

4 Prior Work

The use of SFTDs and coincidence techniques is well-established in high energy physics [6, 7]. The implementation of ML algorithms for track reconstruction has been pursued [8, 9, 10], this project further explores its possibilities.

5 Timetable

The tasks for the respective months (1-6) are:

1. Prepare detector measurement data for analysis.
2. Implement positron track reconstruction as proposed in [1], generate experimental data for ML.
3. Code and train ML algorithm to optimize positron track reconstruction.
4. Finish and test positron track reconstruction, implement electron track reconstruction.
5. Implement coincidence verification, optimize coincidence window using ML, test coincidence verification.
6. Write the thesis.

References

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