Momentum spectrum of Sr-90 beta decay with SiTrInEO student tracker

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Measuring the momentum of a charged particle in a magnetic field is crucial for accurately reconstructing its trajectory, making it an essential technique for tracking in experimental physics. SiTrInEO is a tabletop tracker designed to understand this basic tracking technique, using TAF framework for data analysis. In our study, we detail our approach to reconstruct the trajectory of β^- particles from a Sr-90 source, while taking into account and quantifying the uncertainties. We also highlight the enhancements we contributed to the project, building upon the work of previous students.

INTRODUCTION

The goal of this project is to successfully reconstruct the momentum distribution of particles emitted from a Sr-90 radioactive source, as well as their trajectory through a magnetic field. To do so, we use an experimental setup composed of a Sr-90 source which decays in Y-90 by emitting β^- particles, and the SiTrInEO tracker combined with a magnetic field of 0.3 T (further explained in the next section). The project is structured into three phases: the configuration of the setup, detailed in the alignment section; data and uncertainties analysis, done using the Telescope Analysis Framework (TAF) developed in ROOT by Pr. Jerome Baudot [1] and our code [2]; and finally, further development of TAF.

THE SITRINEO SETUP

SiTrInEO (Silicon Tracker with International Education Objective) is a table-top tracker meant to reconstruct trajectories of charged particles and measure their momentum. It is composed of four parallel sensing planes, grouped 2 by 2 and separated by a magnetic field of a Halbach magnet [3]. This way, we can obtain two segments and reconstruct the trajectory knowing the charge of the particle, the value of the magnetic field and the angle of emission from the Sr-90 source. For this experiment, the source is aligned with the detector, the grouped planes are spaced 5 mm apart and the magnetic field is active on a span of 10 mm. An event is detected once a same particle is detected in the four planes.

The four parallel planes are composed of MIMOSA 28 sensors which are CMOS silicon sensors with an electronic layer composed of pixels. These active pixels of 20.7 µm in width are disposed in a pixel array of 928 rows and 960 columns, offering a sensitive area of 3.8 cm^2. Once a particle crosses the sensor, it ionizes the particles present in the silicon layer, liberating electrons that migrate towards the electronic layer, creating a current that is amplified and converted into bits. A self-bias diode ensures 100% efficiency, absorbing any dark current without any dead time. This enables a fake rate of 10^{-4} and a spatial resolution lower than 4 μm.

Each sensor is connected to a Field-Programmable Gate Array (FPGA) board that has a Linux environment, connected to our PC and controlled through the terminal for data acquisition. Once the data is acquired, it is analyzed using the TAF framework. We then decided to develop a graphical user interface to make it easier for the user to initialize the tracker, acquire and transfer data from the the FPGA to the PC without any terminal commands.

THE ALIGNMENT PROCEDURE

Before taking any data, because the sensors are physically parallel, but not perfectly aligned, we must record their position in the configuration file. This way, TAF properly understands the position of each recorded hit with respect to the different planes, and correctly assigns a probable event and reconstructs trajectories. To do so, we remove the magnetic field and use the smallest collimator of 1 mm in front of our source, and bring it as close as we can to the first plane. Next, we collect data of the cumulated 2D hits thanks to TAF and determine the positions of the centers of the impact spots on each plane. The distribution exhibits a Gaussian tendency, as more particles are emitted at a 0-degree angle before spreading uniformly in a conical pattern. We then measure the displacement of each center relative to the first plane, record it in our configuration file and proceed confidently with data collection. The first two planes are the best aligned since the impact spot is dense, making a clear Gaussian, compared to the last two, since the particles are deviated due to Coulomb scattering and may lose energy in the sensors.

RESULTS

During our work with SiTrInEO's sensors, we encountered a problem. The collected data was sufficient for the alignment, however, additional acquisition was necessary to obtain the momentum spectrum. Therefore, following the advice of Professor Baudot, we took previously collected data, analyzed the data and results obtained, and made a simulation to quantify the impact of the uncertainties on particle trajectories.

Trajectory comparison

We first simulated the trajectory of a β^- particle through a uniform magnetic field (B-field), as well as a more complex one, in order to quantify the error on the uniform field hypothesis. This complex field is composed of three regions: the main region corresponds to the peak value of the magnetic field, and the external region corresponds to the value measured right outside the magnet. The resulting trajectory was less deviated in the complex model. Then, we plotted the trajectory for multiple values of B and derived an error on the position if the B field was measured with an error of 0.05 T, seen in Table I. If B is superior to 0.3 T, the particle does not go through the last plane.

Afterwards, we added the multiple scattering effect through each plane as seen in Fig.1, using Highland's formula [4]. By running this simulation 100 times, we found that the mean absolute error was of 2681.11 μm, for a B field of 0.2 T. For this same field, the maximum error on the field is of 1560.05 μm, which is less than the uncertainty of the scattering.

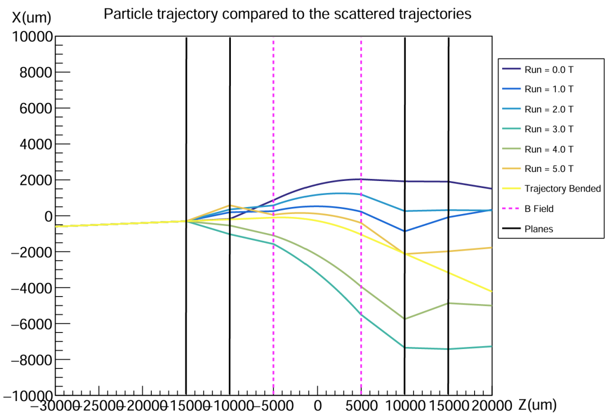

Figure 1. Comparison of the trajectory with scattered electrons.

Table I. Error on impact position when choosing the wrong B-Field

B	X (μm)	+ error (μm)	- error (μm)
0.2	-4693.74	1560.05	1353.98
0.25	-6253.79	1929.01	1560.05
0.3	-8182.8	-	1929.01

Global uncertainty

Using last year's data, we were able to plot an experimental momentum spectrum. This spectrum takes into account the uncertainties from the multiple scattering and the magnetic field. In order to mitigate the effect of these uncertainties, a cutoff around 0.6 MeV has been added. Indeed, particles with low energy are significantly impacted by multiple scattering, making it difficult for them to reach all the sensors.

The particles emitted by the source have an initial energy distribution which can be represented by a Fermi distribution. We used a Monte Carlo simulation to plot a theoretical spectrum, which is the result of the convolution between the Fermi distribution and the global uncertainty distribution. The simplest approach was to use a Cauchy distribution for the uncertainties, as it is the most representative of the global uncertainty dominated by multiple scattering, with large angles of deviation. We then performed a χ^2 test to evaluate the consistency between the two distributions. However, as the resulting χ^2 was too high, we are exploring a new approach: to implement a deconvolution method to deconvolve the Fermi distribution and the experimental momentum spectrum to obtain the real uncertainty distribution function.

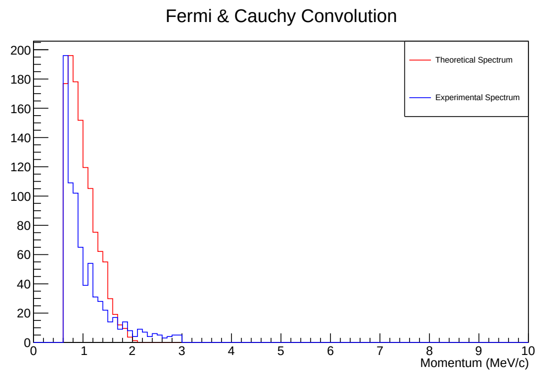

Figure 2. Experimental histogram (blue) and Monte Carlo histogram (red) with normalized amplitude.

CONCLUSION

We have been able to get data on the particle momentum distribution, using the SiTrInEO setup. While we were not able this year to draw a precise distribution of the momentum due to the setup breaking, we brought a meaningful input with the uncertainties analysis as well as a potentially useful graphical user interface for future acquisitions. Indeed, we were able to approximate the main uncertainty to a Cauchy distribution and confirm that the major source of uncertainty on position was multiple scattering.

[1] J. Baudot, *TAF: A Tracking Algorithm Framework*, available at https://github.com/jeromebaudot/taf.

[2] D. Senina, R. Techi *M2 Project - Sitrineo*, available at https://github.com/Dariasnn/M2_Project-SITRINEO.

[3] Wikipedia, "Halbach array," *Wikipedia, The Free Encyclopedia*, available at https://en.wikipedia.org/wiki/Halbach_array (2024).

[4] H. Paganetti, *Techniques of Proton Radiotherapy - Multiple Scattering*, available at https://gray.mgh.harvard.edu/media/com_dpattachments/attachments/com_content.article/Techniques-of-Proton-Radiotherapy-06-Multiple-Scattering.pdf (2023).