Python Simulaton of $\pi E5$ Beam Line at Paul Scherrer Institute

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Abstract

In order for particle accelerators to properly store and record data from particles, the incoming beam of particles must be centered and, at times, be manipulated to redirect its direction of travel. This action of influencing particle beams can be simulated using computer programming. I plan on using the programming language Python to simulate these particle beams and the effects of various "magnetic lenses" on the beam's path along with filtering out unwanted particles from the beam. This program will aid additional research by increasing the confidence in experiments using pion beams before their testing has begun.

1 Introduction

In recent years, there have been increasing results from experiments that hint at lepton flavor universality violation (LFUV). A promising measurement that could provide more information on LFUV is the ratio of pion decay to positrons to pion decay to muons ($R_{e/\mu}$). However, the current experimental values of $R_{e/\mu}$ are not precise enough to arrive at any new conclusions of LFUV. This is one of the primary motivations for the upcoming PIONEER experiment taking place at the Paul Scherrer Institute (PSI). The experiment is expected to reach a result that is an order of magnitude more precise. To measure $R_{e/\mu}$, PIONEER requires a continuous beam of pions. The pion beam line that has been chosen to be used for PIONEER is the $\pi E5$ Beam Line located at PSI. This beam is theorized to be more than sufficient to produce results that will have a level of uncertainty that meets the goals of the experiment. [1]

I plan on using Python to simulate these pion beams using the specifications of the $\pi E5$ Beam Line. Once an accurate simulation of the beam is established, I will further simulate focusing and steering of the beam. Additionally, I will be studying methods of filtering particles using the Lorentz force to remove non-pions from the beam.

2 Problem and Objectives

One of the most apparent and important obstacles faced when using a pion beam is ensuring that the beam itself is focused. An unfocused beam can result in pions improperly colliding with the target. A beam that has a sharp focus is necessary for the experiment in order to negate background and systematic uncertanties. To overcome this, I will be simulating the effects of magnetic quadrupole doublets and magnetic quadrupole triplets along with single magnetic dipoles and magnetic dipole doublets to focus the beam. The magnetic fields will not only focus the beam, but also allow for me to manipulate the travel path of the pions so that we can redirect the particles as needed.

Another problem that will need to be addressed is filtering the pion beam. It is expected that the initial beam will contain particles other than pions. Since the goal of PIONEER is to solely study pion decay, the beam must be "filtered" from other particles before colliding with the target. Once again, I will be studying the implementation of electric and magnetic fields as a means of removing unwanted particles from the beam.

3 Significance of the Research

The overall of this research project is to provide an accurate simulation of the behavior of a pion beam in a setup similar to that of the PIONEER experiment. I am aiming to create this simulation in hopes that it provides more insight into how the pion beam can be optimized to the requirements of the PIONEER experiment. This will provide a higher level of confidence in experiments using pion beams before they begin initial testing.

References

[1] PIONEER Collaboration, W. Altmannshofer, H. Binney, E. Blucher, D. Bryman, L. Caminada, S. Chen, V. Cirigliano, S. Corrodi, A. Crivellin, S. Cuen-Rochin, A. Di Canto, L. Doria, A. Gaponenko, A. Garcia, L. Gibbons, C. Glaser, M. Escobar Godoy, D. Göldi, S. Gori, T. Gorringe, D. Hertzog, Z. Hodge, M. Hoferichter, S. Ito, T. Iwamoto, P. Kammel, B. Kiburg, K. Labe, J. LaBounty, U. Langenegger, C. Malbrunot, S. M. Mazza, S. Mihara, R. Mischke, T. Mori, J. Mott, T. Numao, W. Ootani, J. Ott, K. Pachal, C. Polly, D. Počanić, X. Qian, D. Ries, R. Roehnelt, B. Schumm, P. Schwendimann, A. Seiden, A. Sher, R. Shrock, A. Soter, T. Sullivan, M. Tarka, V. Tischenko, A. Tricoli, B. Velghe, V. Wong, E. Worcester, M. Worcester, and C. Zhang. Testing lepton flavor universality and ckm unitarity with rare pion decays in the pioneer experiment, 2022.