Python Simulation of the πE5 Beam Line at Paul Scherrer Institute

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1 Introduction

The Standard Model considers weak forces between particles to be universally equal. That is, that the weak force between any two particles is exactly the same as the weak force between any other two particles. [1]

However, there has not been sufficient testing of this hypothesis to demonstrate whether it is precisely correct, or whether the weak forces are in fact slightly different, depending on the particles involved.

Charged pions decay in three possible ways:

1. into muons:
$$\Gamma(\pi^+ \to \mu^+\nu(\gamma))$$
2. into positrons:
$$\Gamma(\pi^+ \to e^+\nu(\gamma))$$
3. into neutral pions (via pion beta decay):
$$\pi^+ \to \pi^0 e^+\nu(\gamma))$$

The vast majority of charged pions decay into muons, with only a tiny fraction decaying into positrons (10^{-4}), and even fewer decaying into neutral pions (10^{-8}). [1]

The ratio of positrons to muons produced in pion decay is well-known, making it an excellent candidate as a test of weak-force-universality (particularly Lepton Flavor Universality (LFU)). [2]

$$R_{e/\mu} = \frac{\Gamma(\pi^+ \to e^+\nu(\gamma))}{\Gamma(\pi^+ \to \mu^+\nu(\gamma))}$$

Pion decay ratios including the neutral pions, which are quark-based particles, would provide a weak-force-universality test between leptons and quarks as well.

The Standard Model (SM) calculation for the positron to muon ratio is one of the most precise, having an uncertainty of 1.2×10^{-4}. However, the average experimental uncertainty to date is larger than SM uncertainty by a factor of 15. [2]

To test the weak-force-universality hypothesis, we need an experiment with increased precision, so as to decrease the uncertainty to a comparable level with that of the SM calculation.

A new experiment, called PIONEER, has been proposed by the Paul Scherrer Institute (PSI), which will utilize the highest intensity low energy pion beams, and will be capable of precise measurements within 0.01% (10^{-4}) for muons and electrons, and 0.1% (10^{-3}) for neutral pions. This precision will effectively eliminate the former factor of 15 from the experimental uncertainty for muons and electrons, as required to test the SM weak-force-universality hypothesis. [2]

2 Goals and Procedure

My goals for this research project are to experiment with Pion beam simulations in Python, and to investigate and optimize the affects of beam focusing devices used in various versions of the experiment.

In particular, I will be working on simulating PSI's πE5 beamline, shown in Figure 1.

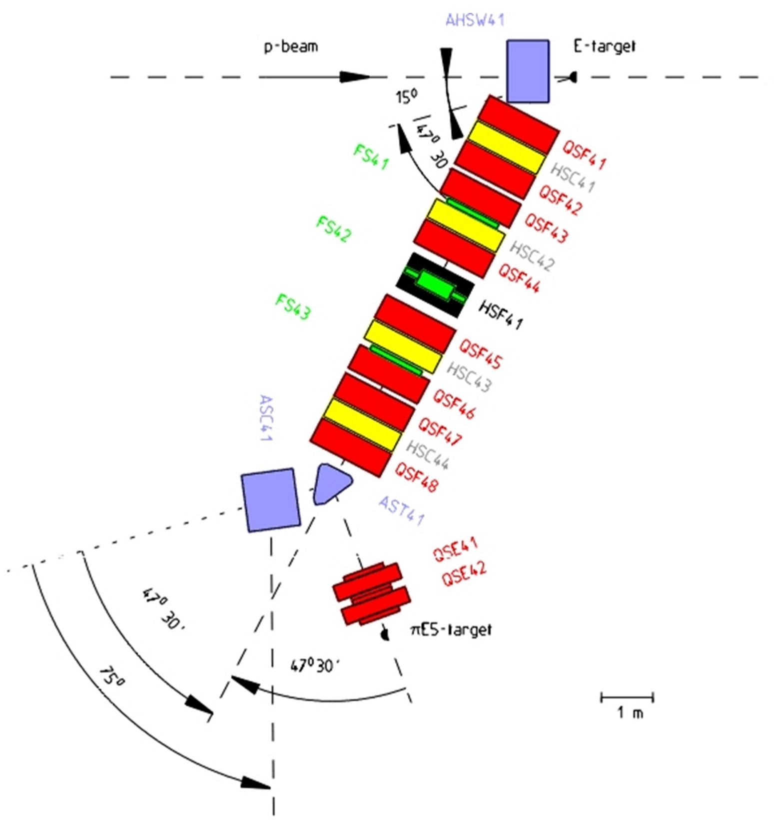

Figure 1: πE5 Beam Line [4]

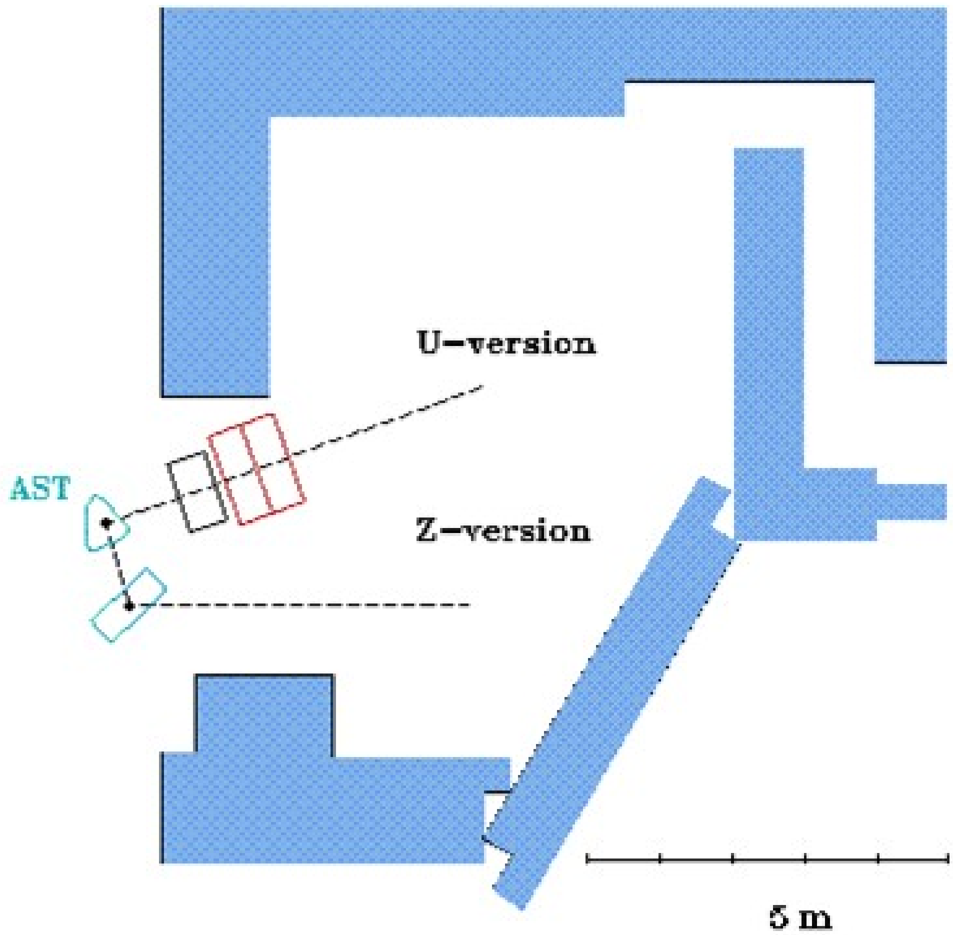

Figure 2: πE5 Experiment Layout [4]

I will begin by familiarizing myself with the concepts and tools by working through a series of exercises on Transverse Linear Beam Dynamics in Python. [3]

Investigations to pursue following this introductory practice:

1. Study and optimize focusing, aberrations, and steering affects of magnetic quadrupole, and magnetic quadrupole doublet
2. Study and optimize focusing, aberrations, and steering affects of magnetic dipole, and dipole doublet
3. Study particle selection using crossed electric and magnetic fields
4. Study simulations of single particle trajectories
5. Study simulations of many-particle distributions
6. Study simulations of simple beam lines
7. Study simulations of periodic structures
8. Study simulations of closed machines

References

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