Monte Carlo Simulation Study for Verification of Target and Beamline on μSR Facility in RAON

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1. Introduction

Muon Spin Rotation, Relaxation, and Resonance (μSR) facility has been designed as the material science research facilities in Rare isotope Accelerator complex for ON-line experiments (RAON) Heavy Ion Accelerator, which is under construction at the Rare Isotope Science Project (RISP). The facility uses surface muons which is 100% polarized [1]. Through nuclear reaction between 600 MeV proton beam and low-Z target (graphite or Be), pion and other particles are produced, and the pion decays into muon and neutrino, where the muon become 100% polarized. Momentum and spin direction of the muon are in opposite to each other. Muon originating from pion stopped on the target surface is called surface muon. In μSR facility, generated surface muons, which have momentum bite of 28.5 MeV/c ±3%, are collected and transmitted to a sample via muon beamline. In order to achieve enough production of surface muon from target and high transmission rate of surface muon via beamline were designed. In addition, contamination of other particles is removed during transmission. Once the components have been installed, verification experiments on these components will be perform. In this study, proper measurement location and particle identification (PID) method for the verification were determined using Monte Carlo simulations, and the results were discussed.

2. Methods and Results

The measurement locations should be placed where the surface muon beam emittance is smallest of installing each component, and these locations were defined as a focal plane. The muon beamline currently planned is shown Fig. 1. Monte Carlo simulations proceeded in three steps: 1. Determination of locations of the focal planes, 2. Collection of particle information at each focal plane, 3. Determination of PID method at each focal plane. The simulations were done using G4beamline [2] based on GEANT4 toolkit [3].

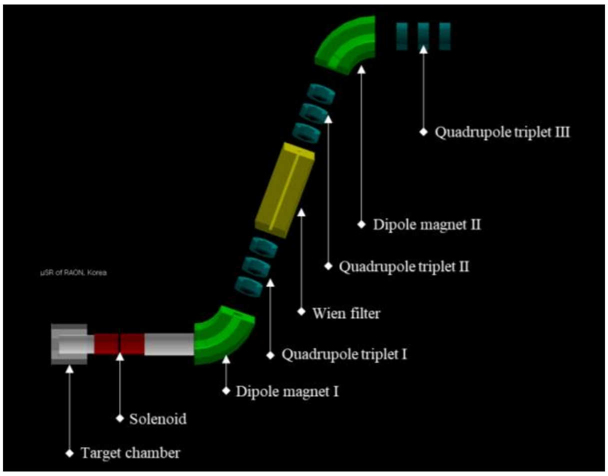

Fig. 1. 2D plot using G4beamline of muon beamline components at μSR facility.

2.1 Determination of locations of the focal planes

The planned muon beamline has 3 focal planes. The locations of the focal planes are as follows: downstream of solenoid, downstream of first quadrupole triplet, and center of the sample. The smallest beam emittance at each focal plane is derived from change in distribution of the surface muon. In order to detect, virtual detectors that made perpendicular from the beam direction were placed at the intervals. Positions of virtual detectors are shown Table I below.

Table I: Virtual detector information

Virtual detector	Distance from the end of components	
	Components position	Distance (mm)
Virtual detector A	Solenoid	1100
Virtual detector B		1550
Virtual detector C		2000
Virtual detector D	Quadrupole triplet I	390
Virtual detector E		1290
Virtual detector F		2190
Virtual detector G	Quadrupole triplet III	700
Virtual detector H		1000
Virtual detector I		1300

The focal planes were determined from virtual detector B, E, and H. These focal planes are defined 1st, 2nd, and 3rd Focal plane. In the positions around each focal plane, focal planes have the smallest standard deviation of a beam having a gaussian distribution. The surface muon position distributions of X and Y axis are shown Fig. 2 below.

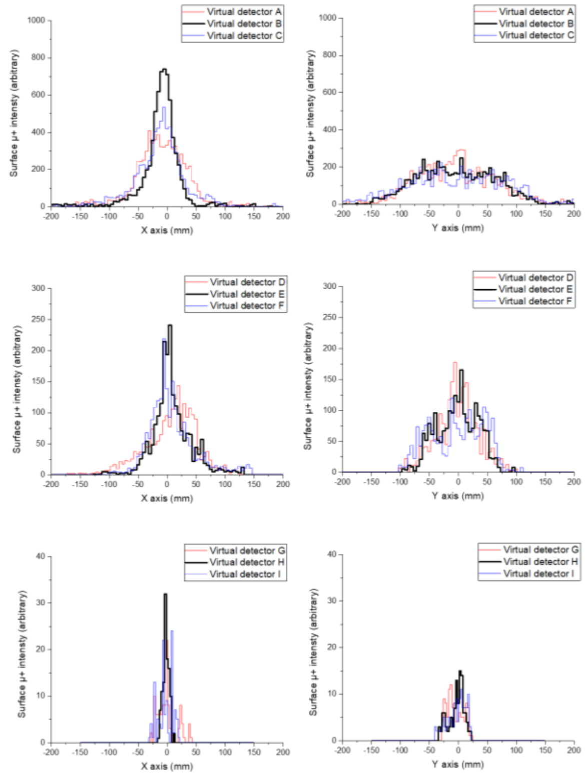

Fig. 2. Surface muon position distribution of X and Y axis at virtual detectors.

At three focal planes, each intensity and spot size of surface muon beam should be measured for performance verification of target and beamline. In order to measure only surface muon, PID is required. Therefore, collection of particle information for PID, and PID simulation was performed on each determined focal plane.

2.2 Collection of particle information at each focal plane

The various particles were measured at focal planes. These particles were produced through the nuclear reaction of incident protons and target nucleus. There dominantly are μ^+, π^+, and $e^{\pm}$ through spallation reaction, and scattered p^+. Intensity of particle beams depends on primary beam intensity. It is assumed that the test beam of proton for verification has a current of 10 nA. Each particle beam intensity at each focal plane on the test beam is shown in the Table II.

Table II: Beam intensity at each focal plane on test beam.

Particle	Beam intensity at focal planes (particles/s)		
	1st Focal plane	2nd Focal plane	3rd Focal plane
μ^+	1.78×10^6	2.10×10^4	8.00×10^2
surface μ^+	1.47×10^5	1.29×10^4	6.82×10^2
e^+	3.23×10^5	2.11×10^4	N/D
p^+	9.43×10^6	7.88×10^3	N/D
π^+	9.36×10^4	N/D	N/D
e^-	8.62×10^7	N/D	N/D

Since there are more than single type of particle in Focal planes, method of PID should be considered. The purity of muon at center of 3rd Focal plane (sample position) can indicate one of the beamline performances.

2.3 Determination of PID method at each focal plane

In the 1st Focal plane, these charged particles have wide momentum spectrum. Therefore, in order to measure only surface μ^+, PID is performed by using both momentum and time of flight (TOF) method. Momentum information is stored as particles pass through a virtual detector. TOF was measured using the time difference detected by a virtual detector placed to 100 mm downstream from 1st Focal plane. Simulation result of this method is shown Fig. 3.

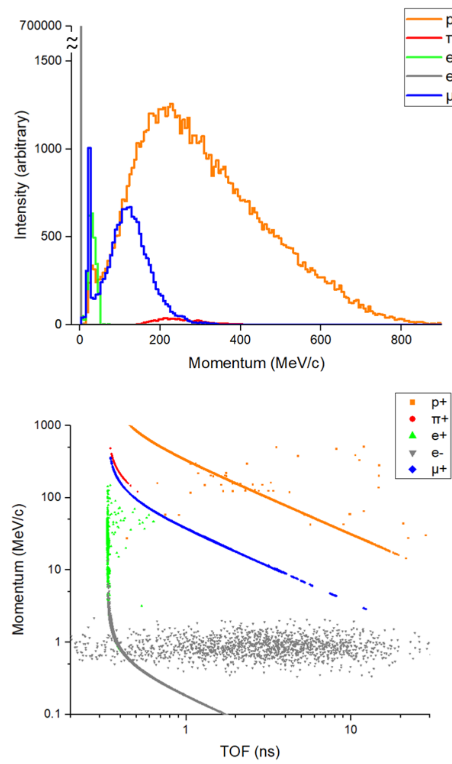

Fig. 3. Relative intensity of particles depending on their momentum (top), and PID result using both momentum and TOF at 1st Focal (bottom).

In the 2nd Focal plane, charged particles have almost the same momentum. Since their rest masses are different, it is possible to PID using only TOF method. The momentum and TOF were measured the same as in 1st Focal plane. This method is shown Fig. 4.

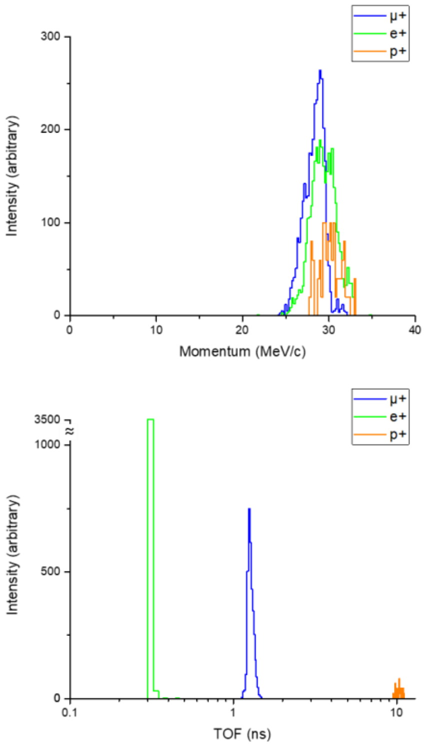

Fig. 4. Relative intensity of particles depending on their momentum (top), and PID using only TOF at 2nd Focal (bottom).

3. Conclusions

Verification of target and beamline for μSR facility is necessary procedures at installation. Target and beamline verification will be performed by measuring the amount of surface muon at 3 focal planes. The proper measurement locations and PID method for the verification were determined using Monte Carlo simulations, and the result of validity was verified. The beam profile monitor (BPM) is required to perform measurements, and the basic data for BPM design was derived.

REFERENCES

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