Track Reconstruction System in g-2/EDM Experiment at J-PARC

[1] WOODO LEE, [1] EUNIL WON, [2] SEONHO CHOI, [3] Takashi Yamanaka,
[5] Yutaro Sato, [4] Taikan Suehara, [6] Soohyung Lee, [7] Yuki Sue, [8] Wilfrid da Silva,
[5] Tsutomu Mibe, [9] Tamaki Yosioka

[1] Department of Physics, Korea University, [2] Department of Physics, Seoul National University,
[3] Research Center for Advanced Particle Physics, Kyushu University, [4] Department of Physics, Kyushu University,
[5] Institute of Particle and Nuclear Studies(IPNS) , High Energy Accelerator Research Organization(KEK),
[6] Center of Axion and Precision Physics Research, Institute of Basic Science, , [7] Department of Physics, Nagoya University, [8] LPNHE, IN2P3,
[9] Research Center for Particle Physics, Kyushu University

Abstract

The J-PARC muon g-2/EDM experiment is under development with a new approach. Compared to the previous experiment, this experiment will use lower emittance muon beam with a smaller storage ring. The 300 MeV/c muon will be injected into the 3 T MRI-type solenoid storage magnet. Tracking detector will measure the momentum of decay positrons with time in the storage magnet. We discuss our track reconstruction system for positron track .

keyword: g-2, EDM, J-PARC, muon, fitting, Kalman filter, track fitting, fitter, GENFIT, positron tracking, track reconstruction, Track finder .

Introduction

g-2/EDM experiment will be launched at J-PARC[2] and aims at measuring muon g-2 value under 0.1 ppm sensitivity. The detector is thin strip made by silicon that can measure the time and position. The important thing of this experiment estimates the muon decay time very precisely from the decay positron by detector. The detector will be a place like a windmill with 40 vanes. Every vane has 512 silicon strip sensors. We can get the time, energy information of the decay positron from these vanes and reconstruct the track for extracting muon g-2 value.

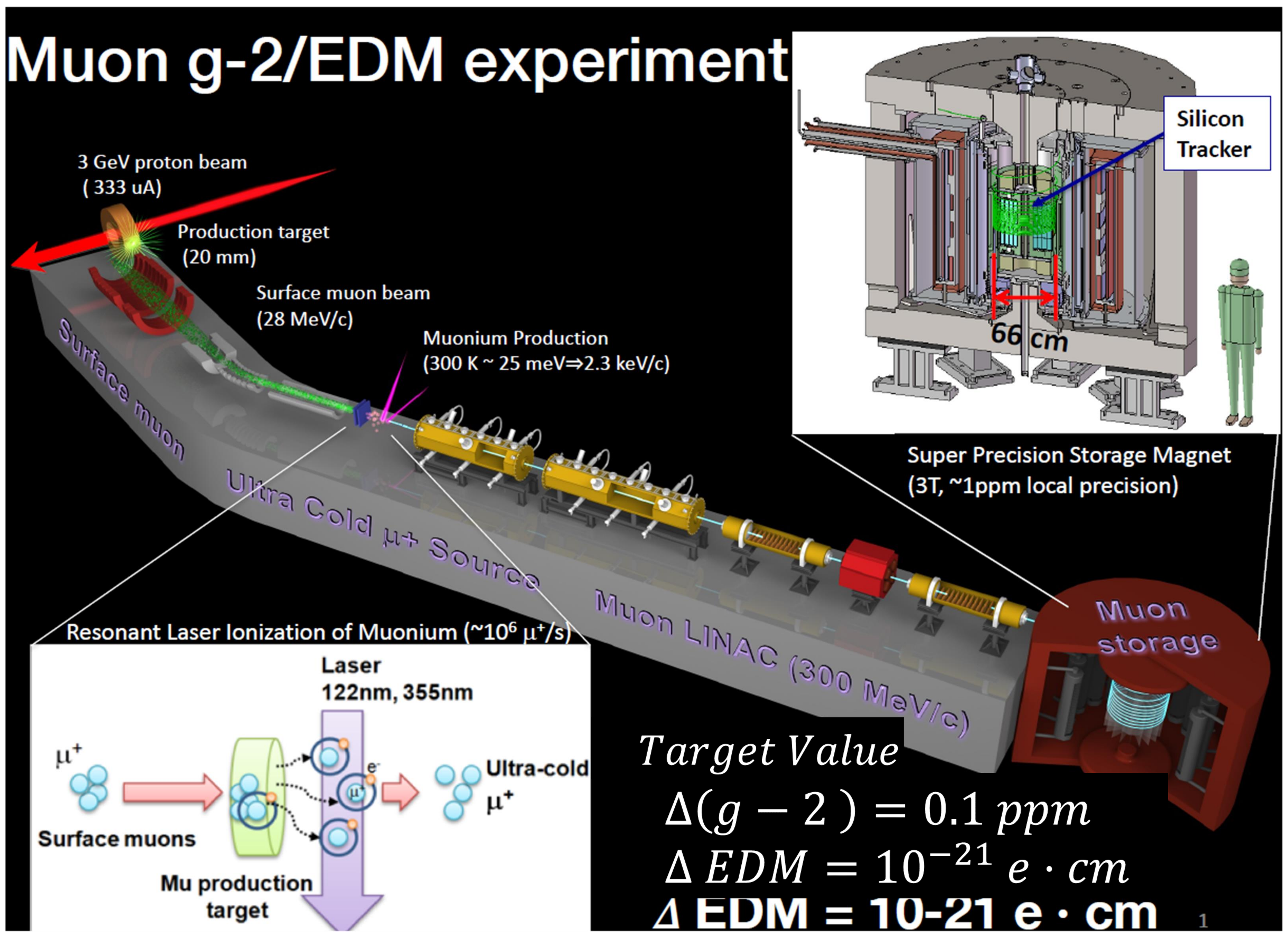


Fig. 1 Overview of g-2/EDM experiment.
The proton beam generates the pion which generates surface muon beam. This beam hit the silica aerogel target that makes the muonium. Certain laser can detach the electron from the muonium and become the polarized muon. This muon accelerate to Muon storage which includes the detector. This muon decays to positron and neutrinos in the Muon storage. We can extract the g-2 value from distribution of positron numbers.

Strategy

Current Software package can be divided into 3 sections. First Section is generating data with geant4 simulation. Second is track reconstruction part. We can find and fit the positron tracks. We can calculate the efficiency of whole track package by comparing MC truth momenta data and reconstructed momenta of positron. Also WE can get the muon decay time from this reconstructed track with vertex finder. The third part is about physics analysis. We can get the ω_a by fitting 1D histogram of muon decay time.

Fig. 2 Track Reconstruction Software package diagram.
1st step is generating data with GEANT4 simulation. 2nd step is reconstructing and finding muon decay time. 3rd step is physics analyzing with simulation data based on ROOT.

Purpose

Tracking system is one of the most important parts for measuring g-2/EDM for muon. Track reconstruction efficiency should be higher than 90% especially in the target momentum range(200MeV/c ~ 275 MeV/c).

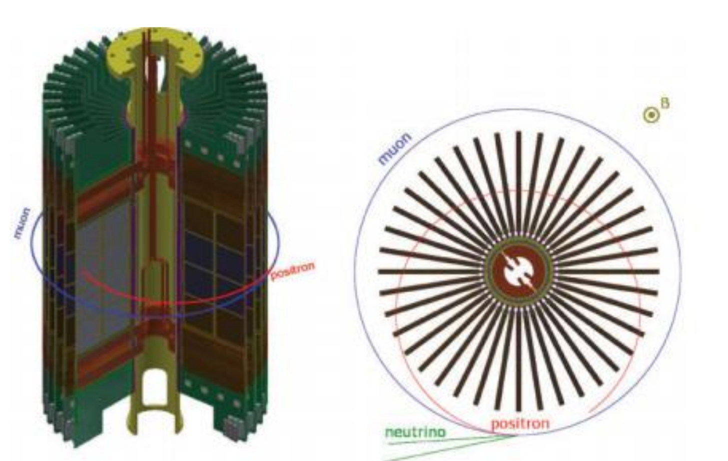
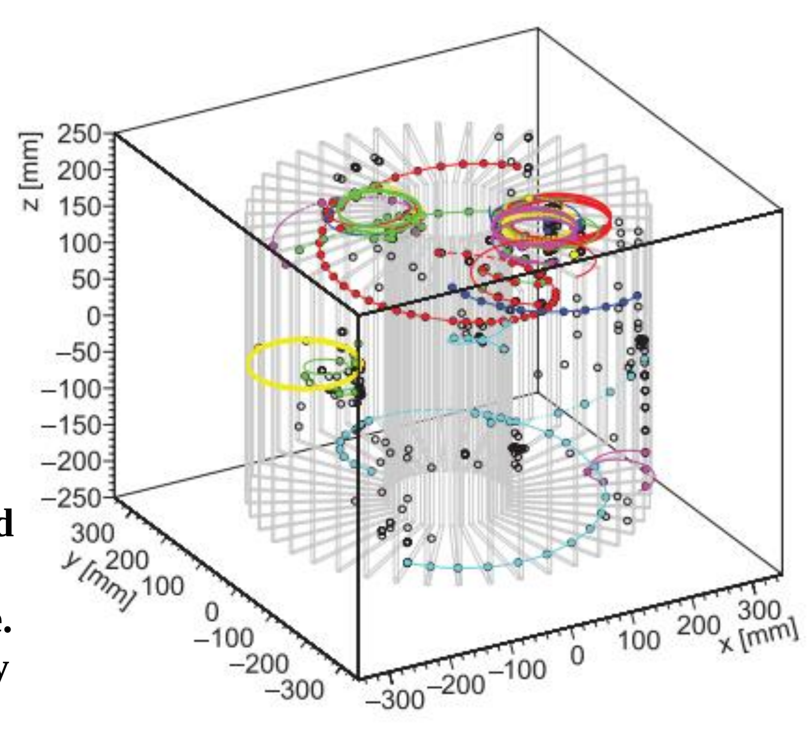


Fig. 3 Detector Geometry
Detector for g-2 /EDM experiment is called vanes. Each vane has single sided silicon with 512 strips that attached in double side. The positron leaves the position and energy deposit information.



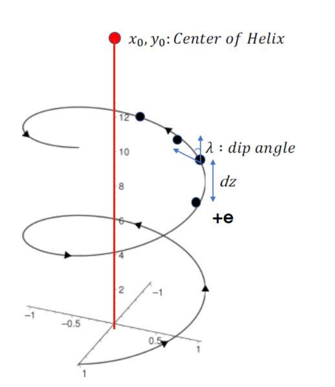


Fig. 4,5 Positron Track
Muon decay to one positron and two neutrinos. Positron moves to Helix orbit in the detector because 3T B-field is applied in the detector.

Specification

Track Finder and Fitter are the main key of our track reconstruction system. We adopted the Hough transformation to find track and Kalman filter to fit the track.

Track Finder

The track finder find the appropriate line in radius and angle domain. Our finder detects a line that has maximum peak in the Hough space. After detecting a line, the finder extrapolated the line and seeded the point on adjacent vanes.

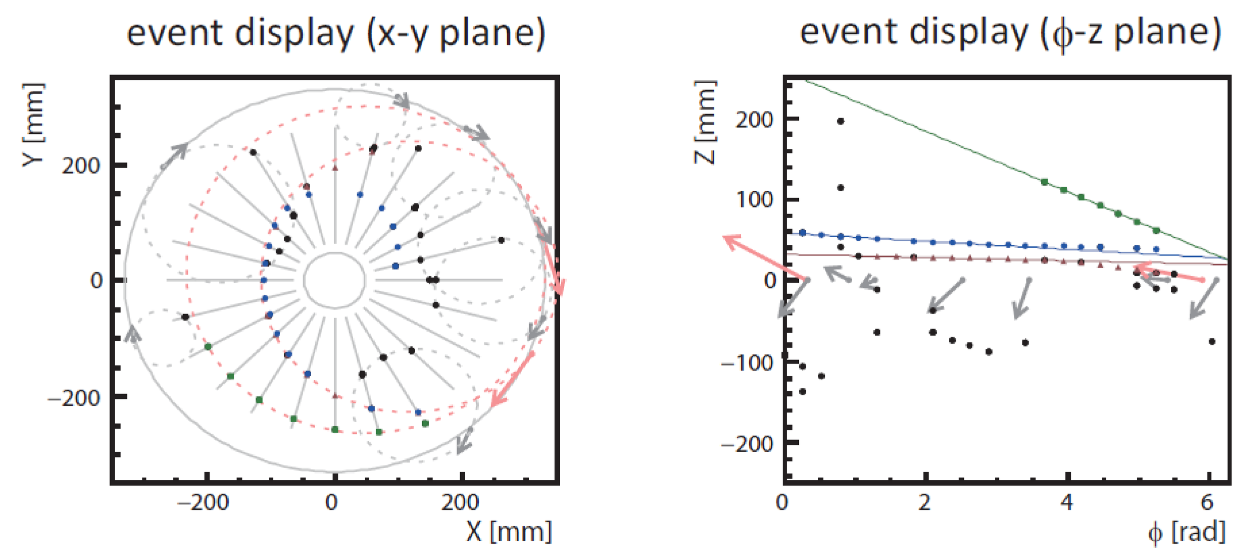
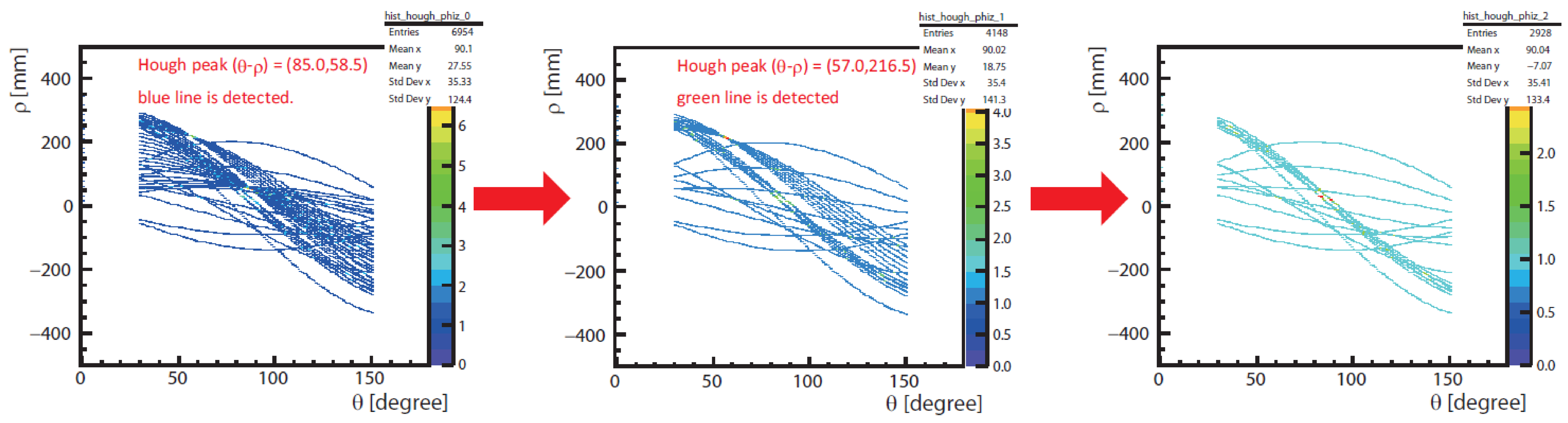


Fig. 5 Example of Track finding from x-y plane to radius($\theta - \rho$) plane. There are 9 tracks in this example. Each Red and grey arrows mean Initial direction and momentum from MC truth in Top two figures. Bottom three pictures show the event in Hough space. We detected blue line in this space from finding peak.



Track fitter

We used the GENFIT2 package for fitting which is a c++ package including "Kalman filter" and "Runge-Kutta extrapolation algorithm". algorithm. Kalman Filter is one of the most powerful tool for tracking predictable object. It is widely used in the Science and Engineering field. The core algorithm of GENFIT2 is Kalman filter that can determine the suitable track trace with limited signals such as silicon strip sensor.

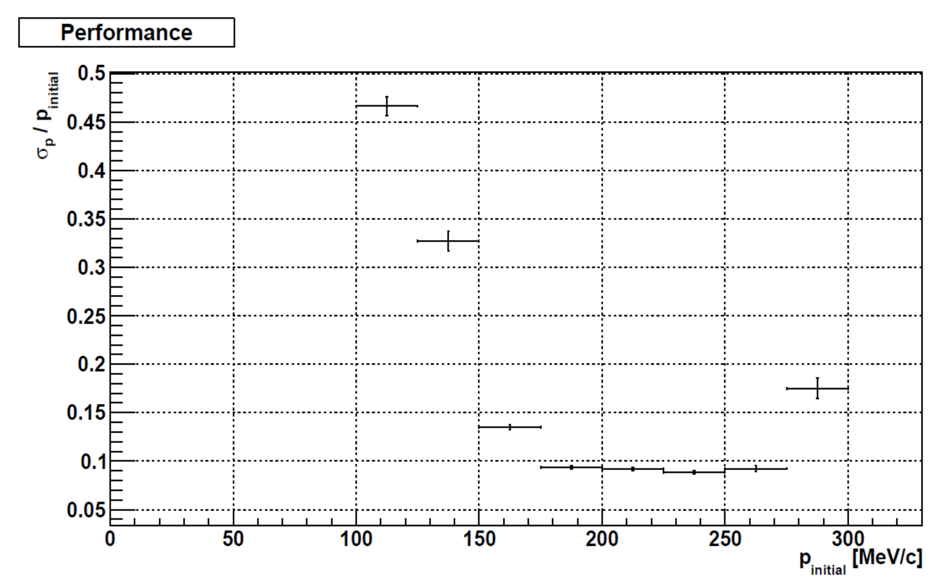


Fig. 6 Estimating Detector Performance
We estimate the Detector performance with fitter this figure is Zooming initial momentum(MC truth momentum) in 100 ~ 300 MeV/c range .
The performance is defined as sigma for fitting momentum over initial momentum. This value is lower in 175 MeV/c ~ 275 MeV/c than the other range. This means the Detector is good at 175 ~ 275 MeV/c for detecting positron. The reason of bad performance of the other range is few hits information due to the Detector geometry. We will figure out this systematic error precisely.

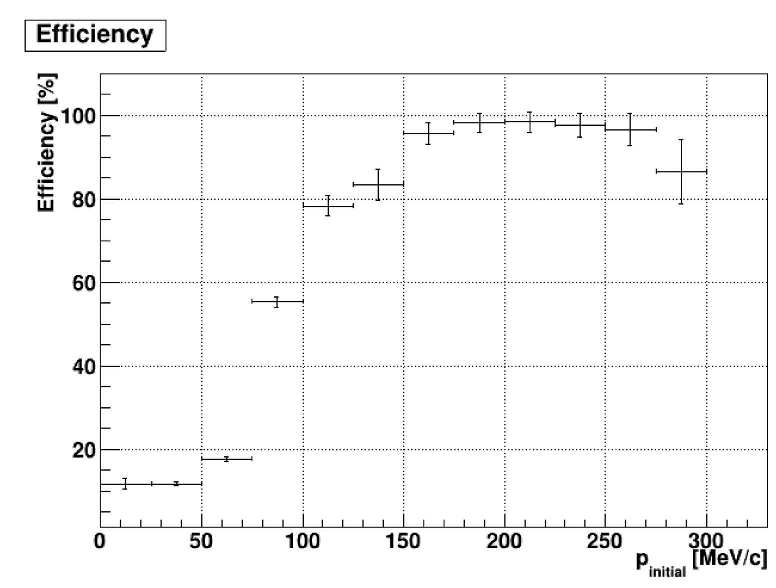


Fig. 7 Fitting Efficiency – 40k tracks
Fitting Efficiency is the best in 200 MeV/c ~ 275 MeV/c range. (efficiency is up to 97%) Due to the few hit information and limitation of the detector, fitting performance is not good at low momentum range. (under 150 MeV/c) . This result is similar as Fig.9. Track finder cannot find the sufficient hits because of Detector geometry. We will use 200 MeV/c ~ 275 MeV/c for real experiment. Even if we are concentrating this range, we will study the low momentum range and try to get the better performance in low momentum range and very high momentum range.

Results

We have made the reconstruction track package successfully – the efficiency of the reconstruction reached nearly 97% in 200MeV/c ~ 275MeV/c momentum range. It is still hard to reconstruct the track in the low momentum range – it's related to detector geometry.

Future plans

Even though the the efficiency is sufficient to analyze the track, there are still exist some missing track that didn't find, which was resulted from limits of the current tracking system. Thus, it will be meaningful to study where exactly the error comes from. We will investigate these systematic errors for more precise experiment. Specifically, the track finder performance is not good when the 2 or more positron is coming at the same time. We called this effect as "Pile up "effect. This bad performance can cause the performance of the whole track reconstruction package . It needs more study to reduce this pile up effect.

References

[1] T. Bilka et al., "Implementation of GENFIT2 as an experiment independent track-fitting framework", arXiv:1902.04405

[2] M. Abe et al., "A new approach for measuring the muon anomalous magneticmoment and electric dipole moemnt", Prog. Theor. Exp. Phys. 2019 (2019) 053C02