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GNN based track finding for J-PARC muon g-2/EDM experiment

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The recent measurement of the anomalous magnetic moment of the muon by Fermilab points to possible new physics and undiscovered particles. However, it also necessitates validation from other experiments. The proposed J-PARC muon g-2/EDM experiment aims to measure the anomalous magnetic moment of the muons with a precision of 0.01 ppm using a technique different from that used by Fermilab. The J-PARC technique uses a low emittance muon beam injected into a storage magnetic field, eliminating the need for electric fields for focussing. The muons decay to positrons, the hits of which are tracked by silicon detectors placed inside a cylindrical geometry. The reconstruction of the positron tracks play a vital role in the experiment. However, simulation studies have indicated that the current Hough transform based approach of track finding is time consuming under pile-up conditions and further that a 40 fold improvement is essential. Therefore, alternate track finding approaches have been proposed and are being tested. In this, we provide an overview and status of our attempt to develop a Graph Neural Network based model for track finding for the J-PARC muon g-2/EDM experiment.

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1. Introduction

The muon g-2 experiment (E989) at Fermilab (FNAL) has made the world's most precise measurement yet of the anomalous magnetic moment of the muon [1]. Fermilab's recent measurement of the muon anomalous magnetic moment has shown a 5σ difference from the prediction of the Standard Model of Particle Physics, prompting the need for validation through other experiments. The J-PARC muon g-2/EDM experiment aims to precisely measure the muon's anomalous magnetic moment, utilizing a unique technique different from Fermilab's approach.

2. Overview of J-PARC muon g-2/EDM experiment

This experiment aims to measure the muon's electric dipole moment (η) and the anomalous magnetic moment ($a_\mu = \frac{g-2}{2}$) with an improved precision using a different approach [2]. The schematic diagram of experimental setup is shown in figure 1.

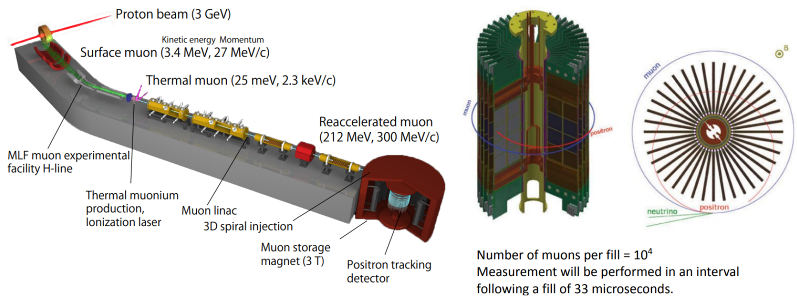

Figure 1: Schematic diagram of experimental setup and the positron detector [2]

The spin precession vector with respect to its momentum in a static magnetic field and electric field is given as,

$$\vec{\omega} = \vec{\omega_a} + \vec{\omega_\eta} = -\frac{e}{m}[a_\mu \vec{B} - (a_\mu - \frac{1}{\gamma^2 - 1})\frac{\vec{\beta} \times \vec{E}}{c} + \frac{\eta}{2}(\vec{\beta} \times \vec{B} + \frac{\vec{E}}{c})] \tag{1}$$

where, $\vec{\omega_a}$ and $\vec{\omega_\eta}$ are the precession vectors due to g-2 and EDM [2]. β and γ are the velocity and Lorentz factor of the muon, respectively. This experiment uses a low emittance beam, so that very weak magnetic focussing is enough to store the muon beam, and no electric field is used for focussing. Therefore, the equation reduces to,

$$\vec{\omega} = -\frac{e}{m}[a_\mu \vec{B} + \frac{\eta}{2}(\vec{\beta} \times \vec{B})]. \tag{2}$$

Thus, the anomalous magnetic moment (a_μ) and the EDM can be directly measured from a measurement of the spin precession frequency and the systematics governed only by the magnetic field and not by any electric field.

3. Challenges faced and the proposed GNN based track finding algorithm

The track finding part is important in this experiment because a_μ is estimated from the time spectrum of maximum energy positron tracks. The current algorithm, based on Hough transform [2] is slow for pileup events (10^4 muon decays per second) becoming a bottleneck in the entire analysis chain [3]. Therefore, an algorithm, which is at least 40 times faster than the existing one and at the same time efficient, is a crucial requirement for the experiment. One of the proposed ideas is Graph Neural Network based algorithm and we have followed the approach presented in [4].

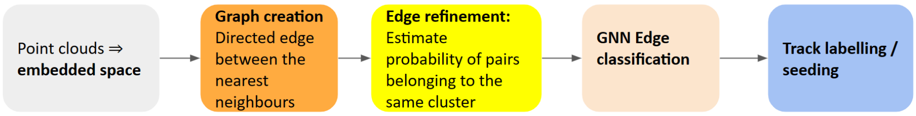

Figure 2: Proposed GNN based track finding algorithm pipeline [4]

The track-finding pipeline is presented in figure 2. The first step is embedded space creation [4] from the data (spatial and time coordinates) of the hit points. In embedded space, points that belong to the same track are closer, while others are pulled away by a hinge embedding loss function. Next, a point is chosen as query point and its nearest neighbours are found using ϵ-ball query [4] (search for all points within a certain distance (ϵ) from the query point) and a graph is created with directed edges between them. At this stage, there may be hit points present in the graph which may not belong to the same track as that of the query point. Therefore, as a next step, probability of an edge between two nodes is calculated using a sigmoid function and then edges with the score of 0.5 or less are removed. These steps are illustrated in figure 3.

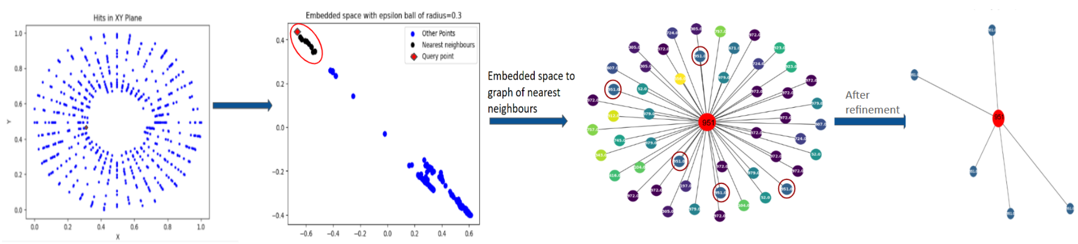

Figure 3: (i) XY hit data (◇ shaped point is the query point chosen) (ii) Embedded space created (query point and neighbour points are inside the circle). (iii) Graph created using query point (center) and neighbor points (with hit points belonging to the same track as that of query point circled) (iv) Refined graph with points that are probably belonging to the same track.

4. Preliminary results

We tested this algorithm using a small dataset with 73 muons piled up in a single event. The tracks reconstructed using the hits found are shown in figure 4. To quantify the performance of our algorithm, we define two quantities, the track purity (t_p) and track reconstruction efficiency (η):

$$t_p = \frac{N_{mh}}{N_{rh}}, \qquad \eta = \frac{N_{gt}}{N_{rt}}. \tag{3}$$

N_{mh} = Number of matching hits; N_{rh} = Number of hits in the original track
N_{gt} = Number of tracks generated; N_{rt} = Number of original tracks

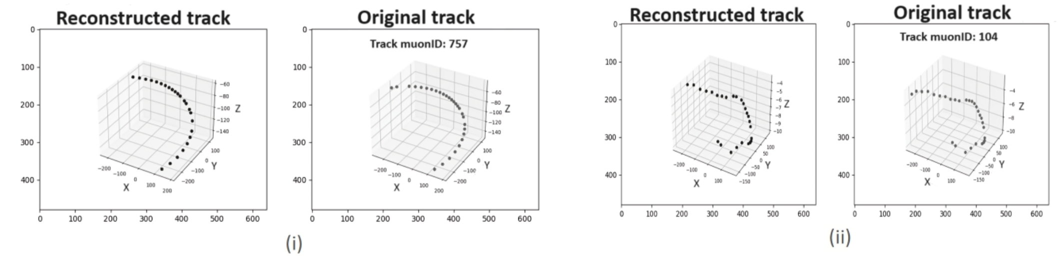

Figure 4: Sample reconstructed events. The track purities are (i) 92% and (ii) 89%.

5. Summary

Development of GNN based algorithm for positron track reconstruction is currently in progress. Preliminary studies under low pileup conditions has given a track finding efficiency of 88% with an average track purity of 82%. As a next step, we plan to test the algorithm using datasets with higher pileup rate and to convert python codes to C++ in order to reduce the execution time.
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References

[1] Aguillard, DP and Albahri, T and Allspach, D and Anisenkov, A and Badgley, K and Baeßler, S and Bailey, I and Bailey, L and Baranov, VA and Barlas-Yucel, E and others, *Measurement of the positive muon anomalous magnetic moment to 0.20 ppm*, *Physical review letters*, **2023**

[2] M. Abe, S. Bae, G. Beer, G. Bunce, H. Choi, S. Choi, M. Chung, W. Da Silva, S. Eidelman, M. Finger, and others, *A new approach for measuring the muon anomalous magnetic moment and electric dipole moment*, *Progress of Theoretical and Experimental Physics*, **2019**(5), 053C02, Oxford University Press (2019).

[3] Otani, Masashi, *Status of the Muon g − 2/EDM Experiment at J-PARC (E34)*, *Proceedings of the 2nd International Symposium on Science at J-PARC—Unlocking the Mysteries of Life, Matter and the Universe*—, 025008, 2015

[4] Choma, Nicholas and Murnane, Daniel and Ju, Xiangyang and Calafiura, Paolo and Conlon, Sean and Farrell, Steven and Cerati, Giuseppe and Gray, Lindsey and Klijnsma, Thomas and Kowalkowski, Jim and others, *Track seeding and labelling with embedded-space graph neural networks*, *https://www.osti.gov/biblio/1656641*, 2020.