Name: Sara Shinde

shindesc@mail.uc.edu

Mentors: Dr. Simone Griso and Dr. Sergo Jindariani

IRIS-HEP Fellowship Proposal

Charged-Particles Reconstruction at Muon Colliders

Motivation:

The Standard Model (SM) in particle physics has been quite successful in explaining some of the observed physical phenomena. However, several phenomena such as the existence of dark matter, matter-antimatter asymmetry in the universe, origin of neutrino masses, etc. cannot be explained by the Standard Model. There is a need to look beyond the Standard Model (BSM).

Collision energy can be expected to increase by at least an order of magnitude due to the recent technological developments that have taken place. There is a need for future particle colliders in the multi-TeV scales that can increase the energy range for direct and indirect searches. One of the ways in which this can be achieved is by building the proposed 100-km-long Future Circular Collider (FCC-hh), which will collide protons at 100 TeV centre-of-mass energy. The energy of a relativistic proton is divided among the quarks and gluons that constitute it. There are strict limits on the energy reach of circular electron-positron colliders because of electrons and positrons losing energy in the form of synchrotron radiation. Thus, a lepton collider with the same energy would have a much wider energy reach. Alternatively, long linear colliders are being proposed for achieving electron–positron collisions of high energy, but these are expensive and power hungry . Muons are more than 200 times heavier than electrons. Therefore, they emit around 10^9 times less synchrotron radiation compared to electrons at the same energy. A reasonably compact circular collider can be used to produce multi-TeV collisions. A high-energy muon collider is highly efficient in terms of power per unit luminosity. This is significant due to the increased emphasis that continues to be placed on sustainability and energy efficiency in recent times.

Despite the several advantages of muon colliders, building one poses significant technological challenges. Muons are unstable and decay into an electron or positron accompanied by a neutrino and an antineutrino. However, rapid acceleration of muons can increase their lifetime in proportional to their energy. At an energy of 1 TeV, the lifetime of a muon is 21 ms. Thus, high-gradient normal and superconducting radiofrequency systems would have to be used to accelerate muon beams before they decay. Another related problem caused by muon decay is that it causes dissipation of the muon beam. To maximise the number of muon collisions before muons start decaying, superconducting dipole magnets providing magnetic fields up to 20 T need to be used so that the collider ring would be small enough.

After muons decay, they tend to scatter in all directions. Some enter the detector and cause noise. A muon collider detector (MCD) faces the challenge of separating the products of muon collisions from an intense beam-induced background (BIB) from secondary and tertiary interactions of muon decay products. Thus, tungsten nozzles covered with borated polyethylene are an integral part of the Machine Detector Interface (MDI) of the collider. They reduce the rate at which the BIB particles reach the detector and their energy by several orders of magnitude.

Every square centimetre of the active area of the tracker detector is hit hundreds of times. The sensors of the detector are thus required to be finely segmented. By measuring the momentum of the particles, we can reconstruct the particle tracks. A track is an object reconstructed from hits positions of charged particle trajectories. Track reconstruction is complicated by the large number of hits due to the beam-induced background (BIB-hits). The spatial distribution of BIB-hits is different from the hits created by the particles generated from muon-muon collisions.

Objectives:

The tracking algorithm helps differentiate the BIB-hits from the tracks of charged particles generated by primary collisions. The current tracking algorithm is relatively slow and takes several seconds to process one single event. I propose to work on making it faster and more efficient. I plan to investigate how timing and reconstruction performance of the tracking algorithms can be improved by utilising directional information from specially-arranged silicon-detector layers in the particle detector.

I also propose to work on moving the current setup to use the latest implementation of track reconstruction base algorithms available in the latest version of the ACTS library, after helping to port the modern track reconstruction algorithms from the older ILCSoft framework to the new Key4HEP software framework, which supports parallel multi-threaded execution of algorithms. This is to ensure that the performance of the algorithm is scaled to the needs of the collaboration. I plan to work on validating the improved algorithms to ensure that they can be used by all members of the collaboration, as well as explore other ways the algorithms can be improved/optimised.

Timeline-

--> Weeks 1 and 2: Learn to code in the existing framework and thoroughly familiarise myself with it.

--> Weeks 3 and 4: Establish benchmark performance for the existing algorithms. Familiarise myself with Key4HEP ACTS setup.

--> Weeks 5,6 and 7: Improve reconstruction algorithms, make them faster. Test using directional and/or timing information directly in track reconstruction.

-->Weeks 8 and 9: Evaluate performance of the improved algorithms using metrics developed in weeks 3 and 4. Study feasibility and granular improvements for the future.

-->Weeks 10: Study additional ways to optimise or improve the timing of the algorithms via finely-grained parameters optimization.

-->Weeks 11 and 12: Compile results, complete comprehensive documentation and create a presentation to discuss results.

References:

1. https://doi.org/10.48550/arXiv.2203.07964
2. https://doi.org/10.1038/s41567-020-01130-x
3. https://doi.org/10.48550/arXiv.2209.01318