Algorithms for electron reconstruction in the Muon Collider
IRIS-HEP summer fellows project proposal

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Background on colliders and noise effect

Since the construction of the Large Hadron Collider (LHC), the world's premier particle accelerator, researchers have argued that having an even larger-loop collider would be beneficial so as to reach higher voltages and particle velocities. The Future Circular Collider (FCC) is planned to be 100 KM in circumference to meet this need. With that said, the development of other methods of creating similar particles from smaller colliders would be beneficial. The proposed work is to examine the feasibility of using a Muon Collider for this purpose; as of quite recently, much effort has been directed toward the development of a simulator and analysis tools for this collider. A challenge in using a Muon Collider is the significant amount of beam-induced background noise that occurs from a large number of particles hitting the sensors; these background reflections make it difficult to properly interpret the results from experiments. Tungsten cones can be placed near the site of collisions to mitigate some of this effect, but this is not a complete solution. Out of all of the particles that are introduced into the detector area, the hardest to manage is the electron because of how it behaves as a fundamental particle and in its interaction with the detectors.

The difficulties with electrons

Electrons are prone more than any other fundamental particle to have their course altered by their interactions with matter via multiple scattering and bremsstrahlung effects. This course altering can have severely detrimental effects and requires dedicated methods to achieve a satisfactory resolution in measuring an electron's kinematic properties. The particles that we want to track generally form a helix shape, so the algorithms have been tuned to specifically isolate that group of particles from this bunch. Because of bremsstrahlung effects, electron reconstruction algorithms need to have additional flexibility to track their trajectory. This detrimental effect is due to particles being mislabeled and thus letting mundane events get mixed into the pool of interesting events. Dedicated algorithms have been implemented in the ACTS library to handle electrons but have only been tuned in very "clean" environments such as the ones of the e^+e^- colliders.

The solution

To address this issue regarding electrons, I will be incorporating the electron reconstruction algorithms implemented in ACTS into the already existing iLCSoft software. I will tune such algorithms to identify electrons from the given data by refining the configuration of the software and employing other techniques for discerning whether a particle is an electron or not.
The analysis program that I will develop will:

- Run the iLCSoft software with ACTS to produce dedicated Muon Collider simulation data.

- Create metrics that will be used to analyze the accuracy and dependability of any changes I make to the existing software
- Look at multiple categories of particle data such as, but not limited to, their momentum, particle type, and position
- Use ROOT and NumPy alongside their languages C++ and Python.

I will also work with the configuration files inside of iLCSoft in order to better recognize electrons. This will be completed in an iterative process that will involve looking at what the current iLCSoft software is reporting using my analysis program and then changing the configuration files. If needed, I will also make additions to the existing code in the ACTS repertoire to better allow it to detect and track electrons.

Timeline

With feedback and direction provided by Simone Pagan Griso and Sergo Jindariani throughout the project, I anticipate the following schedule for the work:

In the first two weeks: Once this project gets underway, a small buffer of time will be needed to adjust to working with the ACTS software and developing the aforementioned analysis program. At the end of the two weeks, the analysis program should be usable, but it might not have all of the analysis abilities that would be desired or possible. This will be a base version which will be further developed as needed.

By the end of the summer: Any additional updates that will better help the ACTS software track electrons will have been submitted and added to the existing iLCSoft code. In addition, a modified configuration file will be provided that will get the software working to an acceptable margin of error.

With any remaining time: I will work on other projects as designated by Simone Pagan Griso and Sergo Jindariani, on a topic connected with tracking in the muon collider environment. The experience gained from working on electron reconstruction will be useful to make fast progress on any additional study that can be carried out if time allows.

References

Bartosik, Nazar, et al. “Detector and Physics Performance at a Muon Collider”, *Journal of Instrumentation*, Volume 15, IOP Publishing, 2020. *JINST* 15 P05001

Bartosik, Nazar, et al. "Preliminary report on the study of beam-induced background effects at a muon collider.", *High Energy Physics - Experiment*, Cornell University, 2019. arXiv:1905.03725

How a Detector Works. CERN, n.d., https://home.cern/science/experiments/how-detector-works.

Landua R. *THE LHC: A LOOK INSIDE*. Science in School, Issue 10, Winter 2008, pp 34-45.

Long, K.R., Lucchesi, D., Palmer, M.A. et al. Muon colliders to expand frontiers of particle physics. Nat. Phys. 17, pp 289–292, 2021. https://doi.org/10.1038/s41567-020-01130-x