IRIS-HEP Fellows Program Project Proposal

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Project: Charged-particles reconstruction at Muon Colliders

Project Background

The ability of collider experiments to advance high energy physics is highly reliant on reconstruction algorithms that help physicists to discern, from the observed data, the identities of particles, their direction of travel, and their energy. A muon collider offers the promise of probing the fundamental particles of the universe at higher energy levels than ever before. However, the reconstruction algorithm used with muon collider data will have to not only mitigate particle-detector interactions for tens to hundreds of particles from successful muon collisions but do so while also sorting out the interference caused by *millions* of background particles **[1]**. Despite this challenge, a muon collider will still be able to out-perform other types of colliders. Electron colliders are limited at higher energies by synchrotron radiation which causes the electrons to radiate energy at high velocities **[2]**. Hadron colliders often use protons which, as composite particles, collide quarks with only a fraction of their total energy **[2]**. Muon colliders offer promise because muons are fundamental particles whose mass makes them less susceptible to synchrotron radiation. Bridging the differences between electrons and protons in high energy collisions, muons are the perfect tool to reach into the TeV energy sector.

Interference from background particles is a potential concern for muon colliders because muons are unstable particles. As they decay, muons generate a stream of other particles that travel with them, called the Beam Induced Background (BIB) **[2]**. With a lifetime on the order of microseconds, there is not much time to work with muons. This issue is mitigated by the velocities at which they will move in a collider. At these velocities, muon lifetimes are dilated sufficiently to allow for collisions, but estimated lifetimes are only averages, and a substantial number of the billions of muons in the packet used in the collider will decay before collision. The result is an abundance of background particles traveling with the muons and causing interference with measurements in the detector. A muon collider will use shielding to block out as much of the BIB as possible **[3]**, but even the particles that hit the shield can interfere with measurement by creating electromagnetic showers that extend through the shielding material. These BIB particles interact with the detector **[1]** causing *millions* of false hits.

The reconstruction algorithm for a muon collider must have the capability to sort out the BIB from the signal. While much work has been done to develop reconstruction algorithms at other colliders, given the extent of potential interference in a muon collider, the reconstruction algorithm will require more computation resources. The muon collider will benefit from subprocess parallelization and a transition to an optimized software environment that supports efficient analysis and usability.

Project Goals & Objectives

The project goal is to improve the efficiency of the current charged particle reconstruction algorithms. To attain this goal, the project objectives are to:

1. Move the charged particle reconstruction algorithms to the Key4HEP software framework.
2. Optimize the reconstruction algorithm in the new framework.

Most prior work on charged particle reconstruction has used the ILCSoft framework, which is being phased out and therefore this work needs to be transitioned to the newer Key4HEP software framework. The Key4HEP framework improves on ILCSoft in a number of ways, but one of the most important is its multithreading capabilities **[4]**, in which it outperforms the older frameworks. Current charged particle reconstruction algorithms require a massive amount of RAM to run (on the order of 8 Gb for a single event). Current multithreading techniques for reconstruction run different events on different cores and, therefore, are restricted by the total available RAM. With the improved multithreading of Key4HEP, we can parallelize the subprocesses of the reconstruction algorithm in order to reduce both runtime and required RAM.

After transitioning to Key4HEP, many new options for optimizations of the algorithm will be possible. We will study these various optimization techniques and determine which are best suited to the muon collider data. We will assess efficiency improvements offered by the selected optimization techniques and test the algorithm for usability by other scientists.

Project Deliverables

- Charged particle reconstruction algorithm transitioned to the new Key4HEP software framework.
- Optimization improvements for the reconstruction algorithm.
    - These include parallelization of sub-event processes.

Project Timeline

- *Weeks 1-3:* Familiarize with the ILCSoft and Key4HEP frameworks. Develop understanding of the languages and packages used and the current charged particle reconstruction algorithms in ILCSoft.
- *Week 4:* Make initial attempts to begin porting the reconstruction algorithms to the Key4HEP framework. Take note of any issues and correct for them. Begin developing ideas to optimize the algorithm within Key4HEP.
- *Weeks 5-8:* Move the reconstruction from ILCSoft to Key4HEP using methods learned in week 4. Continue planning for algorithm optimization.
- *Weeks 9-10:* Test algorithms in Key4HEP to ensure they will work for others. Begin implementing optimization plans and test to see how much they improve the efficiency of the algorithm by.

References

[1] Bartosik, Nazar, et al. Simulated Detector Performance at the Muon Collider. arXiv:2203.07964, arXiv, 12 Aug. 2022. arXiv.org, https://doi.org/10.48550/arXiv.2203.07964.

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

[3] Accettura, Carlotta, et al. Towards a Muon Collider. arXiv:2303.08533, arXiv, 27 Nov. 2023. arXiv.org, https://doi.org/10.48550/arXiv.2303.08533.

[4] Ganis, Gerardo, et al. Key4hep, a Framework for Future HEP Experiments and Its Use in FCC. arXiv:2111.09874, arXiv, 18 Nov. 2021. arXiv.org, https://doi.org/10.48550/arXiv.2111.09874.