HSF Fellows Project Proposal

Title: *Sustainable Quantum Algorithms for Particle Physics Reconstruction*

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Overview and Motivation

Modern High-Energy Physics (HEP) experiments, such as those at the **Large Hadron Collider (LHC)**, face a monumental data challenge. One of the most computationally intensive tasks is **particle track reconstruction**—determining the curved trajectories of charged particles as they pass through layered tracking detectors. As the LHC continues to increase in luminosity, the number of simultaneous particle interactions surges, resulting in a **combinatorial explosion** of potential hit combinations and track candidates. Classical algorithms such as the **Kalman filter**—though effective—struggle to scale efficiently under these growing demands.

This project proposes to explore **quantum computing algorithms** that are naturally suited for optimisation and pattern recognition. Specifically, it seeks to develop **sustainable and practically realisable quantum solutions** that can run on existing and near-term **NISQ-era** (Noisy Intermediate-Scale Quantum) hardware.

Project Scope

The central idea is to **reformulate the track reconstruction problem** into a quantum-compatible structure. For example, by representing detector hits as nodes in a graph, the search for valid particle tracks can be cast as an **optimisation problem** or a **pattern recognition task**—both of which are promising domains for quantum algorithms.

The project will focus on two main techniques:

- **Quantum Approximate Optimisation Algorithm (QAOA):** Suitable for discrete optimisation problems, QAOA can be used to find the most probable paths or combinations of hits corresponding to particle tracks.
- **Quantum Machine Learning (QML):** Algorithms like **Variational Quantum Classifiers (VQC)** can learn complex patterns in hit data for tasks such as classification or filtering of false tracks.

Implementation will be done using open-source frameworks such as **Qiskit** and **PennyLane**.

Deliverables

- A working Python-based prototype that implements QAOA and/or QML methods on simulated tracking data.

- A performance comparison report covering accuracy, runtime, and quantum resource utilisation versus classical baselines.
- Open-source code contributions and documentation aligned with HSF guidelines.
- A final project report and optional white paper summarizing results and future directions.

Impact

This project contributes to HSF's ongoing effort to integrate **quantum computing into the HEP software stack**, and it aligns well with global initiatives such as **CERN QTI**, **Quantum4HEP**, and **QML@LHCb**. By focusing on **NISQ-suitable solutions**, the work remains grounded in current hardware capabilities while laying a foundation for future scalability.

About Author

I am currently pursuing an M.Tech in Quantum Technology (2024–2026) at the Indian Institute of Science (IISc), Bengaluru. My background includes an M.Sc. in Physics from the University of Delhi and a B.Sc. in Physics (Hons) from Aligarh Muslim University. I also completed a Post M.Sc. Diploma in Radiological Physics at BARC, where I gained hands-on experience with detectors such as Geiger–Müller counters, HPGe detectors, and scintillation detectors. During my Master's studies, I specialised in detector physics and advanced nuclear physics, which provided me with both theoretical and experimental expertise relevant to high-energy physics. My current research interests focus on quantum algorithms for simulation, machine learning, and linear systems, and this project represents a natural continuation of my academic trajectory. **In terms of commitment, I can dedicate approximately 10–12 hours per week to the project**.