INPC 2025
May 25-30, 2025
DCC, Daejeon, Korea

Contribution ID: **32** Type: **Contributed Poster Presentation**

Machine Learning Assisted Beam Tuning for Collinear Resonance Ionization Spectroscopy Experiment

Laser spectroscopy can accurately measure the hyperfine structure and isotope shifts of atoms and ions, enabling the extraction of fundamental nuclear properties such as spins, magnetic moments, electric quadrupole moments, and charge radii in a nuclear-model-independent manner [1]. Laser resonance ionization spectroscopy (RIS) is one of the approaches to measure the HFS spectrum with higher sensitivity based on multi-step laser resonance ionization. Our group focuses on developing advanced laser spectroscopy setups for radioactive ion beam facilities in China [2-3]. Currently, the high-sensitivity collinear resonance ionization spectroscopy setup using the RIS approaches has been developed, which could perform the RIS experiments with bunched atom beam collinearly overlapped with multiple pulsed laser beams [4].

Compared with laser-induced fluorescence (LIF), RIS needs an extended interaction region for excitation and ionization, making it advantageous for specific applications but demanding more sophisticated setups and high-quality and precisely tuned beam. Therefore, efficient beam tuning, which is essential for high stability and intensity during experiments, remains a significant challenge due to the large number of components involved in steering, focusing, and accelerating the particle beam. However, manual optimization based on human expertise is time-consuming and labor-intensive, which is unfortunately most commonly used currently.

To address this challenge, we propose applying Bayesian optimization, a machine learning-based global optimization method suitable for black-box functions. In this context, the relationship between electrode voltages and beam intensity represents a black-box function, as it cannot be explicitly defined and is only evaluated through indirect, noisy measurements from Faraday cups. Each evaluation is time-intensive, requiring tens of seconds to ensure accuracy and reduce noise. Bayesian optimization's ability to efficiently explore the parameter space while minimizing computational costs makes it an ideal solution for automating and accelerating the beam tuning process, significantly enhancing the performance of collinear resonance ionization spectroscopy experiments.

In this presentation, the details of the application of Bayesian optimization in collinear resonance ionization spectroscopy experiments will be presented, as well as an overview of the whole automated EPICS-based beam tuning system.

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Session Classification: Poster Session

Track Classification: Quantum Computing and Artificial Intelligence in Nuclear Physics