Optimization Methods for Track Fitting in the Active-Target Time Projection Chamber

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Abstract

Local and global optimization methods were evaluated for fitting spiral tracks in the Active-Target Time Projection Chamber (AT-TPC) at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University. The NSCL is capable of producing beams of rare isotopes for national and international researchers to study nuclei at the limits of existence. The AT-TPC is a gas-filled chamber that acts as both the target and the detector during nuclear reactions. Using this, we can reconstruct three-dimensional spatial tracks of the reaction products. Track-fitting methods were tested on data from the ^{40}Ar and ^{46}Ar experiments that ran in 2015. We aim to improve on the current fitting method in the analysis software, the naive Monte Carlo algorithm. Various optimization methods were tested, with notable success using global optimization methods, specifically, differential evolution and basin hopping. Results will be presented that compare the accuracy, robustness to noise, and time efficiency of each method.

Motivation

The study of the nuclear structure of short-lived rare isotopes is crucial to our understanding of nuclear science and its applications such as medicine, nuclear energy, and national security. Since the rare isotopes produced in the NSCL are very unstable and short-lived, we need a high efficiency detector to capture the transient events happening during nuclear reactions.

Previous computational physicists apply the naïve Monte Carlo algorithm to fit the current proton tracks, generated by ^{40}Ar and ^{46}Ar experiments (Fig. 1). This research compares the Monte Carlo method with other global and optimization methods to determine the most accurate method during the track fitting process.

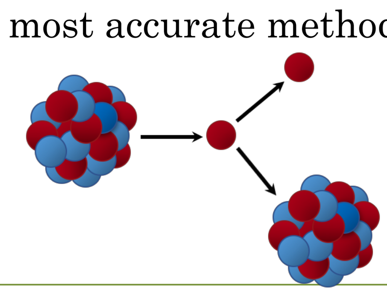


Fig. 1. A schematic diagram of proton-^{46}Ar reaction [1].

The Active-Target Time Projection Chamber

The AT-TPC consists of a cylindrical active volume filled with gas that serves as both the target and the detector for nuclear reactions. The active volume is inside of a solenoidal magnetic field of 2 Tesla. A uniform electric field is generated inside the active volume by the cathode and anode on opposing sides of the chamber. Its detector consists of 10,240 pads spread throughout the sensor plane at the anode end (Fig. 2). The AT-TPC has a close to 4π coverage to capture the reactions happening everywhere within the active volume [2]. The design of the AT-TPC ensures the high efficiency and resolution of the device (Fig. 3).

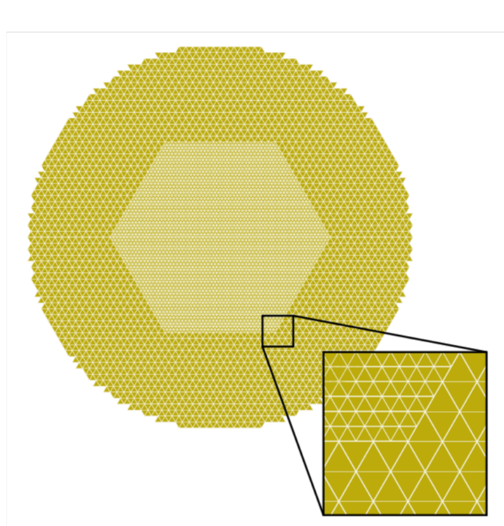


Fig. 2. Layout of the pad plane [2].

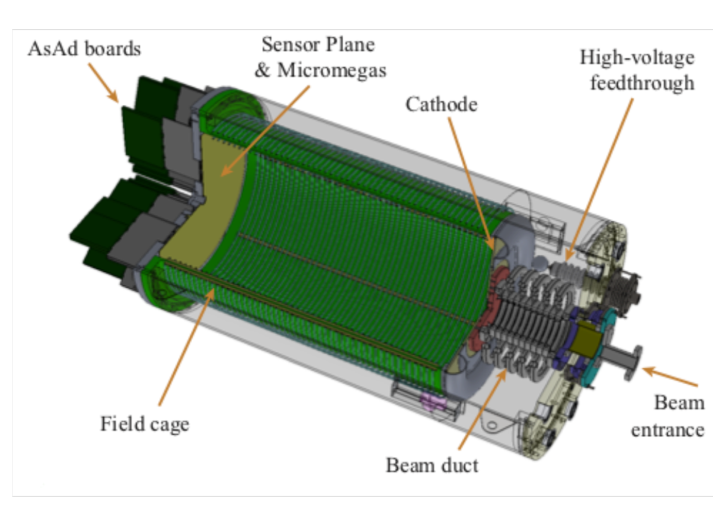


Fig. 3. A schematic diagram of the AT-TPC [2].

Conclusion and Future work

The differential evolution method gives the most accurate results in fitting both the original and the cleaned data. However, when implemented on data from an entire two-week experiment using the AT-TPC, the algorithm's long computation time could be intractable. My research this semester will be focused on tuning the differential evolution algorithm in order to improve time efficiency and accuracy. To further reduce computation time, I will implement parallel programming on my current Python code to make use of more processors on the High-Performance Computing Center (HPCC) at Michigan State University. I will examine our current objective function and attempt to improve it to provide more accurate information on track fitting.

References

[1] Taylor, Jack, Dr. Michelle P. Kuchera, and Dr. Raghu Ramanujan, "Evaluating Machine Learning Methods for Event Classification in the AT-TPC." *Honors Thesis*, Davidson College. 2018.
[2] J. Bradt et al. Commissioning of the Active-Target Time Projection Chamber. *NIMPR section A* (submitted), 2017.

Global Optimization Methods

Two global optimization methods, basin hopping and differential evolution, are examined with the current naïve Monte Carlo algorithm. The accuracy of the methods is indicated by the value of the objective function, which describes how well our model fits the data. We tested the robustness to noise of each method by fitting the tracks before and after the noise cleaning process.

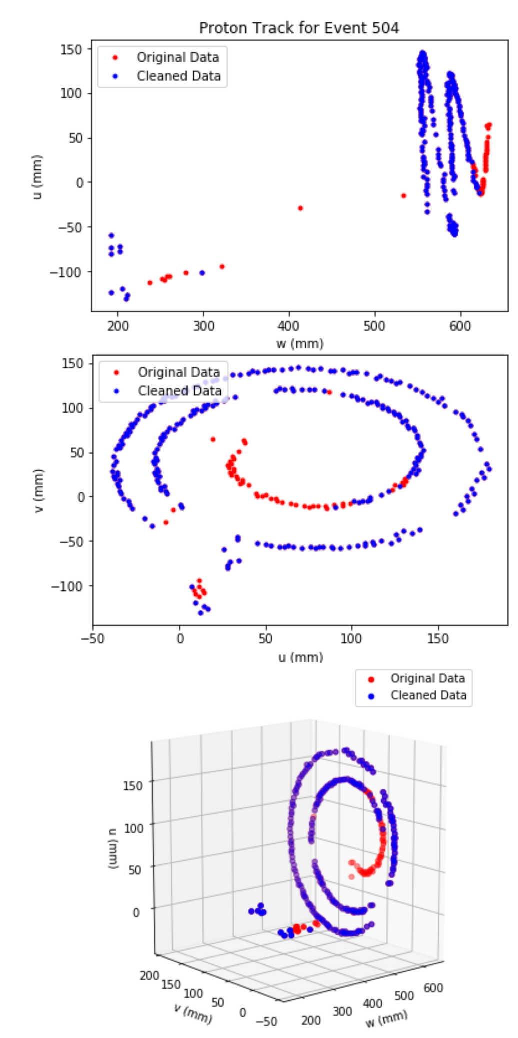
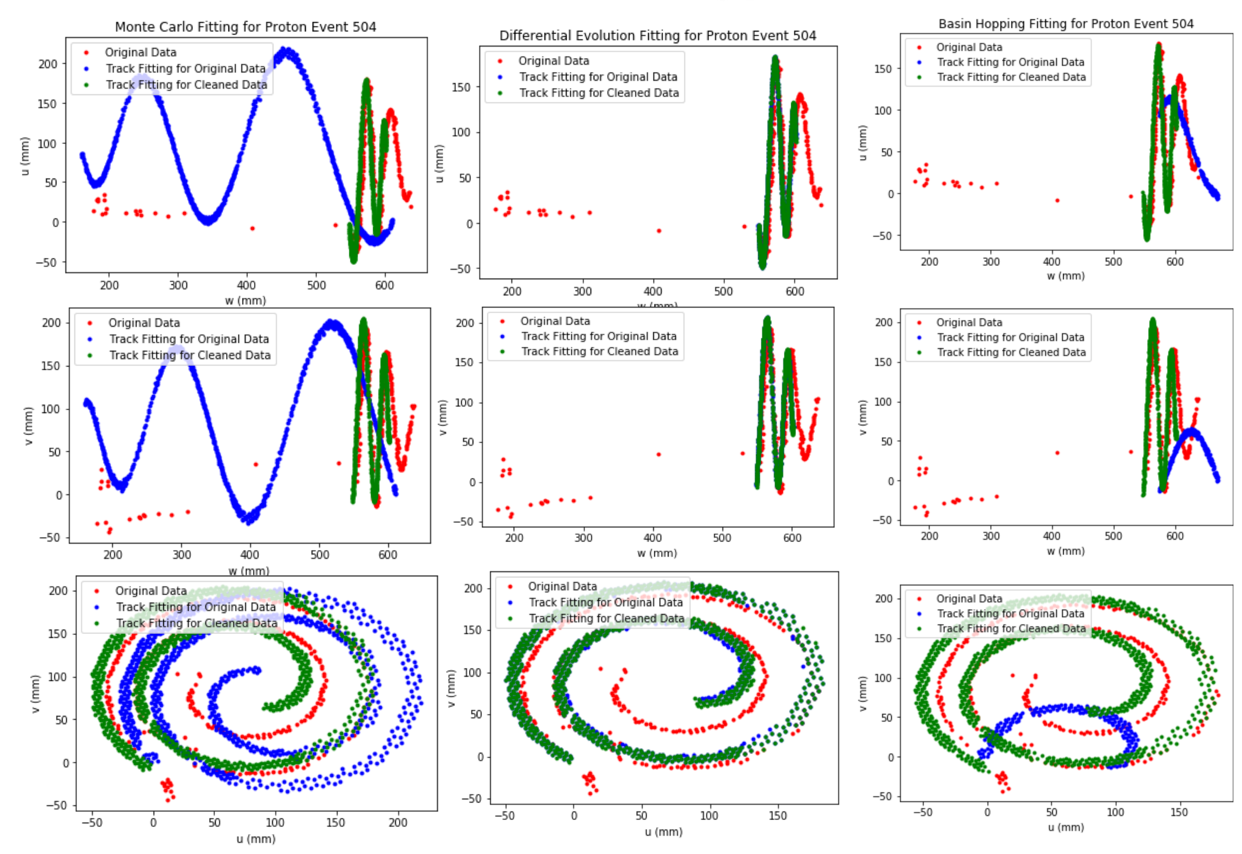


Fig. 3. 2-D and 3-D graphs of a experimental proton track for a single event.



$\chi^2_{orig} = 90.04$ $\chi^2_{clean} = 45.09$
$T_{orig} = 0.947s$ $T_{clean} = 0.901s$

$\chi^2_{orig} = 53.03$ $\chi^2_{clean} = 41.89$
$T_{orig} = 251s$
$T_{clean} = 106s$

$\chi^2_{orig} = 84.21$ $\chi^2_{clean} = 41.90$
$T_{orig} = 10.3$ s $T_{clean} = 4.01$ s

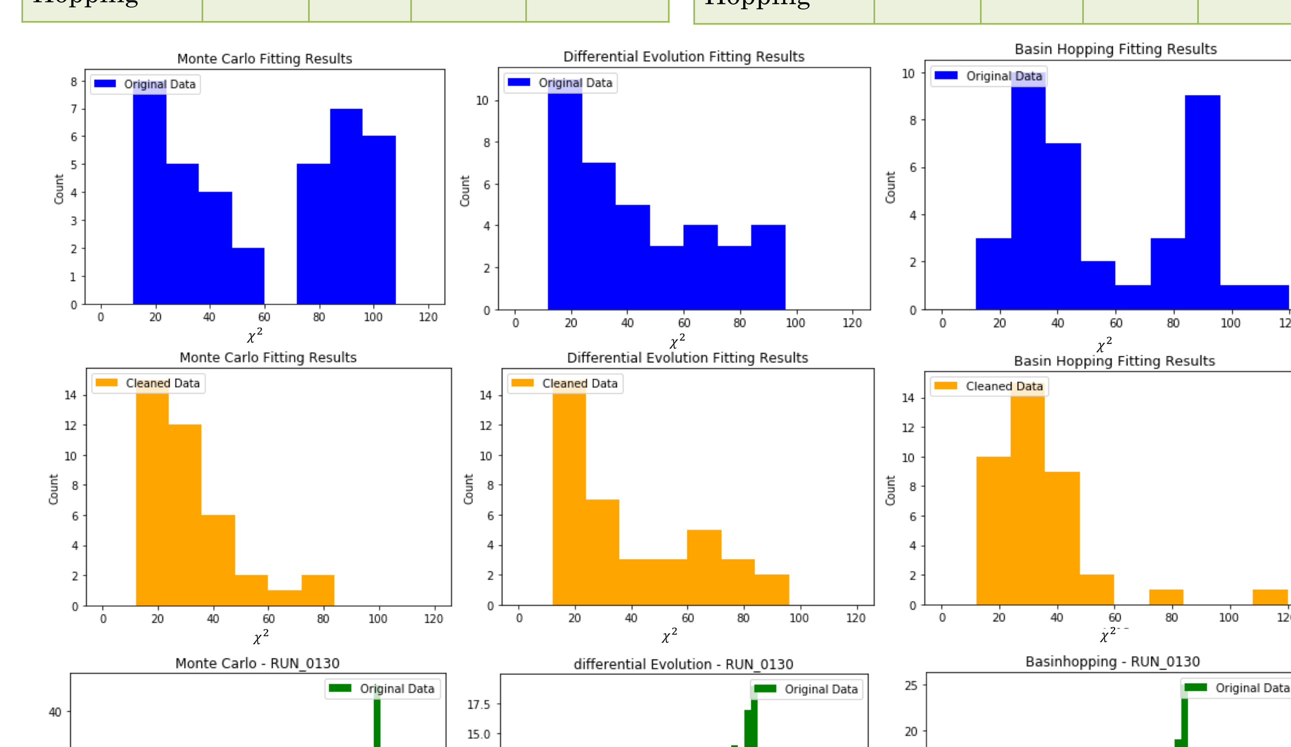
Fig. 4. Real and simulated tracks on a single event of the ^{40}Ar experiment.

Results

38 events Ar^{40}	χ^2_{orig}	χ^2_{clean}	T_{orig}	T_{clean}
Naïve Monte Carlo	56.73	34.57	2.29s	1.36s
Differential Evolution	43.99	39.28	38.99s	39.95s
Basin Hopping	54.87	34.35	9.127s	4.681s

>160 events Ar^{46}	χ^2_{orig}	χ^2_{clean}	T_{orig}	T_{clean}
Naïve Monte Carlo	94.46	39.34	2.15s	0.77s
Differential Evolution	65.27	27.29	68.83s	58.39s
Basin Hopping	83.16	29.51	38.43s	11.43s

Table 1 & 2. Average accuracy, time efficiency and robustness to noise of the three global optimization methods.



38 proton events from ^{40}Ar experiment were fitted with three global methods. Various local optimization methods were also implemented within the basin hopping algorithm in order to examine the performance impact.

Fig. 5. Objective function values of 38 proton events from ^{40}Ar experiment.

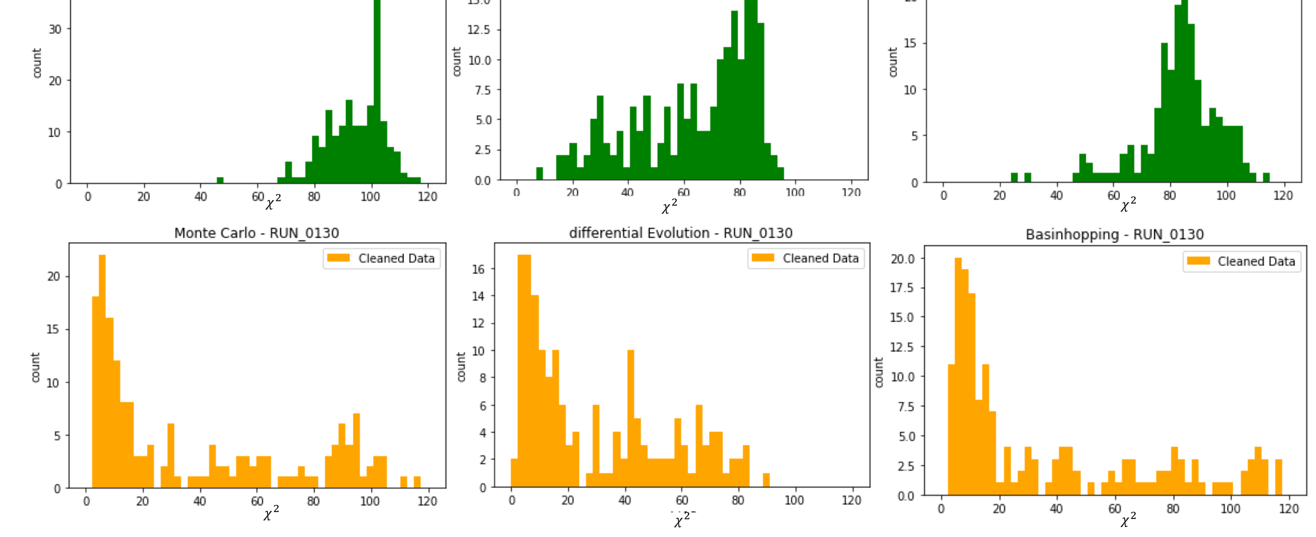


Fig. 6. Objective function values of 200 proton events from ^{46}Ar experiment.

Acknowledgements

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