A Streamlined Python Framework for AT-TPC Data Analysis

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Abstract

Data-analysis software for the Active-Target Time Projection Chamber (AT-TPC) at the National Superconducting Cyclotron Laboratory (NSCL) was documented and used to analyze unbound states in Argon-40 (^{40}Ar). At NSCL, rare isotope beams are produced, accelerated, and delivered to various experimental setups, each with their own physics motivations. One such setup is the AT-TPC, a gas-filled detector that acts as both the detector and target for high-efficiency detection of low-intensity, exotic nuclear reactions. The pytpc framework is a Python package which was used to analyze data produced by the ^{40}Ar(p, p) experiment. Usage of the package was documented in an analysis manual to aid in the work of future AT-TPC users. Software features and analysis methods in the pytpc framework are presented along with the ^{40}Ar results.

Motivation

The study of rare isotopes has applications ranging far beyond the quest for universal discovery, from national security to medicine. Experimental endeavors using low-intensity beams of radioactive ions introduce unique challenges in experimental design and analysis. Rare isotope beams typically have low intensity, leading to fewer reactions and events, thus requiring a detector with high efficiency. The AT-TPC was designed and built for improved data acquisition for rare isotope experiments.

This project involved creating an analysis manual and framework documentation to streamline the analysis process for users and increase the accessibility of the software as well as analyzing data from the ^{40}Ar(p,p) reaction.

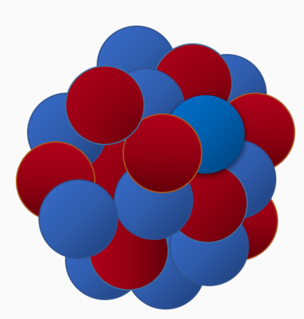


Fig. 1. A schematic diagram of an ^{40}Ar nucleus, which has 18 protons (red) and 22 neutrons (blue).

The pytpc Framework

The pytpc framework is a Python package for analyzing AT-TPC data. The package provides functions for reconstructing, cleaning, and fitting particle tracks produced by beam experiments run on the AT-TPC. Analysis of AT-TPC data is a multi-step process:

1. Baseline Correction for Electronics Signals
2. Track Reconstruction
3. Removal of Noise Using a Hough Transform
4. Modeling and Fitting Tracks with a Monte Carlo Optimizer

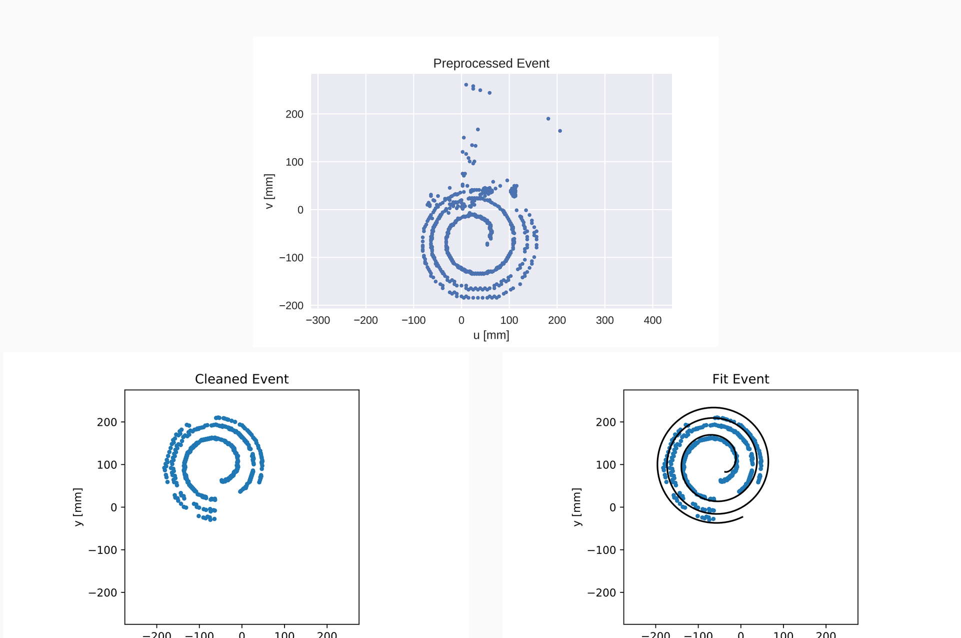


Fig 4. A preprocessed event (top), an event after the Hough Transform cleaning (bottom left), and a Monte Carlo fit event (bottom right).

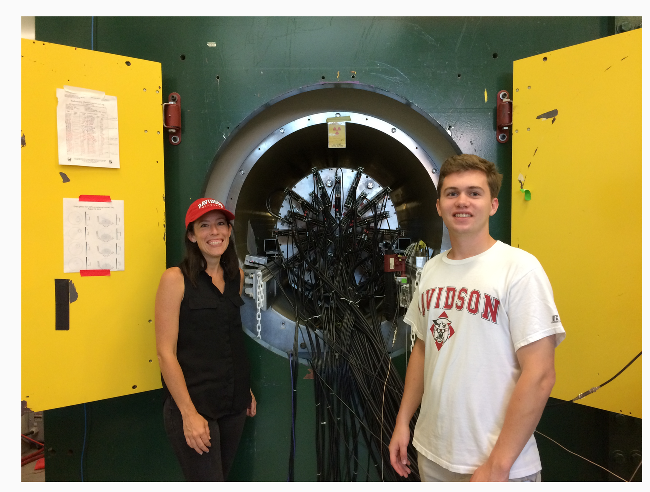
References

[1] J. Bradt et. al. Commissioning of the active-target time projection chamber. *NIMA*, 875:65–79, 2017.

[2] J. Bradt. *Measurement of Isobaric Analogue Resonances of ^{47}Ar with AT-TPC.* PhD thesis, MSU, 2017.

The Active-Target Time Projection Chamber

The AT-TPC is a gas-filled detector that acts as both the detector and target for high-efficiency detection of low-intensity, exotic nuclear reactions. Because the gas target also acts as the detector, the AT-TPC is highly efficient, providing nearly 4π angular coverage. The AT-TPC operates inside a nearly 2 Tesla solenoidal magnetic field. Reactions can be measured over a wide range of energies as the beam loses energy in the gas [1]. In order to obtain this 4π coverage with high resolution, a highly segmented pad plane captures the detector signal. There are 10240 pads in the pad plane which produces on the order of 10MB of data per event.



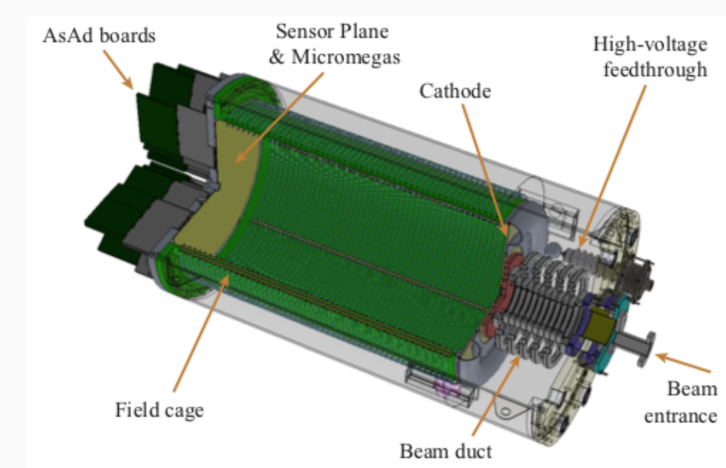
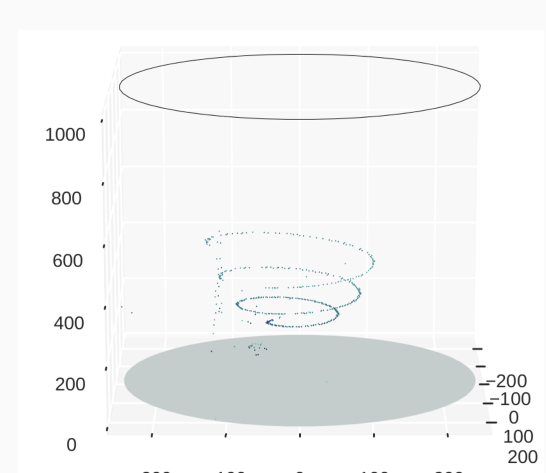
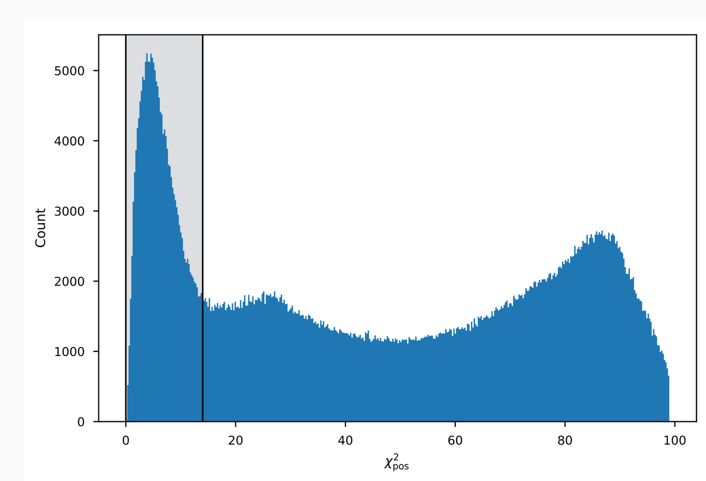


Fig 2. Left, a photograph of the pad plane end of the AT-TPC, shown mounted in the solenoid magnet.
Fig 3. Right, a schematic of the AT-TPC with the outer shielding made transparent. The rare isotope beam enters the the detector on the right-hand side and moves left towards the sensor plane [2].

Analysis of the ^{40}Ar Beam Experiment Data

The analysis code, originally written for a ^{46}Ar data, was applied to data from the ^{40}Ar(p, p) experiment that ran at the NSCL in August, 2015. The Monte Carlo fit results provide the vertex position of a reaction in the detector chamber. The energy of the beam particle at this location can be found by calculating the energy lost by the particle to the gas target that fills the chamber.





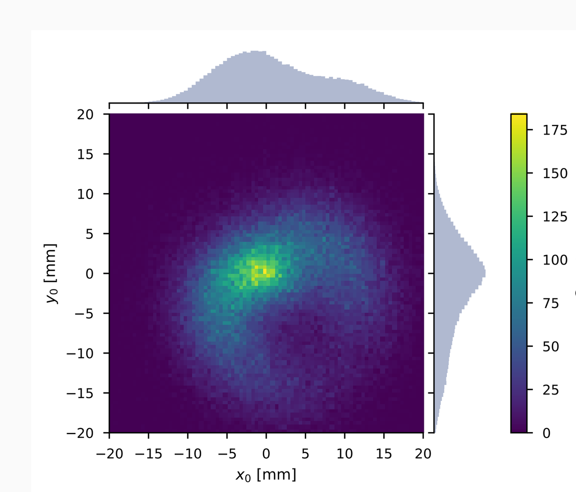


Fig 5. Left, an example of a proton event rendered in the pytpc framework.
Fig 6. Center, the distribution of χ^2_{pos} values. Events falling above the threshold of 14 were discarded.
Fig 7. Right, overall distribution of vertex positions in the plane transverse to the detector.

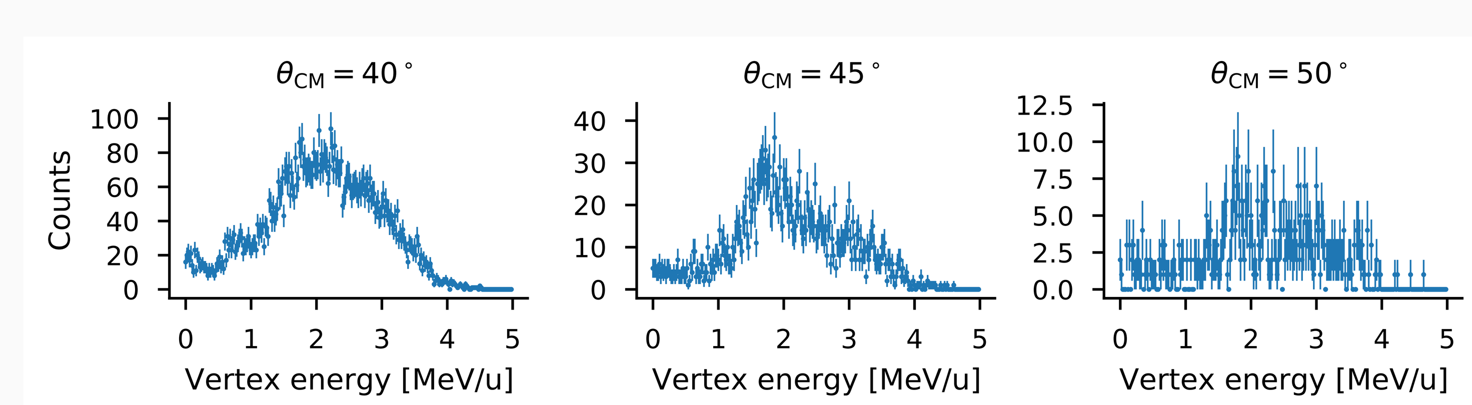


Fig 8. Unnormalized excitation functions as a function of the ^{40}Ar vertex energy in the laboratory frame shown for multiple center-of-mass scattering angles (θ_{cm}).

Conclusion and Future Work

By analyzing the data from the ^{40}Ar experiment I tested the adaptability of the software and examined previously unused experimental data. The analysis manual for the pytpc framework will help experimentalists from around the world apply pytpc to data produced by their own AT-TPC experiments.

I will be continuing my work with AT-TPC data and the analysis process this semester in a more research-focused capacity. My research will explore and apply machine learning methods to the issue of event classification for AT-TPC data. Ideally, this will increase statistics and reduce both error and computational time.