# 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). NSCL is a national user facility funded by the National Science Foundation that provides rare isotope beams to researchers around the world to study cutting-edge nuclear physics phenomena. 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 for analyzing AT-TPC data and was developed for the analysis of $^{46}$Ar(p, p) data. The existing software was used to analyze data produced by the $^{40}$Ar(p, p) experiment that ran in August, 2015. Usage of the package was documented in an analysis manual both to improve analysis steps and aid in the work of future AT-TPC users. Software features and analysis methods in the pytpc framework will be 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 conceived, 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 future users and increase the accessibility of the software as well as analyzing data from the $^{40}$Ar(p,p) reaction.

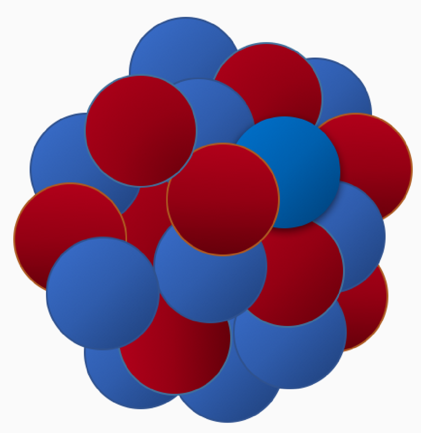


**Figure 1.** This is a diagram of a $^{40}$Ar nucleus.

## 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

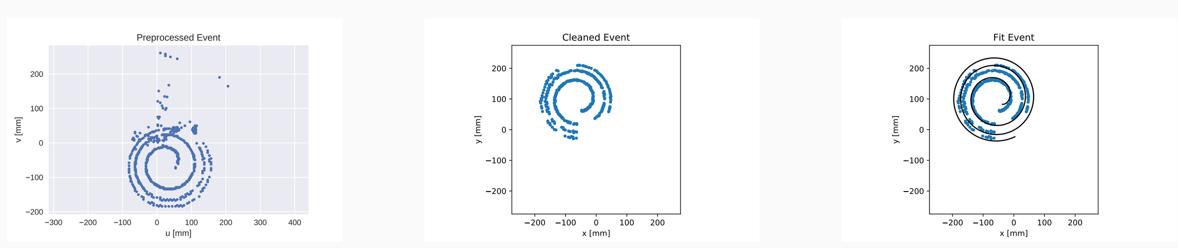
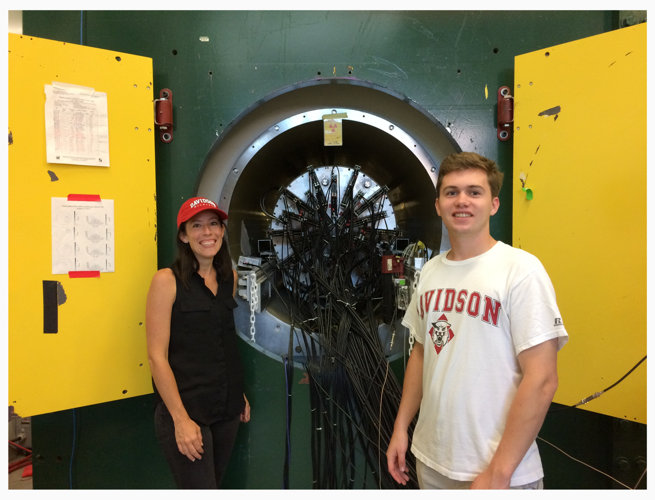



**Figure 3.** From left to right, Here are examples of a preprocessed event, an event after the Hough Transform cleaning, and a Monte Carlo fit event.

## 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 $4\pi$ 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 $4\pi$ 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.



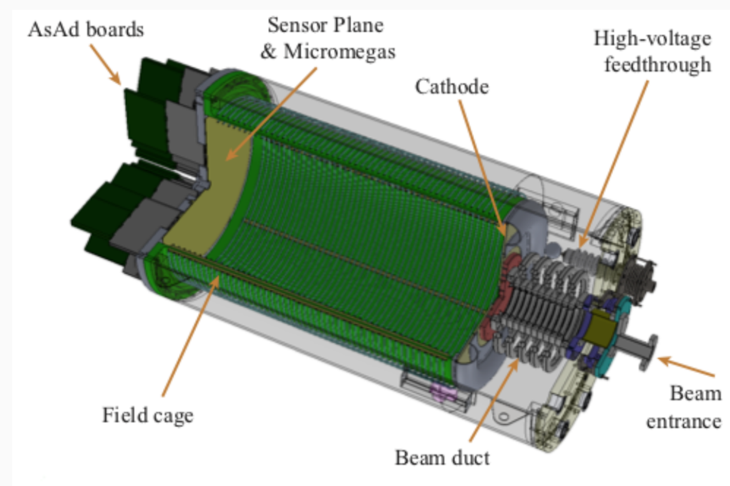
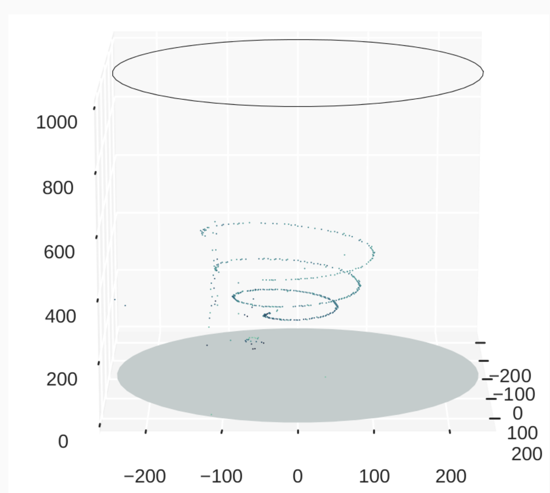
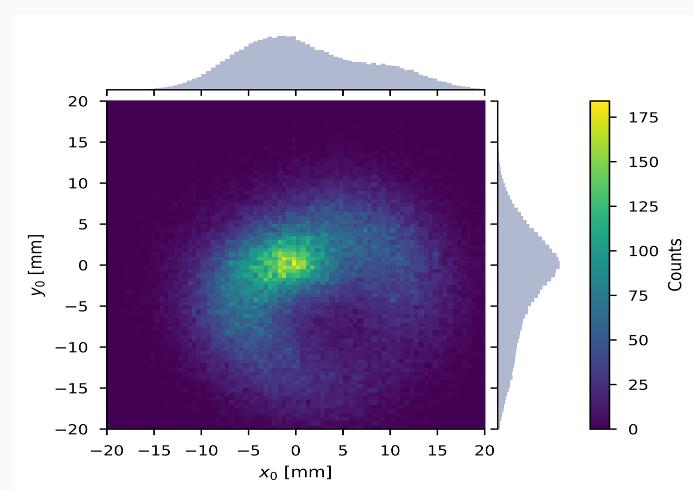



**Figure 2.** This is a schematic of the AT-TPC. The rare isotope beam enters the the detector on the right-hand side and moves left towards the sensor plane [2].
**Figure 3.** Right, This is a photograph of the backside of the AT-TPC lkdda.

## 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.





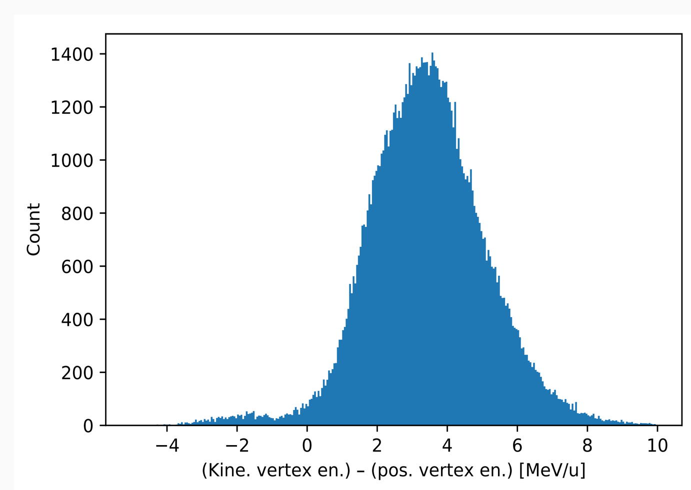




**Figure 2.** This is an example of a proton event rendered in the pytpc framework.
**Figure 4.** Left, distribution of vertex positions in the plane transverse to the detector.
**Figure 5.** Right, difference between the vertex energy as calculated from kinematics and vertex position. The trend of the count away from 0 on the x-axis is indicative of a problem with the vertex energy calculated from kinematics.

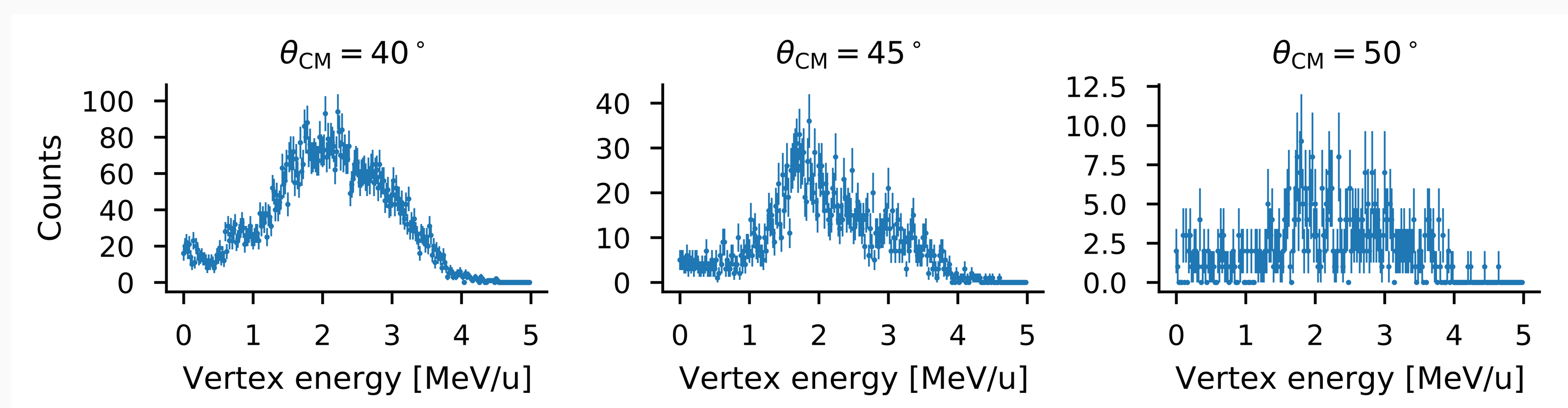



**Figure 6.** Unnormalized excitations functions as a function of the $^{40}$Ar vertex energy in the laboratory frame shown for multiple center-of-mass scattering angles ($\theta_{cm}$).

## Conclusion and Future Work

By analyzing the data from the $^{40}$Ar experiment I gained firsthand experience with the software I was documenting, examined data that was previously unused, and tested the adaptability of the software. The analysis

## References

[1] J. Bradt et al. Commissioning of the at-tpc. *NIMPR Section A* (submitted), 2017.

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