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

Nuclear science and the subfield of nuclear structure and reactions has applications ranging far beyond the quest for universal discovery, from national security to medicine. With the goal of expanding our current understanding of the nuclear landscape, the study of rare isotopes is imperative in investigation of theoretical models such as quantum chromodynamics and the Standard Model. Experimental endeavors using low-intensity beams of radioactive ions introduce unique challenges in experimental design and analysis. Rare isotope beams typically have low intensity due to production constraints, 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.

The pytpc framework, a Python package for analyzing AT-TPC data, was documented in an analysis manual to streamline the analysis process for future users and increase the accessability of the software. By nature of being written in Python, the pytpc package is a more accessible alternative to the preexisting AT-TPC data analysis package written using CERN's ROOT library.

The pytpc Framework

Extracting meaningful physics results from AT-TPC data entails a multi-step process. The package provides functions for reconstructing, cleaning, and fitting particle tracks produced by beam experiments run on the AT-TPC. Specifically, the process involves the following steps that are implemented in a set of scripts:

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

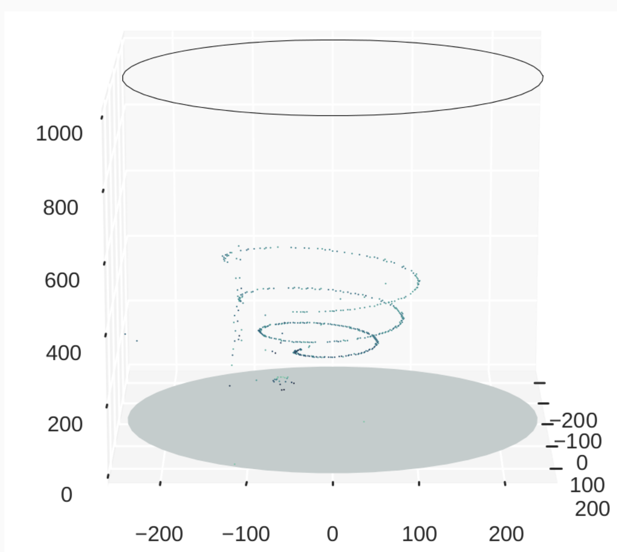


Figure 2. An example ^{40}Ar proton event in a vertically mounted chamber.

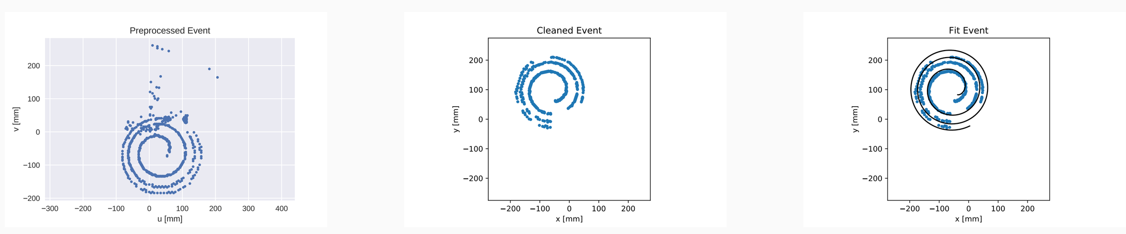


Figure 3. Run 102 Event 93. Left side, a preprocessed event showing all data points recorded. Center, event after Hough Transform cleaning. Right side, a fit event. Note the change to the detector coordinate system during cleaning.

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 2T solenoidal magnetic field. Reactions can be measured over a wide range of energies as the beam loses energy in the gas. 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.

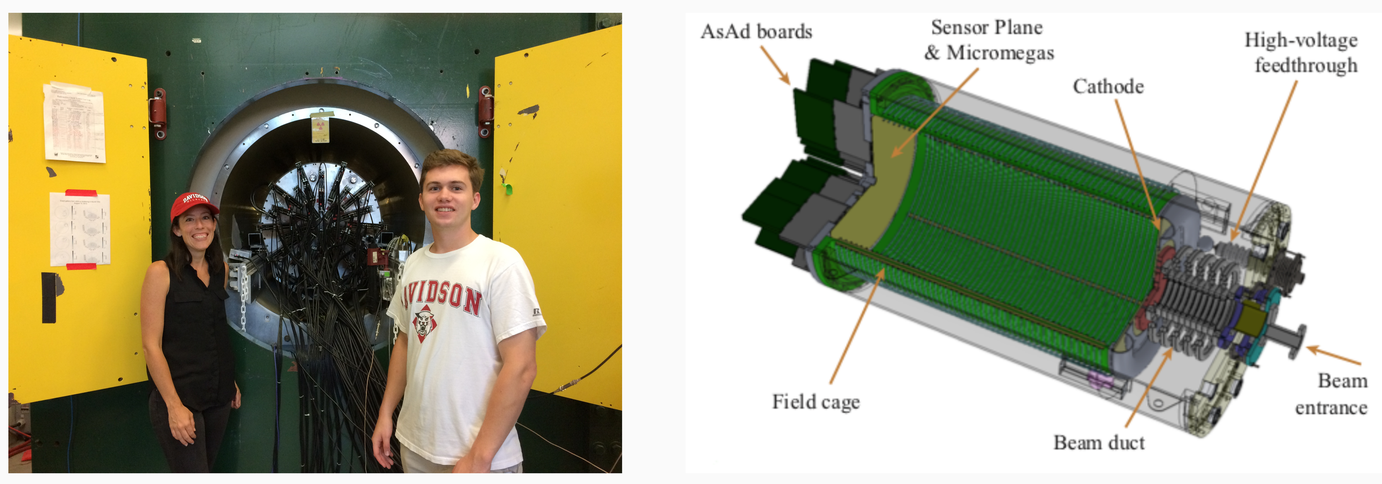
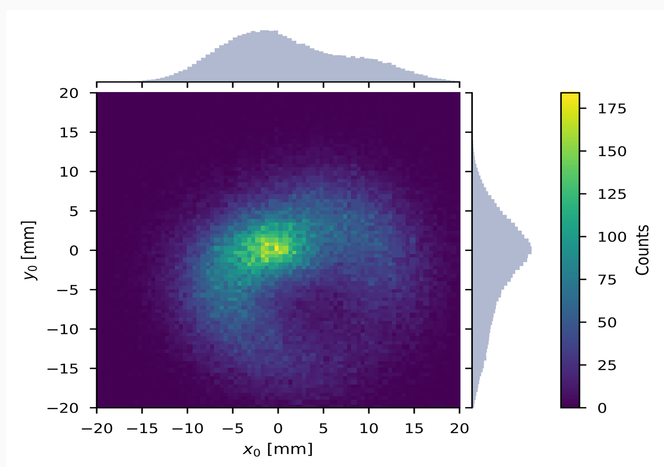


Figure 1. Right side, schematic of the AT-TPC. The rare isotope beam enters the the detector through the right-hand side of the detector and moves left towards the sensor plane

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. Once the data from an experiment has been fit, there is enough information to reconstruct the energy of the projectile (in this case ^{40}Ar) at the vertex of the reaction in two different ways.

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. The vertex energy can also be reconstructed through **kinematics** using the initial energy and scattering angle of the recoil particle which are obtained in the fitting process. The results from analysis of ^{40}Ar data are limited by a smaller dataset due to the magnetic field only being used for about half the experiment.



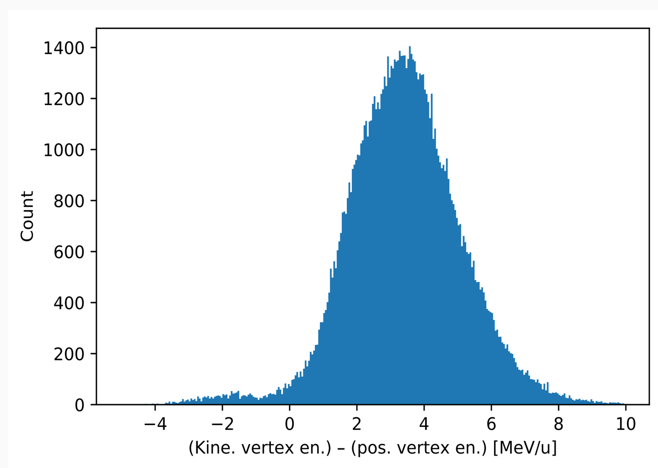


Figure 4. Left side, distribution of vertex positions in the plane transverse to the detector.
Figure 5. Right side, difference between the vertex energy as calculated from kinematics and vertex position. The trend of the count away from 0 on the x-axis is indicative of a problem with the vertex energy calculated from kinematics.

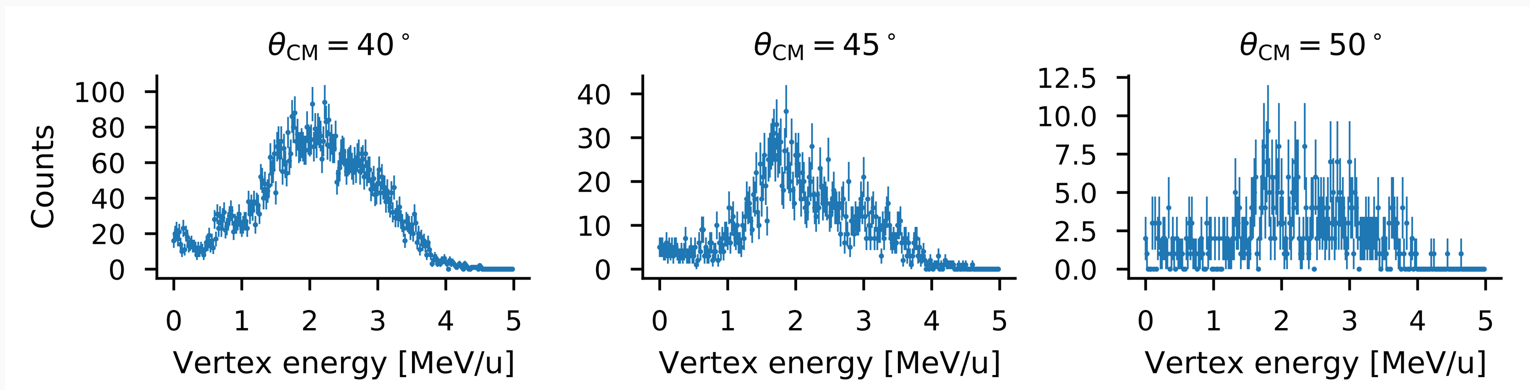


Figure 6. Unnormalized excitations functions as a function of the ^{40}Ar vertex energy in the laboratory frame shown for multiple center-of-mass scattering angles (θ_{cm}). Ideally there would be better statistics for higher θ_{cm} but this was not possible due to the limited dataset.

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 manual for the pytpc framework will help experimentalists from around the world apply pytpc 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-