Probing a possible excited state of tritium via the ^{6}He(p,t)α reaction with TexAT

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The ^{3}H nucleus, or triton, is a well-studied few-body system. However, there remains uncertainty as to whether an exited state, t*, exists or rather, if there are specific reaction dynamics that lead to a resonance-like behavior in the n-d channel. Two previous experiments studying ^{6}He(p,t)α by D.V. Aleksandrov [1] and G.V. Rogachev [2] observed an enhancement in the final α-particle spectrum corresponding to an excitation energy of about 7 MeV in the triton. This enhancement was not able to be differentiated as an excited state or some sort of a final-state interaction due to the measurements being done at single beam energies.

To overcome the limitations of the single-beam energy measurements, the Texas Active Target Time Projection Chamber [3] (TexAT TPC) has been utilized for the current experiment. Using a thick target allows one to measure the incoming ^{6}He beam at multiple energies simultaneously as the beam loses energy in the gas. The pixelated Micromegas (MM) region allows for reconstruction of reaction tracks while the Si+CsI detector wall at forward angles collects the reaction products that are too energetic to stop fully in the gas. The goal of such an experiment is to reconstruct the ^{6}He(p,t) Q-value for multiple energy slices along the beam axis using a reconstructed vertex location and energy deposited by the α-particle in one of the Si detectors. Observing the shape of the outgoing α-particle spectrum can indicate whether a peak as a function of energy is present, therefore whether t* exists.

Fig. 1 shows a cartoon of the schematic for the October 2020 measurement, which was performed at the Texas A&M Cyclotron Institute using the K150 cyclotron and the Momentum Achromat Recoil Separator [4] (MARS) beamline. The active target was 260 Torr isobutane (C_4H_{10}) gas inside the main TexAT volume and the ^{6}He beam was part of a ^{9}Li/^{6}He/^{3}H cocktail beam produced by MARS using a primary ^{7}Li beam on an ^{18}O gas cell. The initial ^{6}He beam was 40 MeV at the MARS silicon detector during the setup and tuning. After passing through a monitoring scintillator, thin aluminum degraders, and the Havar entrance window to the TexAT chamber, the beam energy was about 32.5 MeV. Uncertainty in the beam energy comes from the ^{6}He energy loss in the isobutane, including the beam spot size enlarging in the gas, and from the final slit settings of MARS. However, this beam was still suitable for measuring multiple energy slices along the active MM region of TexAT with about 1 MeV Q-value energy resolution.

Selection of events is done by checking for energy deposited in the side regions of the MM with a corresponding hit in one of the Si detectors on the same side. In addition to the desired ^{6}He(p,t) events, there will of course be background, especially at lower α-particle energies. To demonstrate that the analysis code was functioning, the ^{6}He(p,t) ground state events were the initial focus due to the high, positive reaction Q-value of 7.5 MeV. Events with Si detector hits greater than 16 MeV were selected to eliminate the scattered ^{3}H and ^{6}He beam particles from the initial analysis. Background in this region was

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mostly due to ^{6}He elastically scattering from the protons or ^{12}C in the isobutane. Using the Q-value of 0 MeV for the elastic processes, coupled with eliminating short arm lengths indicative of ^{12}C scattering helps to clean up the ^{6}He(p,t) ground state spectrum.

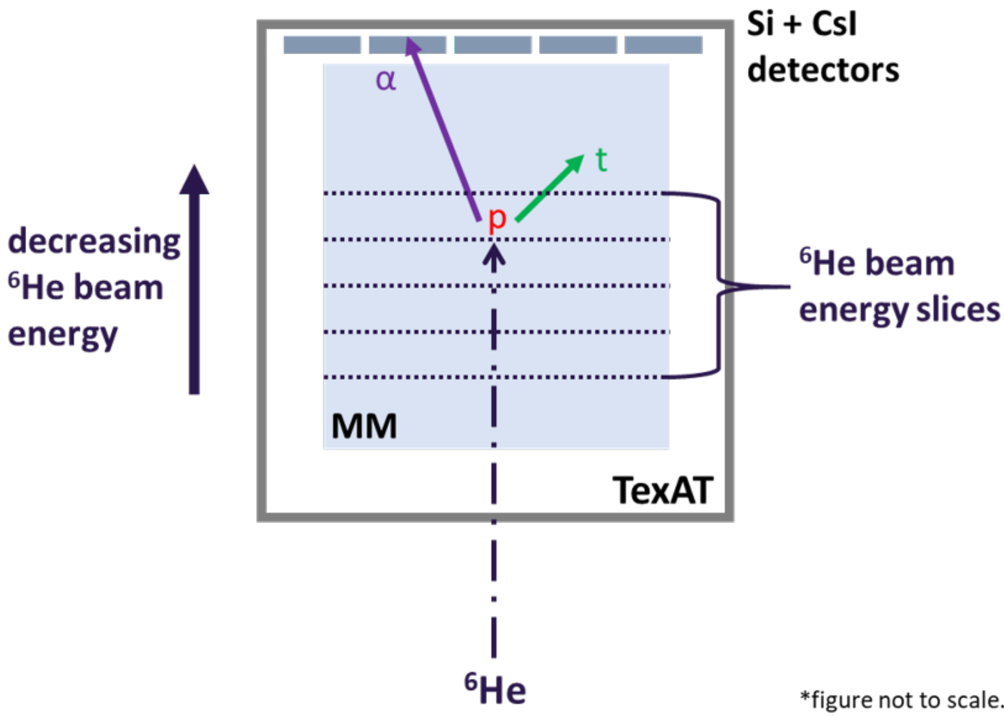

Fig. 1. Concept for ^{6}He(p,t) measurement and subsequent analysis technique using TexAT.

As part of the calculations for the ^{6}He(p,t) track fits, the energy of the beam and the outgoing α-particle at the reaction vertex and the angles of the two outgoing arm tracks are calculated. Utilizing the kinematics for the α-particle track angle versus other particle track angle provides a distinct cut for desired ground state events, and the resulting Q-value plot is shown in Fig. 2. This is an exciting feat because not only does it indicate that the analysis code is working, but more importantly because it represents the first successful two-nucleon transfer reaction using TexAT!

The next steps will focus on the potential t* events, which are more realistically going to be d+n events; the three-body decay to p+n+n is not possible at this energy. The kinematics for the reconstructed vertex α-particle energy versus α-particle angle will be important to distinguish the ground state events from the potential t* events, especially as one reduces the Si detector energy cut. An anti-gate for the ground state events can be implemented because they are separated, reducing uncertainty in the remaining events to analyze. Additionally, working with the well-benchmarked GEANT4 simulation for TexAT will help shed light on how the tracks for the t* decay to the d+n channel should look.

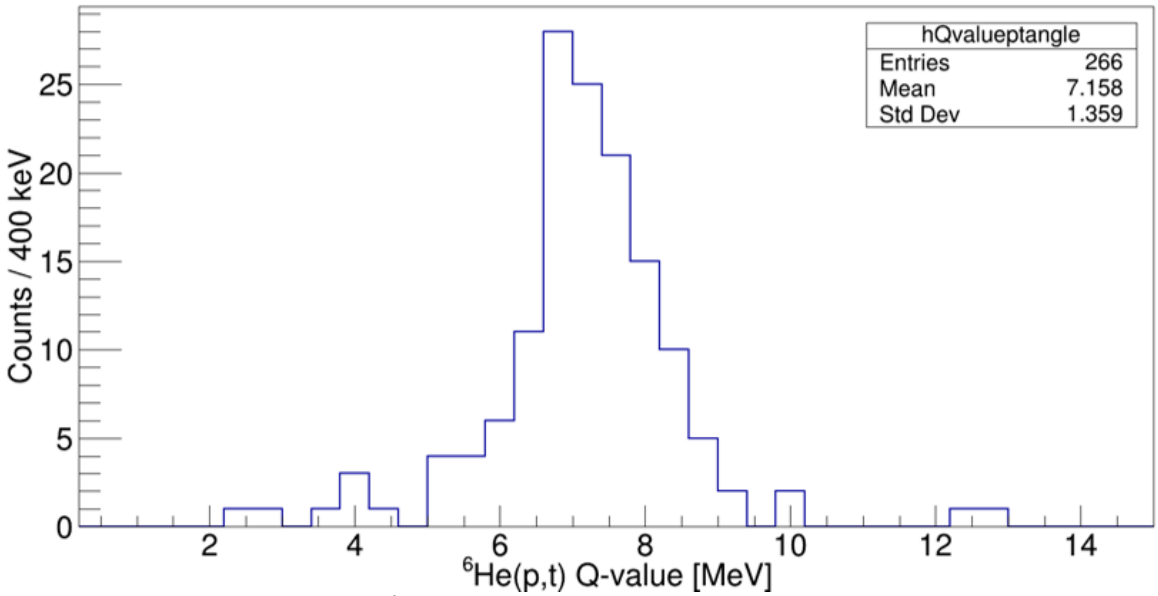

Fig. 2. Q-value reconstruction for ^{6}He(p,t) ground state for kinematically-allowed outgoing α-particle angles. The deviation from the expected 7.5 MeV is likely in part due to uncertainty in the assumed ^{6}He beam energy used in the calculations.

[1] D.V. Aleksandrov *et al.*, JETP Lett **59**, 320 (1994).

[2] G.V. Rogachev *et al.*, Phys. Rev. C **68**, 024602 (2003).

[3] E. Koshchiy *et al.*, Nucl. Instrum. Methods Phys. Res. **A957**, 163398 (2020).

[4] R.E. Tribble *et al.*, Nucl. Instrum. Methods Phys. Res. **A285**, 441 (1989).