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Measuring the ^{15}O(α,γ) ^{19}Ne Reaction in Type I X-ray Bursts using the GADGET II TPC: Software

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Abstract. ^{15}O(α,γ) ^{19}Ne is regarded as one of the most important thermonuclear reactions in type I X-ray bursts. For studying the properties of the key resonance in this reaction using β decay, the existing Proton Detector component of the Gaseous Detector with Germanium Tagging (GADGET) assembly is being upgraded to operate as a time projection chamber (TPC) at FRIB. This upgrade includes the associated hardware as well as software and this paper mainly focusses on the software upgrade. The full detector set up is simulated using the ATTPCROOTv2 data analysis framework for ^{20}Mg and ^{241}Am.

1 Introduction

A type I X-ray burst can occur when a binary system consisting of a neutron star and an ordinary star is gravitationally bound so that hydrogen-rich material is accreted onto the surface of the neutron star [1]. The peak temperature in these bursts is of the order of 1-2 GK, enabling breakout from the CNO cycles and leading to the synthesis of heavy elements with mass number up to 100 [1]. There are a few reaction bottlenecks in the study of type I X-ray bursts whose unknown reaction rates can have large effects on simulated X-ray burst profiles [2]. The ^{15}O(α,γ) ^{19}Ne reaction in particular has been singled out as the most important reaction rate out of all currently unknown rates to measure [3]. At breakout temperatures ($\approx$0.5 GK), this reaction is strongly dominated by a single resonance with center of mass energy 506 keV corresponding to a ^{19}Ne state having excitation energy of 4034 keV [4]. It is technically not feasible to measure the strength of this resonance directly with current facilities due to the need for a very intense and low-energy beam of ^{15}O. However, it is possible to determine the resonance strength indirectly from the spin, lifetime and branching ratio (Γ_α/Γ)

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of 4034 keV state. Since the spin and lifetime are well known one only needs to measure Γ_α/Γ to determine the strength [5]. Attempts have been made to measure Γ_α/Γ using direct reactions to populate the 4034 keV state and search for the α-particle emission, but they have effectively only led to strong upper limits of $(2.9\pm2.1)\times10^{-4}$ [6]. With this strong motivation, we have proposed an experiment to measure a finite value for Γ_α/Γ and hence the reaction rate at FRIB using an upgraded version of GADGET [7]. These measurements will proceed via the ^{20}Mg(βpα)^{15}O decay sequence using β decay of ^{20}Mg followed by a proton-emission to the 4034 keV ^{19}Ne state. We are currently upgrading GADGET's Proton Detector into a TPC with the goal of resolving and identifying the proton and the α-particle tracks. A high granularity MICROMEGAS board with 1024 (2.2×2.2 mm^2) pads and high-density GET electronics [8] has been installed to accommodate the large number of electronics channels. In order to test the functionality of TPC, a ^{241}Am source is placed inside the detector near the upstream end. The TPC has been simulated using the ATTPCROOTv2 data analysis framework based on the FairRoot package for ^{20}Mg and ^{241}Am decay events. LISE++ simulations were also performed in order to model the FRIB beam properties and purity. The paper is organized as follows: Sect. 2 illustrates in detail the ATTPCROOTv2 framework and Sect. 3 highlights the result of these simulations and the conclusions.

2 ATTPCROOTv2 Simulations

ATTPCROOTv2 is a ROOT based framework which requires external libraries (FairSoft and Fair Root) and a set of physics generators to simulate and analyze data from Active Target Time Projection Chamber (AT-TPC) and its prototype detectors [9]. Using this framework, a user can unpack as well as analyze the data and also create a customized geometry of interest for performing realistic simulations on an event-by-event basis using a virtual Monte Carlo package. Each generated event can correspond to a particular decay sequence including ^{20}Mg(βpα)^{15}O and ^{241}Am α-decay for the present case. Once the simulated data is created, pulse shape analysis is used to process the readout from the pad planes. Pattern recognition algorithms can be used to evaluate each event, and the trajectories of the particles in the detector can then be tracked. The Monte Carlo simulations are performed using the Geant4 toolkit and the HDF5 library is needed for data formatting. More information about this simulation package and digitization can be found in Ayyad *et al.* [9].

3 Results and Conclusion

Using the method described in Sect. 2, simulated tracks were analyzed. The ^{20}Mg(βpα)^{15}O events of interest will have a unique 3D topology in the TPC. The proton energies will be roughly 1.2 MeV based on detailed Doppler broadening analysis of the 4034-keV γ-ray peak [10]. For these simulations, P10 gas mixture (90% Ar and 10% CH_4) at atmospheric pressure was considered. The protons will be identified by their characteristic Bragg curves and have a range of 2-3 cm. The α particles will deposit 506 keV of total energy in very short (<4mm), dense tracks at the point of proton emission. The ranges can be extended if desired by lowering the gas pressure at the expense of beam stopping efficiency. Figure 1 (a) shows a simulated event of interest inside the detector geometry and the projection of a proton-α track on the pad plane is depicted in Figure 1 (b). The scattered points between 10-30 mm in Figure 1 (b) refers to the β-particles from the decay of ^{20}Mg to ^{20}Na. ^{241}Am α-decay events were also simulated as shown in Figure 1 (c) and Figure 1 (d), respectively. Based on these simulations, a machine learning algorithm is being developed that will be integrated with the ATTPCROOTv2 analysis framework to identify candidates in the data. Transfer learning will be used to refine the machine-learned models after the experiment using real in-situ data on ^{20}Mg(βpα)^{15}O events for single protons and ^{20}Mg($\beta\alpha$)^{16}O daughter-decay events for single alphas.

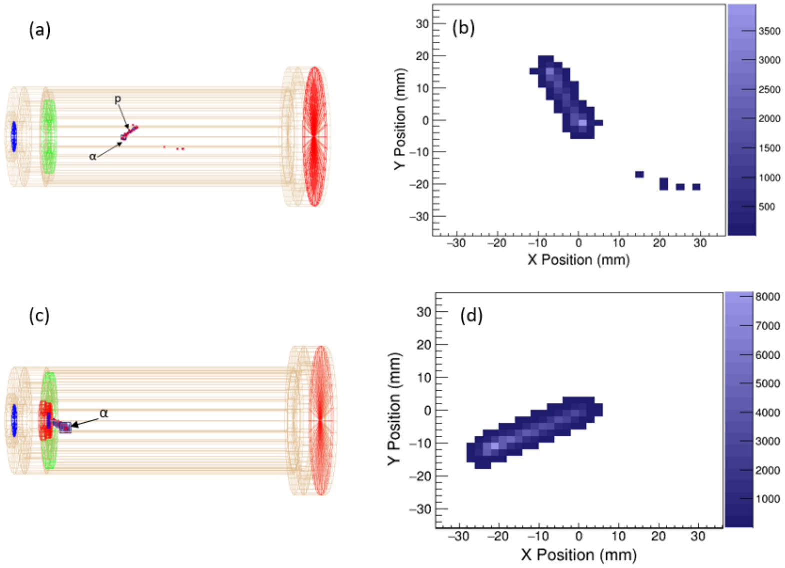

Figure 1. Panel (a) and (b)-ATTPCROOTv2 simulation of GADGET's TPC for ^{20}Mg(βpα)^{15}O, 3D render and 2D projection. Panel (c) and (d)-ATTPCROOTv2 simulation of GADGET's TPC for ^{241}Am α-decay sequence, 3D render and 2D projection.

LISE++ simulations were performed using narrow slit settings in the pre separator stage to reduce the momentum acceptance to 0.16% for ^{36}Ar primary beam with an energy of 200 MeV/A, which produces a ^{20}Mg secondary beam having energy of 107.2 MeV/A. The simulation predicts a beam purity of 99.985% with ^{15}N and ^{16}O as stable contaminants.

These simulations will be useful in selecting events of interest based on their unique signature to provide background free measurements.

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References

[1] H. Schatz *et al.*, Phys. Rev. Lett. **86**, 3471 (2001).
[2] R. H. Cyburt *et al.*, Astrophys. J. **830**, 55 (2016).
[3] M. Wiescher *et al.*, J. Phys. G **25**, R 133 (1999).
[4] B. Davids *et al.*, Astrophys. J. **735**, 40 (2011).
[5] S. Mythili *et al.*, Phys. Rev. C **77**, 035803 (2008).
[6] W. Tan *et al.*, Phys. Rev. Lett. **98**, 242503 (2007).
[7] M. Friedman *et al.*, Nuclear Instrum. Methods in Physics Research A **940**, 93 (2019).
[8] E. Pollacco *et al.*, Nuclear Instrum. Methods in Physics Research A **887**, 81 (2018).
[9] Y. Ayyad *et al.* Nuclear Instrum. Methods in Physics Research A **954**, 161341 (2020).
[10] B. Glassman *et al.* Phys. Rev. C **99**, 065801 (2019).