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Warsaw active-target Time Projection Chamber for studying astrophysical reactions with gamma and neutron beams

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A joint experimental programme is carried out by University of Warsaw (Poland), University of Connecticut (USA), ELI-NP/IFIN-HH (Romania) and Sheffield Hallam University (UK) in view of studying (p,γ) and (α,γ) nuclear reactions of current astrophysical interest, which regulate abundance of carbon and oxygen elements in the Universe. In particular, the production of ^{16}O and burning of ^{12}C via the $^{12}C(\alpha,\gamma)^{16}O$ reaction takes place in stars at energies close to the Gamow peak. Existing theoretical models of stellar evolution have to rely on extrapolated cross sections from the data collected at energies higher than the interesting Gamow peak region due to various limitations of present experimental set-ups, such as maximal available ion beam currents and target deterioration in case of typical direct reaction measurements.

The methodology employed in this work use the principle of detailed balance in nuclear reactions. Time-reverse reactions, such as $^{16}O(\gamma,\alpha)^{12}C$, are studied using a dedicated active-target Time Projection Chamber (TPC) detector by reconstructing energies and angular distributions of the charged products of photo-disintegration reactions induced by intense, semi-monochromatic and collimated gamma-ray beams. Composition and density of the gaseous target can be tuned for reaction of interest and particular energy of the gamma beam. For the benchmark reaction of $^{12}C(\alpha,\gamma)^{16}O$ the envisaged goal is to measure cross sections with uncertainty smaller than 20% down to 1 MeV in the centre-of-mass reference frame. In addition, the relative contributions of E1 and E2 components in the E1+E2 cross section will be extracted from the measured angular distributions at different gamma beam energies.

The developed apparatus (Warsaw TPC) has an active volume of $33 \times 20 \times 20$ cm^3 that is centred around the beam axis. It employs a set of Gas Electron Multiplier micro-pattern structures for amplification of primary ionization induced by charged reaction products in the gaseous target kept under lower-than-atmospheric pressure. The kinematics of charged particles is reconstructed on event-by-event basis from specially arranged, redundant signal strip arrays (*u*-*v*-*w*). The readout system for about 10^3 channels is based on the front-end digitizers developed by the Generic Electronics for TPCs (GET) collaboration with a customized FPGA concentrator developed at UW.

First experiments were conducted in years 2020-2022 with γ-ray beams (8.5-14 MeV photons) from the High Intensity Gamma-Ray Source (HIγS) facility, Triangle Universities Nuclear Laboratory, Durham, NC, USA, and with the neutron beam from the IGN-14 neutron generator (14.1 MeV neutrons) at the Institute for Nuclear Physics, Polish Academy of Science, Cracow, Poland.

In this work, first results on ^{16}O photo-disintegration reaction from the experiment conducted at HIγS will be presented for the gamma beam energies corresponding to nominal E_{CM} from 6.7 MeV down to 1.35 MeV. The results are based on a simplified event reconstruction algorithm after analysing only partial statistics available, while work on more sophisticated data processing is still ongoing. A new multi-purpose version of the TPC apparatus that can study nuclear processes with radioactive ion beams, in addition to γ-ray and neutron beams, will be presented as well.

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