Report on doctoral thesis "Study of 16O(γ, α)12C nuclear reaction with the Warsaw TPC Detector" by Mateusz Fila

Provided by Hendrik Schatz
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Scientific Motivation

The thesis addresses one of the most important open questions in nuclear astrophysics, the rate of alpha capture on ^{12}C in red giant stars. This reaction plays a central role in stellar evolution, and its determination with sufficient accuracy for stellar models has been a challenge for the field since more than half a century. While experimental data have accumulated steadily, measurements are still far from being sensitive enough to probe the extremely slow reaction at the relevant energies for stars. It is therefore imperative to develop novel experimental techniques that can enable progress, and this is a recognized goal of the nuclear astrophysics community. This thesis addresses this challenge by advancing the development of a new approach based on measuring the inverse reaction induced by a gamma-ray beam using an active target time projection chamber.

The importance of improved measurements of the 12C(a,g) reaction in stars, and therefore the importance of this thesis work, have further increased in recent years with two major developments in astronomy: the advent of gravitational wave detection has now opened up new pathways to probe the mass distributions of black holes in the universe by detecting gravitational waves from black hole binary mergers. Stellar evolution predicts specific gaps in the mass distributions, and it has been shown that these gaps depend sensitively on the 12C(a,g) reaction rate. The other development is the advent of asteroseismology of white dwarf stars, which offers pathways to determine the detailed internal composition profiles of the stars. Again, these depend sensitively on the 12C(a,g) reaction rate. A more accurate determination of the rate is therefore needed to interpret these new cutting-edge observational data.

The development described in the thesis indeed offers a promising pathway forward. There are distinct advantages of measuring the inverse reaction, as the thesis nicely explains, and TPCs offer excellent sensitivity to rare reaction events, as the results of the thesis nicely demonstrate.

Evaluation of Individual Chapters

Introduction: The motivation is well described, and the case for measuring the inverse instead of the forward reaction is well made. The important pieces are all there, including the description of previous work, the generation of gamma beams, and the descriptions of different types of detectors. These sections are relatively short, but mostly adequate. I would have hoped the discussion of previous measurements would also have mentioned inverse kinematics efforts, for example at ERNA, and beta-delayed particle emission measurements to place the present work in the variety of techniques that have been attempted or are under further development.

Detector: The detector description is adequate and includes the workings of the detector itself as well as the data acquisition processing chain with different possibilities for trigger choices.
Experiment: The description of the experiment is adequate and complete. Especially Fig. 3.3 is appreciated that shows the different reaction energies probed by the experiment in respect to the results of previous work. The description of the various parameter settings, and the details of the beam centering approach are especially nice. They will be useful for subsequent people working on the detector, and they demonstrate that the student has worked closely with the system.
Reconstruction: The details of the track reconstruction process are nicely explained and illustrated with specific examples. It is amazing that the reconstruction could be done manually, and it is interesting to see how that was organized. The detailed discussion on how to deal with and quantify misidentifications is appreciated.
Analysis: The analysis chapter provides a detailed walk through for all relevant steps of the analysis, including determination of beam intensity integration, energy spectrum, a nice cross check of drift velocity, the fiducial cut investigation, identification of contaminant reactions, energy determination, search for non-uniformities, beam polarization. This section shows that carful experimental work was performed. Also described is the important analysis of angular distributions and the disentangling of the E1 and E2 contributions.
Results: The results section describes the main results adequately (see below for a evaluation of the results themselves).
Outlook: As this work is an intermediate step towards a bigger goal, the outlook is particularly important. Indeed, automatic track recognition and analysis are key aspect of followup work and are discussed nicely. The discussion of the future absolute cross section determination focuses on determination of the beam integral. I am missing a bit a discussion of the efficiency, which will also be important for the absolute cross section determination, in particular in light of the various cuts and event identification challenges.

Comments on Editorial Aspects

The quality of the writing is adequate. There are many English language mistakes, but overall they in most cases do not affect contents understanding. The bibliography is adequate. While a somewhat broader context could be given in terms of previous measurements, all provided material has adequate citations.

Errors, Changes, Improvements

While the thesis would benefit from English language editing, and some of the introductory discussions are quite short, the overall quality is adequate and there aren't any major issues that would affect the acceptance of the thesis.

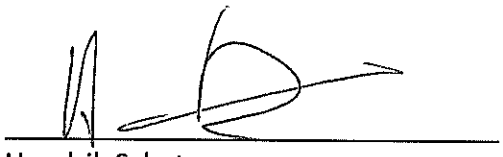
Evaluation of Overall Thesis Work and Results

The thesis work takes the developed detector through a first cycle of data taking with beam and subsequent analysis. It represents an impressive technical achievement, and a very important step towards the ultimate goal of improving the stellar 12C(a,g) reaction rate. It is particularly impressive that in form of the E1/E2 decomposition, data of scientific importance could be

extracted already at this stage. The data show that there is no indication of a breakdown in the standard approach of disentangling the various components, as was postulated in some previous work. On the technical side, the level of agreement of the relative cross section with previous work demonstrates for the first time that the TPC works, and inspires confidence in the technical approach. As such its an important milestone. The analysis also revealed an interesting energy-position correlation in the HIgS beam, which is an additional nice result with potential impact on many other experiments. Of course much remains to be done. It is a bit unfortunate that neither a machine-based identification and analysis of TPC tracks nor a Monte Carlo framework for testing the analysis was available. While the thesis work achieved its goal, the higher statistics and more comprehensive error analysis would have led to even nicer results. Nevertheless, as a consequence of this excellent work, the project made a major step forward towards a new measurement of the low energy 12C(a,g) cross section, and as such represents also a significant step of progress for the field of nuclear astrophysics as a whole.

Final Assessment

The thesis achieves significant technical and scientific progress in a very important area of nuclear astrophysics, is scientifically and technically sound, and describes the work adequately. I therefore recommend to accept the thesis.



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