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Nuclear Astrophysics With Gamma-Beams

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Nuclear Astrophysics With Gamma-Beams

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Abstract. Gamma-Beams now available at the HIγS facility of the TUNL at Duke University and soon to be available at the Extreme Light Infrastructure - Nuclear Physics (ELI-NP) in Magurele, near Bucharest, Romania, present scientific opportunities for progress in Nuclear Physics and Nuclear Astrophysics. In particular the use of Time Projection Chamber (TPC) detectors in these facilities will address the large confusion of conflicting data on the ^{12}C(α, γ) reaction and promise to yield progress on this four decades old problem.

1. Introduction: The ^{12}C(α, γ) Reaction

Over the last four decades conflicting data plagued our attempts to deduce the cross section of the ^{12}C(α, γ) reaction at low energies and did not allow an accurate extrapolation of the astrophysical s-factor to stellar energies. In particular conflicting data did not allow us to chose between the high value ($\sim$80 keVb) and the low value ($\sim$10 keVb) solutions of the E1 s-factor at stellar energies. The so called "cascade" s-factors were deduced with large uncertainty, as large as a factor of 25. And the E1-E2 mixing phase angle (ϕ_{12}) was shown to conflict with unitarity [1]. Recent modern measurement of S_{E1} and S_{E2} at Stuttgart, were demonstrated [1] to have error bars which are considerably larger than quoted by the authors [2, 3]. In spite of the little progress in measurements of the cross section of the ^{12}C(α, γ) reaction, several recent R-Matrix global analyses claim to achieve accuracies of the total s-factor (E1 + E2 + cascade) between 4.5% and 12%. In this paper we first examine one such recently published claim [4] and we point out to the use of gamma-beams to allow for future progress in the field.

The data used in a recent R-Matrix global analysis of the ^{12}C(α, γ) reaction [4] are shown on the left of Fig. 1. We note that in spite of the poor quality of all eight angular distributions measured below E$_\alpha$ = 2.0 MeV, the authors still claim to be within reach of extracting the total s-factor (E1 + E2 + cascade) with accuracy nearing 10%. Furthermore, in the same figure we show the published analysis of the very same angular distribution measured at E$_L$ = 1.79 MeV. Other angular distributions used in [4] were also analyzed in [1] and the extracted error bars are shown to be very large, similar to the error demonstrated at E$_L$ = 1.79 MeV. These analyses (e.g. of the angular distribution measured at E$_L$ = 1.79 MeV) [1] demonstrate that the E2/E1 cross sections cannot be determined with sufficient accuracy (e.g. better than a factor of 6 at E$_L$ = 1.79 MeV!), casting strong doubt on the authors [4] claim of reaching a 10% accuracy in extracting the astrophysical cross section factor of the ^{12}C(α, γ) reaction.

2. Gamma-Ray Fcailities: The HIγS and ELI-NP

A HIγS gamma-ray facility has been operating by TUNL at Duke University [5] over the last two decades and a new gamma-ray facility is constructed by the EU at Magurele near Bucharest
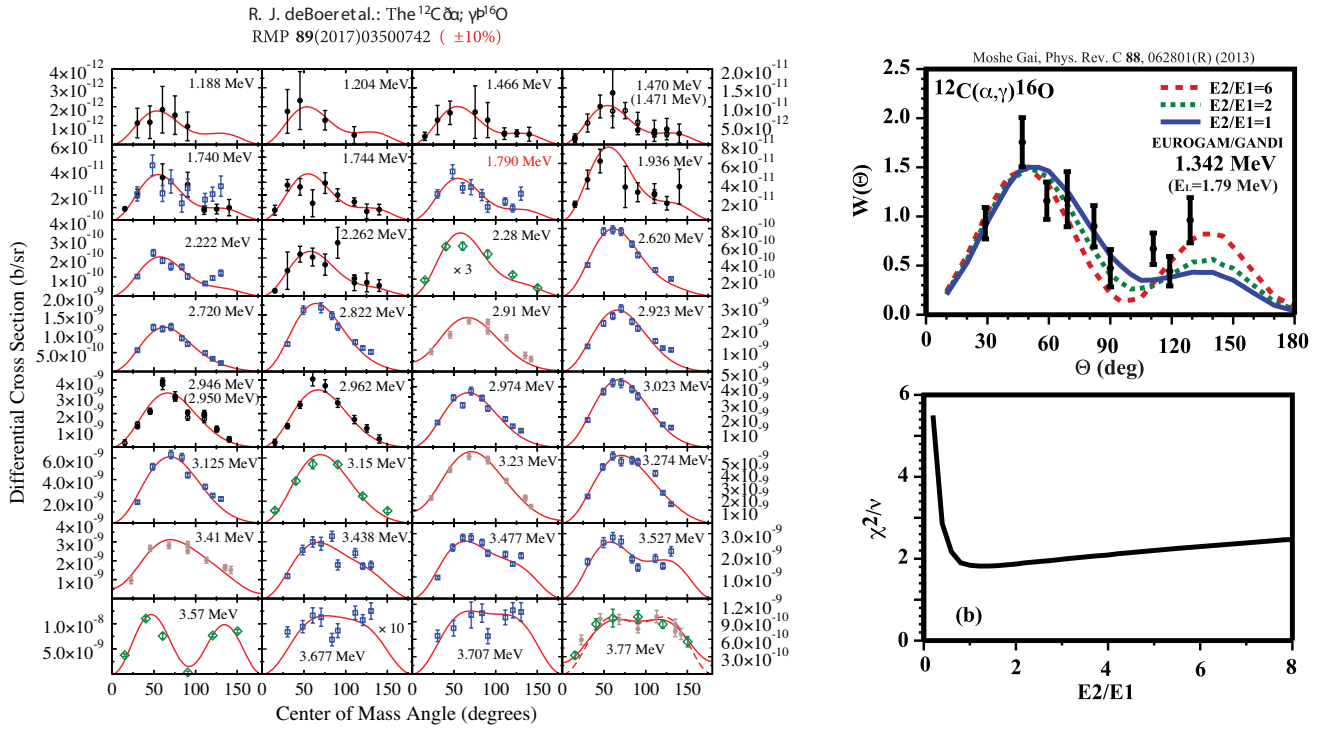
Figure 1. The measured angular distributions of the ^{12}C(α, γ) reaction used in Ref. [4], and analyzed in [1]; e.g. at E$_L$ = 1.79 MeV, as hown on the right.
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Romania [6]. These gamma-ray facilities promise to be essential for progress of measurements in nuclear astrophysics and in particular to resolve the long standing confusion of measurement of the cross section of the ^{12}C(α, γ) reaction.

Active target TPC detectors are a perfect match to gamma-ray ray beams and specifically they allow measurements of complete and detailed angular distributions with unprecedented details since the event can be binned in small size bins (e.g. of 4°) as allowed by the statistics. Such detailed angular distributions measured at the large backward angle range are essential for accurate measurements of the E1 and E2 contributions as shown in Fig. 1.

A schematic diagram of the HIγS O-TPC [7] is shown in Fig. 2 and a rendering of the ELITPC [8] is shown in Fig. 3. While the O-TPC used the opto-electronic chain shown in Fig. 2 for readout of events, the ELITPC will use the electronic u-v-w readout placed on a single multi-layered board as shown in Fig. 3. These detectors are intended among other projects for measuring the ^{12}C(α, γ) reaction with the TPCs operating with 100 torr CO_2 gas [9].

In Fig. 4 we show the anticipated E2 and E1 cross section factors that will be measured at the HIγS (down to 1.7 MeV) and at the ELI-NP (down to 1.1 MeV).

3. Conclusions
R-Matrix global analyses cannot resolve the conflicting measurements on the ^{12}C(α, γ) reaction and a new and bold approach is needed to measure the cross sections at very low energies. This goal quite possibly may be achieved with gamma-ray beams in the newly constructed ELI-NP
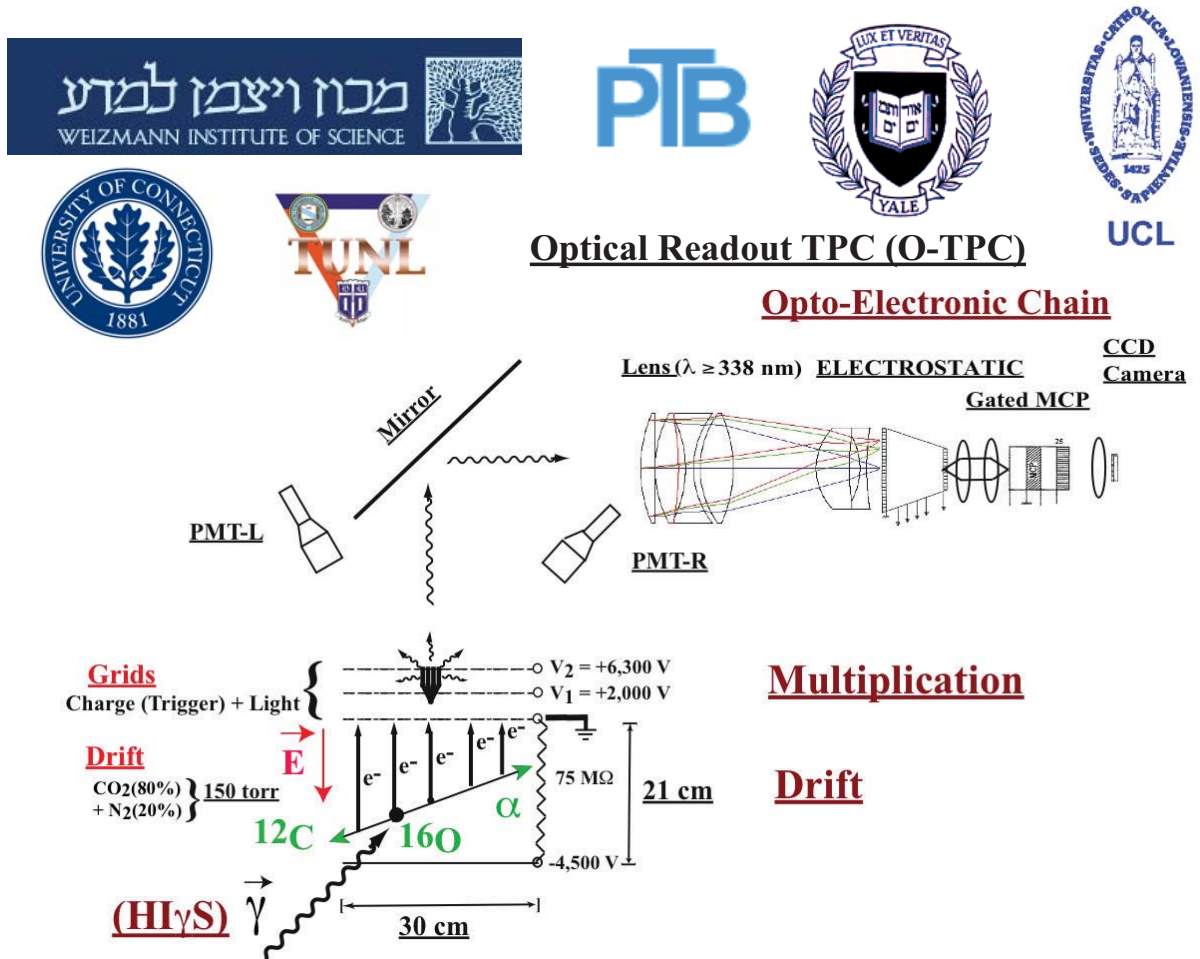
Figure 2. A schematic diagram of the HIγS O-TPC [7].

and the currently operating HIγS facility.
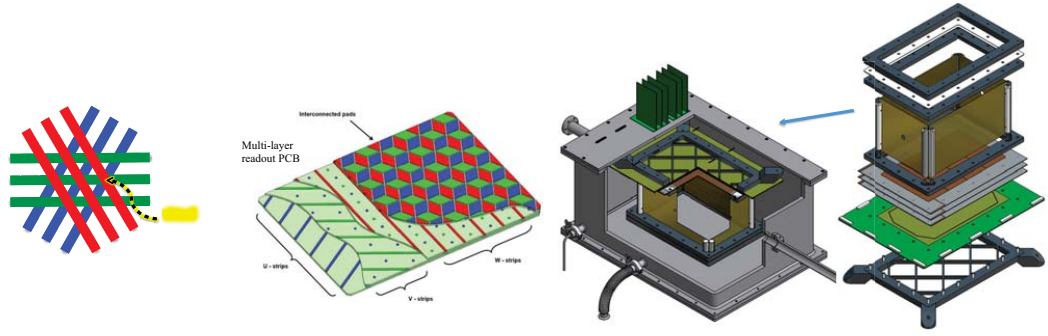
4. Acknowledgements

Figure 3. A rendering of the ELITPC with the u-v-w multilayer board readout [8].
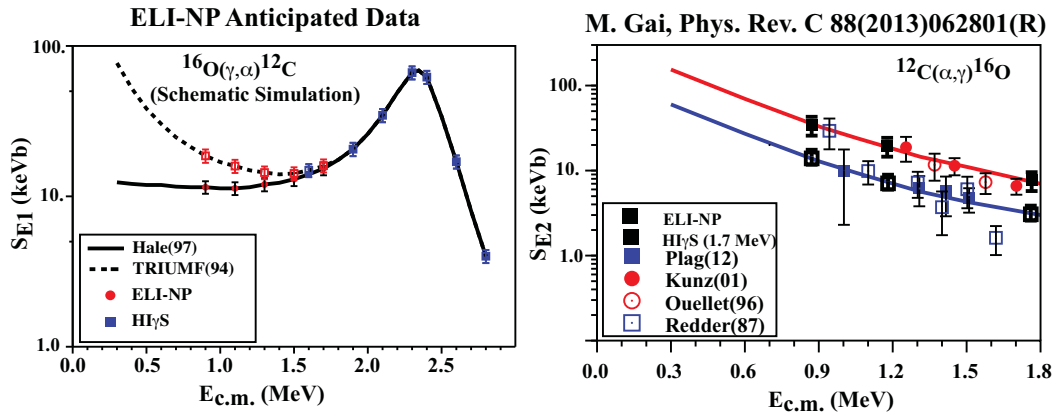

Figure 4. Anticipated results from measurements with the HIγS O-TPC [7] and all ELI-NP ELITPC [8] detectors.

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