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Recent Progress on Heavy-Ion Acceleration: Towards the Fission-Fusion Nuclear Reaction Scheme

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The generation of heavy elements in the universe via the rapid neutron-capture process (r-process) lacks direct experimental probing, as the relevant nuclides lie far-off the last known isotopes near the 'Waiting Point' at N=126. The proposed 'fission-fusion'reaction mechanism aims at investigating this region by using laser-accelerated fissile ions in a two-stage (fission, fusion) scenario, exploiting their unprecedented high bunch density [1]. In a first development step, the acceleration of gold ions is investigated, as recently achieved in our measurement at the PHELIX laser with 500 fs long pulses [2]. In this experiment, the laser-based acceleration of Au ions to kinetic energies above 7 MeV/u was demonstrated. Additionally, individual Au charge states were resolved with unprecedent resolution. This allowed to investigate the role of collisional ionization using a developmental branch of the particle-in-cell simulation code EPOCH [3], showing a much better agreement of the simulated charge state distributions with the experimental ones than when only considering field ionization. This work is presently continued at the Centre for Advanced Laser Applications (CALA), using the ATLAS 3000 laser (800 nm central wavelength, 25 fs pulse length). The laser is focused with an f/2 parabola on Au foils with thicknesses from 200 nm to 500 nm. To analyze the accelerated ion bunch, a Thomson-Parabola Spectrometer was designed to resolve heavy ions in high charge states. Spectroscopically controlled radiative target heating is integrated into the setup in order to facilitate the acceleration of gold ions by removing carbo-hydrate surface contaminations. An integrated IR spectrometer allows for in-situ measurements of the heated foil temperature, while allowing for a simultaneous monitoring with a transmission screen camera to detect possible foil damage [4]. Recent results on Au ion acceleration at CALA will be presented together with preparations for the next stage of the fission-fusion process, i.e. laser-driven fission.
Ultimately, these exploratory experimental campaigns aim at preparing for studies at the 10 PW laser facility at ELI-NP with optimum pulse energy and focused intensity.

[1] D. Habs et al., "Introducing the fission–fusion reaction process: using a laser-accelerated Th beam to produce neutron-rich nuclei towards the N=126 waiting point of the r-process", Appl. Phys. B 103, 471-484 (2011)
[2] F.H. Lindner et al., "Charge-state resolved laser acceleration of gold ions to beyond 7 MeV/u", Sci. Rep. 12, 4784 (2022)
[3] M. Afshari et al., "The role of collisional ionization in heavy ion acceleration by high intensity laser pulses" , Sci. Rep. 12, 18260 (2022)
[4] M. Weiser, "Development of a Spectroscopic Real Time Temperature Diagnostic for Laser Heated Thin Gold Foils", Master Thesis, LMU Munich, 2021

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