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Editorial: Advances in laser-driven nuclear physics

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Editorial on the Research Topic
Advances in laser-driven nuclear physics

Since the groundbreaking discovery of radioactivity by Henri Becquerel in 1896, nuclear physics has stood as one of the cornerstones of physics, driving scientific progress and innovation for over a century. Throughout this time, researchers have harnessed the power of radioactive sources, accelerators, and reactors to unravel the mysteries of atomic nuclei such as their intricate structures and interactions, establishing nuclear physics as a vital pillar of basic scientific research. The profound insights gained from these endeavors have not only enriched our understanding of atomic nuclei but also sparked revolutionary advancements in various fields. Nuclear power, for instance, provides clean and efficient energy. Radiation therapy has revolutionized medical treatment, offering hope to patients battling cancer and other diseases. Medical imaging techniques, leveraging nuclear physics principles, have revolutionized diagnostics, enabling doctors to see inside human bodies with unprecedented clarity. In recent years, the technological progress has ushered in a new method in nuclear physics research. The emergence of high-intensity lasers has opened up a whole new area of possibilities for exploring and manipulating nuclear processes. These laser pulses, with ultra-short durations and extreme intensities, have the potential to trigger or significantly influence nuclear reactions and applications in ways that were previously unimaginable. As a result, lasers are rapidly emerging as a complementary platform to accelerators and reactors, offering scientists a novel toolset for delving deeper into the intricacies of nuclear physics. By harnessing its unique properties, researchers can now study nuclear dynamics under extreme conditions, probe the limits of nuclear stability, and explore new avenues for nuclear energy production and medical treatments.

The field of laser driven nuclear physics currently confronts a multitude of pressing challenges that demand innovative solutions. One important issue revolves around achieving sufficient beam intensities to delve into the complex mechanisms of multiple capture processes in nuclear astrophysics, which are crucial for unraveling the mysteries of stellar evolution and the origin of elements in the universe. Furthermore, the electron screening in extreme plasma environments poses a significant hurdle, necessitating a deeper understanding of how this effect modulates nuclear interactions under such extreme conditions. Another formidable challenge lies in accurately measuring nuclear reaction parameters amidst the dynamic and unstable feature of plasma environments. This requires the development of advanced diagnostic techniques capable of withstanding the conditions while maintaining exquisite precision, enabling scientists to extract reliable data essential for advancing theoretical models and simulations. Concurrently, the quest for robust detection techniques that can effectively shield against electromagnetic interference under intense laser irradiation is imperative. Such technologies are vital for ensuring experimental measurements and advancing the ability to observe and interpret nuclear phenomena. Moreover, the exploitation of intense lasers as a means to manipulate and control nuclear reactions and excitations represents a frontier area of research with immense potential. This endeavor necessitates a comprehensive understanding of the intricate interplay between laser-matter interactions and nuclear dynamics, as well as the design of innovative laser-based schemes tailored to harness these interactions for practical applications.

Hence, we have compiled this Research Topic, which has undergone a series of meticulous processes spanning approximately 1 year, including planning, manuscript processing, peer review, and editing. Following rigorous peer evaluations and editorial scrutiny, we are delighted to present a Research Topic of 18 research papers contributed by prestigious academic institutions and research centers, such as the Extreme Light Infrastructure (ELI) in Europe, the Queen's University of Belfast in UK, Friedrich Schiller University Jena and GSI Helmholtzzentrum für Schwerionenforschung in Germany, Politecnico di Milano in Italy, Wigner Research Centre for Physics in Hungary, Peking University, Fudan University, China Academy of Engineering Physics, National University of Defense Technology, the Chinese Academy of Sciences, and China Institute of Atomic Energy. The Research Topic focuses on cutting-edge and applied research directions that intersect laser-plasma physics and nuclear physics, encompassing experimental and theoretical numerical simulations. Specifically:

- In the realm of intense laser-driven nuclear reactions, the research papers delve into a wide range of topics. They encompass experimental studies on deuterium-deuterium fusion within plasma environments, as well as investigations into hydrogen-boron fusion experiments driven by intense lasers, accompanied by measurement techniques for nuclear reaction products. Furthermore, the issue explores the excitation of isomeric states, such as that of thorium-229, and the measurement of photonuclear reaction cross-sections based on laser-gamma sources. Additionally, it addresses applications in the preparation of radioisotope medicines.
- Advanced particle sources are another key area of coverage. This includes proton acceleration utilizing micro-structured targets, the generation of high-charge electron beams, gamma-ray sources, neutron, and muon sources. The issue also features advancements in advanced targetry techniques for particle acceleration.
- Lastly, the Research Topic includes the latest research achievements in the development of hybrid fluid simulation programs and their applications in Inertial Confinement Fusion (ICF). It also showcases the application of machine learning in optimizing muon sources, highlighting the intersection of advanced computational methods with experimental nuclear physics.

This comprehensive coverage underscores the interdisciplinary nature of the field, bridging fundamental physics with technological applications, and showcasing the research in laser-driven nuclear reactions, advanced particle sources, and computational methods for nuclear physics.

The paper "*Plasma polymers as targets for laser-driven proton-boron fusion*" explored plasma-assisted deposition of oligoethylene films on BN substrates for proton-Boron (pB) fusion, varying RF power to control crosslink density and hydrogen content. The films were tested with high-power lasers (TARANIS and PERLA B) for pB fusion, yielding up to 10^8 and 10^4 alpha particles/sr. Radiative-hydrodynamic and PIC simulations analyzed laser-target interaction and proton acceleration. The results indicate hydrogen content, target morphology, and plasma polymer structure significantly impact laser absorption, target expansion, proton acceleration, and pB fusion reactions (Tosca et al.).

Meanwhile, errata notice was issued for the above paper, while scientific conclusions remain unchanged (Tosca et al.).

The paper "*Deuterium-deuterium fusion in nanowire plasma driven with a nanosecond high-energy laser*" investigated the ns laser-nanowire target interaction for D-D fusion, finding yields comparable to planar targets. Numerical analysis at $E_{c.m.}$ = 10–30 keV matched experiments. The MHD simulations show laser energy blockage by target's critical density, limiting enhancement with ns laser. Further research needed to optimize target structures for laser-target energy conversion (Xi et al.).

The paper "*Feasibility study of nuclear excitation by electron capture using an electron beam ion trap*" proposed experimental scheme using EBIT to detect NEEC, a 50-year-old elusive nuclear excitation process. Calculations show NEEC rates >0.1/s for some nuclei. This may confirm NEEC's existence and aid atomic nuclear excitation studies (Wang et al.).

The paper "*Neutron generation enhanced by a femtosecond laser irradiating on multi-channel target*" showed a multi-channel target enhances neutron yield by 4 orders vs. plane target via femtosecond laser. Transverse sheath field accelerates D^+ ions, triggering D-D fusion with modulated neutron angular distribution (Yang et al.).

The paper "*Detection of limited-energy α particles using CR-39 in laser-induced p -^{11}B reaction*" showed CR-39 detector, etched with PEW-25, outperforms NaOH for laser-induced $^{11}B(p,\alpha)2\alpha$, distinguishing α from protons. Calibrated 3–5 MeV αs in PEW-25. Method to estimate α detection limit under our etching conditions (Wang et al.).

The paper "*Theory of isomeric excitation of ^{229}Th via electronic processes*" proposed a unified theoretical framework encompassing NEET, NEEC, and NEIES for ^{229}Th isomeric excitation. Comprehensive calculations of excitation rates and cross-sections are presented, shedding light on electronic processes (Zhang et al.).

The paper "*New measurements of ^{92}Mo(γ,n) and (γ,3n) reactions using laser-driven bremsstrahlung γ-ray*" measured flux-weighted average cross-sections and isomeric ratios of ^{92}Mo photonuclear reactions using laser-driven bremsstrahlung γ-rays. The results, in line with previous works and TALYS 1.9 calculations, extended experimental data to higher energies, clarified discrepancies in

^{92}Mo(γ,n) isomeric ratios, and provided the first cross-sections for ^{92}Mo(γ,3n)^{89}Mo reactions (Wu et al.).

The paper "*Laser-driven production with advanced targets of Copper-64 for medical applications*" showed that radionuclides like Copper-64 are crucial for nuclear medicine. Laser-driven proton accelerators, using Double-Layer Targets, offer a promising alternative for their production. It numerically shows they can yield relevant activities for studies with existing 150 TW lasers (Maffini et al.).

The paper "*Characteristic diagnosis of supersonic gas jet target for laser wakefield acceleration with high spatial-temporal resolution Nomarski interference system*" used a Nomarski interference system to analyze supersonic gas jet targets for laser wakefield acceleration. By studying jet duration, injection position, and gas back pressure, it aims to optimize laser injection timing and position for improved electron beam and radiation source quality (Liu et al.).

The paper "*Simulation and assessment of material mixing in an indirect-drive implosion with a hybrid fluid-PIC code*" showed that hybrid fluid-PIC simulations explore implosion physics and material mixing in ICF. They address limitations of radiation hydrodynamics by modeling ions (Cai et al.).

The paper "*Numerical study of the effect of a magnetic field on Rayleigh-Taylor instability with different density disturbances*" investigated laser-driven RTI in fluids with varying density perturbations using FLASH simulations. Results show that magnetic fields parallel to perturbation vectors inhibit RTI and KH instability, with magnetic pressure as the dominant factor (Sun et al.).

The paper "*Vibration and jitter of free-flowing thin liquid sheets as target for high-repetition-rate laser-ion acceleration*" produced micrometer-thin liquid sheets by colliding jets, optimizing parameters to minimize surface vibrations (≤ 3.7 μm). Studied motion amplitudes' dependence on generation factors. Results enable stable sheet positioning crucial for high-precision laser-ion acceleration experiments (Cao et al.).

The paper "*Kinetic model of resonant nanoantennas in polymer for laser induced fusion*" showed that the studies of light-resonant nanoantennas to polymer embedding reveals shortened resonance wavelength, reduced electron momentum, but stable resonance lifespan. This enhancement is expected to boost laser-induced nuclear fusion. Simulations using PIC method with polymer background confirm the findings (Papp et al.).

The paper "*Ultra-high efficiency bremsstrahlung production in the interaction of direct laser-accelerated electrons with high-Z material*" demonstrated that a highly efficient method to generate ultra-high flux, high-energy bremsstrahlung using DLA electrons interacting with a high-Z tantalum converter. The approach yields~2% laser-to-bremsstrahlung conversion efficiency, producing~6×10^{22} sr^{-1} s^{-1} photon flux with 18 MeV average energy. Photonuclear reactions confirm the production of Ta isotopes (Tavana et al.).

The paper "*Enhanced laser-driven backward proton acceleration using micro-wire array targets*" showed that micro-structured targets boost laser-driven proton beam energy. An ultra-intense laser pulse interacting with micro-wire arrays generates energetic electrons, enhancing sheath fields for proton acceleration. Backward protons reach 16 MeV, 20%–60% higher than flat targets (Fan et al.).

The paper "*Laser-driven muon production for material inspection and imaging*" showed that PW lasers can produce high-flux relativistic muons for radiography. Simulations show 10-PW lasers like ELI-NP can generate $>10^4$ muons/shot, suitable for enclosed material imaging (Calvin et al.).

The paper "*Bayesian optimization for design of high-repetition-rate laser-driven muon source*" showed the potential of high-repetition laser pulses for high-flux muon sources. Bayesian optimization tunes laser-plasma parameters for high-charge ion beams, enabling high-yield muon production. This scheme achieves 10^4 μ^+ at 10 Hz, demonstrating efficient muon source development (Sha et al.).

This Research Topic showcases the advancements in laser driven nuclear physics, a rapidly developing field that uses high-intensity lasers to explore and manipulate nuclear processes. Since Henri Becquerel's discovery, nuclear physics drives scientific progress, and now lasers offer a complementary platform to accelerators and reactors. The Research Topic of 18 research papers, from prestigious institutions worldwide, addresses challenges in laser driven nuclear physics. These papers cover experimental and theoretical aspects, exploring nuclear dynamics under extreme conditions, new ways for energy production and medical applications.

Author contributions

BG: Writing–original draft, Writing–review and editing. CF: Writing–review and editing. AB: Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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