Politecnico di Torino

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ENERGETICS

MUR DM 118 - Modelling of laser-matter interaction for the sustainable energy production by nuclear fusion

Funded By	MINISTERO DELL'UNIVERSITA' E DELLA RICERCA [P.iva/CF:97429780584] Dipartimento DENERG

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Context of the research activity	Numerical modelling using Hydrodynamic and Particle-in-cell models to support the design of suitable targets and related test matrices, as well as the interpretation of the experiments aiming at the generation of medically useful radioactive isotopes and the production of energy by inertial confinement nuclear fusion. Progetto finanziato nell'ambito del PNRR – DM 118/2023 - CUP E14D23001620006

	The advancements in laser technology have sparked significant interest within the scientific community regarding research on laser-matter interaction. In particular, the growing laser intensity has expanded the potential applications of this technology, ranging from energy production via Inertial Confinement Fusion (ICF) to medical applications such as radionuclide production. Additionally, the achievable high intensity levels (exceeding 1020 W cm-2) enable the acceleration of charged particles to relativistic speeds, opening doors for the utilization of this technology in the development of compact particle accelerators. Consequently, it becomes crucial to simulate such phenomena using computational models to obtain a quantitative understanding of the physical processes that govern the interaction between lasers and matter. The fluid simulations are suitable at high densities of plasmas produced by ns-laser pulses with relatively low intensities (~1015 W cm-2) when non-local particle kinetics is not important due to the frequent collisions between plasma particles. However, the hydrodynamic approach has some limitations. In the process of intense fs-pulse laser–plasma interaction, an assumption of local thermodynamic equilibrium and Maxwellian distribution of the velocities can become invalid. Non-local phenomena such as the generation of

Objectives	energetic (hot) electrons can occur that cannot be described by fluid equations. In this context, the PIC method is more efficient to model high dimensional problems. The PIC studies of laser–plasma interactions can be extended to hundreds of microseconds and micrometers. The macroscopic variables such as density, velocity, pressure, and energy are used in the hydrodynamic (fluid) equations supplemented by the Maxwell's equations to account for the effect of electric and magnetic fields on the laser-produced plasma. In the context of ICF, the target design is crucial for obtaining the best performances from each experiment. This constantly requires researching for new materials. In this context, porous materials, or foams, find remarkable applications in ICF, for increasing the coupling of the laser with the target, also reducing the detrimental effects of parametric and plasma instabilities. All these properties are related to their non-trivial internal structure, constituted by a random distribution of solid parts separated by empty spaces. On the other hand, the modeling of this complex structure with hydrodynamic codes is challenging and requires the development of dedicated models. Experimentally, foams still need to be investigated in depth and many features remain to be completely defined, such as the homogenization time of the plasma generated during the interaction. The target is to develop suitable numerical models to optimize the targets and analyze the experimental data. In particular the activity can be divided in three steps: 1) In the first months a literature survey will be necessary to acquire and extend the competences in the laser-matter interaction, with special reference to the target technology, including the state-of-the-art modelling techniques. 2) Then the computational modelling strategy will be defined, considering both PIC and hydrodynamic approaches. The possibility to couple the two techniques, whenever required, will also be evaluated. 3) The modelling will be used to support the design of suitable targets and related test matrices, as well as the interpretation of the experiments, with the aim of optimizing such targets. In collaboration with ENEA Centro Ricerche Frascati, the experiments will be performed at the ABC laser facility at ENEA Frascati and at the PALS laser facility in Prague (Czech Republic). These models can also be useful to support the development of particle accelerators for the production of medical radioactive isotopes, as well as to develop technologies for the energy production by inertial confinement nuclear fusion.

Skills and competencies for the development of the activity	• Excellent knowledge of the Matlab/Python environment • Knowledge in the PIC modeling • Knowledge of C++ language