

A Multi-Physics Digital Twin for the Integrated Design and Optimization of an Inertial Fusion Energy Power Plant

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The design of a commercially viable inertial fusion energy (IFE) power plant presents a formidable optimization challenge, balancing near-term technological capabilities, scientific uncertainties and the final reactor scale performance. Addressing this requires an integrated digital engineering approach. Focused Energy (FE) is developing a comprehensive digital twin (DTw) of an IFE power plant, designed to act as a high-fidelity virtual replica that captures the intricate interplay between all major systems. The DTw serves not only to guide design and R&D priorities but also to accelerate the entire development lifecycle through advanced simulation and data-driven analysis.

Our digital twin is designed as a modular, multi-physics framework that connects detailed simulations of critical subsystems. Key modules include models for laser-plasma interactions, beam smoothing, and the reactor systems' design and operation. These are coupled with explorations of target design, compression hydrodynamics, and optimizations for beam port geometry. The model extends to target manufacturing and delivery, as well as high-fidelity simulations of target injection and survival. Finally, the DTw integrates the balance-of-plant systems through simulations of neutron transport, tritium fuel cycle and dynamic chamber chemistry.

Tying these disparate physics and engineering domains together is a sophisticated computational backbone centered on machine learning and advanced optimization. FE leverages probabilistic numerics and robust uncertainty quantification to navigate the vast design space. Furthermore, techniques such as causal inference are being explored to de-risk R&D decisions, while machine learning accelerators are being developed to reduce the computational cost of high-fidelity simulations.

In this work, FE will detail the architecture of our integrated digital twin. We will discuss how this framework is used to inform key decisions in our pre-conceptual power plant design. Finally, we will present our efforts to leverage machine learning not just as an accelerator, but as a tool to create novel, performant and cost-effective designs for IFE.

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