PhD Thesis: **Simulation of runaway electron dynamics in tokamak disruptions**

PhD candidate: Olasz Soma

PhD supervisor: Dr. Pokol Gergő

Runaway electrons pose a significant threat in future tokamak-type fusion devices as they can damage the device wall. They are energetic particles generated when a large electric field is induced in the tokamak and are capable of reaching relativistic energies due to the collisional friction decreasing for particles going faster than the thermal speed. Runaway electrons can be generated in two distinct phases of a tokamak discharge: the start-up and the uncontrolled termination, called disruption.

The accurate modeling of runaway electrons is crucial to predict runaway electron generation and test possible mitigation scenarios. Two modeling approaches are used to model the electron population. The fluid approach uses analytical runaway electron generation formulae derived for quasi-stationary scenarios, which is computationally cheap but sometimes inaccurate. It calculates fluid-like quantities, such as density and current density of runaway electrons, hence the name fluid modeling. The kinetic approach, on the other hand, calculates the evolution of the electron momentum distribution function, and it can accurately describe transient scenarios. The downside of kinetic modeling is the large computational cost.

Integrated modeling utilizes different physical models coupled together in a common workflow to simulate complex physical phenomena. I developed a Runaway Electron Test Workflow in the European Integrated Modeling framework to compare fluid and kinetic models in various transient scenarios. I aimed to find a simple parameter describing the rate of change in plasma parameters, which can be used to determine when fluid models can still be used accurately. I found that the collision time of electrons at the critical velocity for runaway electron generation can be used as this timescale. In cases where the changes in plasma parameters are faster than this critical time, the fluid modeling is inaccurate.

Previously, runaway electron modeling in integrated modeling frameworks was handled exclusively by fluid codes, so I integrated kinetic models into the frameworks to develop the runaway electron modeling capabilities. Since the frameworks have simple access to experimental data, the integration of kinetic codes also enabled simulations with initial and boundary conditions directly from experiments.

I created a physical model in the European Transport Simulator (ETS) workflow to self-consistently simulate tokamak disruptions. I simulated a massive material injection from the edge of the plasma based on experimental data from the ASDEX Upgrade tokamak to induce a disruption. I then benchmarked the simulated plasma current evolution against actual measurements from the modeled experiment.

Finally, I performed predictive simulations of a disruption on the JT-60SA tokamak to simulate the expected synchrotron radiation from a runaway electron population and assess the feasibility of the EDICAM visible camera system for the detection of runaway electrons. The study's positive conclusion was later confirmed experimentally in the first campaign of JT-60SA.