Technical and Scientific Progress Report (EUROfusion)

Vojtěch Svoboda

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This report summarizes the main technical and scientific activities carried out in 2025 within the framework of the EUROfusion project, with a focus on experimental research, diagnostics development, data analysis, and advanced computational methods implemented at the GOLEM tokamak. The activities build upon long-term student-driven research programs and contribute to both fusion-relevant physics studies and education-oriented experimental development [1], [2].

Edge plasma studies and probe diagnostics. A major part of the activities in 2025 was devoted to experimental studies of edge plasma physics using electric probe diagnostics. Particular emphasis was placed on the investigation of the mutual relationship between zonal flows and Reynolds stress, as well as on the formation and dynamics of transport barriers, especially in helium discharges. These studies uniquely benefit from ultra-fast ion temperature measurements using swept Ball-pen probes with microsecond time resolution, enabling direct access to turbulence-relevant temporal scales. The achieved diagnostic capabilities allow time-resolved characterization of transport barrier formation and its interaction with edge turbulence.

Fast spectroscopy of edge plasma. Fast optical spectroscopy of selected spectral lines was systematically developed and applied to hydrogen and helium discharges. The primary focus was on helium plasmas, where the presence of an edge transport barrier is reflected not only in probe measurements but also in the temporal evolution of emission from the main gas and impurities. The combined analysis of fast spectroscopy and probe diagnostics provides a consistent picture of edge transport processes and impurity behavior.

Discharge optimization and advanced computational methods. Advanced computational approaches were further developed and successfully applied in 2025. Autonomous discharge optimization based on artificial intelligence methods was extended beyond proof-of-principle demonstrations, allowing efficient optimization of discharge duration and stability directly on the device. In parallel, artificial neural network (ANN) based tomography of visible plasma radiation was further developed, with improvements focused on training data quality, robustness against noise and missing data, and applicability to routine experimental analysis.

Plasma current stabilization. Further progress was achieved in plasma current stabilization, which is essential for reproducible experimental conditions and systematic physics studies. Improved current stability directly supports advanced diagnostic campaigns and enhances the quality of datasets used for both experimental interpretation and machine-learning-based analysis.

Runaway electron physics and diagnostics. Research on runaway electrons (REs) continued in 2025, combining experimental diagnostics and physical interpretation. Hard X-ray detectors, scintillation probes, and pixel detectors were used to study RE losses and their relation to MHD activity. These measurements provide valuable insight into loss mechanisms and contribute to the development of dedicated RE diagnostics suitable for small tokamaks.

Numerical simulations. Selected experimental studies were complemented by numerical simulations using the FLUKA Monte Carlo code. These simulations focus primarily on high-energy particle interactions with tokamak structures and diagnostics, supporting quantitative interpretation of runaway electron measurements and aiding in optimized detector design.

Major implemented investments. An essential part of the activities in 2025 was the targeted reinforcement of the experimental and computational infrastructure. A new computational server equipped with a large-capacity data storage system and a high-performance AI computing unit was acquired to support advanced data-driven methods, including AI-based discharge optimization and neural-network-based tomography. In addition, project resources were partially used to support the development of demanding fast spectroscopy diagnostics, including optical, electronic, and mechanical components required to achieve sufficient temporal resolution and measurement stability.

Conclusion. The activities realized in 2025 demonstrate a coherent and technically mature integration of advanced diagnostics, data-driven methods, and targeted infrastructure development. The GOLEM tokamak continues to serve as an effective experimental platform contributing to fusion-relevant physics, diagnostic innovation, and education within the EUROfusion framework.

Conference proceedings

[1] S. Malec, S. Abbasi, J. Brotankova, *et al.*, "Tokamak GOLEM for fusion education - chapter 16/II," ser. Europhysics conference abstracts, vol. 51A, 2025, ISBN: 111-22-33333-44-5. [Online]. Available: `https://lac913.epfl.ch/epsppd3/2025/html/PDF/P4_184.pdf`.

[2] V. Sedmidubsky, S. Abbasi, J. Adamek, *et al.*, "Tokamak GOLEM for fusion education - chapter 16/I," ser. Europhysics conference abstracts, vol. 51A, 2025, ISBN: 111-22-33333-44-5. [Online]. Available: `https://lac913.epfl.ch/epsppd3/2025/html/PDF/P4_181.pdf`.