PhD Thesis: **Modell-aided design and interpretation of beam emission spectroscopy measurements on fusion devices**

PhD student: Asztalos Örs

PhD supervisor: Dr. Pokol Gergő

Beam emission spectroscopy (BES) is an active plasma diagnostic system used in thermonuclear fusion energy research to measure plasma density and its fluctuations on centimetres and microsecond spatial and timescales. BES diagnostics rely on a mono-energetic neutral particle beam probing the plasma. As the beam attenuates, it also emits characteristic photons caused by excited electrons, that can be collected and used for plasma density calculations. RENATE is a 3D BES synthetic diagnostic calculating the expected photon current on each detector. The current work aimed to develop comprehensive methods for BES measurement interpretation, performance trade-off management and plasma physics model validation.

A novel fluctuation response calculation was developed, which computes the light response observed by a modelled BES system to artificially introduced density perturbations. The resulting response function defines the fluctuation-sensitive area, the centre of mass of the emission and the effective spatial resolution of a BES system. The method was demonstrated during the design of the EAST BES systems while used for modelling-aided measurement interpretation on JET.

A comprehensive methodology was developed – encompassing the fluctuation response calculation – relying on BES synthetic diagnostics to balance performance trade-offs, which emerge during the design process of proposed BES systems. The methodology was used to optimize design parameters and was demonstrated on the following BES systems each featuring a prominent trade-off. The W7-X alkali BES system faced a trade-off between beam penetration and spatial localization. The ITER core and pedestal fluctuation BES systems faced a trade-off between signal to noise and signal to background ratios affected by optical filter optimization considerations. Finally, the JT-60SA lithium and heating beam BES systems faced trade-offs in spatial resolution that could be tuned by the choice of the location of observation positions.

The study and validation of first principle plasma models required the development of a turbulence timescale synthetic diagnostic. As a first application, the upgraded RENATE was coupled to the HESEL, a 2D multi-fluid, first principle, scrape-off layer (SOL) turbulence code. The synthetic diagnostic aimed to place plasma physics models in identical frames of reference as the experimental measurements by accurately accounting for all relevant BES measurement artefacts. The turbulence synthetic diagnostic was validated using the ASDEX-Upgrade lithium BES data.

Finally, the collisional radiative model of RENATE was enhanced to include new cross-sections for handling beam atom collisions with neutral gas. The relevance of the inclusion of beam-with-gas cross-sections in the beam evolution calculations was demonstrated by performing beam attenuation and beam emission calculations in fusion-relevant neutral gas densities. The impact of neutral gas-induced photon emission in the detection and evaluation of SOL turbulence was also demonstrated.