9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Assessment of alternative divertor configurations in TCV via experiments and interpretative SOLPS-ITER modelling

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One of the main challenges in magnetic confinement fusion is power exhaust [1]. In future reactors, intense power fluxes from the confined region are directed through a narrow scrape-off layer towards the divertor targets. If unmitigated, these power fluxes will exceed material limits and cause long-term erosion. Thus, it is necessary to develop divertor solutions able of dissipating power and momentum, through impurity radiation and plasma-neutral interactions, and that allow operation in a detached regime. While detachment is necessary for the targets, impurities may cause excessive radiation and fuel dilution in the core. It is, therefore, essential to determine the operational window for simultaneous safe divertor operation and acceptable core performance. Alternative Divertor Configurations (ADCs) are promising solutions, predicted to broaden the detachment operational window and reduce target loads compared to the conventional lower single-null (LSN) configuration [2]. Leveraging recent improvements in numerical modelling and diagnostic coverage in the TCV tokamak ($R_0 \sim 0.9$ m, $B_0 \sim 1.45$ T, $a \sim 0.25$ m) [3], this work investigates three ADCs, modifying the outer divertor geometry, Figure 1, while the core performance and geometry are kept unvaried: the Super-X Divertor (SXD), which moves the strike point to a larger major radius to increase total flux expansion; the X-Divertor (XD), which flares magnetic field lines to increase poloidal flux expansion; and the X-point Target Divertor (XPT), which introduces a secondary X-point, splitting the divertor leg into two branches.

Ohmic ($I_P \sim 250 - 320$ kA) L-mode density ramps are performed to test the predicted benefits of these ADCs. The impact of poloidal and total flux expansion is smaller compared to predictions from simple analytical models and previous results in the literature. On the contrary, the presence of a secondary X-point along the outer divertor leg, radially close to the primary separatrix ($R_{omp} - R_{omp}^{sep} < \lambda_q$, mapped to the outer midplane), significantly reduces the upstream density at detachment onset and the radiation front sensitivity in the vicinity of the secondary X-point. Simulations with the SOLPS-ITER code [4] reproduce these results: the relative variation in the exhaust performance (*e.g.* the upstream density at the detachment onset, Figure 2), when passing from the reference LSN configuration to the different ADCs, matches the experimental observations. Moreover, the simulations highlight how processes often neglected in simple models, such as plasma drifts and parallel flows, are necessary to explain the discrepancies with analytical predictions. This extensive set of experiments and simulations allows for a holistic investigation of the role of the divertor magnetic geometry. These first insights are combined with observations from more reactor-relevant experiments and simulations (with auxiliary heating and seeding), to discuss the extrapolation of ADCs in future reactors.

This work has been carried out within the framework of the EUROfusion Consortium, via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). This work has been funded by the Swiss State Secretariat for Education, Research and Innovation (SERI). Views and opinions expressed are, however, those of the authors only and do not necessarily reflect those of SERI. SERI cannot be held responsible for them. This work was supported in part by the Swiss National Science Foundation.

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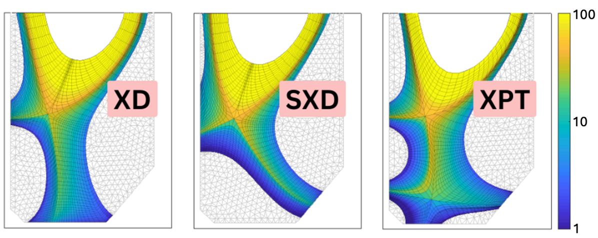

Figure 1 – Electron temperature distributions [eV] obtained in SOLPS-ITER simulations, based on ADC geometries from TCV experiments.

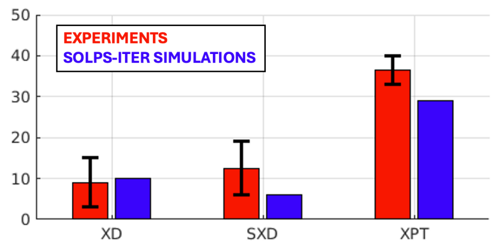

Figure 2 – Relative reduction [%] of the upstream density at detachment onset for different ADCs compared to corresponding LSN references.