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Advanced Tokamak Studies in Full-Metal ASDEX Upgrade

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Conventional tokamak high-confinement mode (H-mode) scenarios suffer from magnetohydrodynamic (MHD) instabilities and also depend on inductive current from the central solenoid to maintain the plasma current. Advanced Tokamak (AT) scenarios that feature manipulated non-standard q-profiles not only promise to improve the stability and confinement of the discharge by eliminating some of the most common resistive MHD instabilities, such as sawteeth, but also allow to extend the pulse length by increasing the core bootstrap current density $j_{\mathrm{bs}} \sim q\nabla p$.

This contribution presents an overview over recent Advanced Tokamak (AT) studies undertaken in the full-metal ASDEX Upgrade (AUG) tokamak in the context of paving a way to an envisaged steady-state EU-DEMO scenario [1] ($q_{95} \approx 4.5$; $\beta_{\mathrm{N}} \approx 3.5$; $H_{98}(y,2) \approx 1.2$).
Designing such larger next-generation devices requires a thorough theoretical understanding which allows to credibly extrapolate existing models from present-day experiments.

To this end, the experimental thrust at AUG aims at providing the means to verify state of the art models for equilibrium, stability and transport physics in AT plasmas.
The parameter space covered so far experimentally can be broadly divided as follows: \\
1) $q_{95} \approx 5$ plasmas with conventional off-axis co-current drive (co-CD) for $q_{\mathrm{min}} \approx 1.1$ and sustained $\beta_{\mathrm{N,max}} \approx 2.7$ [2],
2) $q_{95} \approx 5$ plasmas with on-axis co-CD for maximum current drive efficiency and anomalous central flux diffusion ("flux pumping") to maintain $q(0)$ clamped at 1, resulting in plasmas with transient $\beta_{\mathrm{N,max}} \approx 3.7$ [3] and sustained $\beta_{\mathrm{N}} \approx 3.1$ at higher shaping, and
3) $q_{95} \approx 4$ plasmas with central electron-cyclotron counter-CD to maintain q_{min} of up to 1.6 [4].

Careful tailoring of the plasma edge properties allowed excellent confinement, transiently as far up as $H_{98}(y,2) \approx 1.6$.

This approach has enabled various modelling advances, such as confirming the fidelity of equilibrium and current drive models or verifying ideal stability codes.
Furthermore, it allowed investigations into the physics behind flux pumping, and to identify gaps in existing fast transport solvers related to turbulence stabilisation through interaction with energetic particles.

This contribution will report on the experimental and modelling results outlined above.

References:
[1] H. Zohm et al 2017 Nucl. Fusion 57 086002
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[4] J. Stober et al 2020 Plasma Phys. Control. Fusion 62 024012

Primary authors: BOCK, Alexander (Max Planck Institute for Plasma Physics); BURCKHART, Andreas (Max Planck Institute for Plasma Physics); CHAO, Yan (Hefei Insitute of Physical Science); DUNNE, Mike (IPP-Garching); FISCHER, Rainer; IGOCHINE, Valentin (Max-Planck-Institut für Plasmaphysik); PÜTTERICH, Thomas (Max-Planck-Institut für Plasmaphysik); REISNER, Maximilian (Max-Planck-Institut für Plasmaphysik); SCHRAMM, Raphael (Max Planck Institute for Plasma Physics); SILVAGNI, Davide (Max-Planck-Institut für Plasmaphysik); STOBER, Joerg (IPP Garching); STRUMBERGER, Erika (Max-Planck-Institut für Plasmaphysik); VAN MULDERS, Simon (Ecole polytechnique federale de Lausanne); ZOHM, Hartmut (IPP); ASDEX UPGRADE TEAM (Max-Planck--Institut für Plasmaphysik)

Presenter: BOCK, Alexander (Max Planck Institute for Plasma Physics)

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