Overview of diagnostic enhancements and physics studies of confined fast-ions in ASDEX Upgrade

P. A. Schneider\textsuperscript{1,\ast}, B. Geiger\textsuperscript{1}, S. K. Nielsen\textsuperscript{2}, G. Tardini\textsuperscript{1}, M. Weiland\textsuperscript{1}, S. Äkäslompolo\textsuperscript{3}, A. S. Jacobsen\textsuperscript{2}, F. Ryter\textsuperscript{1}, M. Salewski\textsuperscript{2}, the ASDEX Upgrade Team\textsuperscript{1} and the EUROfusion MST1 Team\textsuperscript{4}

\textsuperscript{1}Max-Planck-Institut für Plasmaphysik, Boltzmannstr. 2, 85748 Garching, Germany
\textsuperscript{2}Technical University of Denmark, Department of Physics, Dk-2800 Kgs. Lyngby, Denmark
\textsuperscript{3}Aalto University, Finland

At the ASDEX Upgrade (AUG) tokamak the capabilities to diagnose confined fast particles were successively enhanced over the past years. These include the collective Thomson scattering (CTS), the fast-ion D-alpha (FIDA) diagnostic, the neutral particle analysers (NPA) and the neutron spectrometer.

The CTS was upgraded with an additional receiver for continuous background measurements. To extend the coverage of the fast-ion velocity space, the FIDA diagnostic was upgraded from 3 to 5 optical arrays. Red- and blueshifted parts of the FIDA radiation are measured simultaneously with a new spectrometer setup. While FIDA and CTS have a good radial resolution, the measured signal is integrated over a range in energy and pitch. Direct energy and pitch resolved measurements of the central fast-ion content are obtained with a new active NPA. This NPA uses a compact solid state detector and is focused on the same heating beam as the FIDA diagnostic for the active signal. To investigate fast edge localised phenomena, the data acquisition system of the passive $E, B$-NPAs was upgraded. A neutron spectrometer measures the neutron energy distribution resulting from D-D fusion reactions, thus providing an independent diagnostic tool.

The standard tool to interpret FIDA and NPA measurements is a parallel version of the FIDA-SIM code. The run time for simulations of all channels is below 30 min for one time point.

An overview of recent results obtained with the improved set of diagnostics will be presented. The measured impact of MHD instabilities such as ELMs and sawteeth on fast-ion confinement will be discussed. The measured fast-ion redistribution due to sawteeth matches predictions based on the Kadomtsev model very well. Information on the 2D fast-ion velocity space is obtained with tomographic reconstructions using multiple FIDA views. The acceleration of neutral beam injected deuterons by the 2nd harmonic ICRF heating was confirmed with all fast-ion diagnostics and can be modeled using an RF kick operator in TORIC or TRANSP. The radial fast-ion transport is investigated for on- and off-axis heating and the measurements are compared with different transport models. Neoclassical transport can be sufficient to explain the measurements in some cases, but when an anomalous contribution to the fast-ion diffusivity is required to better match the observations, its value is typically below 1 m\textsuperscript{2}/s.

\ast philip.schneider@ipp.mpg.de, \textsuperscript{4}http://www.euro-fusionscipub.org/mst1