Performance optimisation of tokamak operation in ASDEX Upgrade through novel feedback control capabilities

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

W. Treutterer*[1], M. Biasizzo[1], P. David[1], E. Fable[1], M. Gehring[1], L. Giannone[1], I. Gomez[1], A. Gräter[1], J. Illerhaus[1], R. Kermenov[1], D. Kropackova[1,2], O. Kudlacek[1], G. Raupp[1], M. Reisner[1], B. Sieglin[1], M. Weiland[1], T. Zehetbauer[1], The ASDEX Upgrade Team[1] (see author list of H. Zohm et al, 2024 Nuclear Fusion https://doi.org/10.1088/1741-4326/ad249d)
[1]Max-Planck-Institut für Plasmaphysik, Garching, Germany,
[2]Czech Technical University, Prague, Czech Republic

ABSTRACT

- Optimising the performance of tokamak operation needs a holistic approach with a focus on the effective interplay of all control system components.
- Control performance must account for individual function performance and the performance of the integrated system.
- The ASDEX Upgrade Discharge Control System (DCS) addresses these aspects by robust algorithms for measurement data processing and state estimation, a versatile feedback control suite, actuator management and customisable pulse supervision control, reacting to events and plasma state conditions.
- Performant operation should start with proper preparation of scenarios and control strategies. Fenix, a fast "flight simulator" assists in scenario design, validation and control method development.
- Optimisation methods and experience should be applicable to even larger and more complex fusion devices such as ITER and DEMO.

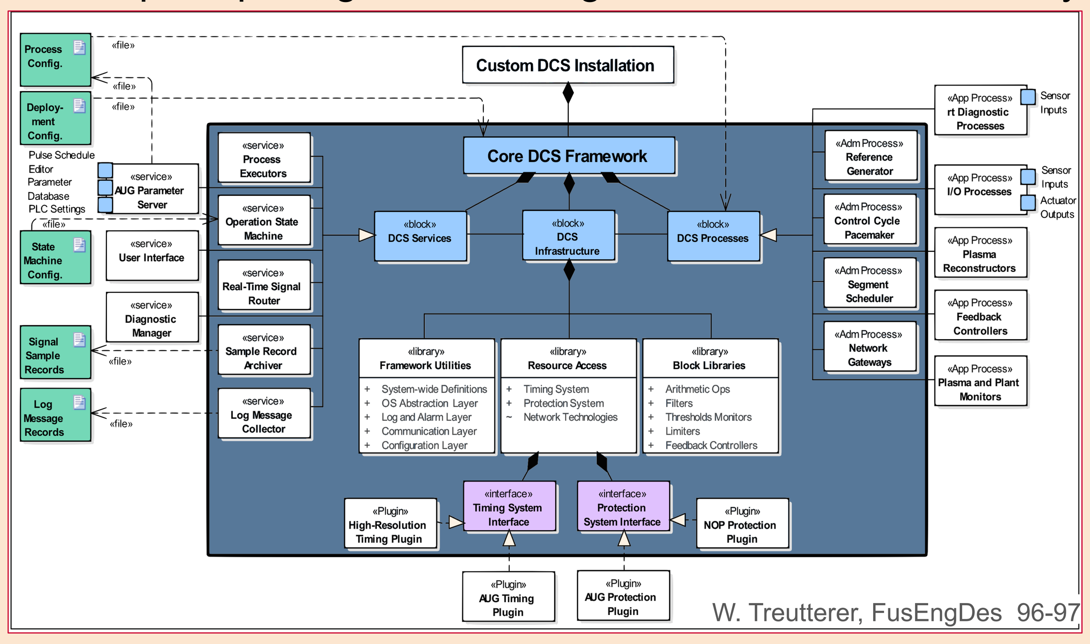
CONCLUSION

- Performant tokamak operation is a moving target with structural, functional and organisational aspects.
- Efficient structuring of the control system and workflows is the most persistent investment.
- Real-time diagnostics, model-based observers and actuator management are key components for precise and efficient feedback control.
- Machine learning is expected to resolve computational bottlenecks in equilibrium and transport solvers or in pattern recognition for control in real-time.
- Rule-based shot sequence automation for parameter studies or scenario optimisation can save significant experiment time.
- Flight simulators like Fenix accelerate the turnaround time from design to exploitation by proper pulse preparation and control room validation.

STRUCTURAL OPTIMISATION

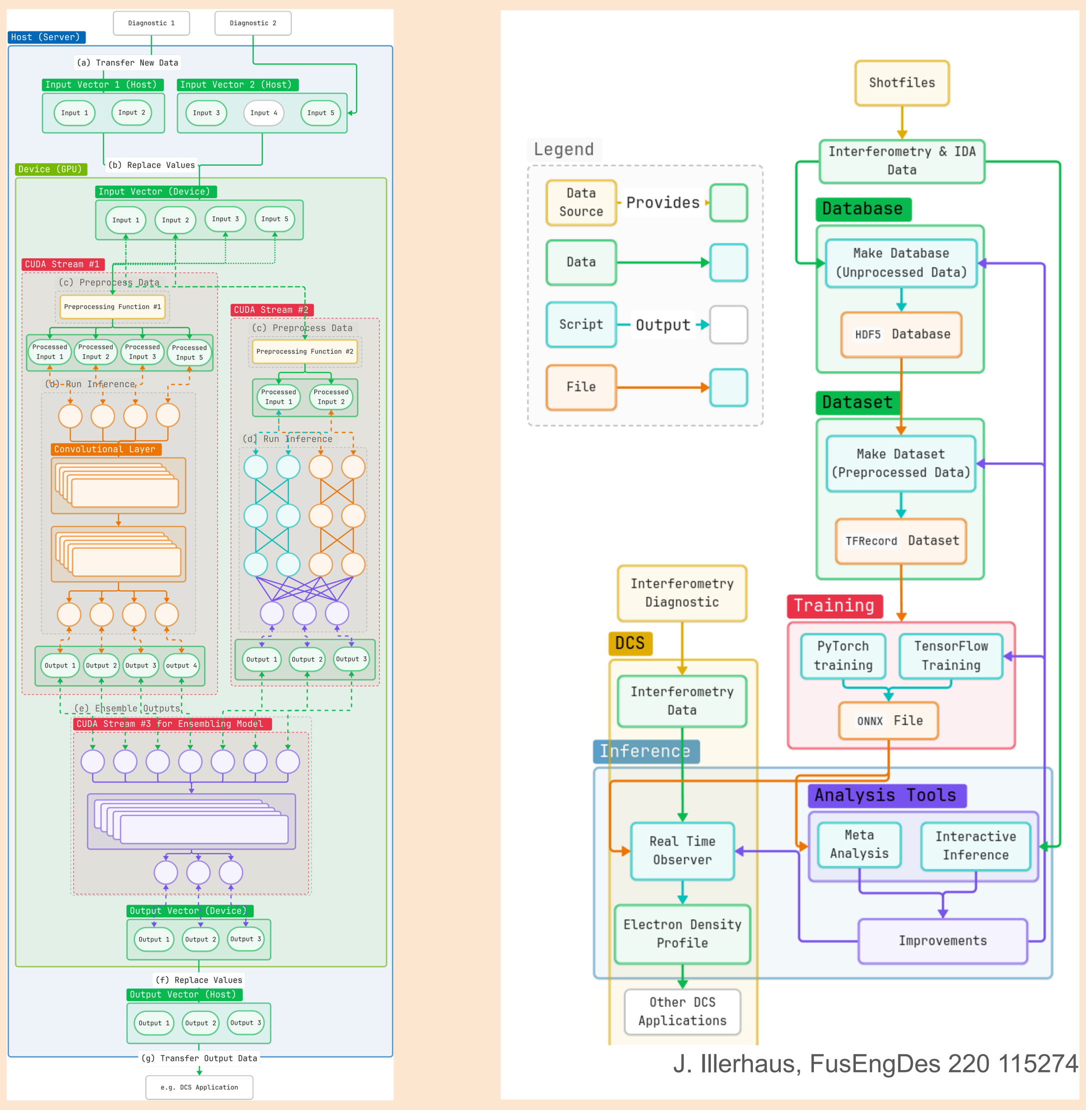
Architecture addresses performance requirements: reliable, flexible, maintainable, separation of concerns

DCS: modular control system framework adhering to SOLID principles, generic, configuration-driven functionality



W. Treutterer, FusEngDes 96-97

Machine Learning: real-time inference on GPU, generic pipeline for data processing, training and inference

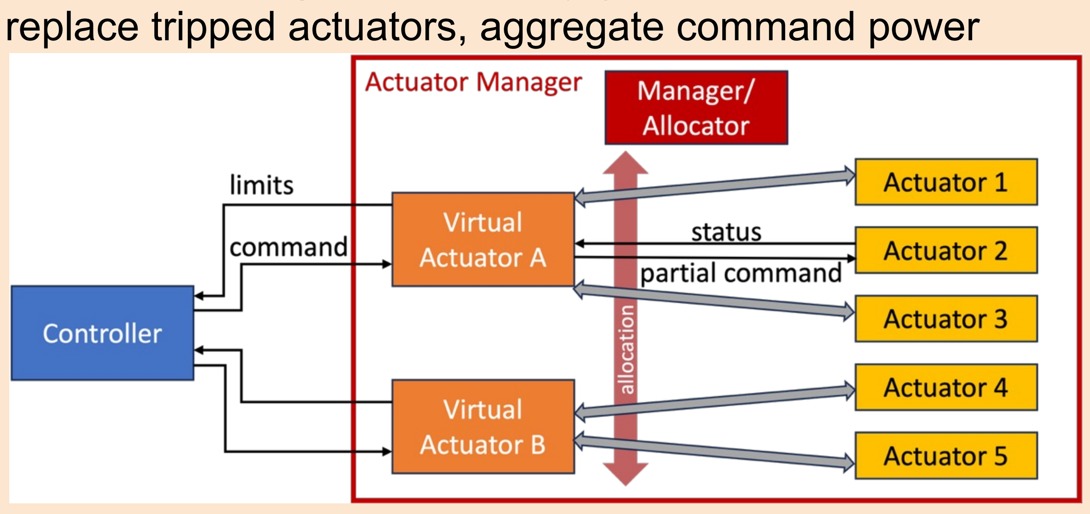


J. Illerhaus, FusEngDes 220 115274

Compact Controllers: attached to actuation groups, selectable control objectives and policies

Controller	Actuators	Control objectives
Plasma current	Central solenoid current	Plasma current
Plasma position	2 Control coil currents	Plasma centre or outer radius
Plasma shape	8 PF coil currents	Strike points, triangularity, elongation
Gas and pellet fuelling	3 gas channels, 1 pellet centrifuge	$n_{e\,core}$, $n_{e\,edge}$, n_0
Radiation	2 impurity gas channels	P_{rad}, $T_{divertor}$, Xpoint-radiation, MARFE
Heating, current drive and MHD	8 NBI sources, 8 ECRH gyrotrons, 4 ECRH mirrors, 2 ICRH antennae	β_{pol}, P_{heat}, P_{ion}, local heating and current drive, MHD, alpha heating simulation
Error field (prelim. fuelling control)	16 RPM coil currents	ELM suppression, density pump-out

Actuator Management: flexibly group alike actuators, replace tripped actuators, aggregate command power

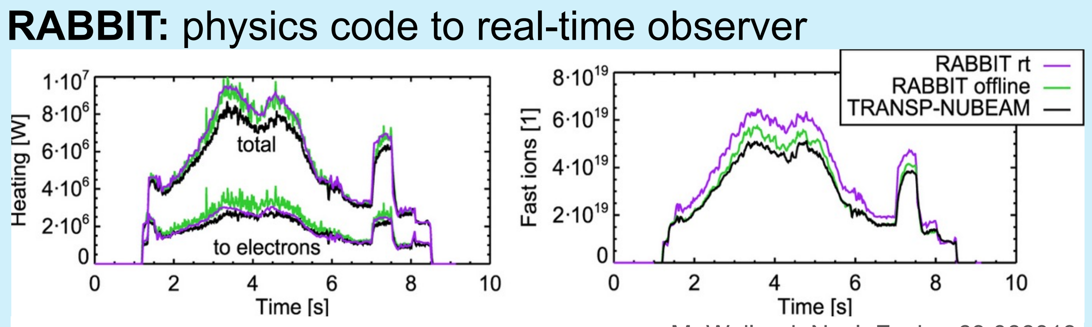


FUNCTIONAL OPTIMISATION

Enhance the performance of individual functions: precision, stationary errors, overshoot, response time, cross-coupling, disturbance rejection, robustness

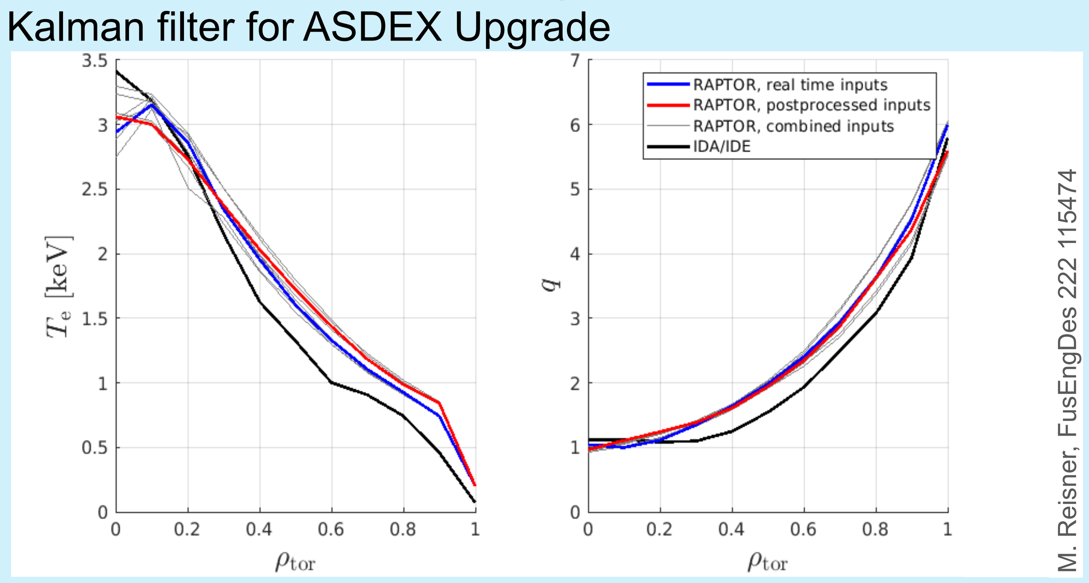
Examples:

RABBIT: physics code to real-time observer



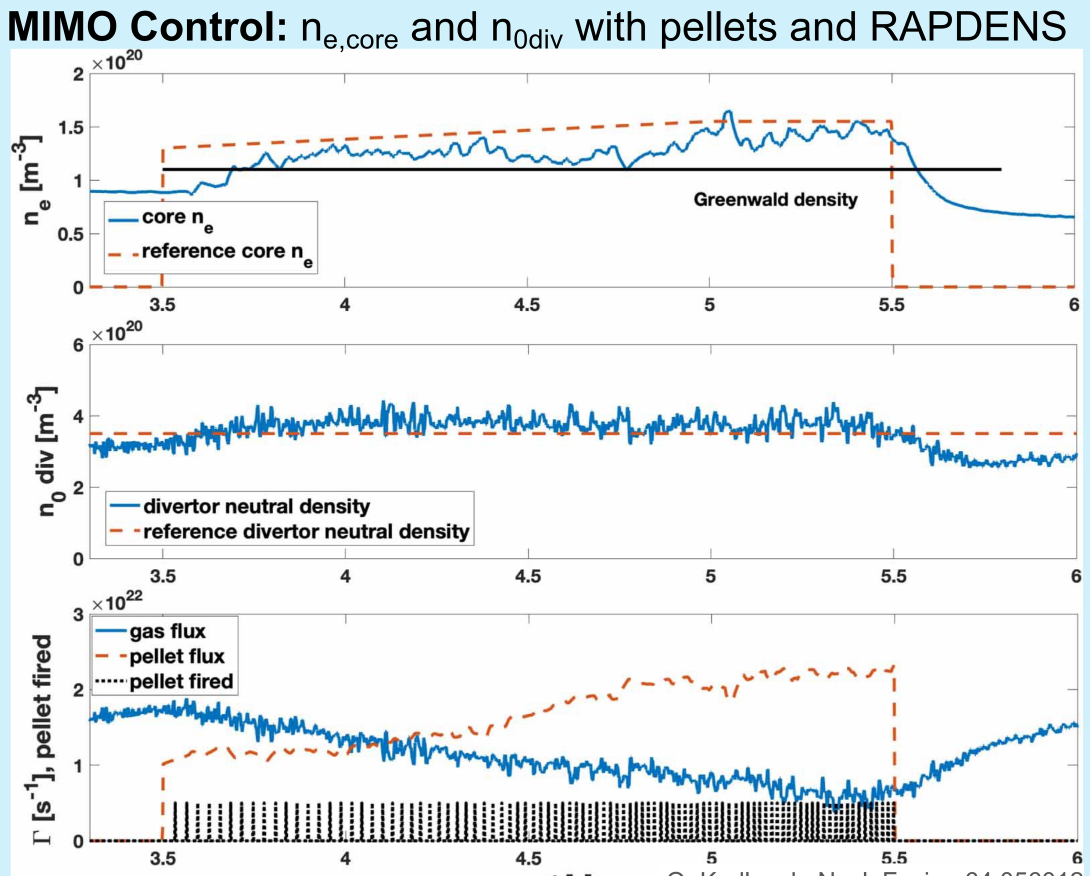
M. Weiland, Nucl. Fusion 63 066013

RAPTOR: model-based transport observer with Extended Kalman filter for ASDEX Upgrade



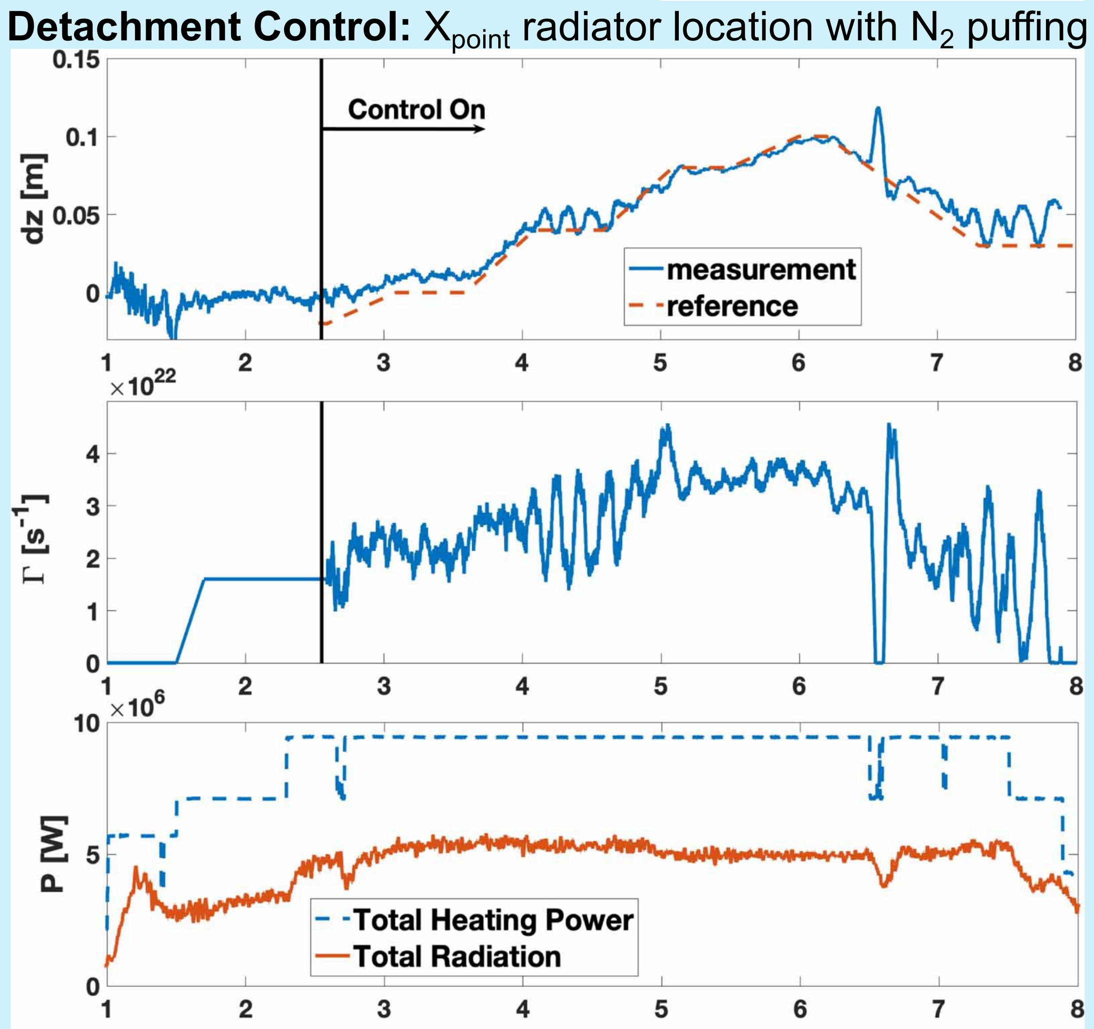
M. Reisner, FusEngDes 222 115474

MIMO Control: $n_{e,core}$ and n_{0div} with pellets and RAPDENS



O. Kudlacek, Nucl. Fusion 64 056012

Detachment Control: X_{point} radiator location with N_2 puffing

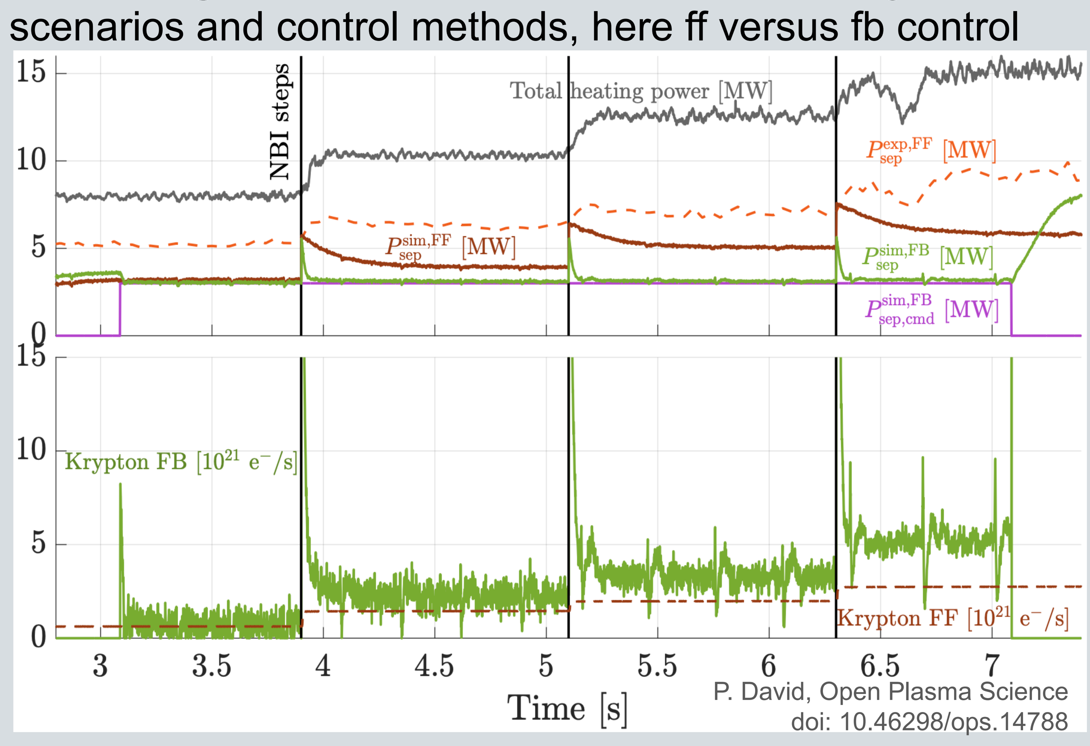


O. Kudlacek, Nucl. Fusion 64 056012

ORGANISATIONAL OPTIMISATION

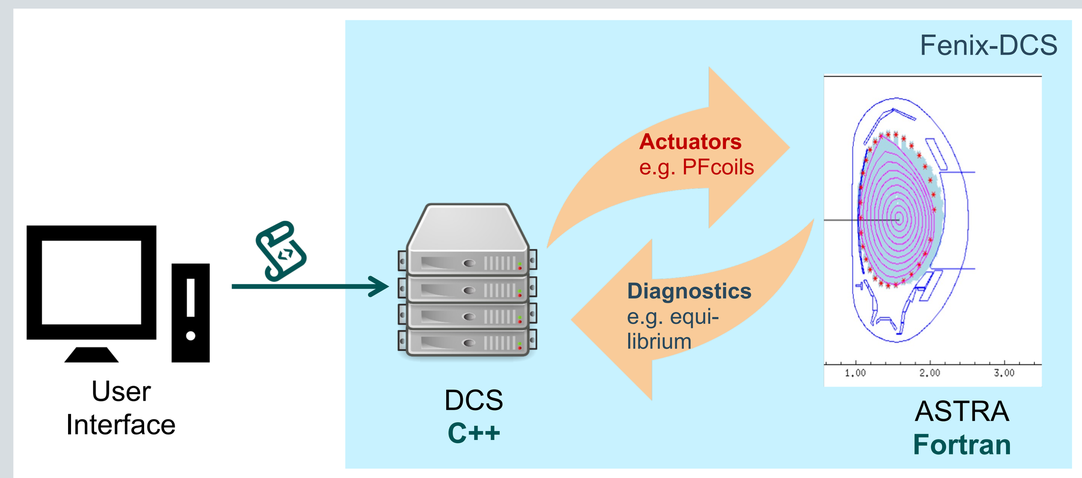
Efficiently use the experimental time: thorough pulse planning and validation, compacted execution using automation

Fenix Flight Simulator: validation and design of new scenarios and control methods, here ff versus fb control

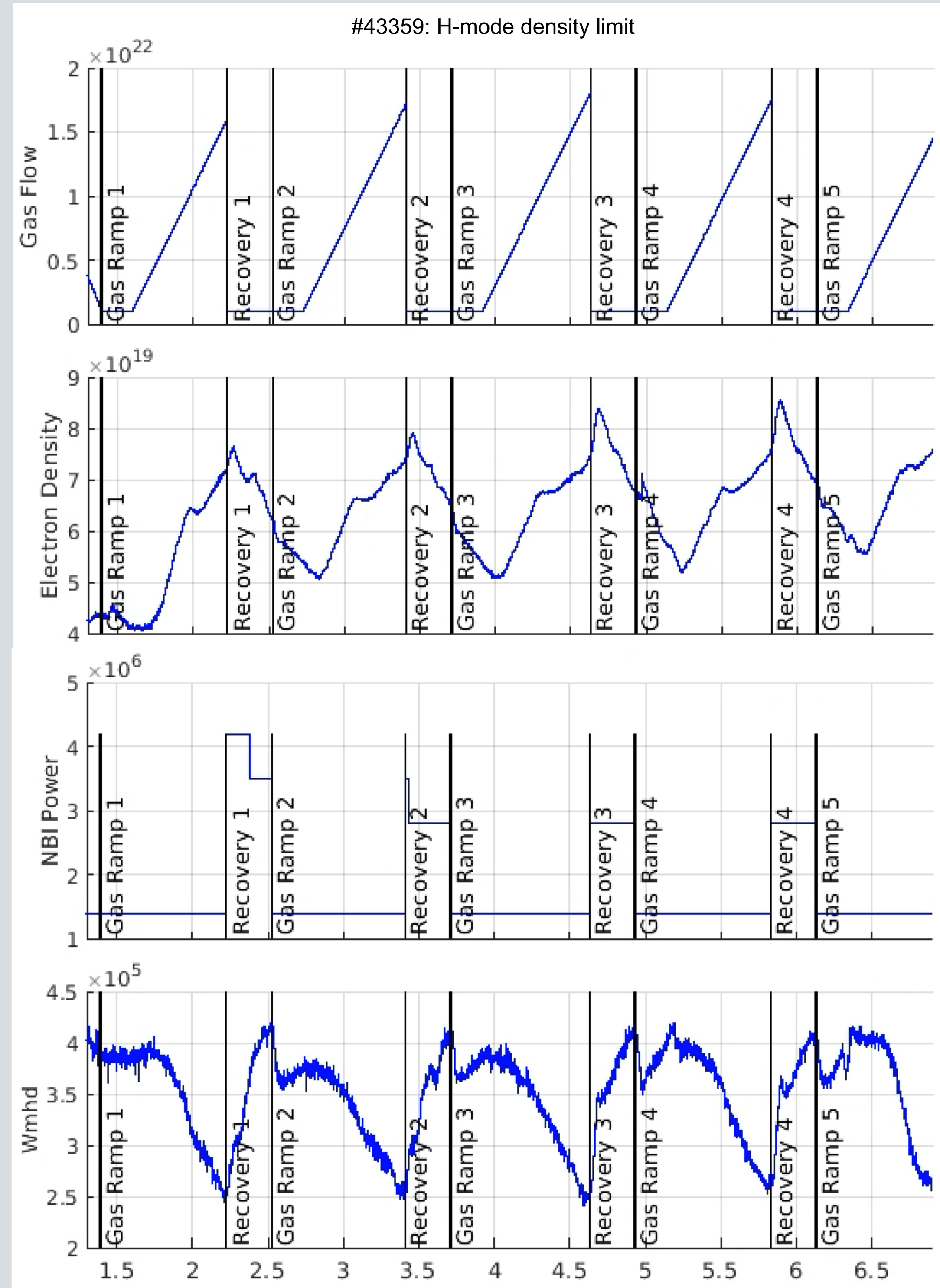


P. David, Open Plasma Science doi: 10.46298/ops.14788

Fenix-DCS: SIL coupling of DCS with ASTRA instead of AUG plant, fast control room validator; under development



Automated Schedules: rule-based disruption avoidance, parameter scans and optimum searches in a single pulse



B. Sieglin, FusEngDes 191 113546

Poster No. 2623
30th IAEA Fusion Energy Conference 2025, Chengdu, China

* corresponding author:
Wolfgang.Treutterer@ipp.mpg.de

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

EUROfusion