28th IAEA Fusion Energy Conference
Virtual Evenet (2021)

EUROfusion

EX/P6-3

THEORY-BASED MODELS FOR THE CONTROL OF PLASMA CURRENTS IN W7-X DIVERTOR PLASMAS

A. Dinklage[1], G. Fuchert[1], R.C. Wolf[1], A. Alonso[2], T. Andreeva[1], C.D. Beidler[1], M. de Baar[3], Y. Gao[1], J. Geiger[1], M. Jakubowski[1], H. Laqua[1], N. Marushchenko[1], U. Neuner[1], N. Pablant[4], A. Pavone[1], K. Rahbarnia[1], J. Schmitt[5], H.M. Smith[1], T. Stange[1], Yu. Turkin[1], W7-X Team

[1]*Max-Planck-Institut für Plasmaphysik, Greifswald, Germany*
[3]*DIFFER, Eindhoven, The Netherlands*
[5]*Auburn University, Auburn, AL, USA*
[3]*CIEMAT, Madrid, Spain*
[4]*PPPL, Princeton, NJ, USA*

MOTIVATION AND OUTLINE

- Goal: physics-based models for plasma control
- Expected benefit: applicability ↔ validity of theory.
- Specific case:
  - Motivation: iota control – effect on divertor strike-lines
  - plasma current in W7-X from neoclassical theory
  - input: plasma profiles
  - output: simplified response model $dI/dt = I/\tau_{L/R}$
- Scope of this paper: focus on model formulation and validation

METHODS

- Develop model-based controller and use plasma theory for the model formulation.
- Sensor: data from plasma profile measurements or parametrization.
- Actuator: current drive
- Derive predictive power (reusability) from validation

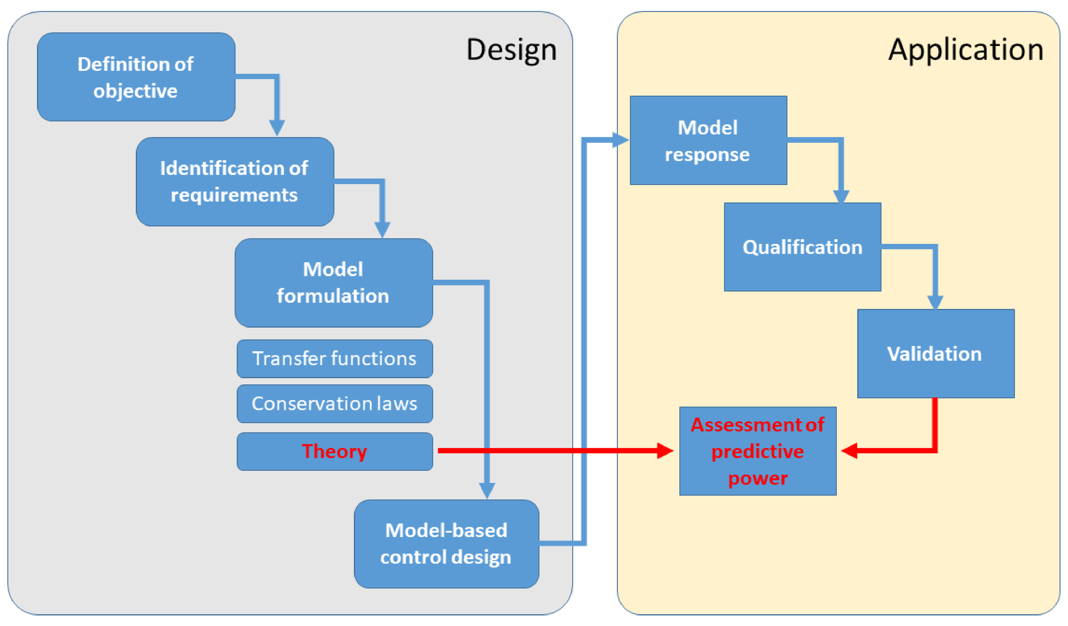


FIG. 1. Workflow for the design and the qualification of model based design.

SURVEY OF ACHIEVED DISCHARGE CHARACTERISTICS IN W7-X AND FUTURE TARGETS

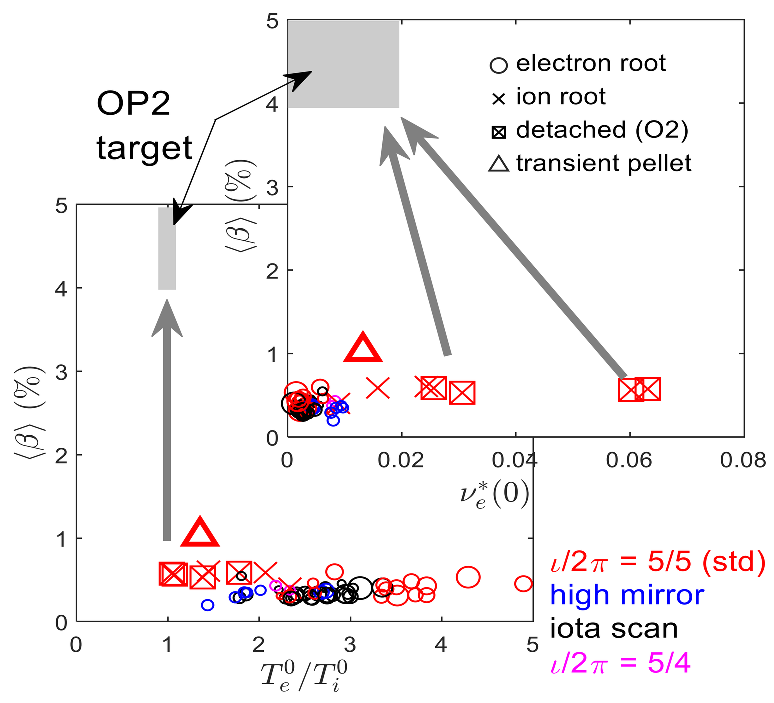


FIG. 2. Operation space of W7-X test-divertor discharges (OP1) with estimates for target values in the forthcoming campaigns OP2. $\nu_e^*(0)$ is the collisionality of electrons in the plasma center, ⟨β⟩ is the volume averaged plasma beta. O2 refers to electron cyclotron heated plasma in O2 polarization. STD abbreviates the standard magnetic configuration.

A SIMPLIFIED MODEL FOR THE PREDICTION OF PLASMA CURRENTS IN W7-X FROM NEOCLASSICAL TRANSPORT CALCULATIONS

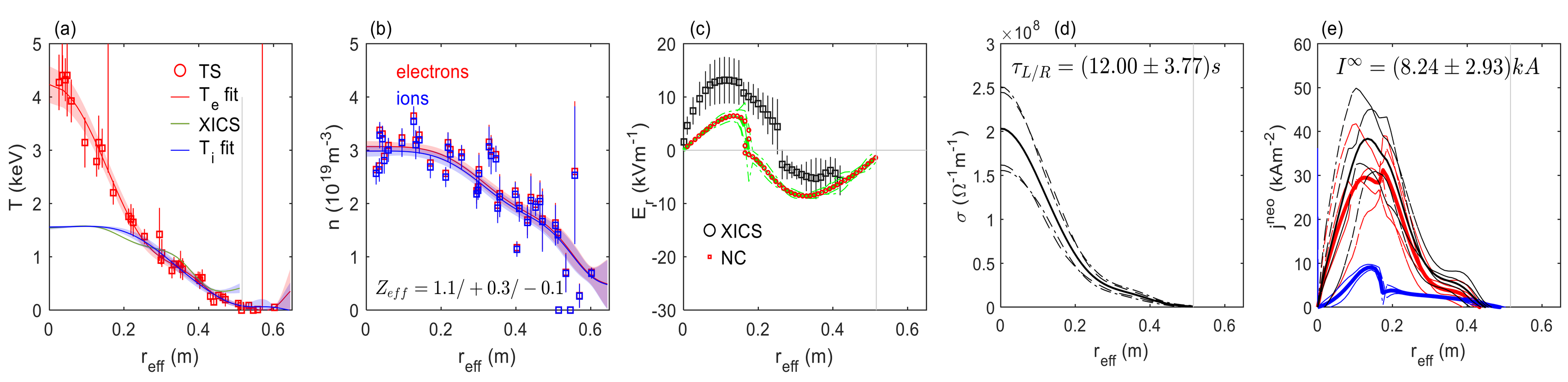
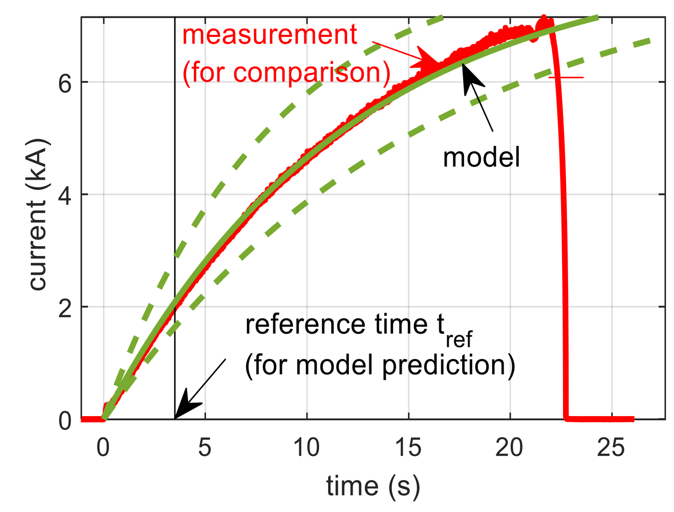


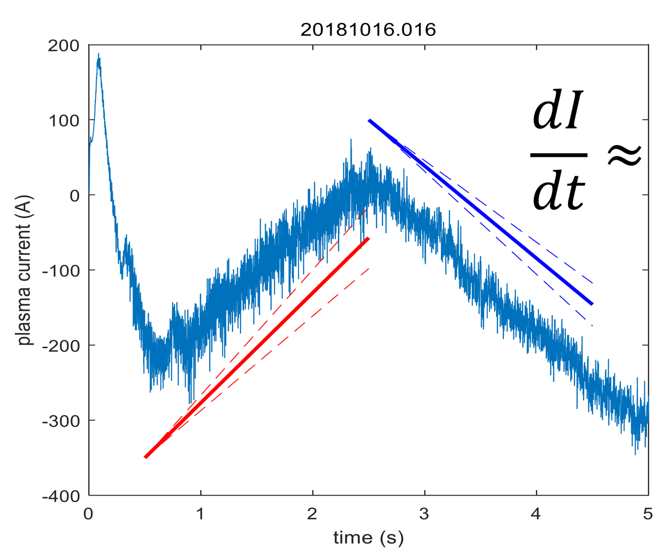
FIG. 3 Profiles of W7-X discharge with the discharge ID 20180927.033 at stationary conditions at t = 3.5s. (TS: Thomson scattering, XICS: x-ray imaging spectroscopy). (d) and (e) are results from modelling with the transport code NTSS employing transport coefficients calculated with the drift kinetic equation solver DKES.

APPLICATION OF THE L/R-CURRENT-RESPONSE MODEL

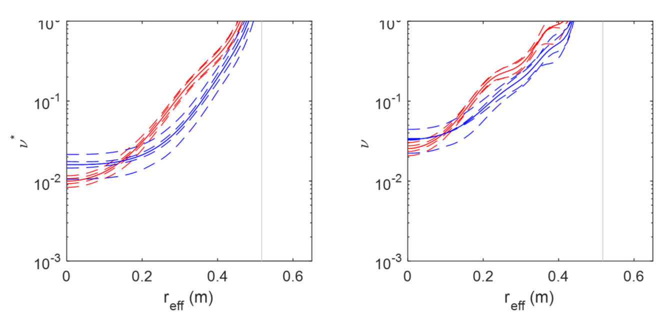


$$I^{plasma}(t) = I^{BS}\left(1 - \exp\left(-\frac{t}{\tau_{L/R}}\right)\right)$$

FIG. 4 Measured plasma current and forward modelled bootstrap current from profile modelling at 3.5s in the W7-X discharge 20180927.033. Dashed lines indicate expected model uncertainties.



$$\frac{dI}{dt} \approx I^{BS}/\tau_{L/R}$$



attached (left) vs. detached (right):
→ core collisionality lower in attached phase
→ much smaller core electron bootstrap current for detached case

FIG. 5. Plasma current evolution in a transition from attached to detached plasmas at t=2.5s. The lines indicate the modelled slope $I^{\infty}/\tau_{L/R}$. The slope of the current evolution is subject of the comparison and the initial value of the modelled slopes (solid lines; red: attached, blue: detached, broken lines for uncertainties) is shifted for convenience.

EXPLORING THE POTENTIAL OF THE THEORY-BASED MODEL FOR PLASMA CONTROL

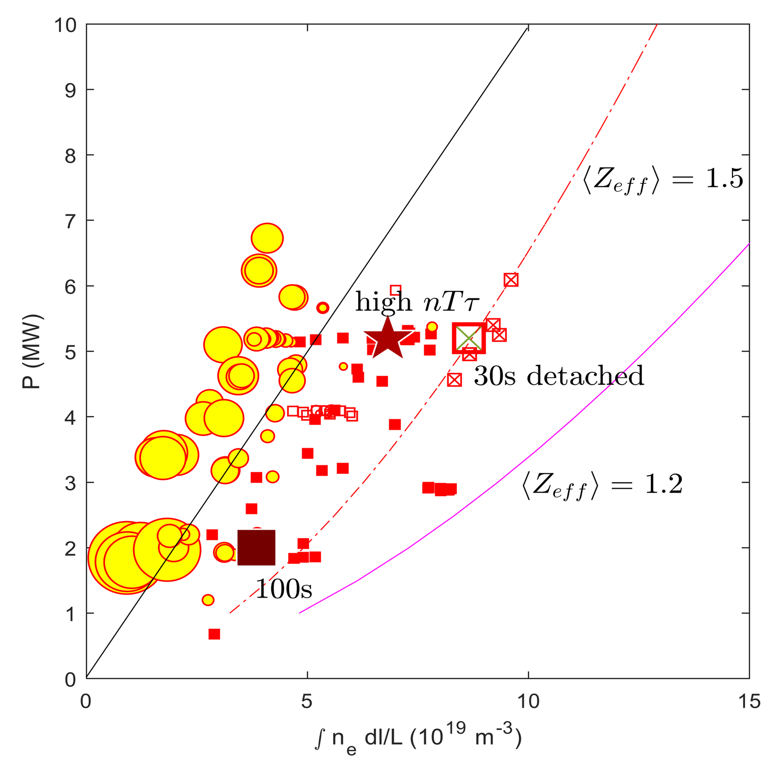


FIG. 6. Operation space of electron cyclotron heated W7-X test-divertor unit discharges (OP1) for the standard magnetic configuration. P is the heating power, the abscissa is the line averaged density. The magenta and broken red lines show density limits at different Z_{eff}. The black line corresponds to P(MW)=n (10^{19} m^{-3}). Yellow symbols are electron root discharges, red squares are ion root discharges. Crossed squares correspond to detached cases.

CONCLUSION

- L/R-plasma response model derived from neoclassical transport modelling
- Deviations: additional current drive?
- Sensor: plasma profiles (or parametetrization)
- Actuator: ECCD

- **Model capable validated to predict plasma currents**
- **Quantitative agreement for stationary conditions**
- **Captures/explains qualitative changes (attached/detached plasmas)**
- **Usability for control of edge rotational transform**

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.