Parameter study of neoclassical toroidal viscous torque for 3D coils in EU-DEMO

G. Graßler*[1], C.G. Albert[1], R. Babin[2], M. Hadwiger[1],
S.V. Kasilov[1,3,4], R. Köberl[2], P. Lainer[1], L. Pigatto[5]

1 Fusion@ÖAW, Institute for Theoretical Physics – Computational Physics, Graz University of Technology, Petersgasse 16, 8010 Graz, Austria
2 Max Planck Institute for Plasma Physics, Boltzmannstraße 2, 85748 Garching, Germany
3 Institute of Plasma Physics, National Science Center „Kharkov Institute of Physics and Technology", 61108 Kharkov, Ukraine
4 Department of Applied Physics and Plasma Physics, V. N. Karazin Kharkiv National University, 61022 Kharkiv, Ukraine
5 Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete SpA), C.so Stati Uniti 4, 35127, Padova, Italy

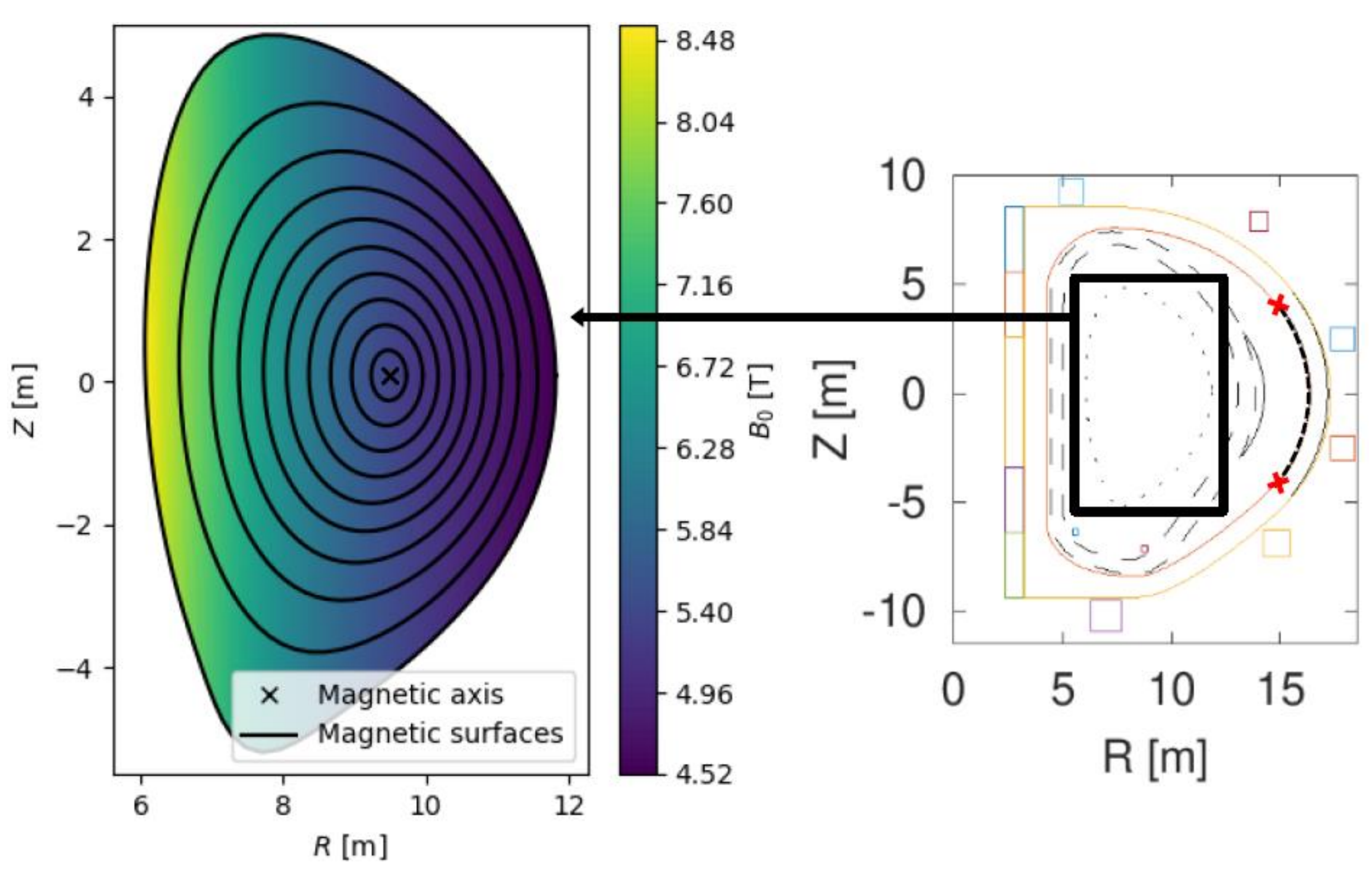
* georg.grassler@tugraz.at

itpplasma.github.io

Motivation

- **3D coils** are planned as part of the EU-DEMO design for the suppression of three-dimensional error fields [1]
- Field of 3D coils induces **neoclassical toroidal viscous (NTV) torque** as a side effect [2]
- Results in **plasma rotation speed reduction** and may lead to unstable locked modes
- **Mapping** the dependance of **NTV production** on configuration parameters facilitates **finding proper operation point** for EU-DEMO in terms of
  - **poloidal width** $\Delta\chi$ of the equatorial 3D coils and
  - **toroidal plasma rotation velocity** V^φ

The baseline configuration



Hypothetical DEMO configuration: (left) Axisymmetric field (B_0) inside the separatrix and (right) poloidal width $\Delta\chi$ of the equatorial 3D coil. The baseline run uses $\Delta\chi \approx \pi/4$. The 3D coil is placed inside the toroidal field coils, marked as a dashed line between two red ✖s.

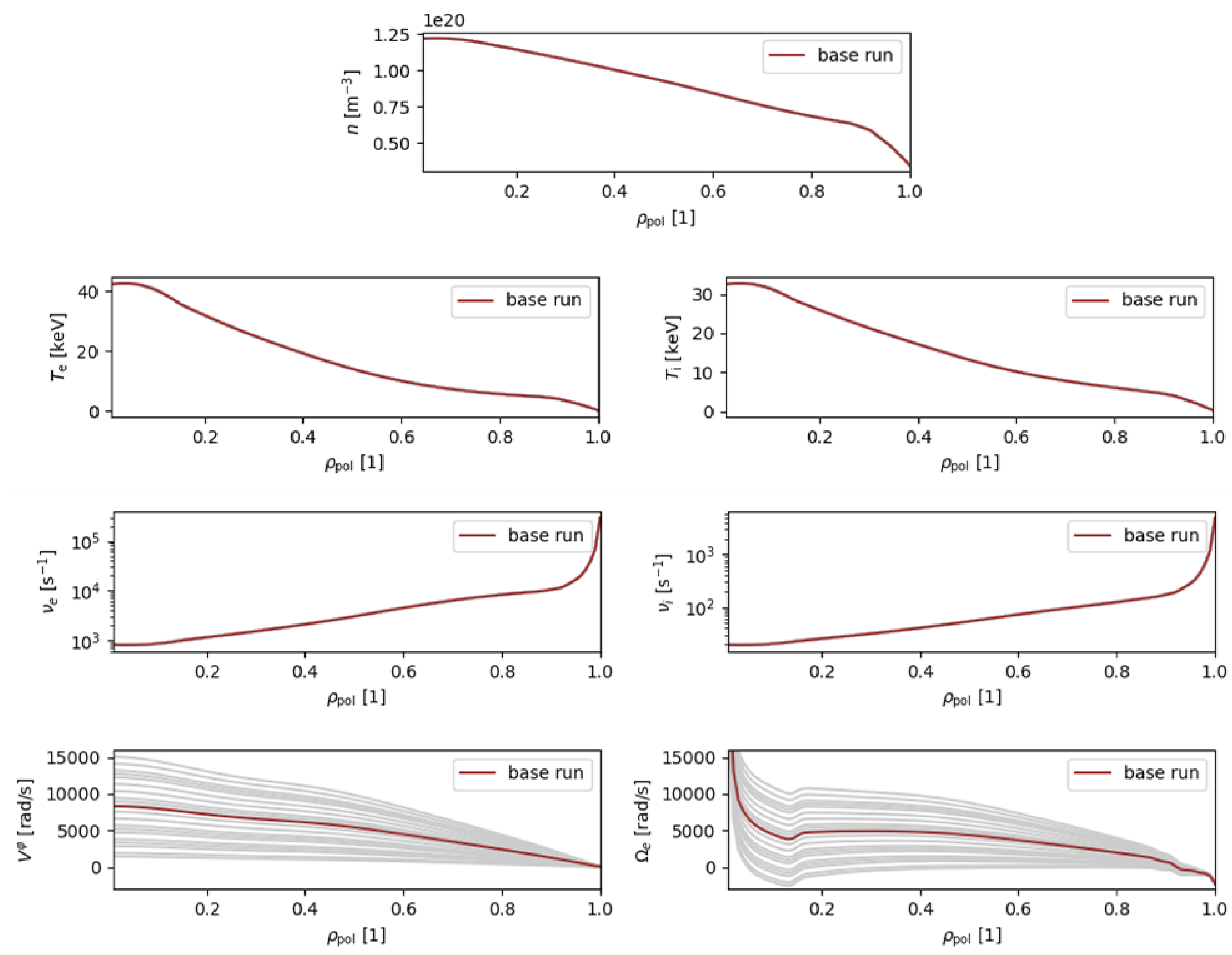
Discussion

- Absolute NTV torque maximum around baseline $\Delta\chi \approx \pi/4$
- NTV torque can **change sign** due to value of (positive) V^φ
- Low absolute NTV torque for small/large $\Delta\chi$
  - **Small** $\Delta\chi$: perturbation vanishes
  - **Big** $\Delta\chi$: poloidal perturbation spectrum narrows, allowing fewer orbital resonance
- Low absolute NTV torque for $V^\varphi \approx 3$ krad/s, corresponding to vanishing Ω_E → only **superbanana** resonance should contribute

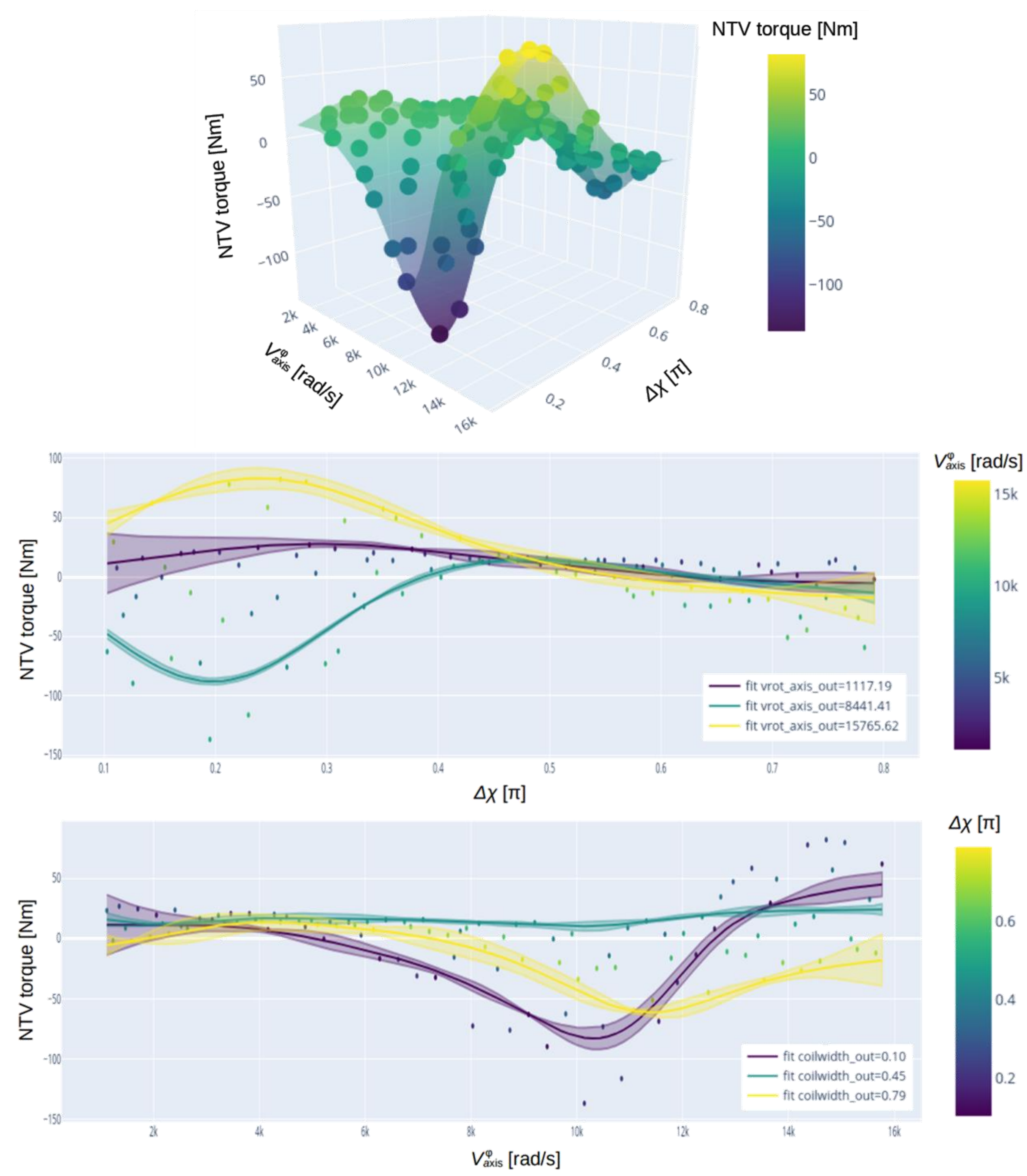
Outlook

- Investigation of **resonance effect** on torque density
- **Separation** of ion and electron contribution
- Evaluation of **error-field suppression** at bigger $\Delta\chi$
- more **sophisticated profile variation**
- Full scans with **NEO-2** [5]

Variations and surrogate model



Variation of profiles and coilwidth: Only V^φ (and accordingly Ω_E from NEO-2 [4]) is varied (gray). Density n, temperatures T_e & T_i and collisionalities ν_e & ν_i are left in base configuration (red). Only 20 of the used rotational profiles are plotted here. The poloidal width of the 3D coil in the figure to the left is varied in range $\Delta\chi = [0.1, 0.8]\pi$.



Gaussian process regression of MARS-K [3] results: Shown is the response function (top plot) over 2D parameter space, and as cuts with (middle plot) constant V^φ_{axis} or (bottom plot) constant $\Delta\chi$. Coloring of the data points in the cuts was chosen to correspond to the value of the quantity that parametrizes the cut-plane, e.g. in the middle plot, the turquoise line is the cut at $V^\varphi_{axis} \approx 8400$ rad/s and has turquoise data points of that V^φ_{axis} regime in its vicinity.

References
[1] F. Maviglia *et al*, Fusion Engineering and Design Volume **196**, 114010 (2023)
[2] K.C. Shaing *et al*, Nuclear Fusion 55, 125001 (2015)
[3] Y. Liu *et al*, Physics of Plasmas **20**, 042503 (2013)
[4] S.V. Kasilov et al, Physics of Plasmas **21**, 092506 (2014)
[5] A.F. Martitsch *et al*, Plasma Phys. Control. Fusion **58**, 074007 (2016)

Acknowledgments
We gratefully acknowledge support from NAWI Graz and thank Clarisse Bourdelle, Rico Buchholz and Hartmut Zohm for their valuable comments and suggestions on this study.

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.