Challenges for high beta modelling at AUG and JET in view of JT-60SA, ITER and DEMO

Philipp Lauber et al, DCT/ENR ATEP/TSVV#10,AUG, JET teams

5.3. 2025

MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

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.

physics background

- mode stability can be roughly described by β_{EP}/β_{back} (caveat: complex dependencies of kinetic drive and damping mechanisms and gradients)
  [Fu,VanDam, 1989 Betti&Freidberg 1992]

- in present day experiments and VNS: $\frac{\beta_{EP}}{\beta_{back}} \sim \frac{n^{-1}T_i^{3/2}}{nT_i} \sim T_i^{1/2}n^{-2}$ scaling (slowing down time/plasma beta) strongly driven externally

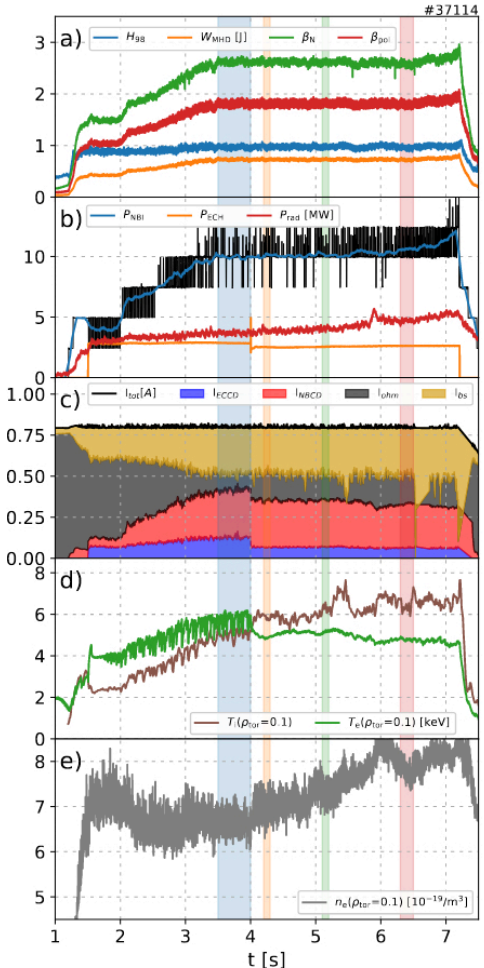
- in reactor: upper limit (note: density cancels) $\frac{\beta_\alpha}{\beta_{back}} \sim \frac{n^2T_i^2 \cdot T_i^{3/2}}{n^2T_i} \sim T_i^{5/2}$ self-organising

- larger non-linearity in Ti : may lead to overshoots and/or limit cycle oscillations in ramp-up/ flat top - how large are they (DEMO design)?

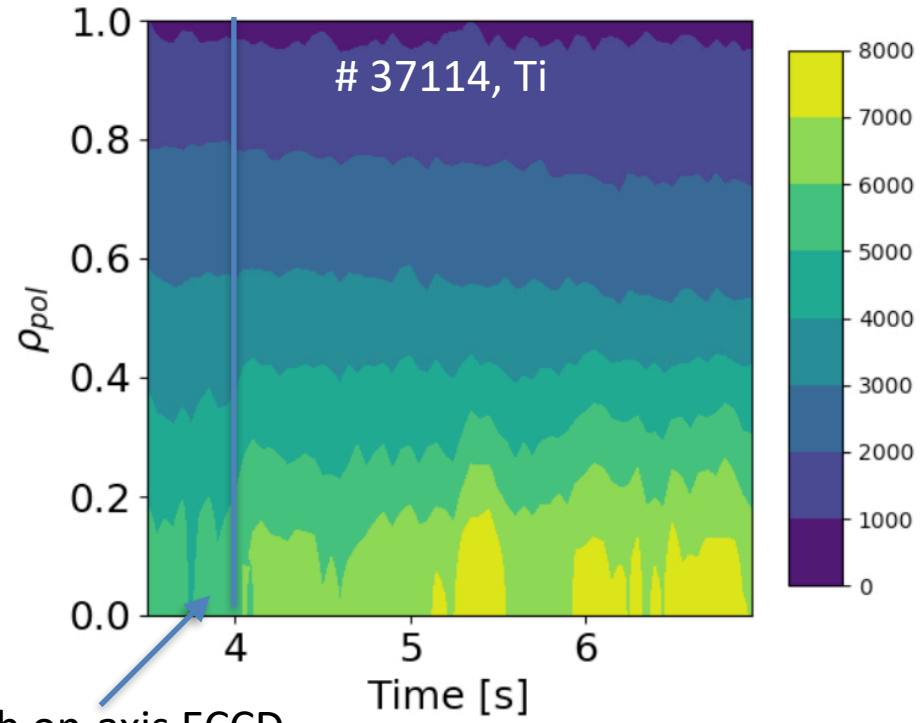
- what questions can present day experiments address?
  - understand q=1 physics: sawteeth, reversed shear, fishbones, Alfvén modes and interaction with background turbulence (Ti peaking)
  - understand flux pumping (see future discussion)
  - fusion power mock-up experiments (see future discussions)

contradicting results on the influence of EPs on background turbulence:
- interaction channel? type of excited modes? importance of mode amplitudes? role of q=1 and fast/reversed shear?
- e.g. DIII-D: fishbones enhance turbulence in some experiments [Du, ITPA]; DIII-D: FB excite zonal fields, stabilise turbulence [Brochard, PRL]

high beta: influence of global MHD and EP-driven modes on Ti peaking



elevated q, counter ECCD 1MA [M. Reisner, 2024]

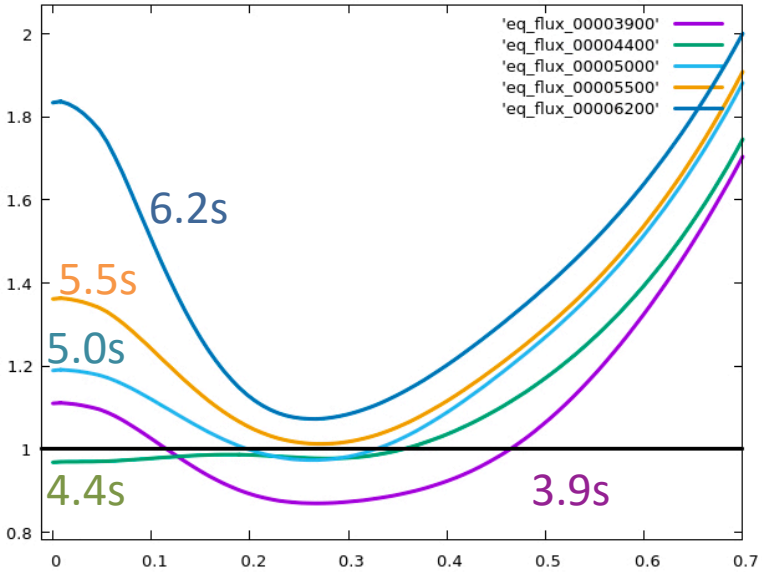


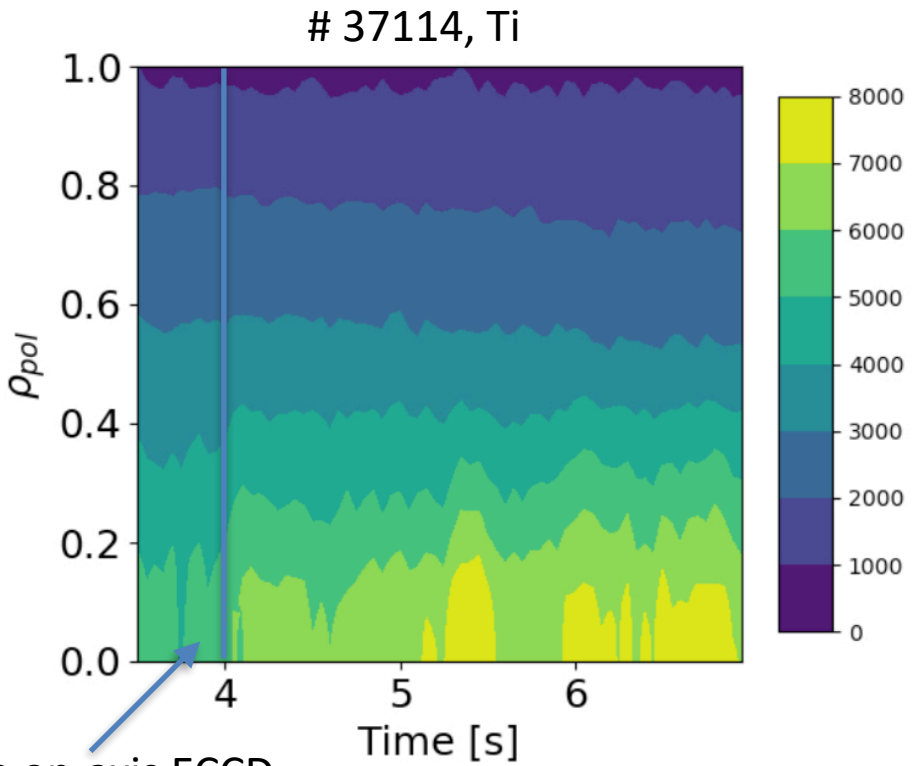
switch on-axis ECCD to off axis

ECCD acts on current - no change in heating

‚self-regulation' - lasts 3s!

influence of global MHD and EP-driven modes on Ti peaking



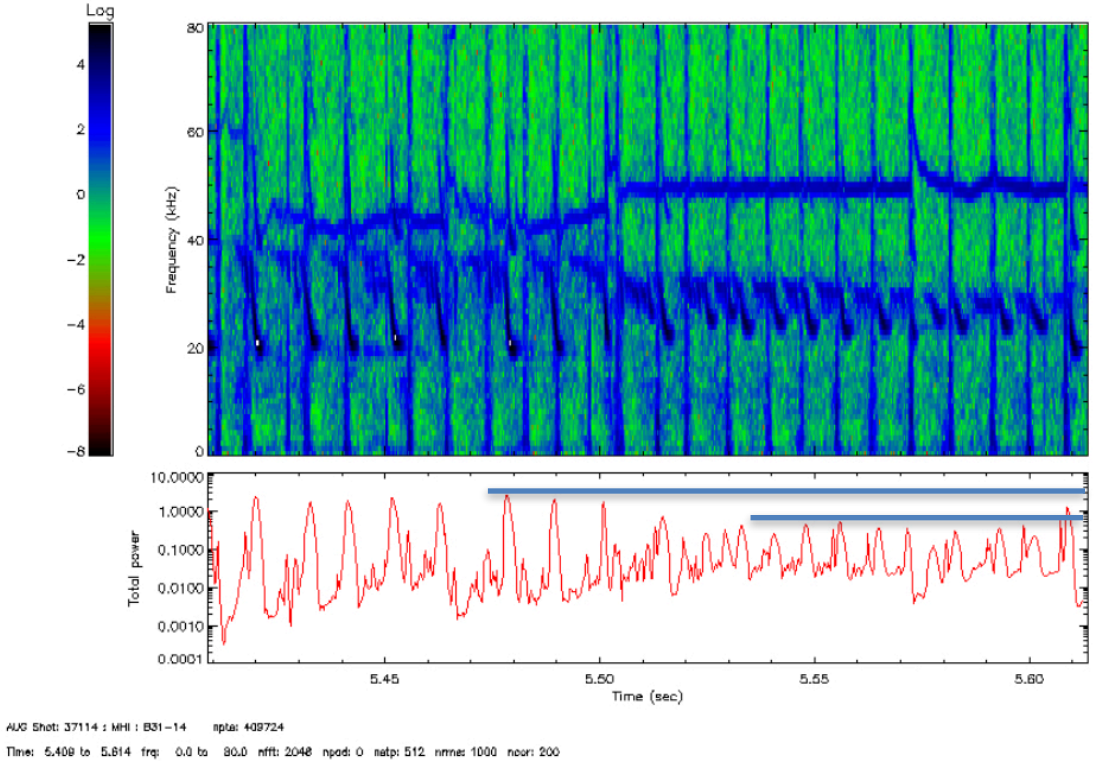


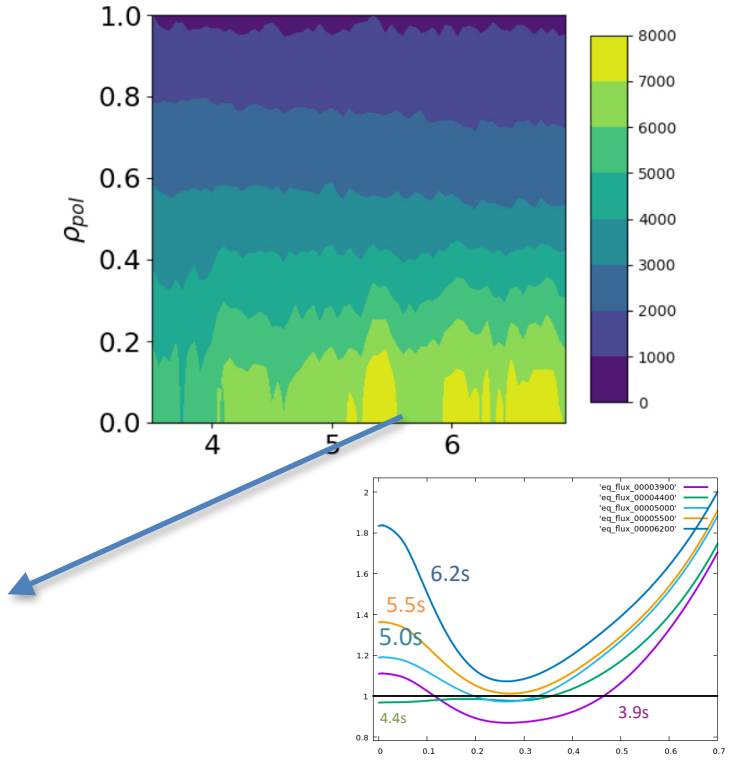
switch on-axis ECCD to off axis

ECCD acts on current - no change in heating

‚self-regulation' - lasts 3s!

magnetics: low-f activity seen - 1/1 kink, fishbones, double-fishbones



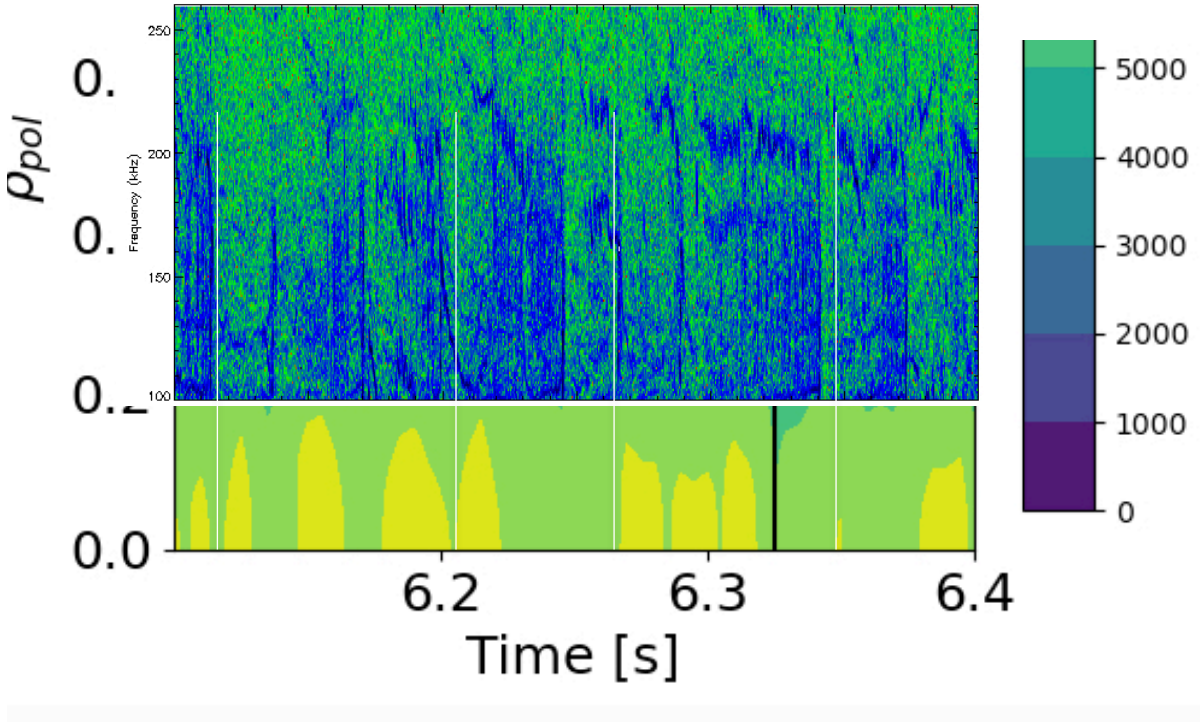


5.45-5.6s: q=1 disappears, fishbone amplitude ~ 3 times smaller

FB driven by fast precessing NBI particles -Ti-depletion happens in 10-20ms

core localised TAEs well visible in soft-X ray - central channels $\rho_{pol} < 0.4$

mode activity seems not to be, or rather anti-correlated to Ti peaking

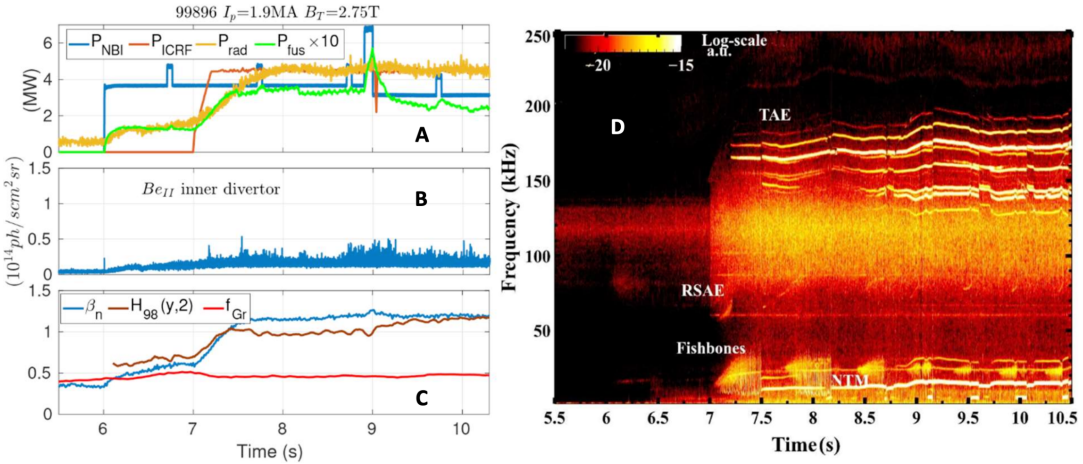


here, TAEs do not stabilise turbulence - code modelling? Ti peaking because of reversed shear?

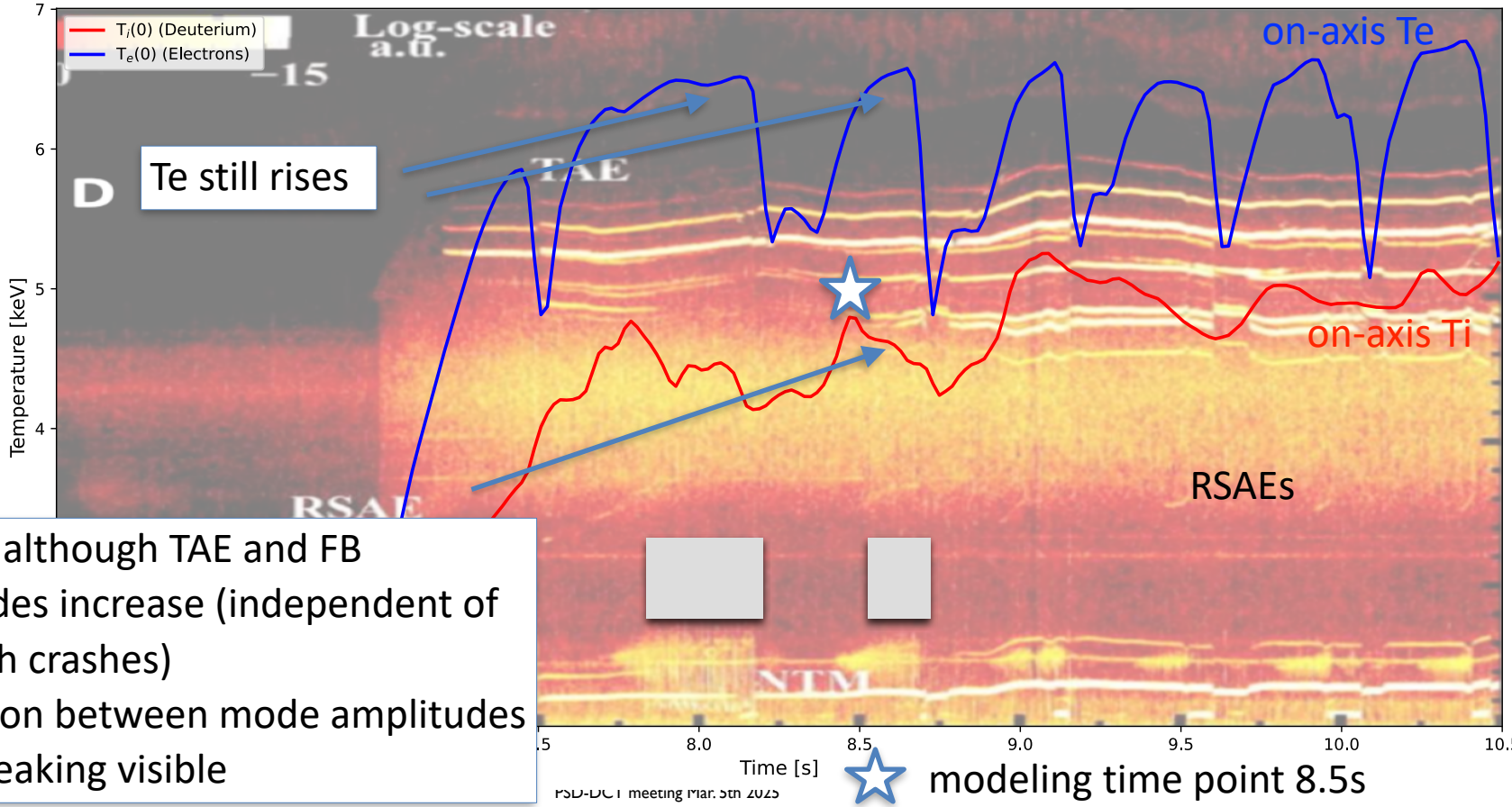
JET #99896

[Nat. Comm, Garcia et al 2024/FAR3D modeling]

- ICRF = 4.5MW; NBI ~ 3.5MW, D beams < 9 s and T > 9s. P_fusion ~ 0.5MW
- main results: good confinement despite many EP-driven modes
- modelling FAR3D: zonal flows driven by TAEs and fishbones (FB) stabilise turbulence @8.5s
- since ~Oct 2024: sufficiently complete TRANSP run #99896 available to TSVV#10 (thx. J Ferreira)
- extension of WF to up to 4 different EP species (H,D,T, alphas)
- still: serious shortcomings of dataset (see below)
- motivation: attempt time-dependent reduced modelling, define sensible control cases



first observation: result that TAEs and FB stabilise ITG and lead to Ti peaking is not universal



Ti drops although TAE and FB amplitudes increase (independent of sawtooth crashes)
no relation between mode amplitudes and Ti peaking visible

modeling time point 8.5s

discussion

- interaction of MHD/EP-driven modes and turbulence is not sufficiently understood
- challenging requirements: global, kinetic, transport time scales, large deviations from neoclassical distribution functions for EPs
- no code available - need to rely on physics based reduced models

- short term (2025):
  - TSVV10/11: coupling of EP-WF and ATEP to transport solvers
  - DCT and WPDES (see 2025 plans): apply to DEMO LAR
  - WPTE: improve modelling of JET data (IMAS availability); engage in discussion with experimentalists in order to prepare proposals for next experimental call (based on results e.g. by R. Bilato)

- mid term (2026/27):
  - TSVV or ENR: need to provide reduced models for assessing comprehensive transport analysis including possible EP stabilising effects (cross scale models to be developed, white paper)
  - DCT and WPDES: EP transport in DEMO; turbulence+EP modeling with presently available tools (ORB5/GENE-Tango/ATEP)
  - WPTE: execution/modelling of further experiments (AUG/TCV?) ~10 discharges/1ppy