IMAS - INTEGRATED WORKFLOW FOR ENERGETIC PARTICLE STABILITY

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[1]IPP [2]ITER

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Motivation and Structure

- **All EP transport models rely on linear properties of instabilities.**
- **In the past:**
  - Damping/drive assessment difficult because global – electromagnetic problem
  - Local – global analysis not connected
  - Problems with centralization of data from different codes
- **Now:**
  - Development of the Integrated Modelling & Analysis Suite (IMAS)
  - Equilibrium and stability codes (HELENA, LIGKA) were further developed and adapted to work with IMAS.

- **This work:**
  - Using IMAS as a centralized database tool
  - Adaptation of HELENA and LIGKA
  - Python time-dependent workflow
  - Impact of Toroidal Alfvén Eigenmodes (TAEs) on various ITER scenarios:
    - ITER baseline DT - METIS[1] -130012
    - pre-fusion plasma - 101006
    - steady state scenario (ITER > 2038)
    - experimental data AUG - 39681
  - Fundamental first step to automated analysis of time-dependent scenarios.

[1]J.F. Artaud et al. (2018)

Numerical Tools: Overview

- **IMAS:**
  - Integrated Modelling & Analysis Suite
- **LIGKA[1]:**
  - Linear gyrokinetic eigenvalue code
- **HELENA[2]:**
  - MHD equilibrium solver
- **EP - WF[3]:**
  - Energetic Particle Stability Workflow (Python)

- **Models form hierarchy of fidelity, complexity:**
  - Use local solvers to have an overview of the scenario before attempting global, more expensive runs.
  - Use global solver to validate the results obtained by the local, faster runs.

1) Lauber JCP (2007); 2) CP90 Conference on Computational Physics. (1991)
3) V.-A. Popa Master Thesis (2020)

Numerical Tools: LIGKA

- **LIGKA:**
  - Solves the linearized gyrokinetic equations -> eigenvalues and eigenfunctions (frequency, damping, mode structure).
  - Different physics in the data structure need to be studied, thus mapping to the underlined data management in order to derive the uncertainty quantification for each model is necessary.
  - Subprograms of LIGKA used in this work are:

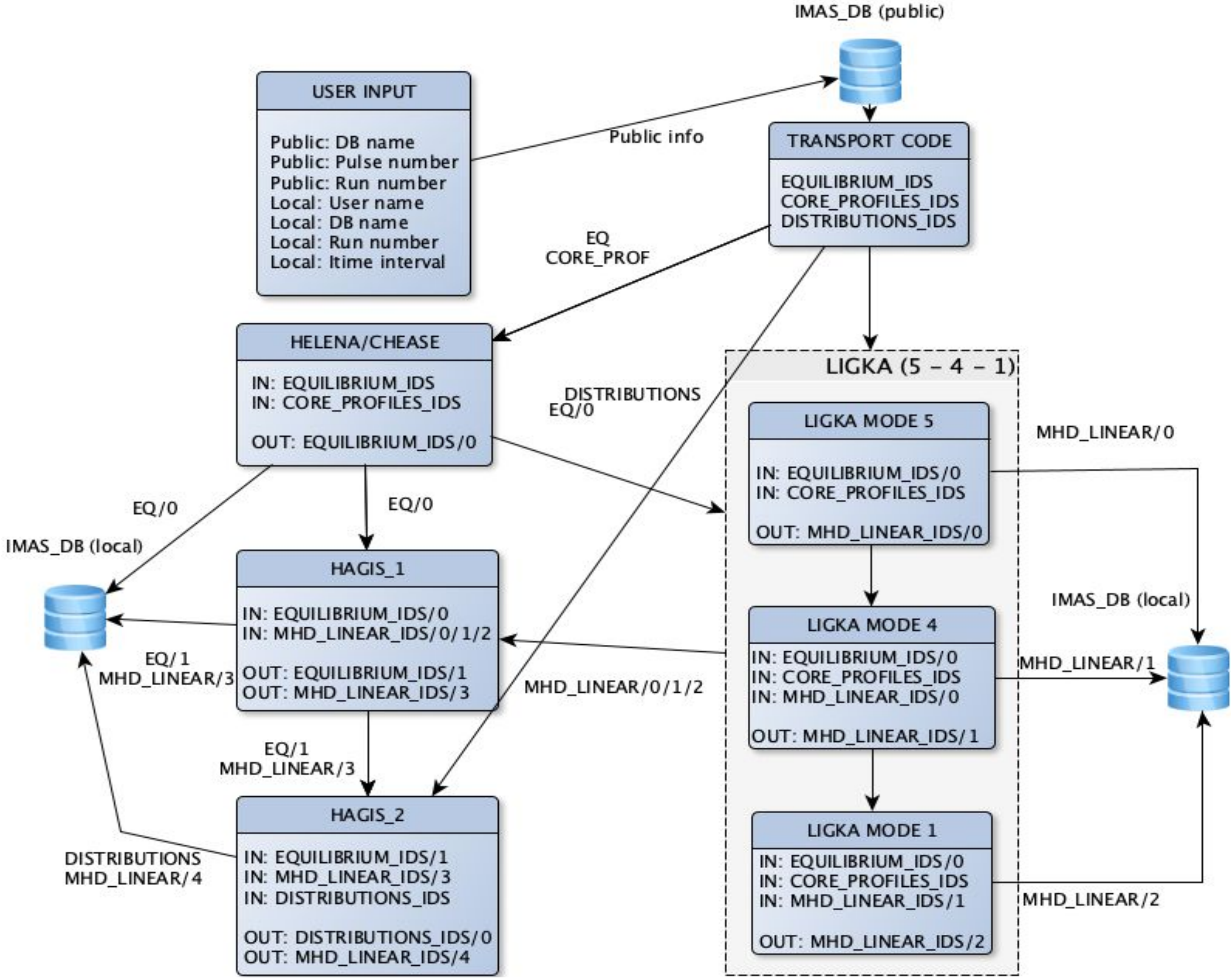
~ 1 s
- Model 5: local analytical estimates of various basic AEs properties: frequency, estimated mode structure, rational surface, next and previous gap informations.

~ 10 s
- Model 4: based on model 5 results, the local analytical dispersion relation for each mode is calculated. Determines the starting point for global calculations.

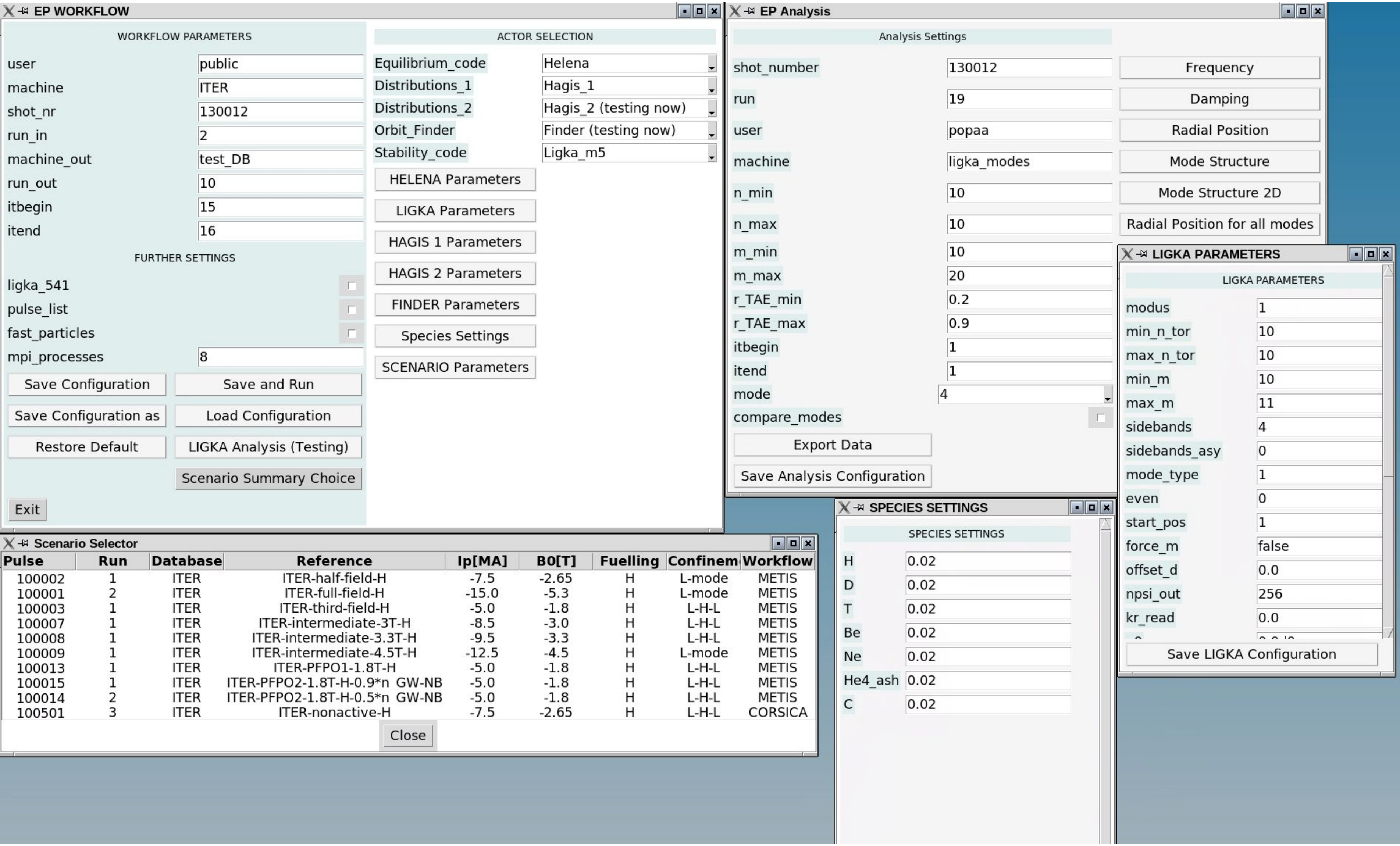
~ 1 h
- Model 1: performs a frequency scan throughout the gap to find global linear properties of the modes.

Numerical Tools: Energetic Particles Stability Workflow

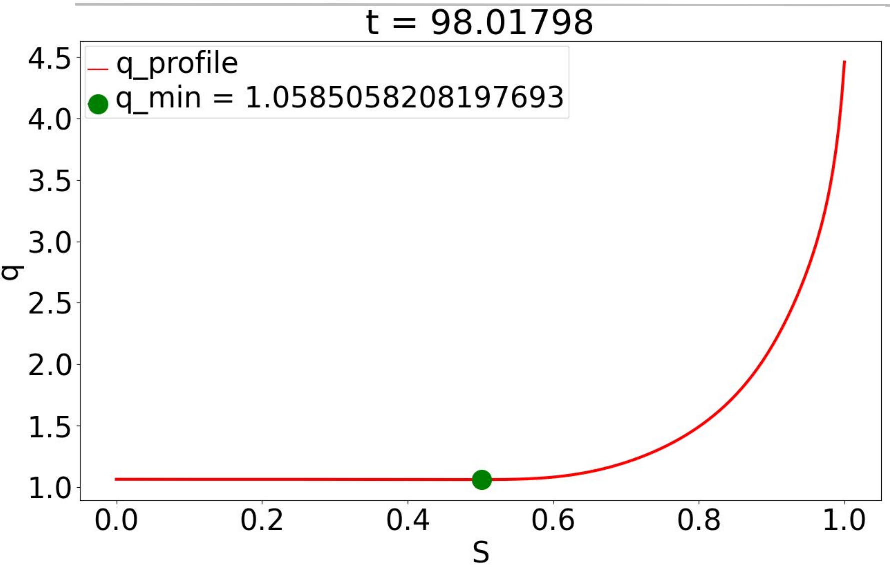
- First time - dependent workflow which makes use of the IMAS infrastructure and various codes.
- **Scope:**
  - Connect the numerical tools with the data infrastructure (IMAS).
  - Facilitates retrieving/saving data from the DB through XML files.
  - Fast configuration of numerical tools.
  - Complete data analysis suite integrated in the interface.



Numerical Tools: EP - WF - GUI

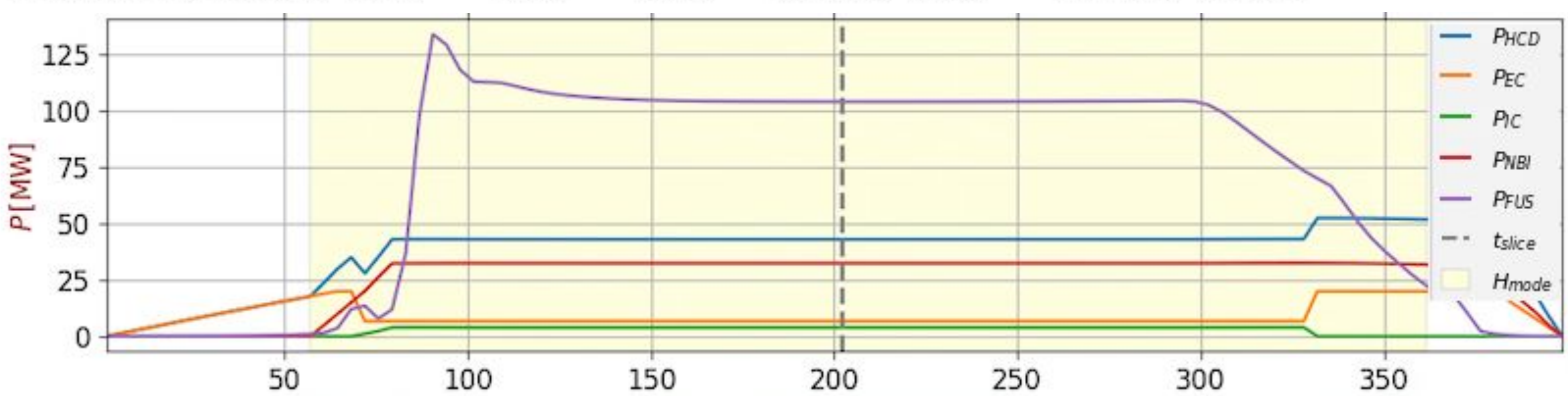


Results: METIS case 130012/2 (ITER DB)

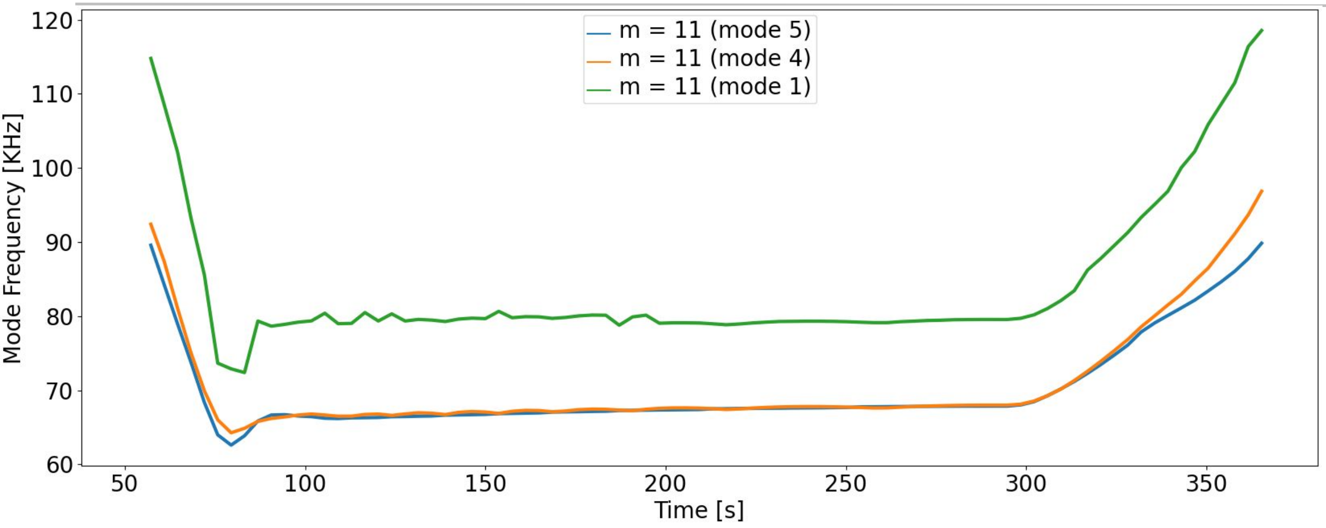


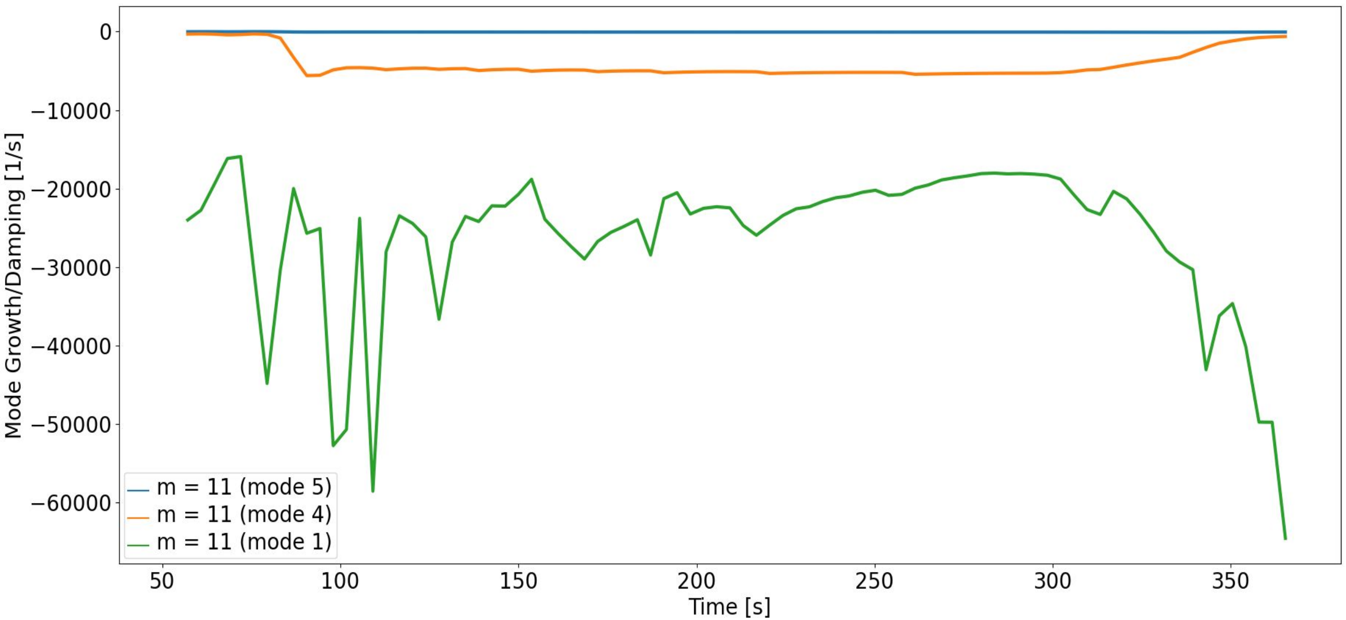
- Time – dependent scenario (METIS)
- ITER baseline DT scenario
- confinement regime: H-L-H
- magnetic field: -5.30 [T]
- main species: D-T
- plasma current: -15 [MA]
- central electron density: 1.01e+20[m-3]

species:	H	D	T	He3	He4	Be	O	W
a:	1.0	2.0	3.0	3.0	4.0	9.0	16.0	183.0
z:	1.0	1.0	1.0	2.0	2.0	4.0	8.0	74.0
n_over_ntot:	1.17e-20	0.468	0.469	0.045	1.43e-03	0.016	1.63e-04	3.81e-06
n_over_ne:	1.07e-20	0.428	0.429	0.041	1.30e-03	0.015	1.49e-04	3.48e-06
n_over_n_maj:	2.50e-20	0.997	1.000	0.096	3.04e-03	0.035	3.48e-04	8.11e-06



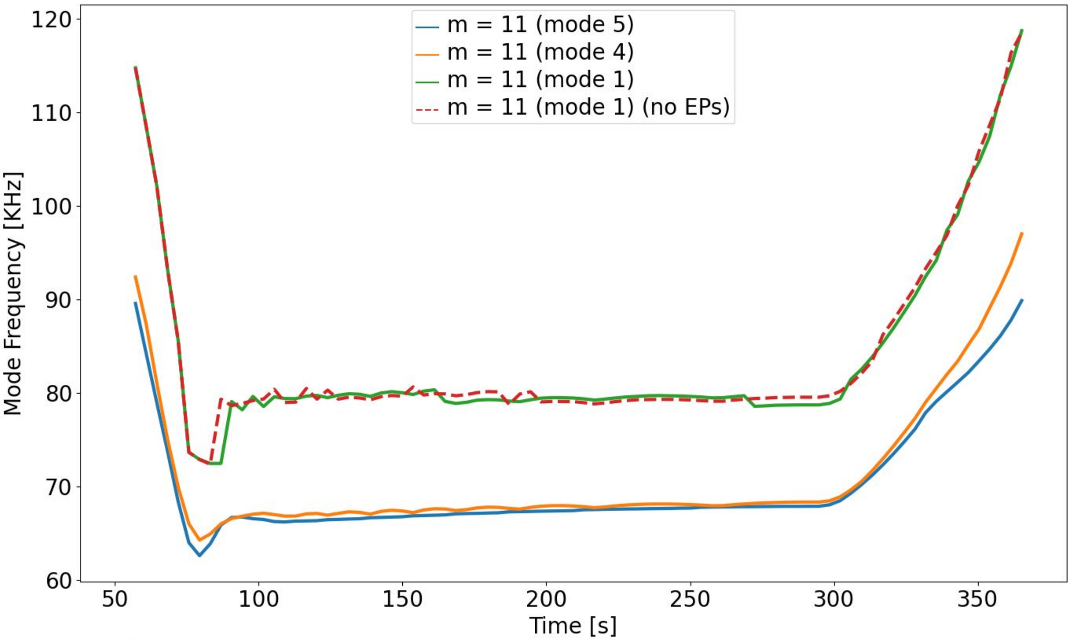
Results: METIS case 130012/2 (ITER DB)

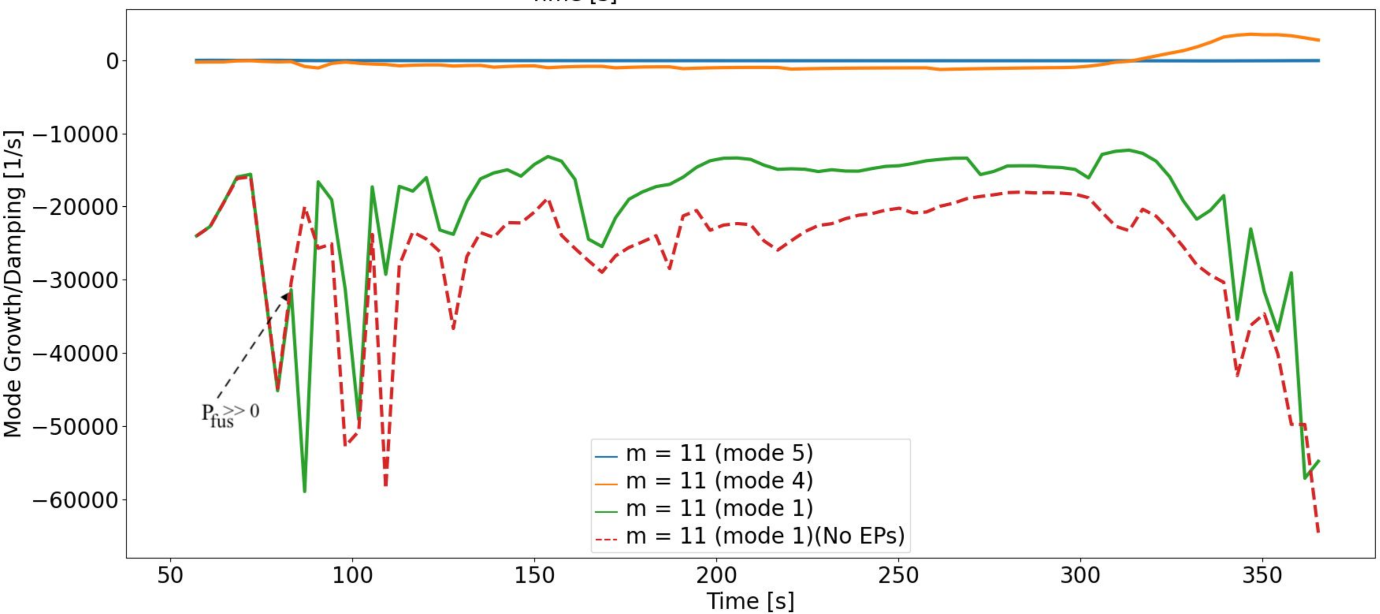




- **n = 10, m = 11:**
- No alpha particles are considered for now.
- A correlation in frequency between local solver and global one with a 10% expected difference.
- Local solvers (mode 5 and 4) do not consider the continuum damping and radiative damping (i.e. coupling to KAW) contributions.

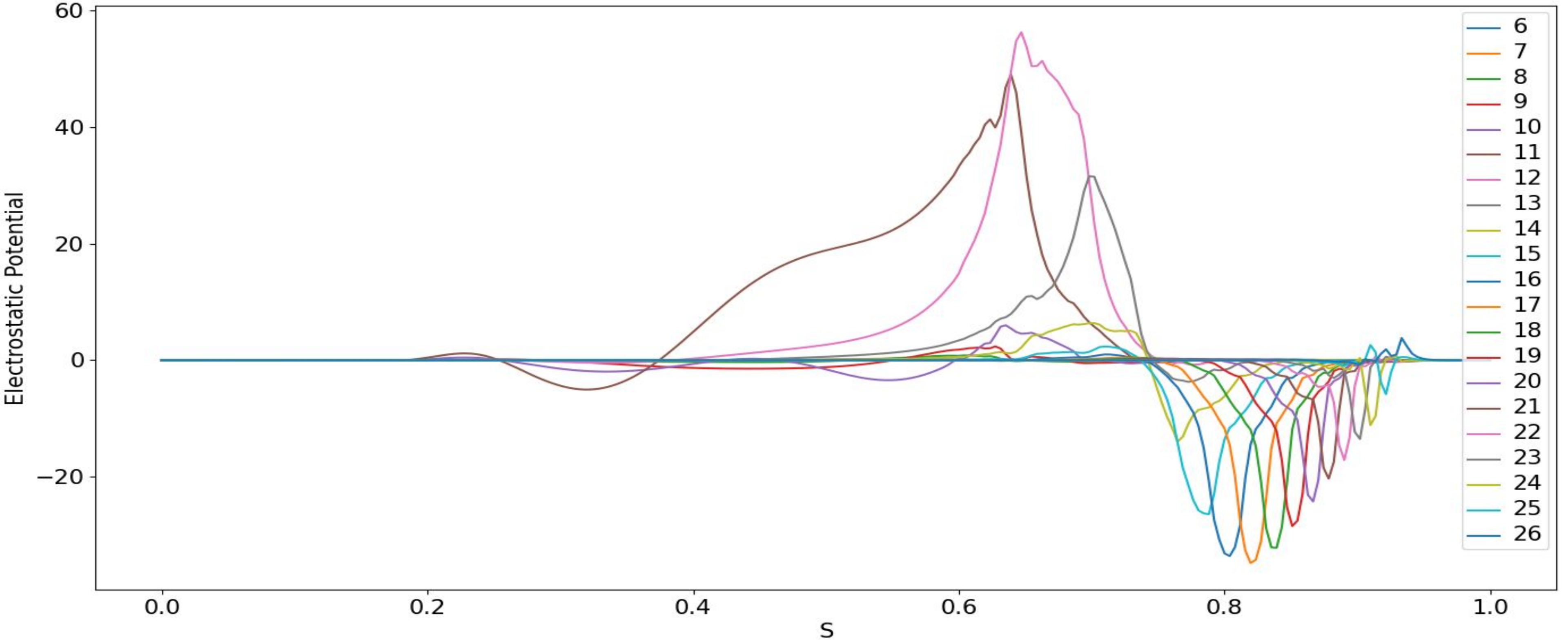
Results: METIS case 130012/2 (ITER DB)





- **n = 10, m = 11:**
- Alpha particles are considered.
- As expected, the frequency did not shift by a semnificative margin.
- In mode 4 (local solver) one can see a growth in the modes once EPs are included.
  - In mode 1 (global solver) a better view towards the growth of the mode can be observed.
  - Until P_{fus} is significant, the modes follow the exact same path. The modes are less damped once P_{fus} is large enough.
  - In this case, the EPs drive is not sufficient to drive the modes unstable.

Results: METIS case 130012/2 (ITER DB)

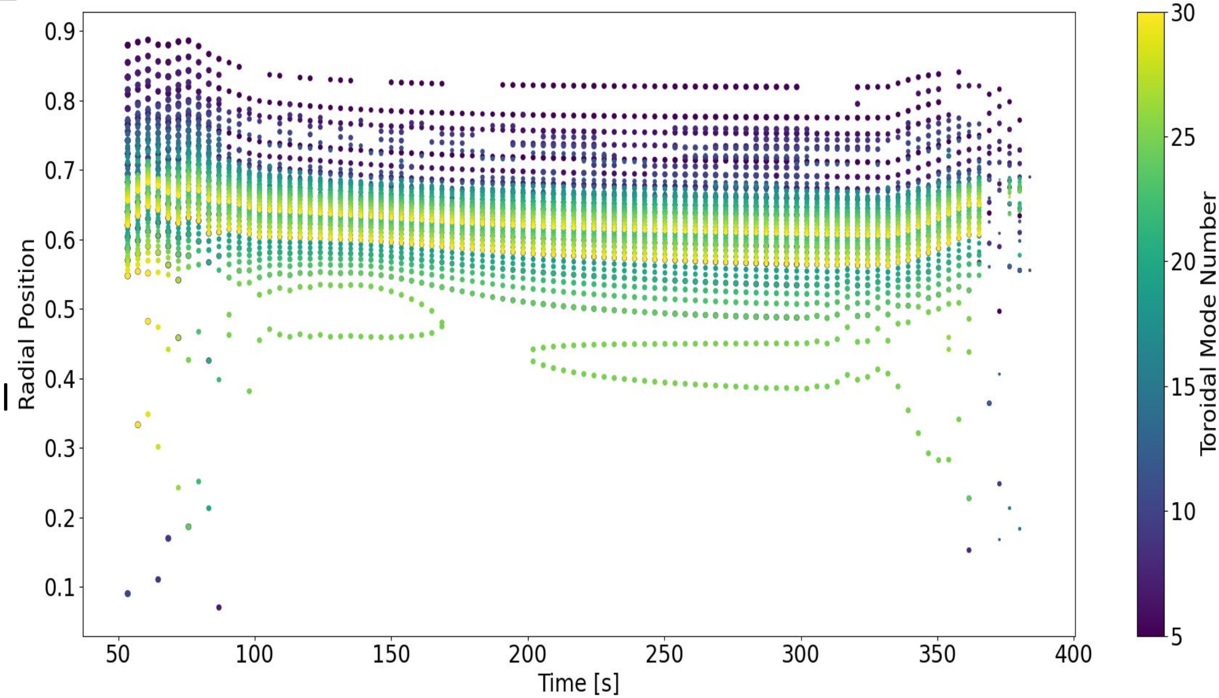


- **Mode structure n = 10, m = 11, t = 201.96s:**
- Due to the extremely flat q - profile (if steep q, poloidal harmonics become smaller and more narrow towards the edge)
- **This case, stable for all modes investigated(n=5-30 TAEs) so far more realistic q leads to more unstable situations (papers [1],[2],[3]).**

[1] S.D.Pinches et al. 2015
[2]Ph.Lauber et al. 2015
[3]T.Hayward-Schneider et al., NF (2021)

Outlook - this work has unlocked possibilities

- **The next steps are:**
  - Consolidation and removal of remaining problems (porting to gateway complete).
  - Mode 5 analytical mode structure improvement, in the future , it will decide when to run mode 1 (global solver) or not.
  - Include and test other AEs (EAE,BAE,RSAE,…)
  - NBI distribution function to be added (Interface to ITER H&CD wf already developed)
  - Non – linear hybrid model (HAGIS 2) to predict saturaturation level of modes (already imported in IMAS).
  - Build transport models from the results obtained in the stability analysis (pursued within Eurofusion Enabling Research Project ATEP).



- Other scenarios tested with the WF:
  - pre-fusion plasma - 101006
  - steady state scenario (ITER > 2038)
  - experimental data TCV (M. Vallar - EPFL)
  - experimental data AUG - 39681