Energetic Particle dynamics induced by off-axis neutral beam injection on ASDEX Upgrade, JT-60SA and ITER

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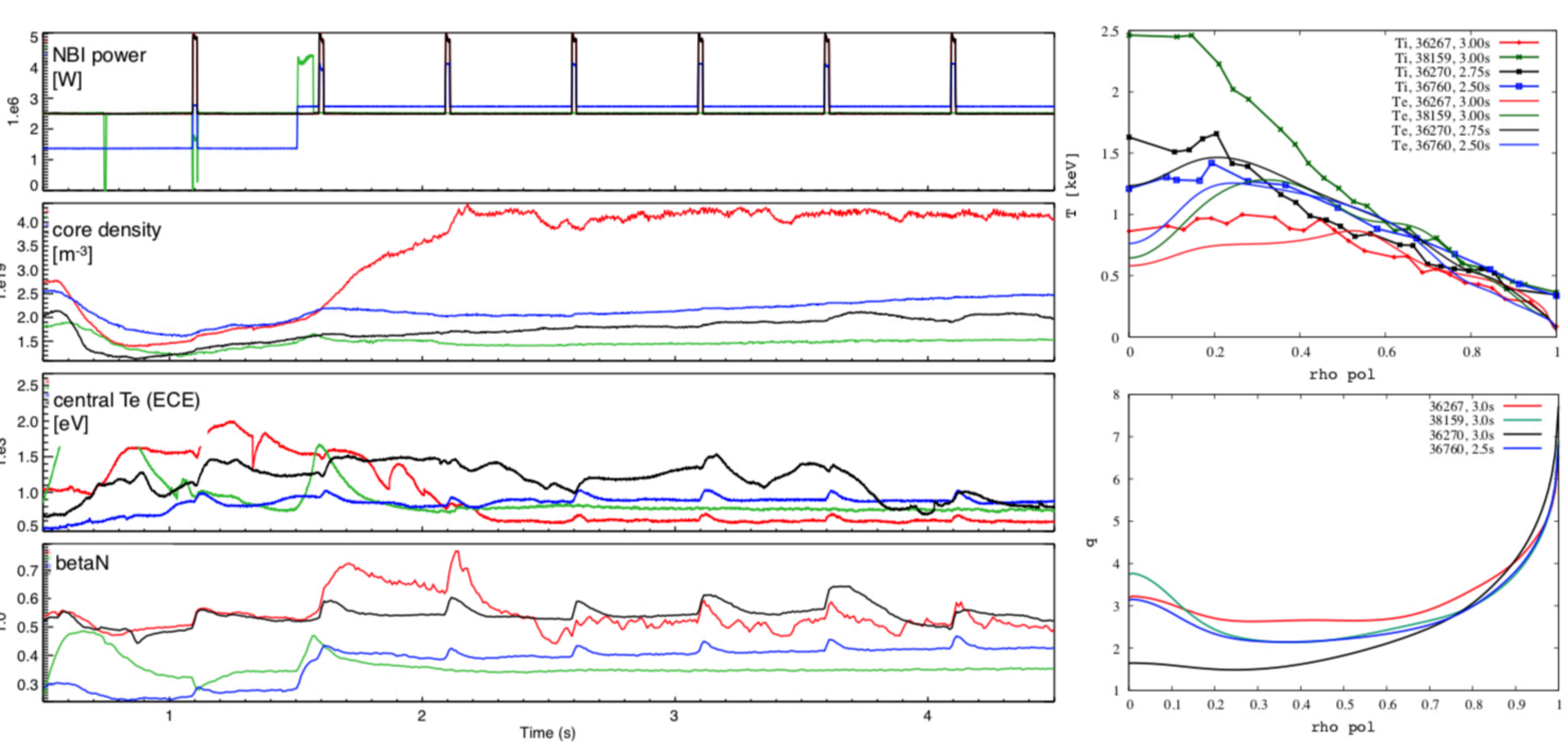
motivation & main results

- off-axis NB heating is crucial for current profile control, particularly in ramp-up phases
- ASDEX Upgrade (AUG) scenarios with exclusive off-axis heating brings $E_{NB}/T_{thermal}$ and $\beta_{fast}/\beta_{termal}$ closer to future experiments
- what is the effect of the observed EP instabilities on the background profiles? First evidence for core ion heating due to inwards redistributed EPs
- validate stability and transport tools on extended AUG data base, including experimental isotope studies: different βs, H,L-modes, non-linear EGAM dynamics
- start to investigate scenario projections of JT-60SA and ITER pre-fusion plasmas, focus on anisotropic distribution functions
- use IMAS to develop and validate an automated EP stability workflow, finalise preparations for the implementation of reduced EP transport models

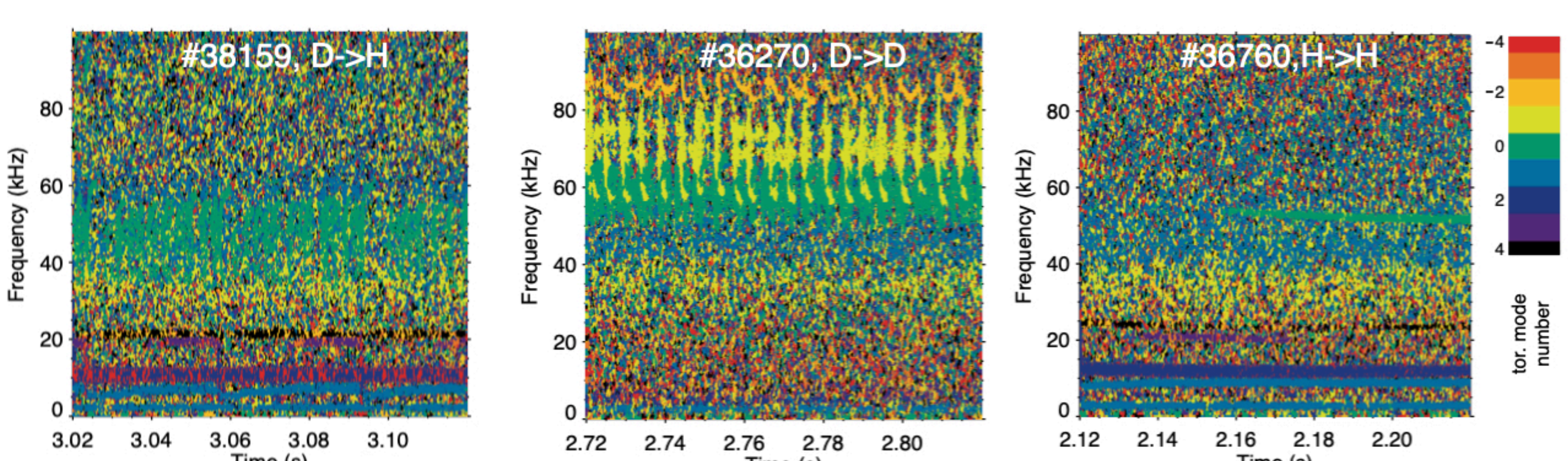
Isotope studies onASDEX Upgrade

investigation of strongly non-linear EP dynamics on AUG is possible [1]:

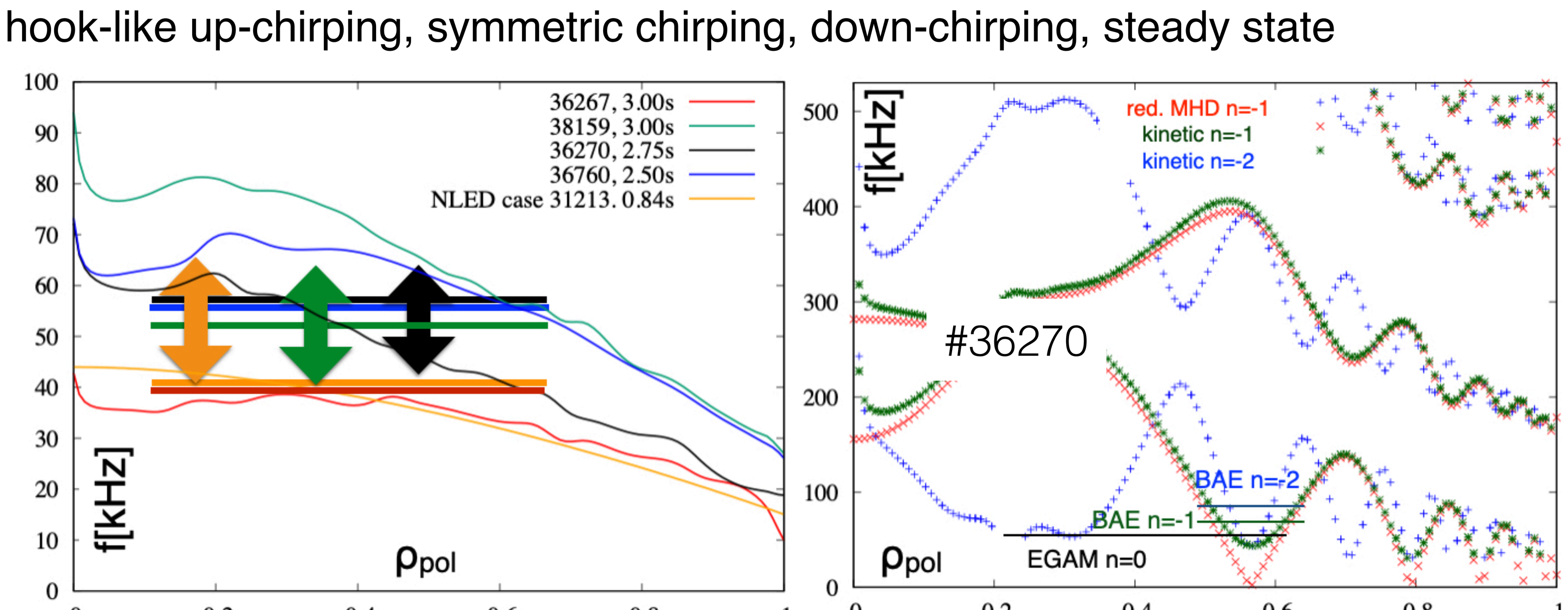
- with sub-Alfvénic beams (2.5-5MW)
- in current flat-top with stationary plasma conditions
- compatible with tungsten wall
- for EP physics relevant parameters: $\beta_{EP}/\beta_{thermal}$ ~1, $E_{NBI}/T_{i,e} \approx 100$
- for different isotope mixes: deuterium (D) and hydrogen (H)



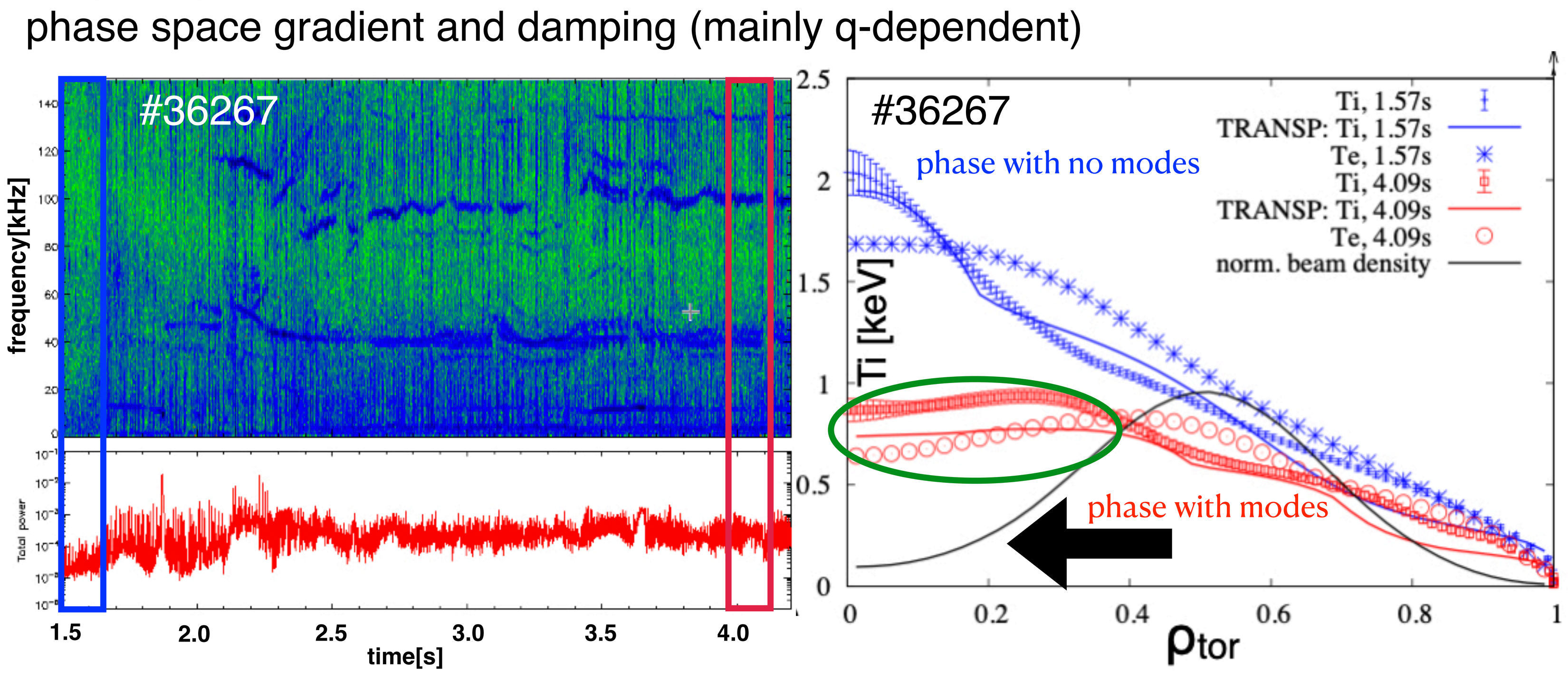
- #36267 D→D, H-mode, 0.7 kA, 2.5MW
- #38159 D→H, L-mode, 0.8 kA, 2.5MW
- #36760 H→H, L-mode, 0.8 kA, 2.8MW
- #36270 D→D, L-mode, 0.8 kA, 2.5MW



mode number analysis: EGAMs and k-BAEs with different non-linear chirping dynamics are found:
hook-like up-chirping, symmetric chirping, down-chirping, steady state

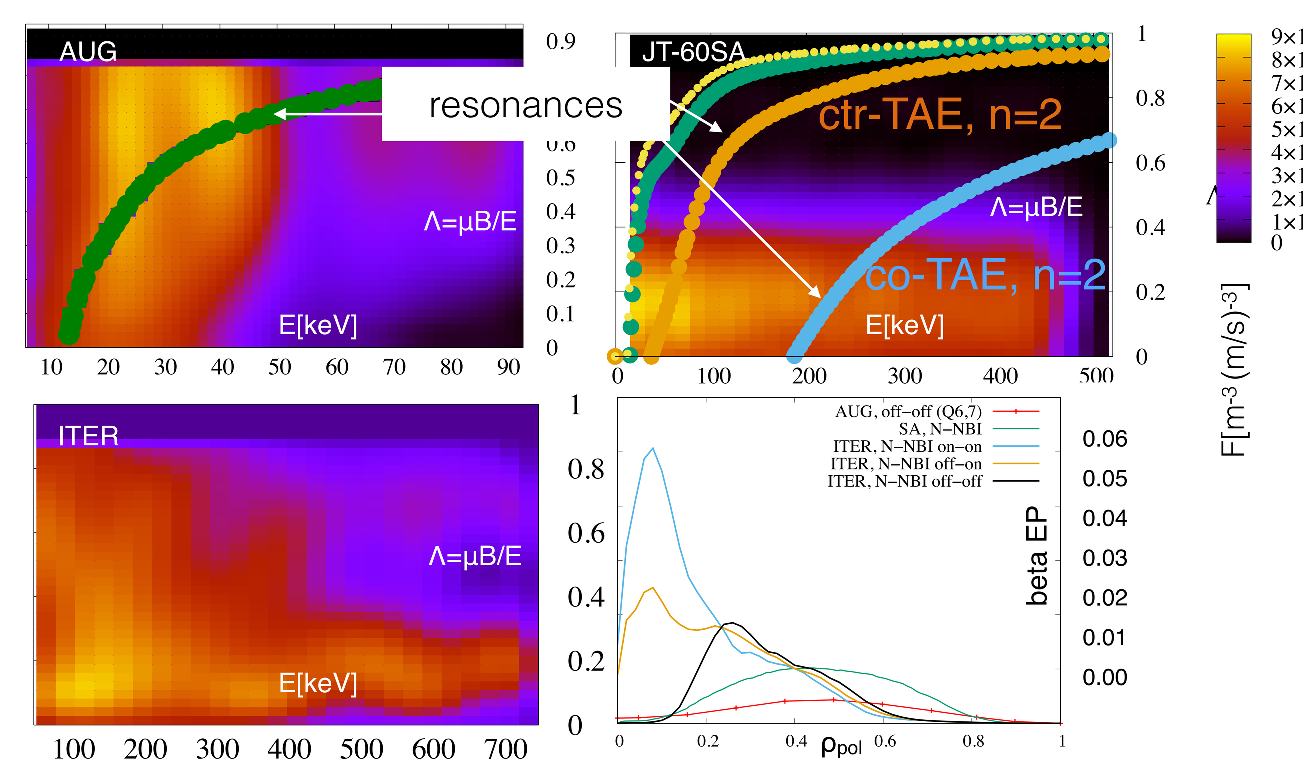


chirping type not directly related to GAM continuum - given by combination of EPs' phase space gradient and damping (mainly q-dependent)

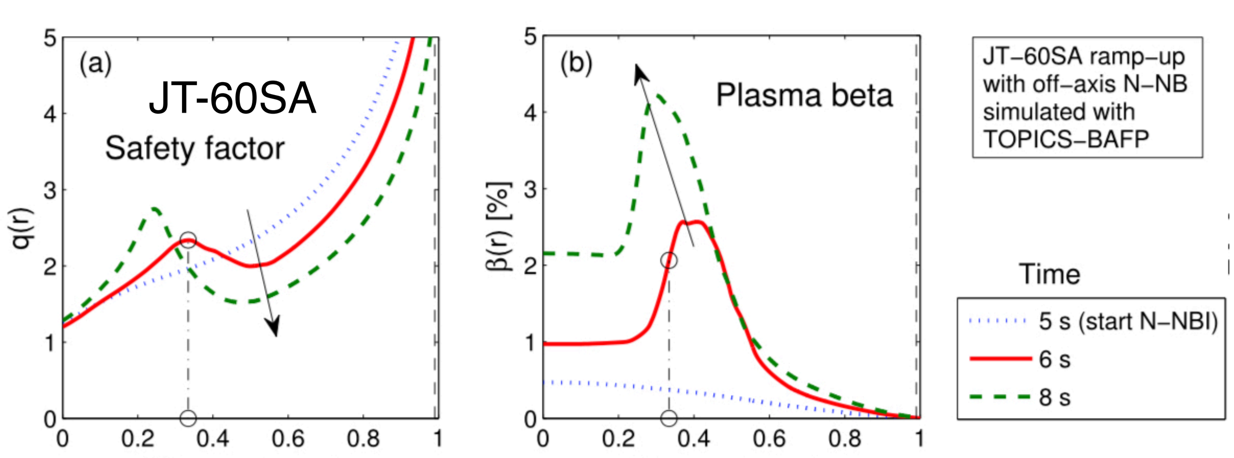


- L-mode profiles facilitate diagnostics coverage: location of reflectometry cut-off layer allows radial mode localisation (s=0.5-0.6) for the EGAMs,BAEs shown above
- EP redistribution directly measured (FIDASIM) [1]
- EP transport seems to affect background profiles: Ti and Te profiles in different phases of the discharges (#36267 at 4.09s)
- in mode-quiescent phase (#36267 at 1.57s): Te~Ti, interpretative classical TRANSP profiles match Ti as measured during beam-blips
- ongoing (challenging!) linear analysis with various codes: HAGIS/ LIGKA, MEGA, HYMAGYK, ORB5 ([3], G. Vlad at this conference) as preparation for non-linear modelling

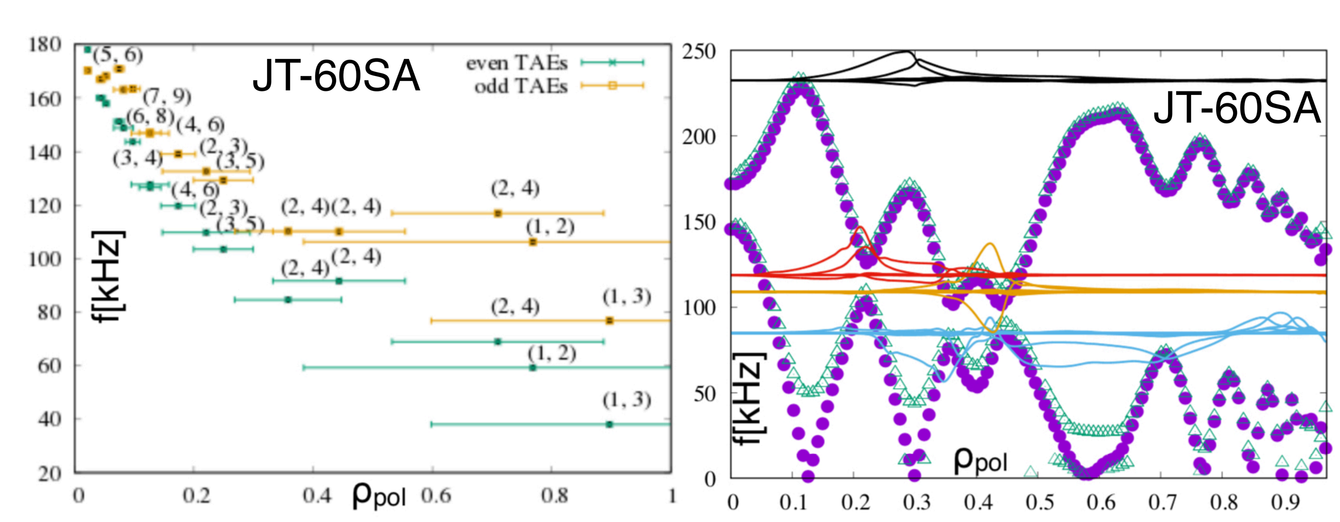
Off-axis NB heating scenarios on JT-60SA & ITER pre-fusion plasma



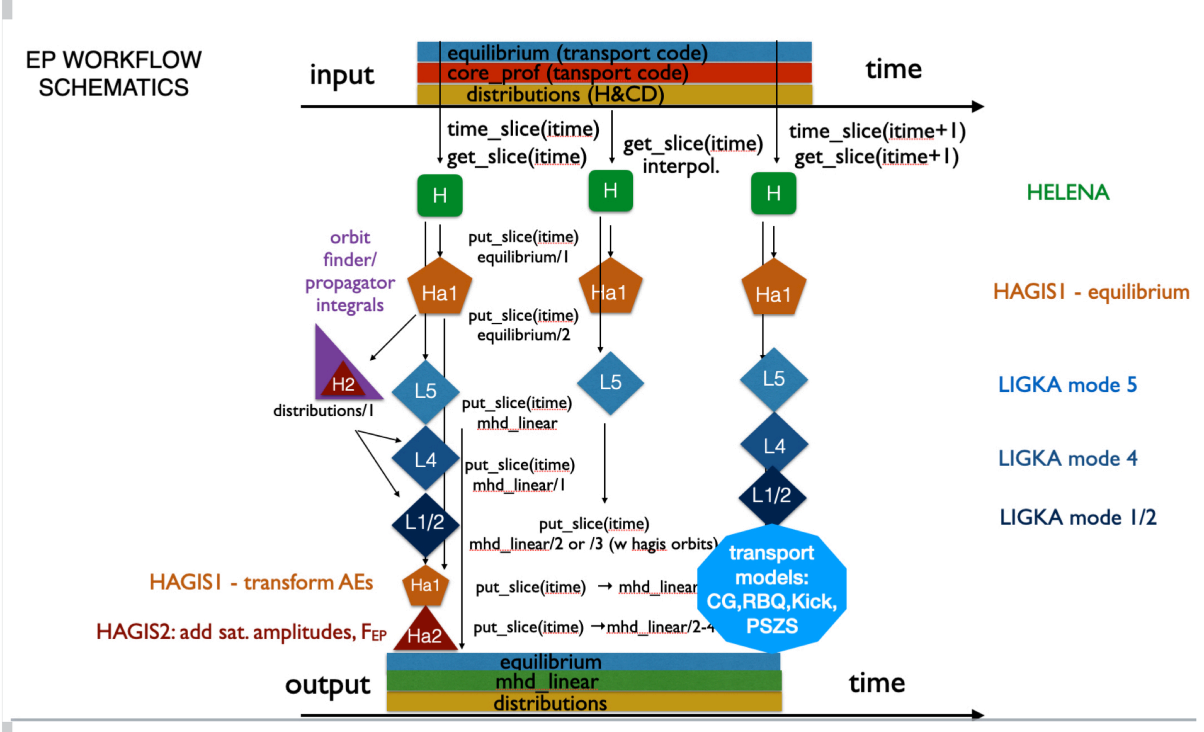
- different injection geometries, energies and background collisionalities lead to F_{EP}'s with substantially different phase space structures
- new interface between MEGA, ITER H&CD workflow, TRANSP/NUBEAM and LIGKA/HAGIS has been developed: bin, smooth, project to COM space
- left: beam β's for the three experiments; for ITER the three possible geometries of the two beam lines (on-axis/on-axis, off/on, off/off) are shown
- selected resonance lines for co (blue) and counter (orange/ beige) propagating n=2 TAEs have been added; green: GAM/BAE resonance at s=0.4: no intersection of counter-propagating resonances with energetic phase space region prevent low-n TAEs to be excited. EAEs likely to be unstable



from reference [2]

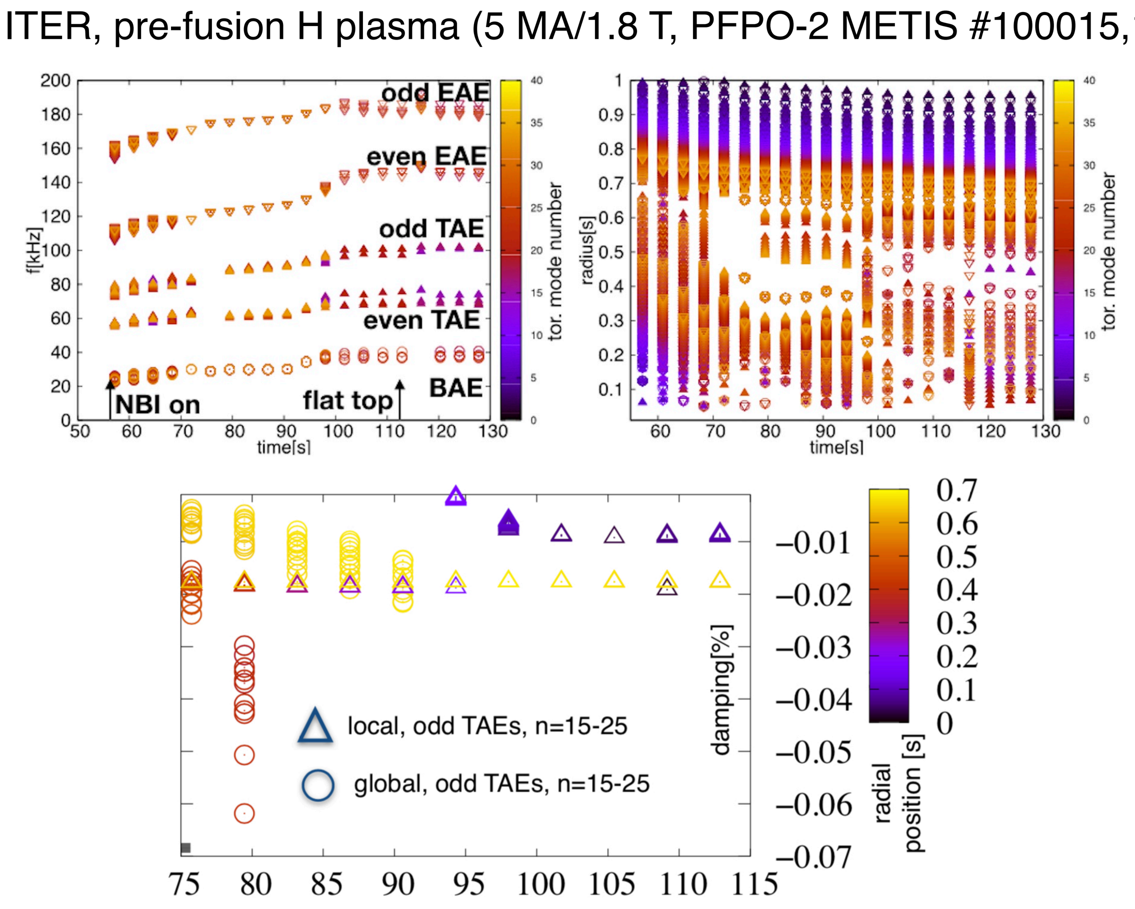


- hierarchical workflow (WF) embedded in LIGKA has been applied for JT-60SA: local estimates, global properties: fast overview runs give clear picture about gaps, frequencies, local damping and mode structures



- AE sensitivity during ramp-up motivates time-dependent analysis as first step to reduced transport models (RTM)
- LIGKA/HAGIS has been ported to ITER-IMAS
- an EP stability python WF has been created, combining different levels of fidelity and speed, including the possibility to run non-linear HAGIS simulations for non-linear EP relaxation

ITER, pre-fusion H plasma (5 MA/1.8 T, PFPO-2 METIS #100015,1)



- regions without AEs (q≳1) in steep EP gradient regions can be predicted and traced
- global calculations differ in many cases from local estimates for damping, drive and existence: example of two branches of odd TAEs, comparing damping rate and mode existence
- although local models can give first insight and overview, global models are needed for reliable prediction (linearly and non-linearly)
- confirmed by recent successful comparison of HAGIS/LIGKA with global GK ORB5 simulations of ITER ITPA 15 MA case (#131018,40) [see poster T. Hayward-Schneider TH/P1-14]

References:

[1] Ph Lauber et al, 2018 EX/1-1 Proc. 27th IAEA FEC, 22-27 October 2018, Gandhinagar(Ahmedabad) Gujarat, India.
[2] Bierwage A, Toma M and Shinohara K 2017 *Plasma Physics and Controlled Fusion* 59125008
[3] G Vlad et al, 2021 TH/P1-3 Proc. 28th IAEA FEC 10-15 May 2021, Nice, France

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