Gyrokinetic analysis of DTT negative triangularity scenarios and TCV, AUG plasmas with similar shapes

Alberto Mariani

ISTP CNR Milano Italy

DTT, EUROfusion TE and TSVV2, ASDEX-Upgrade, TCV teams

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.

Author list

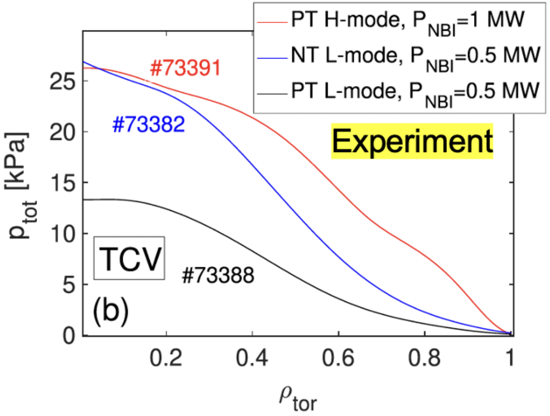
A. Mariani[1], L. Aucone[2], A. Balestri[3], P. Mantica[1], G. Merlo[4], R. Ambrosino[5,6,7], L. Balbinot[8], J. Ball[3], I. Casiraghi[1], A. Castaldo[9], S. Coda[3], T. Happel[4], J. Hobirk[4], P. Innocente[10], T. Pütterich[4], O. Sauter[3]

[1] *Institute for Plasma Science and Technology, CNR, Milano, Italy,*
[2] *Department of Physics "G. Occhialini", University of Milano-Bicocca, Milano, Italy,*
[3] *École Polytechnique Fédérale de Lausanne (EPFL), Swiss Plasma Center (SPC), Lausanne, Switzerland,*
[4] *Max-Planck-Institut für Plasmaphysik, Garching, Germany,*
[5] *DTT S.C. a r.l., Frascati, Italy,*
[6] *Università degli Studi di Napoli Federico II Napoli, Italy,*
[7] *Consorzio CREATE, Napoli, Italy,*
[7] *Università della Tuscia, Dipartimento di Economia, Ingegneria, Società e Impresa (DEIM) Viterbo, Italy,*
[9] *ENEA C.R.Frascati, Frascati, Italy,*
[10] *Consorzio RFX, Padova, Italy*

Lower δ shape

First DTT NT shape: low delta (LD): SUMMARY

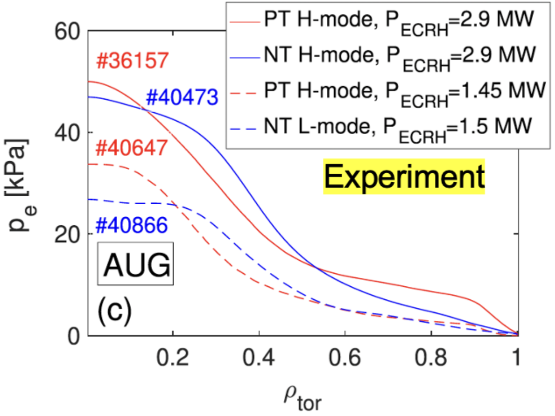
TCV: exceptionally beneficial effect of NT



TCV: experiment:

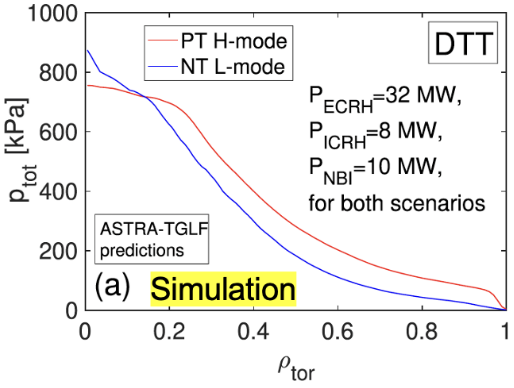
NT L-modes **reach** the central n,T of PT H-modes with **double** power.

AUG/DTT: milder effect



AUG: experiment:

NT H-modes: **smaller pedestal** than PT H-mode with the same power. However, similar **pressure** and **much weaker ELMs**.



DTT: ASTRA-TGLF SAT2 with BC at $\rho_{tor} = 0.94$:

NT L-mode underperforms PT H-mode, but still NT has a total pressure 80% of the PT counterpart, with good performance in absence of ELMs;

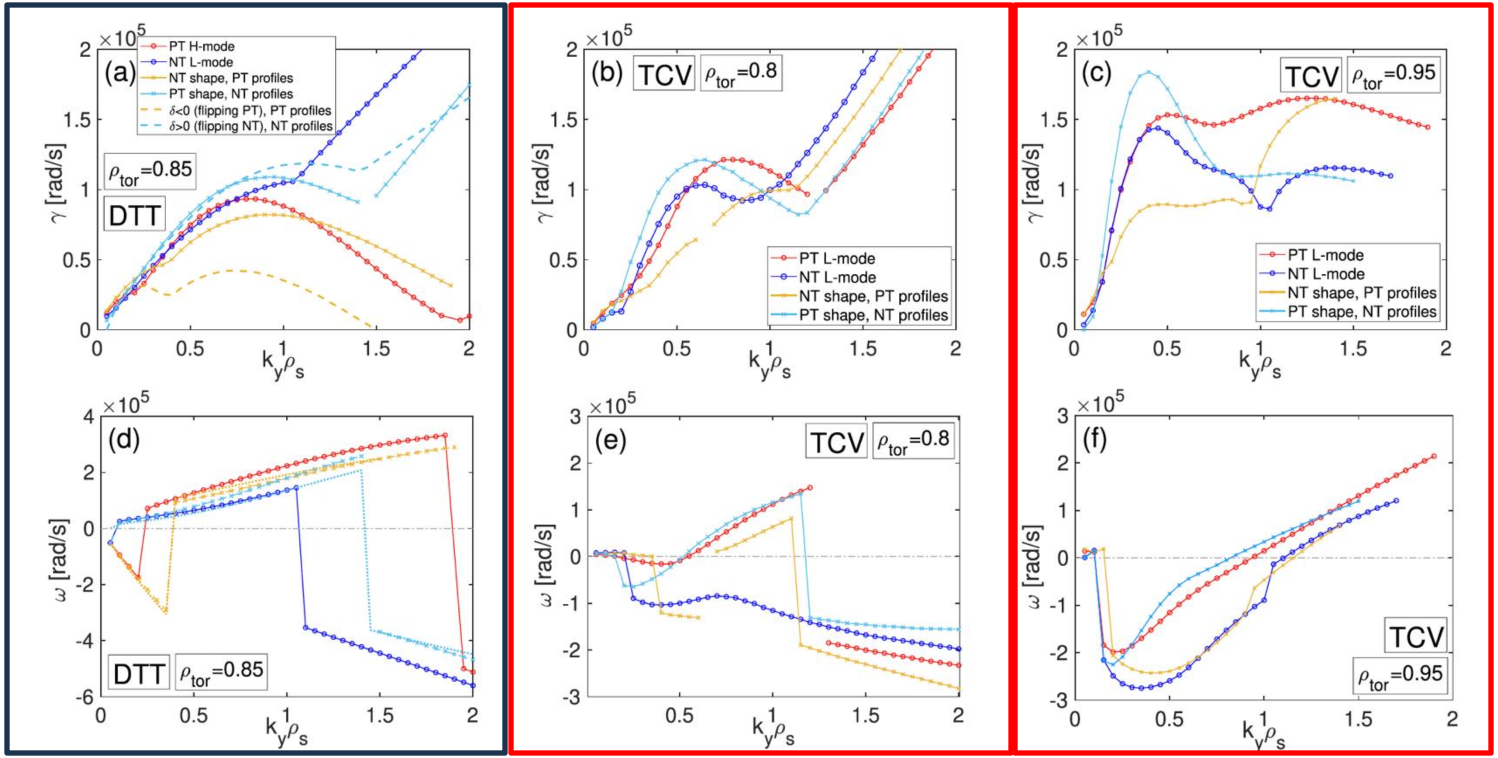
Different strength of NT stabilization for TCV and AUG/DTT

- C (TCV) vs W (AUG/DTT) wall but, *no variation in Zeff and C concentration is seen between PT and NT in TCV; in addition, ongoing gyrokinetic analysis seems to point out that switching from C to W impurity does not affect the NT stabilization.*

- Neutral penetration larger in TCV ➔ *tested by injecting shallow pellets in AUG (shown in the following part on high delta NT shape)*

- Mixed ITG-TEM (TCV) vs ITG-dominant (AUG/DTT): *check with gyrokinetic simulations (next slides)*

Linear GENE gyrokinetic simulations: DTT vs TCV



From NL fluxes:

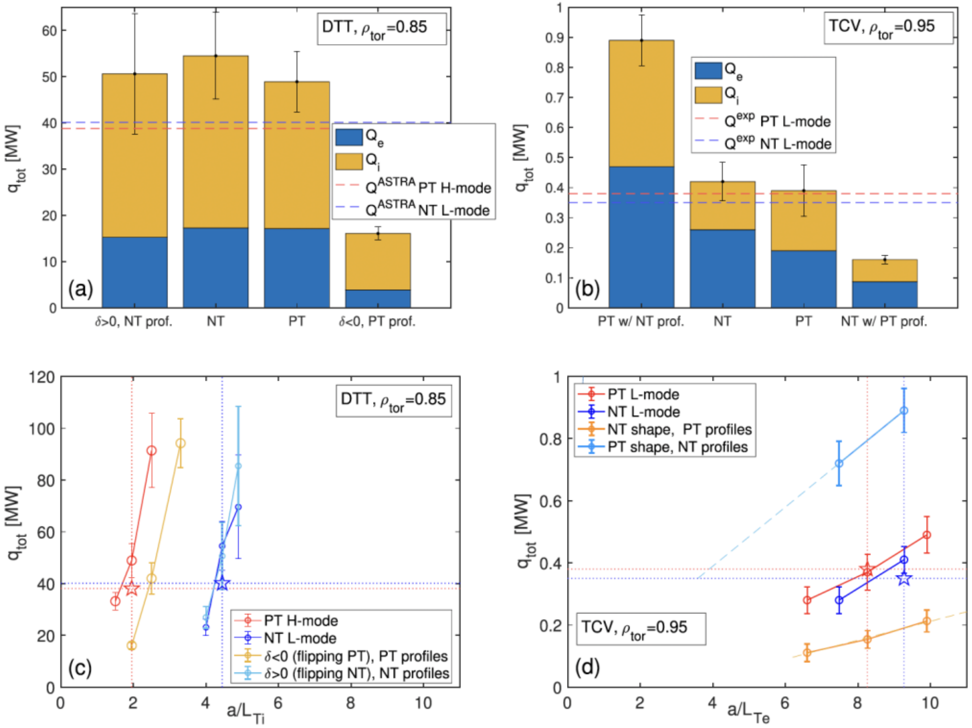
q_e/q_i = 0.54-0.46 (DTT PT H-NT L at ρ_{tor} = 0.85): **PT/NT ITG**

q_e/q_i = 0.77-1.62 (TCV PT L-NT L at ρ_{tor} = 0.8): **PT more ITG, NT more TEM**

q_e/q_i = 1.05-1.85 (TCV PT H-NT L at ρ_{tor} = 0.95): **PT balanced, NT TEM**

- AUG: ITG-dominant for ECH only cases, due to large Pei;
- SUMMARY: DTT-AUG are more ITG-dominant, TCV has more balanced ITG-TEM

Nonlinear gyrokinetic simulations



DTT, ITG dominant: one studies the T_i stiffness

TCV, more *TEM overall: T_e stiffness*

- **TCV:** the exp. beneficial effect of NT is recovered; very low T_e stiffness.
- **DTT:** beneficial effect of NT at ρ_{tor} =0.85: only found when keeping fixed the PT H-mode profiles;

It seems that being in a mixed ITG-TEM state like in TCV is beneficial: test for the TCV case with GENE (next slides, new results)

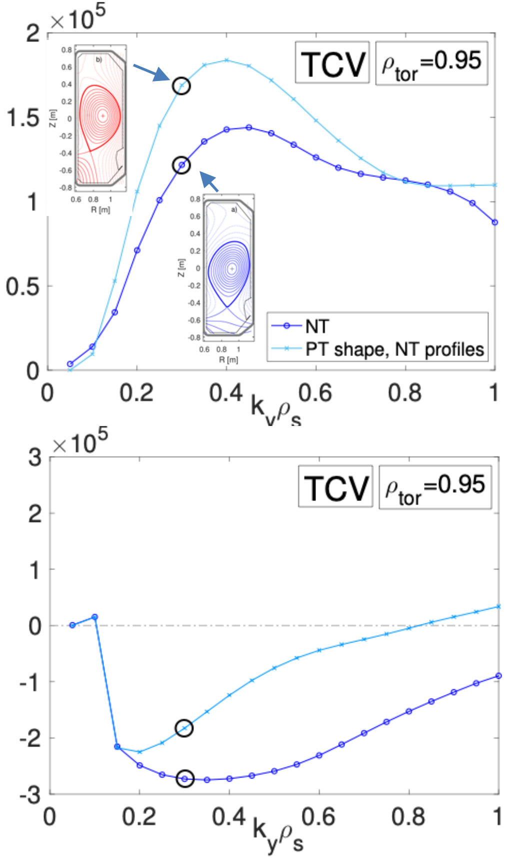
Different linear NT stabilization for ITG and ITG-TEM?

Numerical test (single $k_y\rho_s = 0.3$):

Compare:

TCV NT with DTT LD shape

Same case with DTT PT shape



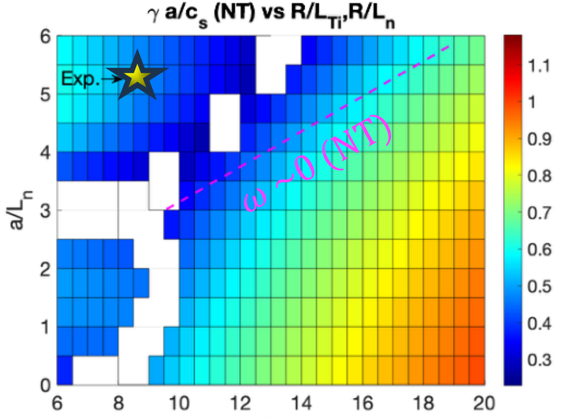
- **~750 linear GENE simulations**, sampling a subsection of the $(a/L_{Ti}, a/L_n)$ plane for the two cases;
- Ranging from TEM-dominant to ITG-dominant micro-instability regime, since $\eta_i = L_n/\ L_{Ti}$ drives the ITGs;
- Compute the ratio $\gamma(NT)/\gamma(NT\ profiles, PT\ shape)$ vs $(a/L_{Ti}, a/L_n)$, to see where it is minimum.

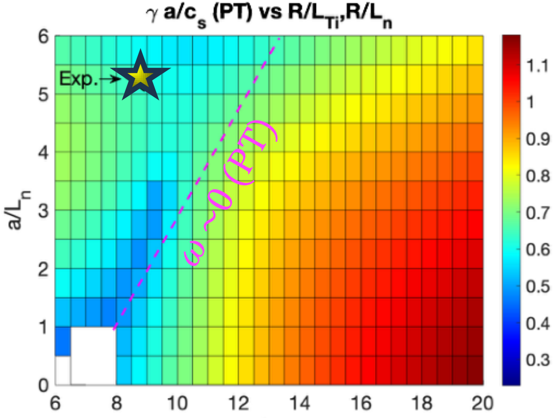
Caveat:

all the following scans

only consider two species!

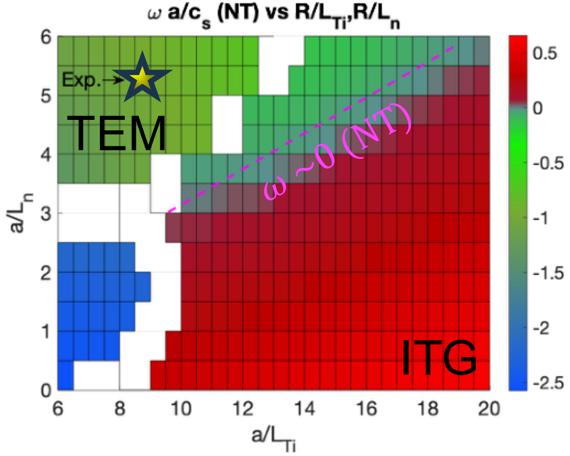
Hypotesis confirmed: max NT stabilization for mixed ITG-TEM

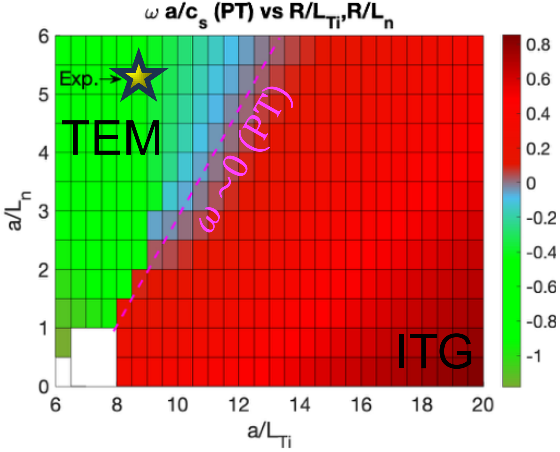


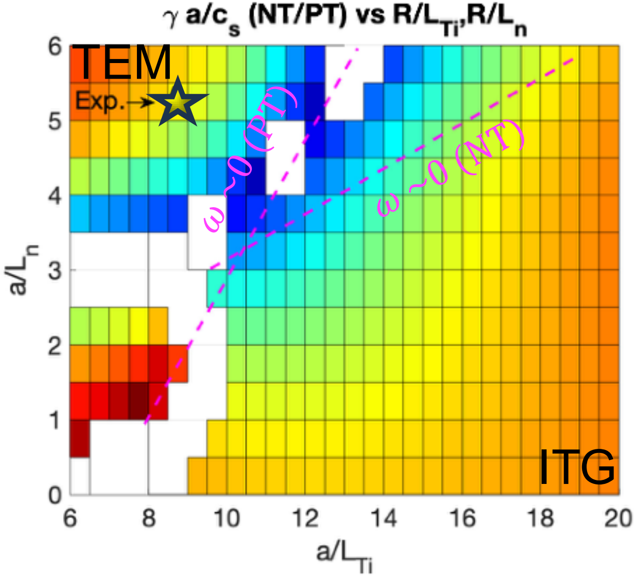


Linear NT stabilization:
Maximum close to $\omega = 0$
~ ITG/TEM boundary

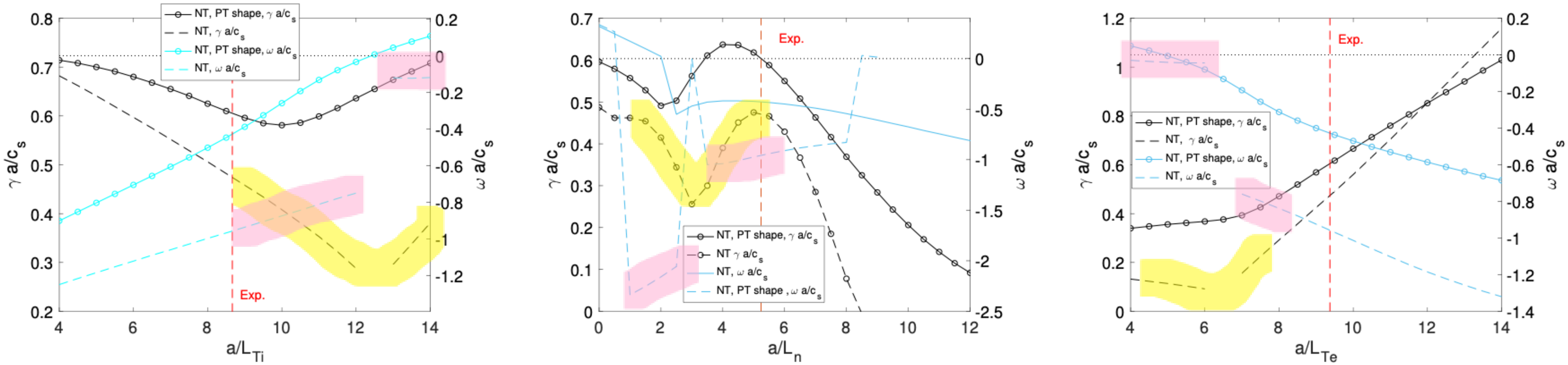
$\rho_{tor} = 0.95, k_y \rho_s = 0.3$







Single a/L_{Ti}, a/L_n, a/L_{Te} scans



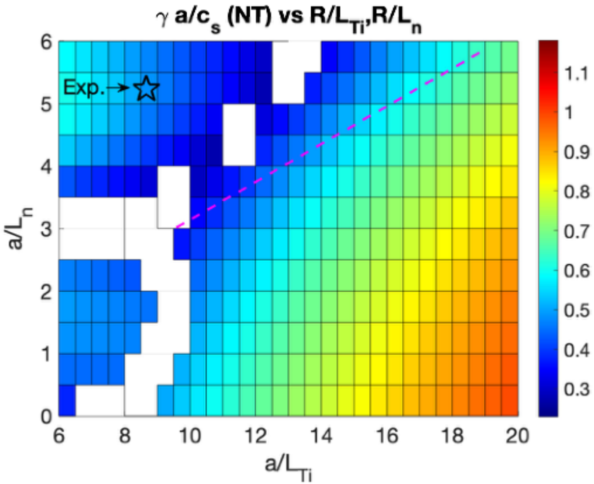
- Stable region ('valley') between the TEMs and ITGs for NT shape (for the a/L_n scan there is a minimum of γ between two $\omega < 0$ branches);

- Very dependent on a/L_{Ti} and a/L_n .

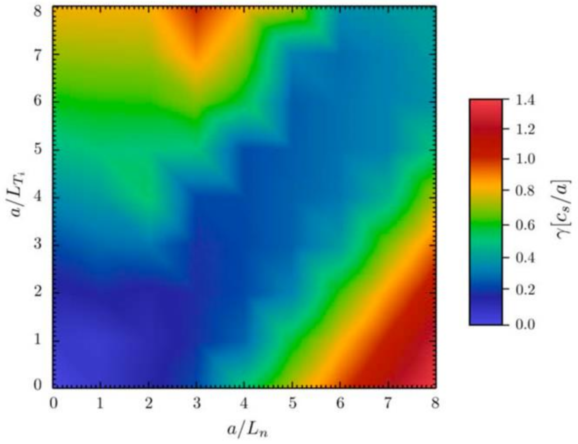
Effect of geometry through the second adiabatic invariant?

Effect: similar to the ‘valley’ for Maximum-J stellarators?

TCV NT



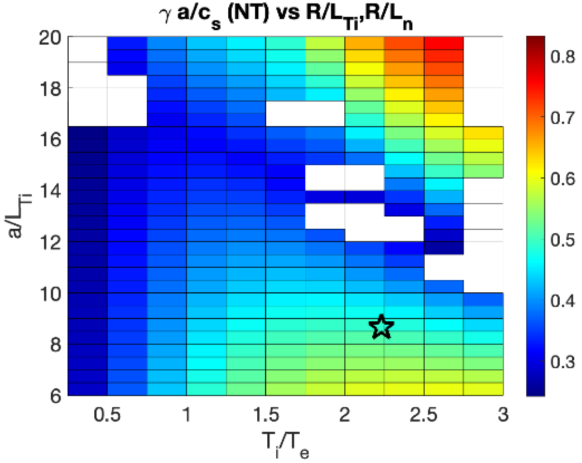
W7-X

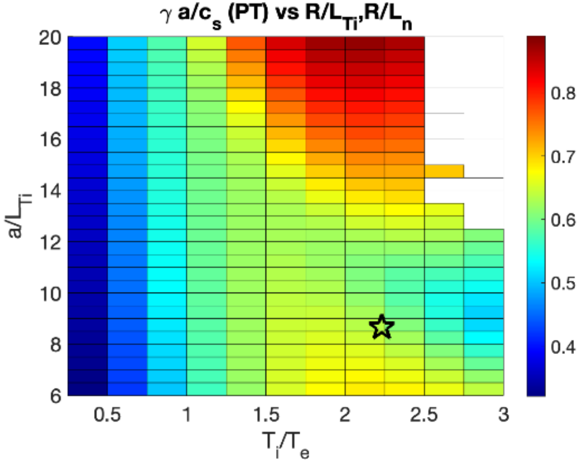


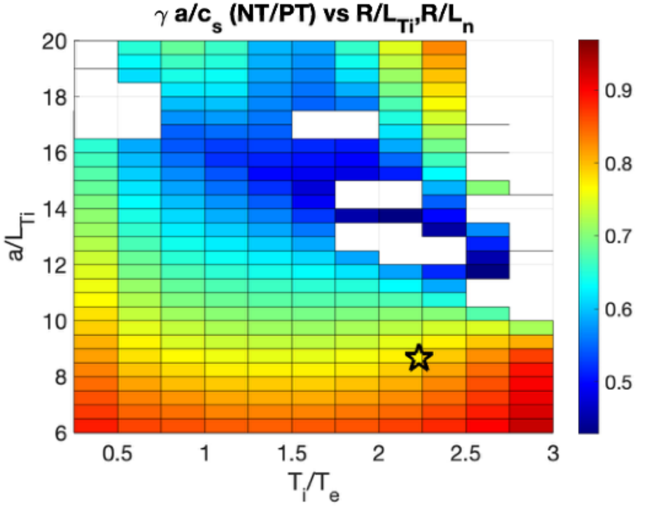
J A Alcusón *et al* 2020 *Plasma Phys. Control. Fusion* **62** 035005

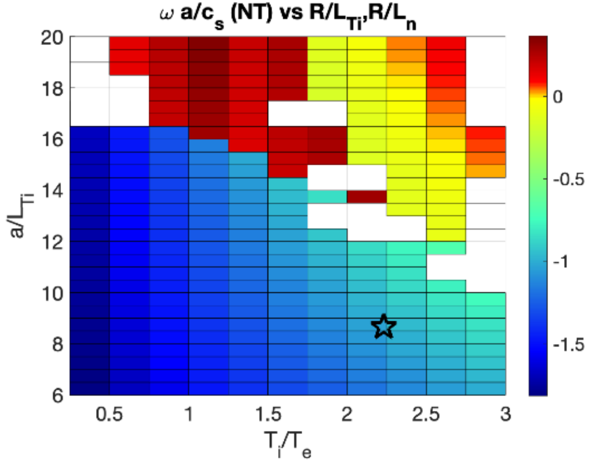
But: the TCV NT case appears to have a large passing electron drive (analysis by M. Kotchenreuter)…so the role of trapped particles and effects of geometry on trapped particle orbits is minor?

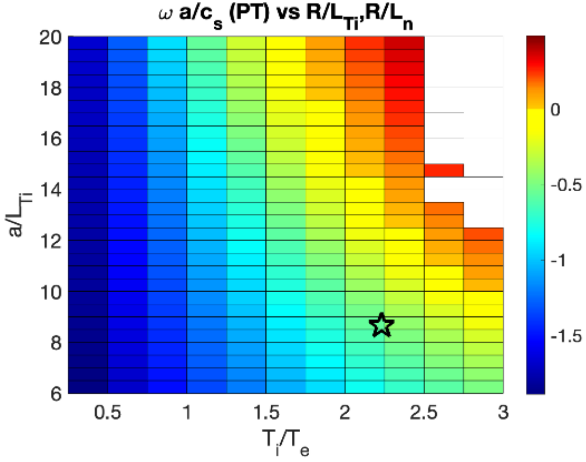
Similar in the T_i/T_e,a/L_{Ti} plane





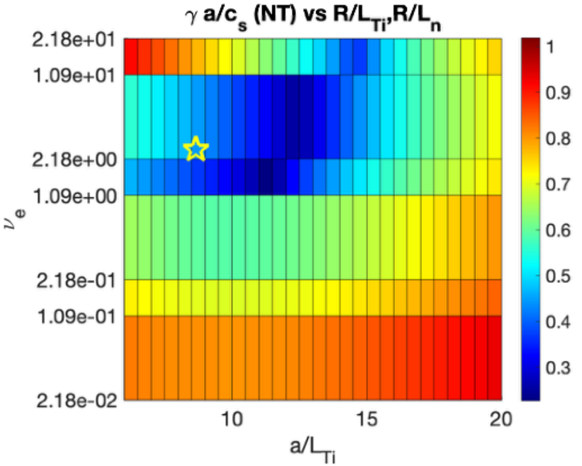


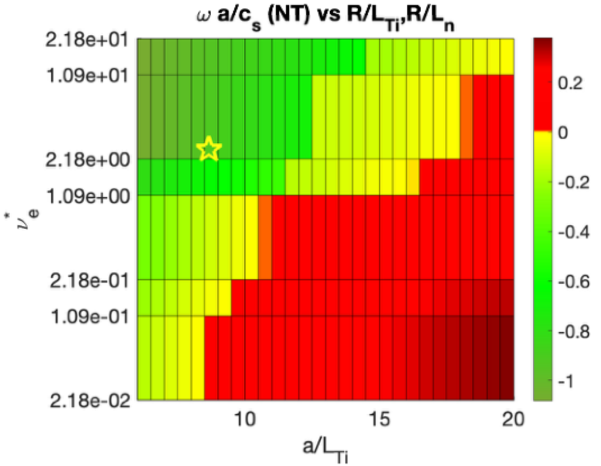


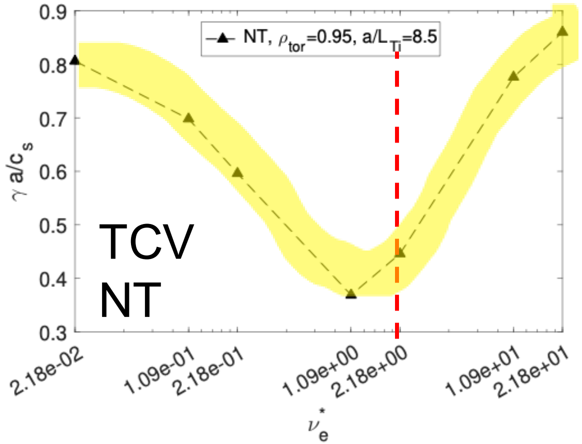


Less NT stabilization at same a/L_{Ti} for T_i=T_e (AUG) than for T_i>T_e (TCV)

Effect of collisionality? a/L_{Ti},collisionality scans



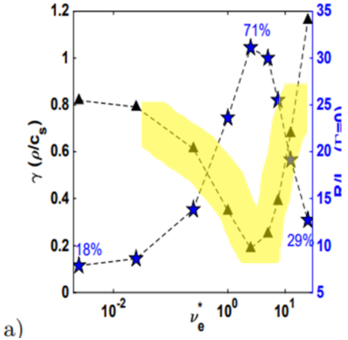




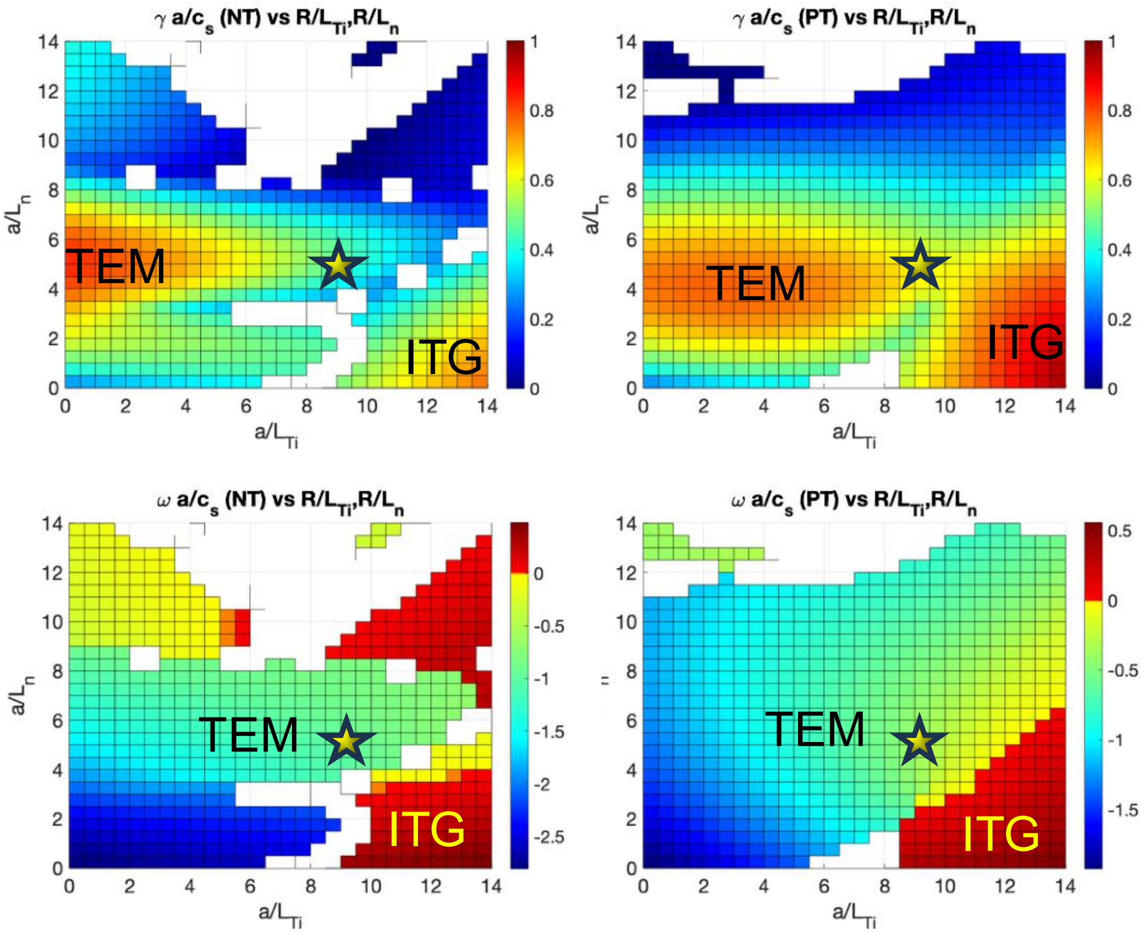
- Dependence of the NT 'stabilized' region on the collisionality;
- In JET, AUG e WEST: between ITG-TEM at low collisionality and resistive drift waves e RBM at high collisionality, there is a minimum growth rate corresponding to inward turbulent pinch (Snoep's ArXiv 2025, Bonanomi PPCF 2025). TCV NT sits within this collisionality interval.
- Important role of particle transport for NT?

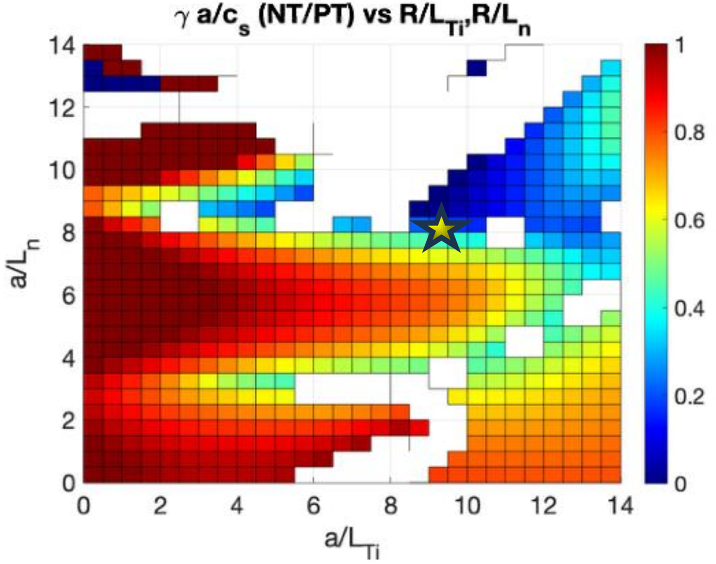
Bonanomi PPCF 2025

AUG L mode edge

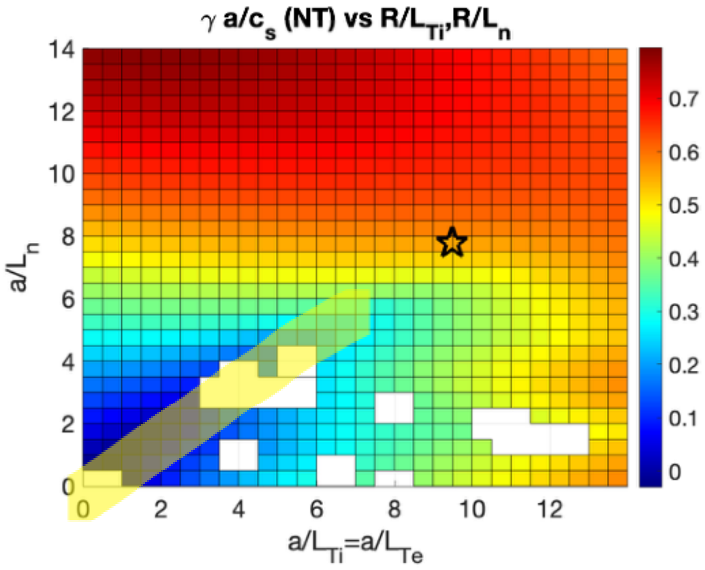


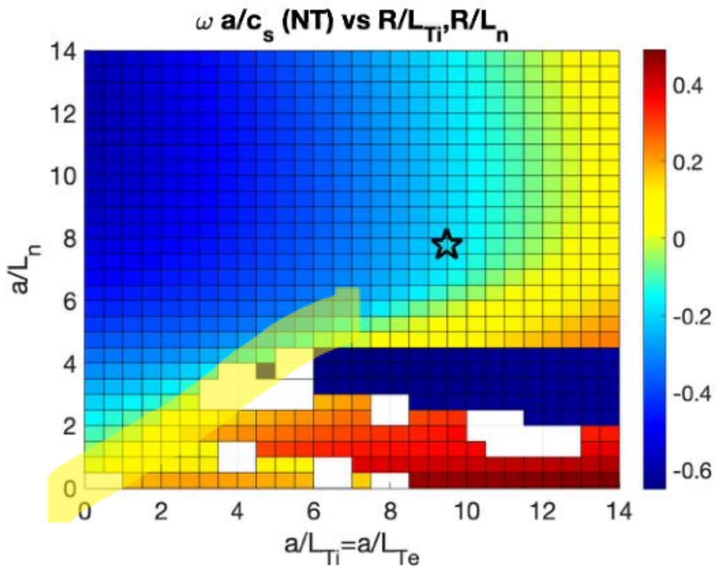
Broader a/L_{Ti},a/L_n scans: complex picture!





Is AUG different? Test for a ECH-only case





- The stability region is there, and it is still at the ITG-TEM boundary;
- It is at lower gradients than for TCV, so it results in a smaller stabilization.

Higher δ shape

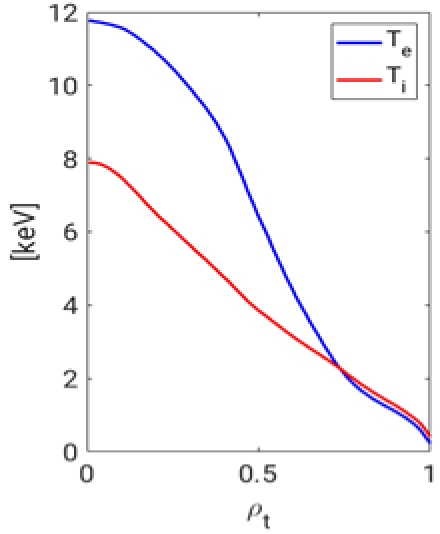
High fidelity prediction: DTT NT HD scenario: GENE +Tango

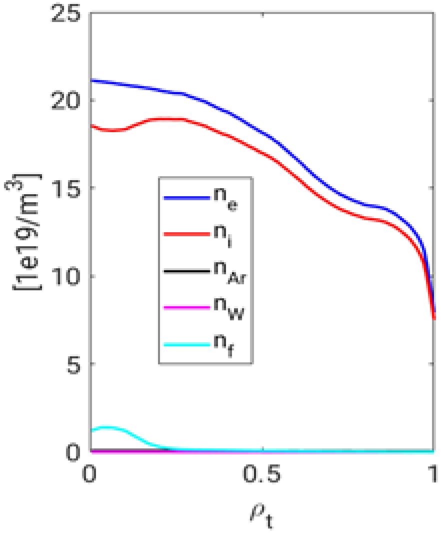
Goal: Compare ASTRA-TGLF prediction with higher fidelity profile prediction via the GENE-Tango framework

Profiles predicted with ASTRA considering main ions, electrons, Ar, W and fast ions. Computationally very expensive to include 5 kinetic species in global GENE, hence:

- fast ions: not included in the modeling;
- W: not included in the kinetic modeling but radiation power accounted for in Tango;
- Ar: considered as dilution species in GENE;

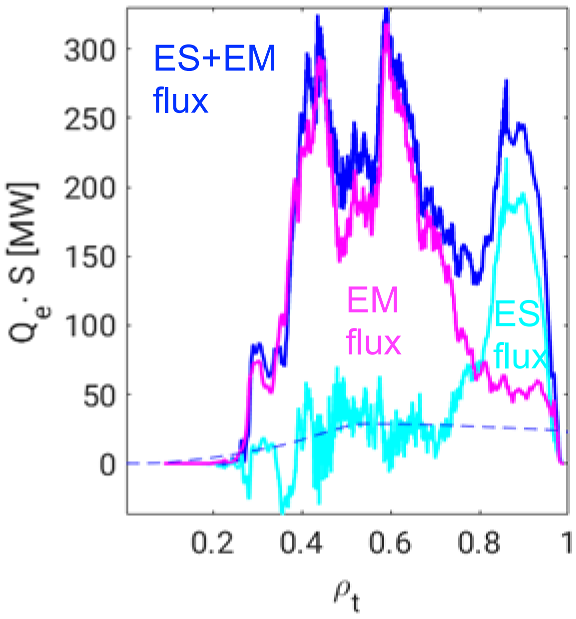
This allows us to evolve ion and electron pressures and electron density using the same electron source as ASTRA, keeping Z_{eff} fixed

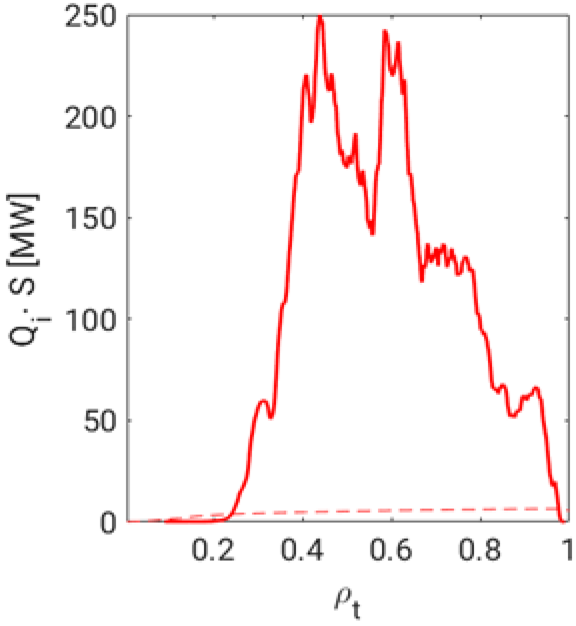




DTT - initial profiles: GENE global

Full physics retained: full EM + collisions (dashed: integral of the source)

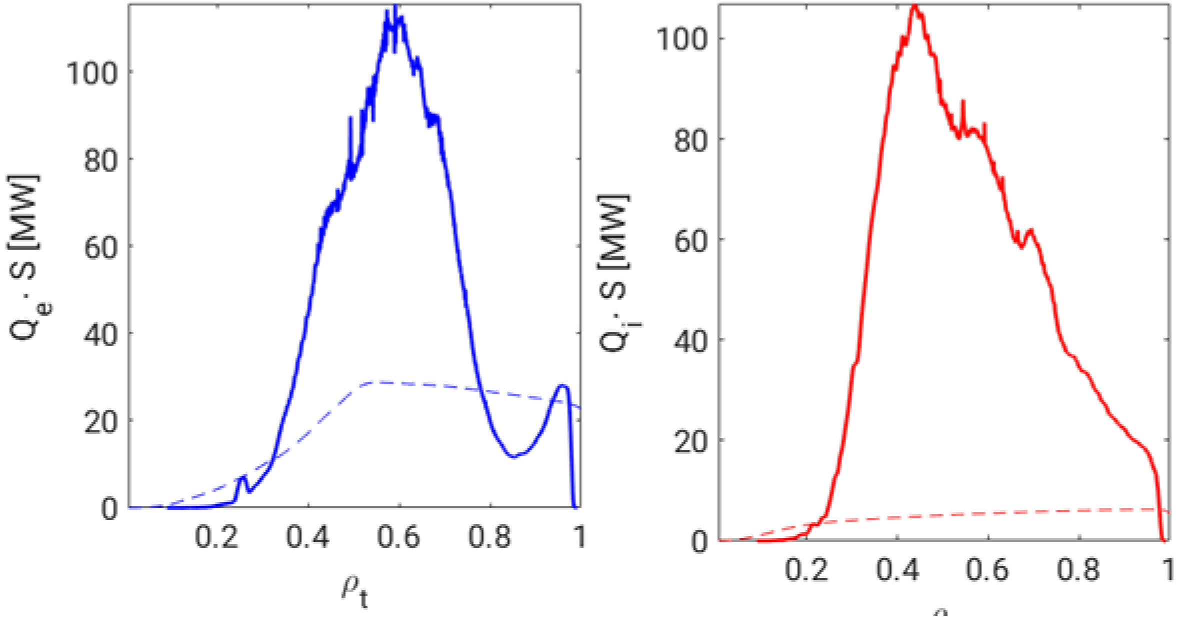




Large overestimation of fluxes, electrons are almost fully EM -> remove the EM fluctuations and try to single out its contribution.

DTT - initial profiles – ES: GENE global

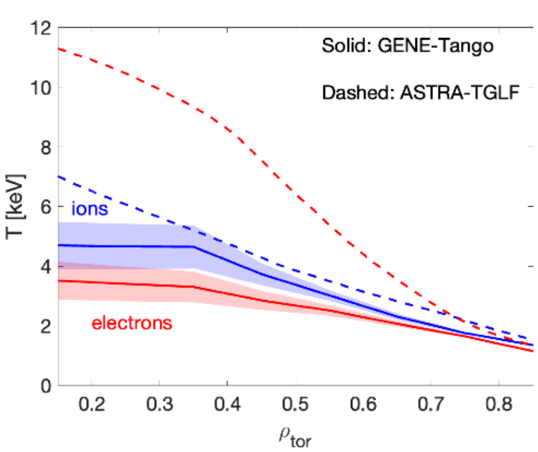
Turn-off electromagnetic fluctuations (dashed: integral of the source)

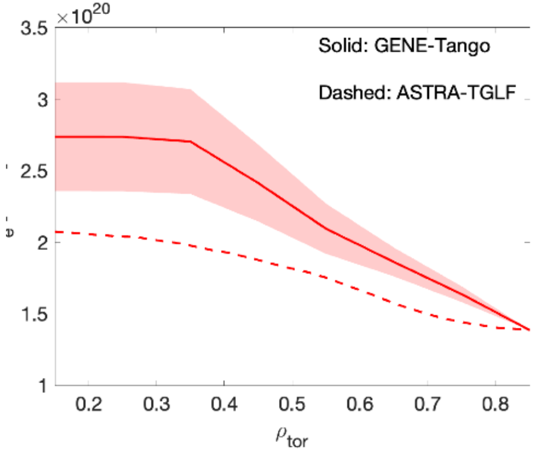


Large overestimation in the core remains, together with inwards particle flux, probably in part due to missing EM stabilization.

DTT GENE local EM +Tango (ongoing)

GENE global+Tango: became computationally unfeasible after few iterations, due to issues on the cluster $\Longrightarrow$ GENE local+Tango



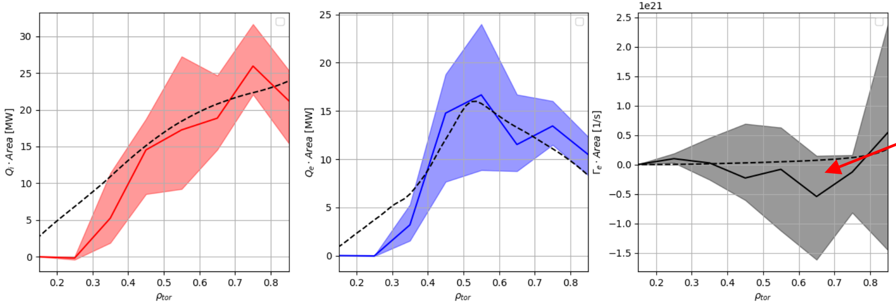


GENE-Tango:

- slightly underpredicts T_i,
- strongly underpredicts T_e,
- strongly overpredicts n_e,

compared with ASTRA-TGLF.

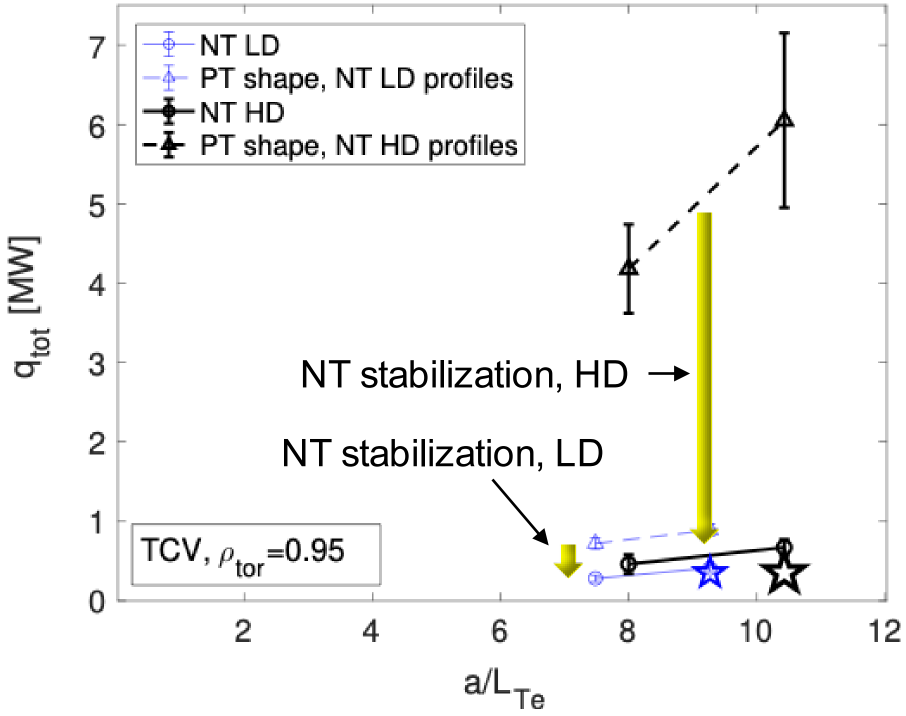
Fluxes/ sources:



Issue: strong pinch at the edge: possible solution: decouple Γ_e and Γ_i by adding gyrokinetic impurities

Flux tube GENE simulations for TCV high / low δ shapes

The T_e stiffness is investigated, since the main micro-instabilities rotate in the electron diamagnetic direction, according to linear runs.



- Direct NT stabilization: much increased with the NT HD shape;
- NT direct effect: even larger than in the experiment. Other parameters that change between PT/NT HD pulses with same input power partially compensate it.

DISCUSSION and CONCLUSIONS

- The cause of the different behaviour between TCV and AUG/DTT is still unclear, and is **key to reliable projections towards NT scenarios in future reactors**
- Amongst the possible hypotheses investigated, the most likely seems **the difference in edge turbulence: AUG and DTT are ITG dominant, TCV is balanced ITG-TEM. There are hints from the gyrokinetic analysis pointing out that being in a mixed ITG-TEM state could be beneficial for NT stabilization.**
- **Stability region** found for NT in the a/L_{Ti},a/L_n plane, with dependence on T_i/T_e and collisionality;
- However, even in the case of AUG and DTT, **NT scenarios can be achieved without ELMs and still good core pressure levels** (-10% from PT H-modes), which make them possible candidates for ELM-free operation in addition to other ELM-free PT options (QCE,EDA, XPR-CRD, I-mode, etc).
- DTT will contribute to NT studies from its early phase, providing new NT data in a plasma scenario more relevant to future reactors
- GENE-TANGO simulations ongoing for the DTT high δ case