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EUROfusion

First-principle based predictions of the effects of negative triangularity on DTT scenarios

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ISTP Consiglio Nazionale delle Ricerche

EPFL

Goal

- Test a possible L-mode NT alternative option for the DTT full power scenario.
- DTT is under construction → **no DTT experimental data available** → **numerical simulations of DTT scenarios.**

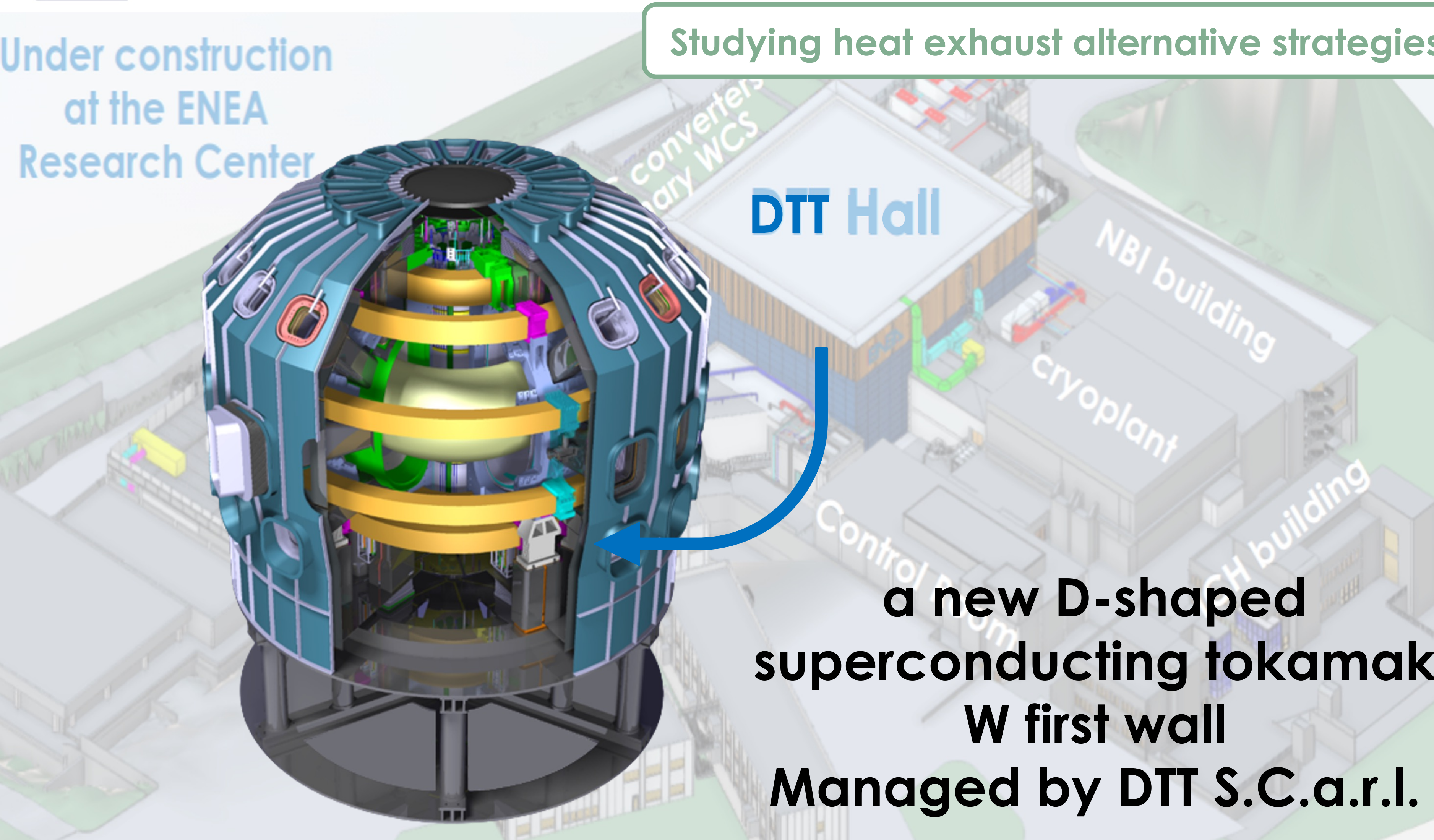
Content of the presentation

- Predictive transport modelling and gyrokinetic local flux-tube simulations of a NT option for the DTT full power scenario with Ne seeding

Divertor Tokamak Test facility (DTT)

Studying heat exhaust alternative strategies

Under construction at the ENEA Research Center



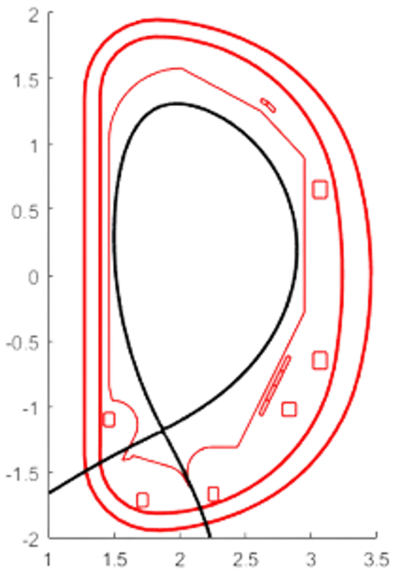
a new D-shaped superconducting tokamak

W first wall

Managed by DTT S.C.a.r.l.

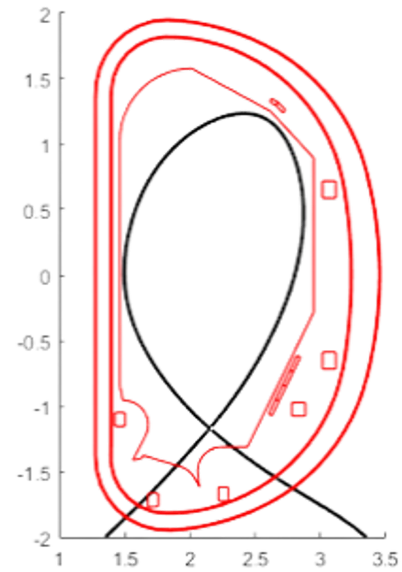
DTT configuration with negative triangularity

Positive Triangularity (PT)



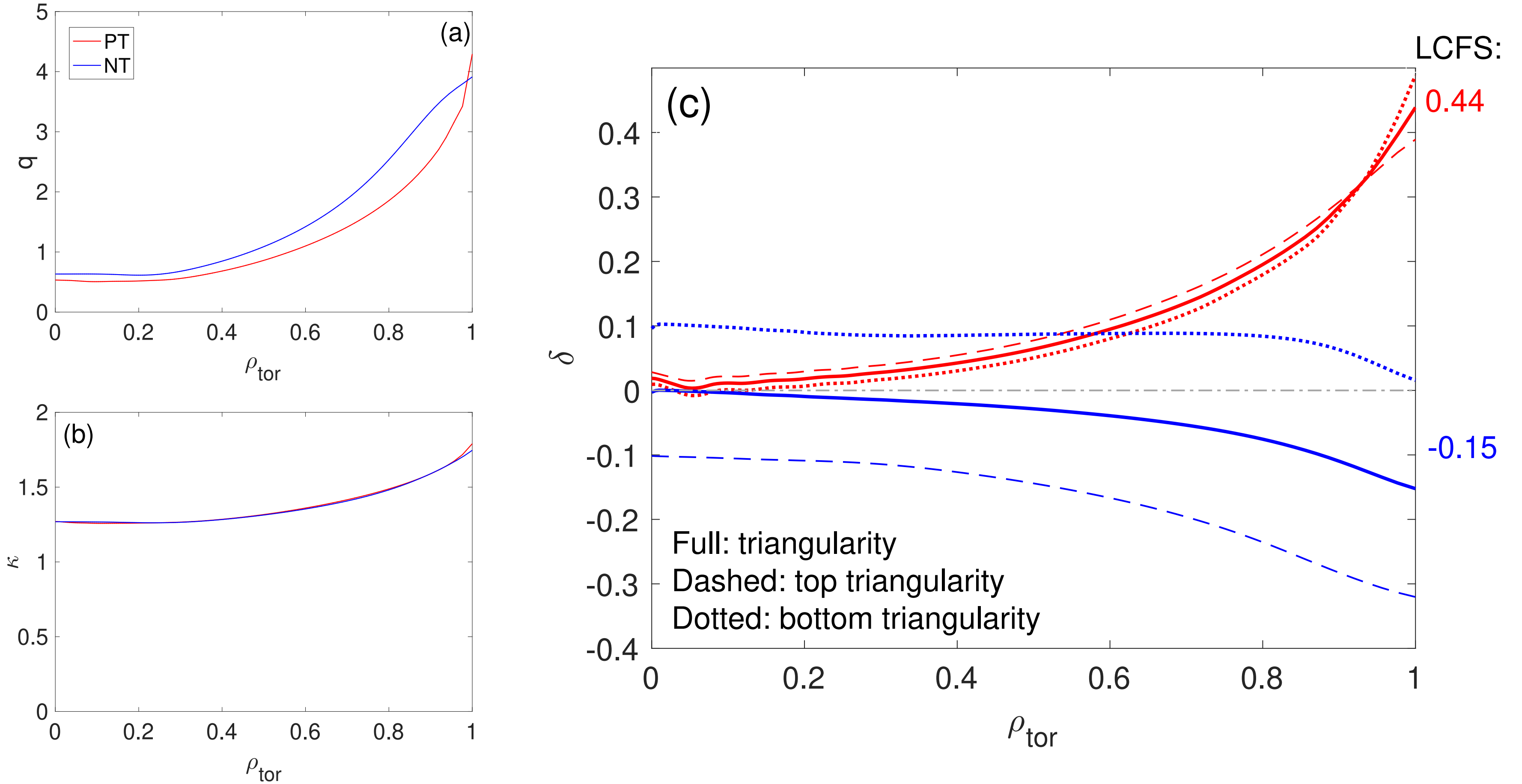
R=2.19 m / a =0.70 m
6 T / 5.5 MA
upper δ=0.33
lower δ = 0.35

Negative Triangularity (NT)



R=2.19 m / a =0.70 m
6 T / 4 MA
upper δ=-0.3
lower δ = 0.05

DTT triangularity profiles



- Poloidally averaged triangularity is lower in NT;
- ellipticity similar;
- The safety factor is larger in NT.

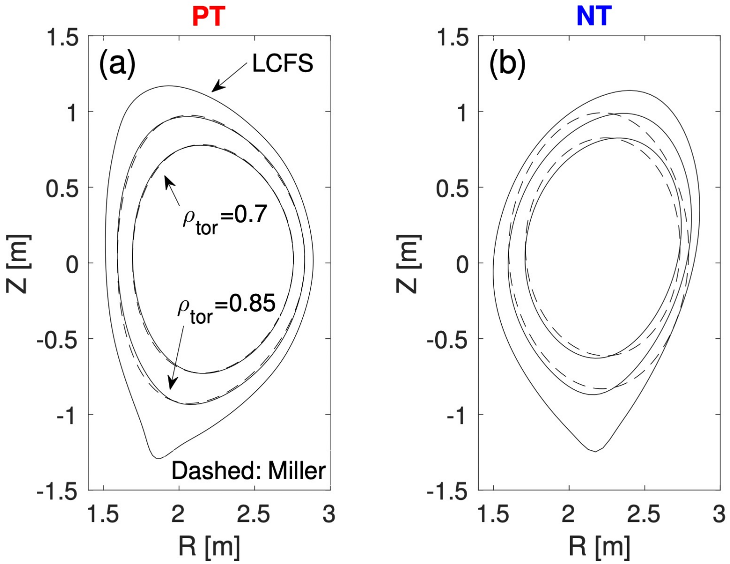
Modelling performed

- Predictive transport simulations (ASTRA - TGLF SAT2),
- Gyrokinetic (GENE) simulations and stand-alone quasi-linear runs (TGLF SAT2);

GOAL:

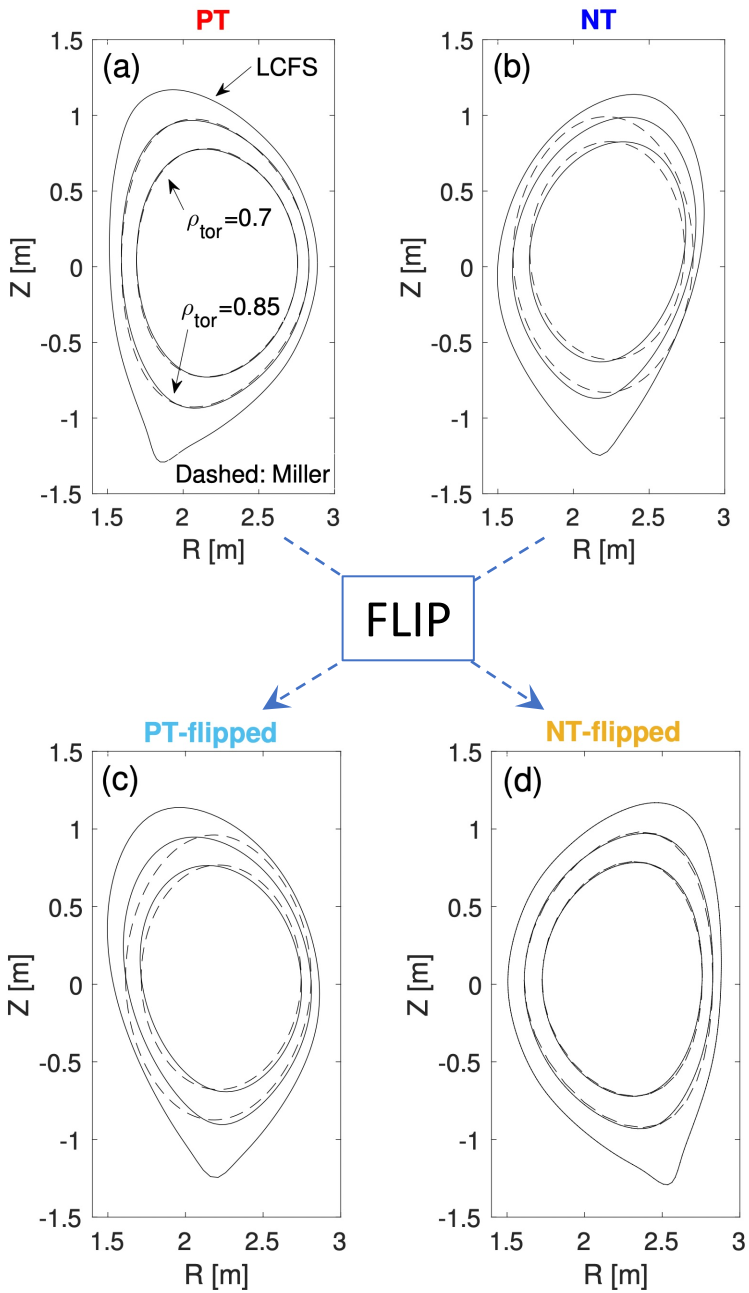
- Transport runs: predict the impact of NT on the density and temperature profiles;
- Gyrokinetic and quasi-linear runs: performed at fixed radius to characterize the turbulence regime and evaluate the effect of the NT on both the growth rates of the linear modes and the nonlinear flux levels; two radii of analysis: mainly ρ_{tor}=0.85; some analysis at ρ_{tor}=0.7;
- The variation of the T_i stiffness, i.e. the degree to which the T_i profile respond to changes in the applied heat fluxes, is also investigated when going from PT to NT;

Four considered shapes



- Reference DTT full power scenario (PT);
- NT DTT option for the full power scenario;

Four considered shapes



- Reference DTT full power scenario (PT);
- NT DTT option for the full power scenario;

- Two additional numerical geometries:
- Obtained by flipping the LCFS and then recomputing the equilibrium with CHEASE, keeping p’ and *TT*’ fixed

Poloidal current flux function

Safety factor, elongation and triangularity (4 shapes)

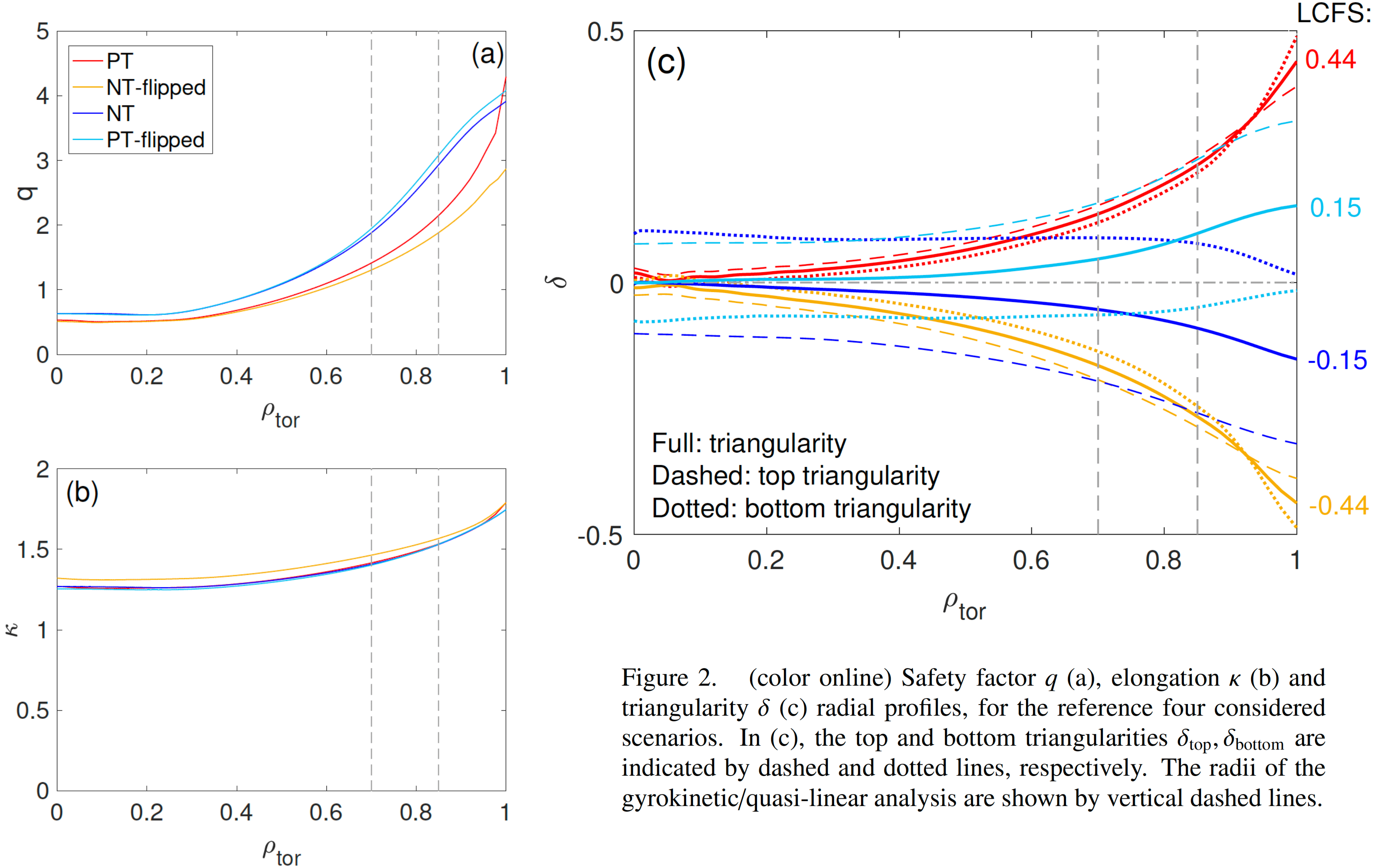
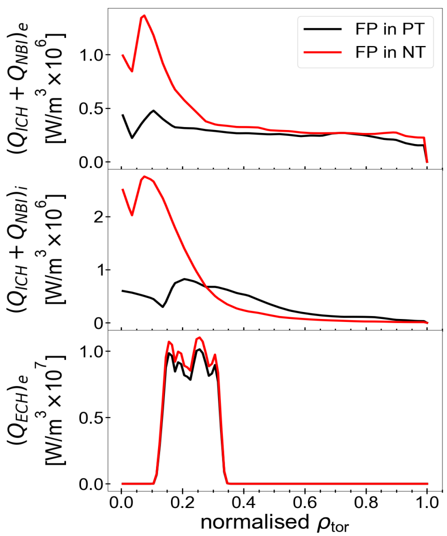


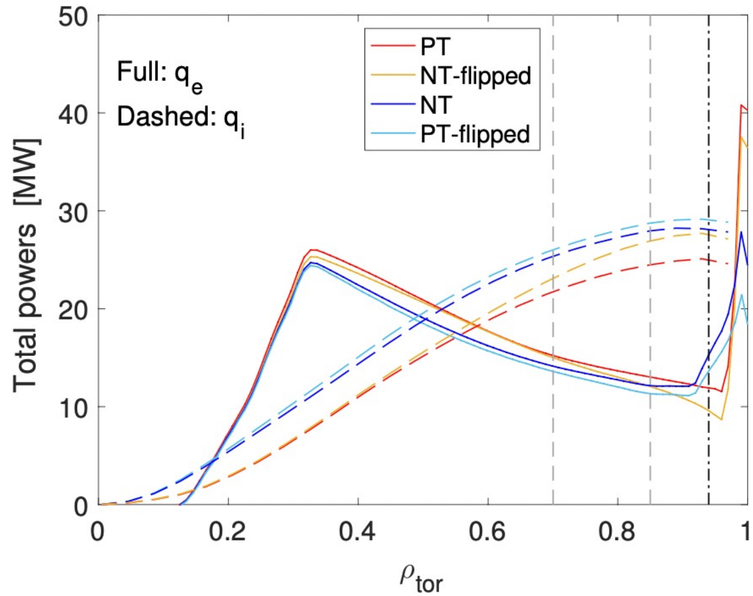
Figure 2. (color online) Safety factor q (a), elongation κ (b) and triangularity δ (c) radial profiles, for the reference four considered scenarios. In (c), the top and bottom triangularities $\delta_{\mathrm{top}}, \delta_{\mathrm{bottom}}$ are indicated by dashed and dotted lines, respectively. The radii of the gyrokinetic/quasi-linear analysis are shown by vertical dashed lines.

Predictive ASTRA-TGLF runs:

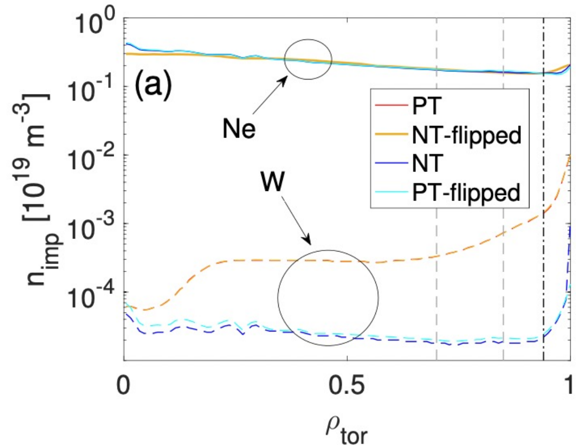
Power densities:

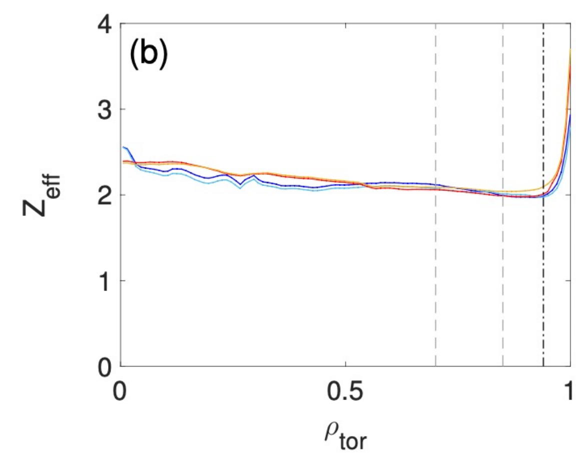


Volume integrated powers:

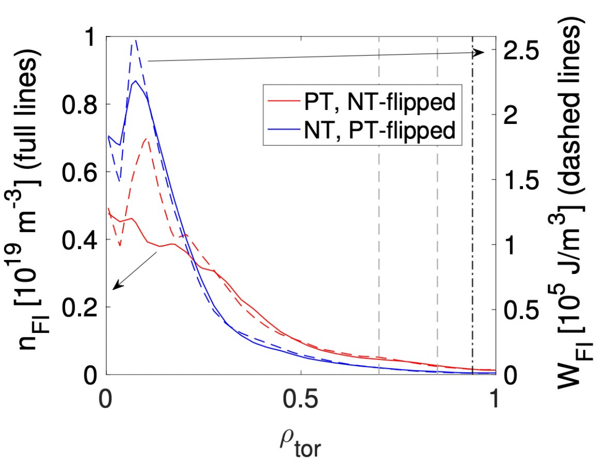


Impurities:

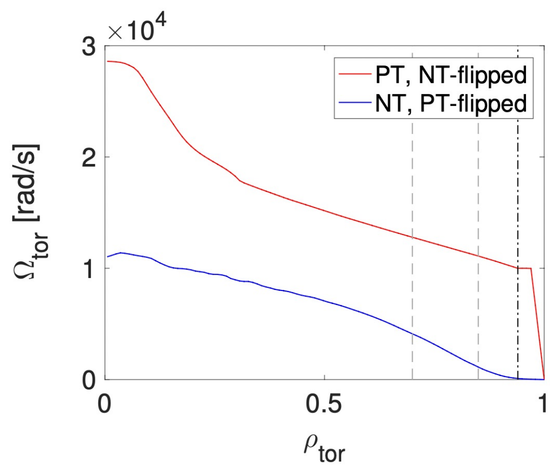




Fast ions:



Rotation:



Predictive ASTRA-TGLF runs:

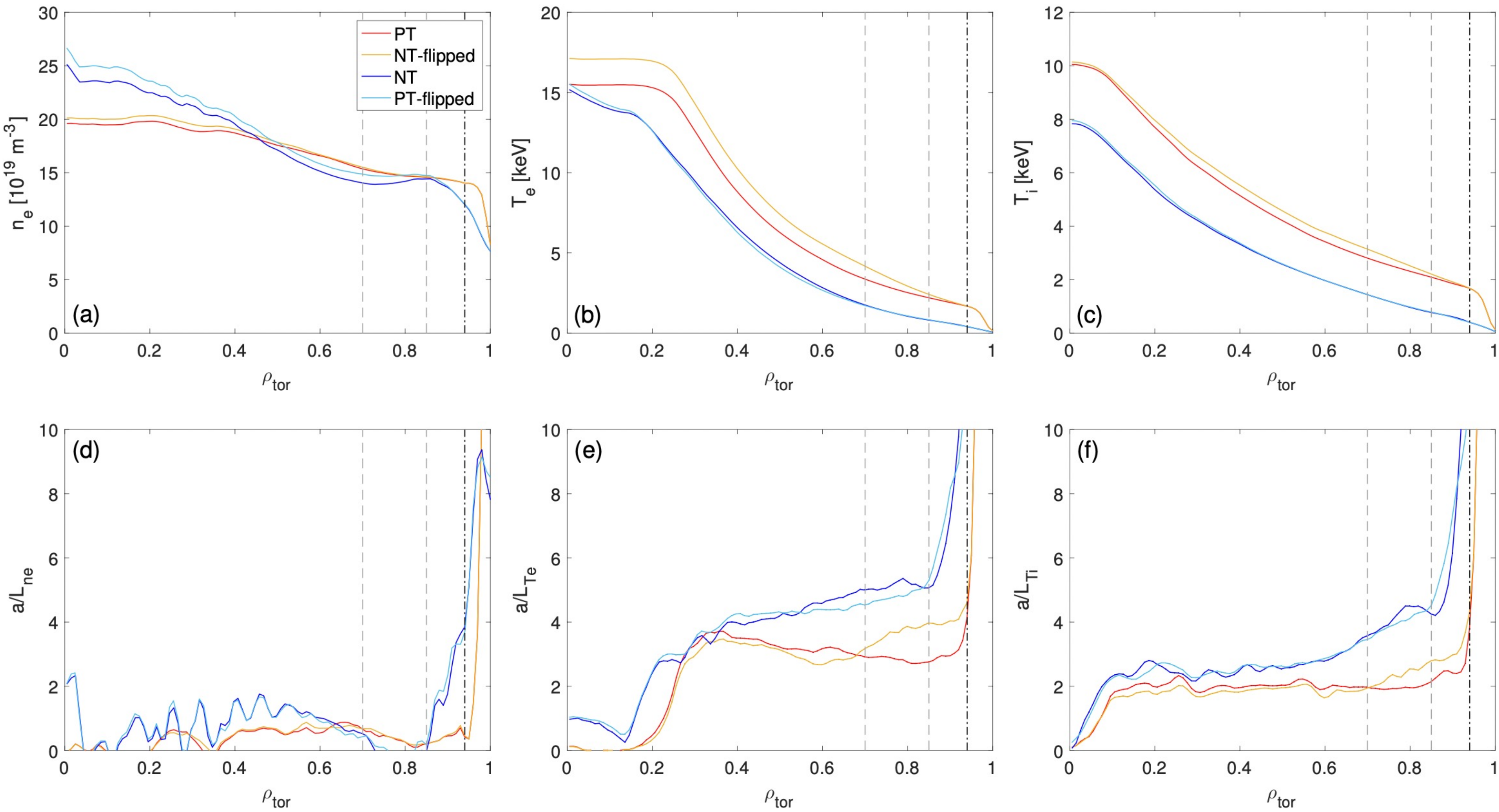
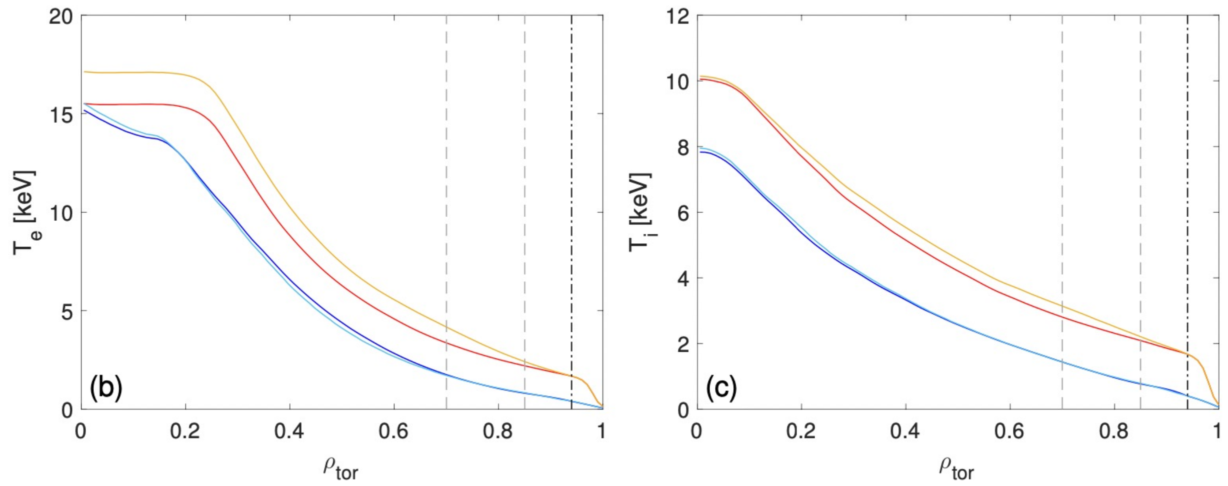


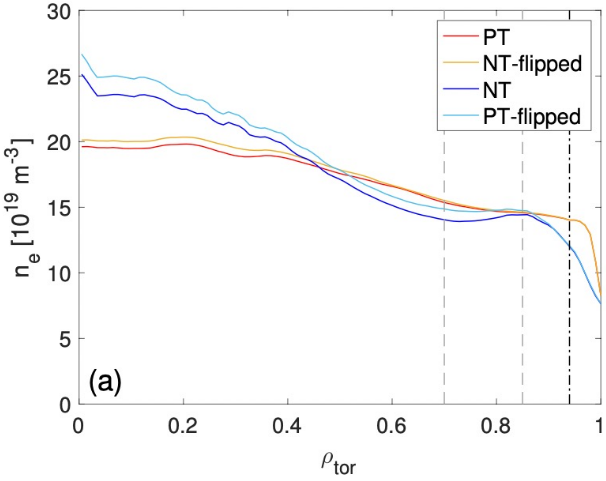
Figure 3. (color online) ASTRA-TGLF predicted density and temperature profiles. The electron density, electron temperature and ion temperature are shown in (a), (b) and (c), respectively, while the corresponding logarithmic gradients are shown in the second row (d)-(f).

Predictive ASTRA-TGLF runs:



NT (L-mode): lower temperatures than PT (H-mode). The larger gradients are not sufficient to recover the loss of the PT pedestal

Predictive ASTRA-TGLF runs:

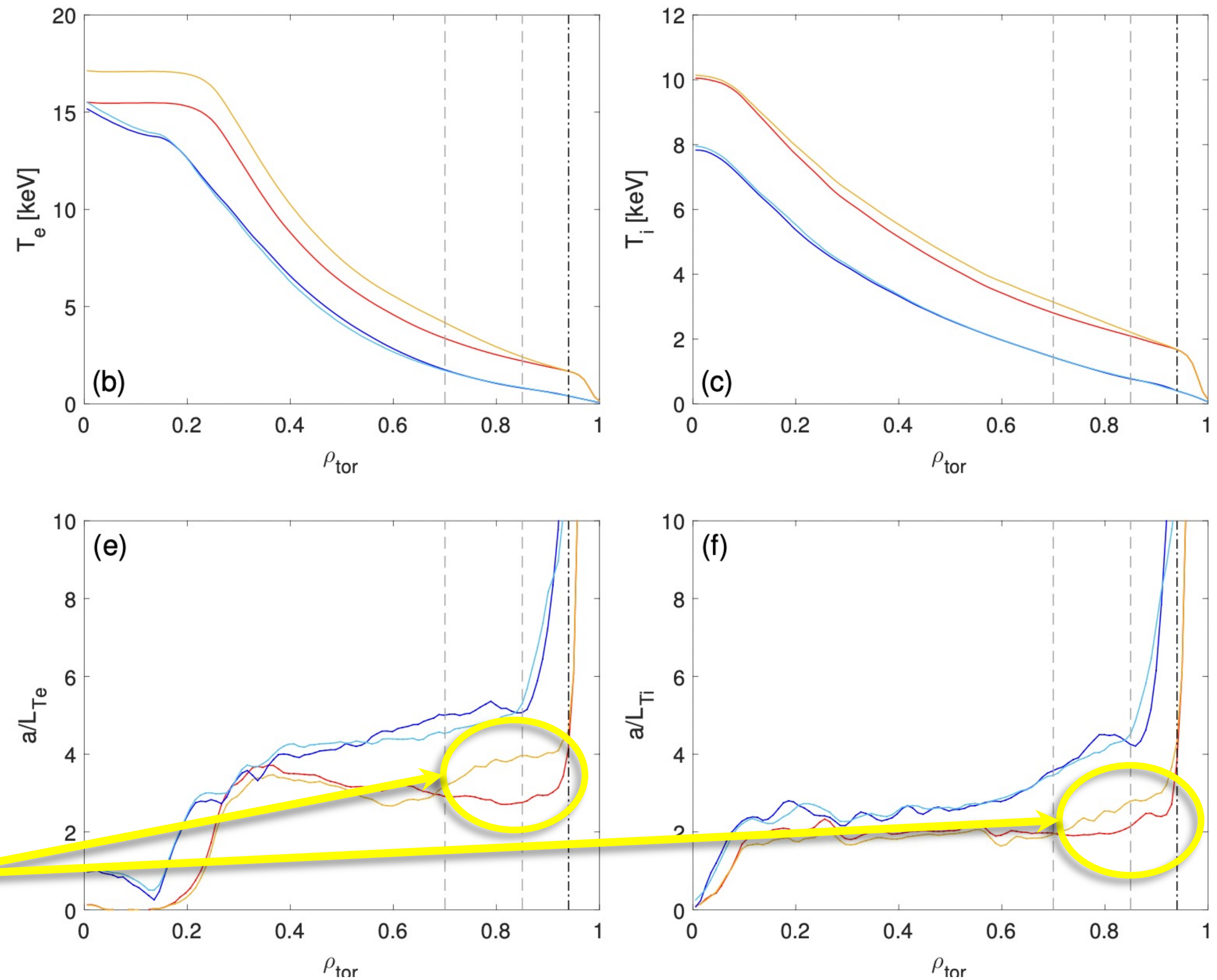


NT: higher density than PT at the plasma center

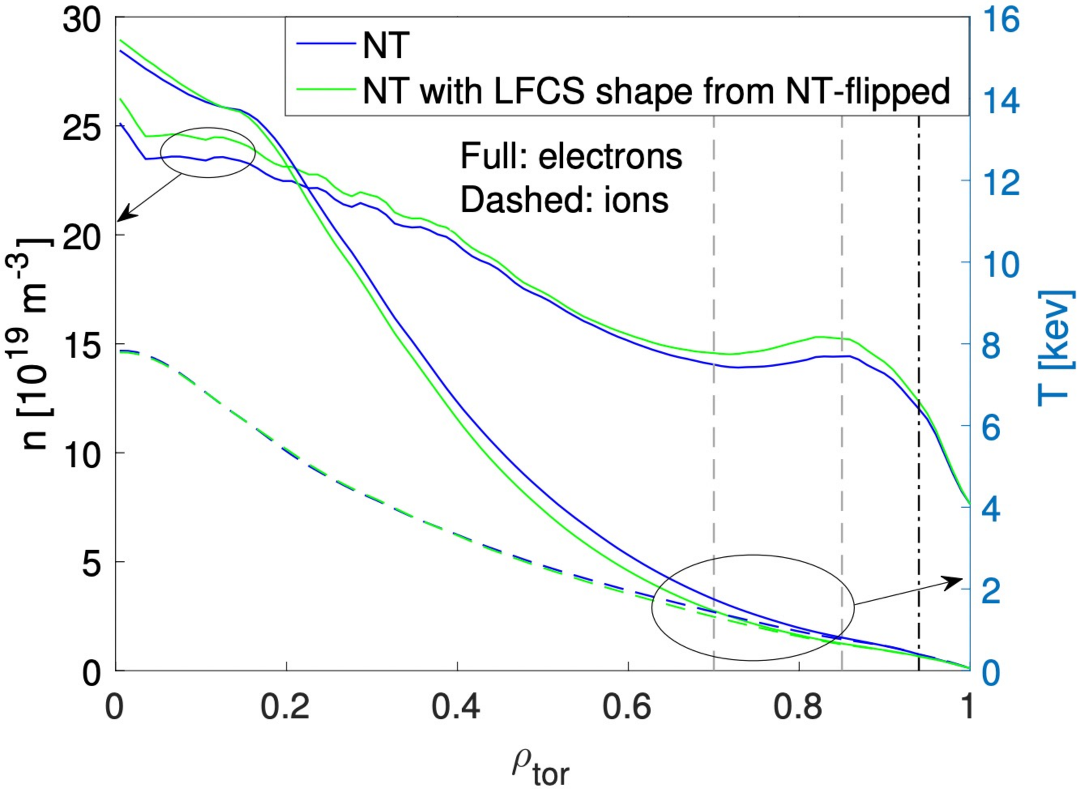
Predictive ASTRA-TGLF runs:

Very small beneficial effect of NT wrt. PT:

non negligible effect on the logarithmic gradients of T_i and T_e only for H-mode comparison (PT/NT-flipped) at $0.7<\rho_{tor}<0.9$



Predictive ASTRA-TGLF runs:



Additional run (green), keeping fixed the NT profiles but LCFS shape from NT-flipped: flipping the LCFS shape does not change the NT results

Key result, since the same holds for the ASTRA-TGLF modelling of TCV and AUG pulses with DTT shapes (see next talk by Paola): ASTRA is unable to see any effect of just plipping the plasma shape!

- TGLF stand-alone numerical experiment indicates that: a significantly higher $|\delta|$ (>0.6!) would be needed for the NT L-mode (wrt. the reference one) to recover the PT H-mode T_i values inside ρ_{tor}=0.7 (outside which δ starts playing a role).

- ➔ need to benchmark TGLF against GENE
- GENE: electromagnetic (EM) runs (with both $\delta B\perp$ and $\delta B\|$), with kinetic impurities (Ne and W), collisions, realistic equilibrium (CHEASE); TGLF: kinetic impurities, collisions and Miller;

Linear GENE and TGLF runs

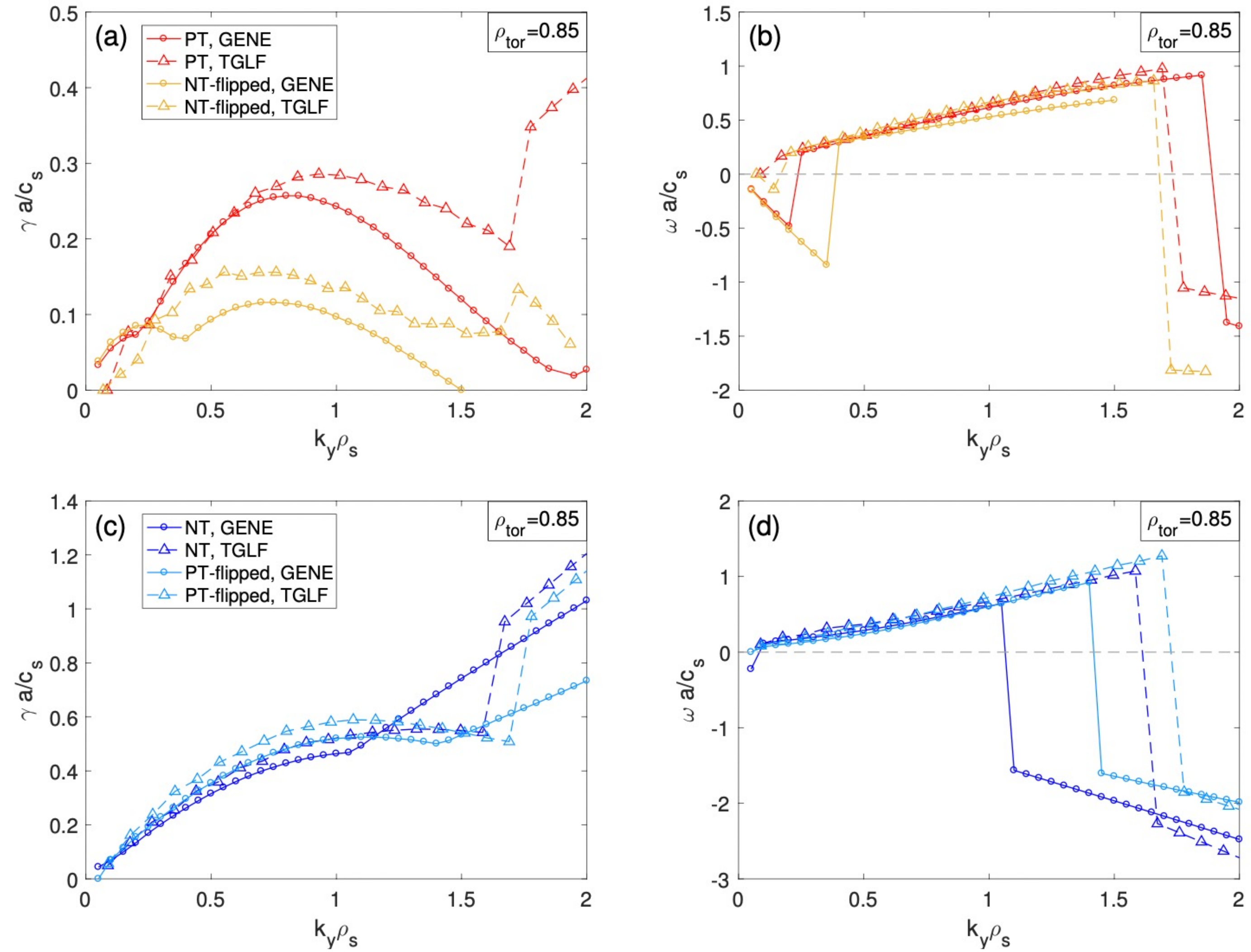
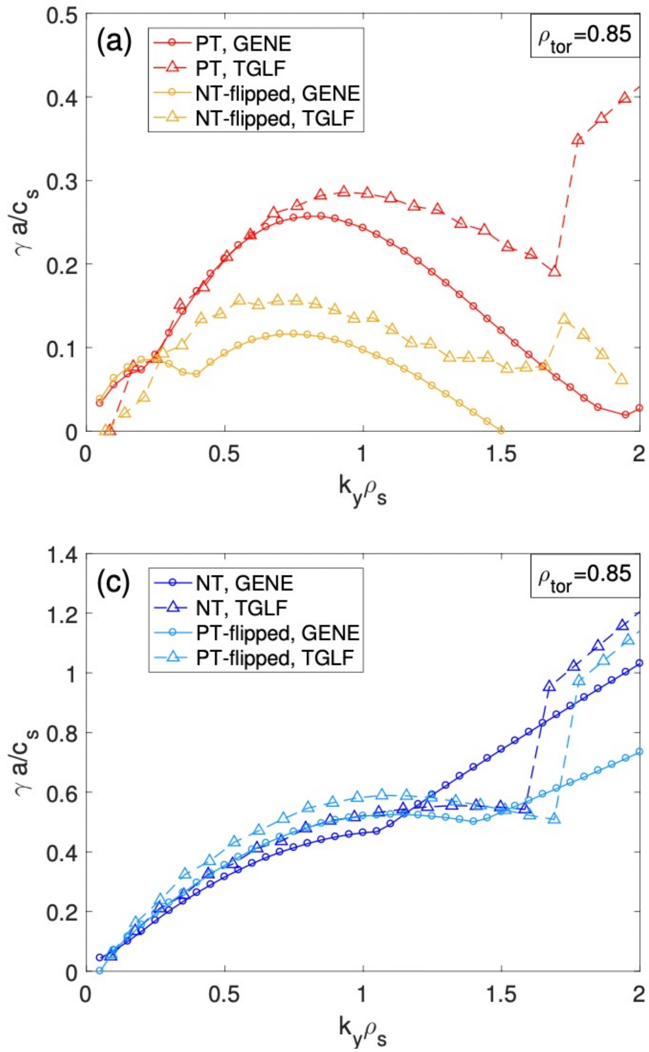
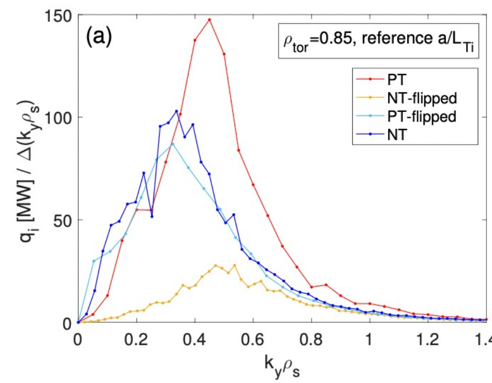


Figure 10. (color online) Linear spectra of the growth rate γ (left) and Frequency ω (right) at $\rho_{tor} = 0.85$, comparing PT with NT-flipped cases (top) or NT with PT-flipped (bottom). GENE results are shown by circles, while TGLF ones by triangles. γ, ω are normalized with c_s/a, while k_y with $1/\rho_s$.

Linear GENE and TGLF runs



ITG dominant turbulence for all cases , with a good agreement between GENE and TGLF, at the wavenumbers that mostly contribute to the nonlinear fluxes ($0.2 < k_y\ \rho_s < 0.8$);



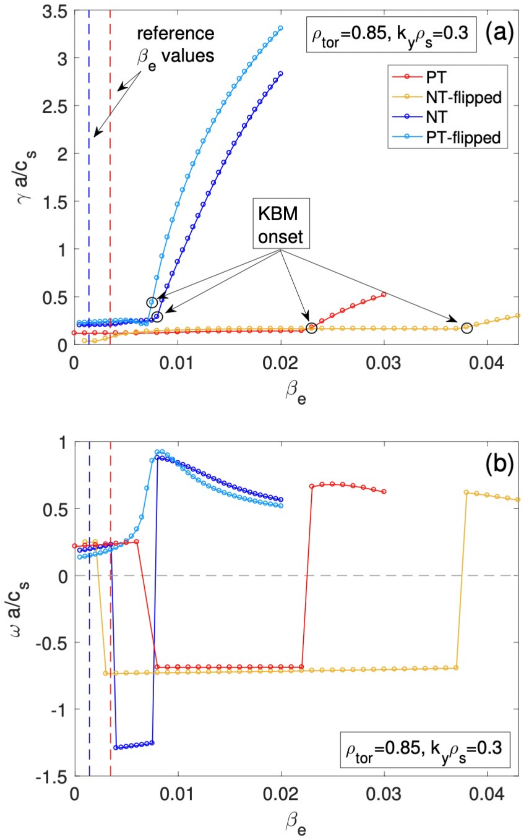
NT observed to have a stabilizing effect for H-mode parameters but very small effects for L-mode parameters

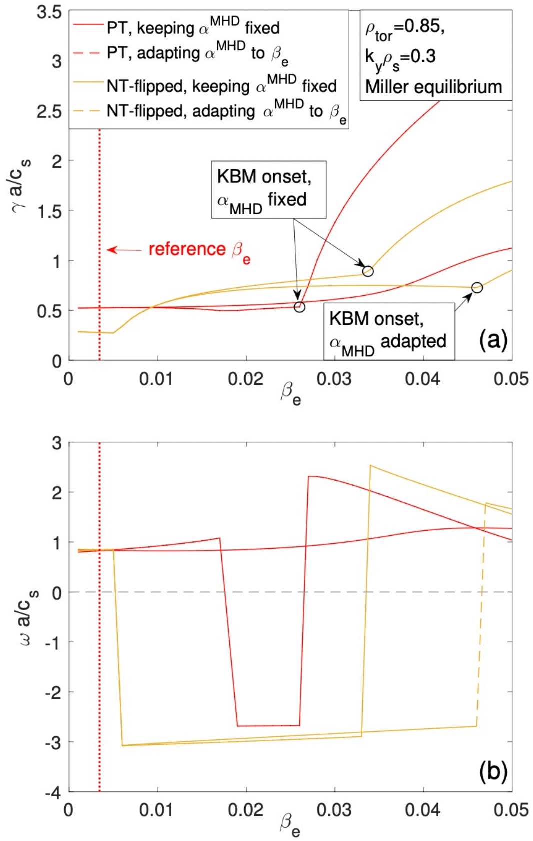
$k_y\rho_s$

Figure 10. (color online) Linear spectra of the growth rate γ (left) and Frequency ω (right) at $\rho_{tor} = 0.85$, comparing PT with NT-flipped cases (top) or NT with PT-flipped (bottom). GENE results are shown by circles, while TGLF ones by triangles. γ, ω are normalized with c_s/a, while k_y with $1/\rho_s$.

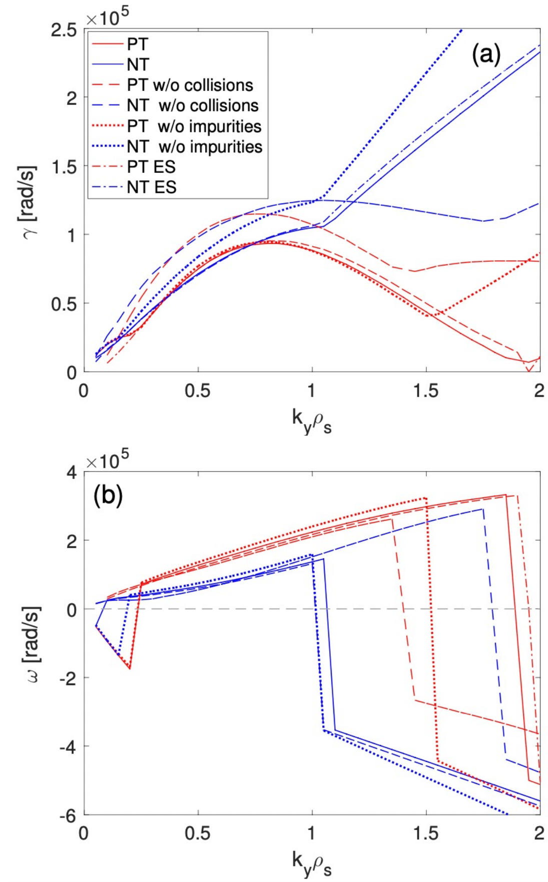
Linear GENE and TGLF runs

KBM stability:





Impact of collisions, impurities and EM effects:



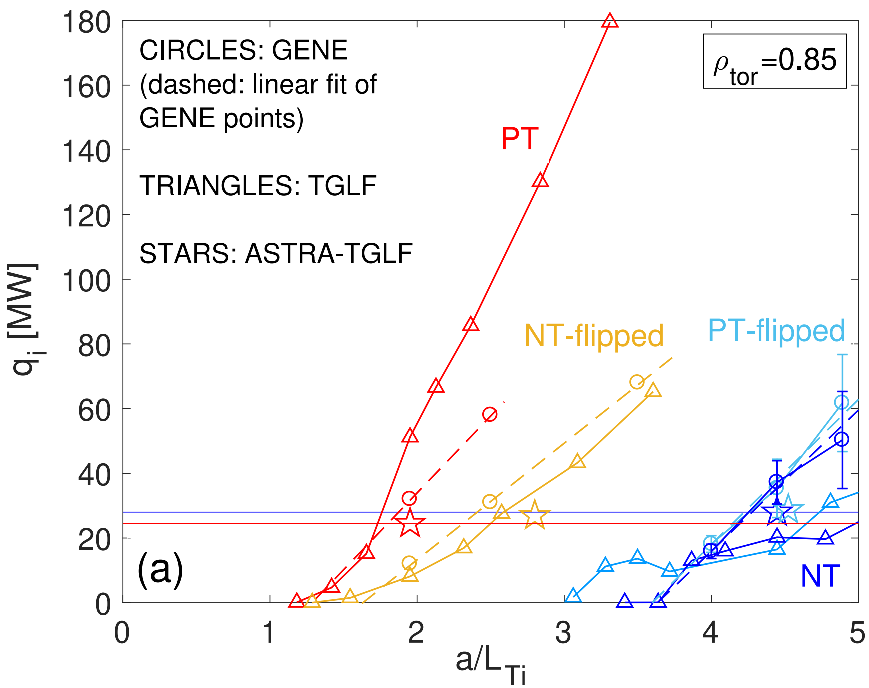
KBM are stable, with $\beta_e/\beta_{e,TH,KBM}$~1/7

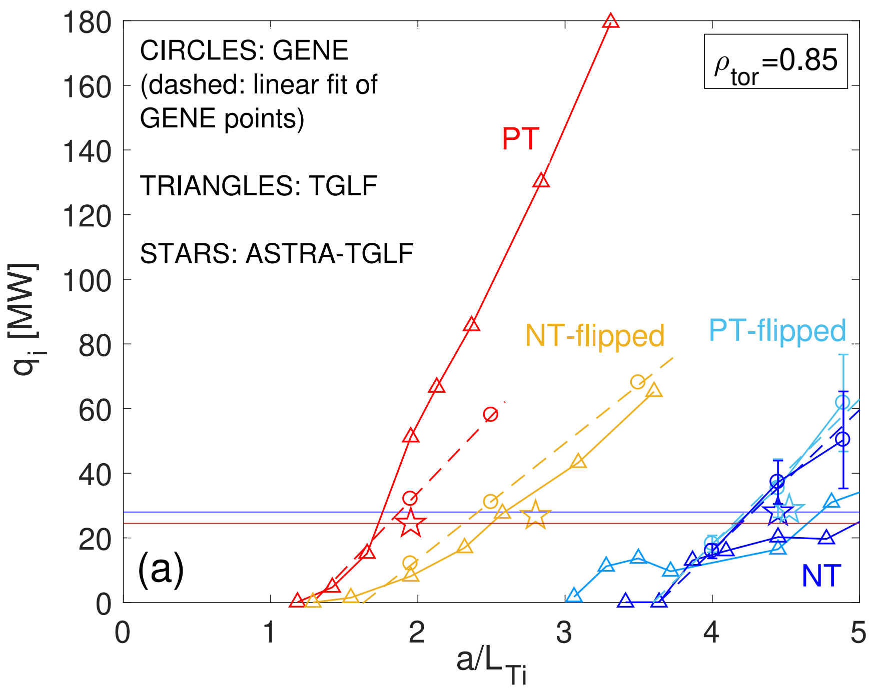
KBM even more stable when considering the β_e dependence of α_{MHD}

collisions provide ~20-30% stabilization of ITG ion-scale γ spectrum, impurities and EM effects are negligible

Nonlinear GENE and TGLF results

Main mode: ITG (driven by a/L_{Ti}) ➡ heat fluxes a/L_{ti} scan (**ion stiffness**) at ρ_{tor}=0.85 :

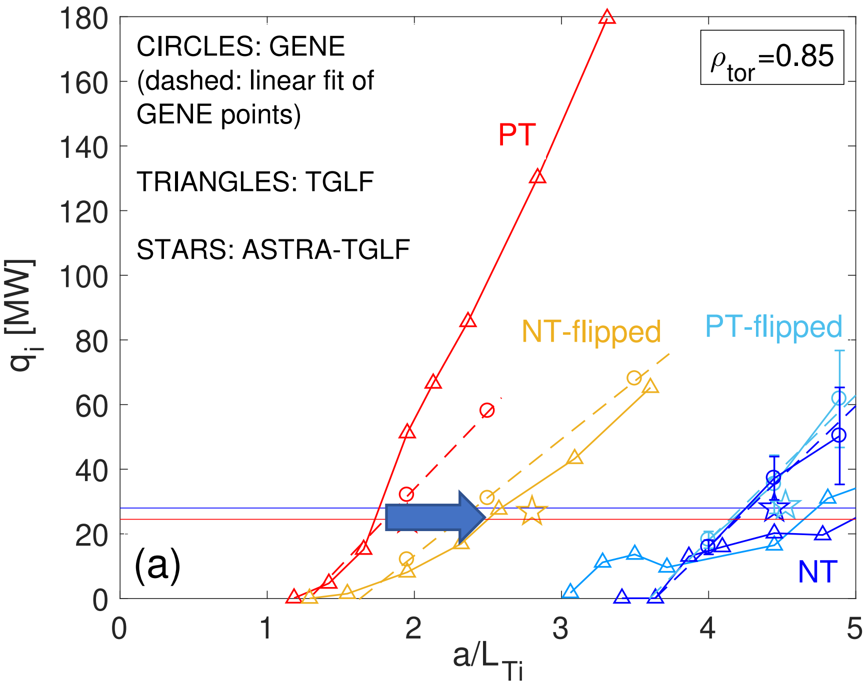


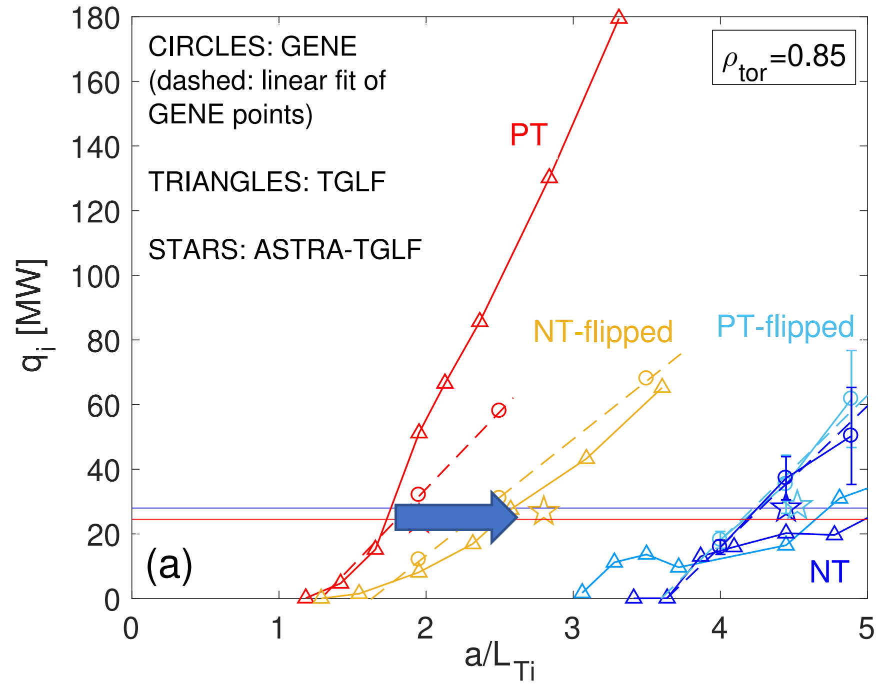


- Very good agreement between GENE, TGLF stand-alone and ASTRA in H-mode close to exp. fluxes, good in L-mode ➡ validates the ASTRA-TGLF transport modelling; TGLF overpredicts the stiffness for the PT H-mode case for a/LTi > exp. value

Nonlinear GENE and TGLF results

Main mode: ITG (driven by a/L_{Ti}) → heat fluxes a/L_{ti} scan (**ion stiffness**) at ρ_{tor}=0.85 :

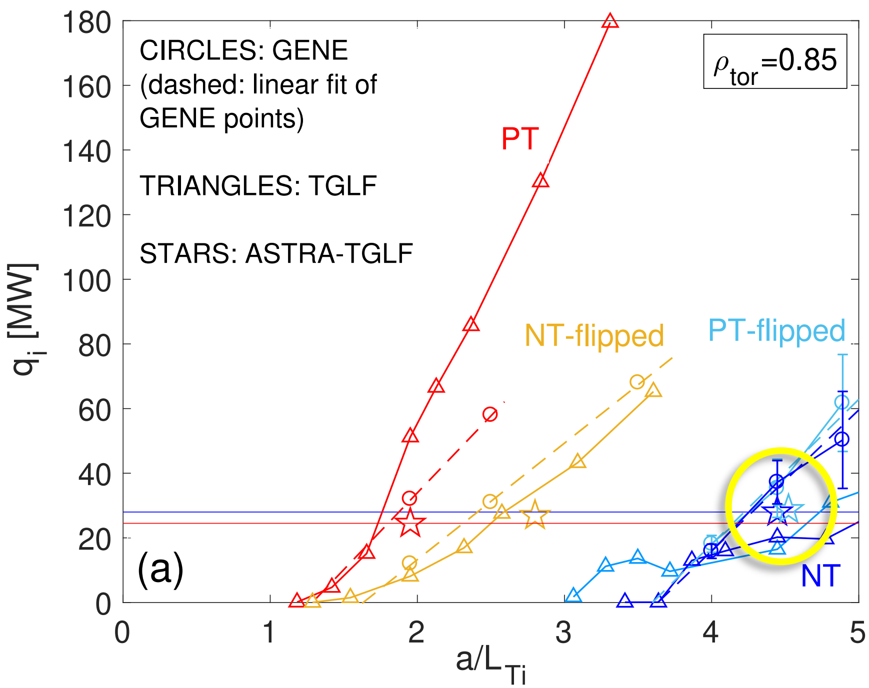


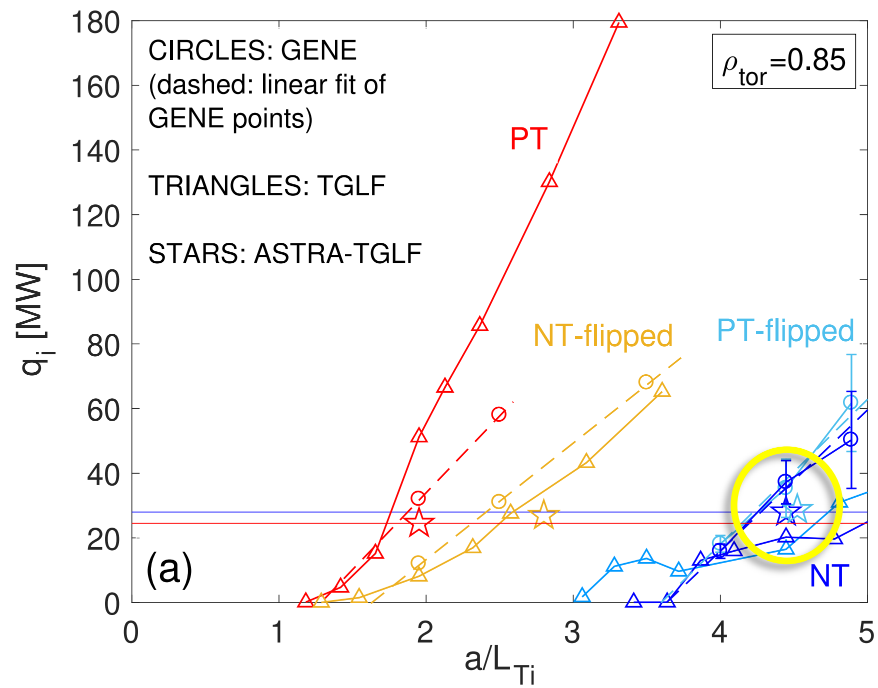


- ~20/30% beneficial effect of NT on ion temperature peaking in H-mode (consistent with ASTRA-TGLF);

Nonlinear GENE and TGLF results

Main mode: ITG (driven by a/L_{Ti}) → heat fluxes a/L_{ti} scan (**ion stiffness**) at ρ_{tor}=0.85 :

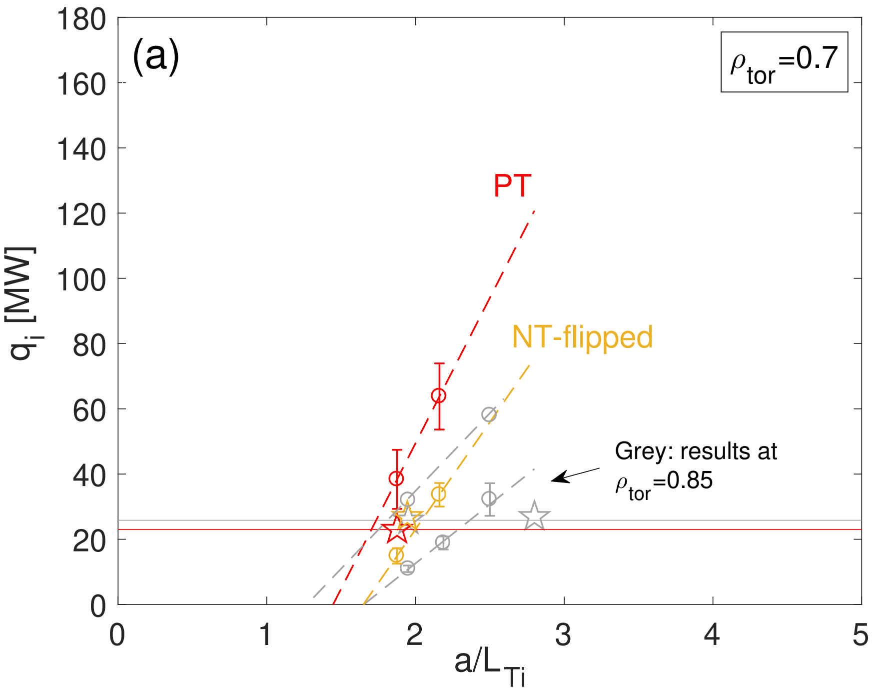


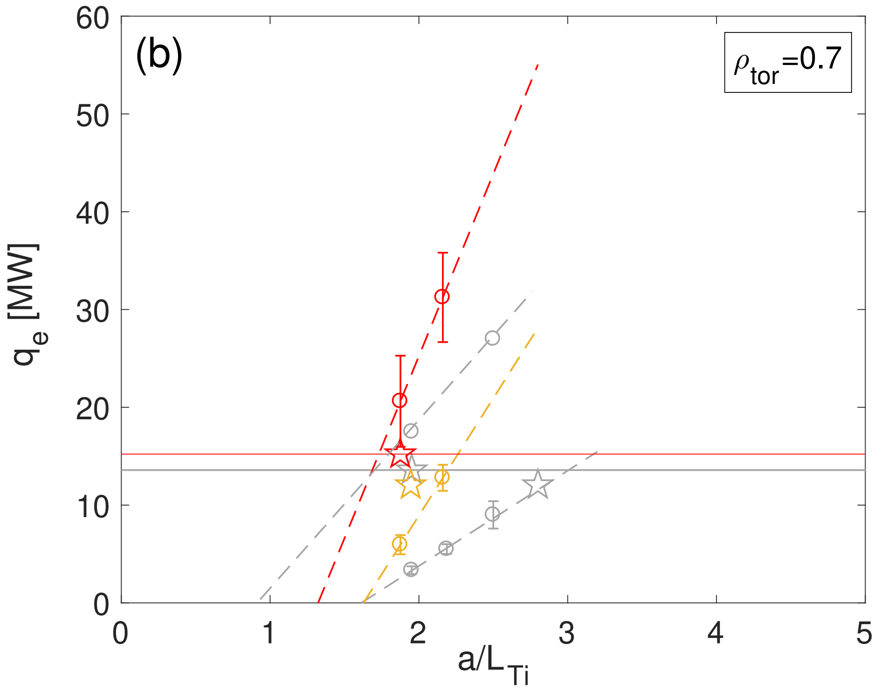


- Negligible NT beneficial effect in L-mode;

Nonlinear GENE and TGLF results

Same exercise at ρ_{tor}=0.7:

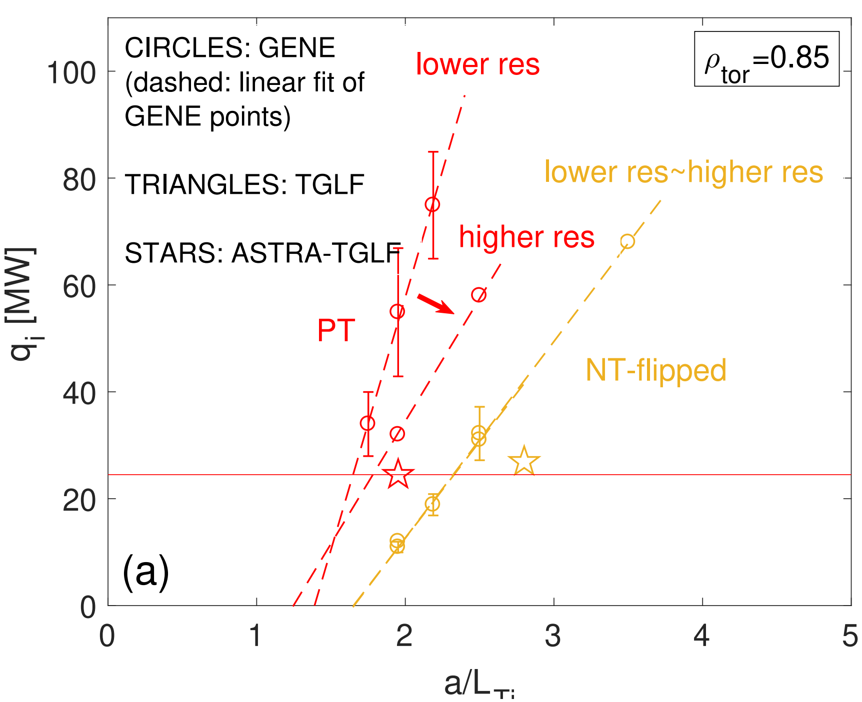


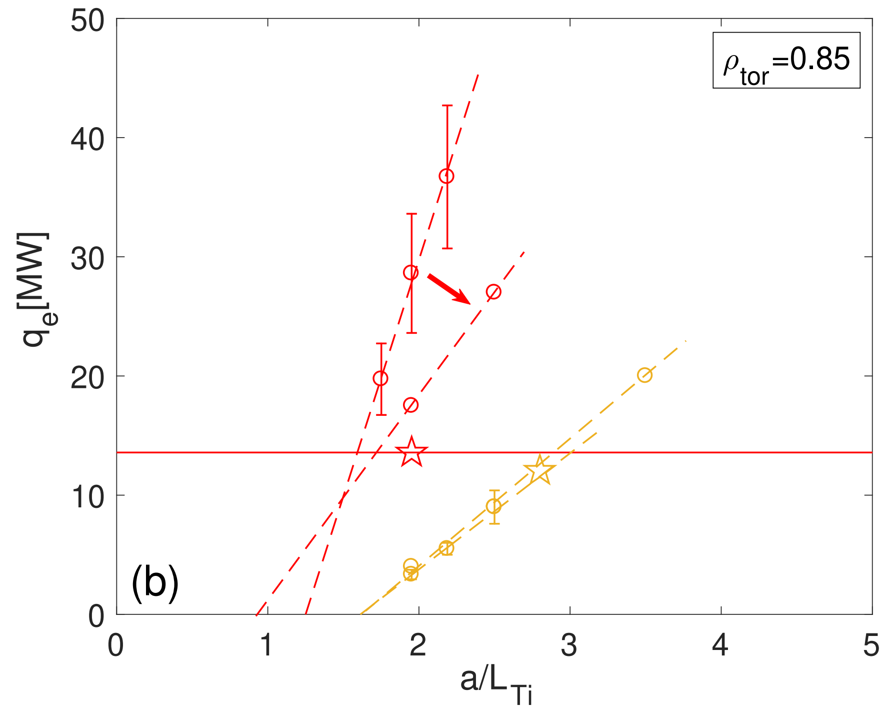


- Beneficial effect of NT: more than halved at ρ_{tor}= 0.7 wrt. ρ_{tor}= 0.85, consistent with ASTRA-TGLF (half triangularity at ρ_{tor}= 0.7 wrt. ρ_{tor}= 0.85). In addition, the effect of NT is almost completely lost on a/LTi due to the largest stiffness at the smaller radius.

GENE resolution test

- Old: nkx x nky x nz x nv x nw= 256 x 32 x 32 x 48 x 15, lx ~ 70 rhos, kymin rhos= 0.05
- New: nkx x nky x nz x nv x nw= 512x64x60x48x12 , lx ~150 rhos, kymin rhos) 0.05





Conclusions on DTT numerical modelling

- ASTRA/TGLF SAT2 first simulations of a pair of full power SN DTT plasmas with positive and negative triangularity are now available; GENE simulations have been run at two fixed radii where the triangularity is sufficiently large to impact the results;

- The beneficial effect of the NT is very small. In particular the NT L-mode is not able to recover the core T_i values of the PT H-mode: **in order to have a NT L-mode without ELMs one has to renounce to part of the plasma performance**.

- NL GENE compared with TGLF stand-alone and ASTRA: good agreement close to the sxperimental fluxes, validating the ASTRA-TGLF transport modelling. **Basically no significant transport reduction due to geometry is foreseen in DTT NT L-modes.**

- **All the simulations done for rhotor<0.9/0.95: a beneficial effect of NT could come from rhotor>0.9.**

- **Analysis: concluded (paper ready to be submitted).**