2024 Annual TSVV 2 workshop September 23-24, 2024

EUROfusion

Investigating the different impact of NT shape on TCV, AUG and DTT plasma

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Consiglio Nazionale delle Ricerche ISTP
DTT
ASDEX Upgrade
IPP Max-Planck-Institut für Plasmaphysik
EPFL

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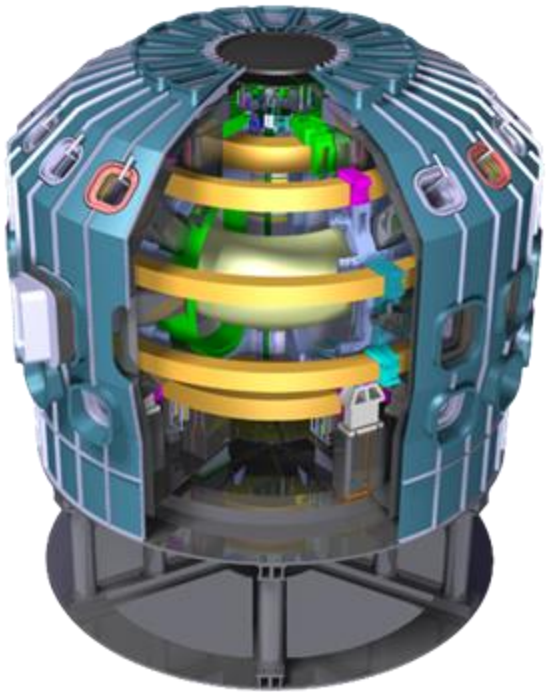
DTT configuration with negative triangularity

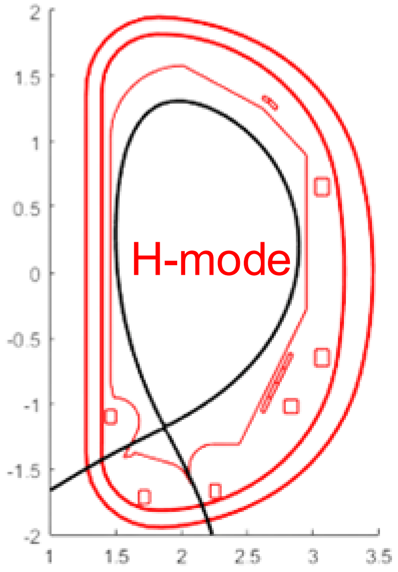
Divertor Tokamak Test facility (DTT)



Under construction in Frascati (Italy)

Full power scenario (45 MW: ECRH+NBI+ICRH)

Positive Triangularity (PT)



R=2.19 m / a =0.70 m
6 T / 5.5 MA
upper δ_{sep} = 0.39
lower δ_{sep} = 0.49

Reference scenario

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DTT configuration with negative triangularity

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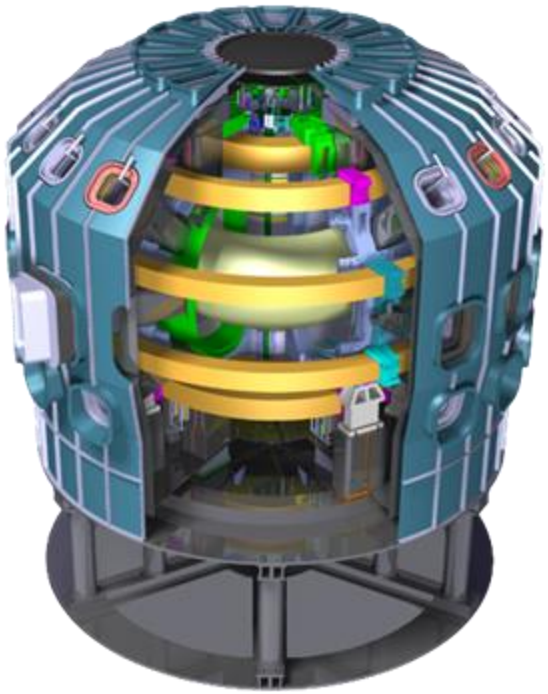
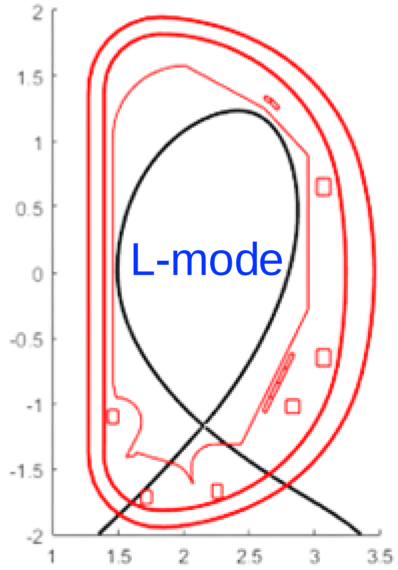


Under construction in Frascati (Italy)

Full power scenario (45 MW: ECRH+NBI+ICRH)

Negative Triangularity (NT)

NT option
(to avoid
ELMs)



R=2.19 m / a =0.70 m
6 T / 4 MA
upper δ_{sep} = -0.32
lower δ_{sep} = 0.016 > 0

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Overview of the analysis

DTT

[A. Mariani et al., NF 2024]

- **No experiments yet** (the device is still under construction);
- Only **numerical analysis**, comparing:
  reference PT H-mode full power scenario ⟷ NT L-mode option;
- ASTRA-TGLF SAT2 **predictive transport simulations**;
- GENE **gyrokinetic** flux-tube linear and nonlinear simulations.

TCV

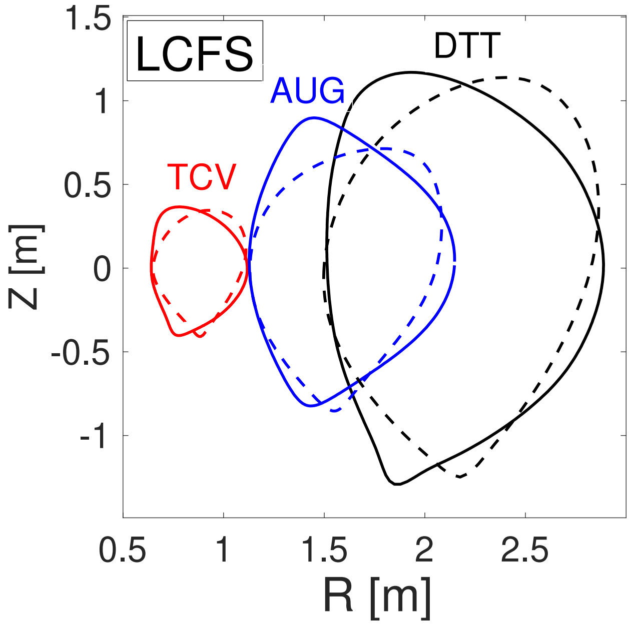
[A. Balestri et al., PPCF 2024]

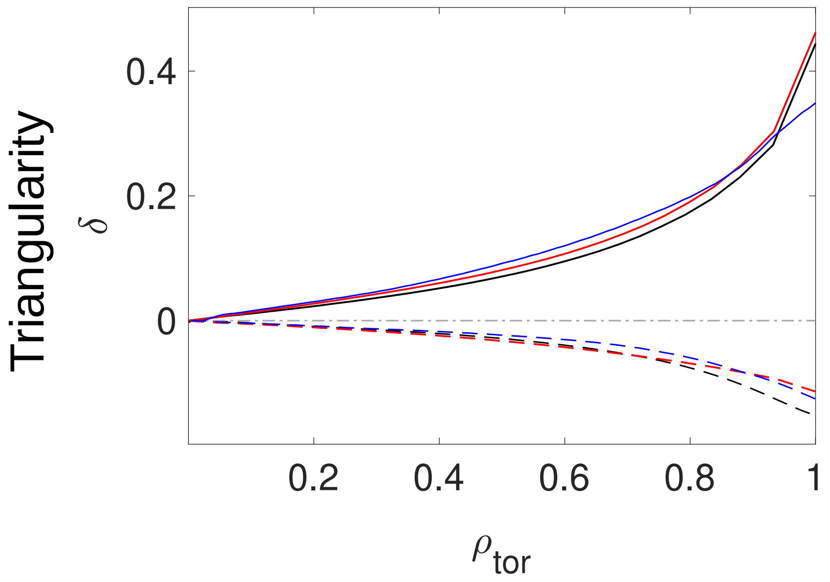
Recent experiments: EUROfusion WP TE 2022

AUG

[L. Aucone et al., NF 2024]

Experiments with DTT-like shapes and transport, to predict DTT NT scenario performance:





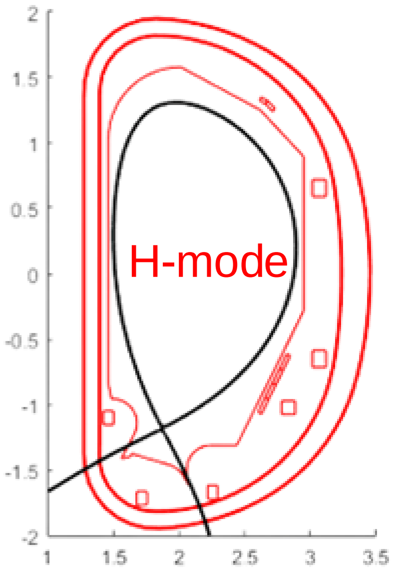
(remark: the PT AUG pulses were not made within NT scope)

New DTT configuration with negative triangularity

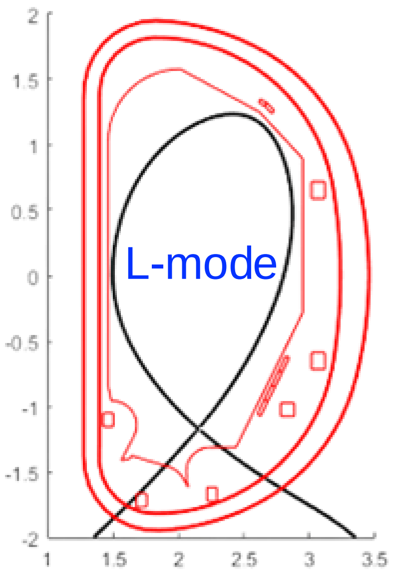
After experimenatal and numerical analysis:
there is room to impove the NT shape

DTT

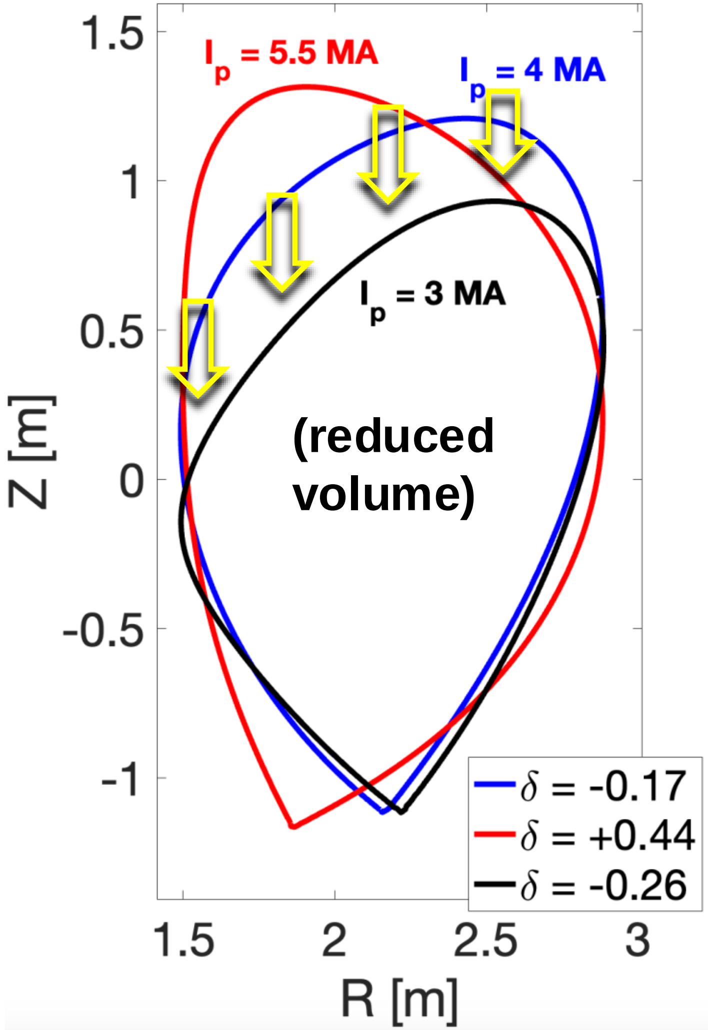
PT



NT: first shape
(low delta: LD)



NT: new shape
(high delta: HD)

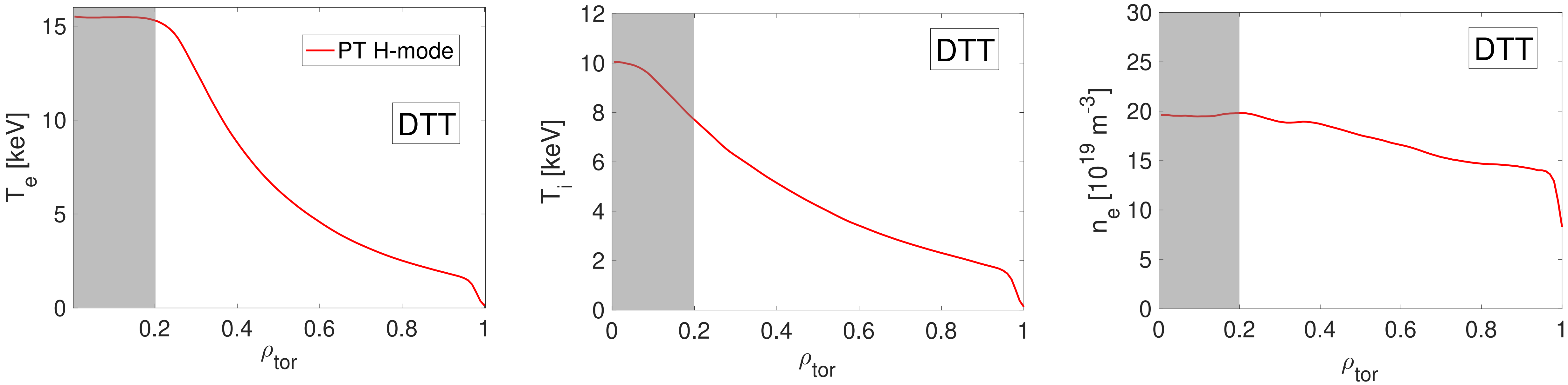


New experiments on TCV with the new DTT shape

We mainly focus on the first DTT NT shape: low delta (LD)

Predictive transport simulations of DTT

- ASTRA-TGLF (SAT2). NBI/ECRH/ICRH power input and impurity profiles (self consistent).
- DTT full power scenario with Ne seeding.
- Reference scenario (PT H-mode)



Predictive transport simulations of DTT

- ASTRA-TGLF (SAT2). NBI/ECRH/ICRH power input and impurity profiles (self consistent).
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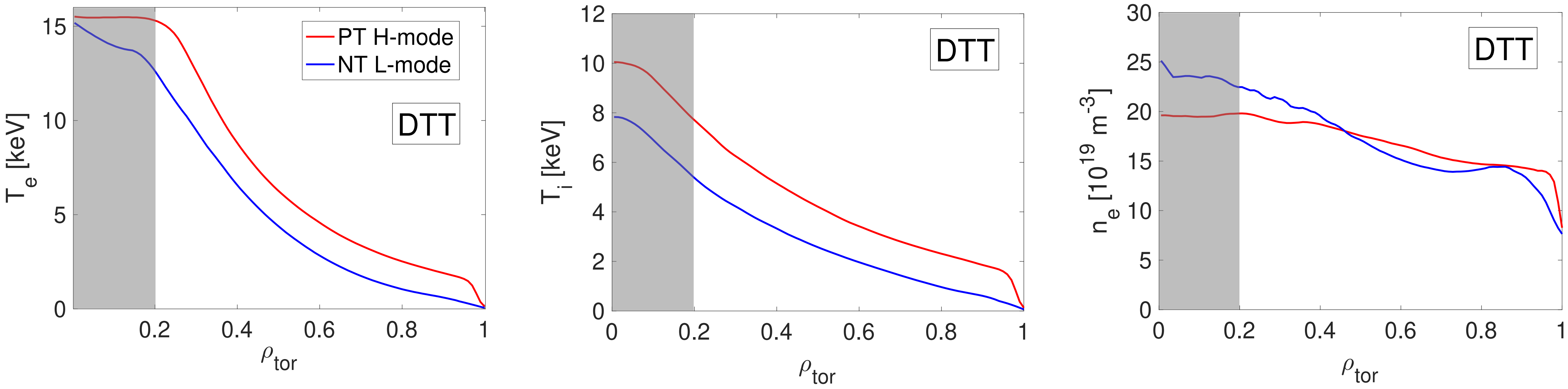
- Reference scenario (PT H-mode), compared with the $\delta < 0$ option (NT L-mode):



(adapted from [A. Mariani et al.,submitted to NF])

Predictive transport simulations of DTT

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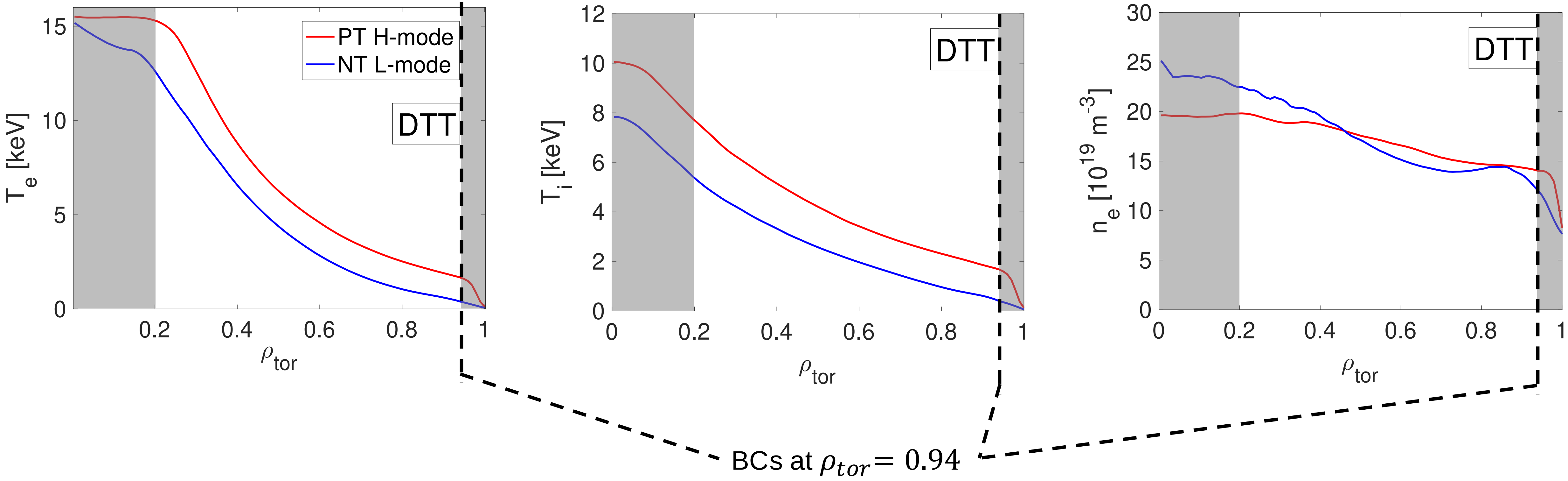

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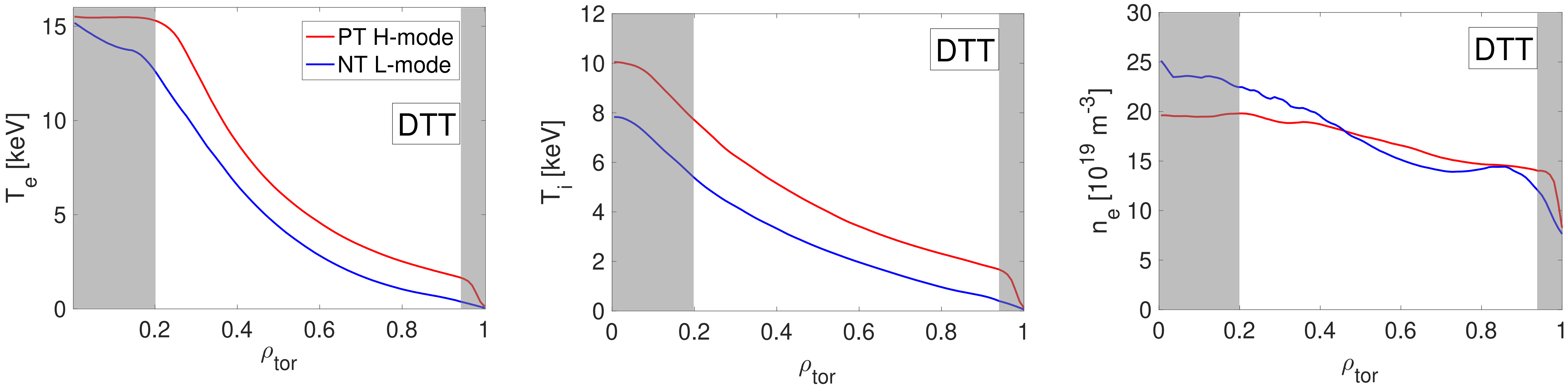
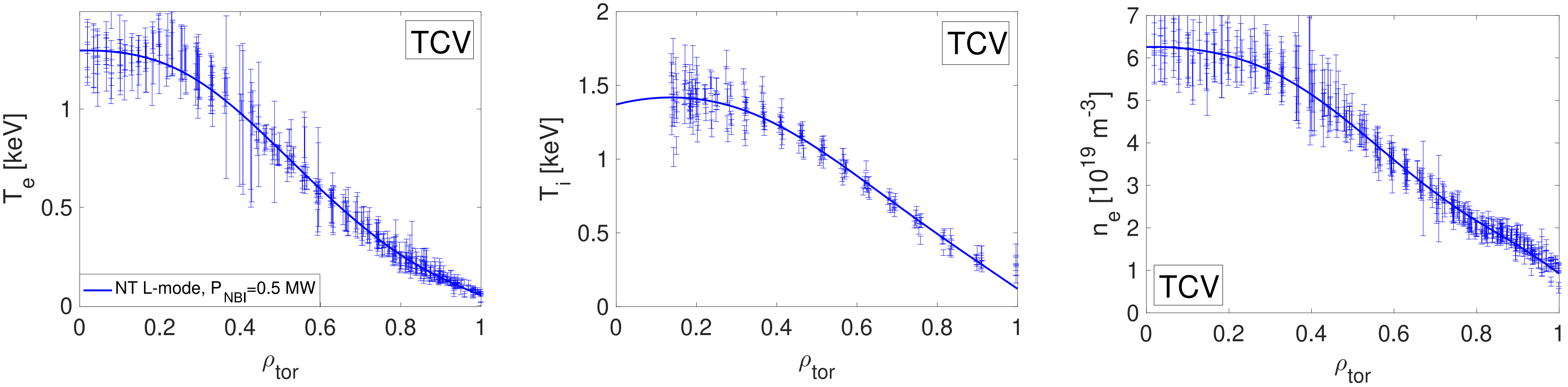


The NT L-mode is unable to recover the loss of the PT H-mode pedestal and reach similar central temperatures.

TCV experiments

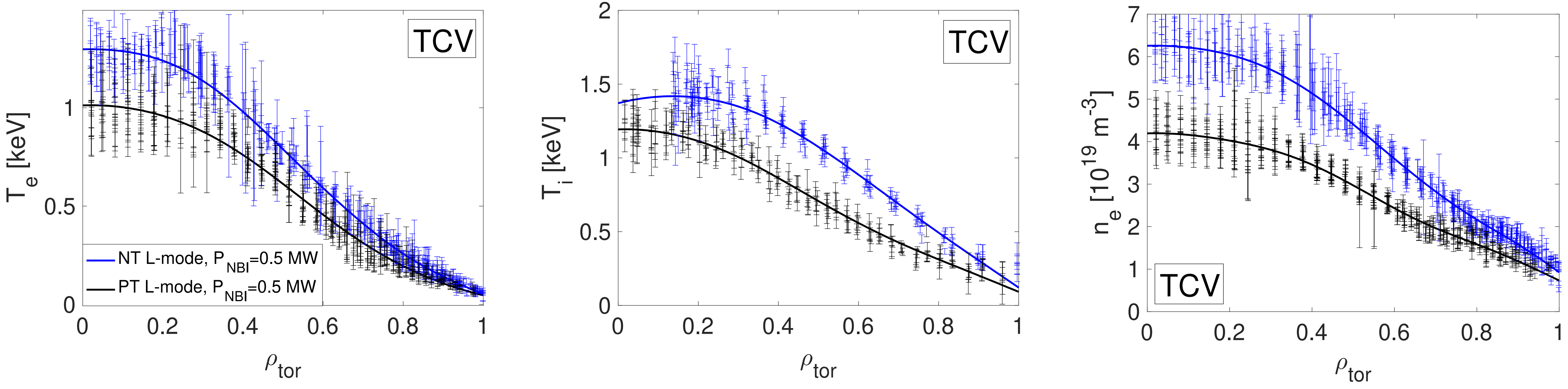
Differently: for TCV experiments, lower power NT L-modes



(NBI only cases: NT L-mode #73382, adapted from [A. Balestri et al., PPCF 2024])

TCV experiments

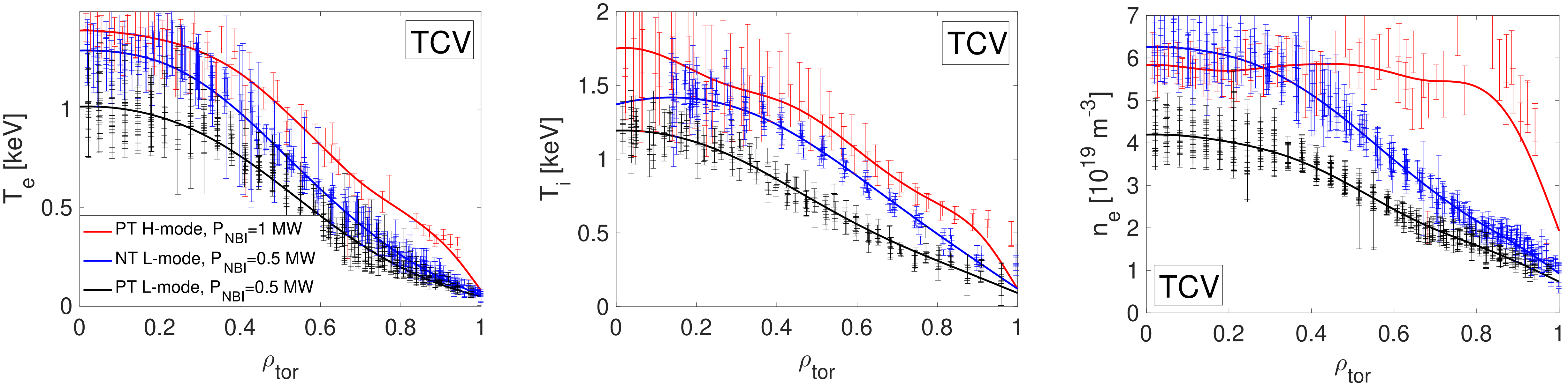
Differently: for TCV experiments, lower power NT L-modes overperform corresponding PT L-modes



(NBI only cases: NT L-mode #73382, PT L-mode #73388, adapted from [A. Balestri et al., PPCF 2024])

TCV experiments

Differently: for TCV experiments, lower power NT L-modes overperform corresponding PT L-modes and reach the central n,T values of double power PT H-modes

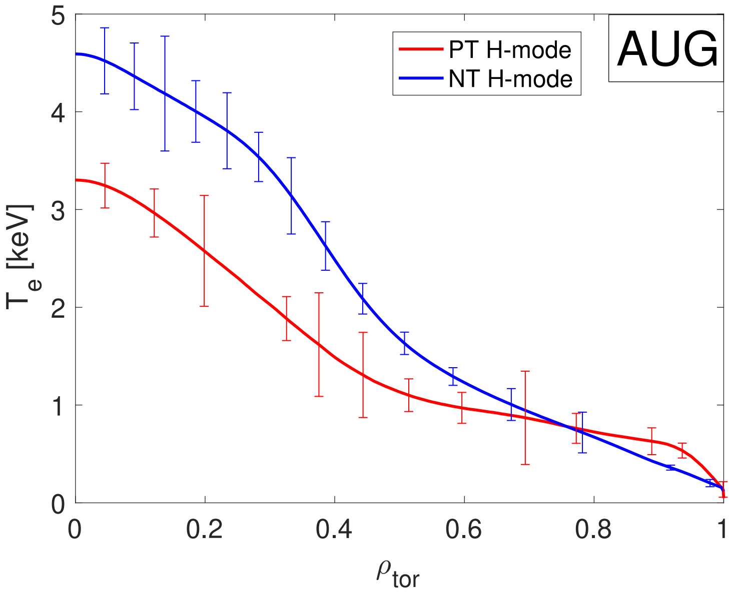


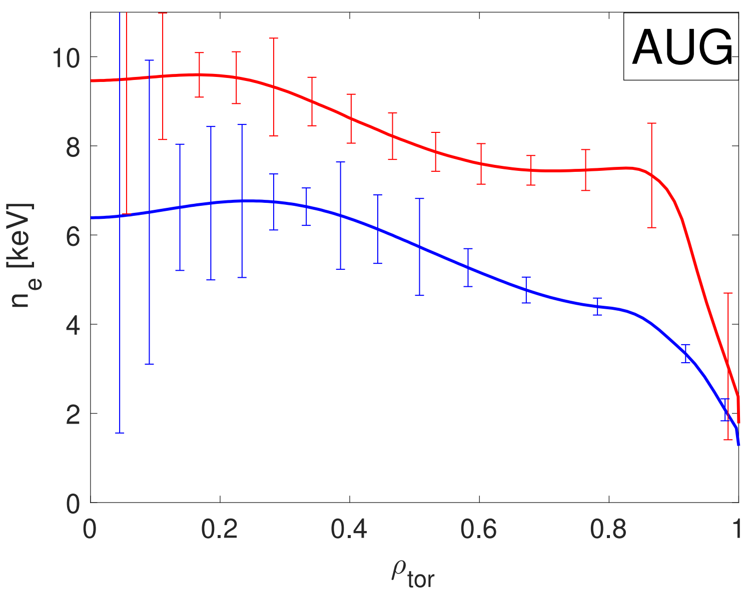
(NBI only cases: NT L-mode #73382, PT L-mode #73388, PT H-mode #73392, adapted from [A. Balestri et al., PPCF 2024])

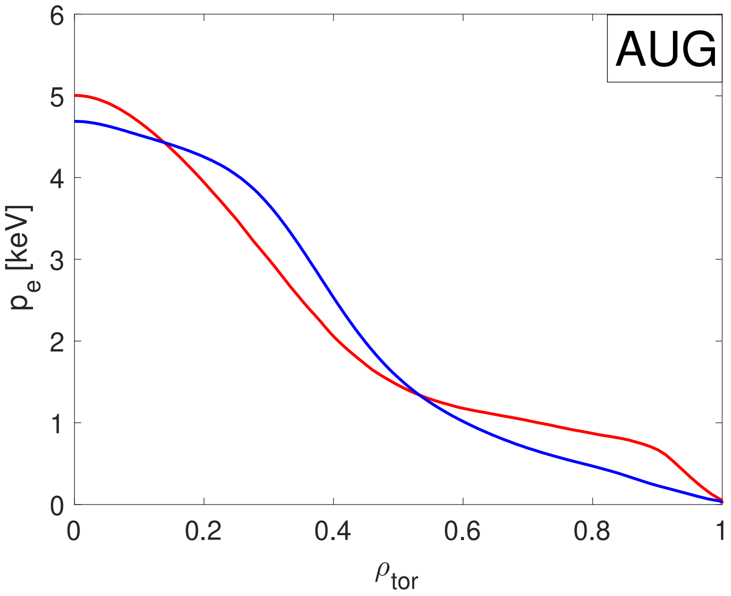
AUG experiments and transport simulations

Unlike TCV plasmas, NT discharges in AUG ⇒ go into H-mode at lower input power (ion ∇B drift ⟶ X-point);

- ⇒ Most of the comparisons: between PT and NT **H-modes**;
- **Largest effect** of **NT: ECRH only** pulses with same power:







(ECRH only cases with P_{ECRH}=2.9 MW: PT H-mode #36157, NT H-mode #40473, adapted from [L. Aucone et al., PPCF 2024])

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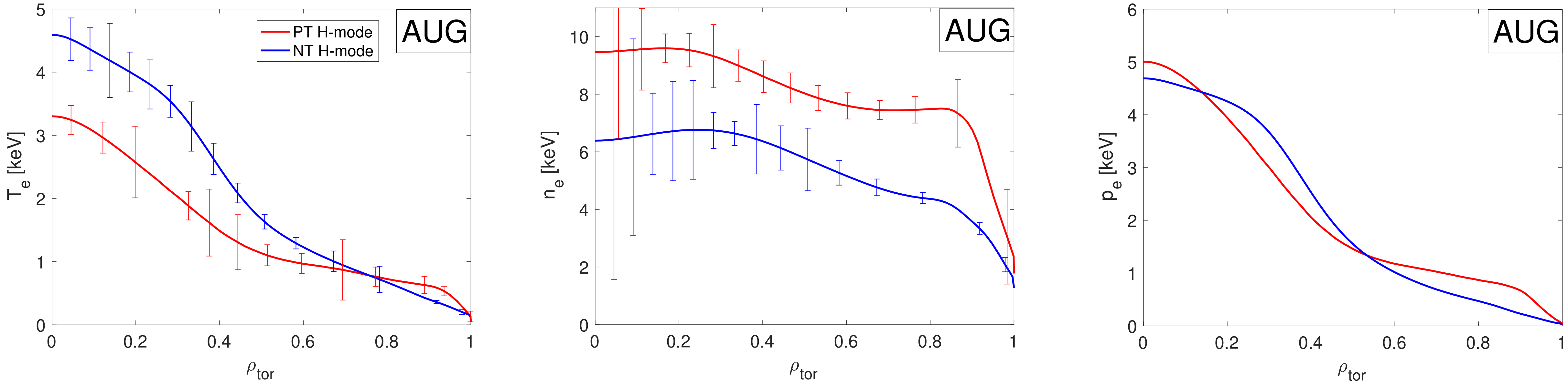
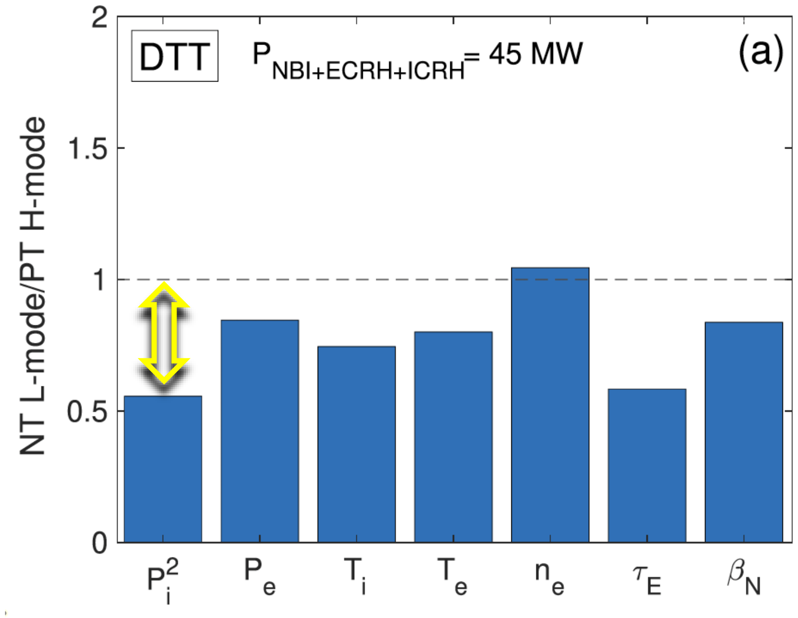
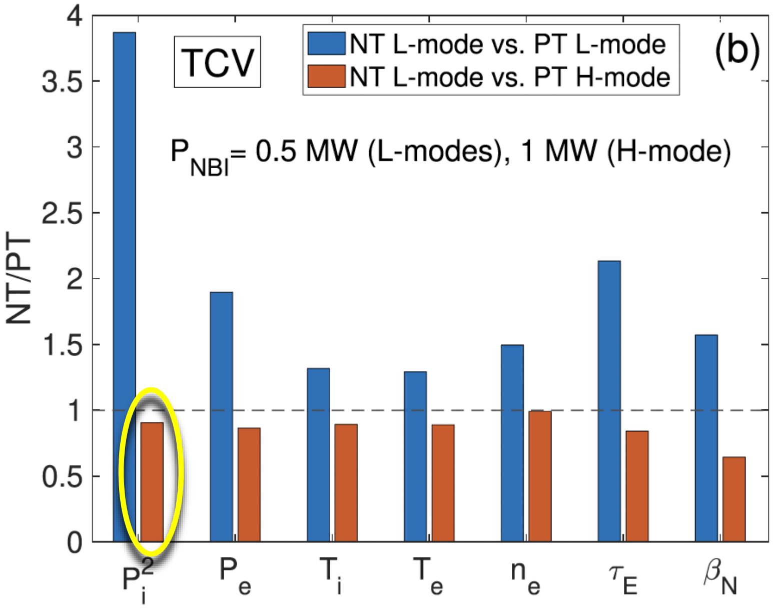


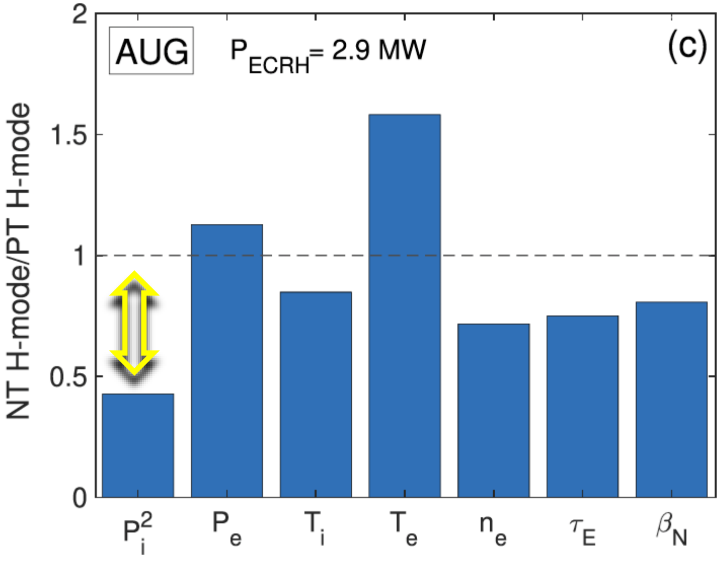
(ECRH only cases with P_{ECRH}=2.9 MW: PT H-mode #36157, NT H-mode #40473, adapted from [L. Aucone et al., PPCF 2024])

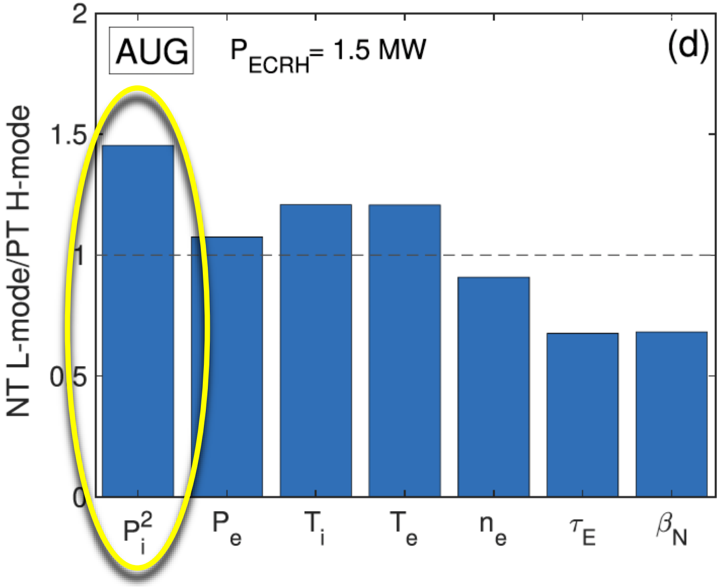
- **NT** pulse, **despite** the **smaller pedestal**, recovers the PT pressure;
- Practical gain for NT, compared with PT: much weaker ELMs [Vanovac, in preparation]

0D parameters:





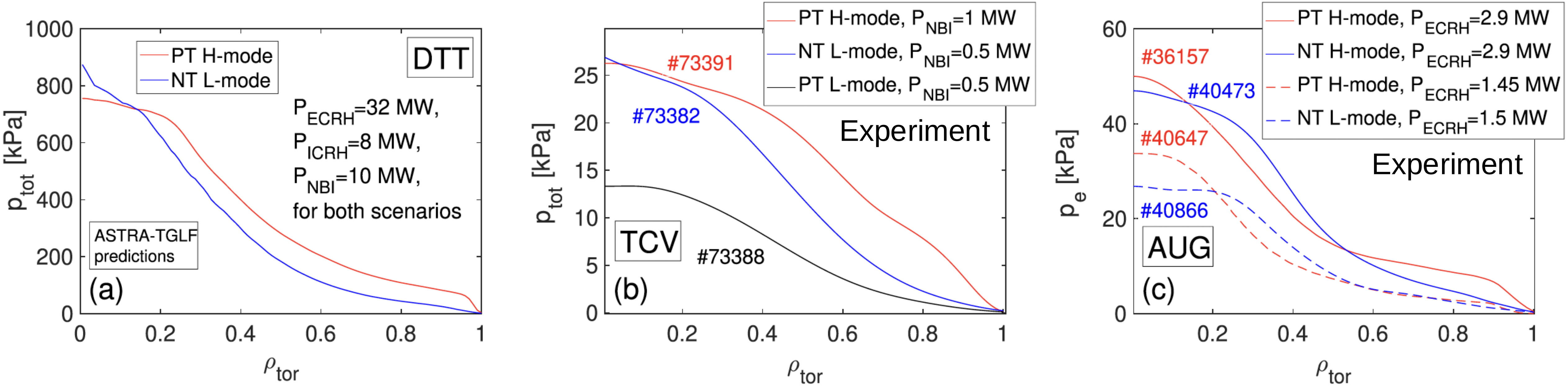




- DTT: NT L-mode underperforms PT H-mode;
- TCV: NT L-modes perform almost the same way as double power H-modes;
- AUG: NT H-mode overperforms PT H-mode only for ECH cases with smaller power

$$\langle p_i^2 \rangle = \frac{1}{V}\int_0^{0.4} p_i^2 \frac{dV}{d\rho_{tor}} d\rho_{tor} \quad \propto \quad \text{Fusion power}$$

Summary: main differences between DTT, TCV and AUG



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

NT L-mode **does not reach** the central n,T values of a PT H-mode with the same power.

TCV: experiment:

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

AUG: experiment:

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

Role of turbulence drive: logarithmic gradients

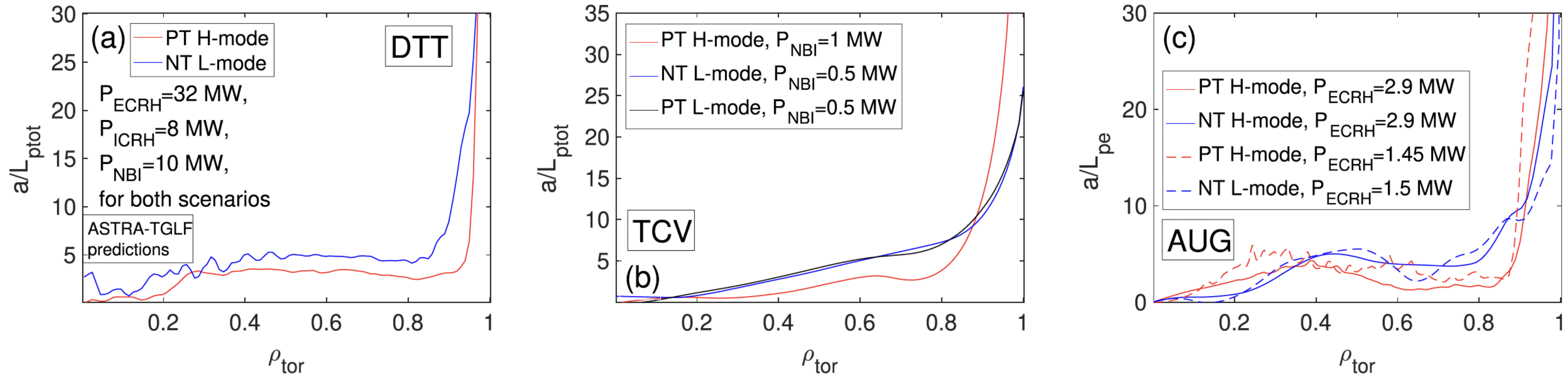
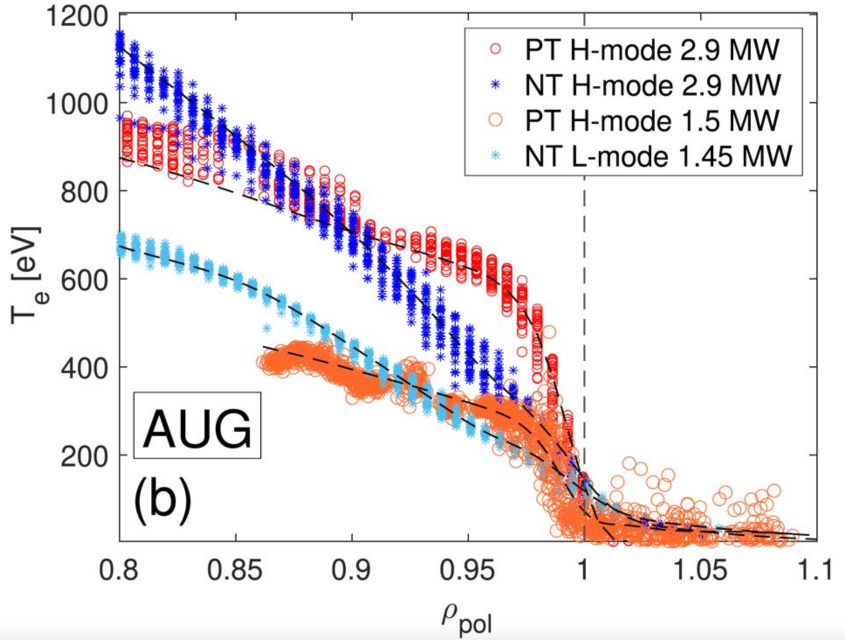


Figure 4. Normalized logarithmic gradients of p_{tot}, corresponding to the profiles of figure 2, for DTT (*a*), TCV (*b*) and AUG (*c*). (*a*) Reproduced from [18].

- Gradients are larger for NT L-mode than for PT H-mode inside the H-mode pedestal, and the opposite outside it (nothing unexpected, it is just the usual difference between L- and H-mode);

- **More interesting:** The **NT H-modes in AUG have logarithmic gradients that resemble L-modes**. Indeed, also their pedestal is very much reduced compared with a usual H-mode.



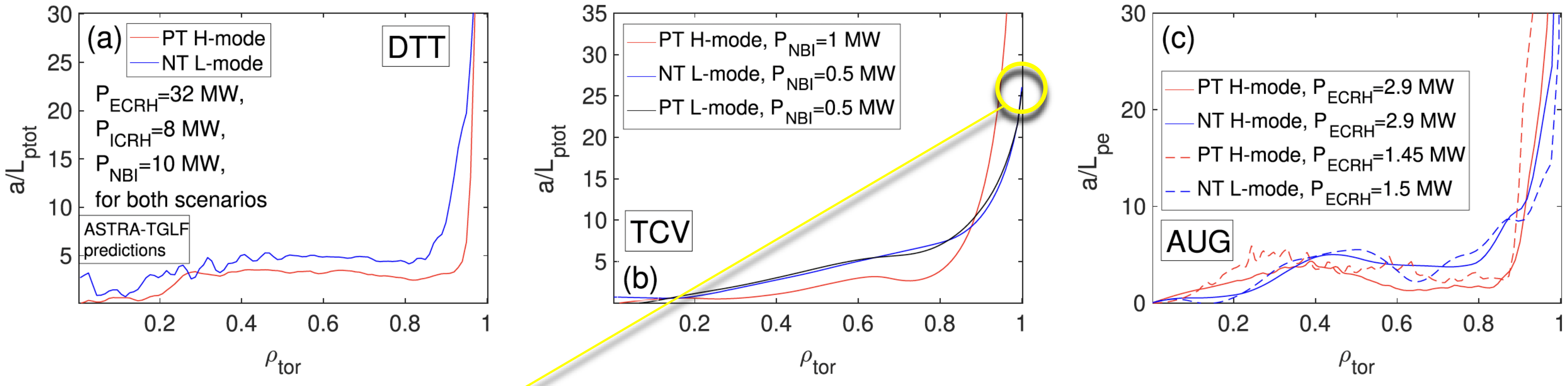


Figure 4. Normalized logarithmic gradients of p_{tot}, corresponding to the profiles of figure 2, for DTT (*a*), TCV (*b*) and AUG (*c*). (*a*) Reproduced from [18]. © 2024 The Author(s). Published by IOP Publishing Ltd on behalf of the IAEA. All rights reserved CC BY 4.0.

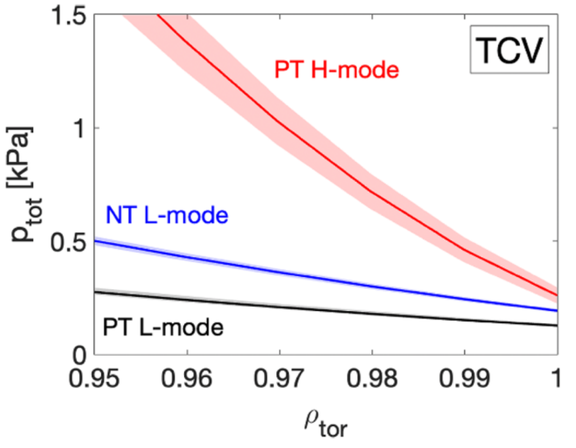
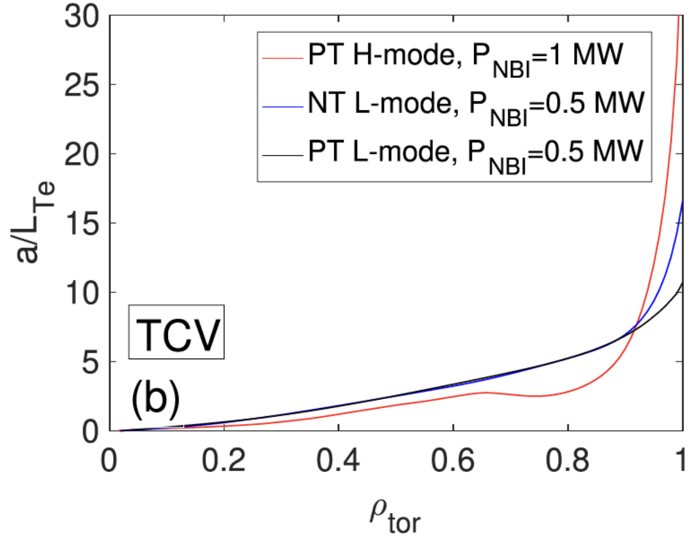


Figure 5. Total pressure profiles of TCV NBI-only pulses in the plasma edge (detail of figure 2 (*b*)). Reproduced from [19]. © The Author(s). Published by IOP Publishing Ltd. CC BY 4.0.

TCV: only case with PT/NT L-modes comparison:

TCV improvement of p_{tot}: just due to the BC?

More complicated: a improvement of $n_e, T_{e,i}$, due to NT, compensates the accumulation of carbon impurity at the edge for the NT case.



Why do DTT simulation miss the beneficial effect of NT?

Possible reason #1:

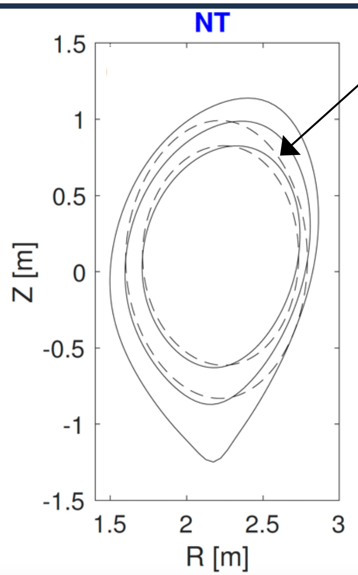
- ASTRA-TGLF: run with BCs at $\rho_{\mathrm{tor}} = 0.95$
- GENE simulations for $\rho_{\mathrm{tor}} < 0.85$

Beneficial effect of NT:

could come from the edge-SOL region $\rho_{\mathrm{tor}} > 0.95$

Possible reason #2:

- DTT NT shape: highly up-down asymmetric, with upper $\delta_{sep} < 0$ and lower $\delta_{sep} \gtrsim 0$
- TGLF: up-down symmetric Miller equilibrium



Dashed: Miller

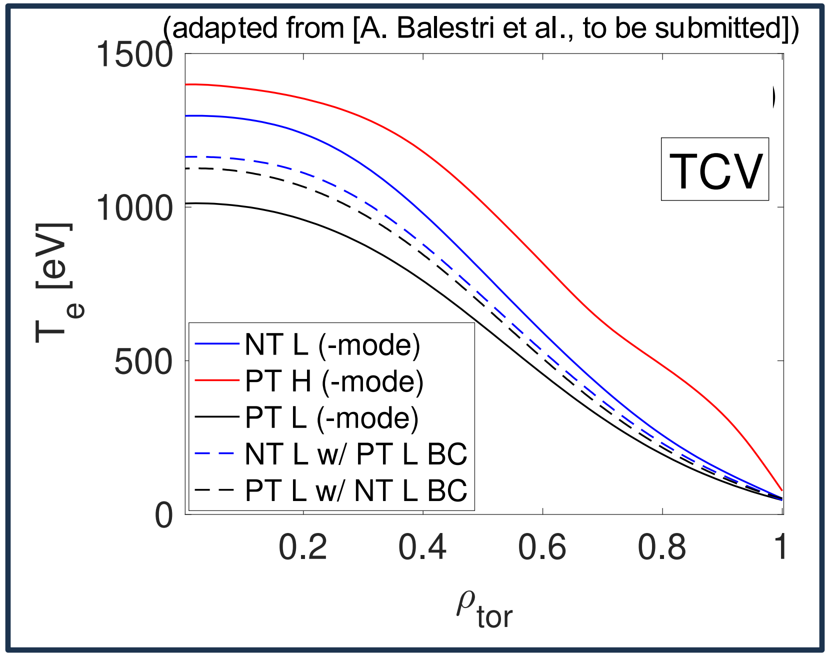
TGLF averages upper and lower δ, possibly seeing a reduced $\delta < 0$ stabilizing effect.

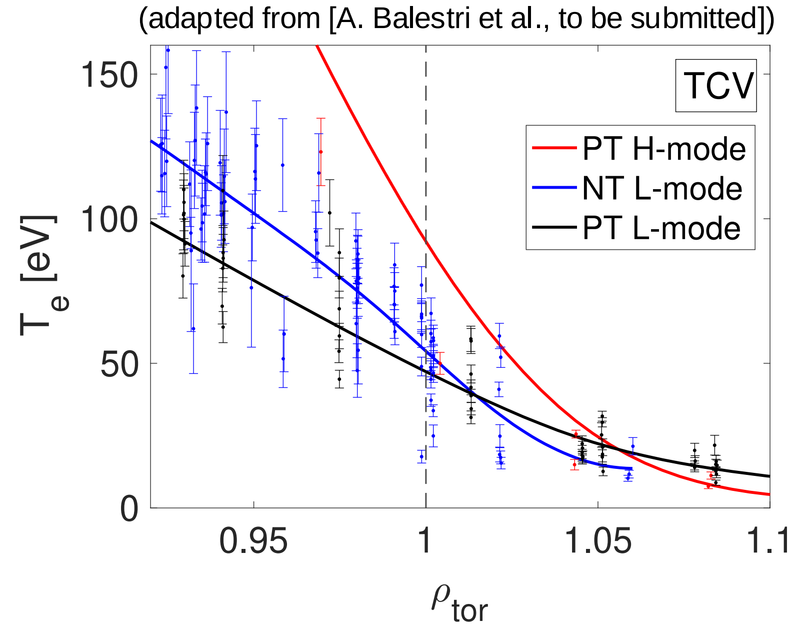
New TGLF version: Elite, with generalized geometry (see the next talk)

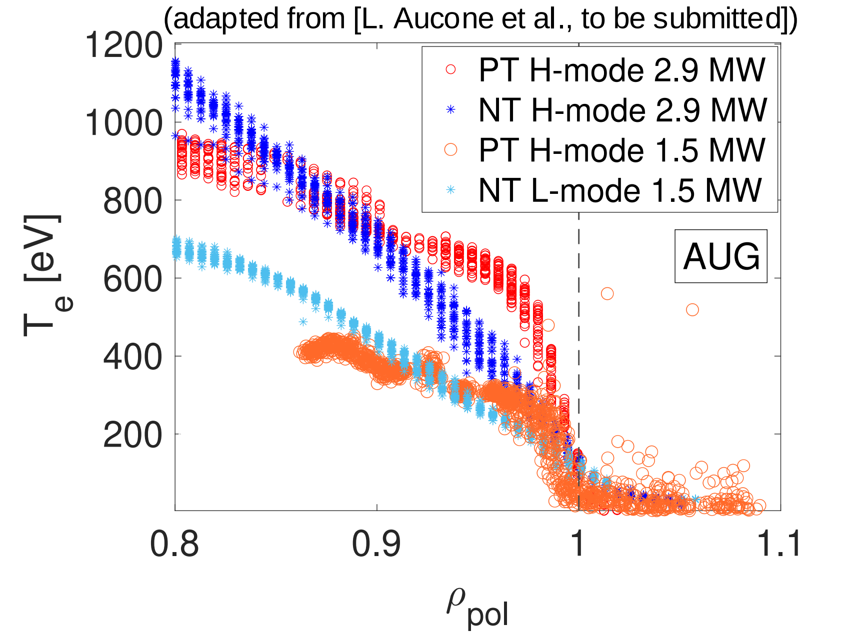
Effect of boundary conditions and SOL physics (IAEA)

TCV: improvement of central n,T: equally shared between increased gradients in the outer core and larger values of temperature and density at the separatrix.

TCV and AUG: steeper density and temperature in the SOL for NT L-modes compared with PT ones.







Effect of boundary conditions and SOL physics (IAEA)

TCV: improvement of central n,T: equally shared between increased gradients in the outer core and larger values of temperature and density at the separatrix.

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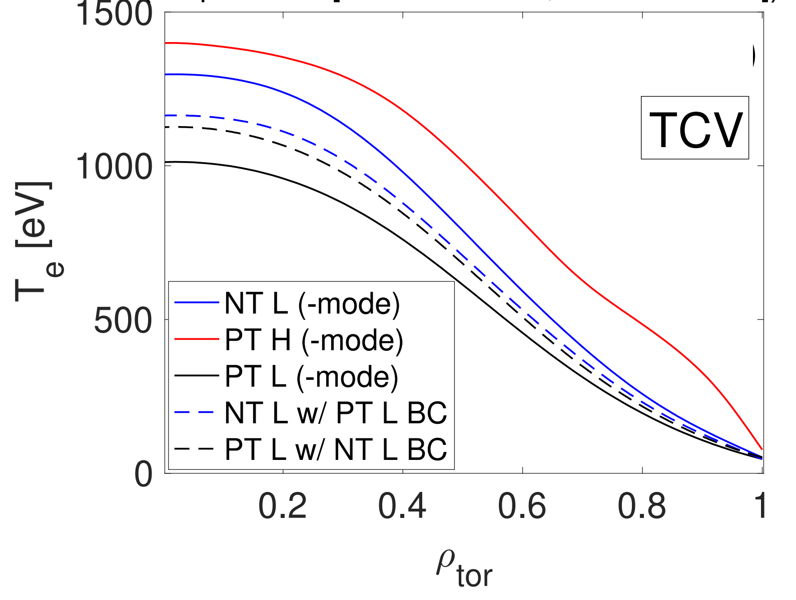
(adapted from [A. Balestri et al., to be submitted])



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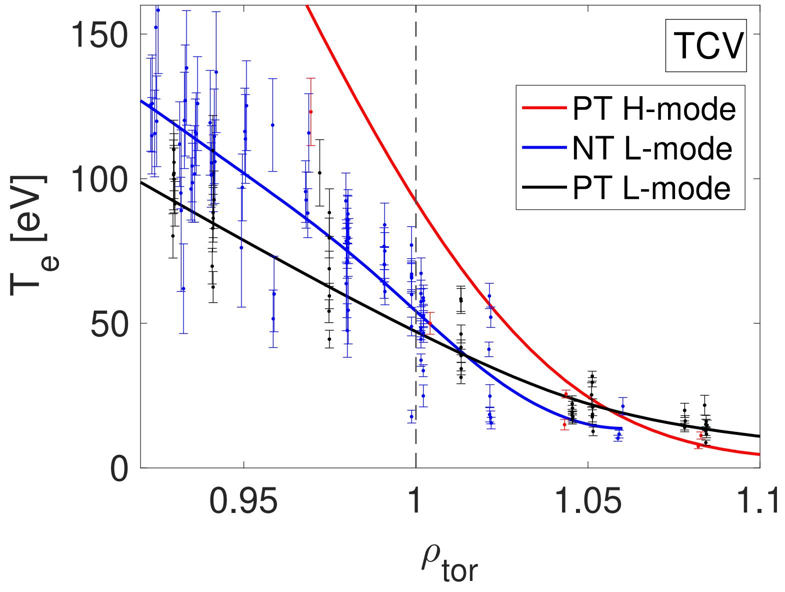

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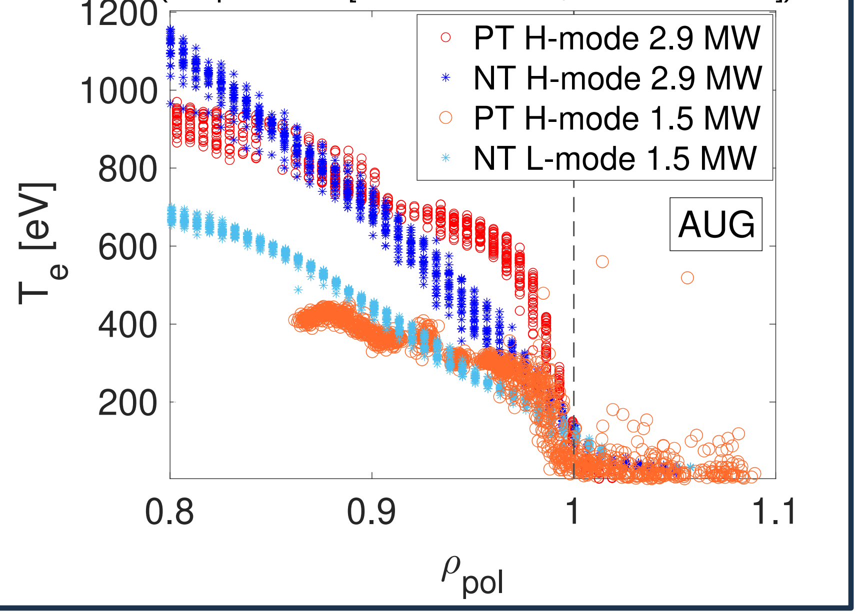
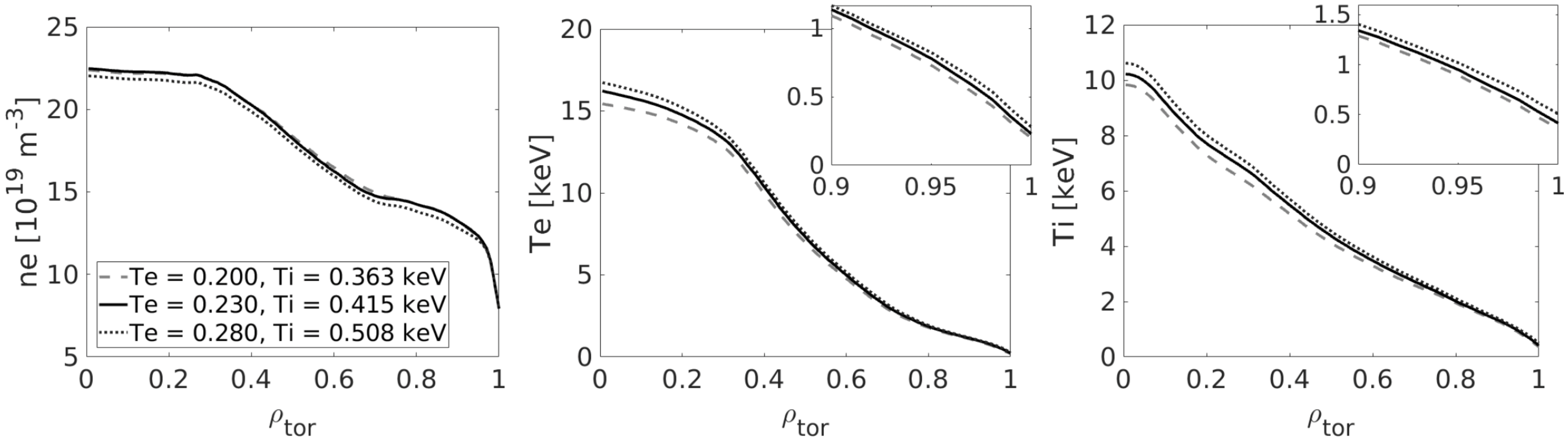


Beneficial effect of $\delta < 0$: partially comes from the SOL

to entirely capture this effect: simulate the region across the separatrix.

After IAEA…the picture changes



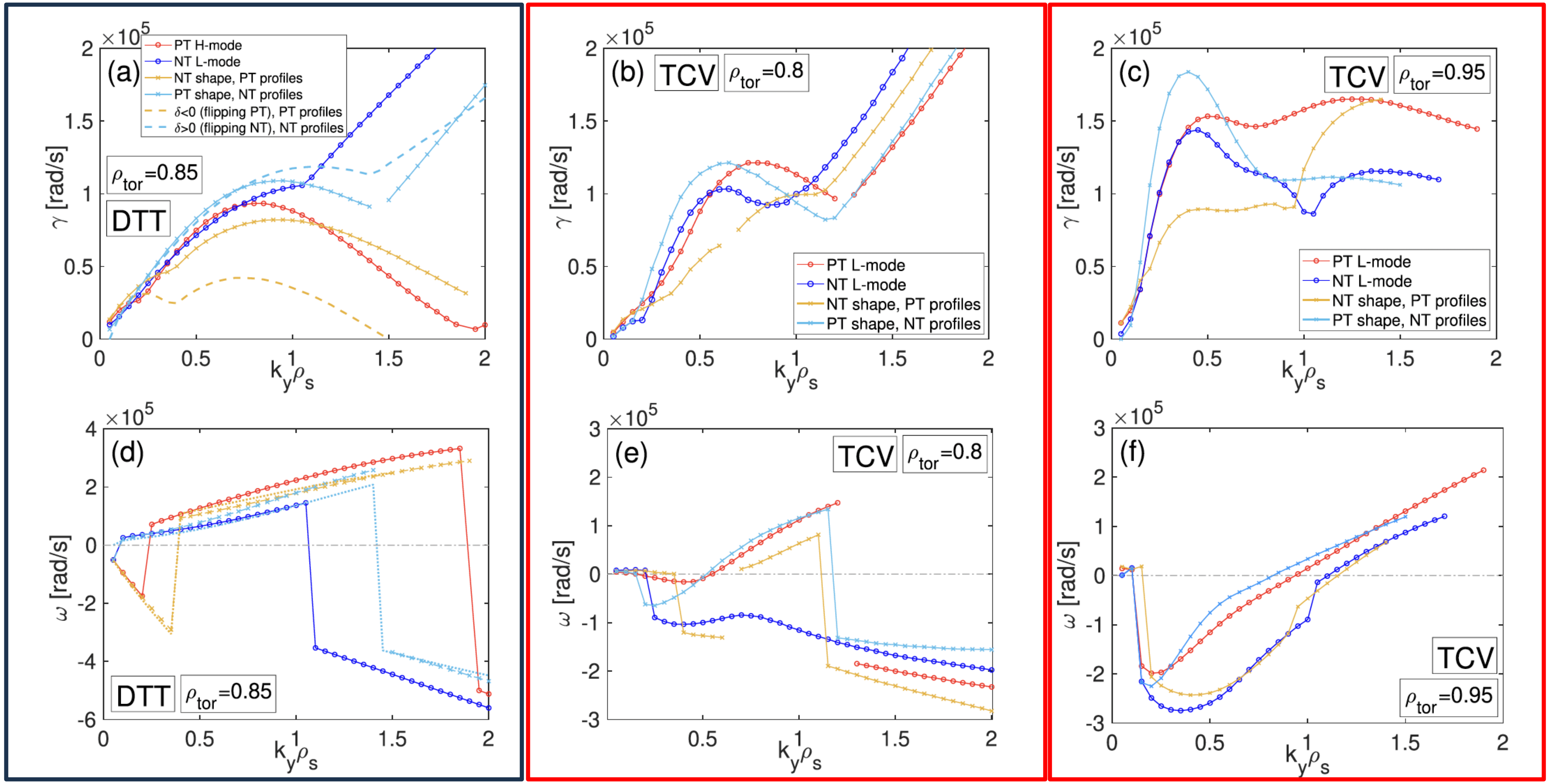
ASTRA-TGLF predictive simulations for the DTT NT high delta scenario

Figure 7.11: ASTRA-TGLF predictions with different temperature boundary conditions. Starting from the left: electron density n_e, electron temperature T_e, and ion temperature T_i. The BCs do not significantly affect the core profiles.

Te BCs change by 40%, but the central values only change by 8%

More information in the next talk

Linear GENE gyrokinetic simulations



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 balanced, NT TEM**

q_e/q_i = 1.05/1.85 (DTT PT H/NT L at ρ_{tor} = 0.85): **PT balanced, NT TEM**

- Naively: DTT more ITG, TCV more TEM: TCV sees more NT stabilization since it is more TEM dominant.
- AUG: ITG dominant for ECH only cases, due to large Pei;

Nonlinear gyrokinetic simulations

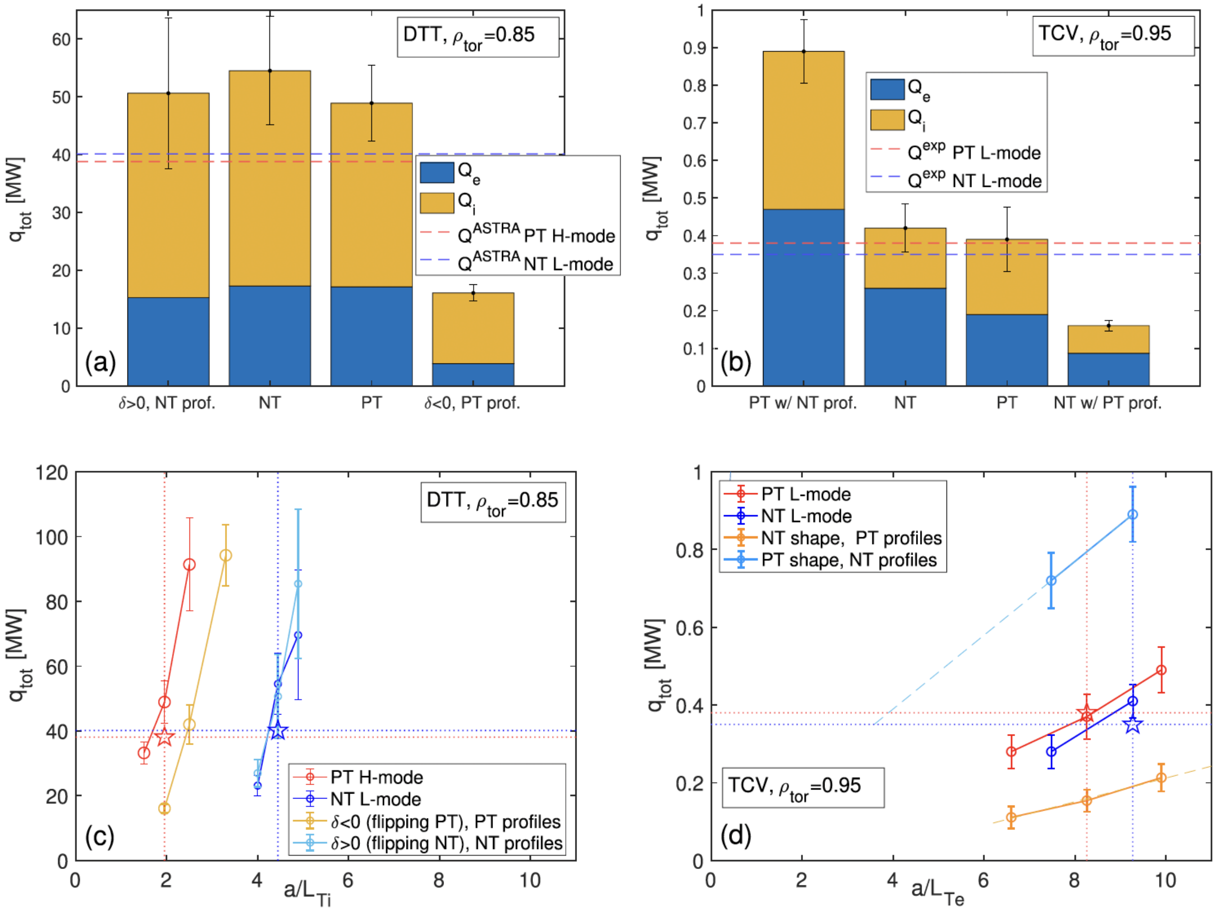


Figure 12. Nonlinear GENE simulations. (*a*) and (*b*) total heat fluxes, splitted in electron (blue) and ion (yellow) contributions, for DTT at $\rho_{\rm tor} = 0.85$ and TCV at $\rho_{\rm tor} = 0.95$, respectively. The red and blue dashed lines for DTT indicate the predicted fluxes by ASTRA-TGLF, while for TCV they show the experimental fluxes. (*c*) and (*d*) $T_{\rm i}$ stiffness plot for DTT and $T_{\rm e}$ stiffness plot for TCV, varying only the temperature logarithmic gradients, starting from the reference parameters of (*a*) and (*b*), respectively. The total heat flux is reported as a function of the logarithmic gradients $a/L_{T{\rm i}}$ and $a/L_{T{\rm e}}$ for DTT and TCV, respectively. The dashed lines are a prolongation of the solid lines to find the intercept with the x-axis. The dotted blue and red horizontal lines for TCV are the experimental heat fluxes, while the vertical ones are the experimental gradients of PT (red) and NT (blue). The stars represent the point where the vertical and horizontal lines meet. For DTT, instead of the experimental values, the predicted ones by ASTRA-TGLF are shown. (*b*)/(*d*) Reproduced from [19]. © The Author(s). Published by IOP Publishing Ltd. CC BY 4.0, while (*c*) Reproduced from [18]. © 2024 The Author(s). Published by IOP Publishing Ltd on behalf of the IAEA. All rights reserved CC BY 4.0.

- *DTT, ITG dominant: one studies the T_i stiffness*
- *TCV, more TEM-dominant overall: T_e stiffness*

- For TCV, the exp. beneficial effect of NT is recovered, partially compensated by the other different parameters between the PT/NT pulses;
- For DTT, a beneficial effect of NT is only found at ρ_{tor} =0.85 for the H-mode;

Also for AUG PT/NT H-modes a stabilizing effect of NT is observed in the $0.7 < \rho_{tor} < 0.9$ region: it is possible that for H-mode parameters, the beneficial effect of NT could penetrate to inner radii compared with L-mode.

TCV and AUG: predictive transport simulations

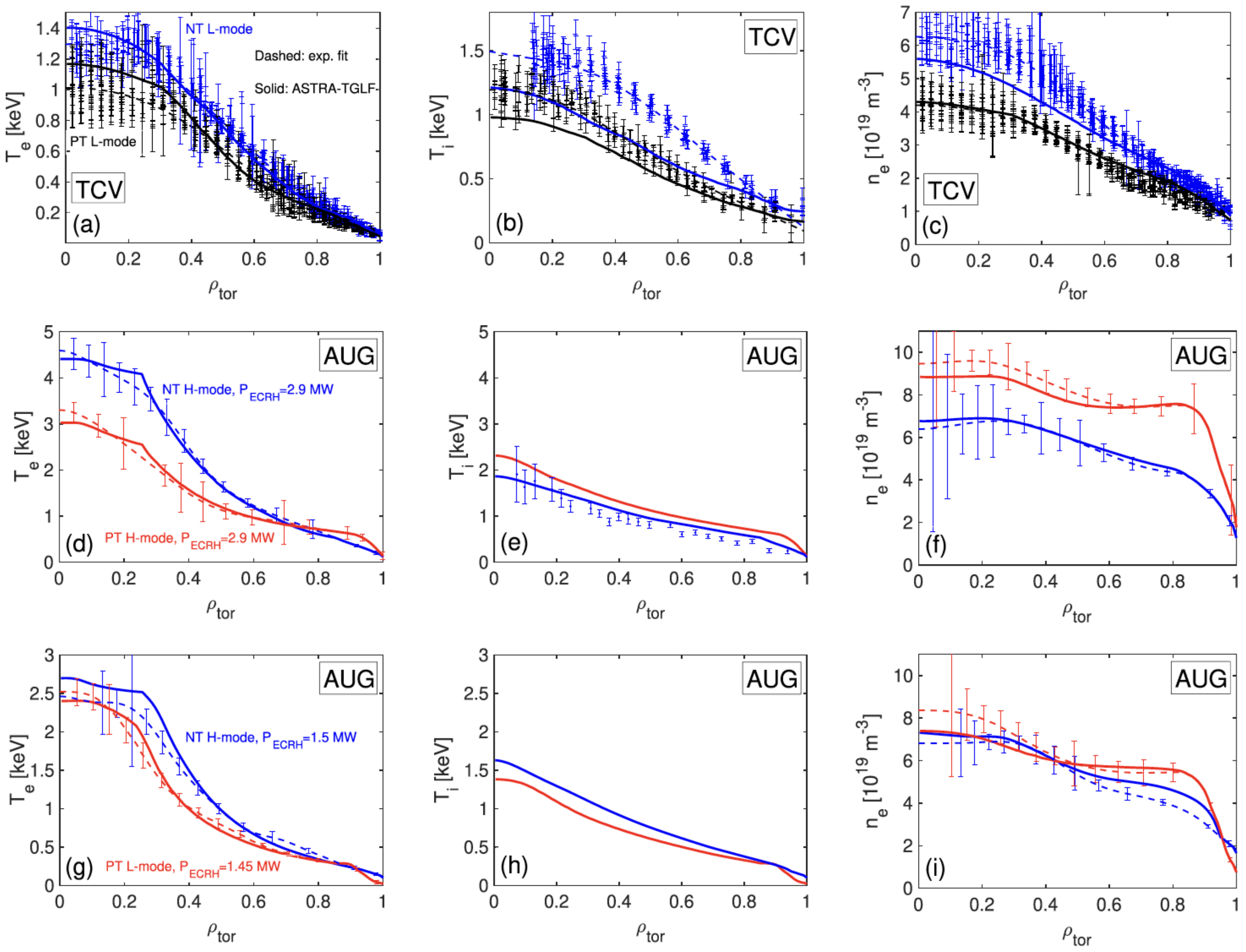


Figure 9. ASTRA-TGLF predictive transport simulations. The predicted $T_e/T_i/n_e$ profiles (solid thick lines) are shown in the first/second/third column, respectively, and compared with the experimental data, when available. The dashed lines indicate the fit of the experimental data. (*a*)–(*c*) TCV NBI-only L-modes; (*d*)–(*f*) AUG ECRH-only higher power H-modes; (*g*)–(*i*) AUG ECRH-only lower power PT/NT H-mode/L-mode couple. (*a*)–(*c*) Reproduced from [19]. (*d*)–(*i*) Reproduced from [20].

TCV

- T_e: reproduced; n_e: slightly underestimated.
- **T_i: strongly underestimated**.
- NT effect: reproduced, but almost coming from the BC only, while in the experiment it comes from ρ_{tor}>0.95.

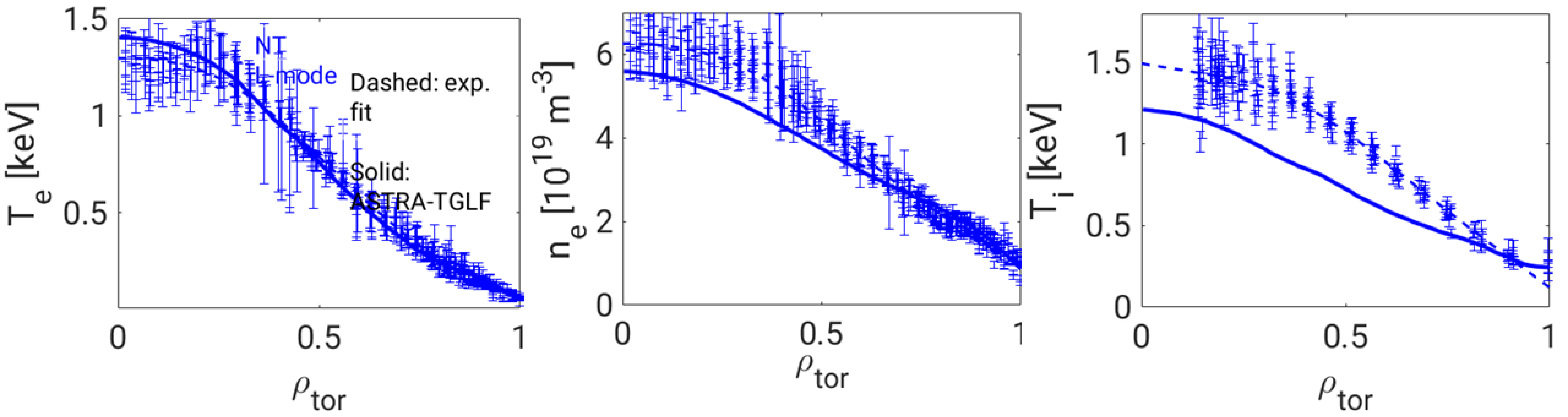
AUG

- Electron n,T: perfectly reproduced;
- T_i: good agreement when measured;
- NT effect: reproduced:

CAVEAT:

This NT effect is not a ‘direct’ one: when only flipping δ, a noticeable beneficial effect is only found when flipping the PT up-down symmetric shape. Reason: TGLF uses Miller

ASTRA -TGLF analysis for TCV NT L-mode: GENE+Tango runs

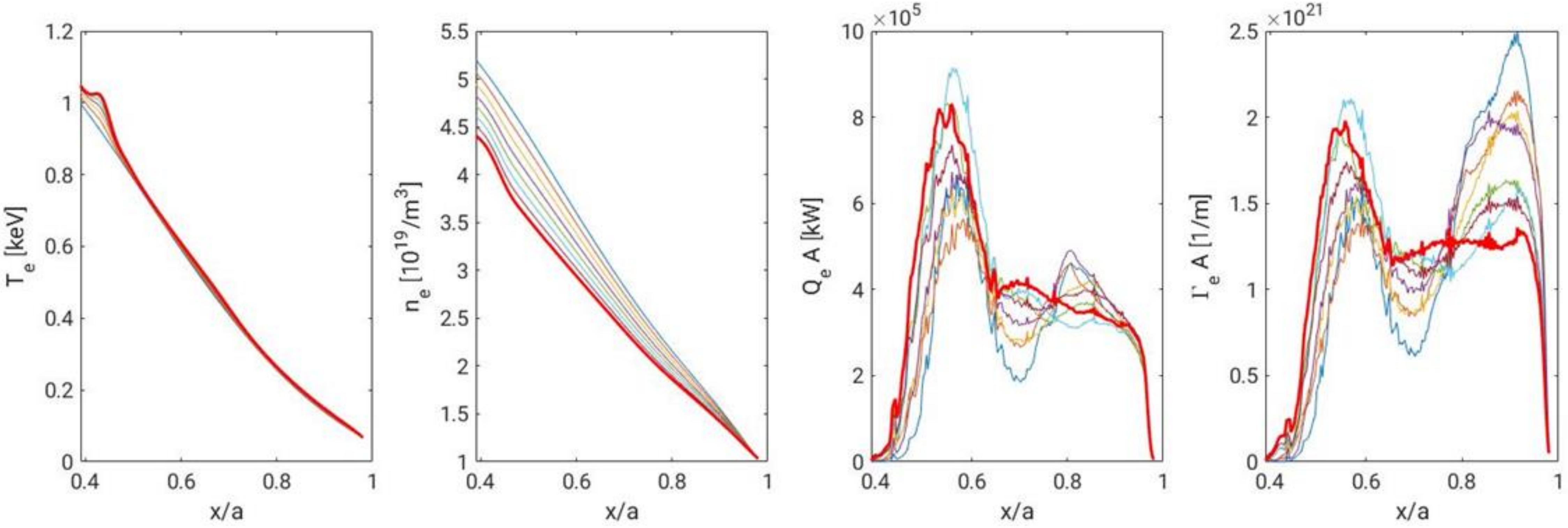


- Electron temperature well reproduced
- Large underestimation of ion temperature and slight underestimation of the density

GOAL: compare this to higher fidelity GENE+Tango global simulation of steady state. Are we missing physics? Global effects?

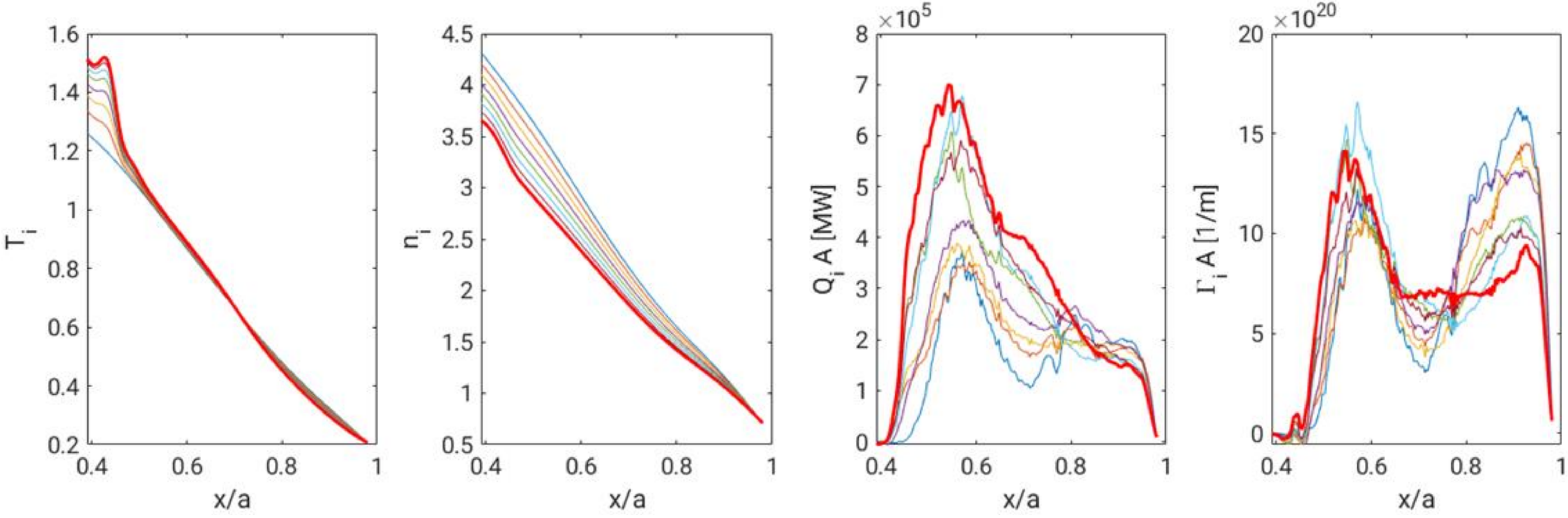
GENE-Tango electrons

Result of last 8 iterations (not steady, profiles are still evolving)



Evolving T_e, T_i and density assuming a fixed Z_{eff} profile
Sources from ASTRA

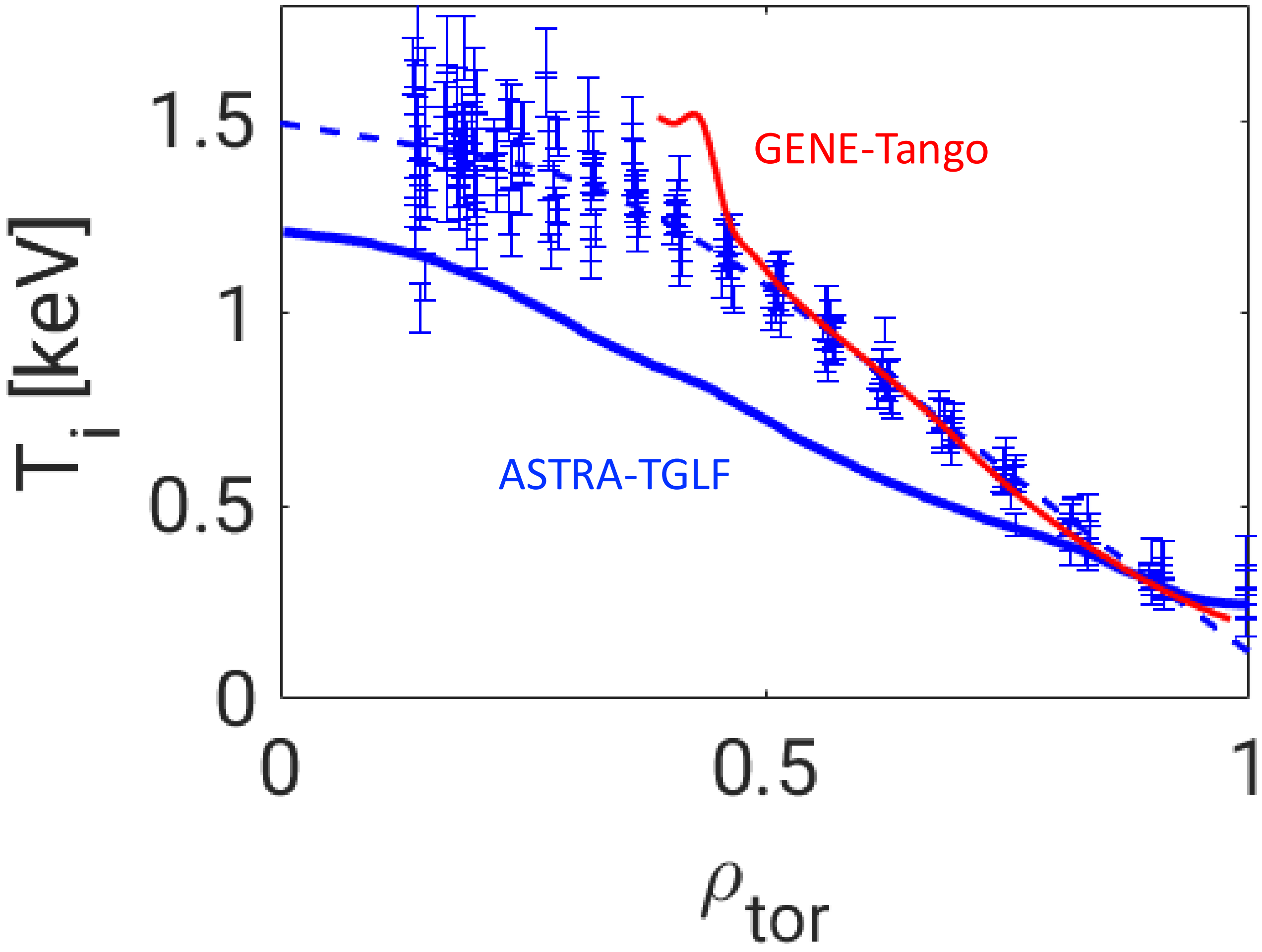
GENE-Tango ions



T_i is for now not collapsing, artifact near the inner boundary due to having shifted the source (not simulating inside inversion radius)

Main adjustment in density to match the particle source

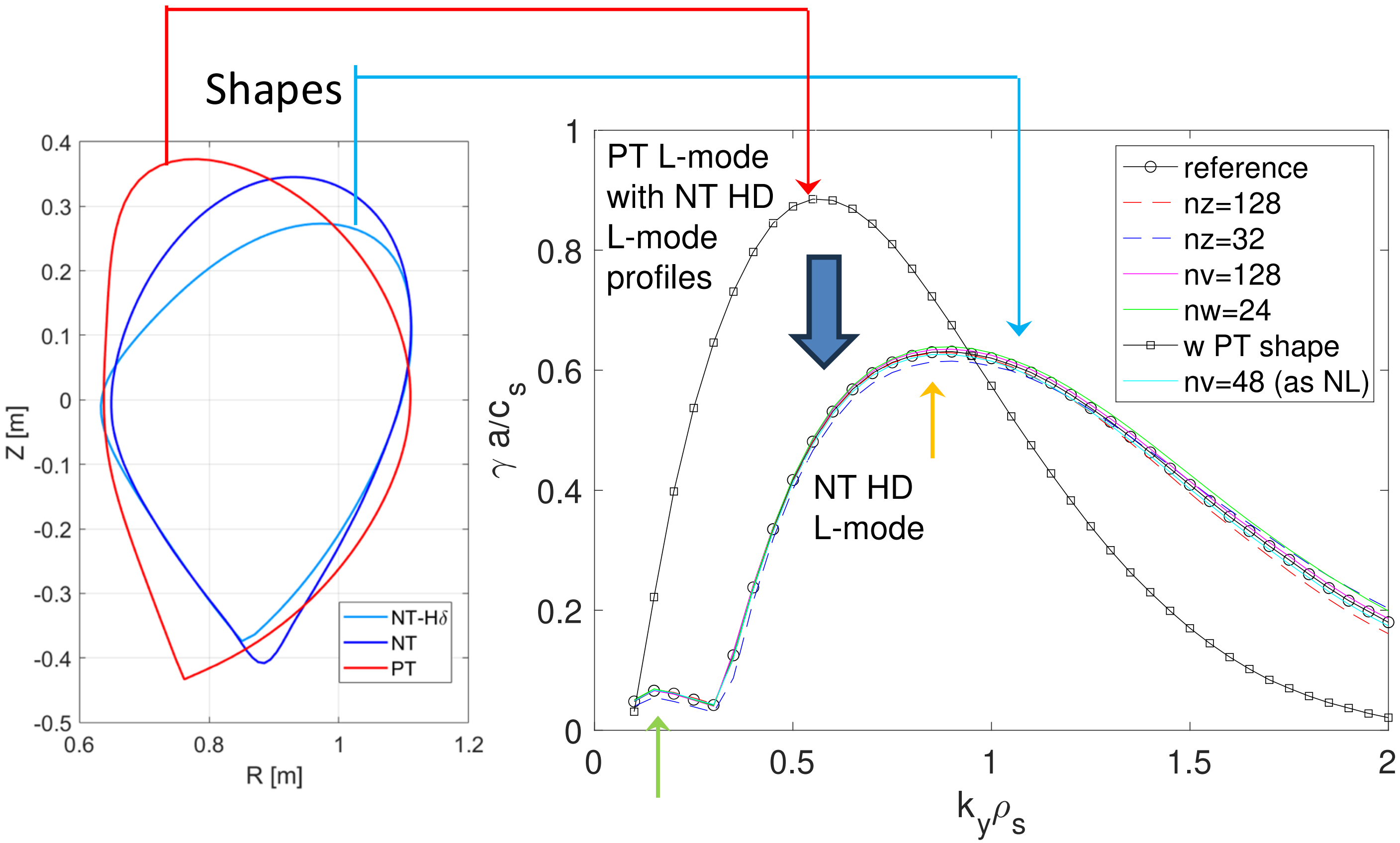
Exp., ASTRA-TGLF and GENE-Tango Ti

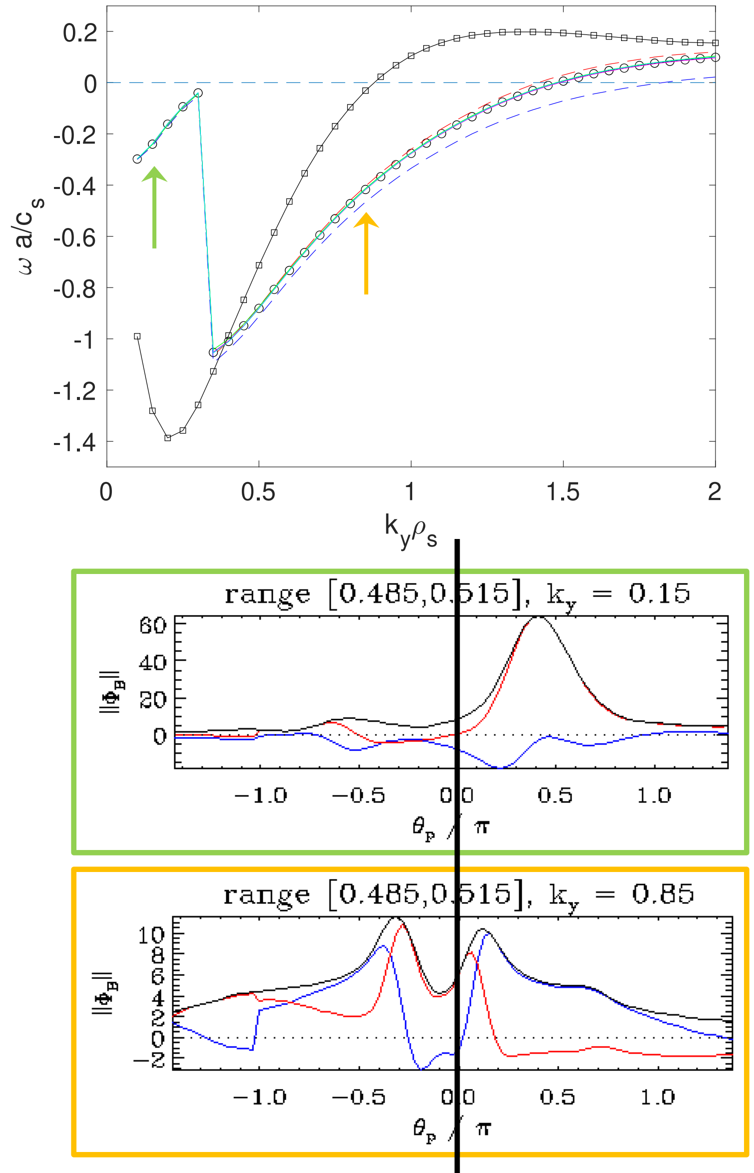


Preliminary GENE runs for the TCV experiments with DTT high delta (HD) NT shape

Linear runs (changing the shape with NT profiles)

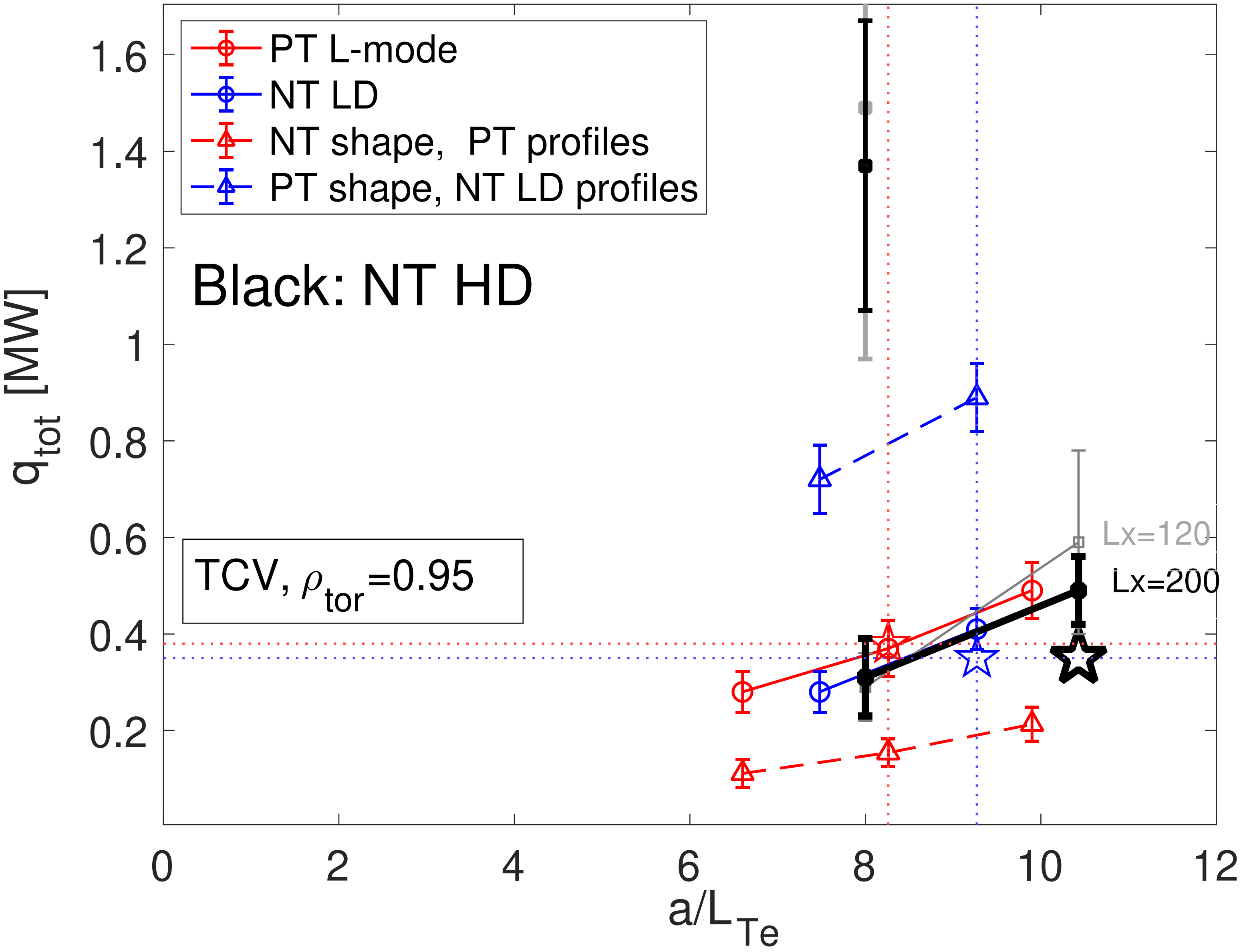
Kinetic profiles from NT HD L-mode





Difference: NT (3.5 MW input power), PT (4 MW).

Nonlinear runs (lack of statistics, very preliminary results)



The direct NT stabilizing effect seems stronger for HD than for LD, as expected.