EUROfusion

Main results from NT experiments on TCV and AUG with iDTT shapes and their modeling

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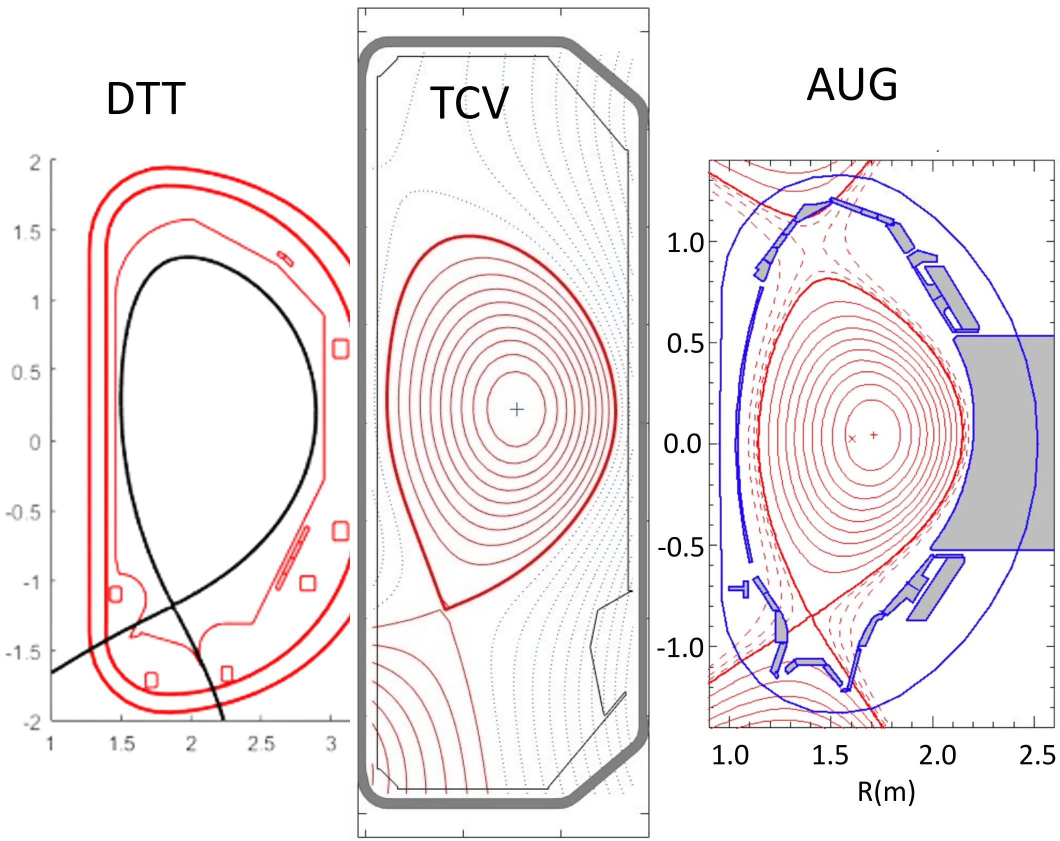
With thanks to the IPP ASTRA group

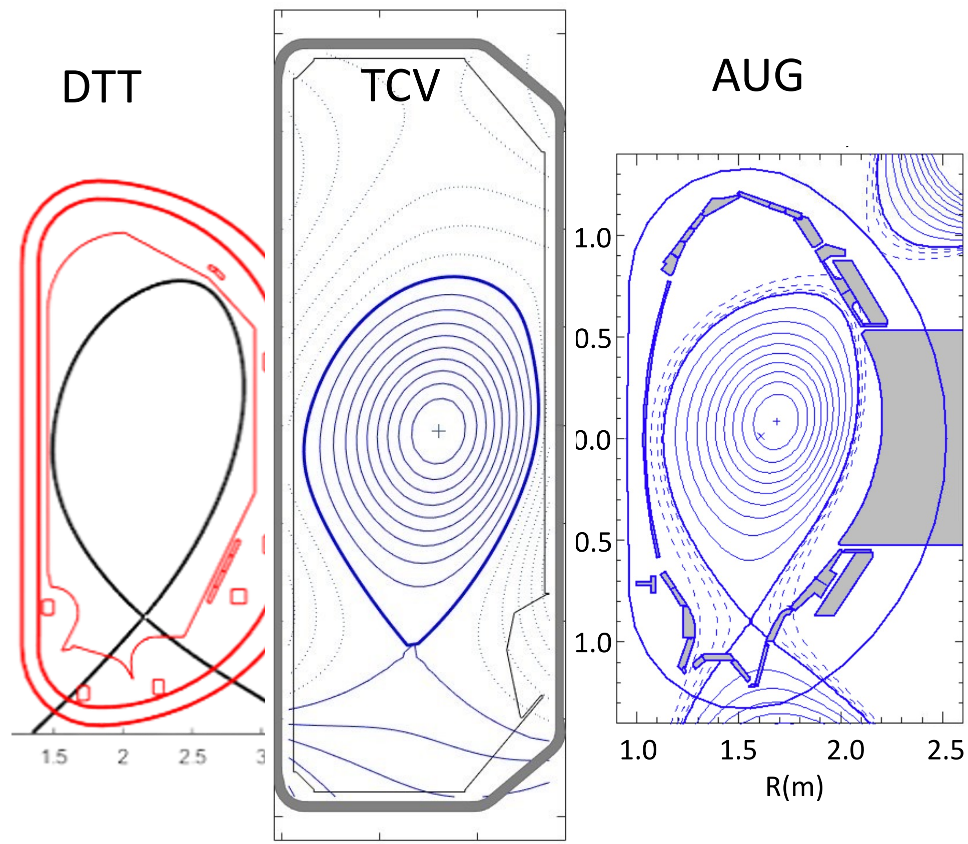
iDTT NT shapes in AUG and TCV

Positive Triangularity (PT)



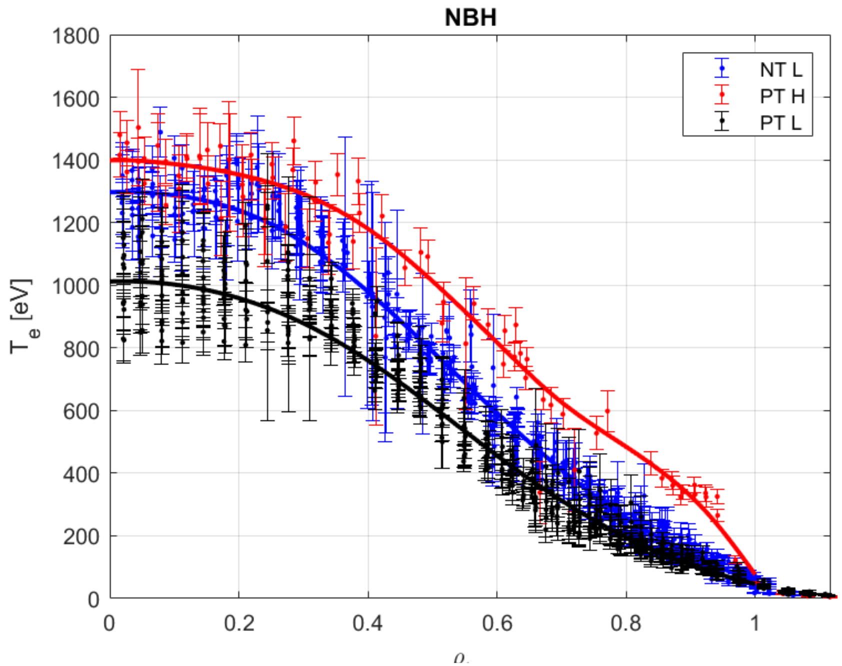
upper δ=0.33
lower δ = 0.35

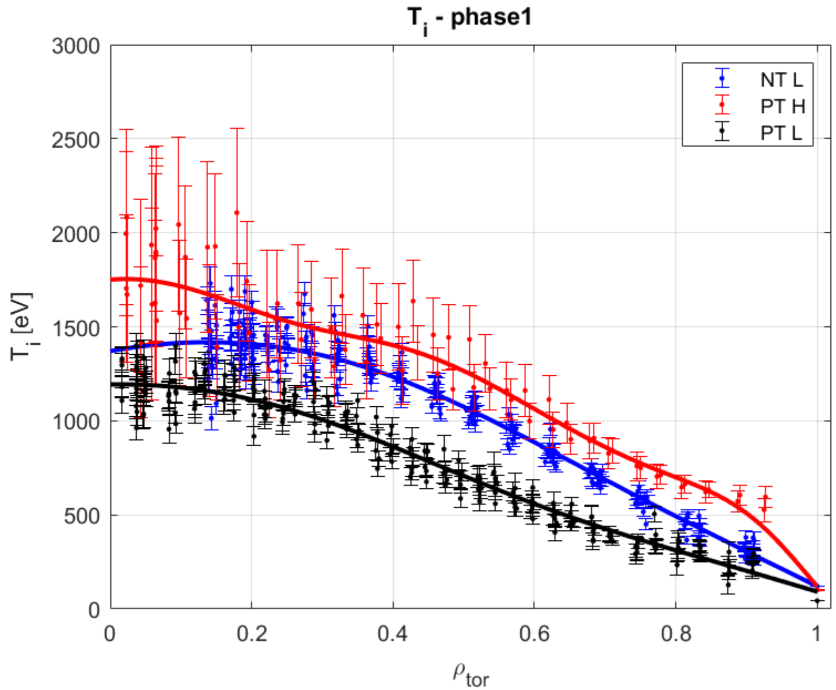
Negative Triangularity (NT)

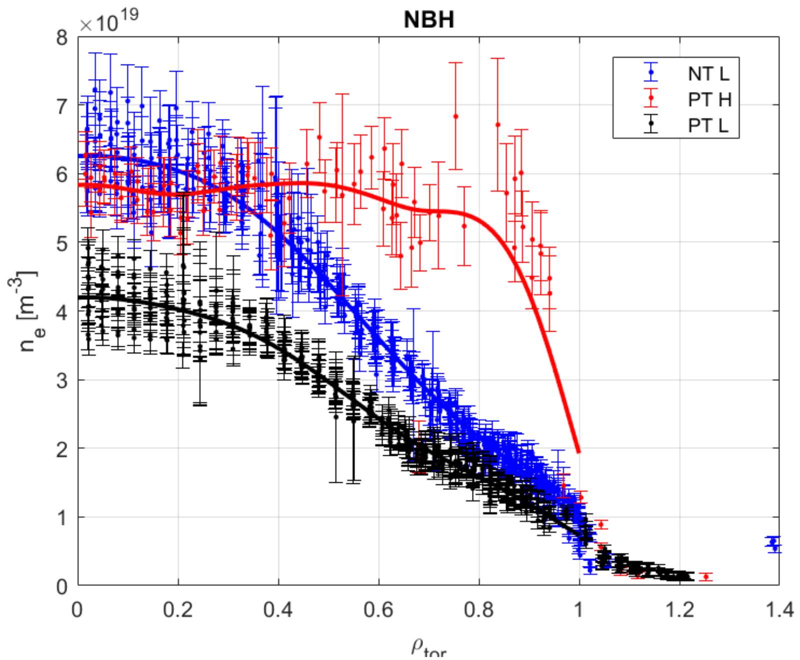


upper δ=-0.3
lower δ = 0.05

TCV results: case with NBI only



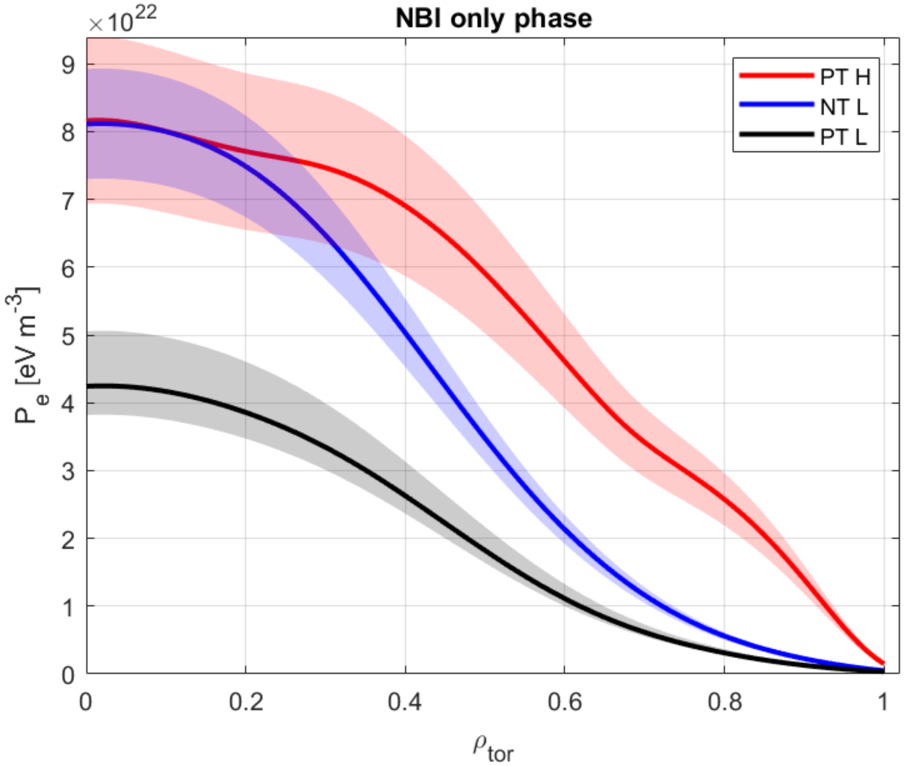


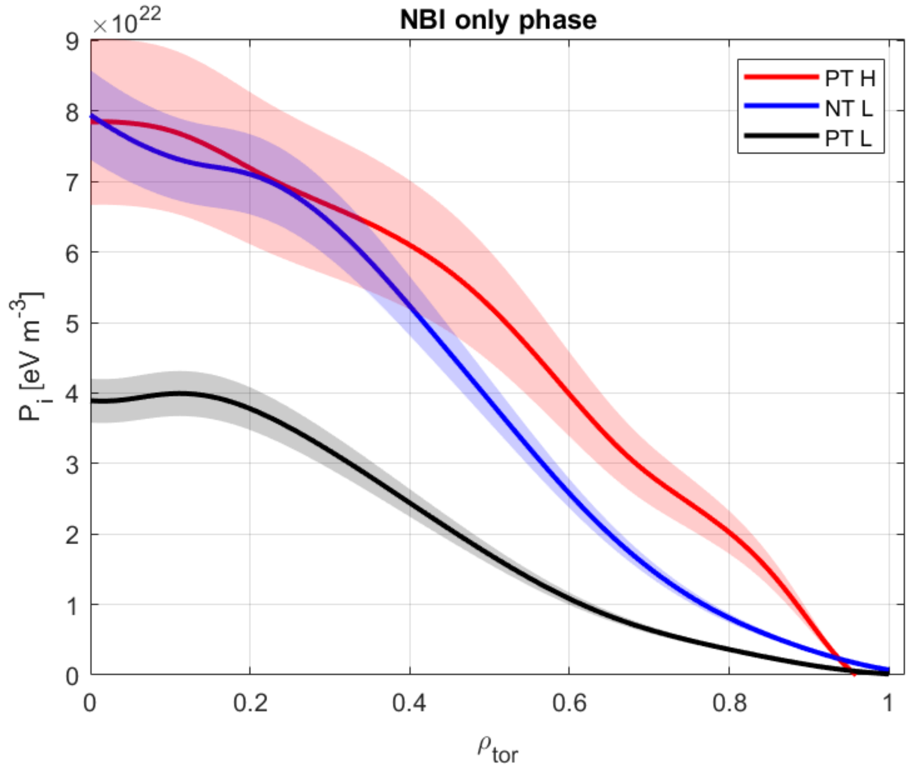


73382: NT Lmode 0.5 MW NBI
73388: PT L-mode 0.5 MW NBI
73391: PT H-mode 1 MW NBI

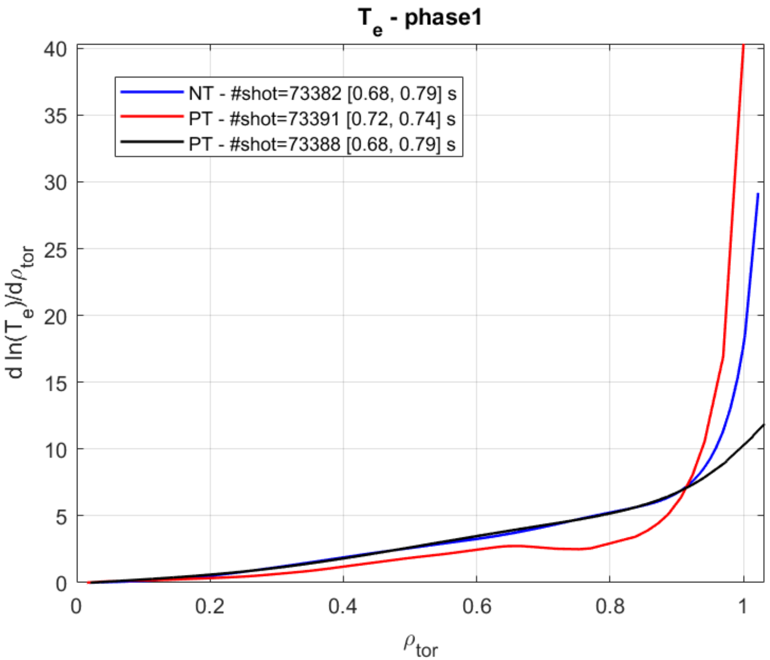
NT L-mode is much better than PT L-mode and almost recovers the central values of PT H-mode which has twice the power

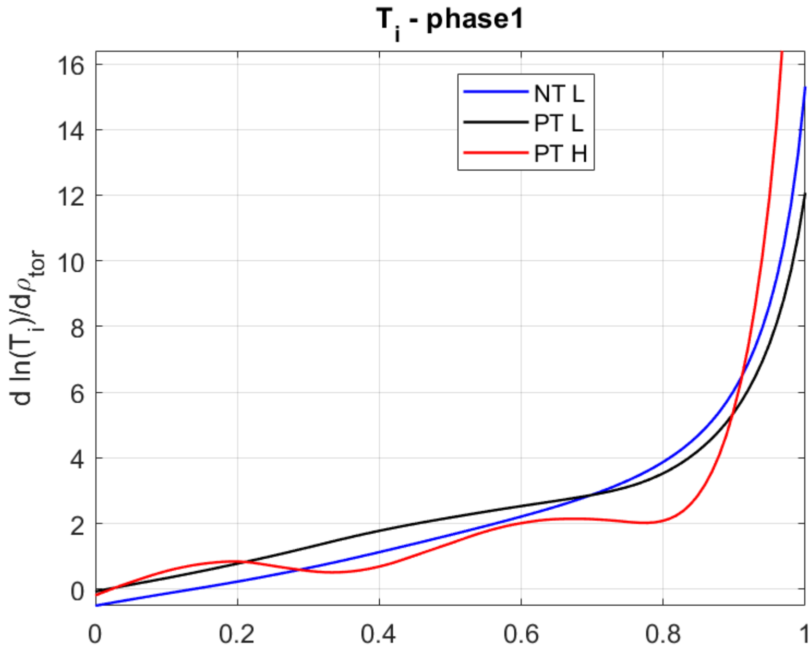
TCV results: case with NBI only

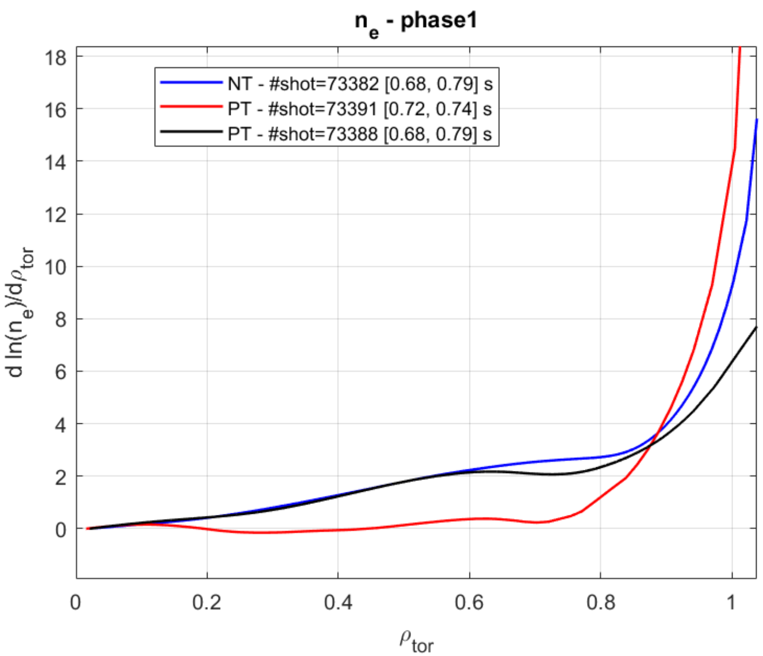




TCV results: case with NBI only



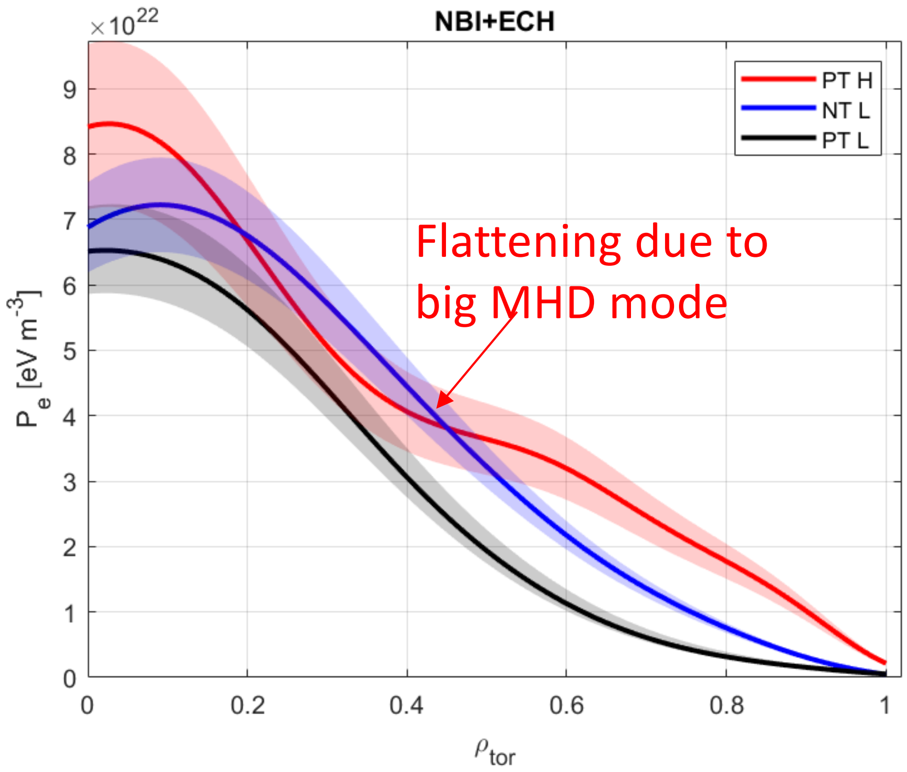


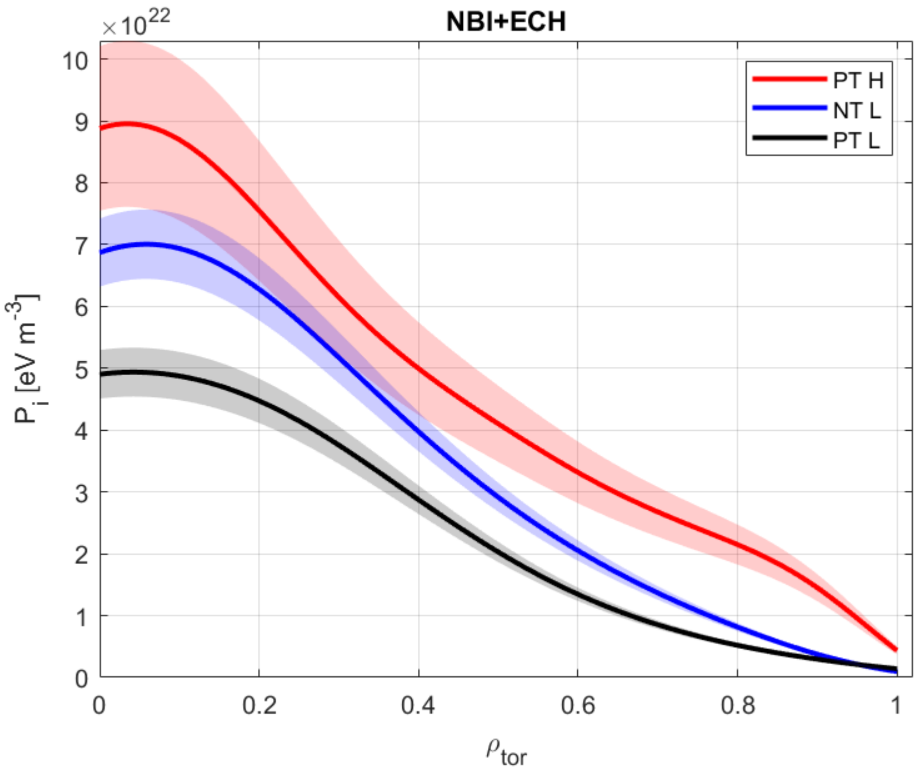


The improvement in R/LT and R/Ln takes place outisde ρ_{tor}=0.9

TCV results: case with NBI +ECH

Very similar results also for the case NBI+ECH

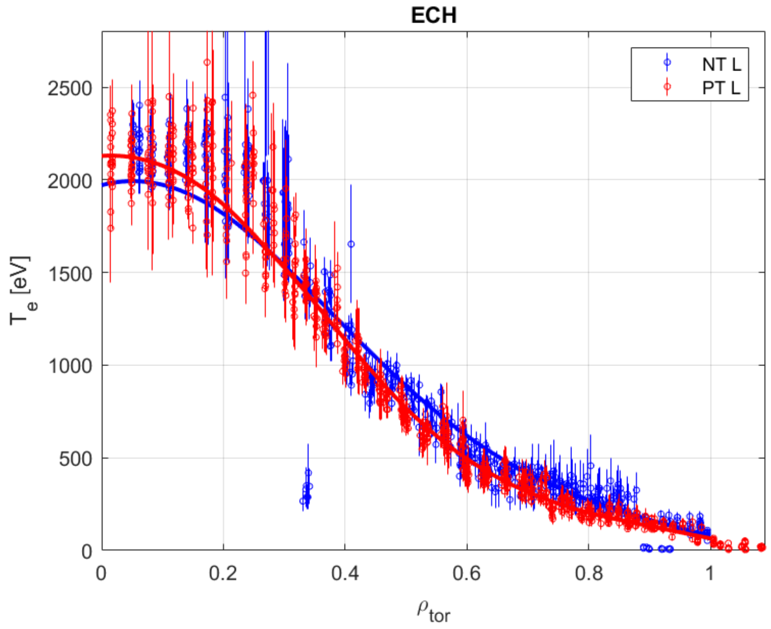


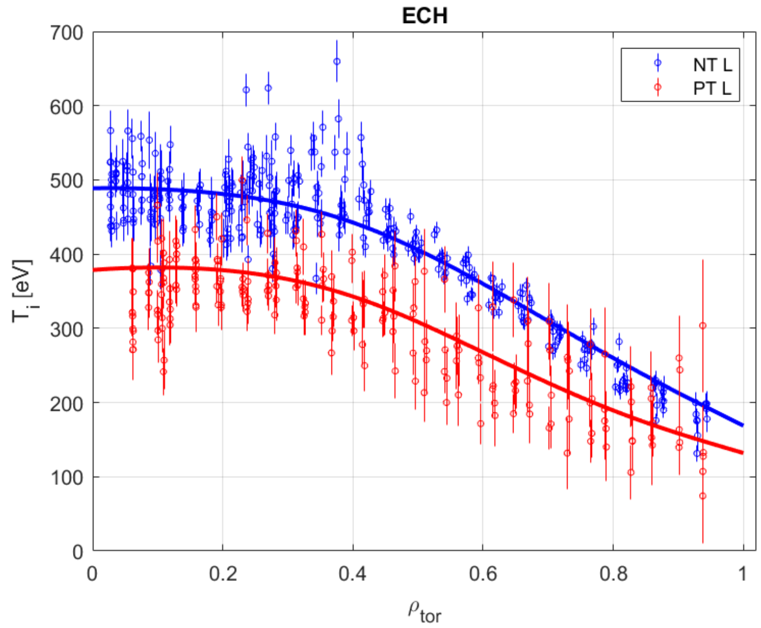


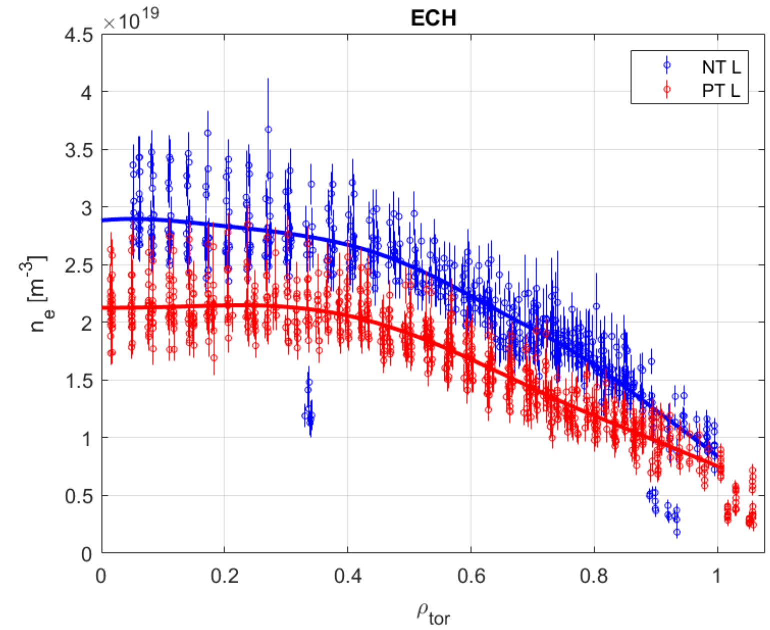
In this case, the improvement in R/LT and R/Ln takes place outisde ρ_{tor}=0.8

76735: NT Lmode 0.42 MW NBI + 0.9 MW ECH
76704: PT L-mode 0.42 MW NBI + 0.9 MW ECH
76702: PT H-mode 1.15 MW NBI + 0.9 MW ECH

TCV results: case with ECH only



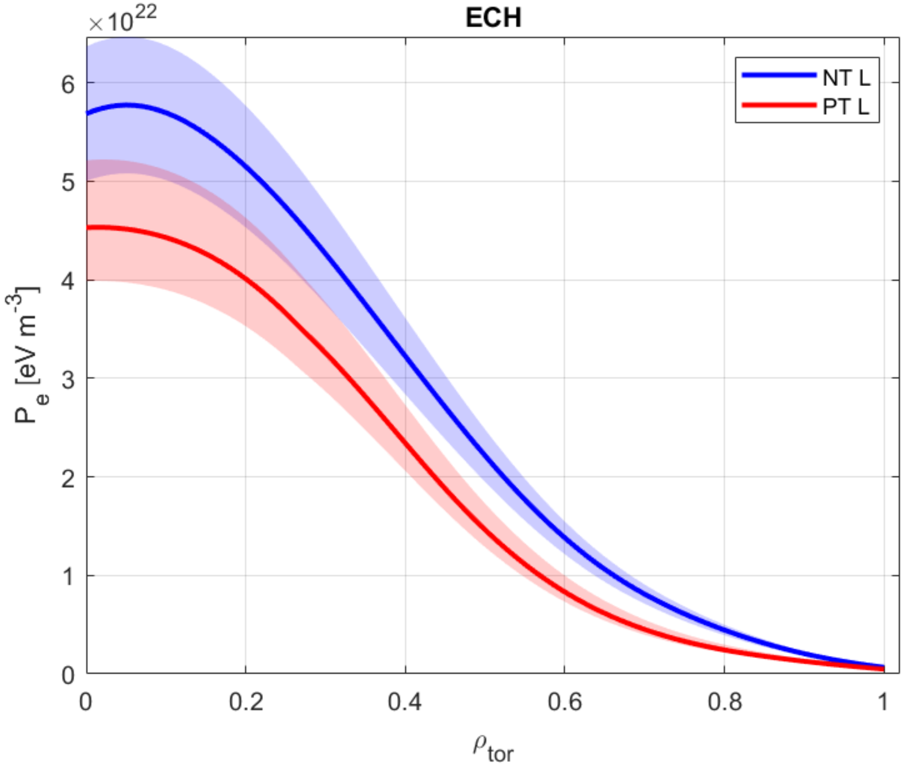


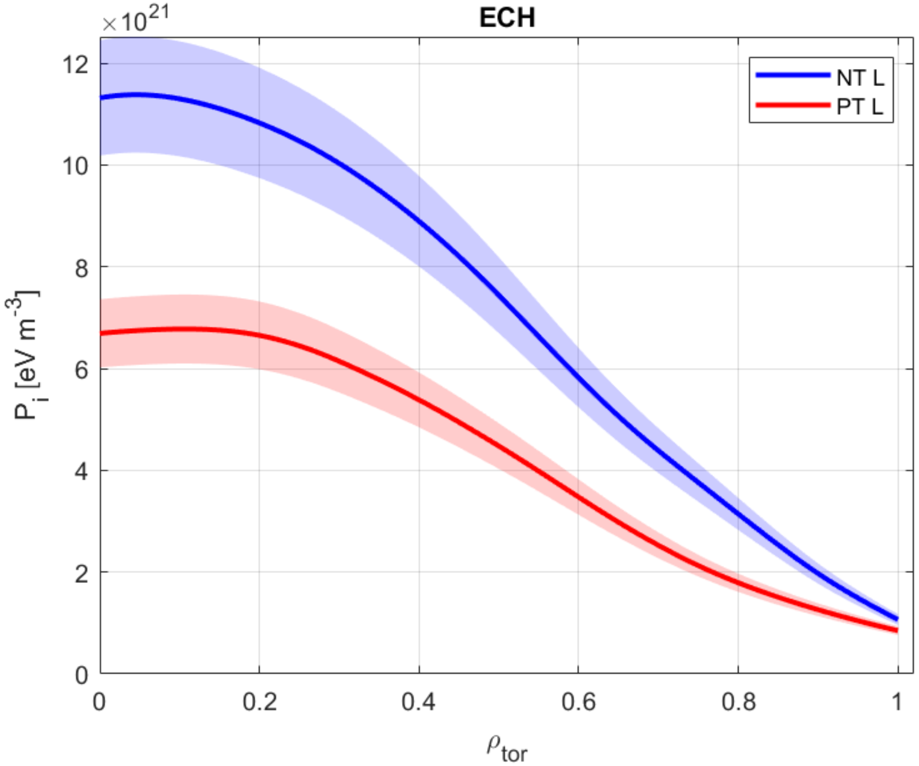


76740: NT Lmode 0.67 MW ECH
76742: PT L-mode 0.67 MW ECH

NT L-mode is better than PT L-mode for Ti and ne, similar for Te

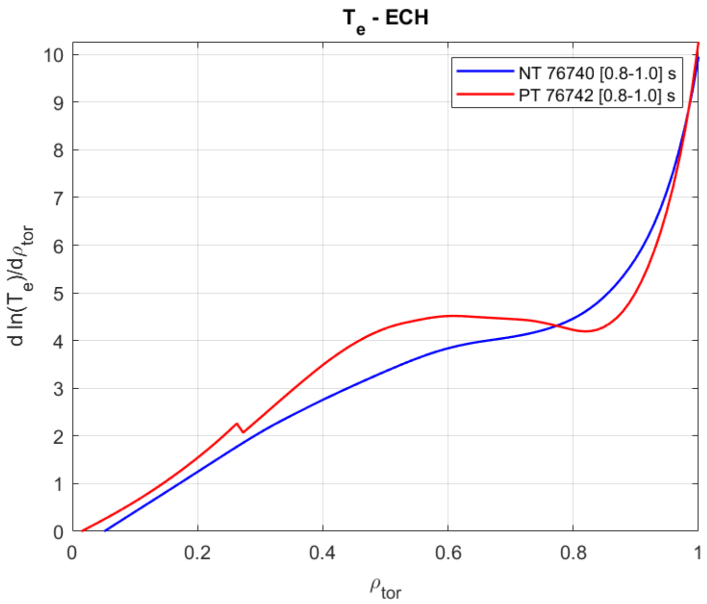
TCV results: case with ECH only

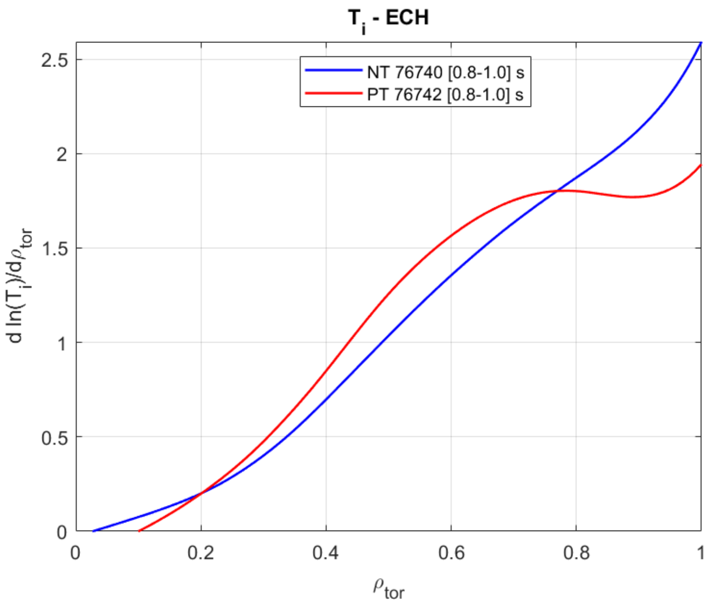


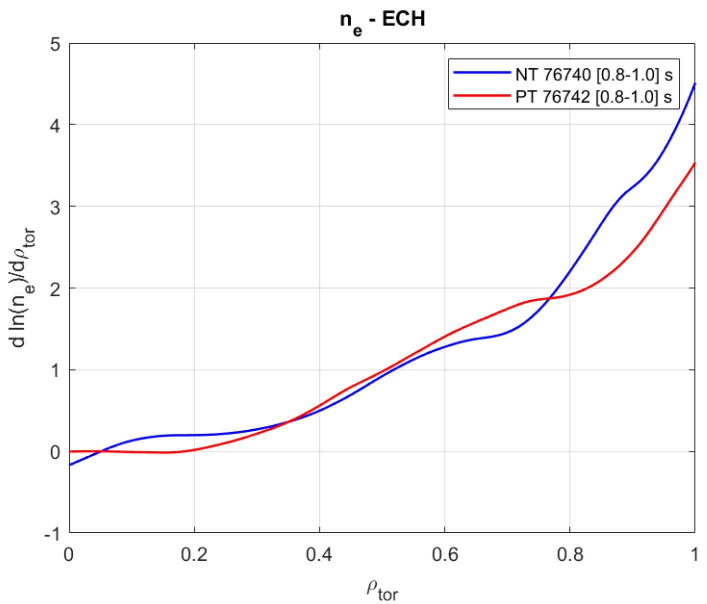


Largest improvement is in Pi

TCV results: case with ECH only







The improvement in R/LT and R/Ln takes place outisde ρ_{tor}=0.8

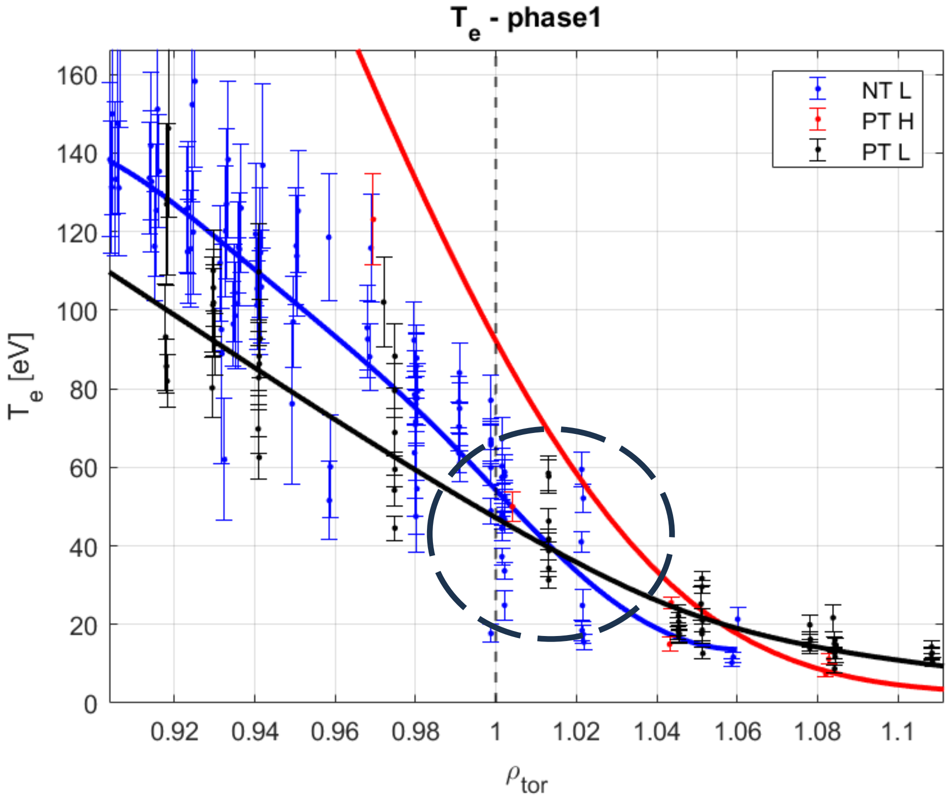
Summary of experimental results

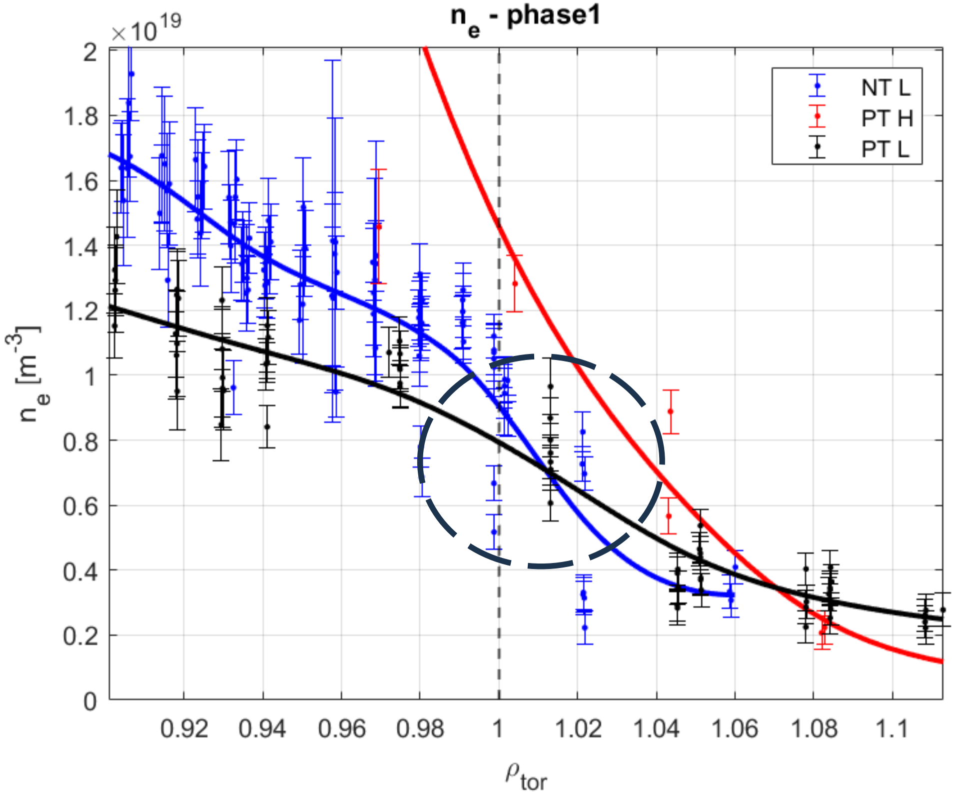
- Regardless of the turbulent regime, NT L-mode always recover the central values of thermal pressure of the PT H-mode counterpart and outperforms PT L-mode.

- The effect of NT seems to be confined at the very edge of the plasma. Depending on the case the range goes from rho=[0.8,1.0] or rho=[0.9,1.0]

Role of boundary

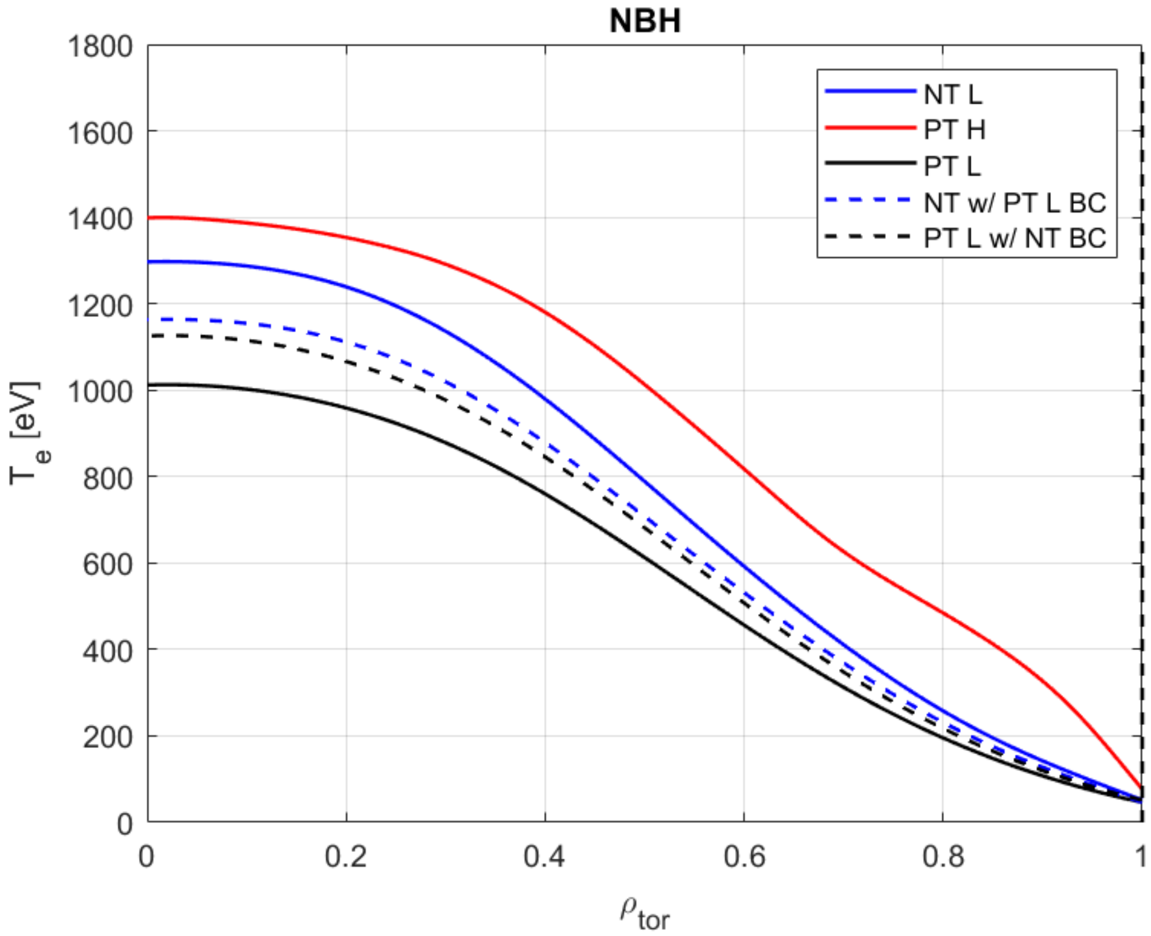
Is NT improvement coming from an increase in the gradients inside the separatrix or from the higher values of density and temperature at the edge, i.e. due to the SOL?





Higher gradients in NT L-mode wrt PT L-mode in the region around the separatrix, on both sides

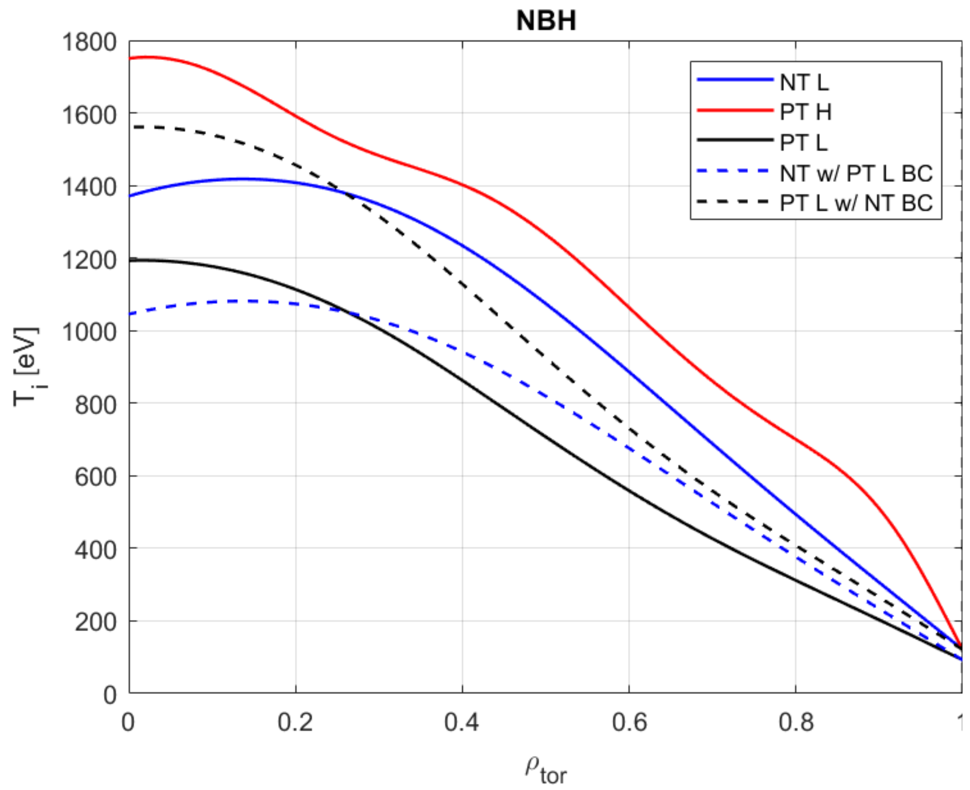
Role of boundary

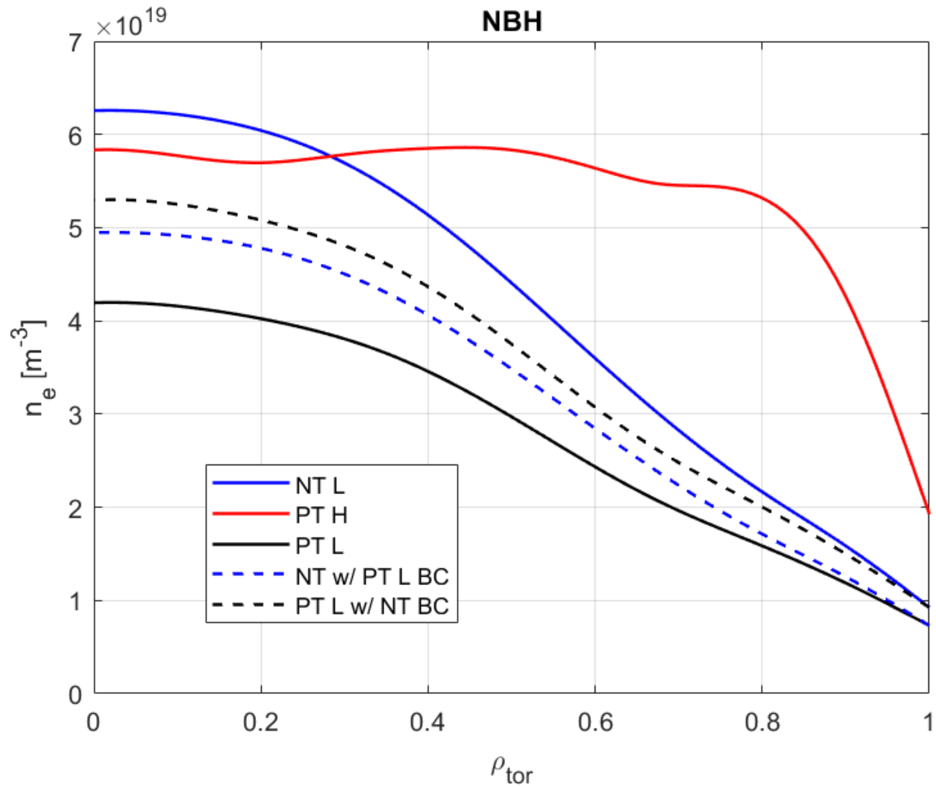


To disentangle the effect of the gradients in the core and the higher values at the boundary we artificially swapped the values at rho=1.0 and reconstructed the kinetic profiles keeping fixed the log gradients.

At least 50% of the improvement in NT Te is a consequence of the higher NT boundary values.
This is an underestimate because the log gradient in fact is higher in NT than in PT.

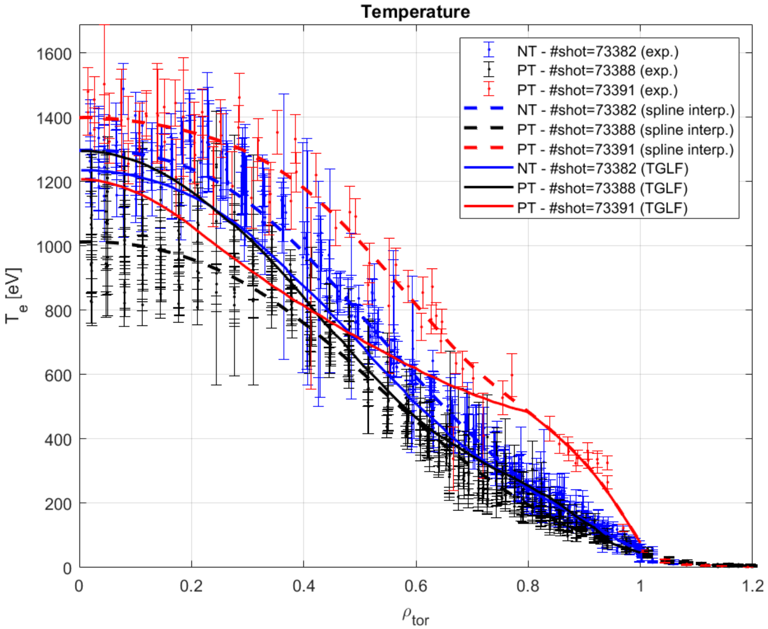
Role of boundary

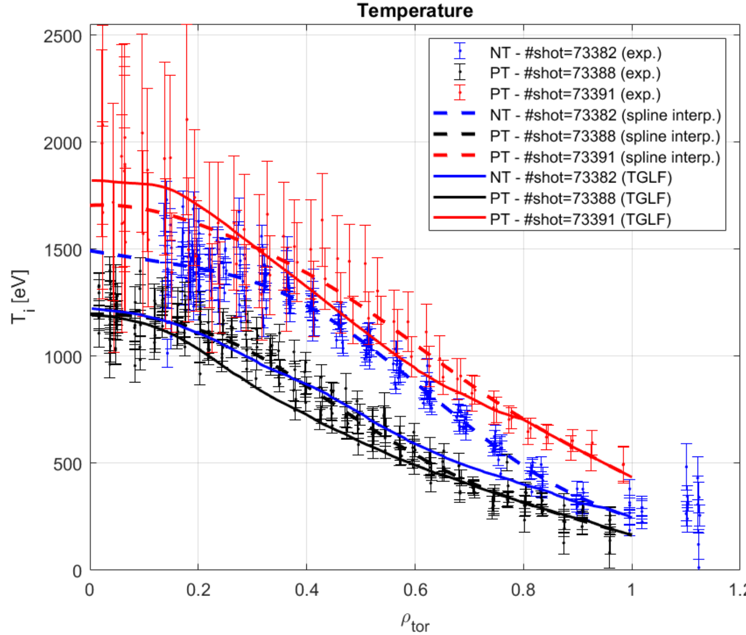


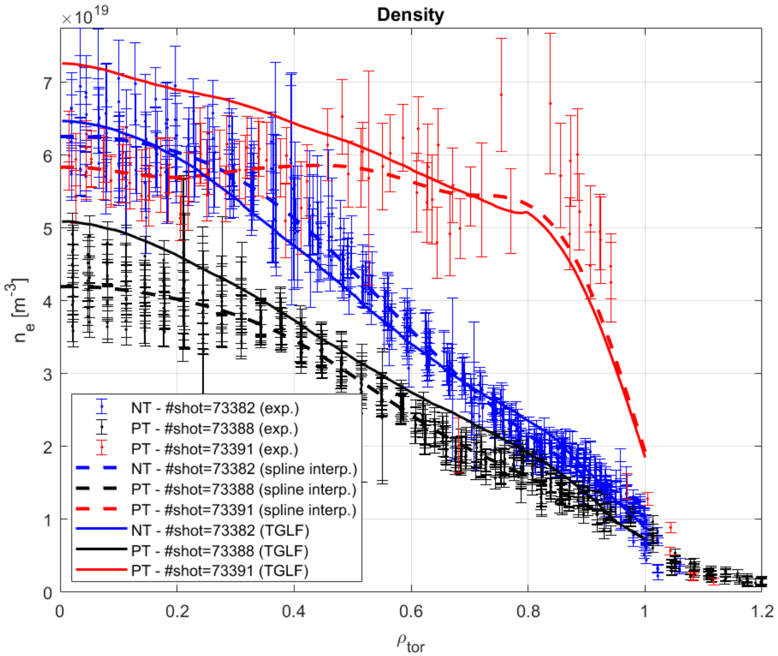


Even higher effects of the boundary on Ti and ne

TGLF simulations for NBI only case







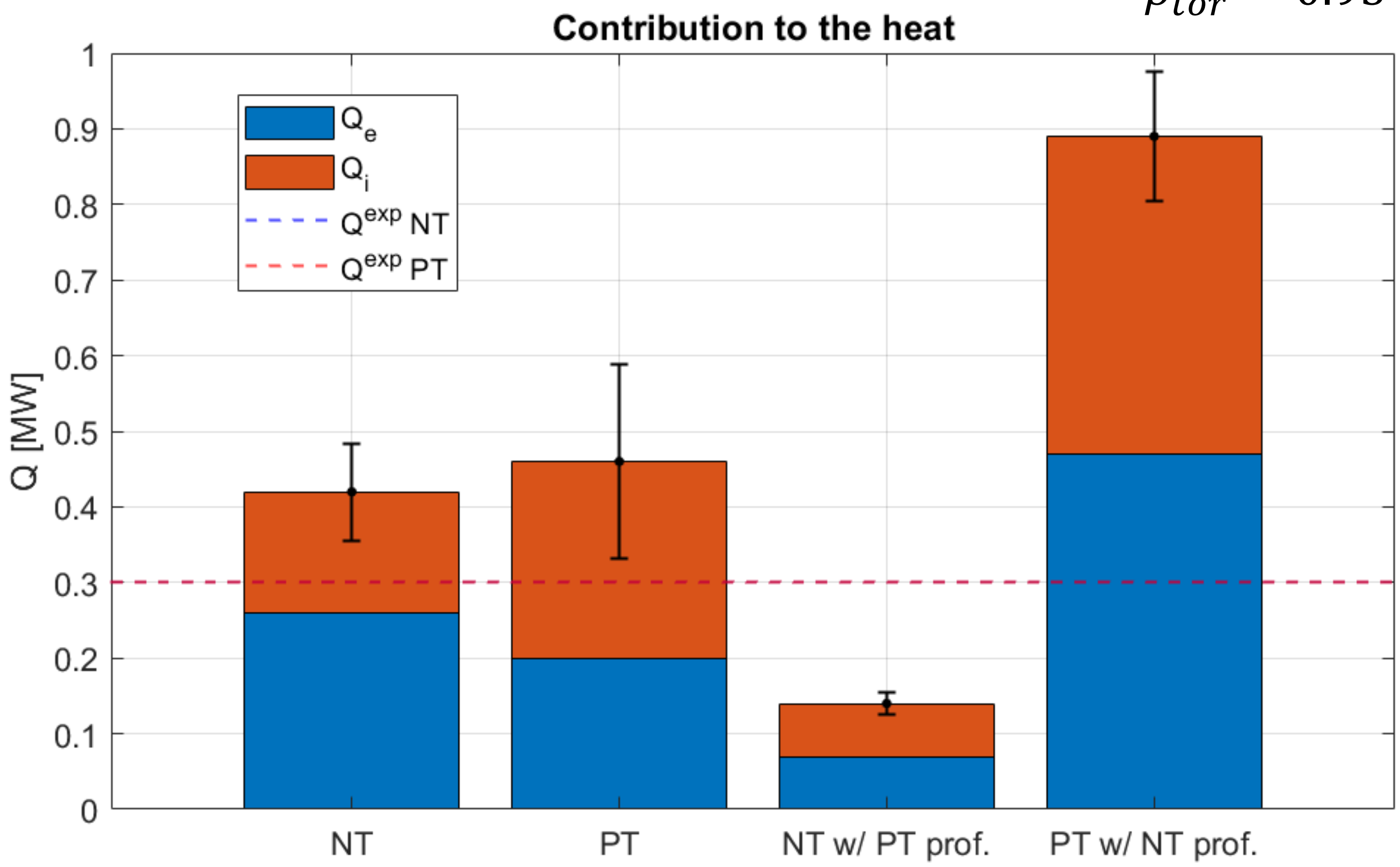
Boundary conditions are set at ρ_{tor}=0.95 for L-mode and ρ_{tor} =0.8 for H-mode

TGLF does not predict any improvement in temperatures for NT but only for ne

However swapping the shapes there is no dfference in the TGLF simulations, so any effect is not due to the shape in the simulated region

GK simulations - NBI only

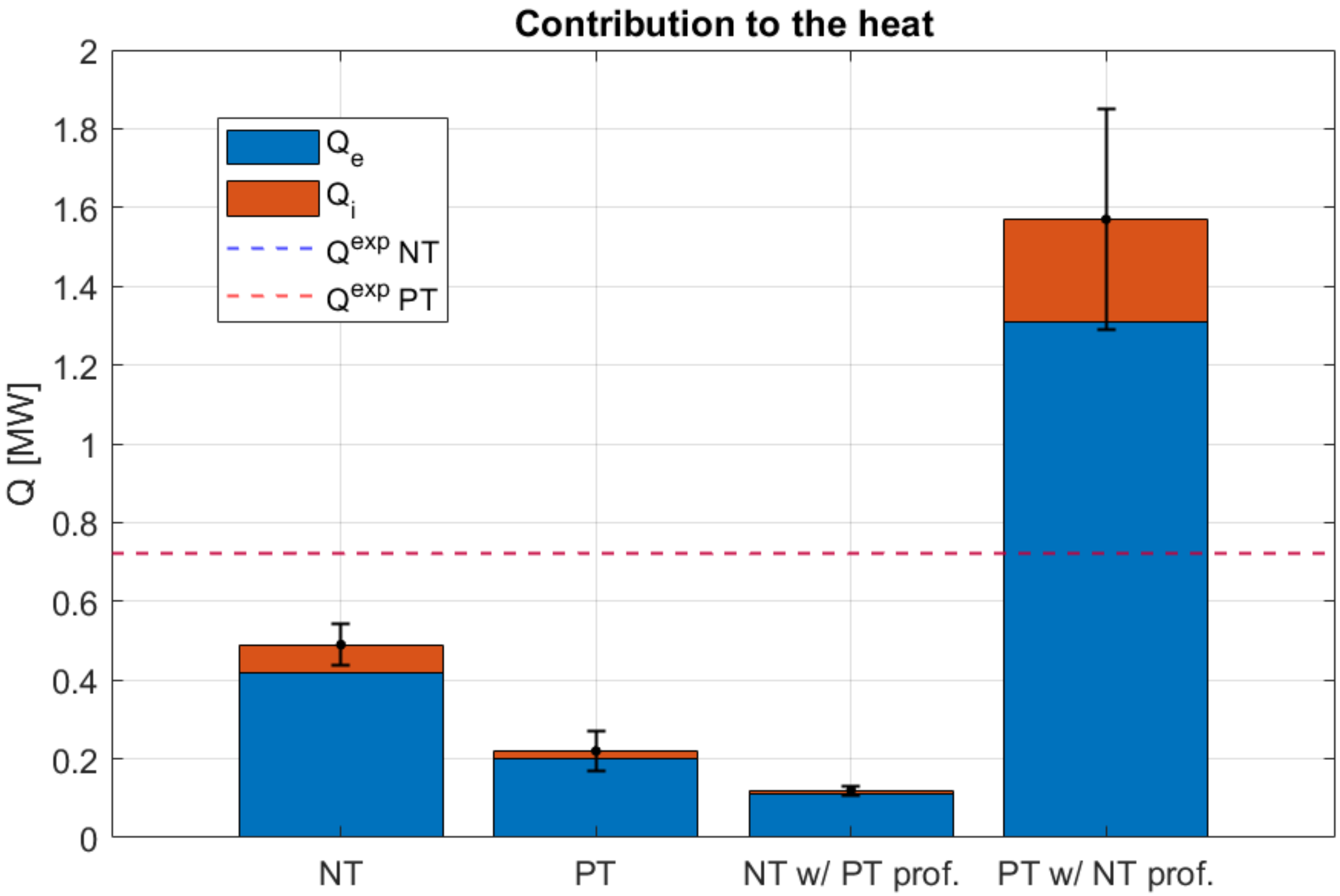
$\rho_{tor} = 0.95$



Changing shape produces significant changes on the turbulent fluxes – NT stabilizing

The flux reduction comes from a mixture of decrease of stiffness and increase in critical gradient

GK simulations - ECH only



Conclusions for TCV

- The experimental campaign showed that on TCV NT shapes similar to iDTT provide beneficial effects. Regardless of the heating mix, NT was always able to recover the central values of plasma pressure of the PT H-mode counterpart with half of the injected power.
- The beneficial effect of NT is equally shared between increase gradients in the outer region of the core and large values of temperature and density at the LCFS. The latter is a result of increased gradients in the SOL.
- TGLF did not reproduce well the experimental profiles (but uncertainties in NBI deposition on TCV) and misses completely the effect of the geometry in the region inside ρ_{tor} =0.95.
- GENE is able to catch the effect of the geometry on the turbulence. When the profiles are kept fixed and the geometry is changed from PT to NT, it always predicts a reduction by a factor of 2.5 of the heat fluxes.

NT vs PT discharges at ASDEX upgrade in view of DTT design

AUG #PULSE	δ	B_T	Ip [MA]	I	II	III	IV	V
#40473	NT	FW	0.8	2.5-2.8 s **1.6* ECH**	2.8-3 s **2.3 ECH**	3-3.5 s **2.9 ECH**	3.5-4 s **2.3 ECH**	4-4.5s **1.6 ECH**
#36157	PT	FW	0.8	2.8-3.1 s **1.6 ECH**	3.7-4 s **2.2 ECH**	4-4.3 s **2.4 ECH**	4.6-4.9 s **2.9 ECH**	
#40470	NT	FW	0.8	3.1-3.4 s **4 NBI + 3 ECH**	3.74-3.94 s **4 NBI + 1.6 ECH**	4.22-4.4 s **6.1 NBI + 1.6 ECH**		
#41149	PT	FW	0.8	2.5-3.5 s **1 NBI + 1.6 ECH**	3.7-4.2 s **4 NBI**			
#40866	NT	RV	-0.6	2.5-2.8 s **1.5 ECH**				
#40647	PT	FW	0.6	3-4 s **~1.5 ECH**				

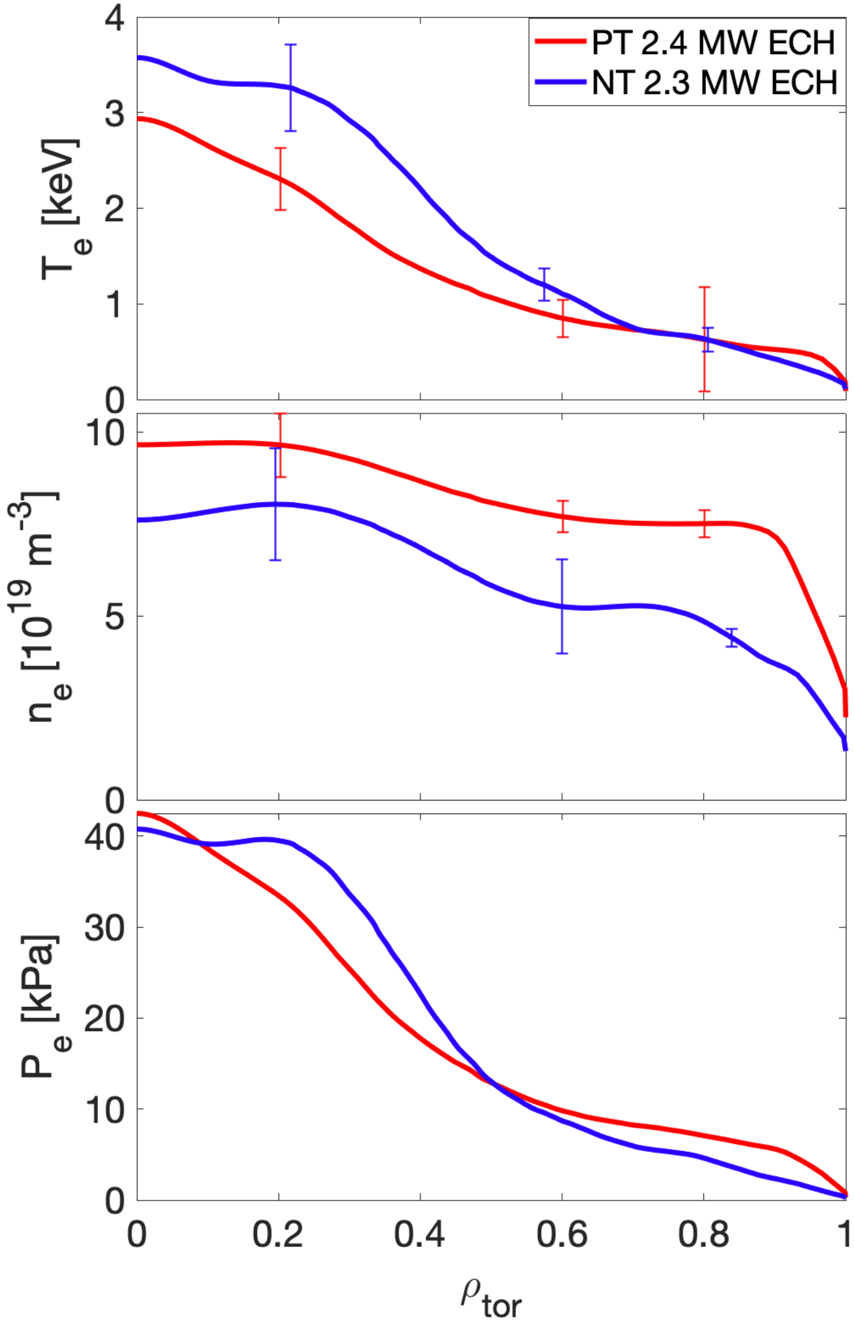
NT vs PT discharges at ASDEX upgrade in view of DTT design

AUG #PULSE	δ	B_T	Ip [MA]	I	II	III	IV	V
#40473	NT	FW	0.8	2.5-2.8 s **1.6* ECH**	2.8-3 s **2.3 ECH** **ELMs**	3-3.5 s **2.9 ECH**	3.5-4 s **2.3 ECH**	4-4.5s **1.6 ECH**
#36157	PT	FW	0.8	2.8-3.1 s **1.6 ECH**	3.7-4 s **2.2 ECH** **No ELMs**	4-4.3 s **2.4 ECH**	4.6-4.9 s **2.9 ECH**	
#40470	NT	FW	0.8	3.1-3.4 s **4 NBI + 3 ECH**	3.74-3.94 s **4 NBI + 1.6 ECH** **ELMs**	4.22-4.4 s **6.1 NBI + 1.6 ECH**		
#41149	PT	FW	0.8	2.5-3.5 s **1 NBI + 1.6 ECH**	3.7-4.2 s **4 NBI** **ELMs**			
#40866	NT	RV	-0.6	2.5-2.8 s **1.5 ECH** **No ELMs**				
#40647	PT	FW	0.6	3-4 s **~1.5 ECH** **no ELMs**				

AUG NT experimental overview

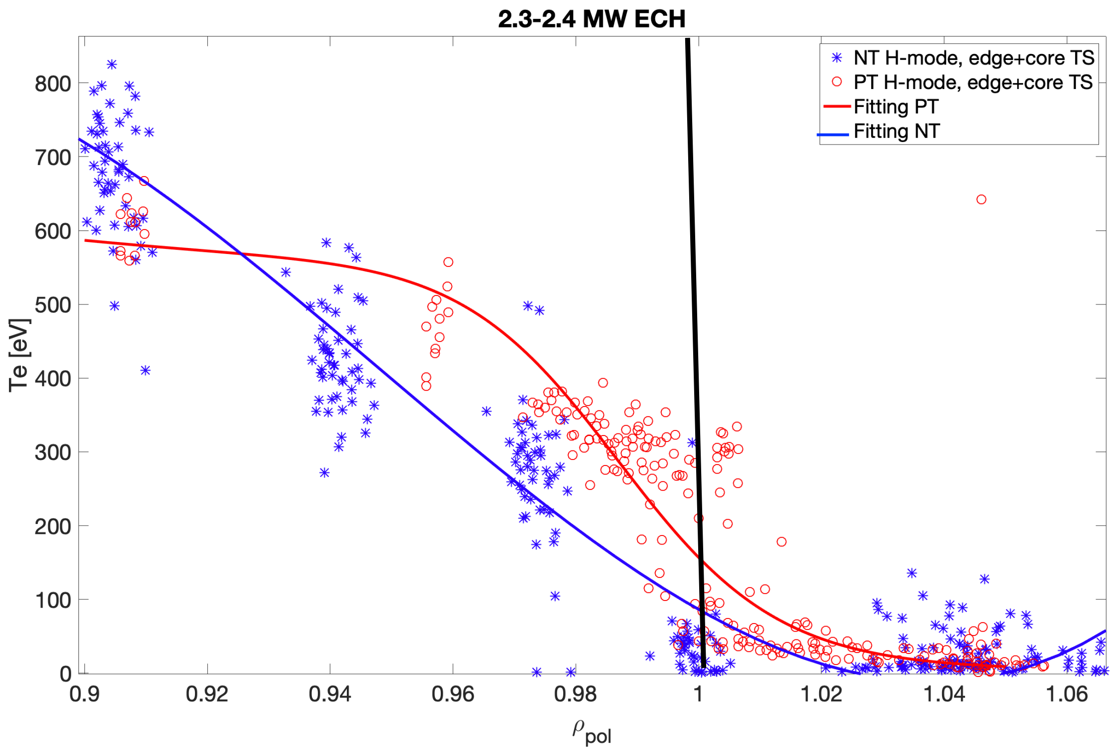
- The shots are obtained varying:
  - $-0.2 \leq \boldsymbol{\delta_{avg}} \leq 0.4$. (negative values limited by vessel geometry!)
  - $1.55 \leq \boldsymbol{\kappa} \leq 1.70$
  - $0.6 \leq$ **Ip** ≤ 0.8 MA (in 2022 campaign Ip=0.8 MA)
- The toroidal magnetic field $B_T = 2.5$ T is kept constant.
- Low-Z species (B, C, N, O), W coming from the metallic wall, and Fe/Ni from uncovered pipes contribute to an effective charge of $Z_{eff} = 1.3 \div 2$.
- The EC power deposition, calculated using the paraxial beam tracing code TORBEAM, is radially peaked and localized inside $\rho_{tor}=0.4$, varying between 0.1 and 0.4 depending on the equilibrium.
- Gas puff is exploited to sustain densities (ranging from 6×10^{19} to 1×10^{20} m^{-3})

Negative vs positive triangularity:
2.3-2.4 MW ECH (40473 vs 36157)

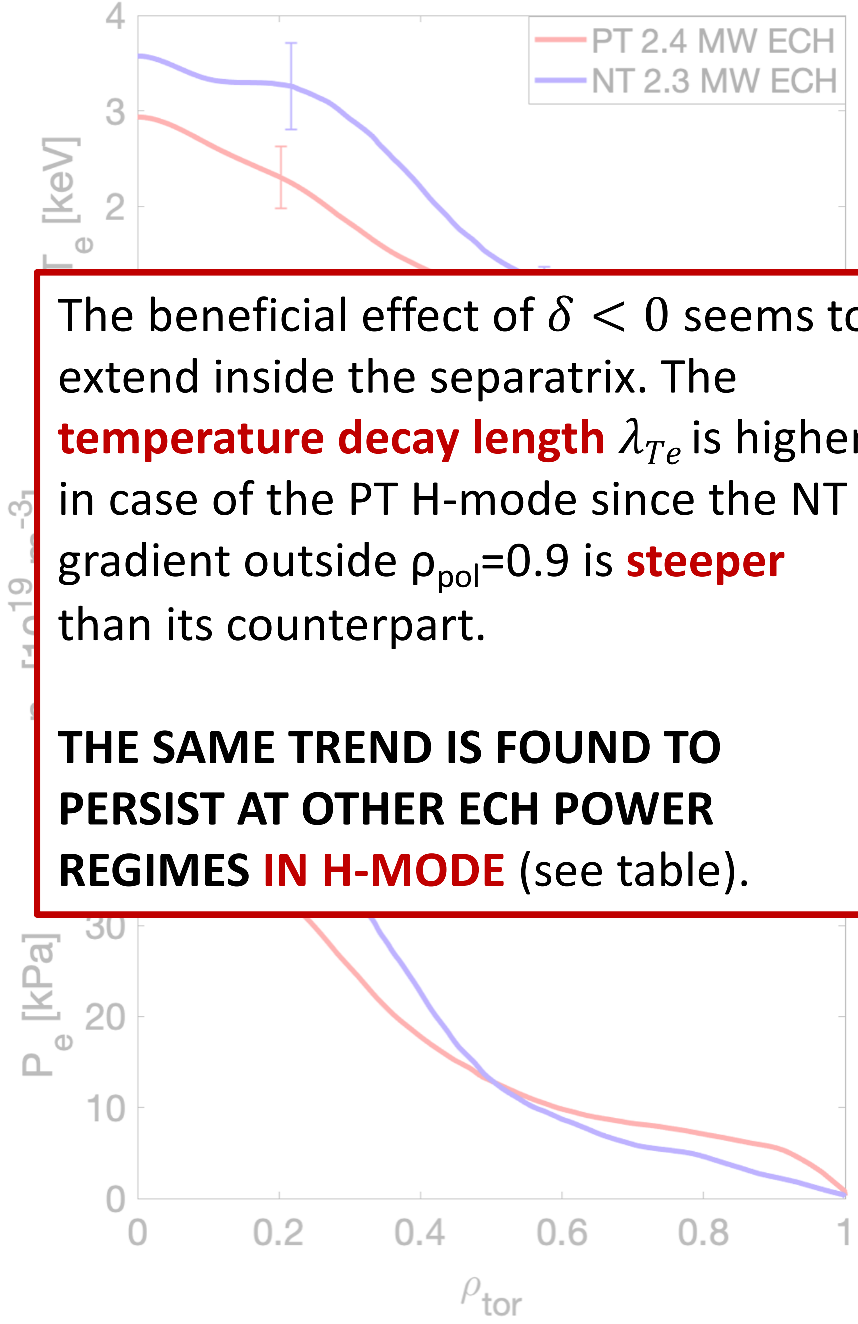


The NT **electron heat transport** in the region $0.7 < \rho_{tor} < 0.95$ is such as to drive temperature gradients **steep enough** to overcome the Te and match the electron thermal energy of the PT pulse around mid-radius. (from Integrated Data Analysis, IDA).

The same is confirmed looking at edge+core Thomson scatt. Te profile outside ρ_{pol}=0.9



Negative vs positive triangularity:
2.3-2.4 MW ECH (40473 vs 36157)

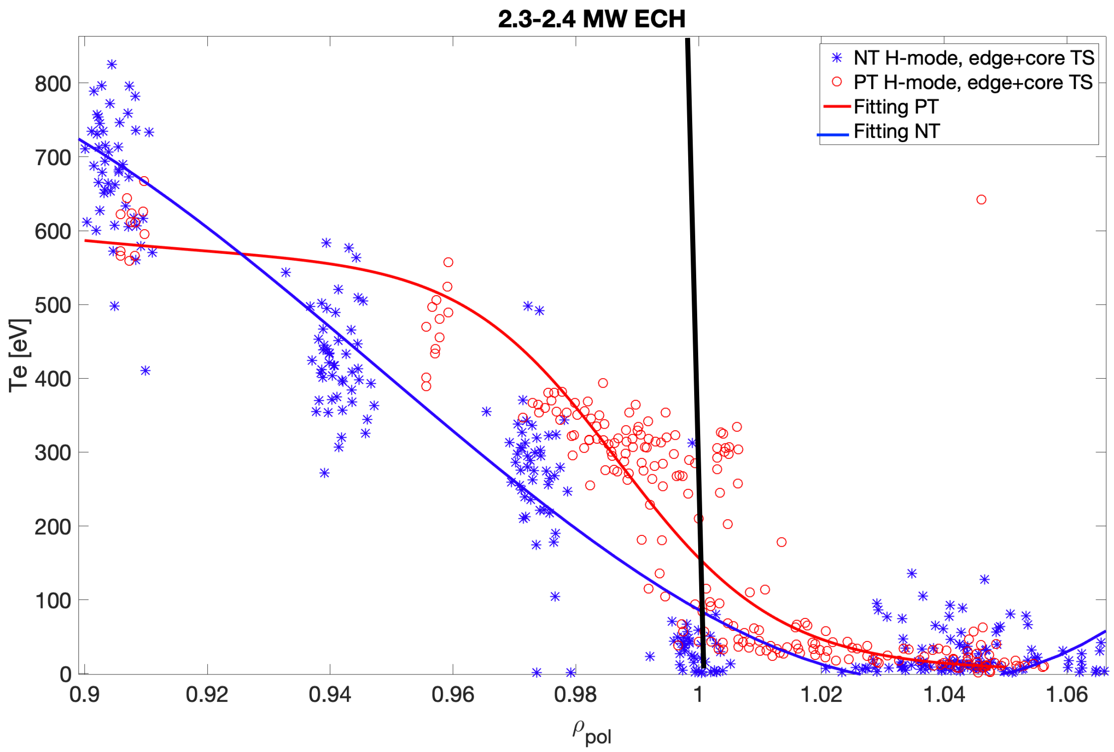


The beneficial effect of $\delta < 0$ seems to extend inside the separatrix. The **temperature decay length** λ_{Te} is higher in case of the PT H-mode since the NT gradient outside ρ_{pol}=0.9 is **steeper** than its counterpart.

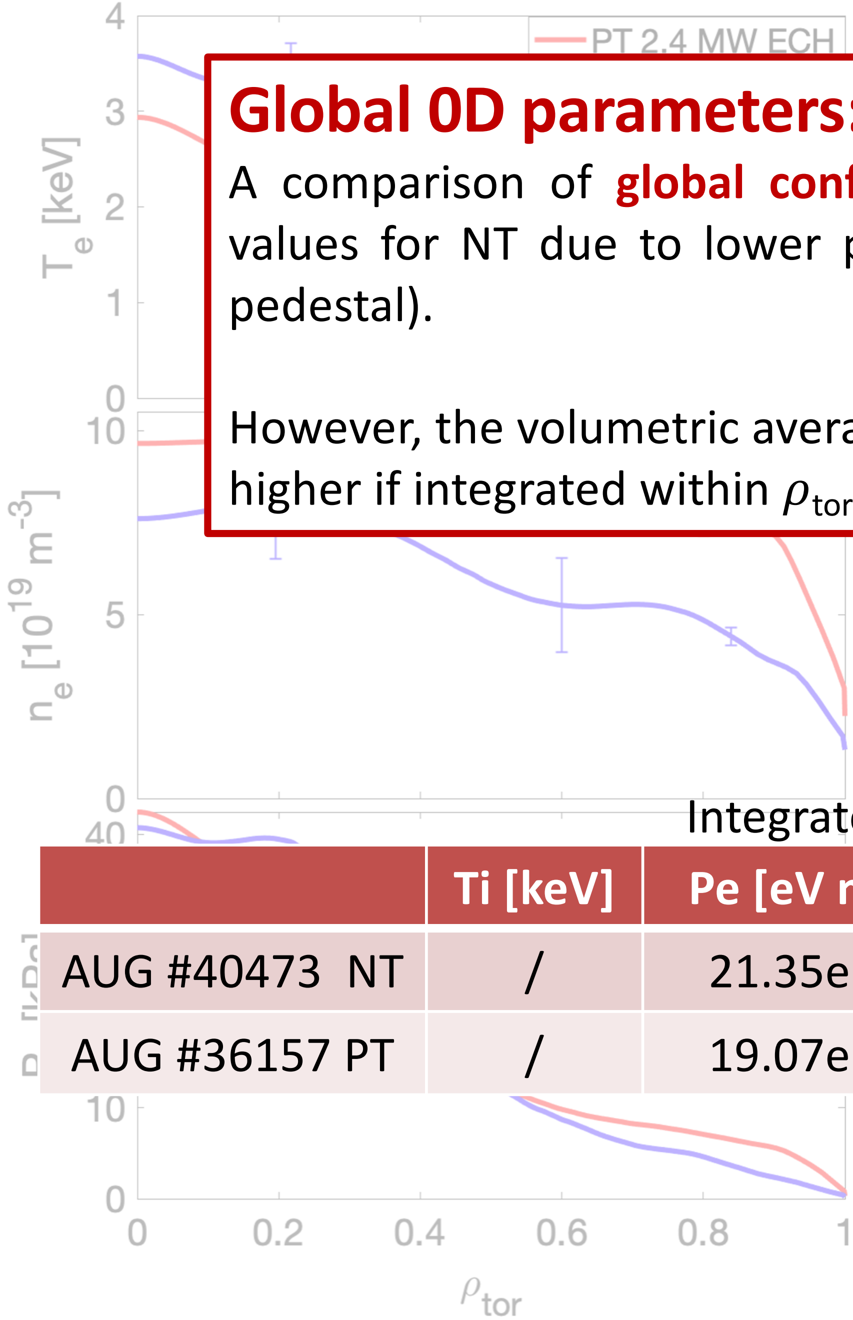
THE SAME TREND IS FOUND TO PERSIST AT OTHER ECH POWER REGIMES IN H-MODE (see table).

The NT **electron heat transport** in the region $0.7 < \rho_{tor} < 0.95$ is such as to drive temperature gradients **steep enough** to overcome the Te and match the electron thermal energy of the PT pulse around mid-radius. (from Integrated Data Analysis, IDA).

The same is confirmed looking at edge+core Thomson scatt. Te profile outside ρ_{pol}=0.9



Negative vs positive triangularity:
2.3-2.4 MW ECH (40473 vs 36157)



Global 0D parameters:

A comparison of **global confinement parameters** shows slightly lower values for NT due to lower parameters in the outer region (no or low pedestal).

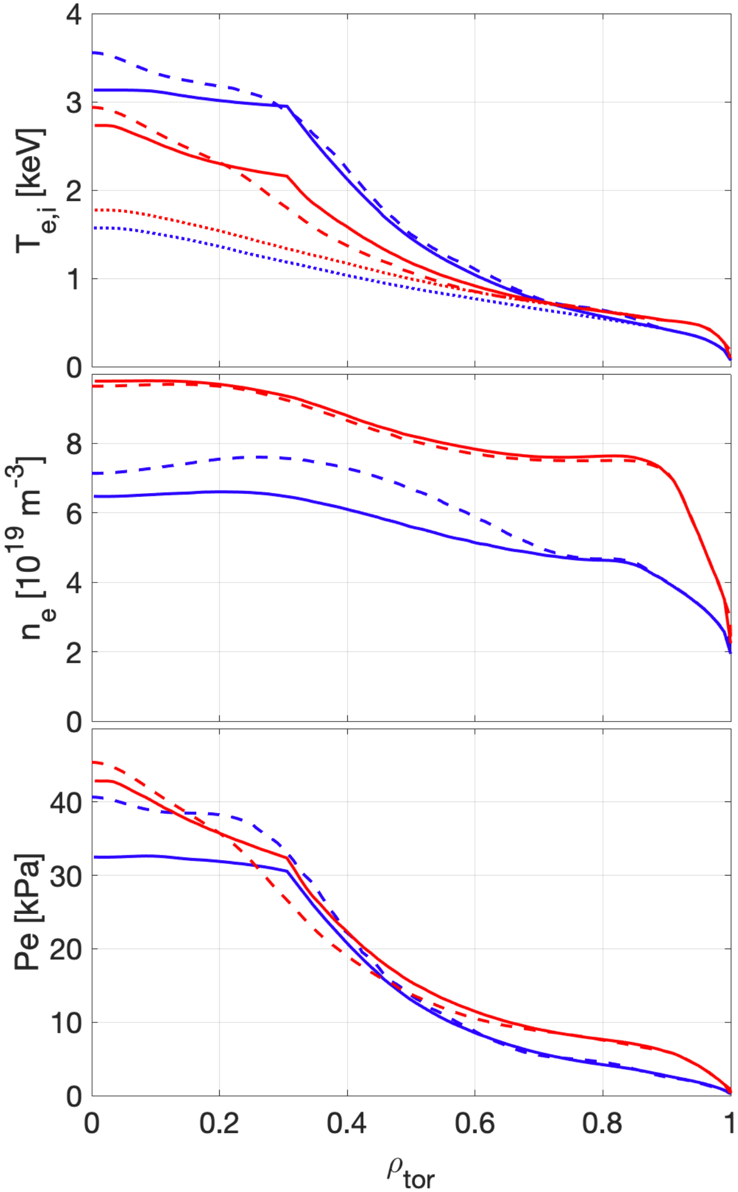
However, the volumetric averages of the NT kinetic profiles (P_e and T_e) are higher if integrated within ρ_{tor}=0.4.

Integrated inside 0.4

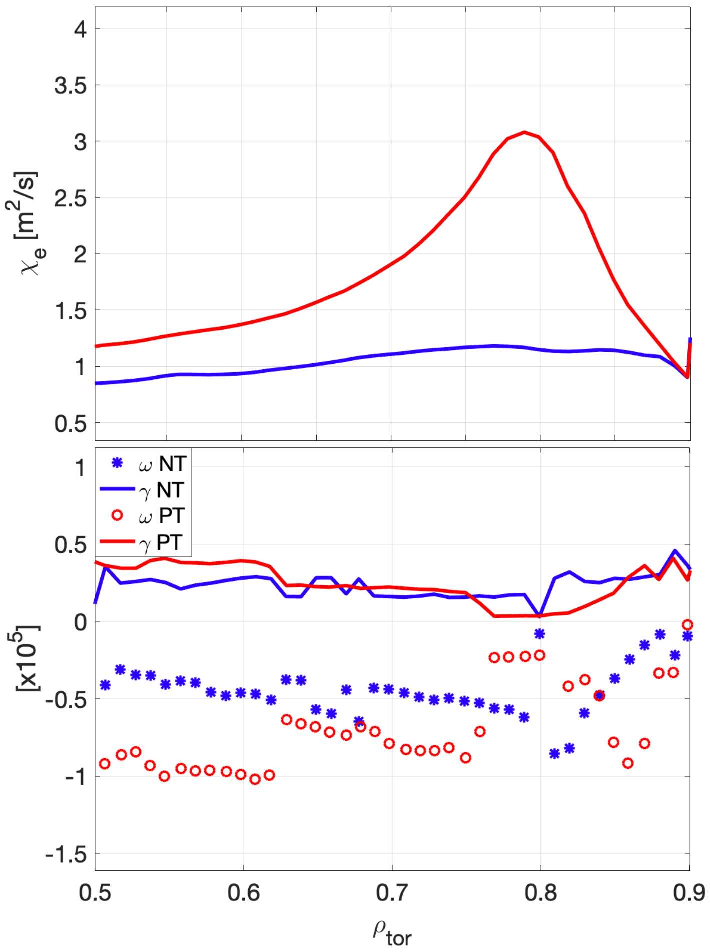
	Ti [keV]	Pe [eV m^{-3}]	Te [keV]	ne [10^{19} m^{-3}]	τ_E [s]	β_N
AUG #40473 NT	/	21.35e22	2.81	7.79	0.14	1.2
AUG #36157 PT	/	19.07e22	2.03	9.53	0.15	1.3

TGLF simulations:
2.3-2.4 MW ECH (40473 vs 36157)

The experimental results are **reproduced well** inside the separatrix by ASTRA+tglf predictions.

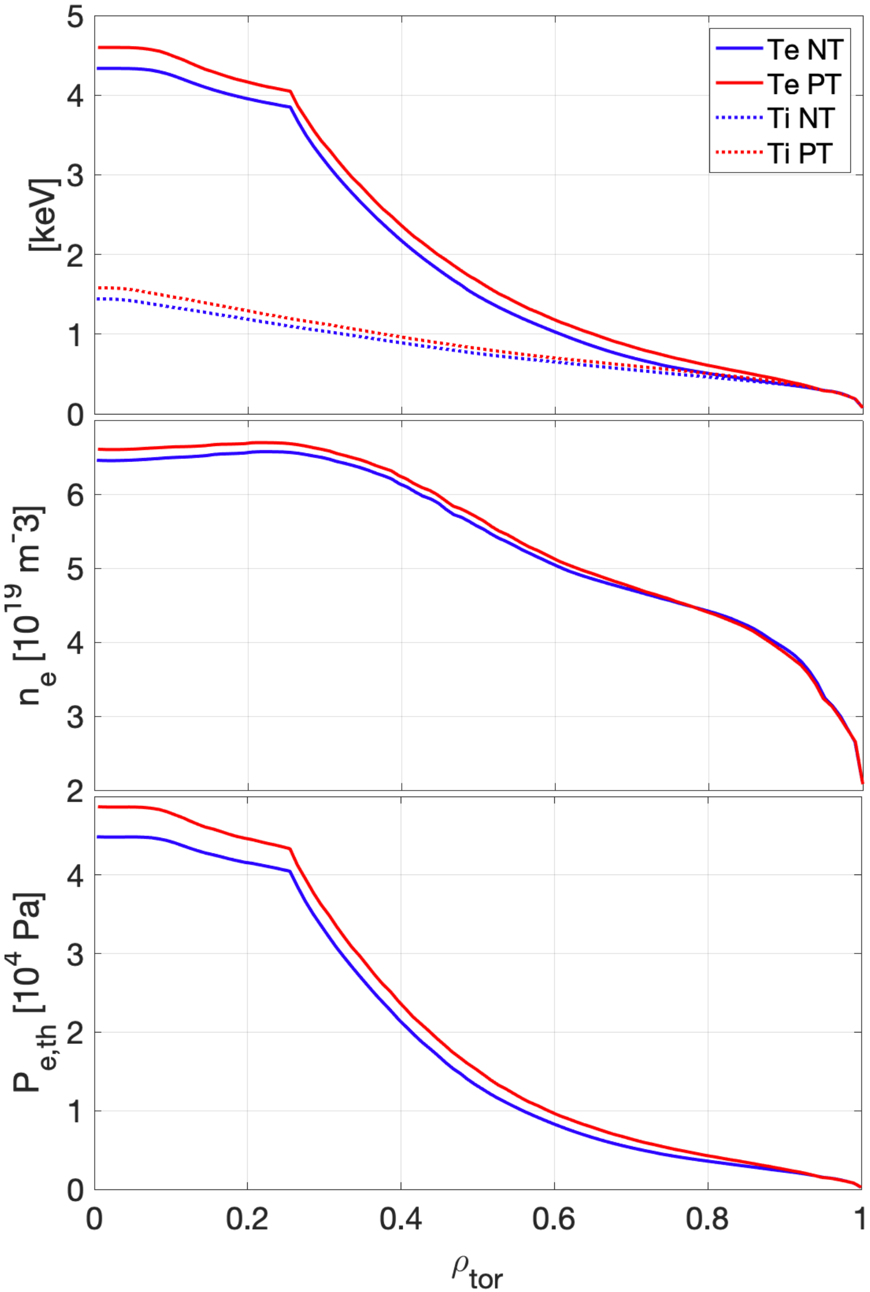


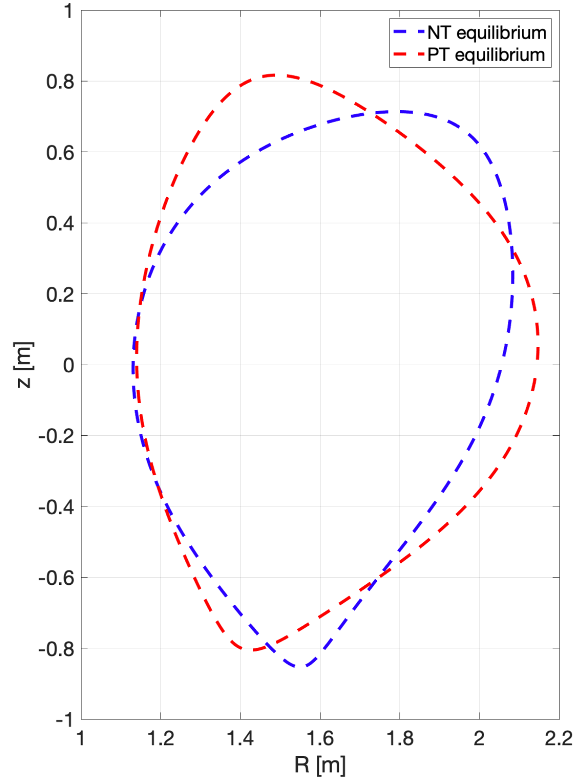
The **electron heat diffusivity χ_e** is consistently predicted to be **lower in case of the NT discharge**



Although only ECRH is used to heat up the plasma, tglf predicts the ITG modes as the most unstable drifts ($\omega < 0$).

impact of delta on ASTRA+tglf simulations





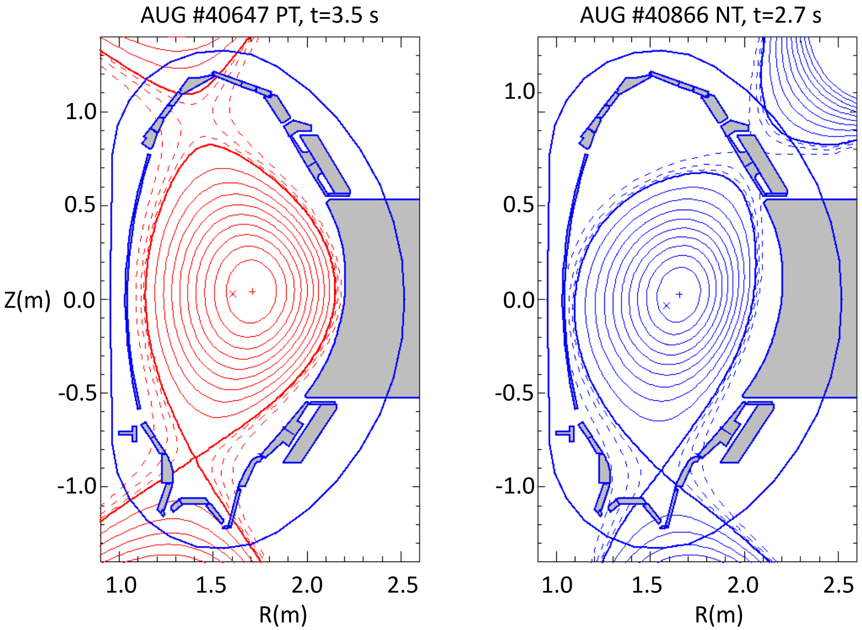
- Same **boundary conditions**
- Same experimental profiles
- Same heating deposition profile
- Same impurity distribution
- **Different boundary**

AUG #40473
phase III
2.9 MW ECH

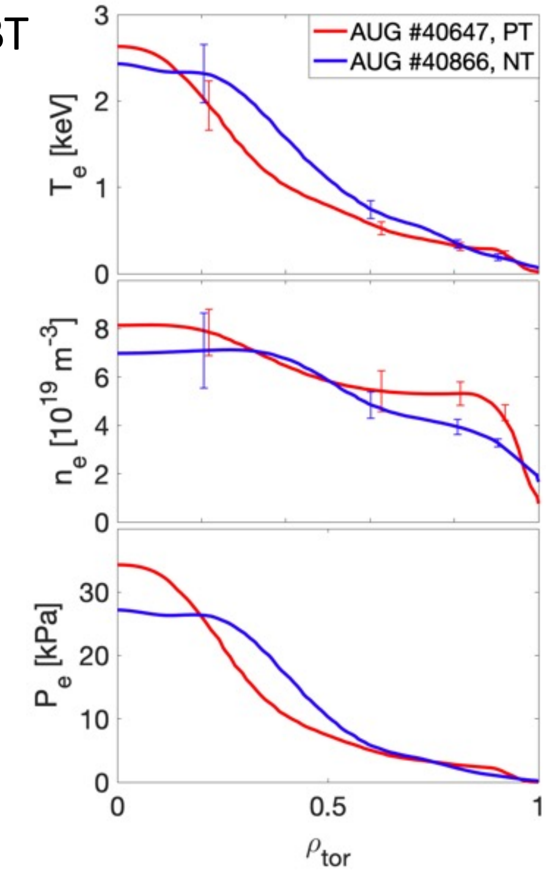
➔ Basically no impact of geometry in the TGLF simulations inside ρ_{tor} =0.95

Negative vs positive triangularity: 1.5 MW ECH (40866 vs 40647)

NT is in L-mode due to RV BT

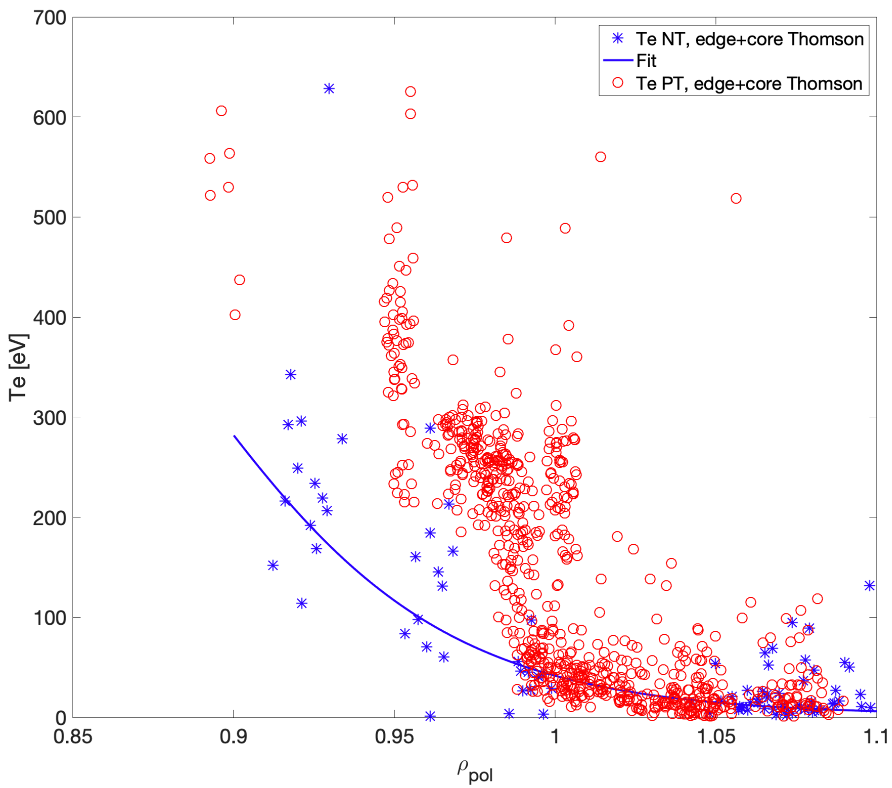


As in the case at higher power, the NT Te has gradients **steep** enough to **recover** the PT counterpart.

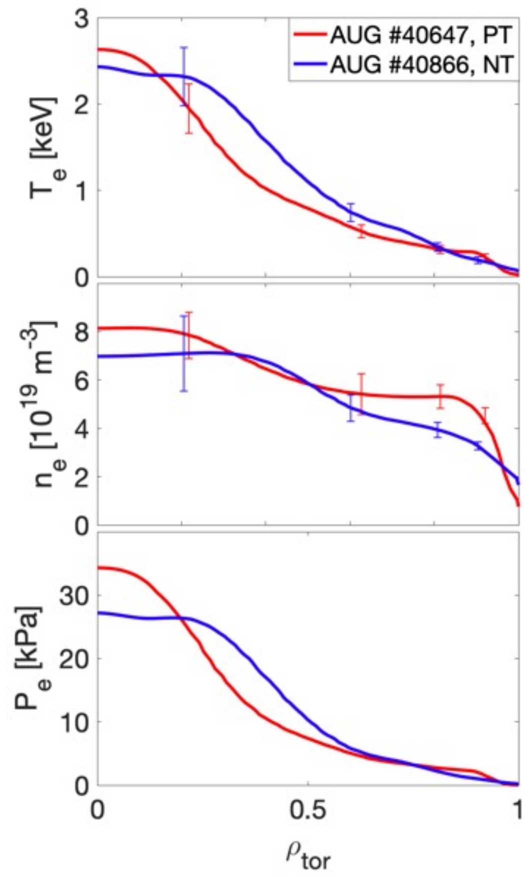


- **AUG #40647 (δ_{avg} =0.40):**
  PT EDA H-mode (ELM free scenario), stationary, ECH constant at 1.5 MW
  No beams during the whole discharge → no ion profiles (CXRS)
- **AUG #40473 (δ_{avg} =-0.13):**
  NT **L-mode** up to 2.8 s (NBI power on), stationary, ECH constant at 1.5 s
  No beams in the analysed phase → no ion profiles (CXRS)

Negative vs positive triangularity:
1.5 MW ECH (40866 vs 40647)

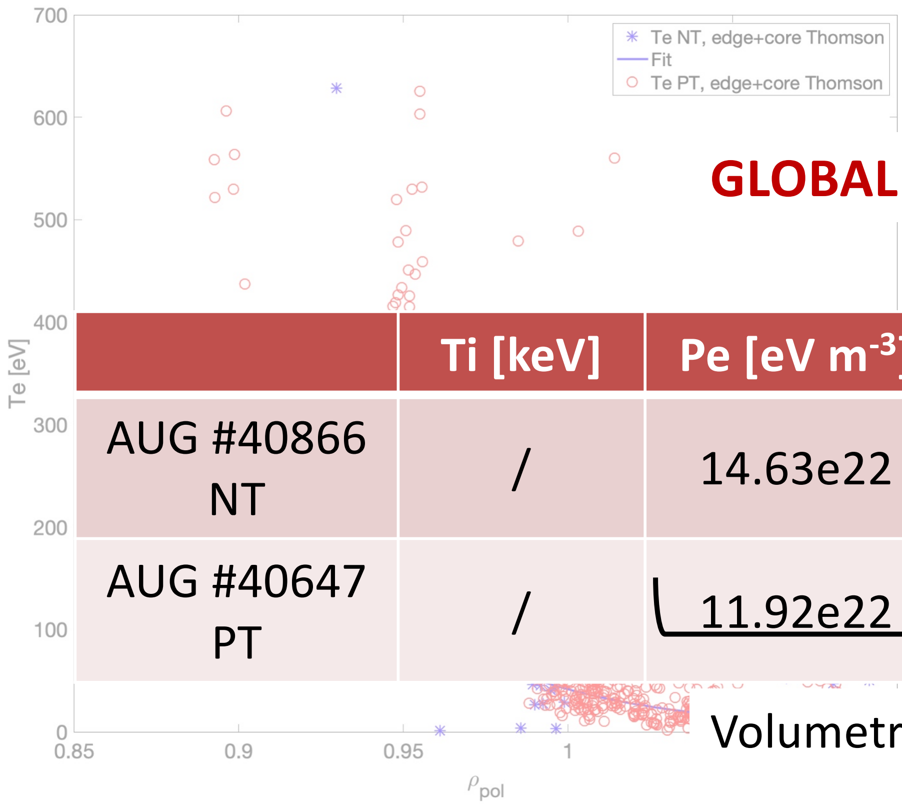


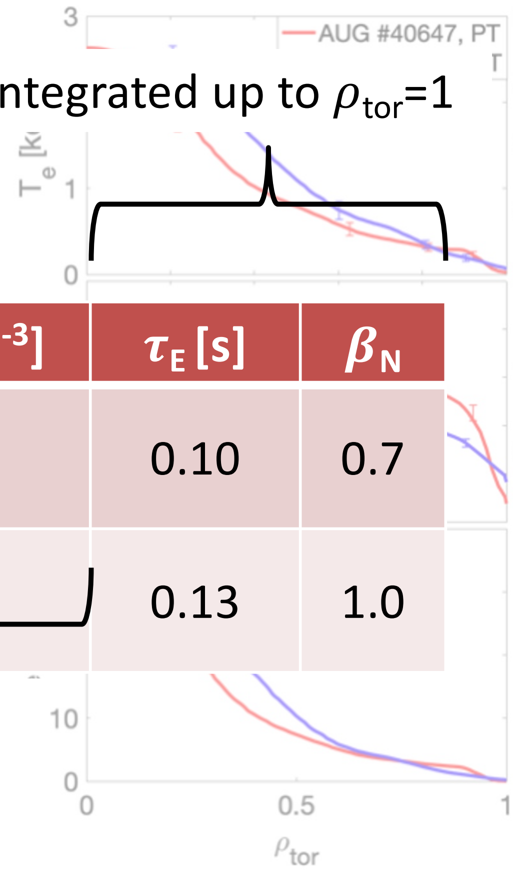
The NT Te gradient in the external region is not steeper than its counterpart, **BUT the comparison is between NT L-mode and PT H-mode.**



- **AUG #40647 (δ_{avg} =0.40):**
  PT EDA H-mode (ELM free scenario), stationary, ECH constant at 1.5 MW
  No beams during the whole discharge → no ion profiles (CXRS)
- **AUG #40473 (δ_{avg} =-0.13):**
  NT **L-mode** up to 2.8 s (NBI power on), stationary, ECH constant at 1.5 s
  No beams in the analysed phase → no ion profiles (CXRS)

Negative vs positive triangularity:
1.5 MW ECH (40866 vs 40647)





Integrated up to ρ_{tor}=1

GLOBAL 0D parameters:

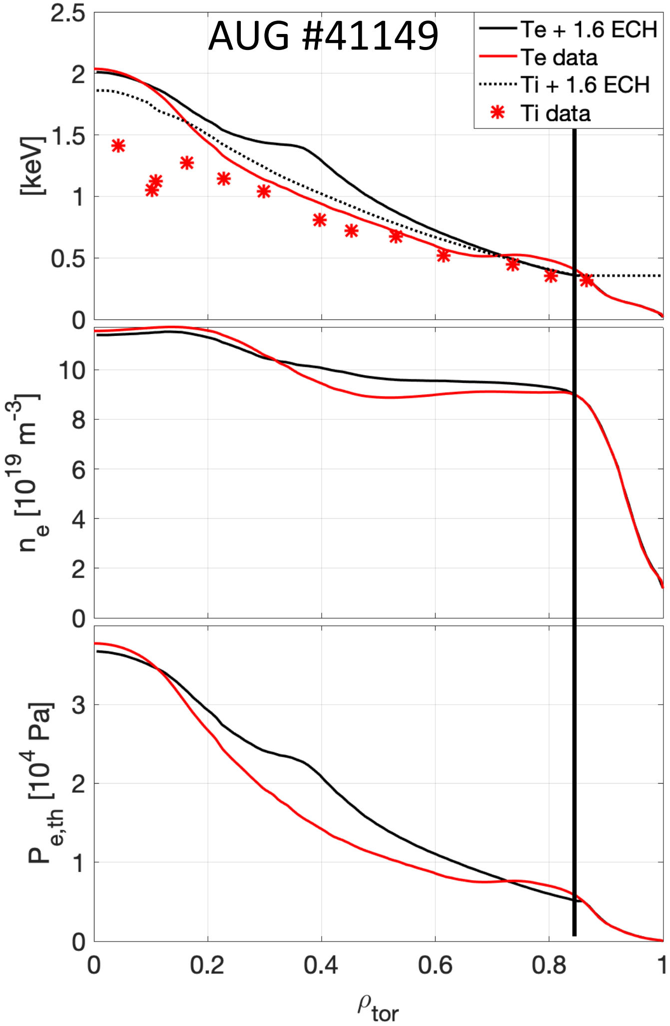
	Ti [keV]	Pe [eV m^{-3}]	Te [keV]	ne [10^{19} m^{-3}]	τ_E [s]	β_N
AUG #40866 NT	/	14.63e22	2.13	7.04	0.10	0.7
AUG #40647 PT	/	11.92e22	1.60	7.39	0.13	1.0

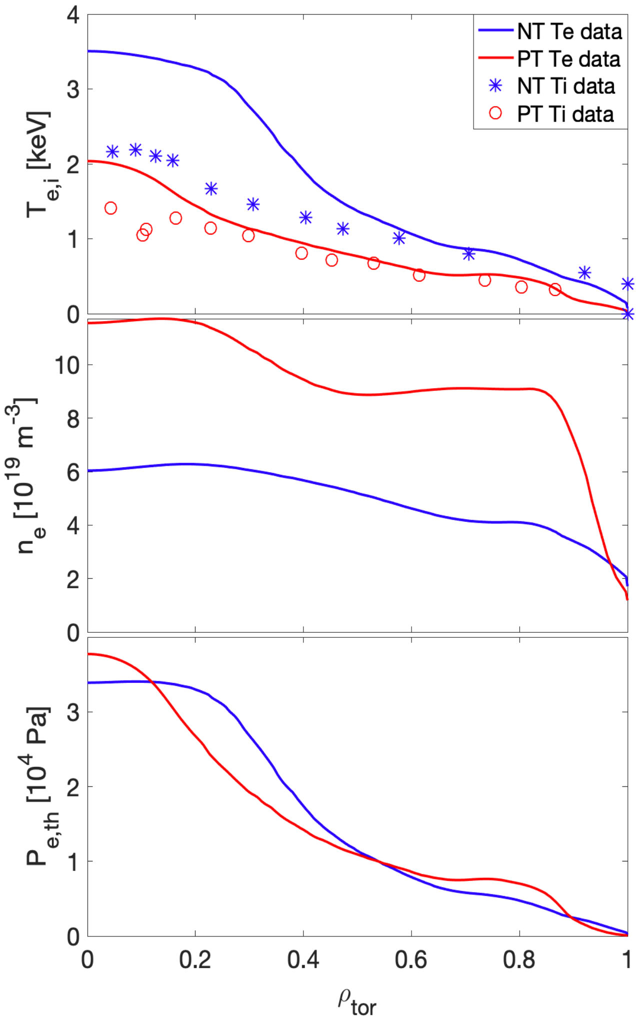
Volumetric average within ρ_{tor}=0.4

- **AUG #40647 (δ_{avg} =0.40):**
  PT EDA H-mode (ELM free scenario), stationary, ECH constant at 1.5 MW
  No beams during the whole discharge → no ion profiles (CXRS)
- **AUG #40473 (δ_{avg} =-0.13):**
  NT **L-mode** up to 2.8 s (NBI power on), stationary, ECH constant at 1.5 s
  No beams in the analysed phase → no ion profiles (CXRS)

NBI case: 41149 PT vs 41149 PT + 1.6 ECH vs 40470 NT

Since in the PT shot the ECH misses, we do not have a real experimental comparison between PT and NT NBI plasmas.
With ASTRA+tglf we can estimate how much the ECRH should impact on AUG #41149 electron temperature profile:





The NT T_e is much higher than the PT profile, even accounting for the missing 1.6 MW ECH.

Although the PT density is consistently higher than the NT counterpart, **the electron thermal pressures are similar**.

Conclusions for AUG

- The experimental campaign showed that on AUG NT shapes similar to iDTT provide beneficial effects although they remain in smaller pedestal H-mode unless BT is reversed. Regardless of the heating mix, NT was always able to recover the central values of plasma pressure of the PT H-mode counterpart with similar power.
- High gradients are seen inside the separatrix extending to $\rho_{tor} \sim 0.8$.
- TGLF reproduces well the experimental profiles but shows no effect of the geometry in the region inside the simulation boundary.