Annual Meeting TSVV2

Negative triangularity studies in view of DTT operations

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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.

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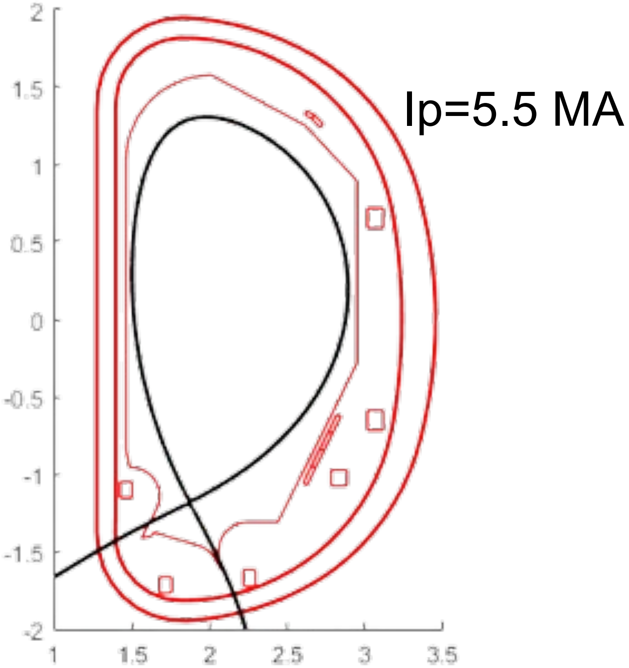
DTT Single Null Shapes

Positive Triangularity (PT)

Upper triangularity
δ_{up} = 0.4

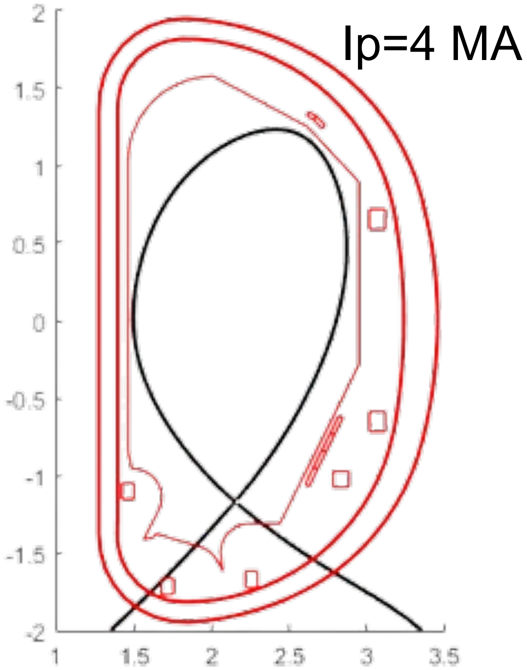


Lower triangularity
δ_{low} = 0.48

Negative Triangularity (NT)

lower δ

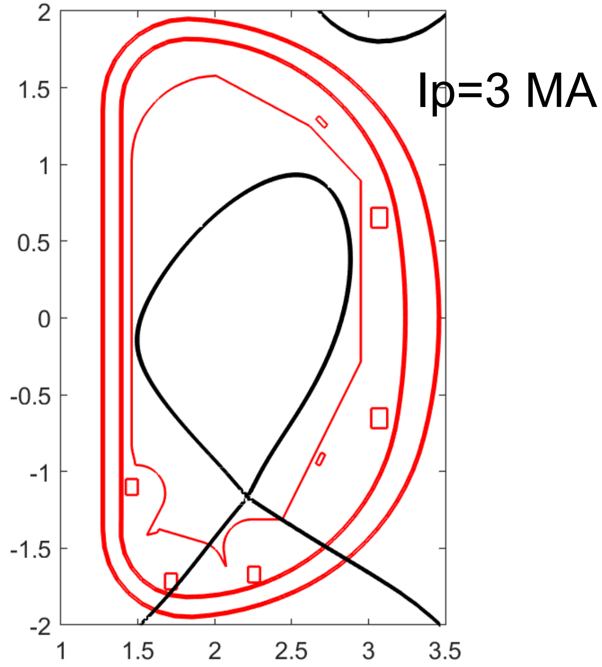
Upper triangularity
δ_{up} = – 0.35



Lower triangularity
δ_{low} = 0.05

higher δ

Upper triangularity
δ_{up} = – 0.5



Lower triangularity
δ_{low} = 0.05

Cross-machine NT experiments lower δ NT vs standard PT shapes

DTT

A. Mariani et al., NF 2024

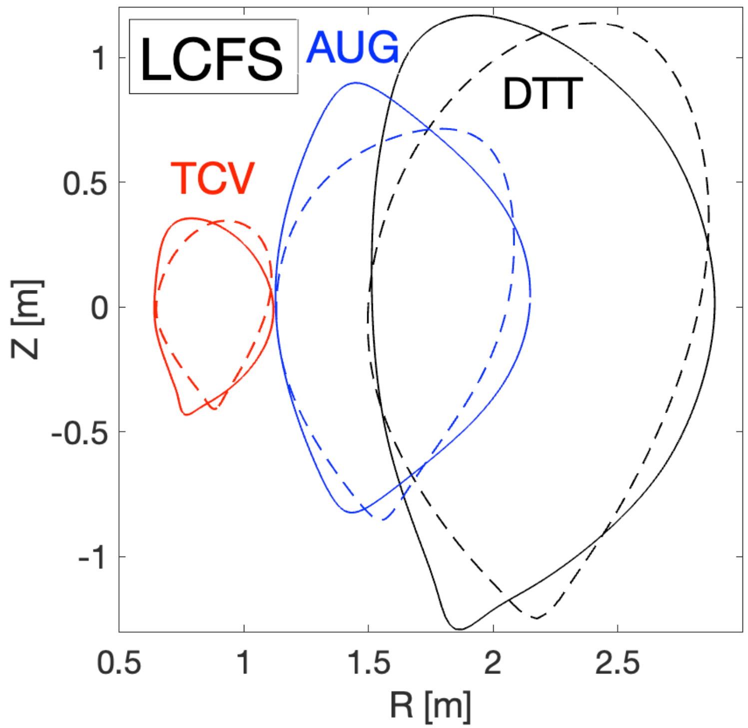
- **No experiments yet…**
- Only **numerical analysis**, comparing the reference PT H-mode full power scenario with the NT L-mode option;
- ASTRA-TGLF SAT2 **predictive transport simulations**;
- GENE **gyrokinetic** flux-tube linear and nonlinear simulations.

TCV

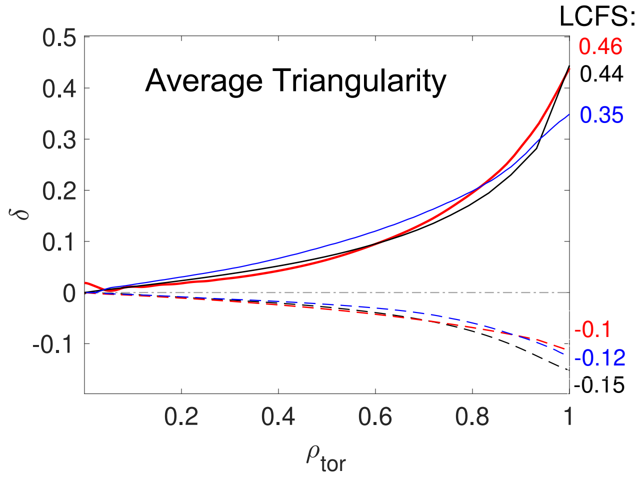
A. Balestri et al., PPCF 2024

AUG

L. Aucone et al., PPCF 2024



- Experiments with DTT-like shapes and transport conditions on TCV and AUG
- ASTRA/TGLF and GENE modelling of results



Cross-machine NT experiments
higher δ NT vs standard PT shapes

DTT

Not published

- **No experiments yet…**
- Only **numerical analysis**, comparing the reference PT H-mode full power scenario with the NT L-mode option;
- ASTRA-TGLF SAT2 **predictive transport simulations**;
- GENE **gyrokinetic** flux-tube linear and nonlinear simulations.

TCV

Not published

Last TCV session in July 2024

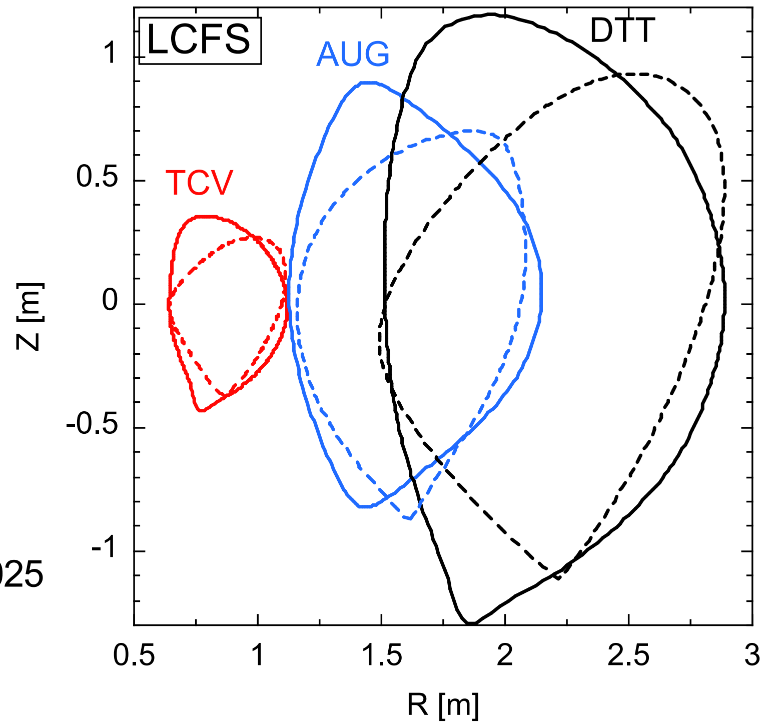
One more planned with baffles

AUG

Not published

Last AUG session on 8th July 2025

Data still only partially validated



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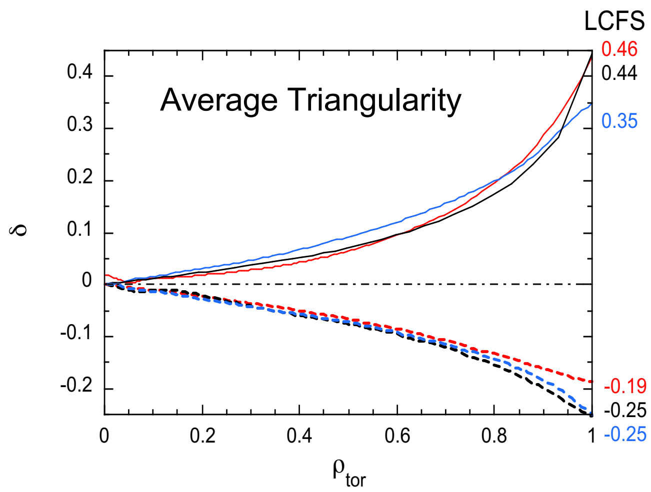


Low δ shape :

experimental results and modelling

Some recaps and indications from low δ NT work

- The effect of NT is stronger in TCV than in AUG for similar shape and heating mix
- In TCV, NT increases strongly ne, Te, Ti whilst in AUG the main effect of NT is on Te only
- In both machines the improvement is localized in a region outside ρ_{tor}=0.8
- Modelling using TGLF reproduces well the AUG NT H-mode discharges (BC at top pedestal) but is not able to reproduce the large increase of Ti and ne in TCV NT L-modes (BC at ρ=1)
- It could be that TGLF misses the edge improvement because it is using Miller geometry or because it misses the complete edge physics ➔ implement use of TGLF with real geometry
- GK simulations with real geometry show negligible effects of NT at ρ_{tor} =0.85 in DTT but an effect consistent with experiments in TCV at ρ_{tor} =0.95

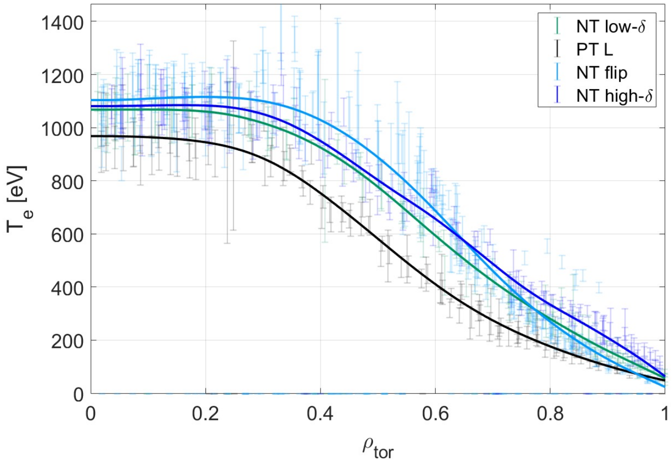
  ➔ More studies developing higher values of NT δ in DTT and test it in TCV and AUG

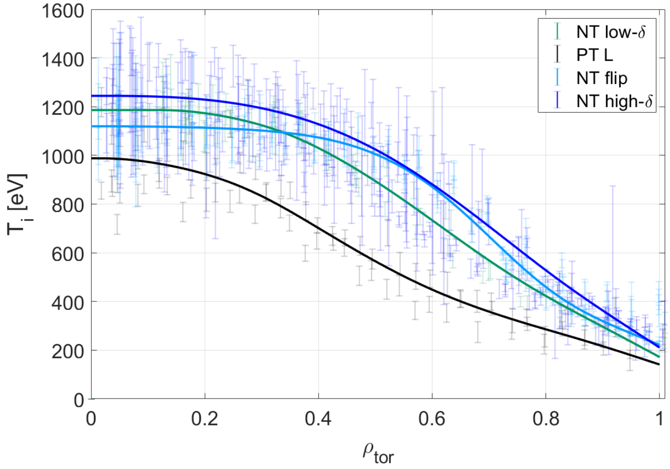
- Main question: what is the cause of the different behaviour of TCV and AUG?
- Many differences:
  - C vs W wall *but no variation in Zeff and C concentration is seen between PT and NT in TCV*
  - TEM dominant vs ITG dominant *from GK simulations DTT and AUG are ITG, TCV is TEM*
  - Neutral penetration larger in TCV ➔ *to be tested by injecting shallow pellets in AUG*

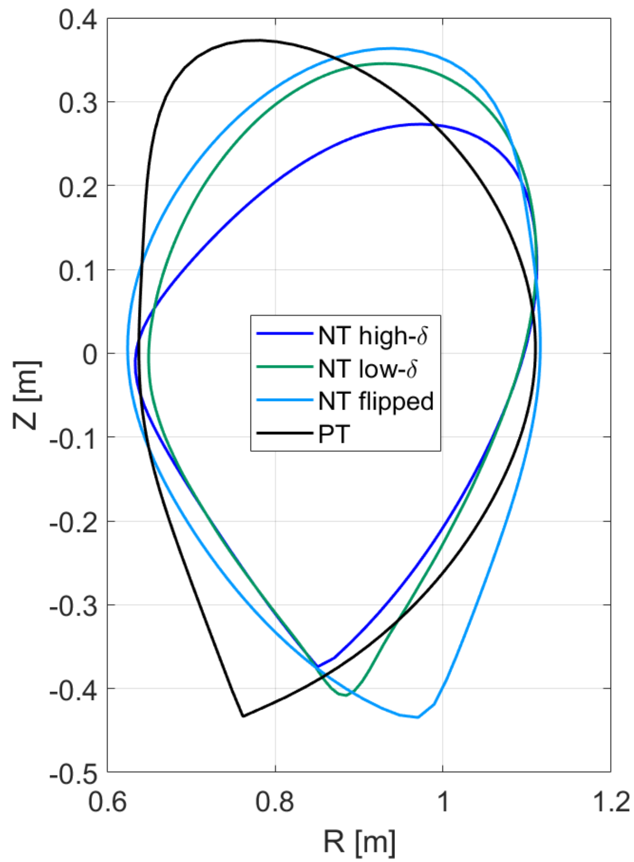
High δ shape :
experimental results and modelling

TCV higher δ NT vs lower δ NT vs standard PT shapes

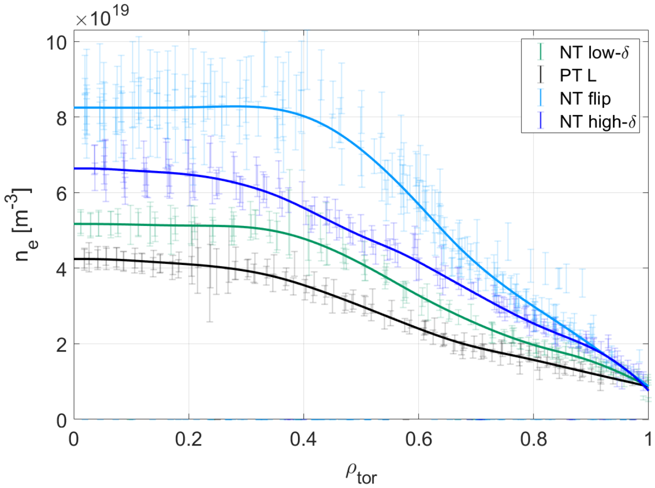
At same power NT high δ performs even better than NT low δ and both much better than PT L-mode







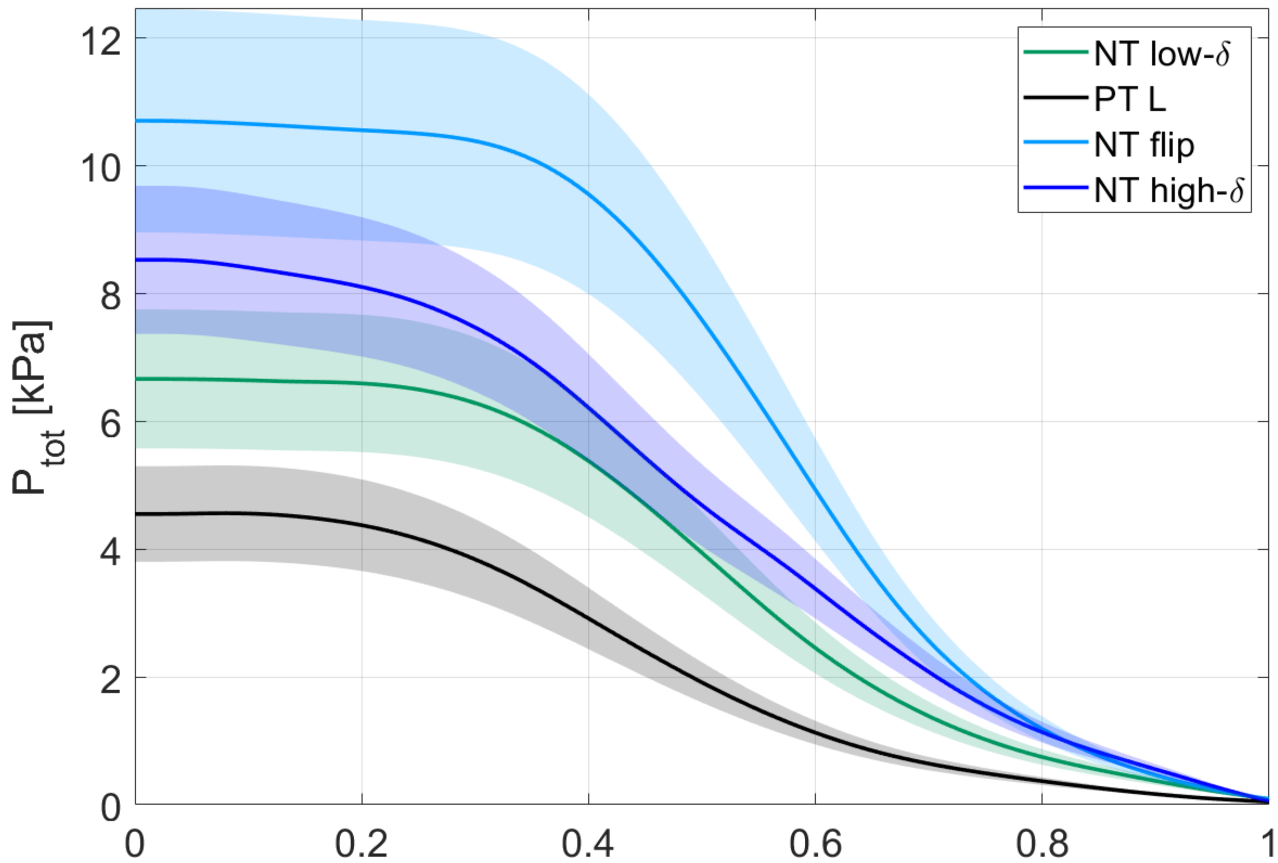
Main effect is on density

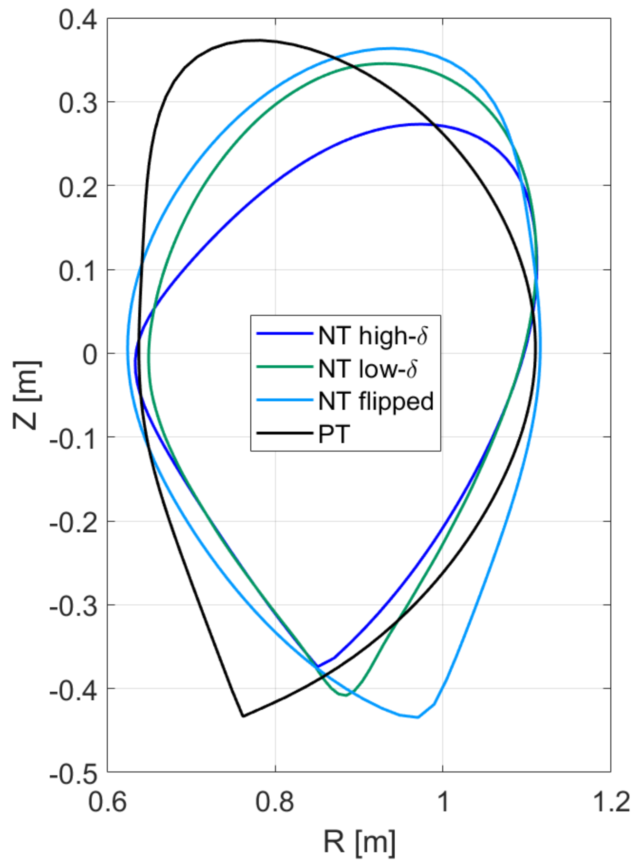


NT-flipped shape has the highest performance (δ_{bottom} also negative)

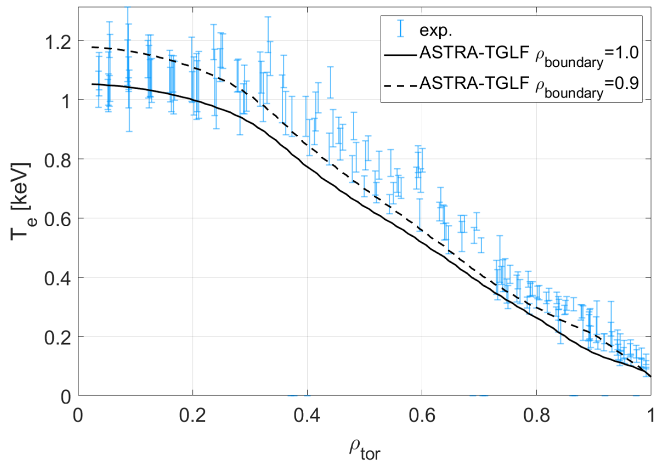
TCV higher δ NT vs lower δ NT vs standard PT shapes

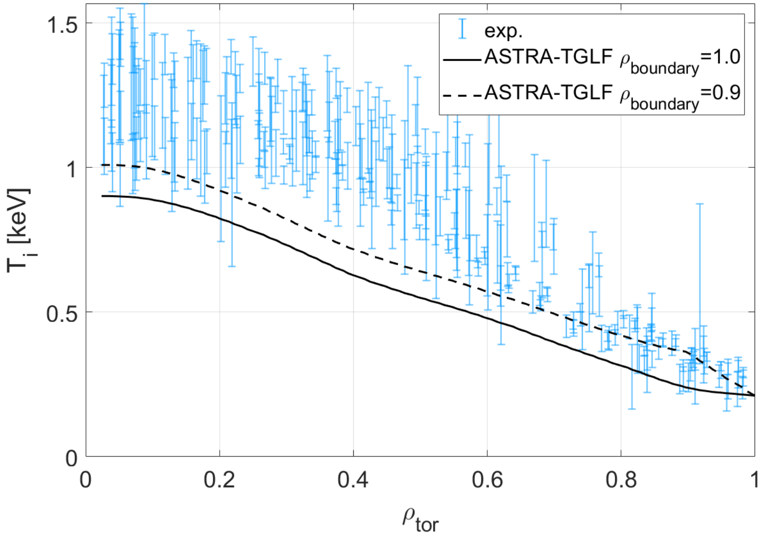
At same power NT high δ performs even better than NT low δ and both much better than PT L-mode

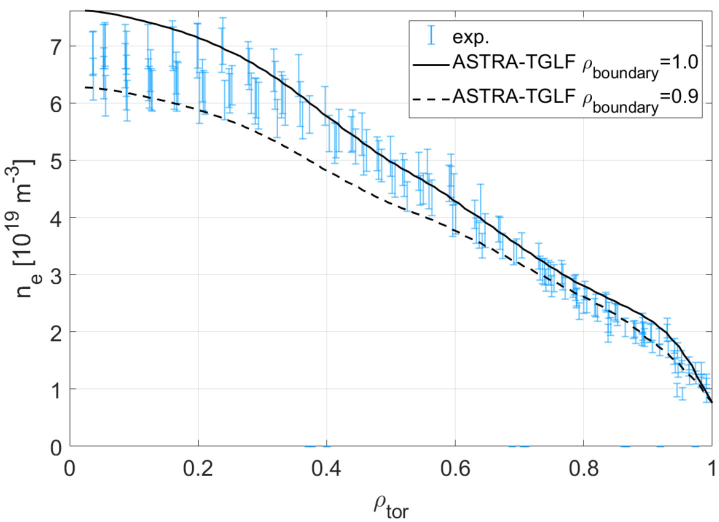




ASTRA/TGLF simulations of TCV high δ shapes

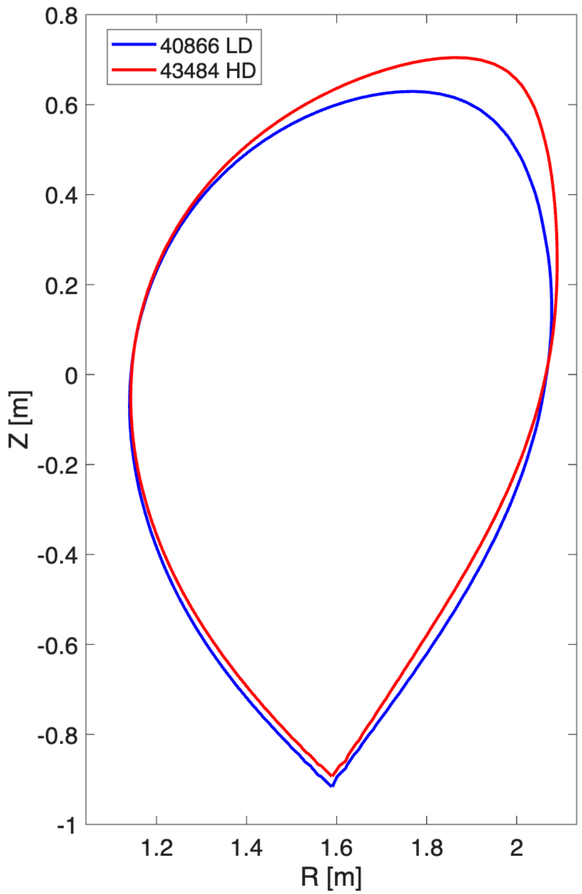






Same difficuties in reproducing Ti as with low δ shape

AUG higher δ NT vs lower δ NT



Sessions on 13-16 May and 8 July

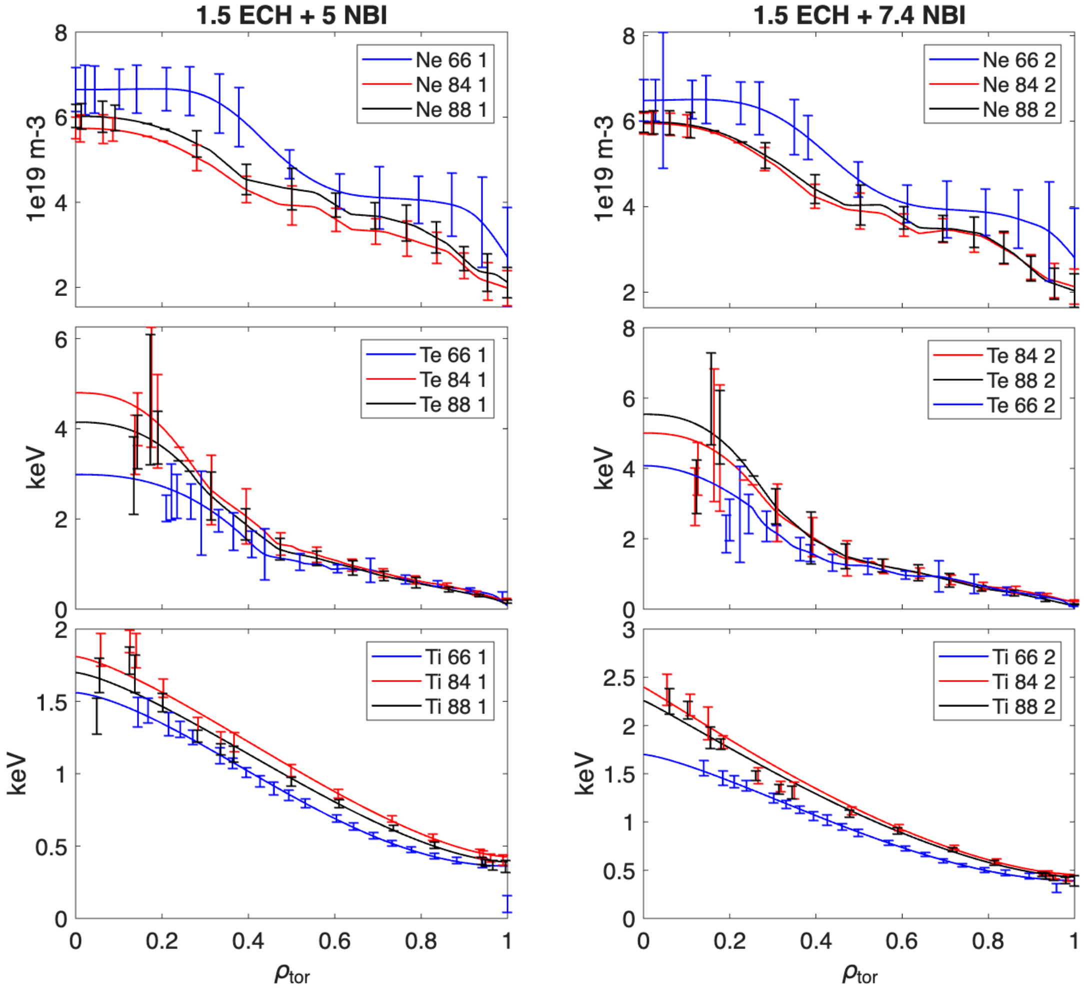
High δ shape developed on AUG and optimized→ upper δ moved from -0.33 to -0.5 (lower δ~ +0.05)

L-mode edge achieved in AUG with the HD shape even in favourable drift configuration

Shallow pellets injected at 5-10 Hz

Various combinations of power to compare with the LD experiments from 2022

AUG higher δ NT vs lower δ NT



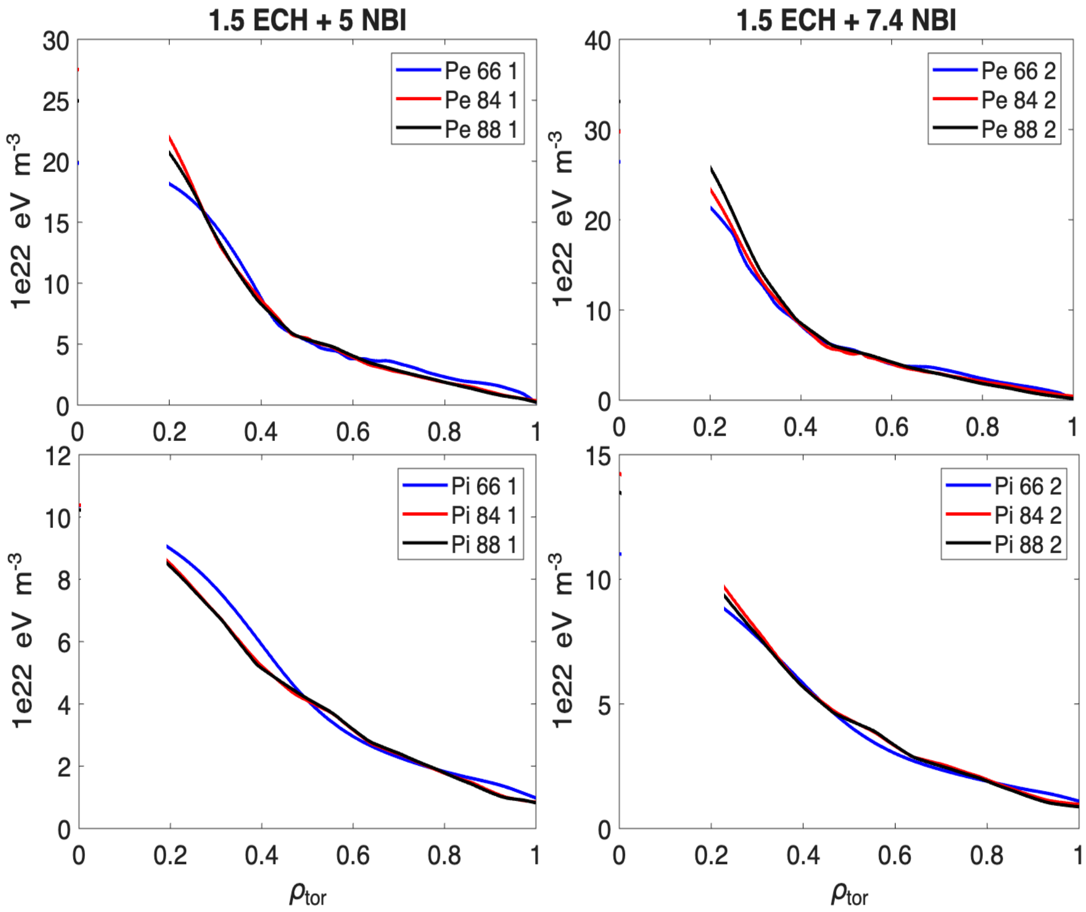
40866 LD L-mode shot (unfavourable drift)

43484 HD L-mode (favourable drift) gas

43488 HD L-mode (favourable drift) pellets

HD shots tend to have lower density and higher temperatures than LD shots

AUG higher δ NT vs lower δ NT



40866 LD L-mode shot (unfavourable drift)

43484 HD L-mode (favourable drift) gas

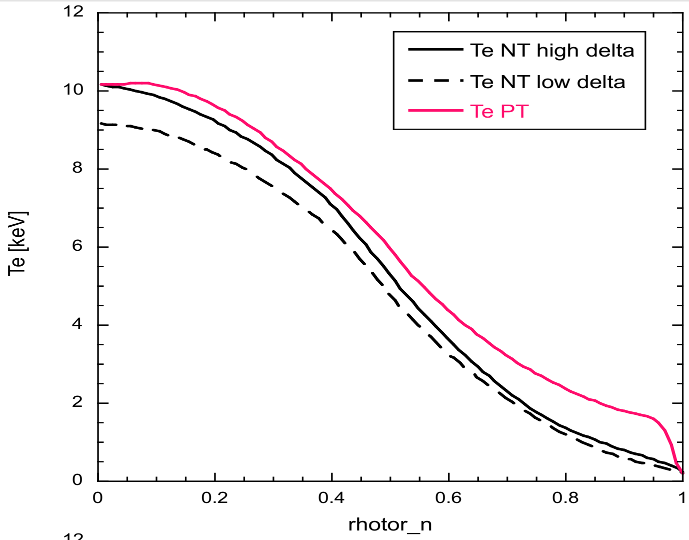
43488 HD L-mode (favourable drift) pellets

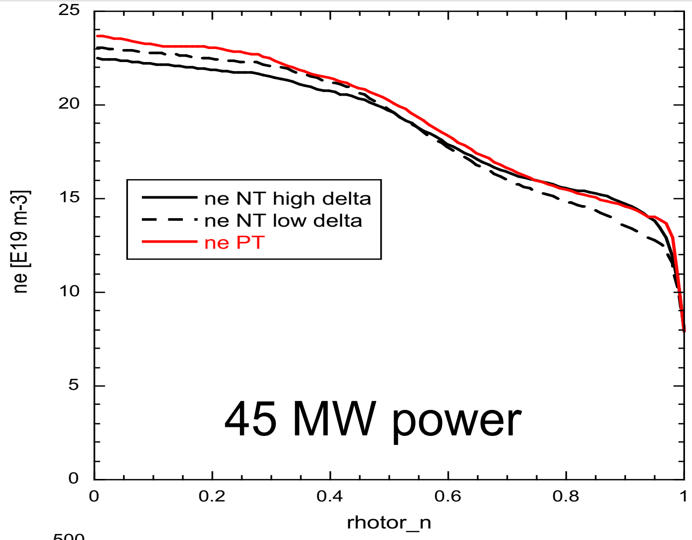
HD shots tend to have lower density and higher temperatures than LD shots

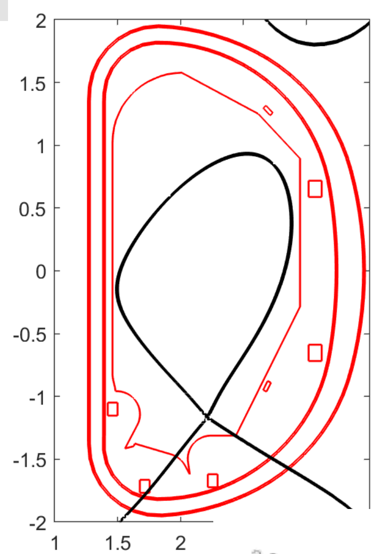
Pressure is basically unchanged from LD to HD, at variance with TCV

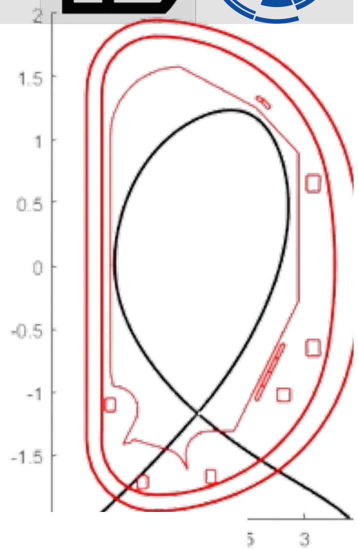
Pellet fuelling to increase neutrals in the higher δ region did not increase performance

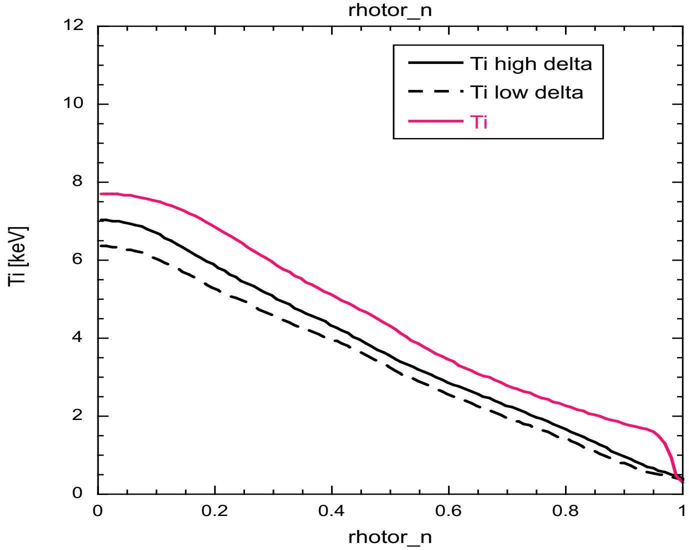
DTT higher δ NT predictions : Miller

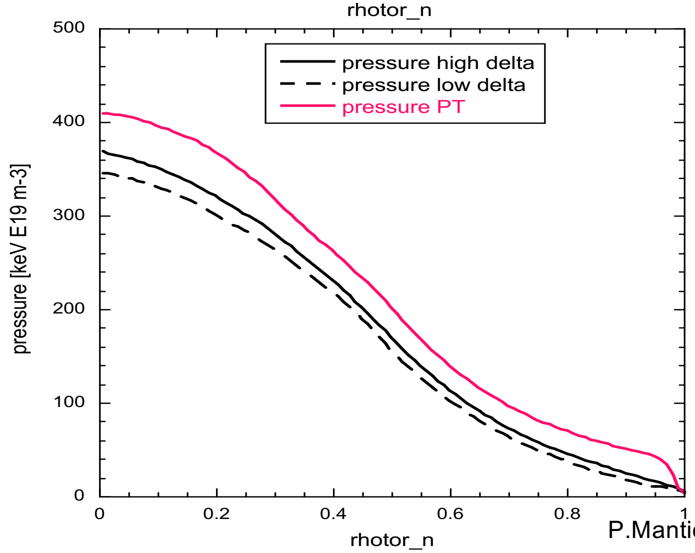


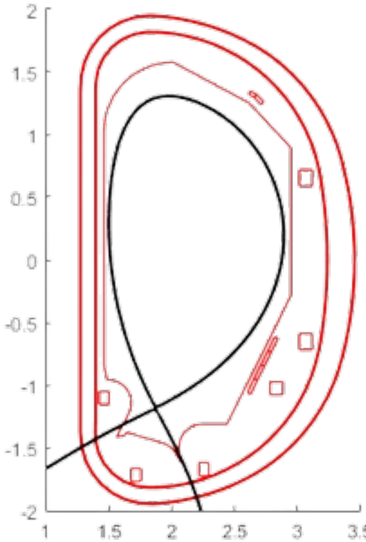




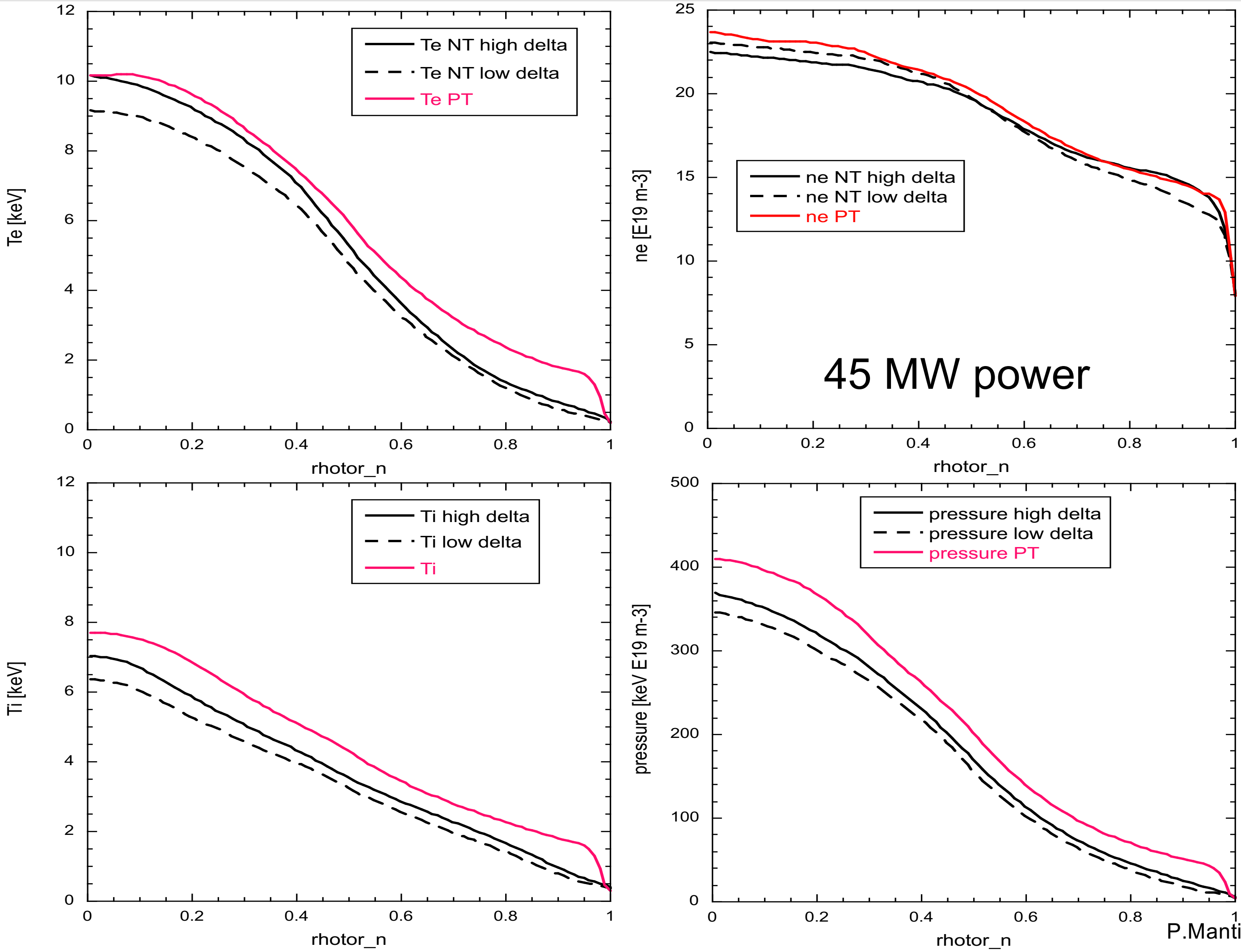








DTT higher δ NT predictions : Miller

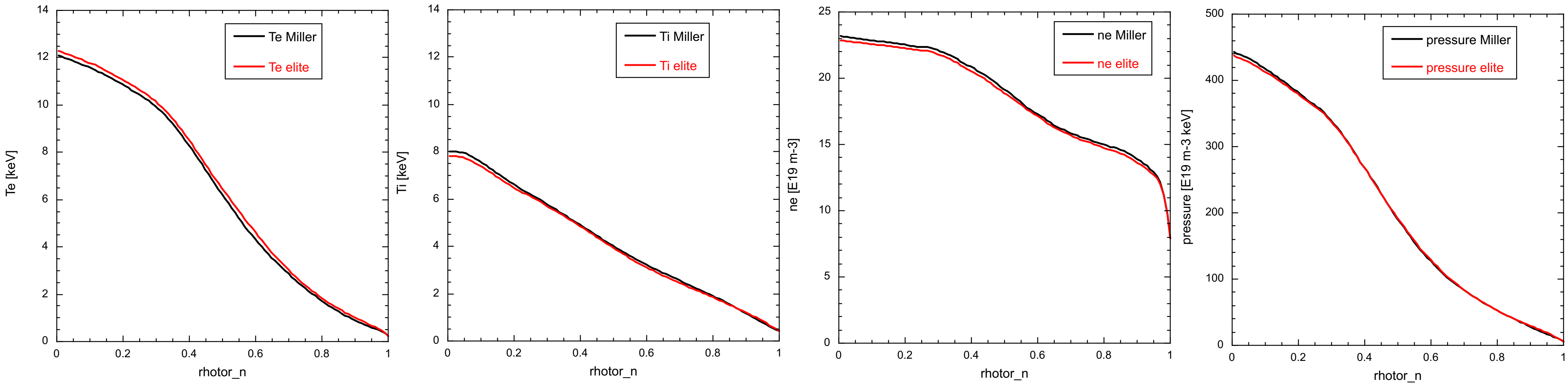


- Modelling using ASTRA/TGLF SAT2 with Miller geometry up to ρ=1 in NT and pedestal top in PT
- Te, Ti, ne, J, Ar, W predicted
- **The high δ shape improves central T values for similar n and radiation**
- NT core pressure is reduced by ~ 10% wrt PT H-mode

➔ NT scenarios in DTT will allow L-mode edge operation with good core performance

DTT higher δ NT predictions : Miller vs ELITE geometry

In ASTRA a new interface to TGLF SAT2 has been implemented that allows the use of full geometry instead of the Miller approximation. The geometrical coefficients are calculated by ELITE and passed to TGLF. Tested on the HD DTT shape.



Using full geometry in TGLF does not seem to make appreciable difference in predicted profiles

DISCUSSION and CONCLUSIONS

- In order to prepare future DTT operations exploring negative triangularity scenarios, an intensive experimental and modelling activity has been conducted during the last 5 years, with support from DTT and EUROfusion (WPTE, TSVV2)
- Experiments were performed on TCV and AUG using same NT shapes foreseen on DTT
- Integrated modelling was performed using ASTRA/TGLF and gyrokinetic simulations using GENE

- The effects of NT on plasma profiles are **clearly different between TCV and AUG** for both low and high δ shapes (on TCV strong effect on ne, Te and Ti, on AUG mild effect on Te). Increasing $-\delta$ is very effective on profiles in TCV but not in AUG. Shallow pellets in AUG did not change the picture.
- **ASTRA/TGLF simulations reproduce well AUG and predict similar behaviour for DTT**. They do not reproduce the Ti increase in TCV. Using full geometry in TGLF yields similar results as Miller geometry. Important to test on AUG new L-mode NT shots.
- A benchmark of TGLF vs GENE for DTT yielded good match in the predictions
- Local GENE simulations show negligible effects of NT at ρ_{tor} =0.85 in DTT but an effect on R/LTe consistent with experiments in TCV at ρ_{tor} =0.95

DISCUSSION and CONCLUSIONS

- The cause of the different behaviour between TCV and AUG 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 TEM dominant.** In fact AUG shots with only ECH are the ones where beneficial effects of NT are strongest ➔ more work is needed to check this hypothesis which would not be favourable for extrapolation to a reactor. **See some new results in A.Mariani's talk.**
- DIII-D shows strong NT effects as TCV and also has electron turbulence dominant in the edge (e.g. S D Stewart et al 2025 Plasma Phys. Control. Fusion 67 025032)
- 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
- Some JET NT results under analysis