Fourth IAEA Technical Meeting on Divertor Concepts - 7 – 10 Nov. 2022, IAEA Headquarters, Vienna, Austria

EPFL

Divertor Detachment In Negative-Triangularity Configurations In The TCV Tokamak

PI 103

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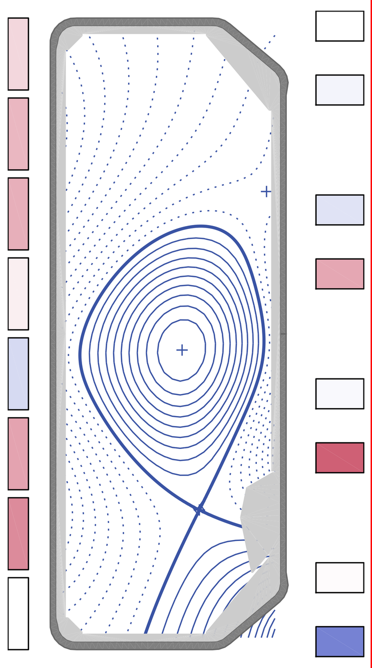
Introduction & Motivation

- To achieve good fusion performance, operation of future tokamaks is typically envisionned in **H-Mode** (High-Confinement) :
  - → Achieved with **power crossing the separatrix above a certain threshold**
  - → ELMs (Edge Localized Modes), periodic relaxation of the pressure pedestal
  - ***→ Large heat/particle-flux towards divertor: ELMs must be avoided***
- Strategies :
  - → Mitigate the ELMs (suppress or reduce amplitude), try to buffer their impact on the divertor (« buffering »)
  - → Explore naturally ELM-free operation scenarios :
    - ELM-free H-Mode
    - **High-performance L-Mode (Low-confinement mode, no transport barriers)**

Negative Triangularity: a route to high-performance L-Modes ?

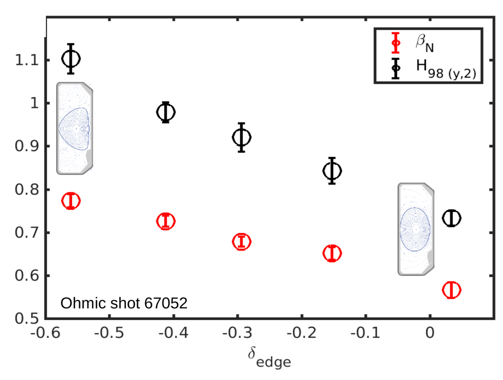
- In recent years, renewed interest for negative-triangularity (NT) plasmas, **with H-Mode grade confinement achieved in L-Mode plasmas** (TCV, DIII-D) [1,2,3,4]
- From the power exhaust point of view :
  - No H-Mode → no ELM mitigation required
  - No H-Mode → No power threshold
    Allow increased core radiation → lower power to the divertor
  - Strike-points at higher major radius
    Heat flux spread over wider area
  - No H-Mode → Higher Scrape-Off Layer width ?

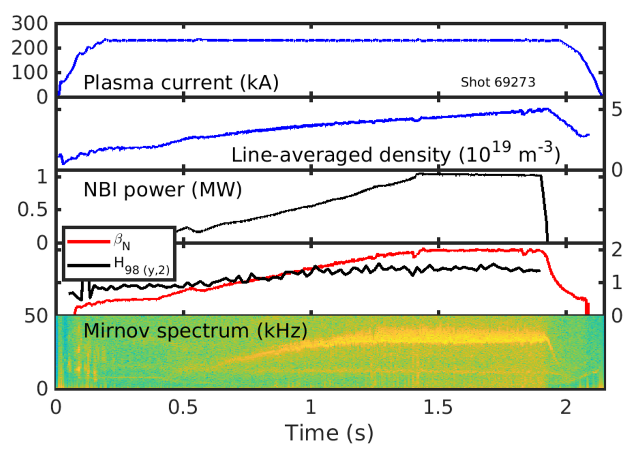
Operation in detached conditions still desirable

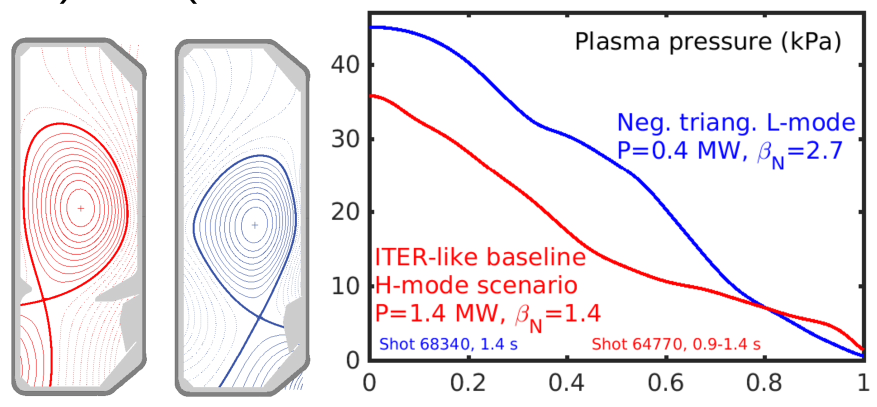


Confinement improvement in NT, a quick overview [2]

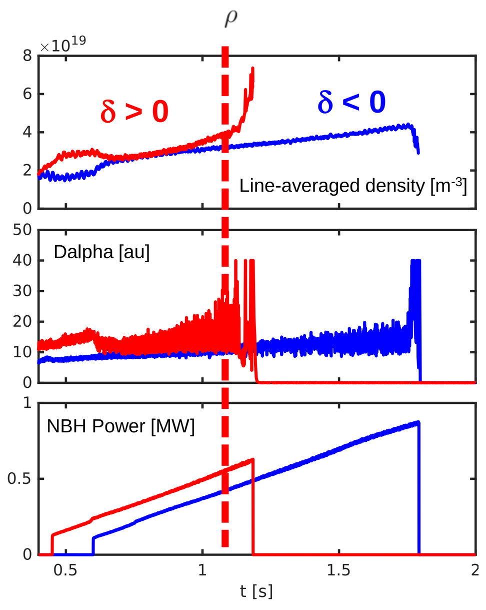
- In ohmic, limited discharges, confinement increase with decreasing triangularity → No saturation observed (***Also true in diverted plasmas)*** [2]
- High-performance (betaN=2.7) achieved in L-Mode NT
- Stationary betaN=2 achieved with Ti (2keV) > Te (1.3keV)





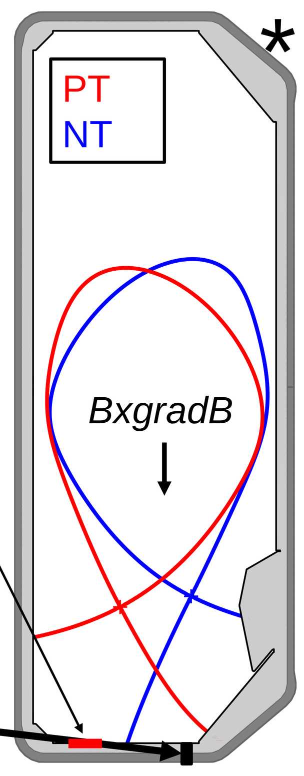


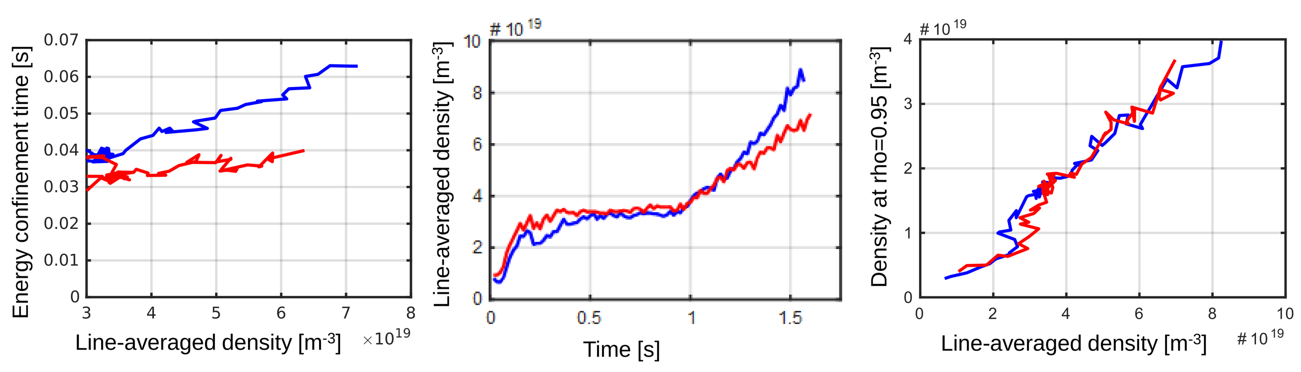
- H-Mode power threshold higher in **NT** compared to **PT**
  → Larger L-Mode operation window
- **No significant difference found for current or L-Mode density limits**



Investigating power exhaust in NT plasma : experimental setup

- L-Mode, I_P = 220kA, Ohmic only.
- Configuration mirrored around R_0=0.88m
  - NT (Negative Triangularity) : $\delta_{top} \approx -0.30$, $\delta_{bot} \approx -0.27$
  - PT (Positive Triangularity) : $\delta_{top} \approx 0.27$, $\delta_{bot} \approx 0.29$
- *Enhanced confinement* observed in NT discharge

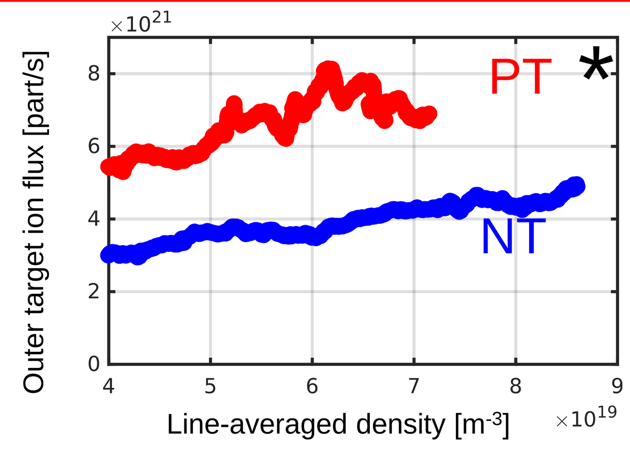


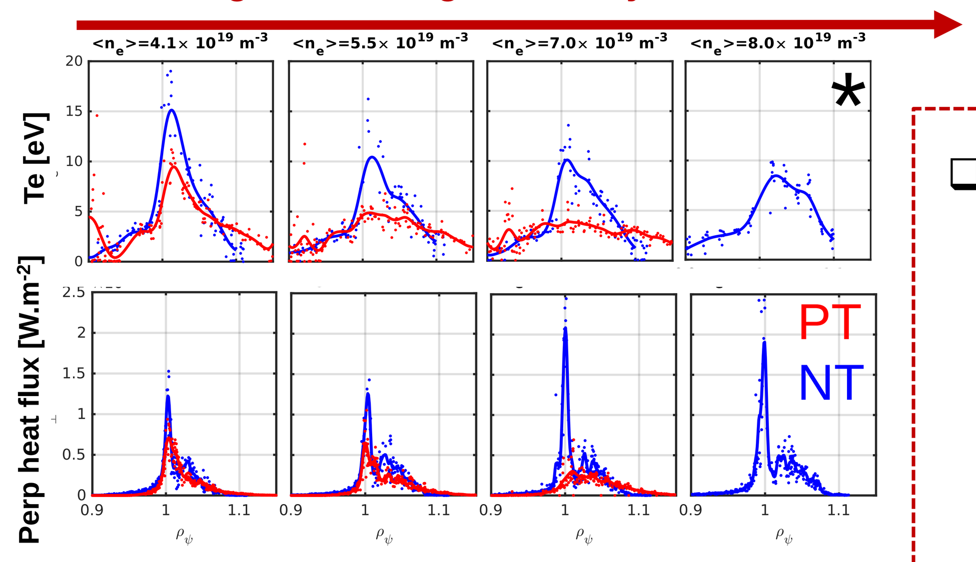


Outer target measurements

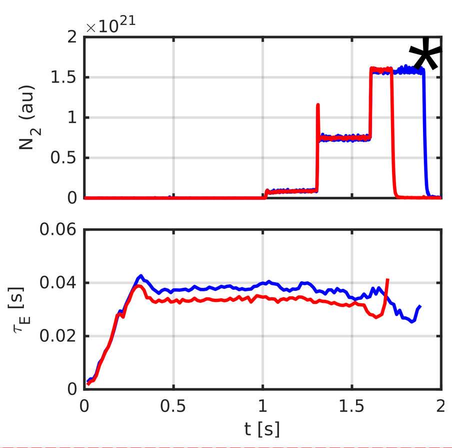
- Jsat roll-over at ***outer*** target observed in PT plasmas, *not in the NT discharges*
  - Reduction of OSP T_e and heat flux PT, not for NT
  - At ISP, low Te < 10 eV in both cases, higher Jsat peak in PT

Increasing line-averaged density



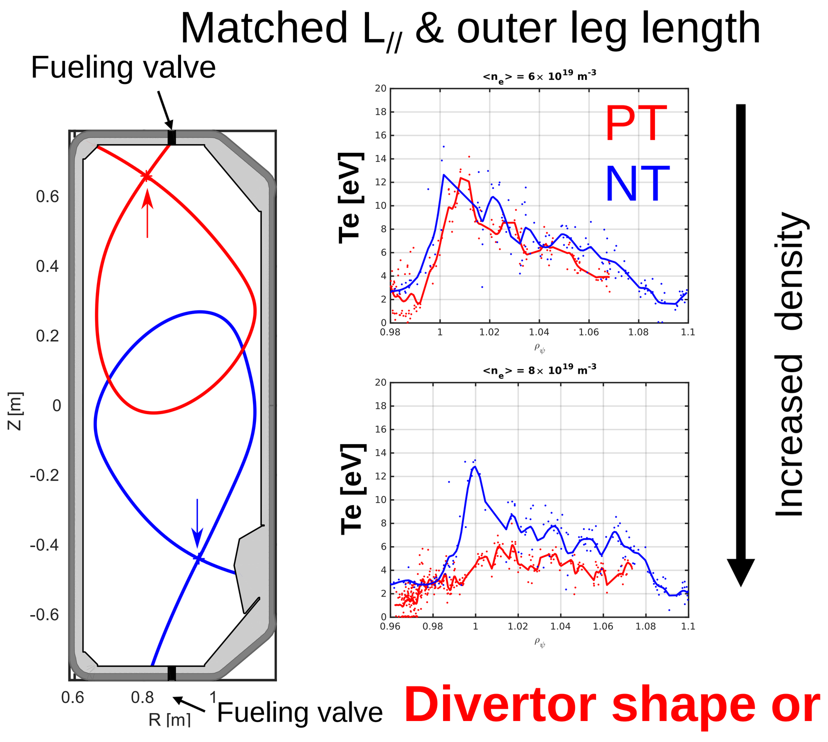


- N_2 seeding : cooling at the expense of confinement

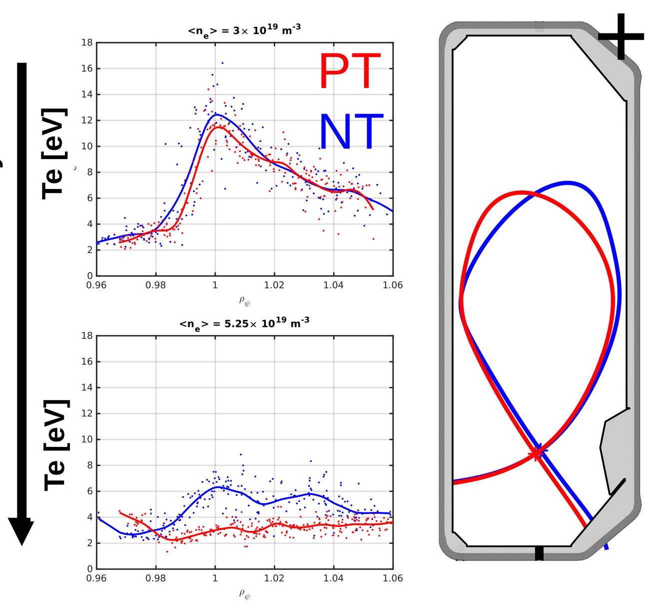


On the role of divertor shape

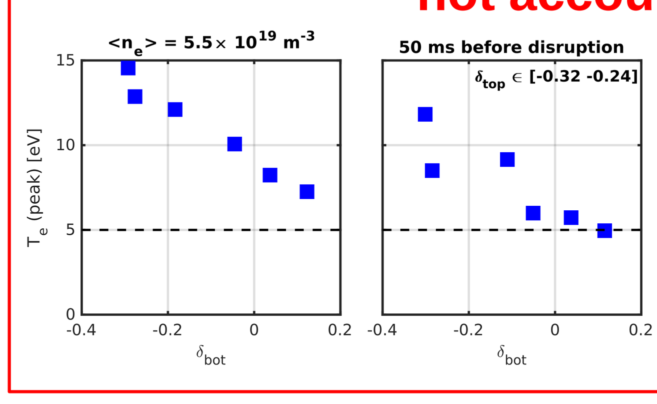
Matched $L_{//}$ & outer leg length



Matched divertor shapes



Divertor shape or connection length ratio do not account for differences in behavior

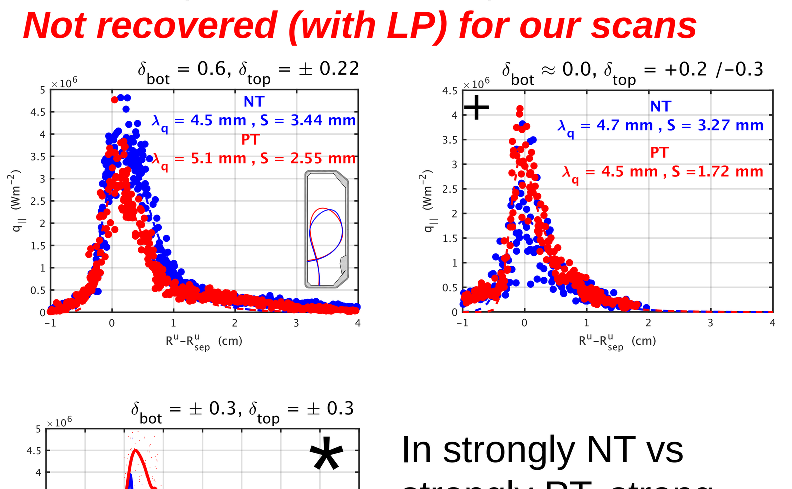


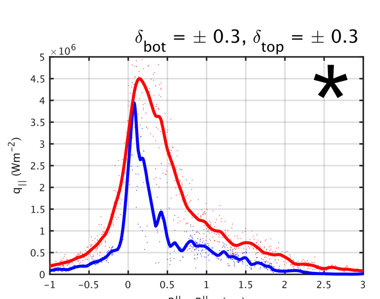
- For given density, peak OSP, T_e increases as lower triangularity is reduced
- Possible indication of a more peaked heat-flux (smaller λ_q) ?
- At ISP (for matched geometries), similar behavior, with low Te < 10 eV from the start

Why is detachment harder to achieve ?

Change in λ_q

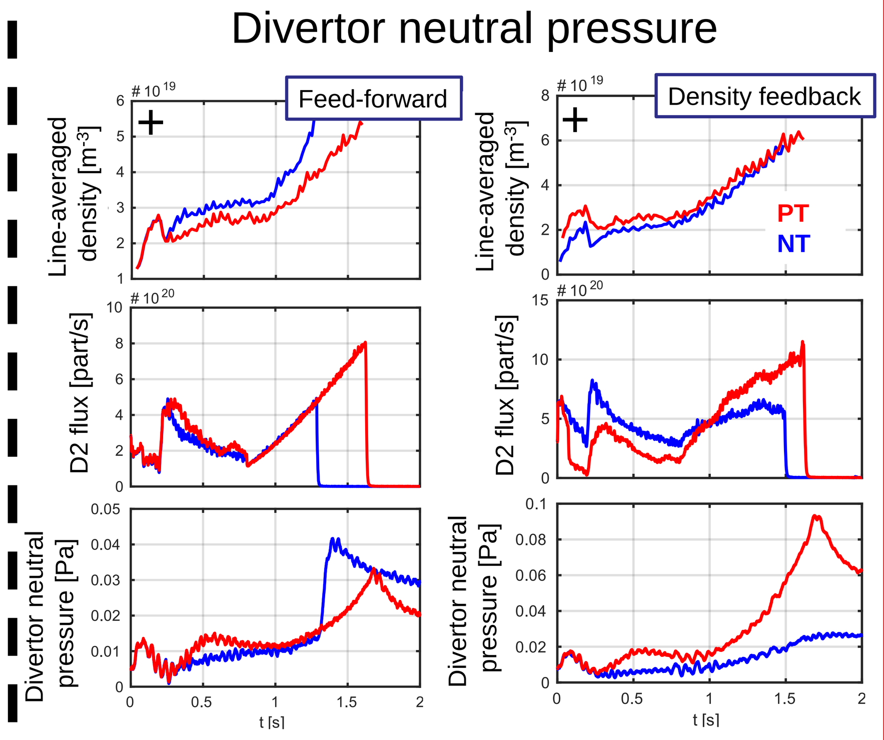
Previous work on TCV [5] found lower λ_q in discharges with neg. top. δ, keeping bot. δ constant (IR measurements)
Not recovered (with LP) for our scans





In strongly NT vs strongly PT, strong difference in heat-flux shape.
More peaked in NT, but integral smaller

Divertor neutral pressure



Systematically lower divertor neutral pressure in NT compared to PT
Consistent with increased difficulty to detach

Conclusions & Perspectives

- **Negative Triangularity** appears as a **good candidate** for intrinsically **ELM-free operation**, associated with several advantages for power exhaust: *No ELMs, no need for* $P_{sep} > P_{LH}$
- Experiments on TCV have demonstrated the **enhanced confinement associated with Negative Triangularity**, but **power exhaust** remains **challenging (harder to detach)**
- Perspective & future work :
  - **Further investigations of the λq scaling**
  - **Extension to high-power (NBH/ECRH) NT, comparison to PT H-Mode**
  - **Exploration of NT with divertor baffles (enhanced detachment access)**

[1] Y. Camenen et al, Nucl. Fusion 47 510 (2007)
[2] S, Coda et al, Plasma Phys. Control. Fusion 64 014004 (2021)
[3] M. E. Austin et al, Phys. Rev. Lett. 122, 115001 (2019).
[4] A. Marinoni et al, Reviews of Modern Plasma Physics 5, 6 (2021)
[5] M. Faitsch et al, Plasma Phys. Control. Fusion 60 045010 (2018).

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This work was supported in part by the Swiss National Science Foundation.

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.