Core-edge Integration Studies In Negative Triangularity In TCV

EX-D - Divertor
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Introduction

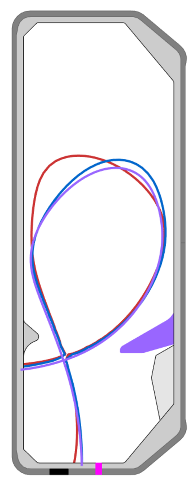
- **Negative Triangularity** (NT) configurations have demonstrated **higher energy confinement** compared to the conventional **Positive Triangularity** (PT) configurations [1].
- Experiments on TCV and DIII-D have shown that **NT L-Mode plasmas can exhibit confinement comparable to H-mode** [1].
- Potential for high-confinement **L-Mode reactors** that circumvent H-mode challenges: **no ELMs, no power thresholds (L-H, H-L).**

In this contribution, we demonstrate the compatibility of NT plasmas with reactor relevant operation and core-edge integration.

Comparing intrinsic differences between NT and PT detachment

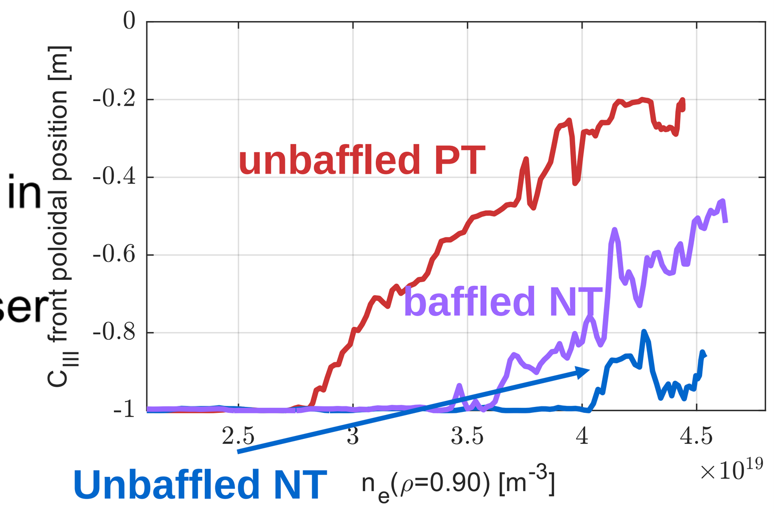
Device: TCV tokamak (R_0=0.88 m, a=0.24 m, B_0=1.44 T)
Ohmic L-Mode, I_p=220 kA, with upwards ion ∇B drifts and density ramps $\langle n_e \rangle \sim 3.5 \rightarrow 8\times10^{19} m^{-3}$

- Fixed divertor geometry: (bottom triangularity) $\delta_l = 0.5$. Divertor baffles increase divertor closure
- NT configurations (top triangularity $\delta_u = -0.3$), unbaffled and baffled
- Compared to an unbaffled PT ($\delta_u = 0.3$)



Results:

- Increased divertor closure: $p_n^{div} \uparrow \rightarrow T_e \downarrow$ at target
- At high $\langle n_e \rangle$, target cooling is **equivalent** in baffled NT and unbaffled PT
- CIII front moves (proxy for Te~10eV) closer to the X-point with higher closure but **does not reach PT levels**



In Ohmic L-mode, achieving divertor detachment is significantly harder in NT configurations compared to Positive Triangularity (PT) [2,3].

- Ascribed, at least in part, to smaller λ_q in NT vs PT, linked to δ_u (and not δ_l) [4,5,6]
- Consistent with SOLPS-ITER simulations of NT vs PT discharges, which require smaller perpendicular transport in NT to match experiments [8,9]

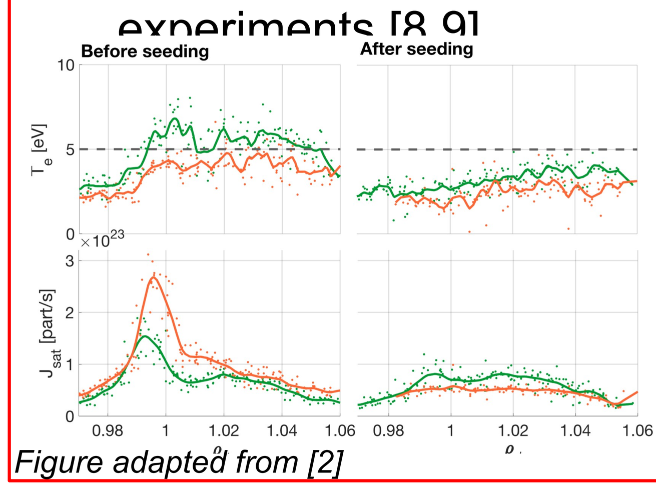


Figure adapted from [2]

Figure adapted from [5]

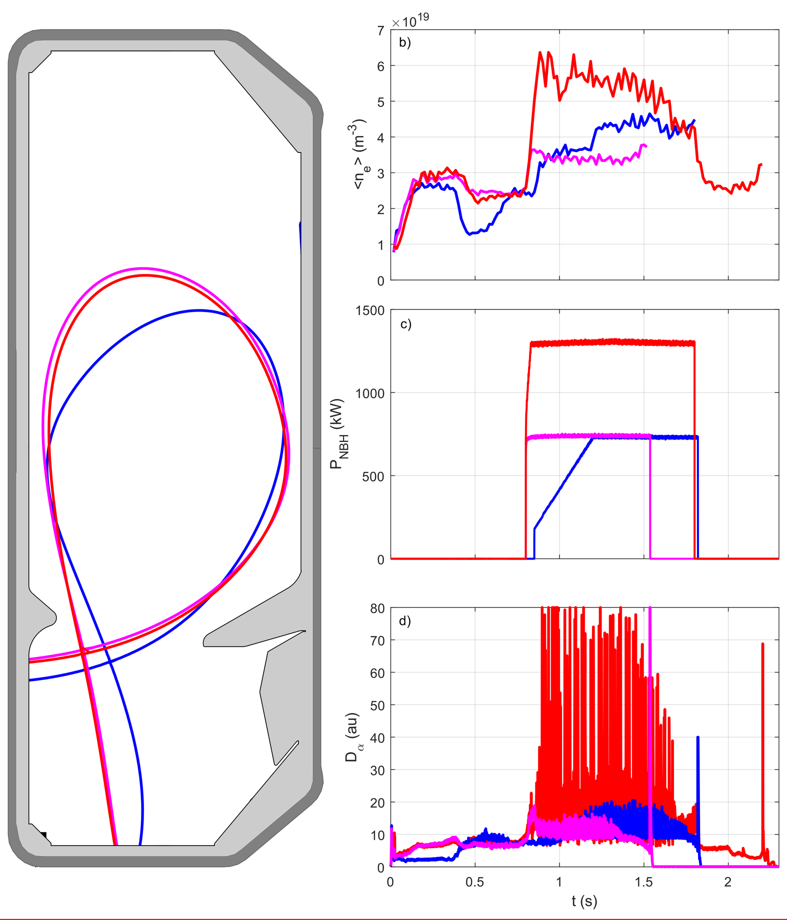
Impurity seeded detachment is **achieved in NT**, with 3 times more N_2 injected than for **PT**, at **the cost of energy confinement and N_2 penetration in the core**

Towards high-performance, fully detached NT scenarios

- NBI-heated L-mode NT compared against NBI-heated L- and H-mode PT
- Ip=170 kA with downwards ion ∇B drifts.
- D_2 fueling and N_2 seeding.

Config,	δ_u / δ_l	NBI power
NT L-Mode	-0.29 / 0.45	750 kW
PT L-Mode	0.19 / 0.7	750 kW
PT H-Mode	0.19 / 0.7	1.3 MW

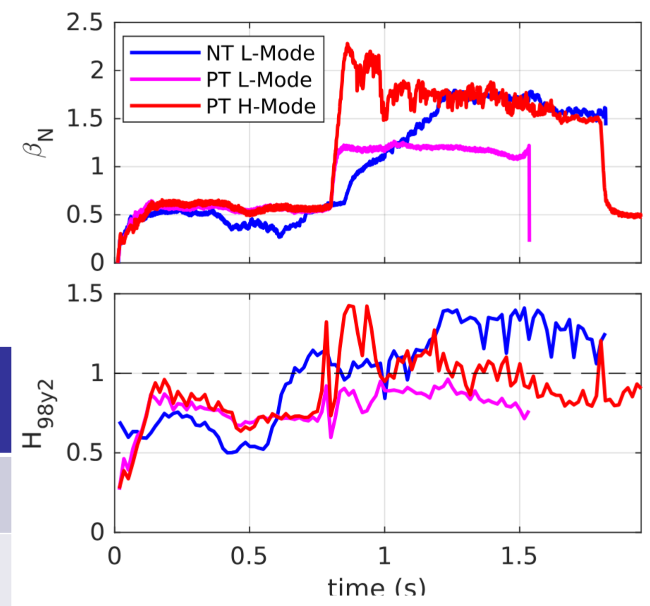
- Density control is a significant challenge in the NT scenarios.



Core performance comparison

MHD Activity:

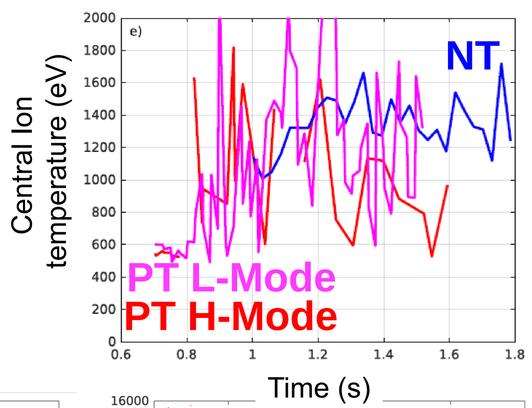
- PT H-Mode: large m/n=2/1 tearing mode, causing significant confinement reduction.
- The NT L-Mode: weak m/n=2/1 mode, reduces confinement by up to ~15%,



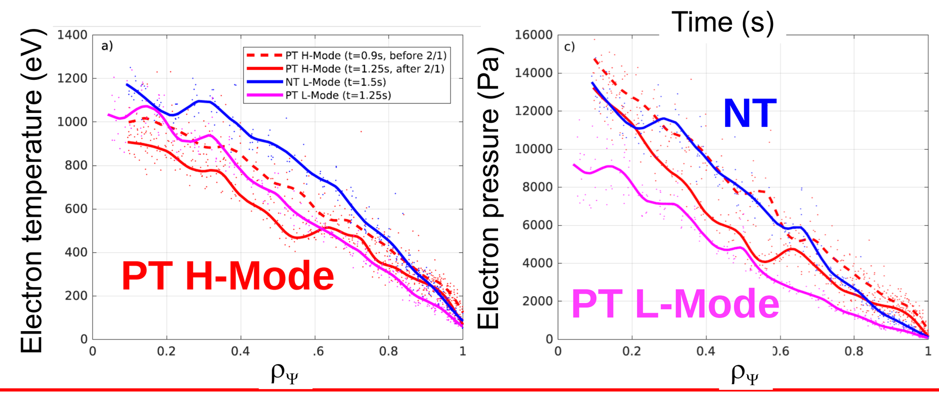
Config,	β_N stationary (peak)	$H_{98,y2}$ station. (peak)
NT L-Mode	1.6	1.3
PT L-Mode	1.2	0.8
PT H-Mode	1.6 (2.1)	1 (1.4)

NT L-mode performance comparable to PT H-Mode

- NT L-Mode shows higher central electron and ion temperatures than the PT H-Mode.

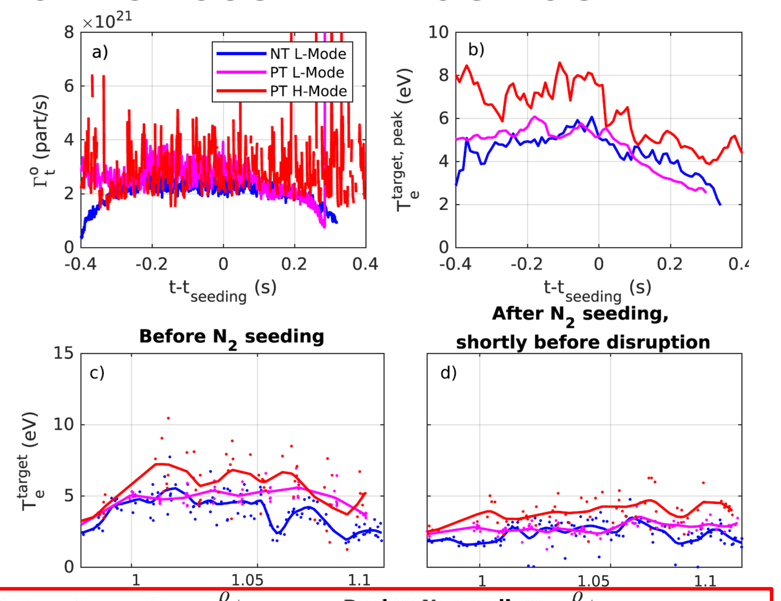


- Electron pressures are similar between NT L-Mode and the pre-MHD PT H-Mode in the core.
- No edge pedestal is observed in NT, unlike PT H-Mode.

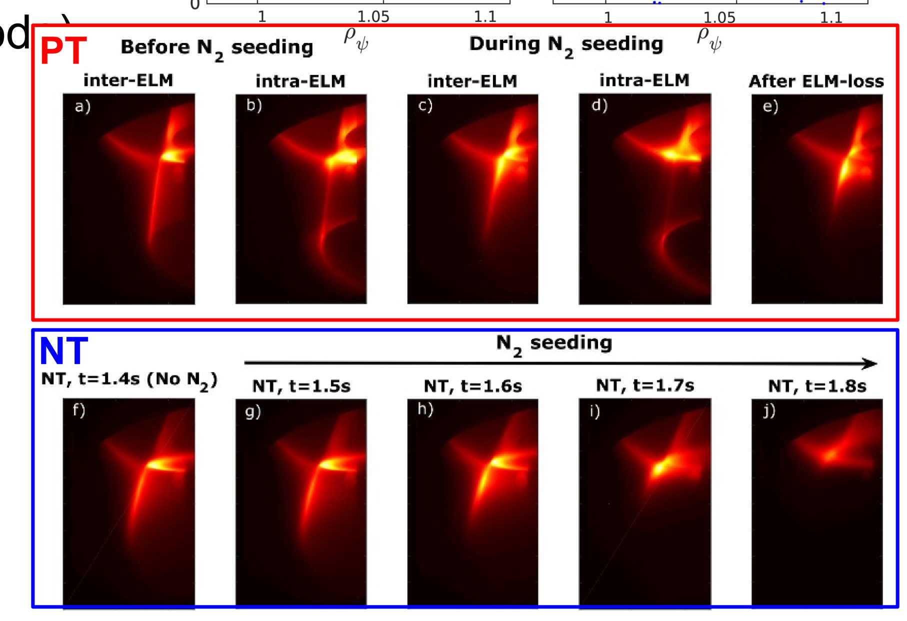


Achieving Detachment in High-Performances NT Plasmas

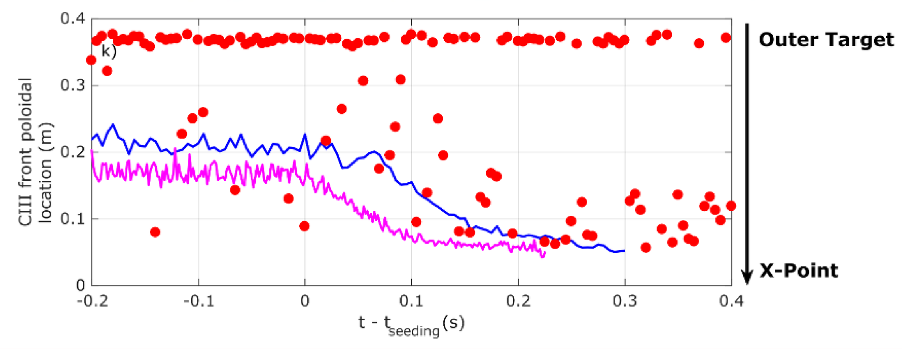
- Before N_2-seeding, peak OSP T_e:
  - 6 eV for both NT and PT L-modes.
  - 8 eV for both PT H-mode (inter-ELMs)
- With N_2-seeding, all three scenarios show signs of detachment :
  - Drop in particle flux to OSP
  - T_e reduction at outer target, peak below 5 eV (inter-ELMs for H-Mode)



- CIII front, (~8-10 eV proxy) :
  - In L-Mode NT and PT, smooth movement towards X-Point
  - In H-Mode PT, movement towards X-Point inter-ELMs, but goes back to OSP at each ELM
    - Interpreted as reattachment / burn- through



- Modest effect of N_2-seeding on NT performances, whereas PT H-Mode ultimately lost
- An X-Point Radiator is formed in the NT L-Mode



Conclusions

- Detachment of Ohmic NT plasmas more difficult than similar PT plasmas, ascribed in part to smaller SOL width.
- **Successfully developed a stationary NT L-mode scenario with performance on par with a PT H-Mode.**
- Demonstrated compatibility with a strongly detached divertor, with only a modest confinement reduction.
- **Establishes NT as an attractive reactor regime by combining good confinement with a quiescent L-mode edge, avoiding ELMs.**
- ***Future Work:*** Extend scenarios to higher input power (NBH and ECRH), coupling with Alternative Divertor Configurations (Snowflake) [7].

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