WPTE-RT07: Negative Triangularity scenarios as an alternative for DEMO

session I - TCV

C. Piron

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Outline

WHY Motivation

WHAT Negative triangularity

- Definition
- Scenario features

HOW WPTE-T07

- TCV
- DTT relevance
- Some results (preliminary)

Conclusions

H-mode is intrinsically challenging in a reactor

The high confinement of H-mode plasmas is beneficial to reduce the capital cost of a power plant, but:

☹ power density that will be convected to the reactor vessel ($P_{sep} > P_{L \rightarrow H}$ and ELMs) is too high to be withstood by the Plasma Facing Components (PFCs)

Though the challenge is being tackled:

- Plasma exhaust strategies
- Active ELM control techniques
- ELM-free H-mode scenario development

Fusion community is questioning whether this regime is optimal for future reactors (no doubts that H-mode-like level of confinement is needed…)

→ **Alternative magnetic configurations are being explored (or revisited)**

Negative triangularity is a promising candidate

Major radius $R_{geo} \equiv (R_{max} + R_{min})/2$

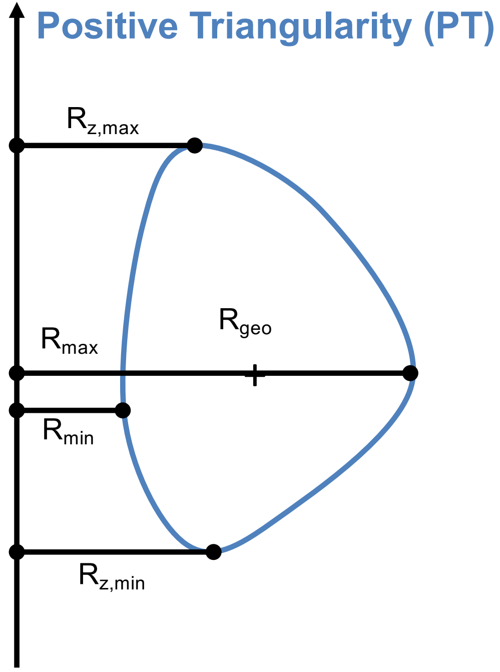
Minor radius $a \equiv (R_{max} - R_{min})/2$

Upper triangularity $\delta_u \equiv (R_{geo} - R_{z,max})/a$

Lower triangularity $\delta_l \equiv (R_{geo} - R_{z,min})/a$

[1]

$R_{geo} > R_{z,*}$



[1] T. C. Luce 2013 Plasma Phys. Control. Fusion 55 095009

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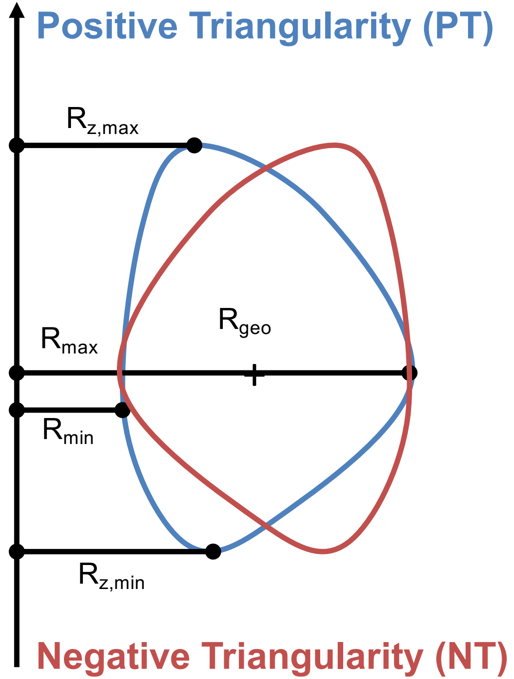

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Negative triangularity is a promising candidate

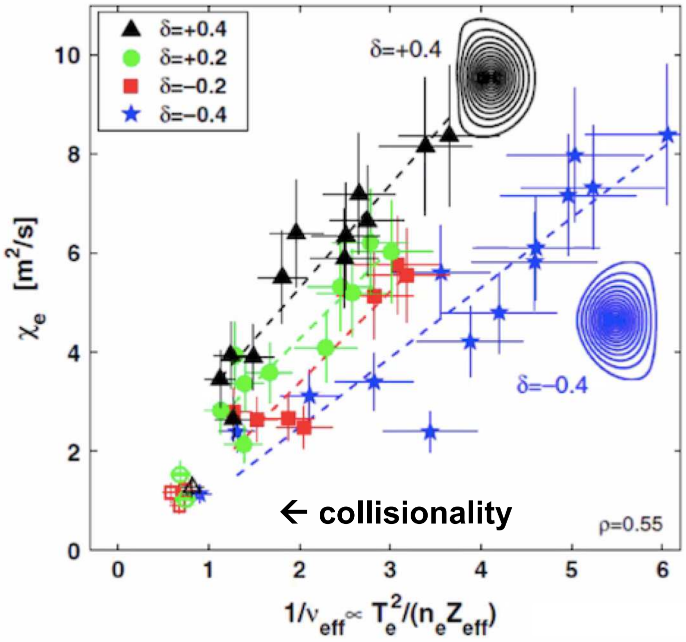
L-mode plasmas with H-mode-like core pressure levels without any pedestal
→ Core confinement and power handling compliant with reactor requirements

Core:

- Improved thermal plasma transport
  EC-heated plasmas [3]:

$$\tau_E \propto (1+\delta)^{-0.35\pm0.3}$$

TCV EC-heated



[2]

[2] J. Camenen Nucl. Fus. 47(7), 510 (2007)
[3] Pochelon et al Nucl. Fus. 39 1807 (1999)

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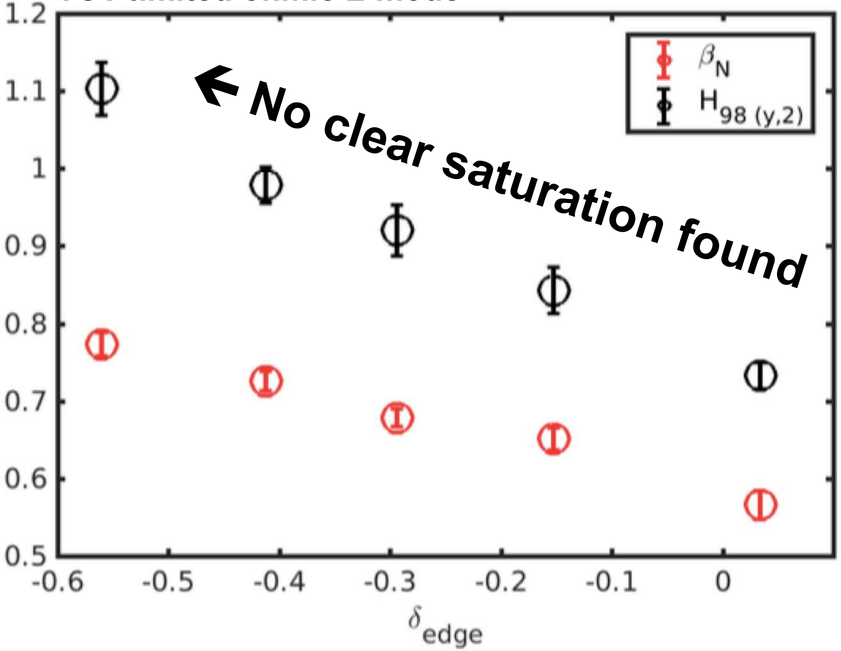
Core:

- Improved thermal plasma transport
  EC-heated plasmas [3]:

$$\tau_E \propto (1+\delta)^{-0.35\pm0.3}$$

- Improved FIs transport [5]
  - Reduced AE
  - Larger FIs content

TCV limited ohmic L-mode



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Core:

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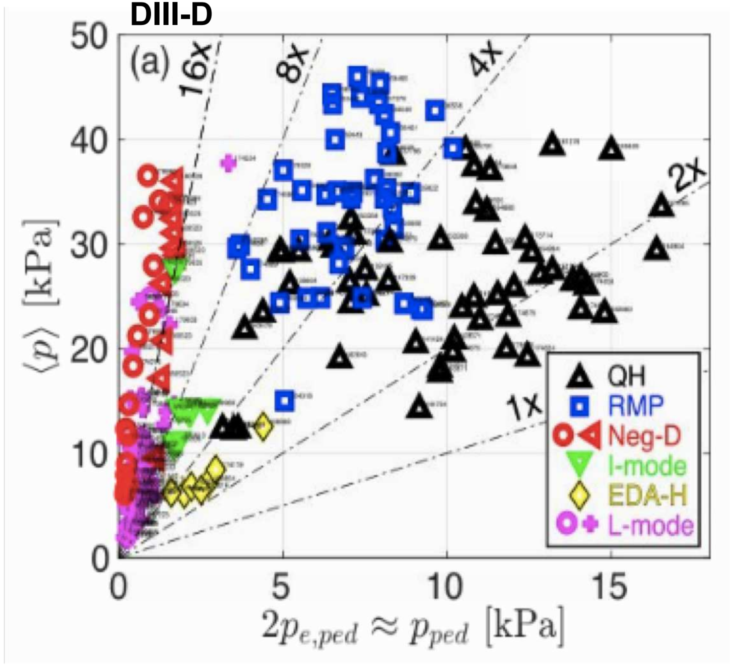
- Improved FIs transport [5]

Edge:

- No ELMs
- No impurity retention

DIII-D



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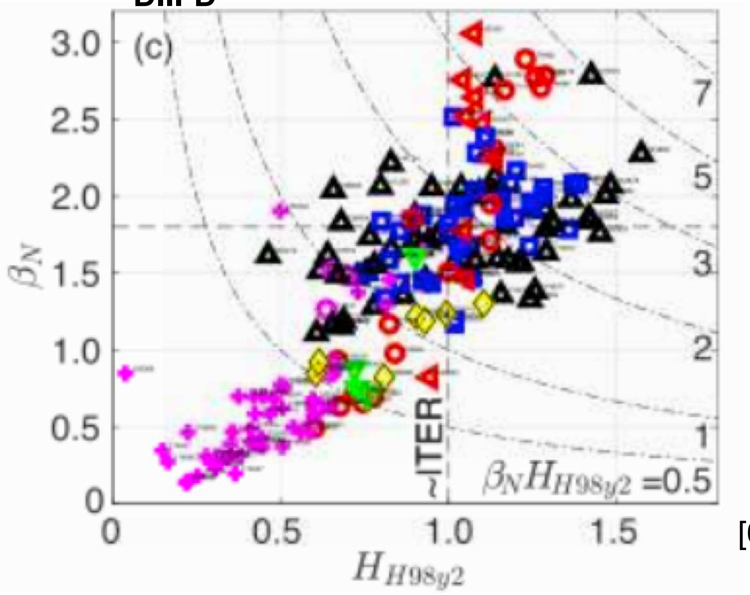
Edge:

- No ELMs
- No impurity retention
- Wider SOL heat flux [7]

DIII-D



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[6] C. Paz Soldan, Plasma Phys. Control. Fusion 63 (2021)
[7] A. Marinoni et al 2021 Nucl. Fusion 61 116010

Motivation for Research Topic 07

- Negative triangularity tokamak operations pioneered in TCV since '90s. (Moret et al, PRL 1997; Pochelon et al, NF 1999; …) and continuously explored up to now (see e.g. Coda et al, PPCF 2021). Recent review paper: A. Marinoni, O. Sauter, S. Coda, *A brief history of negative triangularity tokamak plasmas*, Reviews of Modern Plasma Physics (2021) 5:6
- More recently NT plasmas gained increasing interest in DIII-D (Austin et al, PRL, 2019; Marinoni et al, PoP, 2019; …) and AUG.
- Suggested as DEMO/reactor relevant (in L-mode) for favorable power handling capabilities (Kikuchi et al, EPS conf, 2015; Medvedev et al, NF, 2015, Kikuchi et al, NF, 2019; …)
- Fully part of the EUROfusion general discussion on DEMO scenario integration and on the need to avoid (type I) ELM instabilities (see e.g. F. Maviglia, M. Siccinio, H. Zhom, "Key DEMO Physics Uncertainties and Related Investigation Needs", Sept. 2020, EUROfusion IDM).

T. Bolzonella | RT07 2022 KoM | Remote | 20/01/2022 | Page 2

Since 2021 in FP9 WPTE-RT07 TSVV-02

WPTE-RT07 at a glance

Scientific objectives

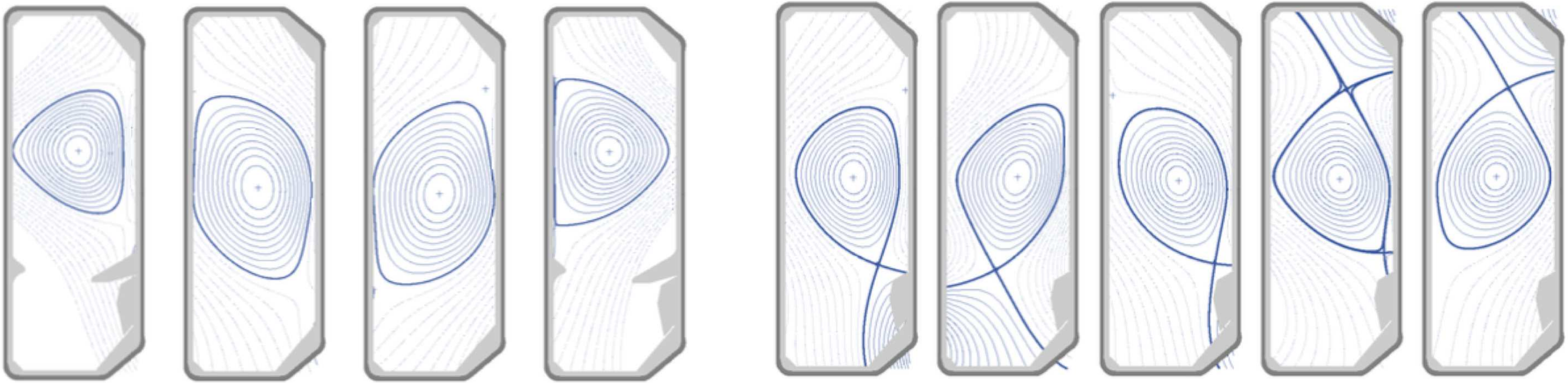
D1. Advanced MHD equilibrium and stability analysis of TCV and AUG plasmas.
D2. Develop similar scenarios in TCV and AUG to support iDTT design.
D3. Investigate power exhaust and detachment with simulations (2021) and in experiments in AUG and TCV (2022).
D4. Provide answers on the plasma core confinement properties (density limit, plasma current limit, …) to the EUROfusion Ad-hoc Group ("Proof of principle Phase").

year	AUG	TCV
2021	0	0
2022	1 / 16 (+ 0 contingency)	0 / 60 (+ 0 contingency)

1st session at TCV in 14-18/02/22
#20 shots

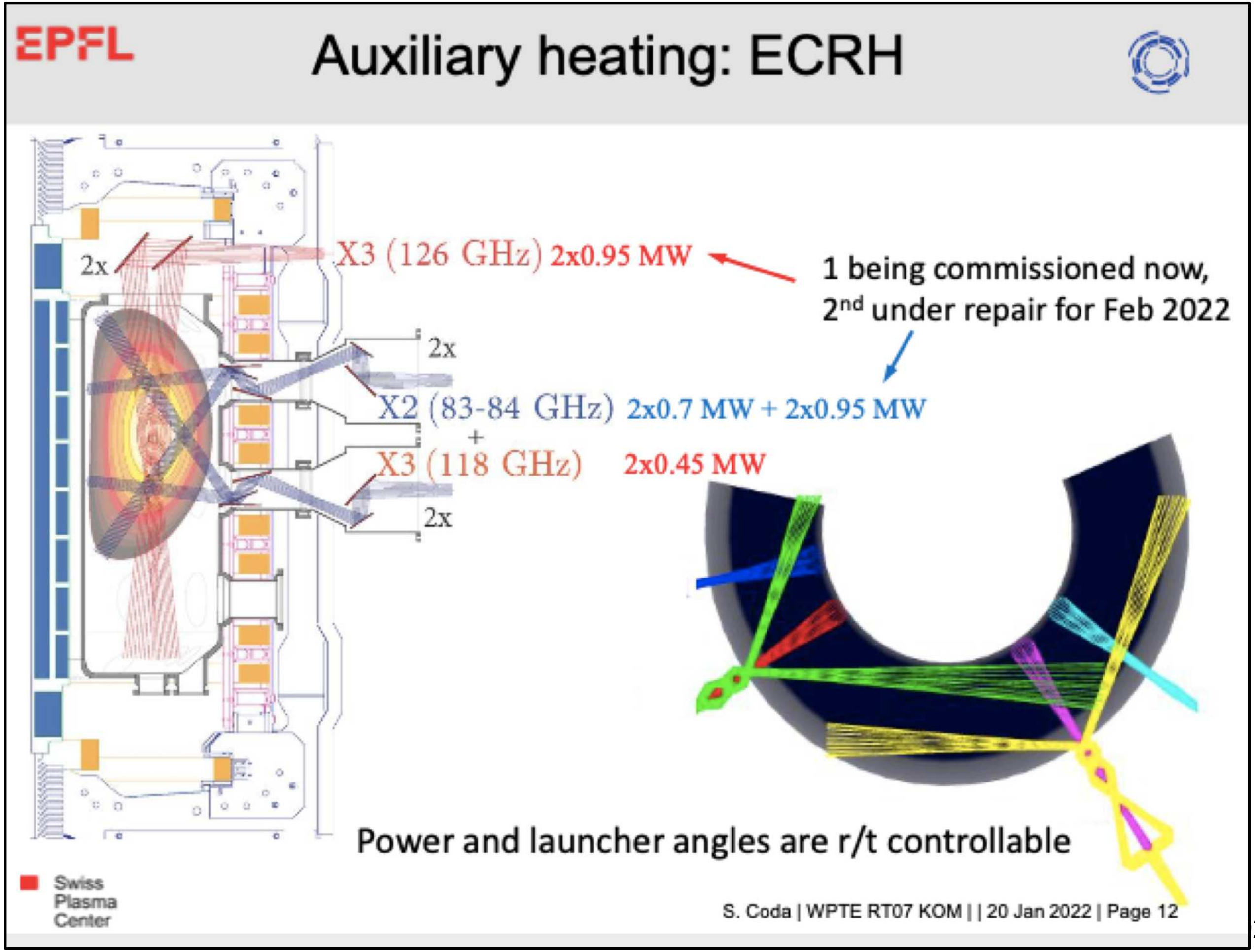
Tokamak à Configuration Variable (TCV)

Large variety of NT shapes:



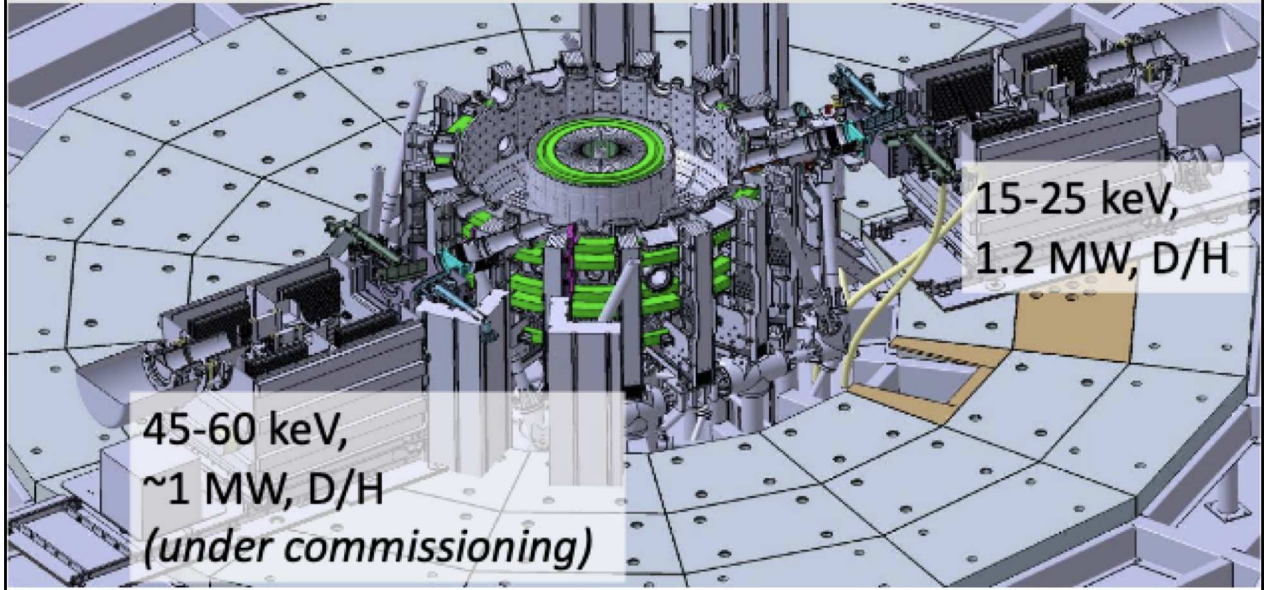
Limiter

Divertor


EPFL
Auxiliary heating: ECRH
X3 (126 GHz) 2x0.95 MW
2x
1 being commissioned now,
2nd under repair for Feb 2022
2x
X2 (83-84 GHz) 2x0.7 MW + 2x0.95 MW
+
X3 (118 GHz) 2x0.45 MW
2x
Power and launcher angles are r/t controllable
Swiss Plasma Center
S. Coda | WPTE RT07 KOM | | 20 Jan 2022 | Page 12

EPFL

Auxiliary heating: NBI



- Enhanced beam duct protection underway ⇨ extension to full specs (full power for 2 s) expected in mid-2022
- Power is r/t controllable
- One beam is always counter-current

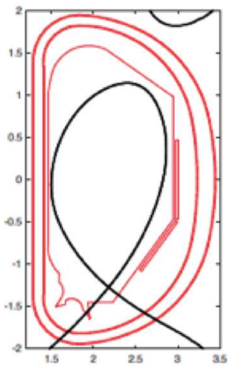
Proposal in support of DTT design

Negative vs positive triangularity plasmas with dominant ITGs in ASDEX-Upgrade and TCV in view of iDTT design

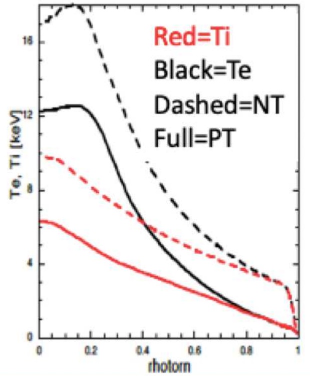
- **Proponents and contact person:**
  paola.mantica@istp.cnr.it, F. Crisanti, P.Innocente, A.Mariani, T.Putterich, T.Happel, J.Hobirk

- **Scientific Background & Objectives**
  -Increasing interest in performance of negative triangularity scenarios for DEMO
  -iDTT under EUROfusion request is able to modify design to allow NT since early days
  -preliminary TGLF simulations do not show the core improvement that should compensate the pedestal loss
  -Difference with respect to DIII-D/TCV may be metallic wall (low Zeff) and dominant ITG
  -Experiments on AUG with similar NT shape as iDTT and NBI+ECH to have dominant ITG could provide precious elements to validate models for extrapolations
  -Complementary data could be obtained from TCV with enhanced NBI (although still C wall)

- **Experimental Strategy**
- Compare NT and PT plasmas with same q95, collisionality, power to identify changes in transport
- Exact strategy to be discussed with domestic team in view of the domestic AUG/TCV programs on NT, which may have already useful pulses for iDTT



iDDT NT shape, $\delta_{95\%}^{up}$=-0.3, $\delta_{95\%}^{bot}$=+0.05



TGLF SAT1 predictions for iDDT NT vs PT shape (density is similar)

Proposed devices/pulses for device

Device	# pulses proposed	# pulses for scenario
AUG	3 (+PT reference)	2
TCV	3 (+PT reference)	2
MAST-U		
WEST		

Scenario target requirements

- **EM**

NT/PT pairs of DTT-like shots (LSN, δ_{top}=-0.3, δ_{bot}=0.05) at q95~ [3, 4] ([-250, -300] kA / -1.4 T → forward BT)

- **PLASMA**

ne ~[2,3]e19m^{-3} → n_{GW} ~0.3
ECRH-X2 density cut-off: ne = 4.3e19m^{-3}

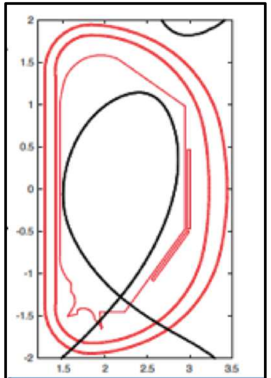
- **H/CD**

(up to) 1MW on-axis co-Ip NBI (15-28keV)
(up to) 0.75MW co-Ip ECRH-X2

- **DIAGNOSTICS**

Core profiles (TS, CXRS, MSE)
Fluctuations (CECE)
Edge (Langmuir)
…

Reproduce DTT NT equilibrium



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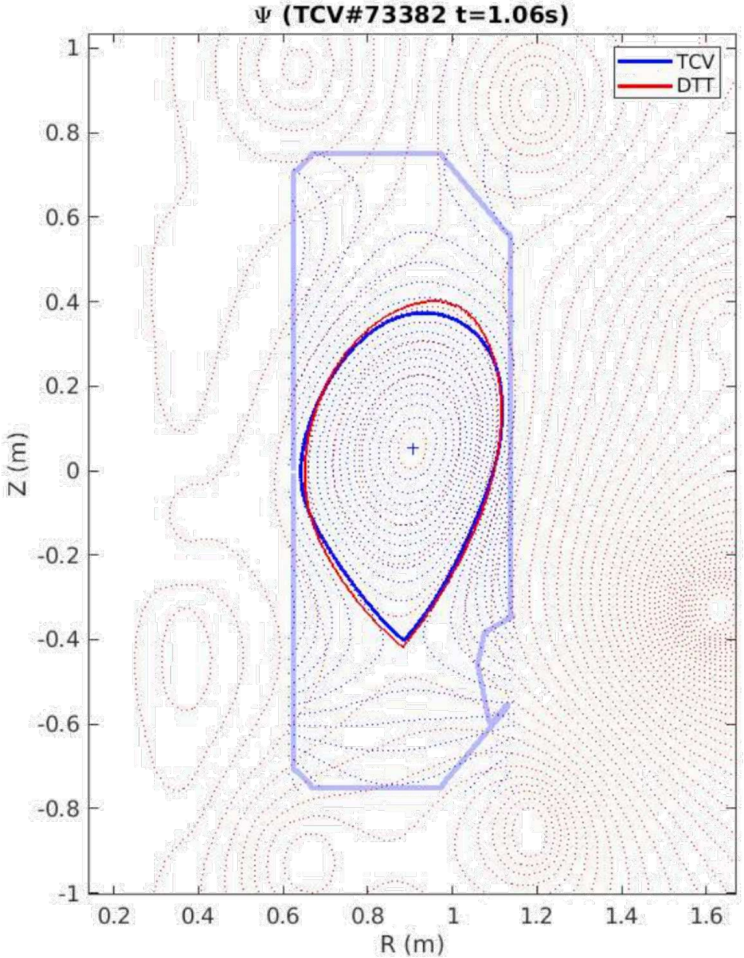
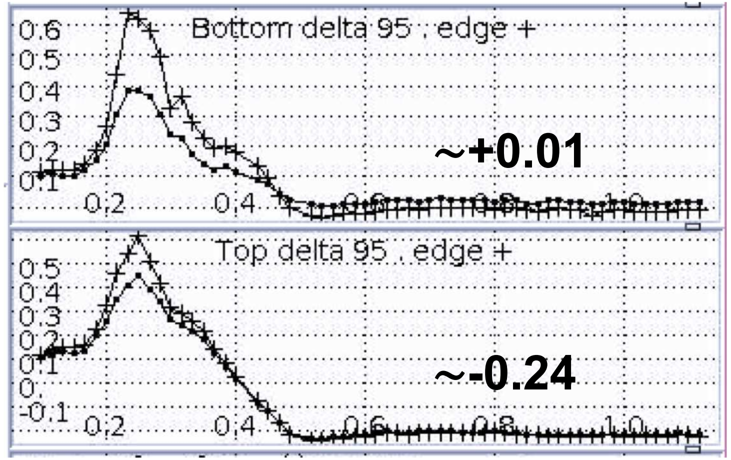
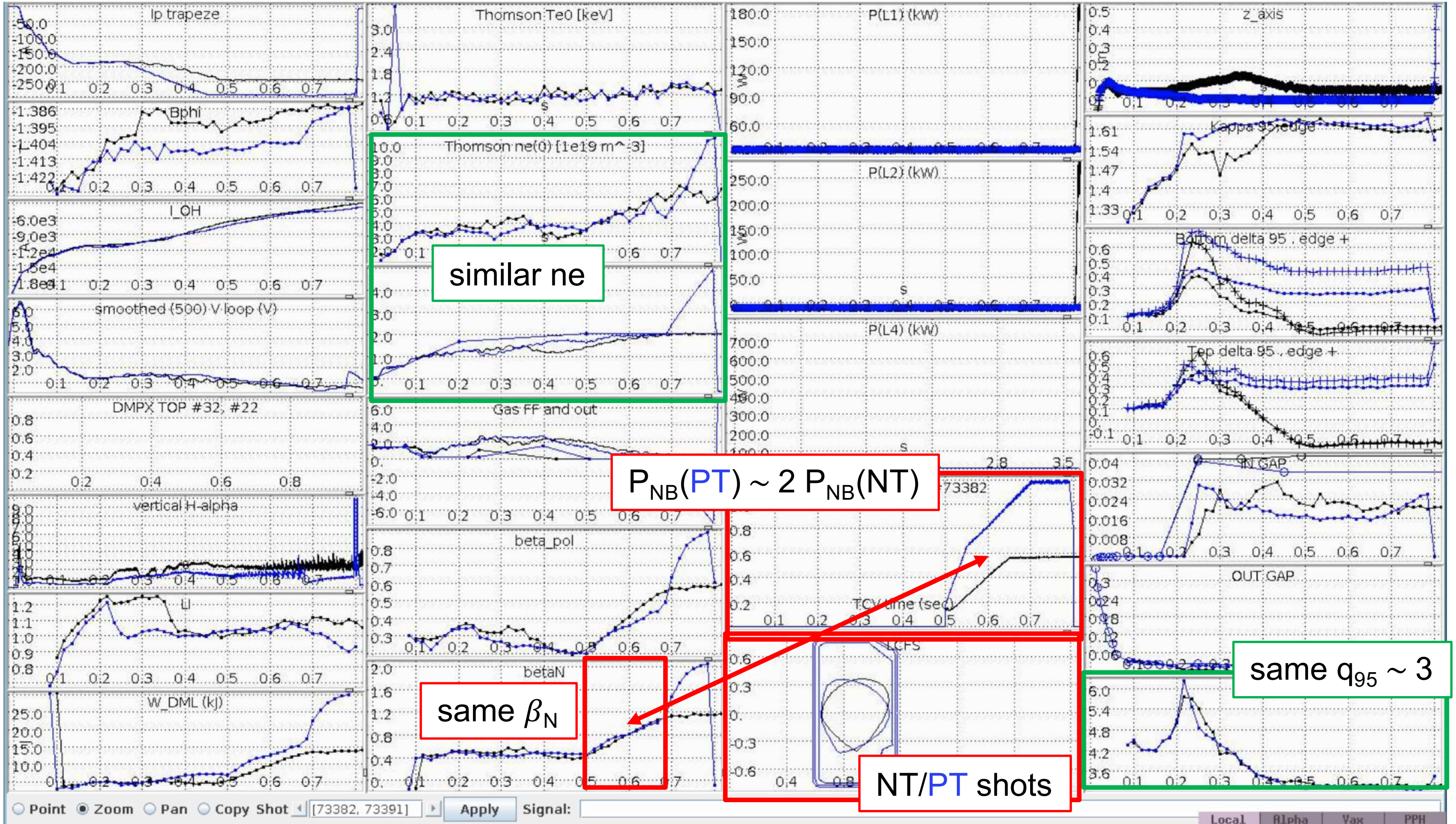




NT/PT pair shots with NBI only



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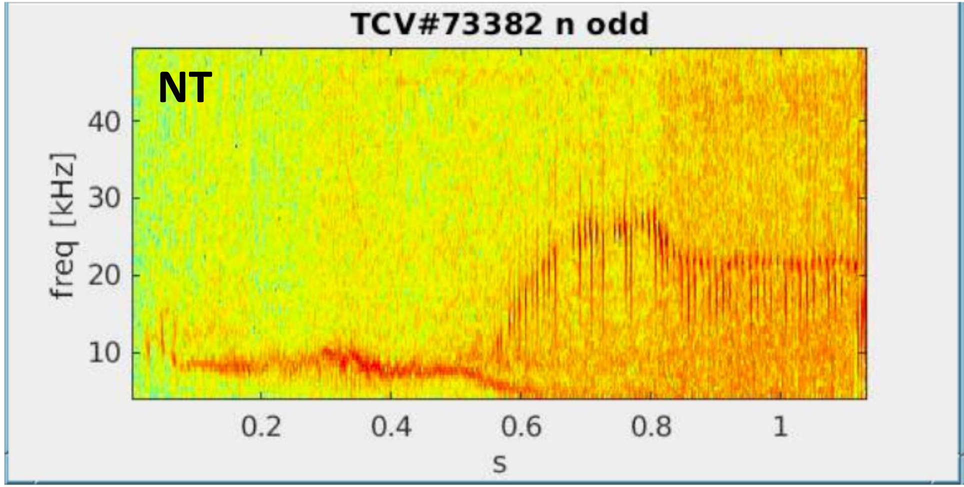
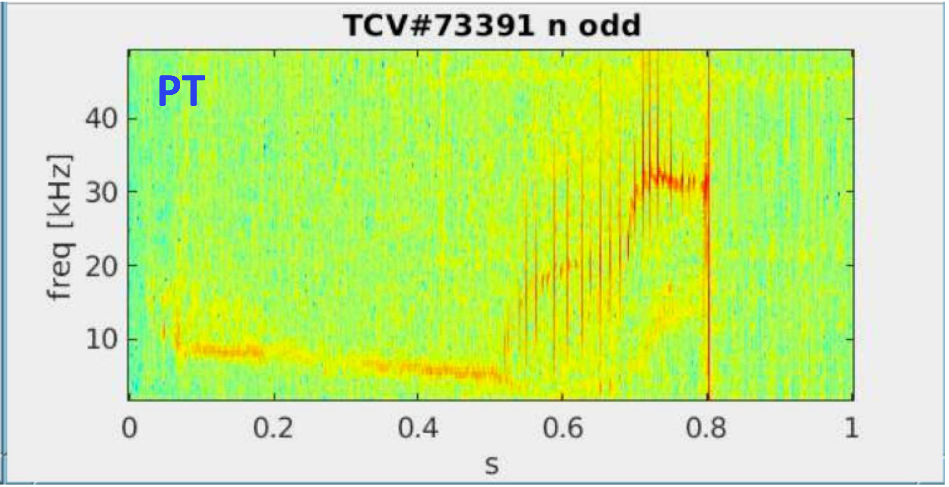
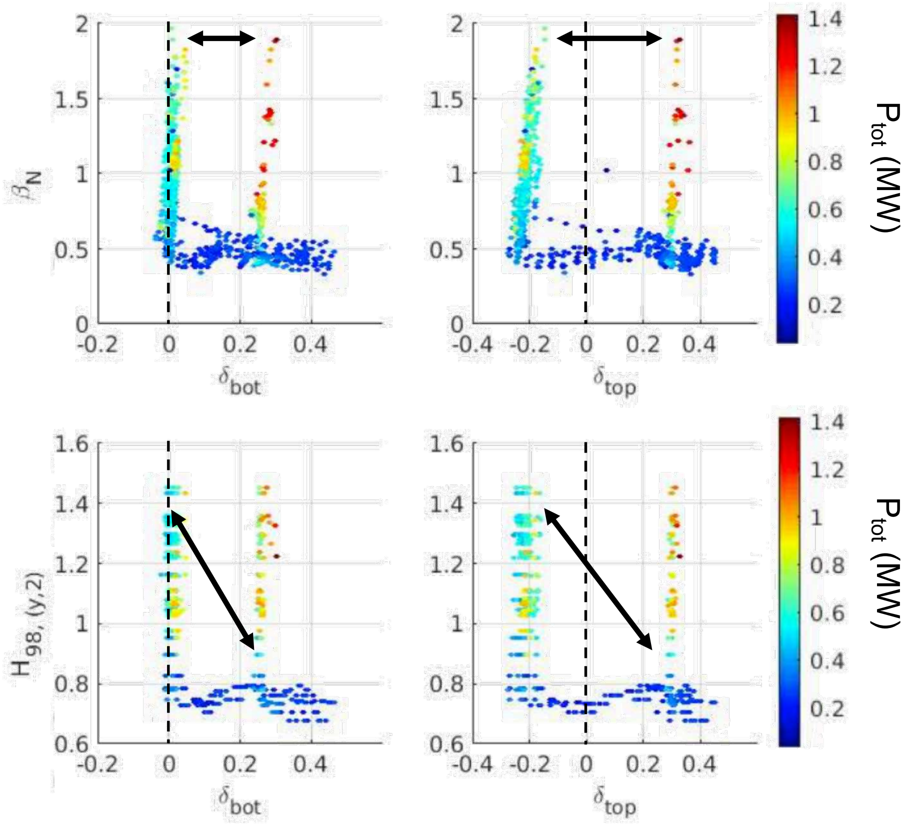




Statistical analyses (preliminary)



NT requires low power to achieve same betaN

NT ~1.5X better confinement at the same power

Preliminary conclusions

WPTE-RT07 I session on TCV:

- DTT-like NT/PT pair shots obtained for Ti>Te (NBI) and Te ~ Ti (NBI+ECRH)
- NT plasmas disruptions mainly due to VDE or for not-optimal equilibrium control (outer wall frequently touched)
- Vivid MHD activity but not disruptive
- Improved NT perfomance wrt PT in L-mode (NT L-mode vs PT H-mode data are not available yet)

- Elevated low-shear NT scenario development was planned too, but has not performed due to ECRH availability