EUROfusion

Topic 13: Control of advanced / non-inductive scenarios

C. Piron and S. Coda

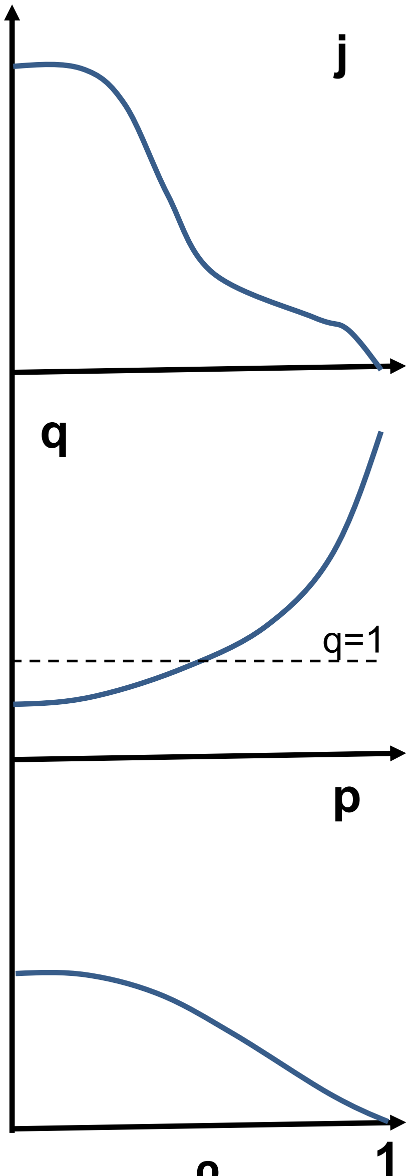
MST1 Review Meeting, Garching, 3.2.2020

EPFL Swiss Plasma Center

ENEA

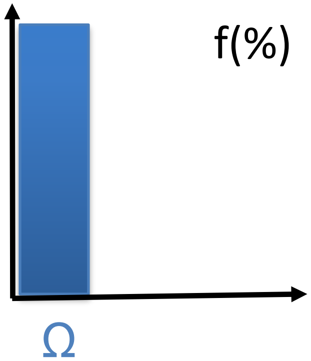
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

From conventional to advanced tokamak scenarios



Conventional scenarios

- $j \sim j_{\Omega} \propto \sigma \propto T^{3/2}$ peaked in the center
- Monotonous q<1 profile
- Low confinement (L-mode)



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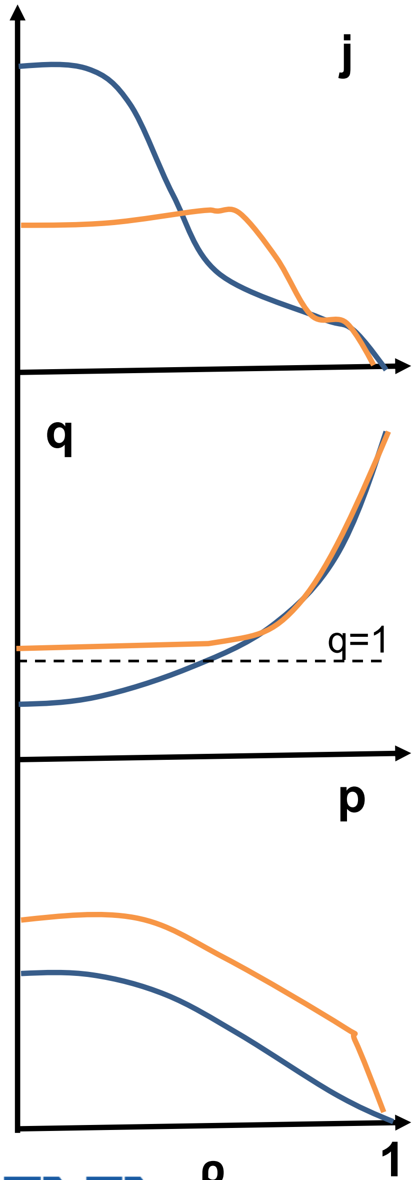

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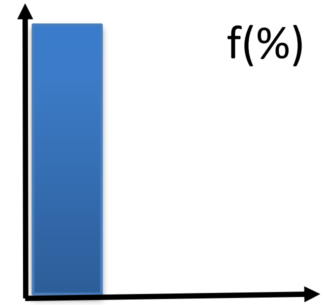
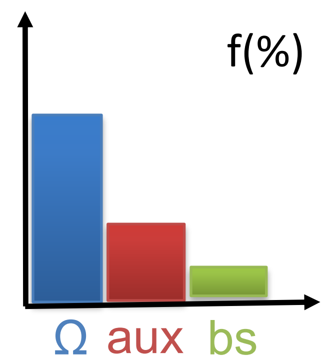


Hybrid scenarios

- $j \sim j_{\Omega} + j_{aux} + j_{bs}\ (\sim \nabla p)$ broad
- Flat q>1 profile
- High confinement (H-mode, External Transport Barrier ETB)



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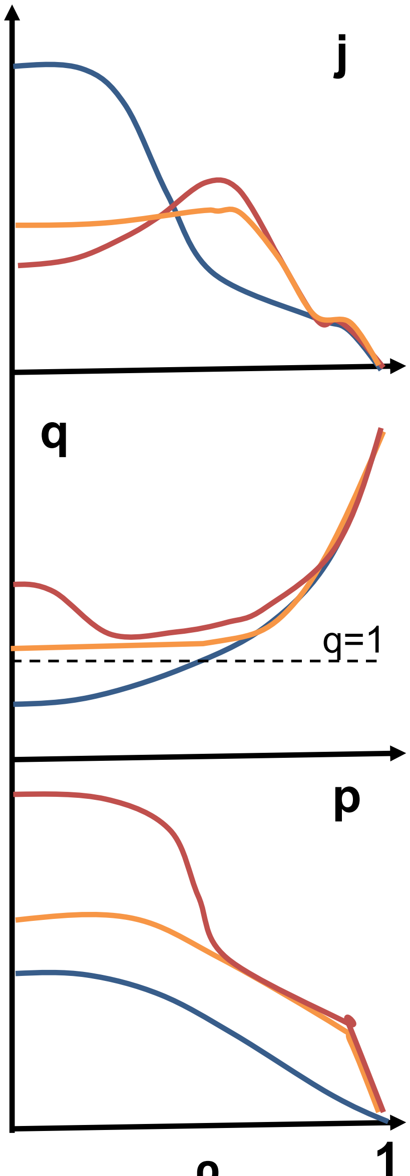

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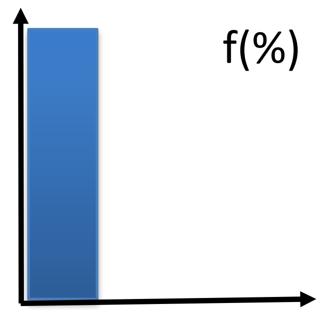

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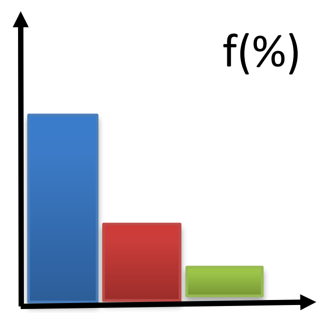
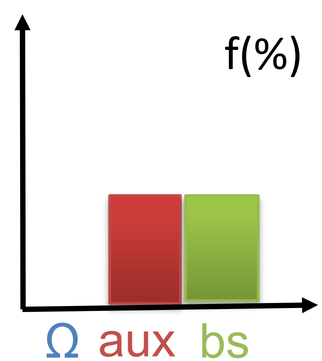


Advanced scenarios

- $j \sim j_{aux} + j_{bs}$ hollow
- Reversed q>1 profile
- High confinement (External + Internal Transport Barrier (E/ITBs))



Outline

- Original proposals
- Objectives and present status
- Planned TCV scenarios
- TCV constraints in 2019
- Observations from 2019 TCV campaign
- Analysis plans
- Plans for 2020 campaign

Topic 13 proposals

1. Investigation and manipulation of MHD in advanced scenarios with reversed shear configurations **TCV MAST-U**
   A.Lazaros, C.Tsironis, V.Kazantzidis, K.Hizanidis, G.Anastassiou, G.Kominis

2. Energy Confinement and Basic Turbulence Measurements in electron internal transport barrier (eITB) **TCV**
   A.T.Biwole, S.Brunner, S.Coda, M.Fontana, A.Iantchenko, L.Porte

3. Extension of the operating space of fully non-inductive high-betaN plasmas towards H-mode on TCV **TCV**
   C.Piron, S.Coda, M.Agostini, T.Bolzonella, G.Giruzzi, S.Nowak, F.P.Orsitto, L.Pigatto, D.Testa, M.Vallar

4. 3D magnetic fields in the first NBI assisted L-mode MAST-U plasmas **MAST-U**
   C.Piron, M.Agostini, F.P.Orsitto, L.Pigatto, L.Piron, M.Vallar

5. VMEC modelling of advanced scenarios **TCV MAST-U**
   C.Ham

6. Modeling of advanced tokamak scenarios with interpretative/predictive Monte Carlo codes **TCV**
   M.Vallar, M.Agostini, F.Auriemma, T.Bolzonella, C.Piron

7. Similarity high beta experiments between MAST-U and TCV **TCV MAST-U**
   F.P.Orsitto, C.Piron

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   ~~*F.P.Orsitto, C.Piron*~~
   ~~**TCV**~~ ~~**MAST-U**~~

Topic 13 objectives

1. Develop advanced scenarios towards β_N>2.5 at TCV and MAST-U.

2. Assess the effect of 3D fields in advanced scenarios (β_N>2.5) on MAST-U.

3. Compare high β_N scenarios between TCV and MAST-U and investigate the physics of spherical tokamaks which can be transferred to conventional tokamaks.

4. Evaluate the H/CD requirements of these scenarios for DEMO advanced scenarios

5. Validate the numerical codes/models based on a systematic comparison between AUG, TCV and MAST-U, clarify the role of the mechanisms stabilising anomalous transport and MHD activity.

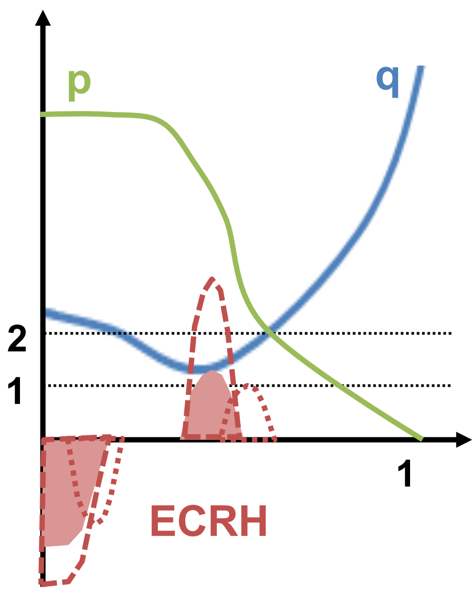
6. Investigate physics processes that control MHD stability and dynamics and quantify the global MHD stability limits of the fully non-inductive and advanced scenarios

Dropping AT on MAST-U is unfortunate©

- Arguably, the need to develop AT scenarios in MAST-U is not in doubt
- It is a wide-open topic with potentially rich returns
- TFLs please reconsider?

TCV strategy #1: ECCD-driven eITB + NBI

- Starting from a MST1 2017/18 fully non-inductive L-mode plasma (LSN, 150kA, 1.45T), scan of X2-(H/CD) and X3-(H) EC power and deposition location in co/cnt-Ip; scan of NB power and off-axis deposition to investigate role of T_e/T_i, fast ions (FIs) and torque on performance and stability (JT-60SA relevant) **P3 O1**



- MARS-F MHD stability analysis to investigate role of q-profile reversal (q0, qmin) **P3 O6**
- Document the conditions for the onset and the dynamics of the MHD activity: **P1,3 O6 P5 O5,6**
  - 3/2, 2/1 D/N-TMs
  - 1/1 helical core mode (VMEC validation)
- TRANSP/NUBEAM predictive / interpretative modeling of NBH/CD and Fis **P6 O1**
- Optimize CECE, TPCI diagnostic set-up to acquire good δTe and δne measurements for GENE modeling validation (TS, CXRS and impurity spectra also needed) **P2 O5**

EPFL

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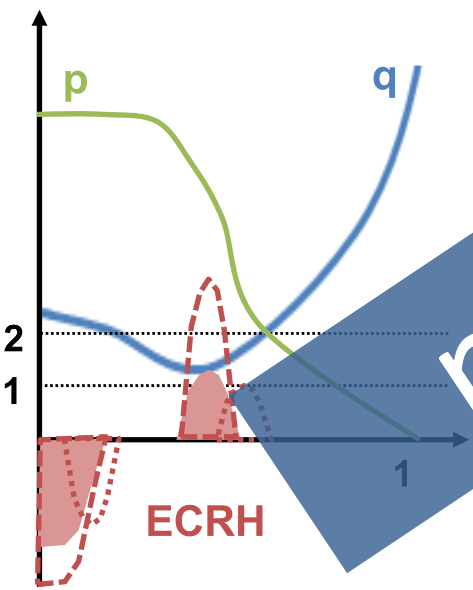

not started yet

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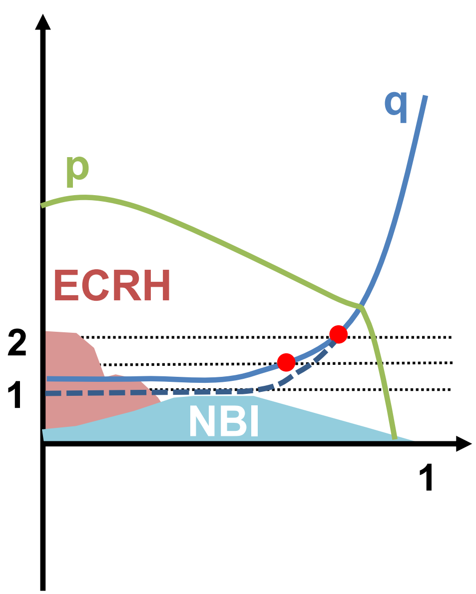
TCV strategy #2: Non-inductive H-mode

- Starting from a MST1 2017/18 fully non-inductive H-mode plasma (LSN, 150kA, 1.45T), scan ECRH and NB power and deposition location to document the role of T_e/T_i, fast ions and torque on L/H power threshold, β_N and f_{BS} (ITER (ITPA) and JT-60SA relevant) **P3 O1**



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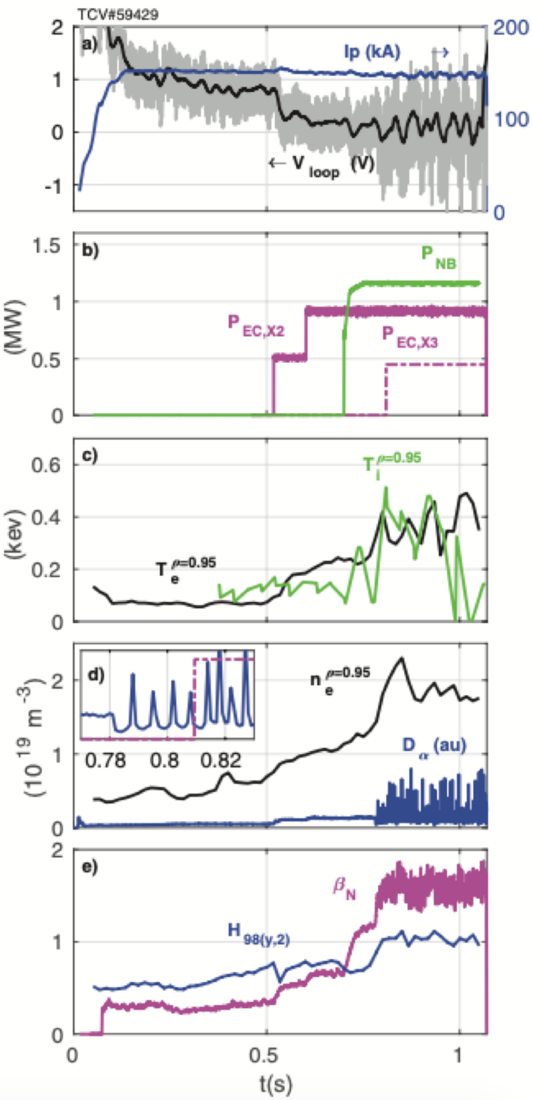
Starting point for «hybrid» scenario development



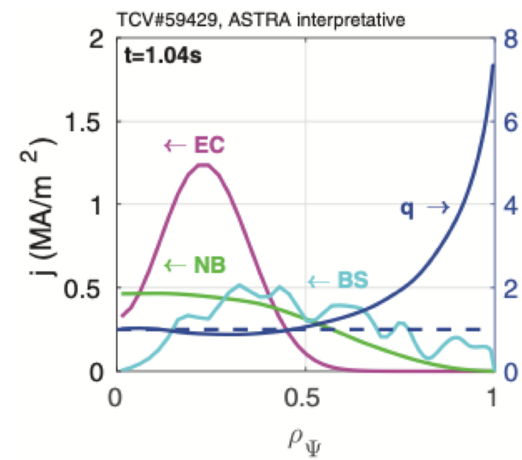
First nearly fully non-inductive H-mode plasma on TCV (2017/18 WPMST1)

✓ Regular type-I ELMs

✓ Ne remains below the EC-X2 density cut-off during H-mode

✗ Disruption caused by an n=1 locked NTM

✗ A more elevate q-profile is desirable



[C. Piron *et al* 2019 *Nucl. Fusion* **59** 096012]

Strategy #1+#2?

- With sufficient ECRH power the two strategies could potentially be merged into a double-barrier scenario

Shot numbers

- Initial allocation:
  - TCV: 40 shots (2019), 38 (2020)
  - MAST-U: 14 (2019), 26 (2020)
- Performed in 2019:
  - TCV: 15 (2 sessions in November and December)
  - MAST-U: 0
- Updated allocation for 2020:
  - TCV: 30 + 18 (moved from 2019, still on 2019 budget)
  - MAST-U: 0

TCV constraints in 2019

- Limited power (⇨ delayed sessions as much as possible, including to 2020):
  - 1.4 MW X2, 0.95 MW X3 in November
  - 2.35 MW X2 possible in December by giving up X3
  - *Note: commissioning of dual-frequency 1-MW gyrotron in X2 mode was an important programmatic step for TCV, largely pushed by T13*

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- Baffles:
  - Initially seen as immaterial, baffles in fact do limit operational space
  - z=0 operation is hampered by poor access from equatorial X2 launcher (refracted out); other locations are hampered by baffles

How the sessions evolved

- Focused on H-mode scenario which in principle requires less ECRH
- We found that accurate density control is required: the operational range compatible with X2 heating is near the minimum in the P_{thresh} vs n_e curve, and P_{thresh} increases steeply below that
- Once mastered density for L-H transition, we need to master it in H-mode. We concluded early on that this was only possible in ECRH-induced H-mode. ELMing character in NBI-induced H-mode leads to excessive density rise.
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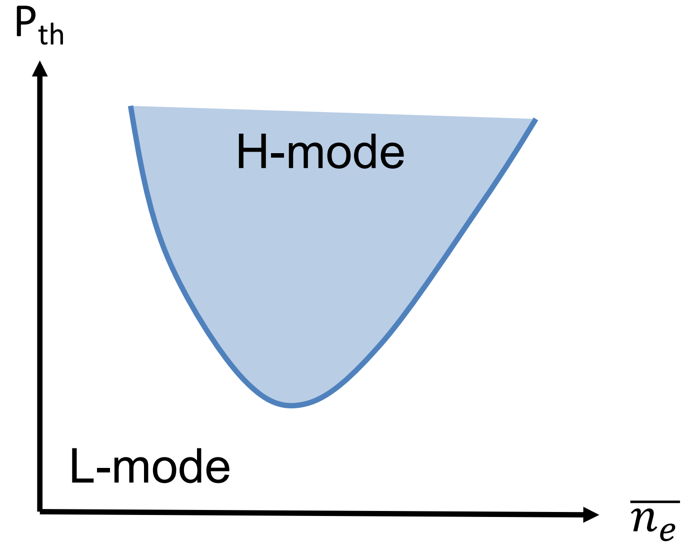

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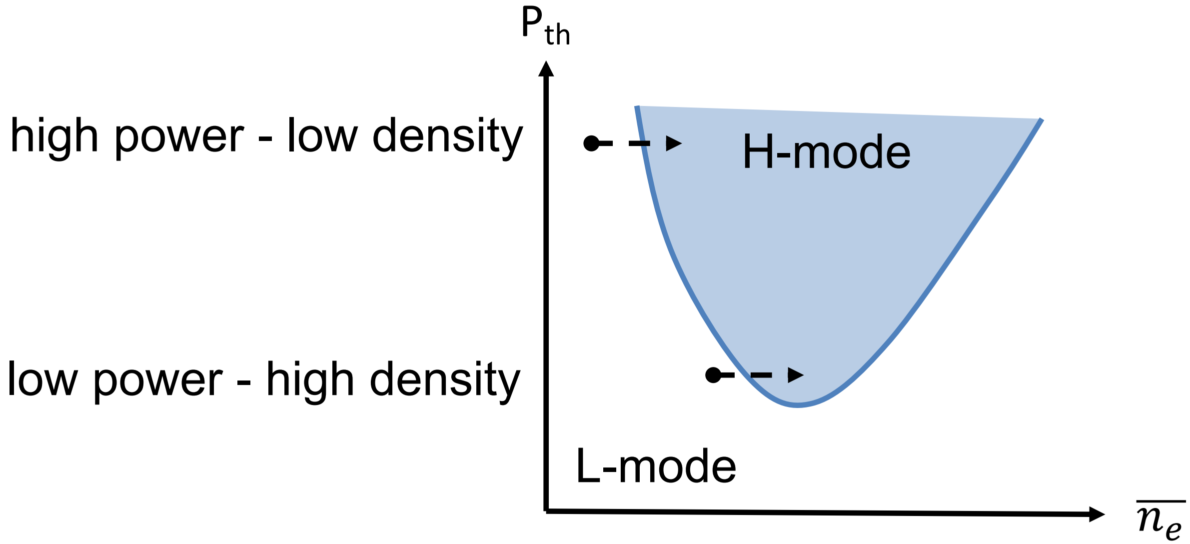

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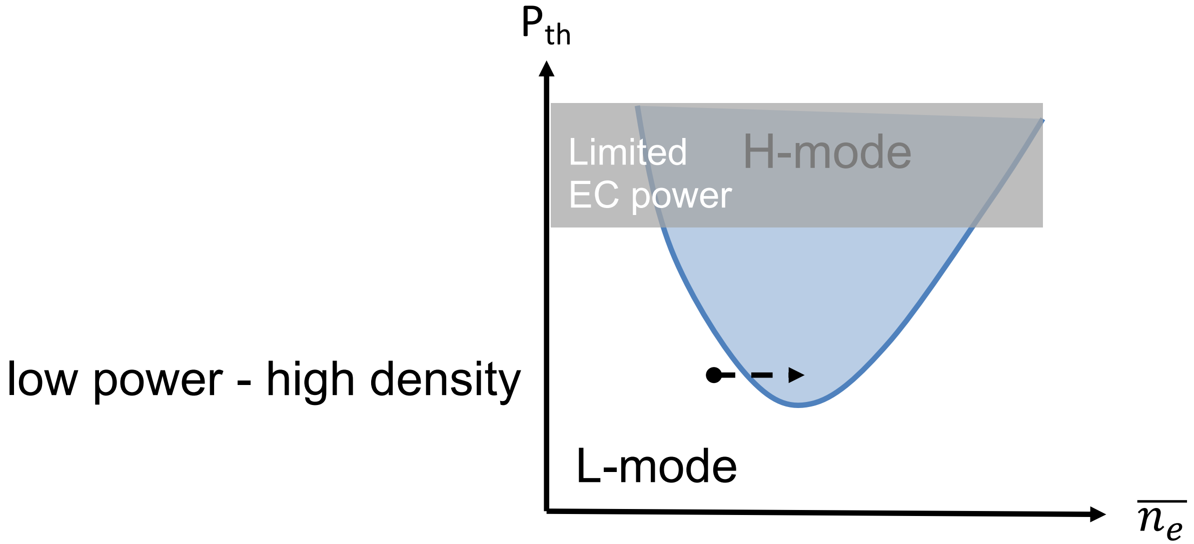

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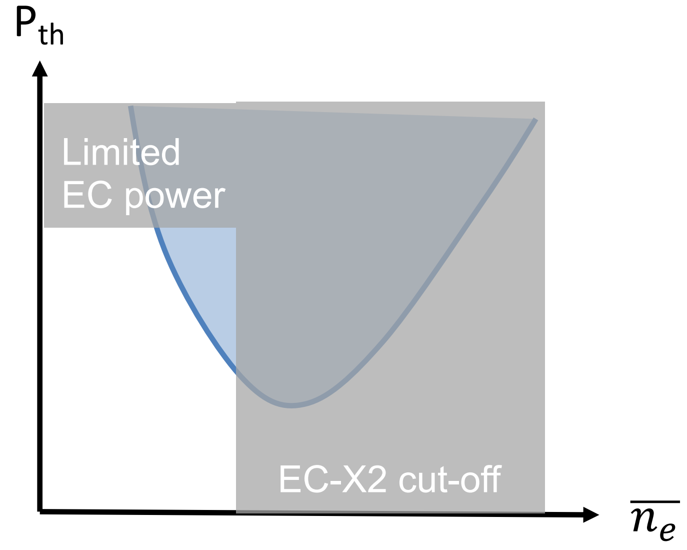

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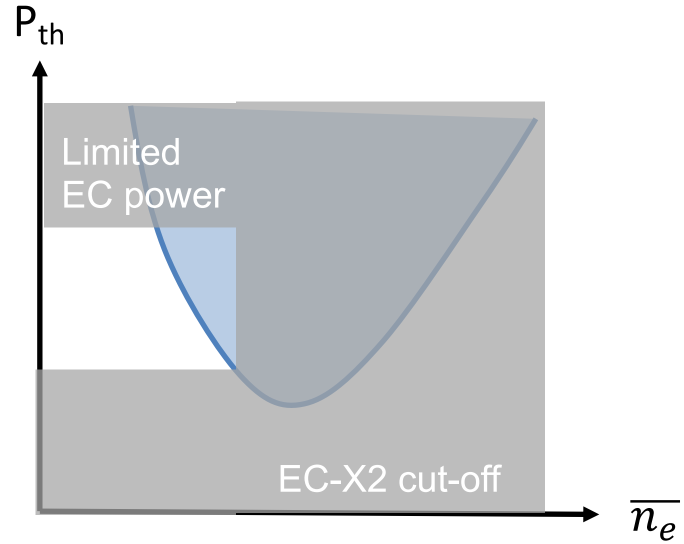

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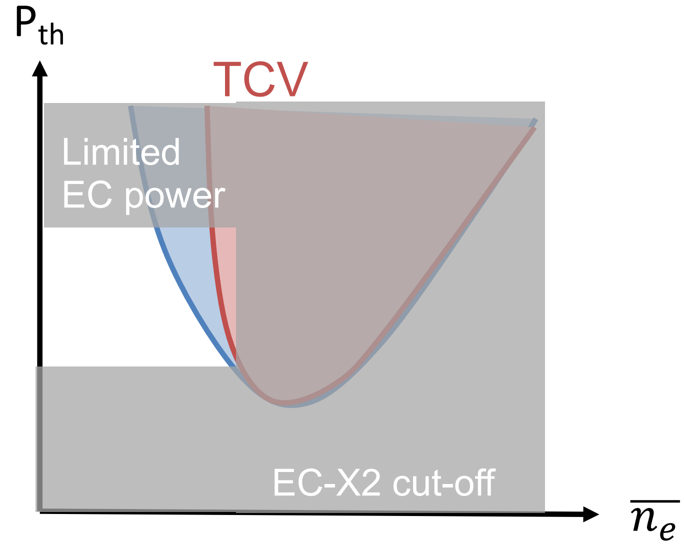

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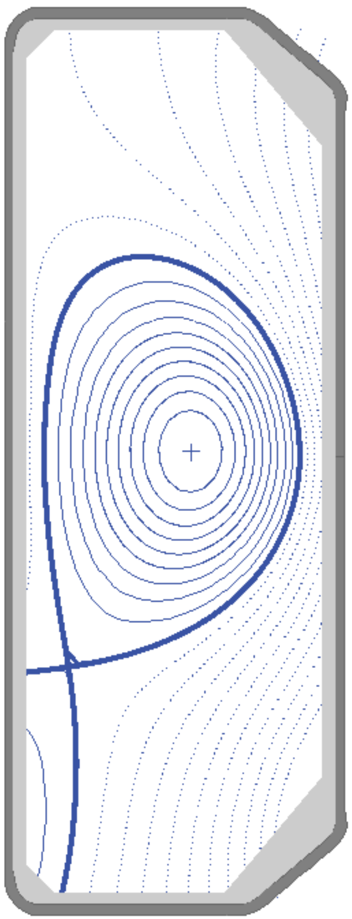
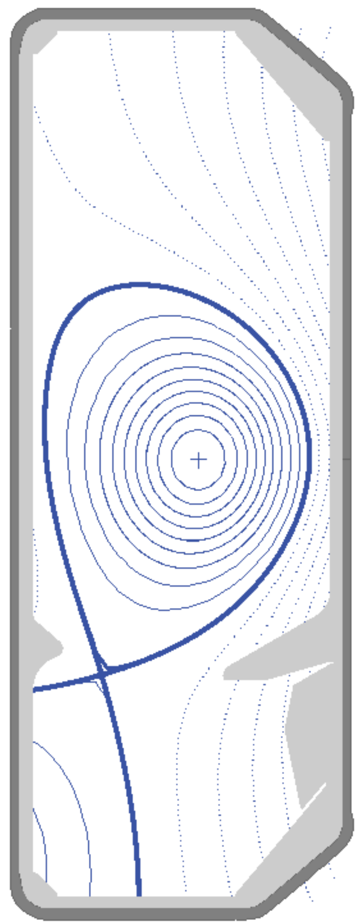
How the configuration evolved

59429 (2017)



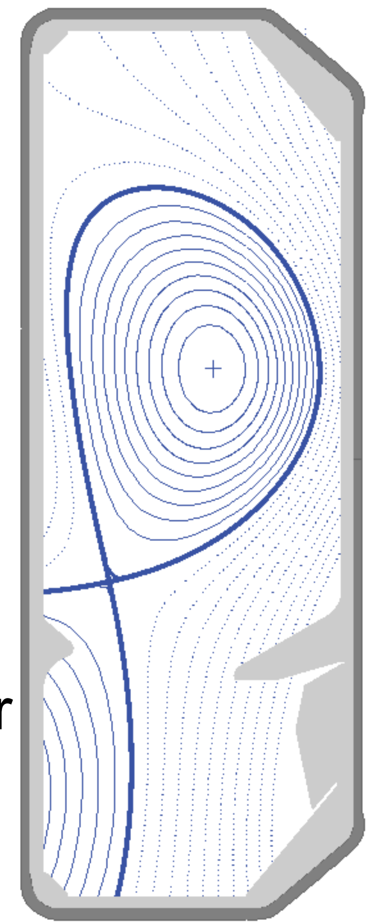
for baffle compatibility

64132

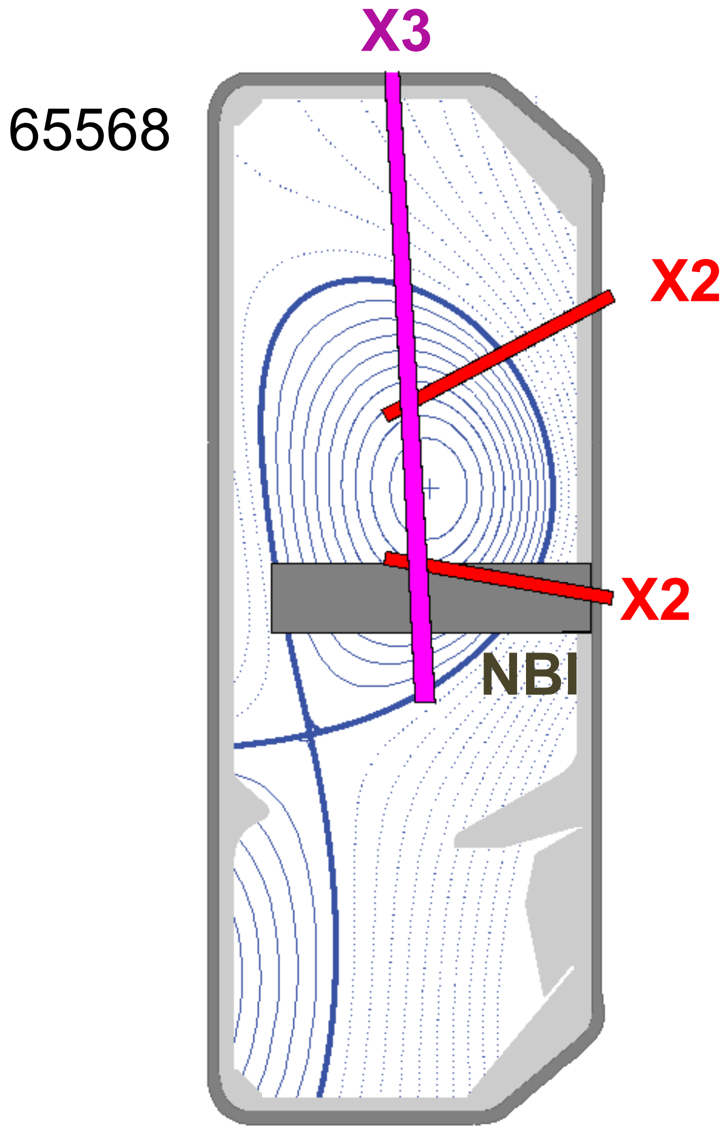


to allow heating from z=0 launcher

65568



Optimal configuration with baffles



Final assessment

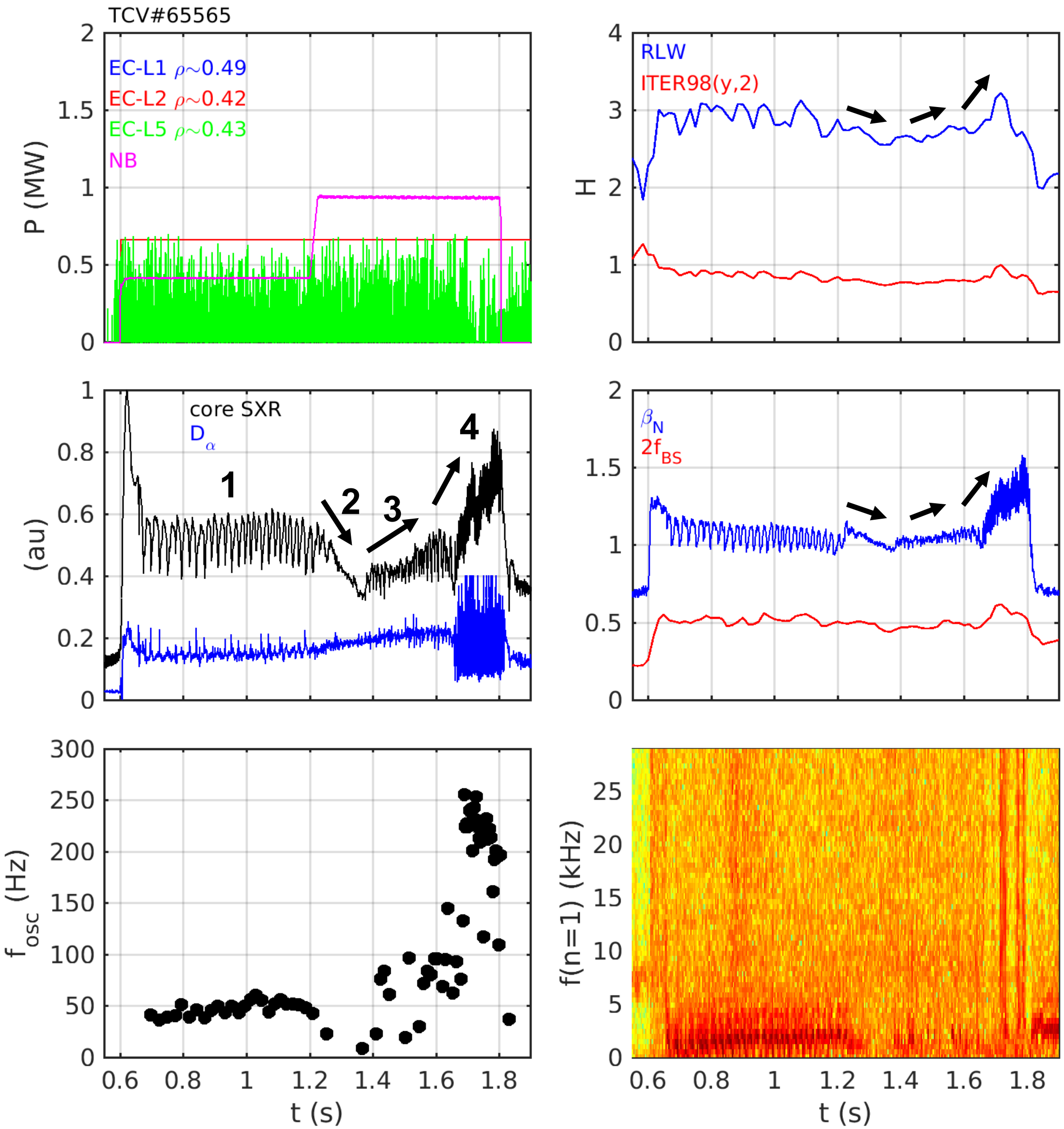
- A viable H-mode scenario with X2 was not found in the end: variations in the timing and amplitude of power sources, and in the density, did not produce a stable H-mode or, indeed, a coherent picture (so far)
- Further analysis and modeling needed to progress on this scenario

The O-regime

- Slow confinement oscillations with periodic crashes observed in these scenarios
- Limit cycle behaviour observed in the past in TCV [1,2] and Tore Supra [3,4]
- Attributed to the development of infernal modes and subsequent post-crash recovery on a mixed confinement/current-diffusion time scale
- High-power NBI appears to reproducibly stabilize this regime

[1] G. Giruzzi et al, PRL **91**, 135001 (2003)
[2] F. Turco et al, Physics of Plasmas **16**, 062301 (2009)
[3] V. Udintsev et al, Plasma Phys. Control. Fusion **50**, 124052 (2008)
[4] C. Turri et al, Plasma Phys. Control. Fusion **50**, 065010 (2008)

The O-regime



Four phases can be identified:

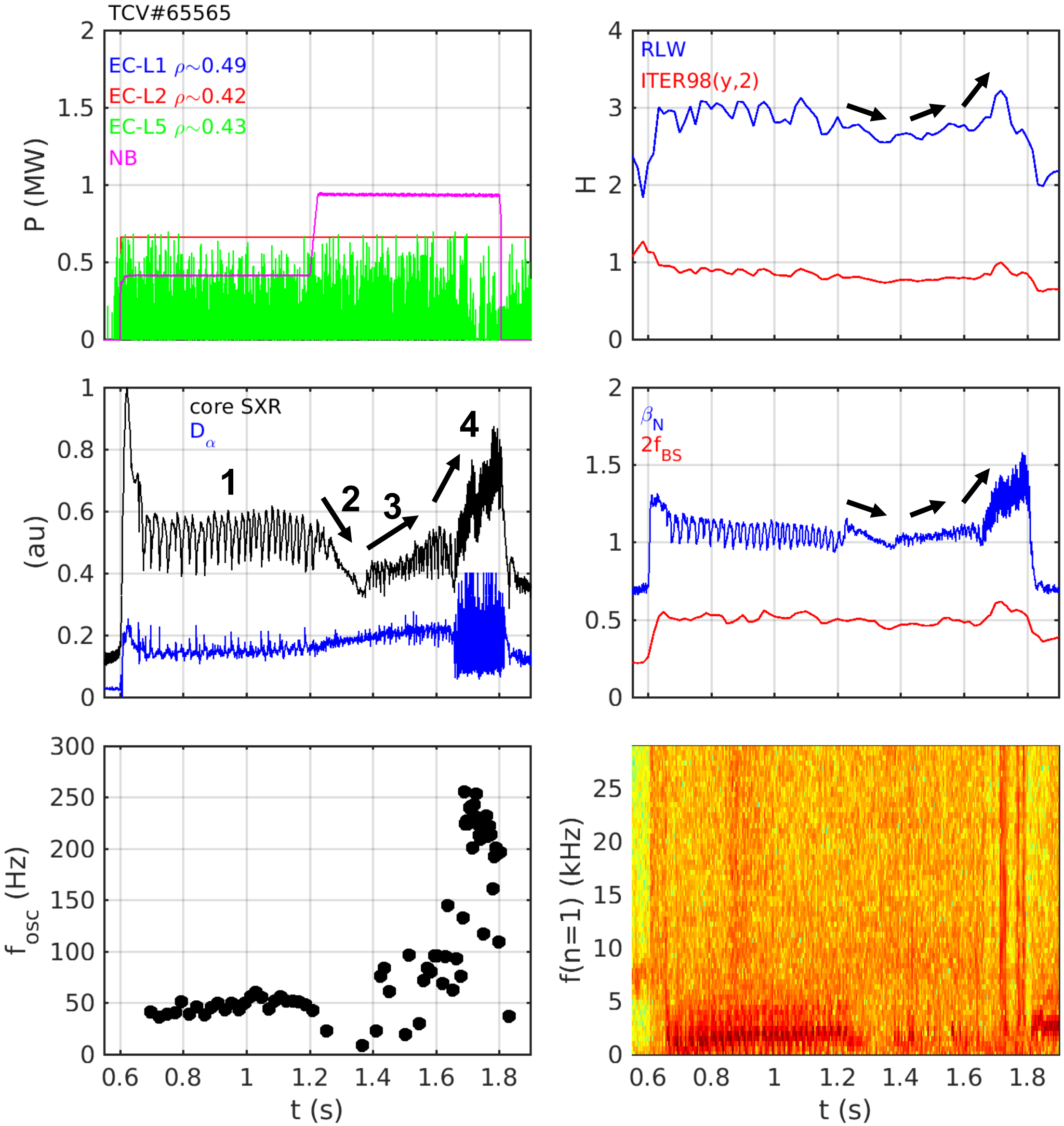
P_{NBI}= 0.5MW

1. f_{osc}=50Hz (similar to ECCD only)

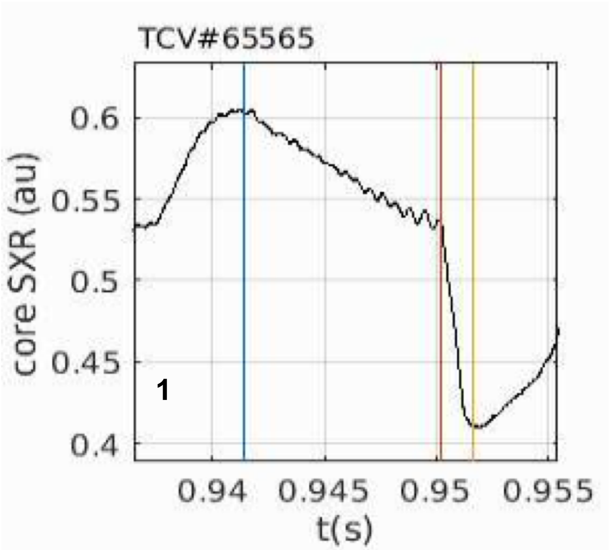
P_{NBI}= 1.0MW

2. No oscillation and confinement degradation
3. f_{osc}=100Hz and confinement improvement
4. f_{osc} =250Hz and confinement improvement (H-mode)

The O-regime



TCV#65565
EC-L1 ρ~0.49
EC-L2 ρ~0.42
EC-L5 ρ~0.43
NB
P (MW)
RLW
ITER98(y,2)
H
core SXR
D α
1
2
3
4
(au)
β N
2f BS
f osc (Hz)
f(n=1) (kHz)
t (s)
t (s)



TCV#65565
core SXR (au)
1
t(s)

Plans for 2020

Before the campaign

- Analysis of 2019 experiments to understand H-mode requirements and parameter space
- Specific analysis and modeling of O-regime and its stabilization by NBI in view of a publication
- Prepare scenarios for both eITB and H-mode strategies

Campaign tools

- Up to 3.3 MW X2, or 2.3 MW X2+0.9 MW X3, should be available
- Lateral X3 can also possibly be used
- More central NBI can also be used if needed (z=0)