



WPTE-RT12-TCV: Development of the steady state scenario

Summary of session II-III at TCV

C. Piron

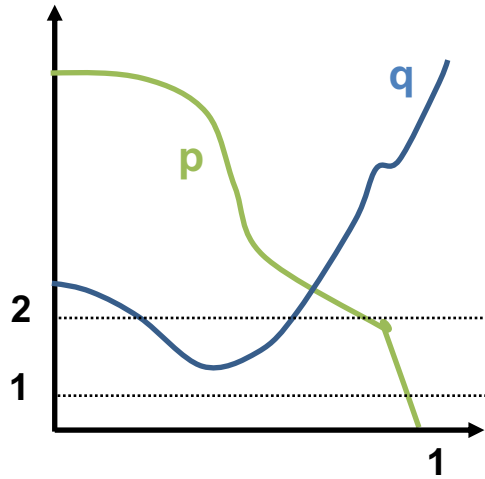


This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.



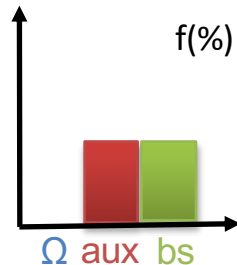
- ❑ Scenario development strategies
- ❑ TCV session overview
- ❑ First results
- ❑ What's next

Explored routes towards AT scenarios

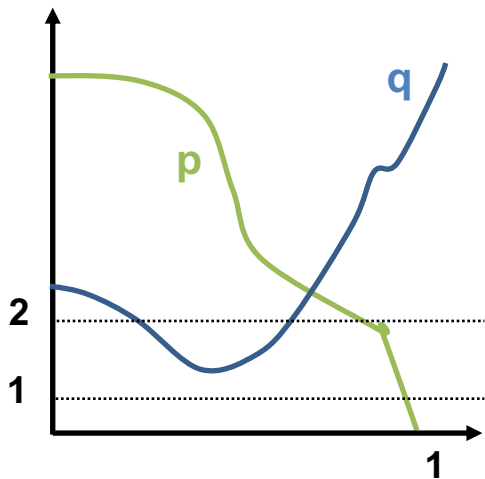


Advanced scenarios

- $j \sim j_{aux} + j_{bs}$ hollow
- Reversed $q>1$ profile
- **E+ITB**

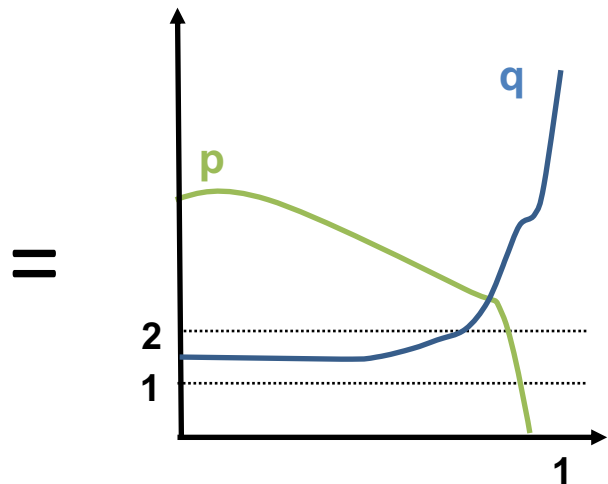
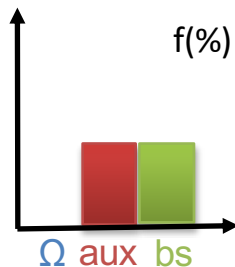


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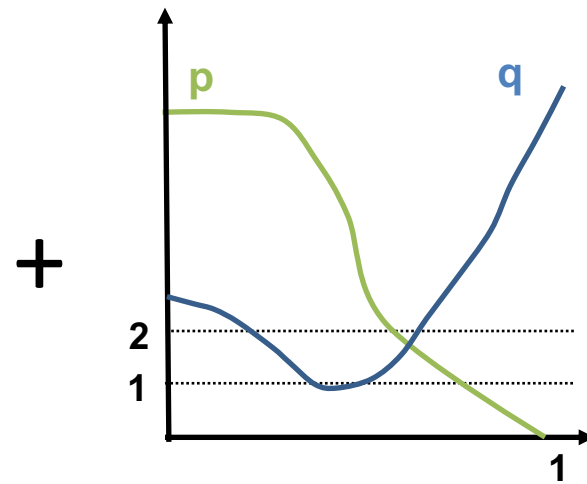
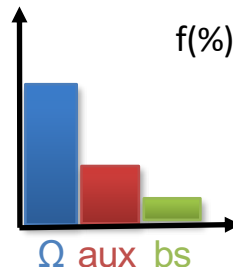
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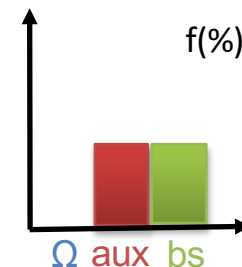
Hybrid scenarios

- $j \sim j_{\Omega} + j_{aux} + j_{bs}$ ($\sim \nabla p$) broad
- Flat $q > 1$ profile
- ETB

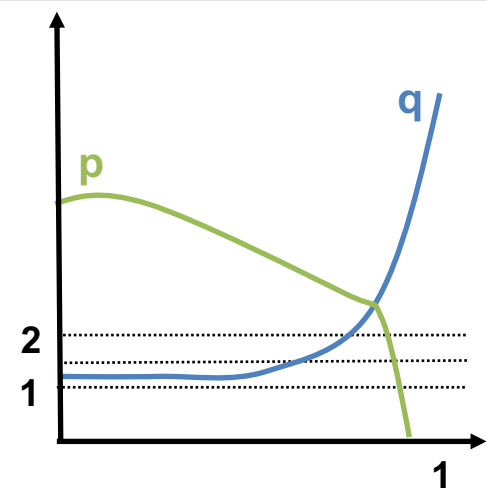


ITB scenarios

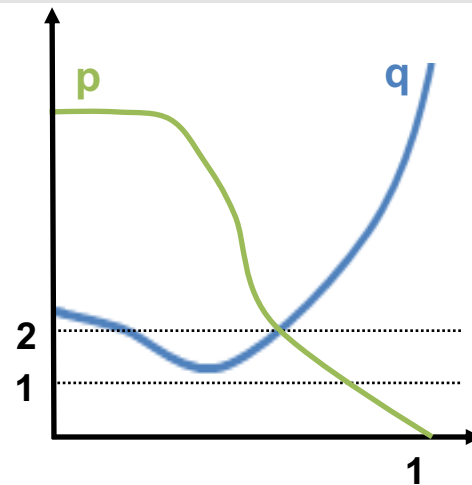
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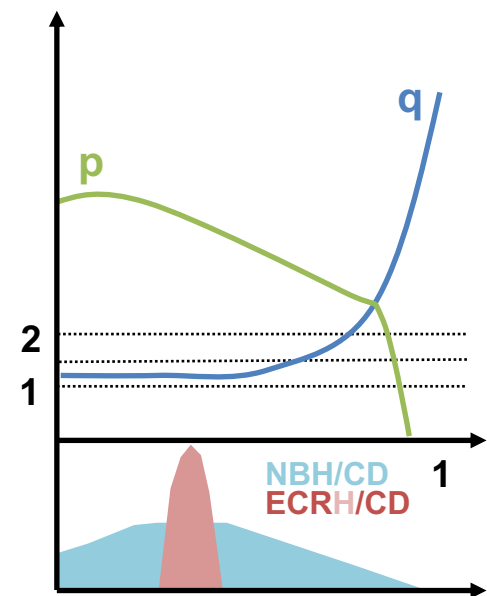


ETB



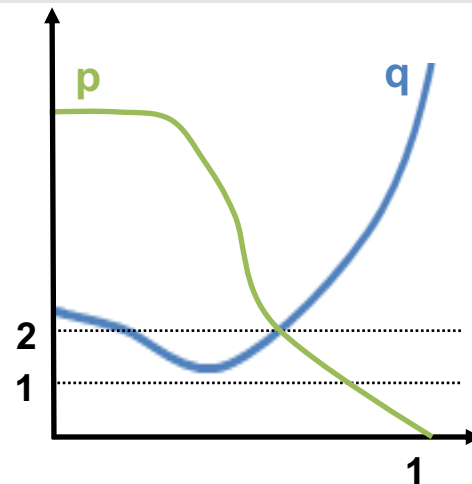
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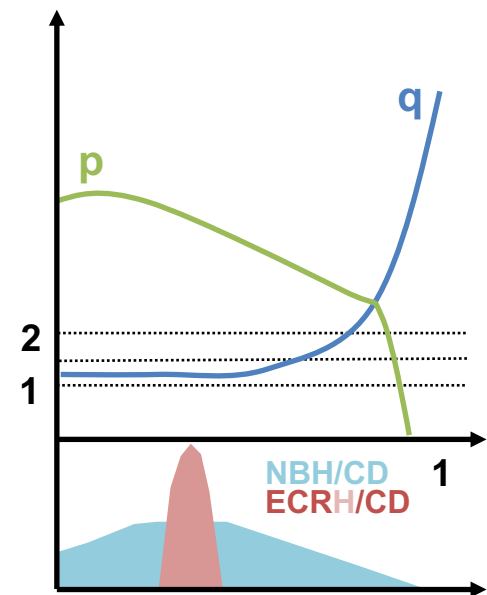
ETB

off-axis co-ECCD +
NBI



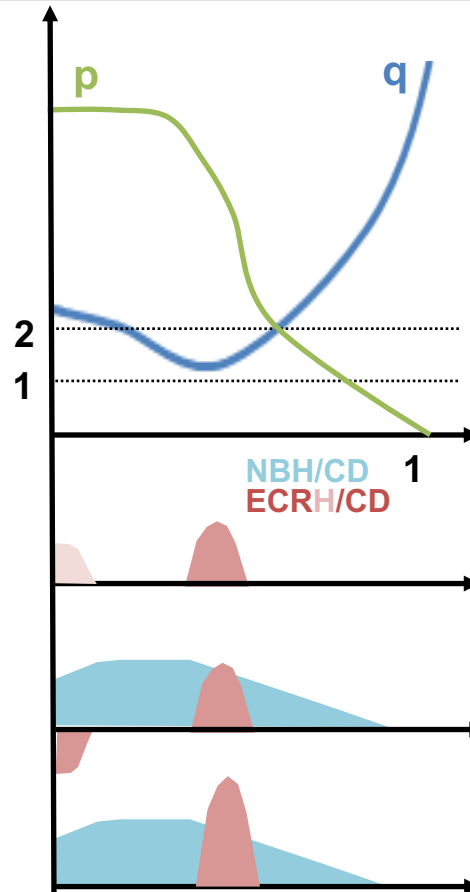
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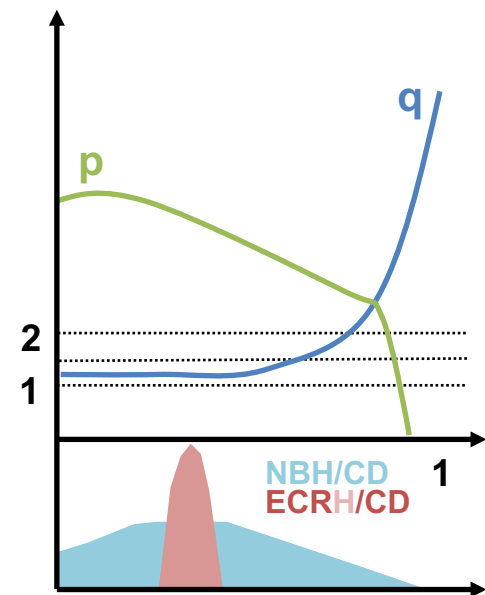
ITB

off-axis co-ECCD +
on-axis ECH

off-axis co-ECCD +
on-axis cnt-ECCD
(NBI)

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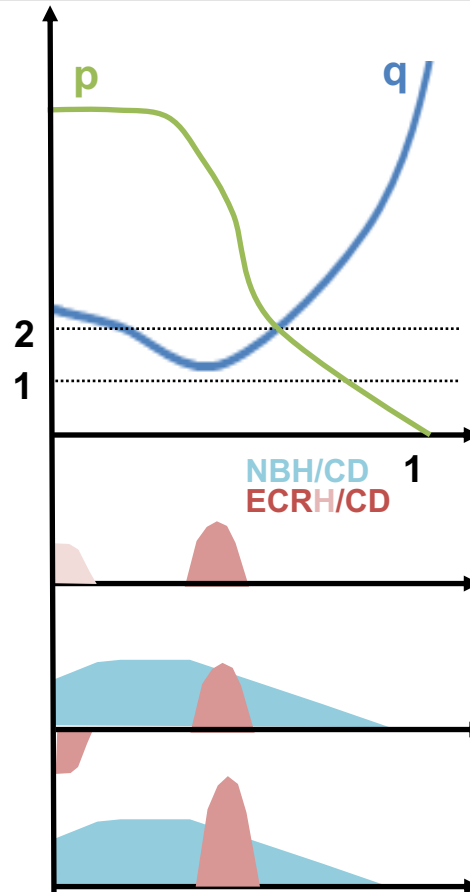
Explored routes towards AT scenarios



ETB

- $I_p = [110, 120, 140, 150] \text{ kA}$
- $n_{e,L}(\text{FIR}) \approx 1.6$
- LSN, $z_0 \approx 10 \text{ cm}$

off-axis co-ECCD +
NBI



ITB

- $I_p = [100, 150, 160] \text{ kA}$
- $n_{e,L}(\text{FIR}) \approx 1.1$
- LSN, $z_0 \approx 10 \text{ cm}$

off-axis co-ECCD +
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off-axis co-ECCD +
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- ❑ Scenario development strategies
- ❑ **TCV session overview**
- ❑ First results
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I session: 15, 22/12/21 [9 shots]

☹ 2 gyros available L1, L2

II session: 24, 25/05/22 [8 shots]

😊 3 gyros available L1, L4, L5

III session: 31/05-03/06/22 [37 shots]

☹ 3 gyros available L1, L4, L5 (but L1 X2 polarization <100%)

[45/65 shots]



- ❑ L1 X2 polarization <100%
- ❑ Density control
 - ❑ very poor reproducibility from shot to shot
- ❑ No spare gyro for locked mode control



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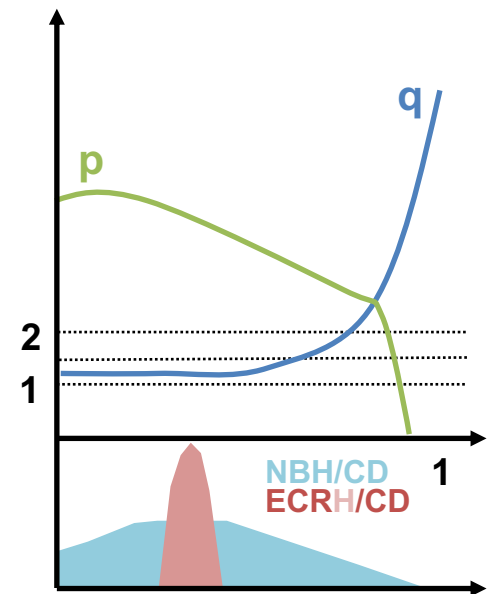
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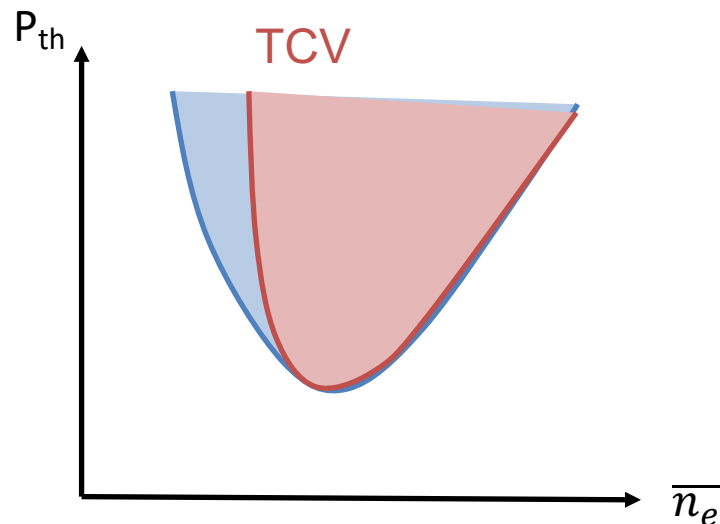




- ❑ A very narrow density margin to be explored
H/L-mode back transition $< n_e < \text{EC-X2 cut-off}$

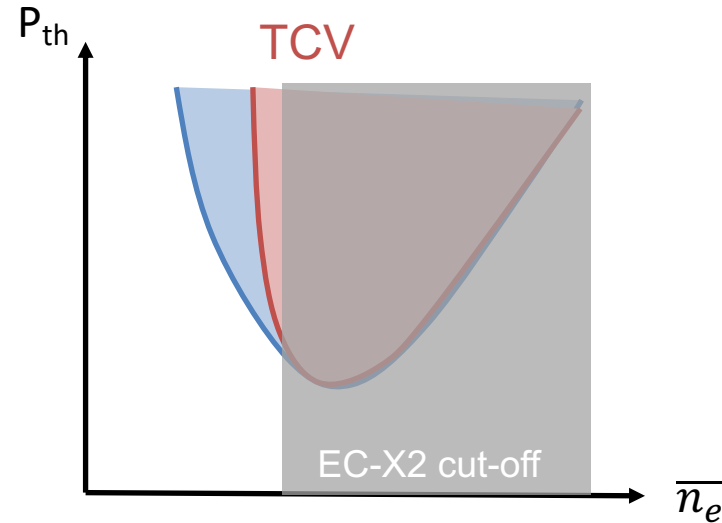
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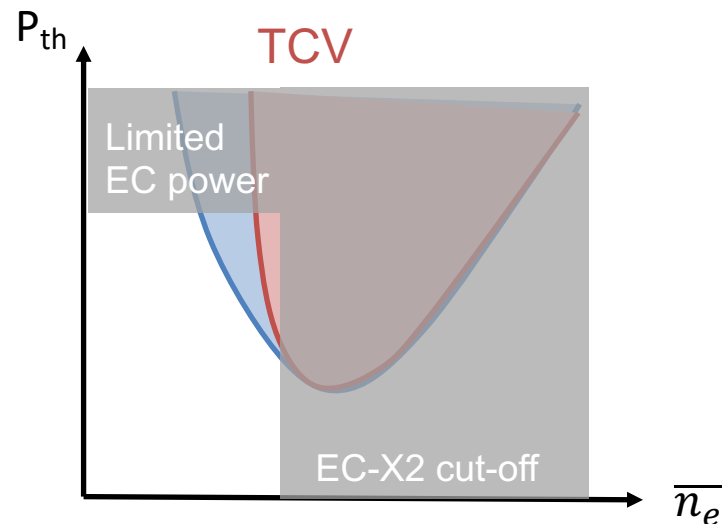
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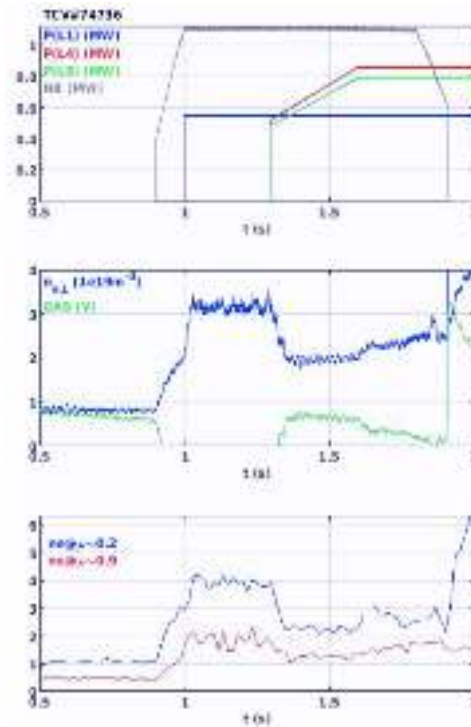
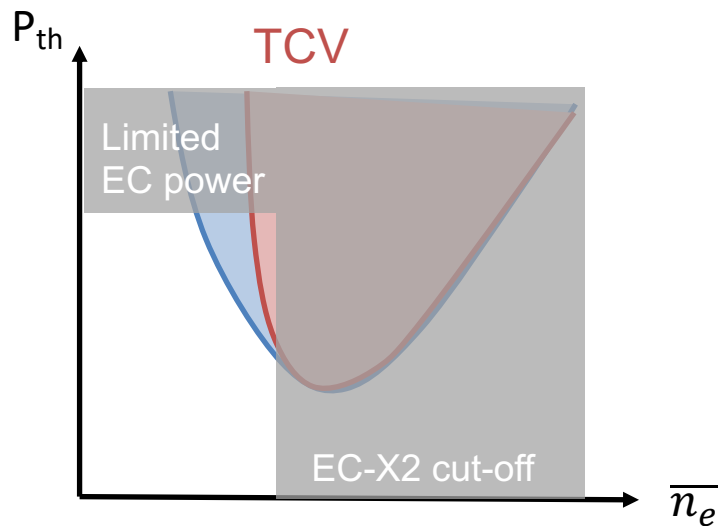


ETB: preliminary observations



- A very narrow density margin to be explored

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Non-linear
interplay:

↑ NBI density
filling

↓ Density
pump-out
from EC
waves

↑ H-mode
transition



- ❑ A very narrow density margin to be explored
H/L-mode back transition $< n_e < \text{EC-X2 cut-off}$
- ❑ Type-I ELMy H-mode with a clear n_e pedestal but
wo/weak T_e pedestal

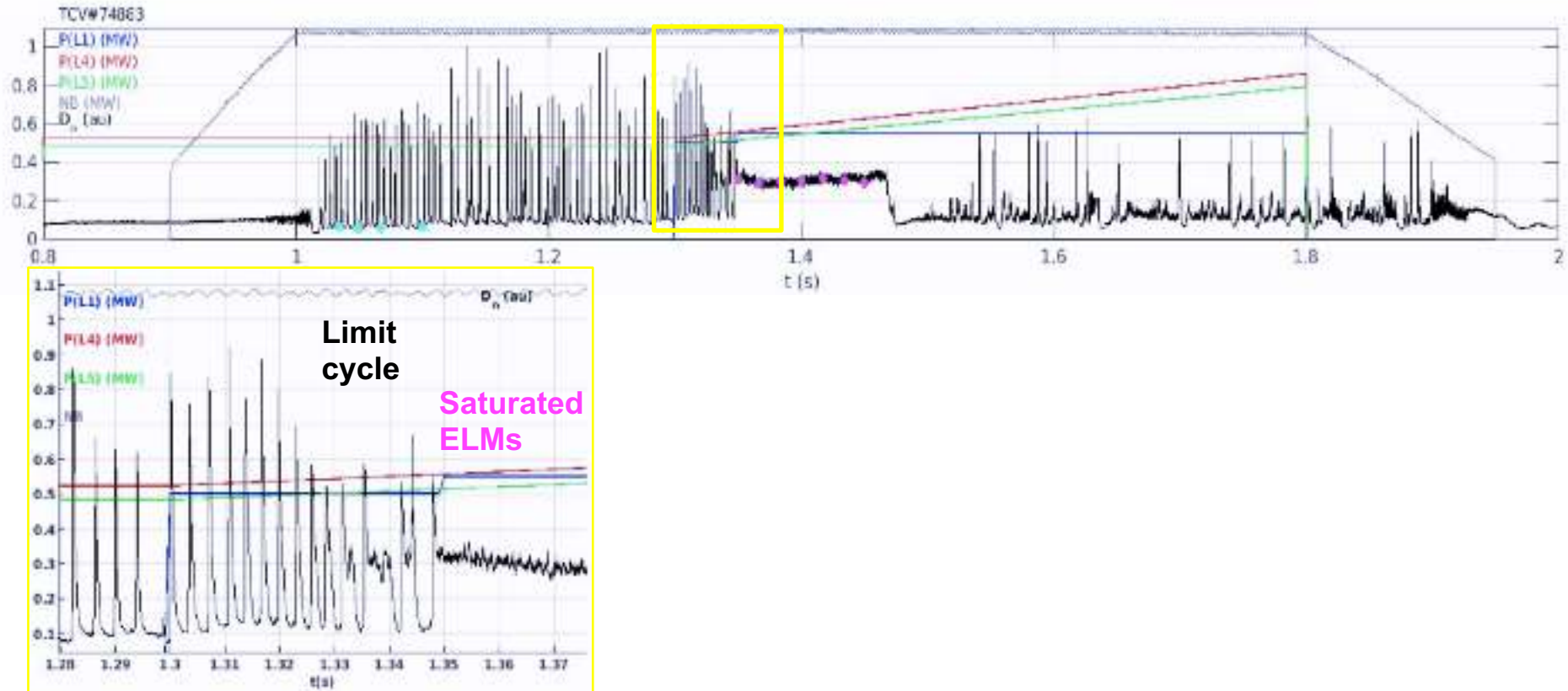


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- ❑ Type-I ELMy H-mode with a clear n_e pedestal but
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- ❑ When further EC power is injected, type-I ELMy H-mode
obtained with EC-X2+NBI enters a limit cycle regime
with a locked $n=1$ mode and performance degradation
Shots at lower current attempted ($I_p=140\text{kA}$) but none with the
same EC heating obtained

Limit cycle ELM regime with ECRH



Representative example, evidence observed in ~10 shots

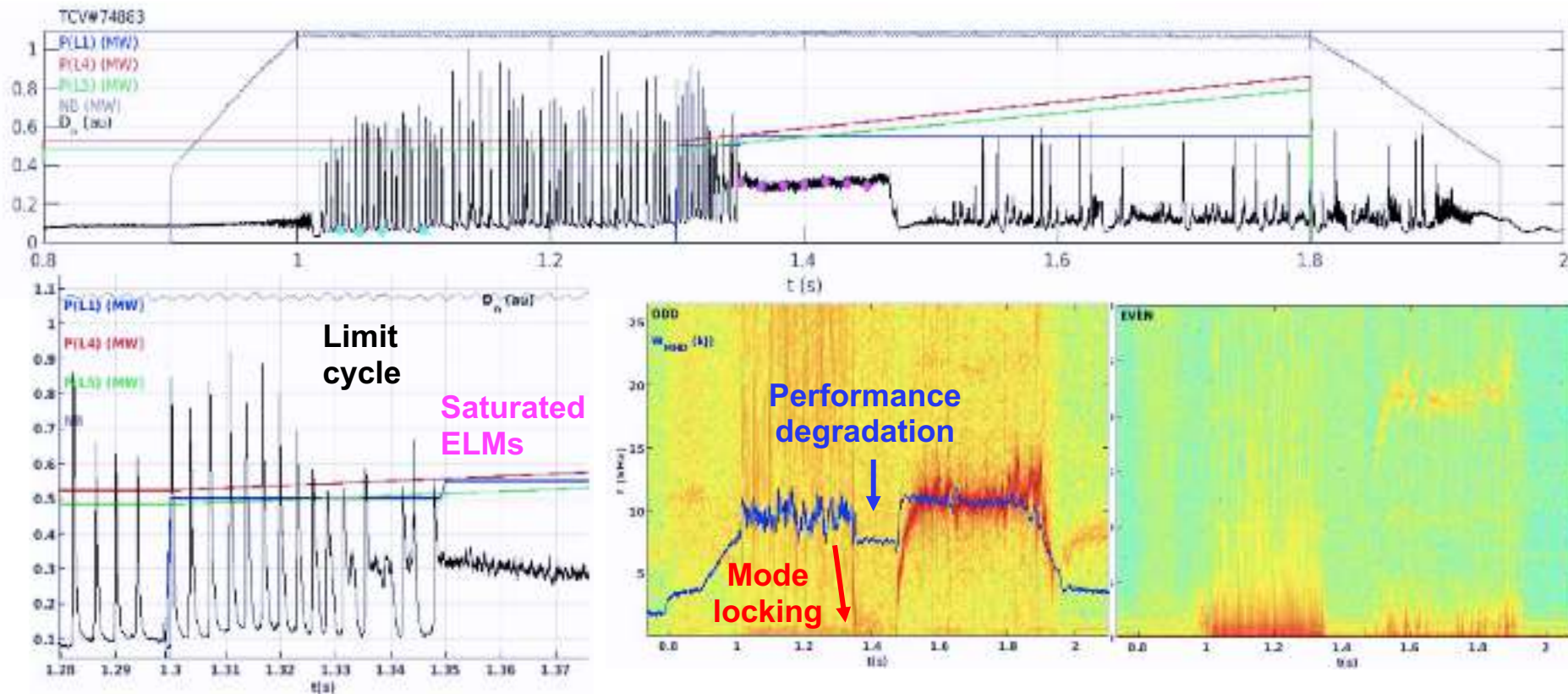


Type-I ELMs

Limit cycle ELM regime with ECRH

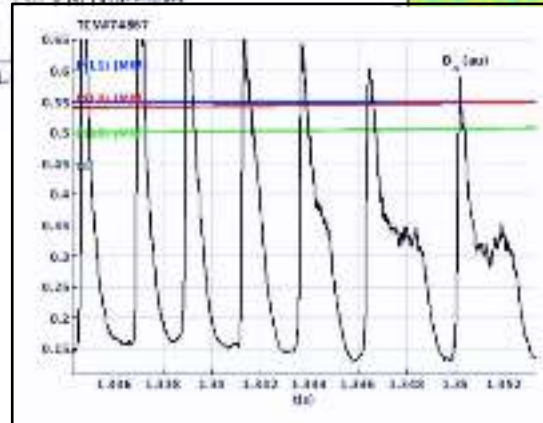
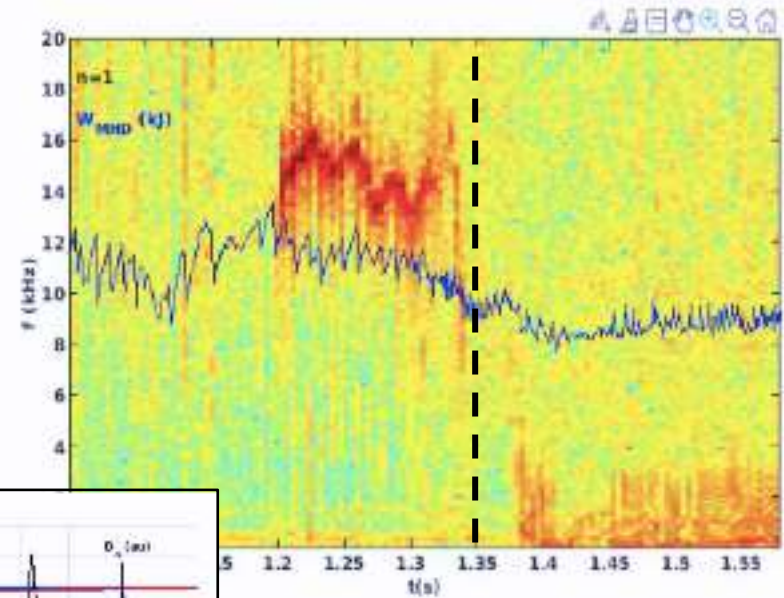
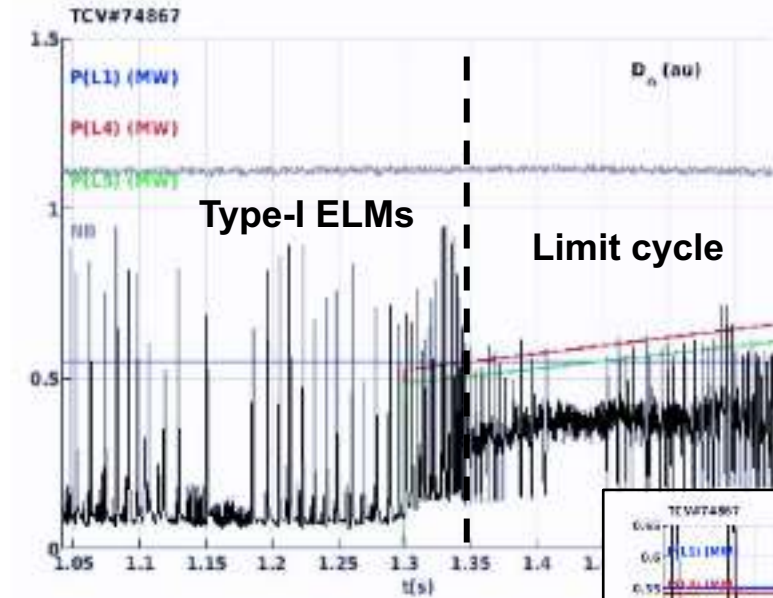


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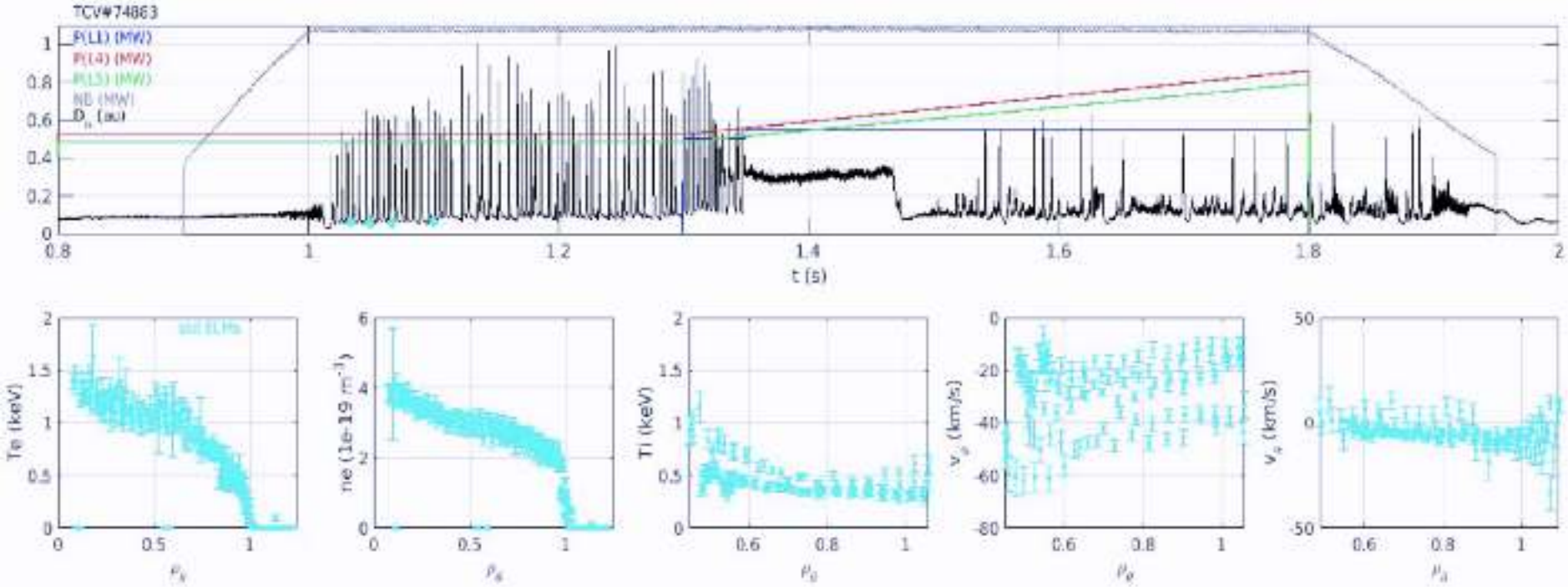
From type-I ELMs to limit cycle at increasing P_{EC}



Limit cycle ELM regime with ECRH



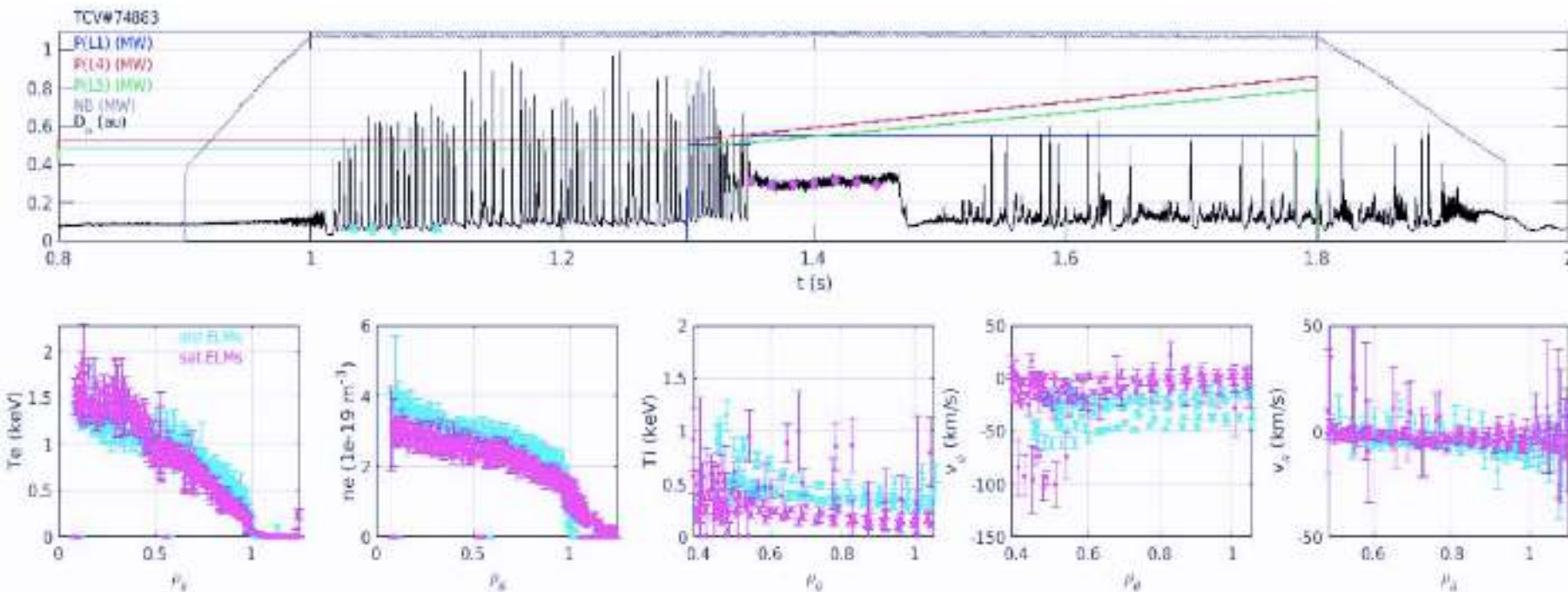
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Limit cycle ELM regime with ECRH



Representative example, evidence observed in ~10 shots



- Pedestal weakening
- $n=1$ mode flattening at $p=0.5$ (?TBI)
- v_{EXB} affected (?TBI)



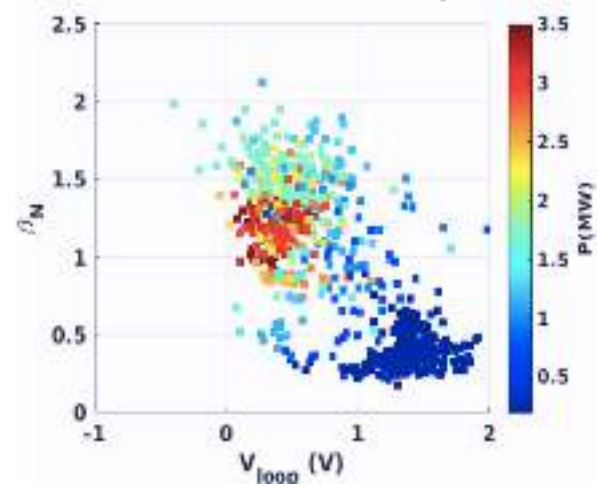
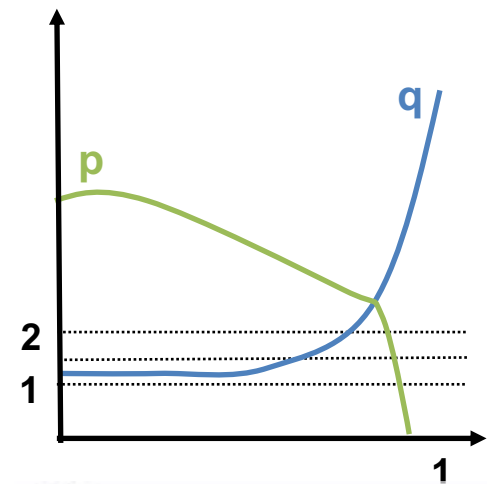
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Shots at lower current attempted ($I_p=140\text{kA}$) but none with the
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- ❑ $V_{\text{loop}} \gtrsim 0.2\text{V}$, $\beta_{N,\text{max}} \approx 2$

Explored routes towards AT scenarios



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$$V_{\text{loop}} \gtrsim 0.2 \text{ V}$$
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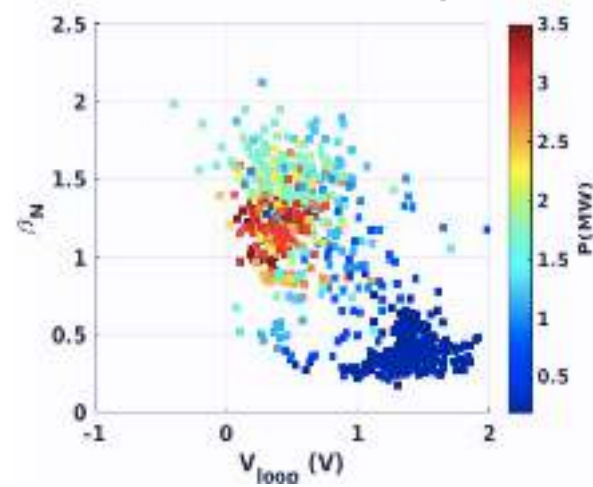
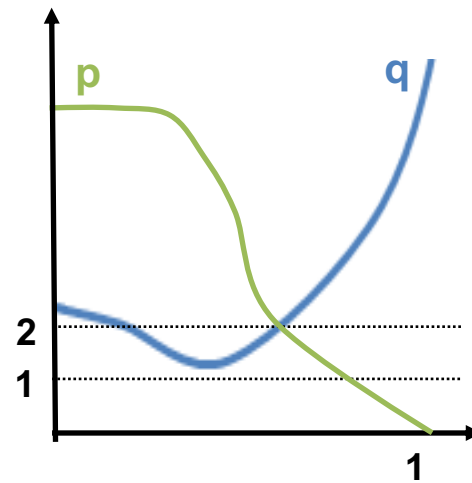
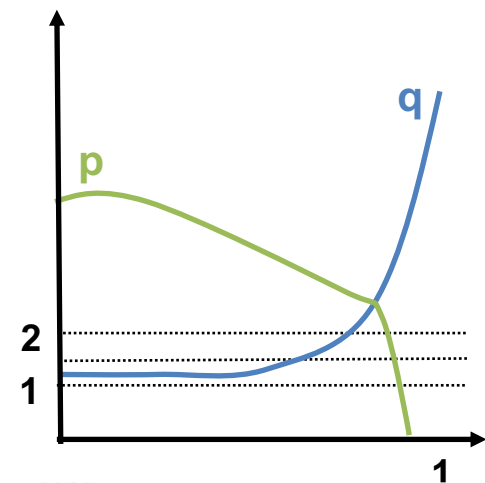


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$$V_{\text{loop}} \gtrsim 0.2 \text{ V}$$

$$\beta_{N,\text{max}} \lesssim 2$$



- ❑ Stationary fully non-inductive operation obtained with clamped IOH (0.8s), 2MW off-axis co-ECCD + 0.5MW NBI
- ❑ Te in central heated ITB peaks less than expected ($T_{e0} \lesssim 3$ keV, likely due to the L1 X2-polarization issue)





- ❑ Te in central heated ITB peaks less than expected ($T_{e0} \lesssim 4.5 \text{keV}$, likely due to the L1 X2-polarization issue)
- ❑ Stationary fully non-inductive operation obtained with clamped IOH (0.8s), 2MW off-axis co-ECCD + 0.5MW NBI
- ❑ $V_{\text{loop}}=0\text{V}$, $\beta_N \lesssim 1.5$

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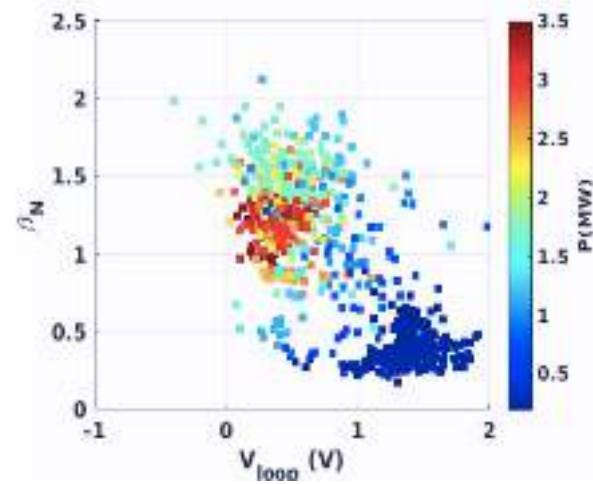
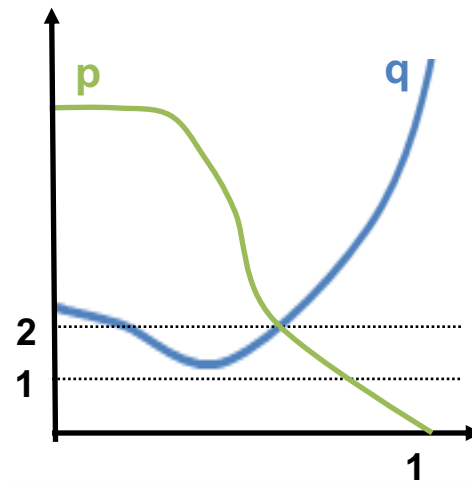
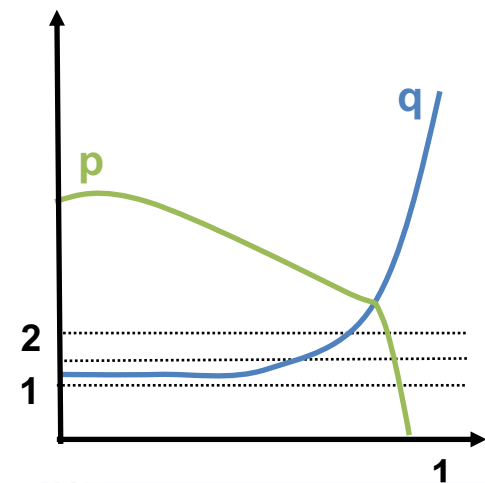


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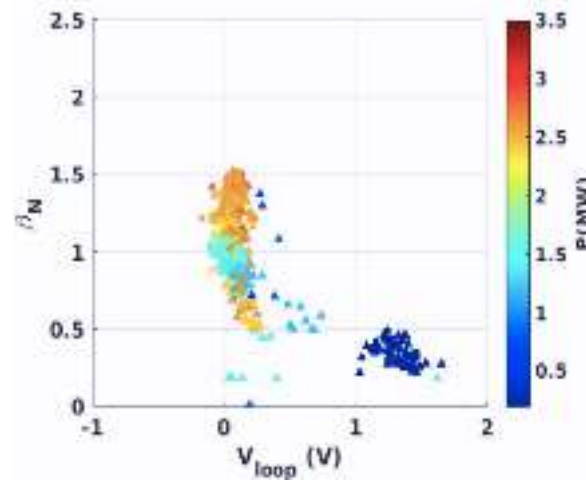
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$$V_{\text{loop}} \gtrsim 0.2 \text{ V}$$

$$\beta_{N,\text{max}} \lesssim 2$$



$$V_{\text{loop}} == 0 \text{ V}$$

$$\beta_{N,\text{max}} \lesssim 1.5$$



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- Analysis and integrated modelling activities are on-going, WPTE review meeting planned in late September 2022
- Call for Participation for the late-2022 & 2023 Experimental Campaign on JET, TCV, MAST-U and WEST is now open in IMS https://wiki.euro-fusion.org/wiki/WPTE_wikipages:_Call_for_participation_2022_2023

Deadline: July 12th (ENEA) 22nd (EUROfusion), 2022

WPTE-RT12 →

WPTE-RT08: Long pulse high- β scenarios

SCs: A. Burckhart (IPP), R. Dumont (CEA), C.Piron (ENEA)



ECRH system at TCV

