



HAL
open science

Operational space for Lower Hybrid scenarios in the full tungsten environment of WEST

J Morales, V Ostuni, C Bourdelle, J.-F Artaud, P Manas, H Ancher, L Dubus, M Doménès, R Dumont, A Ekedahl, et al.

► **To cite this version:**

J Morales, V Ostuni, C Bourdelle, J.-F Artaud, P Manas, et al.. Operational space for Lower Hybrid scenarios in the full tungsten environment of WEST. 64th Annual meeting of the APS Division of Plasma Physics, Oct 2022, Spokane, United States. cea-03863834

HAL Id: cea-03863834

<https://cea.hal.science/cea-03863834>

Submitted on 21 Nov 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

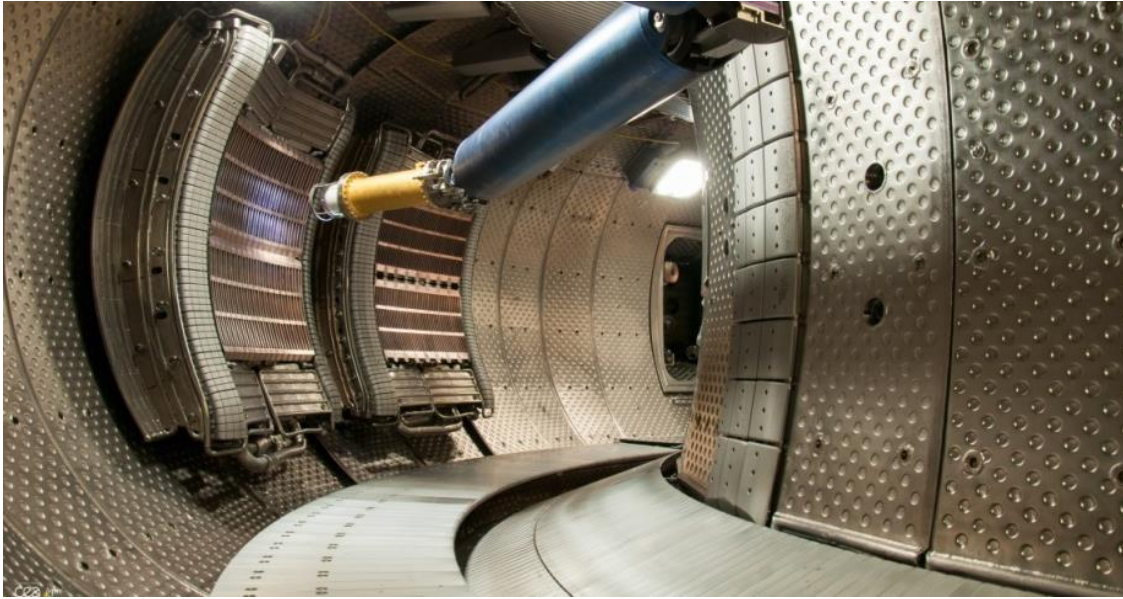


Operational space for Lower Hybrid scenarios in the full tungsten environment of WEST

DE LA RECHERCHE À L'INDUSTRIE

J. Morales, V. Ostuni, C. Bourdelle, J.-F. Artaud, P. Manas, H. Ancher, L. Dubus, M. Doménès, R. Dumont, A. Ekedahl, N. Fedorczak, L. Fleury, C. Gil, D. Guilhem, J. Hillairet, F. Imbeaux, P. Maget, P. Maini, D. Moiraf, V. Moncada, Ph. Moreau, D. Vézinet and WEST team (west.cea.fr/WESTteam)

64th APS DPP Conference, Spokane, 17-21 October 2022

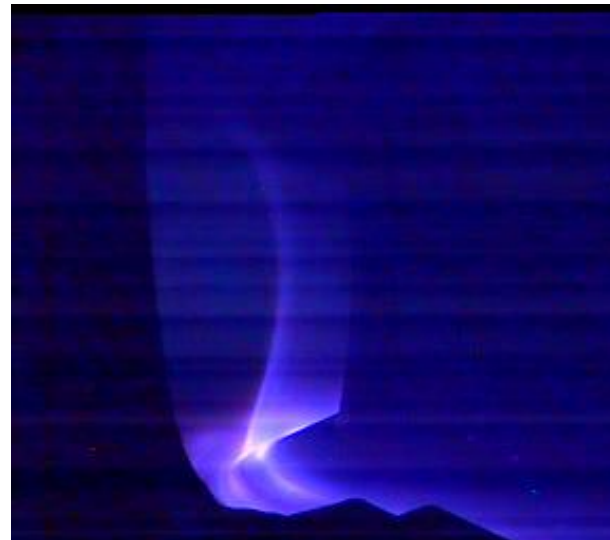
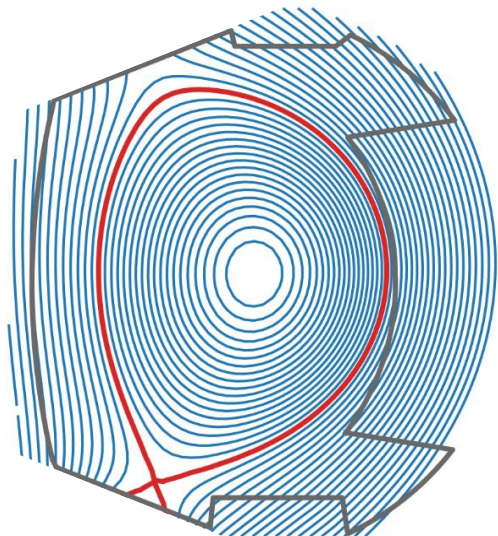


WEST is a device specialized for long pulse operation in a tungsten environment

Main goal: develop reactor compatible high performance long pulse scenarios

[Bucalossi et al., Nucl. Fusion, 2021]

[Bourdelle et al., Nucl. Fusion, 2015]



I_p ($q_{95} \sim 2.5$)	1 MA
B_T	3.7 T
R	2.5 m
a	0.5 m
n_{GW} (1MA)	$1.5 \cdot 10^{20} m^{-3}$
P_{ICRH}	9 MW
P_{LHCD}	7 MW
time_{flattop} (0.8 MA)	1000 s

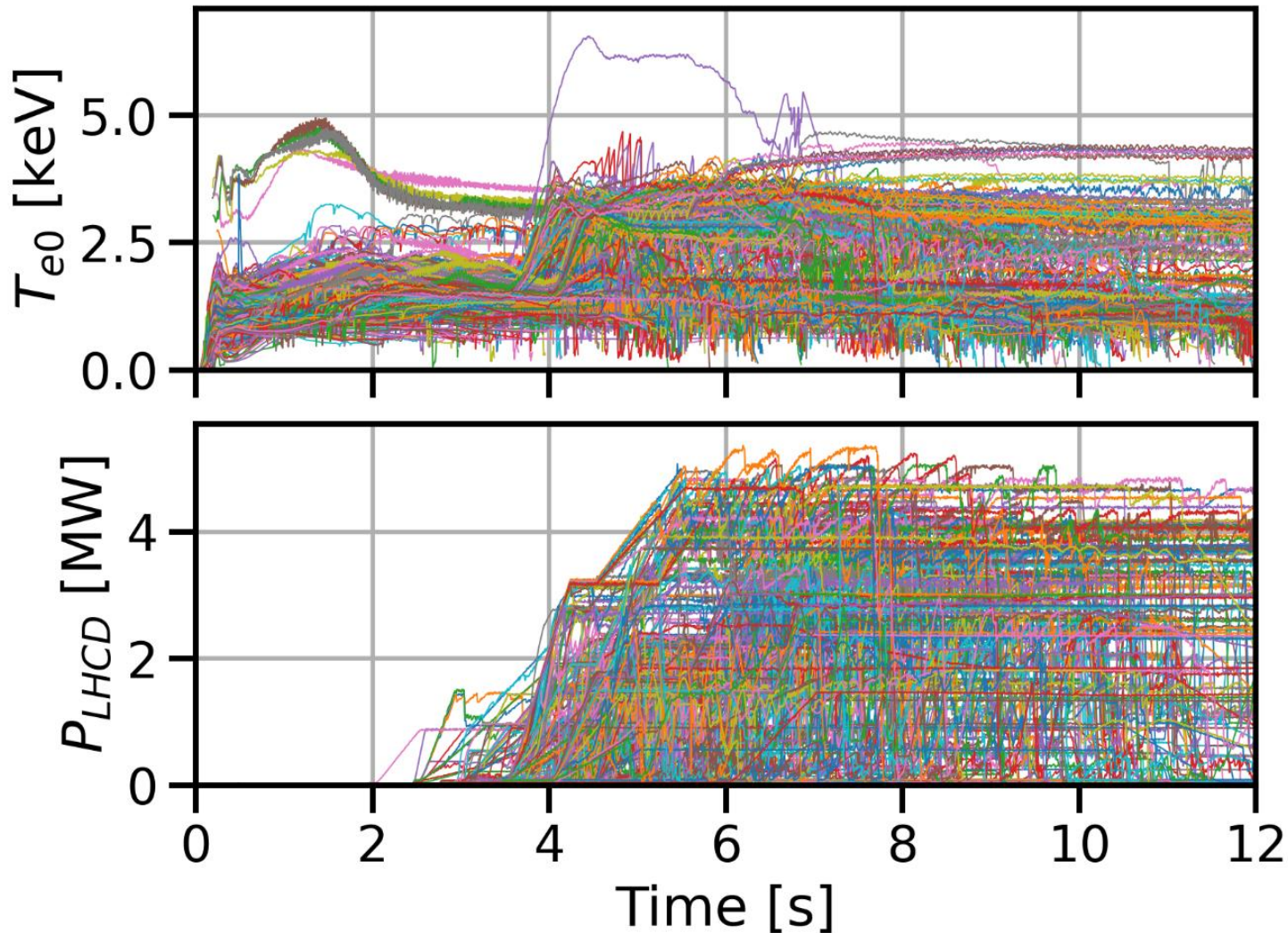
In **WEST**, to achieve **robust steady-state Lower Hybrid Current Drive (LHCD) scenarios**, **three main constraints** need to be considered:

1. power density and initial central electron temperature (T_{e0}) need to be large enough to **burn-through tungsten**,
2. the **power reflected** back to LHCD antennas needs to be below a specified threshold,
3. fast electron **ripple losses** must be limited.

- Experimental data analysis tool
- Conditions to burn-through tungsten
- Obtaining good coupling between LHCD wave and plasma
- Limiting fast electron ripple losses

Question: how to analyze entire experimental campaigns?

Example: 764 pulses from C4 campaign



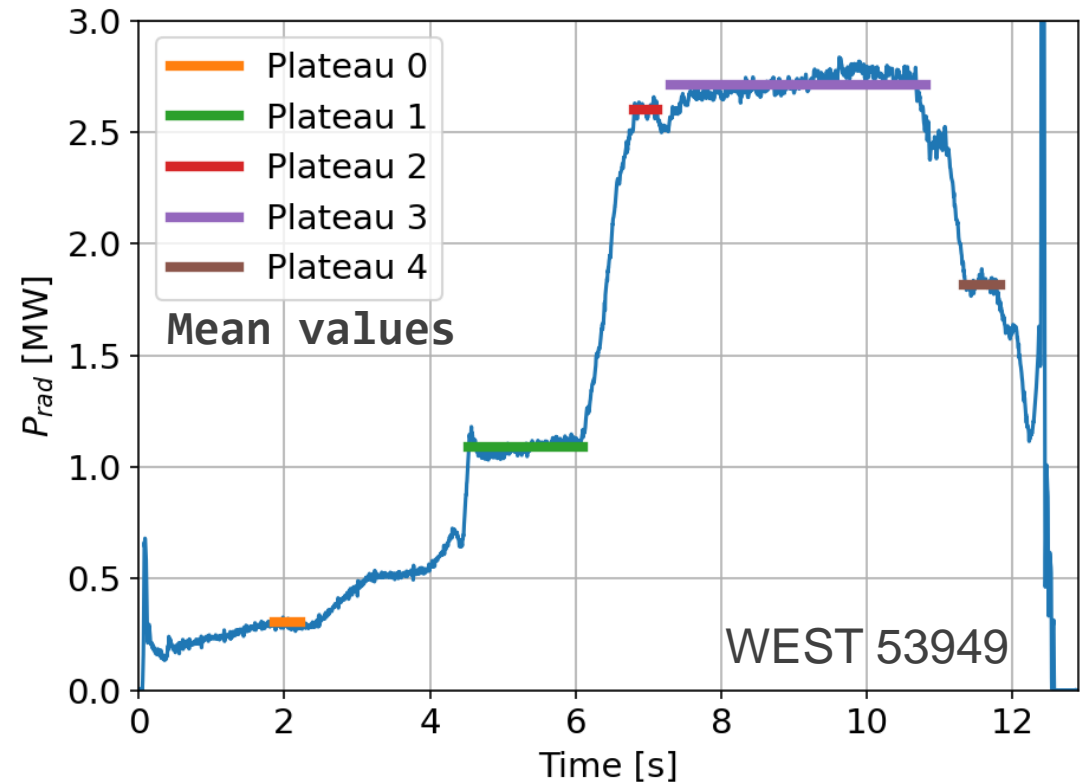
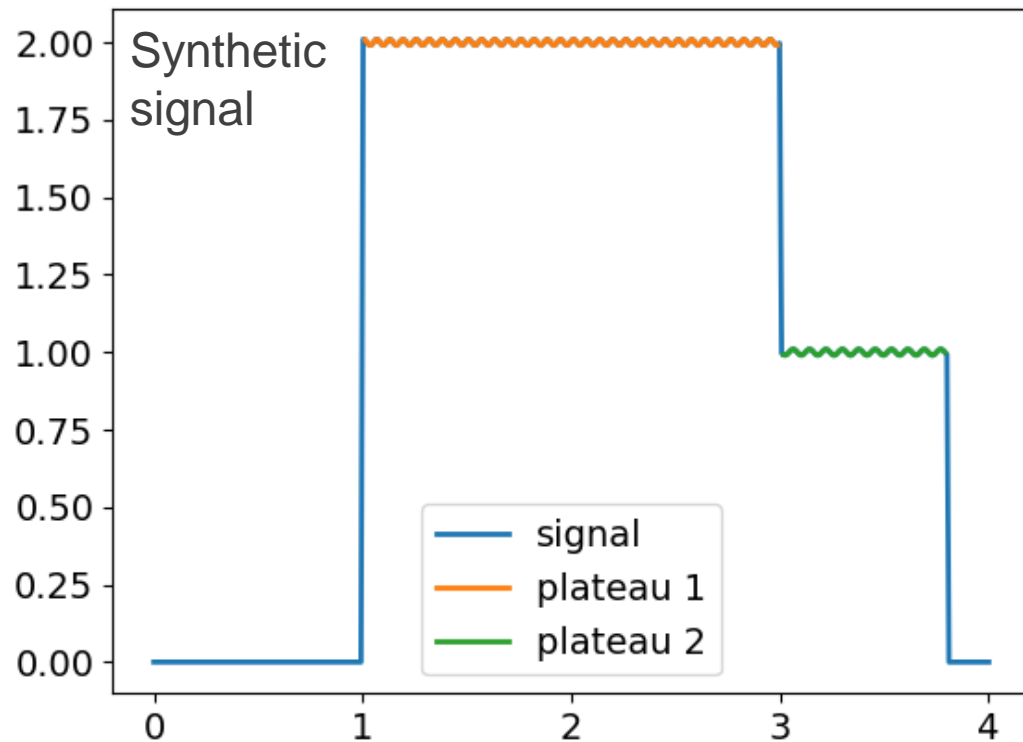
To efficiently characterize one or several experimental campaigns: development of a numerical tool for plateau detections on 1D signals.

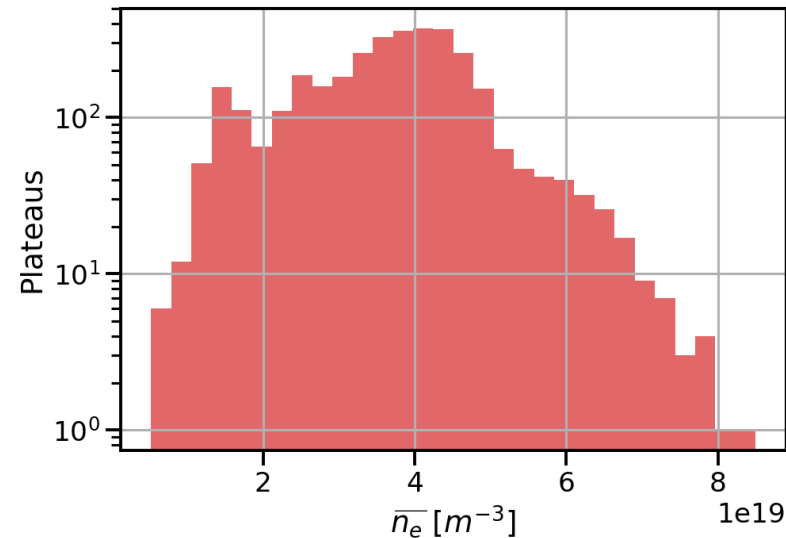
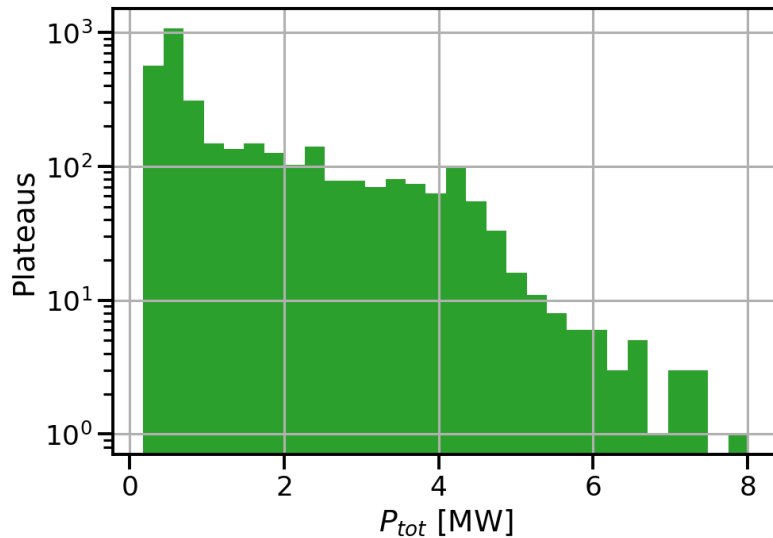
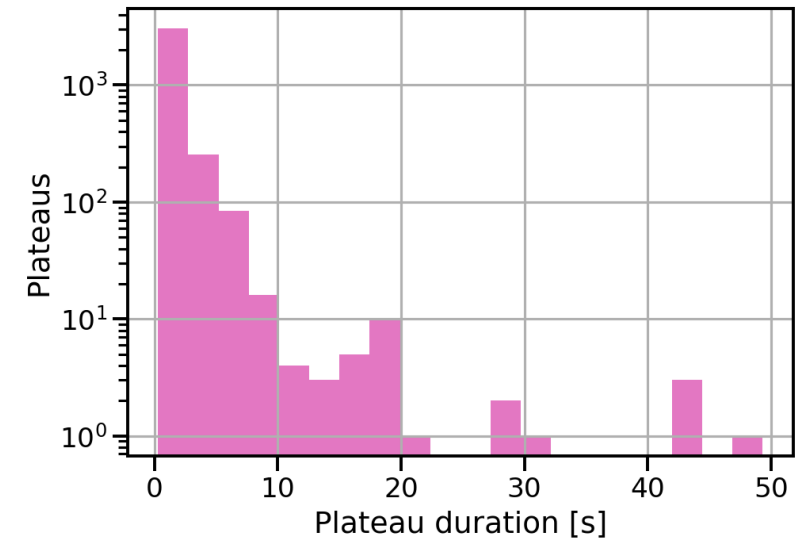
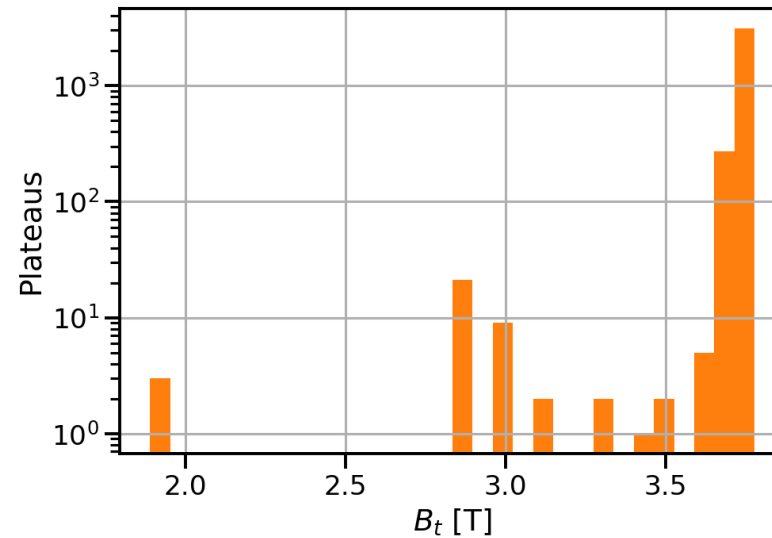
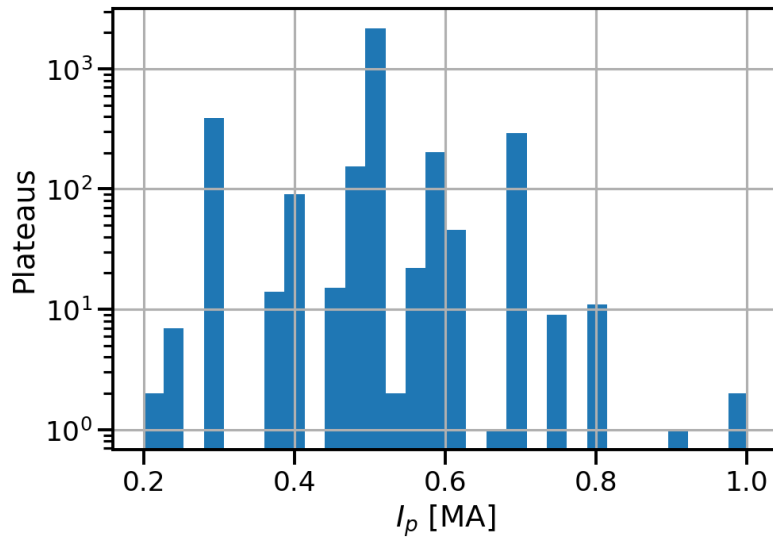
This tool allows to characterize one pulse by a small number of values:

1D signal

Plateau values:
duration, mean,
standard
deviation...

- Plateaus (quasi-steady states) are **detected automatically**, we avoid a bias that can appear when a human selection is made
- The properties of a plateau (min duration, max deviation, etc.) are explicitly given by the user, **numerical code available (open source)** at:
https://github.com/jmoralesFusion/signal_plateau_recognition

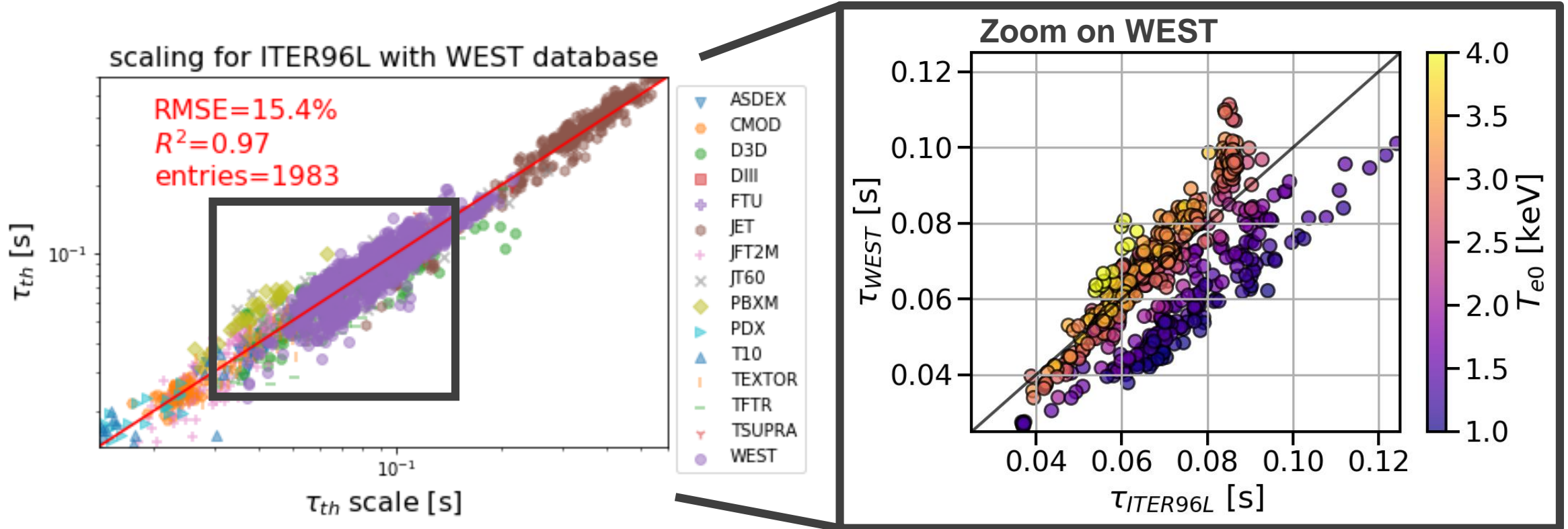




We extract data from IMAS
[Imbeaux et al., Nucl. Fusion, 2015].

Database includes more than 700 quantities (as T_{e0} , P_{tot} ...)
and 6000 plateaus.

Histogram data: quantities in identified plateaus during WEST C4 and C5 campaigns (2019-2021)



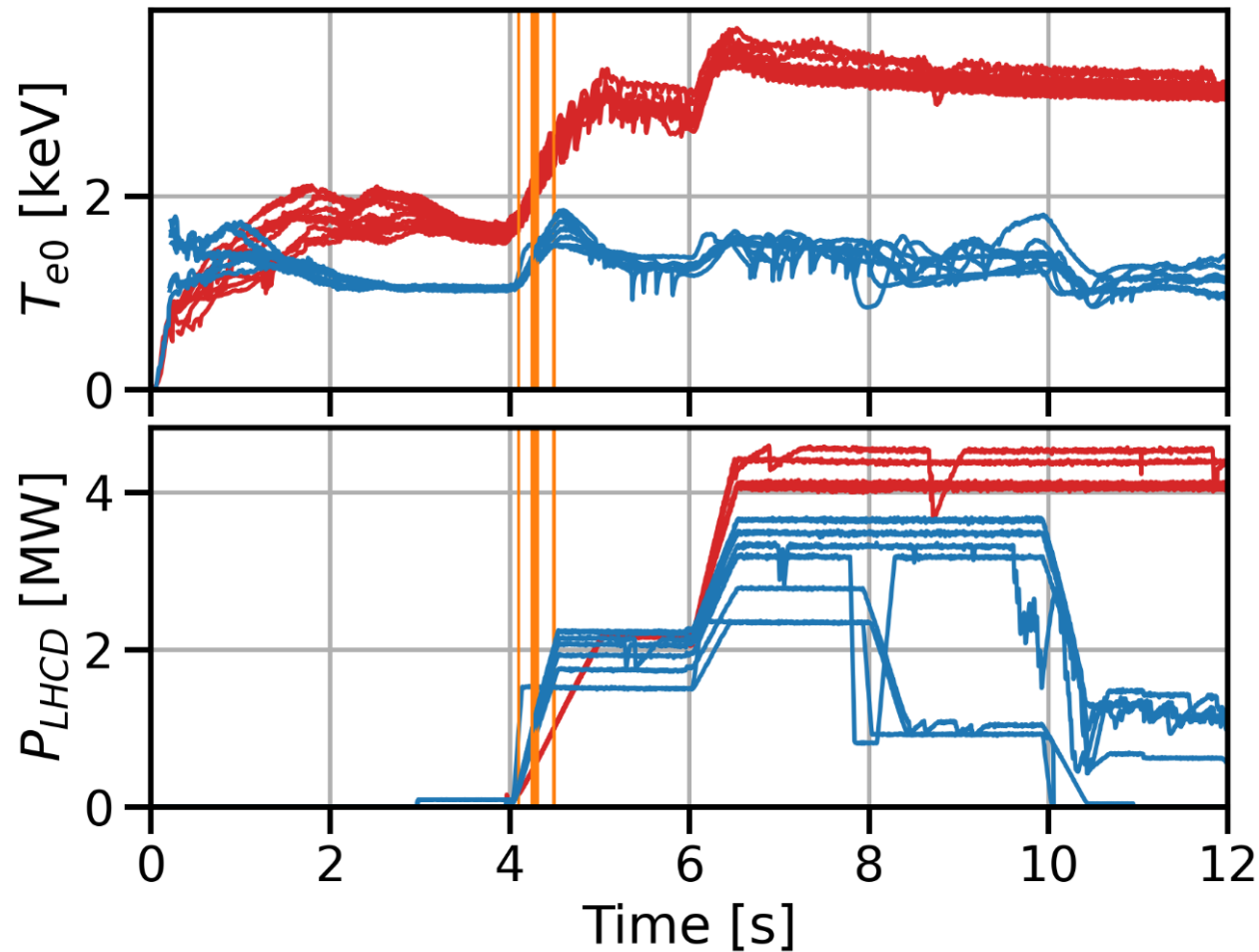
$$\tau_{ITER96L} = 0.023 I_p^{0.96} B^{0.03} P^{-0.73} n_e^{0.4} M^{0.2} R^{1.83} \epsilon^{-0.06} k^{0.64} \text{ [Kaye, NF, 1997]}$$

- Using **plateau averaged quantities**, we find WEST confinement time in L mode **well aligned with ITER96L** scaling law [Goniche et al., Nucl. Fusion, 2022]
- Interestingly in WEST, **two confinement regimes** (clusters) are observed, they are strongly correlated with T_{e0} , we call them **hot and cold branches**

[Ostuni et al., Nucl. Fusion, 2022]

[Bourdelle et al., submitted to Nucl. Fusion, 2022] [Also in this conference: JO05.00012 and TM10.00003]

Pulses with $P_{LHCD} > 1$ MW and $I_p = 0.5$ MA



Hot ($T_{e0} > 3$ keV)

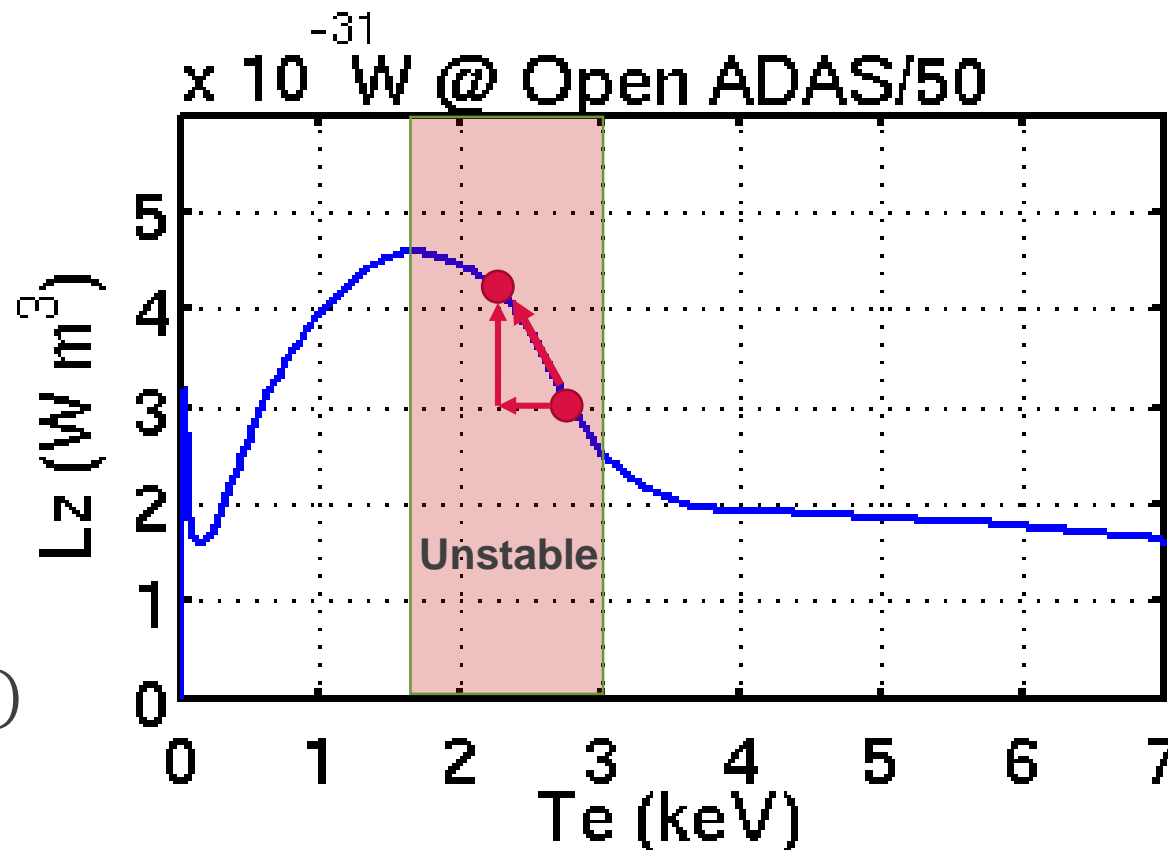
Cold ($T_{e0} < 2$ keV)

Vertical orange lines indicate times when **Lower Hybrid power (P_{LHCD})** crosses 1 MW (heating onset)

Why $T_{e0} > 3 \text{ keV}$? To burn-through tungsten

Tungsten
cooling
factor
(Lz)

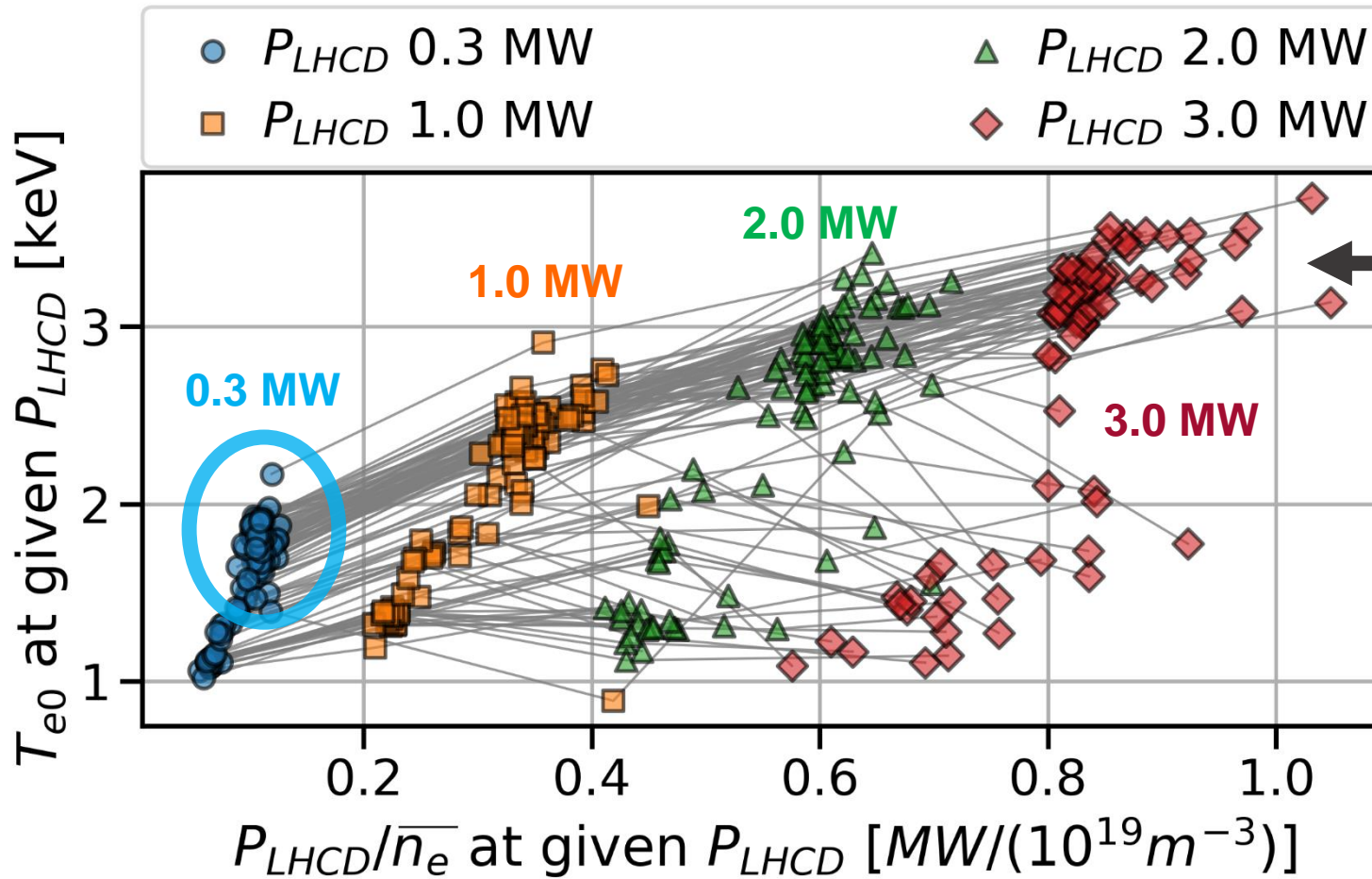
$$p_{rad,W} = n_e n_W Lz(T_e)$$



Unstable plasmas are in the range 1.5 keV to 3 keV.

[Ostuni et al., Nucl. Fusion, 2022]

Pulse trajectories with increasing Lower Hybrid power (P_{LHCD})



Goal temperature of heating phase (reach **hot branch**, $T_{e0} > 3$ keV)

Two trajectories are observed:

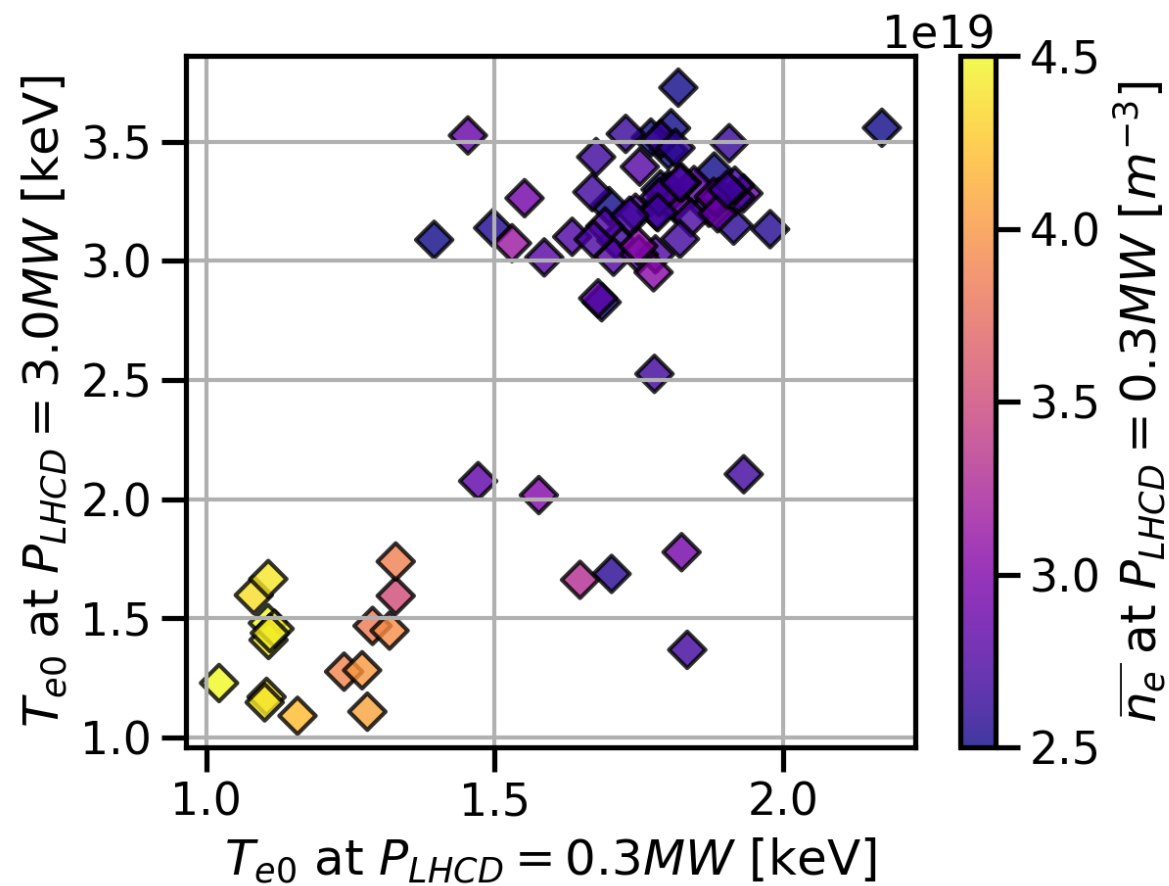
- one reaching **hot branch**,
- second going to **cold branch** ($T_{e0} < 2$ keV)

Each grey line indicates a pulse trajectory

High initial T_{e0} in “good” trajectories

1. High T_{e0} at heating onset needed to burn-through tungsten

T_{e0} at high heating phase

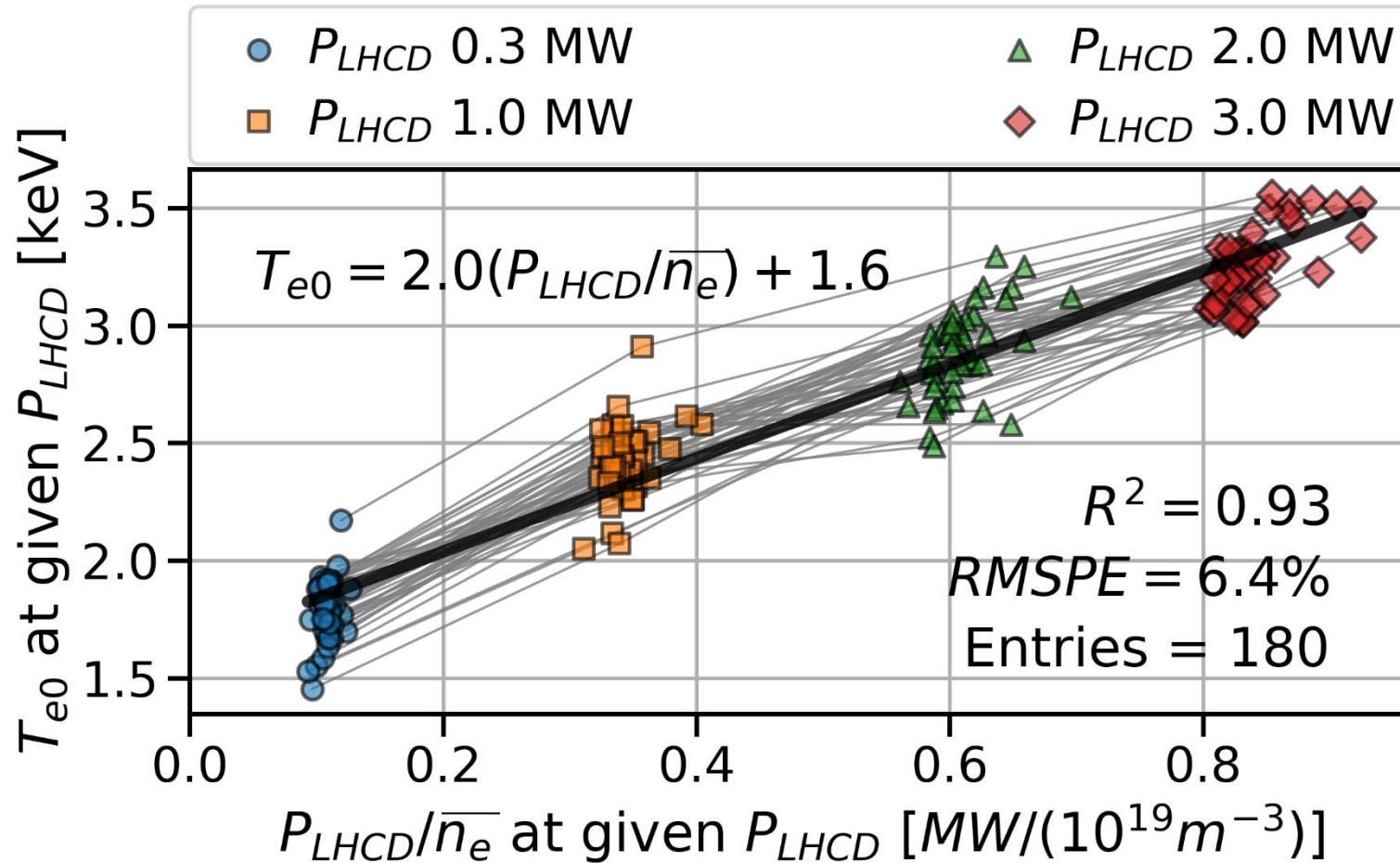


To achieve **large initial T_{e0}** :

$$\bar{n}_e < \sim 3.0 [10^{19} m^{-3}]$$

T_{e0} at heating onset

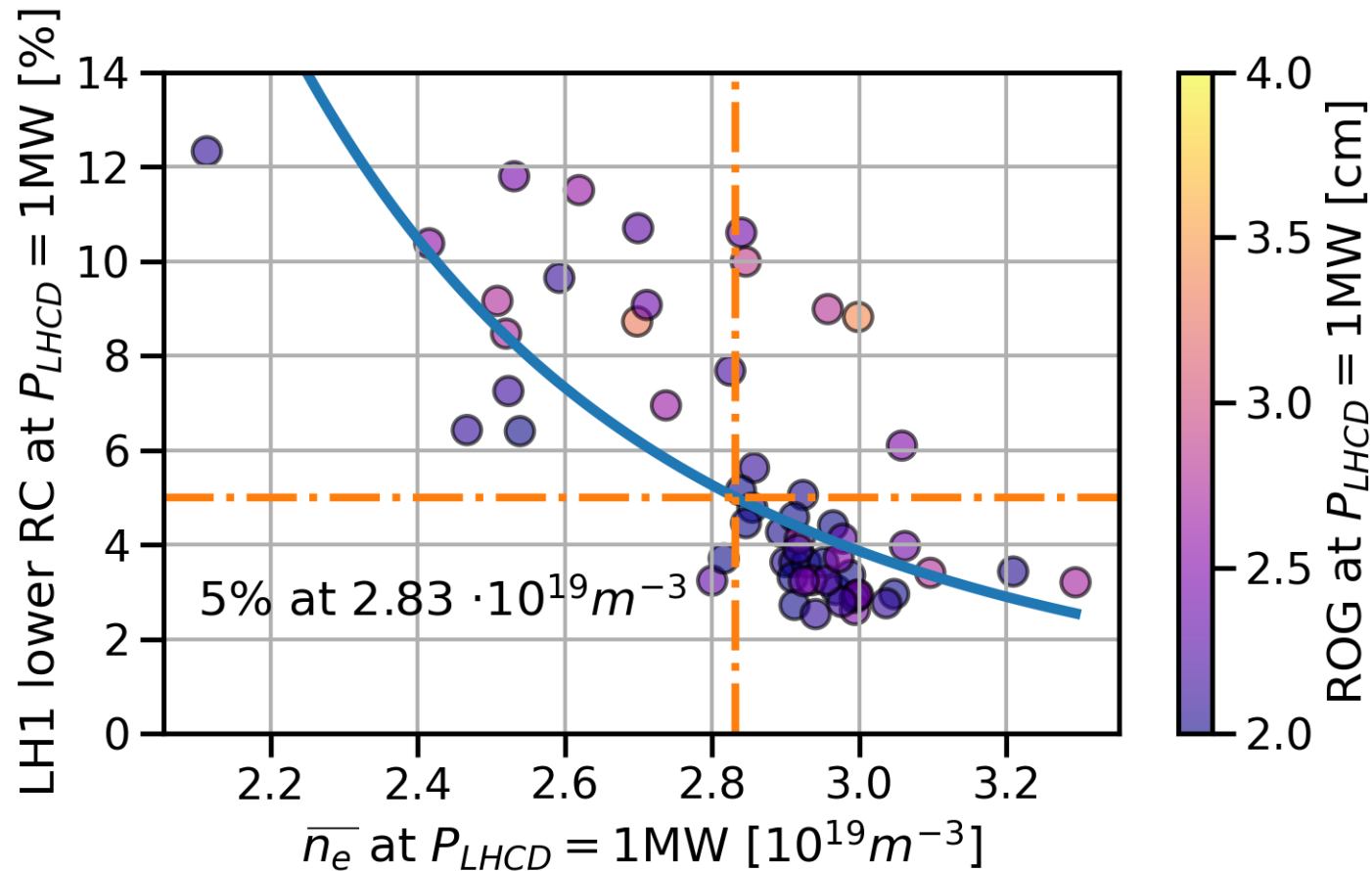
2. High LHCD power density required to burn-through tungsten



To obtain $T_{e0} > 3keV$:

$$\frac{P_{LHCD}}{\bar{n}_e} > 0.7 \text{ [MW}/10^{19}m^{-3}]$$

3. Minimum density to obtain low Reflection Coefficient (RC)



Reflection coefficient on lower LH1 antenna modules
(stronger constraint than in upper modules)

For small Radial Outer Gap (ROG < 4 cm), to achieve RC < ~ 5%:

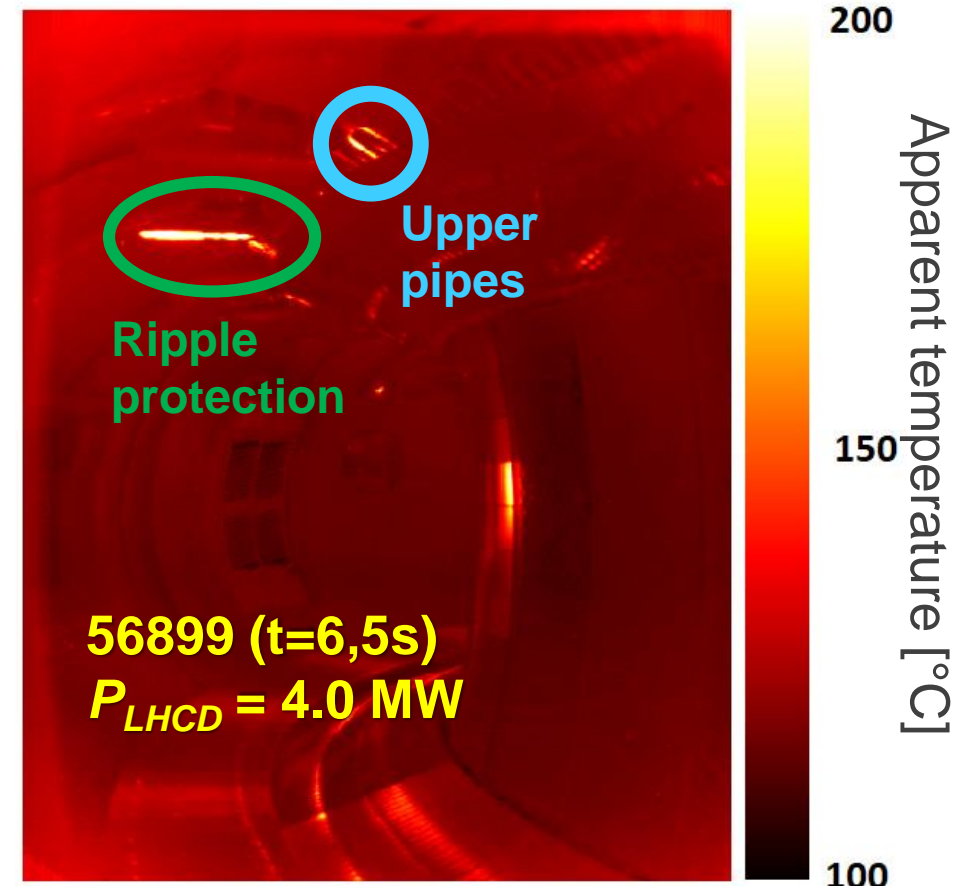
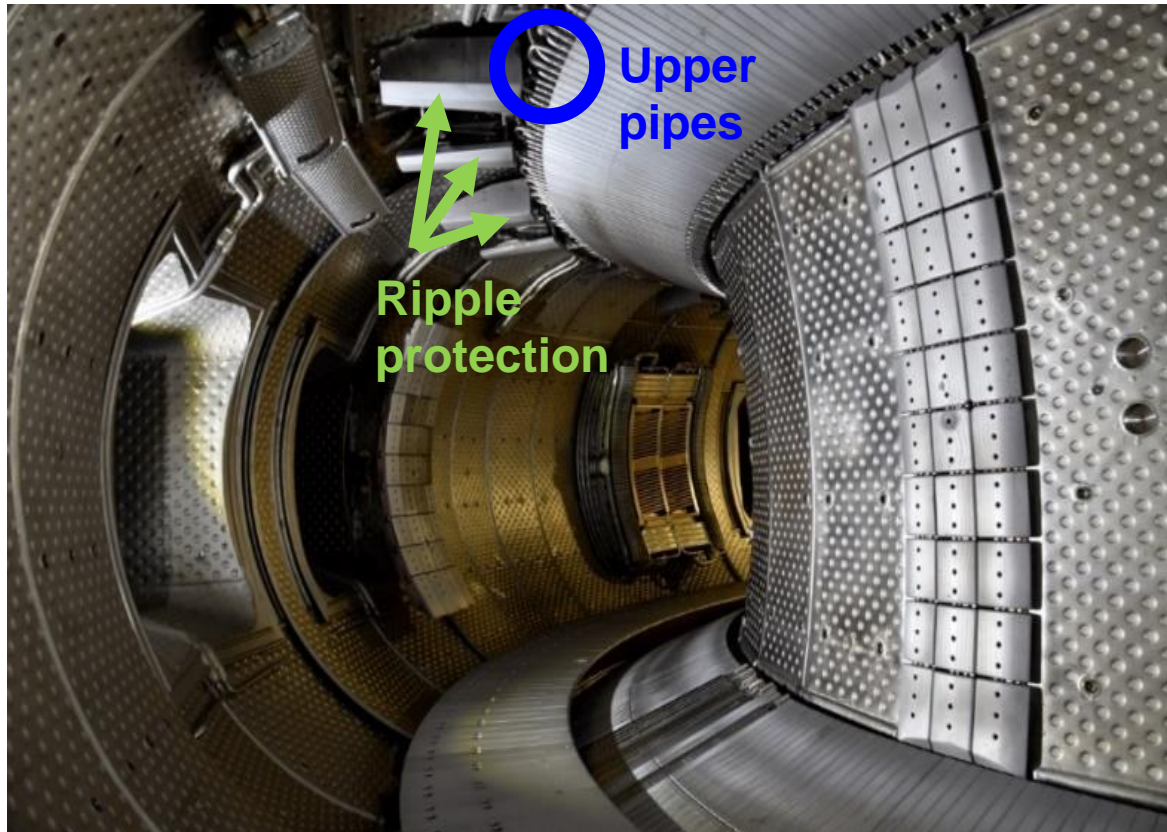
$$\bar{n}_e > 2.8 [10^{19}\text{m}^{-3}]$$

We recall: to achieve large initial T_{e0} :

$$\bar{n}_e < \sim 3.0 [10^{19}\text{m}^{-3}]$$

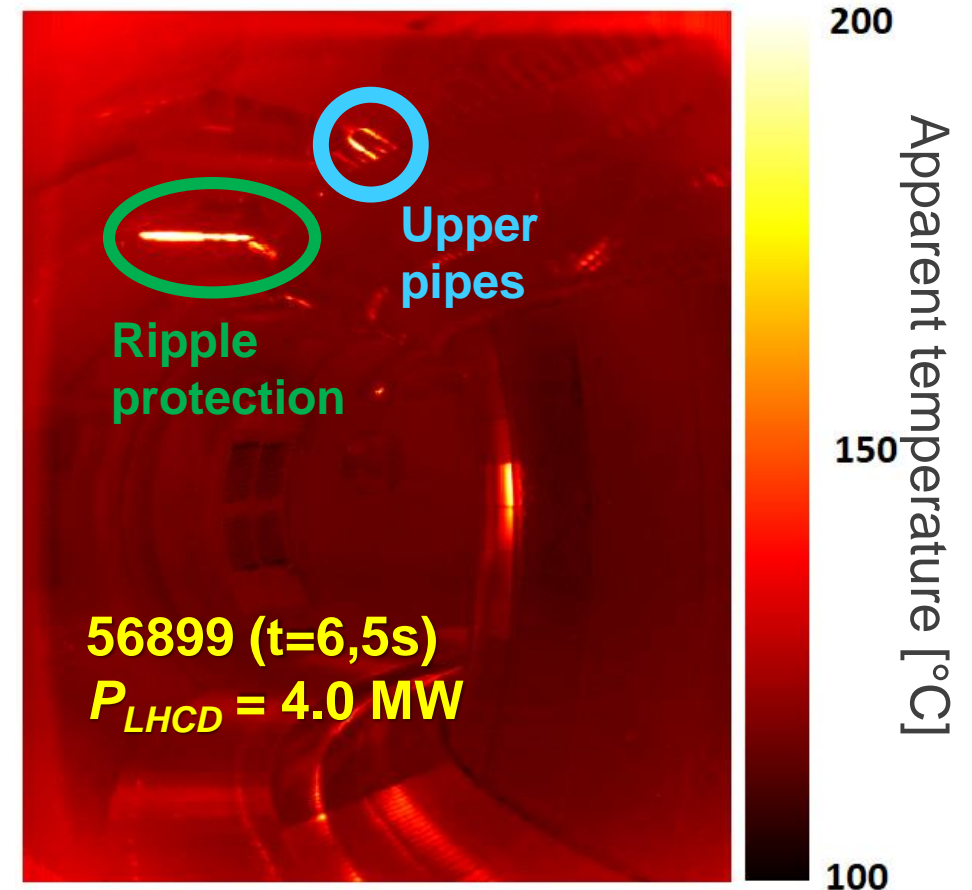
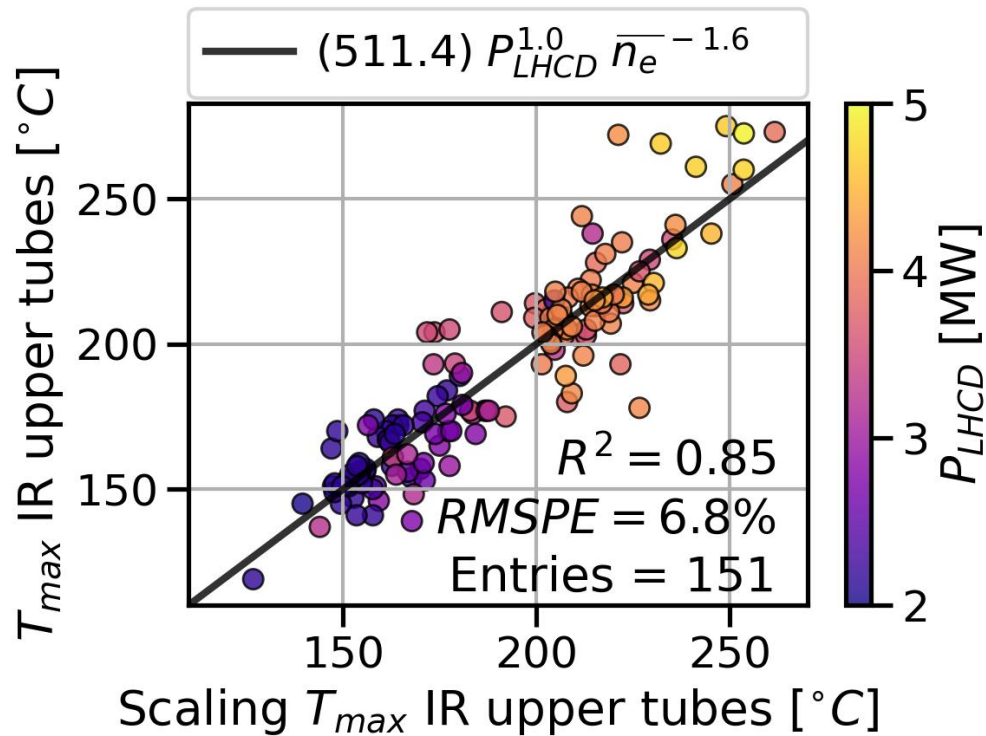
4. Maximum LHCD power density limited by ripple losses

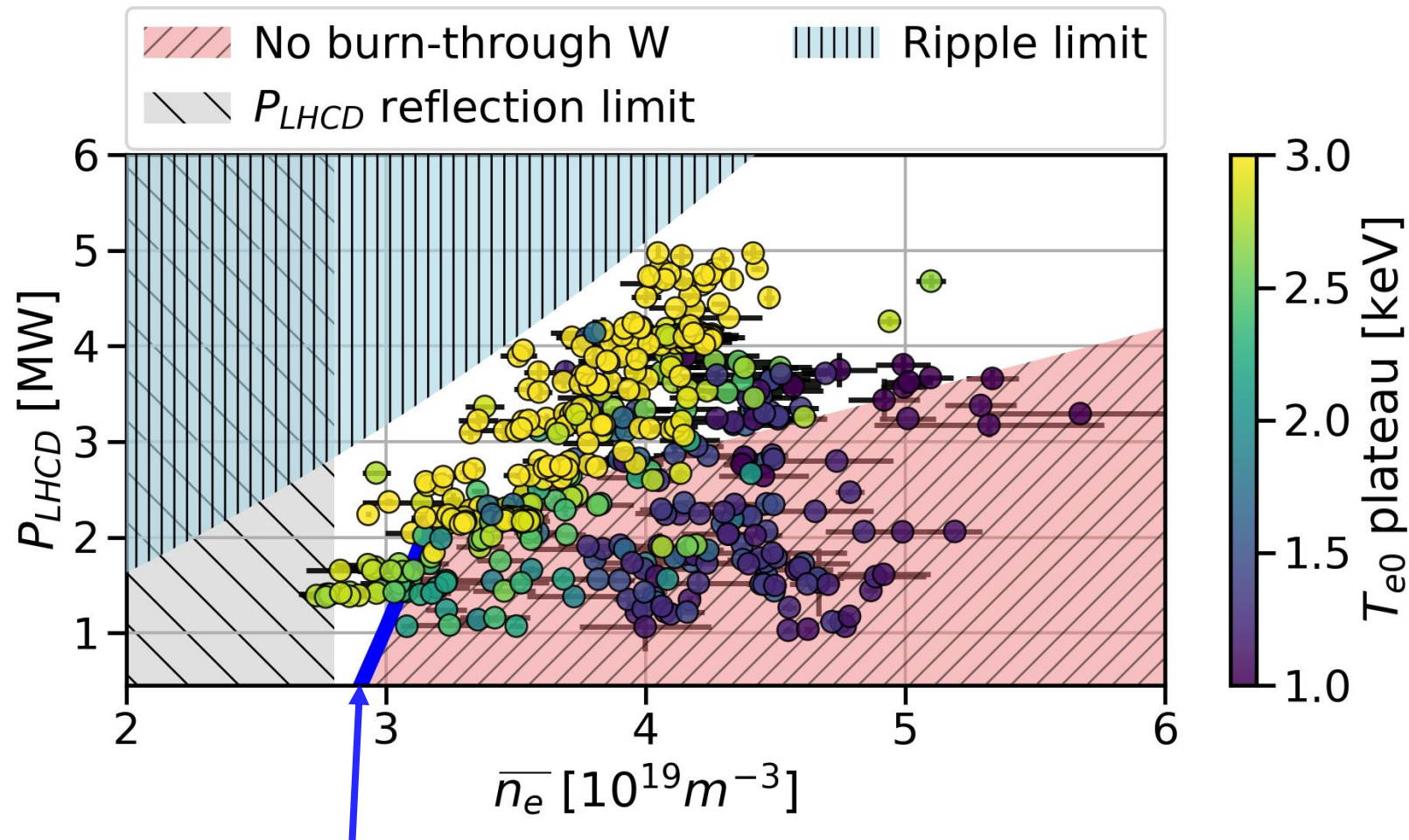
- Electron ripple losses induced by LHCD create hot spots in upper cooling pipes
- To limit the thermomechanical fatigue (to resist at least 2400 thermal cycles) maximal apparent temperature (T_{max}) allowed is **275°C**



4. Maximum LHCD power density limited by ripple losses

- Electron ripple losses induced by LHCD create hot spots in upper cooling pipes
- To limit the thermomechanical fatigue (to resist at least 2400 thermal cycles) maximal apparent temperature (T_{max}) allowed is **275°C**





Initial conditions (for high initial T_{e0})
and P_{LHCD} ramp-up to burn-through tungsten