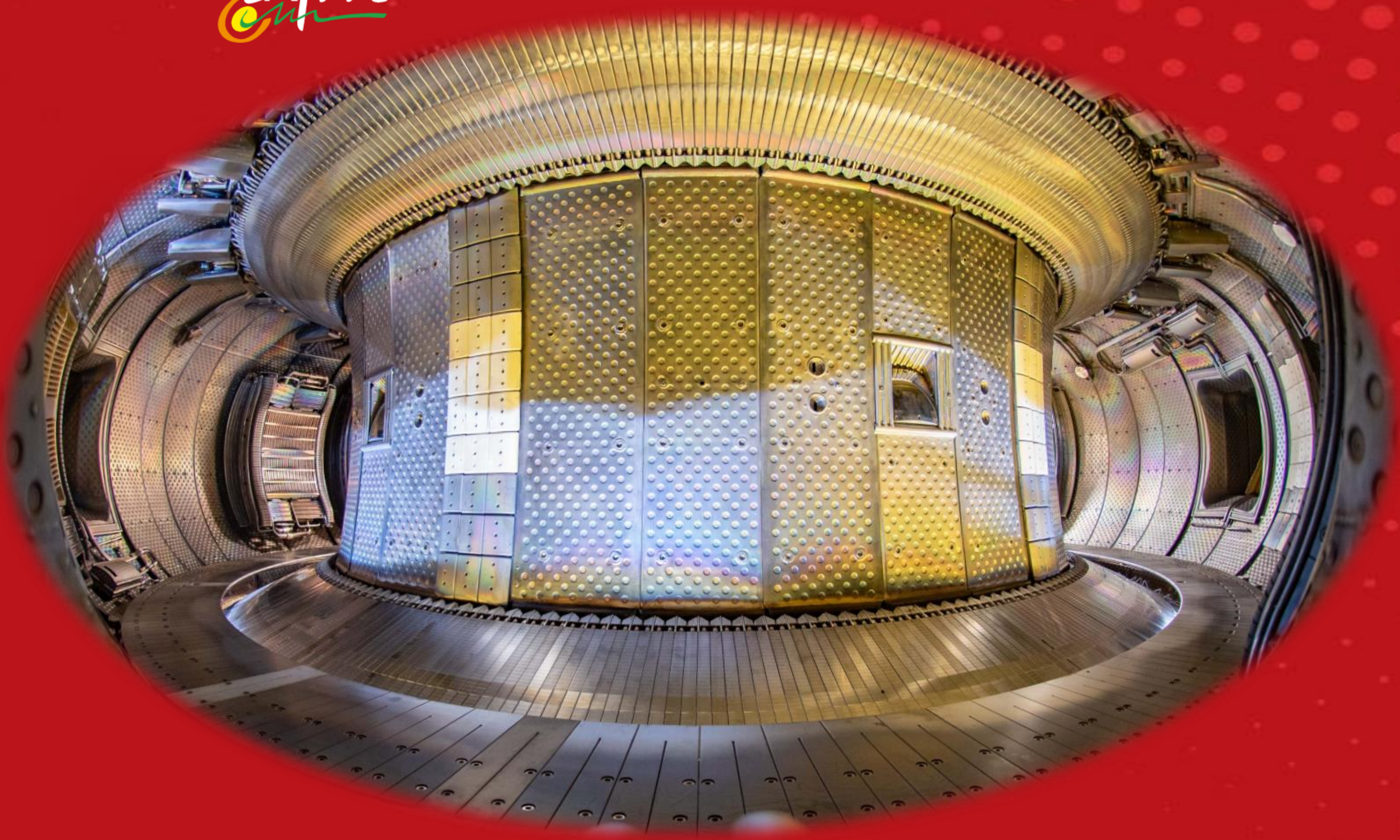
Core radiative collapse in WEST LHCD plasmas: characterization and integrated modelling

Valeria Ostuni, Jorge Morales, Jean François Artaud, Clarisse Bourdelle, Pierre Manas, Y. Peysson, Nicolas Fedorczak, Rémi Dumont, Marc Goniche, Patrick Maget



Core radiative collapse in WEST LHCD plasmas: characterization and integrated modelling

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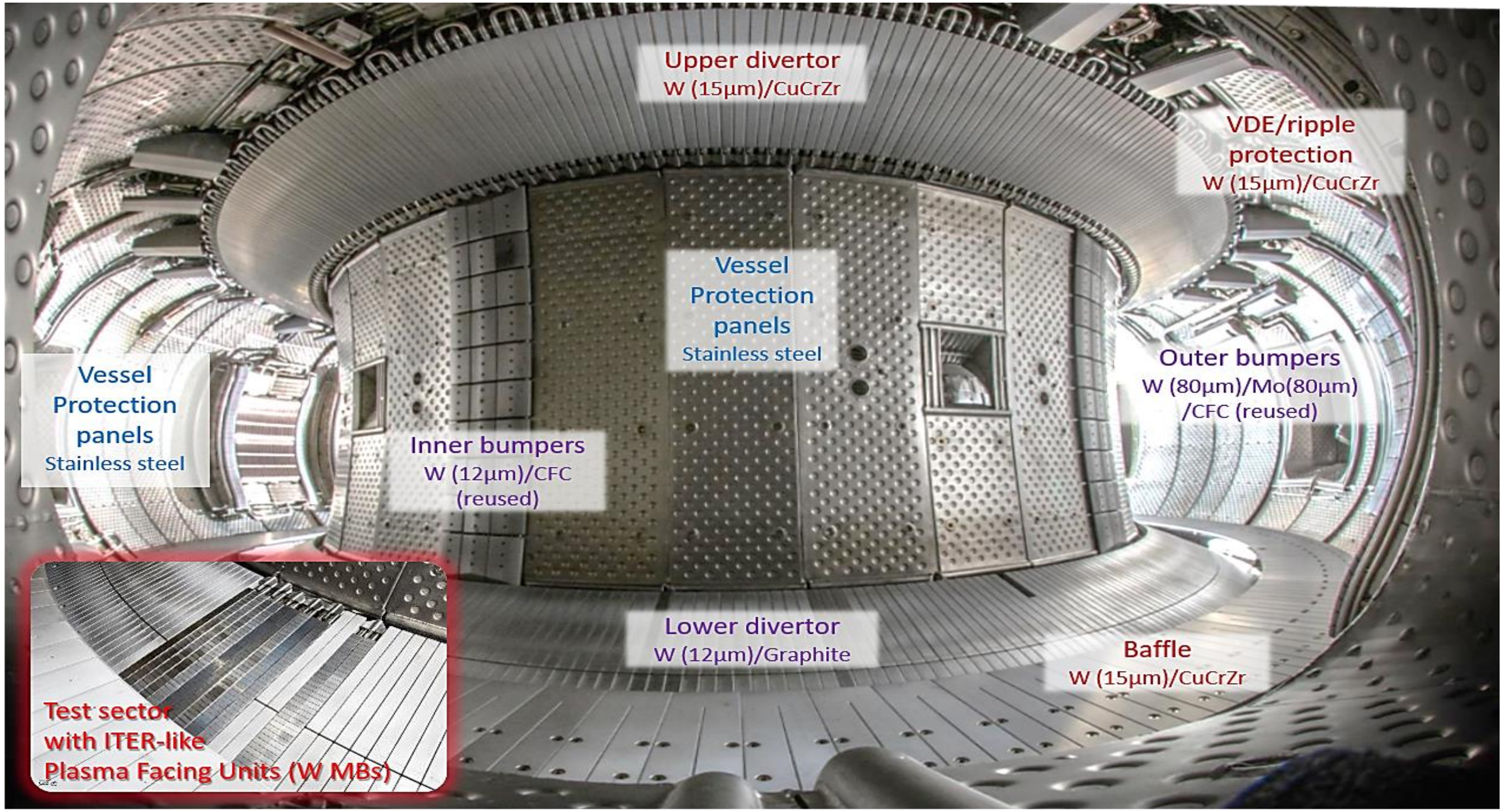
WEST: superconducting full W environment heated by RF

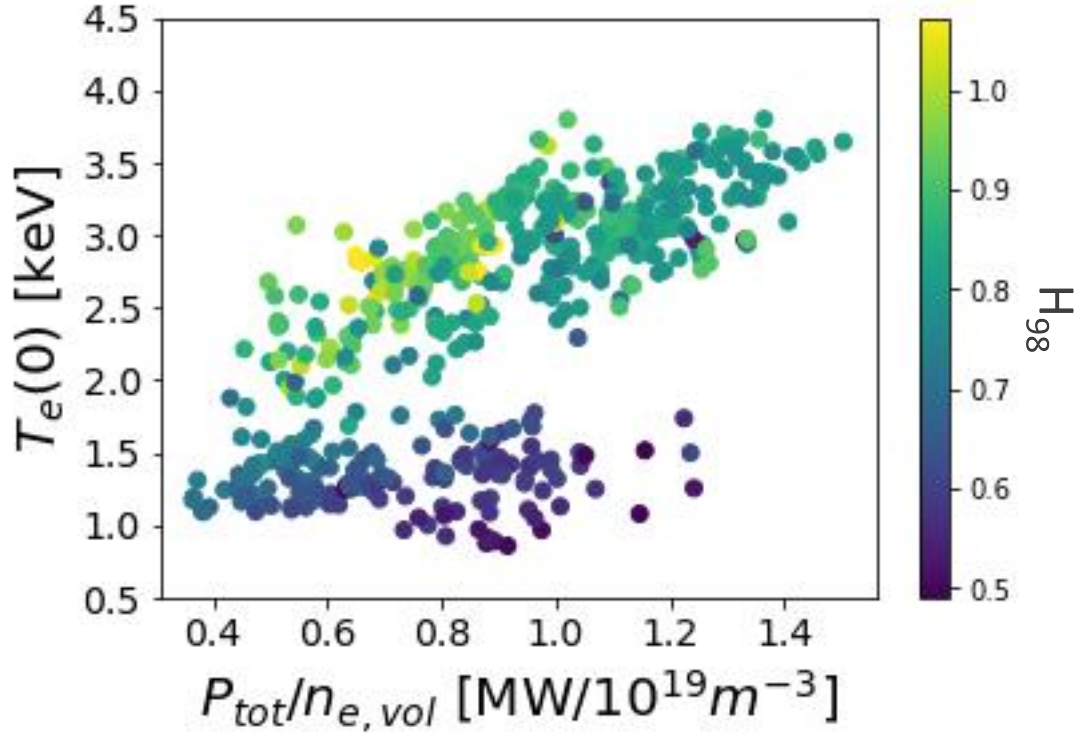


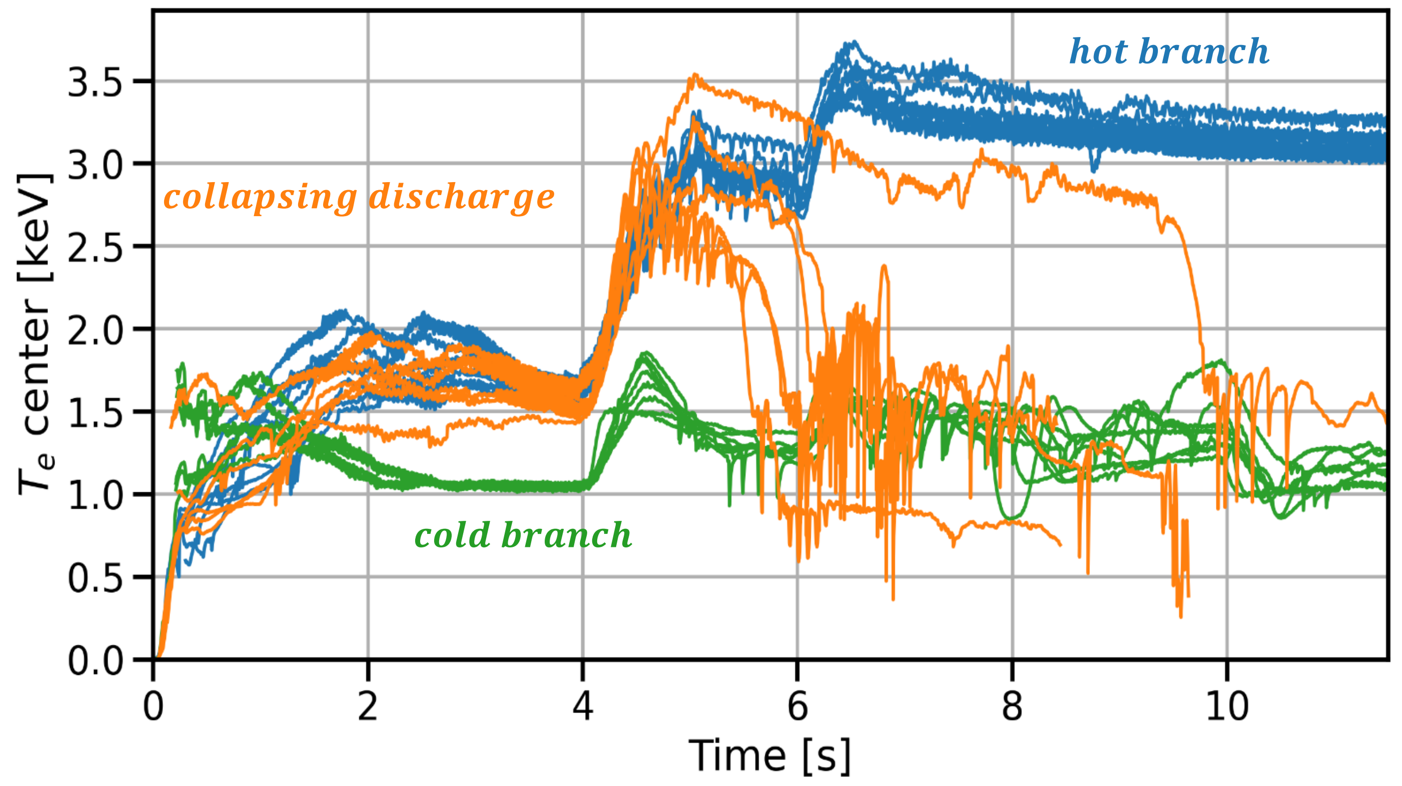
B_T	3.7 T
R	2.5 m
a	0.4/0.5 m
P_{LH}	2 launchers 7 MW
P_{ICRH}	3 antennas 9 MW

Dominant **electron heating**, no **external torque**.

In this talk: **L-mode** experiments, in **deuterium** with **LHCD** dominant heating.

Two different confinement states in WEST database





Two questions arise from this analysis:

- Why are there two branches?

- Why do the **25%** of the **discharges** in the hot branch **collapse?**

Phenomena observed in **JET** during I_p ramp up and **FTU**

[C.D. Challis NF 2020] [P. Buratti PPCF 1997]

Outline

- **Characterize** and **understand** the dynamics of the **radiative collapse**;
- **Reproduce** the rapid **collapse** of **central temperature** using an integrated modelling framework;
- Conclusions.

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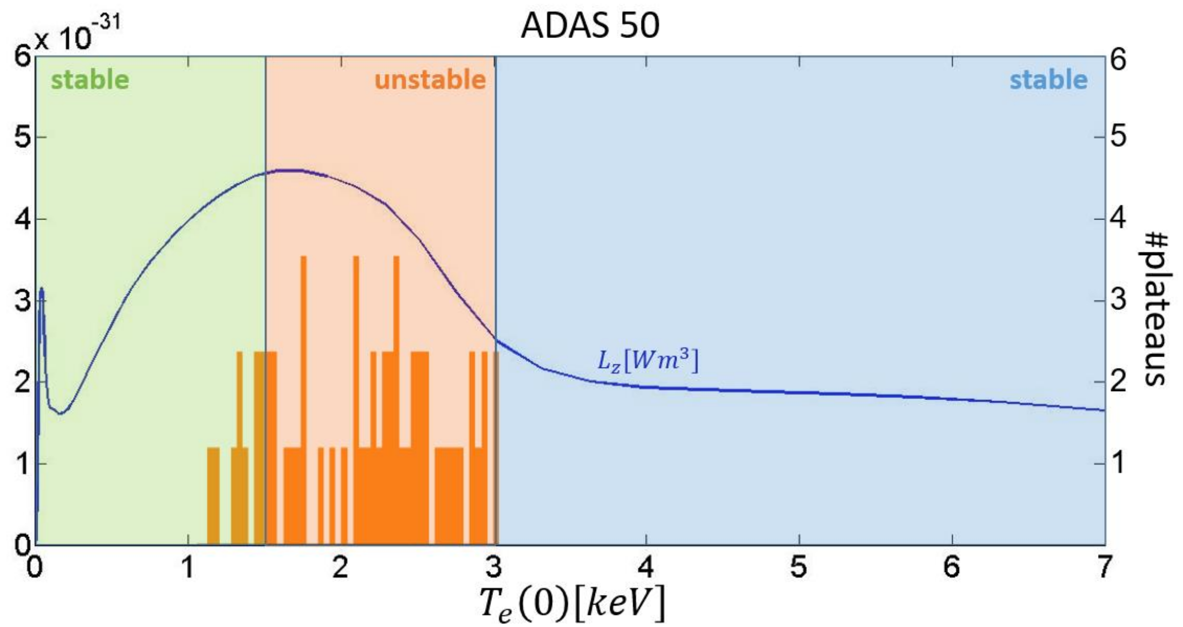
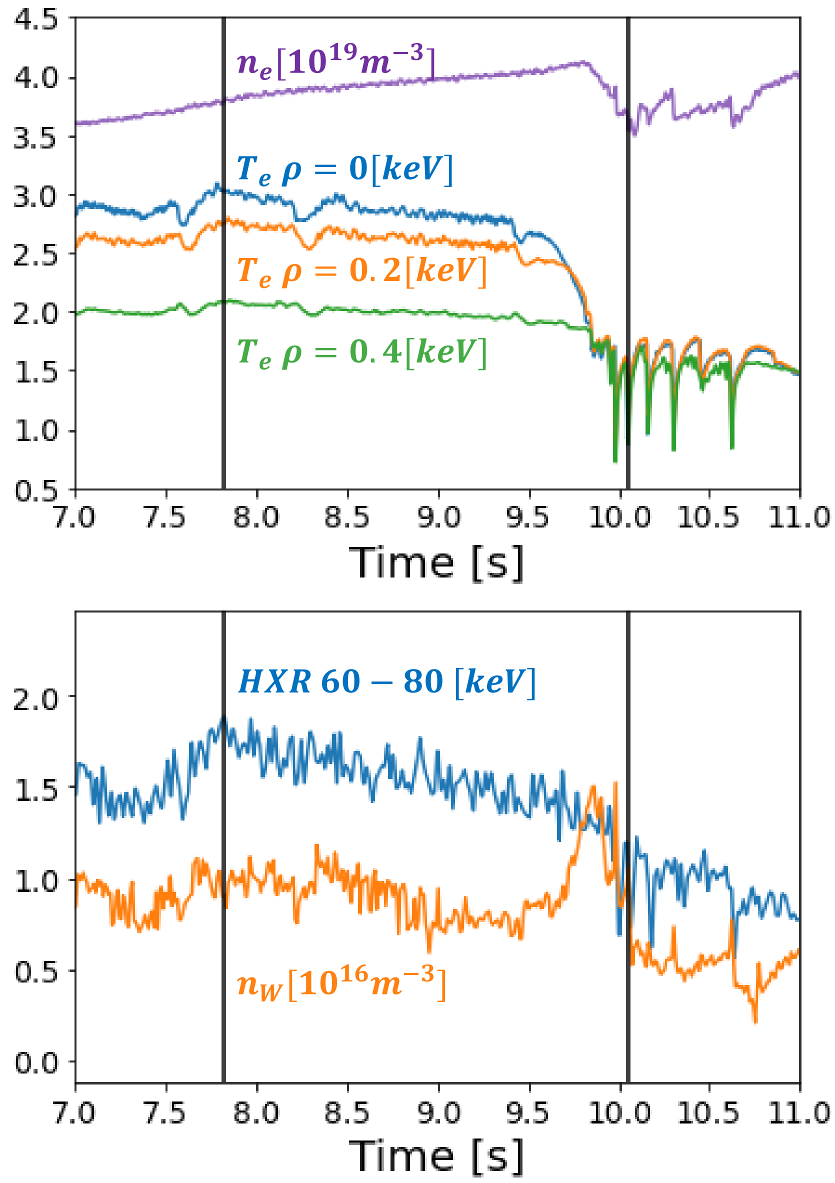
Unstable plateaus consistent with W cooling factor unstable range





Prior to the collapse:

- a slow **increase** of **electron density;**
- a slow **decrease** of **electron temperature;**
- a **constant W** density;
- a slow **decrease** of central **HXR signal**: signature of a lower fast electron production by **LHCD.**

During the collapse : **peaking of the tungsten profile**.

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- Characterize and understand the dynamics of the radiative collapse;
- **Reproduce the rapid collapse of central temperature using an integrated modelling framework;**
- Conclusions.

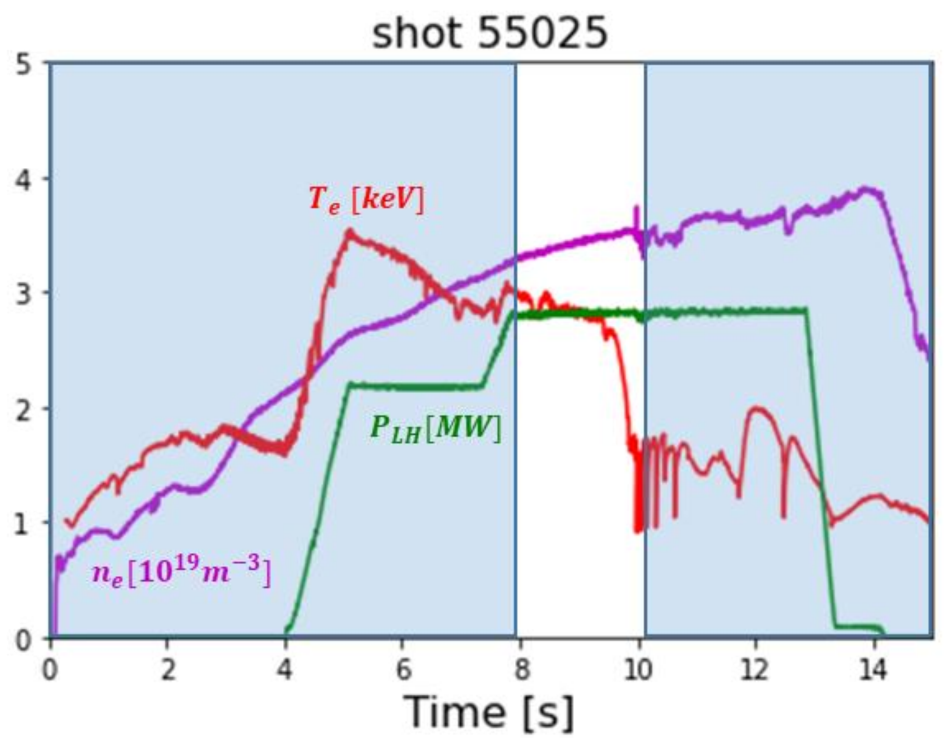
The $T_e(0)$ collapse is captured by the modelling

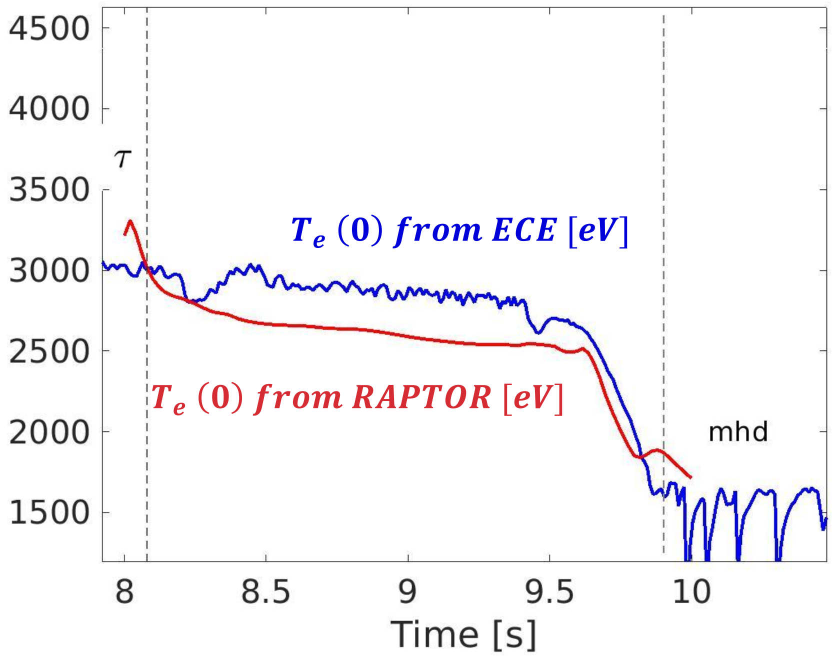
1D transport code: **RAPTOR** [F. Felici NF 2018]

Turbolent transport: 10D Neural Network version trained on **QuaLiKiz**.

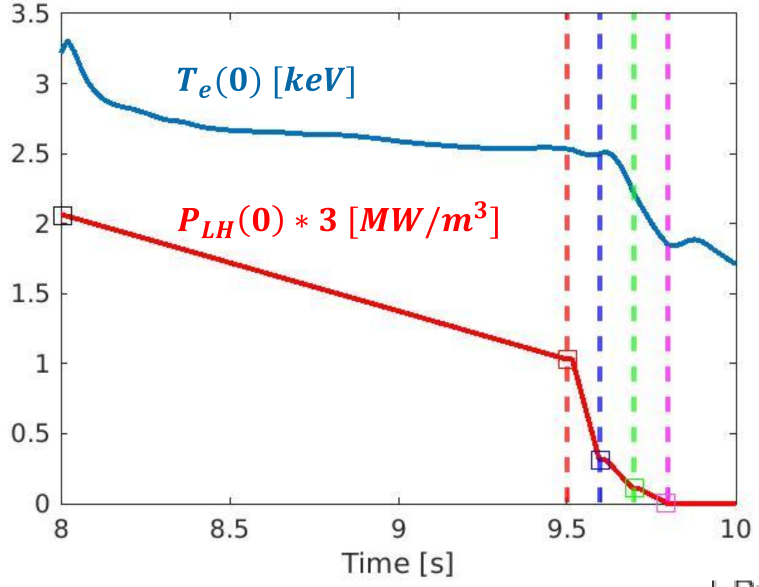
[K. van de Plassche PP 2020]

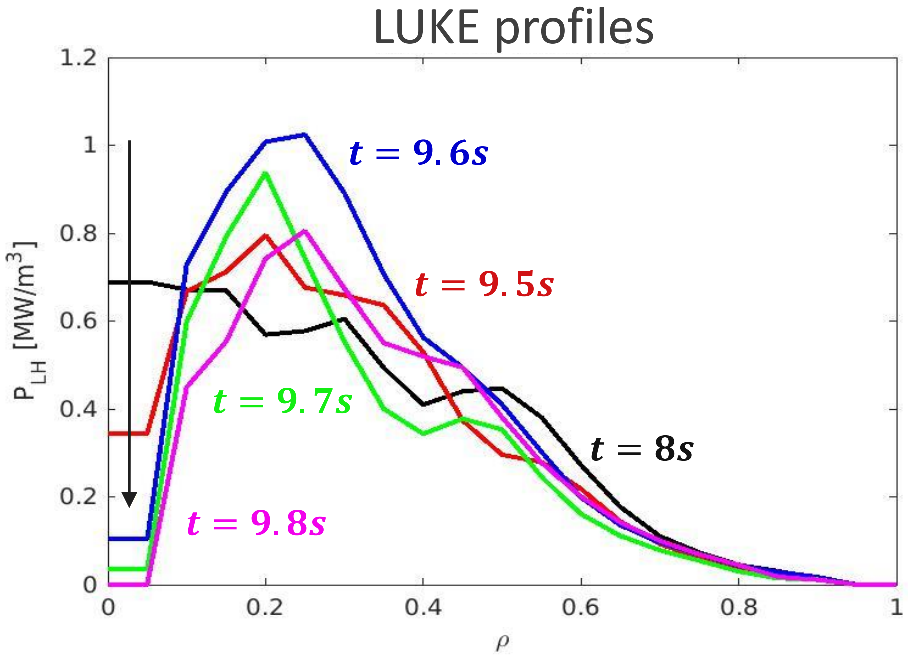
T_e and T_i	Predicted using QLKNN-10D
P_{LHCD}	LUKE
n_e	interpretative
n_w	Interpretative, based on bolometry inversion
P_{rad}	Using ADAS database





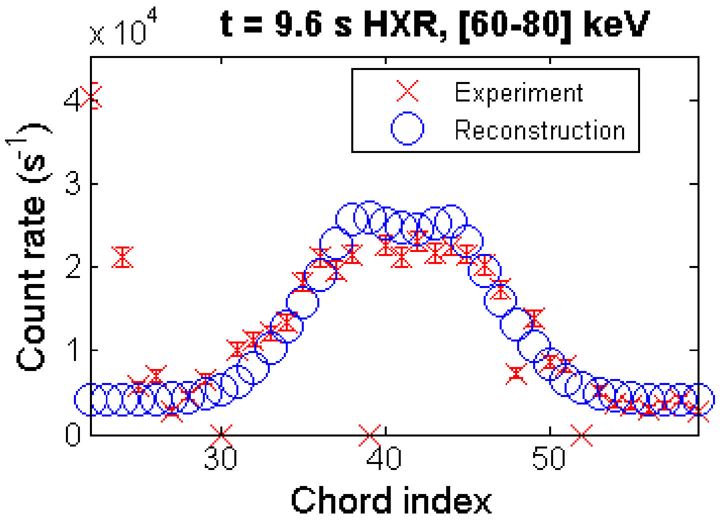
LHCD core absorption reduced to capture $T_e(0)$ dynamics



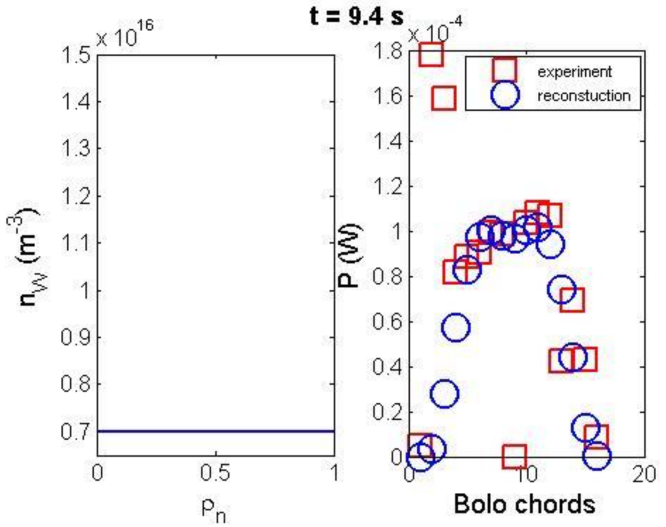


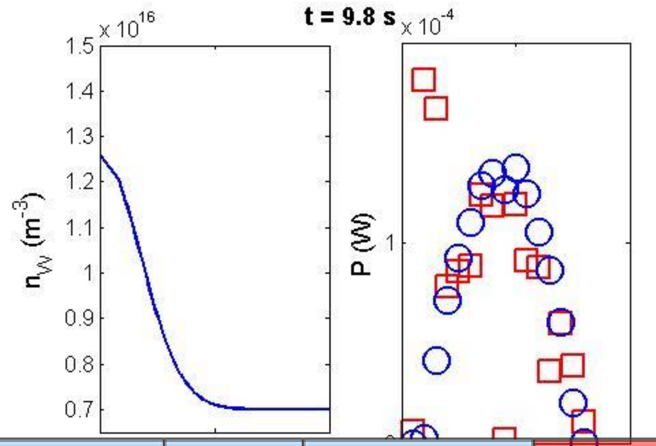
d T_i	P_{LHCD}	n_e
Predicted using QLKNN-10D	LUKE	interpretat

LHCD multipass absorption computed by **LUKE** code [Peysson FST 2014] **challenging** for core **absorption computation**.



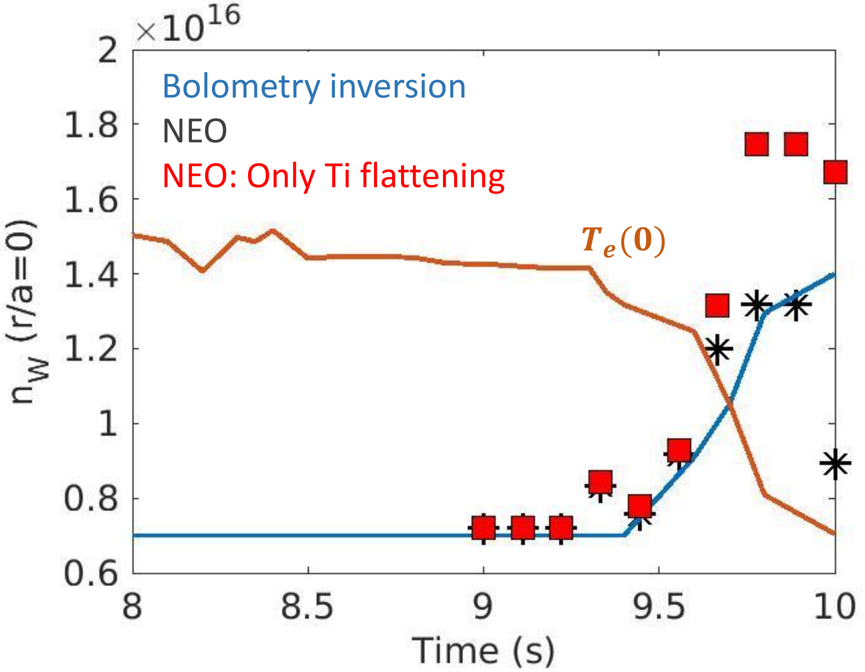
W peaking due to the temperature collapse





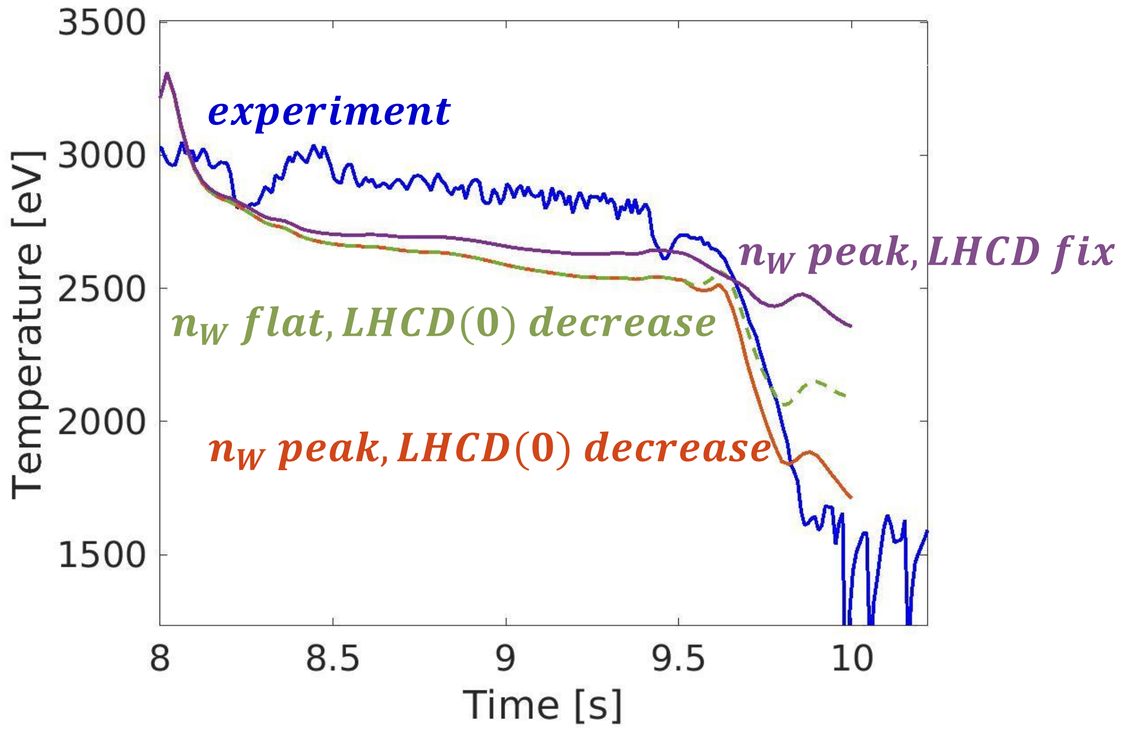
T_e and T_i	P_{LHCD}	n_e	n_W
Predicted using QLKNN-10D	LUKE	interpretative	Interpretative based on bolometry inversion

Neoclassical transport computed with NEO [Belli 2008]

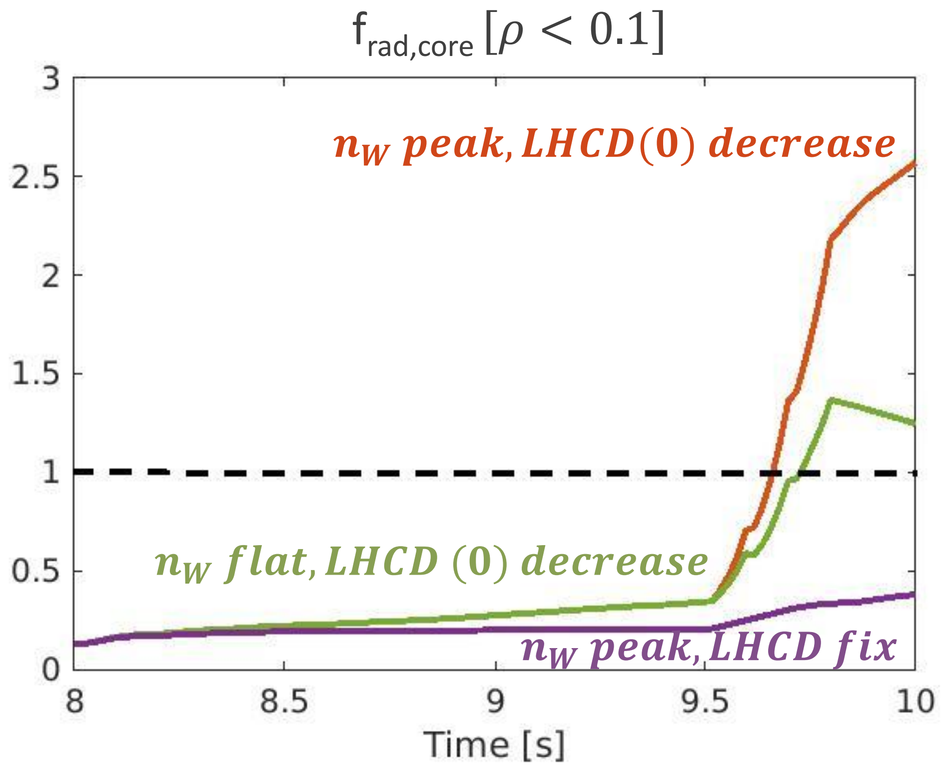


n_W approximated by a **Gaussian symmetric** around the center **on top of a flat profile**.

Tungsten peaking and LHCD core absorption reduction both needed for the collapse dynamics



Only with both the contribution of the **tungsten accumulation** and the **decrease of** the central **LHCD** absorption the **speed of collapse is reproduced.**



The **collapse** is not reproduced if the **radiated power** inside ρ=0.1 does not **overtake the central electron heating**.

Outline

- Characterize and understand the dynamics of the radiative collapse;
- Reproduce the rapid collapse of central temperature using an integrated model framework;
- **Conclusions.**

Conclusions

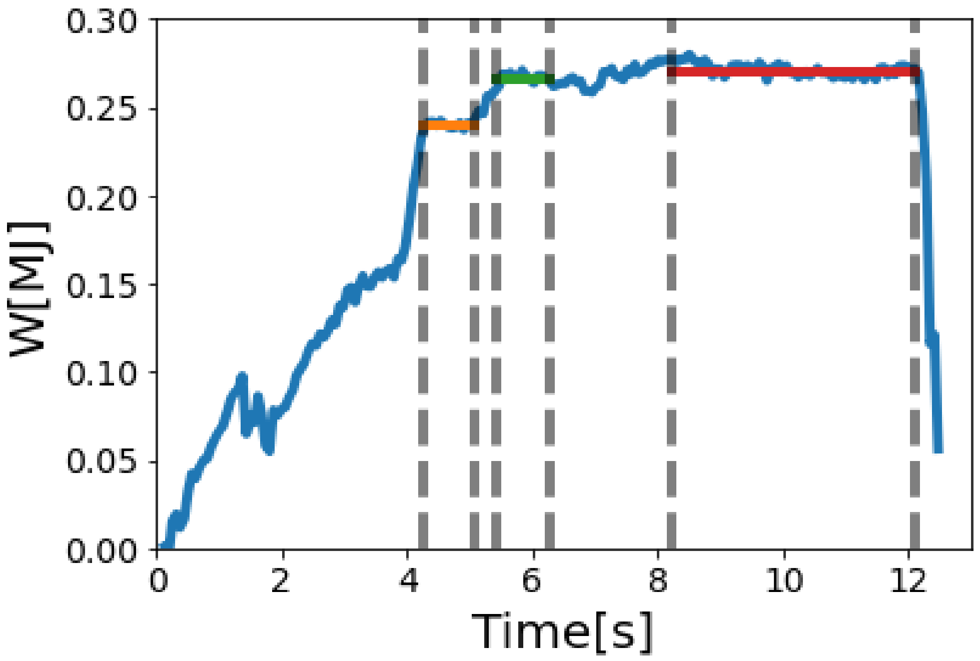
- In the database, L mode **plateaus** where $T_e(0)$ rapidly **collapse** are identified in the range of **1.5 keV** and **3 keV**.
- Time sequence of $T_e(0)$ collapse acceleration:
  - The **slight density rise** leads to **less on-axis LHCD power deposition** enhancing the central **T_e reduction**;
  - **∇T reduction** in core leads to a **reduction of W core temperature screening** hence **to core W accumulation.**
- even in absence of external torque and particle source, **core electron heating is required** to burn-through W cooling factor.
  - Core **ICRH** absorption **optimization** ongoing;
  - 3MW of **ECRH** from 2023.

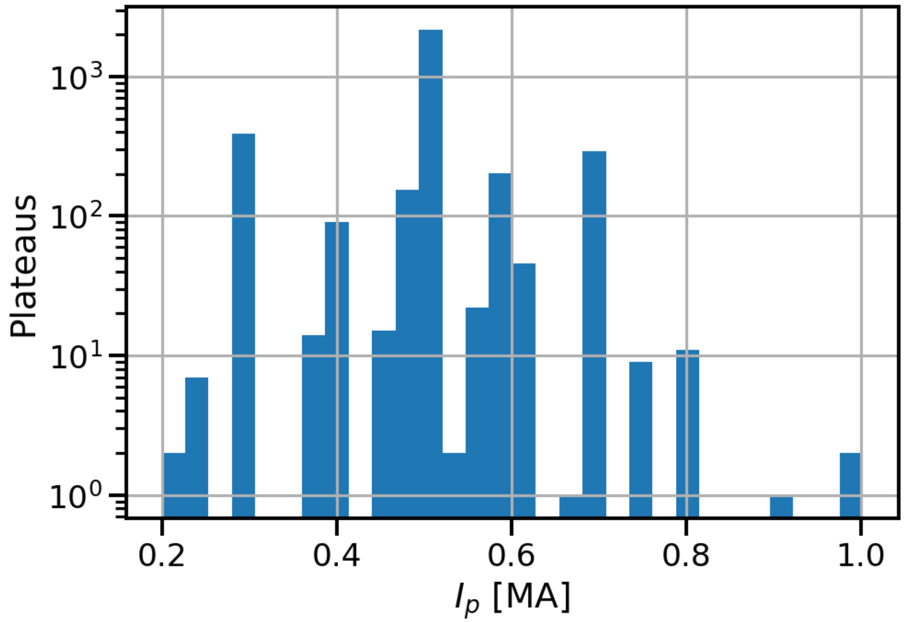
BACK UP SLIDES

DE LA RECHERCHE À L'INDUSTRIE

Plateau Statistics Reduced L-mode Database

- The database contains the **mean values** and the **standard deviations** of different diagnostic measurements at each **plateau** (quasi-steady-state).
- The plateaus are identified intersecting the **total power plateaus** and the **plasma current plateaus**.
- There are **285** discharges with **732** plateaus in the database.



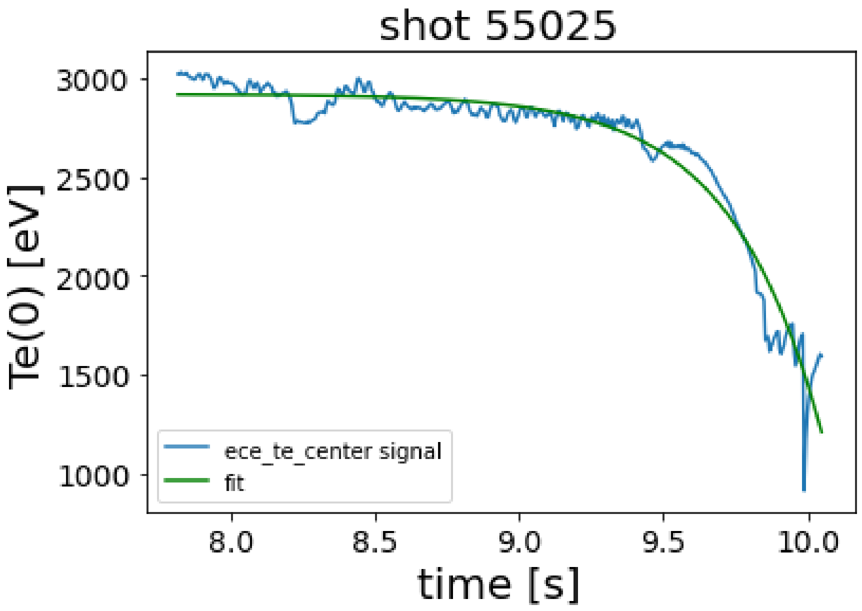


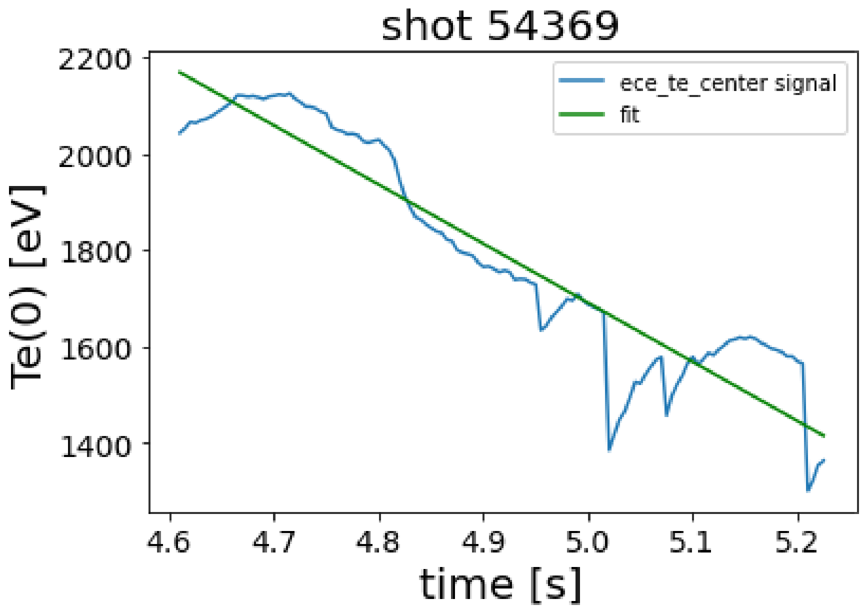
Characterizing the $T_e(0)$ dynamics in the database

Automatic identification of radiative collapses within plateaus:

$$exponential\ fit: T_e(0) = -e^{(a+bt)} + c$$
$$with\ a < 0\ for\ the\ concavity,$$

$$linear\ function\ fit$$
$$with\ slope < -830$$

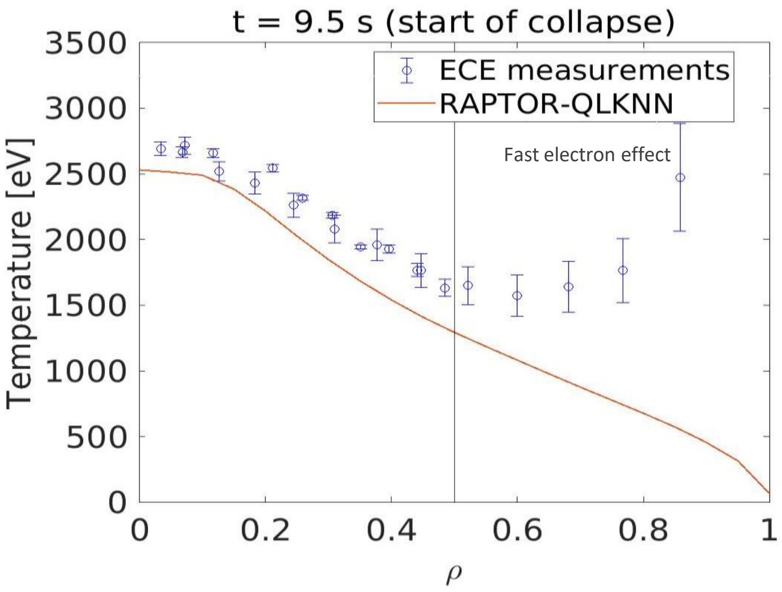


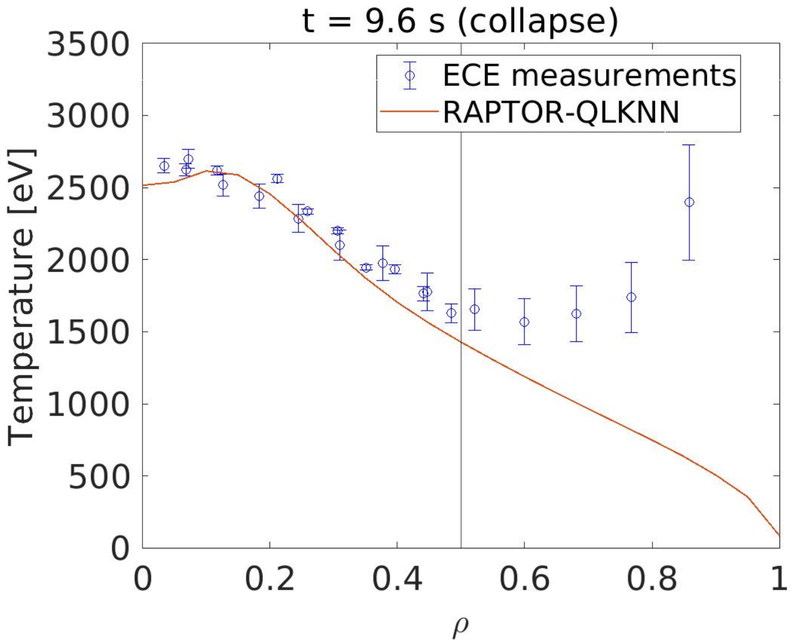


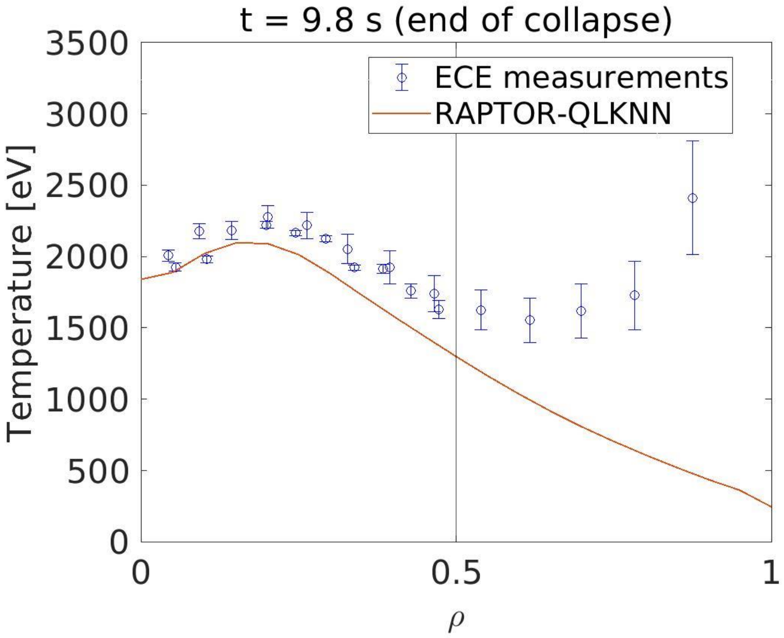
Three categories identified:

unstable plateaus where a collapse takes place, **cold stable plateaus** and remaining plateaus called **stable hot.**

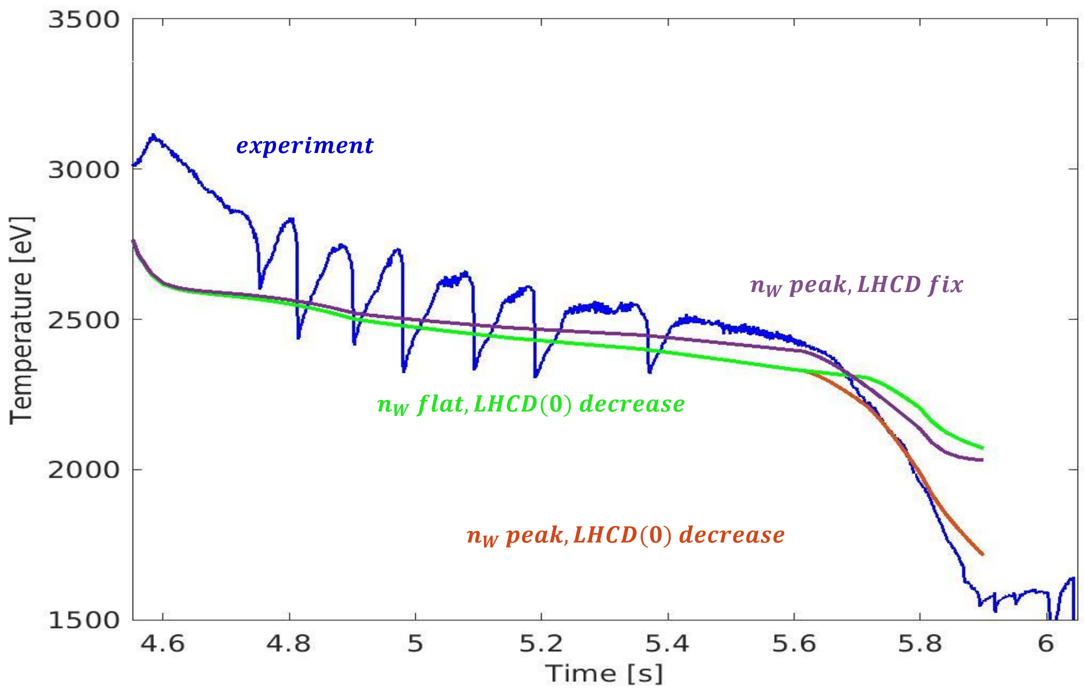
The T_e collapse is captured by the modelling

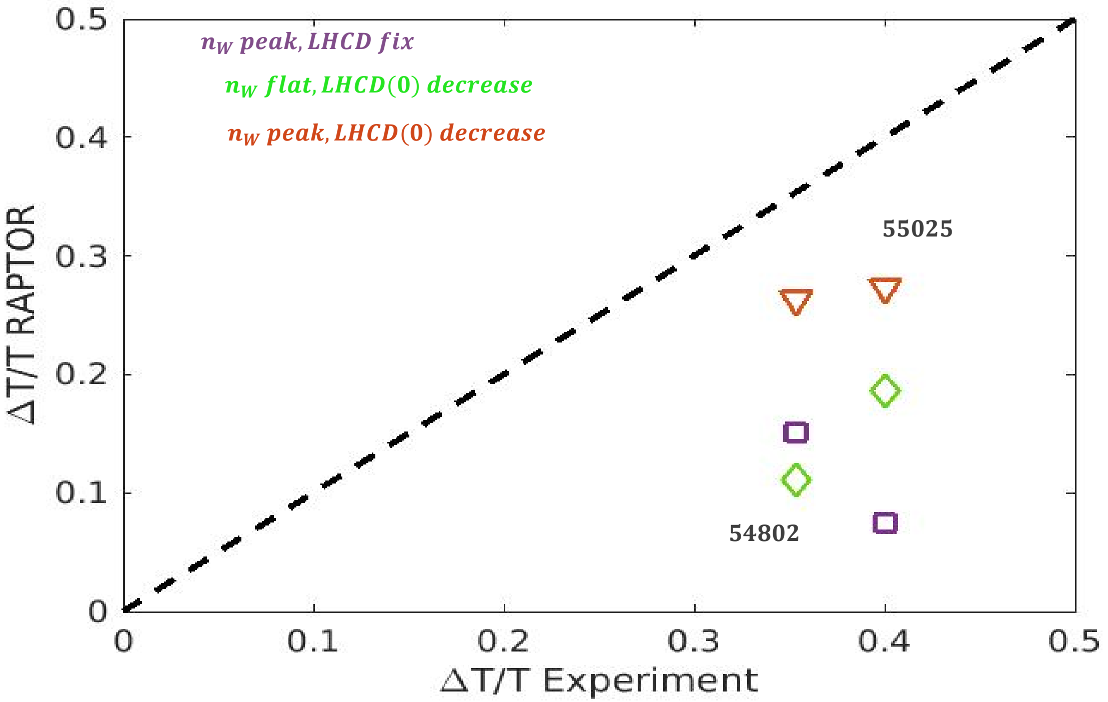






Collapse reproduction in discharge 54802





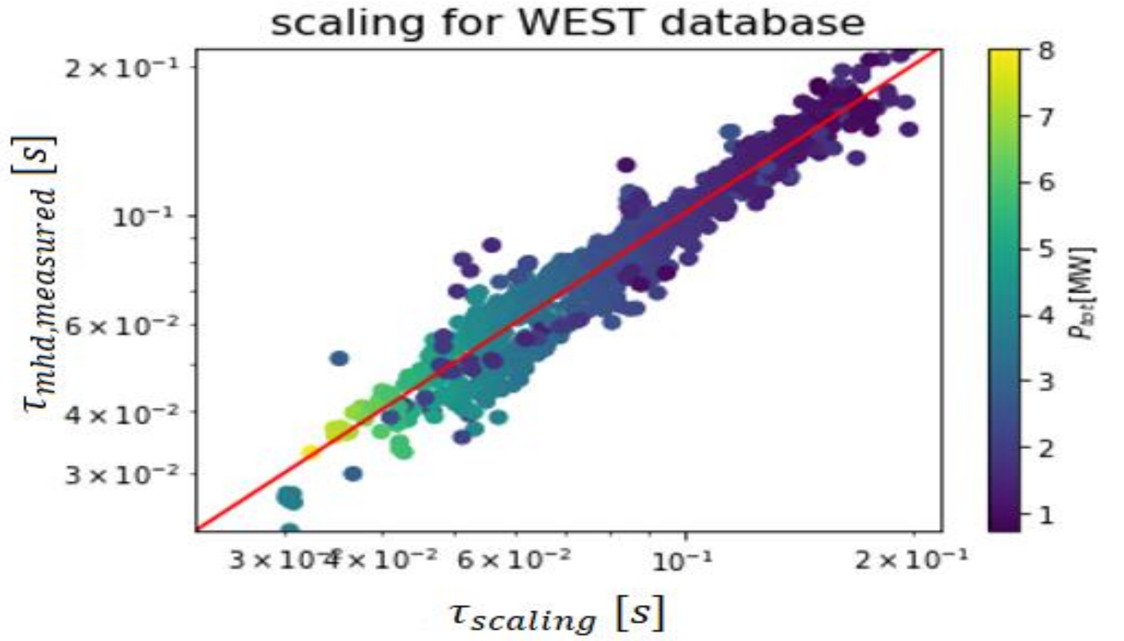
The same procedure was carried out for the **54802 discharge**.

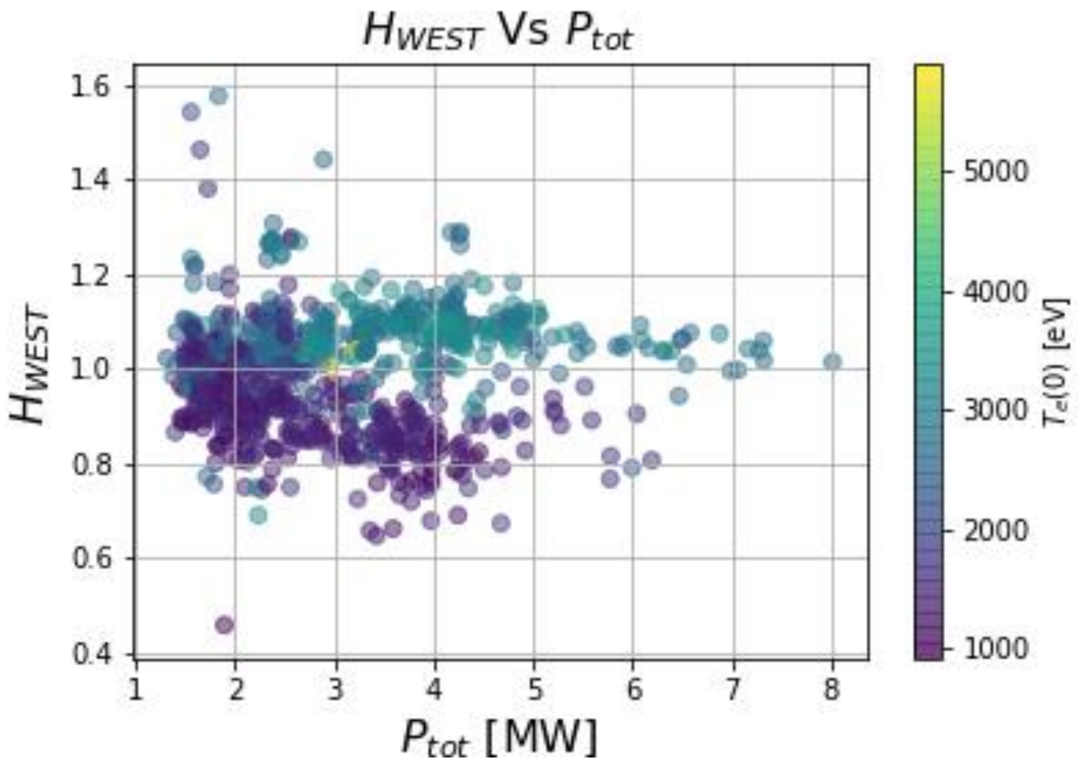
The temperature collapses are associated to **variable contributions** of **LHCD** core heating depletion and **tungsten peaking**.

H_{WEST} for quantifying the quality of the confinement time

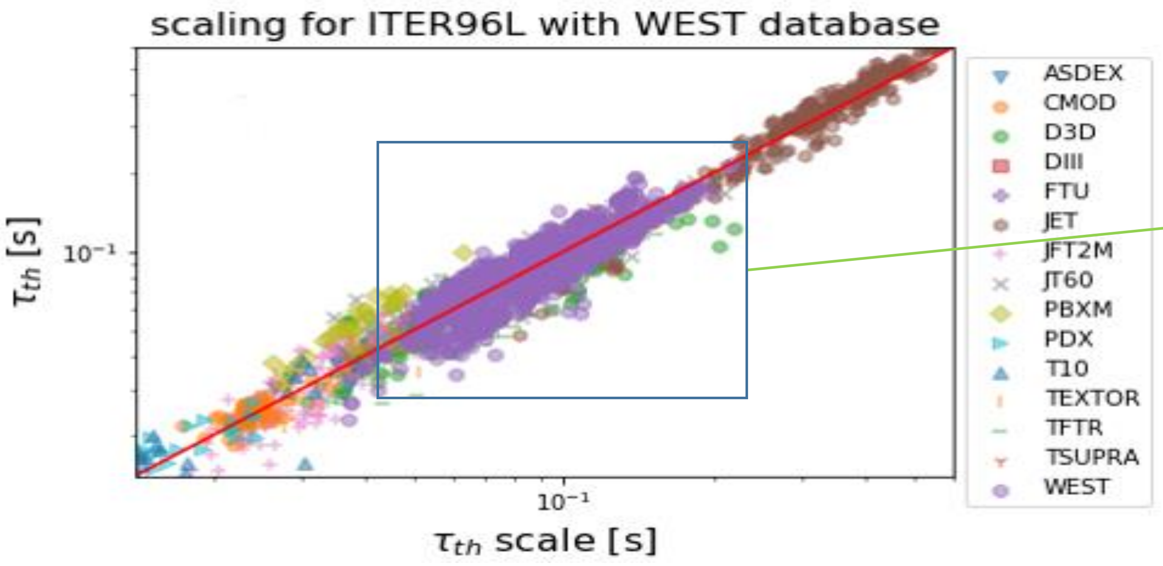
$$\tau_{mhd,measured} = \frac{W_{mhd}}{P_{tot}} = \frac{\frac{3}{2}\int_V P\,dV}{P_{ohmic} + P_{aux}}$$

$$H_{WEST} = \frac{\tau_{mhd,measured}}{\tau_{scaling}}$$





WEST database aligned with ITER96L



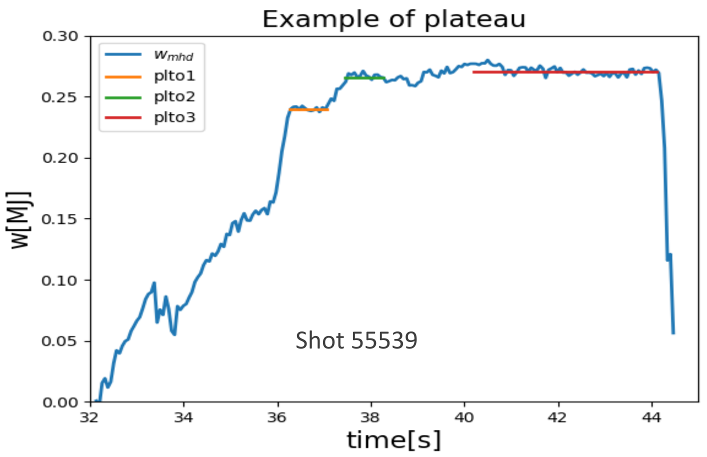
Filter:

- Small reconstruction errors;
- Diverted plasma;
- L-mode plateaus;
- LSN
- Only deuterium shots

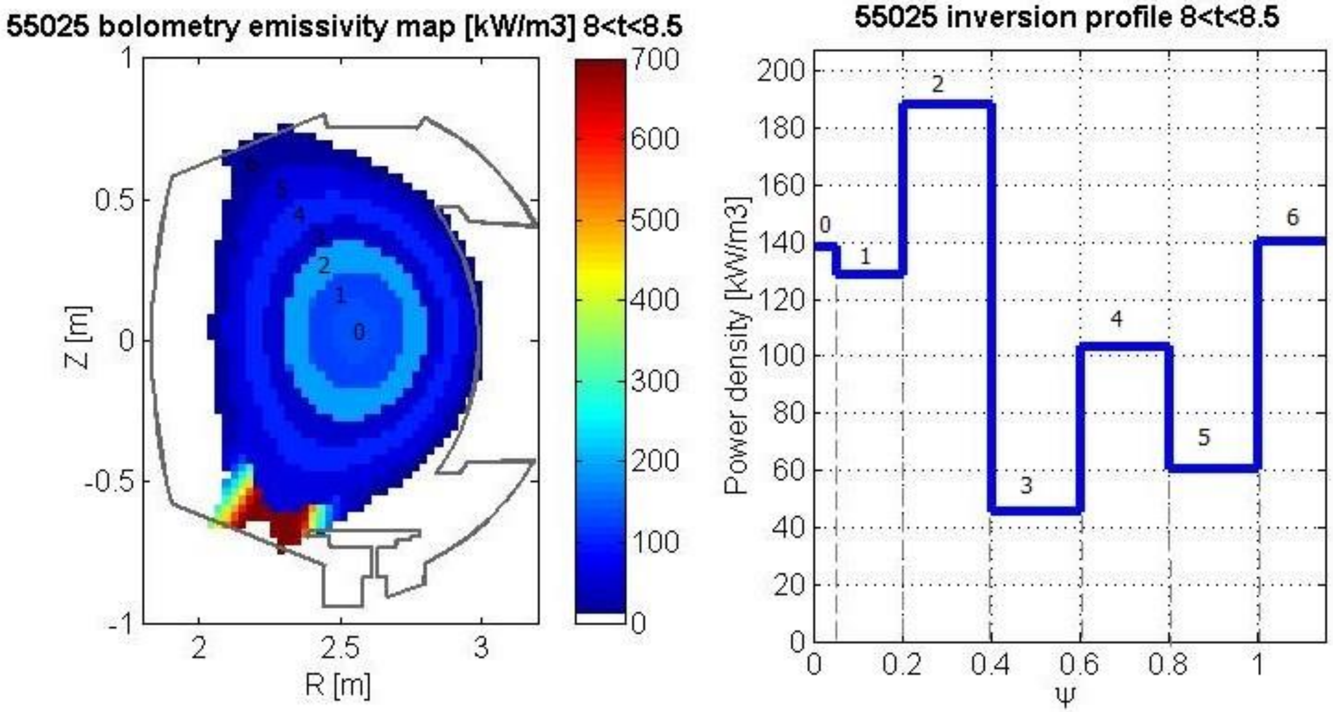
$$\tau = C\, Ip^{\alpha_{Ip}} B^{\alpha_B} P_{tot}^{\alpha_P} n_e^{\alpha_{ne}} M^{\alpha_M} R^{\alpha_R} \varepsilon^{\alpha_\varepsilon} k^{\alpha_k}$$

$$\alpha_{Ip} = 1.35$$
$$\alpha_{n_e} = -0.16$$
$$\alpha_{P_{tot}} = -0.75$$

$\tau_{scaling}$



Bolometry tomography to compute the power emission density profile



A **bolometer** measures a line-integrated value of the **local radiative emissivity** along a viewing line of sight.

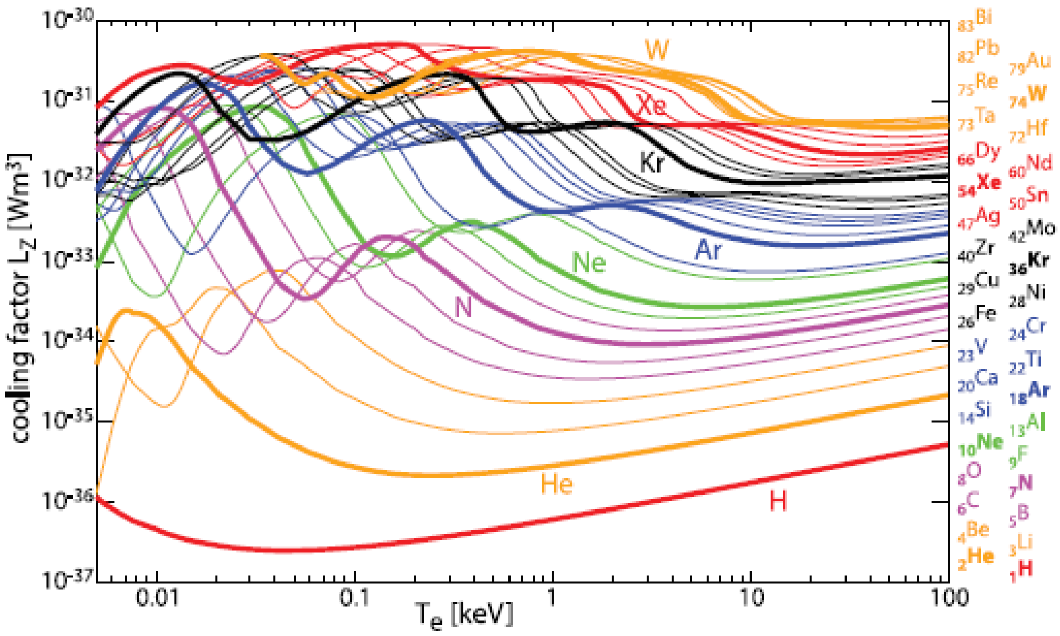
A **concentric layer decomposition** of local plasma emissivity is assumed together **with asymmetric factors** in the SOL and edge. The tomography inversion is computed.

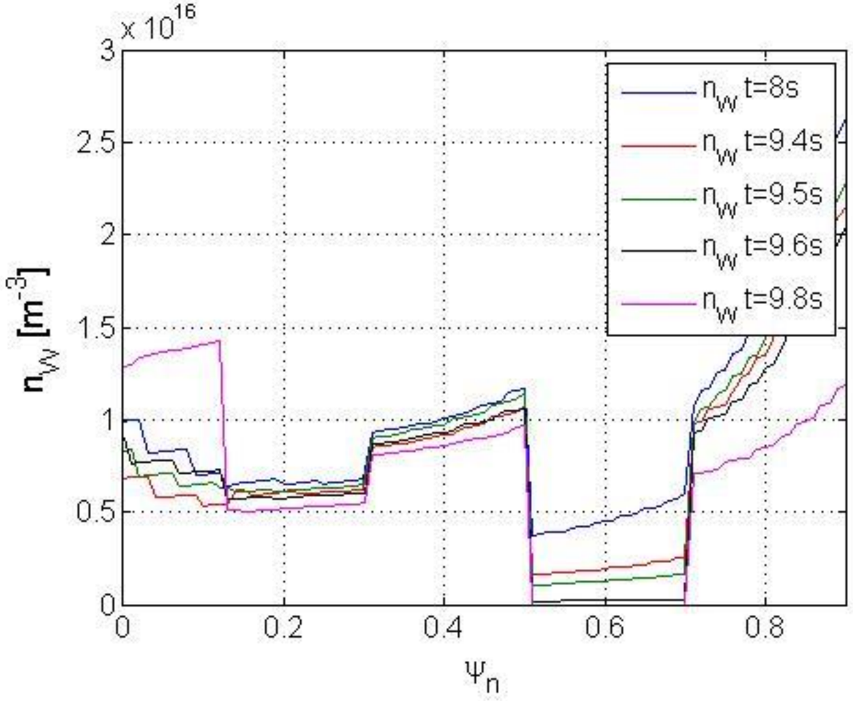
The **power emission** in $\frac{W}{m^3}$ **for each layer** are estimated.

Tungsten density profiles from the inverse of bolometry

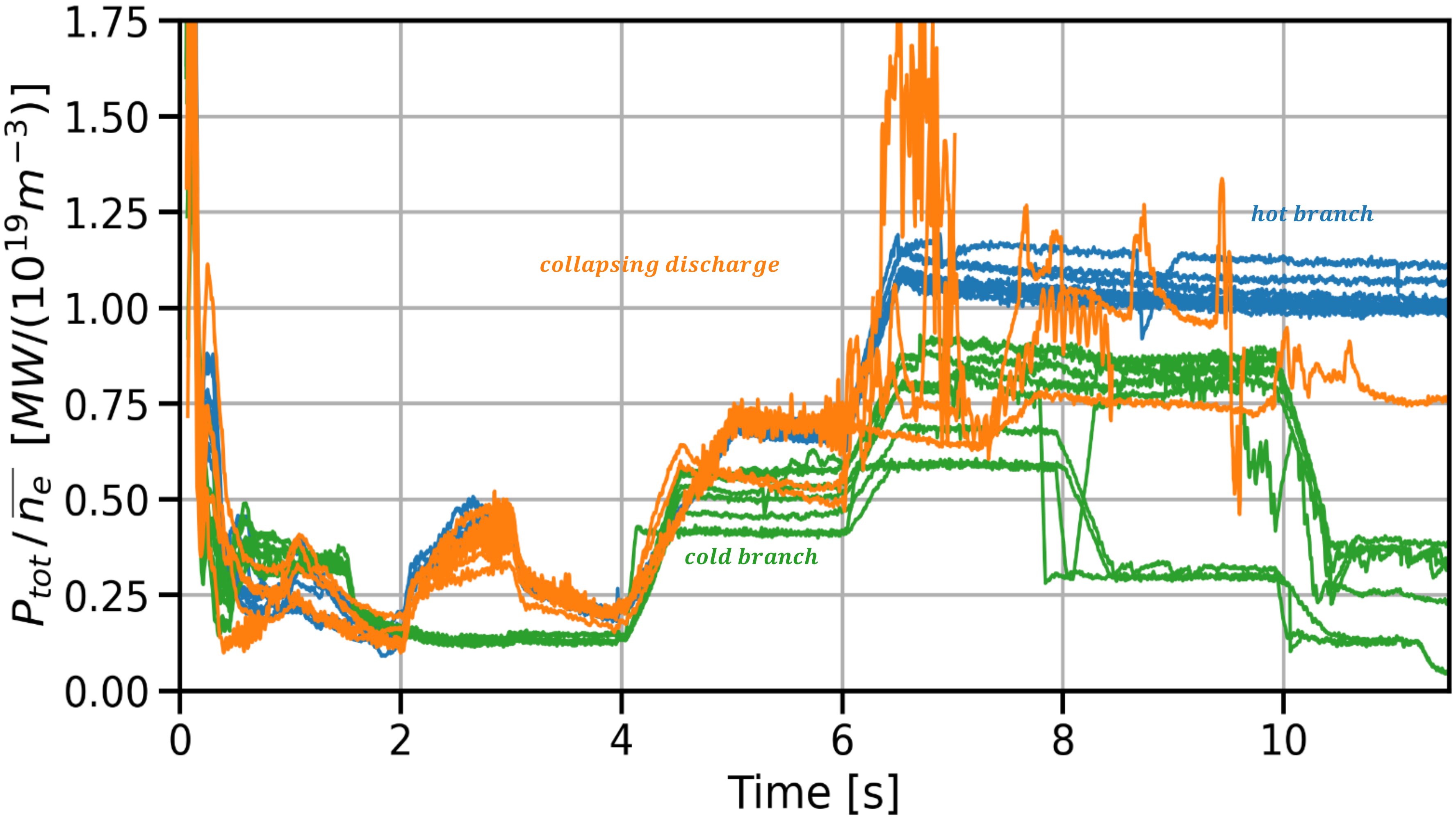
Above **1KeV** the **main radiator** is the **tungsten**.

Assuming that all the **emission radiation** comes from the **tungsten**, it is possible to use the inverse of bolometry to compute **its density** at each layer.

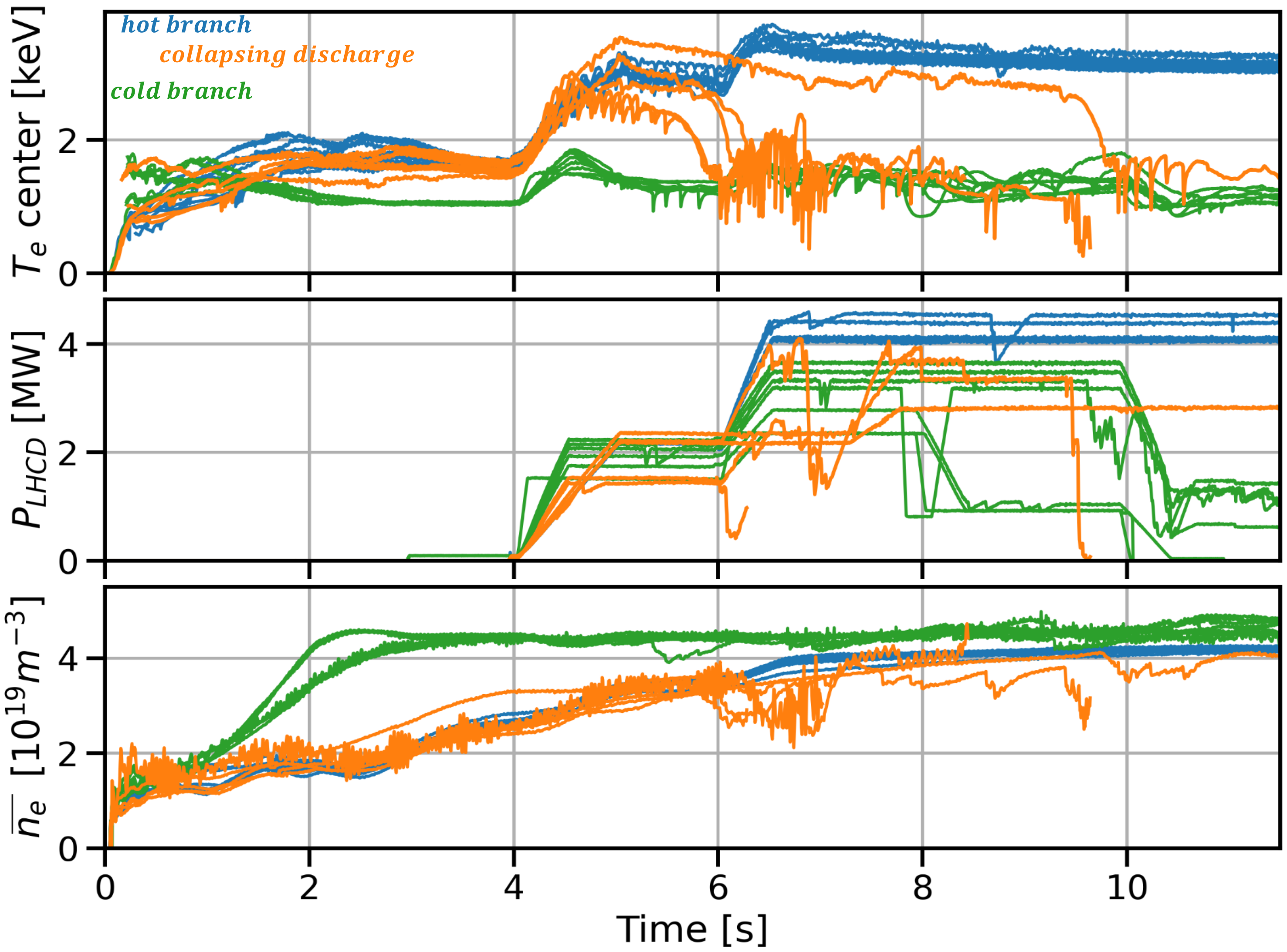




$\frac{P_{tot}}{n_{e,vol}}$ for hot and cold branches and collapsing discharges



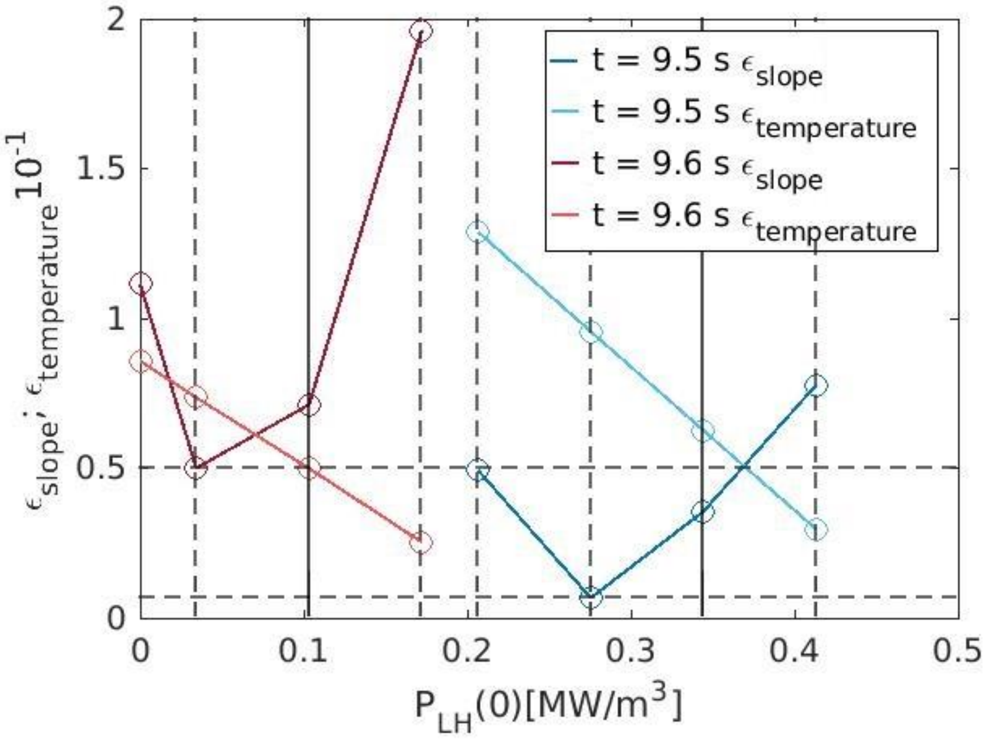
P_{LH} and $n_{e,vol}$ for hot and cold branches and collapsing discharges



The central value is adjusted to find the optimum between ϵ_{slope} and $\epsilon_{temperature}$.

$$\epsilon_{slope} = \frac{\left|\left(T_{t-1}^{exp} - T_{t}^{exp}\right) - \left(T_{t-1}^{simu} - T_{t}^{simu}\right)\right|}{\left(T_{t-1}^{exp} - T_{t}^{exp}\right)}$$

$$\epsilon_{temperature} = \frac{\left|T^{exp} - T^{simu}\right|}{T^{exp}}$$



W neoclassical transport

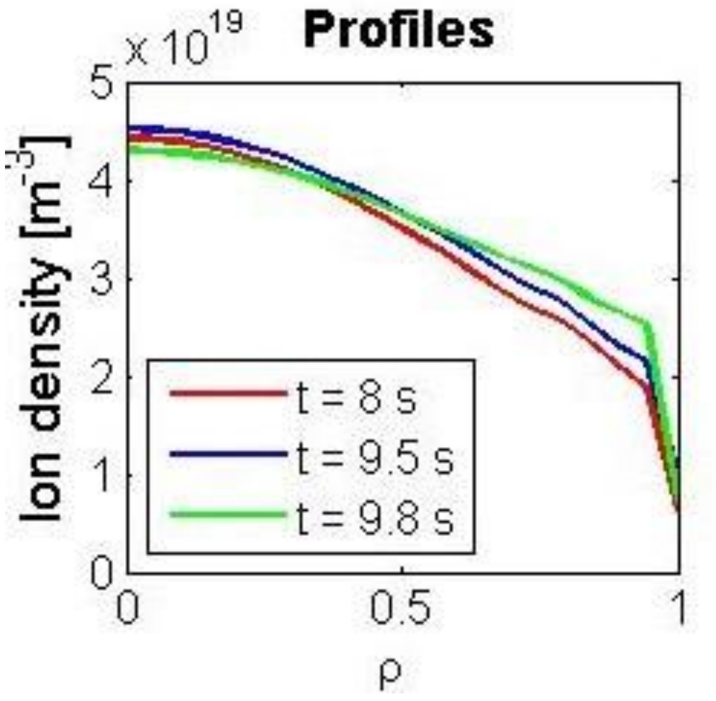
W neoclassical transport (in absence of poloidal asymmetries)

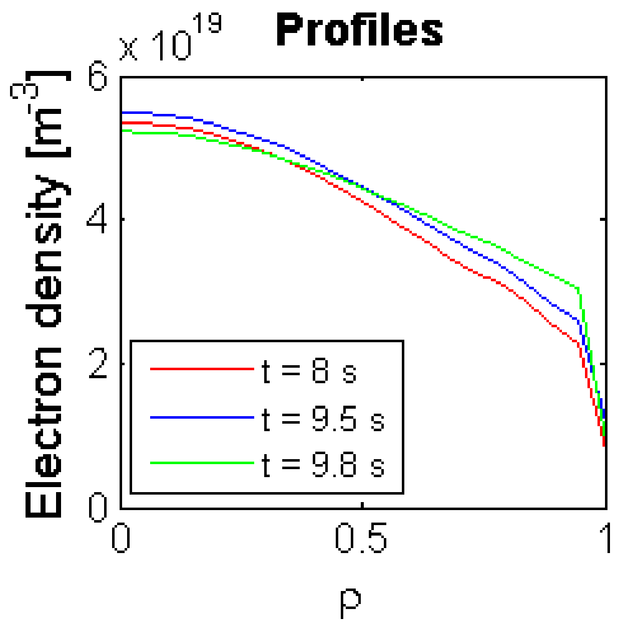
$$\Gamma_W = -Zq^2Dn_W\left[\frac{1}{Z}\frac{\nabla n_W}{n_W} - \frac{\nabla n_i}{n_i} + \frac{1}{2}\frac{\nabla T_i}{T_i}\right]$$

Diffusion

Convection due to ion density peaking **(inward)**

Convection due to ion **thermal screening, outward**





H mode

The plateaus in H mode in C4:

- In USN 4 plateaus
- In LSN 10 plateaus

Max duration of H mode on WEST 4 s.

The transitions are observed in the hot and cold branches.

The transitions are unstable because P_{rad} increases when the pedestal is formed and so the power that crosses the separator is reduced and we go back to L mode.

In C6 we will raise the density to high power because we think we were on the low density branch of the L-H transition.