



**HAL**  
open science

## 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

### ► To cite this version:

Valeria Ostuni, Jorge Morales, Jean François Artaud, Clarisse Bourdelle, Pierre Manas, et al.. Core radiative collapse in WEST LHCD plasmas: characterization and integrated modelling. 48TH EPS CONFERENCE ON PLASMA PHYSICS, Jun 2022, ON LINE, France. cea-03736618

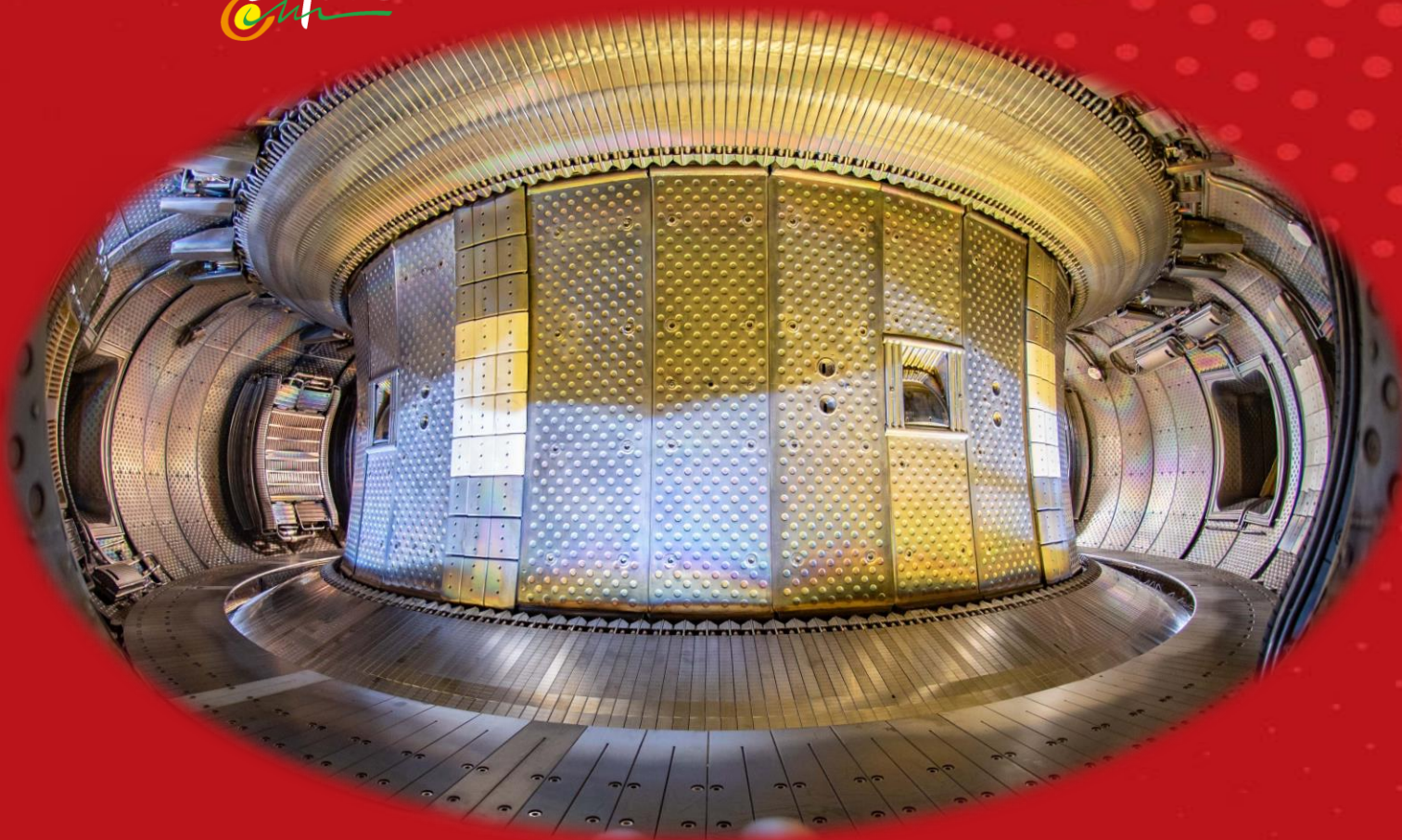
**HAL Id: cea-03736618**

**<https://cea.hal.science/cea-03736618v1>**

Submitted on 22 Jul 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.

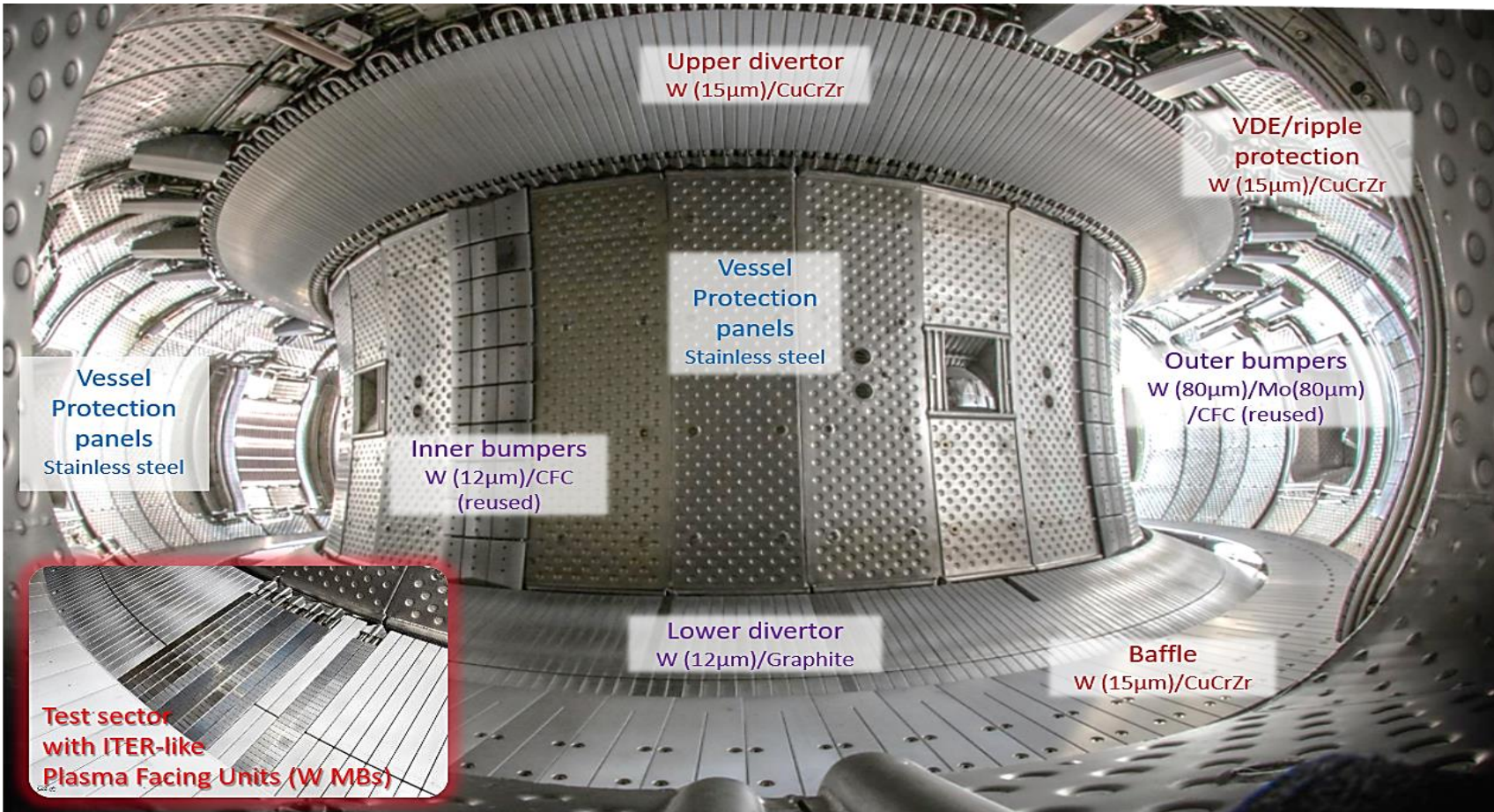
L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



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

EPS 30/06/2022

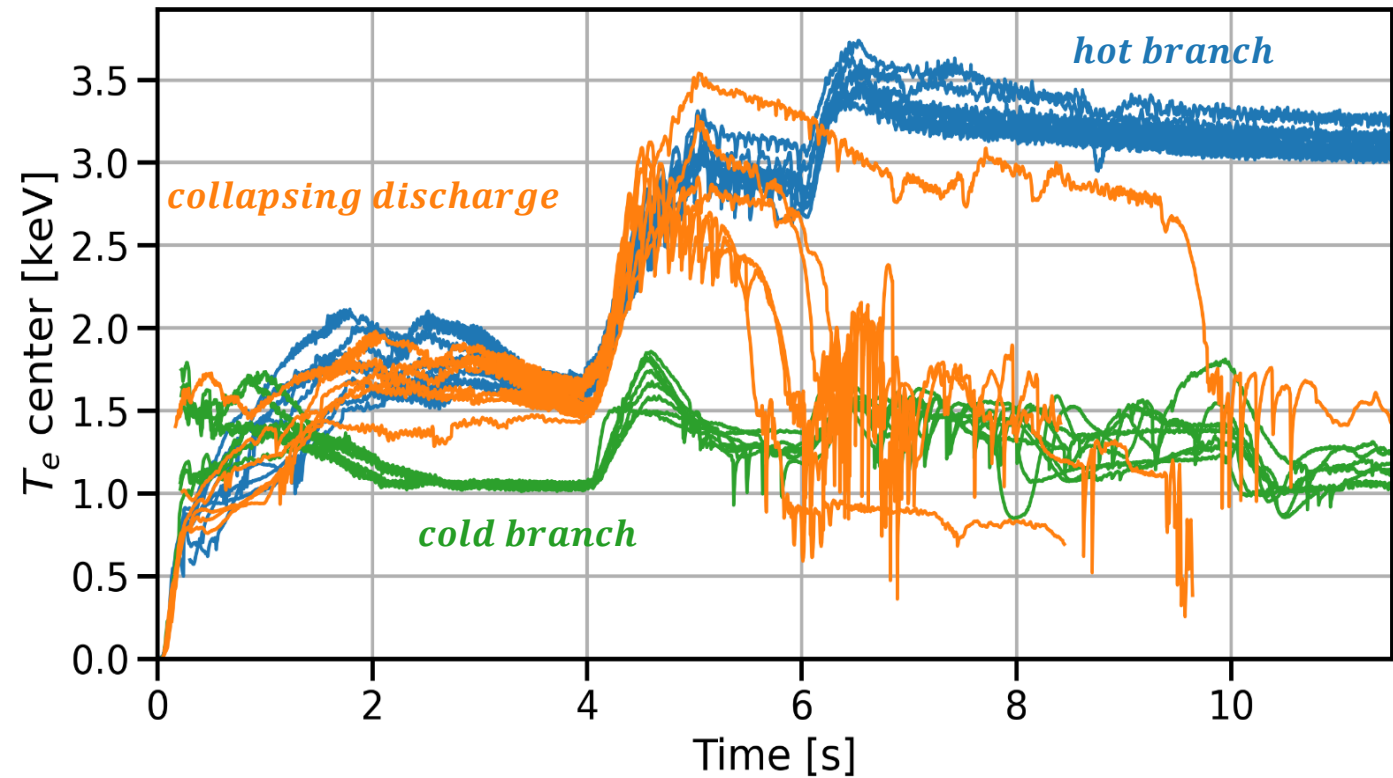
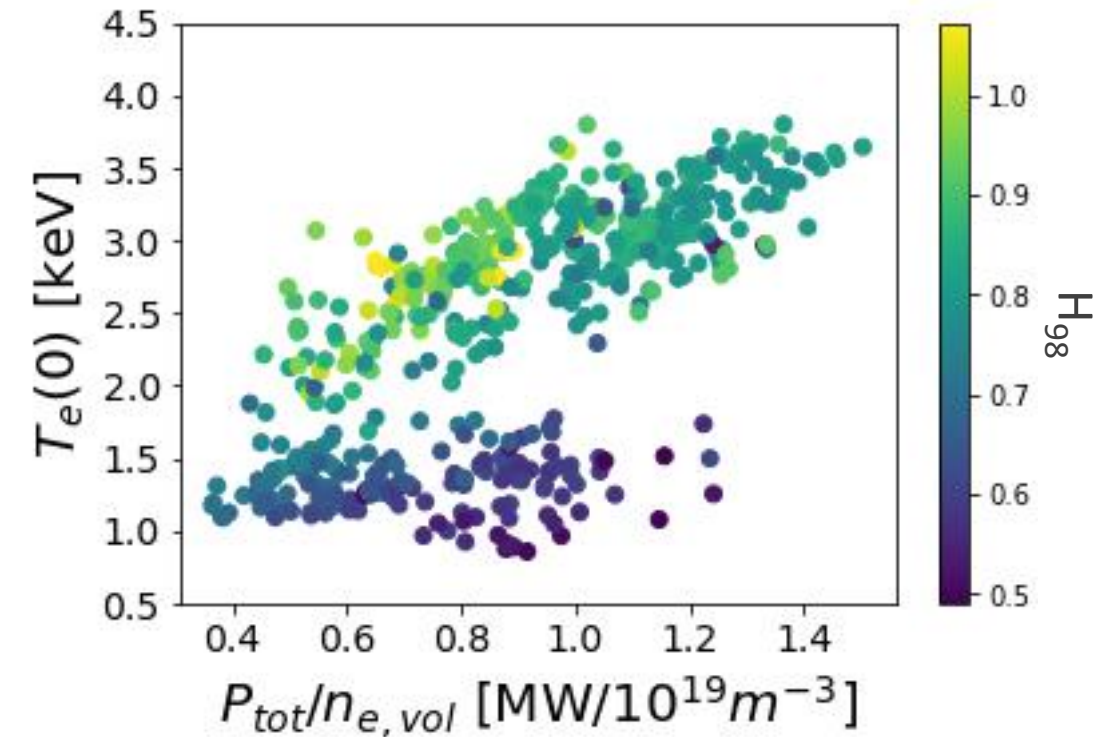
**V. Ostuni, J. Morales, J-F Artaud, C. Bourdelle, P. Manas, Y. Peysson, N. Fedorczak, R. Dumont, M. Goniche, P. Maget & WEST team** [west.cea.fr/WESTteam](http://west.cea.fr/WESTteam)



$B_T$	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 questions arise from this analysis:

- Why are there two branches?

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

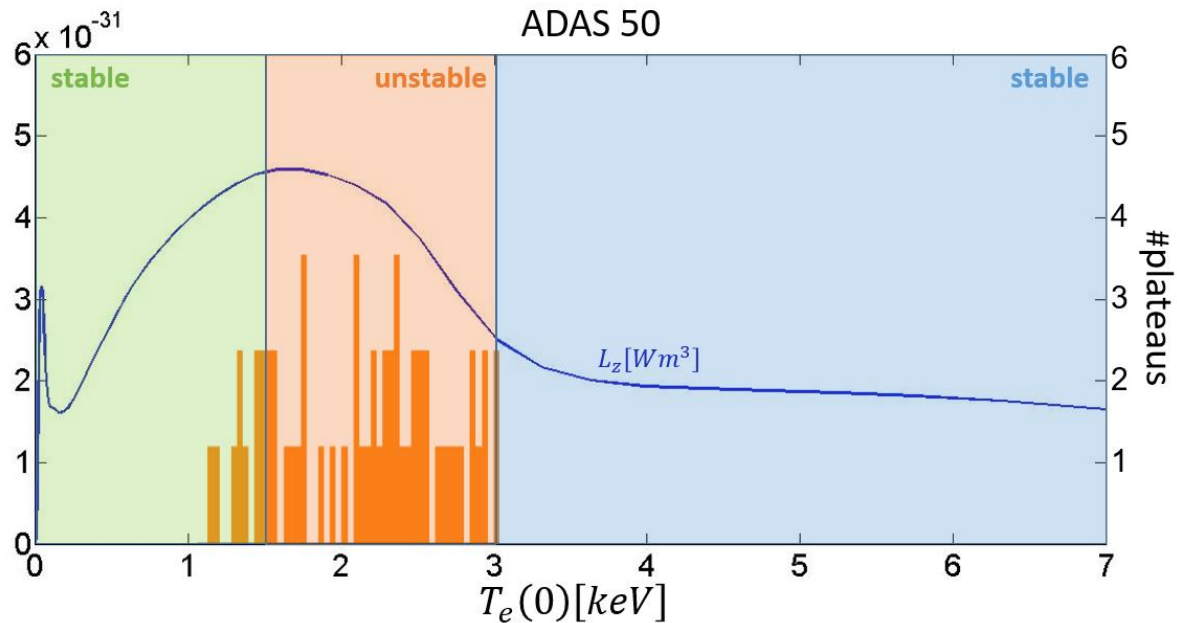
Phenomena observed in **JET** during  $I_p$  ramp up and **FTU**

[C.D. Challis NF 2020]

[P. Buratti PPCF 1997]

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

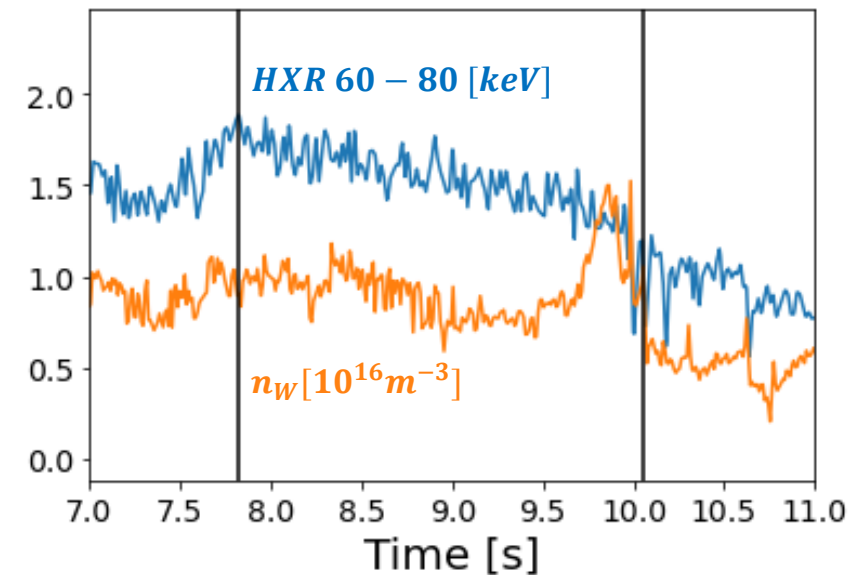
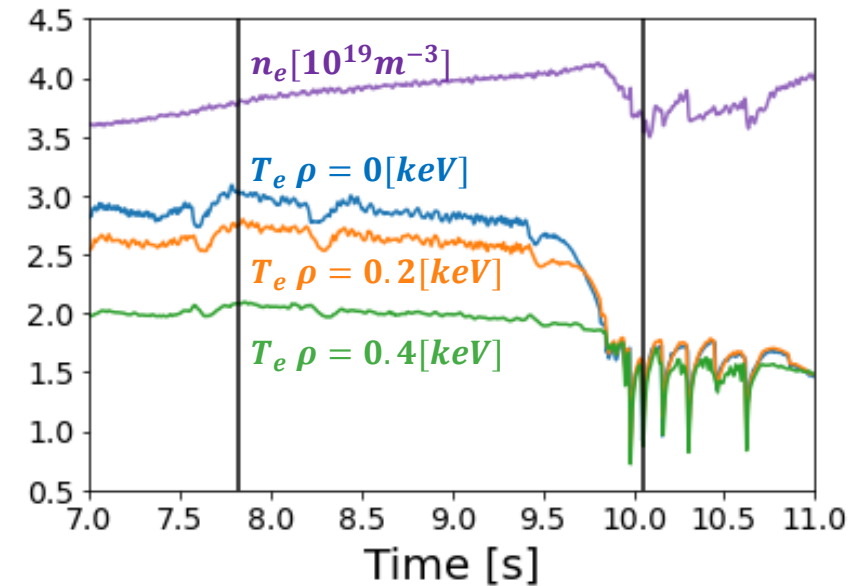
- **Characterize and understand the dynamics of the radiative collapse;**
- Reproduce the rapid collapse of central temperature using an integrated modelling framework;
- Conclusions.



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**.



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

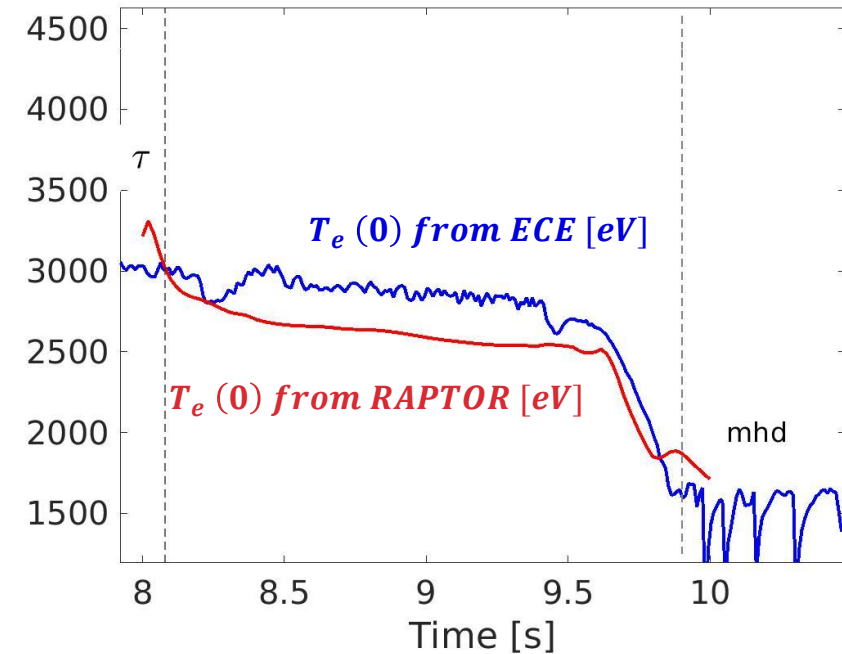
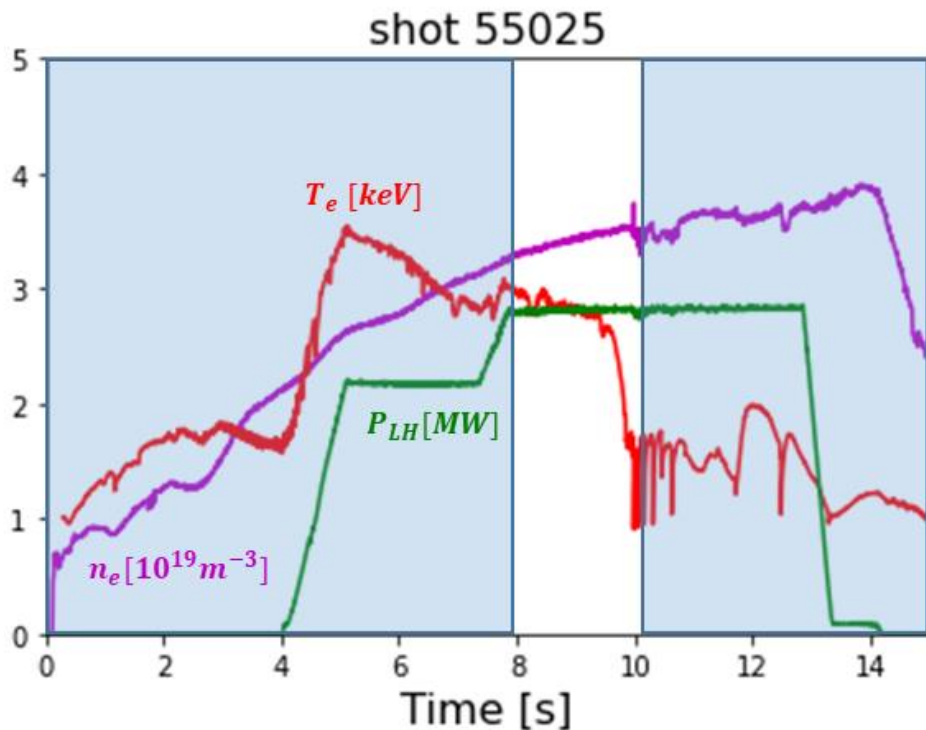


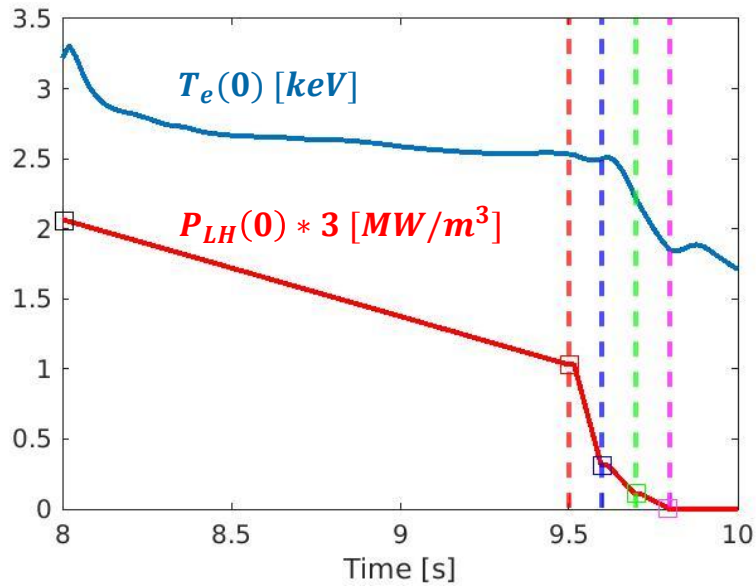
1D transport code: **RAPTOR** [F. Felici NF 2018]

**Turbulent 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



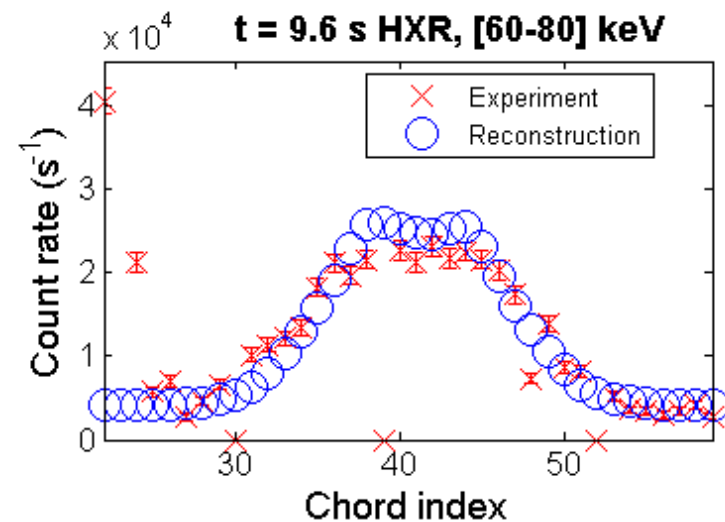
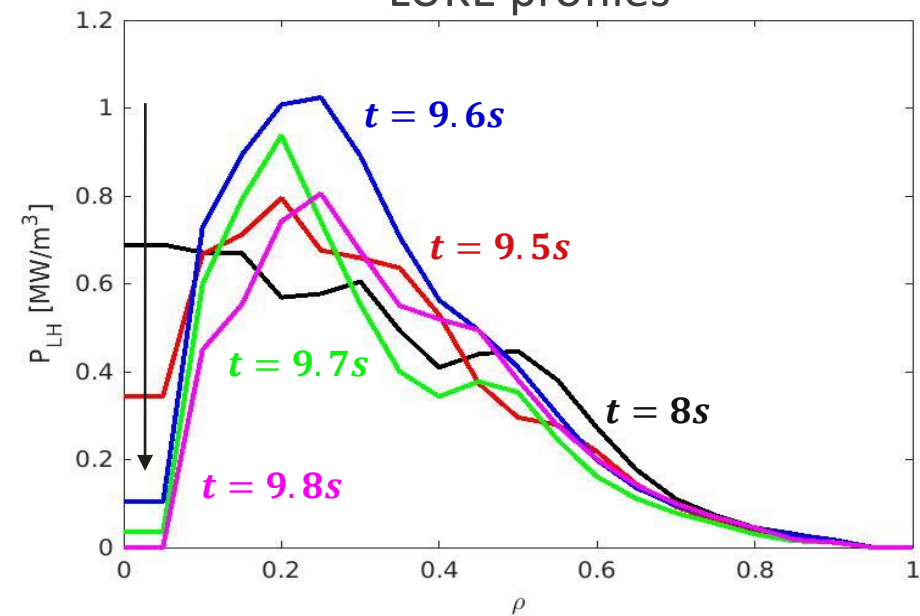


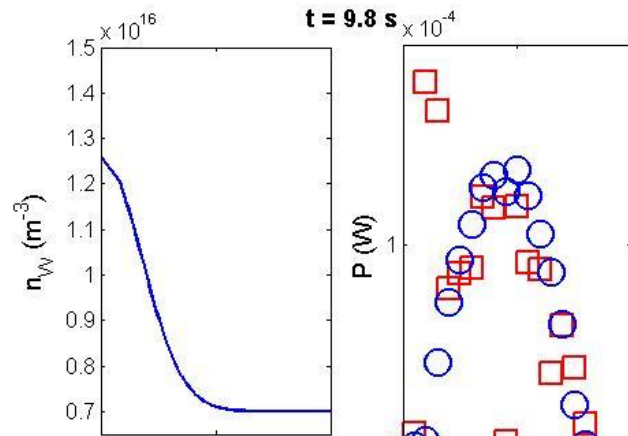
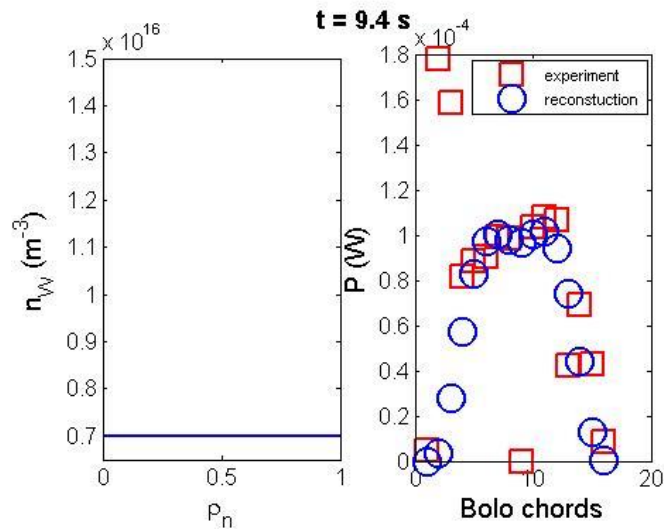
$d T_i$	$P_{LHCD}$	$n_e$
	LUKE	interpretat

Predicted  
using  
QLKNN-10D

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

LUKE profiles

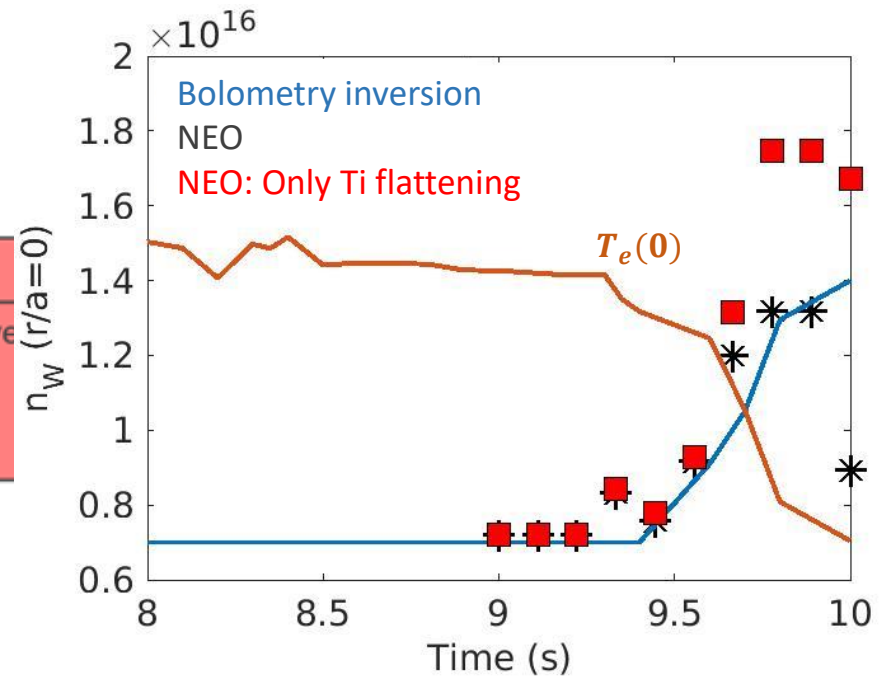


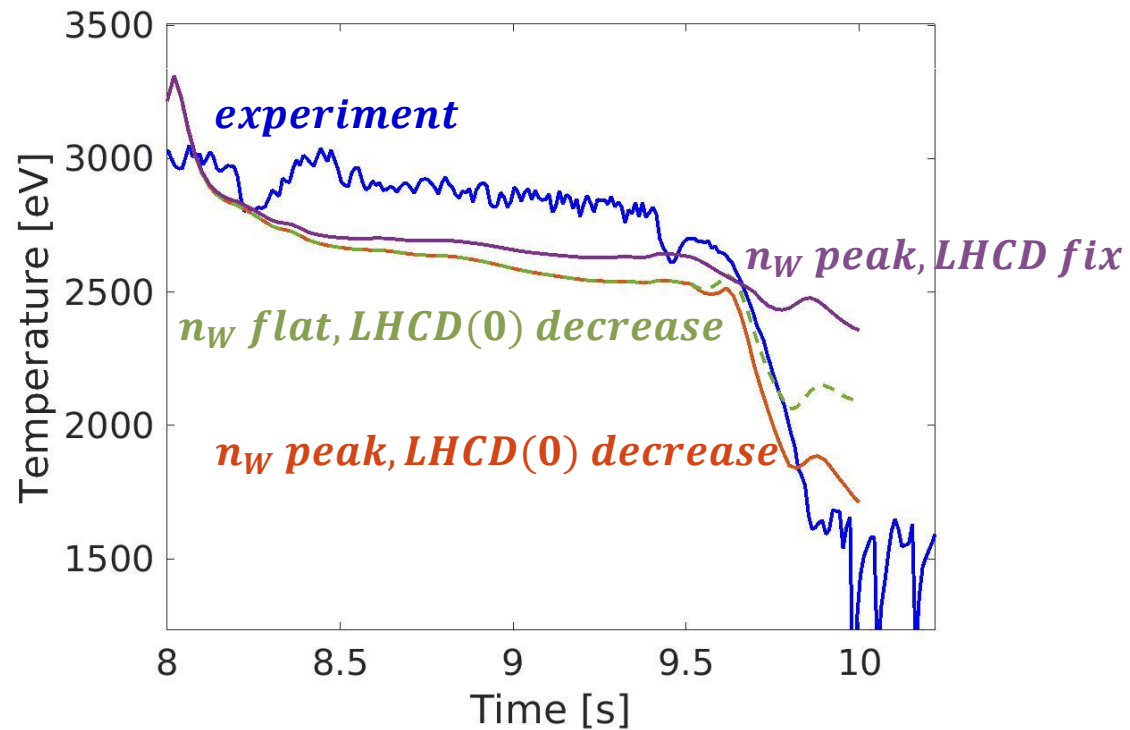


$T_e$ and $T_i$	$P_{\text{LHCD}}$	$n_e$	$n_W$
Predicted using QLKNN-10D	LUKE	interpretative	Interpretative based on bolometry inversion

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

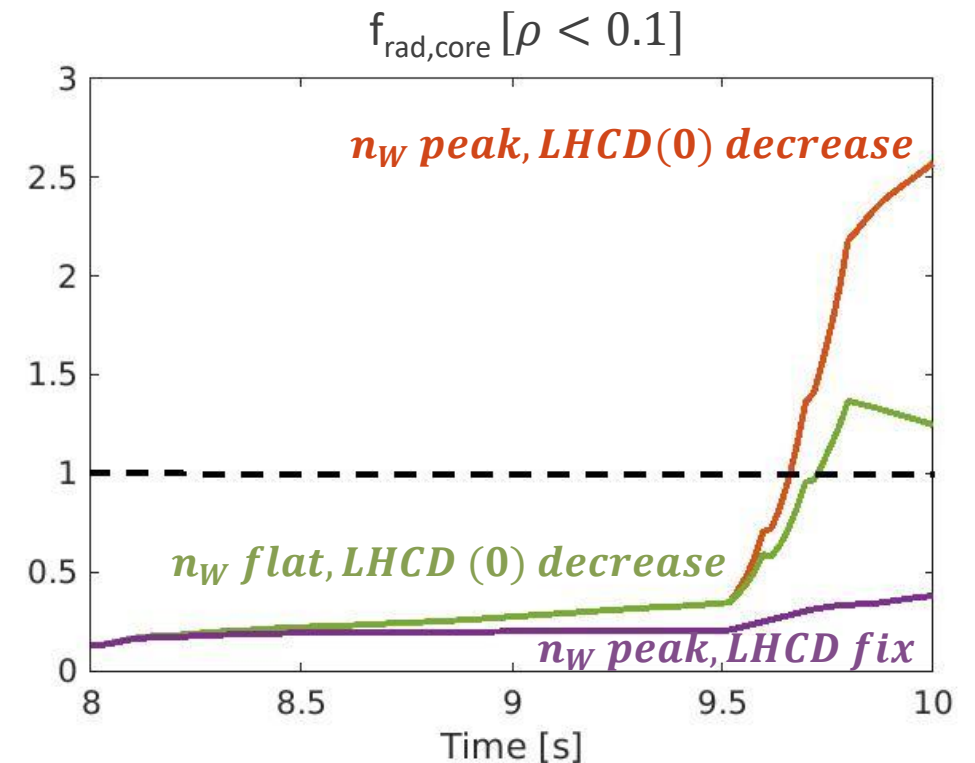
Neoclassical transport computed with NEO [Belli 2008]





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  $\rho=0.1$  does not **overtake the central electron heating**.



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

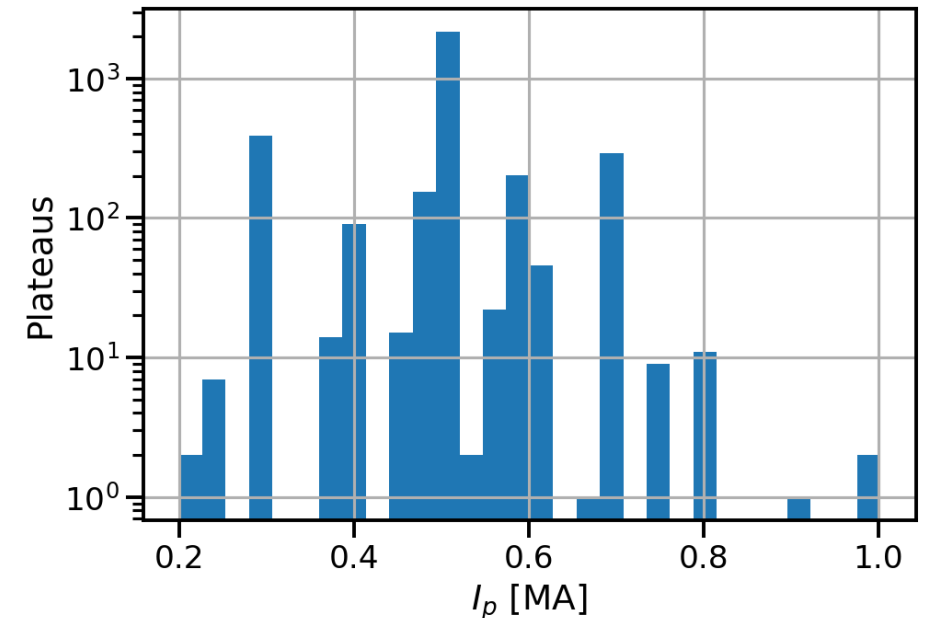
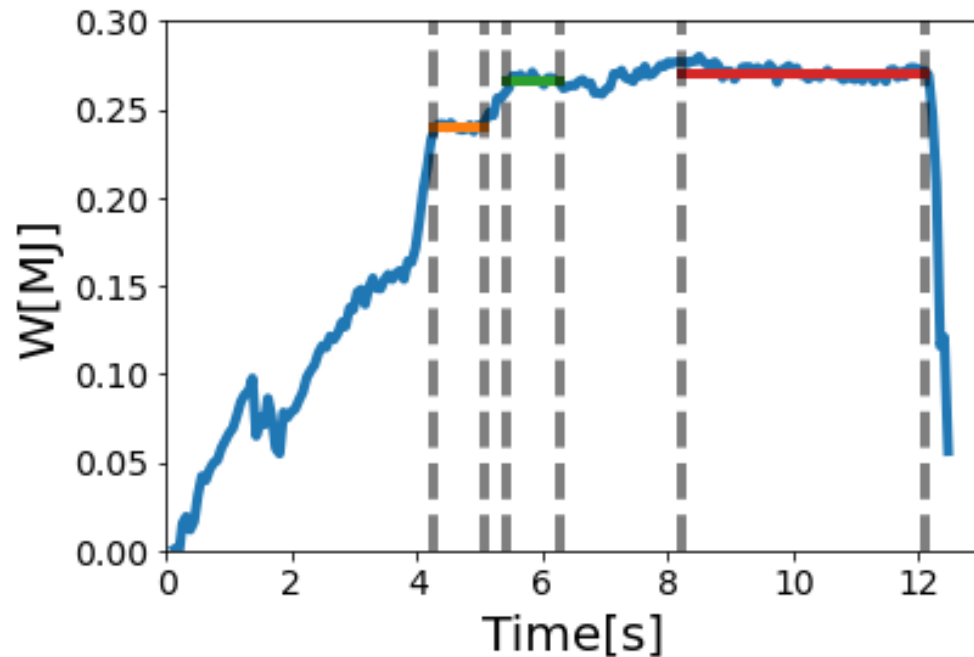
- In the database, L mode **plateaus** where  $T_e(0)$  rapidly **collapse** are identified in the range of **1.5 keV** and **3 keV**.
- Time sequence of  $T_e(0)$  collapse acceleration:
  - The **slight density rise** leads to **less on-axis LHCD power deposition** enhancing the central  $T_e$  **reduction**;
  - **$\nabla T$  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

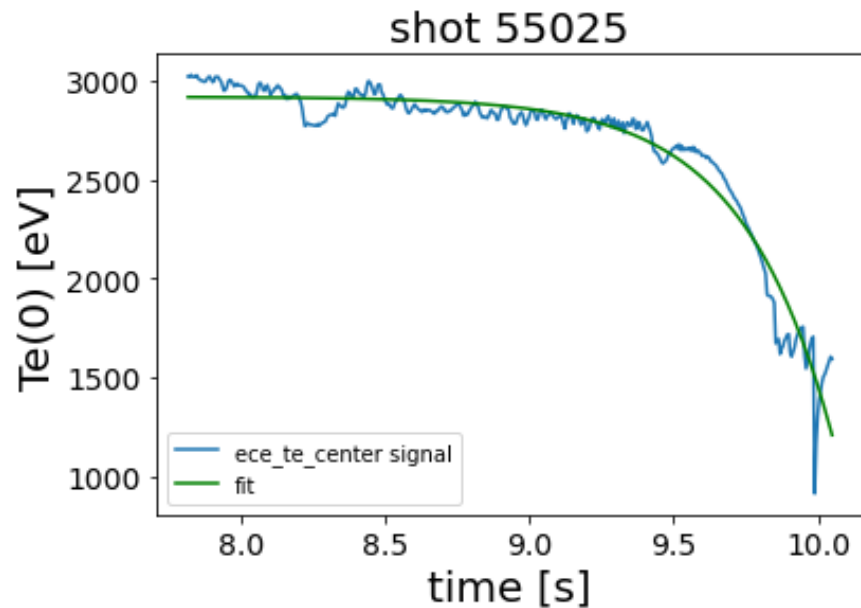
- The database contains the **mean values** and the **standard deviations** of different diagnostic measurements at each **plateau** (quasi-steady-state).
- The plateaus are identified intersecting the **total power plateaus** and the **plasma current plateaus**.
- There are **285** discharges with **732**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



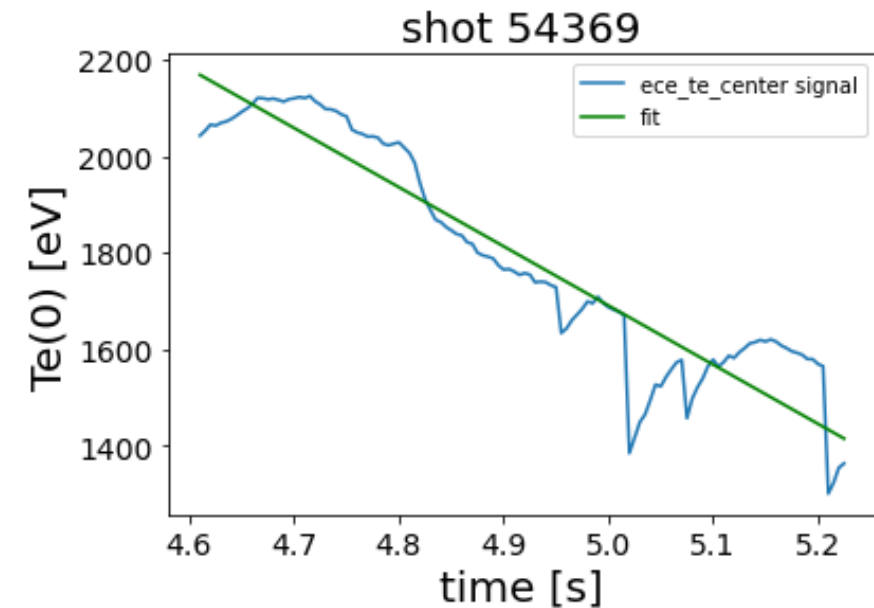


Automatic identification of radiative collapses within plateaus:

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

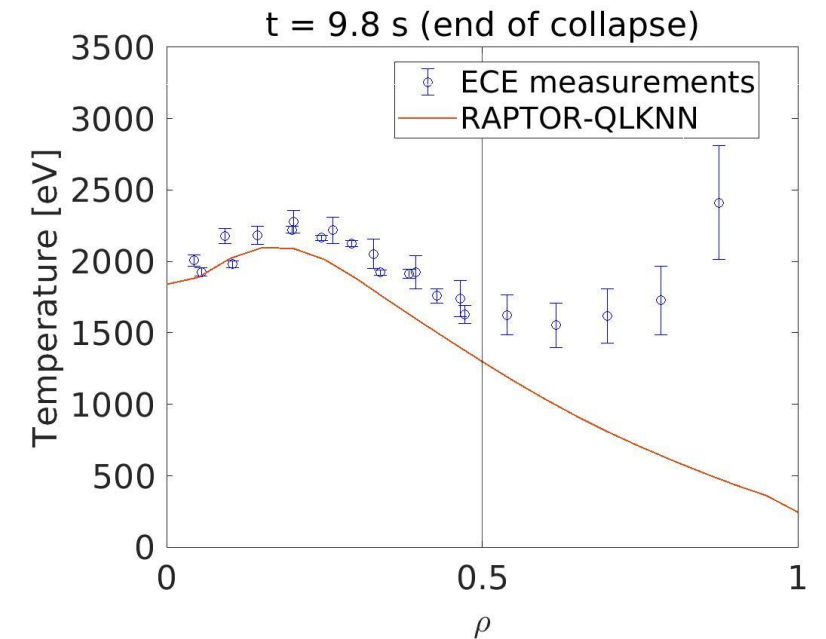
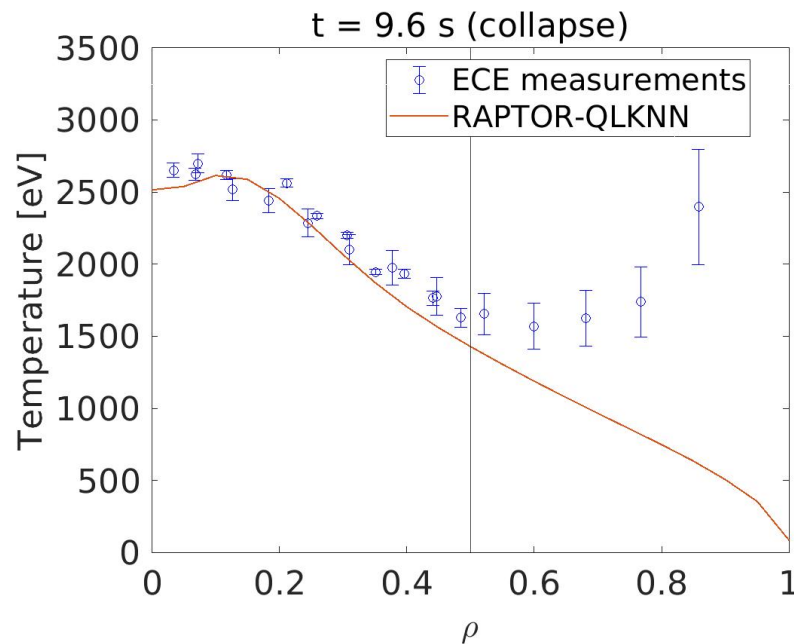
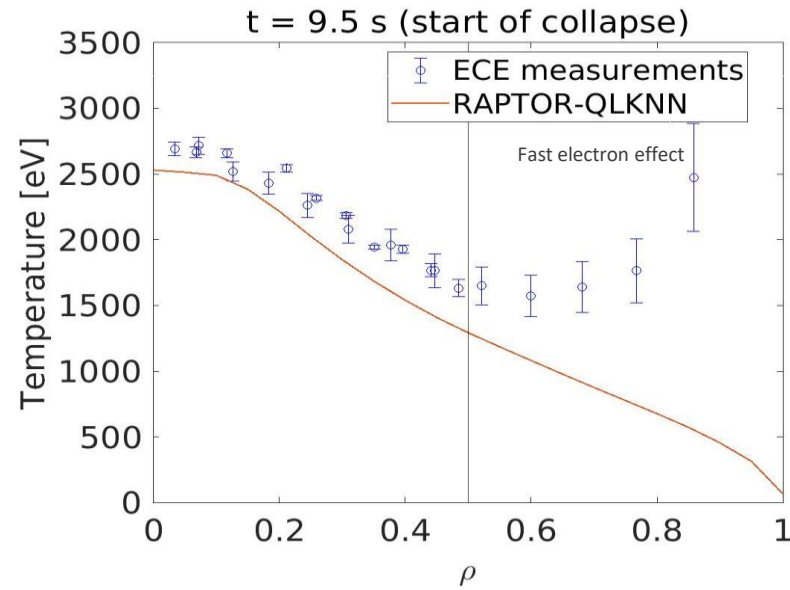


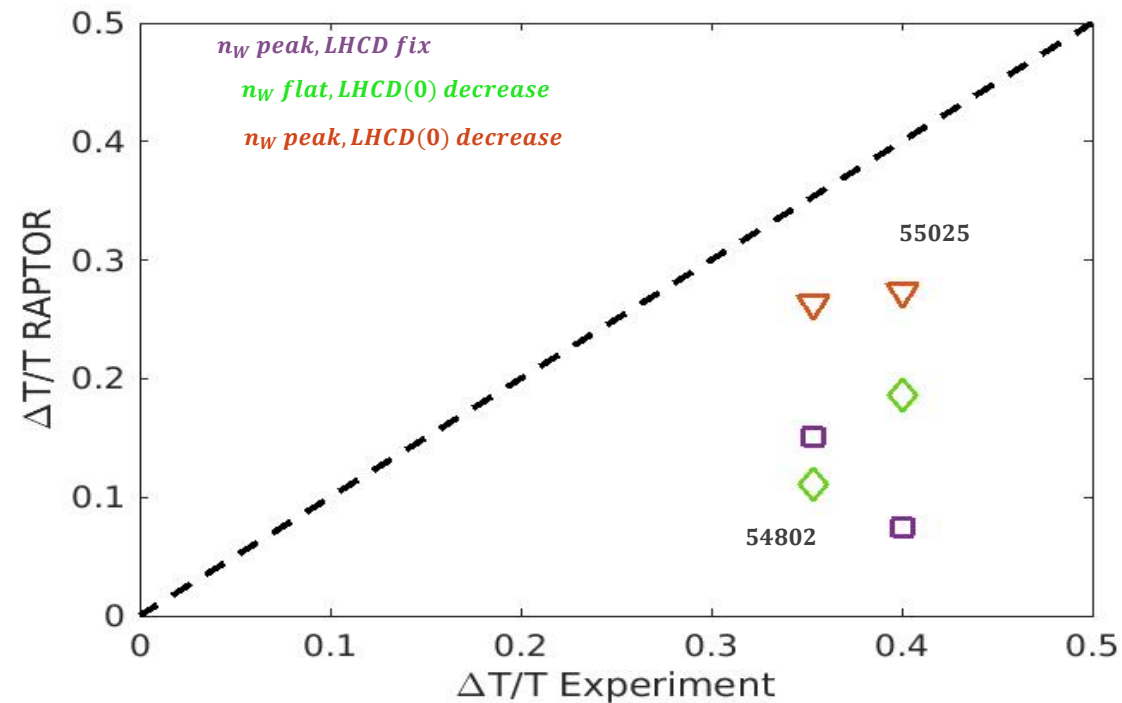
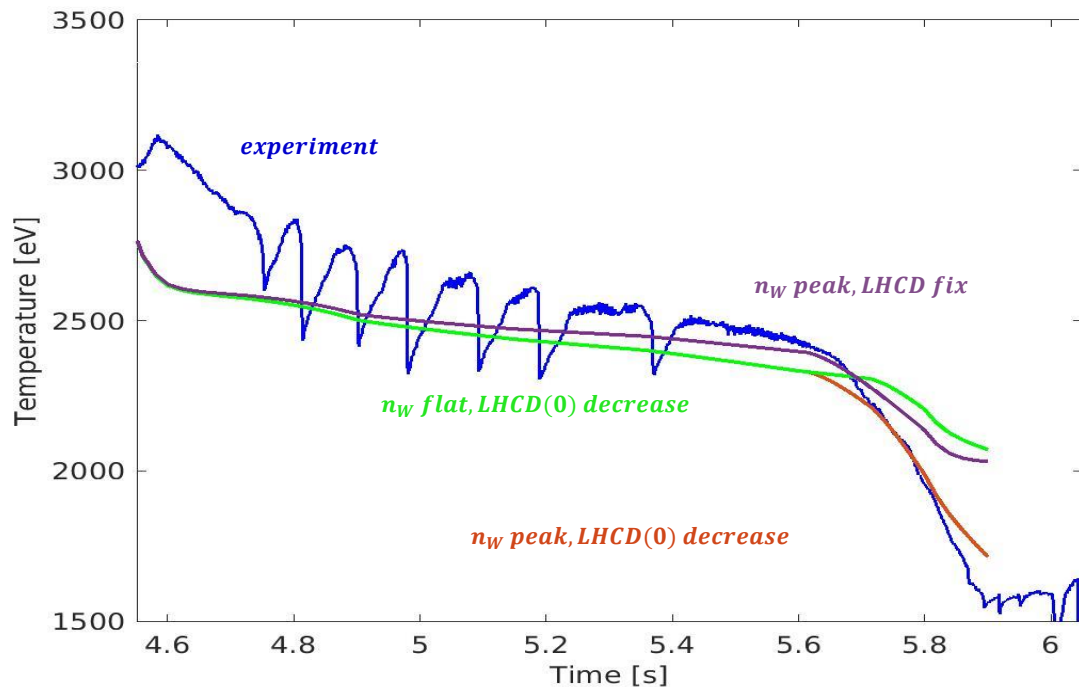
*linear function fit*  
 with **slope**  $< -830$



Three categories identified:

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



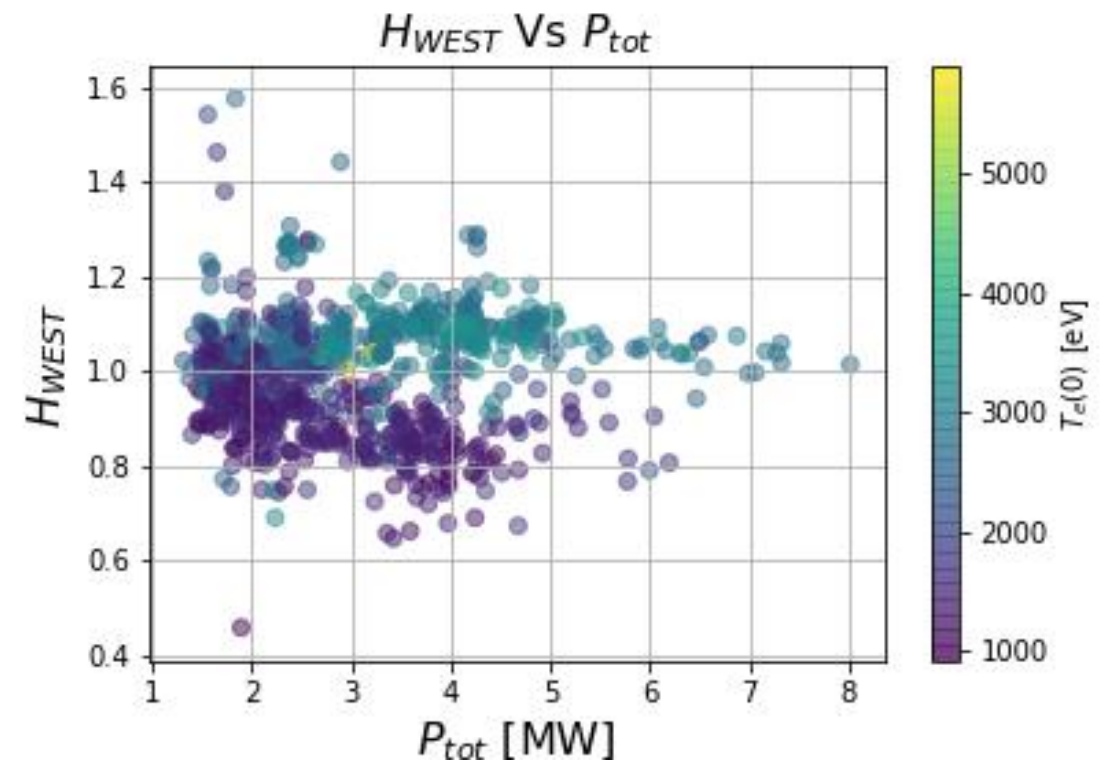
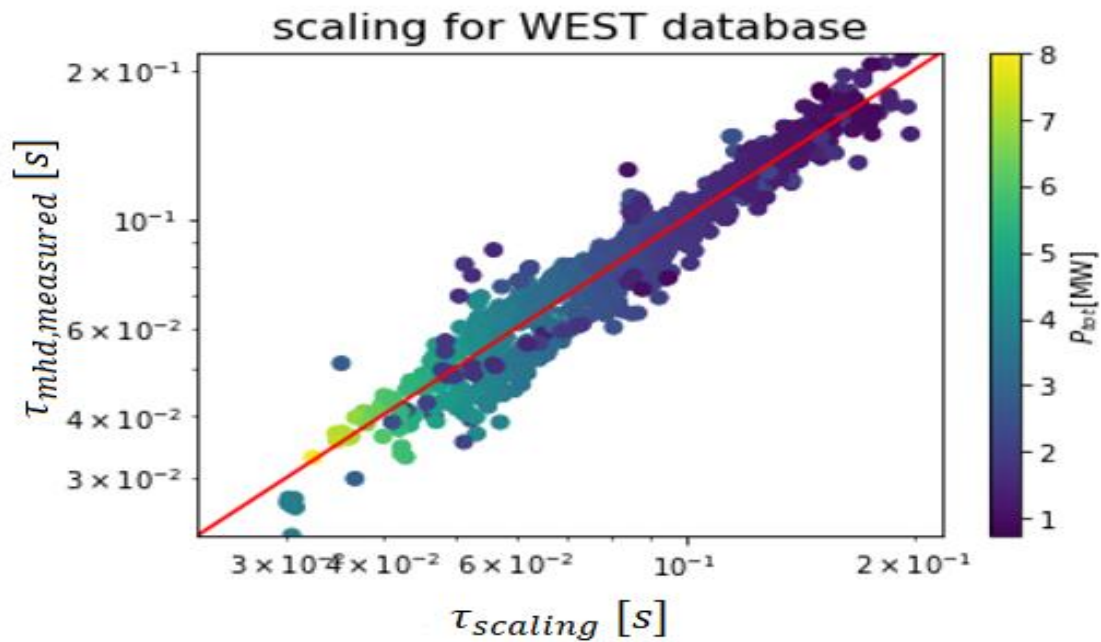


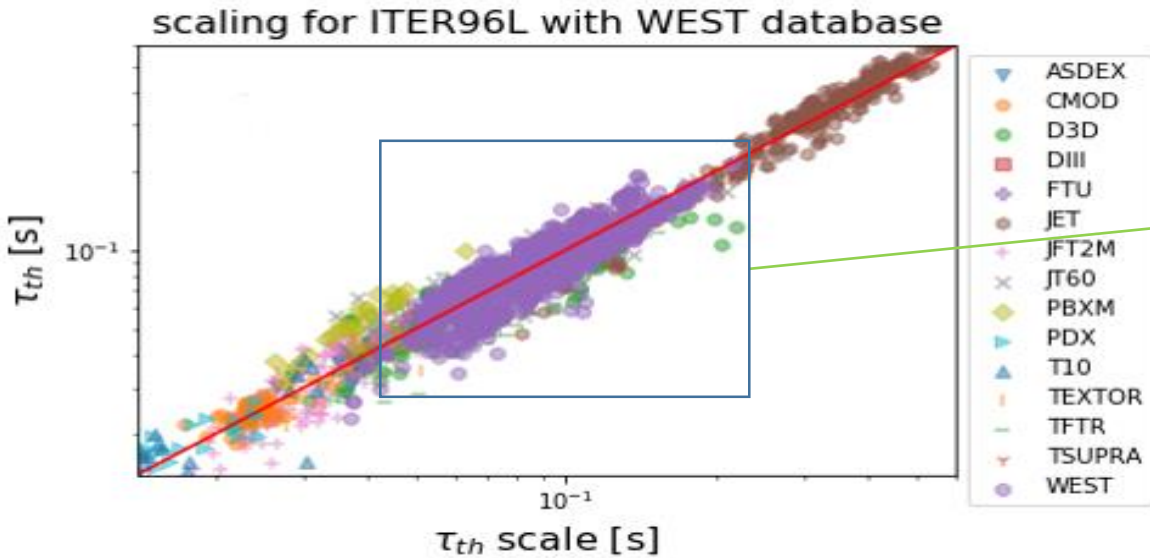
The same procedure was carried out for the **54802 discharge**.

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

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

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

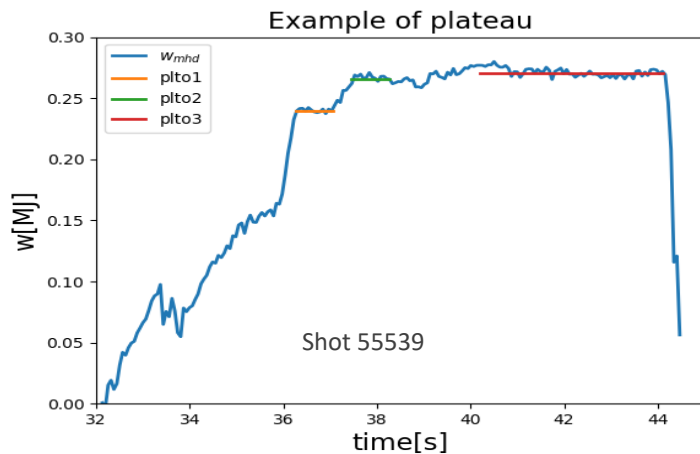




Filter:

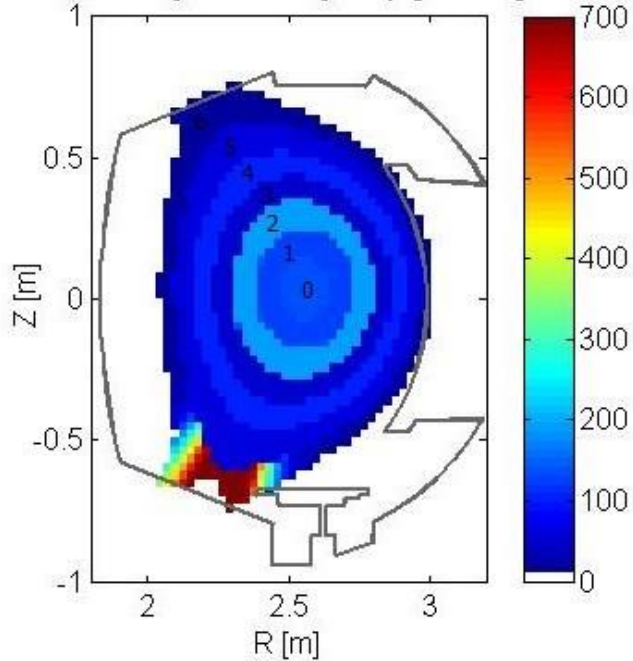
- Small reconstruction errors;
- Diverted plasma;
- L-mode plateaus;
- LSN
- Only deuterium shots

$$\tau = C I_p^{\alpha_{I_p}} B^{\alpha_B} P_{tot}^{\alpha_{P_{tot}}} n_e^{\alpha_{n_e}} M^{\alpha_M} R^{\alpha_R} \epsilon^{\alpha_\epsilon} k^{\alpha_k}$$

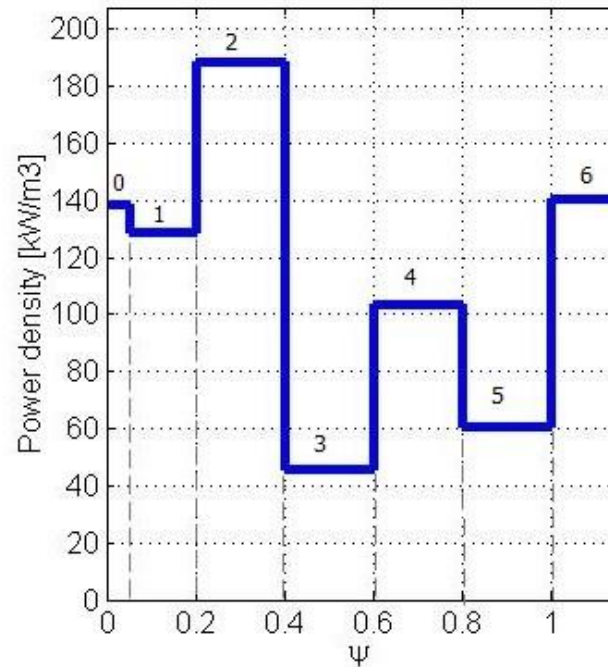


$$\begin{aligned} \alpha_{I_p} &= 1.35 \\ \alpha_{n_e} &= -0.16 \\ \alpha_{P_{tot}} &= -0.75 \end{aligned}$$

$\tau_{scaling}$

55025 bolometry emissivity map [kW/m<sup>3</sup>] 8<t<8.5

55025 inversion profile 8&lt;t&lt;8.5



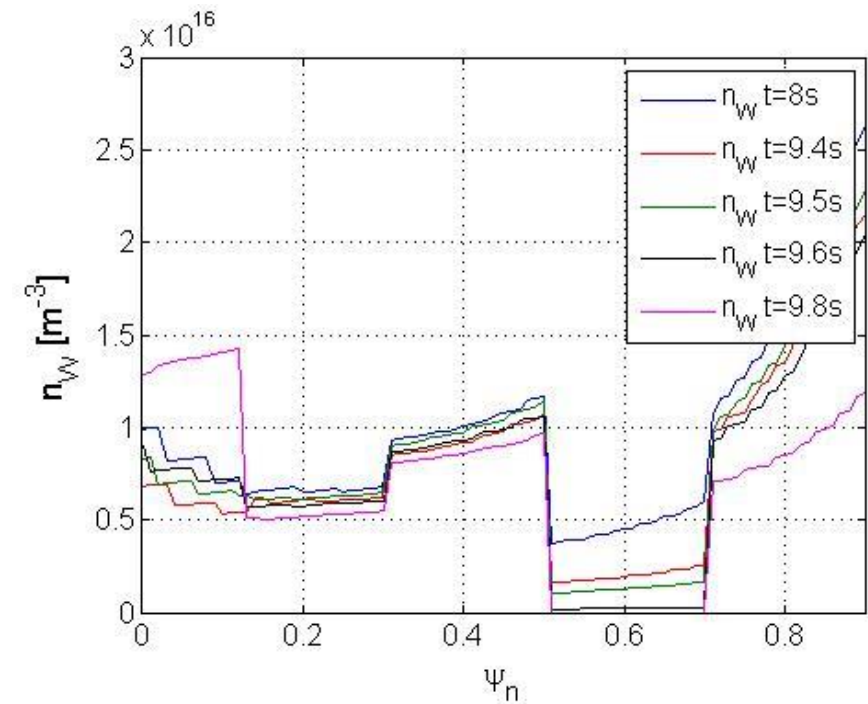
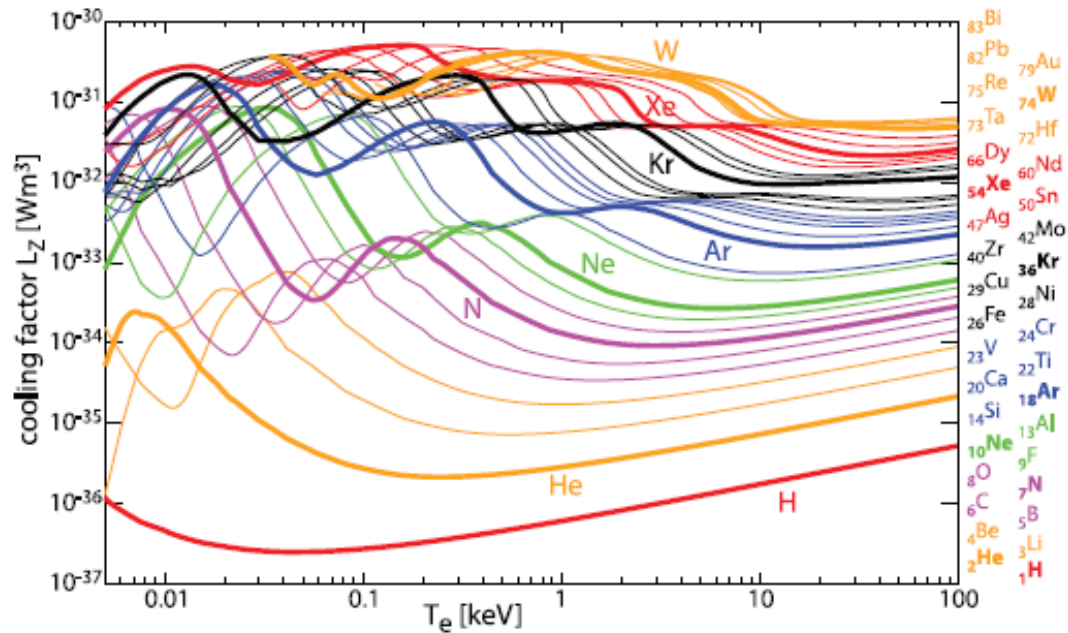
A **bolometer** measures a line-integrated value of the **local radiative emissivity** along a viewing line of sight.

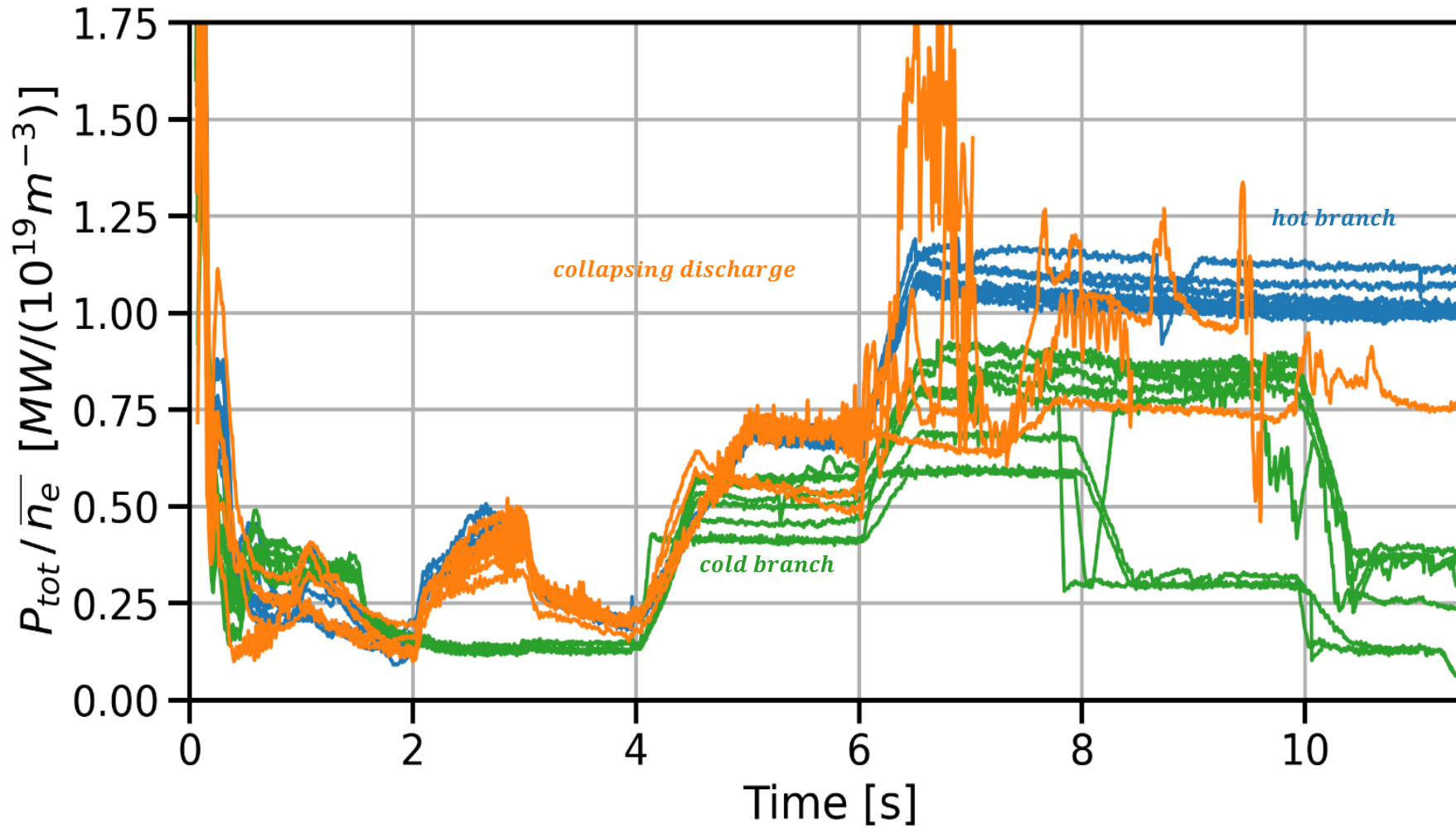
A **concentric layer decomposition** of local plasma emissivity is assumed together **with asymmetric factors** in the SOL and edge. The tomography inversion is computed.

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

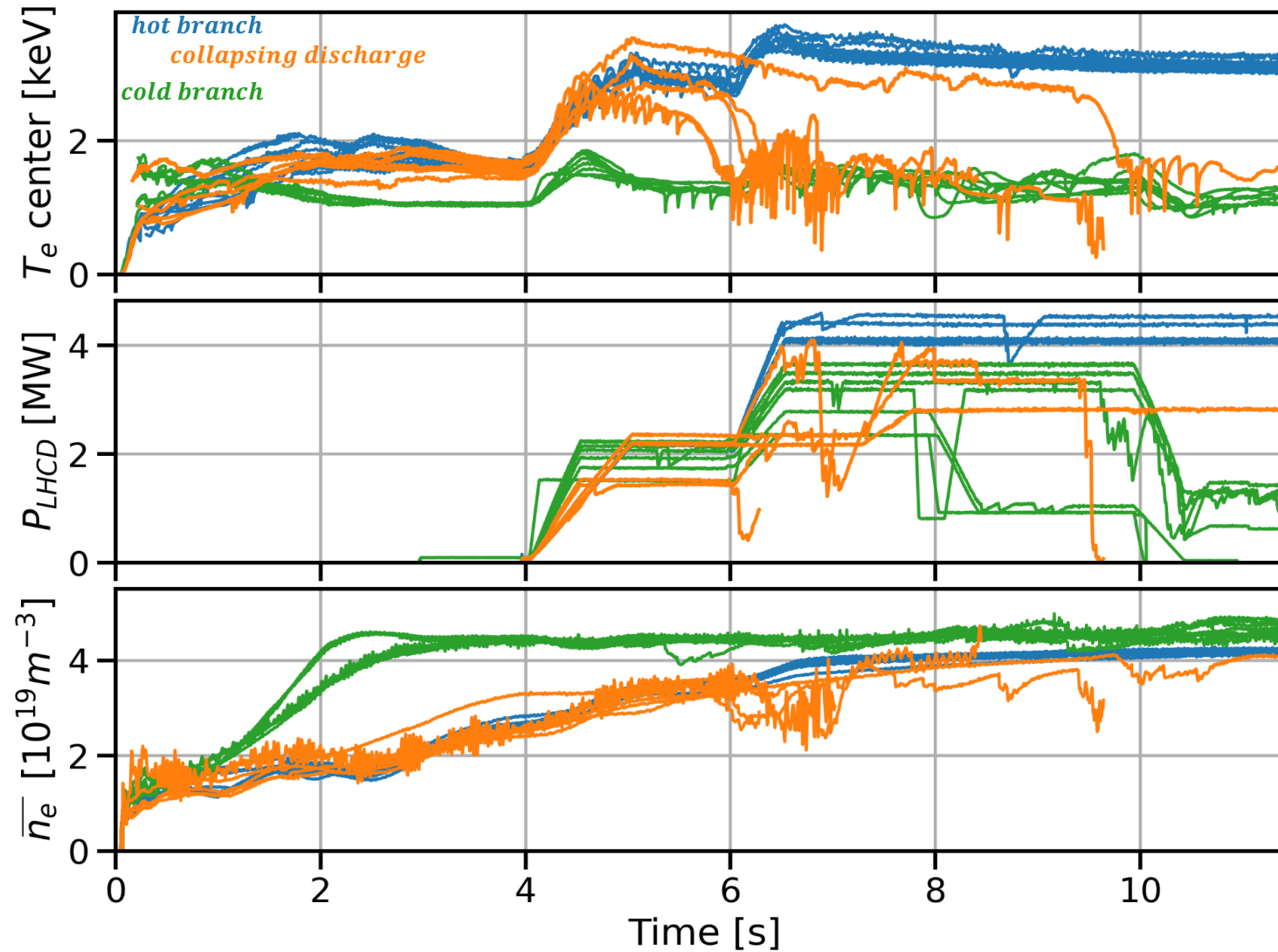
Above **1KeV** the **main radiator** is the **tungsten**.

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.





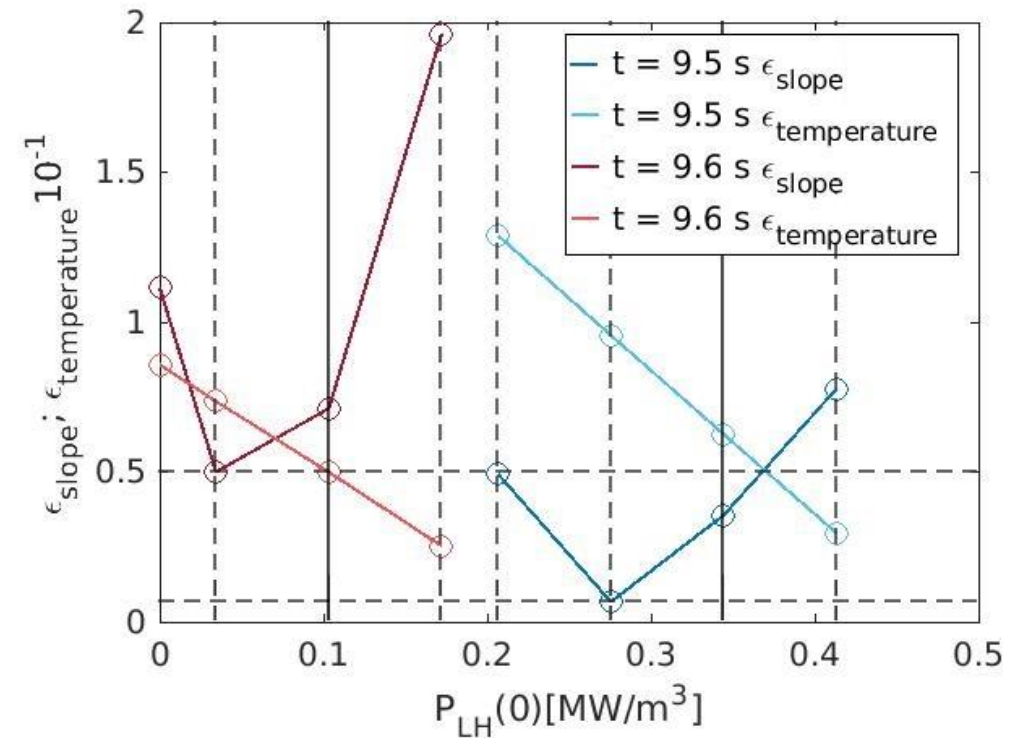




The central value is adjusted to find the optimum between  $\epsilon_{slope}$  and  $\epsilon_{temperature}$ .

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

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



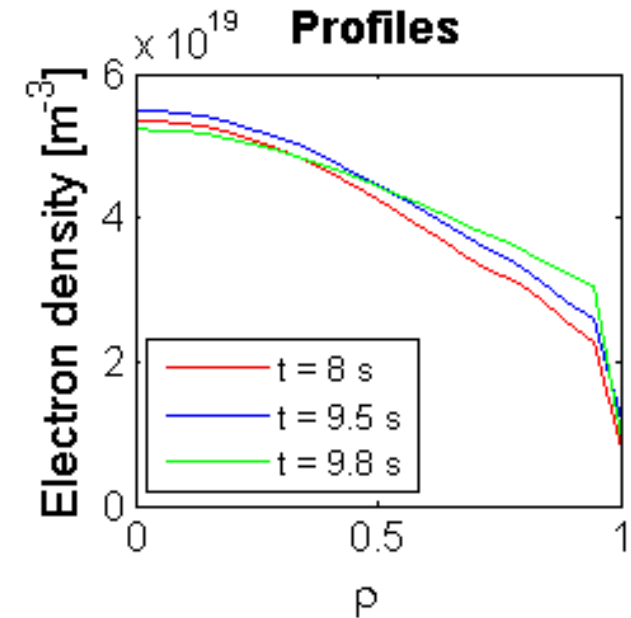
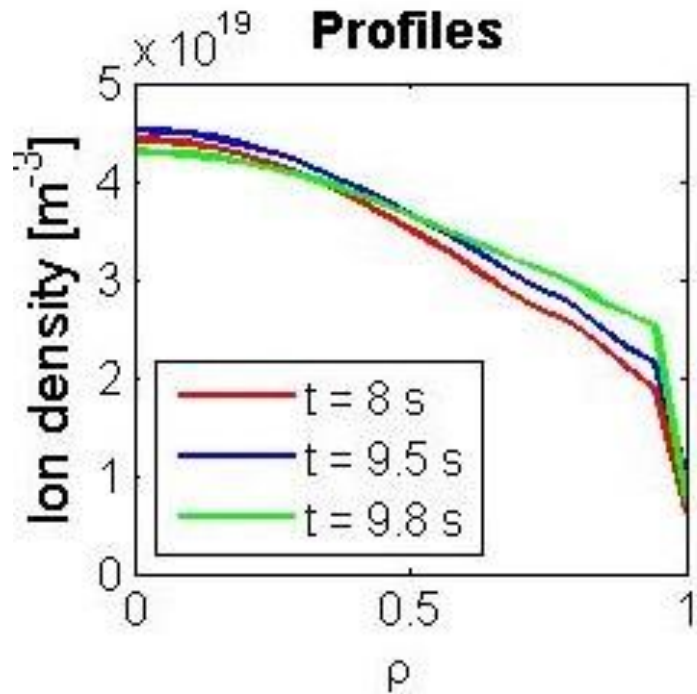
W neoclassical transport (in absence of poloidal asymmetries)

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

Diffusion

Convection due to ion  
density peaking  
(inward)

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



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  $P_{\text{rad}}$  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.