EUROFUSION WPMST2-CP(16) 15246

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Preprint of Paper to be submitted for publication in Proceedings of 26th IAEA Fusion Energy Conference

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.

Contribution to the multi-machine pedestal scaling from COMPASS tokamak

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Abstract. The properties of the edge transport barrier are essential for the performance of ITER and next-step devices. Due to the stiffness of radial density and temperature profiles, the height of the edge pedestal has a direct impact on the fusion performance of the tokamak. At the same time, the plasma stability is determined by the pressure gradient, which depends on the pedestal width. Despite its importance, analytical models capable of predicting pedestal parameters for ITER were not available until a recent success of the EPED model. Validation of EPED and empirical scaling laws requires measurements of pedestal parameters on existing machines in ITER relevant regimes. We report on such measurements in the COMPASS tokamak.

1. The COMPASS tokamak

The COMPASS tokamak [1] is a smaller device capable of operating with the ITER-like plasma cross-section and achieving Type I ELMy H-mode in both Ohmic and NBI-assisted discharges. As such, it provides a unique opportunity to validate the EPED model and to improve the pedestal prediction for ITER. COMPASS is equipped with a set of high resolution diagnostics for measurements in plasma edge. The most important one for these studies is the High Resolution Thomson Scattering (HRTS) [2][3], which allows to measure the edge profiles with a spatial resolution of ~2-3 mm (~a/100), which is sufficient to well resolve the pedestal. HRTS uses two 1.5 J Nd:YAG lasers with a repetition rate of 30 Hz each. In addition, the Lithium beam emission spectroscopy (Li-BES) system [4] provides profiles of edge plasma density with temporal resolution up to 4 μs.

2. Experimental setup

Overview of a typical NBI-assisted ELMy H-mode discharge #10430 (B_T=-1.15 T, I_{plasma} = 330 kA, P_{NBI}=150 kW, q_{95} = 2.1, δ_{lower} = 0.5, δ_{upper} = 0.2) is shown in Fig. 1. Plasma current (orange, top panel) reaches flat top around t=1080 ms, clear H-mode with large ELMs begins at t=1120 ms and shortly after that line averaged density measured by the interferometer (green, middle panel) reaches it natural H-mode value of $8x10^{19}$ m^{-3} (which corresponds to 20% of the Greenwald density limit). HRTS pulses are indicated by vertical lines, at t=1147 ms (green line) the laser pulse falls within the last 20% of ELM cycle (ELM crashes are detected using H-alpha signal – brown, bottom panel). This condition ensures that well developed pedestals are observed – the evolution of pedestal density during the ELM cycle as measured by Li-BES is shown in Fig. 2. Another condition applied is a selection of Type I ELMs, which occur on COMPASS when P_{sep} > 40 kW/m^2 [1]. Due to unfavourable combination of relatively short flat-top duration and slow HRTS laser repetition rate, typically one successful pedestal measurement is achieved per discharge. Therefore, substantial number of discharges had to be performed in order to accumulate sufficient statistics in pedestal parameters. In the first scan in parameter space the plasma current was varied between 160 and 330 kA.

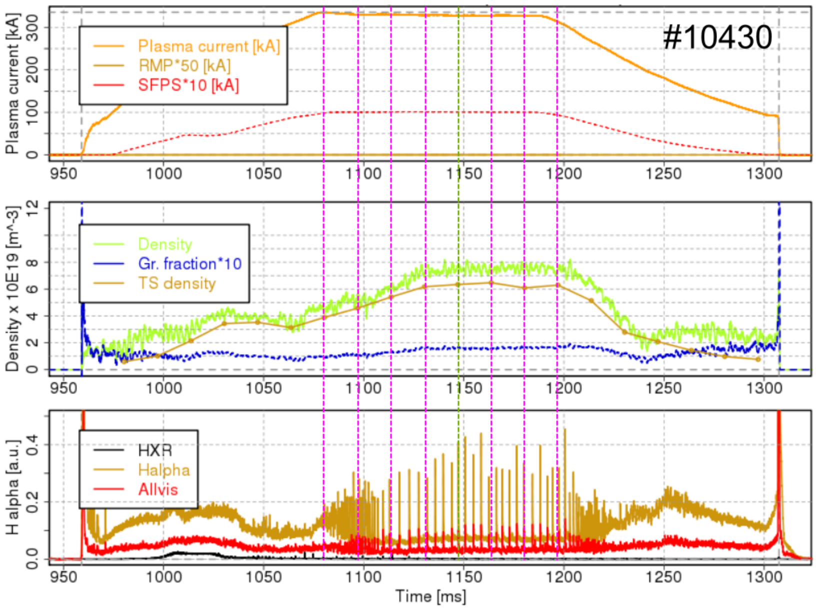

Figure 1: Overview of ELMy H-mode discharge #10430 on COMPASS. Panels (from the top) represent the plasma current (orange), line averaged density (green) and H-alpha (brown) signals. TS pulses are indicated by vertical dashed lines.

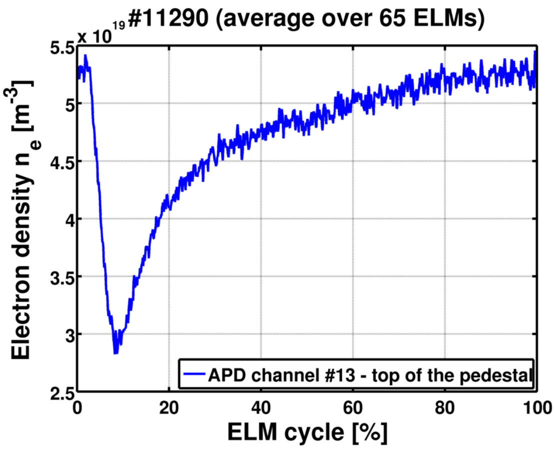

Figure 2: Evolution of electron density on top of the pedestal during the ELM cycle measured by Li-BES

3. Dimensionless pedestal parameters

Pedestal profiles acquired by HRTS were fitted using modified hyperbolic tangent function [5][6] Thanks to good localization of the individual spatial points, fit of a single measured profile is sufficiently accurate, it is not needed to perform profile averaging, which is a technique commonly employed i.e. at JET [5].

The measured density and temperature pedestal heights and widths were translated into dimensionless parameters, which are convenient for inter-machine comparisons of experimental results. Their definitions used further in the article are summarized in Table 1.

Table 1: Definitions of the dimensionless parameters

Pedestal collisionality	$\nu^*_{ped} = \frac{69.3 \ln \Lambda_e \, q_{95} R}{T^2_{e,ped} \epsilon^{3/2}}$ $\ln \Lambda_e = 31.3 - \log\left(\sqrt{n_{e,ped}} / 10^{19} T_{e,ped}\right)$
Pedestal normalized Larmor radius	$\rho^*_{ped} = \frac{\sqrt{T_{i,ped}/m_i}}{\Omega_i a}$
Pedestal poloidal normalized electron pressure	$\beta^{pol}_{e,ped} = \frac{2\, n_{e,ped} T_{e,ped}}{\frac{B_p^2}{2\,\mu_0}}$ $B_p = \mu_0 I_p / L_{LCFS}$

The measurements of ion temperature in the pedestal region are not available in COMPASS, we simply assume $T_i = T_e$.

The dimensionless parameters calculated from the measured pedestal widths and heights are summarized in Fig. 3. In order to compare them with data obtained on different tokamaks, ranges of parameters used of the JET & DIII-D identity experiment [7] are marked in the figure.

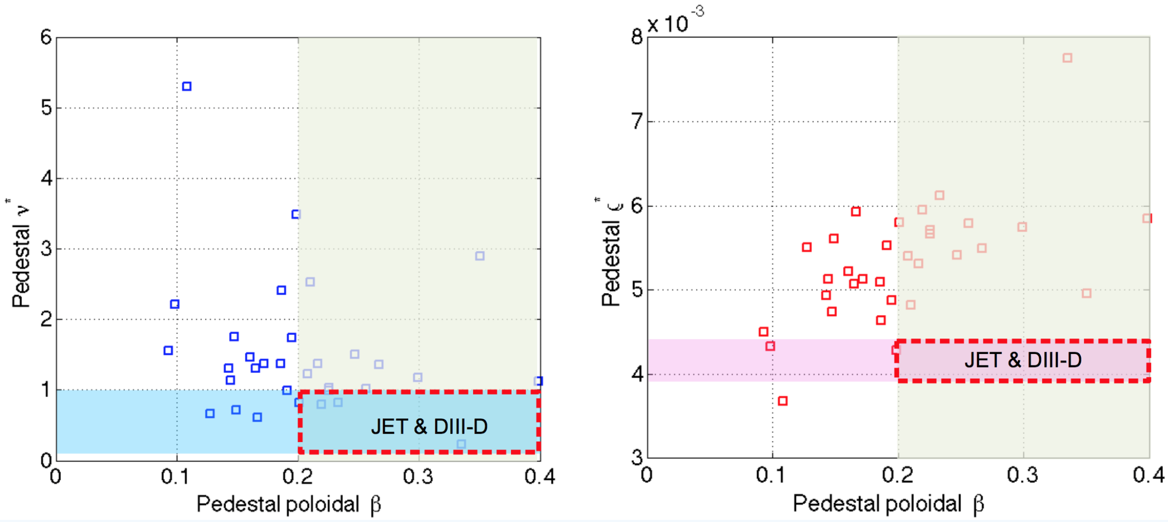

Figure 3: Dimensionless parameters obtained at COMPASS, compared to JET & DIII-D identity experiment [7]

4. EPED model

The experimental conditions at COMPASS have been used as input for the EPED model [8,9], which predicts the pedestal pressure, as shown in Fig. 4. The results are well reproduced by the model and complement data from the other 5 tokamaks.

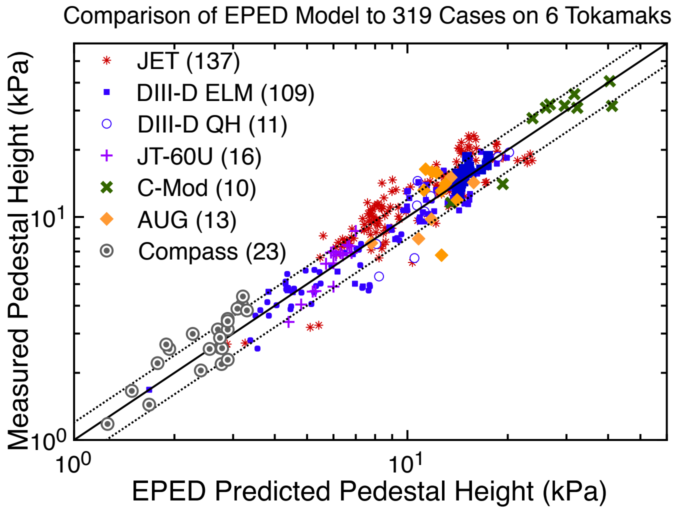

Figure 4: Predictions of the EPED model compared to experimental measurements of pedestal pressure, including 23 cases from COMPASS.

5. Upgrade of the HRTS

In the first experiments it was observed that the field of view of HRTS did not meet the original specification and was not sufficient to allow pedestal observation for the standard plasma shapes. In order to circumvent this issue, plasmas with reduced size and/or shifted downwards had to be used to achieve successful measurements of the pedestal. At the same time, plans for upgrade of the edge HRTS were initiated. This involved cutting and re-welding of the port used by the edge HRTS optics, which was a complex operation mainly due to the spatial constraints in the vicinity of the port. However, the procedure was successfully carried out and port configuration was modified as seen in Fig. 5. The field of view was expanded from z=280 mm up to z=330 mm.

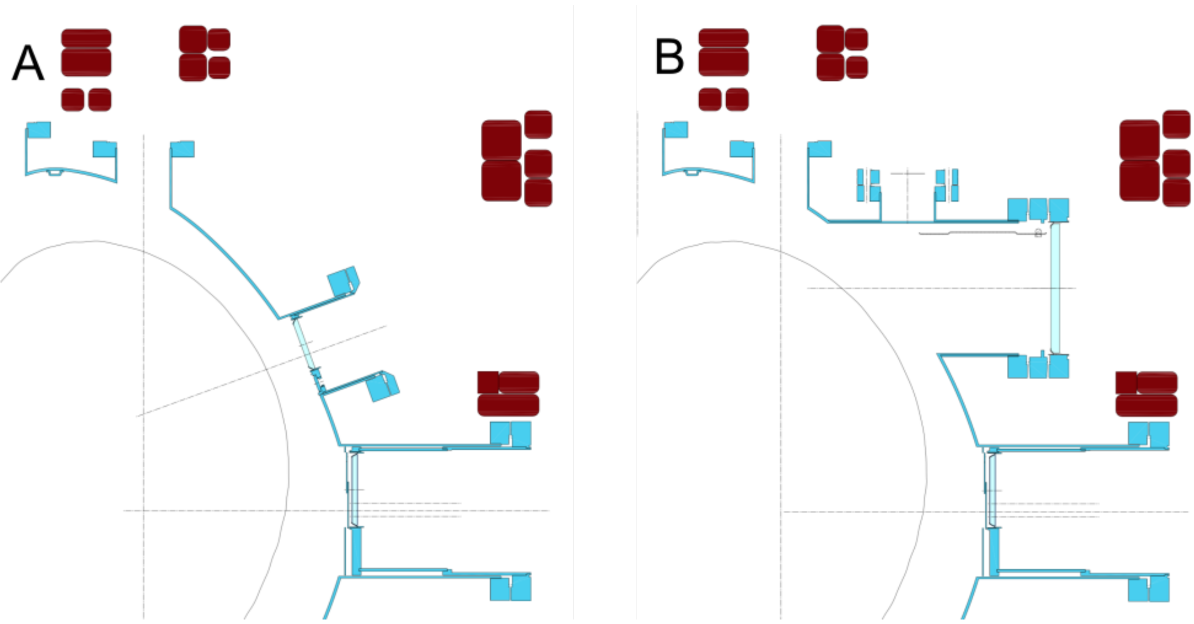

Figure 5: Geometry of the old port for edge HRTS (A) and the new port with increased field of view (B),

6. Conclusions

The first attempt to achieve systematic measurements of the pedestal parameters at COMPASS was performed using the HRTS. The experimental data are in agreement with the EPED model. The range of obtained dimensionless pedestal parameters span $0.1 < \beta_{e,ped}^{pol} < 0.5$, $0.5 < \nu_{ped}^{*} < 5$ and $0.004 < \rho_{ped}^{*} < 0.008$. The measured pedestal parameters were successfully reproduced using the EPED model. Following the first experimental campaign, the HRTS was upgraded to improve the field of view of the edge optics.

Acknowledgements

This work was supported by the project of the Czech Science Foundation GA14-35260S and MSMT Project #LM2011021. It 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.

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