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Integrated density profile analysis in ASDEX Upgrade H-modes

R. Fischer, E. Wolfrum, Ch. Fuchs, ASDEX Upgrade Team

Max-Planck-Institut für Plasmaphysik, EURATOM Association, D-85748 Garching, Germany

The method of Integrated Data Analysis (IDA) provides a full probabilistic model including physical and statistical models of an integrated set of different diagnostics. The goal of IDA is to combine data from heterogeneous and complementary diagnostics to consider all dependencies within and between diagnostics for obtaining validated and most reliable results in a transparent and standardized way. IDA exploits redundancy of complementary diagnostics to provide information for resolving data inconsistencies.

IDA was applied to the reconstruction of electron density profiles from Lithium beam (LIB) emission spectroscopy in the plasma edge region and from a combined analysis of LIB and DCN interferometry data at ASDEX Upgrade to obtain full density profiles. A detailed description of the analysis of the LIB data can be found in [1, 2]. The time resolution achieved is 50 μs and the spatial resolution is about 5 mm at the plasma edge and about 10 cm in the core. This and the numerical stability of the probabilistic IDA approach allows the study of the temporal evolution of electron density profiles of individual edge localized modes (ELMs) in a large set of different ELMy H-mode discharges in ASDEX Upgrade.

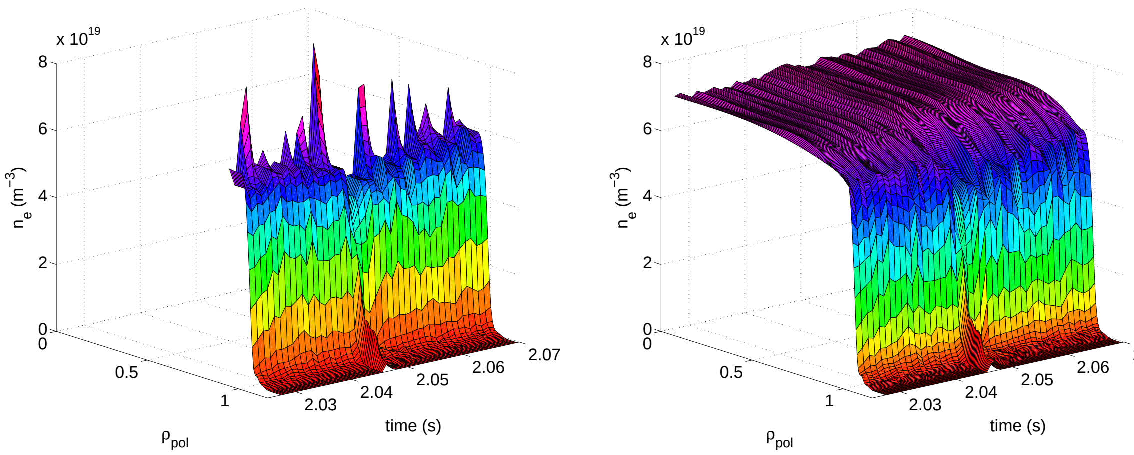

Figure 1: Time traces of density profiles (#22561) obtained with the probabilistic LIB analysis (left) and the combined analysis of LIB and DCN interferometry data (right).

Figure 1 shows the temporal evolution of the density profile for an H-mode discharge (#22561) obtained with the probabilistic LIB analysis (left) and the probabilistic analysis of the combined LIB and DCN interferometry data (right). At t=2.0455s a single type I ELM appears within a stationary phase. The time resolution of 1 ms, chosen for routine analysis of density profiles at ASDEX Upgrade, is not sufficient to resolve details of the temporal evolution of the ELM. Using LIB data only allows one to infer the profile up to the pedestal ($\rho_{pol} > 0.95$) where the pedestal densities become quite uncertain. Combining LIB and DCN interferometry data allows full density profiles where the pedestal density is robustly estimated. Please note that in contrast to the frequently used approach of fitting a parameterized profile to a set of profiles from individual diagnostics, IDA is based on fitting a unique profile to a combination of the *measured* data from different diagnostics within a one-step approach which is necessary for correct error propagation.

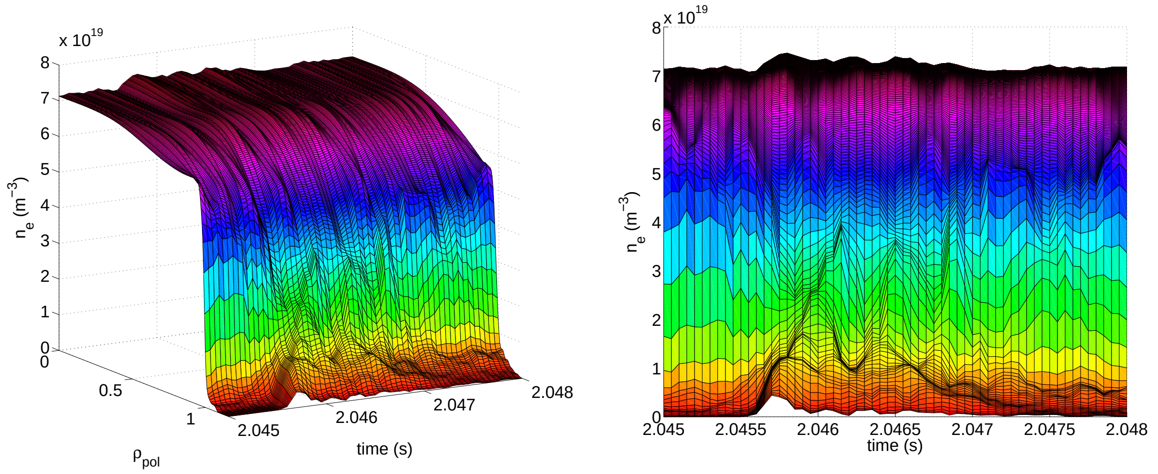

Figure 2: Temporal evolution of the density profile (#22561, t=2.044-2.048s) from the combined analysis of LIB and DCN interferometry data with a time resolution of 50 μs.

Figure 2 depicts the same ELM as shown in figure 1 but with a time resolution of 50 μs. Neighboring time frames were (boxcar) averaged to reduce statistical scatter for visualizing the temporal correlations. The fast ELM crash within 50 μs and spatial sub-structures developing in time can clearly be resolved.

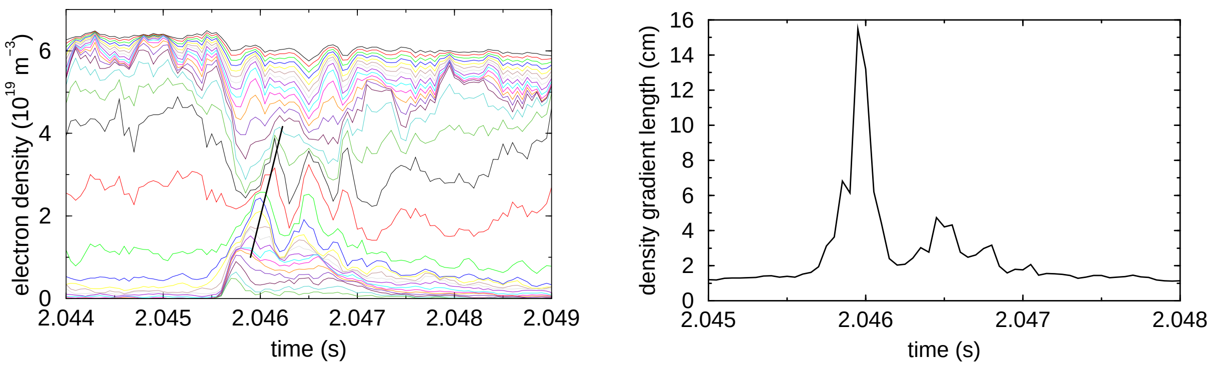

Figure 3: Temporal evolution of the density profile (#22561) for different spatial coordinates (left) and the density gradient length close to the separatrix (right).

The left panel of figure 3 shows time traces of the density for 30 different spatial coordinates equidistantly separated by about 5 mm. The corresponding magnetic coordinates are between $\rho_{\text{pol}} = 0.809 - 1.147$ ($\Delta\rho_{\text{pol}} = 0.012$). For this shot the mapping from spatial to magnetic coordinates is not ELM resolved which makes the absolute values of ρ_{pol} during the ELM difficult to interpret. Three oscillations with a period of 400 μs within the 1.5 ms after the ELM onset at $t_{\text{ELM}} = 2.0456$s are observed. The phase of the oscillation shifts with the spatial coordinate (solid line). This shift is interpreted as a density wave drifting inwards with a velocity of about 150-200 m/s. The origin of this density wave might come from recycled particles of the originally outward drifting ELM filaments impinging on neutral gas or the wall. The inward drift velocity is much smaller compared to the typical outward filament velocities of a few km/s. For this ELM the density drop at the pedestal and the density enhancement in the SOL appears to occur simultaneously within the time resolution.

The right panel of figure 3 shows the temporal evolution of the gradient length $L_n = |\frac{1}{n}\frac{dn}{dr}|^{-1}$ close to the separatrix. Before the ELM onset $L_n(t < t_{\text{ELM}}) \approx 1$ cm. The maximum value for the gradient length 360 μs after the ELM onset is about $L_n(2.04596\text{s}) \approx 15$ cm which slightly depends on the actual position within the gradient region. The gradient region quickly recovers within about 240 μs to $L_n(2.0462\text{s}) \approx 2$ cm. After that recovery the gradient length increases again to $L_n(2.0465\text{s}) \approx 4$ cm about 550 μs after the main ELM crash. About 1.3 ms after the onset of the ELM the gradient length was close to its original value although the complete ELM recovery takes about 5 ms.

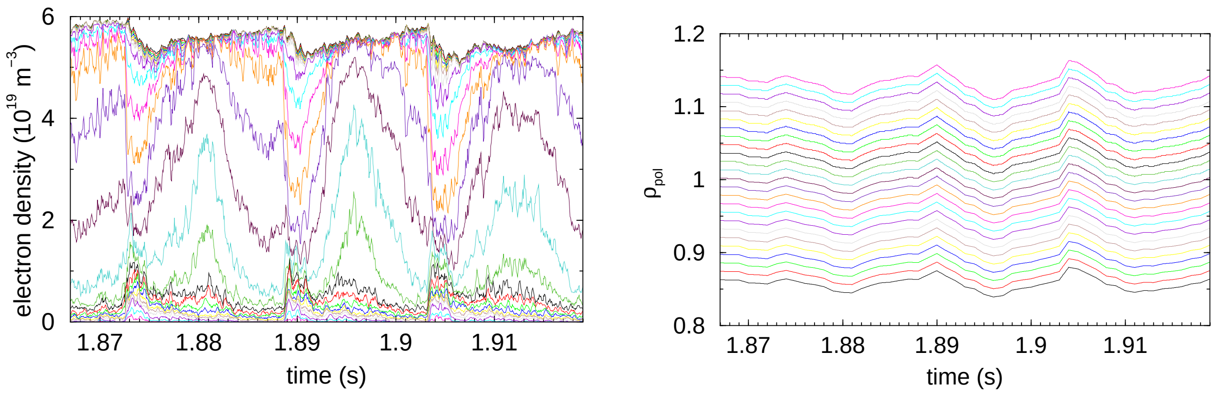

Figure 4: Temporal evolution of the density profile over 3 ELM cycles with a time resolution of 50 μs (left) and the corresponding ρ_{pol} values with a time resolution of 1 ms (right).

The time trace of density profiles over three ELM cycles (#22227, $f_{\text{ELM}} = 30$ Hz) are shown in figure 4. Again, the various lines depict densities for constant spatial coordinates. The corresponding ρ_{pol} values (right panel) are calculated with an equilibrium reconstruction each ms and are linearly interpolated in between. The maximum variation in the separatrix position is about 2.5 cm. The structure between the ELMs is a consequence of the movement of the separatrix. Figure 5 shows the same density profiles as in figure 4 but with lines belonging to the

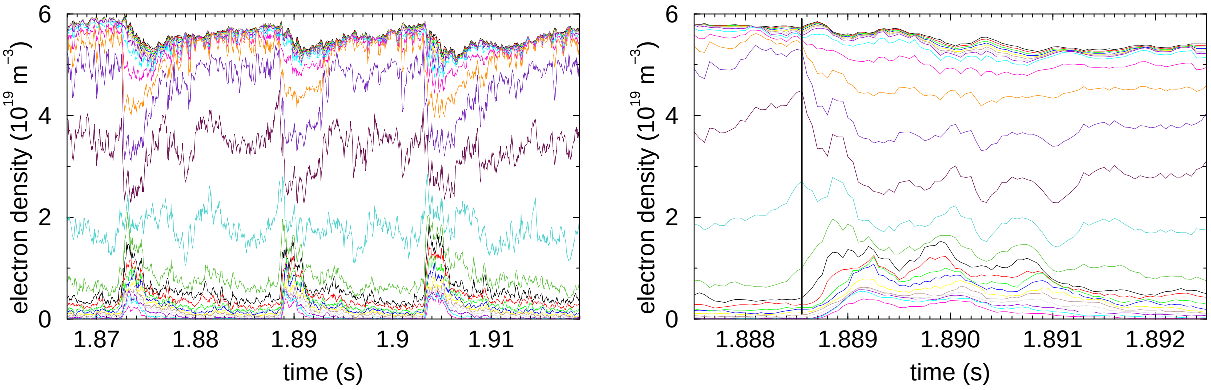

Figure 5: Temporal evolution of the density profile with constant-ρ_{pol} coordinates (left) and a 5 ms selection of the second ELM (right).

same ρ_{pol} value. It is expected that a further increase of the time resolution of the equilibrium reconstruction results in a reduction of structures with temporal variations < 1 ms.

The ELM shown in the right panel of figure 5 starts close to the pedestal top (solid line) and propagates outwards. The re-distribution of density reaches the edge about 200-300 μs after the start of the density change between the separatrix and the pedestal top.

The combination of LIB and DCN interferometer data within the IDA approach allows one to obtain density profiles with high spatial and time resolution so as to resolve the temporal evolution of ELM sub-structures. The density profiles of single ELMs of various plasma scenarios can be studied routinely. The correlation with temperature profiles, gradient lengths of temperature and pressure profiles as well as the natural scatter of different ELM signatures with respect to radial extent, temporal evolution and radial propagation of the perturbation will be subject of a forthcoming paper as well as the correlation with equilibrium reconstructions with a time resolution of 0.1 ms.

References

[1] R. Fischer, E. Wolfrum, J. Schweinzer, and ASDEX Upgrade Team. Probabilistic Lithium beam data analysis. In *34th EPS Conference on Controlled Fusion and Plasma Physics*. 2007.

[2] R. Fischer, E. Wolfrum, J. Schweinzer, and ASDEX Upgrade Team. Probabilistic Lithium beam data analysis. Accepted for publication in Plasma Phys. Control. Fusion.