# Fluctuation measurements in the X-point region of ASDEX Upgrade

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**Introduction:** Density fluctuations in the X-point region are characterized using ion-saturation current measurements obtained from Langmuir probes. These are mounted on the X-point manipulator (XPM) available at the ASDEX Upgrade, which provides the unique possibility of increased poloidal coverage for measuring continuous time series. To characterize the filamentary structures, we implement the Filtered Poisson Process (FPP) model [1] as it provides a way to unify the observations of a probability density functions (PDF), power spectral density (PSD), and the conditional averaged profile (CA). The FPP models a given time series as the superposition of uncorrelated pulses with the assumption that they arrive according to a Poisson distribution. The pulses are also assumed to be independent and their amplitudes are exponentially distributed. Due to the successful implementation of this model in different tokamaks [2, 3, 4] to characterize the filamentary structures in the SOL at the outboard midplane, we implement this method to investigate whether the underlying assumptions of this model is able to describe fluctuations in the X-point region. This provides a fair way to compare the statistics of the fluctuations observed at the outboard midplane to those in the X-point region.

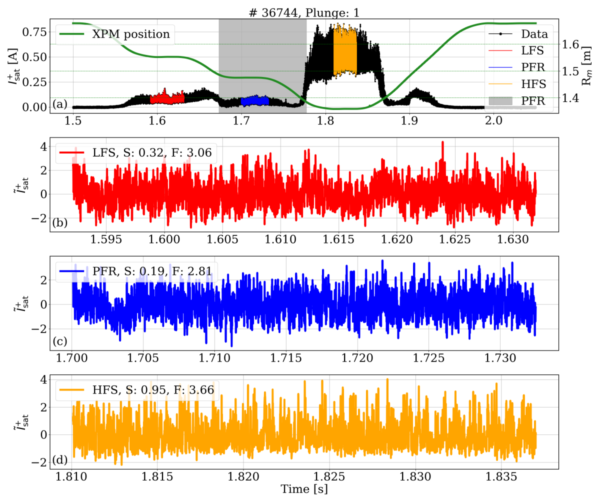


*Figure 1: Time trace of (a) the raw ion-saturation current $I^+_{sat}$ in black and the probe-stationary phases in color. The filtered and normalized probe-stationary phases are measured in (b) the LFS SOL, (c) the PFR and (d) the HFS SOL. The shaded region in grey shows the PFR [5].*

**Diagnostics and experimental details:** The X-point manipulator allows for continuous measurements in the three regions just below the X-point, the low-field side (LFS) and high-field side (HFS) SOL, as well as the private flux region (PFR). The XPM reciprocates starting from the LFS SOL into the PFR and stopping at its maximum position on the HFS SOL. In this contribution we discuss the data collected in three shots. Two of the shots were helium (He) plasmas and one in deuterium (D). The D- (#35466) and the He-plasma (#36736) were heated by electron cyclotron resonance heating, while the second helium shot (#36744) was heated by neutral beam injection (NBI). A more detailed description of the different shots can be found in [5, 6]. In this contribution we present the data of only shot #36744, which as mentioned was a He plasma with NBI heating.

**Data analysis:** For the He plasmas, the XPM was programmed to have stationary measurements in the three regions, i.e., ion-saturation measurements at fixed major radii and data was also continuously collected while the XPM was moving. The stationary phase in the D plasma is located only on the HFS SOL. The fluctuation analysis is, therefore, carried out in two parts. In the first part, a general fluctuation study is carried out on the ion-saturation current measured, where we considered the plunge as a whole. That is, both the stationary phases and the continuously moving phase of the Langmuir probe are considered. Spectral analysis methods reveal the presence of two regions of low fluctuations; one in LFS SOL and yet another one in the HFS PFR. The region of low fluctuation on the LFS SOL has originally been reported by Walkden et al. [7, 8] for MAST and TCV by means of fast visible imaging camera diagnostics. We report for the first time the characterization of the quiescent region on the LFS SOL using a Langmuir probe. Furthermore, we report the presence of a second region of fluctuation in the private flux region. Further details of this investigation can be read in R.D. Nem et al. [6]. The focus of this contribution is the fluctuation analysis of only the stationary phases of the plunges.

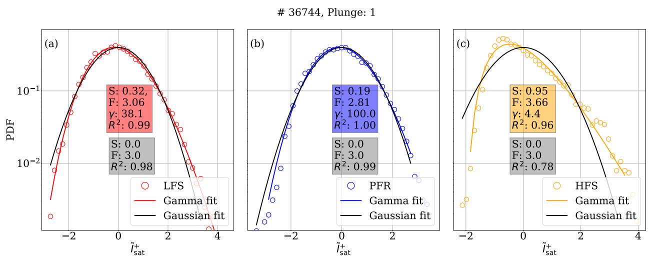


*Figure 2: The probability density function of the filtered and normalized probe-stationary phases in (a) the LFS SOL, (b) the PFR and (c) the HFS SOL. The black line shows an ideal Gaussian distribution, while the colored line shows the PDF determined using the FPP model [5].*

An example of the raw ion-saturation current, measured during a whole plunge by the biased Langmuir probe in a helium plasma, is shown in figure 1. The stationary phases are shown by the plateau in the XPM position (green line). A synthetic data study shows that applying a low-pass filter is necessary to reduce the noise in the signals [5]. To account for trends in the signals, the data is normalized as follows: $\widetilde{I}^+_{sat} = \frac{I^+_{sat} - \langle I^+_{sat} \rangle}{\sigma_{I^+_{sat}}}$, where $\langle I^+_{sat} \rangle$ is the mean of the signal and $\sigma_{I^+_{sat}}$ the standard deviation. The filtered and normalized signals in the three regions are shown in figure 1 (b) - (d).

**Results:** To characterize the fluctuations, we determine the non-Gaussian character of the PDF of the signal, i.e., its degree of intermittency. The PDFs are described by the intermittency parameter $\gamma$ and a Gamma distribution ($\Gamma(\gamma)$). It should be noted that for large intermittency parameter, $\gamma$, the Gamma distribution converge towards a Gaussian distribution. For a detailed analysis, the reader is referred to [5]. In the FPP model the PDF is described as follows [13]: $P_{\widetilde{I}^+_{sat}}(\widetilde{I}^+_{sat}) = \frac{\gamma^{\gamma/2}}{\Gamma(\gamma)} \left( \widetilde{I}^+_{sat} + \gamma^{1/2} \right)^{\gamma - 1} \exp\left( -\gamma^{1/2} \widetilde{I}^+_{sat} - \gamma \right), \widetilde{I}^+_{sat} > -\gamma^{1/2}$. Figure 2 (a) - (c) shows the PDFs determined in the respective regions. It is observed that the PDFs of both the LFS SOL and the PFR can be described by a Gaussian distribution (skewness (S) = 0 and flatness (F) = 3). Thus, indicating the absence of filamentary structures in these signals. Contrarily, the

HFS SOL indicates the strongest intermittent turbulence. When comparing the ECRH and the NBI heated plasmas, it is observed the PDF obtained from LFS SOL deviates slightly from a Gaussian distribution, whereas those of the HFS SOL follow a Gamma distribution. This is observed independent of the plasma species. The PFR, however, gives prominence to a Gaussian distribution, indicating a high degree of overlapping pulses. For comparison with midplane's measurements [2, 3, 4], the conditional averaged pulses and the power spectral density spectrum are considered individually.

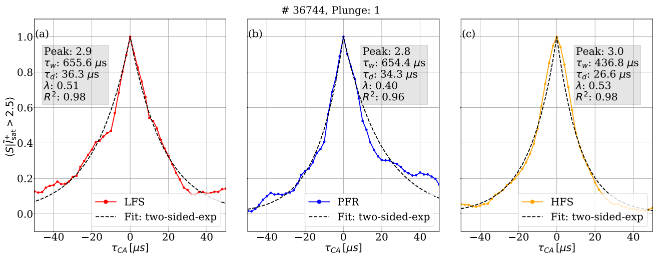


*Figure 3: The conditional averaged pulses of the filtered and normalized probe-stationary phases in (a) the LFS SOL, (b) the PFR and (c) the HFS SOL [5].*

Conditional averaging (CA) method is applied on the Langmuir probe data to obtain the averaged waveform of the bursts for a threshold value of 2.5. Figure 3 shows the CA pulses obtained and they are normalized to their peak values. The dashed black line shows the curve-fit of a double exponential function, giving namely the two fitting parameters; the pulse asymmetry parameter $\lambda$ and duration time $\tau_d$, and the equation describing the fit is given as [13]:

$$\varphi(t,\lambda) = \begin{cases} \exp\left(-\frac{t}{(1-\lambda)\tau_\mathrm{d}}\right), & t \geq 0, \\ \exp\left(\frac{t}{\lambda\tau_\mathrm{d}}\right), & t < 0. \end{cases} \tag{1}$$

The mean waiting time $\tau_w$ in between the pulses are also given figure 3, as well as the goodness of the fit, the $R^2$ coefficient. From the $R^2$ coefficient, it is shown that the double exponential function of the FPP model well describes the CA pulses. It is observed that the CA pulses are rather symmetric in all three regions, as indicated by $\lambda \approx 0.5$. Comparing the shots, we observed that the CA pulses in the X-point region have a symmetric profile, unlike the observations of a fast rise and slow decaying pulse, made at the outboard midplane of different tokamaks.

We further consider the power spectral density (PSD) spectrum, shown in figure 4. Using the assumptions of the FPP model, the PSD is described as a function of the frequency $\omega$ [13]: $PSD_{\tilde{I}^+_{sat}}(\omega) = \frac{2\tau_\mathrm{d}}{\left[1+(1-\lambda)^2\tau_\mathrm{d}^2\omega^2\right]\left[1+\lambda^2\tau_\mathrm{d}^2\omega^2\right]}$. It should be noted that due to the low-pass filter implemented to reduce the noise in the signal, the Nyquist frequency is reduced from the 250 kHz to 50 kHz. The steep slopes above 50 kHz are effects due to the filtering and were not considered during the analysis. The spectra are fitted independently using the PSD equation of the FPP model to obtain the fitting parameters - the pulse asymmetry parameter $\lambda_{psd}$ and duration time $\tau_{d,psd}$ (black line). A clear discrepancy is observed between the independent fits and the purple colored fits that are calculated from the CA parameters obtained (figure 3).

**Discussion and Conclusion:** Our analysis shows that the uniqueness of the FPP model, that lies in unifying the observations, did not hold for the data in the X-point region, as compared to those at the midplane. That is, the parameter pairs $\lambda$ and $\tau$ obtained from the conditional averaged pulse cannot be used to describe the PSD spectra.

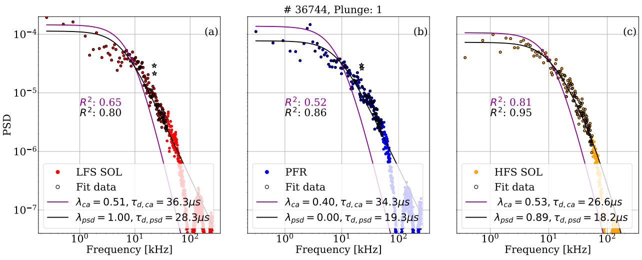


*Figure 4: The power spectral density of the filtered and normalized probe-stationary phases in (a) the LFS SOL, (b) the PFR and (c) the HFS SOL. The black line shows an independent fit of the spectra, whereas the purple line represent the PSD fit as obtained using the parameters determined from the respective CA pulses. The data used to determined the fit are encircled in black [5].*

It is observed that data collected in the X-point region are not sufficiently intermittent, violating the assumption of the FPP model. The HFS SOL showed a moderate intermittency compared to the LFS SOL and PFR. However, when compared to the intermittency of signals measured at the midplane, those determined for the HFS SOL in the X-point region were still larger. Thus, showing that pulse overlapping is not negligible in the X-point region. We conclude that one cannot assume uncorrelated and independent pulses that obey a Poisson distribution in the X-point region. A plausible explanation might be that fluctuations in the X-point region are born locally compared to the outboard midplane, where fluctuations are born in the edge and are propagating towards the measurements position. The analysis indicates that the fluctuations from the outboard midplane are not dominant or surviving in the divertor region. This might be a direct influence of the presence of the X-point, where the strong magnetic shearing at the throat of the divertor shears the fluctuations.

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