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Fast ion distribution results of NBI heated plasmas on ASDEX Upgrade using the Collective Thomson Scattering (CTS) diagnostic

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Introduction:

The importance of measuring the confined fast ion distribution in fusion devices is well known. The principle behind Collective Thomson scattering (CTS) disgnostic is based on an incident electromagnetic radiation beam called the “probe beam”, scattering off fluctuations in a plasma. The receiver beam, defined by the receiver antenna, collects the scattered radiation from the scattering volume which is the region where the probe and receiver beam intersect. The fluctuations are resolved along the wave vector $\mathbf{k}^\delta = \mathbf{k}^s - \mathbf{k}^i$ where $\mathbf{k}^s$ and $\mathbf{k}^i$ are the wave vectors of the received scattered radiation and the incident probing beam, respectively. The extraction of the component of the ion velocity along k^δ from the scattered radiation ($\omega^\delta = \mathbf{v}_{\text{ion}} \cdot \mathbf{k}^\delta$) requires that the scattering is dominantly off collective fluctuations larger than the Debye length ($(\lambda_D \mathbf{k}^\delta)^{-1} > 1$) which is well satisfied in tokamaks by millimetre-wave probes. The CTS system installed on ASDEX Upgrade (AUG) [1] uses the dual frequency gyrotron as its probe (at f_{gyro} = 105 GHz) and the AUG ECRH steerable antenna system enables measurement of the confined fast ion distribution at different spatial locations and different angles of $\mathbf{k}^\delta$ to the magnetic field ($\angle(\mathbf{k}^\delta, \mathbf{B})$). The paper presents first results of fast ion distribution measurements on ASDEX Upgrade in an H-mode plasma and compares the effect of on-axis and off-axis NBI heating.

ASDEX Upgrade experiment:

ASDEX Upgrade is equipped with a versatile NBI system capable of up to 20 MW of power (in deuterium) consisting of two injectors each equipped with four ion sources. The different ion sources have different injection energies and geometries including on/off-axis injection capability [2]. This paper will compare the confined fast ion distribution of NBI heated plasma from two different NBI heating configurations namely source 3 and 6 (S6+S3) and source 8 and 3 (S8+S3). The ion sources S3 and S8 have similar injection beam geometry but different full injection energies $E_{inj}(D^0)$ = 60 keV and 93 keV respectively. Ion source S6 has $E_{inj}(D^0)$ = 93 keV but has more off axis injection geometry [2]. Figure 1 shows the time traces of two NBI heated discharges. Each was a low triangularity standard ELMy H-mode plasmas at $B_t = -2.6$ T and Ip = 800 kA. In both discharges there are no significant MHD modes during the two beam phase (T = 2.2 – 2.3 sec) and small sawteething during the one beam phase (T = 2.6 – 2.7 sec). The CTS results shown in this paper are only during the two beam phase. The higher stored energy during the S8+S3 compared to the S6+S3 shown in Figure 1(a) was also observed in previous studies comparing different beam sources on AUG [3,4] where a higher central current density was measured for S8 compared to S6 [3]. An extensive analysis and discussion of the physics of on-axis vs. off-axis beams can also be found in Ref 5.

The CTS experiments and preliminary fast ion distribution results

The CTS scattering geometry in these experiments is such that the scattering volume lies at the centre of the plasma and $\angle(\mathbf{k}^\delta, \mathbf{B}) \approx 120°$ where $\angle(\mathbf{Ip}, \mathbf{B}) = 180°$ on ASDEX Upgrade (Ip being the total plasma current). Hence, we expect that in this particular scattering geometry, the scattered radiation due to NBI fast ions, which are in the direction of **Ip**, should be frequency up-shifted according to $\omega^\delta \approx \mathbf{v}_{ion} \cdot \mathbf{k}^\delta$. The gyrotron injection power for these experiments was about 250 kW in O-mode with on/off modulated for 2/3 ms. The measured CTS spectra are fit using a least squares fitting procedure which takes prior information about parameters with their error bars and implements a Bayesian method of inference where information from a range of diagnostics is combined with the information provided by the CTS diagnostic. The CTS spectra provided to the inference (likelihood function) was averaged between 2.2 and 2.3 seconds for both discharges. The fast ion distributions are shown in Figure 2 and compares the difference between the two heating scenarios S3+S6 and S3+S8. The figure shows a slightly larger fast ion content for the S3+S8 NBI heating scenario. However this difference is within the error bars. The trend of the velocity distribution, specifically the positive velocities, is in general agreement with the modelling, but the difference is not as large as expected. The error bars in Figure 2 represent the uncertainty of one standard deviation and includes the uncertainties used in the inference about parameters from diagnostics other that CTS such as electron/ion temperature, density.

A clearer separation would allow more insight in the difference between on/off axis deposited ions [5]. By integrating the curves in Figure 2 the total fast ion density for S3+S6 and S3+S8 is 3.72×10^{18} m^{-3} and 3.79×10^{18} m^{-3} respectively. It is important to note that reference 6 compares results between the S3+S8 and S8 heating configuration and the difference in the fast ion distribution between these cases is outside the error bars. The reference also shows reasonable agreement between the fast ion distribution results from CTS to TRANSP simulation in both heating configuration.

Conclusion

The results presented in this paper show the CTS fast ion distribution results at the plasma centre between on-axis and off-axis beam heating scenario. The preliminary results show that the difference between both scenarios are marginal and within the disgnostic's error bars. Further studies to reduce the error bars in the inference and comparison to TRANSP simulation is in progress. The NBI deposition profiles of each source will influence the results and will be studied in detail.

References

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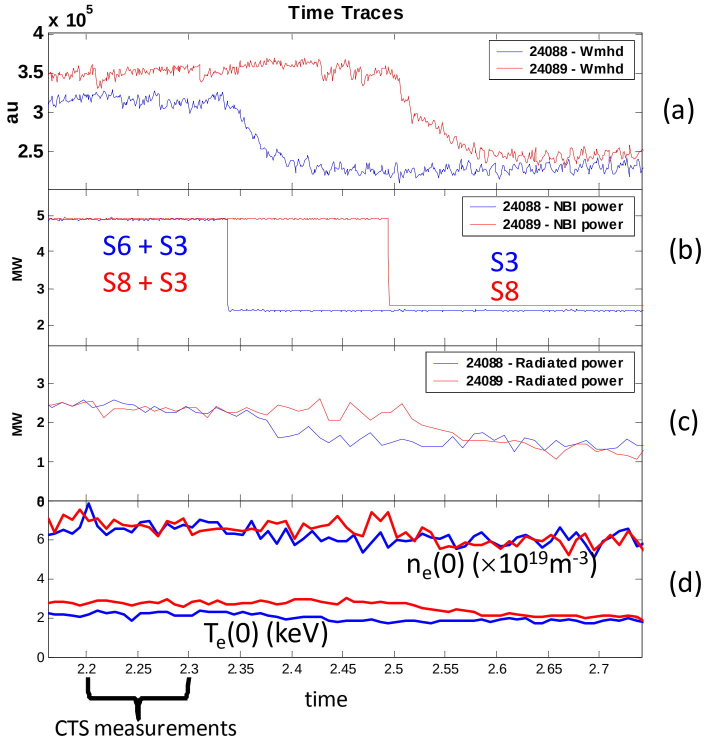

Figure 1. Time traces of plasma parameters of two different discharges #24088 (blue) and 24089 (red). Shown are the comparison between (a) Stored energy, (b) NBI power, (c) total radiated power, and (d) central electron density and temperature. The CTS measurements presented in this paper are between the 2.2 and 2.3 seconds.

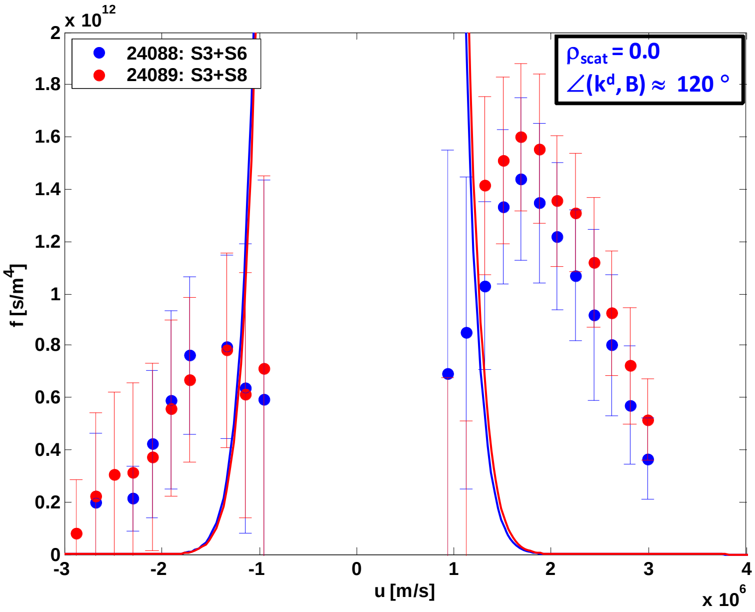

Figure 2. The fast ion velocity distributions from CTS with error bars during the NBI heated discharges with beam source S3+S6 (red) and S3+S8 (blue). The dashed lines are the thermal ion velocity for each discharge from calculation.