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Fast ion behaviour measured from CTS

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INTRODUCTION

In this paper the behaviour of fast ions in TEXTOR is described from collective Thomson scattering (CTS) measurements. The understanding of fast ion dynamics is of great importance. Especially understanding the slowing down process of fusion alpha particles in future tokamak projects is of large interest since these ions need to heat the bulk plasma without driving instabilities. In TEXTOR fast ions are generated using Neutral beam injectors and ICRH. The measurements presented here are focused on the slowing down of beam ions. The evolution of the fast ions is compared with a homogenous Fokker-Planck simulation taking into account both electron and ion drag, diffusion and pitch angle scattering.

COLLECTIVE THOMSON SCATTERING

Collective Thomson scattering is scattering of electromagnetic waves off fluctuations in the electron distribution where the inequality $k^{\delta} \lambda_D < 1$ is satisfied [1]. Here $k^{\delta} = k^s - k^i$ is the resolved fluctuation vector, λ_D is the debye length and k^s, k^i is the wave vector of the scattered and incident radiation. The scattered spectrum reveals the 1D ion velocity distribution projected onto k^{δ} and by changing the scattering geometry the 1D ion velocity distribution may be measured along different directions on a shot to shot basis. The first CTS measurements of fast ions in the MeV range were made at JET as reported in refs. [2] and [3]. After the termination of the JET CTS diagnostic, the work on the CTS system continued at TEXTOR, as a joint effort between TEC and MIT [3, 4], which was joined by Risø National Laboratory in 2001. The TEXTOR fast ion CTS diagnostic pilot project achieved initial successful results during operations in 2000 and 2001 using a 110 GHz

gyrotron with a power of max 350 kW and a pulse length of 200 ms. Recently, major elements of the TEXTOR CTS diagnostic has been upgraded at Risø (QO beam line, data acquisition and receiver) and the first results of this system are presented here.

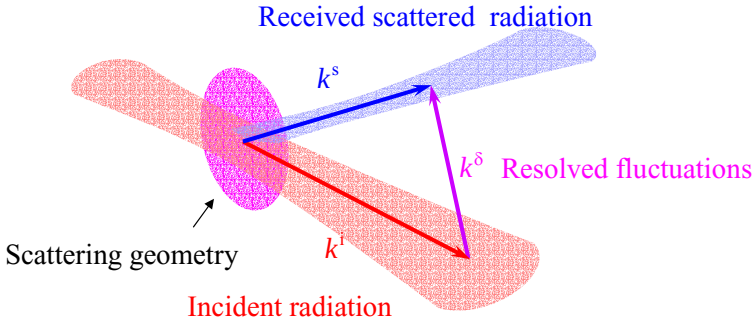

Figure 1: Scattering geometry. The 1D ion velocity distribution is measured along the direction of the resolved fluctuation. Thos direction may be changed on a shot to shot basis resulting in ion distributions in various directions.

CTS results from TEXTOR.

In TEXTOR the fast beam ions are generated by injecting ~50 keV hydrogen or deuterium neutral beams. TEXTOR is supplied with two NBI launchers, one injecting in the co-current direction and the second injecting in the counter-current direction. A typical series of CTS spectra measured during the turn off phase of the co-current NBI are shown in figure 2.

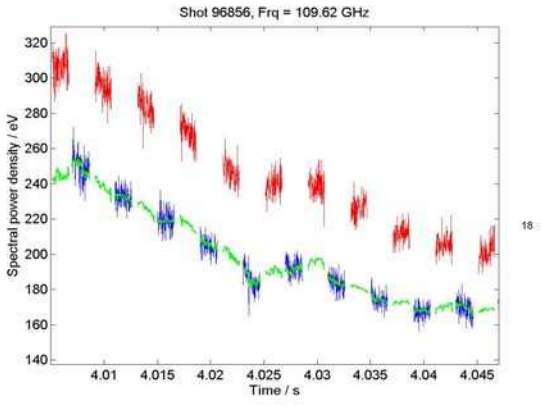

Figure 2a: Raw data in one frequency channel in the CTS receiver. Red signal indicated gyrotron on time and blue signal is gyrogrton off time (background ece). The CTS signal is the difference between red and green(fitted background during gyrotron ontime) signals.

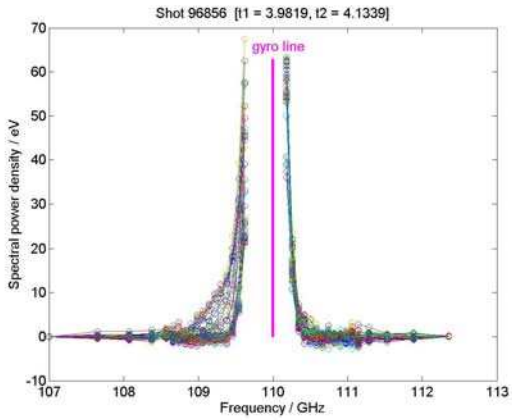

Figure 2b: Series of CTS spectra overlaid. It may be seen that some of the spectra are asymmetric having a larger signal from 109GHz to 109.4GHz. This is due to the fast neutral beam ions. When the NBI is turned off this signal slowly disappears.

The CTS spectra are fitted using a least square fit taking into account nuisance parameters [5]. An example of the inferred velocity distribution is shown in figure 3.

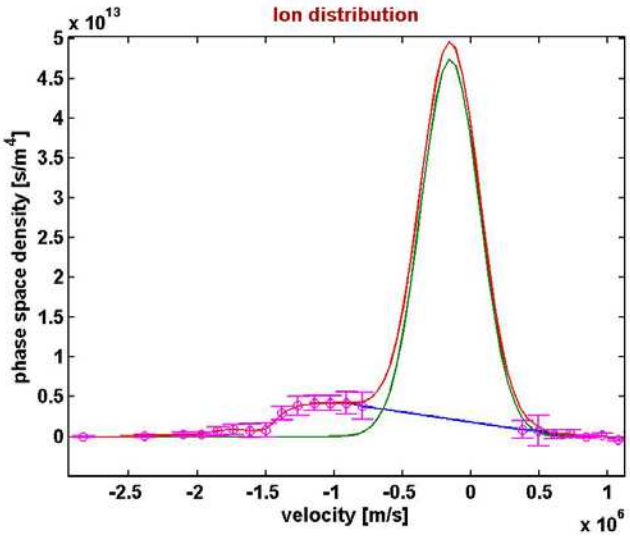

Figure 3: Example of a fitted ion distribution in TEXTOR #96853 while the co-current NBI is turned on. Positive velocities correspond to velocities projected onto a direction with an angle of 45 degrees to the magnetic field (counter-current) and negative velocities corresponds to velocities in the co-current direction.

The time development of the 1D ion distribution is shown in figure 4. It may be seen that the beam ions are thermalized after approximately 40 ms.

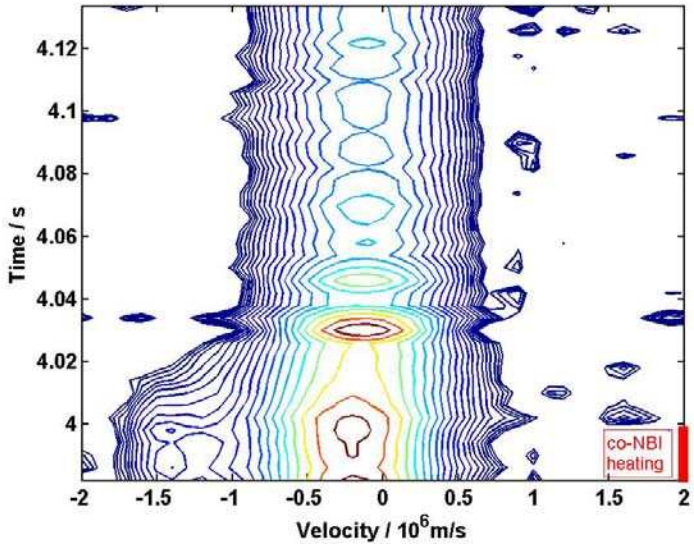

Figure 4: Time development of the ion velocity distribution in TEXTOR #96856 measured using CTS. The co-NBI is turned on at 2s and turned off at 4s. A clear nonzero fast ion density is present between -1.7 10^6m/s and -1 10^6m/s during neutral beam injection and the ion distribution is themalized after approximately 40 ms.

Fokker-Planck simulations of fast ions

The data are compared with a homogenous Fokker-Planck simulation taking into account both ion/electron drag, diffusion and pitch-angle scattering. The turn off of the neutral beam is simulated and the resulting slowing down process has similar thermalization time and distribution shape. The time development of the measured velocity node at 1.3 10^6m/s is shown in figure 5.

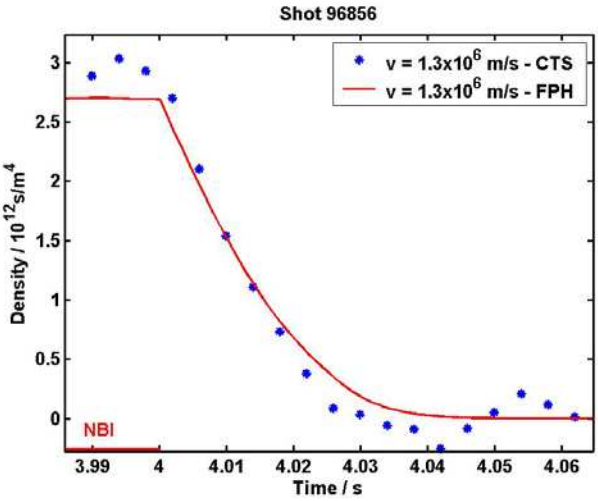

Figure 5: Time evolution of CTS measured velocity node compared with. simulation using the Fokker-Planck equation for a homogenous plasma.

[1] H. Bindslev, *A quantitative study of scattering from electromagnetic fluctuations in plasmas*, J. Atmospheric and Terrestrial Physics, 58, 983 (1996)

[2] H. Bindslev, J. A. Hoekzema, J. Egedal, J. A. Fessey, T. P. Hughes, and J. S. Machuzak, *Fast-Ion Distributions in JET Measured by Collective Thomson Scattering*, Physical Review Letters, 83, 3206 (1999)

[3] H. Bindslev, L. Porte, A. Hoekzema, J. Machuzak, P. Woskov, D. van Eester, J. Egedal, J. Fessey, and T. Hughes, *Fast ion collective Thomson scattering, JET results and TEXTOR plans*, Fusion Engineering and Design, 53, 105 (2001)

[4] L. Porte, H. Bindslev, F. Hoekzema, J. Machuzak, P. Woskov, and D. Van Eester, *Implementation of collective Thomson scattering on the TEXTOR tokamak for energetic ion measurements*, Rev. Sci. Instrum., 72, 1148 (2001)

[5] H Bindslev, Rev. Sci. Instrum., 70, 1093 (1999)