Investigation of suprathermal electron dynamics with ECCD in the TCV tokamak

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Introduction

Suprathermal electron dynamics in both real and velocity spaces play an important role in the physics of electron cyclotron current drive (ECCD), which is crucial for auxiliary current drive and MHD stability and plasma profile control. On the TCV tokamak, a gyrotron power modulation technique is being employed to investigate the dependence of suprathermal electron transport on electron energy and location as well as EC power, utilizing a novel hard X-ray tomographic spectrometer (HXRS). The modulated EC discharge is modelled using the collisional/quasilinear 3D (2D in momentum space and 1D in spatial space) bounce-averaged Fokker-Planck solver LUKE.

Hard X-ray diagnostic in the TCV tokamak

TCV has been equipped with a novel hard X-ray tomographic spectrometer (HXRS) for the study of suprathermal electrons. The system is based on 101 CdTe semiconductor detectors, featuring an energy resolution of $\sim$7 keV in the 10-300 keV range, followed by full-pulse digital data acquisition with digital postprocessing [1,2]. The detectors are distributed over four cameras (three installed, one to be added shortly), which can cover the poloidal plane thus enabling tomographic inversion of photon emission. Each camera has 36 high-pass filter (absorber) combinations which are remotely controlled through pneumatic actuators. The measured Bremsstrahlung emission can be compared with the simulated results from LUKE [3], coupled with a synthetic diagnostic.

The synthetic diagnostic in the LUKE package, the Fast Electron Bremsstrahlung (FEB) module [4], calculates photon emission from the tokamak plasma and expected photon counts by the HXRS detectors: from the electron distribution function calculated by LUKE, the effective photon energy spectrum emitted by the plasma is calculated using the Bremsstrahlung differential cross section, and the pulse energy spectrum, which can be compared to the HXRS measurement, is computed using the detector's response function.

The response function is the detector's own characteristics which relates the input photon energy to the output energy spectrum. Theoretically there are two main types of photon-matter interactions: photoelectric absorption and Compton scattering. Figure 1 (right) shows the re-

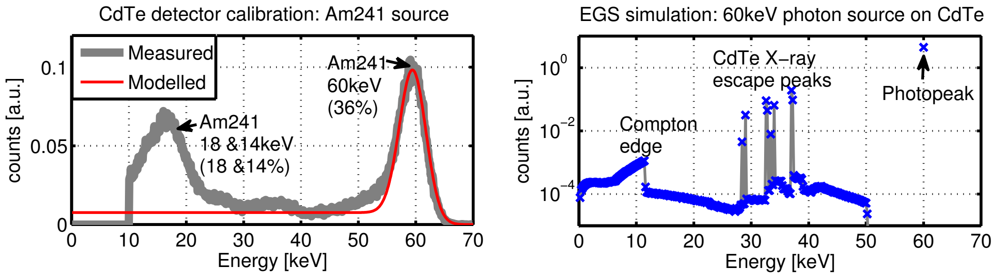

Figure 1: *(left) (Measured) Pulse height analysis of CdTe detector signal from a Am-241 radioactive source and (Modelled) modelled response function for a 60 keV monoenergetic photon source. (right) EGS pulse height analysis simulation for 60keV monoenergetic photon source incident on CdTe.*

sponse function calculated following the theory, using the EGS (Electron-Gamma Shower) Monte Carlo simulation program [5]. In the simulation, a 60 keV monoenergetic photon beam is incident on 2 mm thick CdTe material, which is identical to the HXRS detector's. The photoelectric absorption peak exhibits the highest counts, followed by the CdTe detector's X-ray escape peaks and the Compton continuum by electrons scattered by the photon below the Compton edge.

The LUKE-FEB module uses this theoretical model; however, the calibration result shown in Figure 1 (left) differs from the theoretical model: below the photopeak, a long-shelf structure appears (which covers the Compton continuum) due to the semiconductor detector's incomplete charge collection or metal contact-detector material interaction [5]. From this insight a new response function model is introduced which comprises the long-shelf structure error function and the photopeak Gaussian function. The new response function has been implemented in LUKE-FEB and the response function will be improved further after carrying out more extensive calibrations with multiple radioactive isotopes.

Electron cyclotron power modulation experiment

For the study of creation and transport of suprathermal electrons, short periodic electron cyclotron power pulses are applied and conditional averaging on HXRS signals is used to increase the signal to noise ratio. Three second-harmonic gyrotrons are utilized to provide about 1.8 MW co-ECCD power. The pulse length is kept long enough to obtain high HXRS statistics but short enough not to significantly perturb the plasma: the plasma current profile change is seen to be negligible for pulses shorter than 4ms from the ASTRA code simulation which solves the poloidal flux diffusion equation.

In order to enhance the hard X-ray photon statistics, an equatorial camera is rotated so that

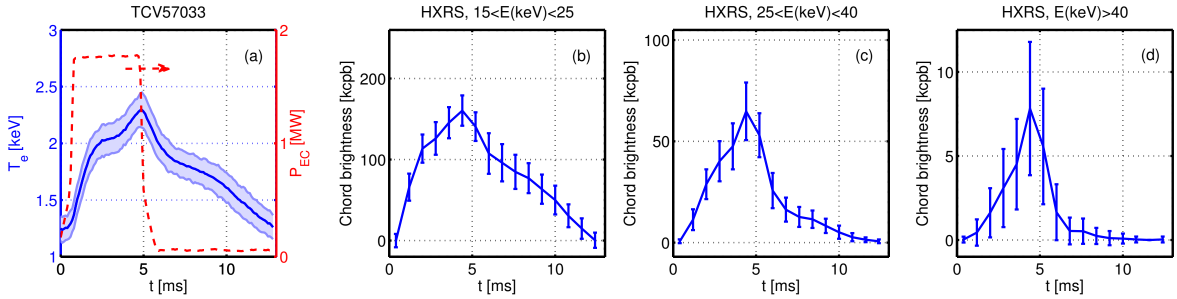

Figure 2: *(a) Time evolution of electron temperature (at $\rho = 0$) from soft X-ray signal (normalized to the temperature given by Thomson scattering) results and total gyrotron power. (b-d) HXRS chord brightness (photon count rate per energy bin) for different energy bins. The data are conditionally averaged on 50 ECCD pulses.*

the detector array is distributed in the toroidal direction, to benefit from the Bremsstrahlung emission angle anisotropy due to the relativistic headlight effect [6]. Figure 2 (b-d) shows chord brightness (photon count rate per energy bin) of a channel of the camera, which is tangential to the magnetic field lines at location where ECCD is deposited. In every energy bin, suprathermal electron population increases when ECCD is applied and decreases after the EC power is turned off, but the evolution behavior is different: the number of higher energy photons increases more slowly and decreases more rapidly than that of lower energy photons. The distribution of the suprathermal electron population from lower to higher energy can be described by the quasilinear diffusion process for the resonant interaction between electrons and radio frequency waves. In addition, since the collisional deflection time of 20 keV electrons is 55 ms (thermal electron's collitional deflection time is 0.016 ms), which is much longer than the modulation period, suprathermal electron transport may have a strong influence on the dynamics [7]. Therefore the more rapid loss of faster suprathermal electrons than slower electrons, despite their lower collisionality, may be explained by anomalous spatial transport.

Fokker-Planck modeling

For the study of the response of suprathermal electrons to high-power ECH/ECCD, modeling of non-steady-state discharges is necessary. The capability to follow the dynamical evolution of the electron distribution function exists in the Fokker-Planck code LUKE; instead of calculating a steady-state electron distribution function by evolving an initial Maxwellian distribution function, at each time step the electron distribution function is evolved from the previous step's distribution function. When combined with the HXRS synthetic diagnostic, this calculation enables a direct comparision of the measured HXRS signal evolution to the simulation.

According to the ASTRA simulation, the ECCD power modulation experiment's pulse is short enough not to perturb the total current profile, and the frozen current mode is therefore used in LUKE for this simulation: as the ECCD driven current profile evolves at each time step, the loop voltage induced by the back-EMF, which compensates the change of current profile change, is calculated assuming that the current density is unchanged everywhere. The preliminary simulation result, figure 3, reproduces this process. Further analysis with different suprathermal transport parameters is ongoing.

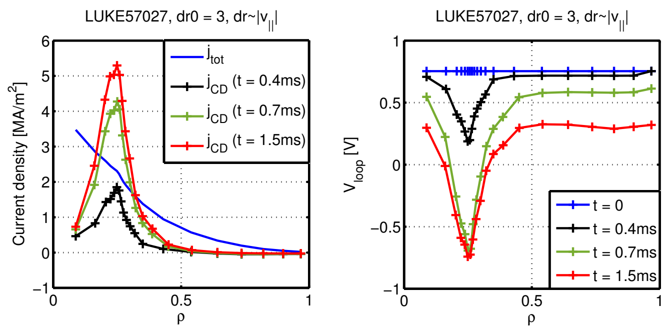

Figure 3: *LUKE simulation results for the TCV discharge #57027. 1.8 MW co-ECCD power was turned on at t = 0 and turned off at t = 2.2 ms. (left) Total current density and time evolution of ECCD driven current, (right) time evolution of loop voltage.*

Acknowledgements

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