Validation of the BEAMS3D deposition model on Wendelstein 7-X

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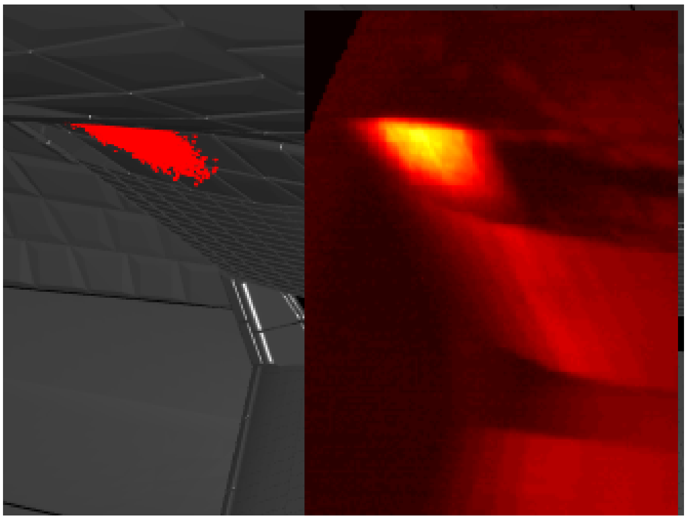

Figure 1: *Simulation (left) and infrared camera image (right) of W7-X NBI injection into an empty torus. A small toroidal shift in the beam line position is required to match experimental IR camera images.*

The Wendelstein 7-X (W7-X) experiment recently commissioned two neutral beam injection (NBI) sources [1] allowing validation of the deposition models in the BEAMS3D stellarator (NBI) code [2]. The geometry of the BEAMS3D NBI model was compared and adjusted to a beam-into-torus discharge. Here comparison to IR camera data was used to tune the geometric properties of the model. A series of discharges scanning plasma density and magnetic configurations was identified which could be used for validation of the deposition model. These were discharges heated by electron cyclotron resonance heating into which the neutral beams were added. In order to model the deposition, the plasma parameters were reconstructed using STELLOPT stellarator optimization code [3]. The reconstructions utilized flux loops, Rogowski coils, electron cyclotron emission (ECE), Thomson scattering, interferrometry, the X-Ray Imaging Crystal Spectrometer (XICS), and charge exchange recombination spectroscopy (CXRS), when available, to reconstruct fixed boundary VMEC equilibria. The reconstructed equilibria, electron density, electron temperature, and ion temperature are then used as inputs to the deposition model in BEAMS3D. Comparisons are then made against beam emission data (shine through measurements are still under analysis).

The validation of the neutral beam injection model in BEAMS3D began with a comparison of the model geometry to measured data. Figure 1 depicts simulated and measured hot spots on the neutral beam dump. Using simulated IR-camera geometry the point of maximum observable temperature rise in the beam-dump was compared to simulations of neutral beam injection with no plasma. A small toroidal displacement was found, and the NBI model shifted toroidally 0.5 degrees. This shift provides excellent correlation between the observed temperature rise on the beam dump and point of maximum heat load in the model. Similar work was performed using the ASCOT code [4].

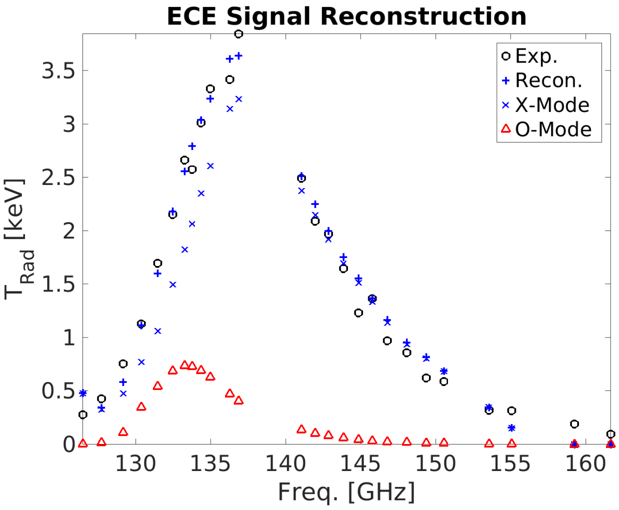

Figure 2: *Reconstructed Electron Cyclotron Emission as computed by the TRAVIS code coupled to STELLOPT.*

Five W7-X discharges were reconstructed using STELLOPT to provide equilibrium and profile information for neutral beam injection calculations. These discharges were nominally 4 MW ECRH heated discharges in which NBI was injected. Three of the discharges provided a scan of plasma density in the standard magnetic configuration (2, 5, and $8 \times 10^{19}\ m^{-3}$). The other two discharges covered the high iota and high mirror magnetic configurations (at $5 \times 10^{19}\ m^{-3}$ densities). A scan of density was chosen as sensitivity studies show this plays the largest role in the BEAMS3D NBI deposition model. Variation of current profile, electron density profile, electron temperature profile, and ion temperature profile (setting the pressure profile equal to $p(s) = k_B n_e(s)(T_e(s) + T_i(s))$) were performed comparing forward models of various diagnostic quantities to measured values. A coupling between the TRAVIS electron cyclotron emission code and STELLOPT allow direct reconstruction of the radiated power as measured by the ECE diagnostic. Additionally, the measured XICS brightness is used to reconstruct the XICS emissivity profile which is combine with the ion temperature to reconstruct the XICS integrated temperature. The XICS W3 factor measurement (related to the electron temperature) was also included in these reconstructions. The use of fixed boundary equilibria were justified by the low plasma beta and small toroidal currents in these discharges ($\beta < 0.5$ %).

Reconstructed VMEC equilibria (and their associated kinetic profiles) are used as inputs to the BEAMS3D code for beam deposition simulations. In these simulations, charge-exchange, ion impact, and electron impact are considered using coefficients as contained in the ADAS database [5]. From the simulations we find that the level of shine-through in the full energy component to be around 30% for plasma densities of 5×10^{19} m^{-3}, with the half and third energies being $\sim 20\%$, and $\sim 10\%$ respectively. At low densities (1.5×10^{19} m^{-3}) the standard configuration simulations shows up to 60% shine-through for the full energy, while at high density 7×10^{19} m^{-3}) shine-through drops to 10%. Currently, calorimetry and thermography estimates are still under assessment.

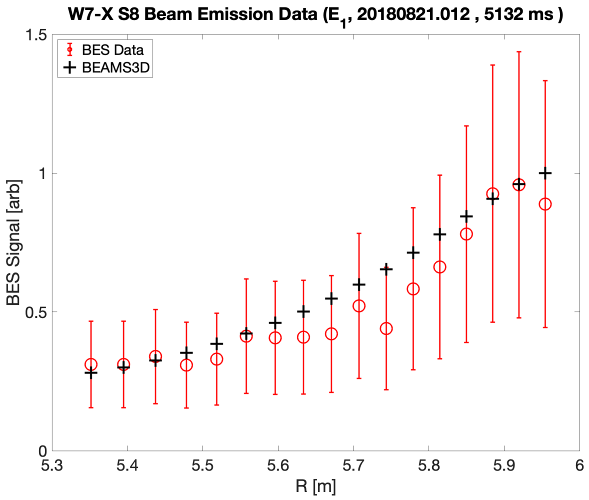

Figure 3: *Comparison between measured beam emission spectroscopy and simulations with the BEAMS3D code.*

Figure 3 depicts a comparison between the simulated and measured beam emission spectroscopy (BES) data for the full energy component of source 8. Generally good agreement between the simulations data and diagnostic measurement are seen. Here a $6cm$ diameter region is used to bin simulation particles around the BES measurement points. The reconstructed electron density and measured beam energy is then used to lookup beam emission cross sections from ADAS. As absolute numbers are not available, the measured data is scaled to the normalized simulation results. Similar agreement is found for the half energy component of the beam.

The first simulations of neutral beam deposition in W7-X using the BEAMS3D code have been conducted and compared to preliminary measurements of beam emission data. These simulations relied upon detailed equilibrium reconstructions using the STELLOPT code. These reconstructions highlighted a newly implemented ECE (TRAVIS) and XICS forward models. Comparison of simulated BES data to preliminary experimental measurements shows good agreement. Future studies will examine the role of plasma profiles on simulated BES data. It may be possible to include BES data in the equilibrium reconstructions, using BEAMS3D to provide a synthetic diagnostic. Preliminary calculations suggest a strong sensitivity to the electron density profile (as compared to ion and electron temperature variations).

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