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Experimental validation of neutral beam current drive simulations in TJ-II plasmas

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Abstract

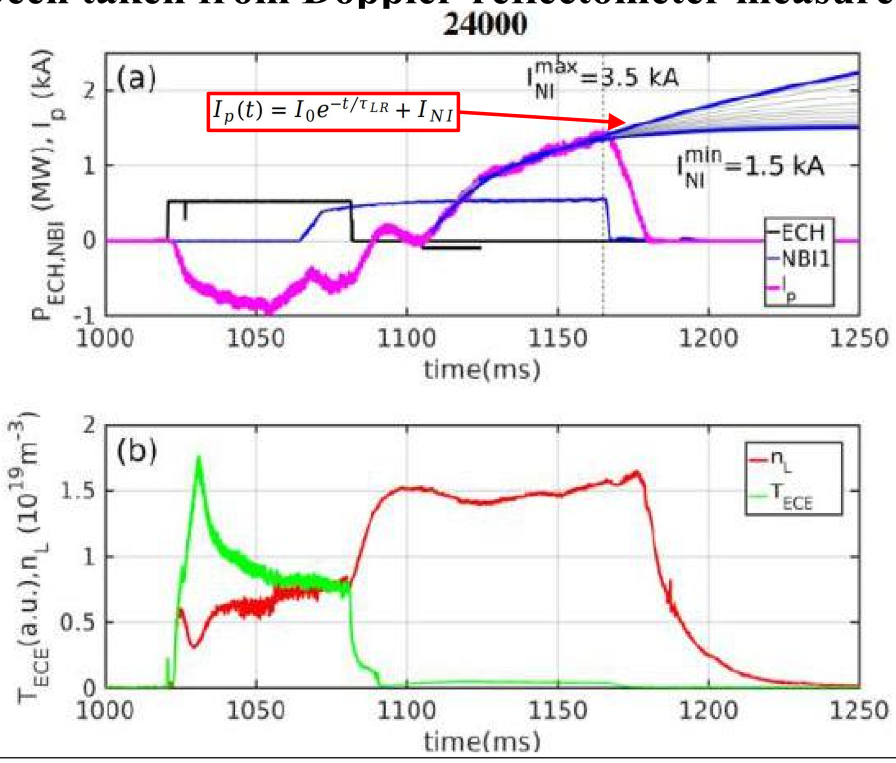
- **The goal of this work is the validation of neutral-beam current-drive (NBCD) calculations against experimental results in NBI TJ-II plasmas.**
- **The current carried by fast ions has been calculated by means of the Monte Carlo code ASCOT and the electron return current was obtained by solving the drift kinetic equation (DKE) for electrons in the low-collisionality regime and for $v_{beam}<v_{Te}$. The DKES code is used to calculate the contribution of the bootstrap current to the total measured plasma current.**
- **The computed current results are significantly higher than the measured ones.**

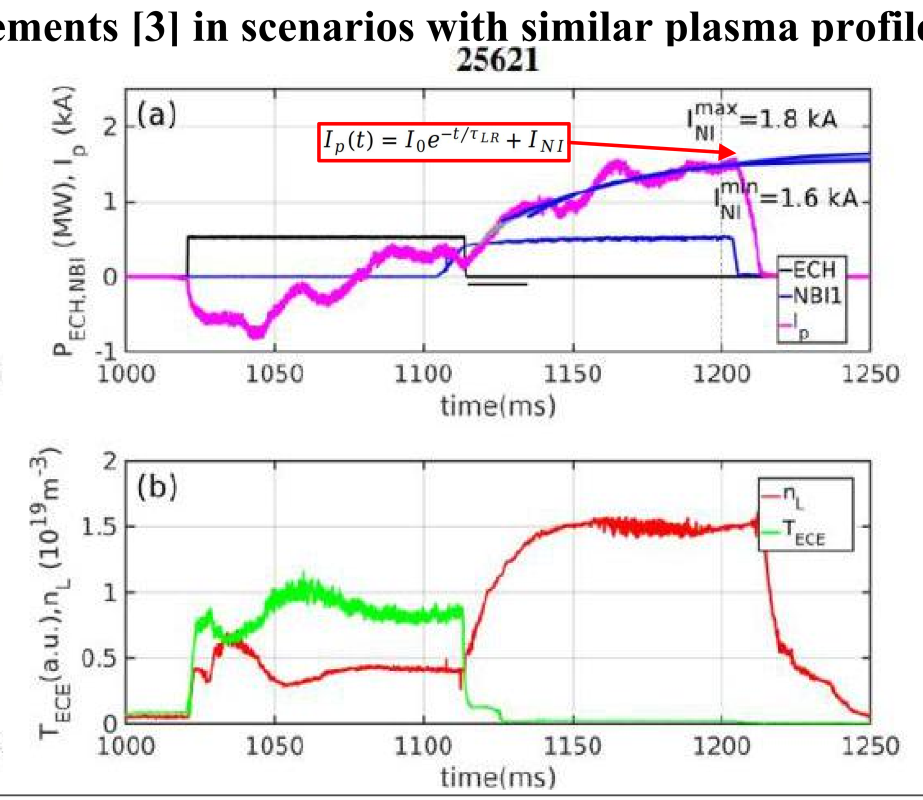
Motivation

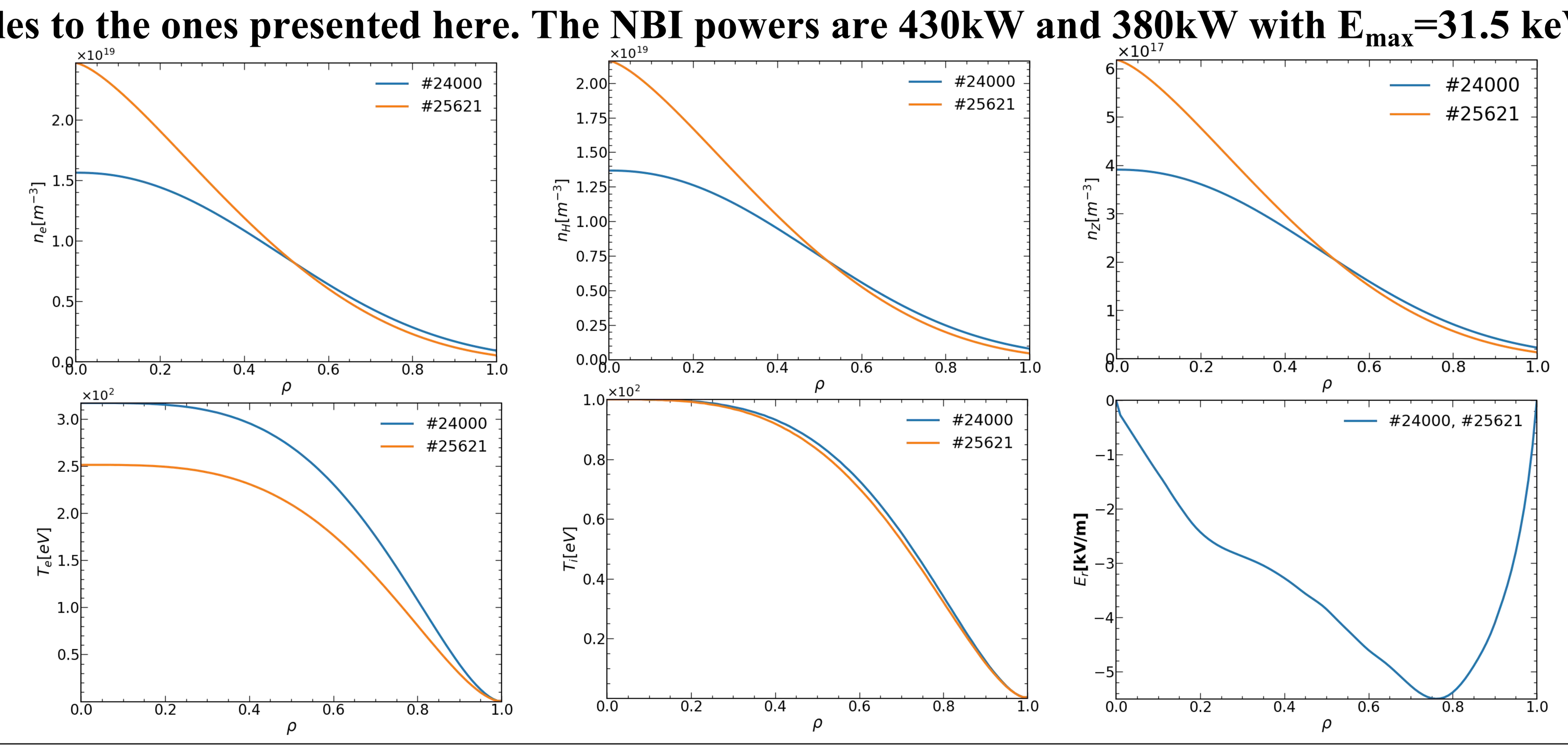
- **Precise knowledge of iota profile is needed in stellarator devices for studies such as the interaction of fast ions with Alfvén Eigenmodes (AEs) [1].**
- **Since no measurements of the iota profile are available, a detailed analysis of the plasma currents is mandatory to reconstruct the equilibrium and estimate it, especially in NBI scenarios where NBCD plays an important role.**
- **In NBI plamas, there are two sources of current: bootstrap, driven by the gradients of the kinetic profiles, and NBCD. In this work, we quantify both contributions and compare the results with the experimantal ones.**

Experimental scenarios

Two NBI shots have been chosen for their relatively stable behaviour. The electron density and temperature profiles were measured using the Thomson scattering diagnostic. Ion temperatures have been estimated as in [2] and ion densities have been calculated from the electron densities assuming a flat profile of Z_{eff}=1.5 with a Z=5 impurity. The electric field has been taken from Doppler-reflectometer measurements [3] in scenarios with similar plasma profiles to the ones presented here. The NBI powers are 430kW and 380kW with E_{max}=31.5 keV.

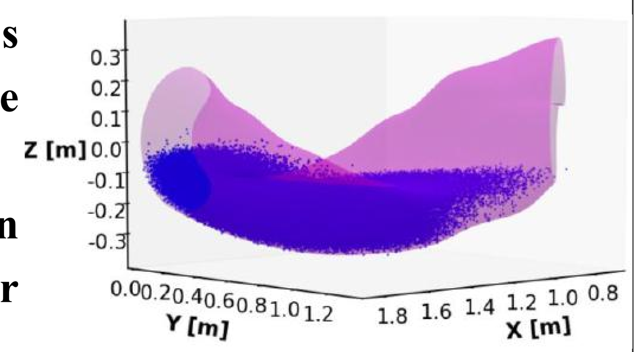


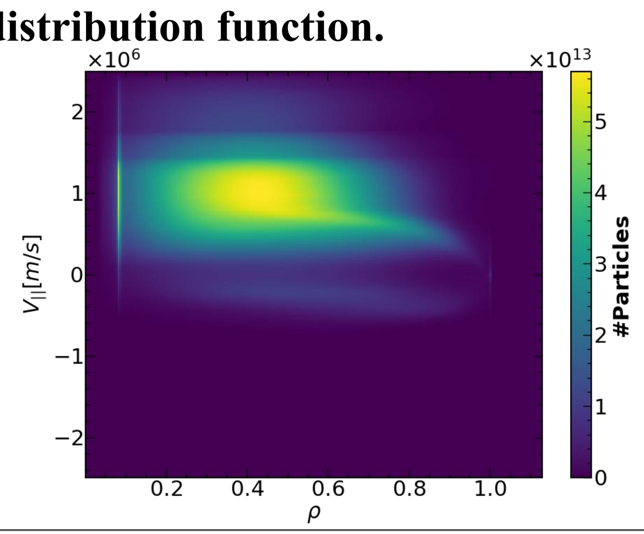


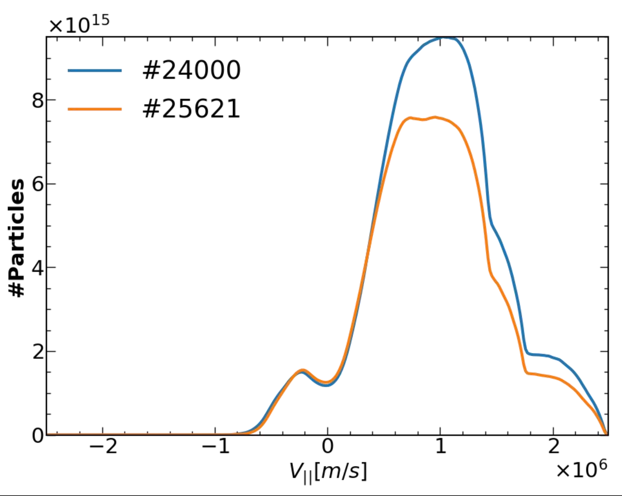


Simulations

- **The ionization of NBI fast-neutrals is simulated with BBNBI [4] to obtain the initial distribution of fast ions.**
- **ASCOT [5] simulates the slowing down process of fast ions and obtains their distribution function.**







Neutral Beam Current Drive

- **The NBCD is the result of modifying the fast-ion-beam current with the electron return current factor. This factor is calculated analytically solving the DKE in the low-collisionality limit [6]:**

$$\langle J_\parallel^{NBCD} \rangle = J_{b\parallel}(1 - \langle A_s \rangle) = e n_b Z_b V_{b\parallel}(1 - \langle A_s \rangle)$$

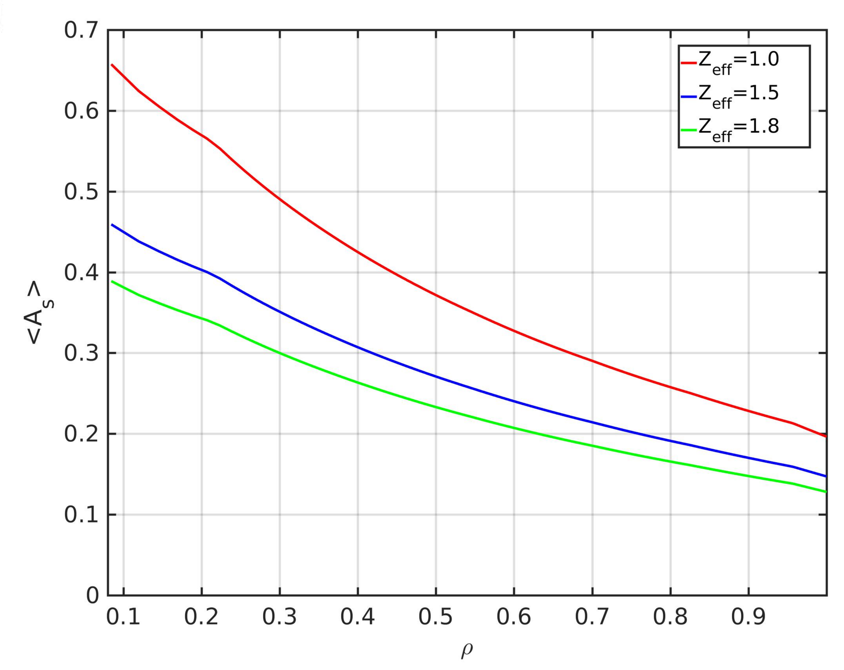
$$\langle A_s \rangle = \frac{Z_b}{Z_{eff}} \frac{\langle B \rangle^2}{\langle B^2 \rangle} f_c \left| 1 - \frac{8}{3\sqrt{\pi}} \frac{I_1}{\left(1 + Z_{eff} + \frac{I_2 f_c}{I_3 f_t}\right)} \right|$$

$$f_c = \frac{3}{4}\langle B^2 \rangle \int_0^{1/B_{MAX}} \frac{\lambda}{\langle \sqrt{1-\lambda B} \rangle} d\lambda \qquad f_t = 1 - f_c$$

$$I_1 = \int_0^\infty \frac{x^4 h(x) e^{-x^2}}{h(x) + Z_{eff}} dx\ , \qquad h(x) \equiv \Phi(x) - G(x)\ ,$$

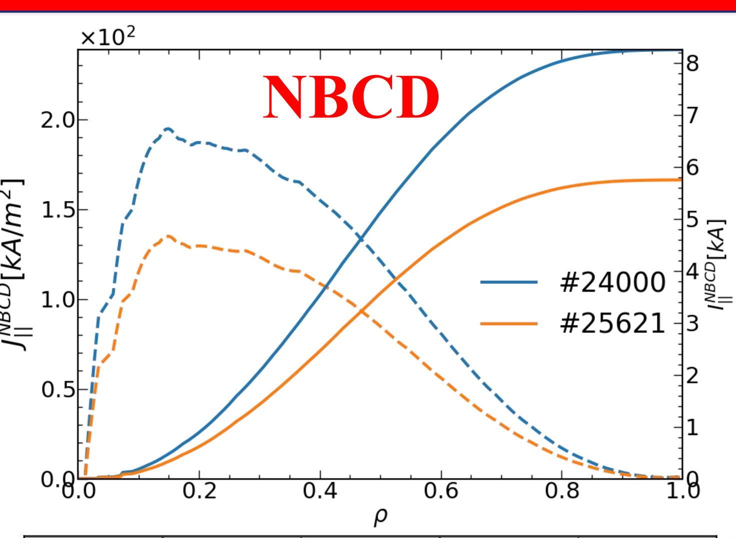
$$I_2 = \int_0^\infty \frac{x h(x) e^{-x^2}}{h(x) + Z_{eff}} dx\ , \qquad \Phi(x) = \int_0^x e^{-y^2} dy\ ,$$

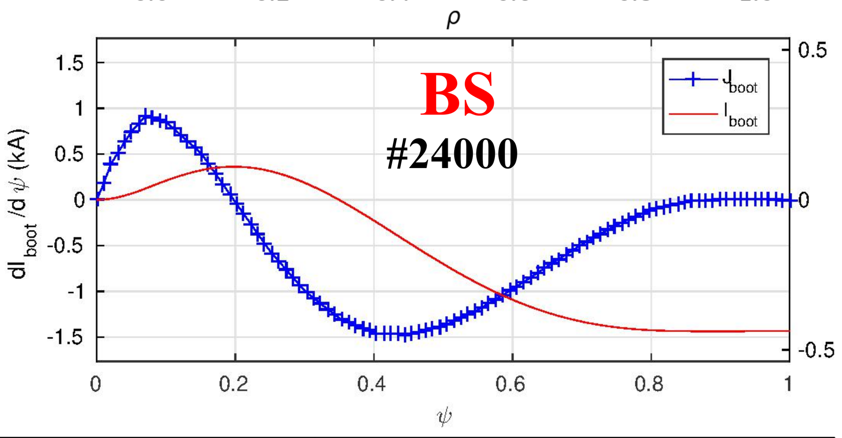
$$I_3 = \int_0^\infty x h(x) e^{-x^2} dx \approx 0.27 \qquad G(x) = \frac{\Phi(x) - x\Phi'(x)}{2x^2}\ .$$



Experimental validation of NBCD

- **The experimental values are obtained fitting the time trace of the plasma current to an exponential in several time intervals.**
- **The plasma current value is chosen as the average of the fits and their standard deviation as an error.**
- **Bootstrap current (BS) profile has been obtained with DKES [7]. The total BS at the edge is very low compared to NBCD.**
- **NBCD is roughly a half of the fast-ion-beam current.**
- **The theoretical values of the plasma current (I_{NBCD}+I_{BS}) are significantly higher than the experimental ones.**
- **No charge exchange (CX) losses have been used in the simulations, which is a large source of error due to their importance in TJ-II (~50% ionized-power loss)**





Discharge	I_{NBCD}(kA)	I_{BS}(kA)	I_{NBCD}+I_{BS}	I_{EXP}(kA)
#24000	+8,3±1,8	-0,4	+7,9±1,8	1,9±0,7
#25621	+5,9±1,3	+0,0	+5,9±1,3	1,7±0,1

Conclusions

- **The plasma current has been computed numerically for two NBI shots in TJ-II.**
- **The comparison against experimental results shows large discrepancies between theory and experiments.**
- **Main sources of error thought to be the absence of CX reactions in the simulations and uncertainties in the experimental measurement of the plasma current, due to poor stability of plasma current.**
- **Plasma impurities can be affecting the NBCD through the dependence of $\langle A_s \rangle$ on Z_{eff}.**

References

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