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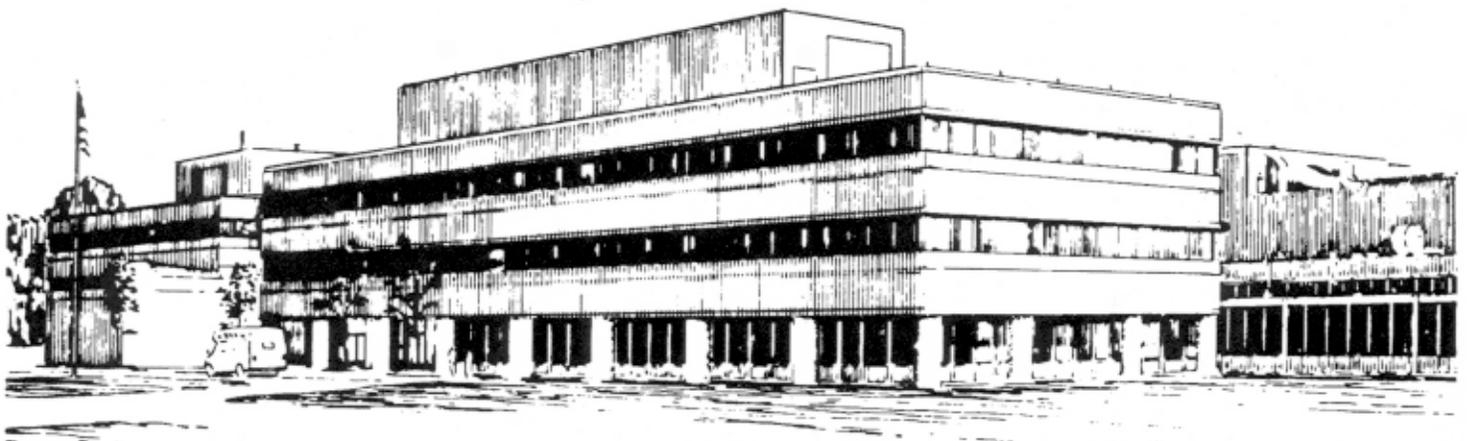
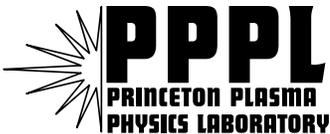
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**Investigation of Ion Absorption of the High Harmonic  
Fast Wave in NSTX using HPRT**

A. Rosenberg, J.E. Menard, and B.P. LeBlanc

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# Investigation of Ion Absorption of the High Harmonic Fast Wave in NSTX using HPRT

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**Abstract.** Understanding high harmonic fast wave (HHFW) power absorption by ions in a spherical torus (ST) is of critical importance to assessing the wave's viability as a means of heating and especially driving current. In this work, HPRT is used to calculate absorption for He and D, with and without minority H in NSTX plasmas using experimental EFIT equilibria and kinetic profiles. HPRT is a 2D ray-tracing code which uses the full hot plasma dielectric to compute the perpendicular wave number along the hot electron/cold ion plasma ray path. Ion and electron absorption dependence on antenna phasing, ion temperature,  $\beta_i$ , and minority temperature and concentration is analyzed. These results form the basis for comparisons with other codes, such as CURRAY, METS, TORIC, and AORSA.

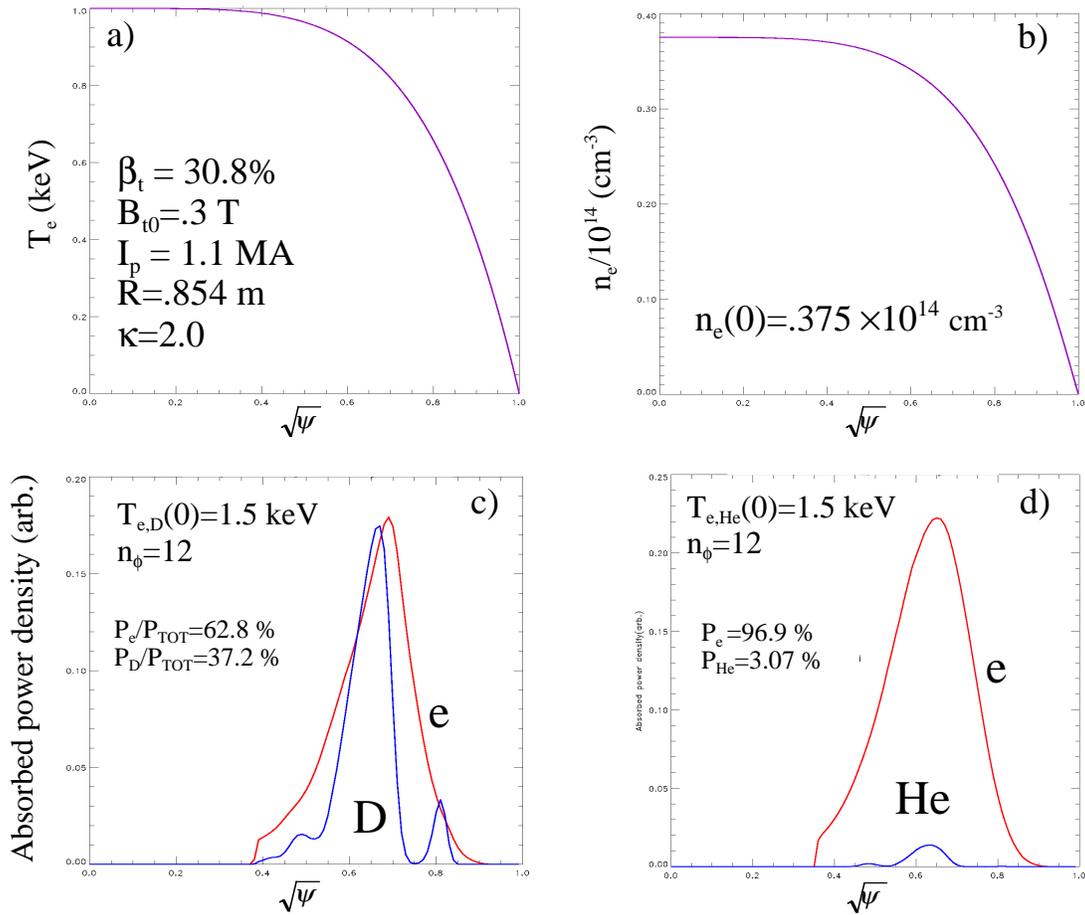
## INTRODUCTION

The National Spherical Torus Experiment (NSTX) has an extensive RF system which launches high harmonic fast waves at 30MHz into the target plasma via a twelve-strap antenna array. Understanding the species breakdown of power absorption is of critical importance to assessing the wave's viability as a means of heating and especially driving current. HPRT is a 2-D ray-tracing code which uses the full hot plasma dielectric to compute the perpendicular wave number, and with this, the power absorption by species along the hot electron/cold ion plasma ray path [1]. In this work, HPRT is used to calculate absorption for He and D plasmas, with and without minority H in a model equilibrium and in NSTX plasmas using experimental EFIT equilibria and kinetic profiles. Ion and electron absorption dependence on antenna phasing, ion temperature,  $\beta_i$ , and minority temperature and concentration is examined.

## MODELLING RESULTS

### A. Model High- $\beta$ Equilibria

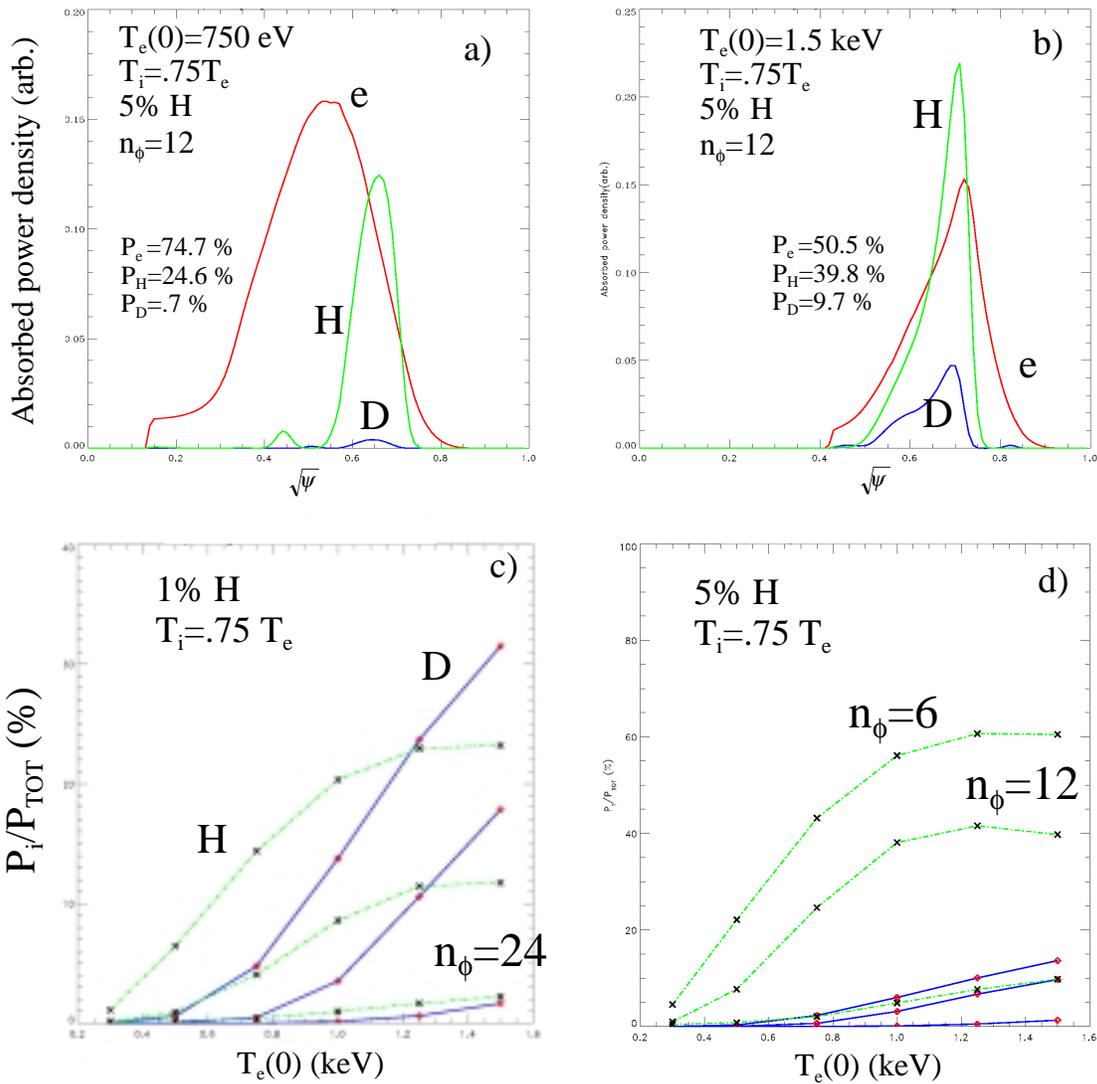
The model equilibrium electron temperature and density profiles are shown in Figures 1a & b. They are quite broad and optimized for MHD stability. Ion and electron profiles in the following studies were made by scaling these profiles while keeping the magnetic field strength fixed.  $n_\phi$  of 12 was often chosen because this is the nominal current drive phasing for NSTX, where  $n_\phi$  is the number of wavelengths that fit toroidally around the plasma, set by the antenna array. In a deuterium plasma, deuterium power absorption can compete with electron absorption, as demonstrated in



**Figure 1:** a) model equilibrium electron temperature profile, b) model density profile, c) power absorption in deuterium plasma, d) in helium plasma

Figure 1c. On the other hand, in a helium plasma, helium absorption is fairly insignificant. (See Fig. 1d) This is due to helium having a lower  $k_i \rho_i$  and  $\beta_i$  for fixed ion temperature and electron density. In either case, ion absorption increases with ion temperature and decreases with  $n_\phi$  [1]. (See Figs. 2c,d).

Minority hydrogen absorption was also analyzed using these profiles. Even at moderate plasma temperatures (setting  $T_i = .75 T_e$ ) and concentration of hydrogen, hydrogen power absorption can clearly dominate the ion absorption (Fig. 2a), and at higher temperatures, compete with electron absorption (Fig. 2b). Comparing Figs. 2a and 2b, it is also evident that electron absorption profiles move outward and become narrower with higher plasma temperatures. Figs. 2c and 2d show the relative ion absorption vs. plasma temperature,  $n_\phi$ , and %H. Hydrogen and deuterium both follow trends of increased absorption with increased plasma temperatures and decreased  $n_\phi$ . The relative hydrogen absorption vs. deuterium appears to increase dramatically with %H, and fractional power absorbed for H saturates at lower temperatures than D.

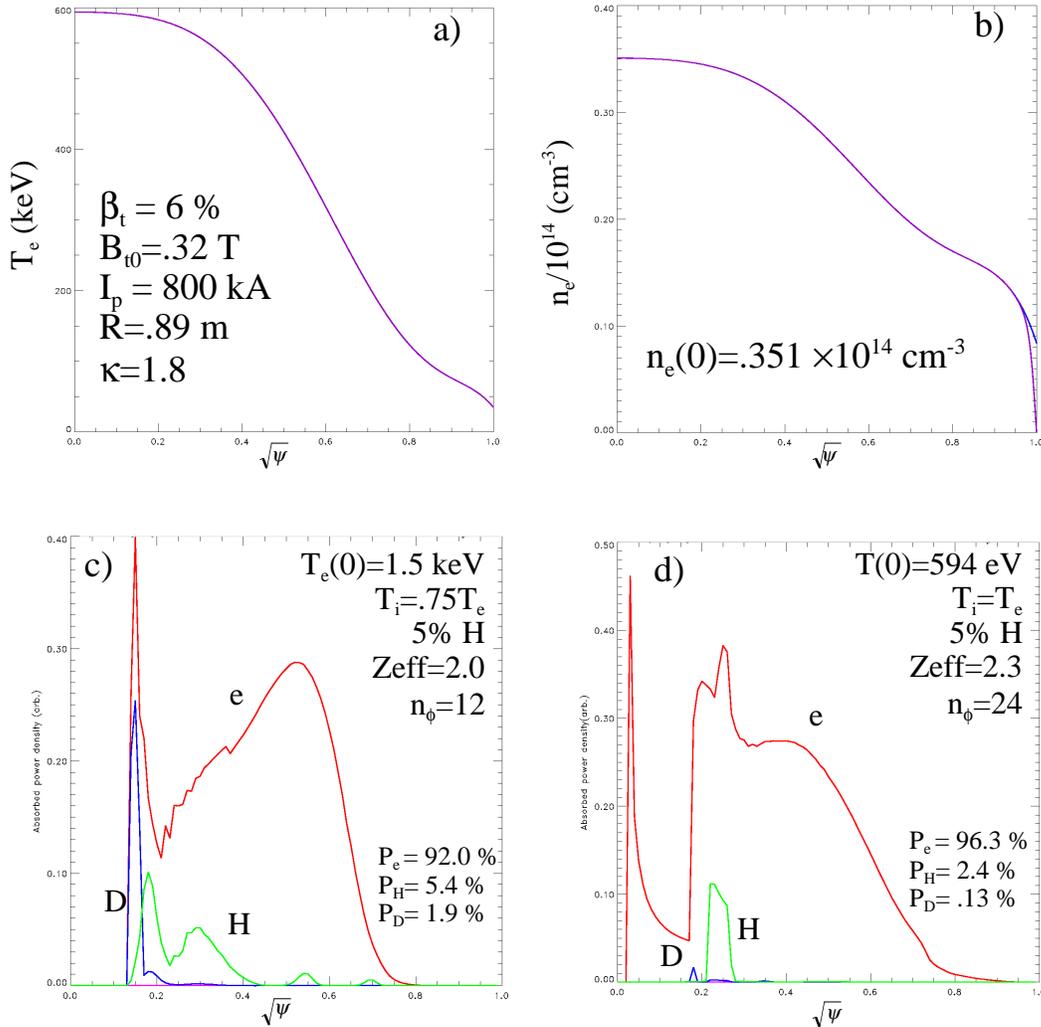


**Figure 2:**  $T_i=.75 T_e$ , a) lower temperature ion absorption with 5% H, b) higher temperature absorption, c) absorption vs.  $T_e(0)$ ,  $n_\phi$  with 1% H d) 5% H

## B. Experimental NSTX Equilibria

Measured NSTX equilibria have also been examined, particularly shot 104476. Electron temperature and density profiles for this shot are shown in Figures 3a & 3b. Notable differences between this and the model equilibrium include a much lower  $\beta_i$  of 6% and more peaked profiles than the model. It should also be noted that in order to prevent the wave from leaving the plasma, the density profile was multiplied by a tanh function, bringing the edge density to zero. Comparing Fig. 3c to 2b, it is clear that even with temperature and %H scaled similarly, the measured data has far less hydrogenic absorption than the model. The sharp peaks are a 2-D effect resulting from the ray path being temporarily tangent to a flux surface. Fig. 3d shows absorption with actual, unscaled data in order to simulate as accurately as possible what happened

during this RF shot. From this, it is evident that ion absorption cannot account for the significantly lower electron temperatures in deuterium vs. helium plasmas observed thus far [2]. Future work will incorporate a distribution of initial antenna phasings into HPRT, analyze more shots, and study the effects of beam-heated ions, all of which will be a part of the first author's thesis.



**Figure 3:** a) NSTX shot 104476 temperature profile b) 104476 density profile, with edge modification c) absorption in measured profile,  $T_e(0)$  set to 1.5keV d) absorption with measured parameters and experimental  $n_\phi=24$

## ACKNOWLEDGMENTS

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2. B.P. LeBlanc et al., this conference.

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