Analysis of Initial High Harmonic Fast Wave Heating Experiments on NSTX

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OVERVIEW: *Strong Electron Damping of HHFW Observed in Experiments, as Predicted by Theory*

- **Broad, off-axis electron heating observed in experiments**

- **1D kinetic integral waves code, METS, used to estimate absorption strength and deposition profiles**

- **METS code indicates:**
  - **100% single pass absorption on electrons in initial HHFW experiments on NSTX**
    - **$n_{e0} < 6 \times 10^{13}$ cm^{-3}, $T_{e0} \sim T_{i0} \leq 1$ keV**
  - **low, but adequate per-pass electron absorption predicted even for very low target densities**
    - **~ 10% per pass with $n_{e0} \sim 5 \times 10^{12}$ cm^{-3} and $T_0 \sim 300$ eV**
  - **ion damping can be significant for lower $k_{//} \sim 7$ m^{-1} and higher ion temperatures**

- **Results consistent with theory by M. Ono [Phys. Plasmas *2* (1995) 4075] and other modeling studies by P.T. Bonoli, T.K. Mau, J. Menard, and Y. Takase.**

WAVE ABSORPTION MODELED IN 1D WITH METS

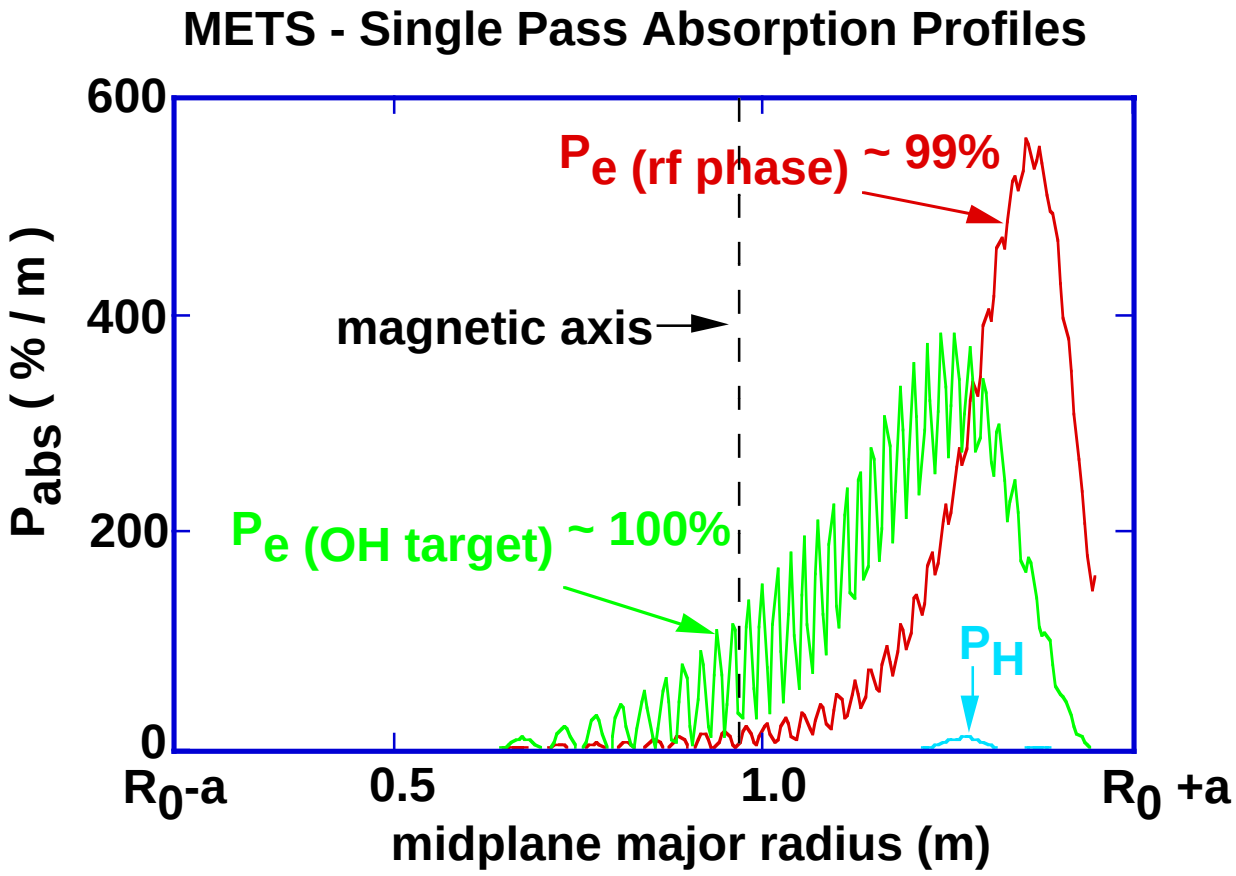
METS code **solves for wave fields and absorption assuming:**

- **1D single-pass absorption formulation >>** ***estimates absolute absorption strength*****;**
- **all orders of $k_\perp \rho_i$ and of Bessel functions retained;**
- **all three components of E field retained;**
- **finite $k_{//}$ and k_y retained;**
- **toroidal upshift of $k_{//}$ retained**

METS code **ignores details of 2D wave propagation and damping such as:**

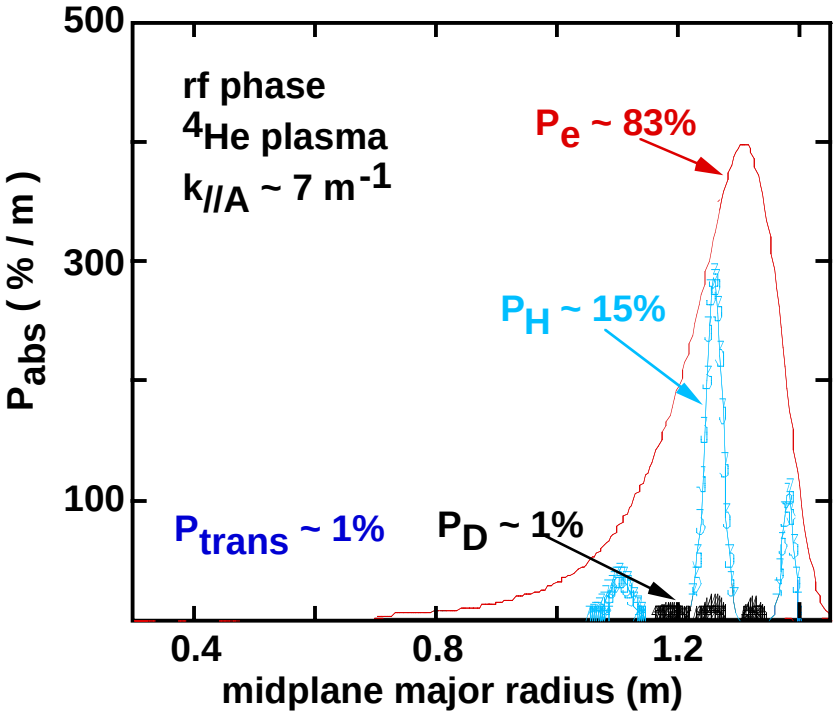
- **2D focusing effects**
- **2D B field gradient effects**
- **B_{pol} (in simulations shown here)**

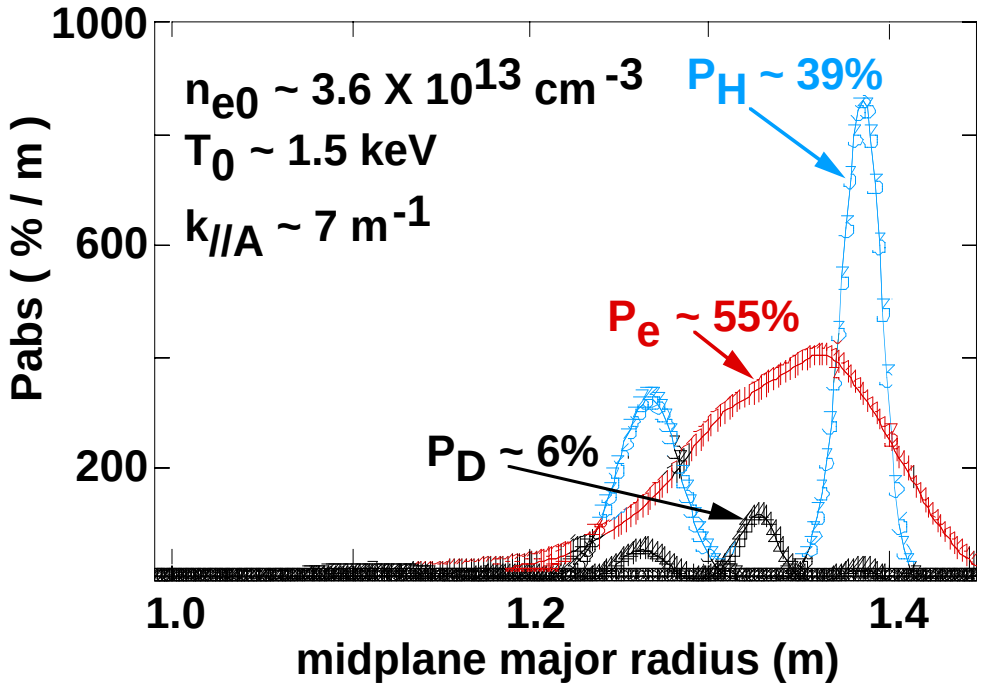
POWER DEPOSITION SHIFTS FURTHER OFF-AXIS WITH TEMPERATURE INCREASE



Helium plasma composition: η_{4He} ~ 39% η_H ~ 2% η_D ~ 8% η_C ~ 2%

ION ABSORPTION INCREASES WITH LOWER $k_{//A}$ AND/OR DEUTERIUM / HYDROGEN CONTENT





helium-4 plasma :

η_{4He} ~ 39% η_H ~ 2%

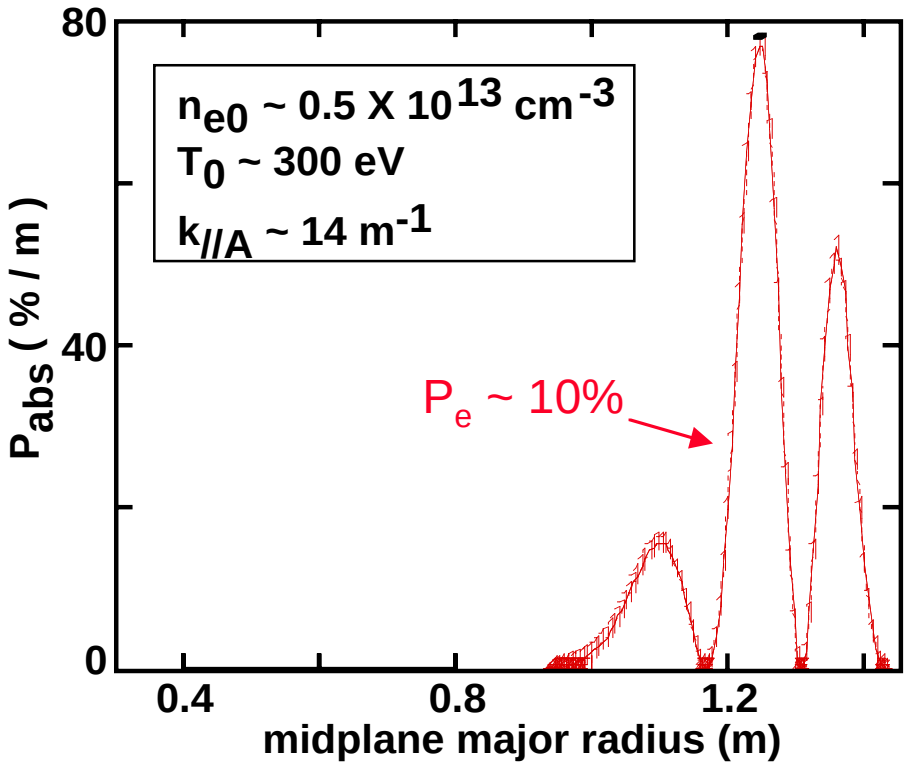
η_D ~ 8% η_C ~ 2%

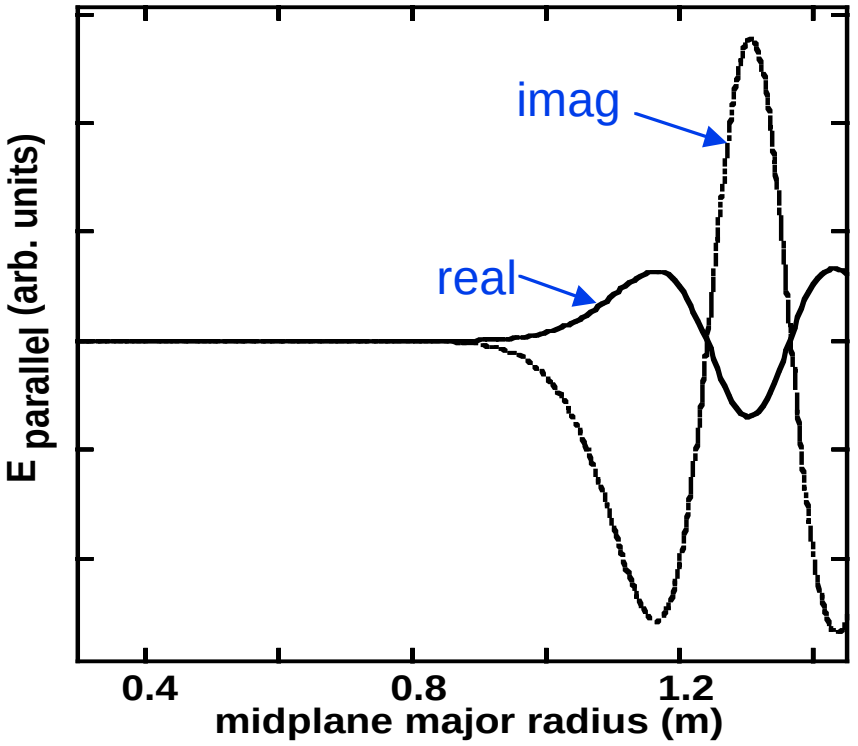
deuterium plasma :

η_D ~ 76% η_H ~ 10%

η_C ~ 2% η_{4He} ~ 2%

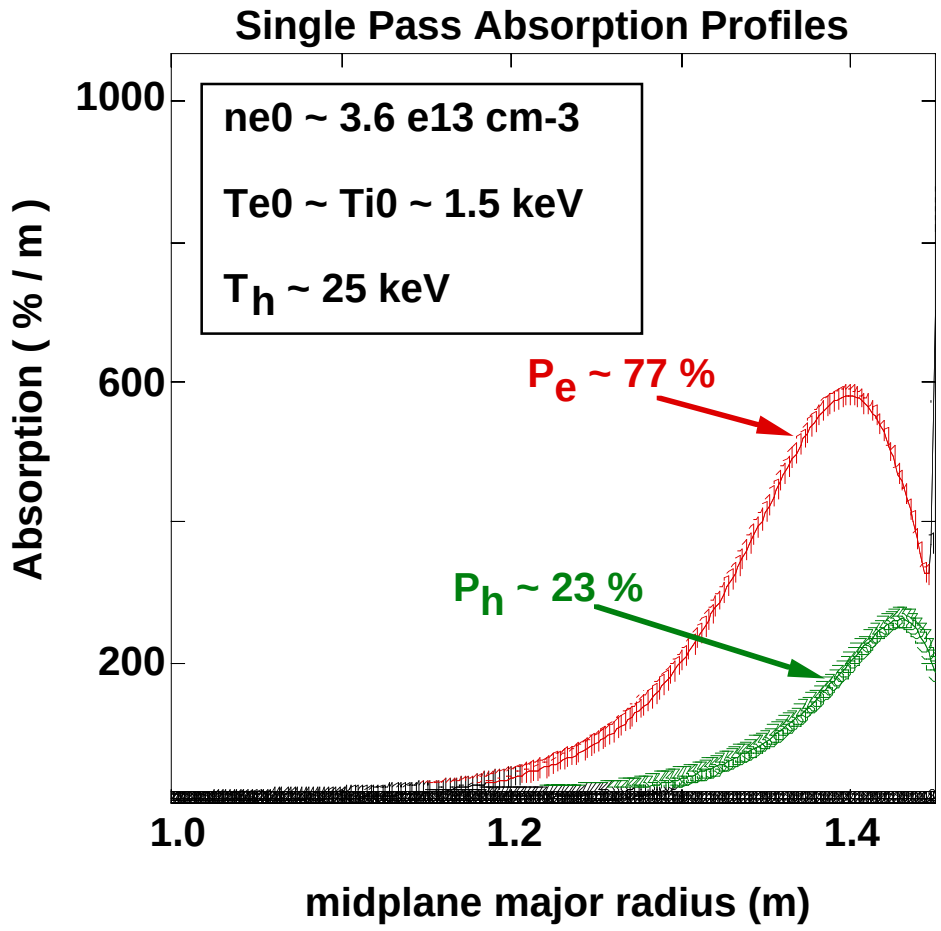
WEAK, BUT ADEQUATE DAMPING PREDICTED FOR LOW TARGET DENSITY AND TEMPERATURE





- electron heating observed on NSTX in these conditions
- absorption rate comparable to direct electron Landau damping in tokamaks

HYDROGEN MINORITY DAMPING INCREASES IF TAIL FORMS



STRONG ELECTRON DAMPING OF HHFW OBSERVED IN EXPERIMENTS ON NSTX, AS PREDICTED BY THEORY

- **strong single-pass off-axis deposition predictions supported by broadening of the electron temperature profile and increase in the central electron temperature**
  - **100% single pass absorption on electrons in initial HHFW experiments on NSTX**
    - **$n_{e0} < 6 \times 10^{13}$ cm^{-3}, $T_{e0} \sim T_{i0} \leq 1$ keV**
- **low but adequate per-pass electron heating predicted even for very low target densities**
  - **~ 10% per pass with $n_{e0} \sim 5 \times 10^{12}$ cm^{-3} and $T_0 \sim 300$ eV**
  - **electron heating observed uner these conditions**
- **weak ion damping predicted in ^{4}He plasmas for $T_i \leq 2$ keV**
  - **will confirm with ion temperature profile measurements with CHERS in future experiments**
- **substantial hydrogen minority damping predicted if H tail forms**
- **ion damping can be significant for lower $k_{//} \sim 7$ m^{-1} and higher ion temperatures**