Wave - plasma interactions in the ion cyclotron range of frequencies: theory and experiment in NSTX

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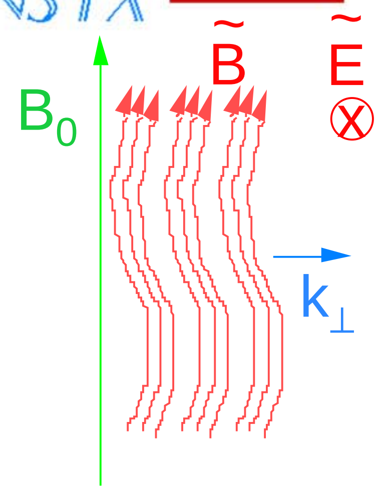
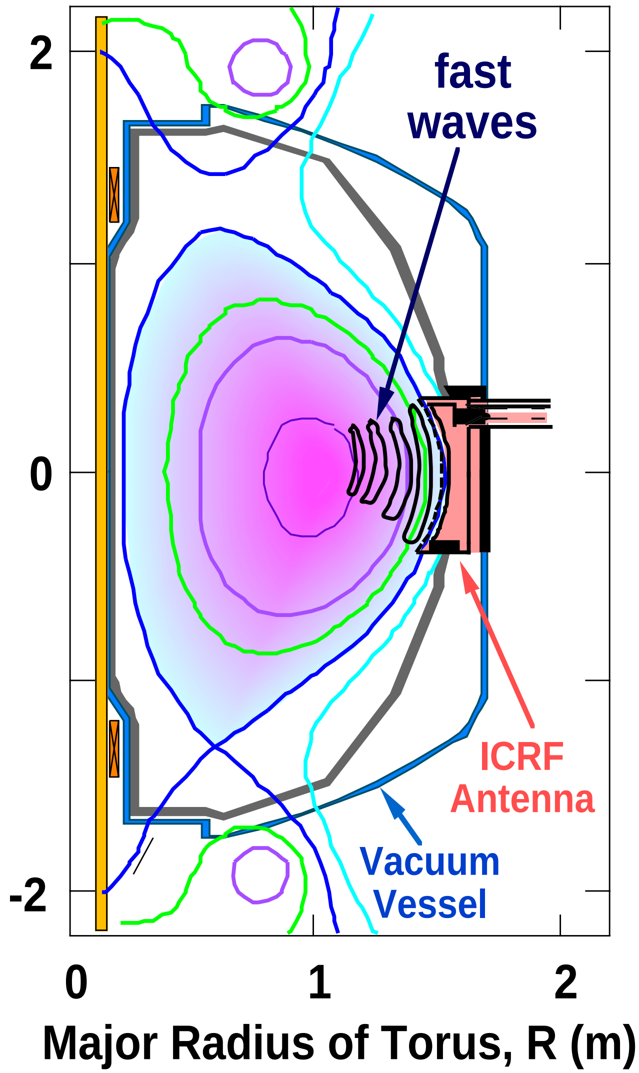
NSTX IS STUDYING HIGH HARMONIC FAST WAVES IN HIGH BETA PLASMAS



- **HHFW are compressional fast Alfvén waves**
  - $\omega \sim k_\perp V_A \sim N\,\Omega_D \sim (6 - 12)\,\Omega_D$
- **plasma beta ~ 4% - 38%**
  - **choose $\omega / k_{//}$ ~ electron thermal speed**
  - **strong electron absorption via transit time magnetic pumping and Landau damping :**
  - **ion cyclotron damping generally weak, except for energetic ions and low $k_{//}$**
- **For NSTX, find $k_\perp \rho_i \geq 1$ and $\lambda_\perp / a << 1$**
- **Since $B_P \sim B_T$, 2D magnetic equilibrium effects important**

RADIO FREQUENCY (RF) WAVES USED FOR HEATING AND CURRENT DRIVE

NSTX

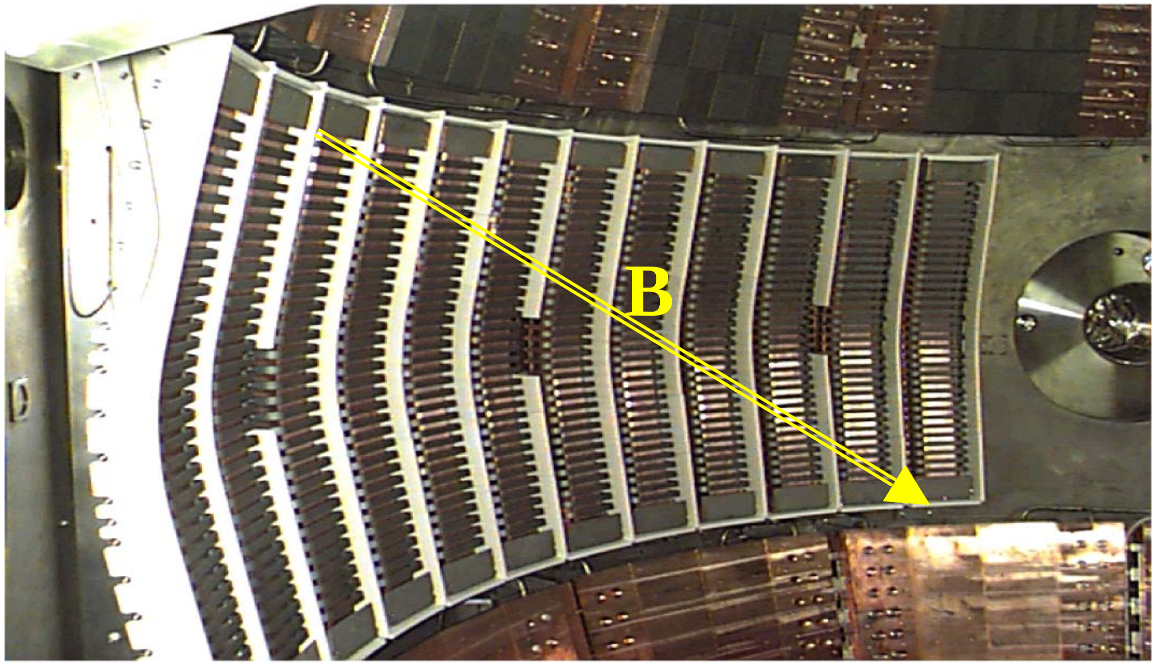


- **ST's need auxiliary heating (H) and current drive (CD)**
  - **choose wave spectra for H or CD**
  - **absorption profile depends on plasma parameters**
- **HHFW are absorbed by electrons in high beta plasmas**
  - **competitive absorption by ions degrades CD efficiency**

POWER SPECTRUM OF ANTENNA IS PROGRAMMABLE OVER A WIDE RANGE OF $k_{\parallel}$ (~ 2 to ~ 14 m^{-1})

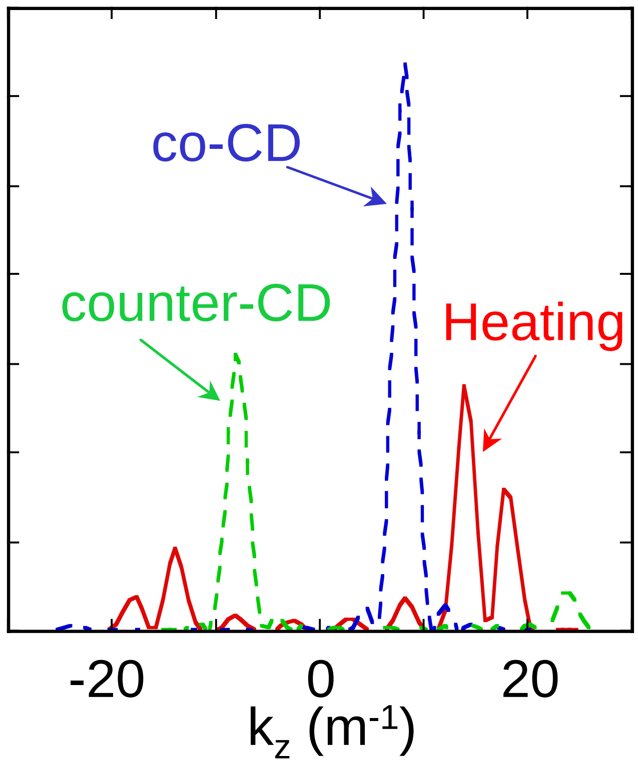
NSTX

12 element antenna for 6 MW @ 30 MHz



antenna extends almost 90° toroidally

Antenna phasing controls heating or current drive



HHFW STRONGLY HEATS ELECTRONS

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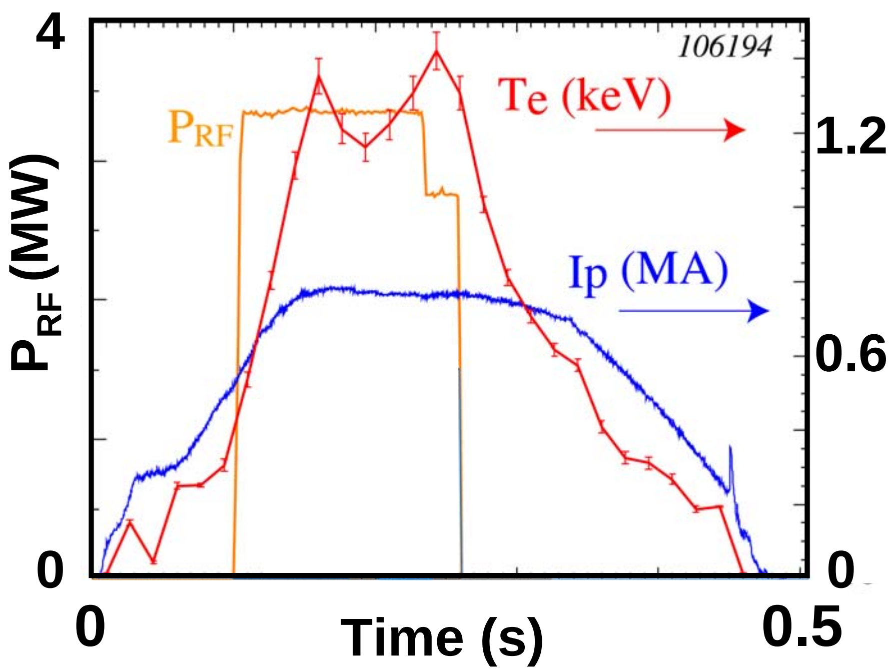
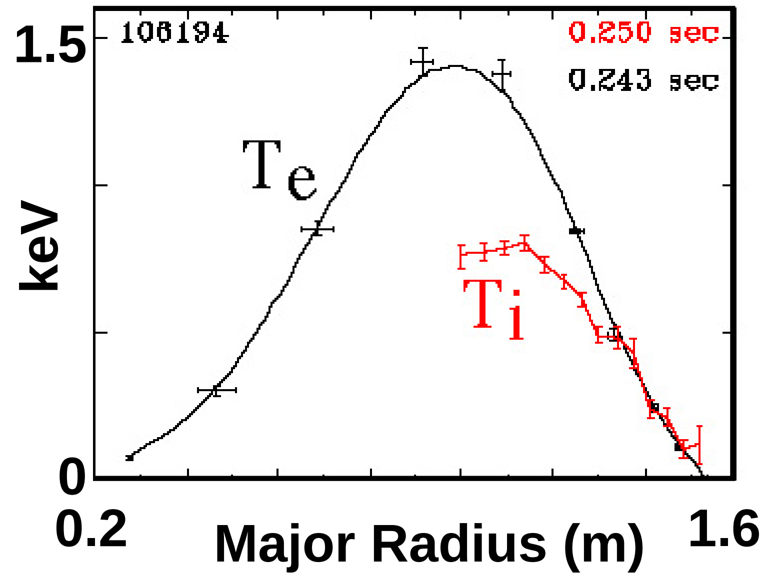
^{4}He Discharge



Note decay of T_e after RF turn-off

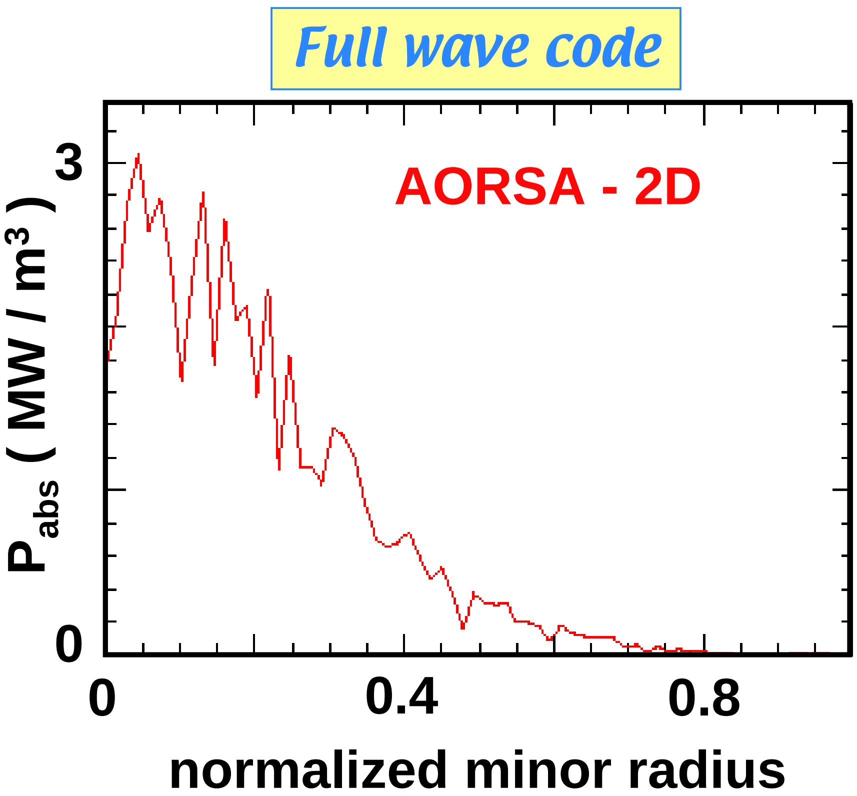
$T_e > T_i$

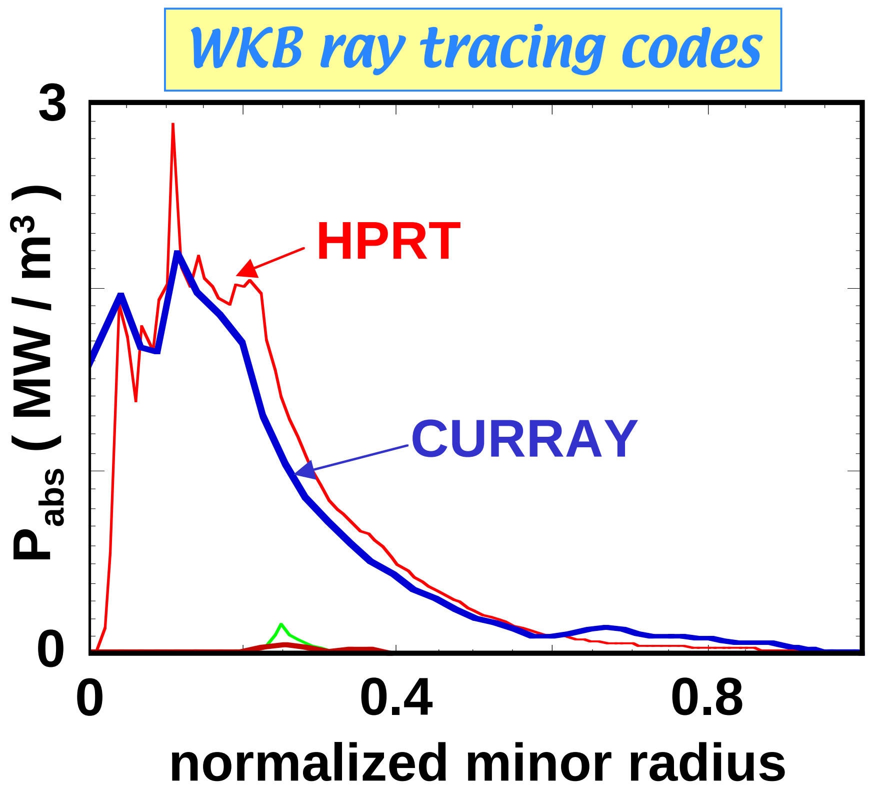


- **B = 0.44 T**
- **k_T = 14 m^{-1}**
- **n_{e0} = 4.0 x 10^{19} m^{-3}**

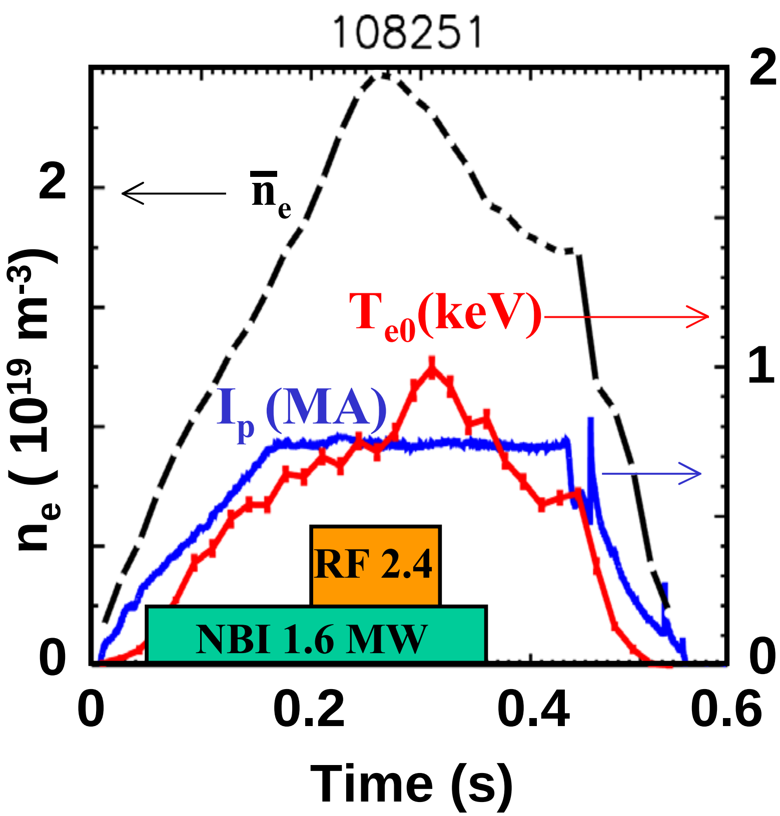
CENTRAL ELECTRON HEATING PREDICTED BY THEORETICAL MODELS

NSTX

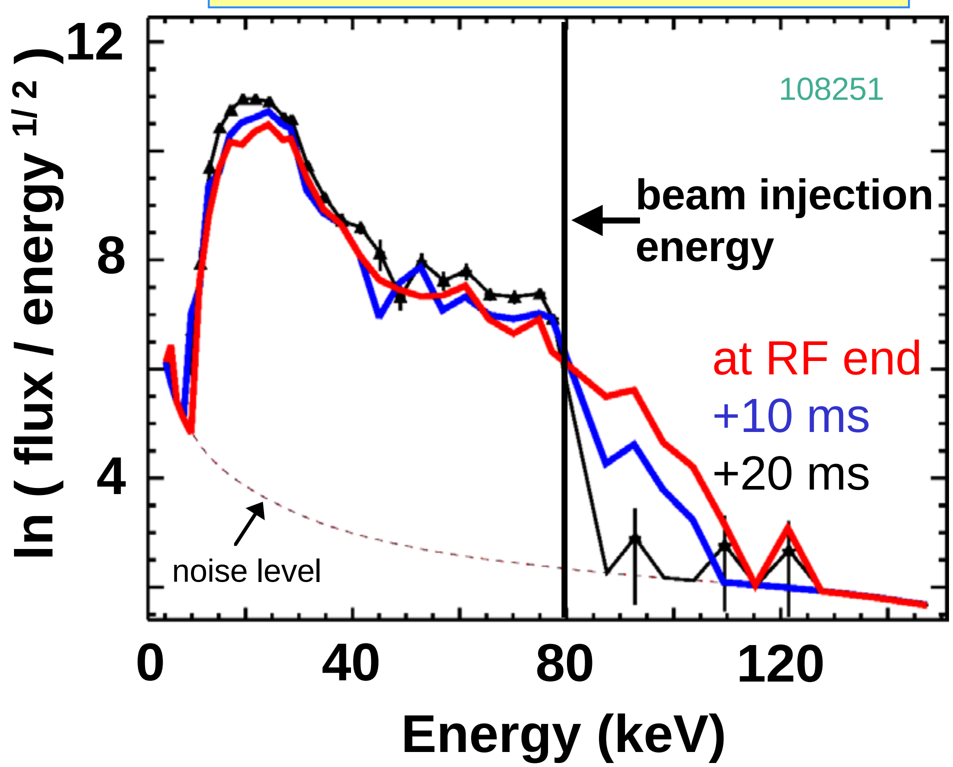




HHFW HEATS FAST DEUTERIUM IONS INJECTED WITH NEUTRAL BEAMS

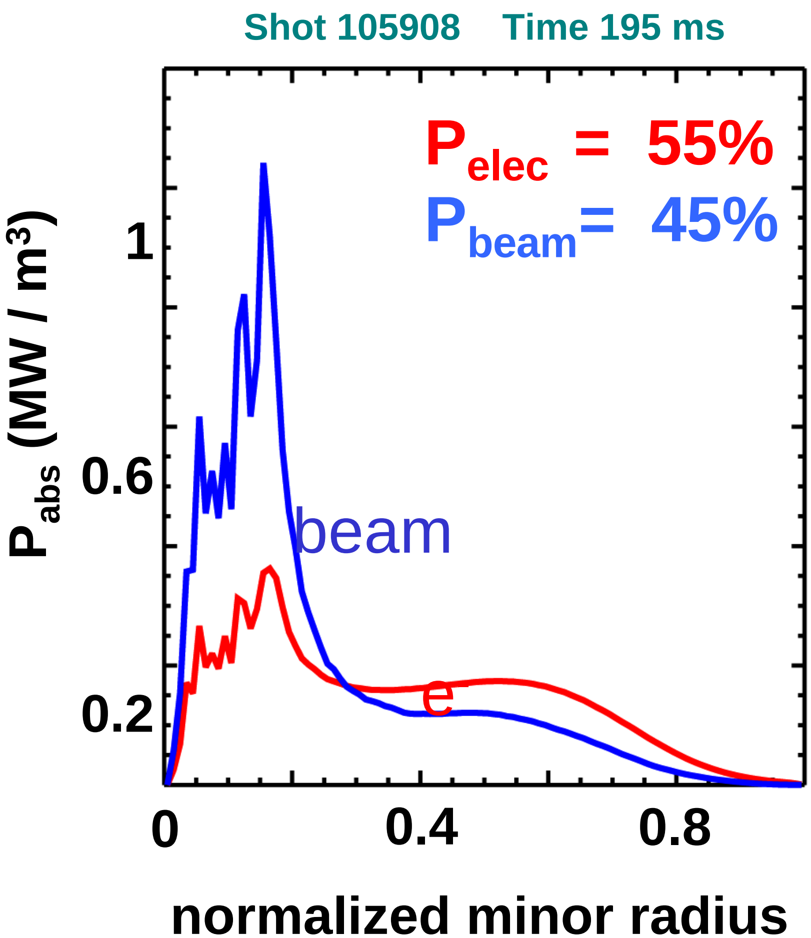


Neutral particle analyzer



- fast D^+ tail builds up during and decays after HHFW

THEORY PREDICTS SIGNIFICANT ABSORPTION BY FAST IONS

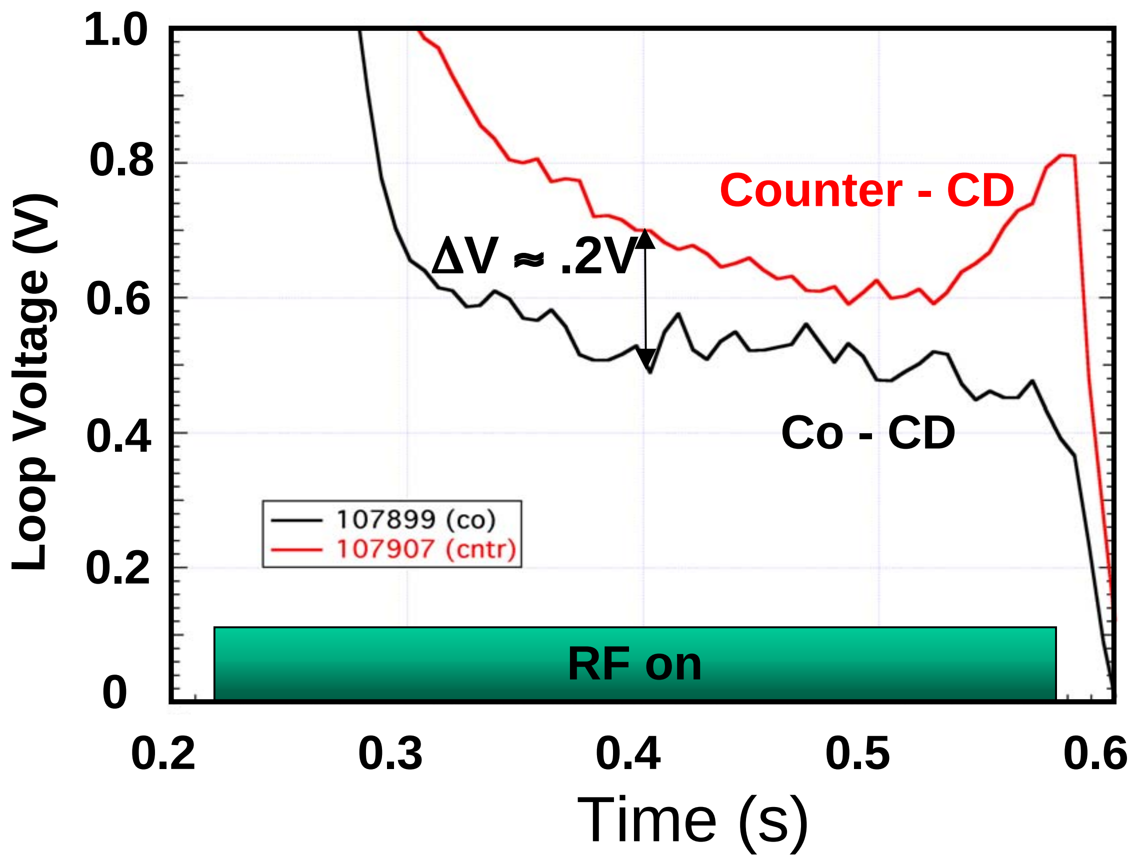


- **fast ion and electron absorption comparable**
- **no thermal ion absorption for this $k_{//}$ range**
- **fast ion absorption degrades CD efficiency**

BUT

- ***fast ion absorption decreases at lower B_T, higher β***
  - ***observed and predicted***

CURRENT DRIVE INFERRED FROM DIFFERENCES IN LOOP VOLTAGE WITH PHASED WAVES



- 2 discharges with similar $n_e(r)$,$T_e(r)$
- inductance similar
- ΔV not caused by dl_i/dt
- less loop voltage required for constant I_P with co-CD phasing

- circuit analysis (0D): $I_P = (V - 0.5 * I_P * dL_i/dt)/R_P + I_{BS} + I_{CD}$

  ➪ I_{CD} ~ 110 kA *inferred* vs 96 – 160 kA *predicted* by codes

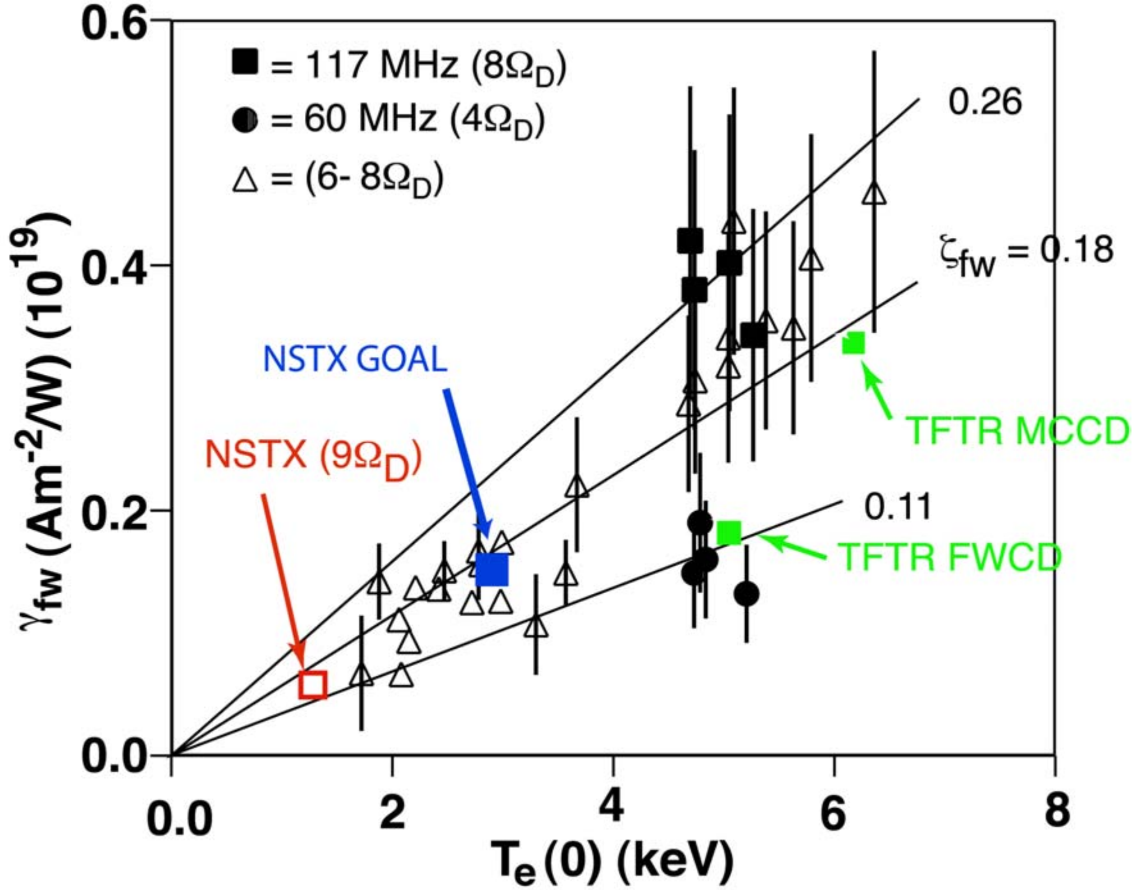
- driven current consistent with previous tokamak experience

WAVE-PLASMA INTERACTIONS PLAY A CRITICAL ROLE IN NSTX RESEARCH

NSTX

- **HHFW provides means of electron heating**
- **Interaction between HHFW and fast ions observed**
  - **ion interaction decreases with increasing electron beta**
- **Initial evidence found for HHFW current drive**
  - **driven current consistent with modeling and previous FWCD experiments**
  - **higher T_e needed to achieve NSTX research goals**

HHFW CURRENT DRIVE CONSISTENT WITH D-IIID AND TFTR CD EXPERIMENTS



C. Petty et al., Plasma Physics and Controlled Fusion **43** (2001) 1747

- Operation at higher Te required to meet NSTX goals
- Increased power and improved confinement should allow this