XP-920: HHFW Heating of Low $T_e(0)$, I_p Plasmas

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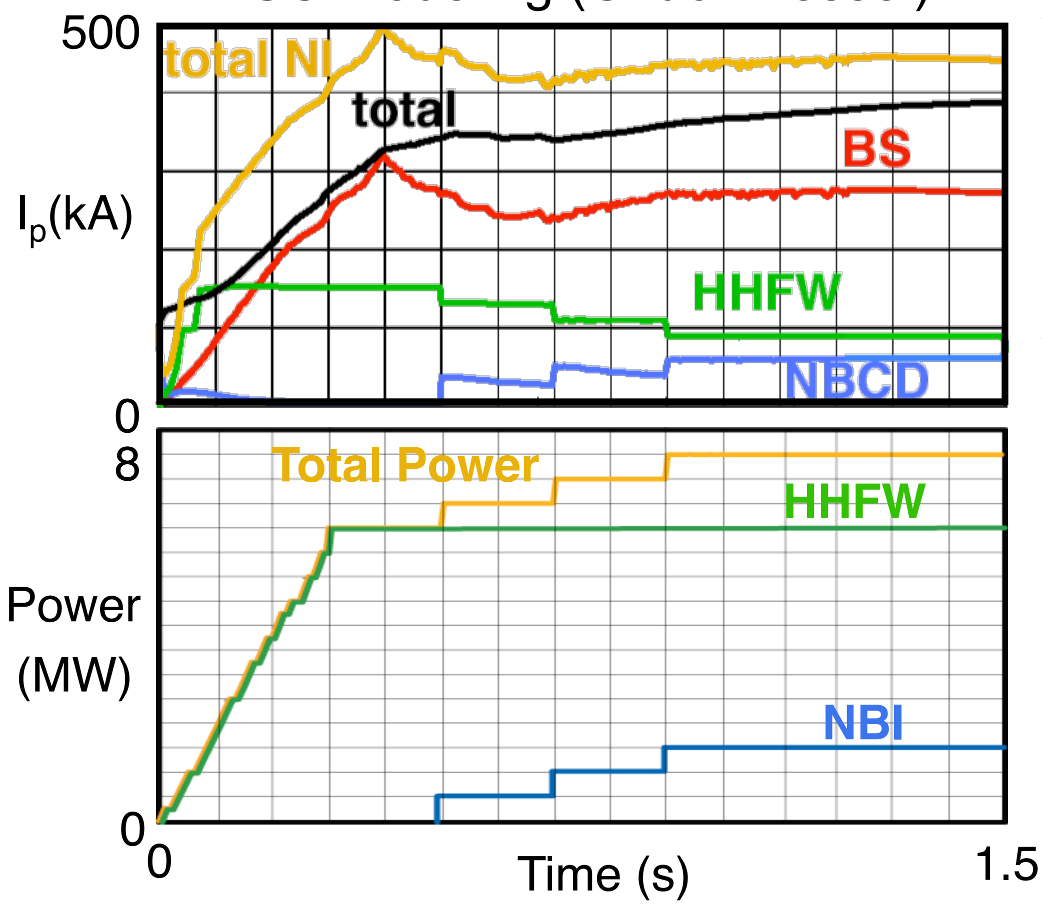
Modeling Predicts 5-6 MW of HHFW Power Can Achieve Fully Non-Inductive I_p Ramp-up in NSTX

TSC Modeling (Chuck Kessel)

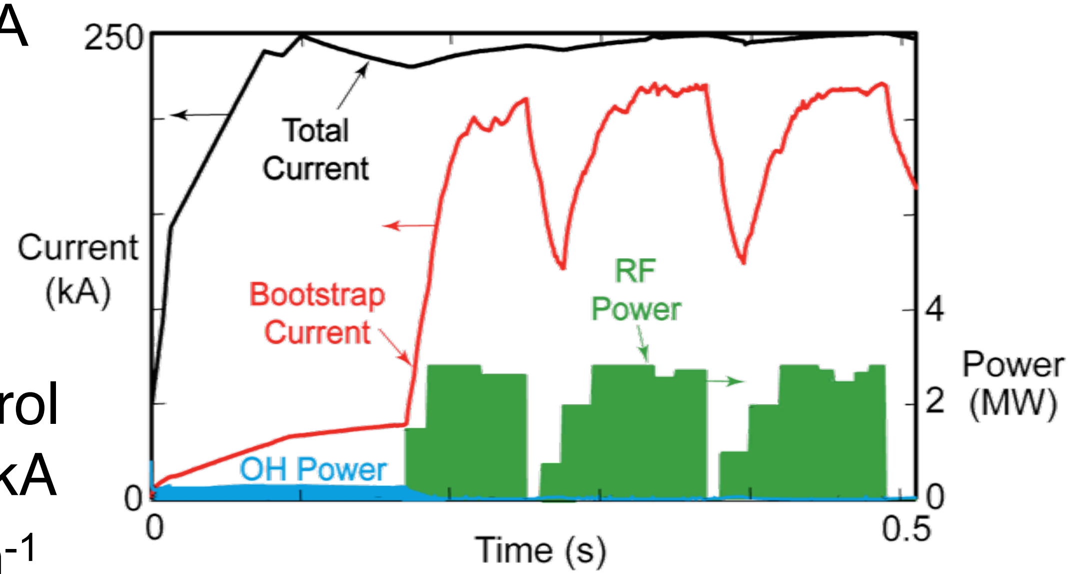


- Simulation of I_p ramp-up at $B_T(0)$ = 0.45 T
  - HHFW provides heating & CD at low I_p and T_e
- HHFW-assisted I_p ramp-up started at 100 kA
  - 6 MW HHFW ($k_{||}$ = 8 m^{-1}) Co-CD phasing
  - 6 MW NBI added when $I_p \geq$ 400 kA (only 2-3 MW absorbed due to slow I_p ramp rate in 1.8 s plasmas)

HHFW Heating of Low I_p Plasmas Since 2005 Show Promise, But Also Problems with Plasma Control

2005: (XP-521)

- 85% bootstrap current in HHFW heated (k_ϕ = -14 m^{-1}) H-mode D_2 plasmas at I_p = 250 kA
- Transiently produced $V_{loop} \leq 0$ and $dI_{OH}/dt \approx 0$



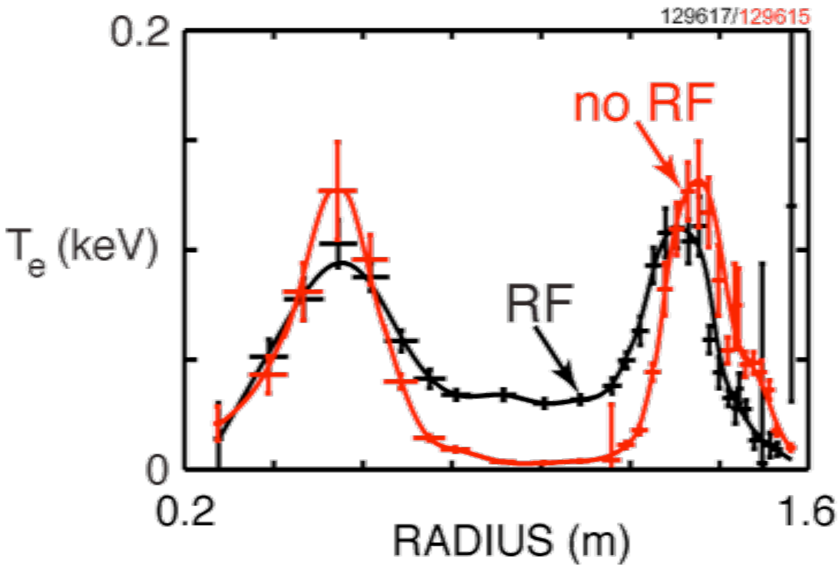
2007: (XP-731)

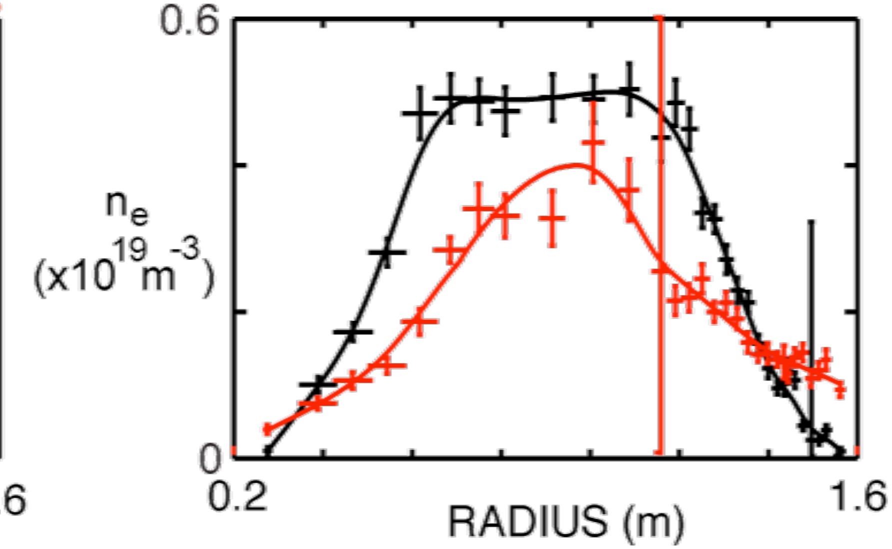
- Problem with rtEFIT control at I_p = 250 kA, used 300 kA
- Many trips with k_ϕ = 14 m^{-1}
- Up to 2.7 MW of k_ϕ = -8 m^{-1} heating, produced transient H-mode

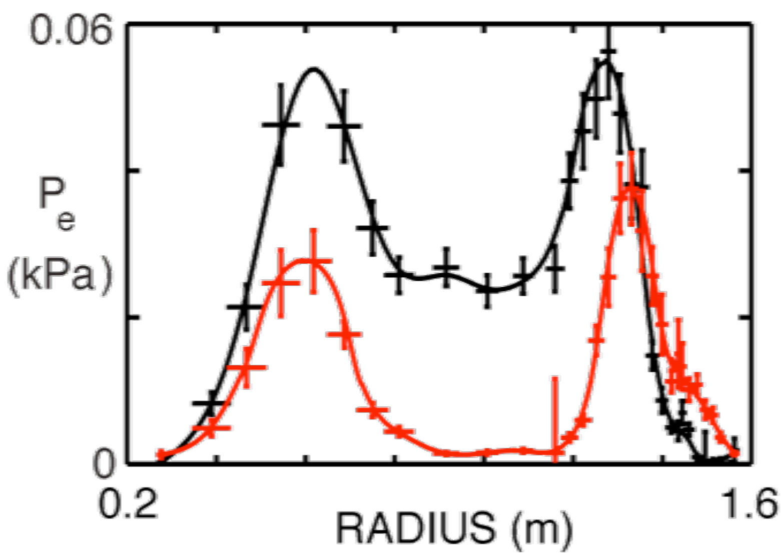
2008: (XP-817)

- Li conditioning reduced edge density, improving HHFW core heating, even in CHI start-up plasmas with $n_e(0) \sim 4 \times 10^{18} m^{-3}$

XP-817: 550 kW k_ϕ = -8 m^{-1} HHFW Heating
18 to 64 ms Increased $T_e(0)$ from ~ 3 to ~ 33 eV



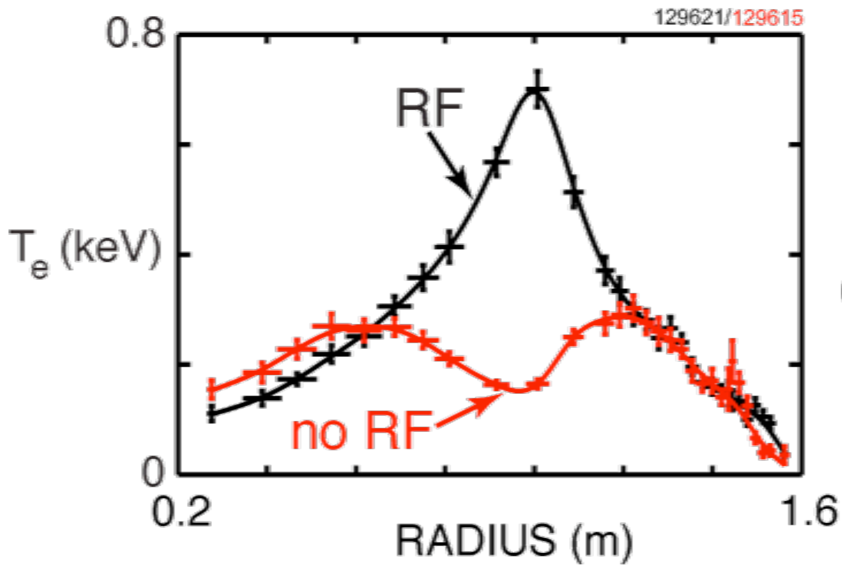


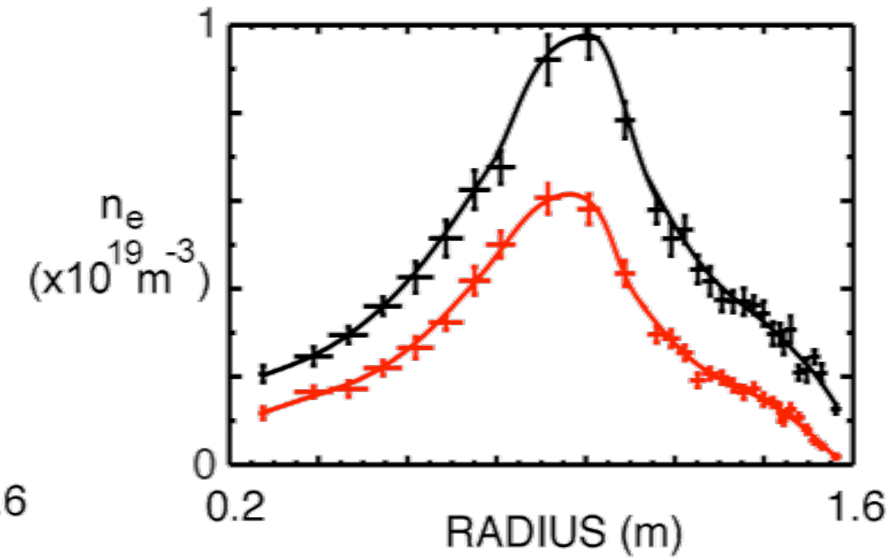


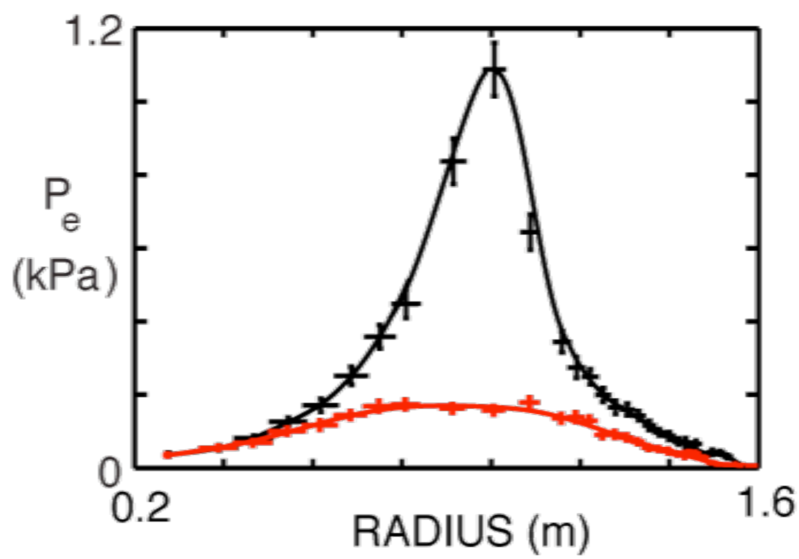
Time = 53 ms

- HHFW coupled from 18 to 64 ms
- T_e , P_e profiles remained hollow during HHFW heating pulse

XP-817: Good k_ϕ = -8 m^{-1} HHFW Heating Core Electron Heating During I_p Ramp from 100-300 kA







Time = 120 ms

- $T_e(0)$ increased from 140 eV to 700 eV at $n_e(0) = 6 \times 10^{18}\ m^{-3}$ and $9 \times 10^{18}\ m^{-3}$, respectively

XP-920: Aims to Study HHFW Heating of $I_p \leq 200$ kA Plasmas; Develop HHFW Ramp-Up in SFSU TSG

- Experiment will benefit from improved coupling possible at low RF loading with the new double-fed HHFW antenna
- Based on our experience in 2008, the experiment will also benefit from lithium conditioning
- Considerable effort may be needed to establish a stable target discharge with $I_p < 200$kA (Dave Gates & Dennis Mueller)
- Experiment has two phases and requires one day:
  – Setup $I_p = 200$ kA plasma, add ~ 3 MW of $k_\phi = -8$ & -14 m^{-1} heating
  – If $I_p = 200$ kA plasma is stable, develop $I_p \leq 200$ kA plasma & add RF

Run Plan

- Before starting experiment rtEFIT control should be setup to operate at low I_p, with I_{pmin} set to 150 kA (I_{pmin} currently set to 200 kA)
- Setup 600 ms I_p flattop plasma, similar to 123712 (B_T = 5.5 kG, D_2), but with I_p = 200 kA, instead of 300 kA **(5 shots)**
  - Adjust outer gap to 5-10 cm and introduce lithium at 20 mg/min, adjust evaporation rate as necessary later for good RF coupling
- If the I_p = 200 kA plasma is stable add $k_\phi = -8\ m^{-1}$ HHFW power, coupled from 100 – 600 ms. Increase RF power to ~ 3 MW **(5 shots)**
  - Adjust lithium evaporation rate, gas injection rate and outer gap to optimize HHFW heating efficiency
- Repeat with $k_\phi = -14\ m^{-1}$ HHFW heating **(5 shots)**
- If the I_p = 200 kA is stable, adjust I_p < 200 kA, while still maintaining plasma position control so that the outer gap is 5-10 cm **(5-10 shots)**
- Add $k_\phi = -8\ m^{-1}$ heating **(5 shots)** and then $k_\phi = -14\ m^{-1}$ heating **(5 shots)**

Operational Requirements & Analysis

- Experiment should follow high power HHFW experiments: XP-944 (HHFW Edge Effects) and XP-946 (HHFW Heating and Current Drive Phase Scans)
- Experiment needs rtEFIT isoflux control of the outer gap
- NBI blip from source A @ 90 keV required for CHERS data acquisition from 580 to 600 ms
- MPTS is required for electron heating
- SOL reflectometer & ERD ion heating data required for edge power loss and coupling efficiency
- Analysis includes EFIT, TRANSP & GENRAY/CQL3D
- Results will be published in *Physics of Plasmas* or *Nuclear Fusion*