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

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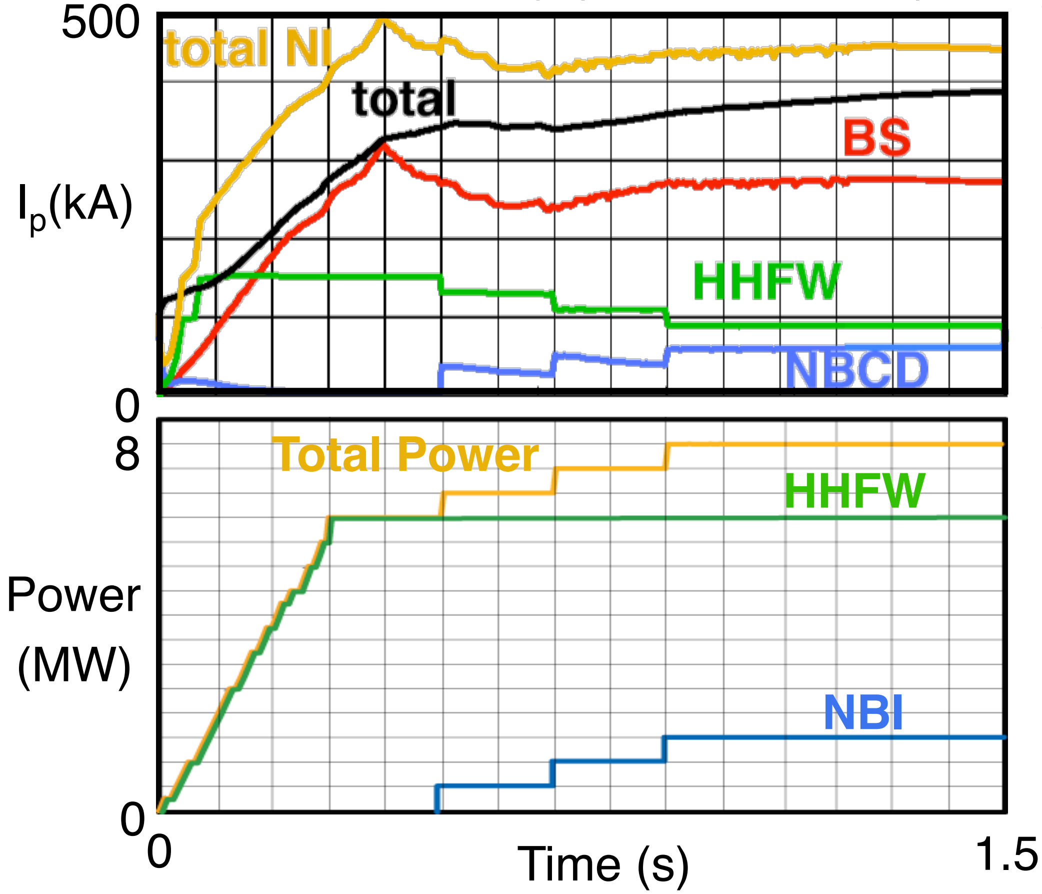
Modeling Predicts 5-6 MW of HHFW Power Can Achieve Fully Non-Inductive I_p Ramp-up in NSTX

TSC Modeling (Chuck Kessel)

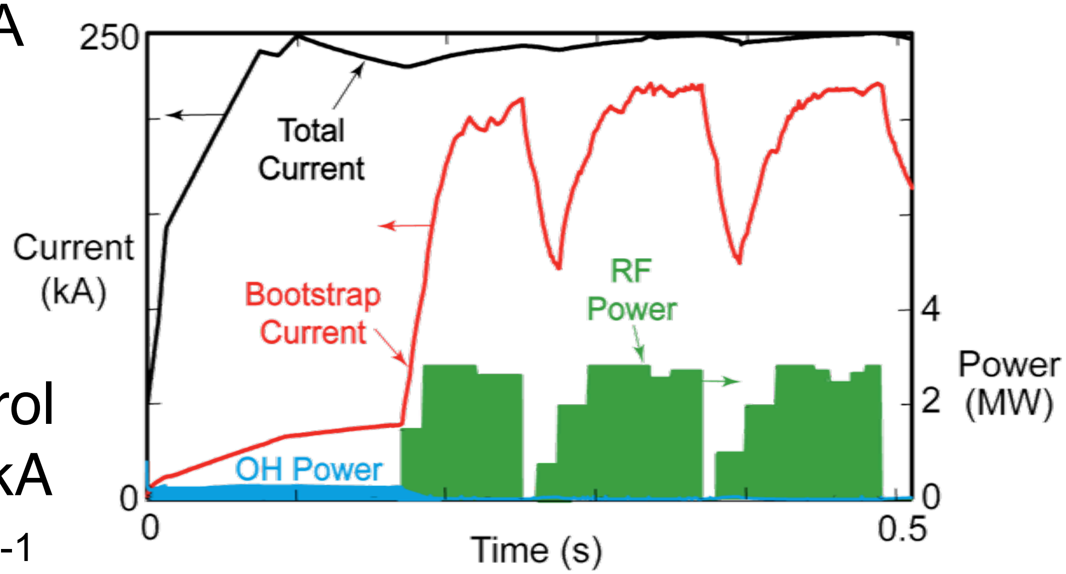


- Simulation of I_p ramp-up at $B_T(0)$ = 0.45 T
  - HHFW provides heating & CD at low I_p and T_e
- HHFW-assisted I_p ramp-up started at 100 kA
  - 6 MW HHFW ($k_{||}$ = 8 m^{-1}) Co-CD phasing
  - 6 MW NBI added when $I_p \geq$ 400 kA (only 2-3 MW absorbed due to slow I_p ramp rate in 1.8 s plasmas)

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 $dI_{OH}/dt \approx 0$



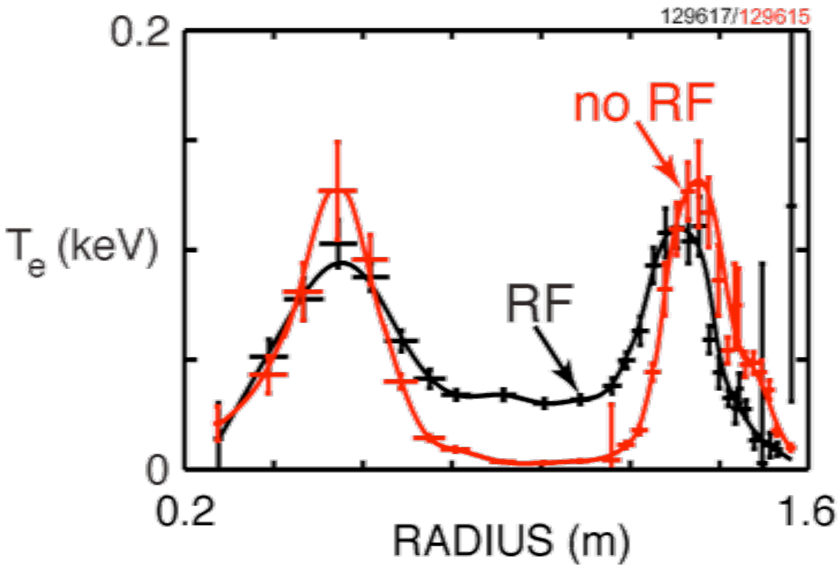
2007: (XP-731)

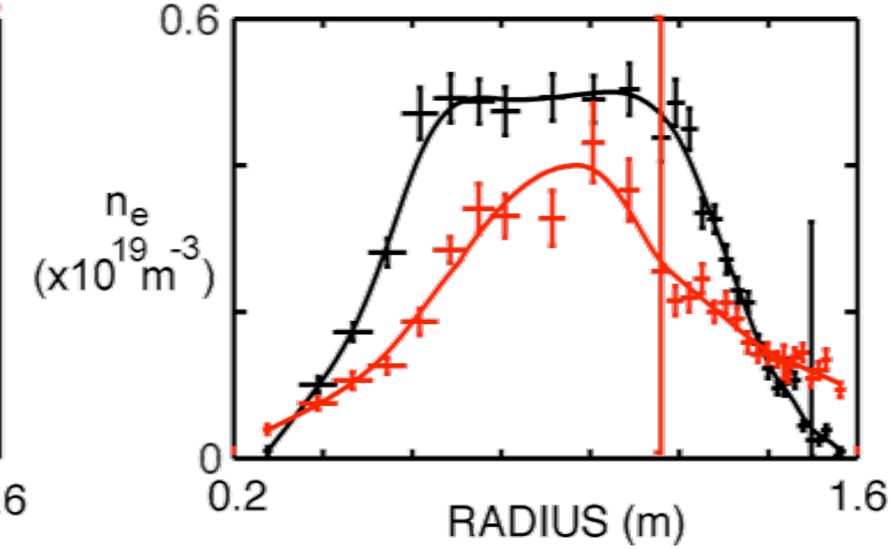
- Problem with rtEFIT control at I_p = 250 kA, used 300 kA
- Many trips with k_ϕ = 14 m^{-1}
- Up to 2.7 MW of k_ϕ = -8 m^{-1} heating, produced transient H-mode

2008: (XP-817)

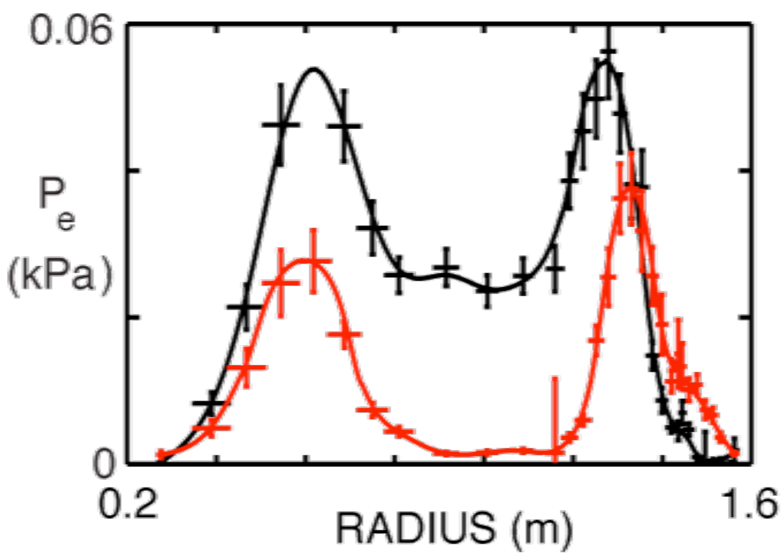
- Li conditioning reduced edge density, improving HHFW core heating, even in CHI start-up plasmas with $n_e(0) \sim 4\times10^{18} m^{-3}$

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



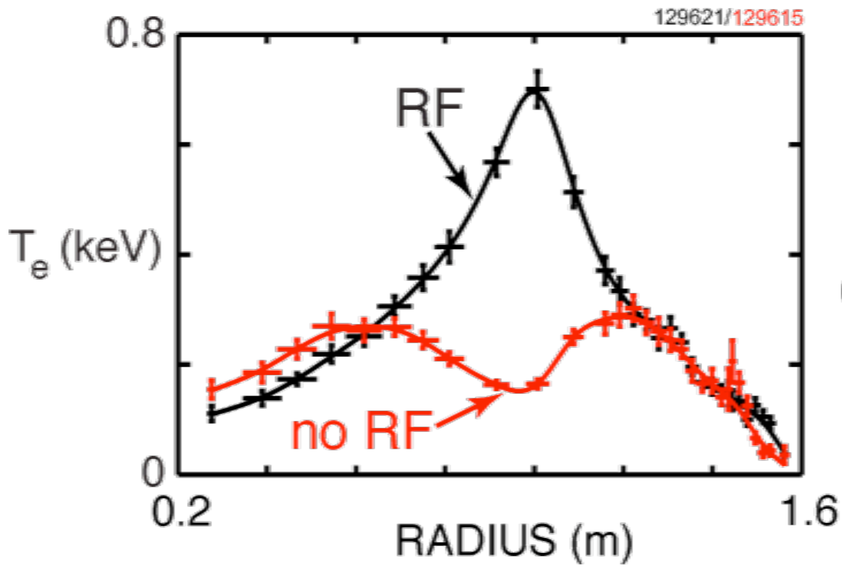


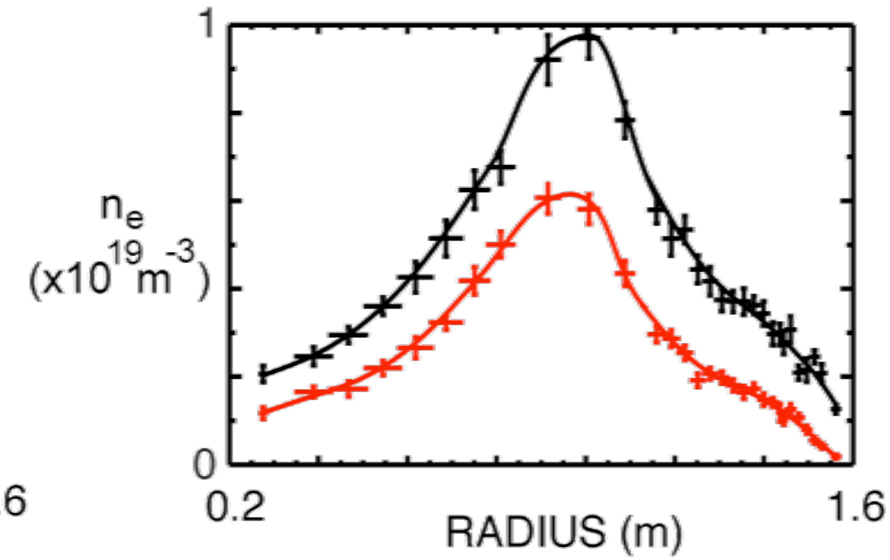
Time = 53 ms

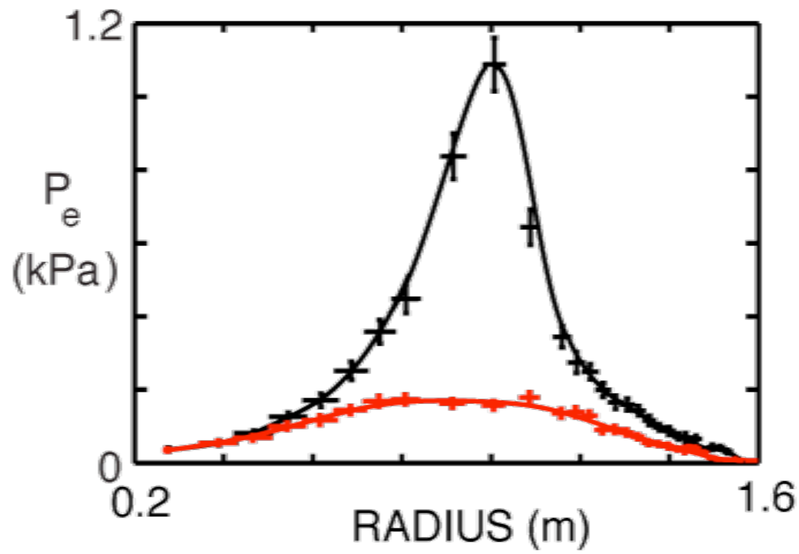


- HHFW coupled from 18 to 64 ms
- T_e , P_e profiles remained hollow during HHFW heating pulse

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 9×10^{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 < 200kA (Dave Gates and/or Dennis Mueller)
- Experiment requires two run days (I day WPI & 1 Day SFSU)

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)

① 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 **(10 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

② If the I_p = 200 kA plasma is stable add k_ϕ = - 8 m^{-1} (-90°) HHFW power, coupled from 100 – 600 ms. Increase RF power to ~ 3 MW **(10 shots)**

– Adjust lithium evaporation rate, gas injection rate and outer gap to optimize HHFW heating efficiency

③ Repeat ② with k_ϕ = 14 + 18 m^{-1} (180°) HHFW heating **(5 shots)**

④ If the I_p = 200 kA is stable, adjust I_p < 200 kA, and as close to I_p = 150 kA as possible while still maintaining plasma position control so that the outer gap is 5-10 cm **(5-10 shots)**

Run Plan (cont.)

⑤ Add k_ϕ = - 8 m^{-1} (-90^o) heating, coupled from 100 – 600 ms. Increase power to ~ 3 MW **(5 shots)**

⑥ Repeat ④ with k_ϕ = 14 + 18 m^{-1} (180^o) heating **(5 shots)**

⑦ Repeat ④ with k_ϕ = -8 m^{-1} (-90^o) heating **(5 shots)**

⑧ Repeat ⑦ with k_ϕ = +8 m^{-1} (+90^o) heating **(5 shots)**

⑨ Perform a density scan with -8 m^{-1} (-90^o) heating **(5-10 shots)**

⑩ If sufficient current drive is observed in ⑦ and ⑨, adjust RF pulse to start as soon as I_p reaches the flattop value

- Use open loop OH programming to provide no Ohmic drive after plasma current reaches the minimum value, (< 200 kA at approximately 25 ms)
  (5 shots to get start time, 5-10 shots to perform CD with Ohmic current flat)

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*