NSTX PPPL PRINCETON PLASMA PHYSICS LABORATORY Supported by U.S. DEPARTMENT OF ENERGY Office of Science

Use of HHFW heating to increase the non-inductive current fraction in NBI-produced H-mode plasmas with triggered ELMs to control impurity buildup

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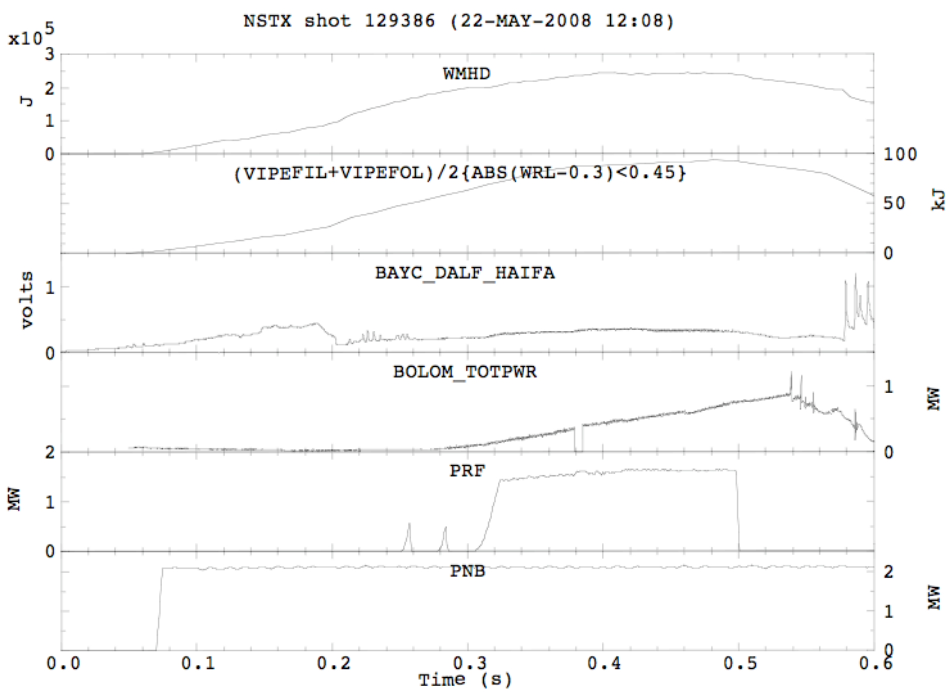
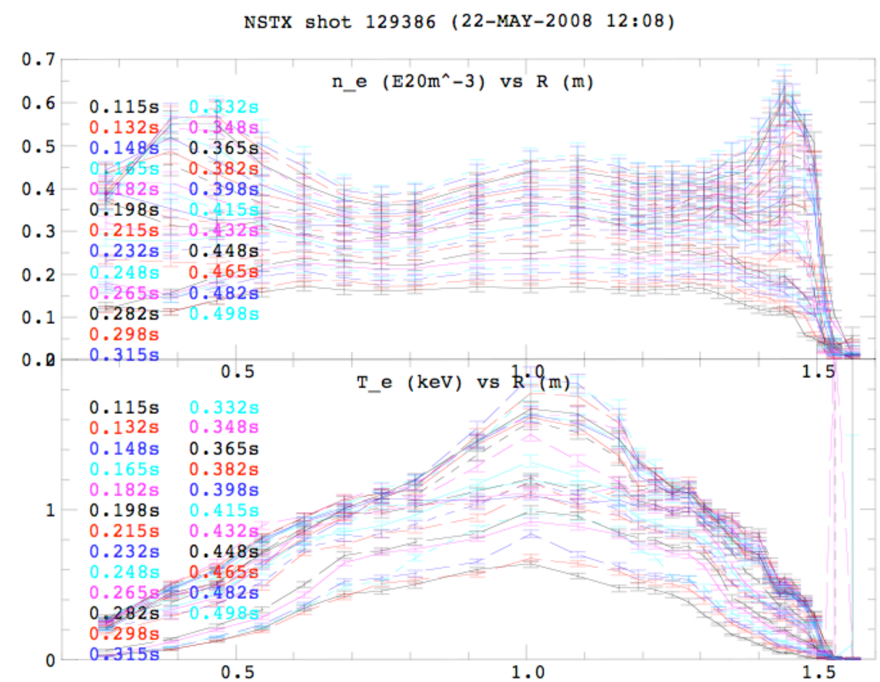
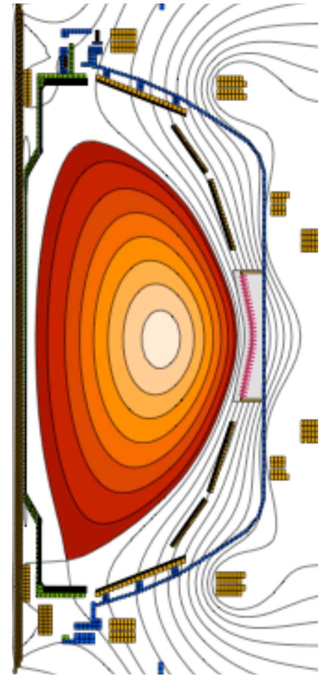
In XP-829: HHFW Successfully Heated Electrons in H-mode LSN Plasmas Produced by NBI

- ~1.8g lithium had been applied over 17 shots in the morning but was discontinued after the preceding shot (before which 40mg were applied)
- Effects of lithium appeared to continue through next 3 shots (129386, *8, *9)
  - Low H-mode power threshold: <2MW at 1.0MA, 0.55T
  - Discharges became ELM-free (and radiated power began to rise)
  - Central density remained relatively low
- *But* ... discharges did not meet requirements of XP and were abandoned





Experimental Plan (1)



- Start from conditions of 129386
  - I_p = 1.0MA, B_T = 0.55T, P_{NBI} = 2MW (NB-A), 0.07 – 0.8s
  - LSN, κ = 2.0, δ = 0.7; no EFC/mode control at outset
  - No HFS gas, modest LFS D puff (20Torr.l @ 0.2s)
- Decision 1: Use LITERs or LLD
  - LITER, use lowest rate to maintain H-mode and obtain good HHFW coupling: 5–10 mg/min
  - LLD: necessary conditions would need to be determined in preceding LLD commissioning experiments
- Attempt to obtain ELM-free, low-density H-mode with NB-A only *(6 shots)*
  - Vary LFS D puff; consider using SGI or HFS puff (last resort) if no H-mode
  - Increase LITER rate if no H-mode, ELMs persist or density too high
    - Edge (HHFW coupling), "ears" (NB penetration), core (fast-ion slowing time)
- Decision 2: If H-mode not reliable, consider adding NB-B or deferring XP
- Apply HHFW power (180° phasing) after H-mode established *(6 shots)*
  - Increase HHFW power (3MW desirable) and pulse length (0.4s desirable)

Experimental Plan (2)

- Optimize $P_{NB}\,T_e(0)^{3/2} / n_e(0)$ during HHFW and document conditions
  - Readjust D puff and/or LITER rate if ELMs reappear or density rises to much
  - Increase NB power to 4MW, possibly 6MW *(4 – 6 shots)*
  - At highest NB power with clear $T_e(0)$ rise, increase HHFW power *(4 shots)*
- In parallel, apply ELM-pacing if P_{rad} or n_e is rising
  - In latter half of HHFW pulse initially
  1. Magnetic triggering
     - Start with 1.5kA, 10ms n=3 pulses at 10 – 20 Hz (non-stressful on coils, plasma)
     - If triggering unreliable, widen pulses or raise amplitude
  2. RF triggering
     - Notch HHFW power at 10Hz, without and with magnetic triggering
  - Raise triggering frequency to gain density control (observe speed limit!) *(4 shots)*
  - If ELMs reduce P_{rad} without impact on $T_e(0)$, move triggering earlier *(4 shots)*
- Scan antenna phase: 120°, 60° (30°) and readjust conditions *(6 - 9 shots)*
- At optimal NBI, HHFW reduce I_p to 0.9, 0.8 MA, to increase β_P (f_{BS}) *(6 shots)*
  - Delay ELM triggering to latter half of HHFW pulse again until ELM behavior assessed

Requirements

- Operational prerequisites
  - B_T to 0.55T available
  - LITERs *or*
  - LLD demonstrated to control density and provide ELM-free H-modes
  - HHFW system conditioned and ready to couple >3MW, preferably in CD phasing
  - EFC/RWM system with odd parity and qualified for up to 2kA pulsed waveforms
    - Note: if density is reduced and mode-locking becomes a problem, we will consider applying EFC in early phase
- Experimental time: 39 – 45 shots
- Diagnostics
  - Full thermal kinetic set (MPTS, CHERS [-T,-P], MSE) required
  - FIDA, NPA, neutrons highly desirable
  - USXR arrays and magnetics for fluctuations
  - Spectroscopy (Filterscopes, VB, SPRED, VIPS, LOWEUS, XEUS, Bolometer)
  - Li-CHERS desirable
  - High-k scattering (mid-radius) and BES desirable

Addresses High-Priority ASC Research Goals

- Research Milestone (R10-2): Characterize HHFW heating, current drive, and current ramp-up in deuterium H-mode plasmas
- Research Milestone R(11-2) Assess the dependence of integrated plasma performance on collisionality
- Attempt to achieve long-pulse density control for increased neutral beam current drive fraction using improved fueling and lithium conditioning
- Develop high non-inductive current fraction plasmas with high-beta and high bootstrap fraction under sustained conditions