NSTX

Supported by U.S. DEPARTMENT OF ENERGY | Office of Science

High-Harmonic Fast Wave (HHFW) Heating Results on NSTX*

Gary Taylor[1]

In collaboration with

R. E. Bell[1], P. T. Bonoli[2], D. L. Green[3], R. W. Harvey[4], J. C. Hosea[1], E. F. Jaeger[3], B. P. LeBlanc[1], C. K. Phillips[1], P. M. Ryan[3], E. J. Valeo[1], J. R. Wilson[1], and the NSTX Team

[1]Princeton Plasma Physics Laboratory
[2]MIT Plasma Science and Fusion Center
[3]Oak Ridge National Laboratory
[4]CompX

*Work supported by US DoE contracts DE-AC02-09CH11466 and DE-AC05-00OR2272

NO4.00013

52nd Annual Meeting of the Division of Plasma Physics
Chicago, Illinois, November 8-12, 2010

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Maryland
U Rochester
U Washington
U Wisconsin

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

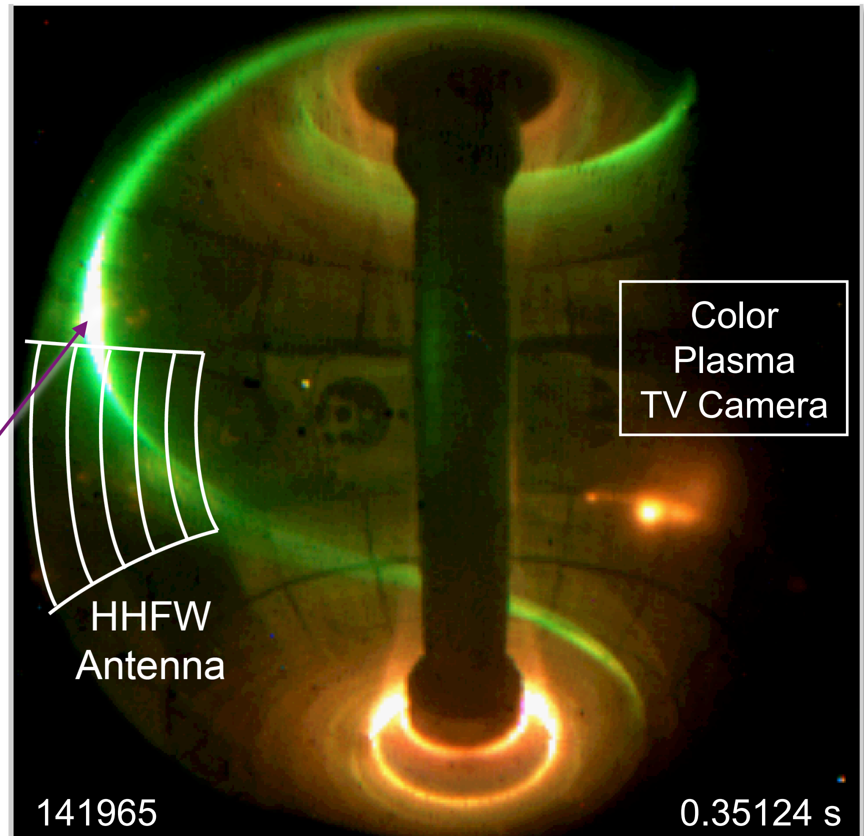
Introduction

- Seek to maximize HHFW heating inside last closed flux surface (LCFS) to support fully non-inductive I_p ramp-up & sustainment
- 12-strap antenna has well-defined spectrum, providing good control of deposition & RF current drive direction
- Double-feed antenna upgrade installed in 2009:
  - ➢ Stand off voltage did not improve as much as predicted
  - ➢ Voltage appears limited by RF currents induced in antenna surface
  - ➢ Voltage limit increases with sufficient antenna conditioning
- Last year reported improved RF coupling to NBI H-modes & low I_p discharges by using lithium conditioning:
  - ➢ This year extensive lithium conditioning seriously compromised RF performance

Extensive lithium conditioning this year significantly degraded antenna performance compared to 2009

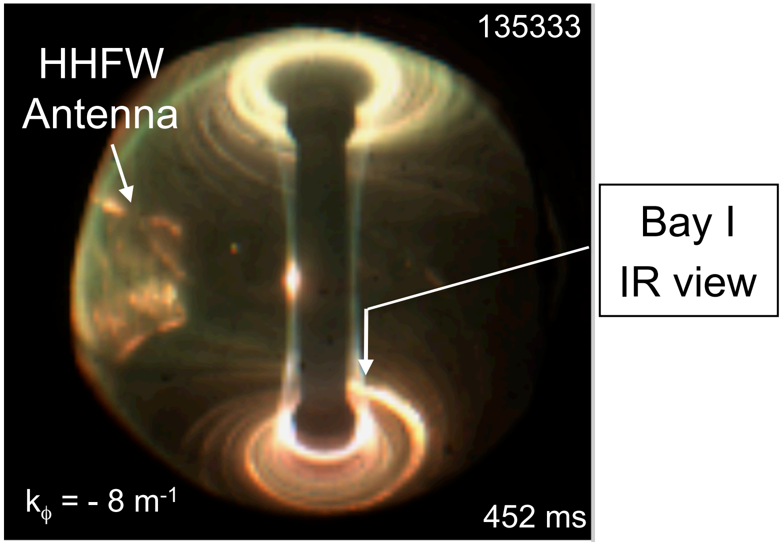
- In 2009 quickly reached arc-free P_{RF} = 2-3 MW & arc-free P_{RF} ~ 4 MW by end of campaign
- Following extensive lithium conditioning this year only reached P_{RF} ~ 1.5 MW arc-free operation & observed copious lithium ejection associated with arcing ➡
  - ➢ Before lithium conditioning quickly reached a stand-off voltage of 25 kV during RF vacuum conditioning
  - ➢ Later in campaign difficult to reach even ~ 15 kV

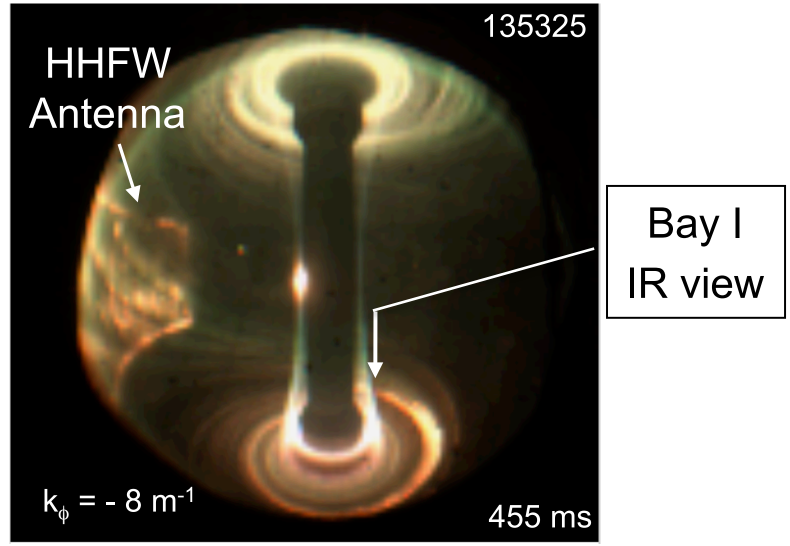
Lithium ejection (green light) from top of antenna at time of RF arc



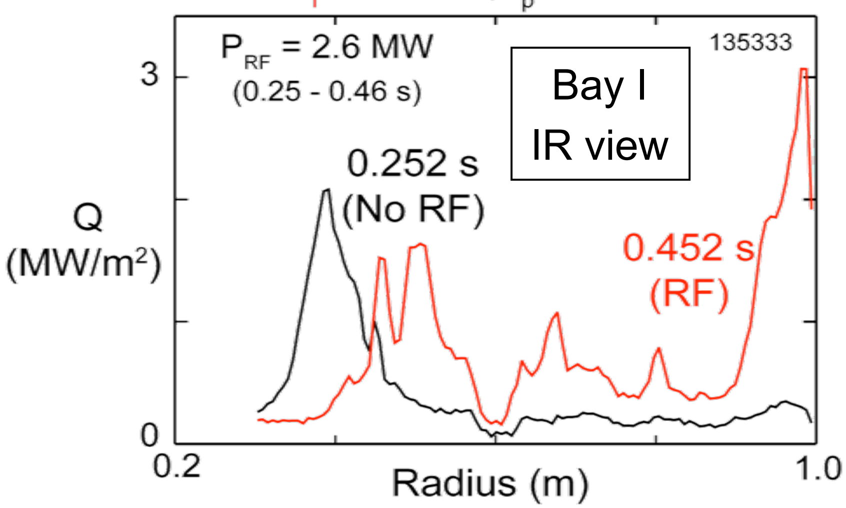
P. M. Ryan, et al., Poster BP9.00073, Mon AM

Significant RF power flow to lower divertor: RF heating pattern on the divertor plate follows the magnetic pitch

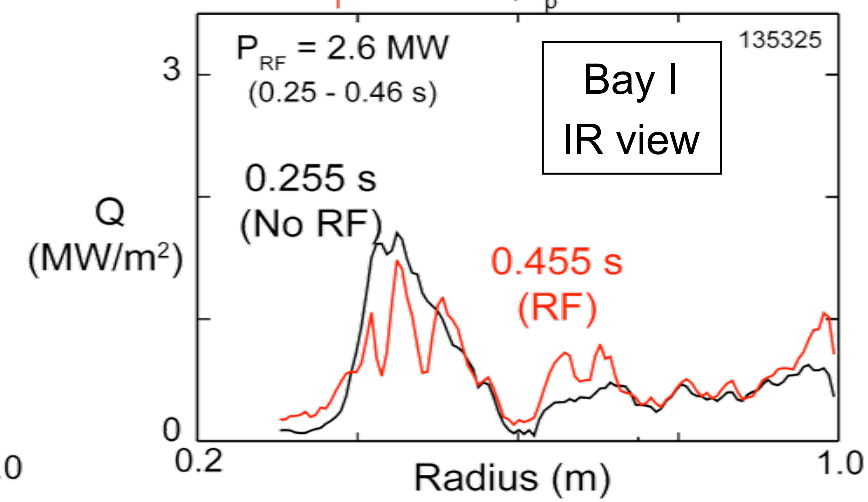




B_T = 4.5 kG, I_p = 0.8 MA

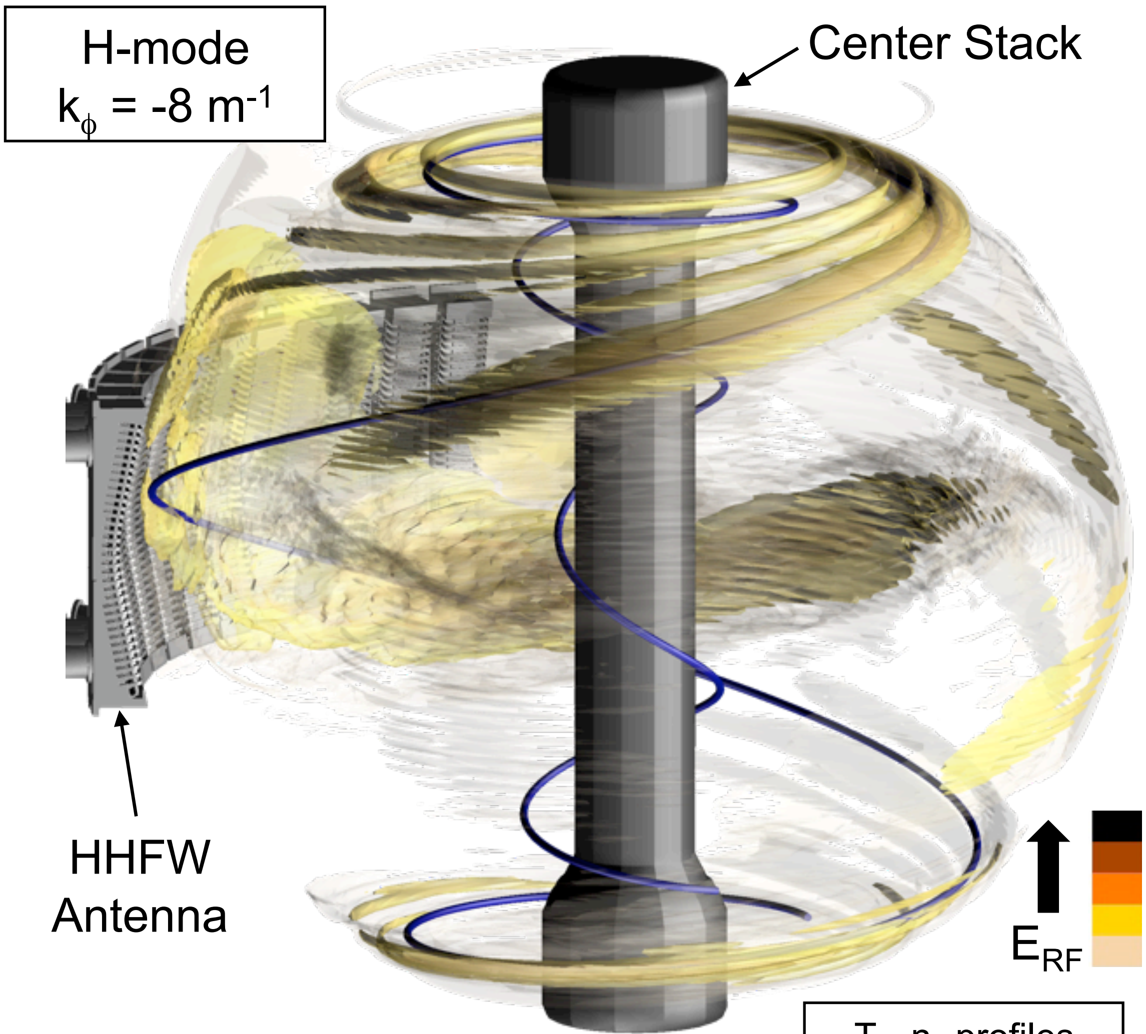


B_T = 5.5 kG, I_p = 0.8 MA



J. Hosea, et al., Poster BP9.00074, Mon AM

AORSA full-wave model with boundary at limiter predicts large E_{RF} fields following magnetic field near top & bottom of plasma



- In addition to RF power coupling to core, some power propagates just inside LCFS as an edge localized eigenmode
- E_{RF} in edge eigenmode is significantly larger for negative antenna phasing
- Similar to plasma TV images
- For k_ϕ = -3 m^{-1}, fast-wave propagates outside LCFS to wall

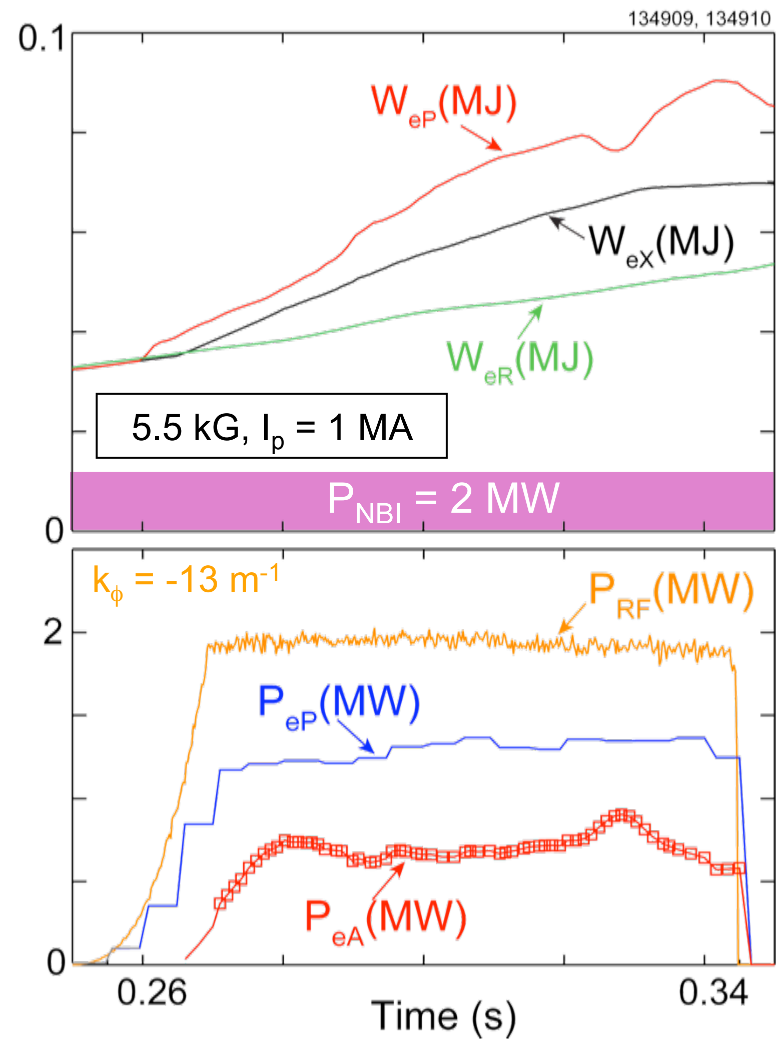
T_e, n_e profiles consistent with 120470, 72 & 45

D. L. Green, ORNL

TRANSP-TORIC analysis of matched NBI+HHFW & NBI-only ELM-free H-modes predicts ~ 50% of P_{RF} is absorbed inside LCFS

- Fraction of P_{RF} absorbed within LCFS (f_A) obtained from TRANSP-calculated electron stored energy:
  - W_{eX} – from HHFW+NBI H-mode
  - W_{eR} – from matched NBI-only H-mode
  - W_{eP} – using χ_e from NBI-only H-mode to predict T_e in HHFW+NBI H-mode
- $f_A = (W_{eX}-W_{eR})/(W_{eP}-W_{eR}) = 0.53 \pm 0.07$
- TORIC used to calculate the power absorbed by electrons (P_{eP}) assuming 100% RF plasma absorption
- Electron absorption, $P_{eA} = f_A \times P_{eP}$

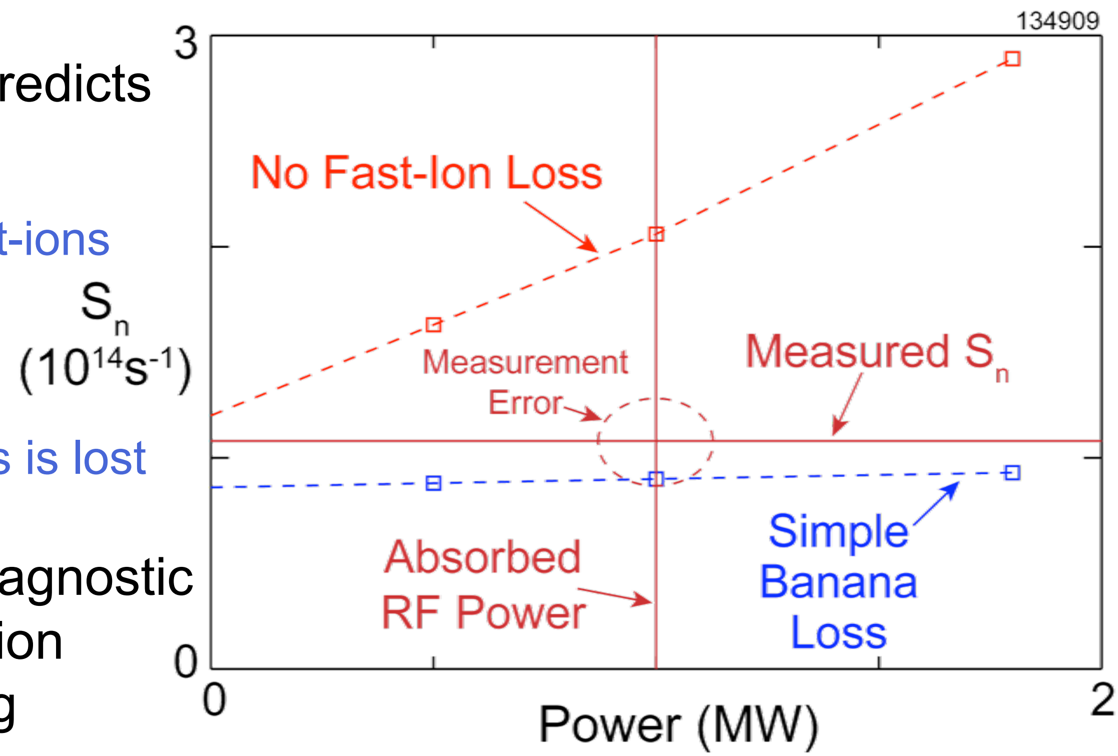
  For P_{RF} = 1.9 MW:
  - 0.7 MW ➡ electrons
  - 0.3 MW ➡ ions



CQL3D Fokker-Planck code predicts significant fast-ion losses in HHFW-heated ELM-free NBI H-modes

- Without fast-ion loss CQL3D predicts much higher neutron production rate (S_n) than is measured

- Simple-banana-loss model predicts S_n just below measured S_n :
  - Assumes prompt loss of fast-ions with a gyro radius + banana width > distance to LCFS
  - ~ 60% RF power to fast-ions is lost



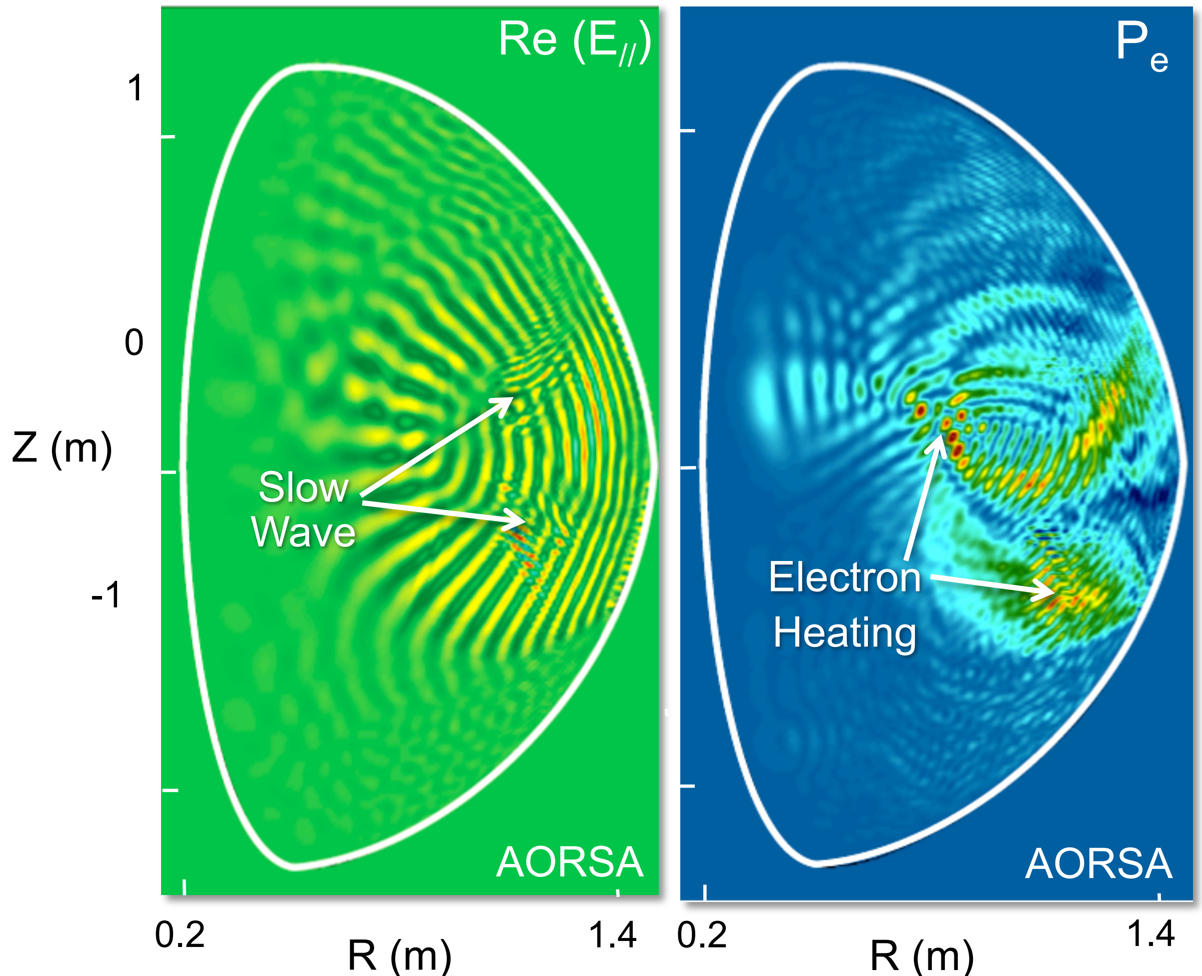
- For this shot FIDA fast-ion diagnostic measures no change in fast-ion density during HHFW heating

- First-order finite-orbit width loss model being implemented in CQL3D

B. P. LeBlanc, et al., Poster BP9.00076, Mon AM

"High-resolution" full-wave simulations predict existence of a new short-wavelength mode that damps on electrons

HHFW+NBI H-mode Shot 130608 with $k_{//} \sim -7.5\ m^{-1}$



- This "Slow Wave" mode is seen mainly in $E_{//}$, not E_+ or E_-
- Mode is localized mainly off mid-plane
- The mode is seen in both AORSA & TORIC full-wave simulations

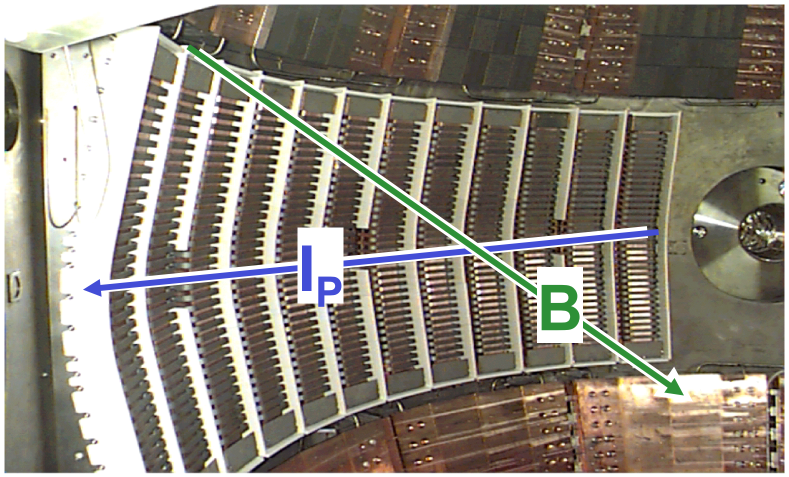
C. K. Phillips, et al., Poster BP9.00075, Mon AM

Summary

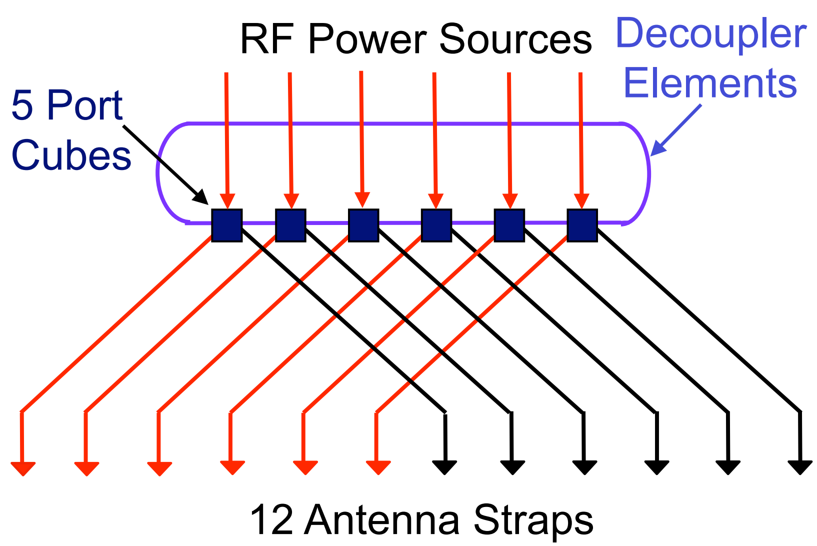
- Extensive lithium conditioning significantly degraded RF performance this year; maximum arc-free P_{RF} ~ 1.5 MW, compared to ~ 4 MW in 2009
- RF heating pattern on divertor during H-mode follows magnetic field
- About 50% of P_{RF} absorbed inside LCFS in ELM-free RF+NBI H-mode
- "High-resolution" full-wave simulations predict the existence of a new short-wavelength mode that damps on electrons
- 3-D full-wave simulations with the boundary at the limiter predict E_{RF} follows the magnetic field near top and bottom of plasma

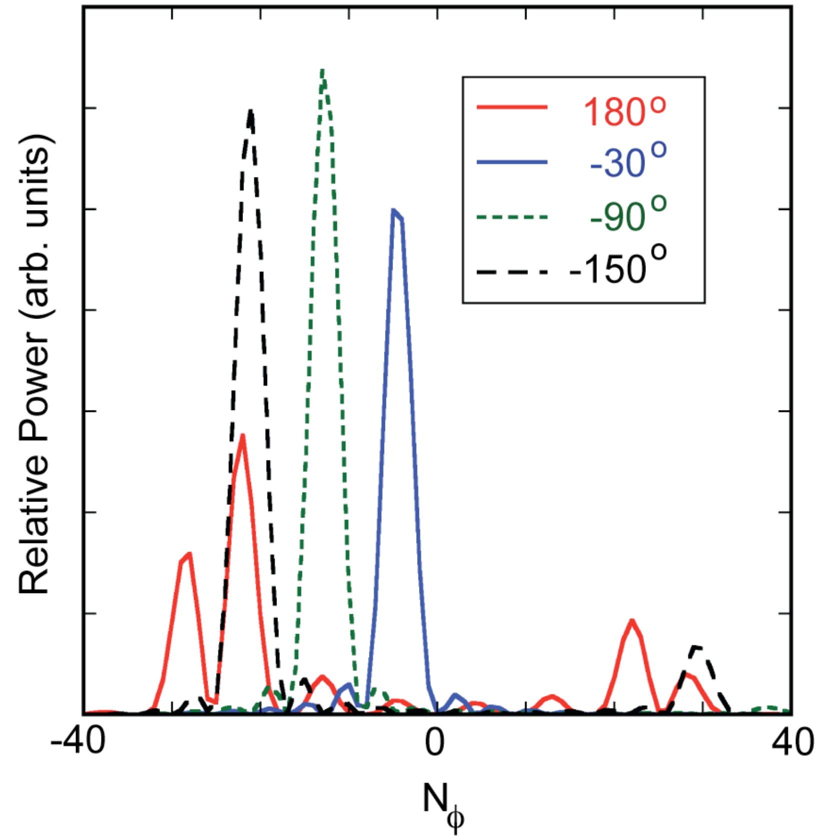
Backup Slides

NSTX HHFW Antenna Has Well Defined Spectrum, Ideal for Studying Phase Dependence of Heating



HHFW antenna extends toroidally 90°

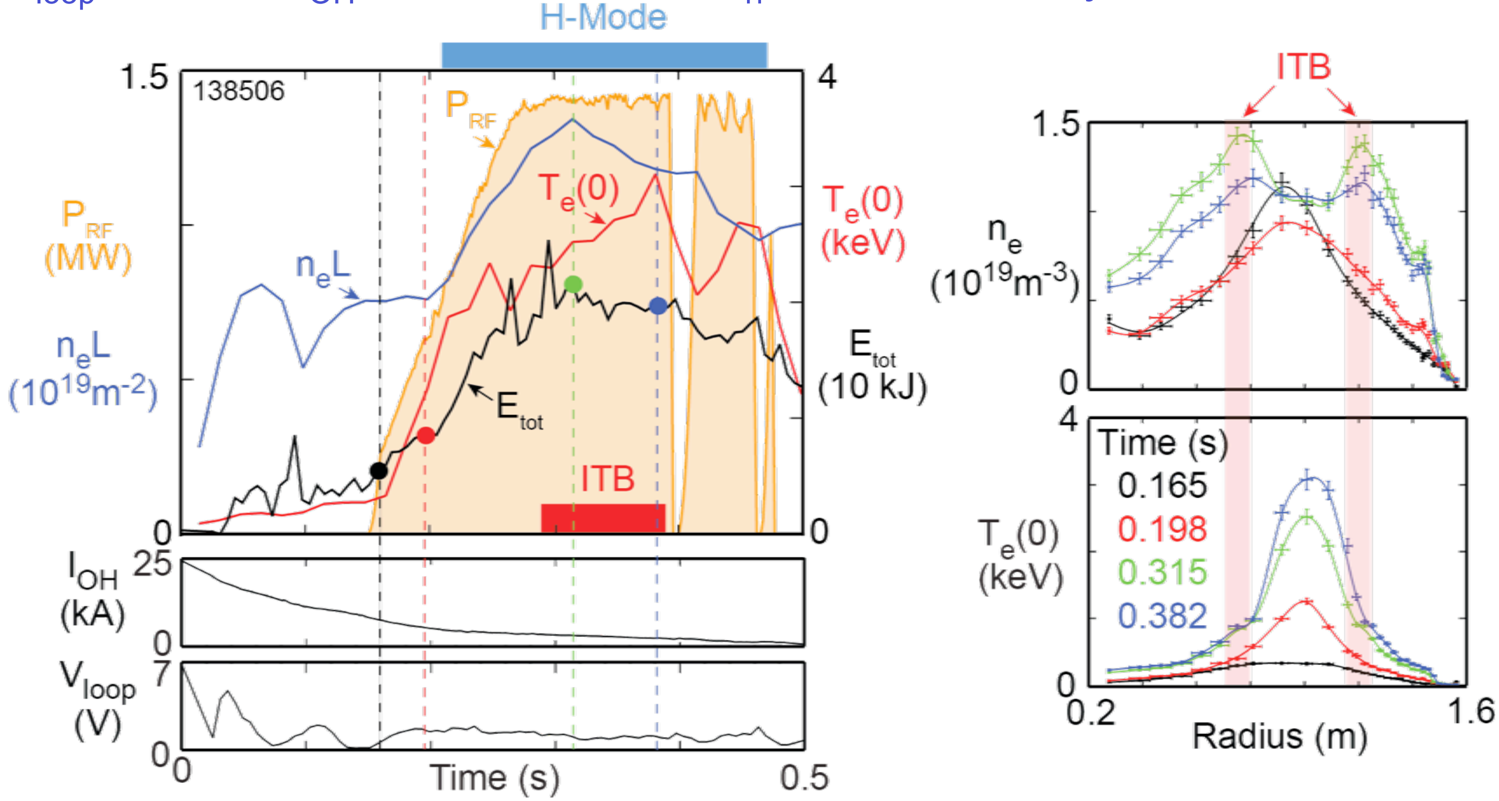




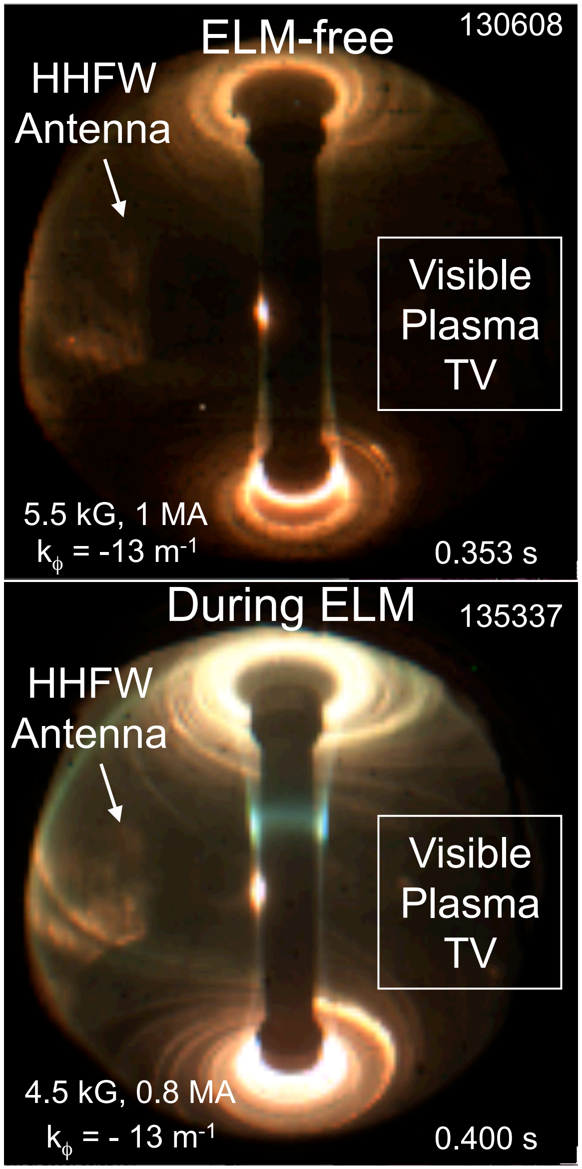
- Phase between adjacent straps easily adjusted between $\Delta\phi = 0°$ to $\Delta\phi = 180°$

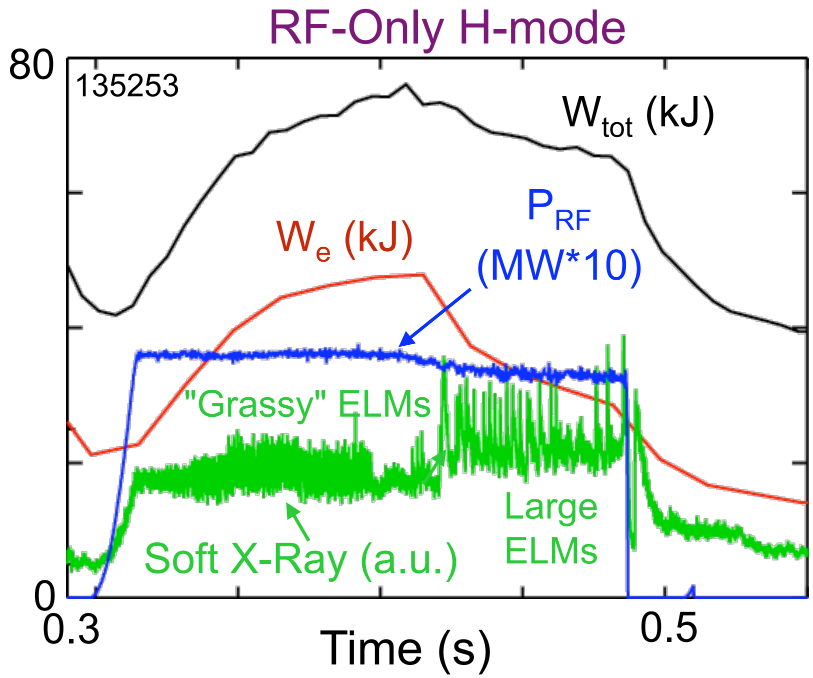
Some progress in heating low I_p (~300 kA) RF-only H-mode plasma, but only achieved f_{NI} ~ 0.6 due to low P_{RF} (~1.5 MW)

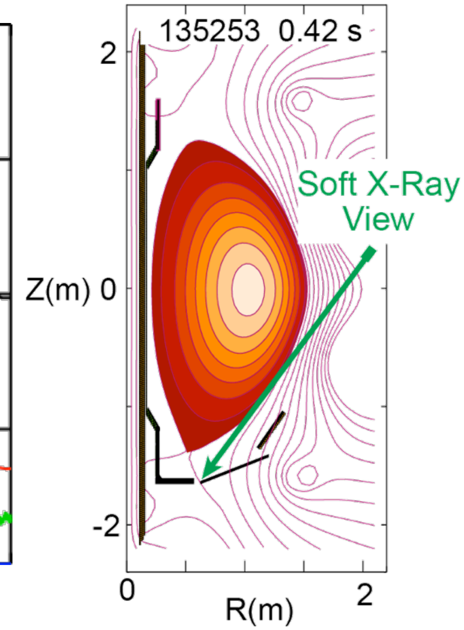
- Spherical torus needs fully non-inductive I_p ramp-up & sustainment
- Low I_p HHFW experiments in 2005 could not maintain P_{RF} during H-mode
- This year generated sustained RF H-mode with internal transport barrier (ITB)
  - Better plasma-antenna gap control than in 2005 (Reduced PCS latency)
  - V_{loop}~ 0 and dI_{OH}/dt ~ 0, but need $P_{rf} \geq 3$ MW for fully non-inductive H-mode



Large ELMs create higher RF power flow to lower divertor & reduce RF heating efficiency in RF+NBI & RF-only H-modes







- Significant RF power loss to divertor during large ELMs due to direct core heat loss and higher edge density:
  - ➢ IR camera images show ELMs heat plasma strike point in divertor, not the primary RF-heated zone
  - ➢ Much less RF power loss to divertor in ELM-free H-mode or during "Grassy" ELMs

J. Hosea, et al., Poster BP9.00074, Mon AM