Draft FY09 - 13 NSTX HHFW Research Plan - June 28, 2007

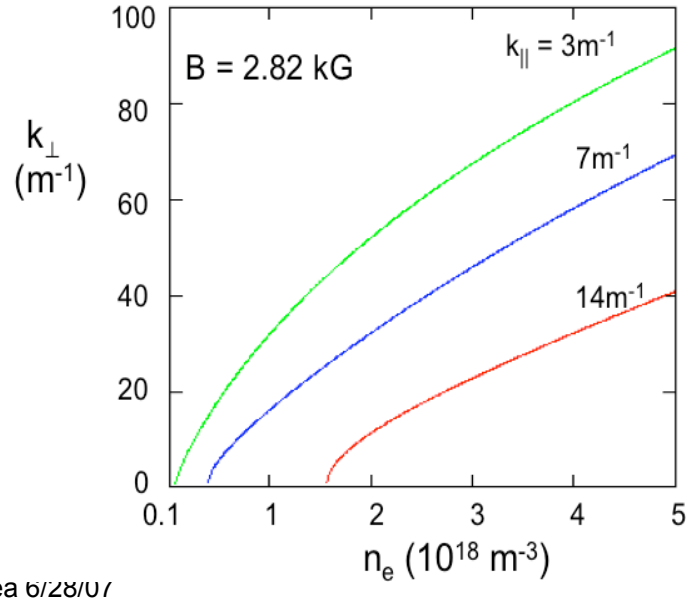
1. HHFW Research Goals
2. HHFW Physics
3. HHFW Heating System
4. Status of HHFW Research
5. HHFW Research Plan for 2009 - 2013

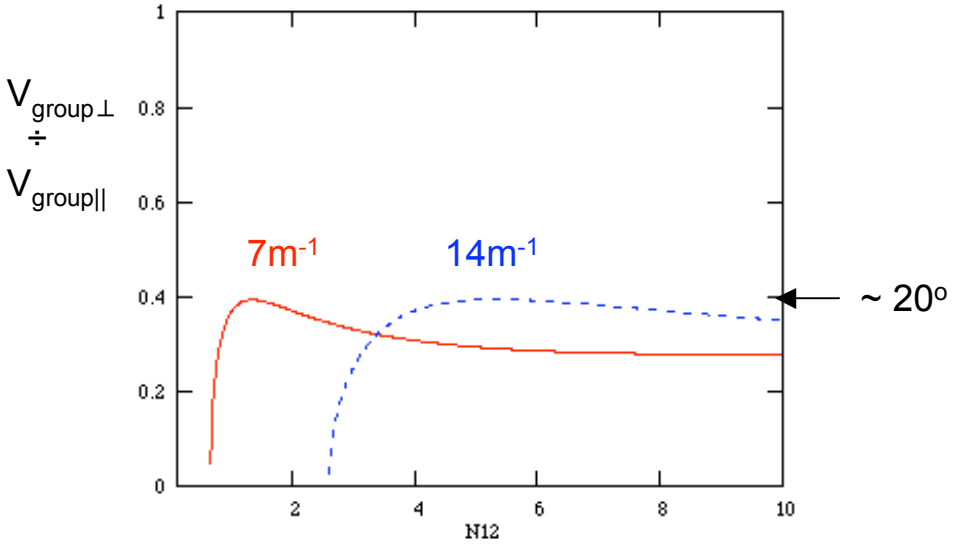
1. Research Goals

- Ultimate goals:
  1. Assist with startup and rampup to improve the ST concept for very long pulse operation
  2. Support heating and current drive of H-mode plasmas to optimize NSTX performance and stability behavior
- Interim goals:
  A. For L-mode plasmas:
     1. Demonstrate efficient HHFW heating with current drive phasing (06-07)
     2. Demonstrate efficient heating during NB heating (06-07)
     3. Demonstrate HHFW CD with MSE (07-08)
     4. Demonstrate HHFW CD for NB heated plasma (07-08)
  B. Optimize H&CD in L-mode and H-mode regimes (08-13)
     1. Enlarge plasma-antenna gap to provide for less interaction of NB ions with the antenna and to reduce the edge density near the antenna to reduce edge power loss, avoid arcing and to help avoid edge MHD
     2. Enhance coupled RF power by moderating high field zones in antenna (minor 07-08 mods)
     3. Enhance coupled RF power substantially by modifying antenna to have two feedthroughs per strap (08-09 mod)
     4. Insert 3 db hybrid ELM dumps to better couple to H-mode without arcs. Modify electronics to avoid feeding power during ELMs (10-11)
     5. Further optimize antenna structure (11-13)

2. HHFW Physics (Cynthia and Phil)

- HHFW coupling, propagation and damping physics are important areas of research for NSTX
  - A. Theoretical/modeling studies (RF SciDac etc.) are addressing these three critical areas for NSTX as well as for tokamaks (Cynthia write-up)
    - Summary of HHFW edge physics, core physics and approaches
  - B. How to optimize coupling of HHFW power to the core plasma
    1. Avoid surface wave interaction with edge plasma and antenna/walls to the extent possible
       - ➢ Keep edge density near antenna low relative to the onset density for perpendicular propagation ($\propto B \times k_{||}^2/\omega$)





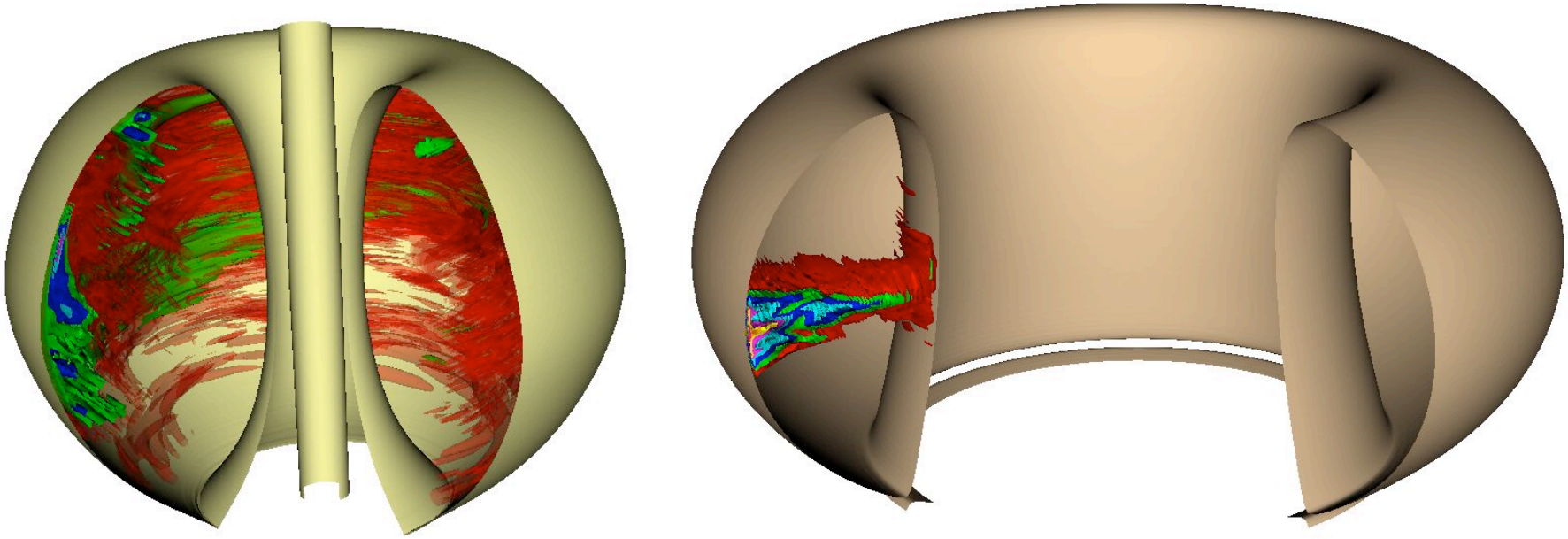
HHFW Physics (cont)

B. 1. Cont.

– 3 D AORSA modeling shows propagation to be near the wall on NSTX

NSTX

ITER Scenario 2



Jaeger, *ORNL*

NSTX simulation summed over 81 toroidal modes.
ITER simulation summed over 169 toroidal modes)
[AORSA run on JAGUAR using 2048 processors for 8 hrs]

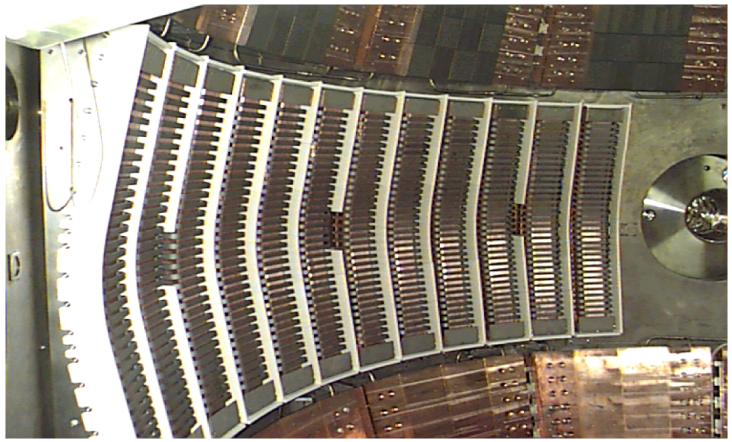
HHFW Physics (cont)

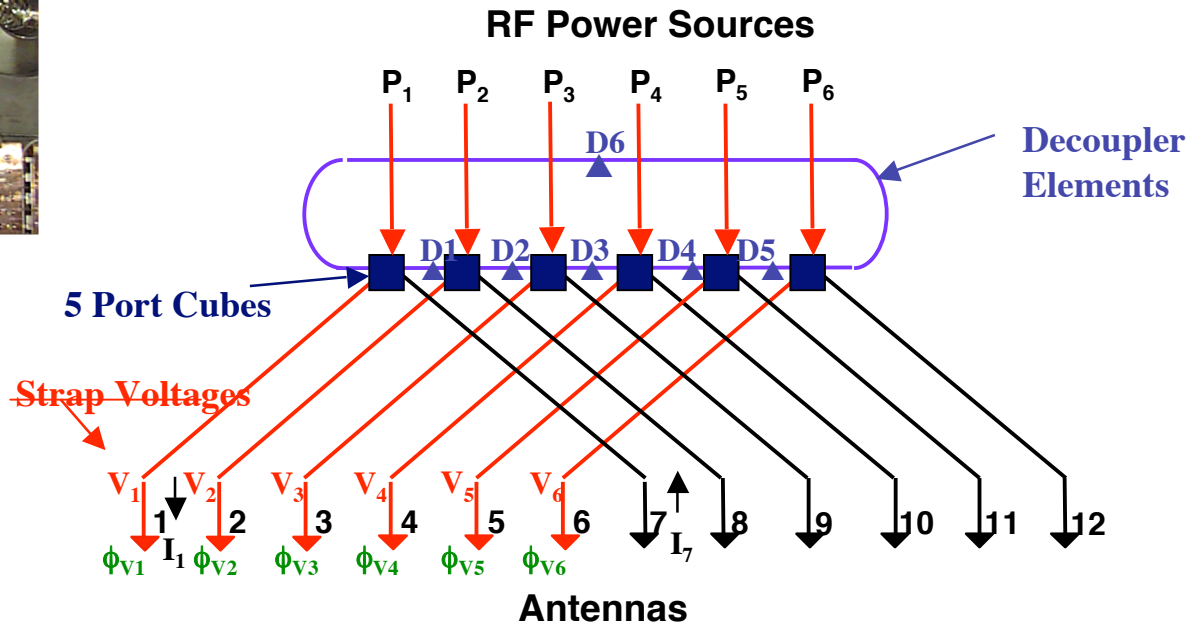
B. Cont.
   2. Optimize MHD stability to limit losses in the electron channel and to reduce plasma/gas flow to the antenna that causes arcing
   3. Understand fast wave damping mechanisms
      – Core: Landau/TTMP and short wavelength mode conversion (Cynthia) effects
      – Edge: Surface Wave damping via collisions, sheaths, wall/antenna currents, etc.. PDI heating.

C. Predict conditions required to optimize plasma heating and CD
   1. Co vs counter CD
   2. Can heating and CD be tailored for on and off axis applications?
   3. Can HHFW CD be used to help stabilize core MHD, e.g., by increasing reverse shear in core with counter CD?

3. HHFW Heating System

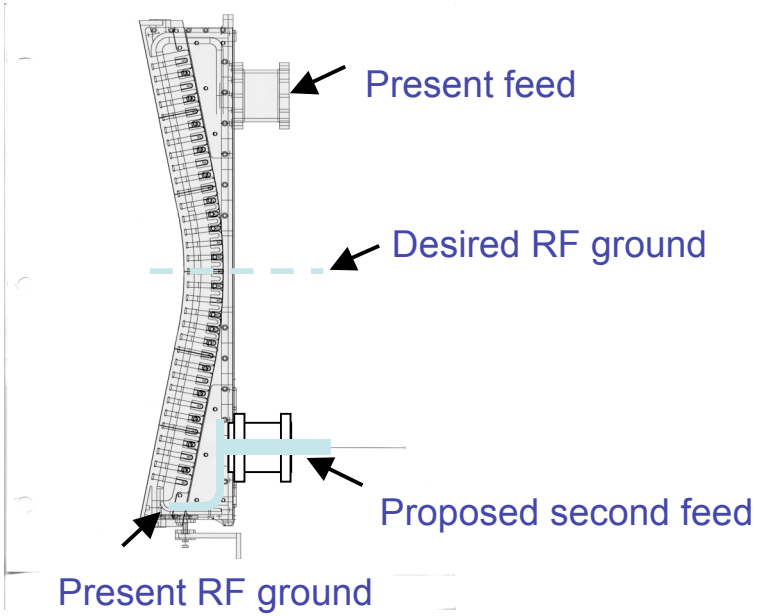
- Present system:
  - 12 antenna straps, six sources, decoupling loops, phase shifters, and stubs
  - Digital control of power and phase
  - Automated matching calculations





HHFW Heating System (cont.)

- Planned upgrades:
  - 07-08 Minor antenna modifications
    - Round edges and increase strap-ground distances to reduce RF electric field/arcing
    - Replace boron nitride with graphite or metal?
  - 08-09 Major upgrade of antenna to have two feedthroughs per strap
    - Important for achieving higher power and for being able to have a larger gap
    - Essential for avoiding edge power deposition at high power

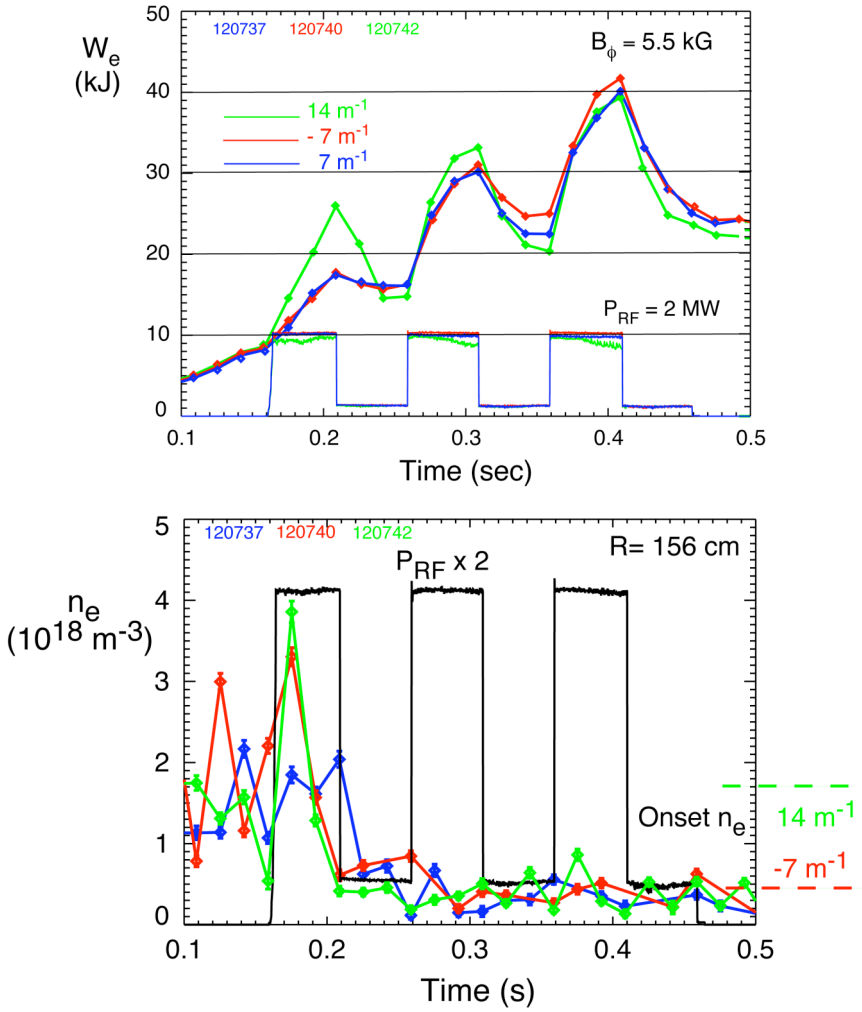


HHFW Heating System (cont.)

- Planned upgrades (cont.):
  - 10-11 Upgrade for resilience to ELMs during H-mode
    - Insert 3 db hybrids to improve operation in H-mode
    - Provide electronics for avoiding feeding ELMs
  - 11-13 Further upgrade antenna for optimum performance
    - Further improvements to V standoff (minimization of RF E field)
    - Make antenna strap with 2 discreet poloidal segments (ITER-like) to permit reversal of exciting RF current in the poloidal direction
      - Provides poloidal spectrum with no m=0 component and peaked away from m=0
      - This upgrade should be made if modeling shows that it could be important for minimizing effects of surface waves and reactive fields on damping

4. Status of HHFW Research

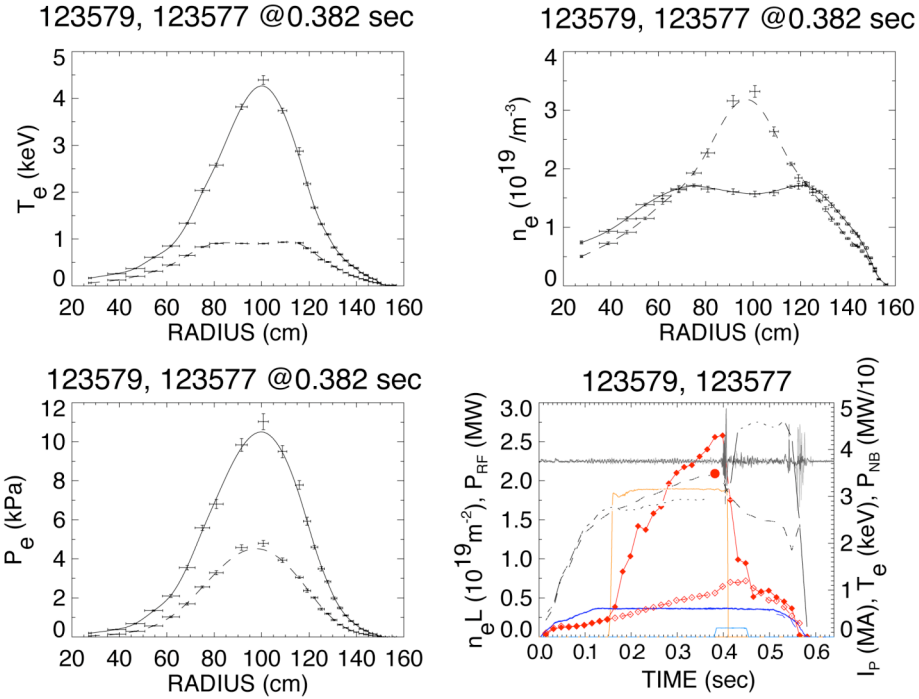
- Role of perpendicular propagation onset close to the antenna/wall on edge power loss revealed



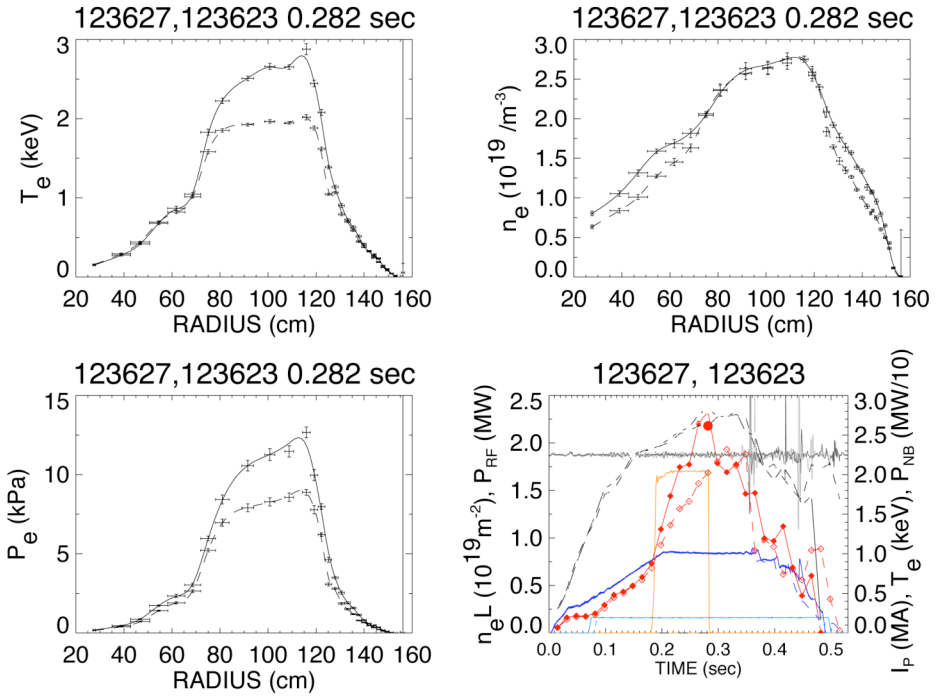
Status of HHFW Research (cont.)

- L-mode heating demonstrated for CD phasing (also for heating phasing) with and without NB

High T_e for high-k scattering run April 25
- compared to no RF case (no NB)



Significant HHFW heating in core for high-k scattering run April 26 with NB
- compared to no RF case (NB only)



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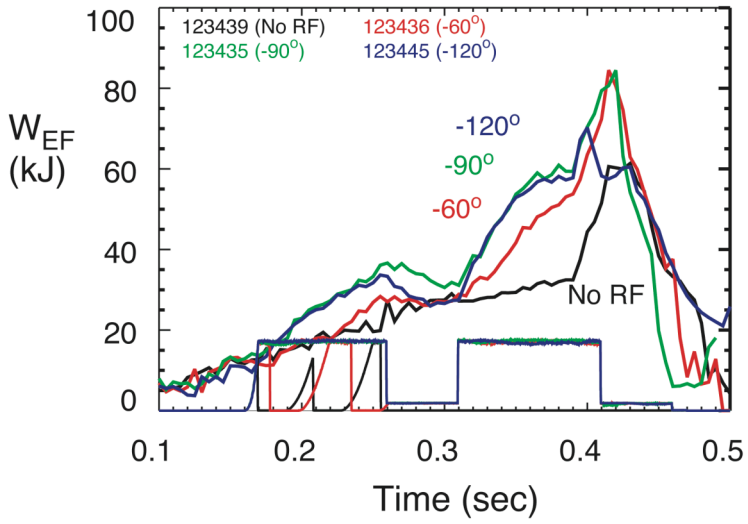
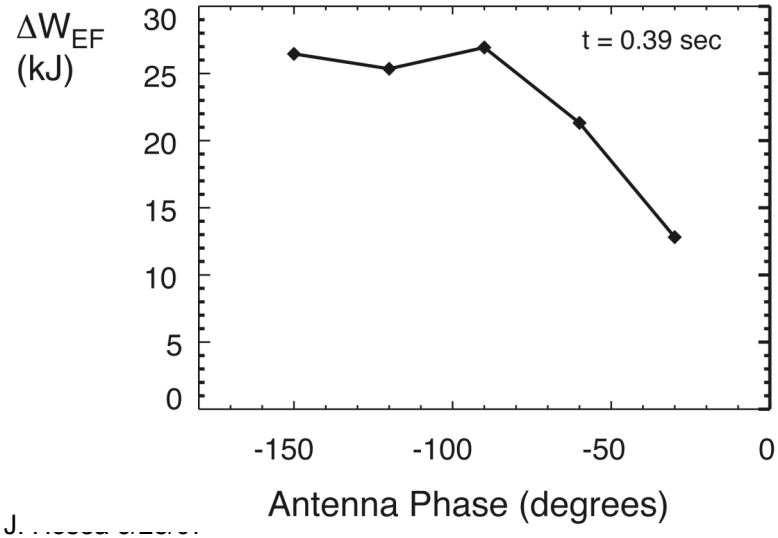
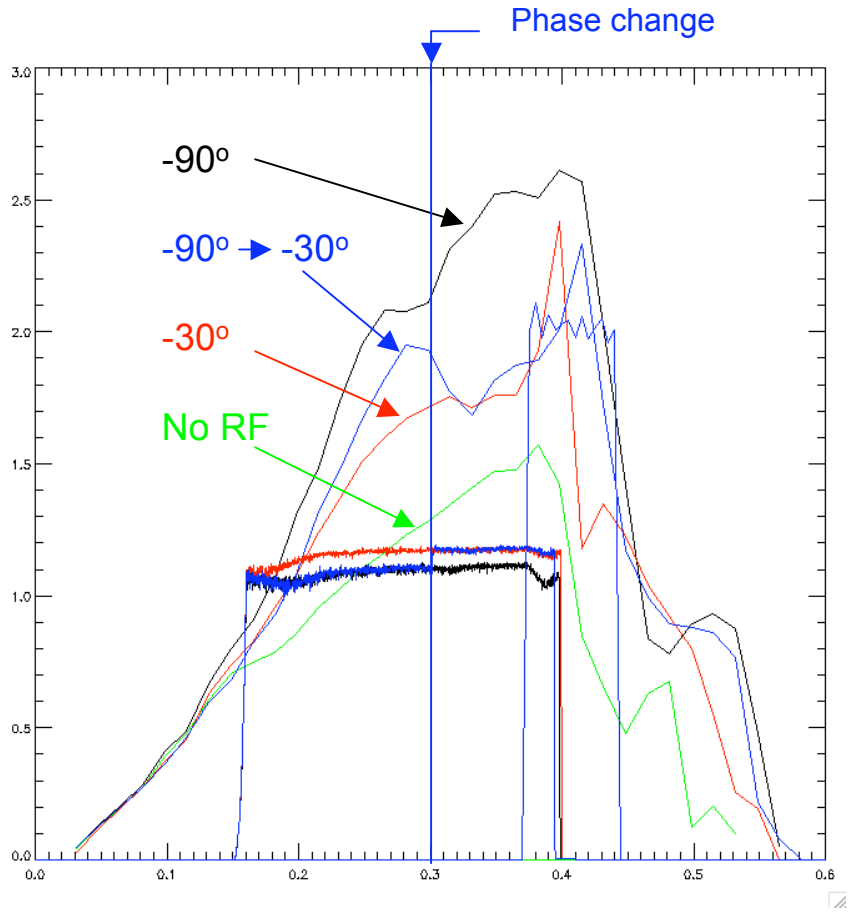
Status of HHFW Research (cont.)

- Heating at longer wavelength is observed with longer RF pulses but with less efficiency than for - 90^{o} (-7 m^{-1}) phasing



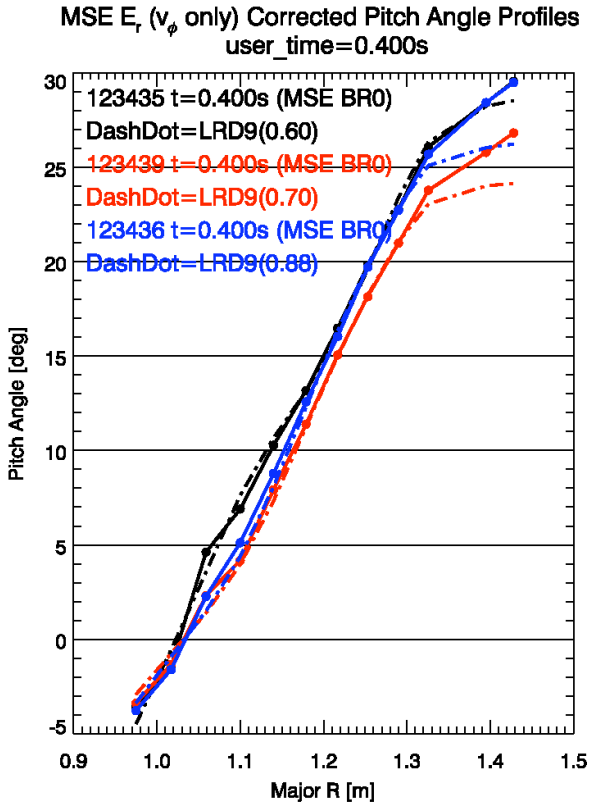


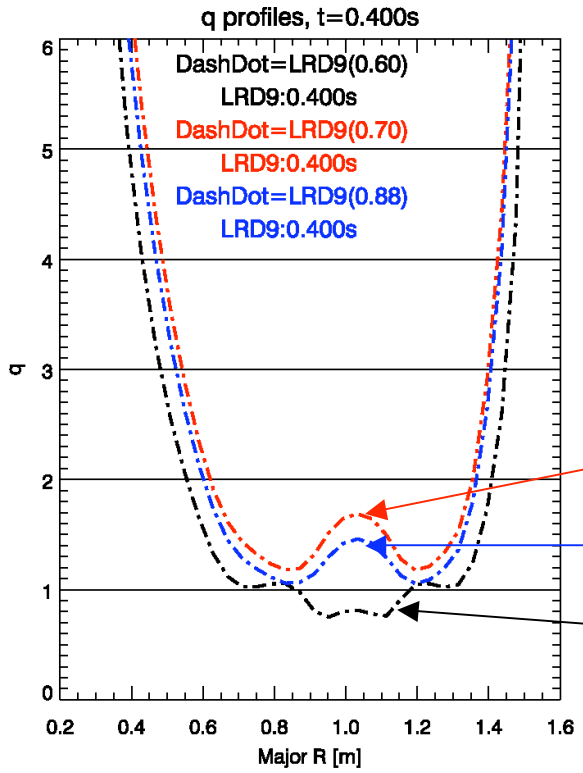
Heating at - 30^{o} is ~ 1/2 that at - 90^{o}



Status of HHFW Research (cont.)

- MSE CD studies have begun - core CD effects seen
  - CD effects rather small at powers used to date
  - Quantitative analysis underway
  - MHD affects comparison between co and counter CD
  - Counter case shows signs of ITB which could be caused by enhancement of negative central shear





Co current drive is apparent on axis for -90° (P_{RF} = 1.8 MW)

No RF

-60°

-90°

H. Yuh

J. Hosea 6/28/07

Status of HHFW Research (cont.)

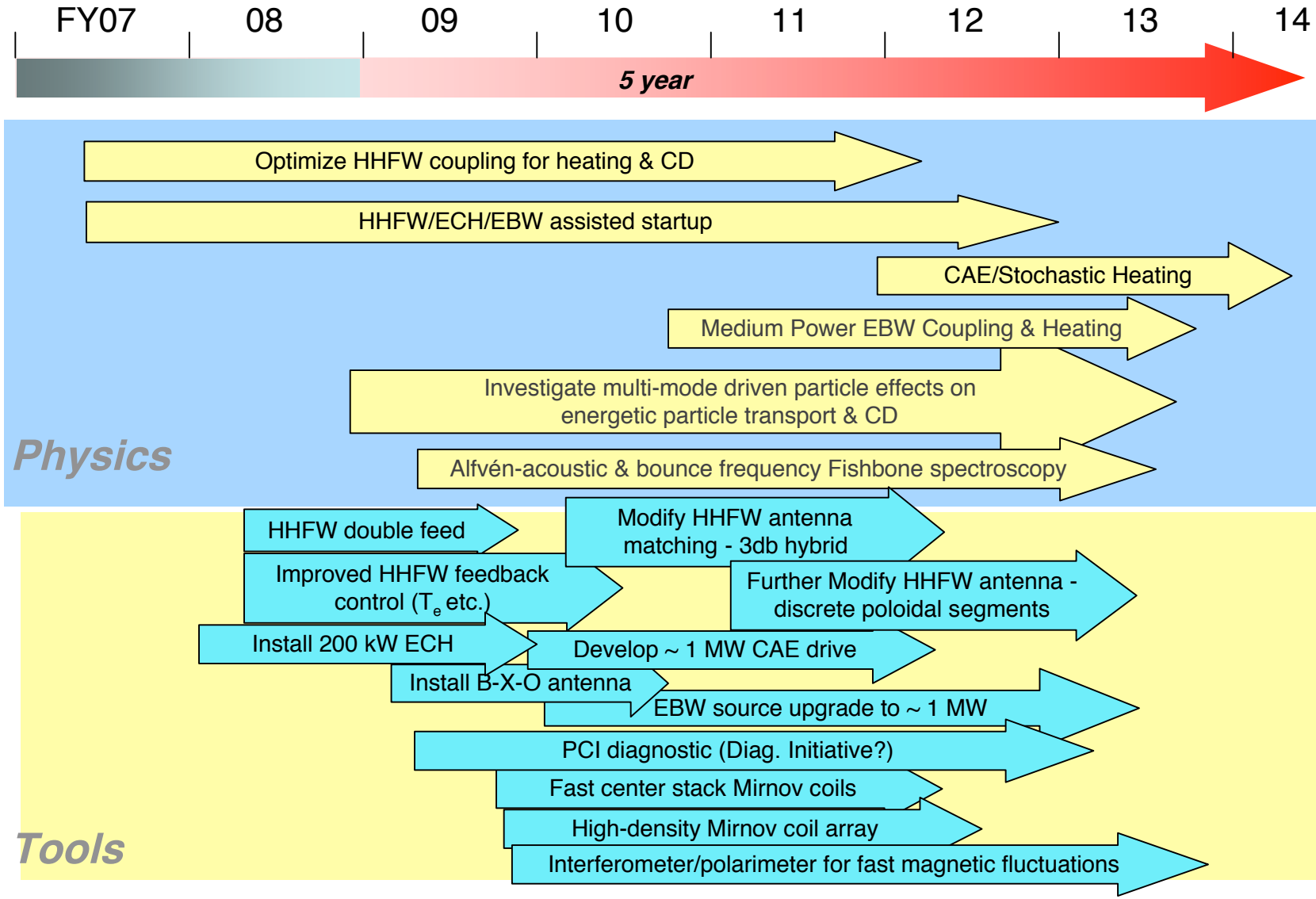
- It is clear that NB ions are interacting with the boron nitride end plates of the antenna
  - A larger plasma-antenna gap improves stability during the NB injection pulse used for the MSE measurement at the end of the RF pulse

5. HHFW Research Plan for 2008 - 2013

- 08
  - Extend physics studies to deuterium plasma improve operation with NB, and optimize heating efficiency
  - Begin H&CD studies for H-mode plasmas
- 09
  - Optimize H&CD operation with NB for L-mode and H-mode with upgraded antenna and using guidance of modeling
    - Larger plasma-antenna gap permitted with more stability and power (more V standoff and greater power for same V)
  - Begin startup/rampup optimization
- 10
  - Continue studies of 09
- 11
  - Begin operations with ELM dump - further optimize H-mode H&CD operation
- 12 - 13
  - Improve antenna based on results to date and continue startup/rampup and H-mode optimization

HHFW Research Plan for 2008 - 2013 (cont.)

Waves-Particle Interaction Research Timeline



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