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NSTX

HHFW Heating Efficiency and Current Drive Results for the 2007 NSTX Experimental Campaign

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NSTX Results Review
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Runs in Support of HHFW XPs: XP712 - Coupling Efficiency and XP717 - Current Drive

- **Goals:** XP712 - Optimize heating efficiency at high B field for +/- 7m^{-1}, 14m^{-1} to determine the determining parameters and in preparation for HHFW current drive/neutral beam studies

  XP717 - Measure current drive for RF into ohmic discharges with the addition of NB for enabling MSE measurement of current profiles

- **2007 Experimental runs:**
  - Feb 23 HHFW conditioning into plasma XMP026
    - » Set matching conditions for a range of phases ~ 1.2 MW
    - » Test adding NB source A for MSE
  - Mar 27 Conditioning at 14m^{-1} to higher power XMP026
    - » ~ 1.8 MW
  - Apr 19 Scan of phase for power balance XP712
    - » 0.6 MA, 5.5 kG, helium
    - » 100 ms RF pulses, NB source A at end of second pulse, ~ 1.7 MW
  - Apr 25 High k Scattering Mazzucato XP735
    - » 700 kA, 5.5 kG, helium
    - » Good heating with 14m^{-1} (180^{o}) and -7m^{-1} (-90^{o})
    - » ~ 1.8 MW
  - Apr 26 High k scattering Yuh XP734
    - » 1 MA, 5.5 kG, helium + deuterium
    - » Good heating during NB @ 14m^{-1} and -7m^{-1}
    - » ~ 1.7 MW
  - Apr 30 Non- solenoidal current rampup Kessel XP731
    - » 0.3 MA, 5.5 kG, deuterium
    - » P_{RF} up to ~ 2.3 MW
    - » H-mode apparent for -90^{o} and -150^{o}

2007 Experimental Runs (cont.)

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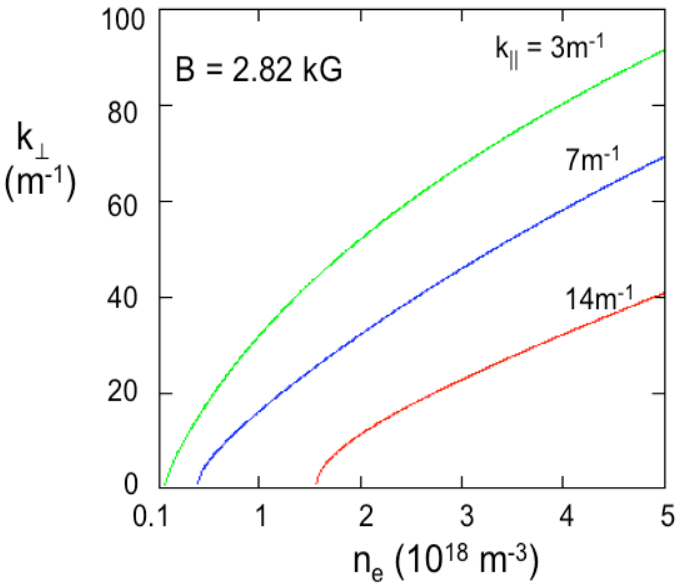
- May 1 — HHFW current drive XP717
  - » RF during NB: - P_{RF} scan for several phases; - gap changes
  - » NB pulse added to RF
  - » Counter CD (90°) try unstable due possibly to ITB formation
  - » Deuterium try but density was not controllable
- Jun 12 — High k scattering Mazzucato XP 735
  - » 600 kA, 5.5 kG, helium
  - » Good heating for ~7m^{-1}
  - » P_{RF} up to 2.5 MW, MHD at highest power
- Jun 13 — High k scattering Yuh XP734
  - » 14m^{-1} mostly, RF during NB
  - » P_{RF} up to ~ 1.6 MW
- Jun 13 — HHFW current drive XP717
  - » +90°, -90°, -150° for ~ 1.6 MW
- Jun 19 — HHFW current drive XP717; High k scattering Mazzucato, Yuh, Smith XPs734-35
  - » $+90^0$, -90°, 90° for ~ 1.2 MW; gap change for 90°, -90° at 1.2 MW
  - » 90°, -90° at 1.8 MW; -90° followed by -30° in same shot
  - » Fill in shots for high k scattering
- Jun 23 — High k scattering Yuh and Smith XP734
  - » Fill in shots
  - » Sources showing signs of aging tubes or oscillating phase control

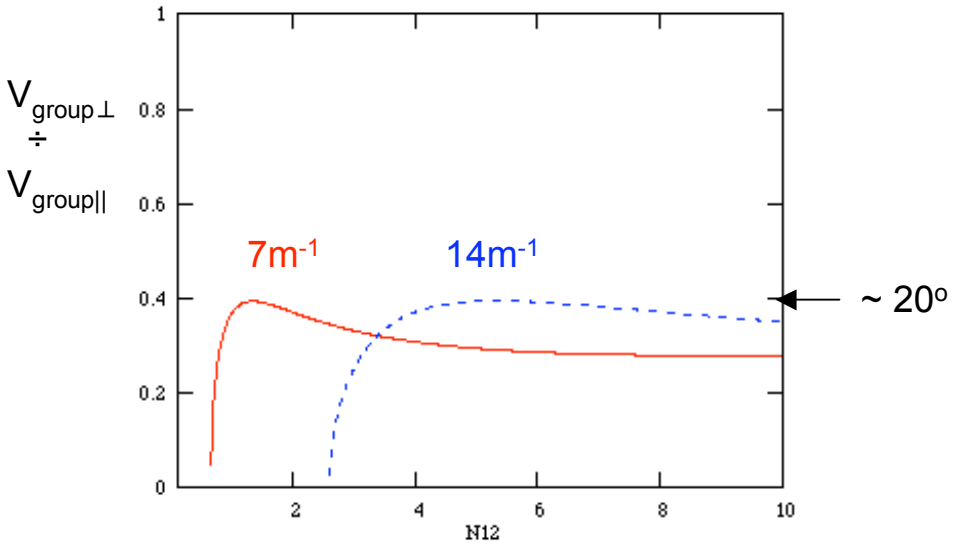
Coupling/heating efficiency studies

- HHFW coupling, propagation and damping physics are important areas of research for NSTX

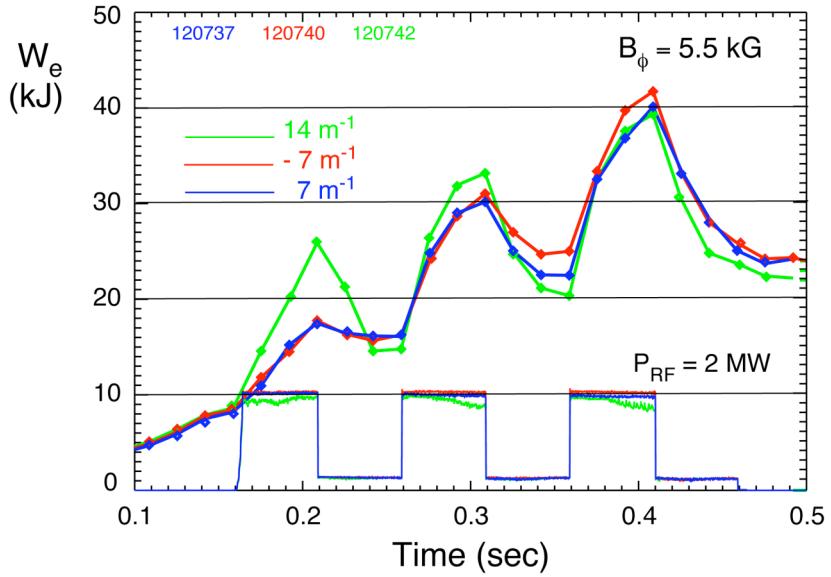
  How to optimize coupling of HHFW power to the core plasma

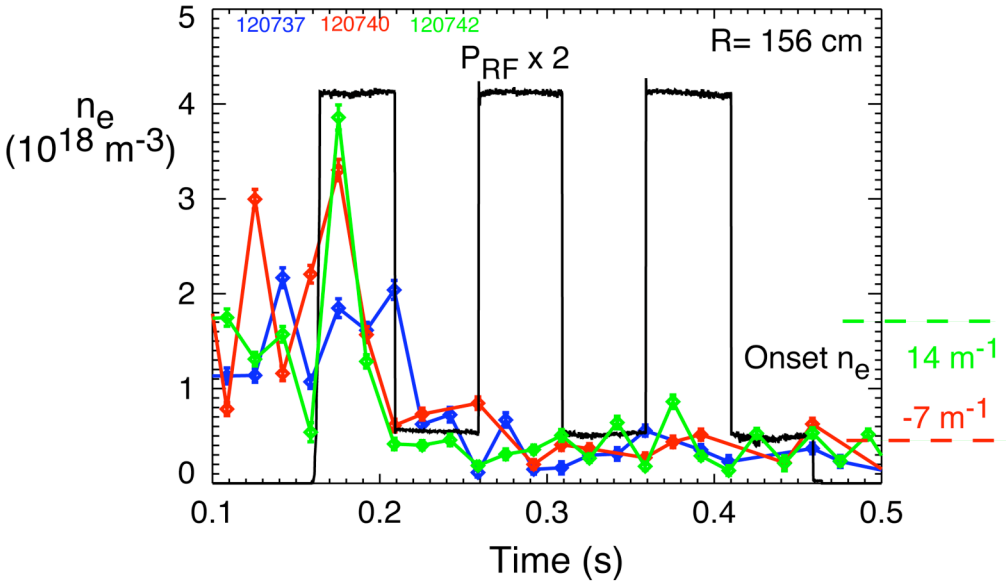
  1. Avoid surface wave interaction with edge plasma and antenna/walls to the extent possible
     - **Keep edge density near antenna low relative to the onset density for perpendicular propagation ($\propto B \times k_{||}^2/\omega$)**
  2. Optimize MHD stability to limit losses in the electron channel 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, PDI heating





Edge density appears to affect the heating when it is above the onset density close to the antenna





- Efficiency for -7 m^{-1} is ~ 1/2 the 14 m^{-1} value for first RF pulse with edge n_e > FW n_e onset value
- Efficiency for -7 m^{-1} is ~ equal to the 14 m^{-1} value for second and third RF pulses with edge n_e ≤ FW n_e onset value
- How does efficiency decrease at even longer wavelength? XP712
  - function of λ only?
  - function of sign of phase?
  - function of reactive field cancellation between straps?
- Can current be driven with improved coupling efficiency at -7 m^{-1}? XP712/XP717

Reduction in Heating Efficiency is Observed at Longer Wavelength at B_ϕ = 5.5 kG (XP712)

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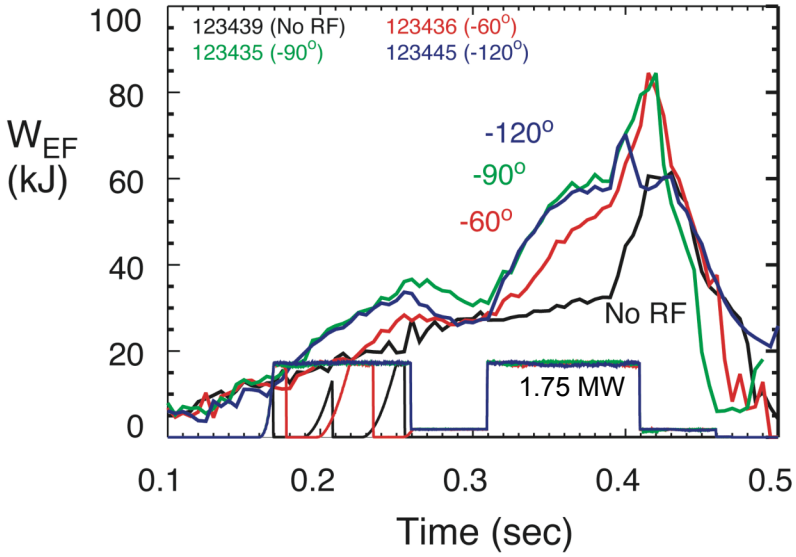
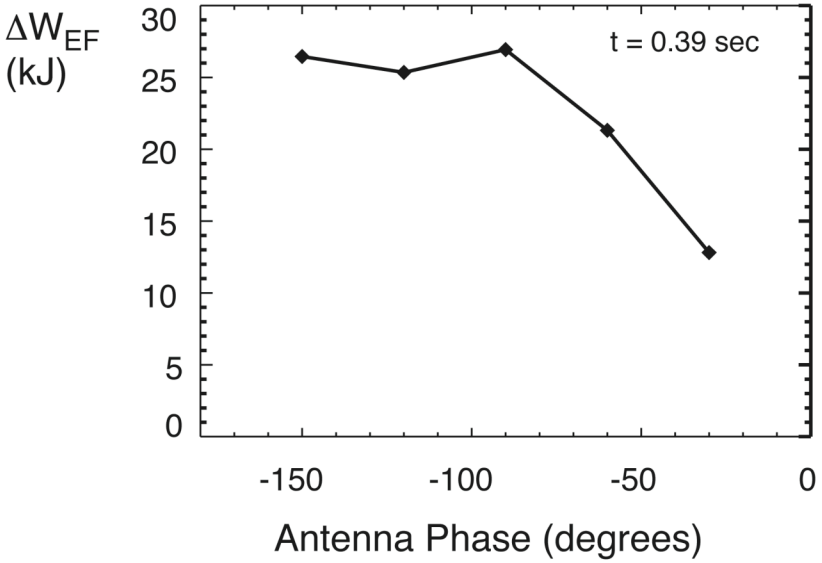
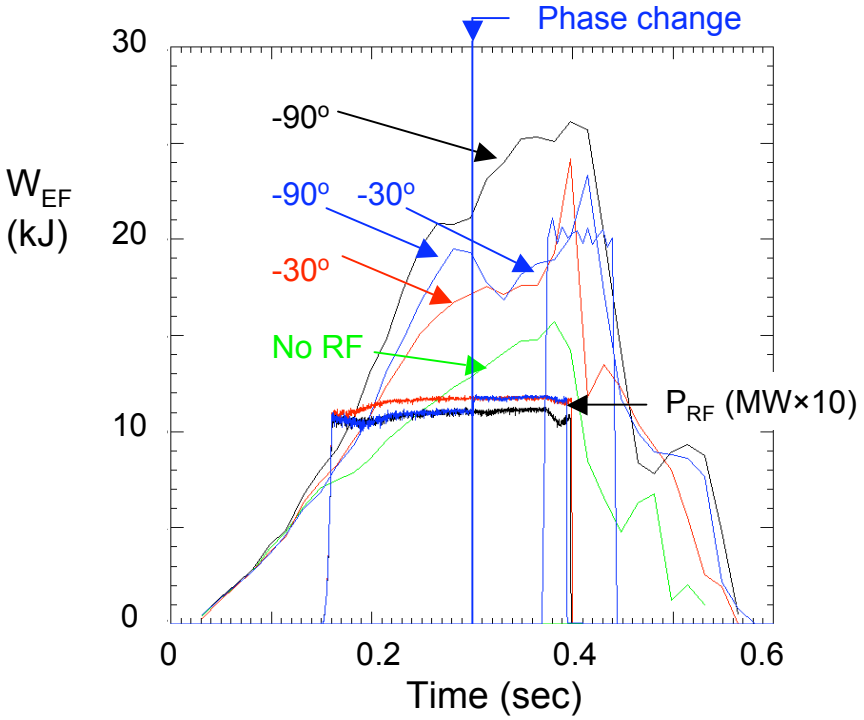
Phase scan in co-current direction





- Wavelength plays a dominant role in RF surface losses
- Cancellation of near strap currents is apparently not as important
- Surface losses appear not to be dependent on core damping

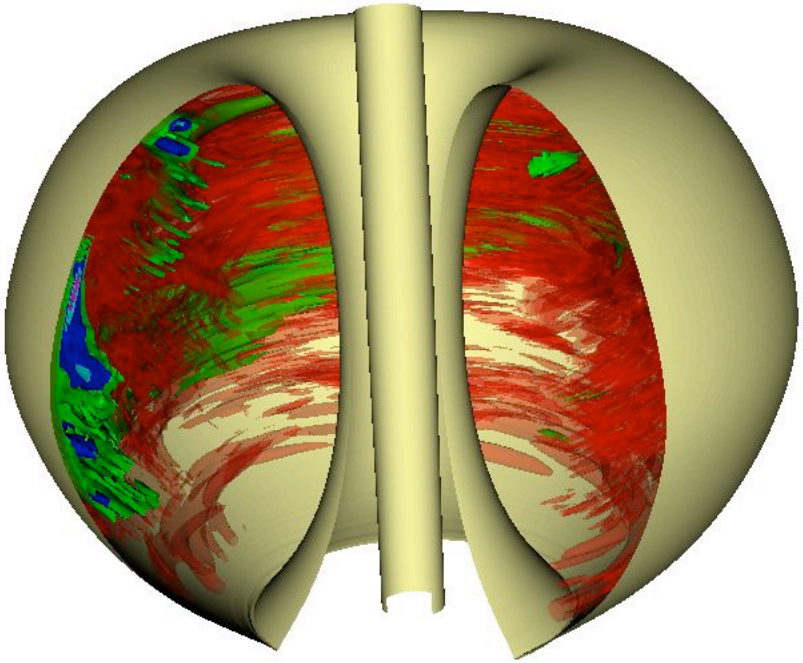
Heating at - 30° is ~ 1/2 that at - 90°



Surface waves around the torus are now being simulated with AORSA for NSTX

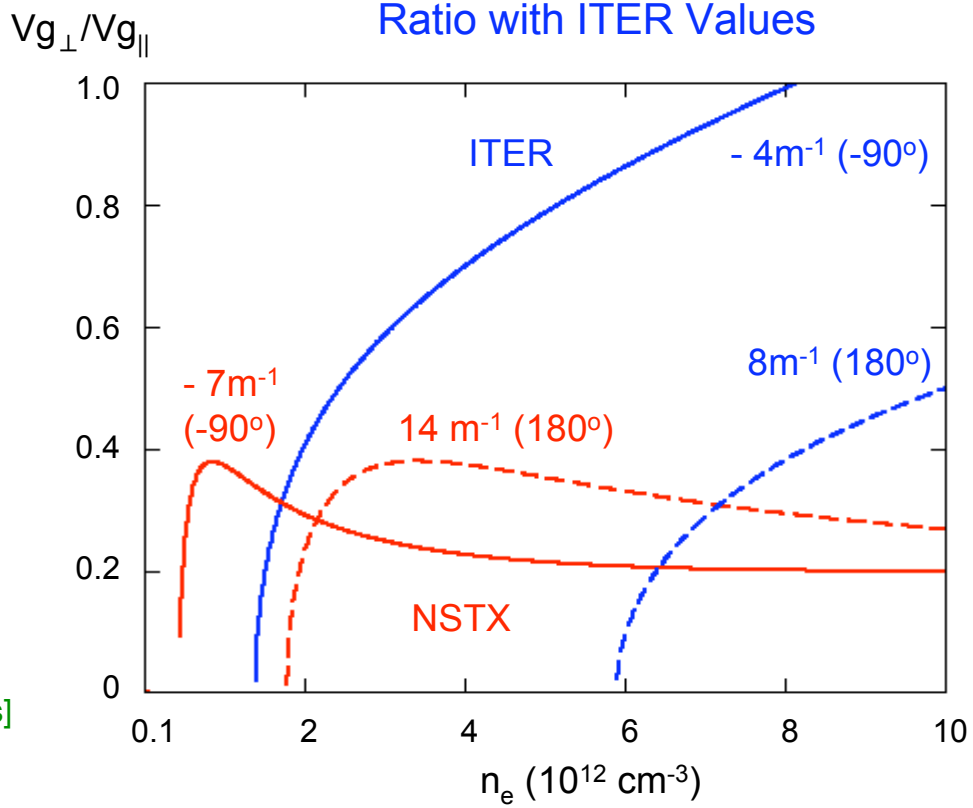
- With edge density enhancement for improved coupling on ITER, onset density could be exceeded at antenna/wall

AORSA simulation for NSTX -90° case



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

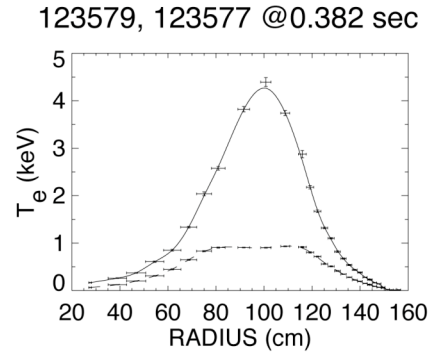
Comparison of NSTX Group Velocity Ratio with ITER Values

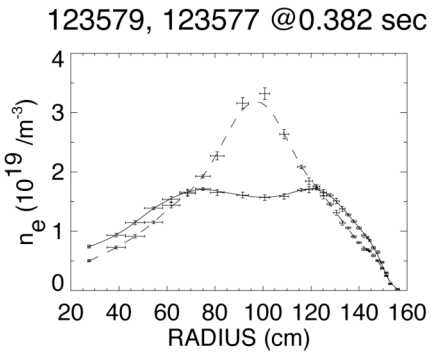


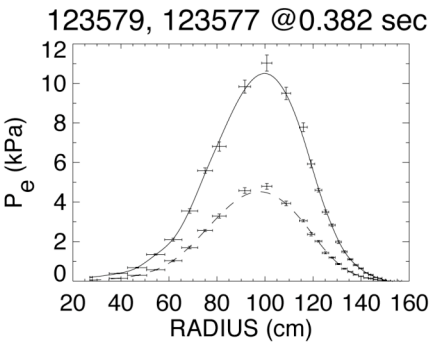
Prerequisite efficient heating demonstrated for CD phasing in L-Mode with and without NB (XP717)

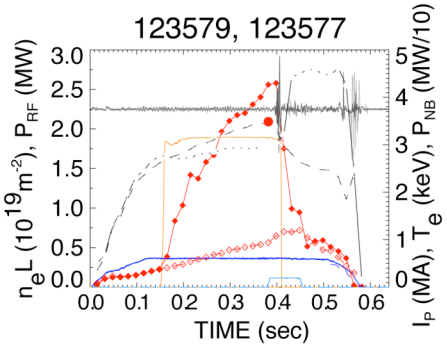
High T_e for high-k scattering run April 25
- compared to no RF case (no NB)

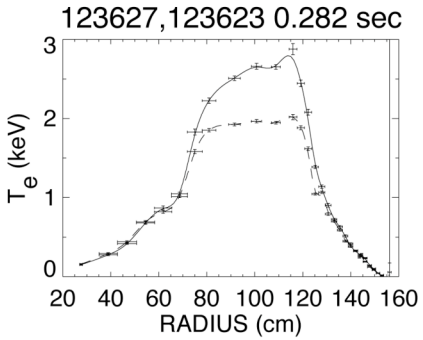
Significant HHFW heating in core for high-k scattering run April 26 with NB
- compared to no RF case (NB only)

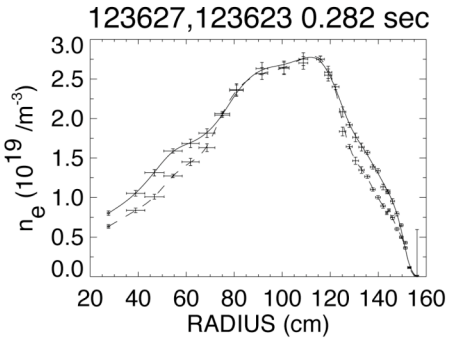


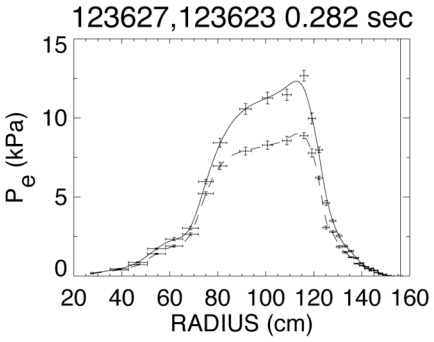


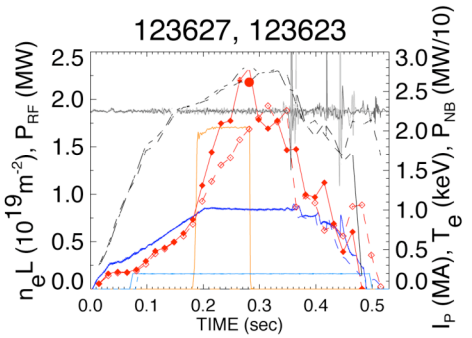






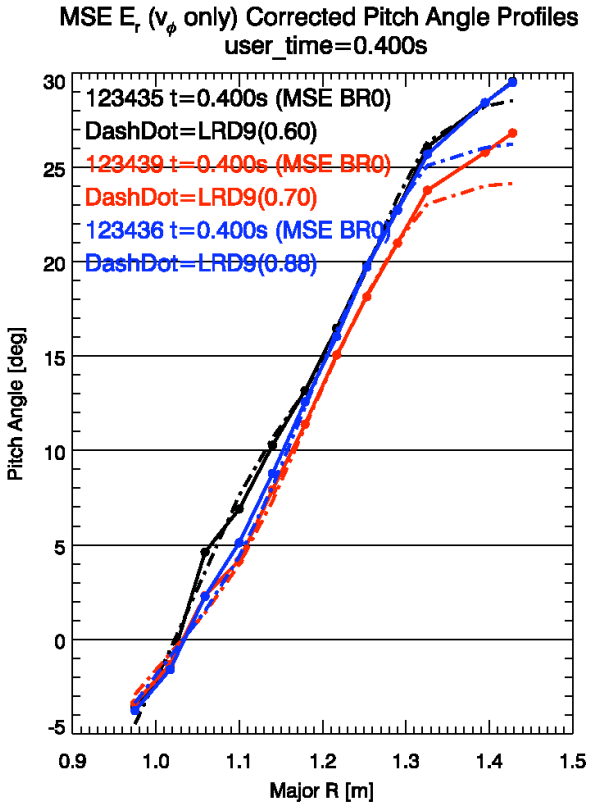


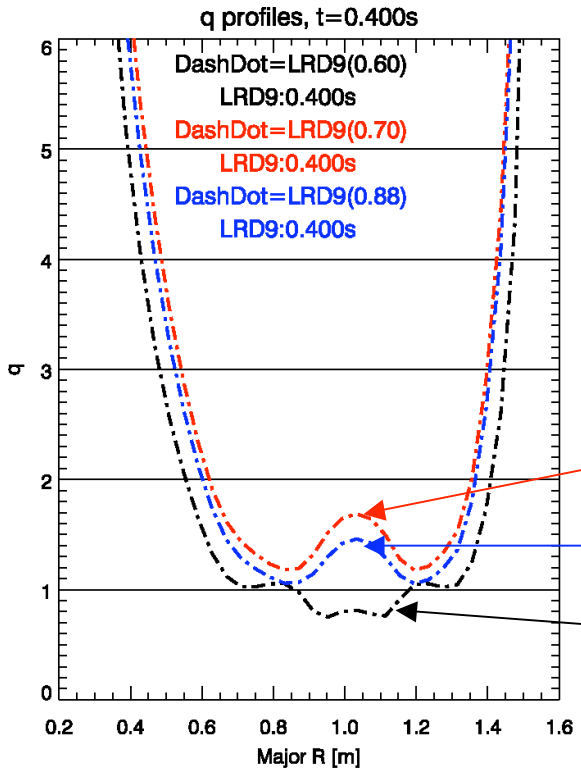




MSE CD studies have begun - core CD effects seen

- 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°

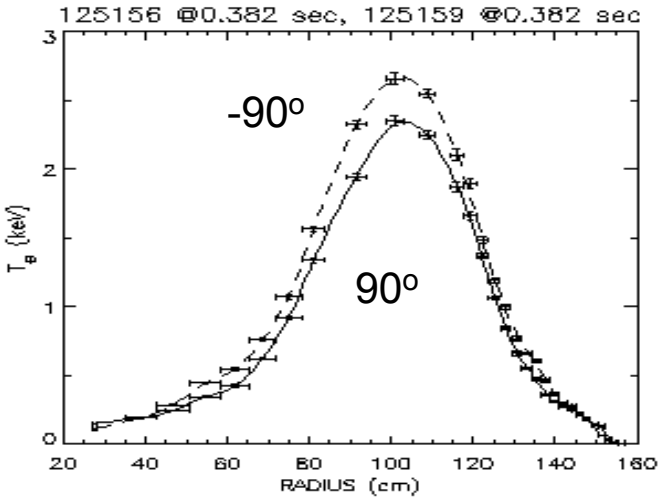
-90°

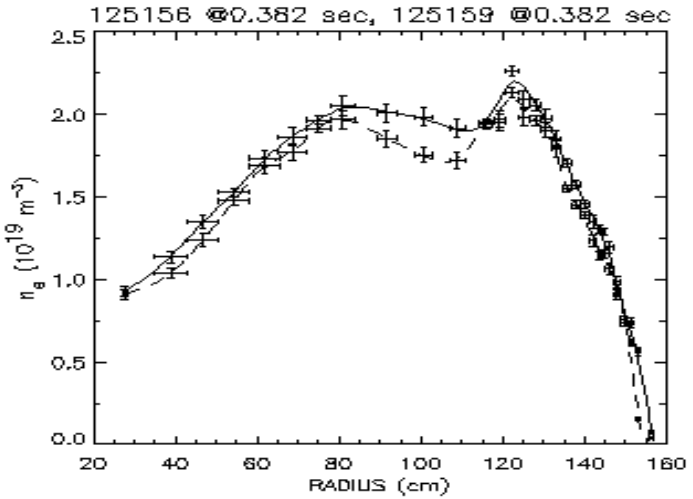
H. Yuh

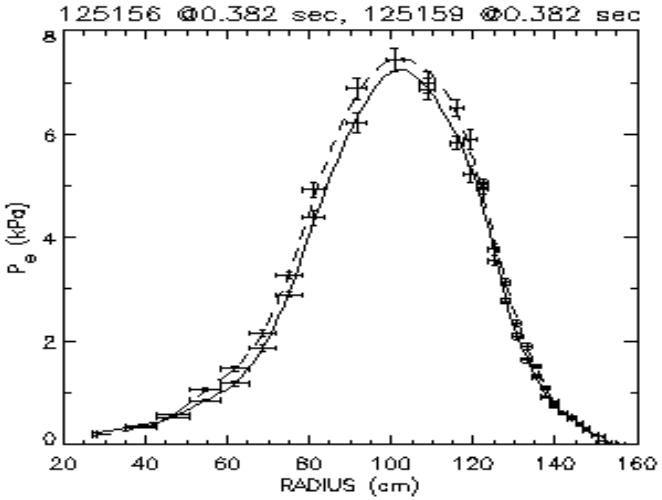
Comparison CD cases being analyzed

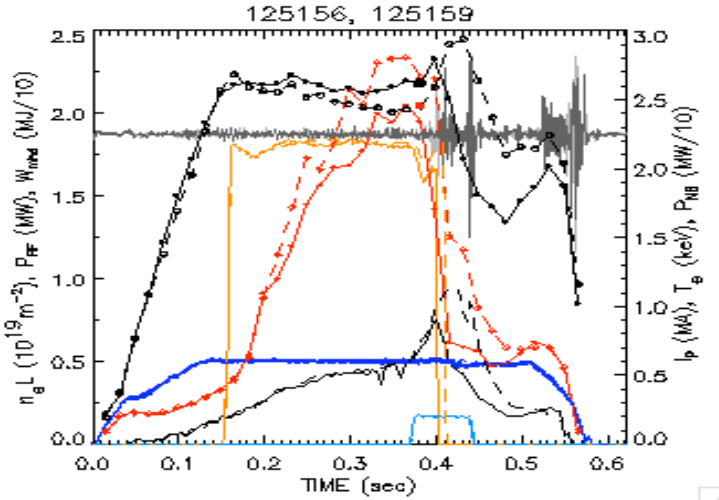
- Selected cases: 1.8 MW ⇒ 90° vs -90°
  1.2 MW ⇒ 180° vs -90° ; +90° vs -90° ; 90° vs -90°
  1.2 MW ⇒ 90° vs -90° with larger gap

1.8 MW case:
——— 90°
- - - - - - 90°









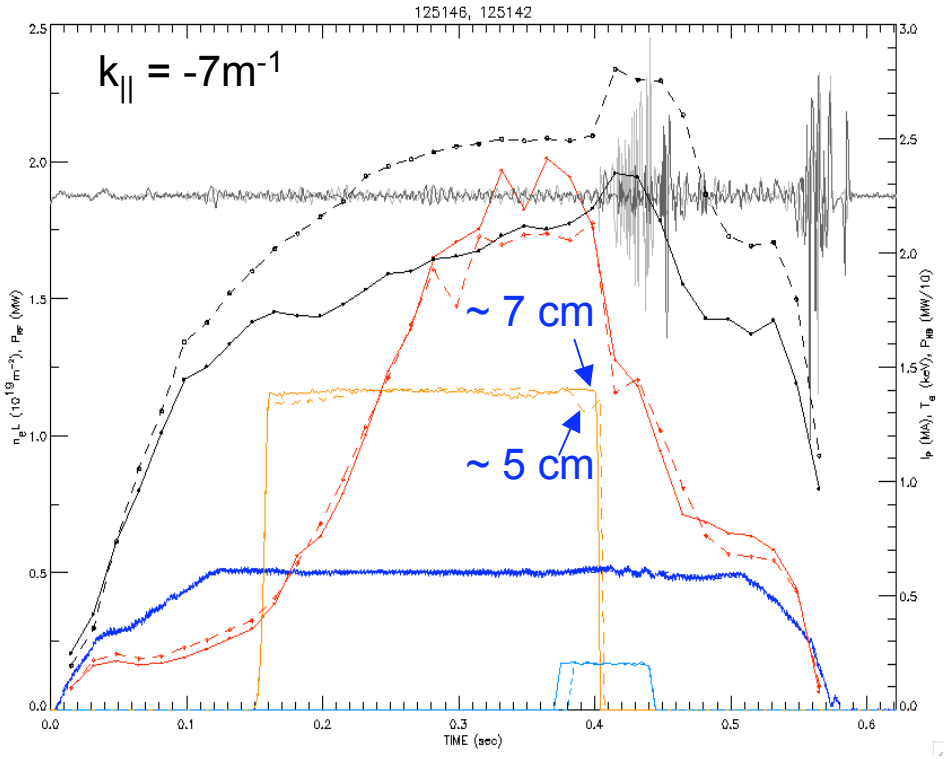
Conclusions

- Role of perpendicular propagation onset close to the antenna/wall on edge power loss revealed
- Efficient L-mode heating demonstrated for CD phasing with and without NB
- CD is indicated by MSE measurements but not very large
  - Comparison with theory underway

Steps needed

- Need larger gap to reduce NB ion interaction with the boron nitride plates of the antenna
  - Improve stability during NB MSE pulse and keep edge density low during NB operation

NB perturbation of RF power is removed by enlarging gap
~ 5 cm ⇒ ~ 7 cm



- Need to upgrade antenna to support higher power with larger gap
  - Optimize CD in L-mode and extend H&CD to H-mode plasmas

- Need theory and modeling guidance for optimizing heating and CD
  - Can heating and CD be tailored for on and off axis applications?
  - Can HHFW CD be used to help stabilize core MHD, e.g., by increasing reverse shear in core with counter CD?