HHFW Propagation and Damping Properties on NSTX vs B_T and Antenna $k_{||}$

NSTX

College W&M
Colorado Sch Mines
Columbia Univ
Comp-X
General Atomics
INEL
Johns Hopkins Univ
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York Univ
Old Dominion Univ
ORNL
PSI
Princeton Univ
SNL
Think Tank, Inc
UC Davis
UC Irvine
UCLA
UCSD
Univ Colorado
Univ Maryland
Univ Rochester
Univ Washington
Univ Wisconsin

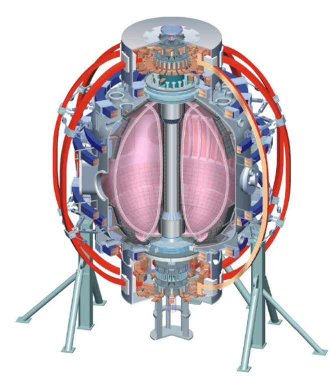
J. Hosea, R. Bell, S. Bernabei, L. Delgado-Aparicio, B. LeBlanc, C.K. Phillips, P. Ryan, S. Sabbagh, K. Tritz, J. Wilgen, J.R. Wilson

Princeton Plasma Physics Laboratory

on behalf of the

NSTX Research Team

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



PPPL PRINCETON PLASMA PHYSICS LABORATORY

Supported by Office of Fusion Energy Sciences Office of Science

HHFW Propagation and Damping Properties on NSTX vs B_T and Antenna $k_{||}$

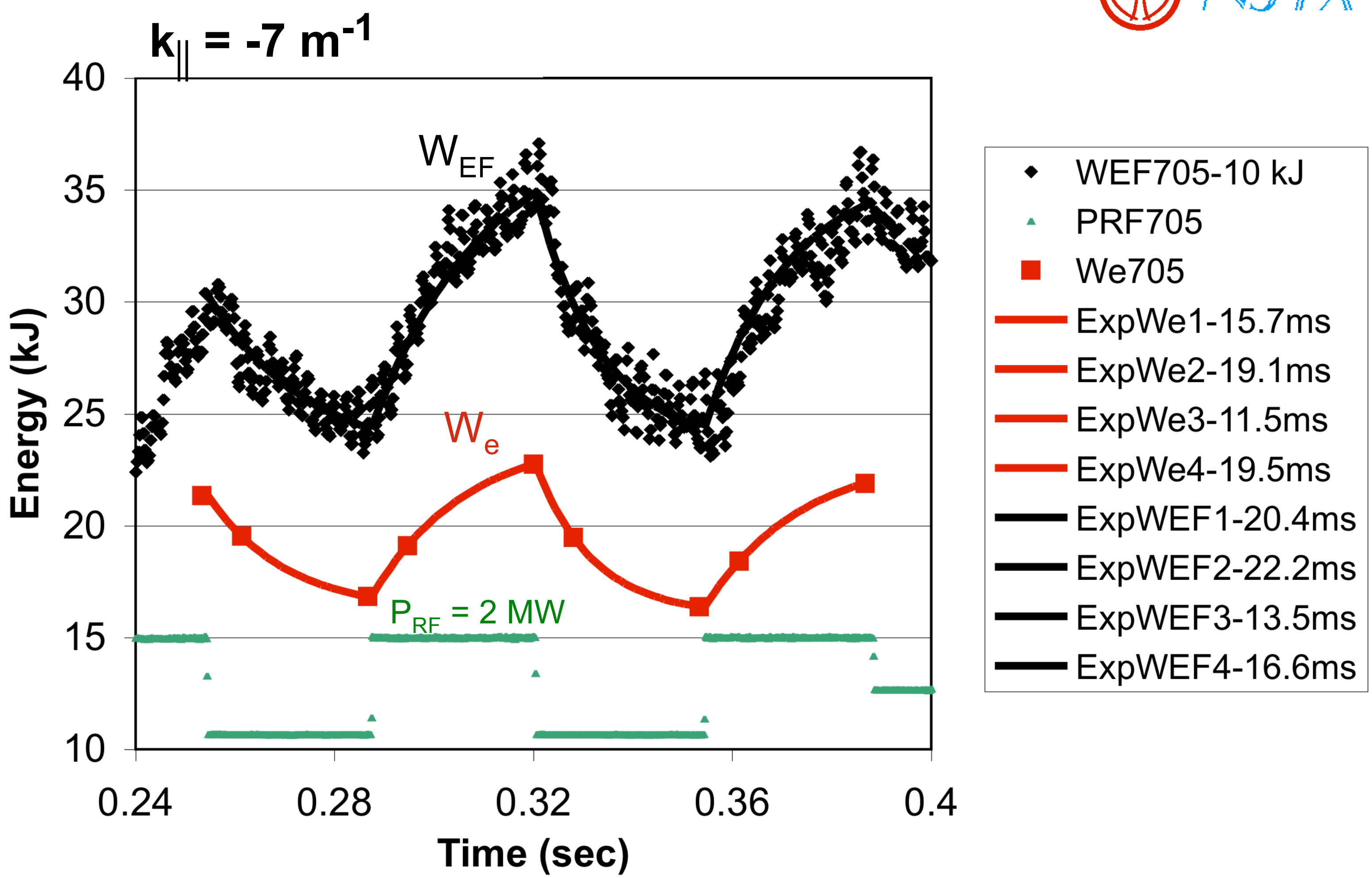
- Goal: Study RF power loss properties at several $k_{||}$ values as a function of magnetic field in order to separate parametric decay instability (PDI) and surface wave losses:
  - PDI ion heating should be somewhat weaker at higher field
    - Edge RF fields should decrease with B since Vgroup $\propto$ B
  - Surface fast wave propagation characteristics should be a strong function of $k_{||}$ and B_T
    - Wave propagation onset density is $\propto B * k_{||}^2$ in front of the antenna
- RF power deposited in the plasma core is evaluated by modulating the RF power and fitting the rise and fall of the stored energy with exponential functions

$$W(t) = W_0 - (W_0 - W_F)*(1 - e^{-t/\tau})$$

  - $P_{RFDep} = \Delta W_F/\tau$

- RF power loss is then $\Delta P_{RFpulse} - P_{RFDep}$

Electron Stored Energy and τ Values Evaluated for $k_{||} = -7\ m^{-1}$, at $B_T = 4.5$ kG, $I_P = 600$ kA



- W_e is obtained by integrating Thomson scattering $P_e(r)$ over the EFIT magnetic field surface volumes
- Electron and total stored energy exhibit exponential rises and τ_{We} is comparable to the corresponding value τ_{WEF}

P_{RF} Losses at Edge of Plasma Are Larger for Lower $k_{||}$

NSTX

- RF power deposited in plasma core is estimated by $P_{RFDep} = \Delta W_F/\tau$

Heating Efficiency [$P_{RFDep}/\Delta P_{RF}$] (%)]:

	Electrons	Total
– 14 m^{-1} :		
Second RF Pulse (Sawtooth instability much weaker for this pulse)	84	101
Third RF Pulse	48	68
– 7 m^{-1} :		
Second RF Pulse	24	39
Third RF Pulse	22	44

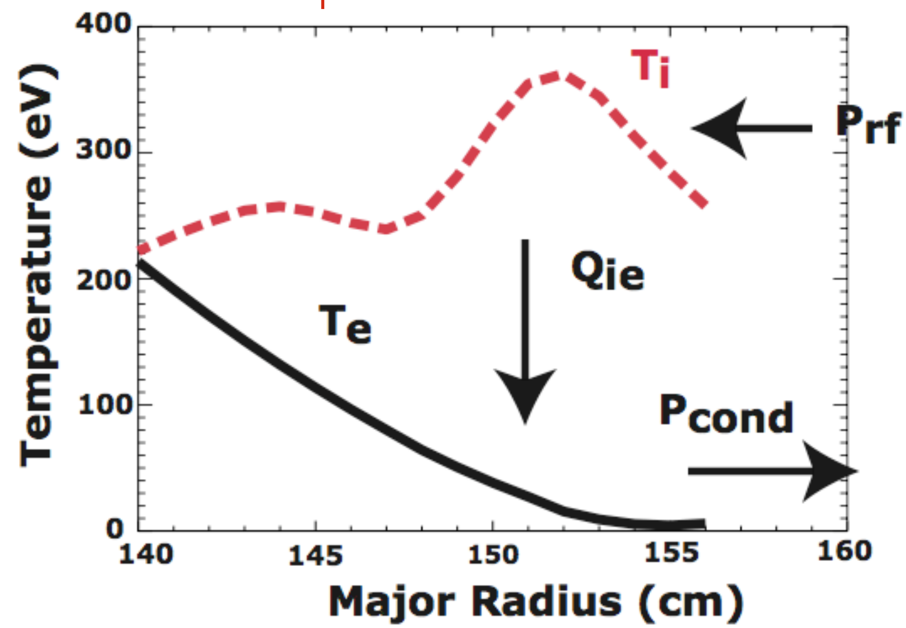
- RF power reaching the core is considerably reduced for the smaller $k_{||}$ case

Parametric Decay Instability (PDI) Losses are Evident at Both $k_{||}$ Values

NSTX

- Strong edge ion heating via parametric decay waves is observed with edge charge exchange spectroscopy
- Significant RF power is required to sustain the large temperature difference between the edge ions and electrons
  - 16%/23% loss for 14 m^{-1}/-7 m^{-1} for P_{RF} = 2 MW
- Power loss increases somewhat with wavelength
  - but other loss mechanism(s) are required to explain much lower heating efficiency at lower $k_{||}$

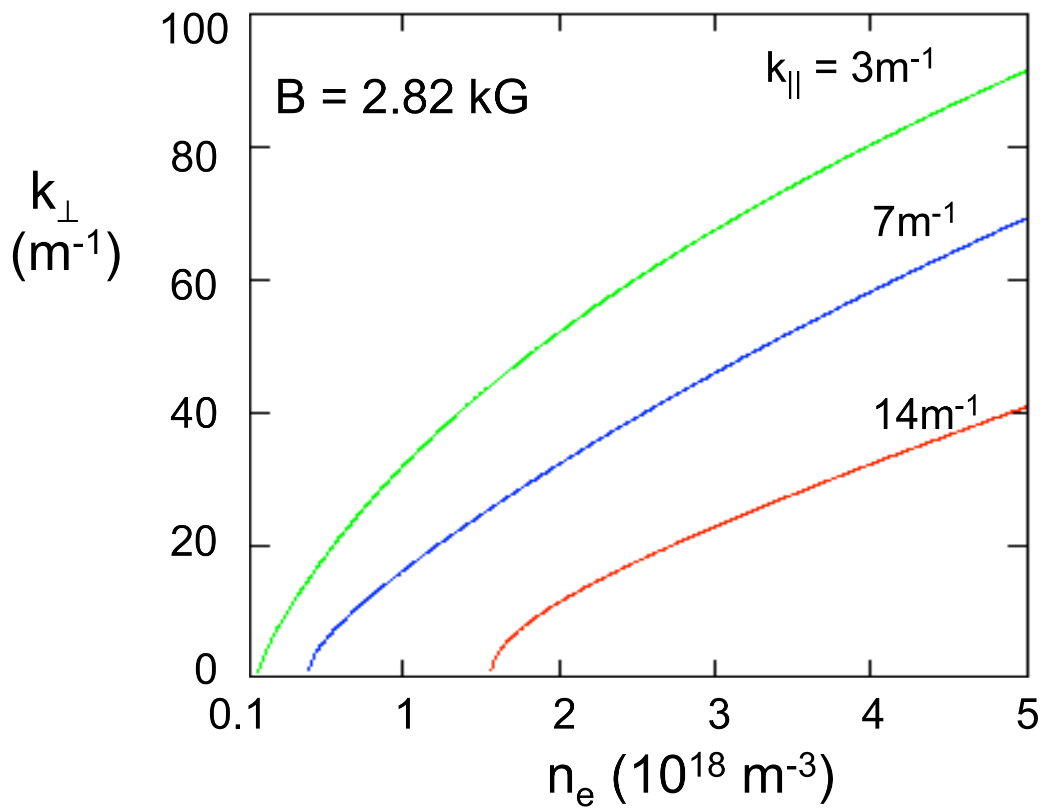
T_i for helium



T.M. Biewer et al., Physics of Plasmas 12 (2005) 056108

Surface waves also appear to contribute to losses – propagation of fast wave begins at lower density for lower $k_{||}$

Propagating $k_\perp$ vs density and $k_{||}$ with B = 2.82 kG (B_T = 4.5 kG) at R = 1.56 m (2 cm from antenna)



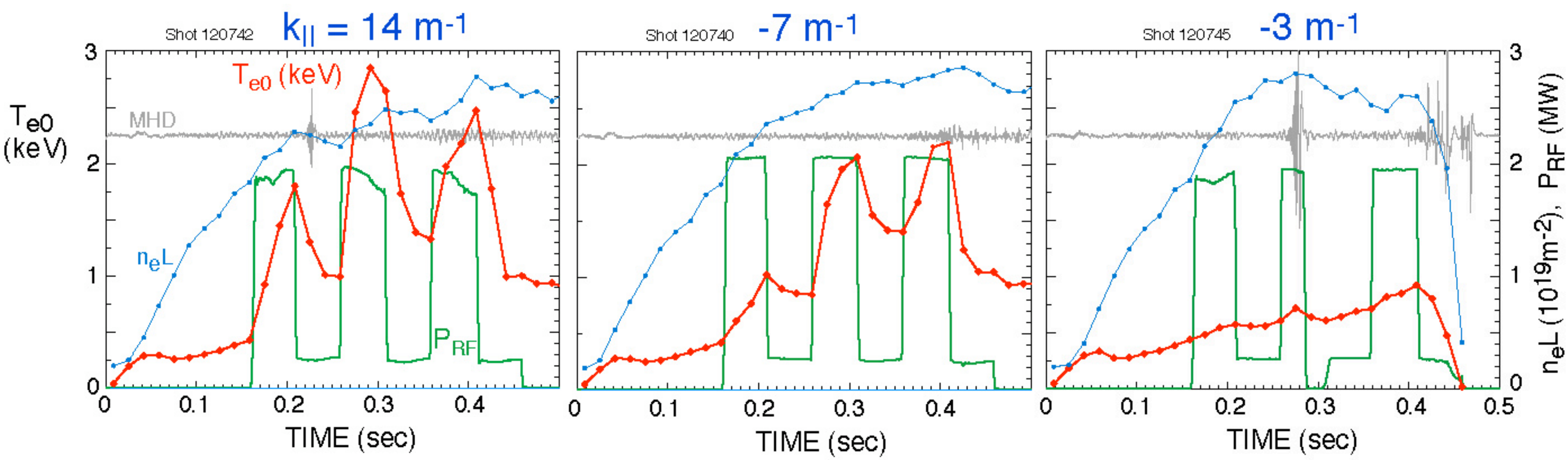
Density onset is function of ~ $B^*k_{||}^2$

- Propagation is very close to wall at 7m^{-1} and on the wall at 3m^{-1}
- Losses in surface should be higher for lower $k_{||}$
- Increasing B should push onset farther from antenna and increase heating

Core Electron Heating Depends Strongly on $k_{||}$ and B

NSTX

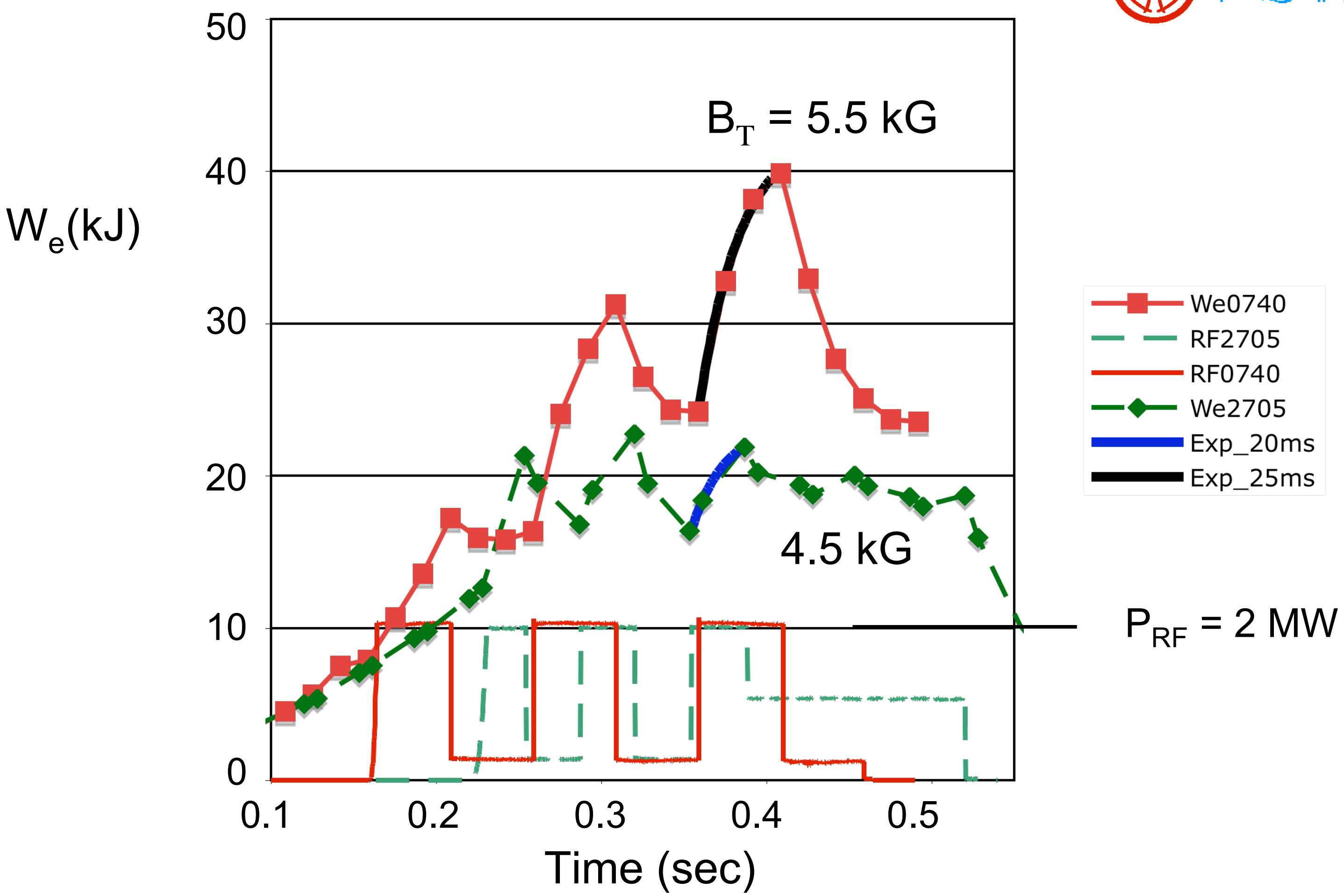
Electron heating for B_T = 5.5 kG, I_P = 720 kA



- Strong dependence on $k_{||}$ is clear — almost no heating at - 3m^{-1}
- Heating at -7m^{-1} is greatly improved over the earlier B_T = 4.5 kG case for the second and third RF pulses
  - comparable to 14m^{-1}
- Heating at -7m^{-1} for first RF pulse is about half that for 14m^{-1}

ΔW_e for $k_{\|} = -7\ m^{-1}$ is Increased Substantially with an Increase in B_T from 4.5 kG to 5.5 kG

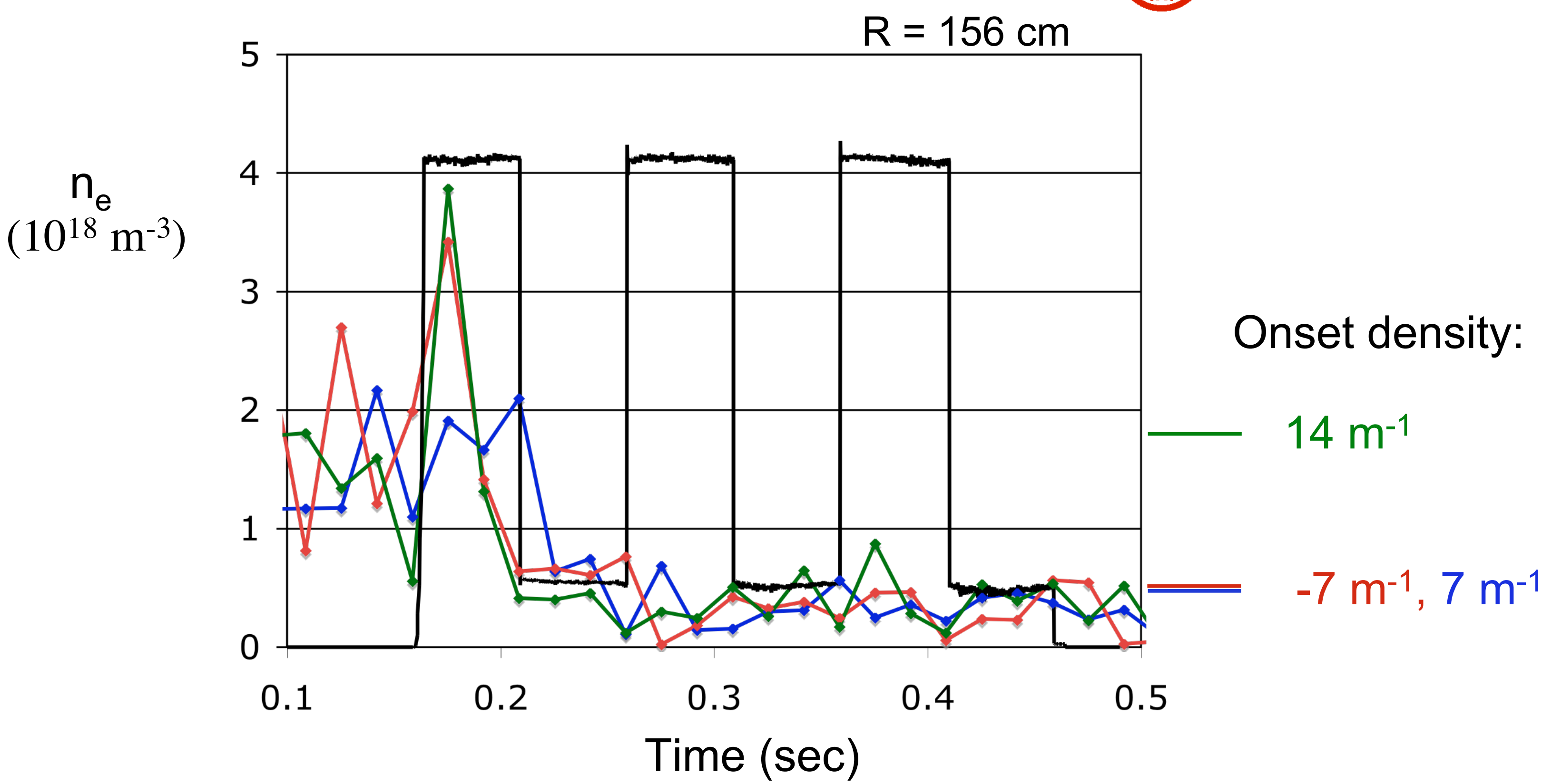
NSTX



- ΔW_e for B_T = 5.5 kG is ~ 2 times the value for 4.5 kG over the same time interval.
- The RF power deposition into the electrons increases from ~ 22% to ~ 40% at the higher field and the total efficiency increases from ~ 44% to ~ 65%.

Thomson Scattering Density in the Plasma Edge is High During the First RF Pulse

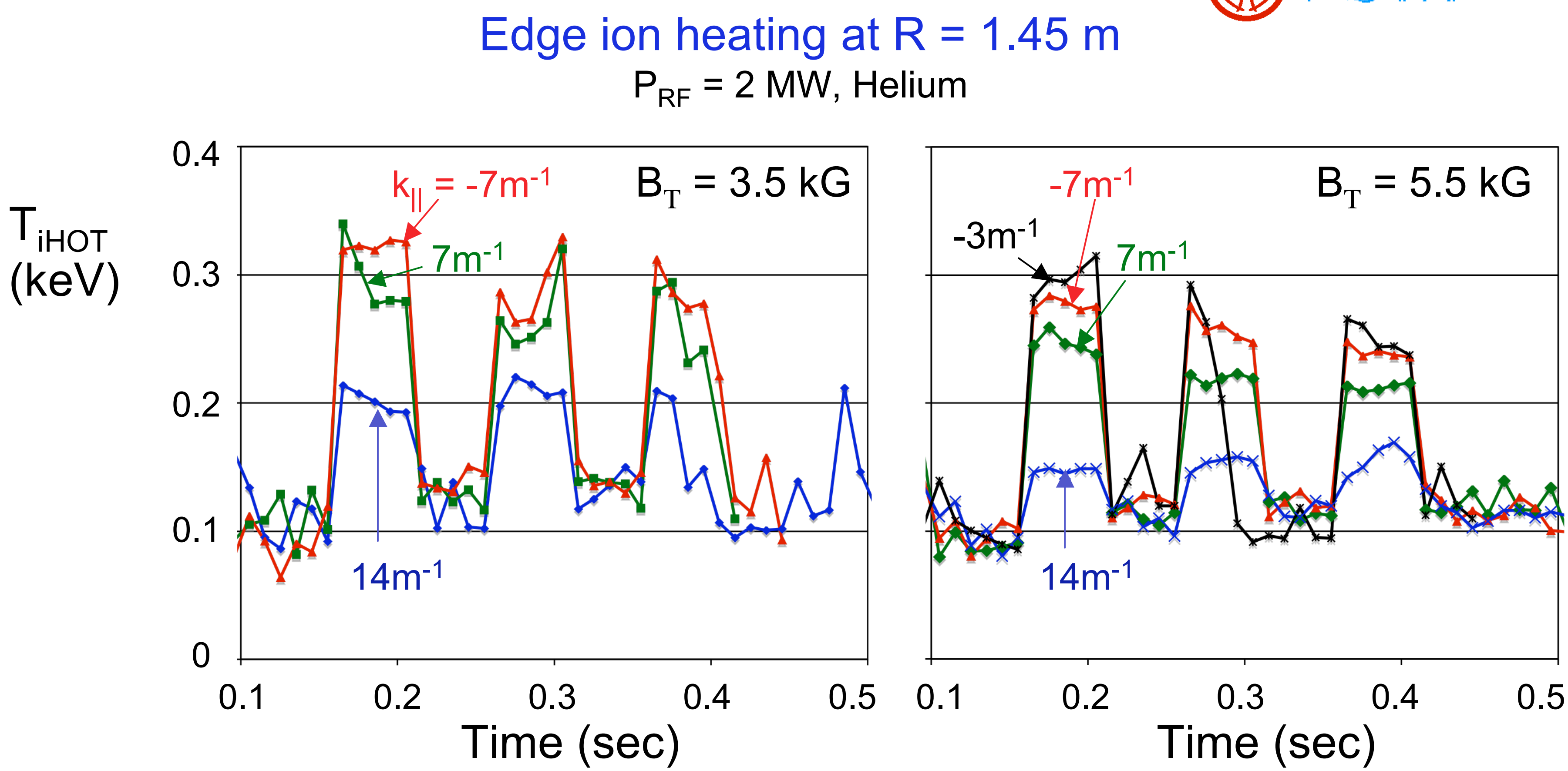
NSTX



- Edge density appears to affect the heating when it is above the onset density close to the antenna
- This suggests that surface wave propagation near the wall/antenna is contributing to RF power losses

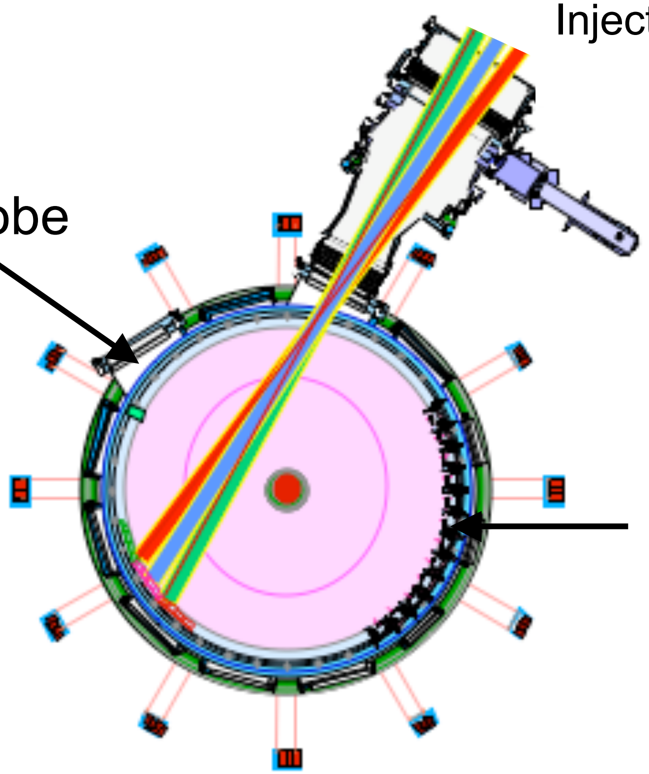
PDI heating is not a strong function of B_T at lower $k_{||}$ and does not account for improved heating at B_T = 5.5 kG

NSTX



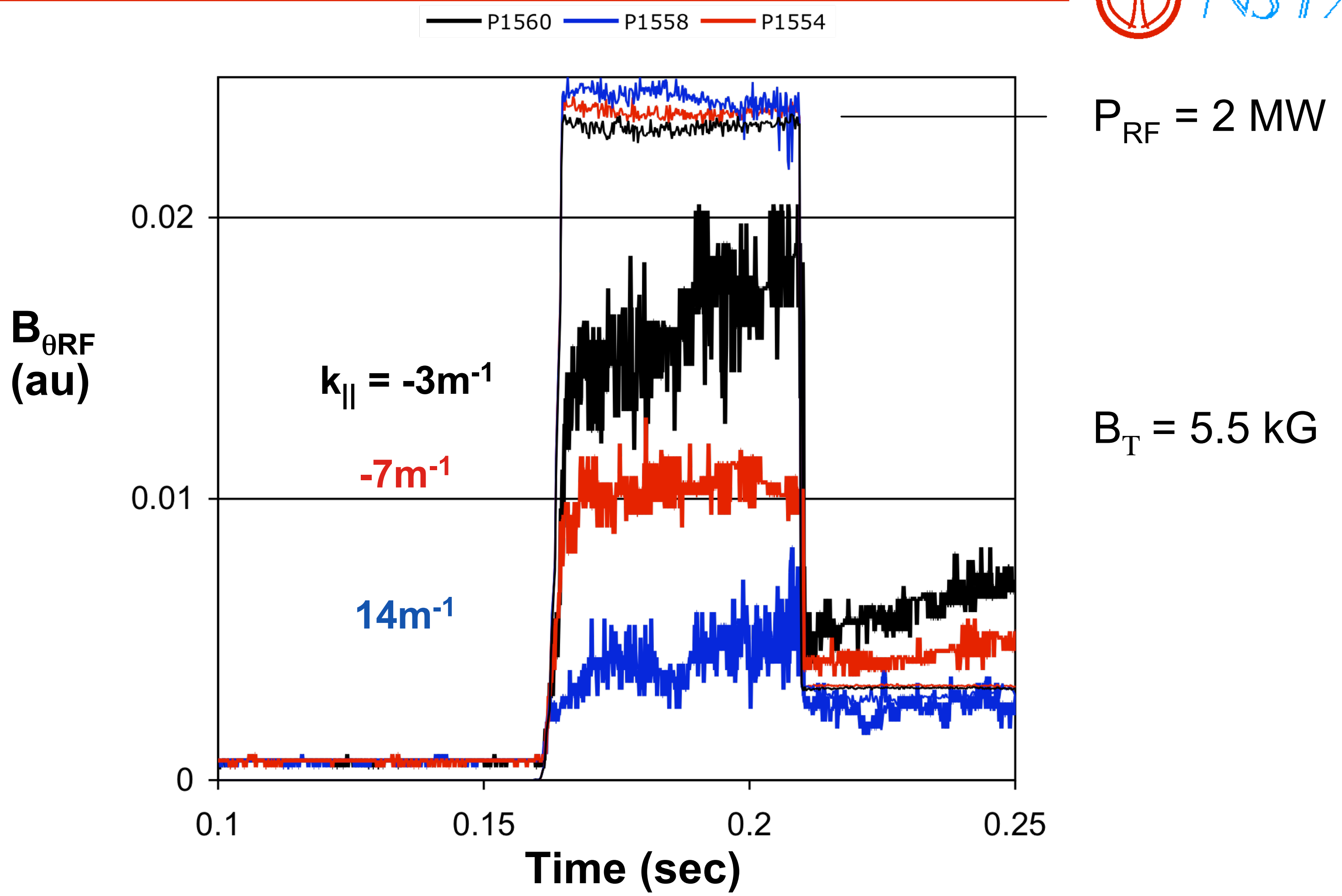
- Small reduction in PDI loss at higher field for 7 m^{-1} but zero PDI loss would be required to match the increase in efficiency
- Very poor heating efficiency at -3m^{-1} and at lower field is not caused by PDI heating alone

Surface waves are detected with an RF probe on the opposite side of the machine from the HHFW antenna



- RF probe is inside a large port ~ 5 cm outside the vessel wall radius
- It detects the poloidal RF field which is indicative of toroidal currents in the vessel structure

RF probe signals are a strong function of $k_{||}$



- $B_{\theta RF}$ at Bay J midplane increases by a factor of ~ 3 for a decrease in $k_{||}$ from 14 m^{-1} to -3 m^{-1}
- This could give rise to around an order of magnitude increase in structure and sheath losses

Conclusions

- HHFW heating increases with increasing $k_{||}$ and improves markedly with B
- PDI edge heating is a relatively weak function of B and does not account for the strong B dependence of RF losses
- Strong improvement in heating efficiency with B at $k_{||} = |7| m^{-1}$ indicates that surface waves are contributing to the RF losses
  - loss level appears to depend critically on the propagation onset location relative to the antenna/wall surface
- Measured edge RF B field is strongly dependent on $k_{||}$ further suggesting that surface waves contribute significantly to RF power losses