HHFW Power Balance vs B and Antenna $k_{||}$ at Constant q

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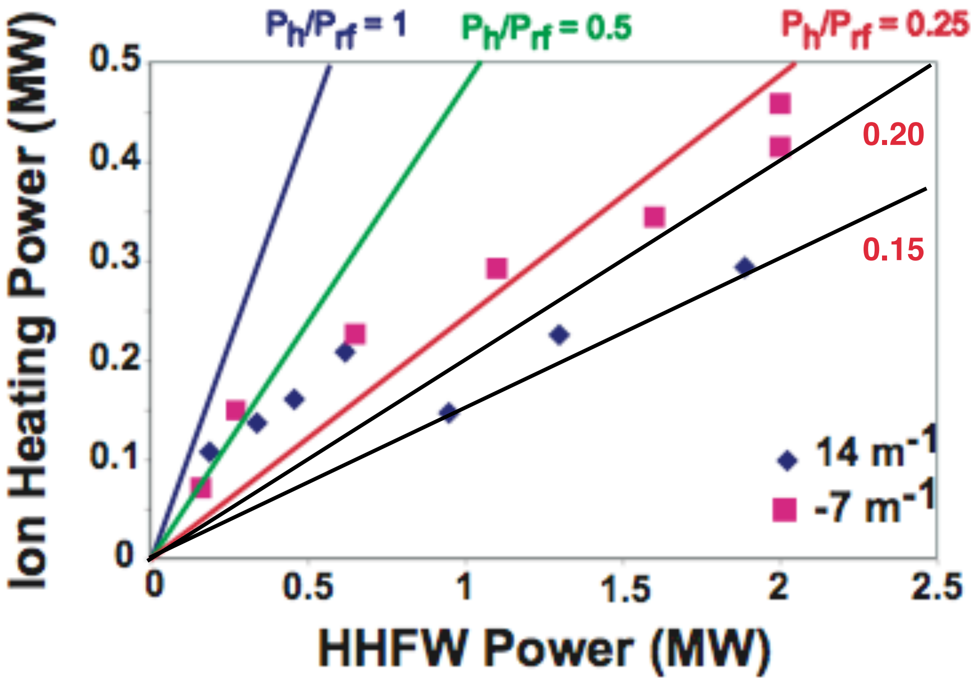
Goal: Measure RF power loss properties as a function of magnetic field at constant q to elucidate:

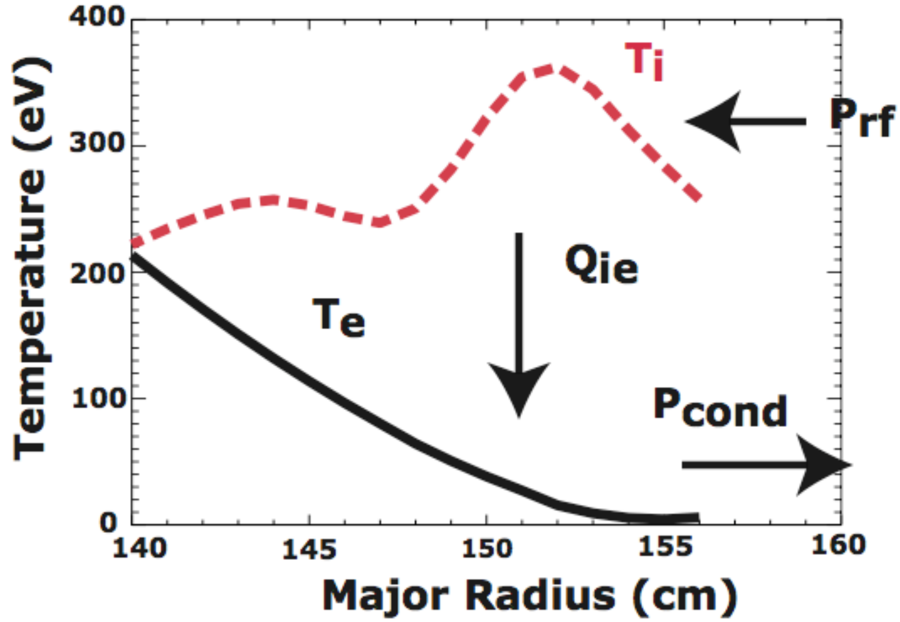
- RF power loss scaling with B under similar stability conditions
- PDI ion heating loss vs B
- Fast wave propagation characteristic effects on surface wave propagation and damping

- Higher field should give higher efficiency of heating
  - PDI instability should be weaker at higher field
  - Onset density for propagation of HHFW is approximately proportional to B at a given $k_{||}$ - waves are propagating farther from plasma edge at higher B
  - V Alfven scales with B - radial group velocity should increase with B so that wave propagation into core (away from surface) is faster - surface fields should decrease with B
  - May explain higher efficiency on DIII-D
- Results from this experiment are important
  - Will help in making projections to the higher field regime of the ST CTF
  - Will provide support for increasing the $k_{||}$ of the NSTX antenna for current drive phasing

PDI Losses Are Evident at Both $k_{||}$ Values

- Significant RF Power is Required to Sustain the Large Temperature Difference Between the Edge Ions and Electrons



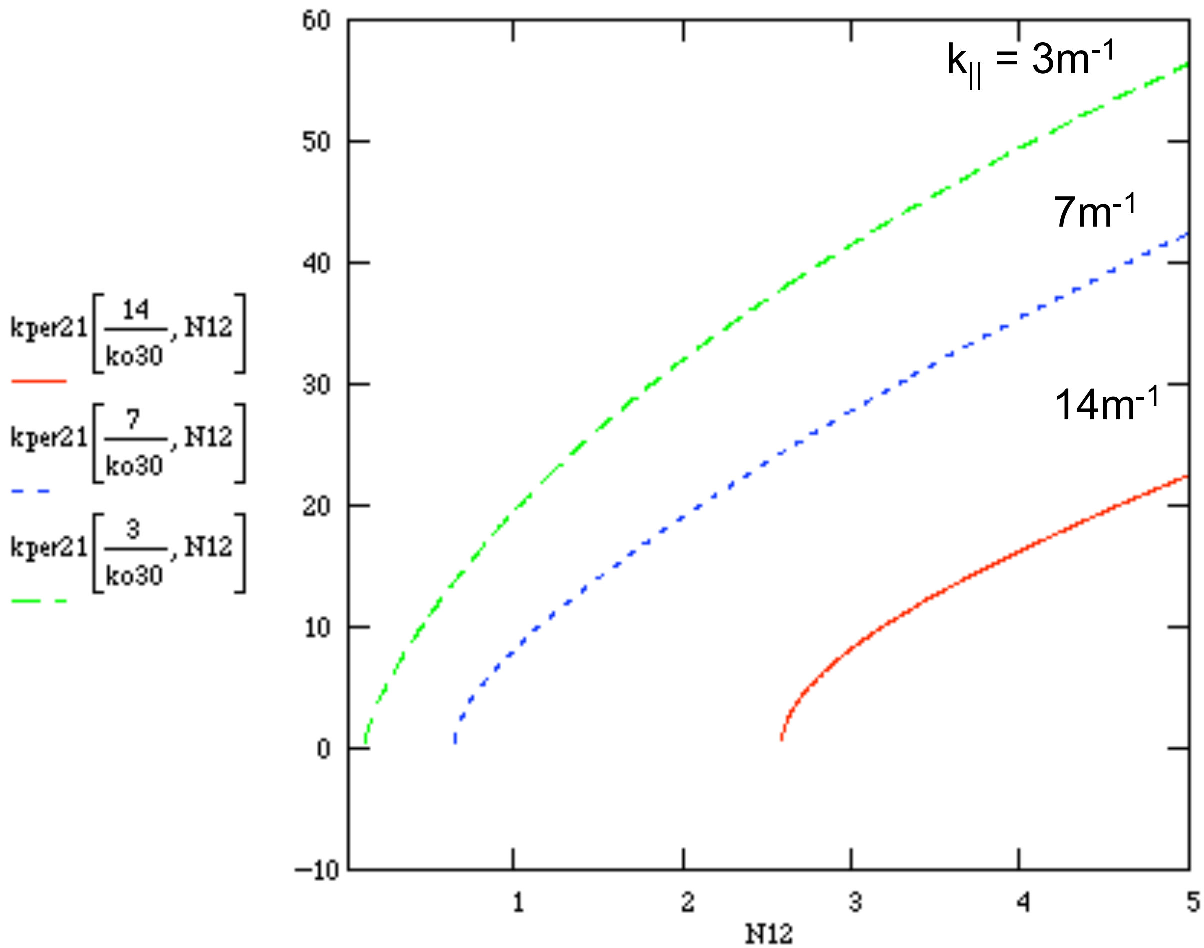


- Edge ion heating via parametric decay waves accounts for a substantial amount of RF power loss which increases somewhat with wavelength - 16%/23% loss for 14 m^{-1}/-7 m^{-1}

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

Propagation of fast wave begins at lower density for lower $k_{||}$

Propagating $k_{\perp}$ vs density and $k_{||}$ with B = 4.5kG

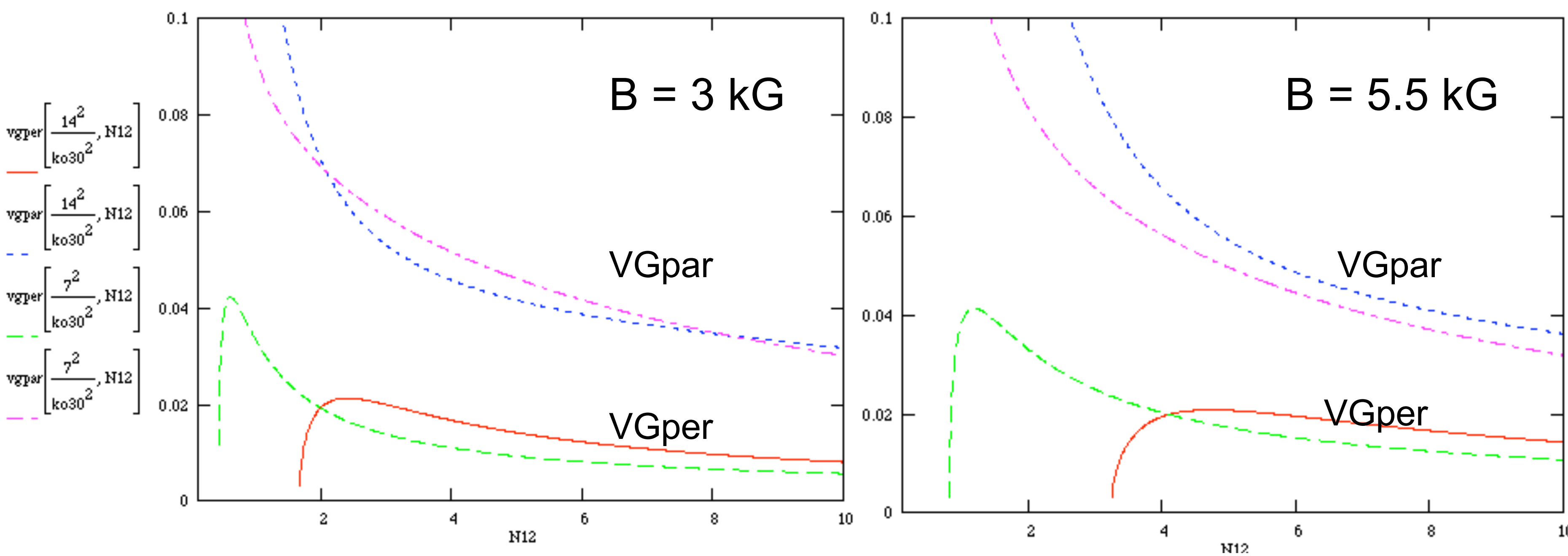


Density onset is function of ~ $B^*k_{||}^2$

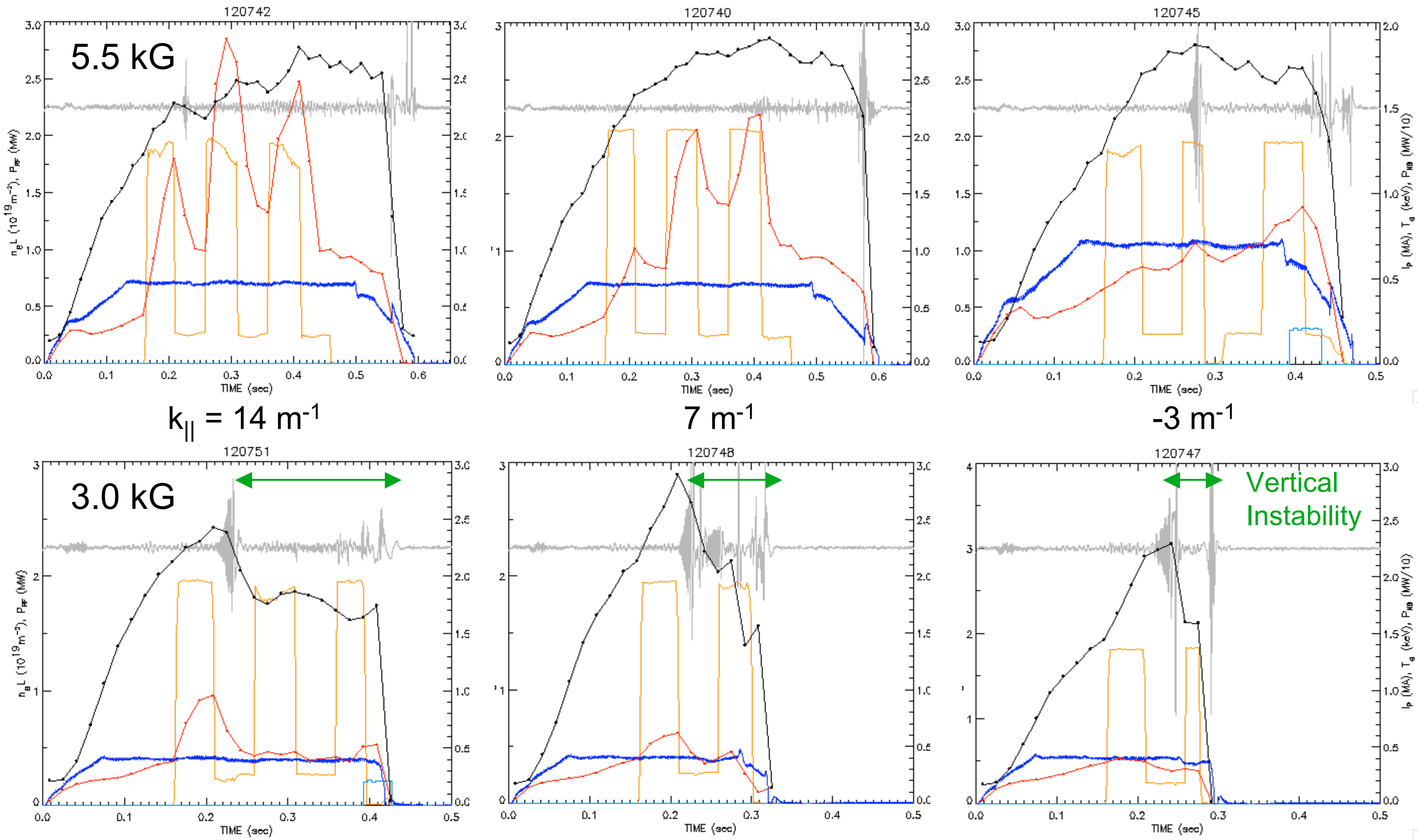
- Propagation is very close to wall at 7m^{-1} and on the wall at 3m^{-1}
- Losses in surface should be higher for lower $k_{||}$

This proposal is to study heating efficiency/power loss over the widest magnetic field range possible

- 3 kG @ 400 kA and 5.5 kG @ 730 kA
- Constant q is desired to control stability
- Propagation onset density decreases a factor of two at the lower field for both $7m^{-1}$ and $14m^{-1}$
- Surface losses should increase substantially at the lower field - even at $14m^{-1}$
- Perpendicular group velocity also decreases by a factor of ~ 2 - surface fields should be enhanced further increasing edge losses
- PDI losses can be expected to increase substantially at the lower field

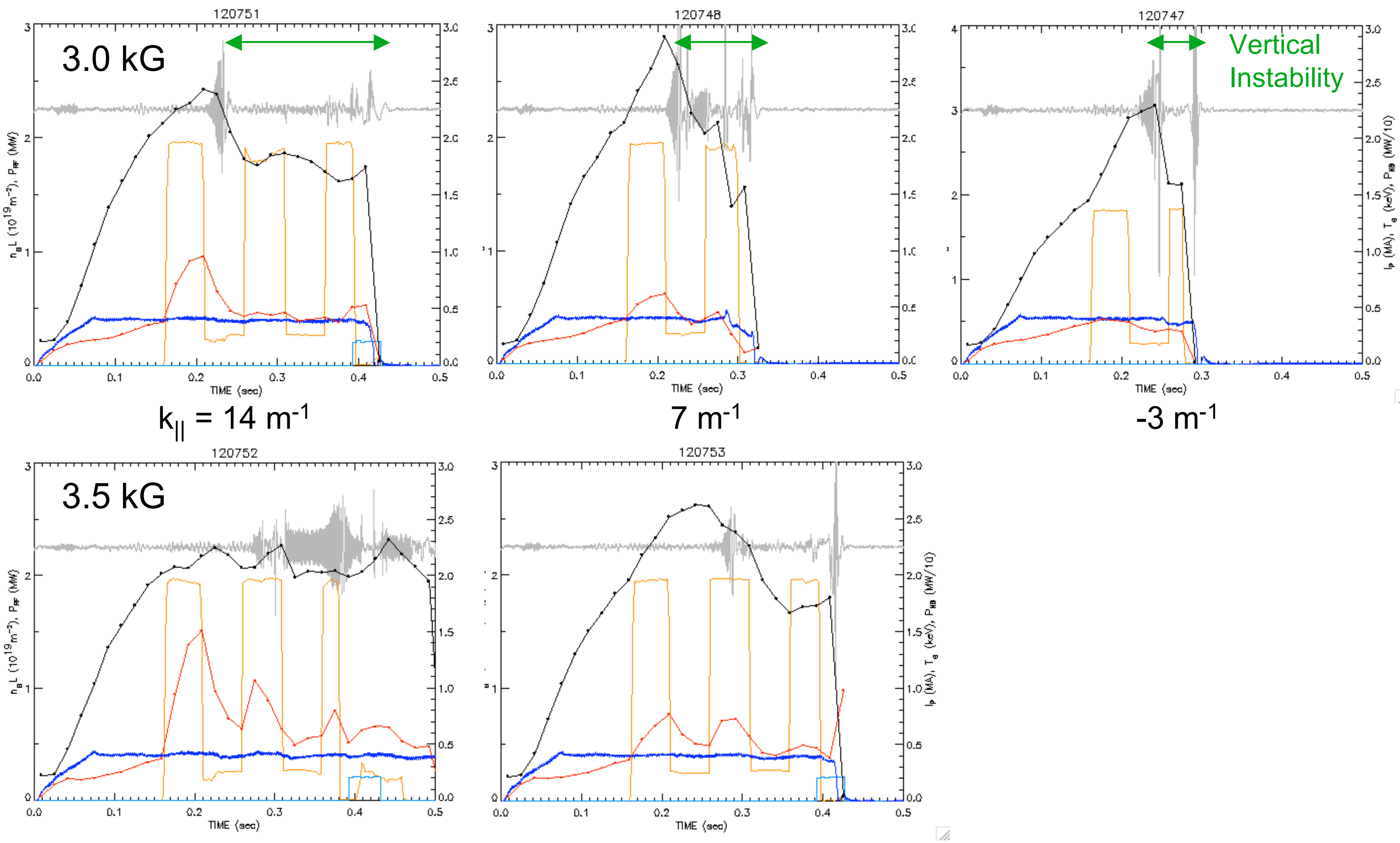


Comparison of Thomson scattering measurements vs $k_{||}$ at 5.5 kG and 3.0 kG

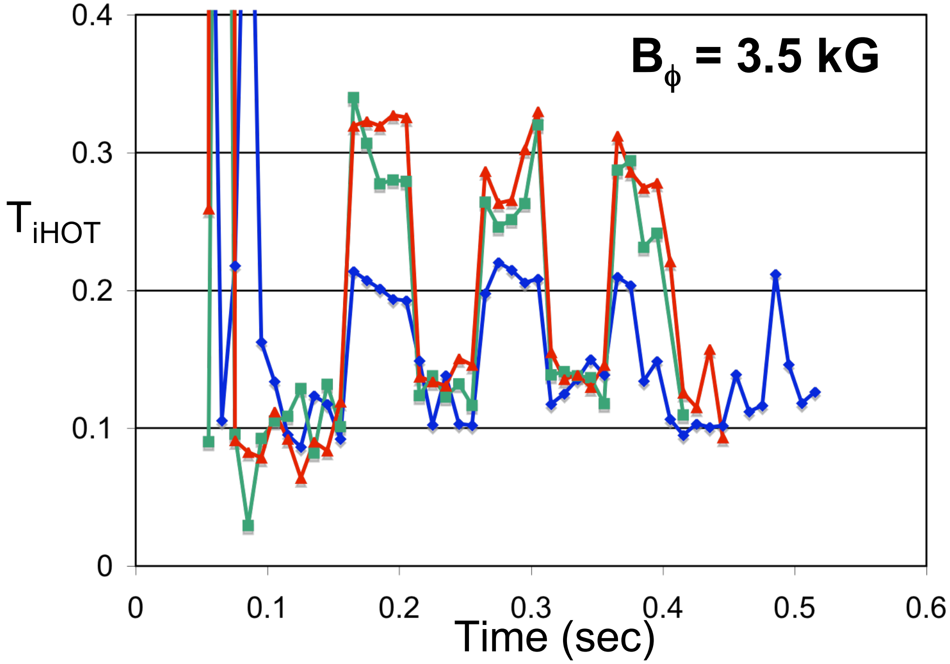


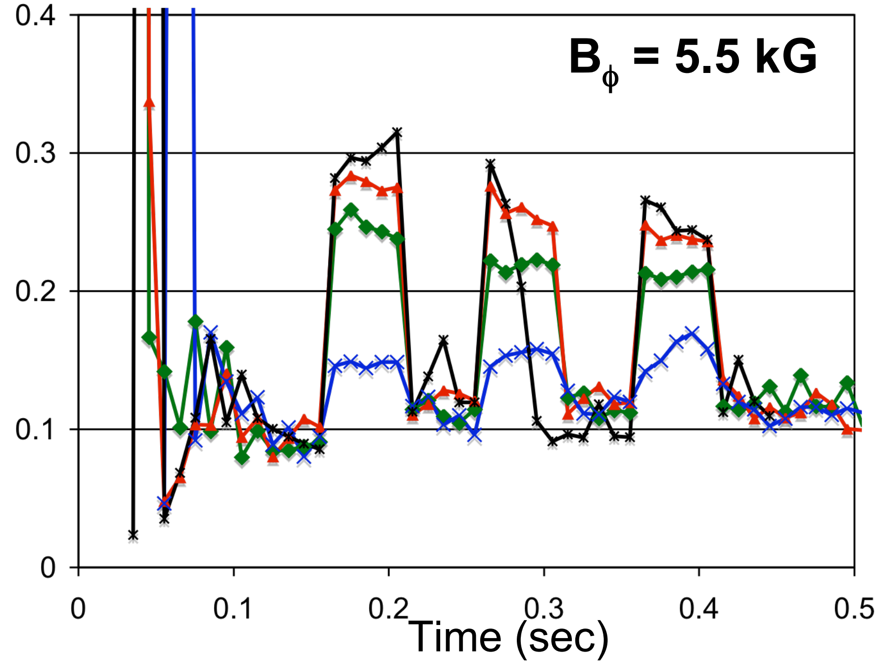
- $\Delta T_e(0)$ is much larger at B_ϕ = 5.5 kG for $k_{||}$ = 7 m^{-1}, τ_{Teo} is also longer
- Heating at -3 m^{-1} is still small at 5.5 kG
- Vertical instability seriously affects the results at 3 kG for time > about 0.23 sec

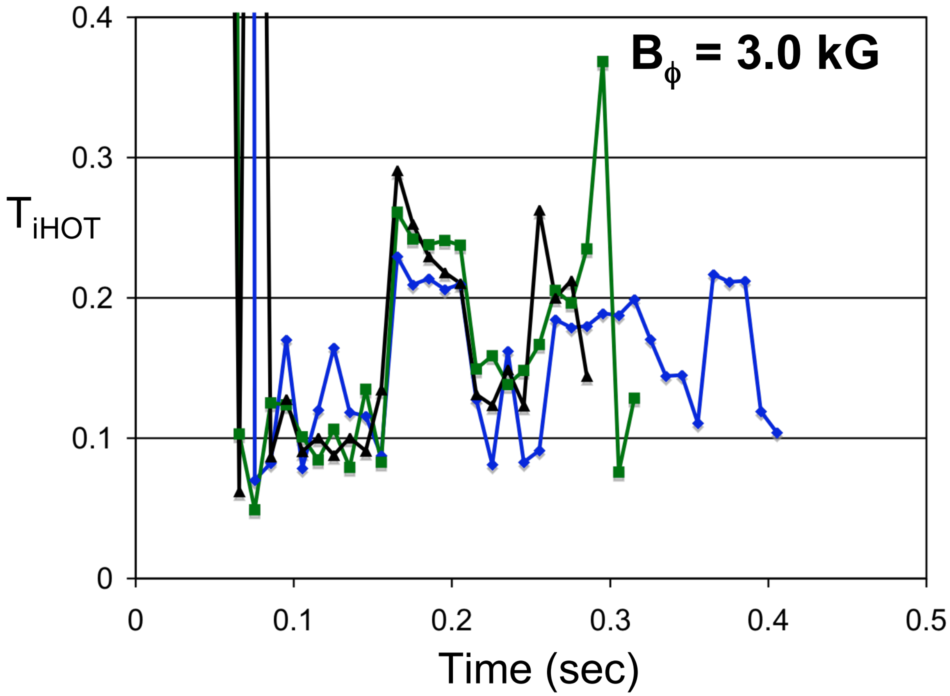
Comparison of Thomson scattering measurements vs $k_{||}$ at 3.0 kG and 3.5 kG



- $\Delta T_e(0)$ is significantly larger at B_ϕ = 3.5 kG for $k_{||}$ = 14 m^{-1}
- Instability still seriously affects the results at 3.5 kG for time > about 0.25 sec







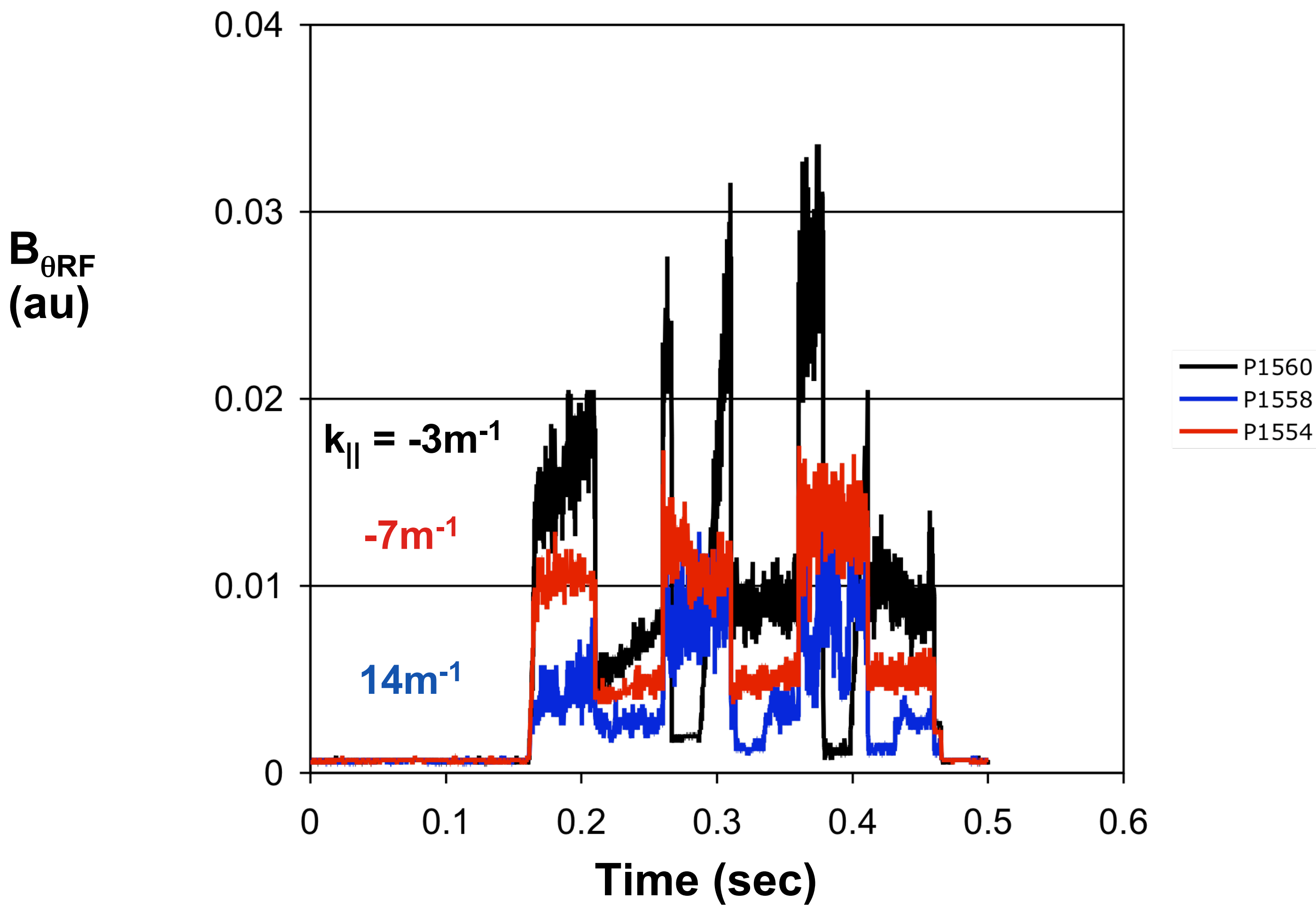
ERD T_{iHOT} vs B_ϕ and $k_{||}$ at R = 145 cm

Helium, P_{RF} = 2 MW

- $k_{||} = -3 m^{-1}$
- $k_{||} = -7 m^{-1}$
- $k_{||} = 7 m^{-1}$
- $k_{||} = 14 m^{-1}$

- Reduction in T_{iHOT} at higher field, especially at $k_{||} = 14\ m^{-1}$
- Reduction at lower field perhaps due to hot ion loss or vertical instability

RF Probe Signals are a strong function of $k_{||}$

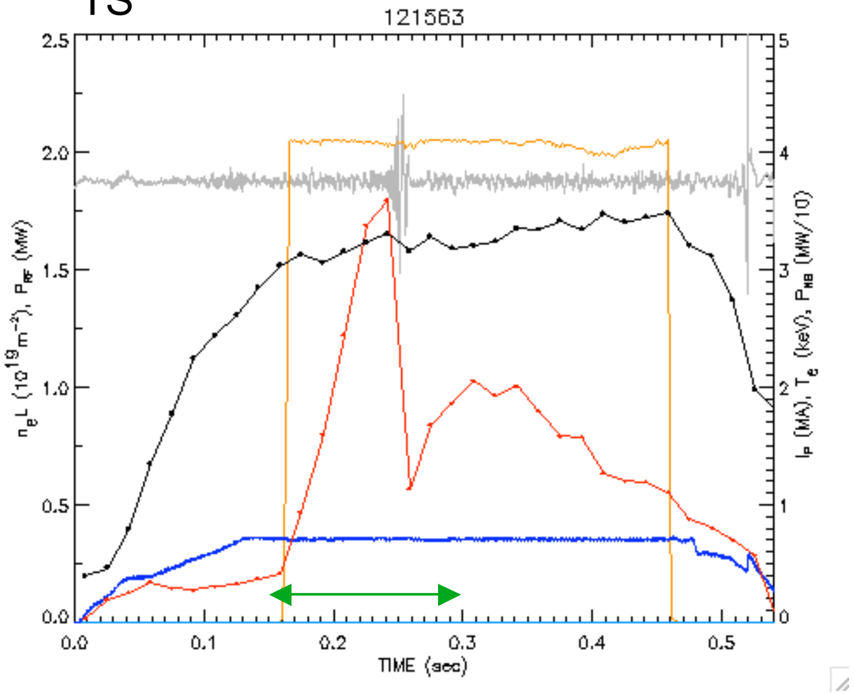


B_ϕ = 5.5 kG
P_{RF} = 2 MW

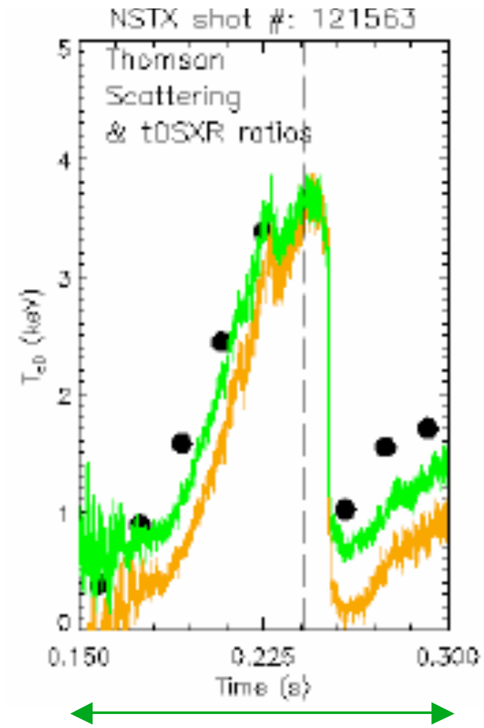
- $B_{\theta RF}$ at Bay J midplane increases by a factor of ~ 3 for a decrease in $k_{||}$ from $14m^{-1}$ to $-3m^{-1}$
- This could give rise to around an order of magnitude increase in structure/sheath losses
- Fluctuation level at high power appears to be large

Good Heating Observed for $k_{||}$ = -7m^{-1} at B_ϕ = 5.5 kG -- T_{eo} > 3.6 keV for P_{RF} = 2 MW

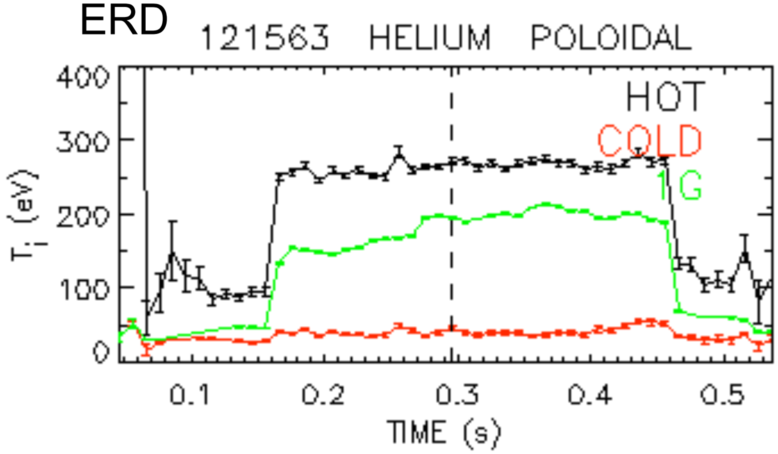
TS



fOSXR



ERD



- T_{iHOT} and T_{i1G} evolve somewhat during pulse
  - but do not see core collapse
- $B_{\theta RF}$ also evolves smoothly (0.012 - 0.016)
- Fast time behavior of $T_e(0)$ is indicated by fast OSXR diagnostic
- MHD is observed at the core temperature collapse

Expected Results

- Heating efficiencies vs B for 14 m^{-1}, -7 m^{-1} (co CD) and 7 m^{-1} (π phasing)
  - Core heating from EFIT W
  - Core electron heating from Thomson scattering
- Edge heating/power loss
  - Edge ion heating from edge rotation diagnostic
  - Edge electron heating from Thomson scattering
- Behavior of PDI characteristics and induced losses with field
- Plasma profiles , core and edge, for permitting predictions of wave propagation and damping characteristics and of PDI produced losses
- Relative surface wave amplitude for comparison to surface power loss for the explored conditions
- Ceramic gap RF emission for the explored conditions

Planned Analysis

- Calculation of τ and ΔW for EFIT W to obtain percent P_{RF} deposited
- Calculation of τ_e and ΔW_e for Thomson scattering W_e to obtain P_{RF} delivered to electrons
- Compare efficiencies for the two field cases
- Analysis of wave propagation and damping characteristics from onset density into the core of plasma - along field and perpendicular directions of the ray path, and including collisions - for predicting surface losses
- Development of predictions for PDI losses
- Projection of heating efficiency expected at 10 kG, with and without PDI present, to compare with DIII-D results and for higher field ST devices

Preliminary Conclusions

- HHFW heating decreases with decreasing $k_{||}$ and improves with B
- PDI edge heating is a relatively weak function of B except for 14 m^{-1}
- Edge RF B field is strongly dependent on $k_{||}$ suggesting surface waves could contribute significantly to RF power losses
- In future, we need to determine RF B toroidally and poloidally as function of B and look at FFT spectra to evaluate edge turbulence
- We should increase current drive $k_{||}$ to improve CD efficiency
- Also, preliminary analysis suggests that increasing the frequency would greatly reduce the PDI heating