XP** W-P ET: HHFW Power Balance vs B at Constant q

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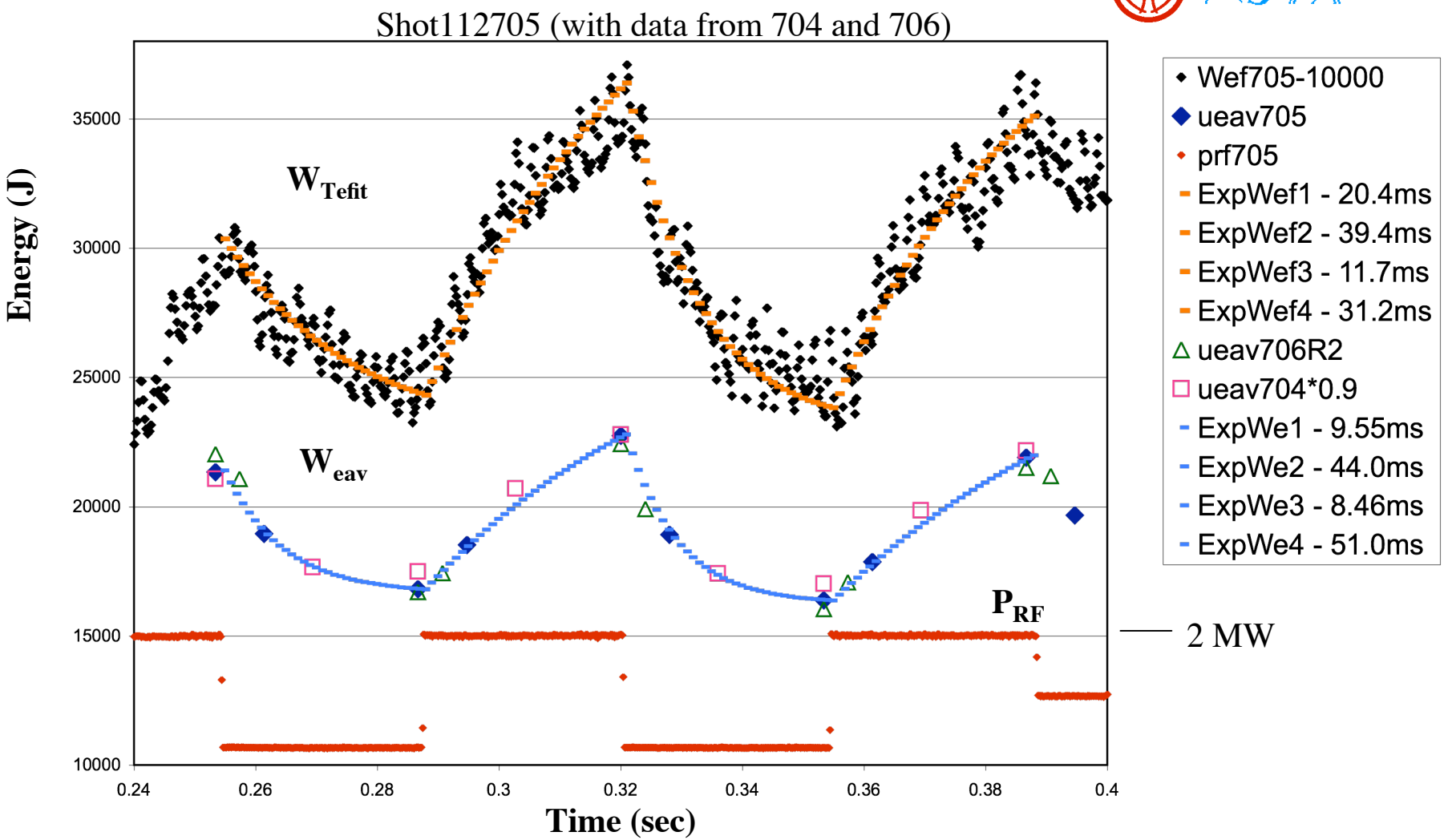
Goal: Measure RF power loss properties as a function of magnetic field at constant q to elucidate:

- 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

Electron Stored Energy Evaluated for -7 m^{-1} (2004)



- Modulation of RF power is used to measure ΔW and τ
- The exponential times for both W_{eav} and W_{tefit} are noticeably longer during the RF pulses than during the decay periods

P_{RF} LOSSES AT EDGE OF PLASMA ARE INDICATED

- An estimate for the power required to give the observed stored electron energy during the RF pulses is obtained from $\Delta W_{eF}/\tau_{We}$ - similarly for total energy W_{EF}/τ_{EF}:

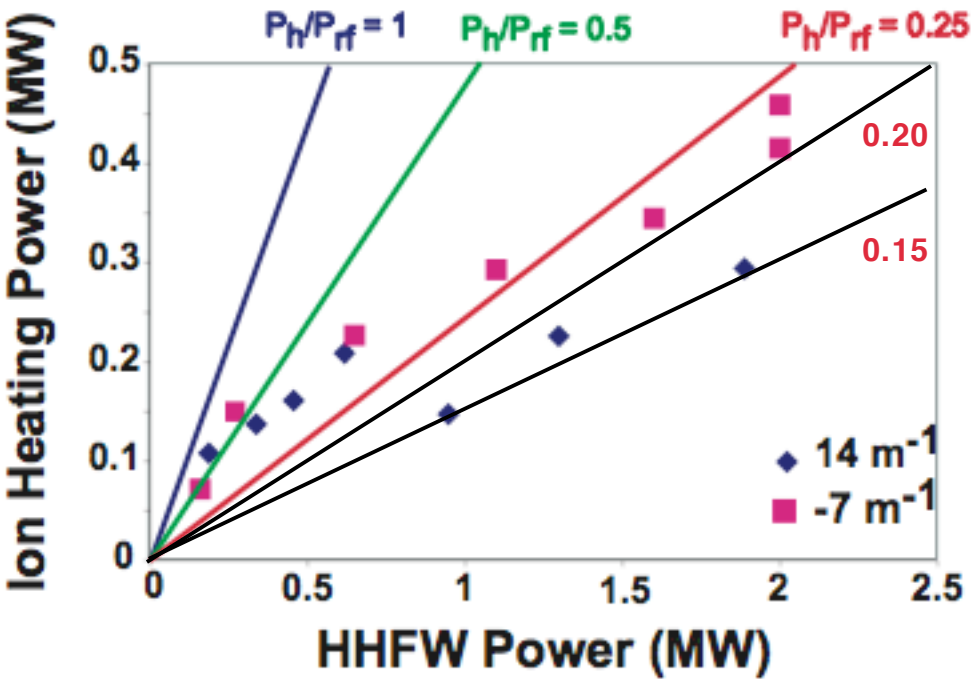
	Percent power deposited [$P_{RFDep}/\Delta P_{RF}$ (%)] Electrons/Total:
– 14 m^{-1} :	
Second RF Pulse	84/101 (Sawtooth instability much weaker for this pulse)
Third RF Pulse	48/68
– 7 m^{-1} :	
Second RF Pulse	24/39
Third RF Pulse	36/44

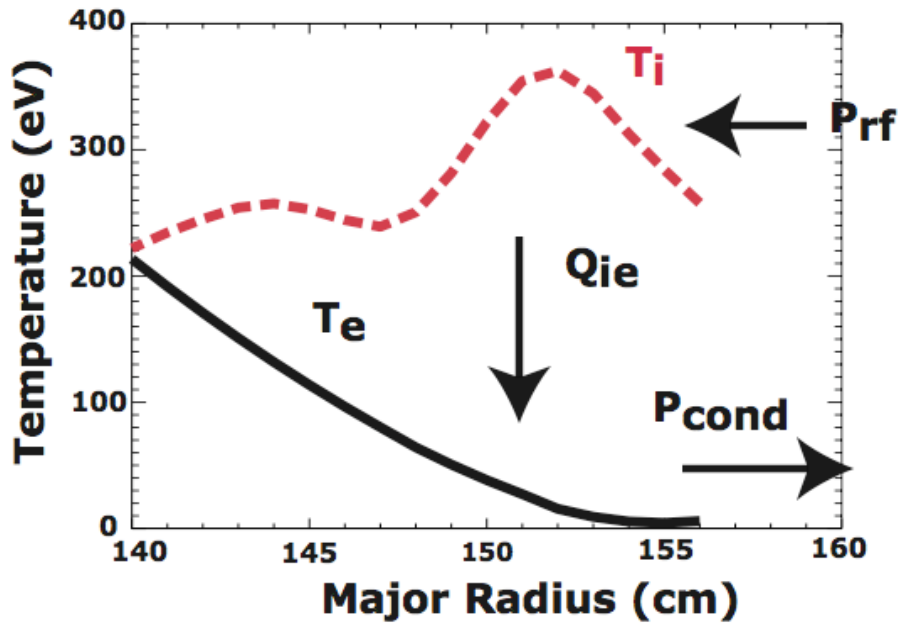
- These power deposition estimates indicate that the RF power reaching the core is considerably reduced for the smaller k_ϕ case and that the power sustaining the electron stored energy is roughly 3/4th that supporting the total stored energy

- the RF power loss is apparently significantly greater for the lower k_ϕ

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

DIII-D heating efficiency at higher field - - $k_{||}$ = 13.8 m^{-1}, f = 60 MHz, π phasing

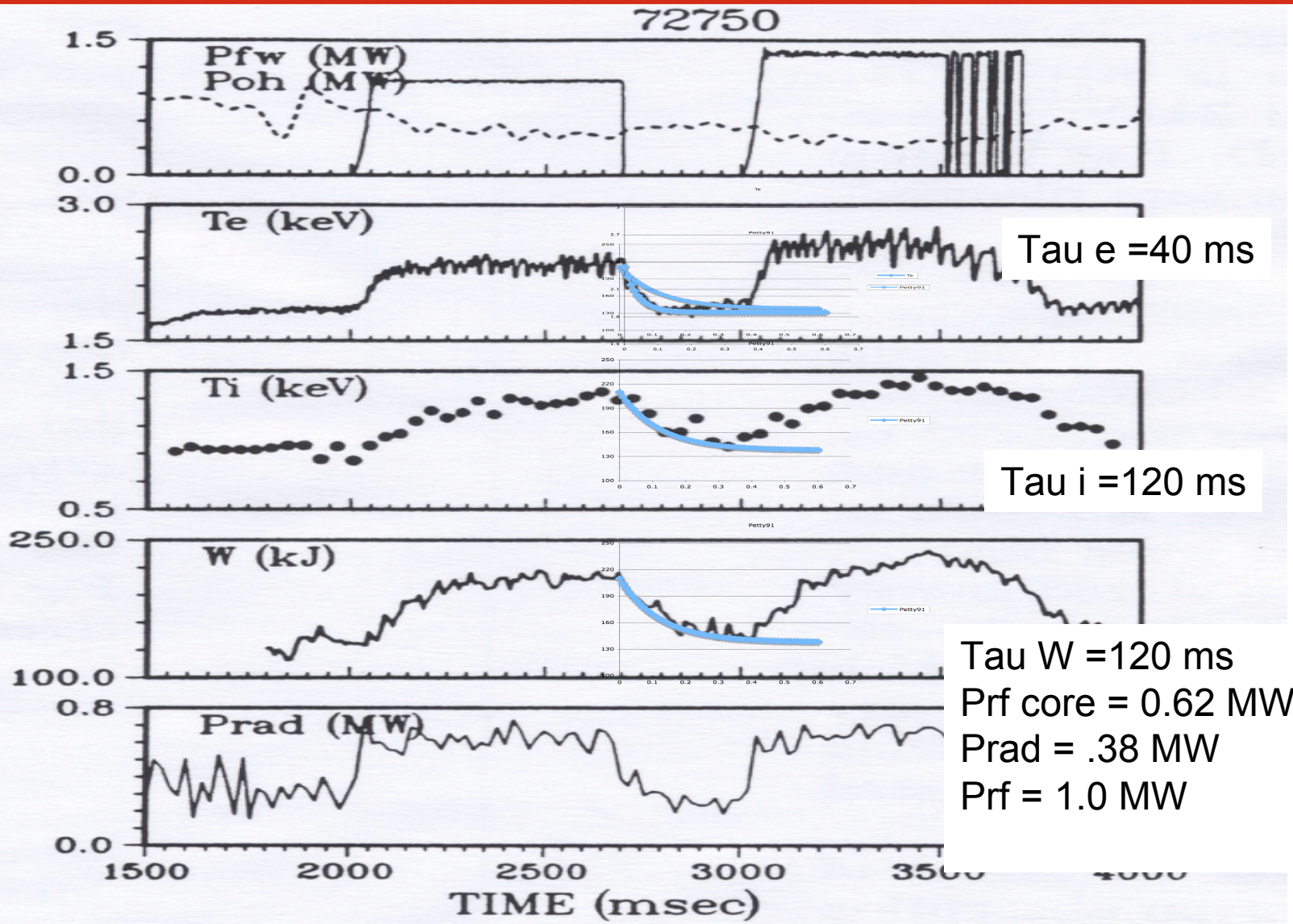
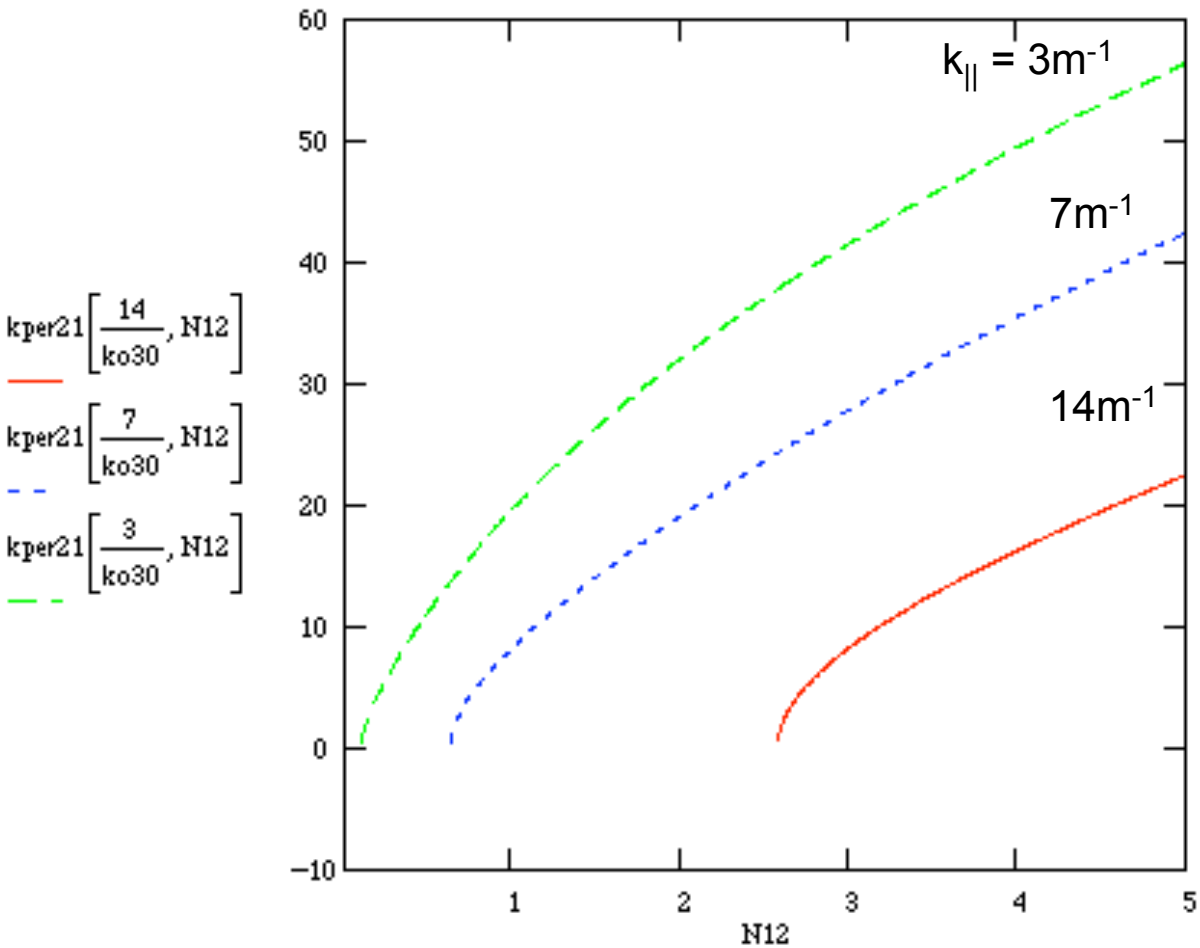


Fig. 2. Time history of 60 MHz fast wave heating (I_p = 1 MA, B_T = 2.0 T, $\bar{n}$ = 2 × 10^{13} cm^{-3}).

91 RF Conf - Petty et al.

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

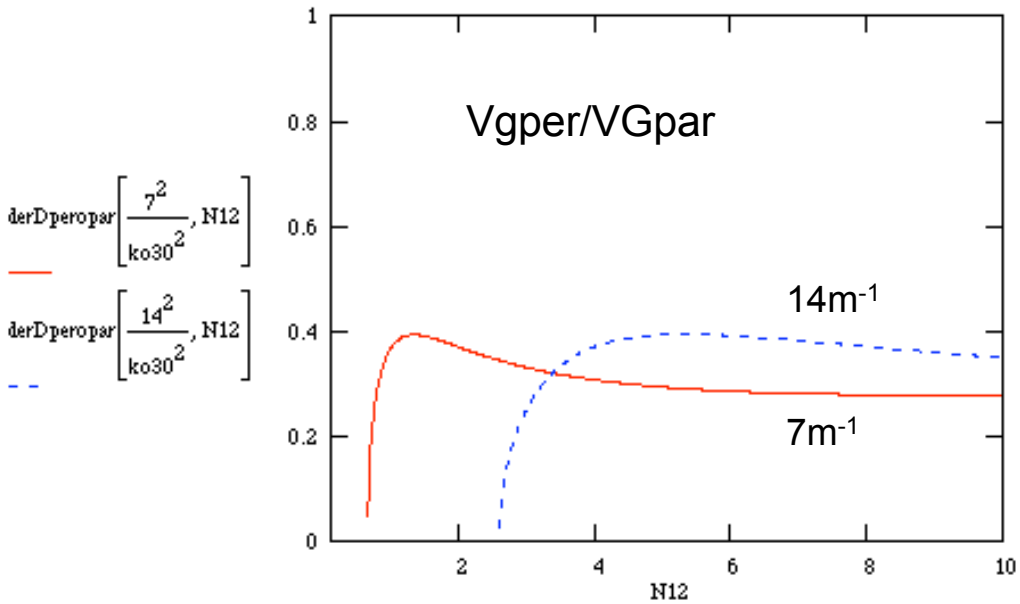
Propagating $k_{\perp}$ vs density and $k_{||}$ with B = 4.5kG



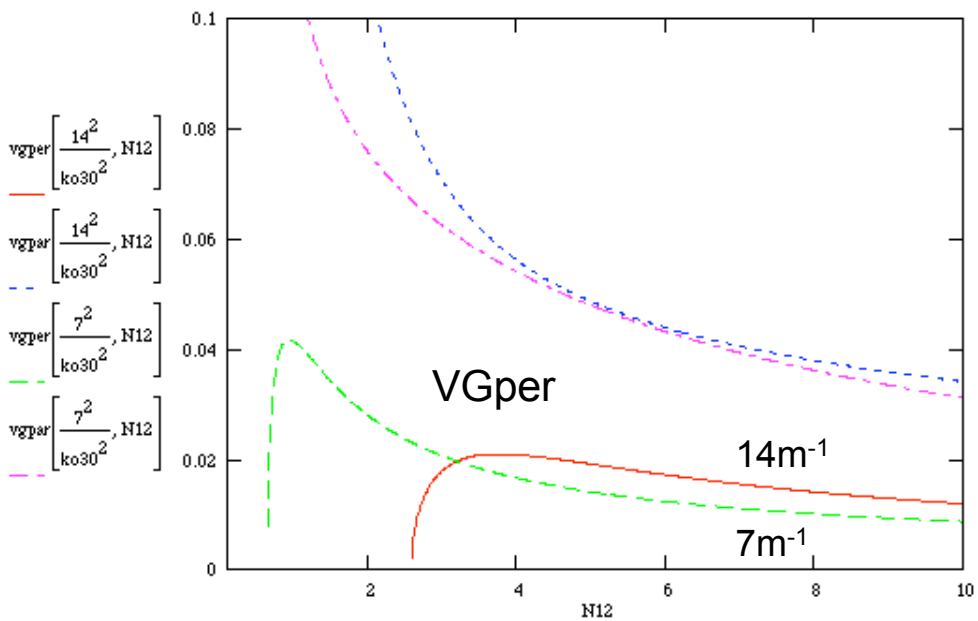
Density onset is function of ~ $B*k_{||}^2$

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

Perpendicular wave propagation is low - surface fields are enhanced



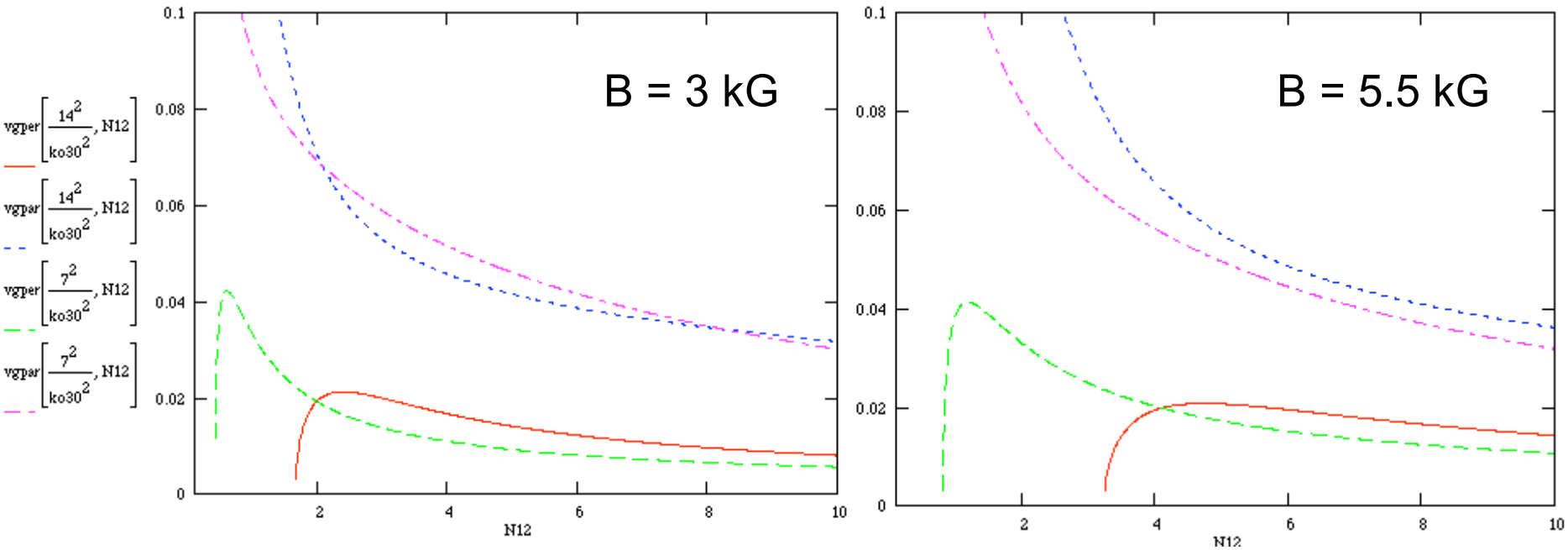
Group velocity is at ~ 20° from field direction



Perpendicular group velocity is lower for lower $k_{||}$ in mid 10^{12} cm^{-3} density range

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



Proposed Run Plan:

1. Setup stable shot at B = 4.5 kG, I_P = 600 kA similar to shot 112699 (or good shot now after Li injection)
   - LSN, helium L-mode, gap 4-5 cm
   - Modulate P_{RF} as for shot 112699 with $k_{||}$ = 14 m^{-1}

   Bring P_{RF} up to ~ 2-3 MW (depending on conditions)
   - 2 shots @ 14 m^{-1}

2. Test low field scaling
   - Setup B = 3 kG, I_P = 400 kA discharge
     - 2 shots @ 14 m^{-1}
     - 2 shots @ -7 m^{-1} (co CD)
     - 2 shots @ 7 m^{-1} (π phasing)
   - Test point: Compare efficiency of 14 m^{-1} case to that for 4.5 kG

3. Test high field scaling
   - Setup B = 5.5 kG, I_P = 730 kA discharge
     - 2 shots @ 14 m^{-1}
     - 2 shots @ -7 m^{-1} (co CD)
     - 2 shots @ 7 m^{-1} (π phasing)

Critical Diagnostics

- Soft x-ray and Mirnov loops for stability
- EFIT with high time resolution for W
- Thomson scattering for electrons
- Edge rotation diagnostic for edge heating
- Radiated power diagnostic
- Reflectometry for edge density and PDI
- Edge probe for PDI
- Gap RF probes for leakage
- RF probe(s) for edge RF field

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

Planned publication of results

- The results will be submitted for publication in Physics of Plasmas