Ion cyclotron range-of-frequency heating scenarios for NCSX.

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ICRF heating scenarios for NCSX
Outline

- Introduction
- Heating in the ICRF with the PPPL 30 MHz rf sources
- Minority heating
- Mode conversion heating
- High harmonic fast wave (HHFW) heating
- Conclusions

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ICRF heating scenarios for NCSX
Introduction

- Heating requirements for NCSX are somewhat different than for conventional stellarators
  - Startup not an issue: ohmic system will be available
  - Modest current drive capability is a plus
- QAS design provides for a more tokamak-like geometry
- Field coil design favors rf launchers on the outboard equatorial plane
  - Net result: rf heating scenarios are similar to low-field side launch tokamak scenarios
- Toroidal field range: 1 - 2 T
- Hydrogen majority plasmas
- Hydrogen NBI
  - Deposition on beam ions would enhance losses
- Direct electron heating desirable

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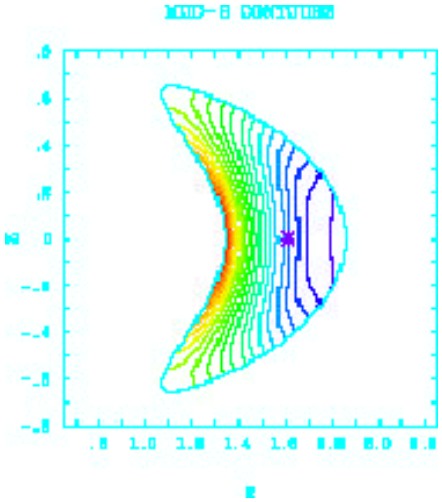
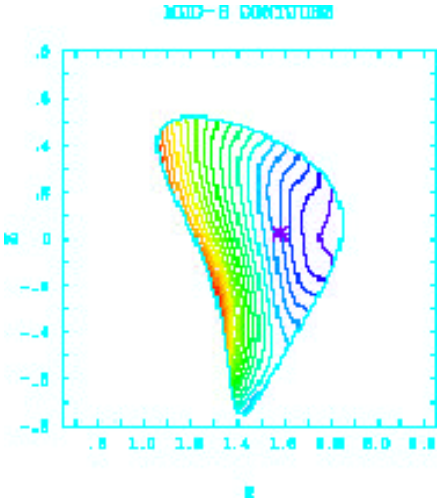
Outboard equatorial plane wave launch in NCSX resembles a low field side launch in a tokamak

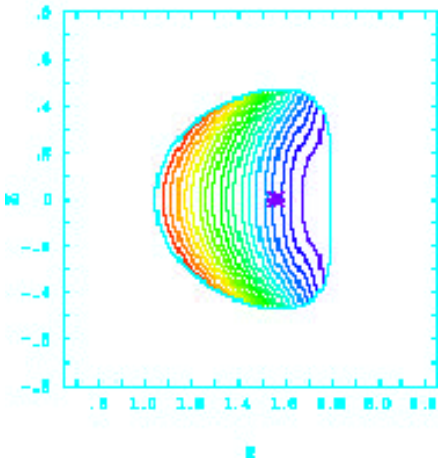
Nζ = 0



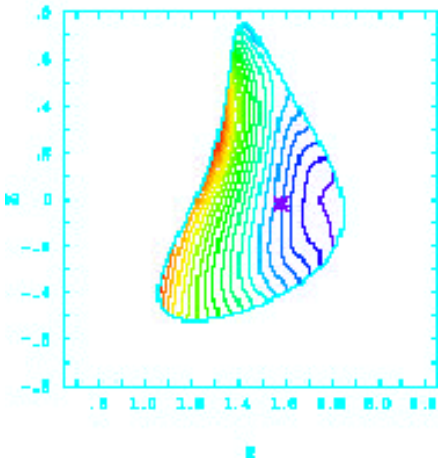
Nζ = 90



Nζ = 180



Nζ = 270



Illustrative mod-B surfaces

C10 configuration

30 MHz heating for NCSX

- First rf heating scenario considered
- Why? PPPL has ample rf power at 30 MHz
  - NSTX HHFW heating system
  - 6 transmitters: 6 MW for 5 sec, 12 MW for 2 sec
  - But: frequency is fixed
    - » Major mechanical modifications necessary to retune.
- Can NCSX share this system with NSTX?
- Issues at this frequency:
  - No useful cyclotron resonances for a wide range in magnetic field
  - Modest electron absorption
  - Doppler-broadened beam ion absorption

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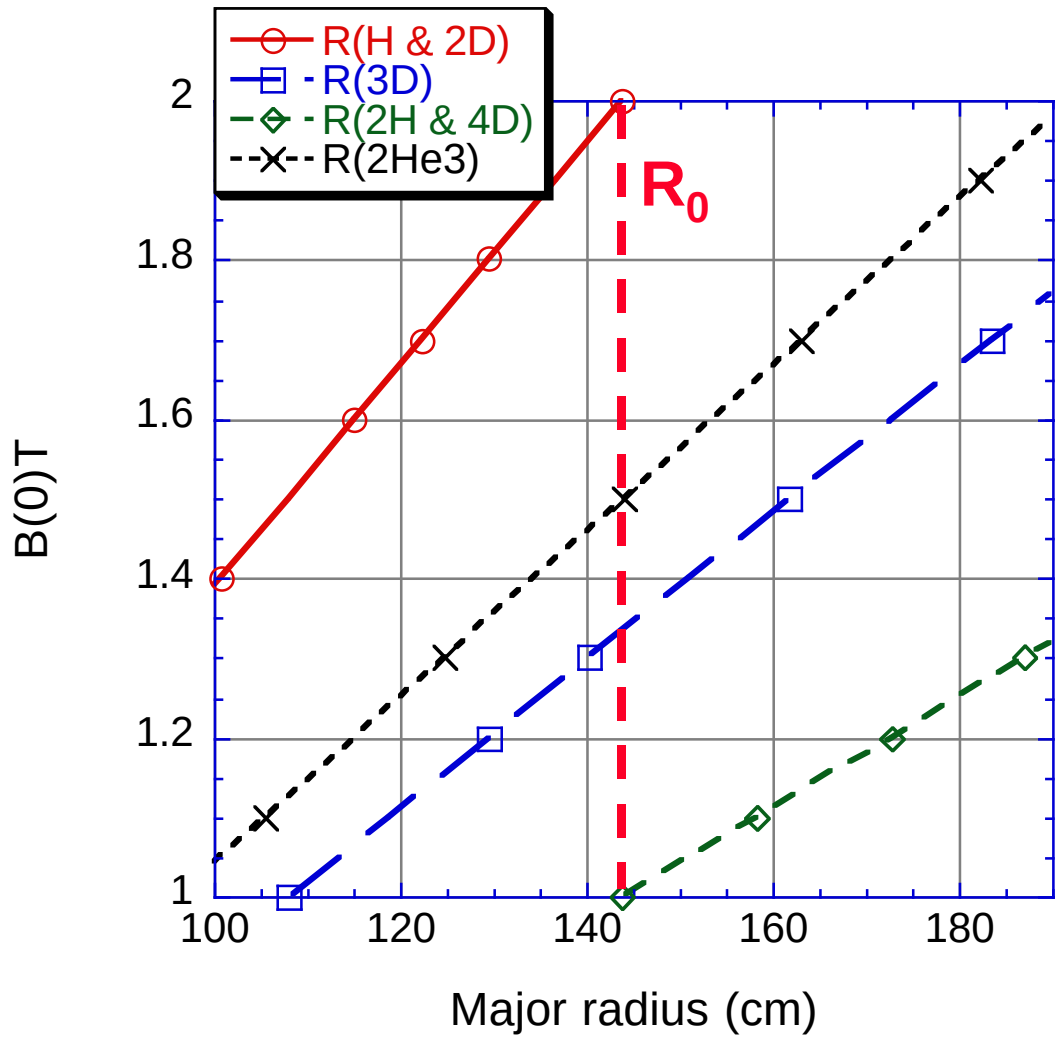
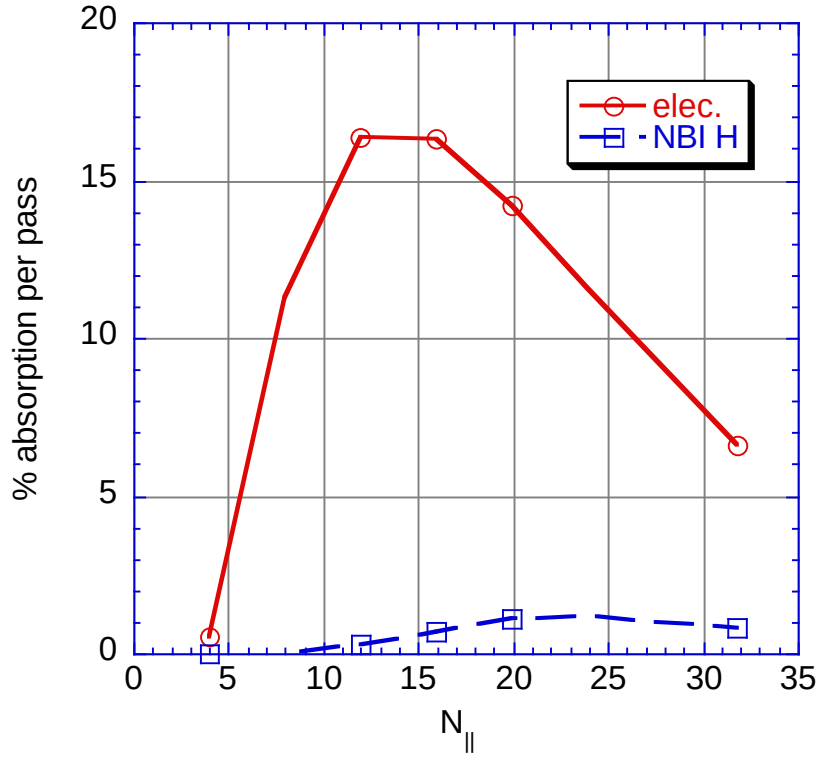
No useful ion resonances at 30 MHz for NCSX with $B_0 \sim 1.2 - 1.6$ T

⇒ Consider direct electron heating

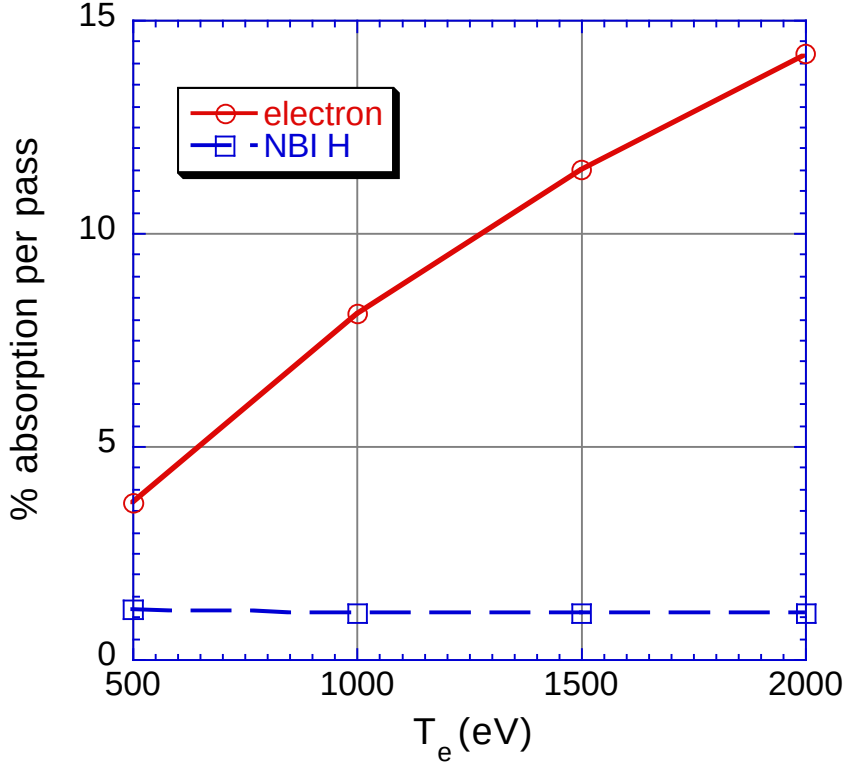


Direct electron absorption at 30 MHz in NCSX is marginal

30 MHz, $n_e(0) = 6 \times 10^{19}\ m^{-3}$ (parabolic$^{0.5}$),
$T_e(0) = T_i(0) = 2$ keV, $B_0 = 1.4T$, 2%NBI H



$N_{||} = 20$



1-D results from METS

Existing 30 MHz rf system at PPPL is not ideal for heating NCSX

- Direct electron heating appears to be the only viable heating scenario
- But: absorption is at best ~ 15% per pass *at high beta*
  - 30 MHz heating will be ineffectual at low beta
- High $N_{||}$ launch is required
  - Low antenna loading resistance
    - » Large antenna
- Low field (< 1.2T) operation will introduce a second harmonic hydrogen cyclotron resonance
  - May lead to high beam absorption
- High field operation (>1.6T) will introduce the fundamental hydrogen cyclotron resonance

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First alternative:
Low frequency heating in NCSX

- Use of rf sources < 20 MHz would permit minority ion, mode conversion heating in NCSX
- NCSX operation will likely entail $H^0 \Rightarrow H^+$ injection
  - Only good candidate for a minority species is He3
    - » D harmonics are degenerate with H
  - H-He3 is the only viable mix for mode conversion
    - » D-H requires a high-field side launch
- He3 concentrations of <10 % (n_i/n_e) would produce minority ion heating
- Concentrations of >10% produce mode conversion electron heating
  - Caveat: Again, high $N_{||}$ required for mode conversion
    - » Low antenna loading
    - » Large antenna

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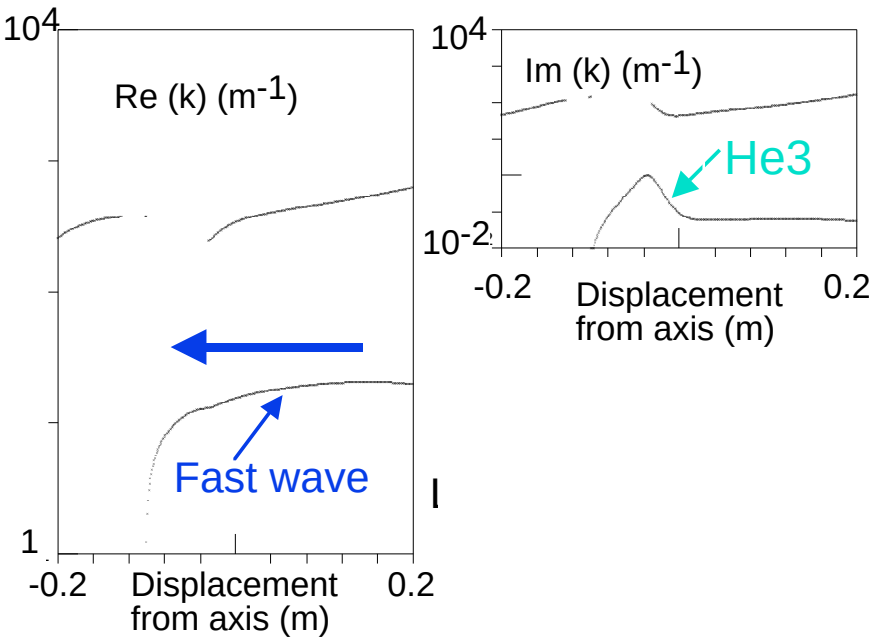
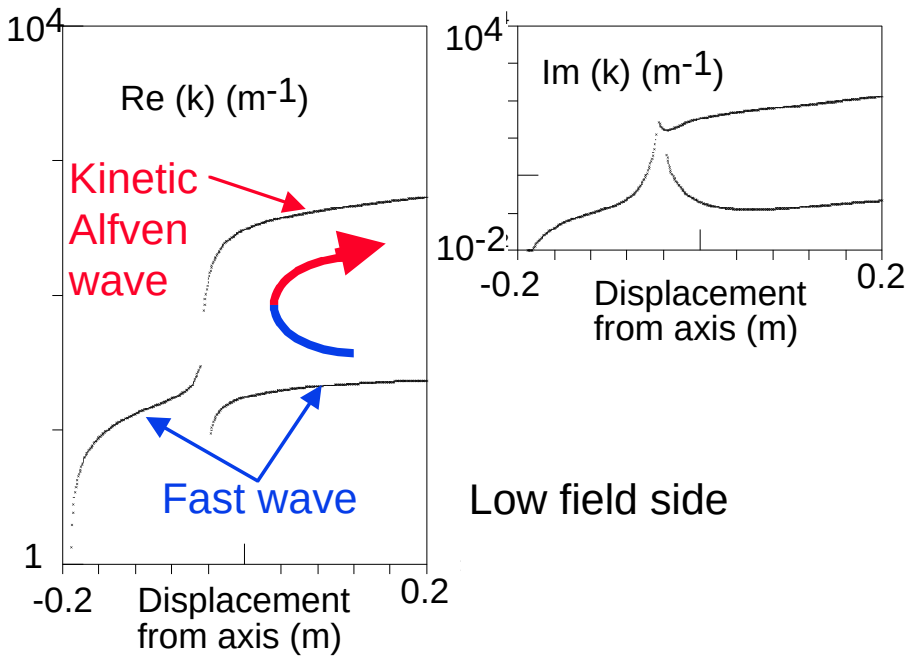
Addition of helium-3 permits minority heating, mode conversion in NCSX

17 MHz, $n_e(0) = 6 \times 10^{19}\ m^{-3}$ (parabolic$^{0.5}$), $T_e(0) = 2$ keV, $B_0 = 1.4T$, 2%NBI H, $k_{||} = 12.5\ m^{-1}$

Minority heating with 5% He3



Mode conversion with 15% He3

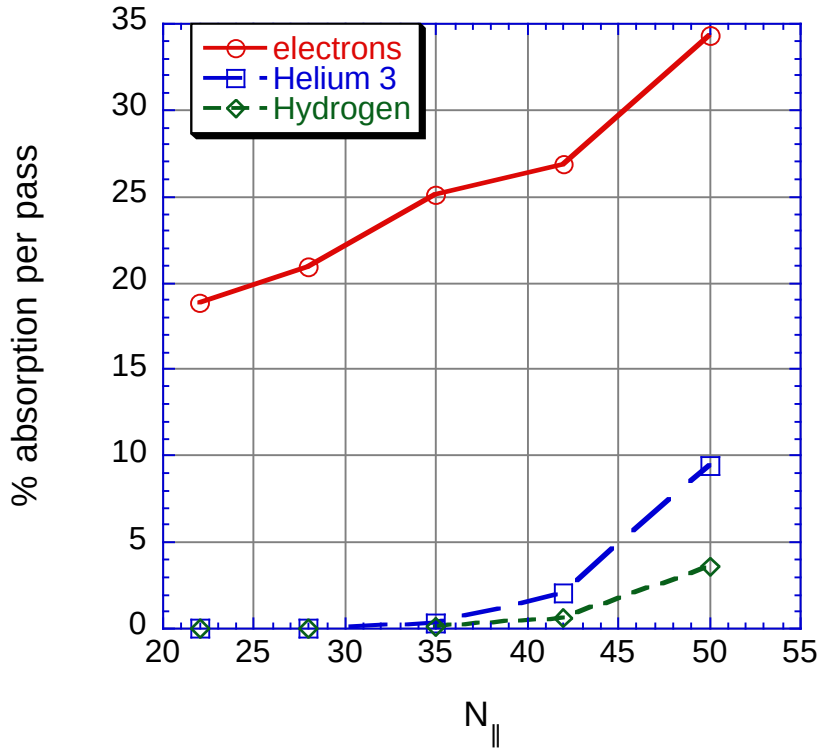


Low field side

Results from CRF hot plasma dispersion relation

Mode conversion can provide electron heating in NCSX

17 MHz, $n_e(0) = 1 \times 10^{20}\ m^{-3}$ (parabolic), $T_e(0) = 1$ keV, $B_0 = 1.4T$, 2%NBI H, 15% He3



1-D results from METS

- He3 concentrations below 10% result in minority ion heating
  - Survey of He3 minority heating not yet complete
  - Favors high field (>1.4T)
- 15% He3 produces mode conversion
- Reflected power in m-c regime is significant (~50%), except for high $N_{||}$
- Antenna loading will be low
  - Large antenna area required
- New rf sources required

High harmonic fast wave (HHFW) heating for NCSX

- HHFW heating and current drive is being implemented on NSTX
- NCSX will typically operate at moderately susceptibility ($\omega_{pe}^2/\Omega_{ce}^2 \sim 5$)
- Very high frequency fast waves can be strongly damped
- High power, CW sources are available for frequencies > 300 MHz
- Here we look at 350 MHz HHFW heating for NCSX
  - Compact launchers, probably folded waveguide
  - Isolators can be implemented at this frequency
    - » Reduces sensitivity of the system to changes in the plasma edge
  - Current drive capability is significant
  - Sources are typically CW, > 1 MW per tube

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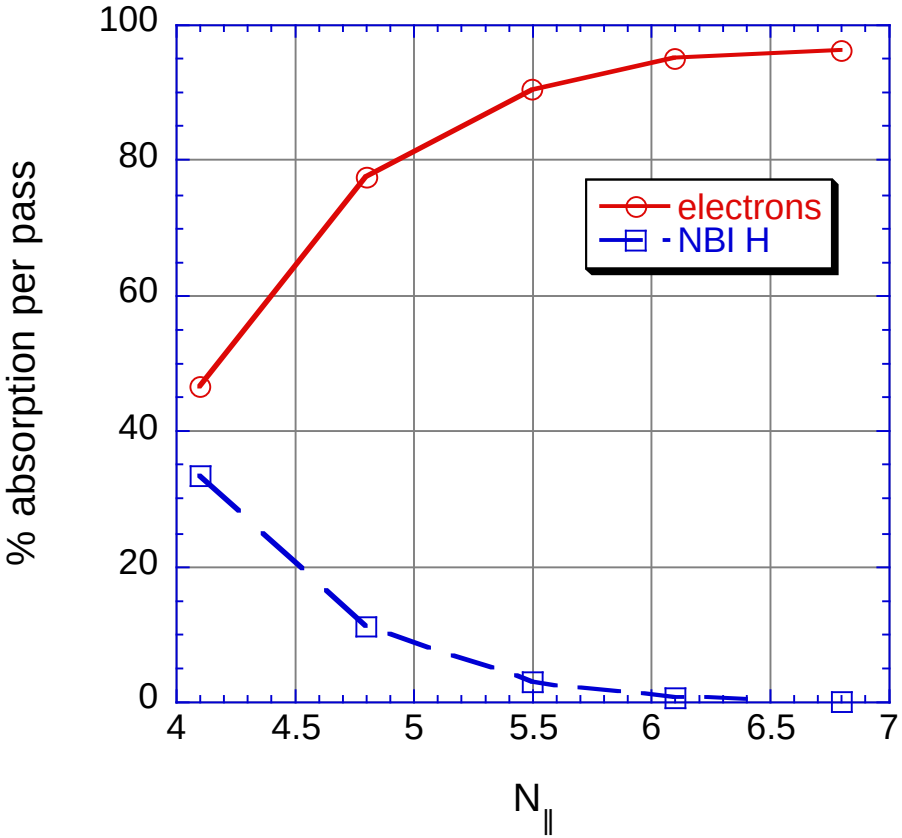
350 MHz HHFW strongly absorbed in NCSX

350 MHz, $n_e(0) = 6 \times 10^{19}\ m^{-3}$ (parabolic$^{0.5}$), $T_e(0) = T_i(0) = 2$ keV, $B_0 = 1.2T$, 2%NBI H

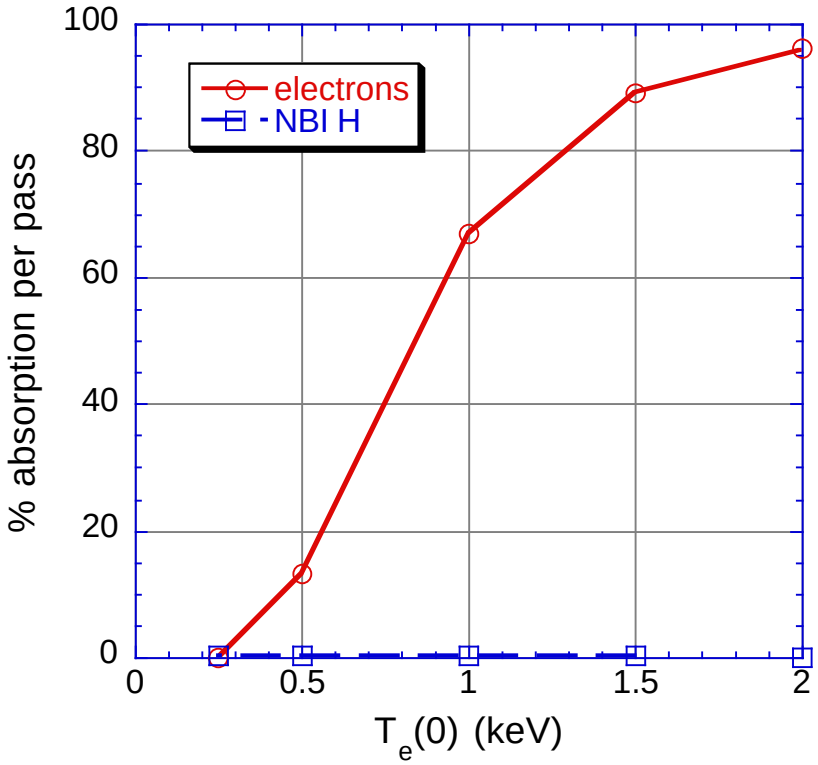


- High $N_{\parallel}$ <u>not</u> required for strong absorption
- Significant noninductive current drive capability
  - ~0.03 - 0.05 A/W (TORIC)
  - Accurate estimate requires detailed geometry

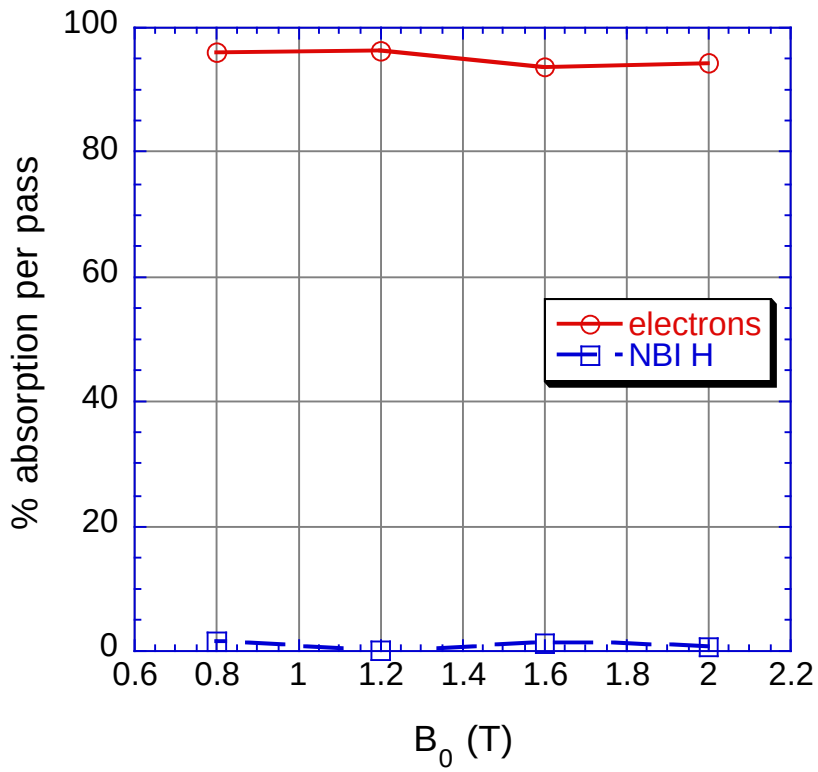
1-D results from METS

HHFW absorption is strong over a wide range in T_e, B_0

350 MHz, $n_e(0) = 6 \times 10^{19}\ m^{-3}$ (parabolic$^{0.5}$), $T_e(0) = T_i(0)$, $N_{||} = 6.8$, $B_0 = 1.2T$, 2%NBI H



350 MHz, constant β, $N_{||} = 6.8$, 2%NBI H



ICRF heating scenarios for NCSX
Conclusions

- RF heating at 30 MHz would be highly desirable, since 6-12 MW is available at this frequency at PPPL
  - But: absorption appears unacceptably low
  - Beam ion absorption may restrict toroidal field range
- Lower frequency minority or mode conversion heating is feasible
  - Large antennas required would be hard to accommodate
  - Requires new rf sources
- High harmonic fast wave heating appears promising
  - Good absorption. Compact, robust launchers possible
  - Increased launcher-plasma separation
  - But: regime, launchers not yet well tested
  - Requires new rf sources
- Further modeling and development of HHFW heating and current drive is needed

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