Porting requirements for the NCSX High Frequency Fast Wave (HFFW) rf heating and current drive system.

NCSX project meeting
PPPL
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Outline

- Introduction: RF choices for NCSX
- Physics considerations
- High frequency fast wave system
- Launchers
- Port requirements
- Summary

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Introduction - rf heating and current drive for NCSX

- Existing 30 MHz NSTX rf sources are poorly suited for NCSX
  - Poor frequency choice for hydrogen operation at 1-2T.
- ICRH would require very low frequency (He^3 at 10-20 MHz).
  - Low loading ⇒ large area launchers
    - » Ruled out by tight port access, close fitting vacuum chamber with poor access.
- ECH = $$$$.
  - High density would also require novel scenario (EBW, third harmonic)
- But: NCSX will typically operate at moderately high susceptibility ($\omega_{pe}^2/\Omega_{ce}^2 \sim 5$)
  - Very high frequency fast waves can be strongly damped
- Consensus of the rf group that 350 MHz HFFW heating and current drive is one of the few possibilities for rf heating in NCSX

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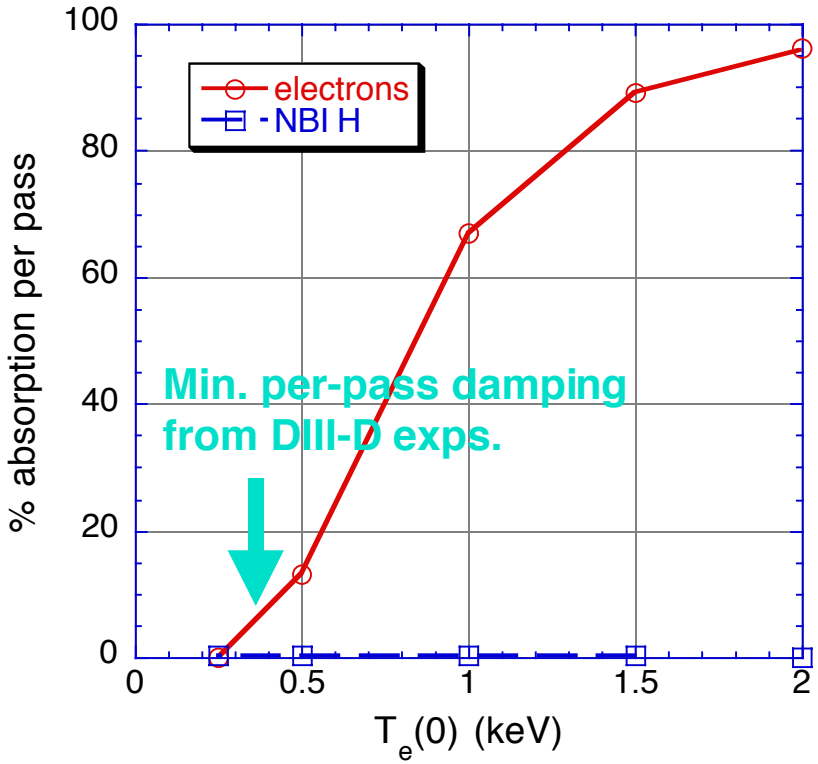
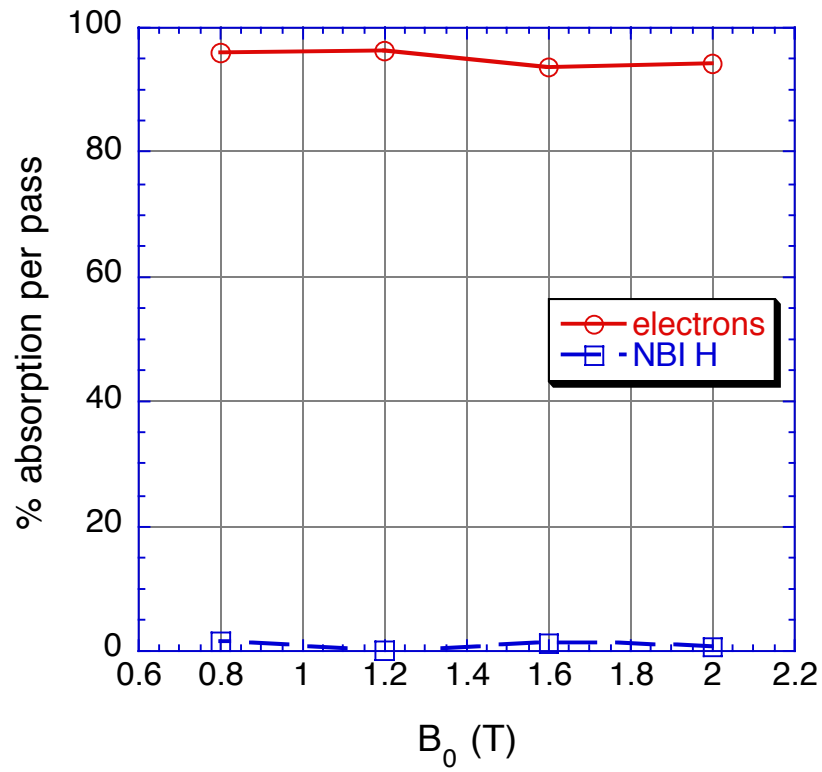
350 MHz HHFW absorption is strong over a wide range in T_e, B_0

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

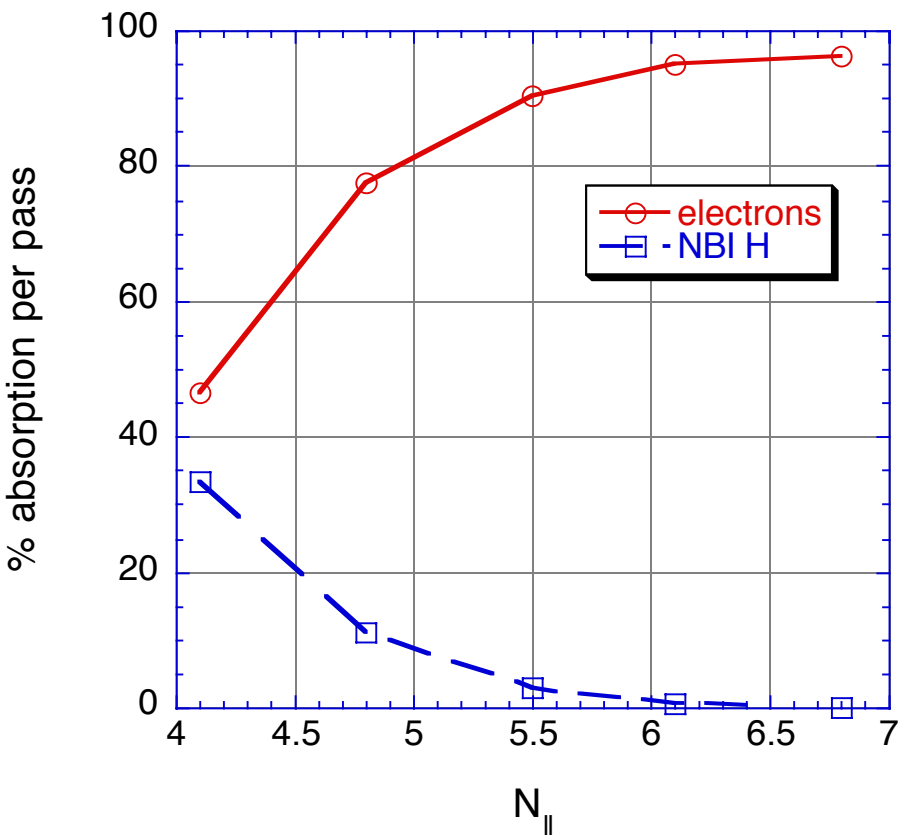


350 MHz, constant β, $N_{||} = 6.8$, 2%NBI H



Best combination of high loading, good absorption, good current drive efficiency for $N_{||}$ ~ 5-6

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 $N_{||}$ <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

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HFFW system

- Summary of wave modeling:
  - Good absorption for $T_e > 300$ eV at $n_e(0) > 6 \times 10^{19}$ m^{-3}.
  - Insensitive to |B|, over range 1-2 T.
  - Best $N_{||}$: 5-6.
- System:
  - Available tubes: 1.2 MW CW klystrons from EEV.
    - » 6 required for 6 MW coupled at 80% efficiency.
  - TFTR NB power supplies are suitable for HV.
  - Launchers can be waveguide based:
    - » Folded waveguide.
    - » Strap loaded waveguide.

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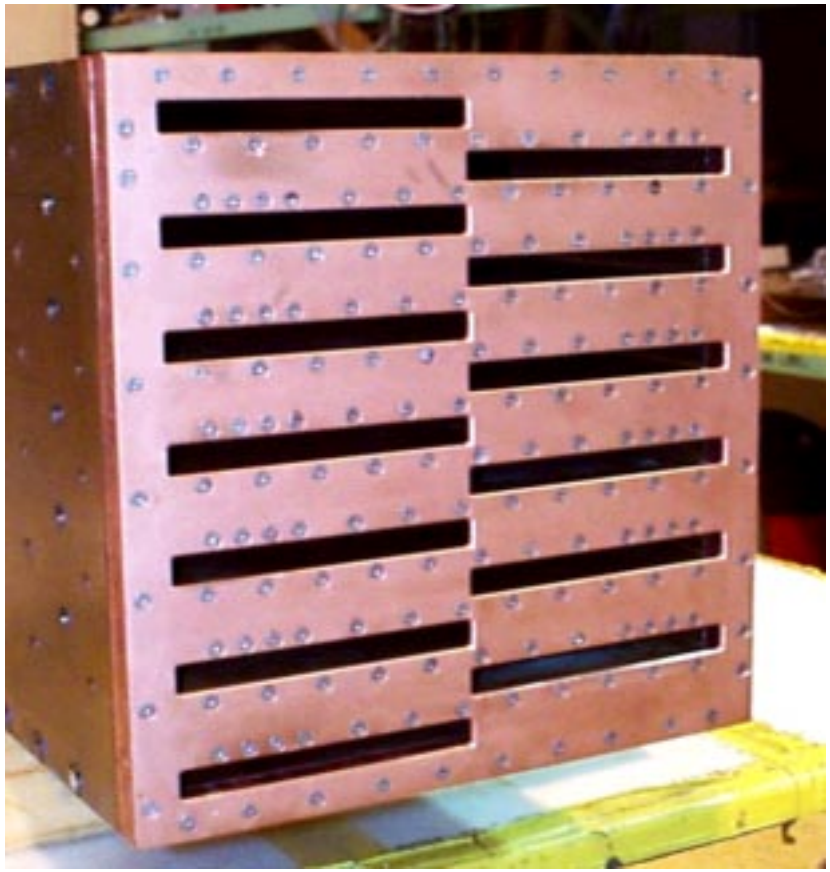
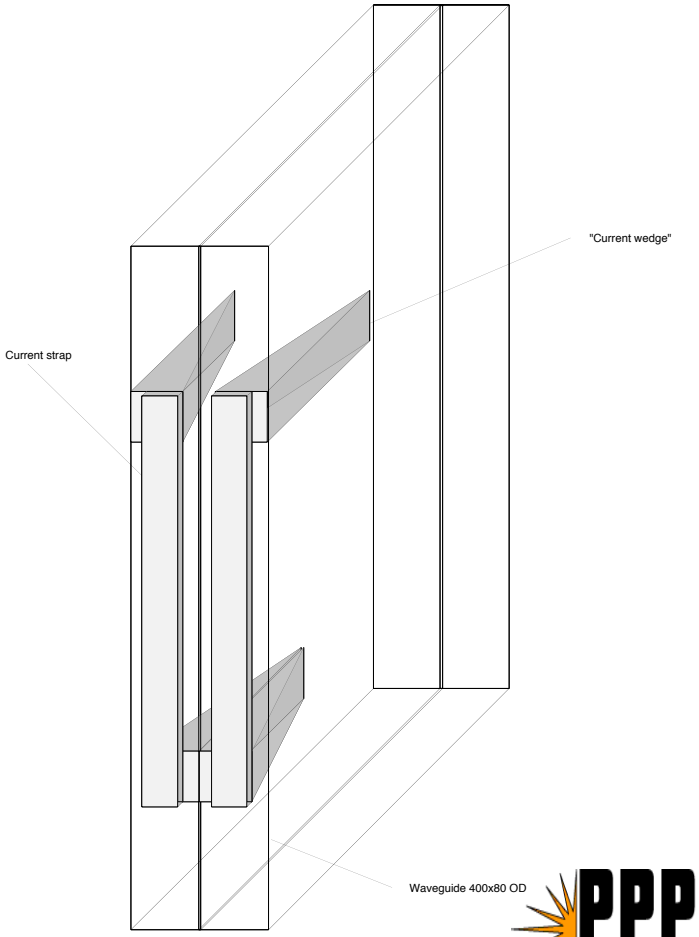
Possible launcher types for HFFW system

ORNL 433 MHz folded-waveguide dipole launcher for FTU



ORNL concept for strap-loaded waveguide for FIRE



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Port requirements for a waveguide-based HFFW launcher

- $N_{\|} = 5\text{-}6 \Rightarrow \lambda_{\|} = 14 - 17$ cm
- Directed launch (CD): at least four phased exciters within this dimension
  - Phased 0, $\pi/2$, π, $3\pi/2$.
- Each "exciter" (folded waveguide or strap-loaded waveguide) will extend ~4 cm in the toroidal direction.
- For a strap-loaded waveguide, the vertical height (poloidal extent) must be $> \lambda_{\text{free space}}/2 = 43$ cm.
  - Minor reductions can be accommodated with a ridged waveguide.
- For a folded waveguide, the "folded" length must be $\lambda_{\text{free space}}/2$.
  - Easy to accommodate within a ~40 cm tall waveguide.
- Assume a unit exciter ~4cm (toroidal) x ~44 cm (poloidal).
  - Allows either concept.

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Port requirements for a waveguide-based HFFW launcher

- Maximum power density for conventional strap-based launchers is 1 - 1.2 kW/cm^2 (experimentally determined).
  - Some expectation that a FWG will achieve higher power densities.
    - » Achieved on a test stand; not tested in a fusion experiment.
- For 6 MW coupled, implies a minimum launcher area of ~0.5 m^2.
- *At most* four ports are available for launchers.
  - Launcher width must be < 32 cm (TF clearance).
- Each launcher can be comprised of 6 exciters.
  - Launcher unit size: 24 cm (toroidal) x 44 cm (poloidal).
    - » Allows for a frame limiter.
  - Phasing of the individual launchers nominally: 0, $\pi/2$, π, $3\pi/2$, 0, $\pi/2$
  - Convenient fit to 6 tubes.
- Power density for 6 MW: 1.4 kW/cm^2.

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Summary

- The best choice for rf heating and current drive in NCSX appears to be High Frequency Fast Waves.
  - ECH and lower hybrid were not considered in detail.
- Launcher complement for 6 MW coupled:
  - Four launchers in 4 ports.
  - Each launcher would be 24 cm in toroidal width, ~44 cm in poloidal height.
  - Modest radial build: ~40 cm.
- What little port space is not used for neutral beams is required for 6 MW of HFFW heating and current drive.

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