RF heating options for NCSX.

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NCSX Physics Validation Review
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RF options for NCSX
Introduction

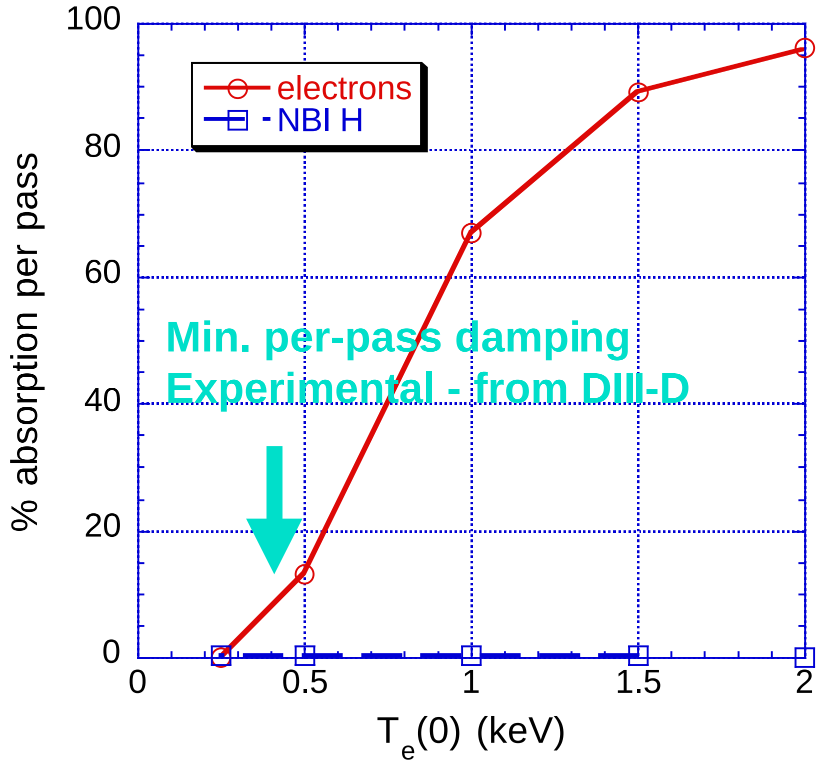
- Two candidates: High Frequency Fast waves and Mode Conversion.
  - Neither option in baseline budget
- High frequency fast waves:
  - Electron heating (independent of ion species)
  - Low field side coupler - easy to install
  - Insensitive to magnetic field (easy field scans w/ identical heating)
  - But - no ion heating option, a completely new system (expensive)
- Mode conversion:
  - Electron or ion heating
  - Highly localized: profile control, transport measurements
  - Potential for localized flow shear generation
  - Very modest cost; maximal use of rf site credits
  - But - high field side coupler: more difficult to fit it in & access it

High frequency fast wave (HFFW) heating for NCSX

- NCSX will typically operate at moderate 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 on the low field side, 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
    - » Aid in countering NB-driven currents
  - Available sources are typically CW, > 1 MW per tube
- Extension of HHFW experiments now under test on NSTX

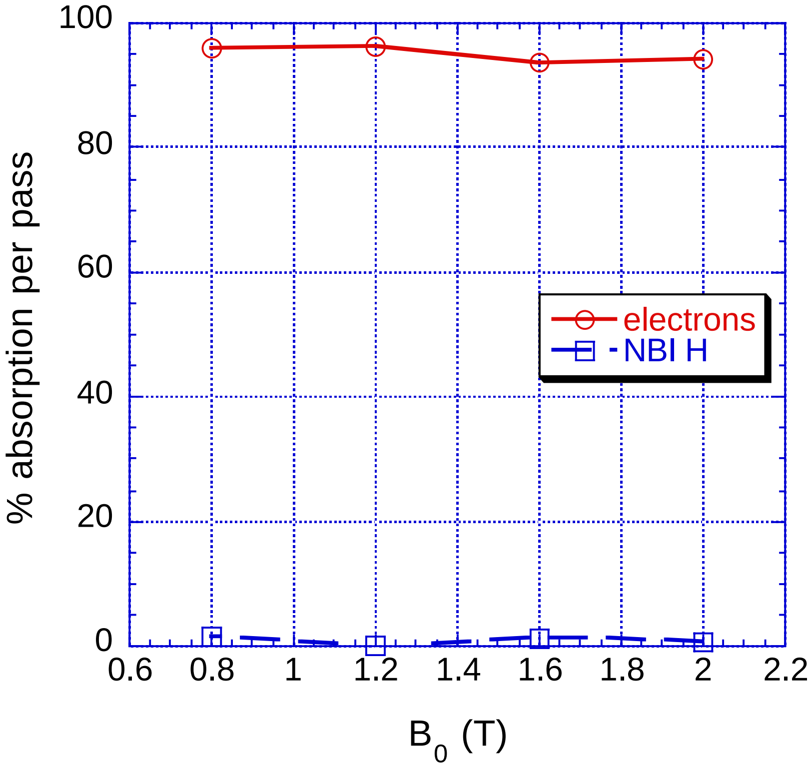
HFFW absorption is strong over a wide range in T_e, B_0

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



Min. per-pass damping
Experimental - from DIII-D

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

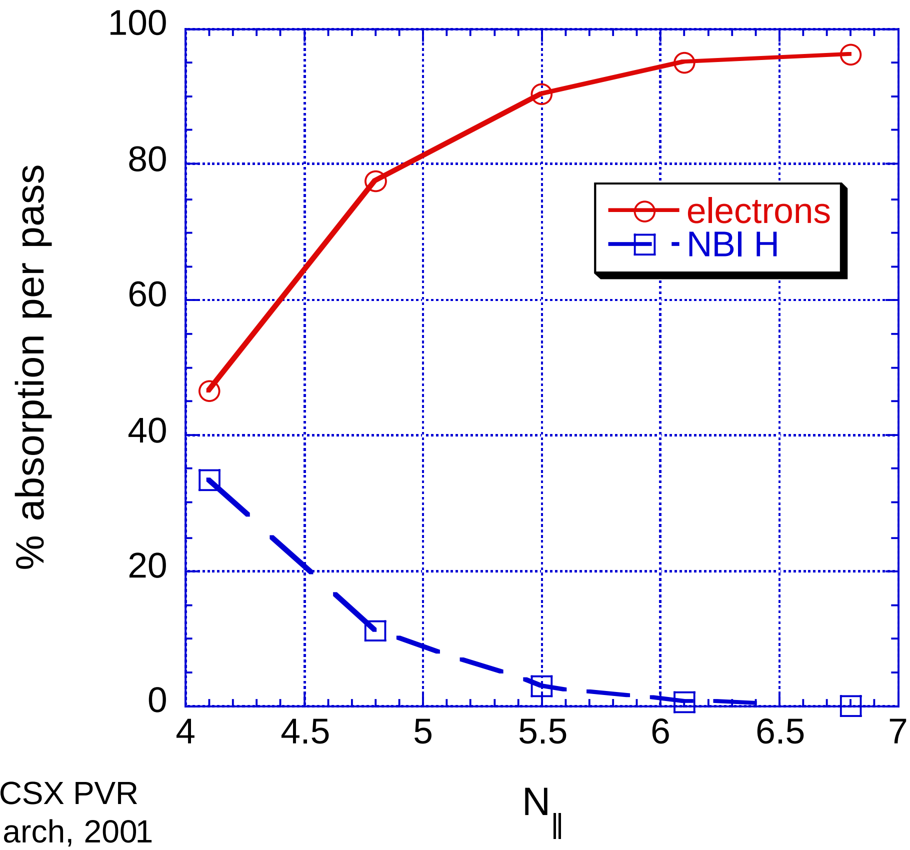


Note that this is a higher harmonic (20th vs ~13th) than NSTX HHFW heating.
Electron β is much lower than for NSTX HHFW.

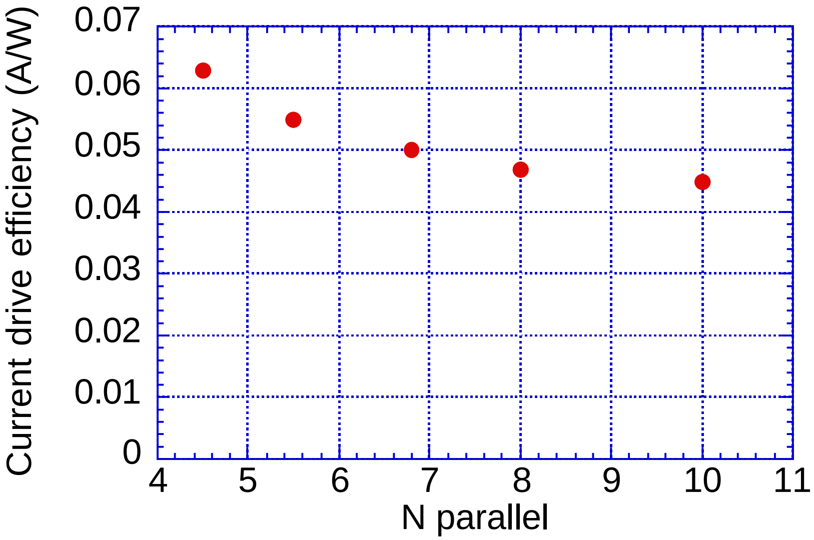
Current drive efficiency is predicted to be more than adequate to counter 100 kA of NB driven current.

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

1-D results from METS



TORIC estimate of the current drive efficiency (Note: axisymmetric code)



NCSX PVR
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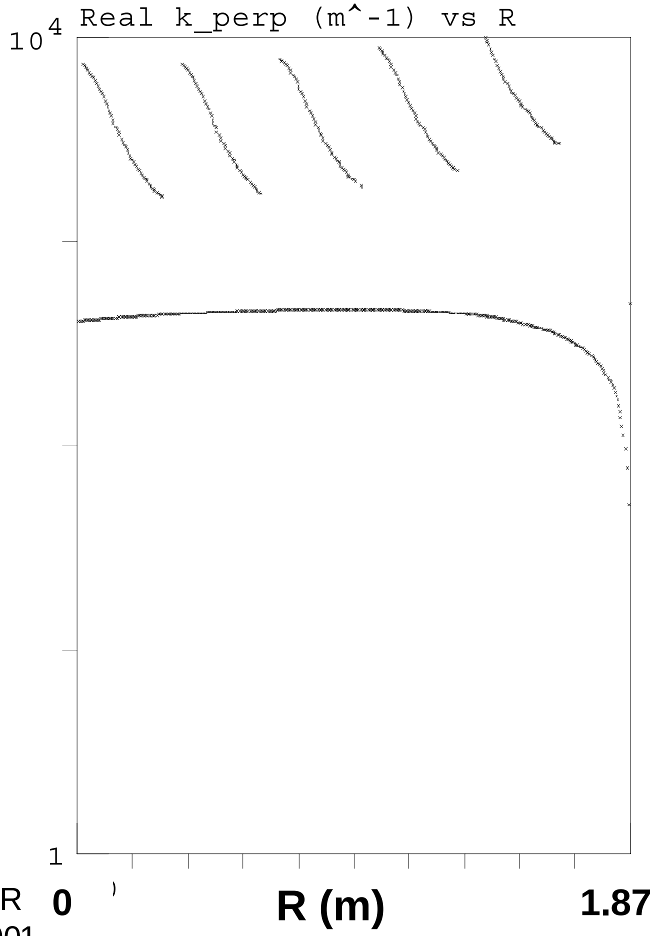
Dispersion relations for 350 MHz in NCSX indicate that coupling to slow waves will be negligible

- 350 MHz dispersion relation
  - Only slow wave in evidence is the IBW; LH root is at very high $k_\perp$.

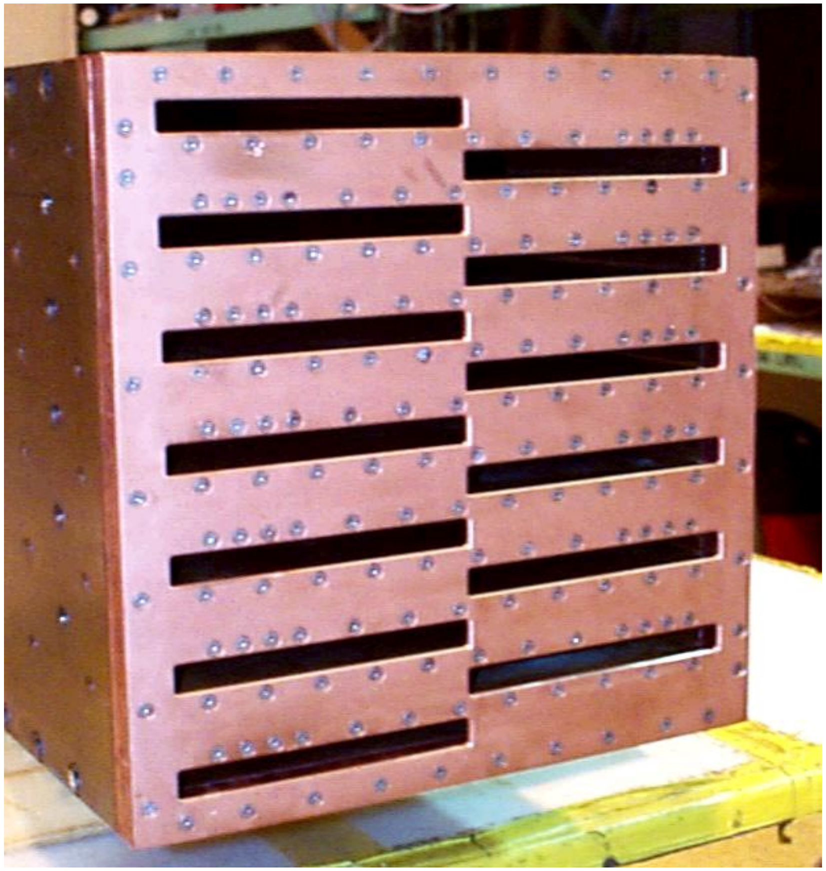


- Launch issues:
  - Required $N_{\|} = 4\text{-}4.8$ for
    - » $k_{\|} = 30 - 35\ \mathrm{m}^{-1}$
  - Modest density ($2\text{-}3 \times 10^{18}\ \mathrm{m}^{-3}$) at cutoff - fast wave propagates well into the edge plasma
- But: vacuum fields have a very short evanescence length (< 1cm)
  - Coupler must be tightly coupled to the edge. No vacuum gap.
- A movable coupler (à la lower hybrid) would be need to accommodate different equilibria

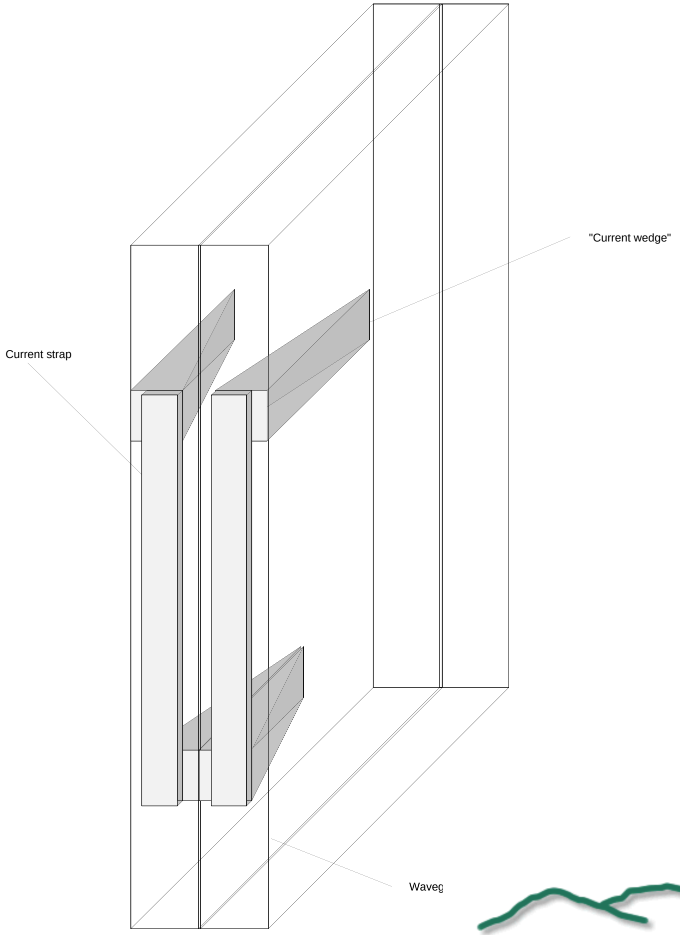
Possible launcher types for HFFW system

ORNL RF Technology

ORNL 433 MHz folded-waveguide dipole launcher for FTU



ORNL concept for strap-loaded waveguide for FIRE



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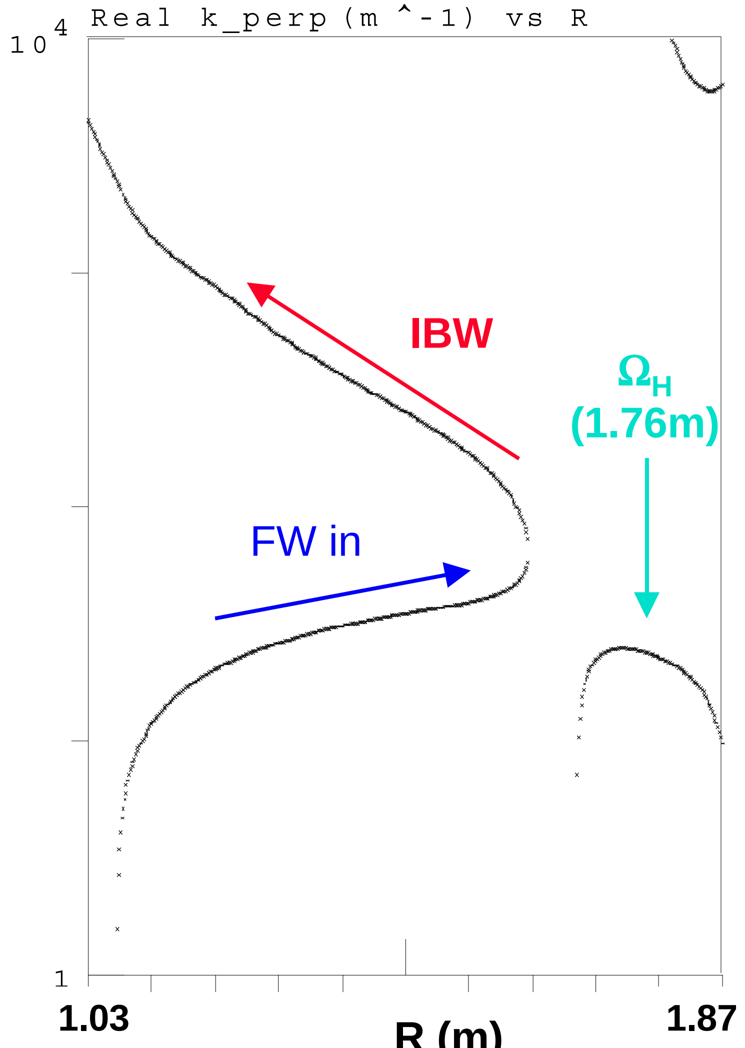
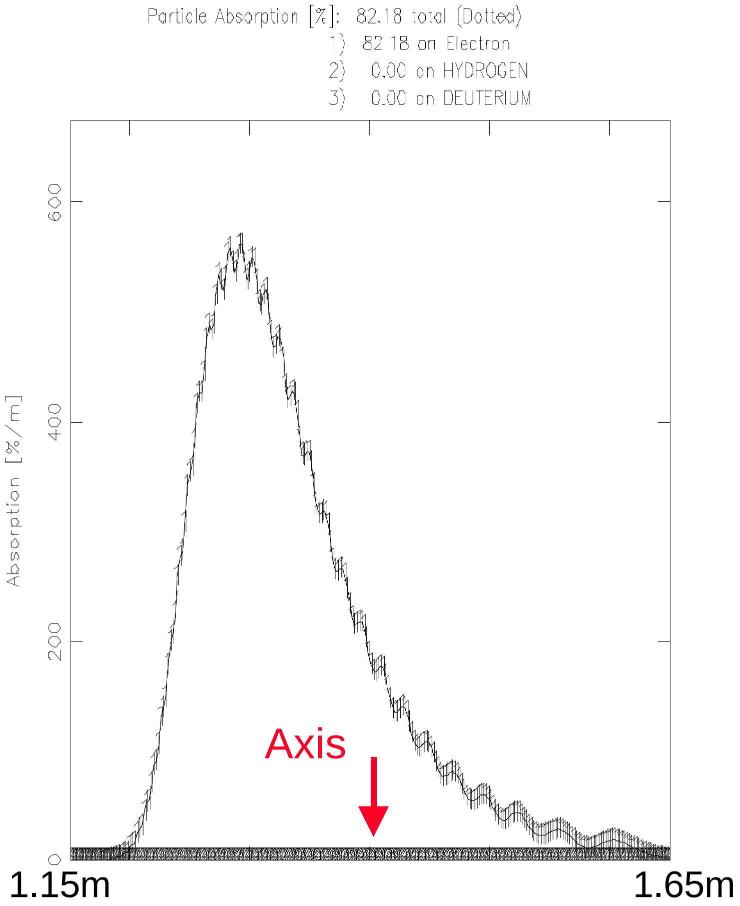
Mode conversion heating for NCSX

- Prior designs for the coils dictated low field side access HFFW
- New solution enabled by the present modular coil design:
  - Mode conversion with a **high field side launch** in a two-ion plasma
    - » A fast wave launched from the high field side of NCSX will mode convert to a strongly damped ion Bernstein wave at the ion-ion hybrid layer with near 100% efficiency
  - Possible ion systems: D-H, H-^{3}He (favored)
- Scenarios surveyed can produce ion or electron heating, narrow or broad deposition profiles, localized current drive
- Inexpensive.
  - Modify existing FMIT units to permit 20-30 MHz operation, share with NSTX
- Builds on experience gained with mode conversion from TFTR, C-mod, CHS, W7AS, LHD…

Mode conversion in 90%D/10%H can provide electron heating with broad deposition profiles



1.6T, 0.9D 0.1H, 20 MHz, Te(0) = 1 keV, ne(0) = 5 x 10^{19} m^{-3}, $k_{||}$ = 9 m^{-1}



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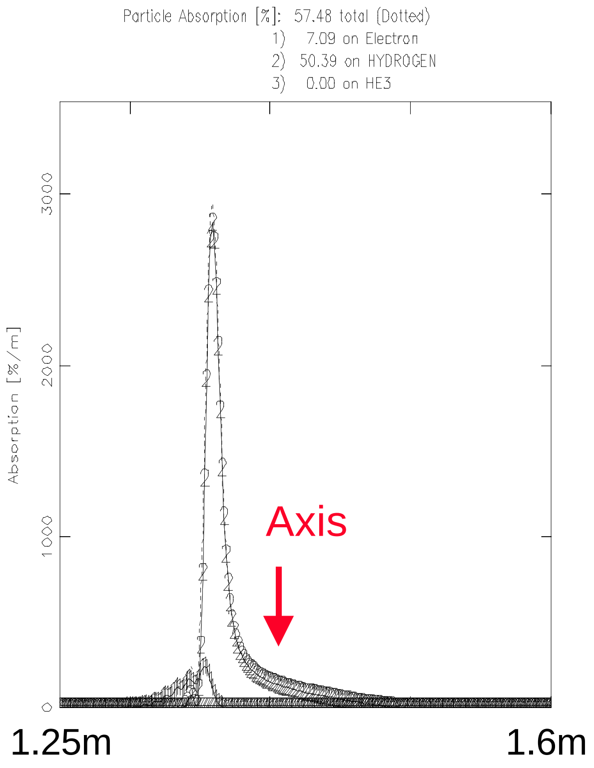
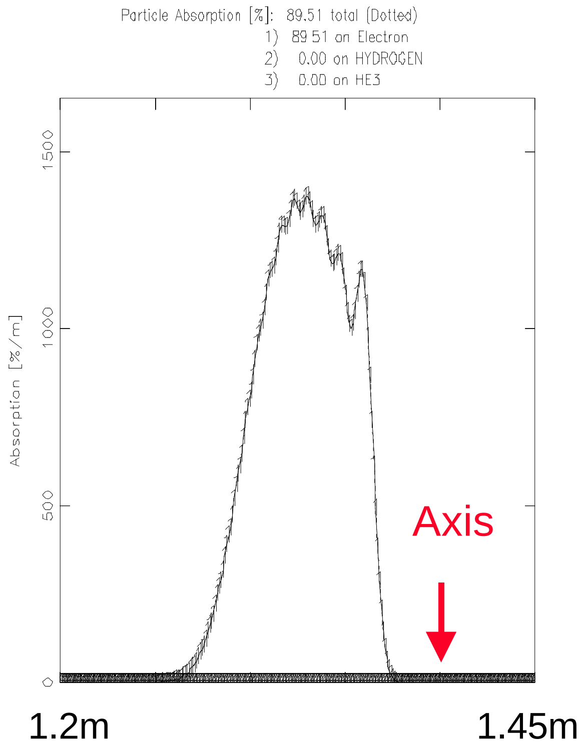
Mode conversion in H - He3 can provide central ion or electron heating over a wide range of magnetic field

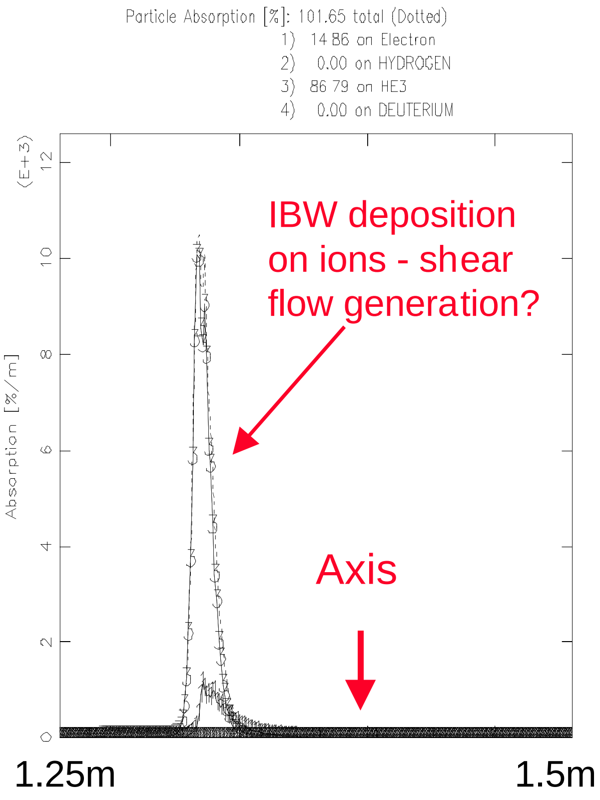
- 10% H (“high light ion minority” in He3 at 20 MHz
  ⇒**Hydrogen heating at 1.3T**



- 25% (n_i/n_e) He3 in hydrogen
  ⇒**Electron heating at 1.5T**
- Electron heating is obtained for a wide range of species mix



- 10%He3 in H
  ⇒**He3 heating at 1.8T**



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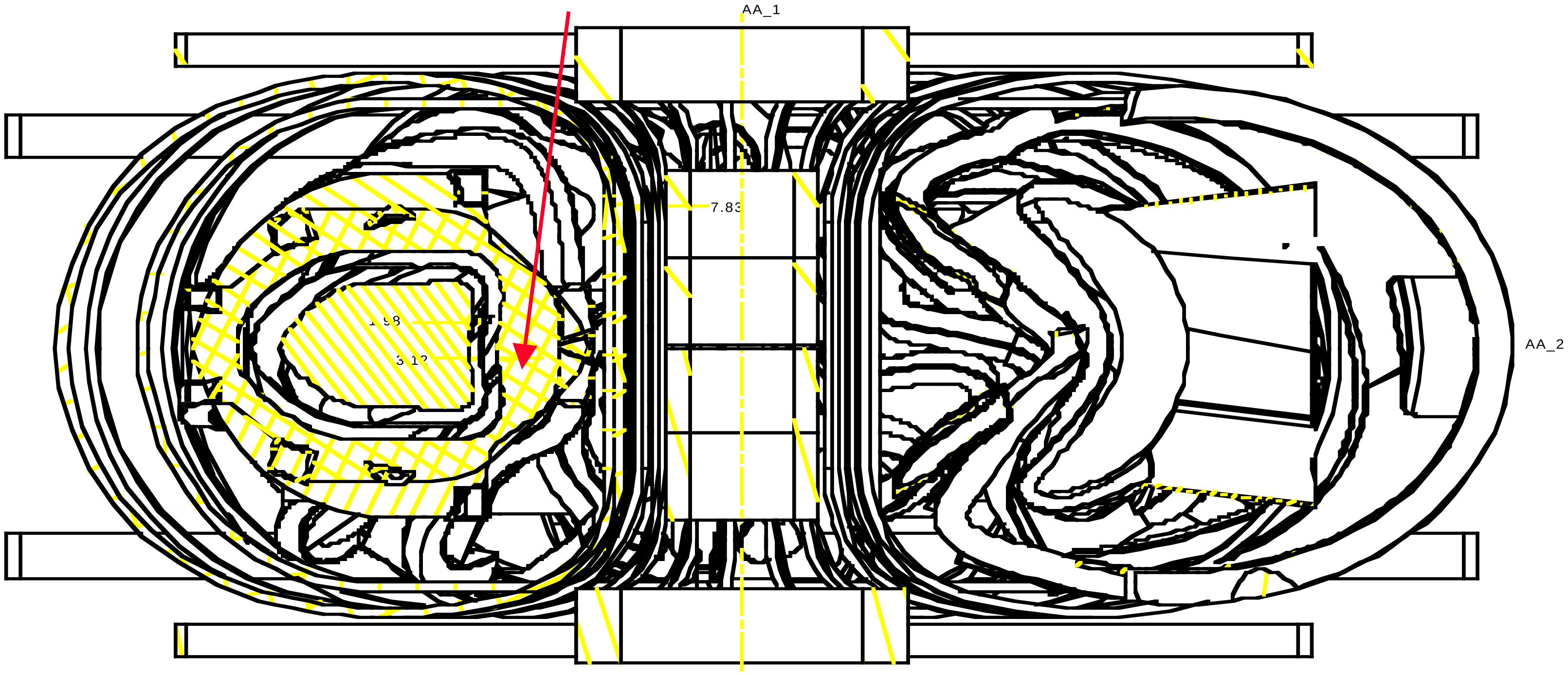
Summary of mode conversion scenarios

- Electron heating
  - Broad or localized deposition, in H - He3 or H - D
  - Can be core localized down to 1.3 T (for 20 MHz)
- Current drive
  - Best suited to scenarios with localized power deposition (H - He3)
  - On or off axis
- Ion heating
  - High minority concentrations can be heated to minimize tails
    - Typically 10% H or He3 minorities
  - He3 minority scenario would lend itself to investigation of shear flow effects

Antennas for mode conversion - comblines


Insert antennas here

- Very close coupling of the antenna to the plasma is not needed
    - Longer evanescence lengths for vacuum fields
    - Combline antenna *favors* weak coupling

RF heating summary
Tradeoffs between HFFW and mode conversion for NCSX

- Installation:
  - HFFW compatible with compact, low field side antennas.
  - High field side M-C antennas leave needed room for diagnostic access
- Flexibility:
  - Insensitivity to magnetic field without retuning favors HFFW for ease of use during magnetic field scans
  - M-C provides more physics tools (Local/broad deposition profiles, ion/electron heating, local current drive at variable radius, possible shear flow drive…
  - Launcher for M-C would be tolerant of wide plasma-antenna gap
- Cost:
  - M-C is much cheaper: <$2M for 6 MW vs ~$18M for 6 MW HFFW
- Conclusion: If the antennas fit, go with mode conversion as the RF upgrade option