Modeling of HHFW Current Drive in NSTX using TORIC

P.T. Bonoli, PSFC, MIT

S. Kaye, J. Menard, C.K. Phillips, PPPL

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Outline of Talk

- Review full wave - adjoint model for computing HHFW current drive
- Simulations of NSTX phasing experiments (Co -, Counter -, and Heating):
  - Results for ICRF power deposition (1-D, 2-D) and driven current density
- Conclusions

Model Description

- Use a full-wave ICRF field solver - TORIC
  - [M. Brambilla, Plasma Phys. Cont. Fusion **41**, 1 (1999)]
  - Code strictly valid in the ion FLR limit of $(k_\perp \rho_i)^2 << 1$
  - Run TORIC with an Order Reduction Algorithm (ORA) to obtain correct electric field polarization for the HHFW - [see D. Smithe et al. Nucl. Fusion **27**, 1319 (1987)].
  - Poloidal field neglected with ORA in TORIC - ($B_\theta = 0$)
- TORIC employs a spectral representation for *E(x):*

$$E(x) = \sum_{m,n_\phi} E_m^{n_\phi}(\rho)\exp(im\theta + in_\phi \phi)$$

Model Description

- Full-wave solver has been coupled to an adjoint solution of the Fokker Planck equation:
  - Use parameterization of current drive efficiency $G_{rf}(\rho, \theta)$ due to Ehst and Karney [see Nucl. Fusion **31**, 1933 (1991)].
  - Obtain driven current density by convolving the spectral representation for absorbed power density with current drive efficiency:

$$J_{rf} = \int_0^{2\pi} d\theta \sum_m G_{rf}^m(\rho,\theta) \sum_{m'} S_{rf}^{m,m'}(\rho,\theta)$$

Parameters Used for TORIC Simulations of HHFW Current Drive in NSTX

- T_i (0) = 1.0 keV
- T_e (0) = 1.4 keV
- n_e (0) = 1.3×10^{19} m^{-3}
- B_t = 0.445 T
- I_p = 500 kA
- Z_{eff} = 3.25
- a = 0.65 m
- R_0 = 0.89 m

- Profiles:
  - $n_e \alpha [1 - (r/a)^4]^{4.1}$
  - $T_e \alpha [1 - (r/a)^2]^{2.5}$
  - $T_i \alpha [1 - (r/a)^2]^{2.5}$

- TORIC Grid
  - N_R = 240 (Radial elements)
  - N_m = 31 (Poloidal Modes)

RF Parameters Used for HHFW Current Drive Simulations in NSTX

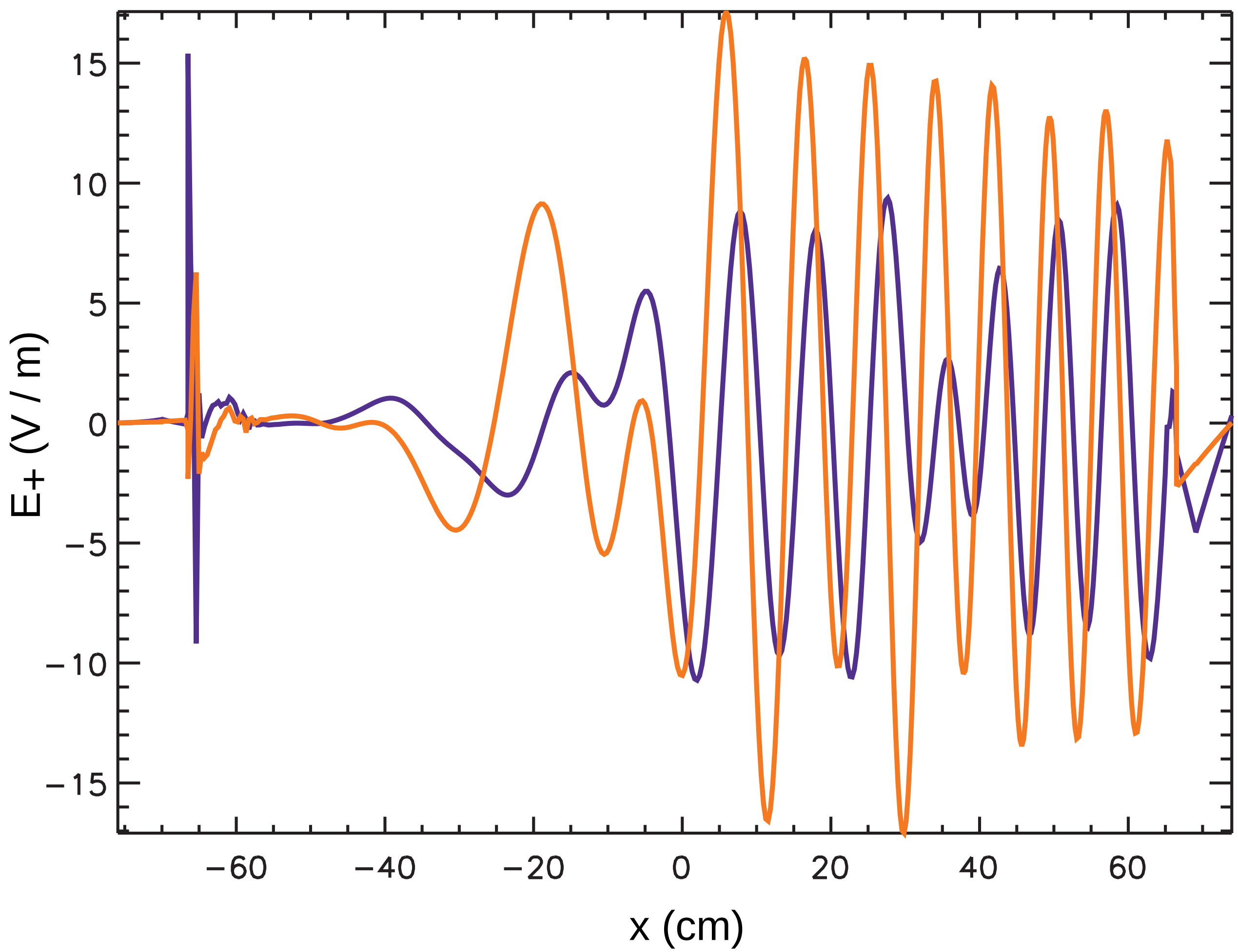
- $f_0 = 30$ MHz
- Co - Phasing
  - Shot 107899
  - $k_{\|ANT} = +7.6\ m^{-1}$
  - $P(n_\phi = +12) = 2.1$ MW
- Counter - Phasing
  - Shot 107907
  - $k_{\|ANT} = -7.6\ m^{-1}$
  - $P(n_\phi = -12) = 1.1$ MW
- Heating Phasing
  - Shot 107906
  - $k_{\|ANT} = \pm 14\ m^{-1}$
  - $P(n_\phi = +22) = 0.66$ MW

    $P(n_\phi = -22) = 0.54$ MW

$$\frac{P(n_\phi = +22)}{P(n_\phi = -22)} = 1.25$$

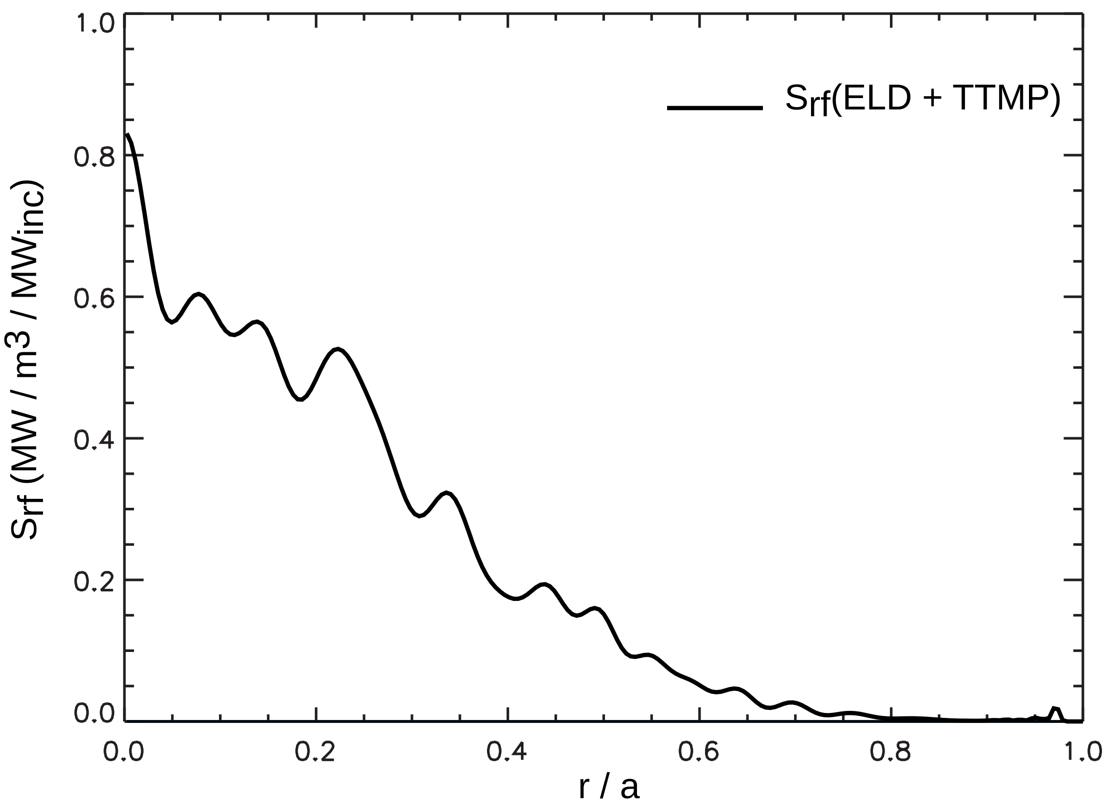
NSTX Co - Phasing [$n_\phi = +12$ ($k_{\parallel\,ANT} = 7.6\ m^{-1}$)]

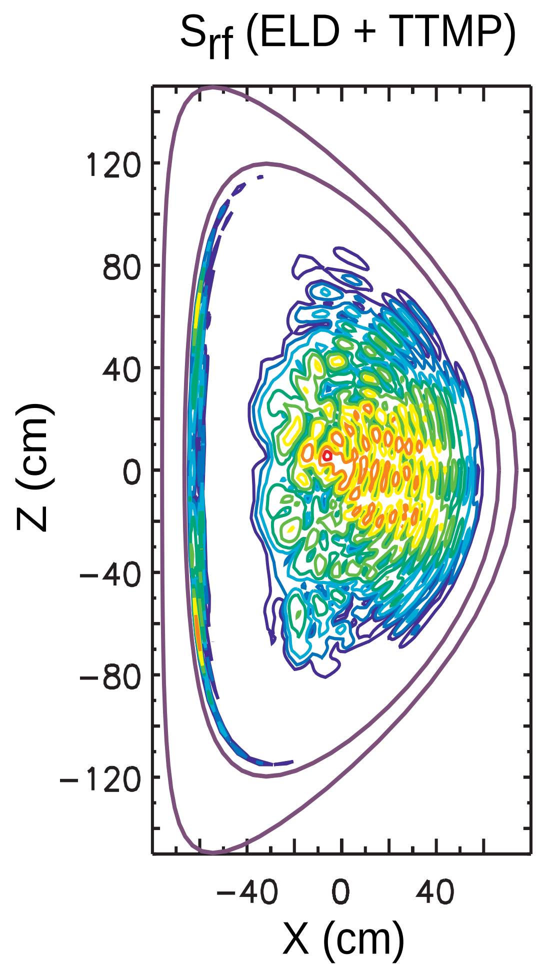
Electric Field Solution along Mid-plane



NSTX Co - Phasing [$n_\phi = +12$ ($k_{\parallel ANT} = 7.6\ m^{-1}$)]

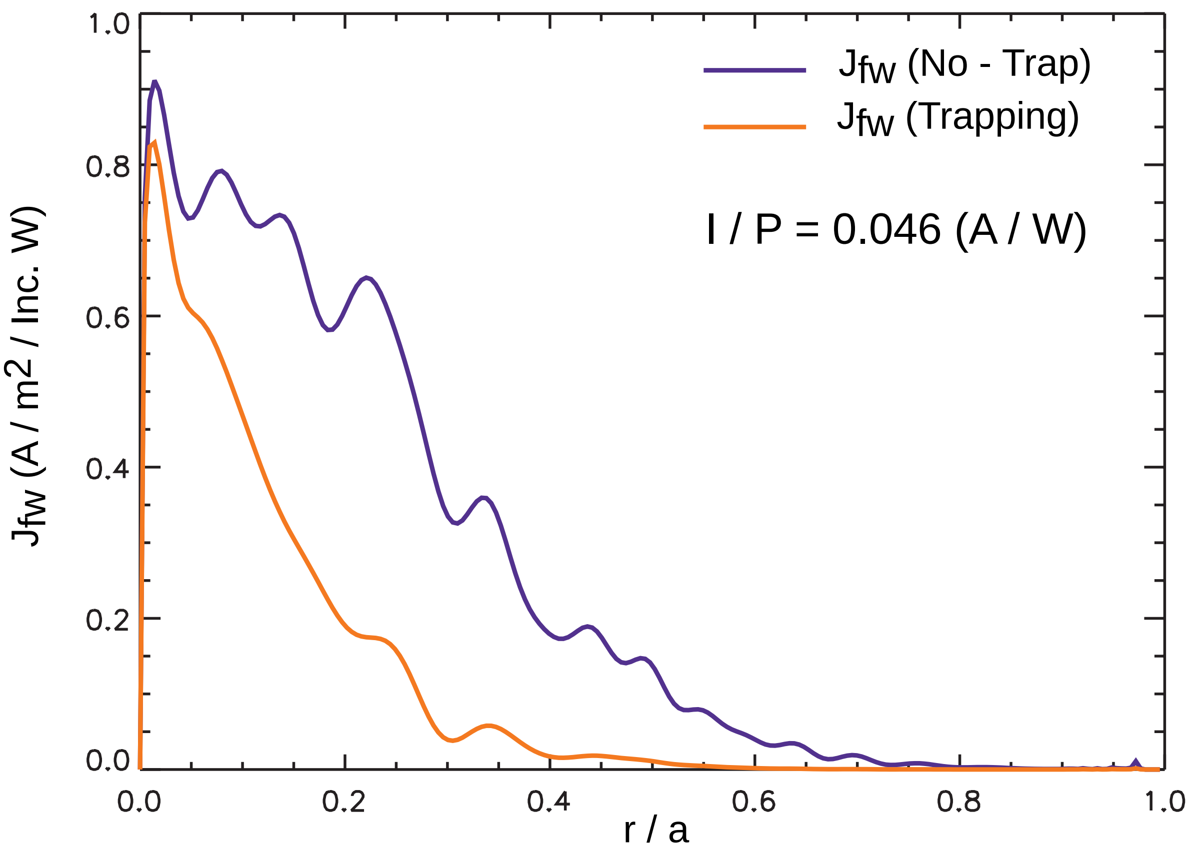
100% Absorption of HHFW via ELD and TTMP





NSTX Co - Phasing [n_ϕ = +12 ($k_{\parallel ANT}$ = 7.6 m^{-1})]

Significant Reduction in J_{fw} due to Trapping effect

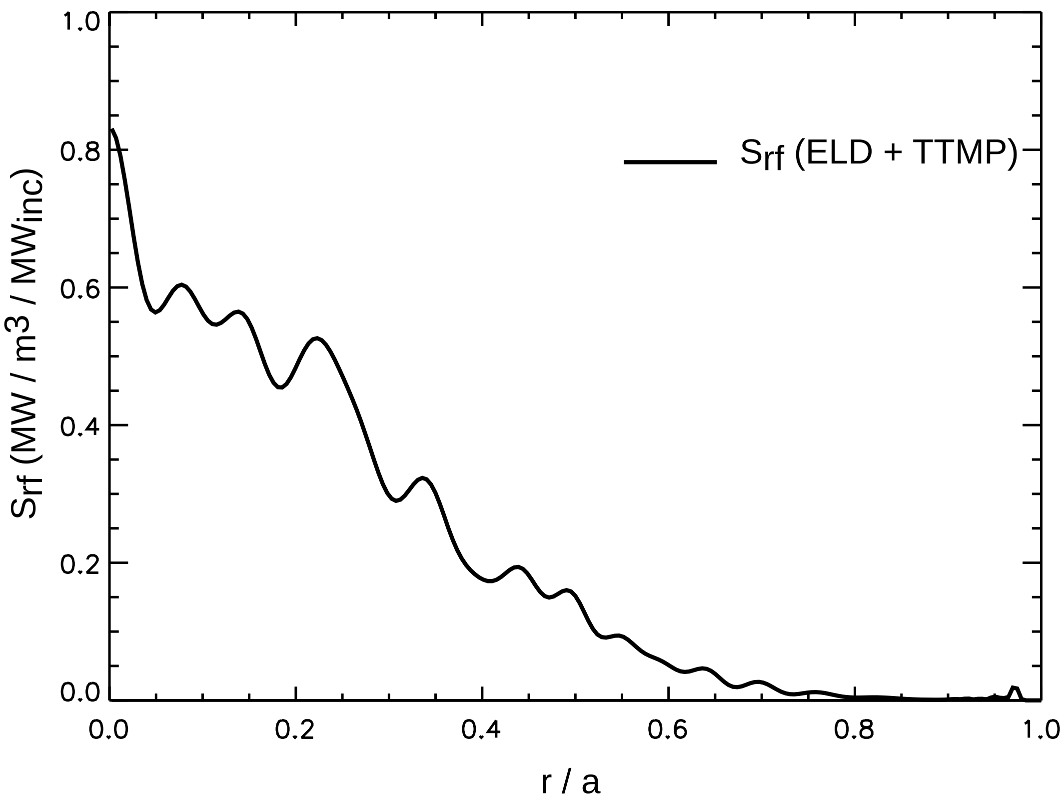


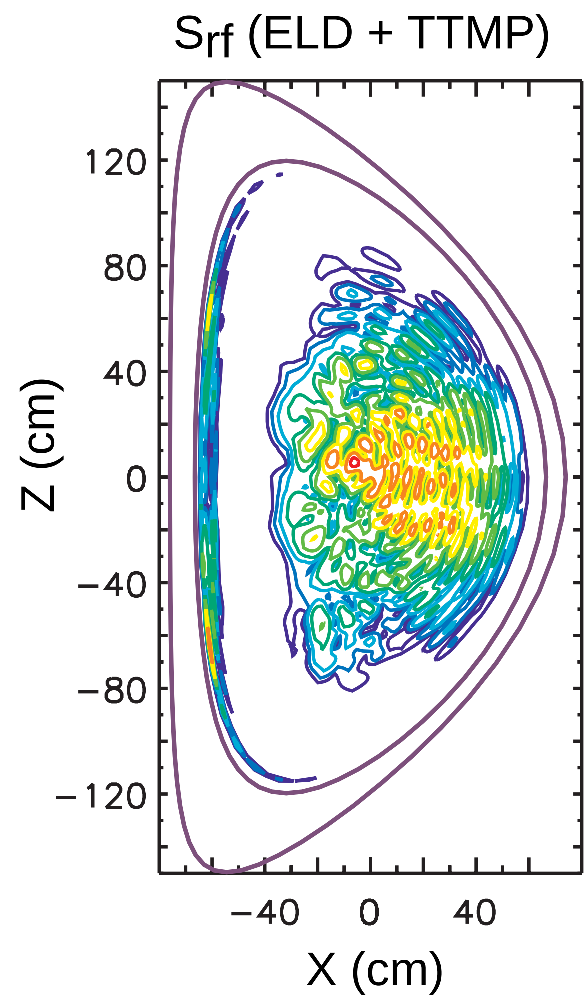
P_{ICRF} = 2.1 MW

I_{FW} = 96 kA (Co-)

NSTX Counter - Phasing [n_ϕ = -12 ($k_{\| ANT}$ = -7.6 m^{-1})]

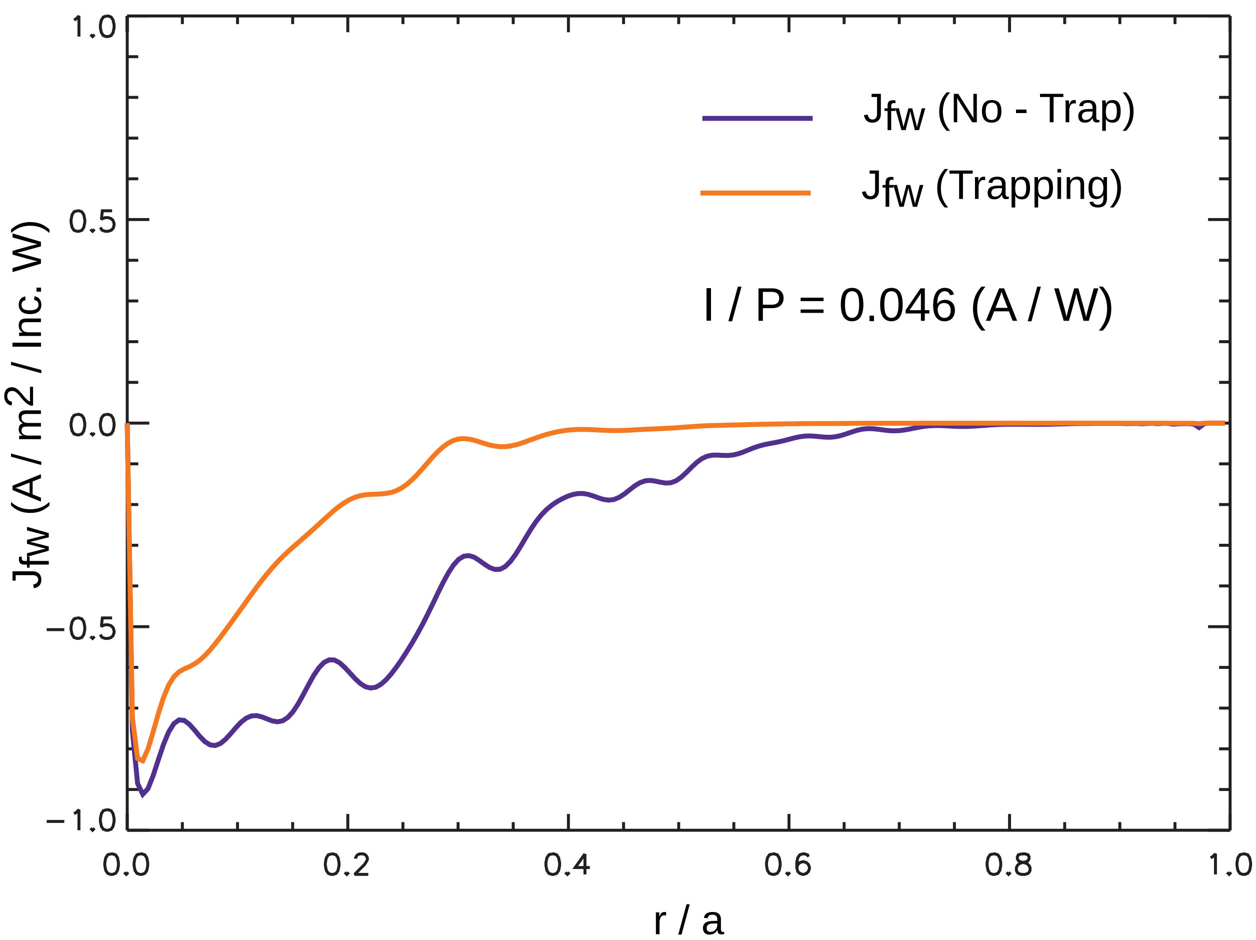
Absorption Profiles Identical to Co-Phase Case (n_ϕ = +12)





NSTX Counter - Phasing [$n_\phi = -12$ ($k_{\| ANT} = -7.6\ m^{-1}$)]

J_{fw} (r) and (I/P) identical to Co-Phase case ($n_\phi = +12$)

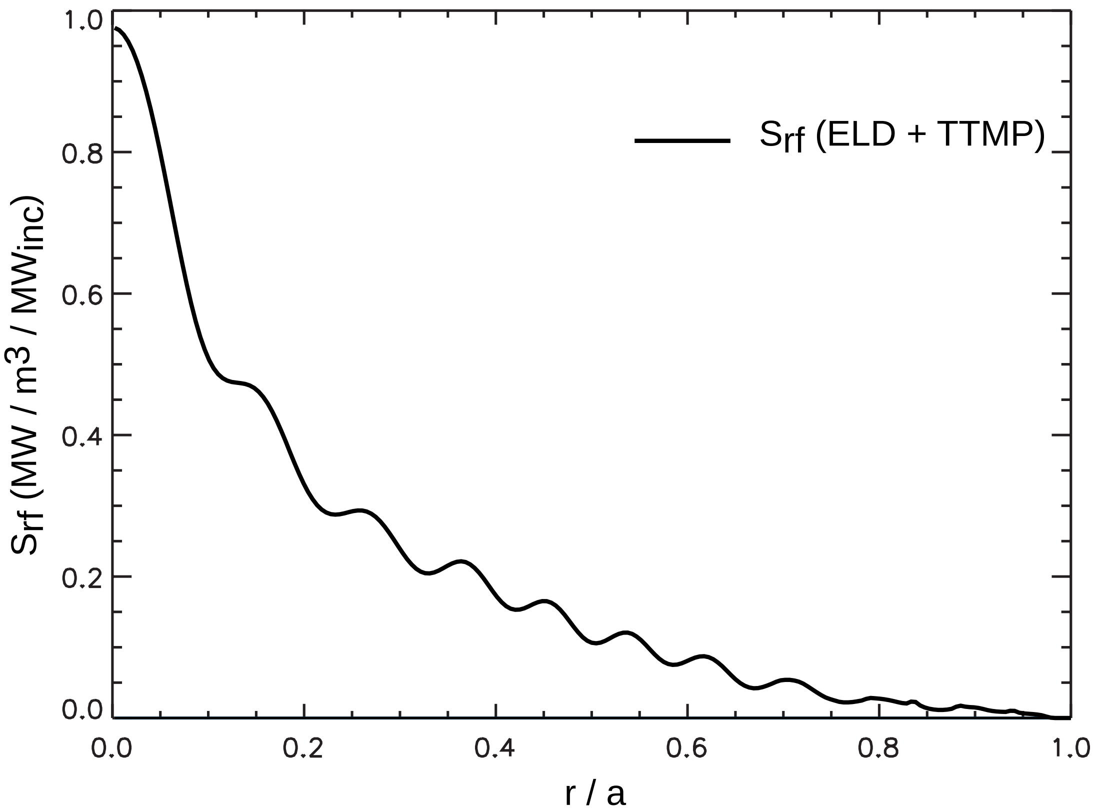


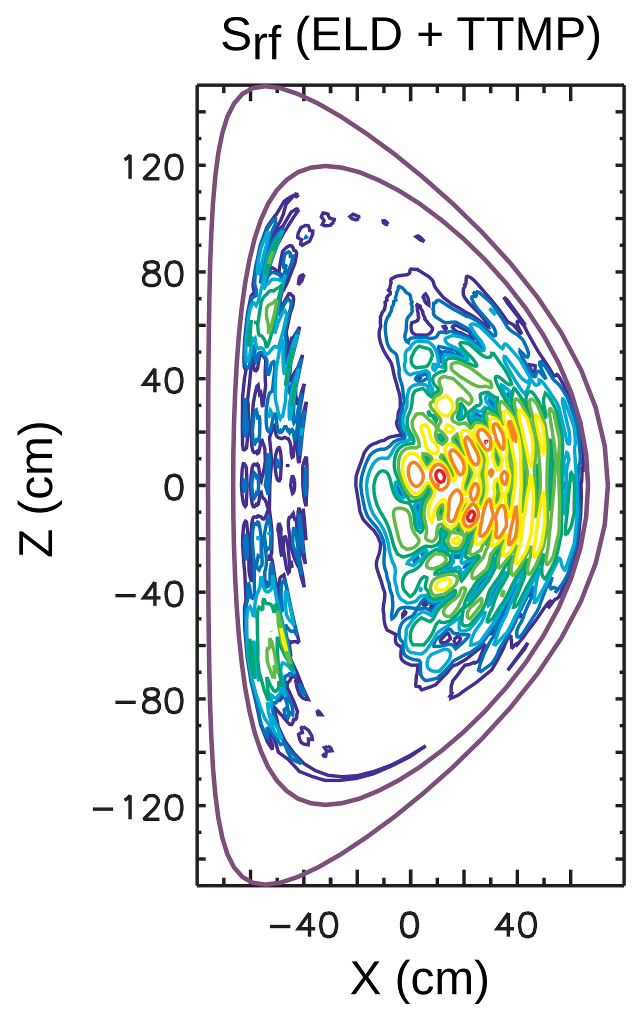
P_{ICRF} = 1.1 MW

I_{FW} = 50 kA (Counter)

NSTX Heating - Phasing [n_ϕ = +22 ($k_{\parallel ANT}$ = 14 m^{-1})]

100% Absorption of HHFW via ELD and TTMP

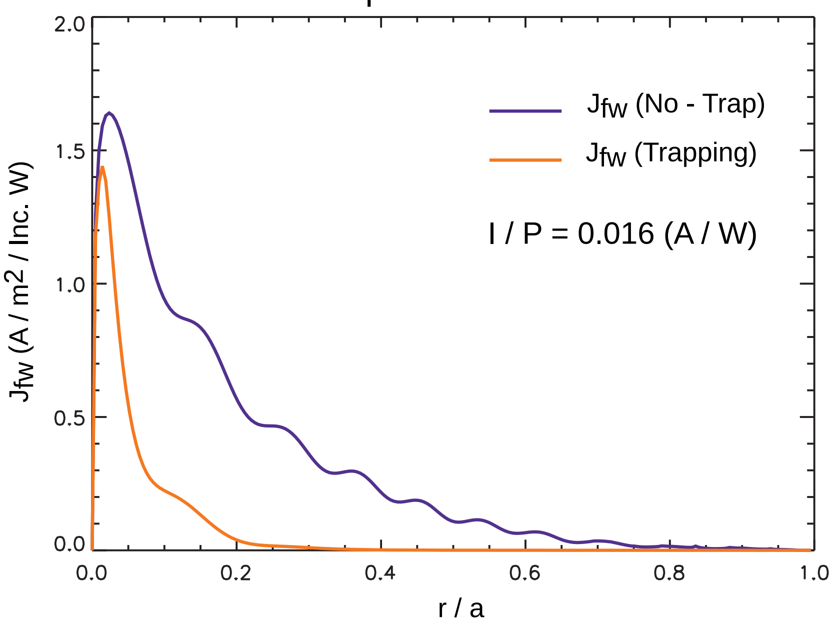




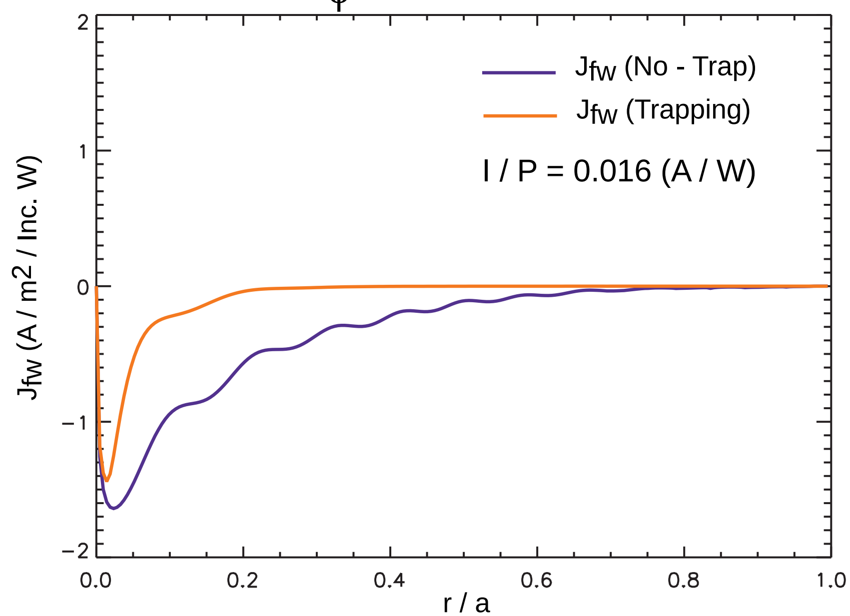
NSTX Heating - Phasing [$n_\phi = \pm 22$]

J_{fw} (r) and (I/P) identical for $n_\phi = \pm 12$

$n_\phi = 22$



$n_\phi = -22$



$\mathbf{P_{ICRF} = 1.2\ MW}$ $P(n_\phi = 22) / P(n_\phi = -22) = 1.25$

$I_{FW} = I_{FW}(n_\phi = 22)$ — $I_{FW}(n_\phi = -22)$

= (10.8 —8.6) kA = 2.2 kA **- Htg Phasing**

Conclusions

- A combined full-wave and adjoint code was used to simulate HHFW current drive phasing experiments in NSTX:
  - Modeling predicts I_{fw}(Co-) > I_{fw}(Cntr) in qualitative agreement with experiment
  - Reduction in J_{fw} (r) due to trapping effect is significant
- Future work should include poloidal field in full-wave simulations in order to account for toroidal variations in $k_{||}$ due to nonconstancy of m.