NSTX

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Recent Results from High Harmonic Fast Wave Experiments on NSTX

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In collaboration with

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[4]CompX
[5]Nova Photonics

50th Annual Meeting of the Division of Plasma Physics
Dallas, Texas, November 17-21, 2008

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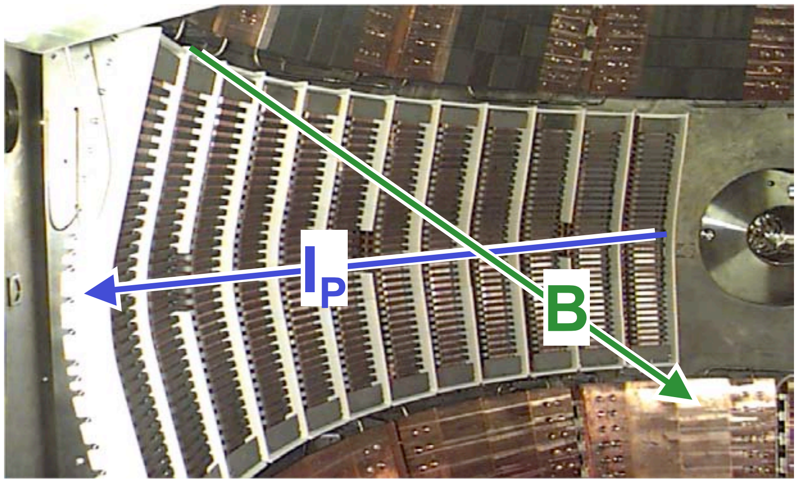
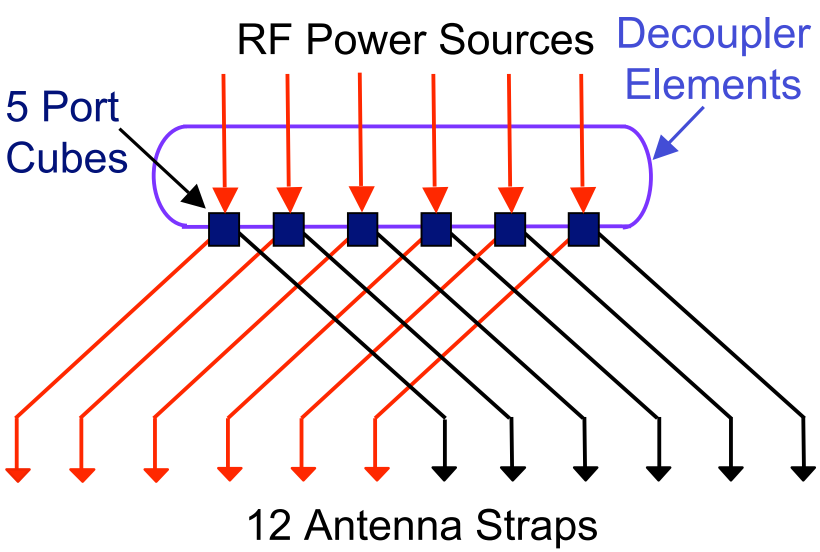
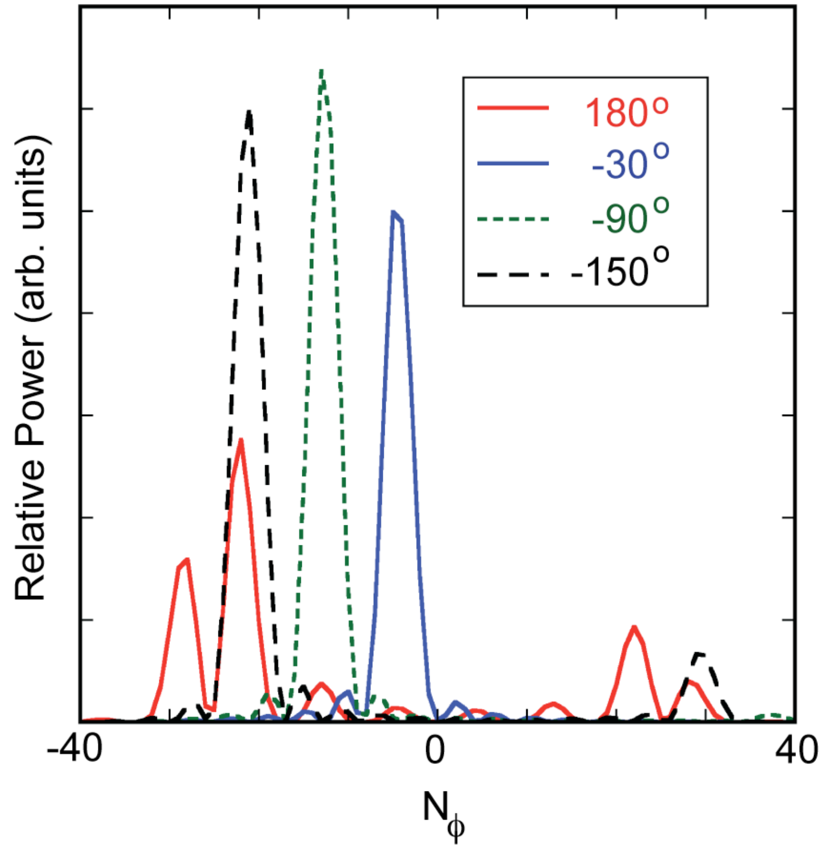
NSTX HHFW Antenna Has Well Defined Spectrum, Ideal for Studying Phase Dependence of Heating



HHFW antenna extends toroidally 90°

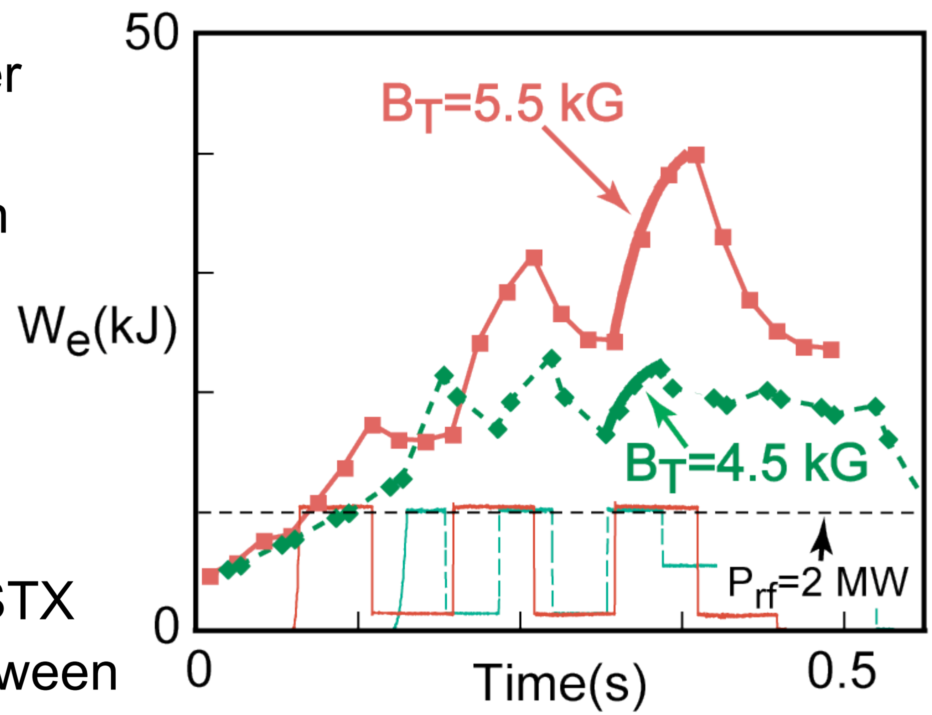




- Phase between adjacent straps easily adjusted between $\Delta\phi = 0°$ to $\Delta\phi = 180°$

Dramatic Improvement in HHFW Heating & CD Through Increased $B_t(0)$ & Edge Density Control

- Improved HHFW heating at higher $B_t(0)$ results from discovery of important role of surface waves in limiting coupling
  - Edge power loss increases when perpendicular propagation onset density is near antenna



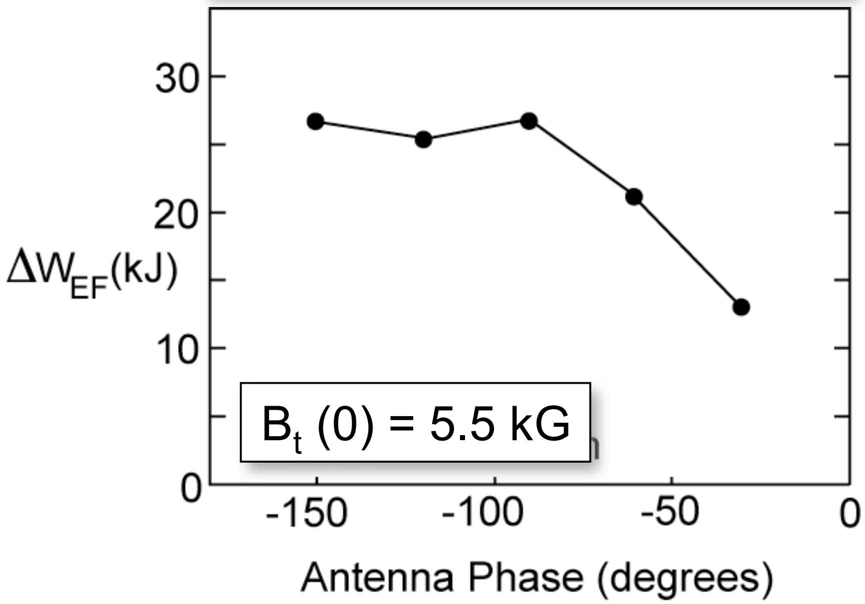
J.C. Hosea, et al. 2007 APS-DPP Meeting

- Strong first pass absorption in NSTX ideal for studying competition between core & edge power loss

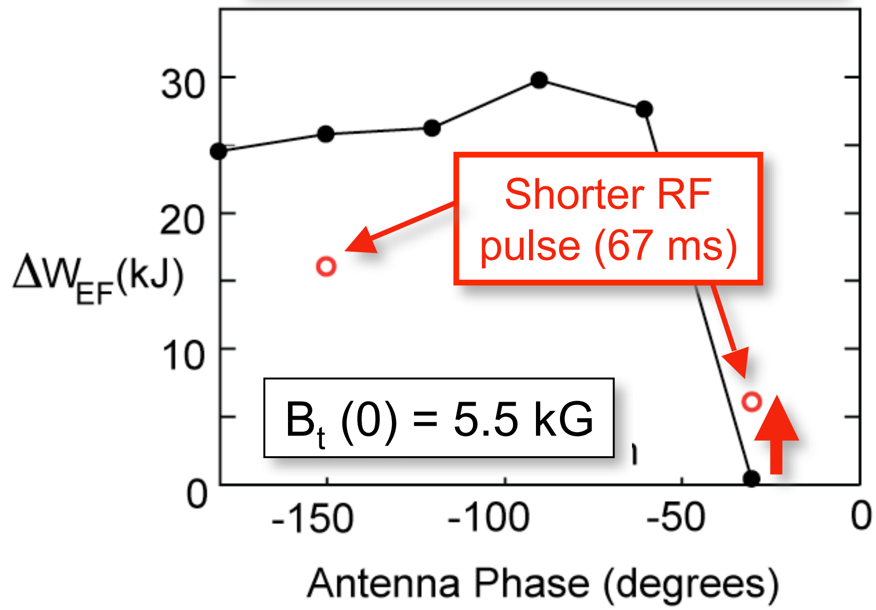
- NSTX results indicate surface wave damping could be important for ITER ICRF heating

RF-Induced Increase in Electron Stored Energy Comparable in He & D_2 Plasmas

P_{rf} ~ 1.8 MW in He_4 plasmas (~ 80 ms duration)



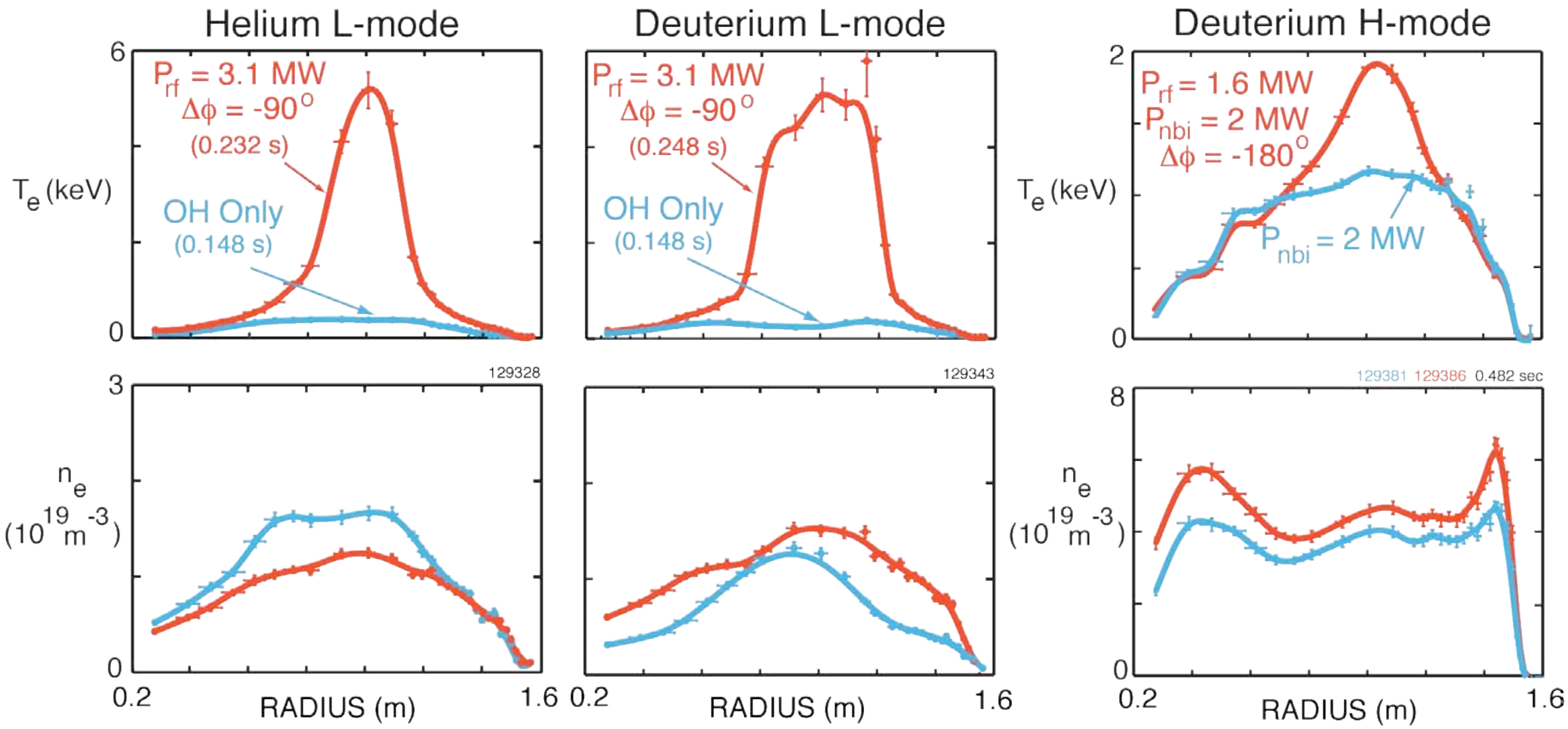
P_{rf} ~ 1.1 MW in D plasmas (~ 230 ms duration)



- Noticeable increase in ΔW_{EF} with $\Delta\phi$ = -30° phasing in D_2 plasmas with lithium edge conditioning duration

P.M. Ryan et al., Poster NP6.00104, Wed AM

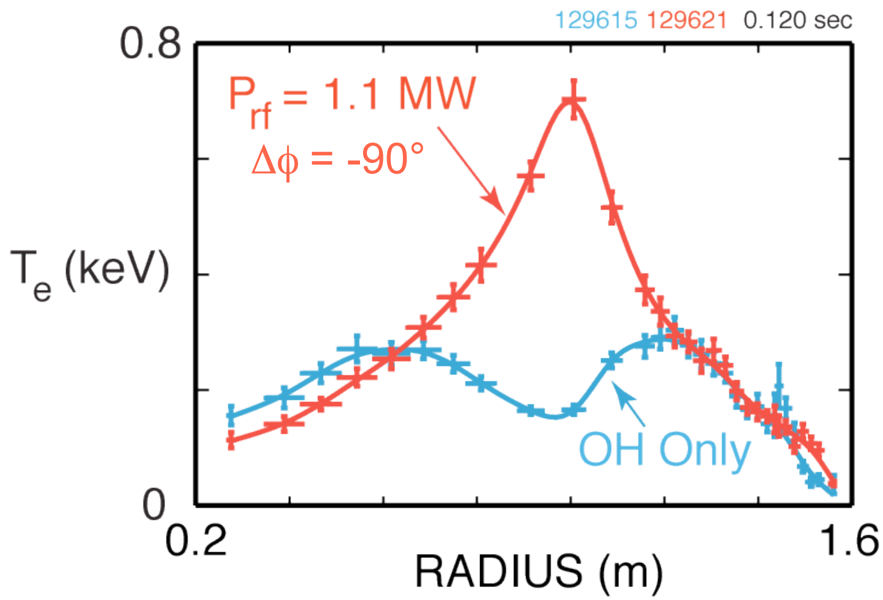
Improved HHFW Heating in NSTX Providing Important Tool for Transport Studies

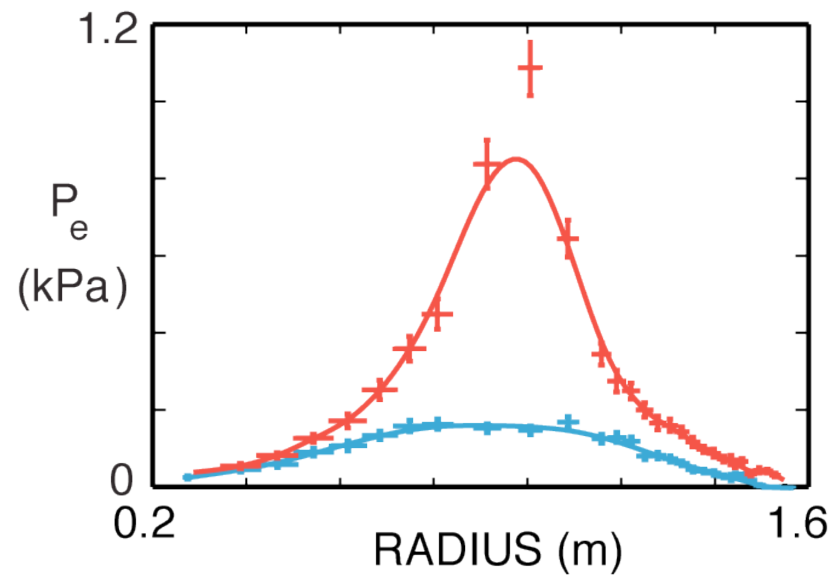


- NSTX record $T_e(0)$ ~ 5 keV & strong T_e gradient
  - Supports high-k scattering study of small scale turbulence in He and D_2
- First HHFW core electron heating in deuterium NBI H-mode
  - Required Li conditioning for edge density control
  - Supports core electron transport study in NBI H-mode

*E. Mazzucato, et al. PRL **101**, 075001 (2008); H. Yuh, et al., Invited talk T12.00005 Thurs 11:30 AM*

Initial HHFW Heating Experiments During Startup & Early I_p Ramp-up Show Good Electron Heating





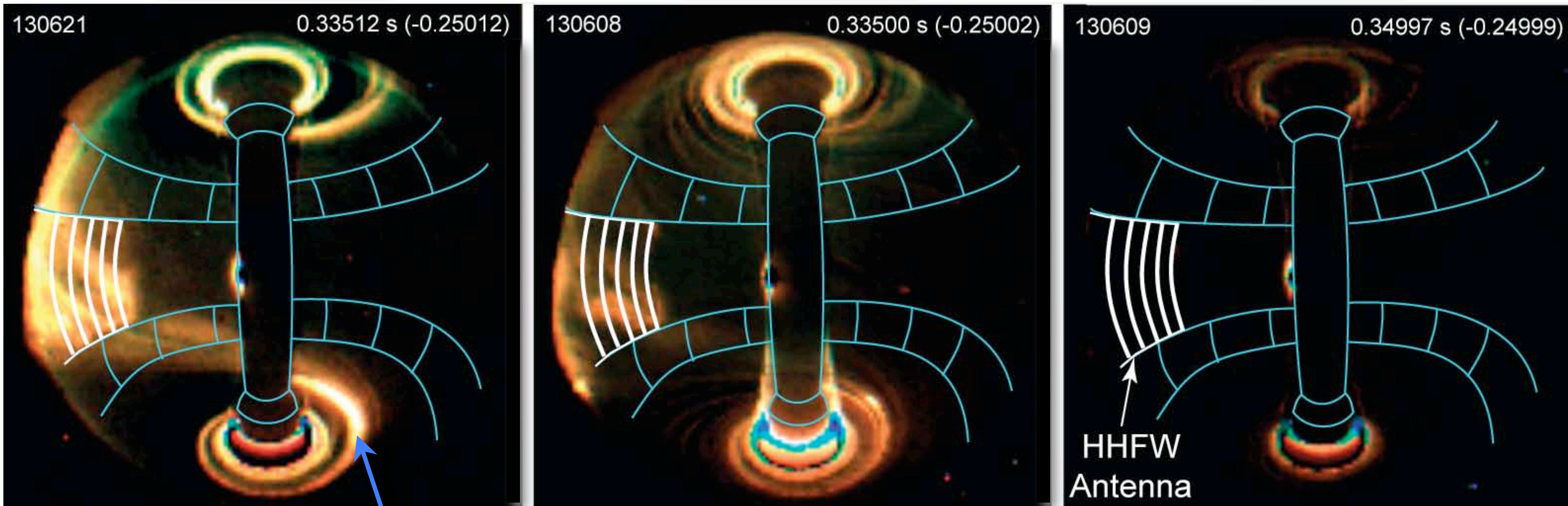
- Coupled P_{rf} ~ 1.1 MW during early I_p ramp-up (t ~ 120 ms), increasing $T_e(0)$ from 140 eV to 700 eV when $n_e(0) < 1\times10^{19}$ m^{-3}
  - Supports proposed NSTX EC/HHFW assisted non-inductive startup & I_p ramp-up scenario

P.M. Ryan et al., Poster NP6.00104, Wed AM

Stronger Interaction Between Antenna & Divertor Along Field Line at Lower Phase/Longer Wavelength

P_{rf} = 1.8 MW, P_{nbi} = 2 MW, I_p = 1 MA, B_T = 5.5 kG

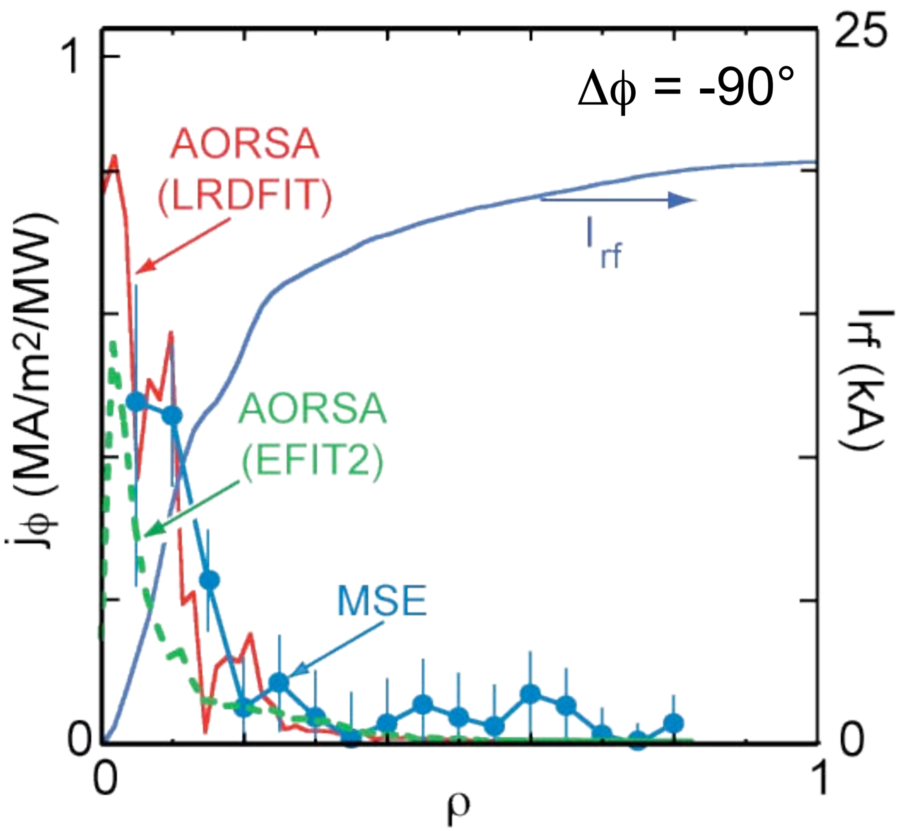
Δφ = - 90° | Δφ = - 150° | No RF



- "Hot" region in outboard divertor much more pronounced at Δφ = -90° than Δφ = -150°
  - Dies away after RF turn off in ~ 20 ms for Δφ = -90° & in ~ 8 ms for Δφ = -150°

J.C. Hosea et al., Poster NP6.00105, Wed AM

Motional Stark Effect (MSE) Measurement of Core HHFW CD Profile Consistent with Modeling



EFIT2: Uses magnetics & kinetic profiles

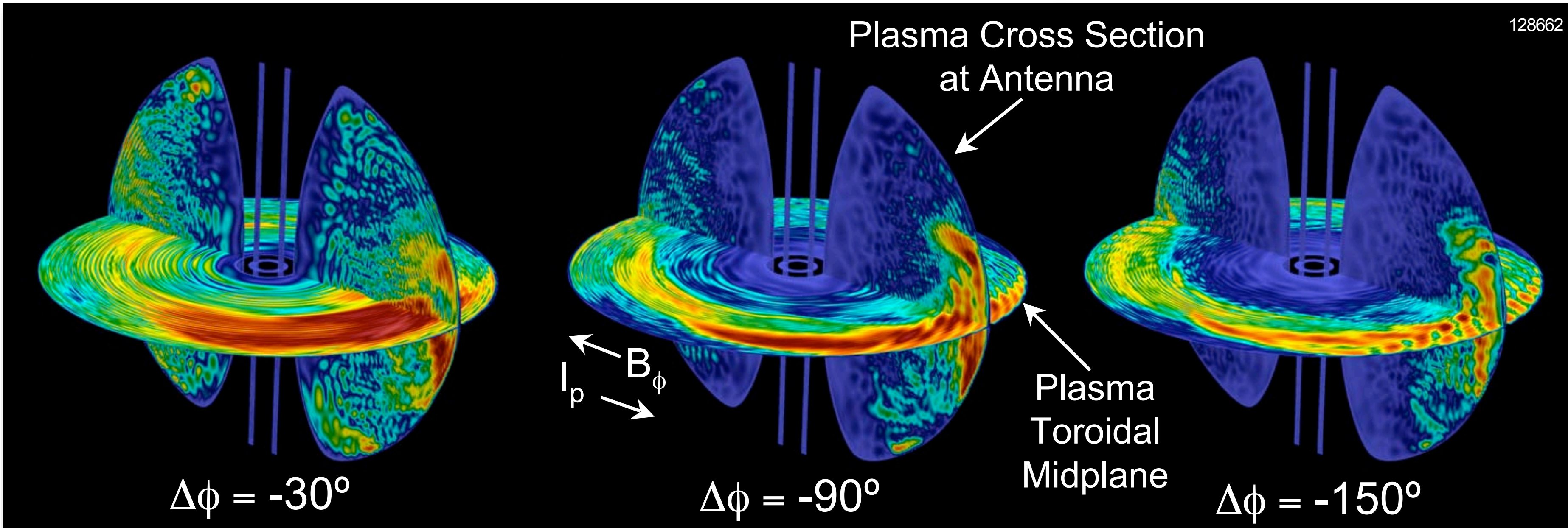
LRDFIT: Uses MSE data, magnetics & kinetic profiles

- Measured CD profile consistent with AORSA prediction using LRDFIT equilibrium, full toroidal spectrum, Ehst-Karney approximation & trapping
- Measured q(0) decreases from 1.0 to 0.6 with HHFW CD at P_{rf} ~ 1.2 MW
  - Offers prospect of controlling q(0) in integrated scenarios
- Electron trapping significantly reduces CD efficiency

C.K. Phillips, et al., Poster NP6.00106, Wed AM

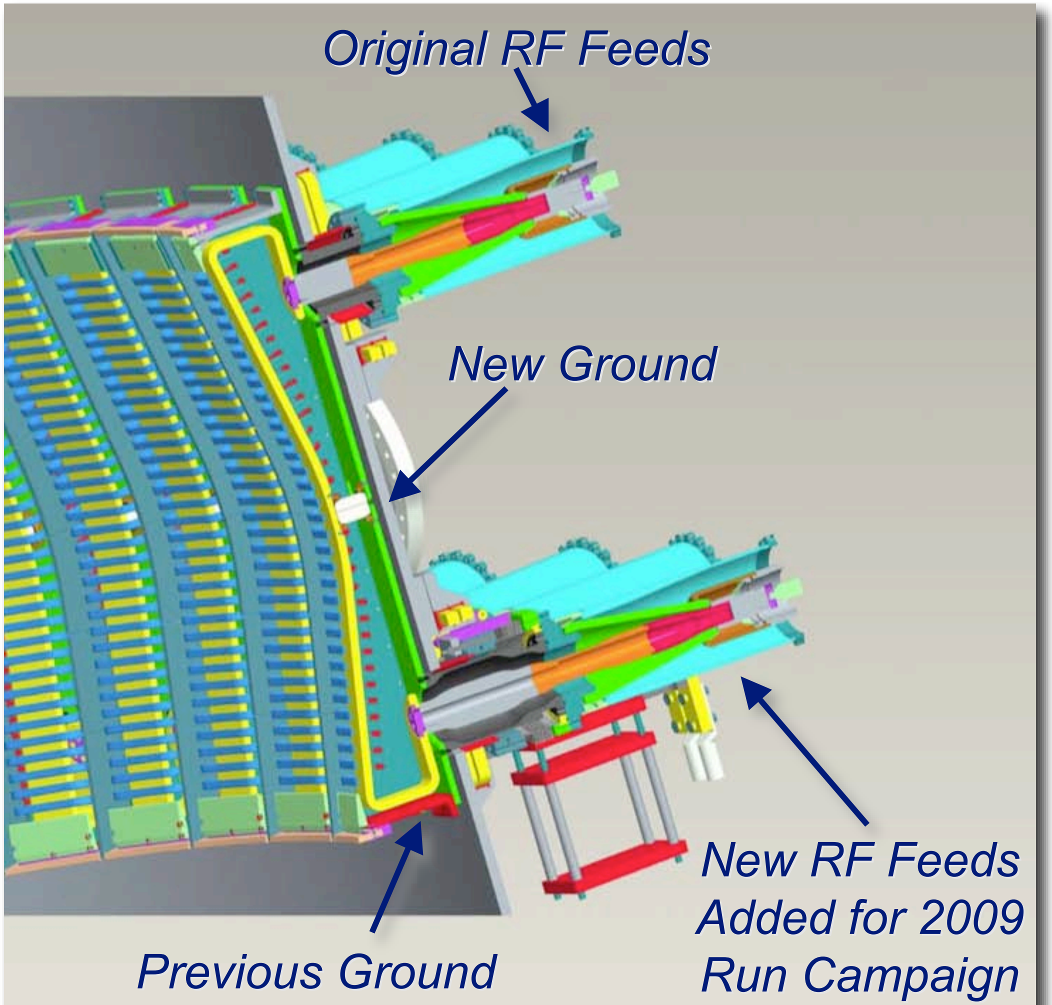
3D Codes Using Full Toroidal Spectrum to Include Surface Damping and CD Effects

AORSA $|E_{RF}|$ field amplitude with 101 n_ϕ modes



- Waves propagate around plasma axis in + B_ϕ direction
- Wave fields very low near inner wall
- Edge loss mechanisms need to be identified experimentally and included by RF SciDAC in advanced codes

Antenna Upgrades in 2009 & 2010 Double Coupled Power & Increase Resilience to ELMs



- Double feed upgrade shifts ground from bottom to center of antenna straps for 2009 run campaign:
  - Doubles power per strap
  - Permits larger plasma-antenna gap, providing reduced fast ion interaction
- ELM dump will be added for 2010 run campaign:
  - more resilient coupling during large ELMs

Summary

- Surface waves can significantly limit HHFW coupling

⇨ *Effect could be important for ITER since wave number will be relatively low for some heating/CD scenarios*

- Dramatic improvement in HHFW heating & CD through increased $B_t(0)$ & lithium edge density control
  - NSTX record $T_e(0)$ ~ 5keV with HHFW heating
  - Good HHFW electron heating during early I_p ramp-up
  - First observation of HHFW core heating in NBI H-mode
- CD measurements consistent with simulations from AORSA & TORIC
  - RF SciDAC initiative will be important for studying edge loss & providing accurate CD estimates
- HHFW antenna upgrades in 2009-10 to provide higher power, reduced fast ion-antenna interaction & better resilience to ELMs

See More Details on NSTX HHFW Results at the Wednesday Morning Poster Session

NP6.00104:

Progress on HHFW Heating and Current Drive on NSTX

P.M. Ryan, et al.

NP6.00105:

Edge Plasma Properties for HHFW Heating on NSTX

J.C. Hosea, *et al.*

NP6.00106:

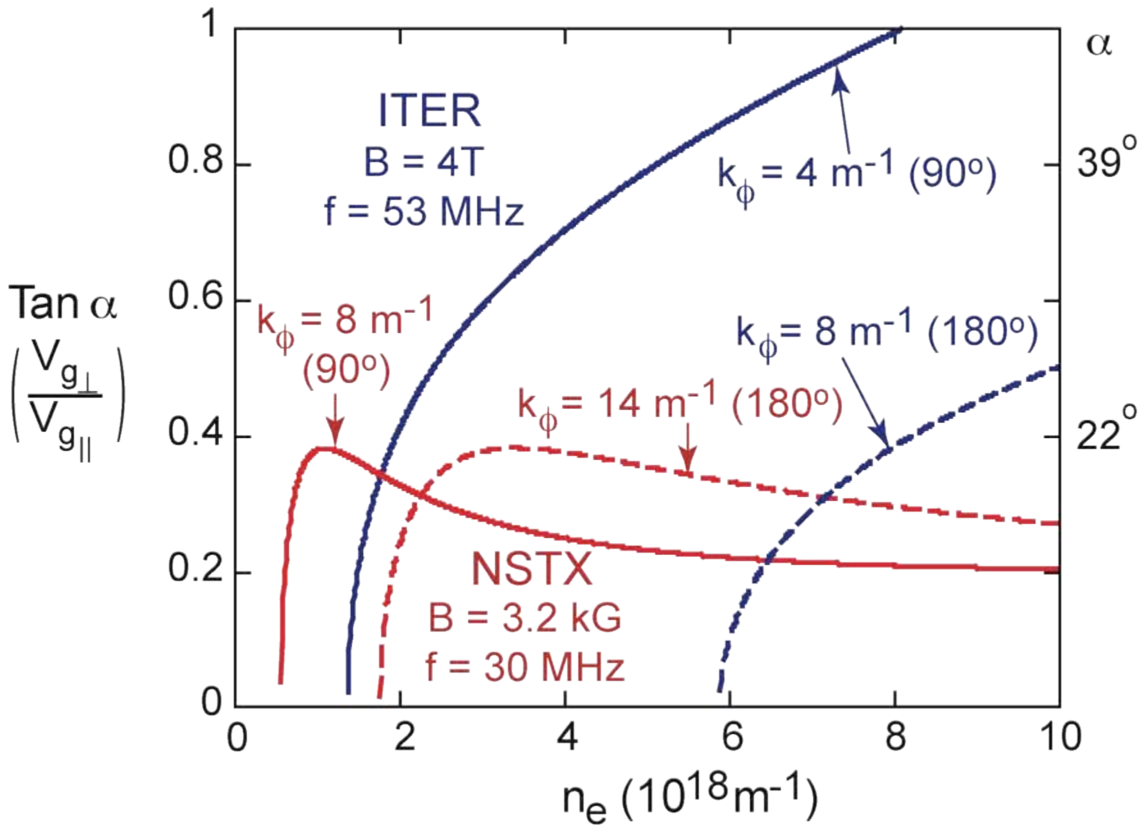
Numerical Modeling of HHFW Heating and Current Drive on NSTX

C.K. Phillips, *et al*

Backup Slides

NSTX Results Indicate Surface Wave Damping Could be Important for ITER ICRF Heating

Angle of wave propagation relative to magnetic field

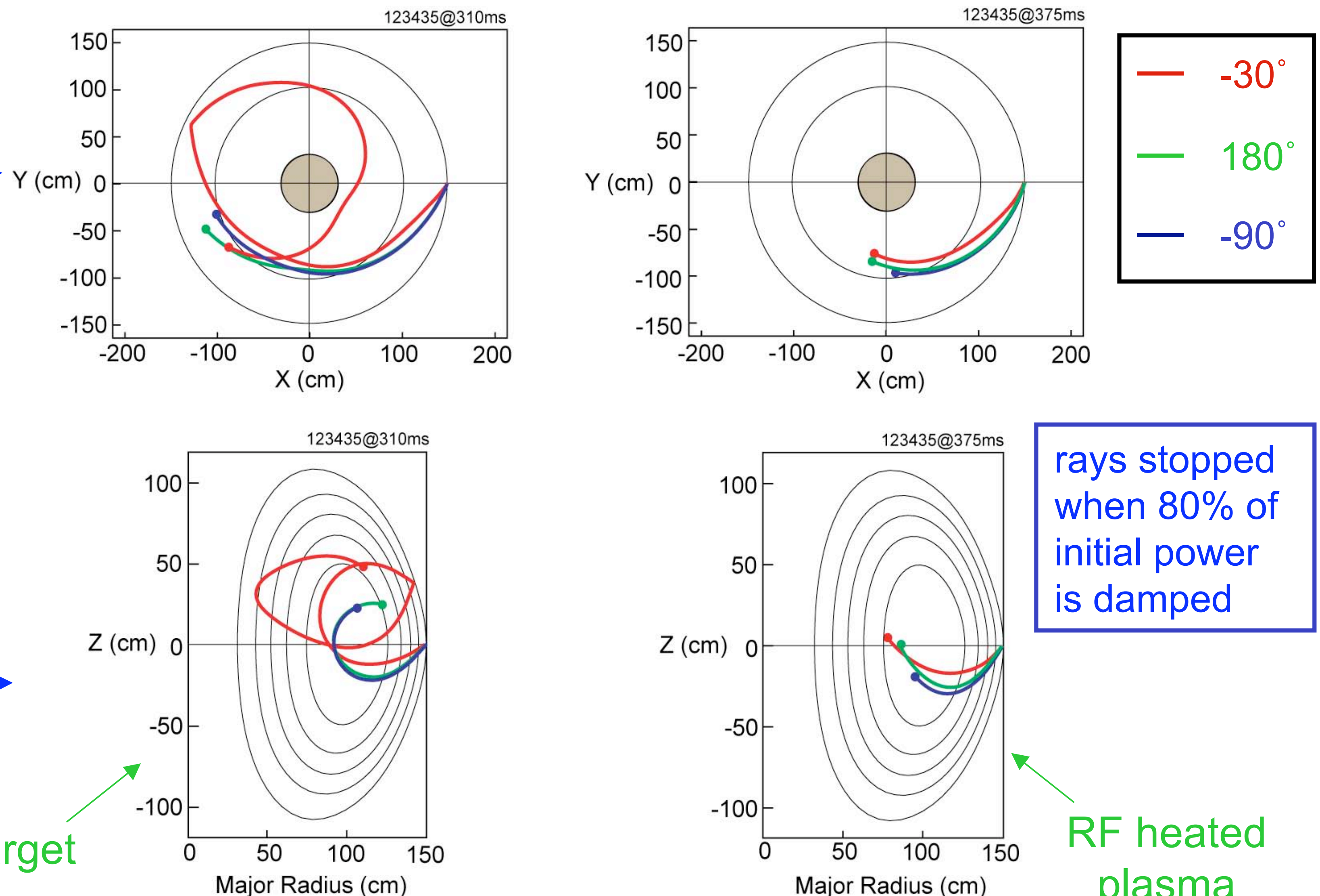


- $k_\phi \sim 4\ m^{-1}$ at 53 MHz for CD phasing in ITER
- Propagation onset density is relatively low: $\sim 1.4 \times 10^{18}\ m^{-3}$
- For scrape off density above onset density, surface wave damping should be significant

Strong "Single Pass" Absorption Ideal for Studying Competition Between Core & Edge Power Loss

Toroidal views →

Poloidal views →



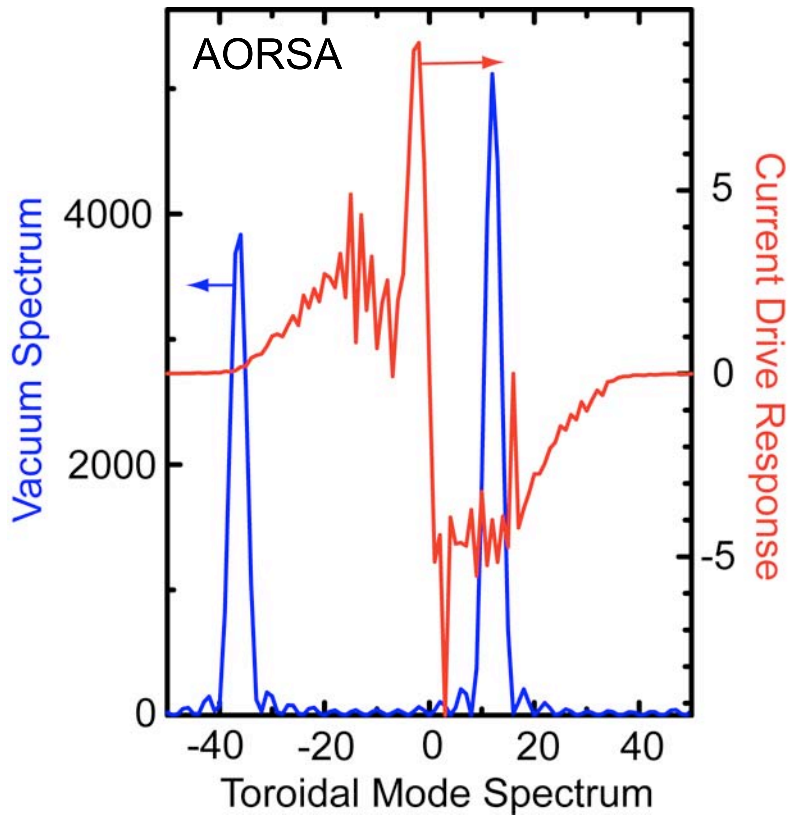
rays stopped when 80% of initial power is damped

OH target

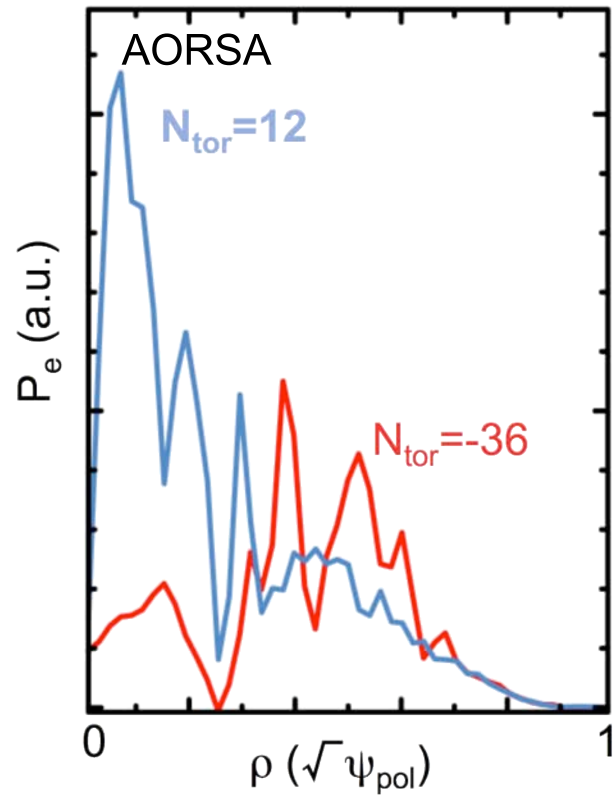
RF heated plasma

Modeling Must Include Power Spectrum of Launched Waves for Quantitative Agreement with MSE

Driven Current Spectrum



Power Deposition Profile



Ehst-Karney:

$$J_{rf} \propto P_e$$

- Large edge field pitch affects wave spectrum in plasma core
- Current driven by the back propagating lobe is localized well off-axis and lost due to trapping effects