NSTX

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High Harmonic Fast Wave Progress and Plans

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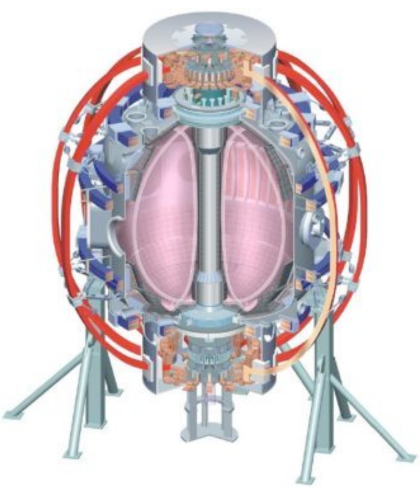
Gary Taylor, PPPL

for the NSTX Team

25th NSTX Program Advisory Committee Meeting (PAC-25)
LSB-318, PPPL
February 19, 2009



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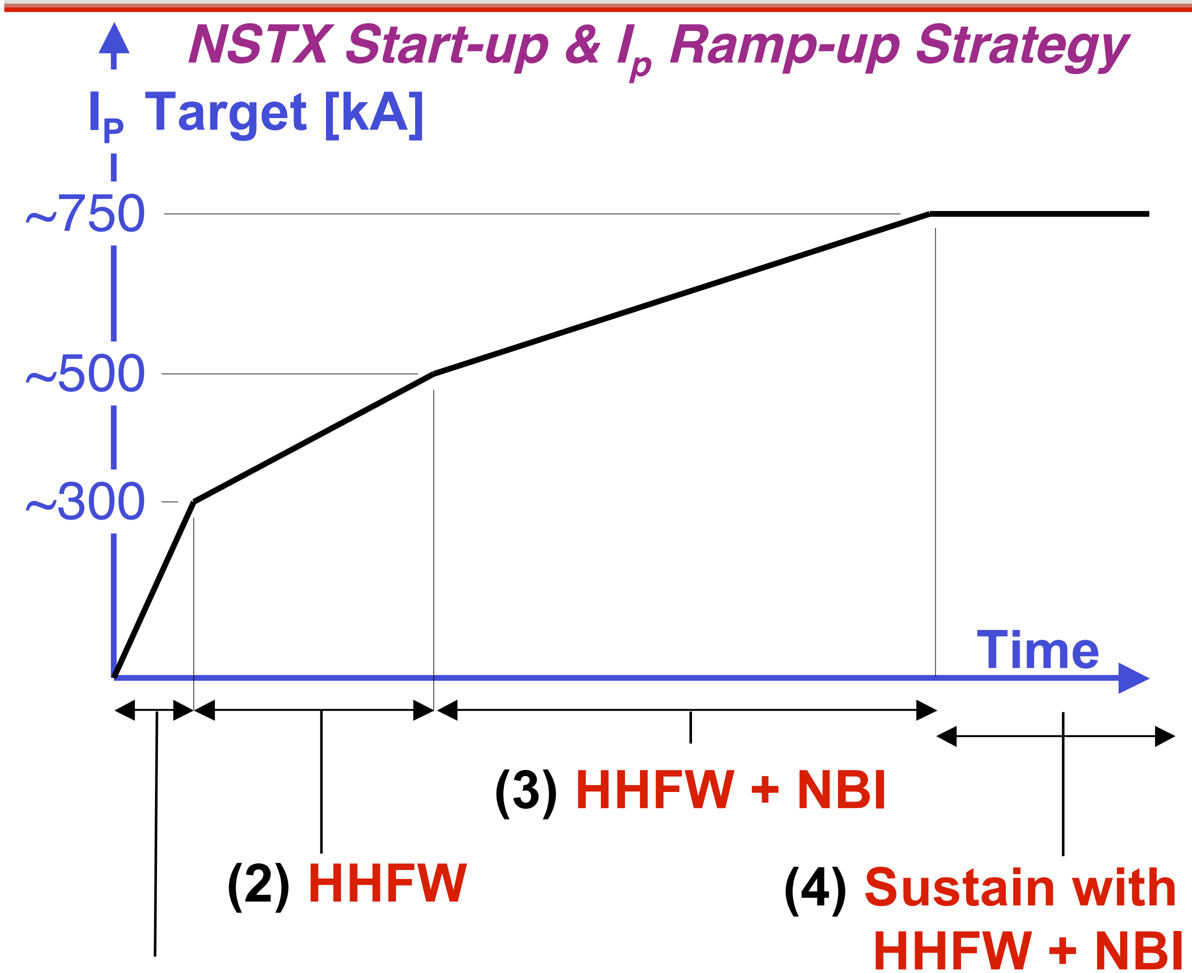
Outline

- Role of HHFW in NSTX Program
- Recent Advances in HHFW Research & Modeling
- Research Strategy for 2009-11 & Beyond

30 MHz HHFW Heating & CD Aims to Support Non-Inductive Ramp-up, Bulk Heating & q(0) Control



(1) CHI, PF, Guns, 28 GHz ECH

⇒ **Non-Inductive ramp-up FESAC-TAP priority #1**

⇒ **Ramp-up will be discussed in next talk**

Start-up/Ramp-up Requirements

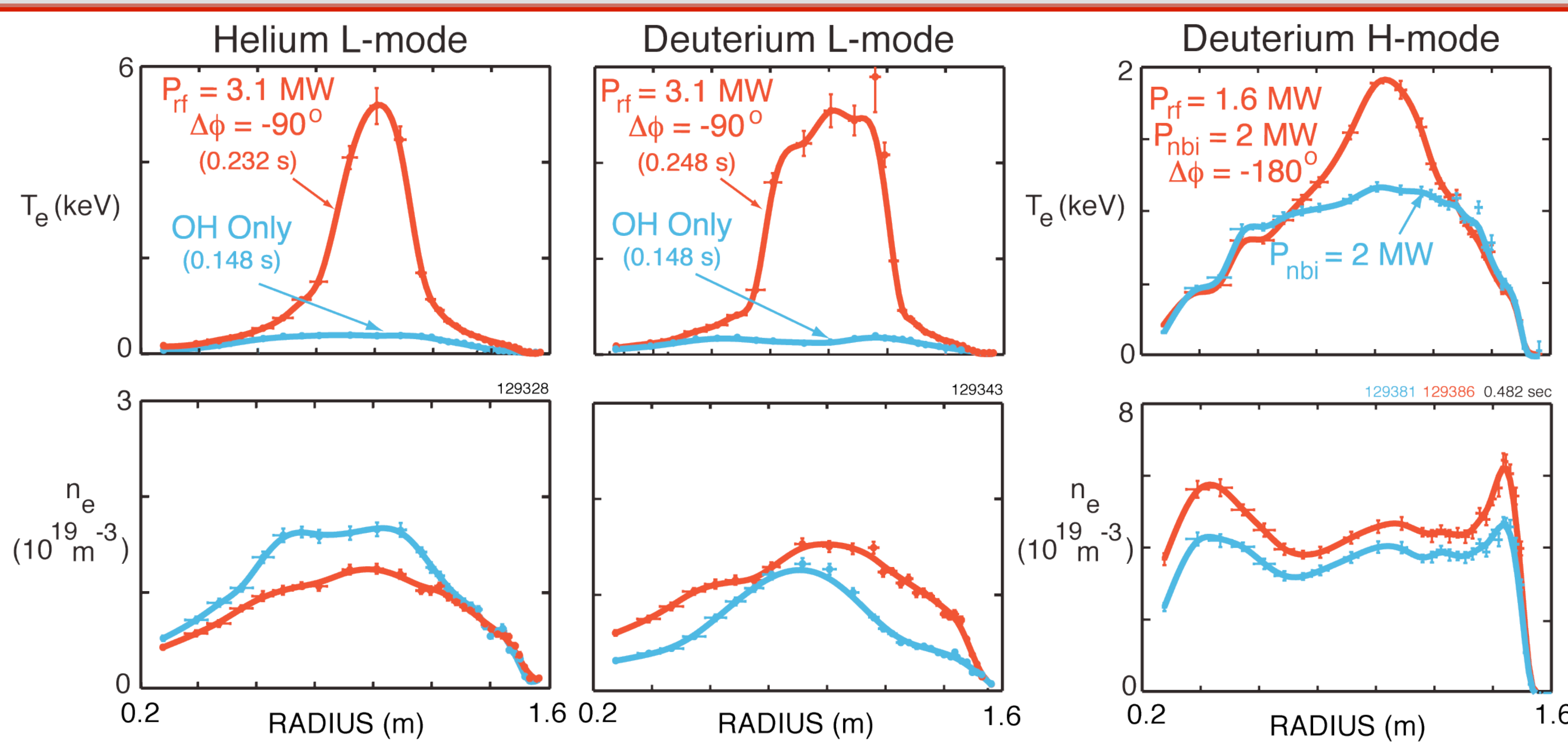
(1→2) Target plasma generated with CHI, guns or PF-only. ECH likely needed to heat plasma to allow HHFW coupling

(2) I_P overdrive using bootstrap & HHFW CD

(2→3) HHFW generates sufficiently high I_P to absorb NBI

(4) HHFW provides q(0) control & bulk heating

Improved HHFW Heating in 2008 Provided Important Tool for Transport Studies

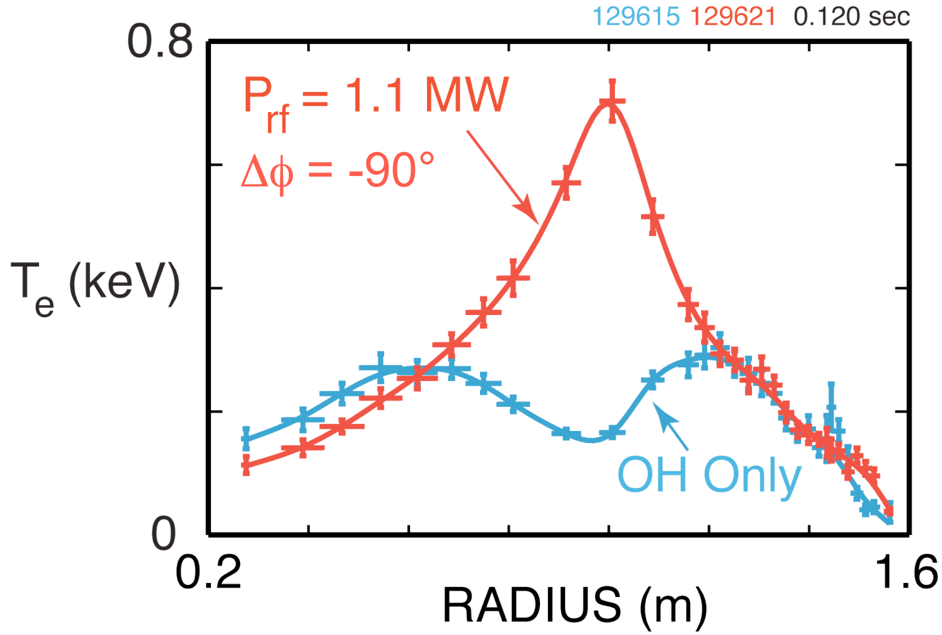


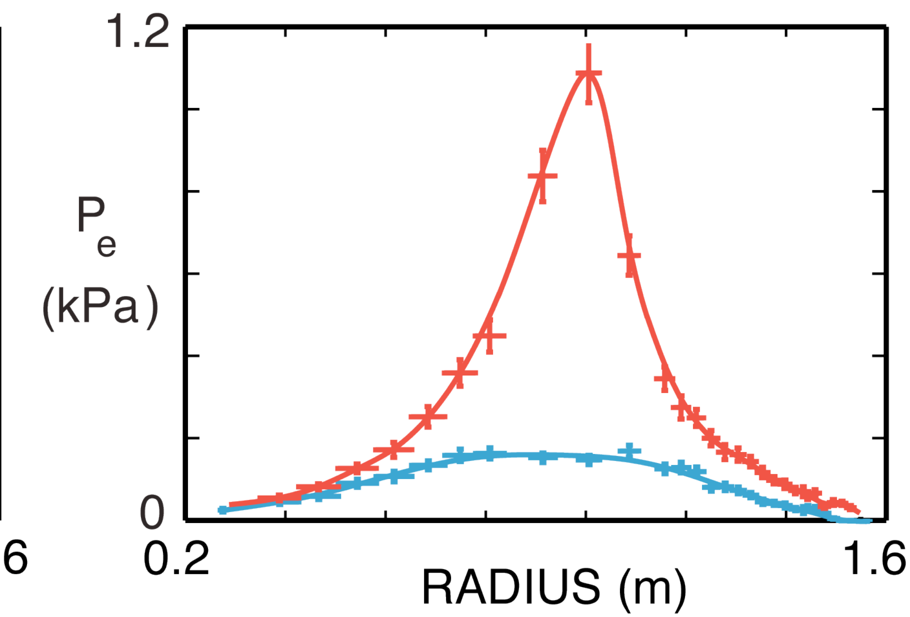
- NSTX record $T_e(0)$ ~ 5 keV & strong T_e gradient
  - Supports high-k scattering study of small scale turbulence in He & D_2
- First HHFW core heating in D_2 NBI H-mode achieved with Li

- Experiments in 2009-10 will use Li injection & LLD to improve HHFW heating & CD in H-mode

PAC23-03
PAC23-10

HHFW Experiments During Early I_p Ramp-up Show Good Electron Heating in D_2 with CD Phasing





- HHFW coupled into I_p ~ 300 kA, $n_e(0)$ ~ 6×10^{18} m^{-3}
- CD phasing in D_2 at low I_p required for ramp-up studies

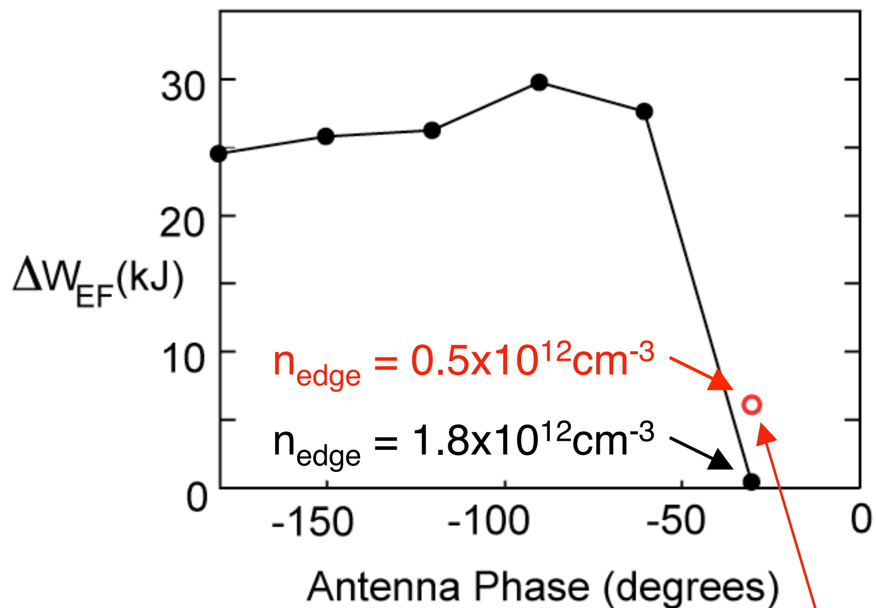
- HHFW-assisted ramp-up experiments, including phase scans & Li conditioning, are planned for 2009

PAC23-10
PAC23-11

Improved Heating due to Better Understanding of Important Role of Edge-Wave Interactions

- Edge power loss increases when perpendicular propagation onset density is near antenna
- Heating efficiency improved (ΔW_{EF}) by reducing edge density (n_{edge}) with Li conditioning
- Strong first pass absorption in NSTX ideal for studying competition between core rf heating & edge-wave power loss

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

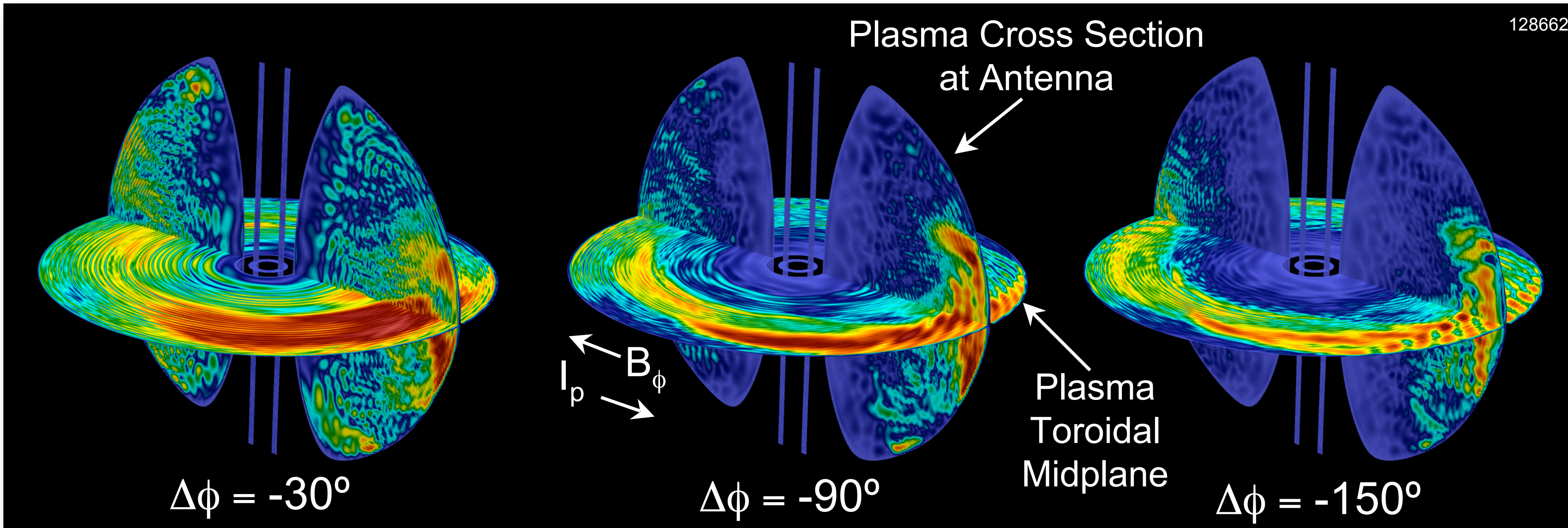


Improved ΔW_{EF} at $\Delta\phi$ = -30° in D plasmas with Li conditioning, even with shorter 67 ms RF pulse

⇒ Edge-wave interactions could be important for ITER ICRF heating

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

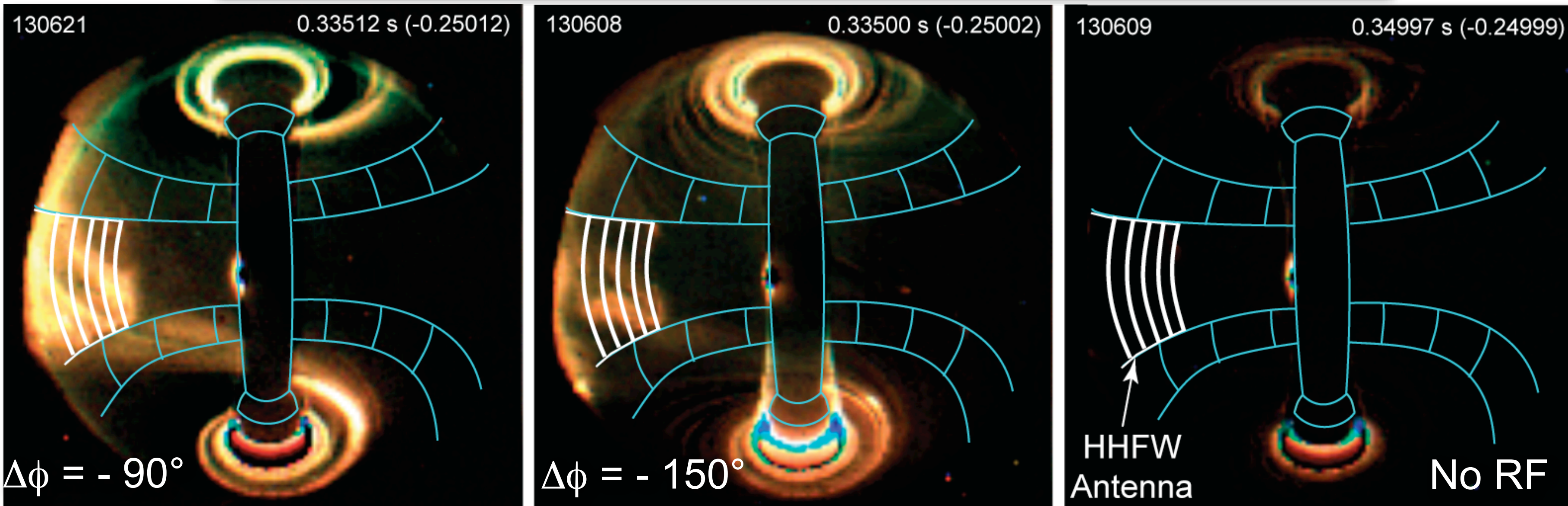
AORSA $|E_{RF}|$ field amplitude with 101 n_ϕ modes



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

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

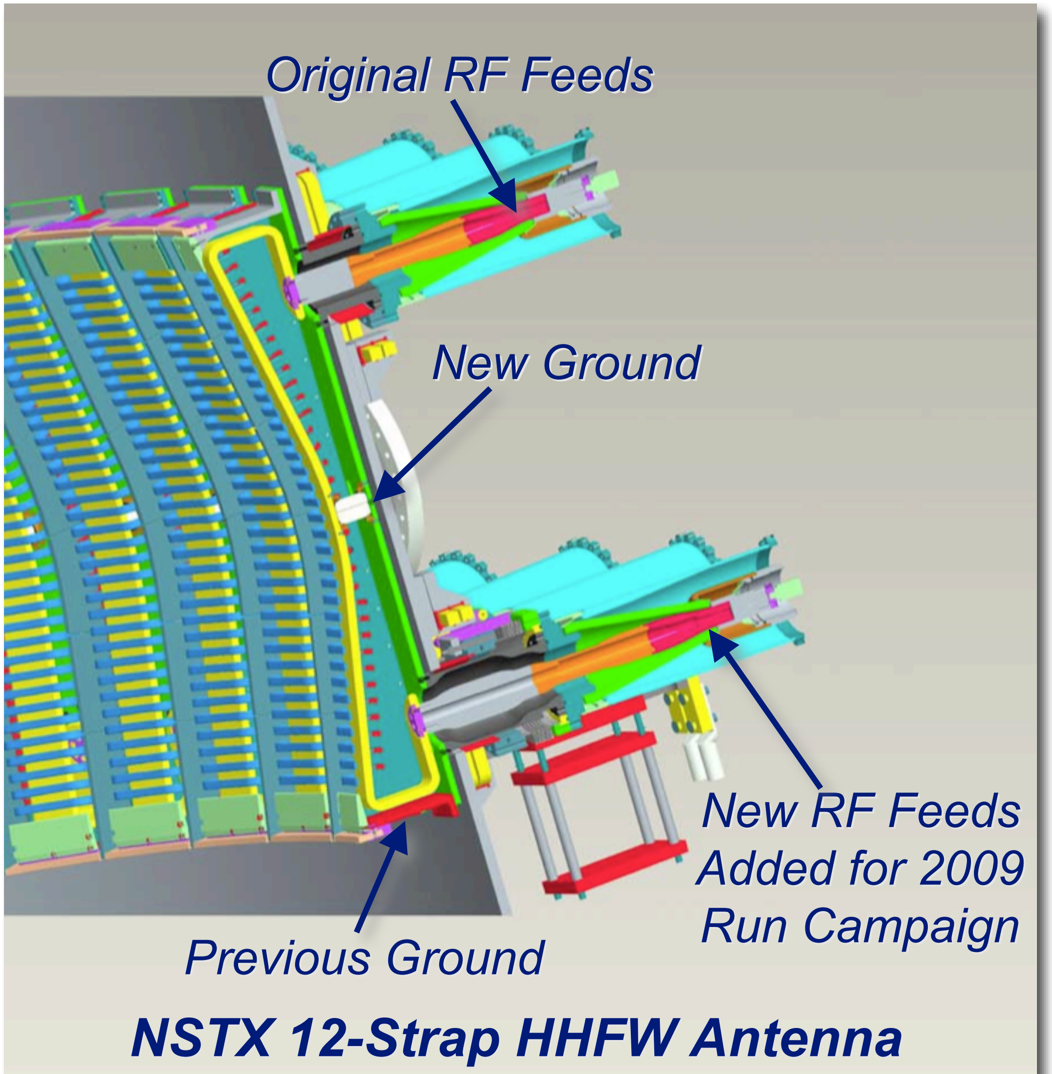
P_{rf} = 1.8 MW, P_{nbi} = 2 MW, I_p = 1 MA, B_T = 5.5 kG, H-Mode



- Do not know how much power is lost through interaction:
  - Implications for CD & HHFW-ELM interaction
  - Incorporate divertor interaction into 3-D ray tracing & full wave modeling

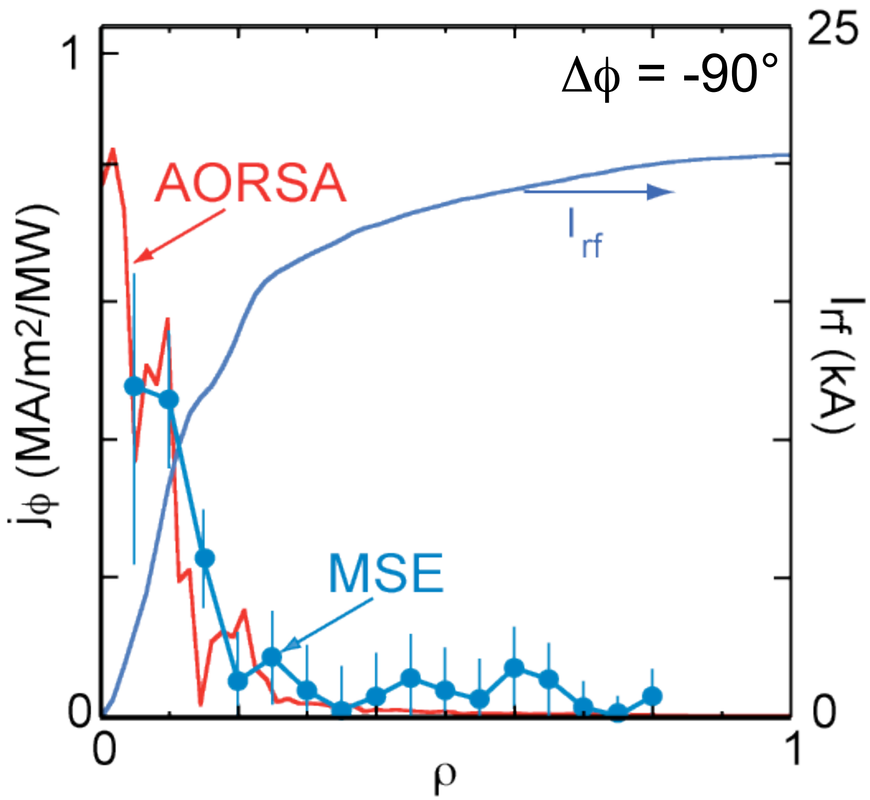
- 2009 HHFW experiment to study edge effects in L- and H-mode

Building on Positive 2007-8 Results, Antenna Upgrades Increase Coupled Power & ELM Resilience



- Double feed upgrade implemented for 2009 run:
  - P_{rf} increased from ~ 3 MW to ~ 6 MW
  - 4-6 MW likely required for BS overdrive ramp-up
  - Permits larger plasma-antenna gap, reducing NBI fast ion interaction with antenna
- ELM resilience system will be added in 2010-2012:
  - Electronic detection & P_{rf} notch at ELM in 2010
  - Hybrid ELM dump in 2011-2012

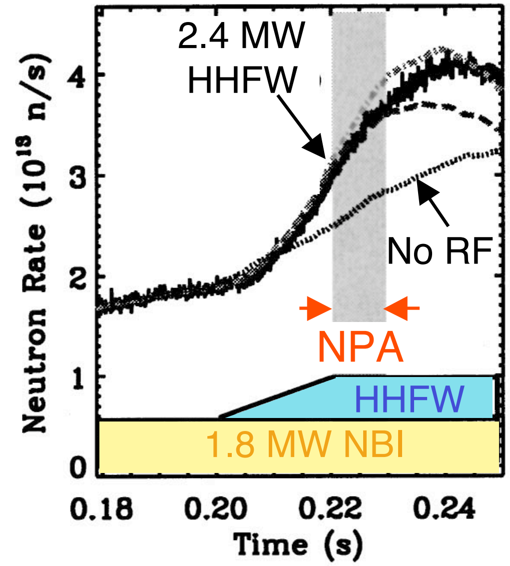
Motional Stark Effect (MSE) Measurement of Core HHFW CD Profile Consistent with Modeling



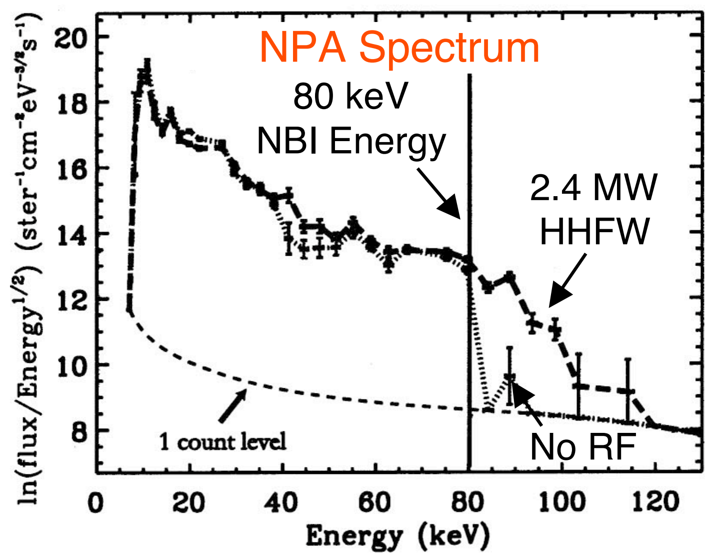
- Measured CD profile consistent with AORSA prediction using MSE-constrained LRDFIT equilibrium, full toroidal spectrum, Ehst-Karney approximation & trapping
  - MSE & AORSA I_{rf} ~ 20 kA
  - MSE reconstructions essential for good match with measured CD
- Measured q(0) drops from 1.0 to 0.6 with P_{rf} ~ 1.2 MW
  - Counter-CD should provide tool to raise q(0) in advanced scenarios, avoiding sawteeth & locked modes
- MSE-LiF will provide q(r) without heating NBI, dramatically enhancing HHFW CD research in 2011

Edge Loss Mechanisms will be Identified & Included in RF Codes; RF-Fast Ion Interaction will be Modeled

- Search for edge RF power loss due to collisions, sheaths, PDI, antenna reactive field & propagating FW:
  - Using edge reflectometry, edge CHERS, PDI probes, visible & IR cameras, core reflectometry with 30 MHz $\delta n(r)$ [& $\delta E(r)$] capability, and enhanced MPTS [incremental]



- Measure & Model RF-fast ion interaction seen previously on NSTX:
  - Perpendicular & tangential FIDA, NPA
  - HHFW-NBI interaction will be modeled with CQL3D (Bob Harvey - CompX)
  - Simulate counter-CD for advanced scenarios



HHFW Research Plan for 2009-10

2009:

- Understand physics of the edge-wave interactions using upgraded double fed antenna:
  - Employ extended edge measurements & guidance from rf modeling
- Heating & CD studies in D_2 H-mode with Li injection
- Coupling/heating into low I_p,T_e during I_p ramp-up
- HHFW heating of H if L-H threshold is studied in H & He PAC23-12

2010:

- HHFW Heating, CD and I_p ramp-up in D_2 H-mode using ELM resilience system [R(10-2) milestone]:
  - Use larger plasma-antenna gap to reduce NBI fast ion interaction with antenna
  - Fast feedback control for greater stability & higher power coupling
  - LLD to likely further reduce antenna neutral pressure

HHFW Research Plan for 2011-13

2011:

- Heating & CD operation with NBI H-mode with fully upgraded HHFW antenna, Li injection & LLD:
  - Benchmark core CD against advanced RF codes upgraded to include interaction with fast ions & use FIDA to diagnose interaction
- HHFW coupling during I_p ramp-up with 28 GHz* ECH-assisted start-up
  - MSE-LiF to provide q(r) without heating NBI

Research Utilizing New CS and/or 2nd NBI (2012-2013):

- High power long pulse HHFW heating & CD with improved heating at $B_t(0)$ ~ 1 T, made possible with new center stack
- HHFW to support very long pulse scenario
- HHFW heating of 28 GHz* ECH-assisted CHI & PF-only startup

* 28 GHz 350 kW ECH only possible with incremental funding

Understanding Importance of Edge-Wave Interaction has Enabled HHFW to be Powerful Tool

- Heating & CD performance significantly improved by increasing $B_t(0)$ & through edge density pumping via Li conditioning
- 2009 HHFW experiments seek better understanding of edge-wave interaction physics
- Antenna upgrades in 2009-10 provide higher power, reduced fast ion-antenna interaction & better resilience to ELMs
  - HHFW experiments also benefit from combining LLD & Li injection
- HHFW experiments in 2009-11 will study heating & CD in D_2 H-mode & heating during I_p ramp-up
- Initial HHFW CD measurements are now consistent with AORSA & TORIC simulations:
  - RF SciDAC initiative important for studying edge loss & providing accurate CD estimates