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NSTX

NSTX Waves and Energetic Particles Research Plan for 2009-2013

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For the NSTX Research Team

National Tokamak Planning Workshop

MIT, Cambridge, Massachusetts

September 18, 2007

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NSTX Operating Regime Important for Studying Wave-Particle Physics Relevant to Burning Plasma and ST-CTF

- High Harmonic Fast Wave (HHFW) system is studying surface wave & edge parametric decay physics relevant to ITER ICRF:
  - *Recent HHFW experiments show improved coupling; results support several proposed upgrades to existing antenna design*
- HHFW & Electron Bernstein Wave (EBW) heating & current drive (CD) can assist non-inductive ST-CTF plasma startup & sustainment:
  - *28 GHz heating system being installed on NSTX to test EBW coupling, heating and CD at up to 1 MW of RF power by 2013*
- NSTX NBI ions resonate strongly with Alfvén modes, providing test bed for studying reactor-relevant energetic particle (EP) physics:
  - *Discovery of CAE/GAE modes, multi-mode transport & new understanding of chirping modes are helping to advance theory*
  - *Install 1 MW CAE stochastic ion heating system*

Long-Term HHFW Research Objective: Sustain Reactor-Grade H-Mode & Assist Non-Inductive ST-CTF Startup

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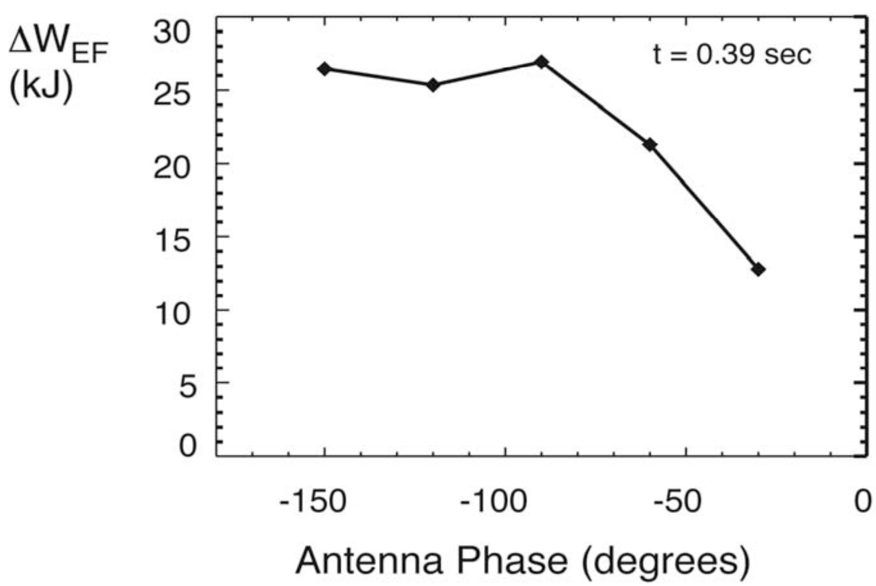
- ITER ICRF will operate at high RF power with large antenna-plasma gap, a scenario where even low levels of RF edge losses could be detrimental
- NSTX HHFW parameters provide an opportunity to quantify RF edge power loss mechanisms:

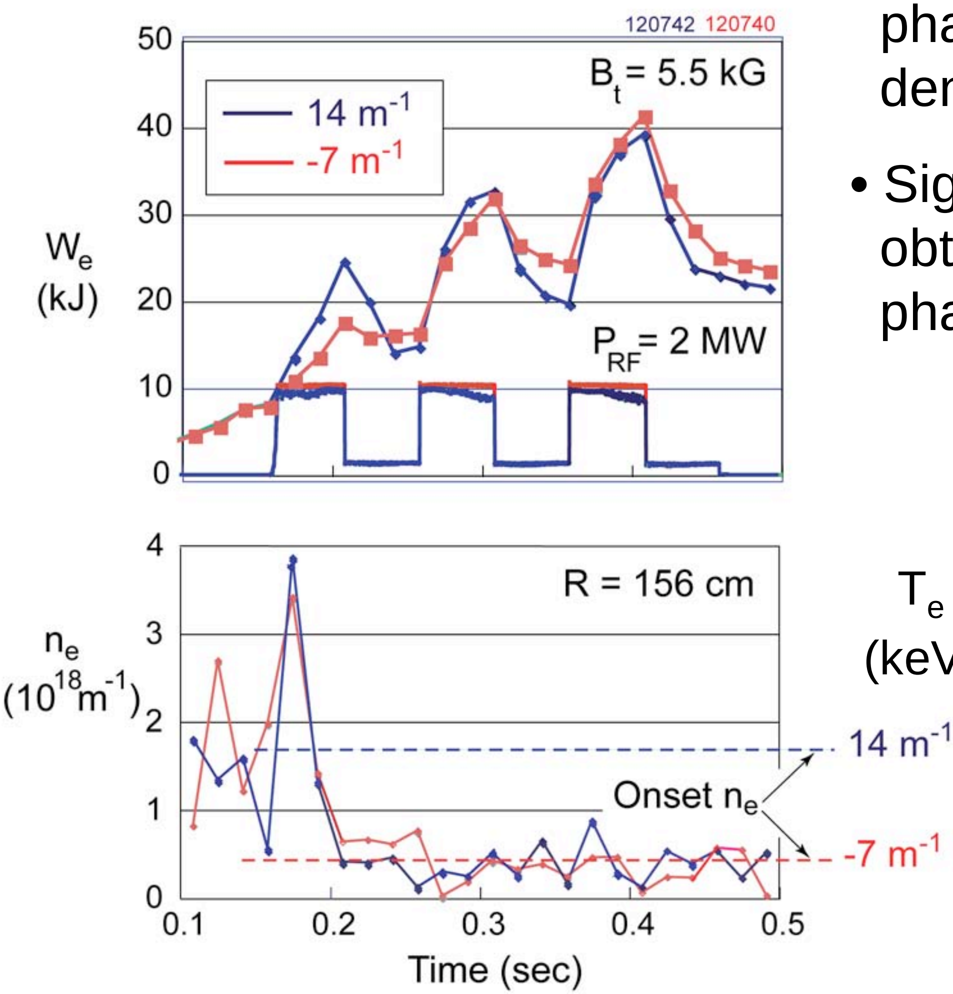
→ *Core heating efficiency shows strong dependence on launched wavelength*

  – *consistent with enhanced surface loss when edge densities exceed density for onset of perpendicular wave propagation*

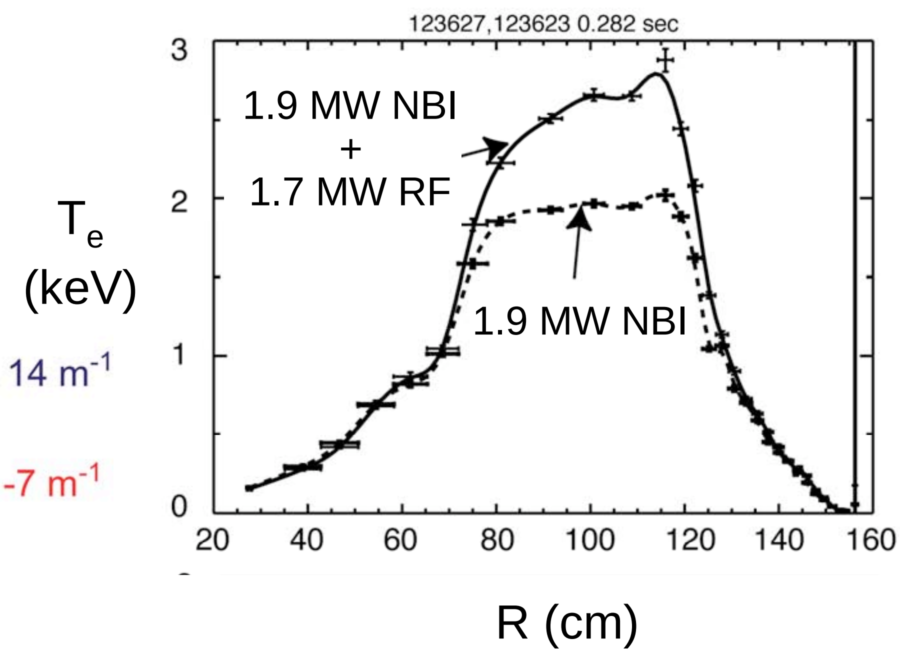
  – *understanding this phenomenon is important for ITER ICRF antenna design*



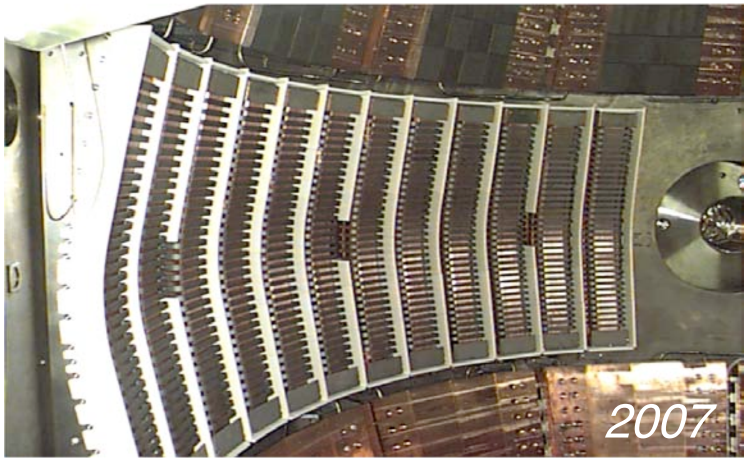
Substantially Improved HHFW Coupling by Keeping Density Near Antenna Below Level Needed to Generate Surface Waves

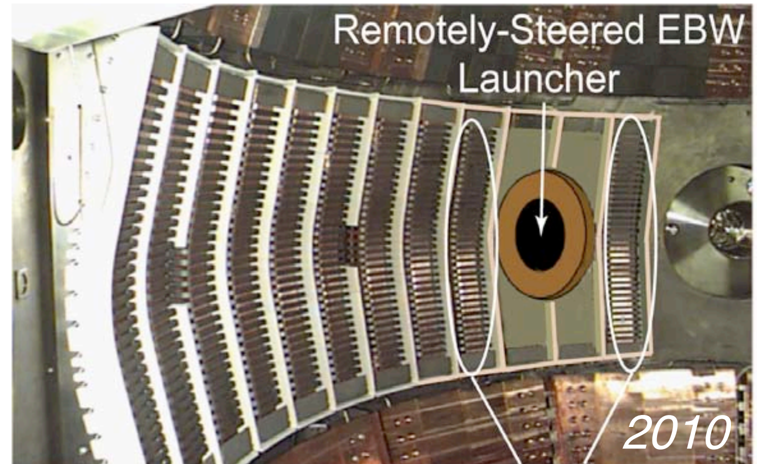


- Improved HHFW coupling for CD phasing obtained by lowering edge density
- Significant core electron heating now obtained in L-mode for CD antenna phasing during NBI at $B_t(0)$ = 5.5 kG



HHFW Antenna Upgrades Provide More Coupled Power Per Strap into H-mode and Provides Space for EBW Launcher

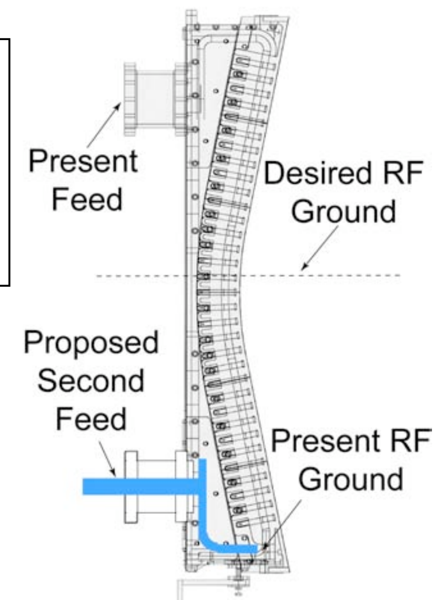




Disconnected HHFW Straps Used for CAE Coupling

- Reduce HHFW antenna from 12 to 8 straps (2009)
- Add 3dB hybrid coupler for increased resilience to ELMs during H-mode (2010-11)
- Improved diagnostics to monitor arcing, surface waves, plasma-antenna interaction and PDI (2008-10)
- Upgrade high-k scattering and FIReTIP for direct observation of RF wave structure in the core (2008)
- Use two disconnected HHFW straps for CAE coupling

Double Feed Upgrade (2009)



2008-13 HHFW Research Plan

2008:

- Extend previous helium plasma coupling physics studies to deuterium plasma; improve operation with NBI, and optimize heating efficiency
- Begin heating & CD studies in deuterium H-mode plasmas

2009-10:

- Optimize heating and CD operation with NBI with upgraded antenna
  - *Antenna upgrade will permit larger plasma-antenna gap with more stability and power*
- Begin HHFW coupling optimization into plasma startup/ramp-up

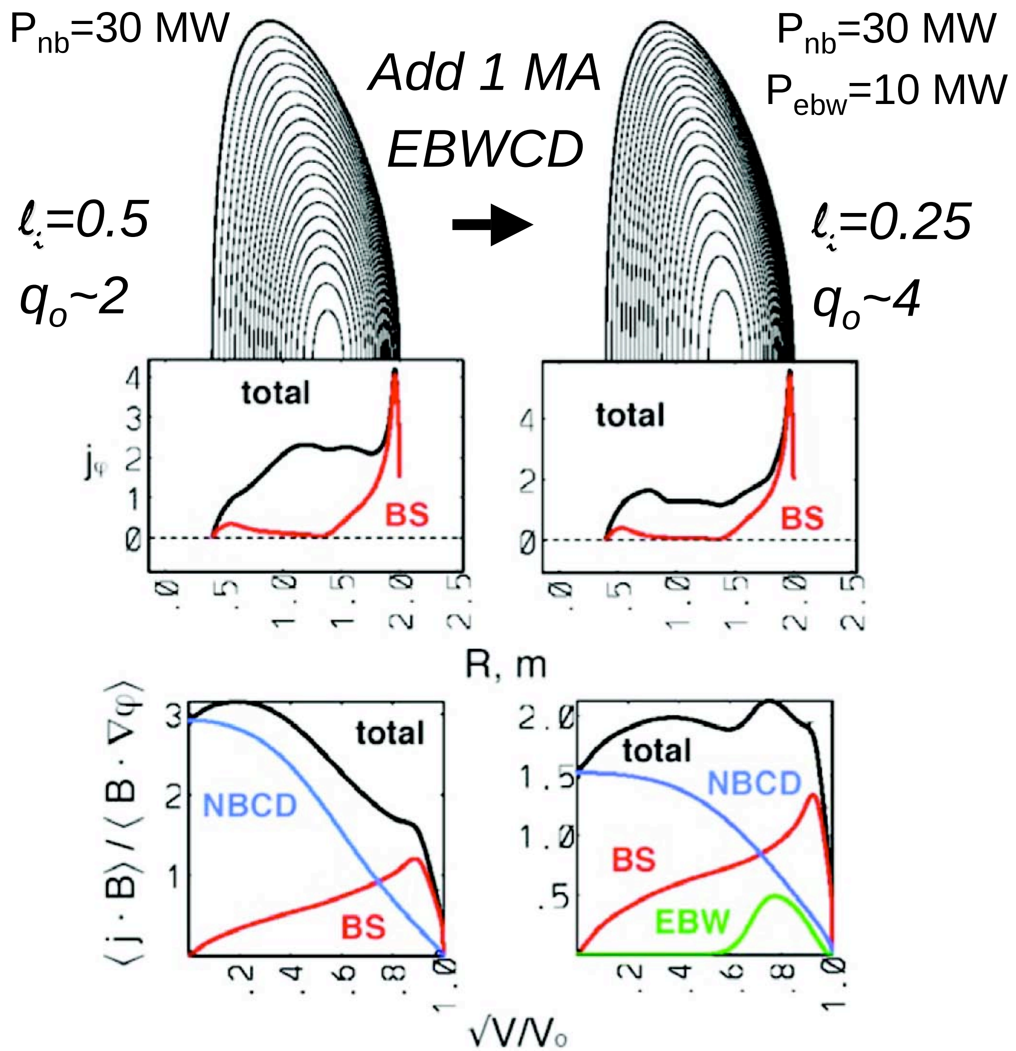
2011:

- Test HHFW coupling during ELMs using 3dB hybrid coupler to further optimize H-mode heating and CD operation

2012-13:

- Combine HHFW and ECH/EBW to provide fully non-inductive plasma startup and ramp-up

Long Term EBW Research Objective: Assess Ability of EBWCD to Generate Off-axis Stabilizing Current in ST-CTF

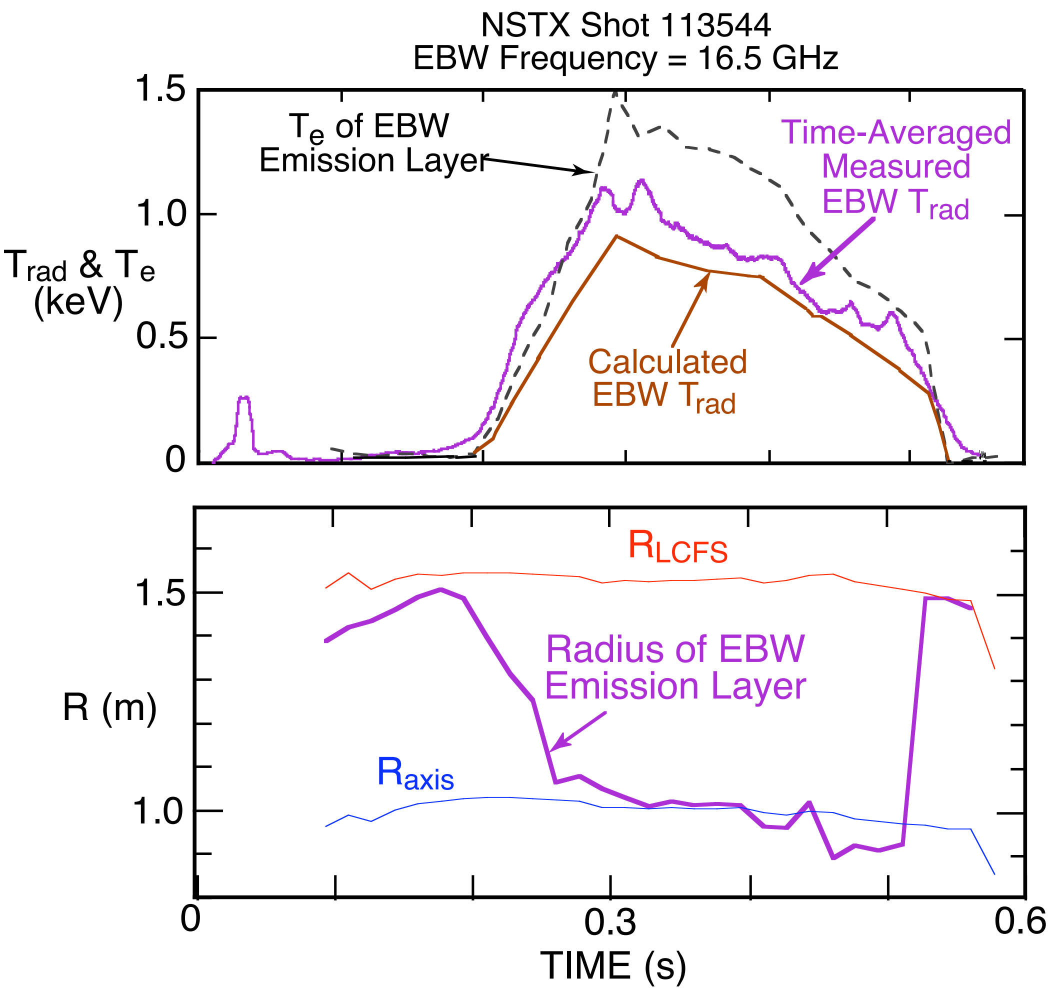


- JSOLVE modeling for steady state TSC simulation shows adding 1 MA of off-axis EBWCD to ST-CTF plasma with wall loading of 1 MW/m^2 can decrease ℓ_i from 0.5 to 0.25 & increase q_o from ~ 2 to ~ 4

- EBWH and/or ECH can also assist solenoid-free ST plasma startup

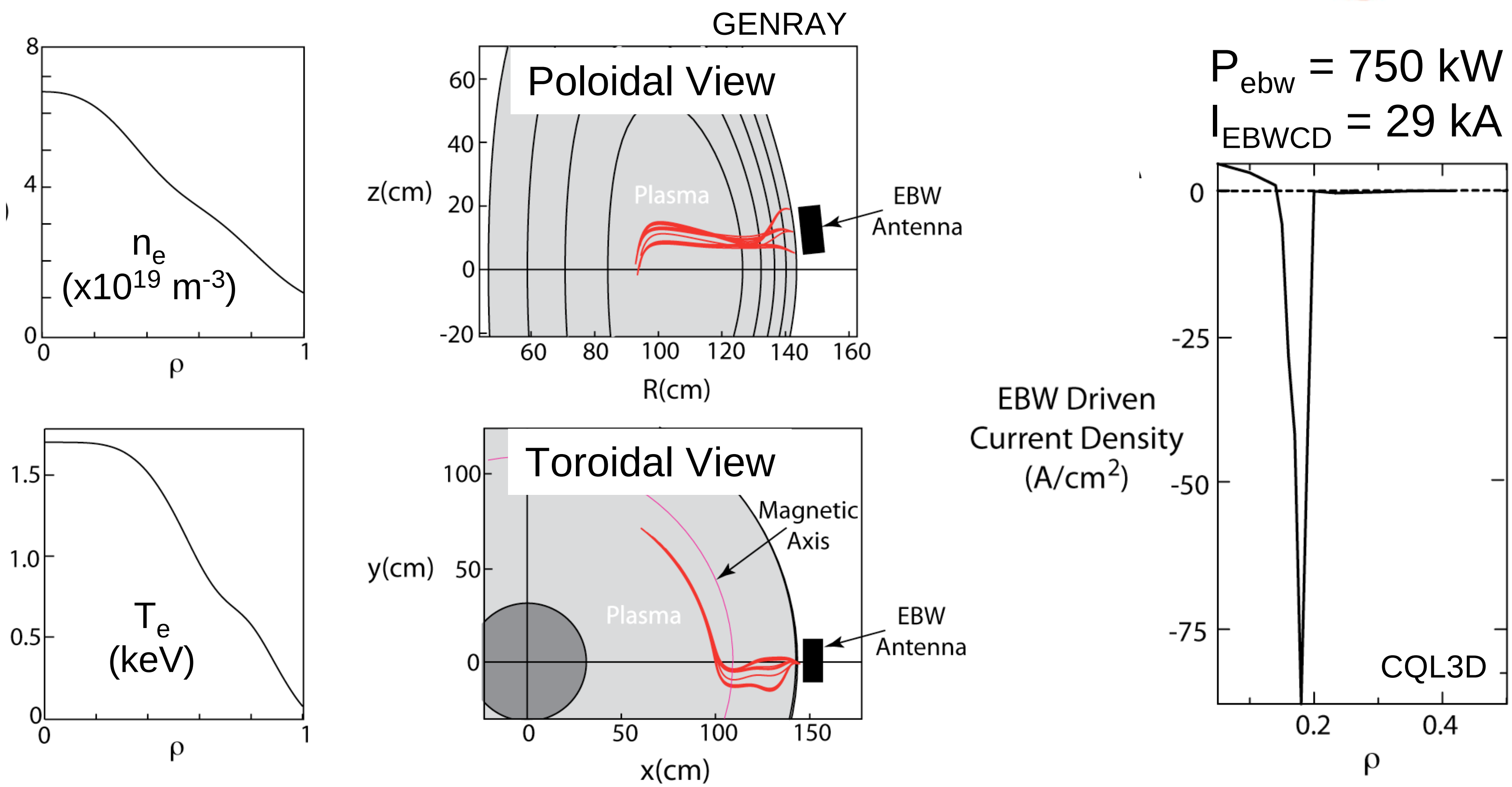
Y-K. M. Peng, et al., Plasma Phys. Control. Fusion, ***47*** *B263 (2005)*

80% EBW to O-Mode (B-X-O) Coupling Measured Via Thermal Emission from Axis of NSTX L-Mode



- Experimental results consistent with modeling
- Recent measurements show ~ 50% EBW coupling during H-mode
- Evidence for 50-60% EBW coupling also measured during O-X-B heating on MAST and TCV during H-mode
- B-X-O coupling experiments in 2008, using thermal EBW emission, will seek H-mode regimes with > 80% coupling

Modeling Predicts Localized Core Heating and ~ 40 kA/MW for On-Axis 28 GHz EBWCD in NSTX β = 20% Plasma



- Off-axis (ρ ~ 0.6) Ohkawa CD possible with similar CD efficiencies at higher T_e and lower n_e
- MSE can measure this level of CD, especially by using RF modulation

2008-13 EBW Research Plan

NSTX

2008:

- Continue coupling studies with EBW emission radiometers

2009:

- 350 kW 28 GHz gyrotron system operational
- ECH-assisted startup using fixed horn launcher:
  - *Heat CHI & PF-only startup plasma to ~ 300 eV for HHFW coupling*

2010:

- Install second 350 kW 28 GHz gyrotron & locally-steered O-X-B launcher next to HHFW antenna
- Coupling studies & core heating:
  - *Edge reflectometer at EBW launcher to measure local* L_n
  - *Lower hybrid antenna probe to measure PDI*

2011:

- Upgrade to remotely-steered O-X-B launcher
- 700 kW core & off-axis heating studies (benchmark deposition codes)

2012-13:

- Install third 350 kW 28 GHz gyrotron
- 1 MW heating & EBWCD (benchmark Fokker-Planck codes)

Long-Term EP Research Objective: Develop Ability to Predict EP Transport for ST and Tokamak Reactors

- Require capability to simulate EP transport by non-linear energetic particle driven modes for future devices (ST-CTF, NHTX, ITER…):
  - *affects heating profiles, ignition thresholds and heating efficiency*
  - *affects beam driven current profiles (ST-CTF, NHTX)*

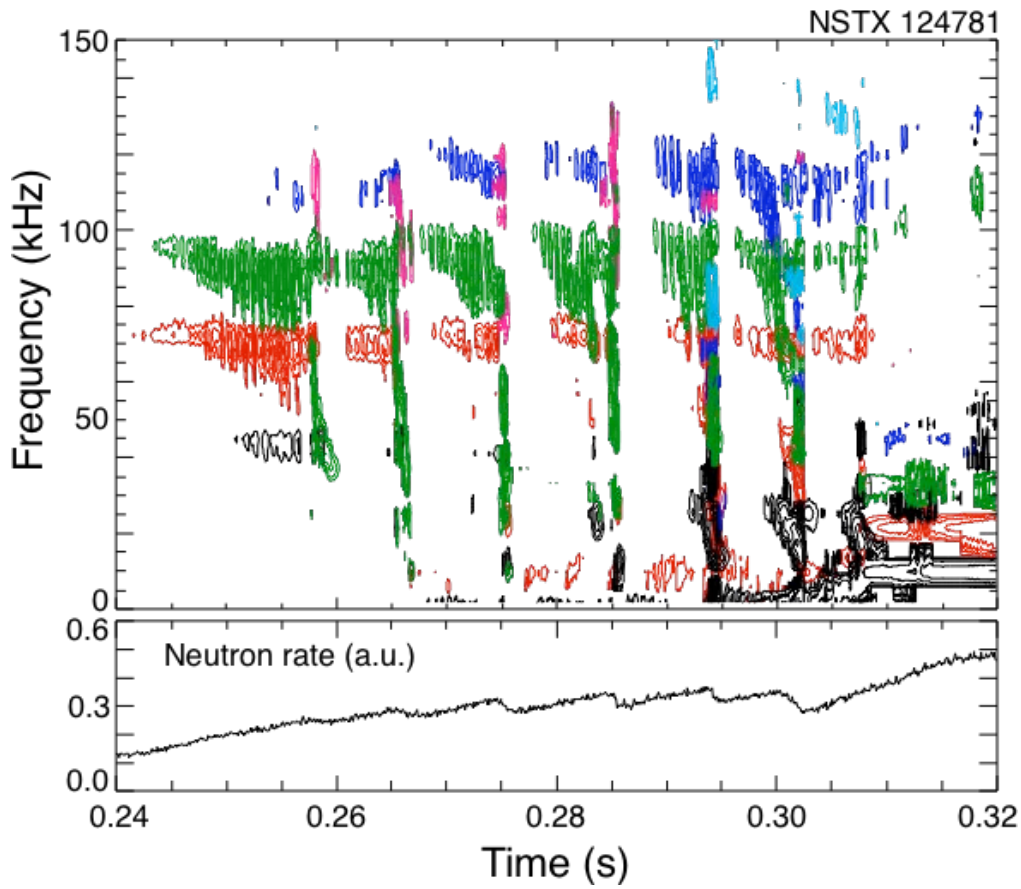
- Transport in small ρ^* devices will be through interaction of multiple modes and/or by global EP modes

- NSTX will study physics of EP instability-driven fast ion transport and confinement for:
  - *TAE avalanches*
  - *Energetic Particle Modes (EPMs) with q(0)>1*

- Measure EP mode structures, EP distributions and redistribution to benchmark codes, and guide development of simulations

Fast Ion Loss on ITER Expected from Multiple Nonlinearly Interacting Modes, Currently being Studied on NSTX

- Strong drops in neutron rate correlate with avalanche events
- Avalanches typically involve strong frequency chirping that may also be important for fast ion transport
- Goal is to develop ability to predict fast ion redistribution by multi-mode interactions



2008-13 Energetic Particle Research Plan

2008:

- Studies of EPMs/TAE avalanches with extended reflectometer array
- Installation and check-out of fast ion D_α diagnostic (FIDA)

2009:

- Extensive documentation of fast ion redistribution with FIDA, NPA, fast lost ion probe (FLIP) and multi-channel reflectometers for studying TAE avalanches and fishbones
- Develop beatwave capability for TAE range of frequencies (in lieu of dedicated antenna for *AE spectroscopy)
- Extend polarization and toroidal Mirnov coil arrays
- Passive observation of CAE/GAE using HHFW antenna strap
- Use high-k scattering to document continuum damping

2008-13 Energetic Particle Research Plan (cont.)

NSTX

2010:

- Extend beatwave capability to CAE/GAE range of frequencies - measure mode damping rates
- Faster “scanning" reflectometer to measure TAE mode structure
- Use low power, low frequency amplifier to excite TAE/CAE using HHFW antenna strap

2011:

- Control mode chirping with HHFW
- Study ITER-relevant multi-mode (fishbones, TAE, CAE, …) driven energetic particle effects
- Determine stochastic ion heating thresholds
- Measure HHFW antenna strap loading at TAE/CAE frequencies

2008-13 Energetic Particle Research Plan (cont.)

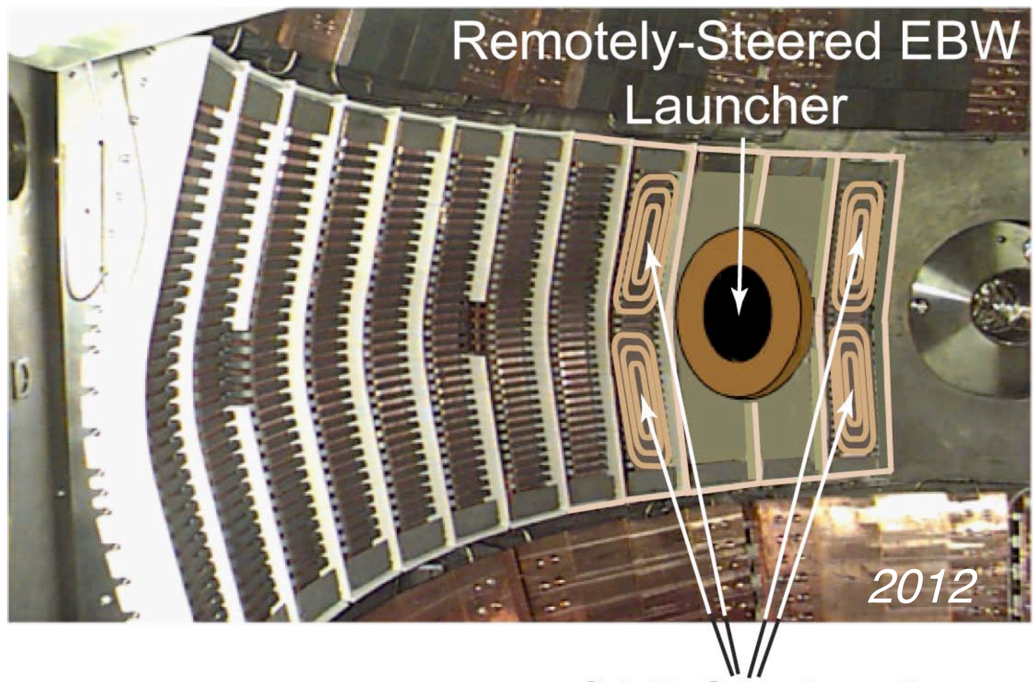
NSTX

2012-13:

- Add high power, low frequency source to excite CAE to stochastic heating threshold using new dedicated, multi-turn, antenna

- Continue studying multi-mode interactions with energetic particles

- Explore effects of fast ion distributions on mode stability with 2nd off-axis neutral beam.



Timeline for 2009-13 NSTX Plan for Waves and Energetic Particles Research

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