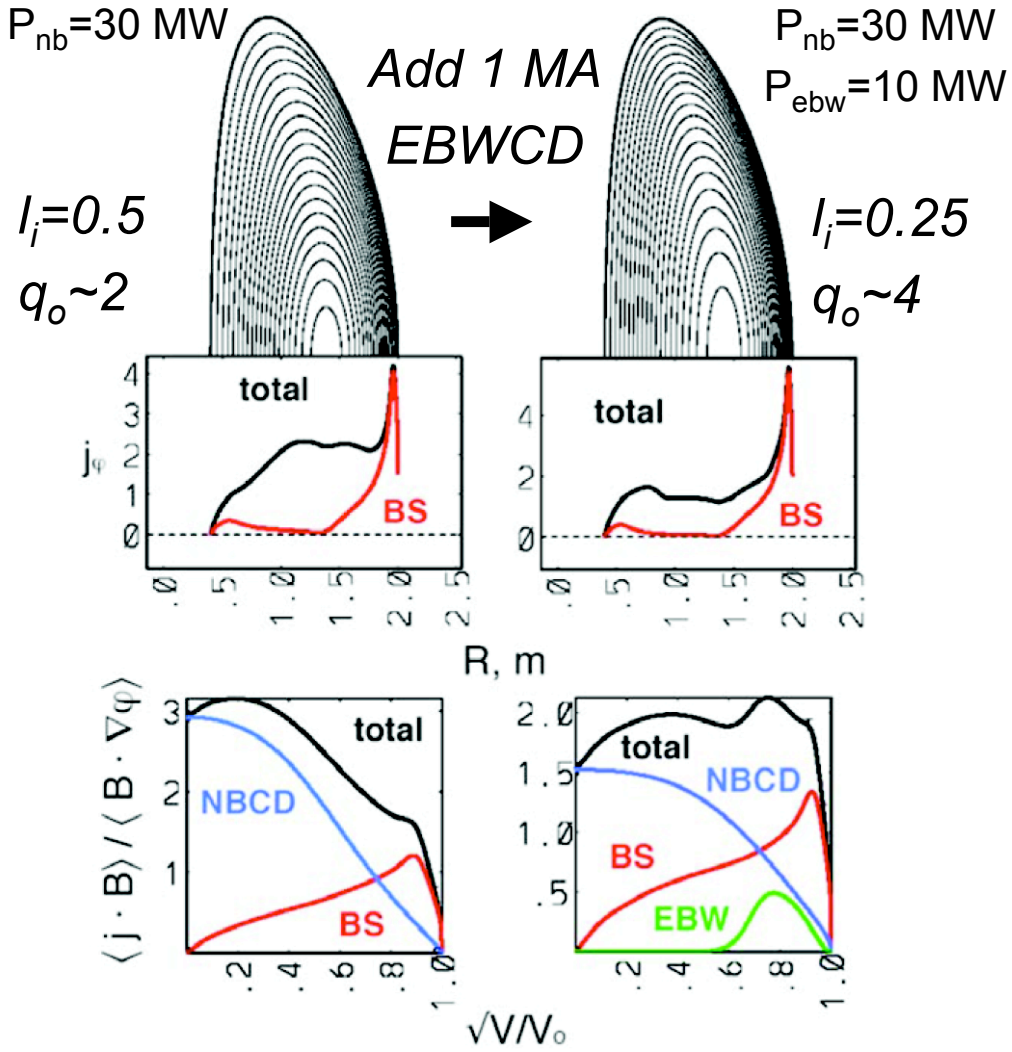
Draft FY09-13 NSTX EBW Research Plan

G. Taylor

- Research goals
- Status of ST EBW research
- FY09-13 NSTX EBW research plan

NSTX Wave-Particle Research Planning Meeting
June 28, 2007

EBWCD Supports Solenoid-Free ST Development & Can Enhance Performance of Fusion Component Test Facility



- EBWH and/or ECH can assist solenoid-free ST plasma startup & off-axis EBWCD can stabilize & sustain β > 20% ST plasmas
- Adding 1 MA of off-axis EBWCD to CTF plasma generating wall loading of 1 MW/m^2 can decrease l_i from 0.5 to 0.25 & increase q_o from ~ 2 to ~ 4

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

Long-Term NSTX EBW Research Goal to Assess EBWCD as a Tool for Sustaining β > 20% Solenoid-Free Plasma

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FY09-13 Research Goals:

- Develop ECH-assisted plasma startup to increase T_e sufficiently for effective HHFW coupling
- Evaluate EBWH-assisted overdense plasma I_p ramp-up
- Demonstrate efficient EBW coupling at RF powers ~ 300 kW
  - Assess effect of ponderomotive force, heating & parametric decay @ UHR on EBW coupling efficiency
- Test EBW heating at RF powers ~ 600 kW:
  - Benchmark EBW code predictions for heating efficiency & localization
- Test off-axis EBWH & core EBWCD with RF powers ~ 1 MW
  - Benchmark EBW code predictions for core Fisch-Boozer CD

Modeling Predicts EBWCD Can Provide Stabilizing Current Needed for β > 20% Non-Inductive NSTX Scenarios

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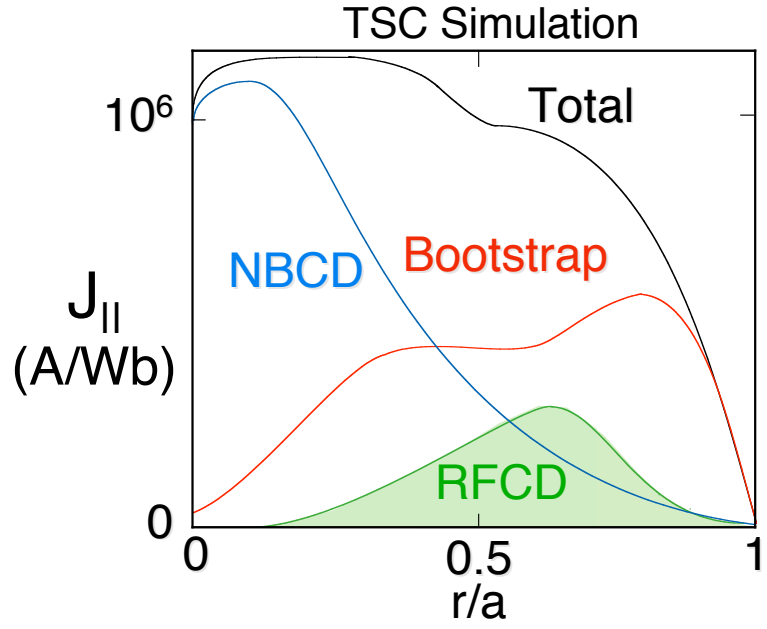
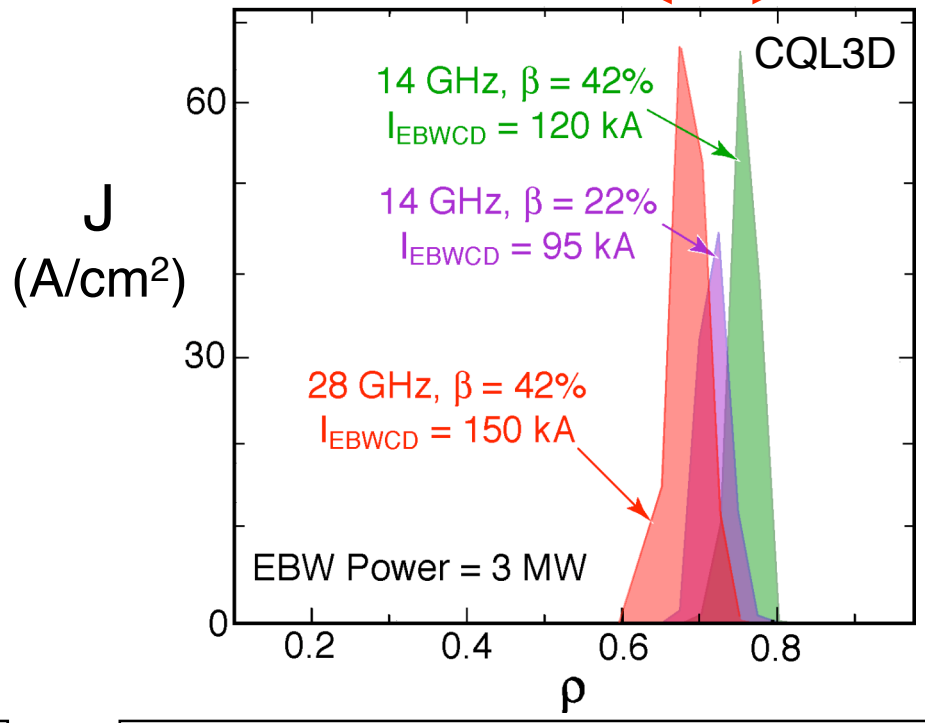
NSTX, β_t = 42%, β_{pol} = 1.6
B_t = 0.34 T , I_p = 1 MA



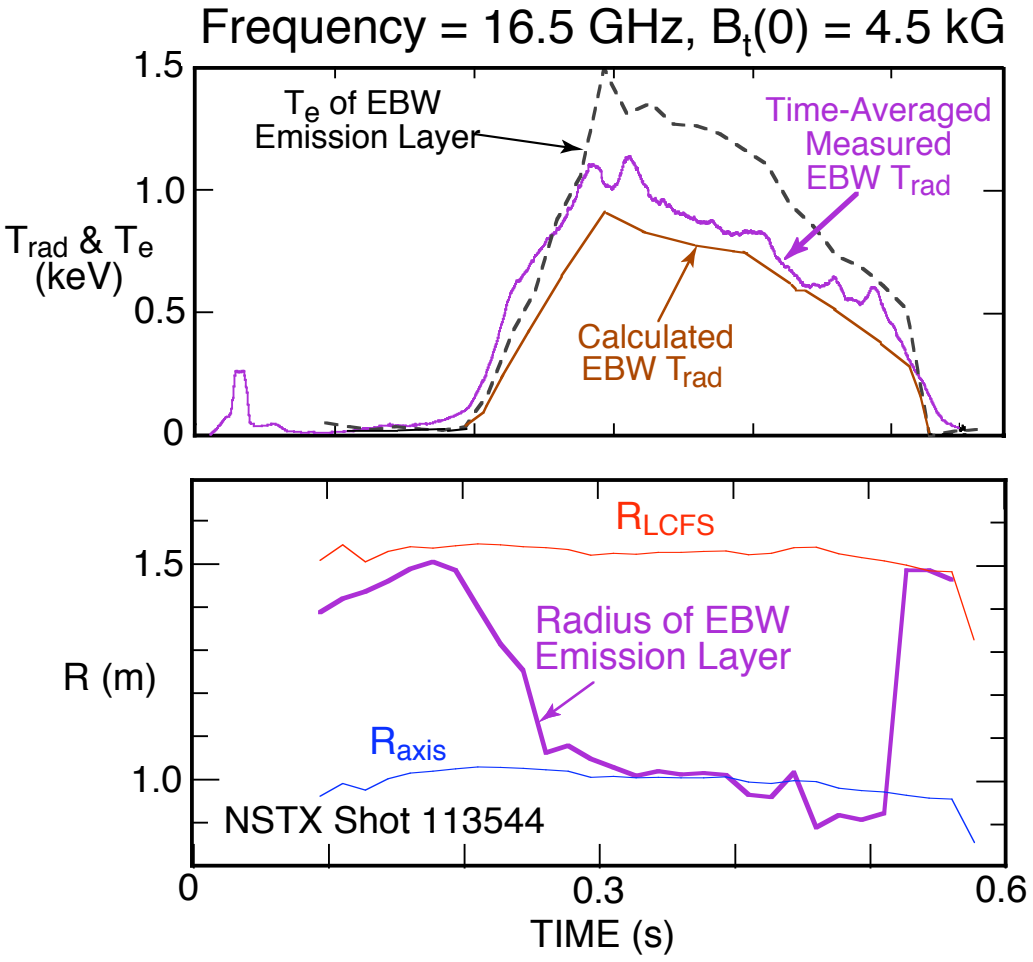
*C. Kessel, et al ., Nucl. Fusion **45**, 814 (2005)*

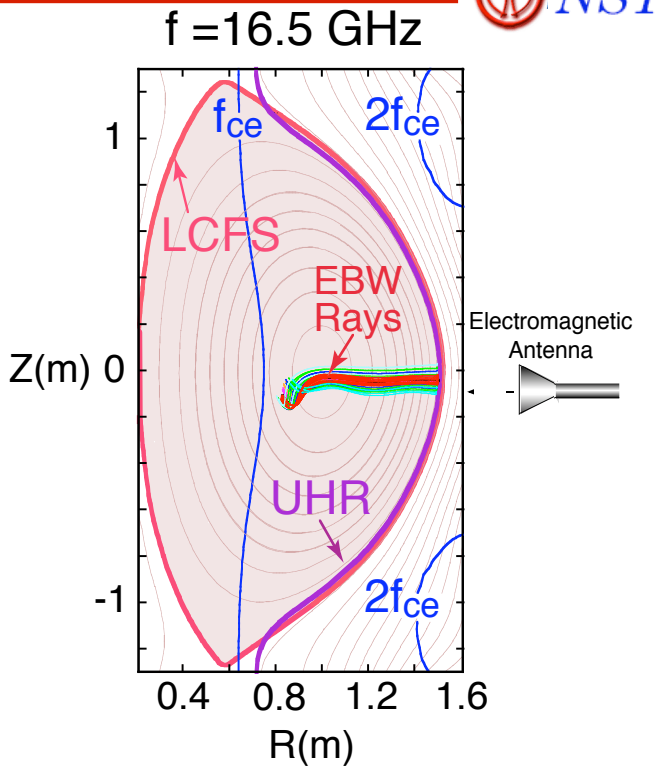
Deposition similar for
14 GHz & 28 GHz and β = 20-40%



*G. Taylor, et al ., Phys. Plasmas **11**, 4733 (2004)*

Measured 80% f_{ce} B-X-O Coupling in NSTX L-Mode Edge Plasmas, Consistent with Modeling





- 3-D ray tracing & full wave EBW mode conversion model using EFIT magnetic equilibrium & Thomson scattering T_e & n_e

*G. Taylor et al., Phys. Plasmas **12**, 052511 (2005)*
*J. Preinhaelter et al., AIP Proc. **787**, 349 (2005)*

30-50% B-X-O Coupling Efficiency Recently Measured at f_{ce} & $2f_{ce}$ in Li-Conditioned, High κ, f_{BS}, H-mode Plasmas

NSTX

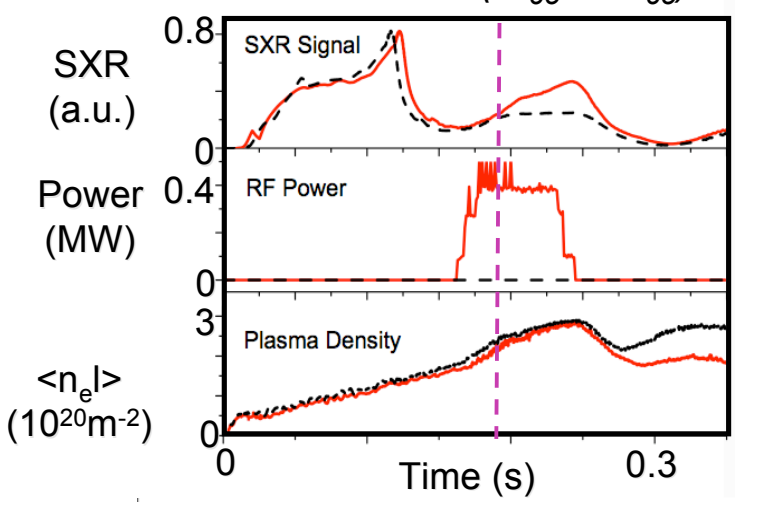
- Preliminary analysis of recent NSTX EBW emission measurements show 30-50% B-X-O coupling for 18 GHz (f_{ce}) & 28 GHz ($2f_{ce}$)

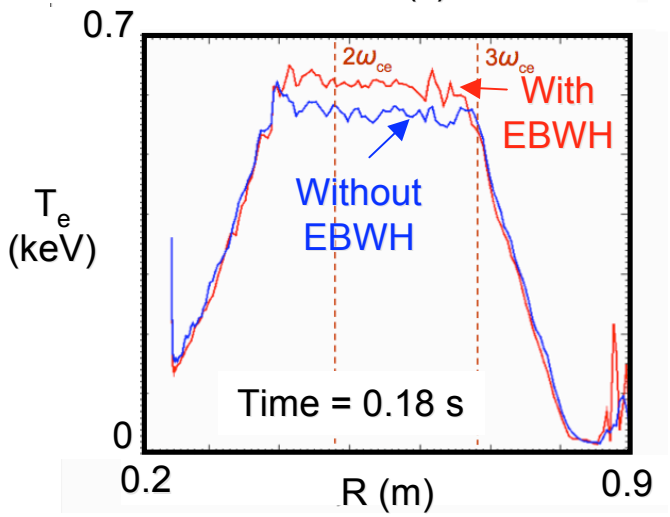
- Li conditioning with LITER increased f_{ce} B-X-O coupling:
  - Li increased T_e in the f_{ce} B-X-O coupling layer, reducing EBW collisional damping

EBW Heating via O-X-B Coupling Demonstrated on MAST & TCV

MAST

f = 60 GHz ($2f_{ce}$ & $3f_{ce}$)

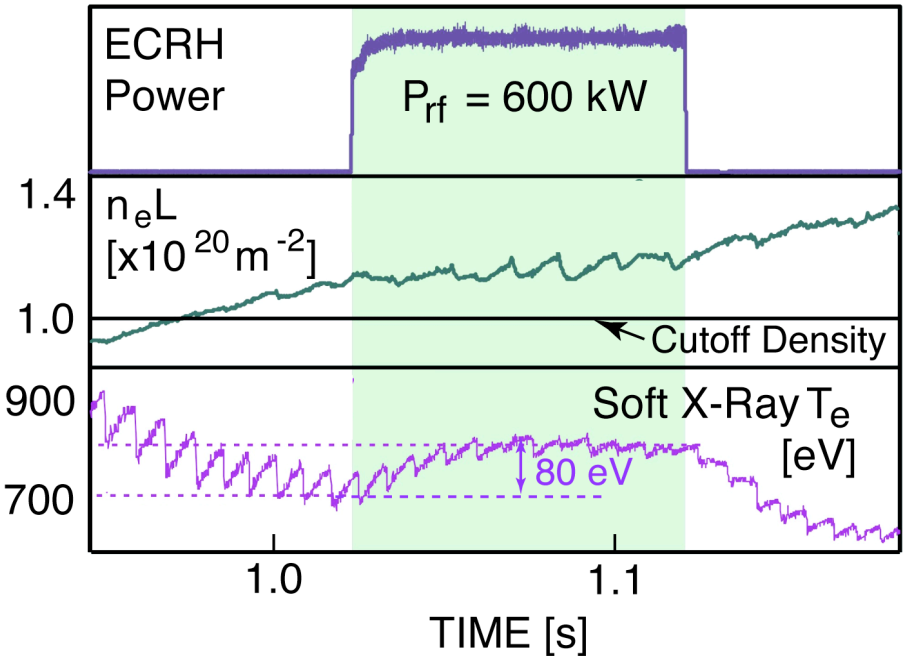




V. Shevchenko, et sl., Proc. EC-14, p. 54 (2006)

TCV

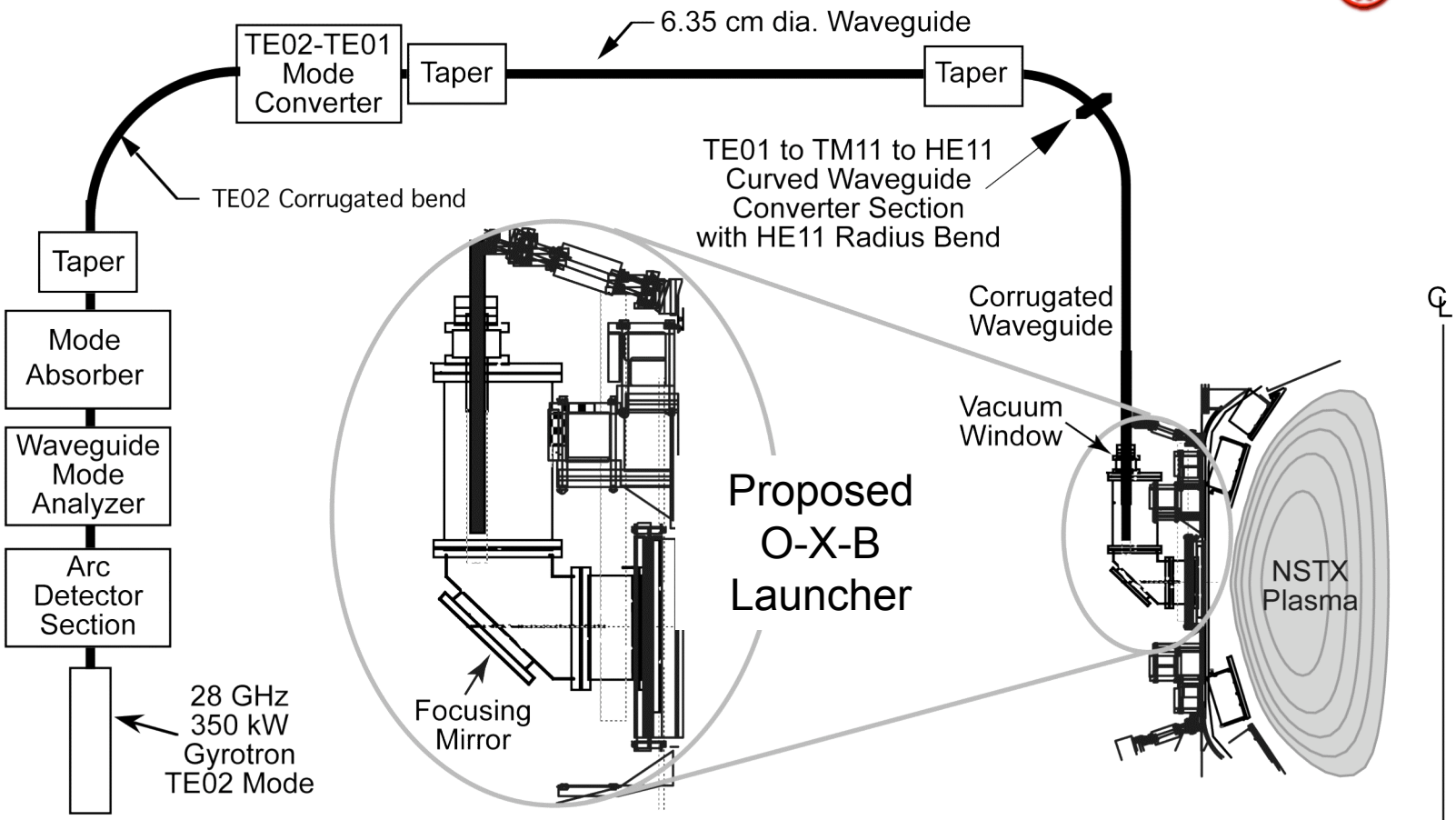
$B_t(0)$ = 1.5 T, f = 82.7 GHz ($2f_{ce}$)



*A. Mueck, et al ., Phys. Rev. Lett. **98**, 175004 (2007)*

- Non-inductive MAST startup plasma recently heated by 90kW, 28 GHz to T_e ~ 500 eV, at n_e ~ 2x10^{18} m^{-3}, generating I_p ~ 32 kA (May 2007)

350 kW, 28 GHz, 500 ms, Heating System Being Installed on NSTX for Initial Operation in FY09



- Additional Gyrotrons proposed for FY10 & FY11 operation, providing ~ 1 MW of 28 GHz power by FY12
- Possible operation at 15.3 GHz for f_{ce} EBWH on NSTX

Proposed Pegasus 2.45 GHz EBW Heating Program Could Complement NSTX 28 GHz EBW Program

NSTX

- Significant hardware available at 2.45 GHz
  - Plan to use PLT LH system
  - Klystrons at PPPL and ORNL (up to 1 MW available)
- EBW heating power comparable to Ohmic heating
- New tools coming online
  - Plasma control system to maintain stationary edge in 2007
  - Hard/soft X-ray camera for absorption imaging / q-profile diagnostic
- Extended periods of dedicated runtime available
- $300k to implement
- Could be install & commissioned in 2 years

Pegasus 2.45 GHz EBW Program has Important Goals but Lacks Funding

NSTX

- Program could demonstrate significant EBW heating & current drive in an ST at f_{ce}
  - 1 MW of 2.45 GHz microwave power -> ~ 400 kW coupled to EBW
  - Presently plan for O-X-B launch
  - $P_{ebwh} \sim P_{oh}$
- Validate models of ray tracing and absorption
  - Recent observation of possible peeling modes at edge complicates coupling physics
- Study lower hybrid parametric instability
  - Should be readily destabilized with 20-100 kW for Pegasus conditions
- Originally planned to start installation in 2007, but now indefinitely delayed due to lack of funding

FY09-10 EBW Research Plan

NSTX

FY09

- 350 kW 28 GHz gyrotron system operational
  - 500ms pulse length
  - Possibly 100-200 kW at 15.3 GHz
- ECH-assisted startup using fixed horn launcher at Bay G midplane:
  - Heat CHI & PF-only startup plasma to ~ 300 eV for HHFW coupling

FY10

- Install second 350 kW 28 GHz gyrotron
- Install fixed (or locally-steered) O-X-B launcher for I_p flat top at Bay G:
- 300 kW EBW coupling & core heating expts:
  - High resolution edge T_e MPTS
  - Edge reflectometer at launcher for measuring local L_n
  - Antenna probe for measuring lower hybrid parametric instability
- Install fixed EBW horn launcher for EBW-assisted startup & I_p ramp up expts.

FY11-13 EBW Research Plan

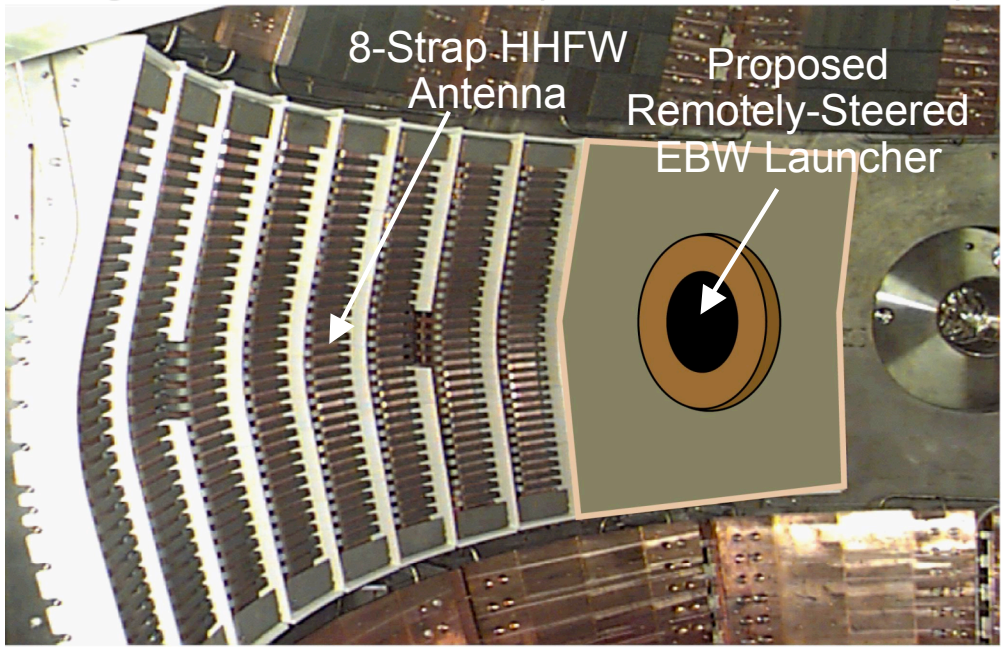
FY11

- 600 kW EBW core & off-axis heating expts
- Continue EBW-assisted startup & I_p ramp up expts.

FY12-13

- Install third 350 kW 28 GHz gyrotron
- Install remotely-steered O-X-B launcher next to HHFW antenna
- 1 MW off-axis EBW heating & core EBWCD (Fisch-Boozer CD) expt.

NSTX Double Feed HHFW Antenna (circa 2012)



2009-13 EBW Research Plan Timeline