200 kW, 28/15.3 GHz ECH/EBWH System for NSTX Plasma Start-up & Current Ramp-up

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Physics Review
NSTX Physics Meeting
December 4, 2006

Outline

- Physics Justification
- Technical Details
- Budget & Schedule
- Summary

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200 kW ECH/EBWH System Supports Non-Solenoid Start-up & EBWH Tests Into I_p Flat Top

NSTX

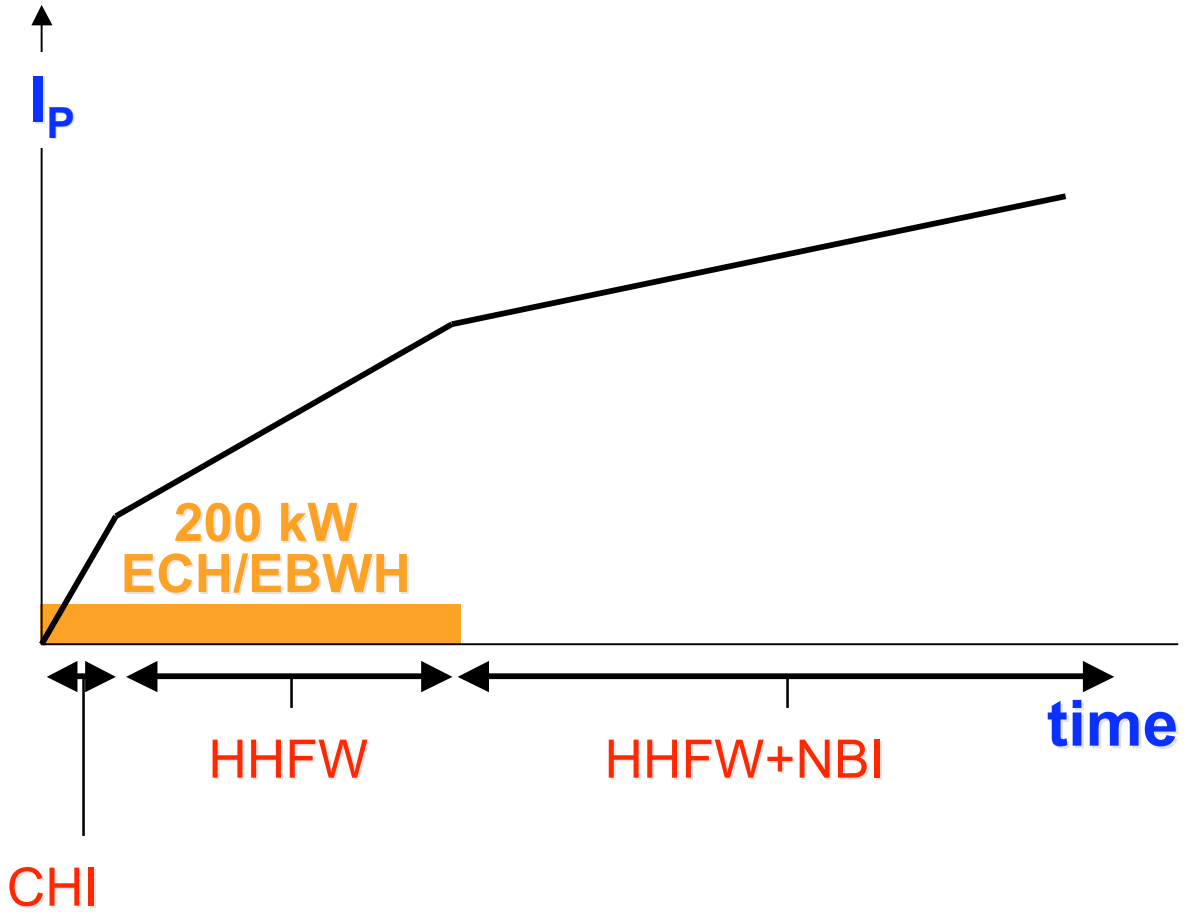
- EC pre-ionization for standard inductive discharges
- Heating for CHI & PF-only start-up plasmas (low n_e, T_e)
- Heat start-up plasma to ~ 100 eV to enable effective HHFW electron heating
- Support transition from ECH/EBWH/CHI start-up to HHFW current ramp-up
- Support low power EBW coupling studies & initial on-axis electron heating experiments during I_p flat top
- Operational for 2008 NSTX run

ECH/EBWH System Provides Transition from Non-Solenoid Startup to HHFW I_p Ramp

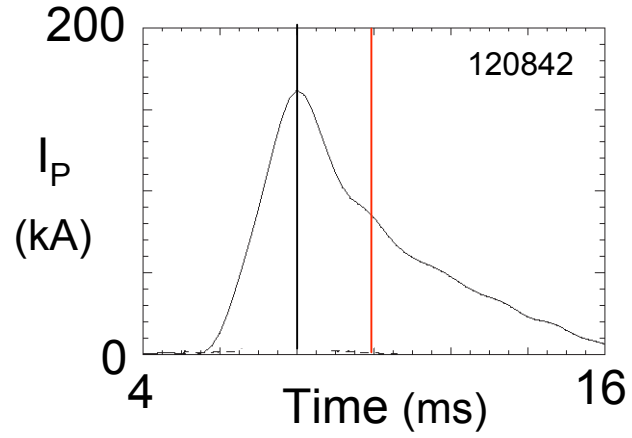
CHI for plasma initiation, early ramp
(also PF-only ramp-up)
- **High power EC pre-ioniz.**
- **EBW heating to T_e > 100eV**

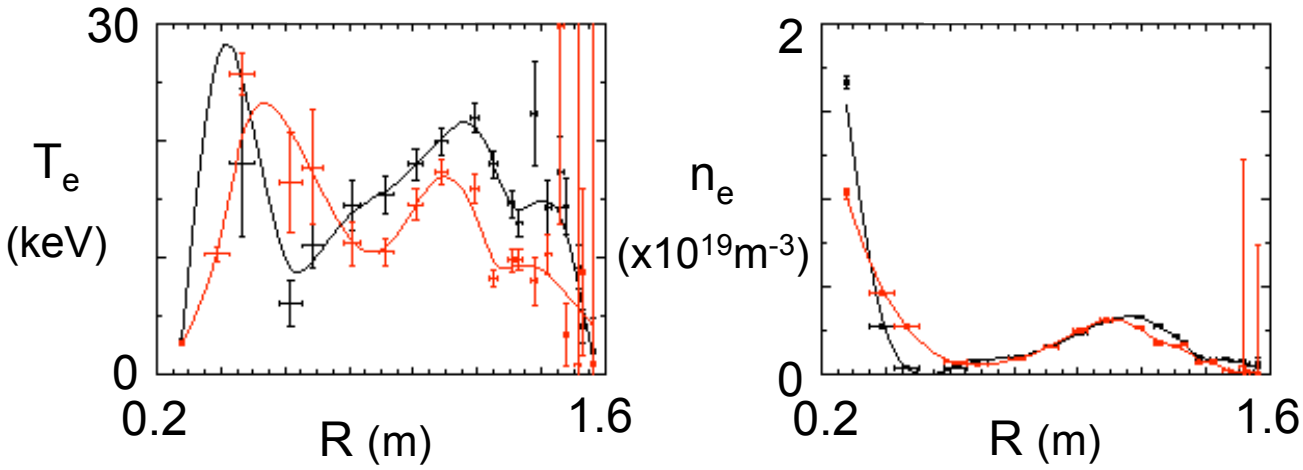
HHFW for ramp-up of low I_P CHI plasma
- Bootstrap + FWCD

NBI+HHFW for higher I_P ramp-up
- Bootstrap + FWCD + NBICD



CHI Start-up Plasma Reaches $T_e(0) \sim 15$-20 eV, $n_e(0) \sim 3 \times 10^{18}$ m^{-3}





- n_e and T_e with CHI or PF-only start-up are likely too low for effective HHFW heating

If CHI Plasma T_e can be Increased to >100 eV HHFW Electron Heating Significantly Improves

NSTX

- HHFW electron TTMP heating rate approx. scales as:

$$P_e \sim \beta \frac{\omega^2}{k_{//} v_{T_e}} e^{-\left(\omega / k_{//} v_{T_e}\right)^2}$$

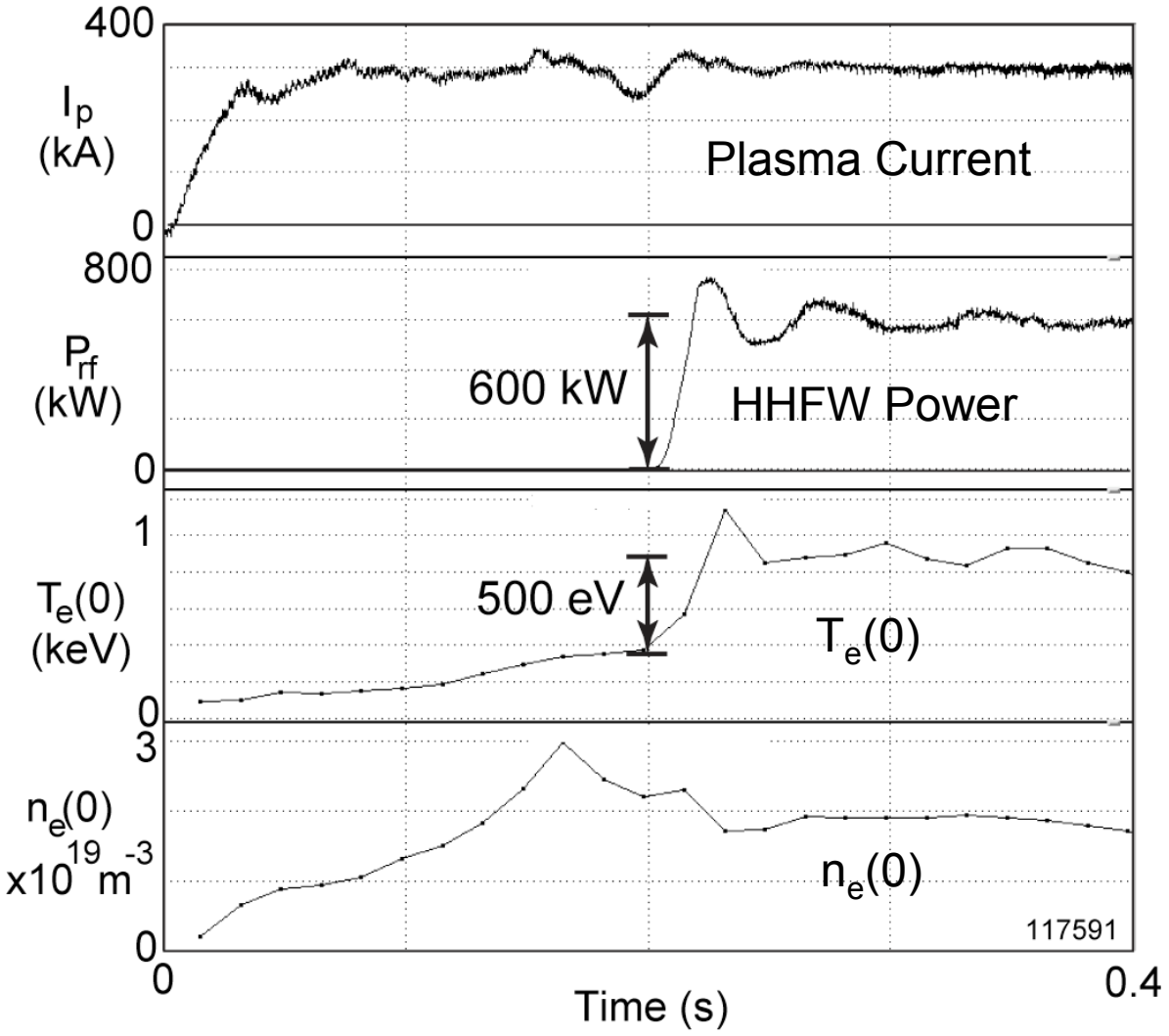
For T_e ~ 100 eV, $e^{-\left(\omega / k_{//} v_{T_e}\right)^2}$ ~ 0.006

For T_e ~ 300 eV, $e^{-\left(\omega / k_{//} v_{T_e}\right)^2}$ ~ 0.170

- For $B_t(0) \sim 0.43$ T, $k_{//} = 14$ m^{-1} "quick & dirty" METS runs (by CKP) predict:

$T_e(0)$	$n_e(0)$	Single Pass Absorption
100 eV	0.5x10^{19}m^{-3}	2%
100 eV	2.4x10^{19}m^{-3}	18%
300 eV	2.4x10^{19}m^{-3}	50%

Low I_p, n_e & T_e HHFW Supports ~100 kW of EBWH Being Detectable with <100% Coupling



28 GHz $2f_{ce}$ On-Axis ECH at B_o = 0.55 T when $n_e(0) < 9x10^{18}$ m^{-3}

NSTX

ECH Resonance Locations on NSTX
R = 0.85 m, r = 0.62 m, B_o = 0.3 T

Frequency/ Harmonic #	Resonant Field (T)	Major Radius (m)	Normalized Minor Radius	Critical Density $x10^{18}$ m^{-3}
28 GHz/fund	1	0.26	-0.9	9.2
2nd	0.5	0.52	-0.5	
3rd	0.33	0.78	-0.1	
15.3 GHz/fund	0.55	0.47	-0.58	2.7
2nd	0.27	0.94	0.15	

ECH Resonance Locations on NSTX
R = 0.85 m, r = 0.62 m, B_o = 0.55 T

Frequency/ Harmonic #	Resonant Field (T)	Major Radius (m)	Normalized Minor Radius	Critical Density $x10^{18}$ m^{-3}
28 GHz/fund	1	0.47	-0.61	9.2
2nd	0.5	0.94	0.14	
3rd	0.33	1.41	0.9	
15.3 GHz/fund	0.55	0.86	0.02	2.7

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ORNL Can Provide 28 GHz Gyrotron; 15.3 GHz Operation Needs to be Demonstrated

NSTX

- 350 kW pulsed (200 kW cw) 28 GHz gyrotrons available from ORNL for loan to PPPL
- Test transition to 15.3 GHz (TE02→TE01) with 40 kW 28 GHz gyrotron at ORNL by February 2007:
  - *Controls, magnet, waveguide all compatible with either 15.3 GHz or 28 GHz operation*
  - *Efficiency and mode purity may be reduced at 15.3 GHz*
  - *Double disk window gap tuning and some component changes needed to change from 28 GHz to 15.3 GHz*
- ORNL has sockets and 1.2 MW HV modulator/regulator that are available for loan to PPPL
- Use modified PPPL TFTR NBI power (-90 kV @ 40 A)

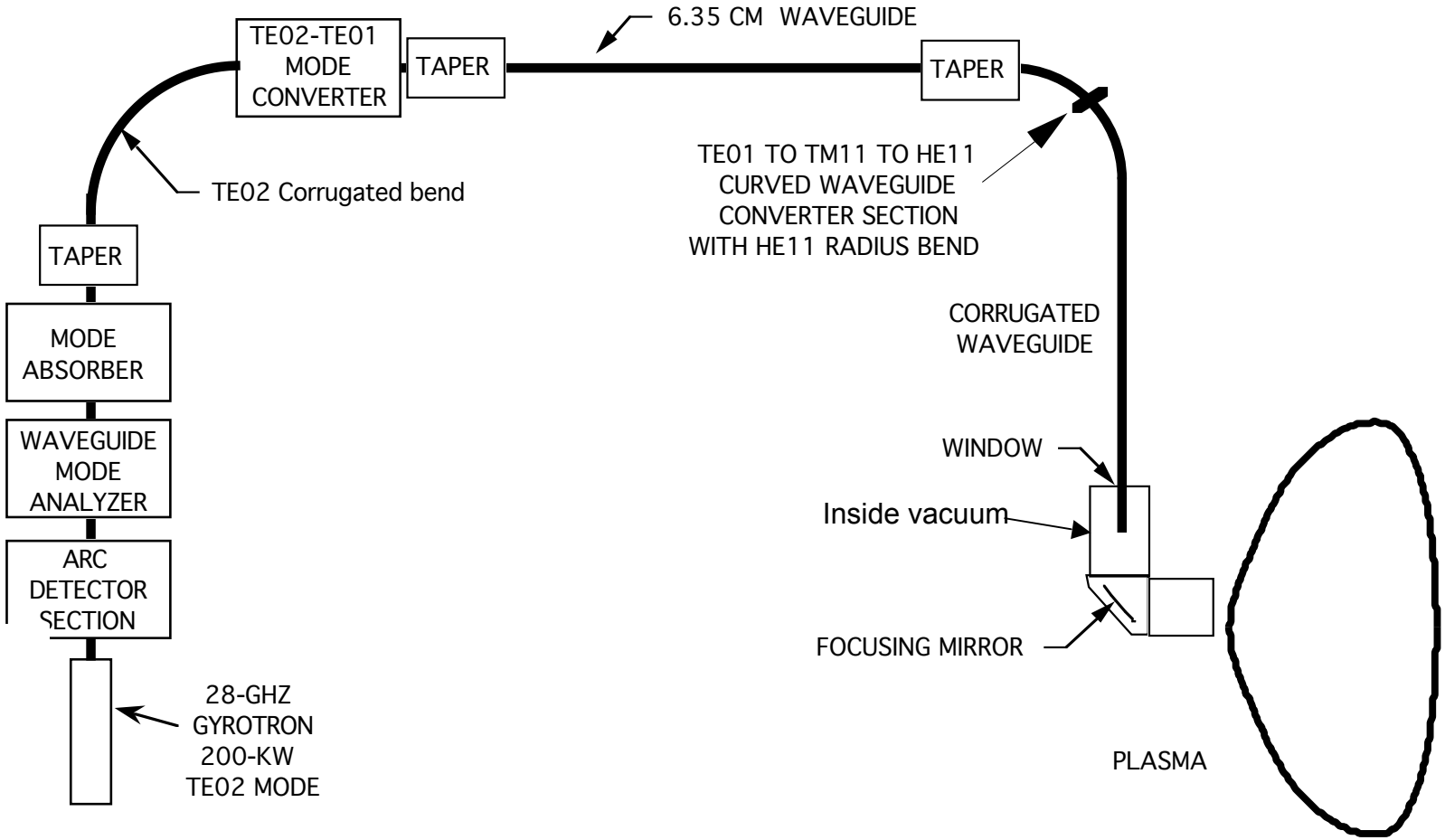
Test 15.3 GHz TE01 Mode Operation with 40 kW Standalone 28 GHz Gyrotron System at ORNL

ORNL 40 kW Standalone 28 GHz Gyrotron System

Four 28 GHz 200 kW CW Gyrotrons, Magnets & Sockets Available at ORNL

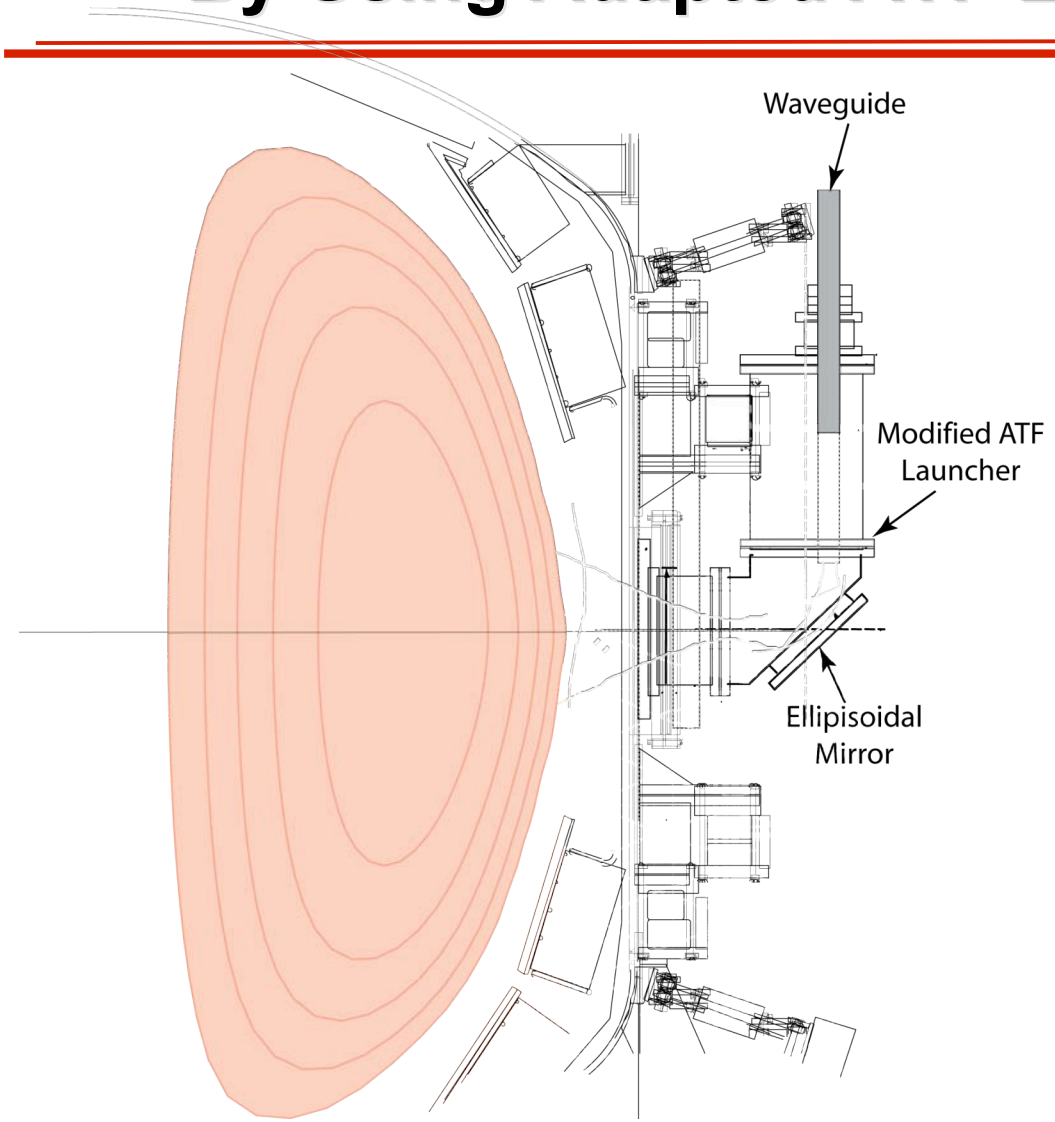
- 350 kW pulsed (~ 500 ms) gyrotron operation needs 80kV @ 12A
- Gun and collector magnets, with supplies, available from ORNL:
  - *26V @ 480A typical operating point*
  - *Remote control and monitoring*
- FC-75 cooled window
- Several possible locations for installing Gyrotron, both inside & outside NSTX test cell, identified

28/15.3 GHz Waveguide and Launcher Hardware Available from ORNL



- TE02, TE01 and HE11 (corrugated) waveguide

Minimize Cost for Initial Installation By Using Adapted ATF ECH Launcher



ATF ECH Launcher

- Require 16 inch conflat flange on midplane port

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Budget

- ORNL - ~ $950k (requires increased collaboration funding)
  - *Test 28 to 15.3 GHz conversion (~$110k, funding approved)*
  - *Gyrotron, socket, magnet, waveguides, mode converters, launcher*
  - *Mod/Reg, magnet supplies, local controls & interlocks*
  - *Decision on increase NSTX collaboration funding in March 2007*

- PPPL - ~ $1350k (FY07: ~$650k, FY08: ~$700k)
  - *Utilities: water, power, oil containment*
  - *Installation of gyrotron, transmission line & launcher*
  - *Modification & installation of HV supply, remote controls*
  - *Safety review*
  - *Requires only ~ $100k of M&S funding at PPPL (mostly in FY08)*

Schedule

- 28 -> 15.3 conversion test at ORNL (Dec 06 - Feb 07)
- Refurbish gyrotron, socket & mod/reg at ORNL (FY07)
- Site layout & preparation at PPPL (FY07)
- Install system on NSTX (Oct 07 - Jan 08)
- In-situ system commissioning (Feb 08)
- Delay in HHFW antenna upgrade schedule:
  - Double feed upgrade to increase power capability by factor of two delayed until late 2008
  - Faraday shield modification to reduce reactive field - plasma interaction delayed until late 2008

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Summary

- ORNL & PPPL are proposing ~200 kW ECH/EBWH that can benefit NSTX in several areas:
  - *Intense ECH pre-ionization for standard inductive discharges*
  - *Heating for CHI & PF-only start-up plasmas*
  - *Provide ~ 100eV start-up plasma for effective HHFW heating*
  - *Support ECH/EBWH/CHI transition to HHFW current ramp-up*
  - *Conduct low power EBW coupling & heating during I_p flat top*
- System can be operational at 28 & 15.3 GHz for FY08 NSTX run campaign:
  - *Needs only modest development and testing (e.g. verify 15.3 GHz operation)*
  - *Requires only ~ $100k of M&S at PPPL*
- Most significant negative impact on NSTX is to delay HHFW antenna upgrade by ~ 1 year