Preliminary ECH pre-ionization and EBW coupling experiments on NSTX

NSTX

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ABSTRACT

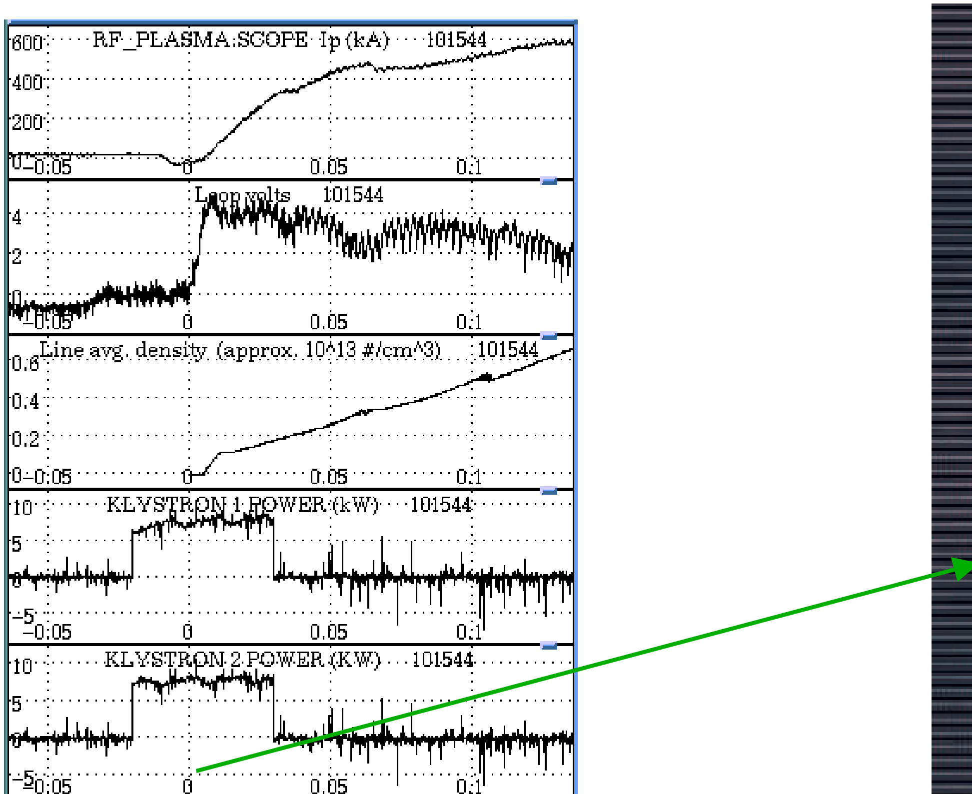
A 30 kW 18 GHz ECH system has been installed on NSTX to provide plasma pre-ionization and is also being used to conduct electron Bernstein wave (EBW) coupling experiments for $n_{||}=0$ launch. This system consists of two klystrons with separate waveguide transmission systems and corrugated horn launchers. The launch polarization is linear and can be adjusted to any plane by installing waveguide twists. The horns generate a launch beamwidth of 24° and are aimed at the NSTX centerline from an above axis port. The launch beam crosses both fundamental and second harmonic resonances so strong first pass absorption can be obtained with either O or X mode launch during the plasma startup process. The launcher horns point inline with the plasma edge density gradient. By studying wave reflections from the plasma during high density (above cutoff) portions of the discharge, it should be possible to determine the optimum density gradient conditions for direct coupling to the EBW wave for the $n_{||}=0$ case. Edge density information is expected to be available from the ORNL reflectometer system located nearby. Both pre-ionization and EBW coupling studies are planned for the second phase of NSTX operation.

Topics

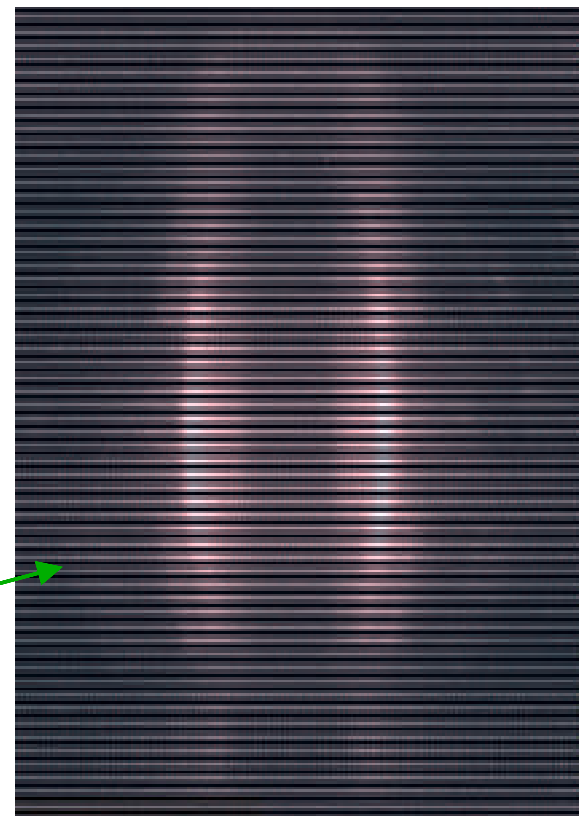
- ECH Preionization: routine operation
- Preliminary EBW coupling experiment
- Hardware options for 28 GHz high power ECH/EBW system
- ECH assisted startup

ECH Preionization in NSTX generates good startup plasma

- Applying ~15 kW of 18 GHz ECH power produces plasma breakdown, allows plasma current initiation with low startup loop voltage



50-ms ECH pulse from 2 klystrons



Picture at t ≈ 0 ms showing ECH plasma

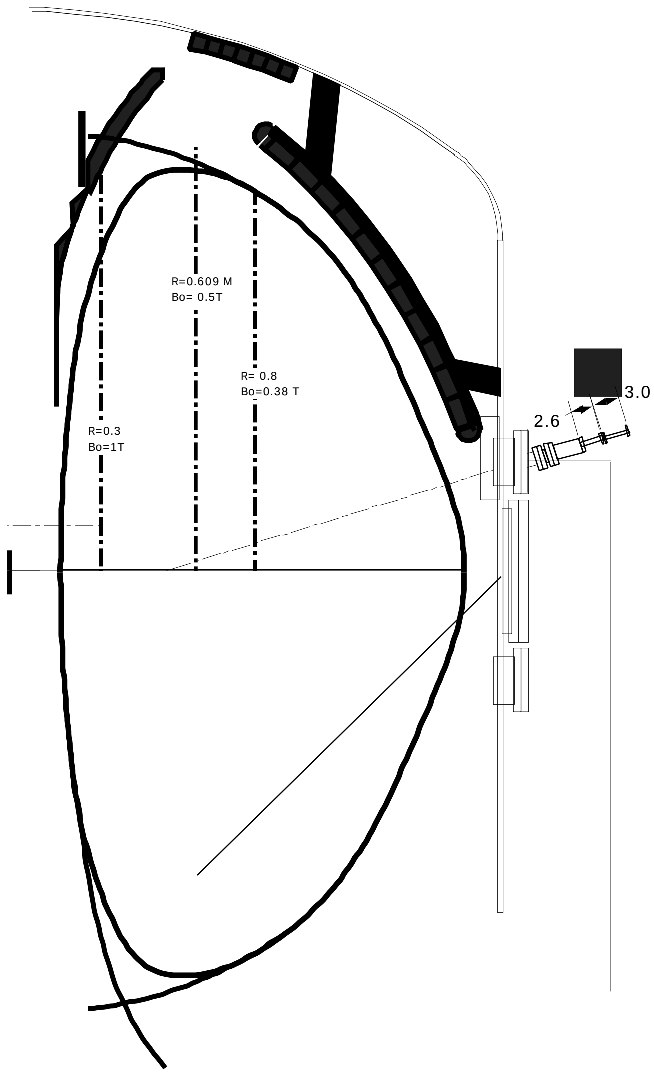
X-EBW Coupling study

- Investigate direct X-EBW (direct) coupling using the NSTX 18 GHz ECH pre-ionization system
- Theoretical predictions (Ram et al) indicate efficient X-EBW mode conversion may be possible at 18 GHz given optimum n_e and n_e profile
- High coupling efficiency would result in wave tunneling and low reflection at the critical density layer
- Efficient should be detectable as reduced reflected power at the launcher if closely coupled

Experimental setup details

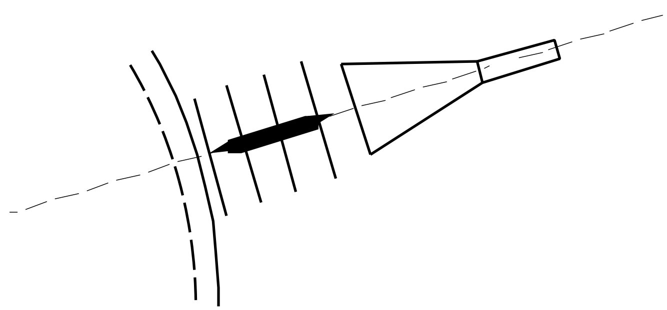
- One ECH-PI launcher set to X-mode polarization; pulse lengthened
- Launcher designed to launch parallel to edge density gradient
- Monitor reflected power as high density cutoff layer approaches the launcher
- Reflected power amplitude would increase then decrease as the optimum EBW wave tunneling approaches

ECH PI Launcher



Experimental setup results

- Small antenna-plasma gap can required to
- ECH launcher-plasma gap ~ 15 cm
- Reflected (backscattered) signal coupling to the launcher is small but measureable
- Reflected signal is noisy mixture caused by interference from vacuum window reflection



Future ECH Applications on NSTX

ECH assisted startup

- Utilize two or more 200 kW, 28 GHz gyrotrons
- Drive “bootstrap current”
- Investigate non-inductive current drive through several mechanisms- Goal of 100 kA total N-I current
- Initial plasma heating for medium plasma density
- Reduce loop voltage during inductive startup (small but significant effect)

ECH “bootstrap” scaling

- with 400 kW of 28 GHz we can expect as much as 42 kA (C.Forest scaling)
- With 1.4 MW of 28 GHz, ~ 150 kA expected
- A priority experimental objective will be to improve this current drive technique
- Extend current capability upward to “meet” minimum current required for HHFW coupling

Electron-Bernstein wave heating

- Provides access to “overdense” portions of the discharge
- New technique requires some development
- Excellent theoretical and some experimental results (Batchelor, Ram, W7AS experiments)

Direct X-mode conversion to EBW

- Perpendicular X-mode launch
- Wave tunneling at edge through critical layer
- Plasma density and profile are important
- Interesting technique
  - Launcher is simpler than O-X-EBW route
  - Coupling efficiency is a concern

O-X-B EBW scenario

- O-mode propagation to cutoff
- Conversion to X-mode at turning point ($N_x=0=N_o$) (H. Laqua, Stellarator news March 96)
  - wave cannot pass through cutoff
  - density scale length must be small
  - density fluctuations spoil the process
- X-EBW conversion through parametric instability
  - resonant and non-resonant absorption
- W7AS results quite encouraging
  - 70 GHz; 40° launch; ΔWj=1.5 KJ at twice cutoff

Fisch-Boozer ECCD scenario

- Possible application at 1 T for edge current drive
- oblique launch
- requires high Te and first pass absorption
- 2nd harmonic more practical on NSTX
- ITER scaling indicates 50 kA with 350 kW or 200 kA with 1.4 MW

Other ECH applications on NSTX

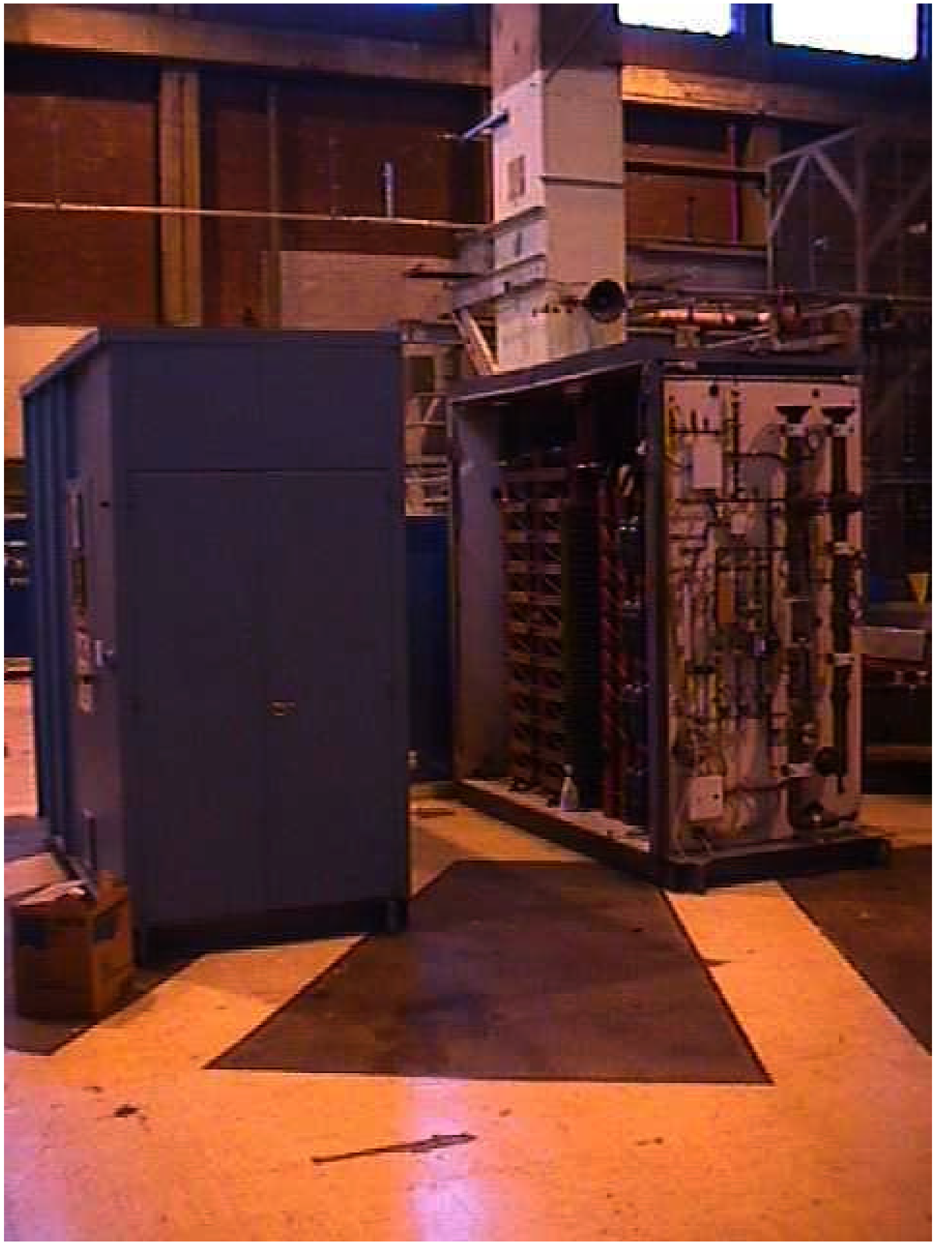
- Edge current drive
- Heating & CD in synergy with other systems- HI, HHFW
- Utilize ECH whenever useful for bulk heating
- Wall conditioning with & without plasma
- Transport diagnostic with modulated power
- Edge heating experiment at 1T.
- Investigate 3rd harmonic heating with higher frequency gyrotron
- Make high density background plasma for NBI-cd target
- Study H-mode like behavior with edge heating

ECH Hardware available

- Utilize existing hardware to make experiments affordable
- Two to four 28 GHz, 200 kW, gyrotrons available at ORNL
- CW tubes can be refurbished and generate 350 kW each (up to 1.4 MW from 4 tubes)
- Four sockets and HV modulator/regulator are available at ORNL
- Utilize installed PPPL "NBI" power supply available at D-site (-90 kV at 40 A) or DNB supply (-90 kV, 30A)
- ATF beam launcher assembly

28 GHz CW
Gyrotrons at ORNL

Gyrotron sockets at ORNL



ECH HVDC
Power supply

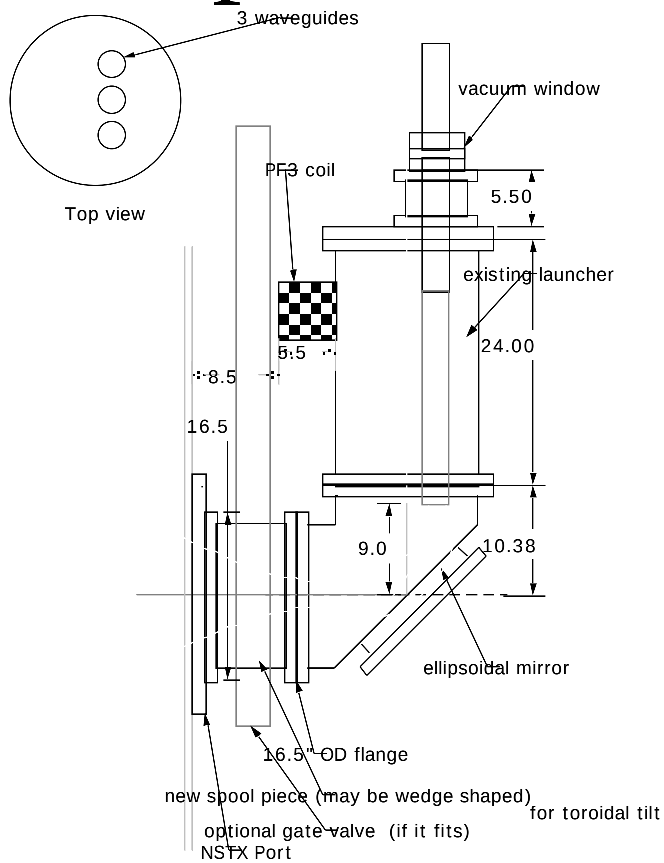
Modulator/
Regulator

at ORNL

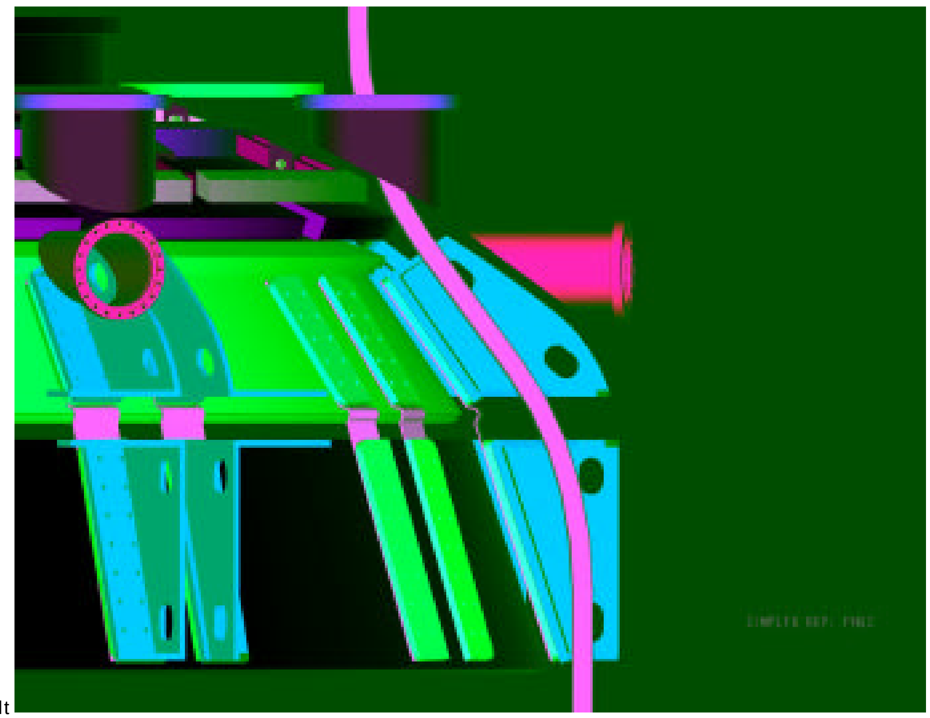
Launcher configuration

- For EBW and current drive schemes, high beam quality required
- Focusing mirror close to plasma is optimum
- Some beam steerability desired
- Polarization control can be provided by external waveguide or by mirror grooves
- Two options under consideration

Two possible launcher schemes

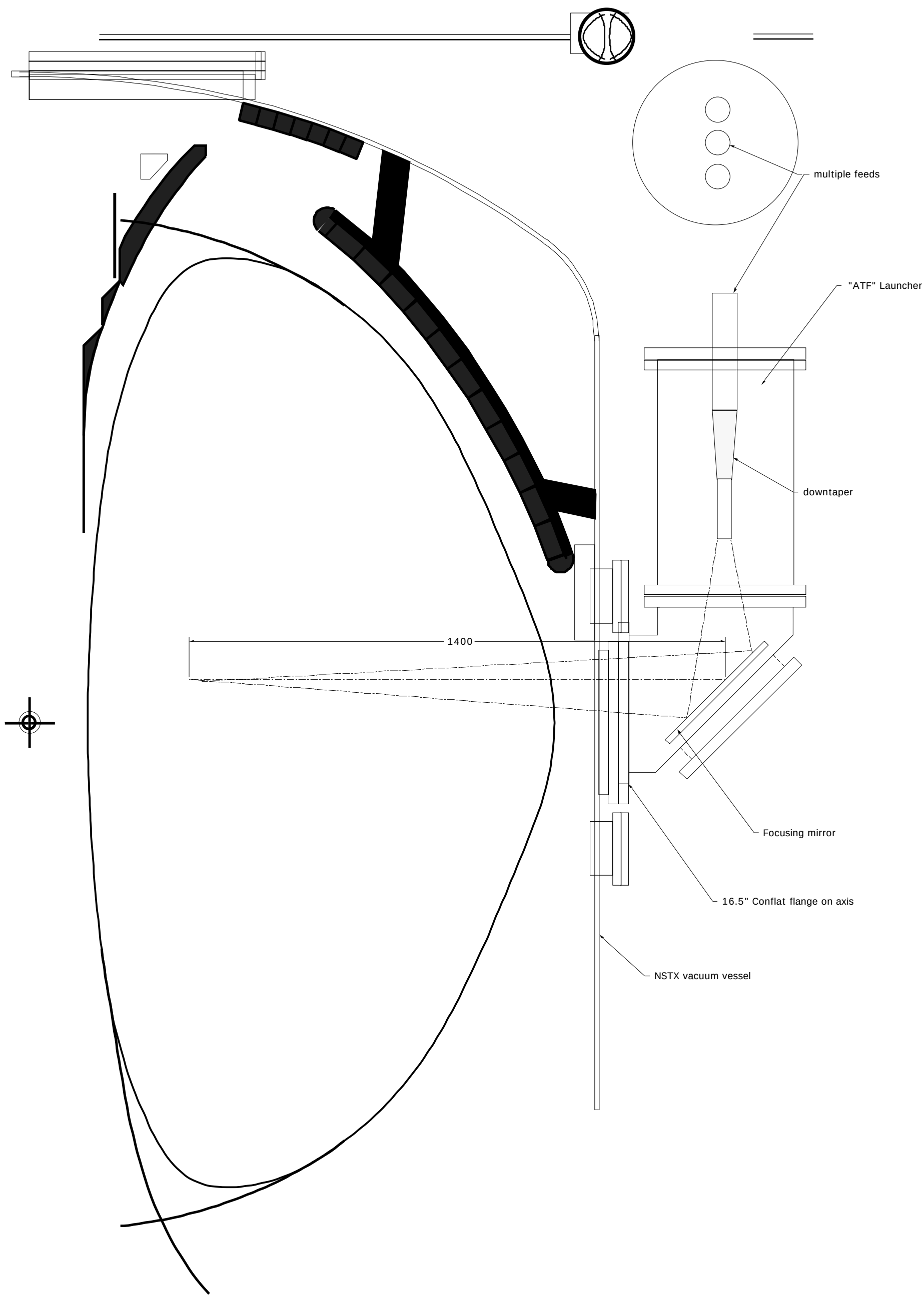


External mirror



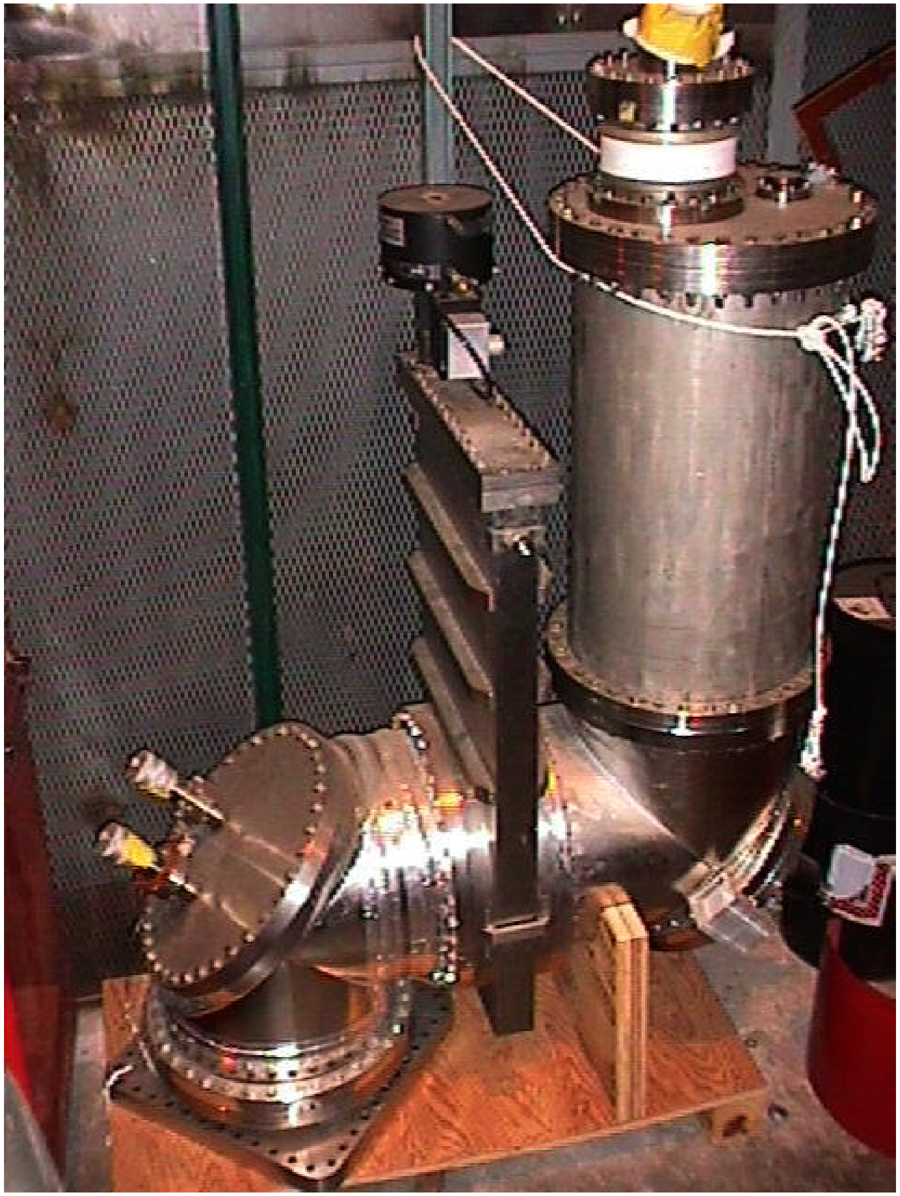
Curved waveguide through top port

Internal mirror



Multiple gyrotron Outside-mirror Launcher configuration

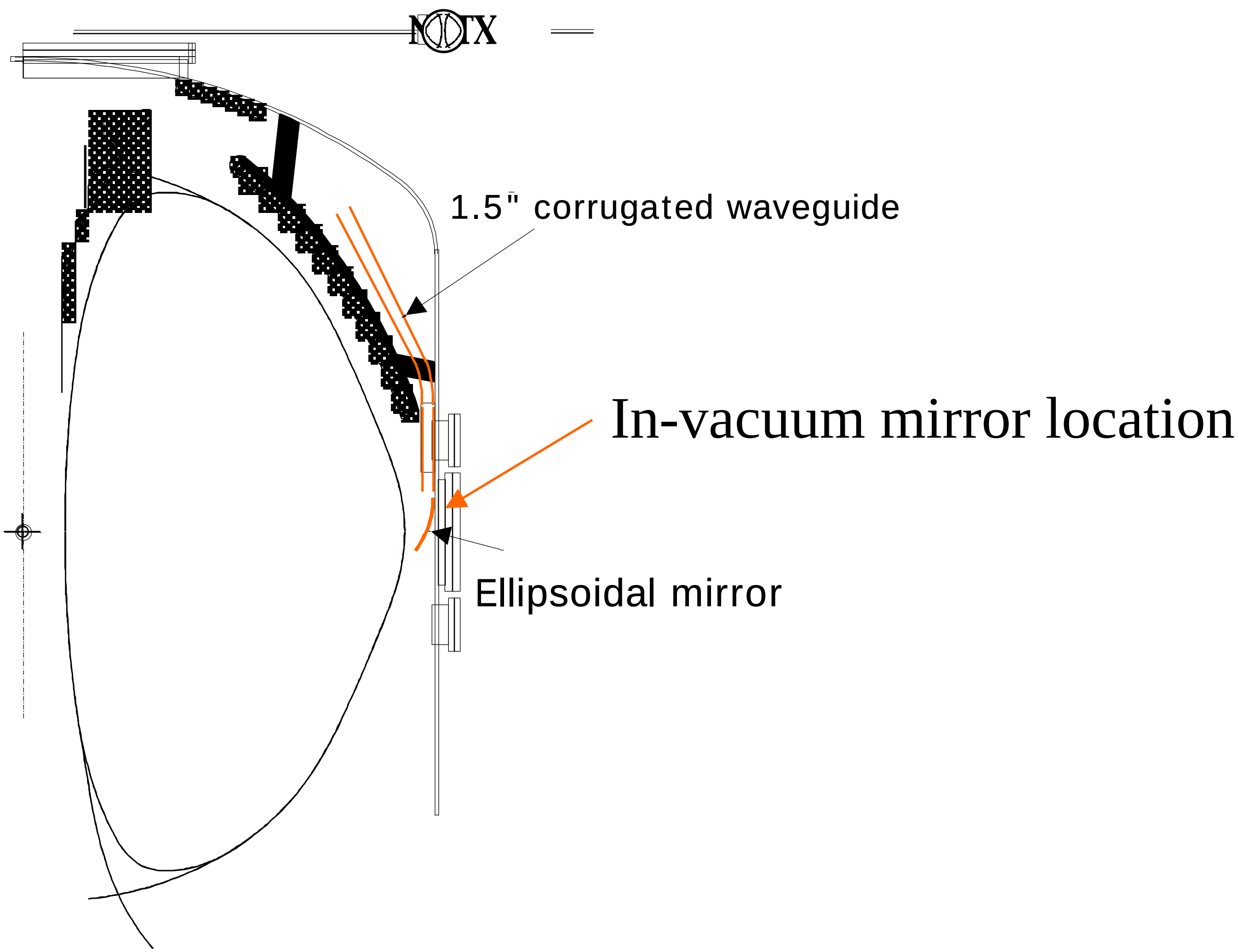
- Utilize existing launcher
- Need large midplane port
- Narrow focused beam
- Adjustable pointing angle
- Less beam steering possible



ECH Launcher
from ATF

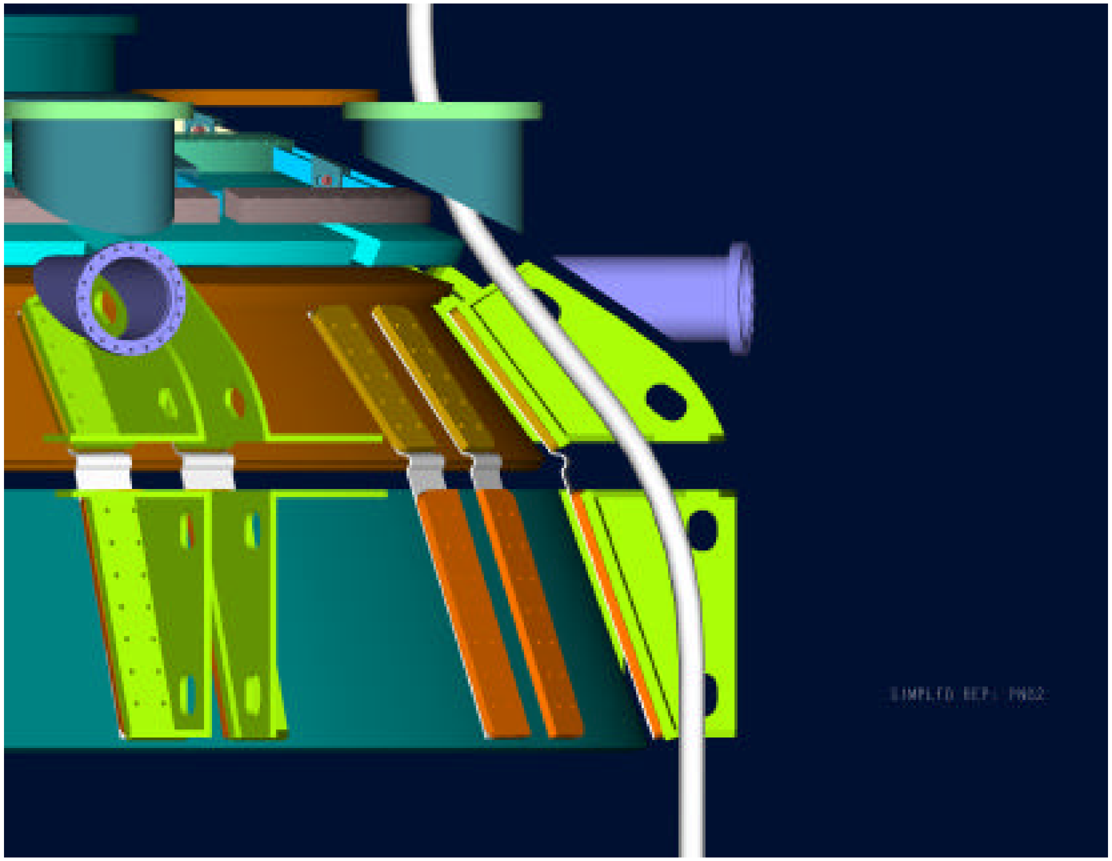
Top port launch option

- Use several available top ports
- Route curved corrugated waveguide to midplane behind stabilization plates
- Use inside focusing mirror for launch
- Advantages
  - Ports available
  - Better launch optics
- More difficult for installation & beam steering



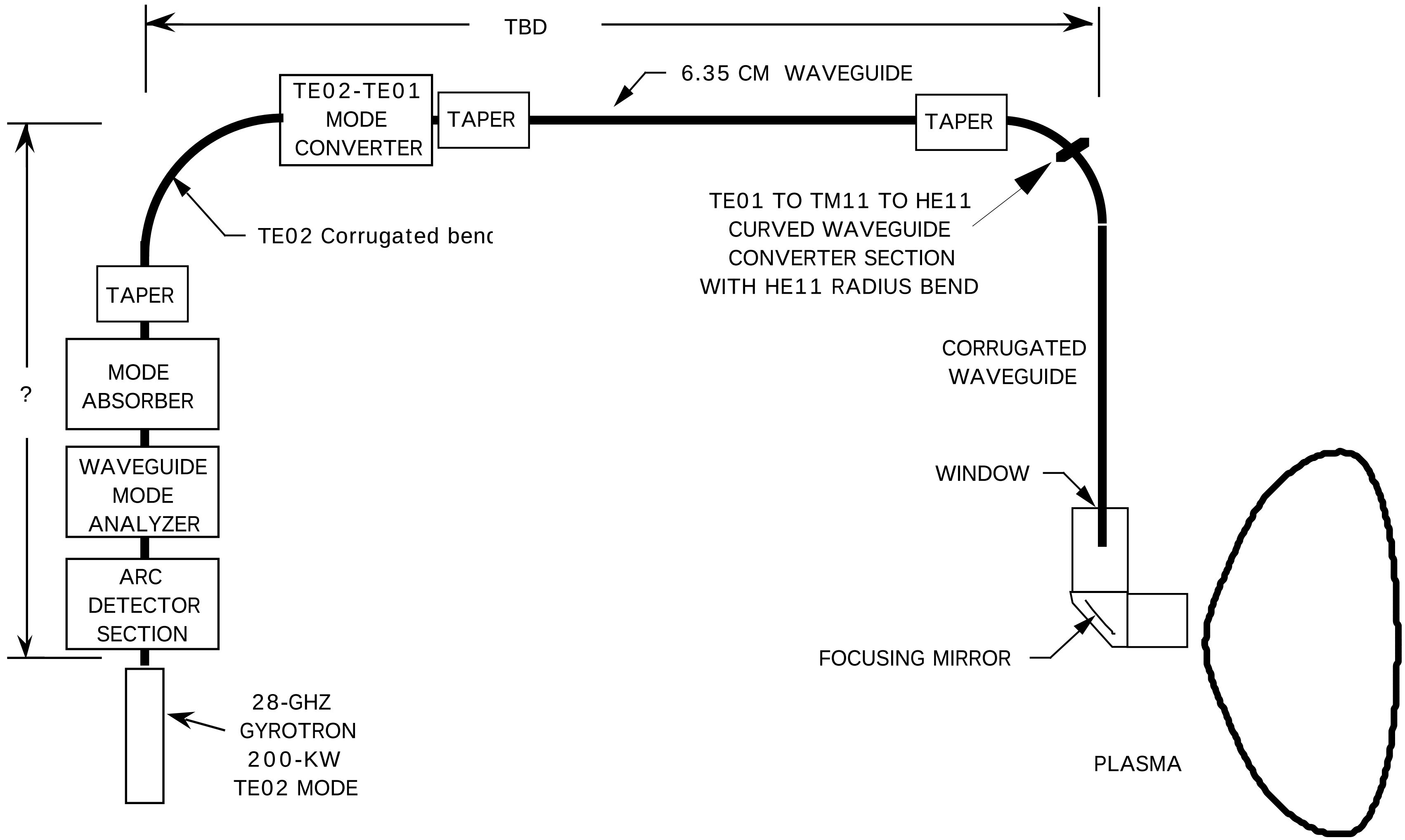
NSTX
1.5" corrugated waveguide
In-vacuum mirror location
Ellipsoidal mirror

Inside waveguide route looks feasible



Transmission lines & launchers

- Maximum experimental capability requires high mode purity
- Utilize TE02, TE01 and HE11 (corrugated) transmission)
- Utilize HE11 gaussian-like launch into focusing mirror
- Place maximum size mirror as close to plasma for greatest capability
- Elliptical polarizer in waveguide for optimizing oblique launch
- High field launch option available



BLOCK DIAGRAM PROPOSED NSTX 28 GHZ ECH SYSTEM

28 GHz system installation on NSTX

- ORNL hardware ready for refurbishment and installation
- Adequate space and support hardware exists near NSTX site
- 18 month schedule for system completion possible

Conclusions

- ECH pre-ionization system installed and performing well
- Experiments currently underway will test X-EBW coupling
- ECH quite useful on NSTX- especially with EBW capability
- High power hardware is available at ORNL at low cost
- ECH pressure driven current demonstrated elsewhere; NSTX is ideal site for high power optimization

NSTX ECH resonance locations for 0.33 T operation

Frequency/ harmonic #	Resonant field (T)	Major radius (m)	Minor radius (normalized)	Critical density $x10^{12}\ cm^{-3}$
28 GHz/fund	1	0.26	-0.9	9.2
2nd	0.5	0.52	-0.5	
3rd	0.33	0.78	-0.1	
18 GHz/fund.	0.64	0.40	-0.7	3.8
2nd	0.32	0.80	-0.07	
15.3 GHz/fund	0.546	0.47	-0.58	2.7
2nd	0.27	0.94	+0.15	