Proposed ECH/EBW NI startup experiments and hardware for NSTX

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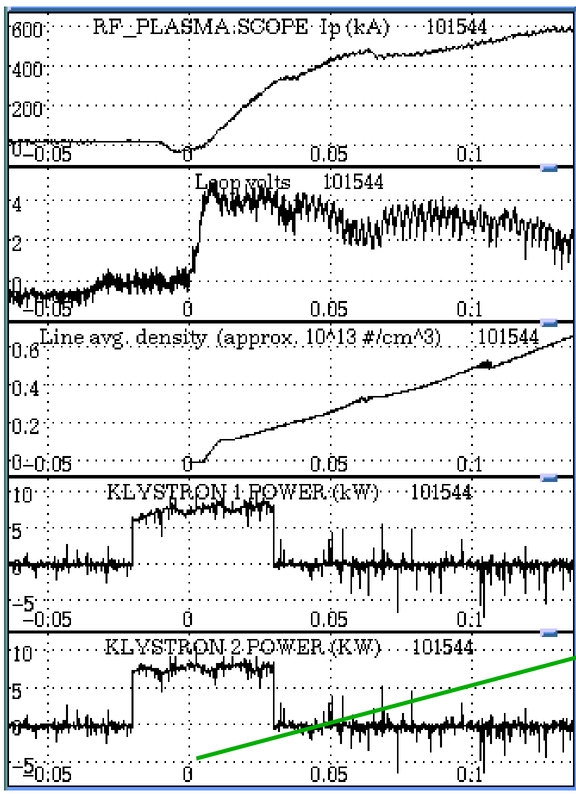
Topics

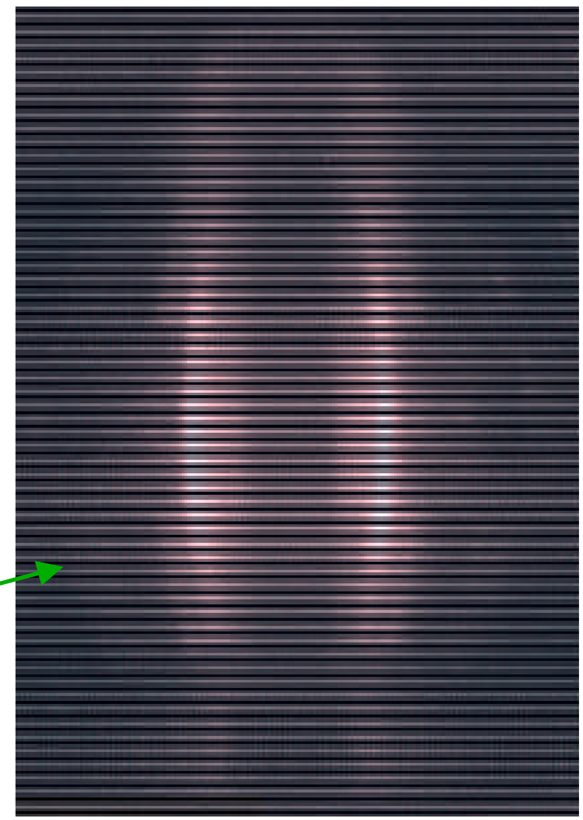
- ECH Preionization: routine operation
- Preliminary EBW coupling experiment
- Hardware options for 28 GHz high power ECH/EBW system
- ECH assisted startup

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

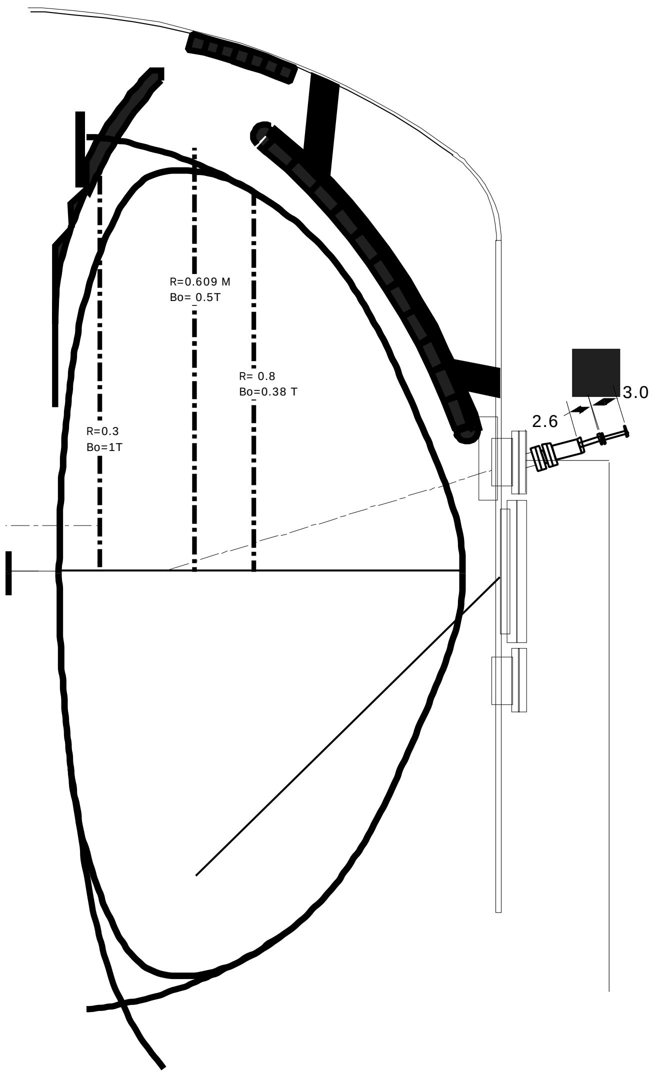
X-EBW Coupling study

- 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

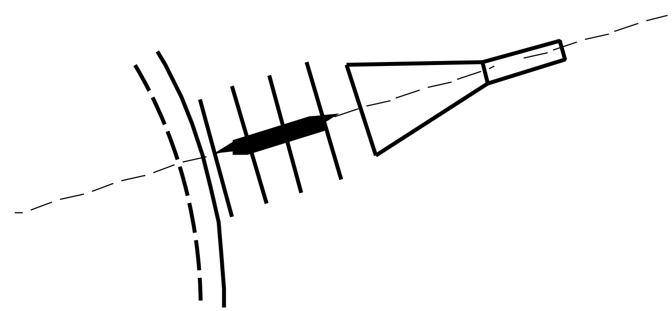
- One ECH-PI launcher set to X-mode polarization; pulse lengthened
- Launcher designed to launch parallel to edge density gradient
- Monitor reflected power as high density cutoff layer approaches the launcher
- Reflected power amplitude would increase then decrease as the optimum EBW wave tunneling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

ECH PI Launcher



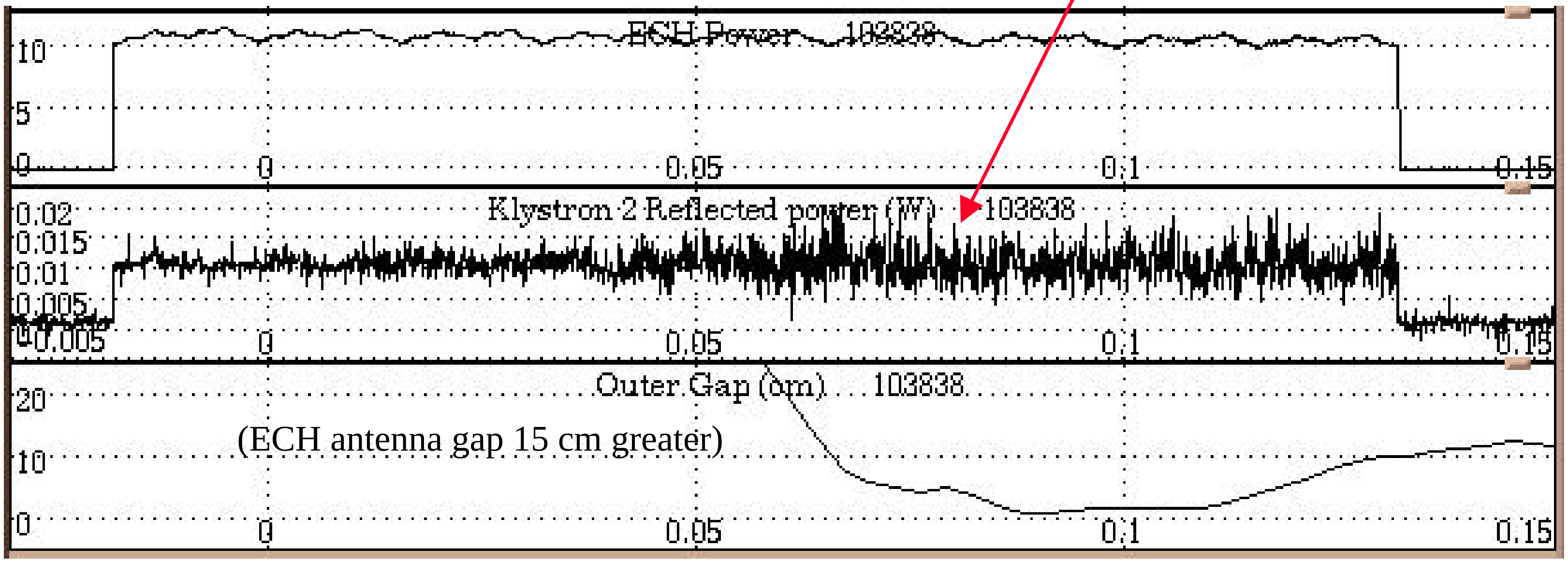
Experimental setup results

- 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



X-EBW coupling study typical data

Reflected signal grows as density
Increases and plasma moves closer



Improvements suggested for subsequent experiments

- Improve plasma coupling to the plasma by improving and extending the launching horn
- Reduce system reflected power - primarily from the vacuum window
- Need edge density profile data to establish optimum plasma conditions
- Use modulation in conjunction with EB emission diagnostic
- Build waveguide twist to match optimum edge polarization angle for X-mode

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

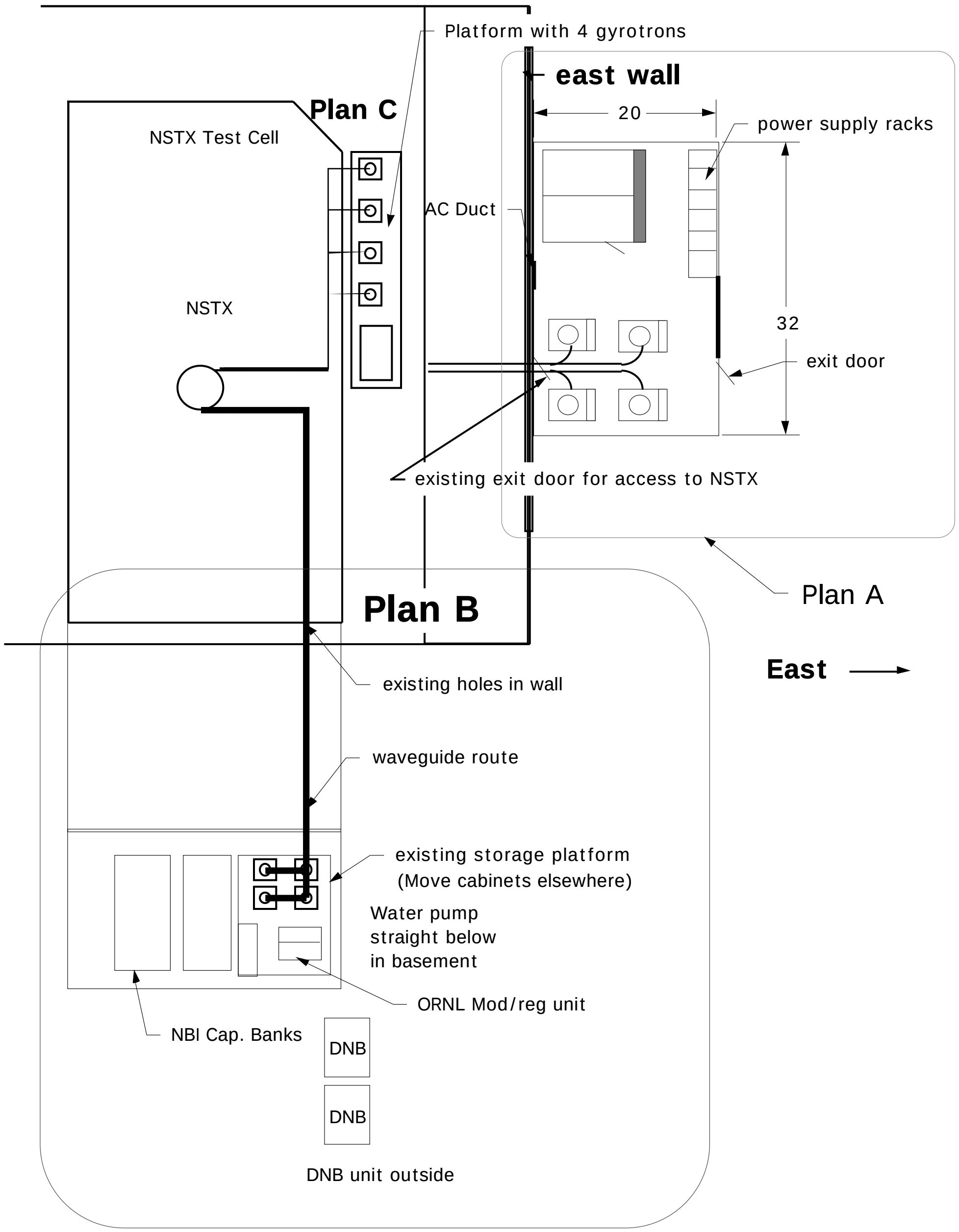
- Edge current drive
- Heating & CD in synergy with other systems- HI, HHFW
- Utilize ECH whenever useful for bulk heating
- Wall conditioning with & without plasma
- Transport diagnostic with modulated power
- Edge heating experiment at 1T.
- Investigate 3rd harmonic heating with higher frequency gyrotron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

ECH Hardware available

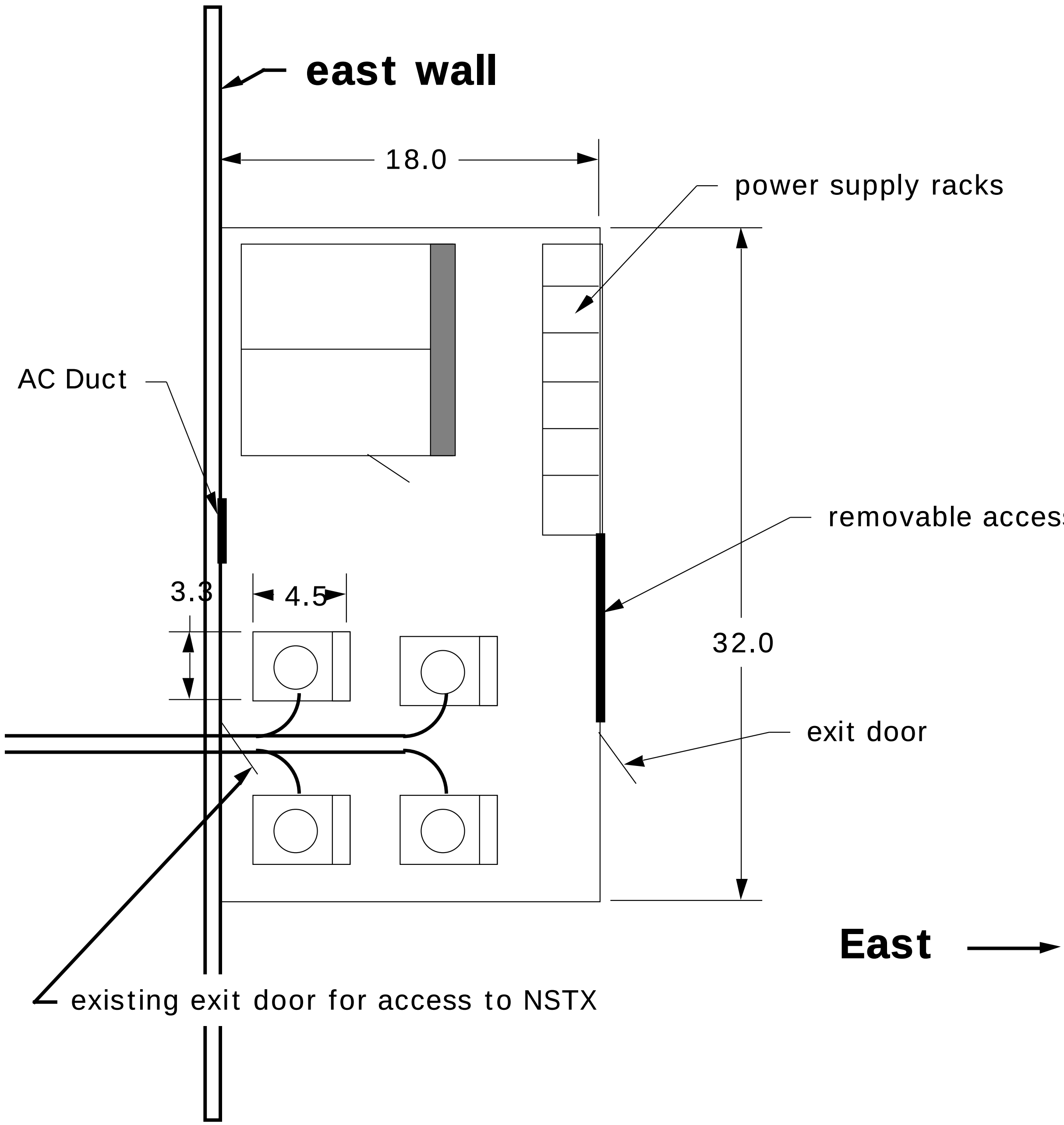
- Utilize existing hardware to make experiments affordable
- Two to four 28 GHz, 200 kW, gyrotrons available at ORNL
- CW tubes can be refurbished and generate 350 kW each (up to 1.4 MW from 4 tubes)
- Four sockets and HV modulator/regulator are available at ORNL
- Utilize installed PPPL “NBI” power 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

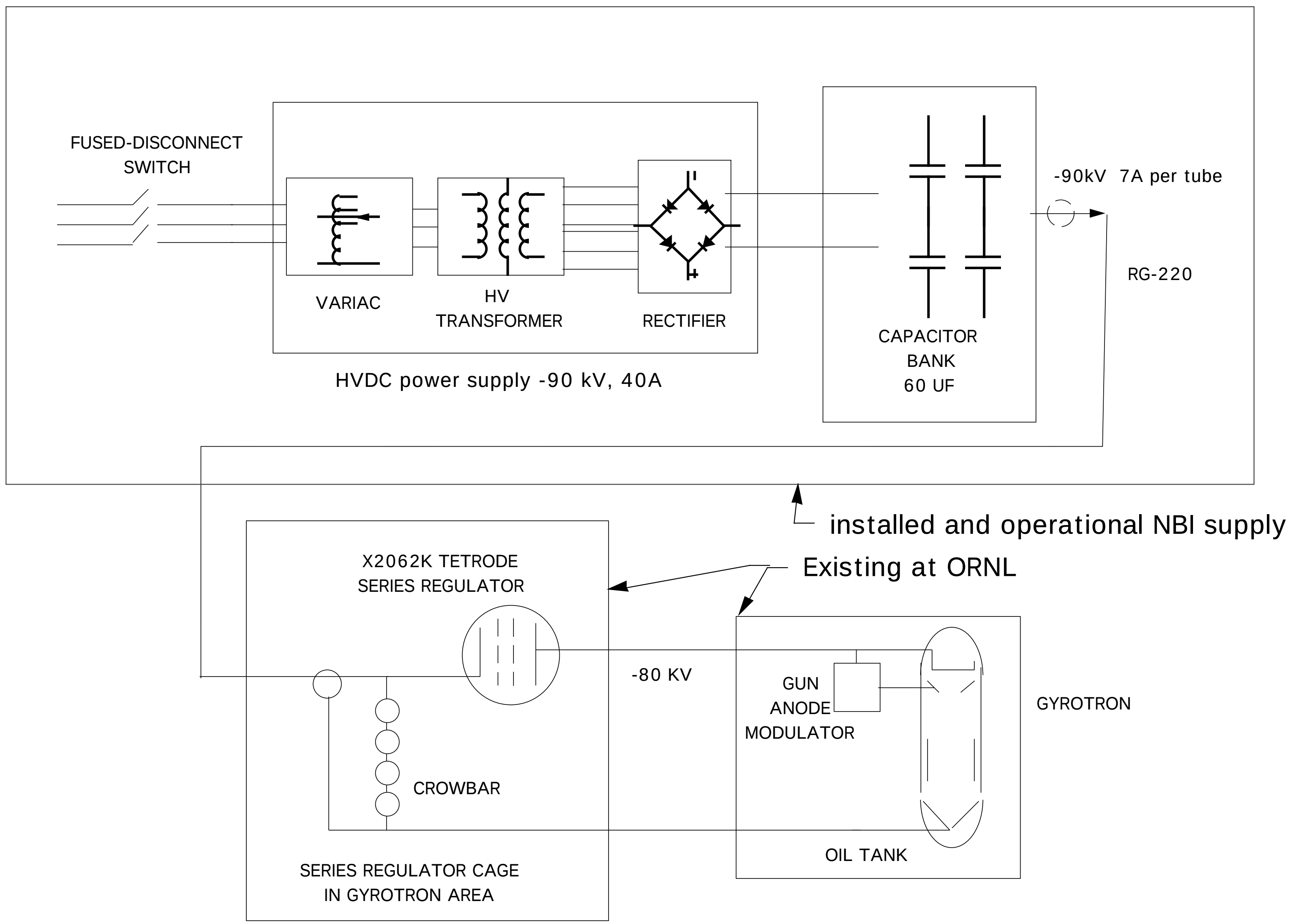


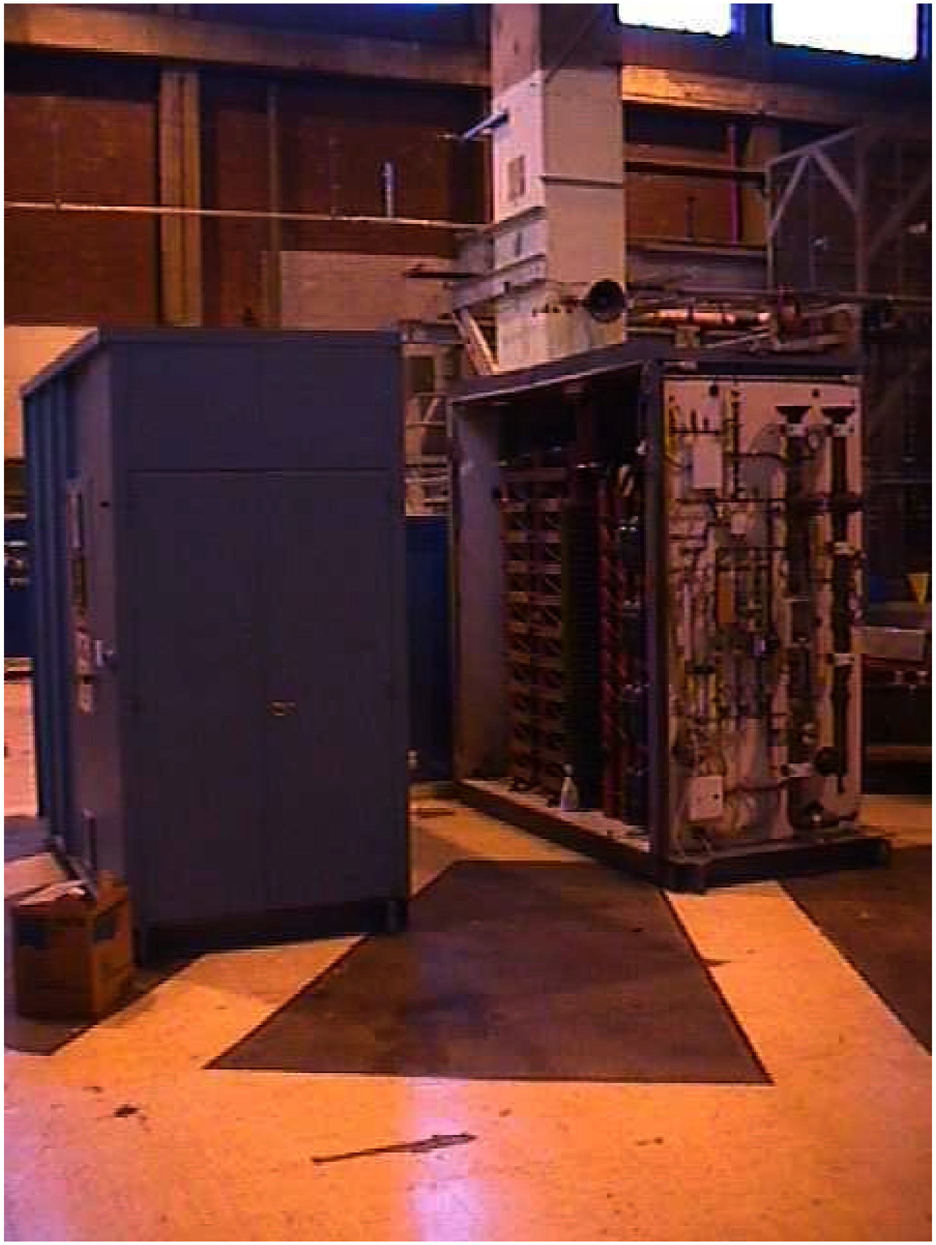
Two options for up to 4 gyrotrons installed on NSTX



Proposed option for
new addition building
for 28 GHz ECH sockets
and Modulator/Regulator

Proposed ECH power supply configuration





ECH HVDC
Power supply

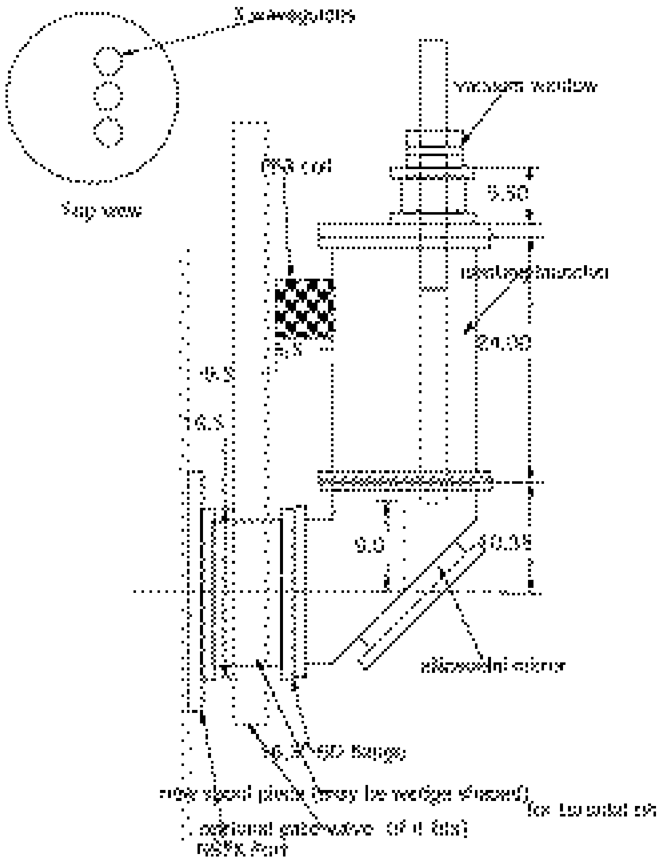
Modulator/
Regulator

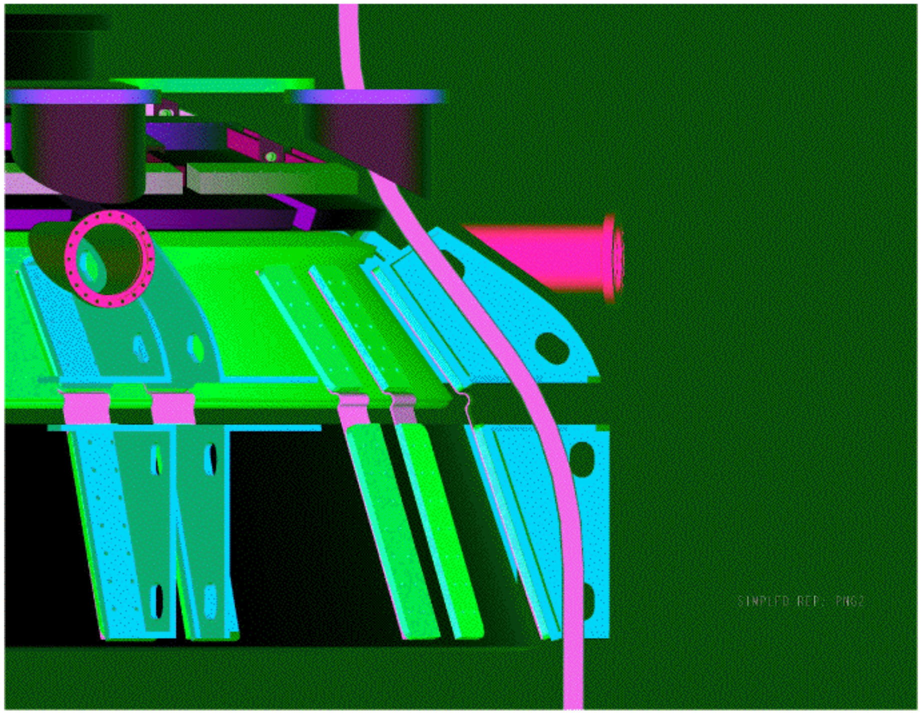
at ORNL

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

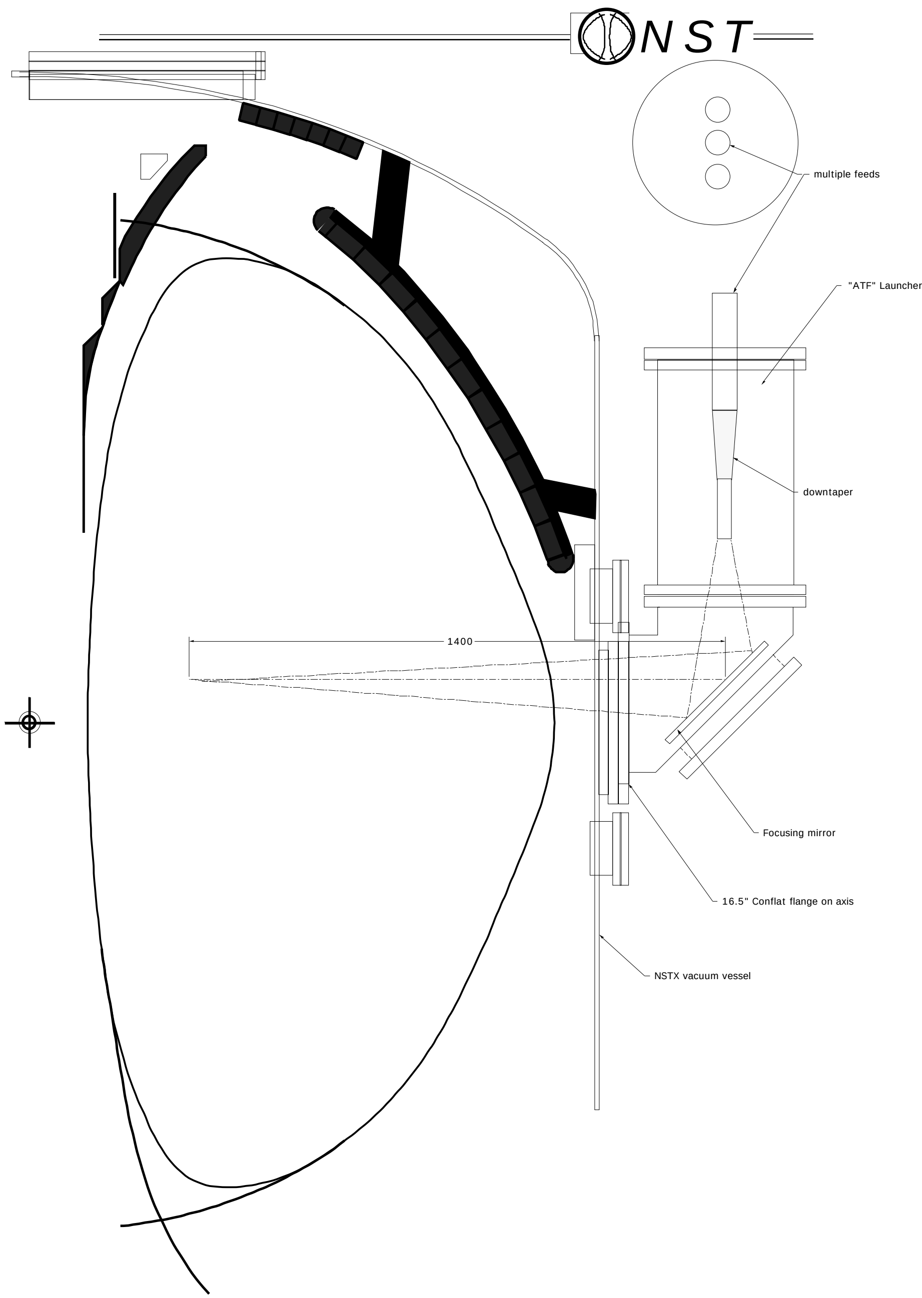




Curved waveguide through top port

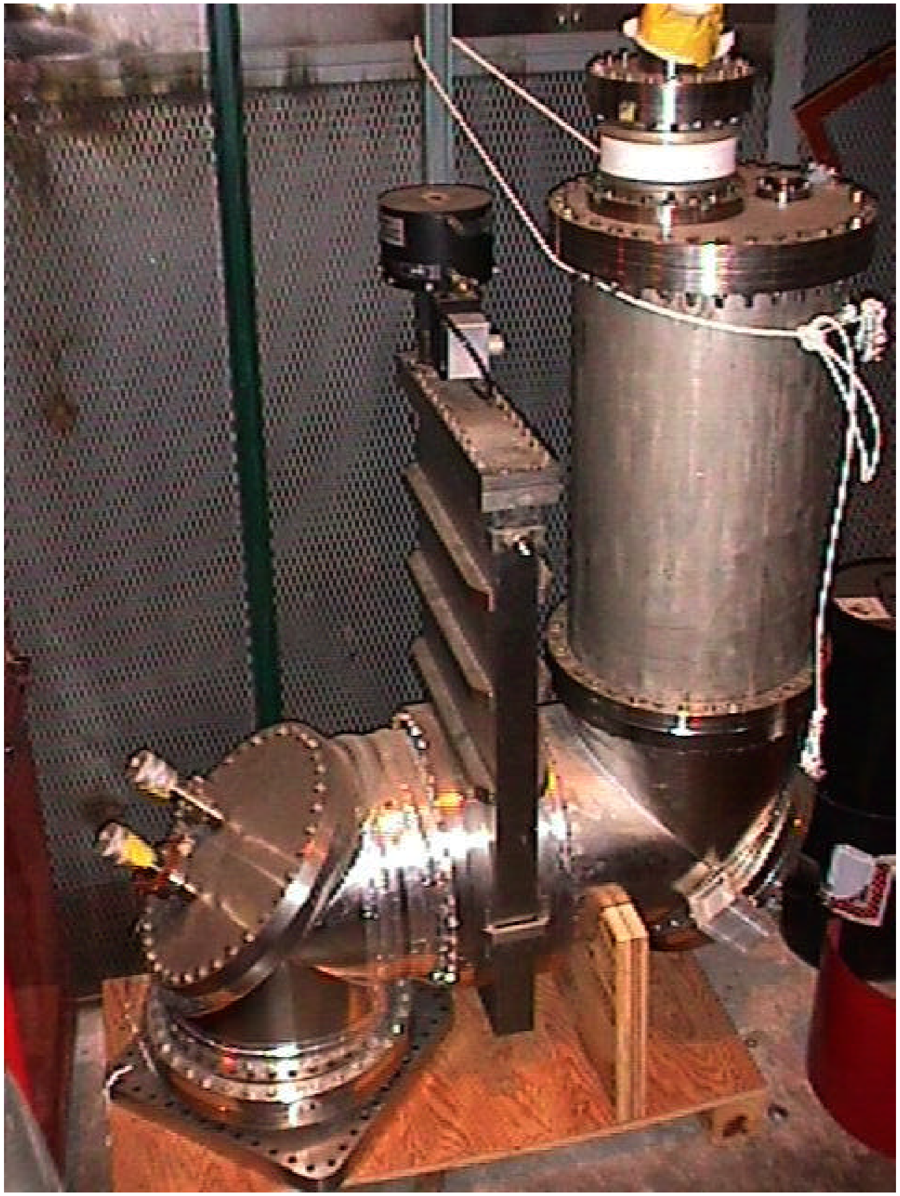
External mirror

Internal mirror



Multiple gyrotron
Outside-mirror
Launcher configuration

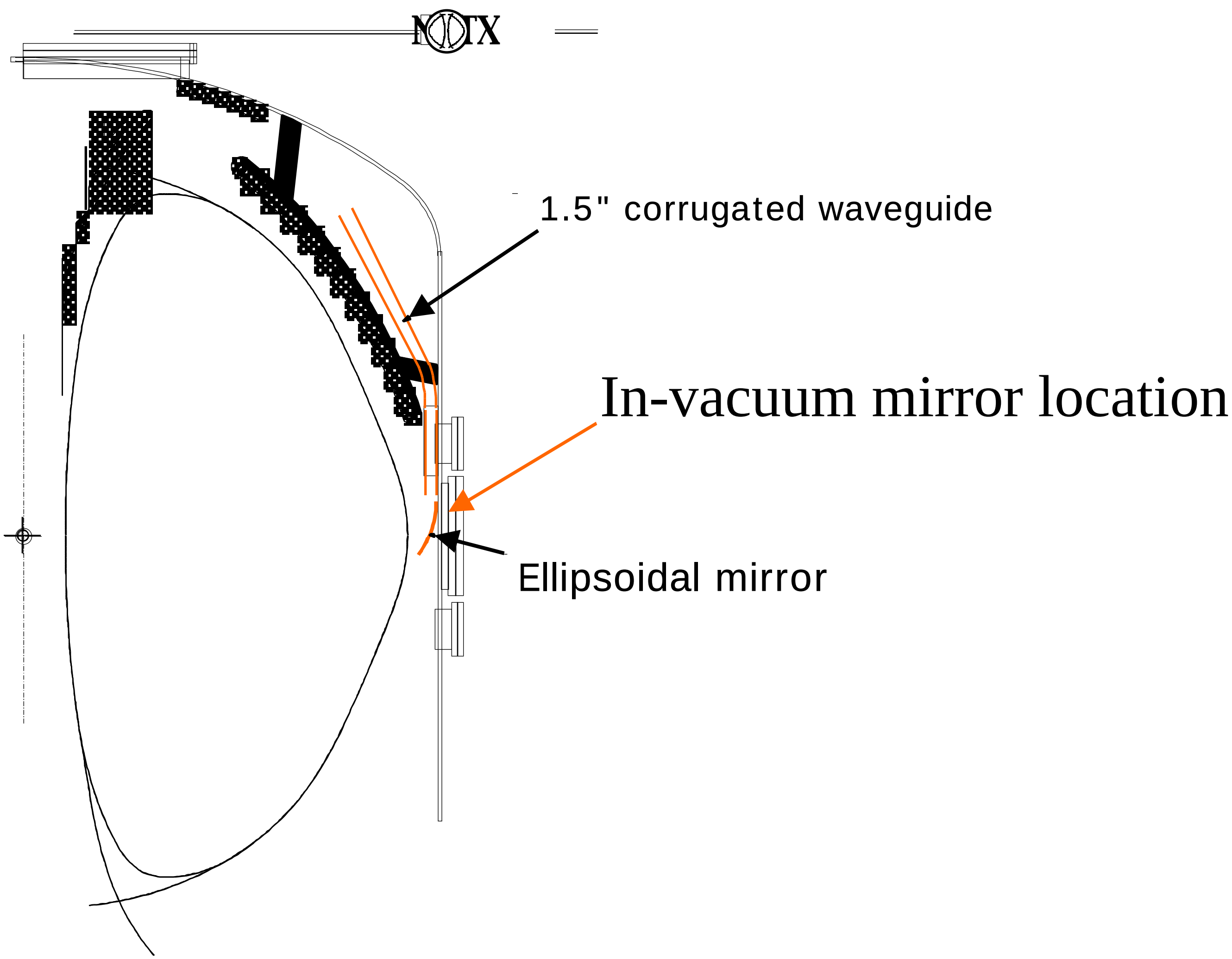
- Utilize existing launcher
- Need large midplane port
- Narrow focused beam
- Adjustable pointing angle
- Less beam steering possible



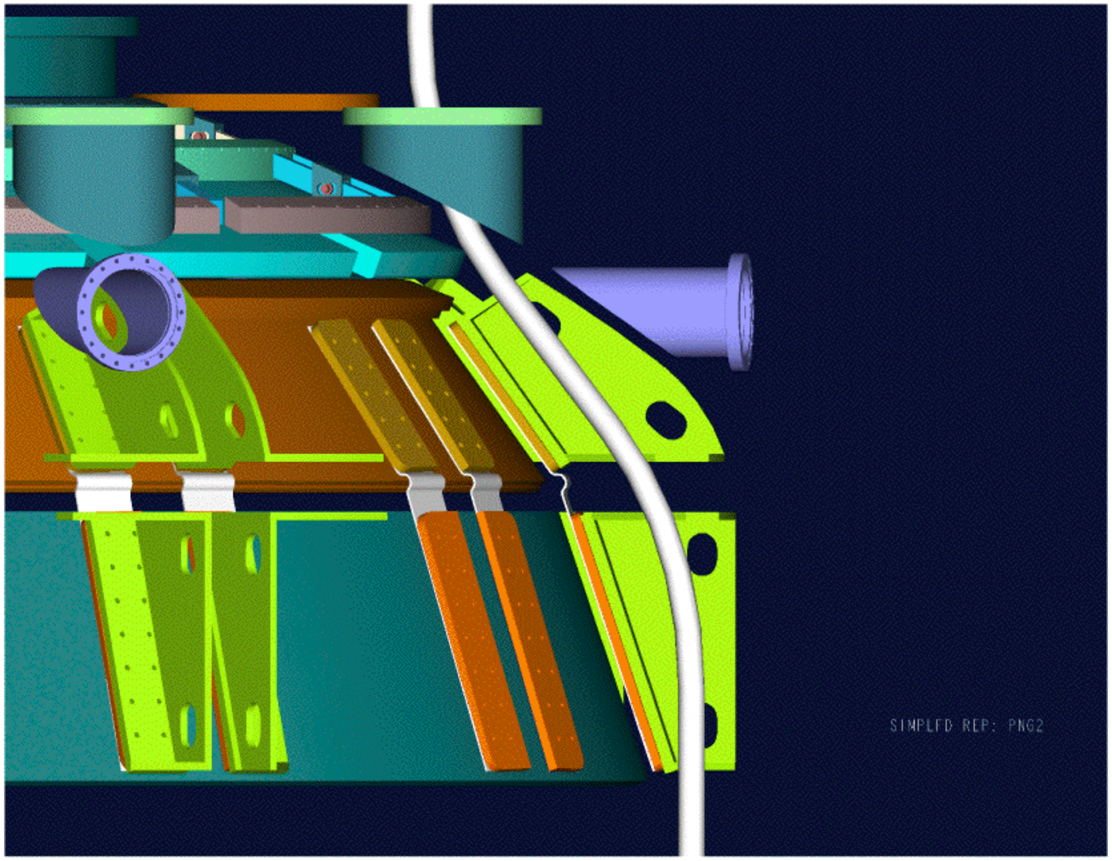
ECH Launcher
from ATF

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

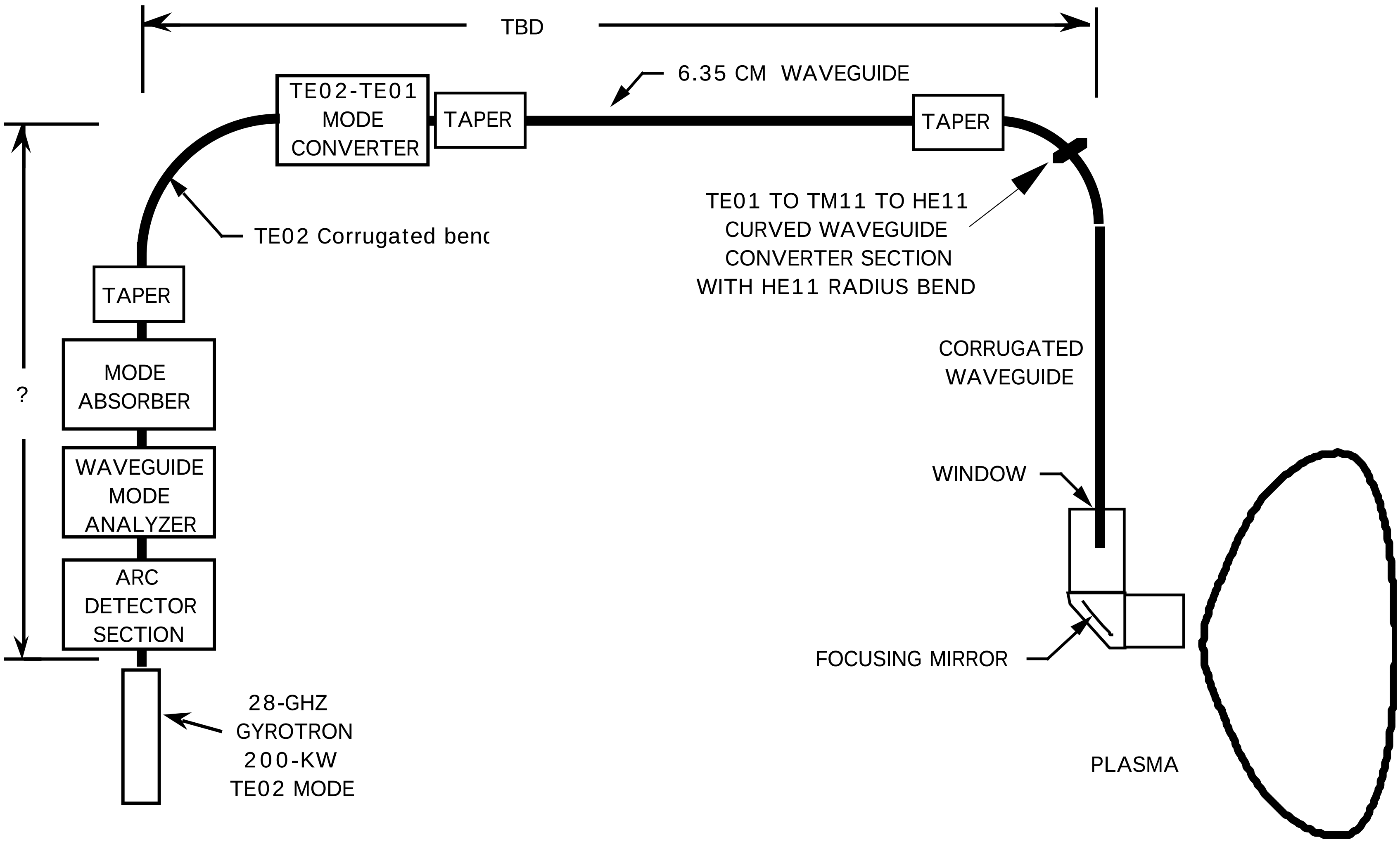

NSTX
1.5" corrugated waveguide
In-vacuum mirror location
Ellipsoidal mirror

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	