NSTX EBW
Physics & Technology Considerations

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EBW heating, CD and NTM stabilization roles

- Core Heating
- ECH or EBW Startup
- EBW CD ~ 400 kA with ~ 5MW
- NTM Stabilization at β ~ 40% ~ 5MW ?
- Edge CD

- Requires efficient coupling, high power localization, efficient CD

EBW frequency choice for heating, CD and NTM stabilization involves a complicated set of tradeoffs

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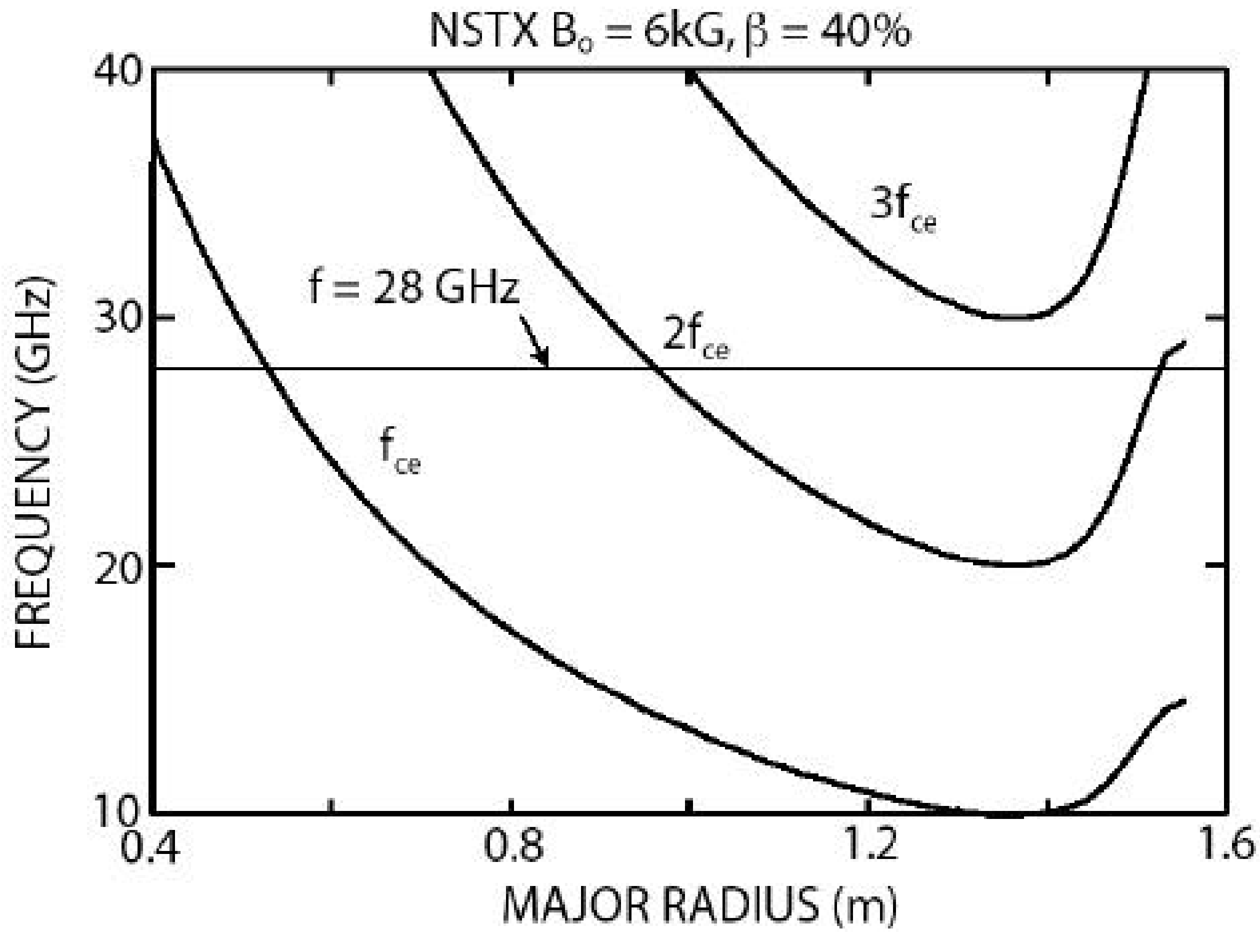
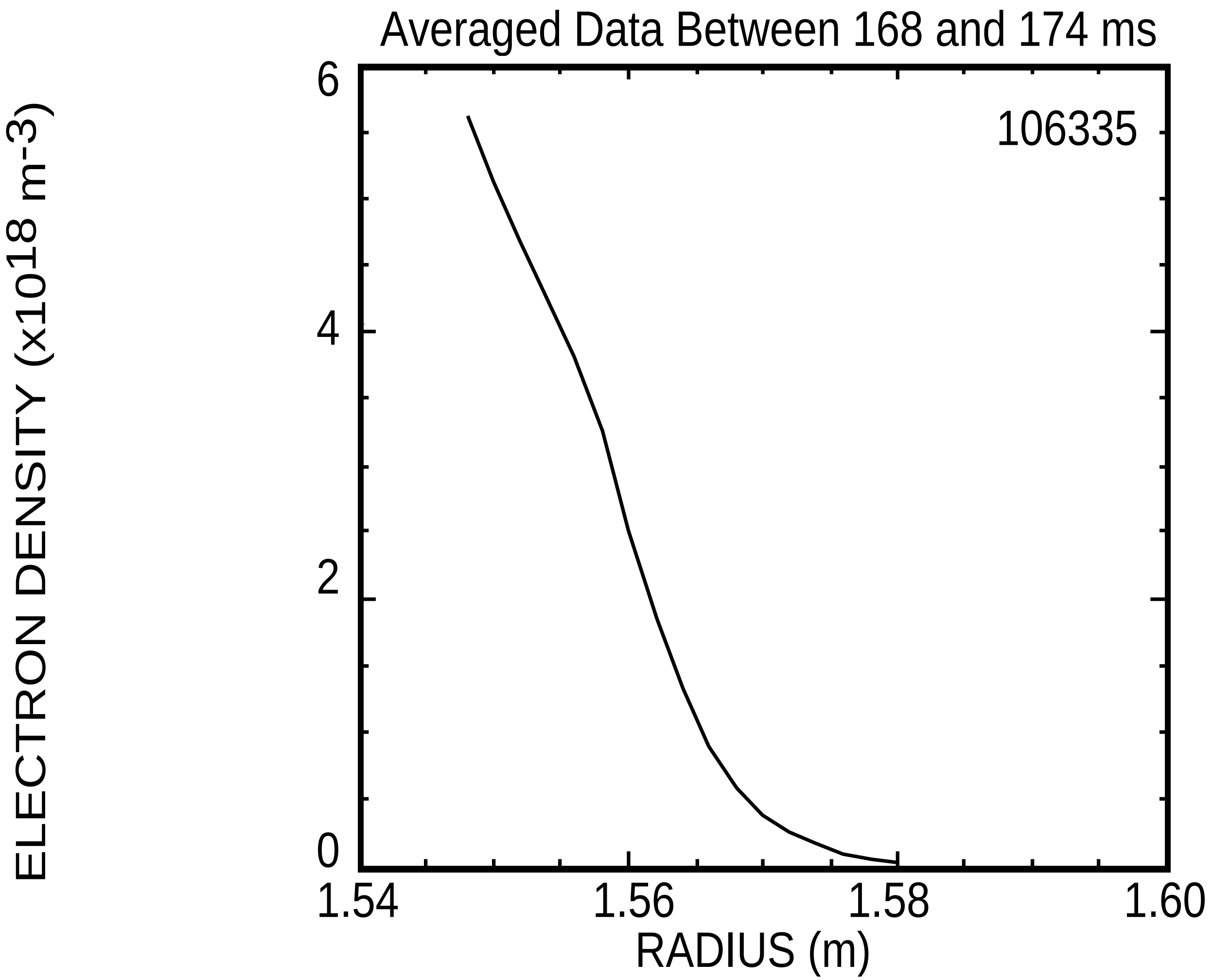
- **Coupling** (X-mode, O-X-B, density scale lengths, limiters, fluctuations, profile evolution)
- **Resonant location** (center, profile, NTM, edge, harmonics)
- **Power localization** (launch aperture, acceptance angle)
- **Critical density** (ECH startup, EBW coupling)
- **CD target density** (> critical density, < 4 x 10^{13} cm^{-3})
- **High β effects** (Shafranov shift, B field scale lengths)
- **Source power** (MW/ unit)
- **Nonlinear effects at edge** (parametric, ponderomotive)

EBW heating, CD and NTM stabilization target plasma

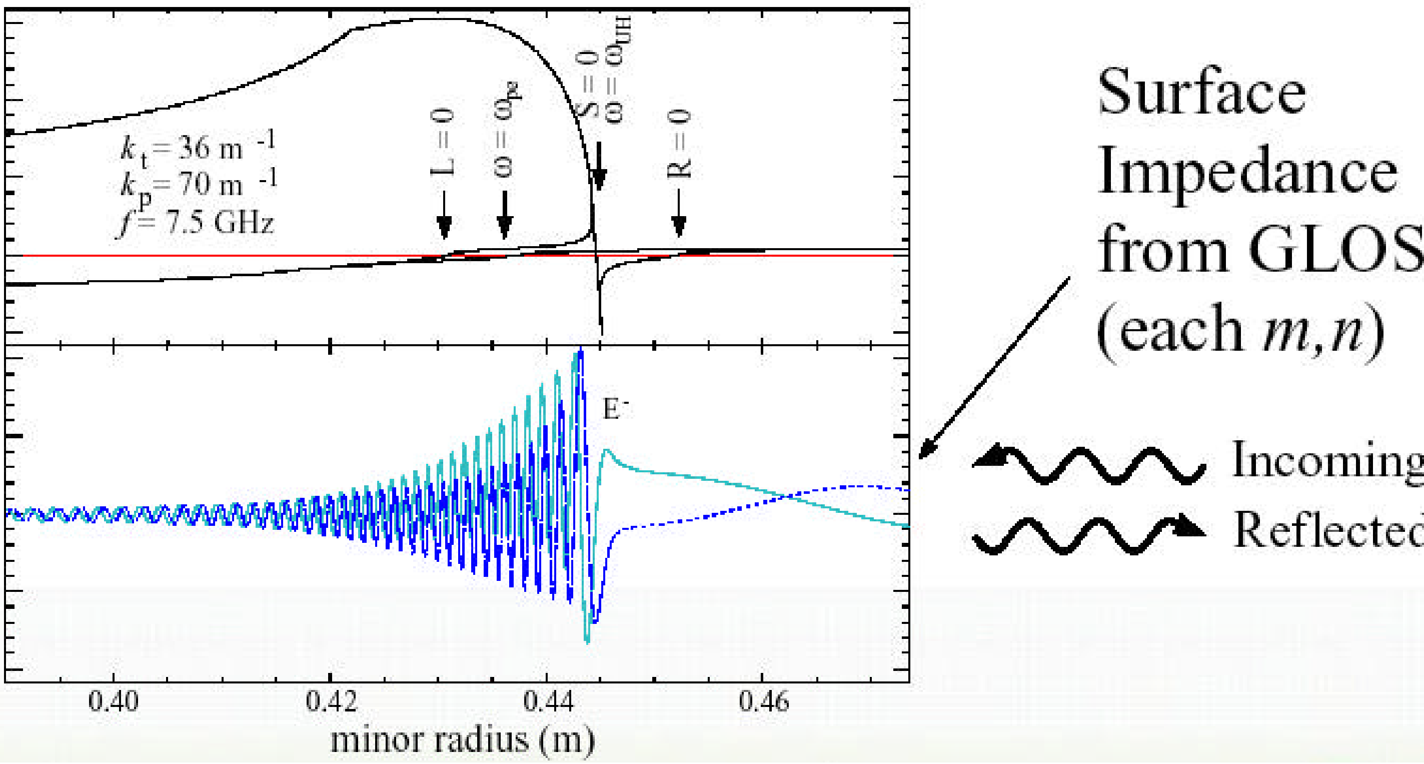




Averaged Data Between 168 and 174 ms
106335
ELECTRON DENSITY (x10^18 m^-3)
RADIUS (m)
6
4
2
0
1.54
1.56
1.58
1.60

GLOSI solves for mode converted wave fields in plasma edge

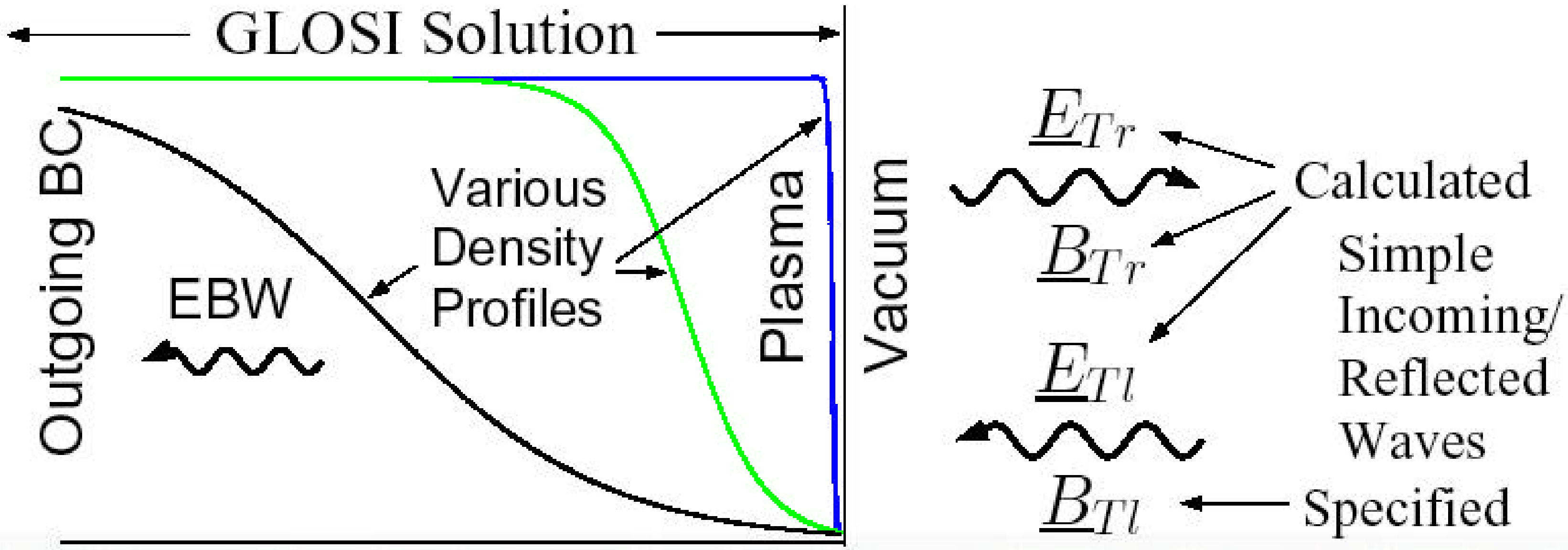
- For each poloidal and toroidal mode, generates a 2x2 surface impedance for tangential components of the RF fields at the plasma/vacuum interface



Surface Impedance from GLOSI (each *m*,*n*)

Systematic variation of density gradient near upper hybrid layer gives good idea about optimum angle for coupling

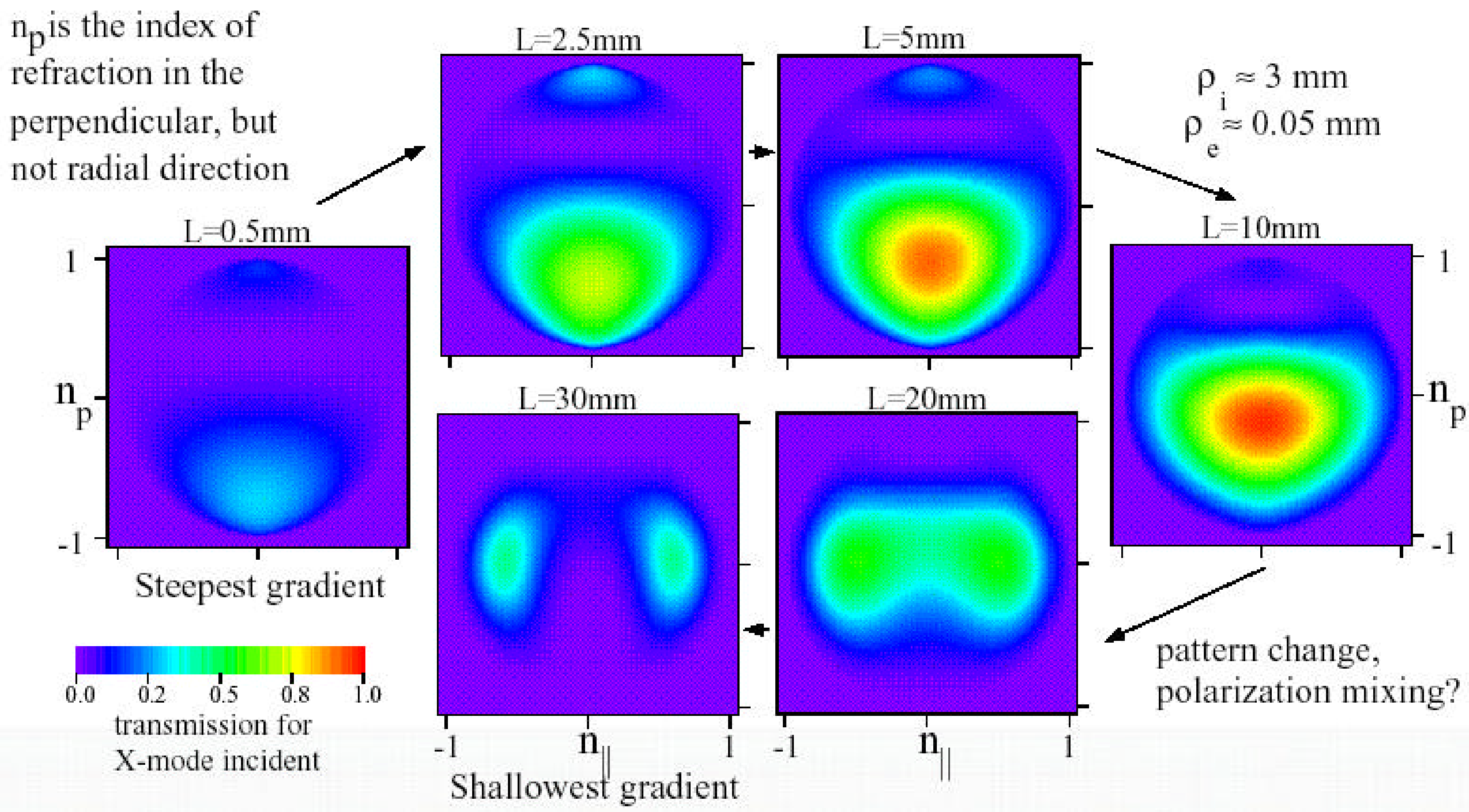
- Emission at same angles as absorption
- Te = Ti = 10 eV, B = 0.13 T, 7 GHz



$$n_e = 1 \times 10^{18}\mathrm{m}^{-3}\left[1 - tanh\left(\frac{x - x_r + 2L}{L}\right)\right]$$

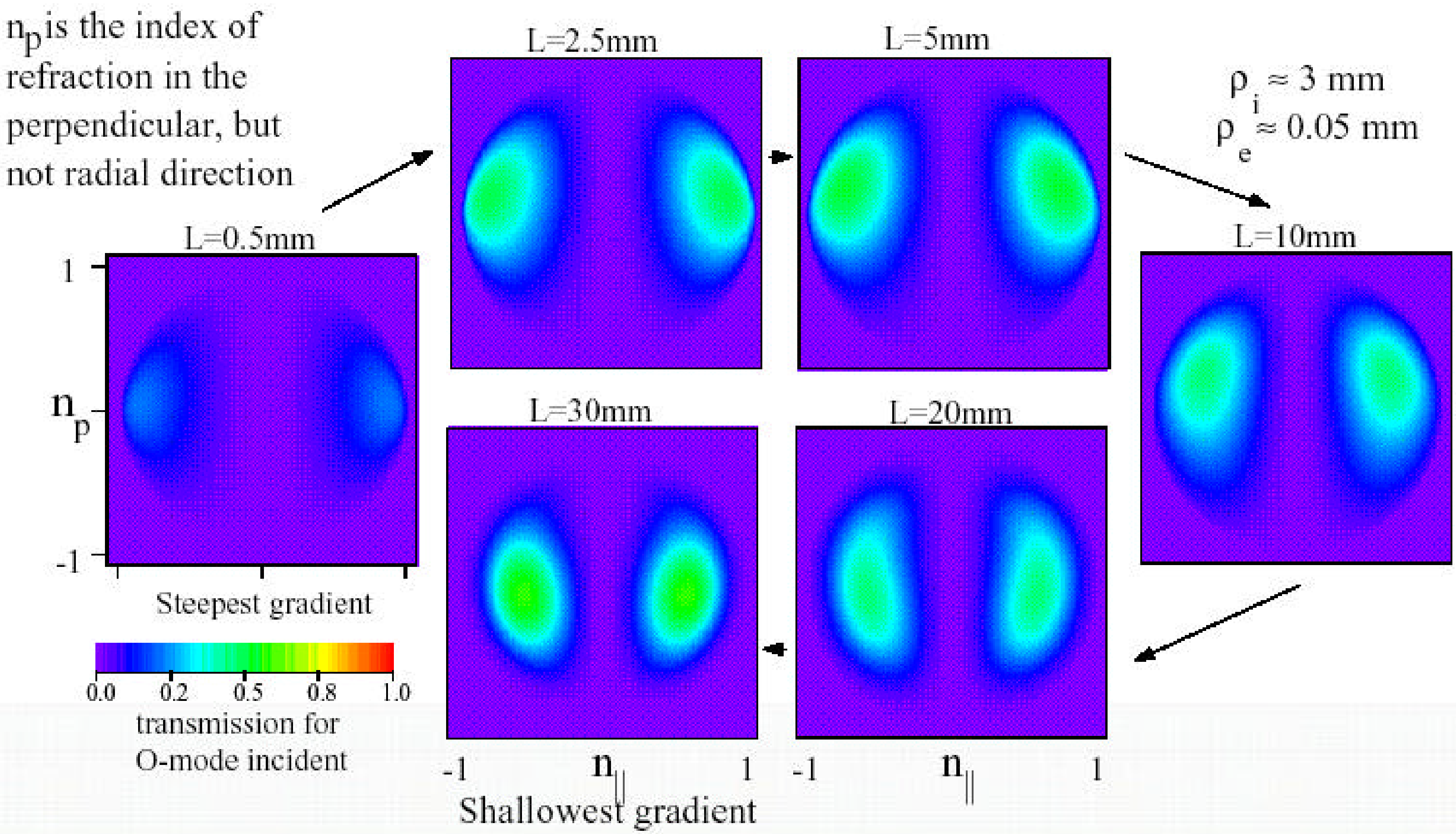
X-mode

Transmission angle is a strong function of density gradient for $B_{rf}||B_0$ incidence



O-X-B

Optimum transmission angle depends weakly on density gradient for $B_{rf} \perp B_0$



EBW frequency tradeoffs

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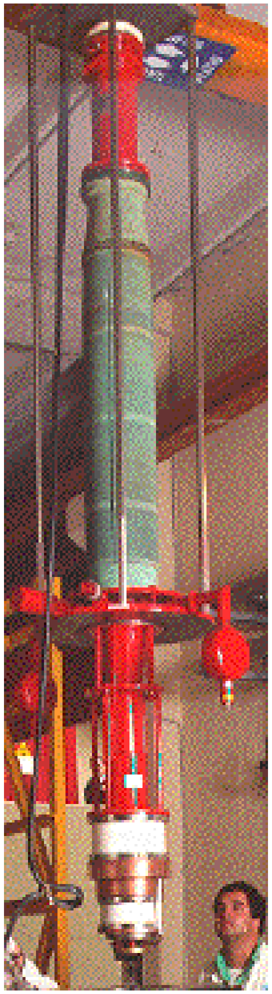
Frequency/ harmonic #	Resonant field (T)	Critical density $x10^{12}$ cm^{-3}	Scale length (mm) Coupling X O-X-B	Sources (MW)	Deposition spot size	Potential for driving edge parametric instabilities	Heating, CD, EdgCD or NTM
28 GHz/fund	1	9.2	~ 1 ~10	0.3	++	1	H, CD?
2nd	0.5						H, EdgCD, NTM
3rd	0.33						EdgCD, NTM
18 GHz/fund.	0.64	3.8	~1.5 ~15	0.015	+	2 - 8 X	H, CD
2nd	0.32						EdgCD, NTM
15.3 GHz/fund	0.546	2.7	~ 2 ~20	0.2 Modified 28 GHz	+	4 - 16 X	H, CD, NTM
2nd	0.27						H, EdgCD, NTM
12 GHz/fund	0.43	1.3	~2.5 ~25	??	+	6 - 24 X	CD, NTM
2nd	0.21						?
8 GHz	0.29	0.95	~ 3 ~30	0.5	-	8 - 32 X	EdgCD, NTM
2nd	0.14						?



Thales 8 GHz
1 MW Gyrotron

Cavity Oscillation Mode	TE_{511}
Nominal Output Frequency	8 GHz
Frequency Stability	+/- 1 MHz
Output Power (TE_{01})	1.1 MW
Peak Power @ VSWR = 4:1	700 kW
Frequency Pulling @VSWR=4:1	+/-2 MHz
Beam Voltage (typ)	84 kV
Beam Current (typ)	27 A
Efficiency	<= 46 %
Gun-anode Voltage (typ)	51 kV

The RF output is through a single disk, alumina (Al_2O_3) window, edge cooled by water flow.

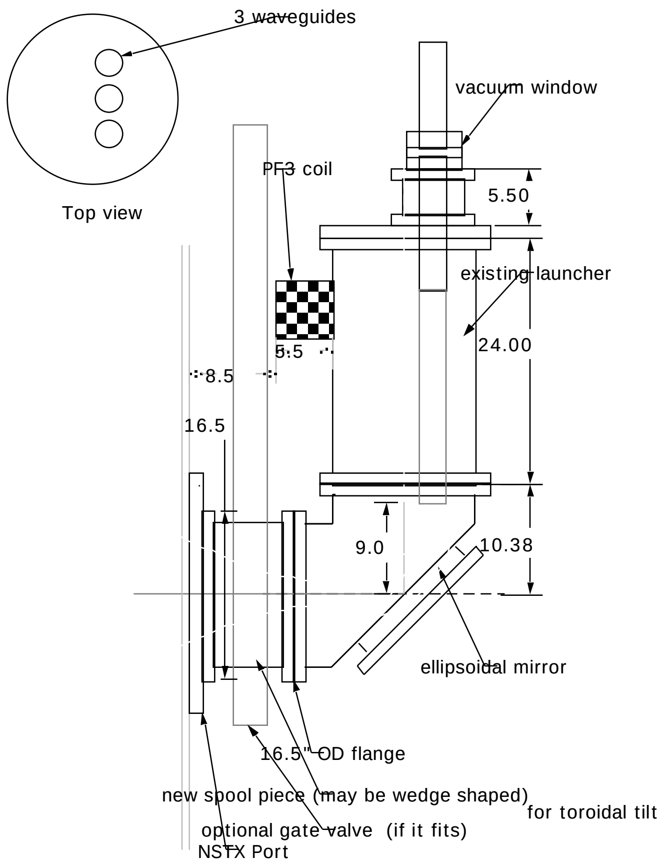
ECH Hardware available

- Utilize existing hardware to make experiments affordable
- Four 28 GHz, 200 kW, gyrotrons available at ORNL
- May be possible to retune and operate at 15.3 GHz
- 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

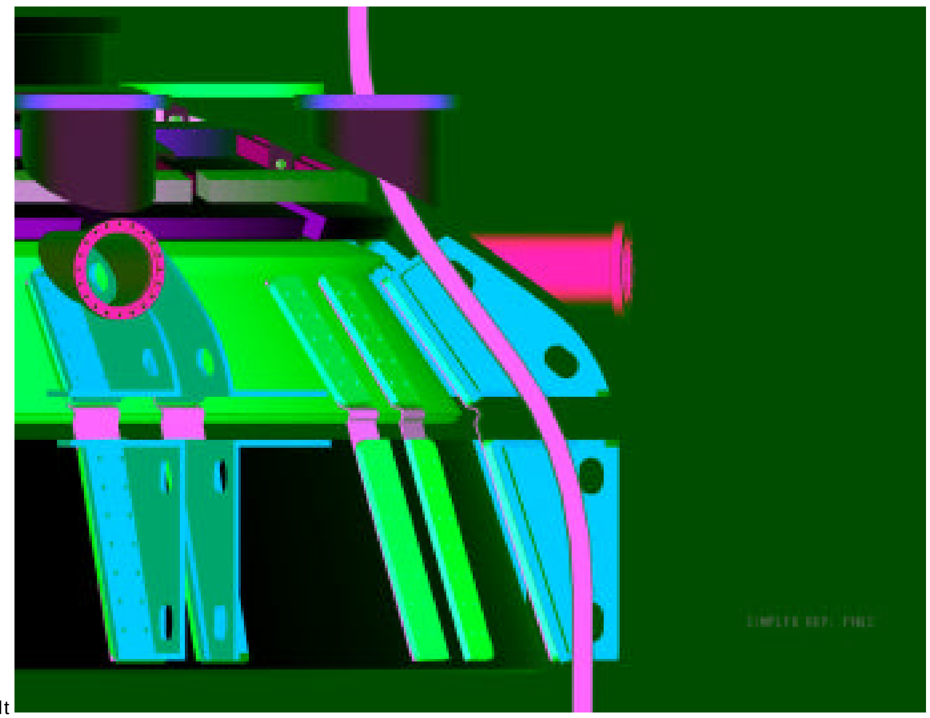
Launcher configuration

- **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



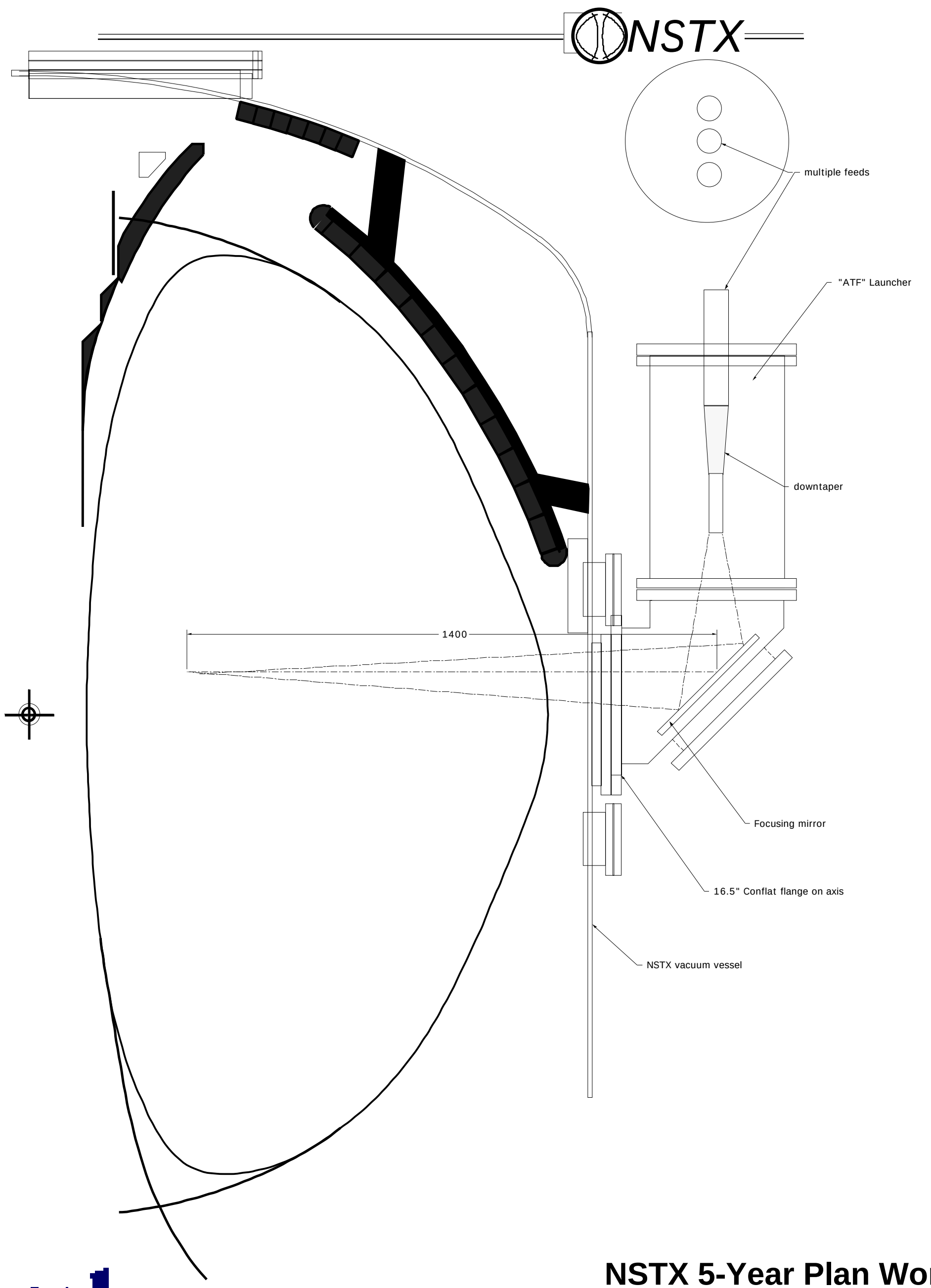
External mirror



Curved waveguide through top port

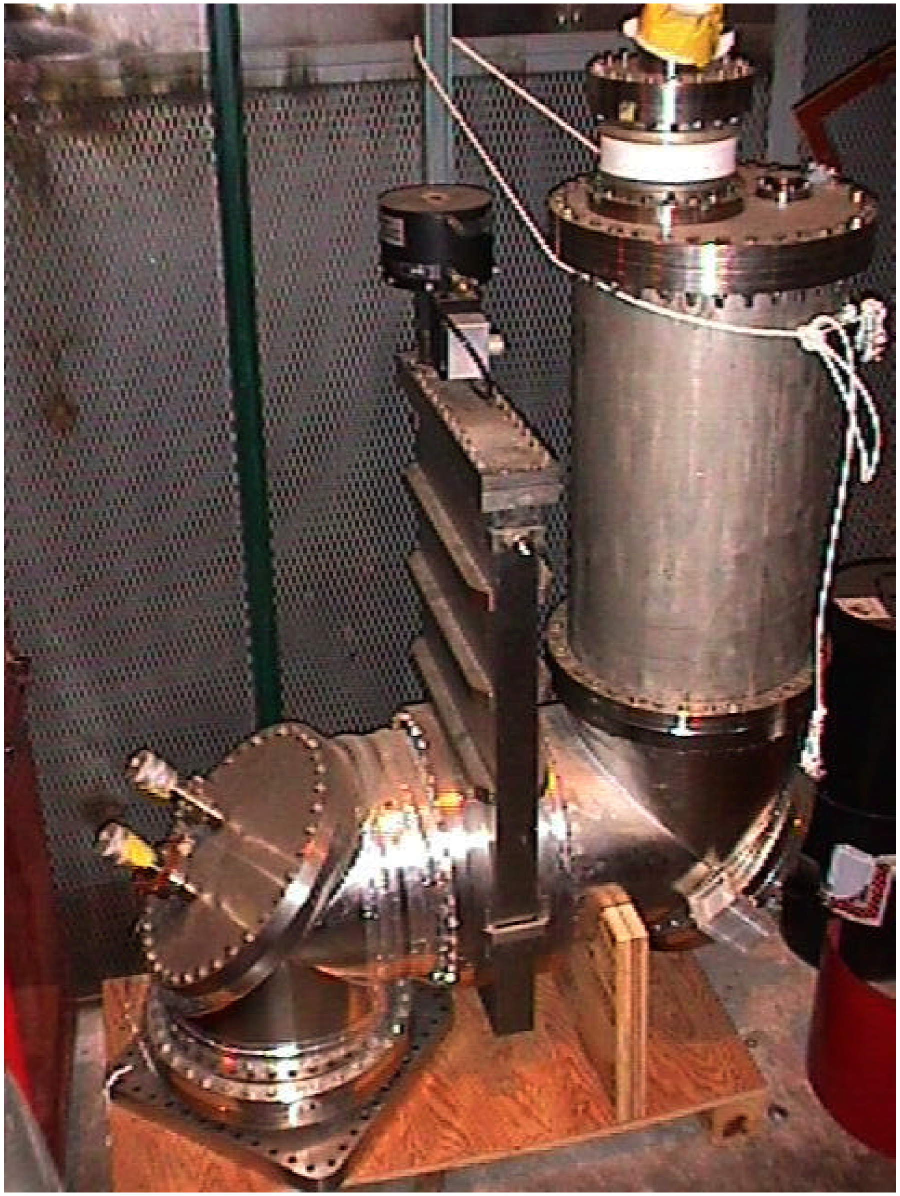
Internal mirror

Backup



Multiple gyrotron
Outside-mirror
Launcher configuration

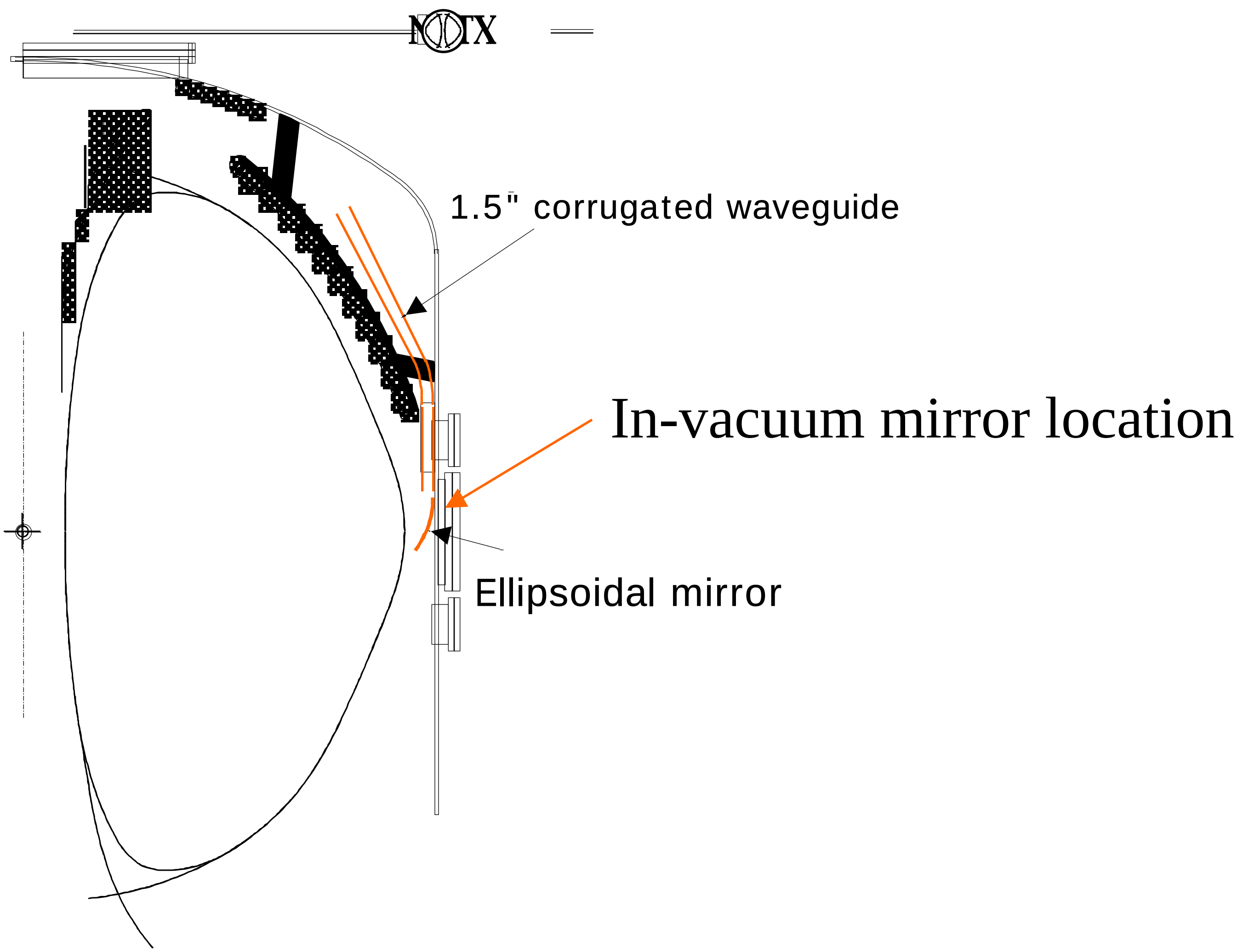
- Utilize existing launcher
- Need large midplane port
- Narrow focused beam
- Adjustable pointing angle
- Less beam steering possible



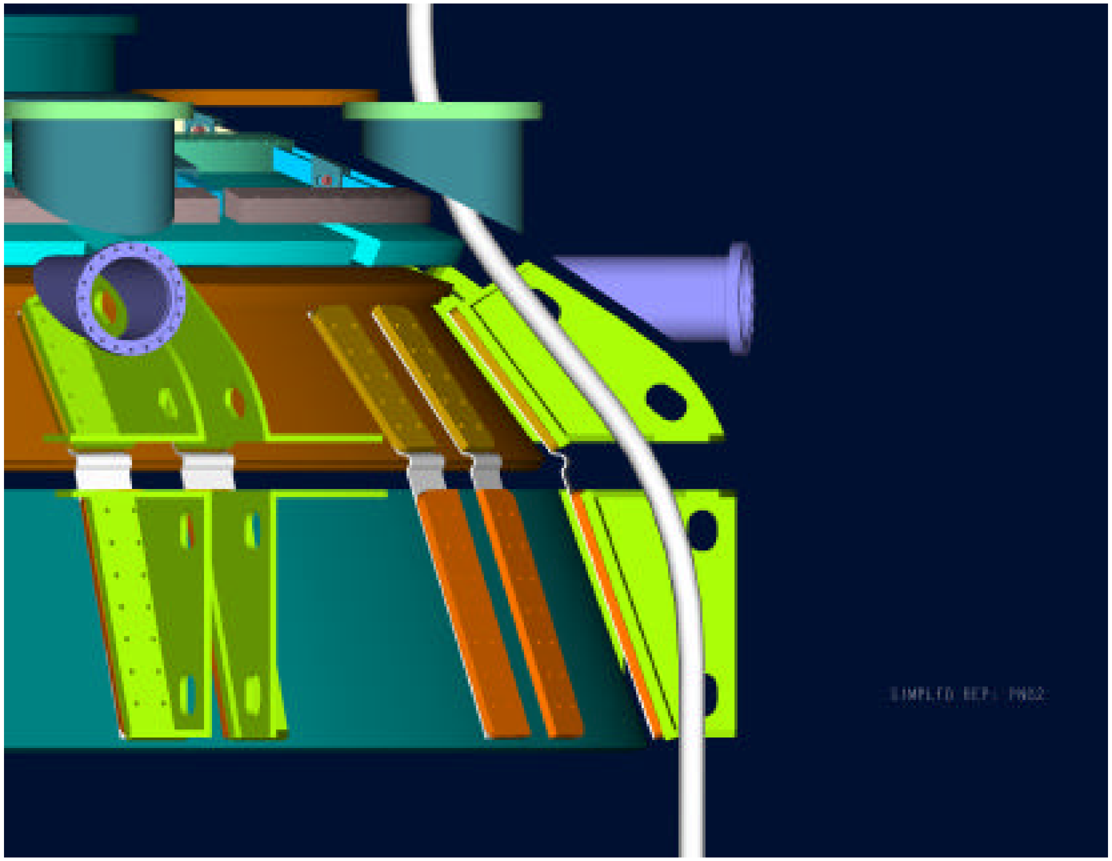
ECH Launcher from ATF

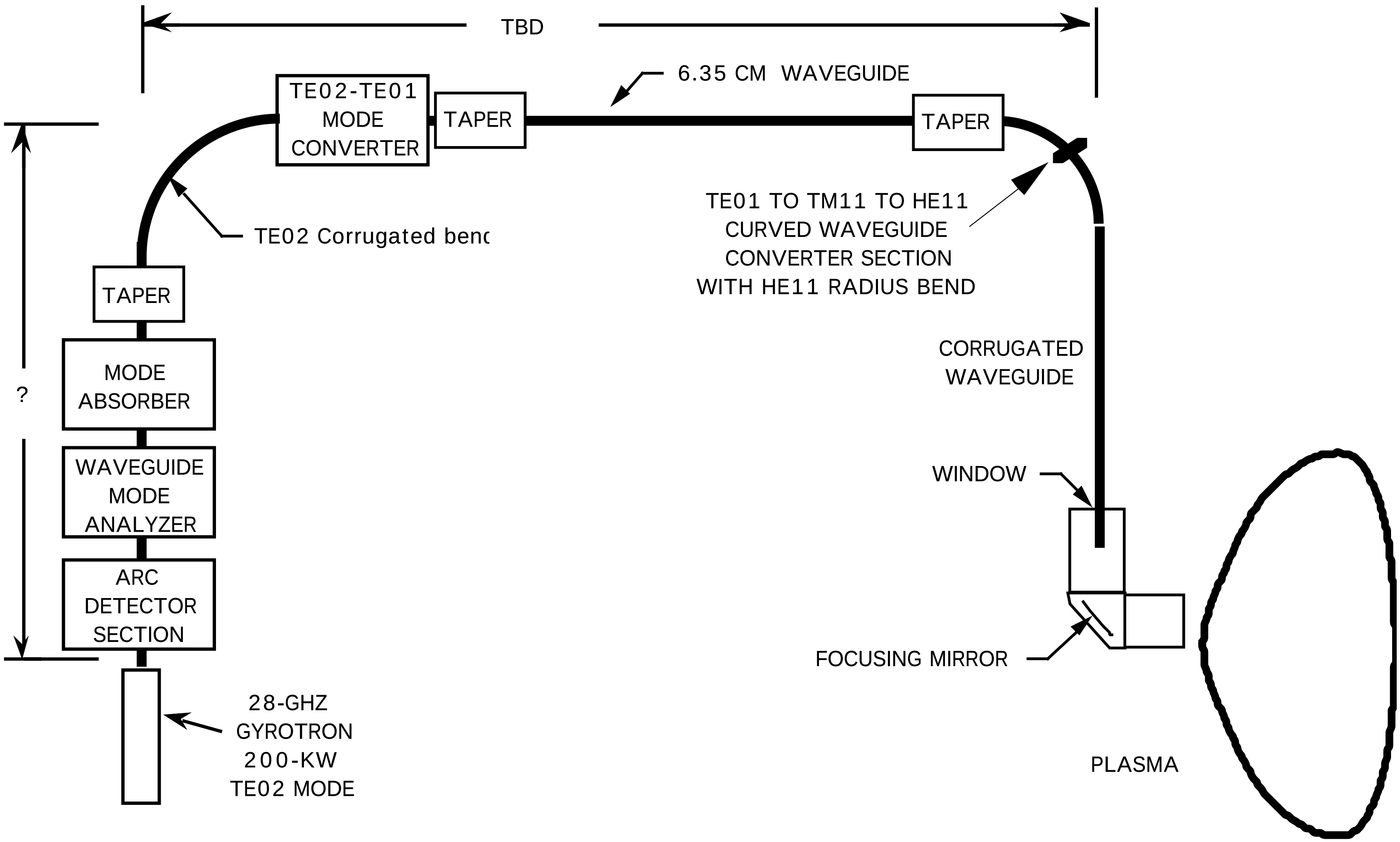
Top port launch option

- 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





BLOCK DIAGRAM PROPOSED NSTX 28 GHZ ECH SYSTEM