COUPLING TO THE ELECTRON BERNSTEIN WAVE WITH WAVEGUIDE ANTENNAS

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GENERAL ATOMICS

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INTRODUCTION

- Electron cyclotron heating and current drive has proven very useful in toroidal plasma devices, due to its strong, localized absorption and its utter lack of coupling difficulties

- However, wave physics dictates that in plasmas in which $\omega_{pe}^2 / \omega_{ce}^2 >> 1$ (low field / high density), conventional ECH is not possible as a method of heating the core plasma

- The Electron Bernstein Wave (EBW) has been investigated as a means of heating such plasmas by Ram, et al. Several methods of coupling to the wave by mode conversion from 'conventional' EC waves (O- and X-modes) have been studied

- In the present work, we solve an antenna coupling problem relevant to this problem, in which the coupling structure is a phased waveguide array, similar to a LH grill

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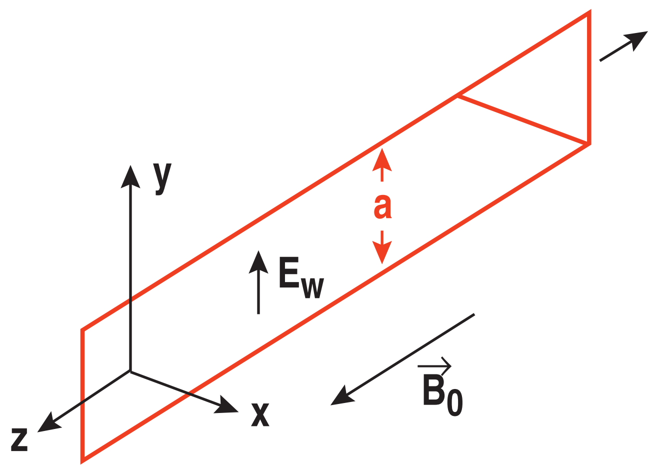
Description of coupling problem geometry

- Antenna: arbitrary rectangular array of rectangular waveguides, long dimension either aligned with or perpendicular to static B-field
- Plane stratified cold plasma with small collisionallity (complex electron mass) to resolve hybrid resonance



- Modified version of code described in R.I. Pinsker, R.E. Duvall, et al., Nucl. Fusion 26 (1986) 941.

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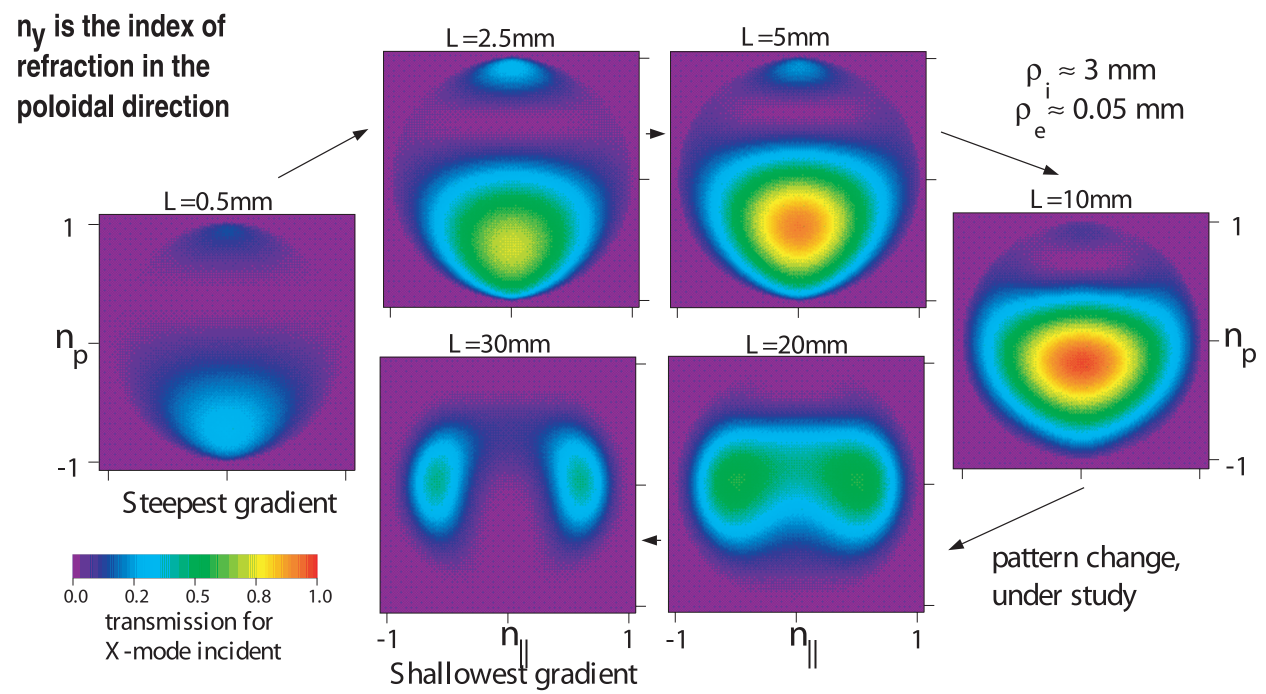
Using a cold plasma model to calculate coupling to a hot plasma mode

- How can a cold plasma model, in which no Bernstein waves exist, be used to calculate coupling to the EBW?
- Answer: by adding an arbitrary small collisionality to the model, power incident to the upper hybrid resonance is absorbed (resonant absorption), while in a warm plasma model, this power is converted to the EBW and propagates inwards
- Work by Ram, et al., has shown excellent agreement between this kind of Budden model and a warm plasma code - the fraction of the incident power that is absorbed at the UHR in the cold model agrees very well with the fraction of mode-converted power in the warm model
- We have compared detailed calculations of surface admittance performed with the GLOSI full-wave code at ORNL with calculations done with the cold plasma model, with collisions, and detailed agreement has been found
- Hence, a general, cold plasma waveguide coupling code (generalization of the Brambilla grill code) can be extended to this problem by adding collisions to resolve the hybrid resonances

GLOSI code shows that poloidal wavenumber at which minimum reflection is obtained is a strong function of density gradient



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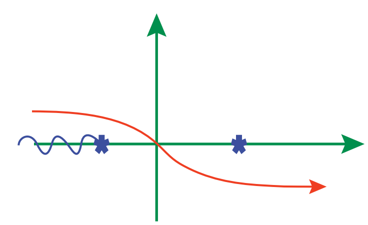
Solution obtained with Brambilla's method

- Matching Ey at x = 0, B_z only in waveguide opening, obtain equation for waveguide reflection coefficient ρ:

$$\frac{1-\rho}{1+\rho} \int \Lambda = \frac{(k_0 a/2)}{\pi \sqrt{\varepsilon_w}} \int dn_y \, \underbrace{Y(n_y)}_{\text{plasma admittance}} \, \underbrace{\frac{\sin^2\left(\frac{k_o a}{2} n_y\right)}{\left(\frac{k_o a}{2} n_y\right)^2}}_{\text{antenna spectrum}}$$

$$Y \int \left.\frac{B_z}{Ey}\right|_{x\,=\,0^+}$$

- Integral must be performed over the path determined by causality if there are any singularities of Y (n_y) for real n_y



Brambilla, M., Nucl. Fusion 16 (1976) 47.

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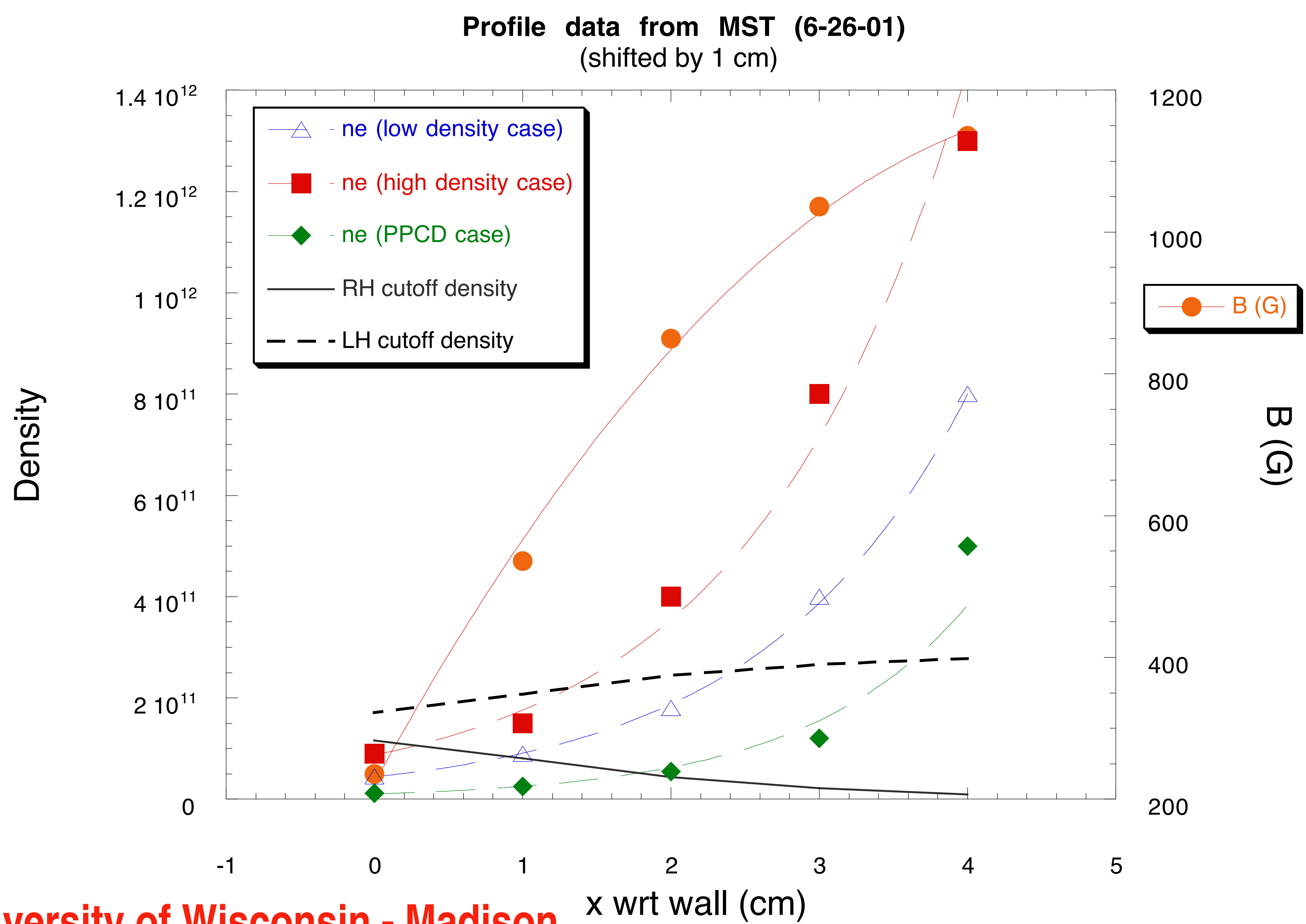
Measured edge density, B-field profiles from the Madison Symmetric Torus are used in the coupling model



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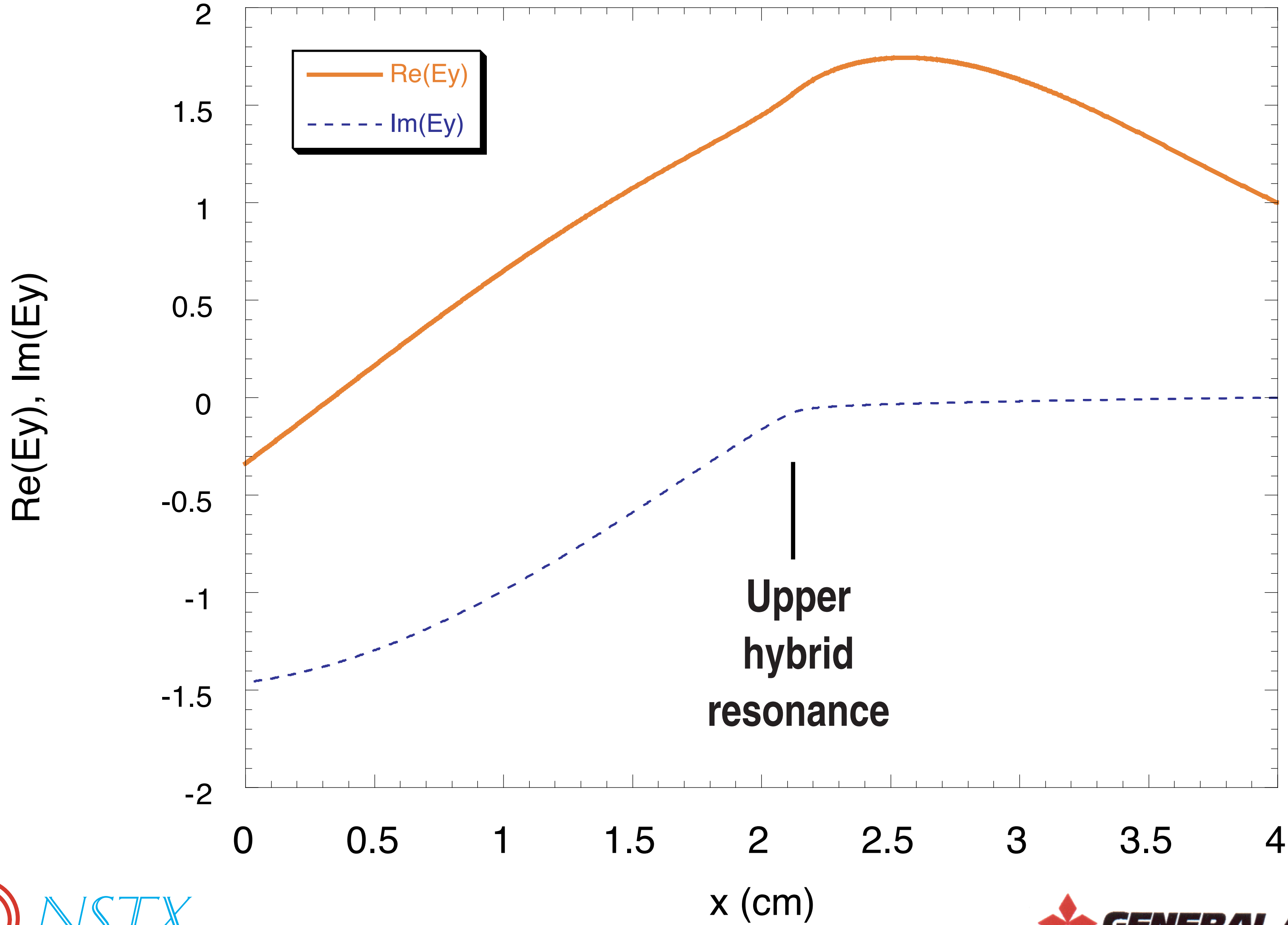
Ey fields for a plane wave with $n_y = n_z = 0$ for MST-like conditions



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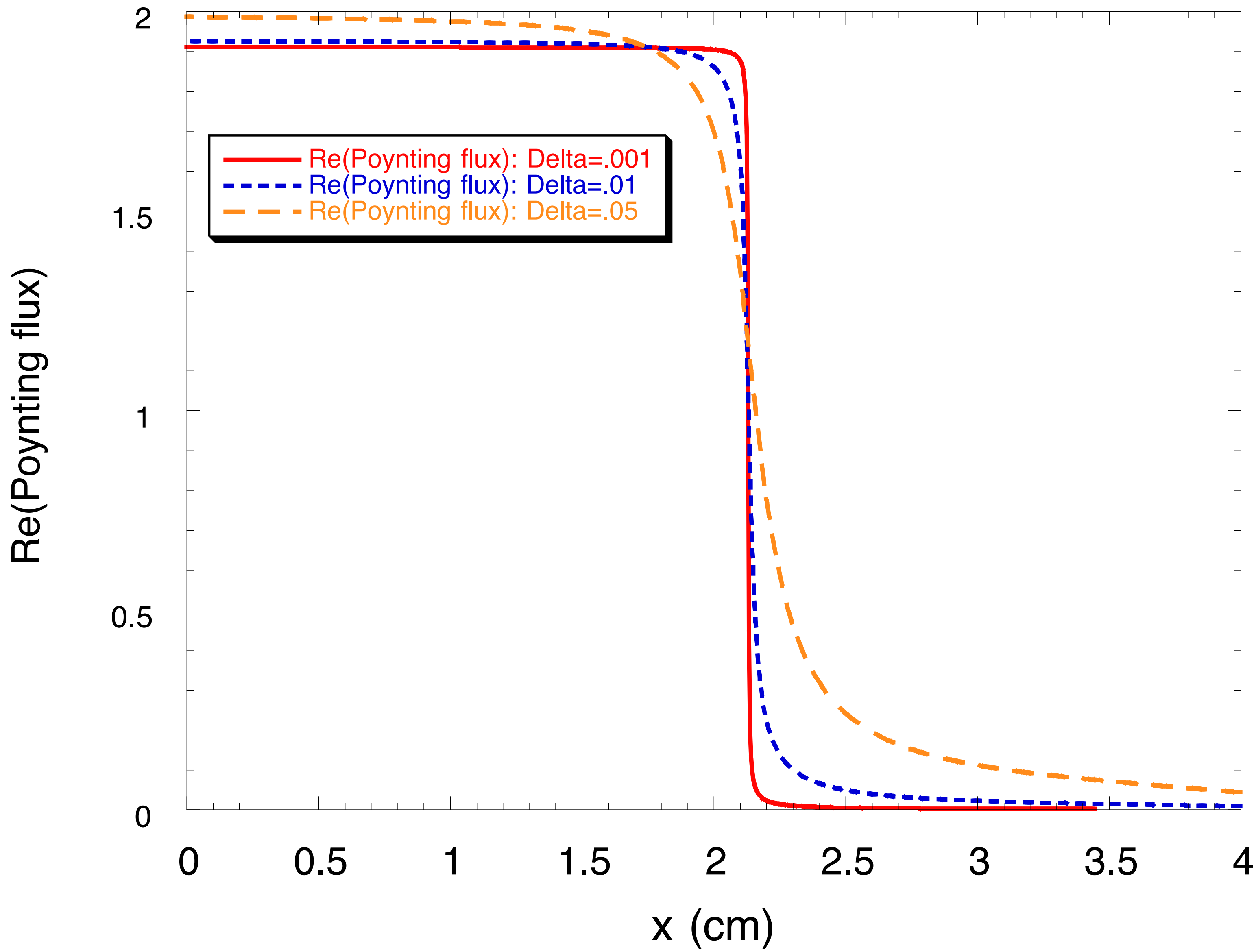
Thickness of layer in which power is absorbed at upper hybrid layer is determined by collisionality



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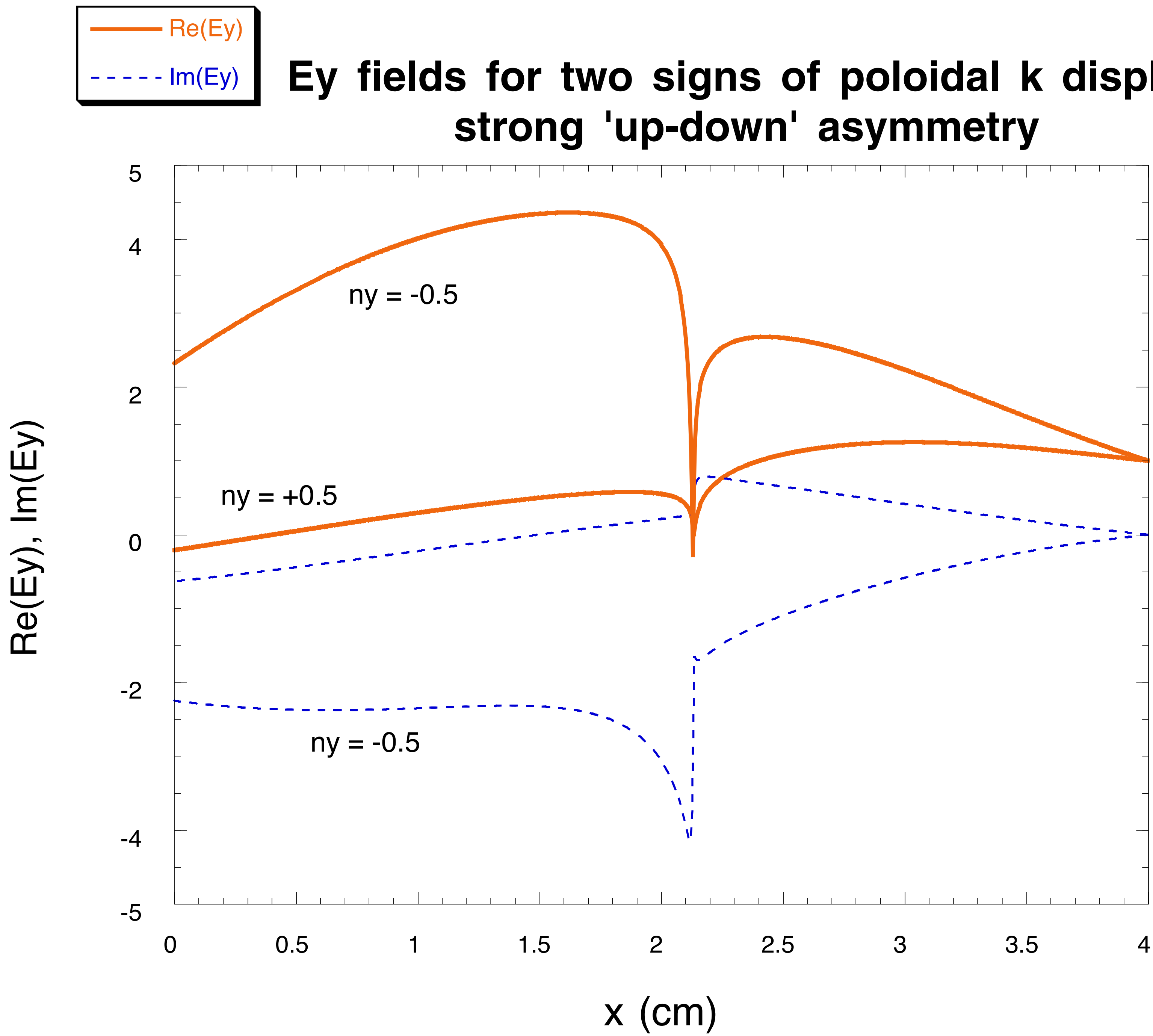
Ey fields for two signs of poloidal k display strong 'up-down' asymmetry



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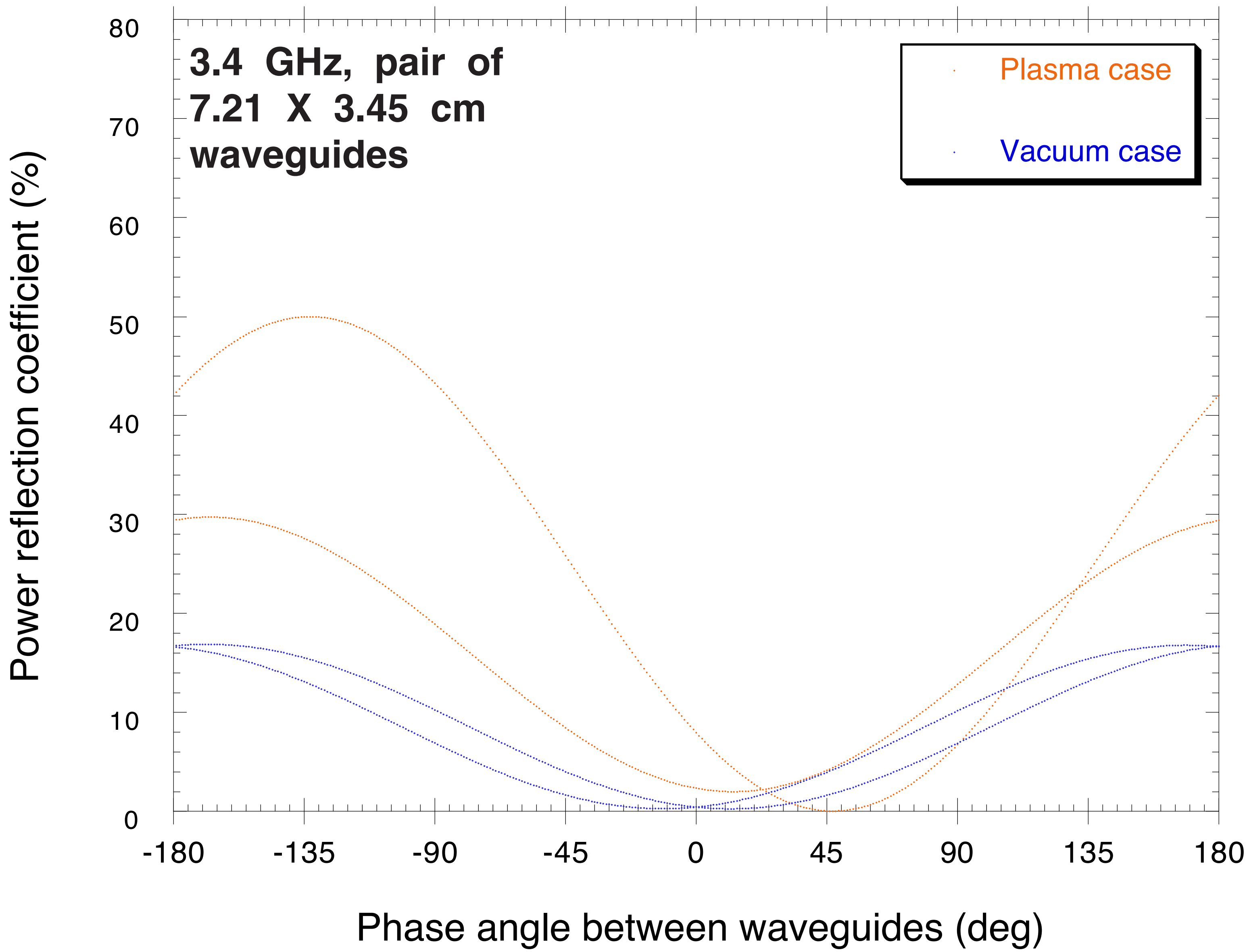
Twin waveguide coupler is about to be tested on the Madison Symmetric Torus at U. Wisc. Madison

Reflection coefficient as function of phase angle for twin-guide case, X-mode orientation, shows strong poloidal phasing asymmetry for MST-like conditions



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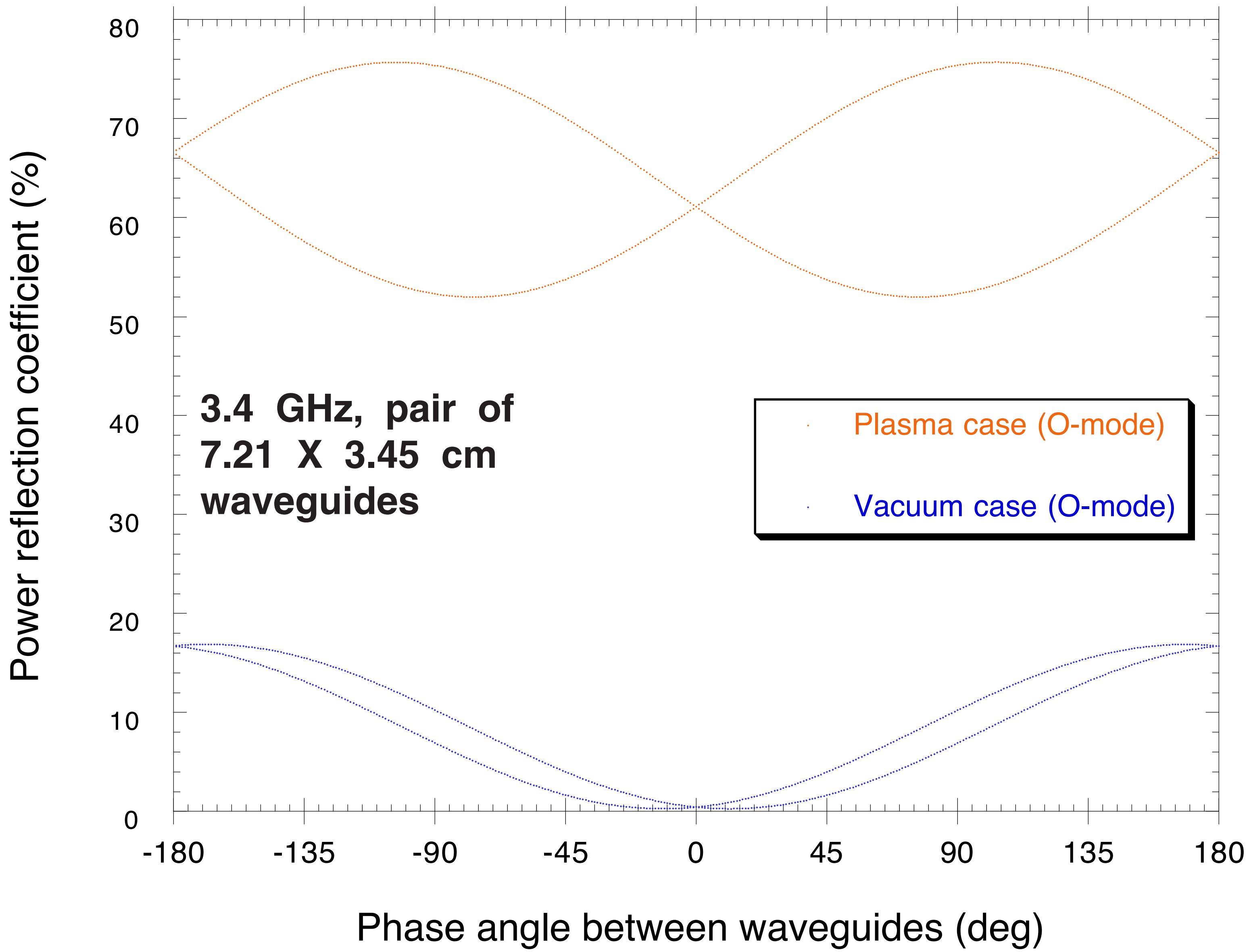
Coupling for same twin waveguide oriented to launch O-mode is poor at any phase angle: O-X(-B) coupling is weak under these MST-like conditions



Conclusions

- The modified waveguide coupling code is capable of computing EBW coupling
- A strong poloidal phasing asymmetry is predicted for the MST-like cases computed thus far. Satisfactory coupling via the X-B scheme is predicted for MST. Coupling via the O-X-B scheme is predicted to be relatively poor.
- The code will be used to predict coupling results in experiments that are underway on the MST and CDX-U devices, and possibly on NSTX and Pegasus
- We would like to extend the code to allow for TM11 excitation, which might be expected to be even better under some circumstances