Applications of Twisted Hollow Waveguides as Accelerating Structures

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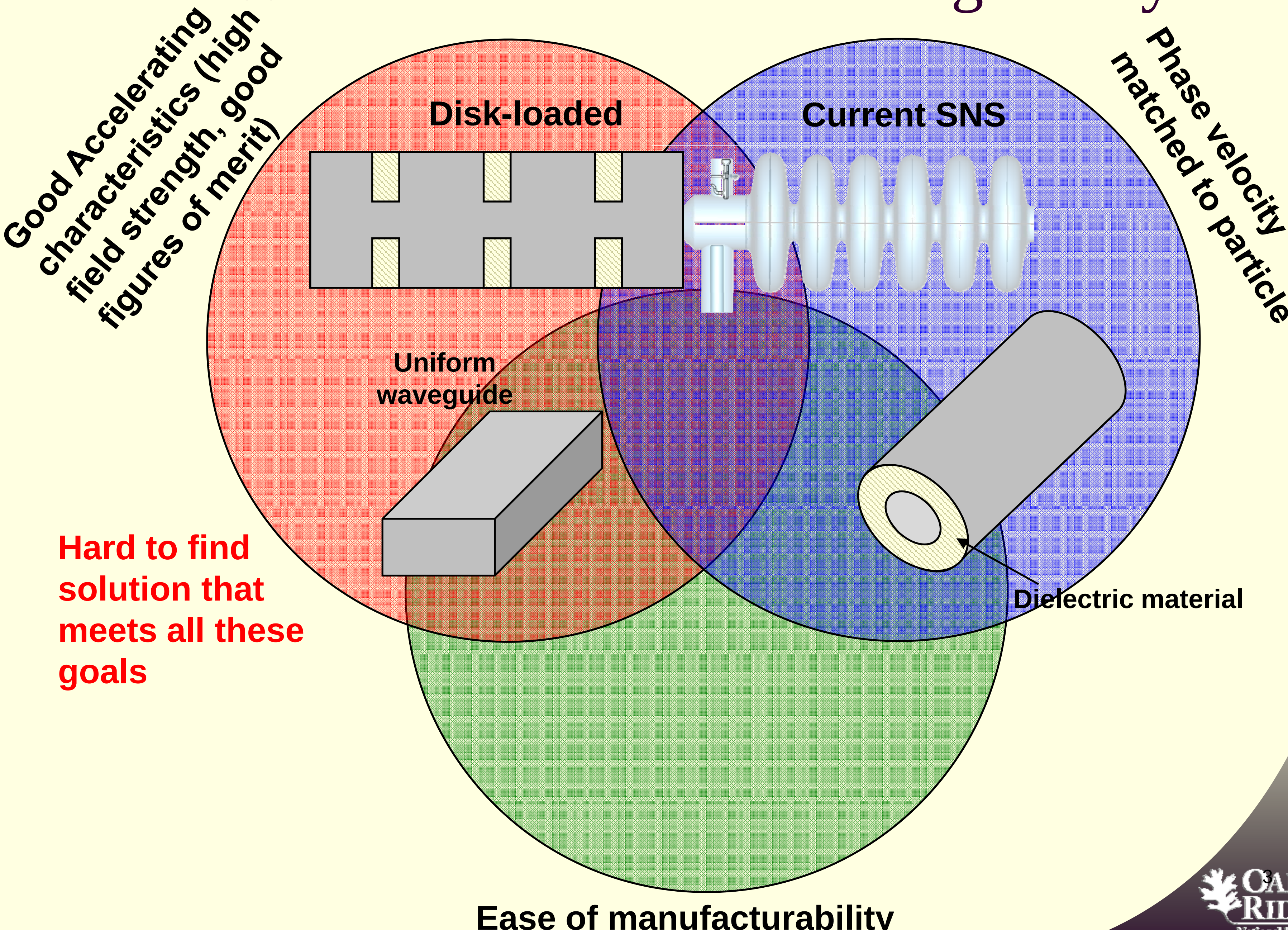
Outline

- Motivation
  - Background
  - Selection of twisted guides
- EM Properties of twisted guides
  - Accelerating modes
  - Dispersion characteristics
- Experimental Results

What is a Good Accelerating Cavity?

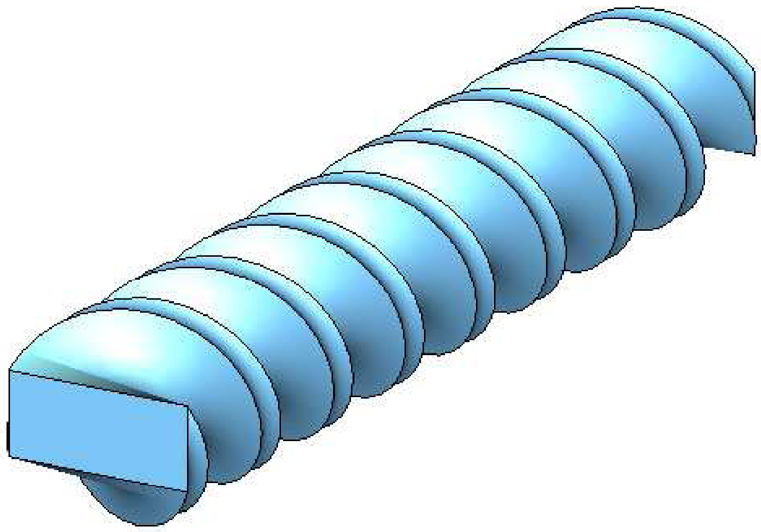


Hard to find solution that meets all these goals

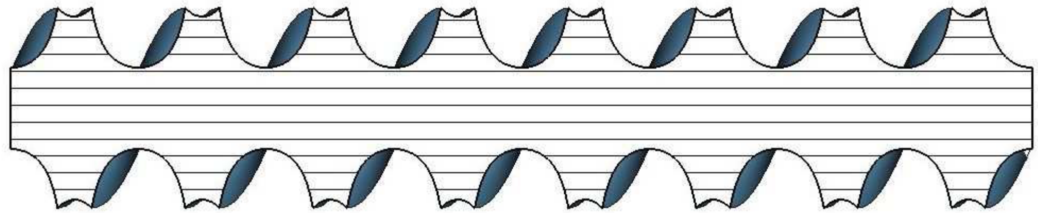
Twisted Guide- Attractive Candidate

- Twisted Guides are slow wave structures
- Could be simple to manufacture
- No dielectric loading

Simple Twisted Waveguide



Potentially can meet all design criteria [1]

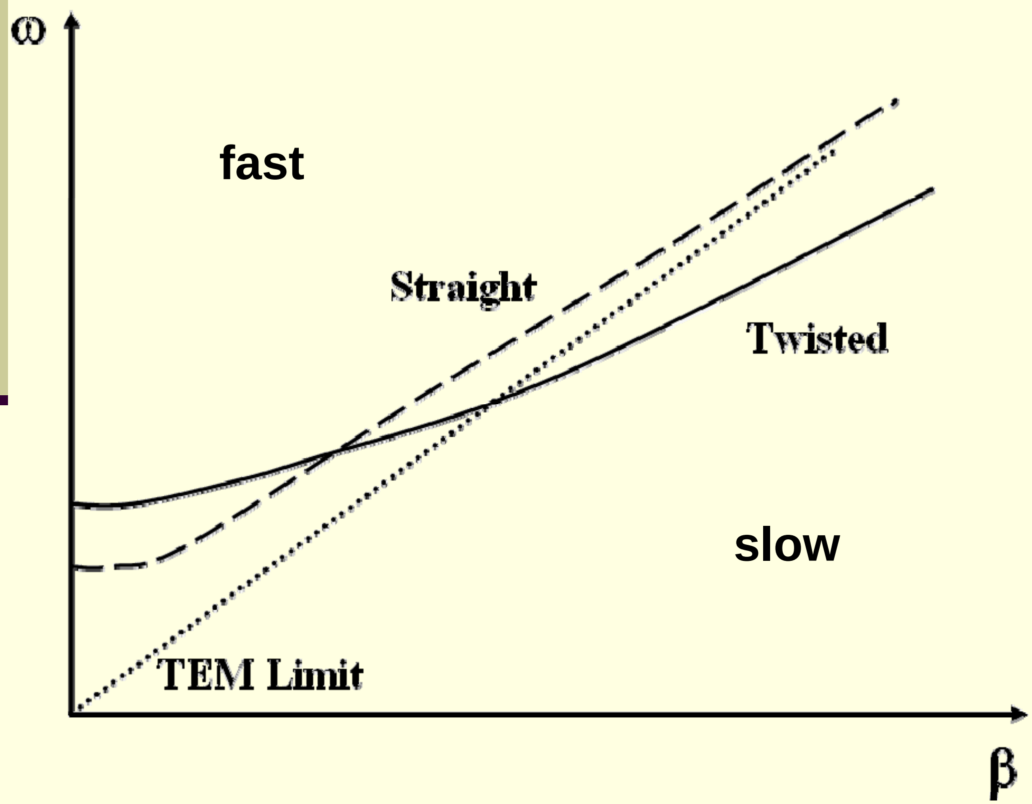


[1] Y. W. Kang, "Twisted waveguide accelerating structure," in 9th Workshop on Advanced Accelerator Concepts, Aug. 2000.

Simple Example: Twisted Rectangular Guide

- Perturbation theory can give propagation characteristics of twisted RWG

Typical dispersion characteristic



Generally,

Rapid twist rate ⇒ **slower wave**

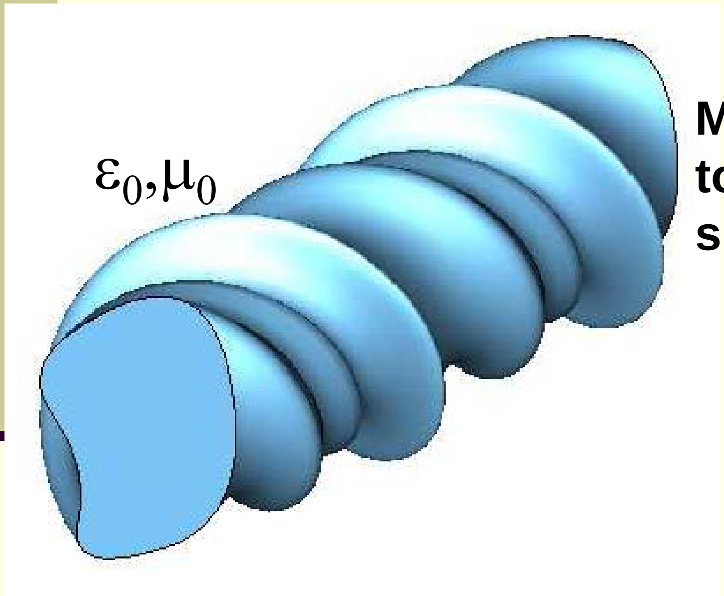
Perturbation theory accurate for slowly twisted rectangular guides.

[1] L. Lewin, Theory of Waveguides. London, Newness-Butherworths, 1975.

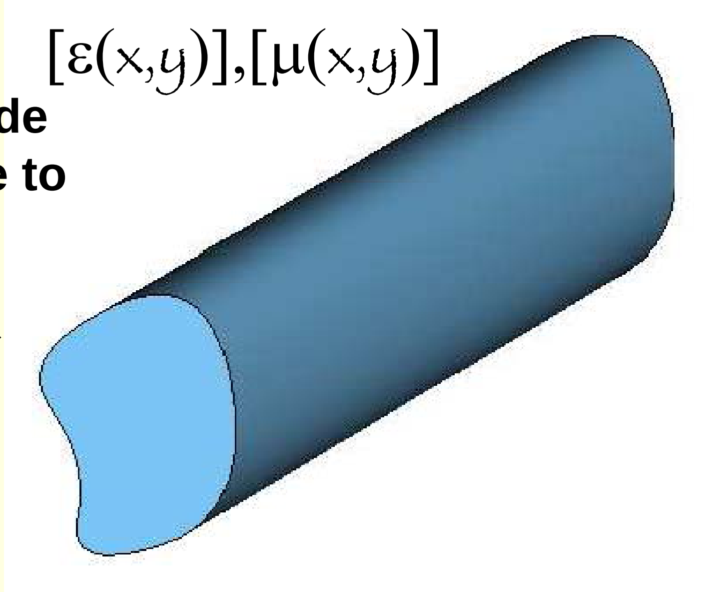
Basic Modeling Approach

Use twisted coordinates to solve the structure.

$$\begin{aligned} x' &= x\cos pz + y\sin pz \\ y' &= y\cos pz - x\sin pz \\ z' &= z \end{aligned}$$



Map twisted guide to straight guide to simplify BCs.



J. Wilson, C. Wang, A. Fathy, and Y. Kang, "Analysis of rapidly twisted hollow waveguides," Accepted for publication in IEEE Transactions on Microwave Theory and Techniques, Sept. 2008.

Accelerator Performance – Field smoothness

- Twisted guide can be represented as a periodic structure and the fields are sum of all space harmonics:

$$\boldsymbol{E} = \sum_{n=-\infty}^{\infty} \boldsymbol{E}_n(x, y) e^{j\beta_n z}$$

where

$$\beta_n = \beta_0 + \frac{2\pi n}{\Delta z}.$$

- For twisted guide:

$$\boldsymbol{E}_n(x = 0, y = 0) = 0, n \neq 0.$$

Very desirable, since only the fundamental space harmonic contributes to particle acceleration along the z-axis.

Accelerator Design

Idea: Start with twisted structure whose cross section matches well-known one.

1. Start with rotationally symmetric structure with period Δz.

$$\rho < g(z),$$

2. Define transverse cross section in polar coordinates.

$$\rho(x,y) < g\left(\frac{m\phi(x,y)\Delta z}{2\pi}\right)$$

for even integer m

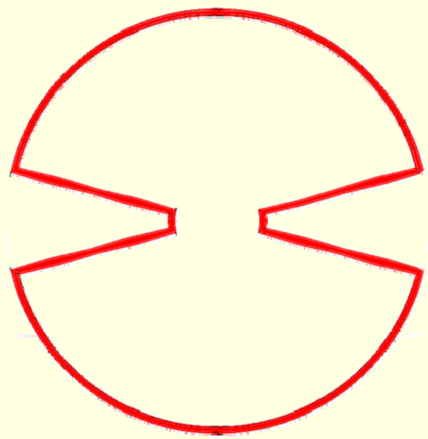
3. Twist the cross section from (2) with twist rate

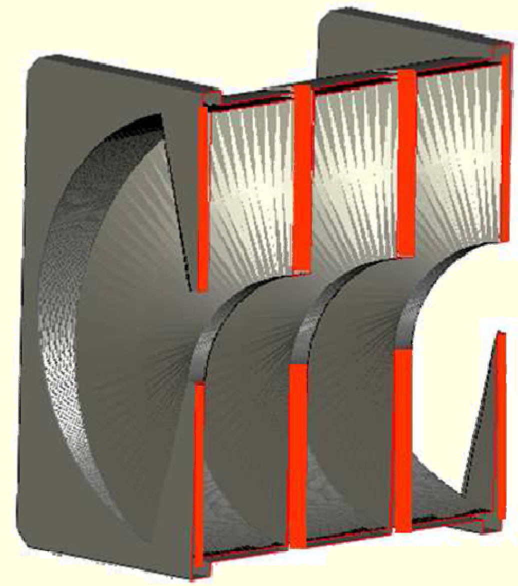
$$p = \frac{2\pi}{m\Delta z}$$

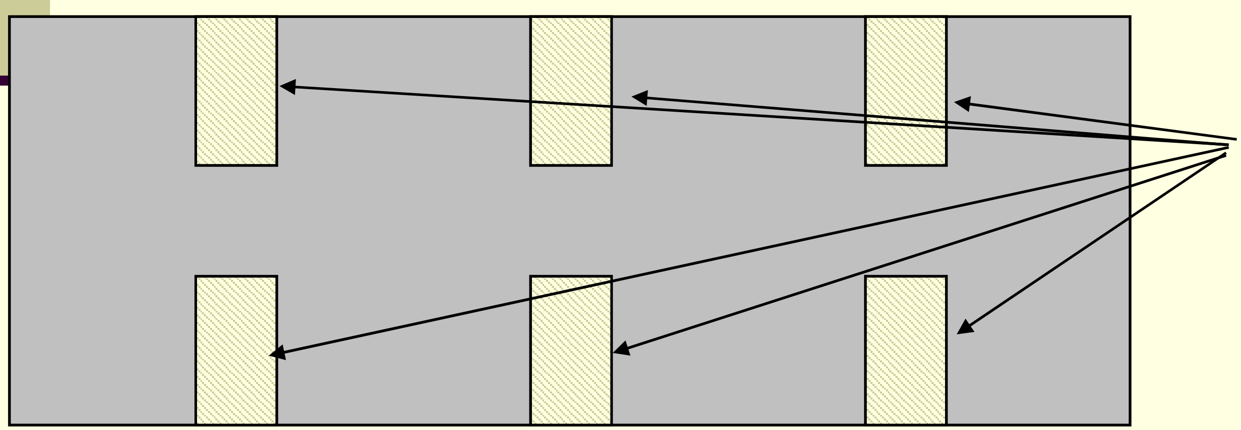
Structure will have identical longitudinal cross section to original structure.

Design Example

- Disk loaded cavity



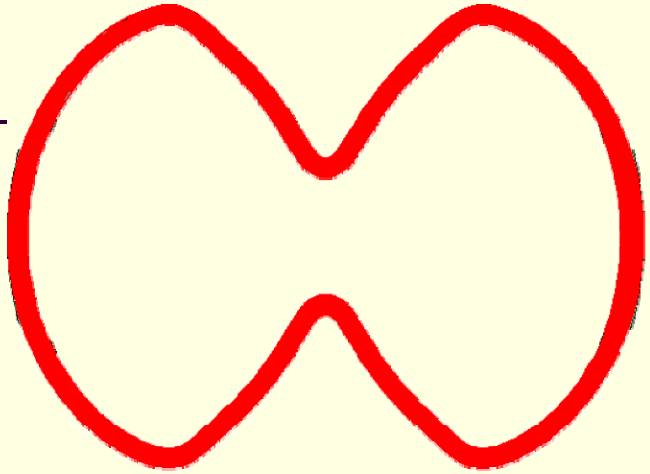


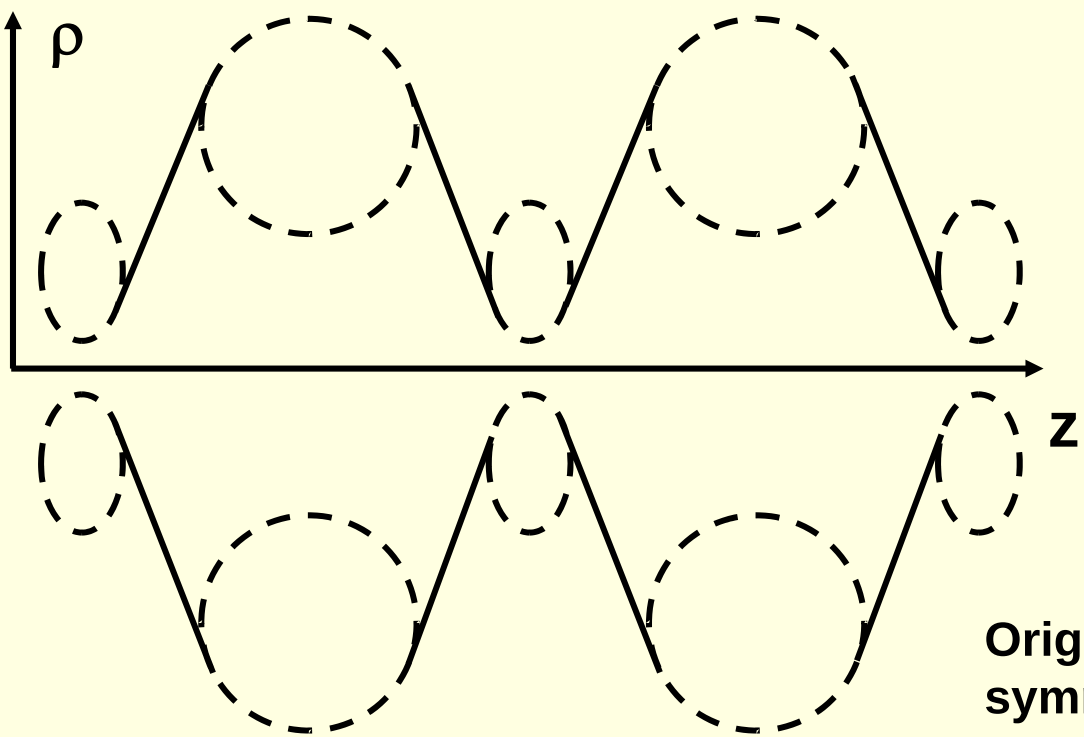


Metal disks

Design Example

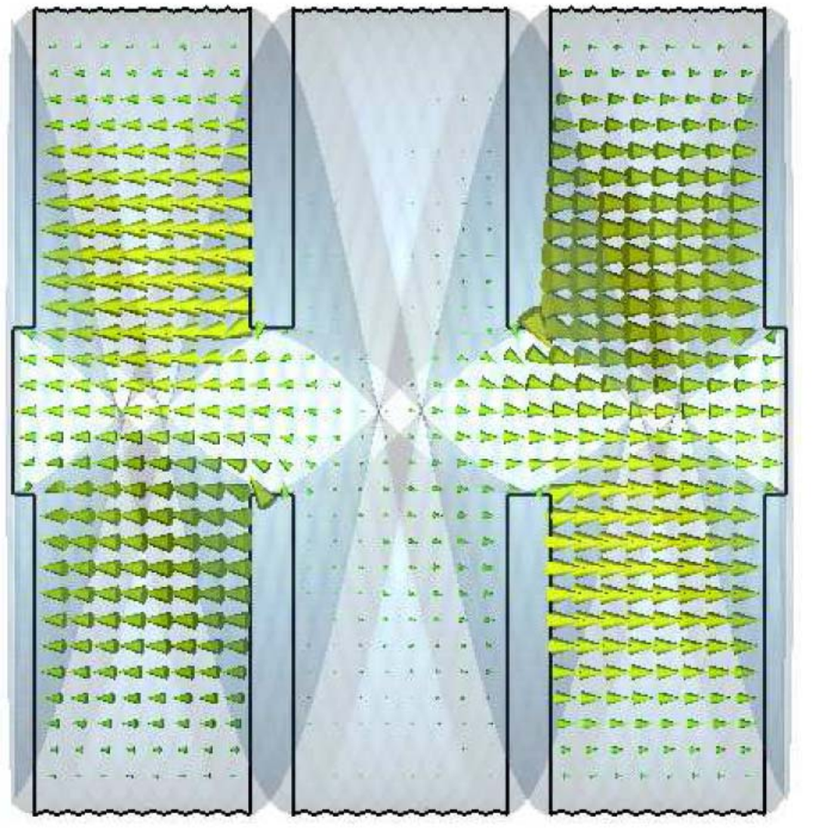
- Elliptical, or TESLA-style cavity



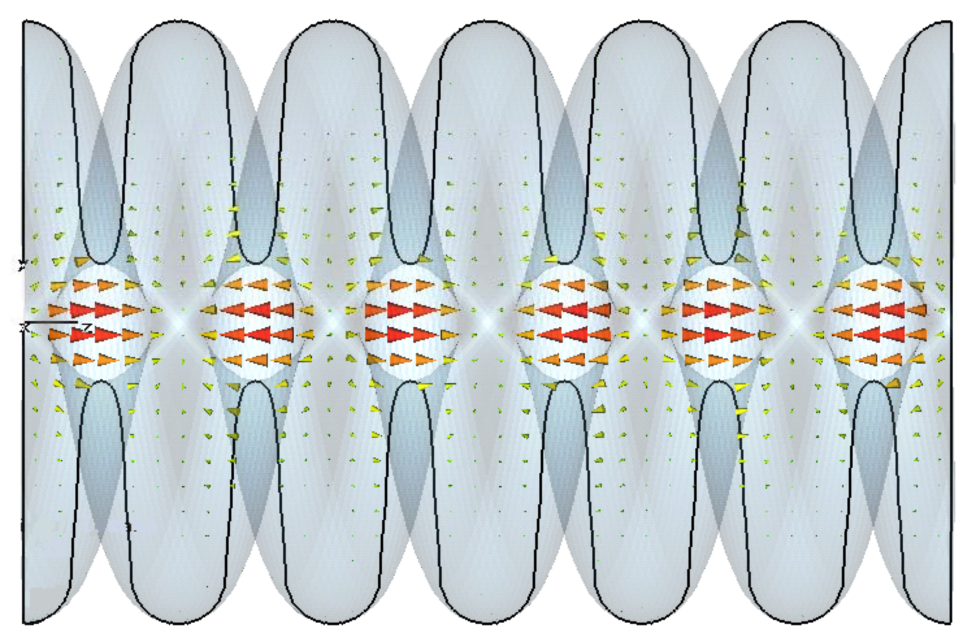


Original rotationally symmetric structure

Simulated Electric Fields



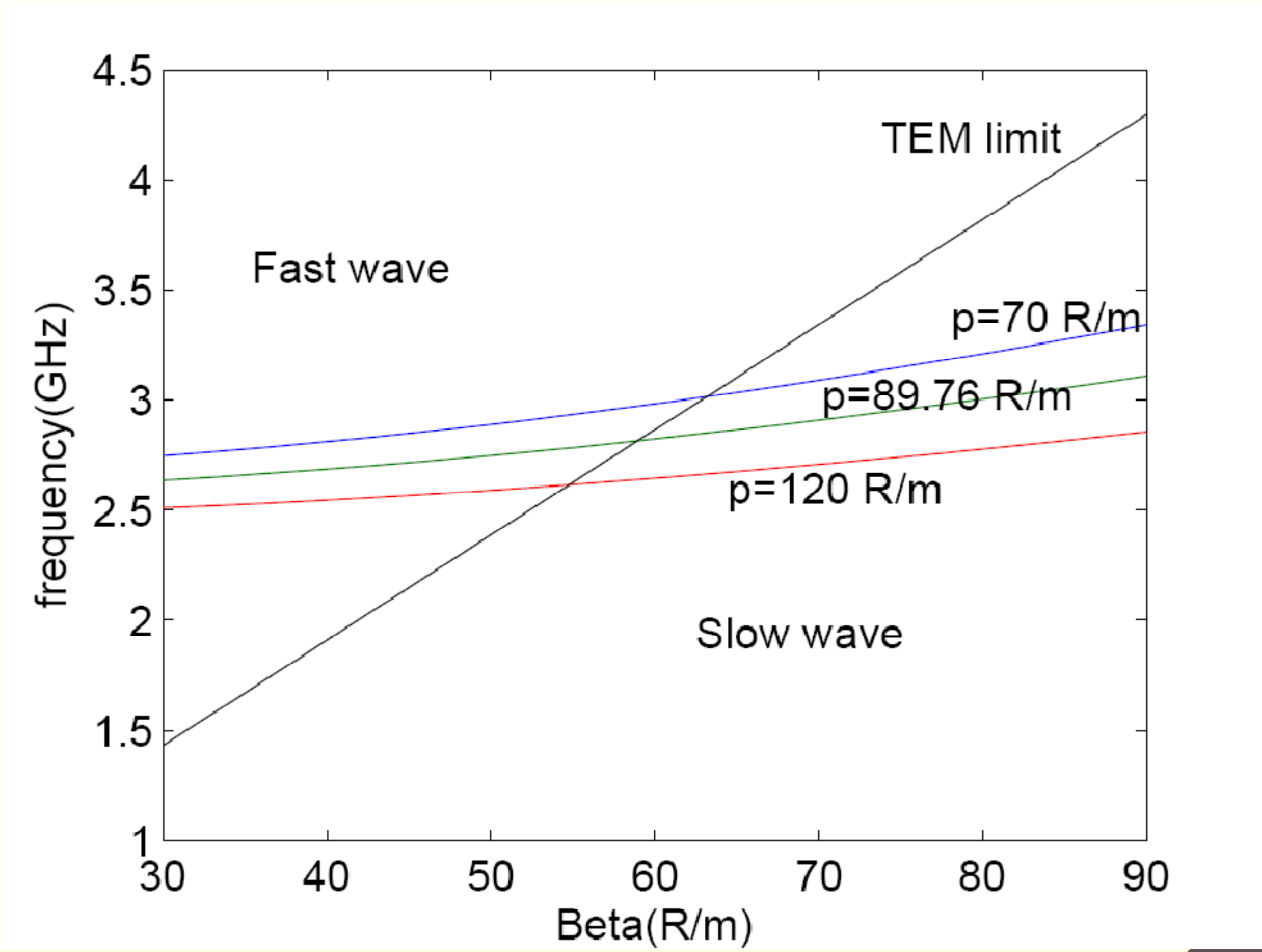
Disk-loaded analog $\beta=1$



Elliptical analog $\beta=0.61$

Dispersion characteristics

Simulation for twisted disk-loaded analog for varying twist rate p.

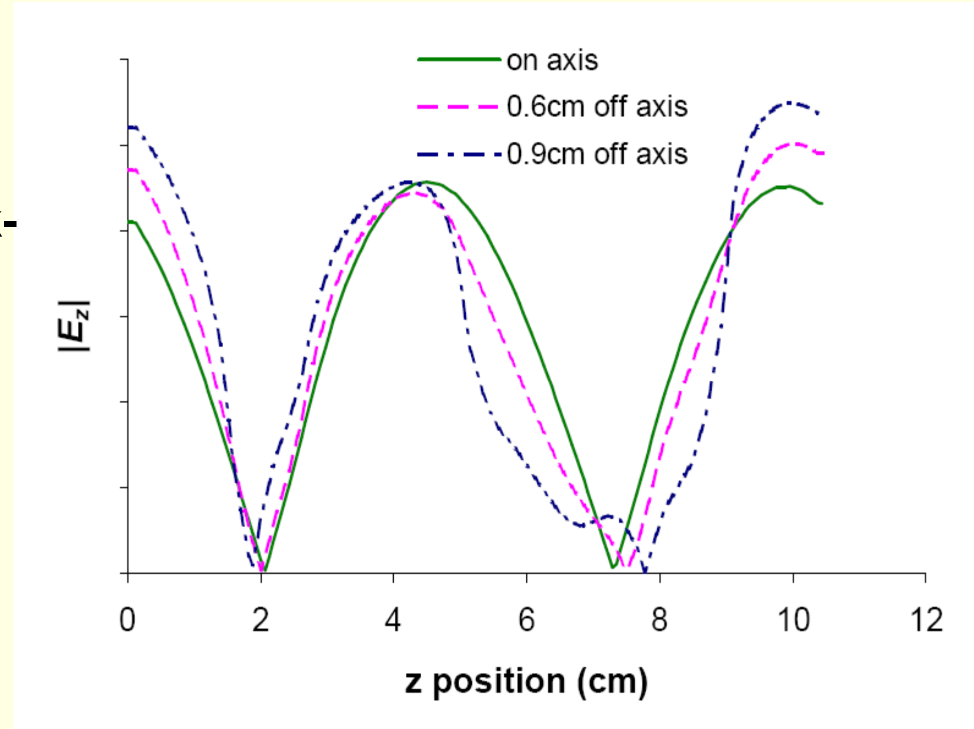


Simulated Electric field distribution

- Fields along the center axis of twisted guide should have purely sinusoidal dependence.
- Our code and CST (commercial software) were used to validate the dominance of the fundamental harmonic along the center axis

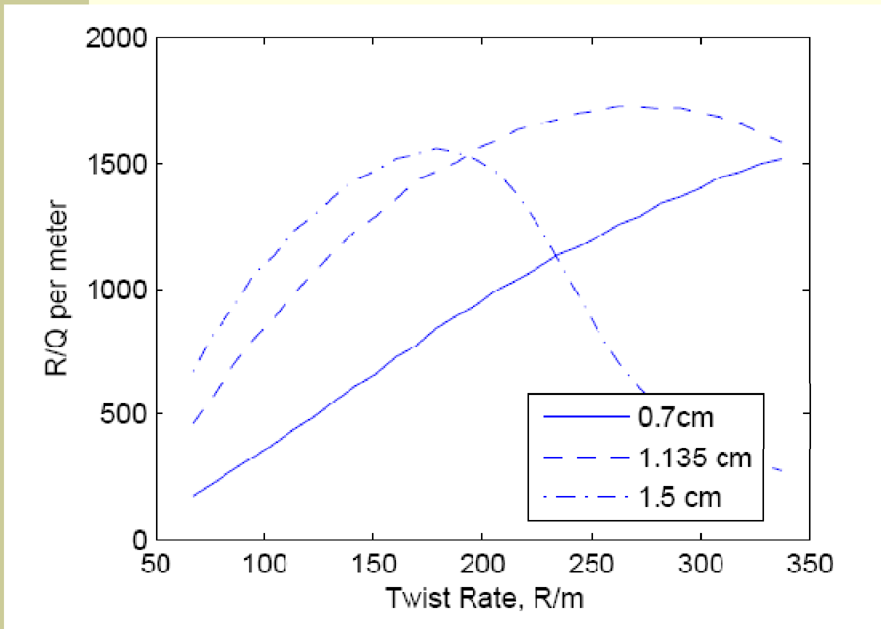
Results for disk-loaded analog

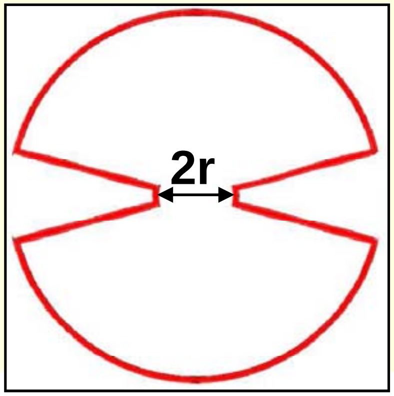
On axis field is sinusoidal
Off-axis higher harmonics exist

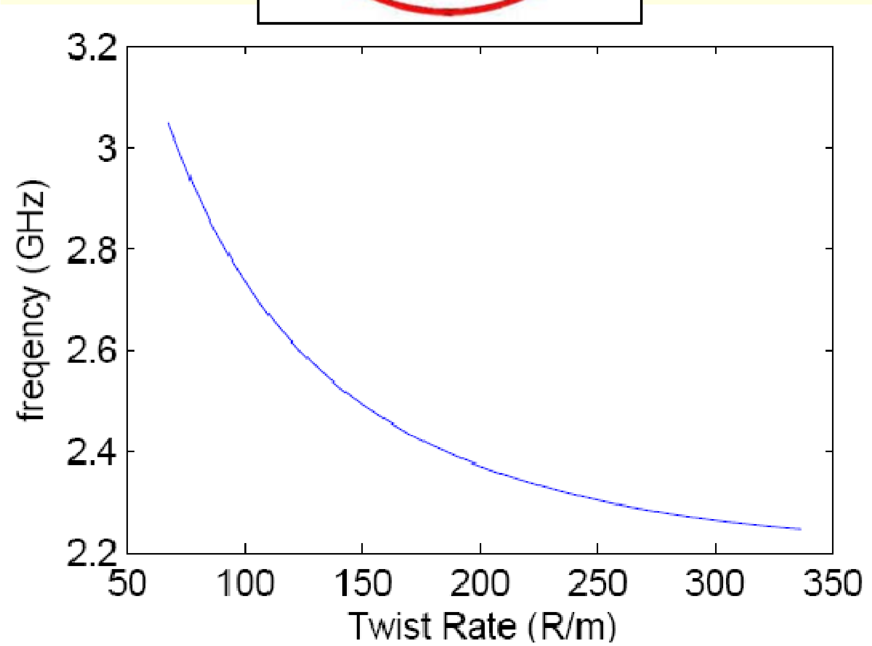


Design Issues: R over Q Optimization

For a fixed beta, select radius, twist rate to maximize R/Q



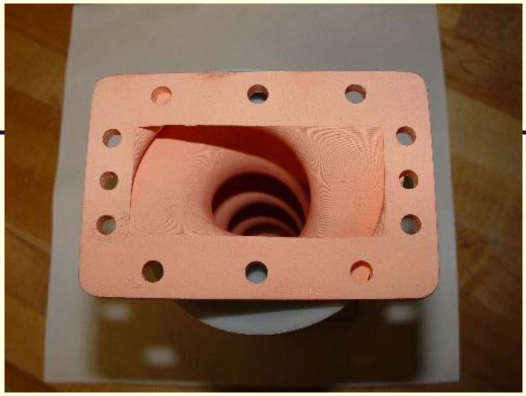


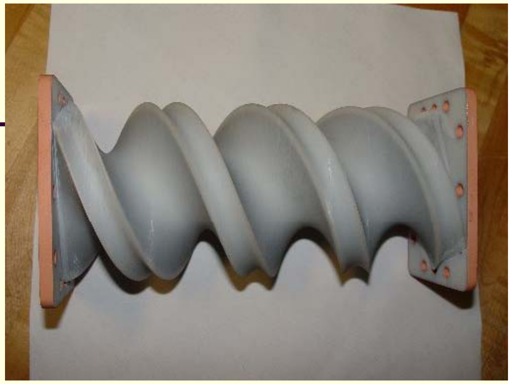


Operating frequency should be adjusted to keep phase velocity constant

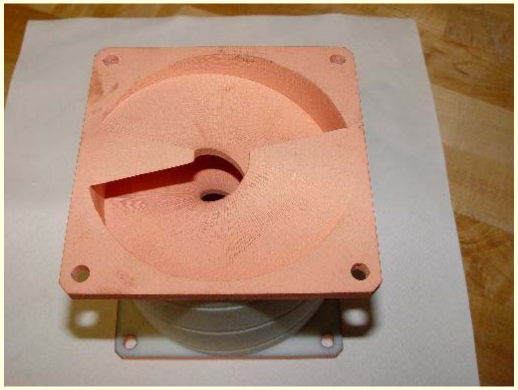
Designed Twisted Prototypes – 2.8 GHz

1) Twisted rectangular guide

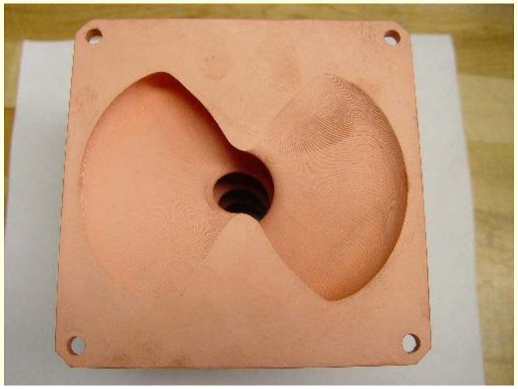


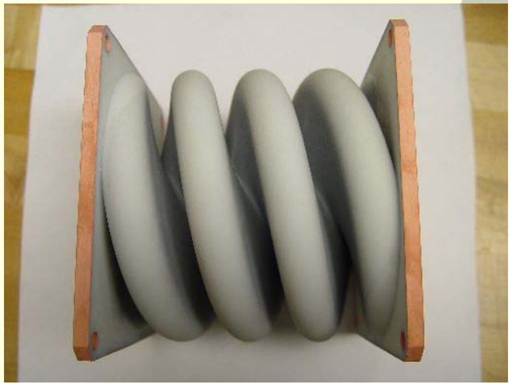


2) Twisted disk loaded analog



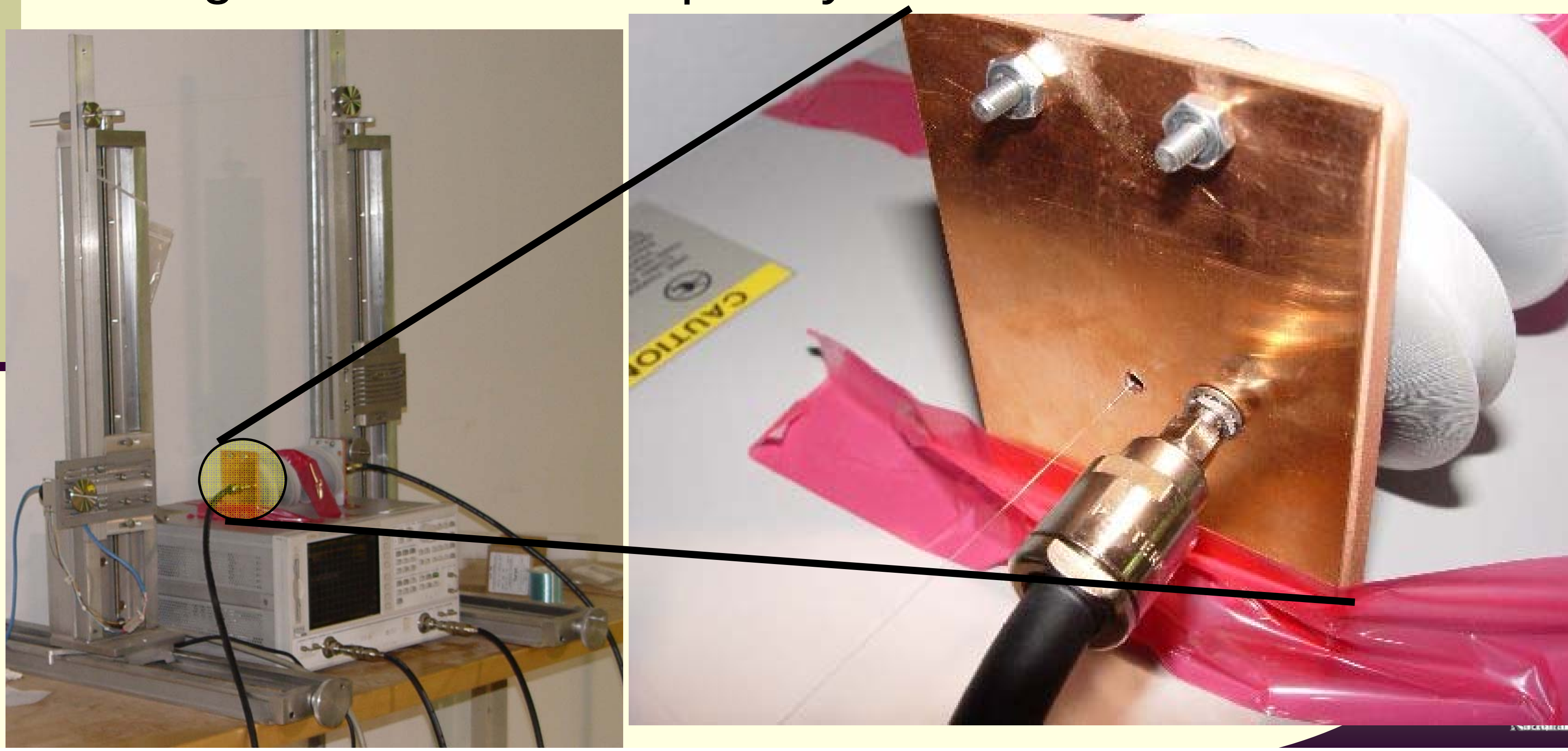
3) Twisted SNS (Elliptical) Cavity analog





Experimental Method

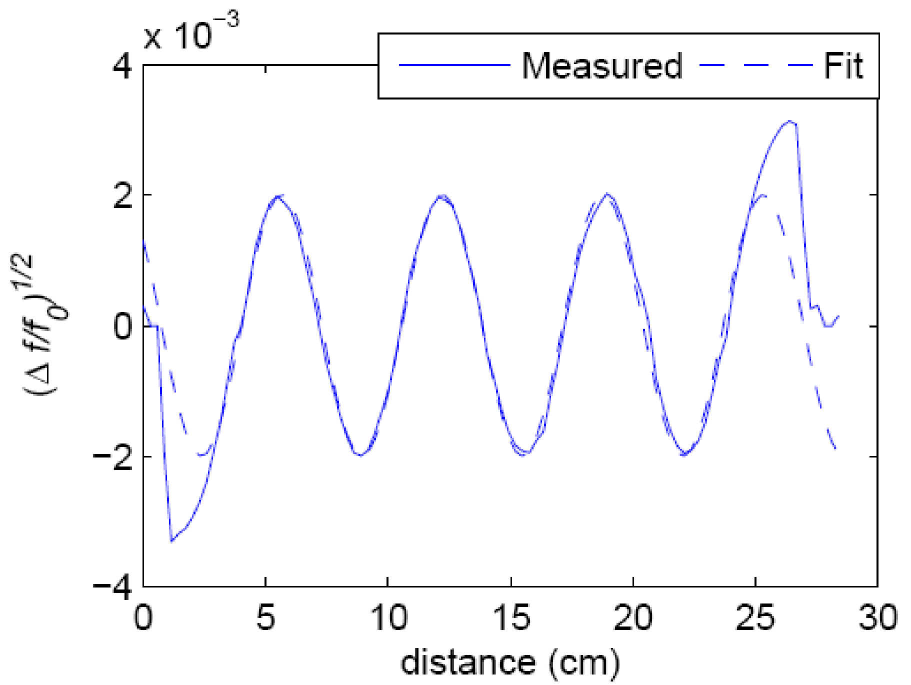
- Twisted guides were terminated by copper endplates to form a cavity, used small probes on each end to measure S_{21}
- Used bead pull technique to perturb electric field along the guide. Extract frequency, Beta, etc.



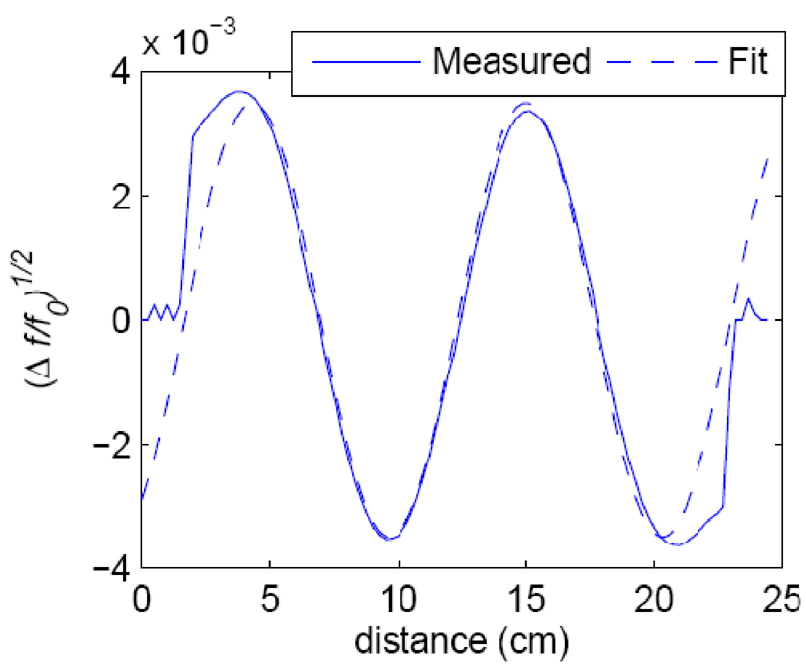
Accelerating Mode Field Distributions

Relating cavity resonance frequency shift to local field values

Twisted SNS analog



Twisted disk-loaded analog



Fields appear sinusoidal toward center of cavity. End effects dominate close to copper walls

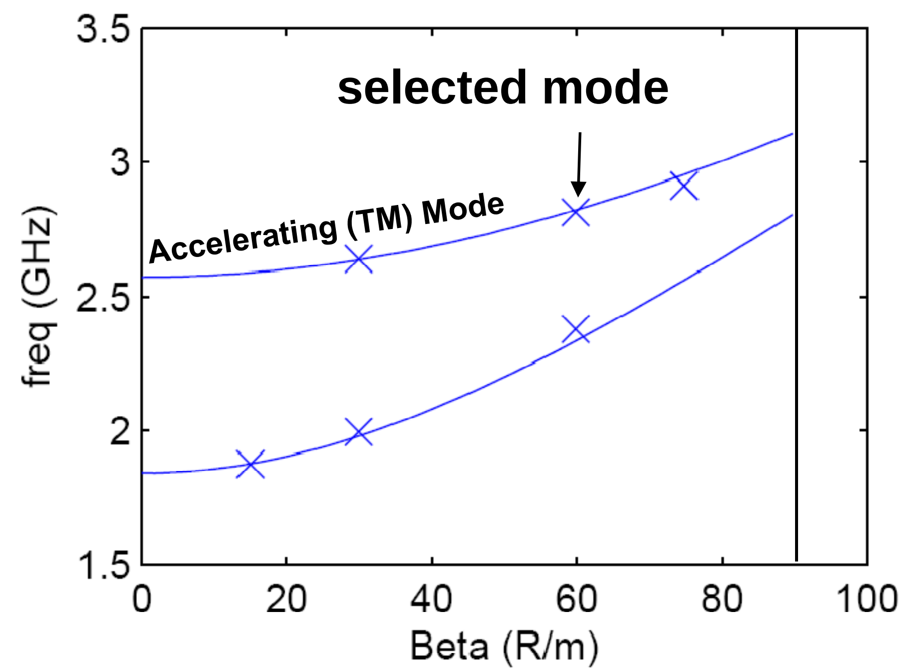
Dispersion Characteristics of Twisted Disk-Loaded Analog

Parameter	Value	Unit
Outer radius	5.493	cm
Inner radius	1.135	cm
Twist Rate	89.76	Radians/m
Phase advance per $\frac{1}{2}$ turn	$\frac{2\pi}{3}$	Radians
Notch angle	30	Degrees

Cross section and twist rate selected for operation at a velocity of c.

Solid lines = 2D frequency domain simulation

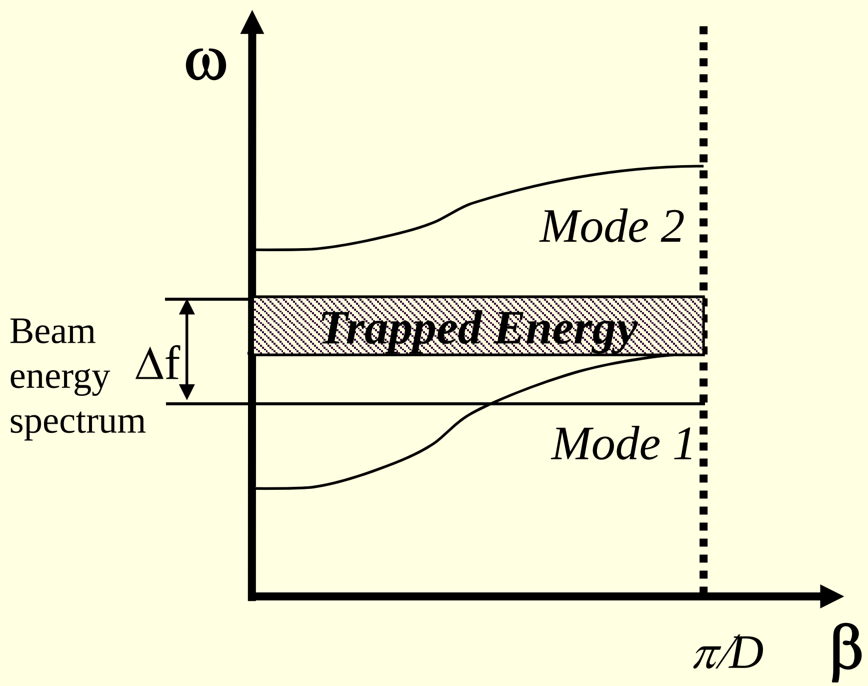
x's = experimental points



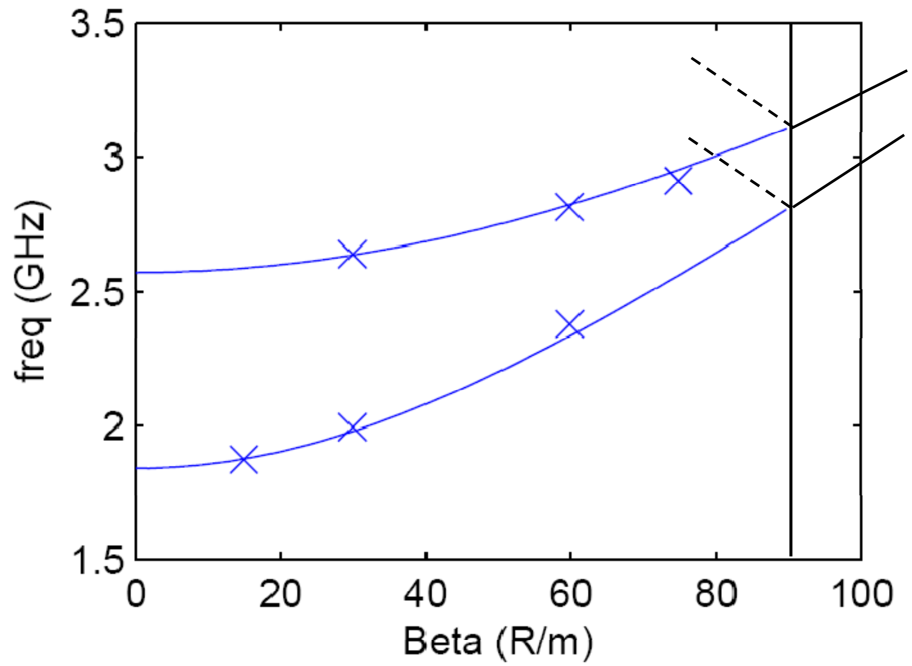
Trapped Mode Considerations

- Twisted guides – stop band does not appear above pi mode.
- Easier for modes to move out of the structure

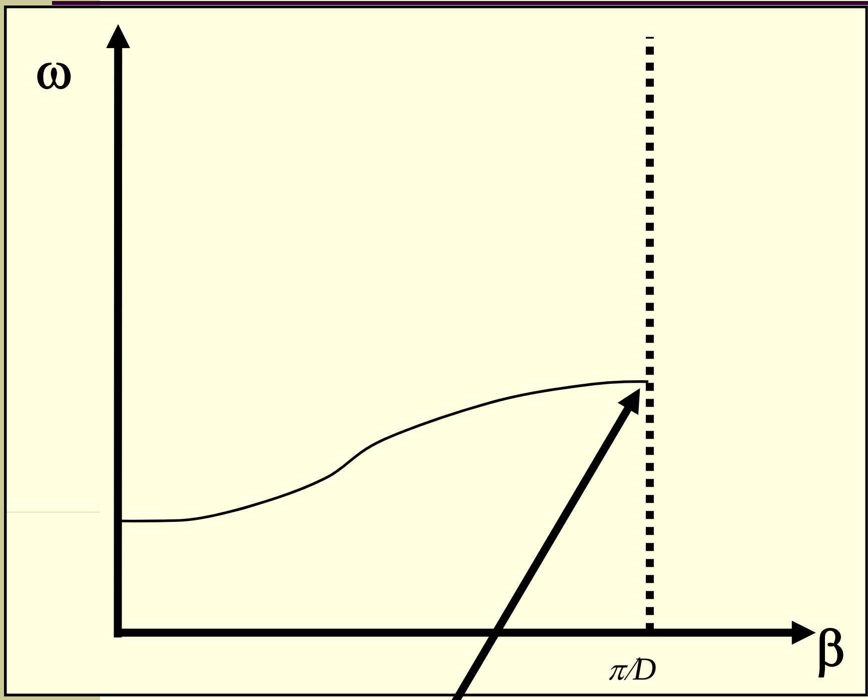
Stop bands hinder HOM damping.



Twisted case: modes actually continue indefinitely



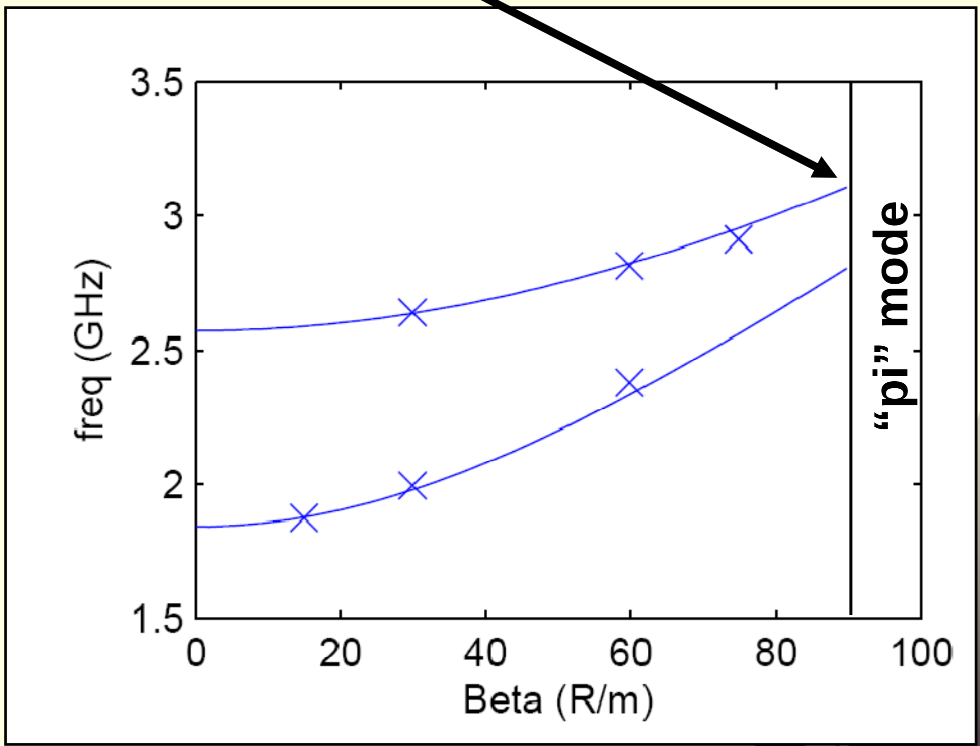
Pi mode and group velocity considerations



Reactively loaded accelerating structures: small or zero group velocity at pi mode.

“pi mode” means 180 degree phase shift per ½ turn

Twisted accelerating structures: nonzero group velocity at pi mode.



Conclusions

- Twisted waveguides support TM-like modes with velocities slower than c
- The presence of only the fundamental space harmonic along the axis enhances performance.
- Twisted guides can be designed to circumvent mode trapping problem.
- Offers possibility of easier manufacturing than conventional structures

Conclusions

- **Twisted waveguides are very neat and cool!**

Thank you!