A Novel SC RF Coupler Using the TE_{01} Mode in a Dielectric Loaded Coaxial Waveguide

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problem:

Superconducting cavity coaxial rf couplers:

- are mechanically complicated, expensive, and bulky,
- can take over a hundred hours to process due to multipactoring,
- and must withstand severe thermal gradients.

observation:

The TE_{01} mode in circular waveguide is a *miracle* mode that solves many problems. It has been applied to:

- high Q storage for pulse compression.
- low loss transmission
- high power rf windows
- high power fast switches
- an rf phase shifter
- pulsed heating & superconducting materials testing

thought:

Why not apply this mode to sc rf cavity couplers?

advantages:

- Absence of surface electric field eliminates multipactor in TE_{01} region, allowing fast rf processing.
- Absence of longitudinal currents allows a gap between thermally decoupled sections.

but:

At 1.3 GHz, the waveguide would need to be *larger* than the cutoff diameter for TE_{01}, d_c = 11.074” = 28.12 cm.

A mode launcher would be very bulky, either considerably larger in diameter (wrap-around) or quite long (rectangular-to-circular taper).

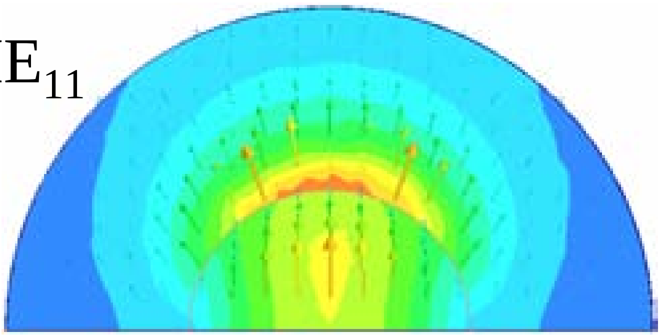
solution:

A coaxial rod of dielectric placed inside a circular waveguide can considerably lower the TE_{01} cutoff diameter ***and***, at the same time, reverse the mode order of TE_{01} and TE_{21}. With the latter cutoff, one can launch the former simply with a double feed.

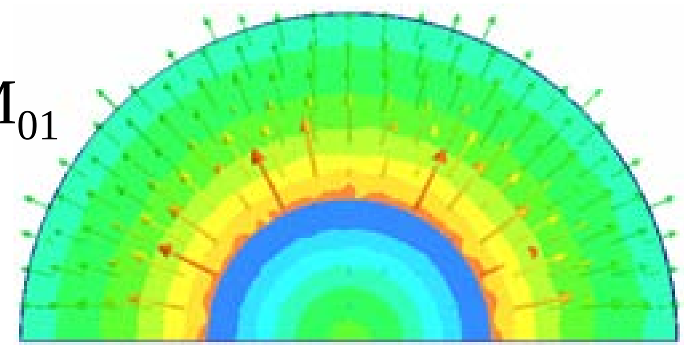
modes:

waveguide diameter = 14 cm
dielectric rod diameter = 6.1 cm
$\varepsilon = 9.7$

HE_{11}

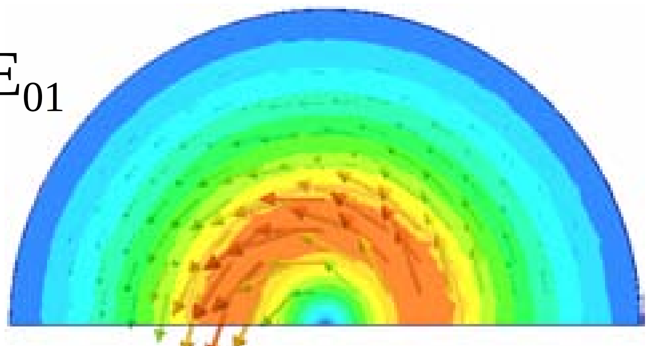


TM_{01}



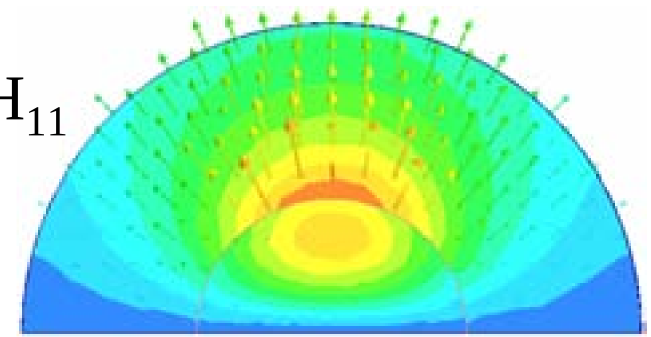
λ_g = 22.9 cm = 9.02”

TE_{01}

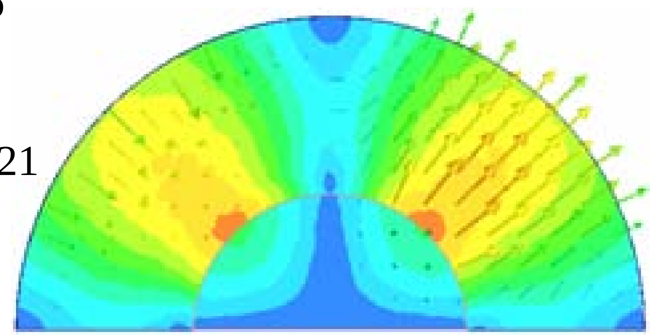


$\lambda_g \cong$ 34.5cm= 13.6”

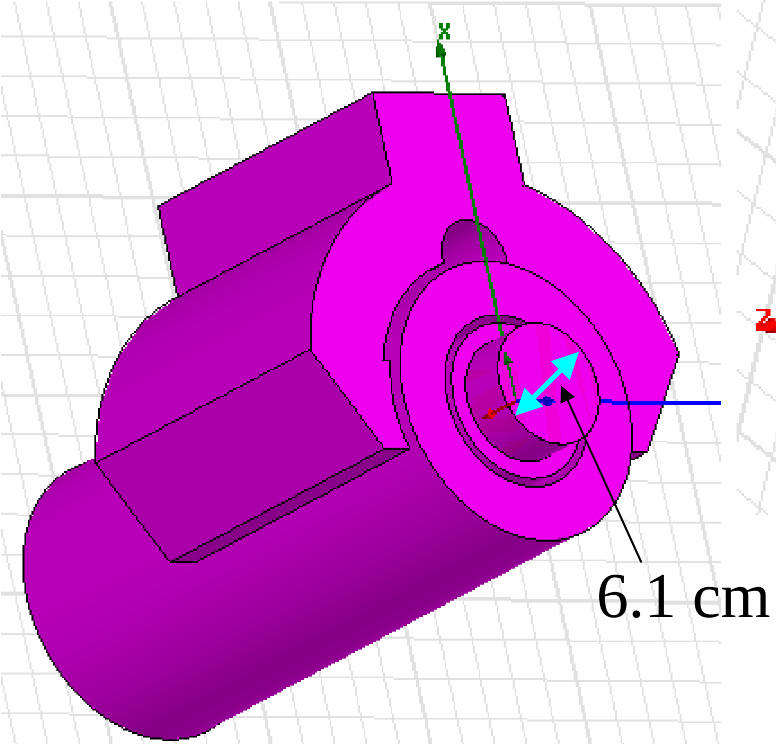
EH_{11}

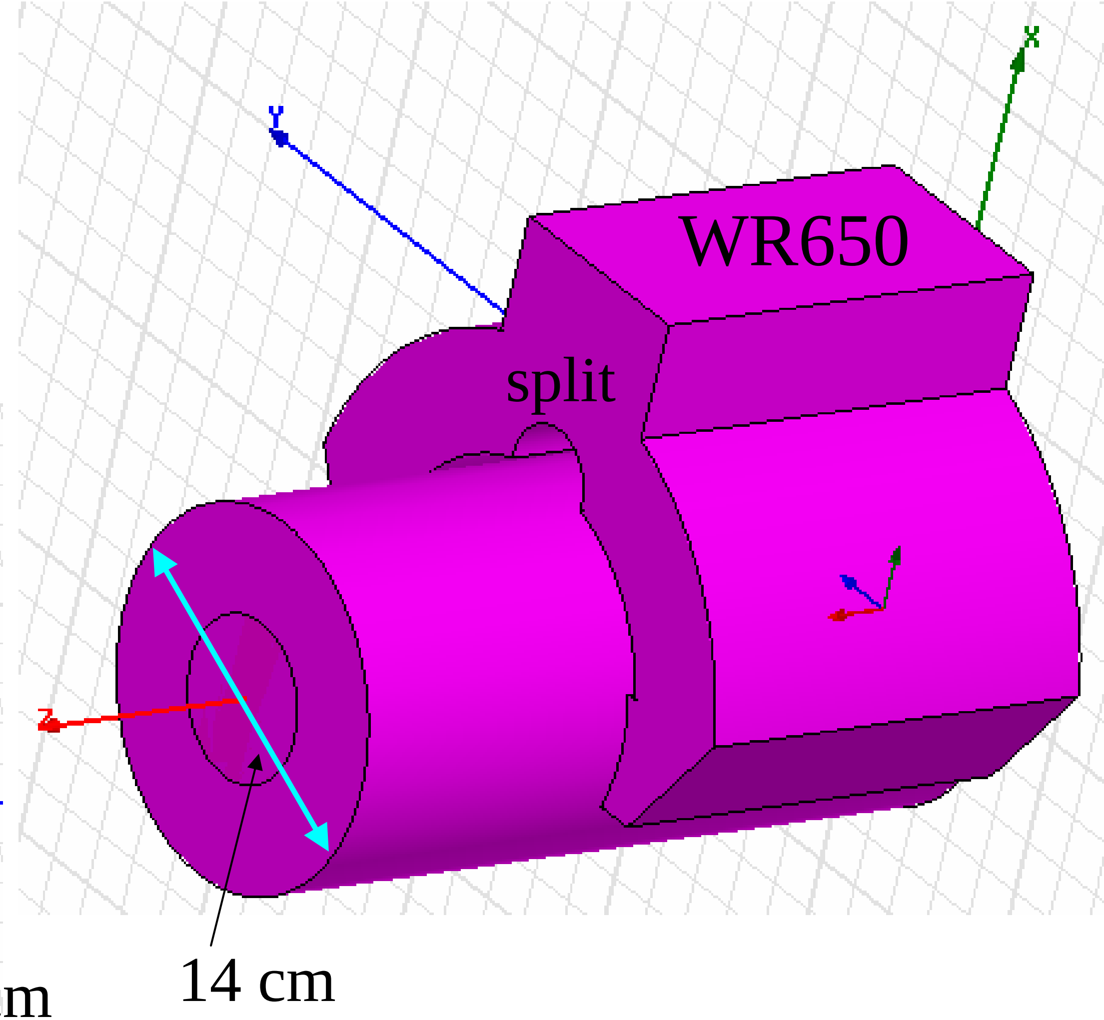


cutoff HE_{21}

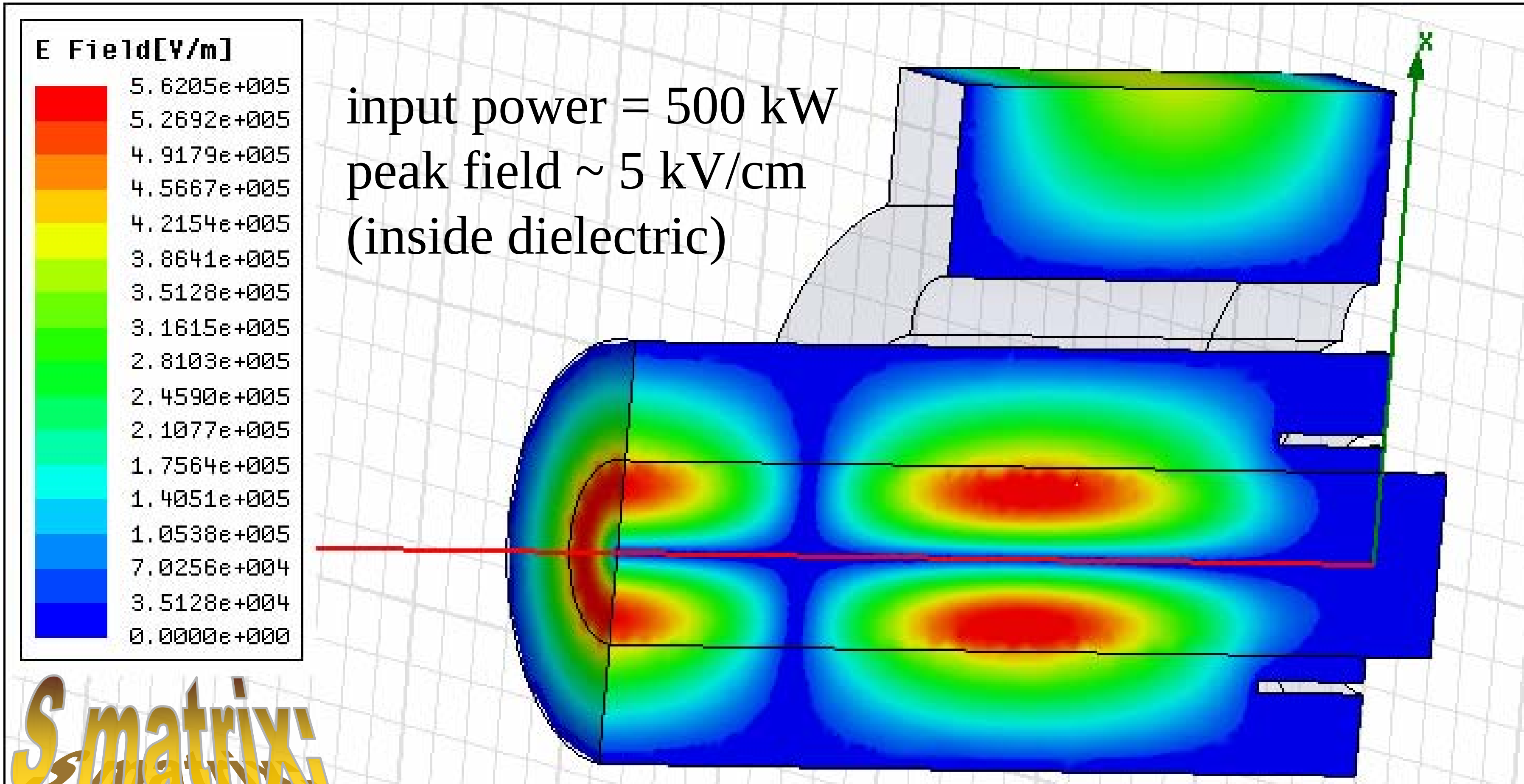


launcher:





field:

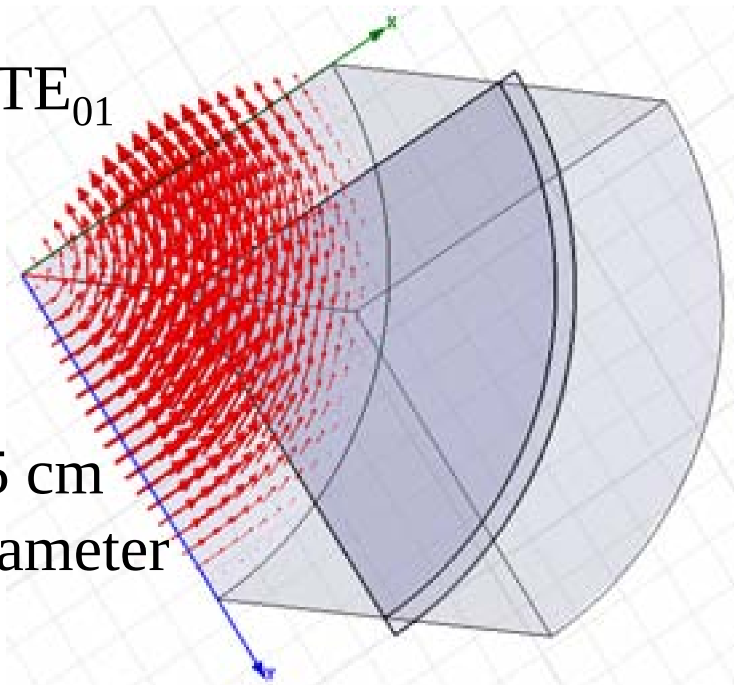


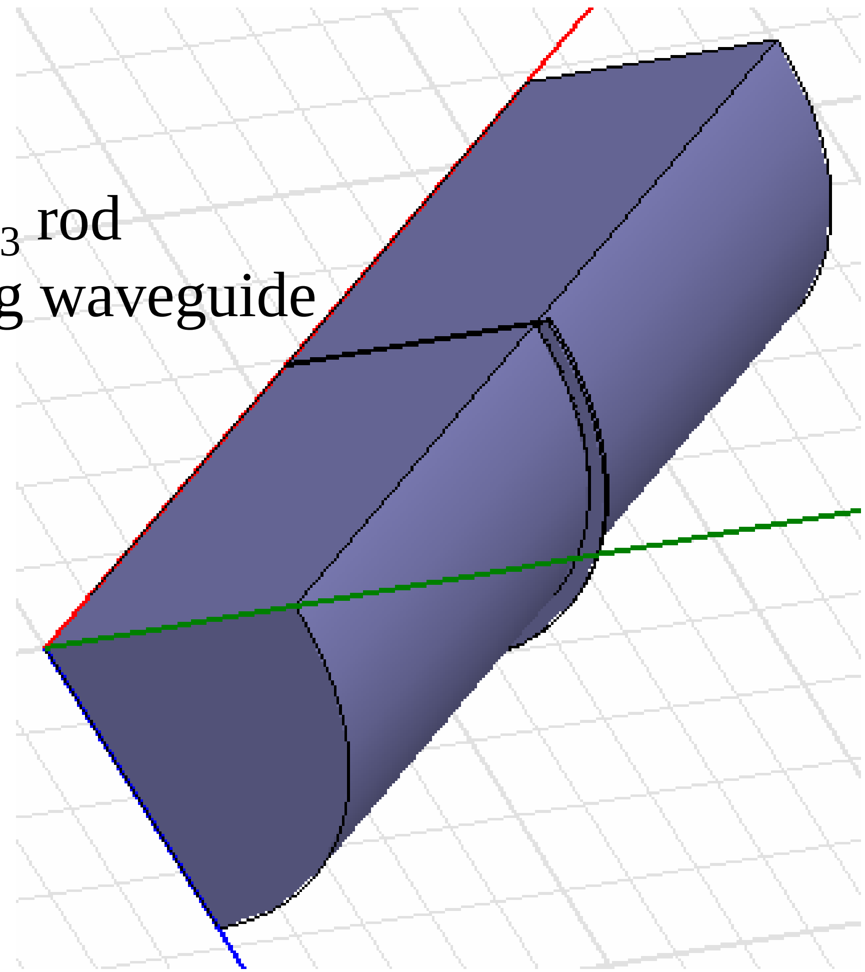
S matrix:

Freq		S:WavePort2:1	S:WavePort2:2	S:WavePort2:3	S:WavePort2:4	S:WavePort1:1
1.3 (GHz)	WavePort2:1	(0.87217, 127)	(0.020061, 132)	(0.48835, 77.9)	(4.3594e-005, 142)	(0.020683, -103)
	WavePort2:2	(0.020061, 132)	(0.069899, -75.9)	(0.070099, -119)	(0.0016971, -157)	(0.99489, -140)
	WavePort2:3	(0.48835, 77.9)	(0.070099, -119)	(0.86658, -151)	(0.00022389, -87.4)	(0.075146, 4.83)
	WavePort2:4	(4.3594e-005, 142)	(0.0016971, -157)	(0.00022389, -87.4)	(0.0014882, -0.118)	(0.0017944, -70.8)
	WavePort1:1	(0.020683, -103)	(0.99489, -140)	(0.075146, 4.83)	(0.0017944, -70.8)	(0.064246, -24.4)

windows:

1 mm gap
at interface between
warm and cold sections





WavePort1:1	(0.049153, -77.6)	(0.00082544, -38.5)	(0.036449, -153)	(0.00037183, -139)
WavePort1:2	(0.00082544, -38.5)	(0.048257, 31.8)	(0.00099019, -129)	(0.0018369, -98.4)
WavePort1:3	(0.036449, -153)	(0.00099019, -129)	(0.35788, 90.4)	(0.00062594, 87.3)
WavePort1:4	(0.00037183, -139)	(0.0018369, -98.4)	(0.00062594, 87.3)	(0.081314, -96)
WavePort1:5	(0.00059167, -97.3)	(0.00021073, -53.8)	(0.00042897, -126)	(0.00052917, -72)
WavePort1:6	(0.00011281, 162)	(0.00013672, 99.1)	(0.00021635, 168)	(0.00048987, -102)
WavePort1:7	(8.793e-005, -29.8)	(8.3215e-005, -99.4)	(0.00013324, 169)	(0.00022646, 114)
WavePort1:8	(0.00014093, 33.2)	(8.2768e-005, -122)	(0.0001201, -0.864)	(0.00015057, -49.5)
WavePort2:1	(0.97455, -138)	(0.0005176, -156)	(0.036007, 28.7)	(0.0016224, 92.7)
WavePort2:2	(0.00056798, 137)	(0.99883, -59)	(0.00094021, -45)	(0.0011825, 76.9)
WavePort2:3	(0.037681, 27.8)	(0.00061747, -16.5)	(0.87657, 171)	(0.00058512, -76.7)
WavePort2:4	(0.0016785, 132)	(0.0010901, -127)	(0.00034554, -25.9)	(0.97458, -170)
WavePort2:5	(0.00025323, 179)	(0.00028286, 15.9)	(0.00037918, 73.1)	(0.00016505, 159)
WavePort2:6	(0.00024744, 92.7)	(0.00048944, 110)	(7.5718e-005, 112)	(0.00016009, 134)
WavePort2:7	(0.00023516, -16.5)	(6.4999e-006, -154)	(6.6744e-005, 106)	(0.00037367, -14.3)
WavePort2:8	(0.0001685, -170)	(4.6638e-005, 18.2)	(0.0001791, -91.8)	(0.00052327, -81.7)

1 mm gap

99.766% transmission

0.236% reflection

Freq		S:WavePort1:1	S:WavePort1:2	S:WavePort1:3	S:WavePort1:4
1.3 (GHz)	WavePort1:1	(0.48753, -97.3)	(0.00043546, -132)	(0.11037, 86)	(0.0026959, -6.53)
	WavePort1:2	(0.00043546, -132)	(0.4406, 21.4)	(0.0010617, -166)	(0.0017539, -152)
	WavePort1:3	(0.11037, 86)	(0.0010617, -166)	(0.92852, 134)	(0.00045429, -91.5
	WavePort1:4	(0.0026959, -6.53)	(0.0017539, -152)	(0.00045429, -91.5)	(0.68553, -78)
	WavePort2:1	(0.64867, -155)	(0.00037367, 21.2)	(0.11115, -93.8)	(0.0020715, 21.4)
	WavePort2:2	(0.00039669, 105)	(0.8977, 111)	(0.00080201, -143)	(0.00033916, 78.2
	WavePort2:3	(0.11179, -94.1)	(0.001019, 178)	(0.24118, -147)	(0.00048531, 32.1
	WavePort2:4	(0.0011089, 46.6)	(0.0012699, 91.6)	(0.00077955, 30.8)	(0.72262, 12)

1 cm gap

80.59% transmission

19.41% reflection

ceramic:

NTK model # HA-997*

99.7% pure Alumina

ε= 9.8–9.9

tan $\delta = 3\times10^{-5}$ (8 GHz)

specific gravity = 3.95

Three Main Causes of Ceramic Breakdown:

1. voids (high field)	s.g. close to ideal (4)
2. binder (heating due to large tan δ)	high purity
3. multipactoring	no E-field $\perp$ to surface

* Data provided by H. Matsumoto of KEK

coupling to cavity:

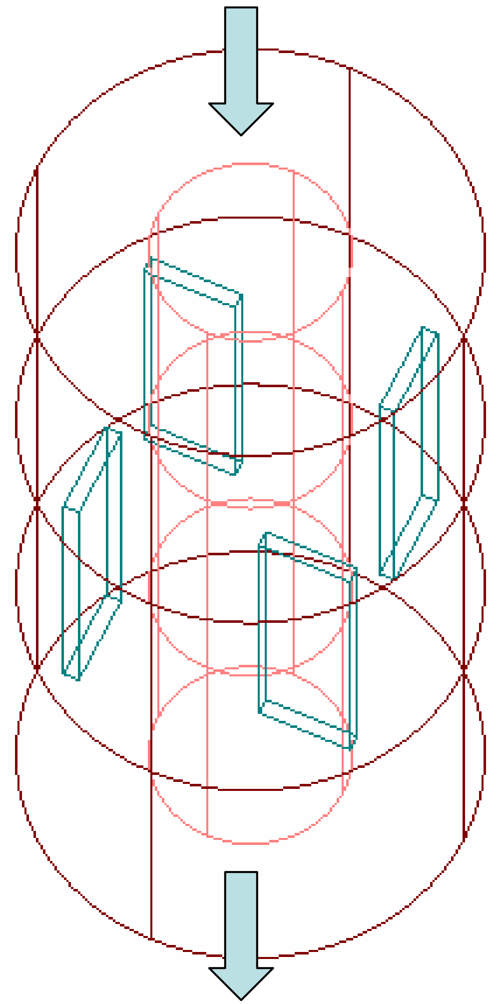
For coupling to the cavity without bringing ceramic close to the beam, conversion to a coax TEM mode might be desired.

This is straightforward if one can first convert TE_{01} to TM_{01} in the ceramic coax guide. This, however is not straightforward, since these modes are “absolutely” orthogonal.

Furthermore, the conversion section must be compact to fit in inner envelope of cryostat. Since λ_0=9.079”=23.06cm, adiabatic coupling is not an option.

Some ideas follow.

TE_{01}

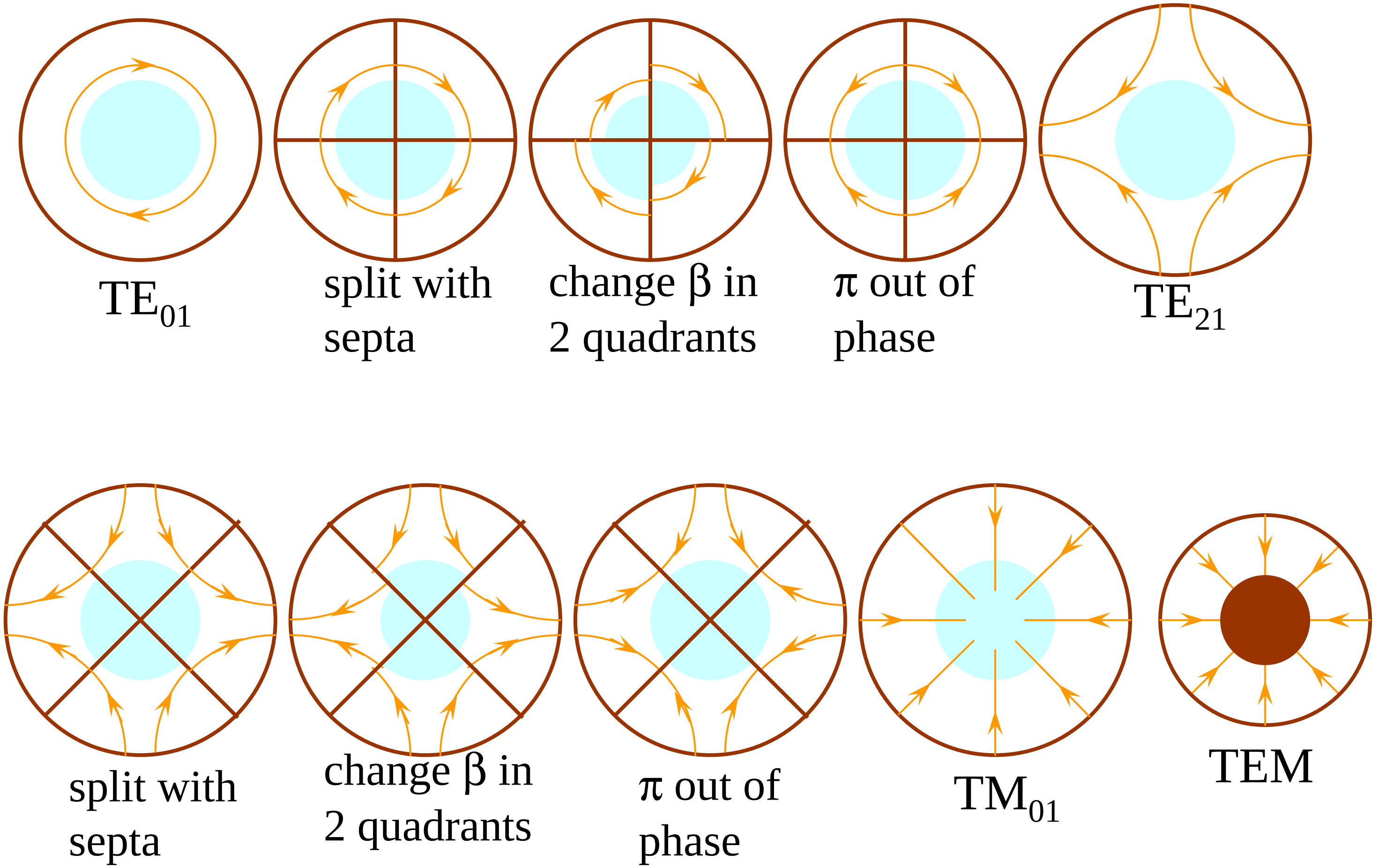


Angled fins can be introduced to couple TE_{01} and TM_{01}, but they give too little too slowly.

(And require the full 360° geometry to be modeled despite the azimuthal symmetry of both modes!)

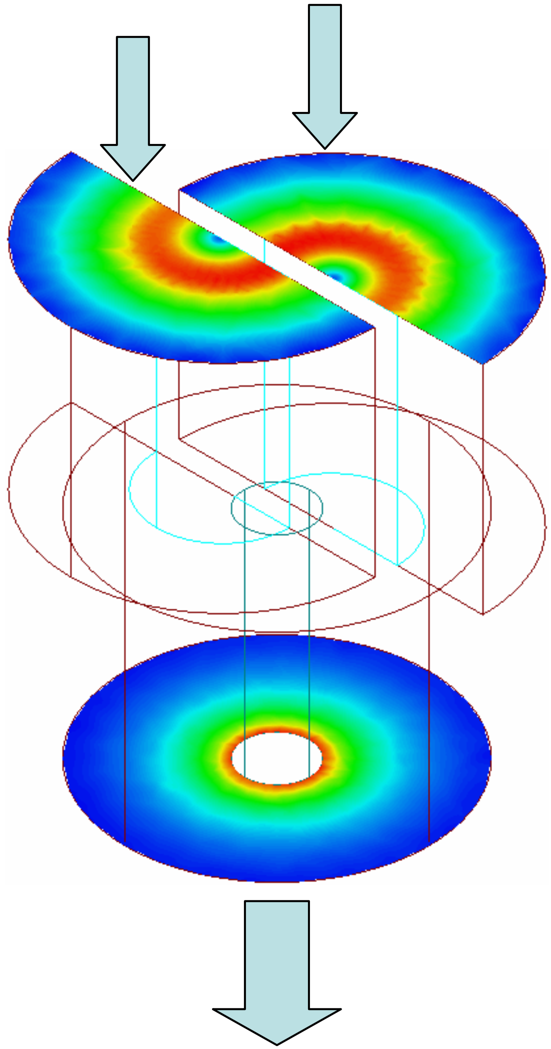
	port1:m4	
	(0.01451, 54.495)	
	(0.01365, 3.999)	
	(0.05996,-136.941)	
	(0.07499, -82.343)	
	(0.07126,-112.745)	
	(0.01455, -76.424)	
	(0.01849,-129.028)	
	(0.00633, 138.365)	
TM_{01}	(0.17427,-134.466)	3% in 10 cm
TE_{01}	(0.97680, 37.479)	
	(0.01351, 160.016)	
	(0.00405, 172.505)	

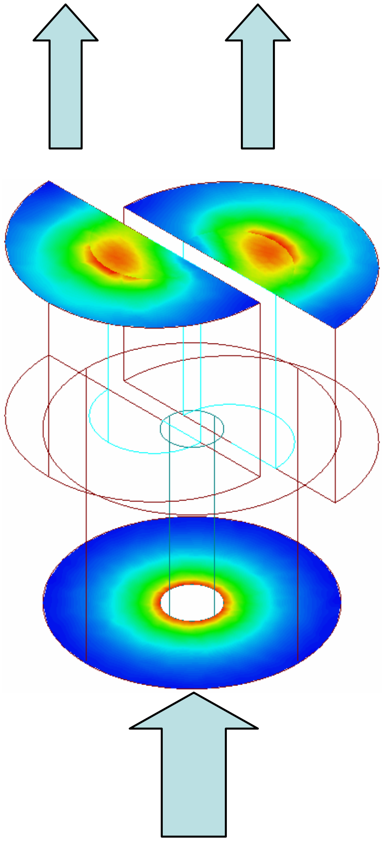
We could couple through TE_{21} as follows:



but the phase slip sections would make it rather long.

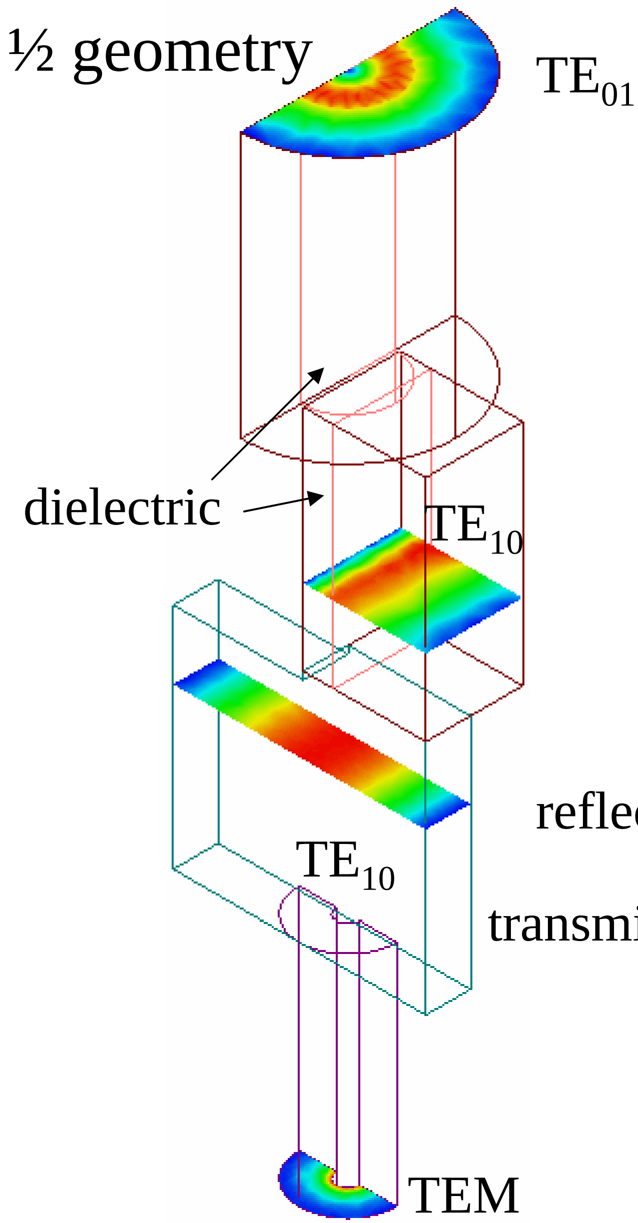
TE01 could be coupled to a coax TEM mode after splitting and shifting, but the shifting would have to be done without coupling in 11 modes.





Dipole content should be blocked by symmetry from propogating past split.

This could work after junctions are matched.



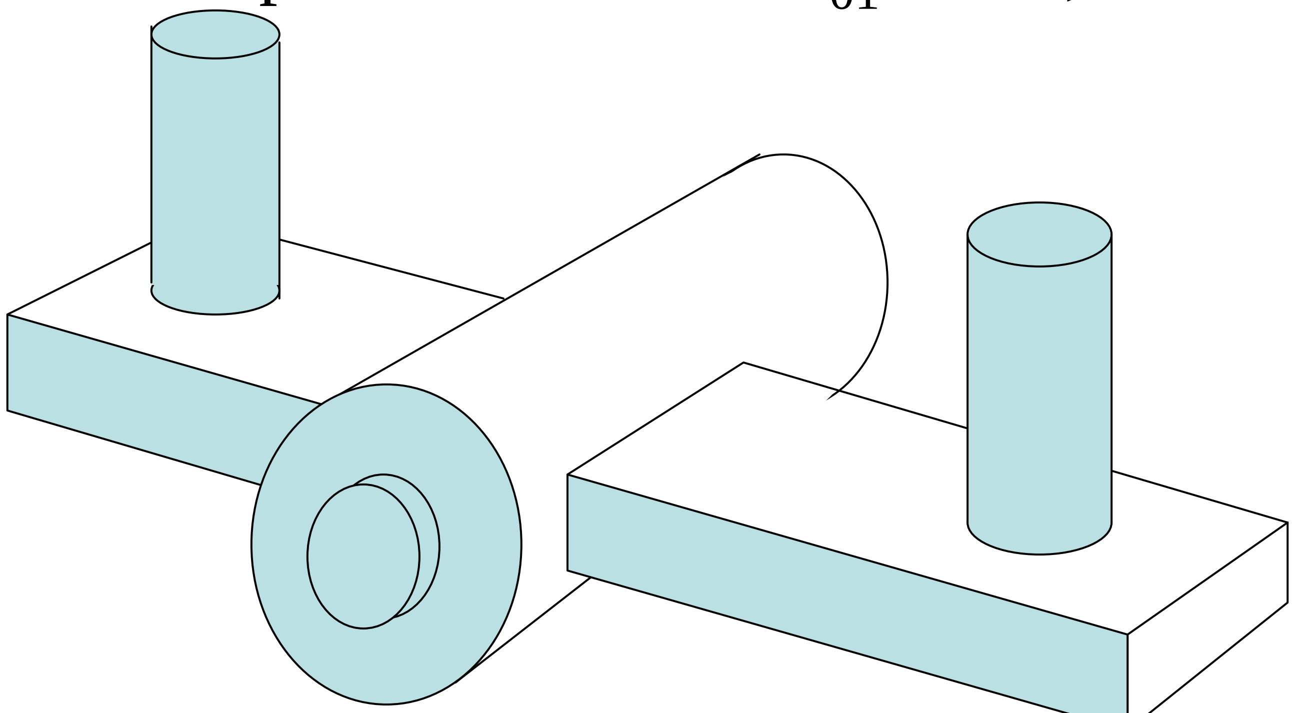
port1:m2		
	(0.02465, -32.596)	
reflection	(0.85000, -144.392)	~72.3%
	(0.03365, 89.471)	
transmission	(0.52513, -131.514)	~27.6%

full geometry

double coupler?:

double coupler?:

If space permits, one could use the launcher geometry to extract the power from the TE_{01} mode,



perhaps going to *two* TEM coax feeds to power adjacent structures (if power handling permits). Such a superstructure would have *no power flow* across the superconducting joint.

conclusion:

We present a novel method of coupling rf into a cryomodule using the circular TE_{01} mode for powering superconducting accelerating structures.

Advantages include:

- eliminating multipactoring along most of the coupler,
- windows with no field at the braze joint,
- and a thermally insulating gap between sections at different temperatures, reducing heat leak and stresses.

We would like to:

- complete the rf design,
- produce a mechanical design,
- fabricate a prototype using ceramic obtained through Matsumoto-san of KEK,
- and test it at DESY with the help of W.D. Moeller.