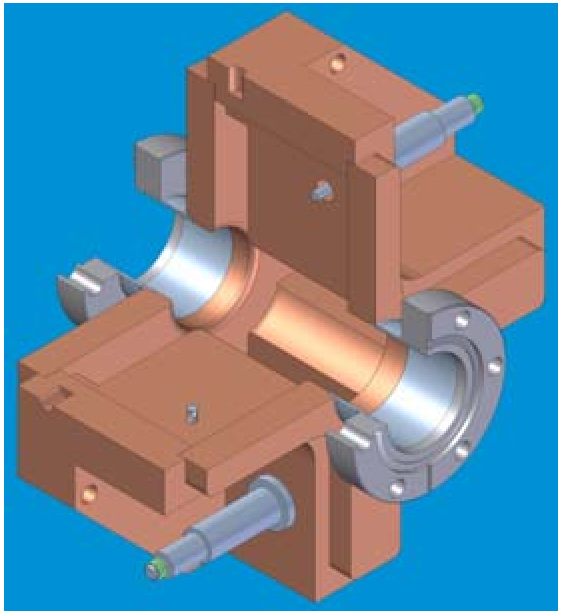
S-Band Cavity BPM For ILC



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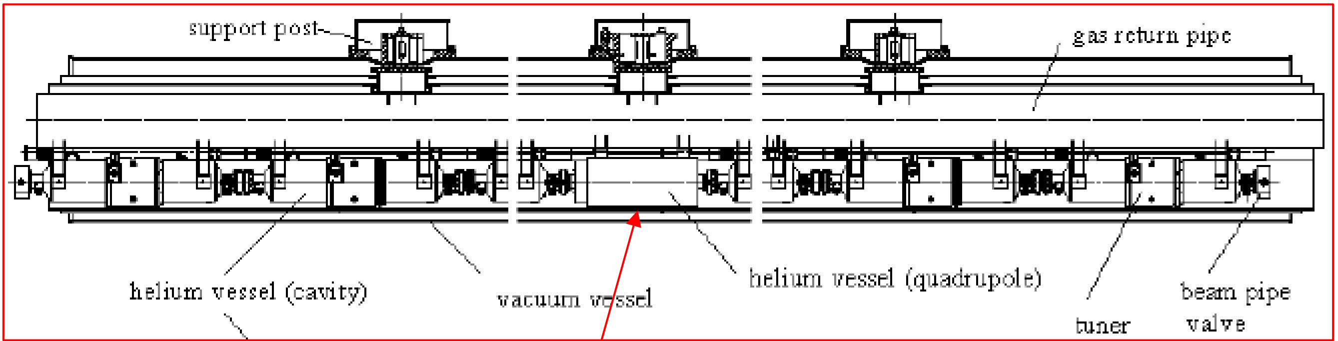
Content

- Design requirement
- Selective coupling scheme
- Beam simulation
- Resolution estimation
- Mechanical tolerance
- S-band prototype

ILC Cryomodule



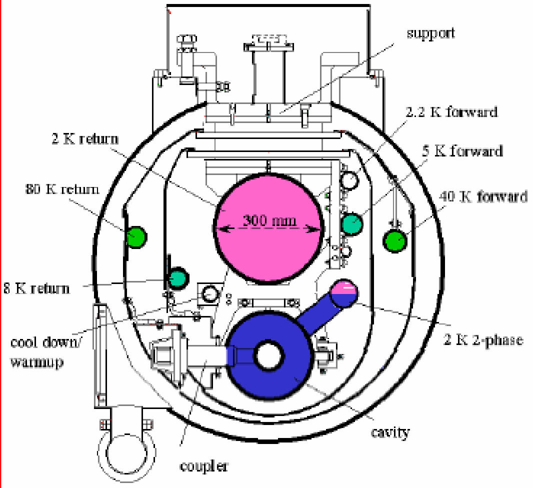


Figure 3.2.11: *Cross section of cryomodule.*

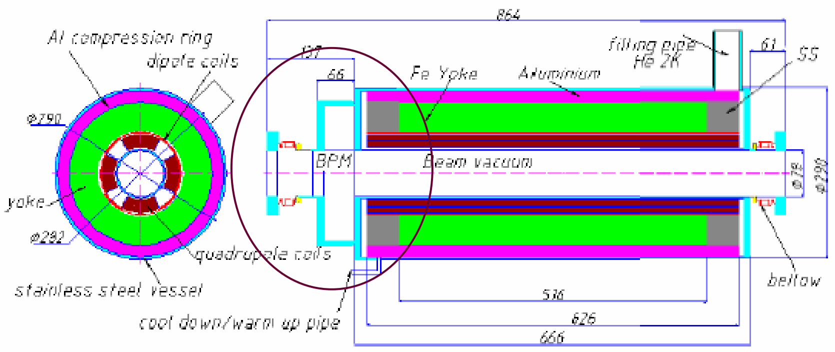


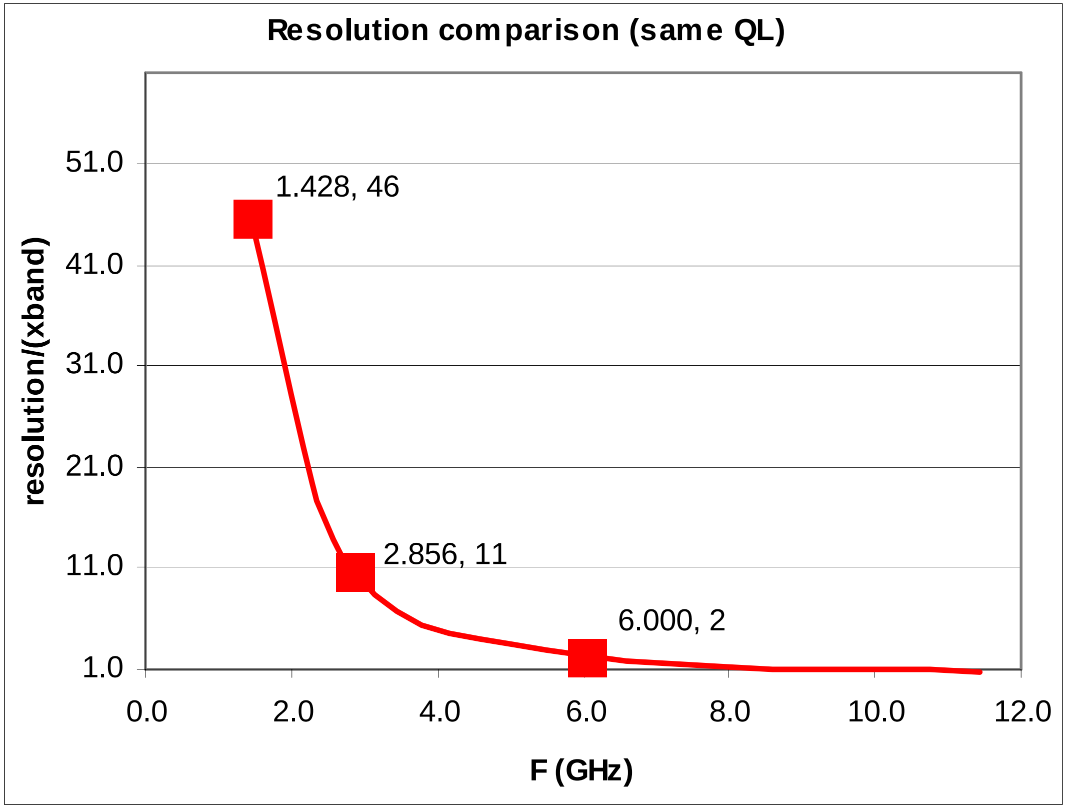
Figure 3.2.12: *Cross-section and longitudinal cut of superconducting magnet package.*

Space tight

Design Considerations

- Resolution requirement: 1 μm
- Response time < bunch spacing (300ns) – Q~500
- Need to fit in tight space
- BPM in cryomodule clean environment, need be cleanable
- Choice of frequency: L or S band
- Beam pipe radius:
  - 30-mm
    - L-band good choice, but BPM large in dimension
    - S-band is possible
  - 17.81-mm (1.5 inch OD) (Chris)
    - Both S and L band
    - Beampipe need to step down from 30 to 17.81mm. Wakefield is OK (Bane)
- Prototype design: S-band with 17.81mm beampipe radius

Resolution v.s. Frequency

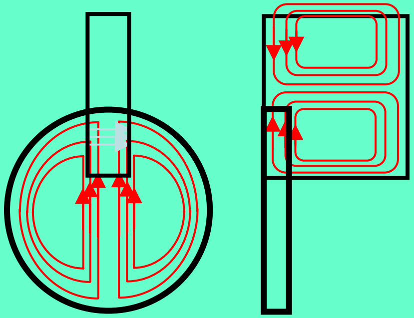


- Comparison
  - Beampipe radius is 5mm for all cavities
  - Resolution is relative to X-band resolution

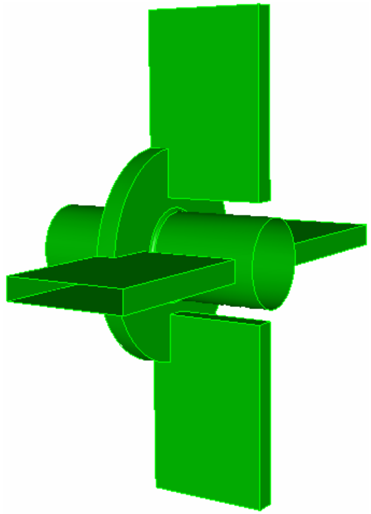
- Beam pipe radius limits cavity frequencies to lower than the C-band

TM11-TE10 Selective Coupling

TM11 couple to TE10

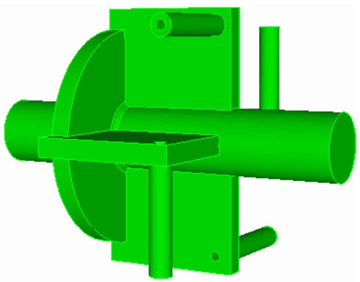


Matched to coax



- Waveguide does not cut through the beampipe
- Waveguide matched to coax
- Need “larger” space for the waveguides
- Not easy to clean
- No waveguide modes

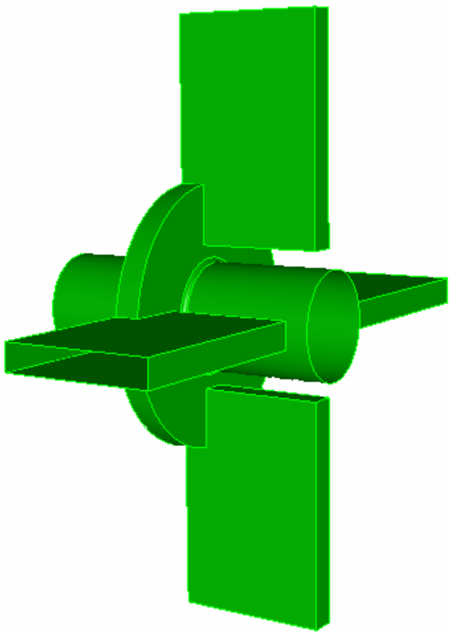
Coax coupling

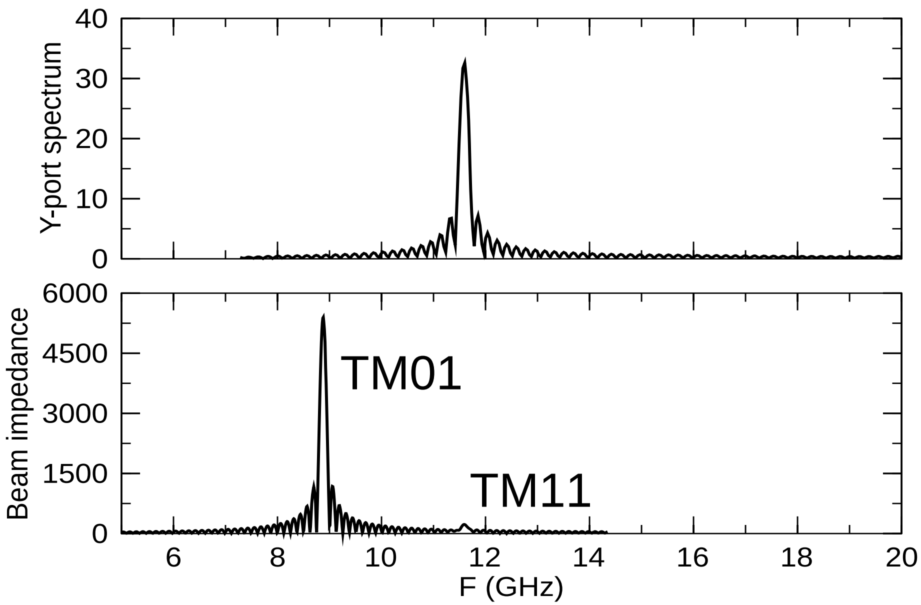


- Waveguide cut through beampipe
- Easy to clean
- Overall size small
- Coax do not need to be fully matched
- Coax adaptor far from cavity so not couple to other modes
- Will have waveguide modes?

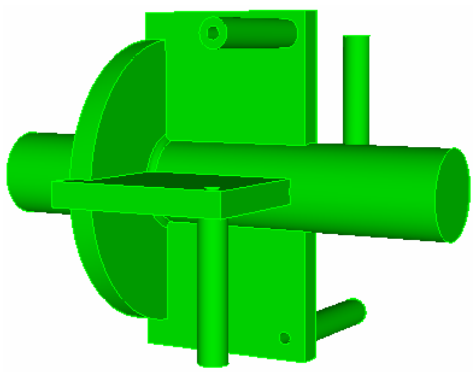
X-band Design For NLC

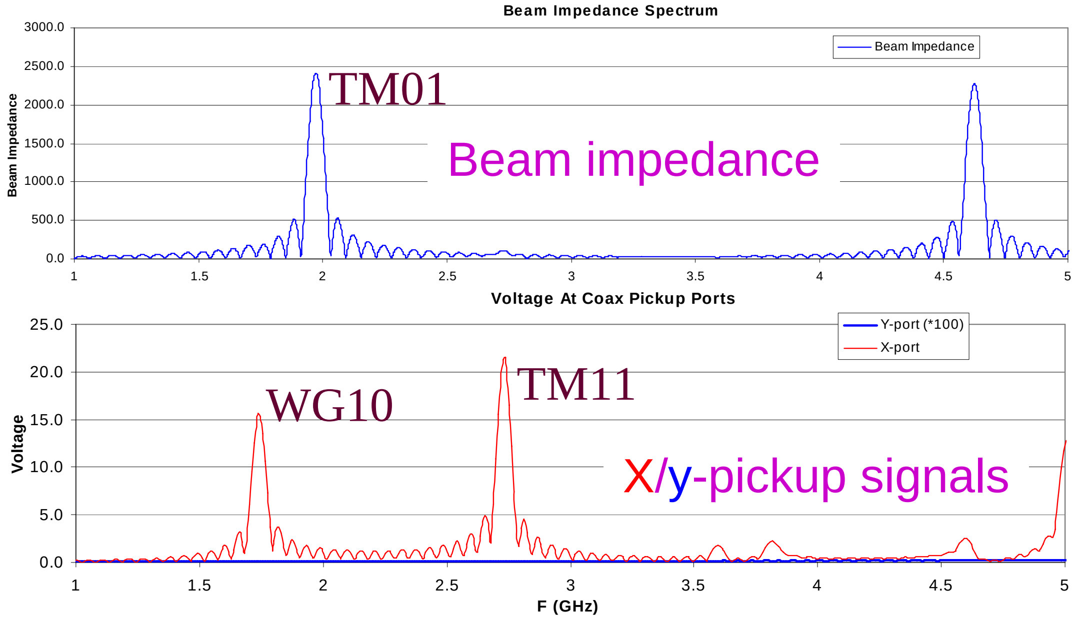
- Waveguide does not cut through beampipe
- Waveguide matched to coax





S-band Cavity BPM Spectrum

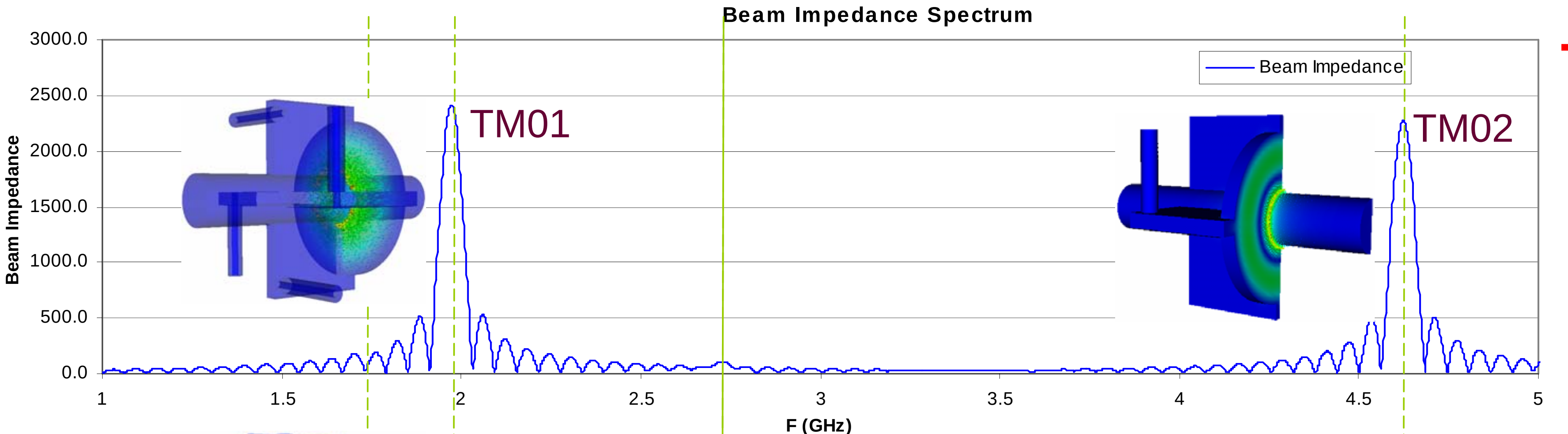


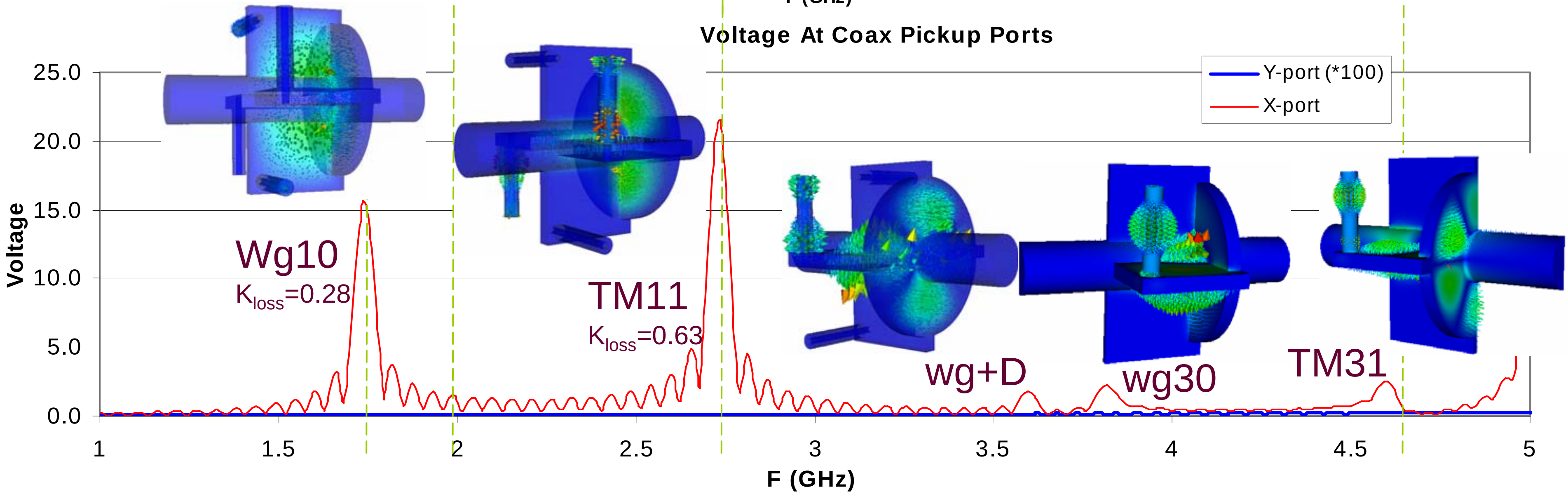


Time domain Simulation

- Beam off in x direction
- One more dipole like mode below TM01 frequency. Waveguide dimensions were chosen to have this mode much lower in frequency so can be easily filtered. Only TM11 mode will be used for position measurement
- No significant x-y coupling
- No significant TM01 coupling

Beam Impedance And Pickup Spectrum In Detail





RF Parameters That Affect Resolution

- Beam-cavity interaction – loss factor
  - Position signal strength
- Thermal noise
  - N/S ratio
- Mode contamination (TM01,02…)
  - Dynamic range
- Others, instrumentation, etc

Thermal Noise

- Position signal

$$V_{dipole} = qx\sqrt{Z_0 \frac{k_{loss,TM11}}{2} \frac{\omega_0}{Q_L} \frac{\beta}{1+\beta}}$$

(1/2 is due to the power splitted to two pickups)

Cavity gap (mm)	Kloss_11 (V/nC/mm^2)
10.000	0.633
15.000	0.998

$$V_{dipole} = 0.78 \cdot 10^{-6} V/(nC \cdot nm)$$

$$\text{cavity gap} = 10\text{mm}, \text{Q}_\text{L} = 500$$

- Thermal Noise

$$V_{therm} = \sqrt{Z_0 kT\Delta F}$$

$$V_{therm} = 1.1 \cdot 10^{-6} V$$

$$\text{at } 300^0\text{K}, \Delta\text{F} = 5.6\text{MHz}$$

- NS ratio

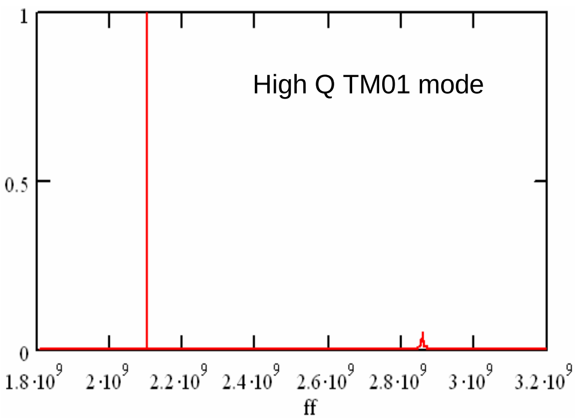
$$\frac{V_{dipole}}{V_{therm}} = qx\sqrt{\frac{\pi}{kT} \frac{\beta}{1+\beta} k_{loss,TM11}}$$

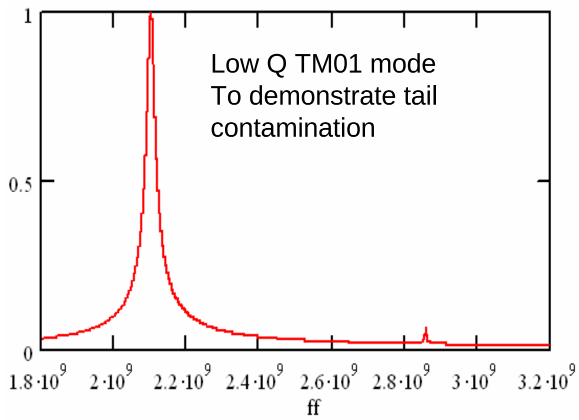
$$\frac{V_{dipole}}{V_{therm}} = 0.7/(nC \cdot nm)$$

Mode Contamination

TM01/02 mode leakage

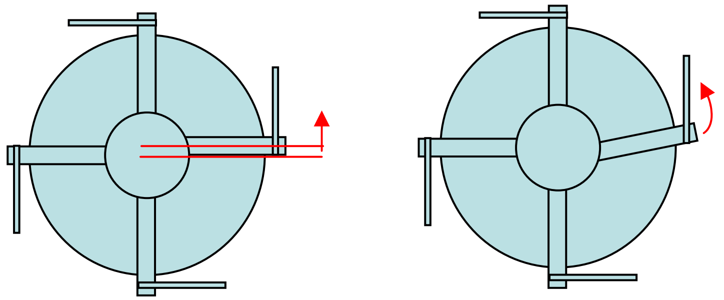
- Mechanical imperfection
- Evanescent coupling if coax adaptor too close to cavity
- Q finite, large tail signal at dipole frequency





TM01 Leakage Due To Imperfection

- Azimuthal offset and azimuthal rotation of a waveguide cause TM01 to TE01 coupling
- Coupling mechanism for both type misalignments is similar
- The radial offset of waveguide is less important



- Consider the +x waveguide is off 0.5mm in the y direction
- The tail of the TM01 mode at the dipole frequency is still much smaller than dipole signal at 1nm beam offset
- The mechanical tolerance on waveguide position is reasonably loose

F (GHz)	2.1
Kloss (V/nC)	150
Q0	1.0E+10
Qext (0.5mm offset)	5.0E+06

$V_{TM01}(2.856GHz)=2.3*10^{-8}\ V$

$V_{TM11} = 0.78*10^{-6}\ V/(nC.nm)$

TM01 Leakage Due To Evanescent Coupling

- Coax adaptor is far from the cavity
- Evanescent coupling for the S-band prototype is negligible
- Need to evaluate if need more compact waveguide design

Wakefield

- Selective coupling result in high Qs of TM01/02 modes
- Wakefield damping needed
- Scheme
  - Coupling probes on cavity end wall?
  - Should not break mode symmetry
- How low should Q_{ext} be? 1E+5?

Resolution Of The X-Band Design

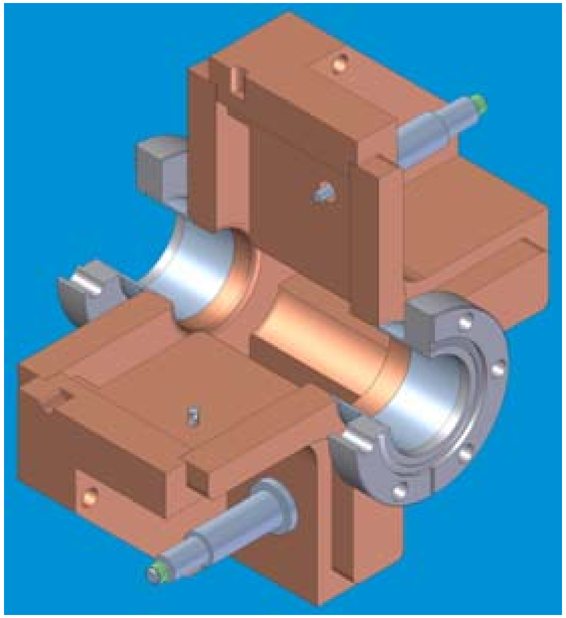
F (GHz)	Cavity gap (mm)	Rpipe (mm)	Kloss (V/nC/mm^2)	Theoretical Resolution (nm/nC)
2.856	10	17.81	0.63	1.5
2.856	15	17.81	1.00	1.2

- Assuming point charge
  - need to scale by thee bunch spectrum for finite bunch length
- No cable attenuation included
- Assuming reasonable mechanical tolerance achieved

  (e.g. <0.5mm azimuthal offset for the waveguides)

S-Band Cavity BPM Prototype

Frequency (GHz)	2.856
External Q	553
Beam pipe radius (mm)	17.81
Cell radius (mm)	60.0
Cavity gap	10.0
Waveguide radial dimensions (mm)	70.0
Waveguide axial dimension (mm)	75.0
Waveguide height	10.0



Summary

- S-band prototype cavity BPM was design for the ILC
  - Selective coupling scheme to reject TM01 mode
  - Compact coupling waveguide to save space
  - Waveguide dipole like mode frequency was designed 1 GHz lower than the position dipole mode so can be filtered
- Much better than 1 micron resolution can be achieved
- Tolerance is reasonably loose
- Prototype dimensions are being finalized