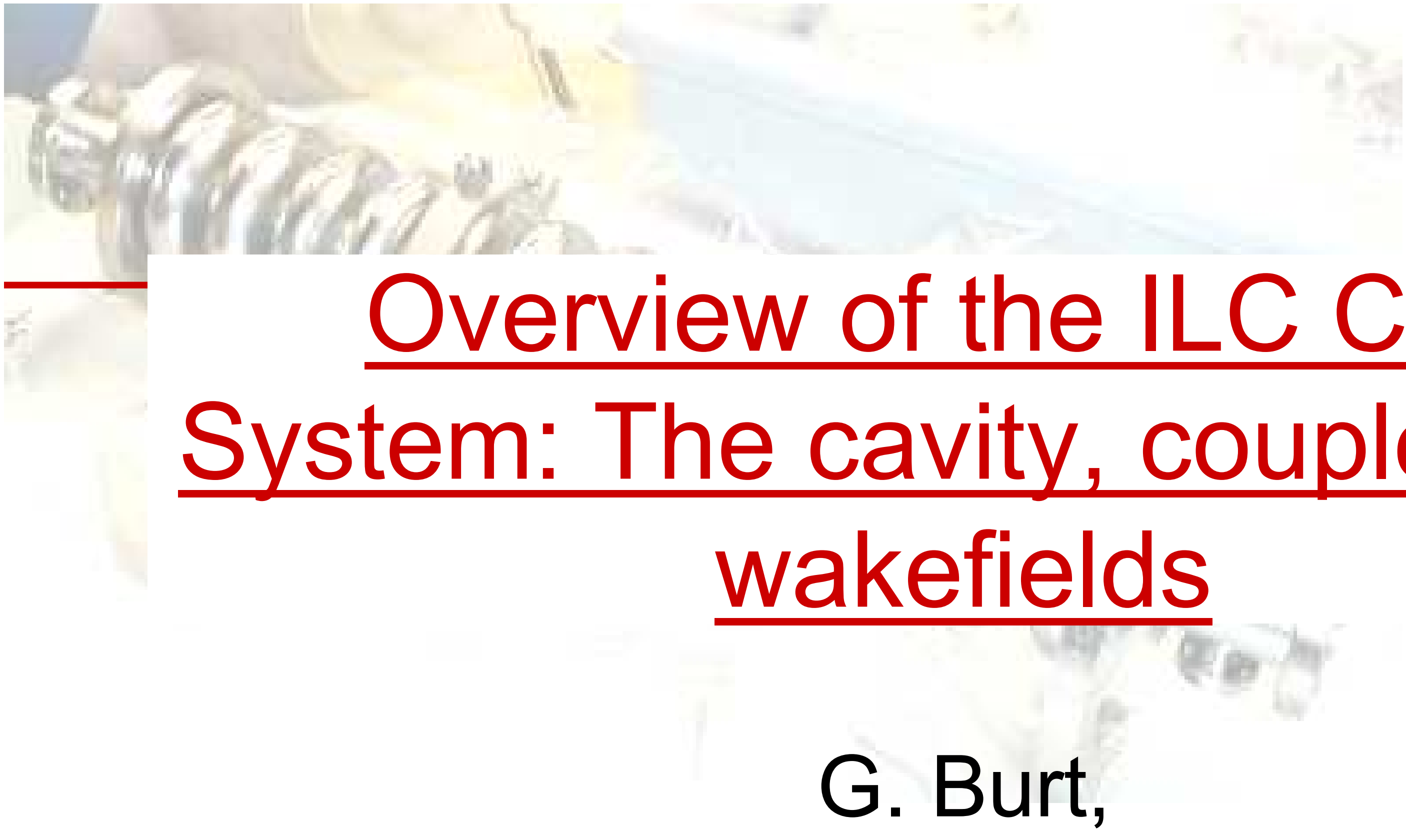

Overview of the ILC Crab System: The cavity, couplers and wakefields

G. Burt,

Cockcroft Institute/ Lancaster University

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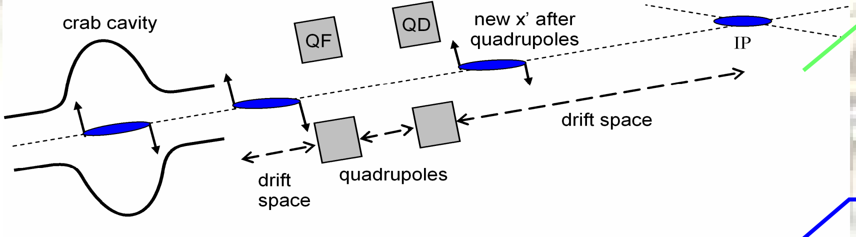
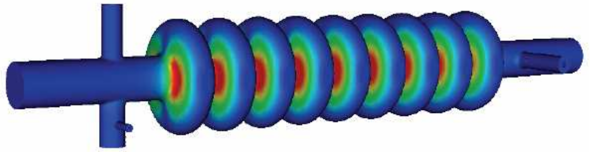
ILC Crab Cavity Collaboration Team

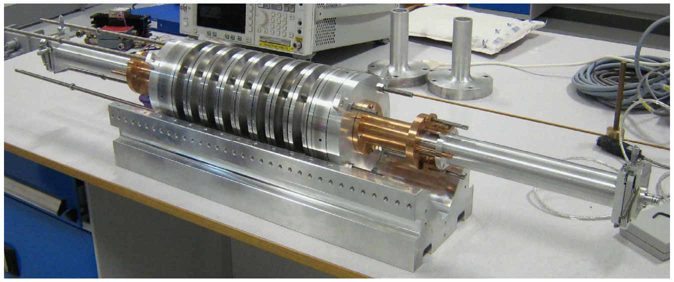
- Cockcroft Institute:
  - Graeme Burt (Lancaster University)
  - Richard Carter (Lancaster University)
  - Amos Dexter (Lancaster University)
  - Imran Tahir (Lancaster University)

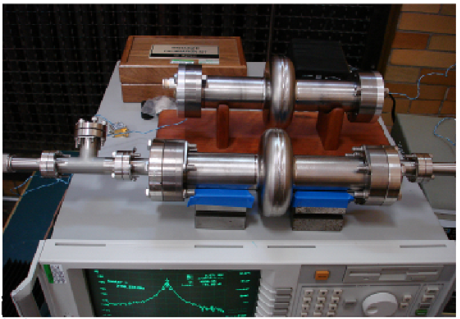
  - Philippe Goudket (ASTeC)
  - Alex Kalinin (ASTeC)
  - Lili Ma (ASTeC)
  - Peter McIntosh (ASTeC)
- FNAL:
  - Leo Bellantoni
  - Mike Church
  - Timergali Khabiboulline
- SLAC:
  - Zenghai Li
  - Andrei Seryi
  - Liling Xiao

Crab Cavity Development









2005 14mR Crab System Specification Developed:

- 0.095° RMS relative phase stability
- 0.33 % RMS beam energy jitter
- 2.64 MV rotational field required for 1 TeV CM

2006 ILC Crab Cavity Design Developed:

- 3.9 GHz superconducting RF cavity
- 9-cell configuration
- Independent LOM, SOM and HOM couplers

Jul 2007 ILC Crab Cavity Design Model Verified:

- Modular multi-cell aluminium model designed & built
- Bead-pull & stretched wire measurements completed
- MAFIA & MWS simulation results confirmed

Sep 2007 Single-cell SRF Cavities Built and Verified:

- 3 x single-cell cavities fabricated at Niowave Inc. USA
- Vertical tests showed > 7 MV/m achieved - no quench
- Low Qo (3e8)

Technology Choice

CKM Cavity design parameters

3.9 GHz

13 cells   length = 0.5 m

B_{max} = 80 mT

E_{max} = 18.6 MV/m

L_{eff} = 0.5 m

$P_{\perp}$ = 5 M V/m

Courtesy: FNAL

Our recommendation to the GDE has been to develop a cavity based on a Fermi-lab design.

To tune the cavity and to avoid spurious mode excitation, the number of cells must be optimised against overall length and new couplers designed.

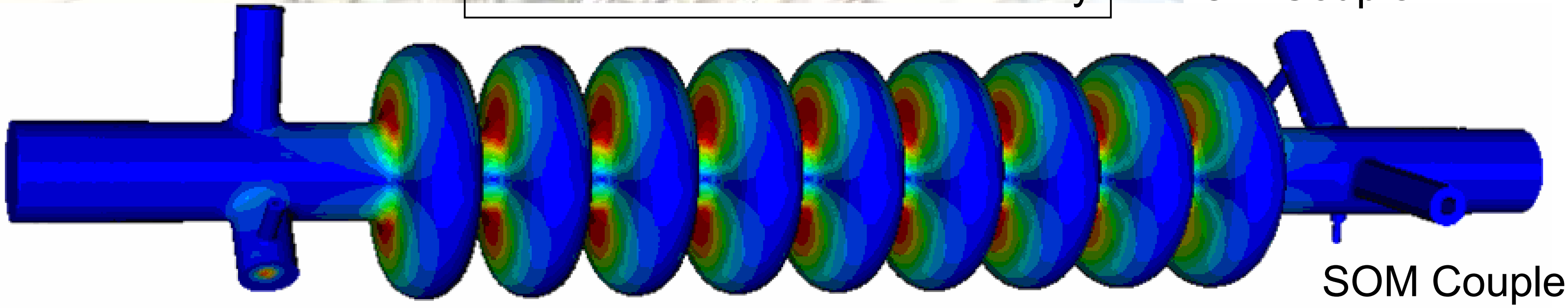
A 3.9 GHz cavity was favoured it is compact longitudinally and transversely.

ILC Crab Cavity Design

Input Coupler

Based on the FNAL CKM Cavity

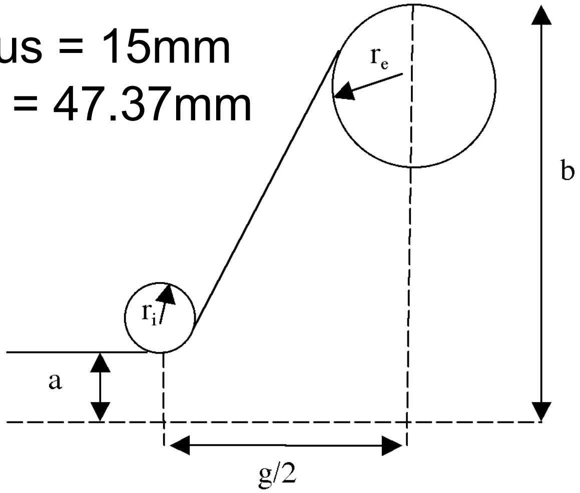
LOM Coupler

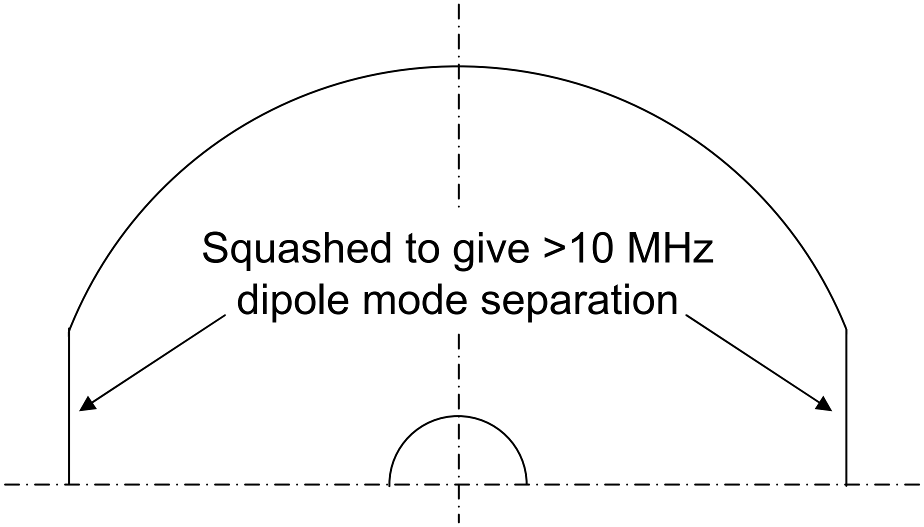


SOM Coupler

HOM Coupler

Beam-pipe radius = 15mm
Equator Radius = 47.37mm





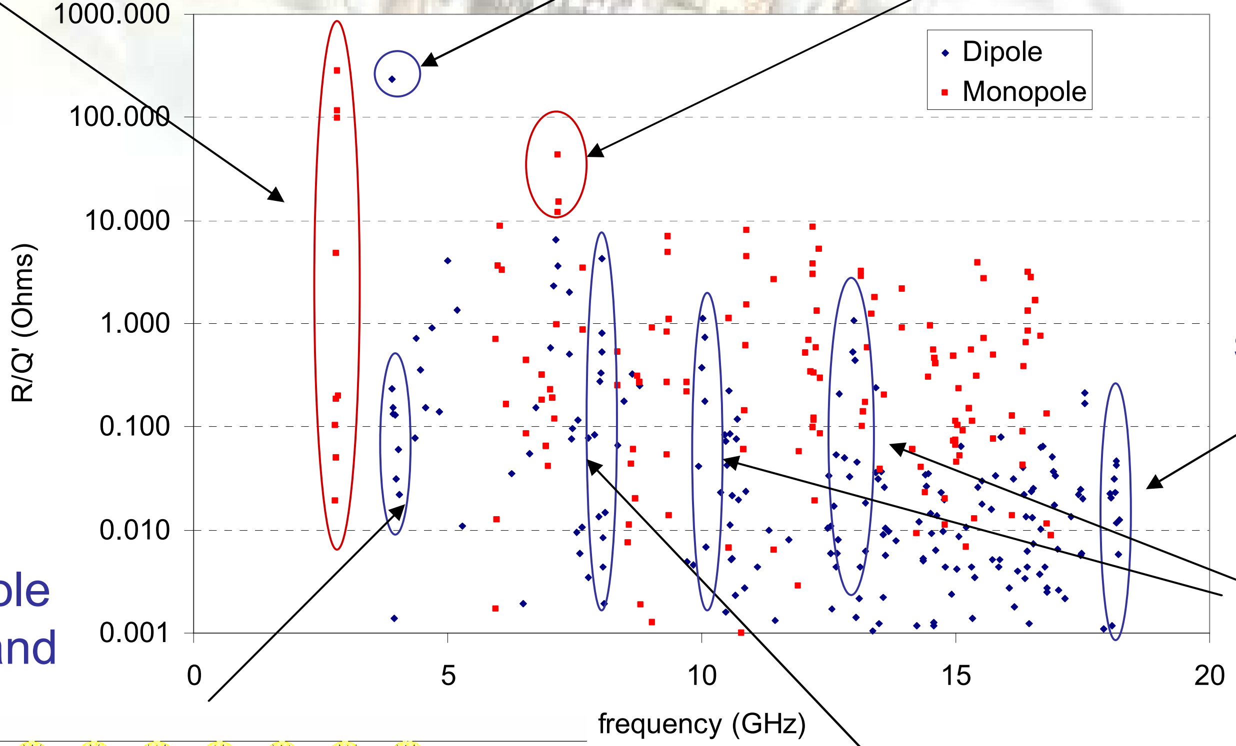
Squashed to give >10 MHz dipole mode separation

Modal Calculations in MAFIA

Lower Order Modes, 2.8 GHz

Operating and Same Order modes at 3.9 GHz

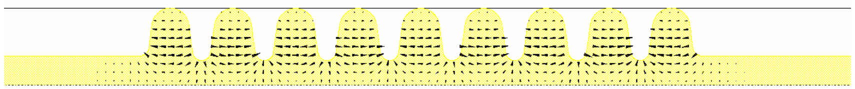
High impedance monopole modes are not a problem



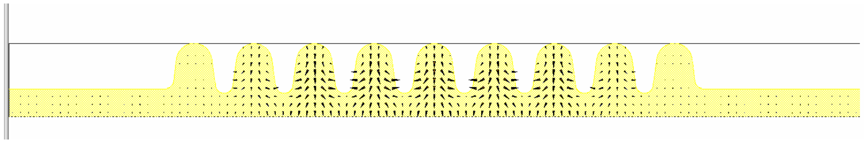
Narrowband dipole modes seen up to 18 GHz

High dipole impedances seen at 10 GHz and 13 GHz

1st Dipole passband

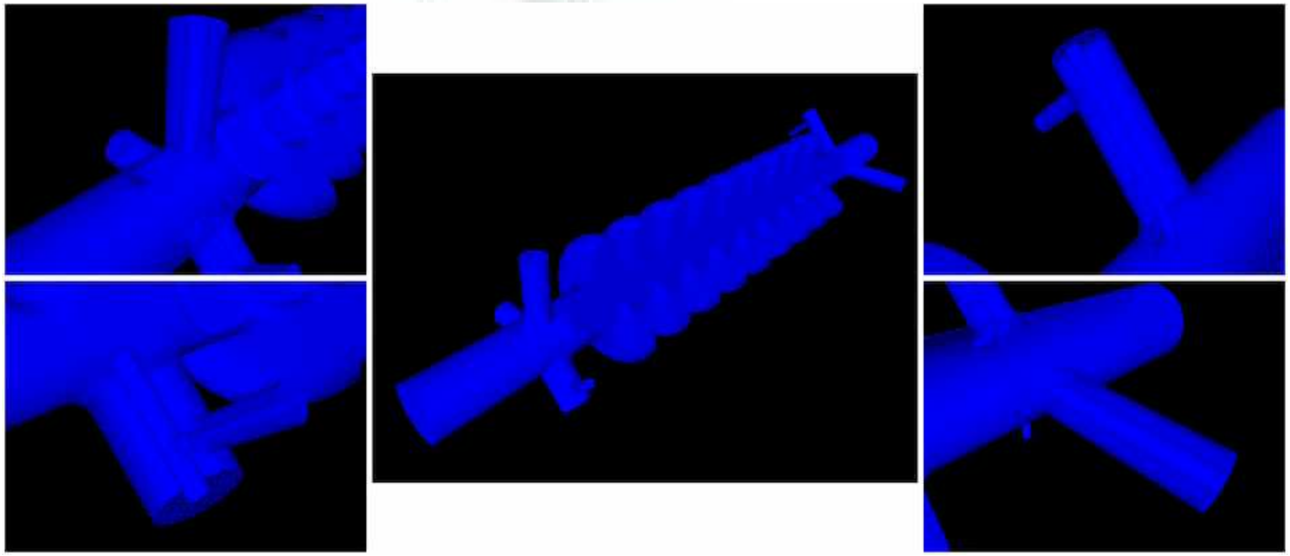


Trapped 5th dipole passband at 8 GHz



Wakefield Verification

- The proposed 9-cell crab cavity has been simulated using MAFIA and Omega 3P:
  - All modes to 18 GHz identified,
  - R/Qs calculated,
  - Mode damping requirements determined from analytical and PLACET wakefield analysis.
- All calculated cavity parameters have been confirmed up to 15 GHz with a cold testing program of bead pull and stretched wire measurements.



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Damping Requirements

If the bunch repetition rate is an exact multiple of the unwanted modal frequency the induced wakefield has a phase such that it does not kick the beam. Maximum unwanted kick occurs for a specific frequency offset. This value must be used to determine damping.

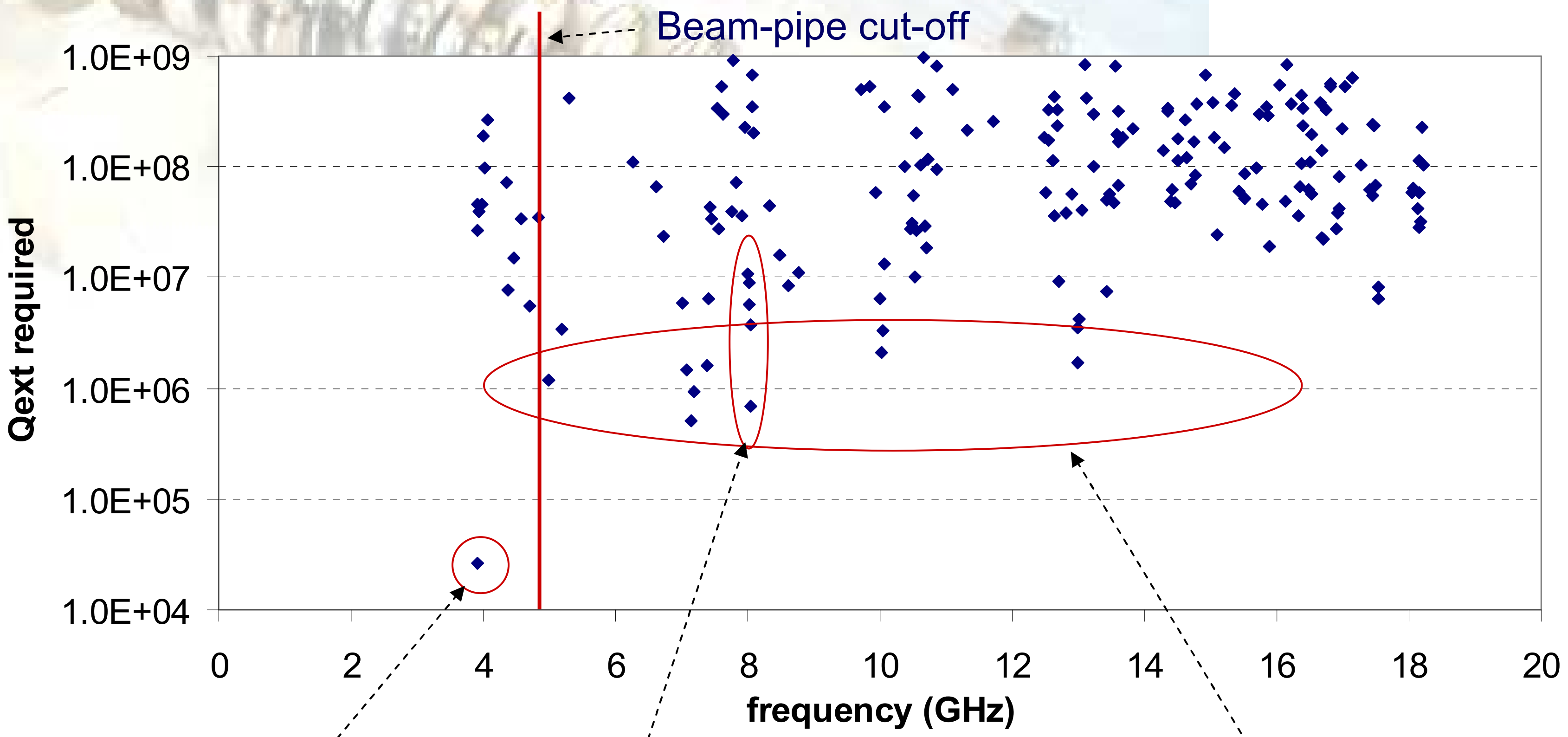
For each unwanted mode determine the required external Q factor using

$$Q_{ext}(m) = \frac{\omega_m t_b}{2} \operatorname{cosech}^{-1}\left\{ \frac{4\,\Delta y_{ip} E}{q\, c\, r_{off}\, R_{12} \left(\frac{R}{Q}\right)_m} \right\}$$

m = mode
ω_m = mode freq.
t_b = bunch spacing
q = bunch charge
r_{off} = max bunch offset
E = bunch energy
Δy_{ip} = max ip offset
c = vel. light

G. Burt, R.M. Jones, A. Dexter, “Analysis of Damping Requirements for Dipole Wake-Fields in RF Crab Cavities.” IEEE Transactions on Nuclear Science, Vol 54, No 5, pp 1728-1734, October 2007

External Q factors required for couplers



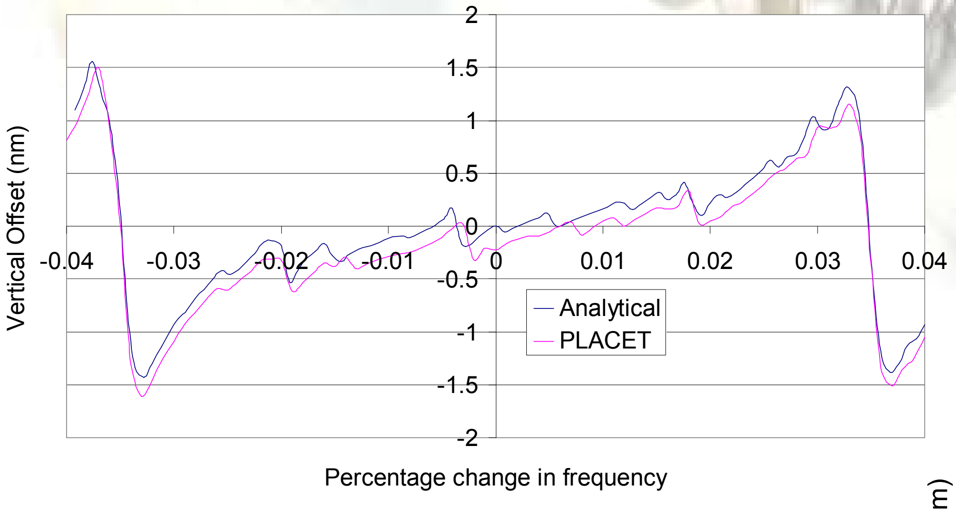
Same Order Mode, tough spec, requires active damping

Trapped modes might need attention

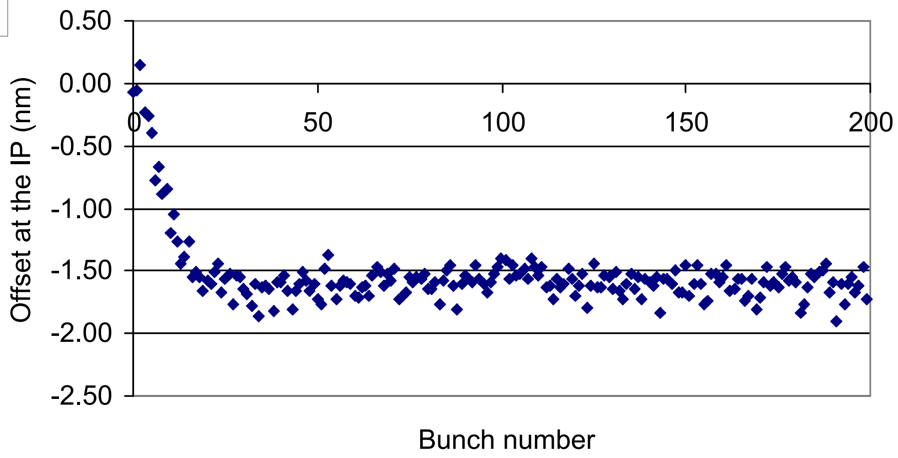
These specs are not tough but might need checking

PLACET Simulations

- A 9-cell SRF cavity design developed to achieve ILC specs.
- 35 μm vertical offset at cavity with nominal ILC parameters.



- The PLACET results show when the damping specifications are met the maximum vertical offset is 1.5 nm.



- Gives good agreement with analytical results, and shows little emittance growth.

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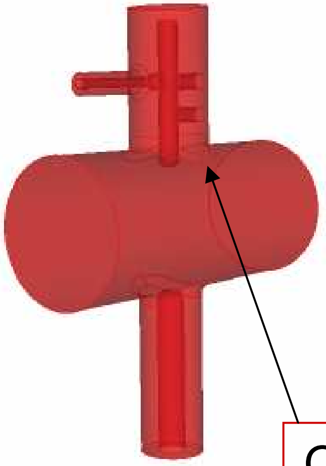
Redesign of the HOM coupler

FNAL DESIGN

loop coupling:

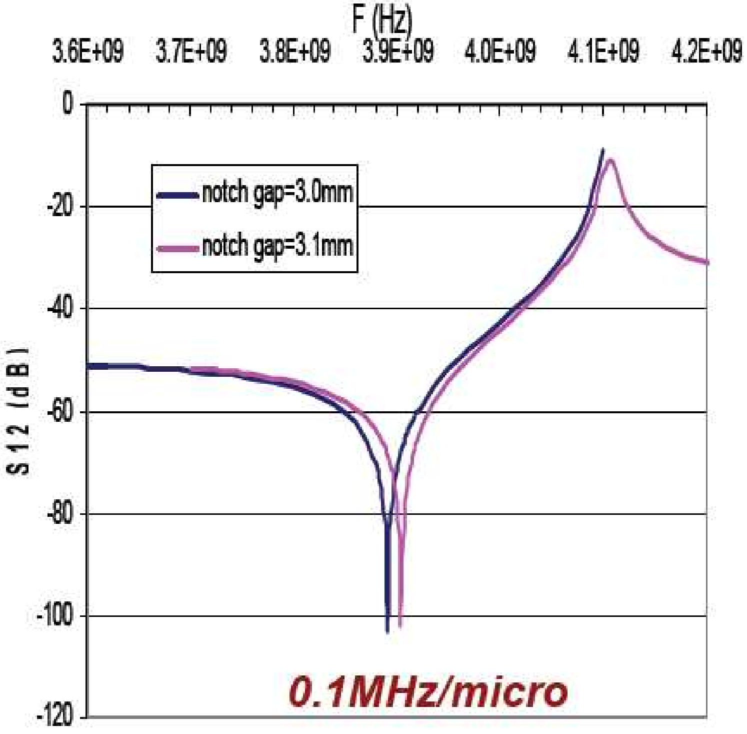
Reduce Notch Gap Sensitivity



SLAC DESIGN

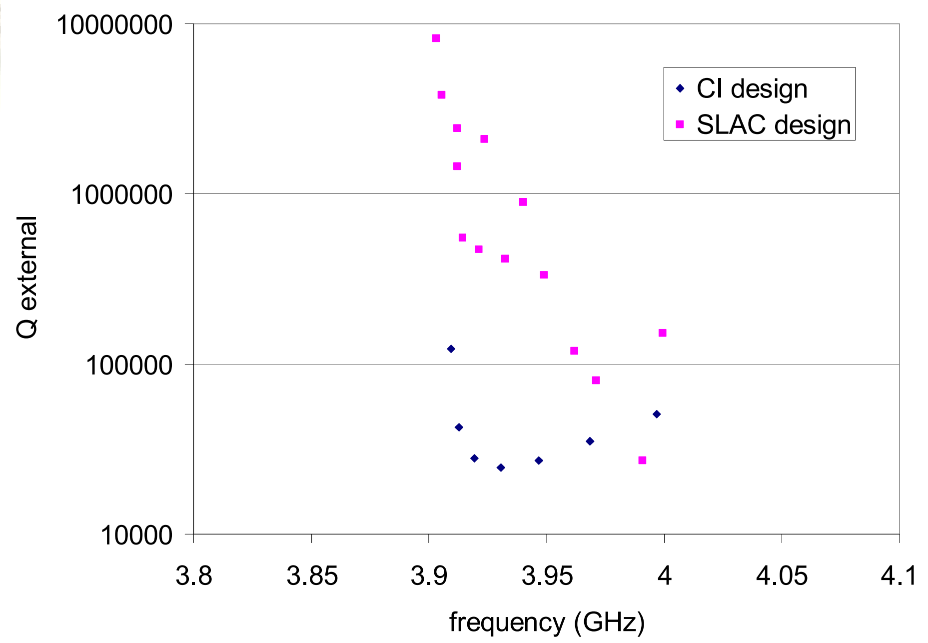
probe coupling

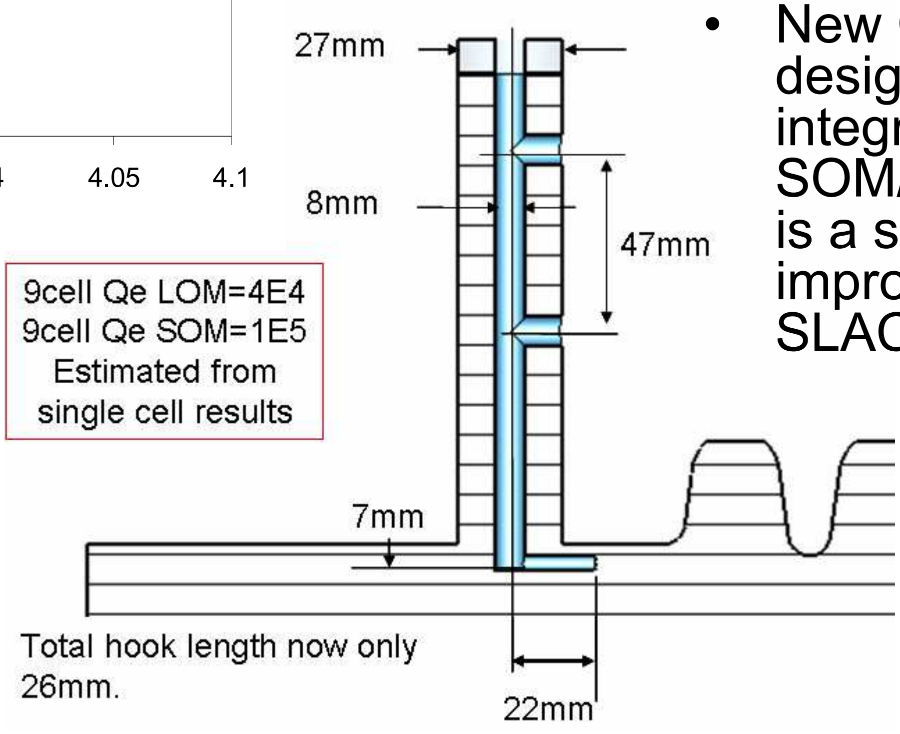
Optimised for 1^{st} 2 dipole bands



~TESLA(0.13MHz/micro)

SOM/LOM Coupler Development





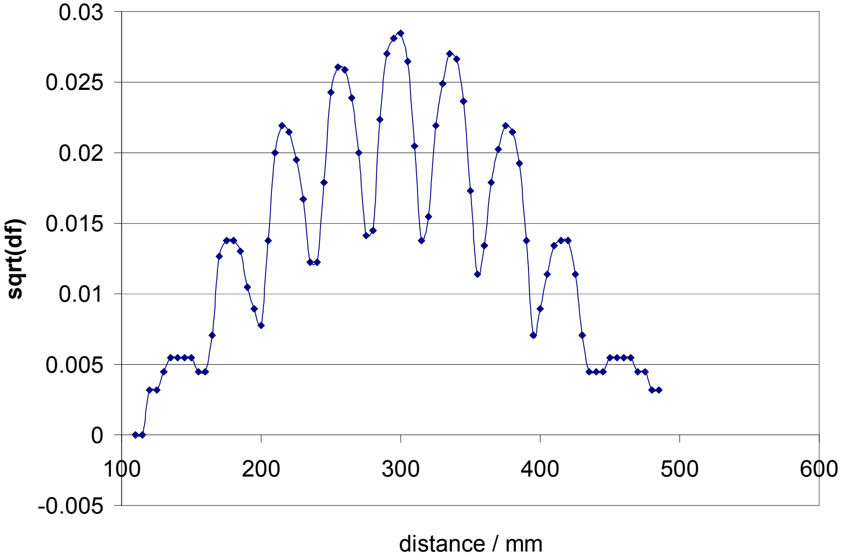
9cell Qe LOM=4E4
9cell Qe SOM=1E5
Estimated from
single cell results

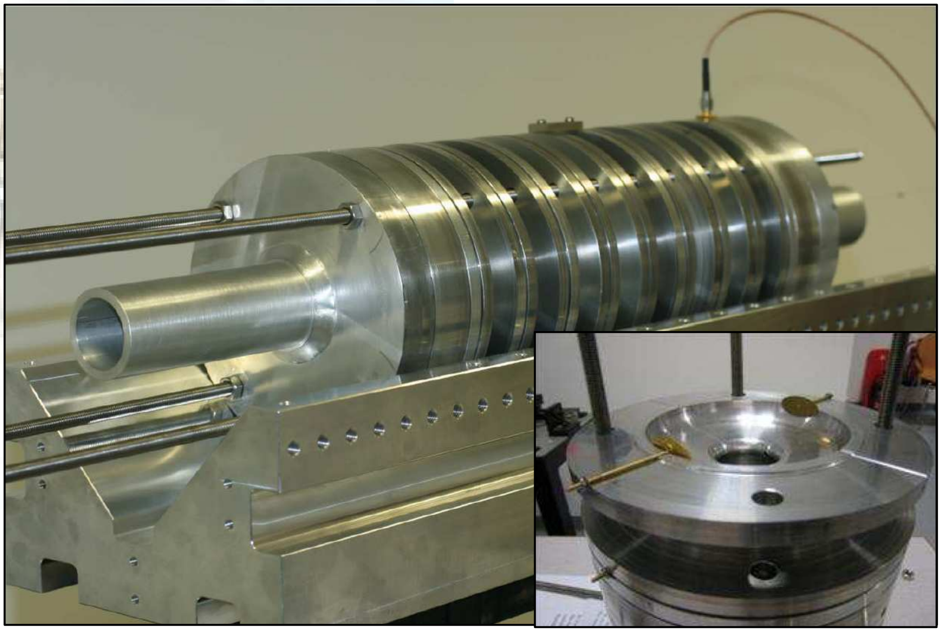
Total hook length now only 26mm.

- SLAC design for HOM and LOM couplers and Cockcroft Institute SOM and Power coupler designs used in prototypes.
- New Cockcroft design for integrated SOM/LOM coupler is a significant improvement on SLAC designs.

Model Verification

- Model fabricated at DL and used to evaluate:
  - Mode frequencies
  - Cavity coupling
  - HOM, LOM and SOM Qe and R/Q

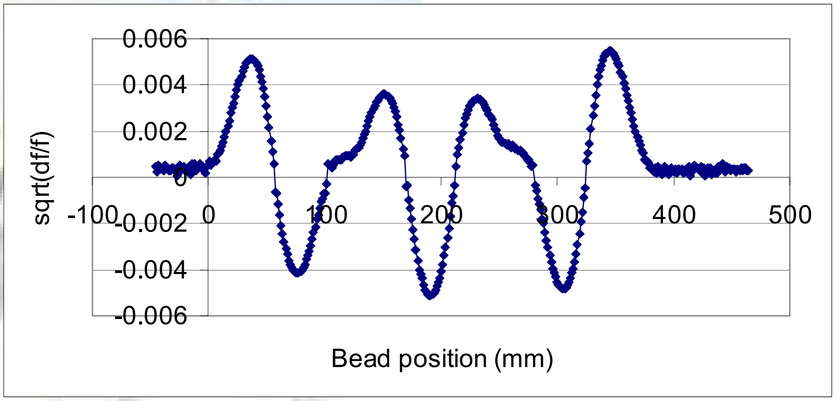


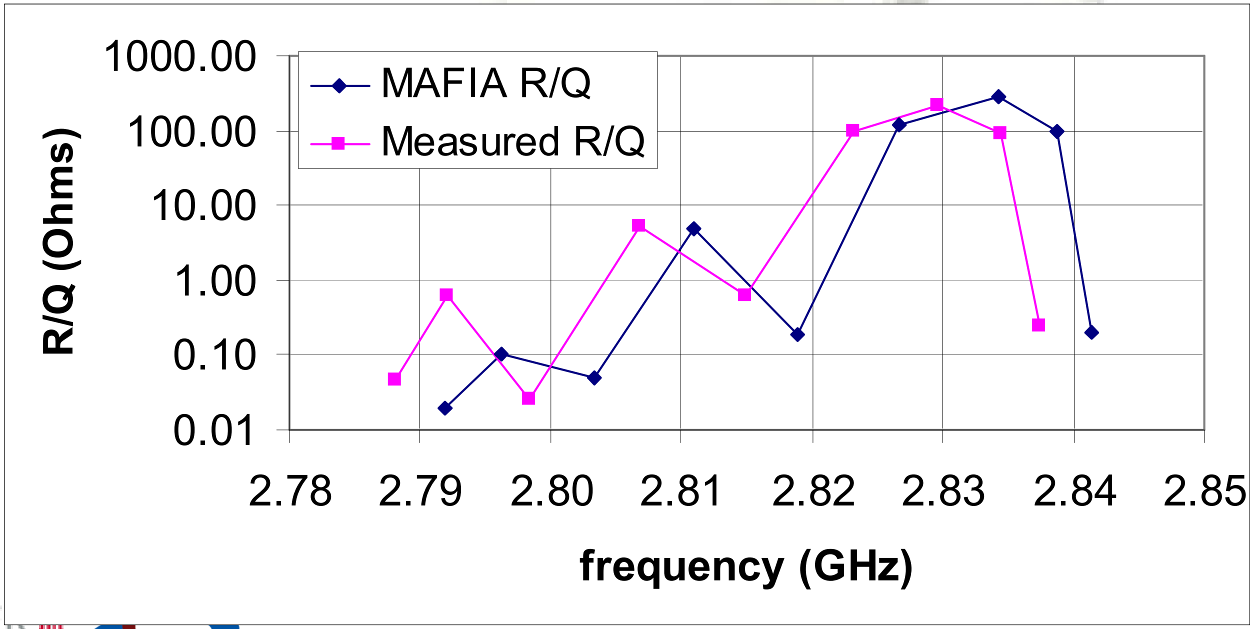


- Modular design allows evaluation of:
  - Up to 13 cells.
  - Including all mode couplers.

LOM measurements

Monopole modes can be measured by directly measuring the frequency shift (or phase) by pulling a metallic circular bead along the cavity axis as the Ez field strongly dominates in this region.

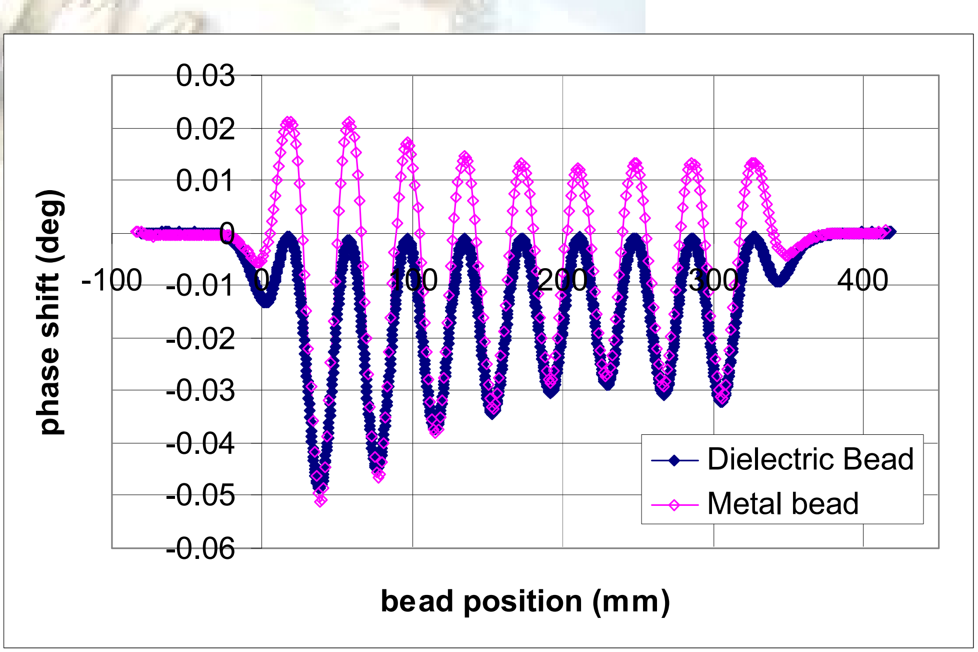




As can be seen we achieved good agreement with simulations for R/Q.

Dipole Bead-pull results

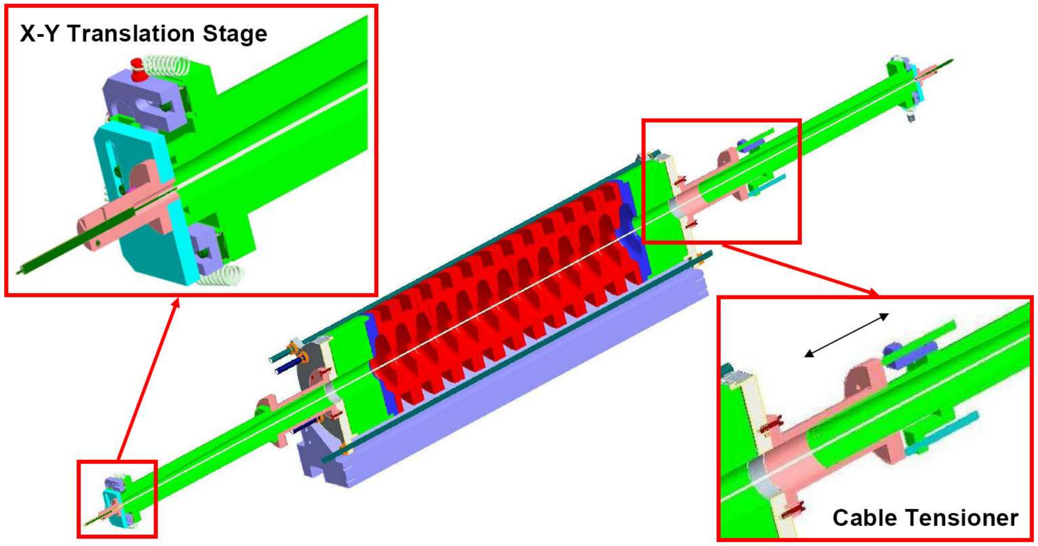
- If we pull a dielectric bead along the axis we can find the transverse E field on axis
- We can then use this to separate the transverse E and B fields perturbing a metal bead.

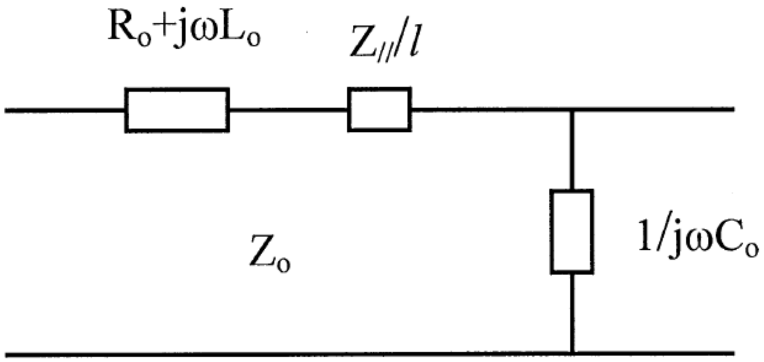


- Hence we can calculate the R/Q from Panofsky Wenzel theorem.

Wire Measurements Technique

A pulse travelling along a wire has a similar field profile to a relativistic bunch. The wire can move off axis to induce dipole modes.

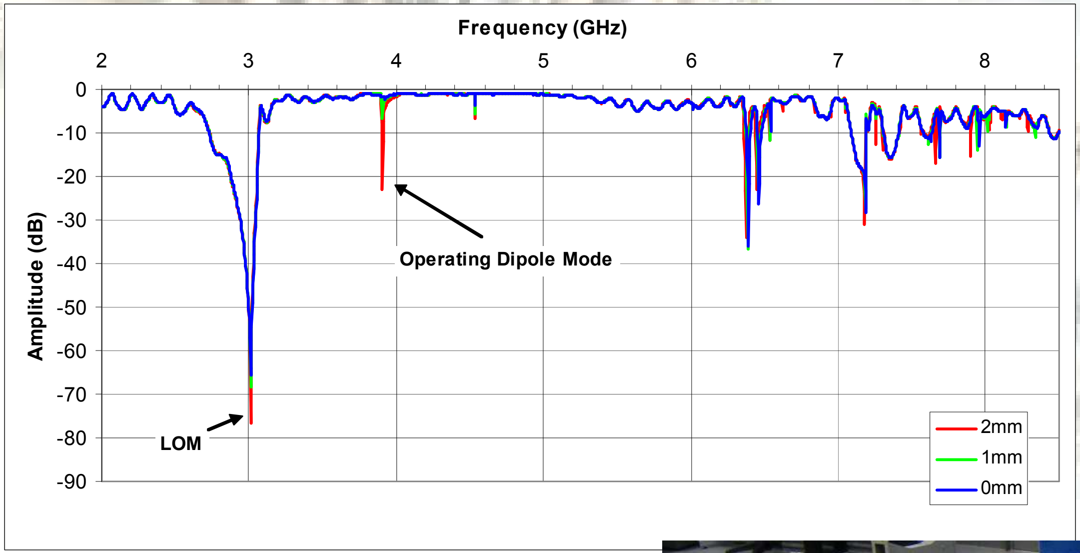




A wire through a uniform reference tube can be regarded as a transmission line characterised by R_o, L_o and C_o

A wire through the cavity under investigation is modelled with an additional series impedance $Z_{//}/l$

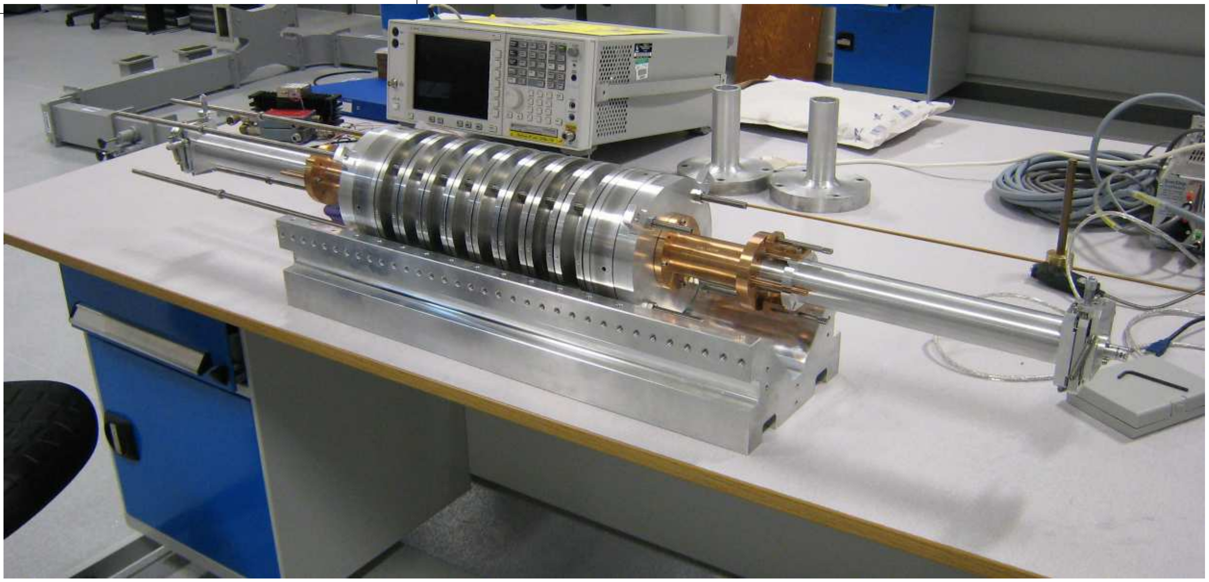
Wire Measurements Technique



We use an on-axis measurement as our reference and off-axis measurements as the DUT.

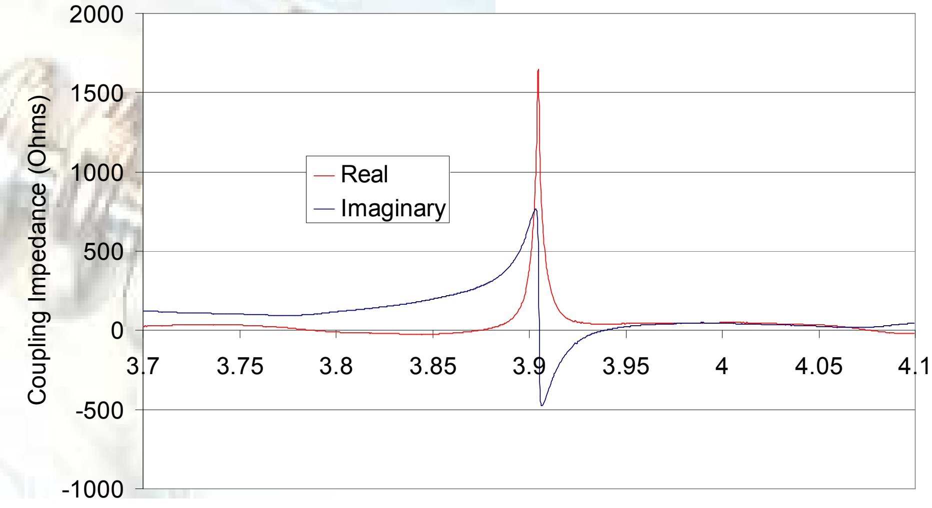
By observing how the coupling impedance varies with offset we can ascertain the mode order.

This technique is a fast method of measuring the impedance over a large bandwidth.

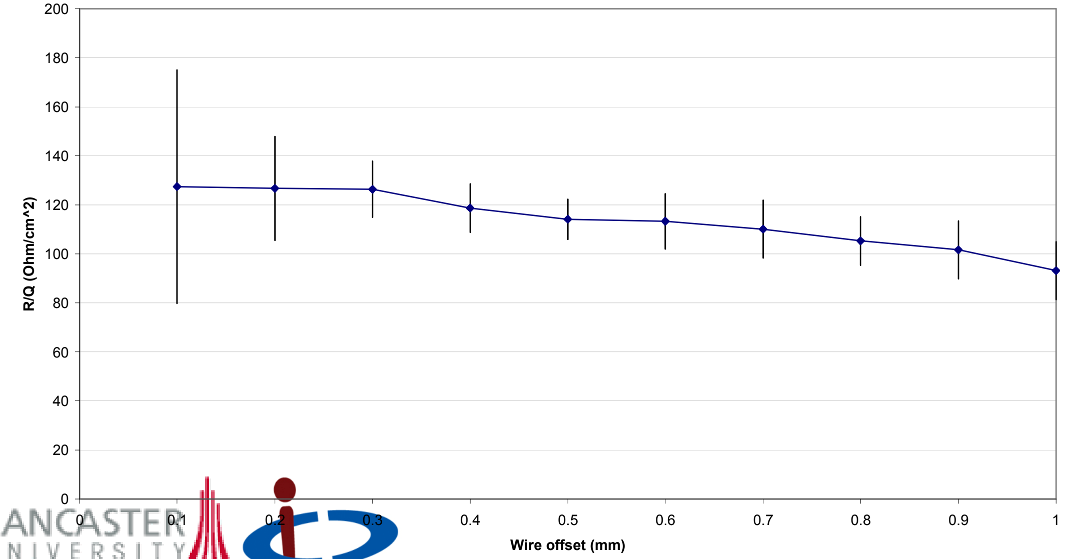


Operating Mode Measurements

The coupling impedance was measured for 3 and 9 cell cavities and was in good agreement with bead-pulls and MAFIA simulations.

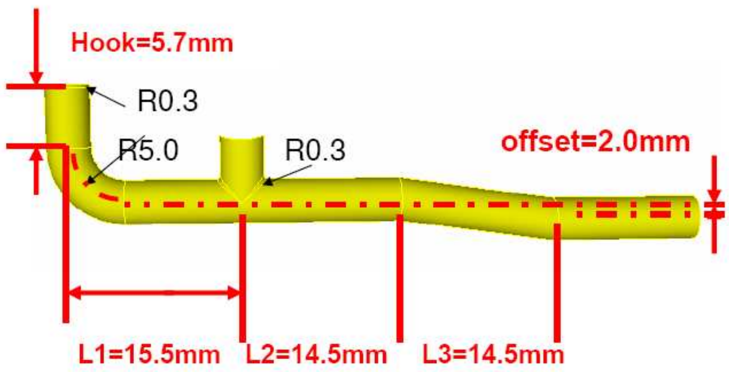


R/Q of the 3.9GHz dipole pi-mode

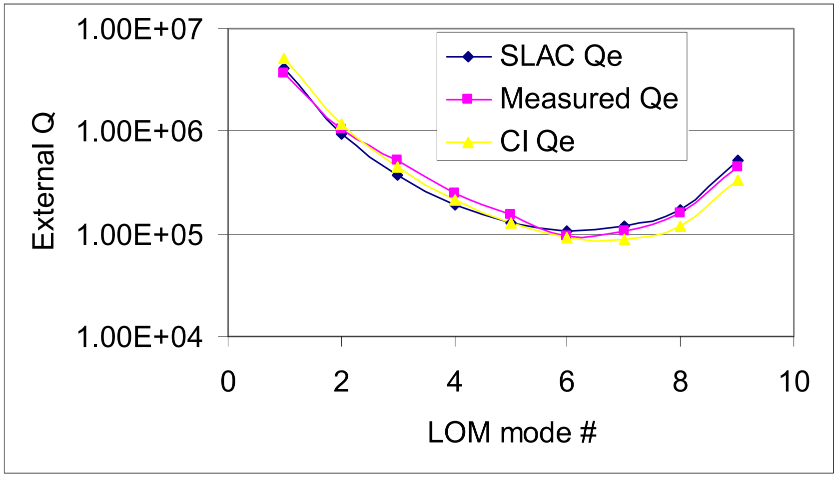


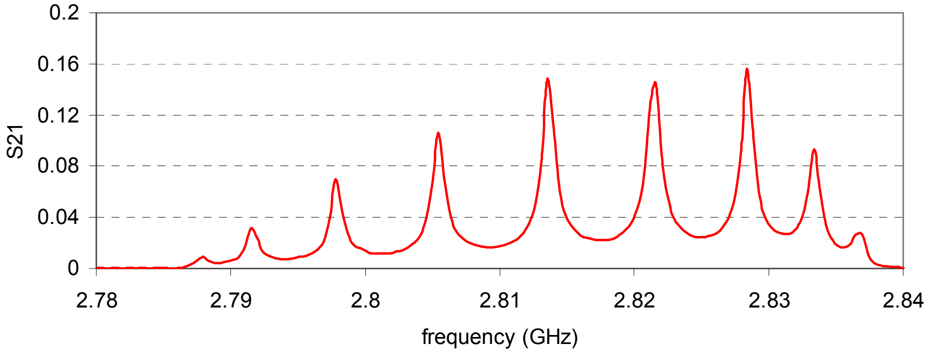
We investigated how the measurements varied with wire offset. As we can see the R/Q decreases at large offsets due to the wire perturbation.

LOM Coupler Prototype measurements



The external Q of the couplers were measured using the transmission from a calibrated probe of known Qe.





The LOM coupler was found to give good agreement with simulations.

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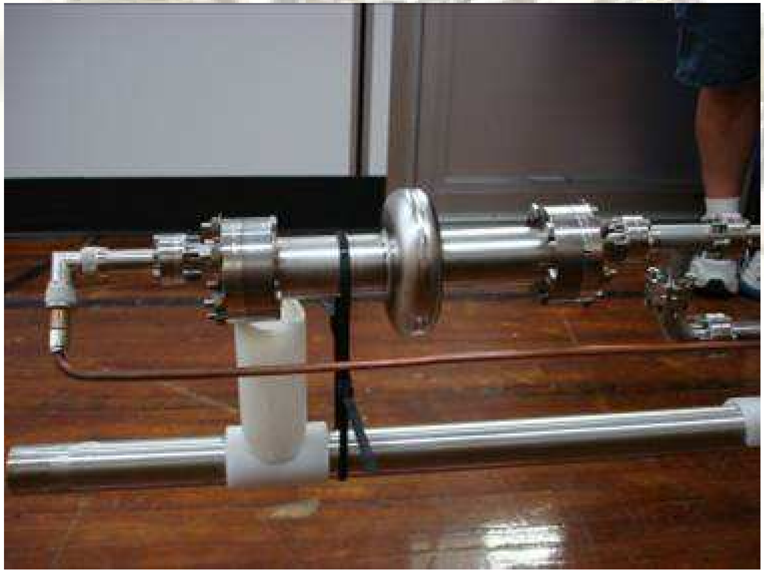
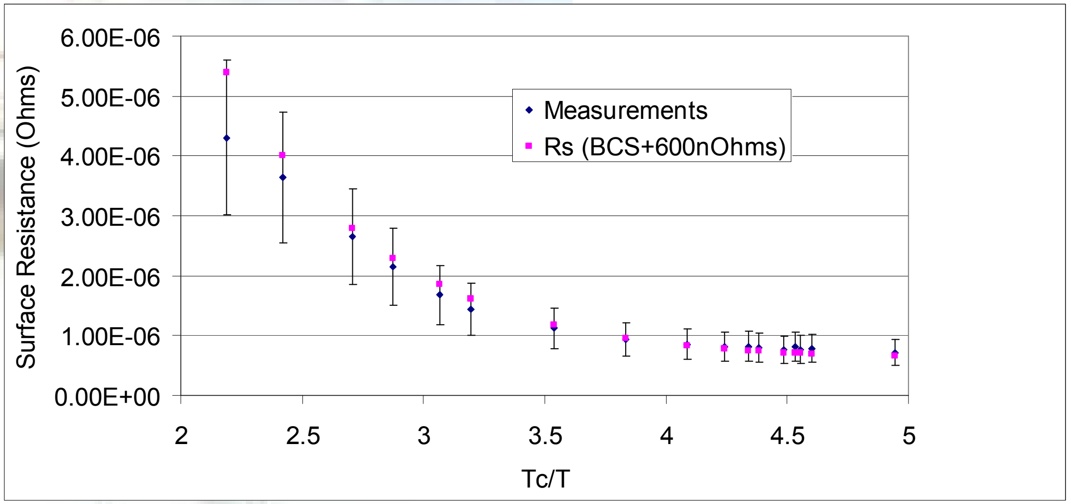
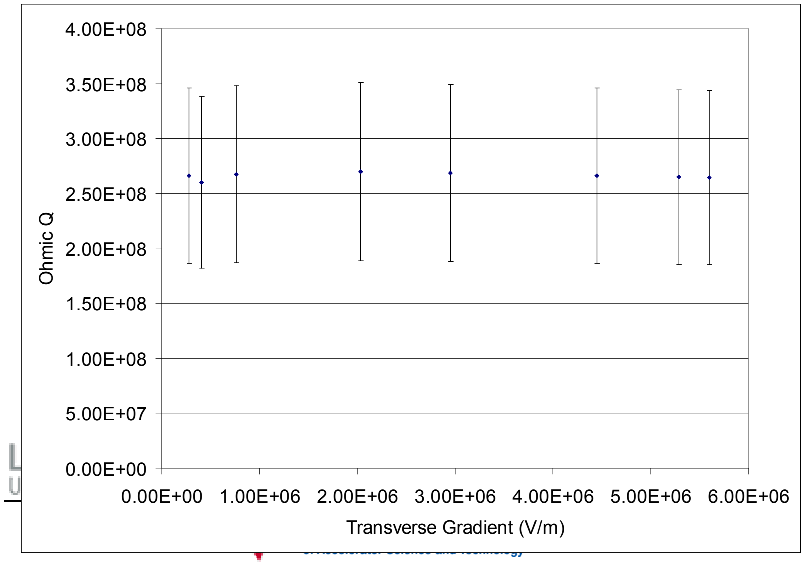
SRF Cavity Tests







- •The cavities had a relatively large residual resistance.
- •Losses are acceptable for phase control tests but too large for ILC.
- •Cavities achieved the required gradient without quench.