



ILC Crab Cavity (ILC-CC) System Overview

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(on behalf of the ILC Crab System Design Team)

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16th - 20th November 2008



Overview

- ILC-CC Collaboration Team
- Crab System Specifications
- Key Technical Design Challenges:
 - **Cavity Wakefields**
 - **Coupler Developments**
 - **LLRF and Synchronisation**
- Integrated System Tests
- CLIC-CC Specifications
- Summary



ILC-CC Collaboration Team

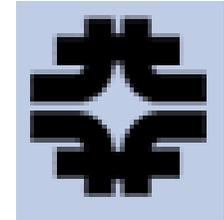
- Cockcroft Institute:

- Graeme Burt (Lancaster University)
- Richard Carter (Lancaster University)
- Amos Dexter (Lancaster University)
- Philippe Goudket (ASTeC)
- Roger Jones (Manchester University)
- Alex Kalinin (ASTeC)
- Lili Ma (ASTeC)
- Peter McIntosh (ASTeC)
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- FNAL:

- Leo Bellantoni
- Mike Church
- Tim Koeth
- Timergali Khabiboulline
- Sergei Nagaitsev
- Nikolay Solyak



- SLAC:

- Chris Adolphson
- Kwok Ko
- Zenghai Li
- Cho Ng
- Andrei Seryi
- Liling Xiao

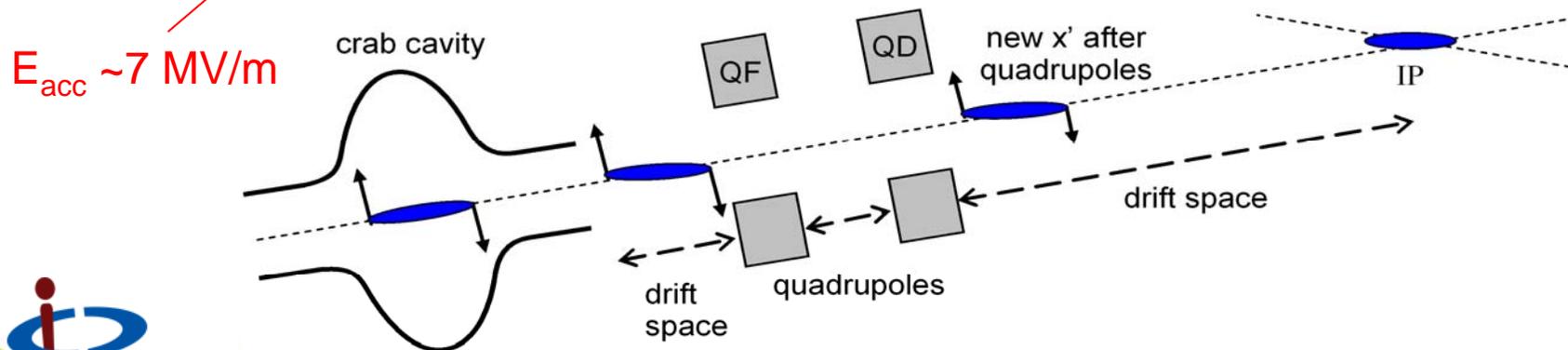




ILC-CC System Specification

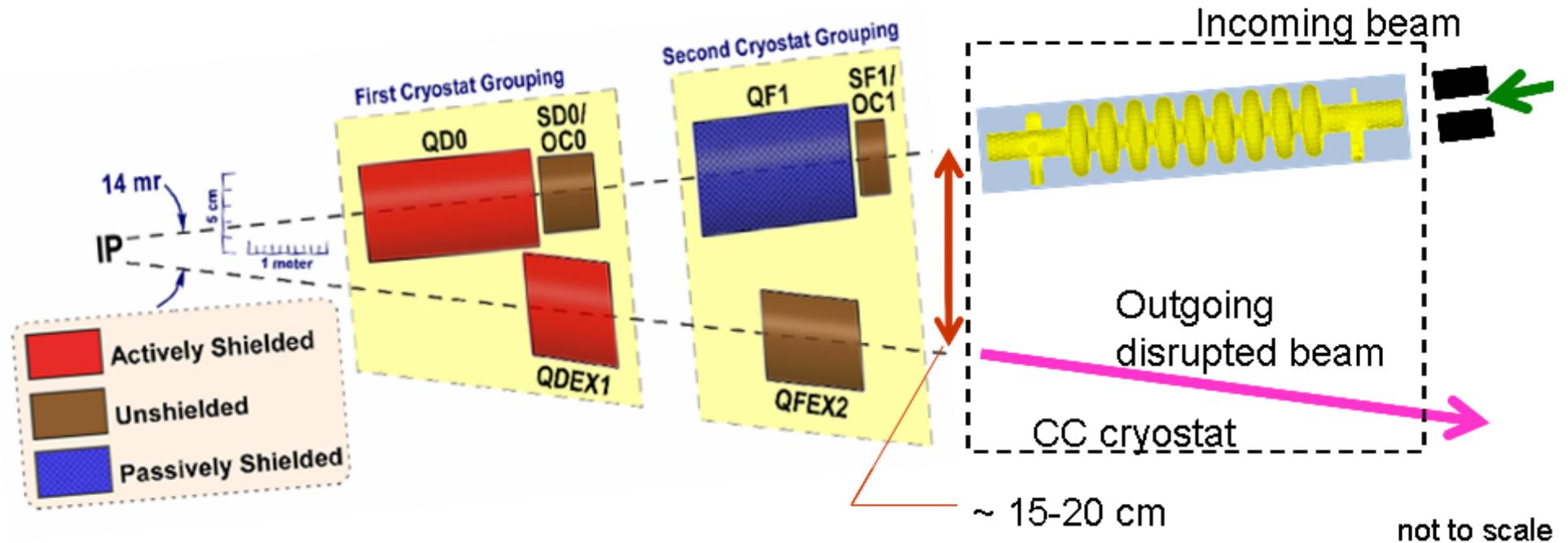
Crossing angle	14 mrad
Number of cryovessels per IP	2
Number of 9-cell cavities per cryovessel	2
Required bunch rotation, mrad	7
Location of crab cavities from the corresponding IP, m	13.4 – 17.4
Longitudinal space allocated per cryovessel, m	3.8
RMS Relative Phase Stability, deg	0.095
RMS Beam Energy Jitter, %	0.33
X offset at IP due to crab cavity angle (R12), m/rad	16.3
Y offset at IP due to crab cavity angle (R12), m/rad	2.4
Amplitude at 1TeV CM, MV	2.64
Max amplitude with operational margin, MV	4.1

- TM_{110} mode dipole cavity.
- e^+ and e^- beams receive transverse momentum kick:
 - Each bunch rotated to maximise Luminosity at the IP.
- Crab cavities positioned close to IP @ ~ 15 m.
- Not using the crab cavities loses about 80% of the luminosity.





Crab Cavity Integration on ILC



- Crab cavity just behind the Final Doublet
- FD aperture $r \sim 1 \text{ cm}$ \Rightarrow constraint on crab aperture and coupler penetration (to not limit collimation depth)
- Limit for couplers outputs oriented toward outgoing beampipe
- Outgoing beam ($\sim 17 \text{ MW}$, highly disrupted) goes through crab cryostat

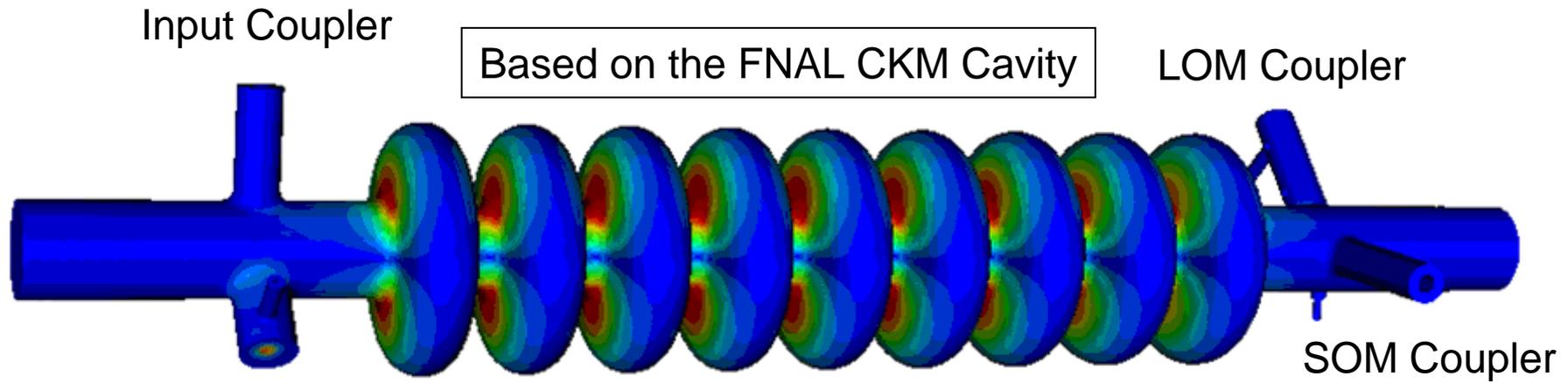


Key Technical Challenges

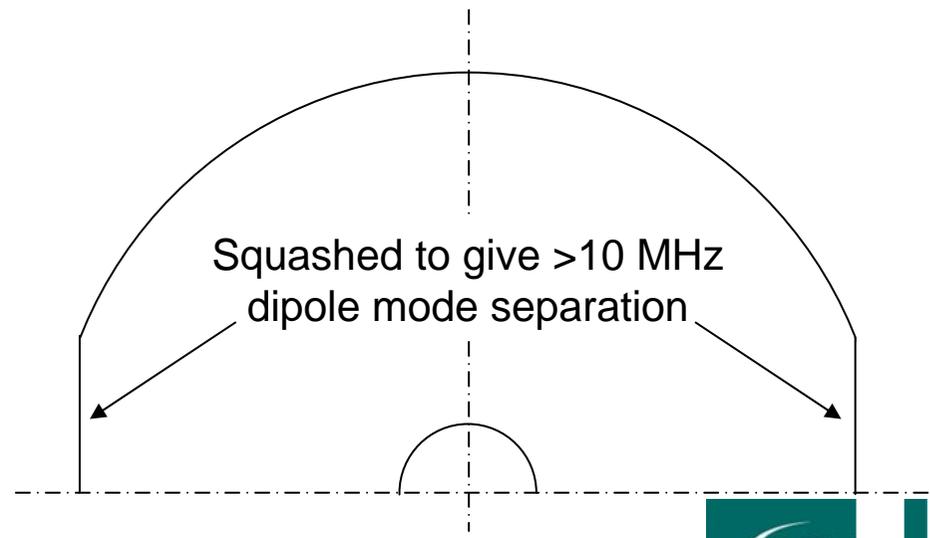
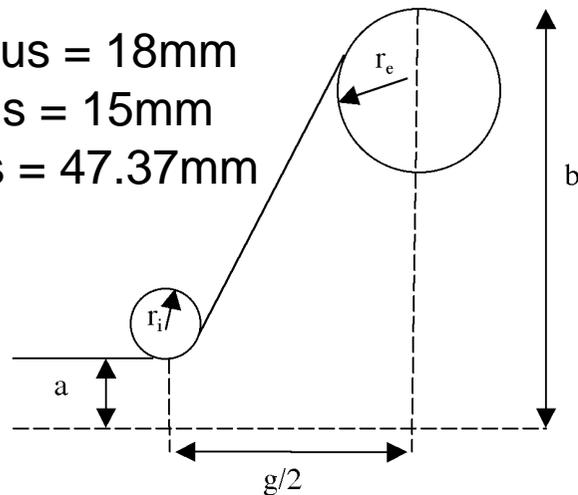
- Crab Cavity:
 - Wakefield suppression
 - Deflecting gradient
- Damping and Couplers:
 - Input (based on DESY/FNAL 3rd harmonic),
 - LOM (multipacting, tuneability, fabrication),
 - SOM (very high damping required, tuneability),
 - HOM (multipacting, tuneability, fabrication).
- LLRF and Synchronisation:
 - LLRF phase/amplitude-lock performance (single cavity),
 - Synchronisation stability (dual cavity),
 - Microphonics rejection capability.
- Cryomodule:
 - Field polarisation (± 1 mrad),
 - Microphonics rejection (cryogenic distribution),
 - Cavity alignment (5 nm sigma vertical beam size at IP),
 - ILC installation constraints (extraction beamline ~ 18 cm away).



ILC-CC Design



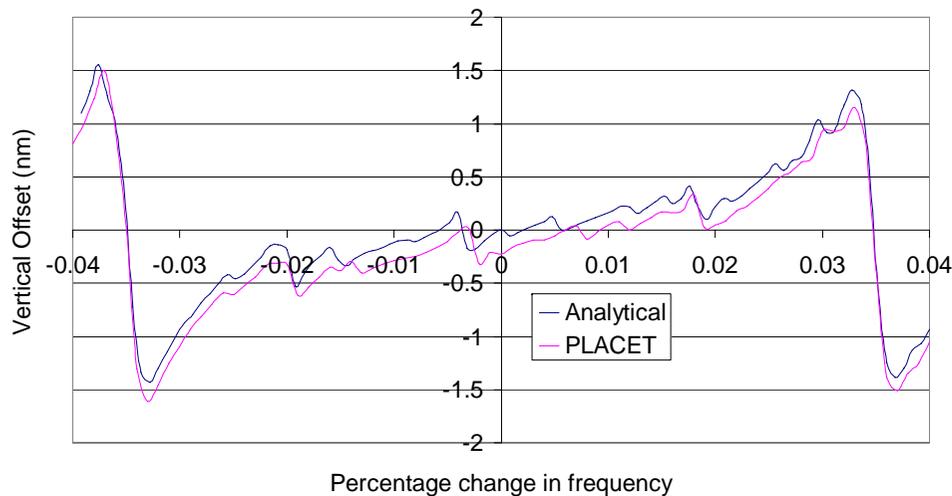
Beam-pipe radius = 18mm
Cavity iris radius = 15mm
Equator Radius = 47.37mm





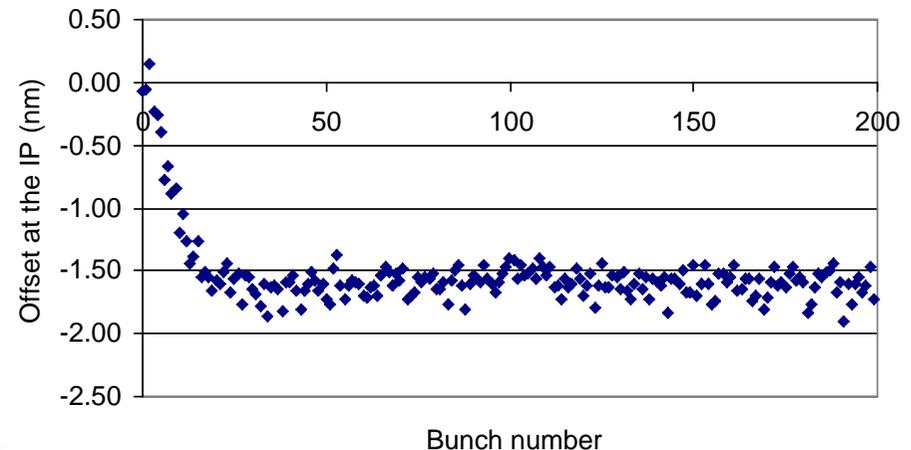
Wakefield Suppression

- 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.

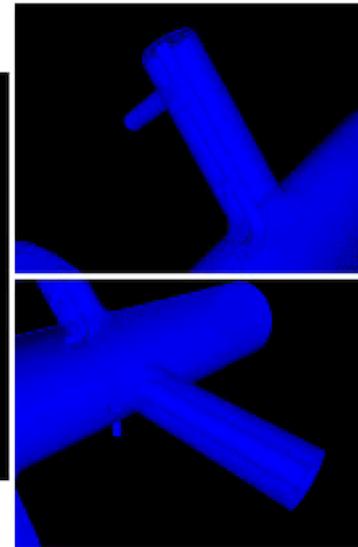
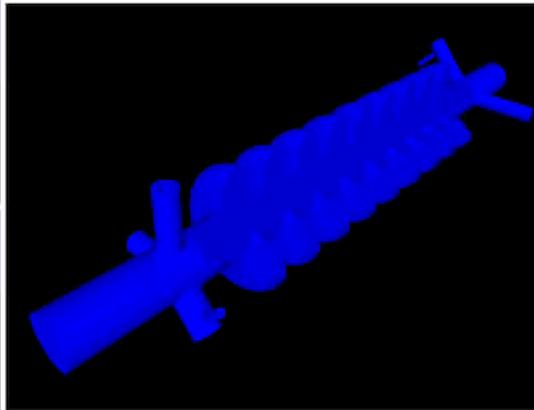
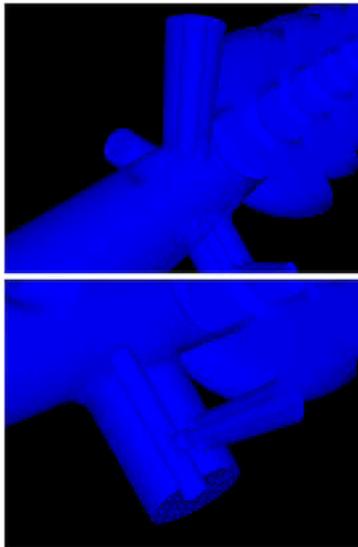
- Gives good agreement with analytical results, and shows little emittance growth.



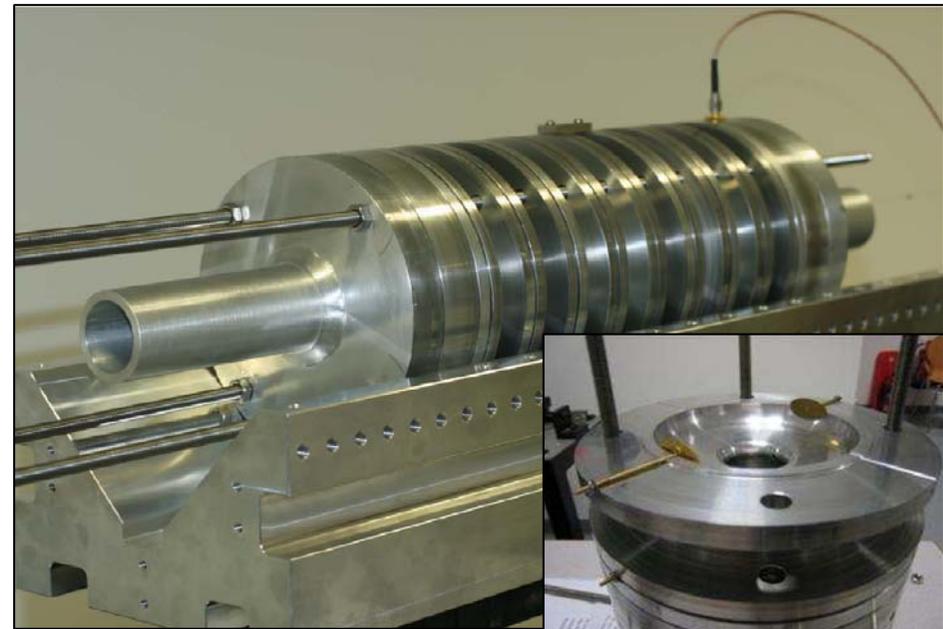
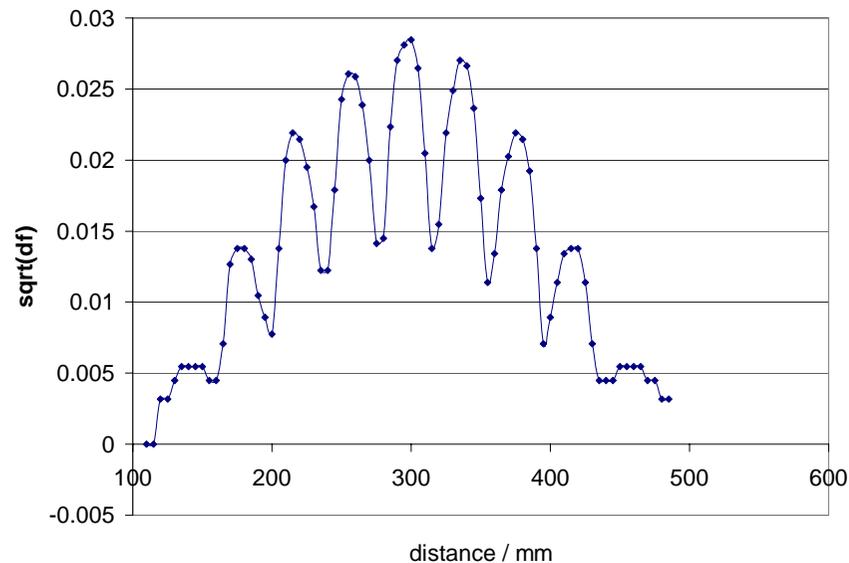


Wakefield Verification

- The proposed 9-cell crab cavity has been simulated using MAFIA, MWS 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.



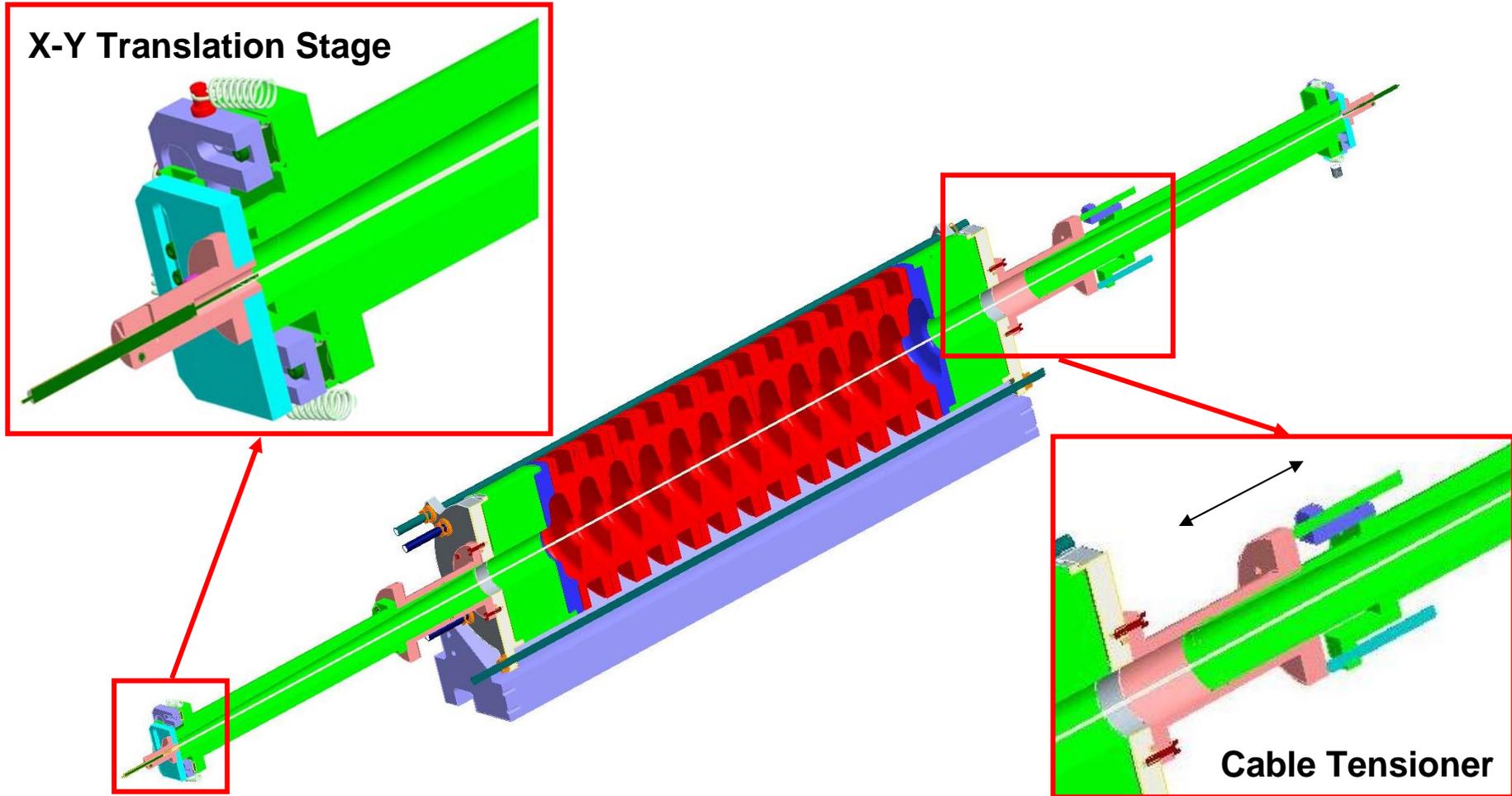
- Model fabricated at DL and used to evaluate:
 - **Mode frequencies**
 - **Cavity coupling**
 - **HOM, LOM and SOM Qe and R/Q**



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



Stretched Wire Characterisation



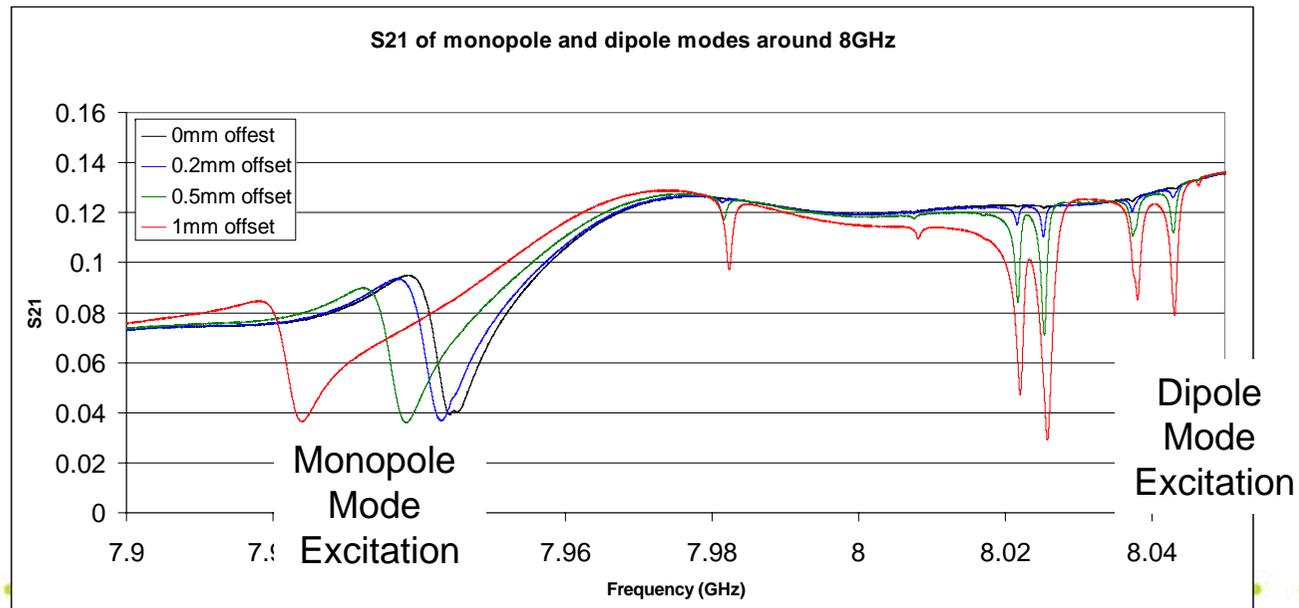
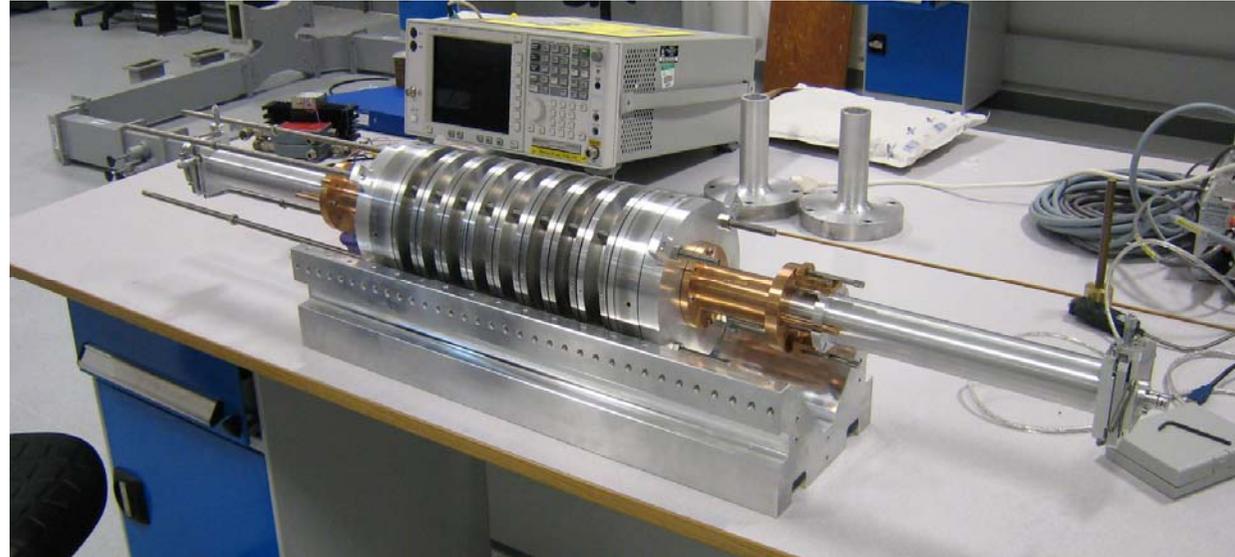


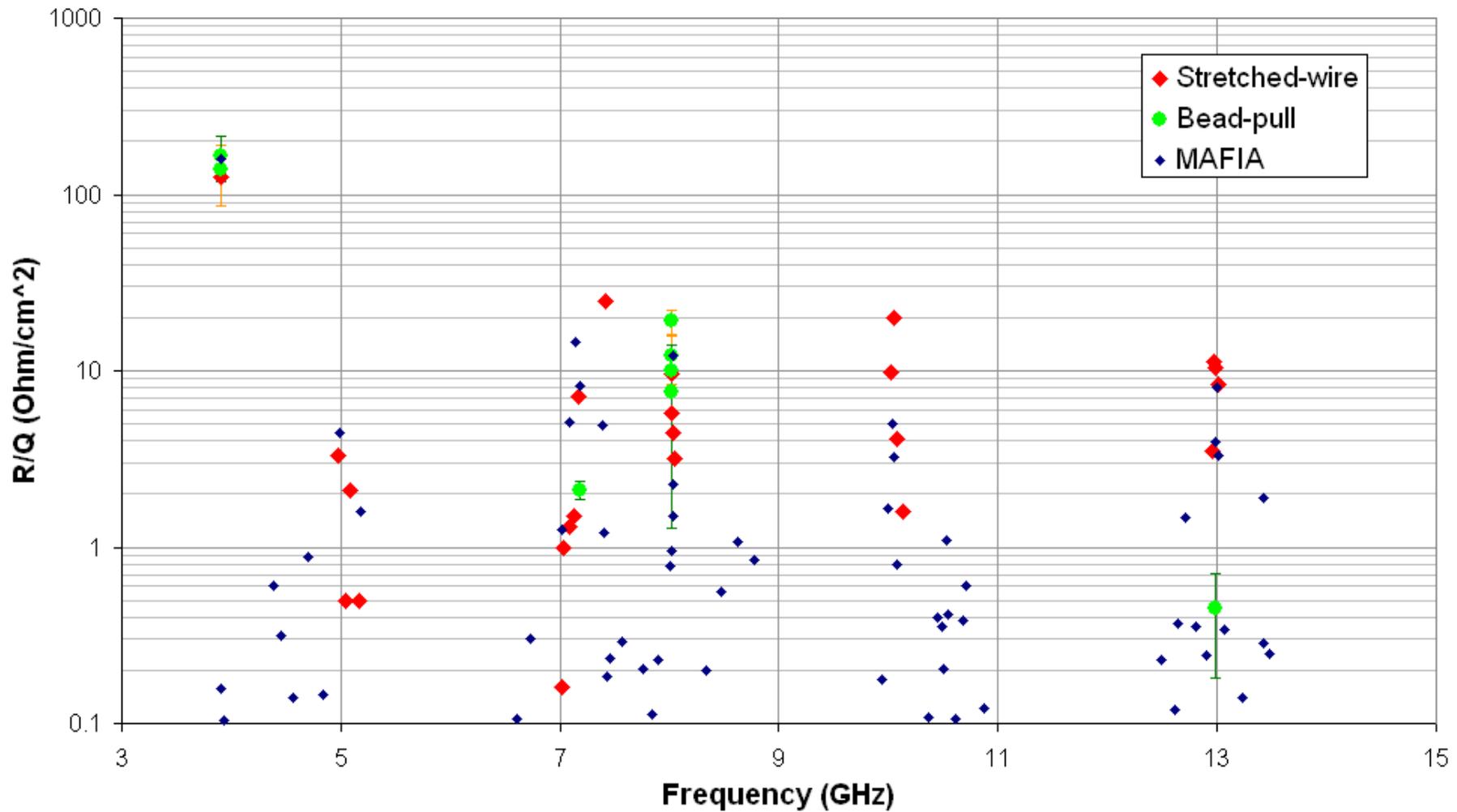
Stretched Wire Technique

- Provides for characterisation of mode:
 - **Frequencies**
 - **Kick factors**
 - **Loss factors**
 - **R/Q**
- Principle based on similarity of e-m fields in the presence of beam and thin wire.
- Frequency domain signal launched down wire, which then probes the wakefields within the device under test.
- Launch cones optimised for minimal reflections (VSWR < 1.3 up to 15 GHz).



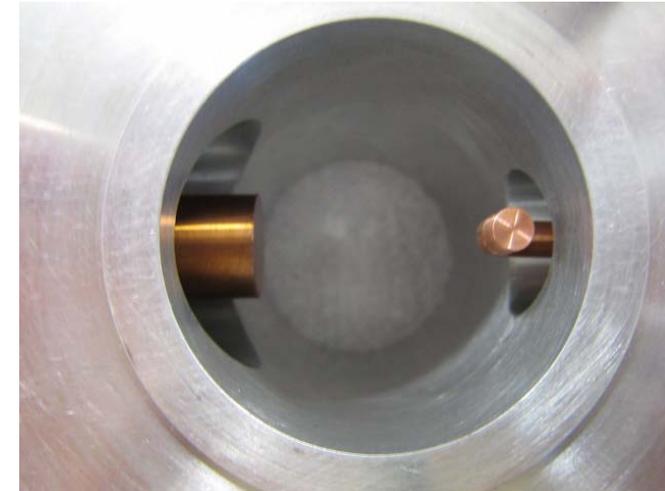
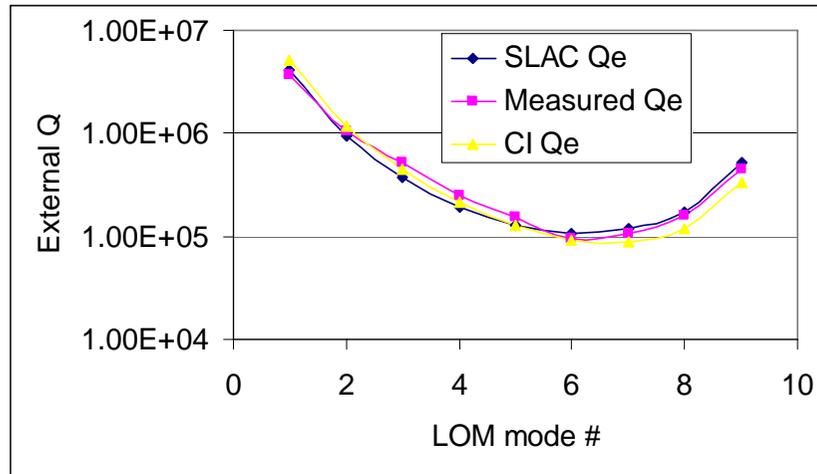
Stretched Wire Characterisation



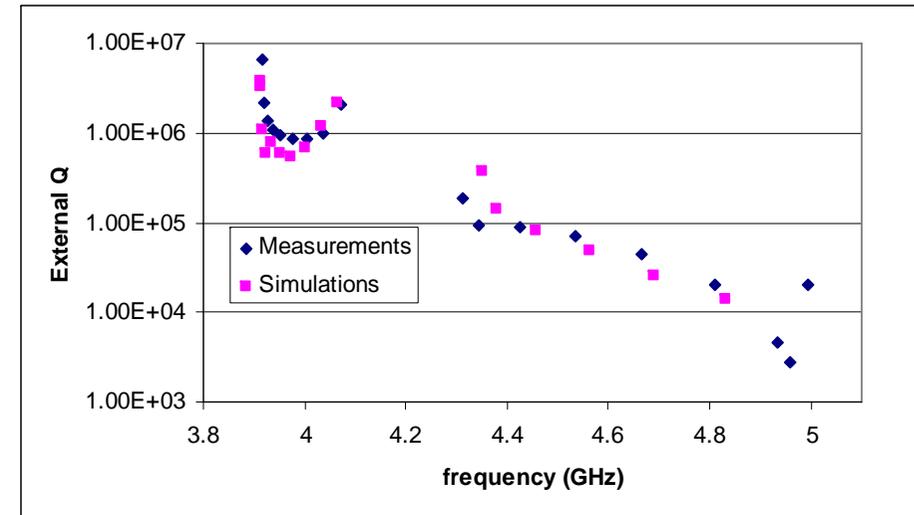
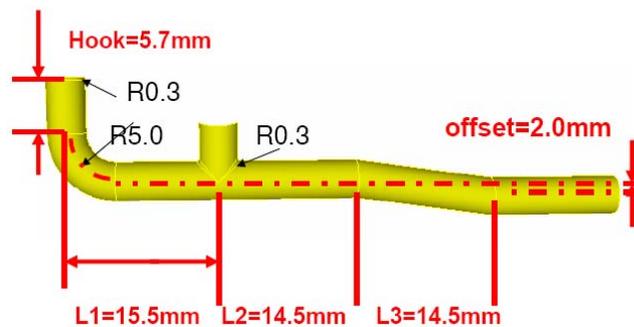




Prototype LOM Qe Measurements



The LOM coupler was found to give good agreement with both MWS and Omega3P simulations.





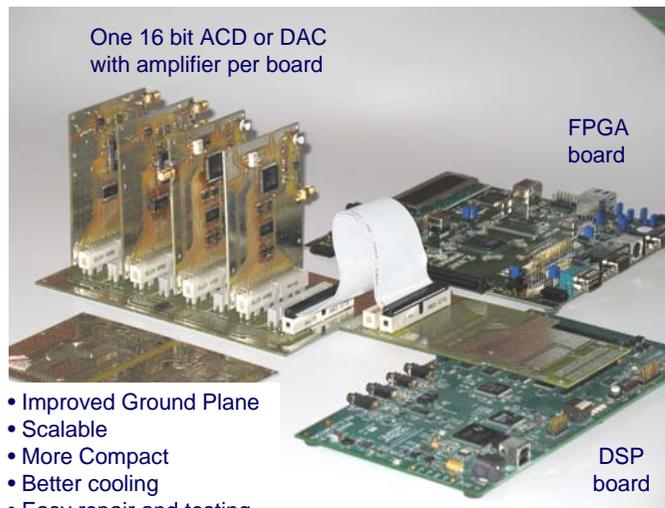
LLRF and Synchronisation

- Bunch-RF phase error in a crab cavity causes unwanted centre-of-mass kick.
- Providing both crab cavities are phase balanced, can compensate these COM kicks.
- ILC crab cavity zero crossings need synchronisation to 94 fs for the 2 % luminosity loss budget.
- Main linac timing requirement is nominally 0.1° at 1.3 GHz or ~ 200 fs and hence cannot be relied upon directly to provide timing signals for the crab cavities:
 - \Rightarrow **$\sim 30\%$ luminosity loss.**



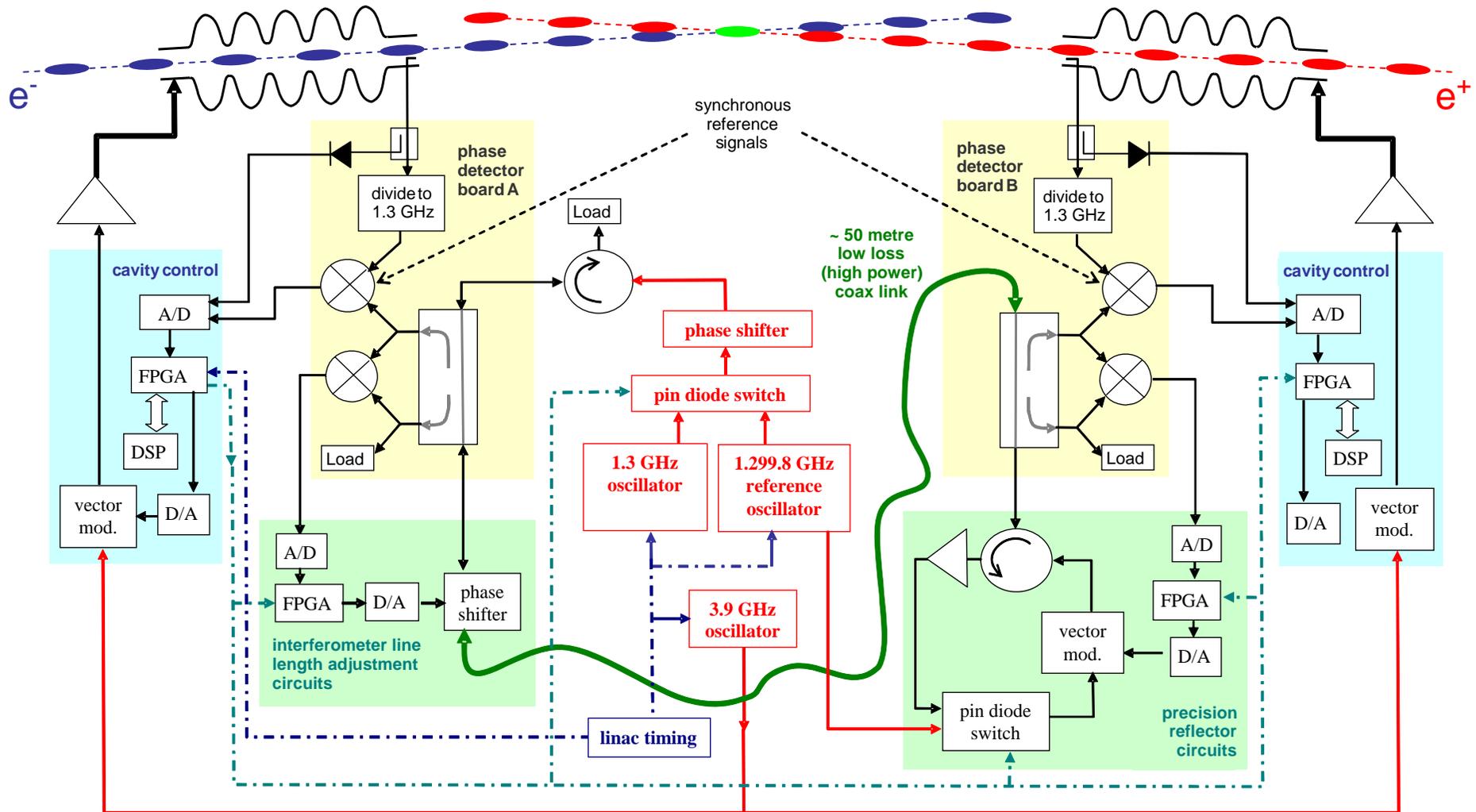
ILC-CC System Verification

- The phase of the field in each cavity is sampled, compared to the timing reference and the error sent to a digital signal processor (DSP) to determine how the input signal must be varied to eliminate the error.
- Provide an RF interferometer between each crab cavity so that the same cavity clock signal is available at both systems.
- 16-bit DAC/ADC architecture (high resolution)



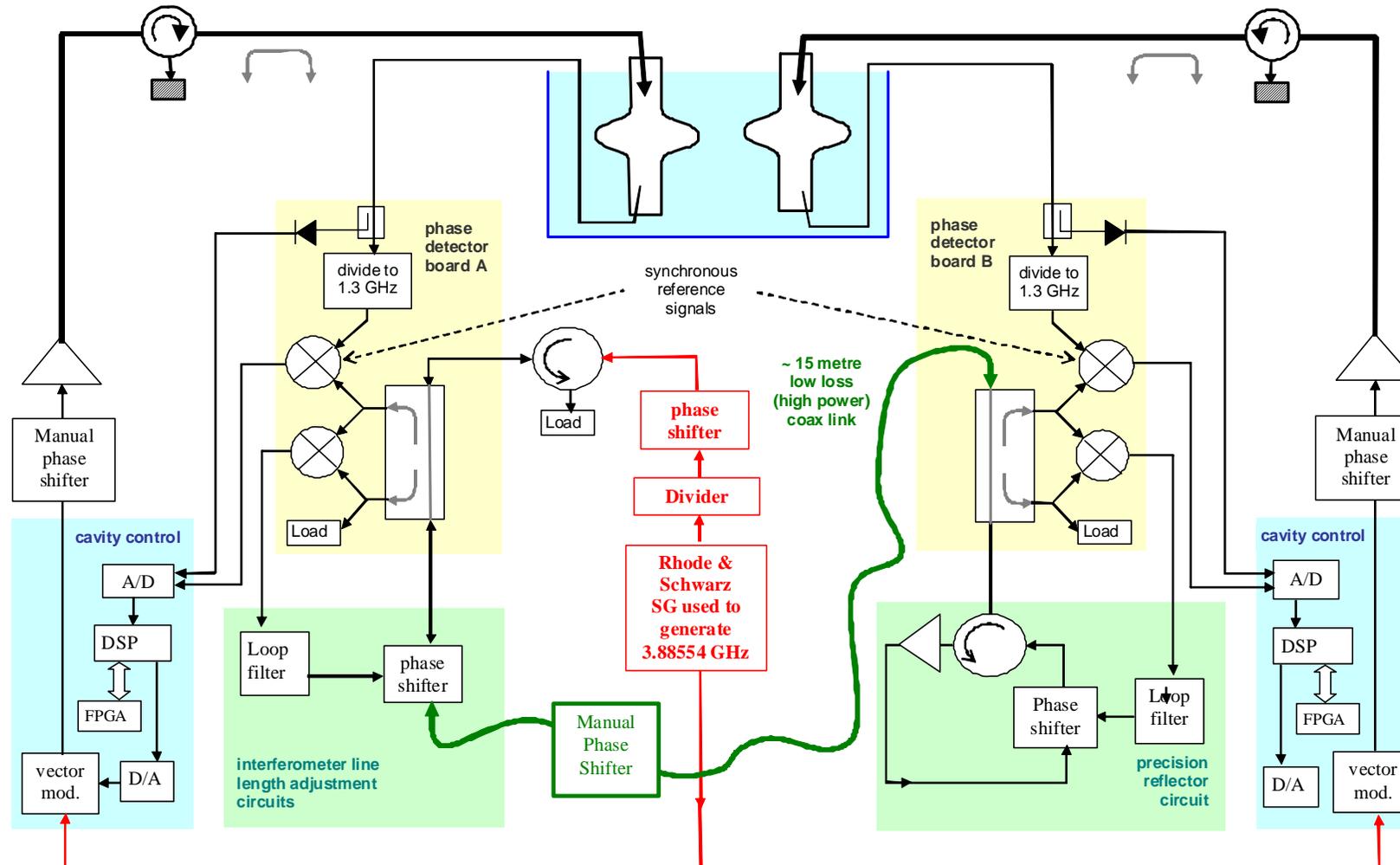


LLRF/Synchronisation Scheme (Final)





LLRF/Synchronisation Scheme (Preliminary)

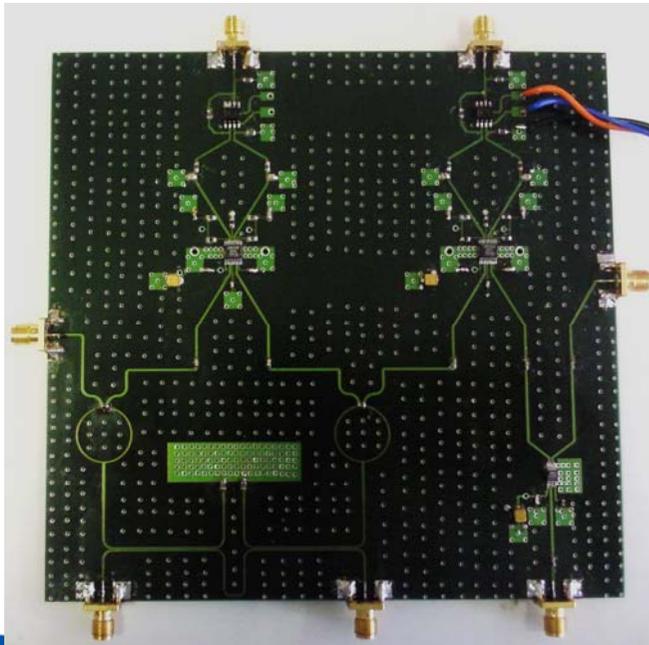




RF Interferometer Controls

- Precision reflector
- Interferometer termination
- Aluminium cavity
- 15m medium loss cable
- Manual phase shifter
- 3.9 GHz source

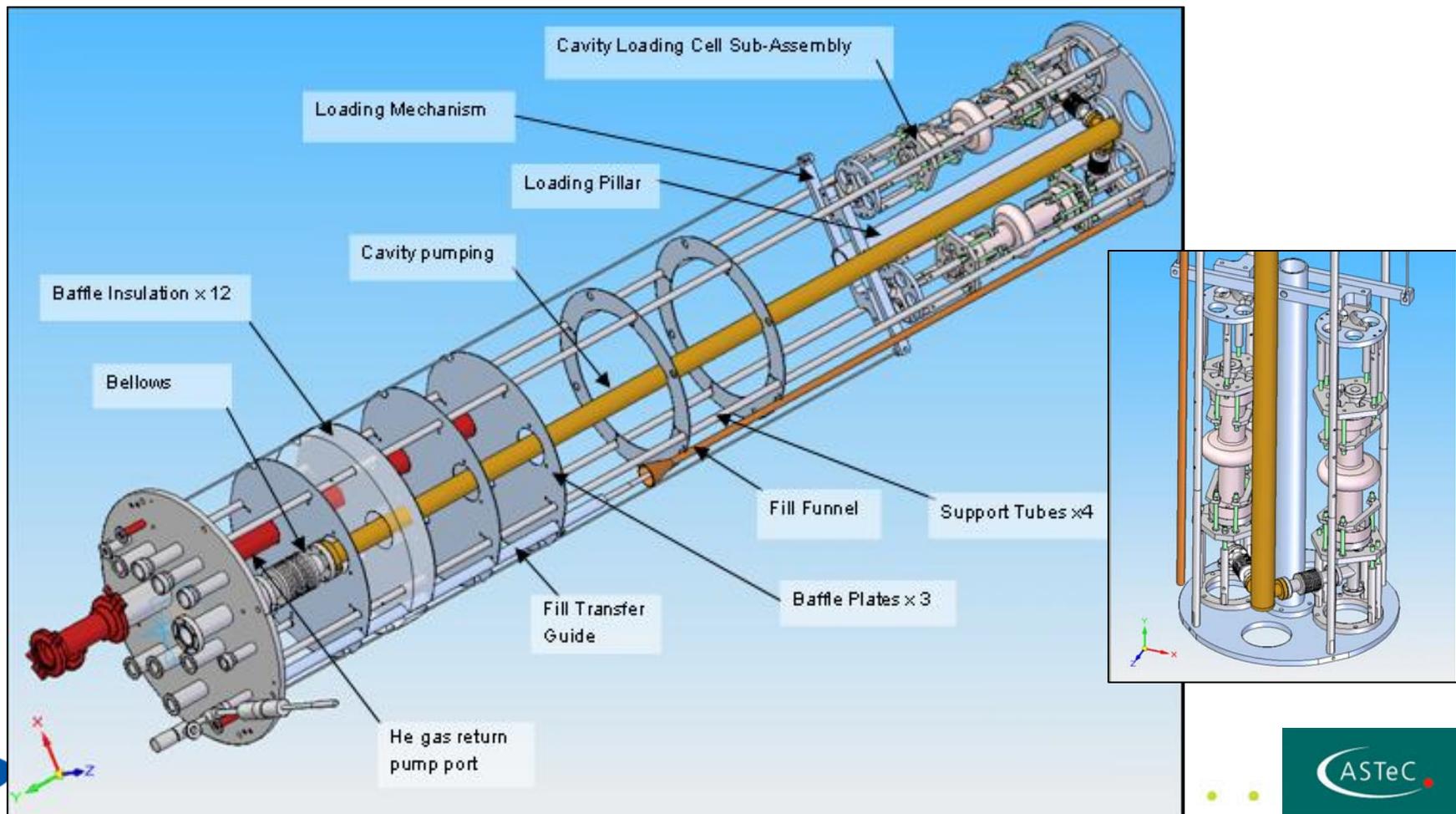
Integrated interferometer termination





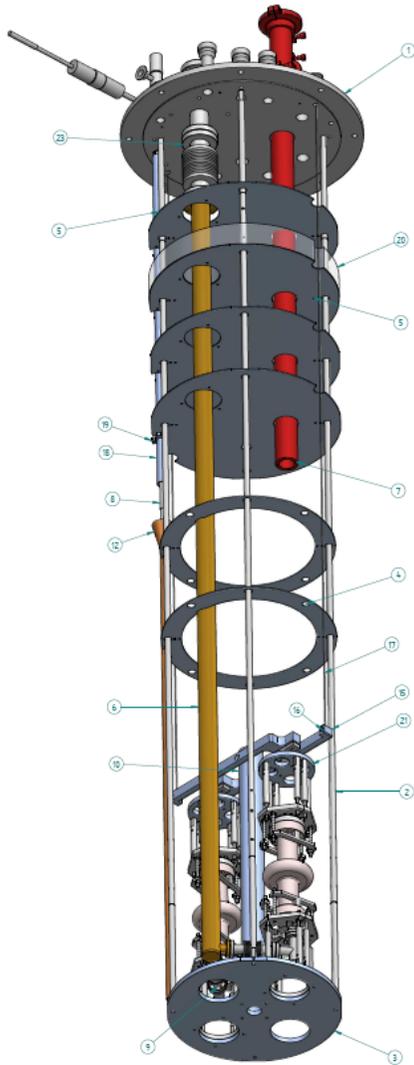
ILC-CC System Validation Tests

- Aim: to verify LLRF control and synchronisation of 2 x 3.9 GHz SRF crab cavities.





ILC-CC Testing Hardware



Cavities limited in gradient to 1 MV/m ($\sim 40\text{kV}/\text{cell}$) – shielding implications.



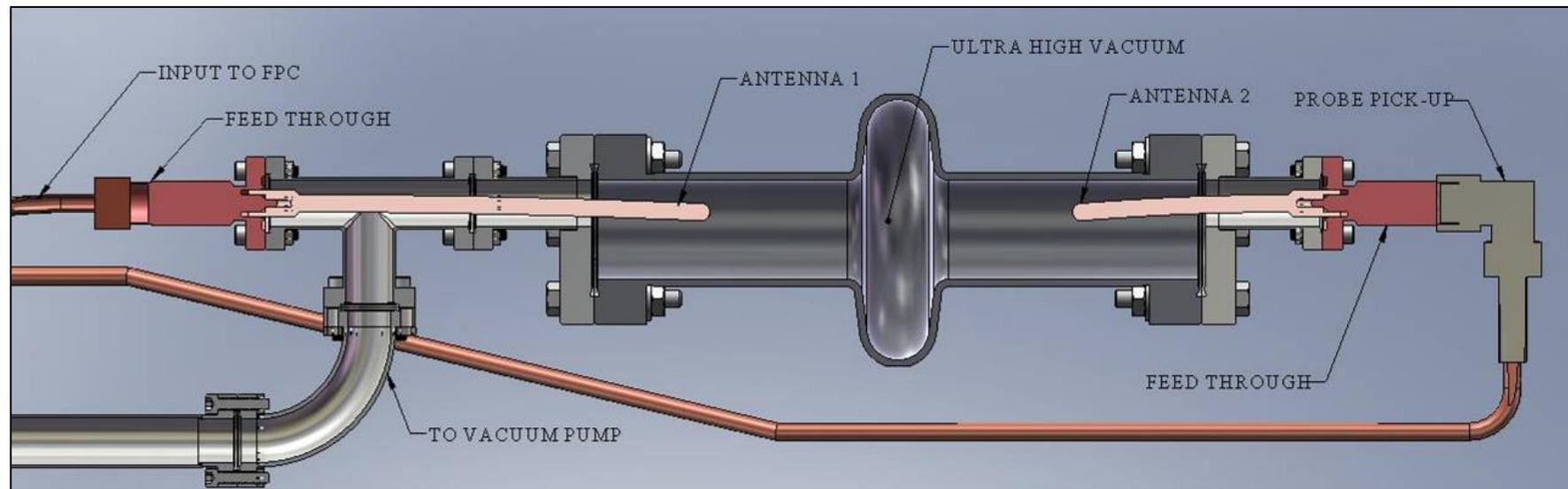
Cavity Tuning Issues

Cavity S/N 001

Q_L = $0.97e7$
 Q_e (input) = $1.44e7$
 Q_e (output) = $3.0e9$
 Q_o = $3.0e7$
Bandwidth = 400 Hz
Drift ~ 300 Hz
Fixed Tuner

Cavity S/N 003

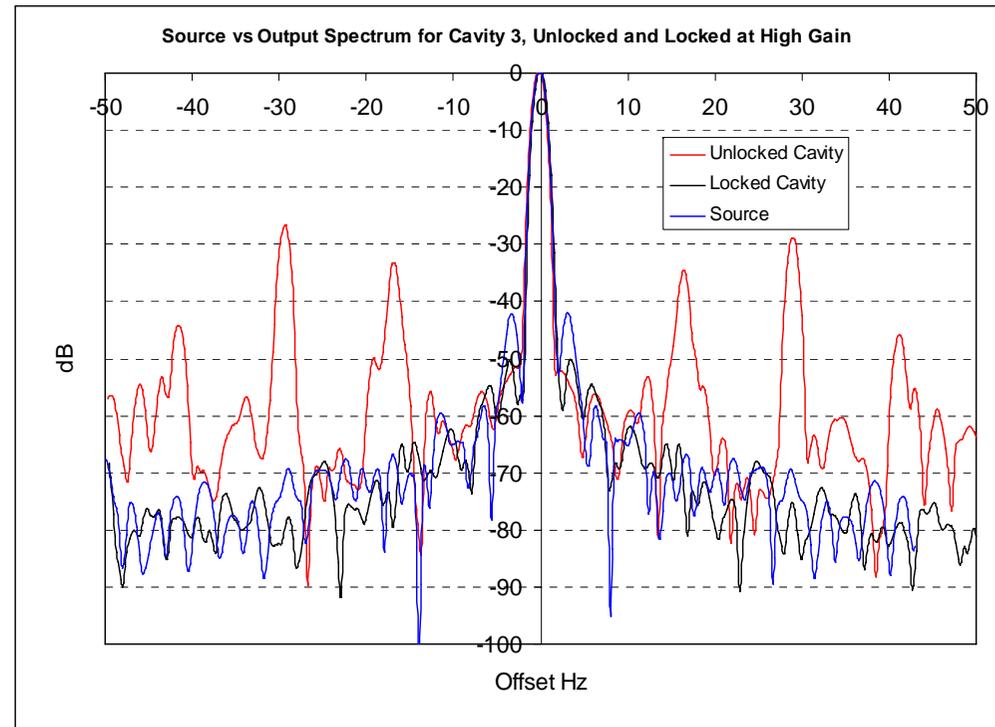
Q_L = $1.52e7$
 Q_e (input) = $2.57e7$
 Q_e (output) = $9.6e9$
 Q_o = $3.7e7$
Bandwidth = 256 Hz
Drift = 5 kHz to 20 kHz
Small tuning range





Preliminary Measurement Results

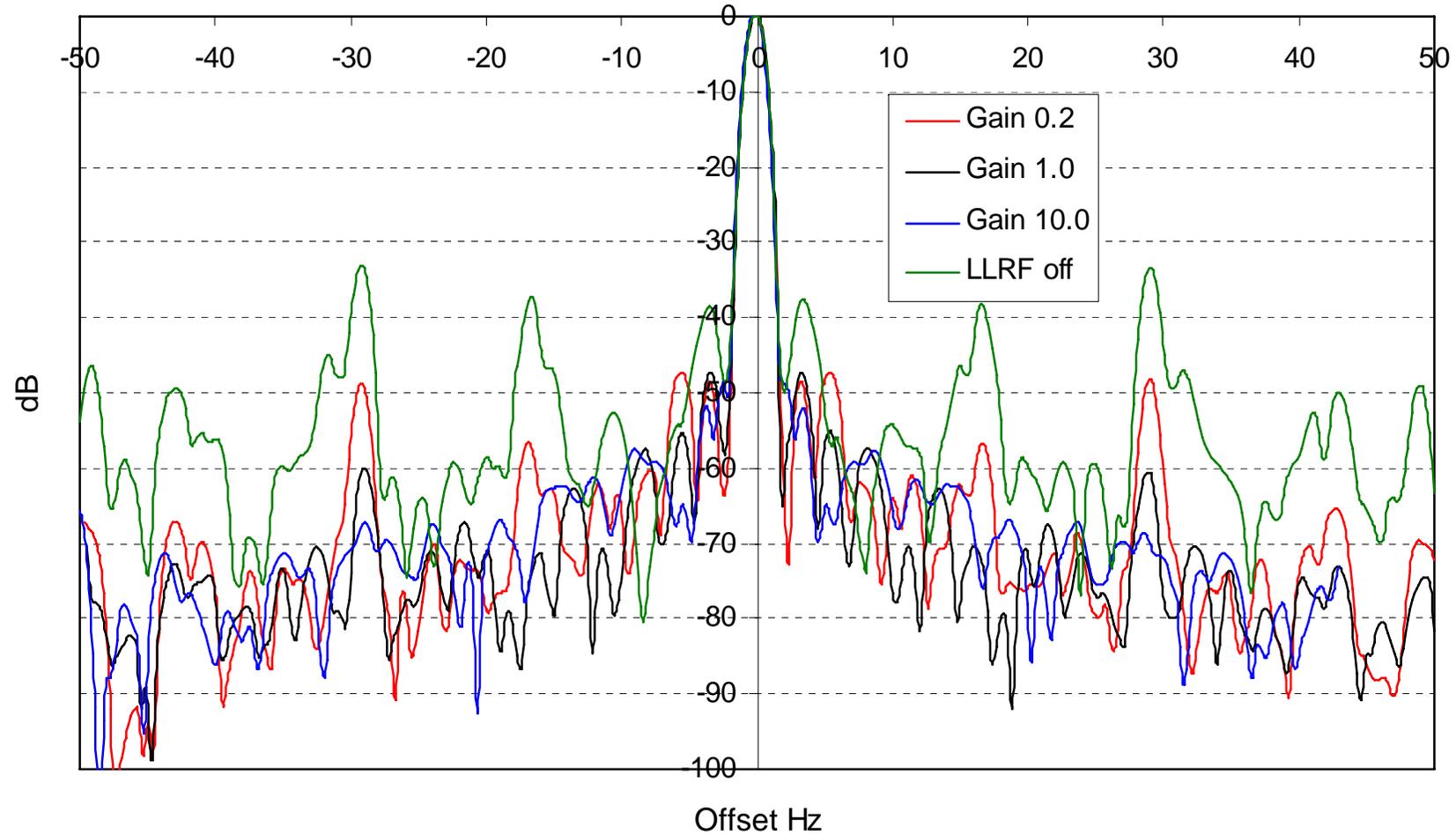
- Independent phase lock achieved for both cavities:
 - **Unlocked** \Rightarrow **10° r.m.s.**
 - **Locked** \Rightarrow **0.135° r.m.s.**
- Performance limited by:
 - **Source noise (dominant)**
 - **ADC noise**
 - **Measurement noise**
 - **Cavity frequency drift**
 - **Microphonics**
- Improvements being made.
- Next tests scheduled for December 08.





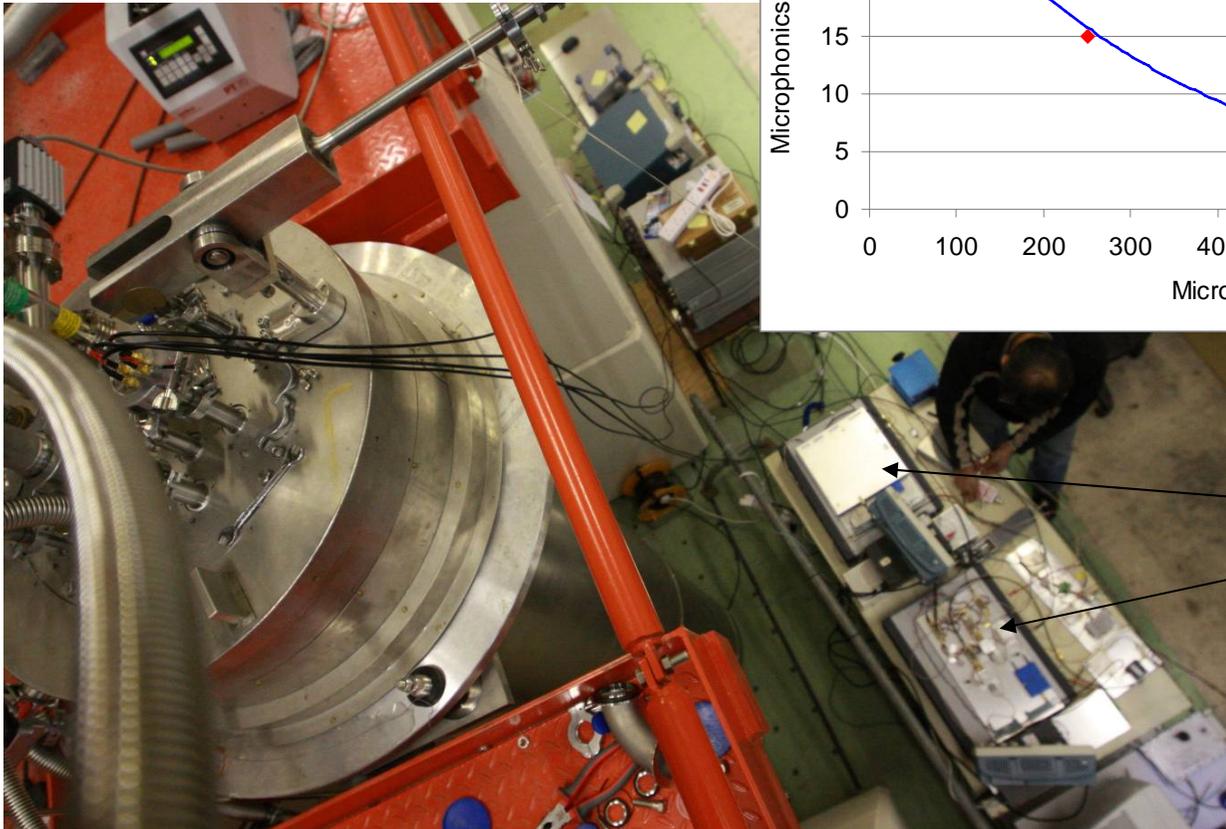
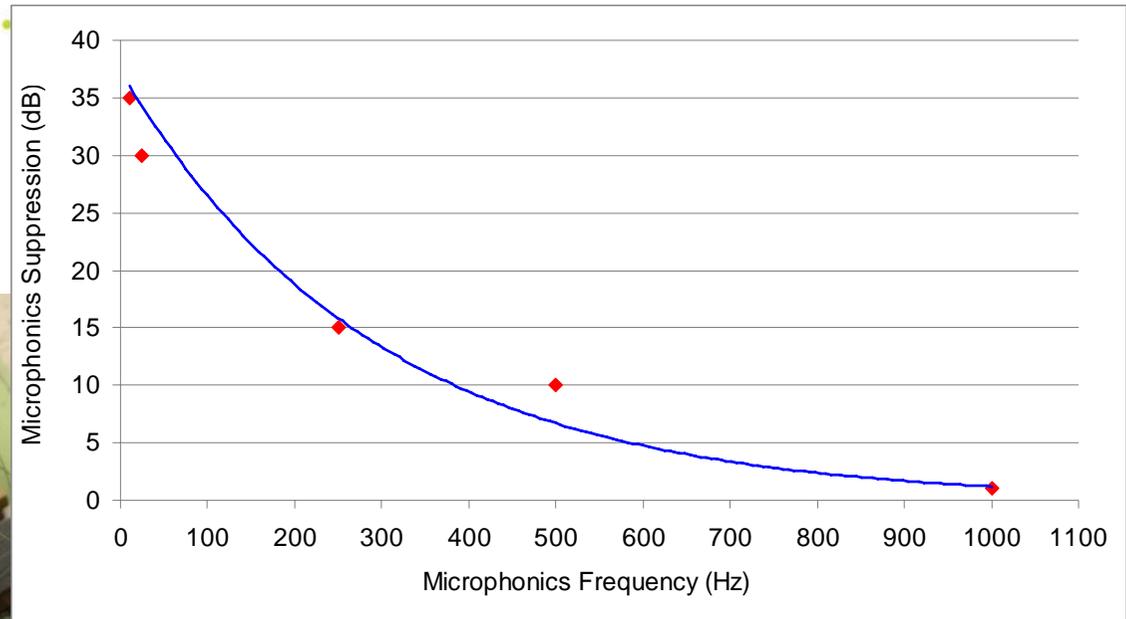
LLRF Gain Response

DSP Clock Speed of 50 MHz





System Microphonics Performance



**Control boxes
with
interferometer
components
on top**



Future Work

- December Tests:
 - **Improve cavity tuning to ensure sustained lock:**
 - Increase cavity BW to $\sim 1\text{kHz}$ ($Q_L \sim 4e6$)
 - Control cavity frequency to within $\pm 100\text{ Hz}$, to allow use of precision drive oscillator.
 - **Quantify interferometer performance.**
- Longer Term:
 - **Implement FPGA control for fast interferometer feedback.**
 - **Implement amplitude feedback electronics.**
 - **Implement dynamic phase and amplitude calibration.**
 - **Develop ILC-CC cryomodule design:**
 - **needs more resources.**
 - **Build full cryomodule and validate with beam on ILCTA:**
 - **needs lots more resources!**

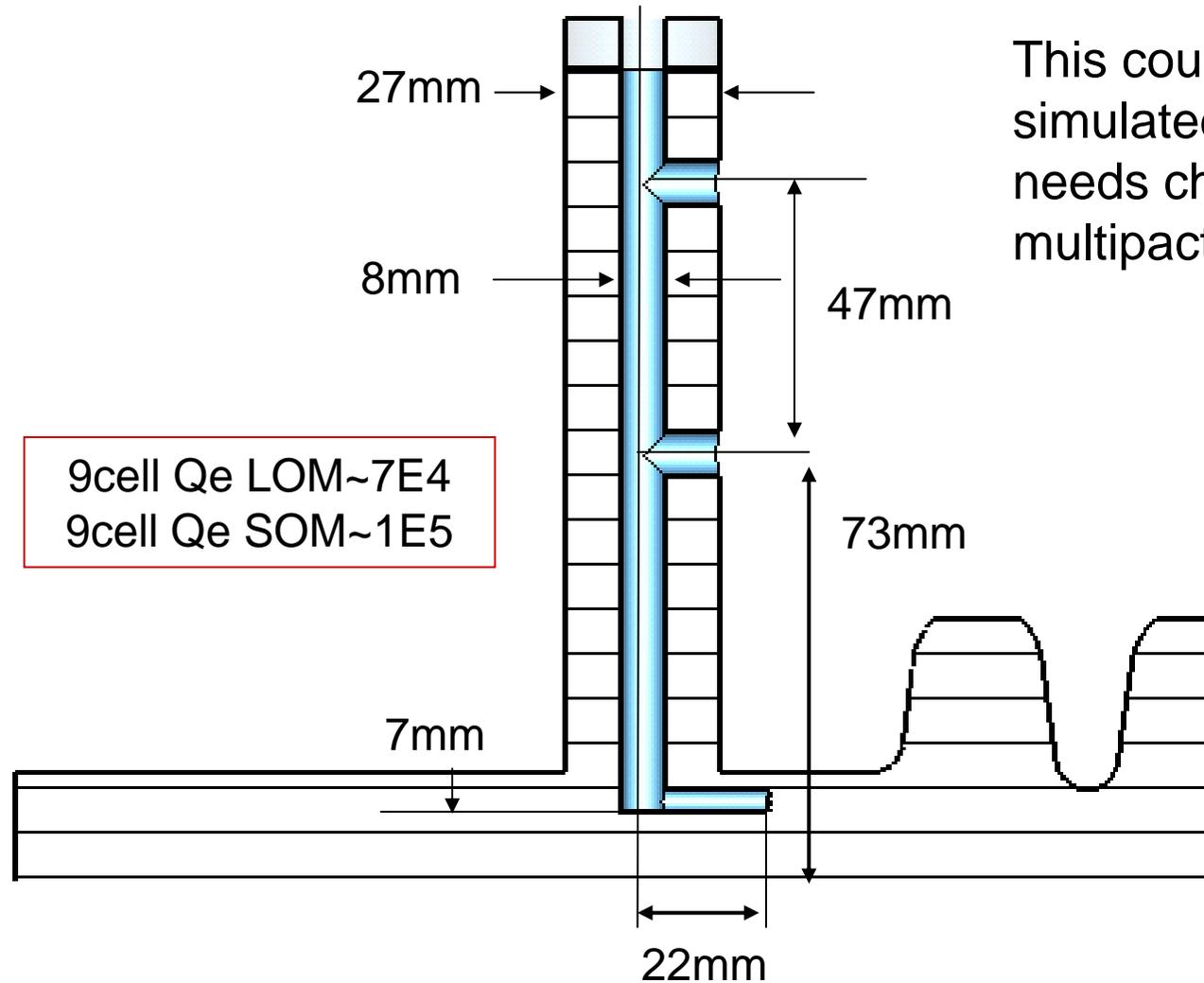


Previous Modelling Results

- A full set of couplers were designed, built, tested and checked for Multipactor.
- Measurements found problems with the SLAC HOM coupler above the 2nd dipole passband.
- CI Simulations found that the HOM coupler could not be modified to fix the problems without a significant redesign.
- CI staff are finishing a new HOM coupler design which addresses these problems.
- CI LOM/SOM coupler has been designed.



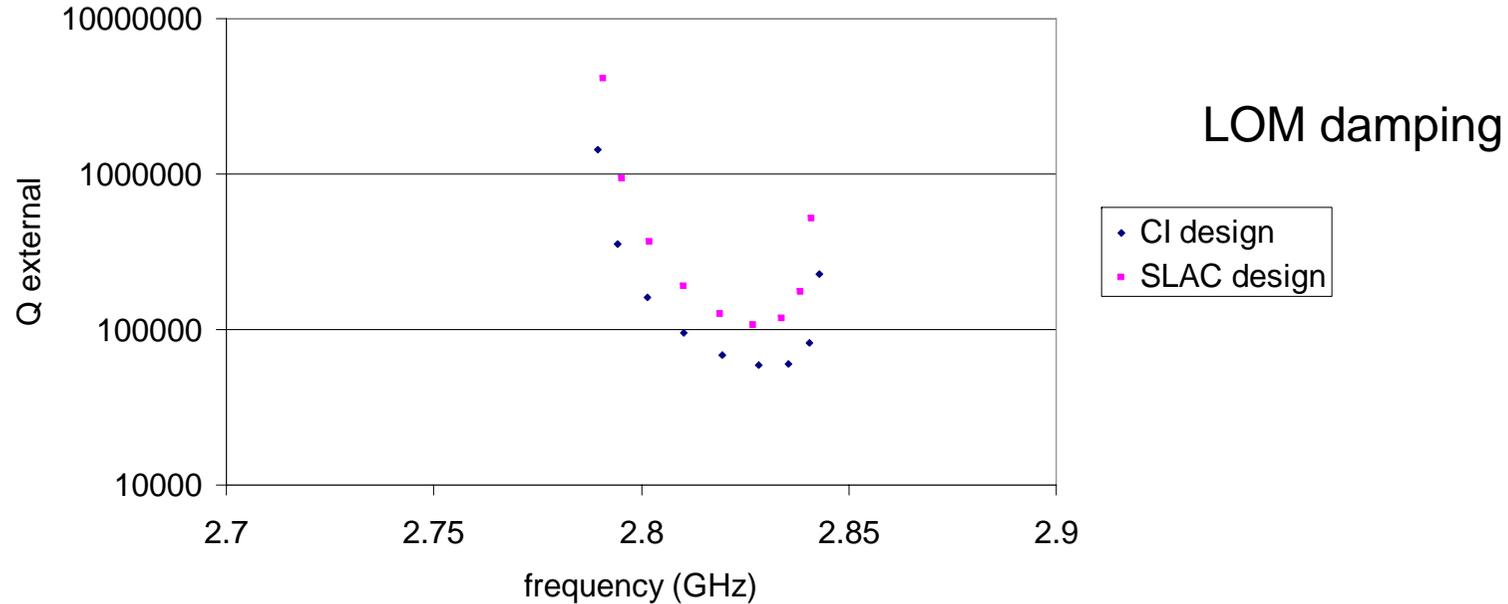
Combined SOM/LOM Coupler



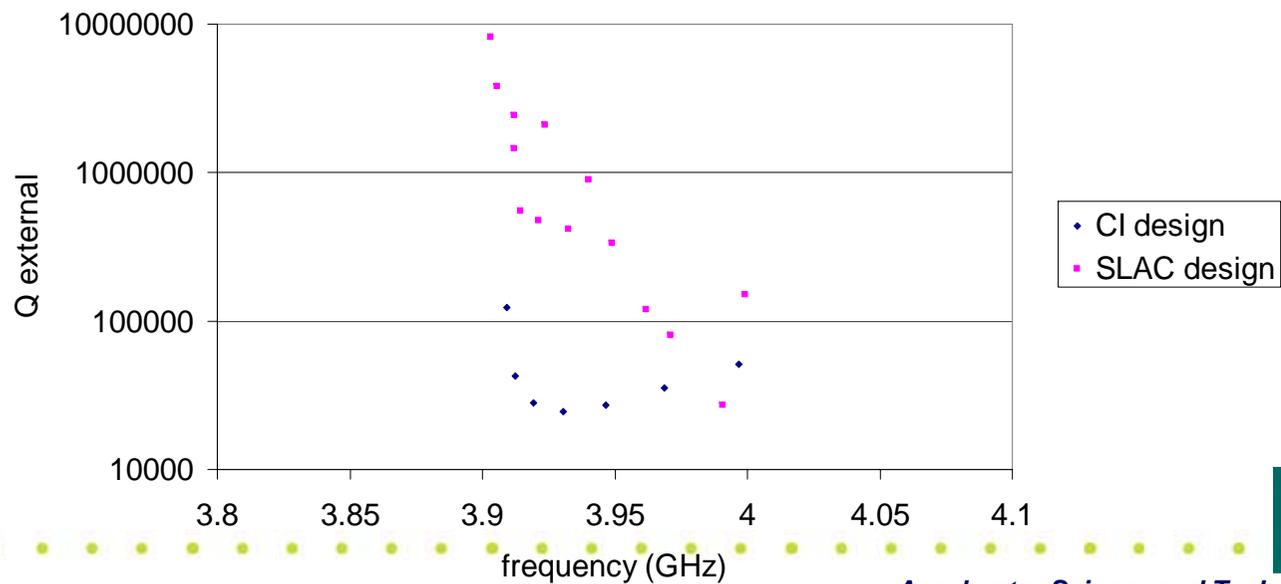
This coupler has been simulated in MWS but needs checked for multipactor.



Comparison with SLAC Design



SOM Damping





2nd HOM Coupler

- The 2nd HOM coupler is currently still being optimised by CI.
- Design based on novel analytical techniques for studying high frequency behaviour of HOM couplers.
- Results will be submitted to PRST-AB.
- After the publication, the dimensions can be passed to SLAC for simulation of the final ILC Crab Cavity couplers.



VORPAL Simulations

- CI is setting up use of some HPC facilities within the UK for RF simulations.
- VORPAL is installed on at least one cluster.
- CI can now simulate a full ILC crab structure.
- This allows us to verify the Omega3P simulations.





CLIC-CC Synergies (?)

- Proposed CLIC-CC structure:
 - 12 GHz NC TW cavity $\Rightarrow V_{\perp} \sim 2.4$ MV for 20 mrad IP crossing angle
- ILC-CC phase tolerance @ 3.9 GHz:
 - 0.095° or 67 fs
- CLIC-CC phase tolerance @ 12 GHz:
 - 0.025° or ~6 fs! (10 x tighter)
- Optical interferometer required with ~ 1 fs resolution.
- Much more stringent management of system phase noise sources.
- Much of the ILC-CC design methodologies can be directly applied to CLIC-CC.
- FP7 EUCARD funding available for CLIC-CC R&D (CI and CERN) from 2009.



Summary

- Cavity design developed that meets ILC wakefield thresholds:
 - **Simulations verified with cavity model.**
- Mode coupler designs maintain cavity wakefield compliance:
 - **Prototype couplers verified with cavity model.**
- LLRF and synchronisation architecture developed to reach ILC phase and amplitude tolerances:
 - **Initial tests have demonstrated ability to lock 2 SRF cavities, close to ILC specs ⇒ very promising!**
 - **An RF interferometer (utilising digital phase detectors) looks to be able to achieve ILC-CC stability requirements.**
 - **Dominant sources of phase noise identified.**
 - **LLRF has demonstrated microphonics suppression.**
- Further tests planned for next month.
- Starting to develop ideas for CLIC-CC system solutions.