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

The Cockcroft Institute of Accelerator Science and Technology
Accelerator Science and Technology Centre

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)**
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  - **Peter McIntosh (ASTeC)**
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- FNAL:
  - **Leo Bellantoni**
  - **Mike Church**
  - **Tim Koeth**
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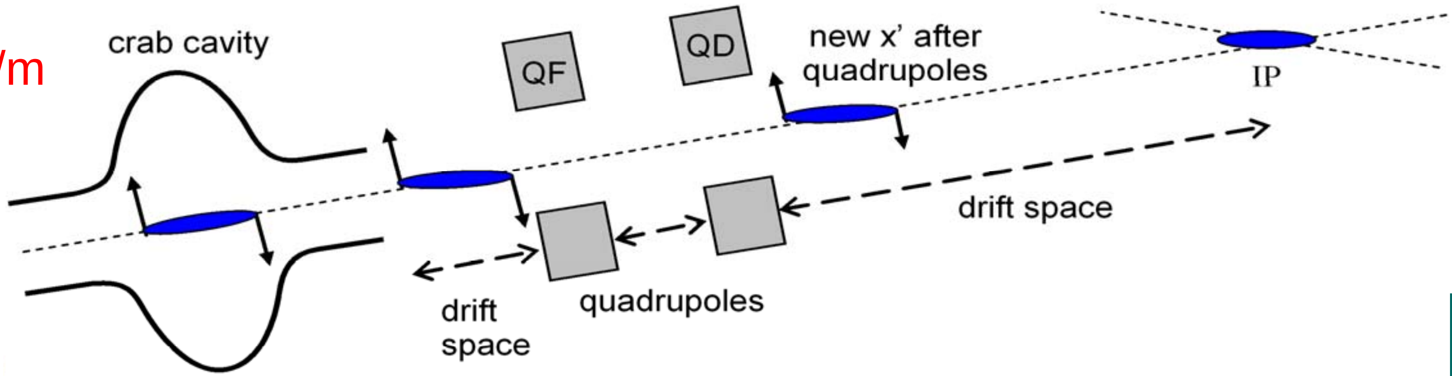
  - **Sergei Nagaitsev**
  - **Nikolay Solyak**
- SLAC:
  - **Chris Adolphson**
  - **Kwok Ko**
  - **Zenghai Li**
  - **Cho Ng**
  - **Andrei Seryi**
  - **Liling Xiao**

ILC-CC System Specification

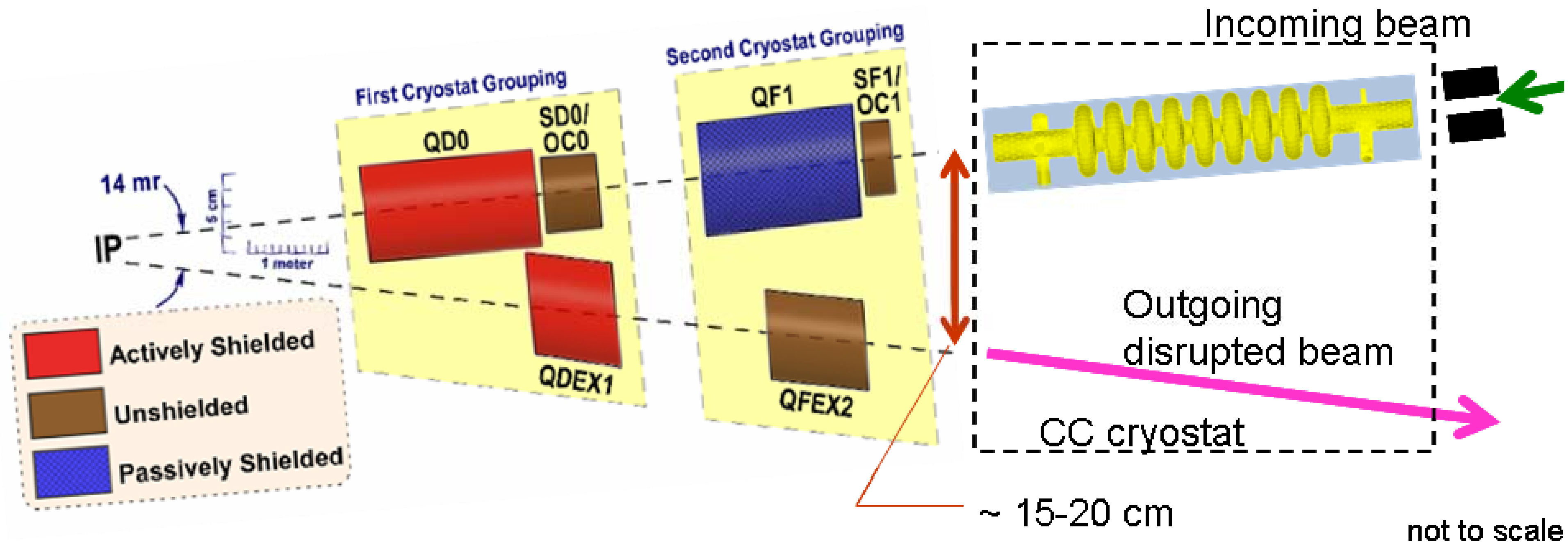
Crossing angle	14 mrad
Number of cryovessels per IP	2
Number of 9-cell cavities per cryovessel	2
Required bunch rotation , mrad	7
Location of crab cavities from the corresponding IP, m	13.4 – 17.4
Longitudinal space allocated per cryovessel, m	3.8
RMS Relative Phase Stability, deg	0.095
RMS Beam Energy 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.

E_{acc} ~7 MV/m



Crab Cavity Integration on ILC

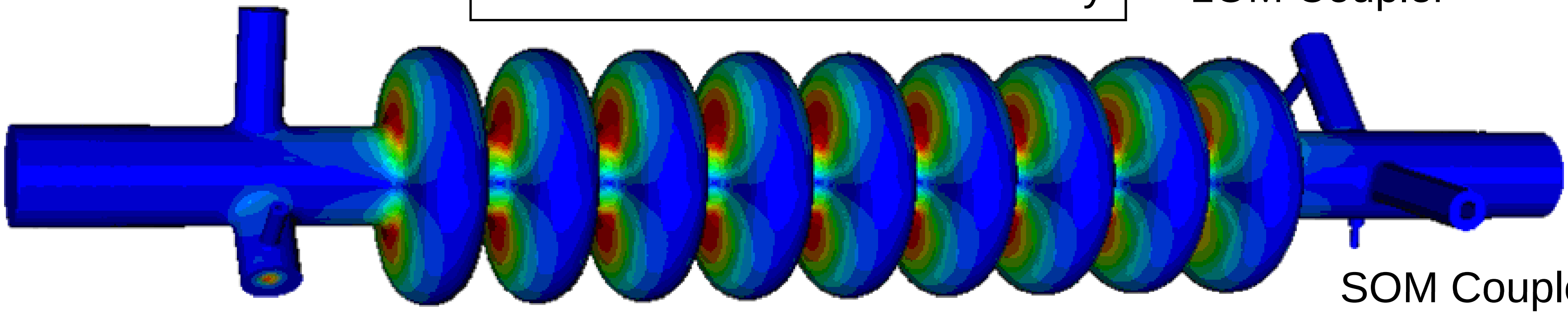


- Crab cavity just behind the Final Doublet
- FD aperture r~1cm => constraint on crab aperture and coupler penetration (to not limit collimation depth)
- Limit for couplers outputs oriented toward outgoing beampipe
- Outgoing beam (~17MW, highly disrupted) goes through crab cryostat

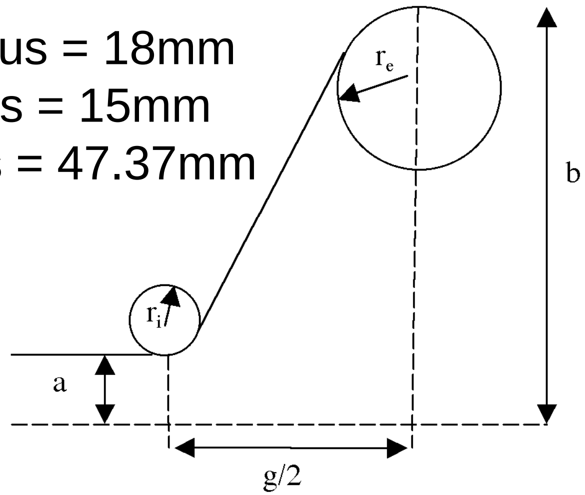
Key Technical Challenges

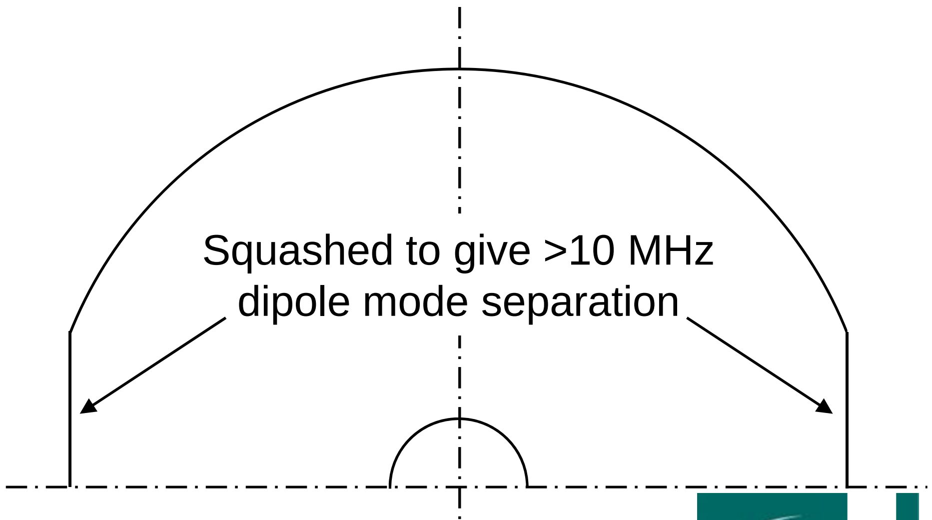
- Crab Cavity:
  - **Wakefield suppression**
  - **Deflecting gradient**
- Damping and Couplers:
  - **Input (based on DESY/FNAL 3rd harmonic),**
  - **LOM (multipacting, tuneability, fabrication),**
  - **SOM (very high damping required, tuneability),**
  - **HOM (multipacting, tuneability, fabrication).**
- 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



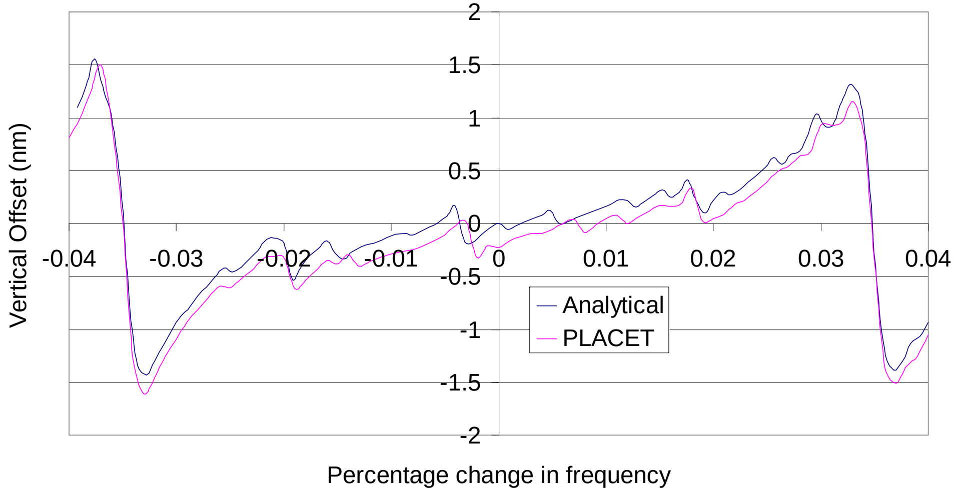
Beam-pipe radius = 18mm
Cavity iris radius = 15mm
Equator Radius = 47.37mm





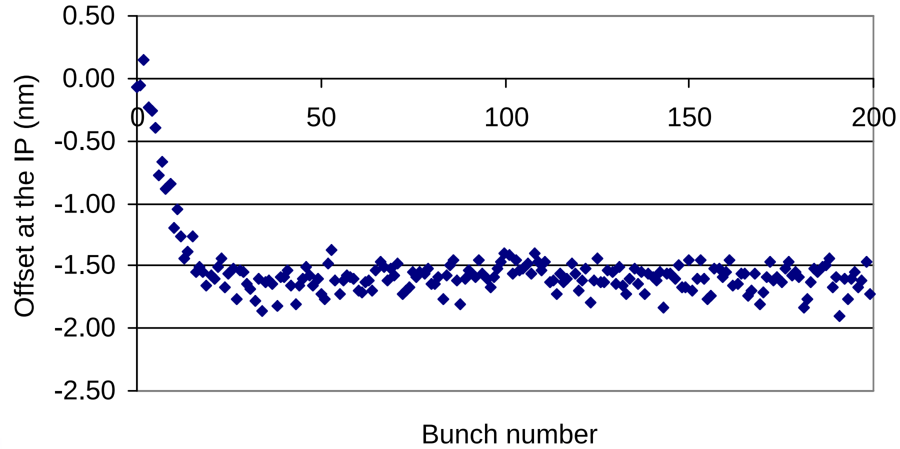
Wakefield Suppression

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



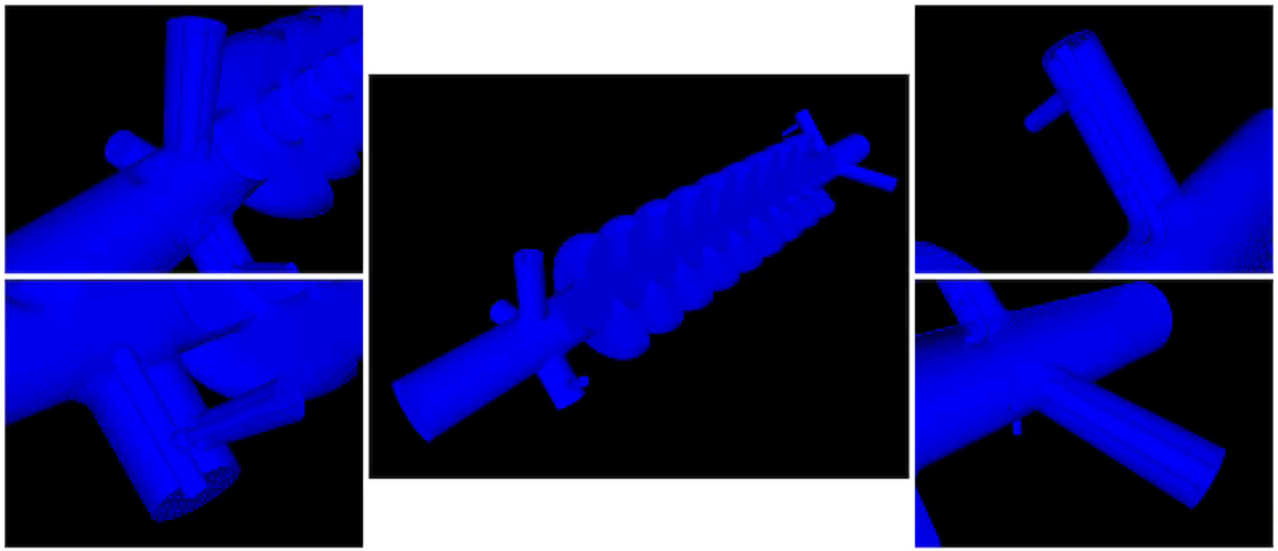
- The PLACET results show when the damping specifications are met the maximum vertical offset is 1.5 nm.

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



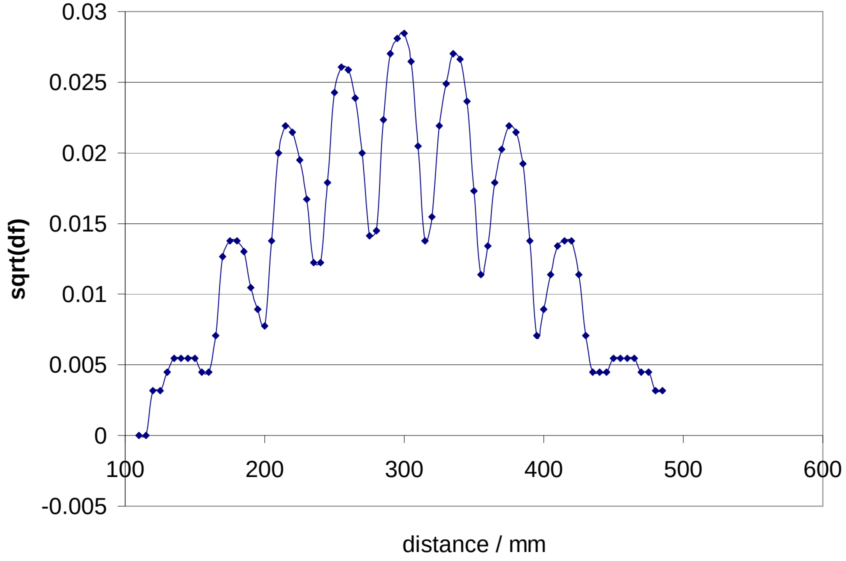
Wakefield Verification

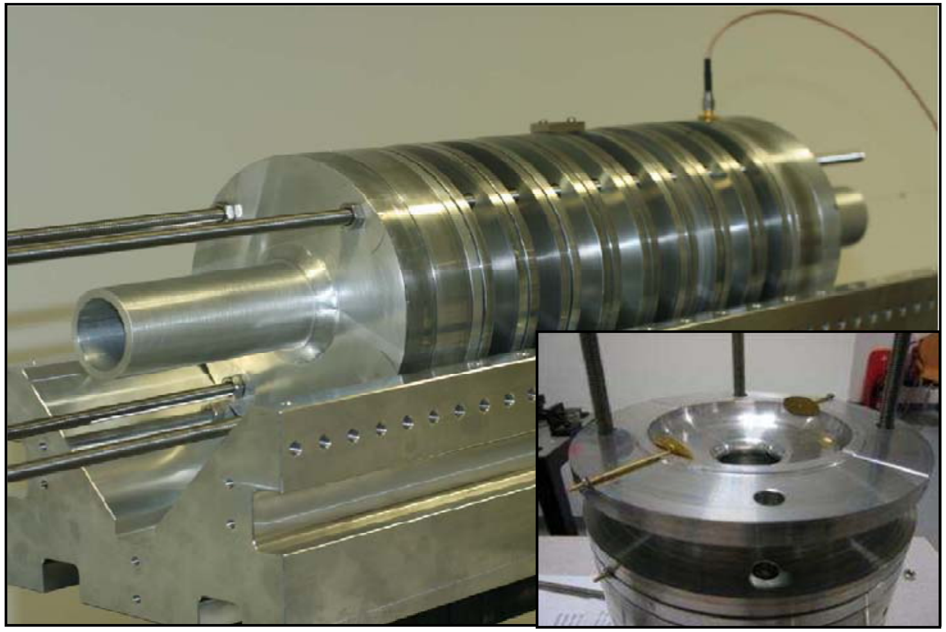
- The proposed 9-cell crab cavity has been simulated using MAFIA, MWS and Omega 3P:
  - **All modes to 18 GHz identified,**
  - **R/Qs calculated,**
  - **Mode damping requirements determined from analytical and PLACET wakefield analysis.**
- All calculated cavity parameters have been confirmed up to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



Structure Characterisation

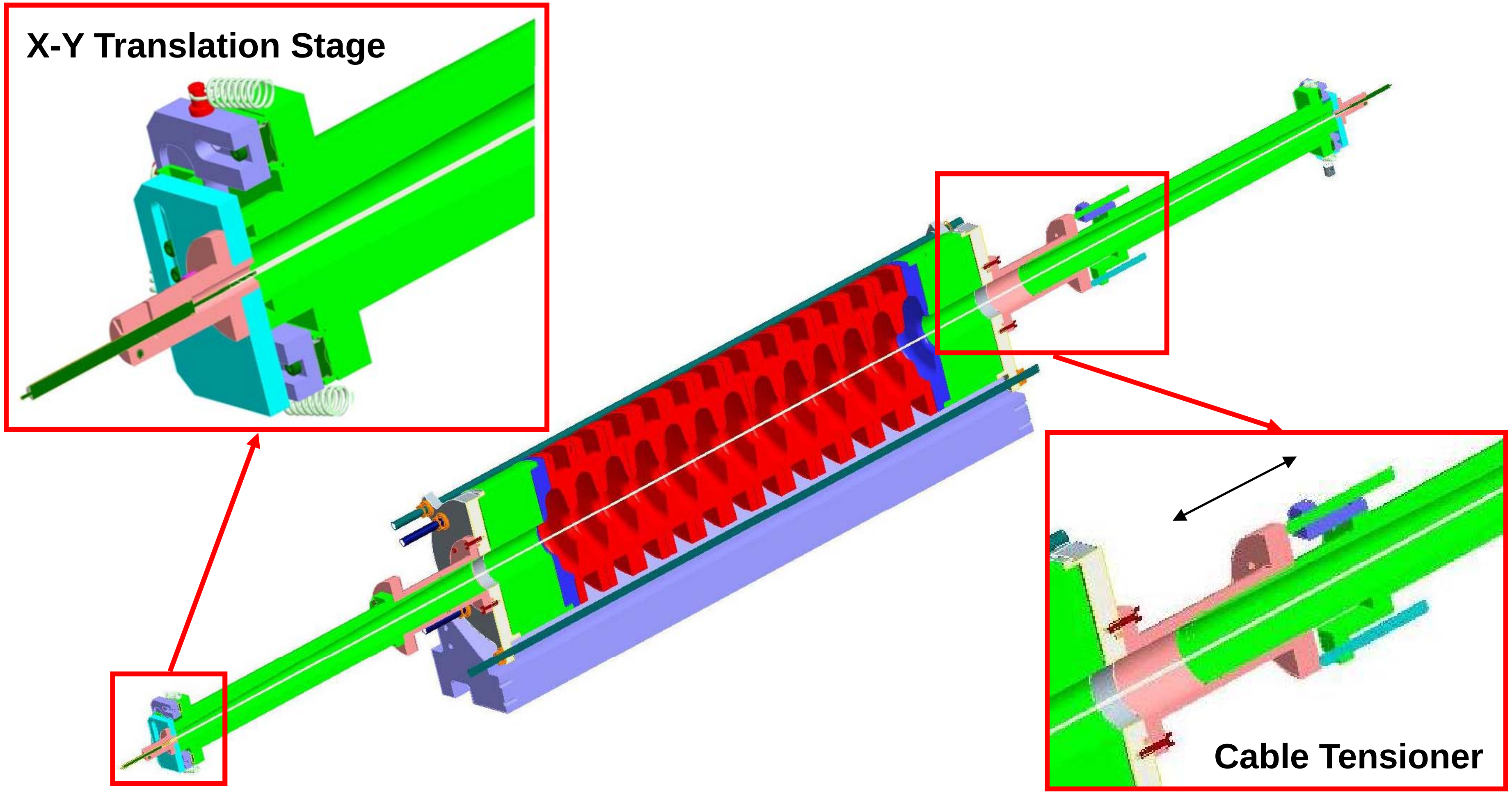
- Model fabricated at DL and used to evaluate:
  - **Mode frequencies**
  - **Cavity coupling**
  - **HOM, LOM and SOM Qe and R/Q**





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

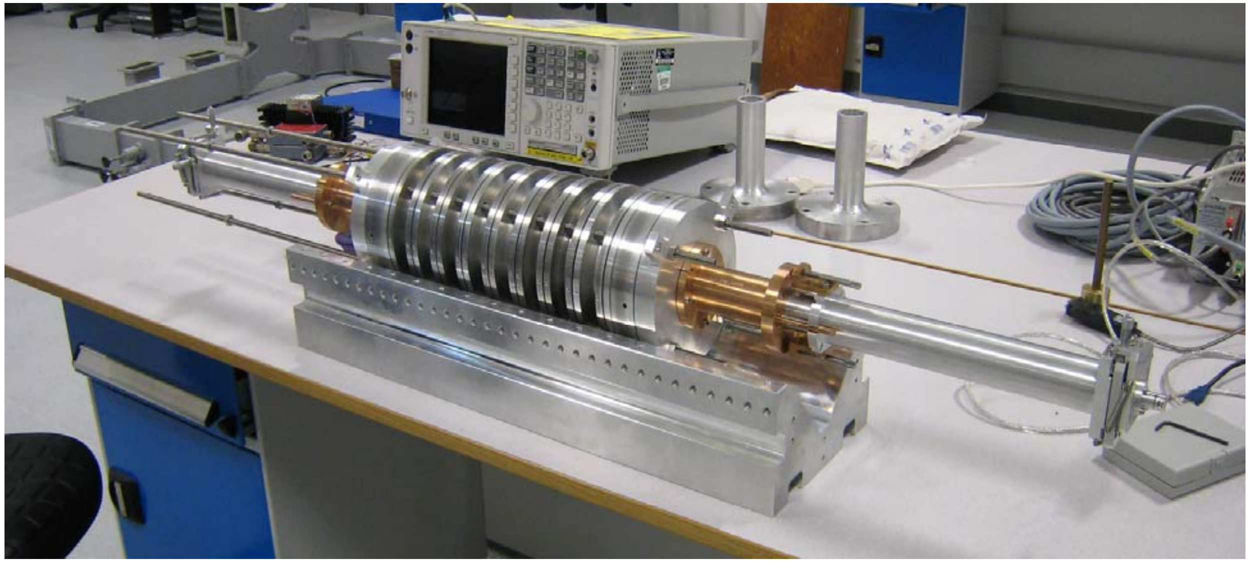
Stretched Wire Characterisation

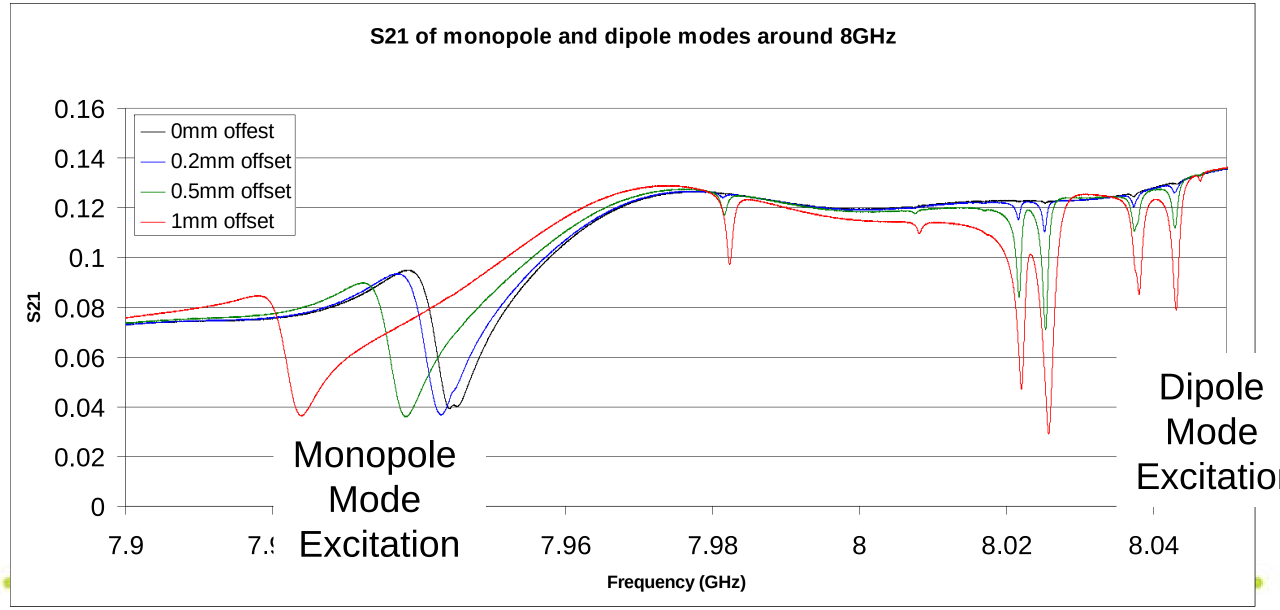


Stretched Wire Technique

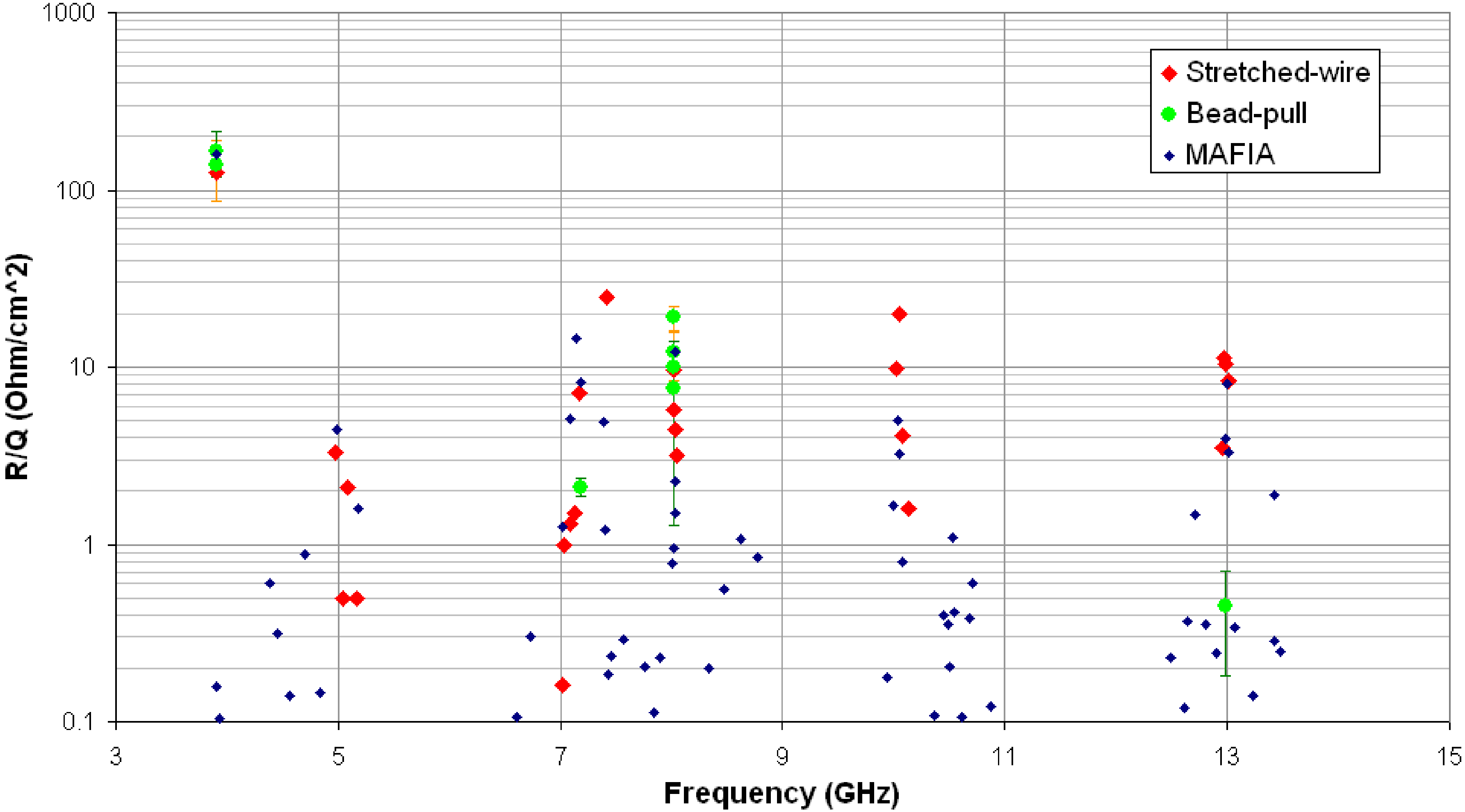
- Provides for characterisation of mode:
  - **Frequencies**
  - **Kick factors**
  - **Loss factors**
  - **R/Q**
- Principle based on similarity of e-m fields in the presence of beam and thin wire.
- Frequency domain signal launched down wire, which then probes the wakefields within the device under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

Stretched Wire Characterisation

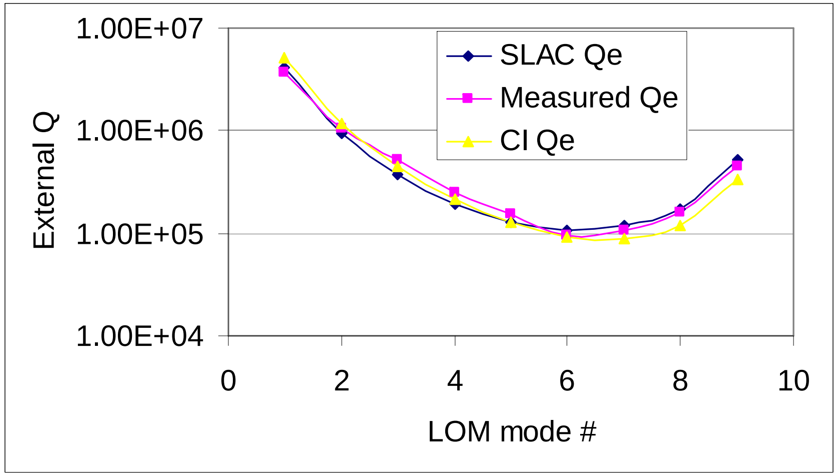


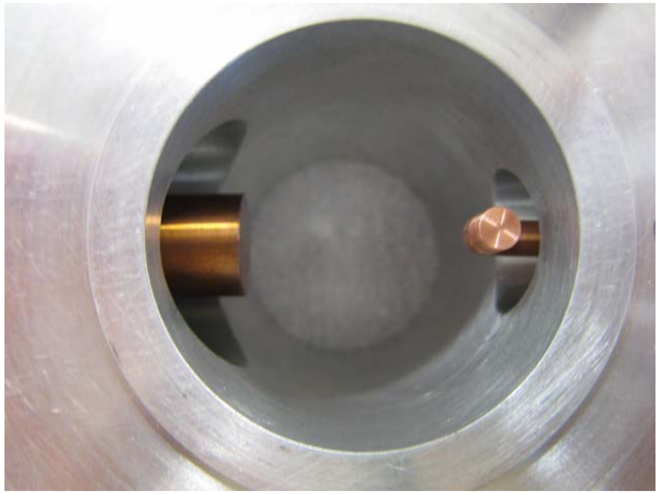


Mode Measurements

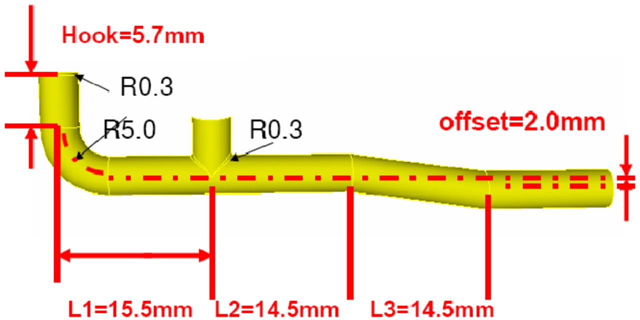


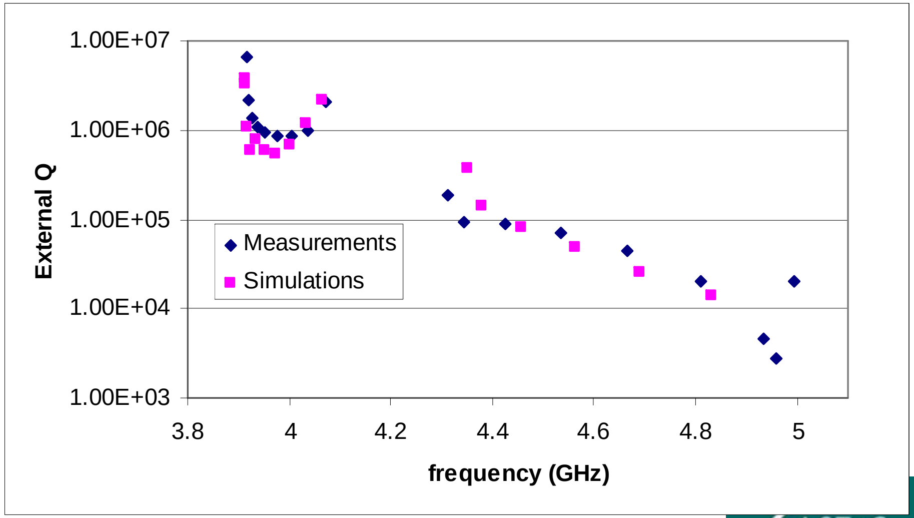
Prototype LOM Qe Measurements





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



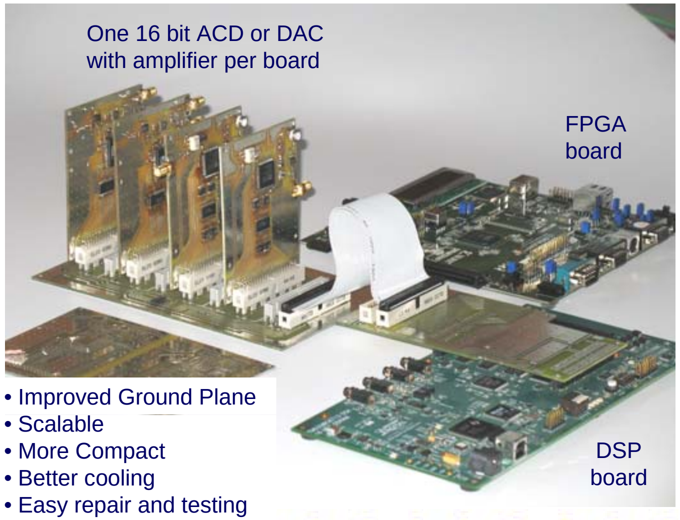


LLRF and Synchronisation

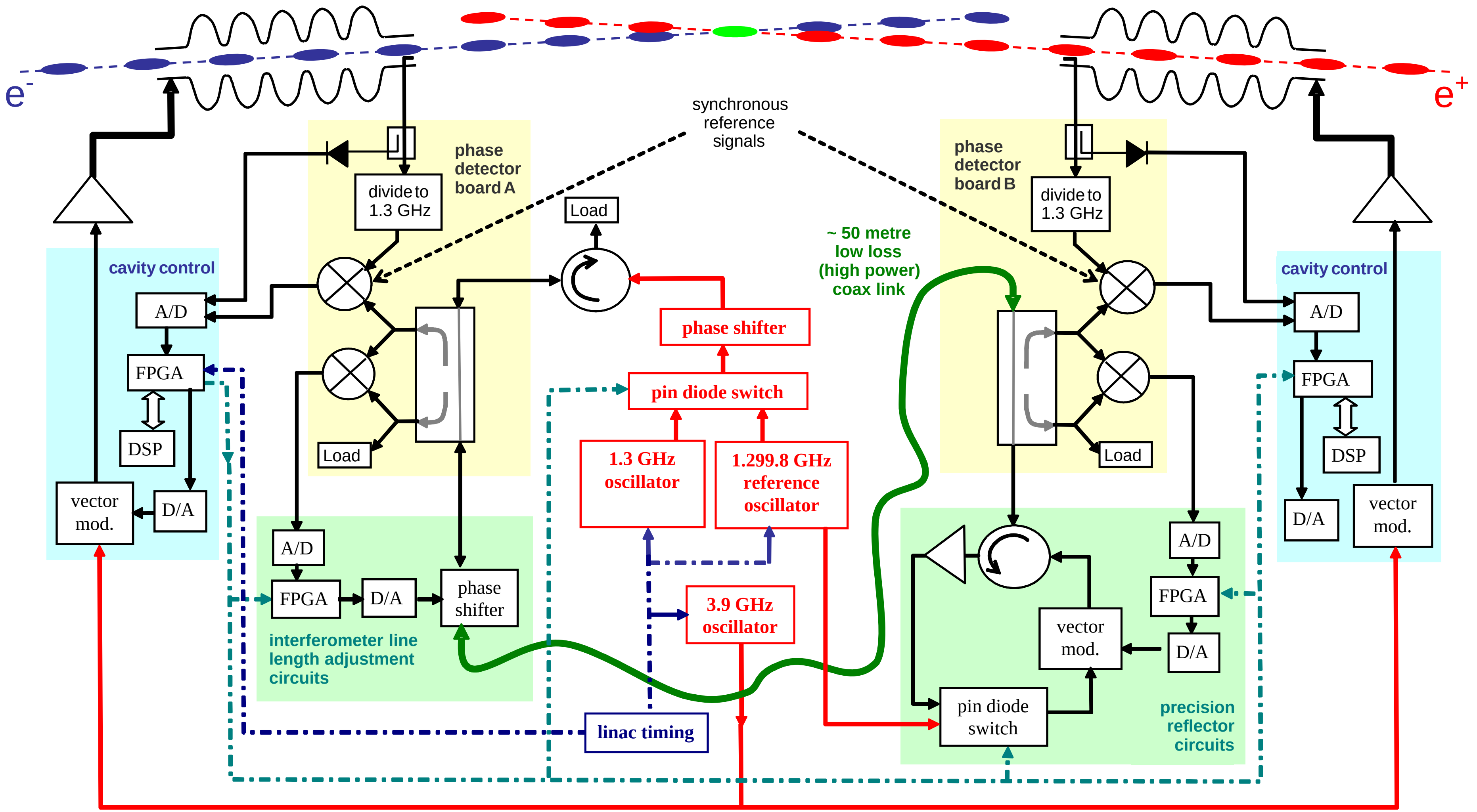
- Bunch-RF phase error in a crab cavity causes unwanted centre-of-mass kick.
- Providing both crab cavities are phase balanced, can compensate these COM kicks.
- ILC crab cavity zero crossings need synchronisation to 94 fs for the 2 % luminosity loss budget.
- Main linac timing requirement is nominally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

ILC-CC System Verification

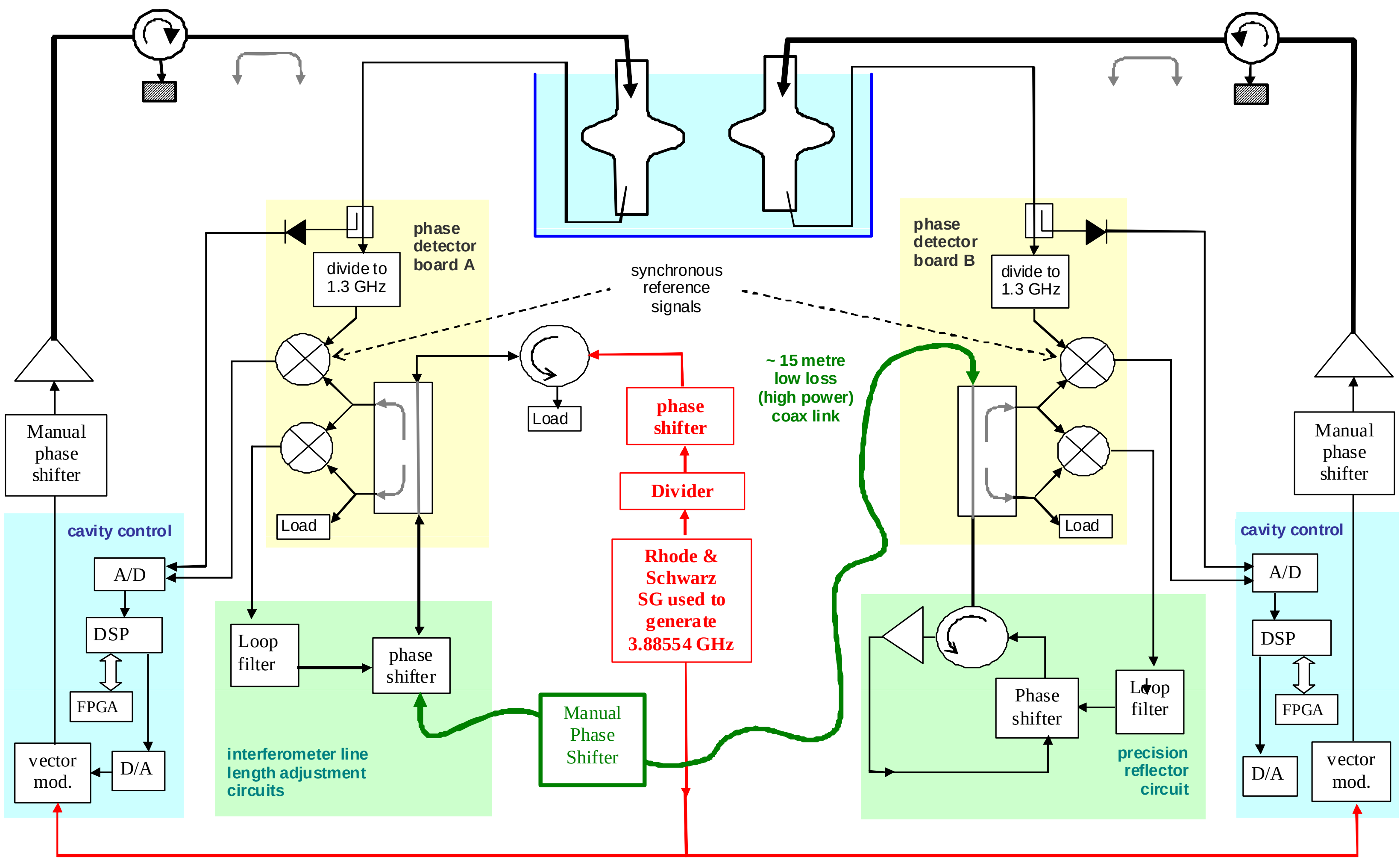
- The phase of the field in each cavity is sampled, compared to the timing reference and the error sent to a digital signal processor (DSP) to determine how the input signal must be varied to eliminate the error.
- Provide an RF interferometer between each crab cavity so that the same cavity clock signal 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

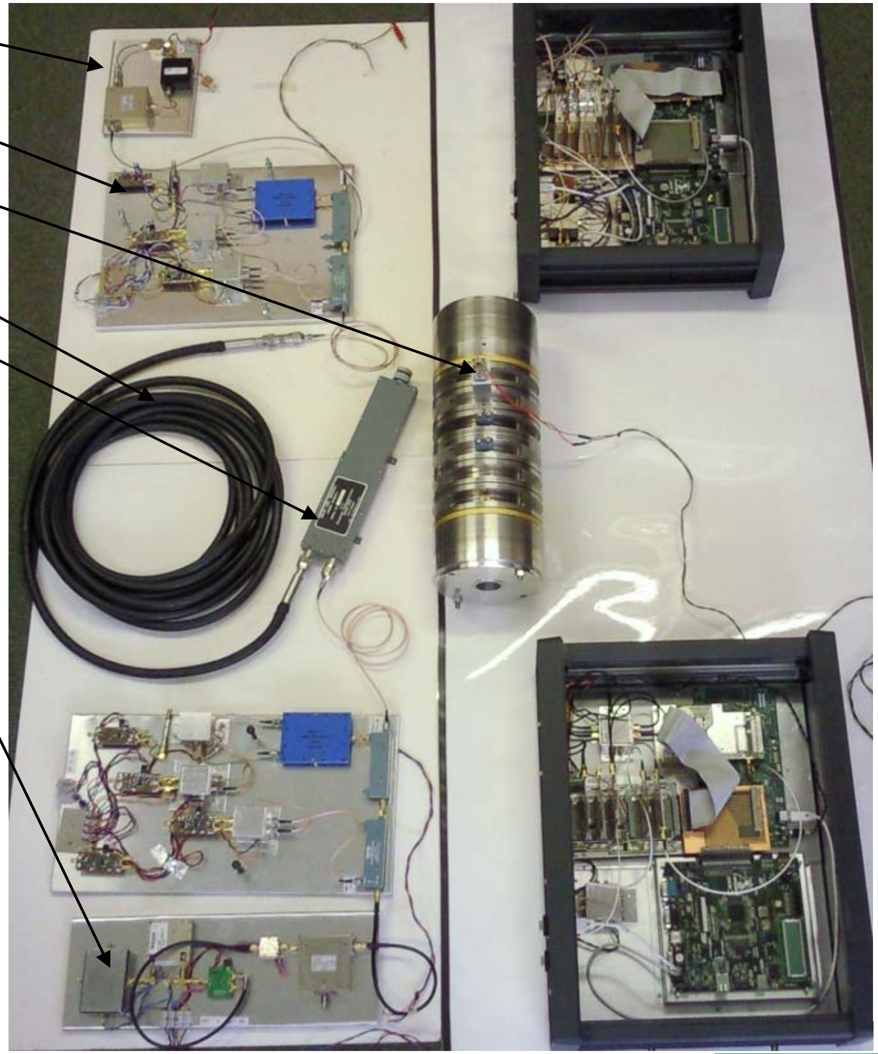
Interferometer termination

Aluminium cavity

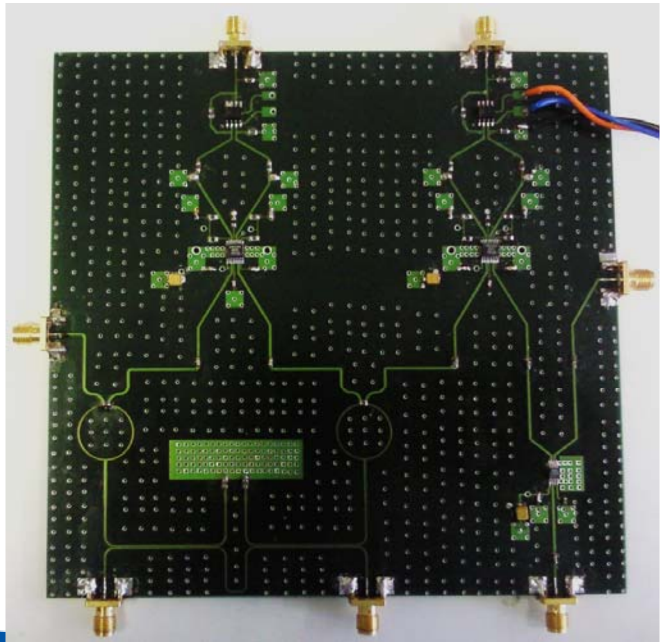
15m medium loss cable

Manual phase shifter

3.9 GHz source

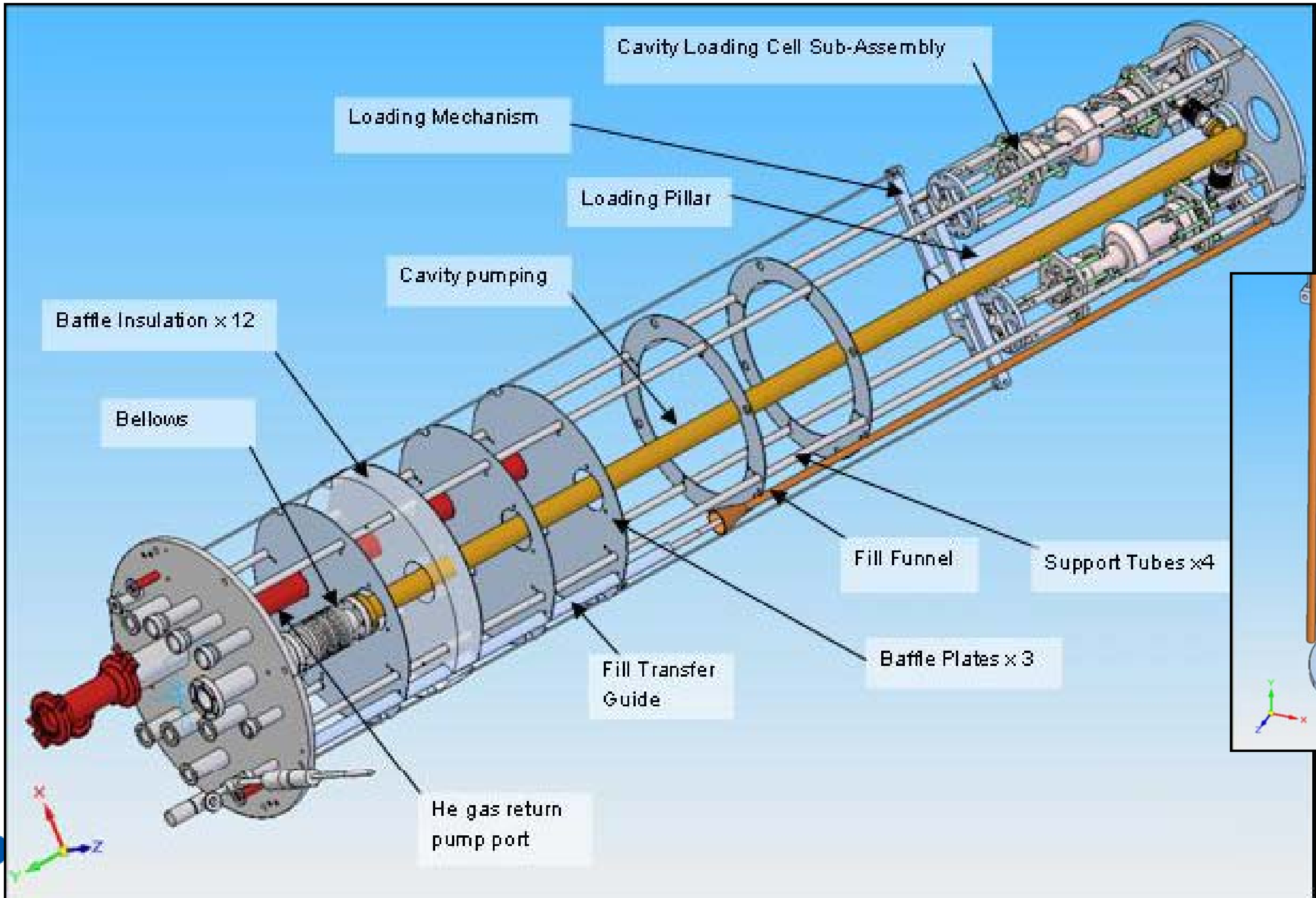


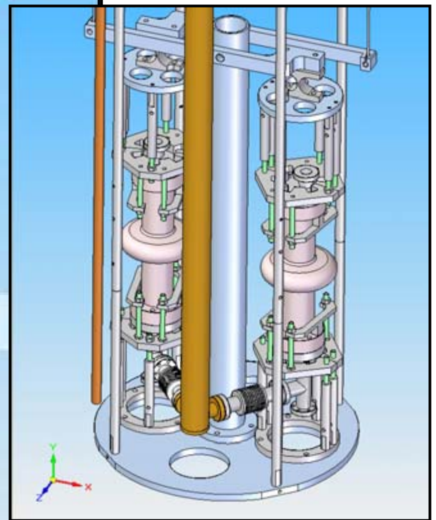
Integrated interferometer termination



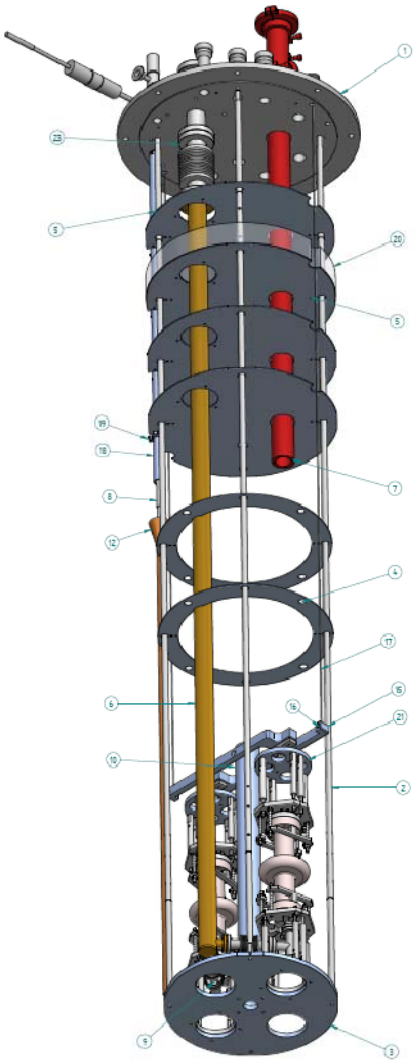
ILC-CC System Validation Tests

- 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 (~40kV/cell) – shielding implications.

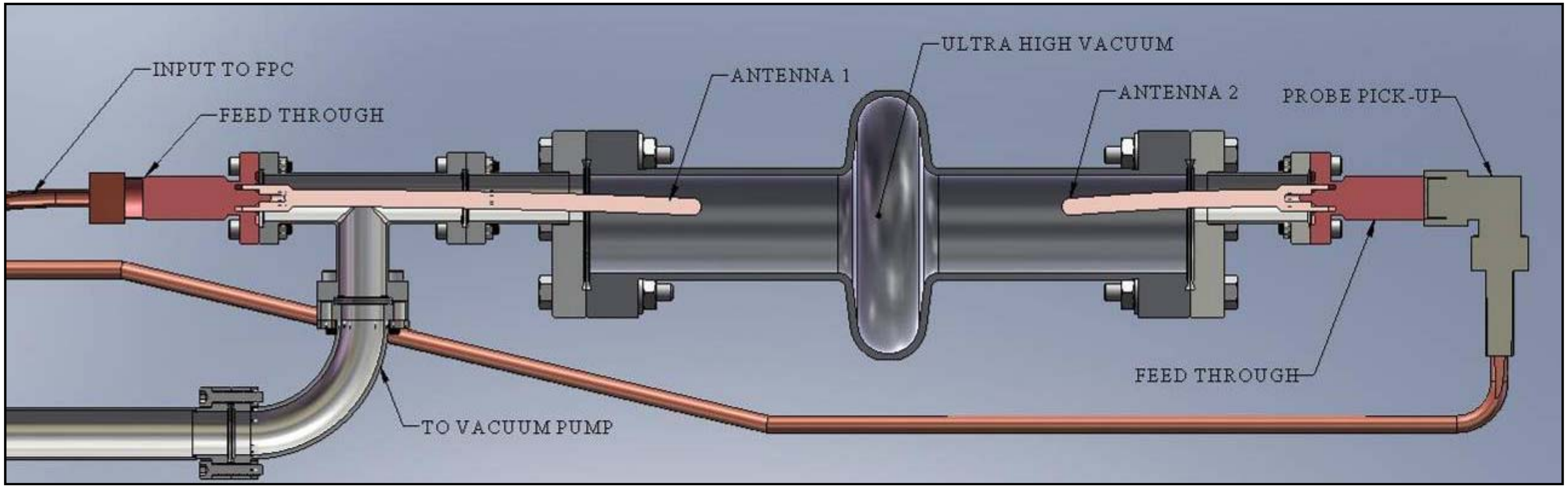
Cavity Tuning Issues

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

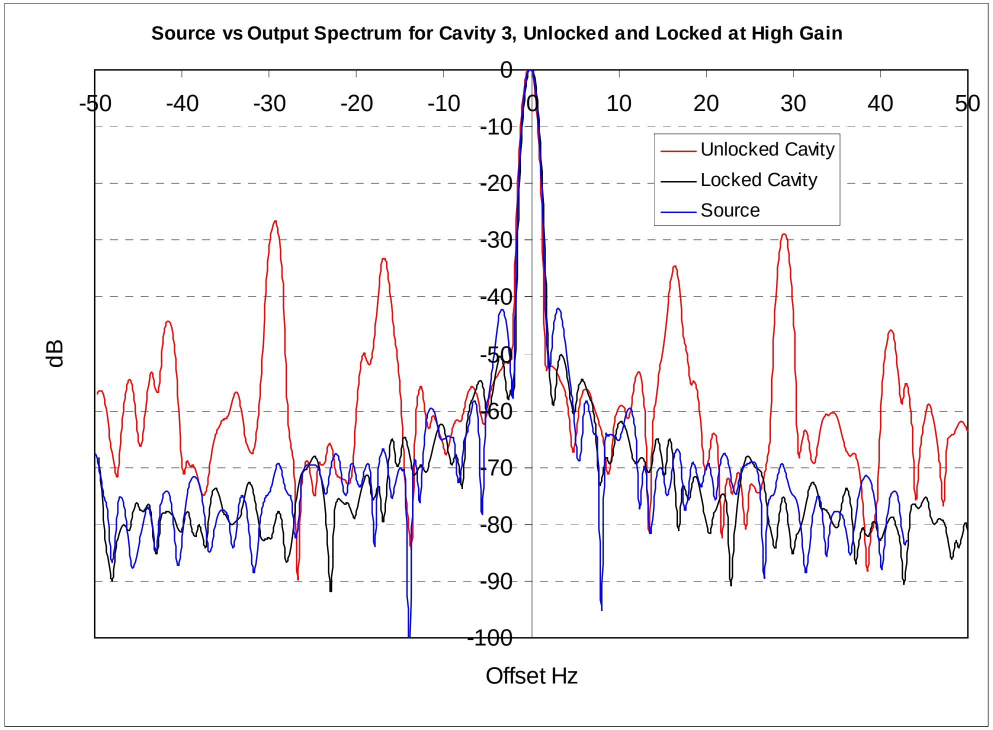
Cavity S/N 003

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



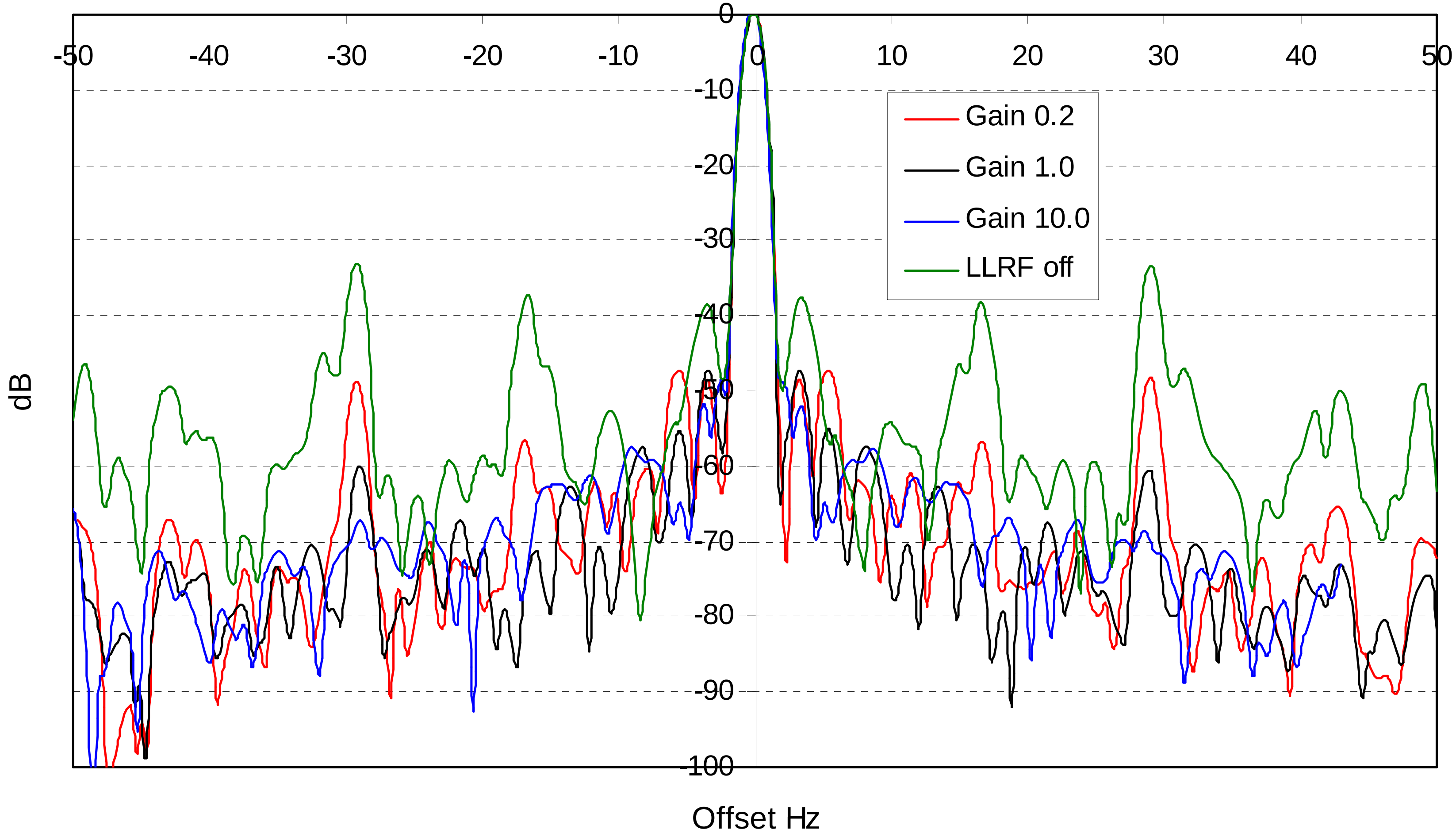
Preliminary Measurement Results

- Independent phase lock achieved for both cavities:
  - **Unlocked ⇒ 10º r.m.s.**
  - **Locked ⇒ 0.135º 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.

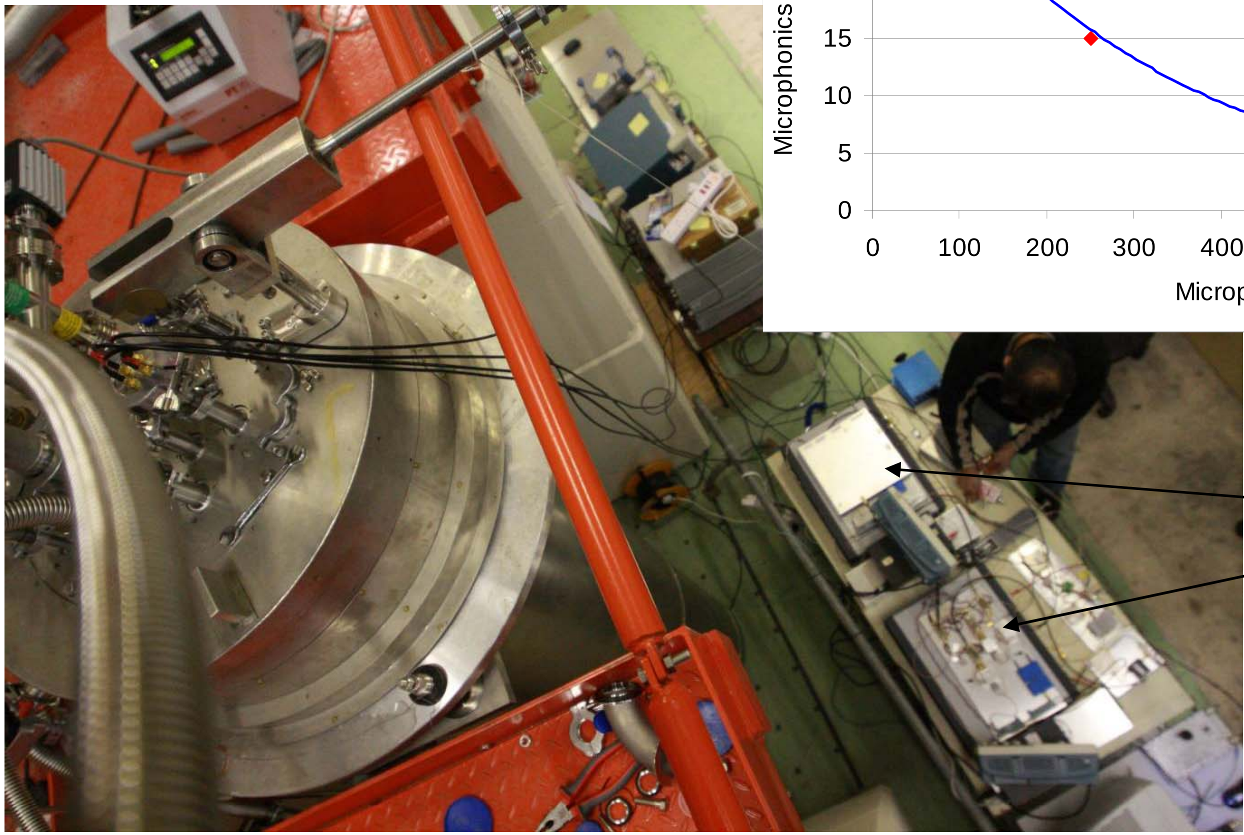


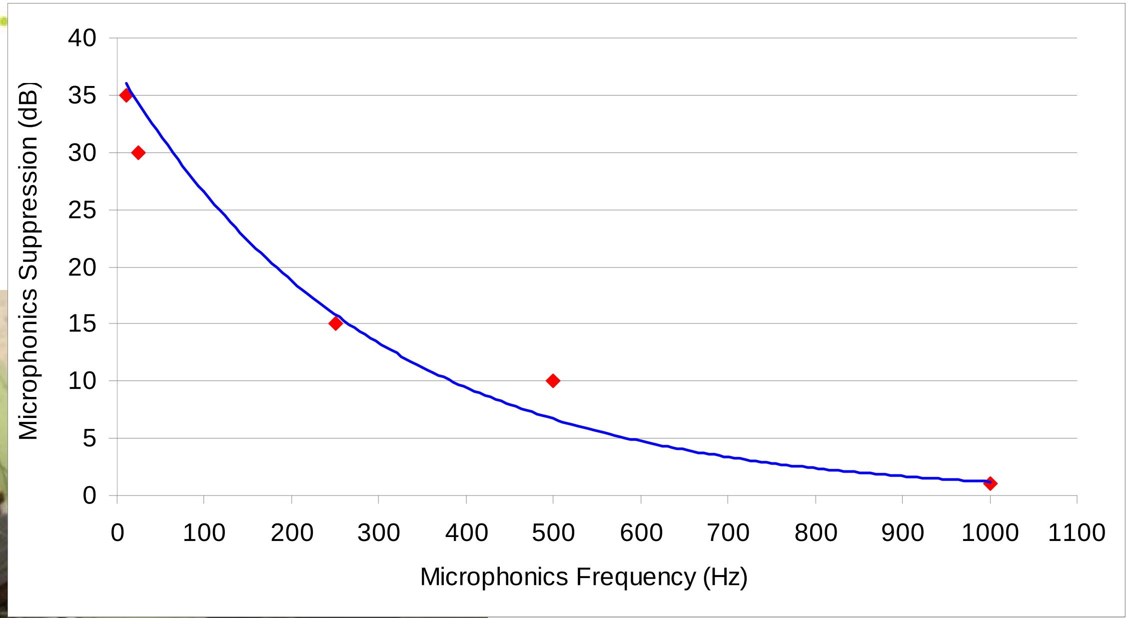
LLRF Gain Response

DSP Clock Speed of 50 MHz



System Microphonics Perfomance





Control boxes with interferometer components on top

Future Work

- December Tests:
  - **Improve cavity tuning to ensure sustained lock:**
    - Increase cavity BW to ~1kHz (Q_L ~ 4e6)
    - Control cavity frequency to within ± 100 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!

CLIC-CC Synergies (?)

- Proposed CLIC-CC structure:
  - **12 GHz NC TW cavity ⇒ $V_{\perp}$ ~ 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 $\Rightarrow$ 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.