ILC Crab Cavity System Status

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(on behalf of the ILC Crab System Design Team)

LCUK Review, Birmingham University
17th April 2008

Overview

- ILC Crab Collaboration Team
- Crab System Specifications
- Key Technical Design Challenges:
  - Cavity Wakefields
  - Coupler Developments
  - Crabbing Polarisation
  - LLRF and Synchronisation
- Proposed Beam Testing
- System Design Synergies with CLIC
- Summary

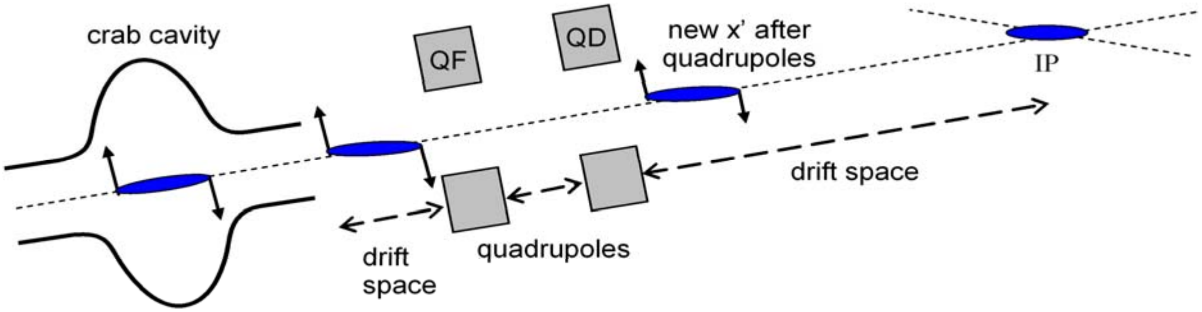
ILC Crab Cavity Collaboration Team

- **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)
  - Imran Tahir (Lancaster University)
- **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.



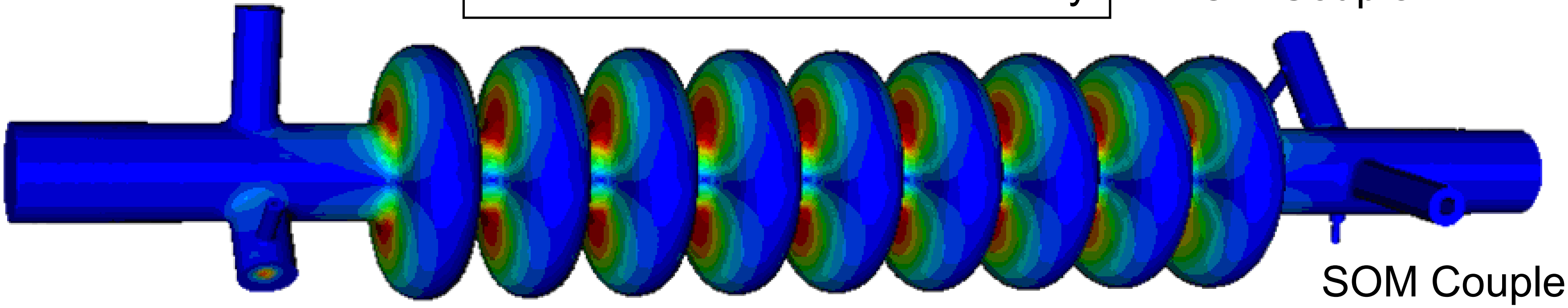
Key Technical Challenges

- Damping and Couplers:
  - Input (based on DESY/FNAL 3rd harmonic),
  - LOM (multipacting, tuneability, fabrication),
  - SOM (very high damping required, tuneability),
  - HOM (multipacting, tuneability, fabrication).
- Cryomodule:

  Unfunded
  - Field polarisation (±1 mrad),
  - Microphonics rejection (cryogenic distribution),
  - Cavity alignment (5 nm vertical beam size at IP),
  - ILC installation constraints (extraction beamline ~18 cm away).
- Beam test verification:
  - Verify cavity/wakefield design (single cavity),
  - Verify LLRF and synchronisation stability (single/dual cavity),
  - Verify crabbing field polarisation (single/dual cavity).
- LLRF and synchronisation stability.

ILC Crab Cavity Design

Based on the FNAL CKM Cavity



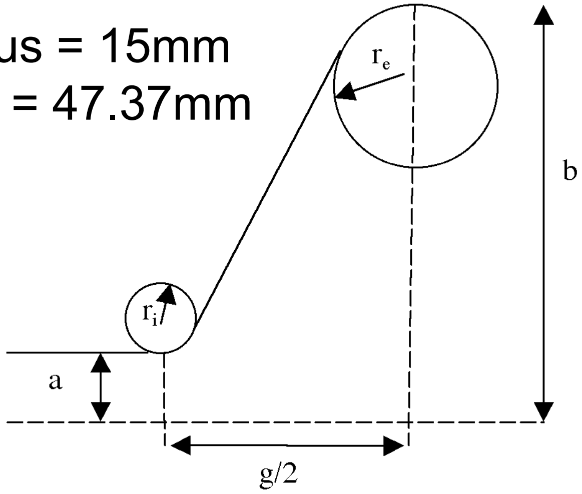
Input Coupler

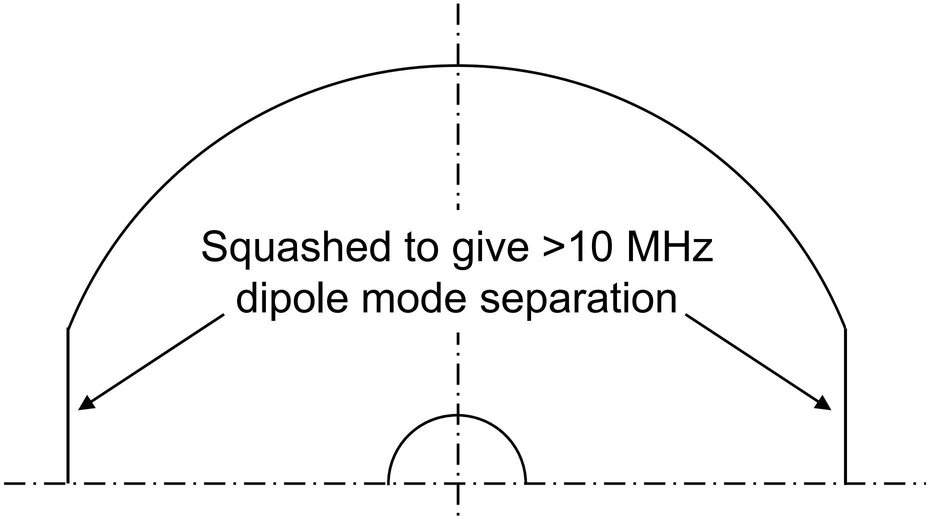
LOM Coupler

SOM Coupler

HOM Coupler

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

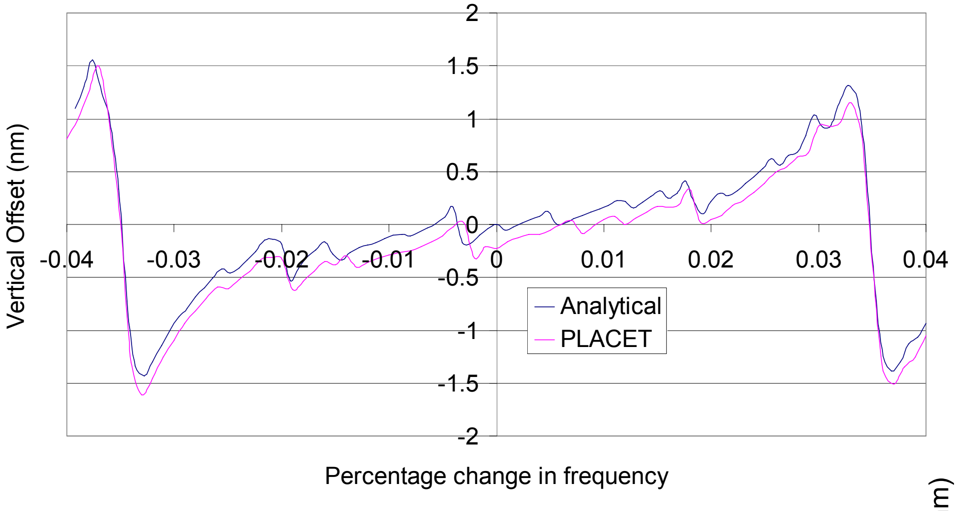




Squashed to give >10 MHz dipole mode separation

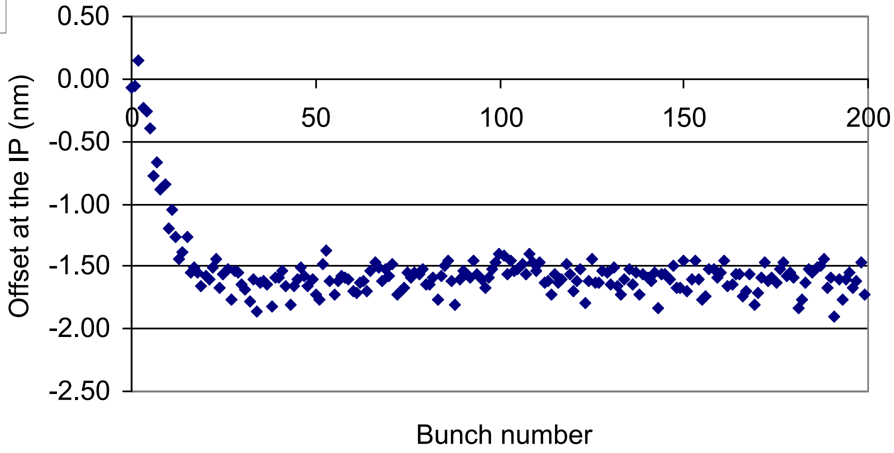
Wakefield Suppression

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



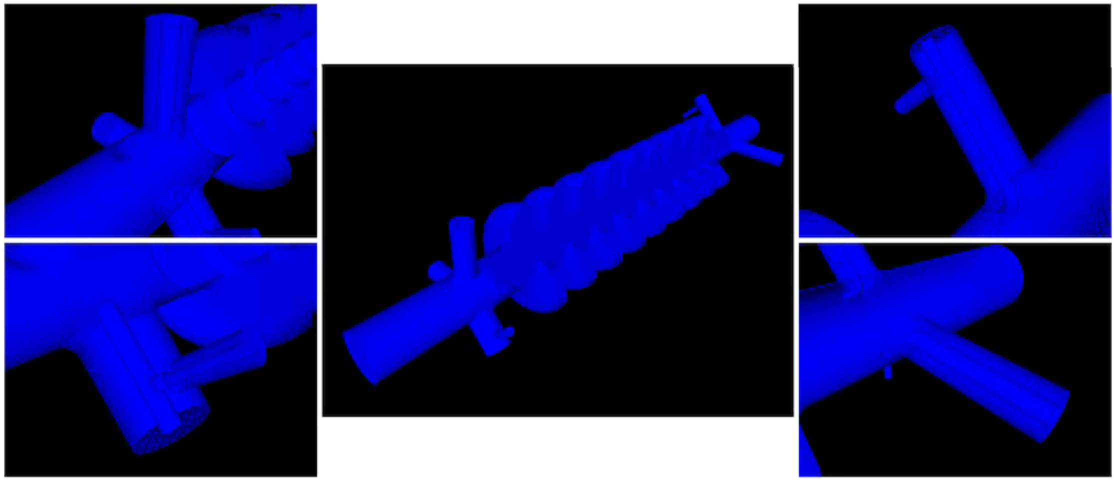
- Gives good agreement with analytical results, and shows little emittance growth.

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

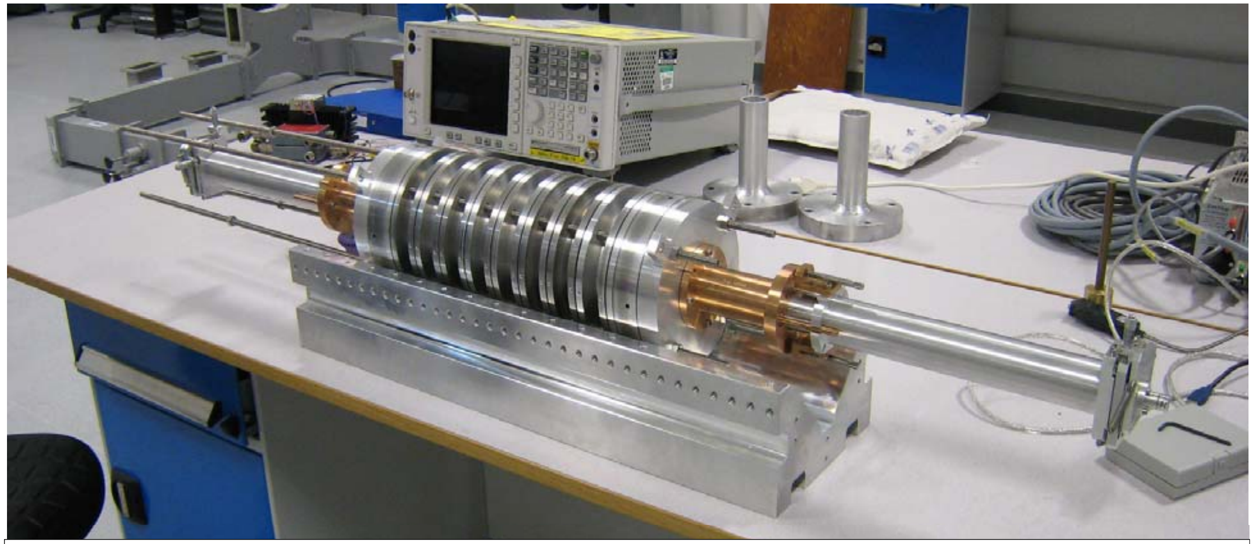


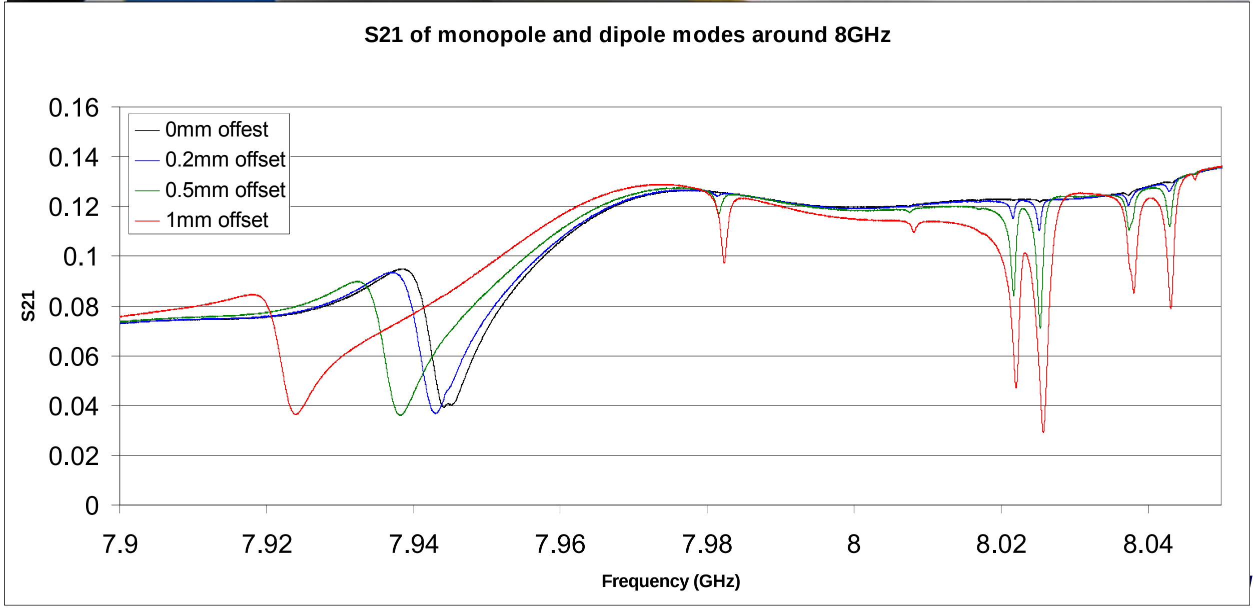
Wakefield Verification

- 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.

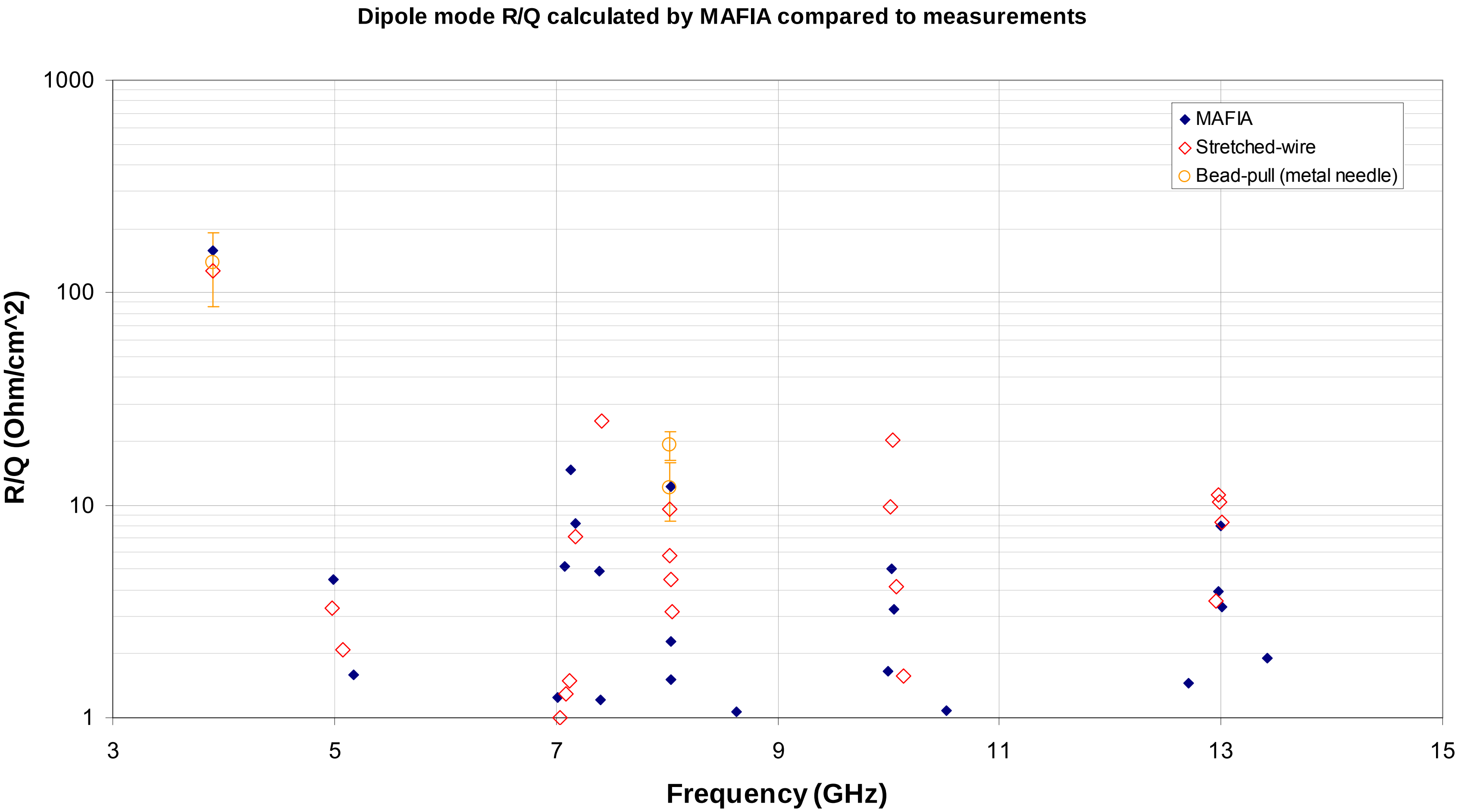


Stretched Wire Characterisation

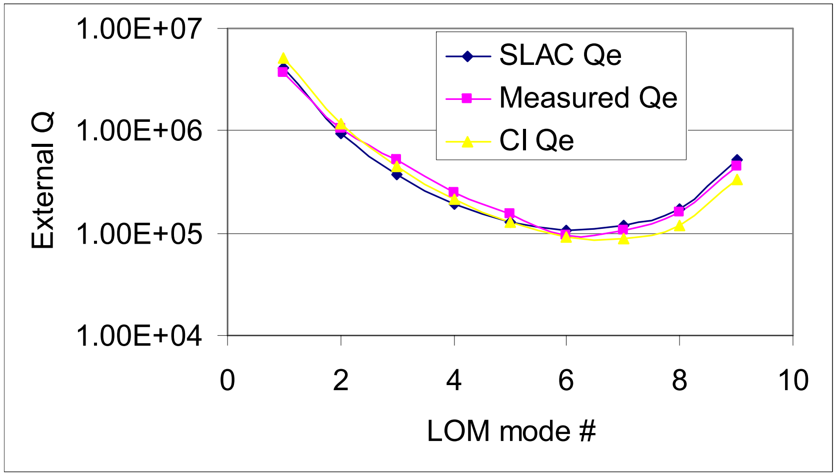


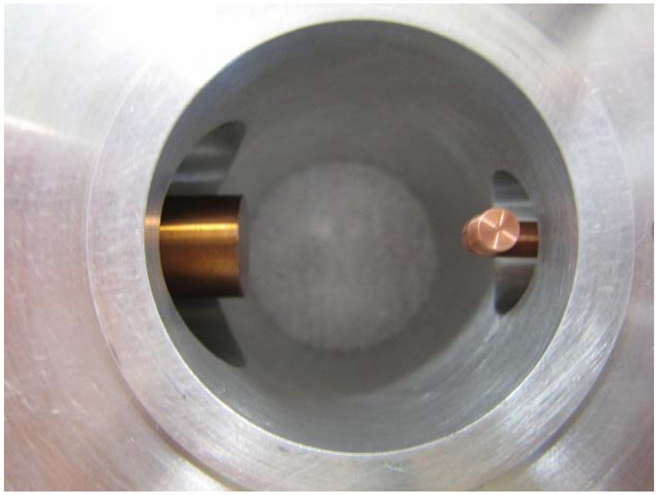


Mode Measurements

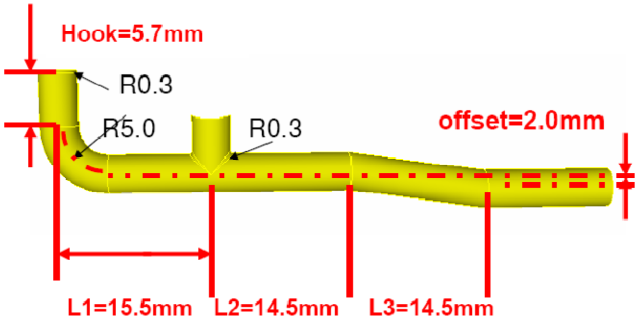


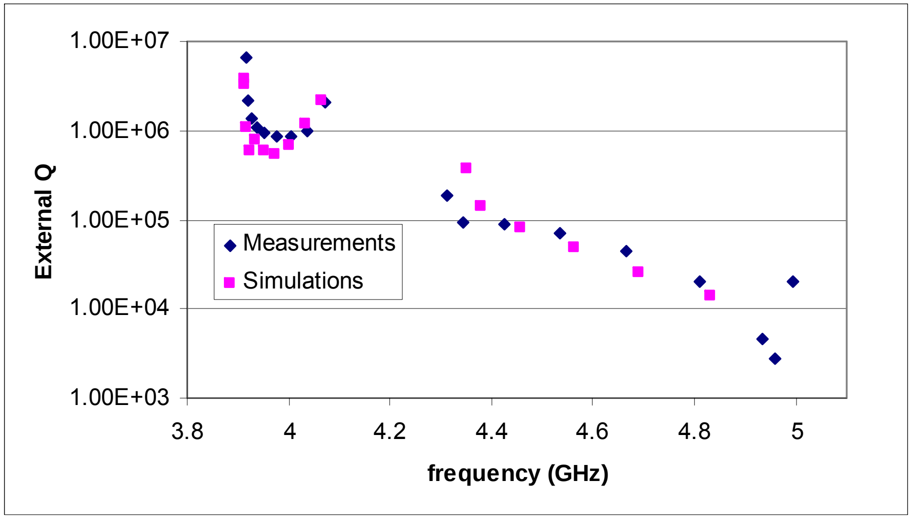
Prototype LOM Qe Measurements



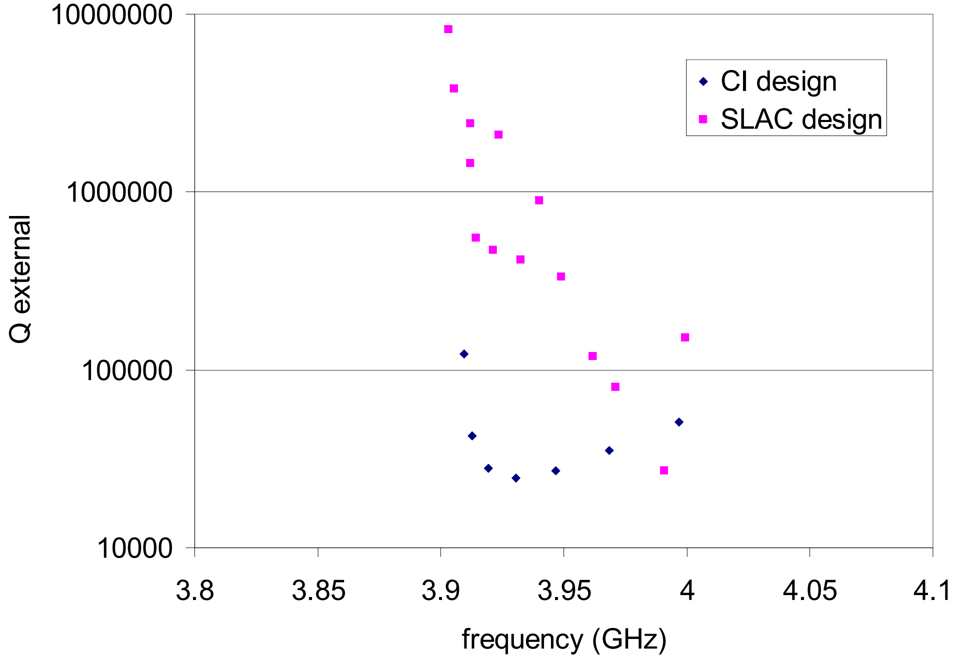


The LOM coupler was found to give good agreement with both MWS and Omega3P simulations.



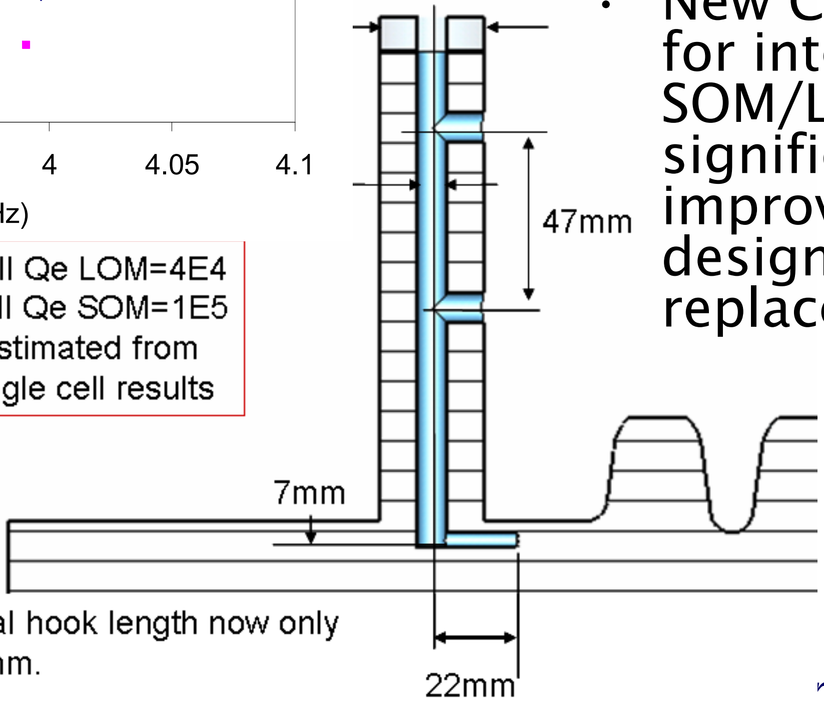


SOM/LOM Coupler Development



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

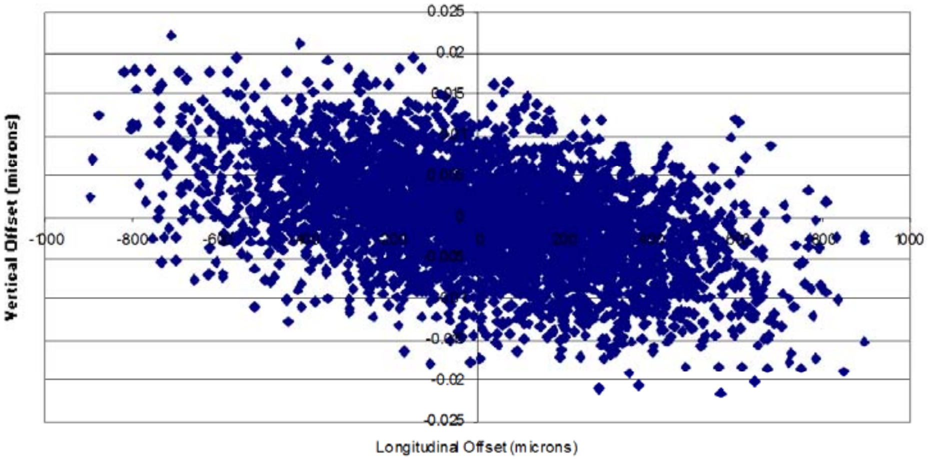
- SLAC design for HOM and LOM couplers and Cockcroft Institute SOM and Power coupler designs used in prototypes.
- New Cockcroft design for integrated SOM/LOM coupler is a significant improvement on SLAC designs and will replace them.

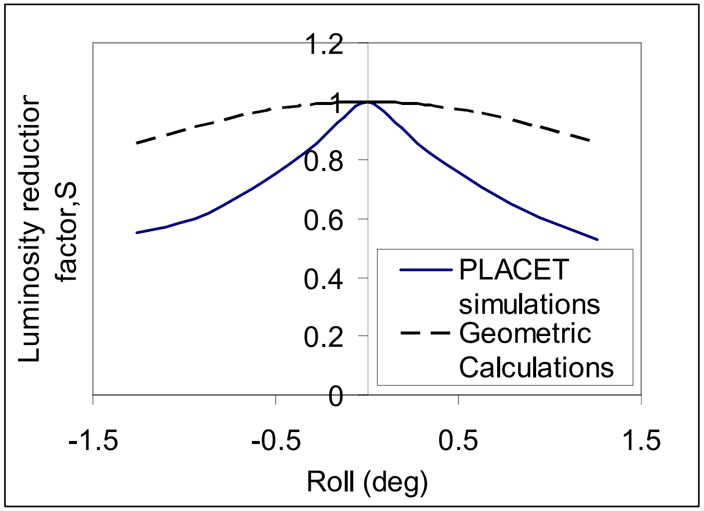


Total hook length now only 26mm.

Crabbing Field Polarisation

- If the crab cavity isn't aligned properly it will cause a spurious vertical crabbing effect (remember σ_y ~ 5nm).

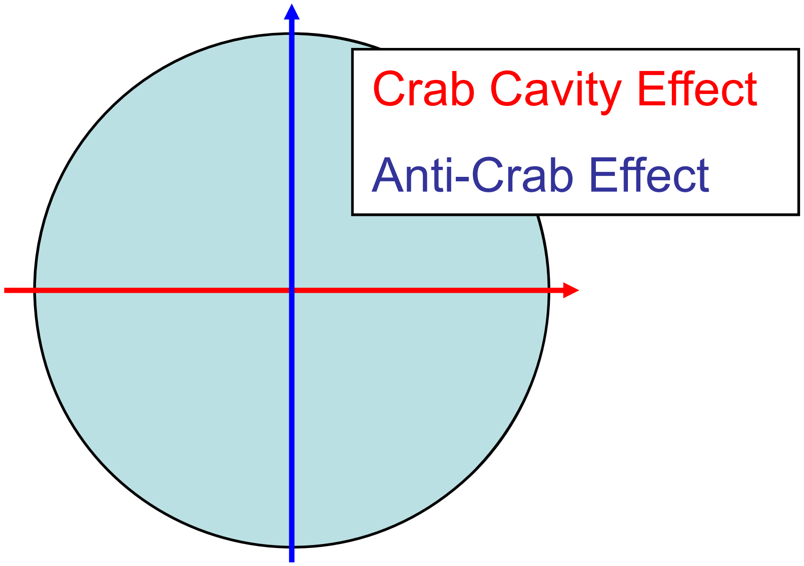


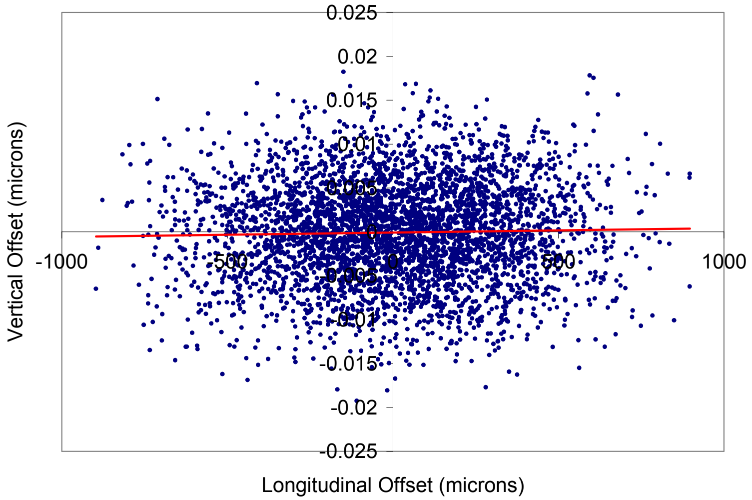


- Need a polarisation alignment tolerance of < ±1 mrad!
- Can employ:
  - Reduced fabrication tolerances (costly),
  - Field polarisation adjustment mechanically in the cryomodule (not easy),
  - An additional dipole cavity (single-cell) to compensate for this effect (preferred).

Anti-crab Compensation

- Adding a single cell crab cavity in the vertical (rather than horizontal) plane can correct for vertical crabbing due to cavity misalignment, wakefields or other sources of error.
- This work has been submitted for publication in PRST-AB.



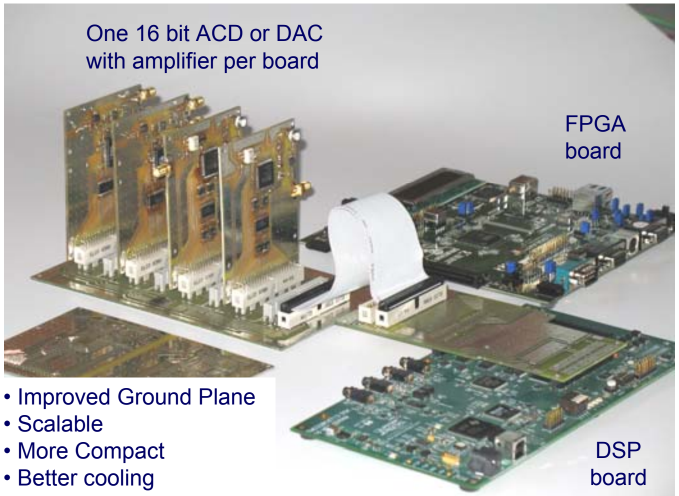


LLRF and Synchronisation

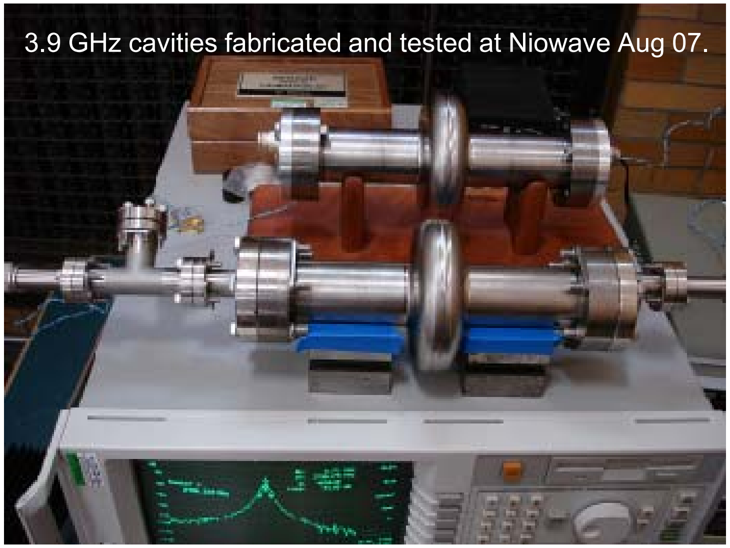
- Bunch-RF phase error in a crab cavity causes unwanted centre-of-mass kick.
- Providing both crab cavities are phase balanced, can compensate these COM kicks.
- ILC crab cavity zero crossings need synchronisation to 94 fs for the 2% luminosity loss budget.
- A crab cavity to crab cavity timing error of 250 fs loses about 30% of the luminosity.
- 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.

Synchronisation System

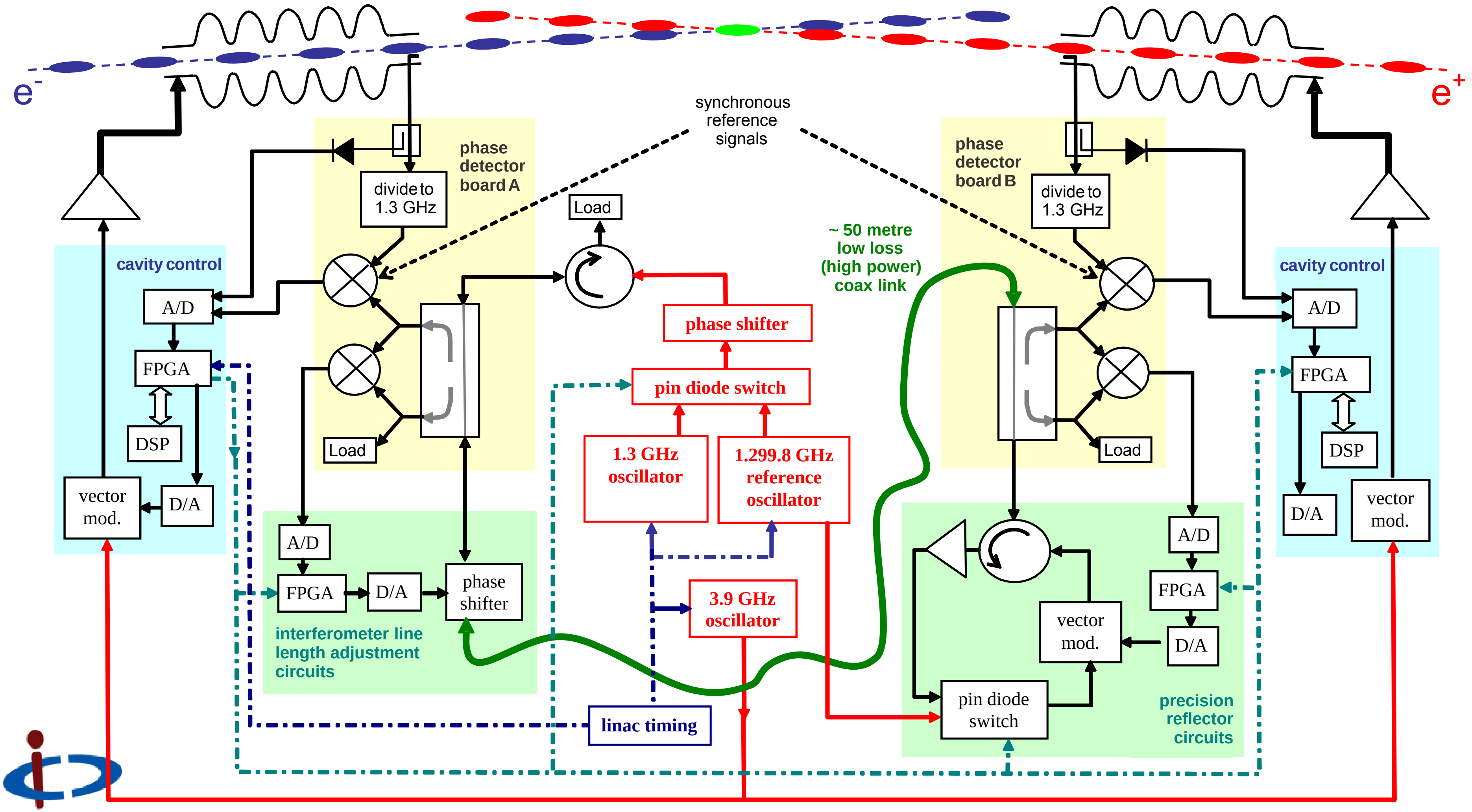
- The phase of the field in each cavity is sampled, compared to the timing reference and the error sent to a digital signal processor (DSP) to determine how the input signal must be varied to eliminate the error.
- Provide an interferometer between each crab cavity so that the same cavity clock signal is available at both systems.
- 16-bit DAC/ADC architecture (high resolution).
- Scheduled to test system with 2 x single-cell SRF 3.9 GHz cavities in May 08.



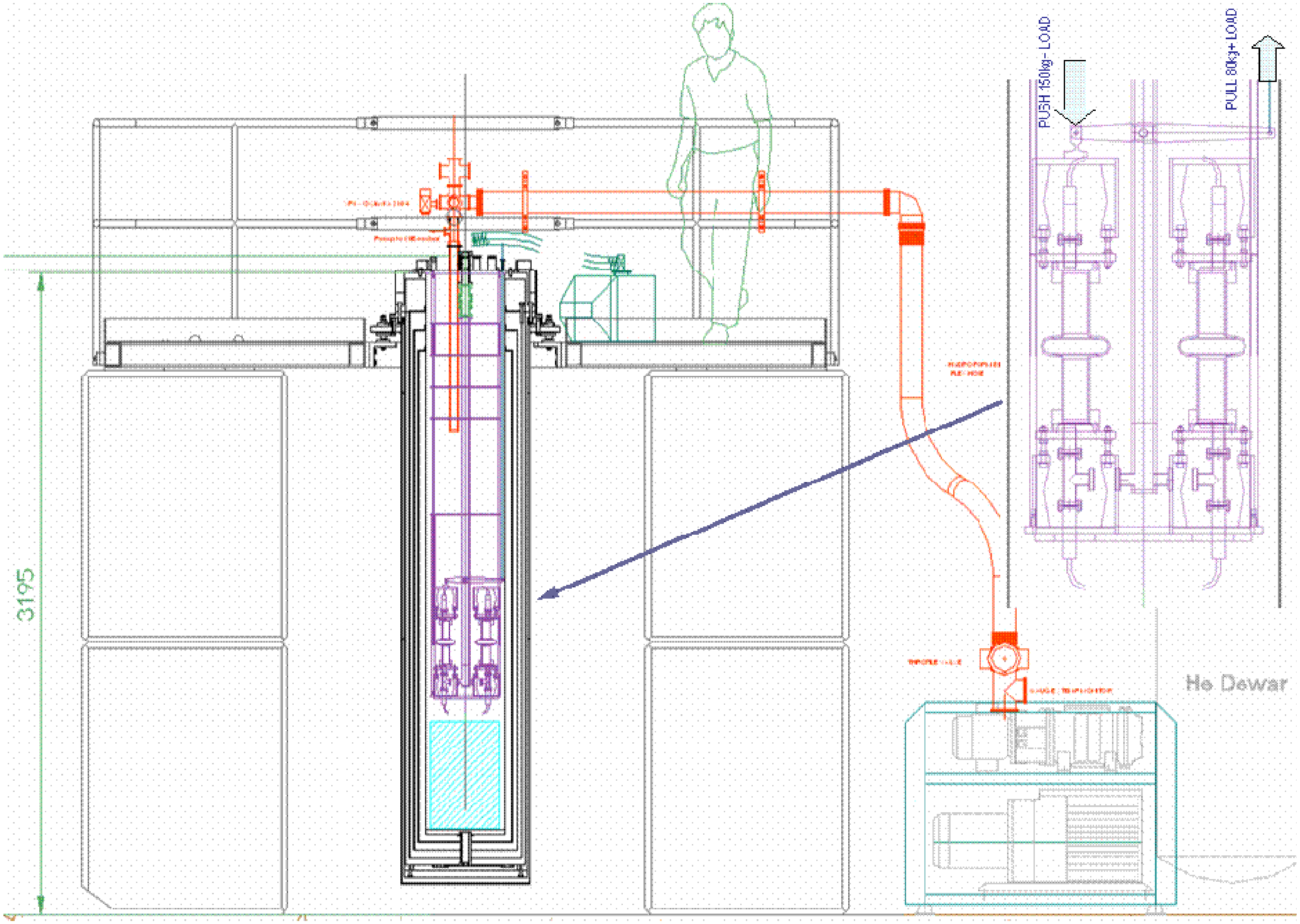
- Improved Ground Plane
- Scalable
- More Compact
- Better cooling
- Easy repair and testing


3.9 GHz cavities fabricated and tested at Niowave Aug 07.

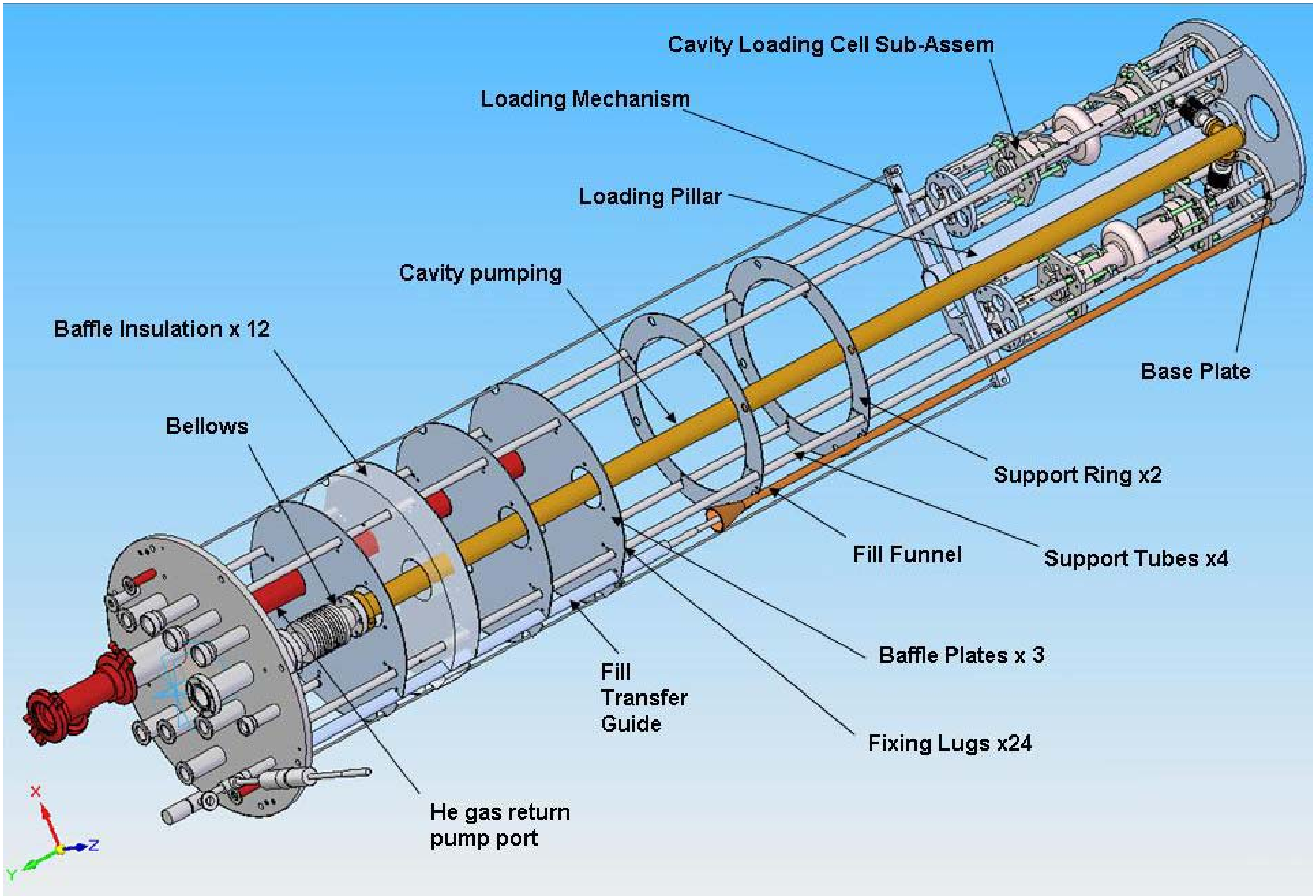
LLRF/Synchronisation Scheme



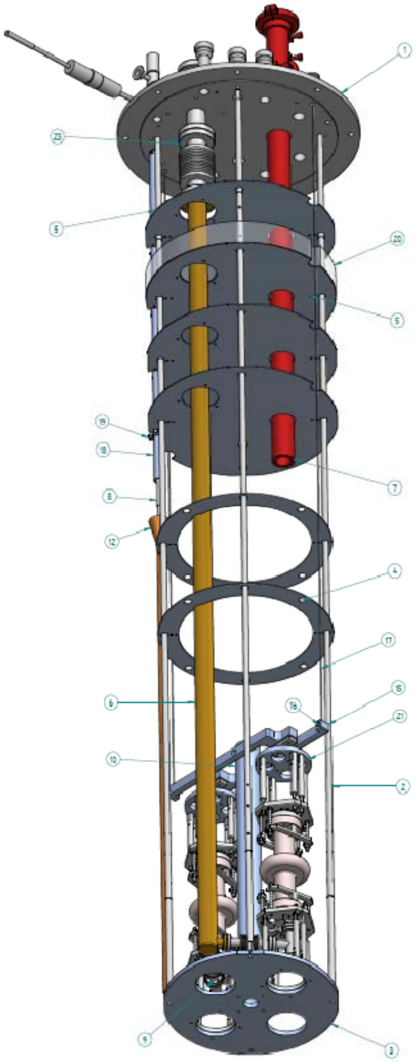
LLRF and Synchronisation Tests



Dual Cavity Insert Design



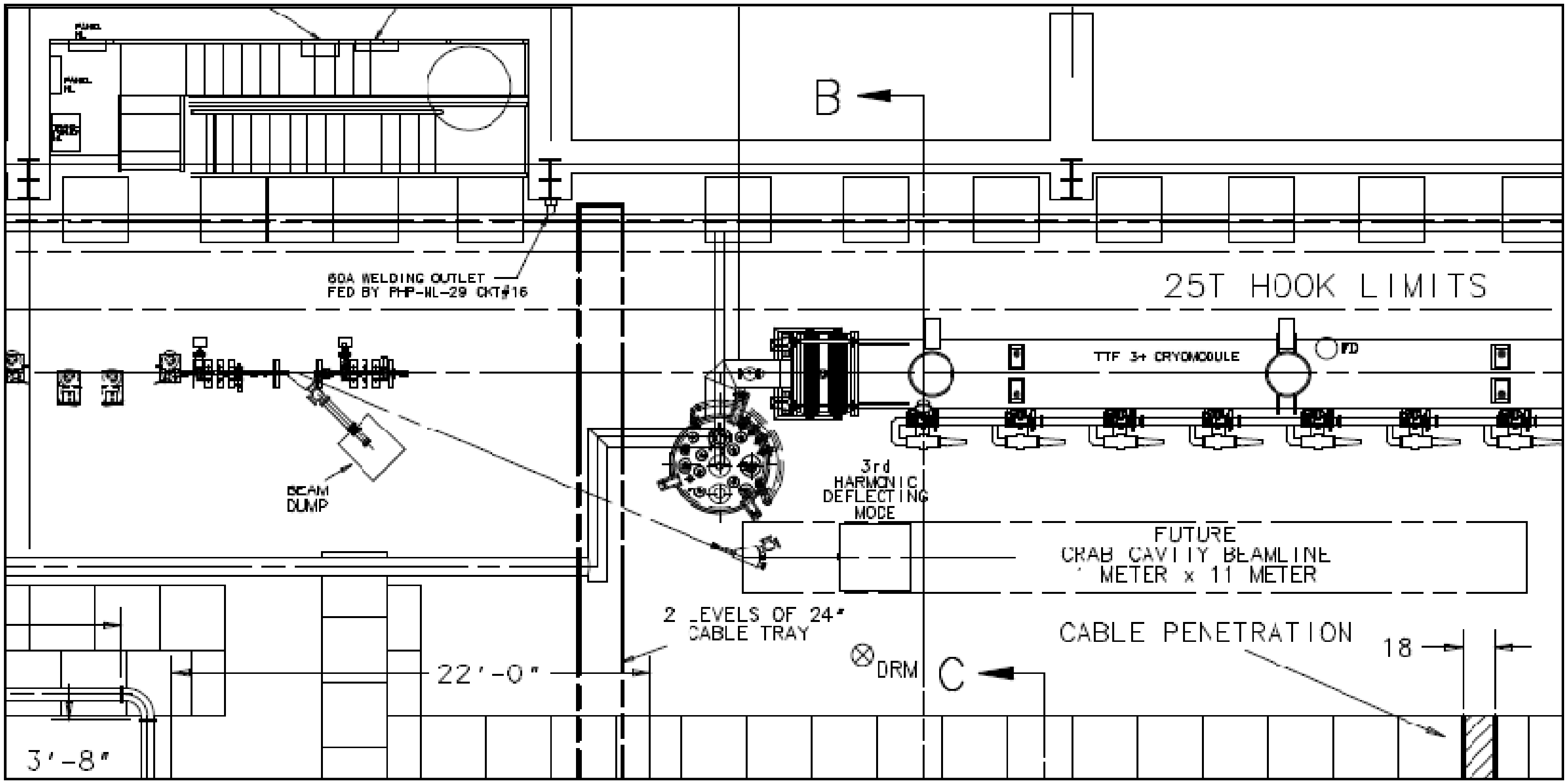
Cavity Testing Hardware




Cryostat


Vertical Test Stand

ILCTA Testing Provisions

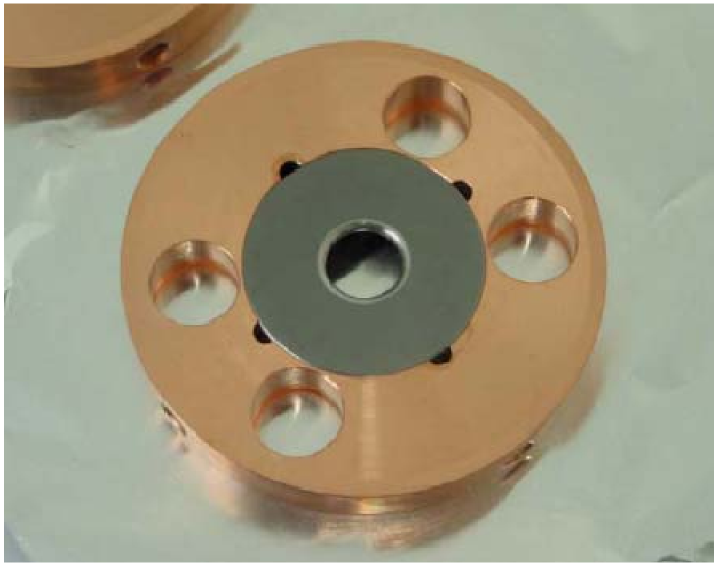


- ILCTA (FNAL NML) will have an isochronous dogleg (40 MeV) to a second beamline for crab system testing.

CC System Tests

- Prototyping and testing without beam would:
  - Verify cavity design and manufacturability.
  - Resistance to multipacting.
  - Verify modes, Qs and wakefields via bead-pull and stretched wire measurements.
  - Assess CKM-style cold tuner, power coupler.
- Tests of a single cavity with beam on ILCTA would:
  - Verify cavity (long and short range) wakefields as a function of beam offset.
  - Assess beamloading.
  - Verify mode coupler power handling capability, 2nd Qe study.
  - Verify bunch to single cavity timing stability.
  - Allow for measurement of beam profile (long and trans)
  - Determine microphonics sensitivity and impact on LLRF control.
  - Provide operational experience.
- Tests of two cavities with beam on ILCTA would:
  - Verify the dipole field polarisation stability.
  - Verify stability of phase balance between 2 crab cavities.
  - Verify the requirements to parasitic COM kicks are met.
  - Provide full system microphonics sensitivity measurments.

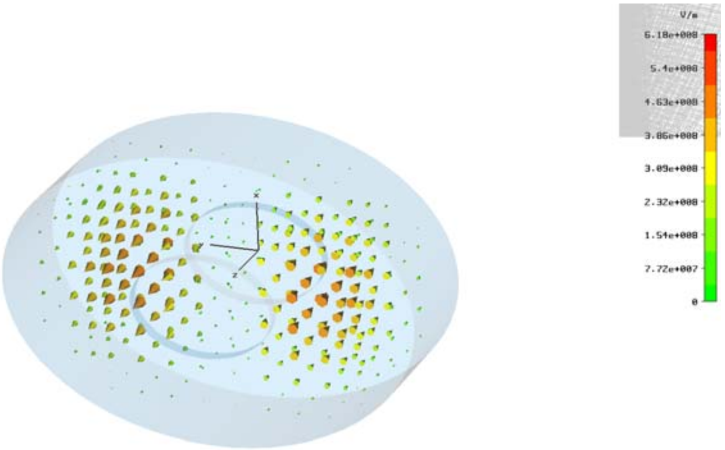
Design Synergies with CLIC

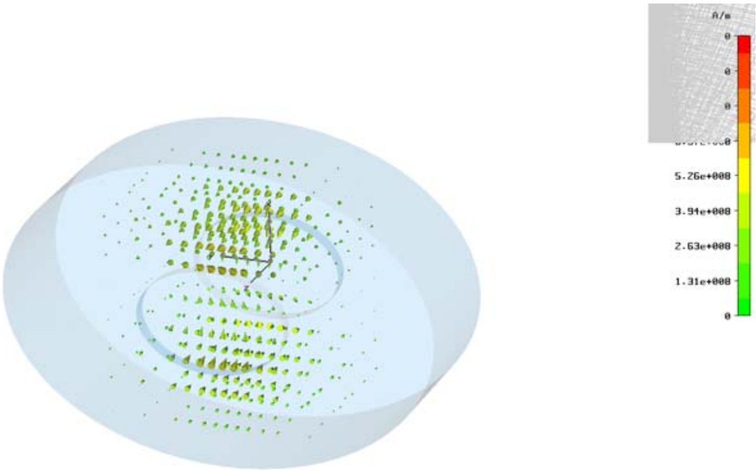


- Travelling wave cavity at 12 GHz.
- Damped, detuned structure.
- Synergy with the main linac.
- Require 2.4 MV (for R12 = 25 m).
- Can achieve a transverse gradient of ~20 MV/m.
- This means about 20 cells using a 2pi/3 TW mode for example.
- This requires up to 5 MW of X-band RF power.

Possible CLIC Crab Structure

- Elliptical Damped Detuned structures (EDDS)



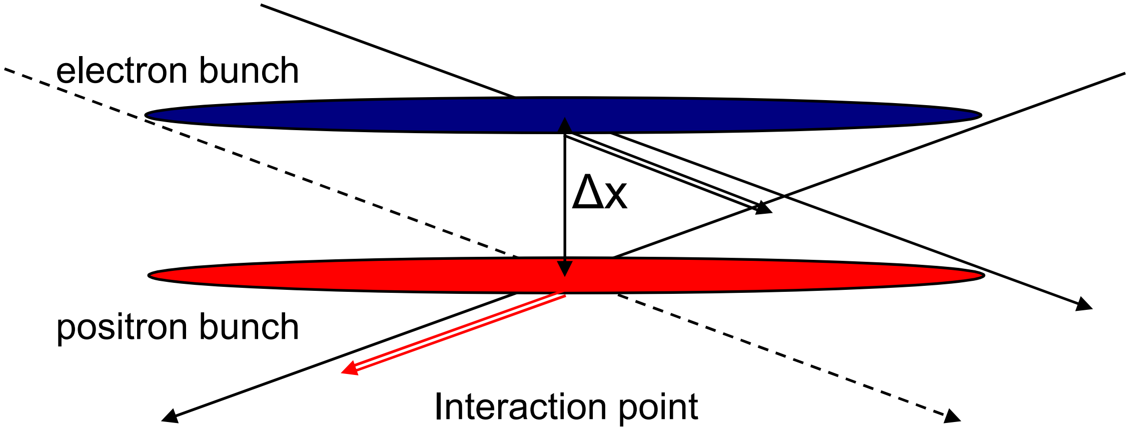


- Ellipticity of each cell is altered to detune the SOM throughout the structure.
- Iris could have the opposite polarisation to reduce short range wakes.

CLIC LLRF Tolerances

Crabbed crossing angle with phase jitter

For a 20 mrad crossing timing tolerance is ~3.5 fs



Hybrid digital-analogue system
Digital for train to train effect (Synergetic with ILC)
Analogue for fast control

Interferometer required between cavities
Synergetic with ILC development

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 control stability:
  - Prototype system fabricated and awaiting full system test with SRF cavities in May 08.
- Exploitation of ILC crab system design synergies with CLIC being explored.