Development of a High Resolution Cavity BPM for the CLIC Main Beam

J.R. Towler, S. Boogert, F.J. Cullinan,
T. Lefevre, A. Lyapin, L. Soby, M.Wendt

clic

CERN

JAi John Adams Institute for Accelerator Science

ROYAL HOLLOWAY UNIVERSITY OF LONDON

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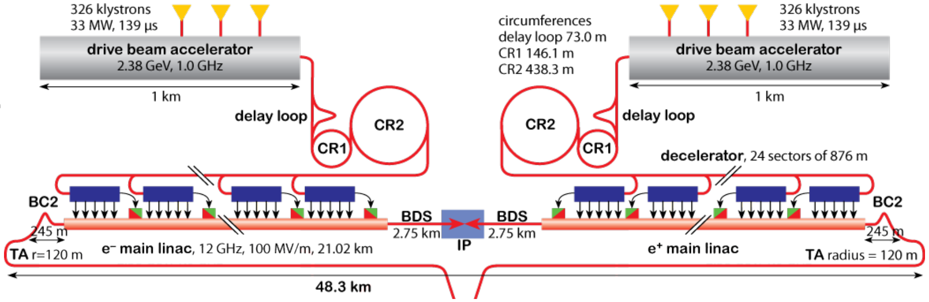
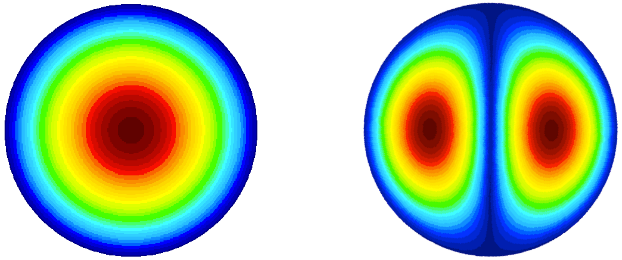
CLIC/CTF3 Cavity BPM Specs.

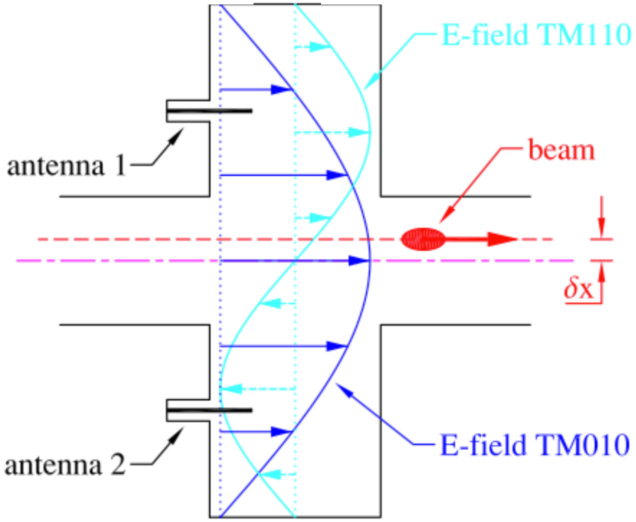
- 50 nm and 50 ns time and spatial resolution.
  - Multiple measurements in 156 ns train
  - Dynamic range of ±100μm
  - >4000 BPMs
- Cavity BPM good candidate
  - High position resolution
- 14 GHz for CLIC
  - Design is scalable
- 15 GHz resonant frequency for CTF prototype.
  - 10^{th} harmonic of 1.5 GHz spacing frequency
- Low Q factor
  - Time resolution

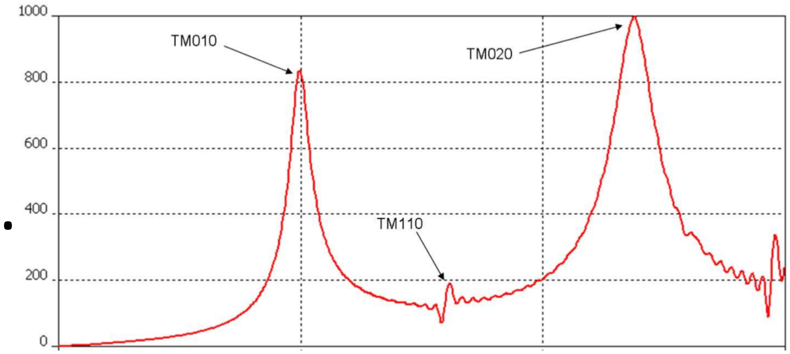


Cavity Beam Position Monitors

- Centered beam excites monopole mode (TM_{010}).
  - Amplitude dependent on charge
- Away from the center, other modes are excited. The first order dipole (TM_{110}) depends linearly on beam offset and charge.
- Two orthogonal modes.
- Higher order modes.
- Supression of unwanted modes.

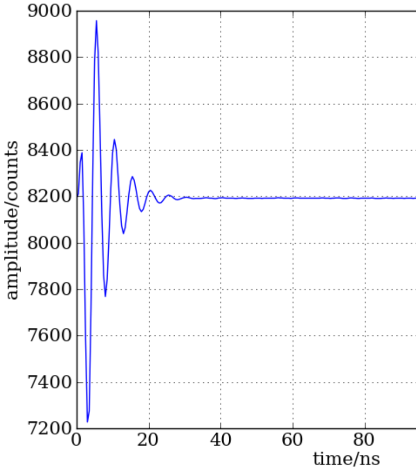


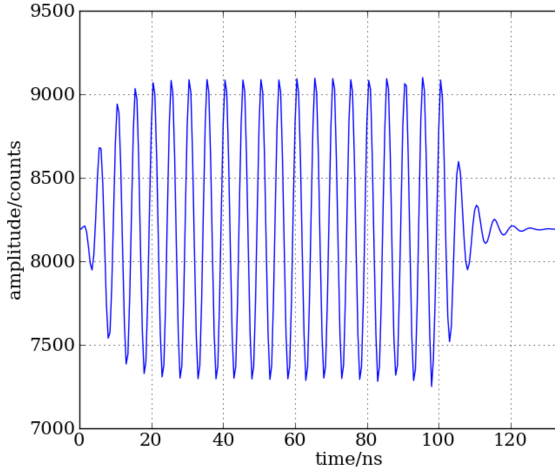




BPM Signal

- The signals from the cavity are in the form of a decaying sine wave.
- Multibunch signal converges to periodic.
- Position signal is linear with offset and charge.
- Monopole similar.
- Beam divergence and tilt also have contributions to signal which are 'in quadrature'.





$$V_{out} = \frac{\omega}{2}\sqrt{\frac{Z}{Q_{ext}}\left[\frac{R}{Q}\right]_0} q \frac{x}{x_0}$$

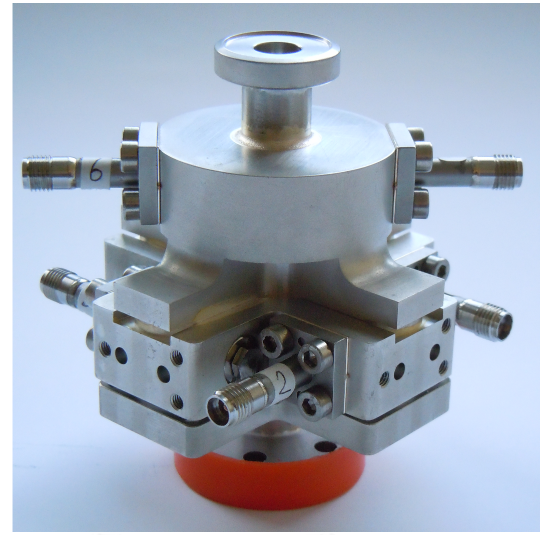
$$V_x(t) = V_{out} e^{-t/2\tau} \sin(\omega t)$$

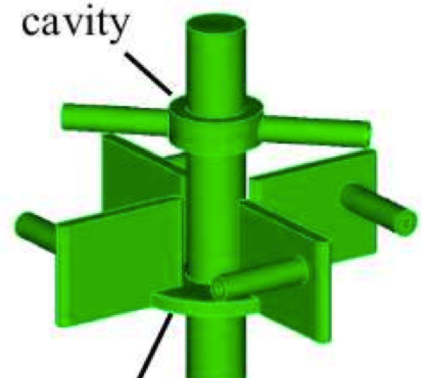
$$V_\alpha(t) \propto -\alpha e^{-t/2\tau} \cos(\omega t)$$

$$V_\theta(t) \propto \theta e^{-t/2\tau} \cos(\omega t)$$

Stainless Steel Prototype

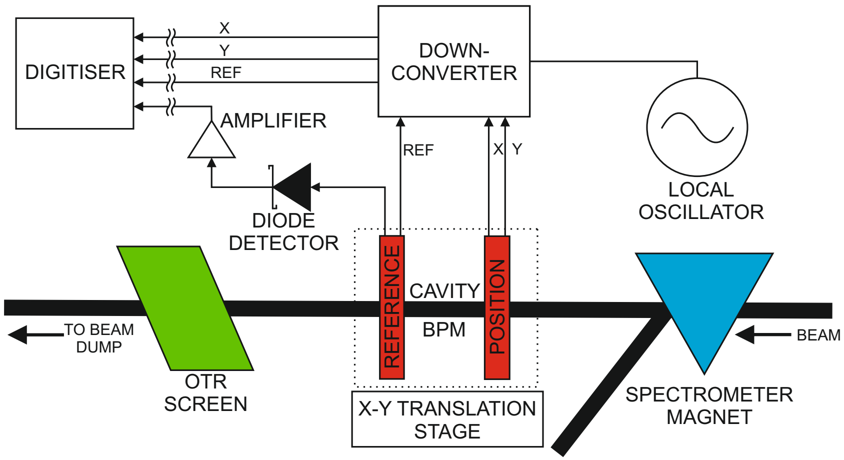
- Two cavities:
  - Position cavity: pillbox
  - Reference cavity reentrant
- Stainless steel to lower Q factor: ~ 250
  - For low temporal resolution
  - Lower Q in reference cavity
- Waveguide/coax Couplers need tuners
  - Very sensitive to antenna/wall separation





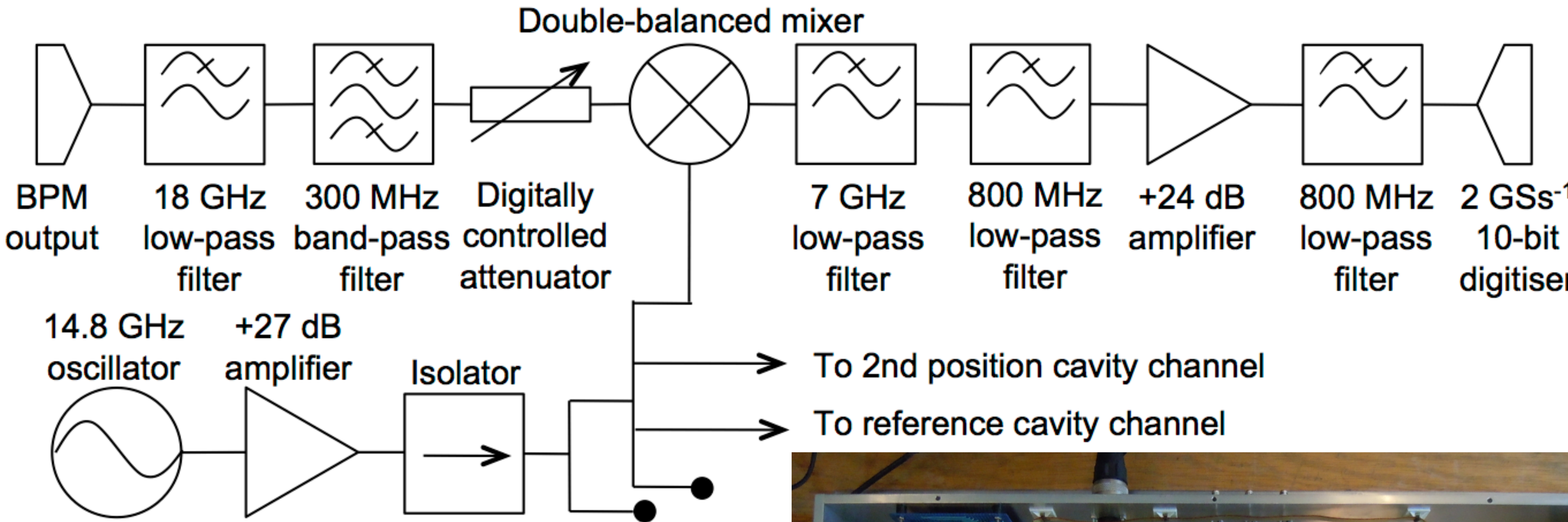
First Prototype Test System

- 15 GHz signal down-converted to 200 MHz.
- 14.8 GHz local oscillator
- Diode detector, timing
- OTR screen, centring, position information
- Translation stages, centring, calibration and sensitivity measurement

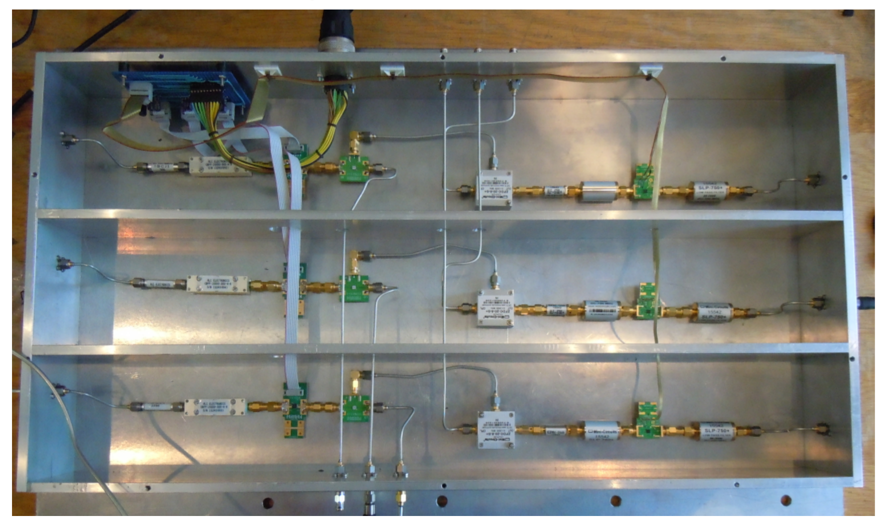


Electronics

- Downconvert the 15GHz signals to 200MHz.



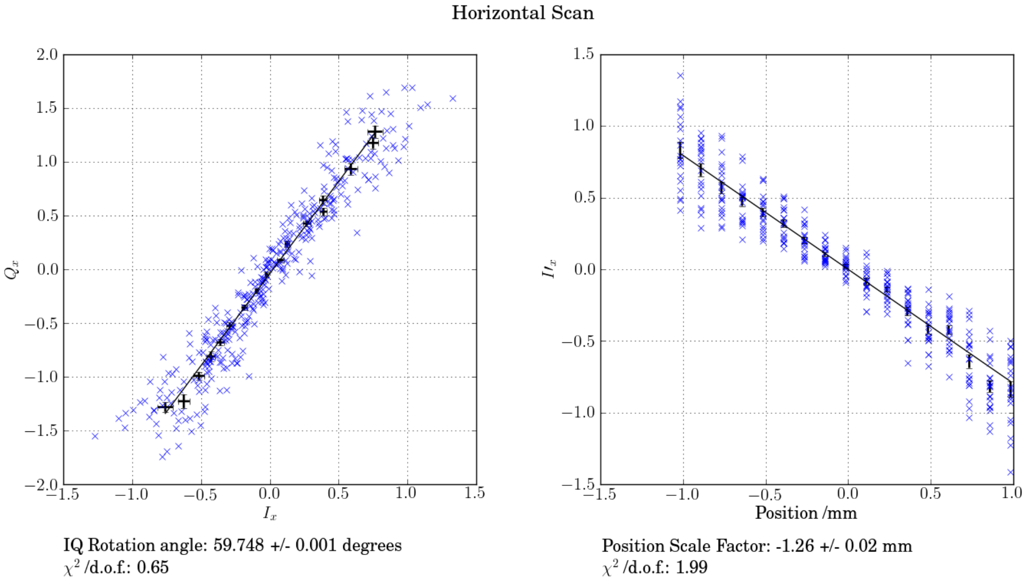
- Gives 5dB gain at 15GHz.
- 2Gs/s, 10-bit digitiser.
- Diode rectifiers.
  - Timing and charge



Beam Tests of St. Steel Prototype

- Calibrations using translation stages
  - Originally used corrector magnets
- Charge sensitivity measurement
  - Reference Cavity
- Position sensitivity measurement
  - Position cavity with reference sensitivity
- Effects of pulse length

Calibration of St. Steel Prototype



$$I = \frac{A_{pos}}{A_{ref}} \cos(\varphi_{pos} - \varphi_{ref})$$

$$Q = \frac{A_{pos}}{A_{ref}} \sin(\varphi_{pos} - \varphi_{ref})$$

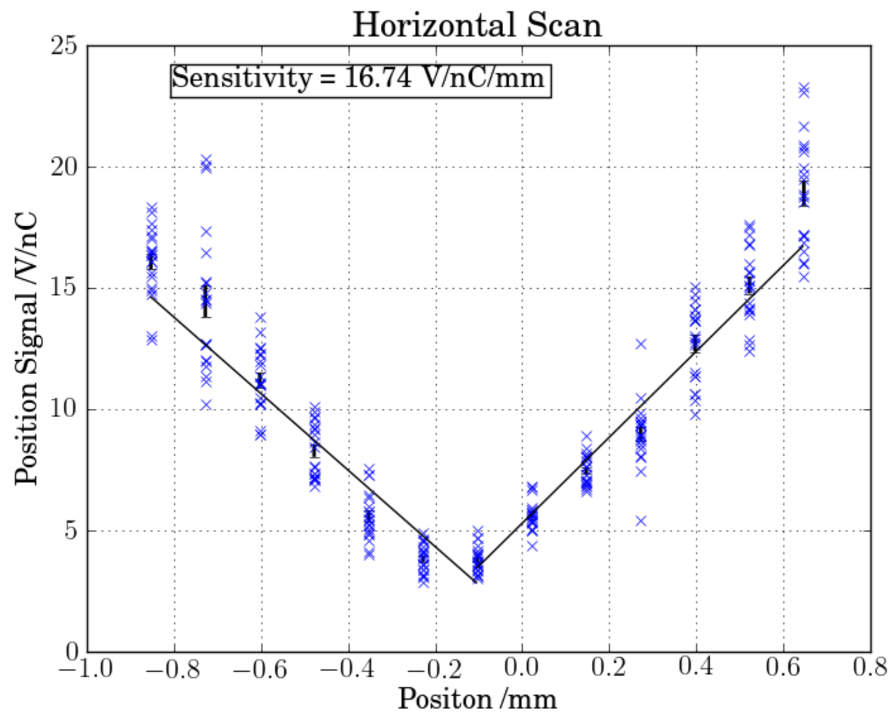
$$x = S(I\cos\theta_{IQ} + Q\sin\theta_{IQ})$$

$$x' = S'(-I\sin\theta_{IQ} + Q\cos\theta_{IQ})$$

- Calibration performed by scanning position
  - Digital down conversion, amplitude and phase
  - I and Q recorded, rotation angle measured
- Position measured from using scale factor

Sensitivity Measurements

- Charge sensitivity measurements
  - Laser attenuation, Current monitor
- Position sensitivity
  - Translation stages



Sensitivity Measurement	Measurement	Estimated
X Position (V/nC/mm)	16.6 ± 0.2	17.1
Y Position (V/nC/mm)	15.9 ± 0.4	17.1
Charge (single bunch)	128.8 ± 2	117
Charge(multi bunch)	608 ± 2	-

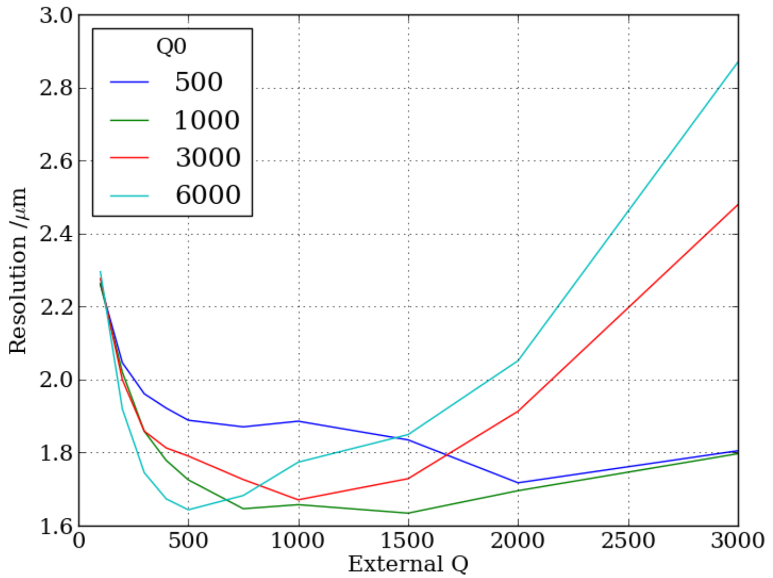
$$\frac{A}{A_0} = \frac{1 - e^{-\frac{Nt_b}{\tau}}}{1 - e^{-\frac{t_b}{\tau}}}$$

Prototype Cavity Redesign

- Issues with first prototype system:
  - High temporal resolution
  - Lower spatial resolution
  - Waveguide-coax coupling very sensitive to separation
  - Tuners needed to optimise coupling
  - Low resolution digitiser
  - Electronics

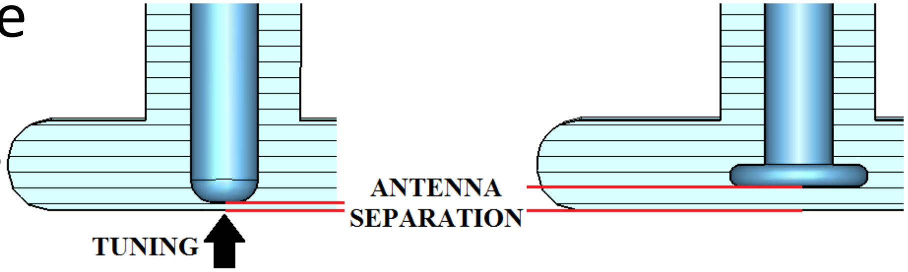
Copper Cavity Redesign

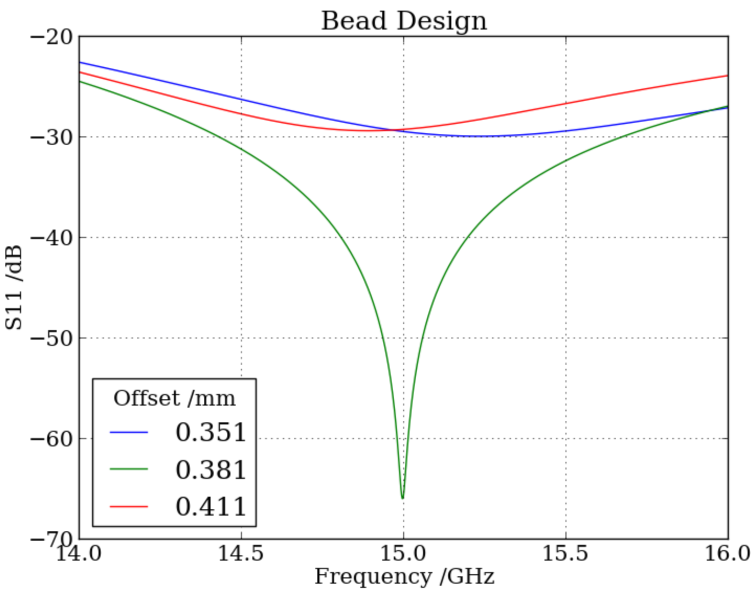
- A copper BPM results in higher Q factor: ~500
  - Double stainless steel cavity Q
  - Results in "50 ns temporal resolution"
  - Will also provide improved spatial resolution
  - Need to optimise internal and external Q
- Design of position cavity does not change
  - Reference cavity design altered to accommodate new feedthroughs



Waveguide-Coaxial Coupling

- First generation very sensitive to antenna wall separation
  - 10 μm change results in 30dB change, tuning necessary
- Several designs were investigated
  - Magnetic coupling, impedance transformers, etc.
- Antenna with bead was decided upon as the best candidate
  - Coupling sensitivity "improved by factor of 2"
- Threaded antenna to easily change

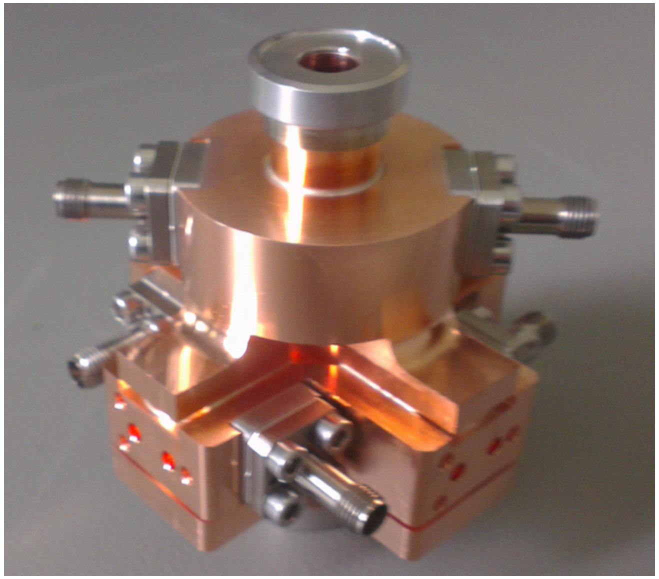




RF Measurement of New BPM

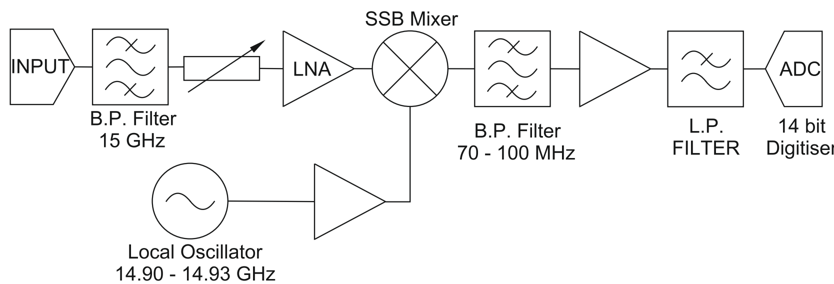
- Prototype manufactured for RF testing
  - Bad dimensions, particularly the reference cavity
- Measurements compared with simulations
  - Before and after brazing
  - Frequencies and Q factors
  - External Q's very high
  - Good cross coupling

Cavity	Q_L	F_0 /GHz
Reference	938	14.772
Predicted	500	15.0
Position	~840	14.996
Predicted	524	15.0



System Upgrade

- 3 BPMs manufactured externally
- Upgraded downconverter electronics
  - 3 BPMs, 3 channels each, lower IF (70 MHz?)



  - New digitiser: better resolution, lower sampling
  - Diode detectors for 3 channels, 1 or 3 BPMs
- New support
  - Movers for 3 BPMs, OTR screen

Future Plans

- Install 3 BPM system in CTF3
  - January, RF measurements made beforehand
- Spatial resolution determined by SVD analysis
- Ultimate goal: Combined spatial and temporal resolution measurement
  - May prove difficult for CALIFES
- Wakefield study will also take place