CLIC Workshop 2016: Main Beam Cavity BPM

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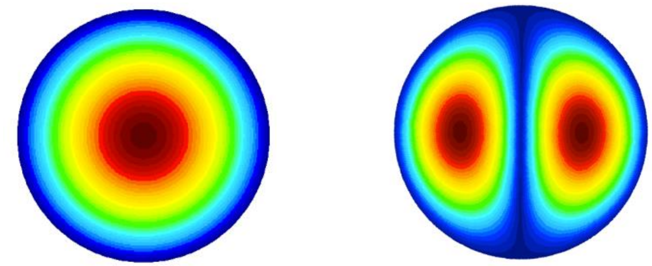
CLIC MB BPM Requirements

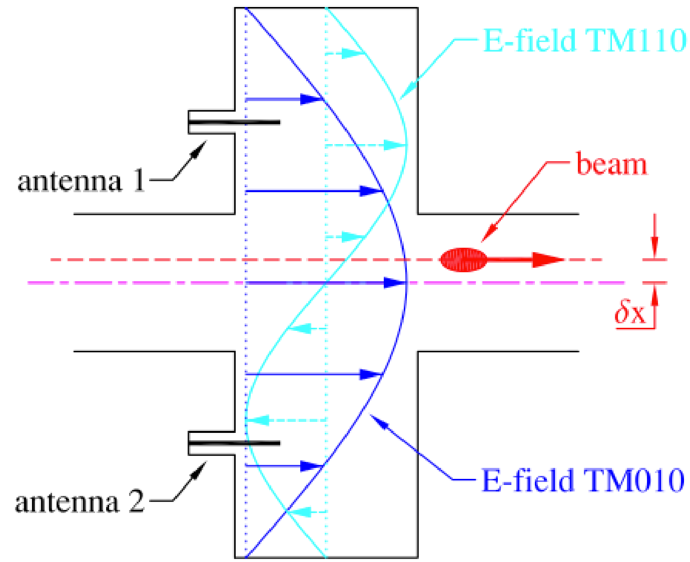
- 50 nm spatial and 50 ns time and resolution.
  - Multiple measurements in a 156 ns long bunch train
  - Range of ±100μm
  - >4000 BPMs
- 14 GHz for CLIC
  - Design is scalable
- 15 GHz resonant frequency for CTF prototype.
- Prototype design based on stainless steel cavity, new design uses copper.
- Q factor tailored to match the required time resolution

MB parameters and BPM Requirements		
Machine	CLIC	CALIFES
Bunch Spacing	0.5 ns	0.667 ns
Bunch Length	44 μm	225 μm
Train Length	156 ns	1 – 150 ns
BPM Spatial Resolution	<50 nm	<50 nm
BPM Time Resolution	<50 ns	<50 ns
BPM Accuracy	<100 μm	<100 μm
BPM Range	±100 μm	± 100 μm
BPM Resonant Frequency	14 GHz	15 GHz

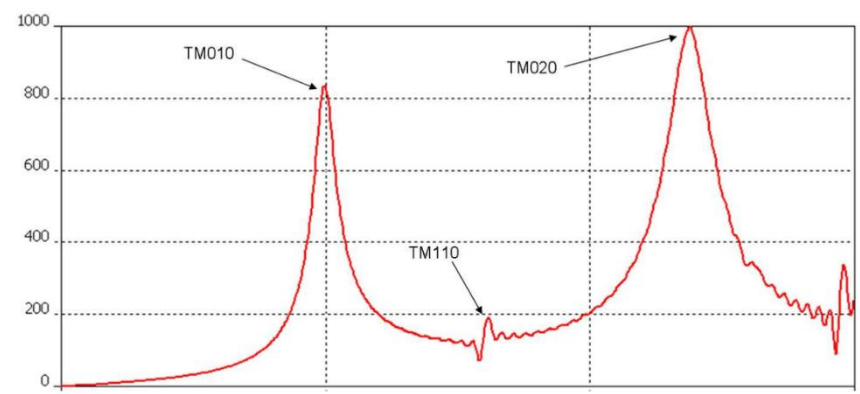
Cavity BPM Basics



- Centered beam excites monopole mode (TM_{010}).
  - Amplitude dependent on charge
- Away from the center, other modes are excited.
  - First order dipole mode (TM_{110}) depends linearly on beam offset and charge.
- TM_{110} splits in 2 orthogonal modes.
- Beam excites other unwanted higher order modes.
  - Requires suppression of unwanted modes.



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



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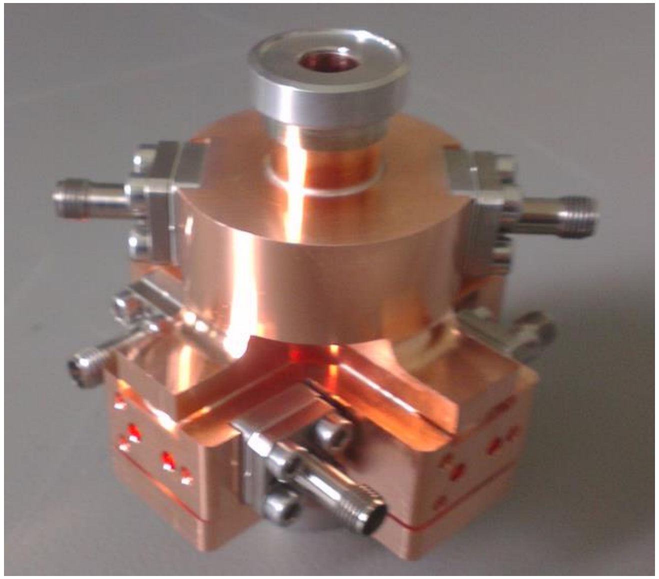
Copper Cavity BPM Design

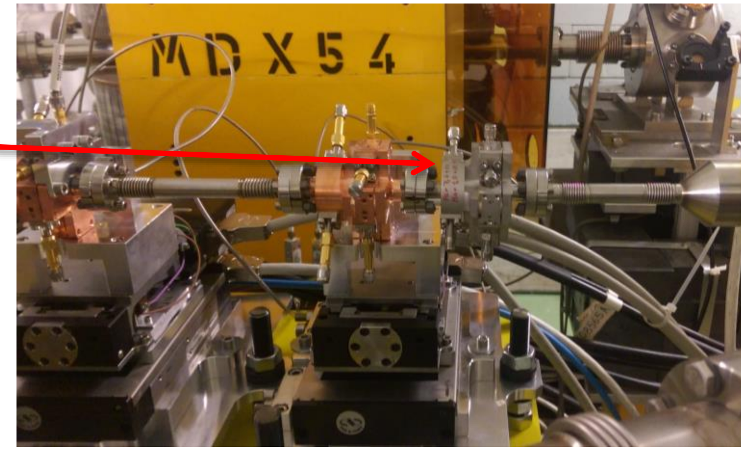
- Modified cavity BPM design
  - Main geometry unchanged.
  - Copper to raise Q to 500
  - New feedthrough design eliminate tuners.
- Prototype manufactured for RF testing
  - Poor dimensions, particularly the reference cavity
- Measurements compared with simulations
  - Before and after brazing
  - Frequencies and Q factors
  - External Q's high – feedthroughs
  - Excellent low cross coupling

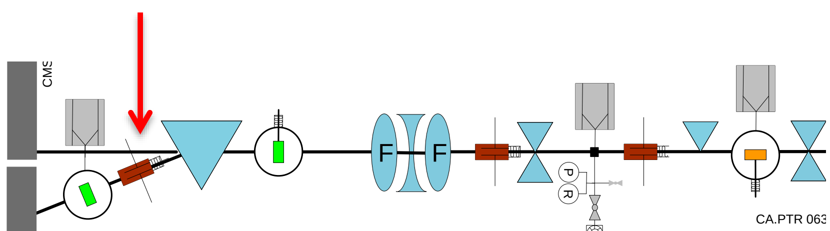


Cavity	Q_L	F_0 /GHz
Reference	938	14.772
Predicted	500	15.0
Position	~830	14.996
Predicted	524	15.0

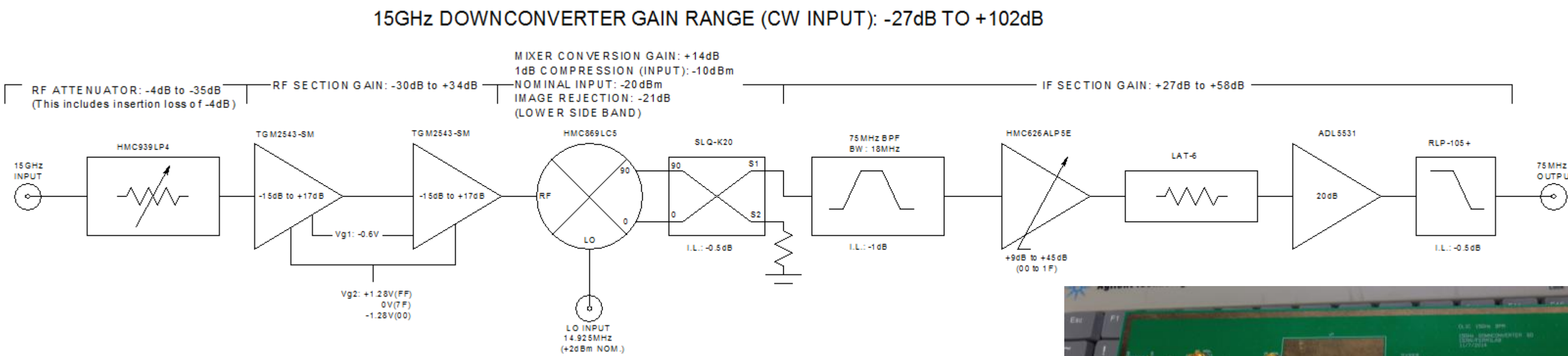
2015 Installation

- Four prototype BPMs in CLEX (CTF3)
  - 3 copper, 1 old stainless steel
- End of probe beam line
- All 3 new BPMs on X and Y movers
- Old BPM added as ref cavity
- OTR screen for ensuring beam transmission
- Electronics next to the beamline
- Higher resolution (12-bit), lower rate (250MS/s) digitiser to demonstrate spatial resolution

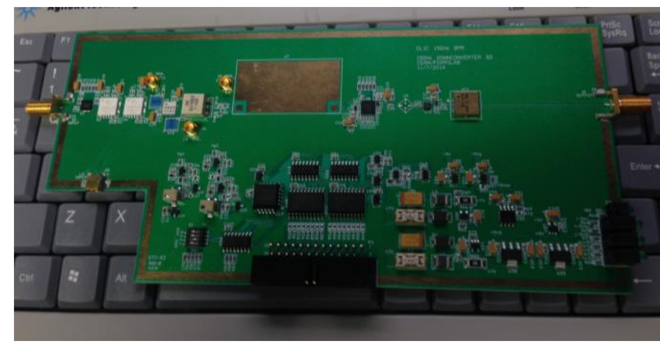


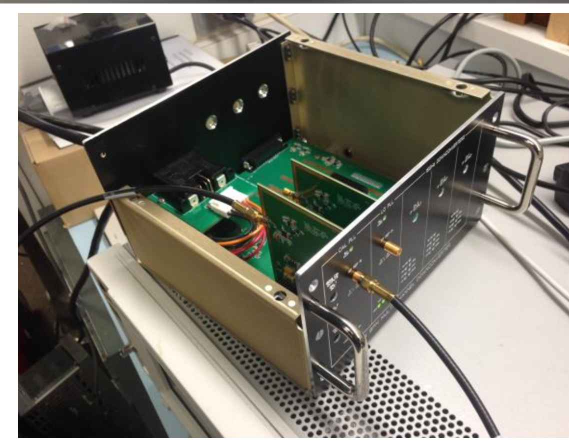


Downconverter Electronics



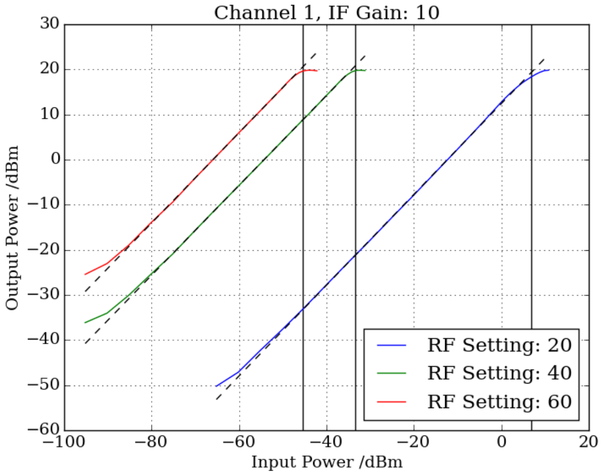
- Concept tested with a single cavity at CTF3
- Single-stage downconverter mixer electronics
- Draft design, signal estimates and control interface by RHUL
- Detailed design and PCB fabrication by FNAL (N. Eddy, B. Fellenz, J. Bogaert)
- Gain flexibility, remote control, custom IF filters
- 9 downmixer channels and 3 LO/CAL signals
- Three units installed in CLEX, one for each BPM

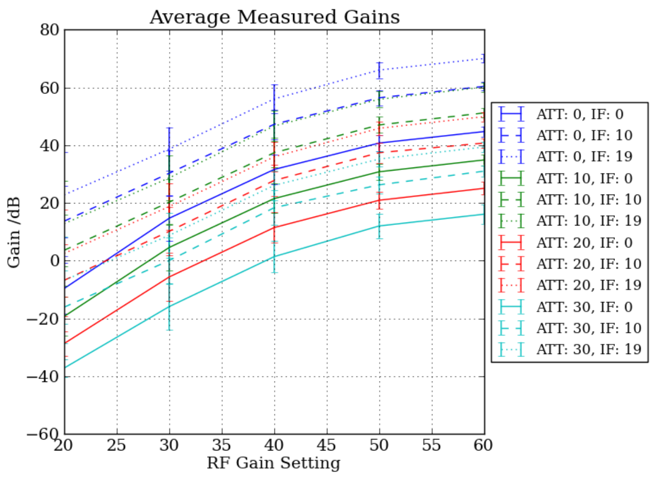




Downconverter Tests

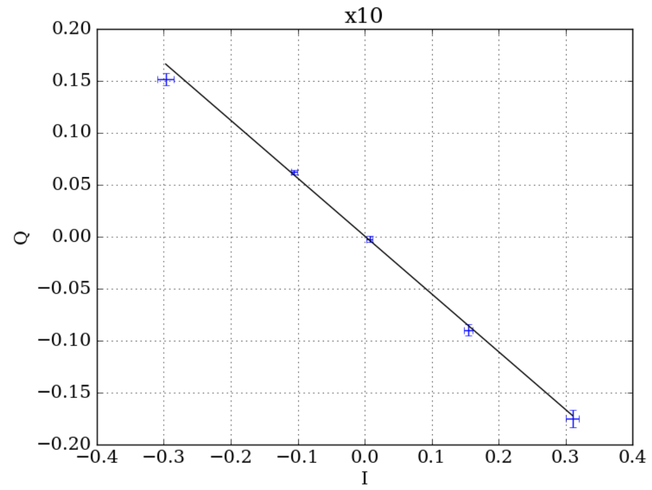
- All 9 downconverter channels were characterised
- Gain measured for range of variable gain and attenuation settings
- Operational values were determined
- Dynamic range also measured at various settings
- A nominal dynamic range of 80dB can be achieved

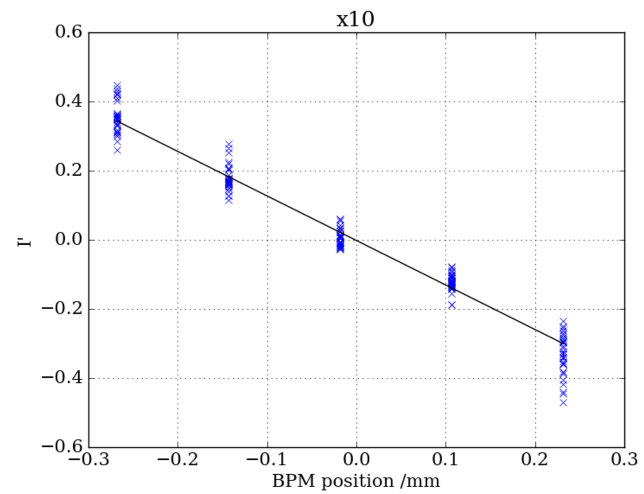




Beam Tests

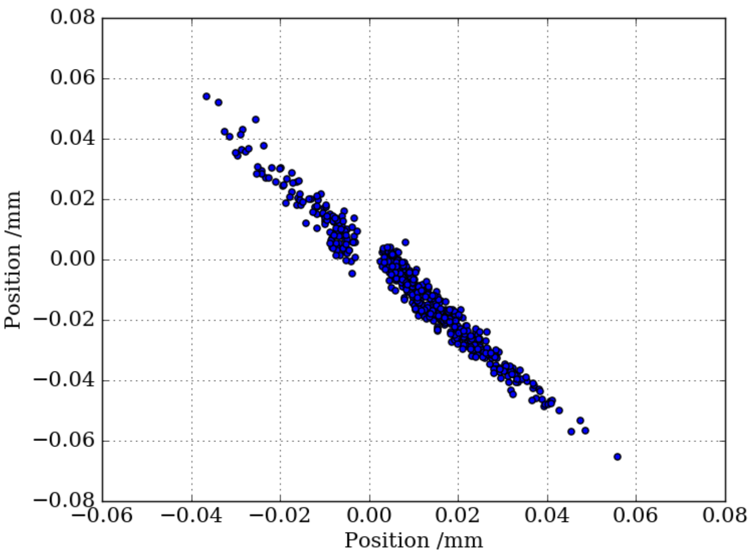
- BPMs calibrated with a stable beam and scanning the BPM position with the stages.
- I's and Q's are measured and the position and tilt dependent parts of the measured signal are determined.
- A position sensitivity factor is calculated from this and is used to measure beam position.
- Charge sensitivity of the reference cavity also needs to be determined.





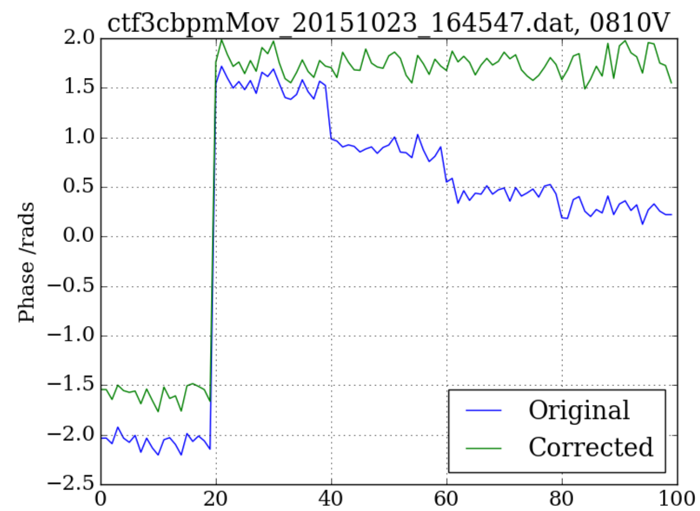
Beam Tests

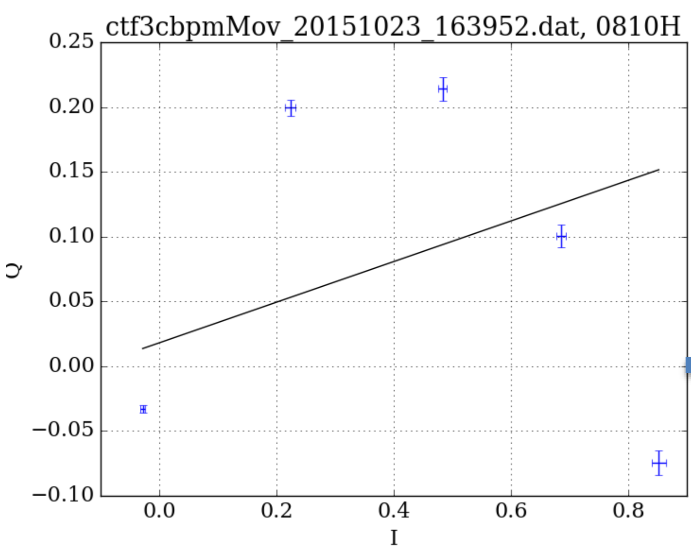
- Resolution measured with 3 BPMs where the position in pickup is predicted by the signals measured in the other 2
- 1000s of shots taken
- Simple correlation between BPMs gives a resolution of ~1 µm.
- Due to the phase behaviour in the centre of the BPM and the angled trajectory of the beam, the position is not accurately measured around 0
  - A model is required to predict the behaviour in this region



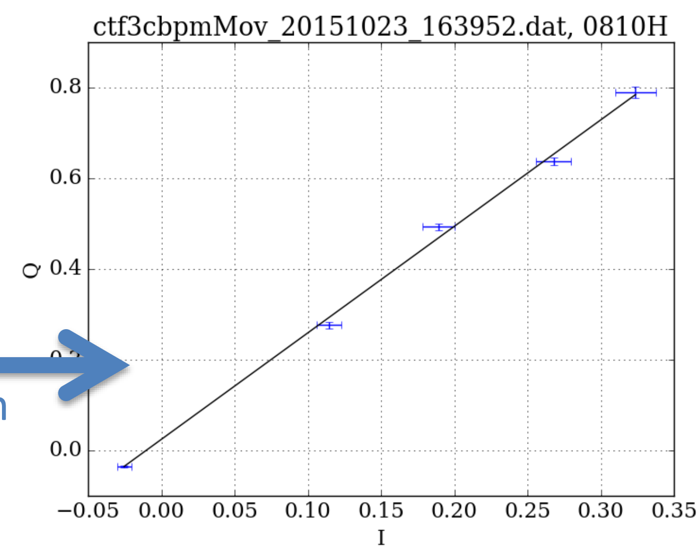
Amplitude-Phase Modulation

- It was seen that phase changed with amplitude due to non-linearities in electronics
- To combat this, the modulation was measured and corrected
- Restores the IQ curve to a line



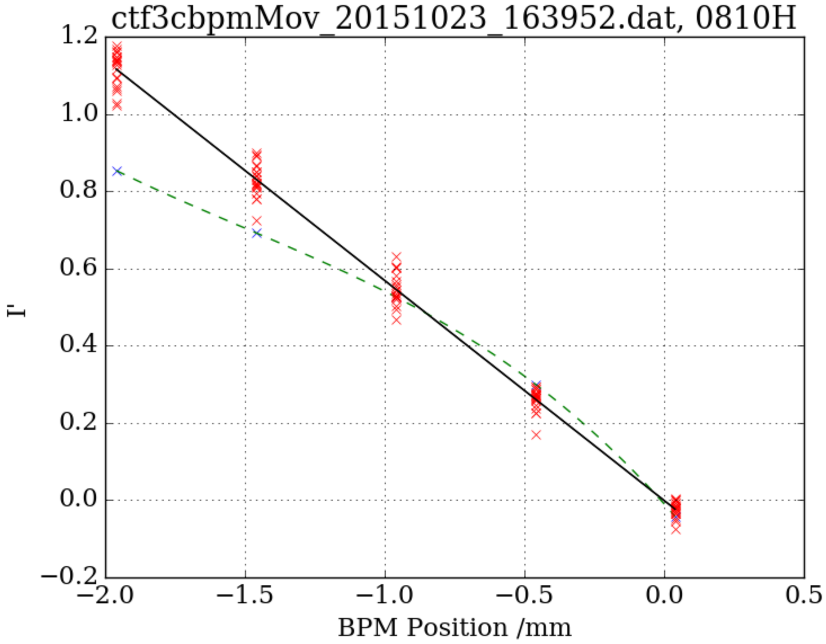


correction



Long Range Nonlinearity

- In long range scans the position response becomes nonlinear
- Fitting a 3rd order polynomial to the measured signal
- Measure the difference and correct for it.



Conclusion and Future Plans

- A system of 4 BPMs has been installed in CLEX
- Beam measurements have been taken
- Resolution measurements so far are sub micron
- With an appropriate model and additional data taken a better resolution is expected
- A simultaneous measurement of the spatial and temporal resolution is required
  - Apply a chirp to the beam