CLIC BPM R&D
MB Cavity BPM and DB Stripline BPM

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CLIC Workshop, January 27th , 2015

Contents

CLIC MB BPM Requirements

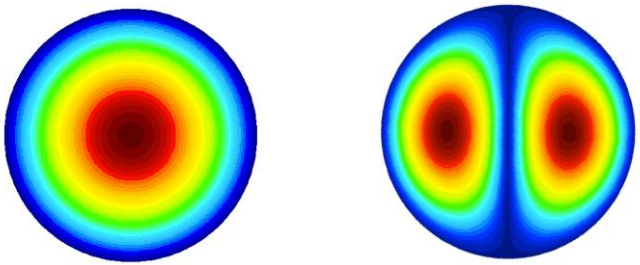
- 50 nm spatial and 50 ns time and resolution.
  - Multiple measurements in a 156 ns long bunch train
  - Dynamic range of ±100μm
  - >4000 BPMs
- 14 GHz for CLIC
  - Design is scalable
- 15 GHz resonant frequency for CTF prototype.
- Q factor tailored to match the required time resolution
  - Prototype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

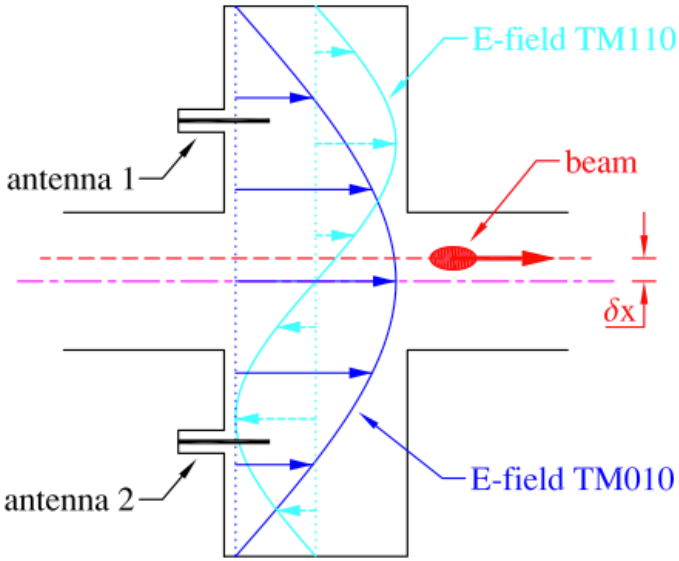
MB parameters and BPM Requirements		
Machine	CLIC	CALIFES
Bunch Spacing	0.5 ns	0.667 ns
Bunch Length	44 μm	225 μm
Train Length	156 ns	1 – 150 ns
BPM Spatial Resolution	<50 nm	<50 nm
BPM Time Resolution	<50 ns	<50 ns
BPM Accuracy	<100 μm	<100 μm
BPM Dynamic Range	±100 μm	± 100 μm
BPM Resonant Frequency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

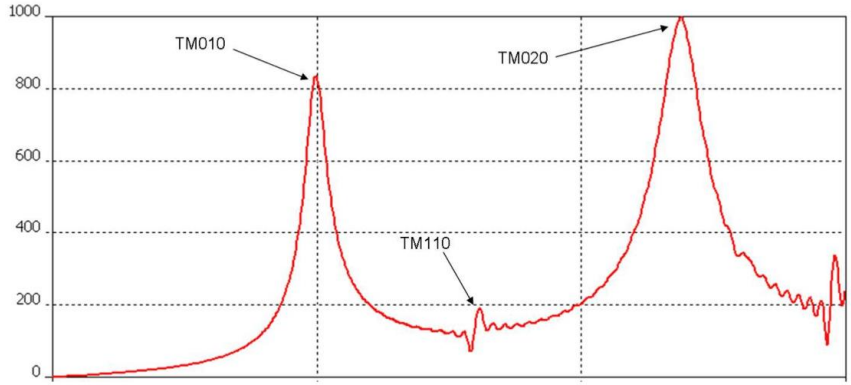
Cavity BPM Basics

- 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.

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

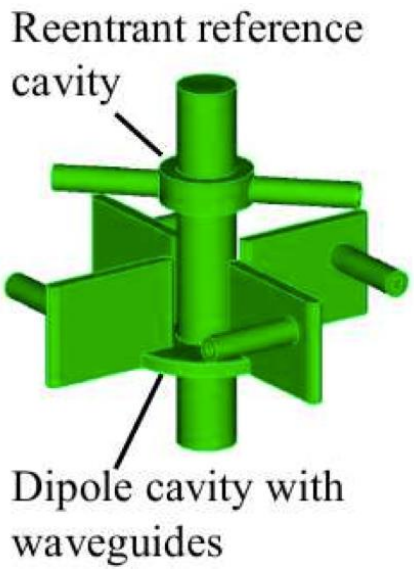


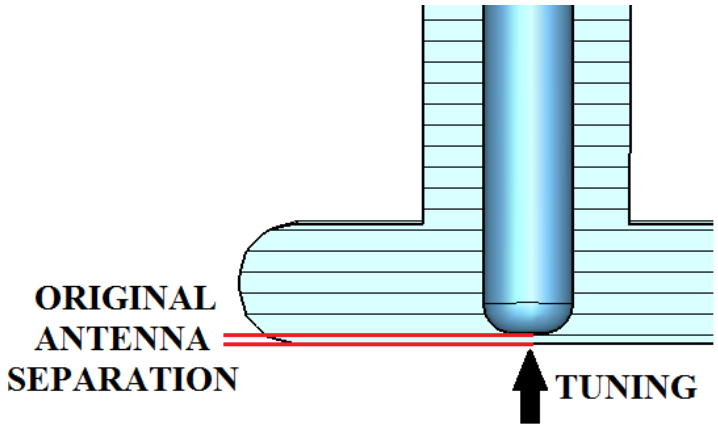




Stainless Steel Prototype BPM

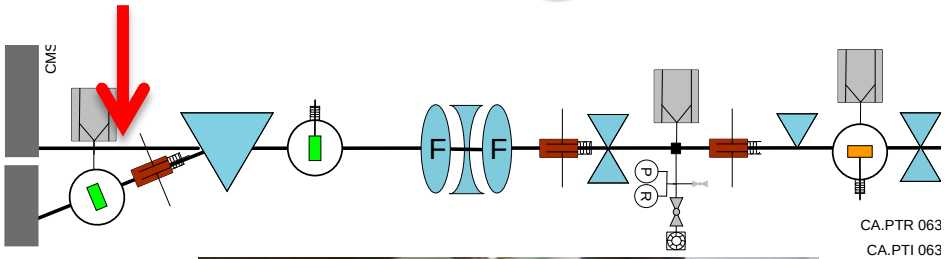
- Two cavities:
  - Position cavity: pillbox
  - Reference cavity: re-entrant pillbox
- Stainless steel used to lower Q factor: ~ 250
  - Results in unnecessary high temporal resolution
  - Matched low Q in reference cavity
- Waveguide/coax Couplers need tuners
  - Very sensitive to antenna/wall separation
  - Mechanical tolerances

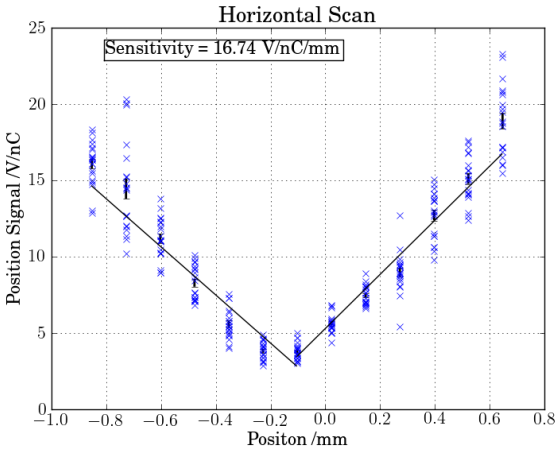




Stainless Steel BPM Testing

- Installation at end of probe beam line.
- Charge sensitivity measurements
  Current monitor reading
  - Fine charge scan not achieved
- Position sensitivity
  - Use hor./vert. translation stages

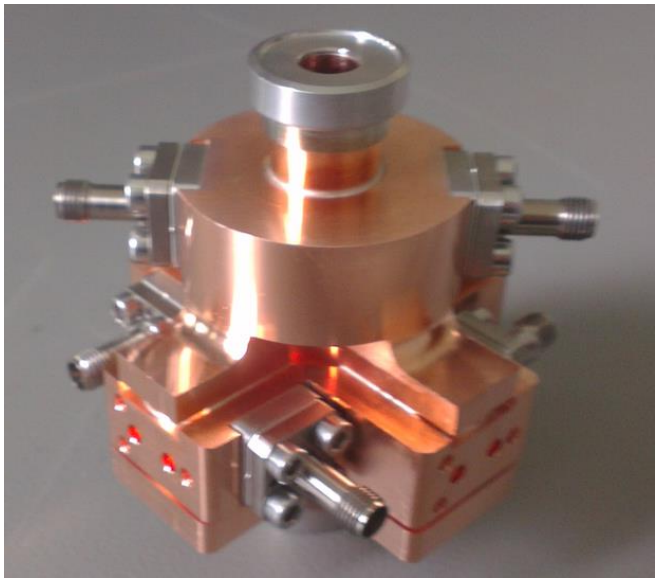




Sensitivity Measurement	Measured	Estimate
X Position (V/nC/mm)	16.6 ± 0.2	17.1
Y Position (V/nC/mm)	15.9 ± 0.4	17.1
Charge (single bunch) (V/mm)	128.8 ± 2	117
Charge (multi bunch)	608 ± 2	-

Copper Cavity BPM Prototype

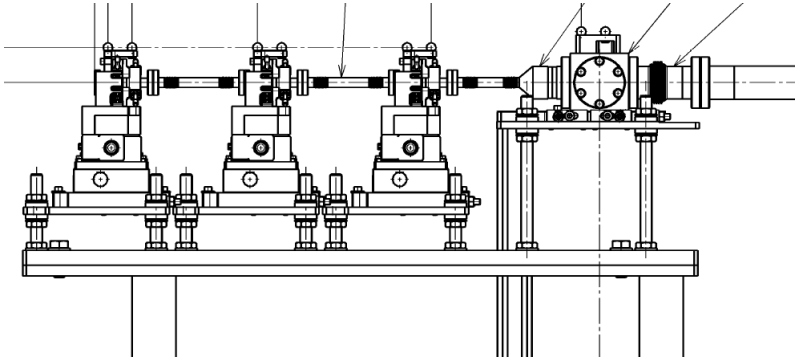
- Modified cavity BPM design
  - Main geometry unchanged.
  - Copper to raise Q to 500
  - New feedthrough design.
- Prototype manufactured for RF testing
  - Poor dimensions, particularly the reference cavity
- Measurements compared with simulations
  - Before and after brazing
  - Frequencies and Q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

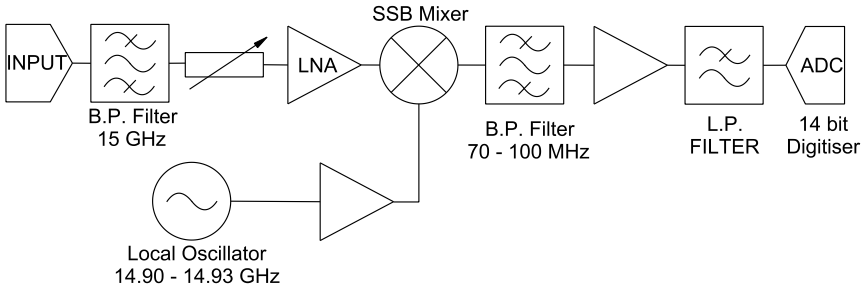


Cavity	Q_L	f_0 /GHz
Reference	938	14.772
Predicted	500	15.0
Position	~830	14.996
Predicted	524	15.0

Conclusion and Future Work

- Stainless steel prototype evaluated during 2013/2014
  - Promising performance, improvements possible
- Improved copper prototype designed
  - Awaiting delivery of mechanical parts, RF measurement and brazing
  - Q higher than expected, time resolution
  - Feedthroughs – variation in Q_{ext}
- 3 copper BPMs to be installed in CTF3
  - Remove beam jitter
  - Determine spatial resolution
  - Simultaneous spatial and temporal resolution?
  - New electronics system





CLIC DB BPM Requirements

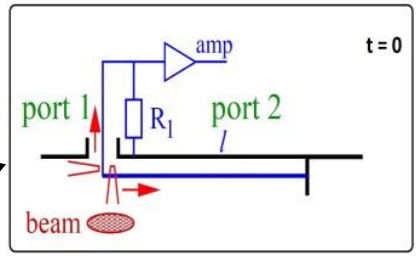
- Close proximity to PETS
  - 130 MW of RF power at 12 GHz propagating along the Drive Beam pipe (fc_{TE11} = 7.64 GHz).
  - Need to measure mW beam signals in close proximity of MW RF pulses.
  - Suppression of 12 GHz PETS interference needed.
- Simple and economic design imposed by number of units and available installation space (<150 mm).
- Tight resolution and accuracy requirements.

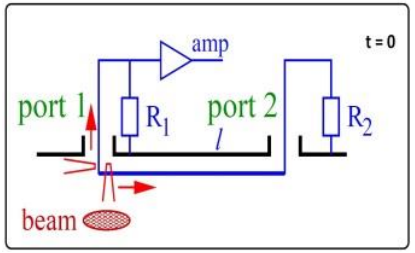
BPM Requirements	
N° BPMs	41580
Beam current	100 A
Bunch frequency	12 GHz
Bunch length	10 ps
Train length	242 ns
Aperture	23 mm
Spatial resolution	2 μm
Time resolution	10 ns
Accuracy	20 μm

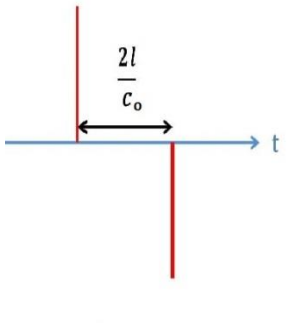
Stripline BPM Basics

- 130 MW PETS RF interference at 12 GHz needs to be suppressed.
  - BPM technology with a suitable frequency response.

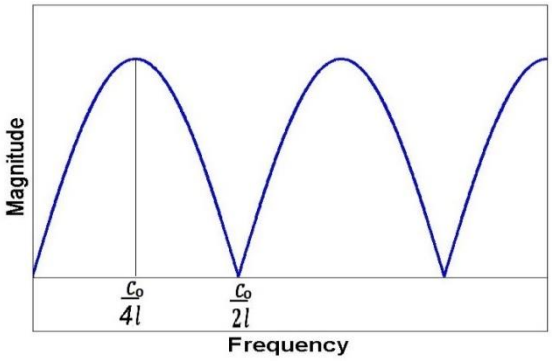
- Two possible versions of stripline BPM:
  - Compact, short-circuited: downstream short-circuited electrodes, simple, low cost.
  - Terminated: 8-ports, improved notch-filter effect, loop-through calibration possible.





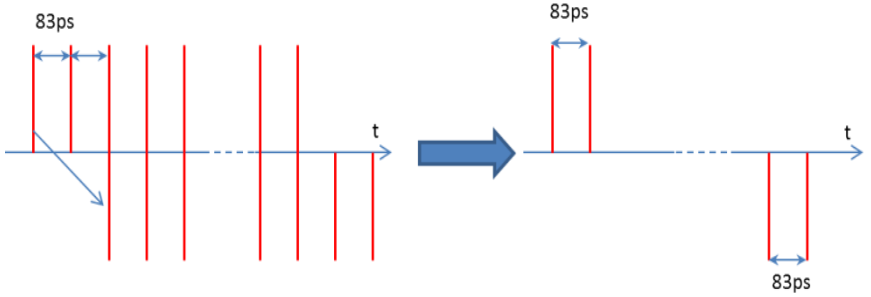


$$z(t) = \frac{Z_C}{2}\left[\delta(t) - \delta\left(t - \frac{2\ell_{strip}}{c_0}\right)\right]$$



$$Z(w) = j Z_c e^{-j\frac{w\ell_{strip}}{c_0}} \sin\left(\frac{w\ell_{strip}}{c_0}\right)$$

Z_c : beam to stripline coupling impedance

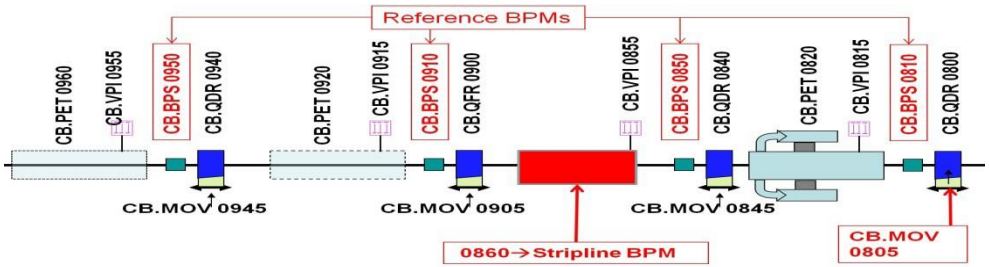


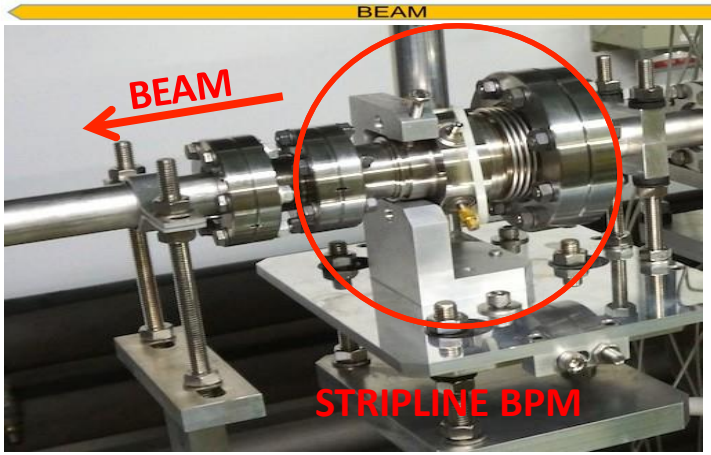
- If → Bunch cancellation

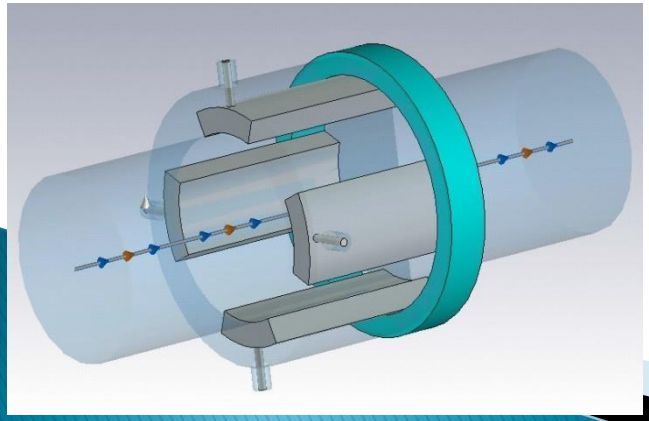
(N^{th} notch tuned to f_{bunch})

Compact Stripline BPM

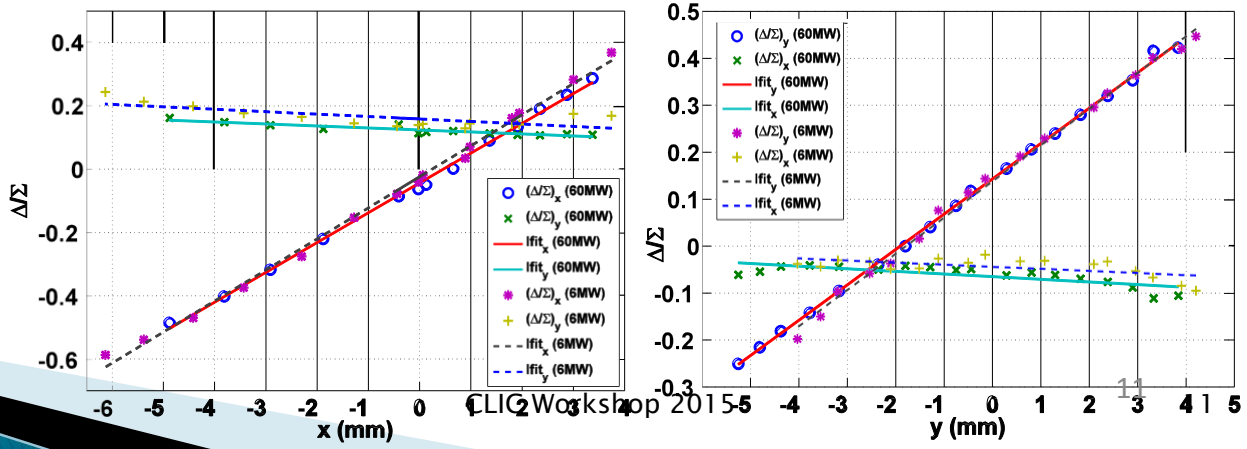
- Stripline prototype with short circuited electrodes installed in TBL at CTF3 and successfully tested with beam.
- FESA class developed for synchronous data acquisition with the rest of TBL BPMs
- Preliminary resolution tests performed using MIA/SVD analysis: **15 µm** (H and V planes) for a 3A beam current.





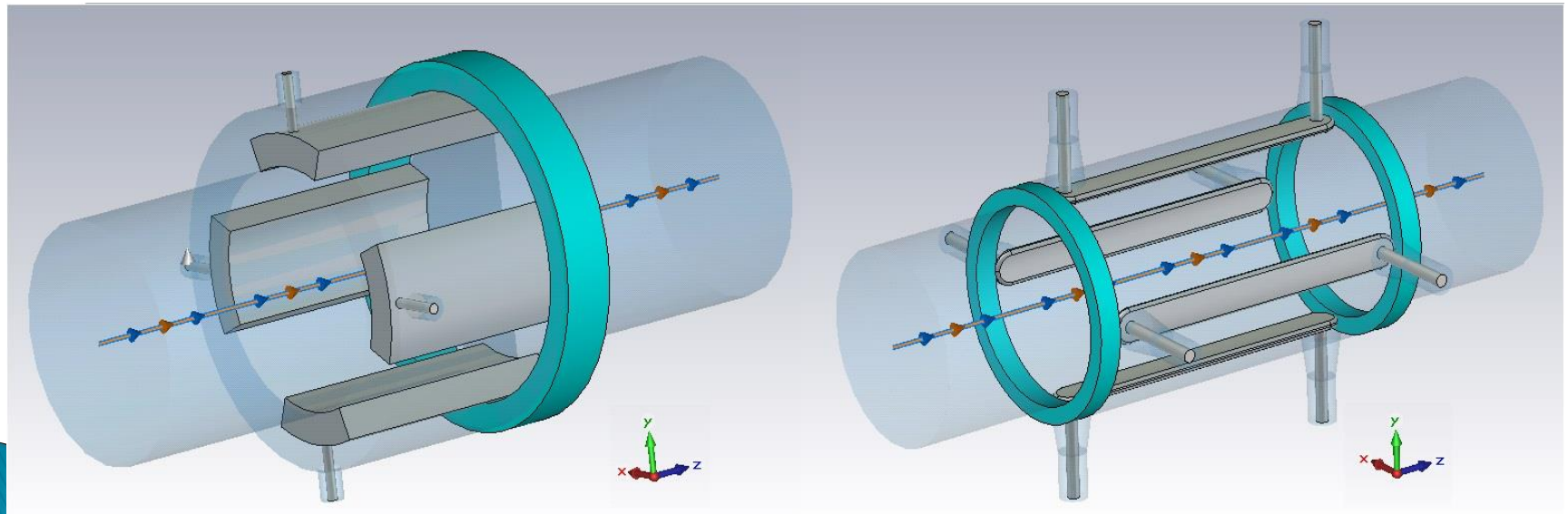


TBL Beam sweep in horizontal and vertical planes



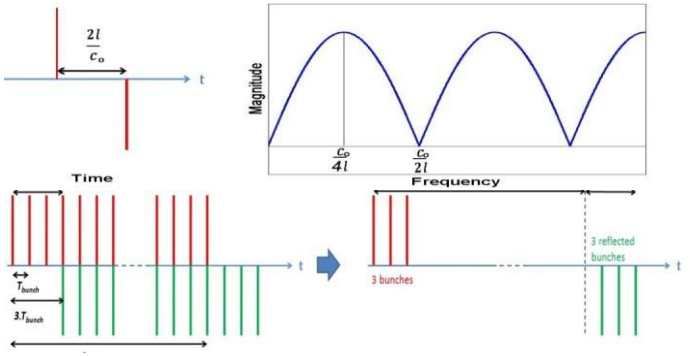
Terminated Stripline BPM for CLIC TBM

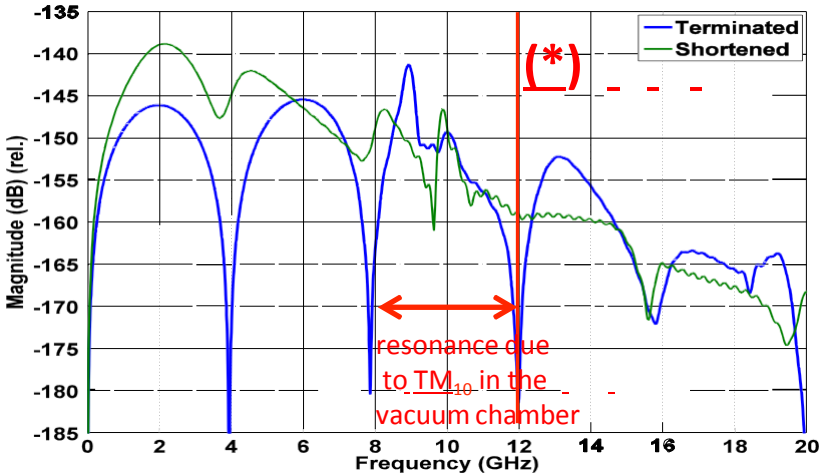
- First prototype provides **insufficient suppression of the 12 GHz CLIC RF power signal.**
- Longitudinal dimensions are very close to transverse ones (25 mm vs 23 mm) → **non-ideal transfer response** (non TEM fields).
- New design intends to tune the **third notch** of the frequency response to 12 GHz → electrode length **l = 37.5 mm**.
- Option for a **loop-thru calibration** via the downstream ports.

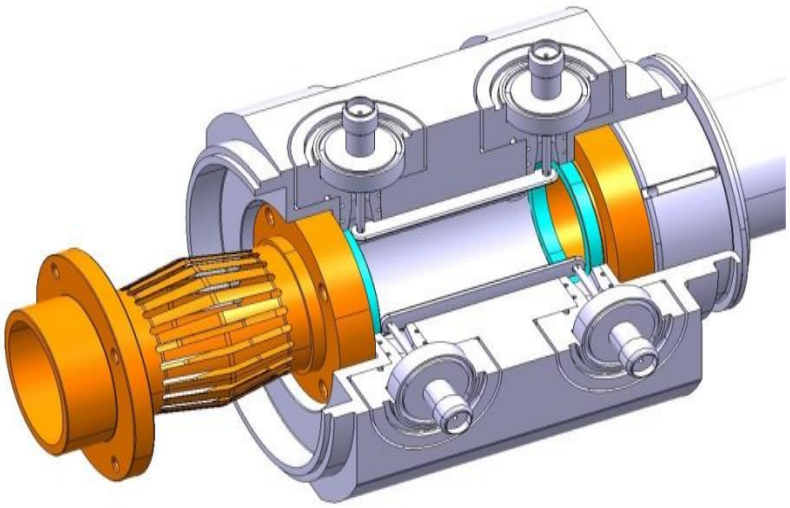


Terminated Stripline BPM for CLIC TBM

- 2 Stripline prototypes with 50Ω-terminated electrodes developed for CLIC Module and installed in summer/autumn 2014.
- 8 port design for better notch filter effect and loopthrough calibration.
- Enhanced PETS interference suppression at 12 GHz **(*)**.





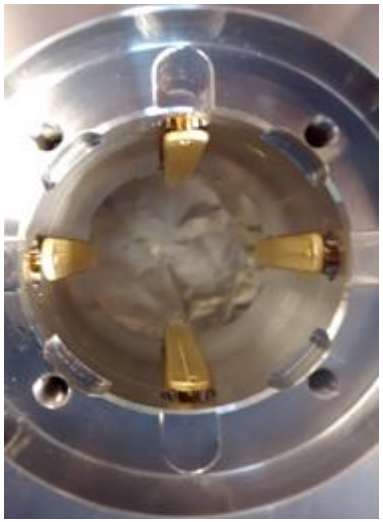


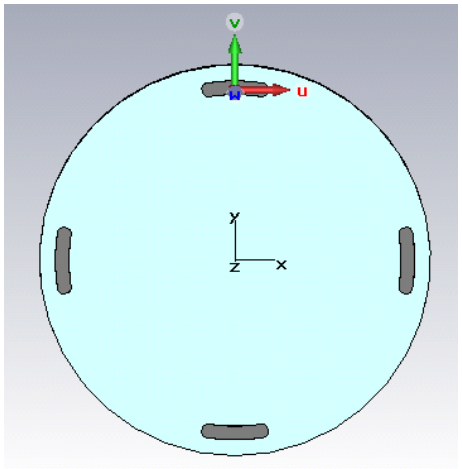
Parameter	Shorted BPM	Terminated BPM
Stripline length	25 mm	37.5 mm
Angular coverage	12.5% (45°)	5.55% (20°)
Electrode thickness	3.1 mm	1 mm
Outer radius	17 mm	13.54 mm
Ch. Impedance	37 Ω	50 Ω
Duct aperture	23 mm	23 mm
Resolution	2 µm	2 µm
Accuracy	20 µm	20 µm
Time Resolution	10 ns	10 ns

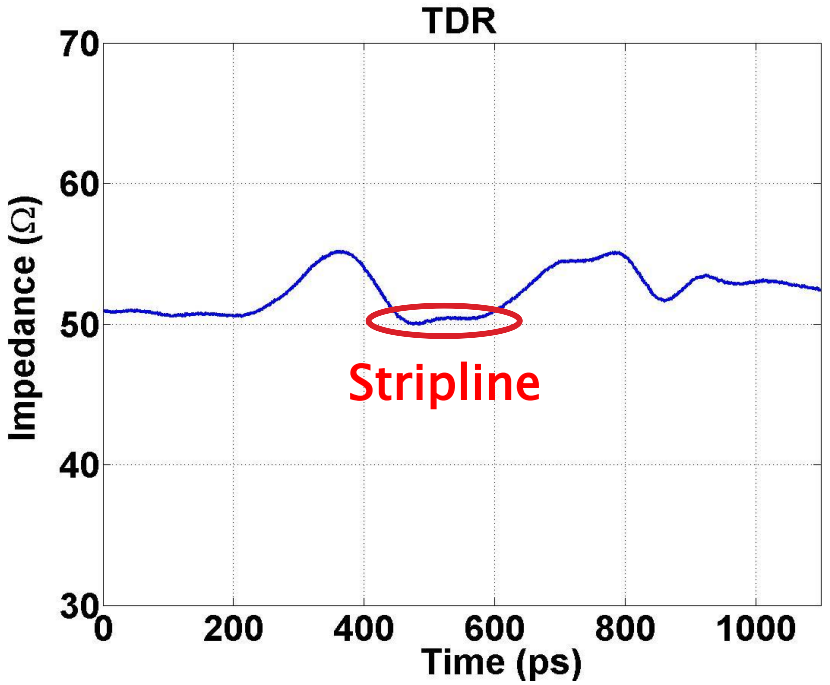
D. Gudkov BE-RF

Terminated Stripline BPM for CLIC TBM

Mechanical realization





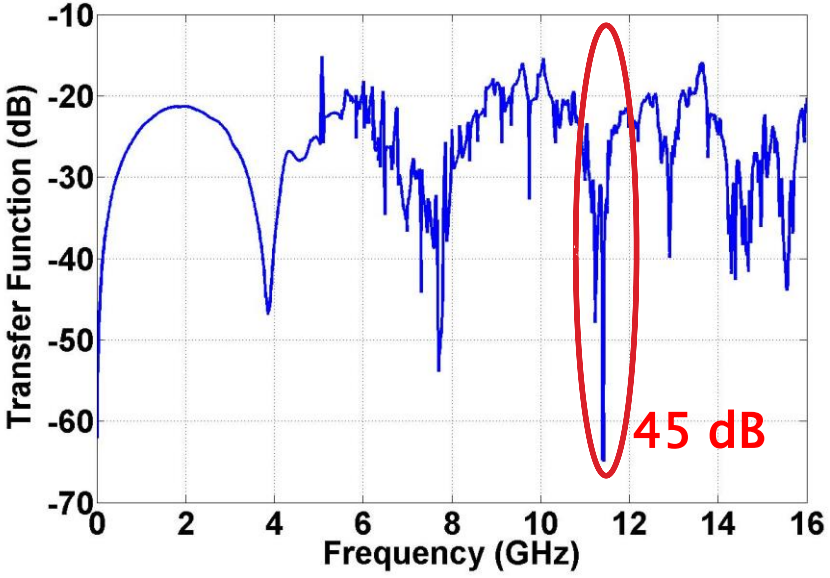


- Z_0 very sensitive to electrode and feedthrough pin fabrication tolerances ($\Delta Z_0 = \pm 3.5\ \Omega$ / 0.1 mm).
- Target range: $Z_0 = 50 \pm 1\ \Omega$

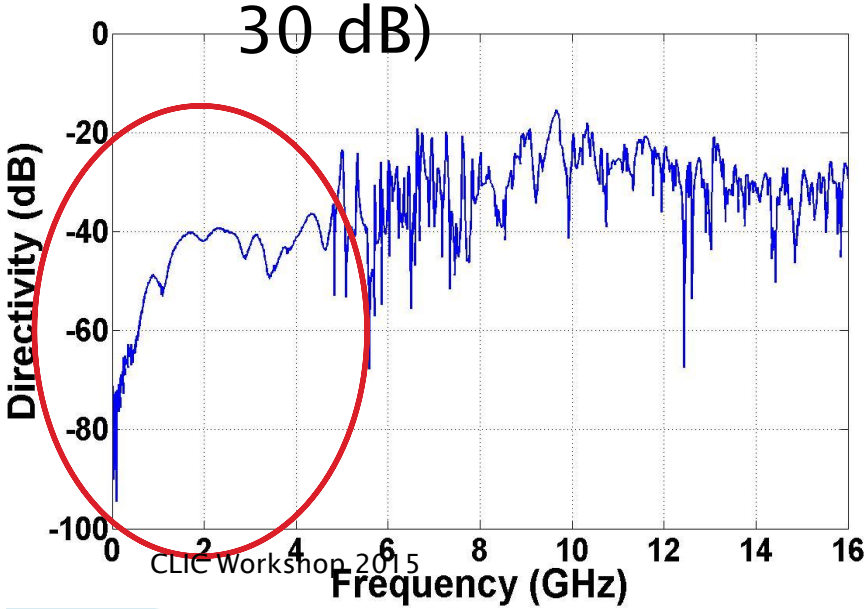
Terminated Stripline BPM for CLIC TBM

Frequency Response Measurement

45 dB-deep 3rd notch, moves between 11.4-12 GHz → Limited RF measurement because of poor flange connection.

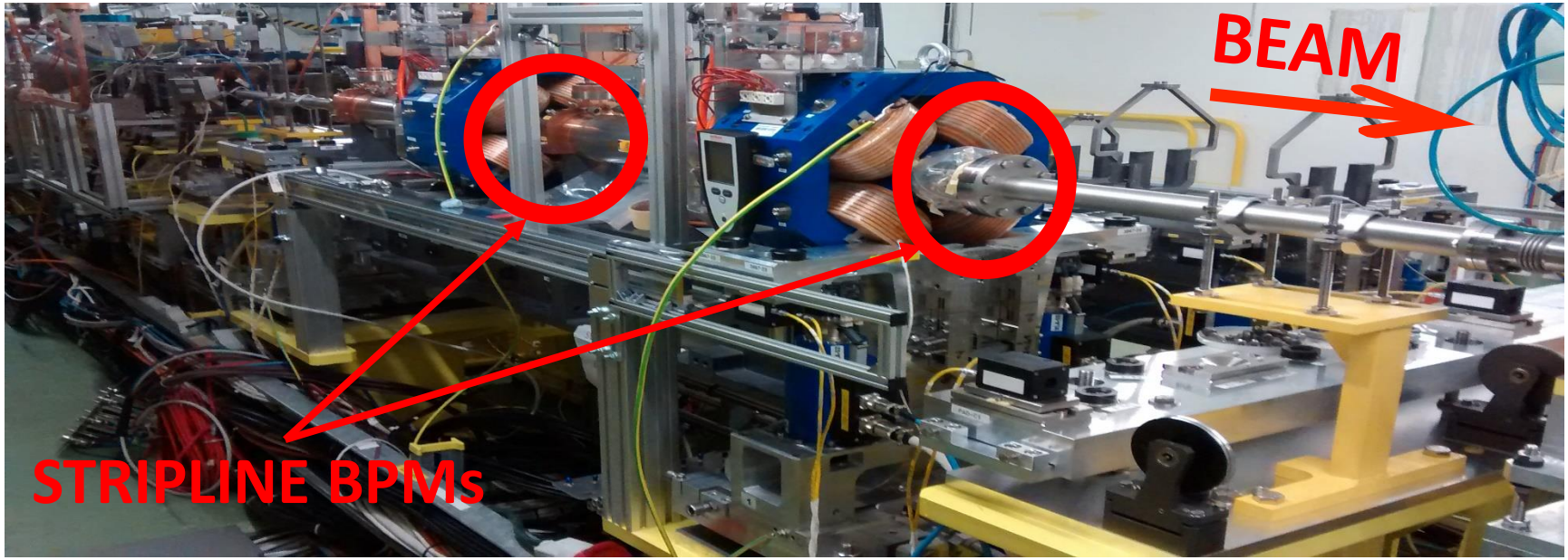


- Directivity: ~40dB up to 4 GHz→ LHC (25-30 dB)



Terminated Stripline BPM for CLIC TBM

Installation in CLEX



- Two installed units:
  - CM.BPL0645
  - CM.BPL0685

- Beam tests planned for spring 2015

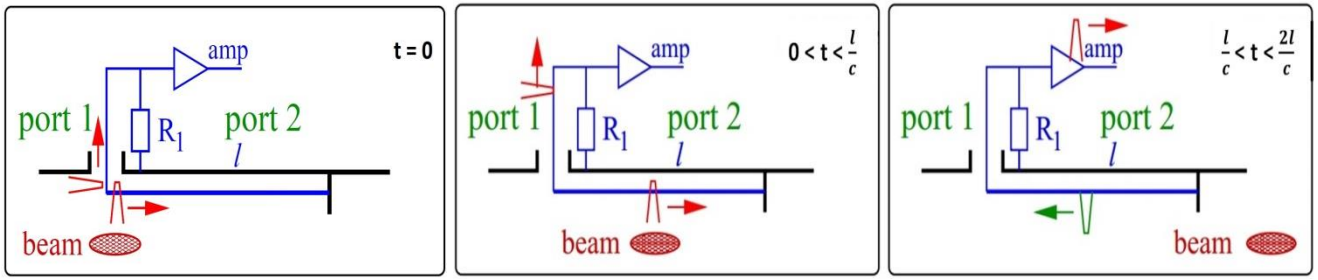
Conclusions and Future Work

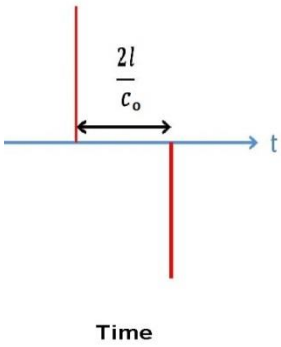
- Compact prototype
  - Insufficient suppression of 12 GHz PETS interference.
  - Good linearity/sensitivity results with beam.
- Terminated prototype
  - Improved suppression of 12 GHz PETS interference.
  - Excellent directivity also interesting for HL-LHC.
  - Practical assembly aspects and cost to be optimized.
- Plans for 2015
  - Beam test at CTF3 (CLIC Module) of terminated prototype (2 units)
  - Study of alternative technologies, e.g. buttons.

Thank you

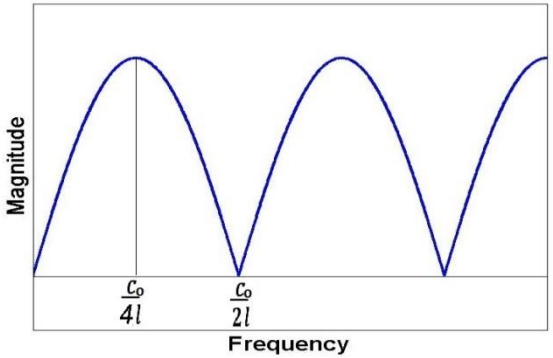
2 – Stripline BPM Basics

- Compact version (shorted electrodes)



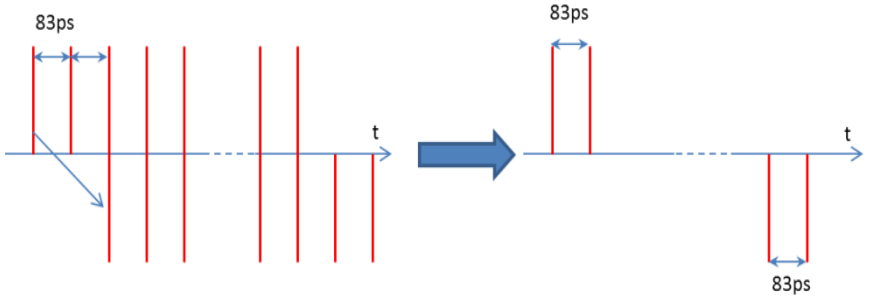


$$z(t) = \frac{Z_c}{2}\left[\delta(t) - \delta\left(t - \frac{2\ell_{strip}}{c_0}\right)\right]$$



$$Z(w) = j Z_c e^{-j\frac{w\ell_{strip}}{c_0}} \sin\left(\frac{w\ell_{strip}}{c_0}\right)$$

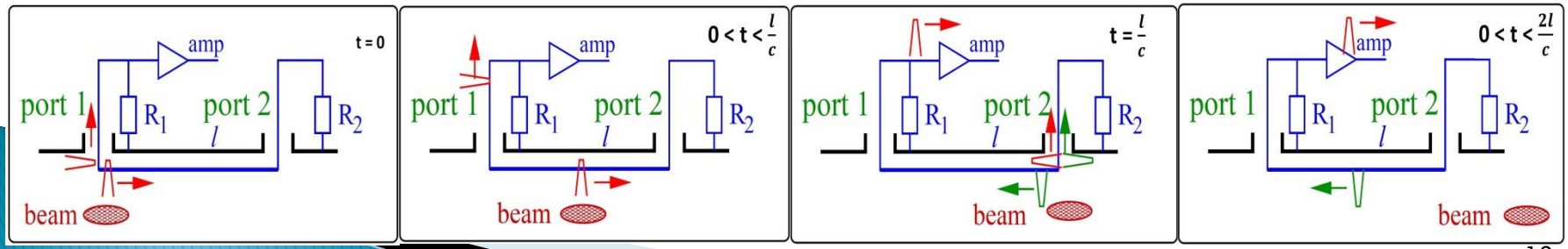
Z_c : beam to stripline coupling impedance



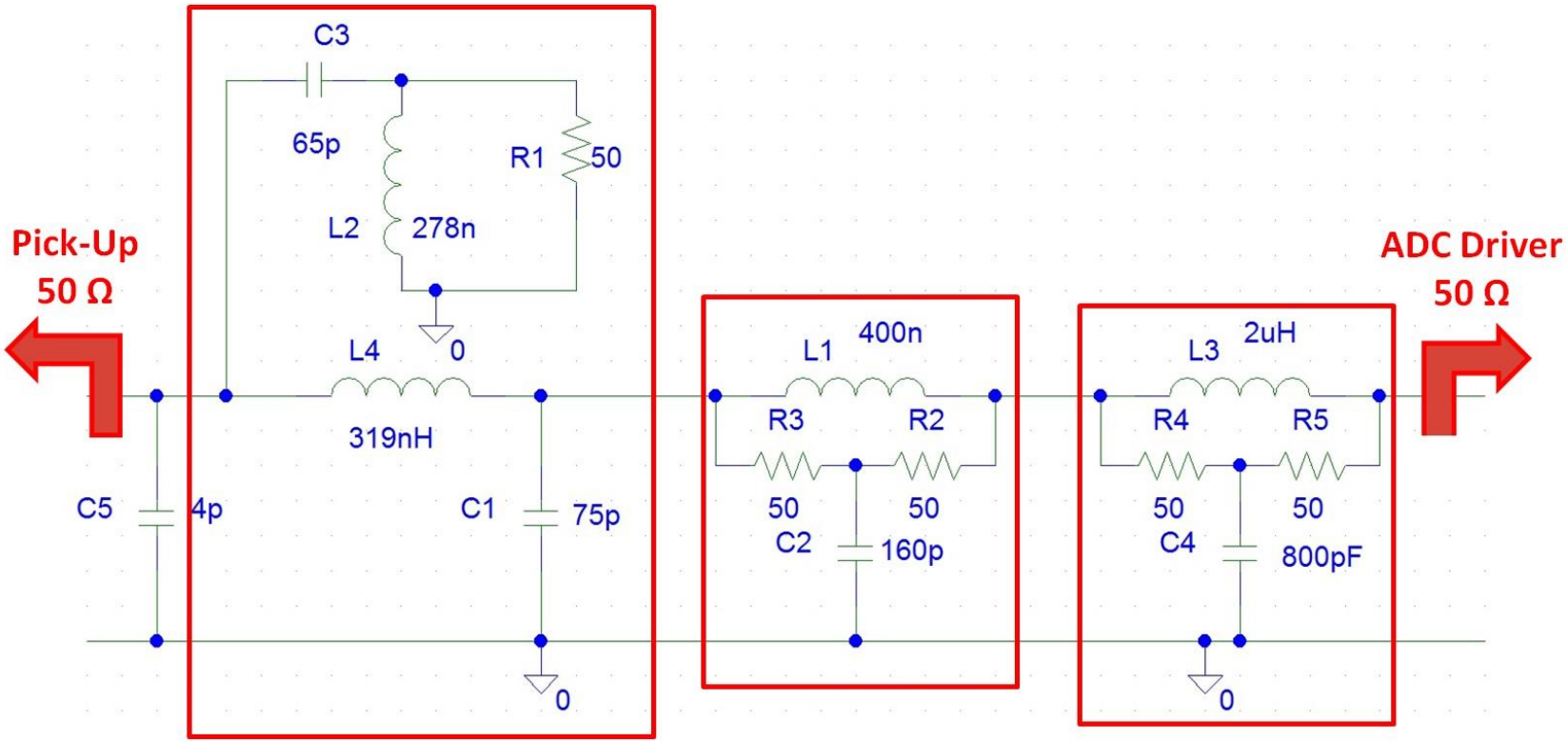
- If → Bunch cancellation

(N^{th} notch tuned to f_{bunch})

- Terminated version (8 ports)



Passive filters for DB Stripline BPM

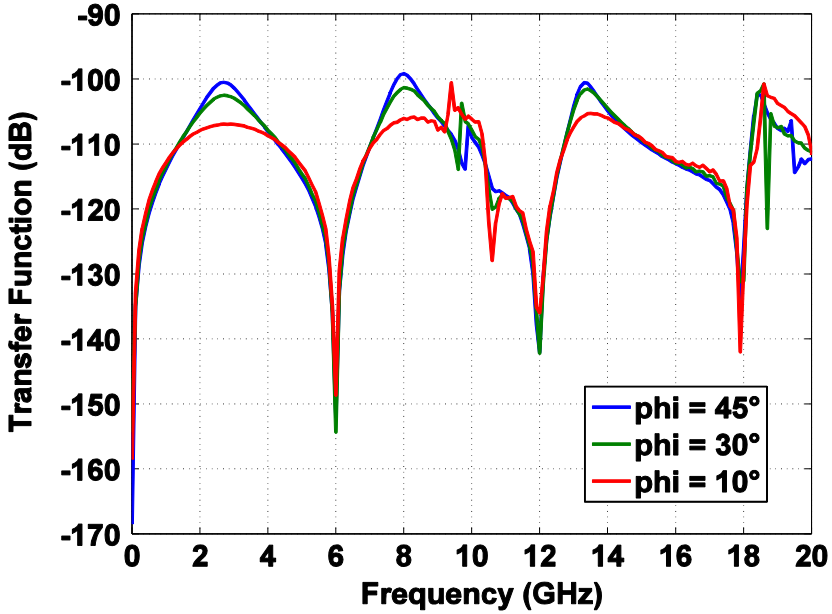


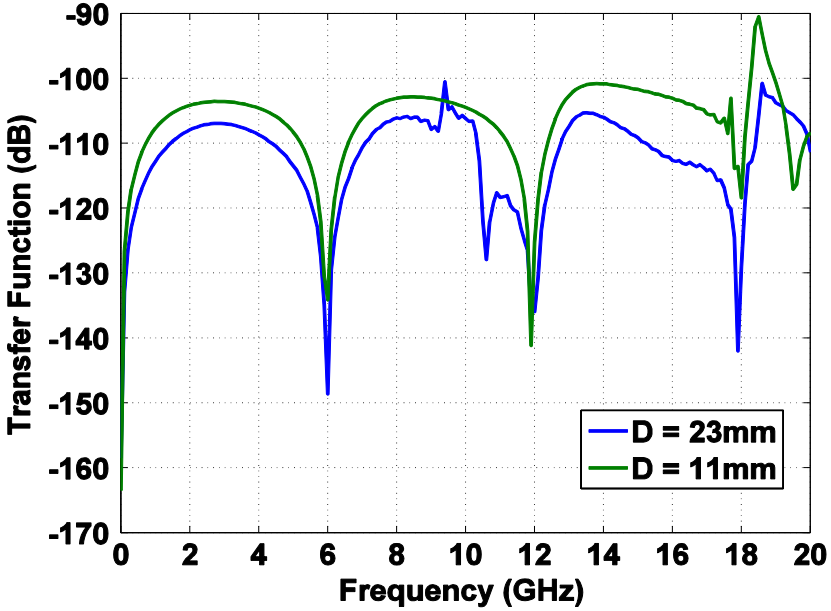
INPUT DIPLEXER 35 MHz
2nd order filter

BRIDGE-T 20 MHz
1st order filter

BRIDGE-T 4 MHz
1st order filter

Geometrical Issues in Compact Prototype





- Lobe distortion grows with electrode width.

- TF sensitive to resonance at f_{TM_01}=9.99 GHz if aperture and electrode length become comparable.

Beam Tests at CTF3