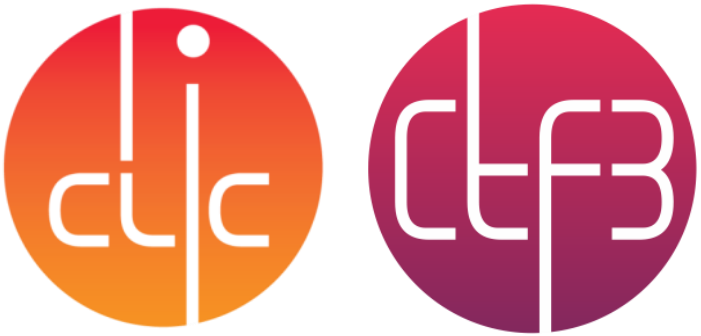
Stripline BPM for the Drive Beam of the CLIC Two Beam Module

Alfonso Benot Morell
Manfred Wendt



CLIC Workshop
18th–22nd January 2016, CERN

Contents

1. The CLIC Drive Beam
2. Stripline BPM basics
3. Acquisition electronics
4. Pick-Up Design
5. Beam Tests at CTF3
6. Noise issues
7. Conclusions and future work

Contents

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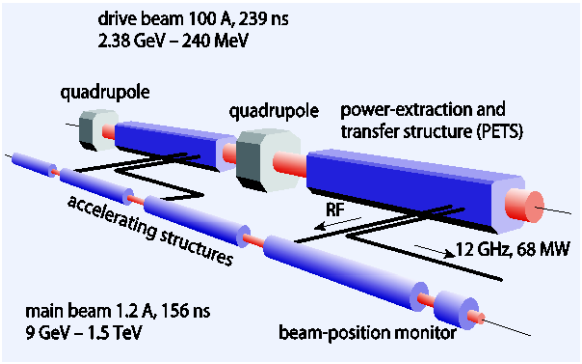
1 – The CLIC Drive Beam

- 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 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

Contents

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5. Beam Tests at CTF3
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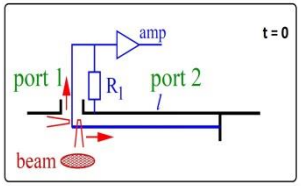
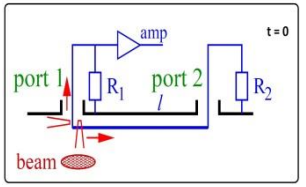
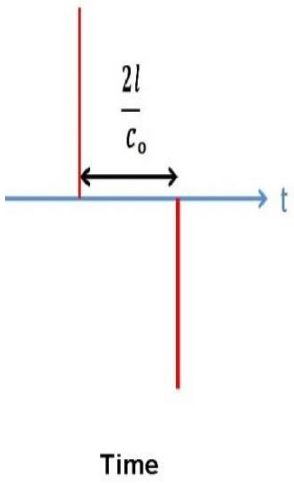
2 – Stripline BPM basics

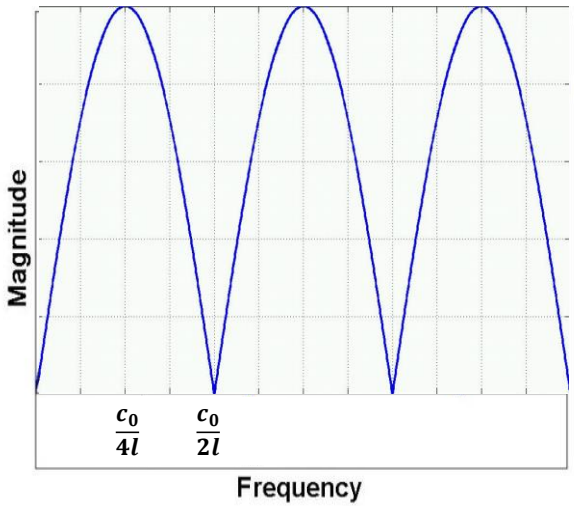
- 130 MW PETS RF interference at 12 GHz needs to be suppressed.
  - BPM technology with a suitable frequency response.

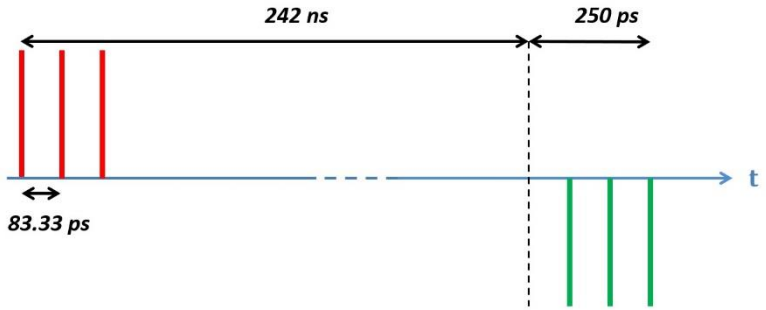
- Two possible versions of stripline BPM:
  - Compact: downstream short-circuited electrodes, simple, low cost.
  - Terminated: 8-port, increased tunability, loop-through calibration possible.











- If $\frac{2l}{c_0} = NT_{bunch}$ → Bunch cancellation

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

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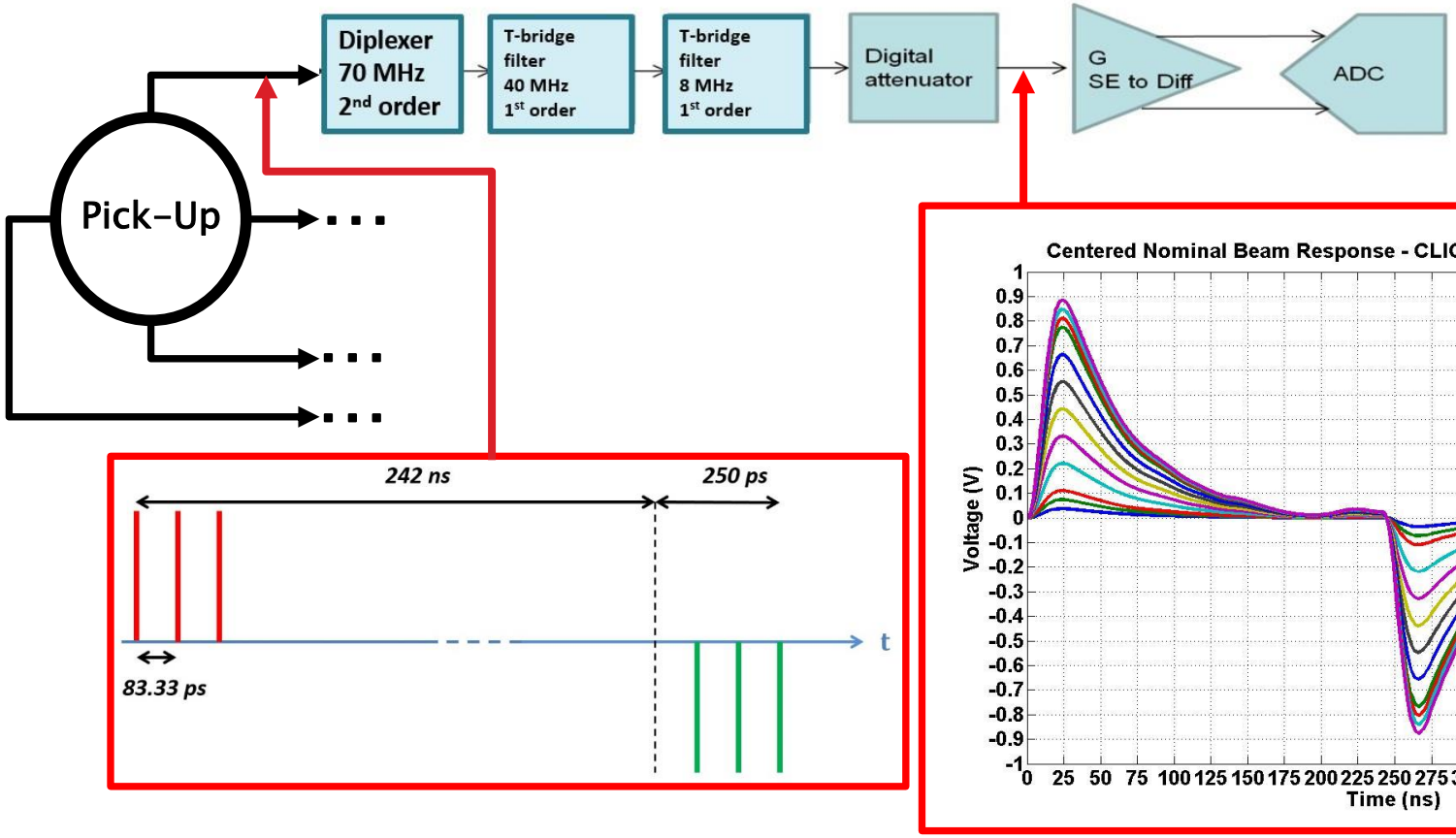
3 – Acquisition electronics

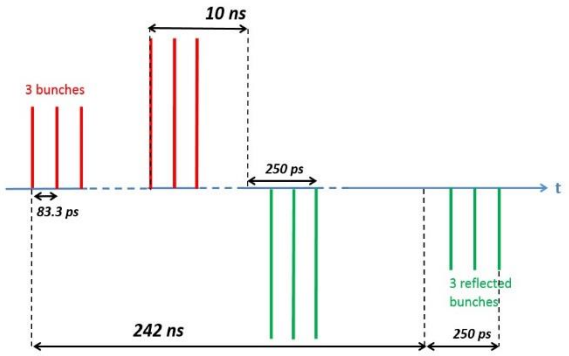


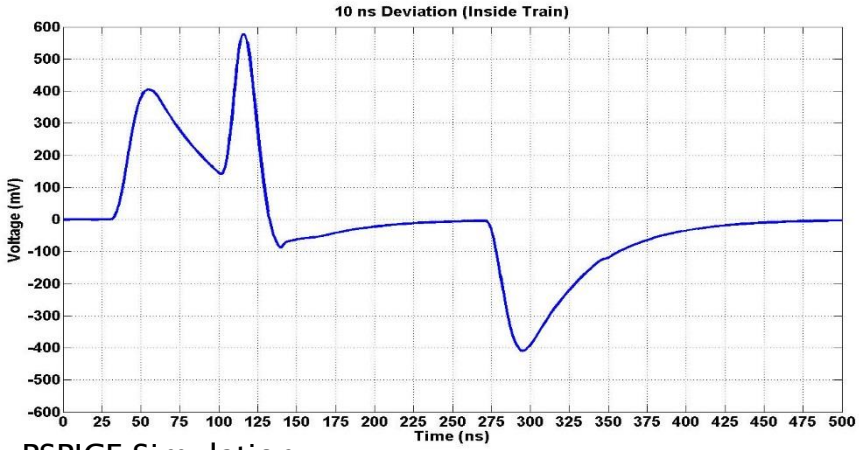
PSPICE Simulation

- <u>Analog signal shaping</u> required for correct acquisition of short and intense BPM electrode signals → Integration / Low-Pass (LP) filtering before ADC.
- Position estimates as $x = k\Delta/\Sigma$, being k the linear calibration coefficient and Δ the difference, Σ the sum of opposite electrode signals.

3 – Acquisition electronics

- Position along the pulse obtained by deconvolution between the electrode signals and BPM transfer response.
- Electrode signals sensitive to >10ns position changes.
- Loop-through calibration, 2 modes:
  - White noise
  - Pulse train





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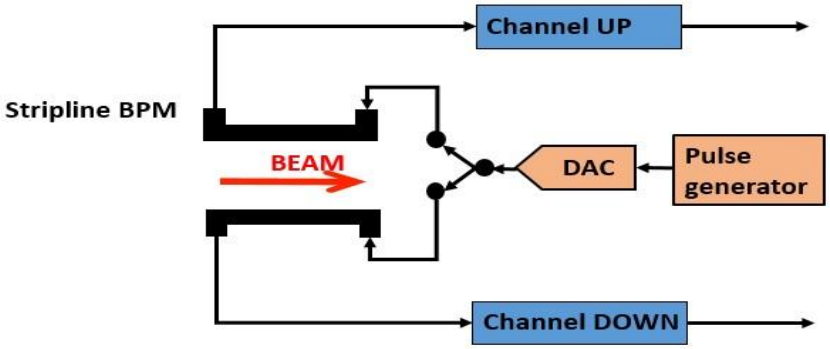

Loop-through Calibration V-Plane (same for H)

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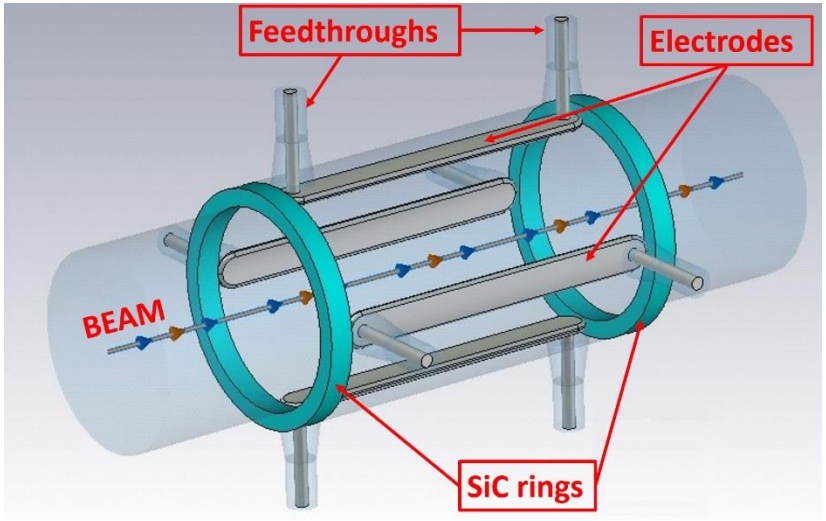
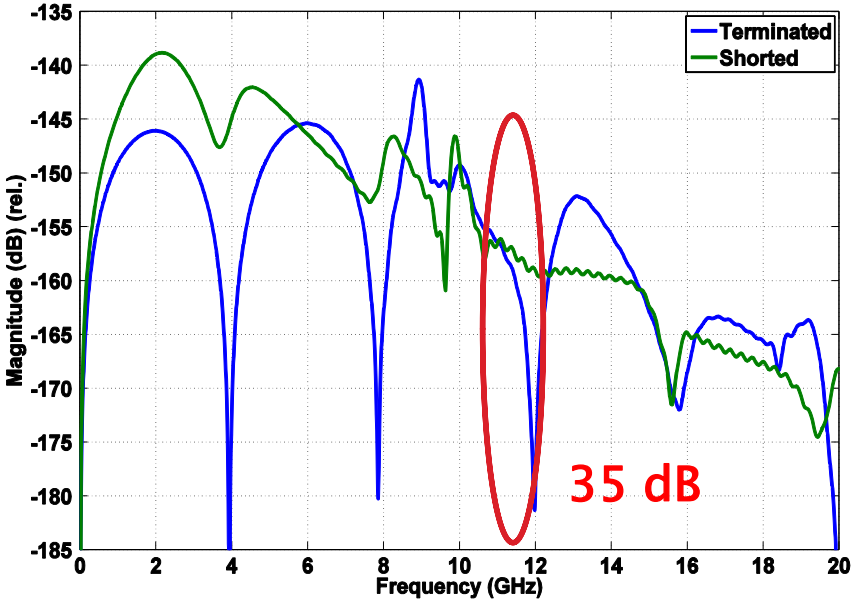
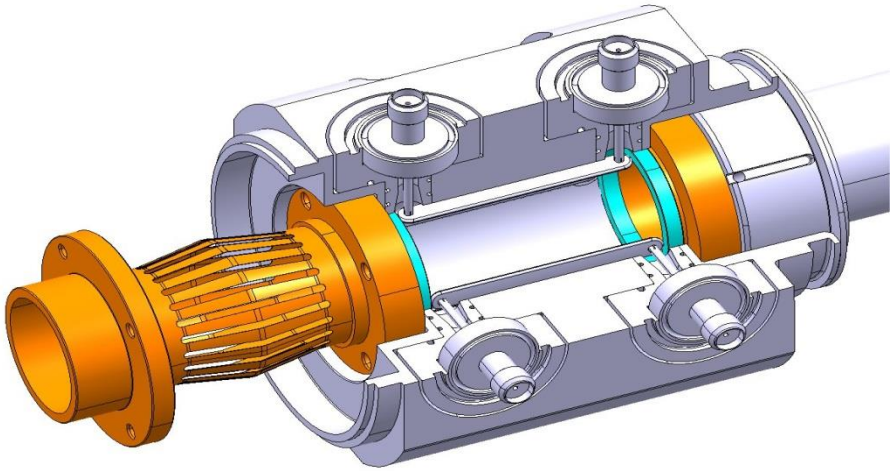
4- Pick-Up Design



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





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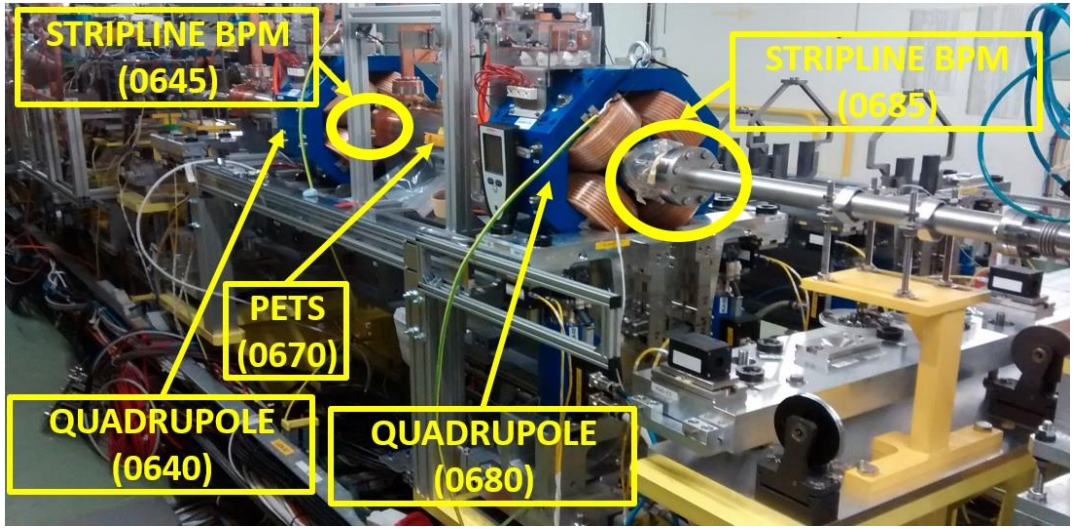
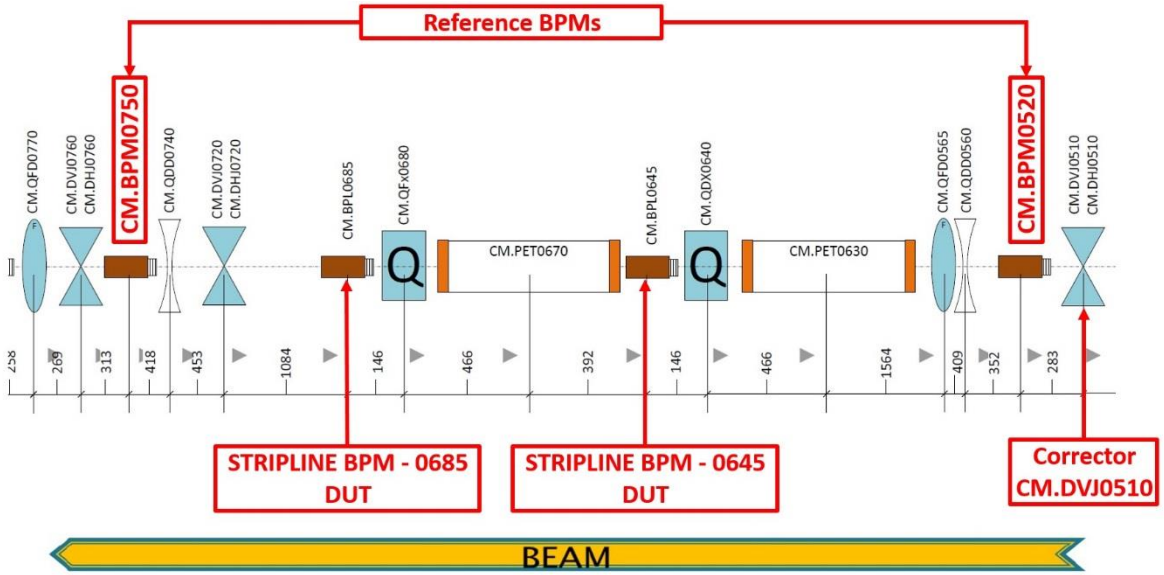
5 – Beam Tests at CTF3

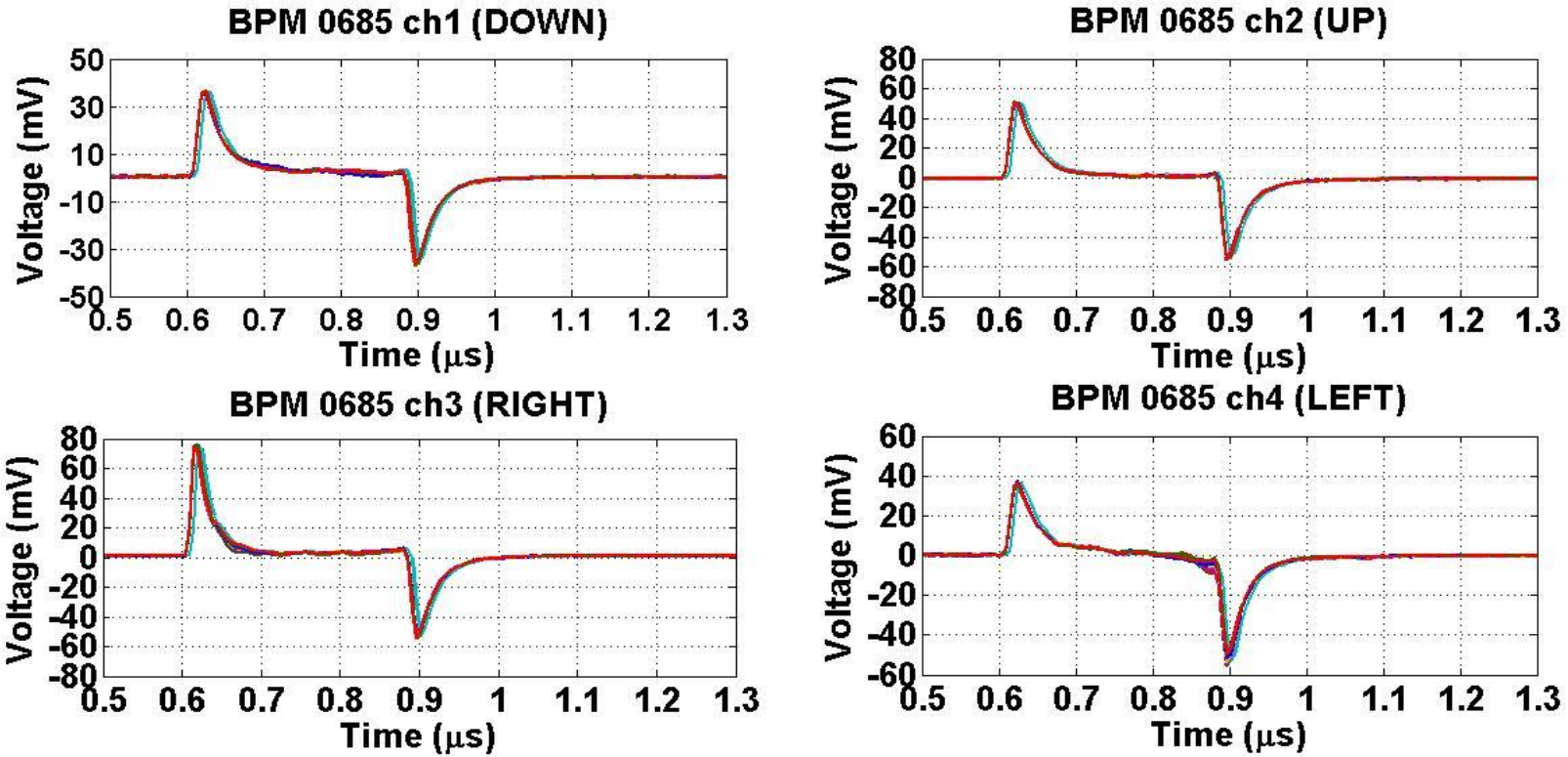




- CTBM, pos. 0645 and 0685
- Evaluate the influence of 12 GHz PETS interference (130 MW in CLIC) in the linearity of the device.
- Beam steered by corrector 0510.
- Reference BPMs: Inductive BPMs 0520 and 0750
- Three test scenarios: 2.4 MW, 40 MW and 60 MW PETS power interference at 12 GHz
- Damaged right electrode in BPM 0645 (only 2.4 MW and 40 MW tested for H-plane) → μ-welding foreseen

5 – Beam Tests at CTF3

- Signals for i.e. (x,y) = (0, 3.25), 40 MW PETS power



- Expected signal shape and levels

5 – Beam Tests at CTF3

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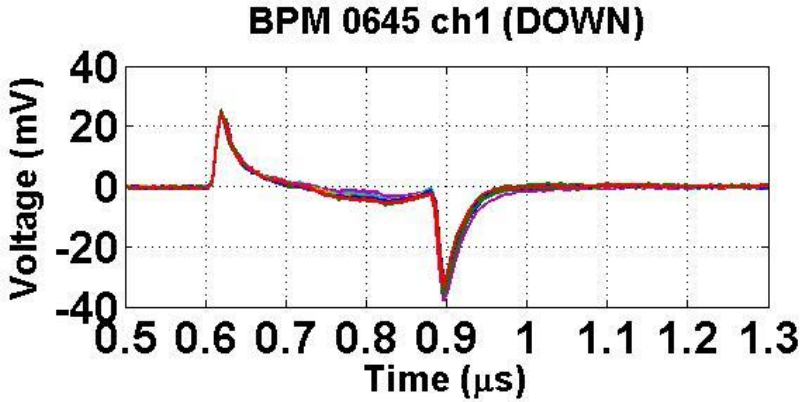
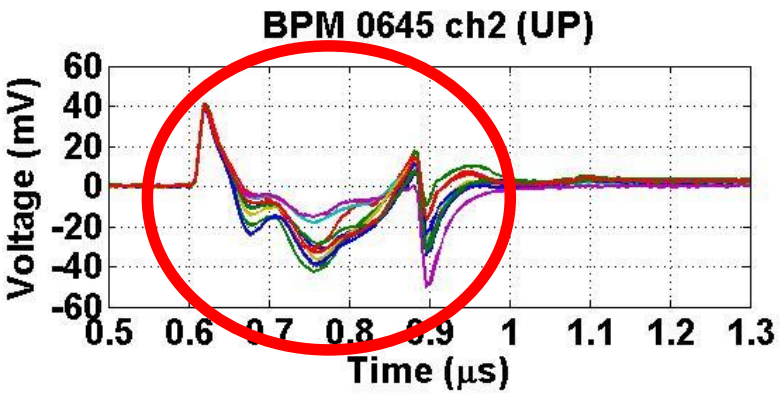
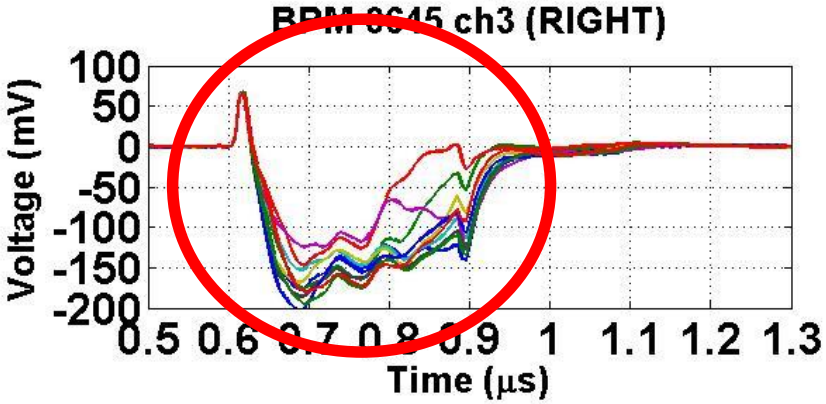
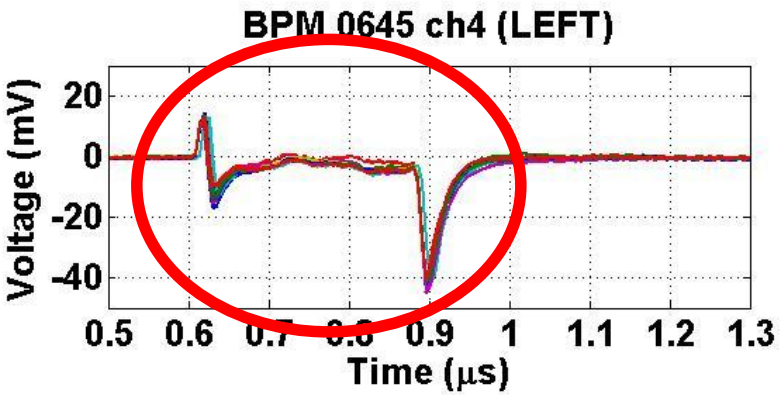




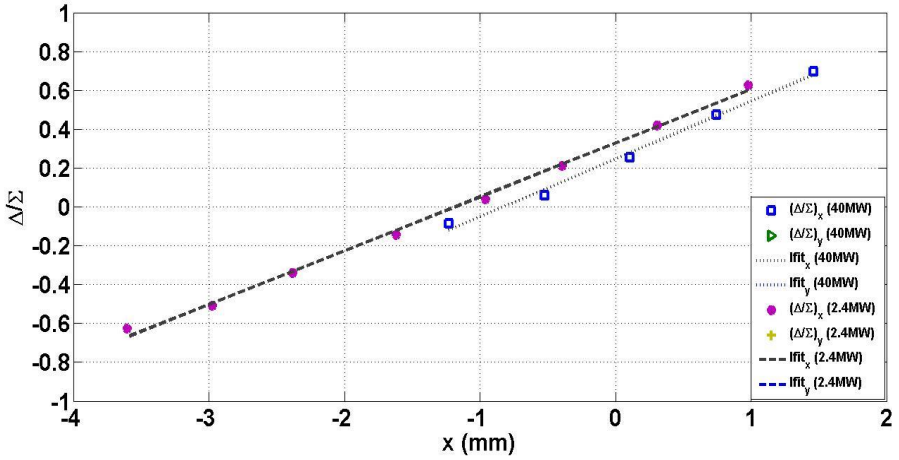


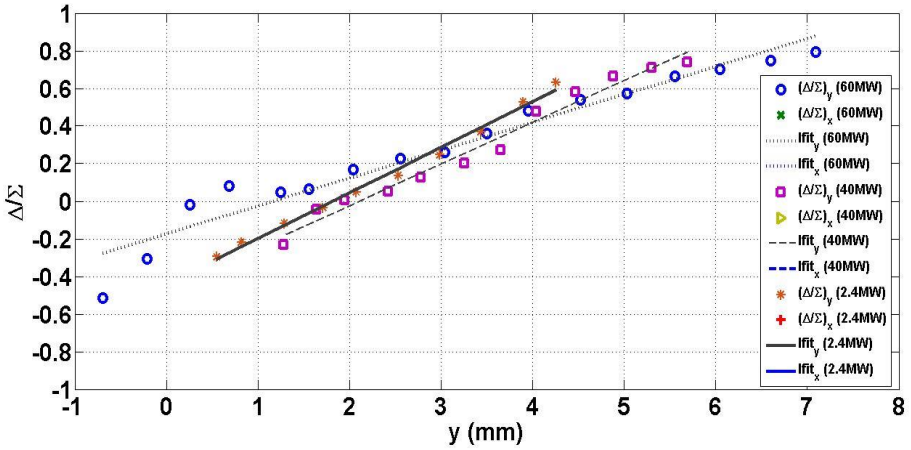


- Strange signals for BPM 0645 → Beam scraping electrode??

5 –Beam Tests at CTF3

- Stripline BPM unit CM.BPL0685
- Three test scenarios: 2.4 MW, 40 MW and 60 MW PETS power interference at 12 GHz





$x_{H,V} = (S_{H,V}^{-1})\Delta/\Sigma + EOS_{H,V}$

Parameter	2.4 MW PETS RF power (Beam current: 3.5 A)	40 MW PETS RF power (Beam current: 15 A)	60 MW PETS RF power (Beam current: 22 A)	EM Simulation
V sensitivity S_V (m^{-1})	242.2 ± 7.4	221.9 ± 10.6	148.1 ± 9.4	155.27
H sensitivity S_H (m^{-1})	276.9 ± 6.2	298.0 ± 15.8	N/A	155.27
V offset EOS_V (mm)	1.82 ± 0.08	2.11 ± 0.18	1.17 ± 0.25	0.00
H offset EOS_H (mm)	-1.18 ± 0.05	-0.83 ± 0.05	N/A	0.00
V RMS lin. error (μm)	105.30	212.32	58.19	0.00
H RMS lin. error (μm)	82.41	86.63	N/A	0.00

5 –Beam Tests at CTF3

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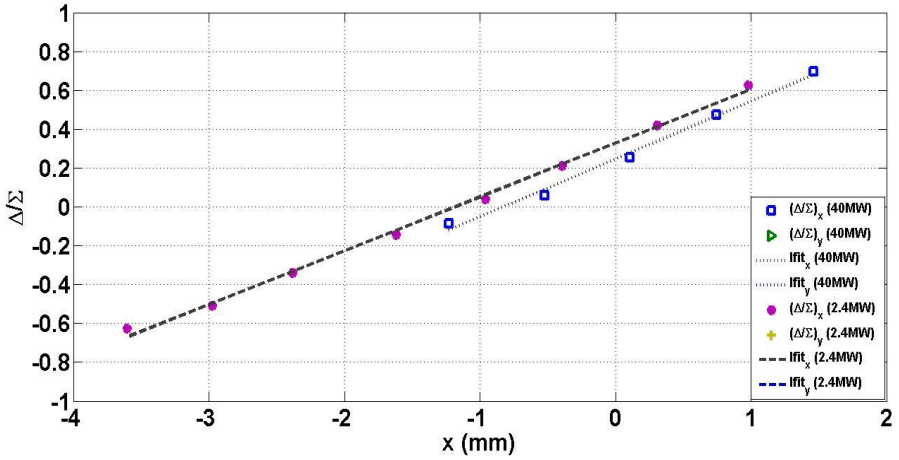

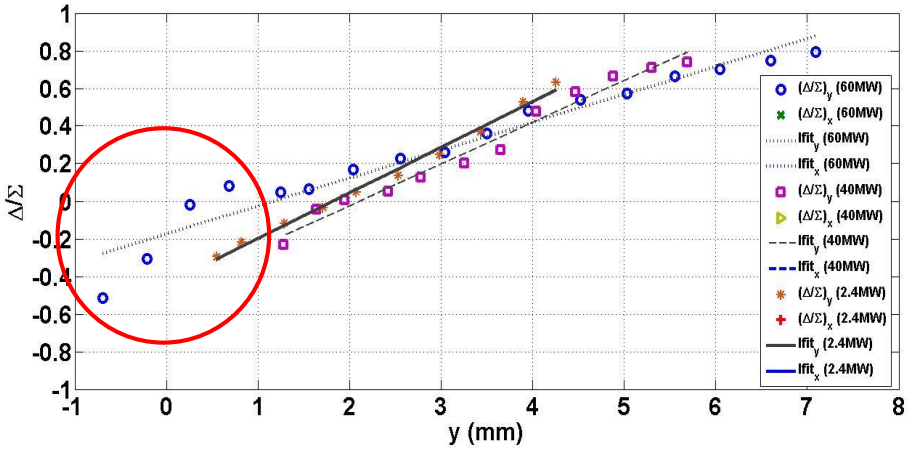

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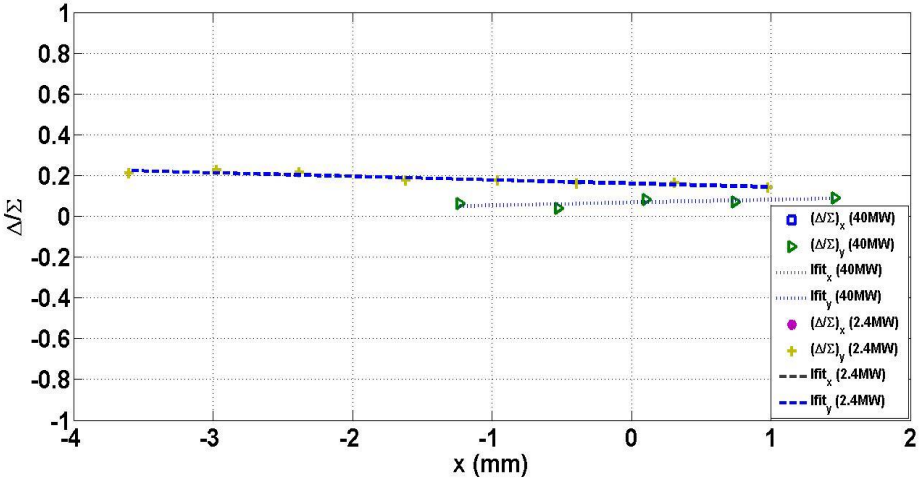
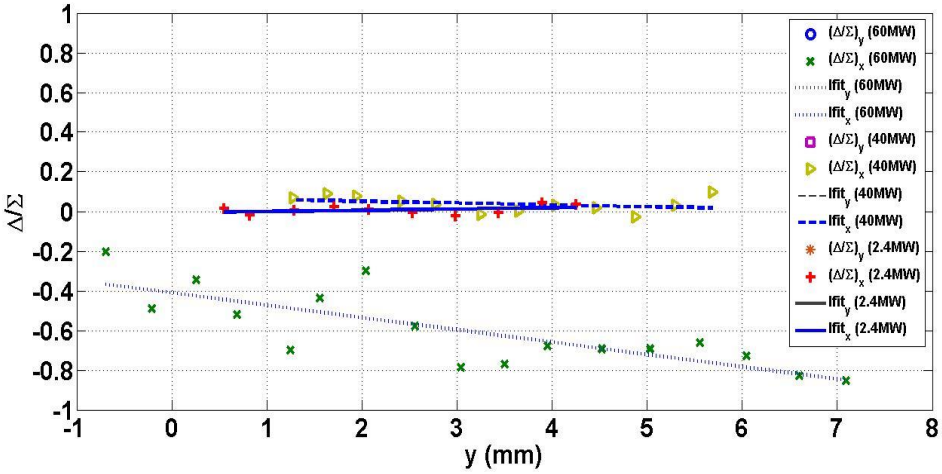
5 –Beam Tests at CTF3

- Stripline BPM unit CM.BPL0685
- Y during H-scan:



Parameter	2.4 MW PETS RF power (Beam current: 3.5 A)	40 MW PETS RF power (Beam current: 15 A)	60 MW PETS RF power (Beam current: 22 A)
std $(\Delta/\Sigma)_V$	0.03	0.02	N/A
Tilt (mrad)	-17.4	13.5	N/A

- X during V-scan:



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std $(\Delta/\Sigma)_H$	0.02	0.04	0.19
Tilt (mrad)	6.2	-9.2	-62.0

5 –Beam Tests at CTF3

- Stripline BPM unit CM.BPL0685
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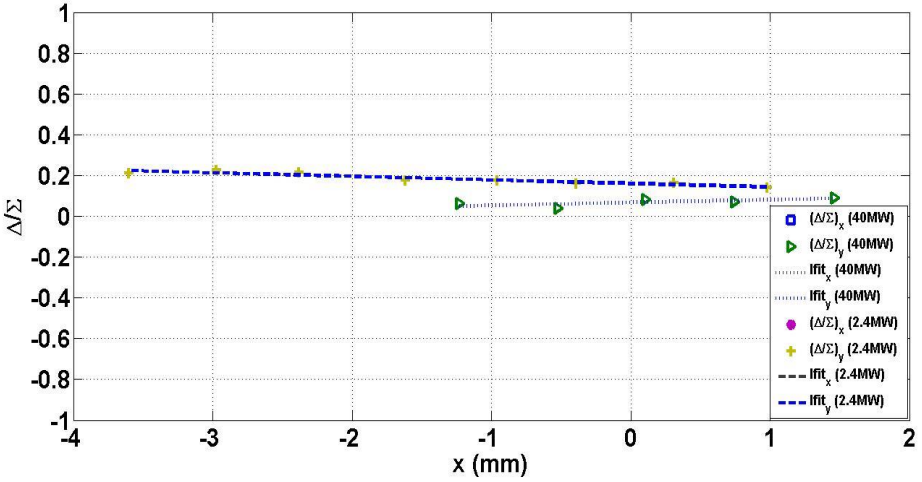

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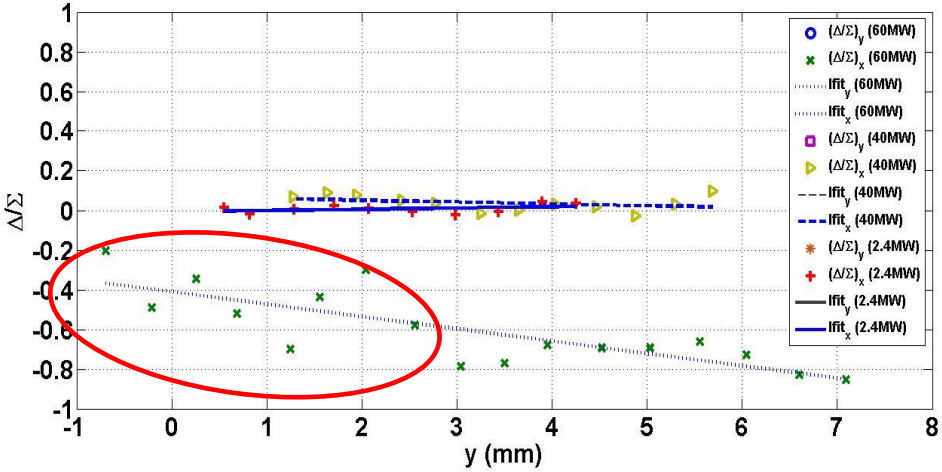

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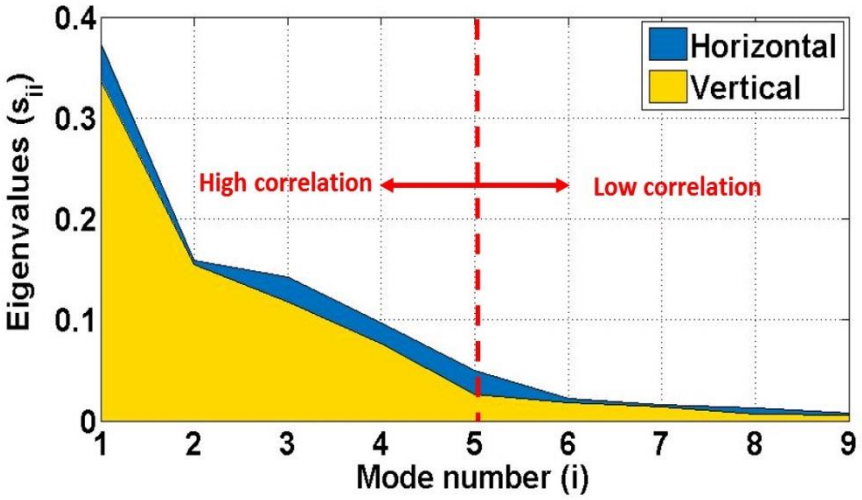
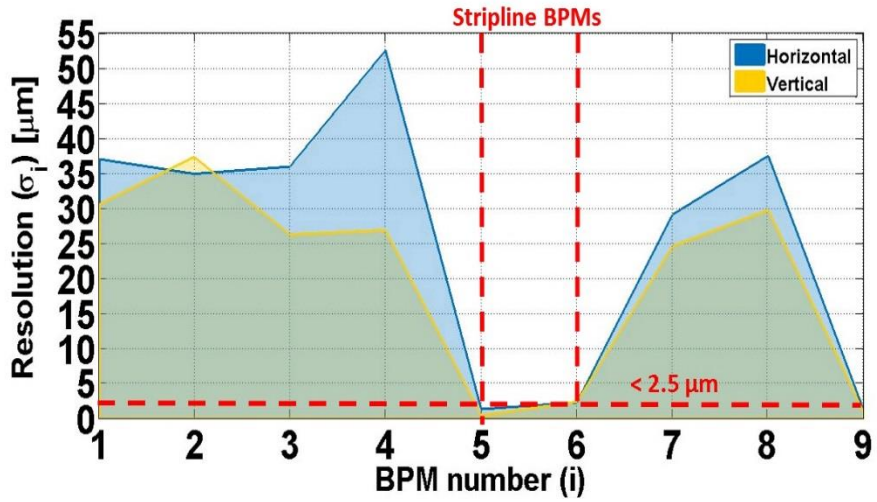
5- Beam Tests at CTF3





- Resolution test using Singular Value Decomposition (SVD):
  - Separate systematic beam effects (i.e. betatron motion, cavity phase/energy errors, RF jitter…) from uncorrelated BPM noise floor
- P=999 consecutive, synchronous shots (22 A beam) analysed for all M=9 BPMs in the Drive Beam of the Two-Beam Module
- $B = U \cdot S \cdot V^T$, where:
  - B_{PxM} → Position data for all BPMs
  - U_{PxP} → Temporal eigenvectors
  - S_{PxM} → Diagonal matrix (eigenvalues s_{ii})
  - V_{MxM} → Spatial eigenvectors
- s_{ii} give correlation level between U and V
- Set $s_{ii} = 0$ in the high correlation region and recompute B →B'
- σ (stdev) of columns of B' : resolution for each BPM. For our prototypes:
  - BPM0645 (#5): **1.4 µm (H) , 0.5 µm (V)**
  - BPM0685 (#6): **2.4 µm (H) , 2.5 µm (V)**

Contents

1. The CLIC Drive Beam
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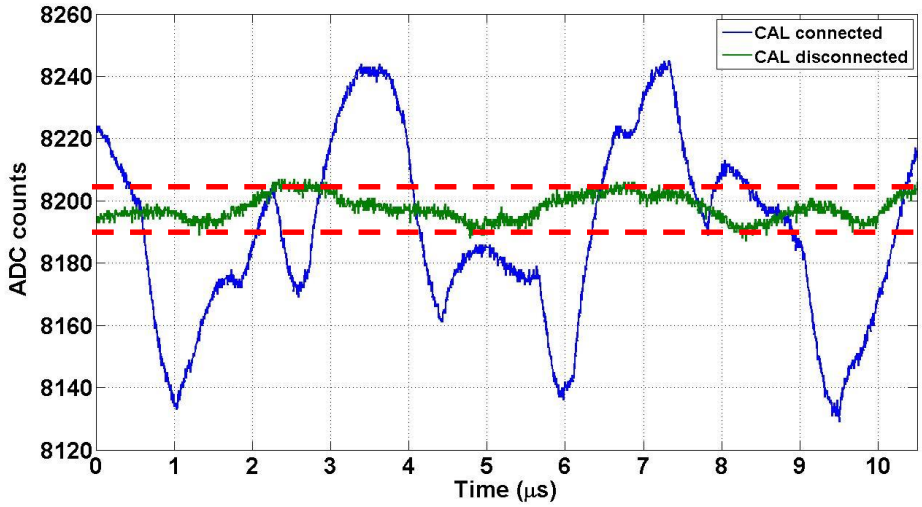
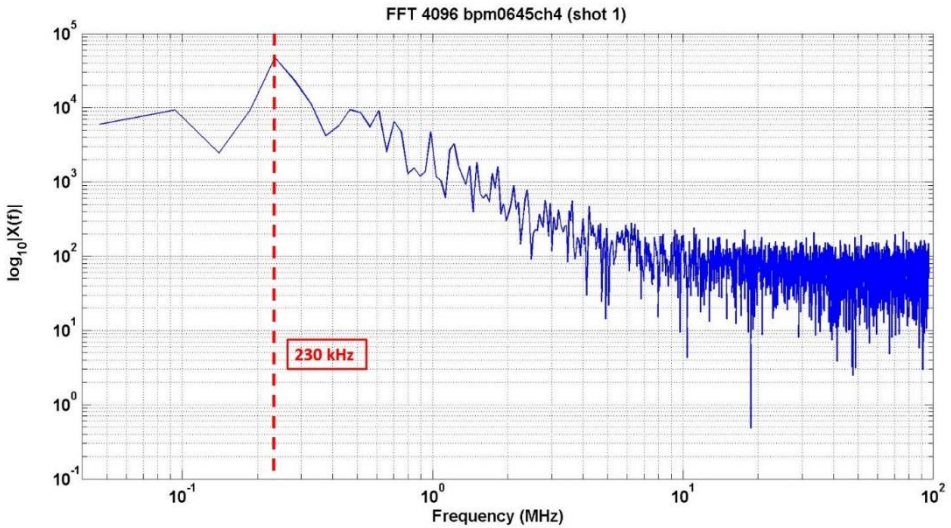
6 – Noise issues

- Unwanted noise observed in the absence of beam / CAL inputs → up to ~100 ADC counts <-> ~25mV → Unacceptable
- Not present when cabling is removed
- Uncorrelated component → Ground loop
- Correlated component → ~230 kHz interference (switched power supply?)
- Mitigation strategies tested:
  - Transformers
  - Inductive common mode chokes
  - Capacitive DC blocks
- Reduced to ~15 ADC counts ←→ ~3.75mV (Acceptable) by disconnecting calibrator during beam operation.





Contents

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6- Conclusions and future work

- Stripline BPM with terminated electrodes
  - Improved suppression of 12 GHz PETS interference
  - Acquisition electronics for improved time resolution and calibration functionality
  - Resolution results close to specified values

- Plans for 2016
  - Linearity/Sensitivity tests:
    - Separate beam scans for units 0645 and 0685.
    - Test H-plane of unit 0685 with 60 MW PETS power.

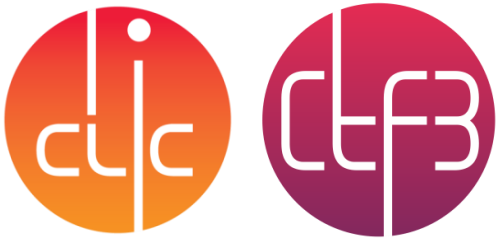
Acknowledgments

A. Faus-Golfe

B.P. Bielawski, D. Gudkov, T. Lefèvre, F. Locci, S. Magnoni, L. Søby, M. Wendt

J.M. Nappa, S. Vilalte

S. Smith



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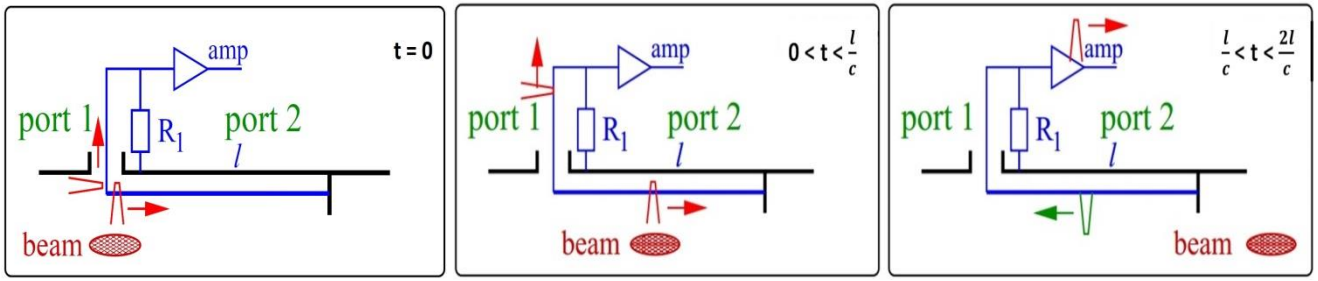
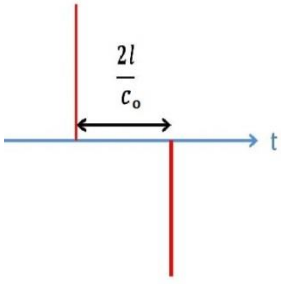
Thank you

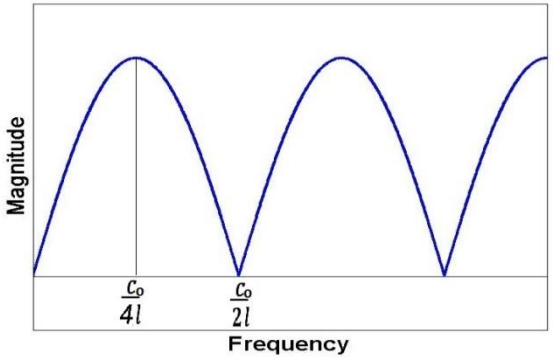
2 – Stripline BPM Basics

- Compact version (shorted electrodes)



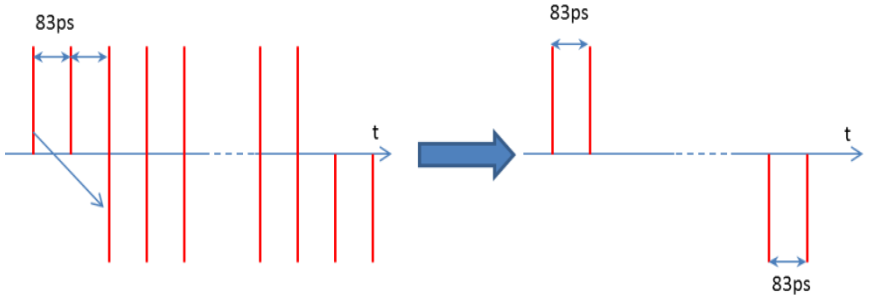


$$z(t) = \frac{Z_c}{2}\left[\delta(t) - \delta\left(t - \frac{2\ell_{strip}}{c_0}\right)\right]$$



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

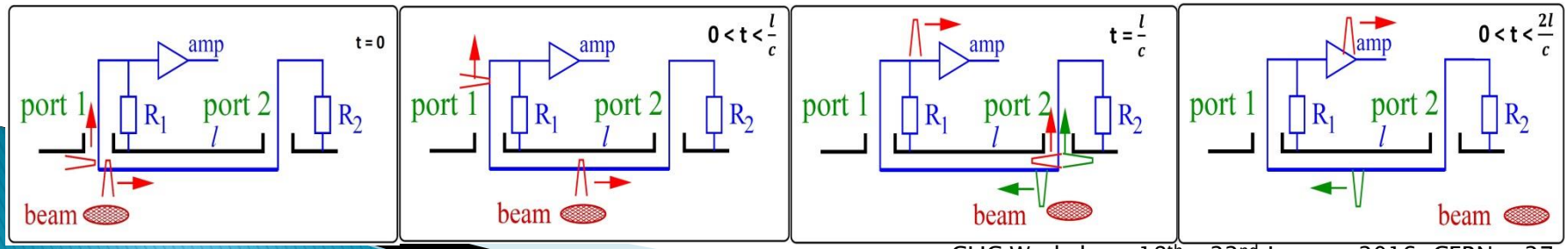
Z_c : beam to stripline coupling impedance



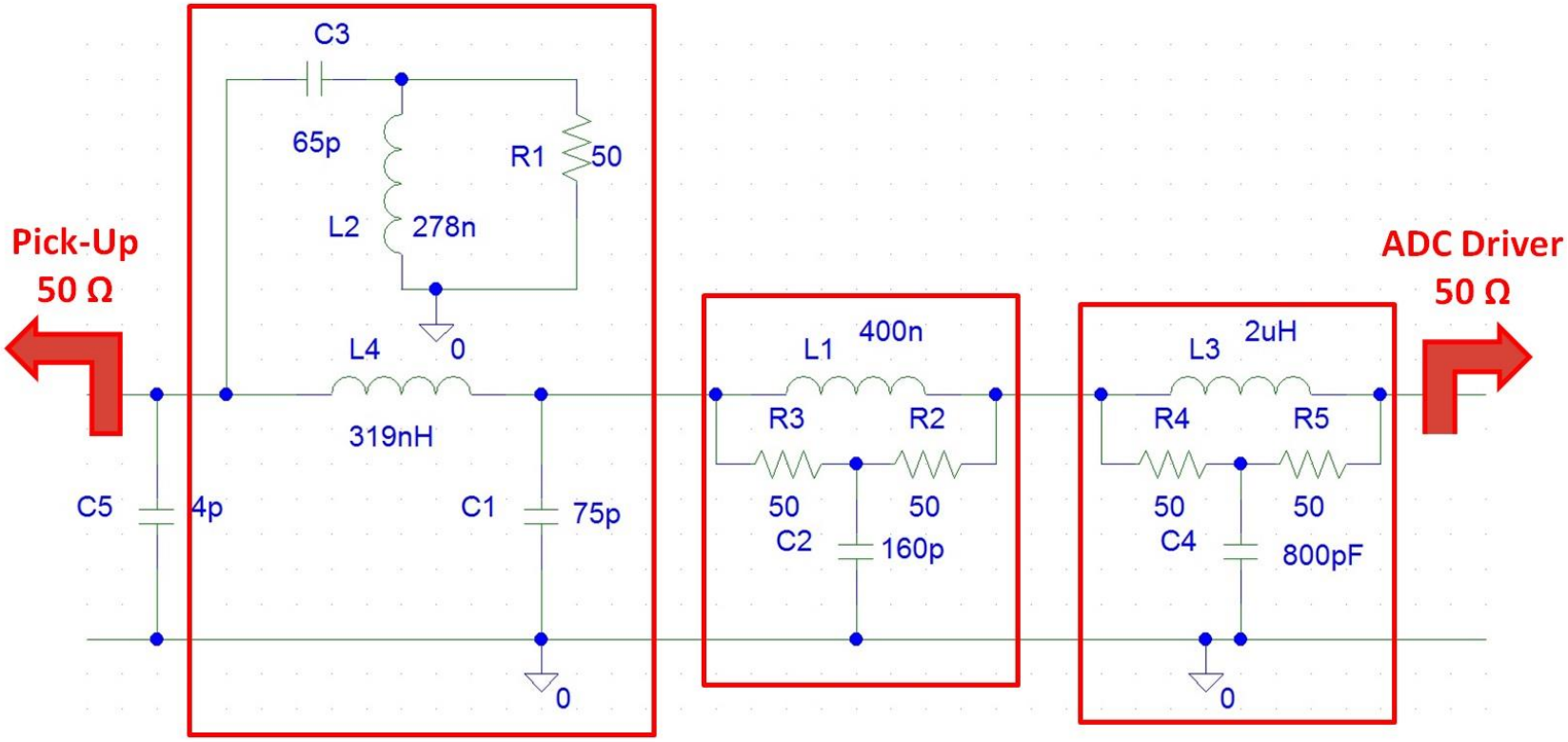
- If $\frac{2l}{c_0} = NT_{bunch}$ → Bunch cancellation

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

- Terminated version (8 ports)



Passive filters for DB Stripline BPM



INPUT DIPLEXER 70 MHz
2nd order filter

BRIDGE-T 40 MHz
1st order filter

BRIDGE-T 8 MHz
1st order filter