Beam Commissioning and Characterization of the CLIC Stripline Kicker at ALBA

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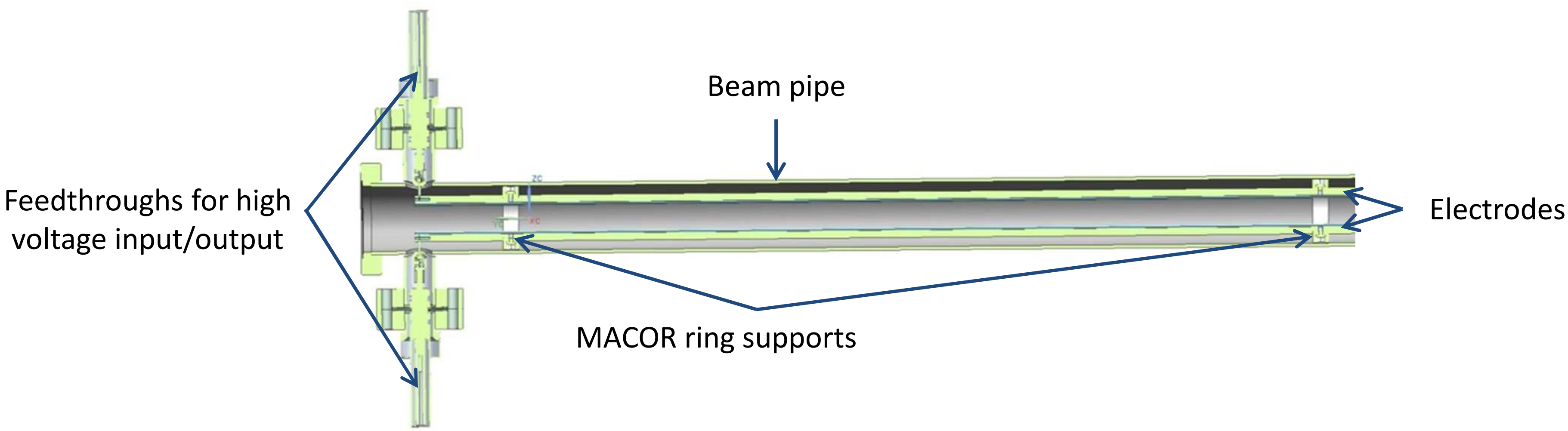
Workshop on "Beam Tests and Commissioning of Low Emittance Rings"
2019/02/19 – Karlsruhe (Germany)

- Introduction
- Installation
- Stripline Characterization with Beam:
    - DC Kick using HV PS
    - AC Kick Inductive Adders
- Transverse Impedance Measurements
- Conclusions

Introduction

- The Extraction Kicker at CLIC Damping Rings needs to provide very stable kicks to guarantee Luminosity in a Bunch-by-Bunch collision rate
- For this purpose, a special Stripline Kicker was designed[*] and manufactured [**] with very stringent requirements
- ALBA signed an agreement signed with CERN to characterize the stripline with beam at ALBA Storage Ring



[*] C. Belver-Aguilar et al, Beam impedance study of the stripline kicker for the CLIC damping ring, Proc. IPAC 2012

[**] Vacuum Trinos S.L. , Valencia (Spain)

Introduction

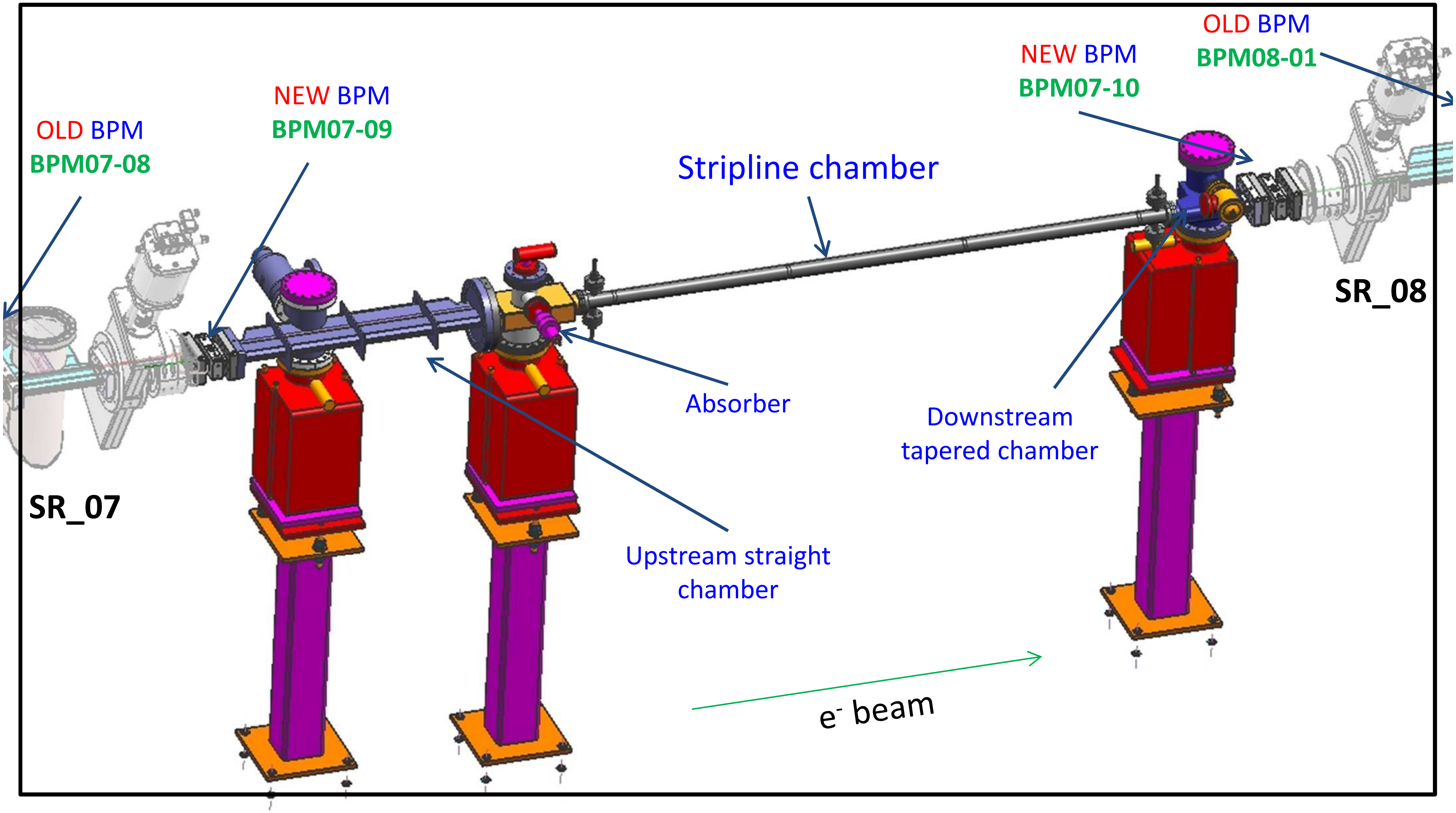
Requirements for the Extraction Kicker at CLIC

CLIC Stripline parameters	
Kick angle, mrad	1.5
Effective length, m	1.7
Good Field Region, mm	±1
Field homogeneity	$\pm 2\cdot10^{-4}$
Flat top reproducibility	$\pm 1\cdot10^{-4}$
Pulse rise & fall time, ns	100
Pulse flat top, ns	160 - 900

How this precision can be achieved and measured within this region??

Installation

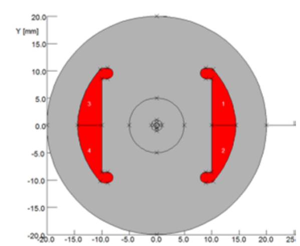
Besides the stripline, the beam characterization required also to design & install **2 additional BPMs**, absorbers and transition chambers , vacuum pumps…



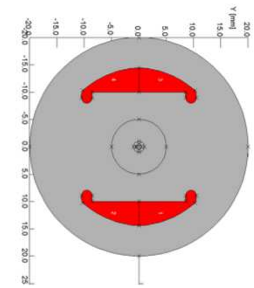
Installation: some issues...

Stripline kicker designed to extract beams in the hor plane

Rotate the stripline by 90º to avoid limit horizontal aperture

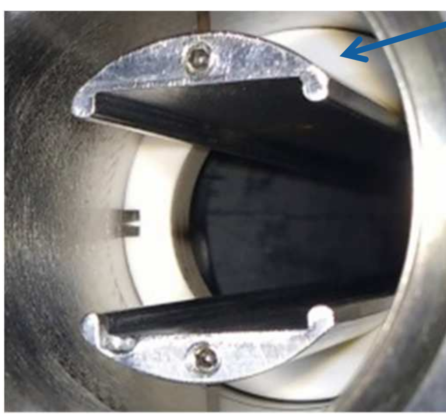


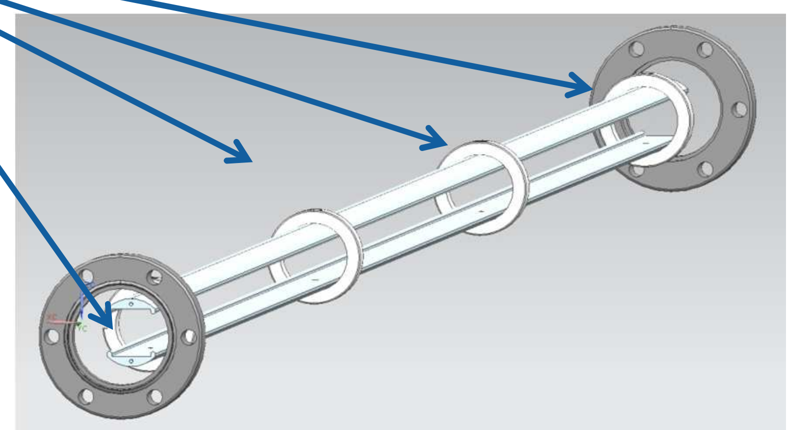
CLIC Configuration



ALBA Operation

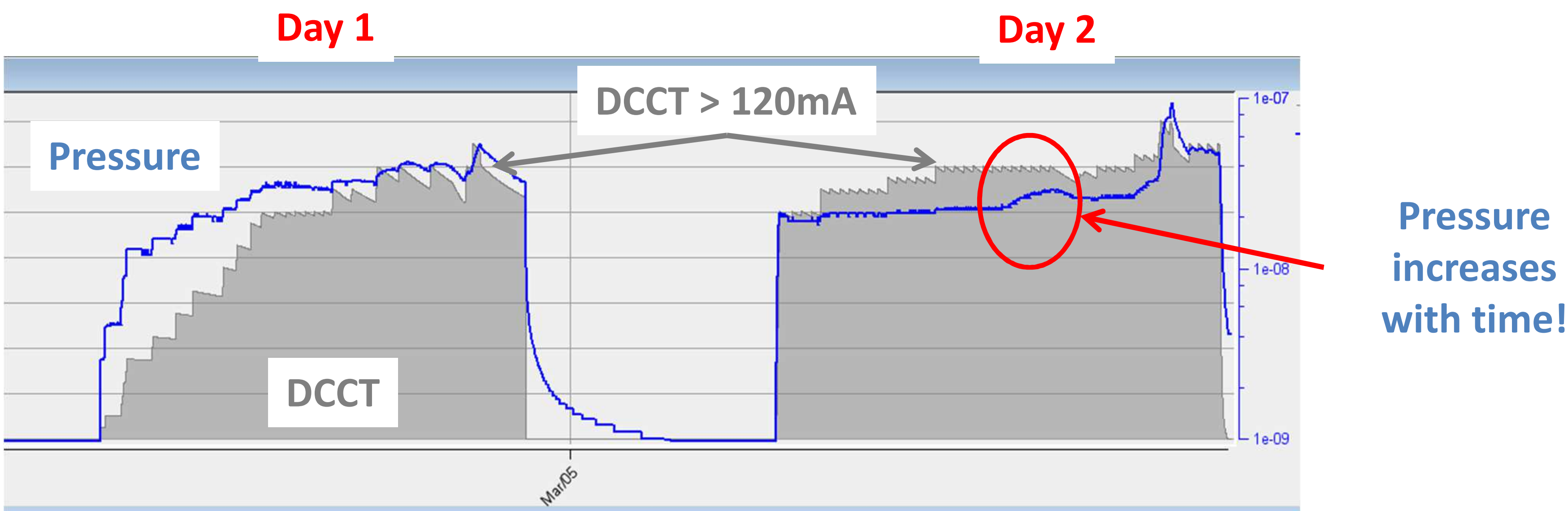
Al Electrodes Length=1.7m, holded by MACOR rings for mechanical stability





Installation – Try 1

The stripline (outgassing) behaviour for large currents limited machine operation
We had to install & uninstall everytime for the measurements!



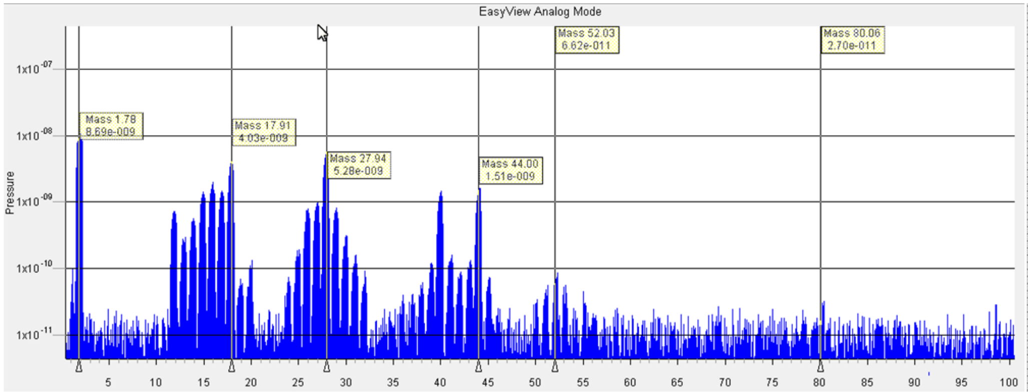
- For DCCT < 120mA, pressure is slowly decreasing, **OK**
- For DCCT > 120mA, pressure run away, **NOK**

Stripline removed to guarantee machine operation for users at 180mA

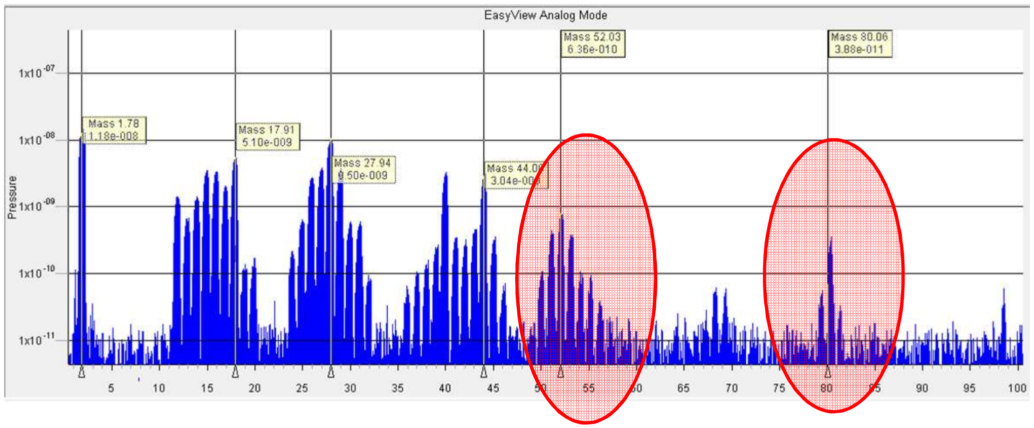
Installation – Try 1

RGA data to analyse pressure increase

115 mA



135 mA



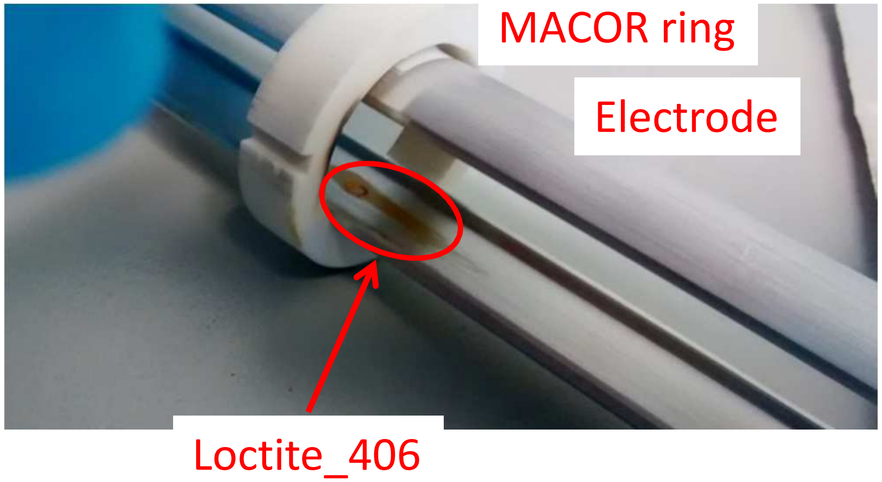
Strange peaks appear: 52 (Cr) and 80 (Br)

ion trapping? SR hitting MACOR rings? desorption due to image currents at electrodes?

Installation – Try 1 Conclusions

When removing and opening the stripline, realized two dangerous things:

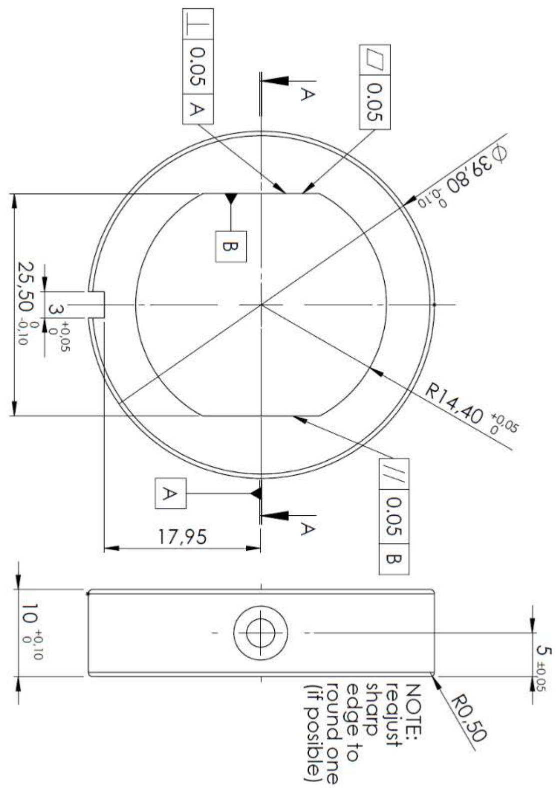
- Synchrotron Radiation might be hitting the MACOR rings
- Manufacturer used Loctite_406 to fix the screws at the electrodes



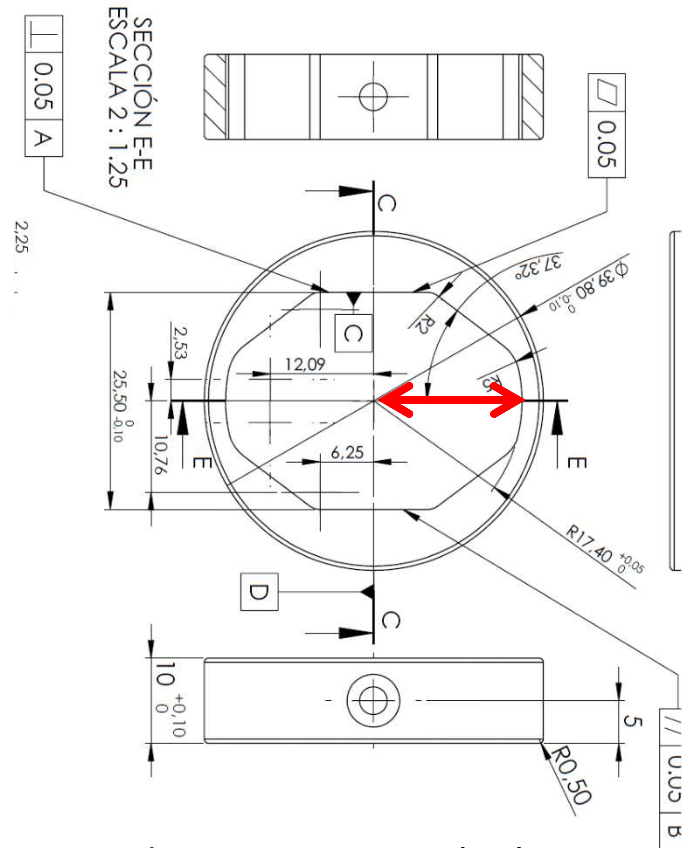
Installation – Try 1 Conclusions

New Installation:

- remove Loctite_406 from electrodes
- trim MACOR rings to enlarge horizontal clearance



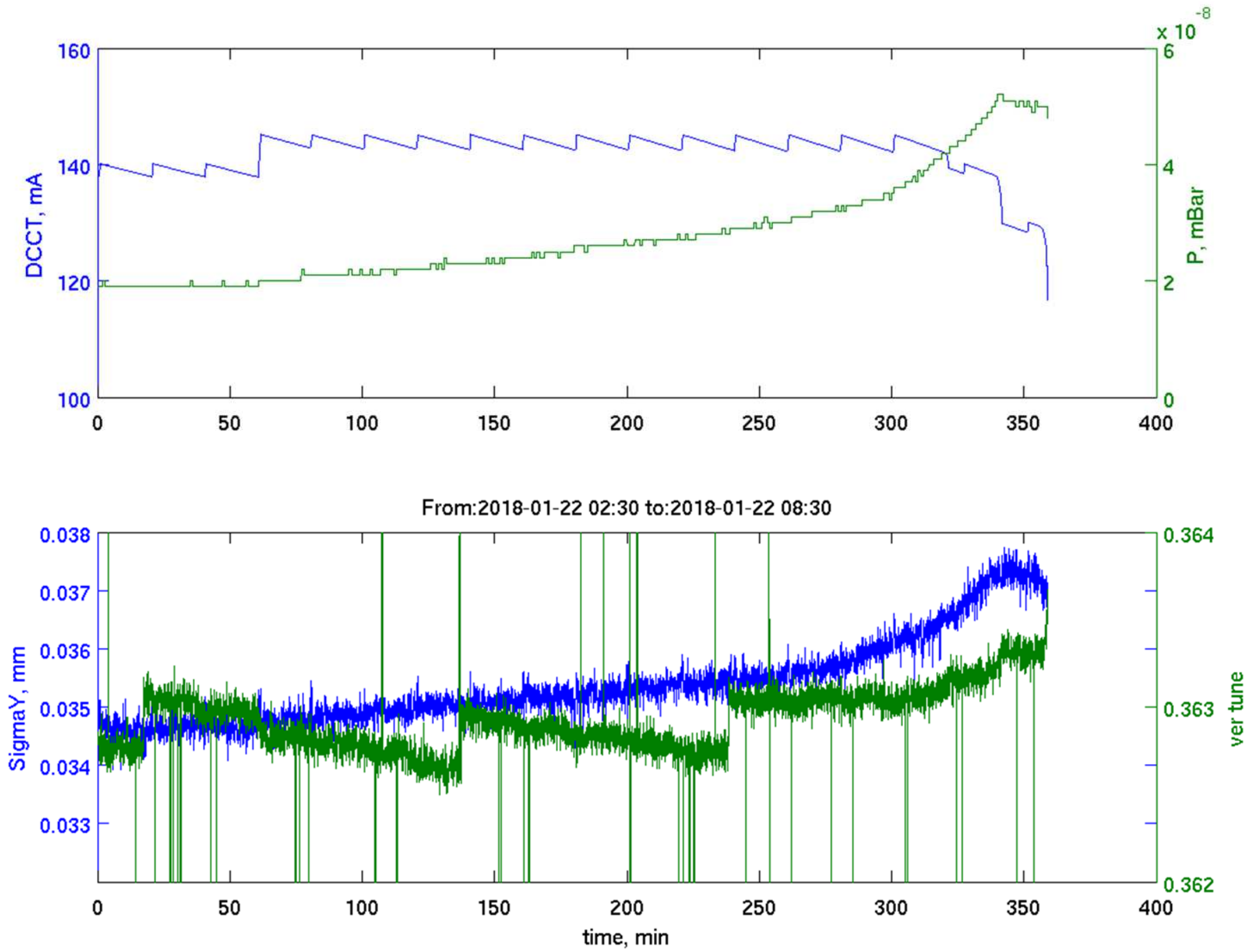
Original design, 5.5 mm thick all around



New design, 2.5 mm thick at synchrotron radiation plane

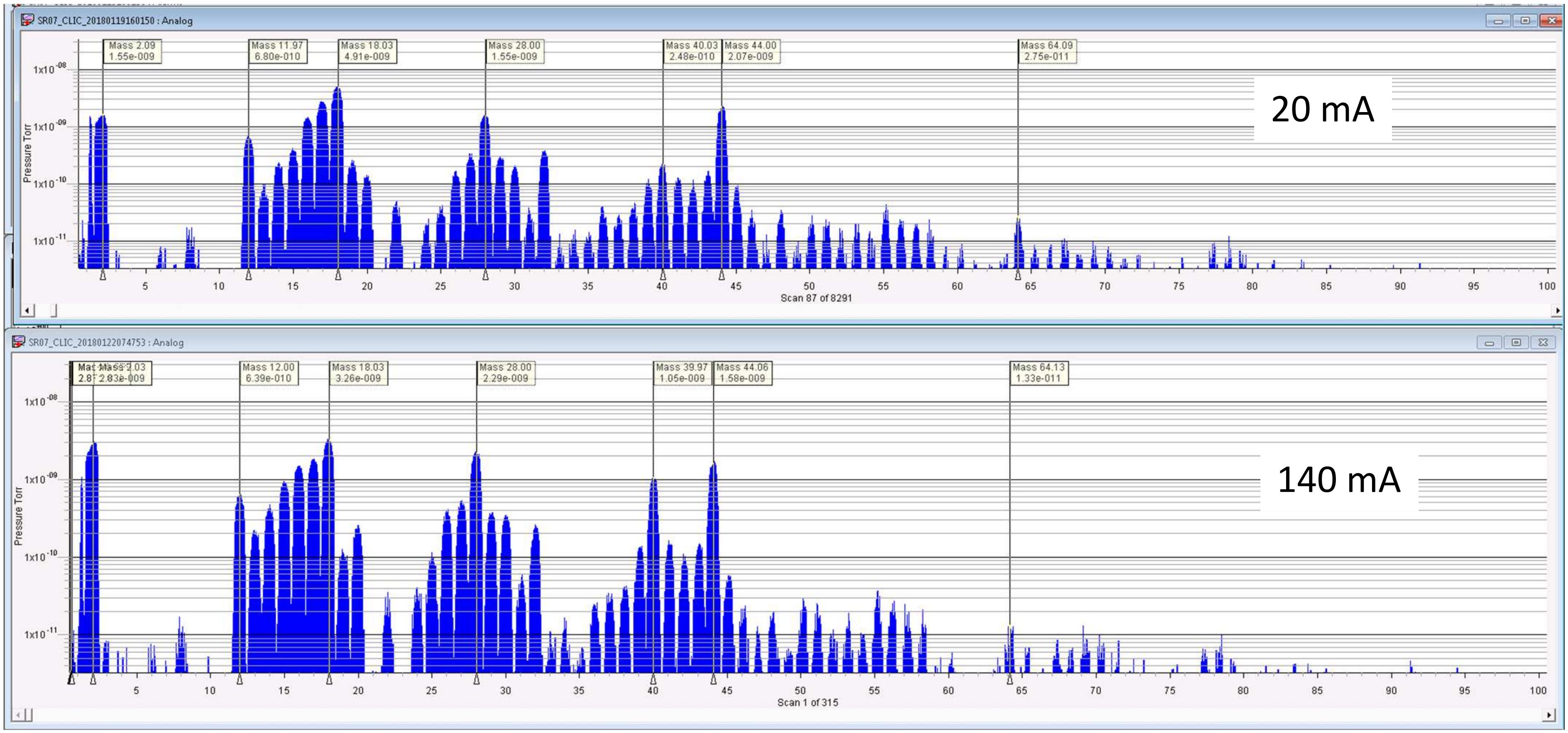
Installation_2.0

Nevertheles… similar behaviour, but this time at 140mA
We also look at tunes and beam size, which pointed out towards ion trapping effects



Installation_2.0

However, this time RGA analysis did not show any weird peaks



CONCLUSIONS

To guarantee machine operation at 180mA, remove stripline

Decided to install & uninstall every time to test the stripline with (low current) beams

Stripline Characterization with Beam

Sep. 2018 (installed during 4 days)

- Transverse Field Homogenety – DC HVPS
- Transverse Beam Coupling Impedance

Jan. 2019 (installed during 5 days)

- Longitudinal Pulse Homogeneity (Inductive Adder)
- Longitudinal Beam Coupling Impedance (incomplete)

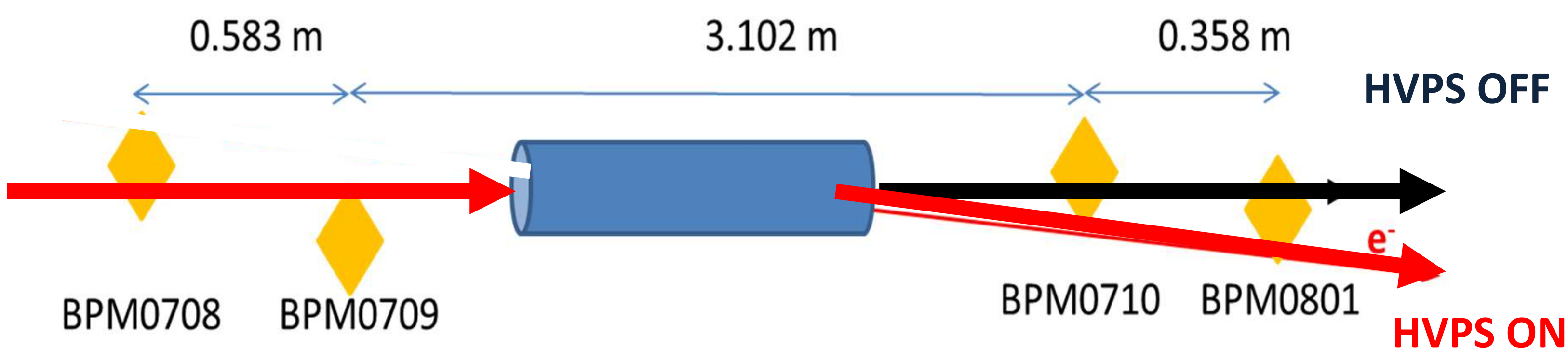
Stripline Transverse Field Homogeinety – DC HVPS

Measurements with the HV DC power supplies:

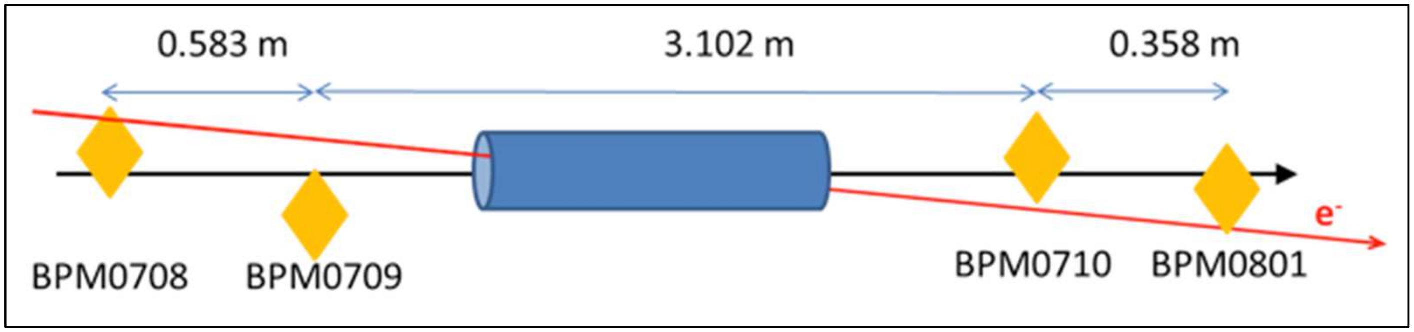
- Commissioning: stripline sparked a lot with beam, and it took ~**2days** to reach +/-10kV and 13mA beam!

- Local Angle Measurement using 4 BPMs

$$\alpha = \frac{y_4 - y_3}{d_{4-3}} - \frac{y_2 - y_1}{d_{2-1}}$$



Stripline Transverse Field Homogeinety – DC PS

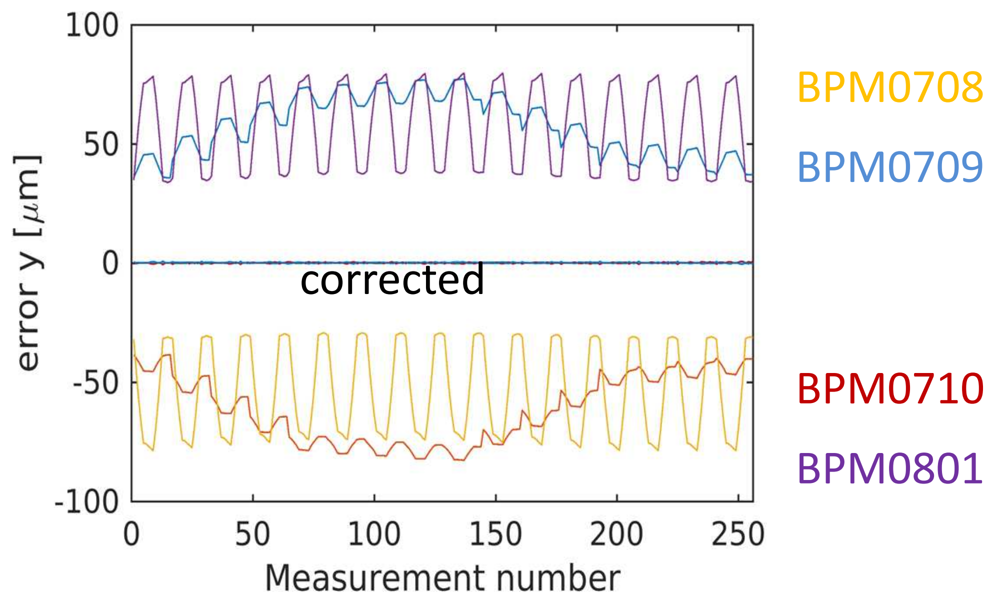


BPM Calibration (Stripline off)

Measurement precision improved if BPM precision improves

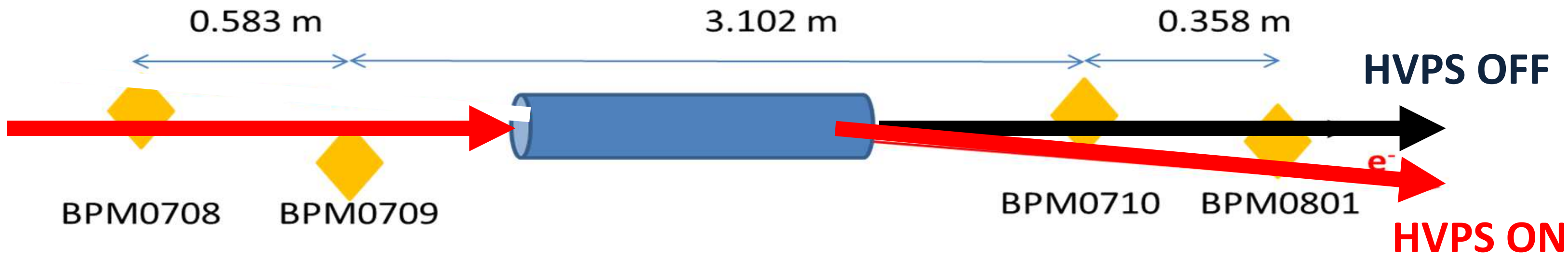
With the stripline off, the position along 4 consecutive BPMs should follow a straight line.

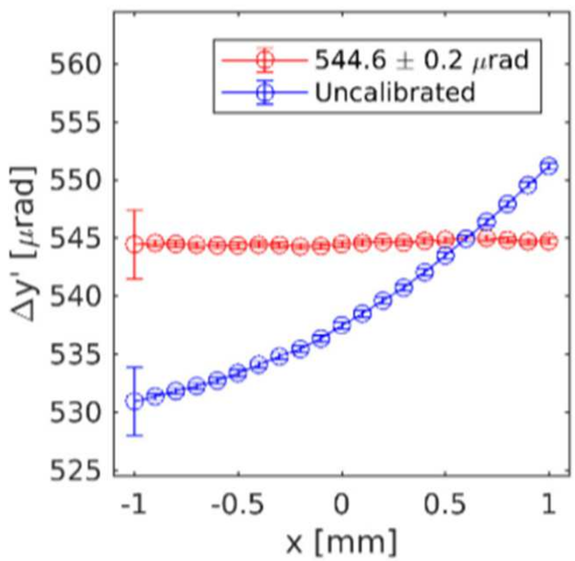
We did bumps along +/1mm, and used the data to fit the BPMs **offsets, gains, & rolls** that minimize the discrepancies

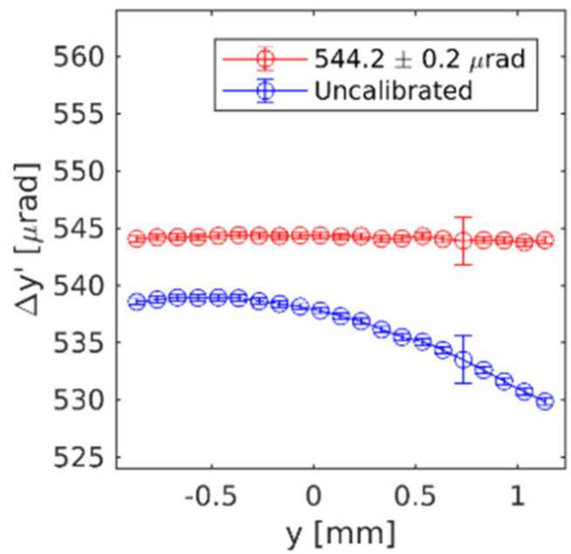


Stripline Transverse Field Homogeinety – DC PS

Measurements (Stripline on @10kV) around ±(1,1)mm







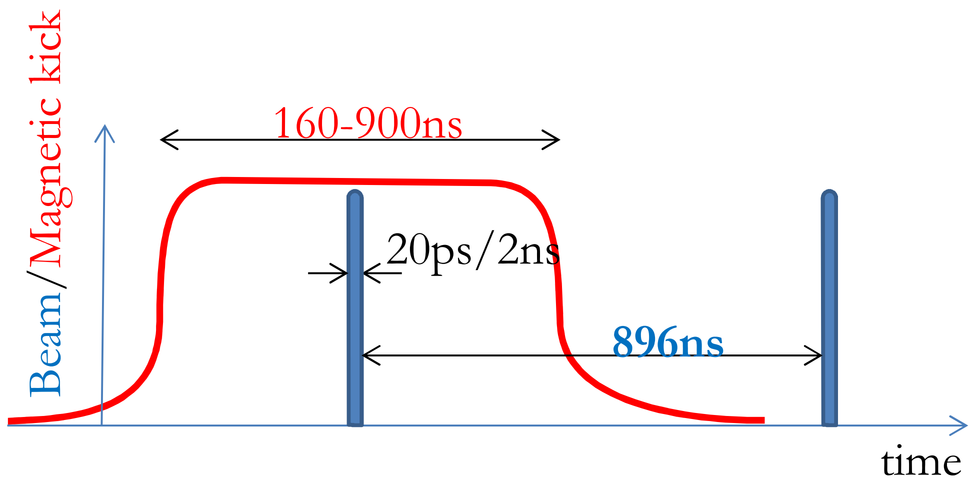
Z. Martí

Effective kick at ±10kV: 544.4±0.2 μrad (theoretically, 560 urad)

➔ Homogeneity of $3.7 \cdot 10^{-4} \pm 5.3 \cdot 10^{-4}$ (compatible with CLIC requirements $< 2 \cdot 10^{-4}$)

Longitudinal pulsed field homogeneity

Measurements: Field flat-top stability and pulse-pulse repeatability

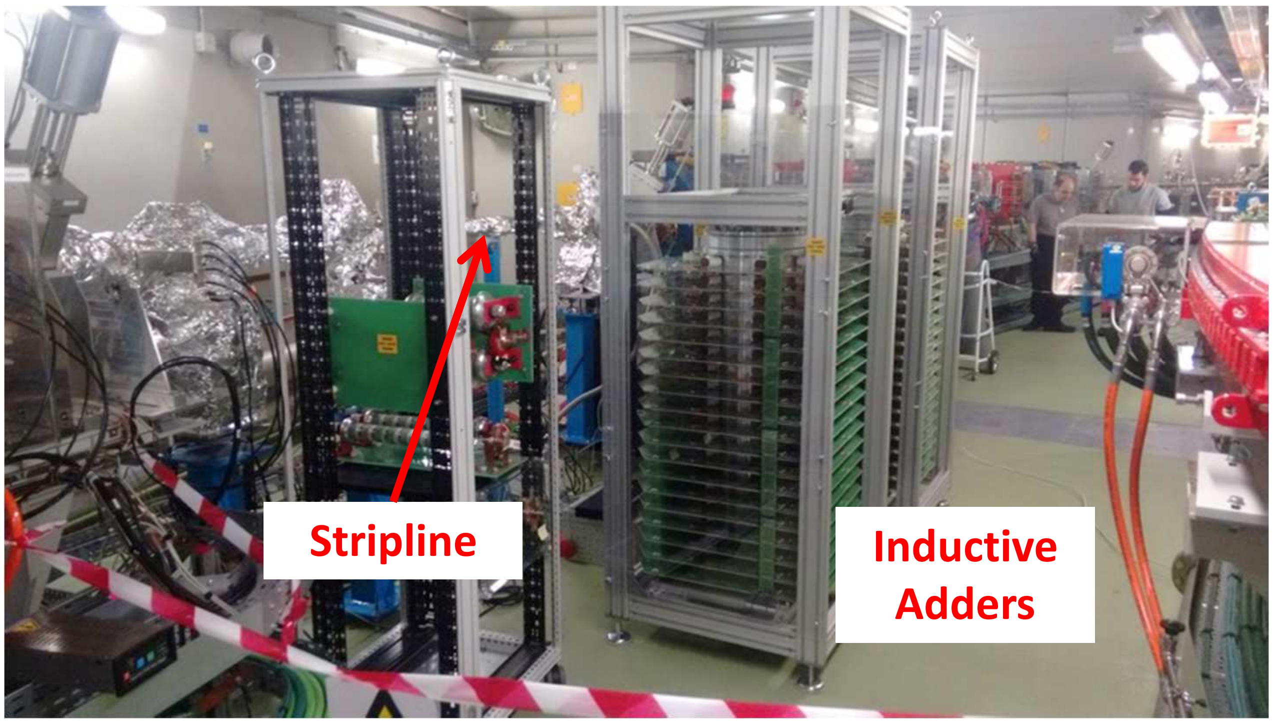


- Measurements in **single bunch:** scan the pulse-bunch delay along the pulse flat-top
- Vary pulse width (160 – 900)ns and delay
- Use global amplitude with all 120 BPMs, TBT data (500 turns), and with enough averaging (50 shots) to reach required precision (1e-4)

Longitudinal pulsed field homogeneity

Lab Tests and Installation @ALBA

- HV (10kV) pulse of length [160 – 900]ns performed with **Inductive Adders**
- Long cables might distort the pulse. To avoid it, the inductive adders were installed inside the ALBA tunnel
- Both the stripline and Inductive Adders were removed after the tests



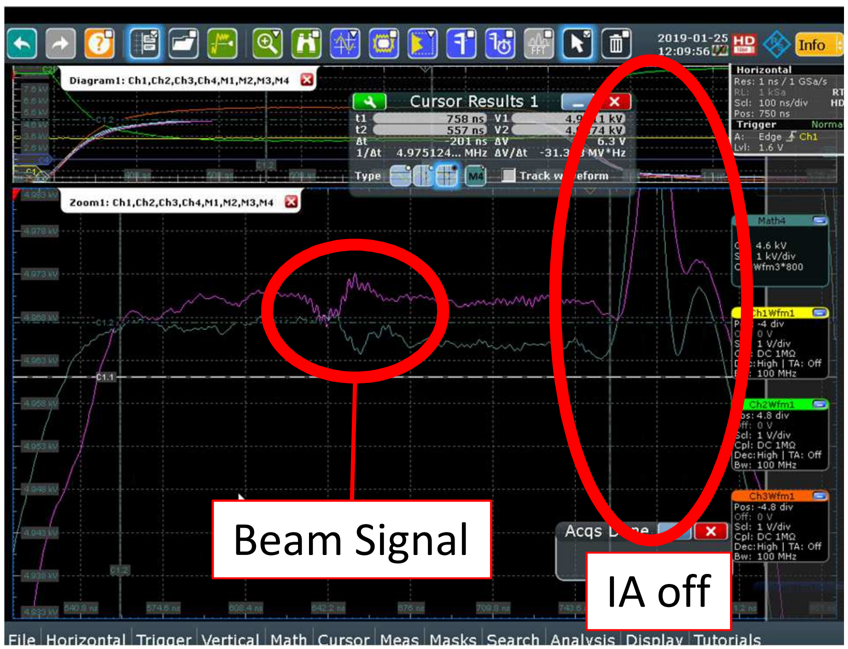
Longitudinal pulsed field homogeneity

Measurements with Beam

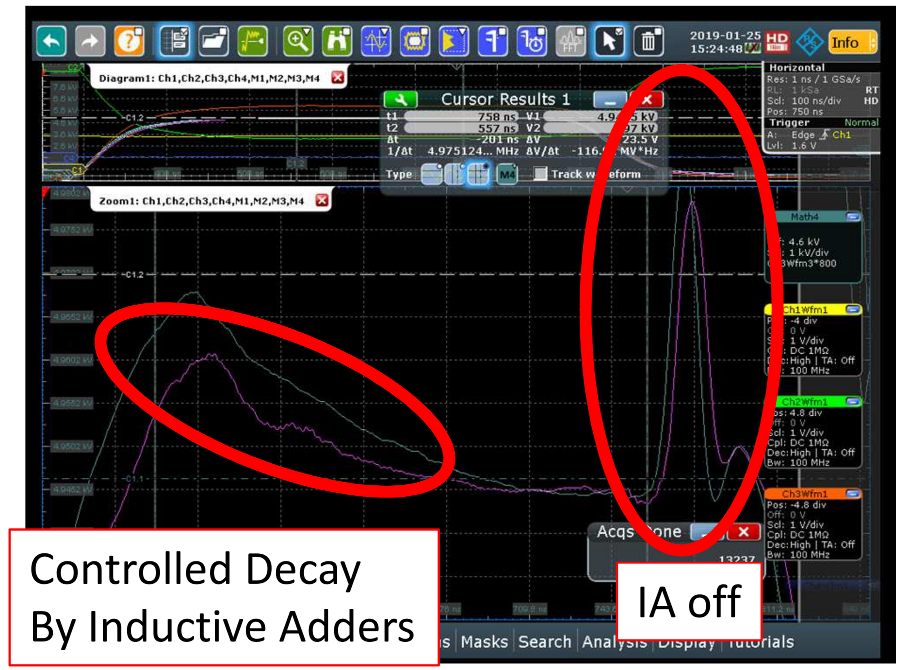
Inductive Adders able to produce an overpulse with slow decay[*], so that the beam can see a flat kick (flat total combination of electric and magnetic fields – see [**])

Reached homogeneity of **+/-0.02%**

Flat-top pulse



Decay Signal pulse



[*] J. Holma, The Prototype Inductive Adder With Droop Compensation for the CLIC Kicker Systems, IEEE Transaction of Plasma Science, Oct. 2014

[**] C. Belver-Aguilar, "Transient Studies of the Stripline Kicker for Beam Extraction from CLIC Damping Rings", in Proc. IBIC'16, Barcelona, Spain (2016)

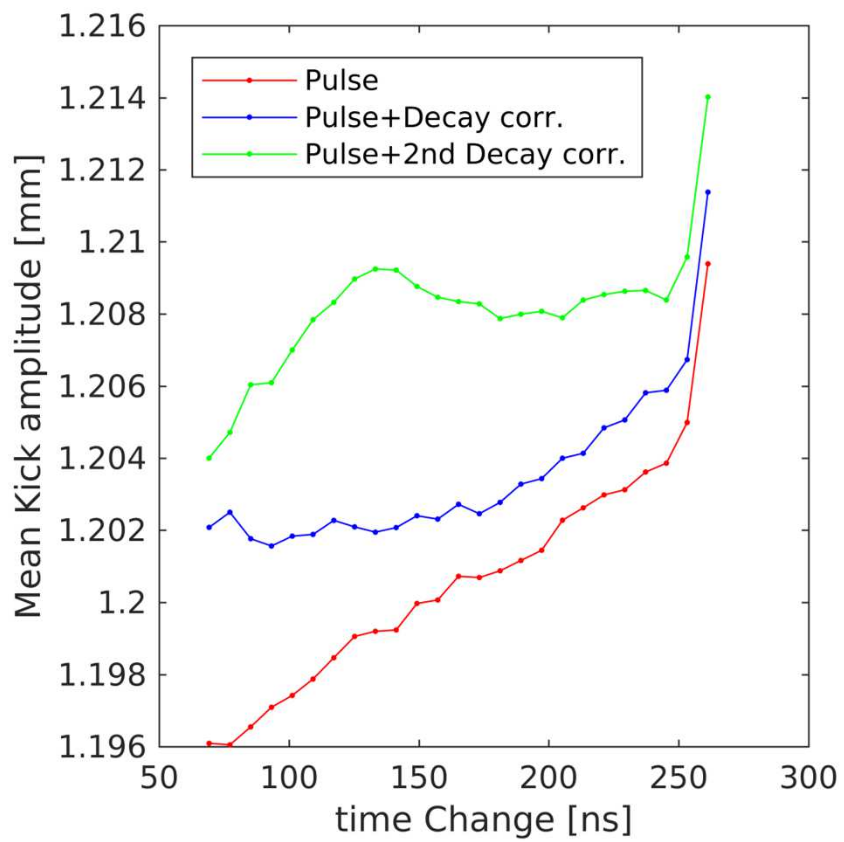
Longitudinal pulsed field homogeneity

Measurements with Beam

Z. Martí and J. Holma

The strip-line kick at **2x5kV** with a 160ns flat-top is measured with different timing delays.

The pulser unit compensation works as expected and pulse correction droop was successfully tested



Longitudinal field homogeneity – Inductive Adders

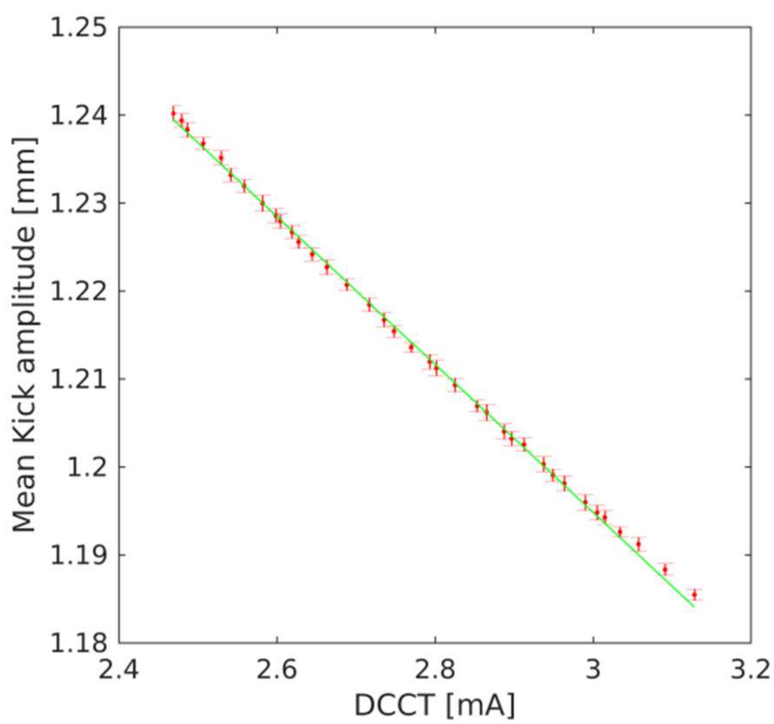
Measurements with Beam

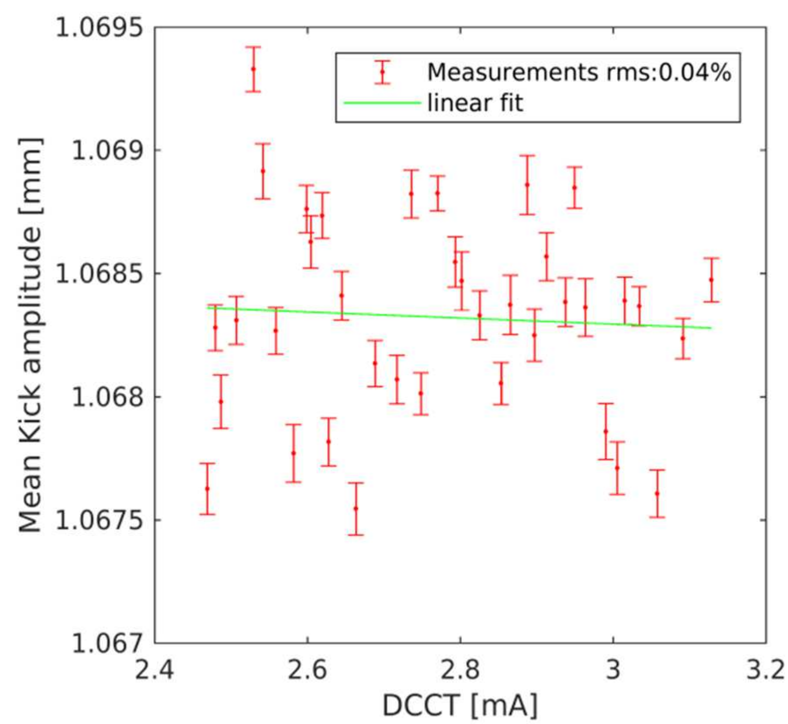
If we only take the TbT data RMS of (or amplitude at the tune line), the kick seems to vary with time following the beam current decay.

If the decoherence effect is compensated, we can see how the current dependence disappears.

Single Meas: **0.01%**

Average Variation: 0.04%

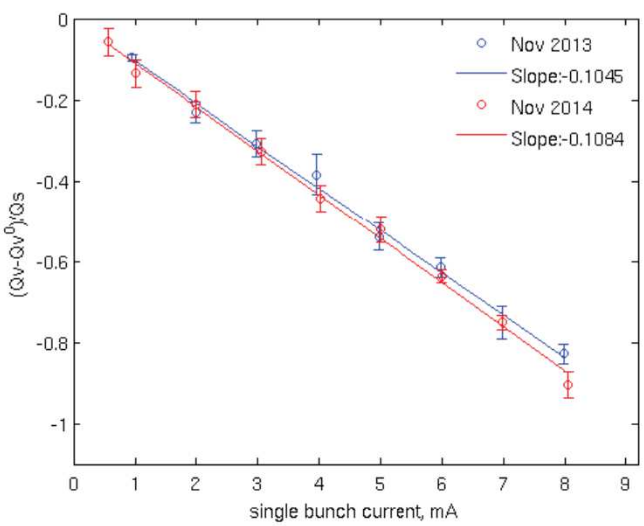




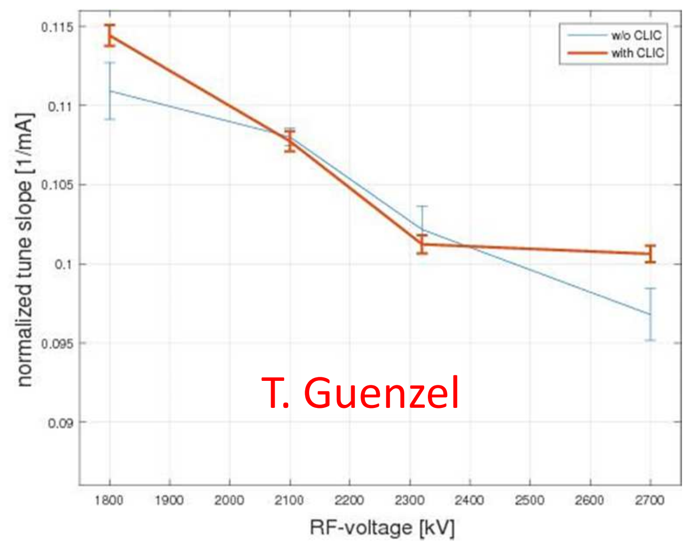
Transverse Impedance Measurement

Strategy 1: Measuring the transverse impedance of the total ring before and after the installation of the striplines.
Single bunch measurements to determine TMCI threshold and detuning slope. (Data taken at ξV=0 and different Vrf).

Example of TMCI measurement



Summary with vs w.o. CLIC SL



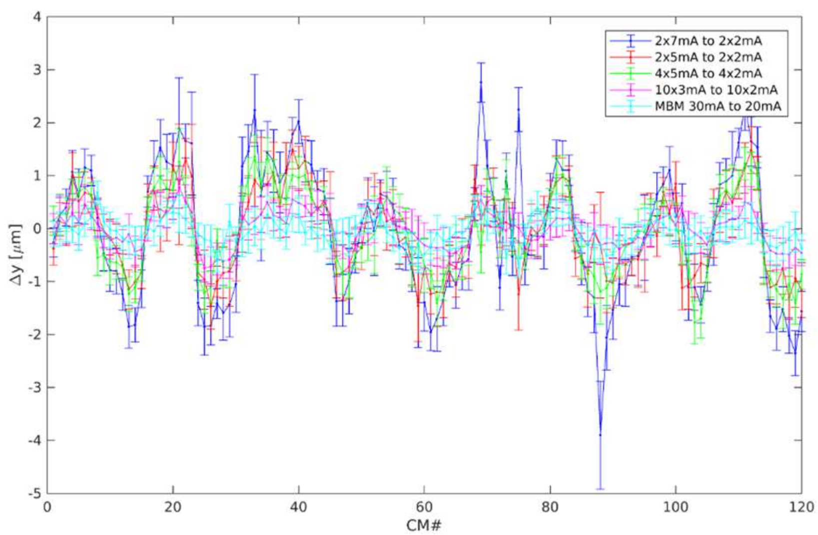
Very noisy, probably due to machine repeatibility. But consistent with expectations:

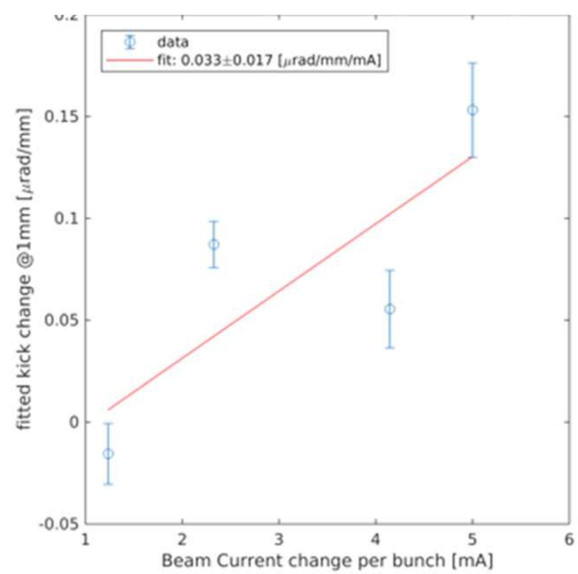
Measured Impedance: $(\beta Z)_{eff}$ = **11.6 kΩ**
From Gdfidl simulations: $(\beta Z)_{eff}$ = **11 +/- 12 kΩ**

Transverse Impedance Measurement

Strategy 2: Local Bump

1. Produce a vertical bump of y_0 at the SL location (+/-1mm)
2. Get orbit at high beam current, I_H (8 mA/bunch, limited by beam instabilities)
3. Scrape down the beam until a "low" beam current is reached I_L (min of 1mA/bunch)
4. Get orbit at low beam current
5. The **difference between the orbits at 2) and 4) is due to the impedance of the SL**





Measured Impedance Kick: **0.033±0.017 μrad/mm/mA**

Kick from Gdfidl simulations: **0.0244 μrad/mm/mA**

SUMMARY & CONCLUSIONS

Beam characterization has been done by installing the Stripline several times Although his limited the time for experiments a lot, a full characterization has been carried out:

- ❖ Vacuum Conditioning: could not reach beam currrents >140mA w.o. compromising machine operation (within the scheduled time)
- ✓ Transverse Field Homogeneity – HV DC tests
- ❖ Longitudinal Field Homogeneity – Inductive Adder
- ✓ Transverse Beam Coupling Impedance

PLAN WELL YOUR MEASUREMENTS!

Example: transverse field homogeneity of 2e-4 was achieved thanks to the installation of 2 additional BPMs

Thanks!

EXTRA-SLIDES

Measurement set up

Possible Field homogeneity techniques:

Power supply	Technique	Measurement limit	Comments
DC	COM (closed orbit measurement)	Trv. Homogeneity 1%	No additional hardware
	LOM (local orbit measurement)	Trv. Homogeneity 0.01%	Additional standard hardware
Pulsed	SBTOM (single bunch TbT orbit measurement)	Trv. Homogeneity 1% Lg. Homogeneity 0.01%	No additional hardware. Systematic error around around 1%. Pulse Repeatability mixed with homogeneity.
	SPLOM (single pass local orbit measurement)	Trv. Homogeneity 0.01%? Lg. Homogeneity 0.01%?	Additional non standard hardware.

MACOR

MACOR®
Machinable Glass Ceramic

- is MACHINABLE with ordinary metal working tools
- allows FAST TURNAROUND, no post firing required
- holds TIGHT TOLERANCES, up to .0005"
- withstands HIGH TEMPERATURE, up to 1000°C (no load)
- is CLEAN, no outgasing and zero porosity

Composition

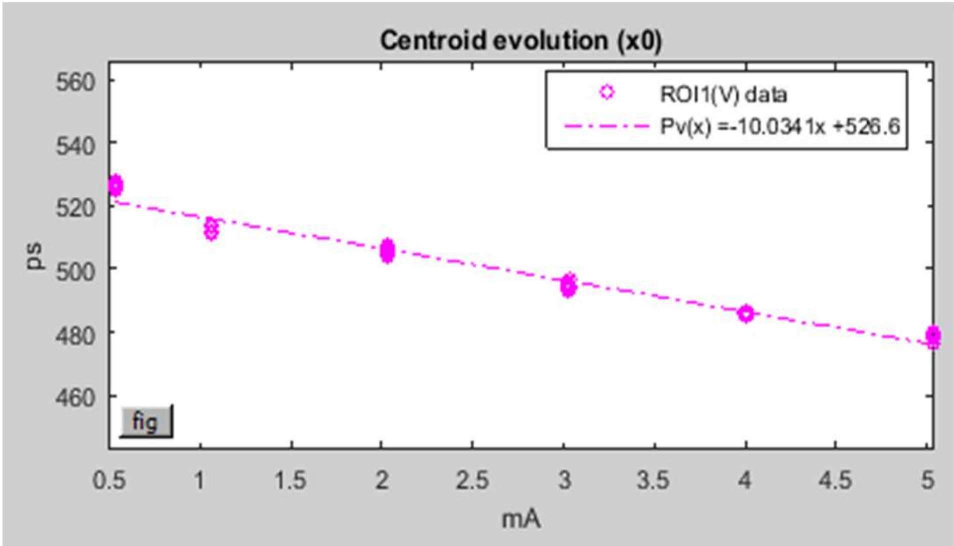
MACOR Machinable Glass Ceramic is a white, odorless, porcelain-like (in appearance) material composed of approximately 55% fluorophlogopite mica and 45% borosilicate glass. It has no known toxic effects; however, the dust created in machining can be an irritant. This irritation can be avoided by good housekeeping and appropriate machining techniques. The material contains the following compounds:

	Approximate Weight %
Silicon - SiO_2	46%
Magnesium - MgO	17%
Aluminum - Al_2O_3	16%
Potassium - K_2O	10%
Boron - B_2O_3	7%
Fluorine - F	4%

Longitudinal Impedance Measurement

- Measured from the **difference between the global longitudinal** machine measurements with the Stripline **IN and OUT** of the Storage Ring.

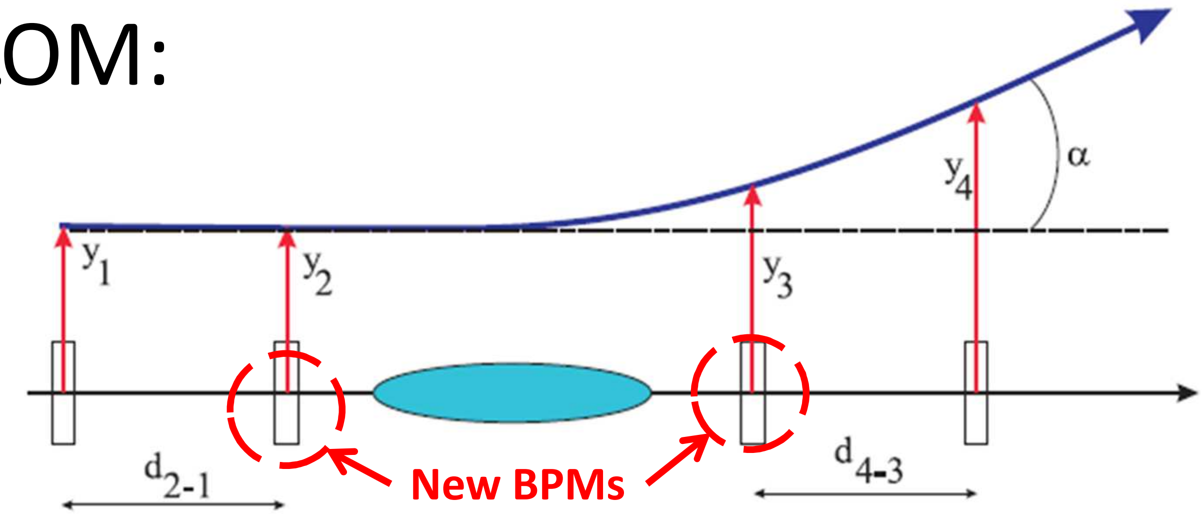
- Global longitudinal impedance measured from the phase variation in the streak camera



Limited by machine repeatability and jitters

Measurement set up

LOM:



$$\alpha = \frac{y_4 - y_3}{d_{4-3}} - \frac{y_2 - y_1}{d_{2-1}}$$

Relative Uncertainty:

$$RU_{MSS} = \frac{\Delta\alpha_{rand}}{\alpha} = 1.3 \times 10^{-3}$$

$$RU_{LSS} = \frac{\Delta\alpha_{rand}}{\alpha} = 0.4 \times 10^{-3},$$

A RU of 1e-4 is achieved:

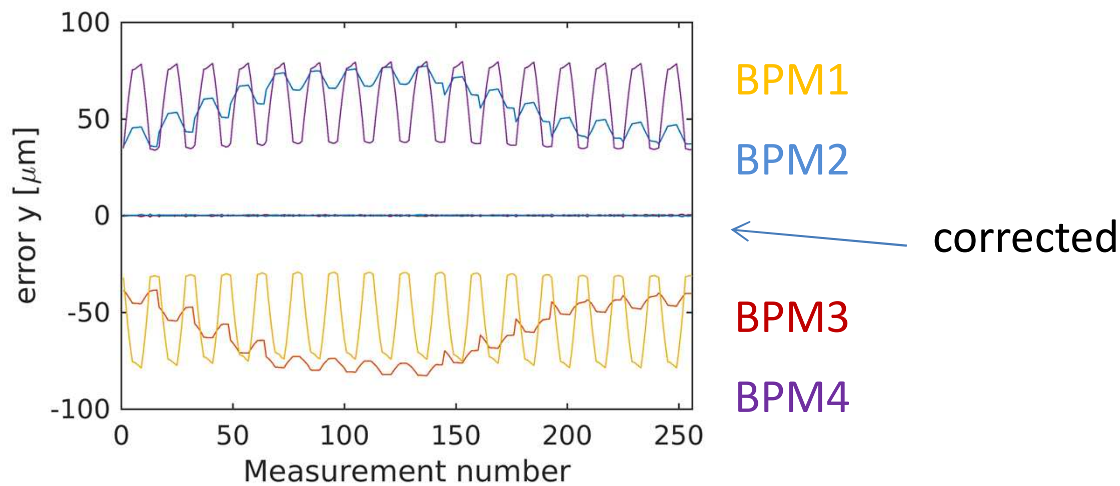
- after ~**200** times for **MSS**
- after ~**20** times for **LSS**

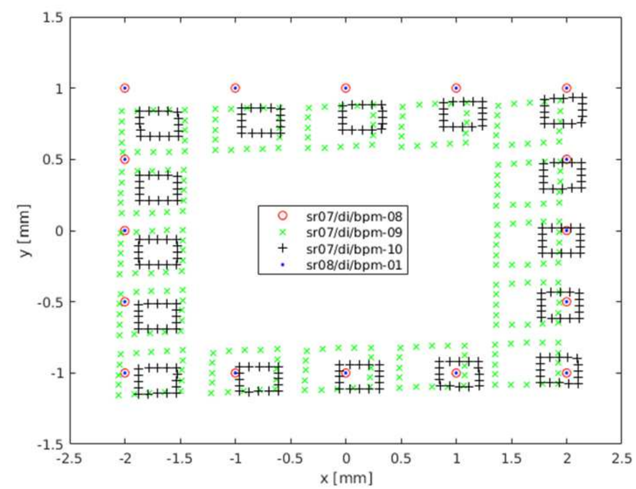
Final BPM position was not optimum. It required **500** measurements to average out the random error.

Results: DC calibration

A set of 256 different orbit bumps are produced at the 4 BPMs (1024 measurements, each one an average of) with the strip-line **OFF**.

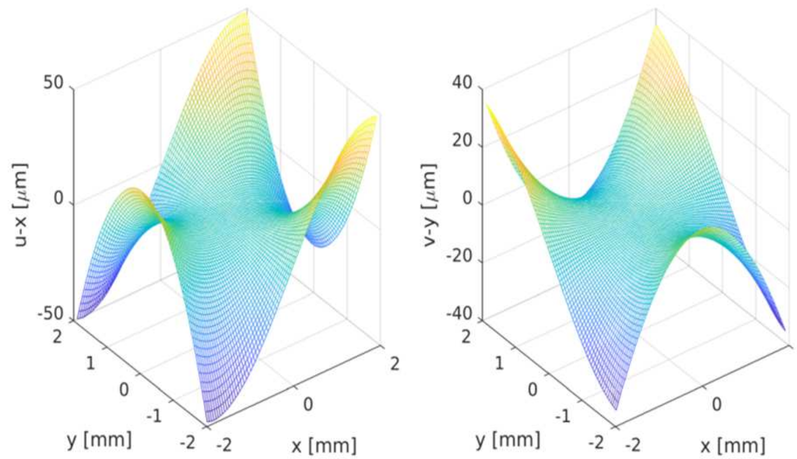
The readings should lay on a straight line, the discrepancy is used to fit their offsets and gains.





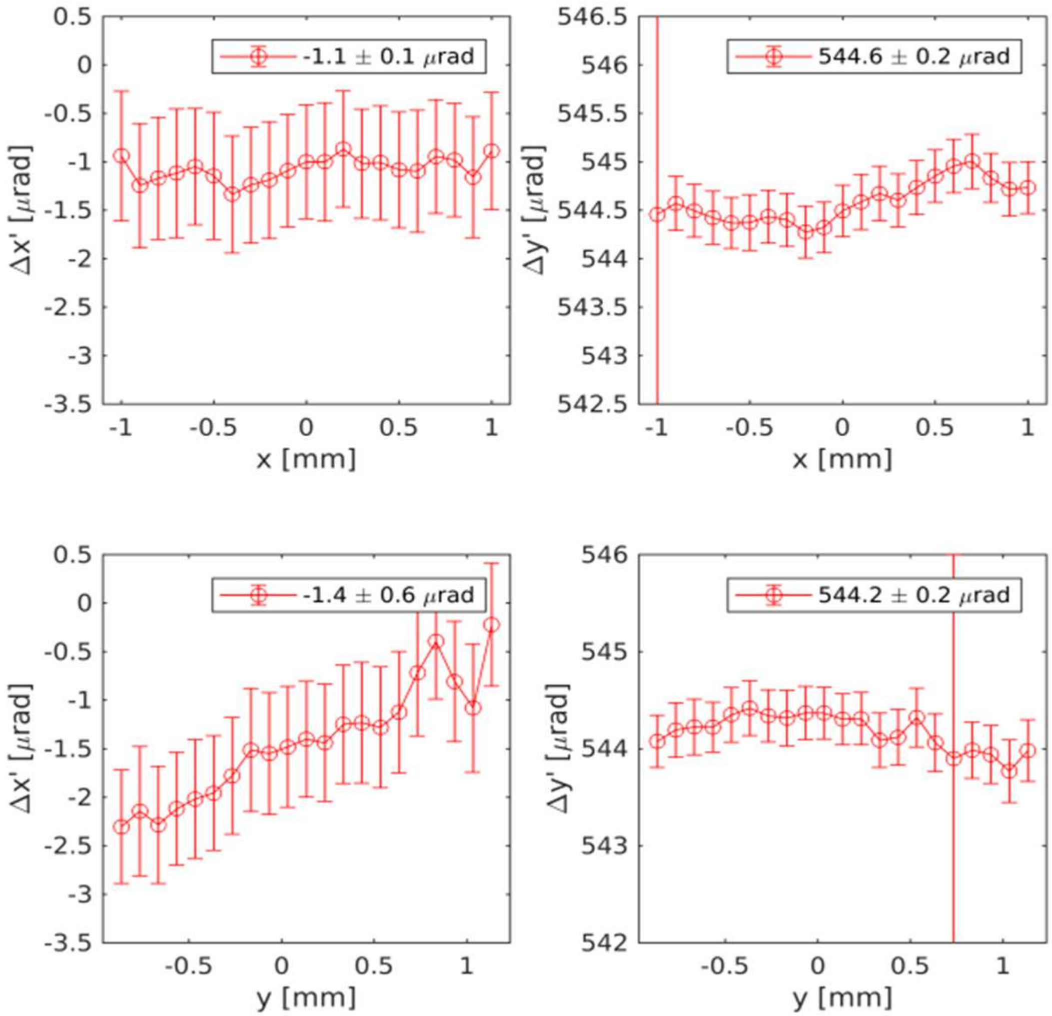
Measurement set up

The **4** BPMs **offsets**, **gains** and **rolls** have to be taken into account together with their geometrical **non-linear** behavior.



With the strip-line installed but OFF, a set of measurements were done in order to take all this into account.

Results: DC



-1.1 ± 0.1 μrad
Δx' [μrad]
x [mm]
544.6 ± 0.2 μrad
Δy' [μrad]
x [mm]
-1.4 ± 0.6 μrad
Δx' [μrad]
y [mm]
544.2 ± 0.2 μrad
Δy' [μrad]
y [mm]

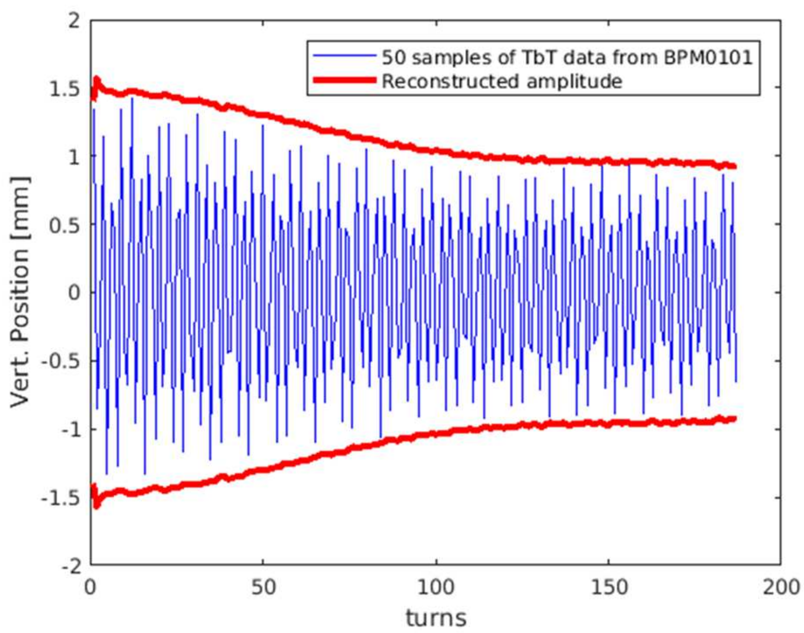
Longitudinal field homogeneity – Inductive Adders

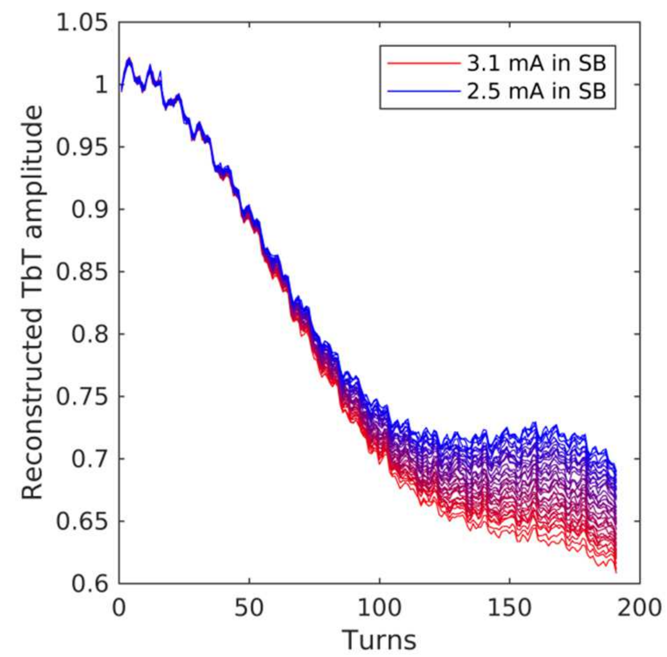
Measurements

Empirically we have seen that the **beam current**, **chromaticity** and **kick amplitude** affect to the beam oscillations **decoherence**.

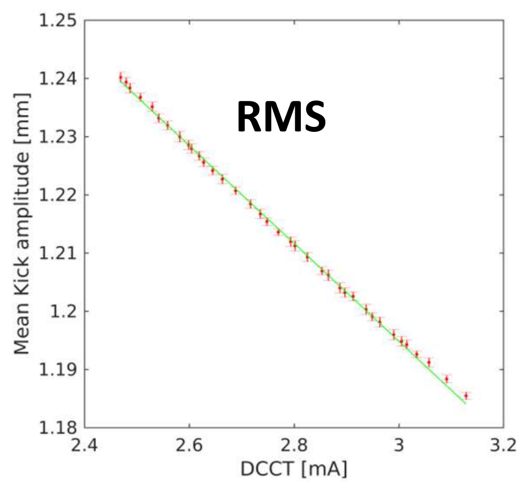
The oscillation decoherence affects the observable kick effect, we will need to minimize its effect.

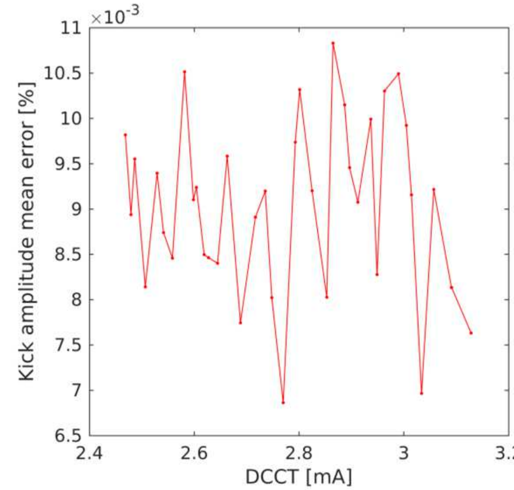
To do that, the TbT oscillations are compensated with the **reconstructed action amplitude**:





Results: Pulsed





Decoherence compensation