Stretched-wire Alignment of a 15 GHz cavity BPM

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Founded by the European Union

Contents

- PACMAN Marie Curie Action
- CLIC Cavity BPM
- Stretched wire techniques for alignment
- BPM Test Bench
- Conclusions

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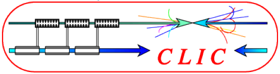
PACMAN Marie Curie Action

For the future electron/positron linear collider **CLIC**, **ultra-low emittance beams** are required to produce a high number of particle collisions (luminosity) at high energy.



- The **Alignment** between the main guide field and acceleration components must be in the **um** regime
  - **Main Beam Quadrupole**[1]: to focus the beam
  - **Beam Position Monitor - BPM**[2]: to detect the beam position
  - **Wakefield Monitor - WFM**[3]: to measure and minimize wakefields in the acceleration structures, in order to minimize beam break-up.

[1] Measuring the magnetic axis of quadrupoles by stretched wires - D. CAIAZZA
[2] CLIC module BPMs - Cavity BPM and DB BPM - J. TOWLER
[3] Measuring the internal geometry of the TD24 Accelerating Structure for CLIC using RF methods - N. GALINDO MUNOZ
[4] Metrology and pre-alignment of the components of CLIC in the PACMAN project - V. VLACHAKIS

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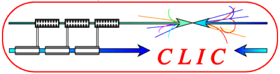

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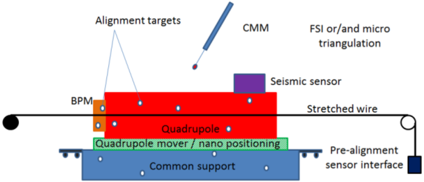

Final objective

Pre-alignment[4] of BPM and main beam quadrupole magnet on a single standalone test bench using **stretched-wire** and high precision metrology techniques.

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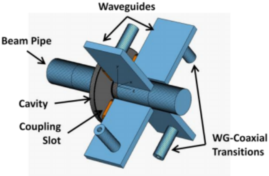
CLIC Cavity BPM

A Beam Position Monitor (BPM) is a **diagnostic instrument** to measure the transverse position of the beam with respect to the center of the vacuum chamber.



Intermediate BPM objectives in the frame of the PACMAN Marie Curie Action

- Instrument characterization
  - Electrical center with a **sub-um** precision
  - Linear region
- Evaluation of the position resolution, expected to be <50nm

CLIC Cavity BPM - Few Concepts

A beam, passing a passive cylindrical “pillbox” cavity, excites many eigenmode resonances, the **transverse magnetic (TM) modes** are of interest for beam position monitoring:

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TM_{010}

Monopole Mode

The longitudinal E-field components are present over the entire cross-section area, also in the center of the resonator.
For the CLIC cavity BPM: **TM010 at 11GHz**.
It is a so-called **fundamental mode**, since it is the lowest frequency eigenmode, with the simplest field pattern.

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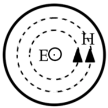

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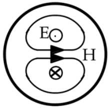

TM_{110}

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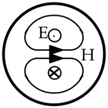

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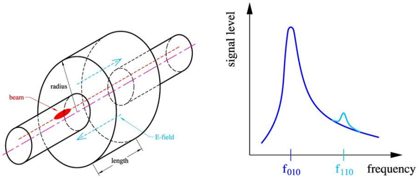
For the CLIC cavity BPM: **TM110 at 15GHz**.

The **electrical center** is the point in which the electric field generated by the dipole mode is zero.
Because of manufacturing imperfections it may not match with the **geometrical center**.

CLIC Cavity BPM - Working Principle



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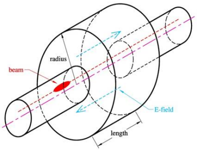

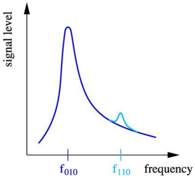

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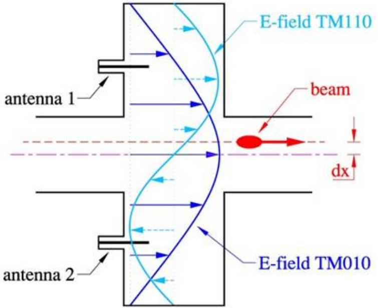

At **15GHz**, both dipole and monopole modes are excited. If the **monopole mode** is **discriminated** the **beam displacement** around the **electrical center** of the cavity is **proportional** to the longitudinal component of the electric field (E_z) of the TM110 mode.

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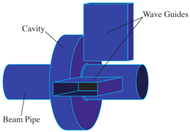

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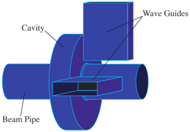

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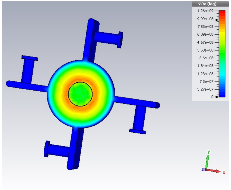

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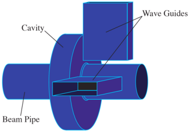

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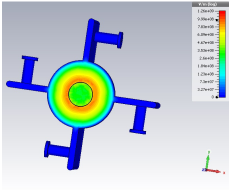

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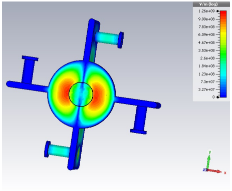

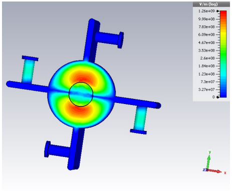

When the **dipole mode** is excited (beam off-center), for both the polarizations the respective set of waveguides transfers the signal to the coaxial output ports.

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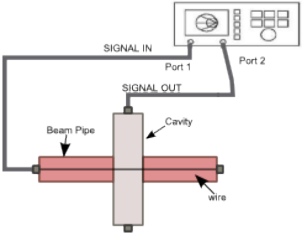
Stretched-wire setup

Two methods identified to locate the **electrical center**, both of them are based on S21 measurements between the ports of interest.

- **Signal excitation**
  A 15 GHz CW **signal is fed on a conductive stretched wire**, causing an excitation of the TM_{110} dipole mode of the cavity BPM, in a similar way as the beam. By small transverse movements of the BPM with respect to the wire it is possible to scan the cavity and find the signal minimum, i.e. the electrical center.



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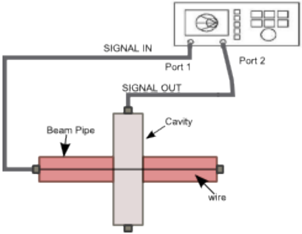
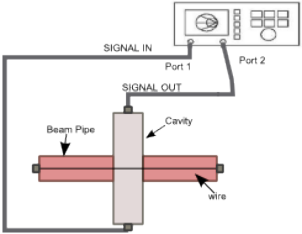
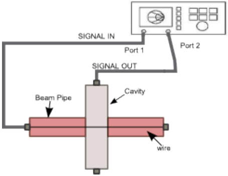


- **Perturbation analysis**
  The **cavity BPM is excited via one of the lateral waveguide-to-coaxial ports**, and the output signal is analyzed on the opposite waveguide. A conductive stretched-wire is used as a perturbation target inside the cavity.



Signal Excitation - Simulation

A simulation was performed, with a metallic wire inside the beam pipe and the cavity BPM, analyzing the $|S21|$ parameter, exciting the wire and picking up the signal on the slot-coupled waveguides.



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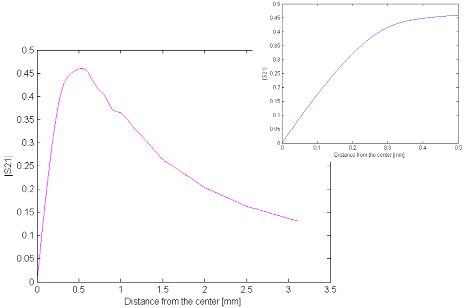

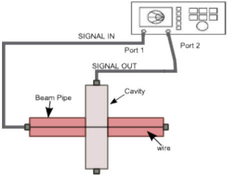

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Linear Region: zone in which the transverse E-filed could be approximated as linear.
Estimated as $\pm 0.3mm$.

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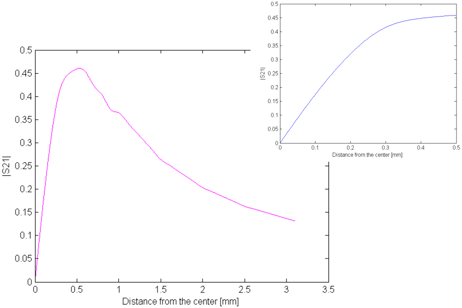

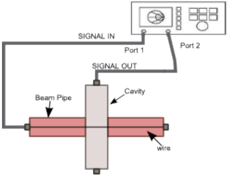

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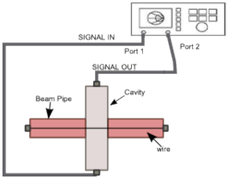
In the final setup BPM and quadrupole magnet will be integrated, with the the BPM operating in the linear zone, to precisely evaluate the **offset between the electrical and magnetic center** (used as a **proportional correction** term on the BPM data post-processing).

Perturbation Analysis - Simulation

A simulation was performed, with a metallic wire inside beam pipe and cavity BPM, analyzing the $|S21|$ parameter of the cavity BPM between two opposite slot-coupled waveguides.



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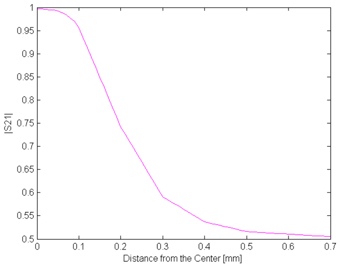

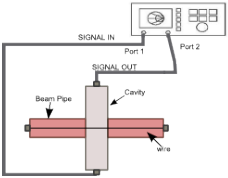

$|S21|$ is maximum with the wire in the center of the cavity, since in that position there is no E-field.

When the wire moves outside the cavity center it drains part of the power.

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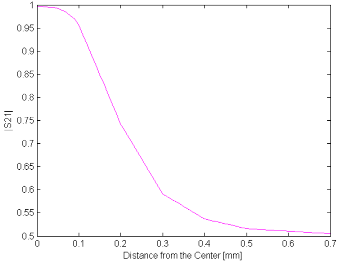

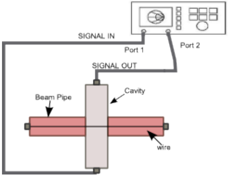

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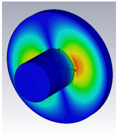
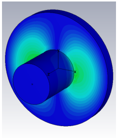
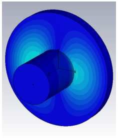


Wire centered in the cavity

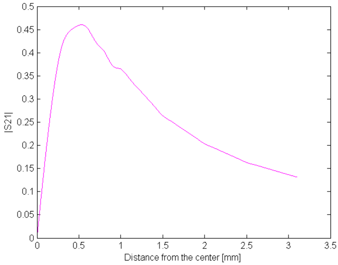


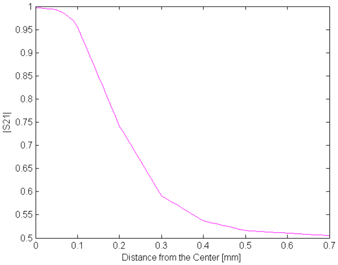
0.2mm wire displacement



0.4mm wire displacement

Methods comparison





Signal Excitation

PROS: Higher **sensitivity** around the electrical center.

CONS: The coaxial line, formed by wire and beam pipe, needs to be **terminated**, which makes the integration with the quadrupole magnet more difficult.

Perturbation Analysis

PROS: The **integration** with the magnet will be easier, and electrical and magnetic center could be measured using a setup without RF impedance. matching

CONS: The **sensitivity** is lower around the electrical center, the measure may be less accurate.

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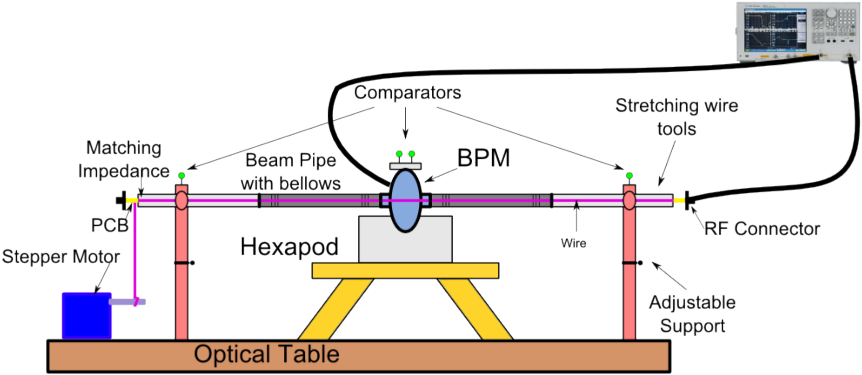
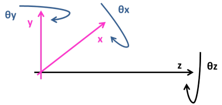
BPM Test Bench

CLIC BPM Test Bench at CERN



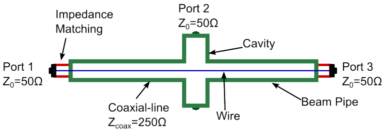
4DOF: Perpendicular to the beam axis (z)

Beam Axis



Impedance Matching

A single wire stretched through the beam pipe and cavity BPM setup yields in a transmission line, whose characteristic impedance depends from the dimensions of pipe and wire cross-section, which are respectively outer and inner diameter of a coaxial transmission line.



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$Z_0 = 50\Omega$: characteristic impedance of the RF external equipment

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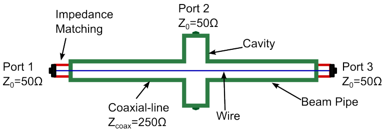

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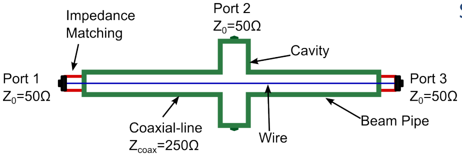
$Z_0 = 50\Omega$: characteristic impedance of the RF external equipment

It is necessary to match those impedances to minimize reflections

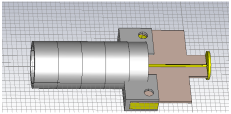
Return Loss Goal: $>$20dB

Impedance Matching Transformer

Two 3-section quarter-wave transformers $50\Omega - to - 250\Omega$



Signal launched through high frequency RF SMA connector, mounted on PCB.



The PCB- Coax transition is also critical for the reflections.

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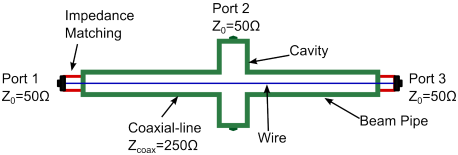

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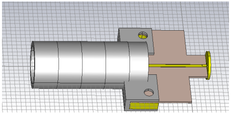

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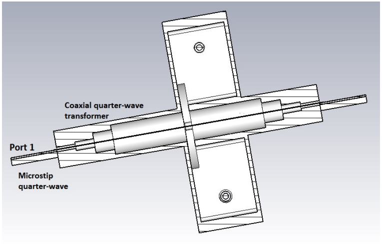
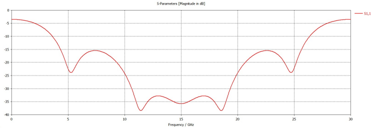
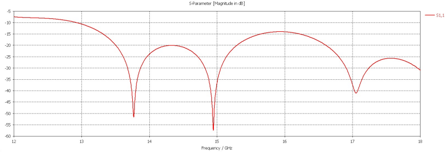
BPM and Transformer Simulation



Transformer theoretical response



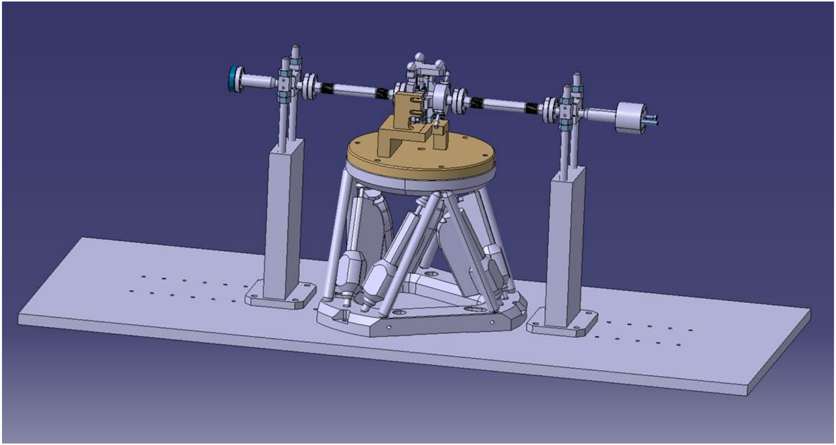
S11 - Reflection coefficient simulation



- PACMAN Marie Curie Action
- CLIC Cavity BPM
- Stretched wire techniques for alignment
- BPM Test Bench
- **Conclusions**

Conclusions

- The BPM test bench has been fully designed
- Two stretched-wire measured methods have been identified. They will be both tested on the BPM test bench, and the most efficient will be chosen for the integrated setup.



Thank You!

S. Zorzetti

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