Progress on wire-based traveling-wave structure alignment

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PACMAN

Outline

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2) Methodology
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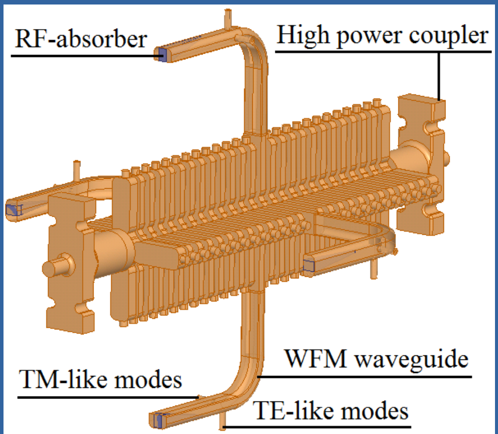
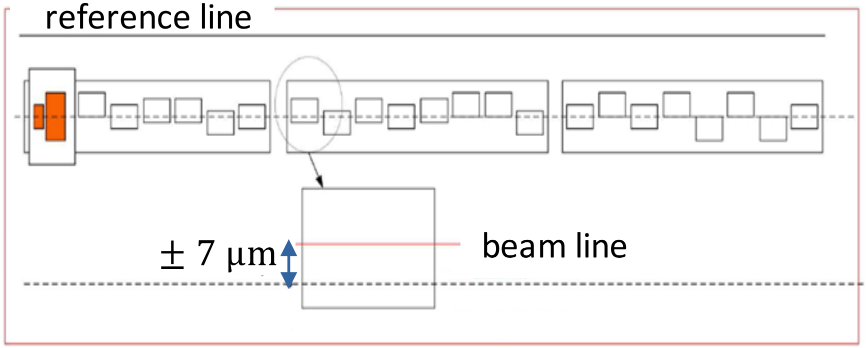
Introduction: The TD24 Accelerating Structure



Objective: development of direct measurement techniques for the in-situ internal alignment of the CLIC TD24 Accelerating Structure (AS).

Pre-alignment requirement for AS:

The absolute position of the electrical center should be found with an accuracy of 7 µm in a laboratory environment using metrology methods.

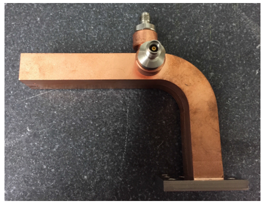


Characteristics:

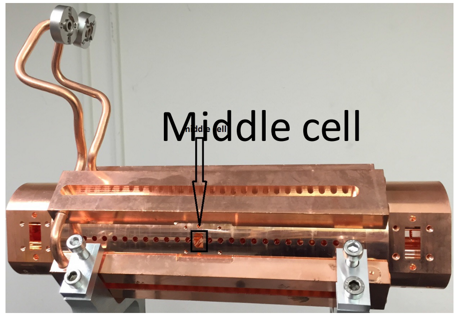
- 23 cm long tapered normal-conducting traveling wave AS.
- 26 cells.
- Accelerating Mode at 12 GHz.
- Iris mean aperture: 5.5 mm
- 4 Wakefield Monitors (WFM) in the middle cell with RF pick-ups.
- 4 radial waveguides in each cell without RF-absorbers with a cut-off frequency of around 16 GHz without distorting the accelerating mode.

Methodology

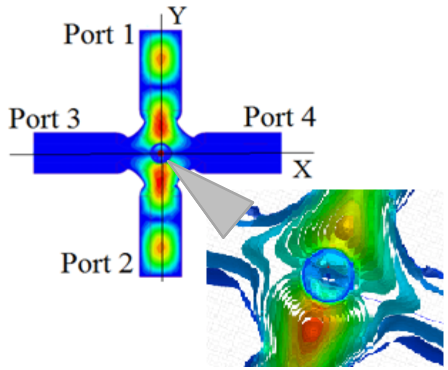
1. The fist dipole mode is excited with a Vector Network Analyzer (VNA) in the middle cell through the RF pick-ups.



WFM: Initially designed for beam position monitoring



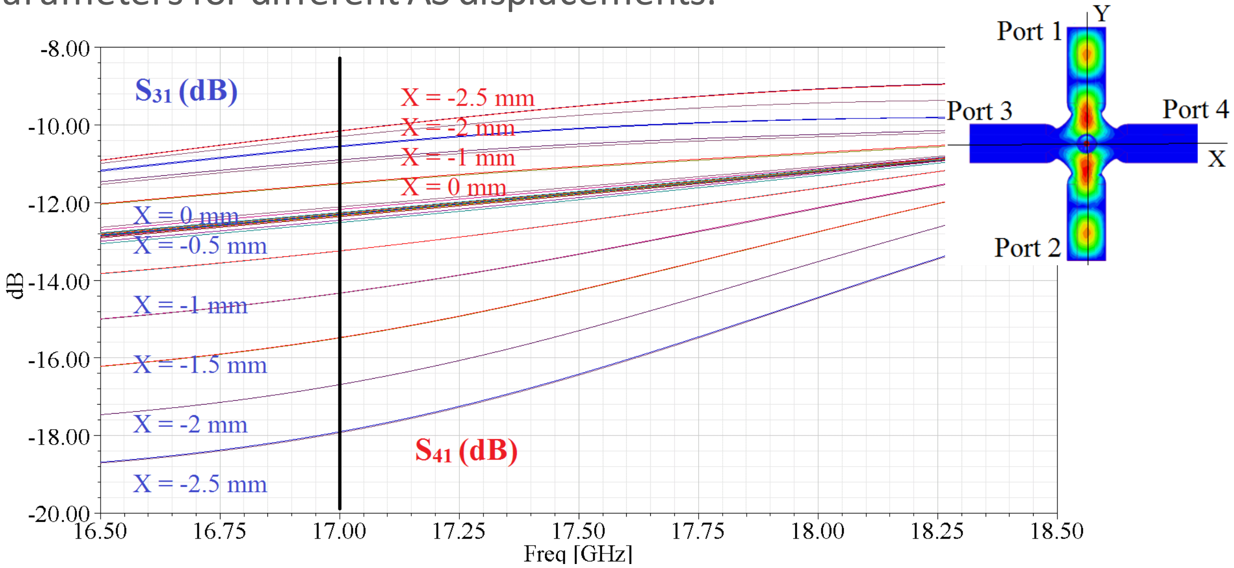
2. A 0.1 mm diameter fixed stretched Be-Cu wire inside the AS perturbs the electromagnetic field by changing transmitted and reflected power signals between ports.
3. We change the position of the wire to minimize this perturbation.
4. We define this position as the electromagnetic axes in the AS and use the wire as a reference to fiducialise the structure in the accurate environment (± 0.3μm) of a 3D Coordinate Measuring Machine (CMM).



Dipole mode in the middle cell of the AS

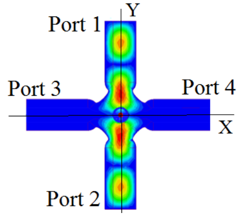
Methodology

S parameters for different AS displacements:

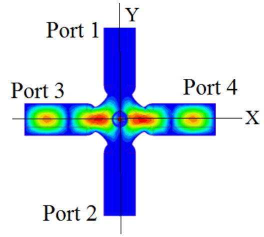


We choose a combinations of S parameters measured in amplitude for maximum sensitivity (two measurements):

S_{41}-S_{31} or S_{42}-S_{32}, when moving the AS along the X axis

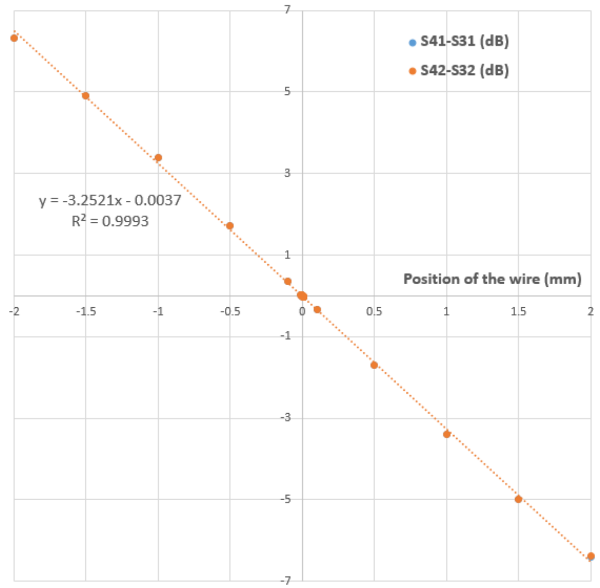


S_{14}-S_{24} or S_{13}-S_{23}, when moving the AS along the Y axis



Methodology

We simulate alternative scans in the X and Y axes with HFSS:

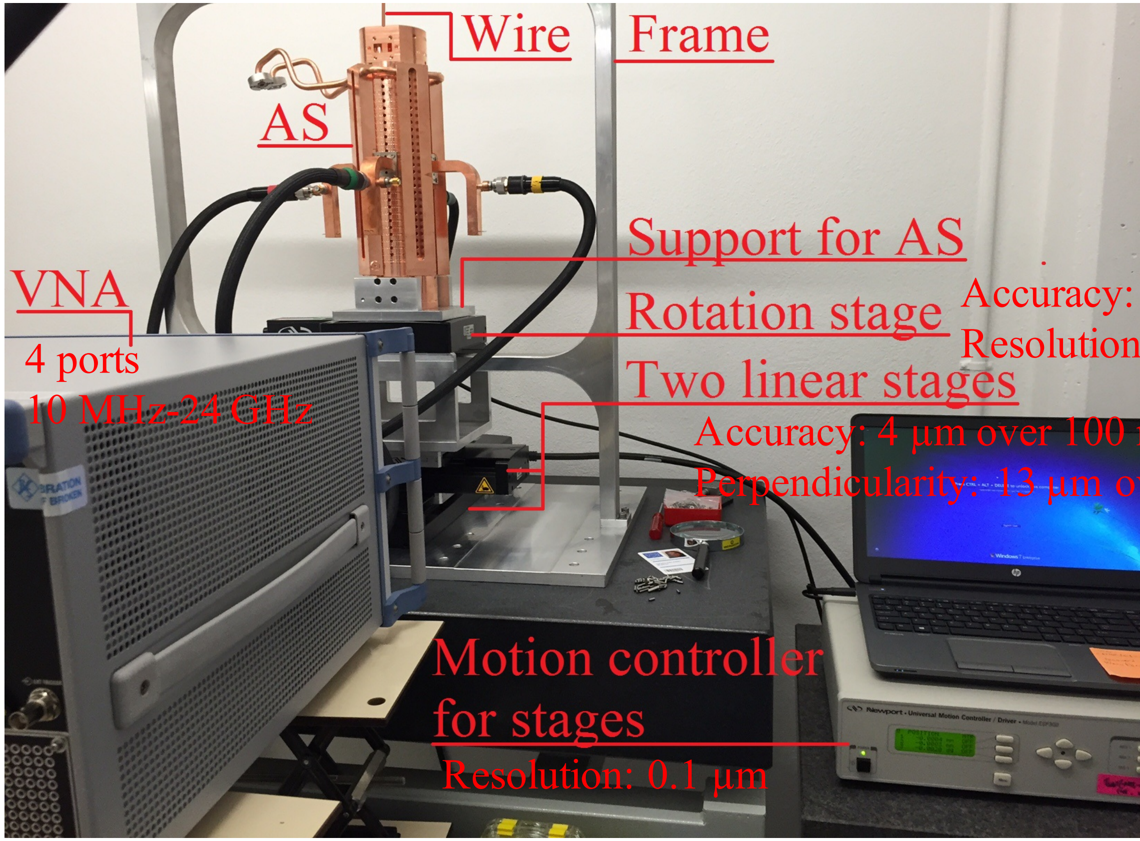


- We do a linear fit of the simulated measurements:
  - The line crosses zero at the positon of the electromagnetic center of the AS.
  - The slope represents the sensitivity of our measurements to the displacement of the wire.
- Asymmetric coupling does not impact the result.

Ideal case:

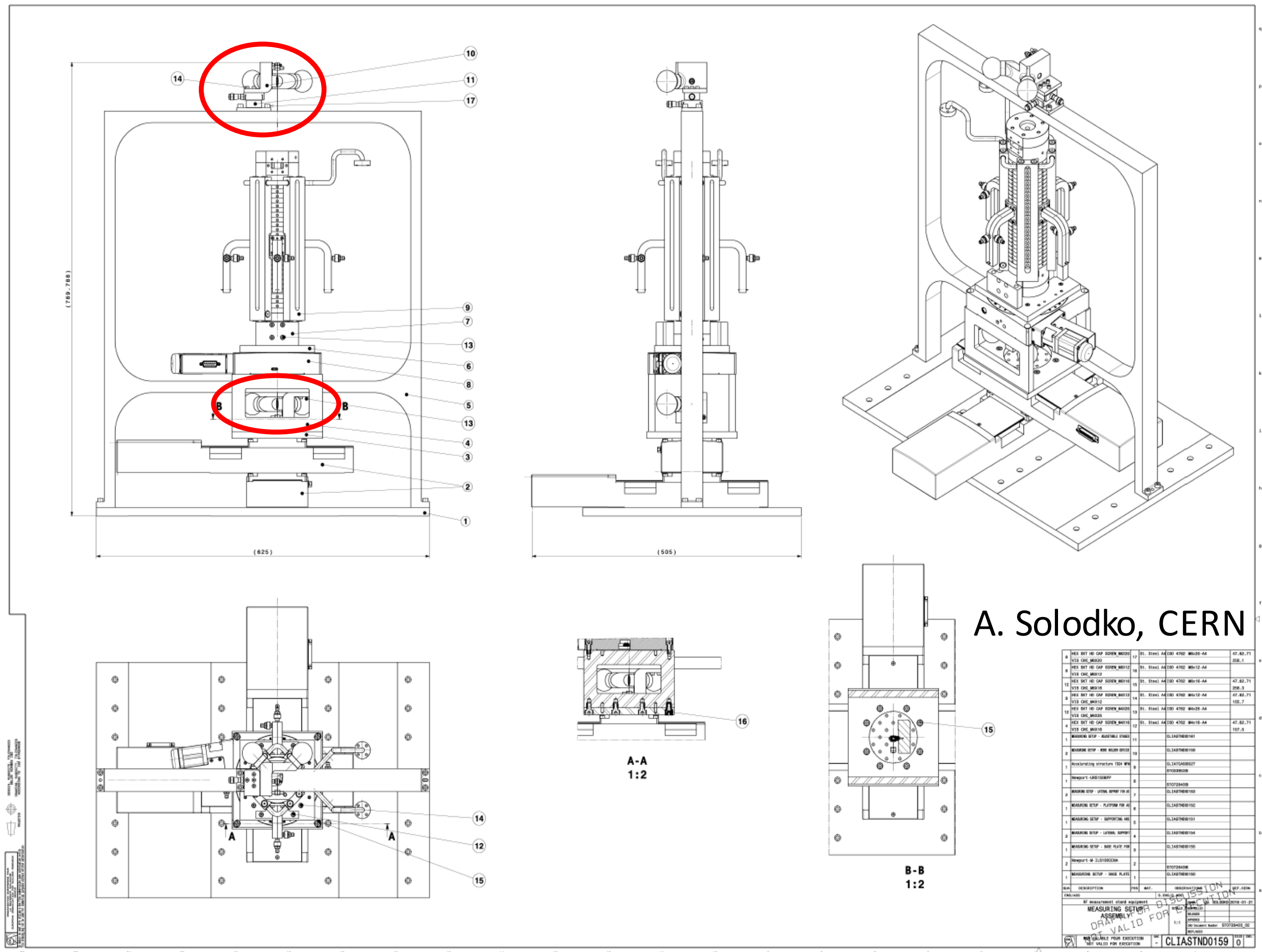
- Geometric center = Electromagnetic center.
- Accuracy is determined by numerical noise.

Experimental Set-Up



Stages provided by IFIC, Valencia, SPAIN, to move the AS in three degrees of freedom around a fixed stretched wire.

Experimental Set-Up

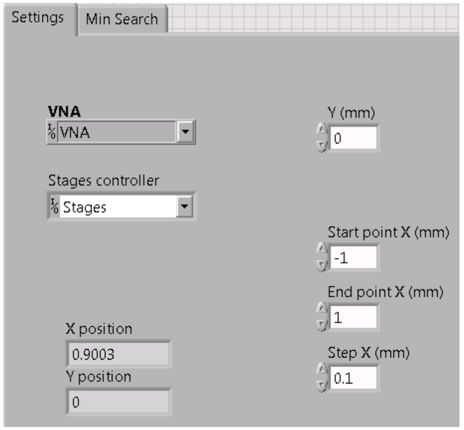


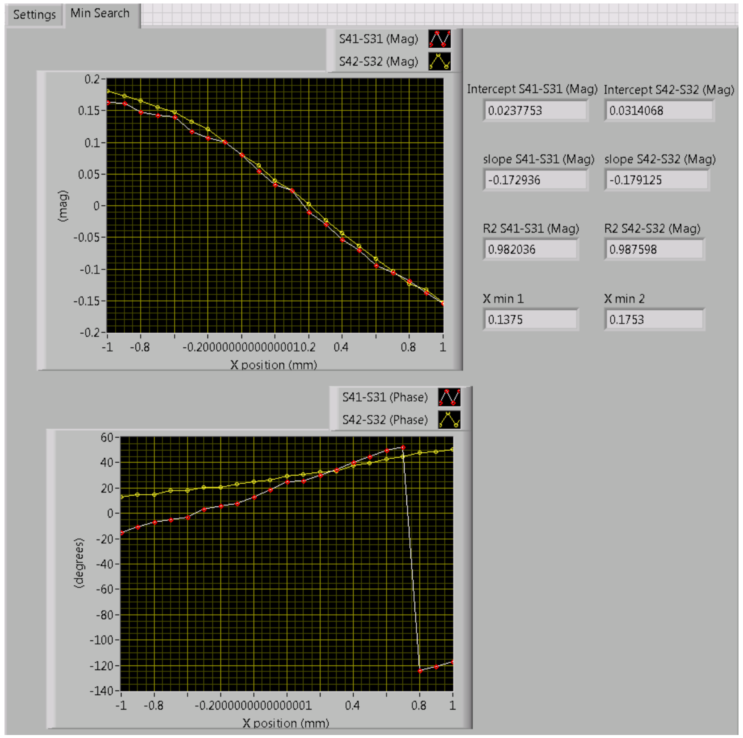
Two wire-positioning system of 1.5 µm of reproducibility are going to be installed soon at both extremes of the frame.

Experimental Set-Up

User platform in LabVIEW:

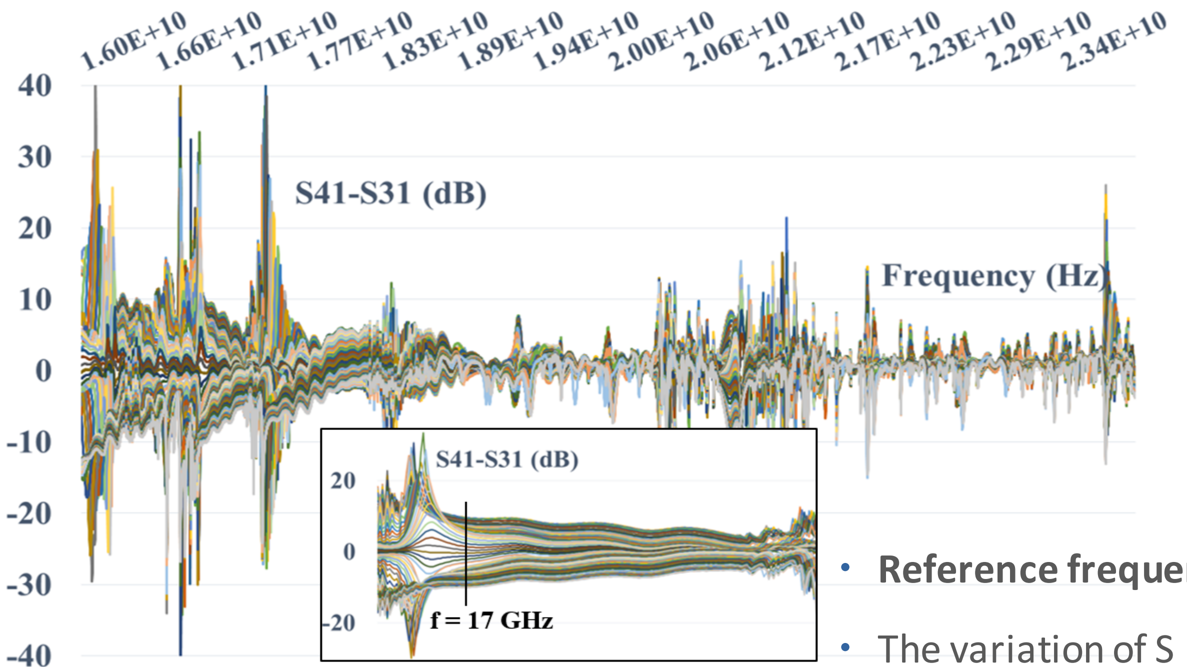
The movement of the stages are controlled based on the acquisition from the VNA and the data processing done by the program.





Choice of the frequency

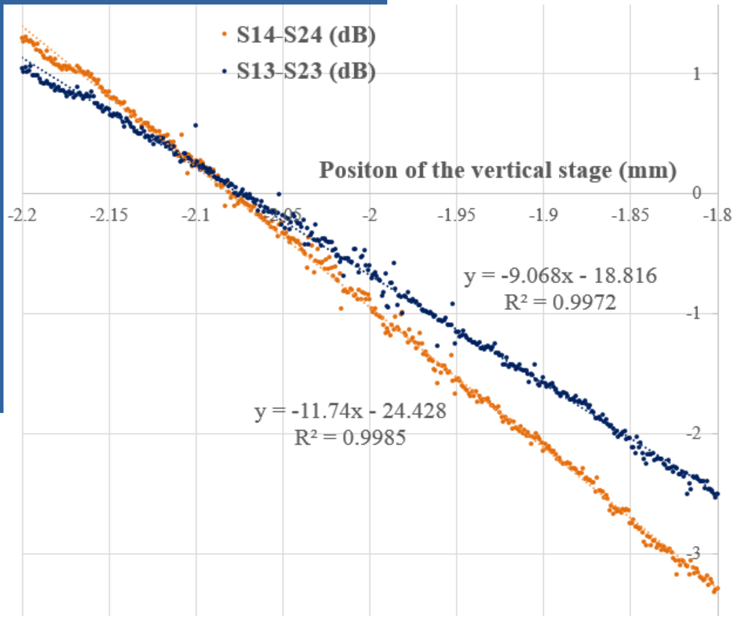
Frequency sweep using a non-calibrated VNA:

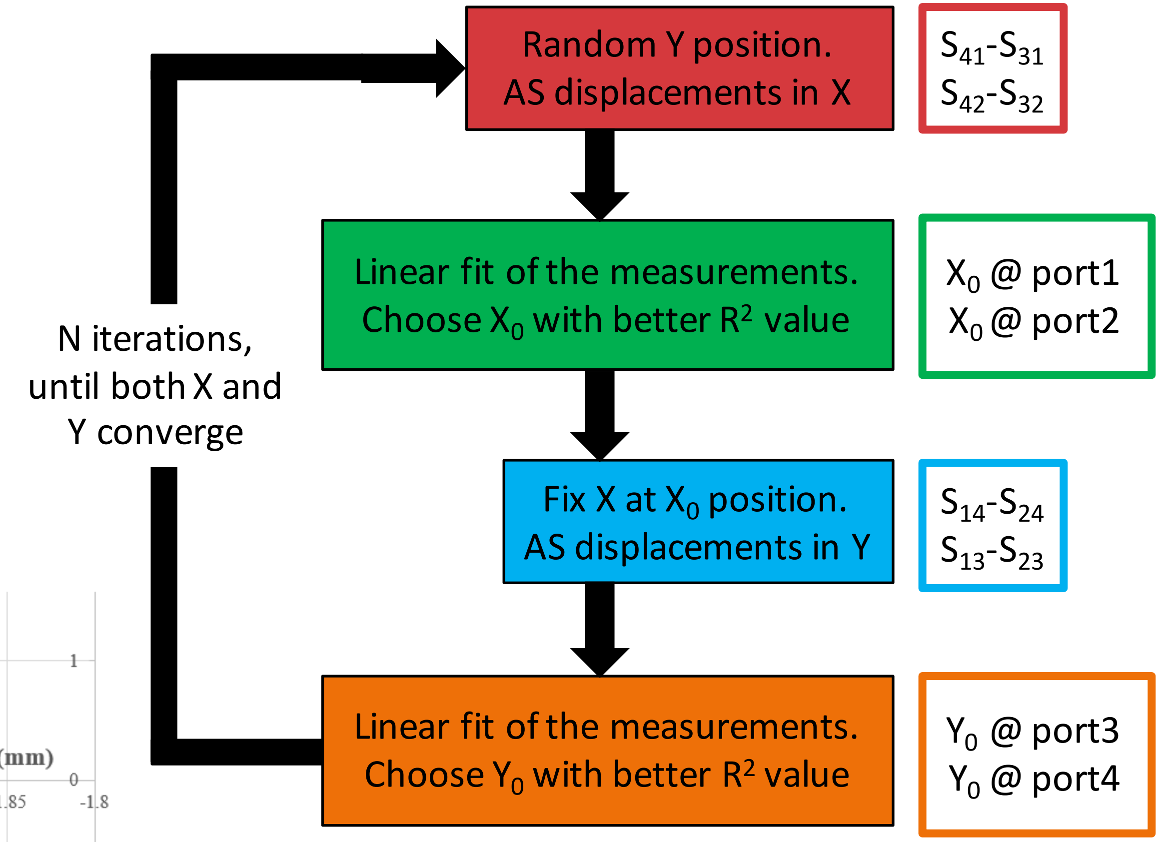


S_{41}-S_{31} (dB) with respect to the frequency for different positions of the wire inside the AS.

- **Reference frequency: 17 GHz**
- The variation of S parameters with the wire displacement is maximized.

Algorithm for experimental measurements

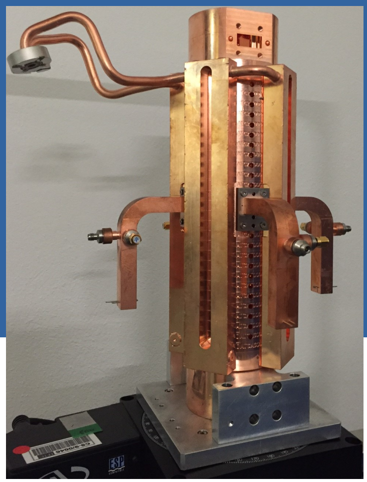




Sensitivity:

- ≈ 7.5 dB/mm in the X axis
- ≈ 10 dB/mm in the Y axis

Experimental results using WFM signals



After the first interactions, the centre as measured by each port converges into a unique value.

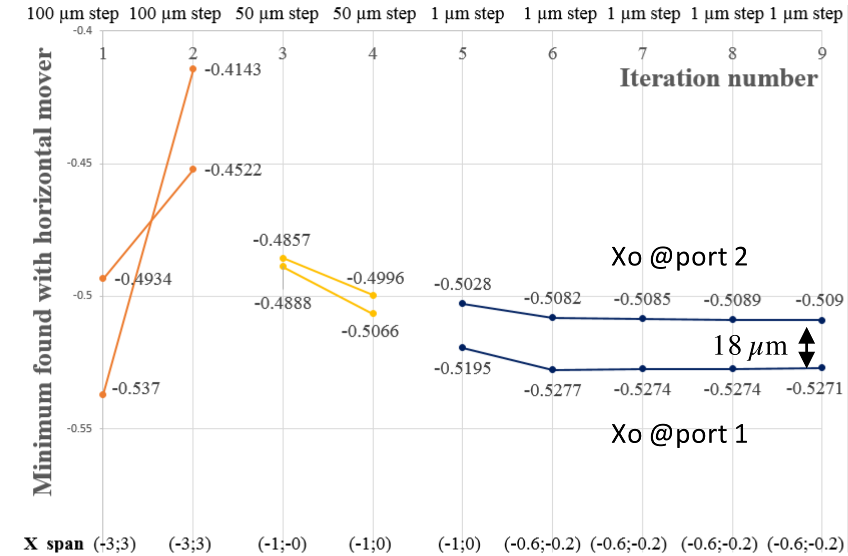
However, we find a different value for the centre when using different ports.

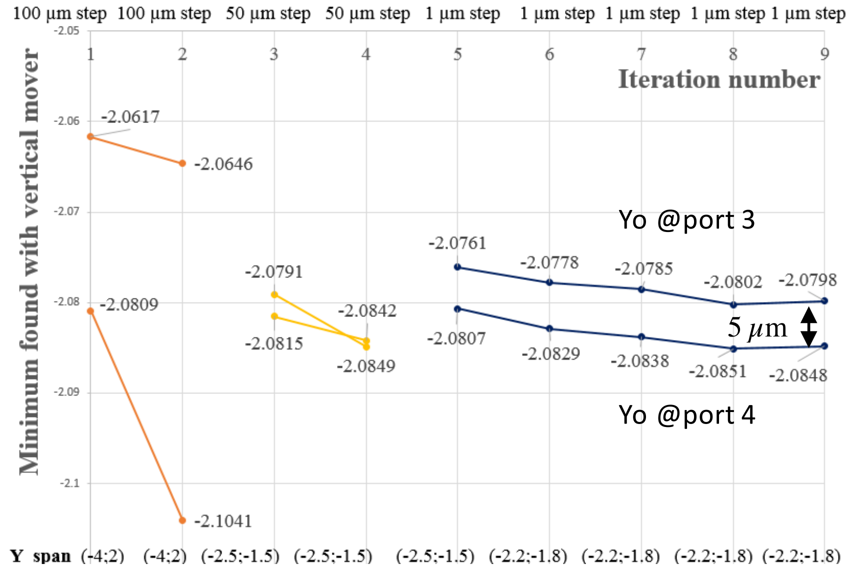
- Lack of matching between the WFM and the structure? Indeed, these ports were designed to extract HOM power and not to input RF signals.

Also, the sensitivity is different depending on the port and in the horizontal and vertical plane.

The difference is an estimation of our accuracy:

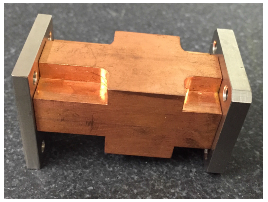
- 18 µm in the horizontal plane
- 5 µm in the vertical plane.



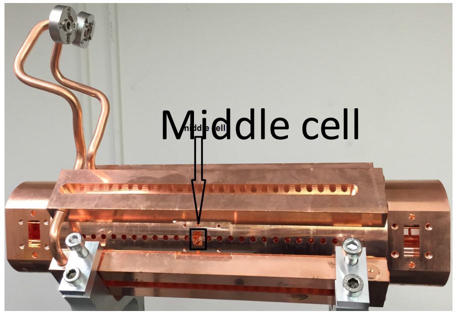


Measurement improvements

- Tapered transitions have been designed and manufactured with low reflection coefficient which will allow us to recover the symmetry and perform new measurements.
- The exact position of the wire wrt. to the structure changes from measurement to measurement. **Repeatability cannot be studied until we install the wire-positioning system.**

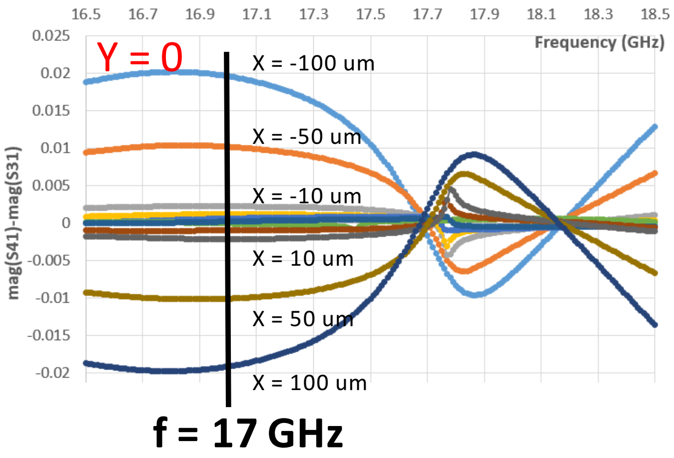


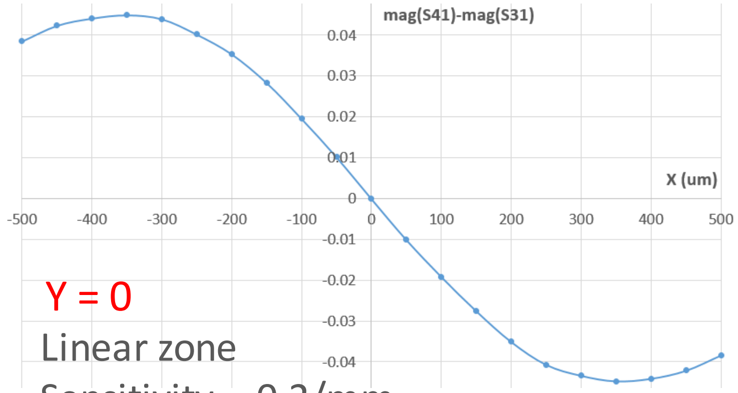
Tapered transitions



Tapered solution: simulation results

Model in HFSS: Middle cell with tapers and irises with perfect H boundaries.

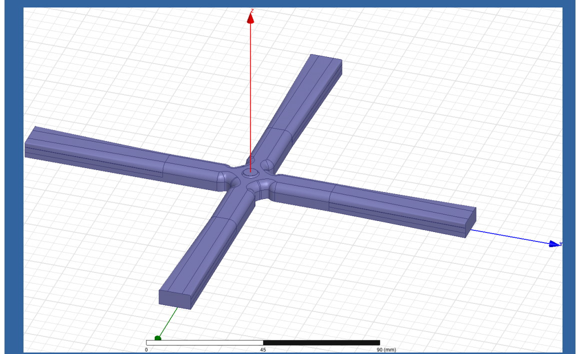


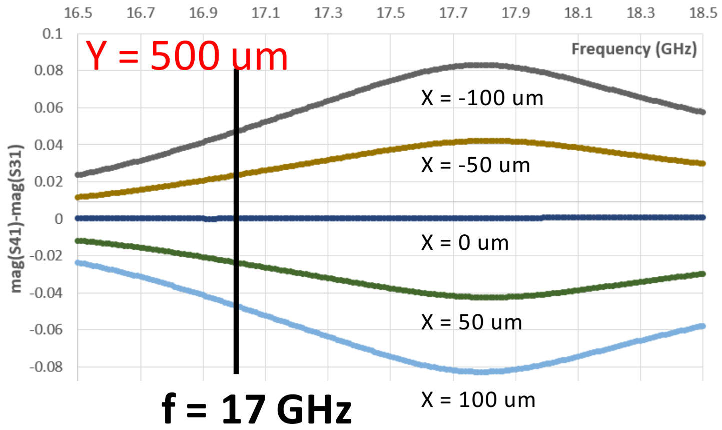


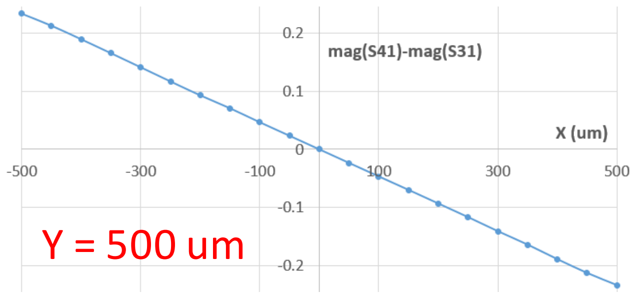
Y = 0

Linear zone

Sensitivity = 0.2/mm





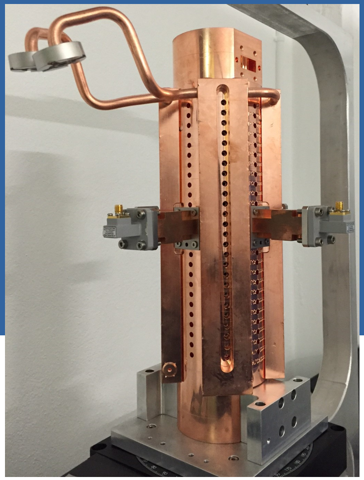


Y = 500 um

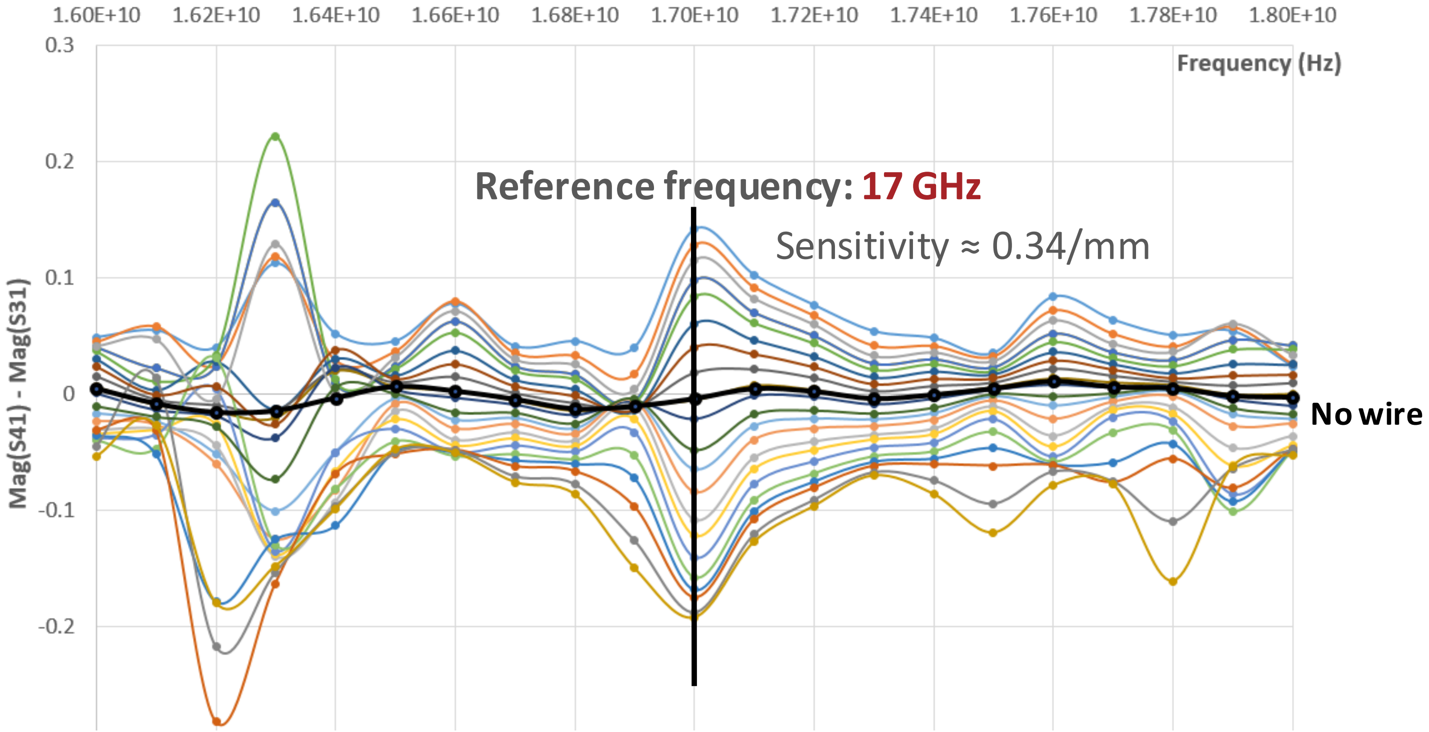
Sensitivity ≈ 0.47/mm

We confirm by simulations that sensitivity depends on the position in the other axes. Converges when approaching the center.

Tapered solution: Experimental results

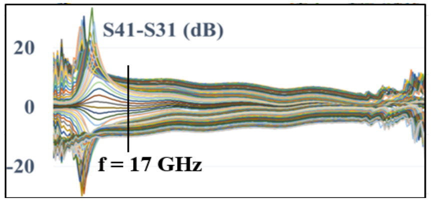


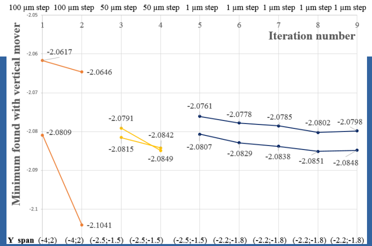
Frequency sweep using a calibrated VNA:



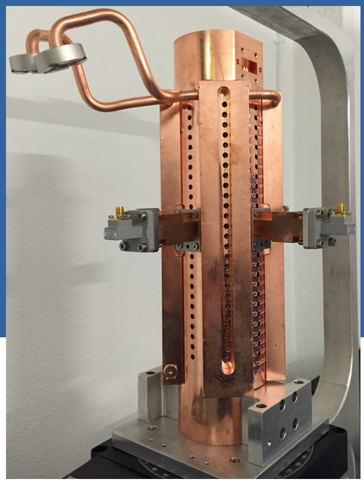
Linear magnitude of S_{41}-S_{31} with respect to the frequency for different positions of the wire inside the AS.

Similar to a non-calibrated VNA measurement using WFM signals:

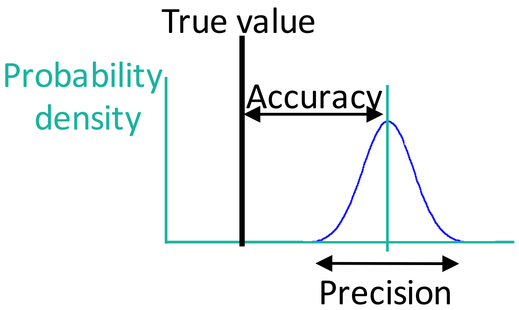




Tapered solution: Experimental results



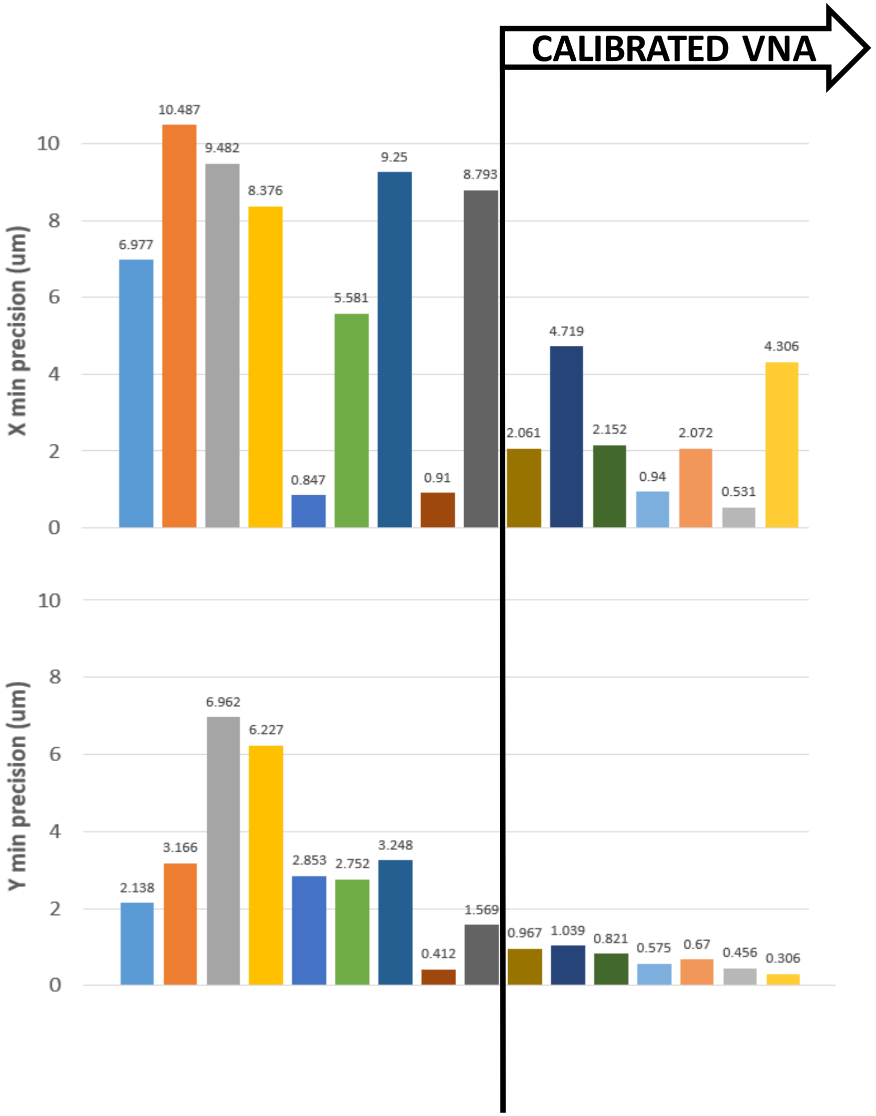
Precision=standard deviation of converging measurements.

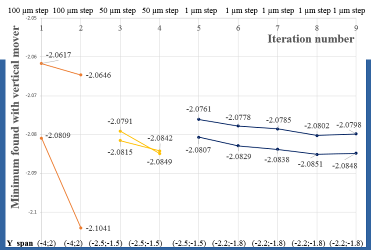


Precision improved and affected by:

- Calibration of the VNA.
- Temperature: 0.5 μm / 0.1°
- Different tensions of the wire applied.

Reproducibility will be improved with the installation of the wire-positioning system.

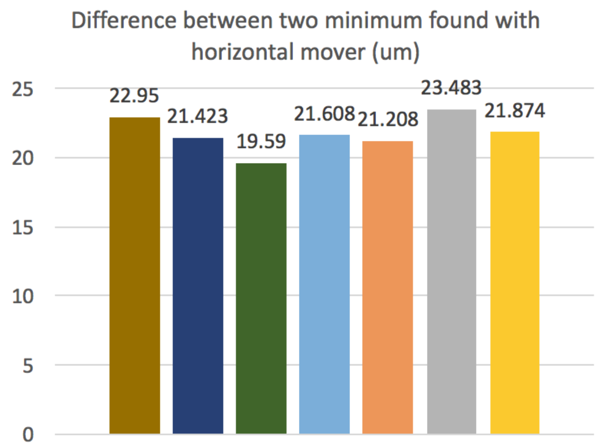




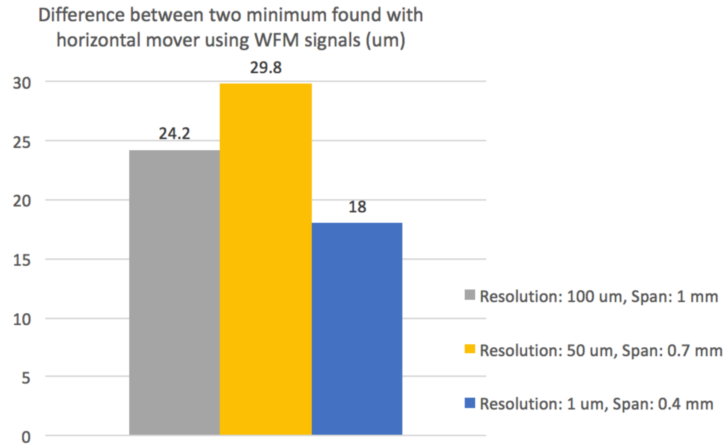
Tapered solution: Experimental results

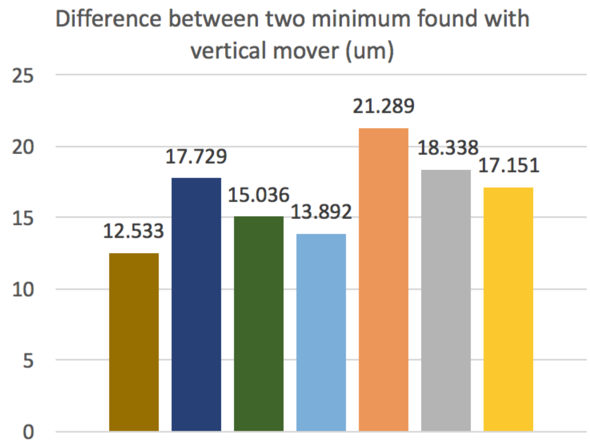
<u>Accuracy=difference between the measurements coming from opposite ports.</u>

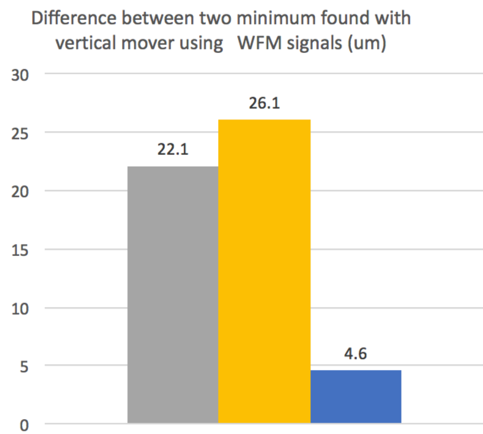
Accuracy can be improved by reducing resolution.



Resolution: 5 µm , Span: 1 mm







Conclusions & Outlook

- We locate the center of the electromagnetic field inside the middle cell of the AS with a stretched wire and a VNA using two different measurements with similar results:
  - Accuracy > 20 µm, still unknown systematic errors.
  - Precision between 1 µm to 5µm for vertical and horizontal plane.
- Tapered transitions have been designed and manufactured with low reflection coefficient which should allow us to recover the symmetry.
  - However, asymmetry is still present between ports and between planes. Might be solved by rotating the AS.
- We have identified main sources of random errors: temperature and tension.

Further work:

- We will use the rotation stage to minimize the tilt of the wire inside the AS.
  - This might lead to a change of experimental algorithm.
  - Effect of the relative tilt between the AS and the wire?
- We will implement a wire positioning system (1.5 µm repeatability) and fiducials to locate the wire wrt the structure.
- Fiducialisation of the structure in the CMM.
- Study cell to cell alignment using the pumping holes at the end of the waveguides in each cell.

Thank you for your attention

Special thanks to:

Nuria Catalan Lasheras, Alexej Grudiev, Angeles Faus Golfe, Anastasiya Solodko, Serge Lebet, Andrej Olyudnin, Wilfrid Farabolini, Pablo Sobrino Mompean, Philippe Guyard, Walter Wuensch, Didier Glaude, Ahmed Cherif, Cesar Blanch Gutierrez, Juan Jose Garcia Garrigos,…

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