Novel RF Tuning of Jacketed Multi-Cell SRF Cavities using Pressurized Balloons

Marco Castellari
Final Review
September 28th, 2017

Supervisor: Donato Passarelli
Mohamed Hassan

A bird's eye view

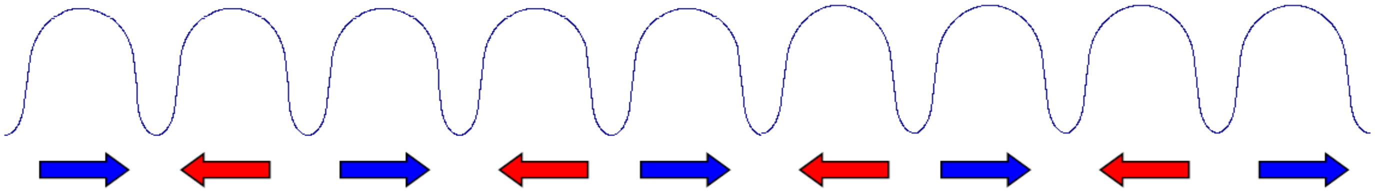
- What is an SRF cavity?
  - SRF cavities parameters
- Dressed cavities problem
  - Why we need a new tuning technique?
- Balloon Tuning Technique
  - How it works?
  - Finite element analysis
  - Tuning procedure
  - Results

SRF cavity : what is it?

- SRF cavity: - Niobium resonating structure that contains an electromagnetic field
  - array of single-gap resonators (multi-cell structure)
  - low temperature → ultra low losses (Resistance ~ $10^{-9}\,\Omega$)

Courtesy : Fermilab

9 cells SRF cavity with frequency of resonance of 1.3GHz



Courtesy : uspas.fnal.gov

- pi-mode standing wave pattern → 180-degrees phase shift between cells

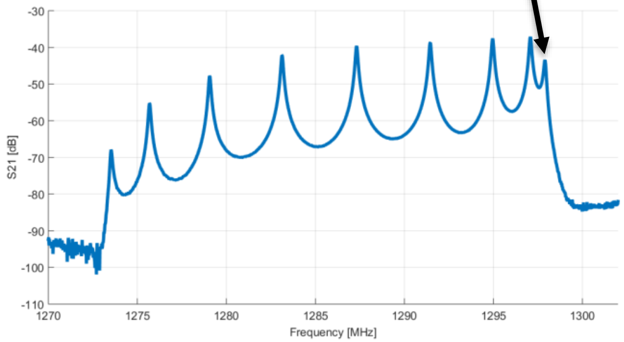
Figure of Merit

- The vitals for RF engineers are:

Frequency of resonance (f_0)

- Crucial parameter for particle accelerators

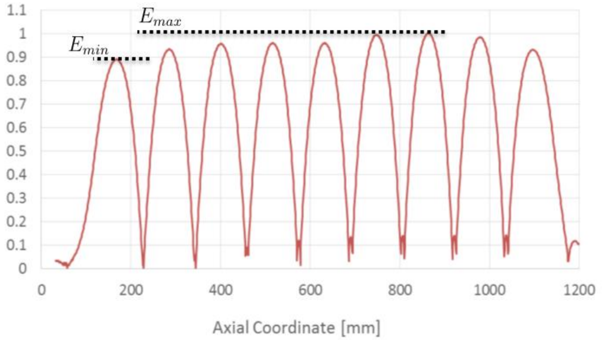
$$\pi - mode$$
$$f_0 \simeq 1298 MHz$$



Field Flatness (FF)

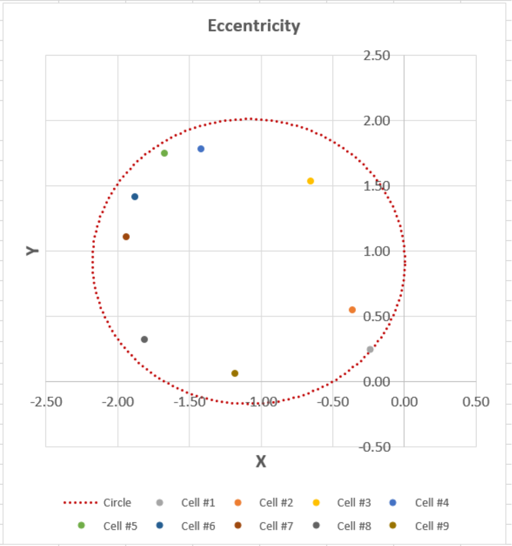
- Goal: $FF > 90\% \rightarrow$ desired accelerating gradient
- Plastic cavity tuning

$$FF = \frac{E_{min}}{E_{max}}$$



Eccentricity

- Electric center measurement



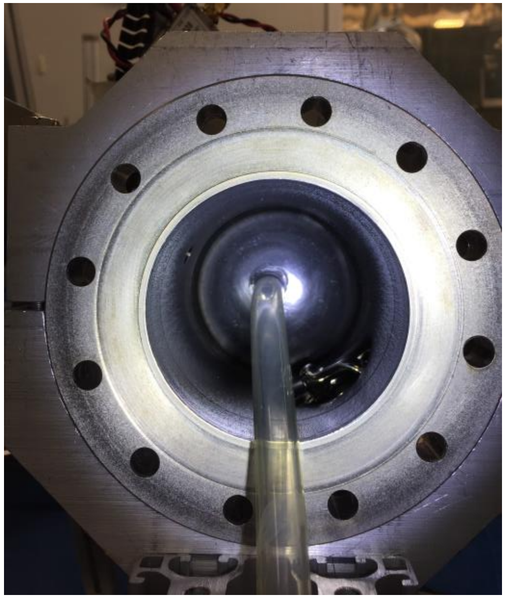
State of the art tuning technique

Previous technique:

- Jaws act directly on the cells from **outside**
- Only for **bare** cavities

Novel technique:

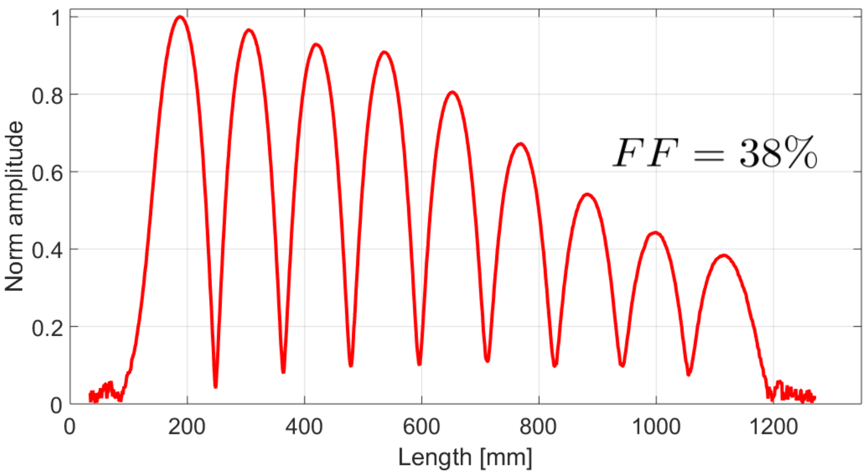
- Access the cell from **inside** via balloons
- Designed for **dressed** cavities



Frequency detuning problem

Dressed cavity problem:

- f_0 shift
- FF deterioration



Current solution:

- Remove the outermost vessel
- Fixing f_0 and FF by the tuning machine
  - Cells deformation
- Welding a new helium tank around the cavity

→

- Procedure full of risks
- expensive

Fermilab

Balloon Tuning Technique

Novel tuning solution for **dressed** multi-cell cavities, using pressurized balloons

Features:

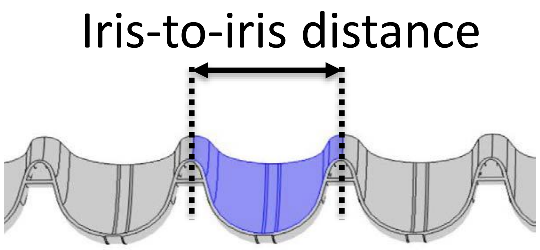
- control the deformation of each single cell
- Inexpensive
- Non-invasive
- Non-destructive

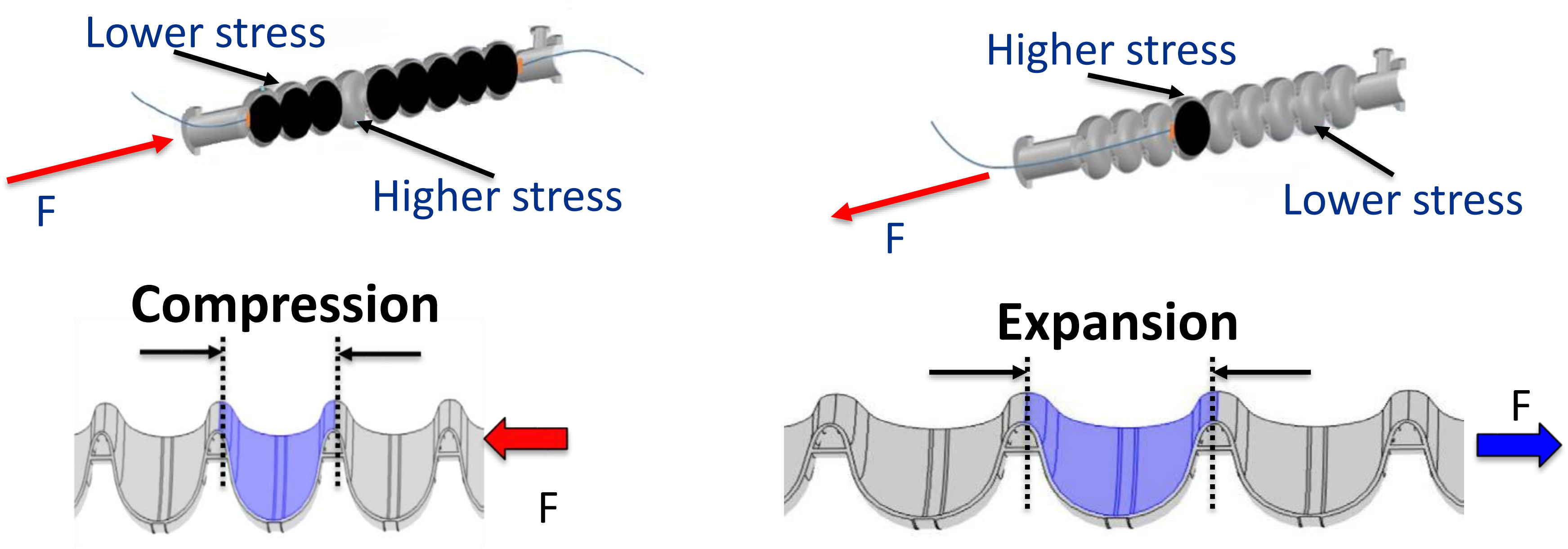
Goal:

- Minimize the impact of a production failure in a large-scale leading project, such as LCLS-II

How does it works?

<u>Idea</u>: change the iris-to-iris cells distances through a plastic deformation



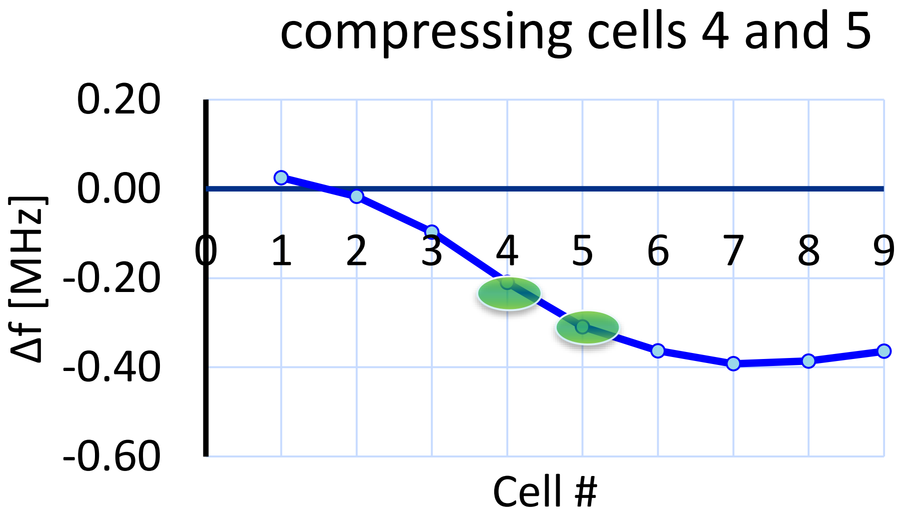


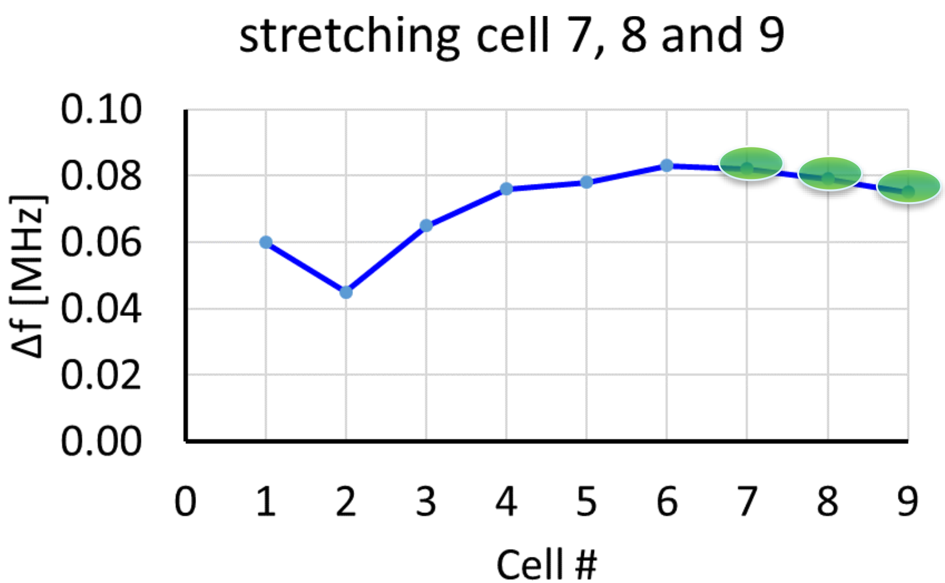
The target cell(s) get <u>plastically</u> deformed and the other cells remain in the linear <u>elastic</u> region because of a lower stress state.

How does it works?

- Plots shows calculated frequency change per cell

- Frequency changes of cell frequencies indicates that <u>the balloon effectively induced the desired effect</u> on targeted cells

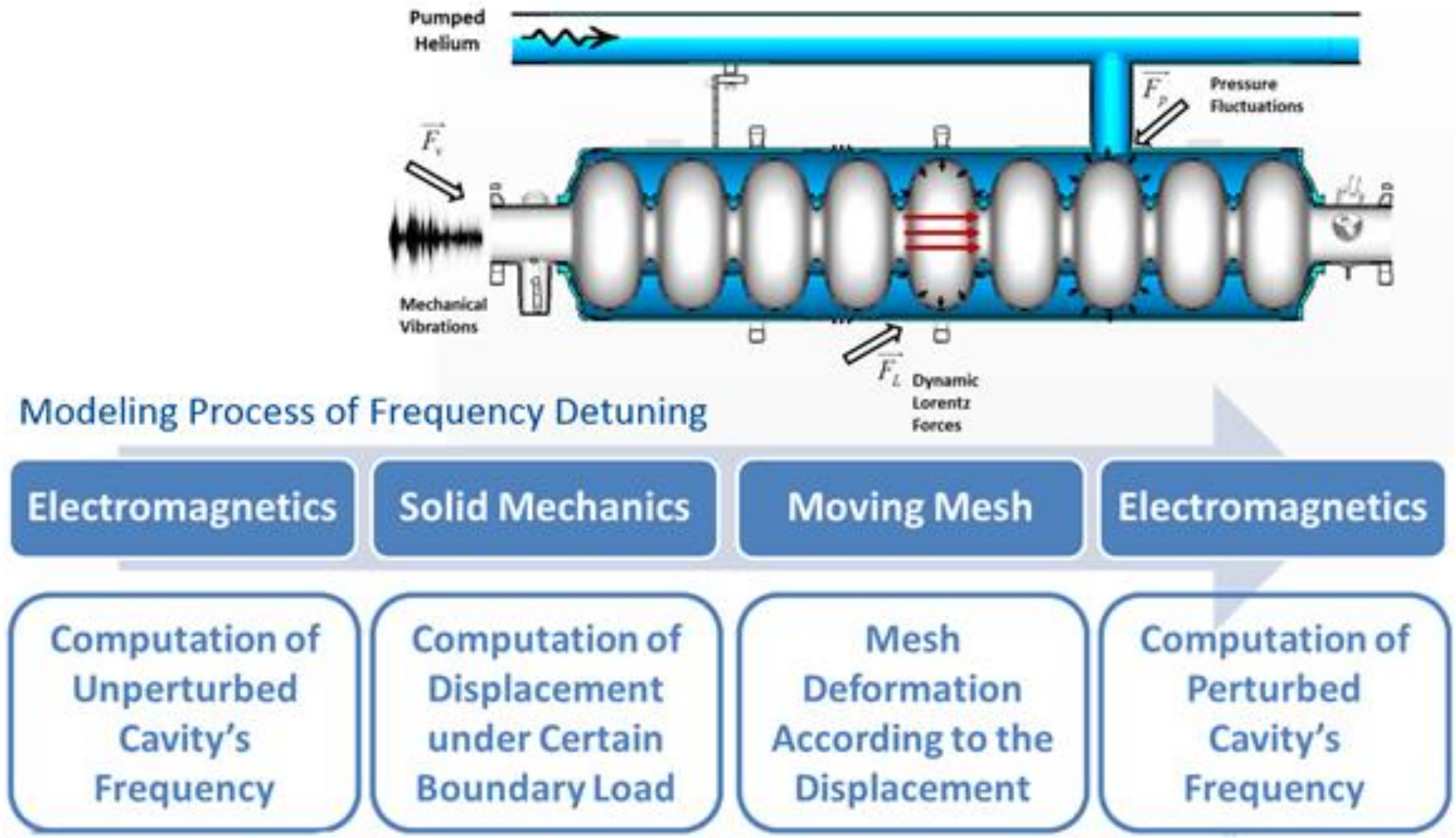




Fermilab

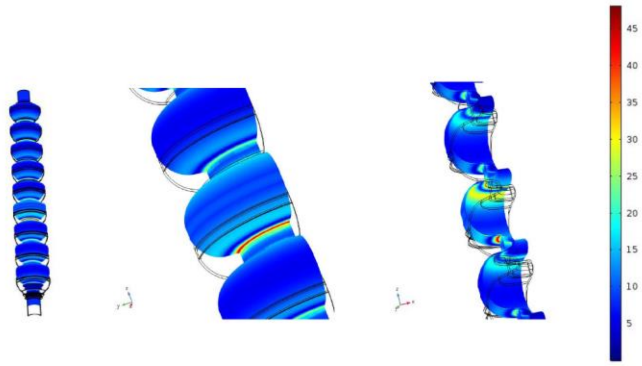
COMSOL Multiphysics Simulations

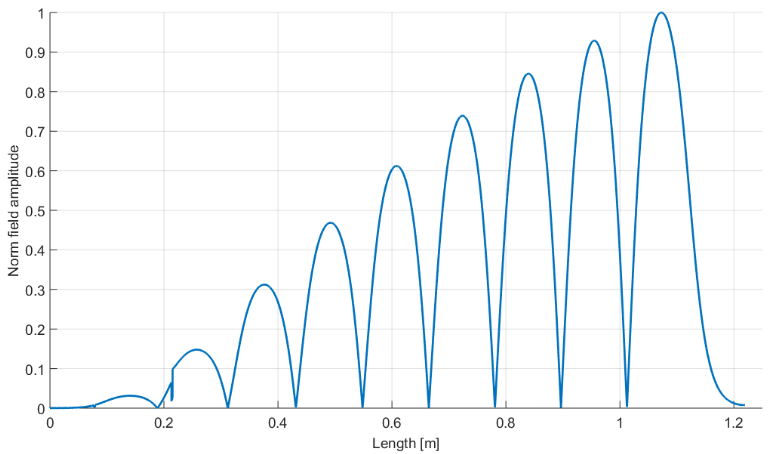
- FE analysis in order to validate the concept



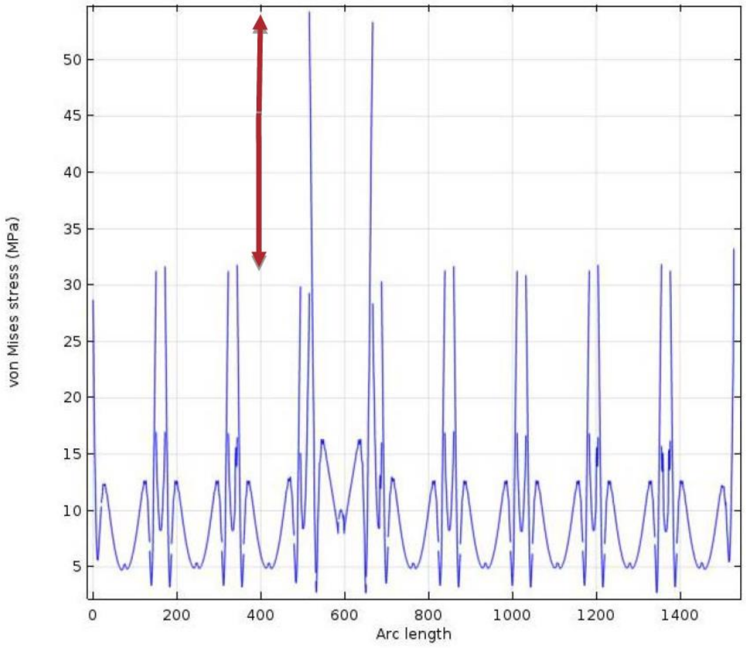
Courtesy : FermiLab

COMSOL Multiphysics Simulations

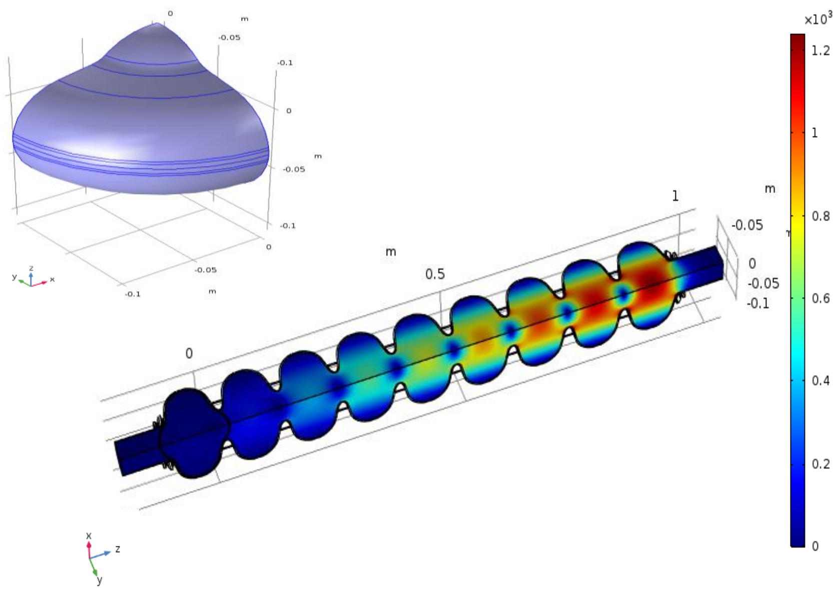




- Stress spikes localized on cell iris

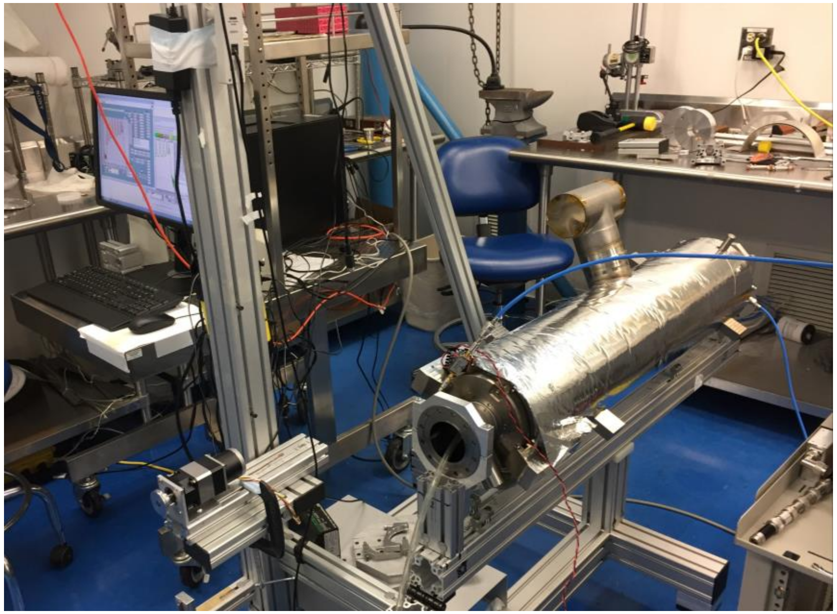


- Balloon modelling via COMSOL

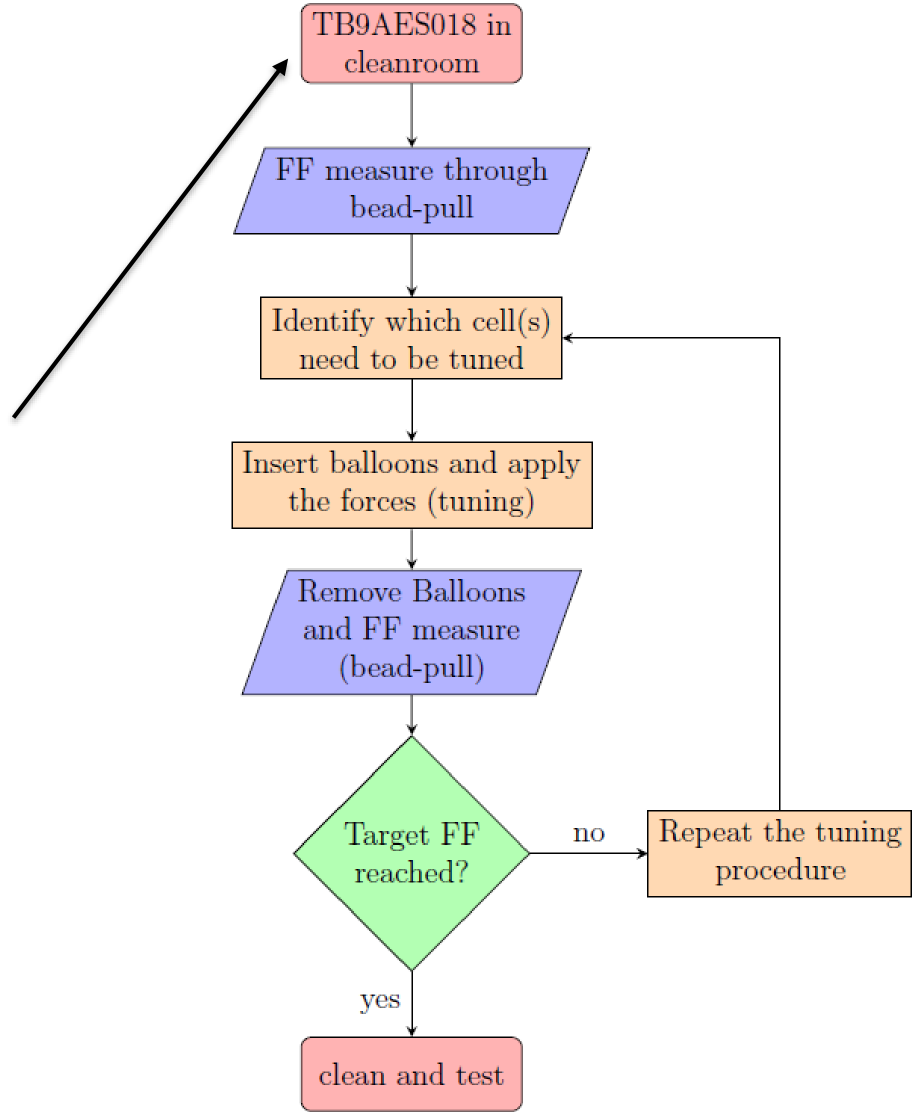


Fermilab

Balloon Tuning procedure

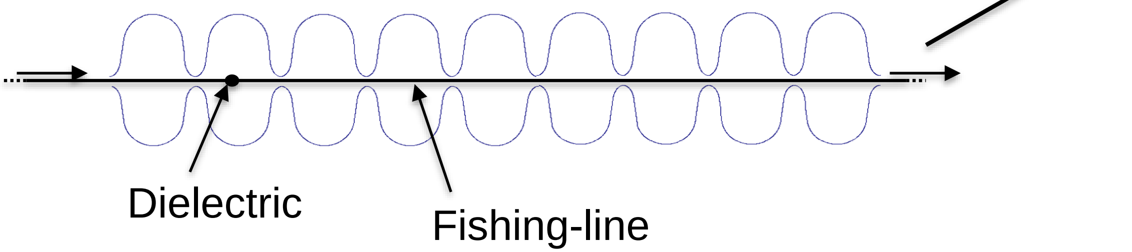


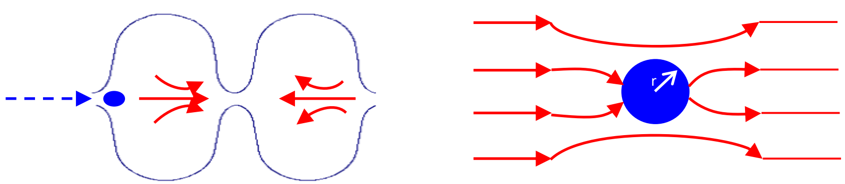
TB9AES018 on the stand in cleanroom



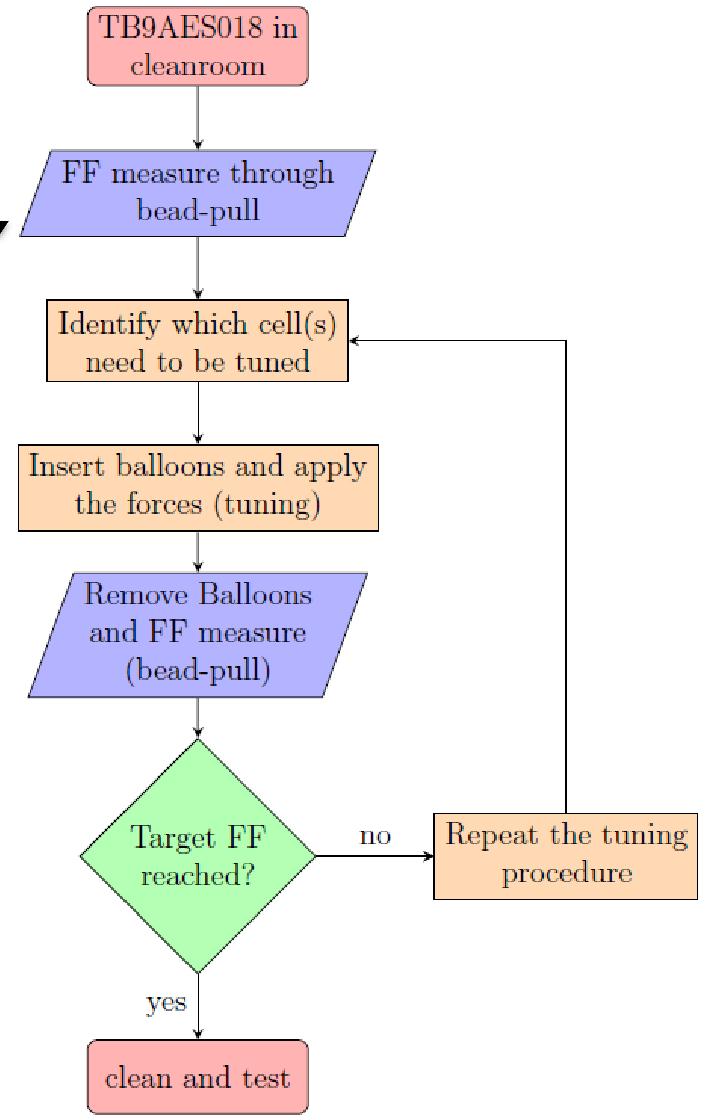
Balloon Tuning procedure

Bead-pulling measurement system:

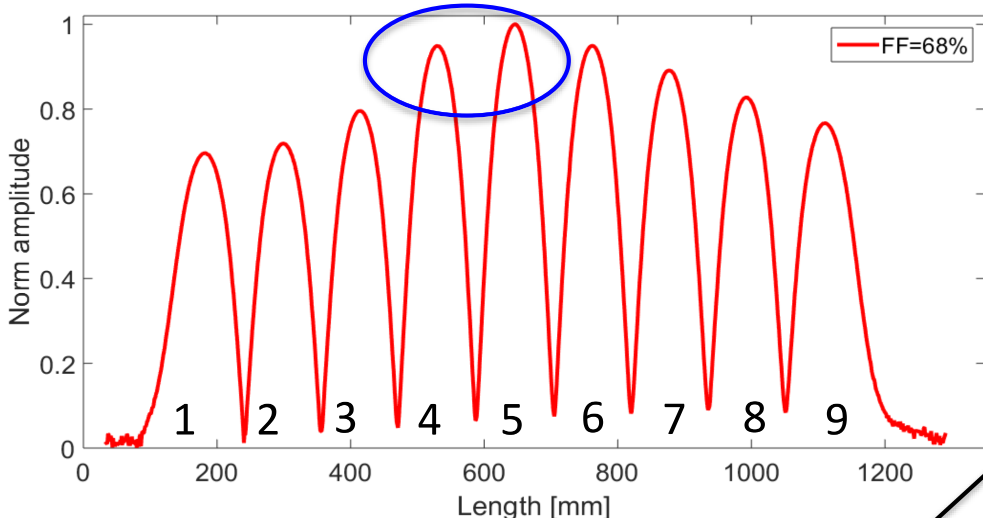


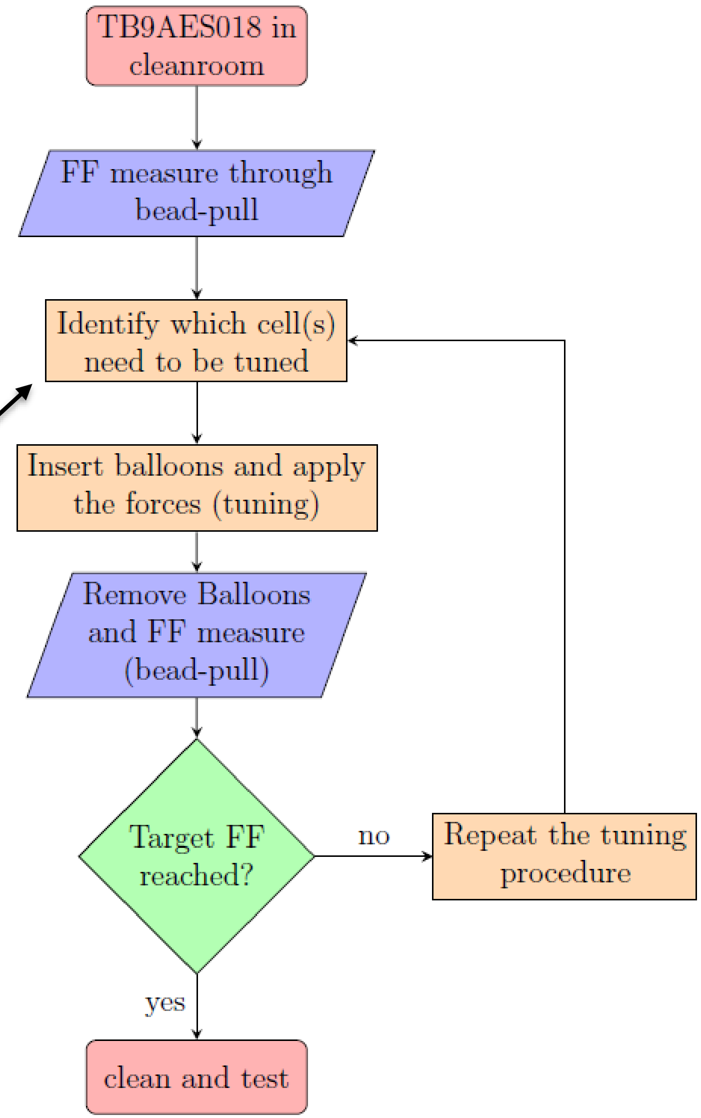


Field “sampled” by introducing a perturbing object and measuring the change in resonance frequency



Balloon Tuning procedure





Initial conditions:

$$f_0 = 1298.129 MHz$$

$$FF = 68\%$$

LCLS-II specs:

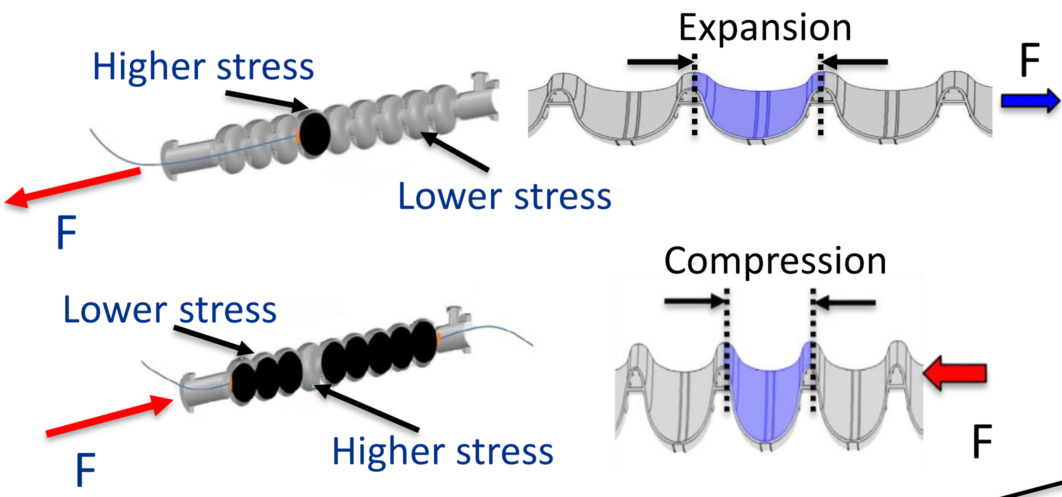
$$f_0 \simeq 1297.95 MHz$$

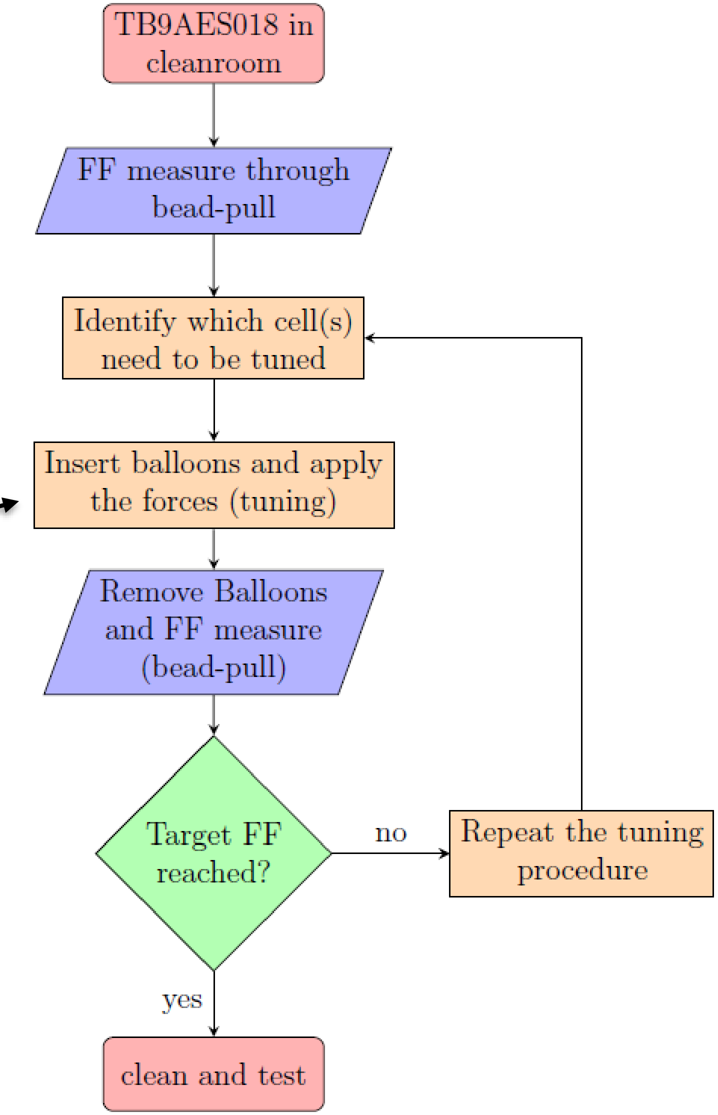
$$FF \geq 90\%$$

Compress cell 4 and 5 : this decrease both f_0 and amplitude

Fermilab

Balloon Tuning procedure



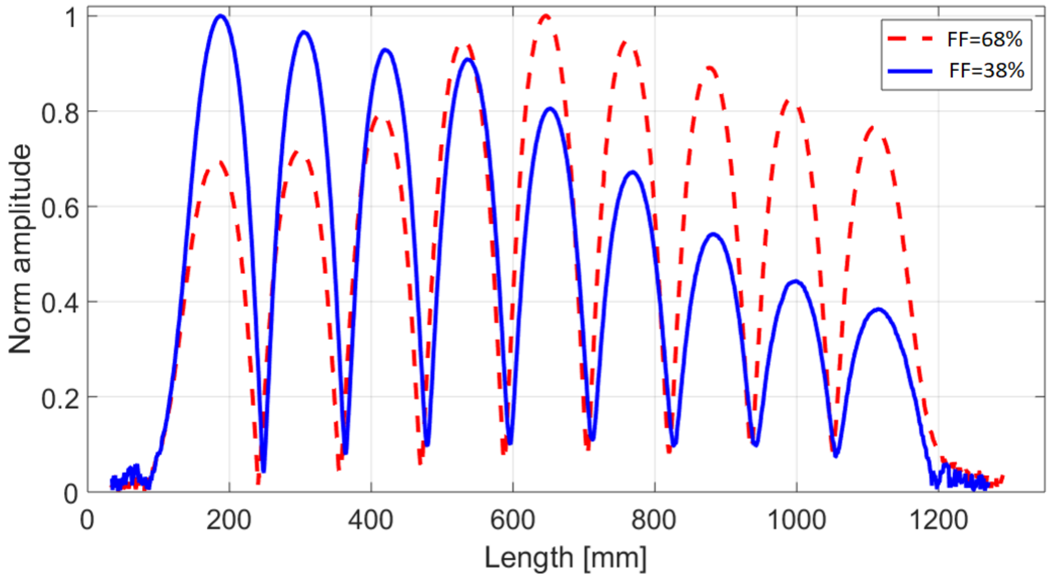


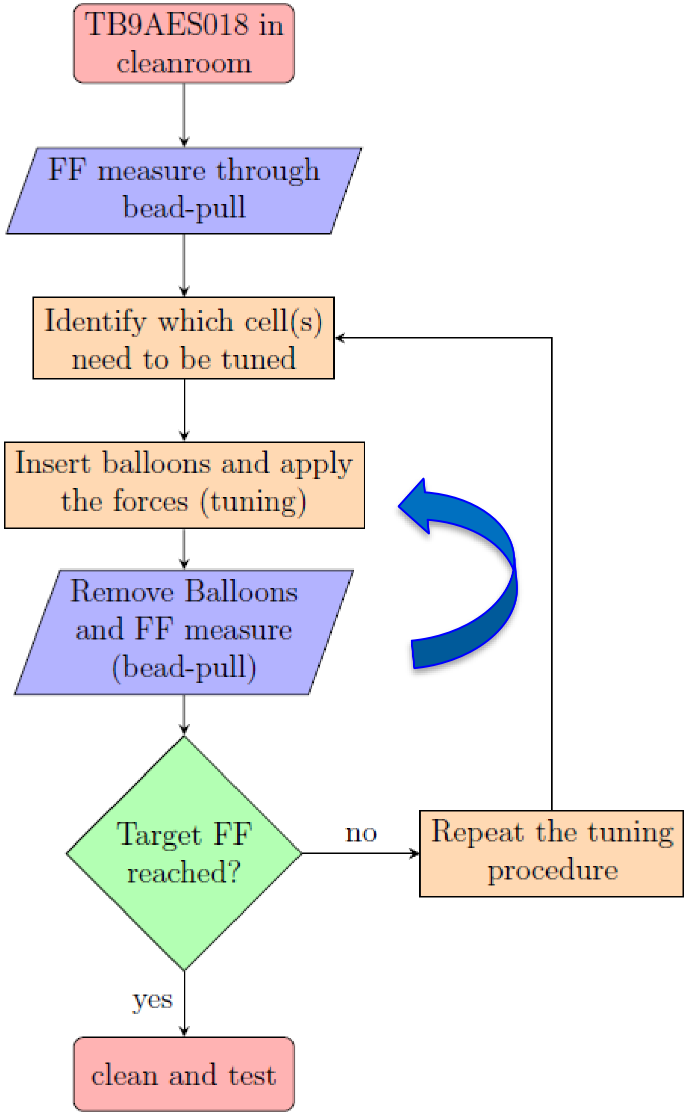
Three cells balloon

Balloon inside the cavity

Balloon Tuning procedure

Tuning iterations:





<u>Compressing</u> cells 4 and 5

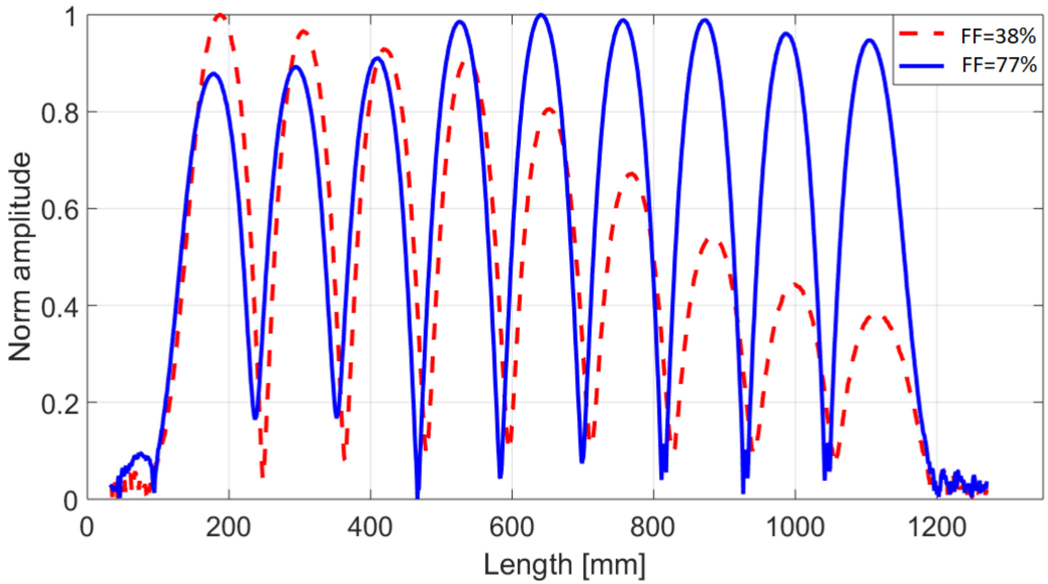
- Decreasing slope → on purpose
- Stretching the end cells (7,8 and 9) the FF can be almost doubled

Balloon Tuning procedure

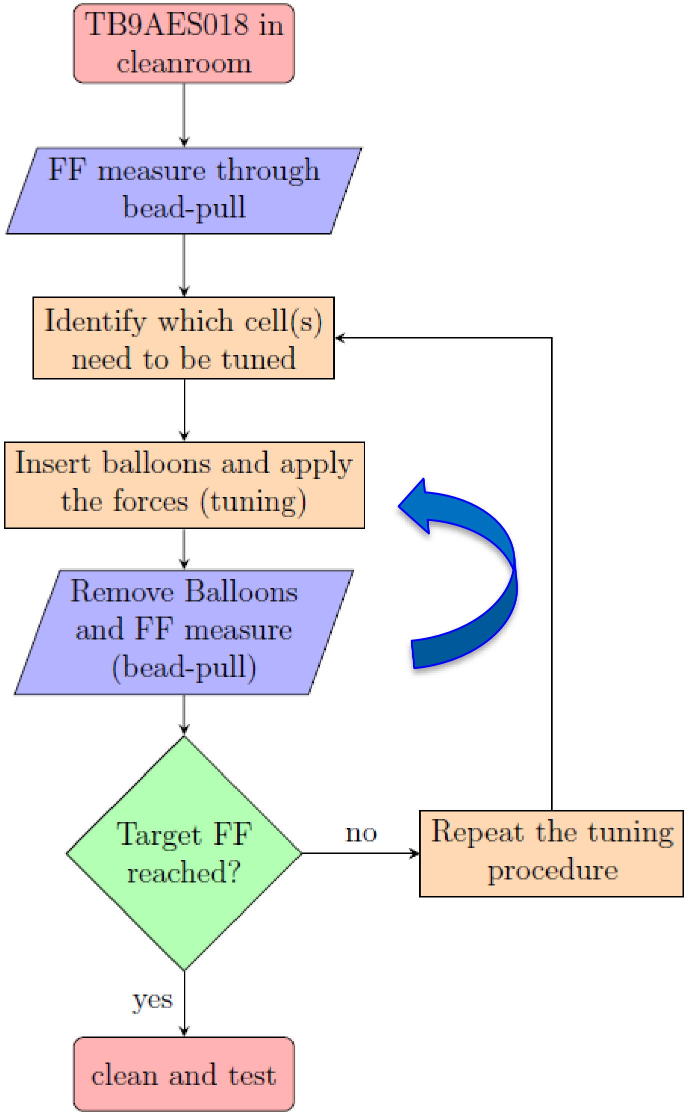
Tuning iterations:

$FF = 38\%$ before stretching

$FF = 77\%$ after stretching

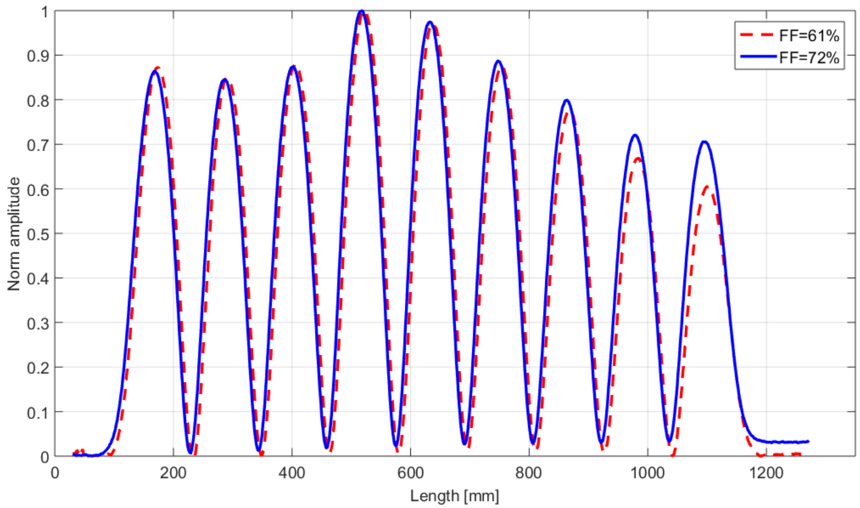


Stretching cells 7, 8 and 9

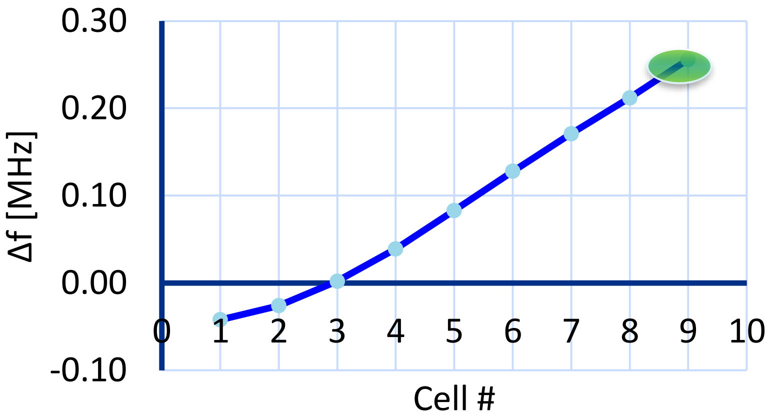


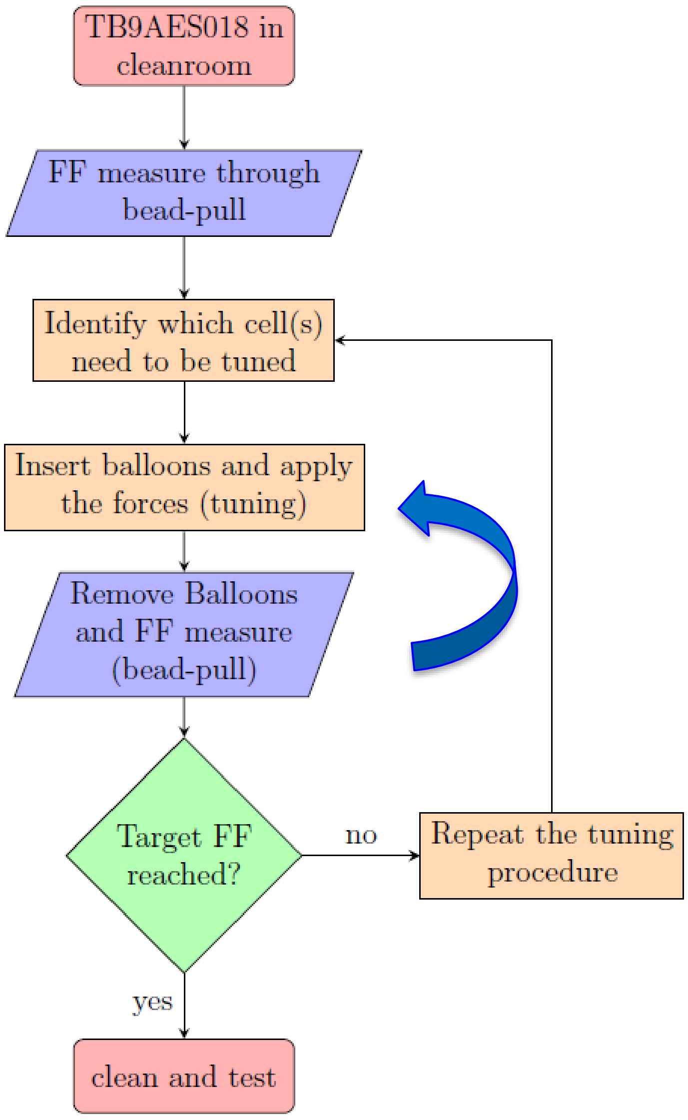
Balloon Tuning procedure

Tuning iterations:



stretching cell number 9

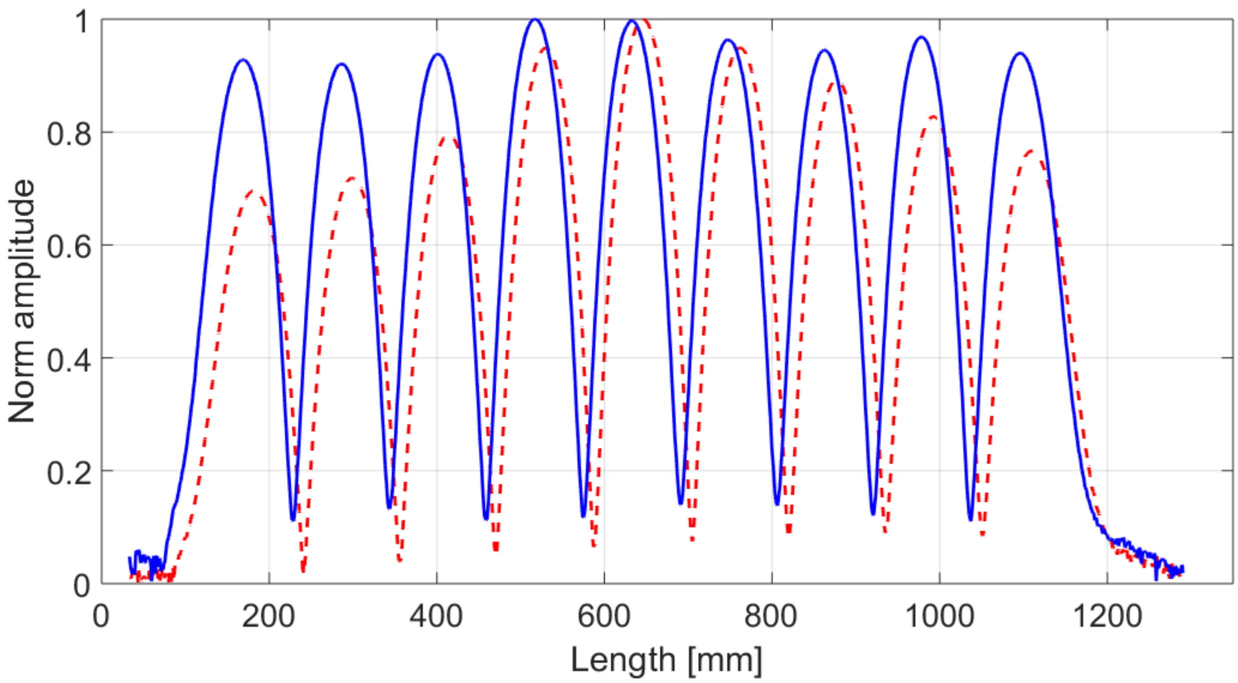




TB9-AES018 successfully fixed

$$f_0 = 1297.989 MHz \quad FF = 68\% \quad (red)$$ Before tuning

$$f_0 = 1297.924 MHz \quad FF = 92\% \quad (blue)$$ After tuning



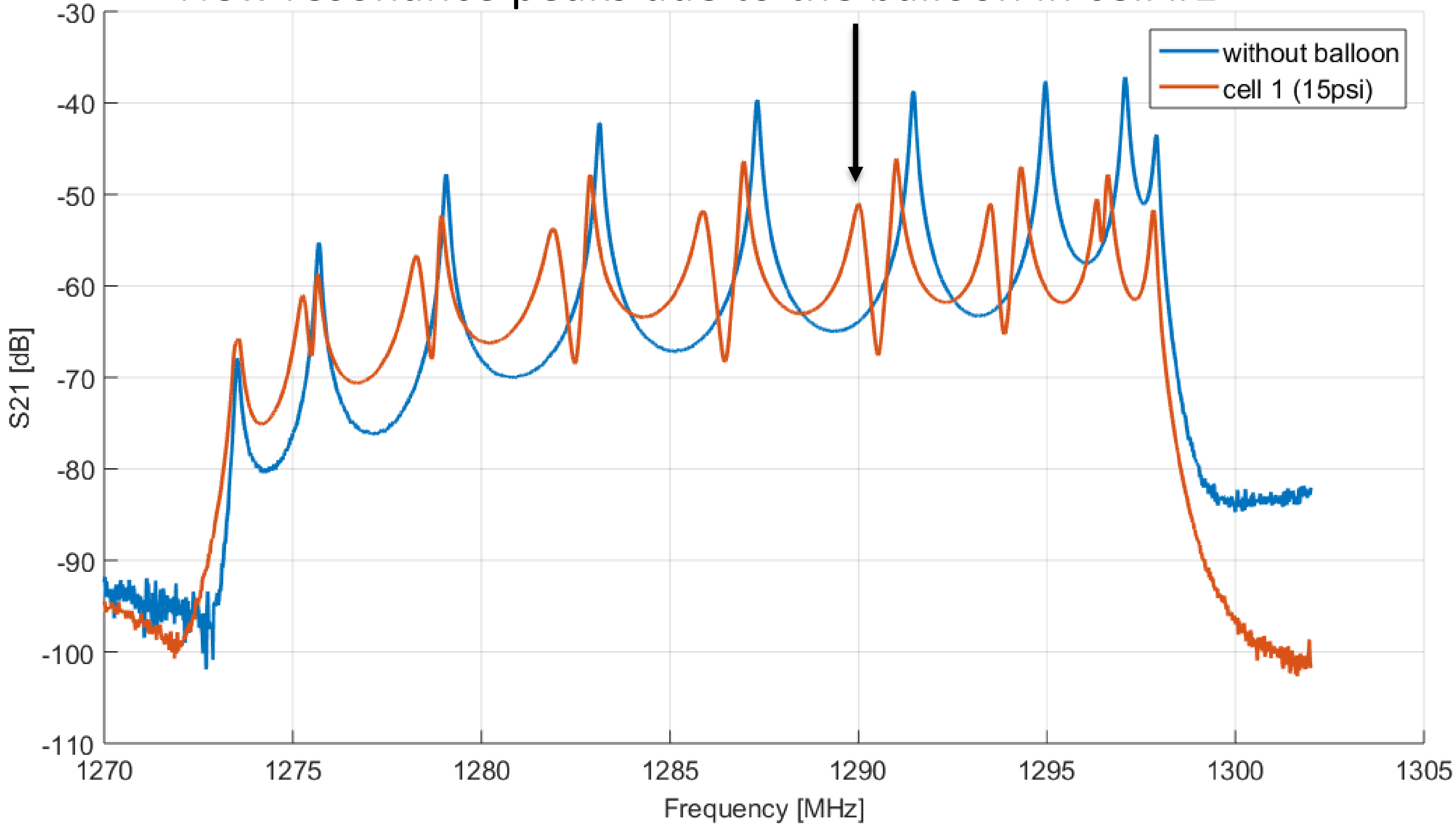
Resonant frequency and **field flatness** meet the LCLS-II specifications!

LCLS-II specifications: $FF \geq 90\%$ and $1297.91\ MHz < f_0 < 1298.01\ MHz$

Transmission measurements (S21)

Measure of the cavity sensitivity when the balloon is placed inside the cavity and inflated at 15psi

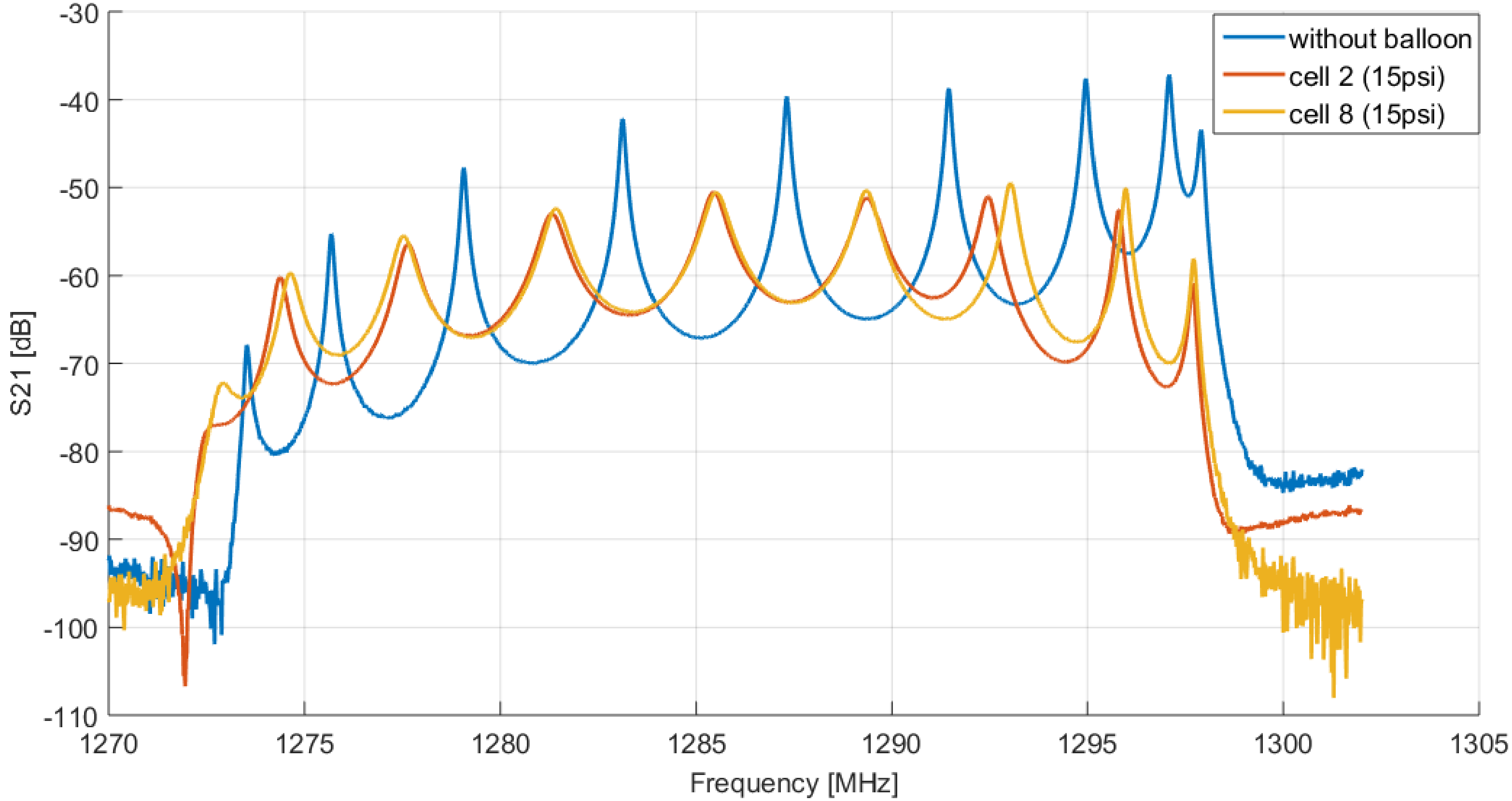
New resonance peaks due to the balloon in cell #1



Transmission measurements (S21)

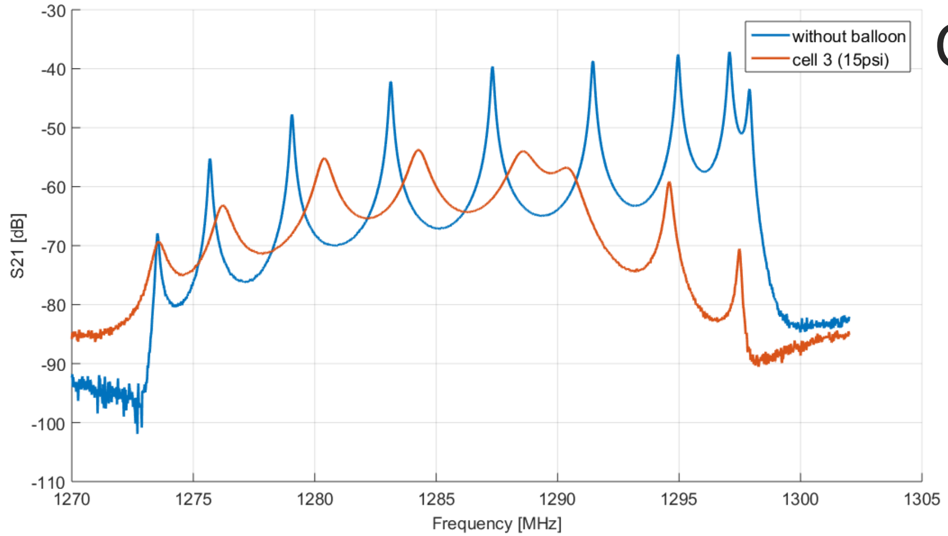
Measure with balloon in cell #2 and #8

- S21 show a symmetric behavior

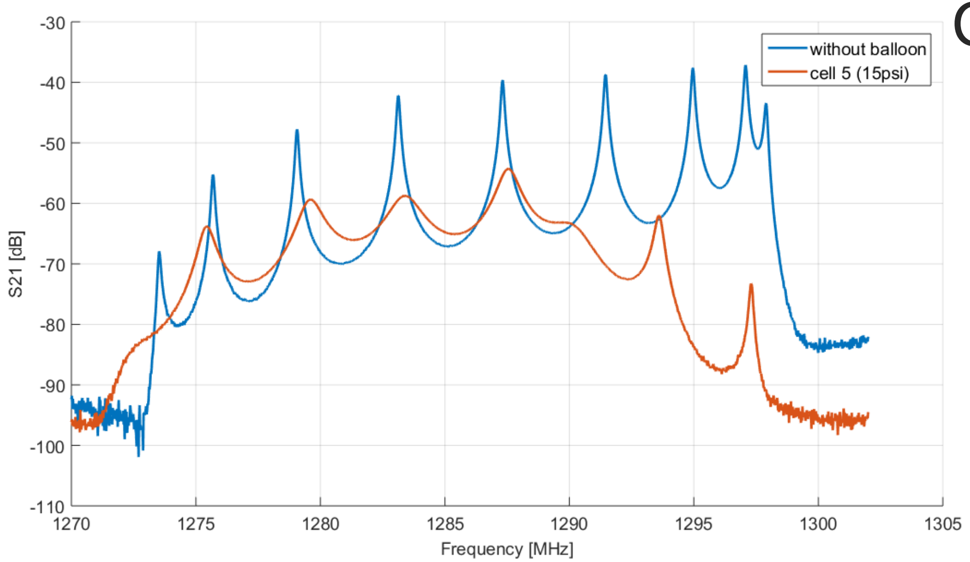


Transmission measurements (S21)

Middle cells (3 and 5) are more sensible to the insertion of balloon



Cell 3

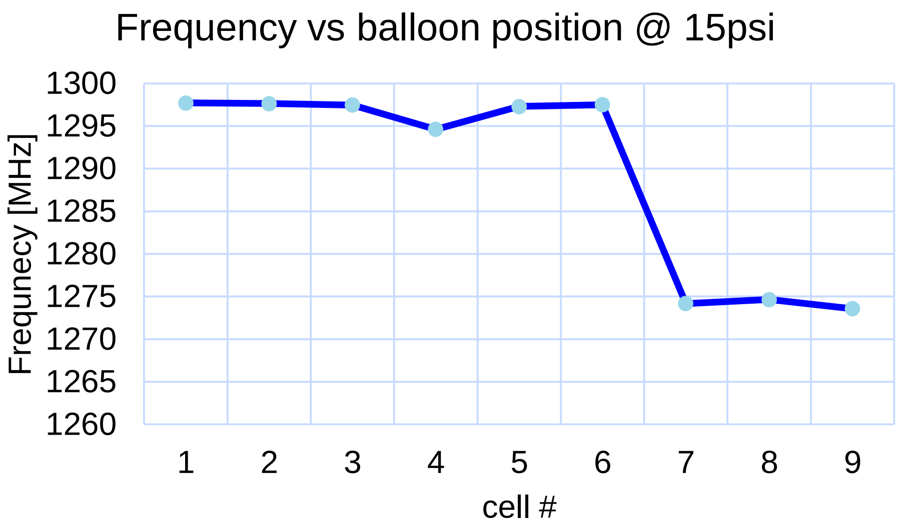


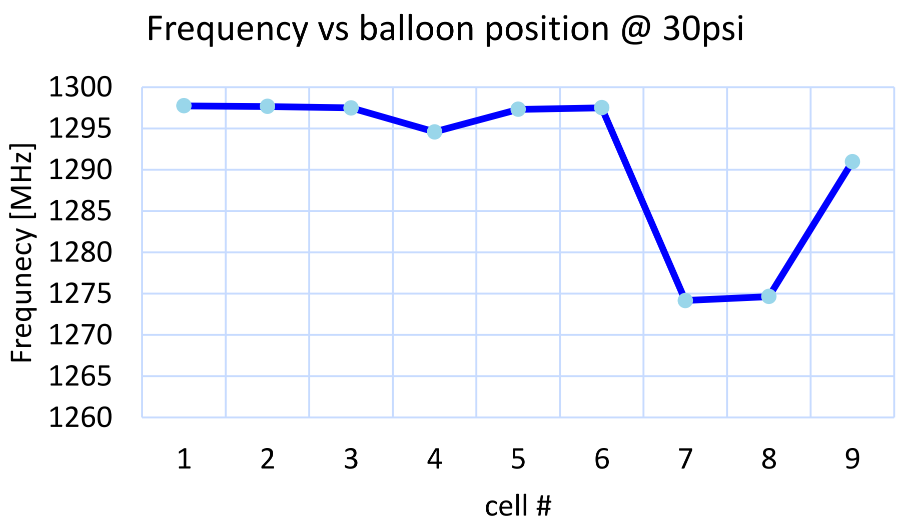
Cell 5

Frequency vs balloon position

- Pi-mode frequency changes due to the single cell balloon

- The frequency has been measured 9 times with the single cell balloon in different cells



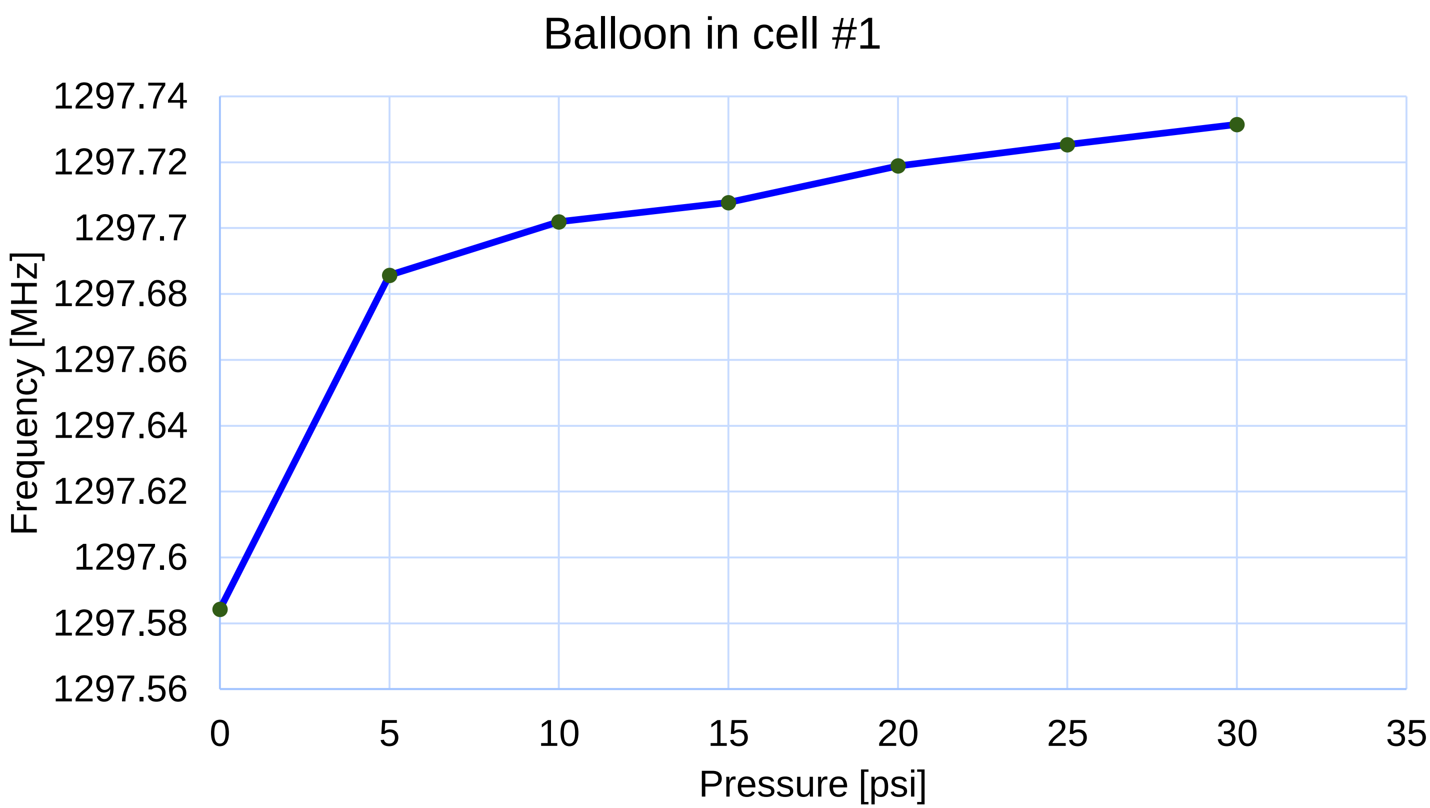


Fermilab

Frequency vs balloon pressure

The frequency of resonance changes due to the pressure of the balloons placed inside the cell #1

Goal: better understand the relationship between frequency and balloon



Summary:

Achievements:

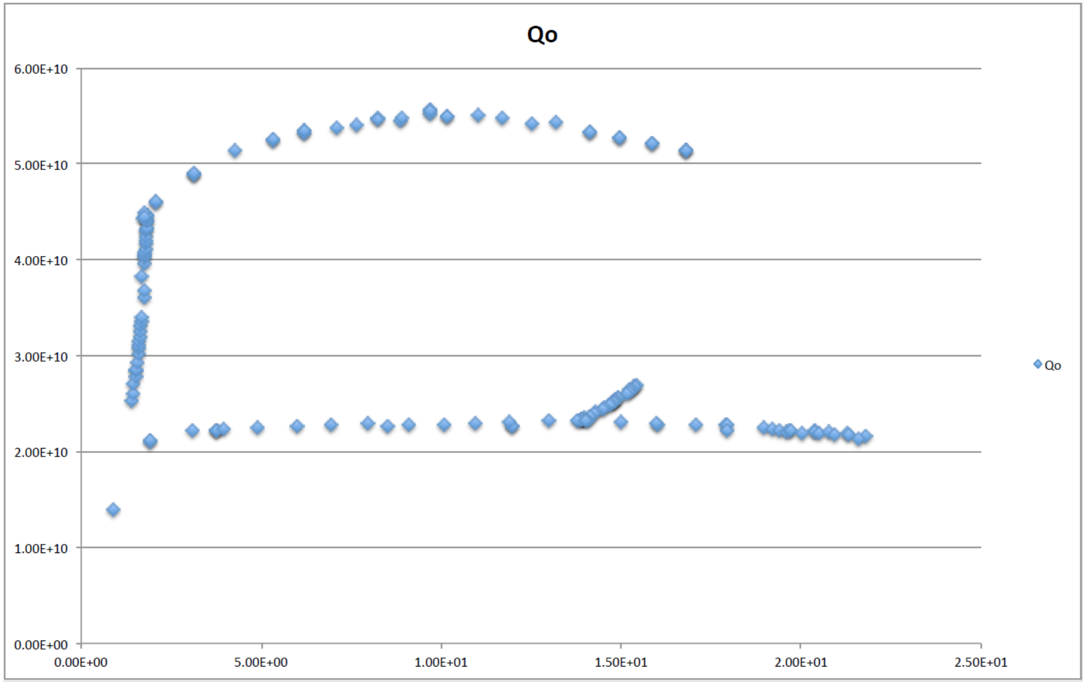
- TB9-AES018 meets the LCSL-II specifications
- Prove of the Balloon Tuning Technique concept
- This can blaze the trial for a great variety of new applications and impact the entire know how of manufacturing and qualifying multi-cell SRF cavities at FermiLab

Summary:

Future work:

- Measure Q vs gradient (VTS) to get the cavity qualified

<u>Goal</u>: determine if the Balloon Tuning Technique has not deteriorated the cavity performances

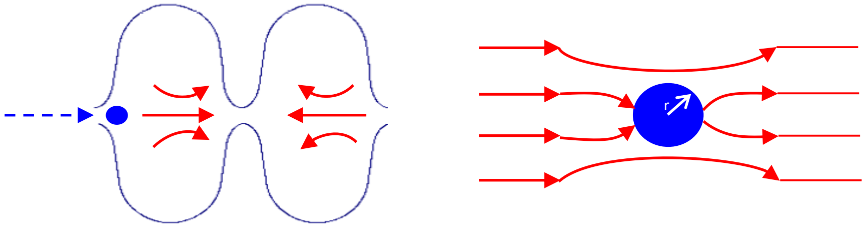


Back-up slides

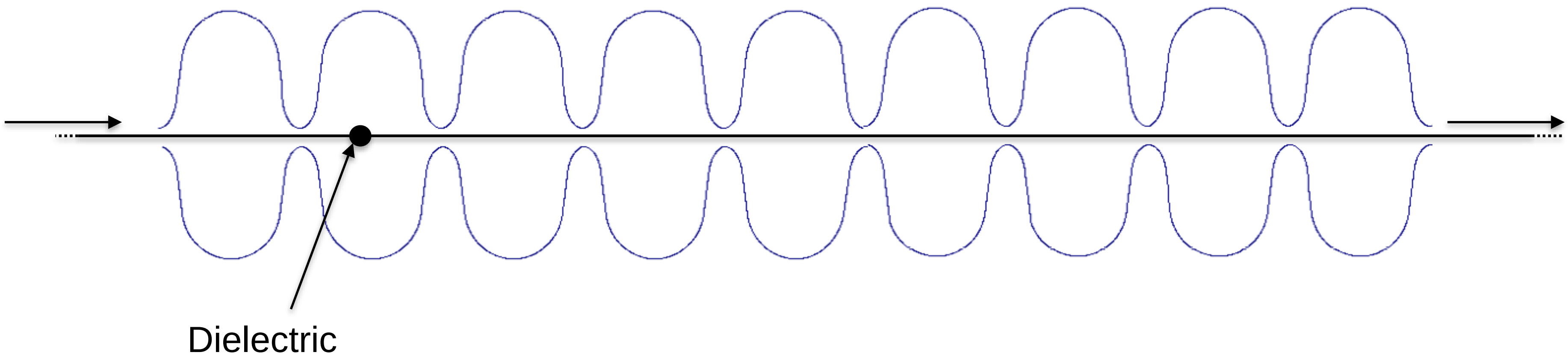
Bead-pull measurements

- In manufacturing or tuning multi-cell cavities it is required to investigate the field profile inside the cavities

Field “sampled” by introducing a perturbing object and measuring the change in resonance frequency



Bead-pulling measurement system:



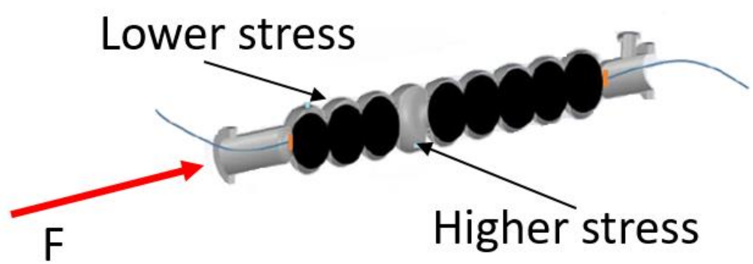
Fermilab

BTT concept : cell compression

Cell compression leads to decrease both f_0 and FF

Deflated balloons are folded and placed in all cell, apart the target cell

Once inside the balloons are pressurized and a compression force is applied by the tuner to one flange

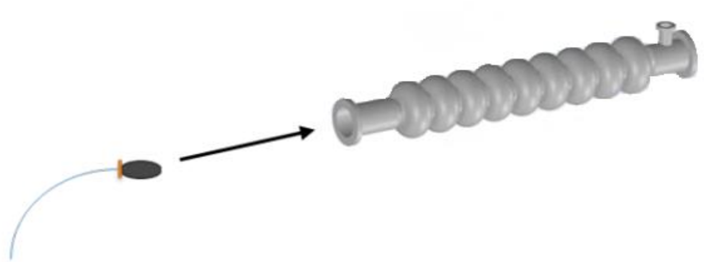


The target cell get plastically deformed and the other cells remain in the linear elastic region because of a lower stress state.

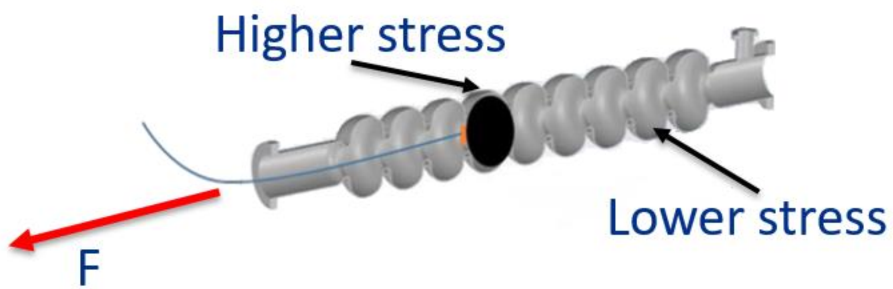
BTT concept : cell expansion

Cell expansion leads to increase both f_0 and FF

Deflated balloon is folded and placed only in the target cell

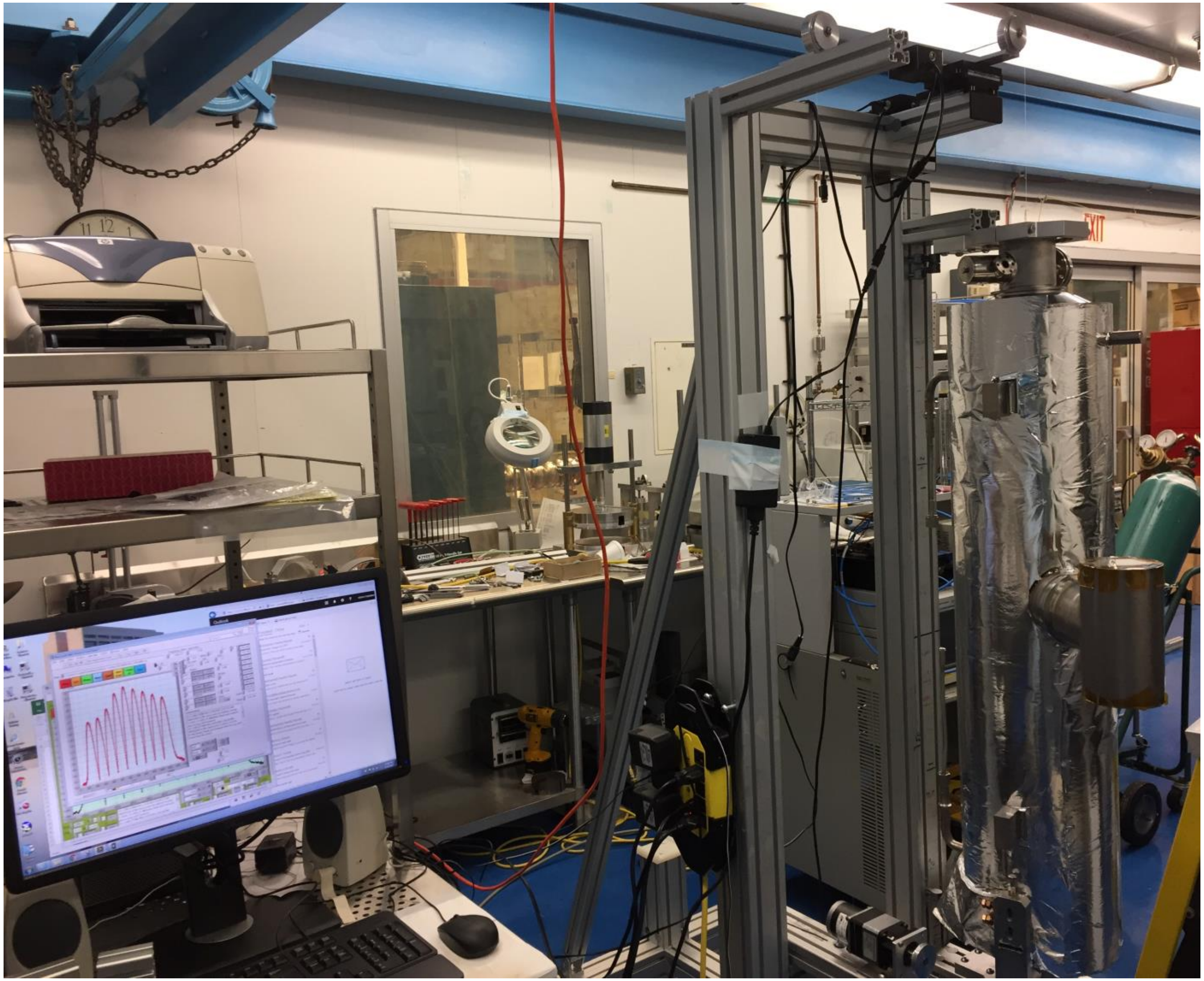


Once inside the balloon is pressurized and a traction force is applied by the tuner to one flange



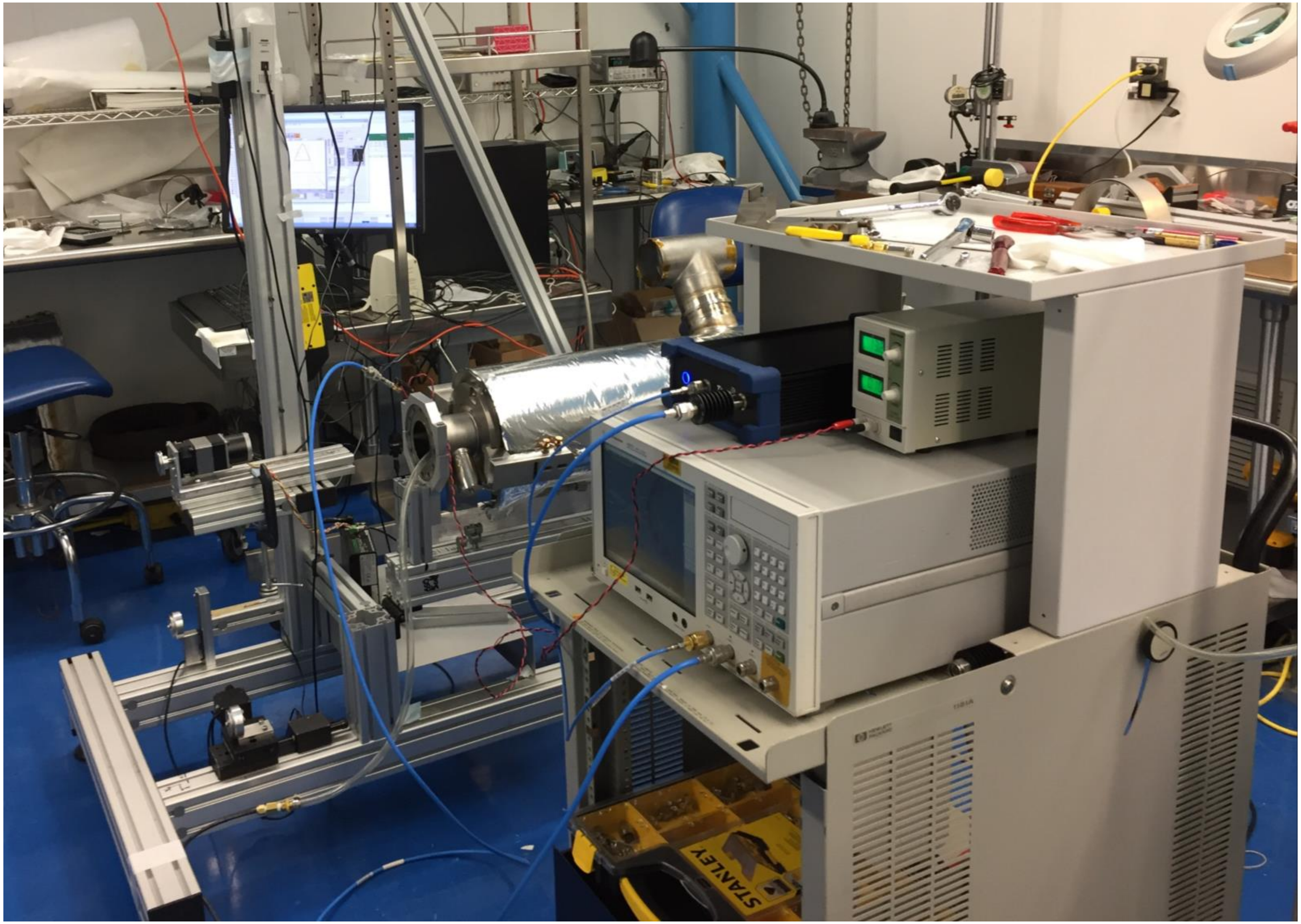
The target cell get plastically deformed and the other cells remain in the linear elastic region because of a lower stress state.

Back-up slides - Bead-pull measure



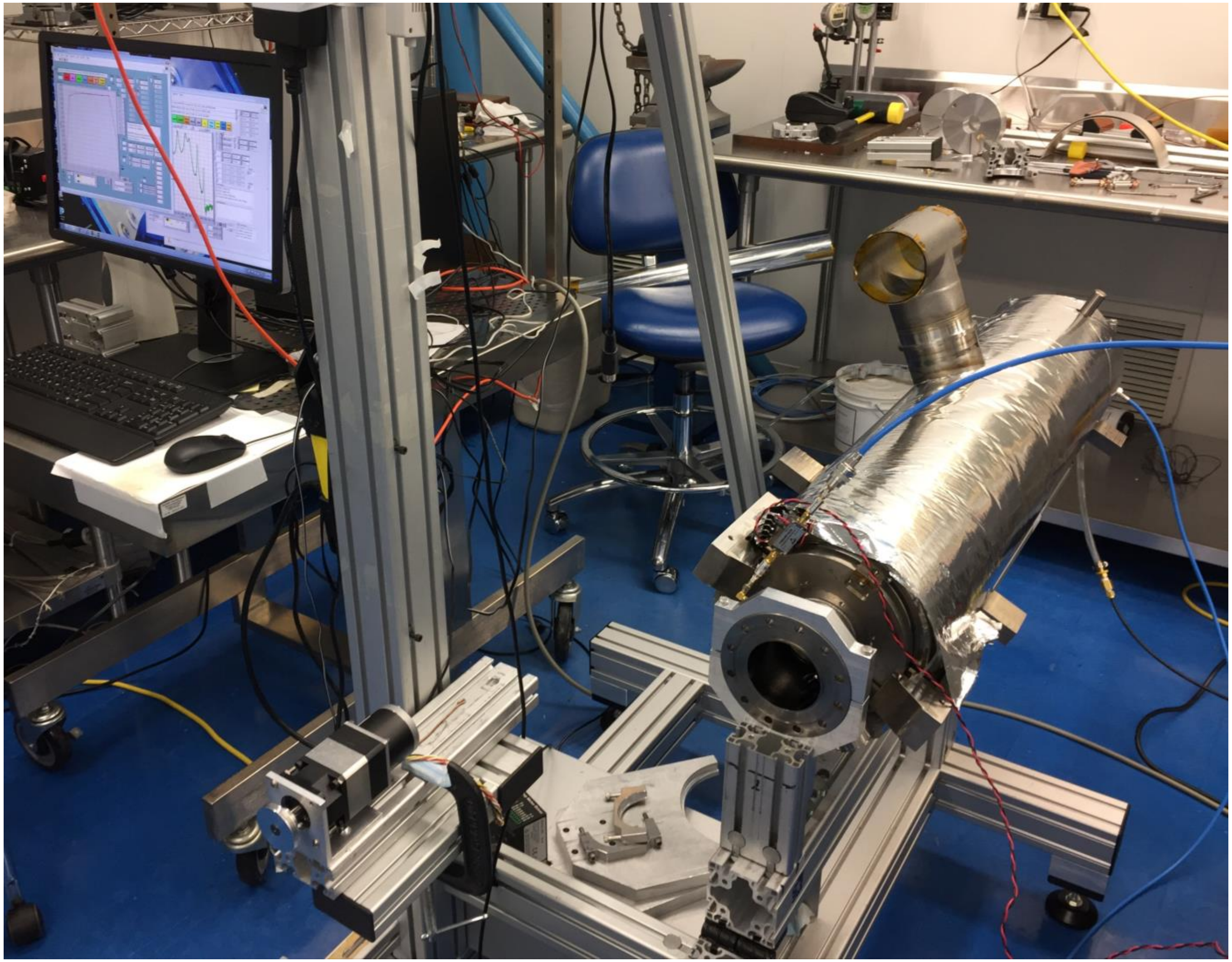
Bead-pull measurement system

Back-up slides – tuning set-up



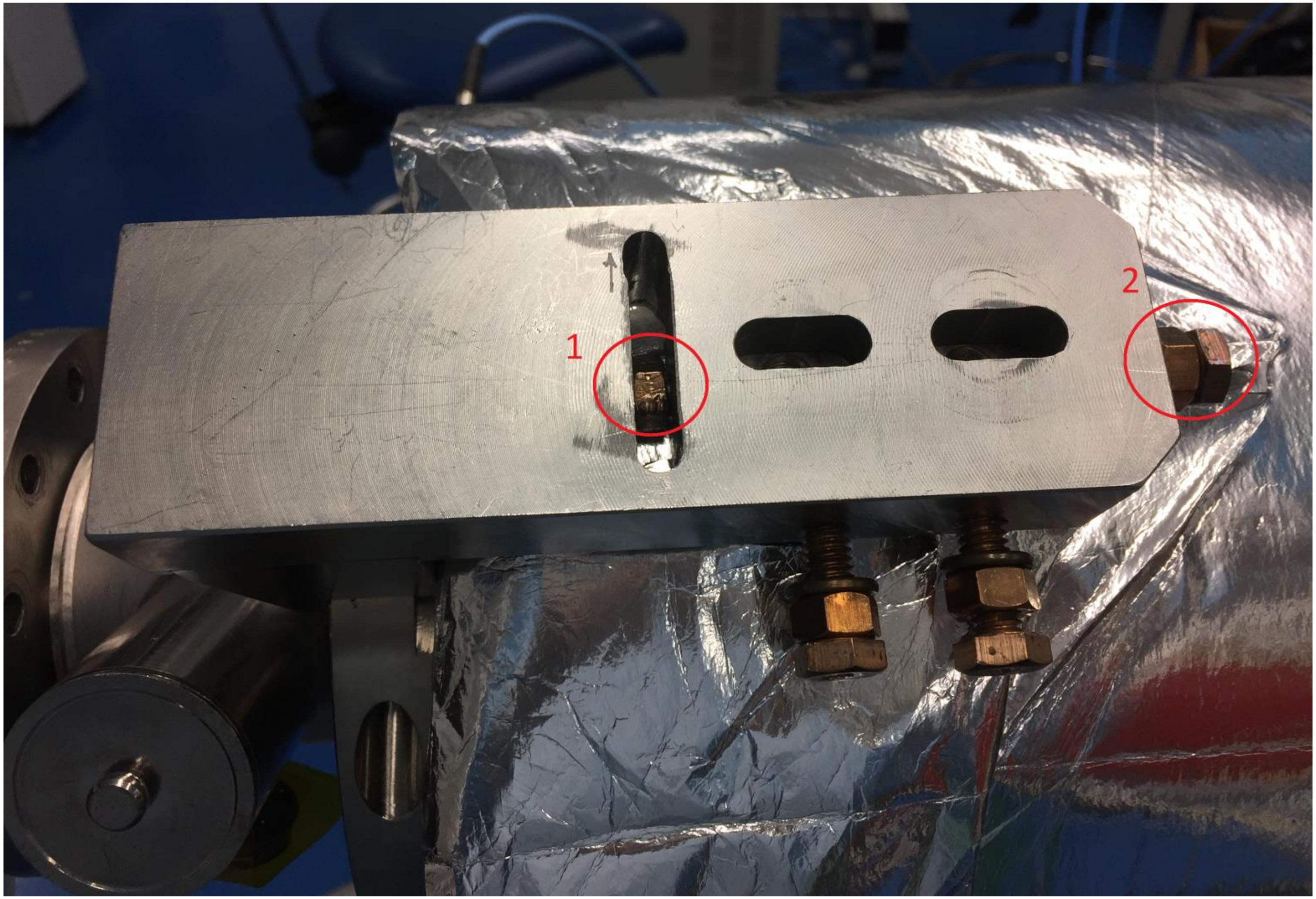
Tuning system set-up

Back-up slides – tuning set-up



Tuning system set-up

Back-up slides – clamps



Clamp used to stretch [1] and to compress [2] the cavity

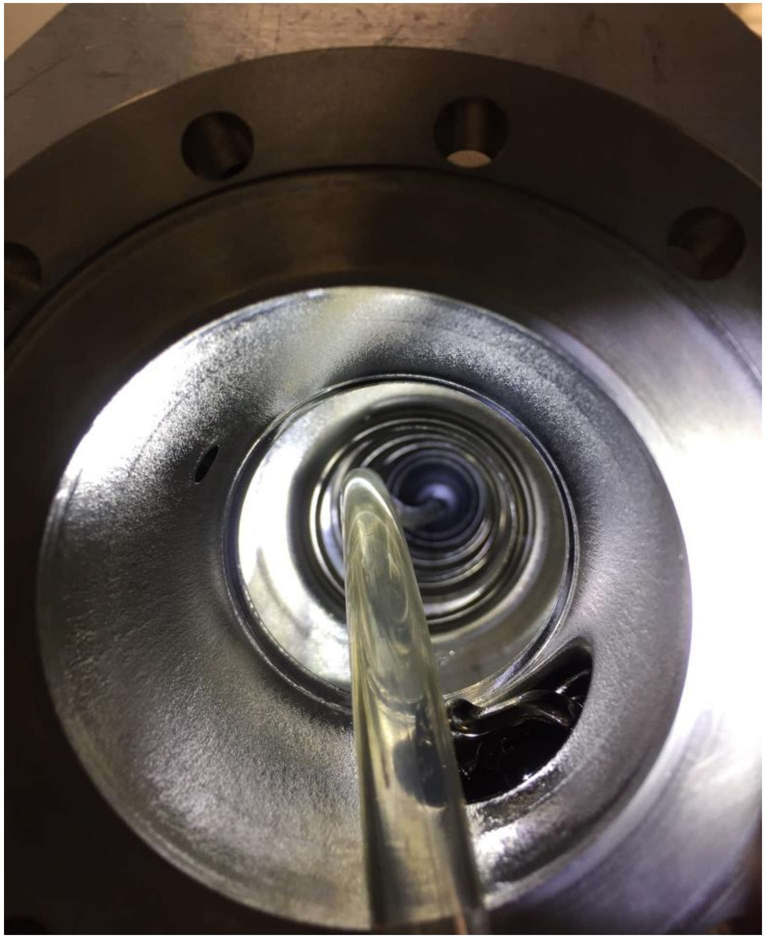
Back-up slides – single cell balloon

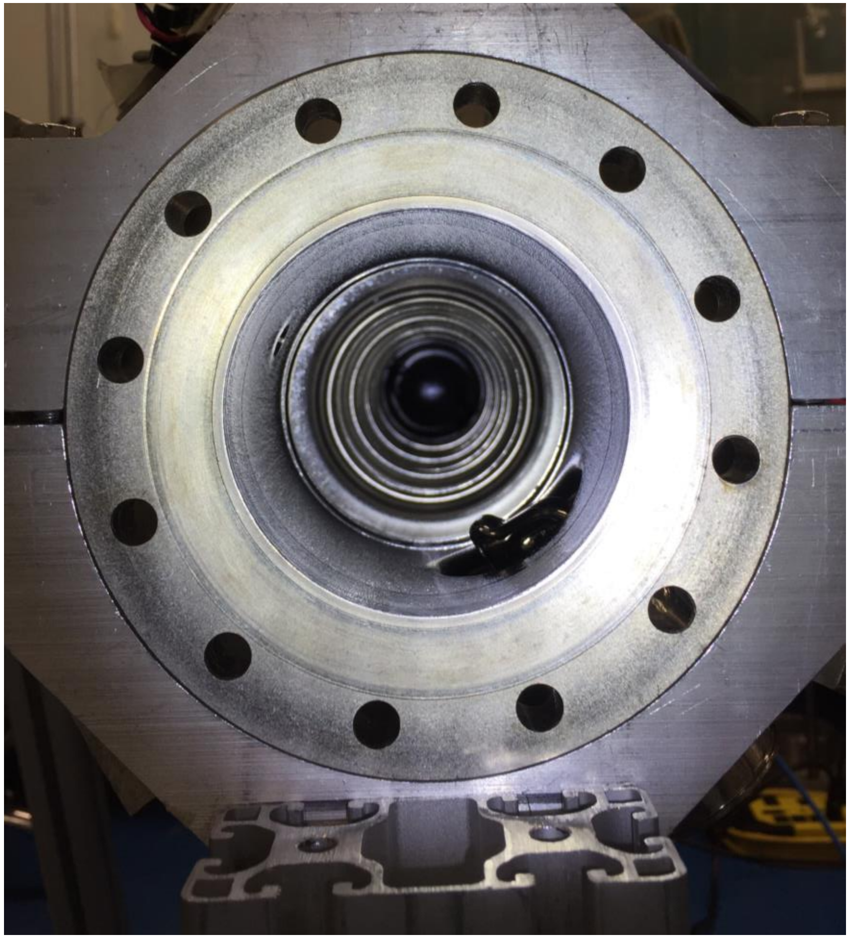
Single cell balloon

Five cells balloon

Three cells balloon

Back-up slides – Balloon inside the cavity





Single cell balloon inside the cavity