Study
of
Dielectric Loaded RF Cavity

MAP meeting - September 23, 2011

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CONTENTS

Achieved during my summer program

WHY A DIELECTRIC LOADED RF CAVITY?

MUON ACCELERATOR

OBJECTIVE: muons production, beam formation and acceleration within few milliseconds

POSSIBLE SOLUTION: helical cooling channel (=>RF structure inside a solenoid)

CONSEQUENT REQUIREMENTS FOR RF CAVITY:

- short length
- high electric field gradient (>20MV/m)
- small radial dimension
- first mode of resonance matched with external power source (Fermilab klystrons: 800 MHz)

But:

$$f \propto \frac{1}{R}$$

So:

Standard vacuum cavity DOESN'T work!

Why a Dielectric Loaded RF cavity? (2)

INSERTION OF DIELECTRIC MATERIAL ⇨ same frequency, smaller radius

PILLBOX CAVITY

$$R = \frac{2.405c}{2\pi f_{TM010}\sqrt{\varepsilon_r \mu_r}}$$

[ε_r: relative dielectric permittivity
μ_r: relative magnetic permeability]

→ GOAL: large ε_r

But also ⇨ lower quality factor

CAVITY COMPLETELY FILLED WITH DIELECTRIC

$$\frac{1}{Q} = \frac{P_{wall} + P_{diel}}{\omega W} = \frac{1}{Q_{wall}} + \frac{1}{Q_{diel}}$$

where:

$$Q_{diel} = \frac{\varepsilon'}{\varepsilon''} = \frac{1}{tg\delta}$$

[ε': real part of dielectric constant
ε'': imaginary part of dielectric constant]

→ GOAL: $tg\delta < 10^{-4}$

Analysis of two **main parameters:**

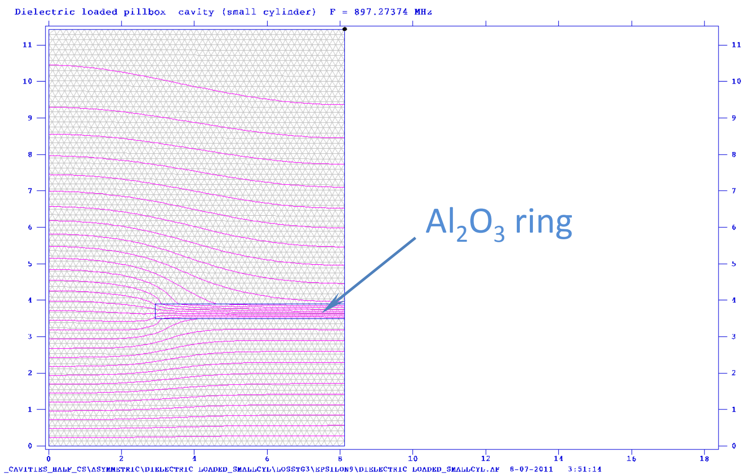
- Resonance frequency
- Quality factor

Conditions considered:

- **Standard** - low power, room temperature
- **Cryogenic** - low power, cryogenic temperature (T=77K)
- **High power**

Means of the analysis:

Simulation in Superfish

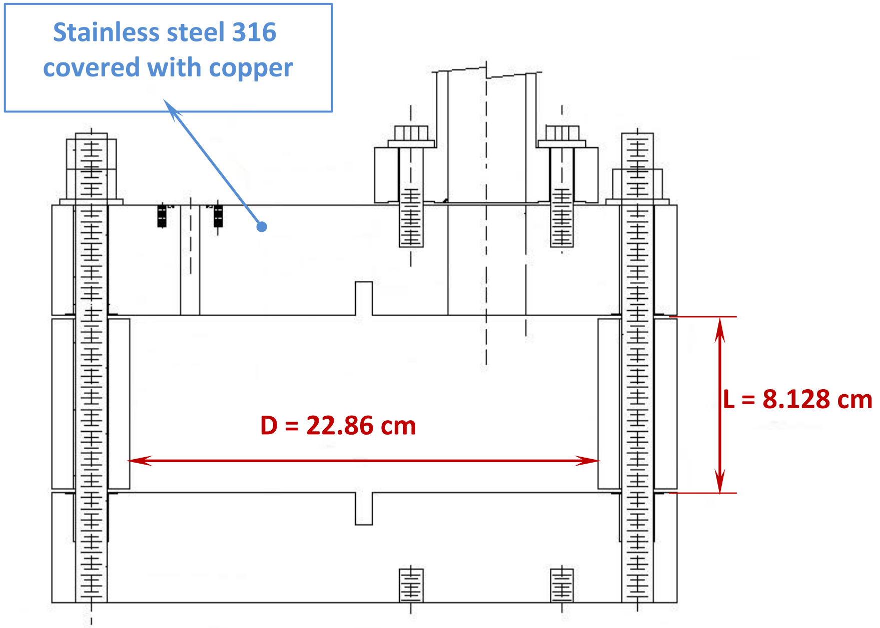


→ E field direction

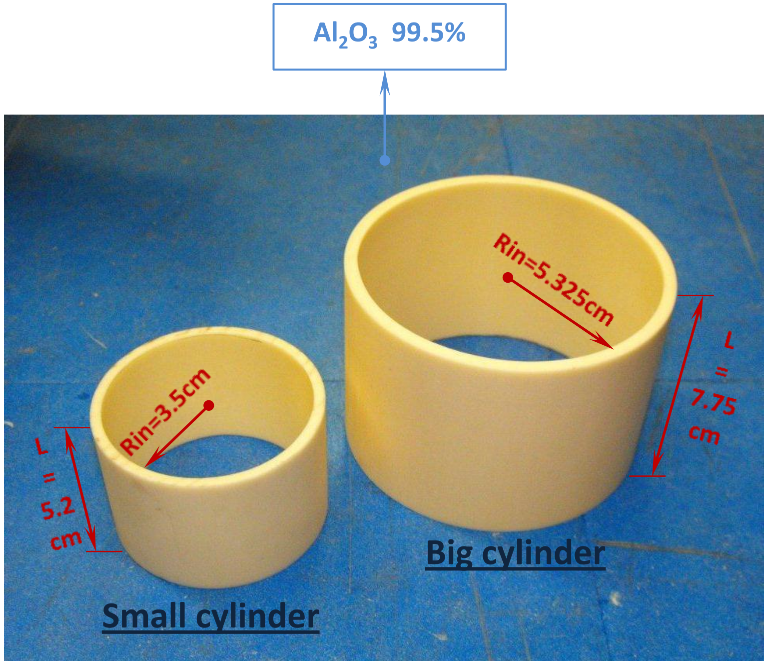
Real Tests

FOR REAL TESTS

PILLBOX CAVITY



DIELECTRIC RINGS

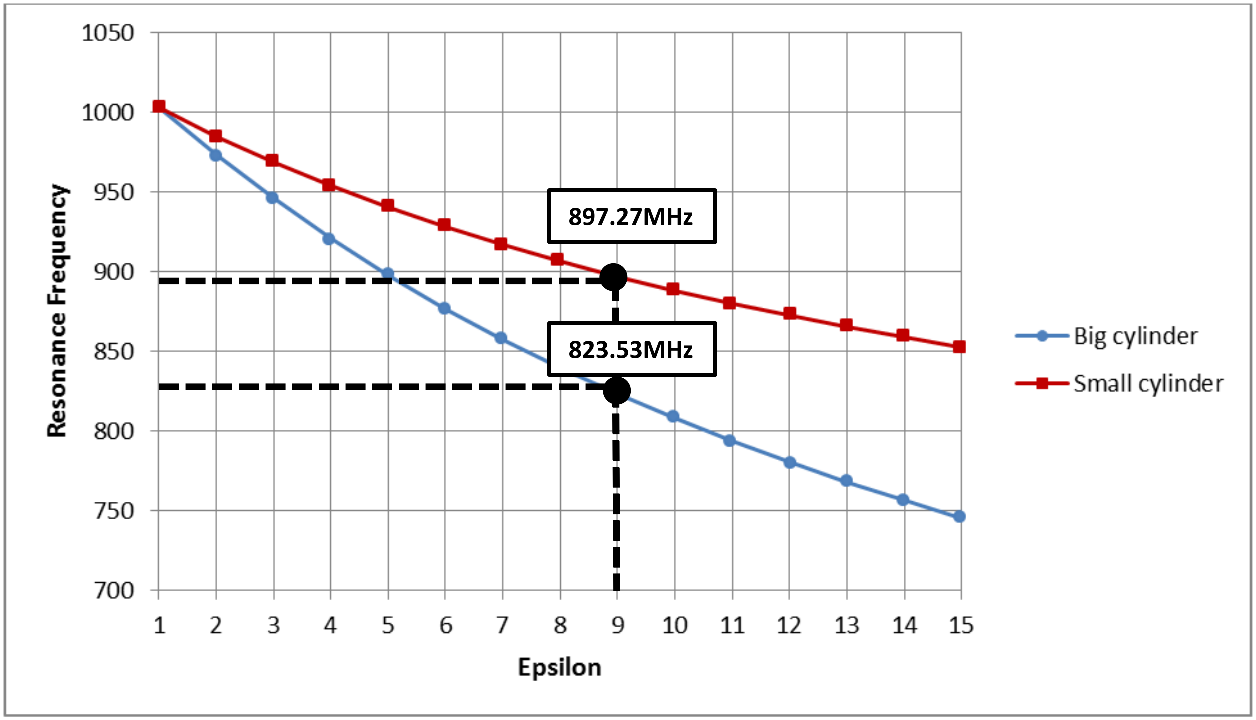


STANDARD CONDITION - SIMULATION

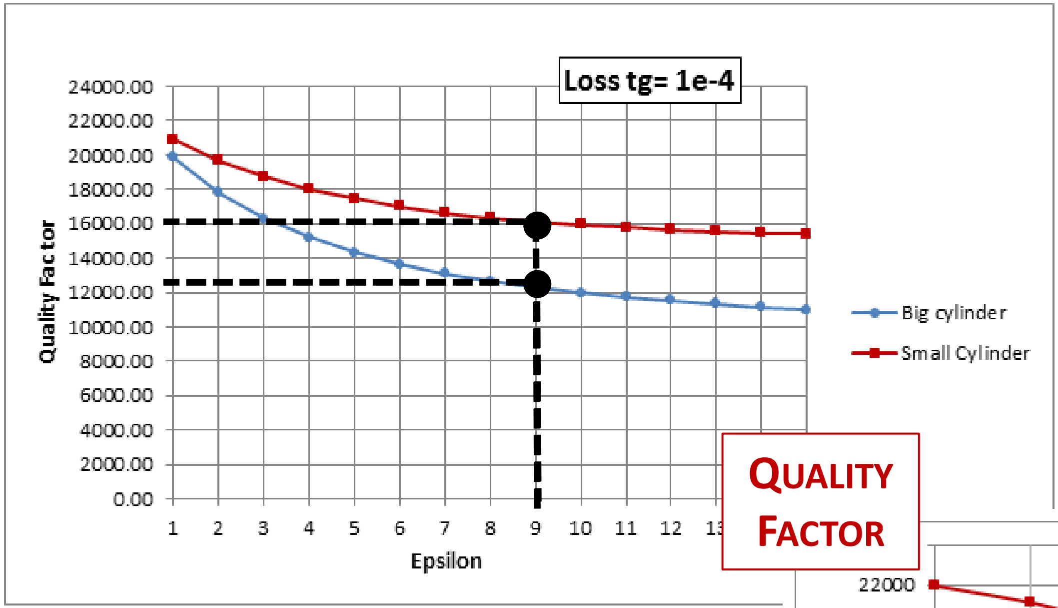
Empty cavity:
- f = 1003.87 MHz
- Q = 22772.3

Dielectric loaded cavity:

F R E Q U E N C Y

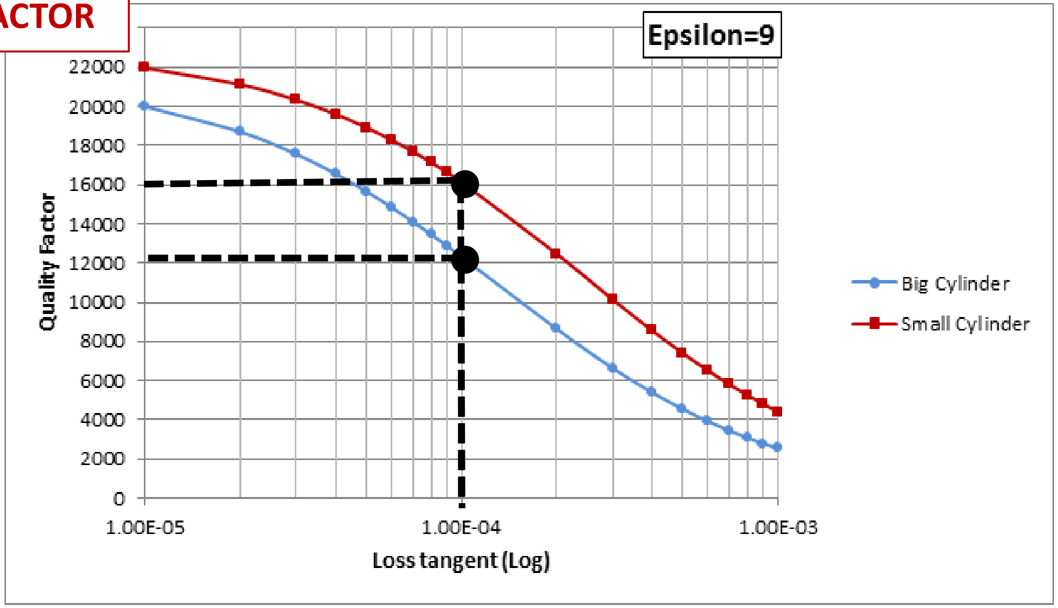


STANDARD CONDITION - SIMULATION (2)



QUALITY FACTOR

Q_{big} = 12310.1



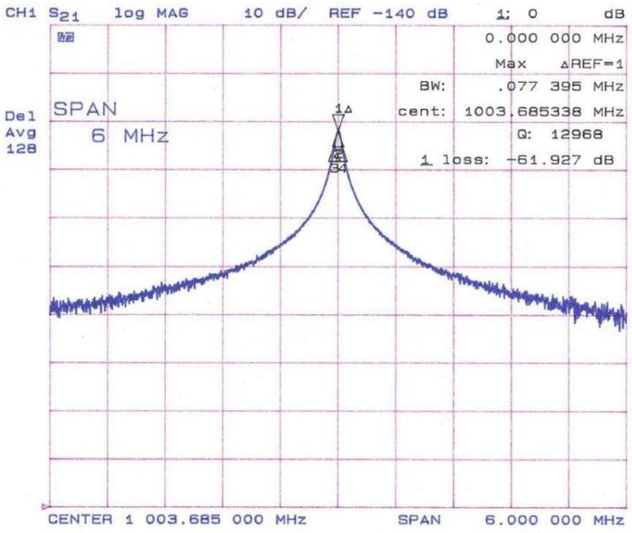
Q_{small} = 16123.6

Cavity set up

- Cavity assembled through stainless steel bolts
- Systematic control of locking torque through torque meter
- Measurement through Network Analyzer (loop coupler)

Measurements for each configuration

- resonance frequency
  → good correspondence with simulation
- loaded quality factor (derivation of unloaded quality factor through coupling coefficient)
  → much lower than simulation (30-40% less)



STD CONDITION – DATA ANALYSIS AND RESULTS

Model used to analyze the data:

- lower Q = higher wall resistivity

→ estimate an equivalent resistivity for the cavity

$$\Omega = 4.677E-6\, {}^{Ohm}\!/_{cm}\, (\pm 4\%)$$

- Introduce this value in the model for the dielectric loaded cavity

→ extract dielectric properties of the ceramic rings

Final results:

SMALL CYLINDER

f = 897.96 (±0.97) MHz
Q = 11823.1 (±1037.1)

→

ε = 8.925 (±0.125)
tgδ = 7.28E-5 (±4.92E-5)

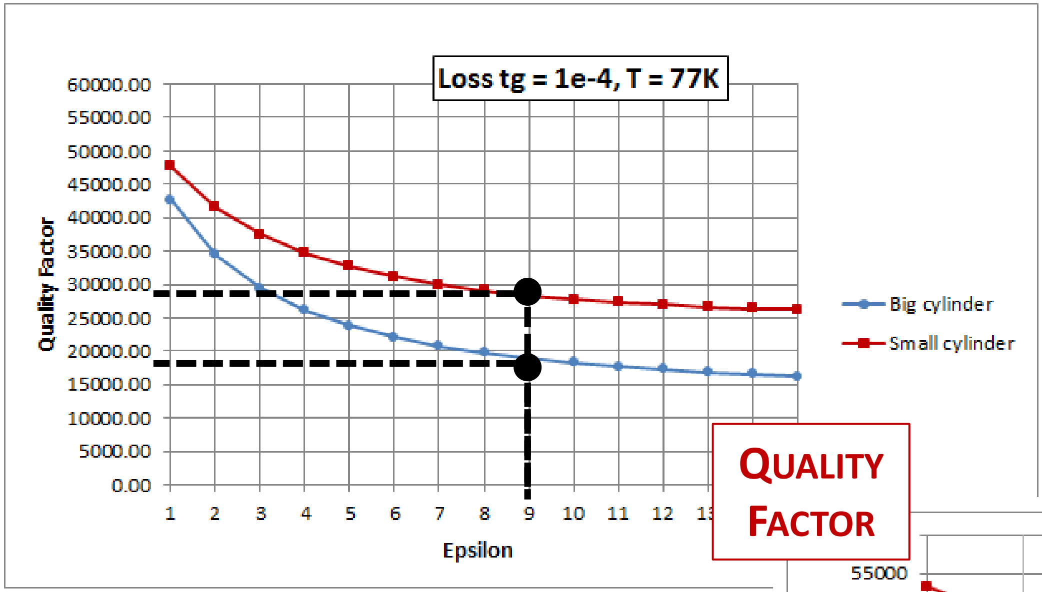
BIG CYLINDER

f = 814.30 (±0.81) MHz
Q = 9415.89 (±828.6)

→

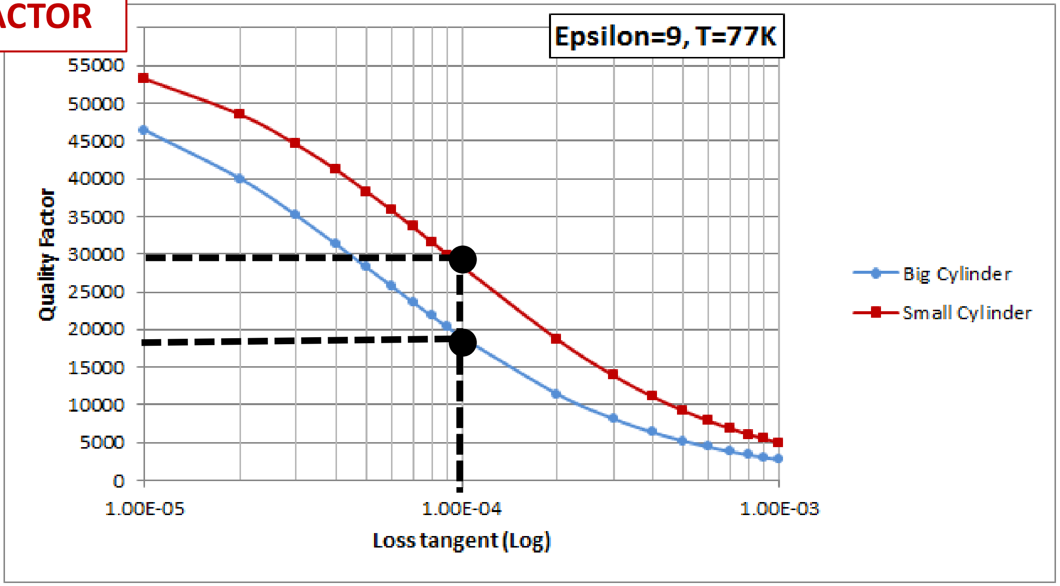
ε = 9.595 (±0.134)
tgδ = 8.17E-5 (±5.52E-5)

Cryogenic Condition – Simulation



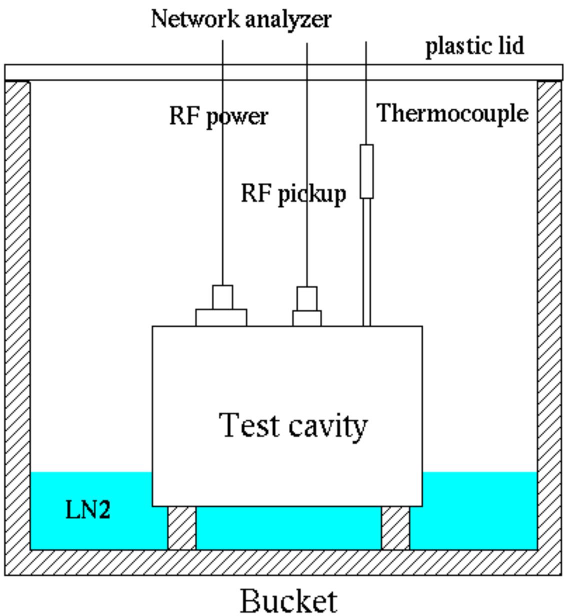
Q_{big} = 18966.9

Quality Factor



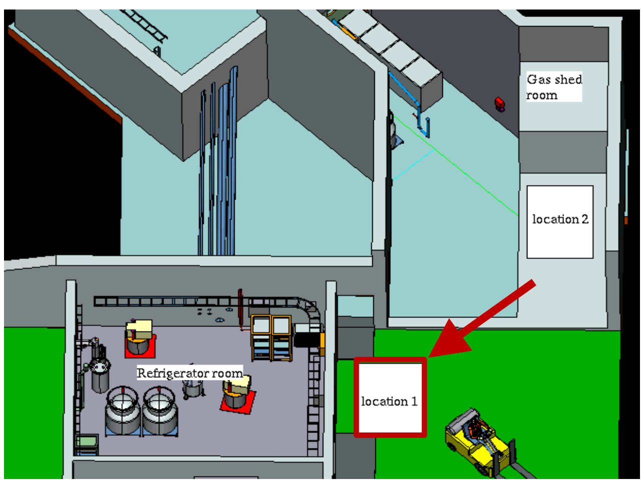
Q_{small} = 28361.7

Cryogenic Condition – Test Preparation



System set up:

- proper bucket to contain the LN2
- temperature sensor
- feeding probe for He



Location choice

- ODH requirements
- need for power supply

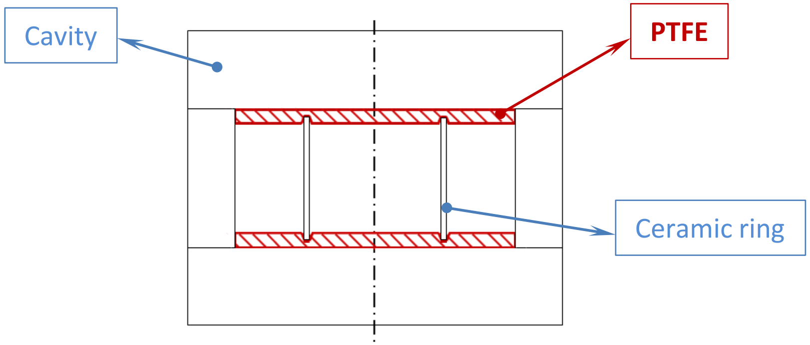
TEST

First result:

$Q_{empty} = 23774.2$

Future High Power Tests

- Location: MTA
- Only big cylinder (for the smaller one the frequency shift is too small)
- Teflon holder for the ceramic ring



- Cavity filled with gas

avoid breakdown

→ GOAL: study the feasibility of using a gas filled dielectric loaded RF cavity at HP

CONCLUSIONS

ACHIEVEMENTS:

LOW POWER ANALYSIS

- Description of the behavior of a dielectric loaded RF cavity under different conditions through simulation
- *At room temperature:*
  - Realization of a complete set of test for the empty cavity
  - Analysis of the data and extraction of the dielectric properties of the ceramic

    → quite good agreement with expected value, provided by the company, both for ε_r (exp. ≈ 9) and loss tangent (exp. ≈ 10^{-4})

    ERROR: mainly due to the sensitivity of the measurements to variation in real resistivity of the cavity
- *At cryogenic temperature:*
  - Set up of the equipment and definition of the procedure to follow for the test
  - Realization of test for the empty cavity

HIGH POWER ANALYSIS

- Design of Teflon holder for the ceramic ring to use during HP test

CONCLUSIONS (2)

WHAT'S NEXT?

- Complete cryogenic tests and analyze the data to extract how the dielectric properties of the ceramic ring change with temperature and how this affects the behavior of the cavity
- Complete the set up of HP configuration and run the test

If all the GOALS of the study will be achieved

- Dielectric material:
  - $\varepsilon_r > 9$, $tg\delta < 10^{-4}$
- Electric gradient
  - > 20MV/m

We'll prove the feasibility of a HPDL RF cavity

↓

such a cavity could allow the realization of a helical cooling channel

AND

it could be applied also to other type of muon cooling channel

↓

GOOD RESOURCE FOR MUON COLLIDER REALIZATION