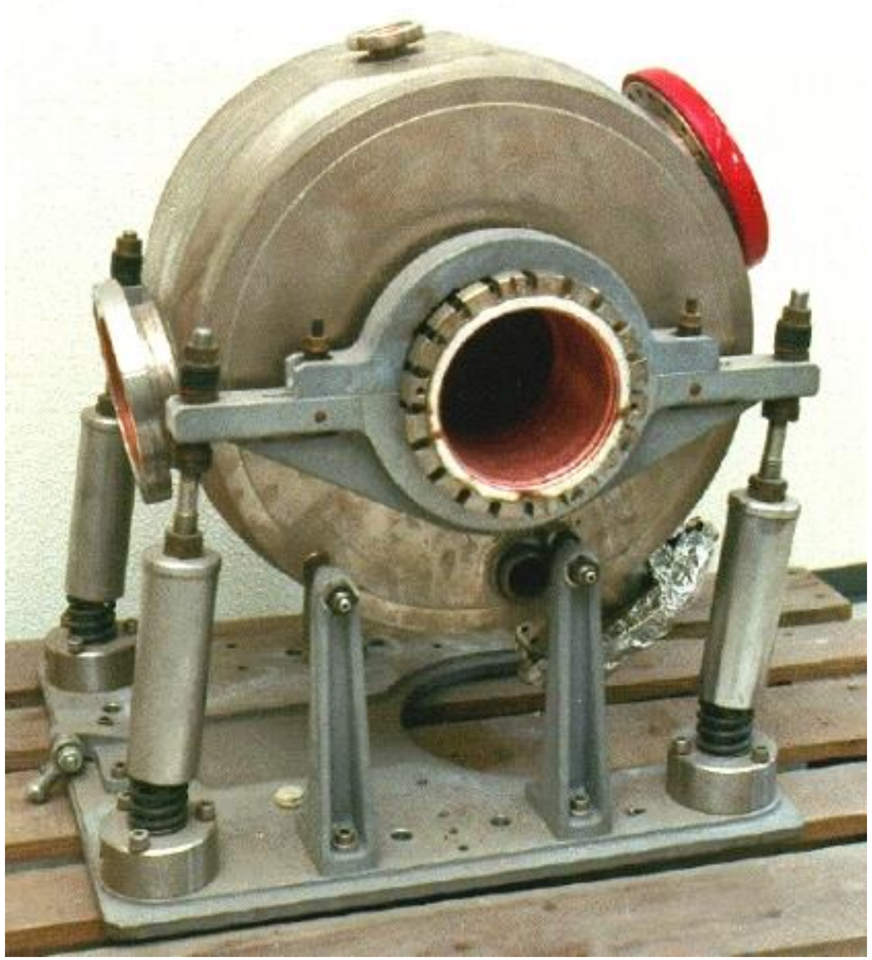
RF Engineering
Beyond Pillbox Resonators

Christine Völlinger (CERN) & Manfred Wendt (BNL)

Pillbox Cavity is not all…



Cavity from DORIS Storage ring (1970-ish, very early electron/positron collider)

Pillbox Cavity is not all…

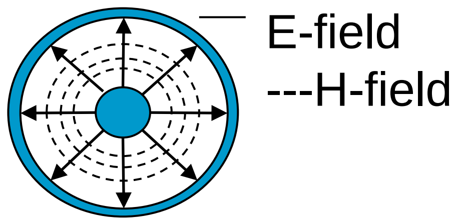
so let’s look at some exotic examples.

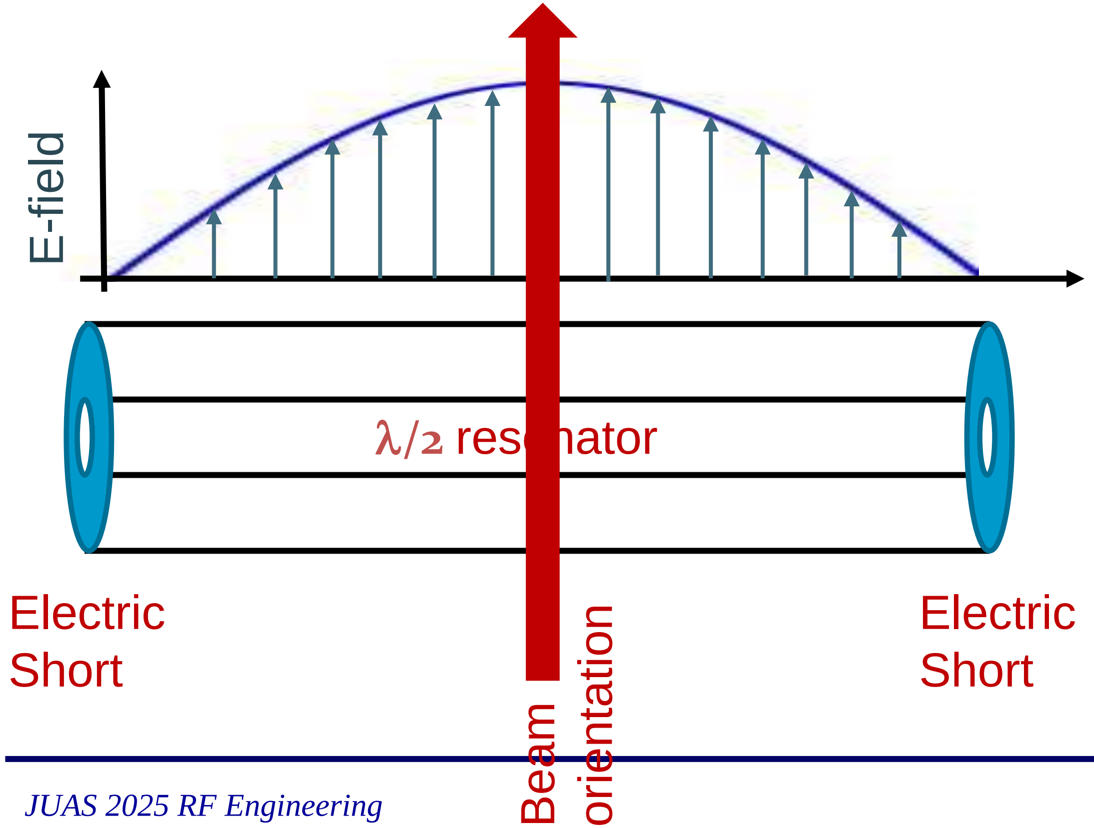
Coaxial Line goes RF Cavity (in low frequency range)

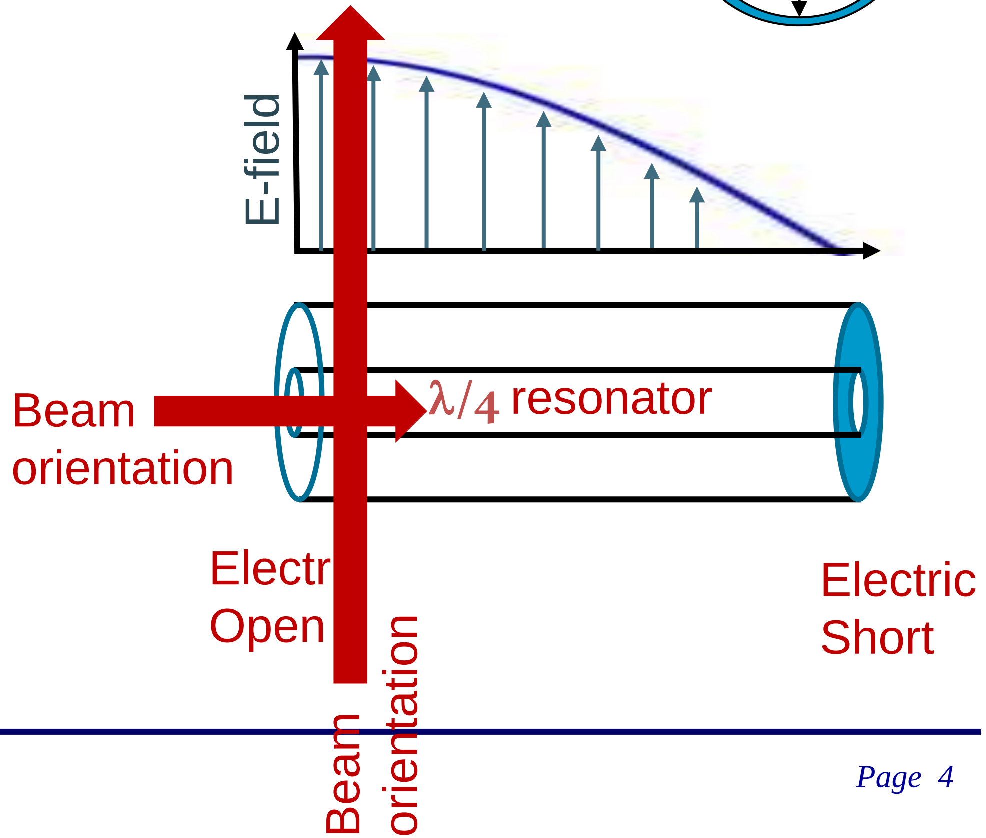
Frequencies below ~10 MHz come with RF wavelengths that are largely above >30 m.

→ With classical cavity (pillbox design), we would need huge cavities → not suited for accelerators

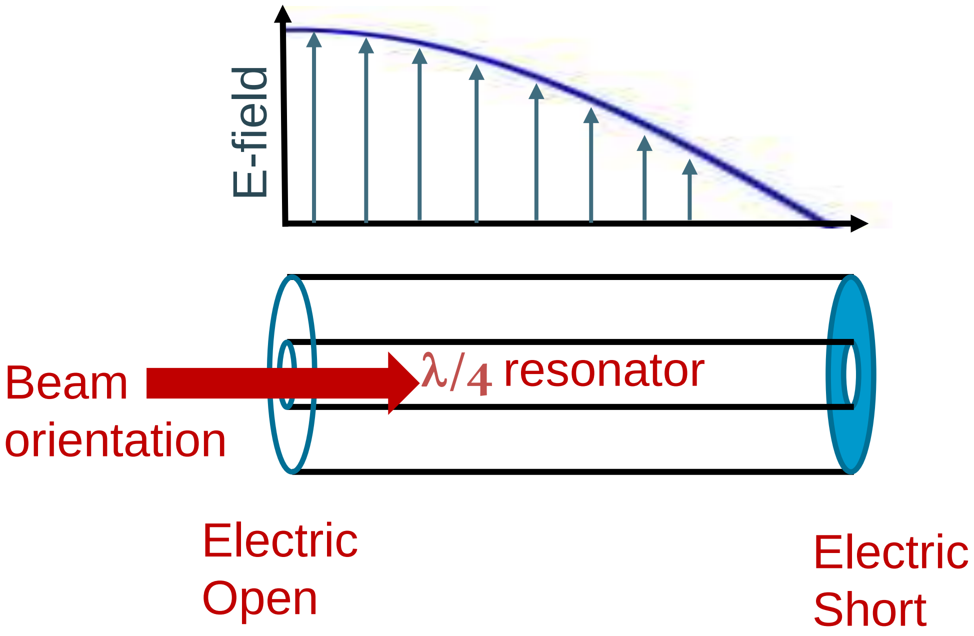
→ Line resonators: $\lambda/2$ or $\lambda/4$ resonator



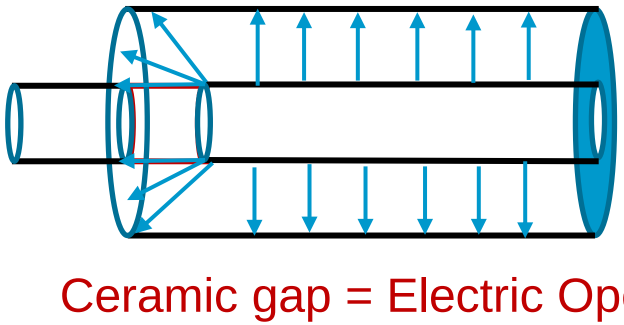




QW-Cavities in low frequency range



How to implement this?



This side acts like a capacito
capacitive loading.

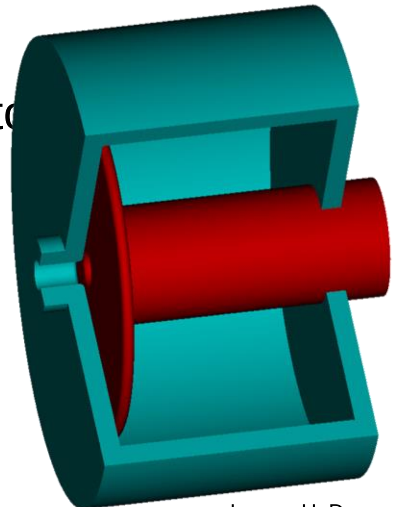


Image: H. Damerau

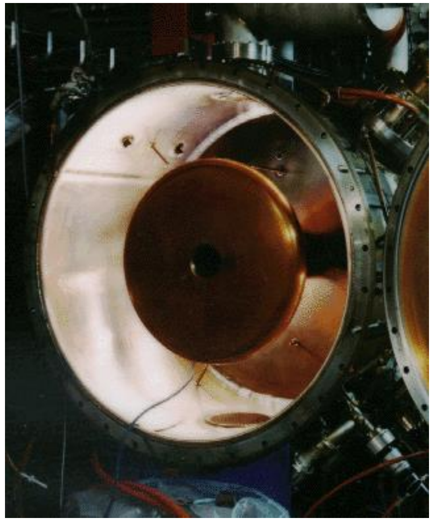
- The interruption of the metallic beam pipe with a ceramic gap is not unusual… has been used since a long time and is no engineering challenge.
- However, the cavity at 10 MHz is still rather long (7.5 m to be precise).

- Solution is: increase the capacitance!

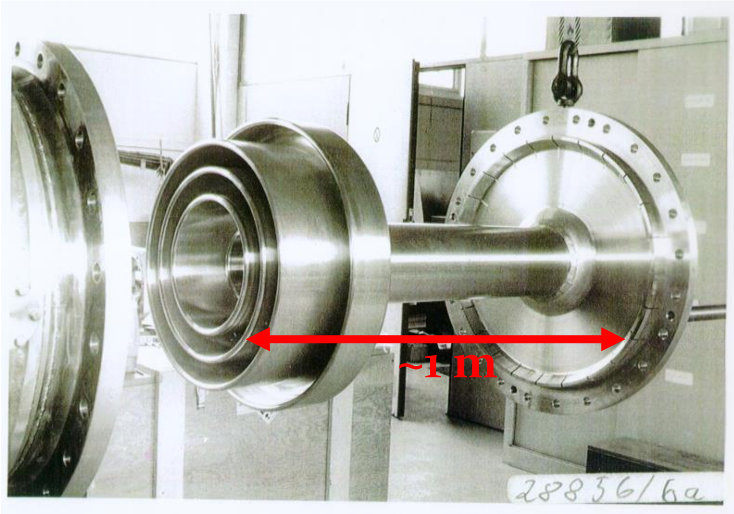
Capacitive Loading in Real World

→ Add capacitive load at gap of cavity to shorten the resonator

NSLS, 52.88 MHz



DESY PIA, 10.4 MHz, inner cond.



Outer conductor

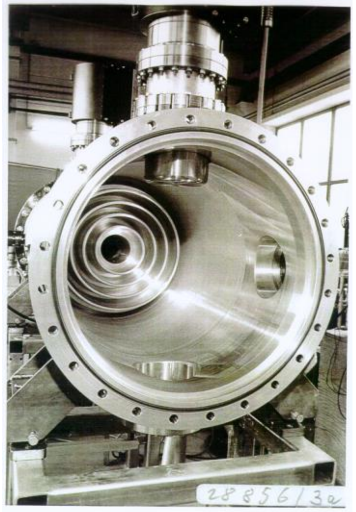


Image: M. Nagl

→ Significantly reduces cavity size (recall: at 10 MHz, QW is 7.5m).

→ Works on a determined, fixed frequency only.

→ Adds small losses due to capacitor implementation.

→ Advantage: entire cavity can be held in vacuum.

RF cavities in low frequency range

- Generally: with same geometric length, the frequency goes down, if inductance or capacitance goes up.
- Leads to an increase in electrical length (i.e. cavity appears longer than it is). Same effect as if you fill your coaxial line with some material to make the line “longer”.

$\rightarrow$ **Add more capacitive or inductive loading**

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

resonance frequency

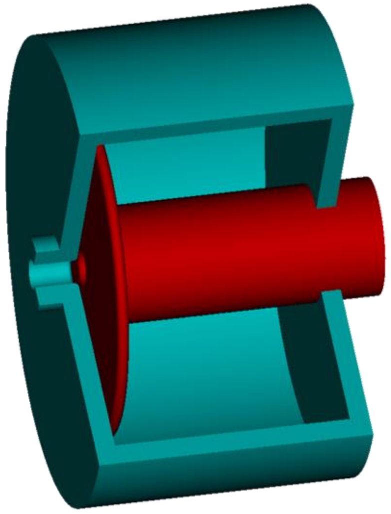
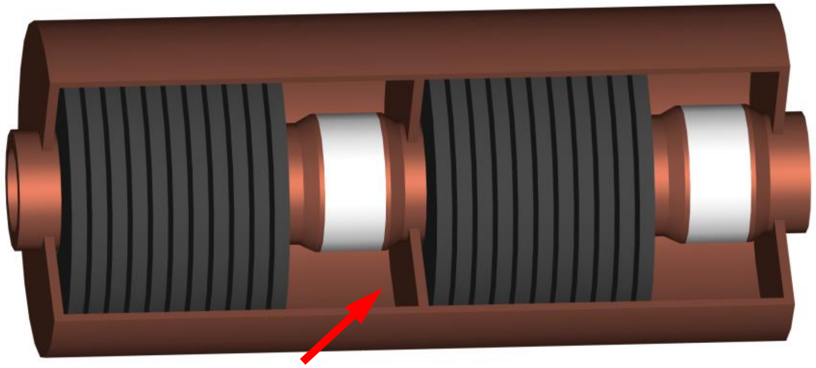


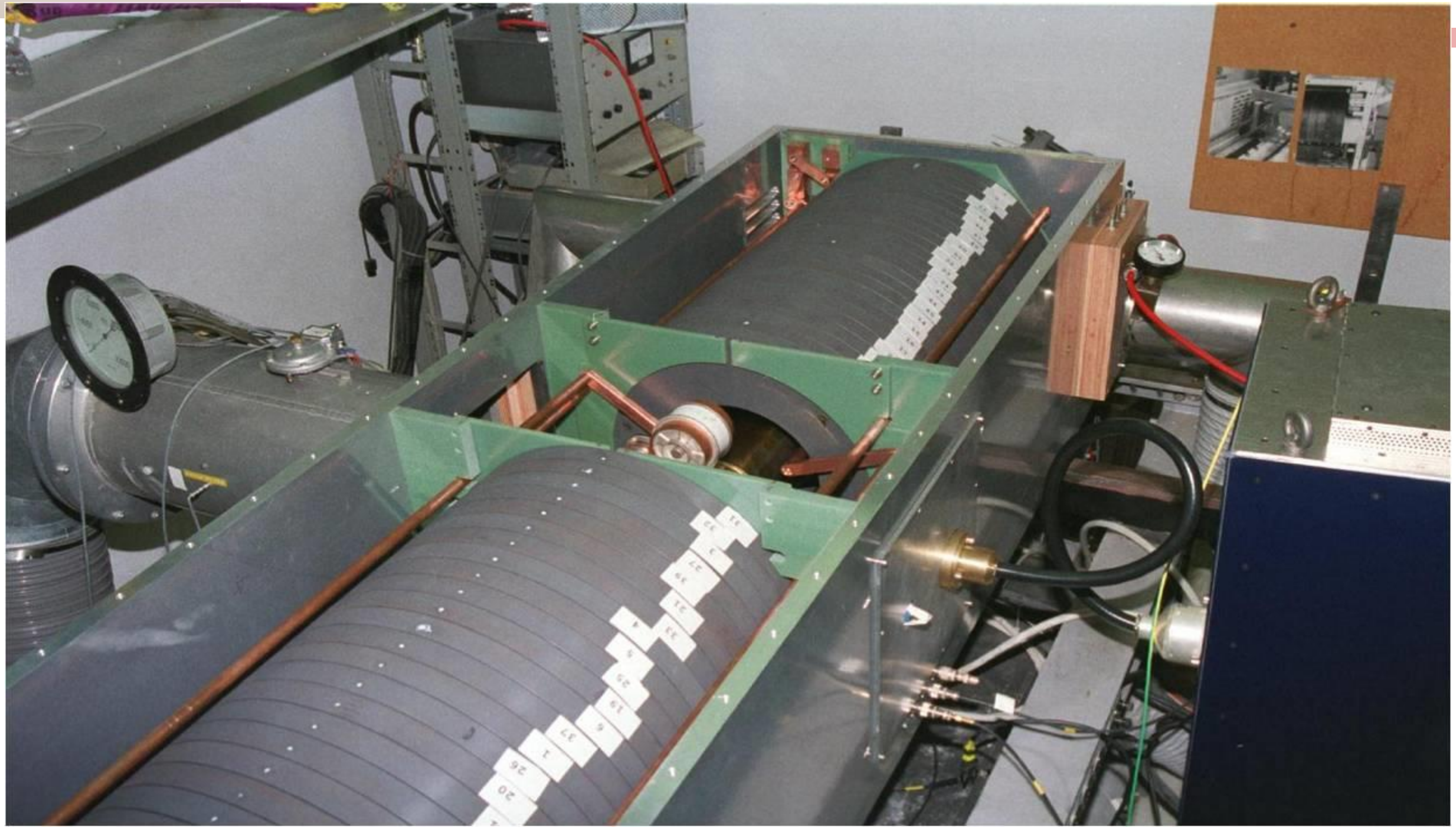
Plate capacitor



Ferrite inductivity (also allows frequency tuning)

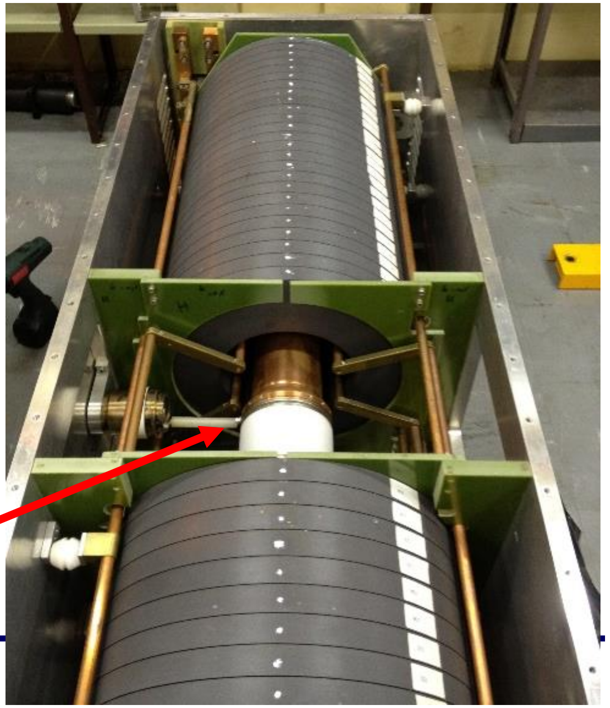
Images: H. Damerau

Tunable cavities – example (former) PSB



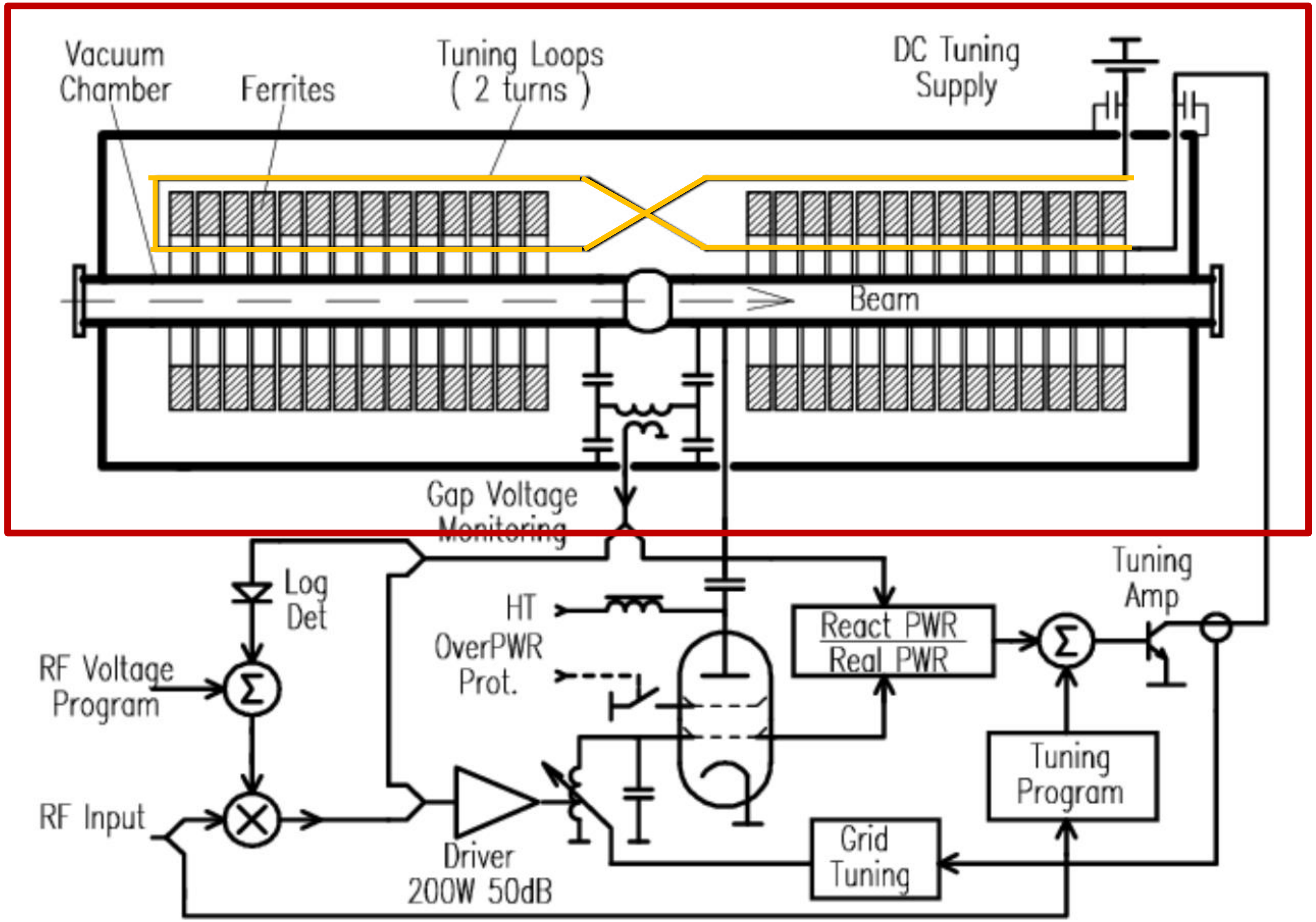
PSBooster Cavity, below 20 MHz

- Makes use of spinnel ferrites.
- Tuning via external magnetic field.
- So-called “figure-of-eight” biasing (= parallel biasing)
- Cavity, operating 8-12 MHz
- Ferrite material is lossy and brings the Q of the cavity down.
- Q_0 = 50

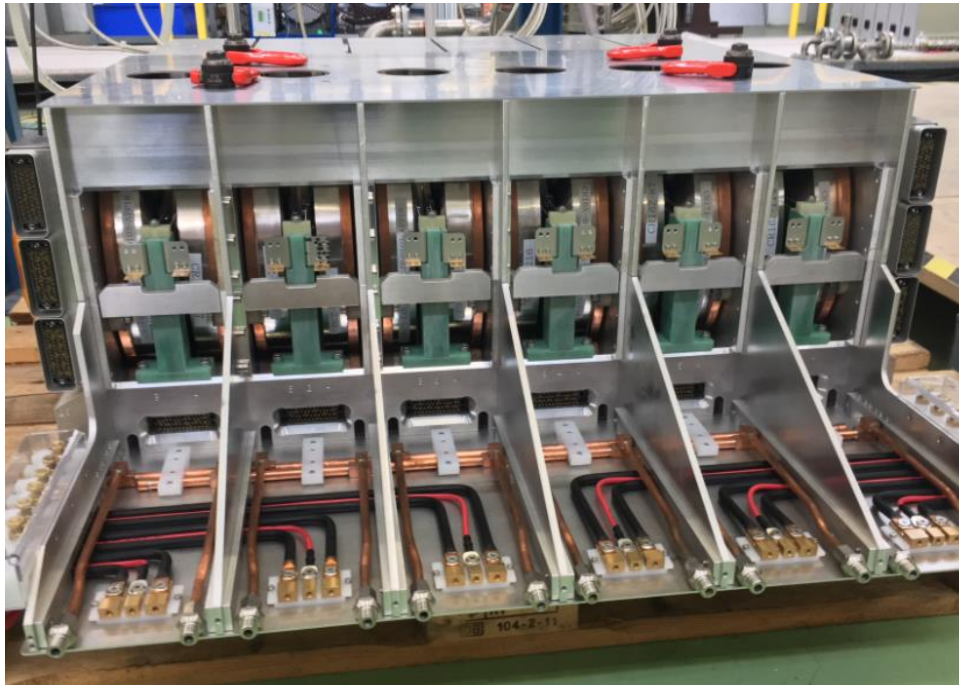


Beam vacuum pipe with ceramic gap.

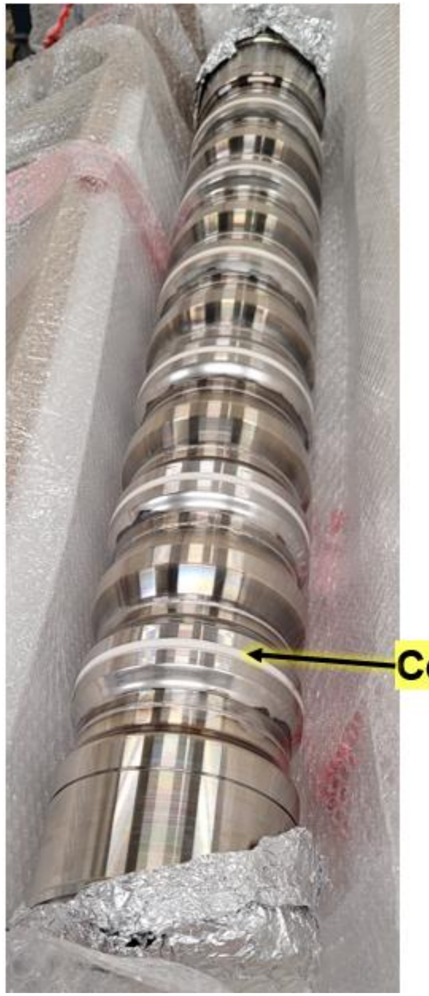
Tunable cavities – figure-of-eight biasing

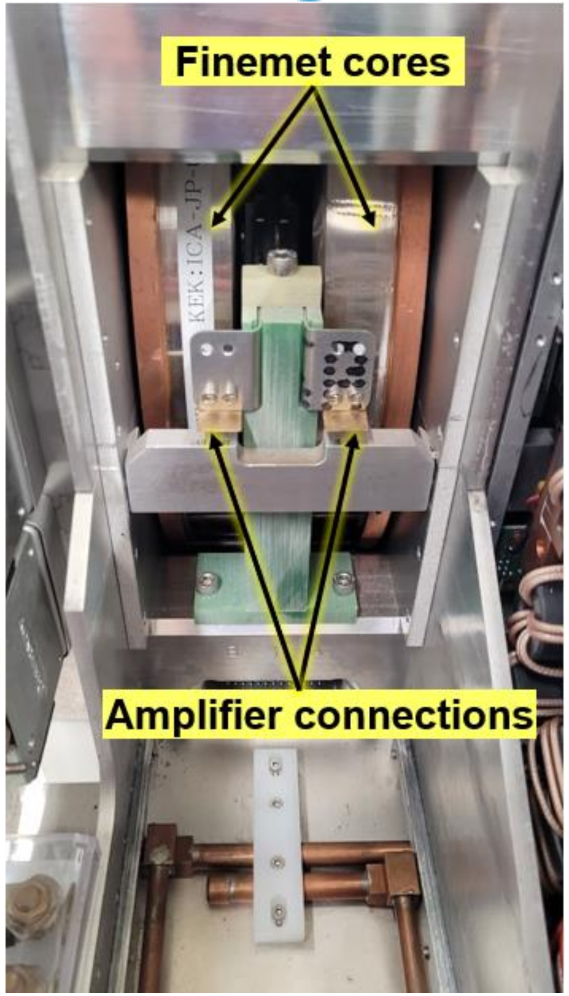


Tunable cavities – the PSB finemet cavity



CERN PSB Finemet cavity,
0.6-18 MHz

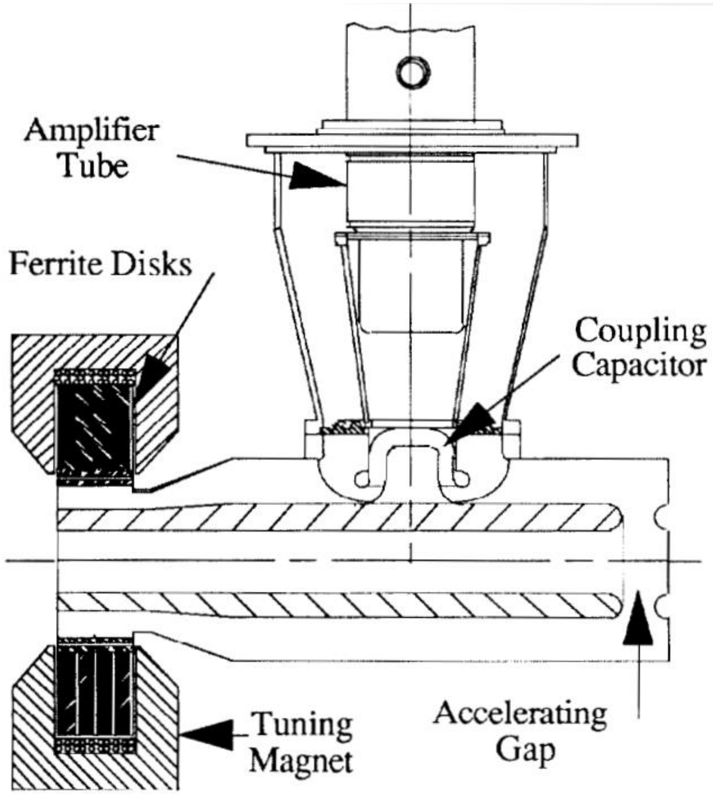




Tunable cavities – higher frequencies

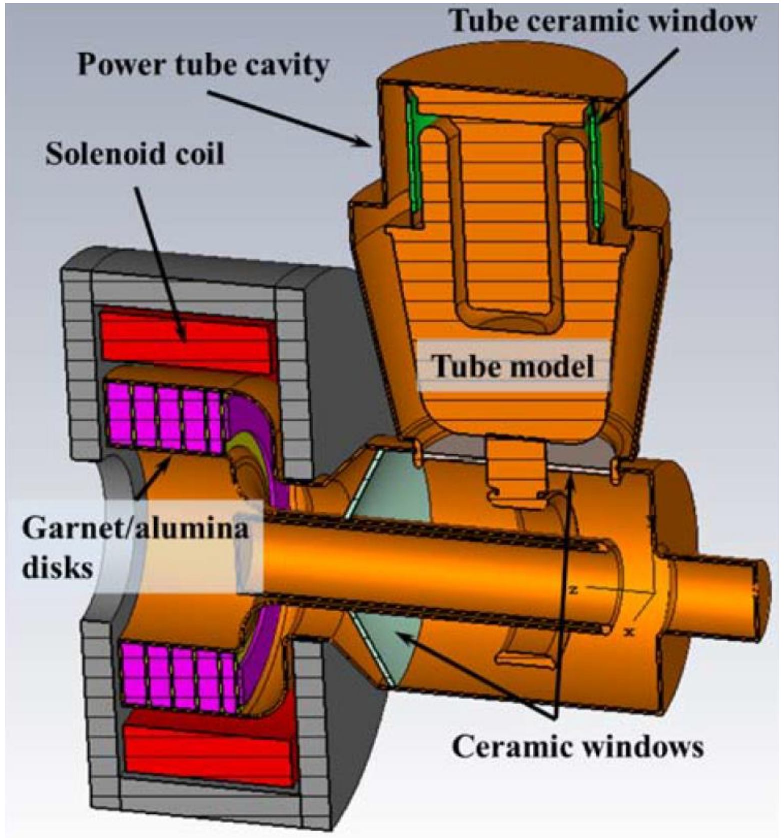
→ **These cavities work with perpendicular biasing, and new type of low loss ferrites (garnet).**

SSC Low Energy Booster,
~47 MHz to 60 MHz



C. C. Friedrichs et al., PAC91, p. 1020

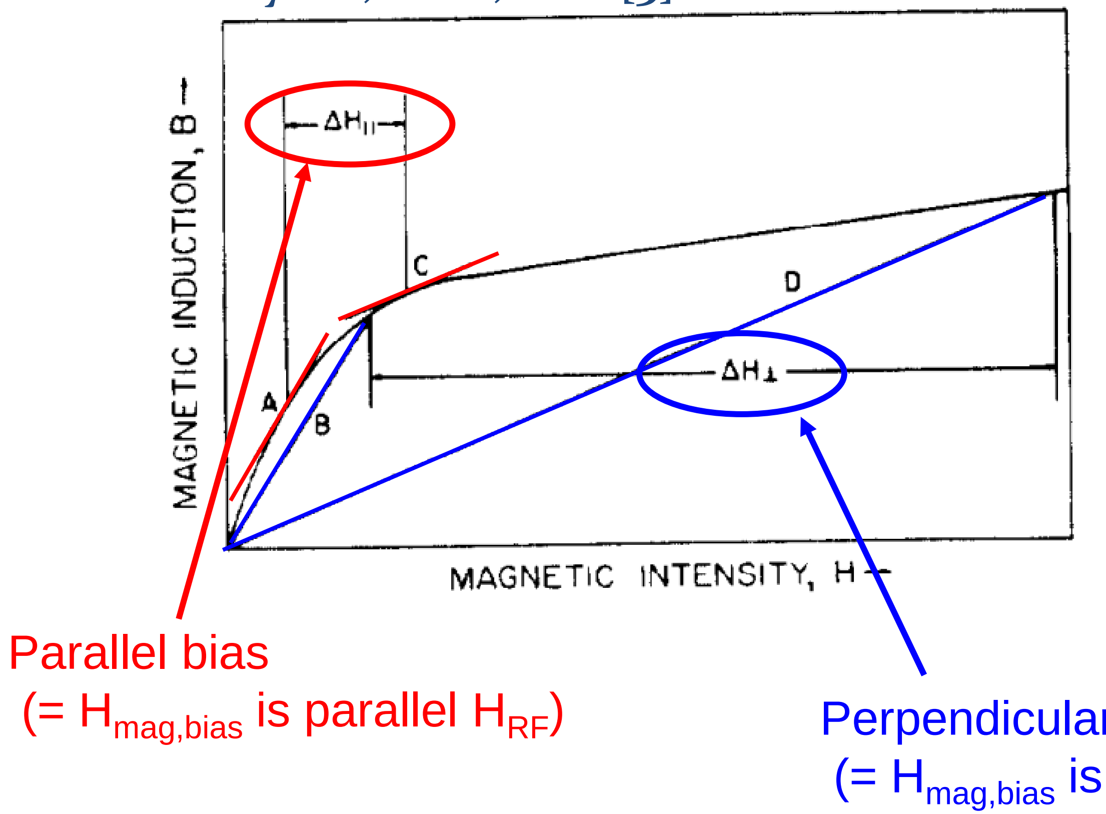
FNAL Booster 2nd harmonic,
76 MHz – 106 MHz, 100 kV

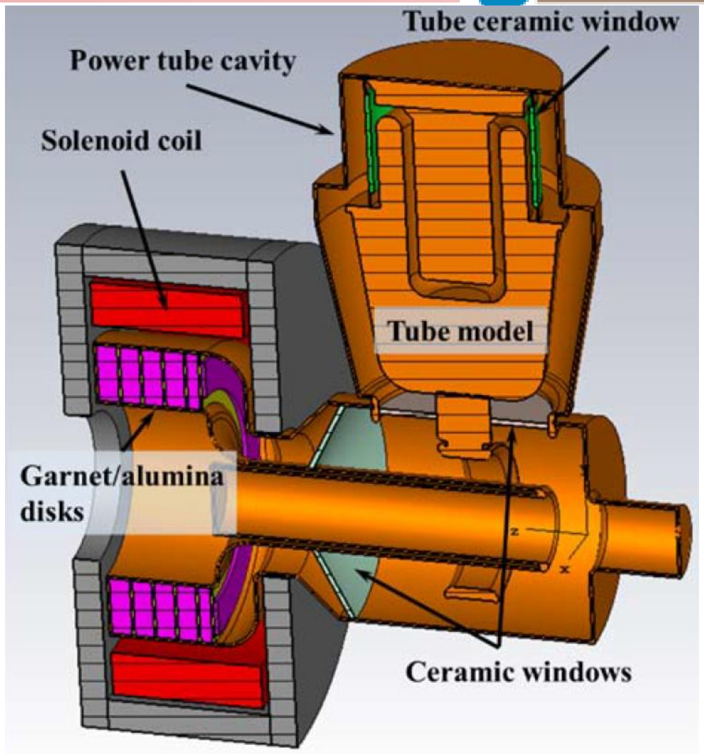


R. L. Madrak, IPAC16, p. 130

Tunable cavities at higher frequencies

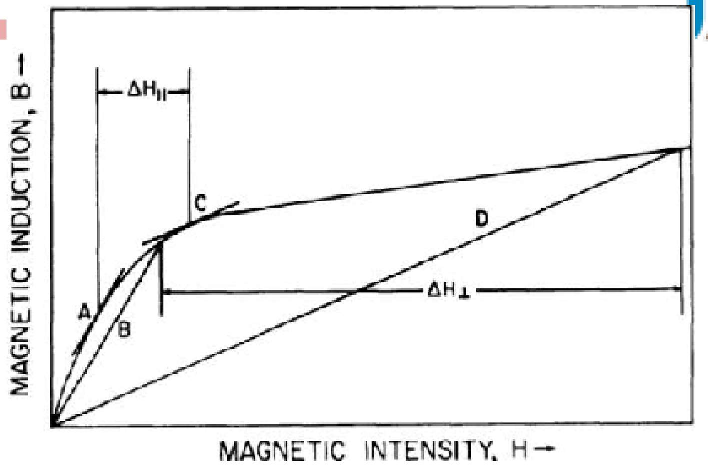
From: Smythe, IEEE, TNS [3]

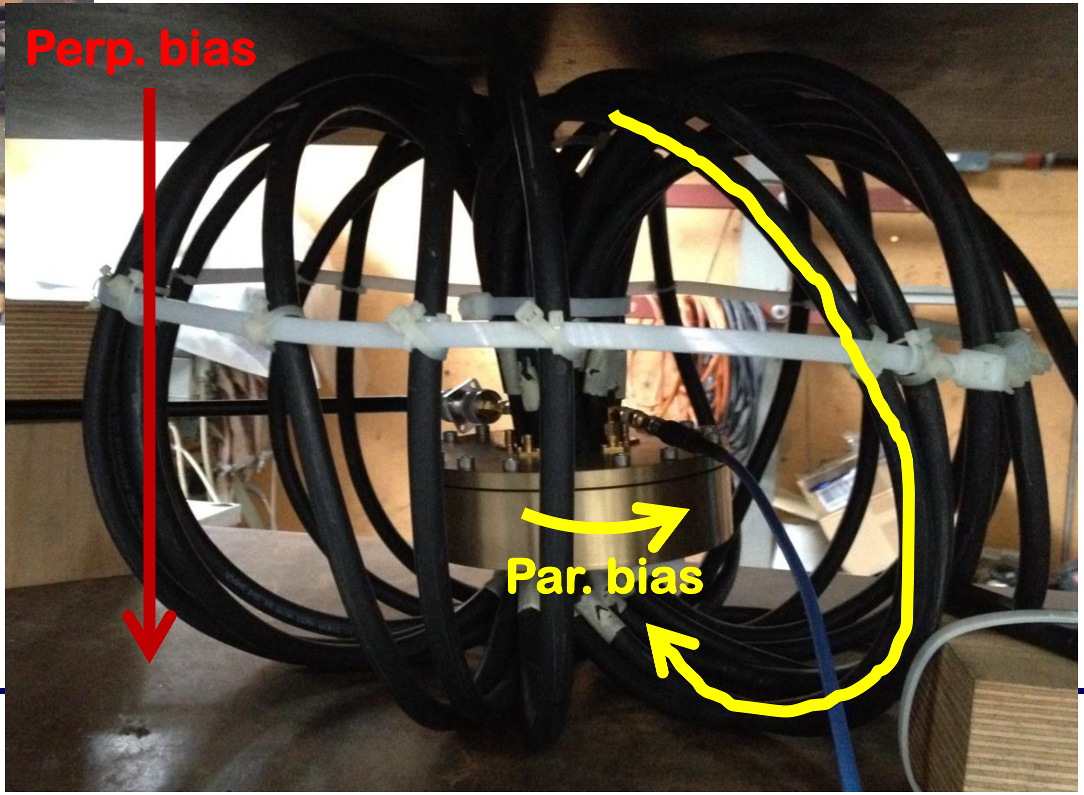




- Garnets are ferrites with a magnetic field-dependent relative permeability.
- Exposed to a (slowly varying) magnetic field, their μ-value covers a certain range until they saturate.
- Problems are the garnet outgassing (cannot be in vacuum), the limited Q-value of the the cavity due to material losses and the rather large H-fields needed.

Can that also work on a single-gap cavity?





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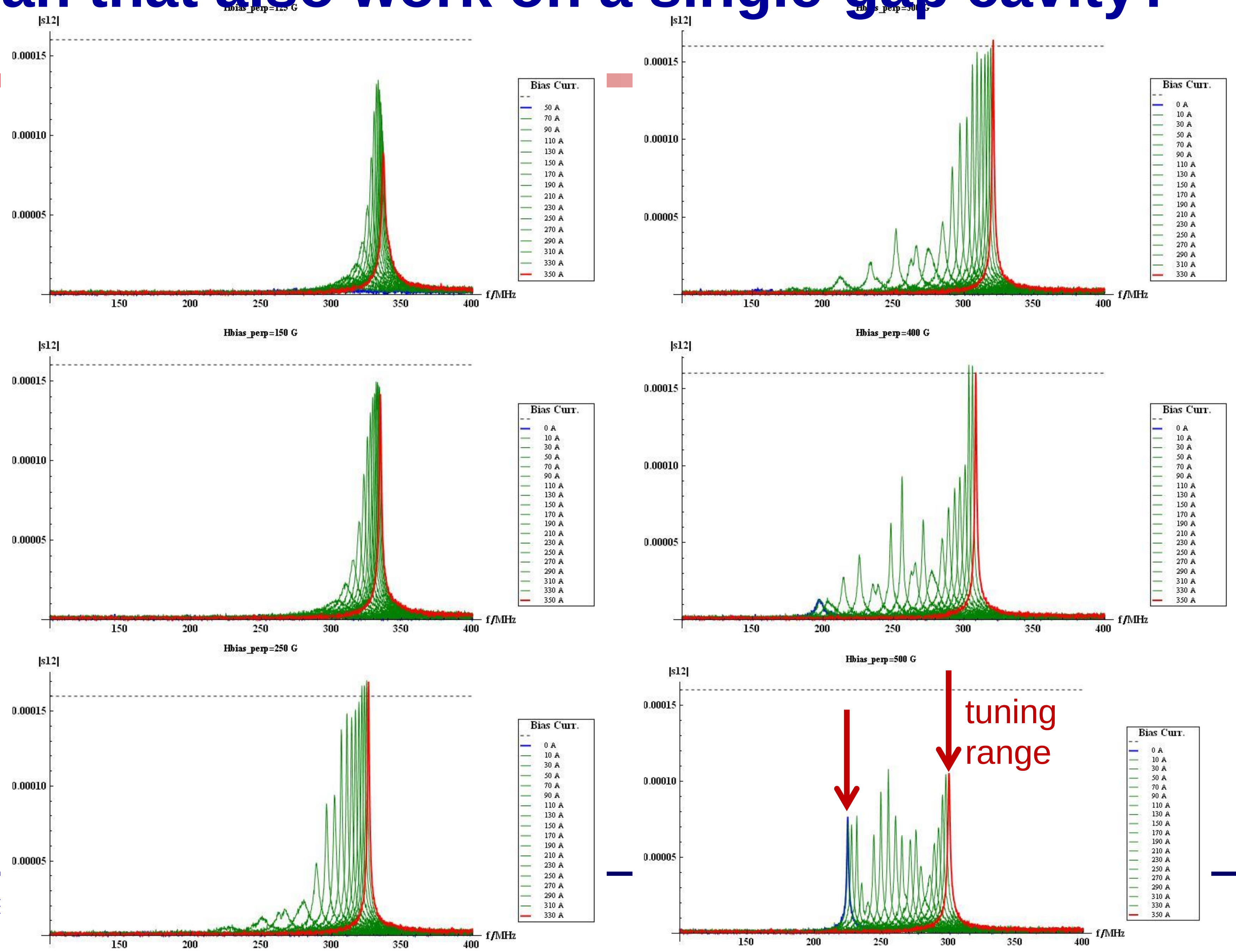
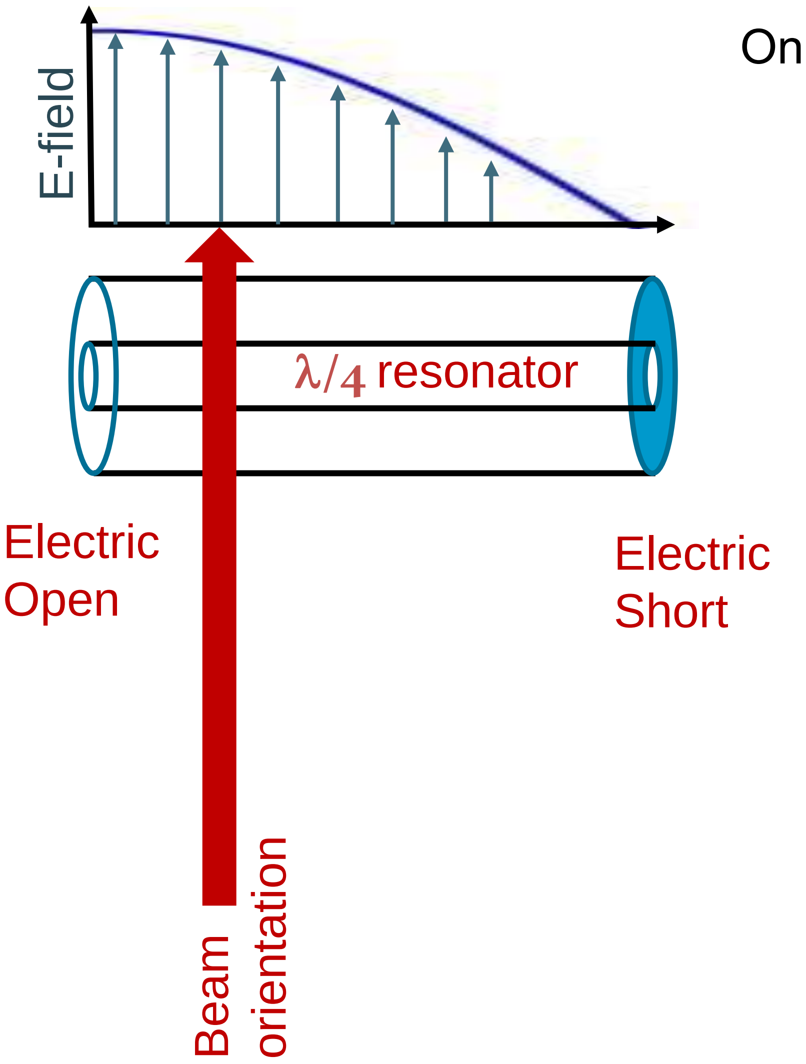


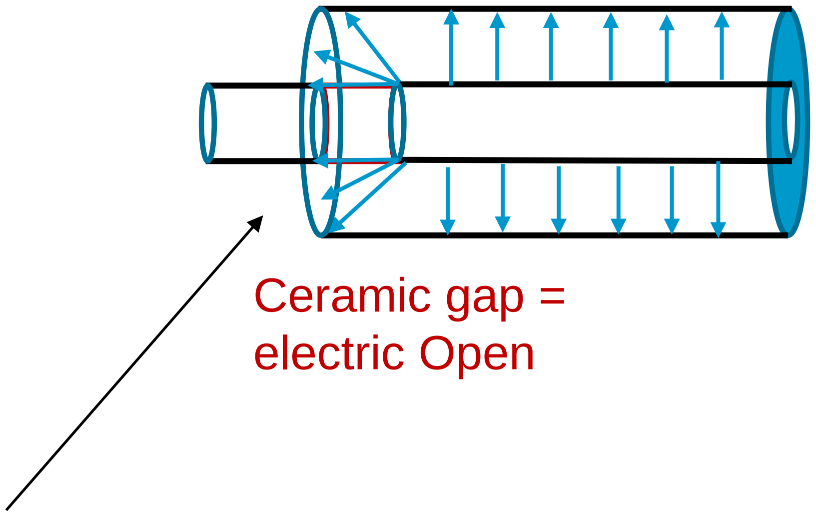
Resonance peaks due to different magnetic bias fields

Applying the tuning principle to a single-gap cavity

QW-Cavities in low frequency range

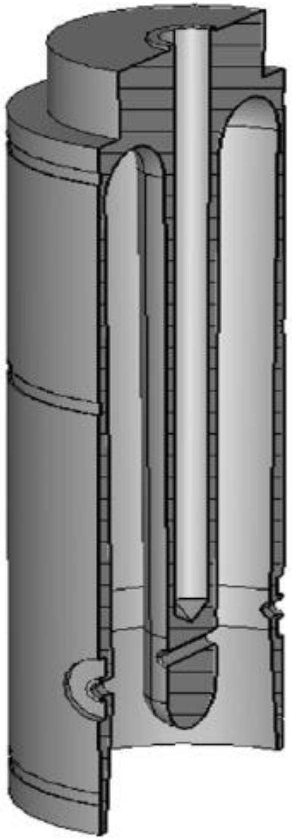


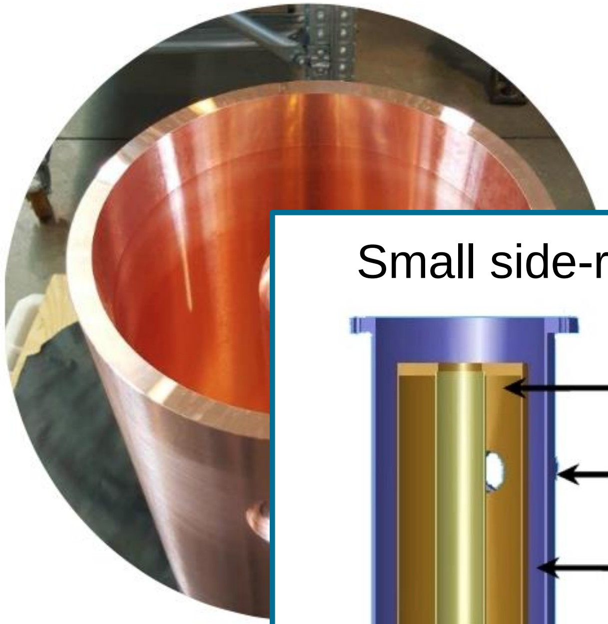
Only remains to look at the last example…

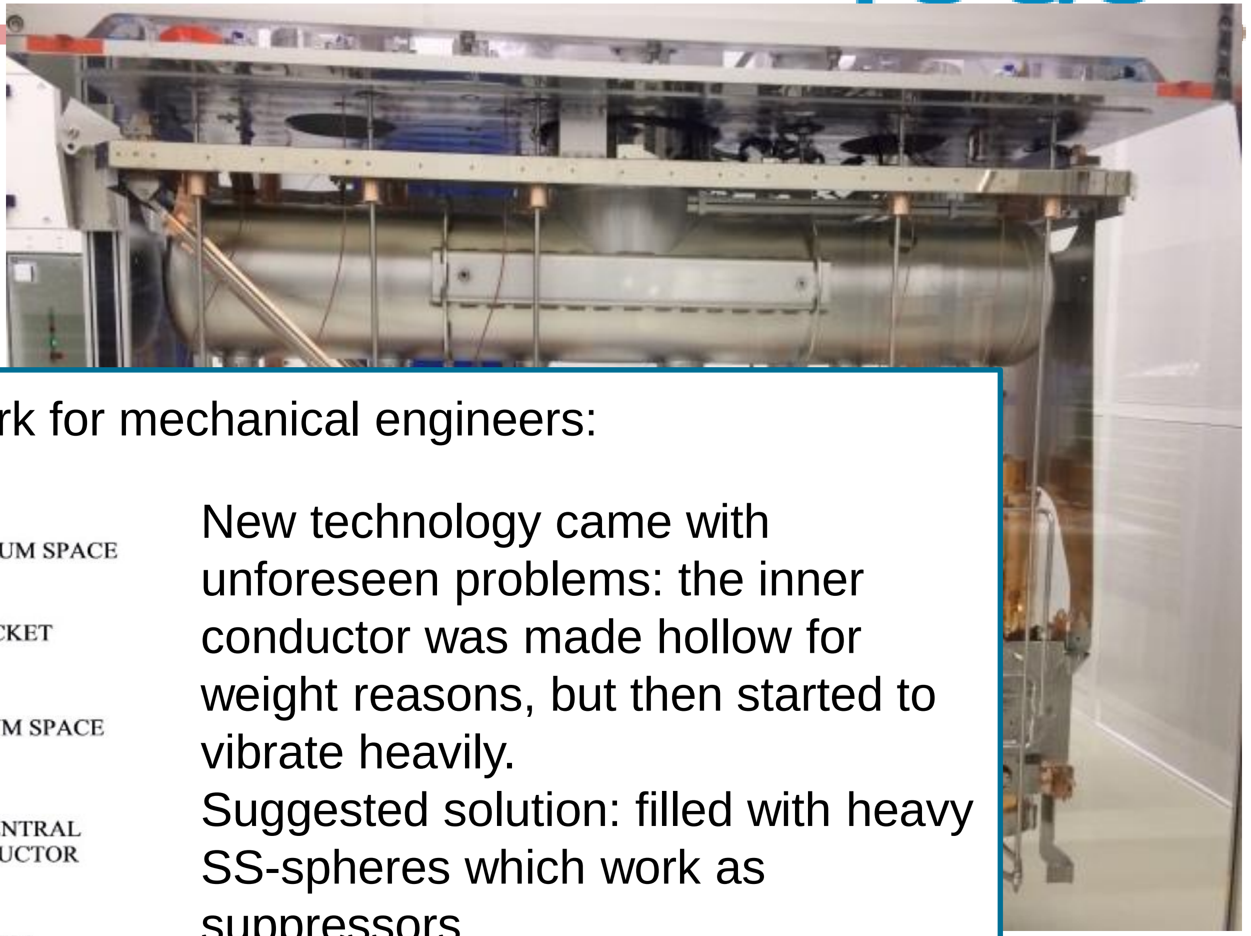


Recall:
this side acts like a capacitor,
making use of capacitive loading.

QW-Cavity at HIE-Isolde (CERN)



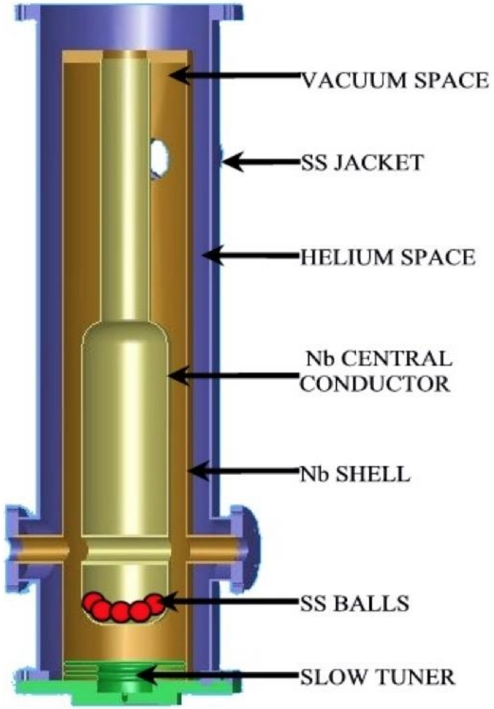




- Accelerator for radioactive ion beams of R
- 100 MHz superconducting Nb on Cu struc
- 6 MV with Q > 5 x 10^8

Gerigk, CERN

Small side-remark for mechanical engineers:



New technology came with unforeseen problems: the inner conductor was made hollow for weight reasons, but then started to vibrate heavily.
Suggested solution: filled with heavy SS-spheres which work as suppressors.

Image: A. Roy, APAC 2007, THYMA04

Exotic TEM-Cavity (Spoke Cavity)

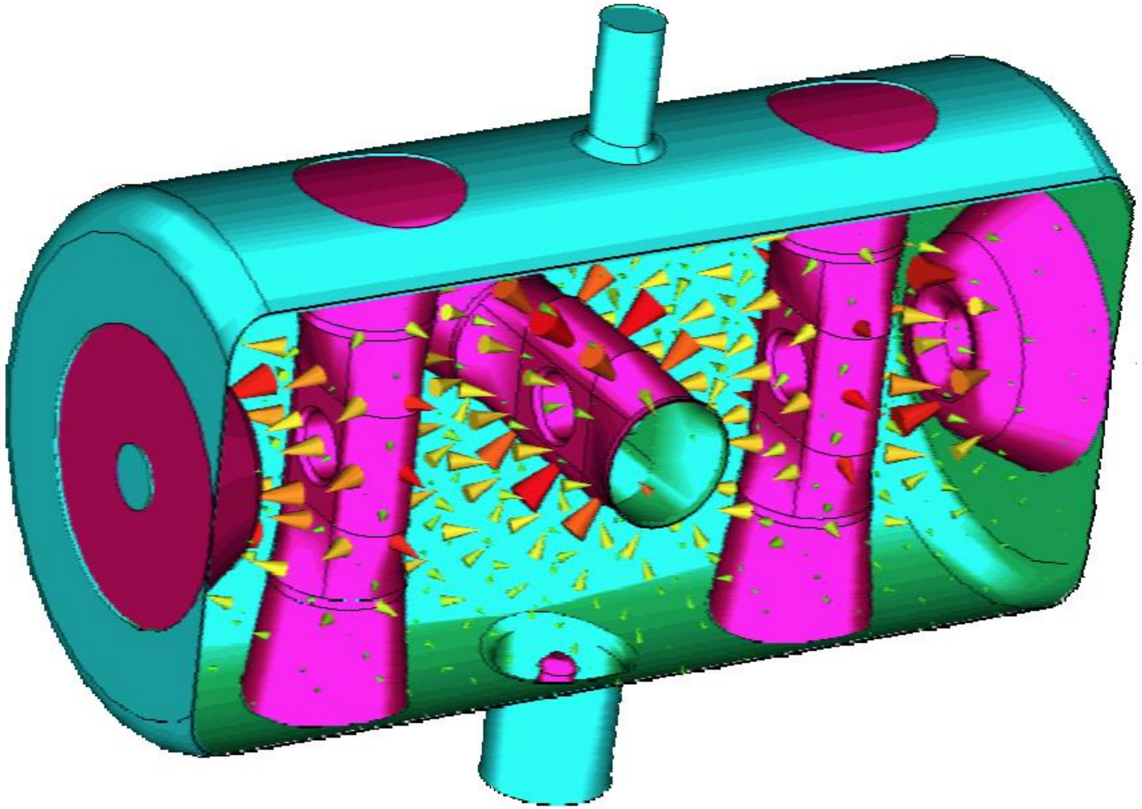


Image: F. Gerigk, RF CAS Berlin 2024.

JUST TO CONFUSE YOU! BUT THIS IS REAL.

- Spoke cavities are made of 1…n combined $\lambda/2$ –wave TEM cavities.
- Typically, they have 1…3 spokes and are superconducting.
- Used for lower to medium beta.

Reference: E. Zaplatin et al: “Triple Spoke Cavities at FZJ” EPAC 2004

Thank you for your attention.

Let's have a break!

Further reading…

1. POZAR, David M., *"Microwave Engineering"*, 4th edition, Wiley and sons.

2. ZHANG, Keqian, "*Electromagnetic Theory for Microwaves and Optoelectronics*", 2nd edition, Springer

3. BHAT, Shiban, *"Stripline-like transmission Lines for Microwave Integrated Circuits"*, New Age International Publishers

4. HOFFMANN, *"Integrated Microwave Circuits"*, Springer

5. SAAD, *"Microwave Engineers' Handbook"*, vol. 1,