805 MHz Cavity and Test Results at Lab G of Fermilab

MUCOOL Collaboration Meeting
October 23, 2002 at LBNL

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Brief Review

Development of the 805 MHz Pillbox cavity

- Purpose
  - Study high gradient accelerating structure for muon cooling channels (high peak surface field → surface damages)
  - Study and engineer RF cavities with Be windows
  - Study RF cavity operation (or conditioning) under strong magnetic fields in either solenoidal or gradient modes
  - Study dark current and x-ray radiation levels versus the gradient
- Progress and Status
  - Designed, built and tested a 6-cell open iris structure with and without external magnetic fields. Reached 20 ~ 25 MV/m acceleration gradient → 52 MV/m peak surface field, BUT found severe surface damages (work conducted at FNAL)

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Brief Review (cont'd)

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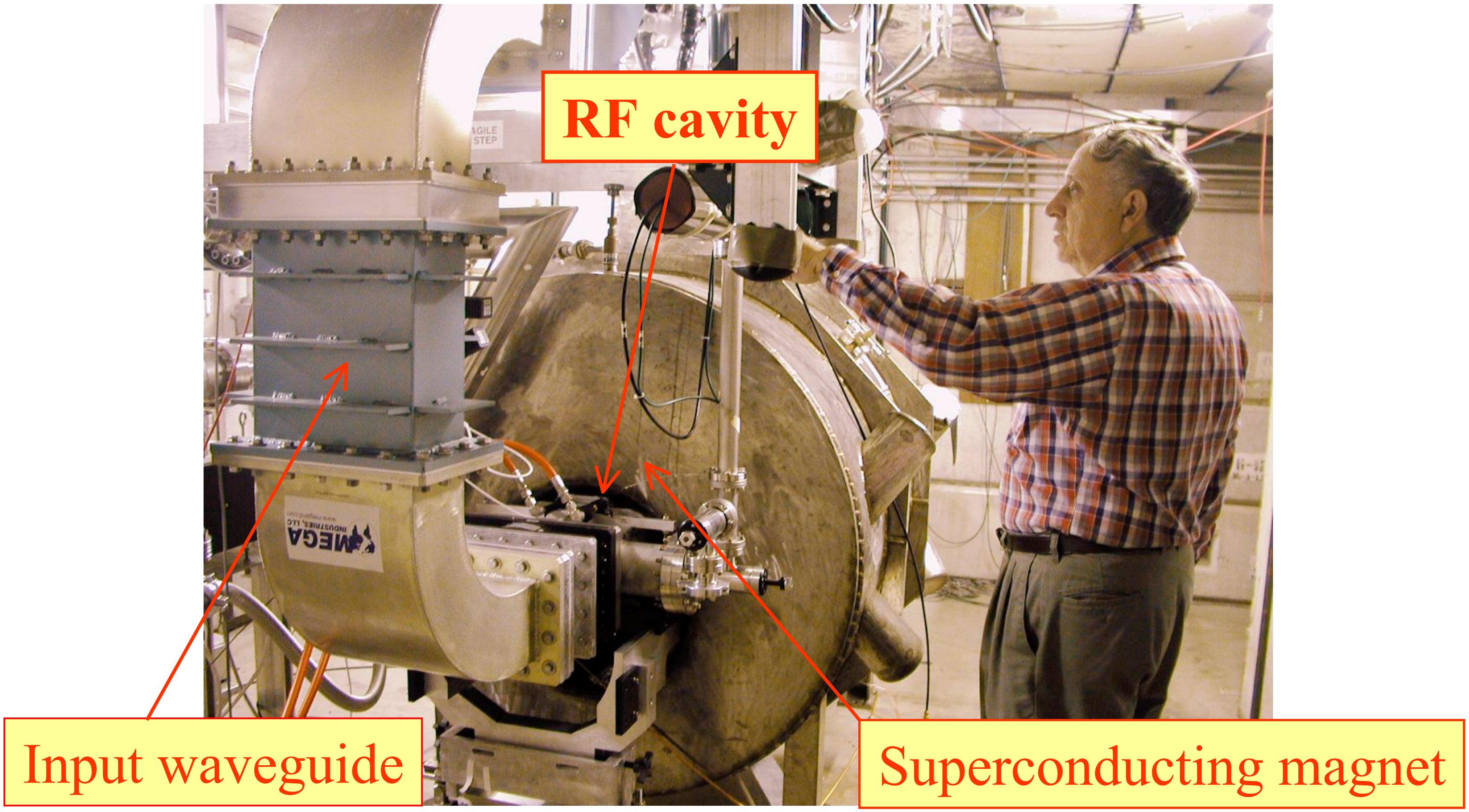
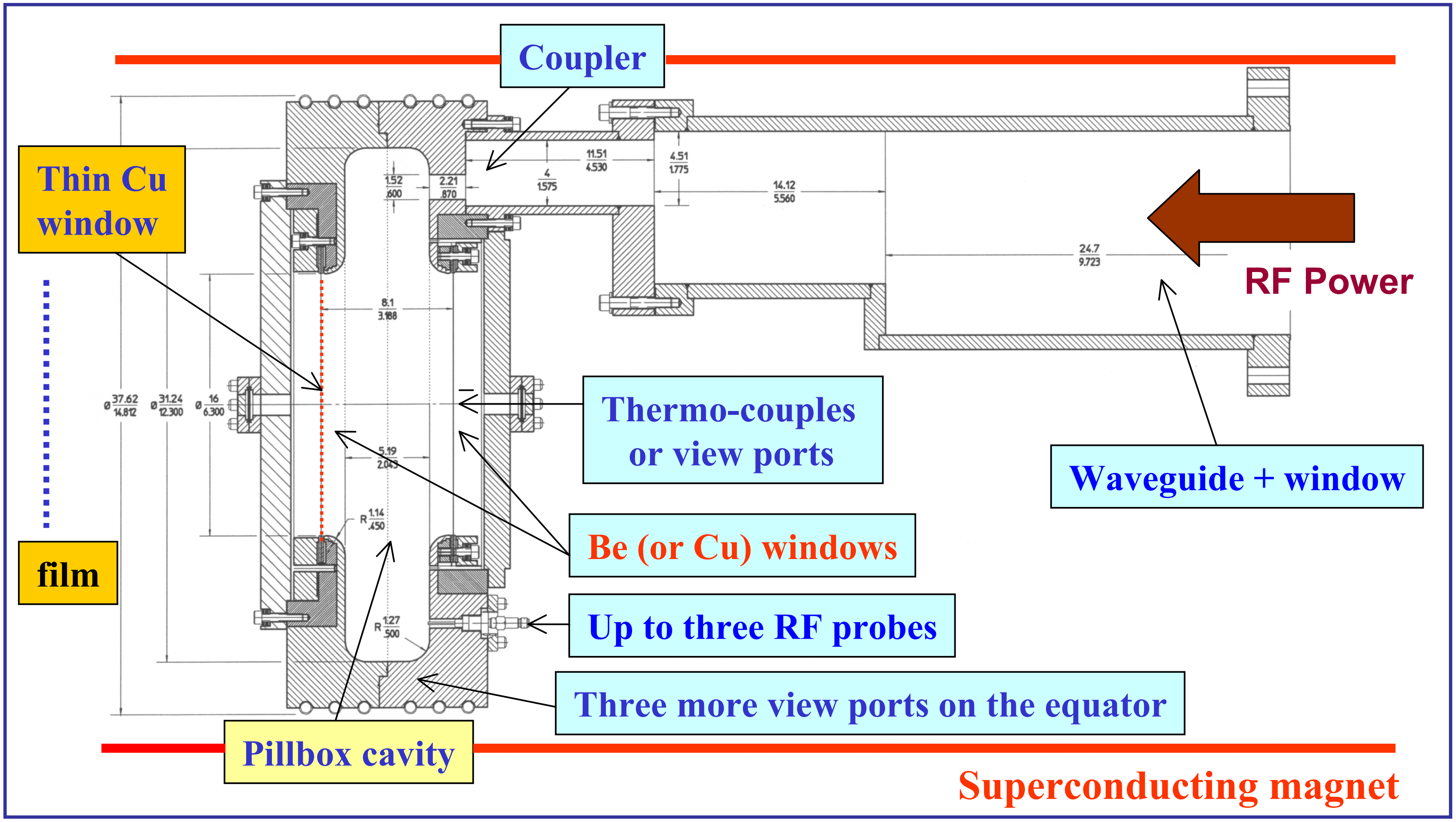
- Progress and Status (cont'd)
  - Open iris cavity work was summarized in a Ph.D thesis (V. Wu)
  - Designed, built and tested (low power) a π/2 interleaved multi-cell copper structure with Be windows at room and LN temperatures. Q value nearly doubled at LN temperature; Pre-stressed Be windows (127 um thickness and 16 cm in diameter) did not buckle at temperature rise ≤ 38 degrees (LBNL).
  - Designed, built and tested a pillbox cavity with demountable Be or Cu windows for high power tests. Reached 34 MV/m with Cu windows (no external magnetic field) at low sparking rate. No surface damages were found. Installed new thin Cu window for better x-ray measurement (Lab G of FNAL).
  - The cavity has been conditioned with 2.5 T magnetic field for three weeks, reached ~ 12 MV/m. Found harder to go through MP zones, much higher radiation levels … (Moretti and Norem's talks)

Test setup at Lab G



The cavity and test setup



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Latest test results at Lab G

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- RF Conditioning started in September 23, 2002 with magnetic field up to 2.5 T in solenoidal mode, and lasted for three weeks
- Good cavity vacuum and RGA spectrum, P ~ 2×10^{-8} Torr
- More multipacting zones were observed, and they are much harder to pass through compared with no-magnetic-field
- Much higher radiation levels (up to ~ 1000 times higher)
- Conditioned with combinations of short and long pulses (3~20 μs) at different input RF powers
- Reached ~ 12 MV/m after three weeks conditioning

What did we learn so far ?

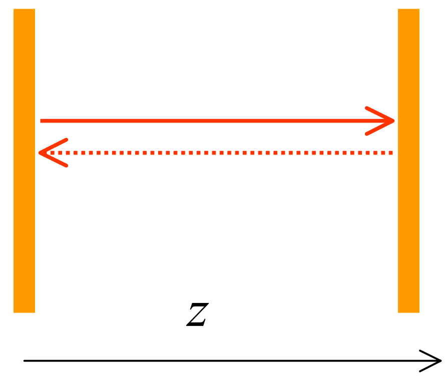
- Harder to condition the cavity with magnetic fields, MP seems does not go away (more zones?)
- High radiation levels with magnetic fields, but may come down if continue to condition without magnetic fields

  → Self Healing (re-conditioning damaged surface?)
- Can we condition RF cavities in a strong magnetic field environment?
- If we can, what's the correct procedure?
- Welcome to make suggestions and ideas

Understand the MP effects

The MP effects in the cavity may be explained in two-plate model:

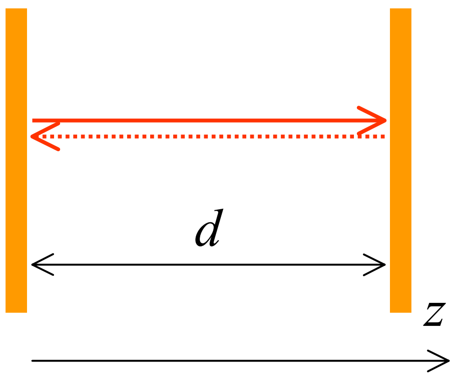
Electrons from one plate are accelerated and hit to the opposed plate $\rightarrow$ more electrons (if average secondary emission coefficient is higher than 1) coming out $\rightarrow$ resonate when electric fields start to reverse direction, and this process continues $\rightarrow$ MP



MP happens when $\omega t = (2n+1)\pi$ They are called 1/2, 3/2, 5/2, 7/2, … cycles of MP. Simple case like two-plate can be studied analytically,

$$\frac{d^2 z}{dt^2} = \frac{eE_0 J_0(kr)}{m_e}\sin(\omega t + \phi) + e\left(\vec{v}_\perp \times \vec{B}_\phi[\propto J_1(kr)]\right)_z$$

A simplified model (1)



Take 1/2 cycle as an example,

$$\frac{T_{rf}}{2}\bar{v} = d, \quad \bar{\beta} = \frac{\bar{v}}{c} = \frac{2d}{cT_{rf}} = \frac{1}{d}\int_0^d \beta(z)\,dz$$

$$\bar{\beta} \approx 0.43 \text{ for } f = 805 \text{ MHz and } d = 8 \text{ cm}$$

$$\text{Note: } \bar{\beta} = \frac{2}{c}[f_{rf} d] \approx \text{constant}$$

This corresponds to an average voltage of ~ 55 kV (~ 0.68 MV/m or 0.38 volts on scope measurement [we had difficult time to pass 0.3 volts]), agree reasonably well with reported data and simulation results.

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A simplified model (2)

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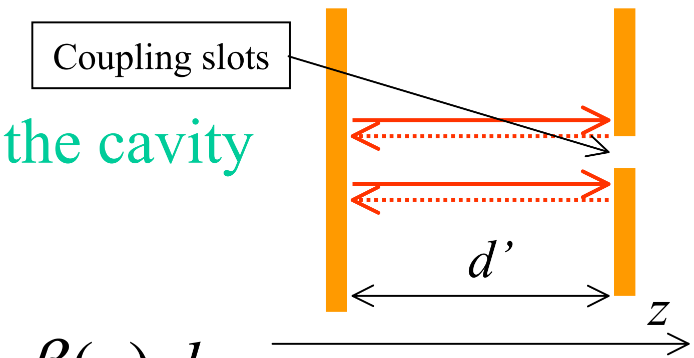


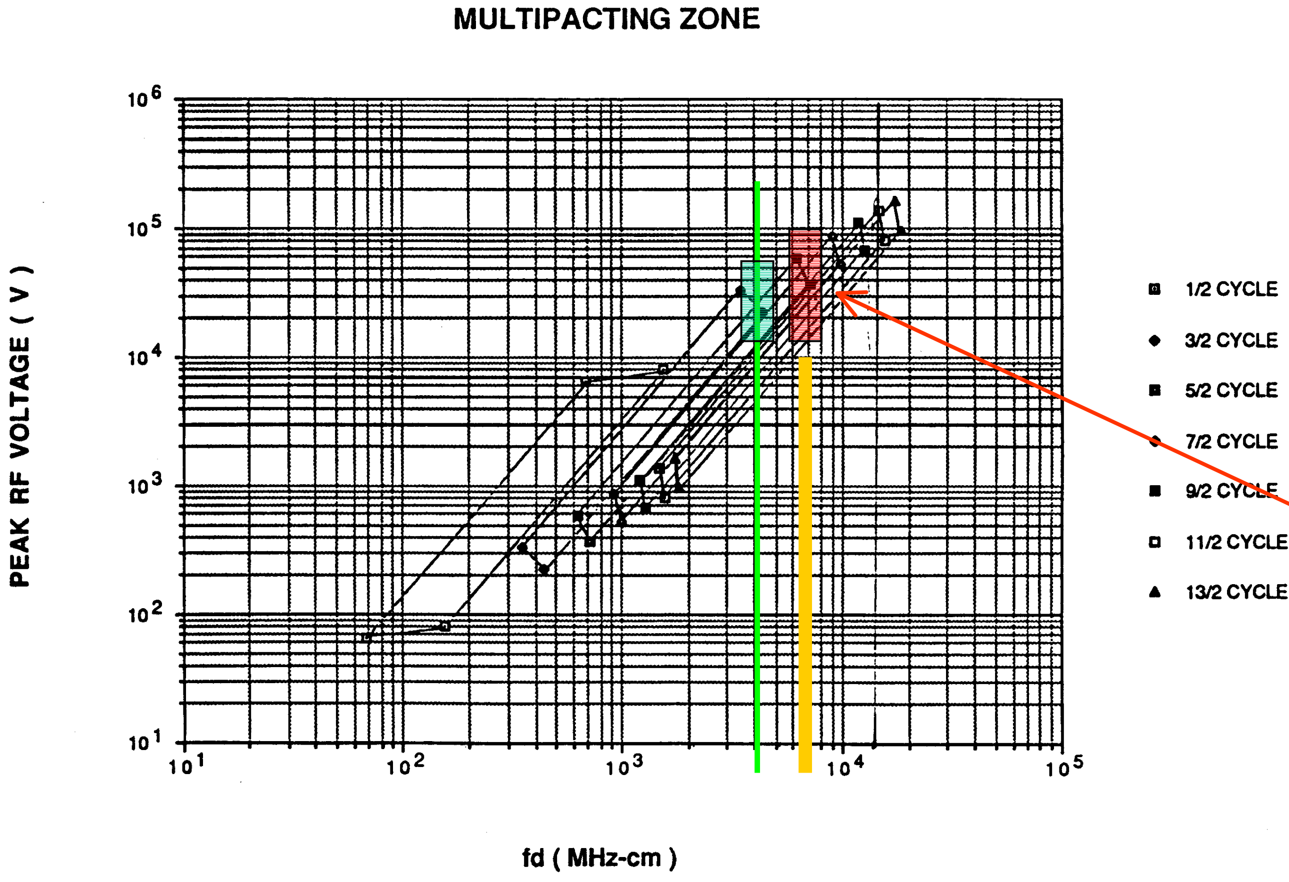
Two upper plates for outer part of the cavity (coupling slot area),

$$\frac{T_{rf}}{2}\overline{v} = d', \quad \overline{\beta} = \frac{\overline{v}}{c} = \frac{2d'}{cT_{rf}} = \frac{1}{d'}\int_0^{d'} \beta(z)\,dz$$

$$\overline{\beta} \approx 0.274 \text{ for } f = 805 \text{ MHz and } d' = 5.1 \text{ cm}$$

This corresponds to an average voltage of ~ 20 kV (~ 3 MV/m to 28 MV/m peak gradient on axis) or 2.4 ~ 33 volts on scope measurement, and indicate PM happens at wide range of peak RF gradients.

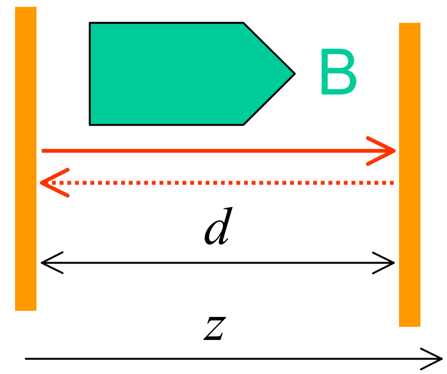
MP zones of two-plate



$f = 805$ MHz
$d = 8$ cm
$f_{rf}\,d = 6440$ [MHz-cm]

MP occurs
15 ~ 80 kV

A simplified model (3)



What happens with magnetic fields?

- Electron motions in *z*-direction should stay almost the same
- External magnetic field (2.5 T) is much stronger compared to the RF magnetic field (max. ~ 0.1 T at 30 MV/m of gradient) → strong focus channels
- Two-plate MP dominates and occurs when the resonate condition is satisfied → MP scans over the windows (two plates) starting from the center and going outwards radially (forms MP rings)
- Electrons trajectories follow the B field lines spirally depending on initial transverse velocities, MP at corners may likely to be suppressed
- More focused electrons are likely to produce higher x-rays

Future plan

- Better understanding of the MP with external magnetic field, and study how to condition RF cavities with **B**
- Near term plan: take the cavity apart and exam the cavity and window surfaces
- Further data analysis (hopefully quantitatively)
- Depending on the findings after the cavity inspection, we may test Be windows with TiN coatings: mechanical and thermal, and x-ray of Be windows
- There will be much more to learn