

The Design of the Orthogonal Box Cavity

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Introduction:

The muon collider and/or the neutrino factory require large accelerating electric field gradients immersed in large (3 to 6 T) solenoidal magnetic fields for ionization cooling of muon beams. Our original vacuum breakdown study demonstrated a loss of achievable peak accelerating gradient in solenoidal magnetic fields by a factor 2 or greater. The Muon Collaboration has developed a theory of a method to suppress high electric field breakdown in vacuum cavities needed for a Muon collider or neutrino factory. It has been shown in our studies and by others that high gradient electric field emitted electrons (dark current) are the primary cause of breakdown. A DC magnetic field orthogonal to the RF electric accelerating field prevents dark current high field emitted electrons from traveling across the accelerating gap and then will prevent breakdown.

We have decided to test this theory by building a special cavity in the shape of vacuum box. Figure 1 is a simplified view of the cavity design. The design is based on an 805 MHz WR975 waveguide cavity resonating in the TE₁₀₁ mode.

For the TE₁₀₁ mode the resonant frequency f_0 is given by the relationship

$$f_0 = c \left[\left(\frac{l}{a} \right)^2 + \left(\frac{m}{b} \right)^2 + \left(\frac{n}{d} \right)^2 \right]^{0.5} / 2$$
 where a and d are the

lengths of the base sides and b is the height of the box in MKS units and c is the velocity of light.

Simplified View of Orthogonal Box Cavity

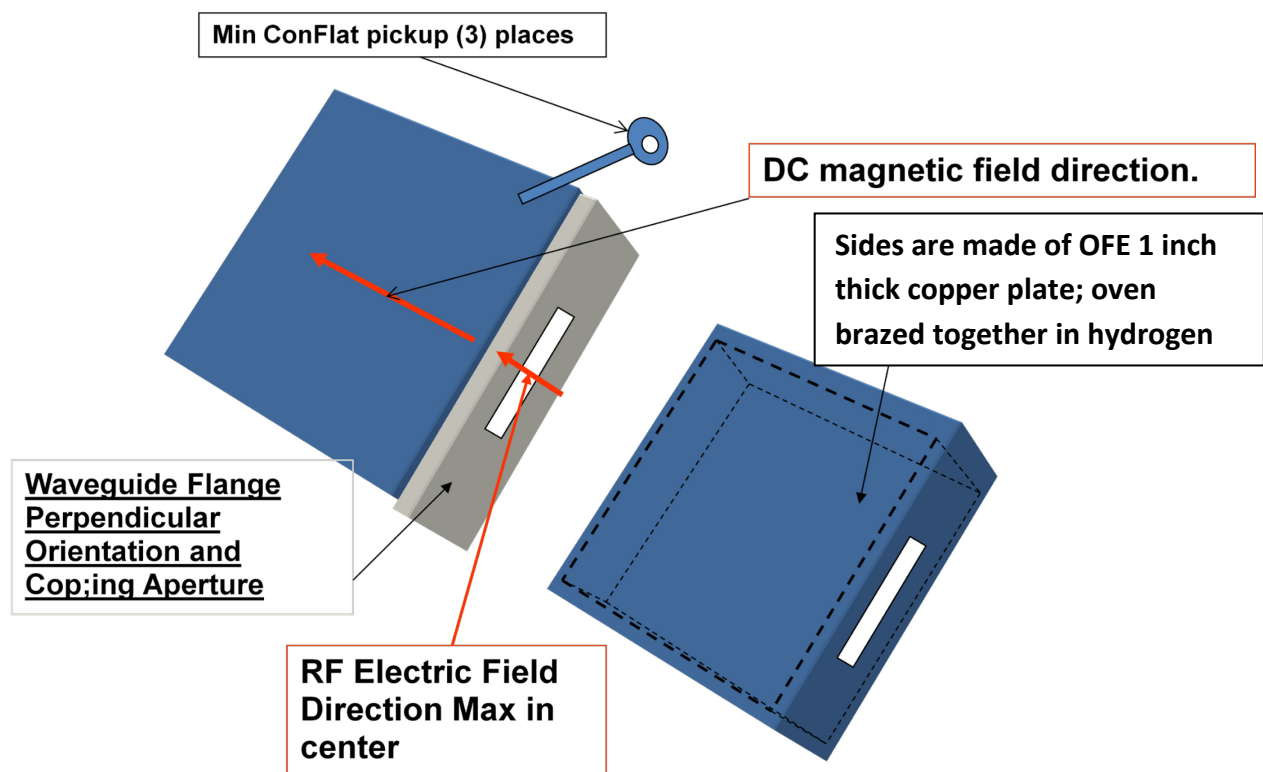


Figure 1, Simplified view of Orthogonal Box Cavity Concept.

The relationship was first used to set the scale of the simulations for the box Cavity. The cavity was then optimized by the use of the computer programs HFSS and Mafia. The program HFSS was used to simulate the cavity with its Coupling aperture and input drive Waveguide. This allowed us to simulate the entire problem up to its high power input drive flange, Figure 2.

Orthogonal Box Cavity Coupled to the Waveguide Input

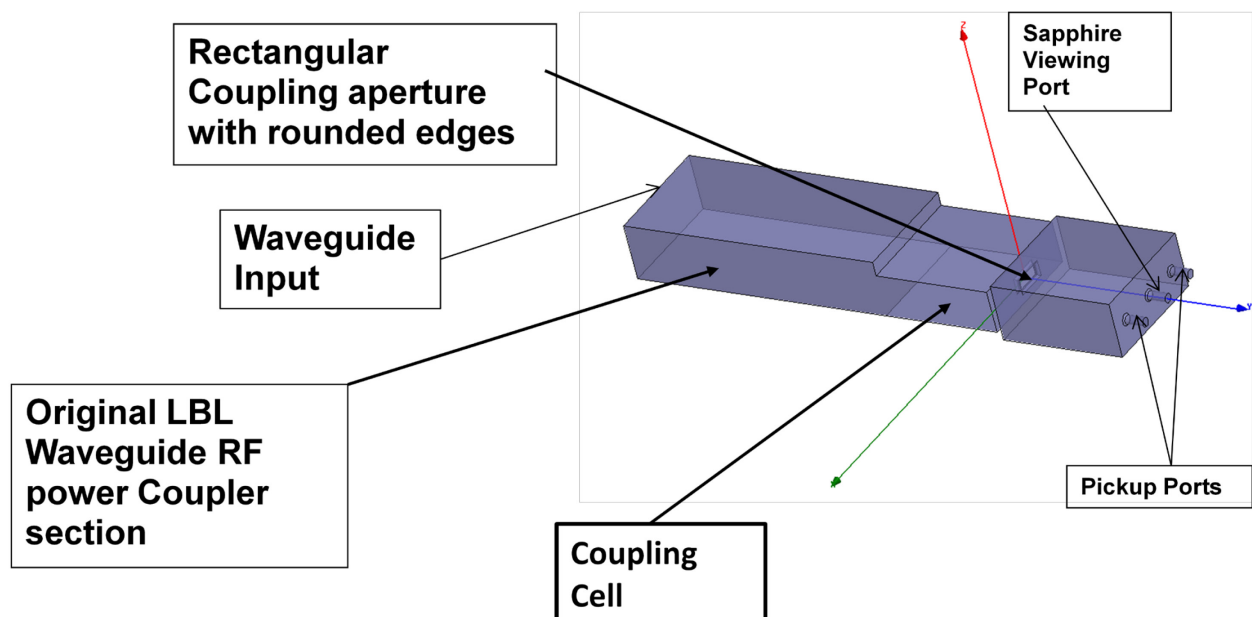


Figure 2, the Entire HFSS Simulation Model

In addition to fully testing the magnetic insulation theory, the cavity was made rotatable upto 12 Degrees relative to the magnets magnetic field axis.

Design Specifications:

The orthogonal box cavity is made of 101 OFE copper plates. Interior Parts and the aperture were machined to 32 μ inch finish. Two hydrogen brazing cycles were required to complete the cavity. The HFSS simulation coupling aperture design has been machined into the cavities. The Box Cavity was designed to match the frequency and bandwidth of the “hot” 12 MW peak spare 805 MHz linac klystron.

Frequency after final hydrogen brazing = 805 MHz +/- 1 MHz

Peak Drive RF power for gradient of 25 MV/m = 1 MW

Tolerance of machined parts = ± 0.003 "

Tolerance after brazing cycles = +/- 0.006"

Inside finish = 30 u inches

Average power = maximum 5 kW with half the power

dissipated equally on the Top and bottom plates the remainder almost equally on the 4 sides.

Pick-up ports: Three min-ConFlat vacuum feed-thru ports in the side opposite the coupling aperture, 2 for field pick-up loops and

one for Sapphire vacuum viewing window on a mini Con Flat flange.

Rotation Angle: 90 +/- Δ12 Degrees.

Leak check: < 2xE-10 ATM cc/sec (He).

HFSS Model and some Simulation Results:

Figure 3 shows the dimensions of the Box cavity developed by the simulation code HFSS as well as the calculated resonant frequency (F_0), Q_0 , Waveguide match, impedance and RF power require for gradient of 25 MV/m. The design frequency for the cavity was free parameter and was chosen as 805.2 MHz at the maximum output power frequency of the 12 MW drive klystron.

HFSS Cavity dimensions and Parameters of Box cavity

HFSS normalizes all parameters to 1 W of input power to the waveguide coupler and solves for the frequency, gradient, coupling factor, Q_0 :

1W produces a gradient of 25 kV/m by scaling:
25 MV/m would take 1 MW ideal.

The Impedance across the center of the cavity is
 $Imp = 9.5 \text{ M}\Omega$.

This is the resistance across the center of the cavity given by

$$Imp = (gap \text{ Voltage})^2 / 1 \text{ W.}$$

This uses the peak voltage and is in agreement with SuperFish and most published accelerator designs codes.

$Q_0 = 27,400$. Match = 1.005

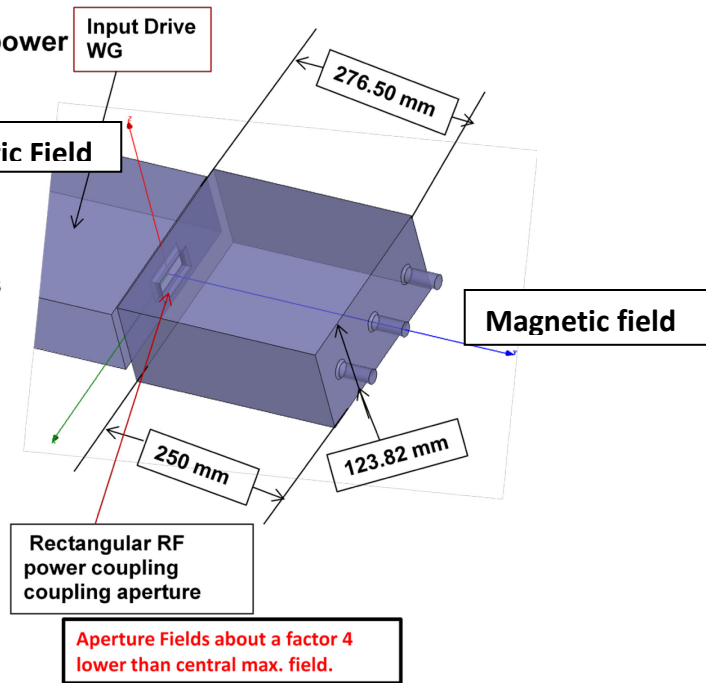
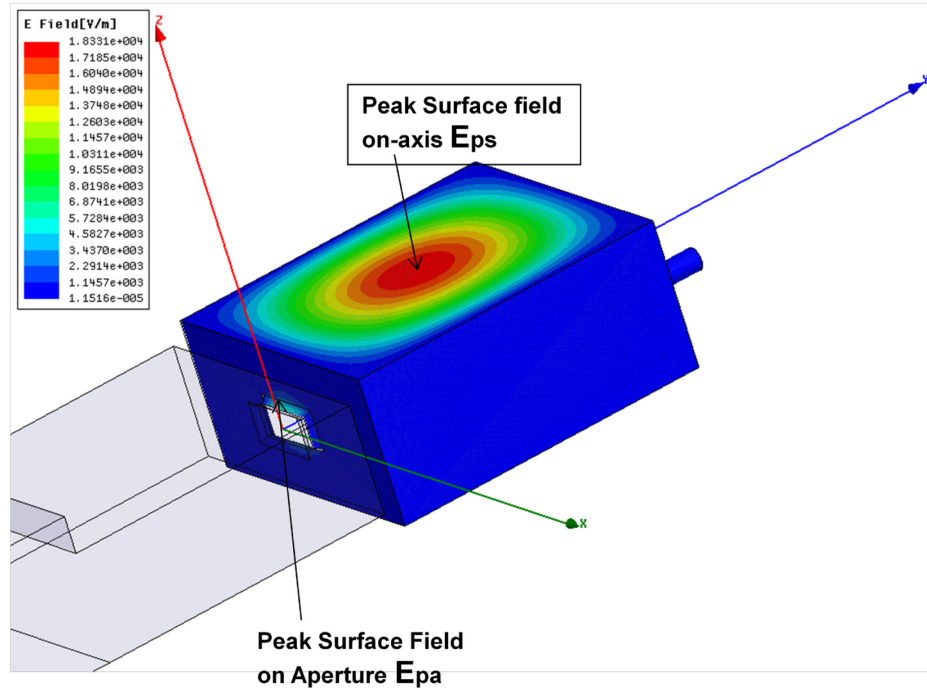


Figure 3 HFSS Model and some Simulation Results

Orthogonal Cavity Electric Field Simulation

Note 1:
Ratio E_{ps}/E_{pa} = 3.5
for orthogonal case.

Note 2:
Ratio E_{ps}/E_{pa} = 2
for parallel case.



Picture of Assembled Cavity in Test Lab and Test results:

After the final brazing at the factory in California, the cavity was returned to Fermilab for testing in the A0 superconducting test lab. The cavity was first Cleaned using superconducting techniques and successfully vacuum checked. The cavity was then connected to a network analyzer for frequency (F_0), Q_0 , and Waveguide input power match.

Box Cavity in A0 Test Lab after successful Vacuum Leak Check

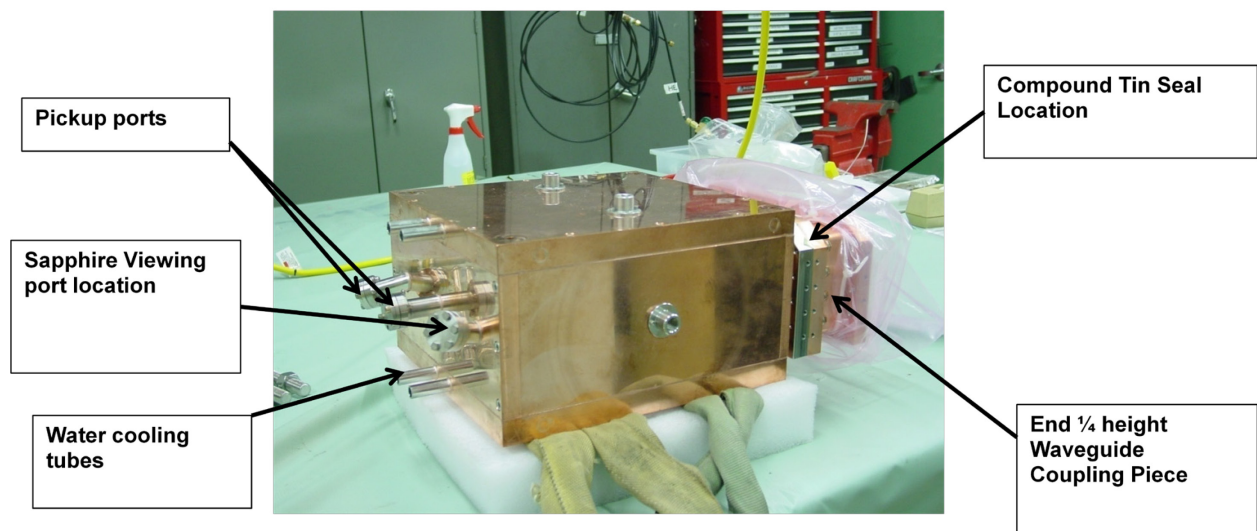


Figure 4, Cavity Test Bench in A0 Lab.

Cavity attached to Tapered waveguide coupler and WG-typeN Adapter.

Network analyzer measurements:

- $F_o = 805.33$ MHz test lab;
Simulation $F_o=806.2$ MHz
- $Q_o = 27,400$;
Simulation $Q_o = 27,400$
- $\beta = 0.96$ coupling factor;
Simulation $\beta = 1.06$.

▪ These values are preliminary and may change when attached to the LBL stepped WG coupler and mounted in the magnet. Even with a coupling factor of $\beta = 0.96$, 99.95 % of the transmitted RF power go into the cavity.

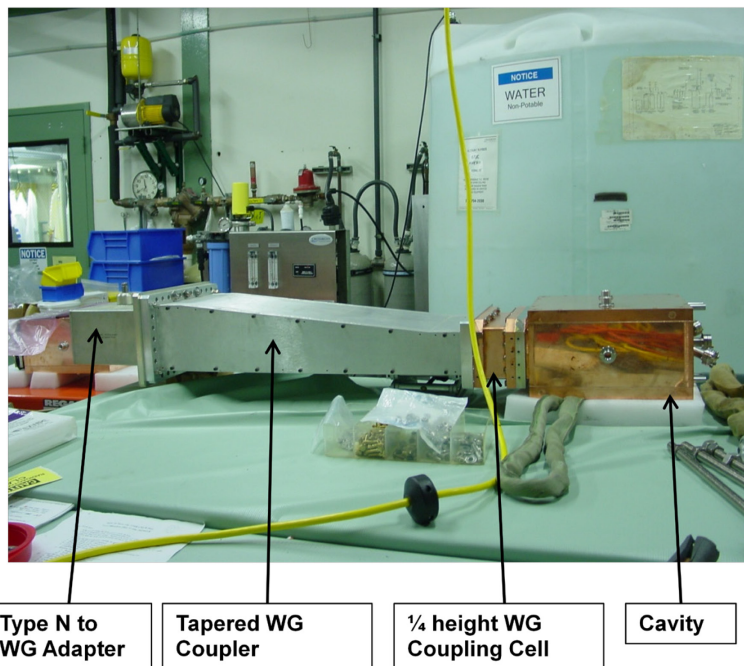


Figure 5, Test Setup before Attachment to Network Analyzer