Electric Gradient Breakdown Results for the Orthogonal Box Cavity in a 3 T Magnetic Field.

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I. Introduction:

The Muon Collaboration (Palmer and D. Stratakis[1]) has developed a theory for A method to suppress high electric field breakdown in vacuum cavities in high magnetic fields that are 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 therefore will prevent breakdown. We have built a test cavity (TM-2473-APC [2]) in the shape of a box to test this theory .

The results of the first study are presented. Because the theory has an angular dependence the cavity was made rotatable upto 12 Degrees between the RF

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electric and DC magnetic field to test the theory.

II. Cavity Modeling and Experimental Arrangement

Figure 1 shows the Box cavity model developed by the RF simulation code HFSS. The cavity was designed to resonate and be matched to the waveguide RF power coupler at 805 MHz. It was also deigned to match the frequency of the high power driver klystron of 805 MHz. Network analyzer measurements showed excellent agreement between experimental and simulation results without any tuning requited:

- **Fo = 805.3 MHz cavity resonant frequency on the test stand; Simulation Fo=806.2 MHz**
- **Qo= 27,400 on the test stand; Simulation Qo= 27,400**
- **β= 0.96 coupling factor on the test stand; Simulation β= 0.97.**

Figure 2 shows the experimental arrangement of the Box cavity in the 5 T Superconducting solenoidal magnet. The setup shown is for the calibration arrangement. It shows the waveguide to type N adapter connection required for the network analyzer measurement of frequency, Qo, and coupling factory. The cables connecting the WG forward and reverse directional coupler ports and cavity voltage pickup signals are calibrated and then connect to a fast 4 channel digital storage scope in the linac gallery control center. The calibration factors are essential in the determination of the gradient versus RF power input and the cavity pickup voltage. The cavity is then connected

to the high power klystron by replacing the waveguide to type N adapter with a 90 degree WG Elbow and short straight WG pieces. The pieces are selected to make the required experimental angle between the RF electric field and the DC magnetic field. The cavity is suspended in a harness that is clamped down in the magnet support frame and allows it to rotate upto 12 degrees or 78 degrees between the electric and magnetic fields. A set of short straight WG pieces and the WG elbow is required for each angle of the experimental study.

Orthogonal E and H Cavity Coupled to the Waveguide

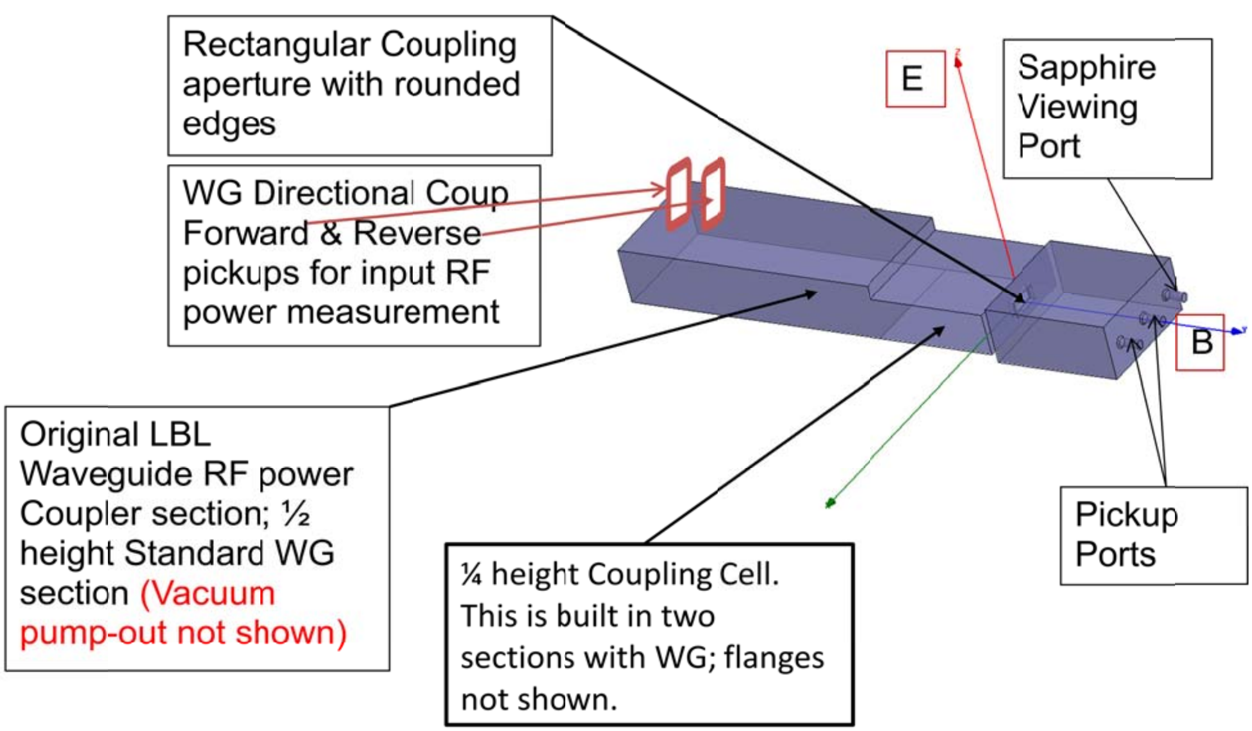


Figure 1. HFSS Model RF cavity and WG coupler

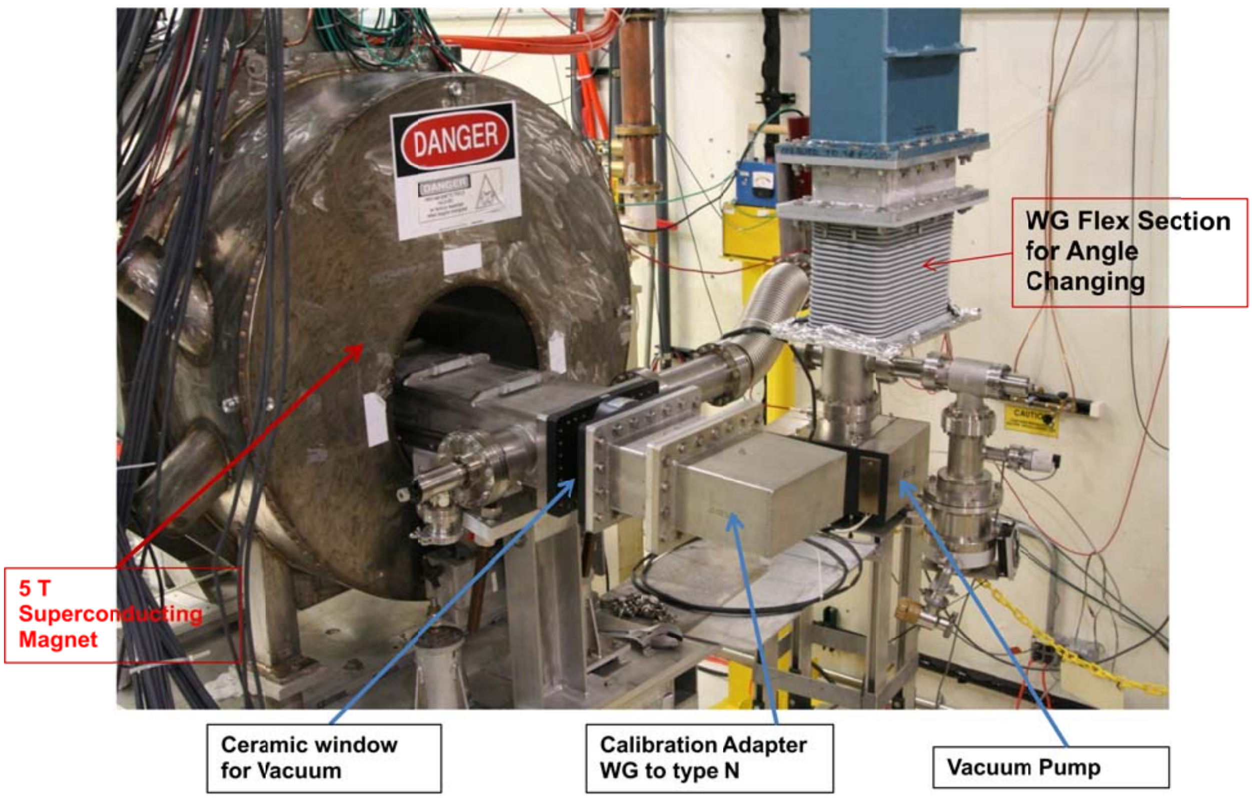
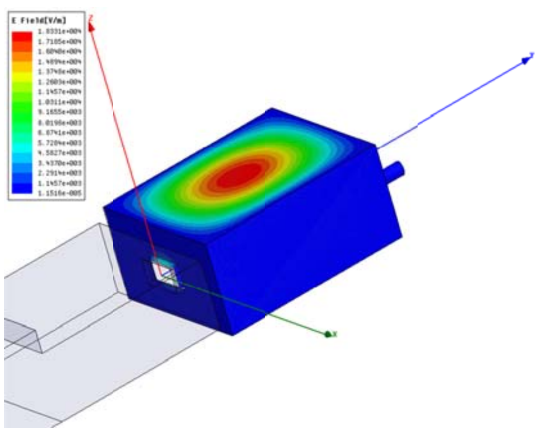


Figure 3 shows the HFSS electric gradient pattern of the cavity. It is peaked in the center of the cavity. The other feature that should be noted is the very low gradient in the coupling aperture. It is down about a factor 4. This could be important in reducing the coupling sparking problem noted in the Pillbox cavity

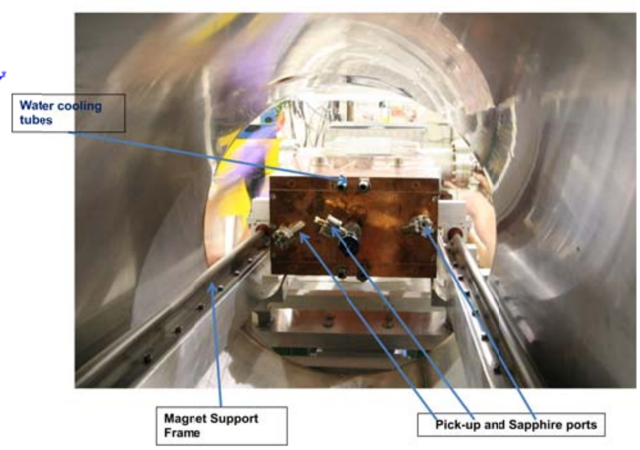
where the field level is much higher. The picture shows the cavity mounted in the magnet on its magnet support frame. The support frame and mounting to the magnet base allows the cavity to be rotated upto 12 Degrees.

Four ½ inch Heliax coaxial cables carry the 2 cavity voltage pick-ups signals and the forward and reverse directional coupler signals up to the central control center 100 m away in the linac gallery.

An optical spectrometer is connected by a light fiber to the sapphire widow port. Its signal is also brought back on a ½ inch Heliax cable. A NaI crystal, a series scintillation counters and laboratory radiation monitors are used to monitor X-Rays and dark current emissions from the cavity. These are used to study the physics of the breakdown and will not be reported on in this TM.

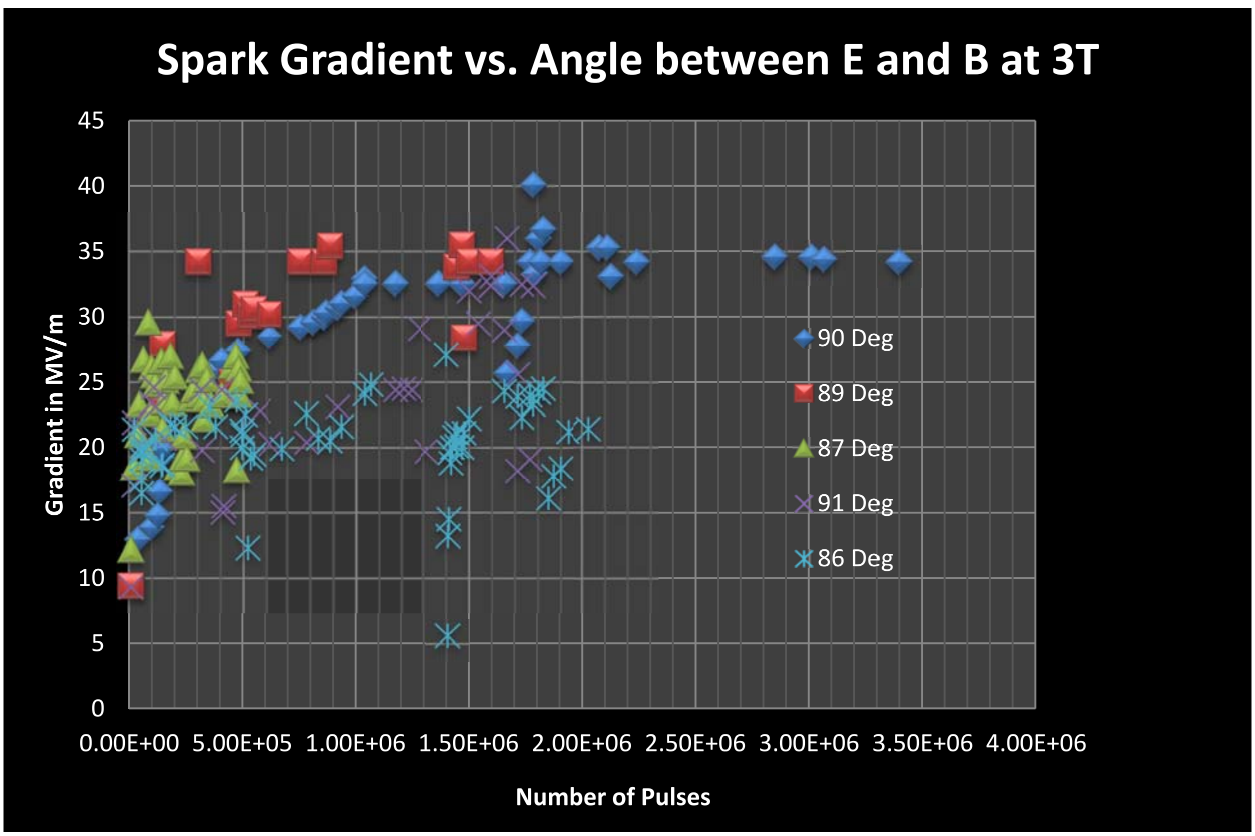


Box Cavity in the MTA Magnet on its Rail Support



III. Experimental Results

The experimental results are displayed in Figure 4. The high power RF was operating at a 15 Hz rate with a pulse length was 20 us for all the experimental test runs. On the horizontal axis is the number of pulses between sparks. On the vertical axis is the achieved spark gradient. The graph shows the epoch history for each angle tested. For example the number of pulses for the 90 degree angle was 3.4 E 6.



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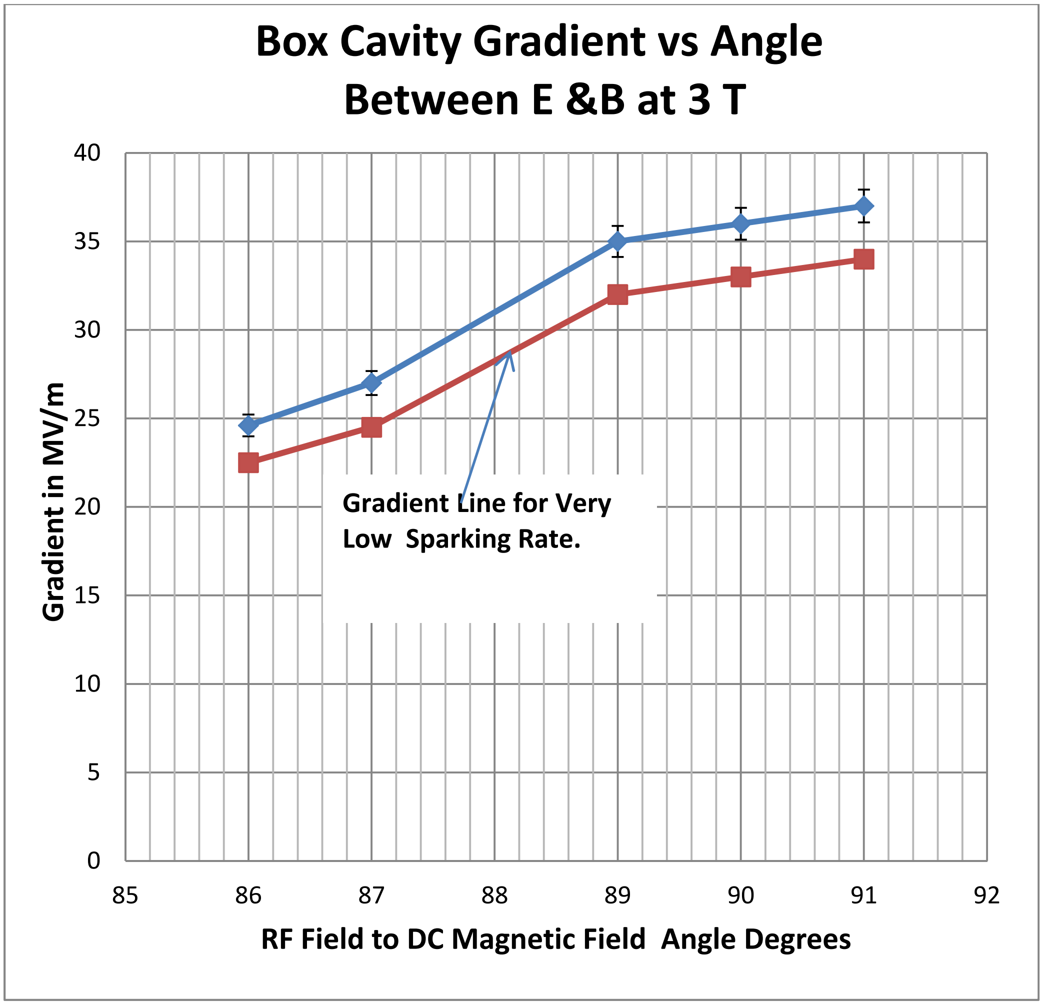
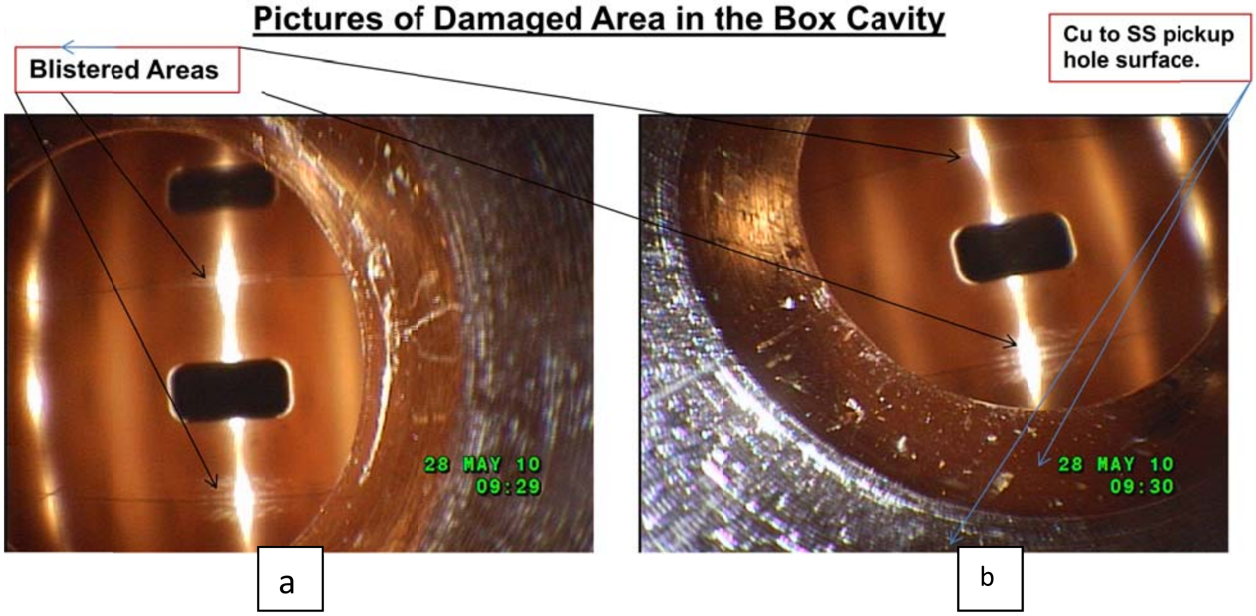


Figure 5. The Breakdown Curves versus E/H Angle.

Figure 5 shows the breakdown limit for low and high sparking rates. The blue Curve is the high sparking rate limit of 1/15000. The red curve shows the very Long sparking rate gradient limit of 1/100000. The curves demonstrate that the orthogonal magnetically insulate cavity can achieve a higher gradient limit than in the parallel magnetic configuration. For example at 86 degrees the gradient

limit is 40 % higher than the parallel case.



It was difficult to get a good view of the inside damage of the cavity because of the highly polished surfaces depending on the observation angle produce multiple reflections (part a of Figure 6). The inside surfaces were very clean with not many spark pits visible. For example the stainless steel and copper transition surfaces highlighted in b of figure 6 are not showing spark damage, but the surfaces as they were at fabrication. The pictures show darkened blistered areas in appearance above and below the RF power coupler aperture

at the intersection of the surfaces. The directly opposite surfaces also shows the same darkened areas. The adjacent sides surfaces did not show theses darkened areas. A second observation after about twice more running time showed these areas further darkening and more spread out.

<u>Summary of Orthgonal Box cavity experimental results</u>

We have completed the Box cavity Study (magnetic field insulation effect) at 91,90, 89, 87 and 86 Degrees at 3. Tesla. Before each run we commissioned the cavity upto 33 MV/m at 0. T except for the first 90 Degree run commissioned to 23 MV/m. In some of the later runs, we commissioned the cavity to 50 MV/m at 0 T. The results have been shown at a low sparking rate of 1/100000 at a gradient limit at 3 T of:

from 89 to 91 deg a gradient limit of 33 MV/m

at 87 deg a gradient limit of 25 MV/m and

at 86 deg gradient limit of 22.5 MV/m.

[1] D. Stratakis, et al., Nucl. Instr. and Meth. A (2010), doi:10.1016/j.nima.2010.03.167.

[2] A. Moretti, TM-2473-APC,The Design of the Orthogonal Box Cavity, 09/15/10.

Summary Of the Box cavity

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- The results have been shown: from 89 to 91 deg we reached a low sparking rate at a average gradient of 33 MV/m

  at 87 deg a average gradient of 25 MV/m and

  at 86 deg a average gradient of 22.5 MV/m.
- We need to decide if the second orthogonal box cavity should be tested with a TiN coating or tested at all?
- We also need to decide if we need to build a parallel Box for testing in the MTA from the copper in storage?
- The second RF test station is now ready for RF commissioning cavities that do not require a magnetic field.

Figure 4, Cavity Test Bench in A0 Lab.