

## SUPERCONDUCTING RF ACTIVITIES AT CORNELL UNIVERSITY\*

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### 1- INTRODUCTION

The present superconducting activities at Cornell University fall into three general categories; B Factory system development, SC Linear collider studies (TESLA), and basic SC studies. This paper will outline and briefly describe the scope, status, and results of these efforts since the last SC workshop at DESY in 1991. The order of discussion is indicative of the relative resources that have been allocated to these three areas. Reference will be made to more detailed reports that will be presented at this workshop in some technical areas.

### 2- B FACTORY EFFORT

High luminosity colliders such as the proposed Cornell B Factory stand to gain from the use of SRF.<sup>1</sup> To achieve the required luminosity, 1-2 amps of current need to be stored in

many bunches spaced a few meters apart. Such high currents and tight bunch spacing make it imperative to lower the cavity impedances.<sup>2</sup> By operating with high gradient (5-10 MV/m), the number of high impedance accelerating cells can be reduced over copper cavities (1-2 MV/m). SRF cavities allow the use of large beam holes which further lowers the impedance. Because the impedance is decreased the demands are greatly reduced on feedback systems needed for controlling fundamental and higher mode driven multi-bunch instabilities. As an added bonus, capital and operating cost savings are realized from the reduced RF installation which no longer needs to provide for RF power dissipation in the cavity walls.

At this time Cornell has an approved phased upgrade plan which includes the use of SC cavities in CESR. A proposal has also been submitted for funding of a complete B Factory which uses 16 SC accelerating cavities and 4 SC CRAB cavities. The configuration of the final B Factory is shown in Figure 1.

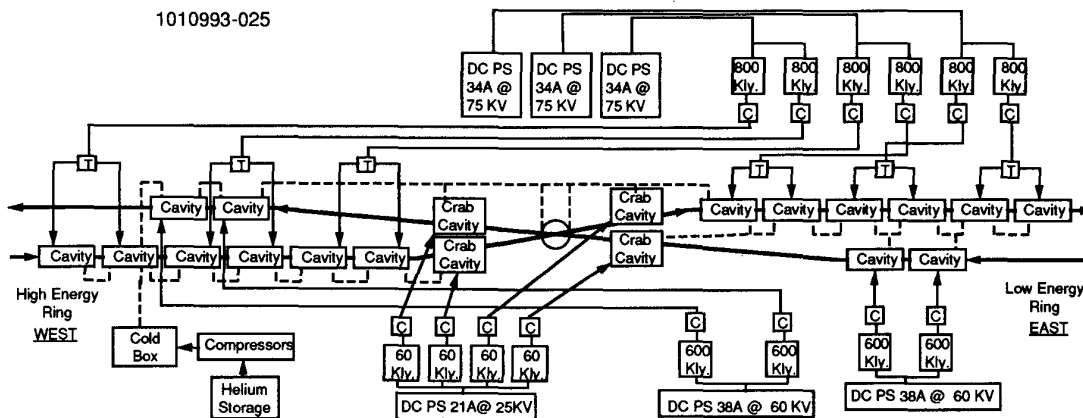


Fig. 1 Layout of SC Cavities in Proposed Cornell B Factory

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### 3- ACCELERATING CAVITY

A sketch of the accelerating cavity is shown in Figure 2 along with the horizontal cryostat and other associated hardware. A 500 MHz niobium cavity and a copper cavity were received from industry and tested. The CESR-B design calls for each cavity to operate at an accelerating field of 10 MV/m (25 MV/m peak surface field).

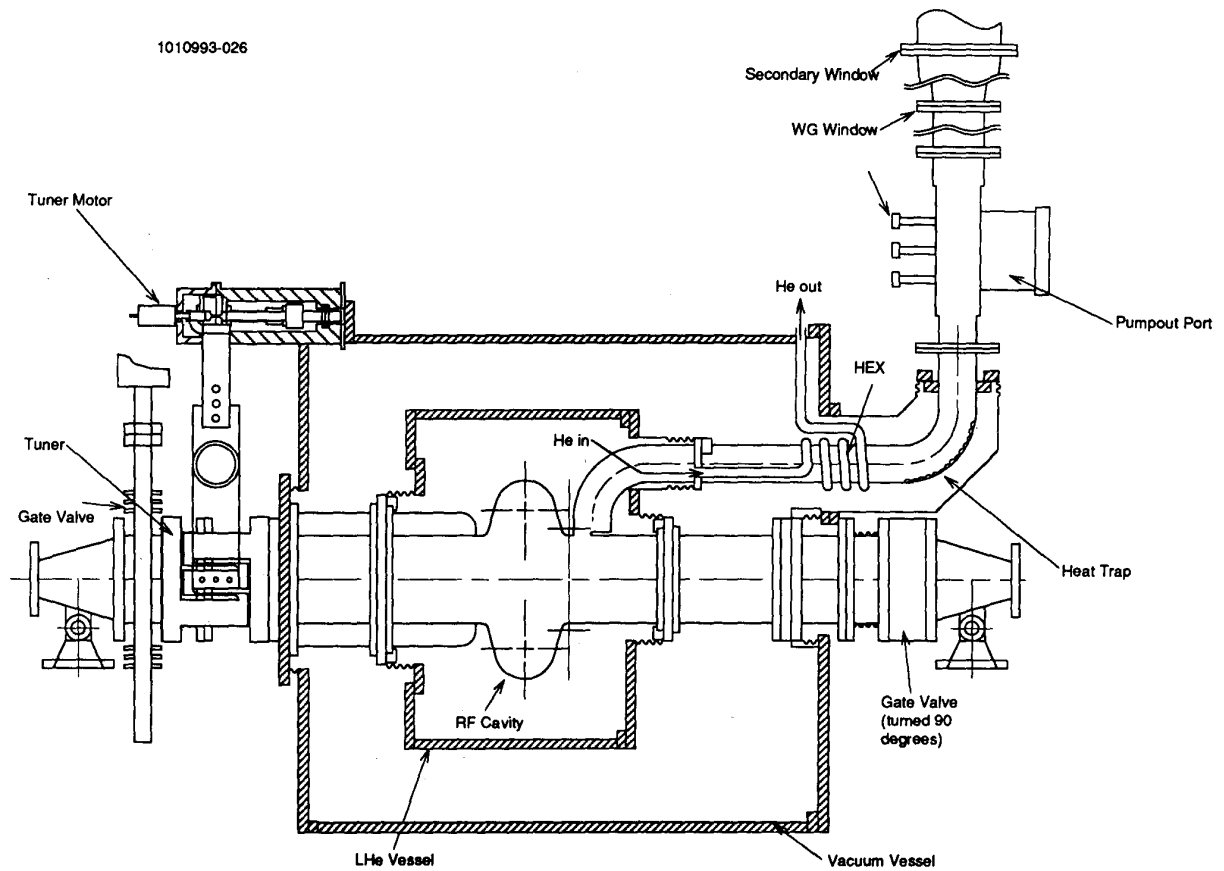


Fig. 2 B Cell Superconducting Cavity and Cryostat for B Factory

To provide the beam power for CESR-B, 400 Kwatts of RF power must be coupled into the beam through a room temperature window<sup>3</sup> and through the input coupler. A waveguide, rather than a coaxial, input coupler was chosen because of the lower power densities and the relative ease of cooling the surfaces subjected to high RF currents. Room temperature measurements on the full scale Nb and Cu cavities showed that the waveguide input coupler achieved the desired  $Q_L = 1.75 \cdot 2 \times 10^5$ .

Several vertical tests have been made.<sup>4</sup> A photograph of the cavity mounted for testing in the vertical dewar is shown in Figure 3.

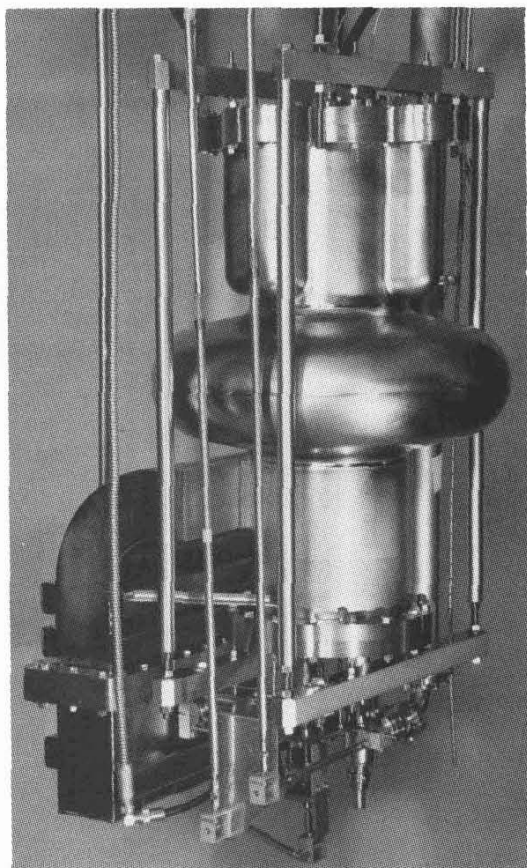


Fig. 3 500 MHz Cavity Mounted for Vertical Testing

Two adjustable coaxial couplers were available for these tests, one on the beam line and one into the resonant waveguide shorting hat. Both of these couplers could be adjusted to achieve critical coupling. Two fixed beamline probes were used to monitor the cavity fields. Four titanium rods attached to the end plates of the cavity braced the cavity against collapse in place of the cavity tuner. The standard cooldown procedure took the cavity from room temperature to

4.2 K in a couple of hours. During the first test on the cavity as received from industry there was difficulty with Indium seals leaking helium into the cavity. Nevertheless, we reached  $E_{acc} = 8.5$  MV/m at  $Q_0 \approx 1 \times 10^9$ . After additional 15  $\mu$ m material removal from the cavity inside surface with 1:1:2 BCP the cavity was retested. The results of this test are shown in Figure 4 and, as can be seen, the desired field of  $E_{acc}=10$  MV/m at  $Q_0=1 \times 10^9$  was surpassed.

Subsequent test showed that the cavity at some time had become infected with the "Q-virus", that is, contaminated with H. This probably occurred when the chemistry was done at Cornell. During this chemistry the temperature of the acid was not sufficiently monitored or controlled to remain below 15-20 C. After several experiments it was determined that the fast cooldown success of our early tests could be duplicated by cooling to 160K very slowly and then holding at this temperature for several hours as long as the subsequent cooling to 4.2K took place in less than 2 hours. This procedure was developed for the HERA cavities at DESY. We believe that such a cool down cycle will permit us to avoid excessive mechanical stresses and the Q degradation caused by slow cool down in the cryostat.

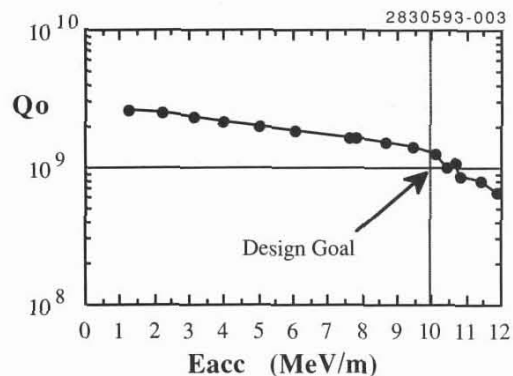


Fig. 4  $Q_0$  vs  $E_{acc}$  after Second Cavity Test

#### 4- HIGH POWER WINDOW DEVELOPMENT

Two planar waveguide windows purchased from industry were tested a second time after copper plating the SS waveguide sections.<sup>5</sup> During this test the windows were powered to 250 Kwatts CW traveling wave power. The major limitation was vacuum trips. It was possible to reach 90 Kwatts CW traveling wave power in less than 2 hours of processing. To reach 250 Kwatts it took another 150 hours. At no point did the the temperature of the water cooled BeO windows exceed 5 degrees above ambient. After the traveling wave power test, the load was replaced with a short. It was possible to run 125 Kwatts CW reflected power, without any trouble for 4 different short positions, spaced 1/8 wavelength apart. After the test, the windows were let up to 1 atmosphere of clean dry nitrogen gas, and immediately pumped out. There was no difficulty in re-establishing the previous power values.

### 5- CRYOSTAT DEVELOPMENT

In order to perform a beam test with the B-Cell in CESR, a horizontal cryostat has been designed and is being manufactured by industry.<sup>6</sup> A drawing of the cryostat that is being made by MTM, Oak Lawn, IL is shown in Figure 5.

The design of this cryostat is challenging because of the very large beam pipes, the very high input power, the requirement to minimize, the requirement of short beam line length, and the necessity to assure the dust free environment on the inside of the cavity at all times during the assembly.

To aid in the early design stages a computer program was written in order to calculate the steady state heat flows and thermal behavior of the cavity, beam pipes and waveguide. The large beampipes (240 mm diameter) and the input waveguide (100 mm x 430 mm) could allow a significant amount of infrared radiation into the cavity. No simple analytical technique could be found to treat both specular and diffuse radiative heating, as well as RF heating, wake field heating and conduction.<sup>7</sup>

The program does not deal with the true geometry but only simple geometries, either cylindrical or rectangular pipes. This avoids the complication of defining and meshing complex shapes and the output can be simple two dimensional plots without loss of information. The variation of thermal and electrical conductivity as a function of temperature is taken into account and the program is arranged so that cryogenic gas heat exchangers can be specified. The name given to the program is ASTModeler.

The one feature that the program was able to predict was that, due to the large diameter beam tubes, most of the radiant heat approaching the cavity down the beam pipe leaves the cavity on the other end rather than depositing the heat in the cold cavity. The final calculations lead us to expect about 30 watts of total residual heat leak into the cavity when 500 Kwatts of RF power is being fed to the cavity. The RF loss in the niobium cavity itself at  $E_{acc}=10MV/m$  and a  $Q_0=1 \times 10^9$  will be about 100 watts.

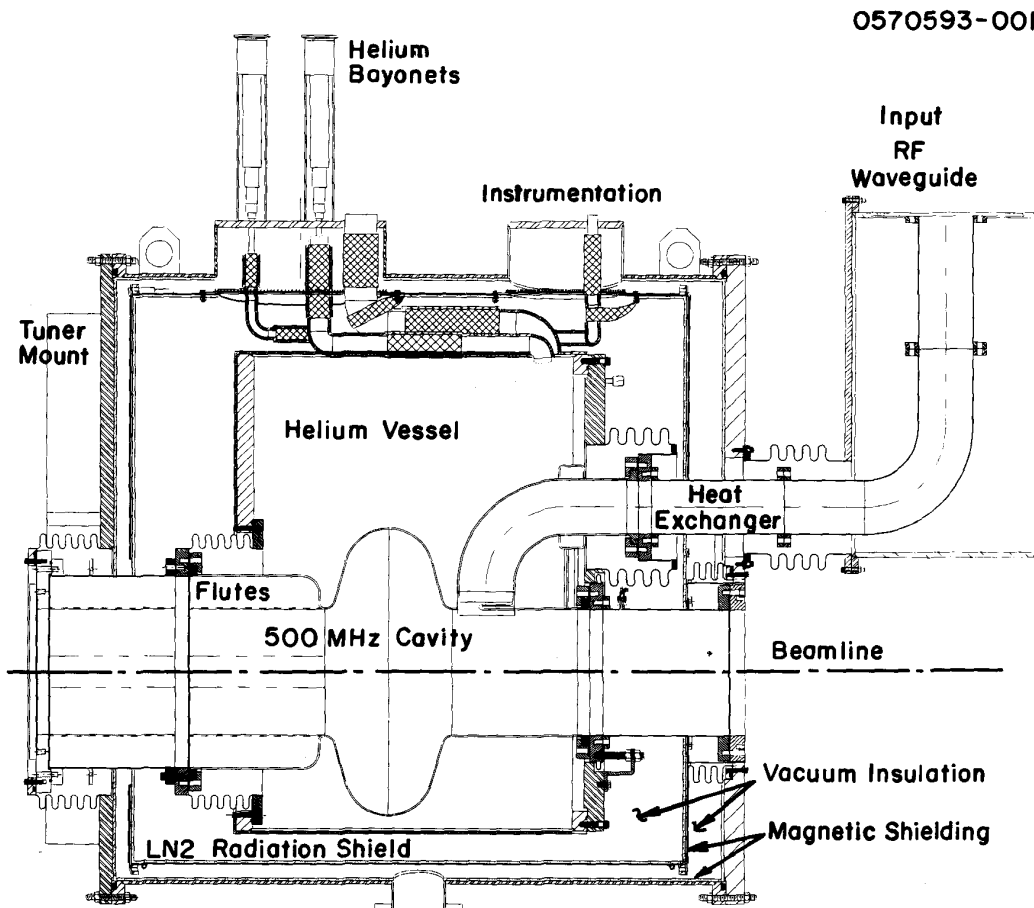


Fig. 5 Assembly Drawing of the cryostat for the CESR-B Cavity

## 6- HOM LOAD DEVELOPMENT

As has been previously described,<sup>8</sup> all of the higher mode power<sup>9</sup> is to be transmitted out the beam tubes of the cavity where it may be absorbed at room temperature.<sup>10</sup> The size and shape of both beam tubes have been designed so that all the higher order modes will propagate down the beam tubes where they are damped in sections of beam pipe that has been lined with ferrite. Much of this work was described at the recent MAMA workshop at CEBAF.

Several aspects of the HOM load development are pursued. These areas are: selection and characterization of the ferrite to be utilized<sup>11</sup>, the resulting damping of all the HOMs<sup>12</sup> in conjunction with the cavity, the impedance of the ferrite loads directly to the beam<sup>13</sup>, and the engineering<sup>14</sup> and manufacturing<sup>15</sup> of the loads so that they can handle the required HOM RF power.

A new analytical calculation was carried out on the coupling impedance of beam pipe ferrite higher order mode (HOM) loads. Knowledge of the coupling impedance gives us information to assess the interaction of the HOM loads with the beam, and to predict beam instabilities. Formulas were derived for the longitudinal and transverse coupling impedance per unit length of an infinitely long conducting beam pipe, with a layer of material with complex permeability  $\mu$  and complex permittivity  $\epsilon$ . Both of these material parameters had been measured for the chosen ferrite. For several reasons the TT2-111 series ferrite manufactured by Trans-Tech have been chosen. This choice was made on the basis of electrical properties and mechanical properties.

The calculated loss factor from the impedance agrees reasonably well with previous results from the AMOS code and with measurements showing that  $K=0.2$  V/pc for each load in the worse case. The analytic result yields a power loss of 7.9 Kwatts per load in the low energy ring of CESR-B and 1.5 Kwatts per load in the high energy ring.

Detailed damping measurements were made at room temperature with the copper B Cell of the Q of all the HOMs. These results indicated that all of the modes were damped to the degree required for stable beam operation in CESR-B, that is  $Q < 100$ .

Engineering studies on the fabrication of the loads continue. A metal bonding technique has been developed in order to achieve adequate heat transfer from the ferrite to the stainless steel beam pipe shell and to assure satisfactory vacuum properties of the loads. A 1/6 scale model load was constructed and tested with high power microwaves (2.45 GHz) to the required power density (10 watts/cm<sup>2</sup>). A full size load has been made and will also be tested. There are indications that the consistency of the metal bonding of the ferrite is not yet satisfactory and further development work will be required.

A test in CESR of a long, small diameter beam pipe lined with ferrite is planned well before the cavity beam test. The purpose of this test is to maximize the beam-ferrite interaction by making the load both longer and smaller diameter as

compared to the cavity loads. This load is presently being designed and manufactured.

## 7- BEAM TEST COMPONENTS

Design and manufacture of other components required for the CESR beam test of the cavity have also been required. The tuner required on the cavity has been made and tested off line. The design is based on the use of flexing of metal hinges and has no high load bearings with the inherent backlash and alignment problems. This concept originated at LANL.<sup>16</sup> The forces required are 500 Newtons and the required motions are of the order of 2 mm. The B cell cavity horizontal cryostat incorporates this tuner in its design.

The various thermal transition sections for the cavity have been manufactured and vacuum tested at cryogenic temperatures. These parts, have in general, been made of 304 SS with a very thin electroless copper plating on the inside in order to minimize both dissipation and thermal conductivity. The tapers to the rest of CESR have been designed to minimize the loss factor of the beam. Sliding joint sections have been made and tested for this large (240 mm) diameter beam pipe size in order to allow for cavity tuning movements and installation.

The horizontal beam test cryostat will require large diameter gate valves in order to isolate the cavity during cryogenic low power tests to allow installation in CESR. Such gate valves have been designed in conjunction with a commercial valve manufacturer. These gate valves have a 240 mm diameter opening and have an "RF smooth" opening when the gate valve is open. These gate valves are complete and tests are in progress to measure their RF and vacuum properties.

## 8- BEAM TEST IN CESR

In the course of development of the superconducting cavities for CESR, during the next 6 months, three definitive tests are planned. The preparation for these tests are presently utilizing most of our resources. All these tests will be done on the existing B Cell cavity mounted into the horizontal cryostat. The first test will be off line with batch fill only of liquid helium and resonantly coupled low power RF only (100-200 watts). During this test we should learn of all the mechanical problems of the system and most of the cryogenic problems.

After this test, the cryostat will be moved to Wilson lab where off line tests will be made, this time with a refrigerator and with the high power, 600 Kwatts, RF transmitter. This test will introduce the factors of the final cryogenic system and the full power RF system. The controls and data logging systems should be fully tested as well as all of the operational control features.

As the final test the cryostat will be moved by about 10 meters where it will be installed in the beam line. The waveguide and the cryogenic transfer lines will be rerouted slightly but the basic systems be unchanged. The new aspect introduced for this test will be the beam and the subsequent beam loading of the cavity as well as the HOM power induced

in the cavity by the beam. We expect single beam currents up to 200 ma during this test. This is well below the final desired beam current but should uncover some of the problems associated with high current. These tests will be done both with and without the NC RF system of CESR also in operation. There should be enough beam current that we can see the effect of both the cavity and the HOM loads on the beam impedance.

### 9- CRAB CAVITY DEVELOPMENT

The design of the Cornell B Factory has chosen to have the beams cross at an angle at the interaction point rather than have the beams collide head on. This angle is about 12 mrad. The reason for this angle is that background rates can be drastically reduced and the required interaction region magnets are simplified.

The consequences of this finite crossing angle is that the luminosity of the interacting bunches will be reduced because all the particles in one bunch will not get a chance to interact with all the particles of the other bunch. The crossing angle can also lower beam-beam stability limits due to synchrotron-betatron coupling resonances.

Both of these effects can be eliminated if the bunches are rotated in  $xz$  space at the interaction point so that the footprint of the two bunches exactly overlay. This is accomplished by a pair of CRAB cavities in each beam, one rotating the bunch and one straightening it back out after the interaction.

Necessary deflecting voltages for the 8 GeV HER and the 3.5 GeV LER of CESR-B are 1.8 MV and 0.8 MV, respectively. Multibunch instabilities have to be considered just as in the accelerating cavities. Q values of dangerous modes should be lowered to values typically of the order of 100. Since the deflecting mode used for crabbing is not the lowest frequency mode, special attention is required for damping all the parasitic modes.

The cavity design<sup>17</sup> that we have been considering is shaped rather like an accelerating cavity with a slight amount of polarization at the equator. The cavity would use the TM110-H mode for crabbing as this mode has the highest transverse shunt impedance,  $R^*/Q$ . As for damping the unwanted modes, we are considering the beam line coupling scheme. In this scheme, higher order modes propagate in the beam pipe and are absorbed by ferrite attached on the beam pipe at room temperature. However, since the TM110 mode is not the lowest frequency mode, there are some modes whose frequency is lower. Four unwanted parasitic modes remained trapped in the cavity region with high Q values even if a beam pipe with a large radius is attached. Those modes are the TM010 monopole mode, the TE111(H), the TE111(V), and the TM110(V) modes.

In order to solve this problem, we attached a coaxial beam pipe to one side of the cavity as shown in Figure 6. In the coaxial line there is no cut-off frequency for the TEM mode waves, but there is a cut-off frequency for the dipole modes. By attaching a coaxial beam pipe to the crab cavity, all monopole modes in the cavity can couple to the coaxial beam pipe as a

TEM mode and propagate. In addition, all dipole modes in the cavity can couple to the coaxial beam pipe as a dipole mode wave and propagate if the frequency is higher than the cut-off.

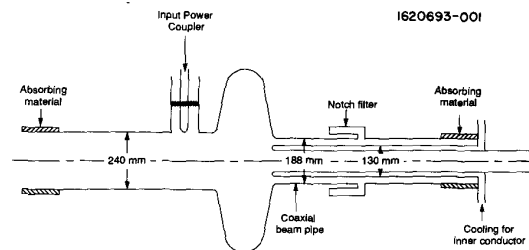


Fig. 6 Drawing of CRAB Cavity

By designing the cell such that  $f(\text{TE}_{111}) > f(\text{cut-off}) > f(\text{TM}_{110})$ , it is possible to make all monopole and dipole modes except the two polarizations of the TM110 mode in the cavity to propagate down the coaxial beam pipe. We choose the inner and outer radii so that the dipole cut-off frequency is 600 MHz, which makes the attenuation for the crabbing mode 60 dB/m.

The one remaining unwanted mode is the TM110(V) mode that must be damped or not driven. There are two possible ways to accomplish this. One is to carefully tune the TM110(V) mode so that it is not excited by the beam. This would require an orthogonal tuner for this mode that would still allow the tuning of the TM110(H) mode to the proper frequency.

The other scheme would entail making the end of the coaxial beam tube non symmetrical in the V plane but symmetrical in the H plane. This would couple the TM110(V) mode but not the TM110(H) mode to the coax in the TEM wave mode. It is not clear that enough damping of the TM110(V) mode can be achieved in this manner.

An alternate "squashed" highly polarized cell shape has been investigated at room temperature. In this shape the polarization is sufficient so that the TM110(V) mode is also above the cut-off frequency of the coaxial beam pipe.

A 1/3 scale niobium cavity was made of the slightly polarized shape. The cavity included the SC notch filter and the coaxial beam tube on one end. An absorber of 410 SS was placed at the shorted end of the coaxial line. This cavity was cooled to 1.5 K in liquid helium and measured in the TM110(H) mode at 1.5 GHz. At peak surface fields of 1 MV/m multipacting was encountered which was considered to occur at the coaxial beam pipe. This was processed away in 1 hour with low level RF processing.

The maximum peak surface field we reached was 25 MV/m, where field emission was the limit. This level achieved the design goals of field and Q value to provide the necessary kick voltage required for CESR-B. When funding is available, we plan to build a full size niobium crabbing cavity, the required horizontal cryostat and perform a beam test of such a cavity in CESR.

### 10- TESLA

The progress over the last few years in the promotion of the use of superconducting RF cavities in the building of a TeV linear collider has been very successful. The TESLA collaboration of past years has coalesced basically around the design and building of the TTF (TESLA Test Facility) at DESY. Cornell has continued to play an important role in this collaboration and has continued our early role in the use of high power processing (HPP) to raise the field emission barriers in the accelerating fields that are possible. Some previous work on the use of vacuum furnace treatment to raise the field emission barrier was completed. The result was that a 6 cell, 1.5 GHz cavity, after a second heat treatment, reached a CW  $E_{acc}$  of 20 MV/m.<sup>18</sup>

Cornell has had for several years a program and the equipment installed for the use of HPP on single cell and multicell<sup>19</sup> 3 GHz cavities. These results have been reported elsewhere but have in general been very successful.<sup>20</sup>

High pulsed power processing (HPP) has been proved to be an effective method to overcome field emission in SC cavities. Many experiments done with 1-cell, 2-cell and 9-cell cavities at 3 GHz are discussed in other papers at this conference. The salient results of these experiments are:

1) Accelerating fields between 15-20 MV/m were reached with two 9-cell cavities (3 GHz) in 7 consecutive tests. For each test the surface of the cavity was prepared anew. In each case, heavy field emission was successfully processed with HPP to reach the final field levels. The low power Q was undamaged from HPP, so damage is not a concern.

2) The effectiveness of the processing depends clearly on the highest surface electric field reached during the pulsed processing stage. The highest pulsed surface field reached was 72 MV/m for a 1-cell, and 60 MV/m for a 9-cell. Power levels up to 50 kwatts were used for 1-cells and up to 200 kwatts for 9-cells.

3) In 9-cell cavities, field emission was completely eliminated for field levels up to  $E_{cw} = 0.5 E_{pulsed}$ . If field emission is tolerated till the Q falls to about  $5 \times 10^9$ , then higher fields can be reached, typically:  $E_{cw} = 0.60 E_{pulsed}$ .

4) Processing takes place by an explosive mechanism. Dissection of processed cavities shows 1 - 10  $\mu$ m size molten craters with traces of the original contaminants responsible for the field emission.

5) The processing is effective against new field emission when additional contaminants are introduced, such as by vacuum accidents.

6) During processing the Q falls to between  $10^7$  and  $10^6$ .

7) It is possible, during pulsed operation, to exceed the field at which cw thermal breakdown is encountered; but then there is a strong competition for the applied high power between field emission losses for processing and the growth of the normal conducting region(s). The method is, therefore, ultimately limited by breakdown, initiated by the maximum

surface magnetic field. A low  $H_{pk}/E_{acc}$  ratio and a high RRR are, therefore, advised.

8) In a special 2-cell cavity with reduced magnetic surface field, it was possible to reach a surface electric field of 113 MV/m pulsed, and 100 MV/m cw, corresponding to a world record accelerating field of 34.6 MV/m.

When the frequency of 1.3 GHz was chosen for TESLA, we decided to contribute to the collaboration by investigating the use of HPP at this frequency.

### 11- TESLA CAVITY MANUFACTURE

We decided to fabricate and test 5-cell structures instead of the final 9-cell structures because the existing SRF facilities at Cornell (chemical treatment, shielded cold test area, furnace, clean rooms, etc.) are not of the appropriate size to handle a 1 meter long cavity. Figure 7 shows the expected peak field that can be reached with 1 Mwatt of power and a 5-cell cavity at the available pulse length. This is assuming that  $Q_0$  falls to  $2 \times 10^6$  during the pulsed conditioning.

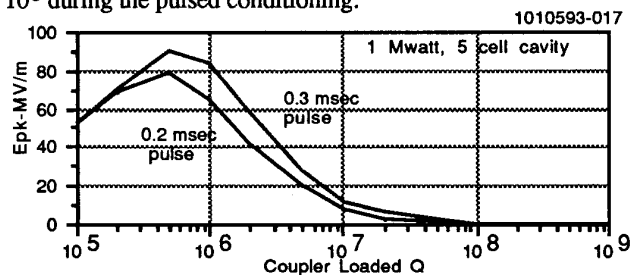


Fig. 7 Expected Field in a 5 Cell Cavity

Two 5-cell Nb cavities of the TESLA shape were built at Cornell. The accelerating mode properties of the cavity are listed in Table 1

Frequency	1308 MHz
R/Q	1088 $\Omega$ /m
$E_p/E_{acc}$	2.1
$H_p/E_{acc}$	42 Oe/MV/m

Table 1.

The cells are polarized so that eventually a single HOM coupler can damp both polarizations of the dipole higher order modes. The measured splitting for the dominant dipole modes was 13 MHz ( $TE_{111}$ ) and 50 MHz ( $TM_{110}$ ) modes. One 2-cell and two 1-cell Nb cavities were also built. The RRR of the Nb used to fabricate these cavities was between 250 and 300. Copper cavities were also built to test the dies and fixtures.

Two additional 5-cell cavities at 1.3 GHz were ordered from industry. These cavities, while not conforming to the most desirable cell shape, were made because the dies were available for this shape, being the same as the HEPL SCA cavities with a  $E_p/E_{acc}$  value of 2.6.

### 12- TRANSMITTER COMMISSIONING

While preparations are proceeding for installation of SRF infrastructure and a TESLA TEST FACILITY at DESY, a program has been launched at Cornell to test HPP at 1.3 GHz as soon as possible.<sup>21</sup> The Boeing Defense and Space Group

kindly agreed to lend us a klystron (Thompson TH2104) and PFN modulator. The system is intrinsically capable of 10 MWatts peak at 200  $\mu$ sec with 185 Kvolts, or 5 MWatts at 300  $\mu$ sec. With commercial constant charge, constant current regulated pulsed capacitor charging supplies, we were successful in providing 110 KV to the klystron to obtain uniform 200  $\mu$ sec long pulses of 2 MWatt peak power.

### 13- TEST STAND COMMISSIONING

A high power cold test set up shown in Figure 8 was built at FNAL. The high power enters the cryostat top plate (not shown) through a WR650 reduced height waveguide. A room temperature teflon window above the top plate allows a vacuum in the waveguide. Near the bottom of the cryostat is a waveguide to coax doorknob transition, with an integrated cylindrical ceramic window to isolate the high vacuum, cavity region. The window was coated with TiN to reduce the secondary emission coefficient. After fabrication, the VSWR of the input coupler was less than 1.6 between 1280 and 1320 MHz. The penetration of the antenna into the cavity is adjustable by a copper plated hydroformed bellow in the outer conductor.  $Q_{ext}$  can be changed from  $10^5$  to  $10^{10}$  with 4" of travel. The slotted region of the outer conductor just above the doorknob is connected to the cavity vacuum pumping line. To check the microwave performance of the coupler, the BCS Q at 4.2 K of a 1.3 GHz Nb cavity was measured and verified for different positions of the antenna.

Two types of coupler conditioning events were seen in the 1.3 GHz HPP coupler. The first type, called the staircase, was usually accompanied by severe vacuum degradation in the waveguide region. After some conditioning, it was possible to process this type of event, with improvement in vacuum and the return of the transmitted RF power signal to the expected exponential decay. The staircase event would restart on raising the power. Above 300 Kwatt, a second type of coupler event was encountered. Nearly all the power was absorbed, so that very little power could be coupled to the cavity.

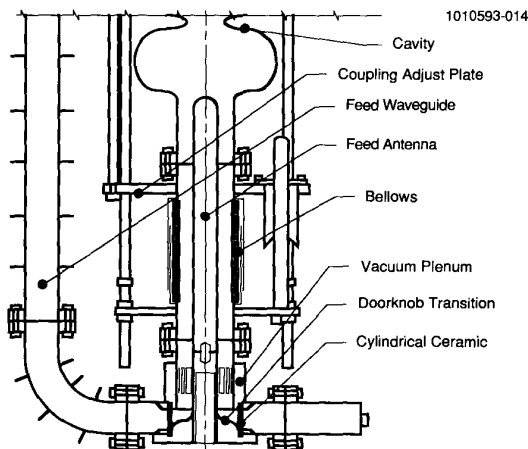


Fig. 8 1.3 GHz HPP Test Stand

This difficulty which limited us to about 300 Kwatts to the cavity plagued us for several months. Often the teflon window showed Al sputtered on the surface in the high E field regions. The Aluminum had to be removed to be able to apply high power again. Diagnostics were difficult. A large number of room temperature measurements and cryogenic coupler tests were made trying to understand the nature of the coupler limitation. One limit was finally removed when the Teflon window was replaced with an all metal brazed ceramic planar waveguide window. It is also clear that the breakdown of the coupler is very much effected by the length of the antenna in the cavity between the cylindrical window and the cavity. The situation is still far from being fully understood. The problems that have been encountered will undoubtedly come back to us in later TESLA HPP test stands and final high power input couplers and windows.

With the use of this warm ceramic planar waveguide window and the adjustment of the phase of the standing wave pattern in the waveguide and coaxial feed line, the test stand could, after a few hours processing, be taken to a peak power level of 1 Mwatt, into a SC 5 cell cavity.

### 14- HPP RESULTS

Another problem that we had was that the top of a 5-cell cavity stands at about 70% of the useable liquid helium reservoir height. Even with several batch fill and pump down iterations, it was difficult to keep the cavity completely under liquid at 2 K. A good solution to this problem was to pump down a 500 liter storage dewar to 2.2 K and then transfer 2.2 K liquid across into the test cryostat. By this method the running time at 2 K could be extended by many hours. While this solution was still being developed, it was decided to test the HPP method with the 2-cell cavity

Figure 9 shows three Q vs E curves for the test of the 2-cell cavity

- a) The initial cw test with low power
- b) after conditioning with cw low power only
- c) after HPP up to 320 kwatts, 200 msec, maximum field 67 MV/m.

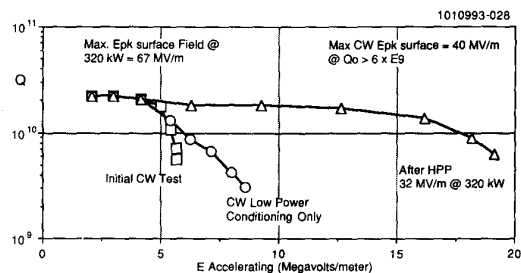


Fig. 9 Result of HPP on LDP2-1 Cavity

During pulsed power application, the maximum peak surface electric field reached was 67 MV/m.

The 2-cell result confirms many of the aspects of HPP that were proved in the 3 GHz program. Field emission was



successfully processed away without damaging the low power Q. The maximum field reached during the pulsed stage shows, as expected, that the Q fell to about  $2 \times 10^6$ . The field level  $E_{CW}$  at which the Q from field emission drops to  $6 \times 10^9$  is 0.6  $E_{pulsed}$ .

After this early success, the 5-cell cavities were tested. Tests of the first Cornell cavity, LDP5-1, gave a field limit first imposed by breakdown in the coupler as described above and later limited by thermal breakdown to a CW field level of  $E_{acc} = 12$  MV/m.

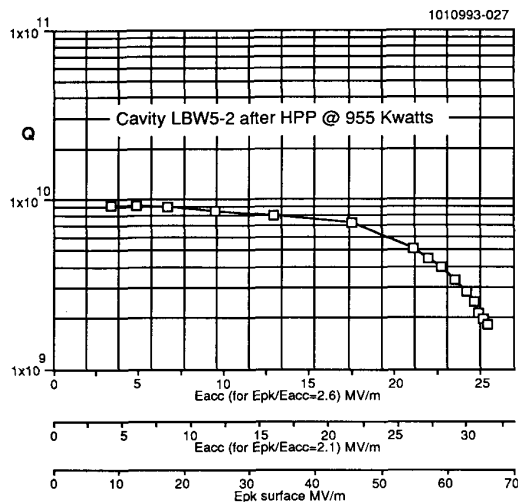


Fig. 10 Result of HPP on LBW5-2 Cavity

The first industry made cavity, LBW5-1, achieved  $E_{acc} = 14$  MV/m ( $E_{pk} = 36$  MV/m), limited by thermal breakdown. The last cavity to be tested, LBW5-2, was the first to benefit from the improved test stand, that is, the first test since the test stand could go to 1 Mwatt with the planar warm ceramic window. This cavity was tested twice. During the first test there was some damage done to the cavity, possibly from breakdown in the coupler, that caused some permanent damage in the cavity resulting in thermal breakdown.  $E_{acc}$  was limited to 14 MV/m with thermal breakdown. The cavity was then given a light chemical cleaning and the results were excellent with HPP at 1 Mwatt.  $E_{acc}$  went to 25 MV/m. FE was the limit. The results of this test are shown in Figure 10.

### 15- BASIC STUDIES

With the large group effort going to the B Factory and TESLA projects, the effort going into basic studies is less than in previous times. The effort that continues is aimed at; a) a better fundamental understanding of field emission<sup>22</sup> and b) an effort to understand thermal breakdown and however higher RRR material can be achieved and used.

Progress was made toward understanding the sources of field emission. In the break-apart mushroom cavity<sup>23</sup> processed emission sites (previously recognized by 100  $\mu$ m starburst features with 10  $\mu$ m central molten craters) occasionally show  $\mu$ m size molten debris of foreign elements. Most sites, however show only molten niobium. The absence of foreign matter points towards sources of field emission more subtle than micro-contaminants particles (for example mechanical imperfections) or simply to the insensitivity of the EDX analysis method. To settle this question, a one inch diameter section from a high field region of the RF cavity was transported under clean conditions to a scanning Auger system at Evans East in New Jersey. Two samples were transported, each after exposure to a maximum surface electric field near 80 MV/m. A total of 30 central craters were examined. Foreign impurities were detected in each and every one of them. The impurities in order of their frequency of occurrence were: Fe, Cr, Si, F, Cu, In, Ni, C, and Mn. None of these impurities were observable with the EDX system on the electron microscope. All evidence for field emission sources still points to foreign particle contaminants.

Using 150 Kwatts in a single cell 3 GHz cavity it was possible to reach surface fields of  $E_{pk} = 90$  MV/m and  $H_{pk} = 2070$  oersted. Analysis of the field level in the cavity during the short RF pulse indicates that at least 99% of the surface area of the cavity was still SC at the 2070 oersted H field level.

Niobium plate has been obtained from Russia with RRR values almost up to 1000. Some cavities have been made of this material and their behavior will be evaluated. So far these cavities are not showing a noticeably improved behavior.

A project has been started to make an improved temperature mapping frame for single cell 1.5 GHz cavities. These cavities will then be cut apart and examined in the SEM-EDX system. Preliminary work was done on 3 GHz cavities.<sup>24</sup> Hopefully some spatial correlation can be made warm cavity spots and features on the inside surface of the cavity.

### 16- FUTURE PLANS

In the coming years the major part of Cornell's SC resources will be dedicated to the design and testing of superconducting cavities that will be used in CESR upgrades or the proposed B Factory. This includes the Crab cavities as well as the accelerating cavities. Within the next year a beam test in CESR will take place with a SC accelerating cavity and if funding allows, the design, manufacture, and testing of the Crab cavity concept will also be tested in CESR. The design of a compact cryostat that can be used in the present CESR tunnel will also be taking place.

We will maintain some level of work within the TESLA collaboration. The 3 GHz and the 1.3 GHz HPP transmitters will hopefully remain operational and tests will continue in this area. The vacuum furnace that we have will be used to continue to investigate the effects of heat treating the TESLA cavities.

The basic studies will continue at least at the present levels of support.

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