Limiting RF fields in superconductors at X-Band

SNS/SLAC/JLab Collaboration

I. E. Campisi, Z. D. Farkas, P. Kneisel,

R. H. Siemann, S.G. Tantawi, J. Weisend

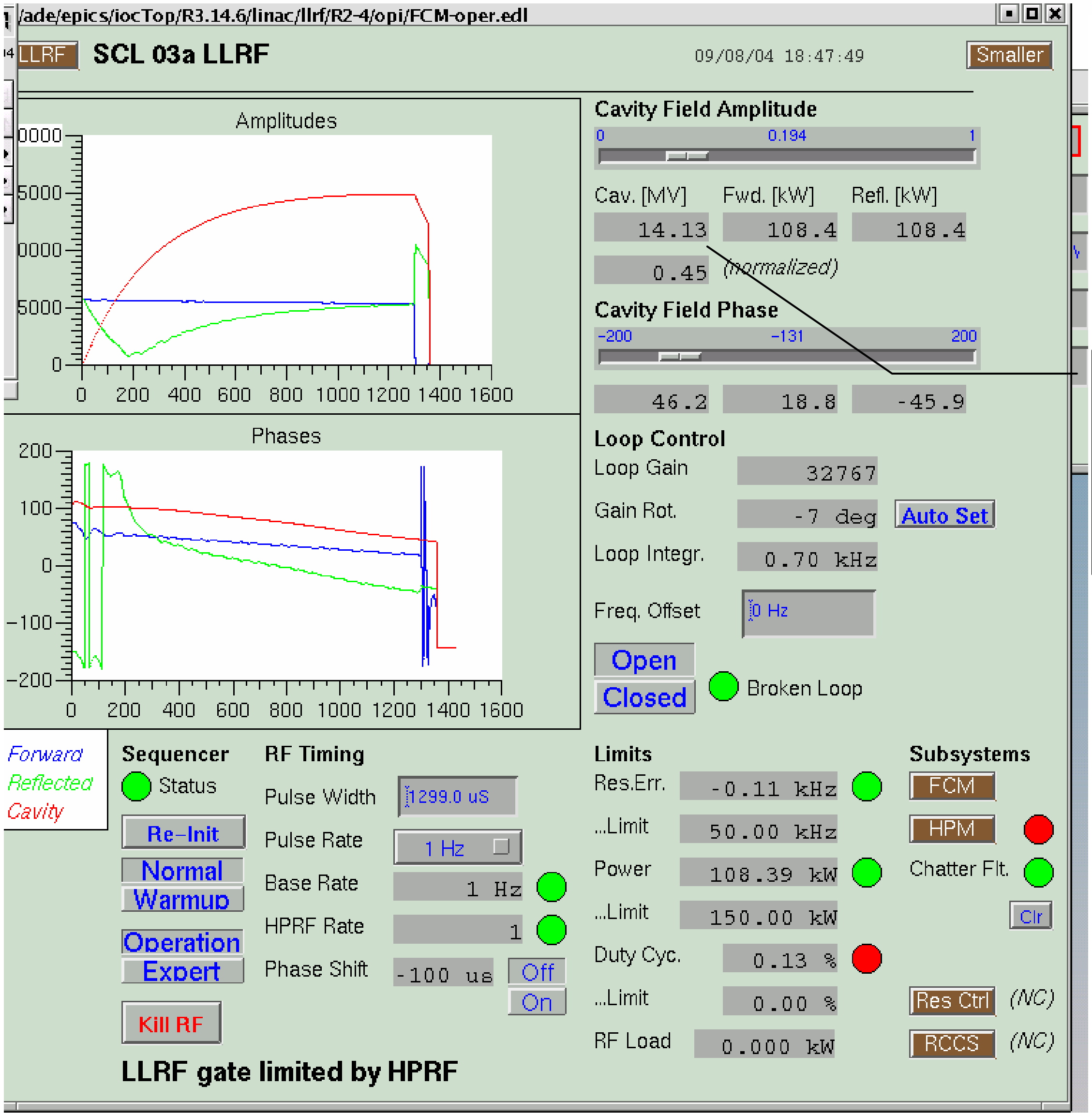
Why?

- It is a well known fact that Nb is the only material suitable for manufacturing superconducting cavities for accelerators
- A large amount of work in going on to extract the last 10% of field from Nb: why not putting some effort into new materials for the future?
- Some new accelerators operate in a pulse mode (SNS, Superconducting Linear Collider), yet cavities for these machines are developed just like for CW applications
- The most important parameter of a superconductor for some applications is the critical field, not the Q_o
- No major effort in studying RF limits of SC's since T. Yogi's dissertation in 1977

Why? Pulse power applications

- Recent test at SNS at 4.2 K show that reliable pulsed operation can be attained under non standard conditions (outside engineering design parameters).
- Evaluate new materials with relatively low Q and high critical temperatures specifically chosen for pulsed accelerators
- Determine thermal response times and thermal recovery times at various temperatures and for various Q's.
  - Optimize pulse length and repetition rate for a given material at a given temperature
- Need bottom up re-evaluation of materials and what application they may be useful for

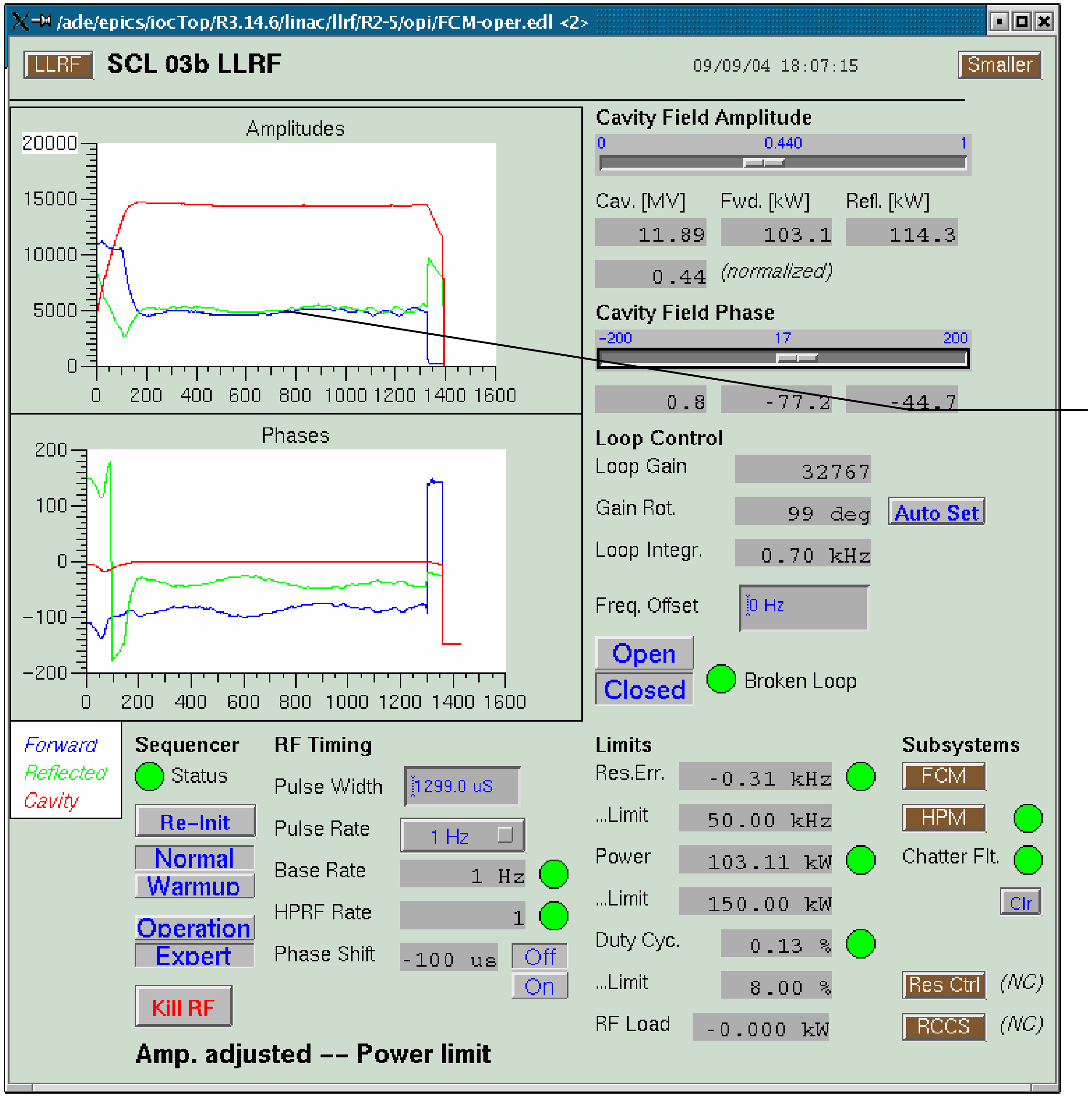
SNS cryomodule at 4.2 K: Open loop performance



14 MV/m
1 pps
1.3 msec

Limited by administrative constraints:
P_i=150 kW

SNS cryomodule test at 4.2 K: closed loop



Lorentz force response at 2 kHz (~200 Hz amplitude)

3 cavity operation
30 pps
1.3 msec
12 MV/m

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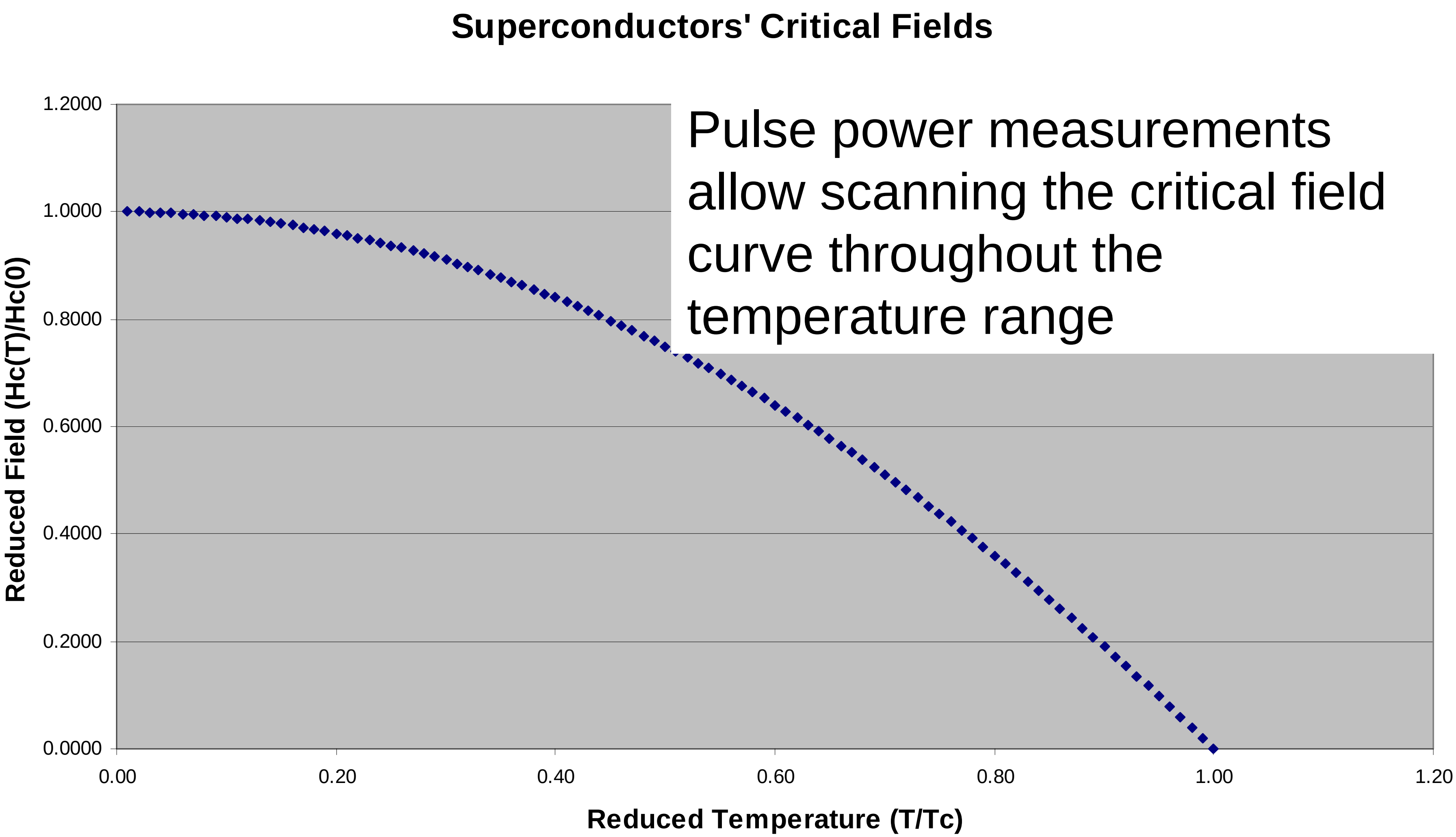
- Logical sequence for development of superconducting materials:
  1. Identify materials with high critical fields
  2. Determine and improve the surface resistance
  3. Develop methods to fabricate extended surfaces and cavities
- Presently, the process is reversed and does not converge: it has effectively killed the HTC materials for RF applications

Limiting RF fields in Superconductors



Pulse power measurements allow scanning the critical field curve throughout the temperature range

How

- Use the pulse method to circumvent surface resistance and extended cavity surface preparation limitations
- Use high frequencies, to limit sizes of samples
- Use TE_{011} cavities to avoid indirect field emission heating and quenches
- Short pulses allow
  - Work in gaseous He or other coolants to any T_c
    - Give an independent measurement of T_c
  - Establish dynamical and possibly non-equilibrium performance of materials
  - Establish thermal response times and thermal recovery times
  - Use cavities with only partial surfaces made out of superconductors
    - Absolute measurements
    - Relative measurements: One reference material, one material under test

Past results (1982-1985)

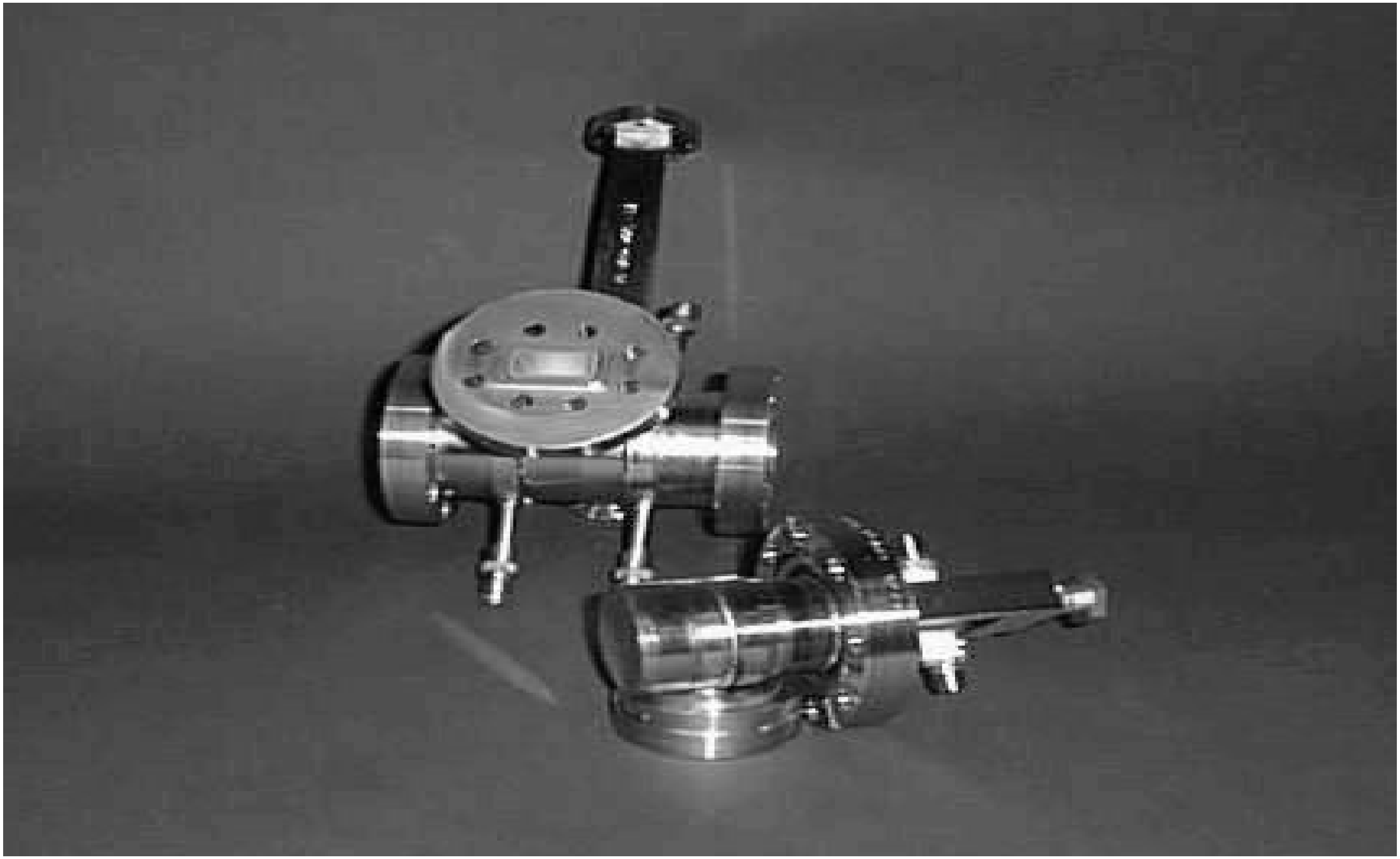
- S band 2856 MHz
- 1 μsec, ~1-2 MW incident power
- Varied repetition rate up to 360 pps (thermal time constant)
- From 2 K to T_c (operation in He gas): independent measurement of T_c
- Nb main features: pulse behavior independent of surface conditions
- Nb3Sn (2 cavities) reached 1300 Oe at 12 K, measured fields up to T_{c}.
  - One cavity quenched at 7 Oe in CW, reached 1000 Oe pulsed, T_c 16 K
- Pb (2 cavities) (interest in type I materials)
- Tin attempt: multiple transitions → partial surface
- Plans never carried out (before discovery of HTC)
  - Tin, In, etc.
  - TE_{011} cavity

Best way of doing tests

- After a LONG hiatus, given a lot of thoughts to optimize the tests
  - At SLAC (if Mohammed….)
  - 11.424 GHz: more bang for the buck
  - Up to 120 MW peak power available
  - TE_{011} cavity
    - Various detection methods: TE_{012}, integrated emitted power
  - Fraction of cavity surface will show transition
  - About 450 kW peak to reach maximum gradients of Nb in 1 μsec

- All done!! Pritzkau's dissertation…..

Copper cavity: Pritzkau's dissertation



Pritzkau's dissertation: TE_{011} cavity parameters

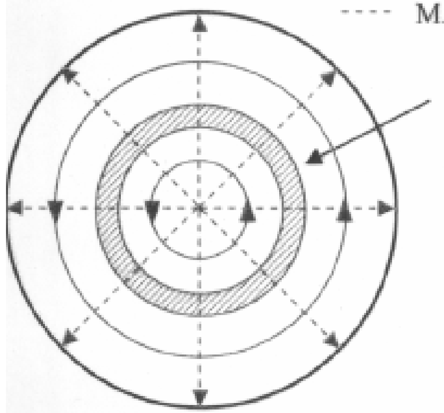
SLAC

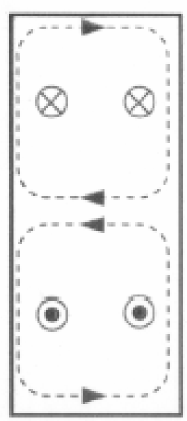
RF PILLBOX CAVITY PARAMETERS

—— ELECTRIC FIELD

- - - - MAGNETIC FIELD

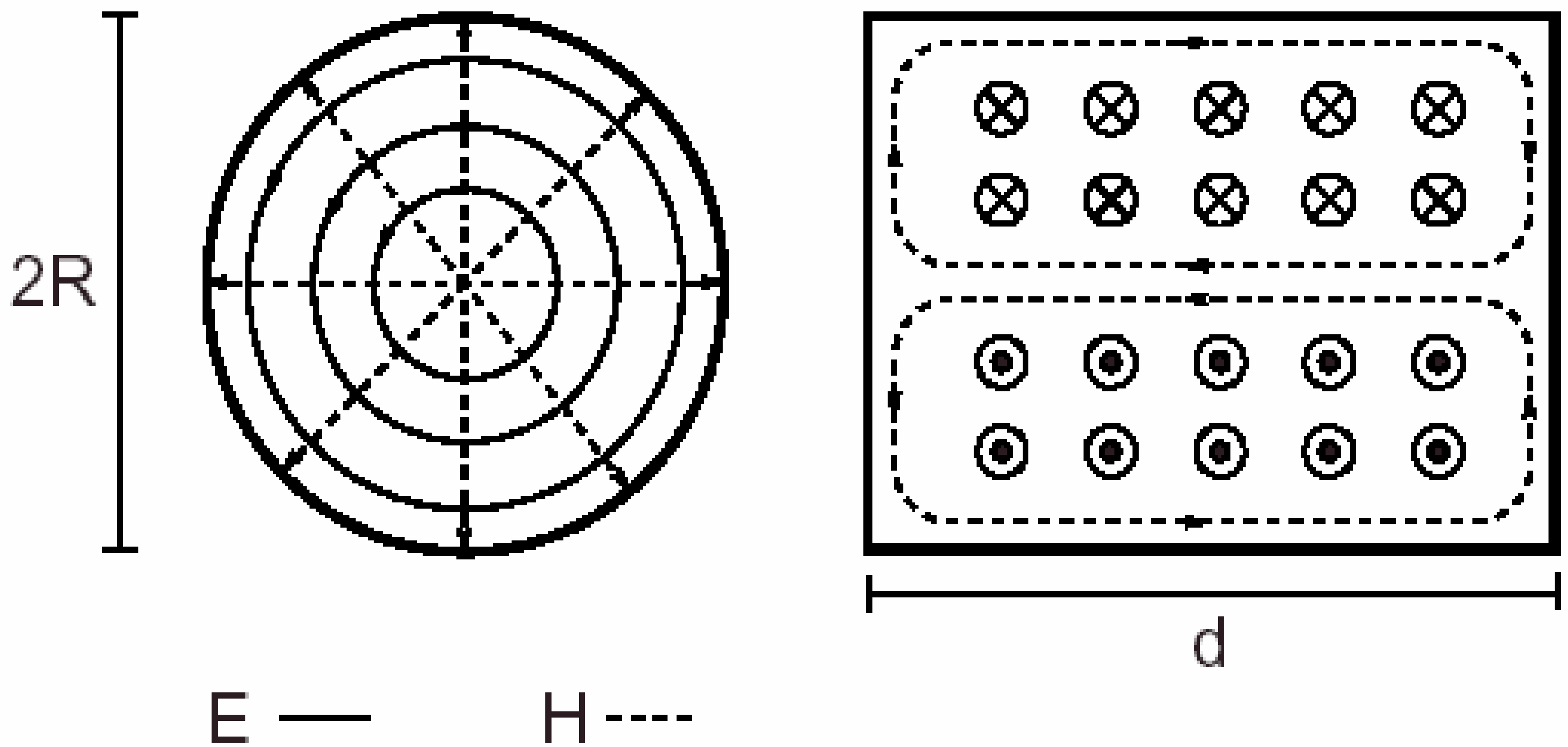
AREA OF MAXIMUM FIELD/TEMPERATURE



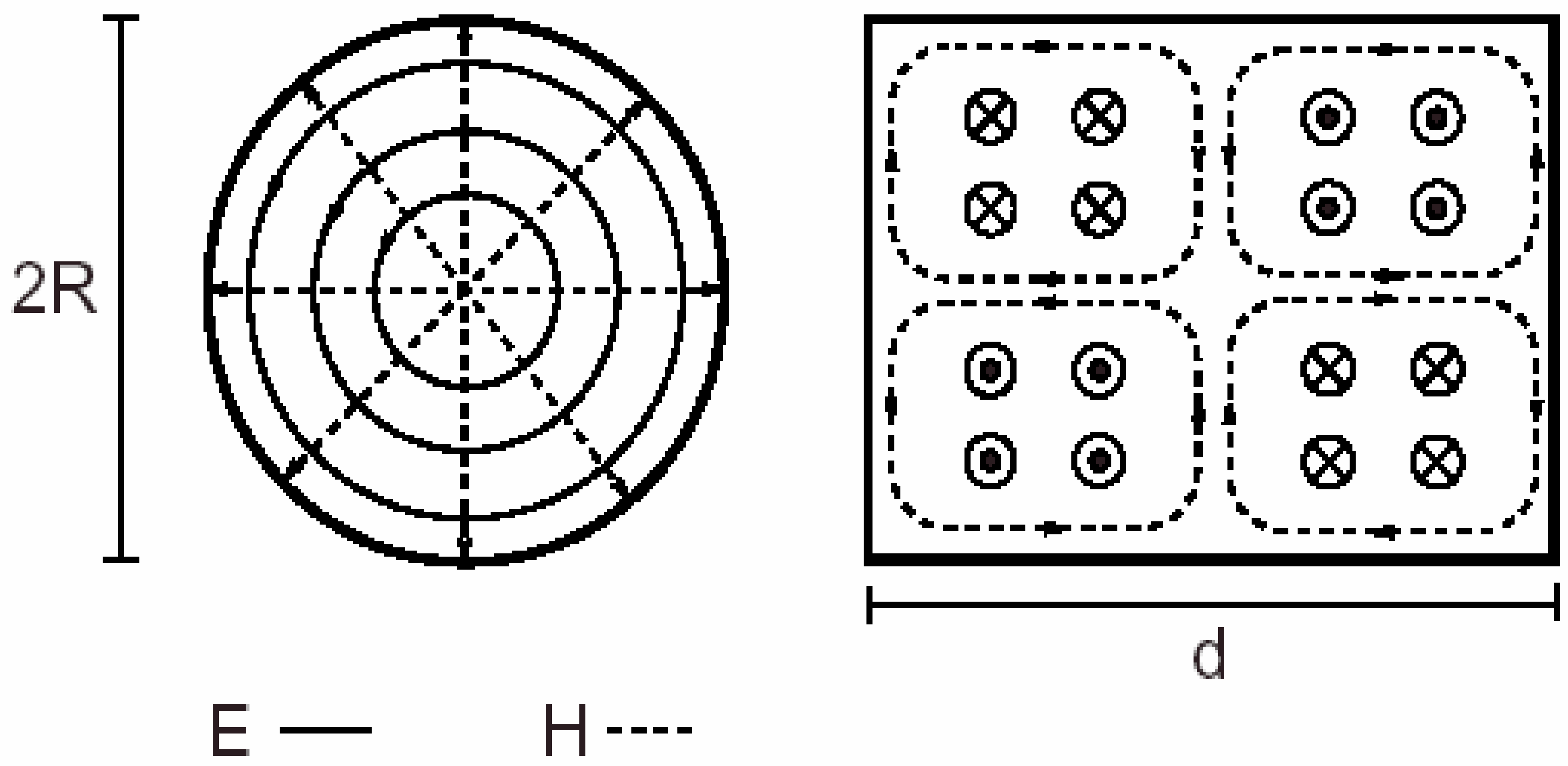


- TE_{011} CIRCULAR CYLINDRICAL CAVITY
  - RESONANT FREQUENCY = 11.424 GHz
  - UNLOADED Q = 21890
  - DIAMETER = 4.415 cm
  - AXIAL LENGTH = 1.90 cm
- INPUT COUPLER
  - WR-90 OPERATED IN TE_{10} MODE
  - COUPLING COEFFICIENT $\beta = 1.28$

TE$_{011}$ fields



TE_{012} fields at 17.8 GHz



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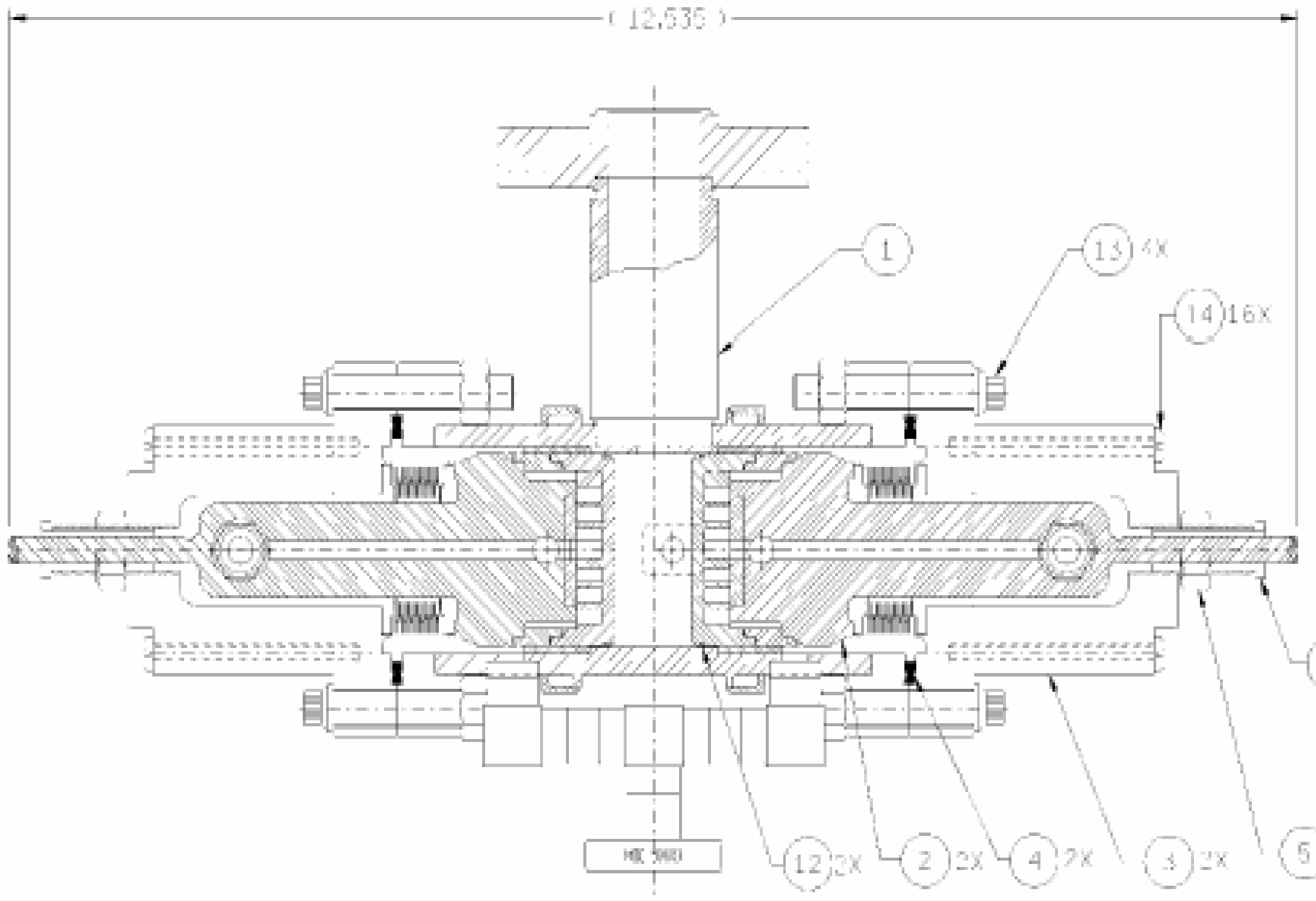
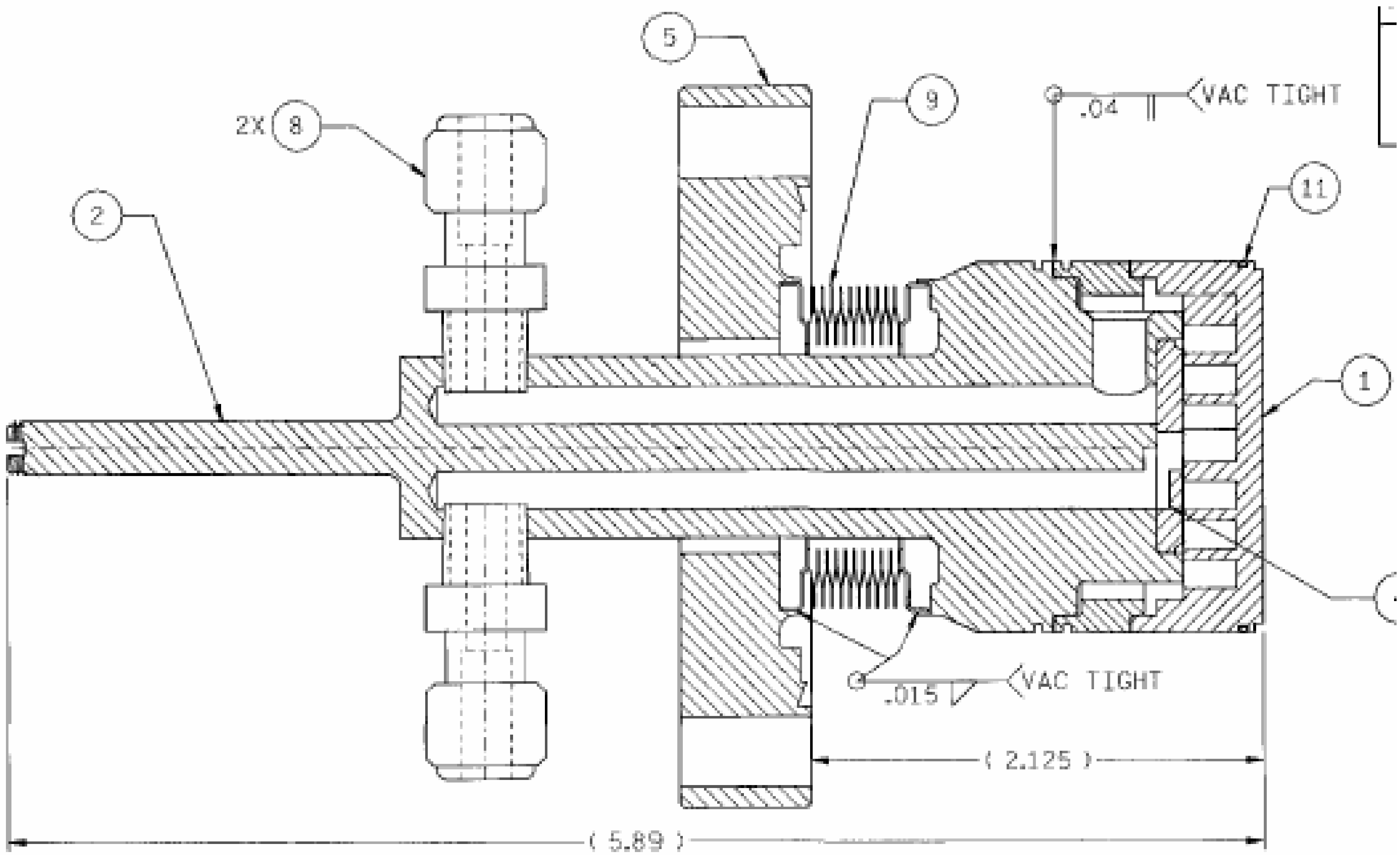
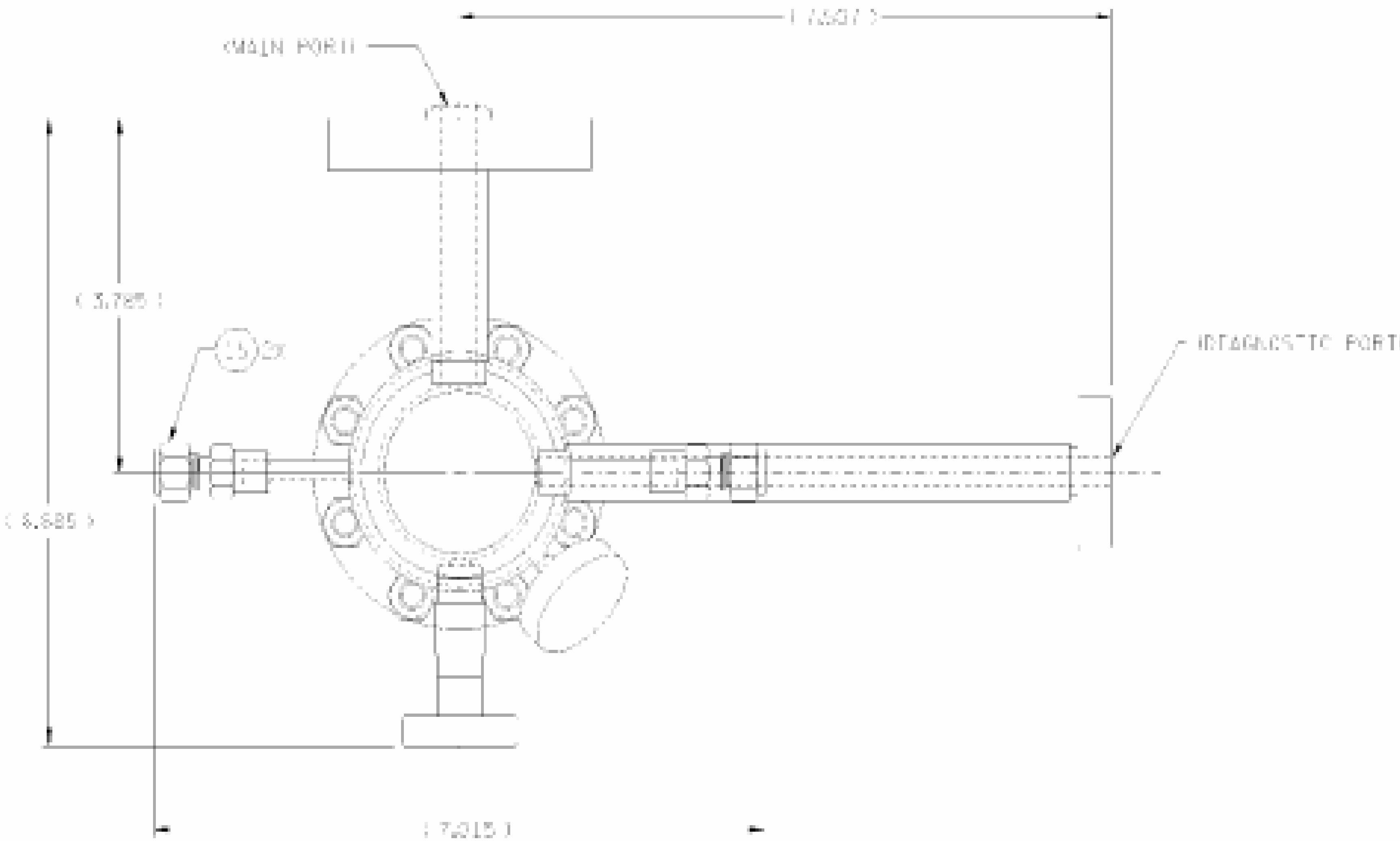
Pritzkau's cavity



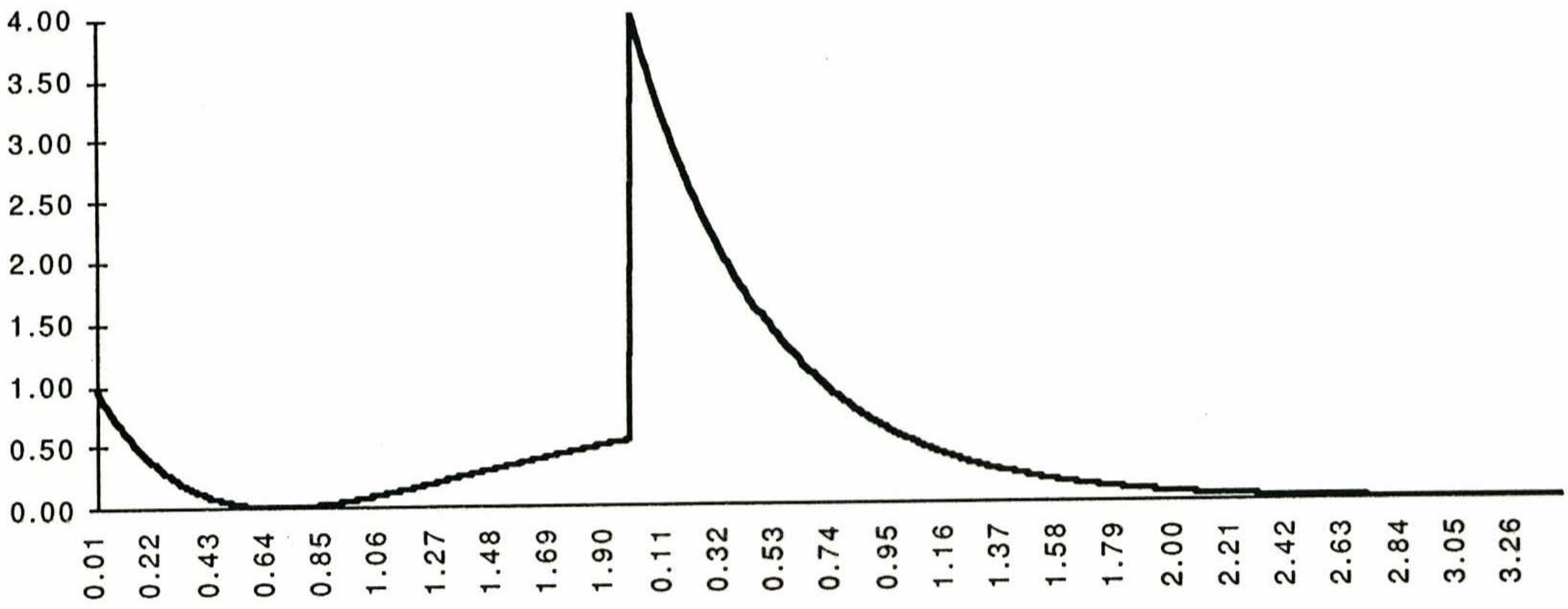
Original Pritzkau's end plate



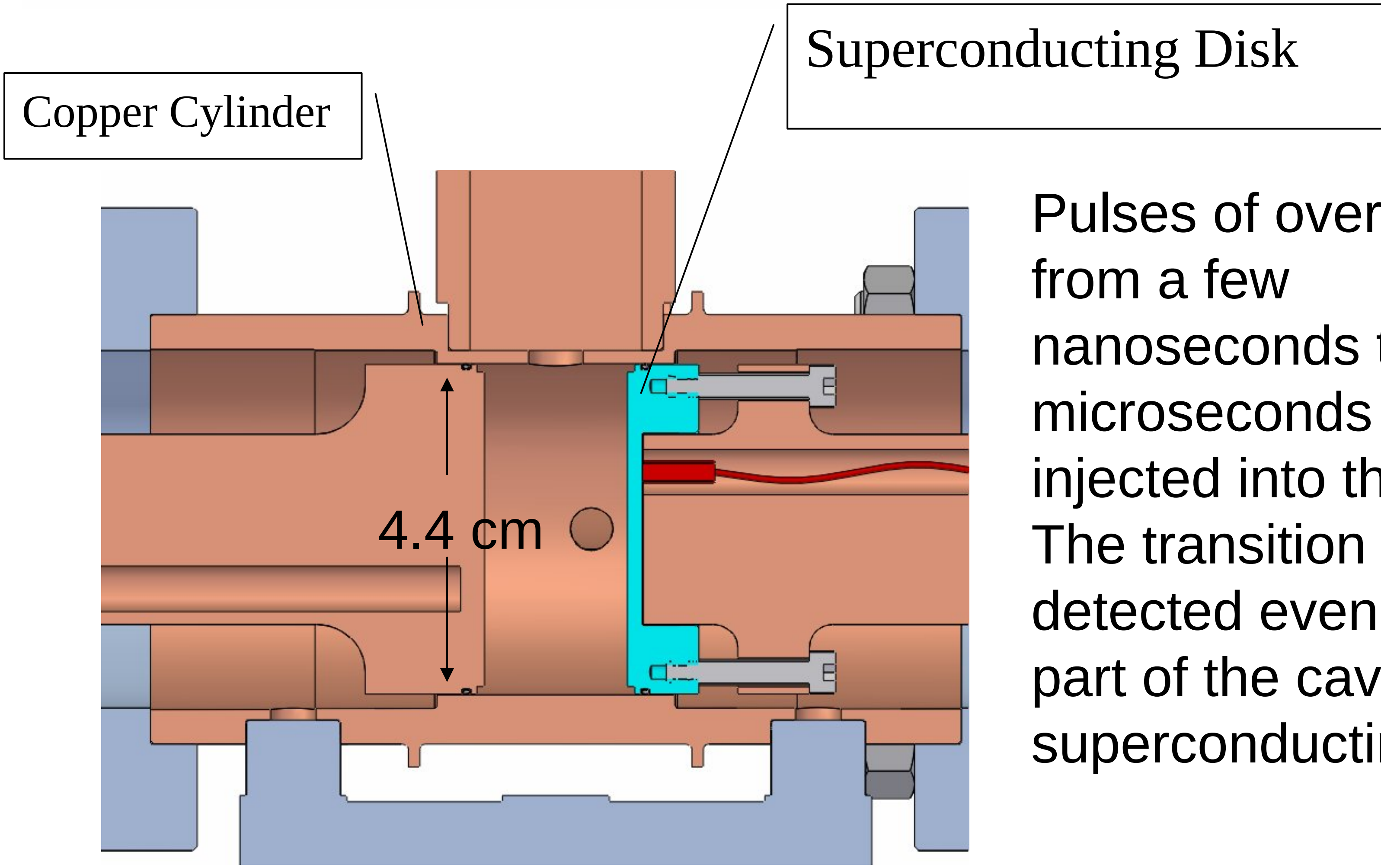
Dual mode coupling



Reflected and emitted power



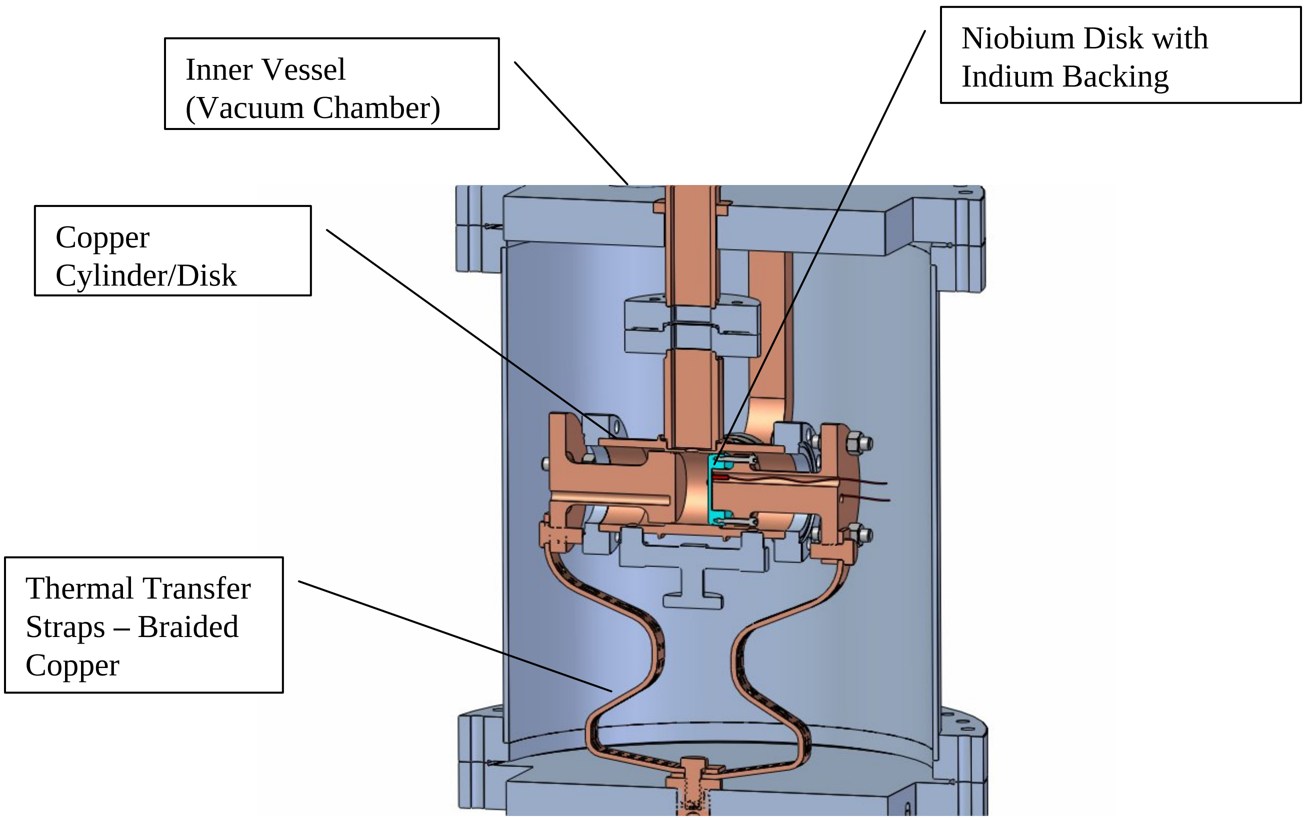
Modified Copper TE_{011} cavity



Pulses of over 100 MW from a few nanoseconds to a few microseconds can be injected into the cavity. The transition can be detected even if only part of the cavity is superconducting.

Cooling in vacuum can: from 2 K to any T_c

Temperatures can be controlled from 2 K to room temperature



Status

- Parts are being machined at SLAC
- Nb disks ready (Kneisel)
- Assembly in October
- High power tests in November

Summary and conclusions

- We are re-establishing a method that will allow the determination of critical RF fields of a wide variety of materials
- From the tests, we expect a map of performance of many materials from type I to HTC
- A clearer picture should emerge of which materials will deserve long term efforts in practical applications
- Pulse power accelerator applications may benefit from having new materials available and from re-evaluating the actual materials requirements

- MATERIALS SCIENTISTS: PROVIDE SAMPLES!!