Activities at LANL on RF superconductivity

Tsuyoshi Tajima

3rd International Workshop on Thin films and New Ideas for pushing the limits of RF Superconductivity, Jefferson Lab, Newport News, VA, USA, 22-25 July 2008

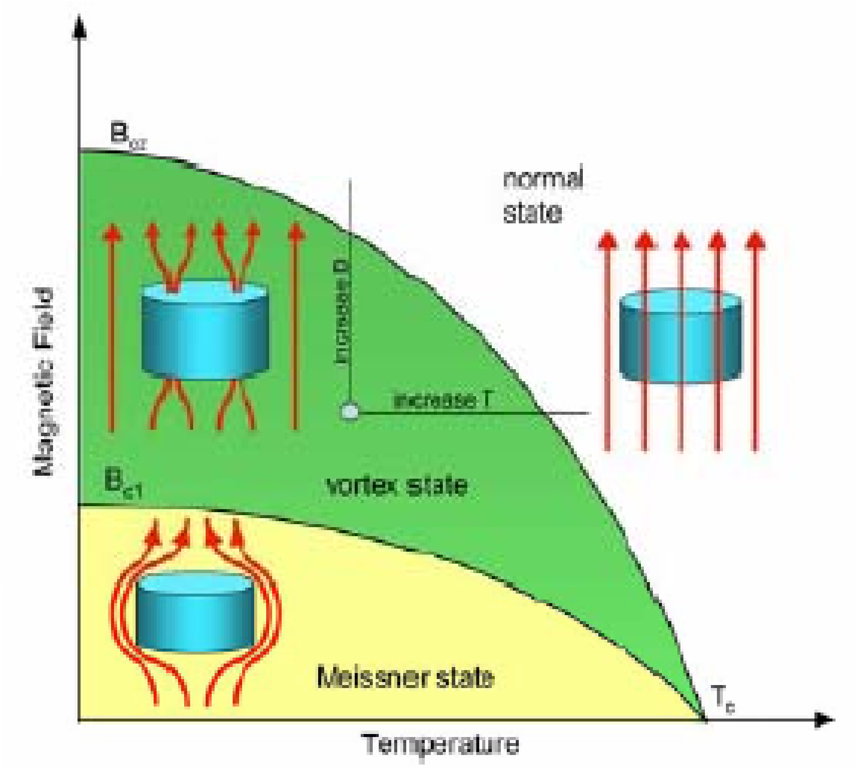
LA-UR-08-04743

Outline

- **RF critical magnetic field measurements at SLAC**
  - See the detail by Alberto Canabal LA-UR-08-2706 http://laacg.lanl.gov/scrflab/pubs/ILC/LA-UR-08-2706.pdf (5.4 MB)
- **Coating of alternative superconductors (MgB_2, NbN) for SRF applications**
- **Cavity diagnostics (9-cell cavity temperature mapping system, optical inspection system)**

RF critical magnetic field measurements at SLAC (This was initiated by Ricky Campisi of SNS/ORNL.)

- **Magnetic critical fields**



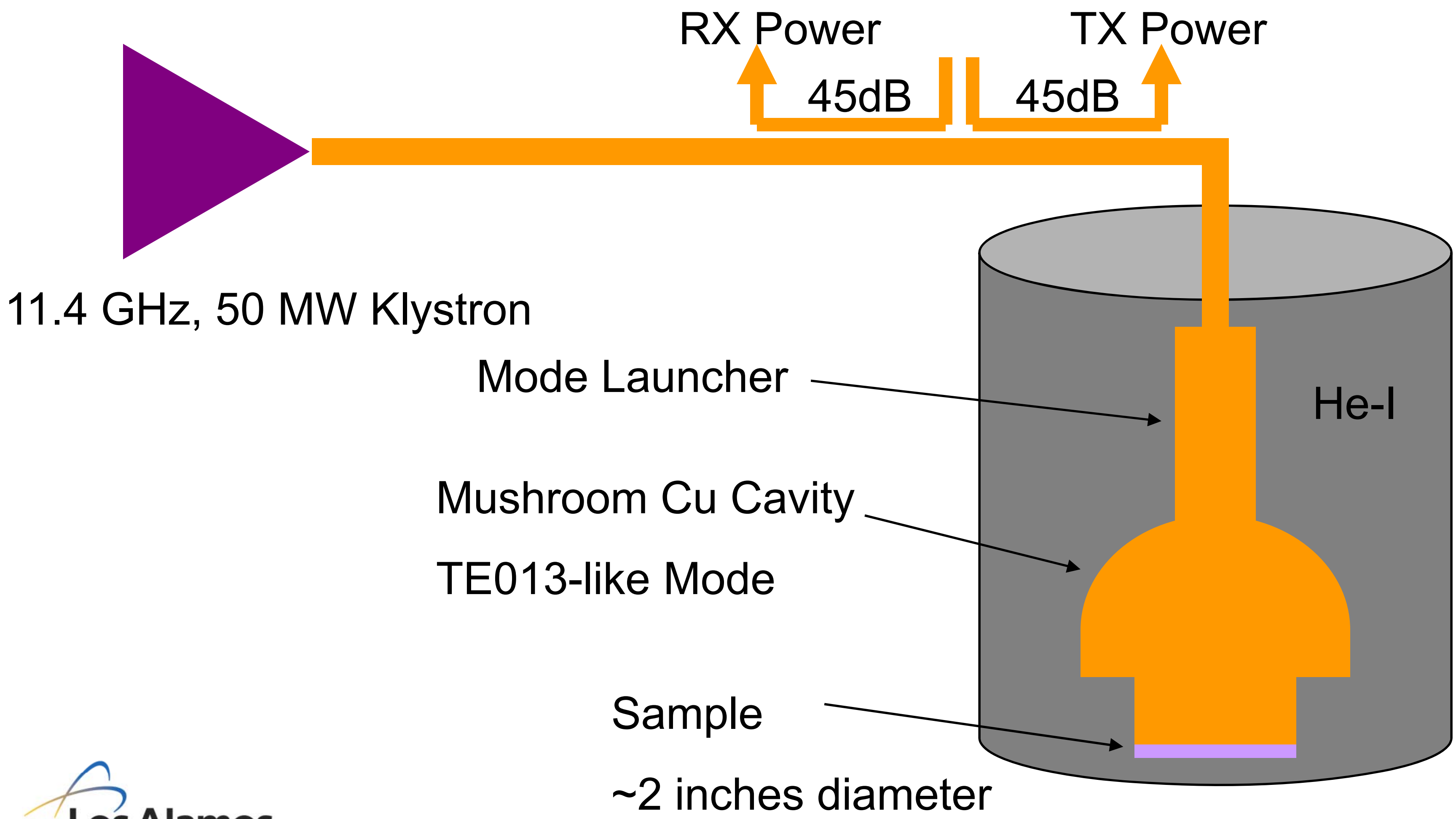
$$H_{c1} = \frac{\phi_0}{4\pi\mu\lambda_L^2}\left(\ln\frac{\lambda_L}{\xi} + 0.5\right)$$

$$H_{c2} = \frac{\phi_0}{2\pi\mu\xi^2}$$

$$H_c = \frac{\phi_0}{2\sqrt{2}\pi\lambda_L\xi}$$

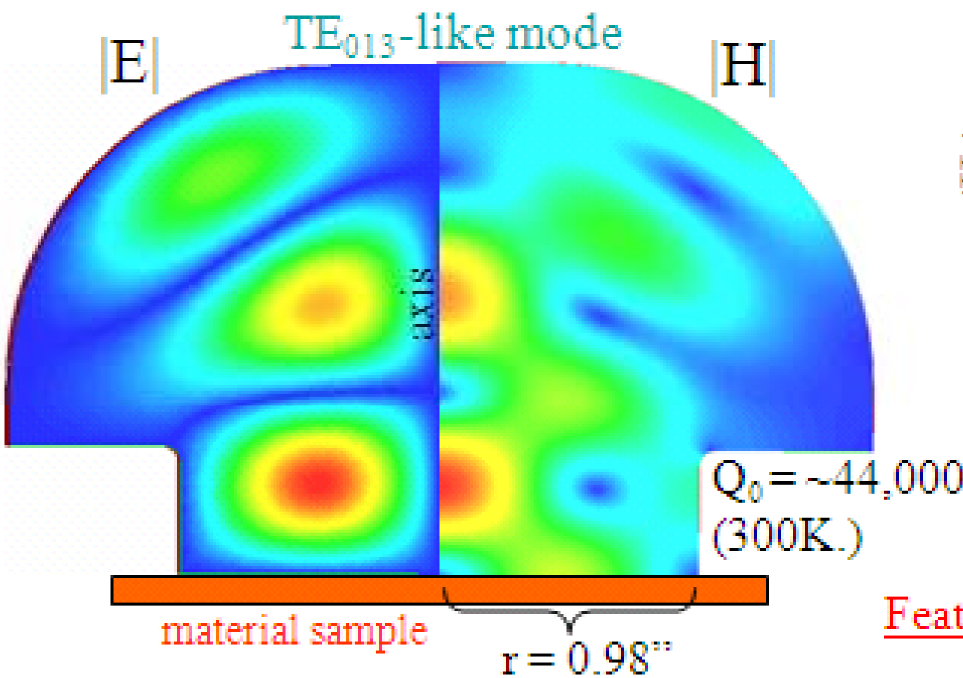
$$H_c^{RF} = ????$$

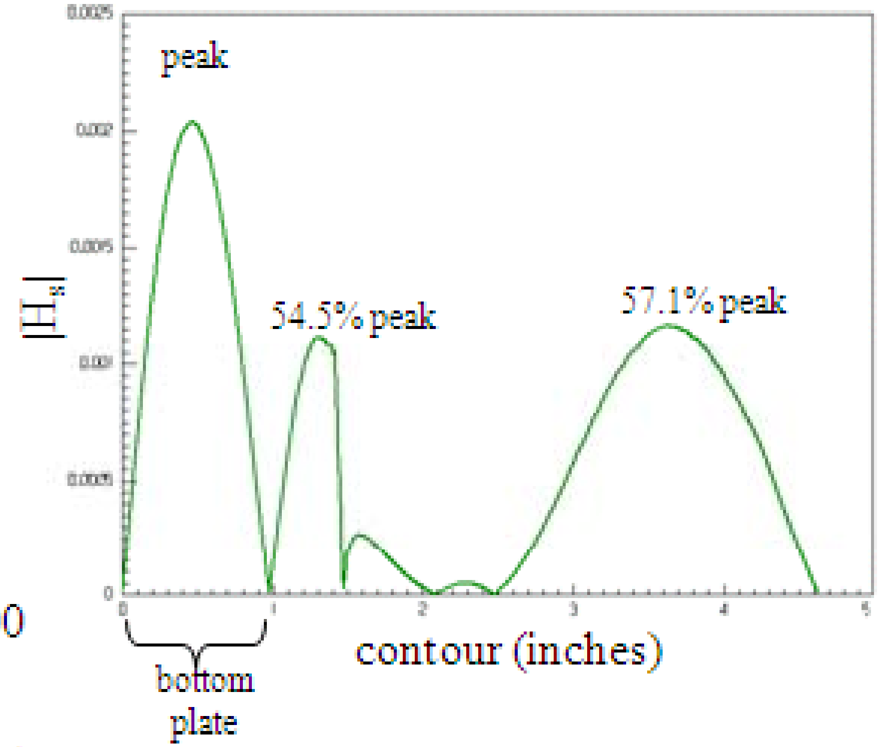
System Schematic: With short pulsed power, heating effect is supposed to be eliminated, thereby the correct RF critical magnetic field can be measured



11.4 GHz mushroom Cu cavity at SLAC

- Mushroom cavity





Why X-band (~11.424 GHz)?:

•High power & RF components available

•Fits in cryogenic Dewar

•Small (3") samples required

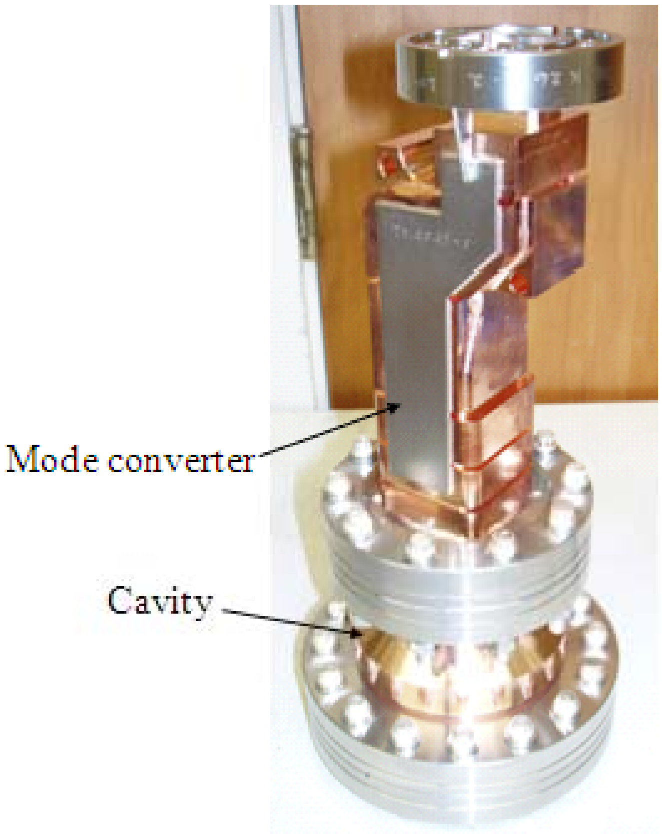
Features:

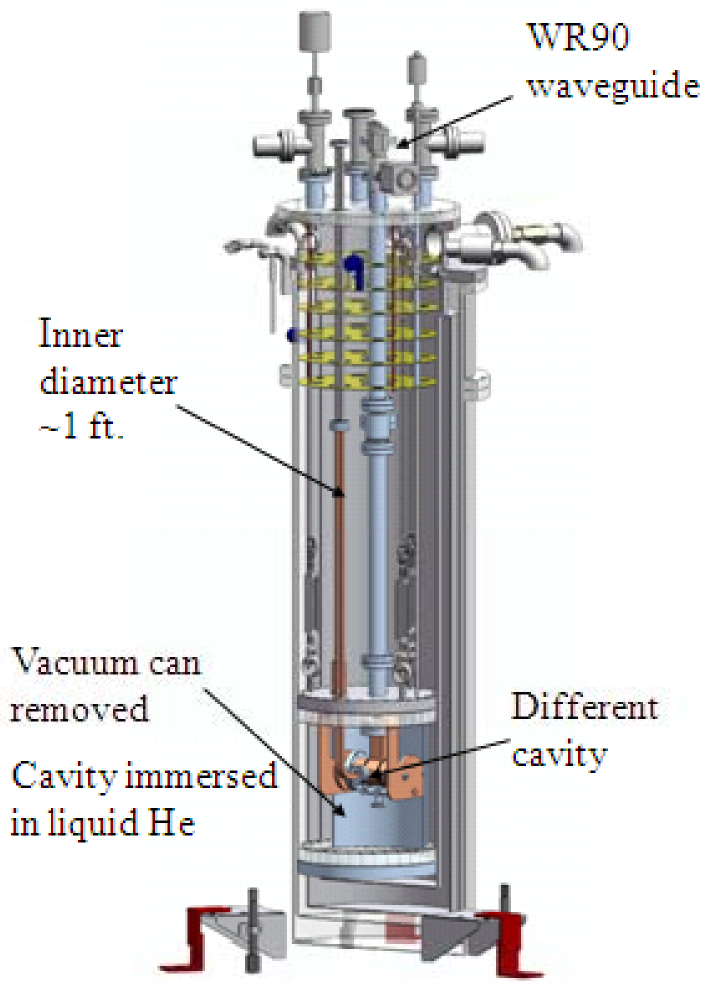
•No surface electric fields (no multipactor)

•Magnetic field concentrated on bottom (sample) face (75% higher than anywhere else)

•Purely azimuthal currents allow demountable bottom face (gap).

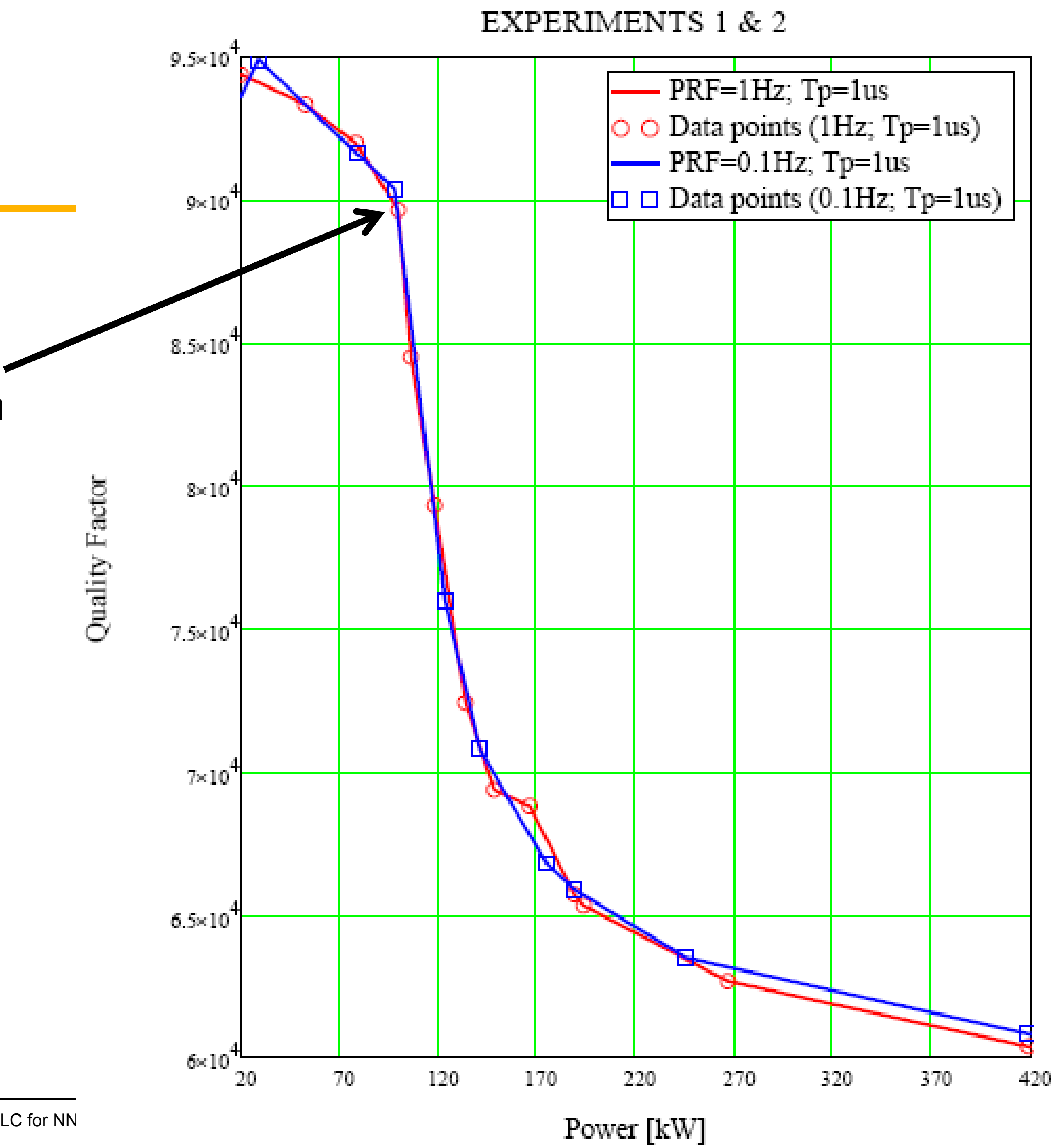
A Nb sample (fine grain, RRR~250) was tested as a reference





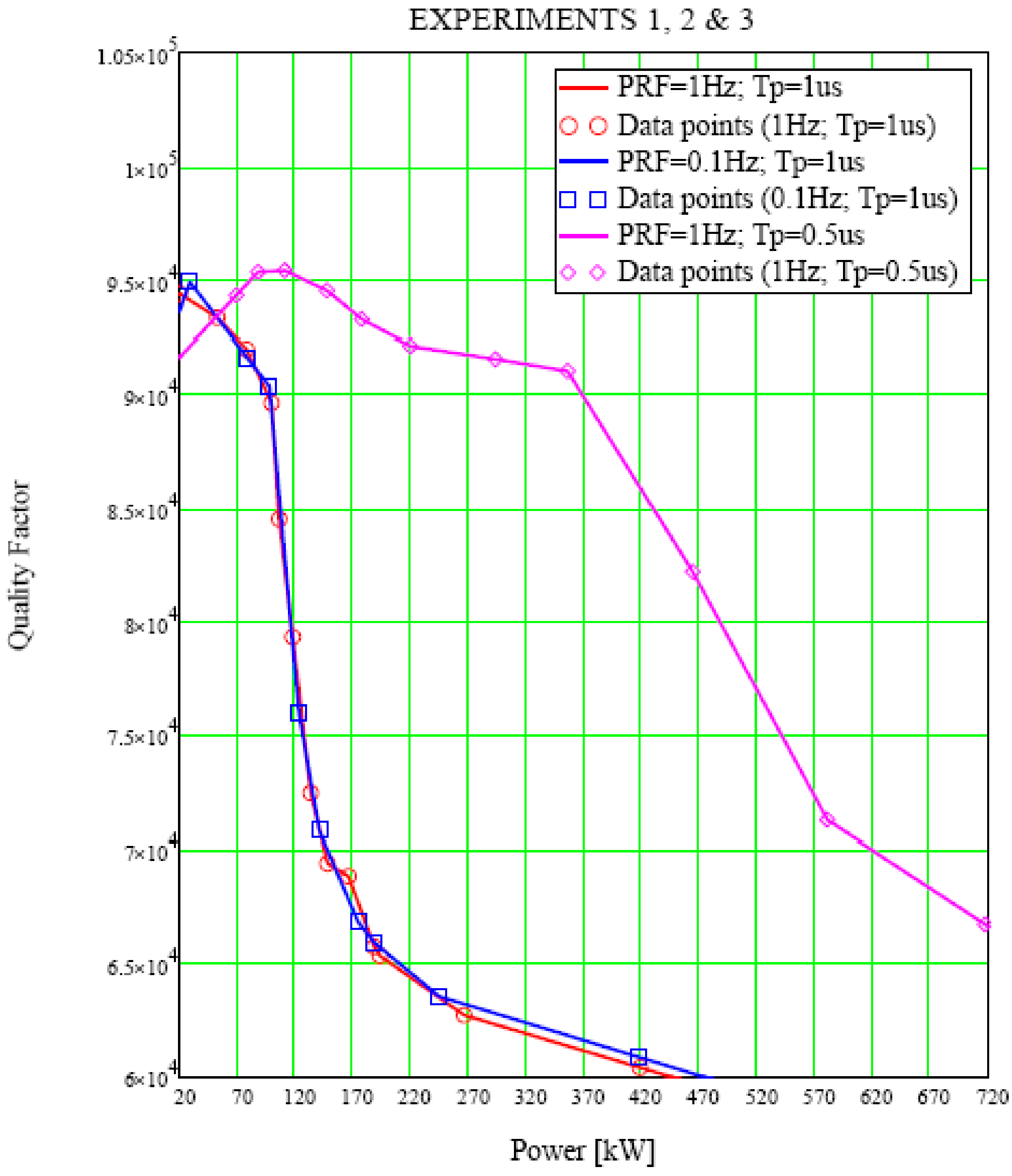
Q vs. incident power

Start of breakdown at RF critical magnetic field at the highest field region



Effect of reducing pulse width from 1 to 0.5 μs

- needed ~4x higher incident power since filling time is longer than pulse width
- 1 μs seems short enough, but we will test shorter pulses

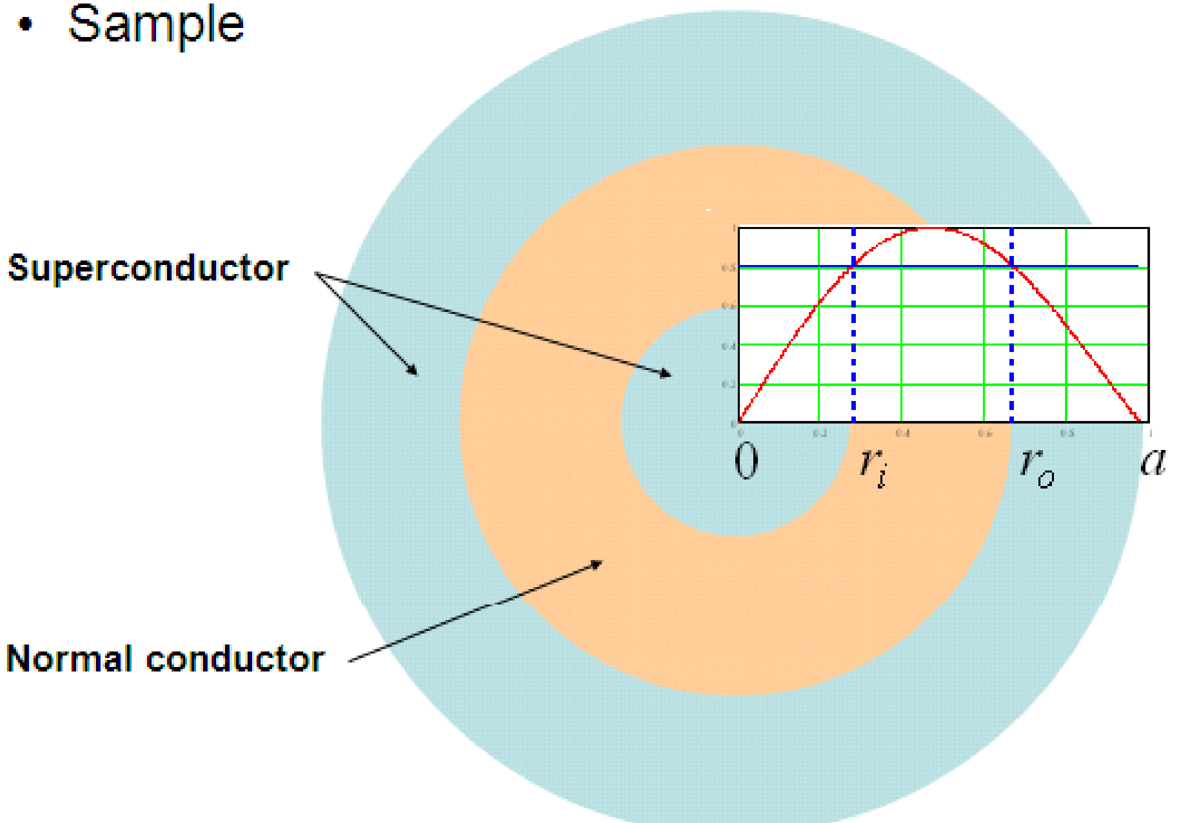


Los Alamos NATIONAL LABORATORY EST.1943

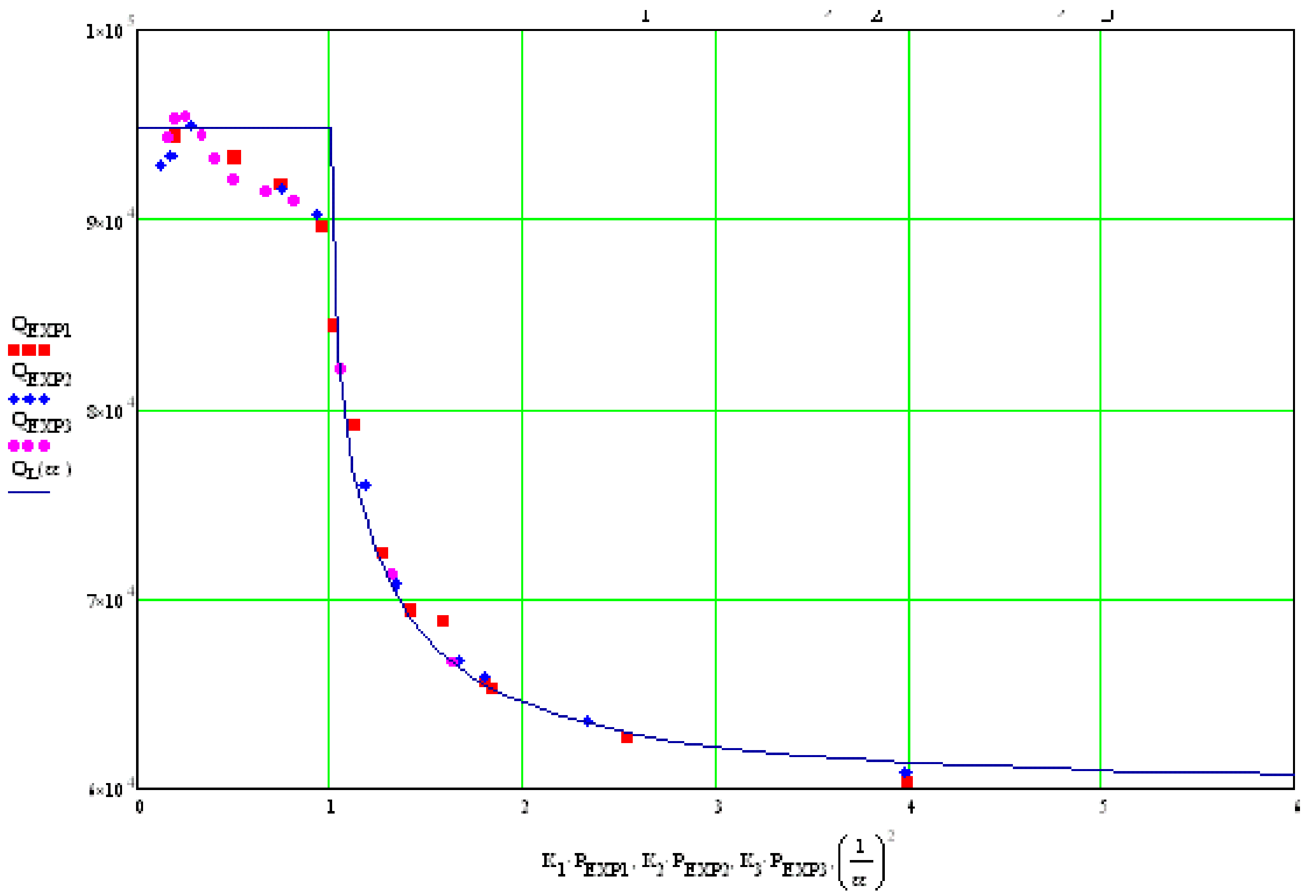
An analytical model to simulate the results was developed and showed a good agreement
Canabal, http://laacg.lanl.gov/scrflab/pubs/ILC/LA-UR-08-2706.pdf

Cavity Model: Critical Magnetic Field

- Sample



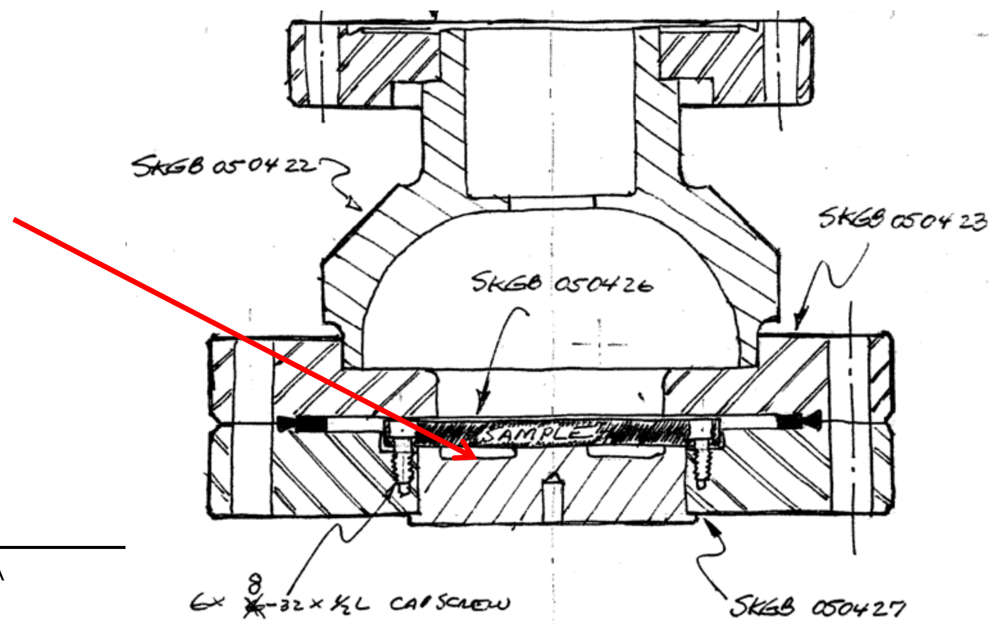
Q vs. normalized incident power with simulation (solid line). Good agreement was obtained.



But, the result was not what we expected!!

- **The RF critical magnetic field of this sample was 60 mT instead of ~140 mT that we expected at 4.2 K assuming ~180 mT at 0 K.**
  - We suspect that the sample surface temperature was raised for some reason, although the pulse itself is not supposed to raise it if it is short enough.

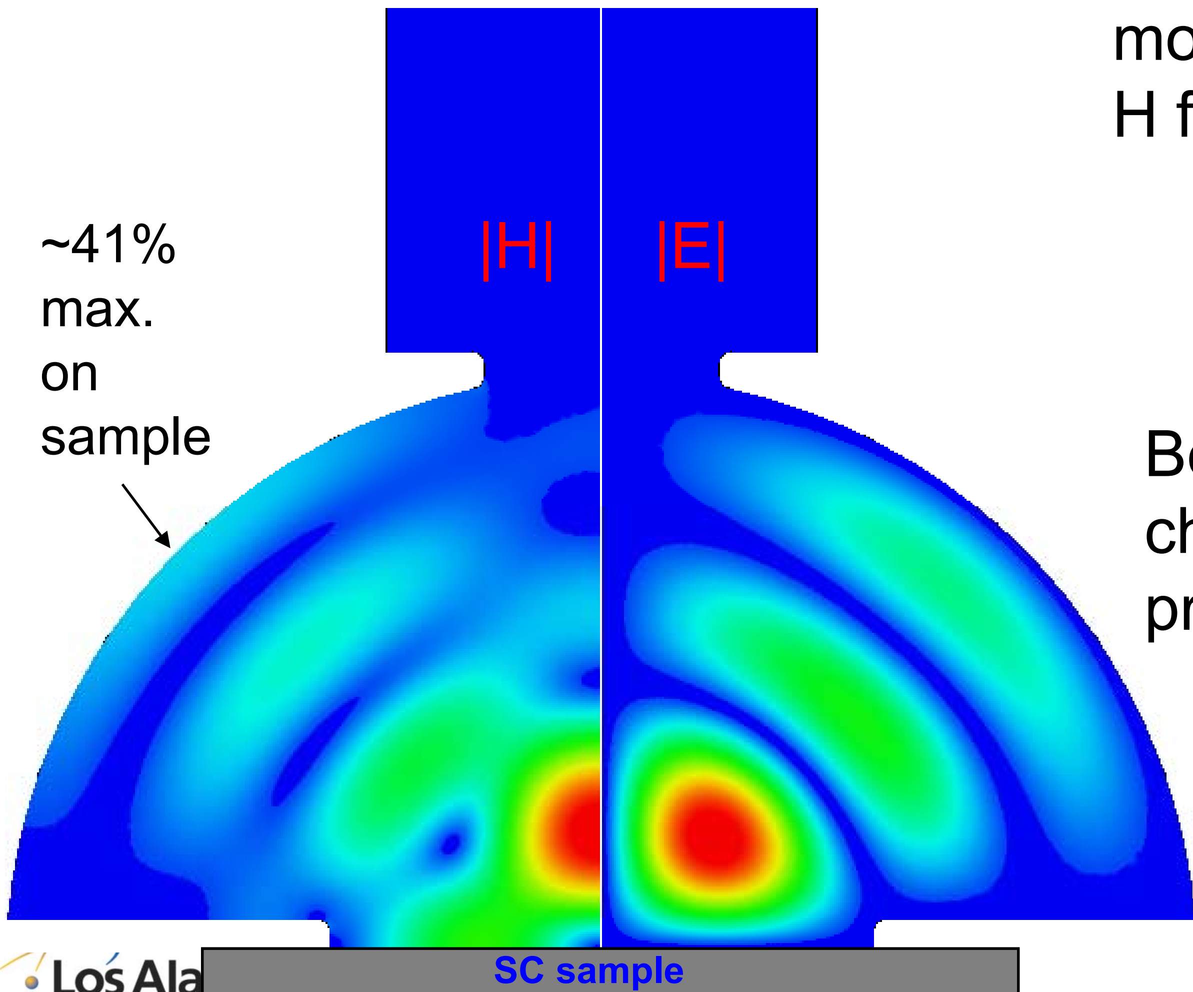
No direct contact with Cu behind the area of highest magnetic field !



Future plans

- **Due to an incident that made the cryostat unavailable, the test has been put on hold.**
- **Move to a system without liquid helium and more compact system, i.e., use of cryocooler and magnetron power source (3-5 MW).**
- **New cavity to increase the sensitivity of the change in the sample. See next slide.**
- **Test plan**
  - Check the effect of thermal contact and get Nb reference data
  - Nb single crystal sample from DESY
  - MgB_2 and $MgO+MgB_2$ prepared by PSU
  - NbN to be prepared by LANL
  - Other samples

A new cavity for RF critical magnetic field measurement was designed at SLAC. (C. Nantista, S. Tantawi)



more concentration of H field on sample

Better sensitivity on the change in sample property

Coating of alternative superconductors (MgB_2, NbN) for SRF applications

Thin film superconductor and its benefit (Alex Gurevich's proposal)

- **For thin films:**

Enhanced lower critical field and surface barrier in films

Use thin films with d < λ to enhance the lower critical field

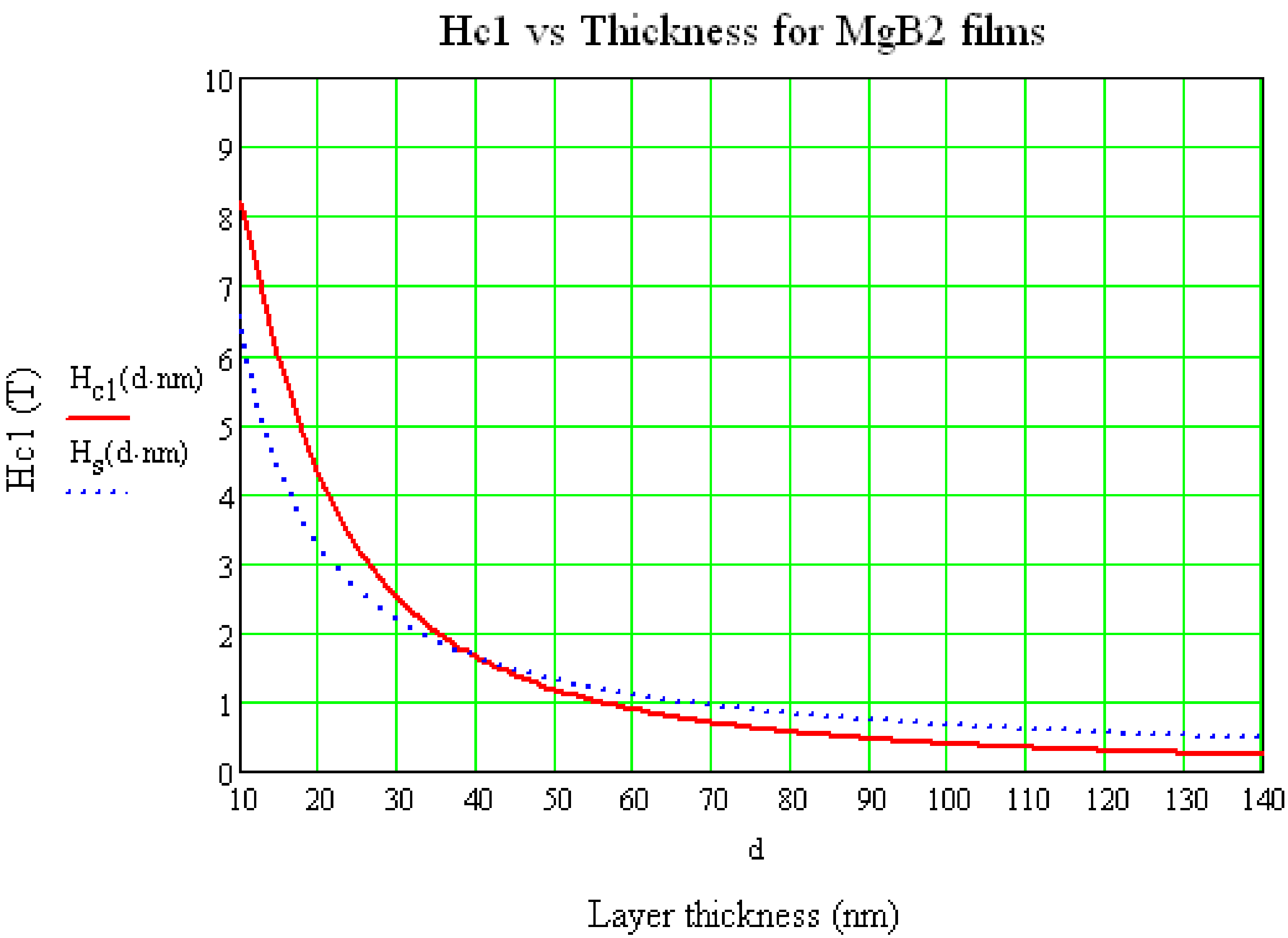
$$H_{c1} = \frac{2\phi_0}{\pi d^2}\left(\ln\frac{d}{\xi} - 0.07\right)$$

where Φ_0, ξ are the fluxon and coherence length, respectively.

Field at which the surface barrier disappears

$$H_s = \frac{\phi_0}{2\pi d \xi}$$

MgB_2 : enhancement of H_{c1} with very thin film



What gradient can we get theoretically?

Simple example

- **Assumptions**

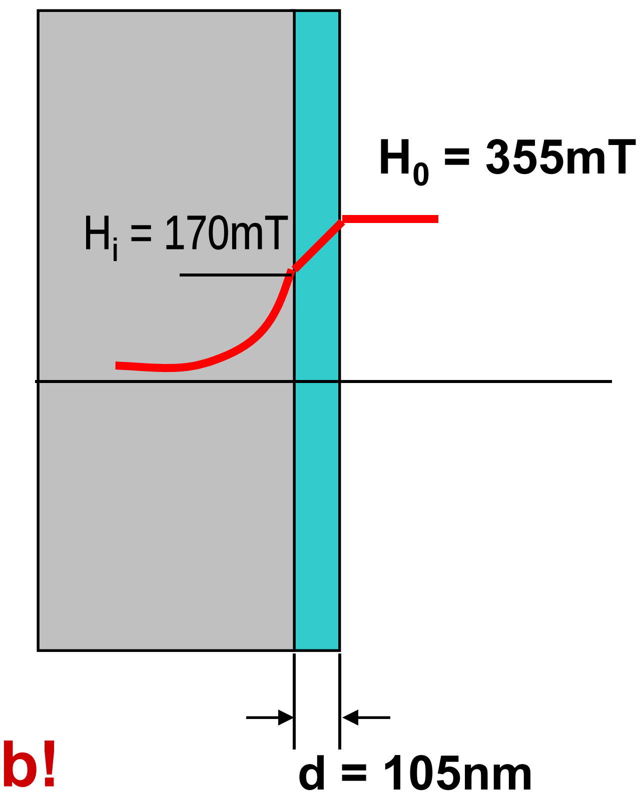
  Hc1(Nb) = 0.17T

  $\lambda(MgB_2)$ = 140nm

  $\xi(MgB_2)$ = 5nm

  What is the optimum [d,Hc1(MgB_2)] ?

- Hc1(MgB_2) = 355mT
- d=105nm



2x greater than Nb!
No vortex penetration
Eacc ≈ 100MV/m

MgB_2 Coating methods

- What is the most suitable coating method for SRF cavities?

Past and ongoing research by LANL in collaboration with other institutions:

- RE – Reactive Evaporation (past)

  Superconductor Technologies, Inc. (STI)

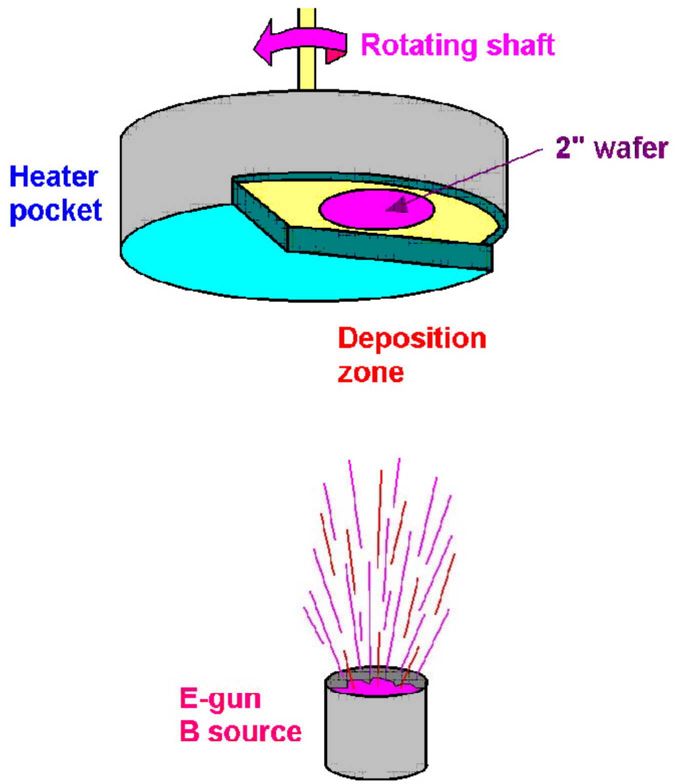
- HPCVD – Hybrid Physical-Chemical Vapor Deposition

  Penn State University

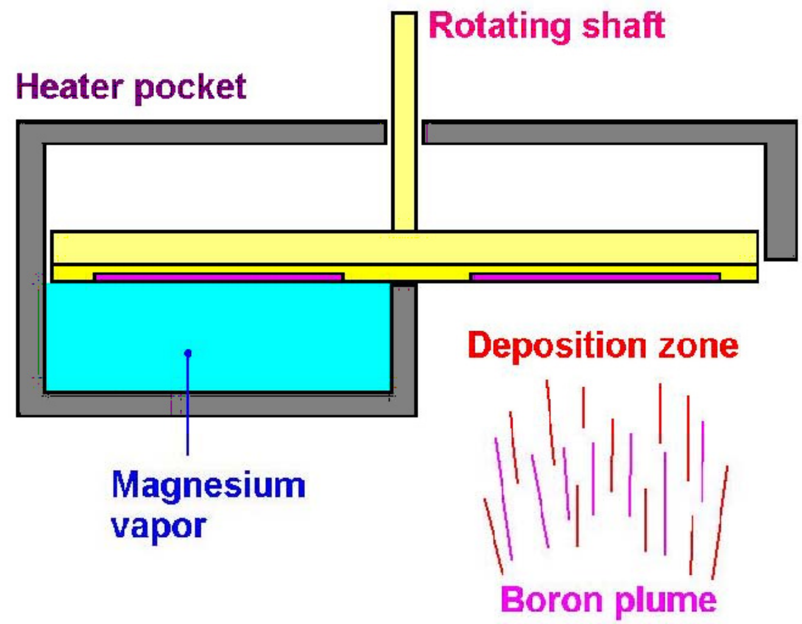
- PAD – Polymer-Assisted Deposition

  LANL

Reactive Evaporation at STI (B. Moeckly et al.)



In-situ reactive evaporation

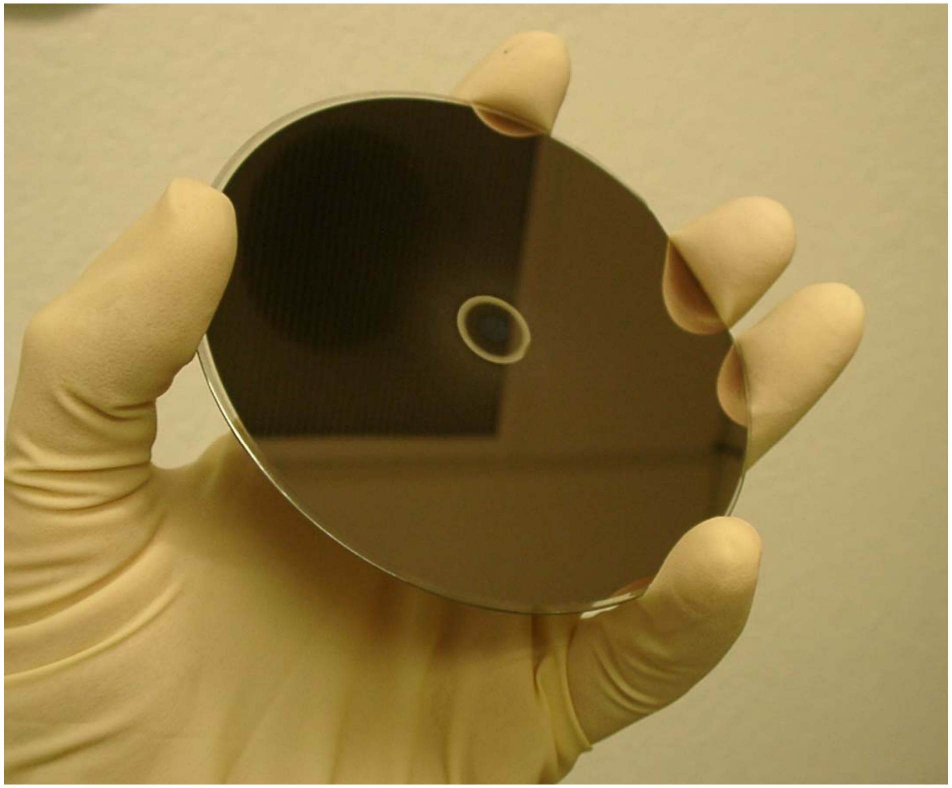


More details are found in
B.H. Moeckly et al., IEEE Trans. Appl. Supercond. 15 (2005) 3308.
T. Tajima et al, Proc. PAC05.

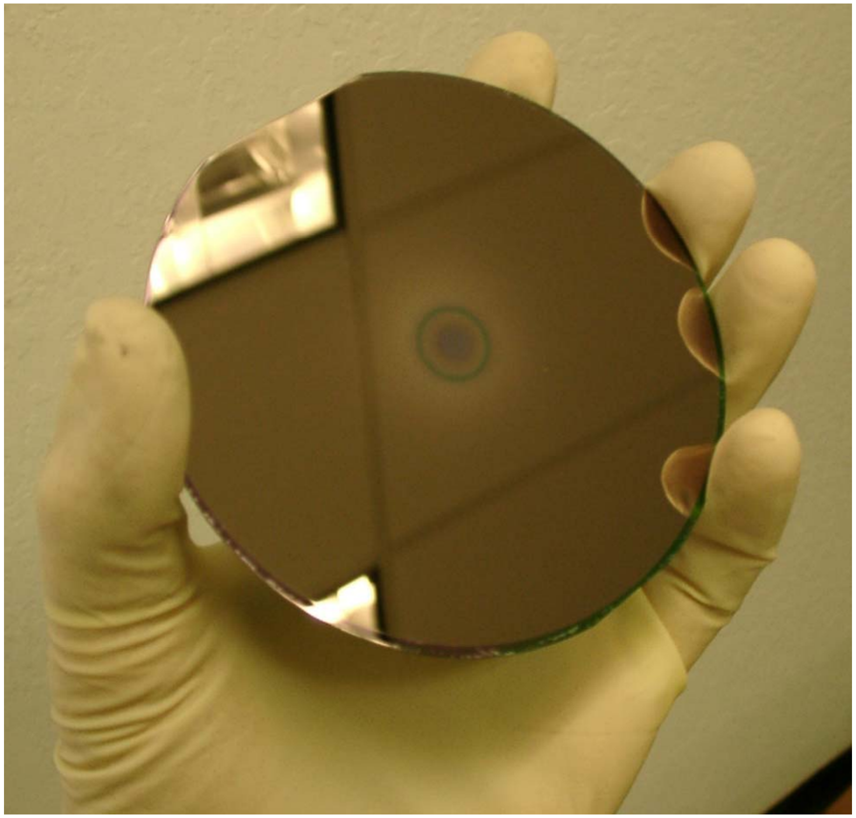
B.H. Moeckly, ONR Superconducting Electronics Program Review
Red Bank, NJ, February 8, 2005

RE at STI (B. Moecly et al.)

R-plane sapphire



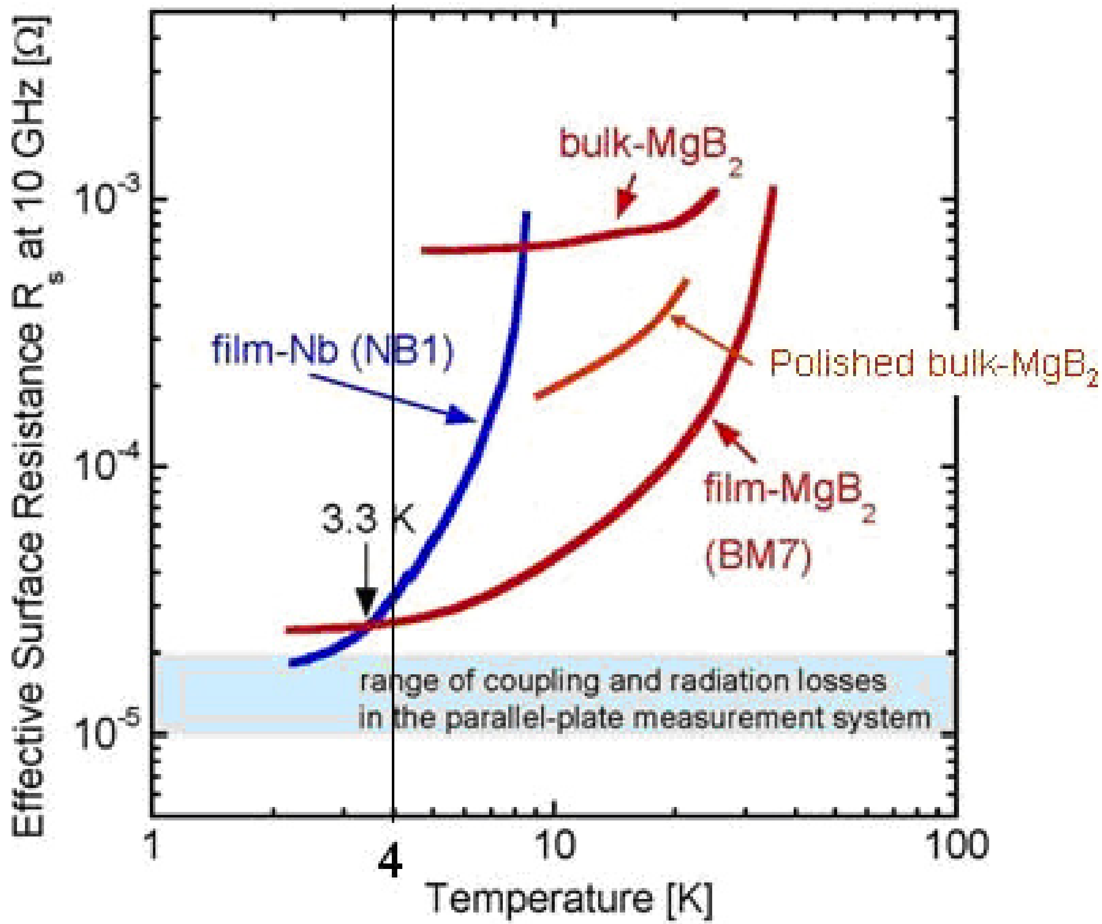
Si_3N_4 / Si



B.H. Moeckly, ONR Superconducting Electronics Program Review
Red Bank, NJ, February 8, 2005

RF Surface Resistance (R_s) at 10 GHz: LANL results with samples from STI (film) and UCSD (bulk)

- **R_s lower than Nb at 4K**
- **Still residual resistance dominates at low temperatures**

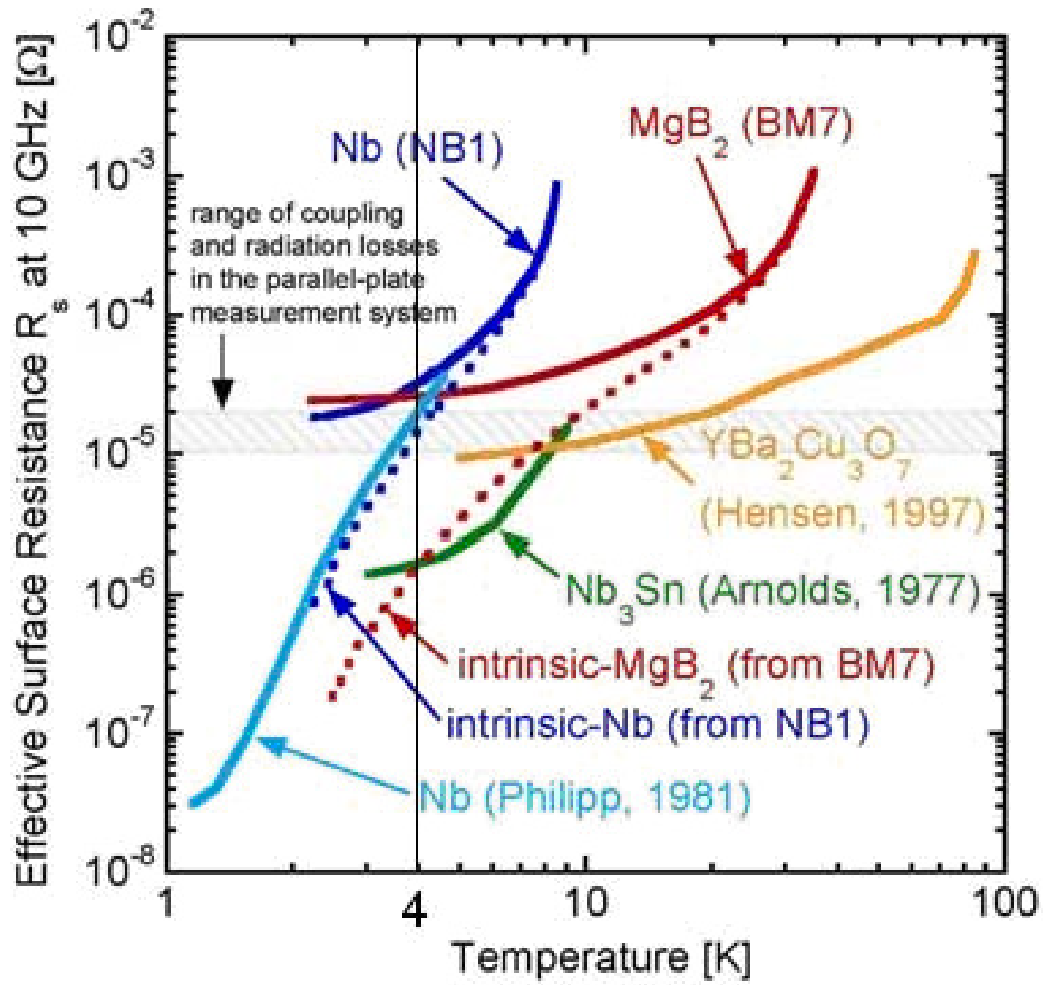


- A.T. Findikoglu et al., NSF/DOE Workshop on RF Superconductivity, Bethesda, MD, Aug. 29, 2003.
- B.H. Moeckly et al., IEEE Trans. Appl. Supercond. 15 (2005) 3308.
- T. Tajima et al., Proc. PAC05.

- Generally, $R_s \propto f^2$ at $T<T_c/2$

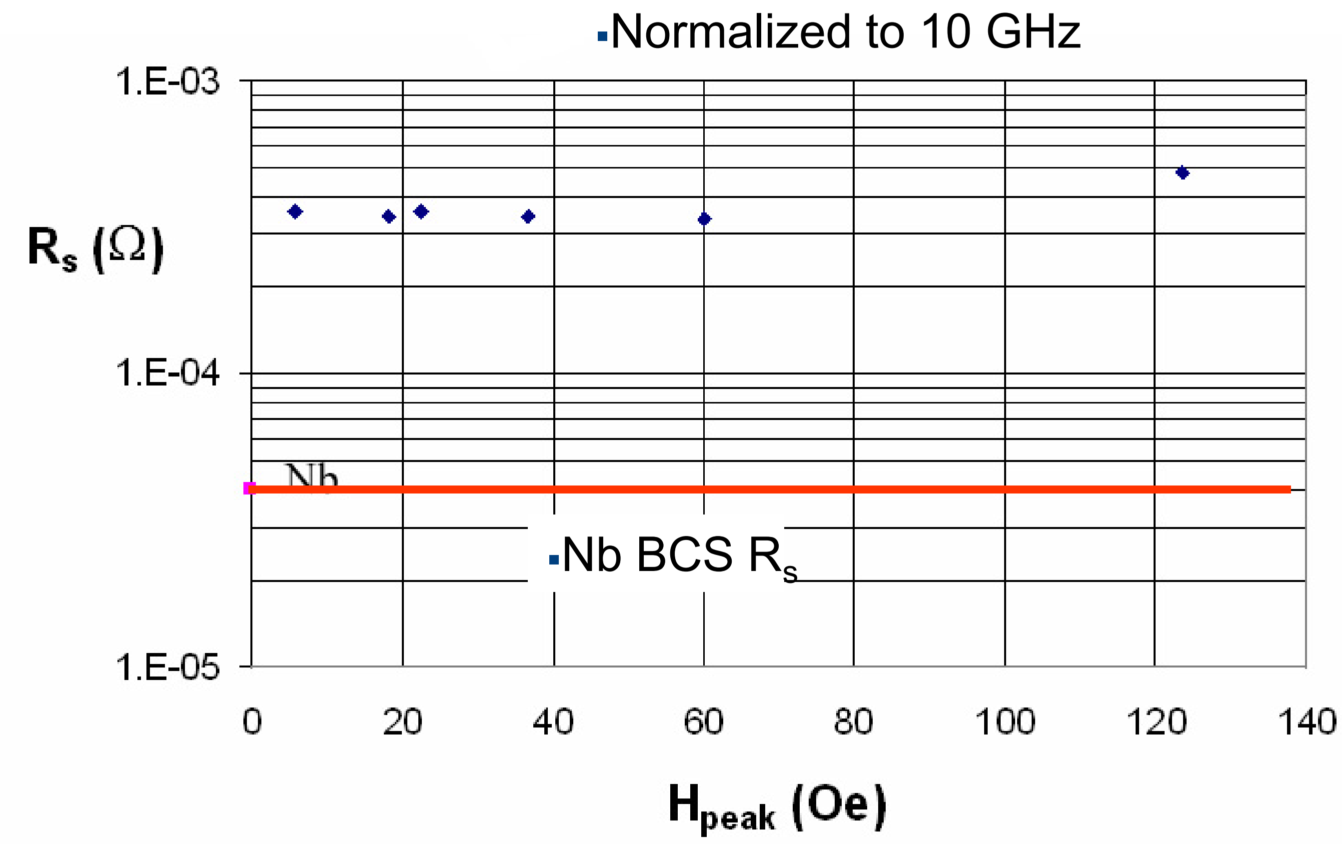
RF Surface Resistance (R_s) at 10 GHz: LANL measurements compared to the data from other references, and prediction

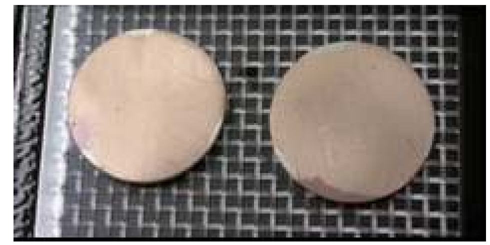
- **Dotted line is the predicted BCS resistance by subtracting the residual resistance (temperature independent)**



- A.T. Findikoglu et al., NSF/DOE Workshop on RF Superconductivity, Bethesda, MD, Aug. 29, 2003.
- B.H. Moeckly et al., IEEE Trans. Appl. Supercond. 15 (2005) 3308.

R_s Power Dependence Test of the sample coated on a rough Nb disk at STI with reactive evaporation method in 2004

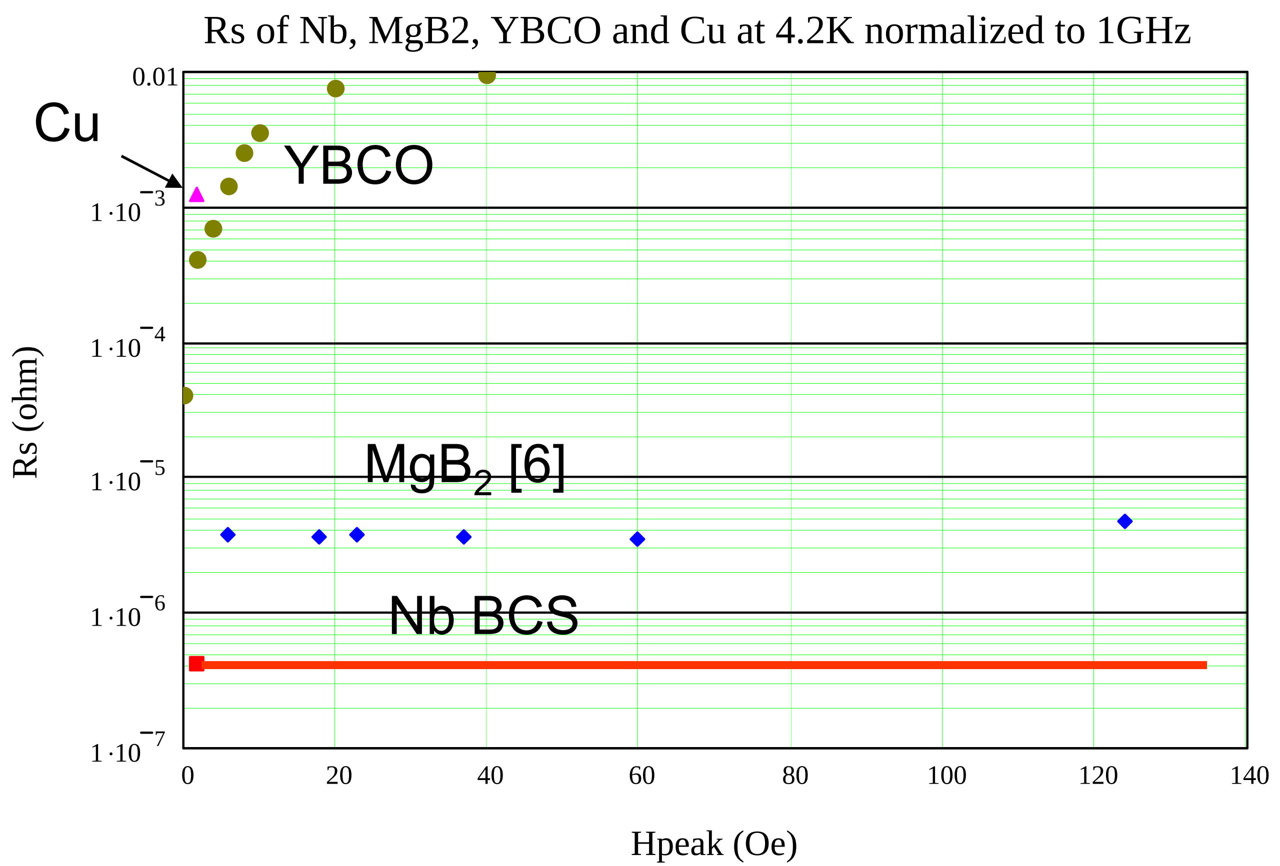




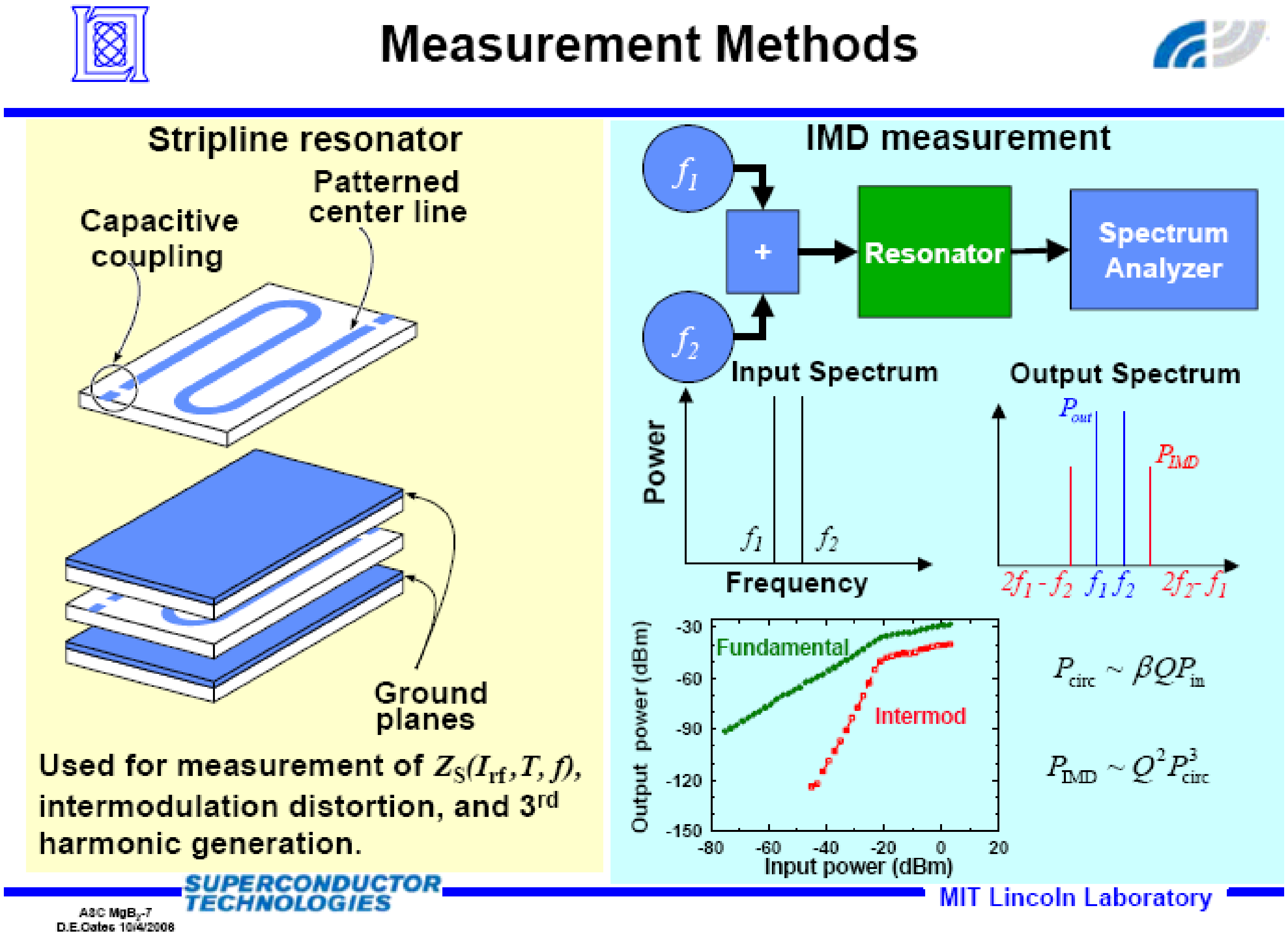
- First attempt to coat on a Nb substrate (1.5 cm disk).
- R_s was higher than Nb due to the rough (R_a~400nm) substrate.

- Test at Cornell with TE_{011} Nb cavity at 4.2 K.
- T. Tajima et al., Proc. PAC2005, p. 4215

R_s Power Dependence Test at Cornell in 2004 showed little increase up to ~120 Oe!

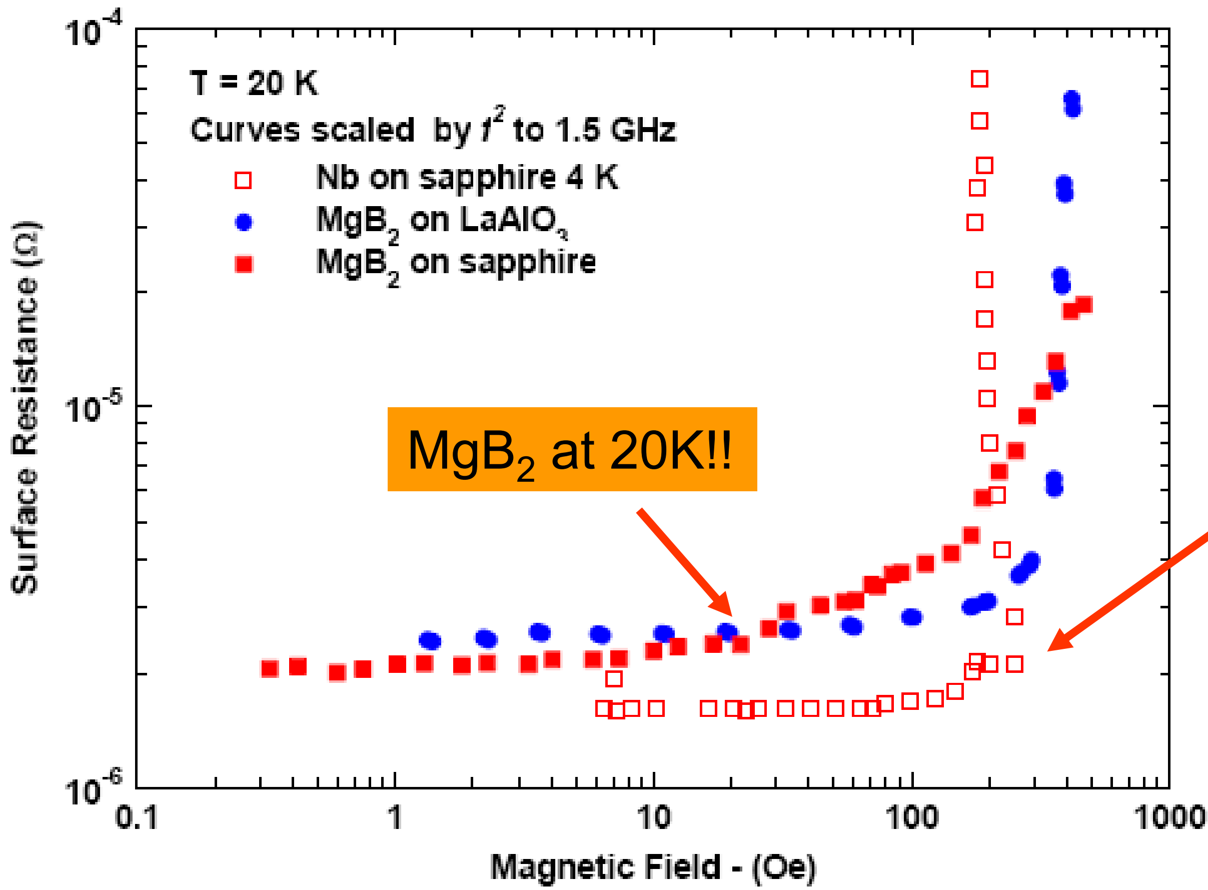


Results from MIT with STI films coated on sapphire and LAO in 2006 [D. Oates et al., ASC2006]



Oates et al., IEEE Trans. Appl. Supercond. 17 (2007) 2871.

Results at MIT in 2006 showed R_s comparable to Nb even at 20 K! and the field at which the Rs start to increase rapidly was higher than Nb!!

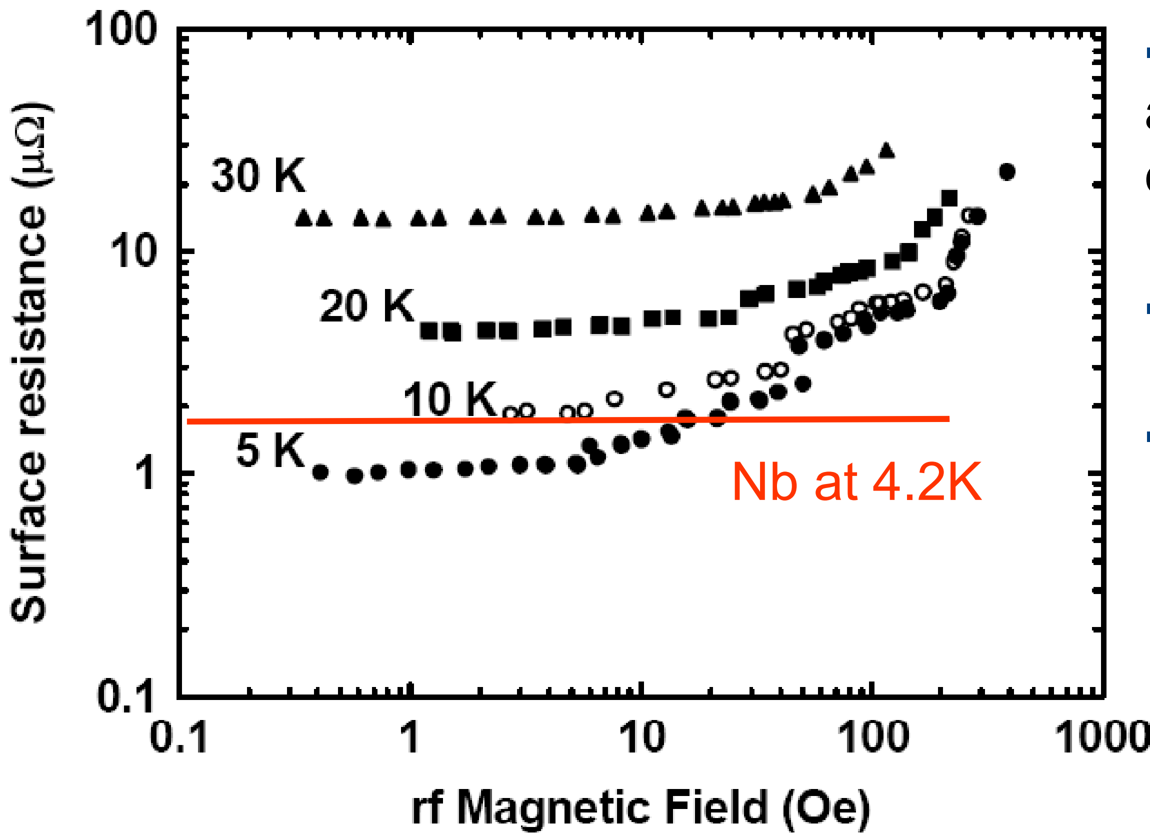


- Coated at STI with reactive evaporation
- Thickness: 500 nm

Nb at 4.2 K, Enhanced field at the edges may have caused this take off at low gradient.

Oates et al., IEEE Trans. Appl. Supercond. 17 (2007) 2871.

R_s Power dependence tests at various temperatures at MIT: The R_s at 5K is lower than that of Nb at 4.2K!, although it seems to increase faster at higher fields

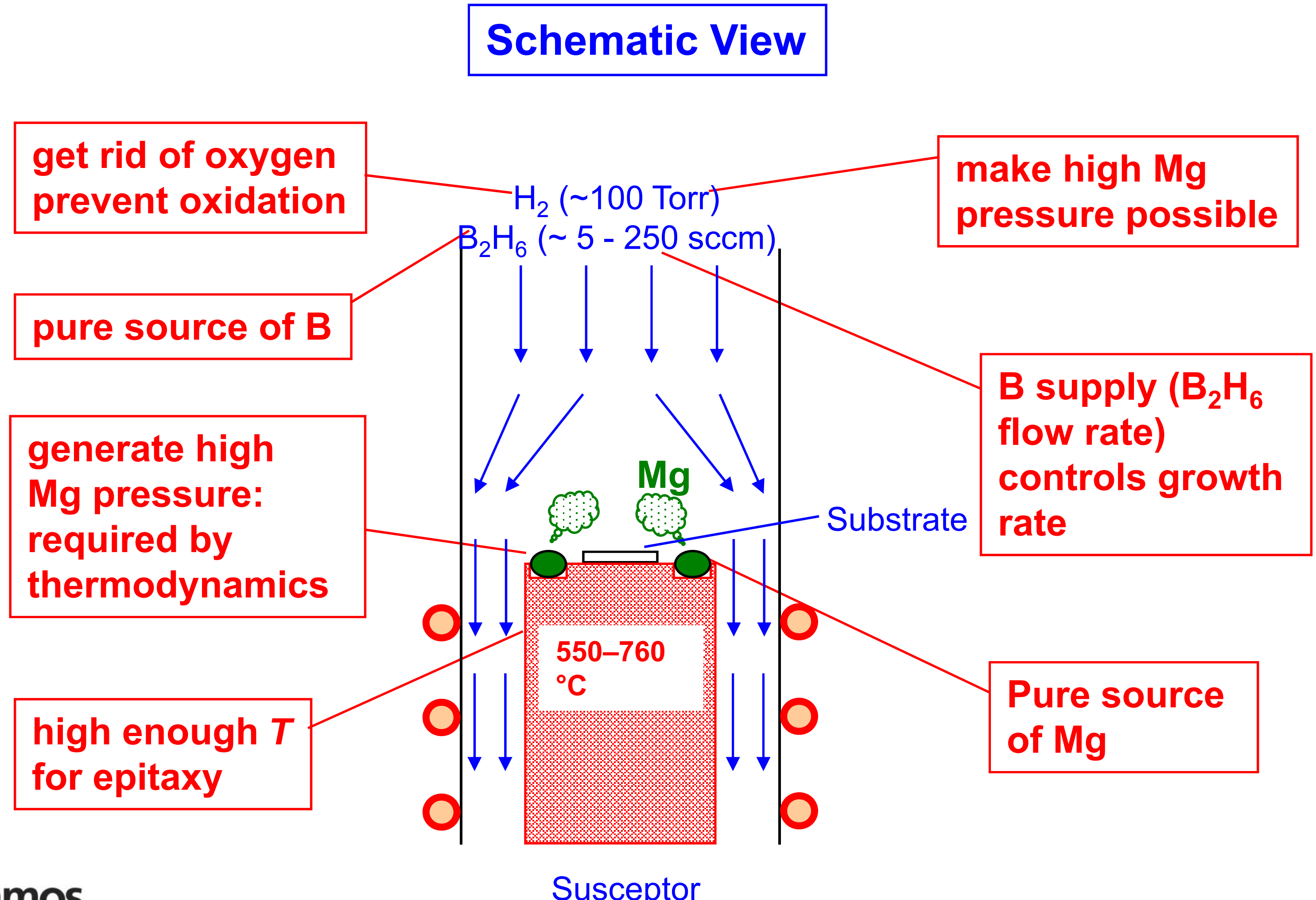


- Coated on Sapphire at STI with reactive evaporation
- Thickness: 500 nm
- Scaled to 1.5 GHz

Fig. 3. R_S vs H_{rf} at several temperatures as indicated on the graph.

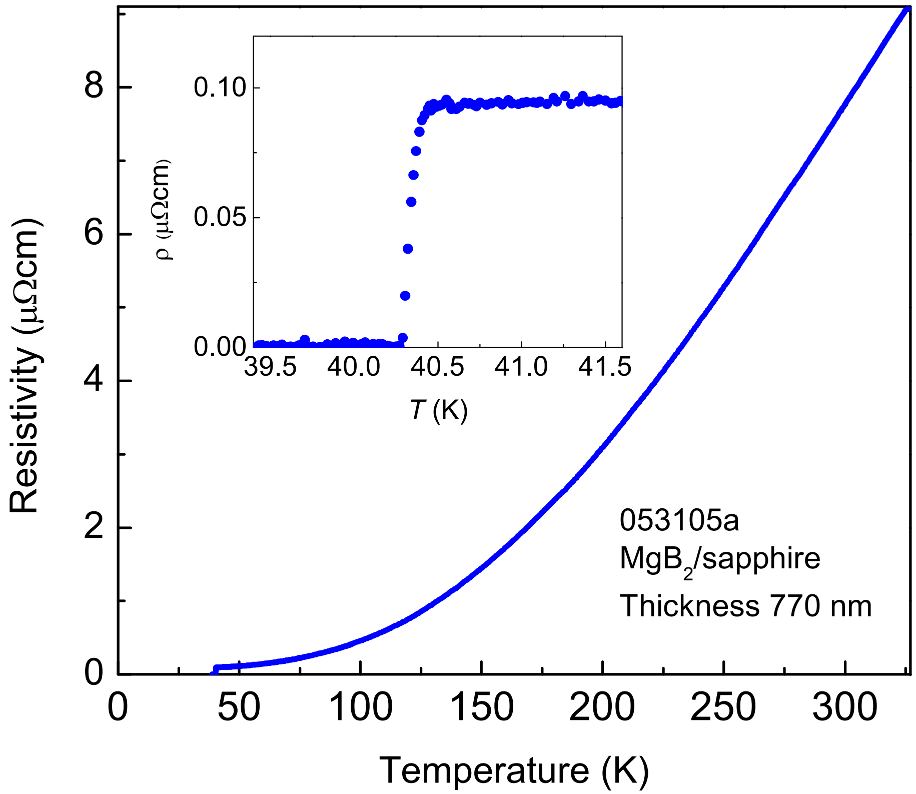
Oates et al., IEEE Trans. Appl. Supercond. 17 (2007) 2871.

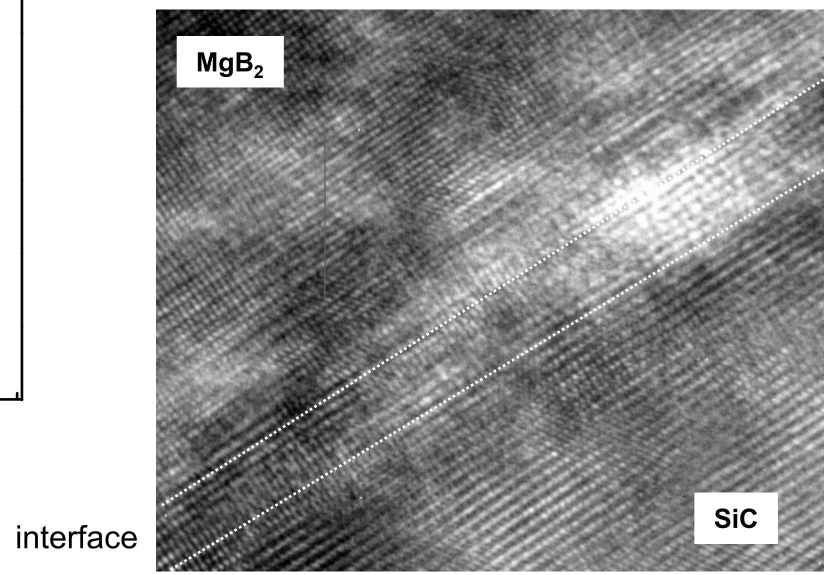
Hybrid Physical Chemical Vapor Deposition (HPCVD) at PSU (Xiaoxing Xi et al.)



HPCVD at PSU (X. Xi et al.)

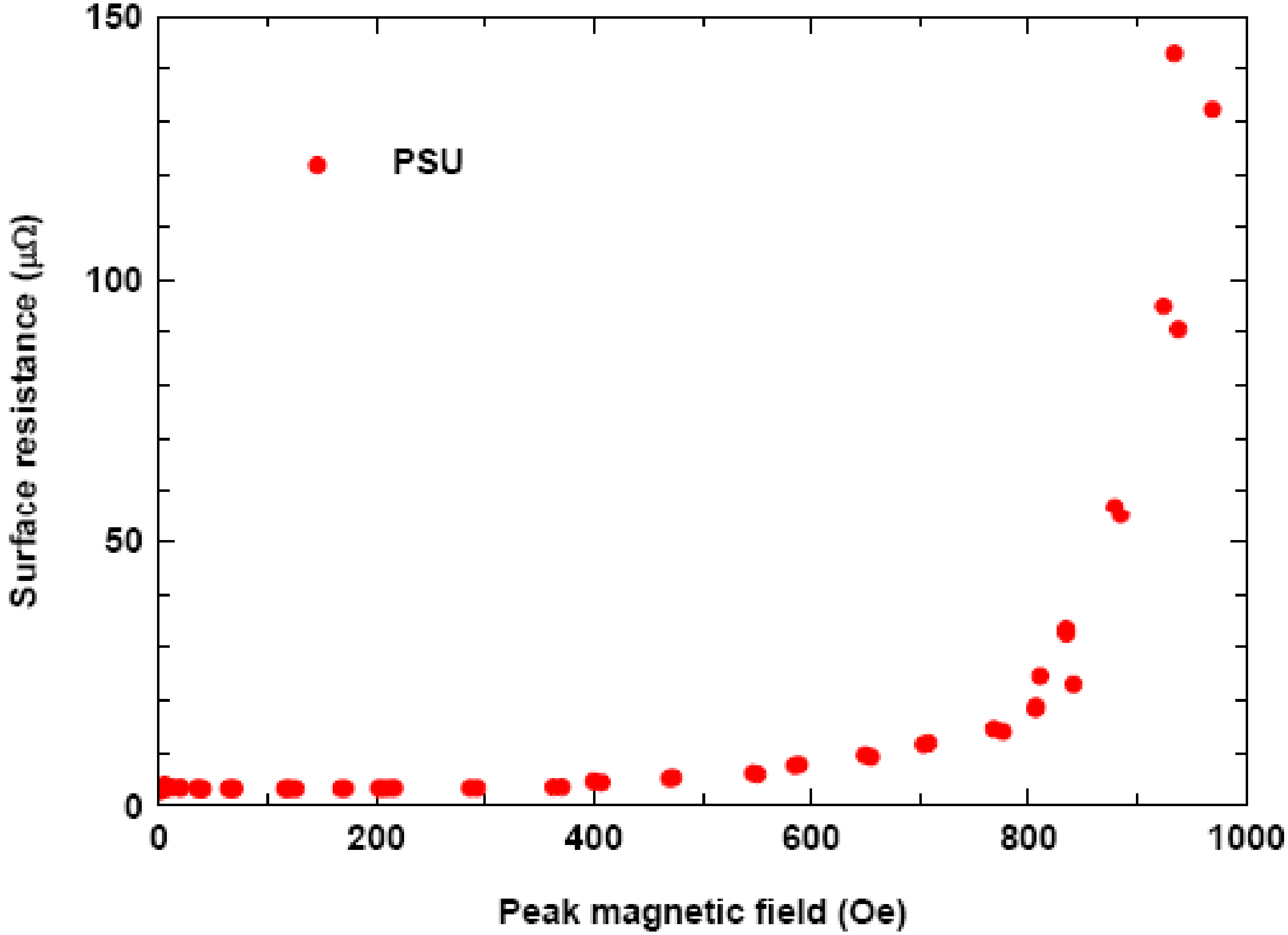
- **Example of epitaxial MgB2 Films by HPCVD: *RRR* > 80**



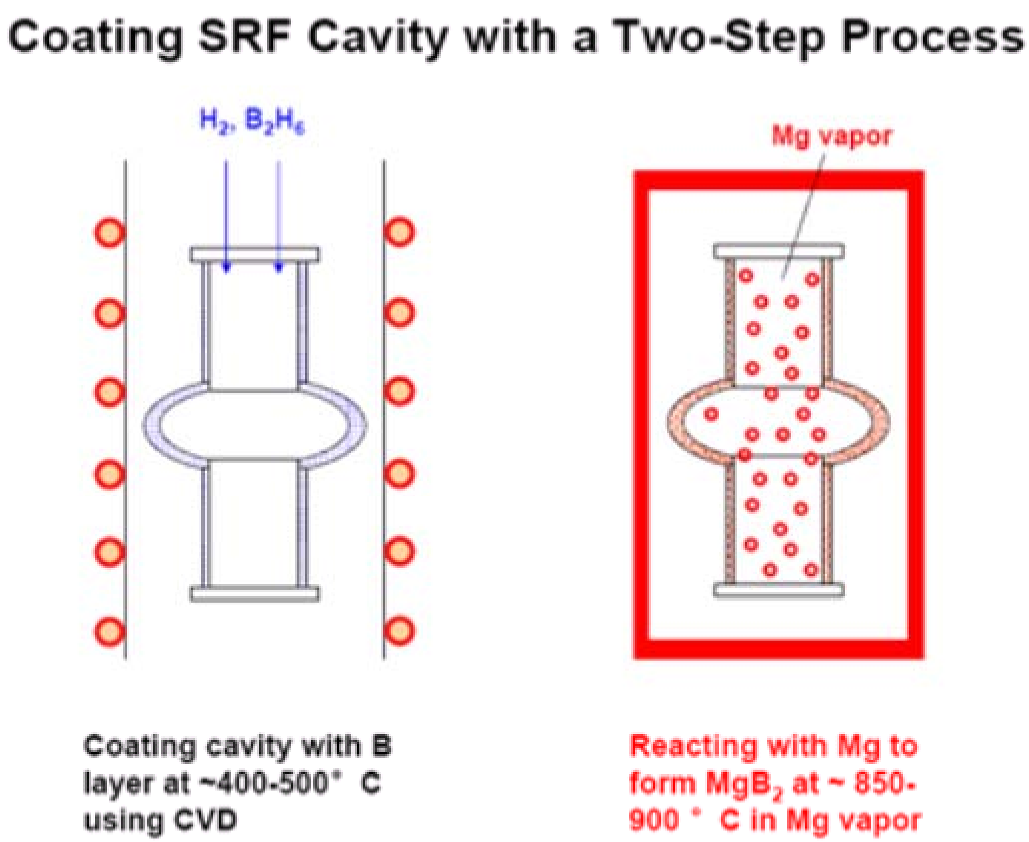


The achieved field with little RF loss is increasing! (Now ~800 Oe or higher considering the field enhancement effect at the edges) (Xiaoxing Xi at PSU)

- Test at MIT
- scaled to 1.5 GHz



An idea for coating a cavity (Xiaoxing Xi)

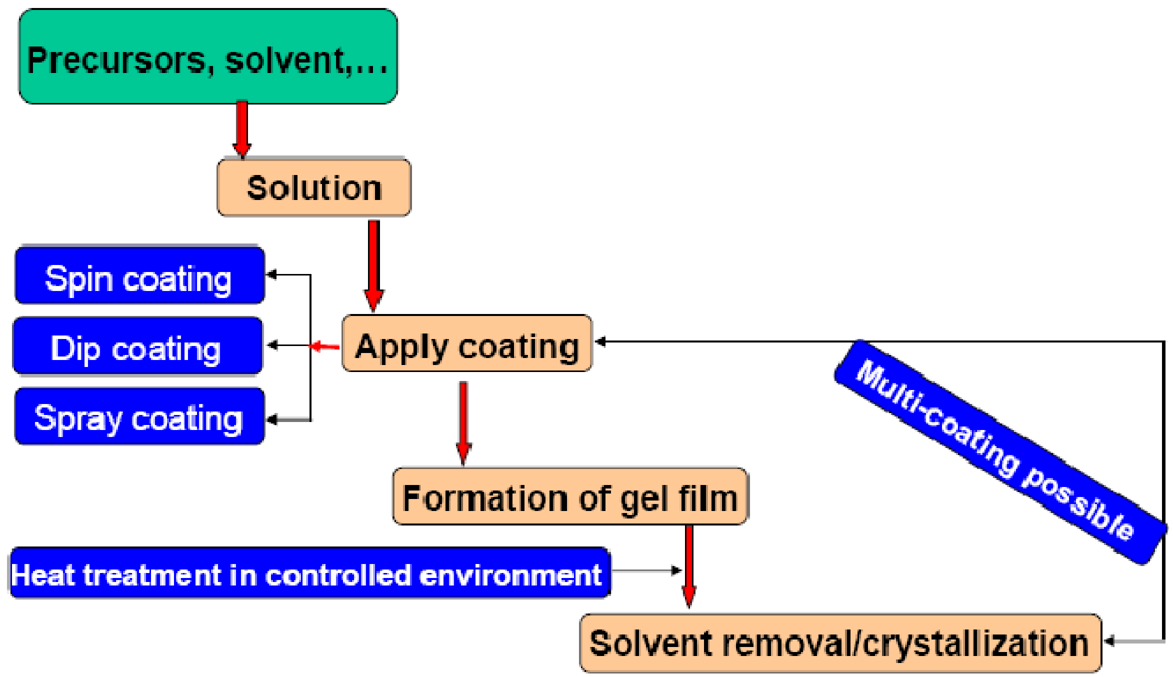


- Design and cost estimate of the coating system will be done by the end of 2008

Polymer Assisted Deposition (PAD) at LANL (Q. Jia et al.)

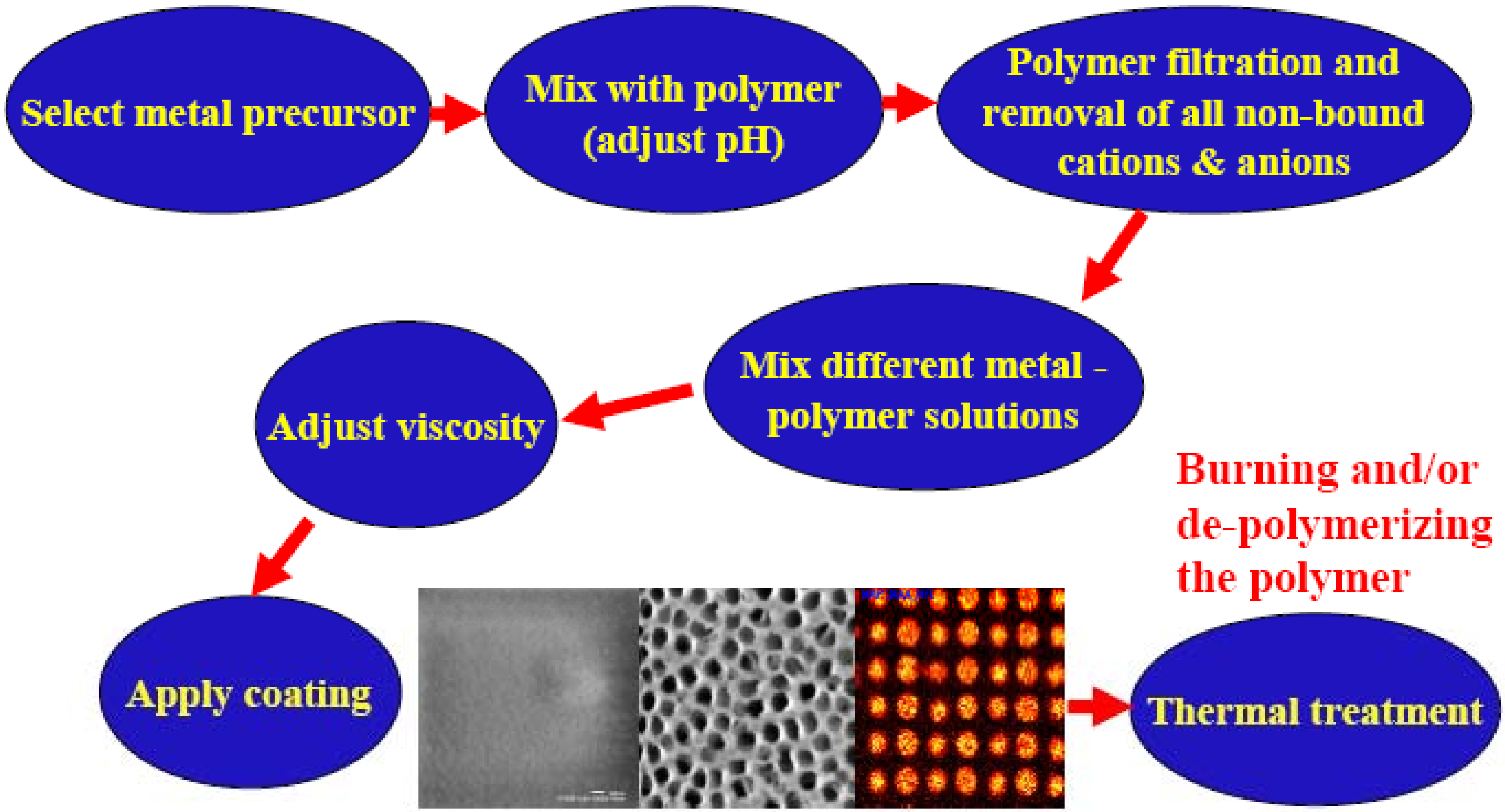
- A chemical solution technique to deposit films of nearly any metal-oxide using aqueous solution by mixing metal precursors with water-soluble polymers
- Polymer plays a critical role in metal-oxide films

Typical chemical solution deposition process flowchart



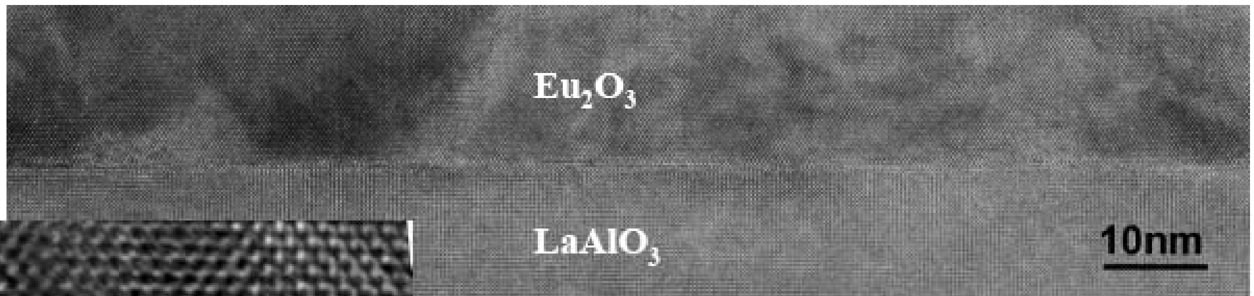
PAD at LANL (Q. Jia et al.)

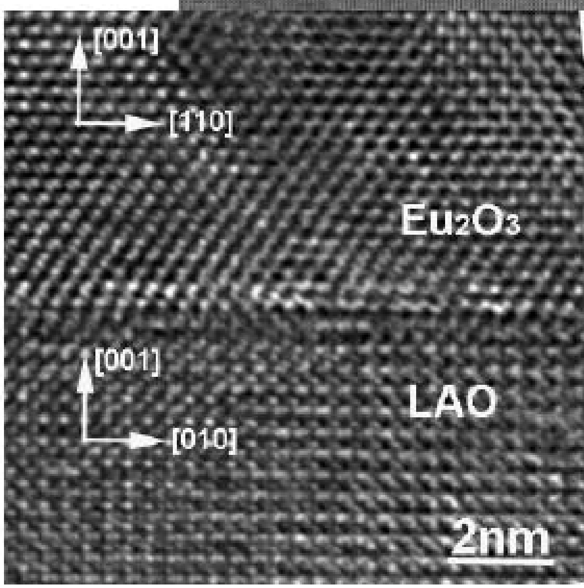
- **Process**

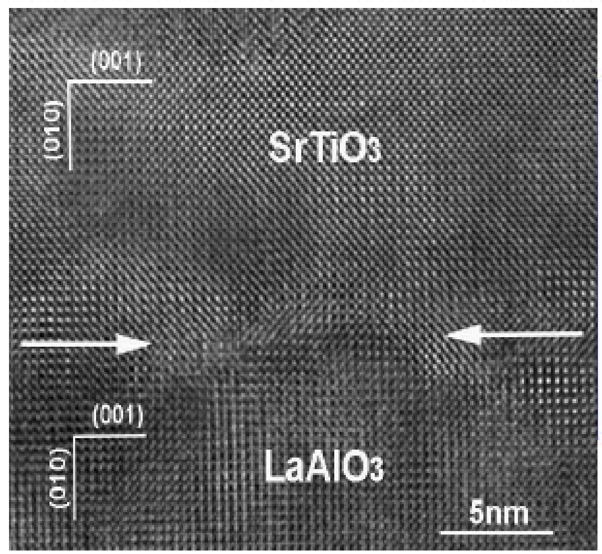


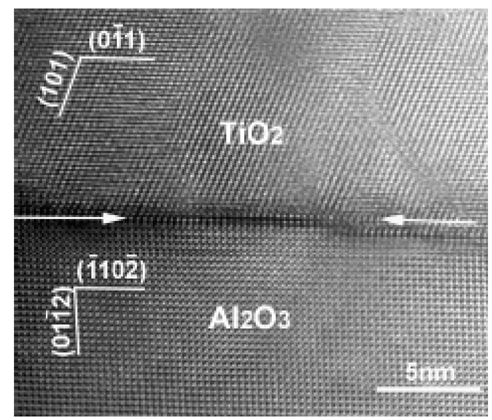
PAD at LANL (Q. Jia et al.)

- **Examples**





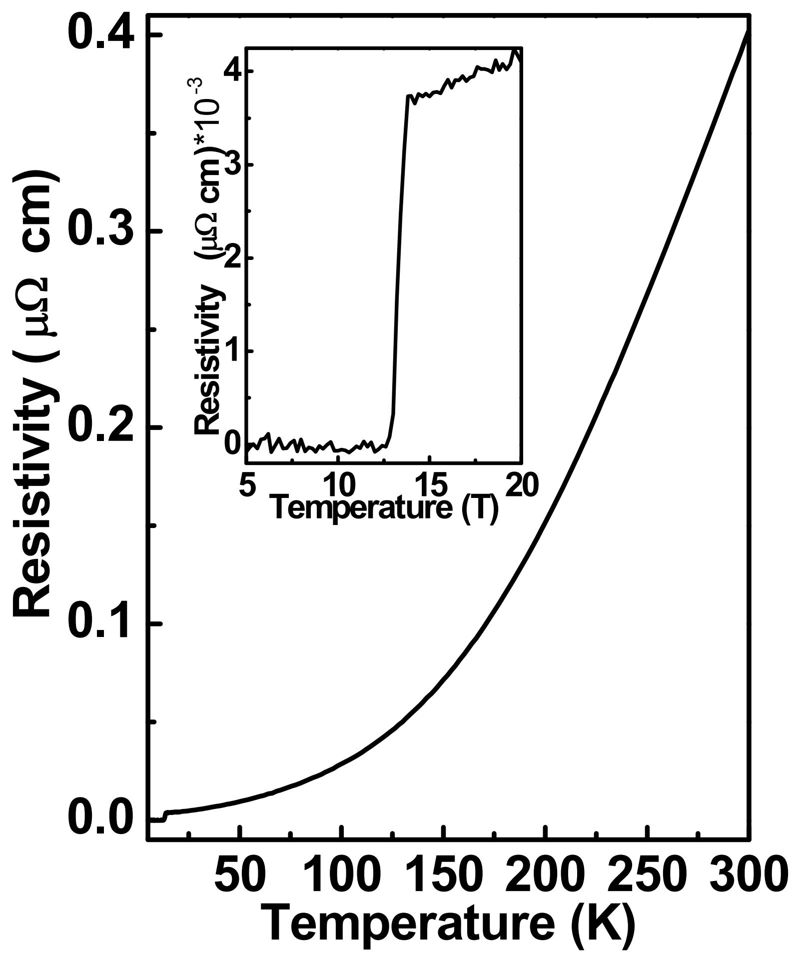




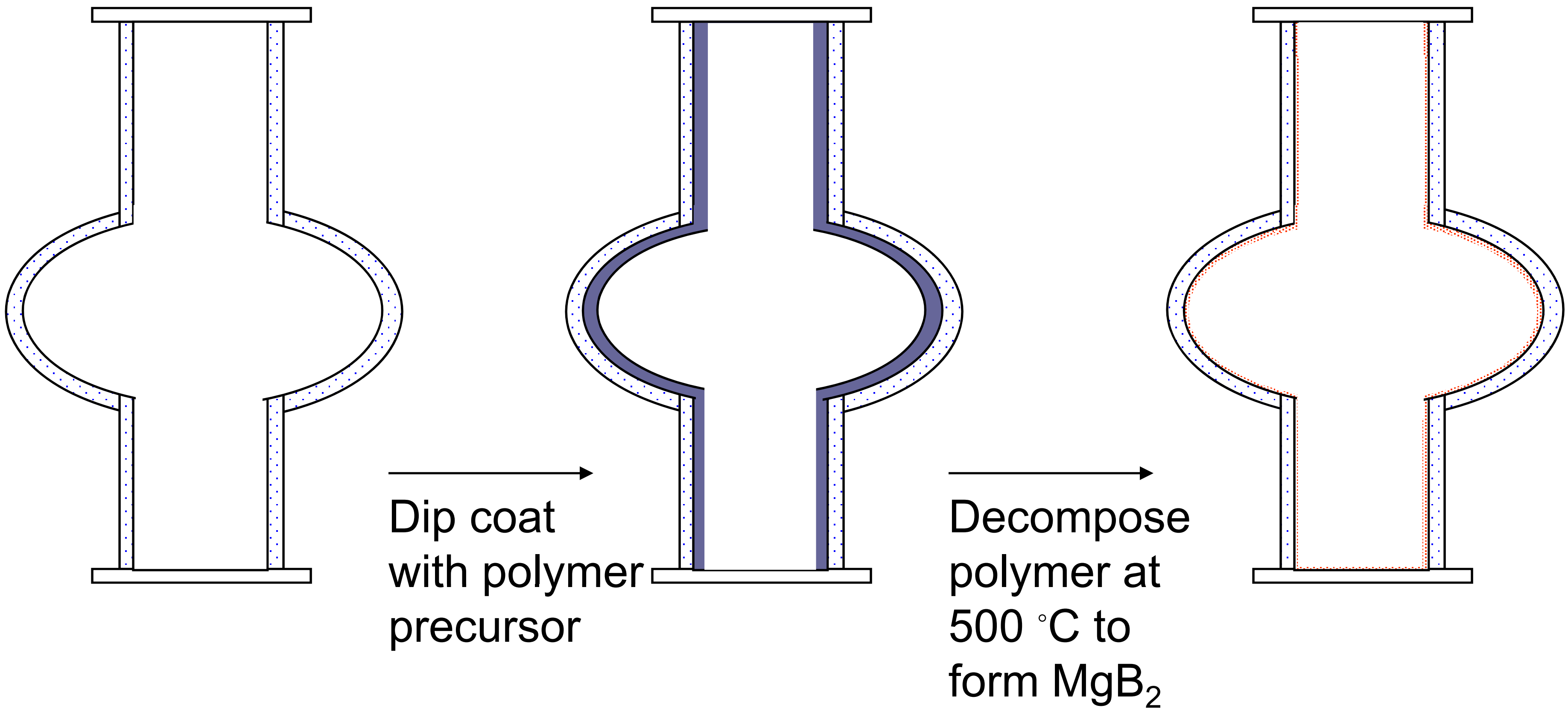
18 nm NbN thin film was deposited on $SrTiO_3$ (STO) with PAD method and showed a good result [*Guifu Zou et al.*]

- ρ_{20K} = 0.0041 μΩ·cm
- RRR (ρ_{300K} / ρ_{20K}) = 98
- T_c = 14 K

- High purity (>99%) $NbCl_5$, NH_4OH, and 20% HF were dissolved in pure water.
- PEI was used as a polymer
- Spin coating at 3000 rpm for 20 s.
- The film was annealed at 550C for 1h in forming gas (Ar + H_2) and then 900C for 5 h in ammonium



An idea of coating MgB_2, but we have not found an appropriate metal precursor and polymer yet. We will try NbN first, then move to MgB_2.



Tony Burrell, Quanxi Jia et al.

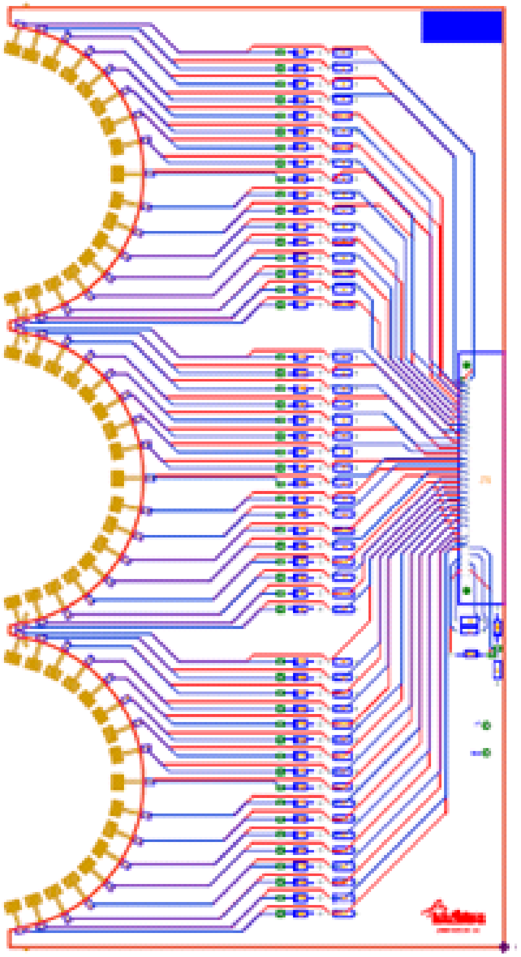
Future plans

- **LANL will pursue the following 2 methods and will try to coat existing LANL 3 GHz single-cell cavities after parameter optimization with small samples.**
  - MgB_2 on Nb with HPCVD at PSU
  - NbN on Nb with PAD at LANL in parallel with trying to find a suitable polymer for MgB_2

Cavity diagnostics

- 9-cell cavity temperature mapping system
- Optical inspection system for cavities

9-cell temperature mapping system for 1.3 GHz cavities: An application of Cornell-type fixed 100-ohm Allen Bradley resistors [Canabal et al., PAC'07 and EPAC'08]



1.3 GHz 9-cell cavity loaned from Fermi Lab

After mounting 4608 sensors

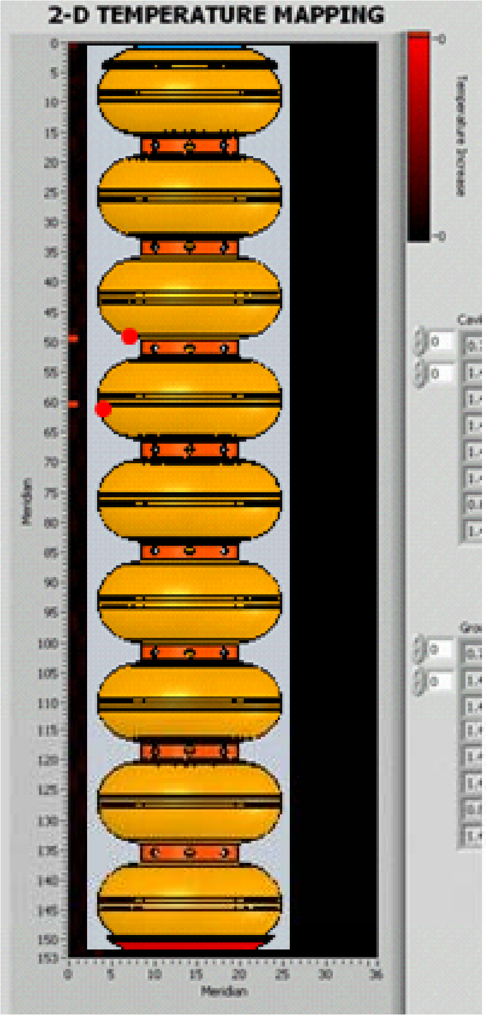
After connecting all the cables

Hermetic feedthrough on the lid with 768 manganin wires

Screen shot of the T-mapping program

- sensors at every 10 degrees azimuthally
- Divided into 9 sectors, i.e., 40 degrees each to reduce the number of cables coming out of the cryostat
- Diodes insensitive to temperature change used to multiplex the power

Locations of heating spots (Only 5 sectors worked and there might be some at the 4 sectors not detected.) Q-E curve was not taken due to a software problem

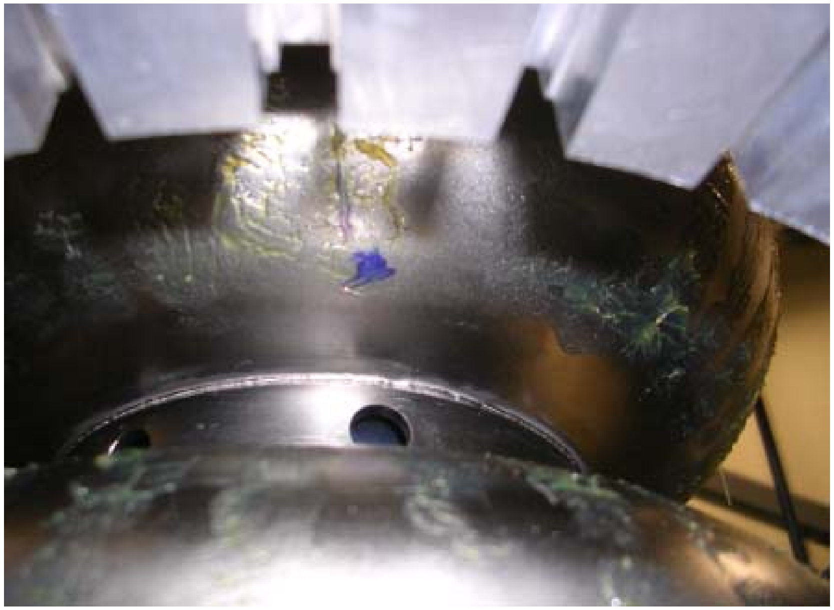


Sensor numbers from top to bottom with the position of equator
Cell 1: 1-17 equator 9
Cell 2: 18-34 equator 26
Cell 3: 35-51 equator 43
Cell 4: 52-68 equator 60
Cell 5: 69-85 equator 77
Cell 6: 86-102 equator 94
Cell 7: 103-119 equator 111
Cell 8: 120-136 equator 128
Cell 9: 137-153 equator 145

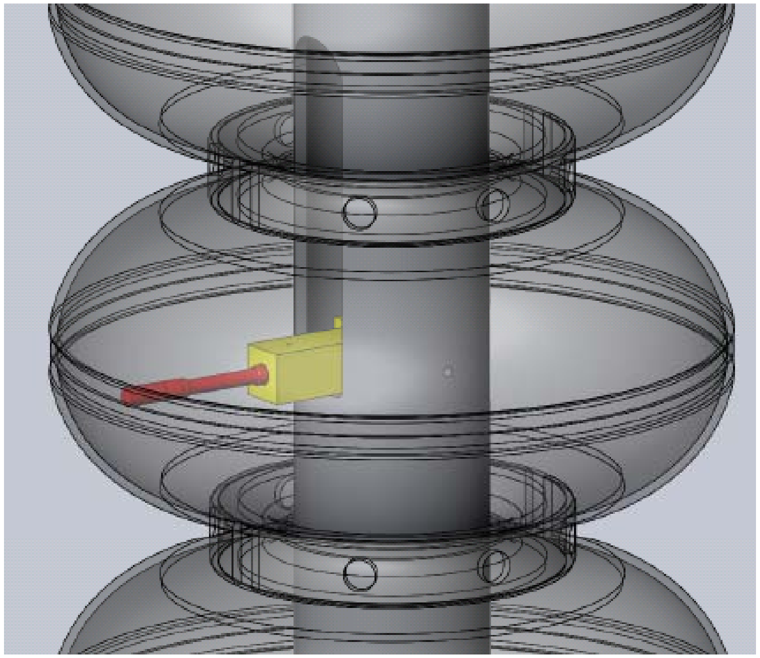
- Previous FNAL measurement was limited at ~20 MV/m with quench.

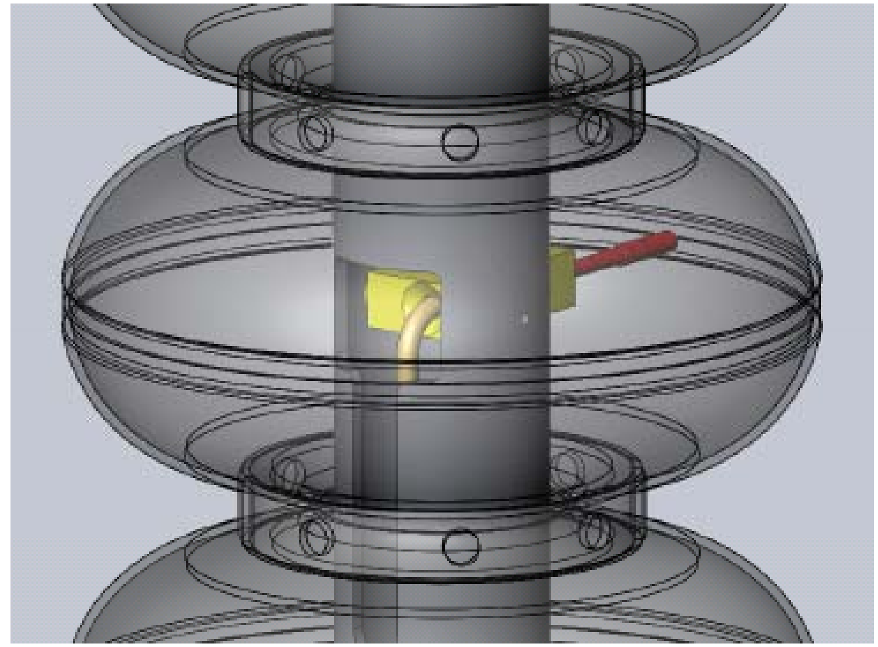
- 1st test
  61@120° cell 4 near eq.
  75@150° cell 5 near eq.
  50+61@160° cell 3 near iris+cell 4 near eq. (X-ray was detected as well)
  23@200° cell 2 in the middle
- 2nd test after warming up to room temperature (we did not re-apply grease!)
  112@220° cell 7 near eq.
  79@230° cell 5 near eq.
  112@260° cell 7 near eq.
  No X-ray was detected.

Heating spots were marked after dismounting the sensor boards to look at the inside surface with an optical system being developed

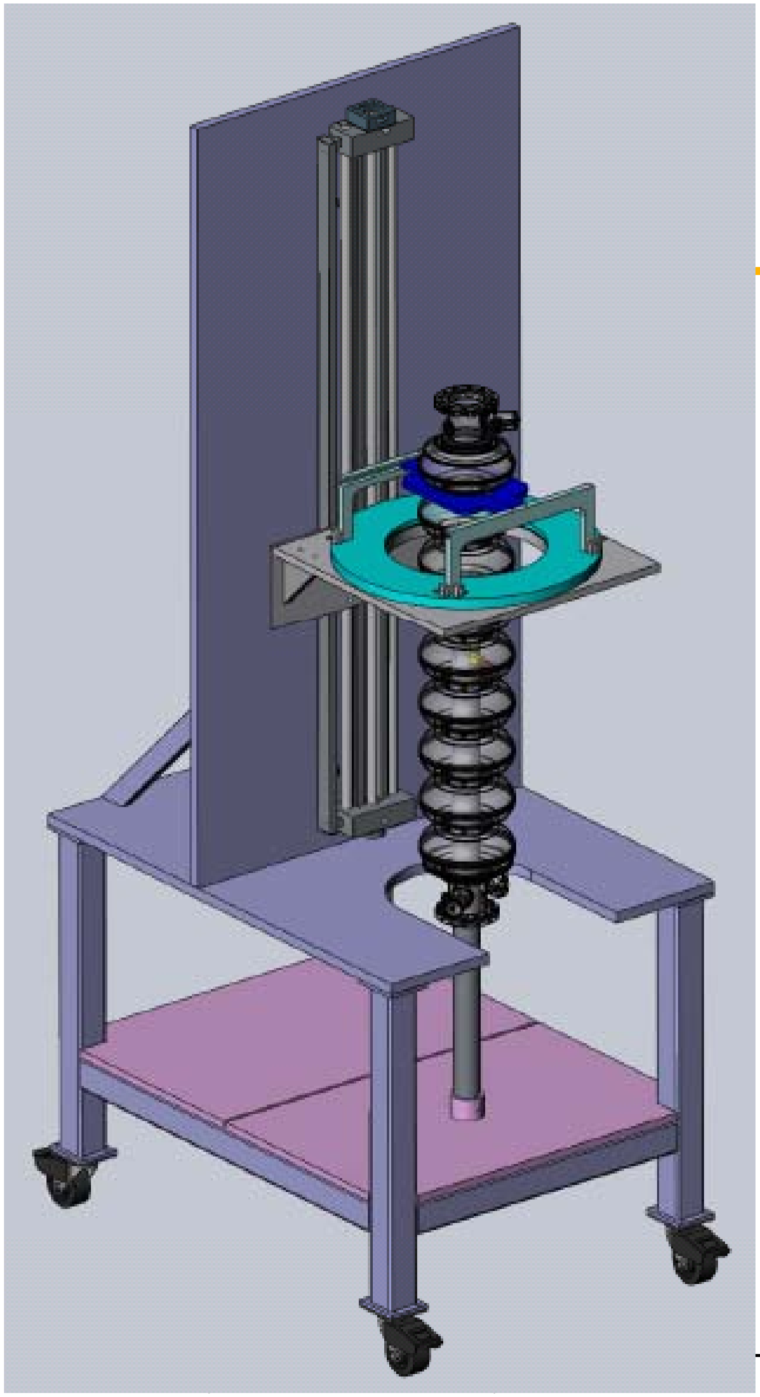


Cavity optical surface inspection system using a 6.2 mm diameter videoscope with remote tip articulation up to 120 degrees





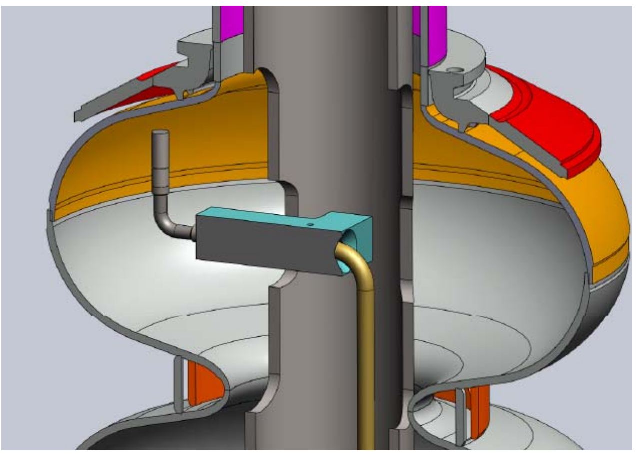
- Working distance of the videoscope is 7-40 mm.
- The tip has a 1/10 inch CCD with >250,000 pixels, in an aspect ratio of 16:9, horizontal to vertical, i.e., <5 μm resolution with magnification of 1.
- Presently, there is no mechanism to move the tip in and out, although there is digital zooming function

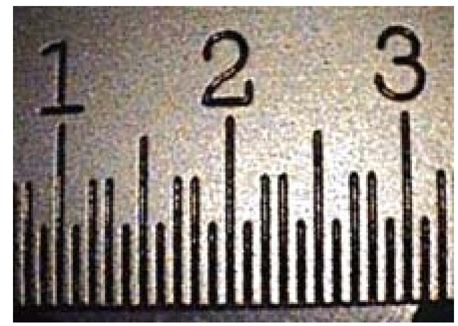


A system to inspect 1.3 GHz 9-cell cavity

- A 805 MHz SNS-type cavity can also be inspected with a minor modification.

A preliminary test result of a videoscope

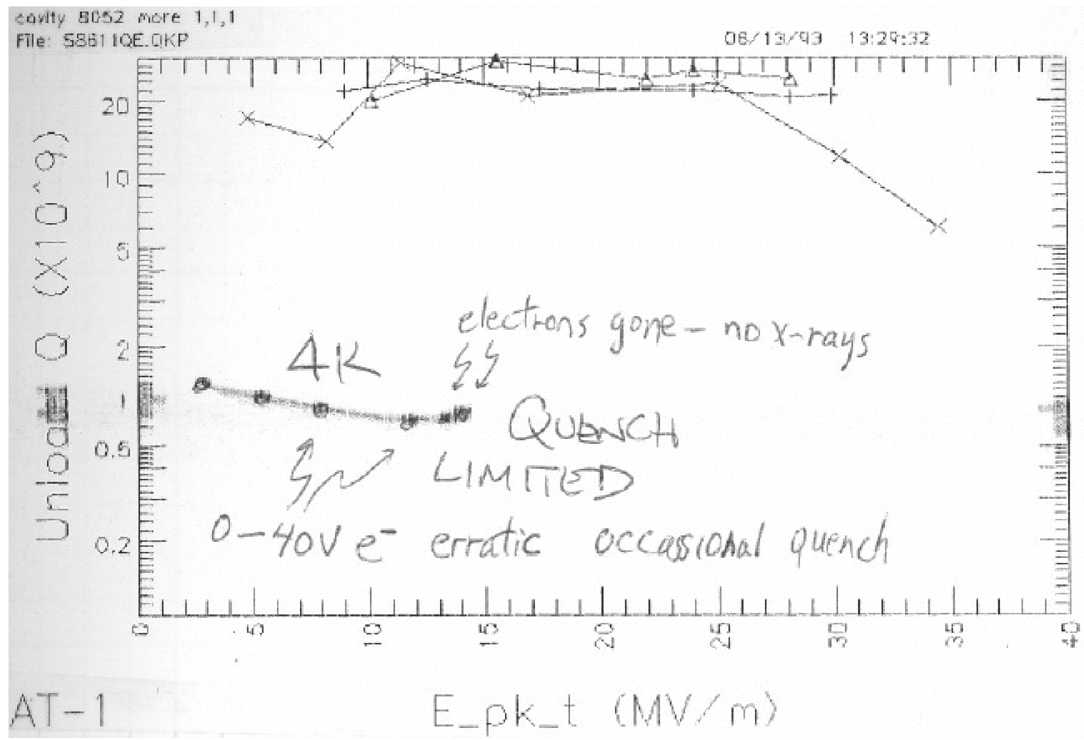




- 254 micron increment scale seen by the videoscope

An 805 MHz single-cell cavity was inspected

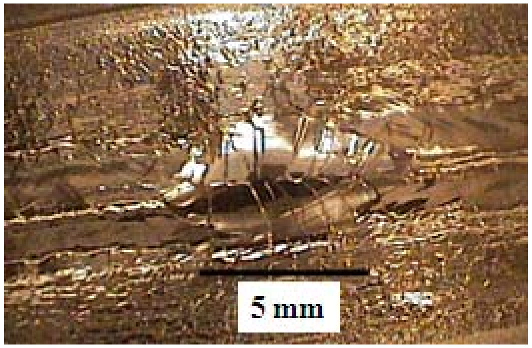
- Q-E curve obtained in 1993 shows quench at ~35 MV/m peak field, i.e., ~18 MV/m E_{acc}

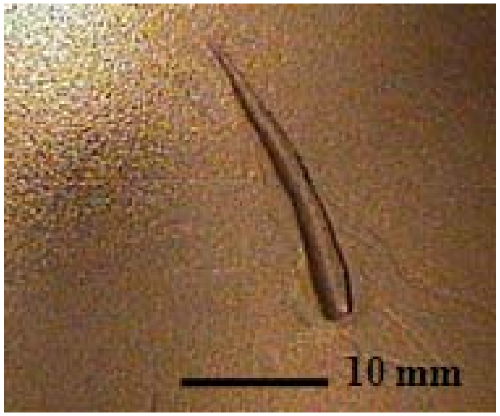


Found defects and imperfections

~ 25 mm away from the bead

on the welding bead





Scratches near the bead

Plans for the diagnostics

- Identify the cable disconnections and fix it as well as suppress noise to be able to get all-area T-map within ~10 seconds.
- The 1.3 GHz 9-cell cavity that was tested with T-map system will be optically inspected late July 2008.
- An acoustic system to detect inner surface defects and imperfections without introducing anything in the cavity will be developed.