RF Critical Magnetic Field Measurements of Nb/(Insulator)/MgB_2 Systems

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The 6th SRF Materials Workshop, NHMFL, FSU,

18-20 February 2010

LA-UR-10-00930

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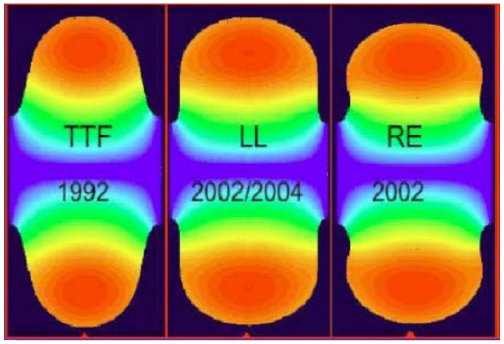
To achieve E_{acc} >50 MV/m, an innovative idea will be necessary since Nb is fundamentally limited by its RF critical magnetic field of ~200 mT at 0 K

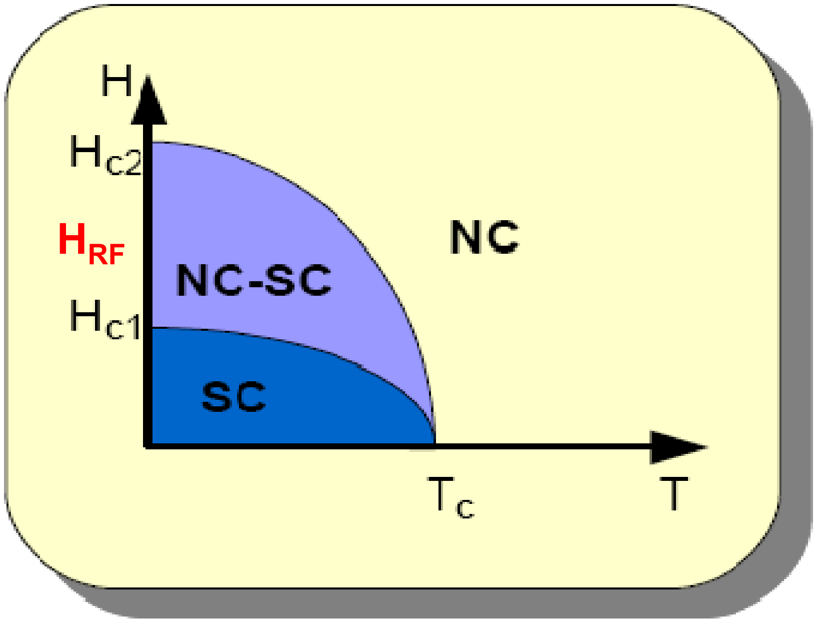
- **Some ideas include:**
  - Improving the cell design to decrease H_{peak} relative to $E_{acc.}$
    - This can improve the E_{acc} by ~10 %, but the shape might not be appropriate for a good cavity cleaning and it is mechanically weaker than the standard shape



  - Changing the RF feeding mode from SW to TW??
  - Coating some thin layers of another superconductor that has higher T_c than Nb (suggested by Alex Gurevich in 2005)
    - This could increase achievable E_{acc} significantly.

The key idea of using a thin film superconductor is the fact that B_{c1} increases when the thickness is $d < \lambda_L$ (penetration depth)

- **The RF critical magnetic field H_{RF} in a type-II superconductor is somewhere between H_{c1} and H_{c2}**

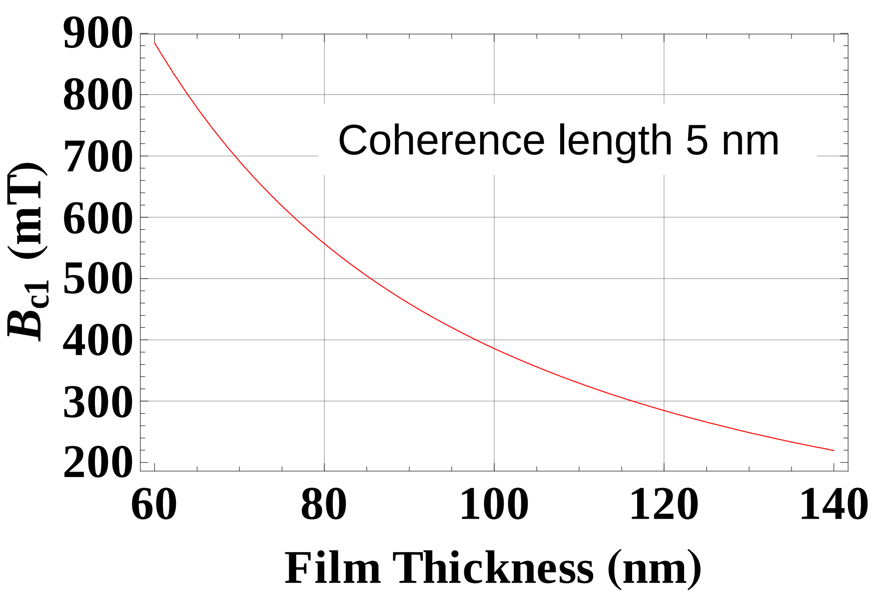


- **Use thin films with thickness $d < \lambda_L$ to enhance the lower critical field**

$$B_{c1} = \frac{2\phi_0}{\pi d^2} \ln \frac{d}{\tilde{\xi}}, \quad d < \lambda$$

[Gurevich, APL 88 (2006) 012511]

Calculated H_{c1} as a function of film thickness



An example: Coating 105 nm MgB_2 layer could sustain 355 mT, corresponding to ~100 MV/m with B_{peak} /E_{acc} ~ 3.6 mT/(MV/m)

Simple single layer example

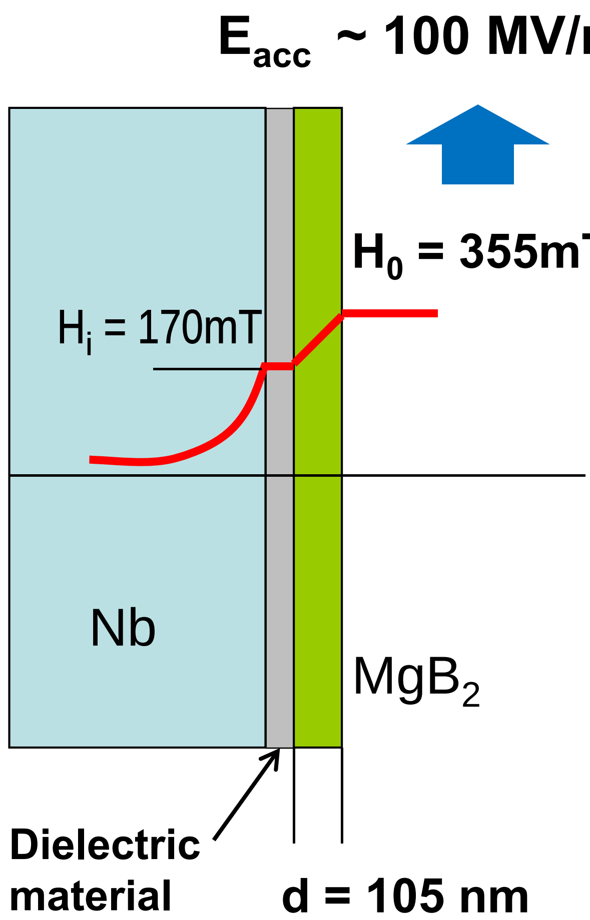
- **Assumptions**

H_{c1}(Nb) = 0.17 T

λ(MgB_2) = 140 nm

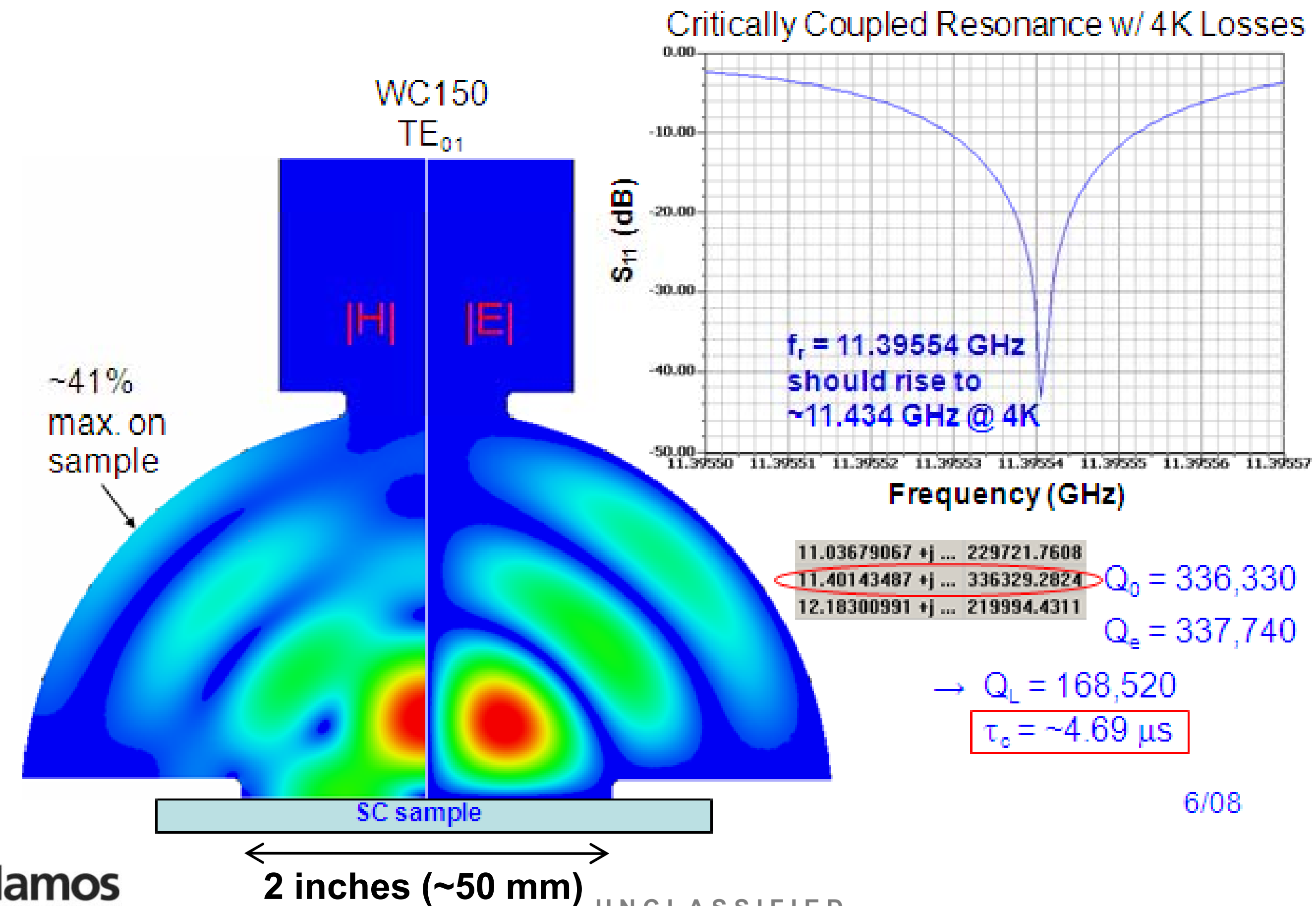
ξ(MgB_2) = 5 nm

- H_{c1}(MgB_2) = 355 mT
- d = 105 nm
- **The film thickness needs to be determined so that the decayed field at the Nb surface is below the RF critical field of Nb (~200 mT).**



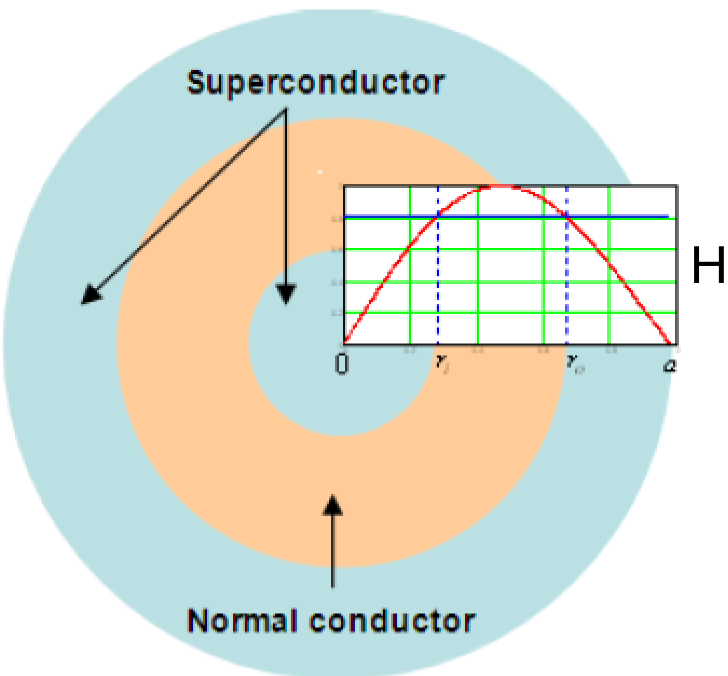
2” disk experiments have been carried out at SLAC using a 11.4 GHz 50 MW Klystron to generate short pulses (≤ 2 μs) and a TE_{013}-mode copper hemispheircal host cavity

New Superconducting Sample Test Cavity



The RF breakdown (quench) normally starts on the ring at half radius where the peak surface field exists

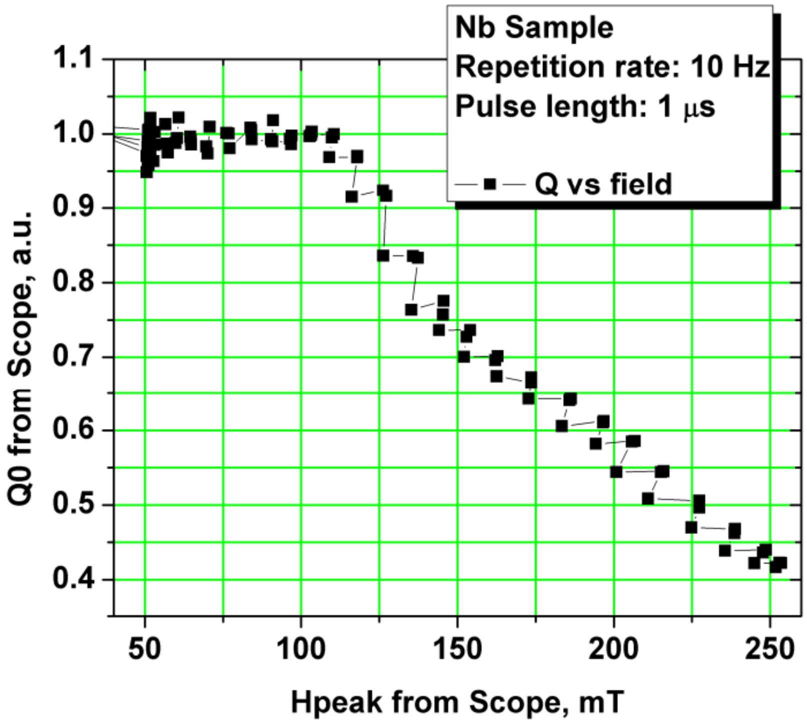
Typical distribution of superconducting and normal-conducting regions after quench

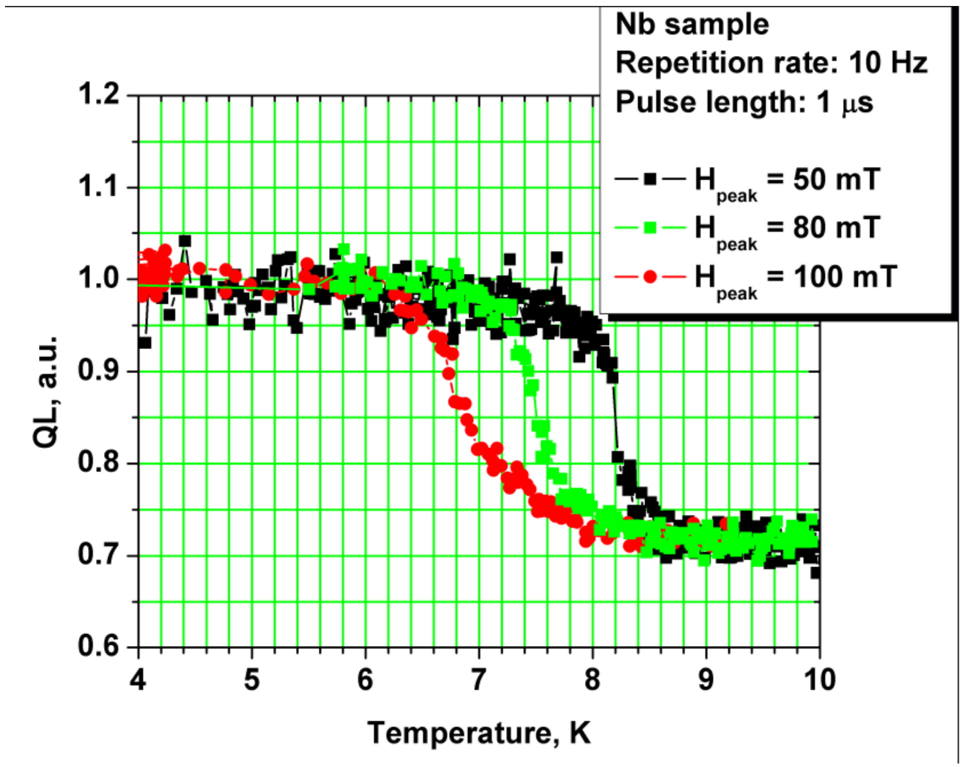


$$\text{Cavity } Q \propto 1/R_{\text{surface}}$$

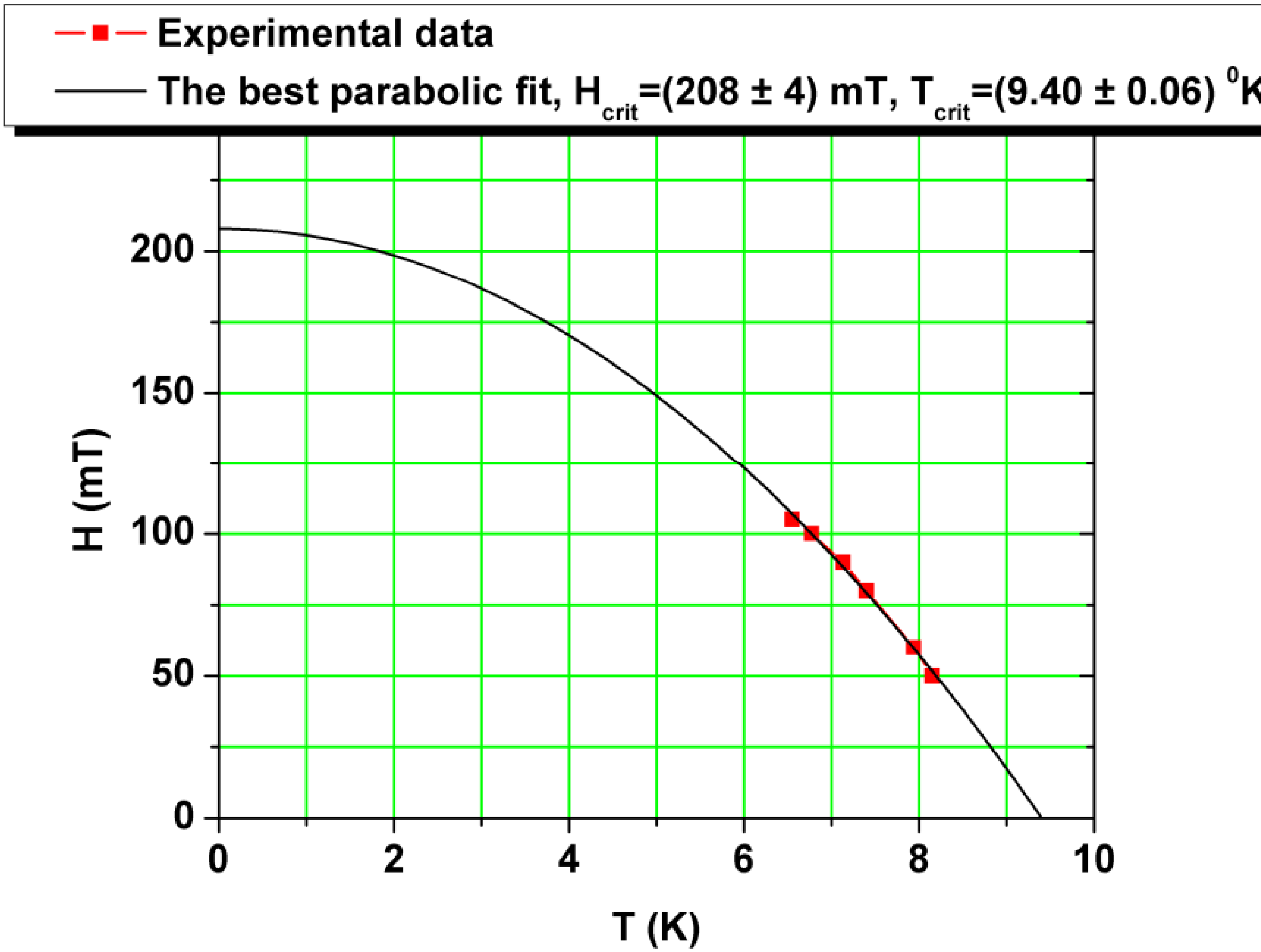
- The cavity Q starts to decrease when part of sample quenches
- The Q includes the info on the surface resistance

First test results of a Nb sample as a reference





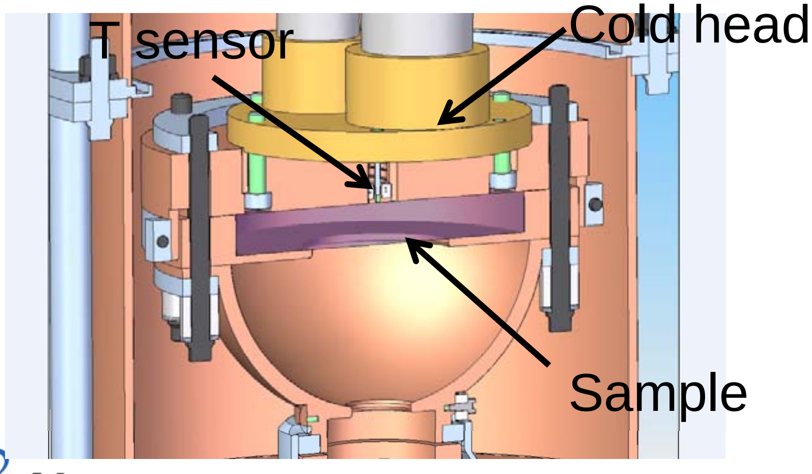
Tests on the reference Nb sample showed reasonable results



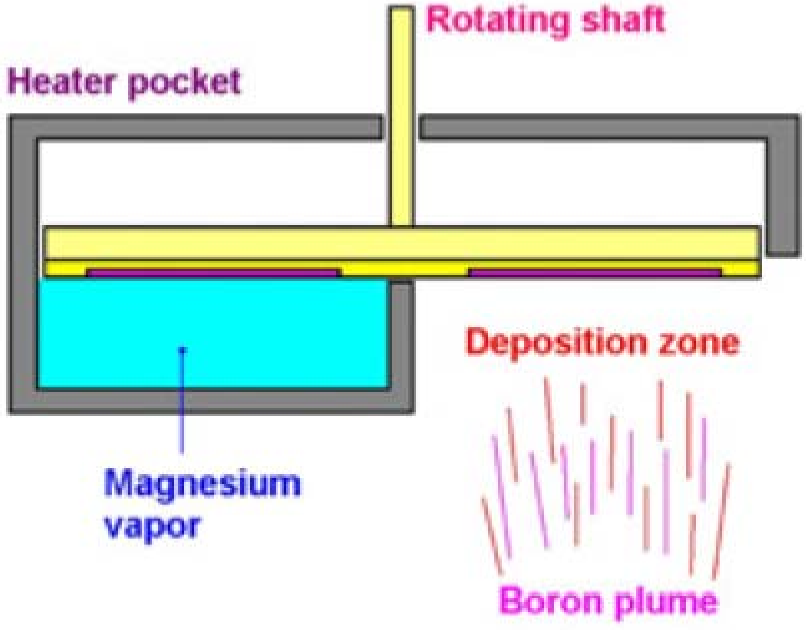
A 100 nm MgB_2 film was coated on a 2-inch diameter single crystal Nb disk substrate using reactive co-evaporation method at STI and measured at SLAC

- **~1 mm thick Nb substrates were chemically polished 150 μm**
- **The substrate and MgB_2 surface roughnesses of 100 x 100 μm^2 areas were measured to be 48-64 nm and 12-18 nm, respectively.**

Sample setup at SLAC



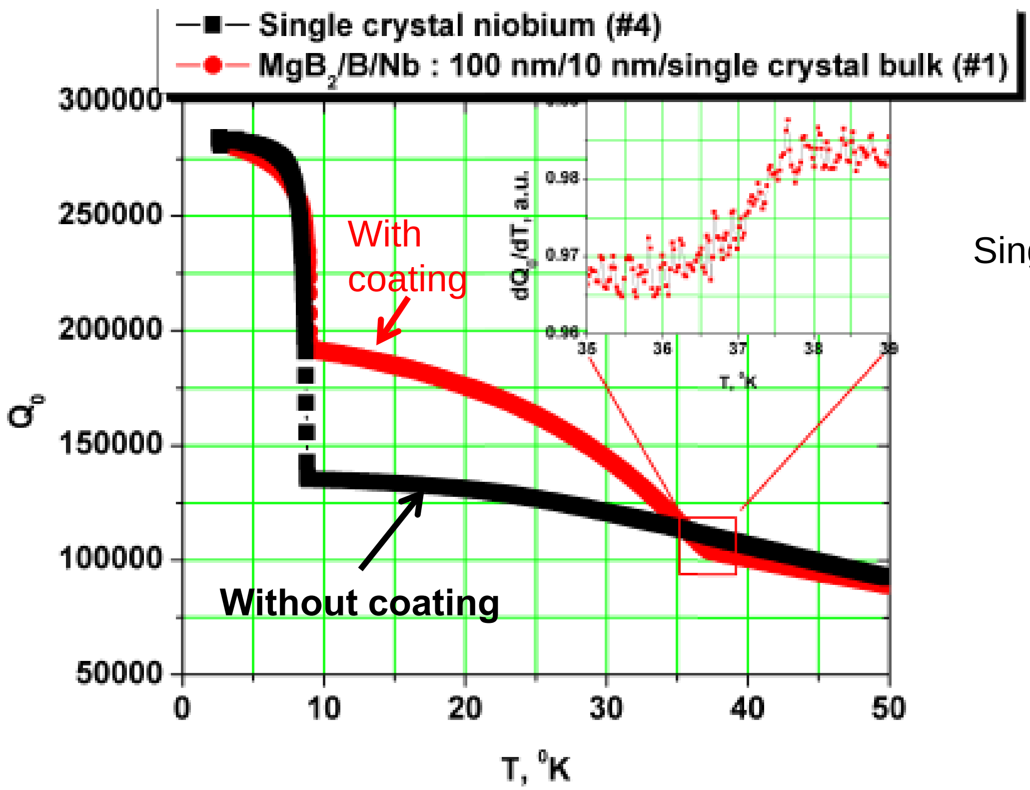
Reactive co-evaporation of MgB_2 at STI



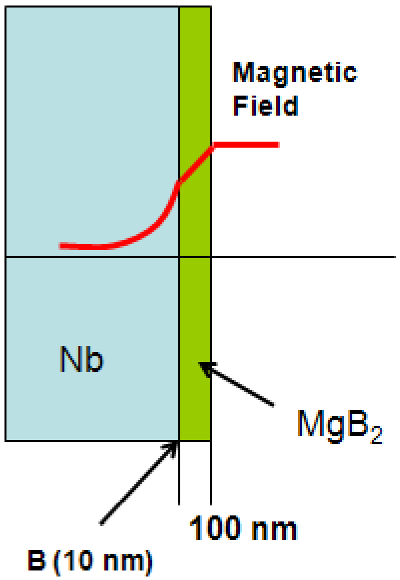
B.H. Moeckly and W.S. Ruby, Supercond. Sci. Technol. 19 (2006) L21–L24

A 100 nm MgB_2 film was coated on a 2-inch diameter single crystal Nb sample with 10 nm B as an insulator

Low-power test result

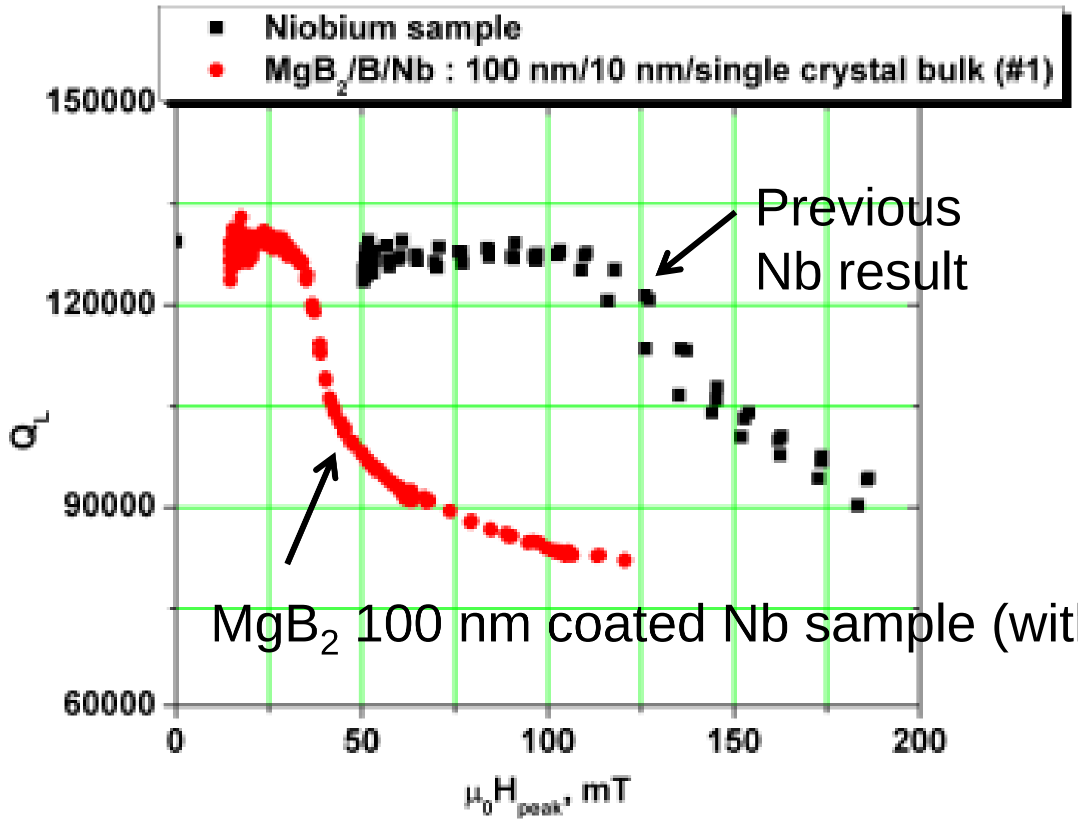


Single-crystal Nb substrate after 150 µm BCP



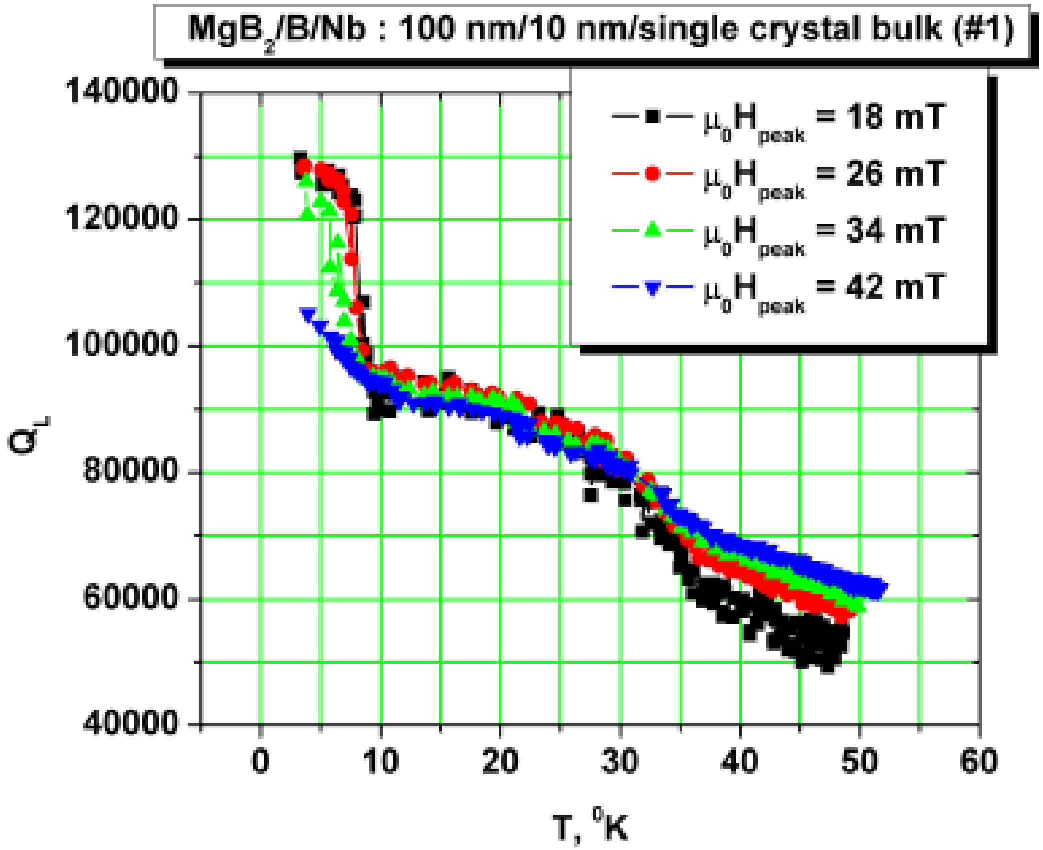
First high-power test results showed a quench at ~30 mT, very low compared to the reference Nb result

High-power test result



- MgB_2 coating was done at Superconductor Technologies, Inc. (STI)
- The measured transition temperatures for MgB_2 and Nb were 37 K and 9 K, respectively.

The Q vs. T data at various magnetic fields showed that the quench at ~30 mT occurred on Nb, not on MgB_2

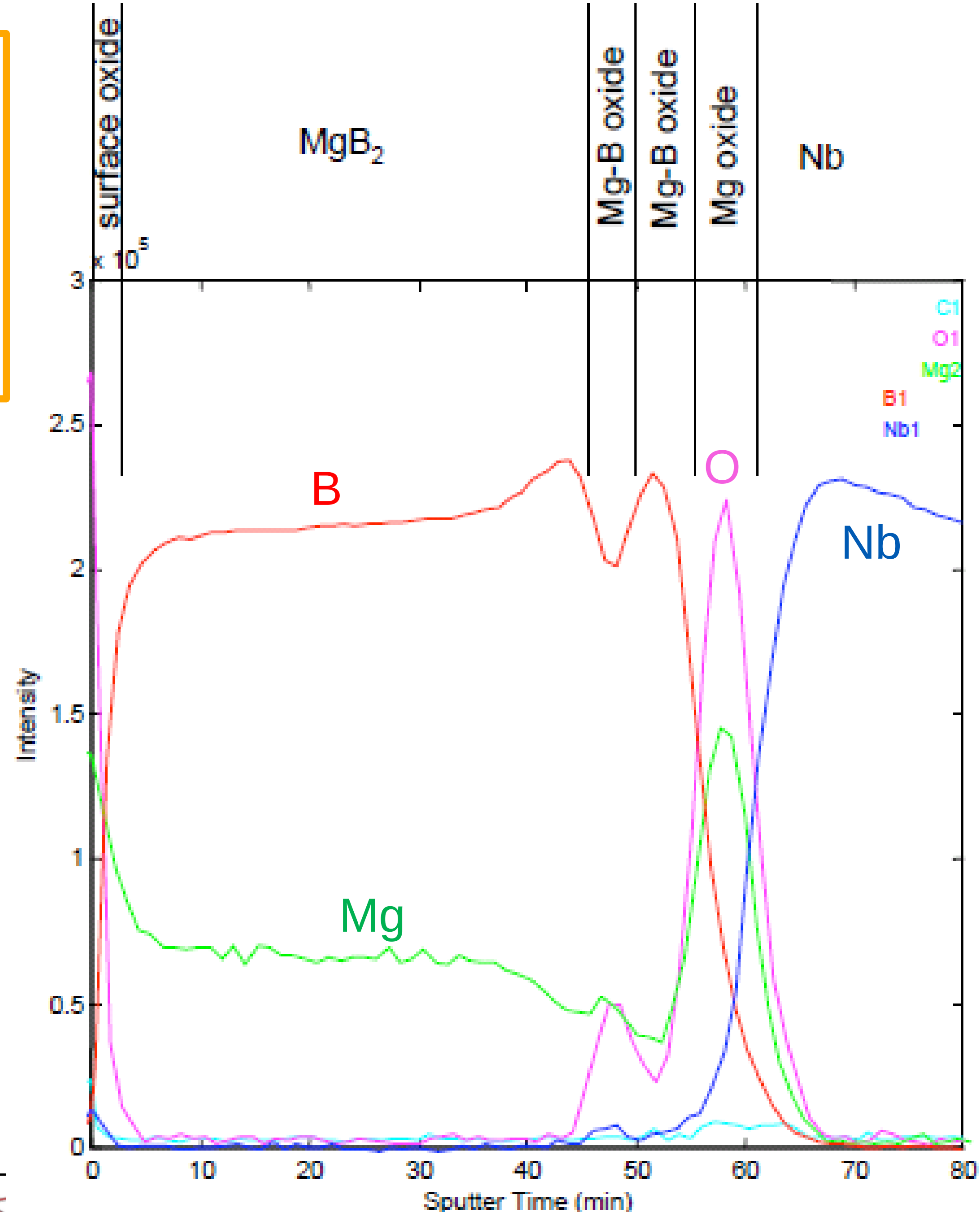


- We observed a similar quench at low field (~30 mT) in a recent test with 1000 nm MgB_2 coated sample
- The reason for this quench at low field needs to be investigated

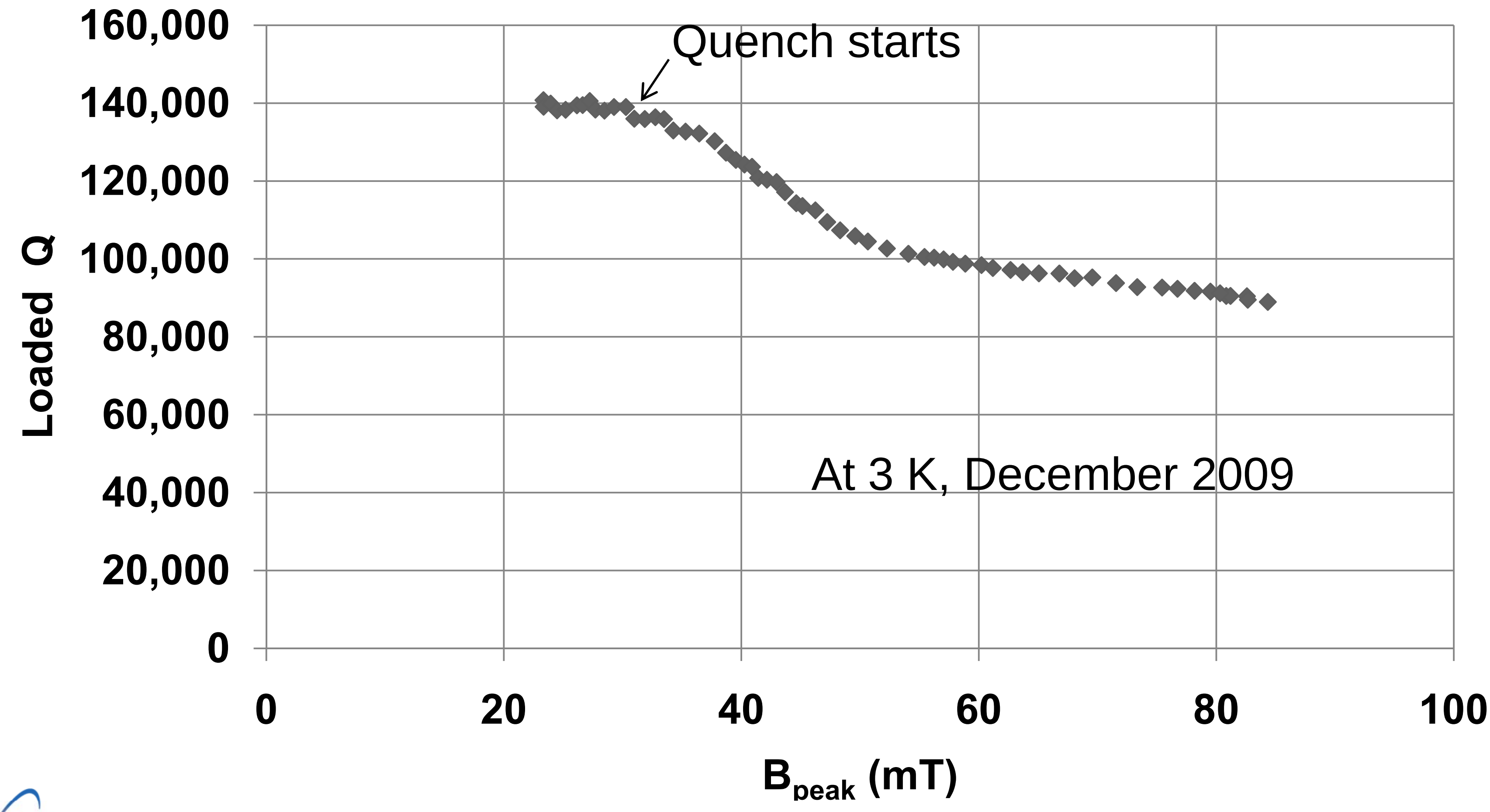
We found an increased amount of Oxygen at the interface between Nb and B layer

Auger sputter depth profile using 4 kev Ar ion

Sputter rate: ~2 nm/min



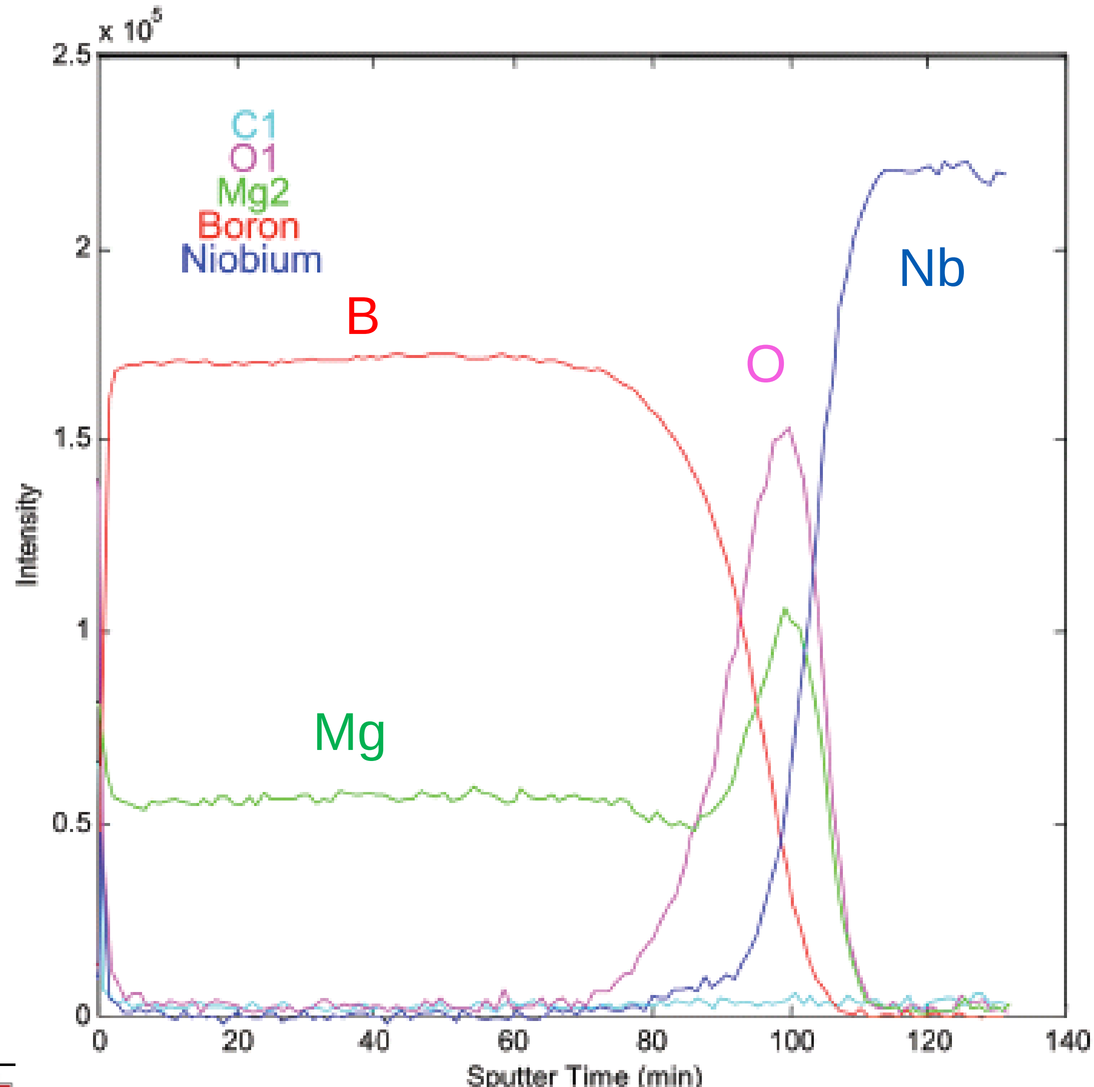
Then, we tried 1 μm MgB_2 directly on Nb to characterize the critical field of MgB_2 alone, but the field penetrated to Nb and the system started to quench at ~30 mT



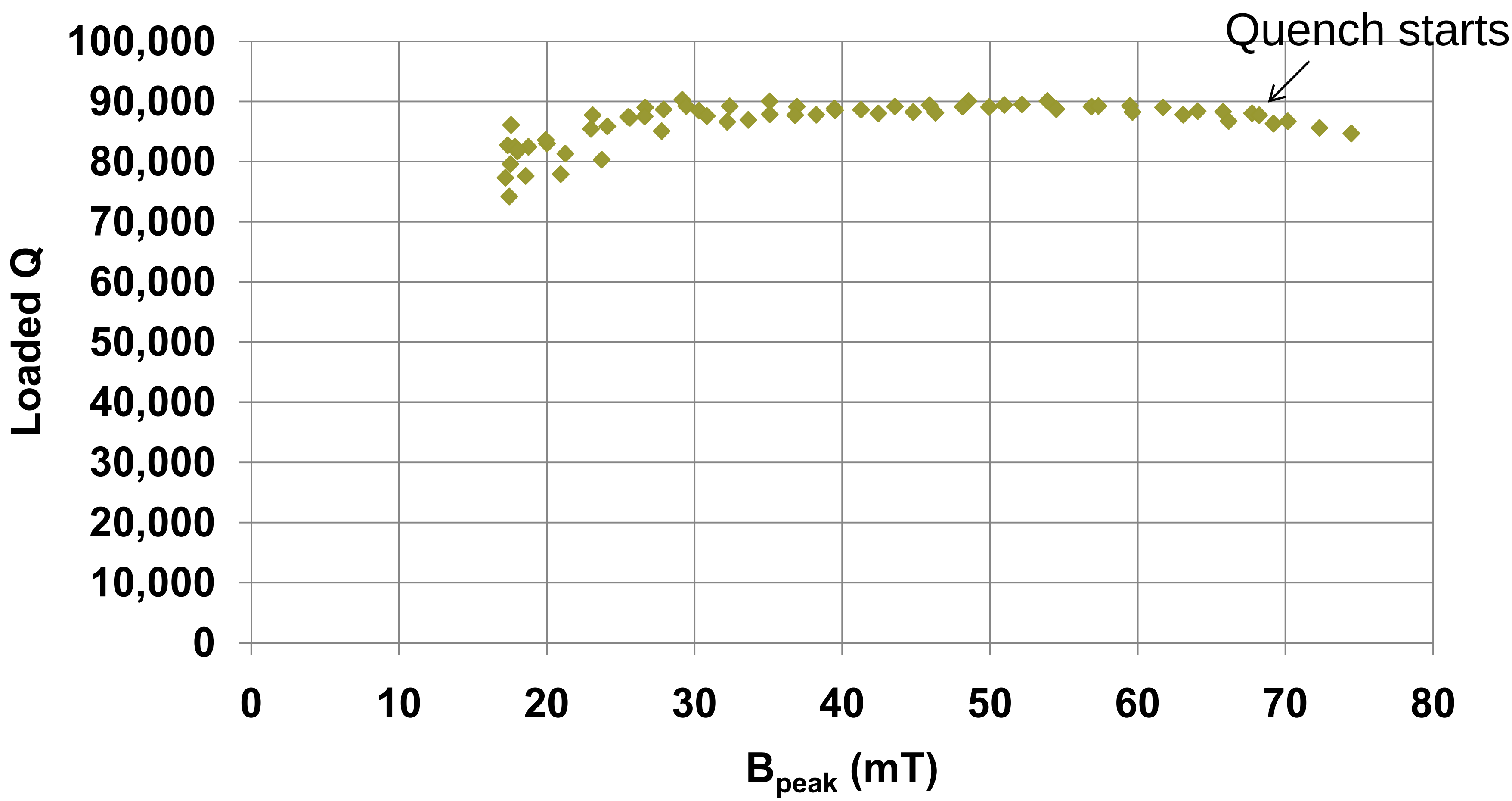
Auger sputter depth profile again showed a large O peak at the interface between MgB_2 and Nb

Auger sputter depth profile using 4 kev Ar ion

Sputter rate: ~8 nm/min

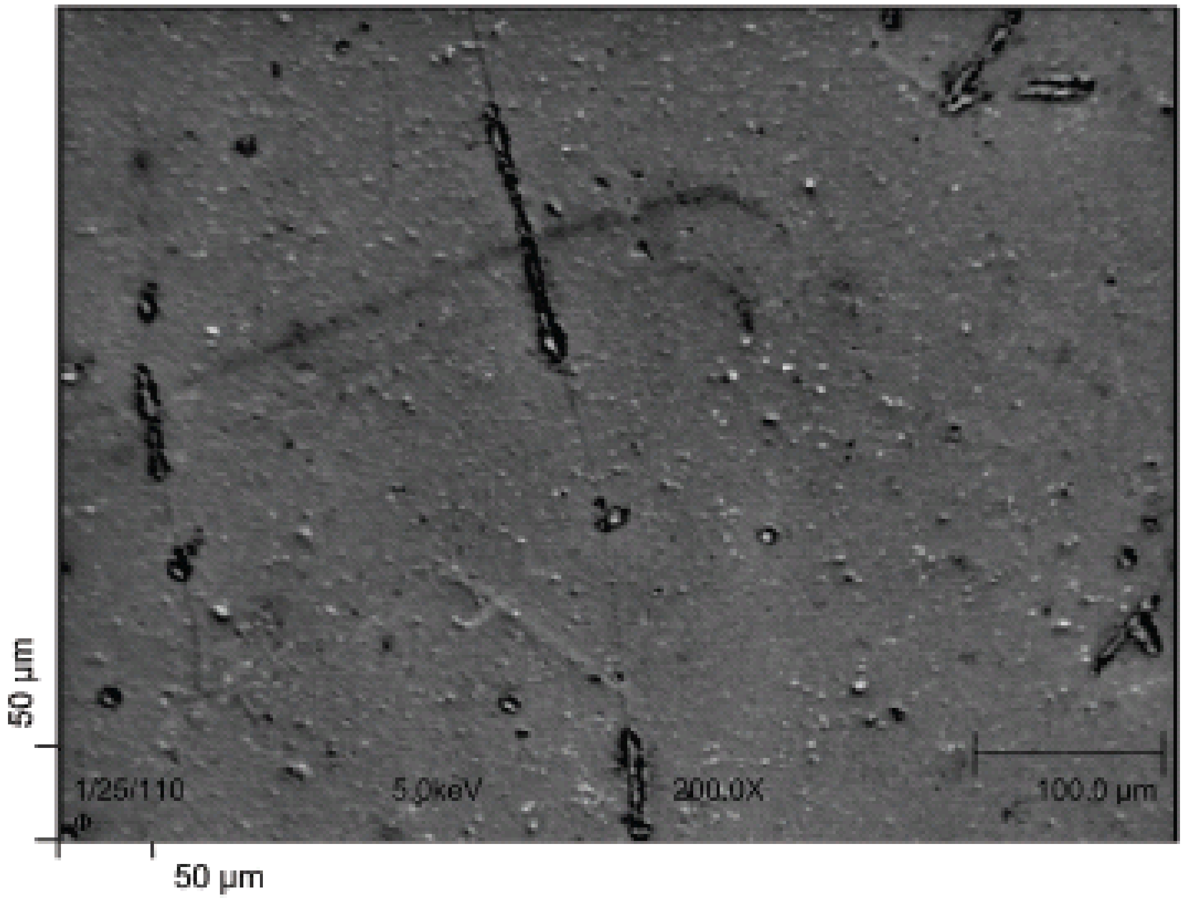


Nevertheless, we were able to measure the critical field of MgB_2 (~68 mT) at ~15 K at which Nb is normal conducting.



A lot of damages (cracks) were observed after SLAC testing of both 100 nm and 1 µm MgB_2 coated samples

SEM



Summary

- RF critical magnetic field measurements of Nb/(insulator)/MgB_2 systems have been carried out in collaboration with SLAC using 11.4 GHz 1-2 μs pulses with a TE_{013} mode copper host cavity
- A low-field quench at ~30 mT as well as surface damages (cracks) have been observed.
- We are tying to identify the causes of these problems, the increase of oxygen level at the interface might be the cause
- Additionally, a 1 μm MgB_2 film coated on Nb was measured to show ~68 mT of peak field at 15 K

Some hot result from the ongoing test on 200 nm MgB_2 /200 nm B/Nb system on a thicker sample (1.2 mm vs. 0.6 mm)

- **Little transition for Nb was shown, indicating little penetration to Nb, i.e., less damage on the surface.**
- **High power testing ongoing now.**