High Power Testing of HTS Samples

Ankur Dhar

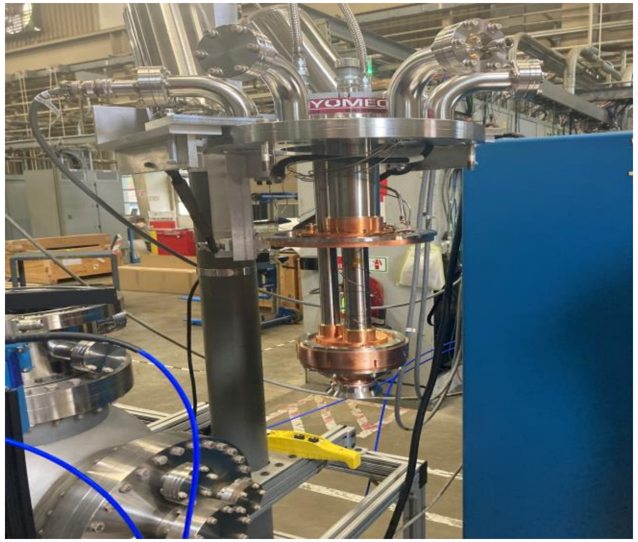
07/09/2024

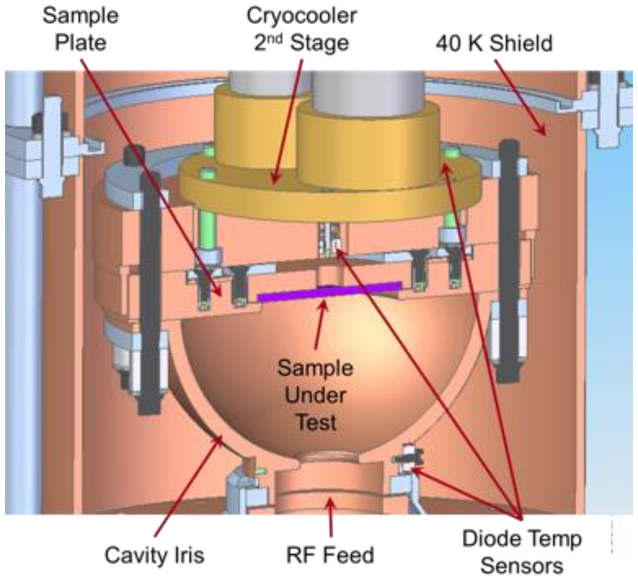
Motivation

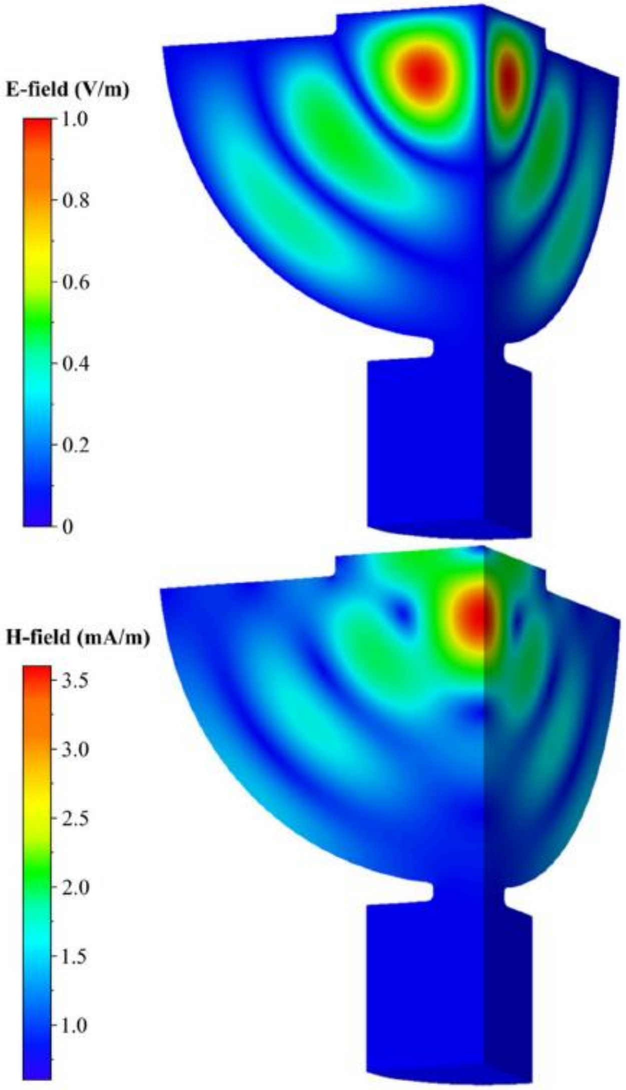
SLAC maintains a cryogenic test stand designed to measure the low and high-power characteristics of SRF materials at 11.424 GHz

A TE11 mode hemispherical cavity with minimal E field and maximum H field on the surface can help determine the quench field for up to 1 MW of power

Recently in collaboration with CERN we have utilized this test stand for studying high temperature superconductors (HTS)

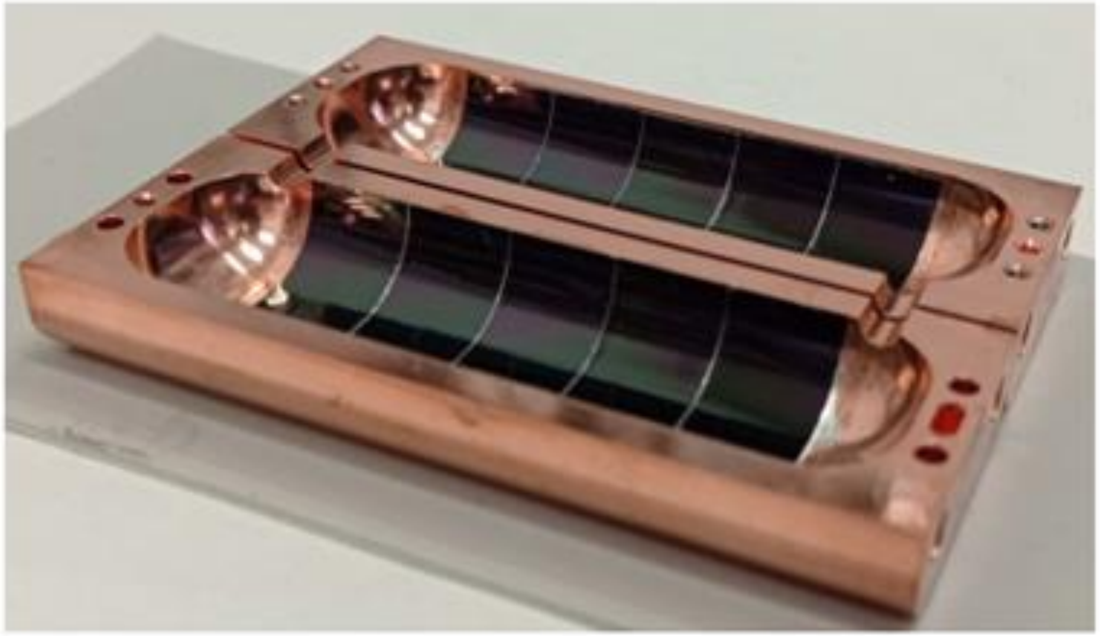


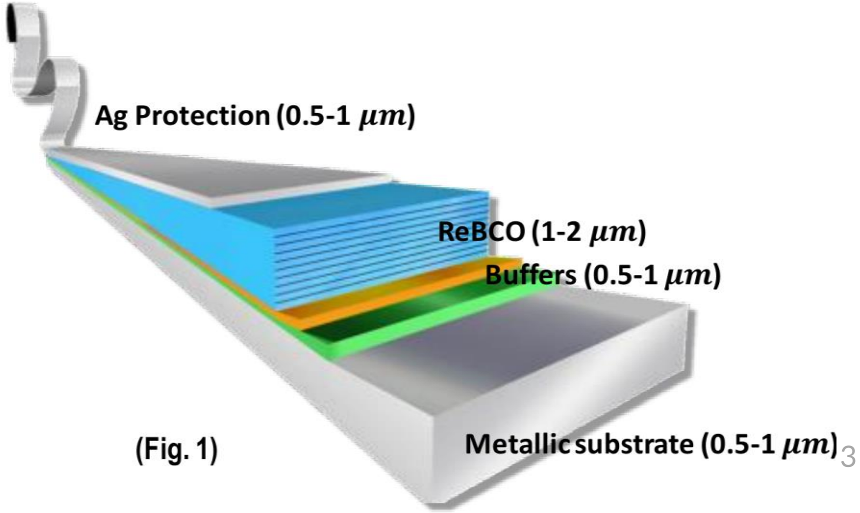




RF with High Temperature Superconductors

- Primarily used for low power high Q applications like axion cavities
- The main material of choice is Yttrium Barium Copper Oxide (YBCO) though other Rare Earths (REBCO) may be used to similar effect
- The most mature form of this technology are tapes optimized for high conductivity along one axis, though experiments are ongoing with film deposition





(Fig. 1)

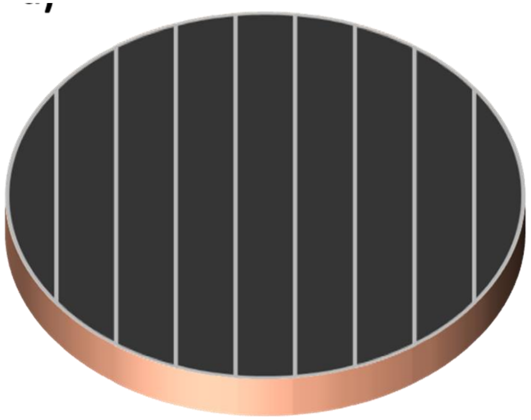
J. Golm et al., Front. Phys. 12:1372846. doi: 10.3389/fphy.2024.1372846

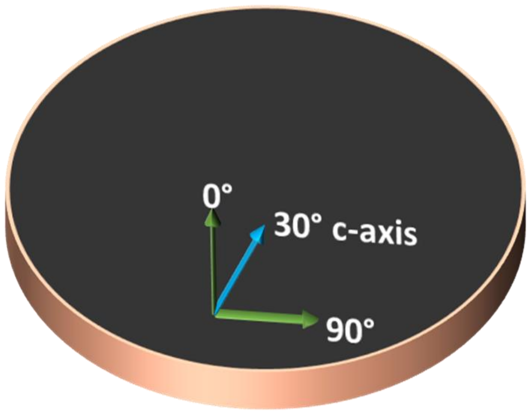
Characterizing HTS samples

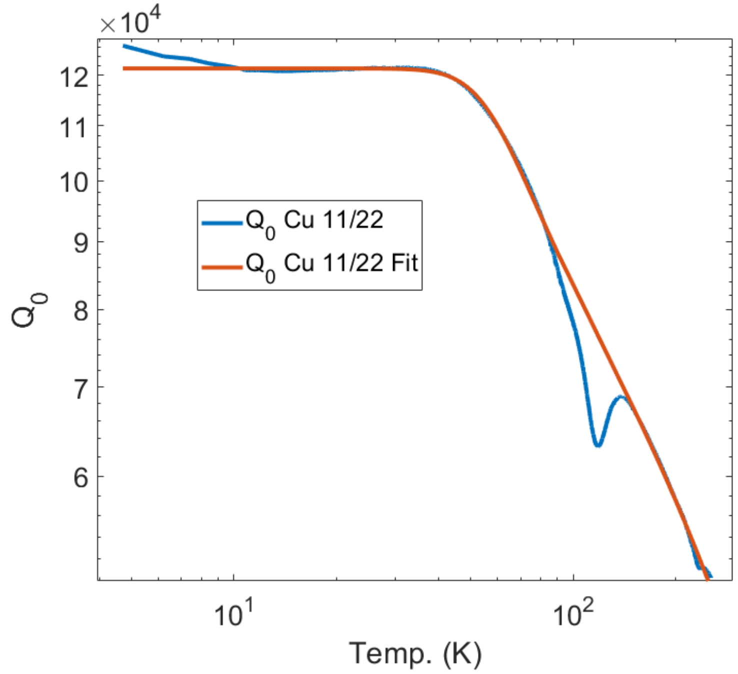
Low power measurements involve measuring reflected power with a VNA, directly measuring quality factor

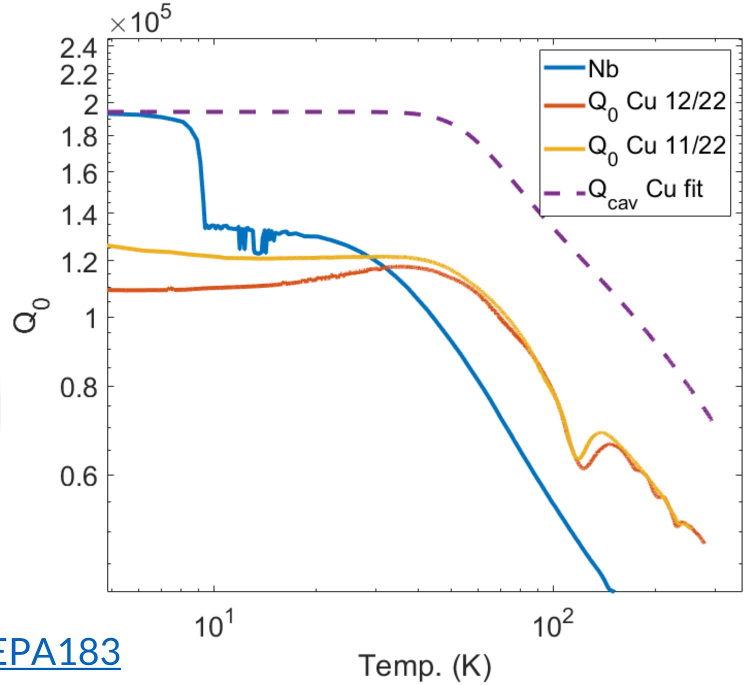
Several calibration runs with copper and niobium allows for the quality factor of the cavity to be determined

Thus the quality factor of both tapes and deposited YBCO samples is determined









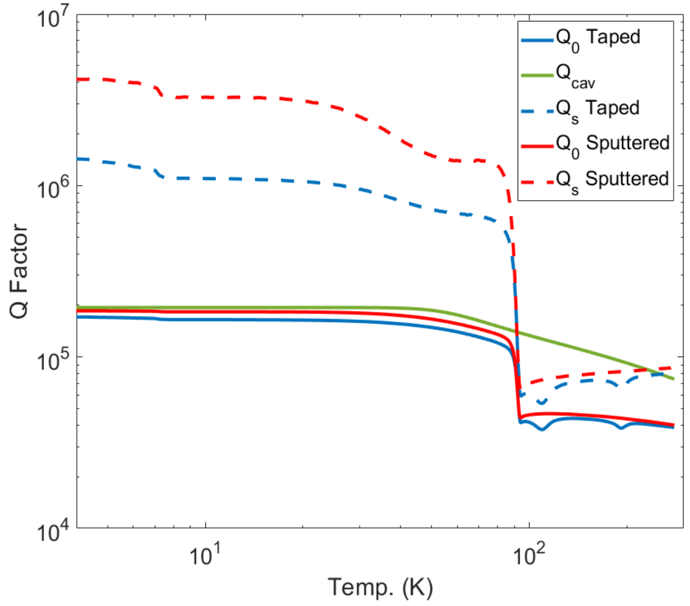
M. Schneider et al., Proc. IPAC'23. doi:10.18429/JACoW-IPAC2023-WEPA183

Determining Conductivity

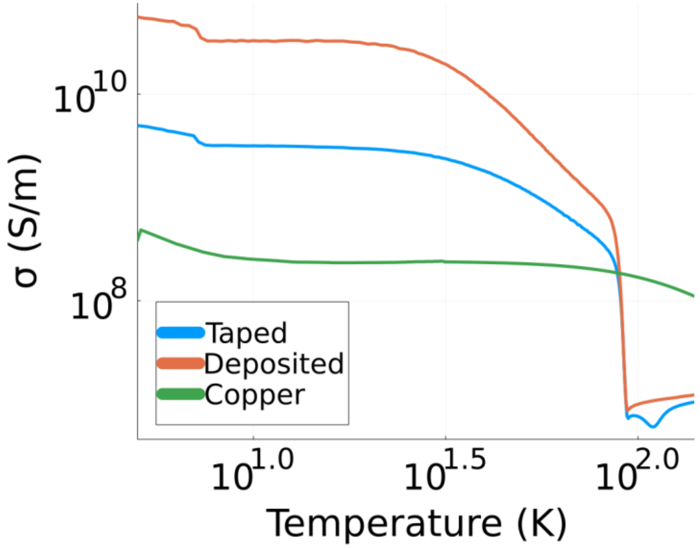
HFSS simulations determined the relation between sample quality and conductivity

Both YBCO tape and film samples showed an increase in conductivity compared to copper

Overall tapes had slightly lower conductivity, possible due to interface layers around YBCO



Sample @ 4K	Q0	Qe	β	Qs	Σ
Nb	194000	133000	1.45	$Q_{cavity} \approx Q_0$	
Cu	109000	158000	0.69	2.5e5	150 MS/m
YBCO Deposited	185000	130000	1.42	4.2e6	42 GS/m
YBCO Taped	171000	134000	1.28	1.4e6	4.7 GS/m



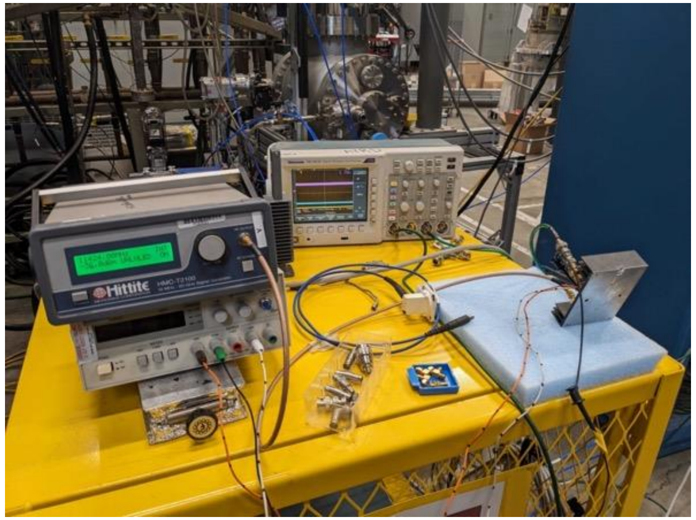
Moving to Higher Power

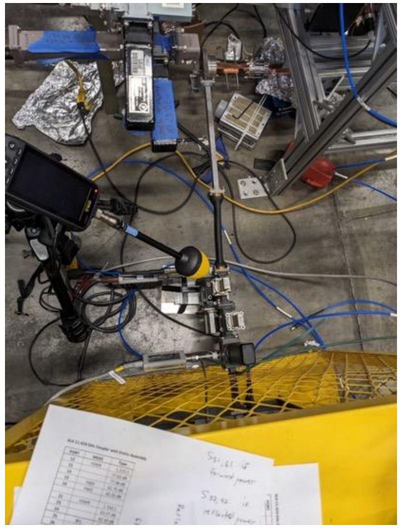
To operate the Traveling Wave Tube (TWT), RF power is sent in from a local oscillator with a RF switch at 8us

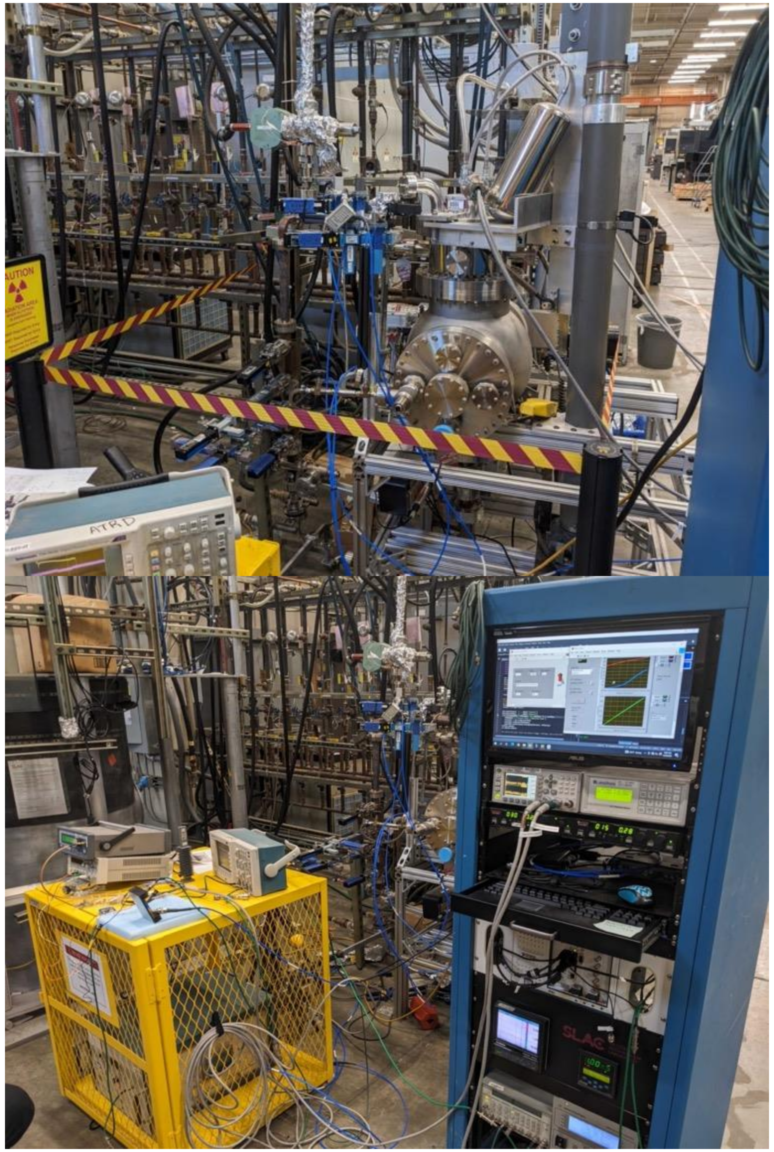
Modulated RF pulse is then amplified in the TWT to 1.6 kW

Forward and reflected power would be measured via directional coupler and power meters

- Temperature range measured was from 40K to 90K
- Power steps of 100W up to 1600W, 5 pulses per step





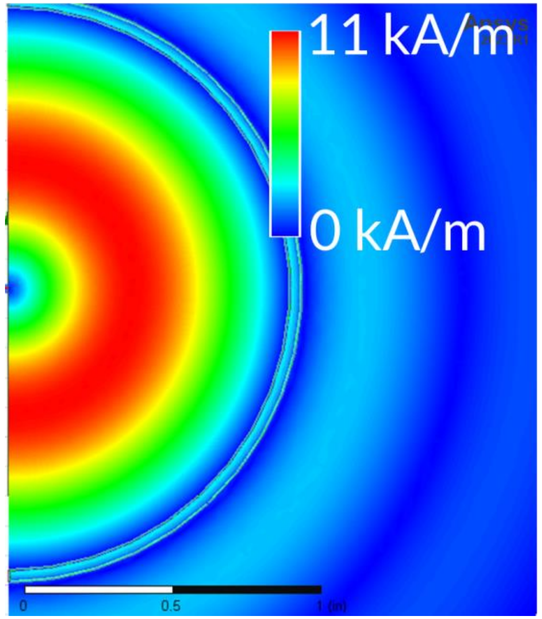


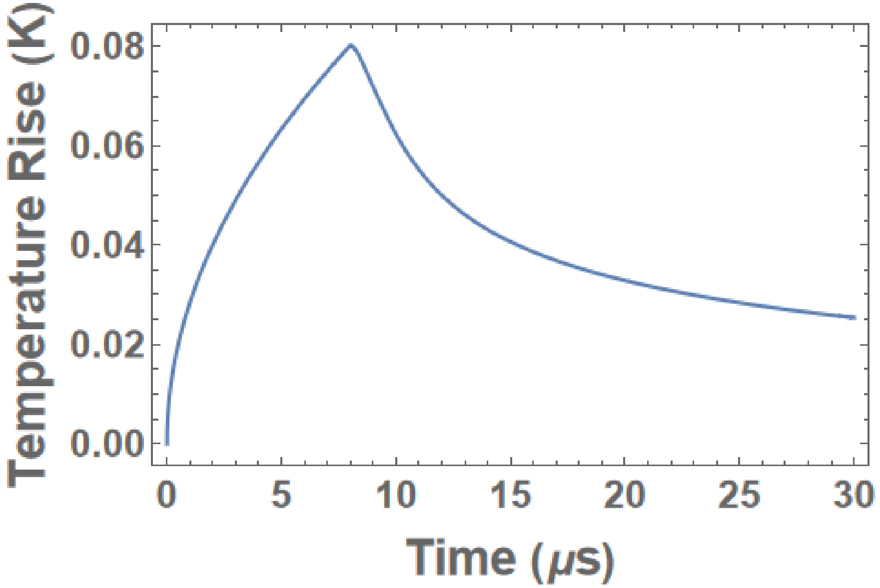
Expected Effects from TWT Pulses

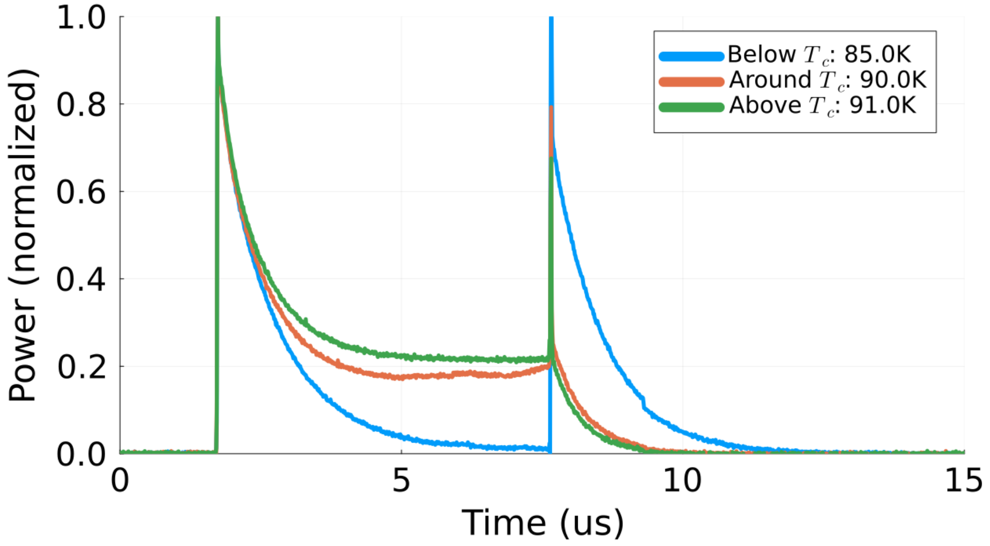
With 1.6 kW, we can expect to generate around 11 kA/m peak H field on the sample

This isn't enough to heat the sample above the critical temperature, but could cause a quench due to the critical current limit

Scanning reflected pulses very close to the critical temperature shows the onset of this quench, seen as a sharper exponential decay

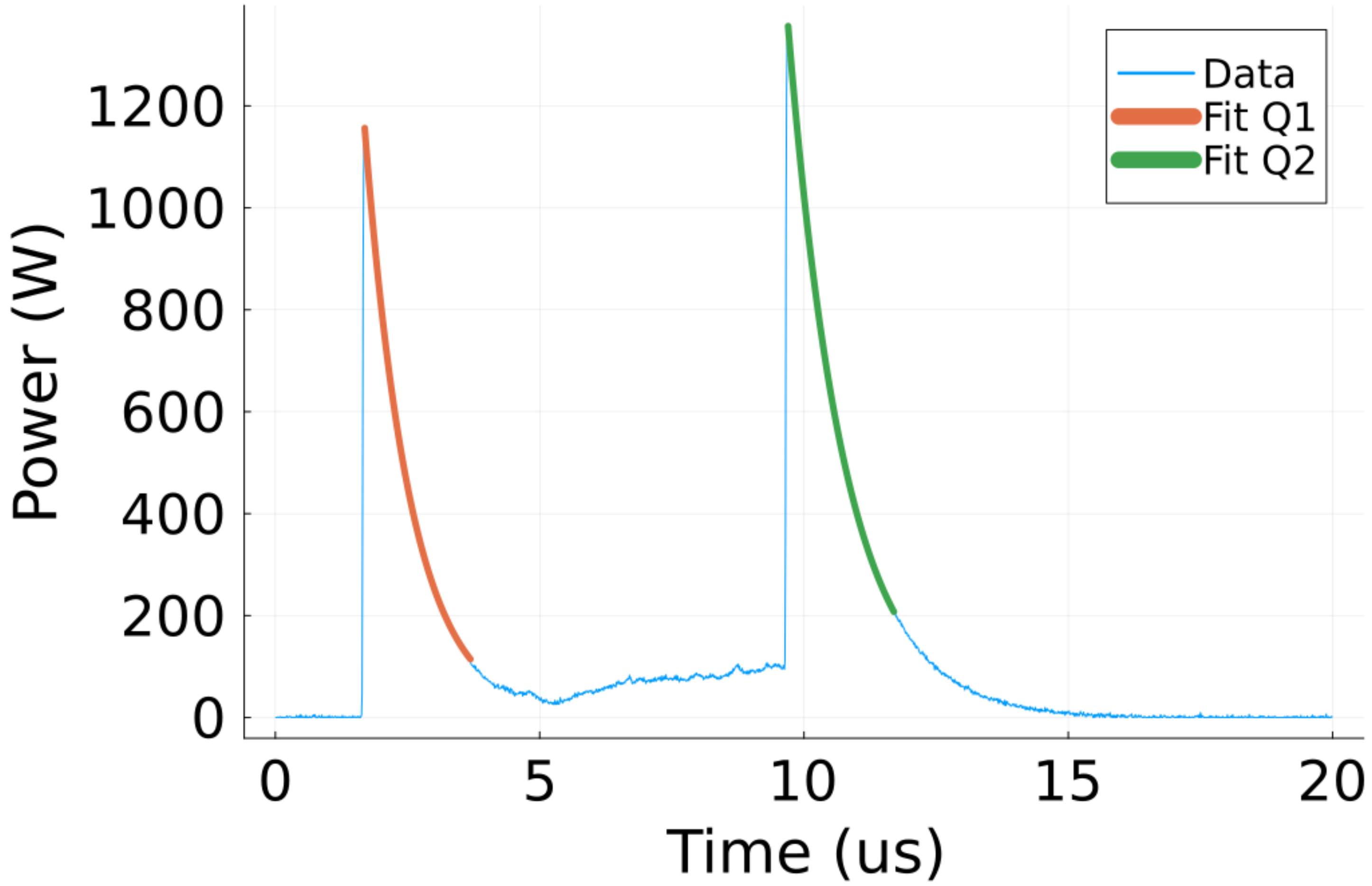






Fitting Quality Factor

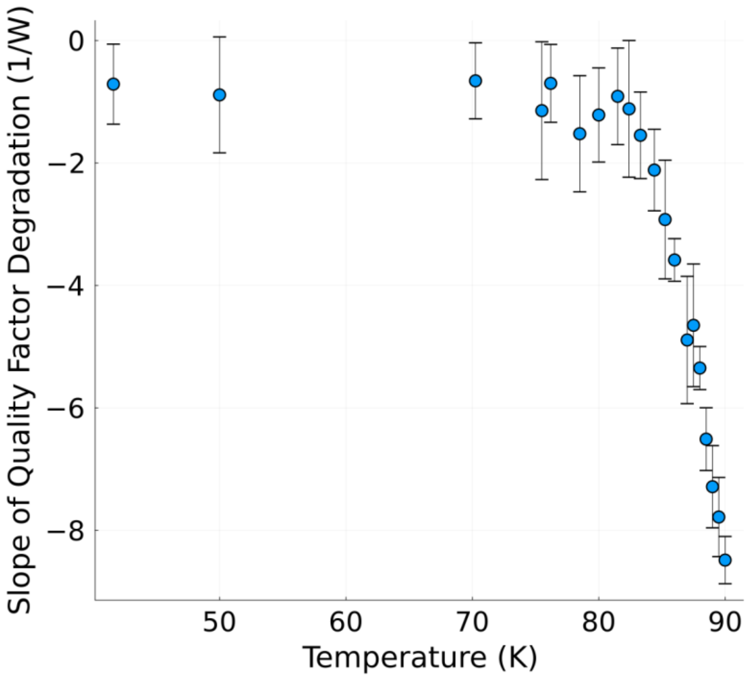
- Quality factor was fitted on both exponential tails of the reflected power, to see the difference before and after peak fields affect sample
- This would help distinguish between global heating effects and local effects

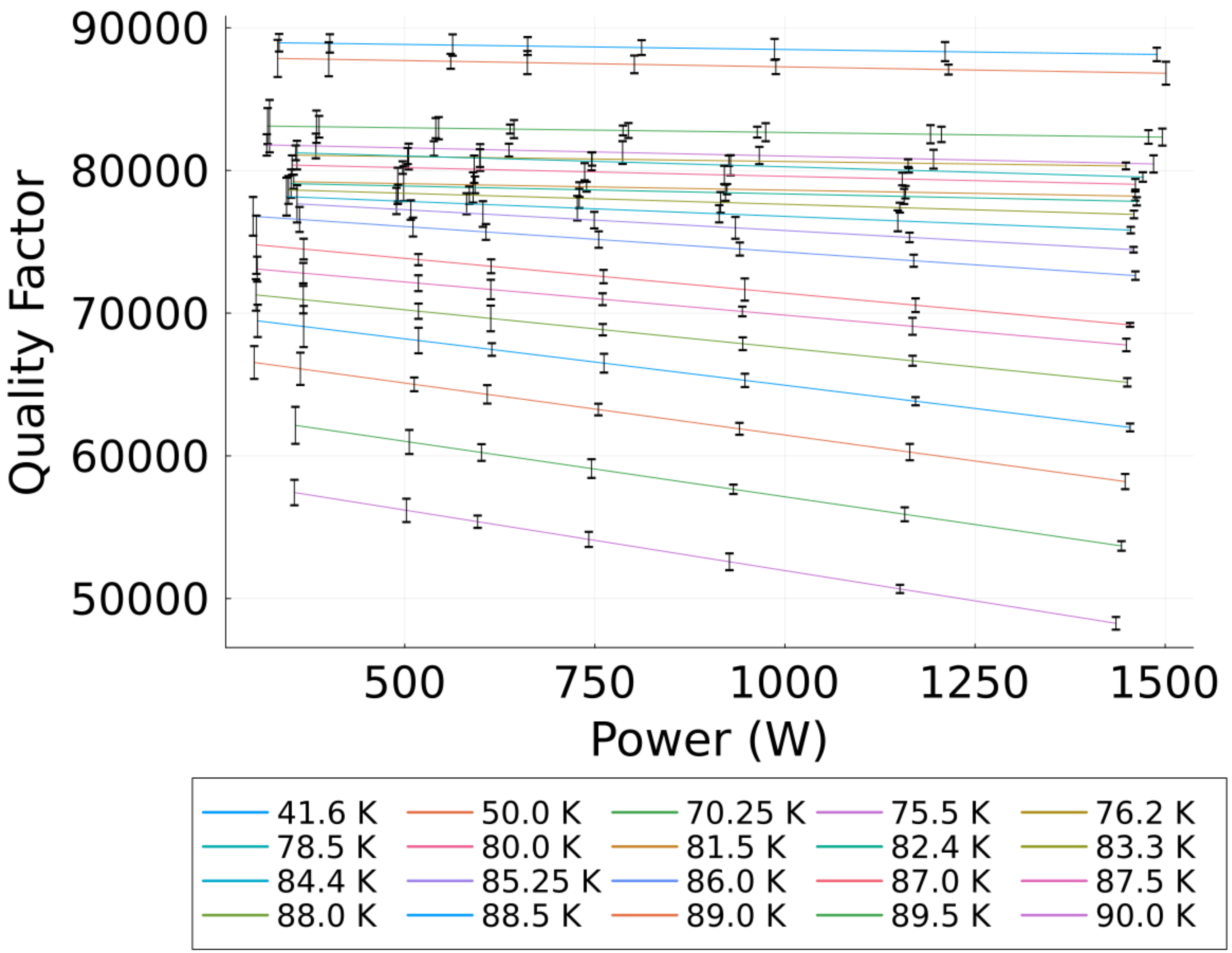


Quality Factor Parameter Space

Due to high variability in reflected power signals at low power, we ignored anything below 300W

As before, slope of quality factor degradation becomes more negative with temperature

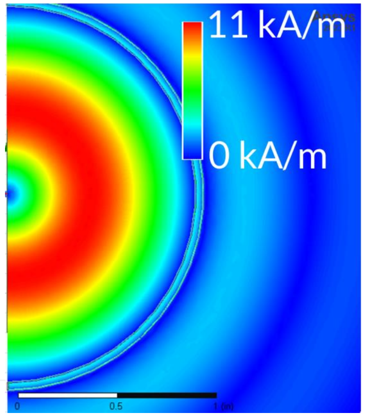


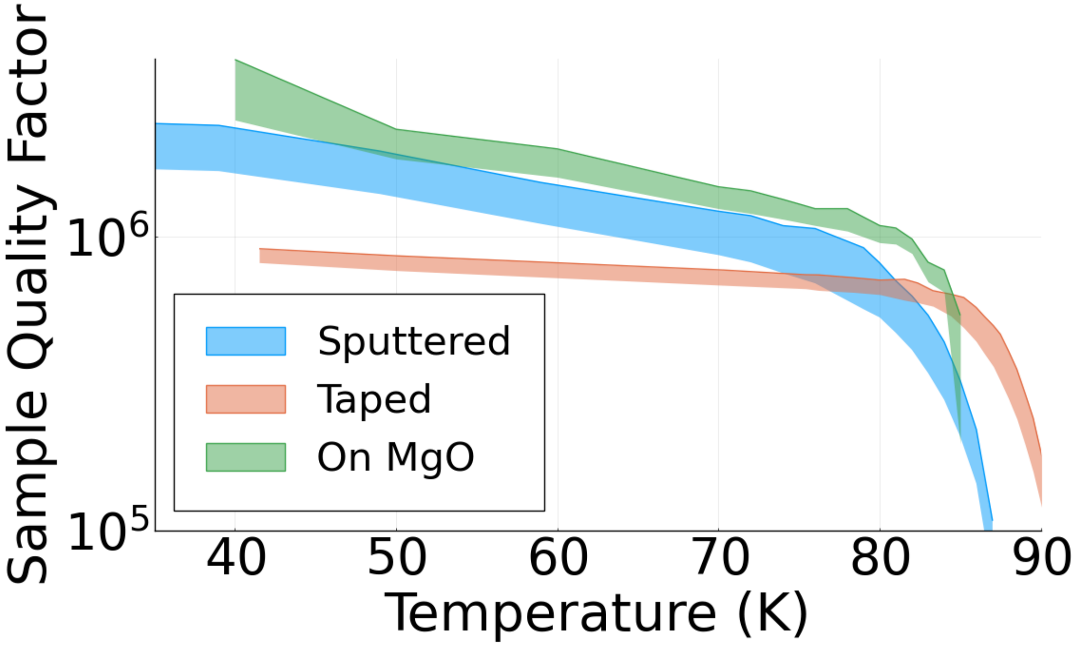


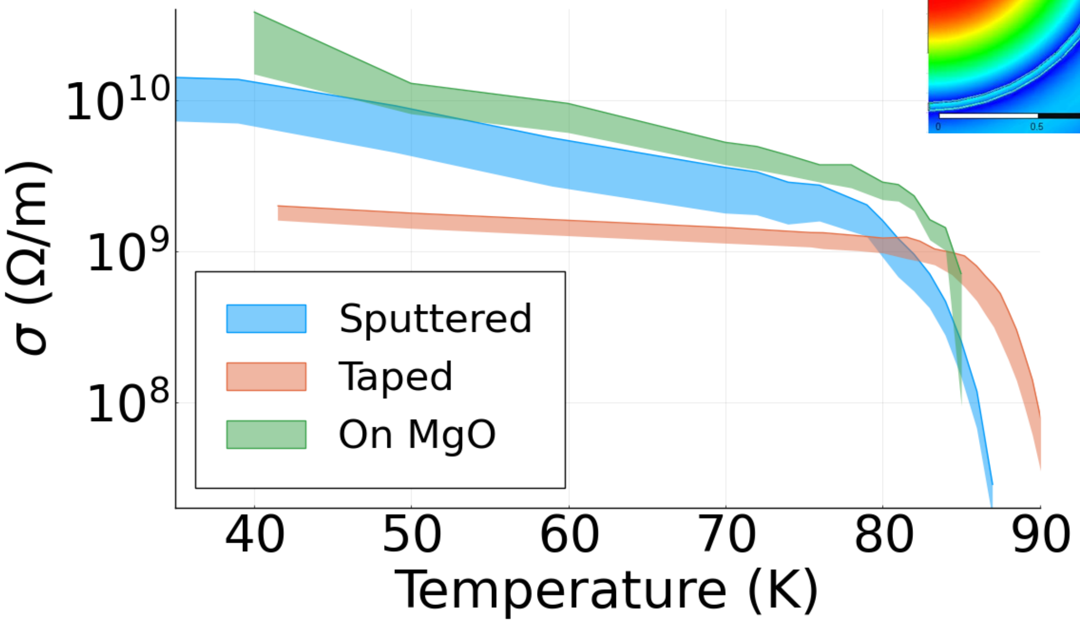
High Power RF Measurements of YBCO

Also tested YBCO deposited on MgO sample for comparison, which appeared to quench faster

Film samples appear to be more strongly impacted by forward power, possible due to anisotropic conductivity in the plane of the sample.

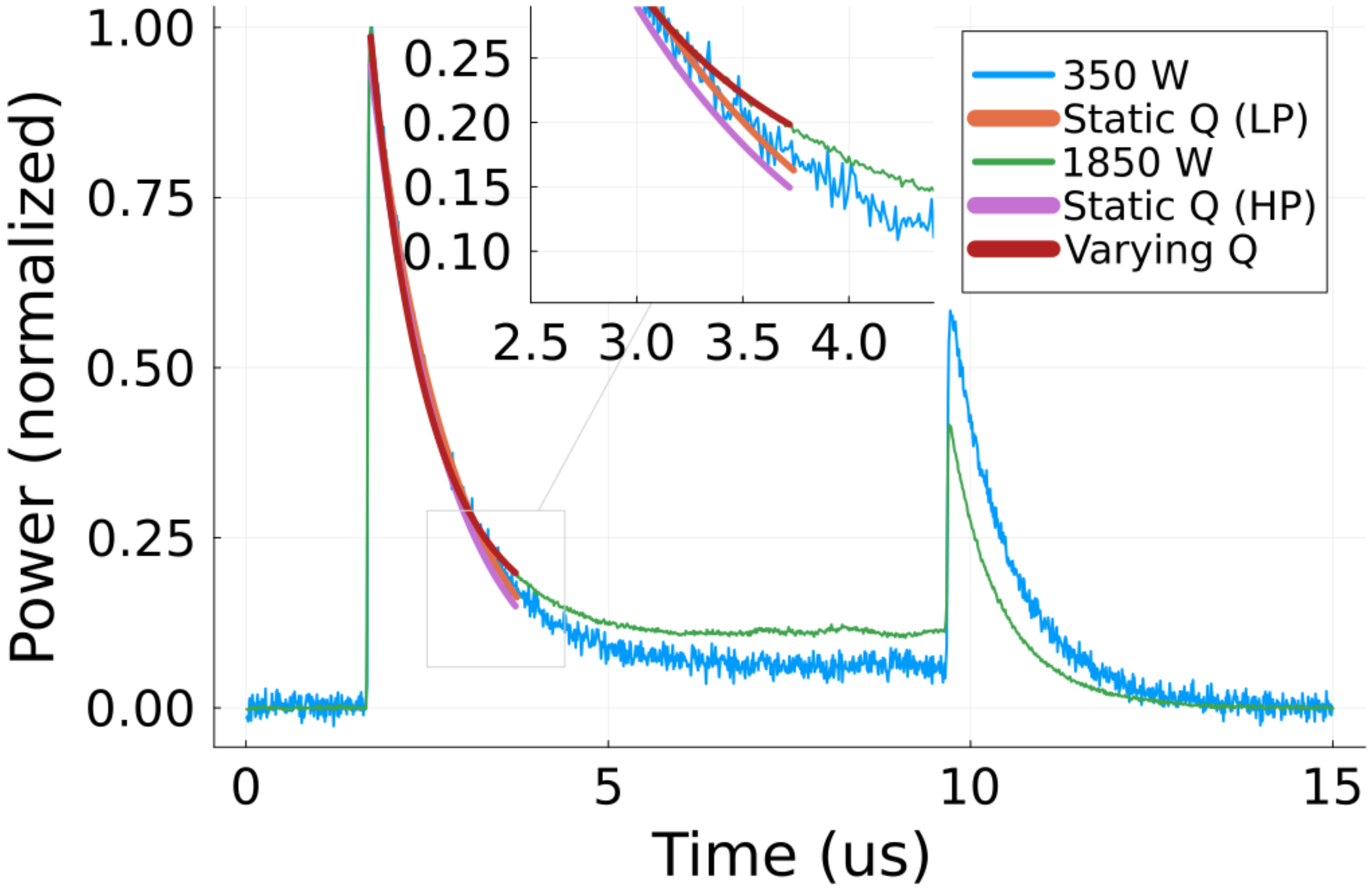






Onset of Quenching

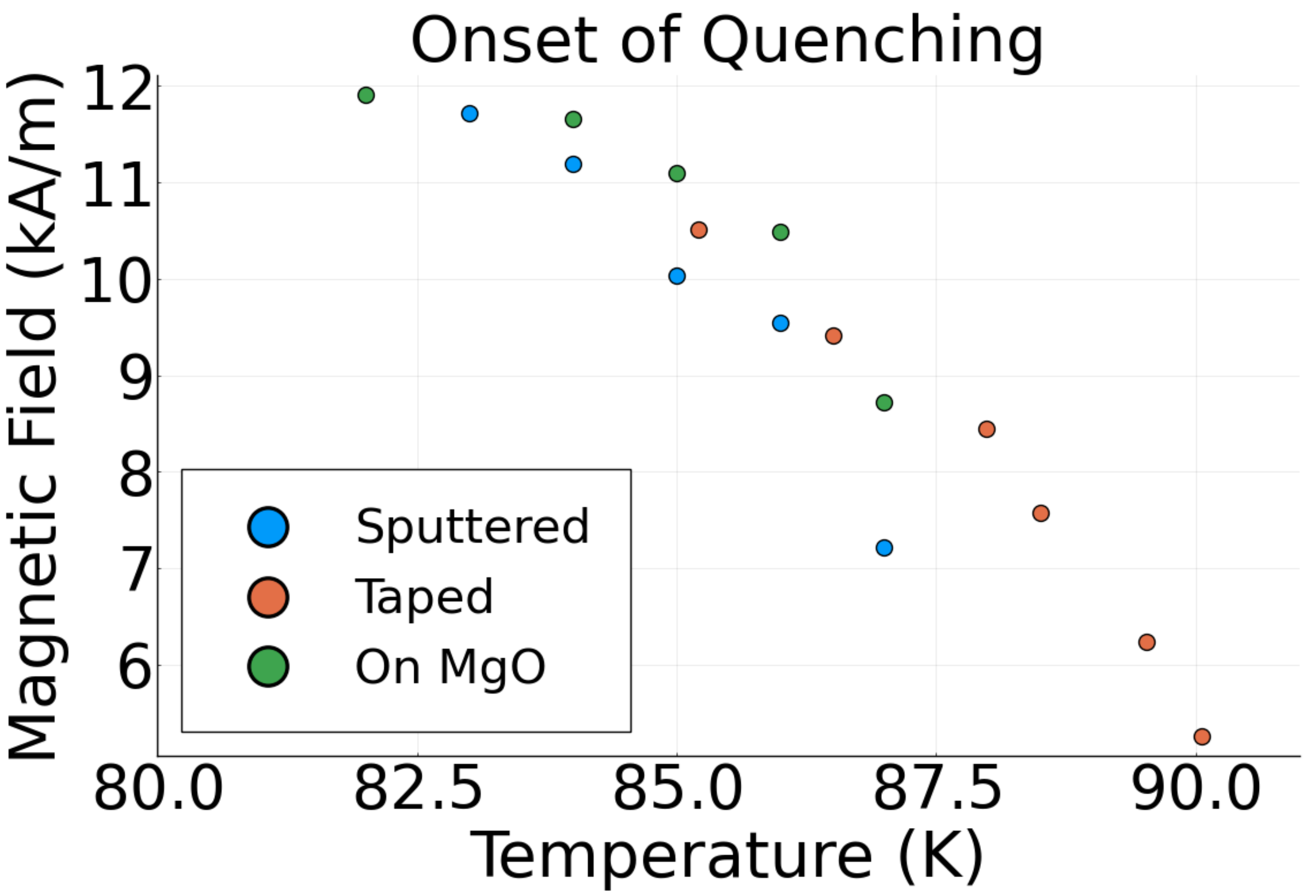
Looking at the onset of quenching based on the first power level where when the quality factor begins to change with time



SLAC

Onset of Quenching

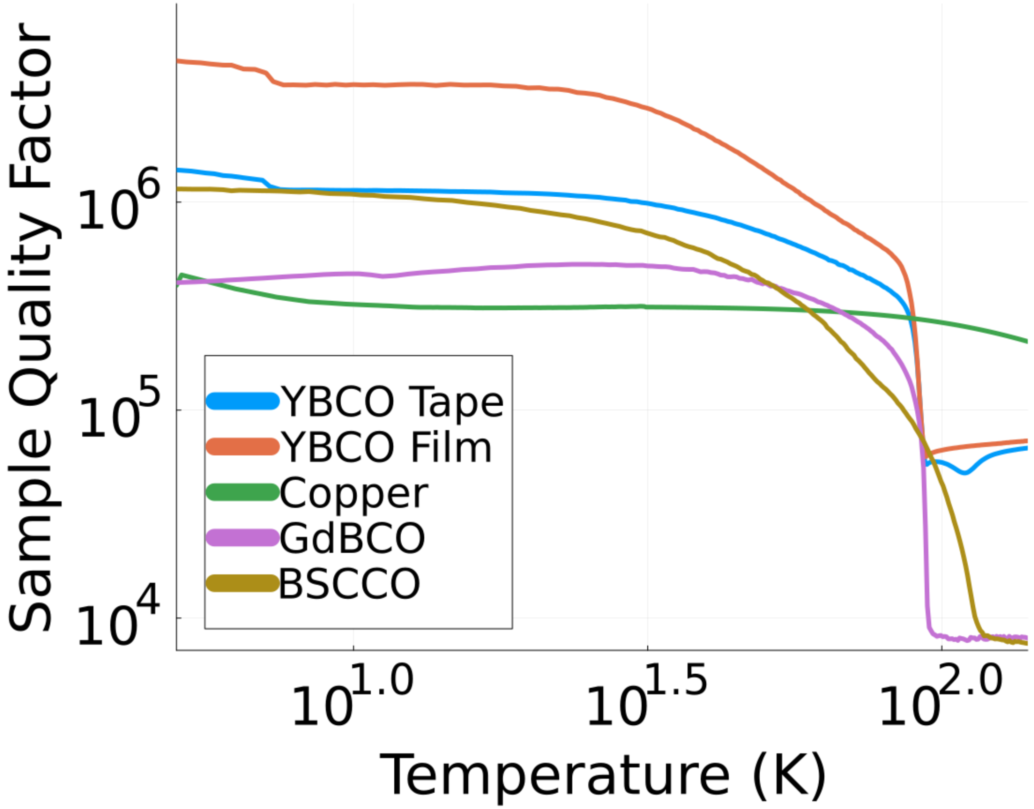
- No quenching was observed above 80 K for any sample
- The quenching within the YBCO on MgO sample seemed to be proportional to I^2, while other samples are closer to linear
- Need to measure this onset more carefully to determine T_cvI dependence

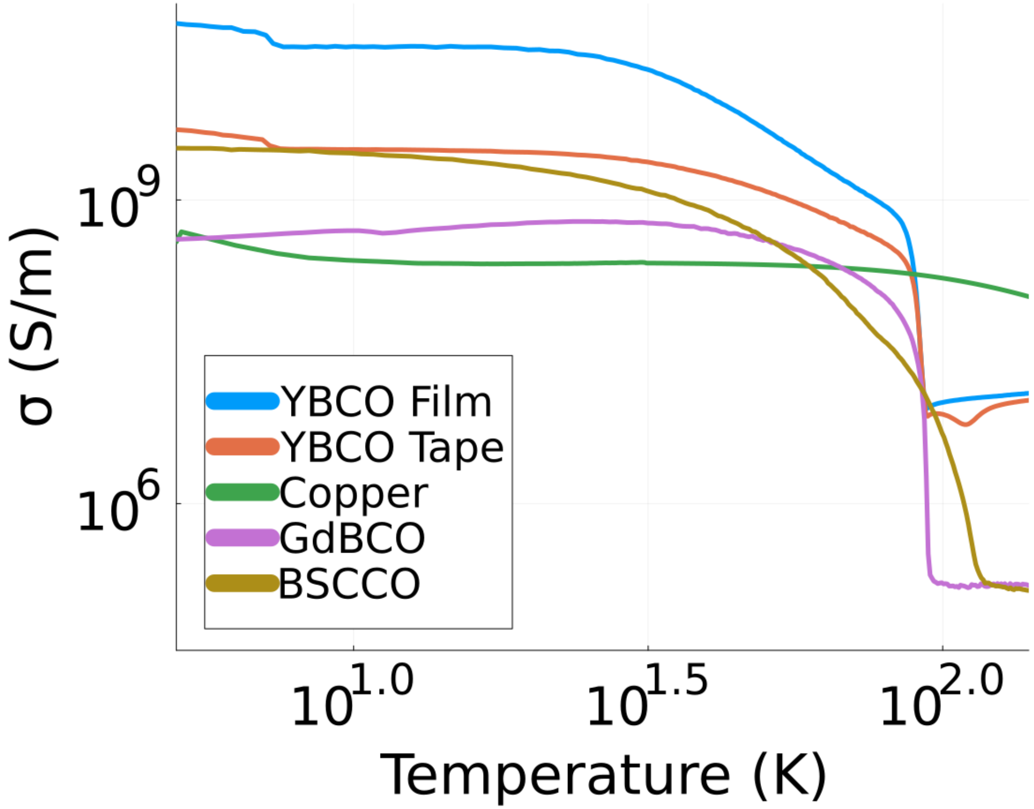


Looking towards other HTS Samples

Low power measurements have just been done with GdBCO and BSCCO sample as well

High power measurements to begin this month



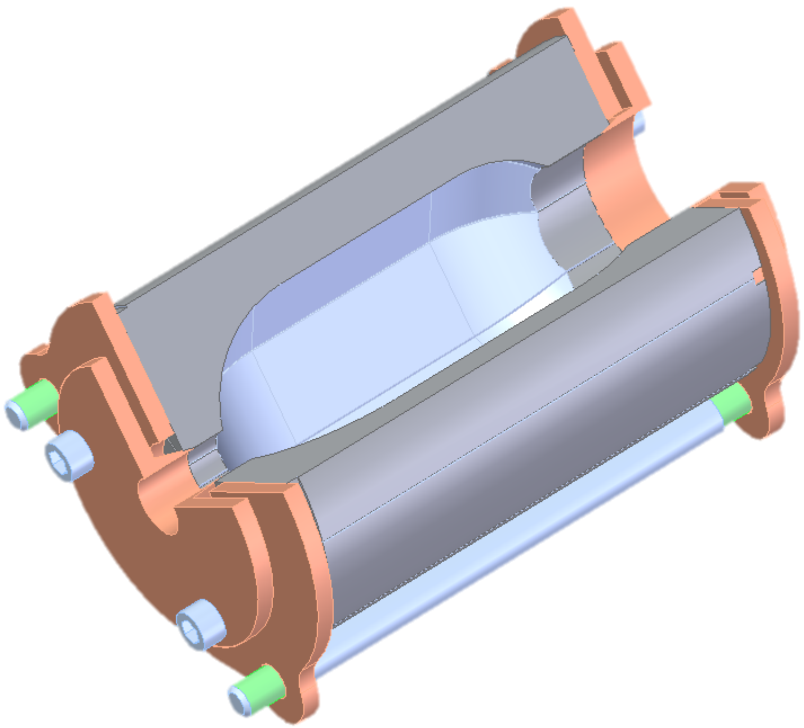


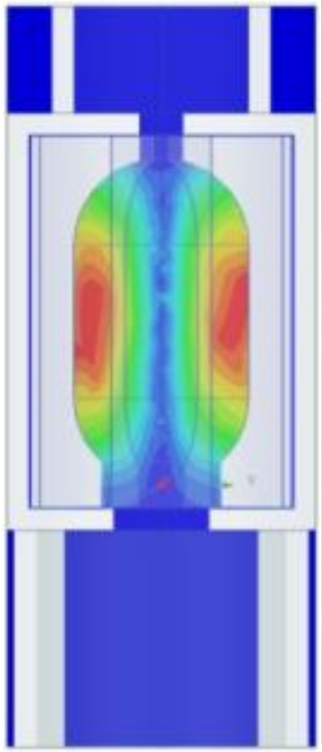
Applying HTS to RF design

As a first potential application, a pulse compressor cavity utilizing the TM010 mode is being built

Cavity is built from 8 facets which will be coated with YBCO tapes, allowing surface current to run longitudinally

Initial cold tests agree with simulation, and once built cavity will be tested in cryogenic test stand





Questions?