Progress on Beryllium Cavity Design

R. Fernow, D. Li, R. Palmer, D. Stratakis, S. Virostek

as told to

Michael S. Zisman
Center for Beam Physics
Accelerator & Fusion Research division
Lawrence Berkeley National Laboratory

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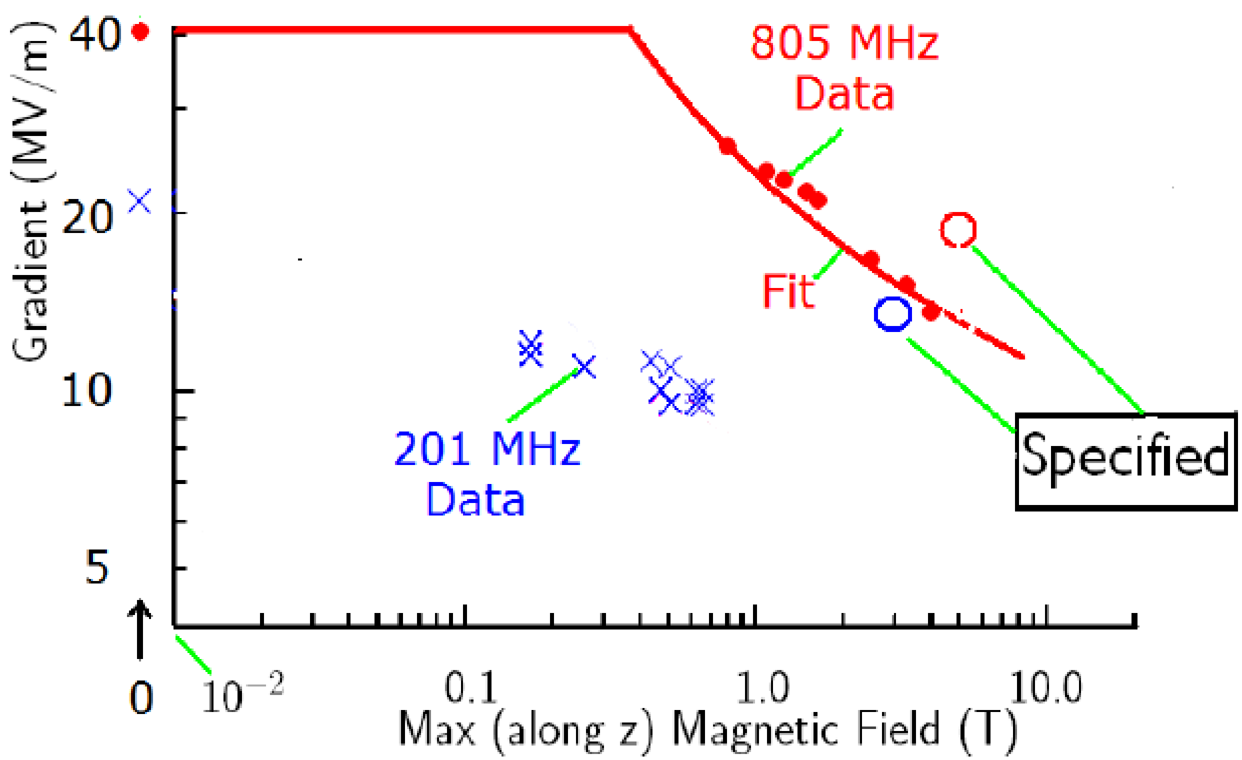
Introduction

- MuCool RF studies have shown significant reduction in maximum gradient when an axial magnetic field is applied
  - seen in 805 MHz test cell
  - hints of problems at 201 MHz also
    - in this case only fringe field is presently available for testing
- In both cases, it appears that problems in the coupler region are playing a strong role in observed breakdown
  - possible that further studies will change our perception of this issue
- Some models have suggested that Be may be a better wall material than Cu
  - motivated by this, plans to fabricate a cavity with Be walls are in progress

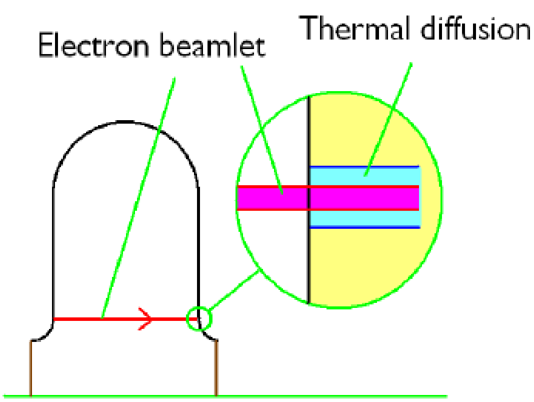
Present Situation

- **Brief summary of experimental data shown below**
  - **note that behavior at 805 MHz and 201 MHz look different**
    - **but fields are also quite different**
  - **"missing" 201 MHz requirement by factor of ~2**

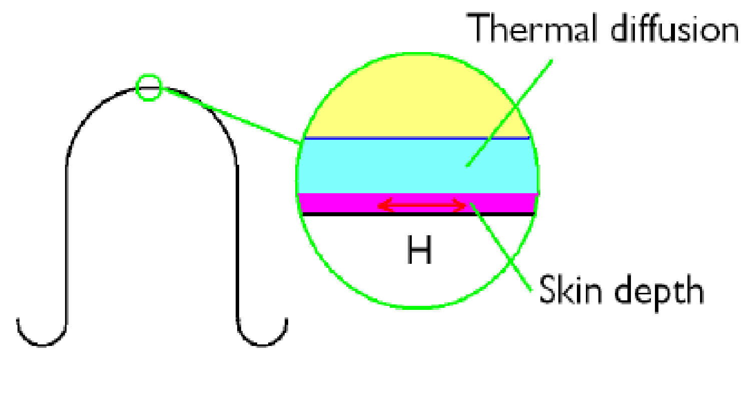


Model

- **Type of data we hope to explain and mitigate:**
  - **damage resulting from focused field emission (a)**
    - **information from surface ohmic heating (b) provides "calibration point" on when damage can occur**
      - **damage believed to be caused by fatigue from repeated strains due to heating**



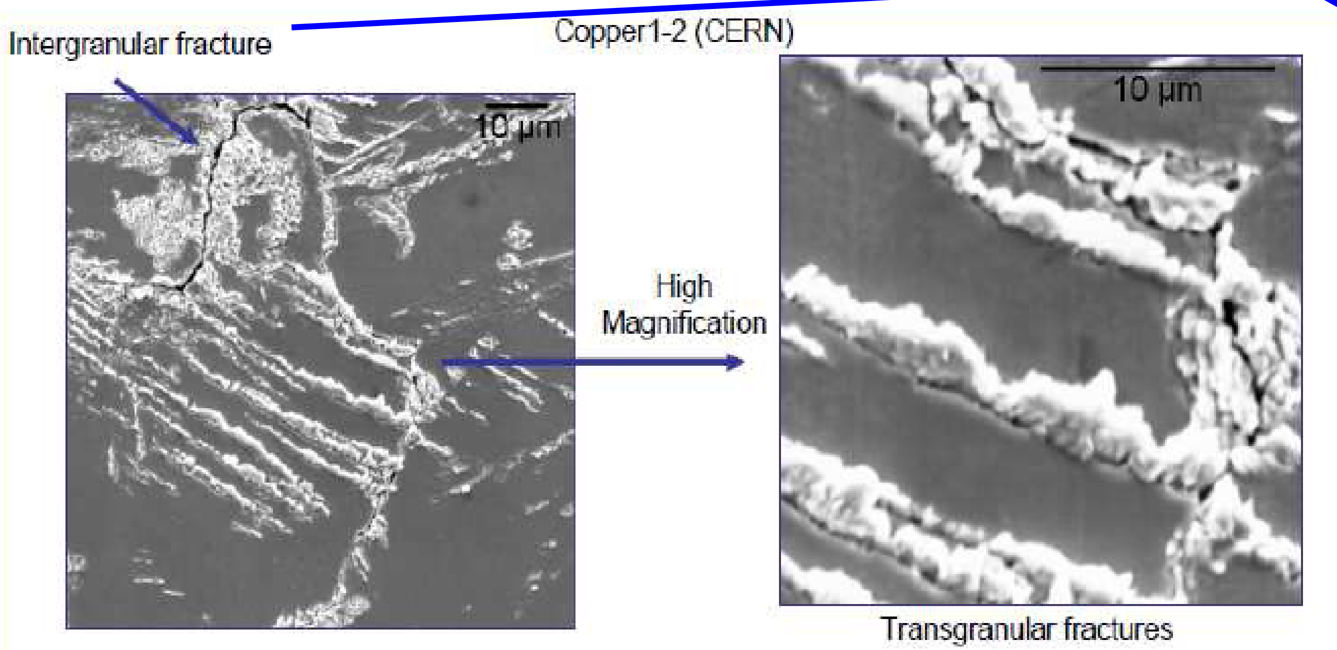
a) Our Mag Field Problem



b) SLAC Ohmic heating problem

SLAC Studies

- **Used special cavity with no surface electric fields but with surface currents**
  - **damage observed (Tantawi *et al.*) on soft copper after cyclical heating**
    - **$\Delta T \sim 45°C$**
  - **we assume similar effect from beamlet heating**



Choice of Materials

- To mitigate fatigue damage, seek materials with
  - low coefficient of thermal expansion
  - high specific heat
  - high thermal conductivity
  - for surface heating effect, also want high electrical conductivity

- Materials being considered
  - copper
  - beryllium
    - low density
    - lack of damage in experiments to date
  - aluminum

Estimation of Strain

- **Approach**
  - **use approximate calculations to estimate temperature rise and resulting strain**
    - **α(T) is coefficient of thermal expansion; A_{beam} is beamlet area at surface; Q(T) is factor to account for thermal diffusion (increases transverse heat zone)**
      - **assumes no temperature variation with lateral diffusion**

$$\Delta T \;\propto\; \frac{dE}{dx} \int_o^t \frac{Q(T)}{A_{beam}\ \rho\ C_p(T)} dt$$

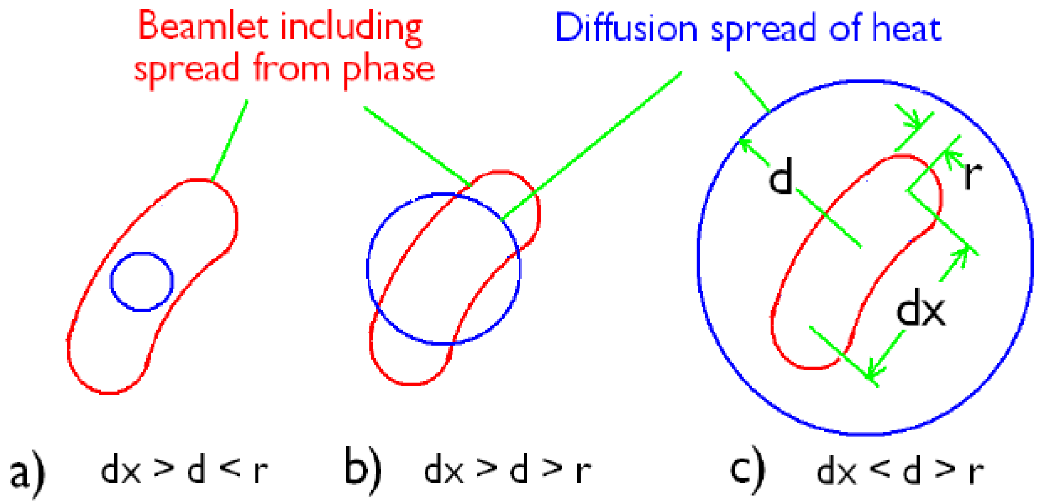
$$\text{Strain} \;\propto\; \frac{dE}{dx} \int_o^t \frac{Q(T)\ \alpha(T)}{A_{beam}\ \rho\ C_p(T)} dt$$

Thermal Diffusion

- Two different assumptions made for thermal diffusion effects
  - diffusion size small compared with spot size
    - $Q(T) = 1$
  - diffusion size comparable to spot size
    - $Q(T) = d(273)/d(T)$

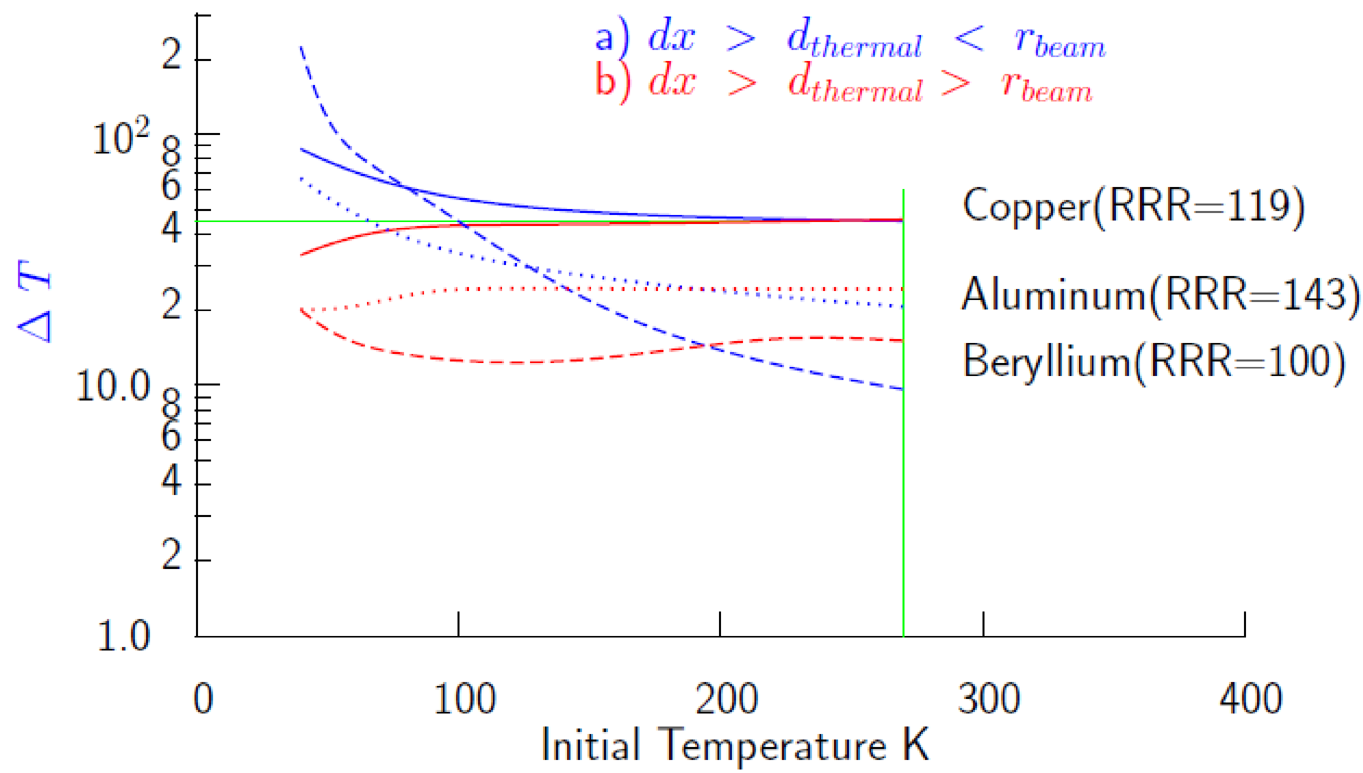
$$d(T) = \sqrt{\frac{K(T)\tau}{\rho C_p(T)}}$$

  - third option, with large diffusion size, would not match observed B dependence



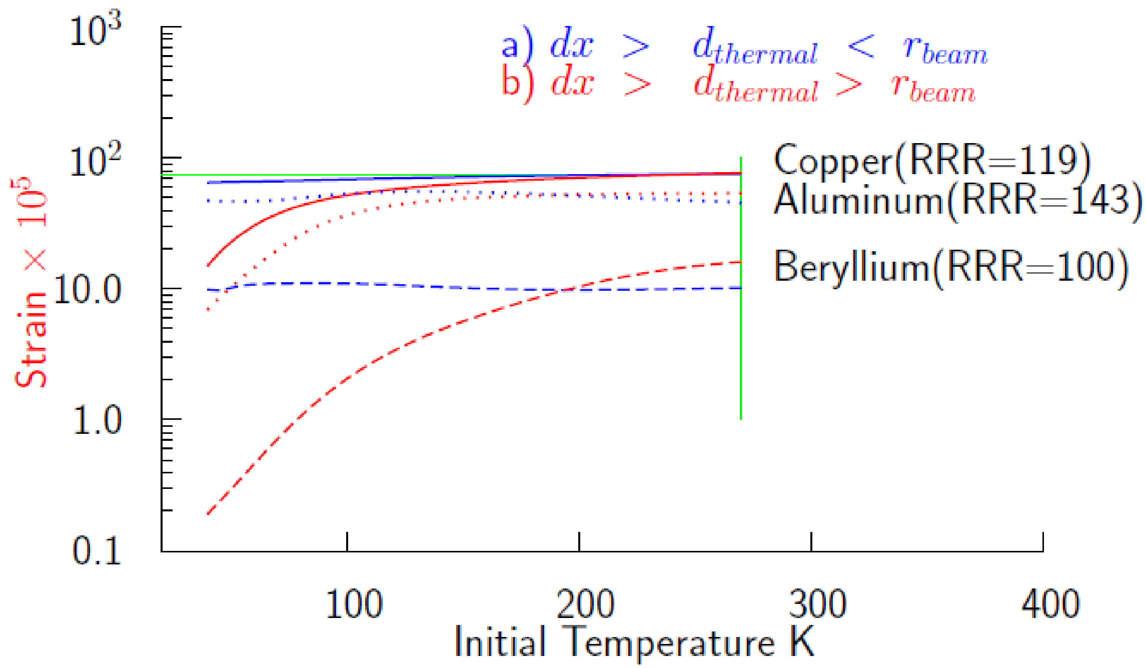
Temperature Rise

- **Normalized to give ΔT = 45°C for Cu at room temperature**
  - **this value resulted in damage for Cu in the SLAC experiments**
  - **Be gives lowest temperature rise**



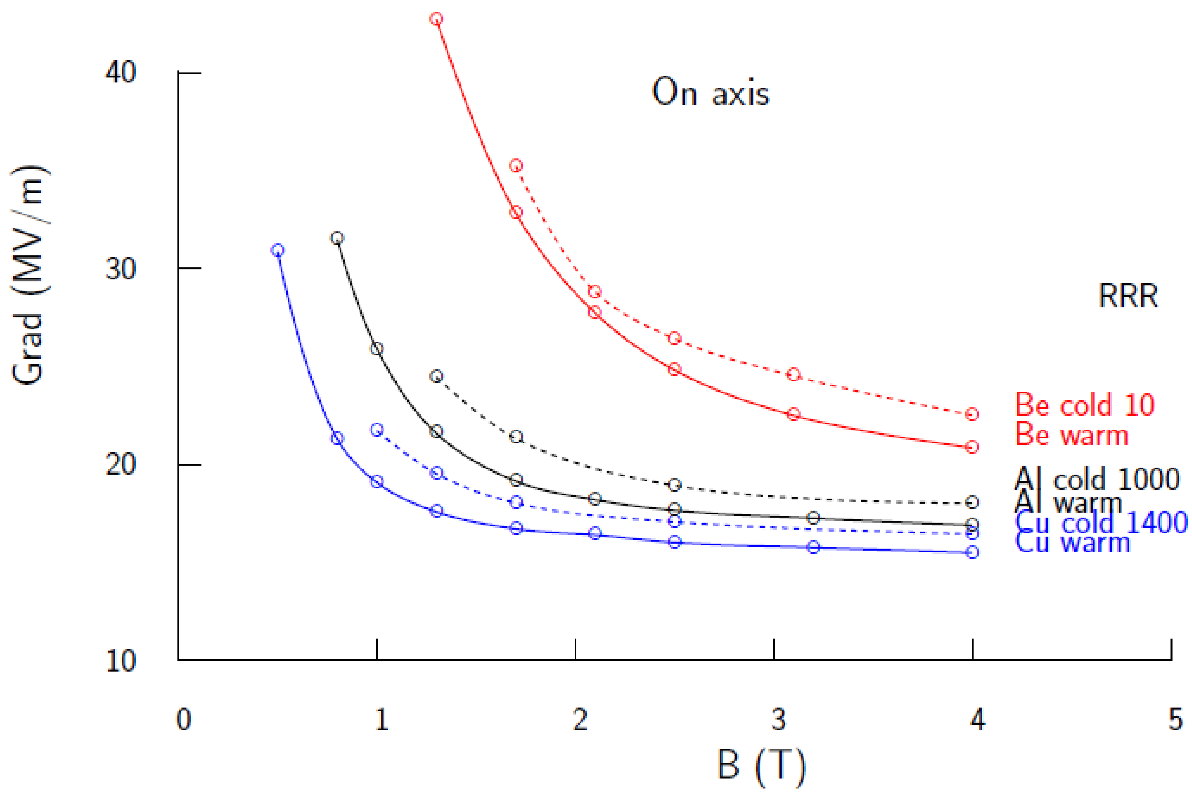
Strain

- Use equation in slide 7 to evaluate strain for different cases
  - Be has much less strain than Cu
  - Al is somewhat better than copper
  - for case b, where thermal diffusion matters, model predicts improvement at lower temperatures for Be and Al



Breakdown Gradients

- **Assume damage occurs at same strain as for Cu at 45°C**
  - **Be looks better**
    - **shape roughly consistent with what we have seen**
      - **needs to be tested!**



Conclusions from Modeling

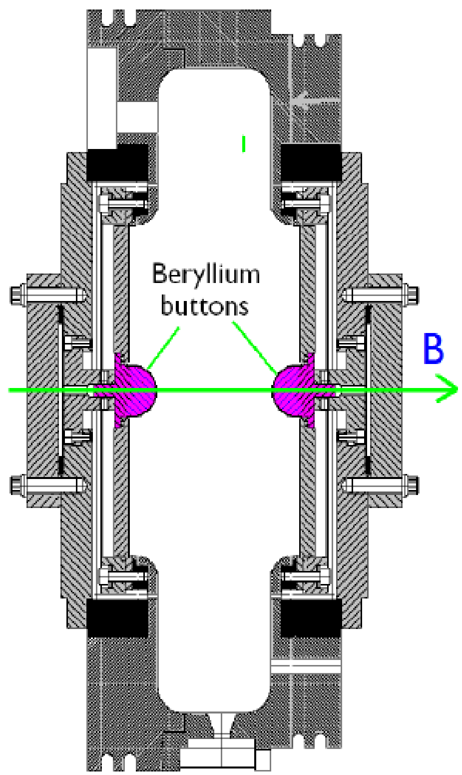
- **Beryllium appears to be ideal cavity material**
  - *except for fabrication issues*
  - *may well solve the observed gradient shortfall*

- **Aluminum also somewhat better than copper**
  - *would need TiN coating*

- **Be pillbox cavities would have substantial advantages over magnetically insulated cavities**
  - *much higher shunt impedance*
  - *better ratio of acceleration field to maximum surface field*

Test Program (1)

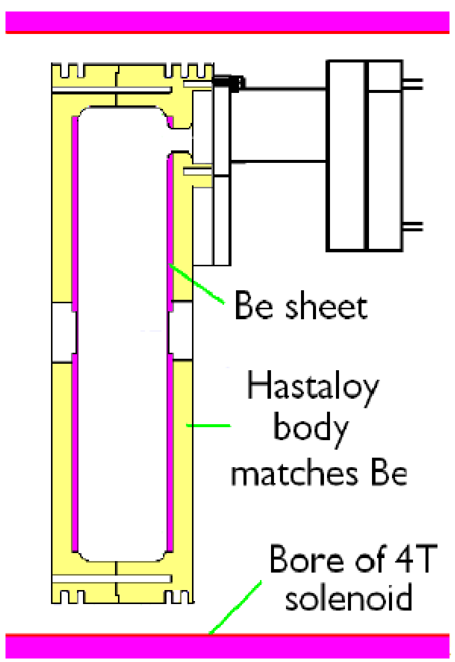
- **Initial tests will use back-to-back buttons**
  - **button field enhancement increased to 3x**
    - **should eliminate possibility of breakdown on Cu surfaces**
  - **will test Be, Al, and Cu and possibly other materials**

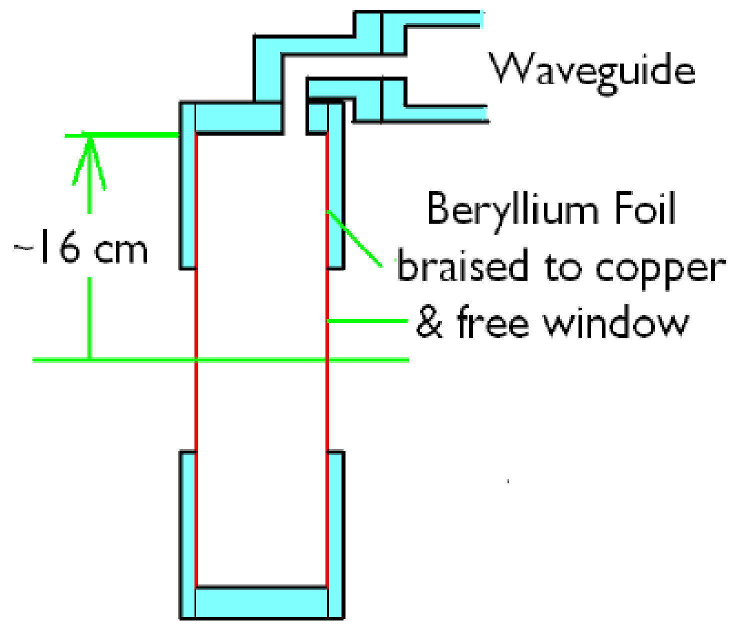


Test Program (2)

- Subsequent experiment will use Be wall cavity
  - funding for design and fabrication in hand

- Two designs have been considered
  - only one fits Lab G magnet





Cavity Fabrication

- Design being done by S. Virostek
  - with guidance from D. Li and R. Palmer

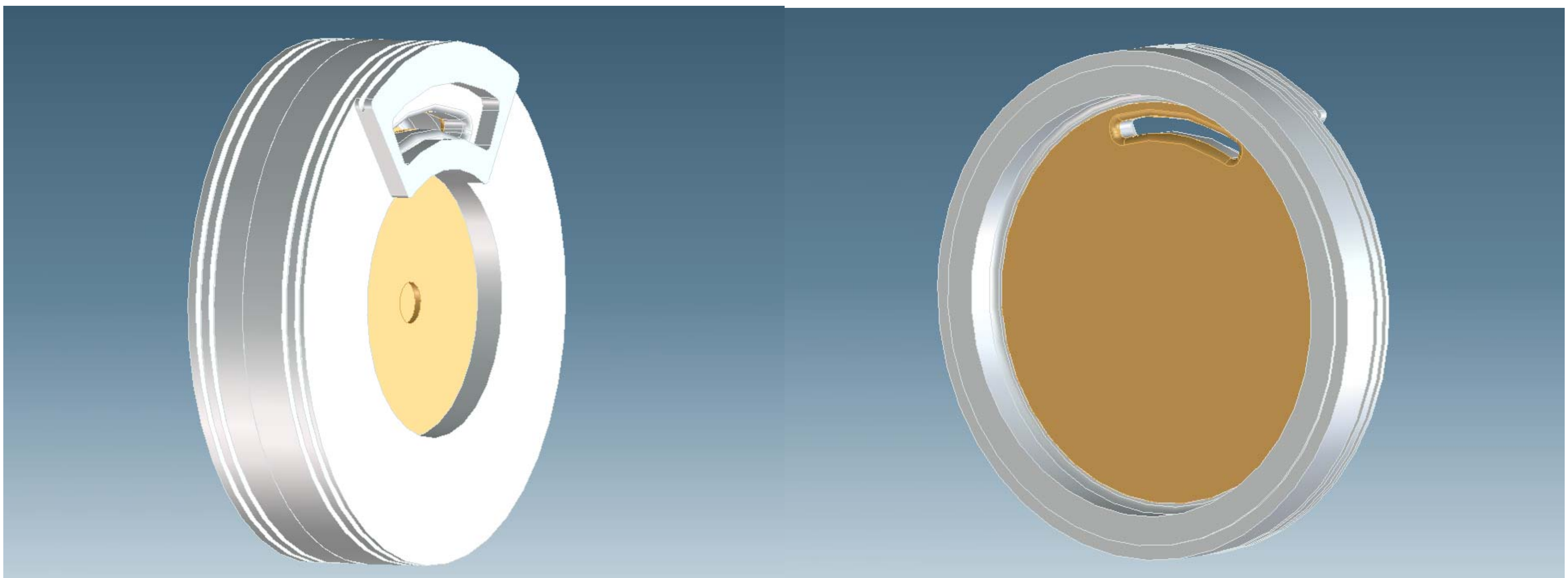
- CAD model for one concept has been completed
  - next steps
    - evaluate cost of beryllium material
    - evaluate cost of various fabrication techniques
    - analyze manufacturing risks
      - brazing
      - coupling port
      - bolted joints
      - machining processes

Cavity Concept

- **Main features**
  - two bolted halves with vacuum and RF seals
    - offers accessibility advantages over e-beam welded cavity
  - main body is Cu-plated Hastelloy or solid Cu
  - coupling port slotted in side wall
  - inner side walls are Be (TiN coated)
- **Side wall options**
  - thin Be foil (0.5 mm) brazed to side walls
  - thick Be plates (6 mm) brazed to side walls
  - solid Be walls (no brazing)
    - all-Be cavity probably impractical

3D CAD Model

- **Initial model has been developed**
  - **progress delayed by other priorities recently**



Manufacturing Issues

- Brazing
  - Be brazing is only done at select shops
  - differential expansion may be a problem for solid Cu body
  - may be some issues with brazing to Cu plated Hastelloy
  - transition from Be side walls to rounded corner at cavity OD presents some challenges
- Coupling port
  - interface between Be and cavity body material at port needs to be fully brazed
  - need to incorporate a connection flange to RF waveguide
- Cavity joints
  - seal(s) between cavity halves needs to provide a good RF connection as well as a vacuum seal
- Machining
  - few shops available to do Be machining

Task List

- **Complete conceptual design layouts**
- **Perform analysis and trade-off studies**
- **Develop final conceptual design**
- **Generate fabrication drawings**
- **Procure long lead materials (Be)**
- **Fabricate cavity components**
- **Braze, coat Be and assemble cavity**

LBNL responsibility
(S. Virostek, D. Li)

Summary

- Observed RF gradient in magnetic field less than required
  - SLAC sees damage due to cyclical RF heating by only 45°C
  - possible that our effect due to cyclical heating from field emitted beamlets
- Damage thresholds estimated
  - with several assumptions
- Indication that performance improved for Be cavity
  - and possibly for cavity operated at LN temperature
- Initial experiments with Be buttons planned
- Be wall cavity design under way
  - will be tested ASAP