805 MHz History

Button Tests

Discussion of Damage

Replacement plans: new cavity design

Replacement plans: next steps

Thanks

805 MHz Button Cavity Results and Replacement Plans

Daniel Bowring*

Lawrence Berkeley National Laboratory

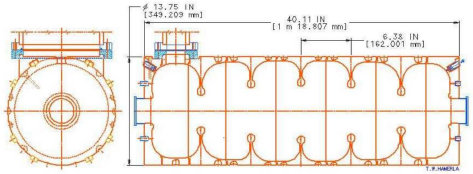
July 24, 2012

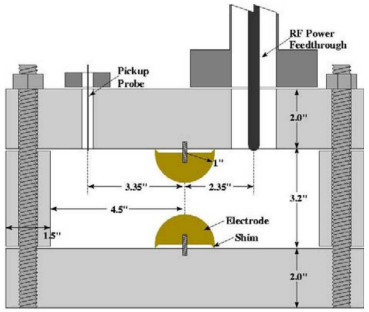
*For a complete list of contributors, see the final slide.

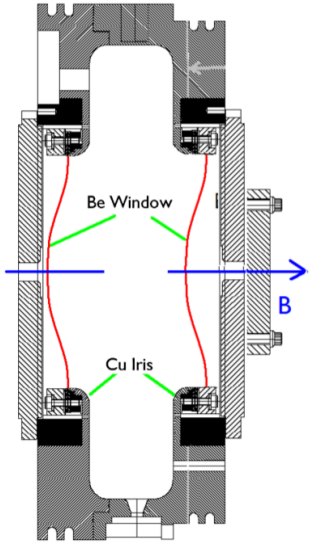
Overview

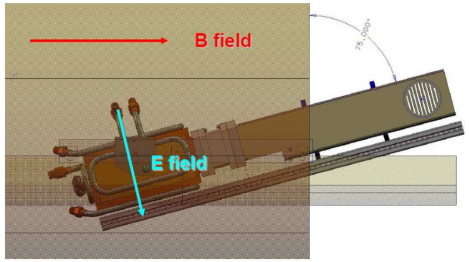
1. 805 MHz history
2. Button tests
3. Discussion of breakdown, damage
4. Replacement plans: New cavity design
5. Replacement plans: New cavity status
6. Plans for the not-too-distant future

805 MHz History

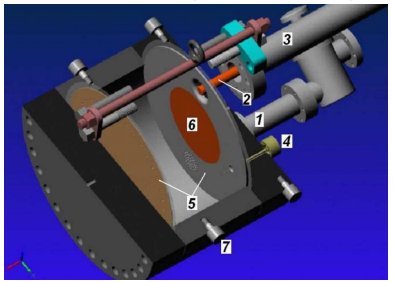








See A. Moretti's talk immediately following.



1 A. Moretti *et al.*, *RF cavities for the muon and neutrino factory collaboration study.* Proc. LINAC'00, Monterey CA, 2000.

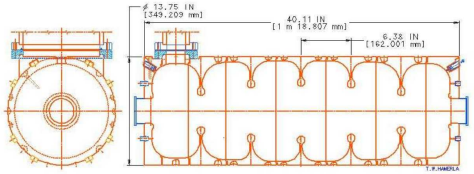
2 R.B. Palmer *et al.*, *RF breakdown with external magnetic fields in 201 and 805 MHz cavities.* PRST-AB **12**, 031002 (2009).

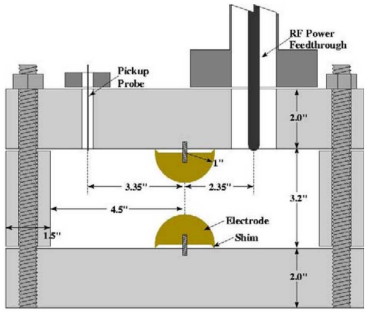
3 M. Chung *et al.*, *Beam test of a high pressure cavity for a muon collider.* Proc. IPAC'10, Kyoto, Japan, 2010. WEPE066.

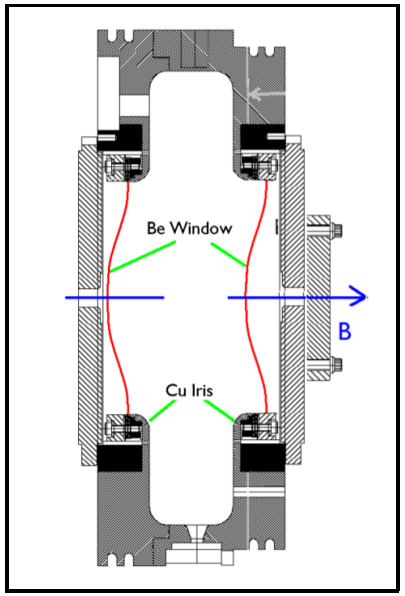
4 Y. Torun *et al.*, *Rectangular box cavity tests in magnetic field.* Proc. IPAC'10, Kyoto, Japan, 2010. THPEA054.

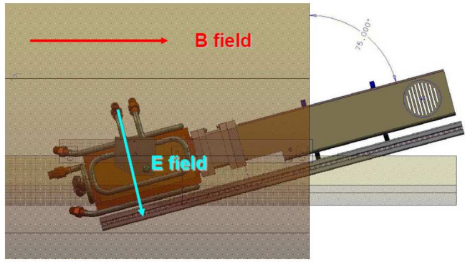
5 G. Kazakevich *et al.*, *Conditioning and future plans for a multi-purpose 805 MHz pillbox cavity for muon acceleration.* Proc. IPAC'12, New Orleans, LA, USA. 2012. THPPC032.

805 MHz History

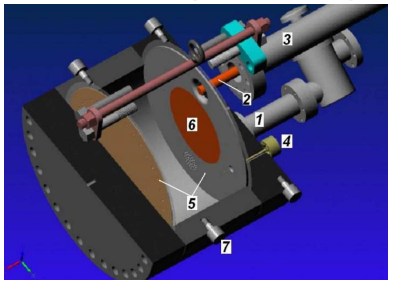








See A. Moretti's talk immediately following.



1 A. Moretti *et al.*, *RF cavities for the muon and neutrino factory collaboration study.* Proc. LINAC'00, Monterey CA, 2000.

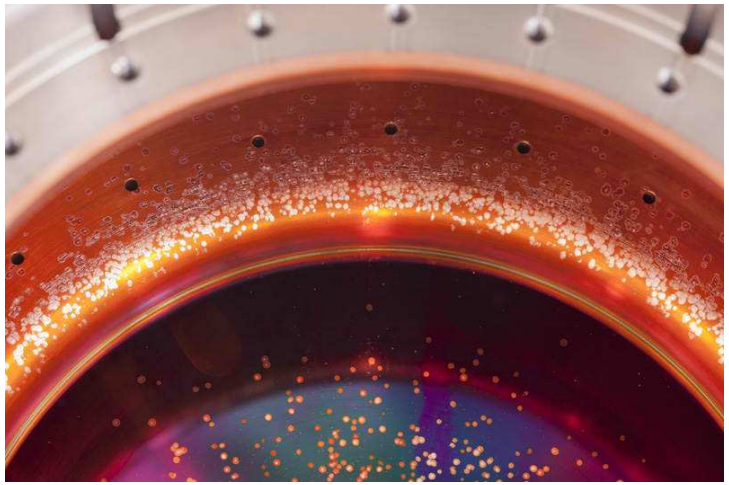
2 R.B. Palmer *et al.*, *RF breakdown with external magnetic fields in 201 and 805 MHz cavities.* PRST-AB **12**, 031002 (2009).

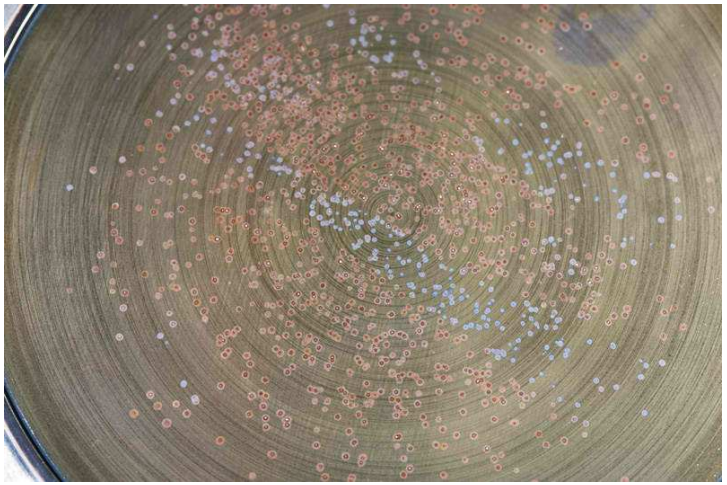
3 M. Chung *et al.*, *Beam test of a high pressure cavity for a muon collider.* Proc. IPAC'10, Kyoto, Japan, 2010. WEPE066.

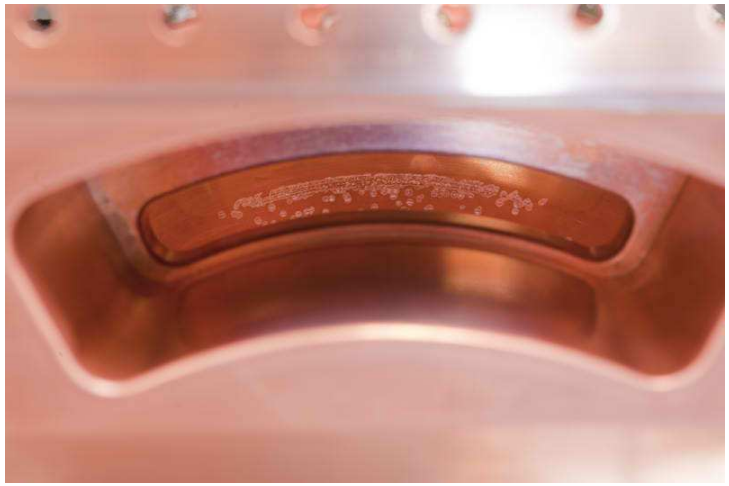
4 Y. Torun *et al.*, *Rectangular box cavity tests in magnetic field.* Proc. IPAC'10, Kyoto, Japan, 2010. THPEA054.

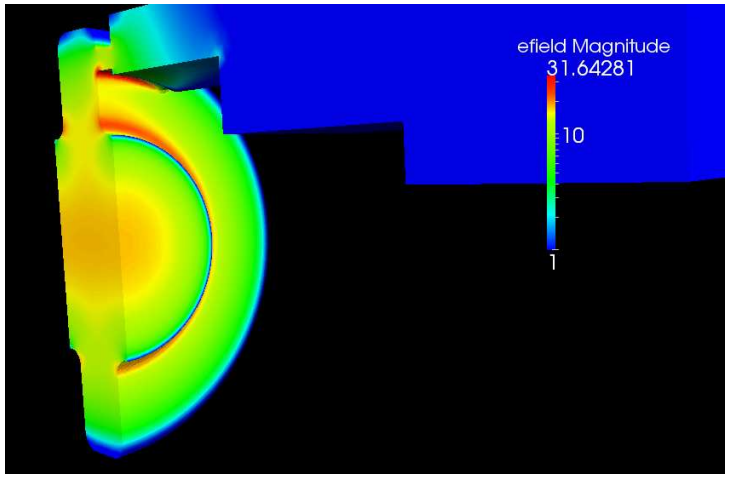
5 G. Kazakevich *et al.*, *Conditioning and future plans for a multi-purpose 805 MHz pillbox cavity for muon acceleration.* Proc. IPAC'12, New Orleans, LA, USA. 2012. THPPC032.

Pillbox with flat windows: extensive breakdown damage.









Use buttons for local field enhancement on cavity axis.

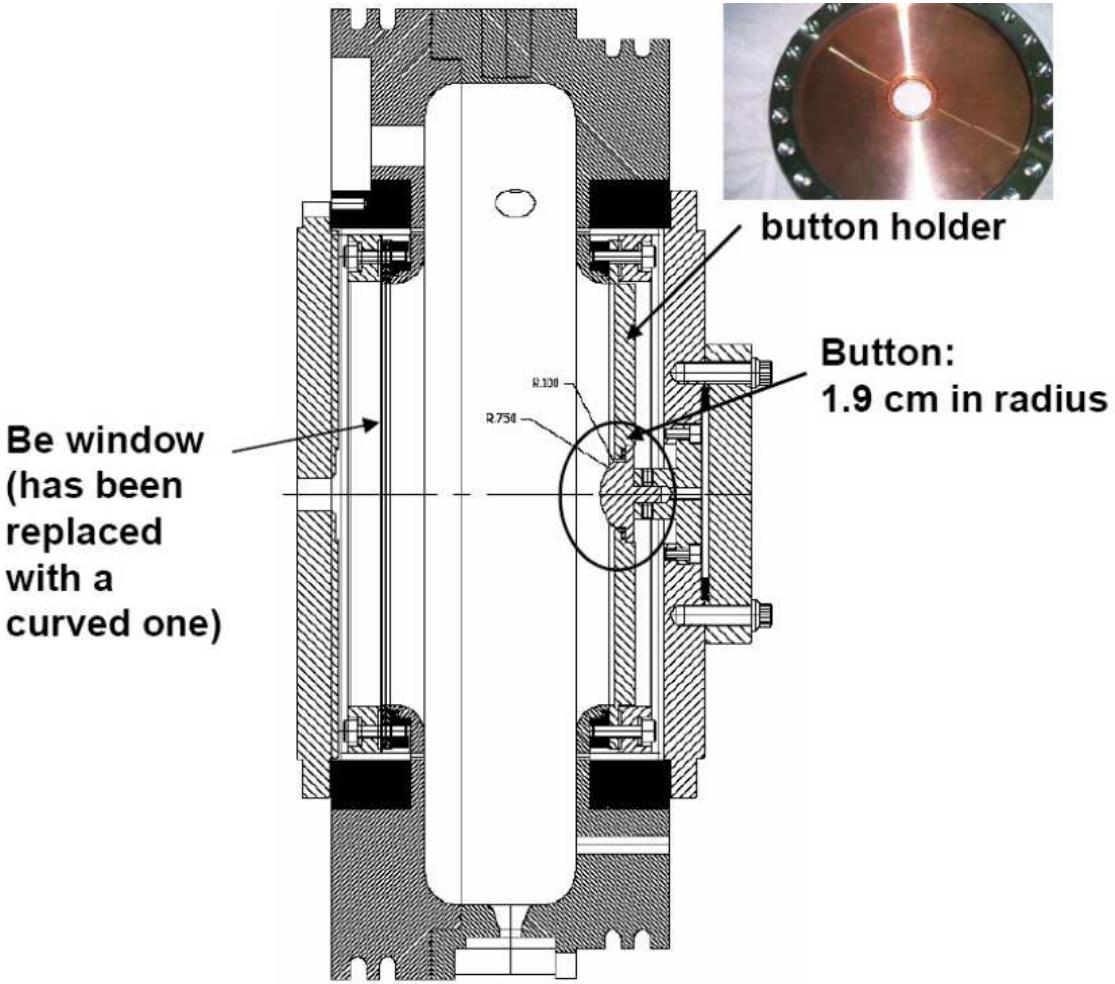


Figure: R.B. Palmer *et al.*, *RF breakdown with external magnetic fields in 201 and 805 MHz cavities.* PRST-AB **12**, 031002 (2009).

Erratic button data: Try for greater field enhancement.

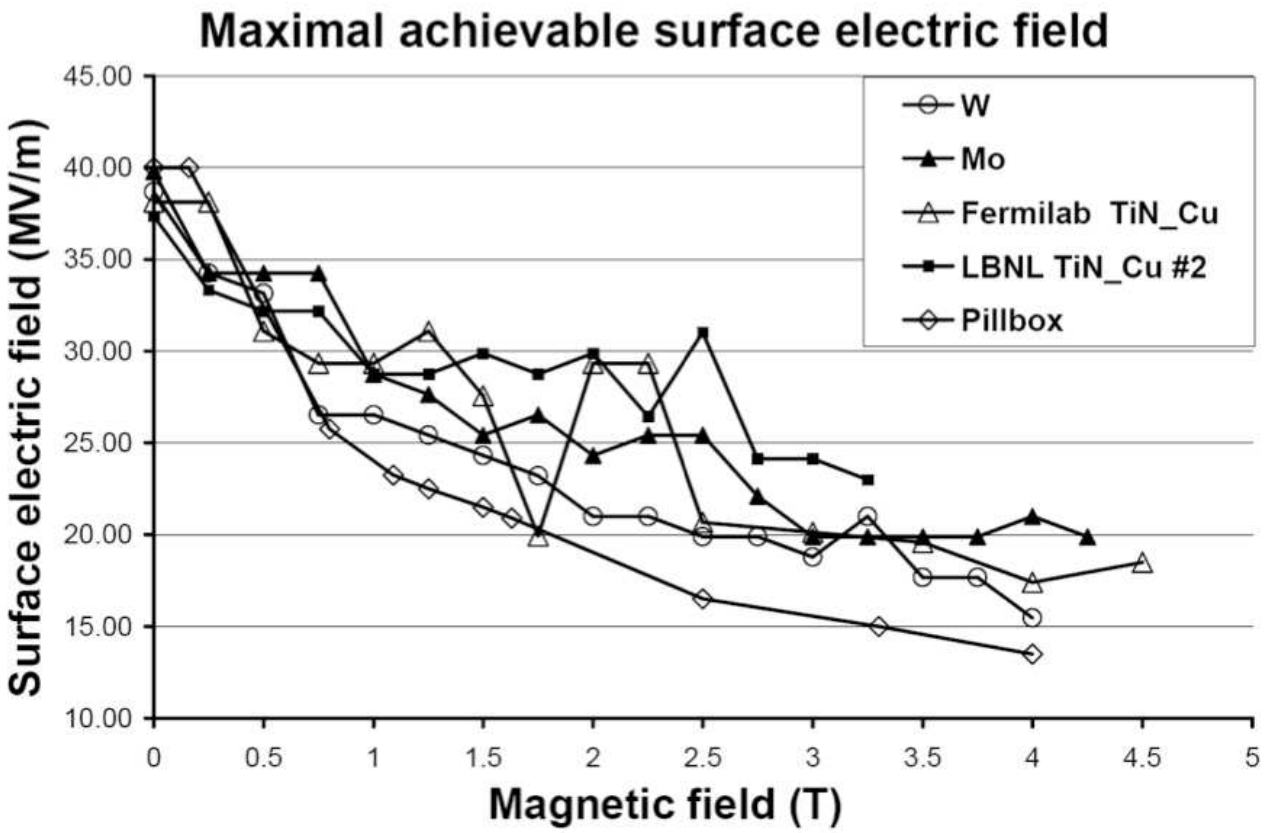
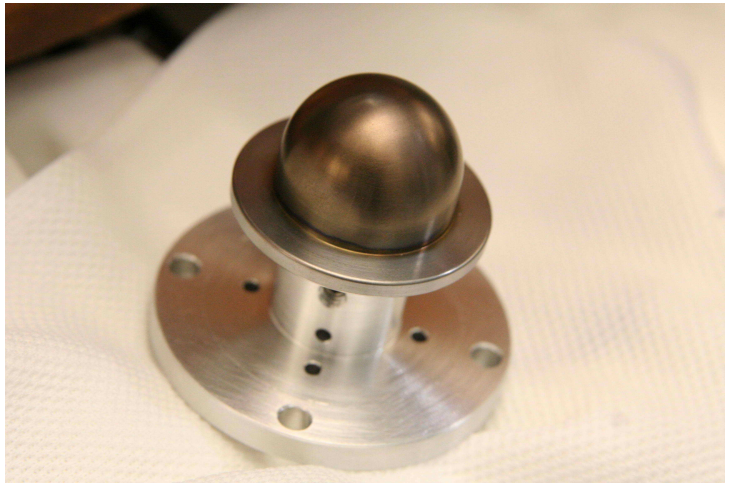
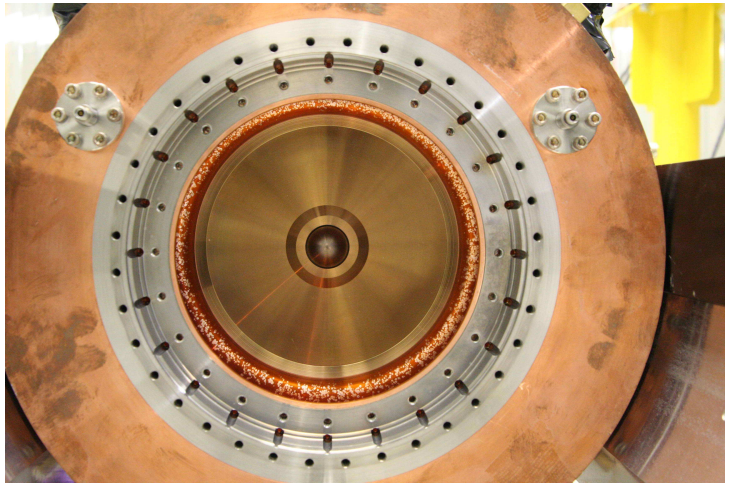


Figure: D. Huang *et al.*, *RF studies at Fermilab MuCool Test Area*, PAC09, Vancouver, May 2009, TU5PFP032, p. 888 (2009), http://www.JACoW.org.

New buttons with greater curvature $\rightarrow$ field enhancement factor of ~ 3.





- Cu and Be buttons tested.
- Be buttons coated with TiN to reduce secondary electron yield.
- Two buttons mounted opposite each other for each test.
- **Central question: Is Be less susceptible than Cu to damage during breakdown?**

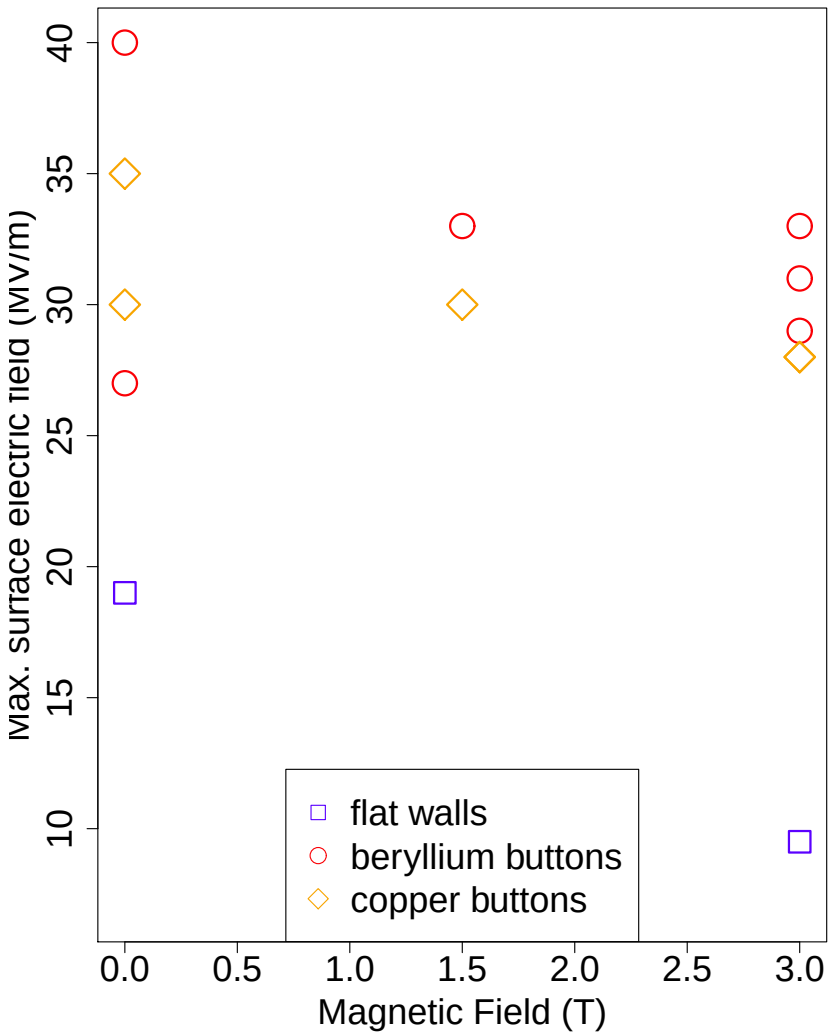
Yes, less energy is deposited in Be components.

PRELIMINARY

Damage observed in Cu buttons requires $\sim$mJ. Damage observed in Be buttons requires $\sim \mu$J. **Further analysis is required here.**

Question remains: How much does surface damage contribute to breakdown?

New button test data has similar scatter.



- Field enhancement factor ~ 3.
- Max. gradient changes between measurements.
- Max. allowable Be particulate: 0.6 mg/14k cubic feet.
- No beryllium particulate detected in MTA.
- Next slides address damage.

Cu, Be buttons both damaged. Be damage is microscoipc.

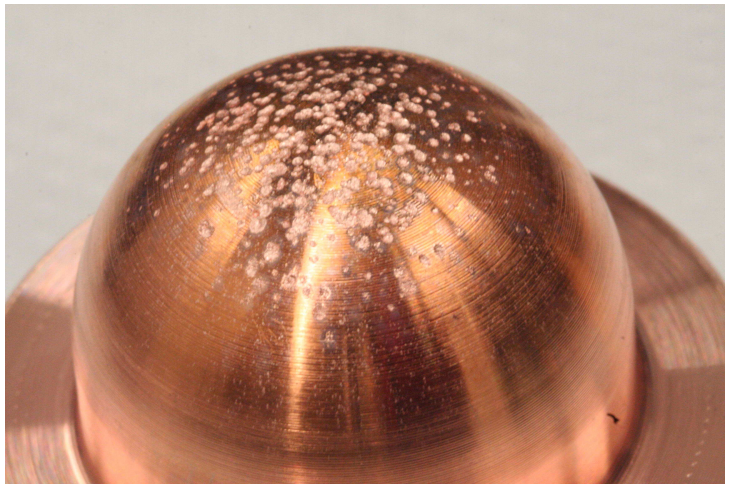


Figure: Copper button.

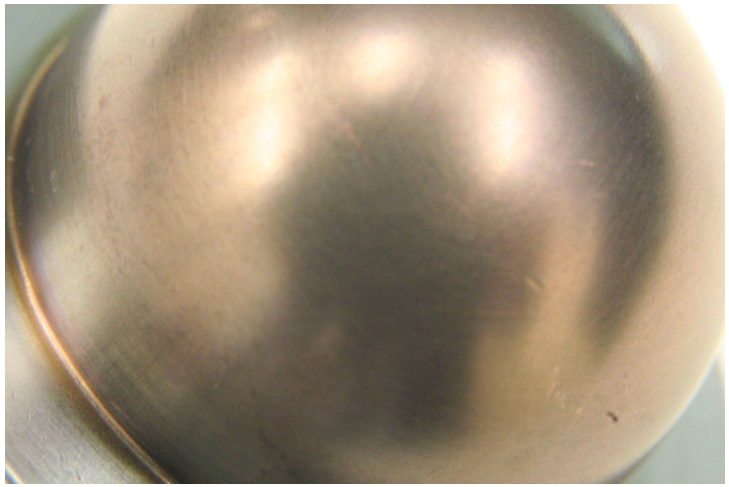


Figure: Beryllium button.

Root Question: : Does beryllium sustain less damage than copper during breakdown?

Answer: Very likely. A few important notes here.

Root Question: : Does beryllium sustain less damage than copper during breakdown?

Answer: Very likely. A few important notes here.

- Damage on the Be buttons is μ**m-scale**. Contrast this with **mm-scale** damage on the Cu buttons and flat samples.

Root Question: : Does beryllium sustain less damage than copper during breakdown?

Answer: Very likely. A few important notes here.

- Damage on the Be buttons is μ**m-scale**. Contrast this with **mm-scale** damage on the Cu buttons and flat samples.
- Does smaller = better? Some breakdown theories require only **nm-scale** surface features.

Root Question: : Does beryllium sustain less damage than copper during breakdown?

Answer: Very likely. A few important notes here.

- Damage on the Be buttons is μ**m-scale**. Contrast this with **mm-scale** damage on the Cu buttons and flat samples.
- Does smaller = better? Some breakdown theories require only **nm-scale** surface features.
- We have no nm-scale measurements with which to address this issue.

Root Question: : Does beryllium sustain less damage than copper during breakdown?

Answer: Very likely. A few important notes here.

- Damage on the Be buttons is μ**m-scale**. Contrast this with **mm-scale** damage on the Cu buttons and flat samples.
- Does smaller = better? Some breakdown theories require only **nm-scale** surface features.
- We have no nm-scale measurements with which to address this issue.
- There are still quite a few interesting things to talk about.

Copper Buttons: Top, 10X Magnification

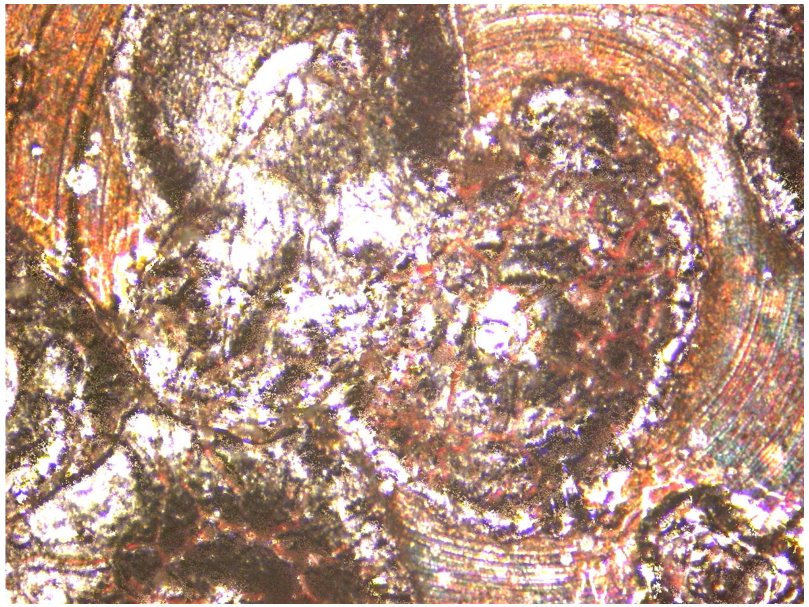


Figure: Upstream Cu button.

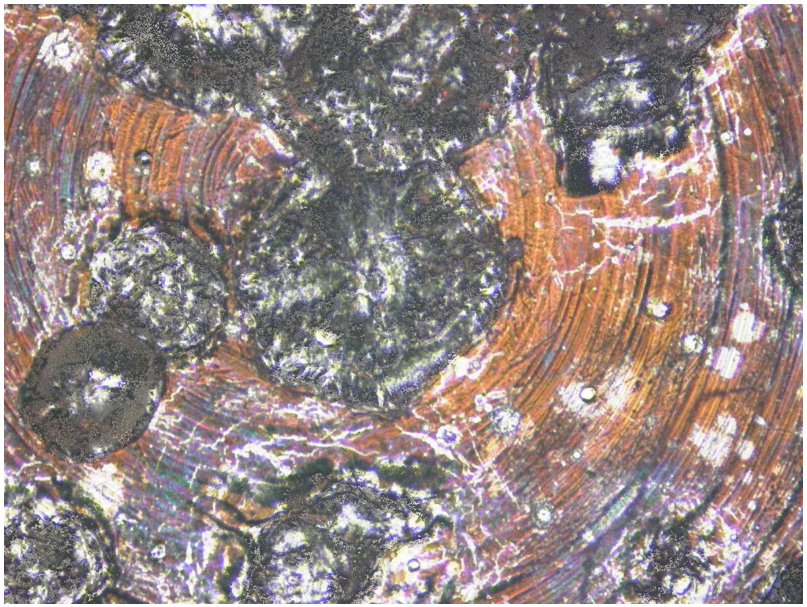


Figure: Downstream Cu button.

Copper buttons characterized by catastrophic damage on an already-rough surface. Craters, copper splashes are common. Note concentric machining marks.

Upstream Beryllium Button: Top, 10X Magnification

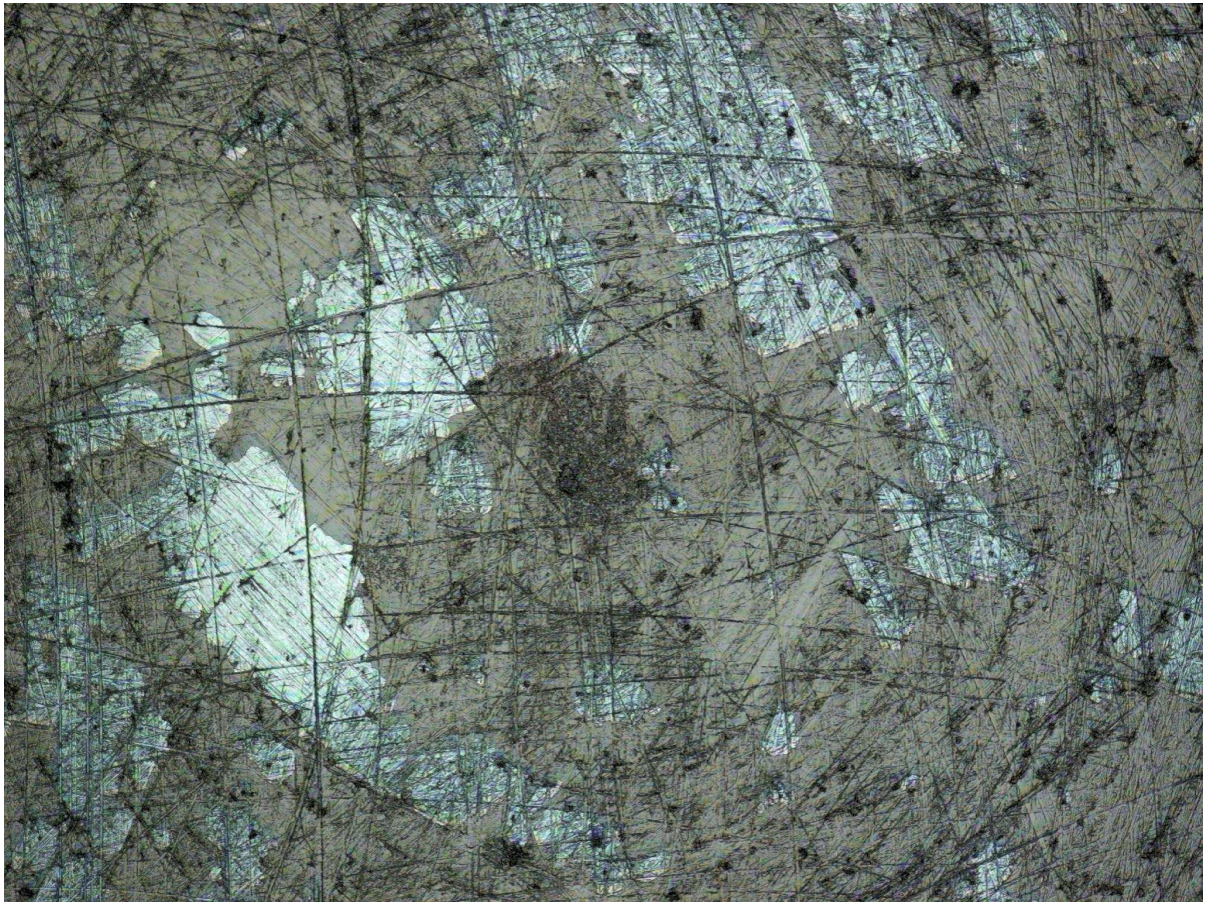


Figure: Upstream Be button surface is rough. Light spots are where TiN has ablated. Dark spots are pits *and* raised bumps.

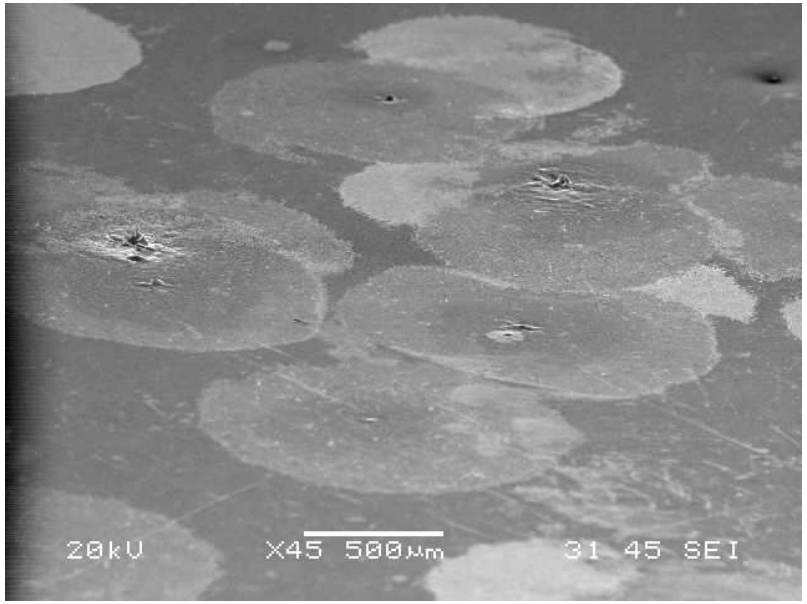
Loosely speaking, there are two types of damage.

1. **Orderly, uniform melting.** Seen in Cu samples cut from flat windows, possibly some Be button sites.
2. **Catastrophic melting.** Seen in Cu buttons, possibly some Be button sites.

The next few slides discuss this distinction.

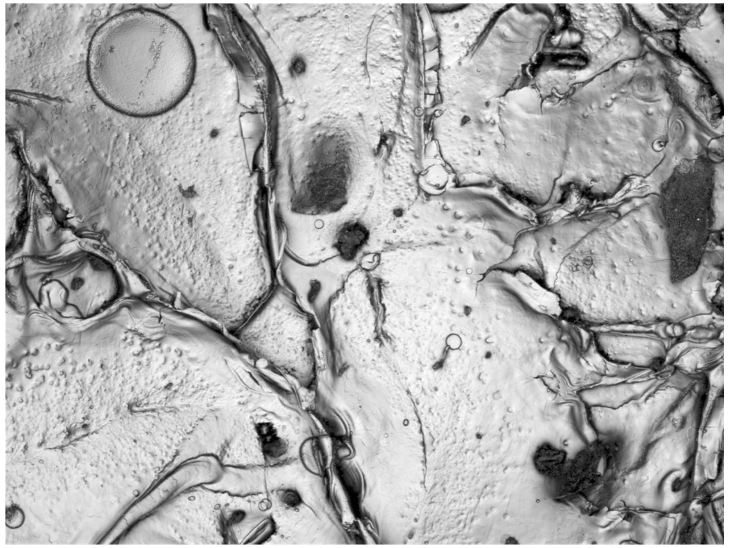
Orderly, uniform melting seen on Cu samples cut from flat windows.

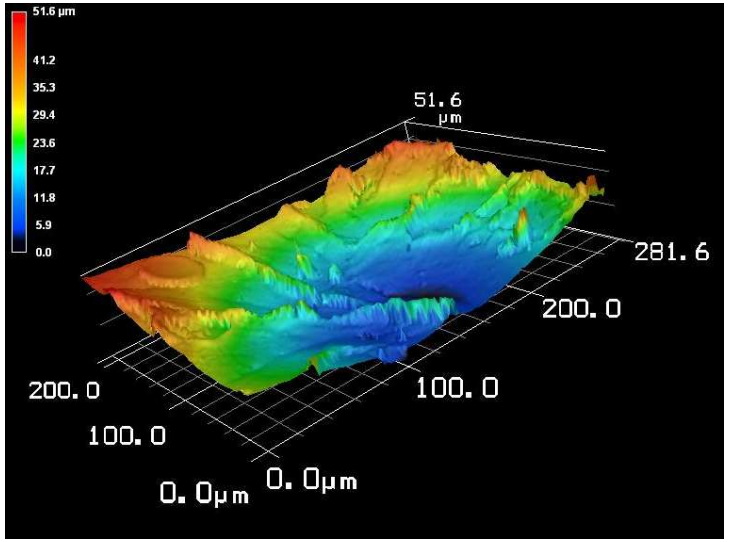
SEM Images

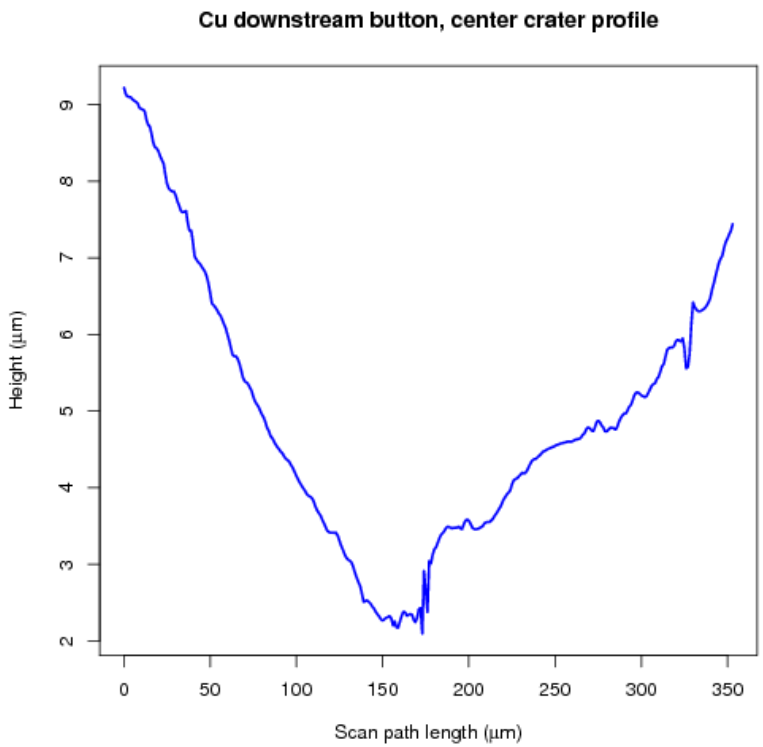


Smooth damage spot with pronounced, "symmetric" central peak. Indicates uniform melting during breakdown impact, followed by rapid cooling.

Catastrophic melting seen on Cu buttons.

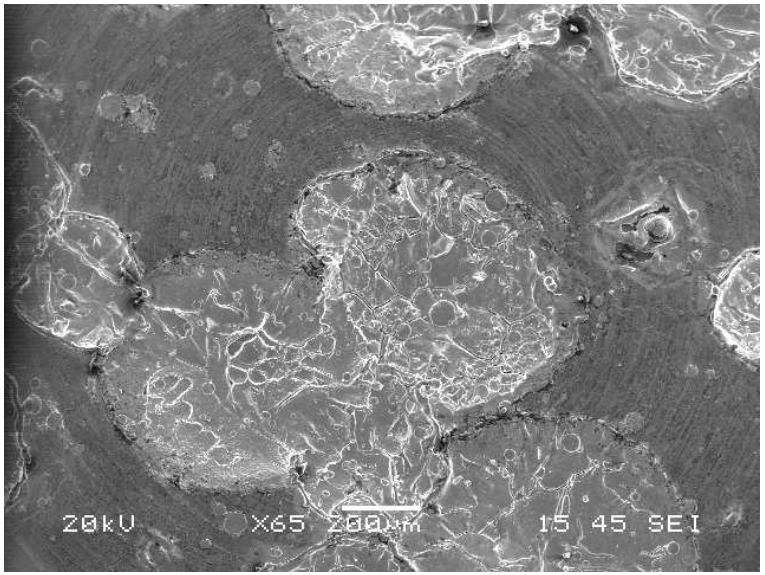


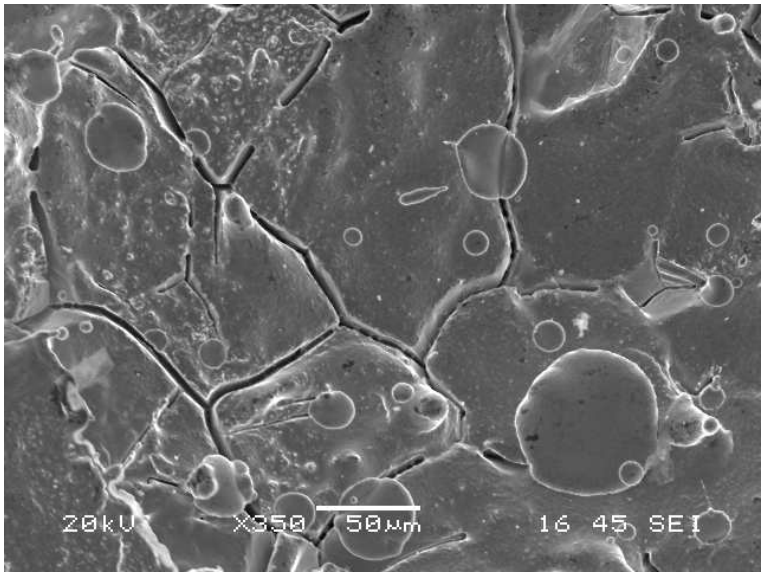


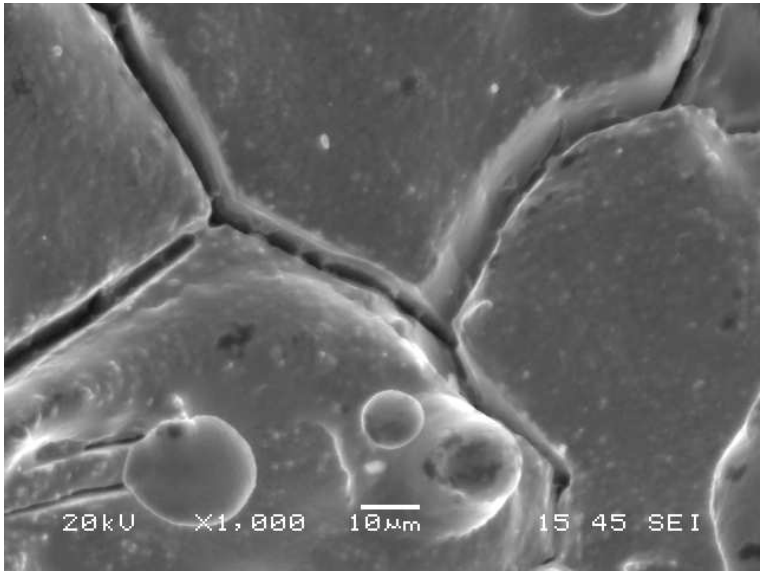


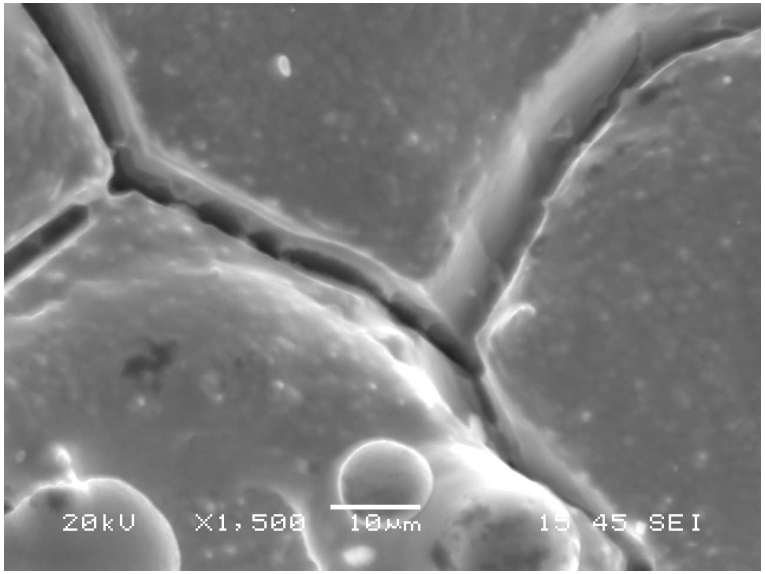
Images: LCSM, 50X, downstream copper button.

Catastrophic melting seen on Cu buttons.

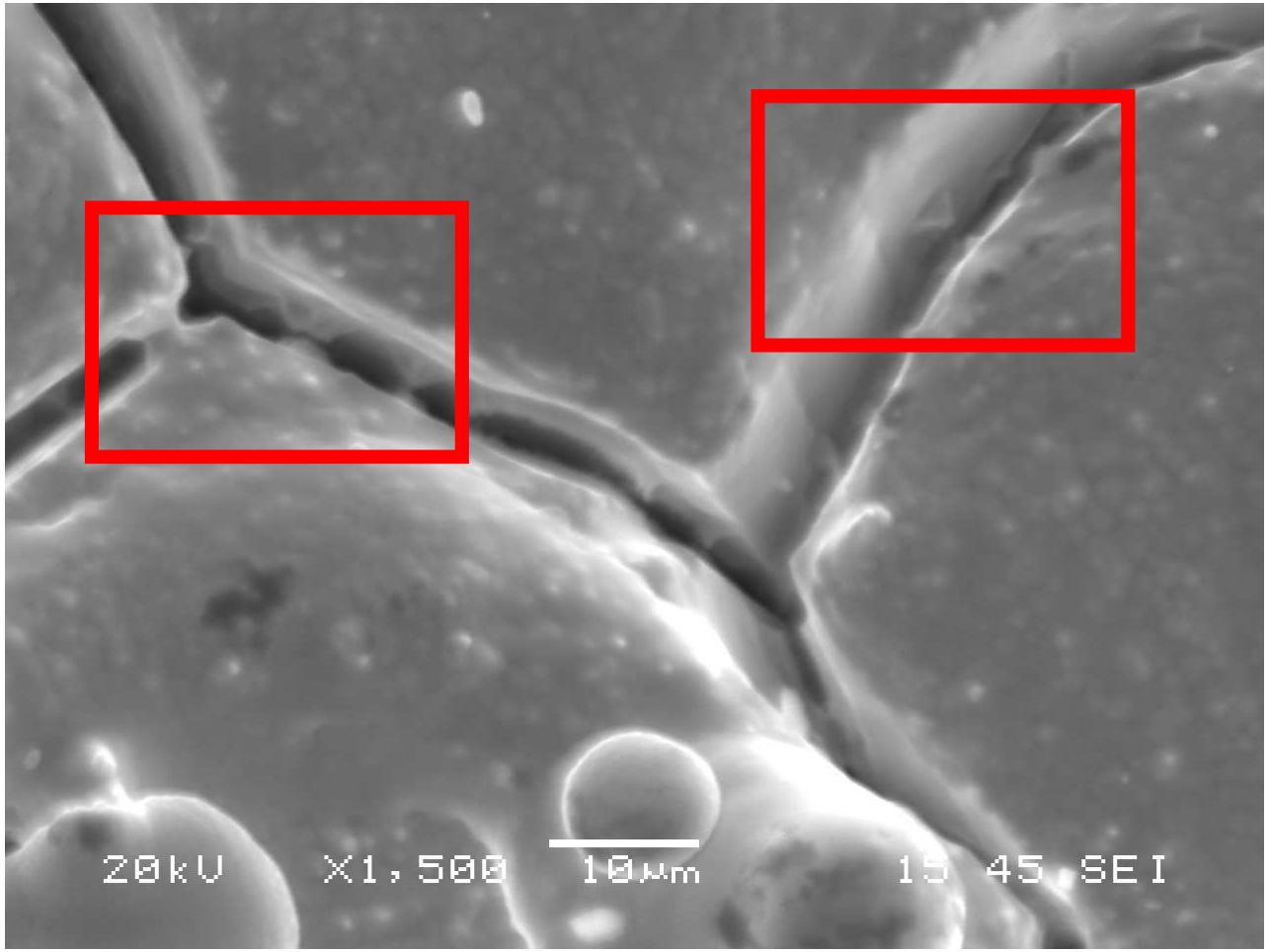








Catastrophic melting seen on Cu buttons.



Surface cracking may be explained by J. Norem's breakdown ideas.

One proposed model of breakdown damage:

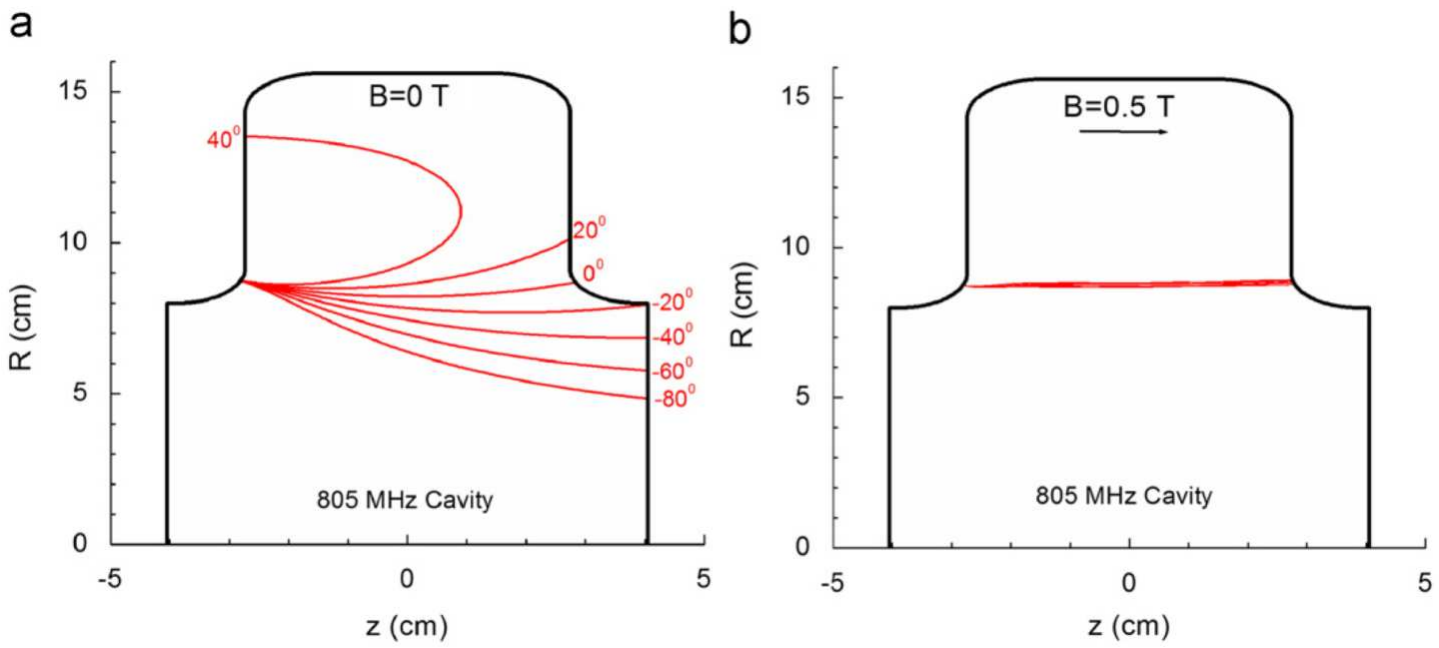


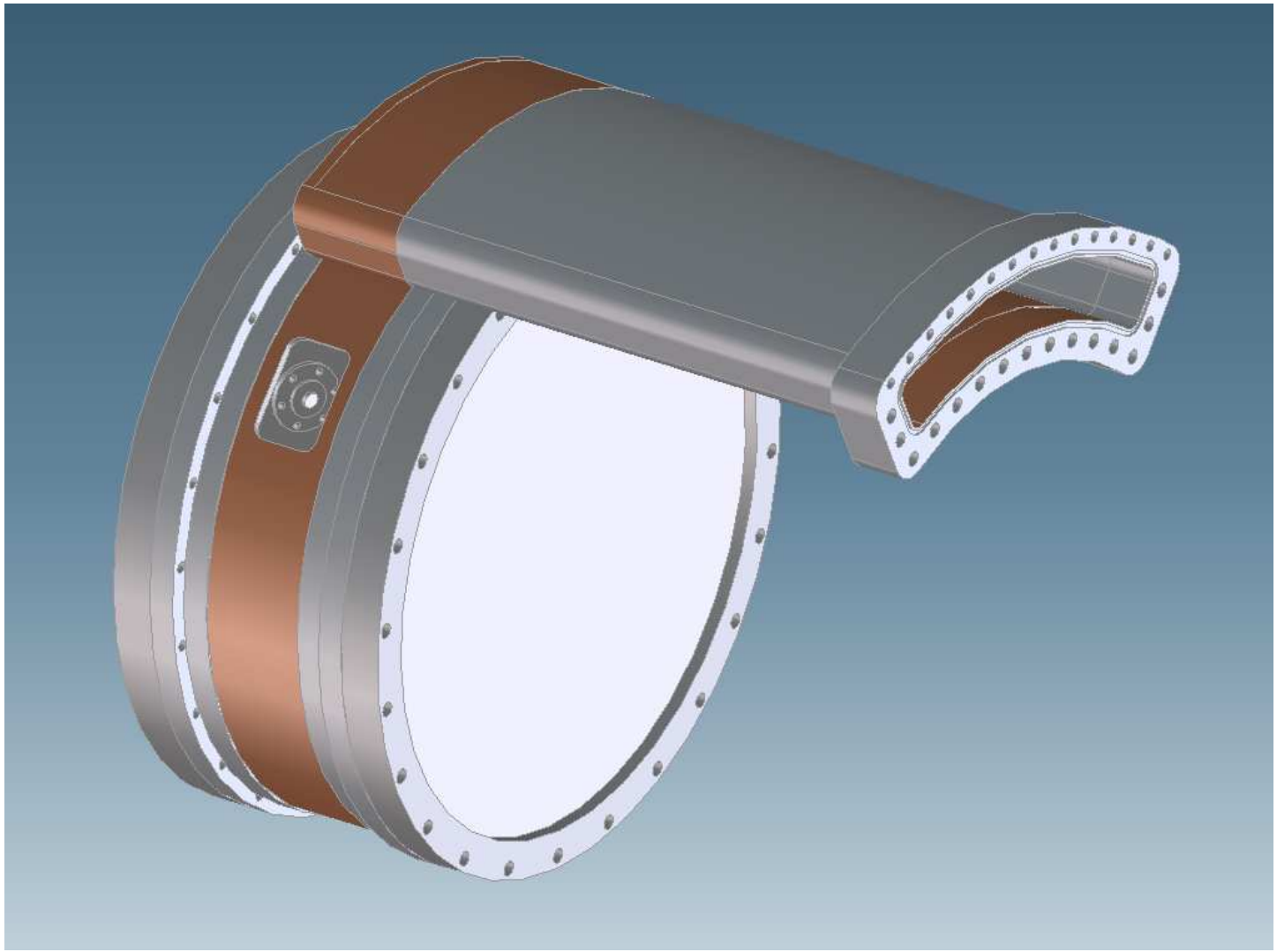
Figure: D. Stratakis, J.C. Gallardo, and R.B. Palmer, Nucl. Inst. Meth. A **620** (2010), 147-154.

Magnetic field focuses field-emitted electrons into a low-emittance beamlet. Beamlet causes cyclic fatigue, damage over several RF cycles.

We are now building a cavity with beryllium walls.

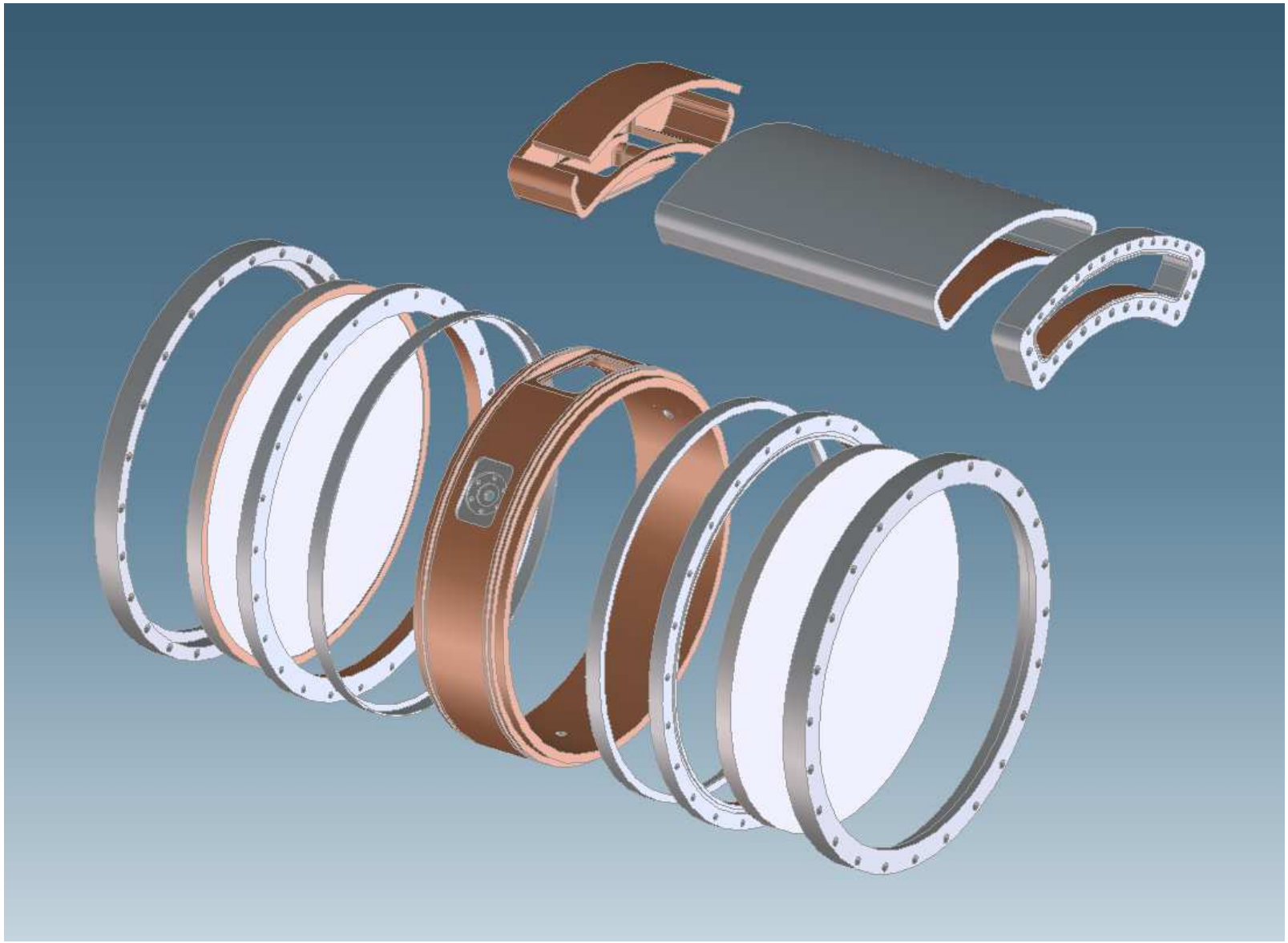
- Extensive Cu damage during breakdown, but not much observed damage on beryllium components.
- Be has a longer radiation length / lower density $\rightarrow$ less beamlet energy deposited in cavity walls.
- **Modularity** is desirable:
  - Replace/study damaged components easily.
  - Test Cu vs. Be walls.
  - Easily, quickly mount other hardware (buttons, detectors, etc.) on cavity walls.
- **Coupler redesigned** so peak field lies on the cavity axis ($E^{\mathrm{surf}}_{\mathrm{axis}}/E^{\mathrm{surf}}_{\mathrm{other}} \approx 4$). This **simplifies breakdown analysis**.

Design Overview

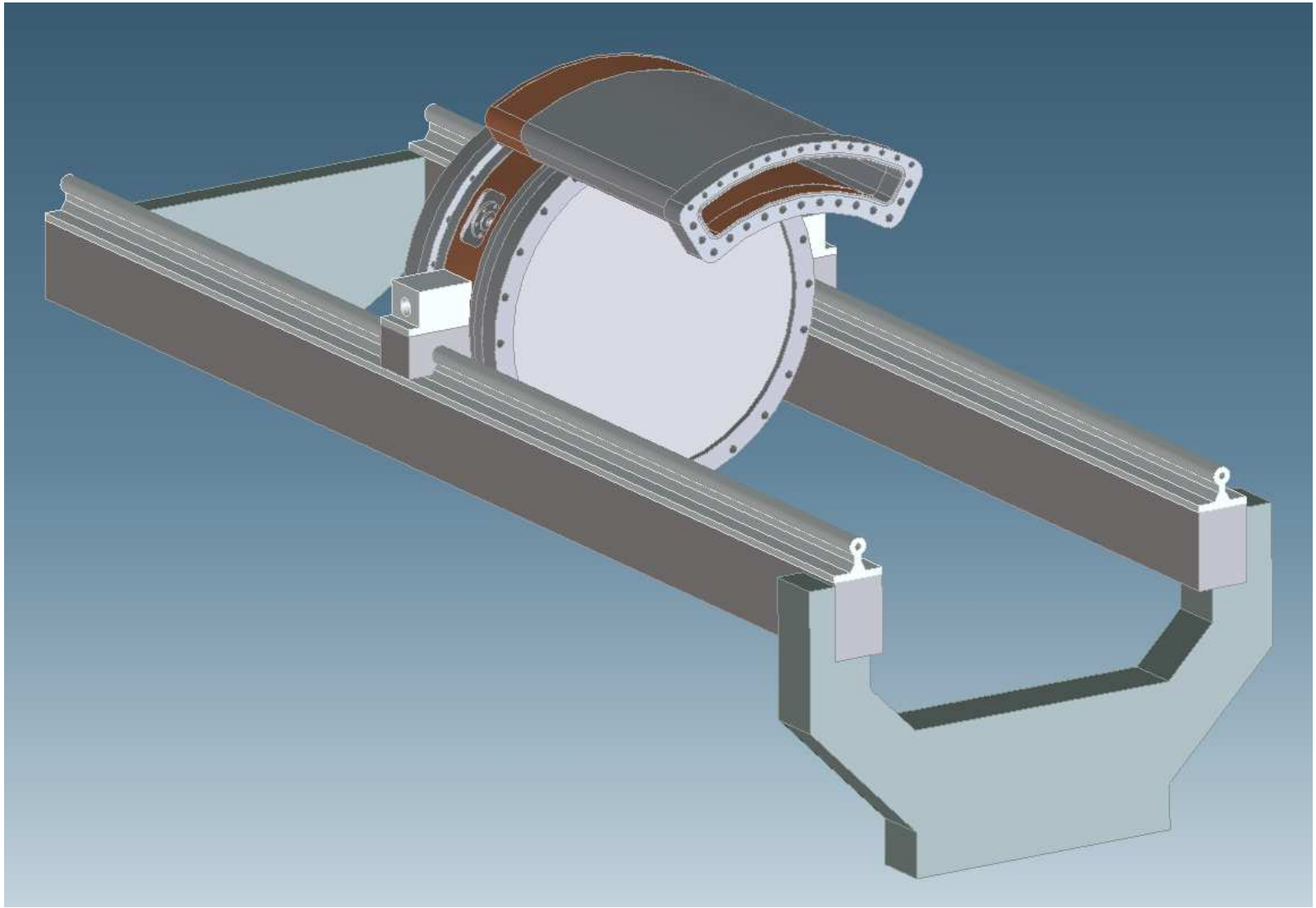


SLAC, LBNL joint mechanical design effort.

Mechanical Design: Exploded View



Mechanical Design: Magnet Rails



Next steps for the Be wall cavity:

1. Final "nuts & bolts" design elements: magnet mounting hardware, final cooling design, etc.
2. Strengthen experimental framework. Apart from E_{surf} vs. B plots, what other measurements? (See next slide.)
3. **Design review!**
4. Cautious optimism: Begin construction in September/October?

It would be interesting to make the following measurements:

- One button mounted opposite a detector: directly measure breakdown current.
- Button vs. anti-button: Separate roles of electric field, cyclic fatigue during breakdown.
- **Vary gap length**, evaluate role of stored energy, transit time during breakdown. Modular design makes this easy. Muons, Inc. cavity may also be helpful here.
- Build, test walls from harder, stronger materials (W, Mo, CuZr, CuAg, Glidcop) to evaluate role of pulsed heating, cyclic fatigue.

Acknowledgements

A growing collaboration indicates a healthy experiment.

- **LBNL**: A. DeMello, D. Kaplan, A. Lambert, D. Li, T. Luo, S. Virostek, M. Zisman
- **BNL**: R. Palmer
- **FNAL** (RF): A. Bross, A. Moretti, Y. Torun
- **FNAL** (surface science): D. Hicks, A. Romanenko
- **SLAC**: C. Adolphsen, A. Haase, Z. Li, D. Martin