Theory of rf breakdown in magnetic fields

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NuFact09

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1. Introduction
2. Hypothesis
3. Calculations
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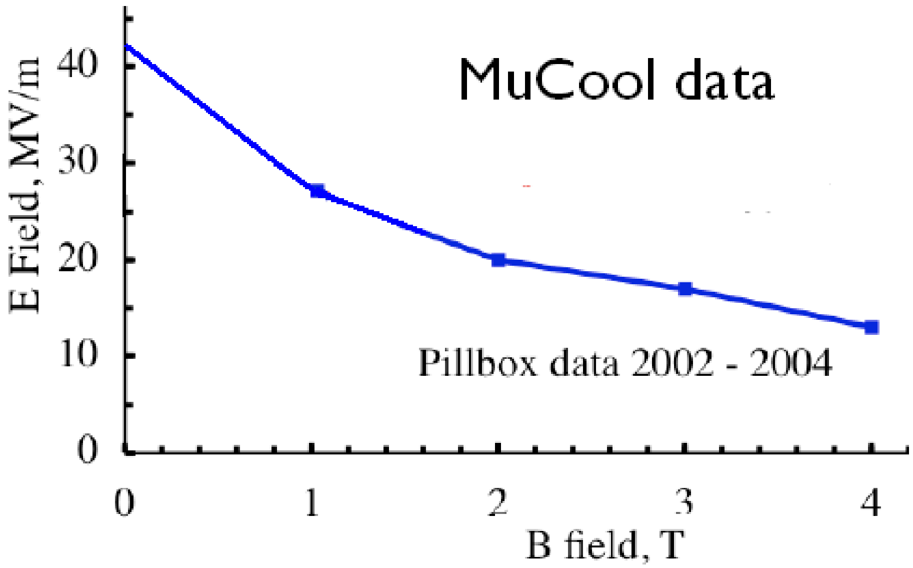
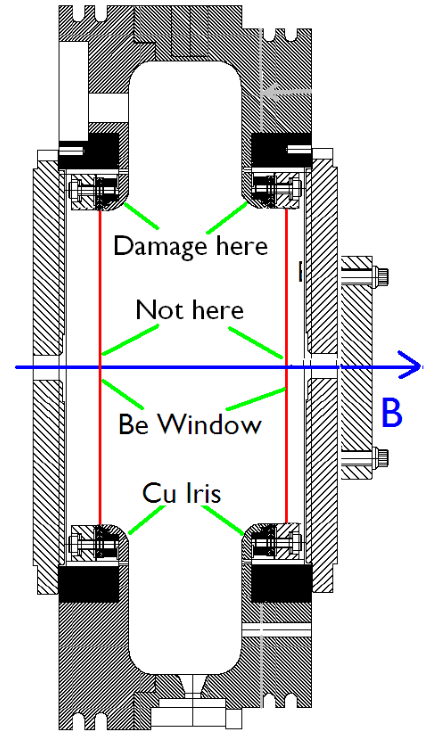
5. Predictions for Be & Al, on and off axis
6. Conclusion

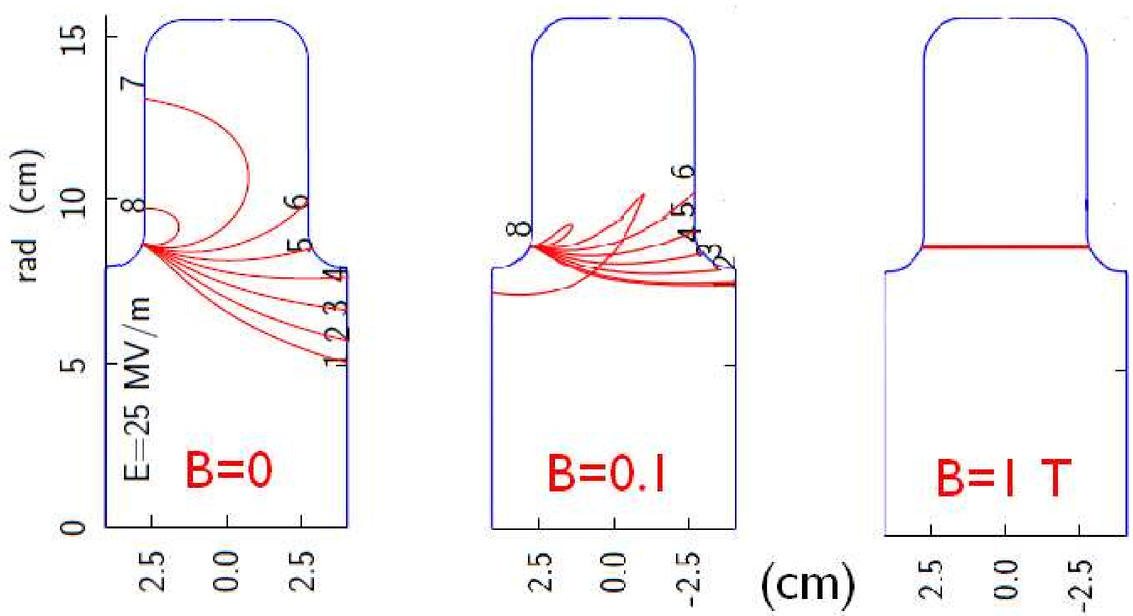
rf in magnetic fields





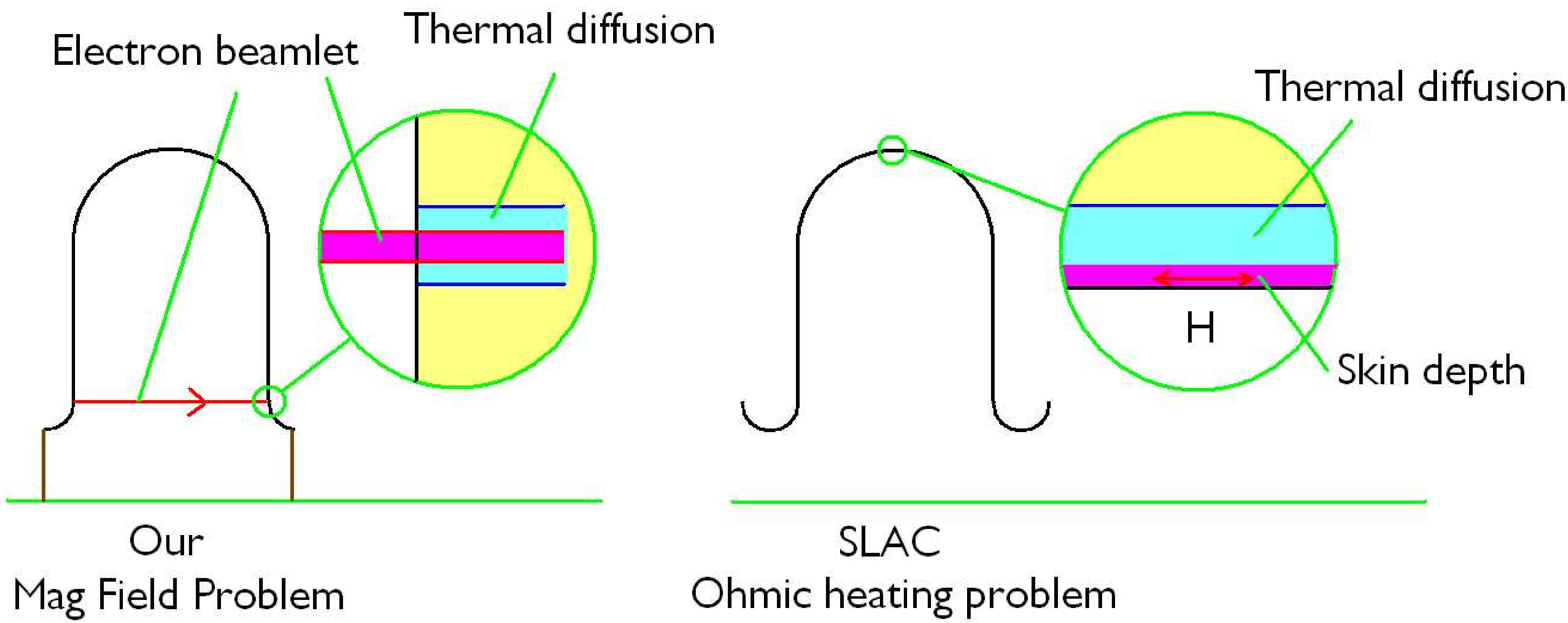
Hypothesis: damage & breakdown from focused field emitted electron beamlets

CAVEL Simulations



What is the damage & breakdown mechanism?

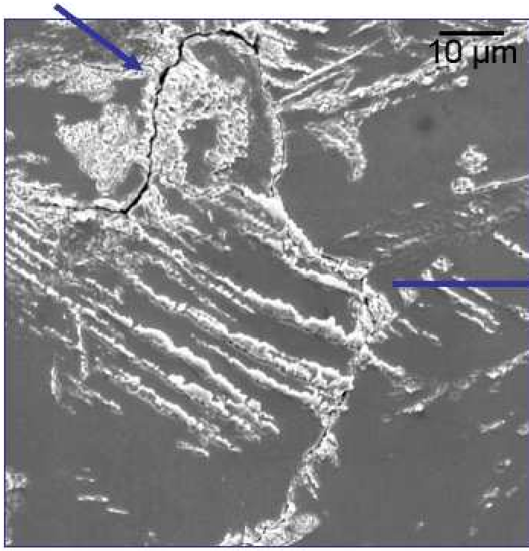
- The beamlets cannot be intense enough to melt the copper
- But they are enough to heat the surface to of order 50 degrees
- SLAC sees surface damage from cyclical surface ohmic heating of soft copper to 50 degrees



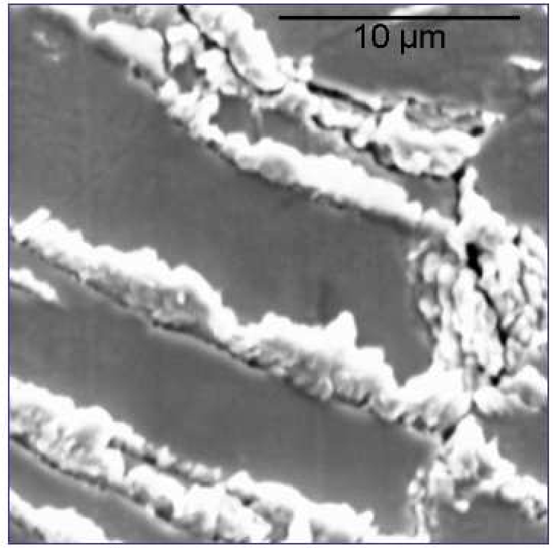
Damage form field emitted focused currents

Intergranular fracture

Copper1-2 (CERN)



High
Magnification



Transgranular fractures

Magnified damage seen by SLAC from cyclical ohmic heating

Damage

↓

Increased FN beta
+
Gas emmission

↓

Breaksown →

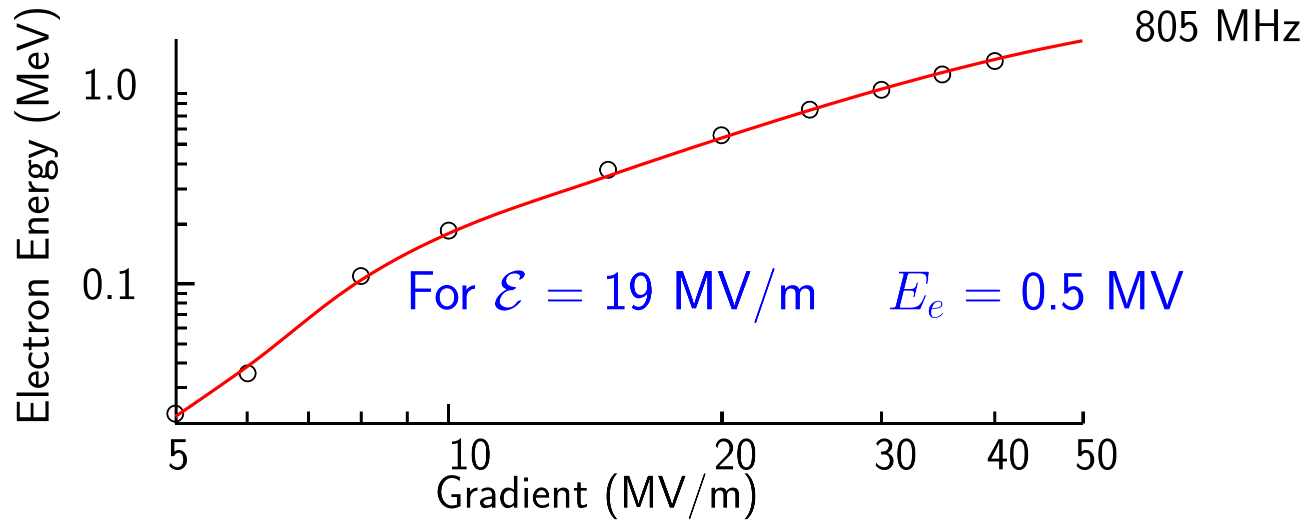
Damage no longer visible

100 μm

As seen by MuCool with Magnetic field

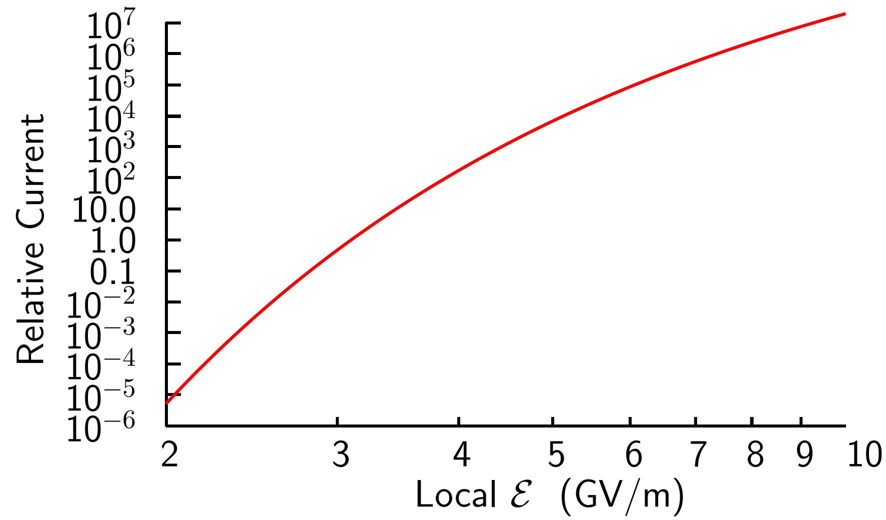
Calculations:

Energy on
arrival at
other side
From CAVEL



I vs. Gradient

Fowler Nordheim
Field emission



Beamlet radius **from PARMELA see Diktys Stratakis talk**

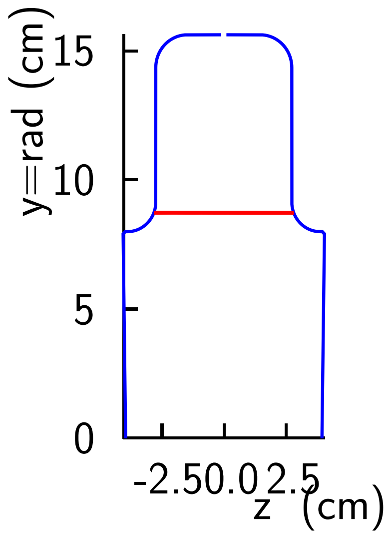
$$R(\mu m) = 22.6 \times \frac{I^{0.33}(\mu A)}{B(T)}$$

For I=105 μm, B=1.7 T:
R=61.6 (μ m)

Phase dependent sweep: dx

From CAVEL simulations

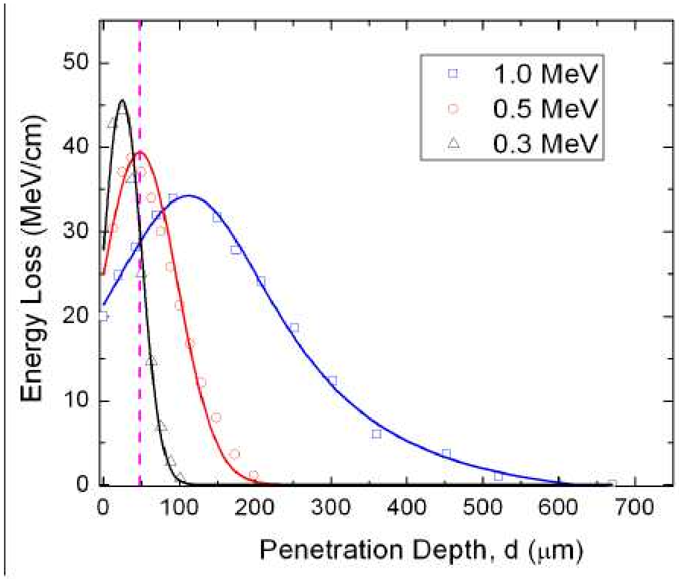
$$dxy \ = \ 0.031 \ \frac{\mathcal{E}}{\mathrm{B}} \sqrt{\frac{10}{n}}$$



$\mathcal{E}$=19 MV/m, B=1.7 T, n=10.7: $dx \ = \ 322 \ (\mu m)$

E deposition vs. depth

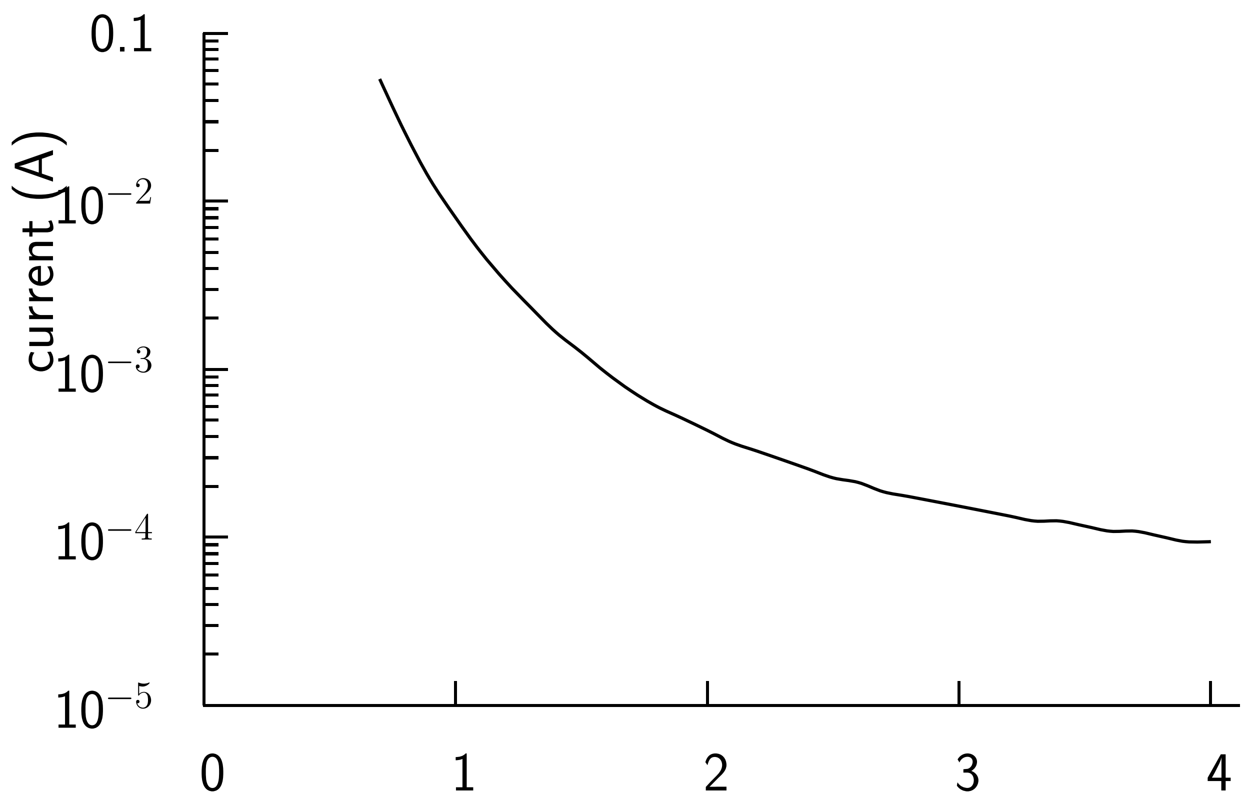
from Sandia Experiment

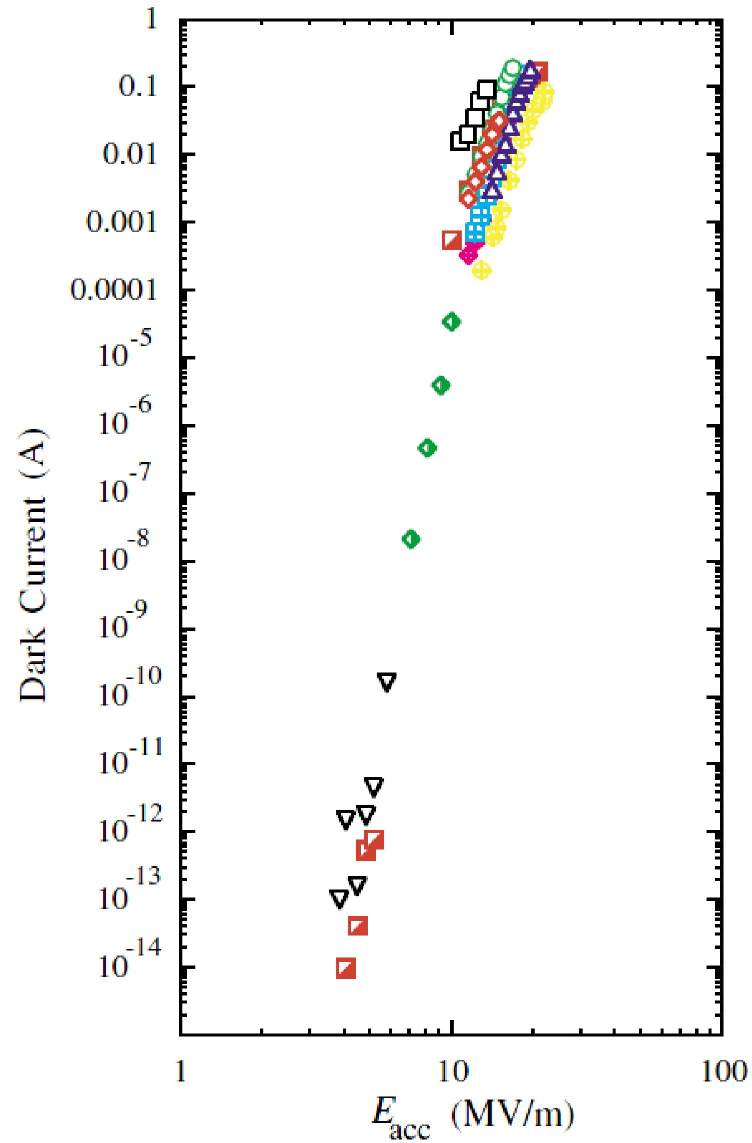


Preliminary treatment of thermal diffusion

- Assume heat deposits Gaussian in x and y with σs from sums in quadrature
- Thermal diffusion = D=0.01$\sqrt{K\tau/\rho C_p}$ (m)
- We are working on a 3D thermal simulation

Calculated required current to cause damage



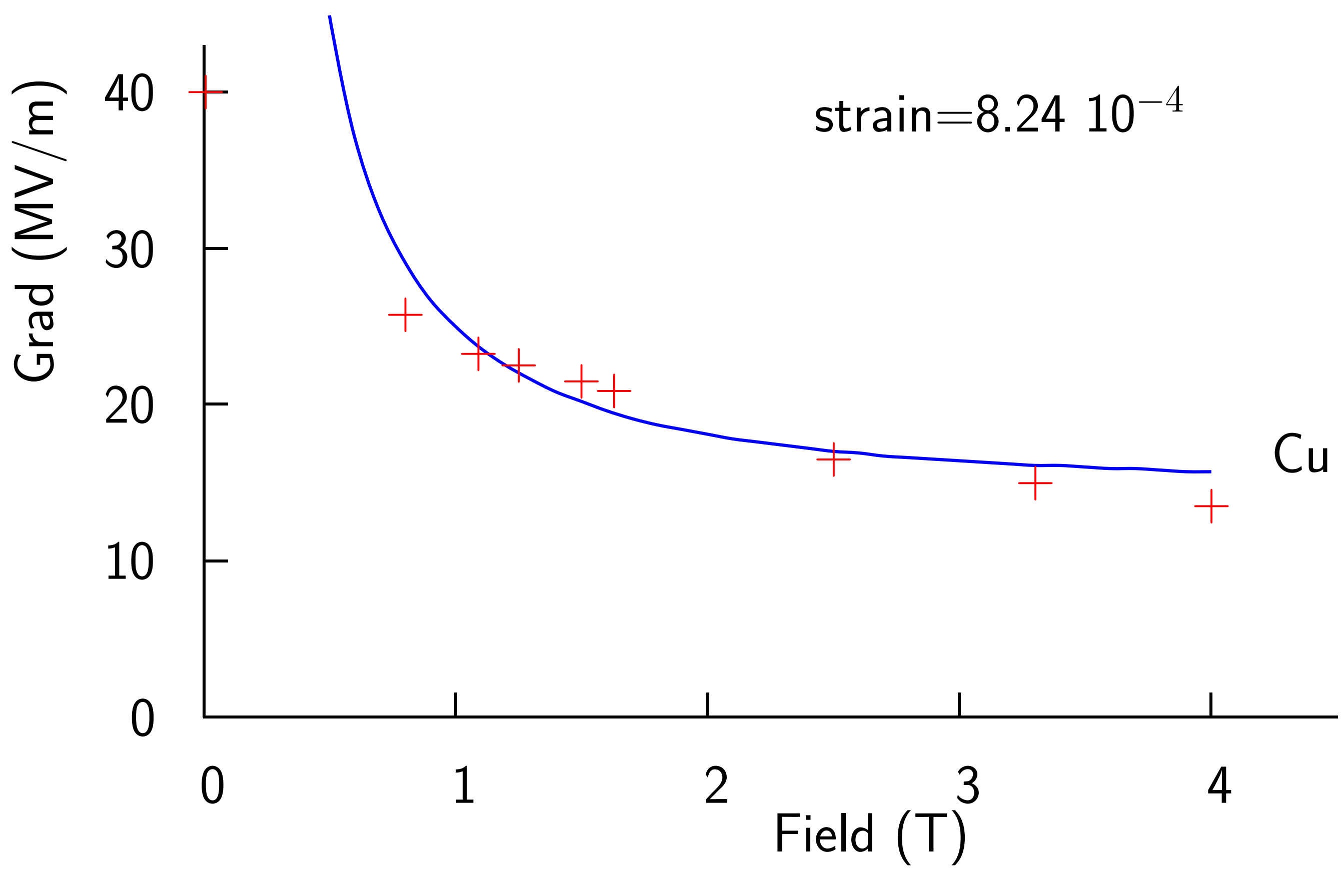


- Needed current of same order as seen in previous open cavity measurements

Breakdown gradient $\mathcal{E}$ vs B for Cu at iris

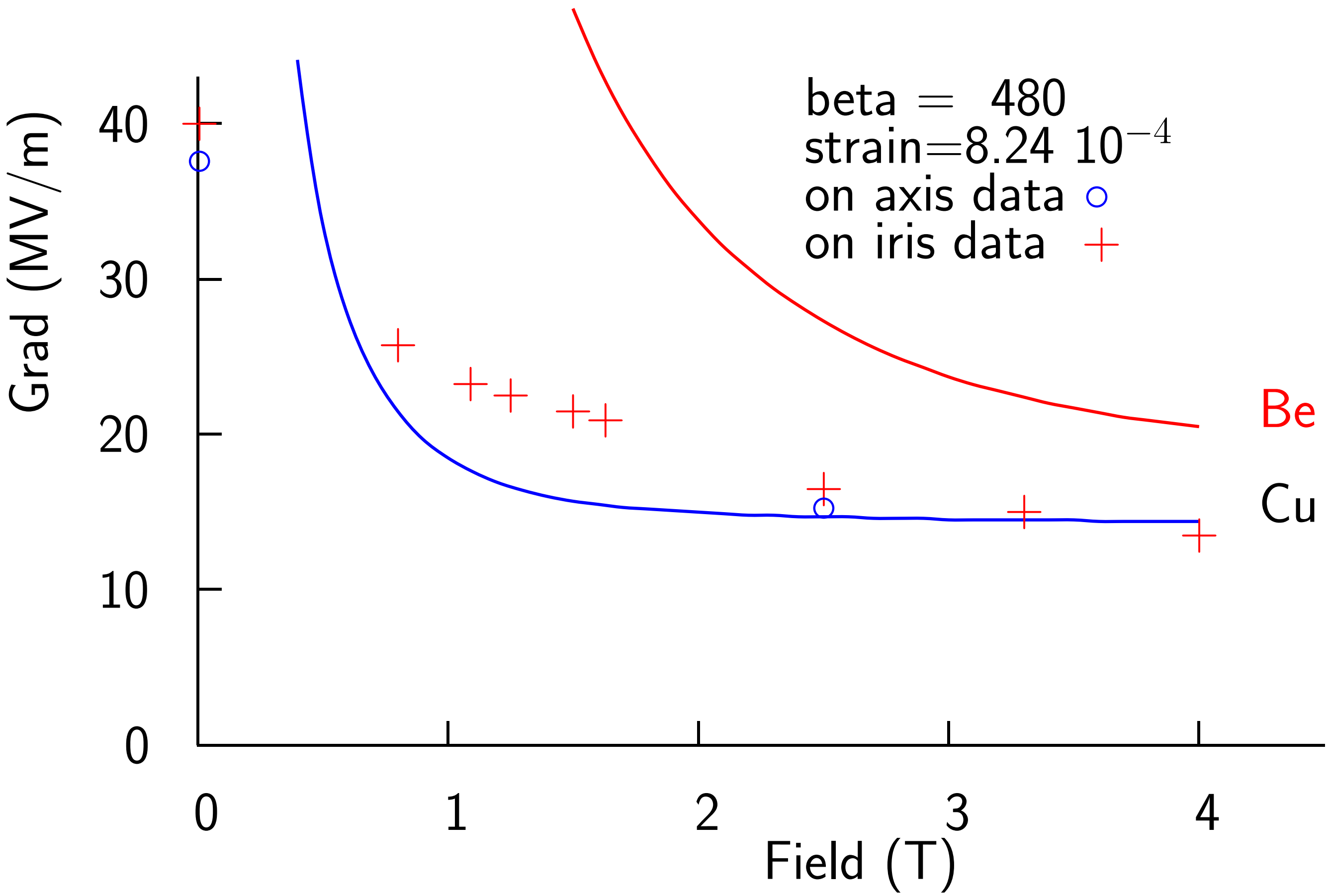
- Pick source radius (30 nm)
- β_{FN} =480,
- to get the required current at one field (1.7 T)

We can now determine the $\mathcal{E}$ that will give the same temperatures at other magnetic fields



Breakdown gradient $\mathcal{E}$ vs B for Cu and Be on axis

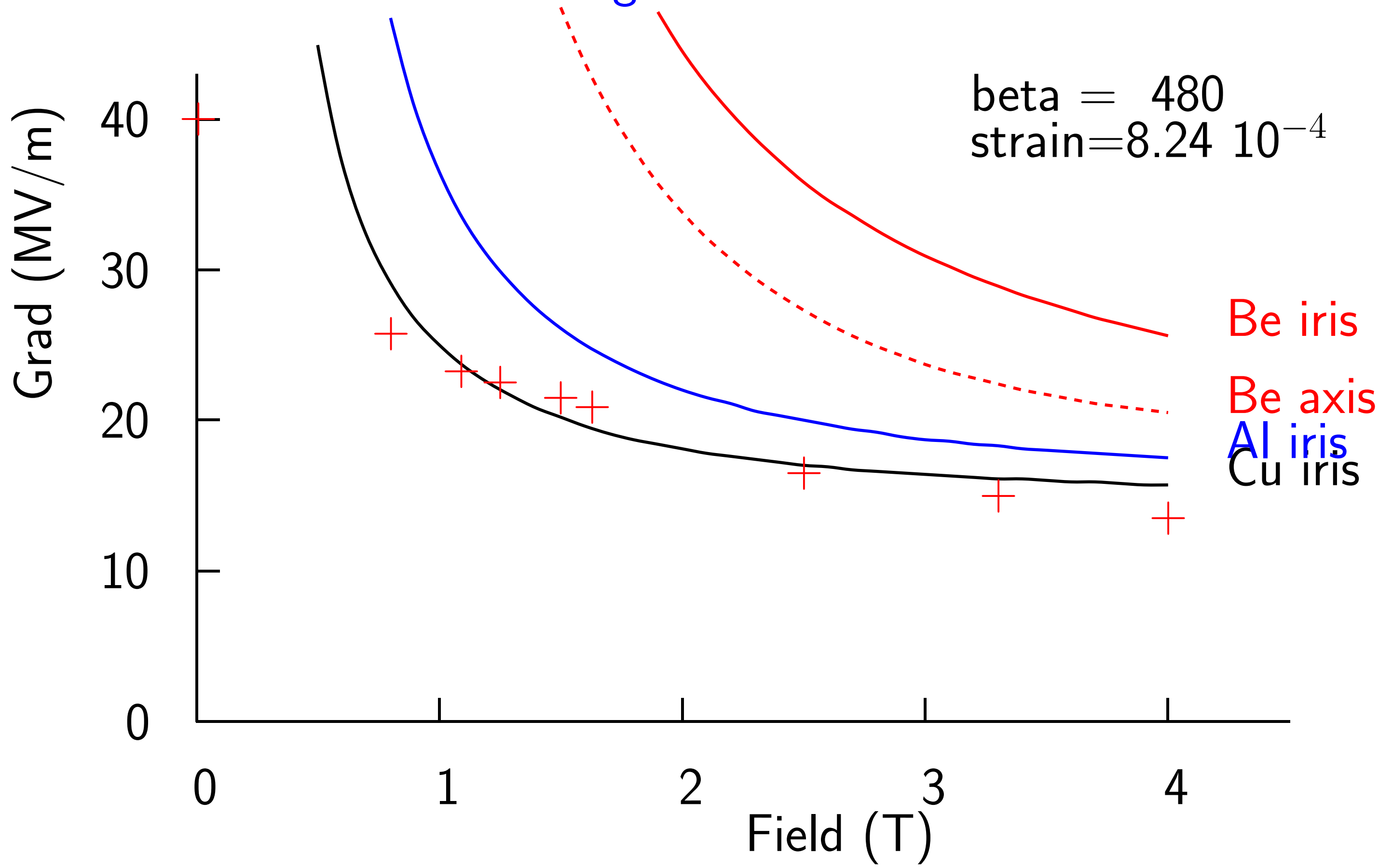
On axis there is no phase pependent sweep in x, and the beam is round and smaller requiring less $\mathcal{E}$ for damage



- Early experiment with copper "windows" got 16 MV/m at 2.5 T
- The gradients for Be are above the data, consistent with observed lack of breakdown on axis with Be windows

Breakdown gradient $\mathcal{E}$ vs B for Cu, Be, Al

For other materials damage assumed at the same strain as Cu at 50 deg.



- Al better than Cu, but not by much
- Be much better than Cu
- Lowering temperatures will increase thermal conduction and decrease expansion, but calculation must include temperature dependence of properties still being worked on

Summary

- Damage probably caused by field focused field emitted currents
- These induce thermal cycling of small areas where beamlets hit surfaces
- Damage creates new disparities that emit gas and induces breakdown
- Leaving molten residue

- Beryllium has much higher damaged threshold than copper

Ditkys Stratakis will discuss experiments to study this