RF Induced Backgrounds at MICE

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fact
Muon Collaboration

People

There are many people involved in this effort:

FNAL: A. Moretti*, A. Bross, S. Geer, Z. Qian,
A. Tollestrup V. Wu

LBL: D. Li*, R. Rimmer, M. Zisman

IIT: Y. Torun, N. Solomey

U of IL: D. Errede, L Ducas

Imp Col: E. McKigney

CERN: P. Gruber

and more . . .

*built the cavities

References

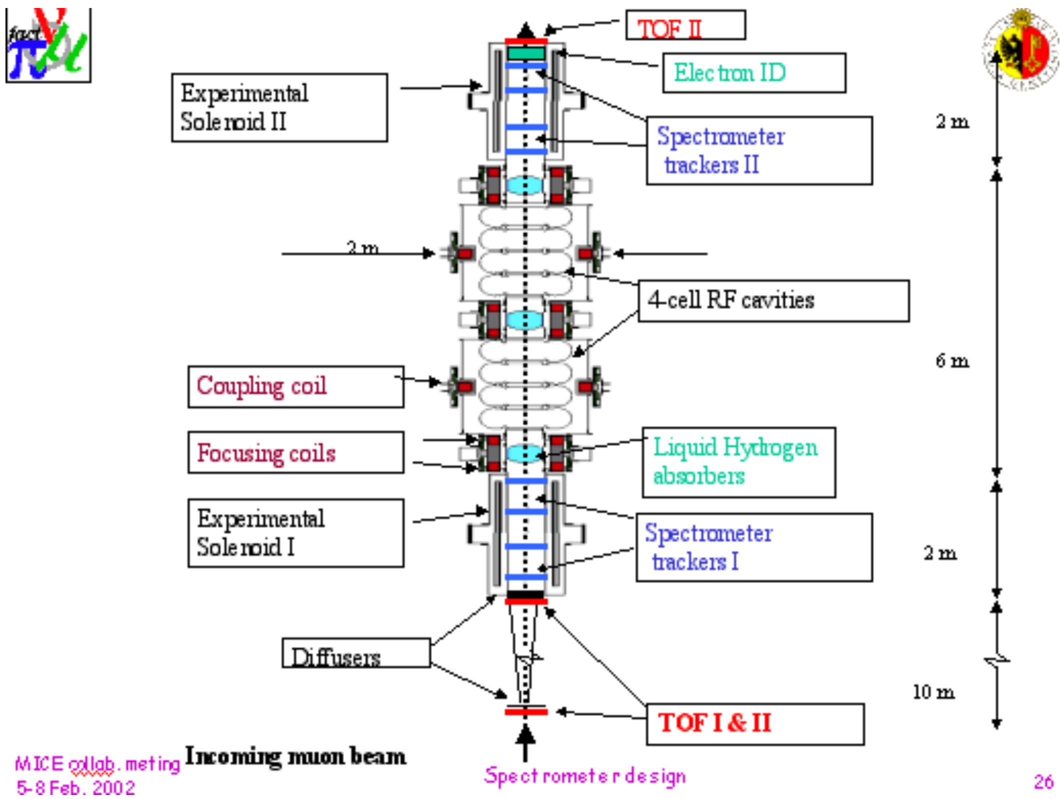
J. Norem, A. Moretti and M. Popovic, NIM, A472 (2001) 600.

J. Norem, V. Wu, A, Moretti, M. Popovic, Z. Qian, L. Ducas, Y. Torun, N. Solomey, Submitted to Phys. Rev. Spec. Top. / Acc. and Beams, (Apr. 2002), MUCOOL Note 235.

RF and Particle Detectors are Incompatible

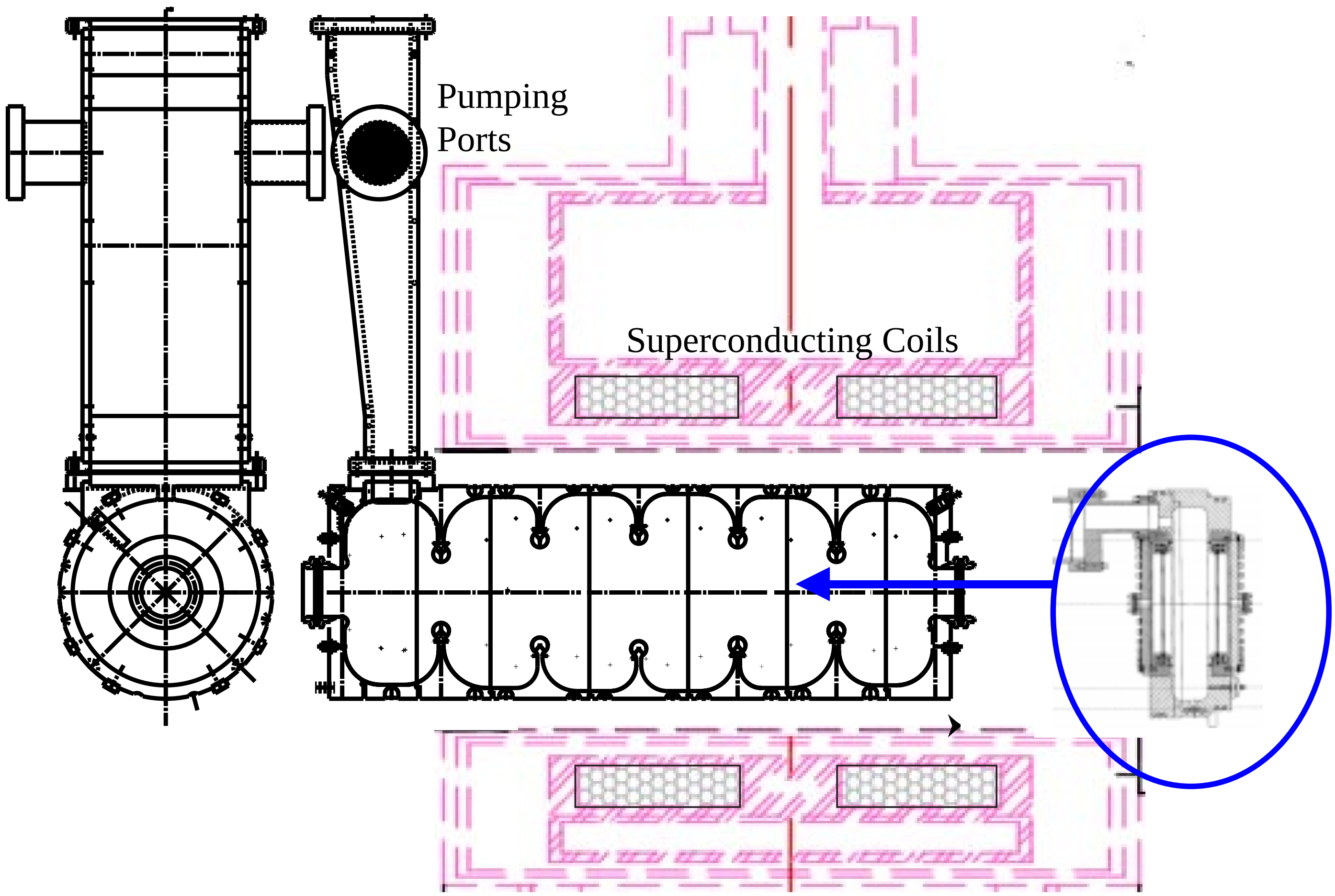
- RF systems produce dark currents and x rays, and these produce backgrounds that interfere with single particle measurements.

- The Muon Ionization Cooling Experiment requires that these systems work close together.



- We try to minimize the backgrounds by low accelerating gradients, and other tricks.

Fermilab Setup



- The cavity is a standing wave, π mode structure designed for 200 MeV/c muons, $\beta = 0.87$.
  $E_{surface} = 2.6\ E_{acc}$ FNAL open cell cavity
  $E_{surface} = E_{acc}$ LBL pillbox cavity

- The magnetic field can be 5 T solenoidal, 3.5 T cusp.

- Fermilab cavity June 20 - Dec 24 2001
  LBL cavity Feb. 1, present

Many Measurements Were Made

- 805 MHz Measurements
  - $I(E_{acc})$ data
  - Momentum spectra
  - I(B) and magnetic effects
  - Pulse length
  - Damage measurements
  - Range
  - Emitter density and beam properties in B field
  - Conditioning methods

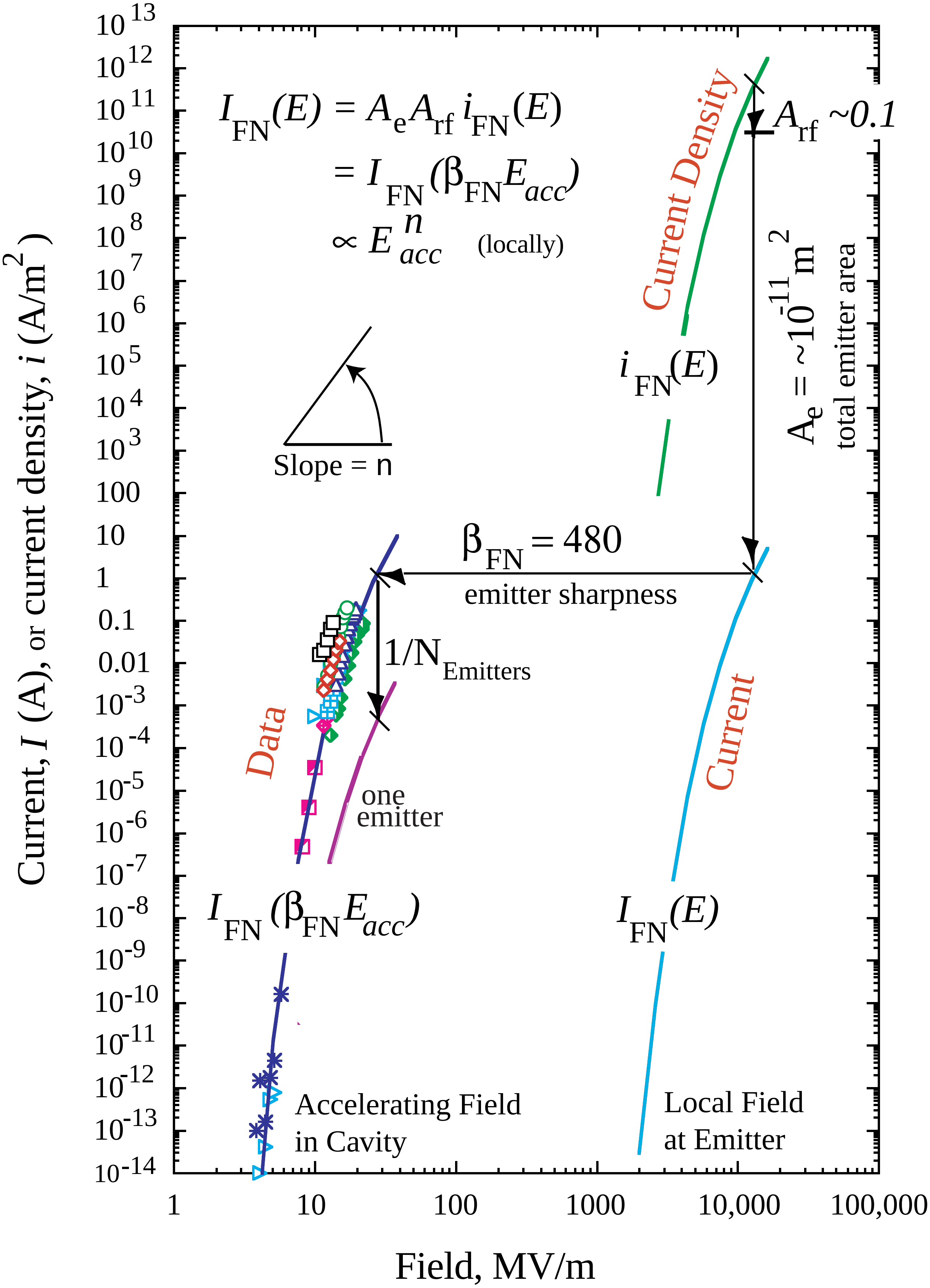
- these were compared with other measurements
  - Proton Linacs
  - NLC
  - Taiwan/AWA photo injector gun
  - Superconducting cavities

- Our measurements give a fairly complete picture of the dark current emission process.

- Our data seems to imply that mechanical failure of the emitter tips can occur due to electrostatic forces.

  - A similar phenomenon can occur in superconducting cavities, causing quenches

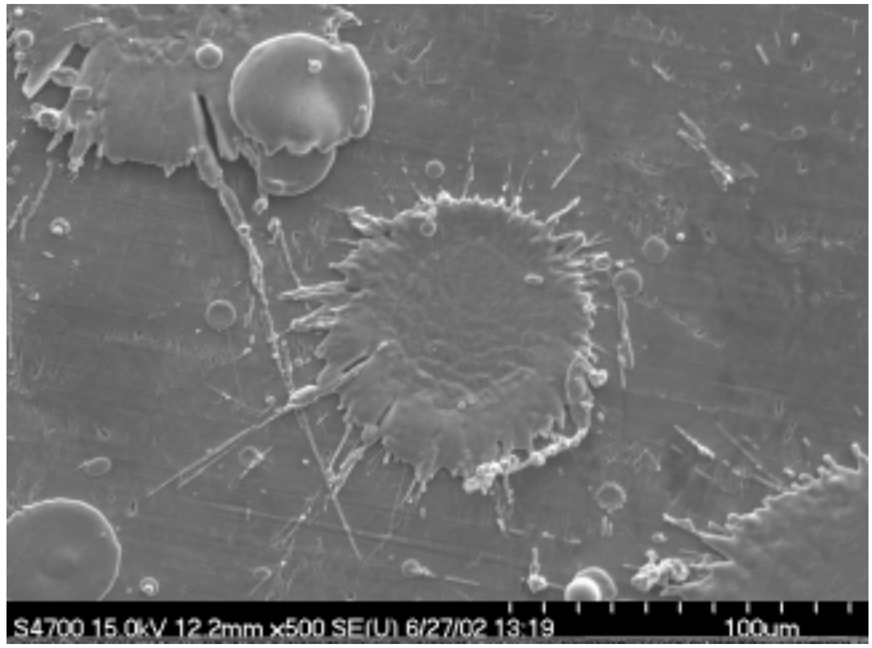
Fowler-Nordheim Field Emission



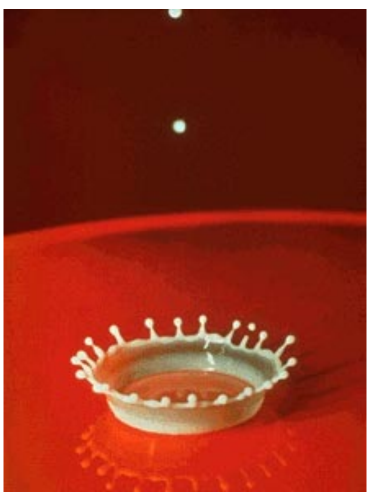
Breakdown Events Produce Emitters

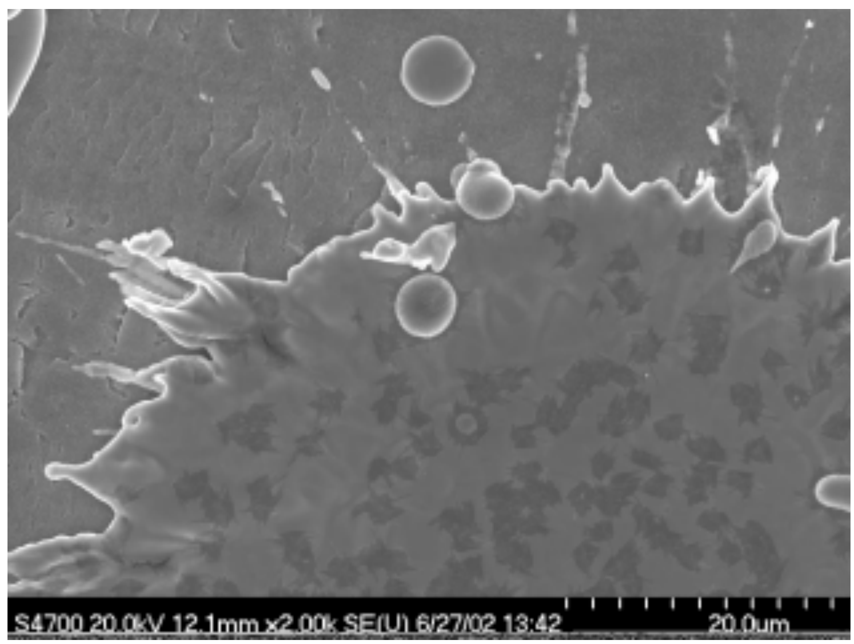
- Copper splashes produce sharp edges and long "wires".

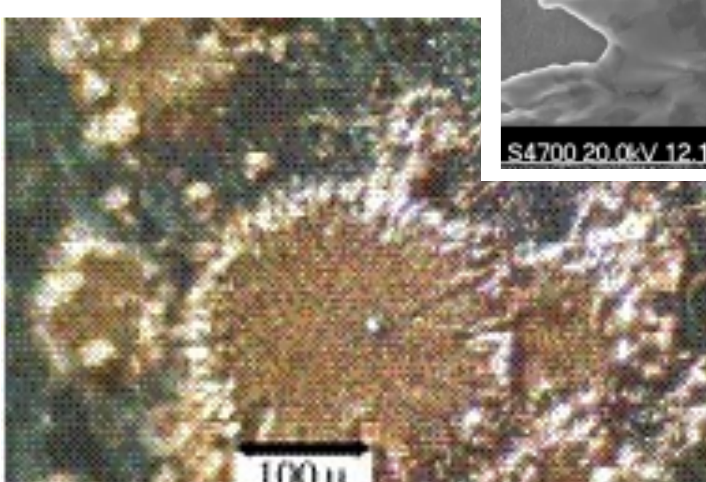
SEM pictures.
made by the Electron Microscopy
Center of ANL under USDOE
Office of Science



Milk Splashes



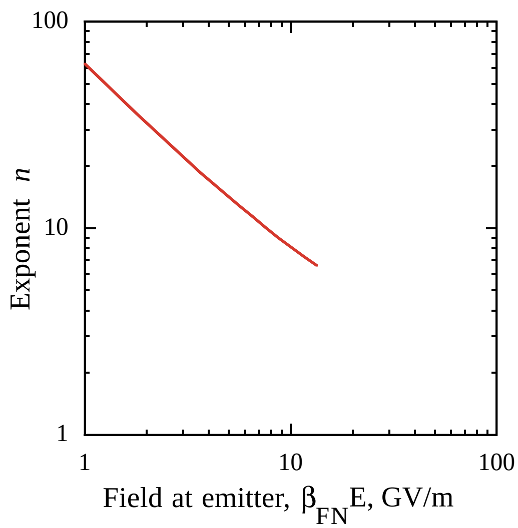


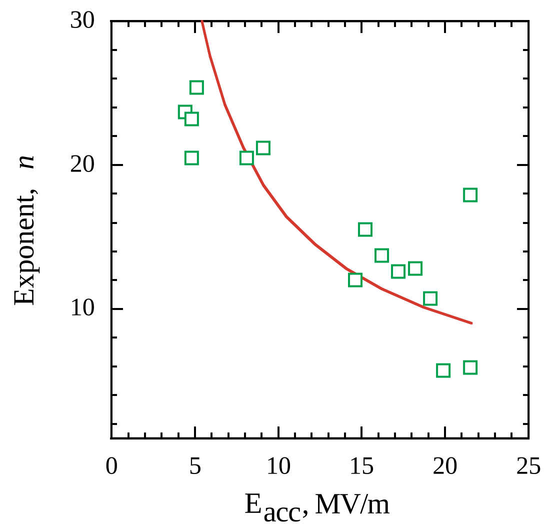


The colors and topography are shown in the optical micrograph.

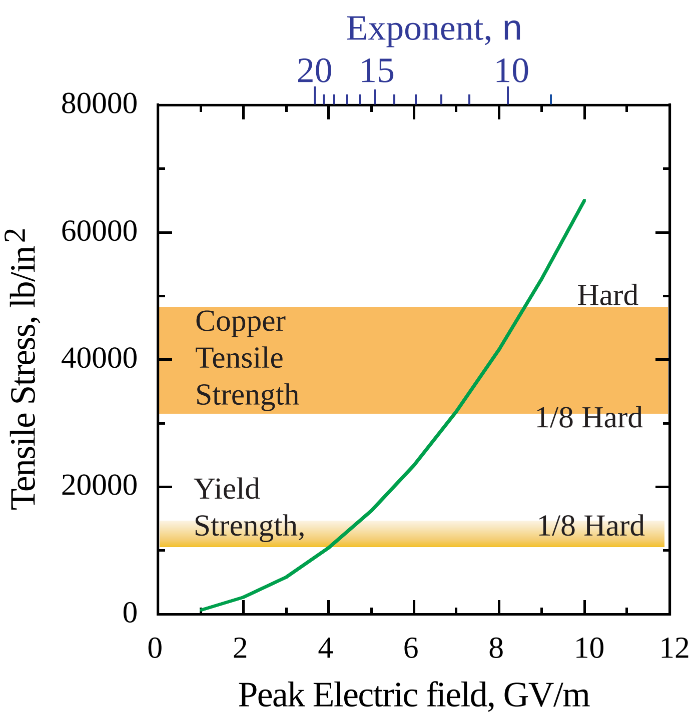
We See Huge Local Fields at Emitters

- E at tips ~ 8 GV/m, fitted from $I \sim E^n$



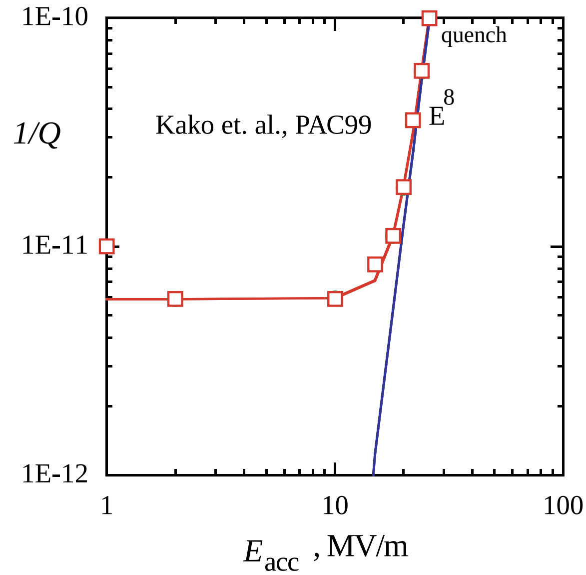


- Electrostatic stresses, $p = 0.5\varepsilon_0 E^2$, are comparable to tensile strength of copper at high fields.



Niobium SCRF Quenches

- The emitter sites we see evidently come from copper splashes, but the arguments are relevant to quenches in niobium cavities.
- Plotting $1/Q$ vs. E_{acc}



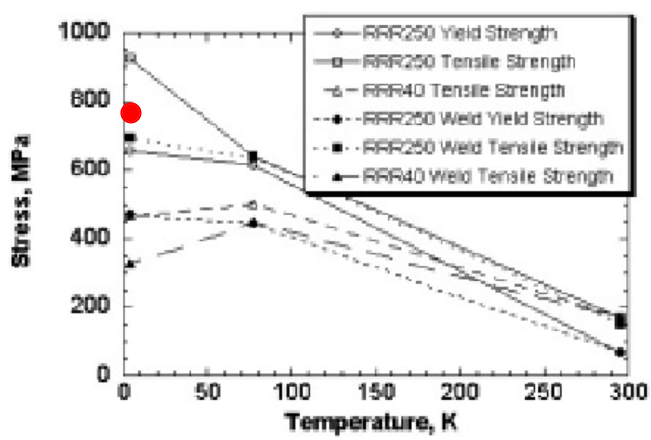
Power Loss ~ $E_{acc}{}^{8}$ ~ (I_{FN} ~ $E_{acc}{}^{7}$) (E_{acc})

$\Rightarrow$ n ~ 7

E_{tip} ~ 13.3 GV/m

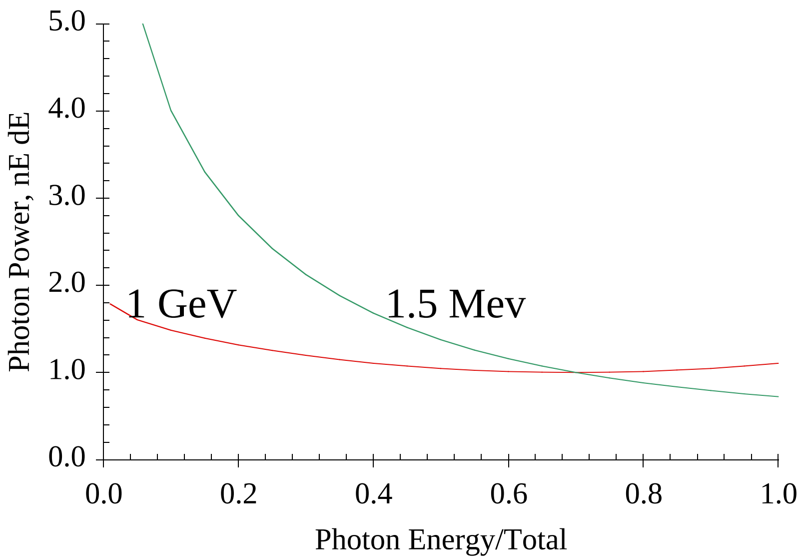
p ~ 770 MPa

This is consistent with Walsh et al ('99)

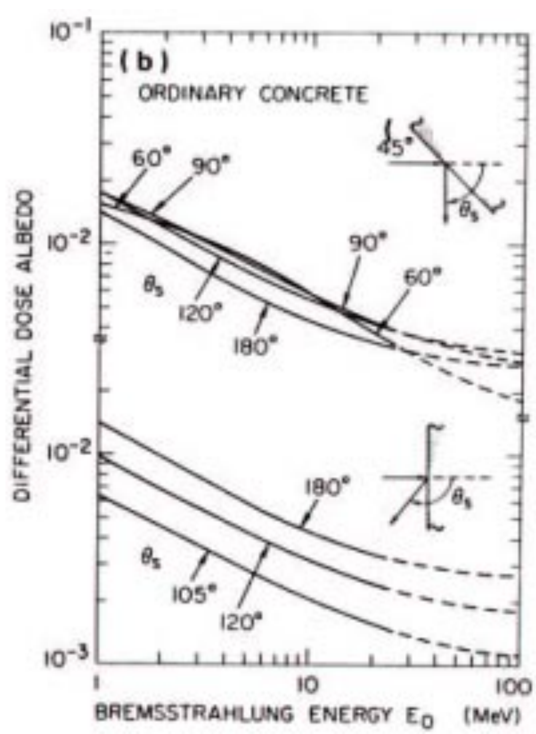


The Electrons We Produce are Low Energy

- Bremsstrahlung spectrum is different at low energies.

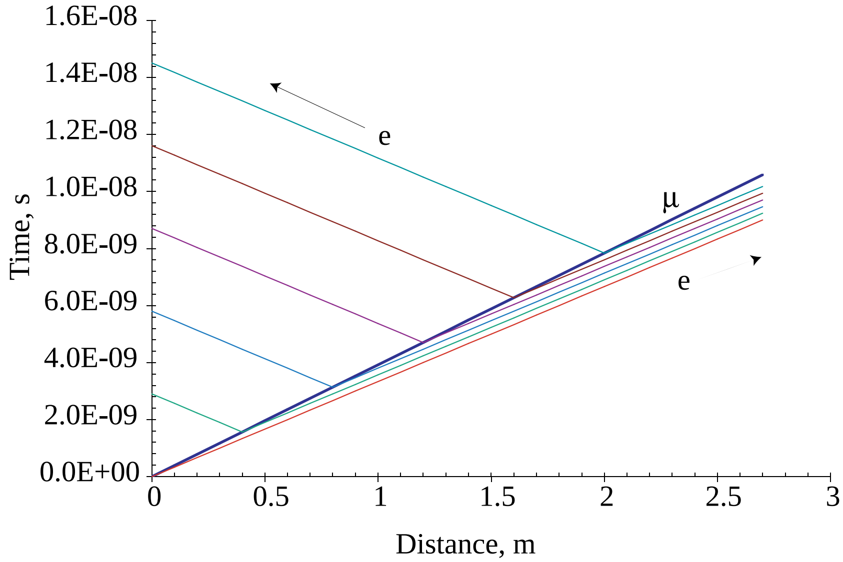


- And the photons bounce around a lot.

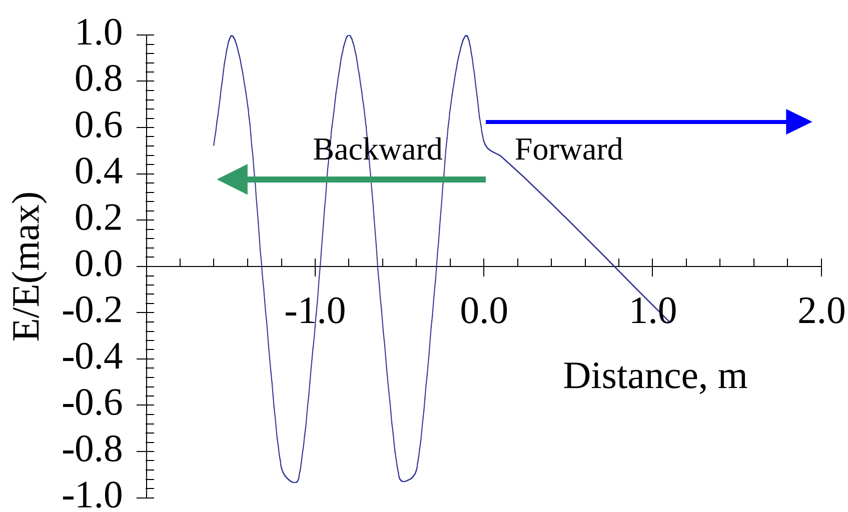


Designing Cavities to Minimize Backgrounds

- The velocities of electrons and muons are different.



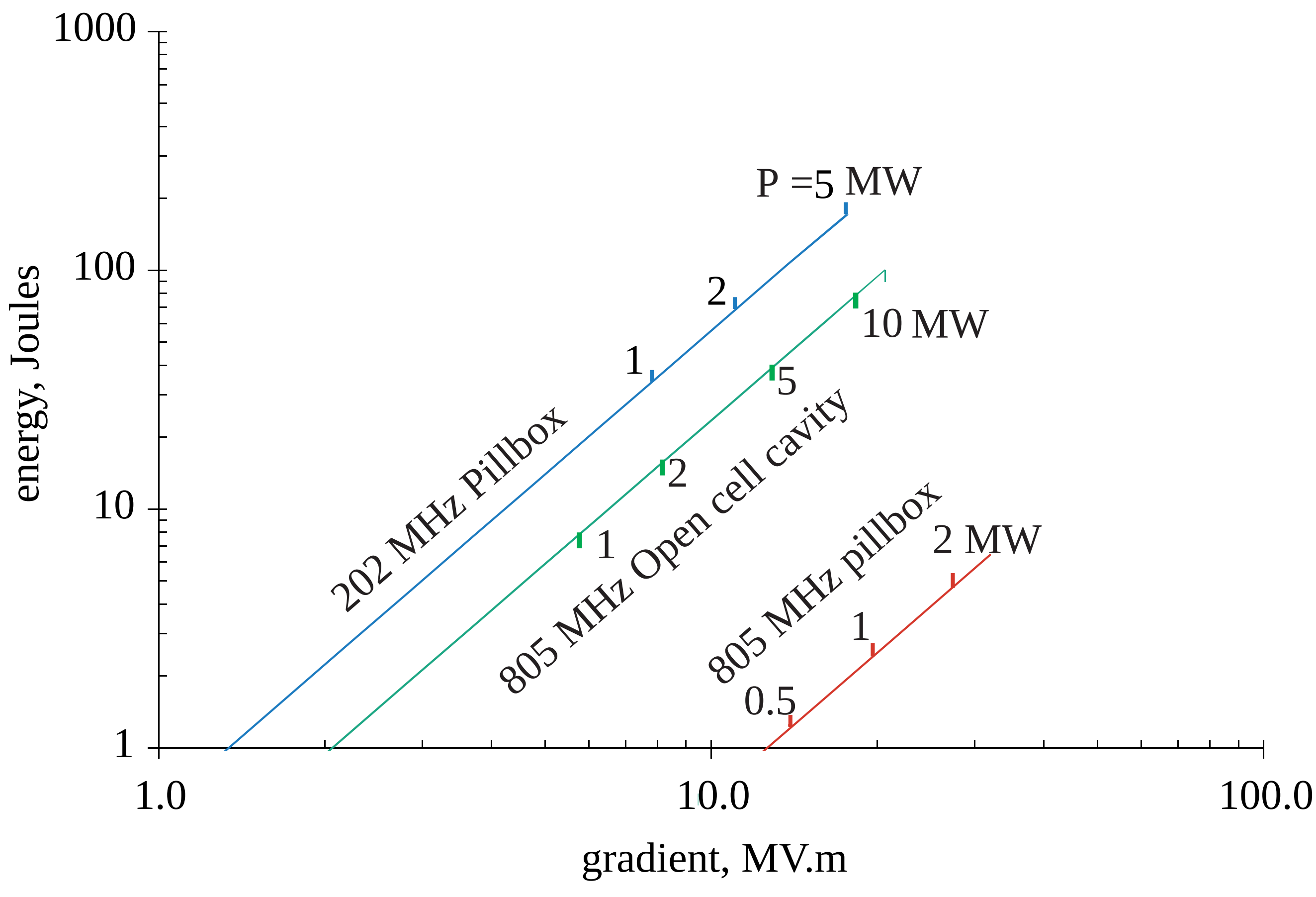
- And electron acceleration can be made inefficient.



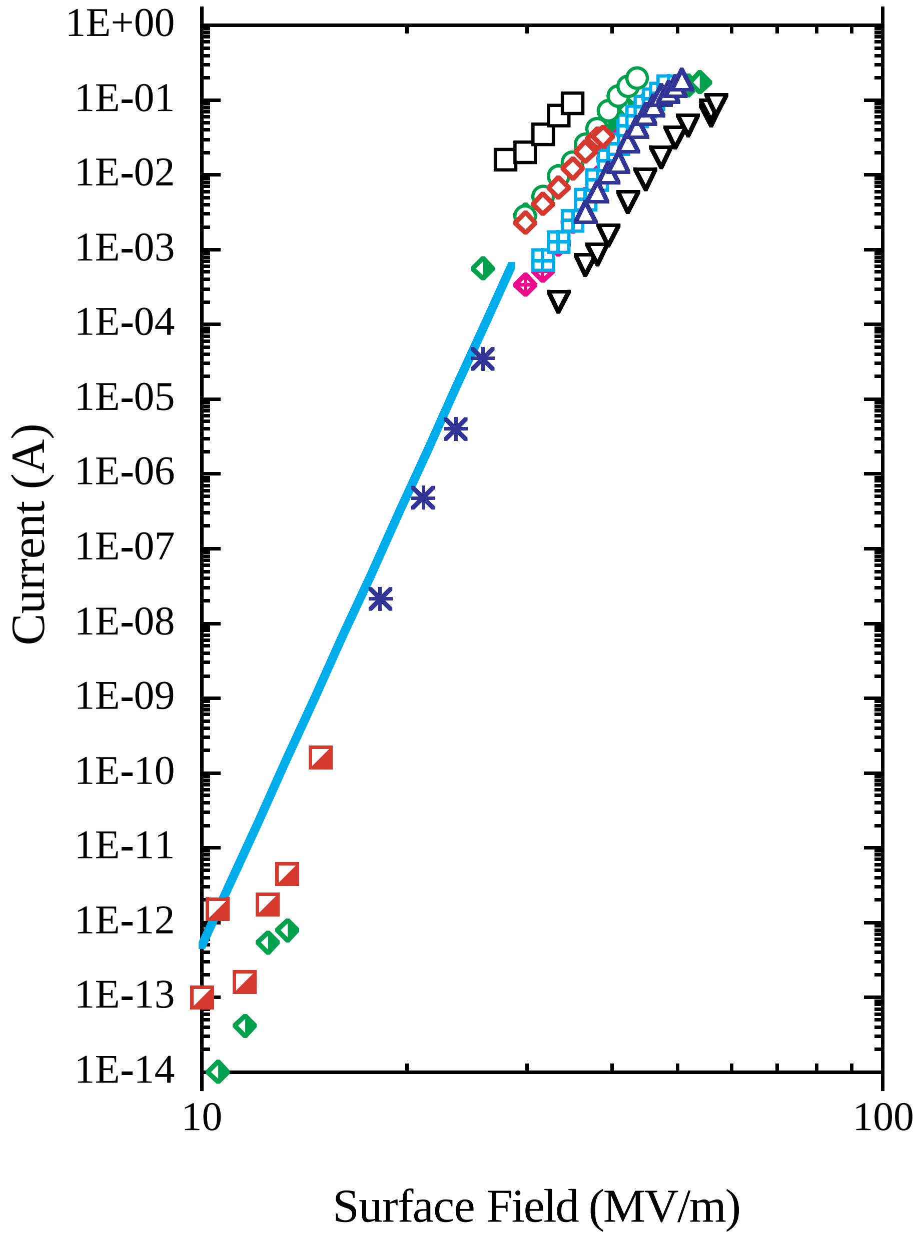
- Thin cavities will not accelerate electrons going in the wrong direction. Unfortunately thin cavities have low impedance. Can we phase thick cavities to minimize acceleration without making them inefficient?

Stored Energy

- The stored energy of the 200 MHz cavities will be comparable to the FNAL open cell cavity we have been using, which implies the same level of damage.

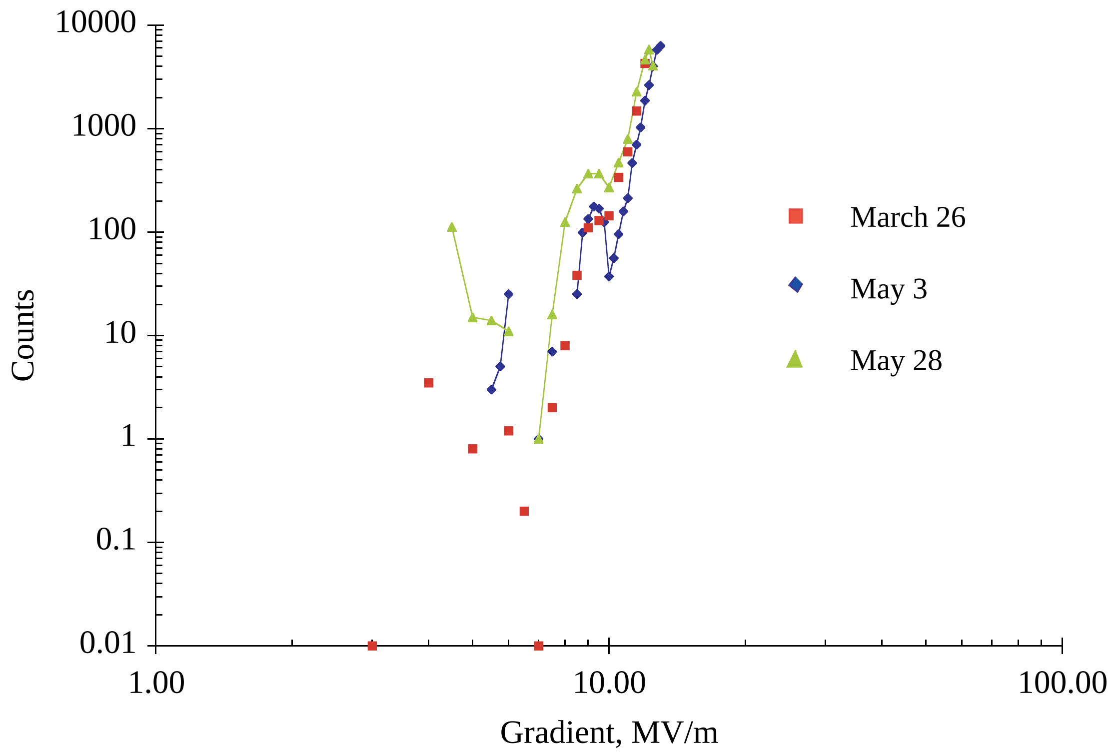


Gradient vs Surface Field from Lab G



- The open cell and estimate of pillbox dark currents are roughly consistent.

The LBL Cavity Shows Multipactoring



- We assume that the count rates below 10 MV.m are due to multipactoring phenomena.
- The rates are not constant over time.

Electron and X Ray Transport

- Electrons are inefficiently accelerated upstream. (We can optimize this inefficiency, but it makes our cavites less efficient.)

- Electrons are deflected by cusps. If

  $$p \,/\, 0.3 = B\rho < B_{sol}r, \sim 100 \text{ MeV/c}$$

  the electrons will be stopped when the field reverses. There will be bremsstrahlung produced though.

- Electrons can range out in absorbers.

- X rays are produced over a large solid angle, σ_θ~15 deg, and will be attenuated before reaching the target.

Conclusions

- Measurements at Lab G have clarified the picture.
  - Field emission causes all the problems.
  - Breakdowns and quenches in all cavities may be due to mechanical failure of emitters due to $p = 0.5\ \varepsilon_0 E^2$ electrostatic stresses. (new and controversial)

- Mechanical polishing may be the best way to improve cavity performance. (chemical and electropolishing large cavities is messy.)

- We will need simulations of dark currents to optimize the system.
  - The transport of low energy electrons is strongly affected by the cusps in the field.
  - Can we tune the cavity length to minimize dark current energies?

- We should be able to operate at respectable gradients, (12- 15 MV/m), with reasonable backgrounds.
  - We assume the Be windows will be OK - they need to be tested ASAP.
  - Cavity surface treatments should improve things.
  - Mutipactoring is also a concern. Nitriding cures this.