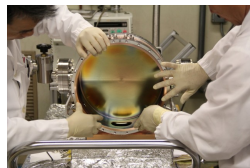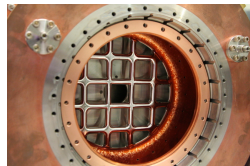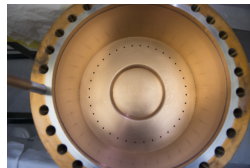# RF Breakdown of 805 MHz Cavities in Strong Magnetic Fields

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APT Seminar, April 30, 2015

Talk overview

1. Background material on ionization cooling, RF breakdown
2. Introduction to Fermilab's MuCool Test Area
3. A model of RF breakdown in strong magnetic fields
4. Operational experience with normal-conducting cavities for ionization cooling R&D at the MTA
5. Current status and future plans

Overview of muon ionization cooling


http://mice.iit.edu/
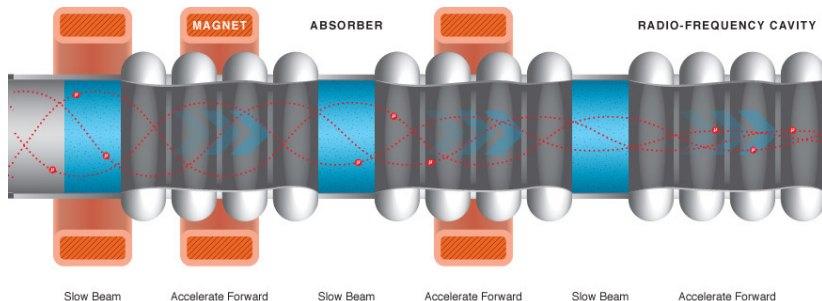
- ▶ Absorbers isotropically attenuate muon momenta
- ▶ Longitudinal momentum replaced by RF cavities
- ▶ Focusing via solenoids
- ▶ **Ionization cooling R&D at Fermilab indicates multi-Tesla magnetic fields increase the rate and extent of RF breakdown in Cu cavities.**

Overview of RF breakdown

- A century-old problem affecting many RF structures
- Sudden, picosecond-scale discharge of cavity stored energy
- Spike in vacuum pressure
- Arc discharge causes damage, limit cavity gradients, luminosities, etc.
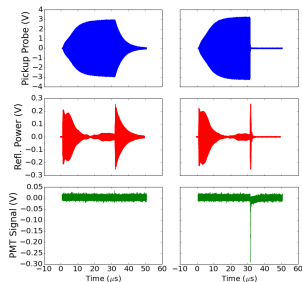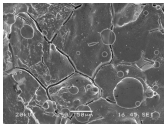
Cavity pickup probe voltage, reflected power from directional coupler, optical fiber → PMT. Left column is a normal RF pulse, right column is a breakdown event.

We have a model that describes the influence of magnetic fields on RF breakdown rates.
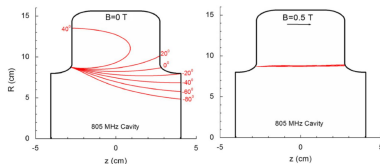
- ► D. Stratakis, *et al., NIMA* **620**, 2010, pp147-154.
- ► Field emission current focused by solenoid into "beamlet".
- ► Beamlet persists, leading to surface failure.
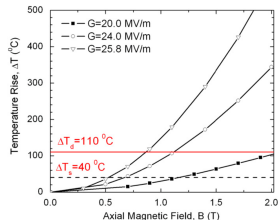
ΔT_d here is the temperature rise required for the onset of local plastic deformation.

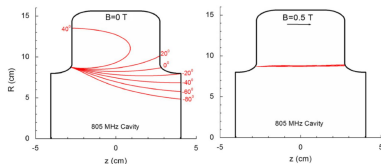# We have a model that describes the influence of magnetic fields on RF breakdown rates.

- ▶ D. Stratakis, *et al., NIMA* **620**, 2010, pp147-154.
- ▶ Field emission current focused by solenoid into "beamlet".
- ▶ Beamlet persists, leading to surface failure.

Mitigation Options

- ▶ Surface polishing and cleaning reduces field emitter sites.
- ▶ Beamlets deposit less energy in materials w/ long radiation lengths.
- ▶ Less plastic deformation for harder materials.

There is experimental support for this model.

- At Fermilab, we have tested several cavities at the MuCool Test Area (MTA). These exhibit breakdown behavior consistent with the model described above.
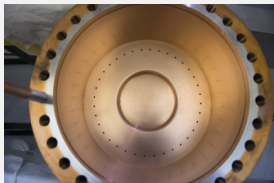- We'll discuss the MTA next, and the relevant work that has been taking place there.

A brief introduction to the MTA

- 400 MeV H^- linac beam, 7.5×10^{12} max particles/pulse
- RF power: 12 MW @ 805 MHz, 4.5 MW @ 201 MHz
- 5 T solenoid, 44 cm ID
- Portable clean room
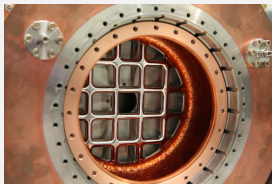- DAQ, control workstation in Linac gallery
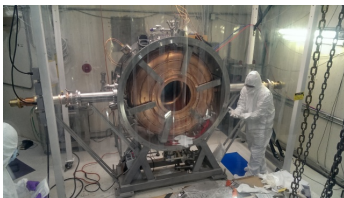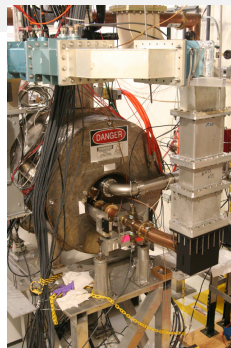
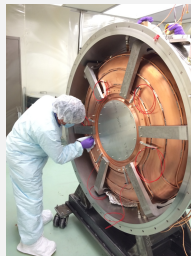# Results from 2+3 cavities are reported here.

"All-Seasons" Cavity

- ▶ Built by Muons, Inc.
- ▶ Vacuum *or* high-pressure gas capability
- ▶ Cu-plated stainless
- ▶ 810 MHz, 14.5 cm gap length
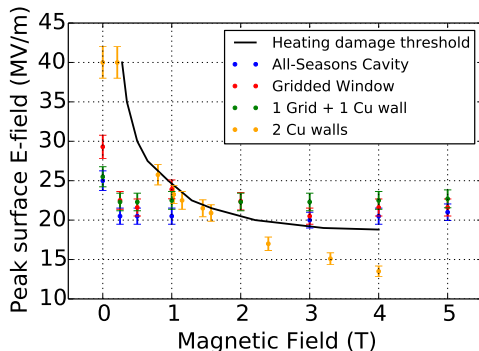
Pillbox w/ grid windows

- ▶ Grid windows ease pulsed heating effects.
- ▶ Cu or grid walls
- ▶ 800-805 MHz, 8.1 cm gap

MICE prototype

- ▶ 201 MHz
- ▶ SRF-style surface prep.
- ▶ **Conditioned to design gradient w/ no sparks.**

Model vs experimental results

- ▶ Data from pillbox cavity with 2 grid windows, with 1 grid + 1 Cu wall, and with 2 Cu walls.
- ▶ Black line indicates threshold for plastic deformation from cyclic beamlet heating.
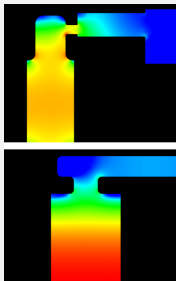- ▶ Fit quality affected by conditioning history, coupler effects.

Breakdown probabilities affected by electric field enhancement at couplers.
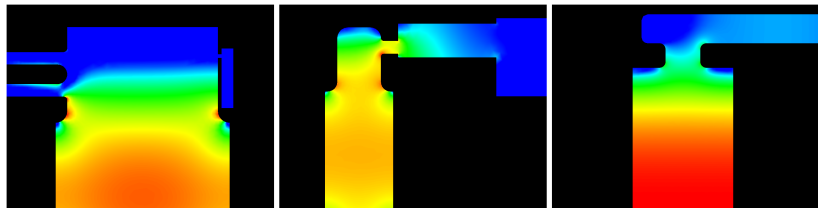
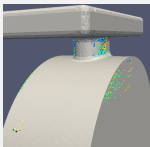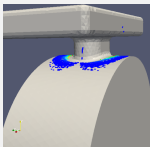Simulations of *E*-field distribution using SLAC's ACE3P code suite.

Improved control over systematics with new cavity.
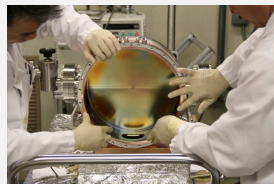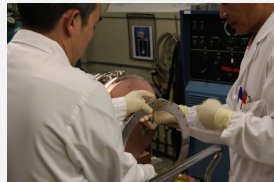
Design focuses breakdown on walls, not coupler.

(Top) Old 805 MHz cavity E-field. (Bottom) Modular cavity.

Multipacting optimized for $0 < B < 5$ T.

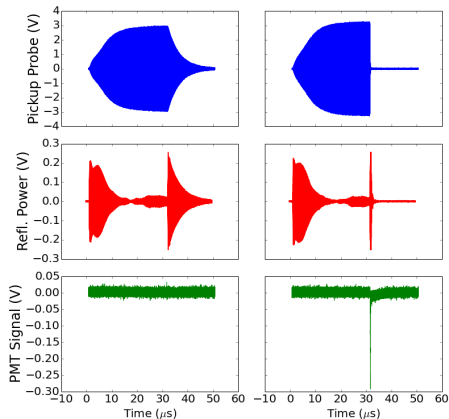ACE3P-simulate MP trajectories for $B = 0$ (top) and $B = 3$ T (bottom).

Removable end walls for inspection, materials studies.

SRF-style surface prep.

The modular cavity is now running in the MTA.

- ▶ ∼2M pulses collected at $B = 0$
- ▶ Commissioned up to 30 MV/m with minimal sparking.
- ▶ Gradient currently limited by anomalous klystron behavior, not fundamental breakdown rates.

Planned work for the modular cavity

1. Resurface, polish plates between runs to control for conditioning history.
2. Determine maximum achievable gradient up to $B = 5$ Tesla.
3. Measure spark rate at constant gradient over many millions of pulses at $B > 0$ to evaluate "surface lifetime".
4. Replace Cu walls with Be to study beamlet pulsed heating.
5. Beam tests are possible with Be walls.

Thanks for your attention.
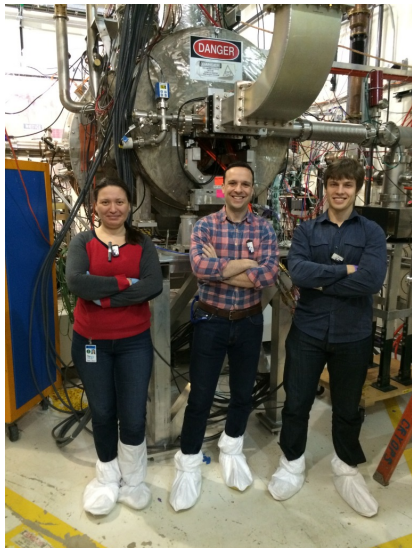
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