The Muon Cooling RF R&D Program

Yağmur Torun

Sep 20, 2005

COOL 05
Eagle Ridge, Galena, IL USA
September 18 - 23, 2005

World Year of PHYSICS 2005
www.physics2005.org

Neutrino Factory Muon Collider

fact Muon Collaboration

ILLINOIS INSTITUTE OF TECHNOLOGY
Transforming Lives. Inventing the Future. www.iit.edu

MuCool

MICE

NFMCC, MuCool and MICE

- Neutrino Factory and Muon Collider Collaboration (NFMCC) aims to tackle technical challenges of Neutrino Factories and Muon Colliders
- MuCool (Fermilab) is developing components for muon ionization cooling
  - Liquid hydrogen absorbers
  - Rf cavities
  - Magnets
  - Instrumentation
  - High power testing in beam
- MICE (RAL) is a system test of a cooling channel section
  - SFoFo cooling cell
  - Low intensity (single-muon)
  - Software bunching
- All are international collaborations

Ionization Cooling

- Muon lifetime is 2.2μs, traditional beam cooling techniques not applicable
  - Ionization cooling works "at the speed of the muon"

$$\frac{d\varepsilon}{ds} = -\frac{\left\langle \frac{dE}{ds} \right\rangle}{\beta^2 E}(\varepsilon - \varepsilon_0)$$

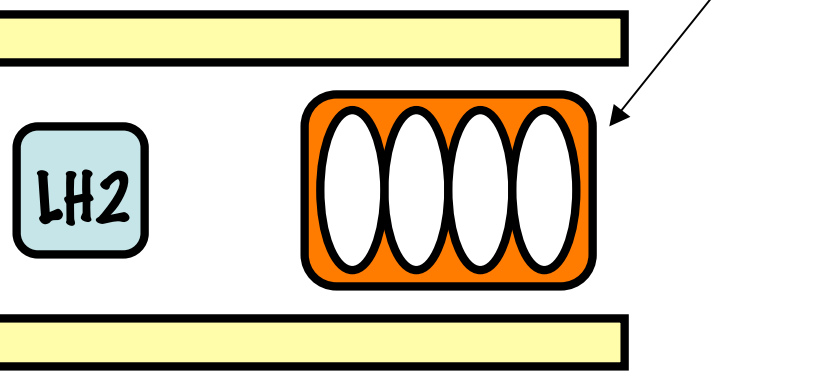
Normalized emittance in solenoidal channel

Equilibrium emittance

$$\varepsilon_0 \sim \frac{\beta_\perp}{\beta \left\langle \frac{dE}{ds} \right\rangle X_0}$$

Solenoidal focusing

Rf cavities



30 MeV/m

μ-momentum

MuCool Collaboration

- Aims to
  - design, prototype and test all cooling channel components
  - perform high-power beam test of cooling section
  - support MICE
- 18 institutions from US, Europe, Japan
- Spokesperson: A. Bross, Fermilab

- **RF development**
  - ANL
  - Fermilab
  - IIT
  - Jlab
  - LBNL
  - Mississippi

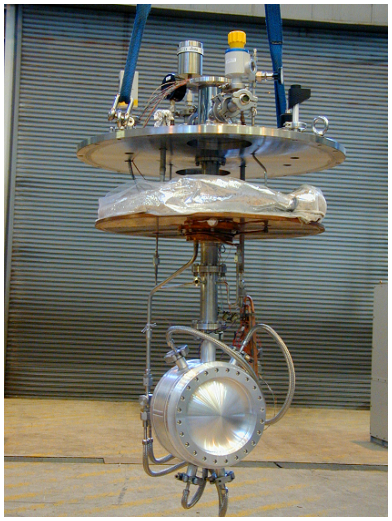
- **Absorber R&D**
  - Fermilab
  - IIT
  - UIUC
  - KEK
  - Mississippi
  - NIU
  - Osaka
  - Oxford

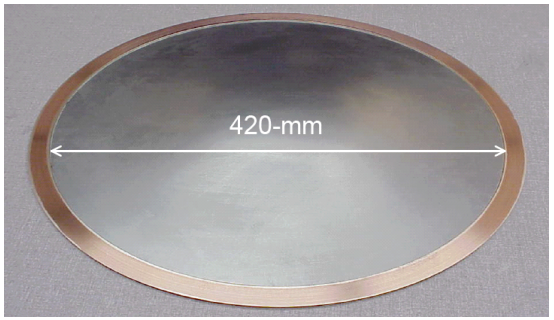
- **Beam diagnostics**
  - ANL
  - Fermilab
  - IIT
  - Princeton

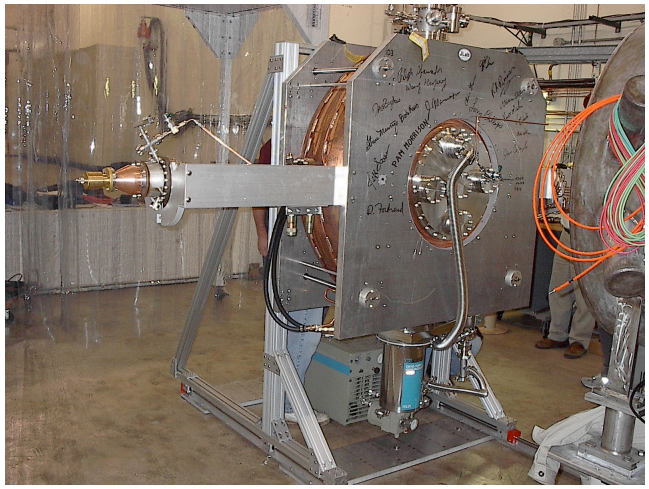
- **Solenoids**
  - LBNL

MuCool Hardware R&D

- Thin windows
  - Absorber, vacuum, rf cavity
- Liquid hydrogen absorbers
  - Forced flow for high power in Neutrino Factory
  - Internal convection for MICE
- Rf cavities
  - 805MHz quarter scale model to study the physics
  - 201 MHz prototype to demonstrate operation





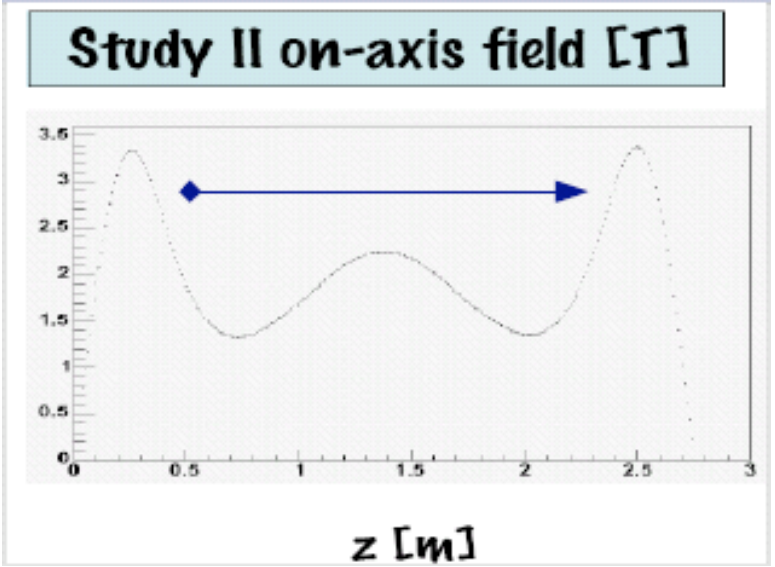


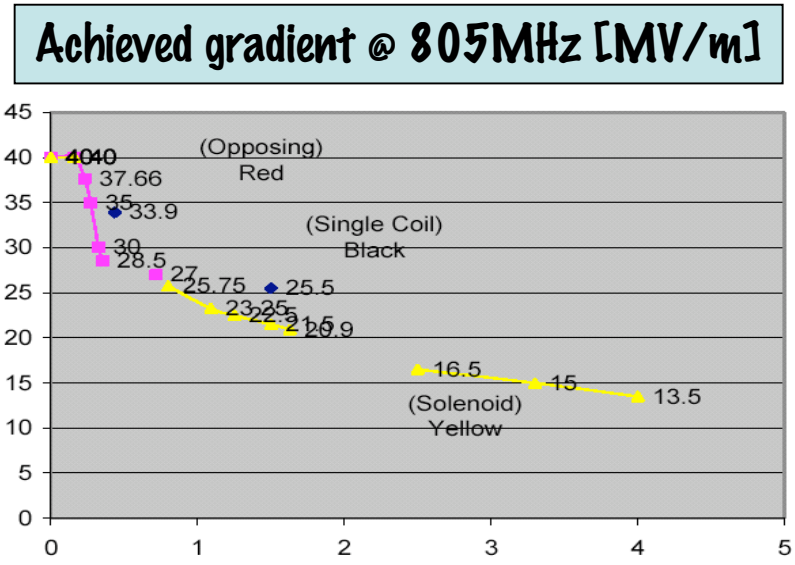
Rf Cavity R&D

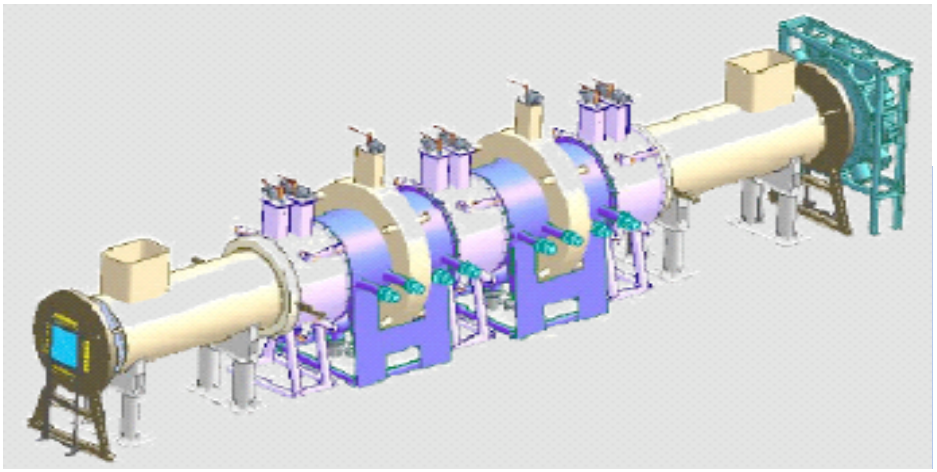
- Systematic study of breakdown for NC rf in high magnetic field
  - Develop general understanding, explore connection to rest of rf research community
- Measure rf-induced background rates, spectra and noise for MICE
- Map cavity performance as a function of magnetic field for MuCool/MICE
- Identify and test promising materials, surface treatment, coatings

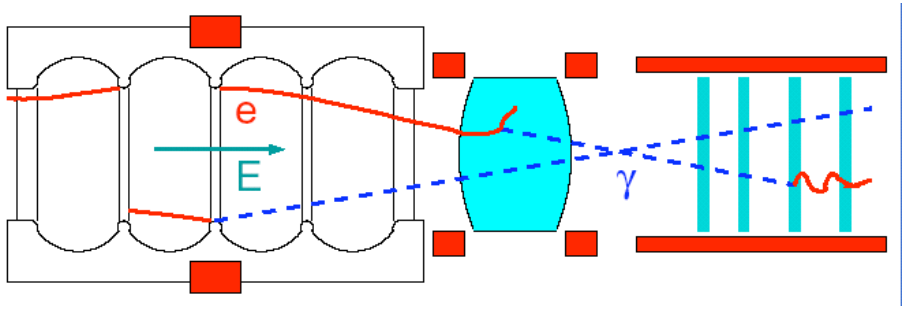
The Problem

- High-gradient Cu rf cavities in high magnetic field is a significant challenge for NFMCC
  - Magnetic field focuses dark currents and lowers onset of breakdown
  - Ionization cooling channel packed with high-stored-energy cavities with thin windows in high magnetic field
  - In MICE, tracking detectors next to rf cavities are subject to x-ray backgrounds
- We have to demonstrate reliable and low-background operation







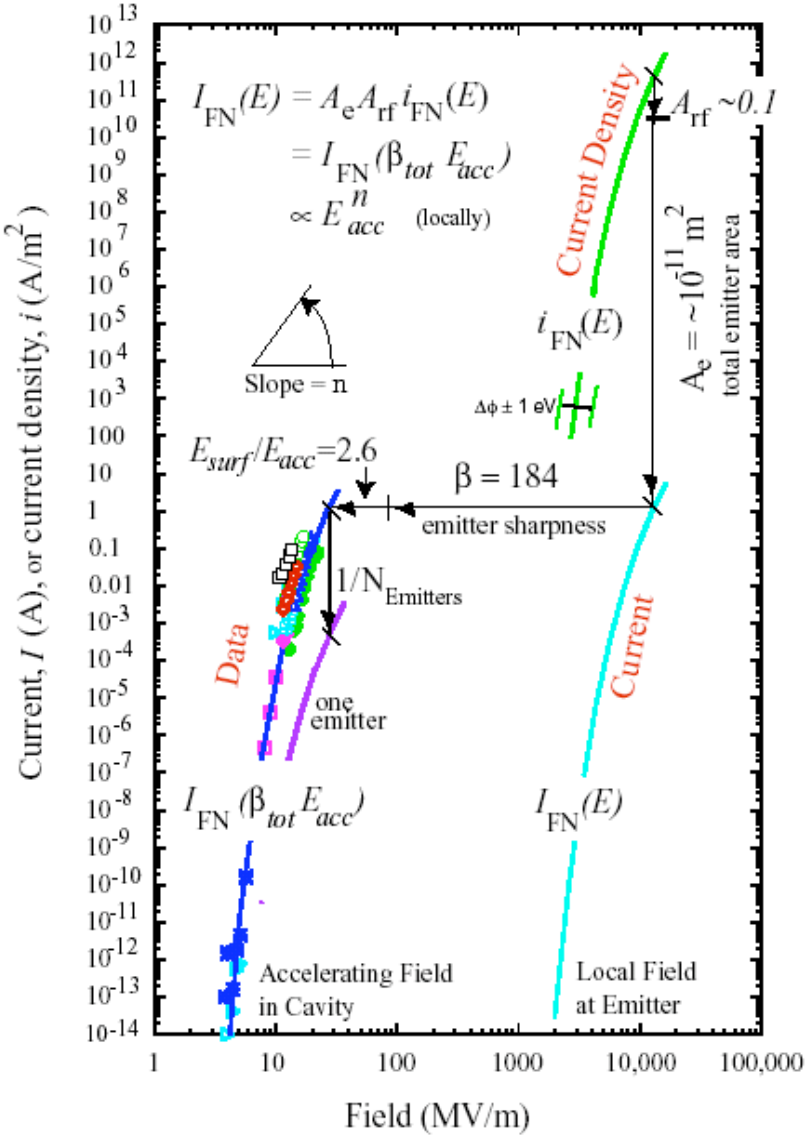


Dark Currents

- Precursor to breakdown
- Electrons tunnel through work function of metal
- Current rises very steeply with field (hard to make measurements)

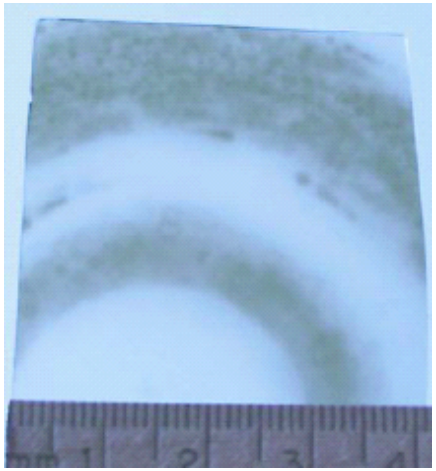
$$j_{FN}(E) = \frac{A}{\phi}(\beta E)^2 exp\left(-\frac{B\phi^{3/2}}{\beta E}\right)$$

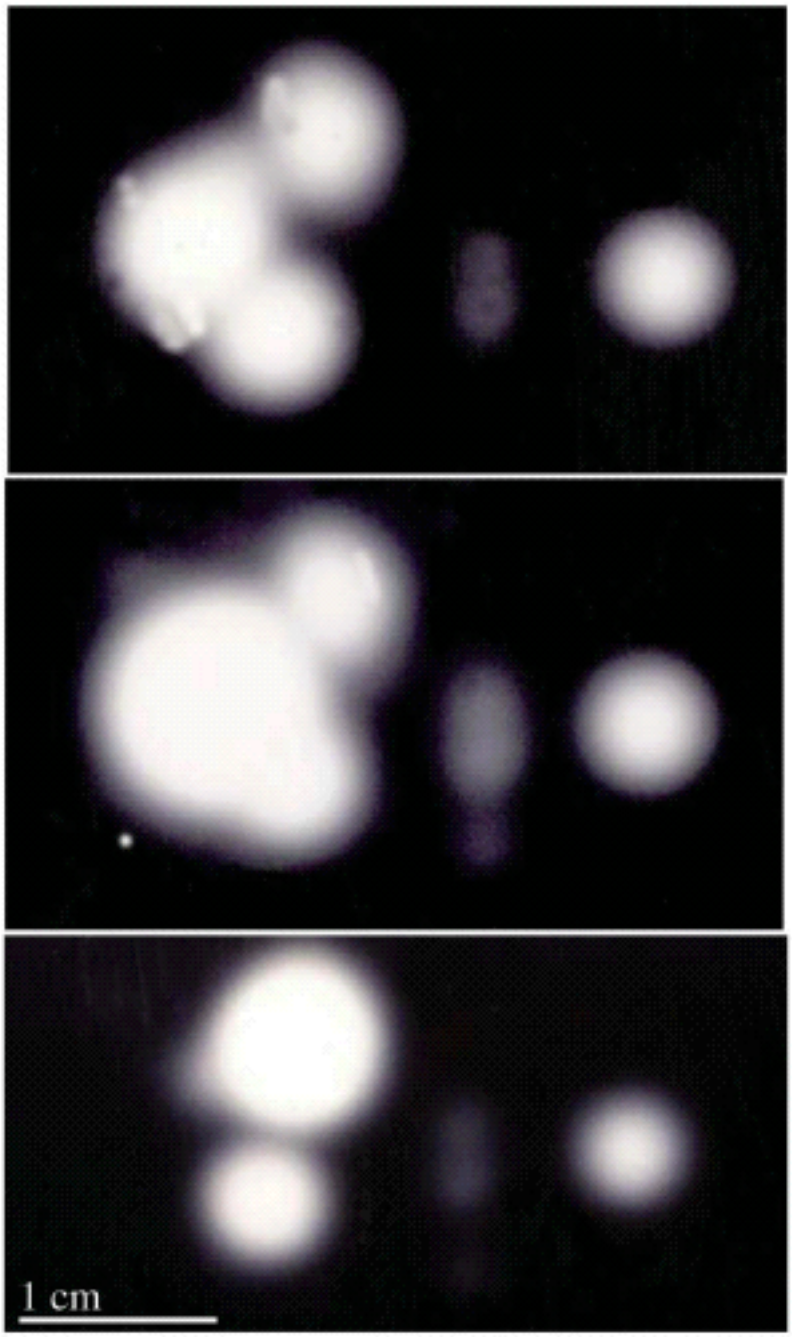
$$n = \frac{E}{j}\frac{dj}{dE} \simeq 2 + \frac{67.4\text{GV/m}}{\beta E}$$



Life of an Emitter

- Emitted current dominated by the few brightest sites
- When an emitter is extinguished, it can form secondary sites
- Cavity history after a big spark is determined by that event
- Dark current beamlets channeled by magnetic field





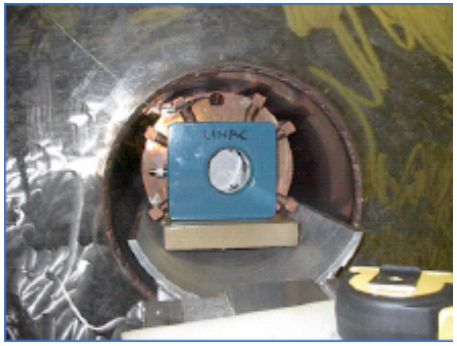
The Cast

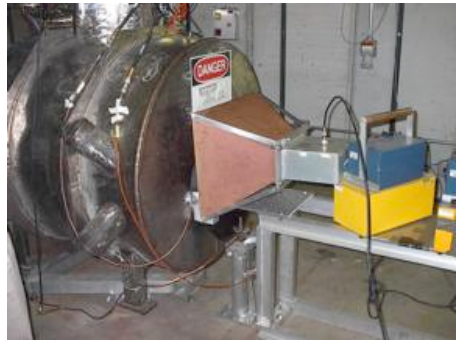
- Argonne: J. Norem
- Berkeley: D. Li, S. Virostek, M. Zisman
- Fermilab: A. Bross, A. Moretti, B. Norris, M. Popovic, Z. Qian
- Geneva: R. Sandstrom
- IIT: D. Kaplan, W. Luebke, Y. Torun, K. Yonehara
- JLab: R. Rimmer
- Muons Inc.: M. Alsharoa, P. Hanlet, R. Johnson

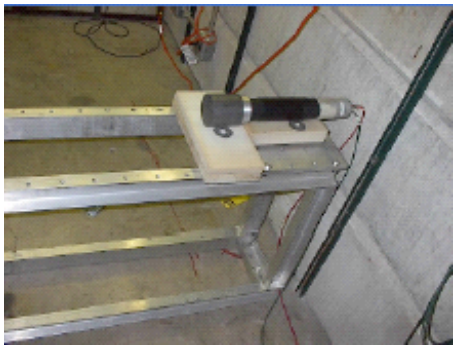
The Tools

- Want to measure electron, photon fluxes, spectra
  - Radiation meter
  - Beam transformer
  - Scintillator blocks
  - Scintillating fibers
  - NaI crystal
  - Ge diode
  - Photographic paper
  - Polaroid film
  - Rf antenna
  - Thermocouples
  - Microphones
  - Microscope, STM



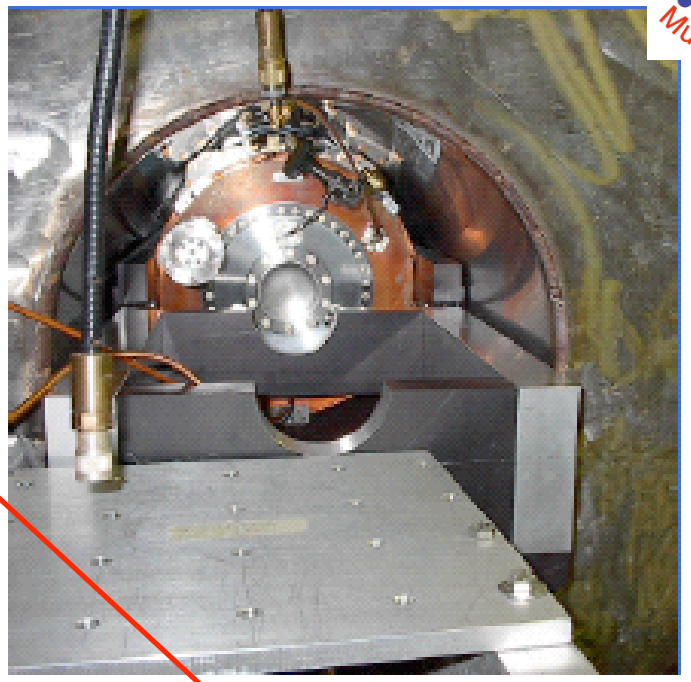



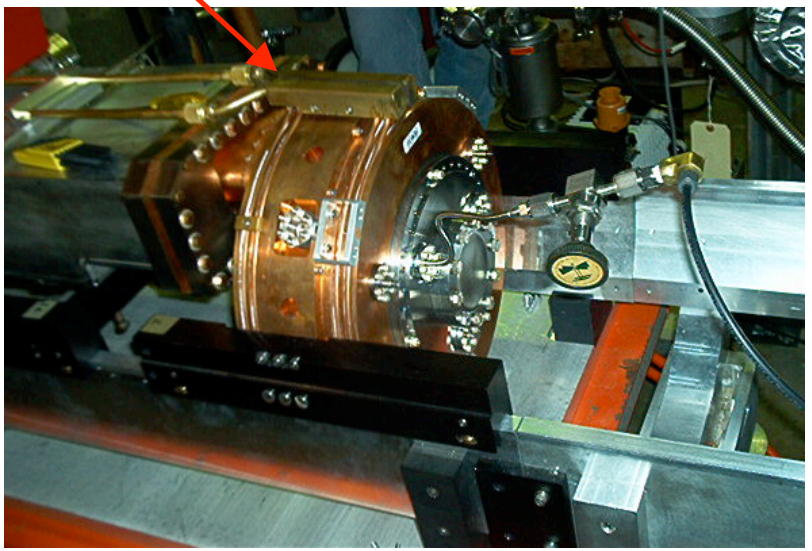




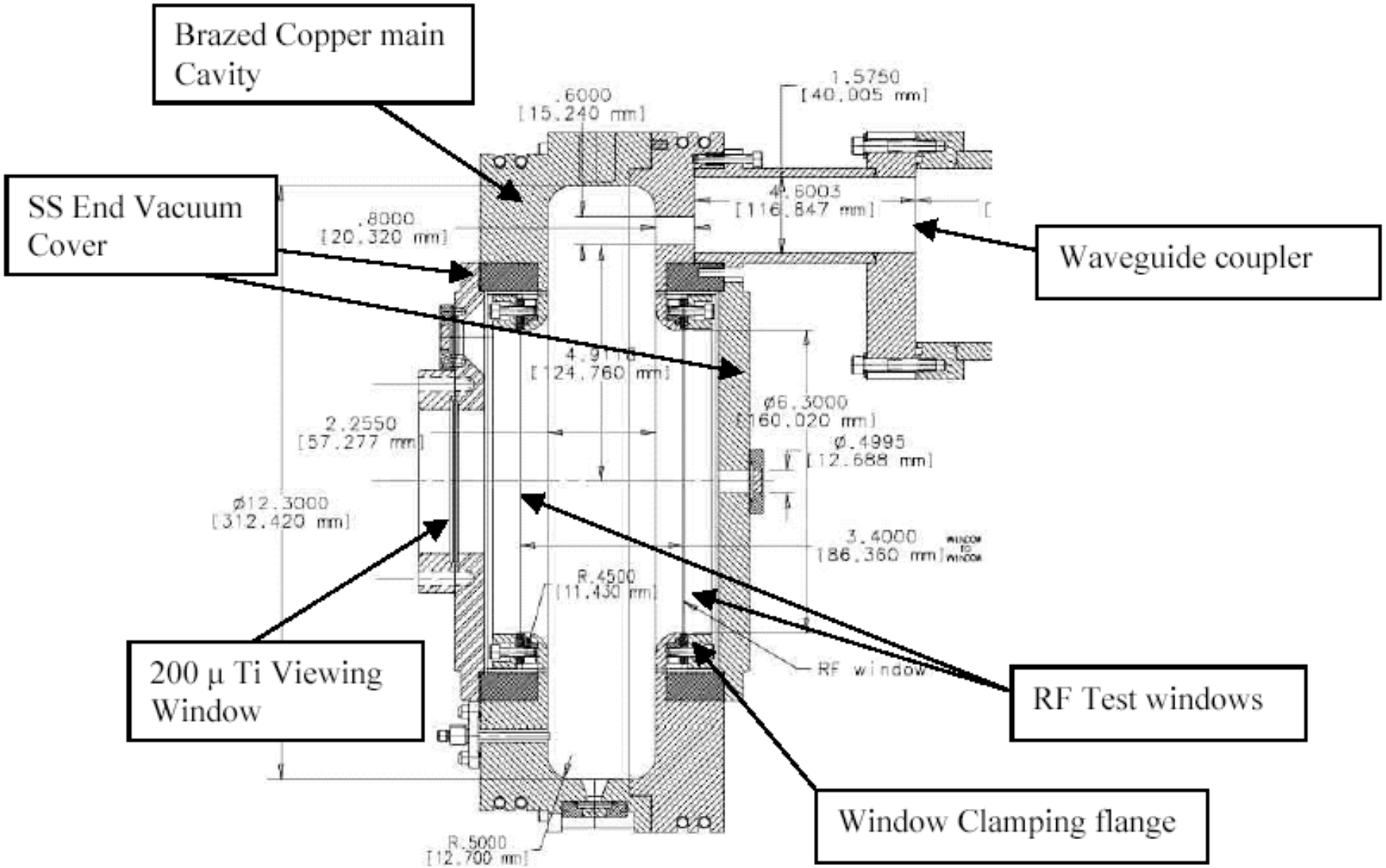

Fermilab Lab-G Facility

- 805MHz pillbox cavity with removable endplates
- In 5T solenoid magnet
- 12MW klystron



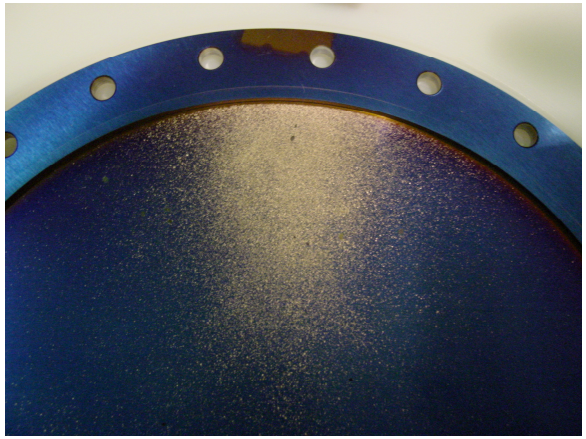


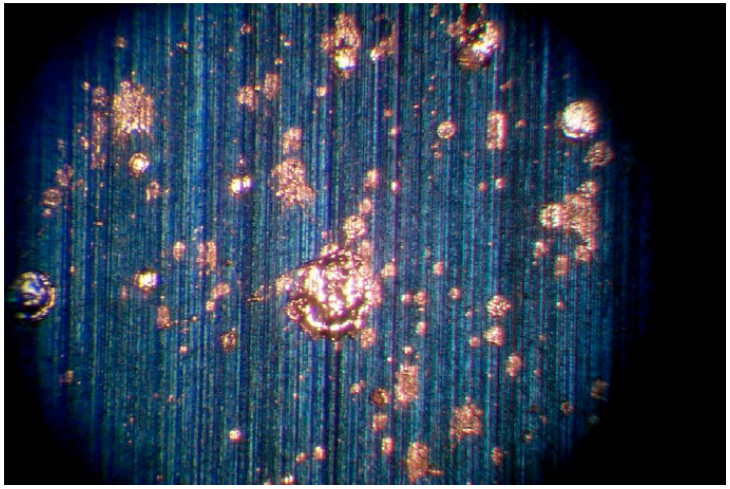
805 MHz Pillbox Cavity

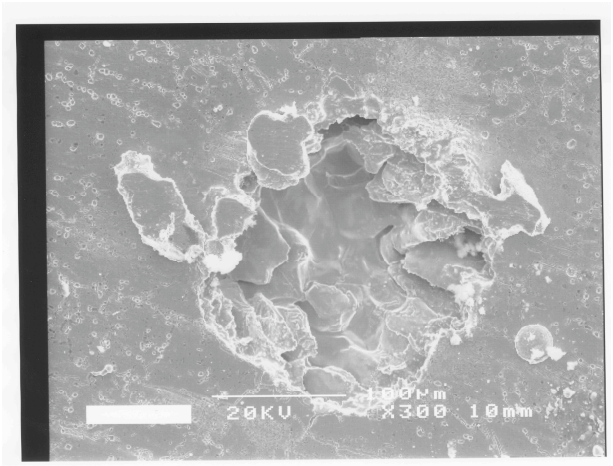


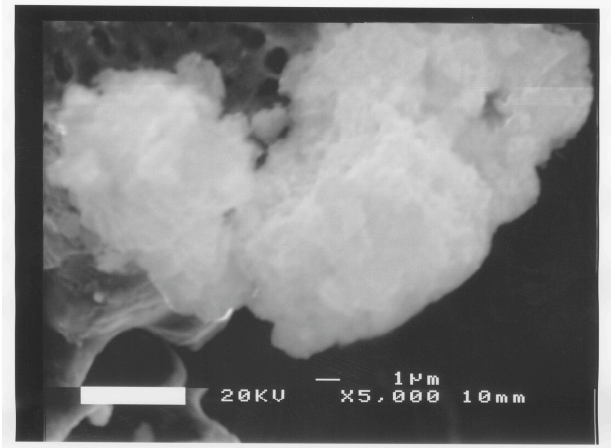
Inspection

- Cu endplate
  - Cu dust, pits
- TiN-coated Be window
  - Cu deposits
  - No coating or window damage
- SEM analysis
  - Cu blobs on surface







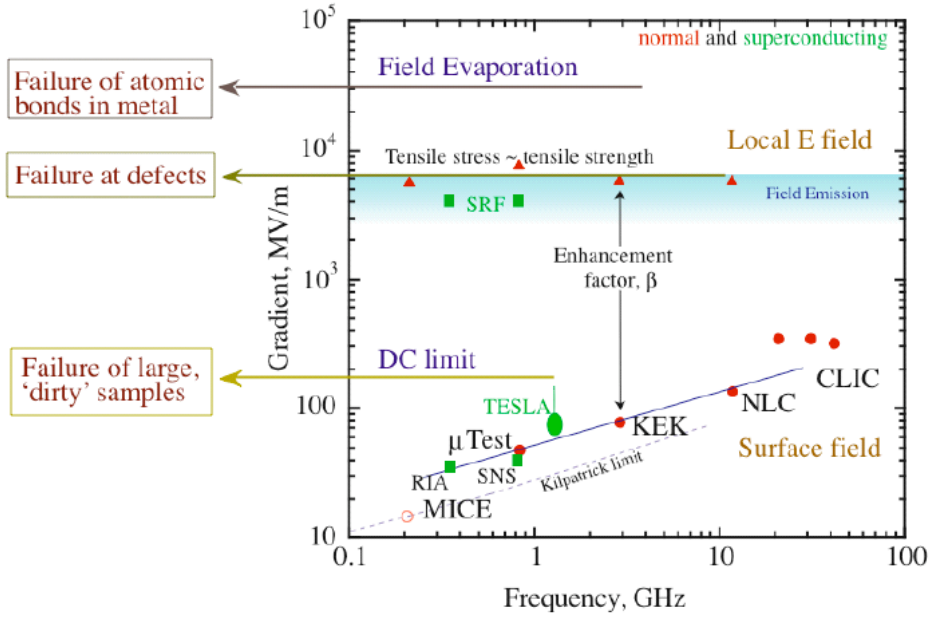


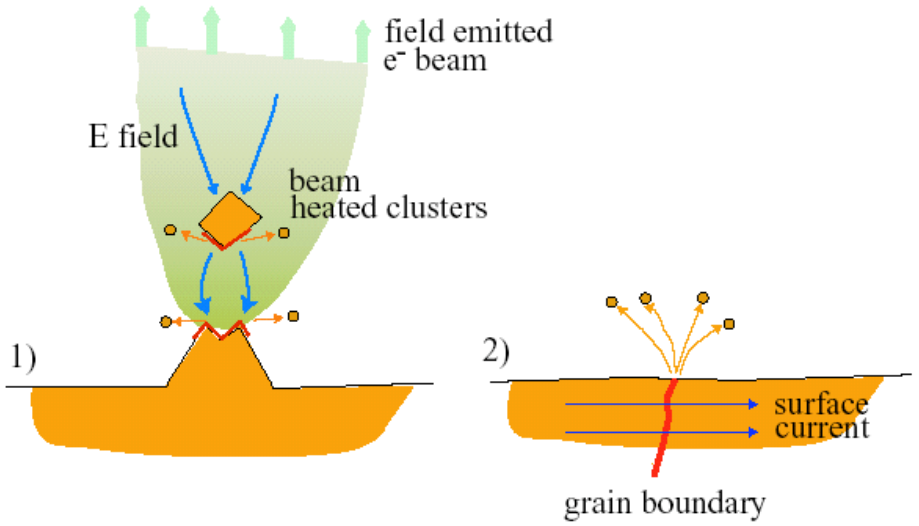
Lab-G Rf Program Summary

- Lab-G klystron reclaimed as Linac spare at Fermilab, Lab-G 805MHz program stopped at the end of 2003
  - Preparing setup in the newly commissioned MuCool Test Area facility
- Cu is the weak link for achieving high gradients, Be and TiN coating seem to work well -- sample insertion device designed for studying other materials/coatings
- Measured rf-induced background rates and spectra
  - Projected dark currents safe for window integrity and background rates for MICE
- Experience in cavity conditioning and operation
  - Mapped performance as a function of magnetic field
    - Magnetic field causes major degradation in achievable gradient
    - Cavity does not remember conditioning history when field switched on/off
  - Flat cavity windows not stable under high-power
- 805MHz cavity data
  - Open-iris 6-cell cavity: Phys. Rev. ST Accel. Beams 6, 072001 (2003)
  - Pillbox cavity: Phys. Rev. ST Accel. Beams 8, 072001 (2005)

Rf R&D Directions

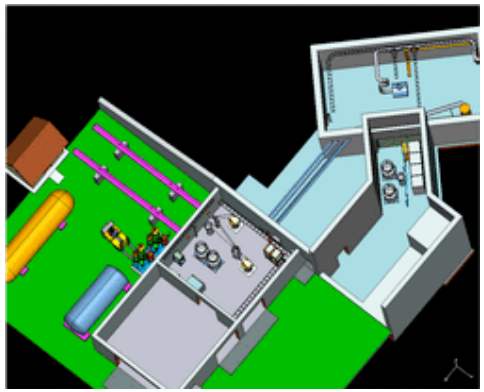
- Many problems are common to
  - DC and rf breakdown
  - Normal and superconducting rf (CLIC, ILC)
- We need help from materials science and surface chemistry
- Surface physics initiative (J. Norem, ANL + D. Seidman, Norhtwestern) for understanding breakdown processes using atom probe tomography and molecular cluster simulations

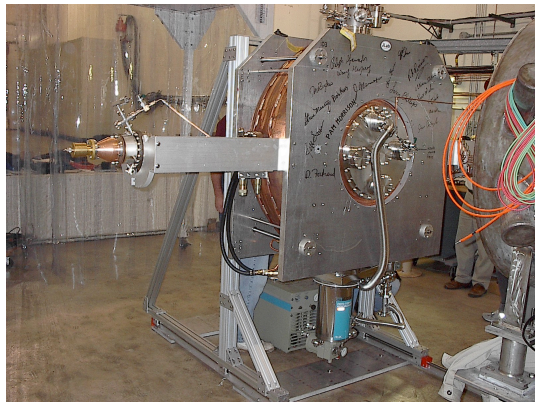




New Facility - MuCool Test Area

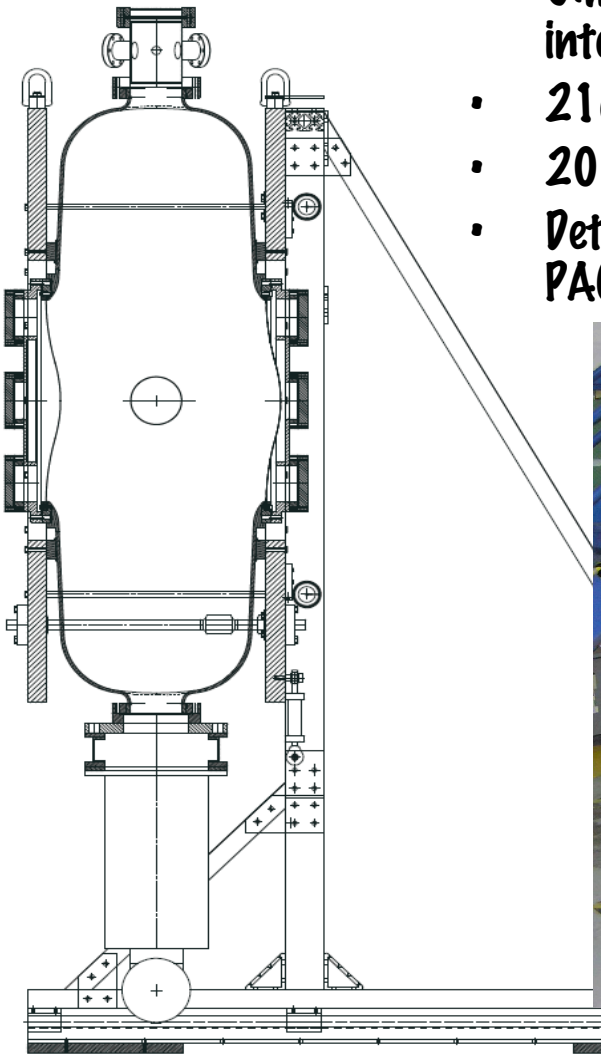
- MTA has
  - 201, 805MHz rf power
  - Cryogenics infrastructure
- We have installed
  - 5T solenoid
  - Cabling for remote diagnostics
  - 805MHz pillbox cavity
  - 201MHz pillbox cavity
  - Clean room for assembly
- Hope to have 400MeV p beam

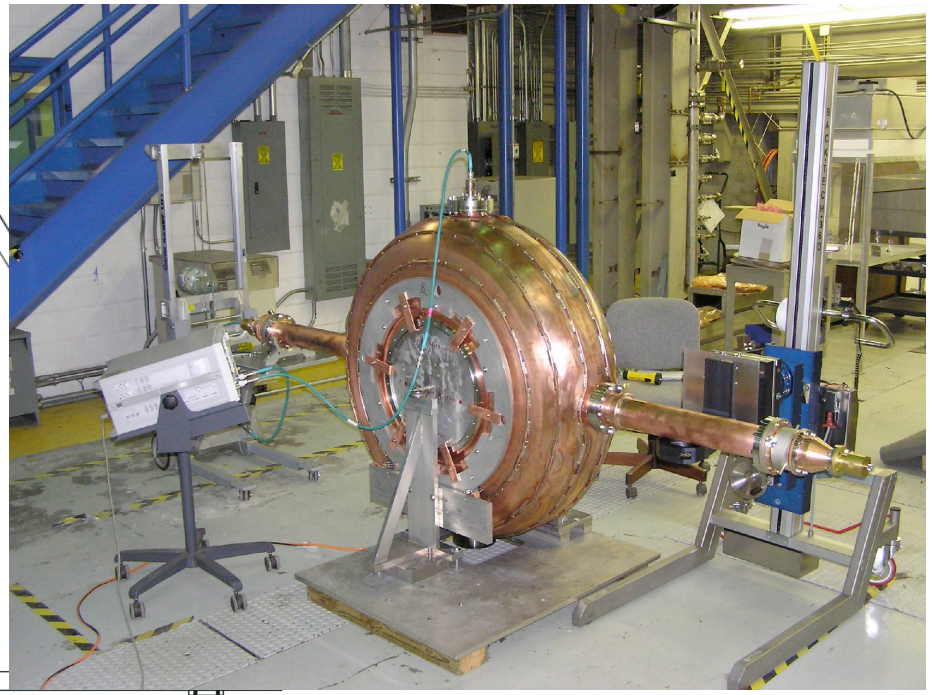




201 MHz Prototype Cavity

- Built by LBNL, Jlab, Mississippi
- 6mm Cu sheet, 43cm-longx61cm-radius, electro-polished interior
- 21cm-radius, 0.38mm-thick curved Be windows
- 201.25MHz, 16MV/m, Q=53000
- Details: D. Li et al., PAC03 (design), R. Rimmer et al., PAC05 (fabrication)





MuCool Rf Status

- 805MHz program to resume soon at the MTA
  - Will start with curved Be windows
  - Button hardware ready to test different materials
  - Have grids to test as alternative to solid windows
  - GH2 pressurized cavity tests also started (R. Johnson et al., Muons Inc)
- Cabling installed, detectors and DAQ being set up
- 201MHz will start up shortly afterward
- Progress within last month
  - Experimental area cleaned and sealed
  - Clean room and 201MHz cavity installed
  - 805MHz cavity hook-up completed (ready to run)