Superconducting RF R&D

H. Padamsee

Outline

- Discuss how Cornell SRF R&D benefits a variety of accelerators for HEP
  - High Luminosity Storage Rings
    - CESR, CESR-C, KEK-B
  - Linear Colliders
    - both TESLA & NLC
  - Neutrino Factory
  - Muon Collider
- Continuation of R&D Plans for LC

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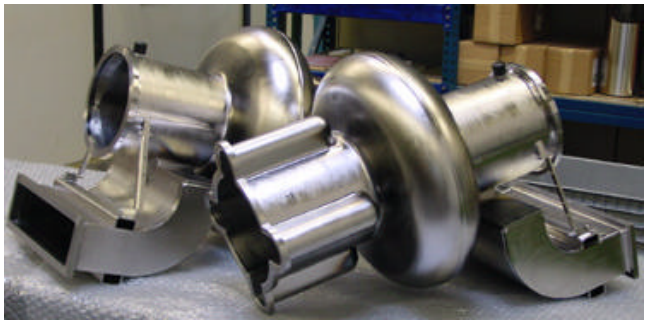
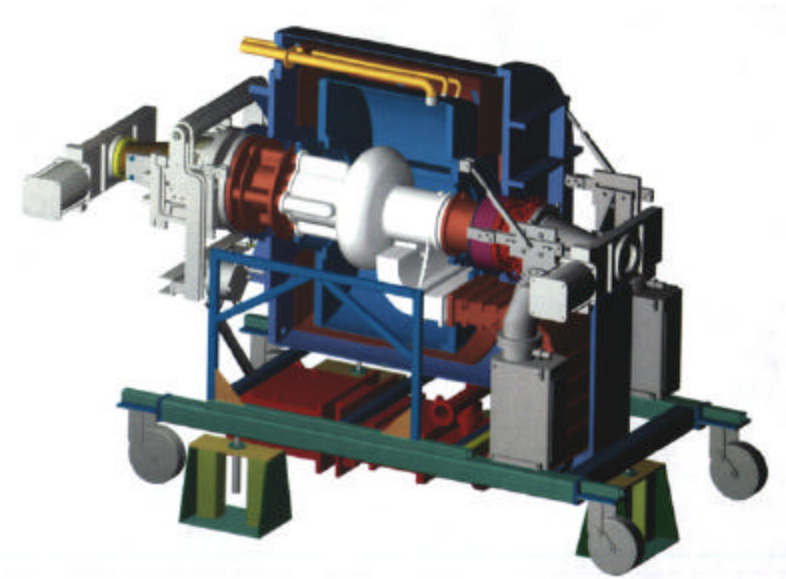
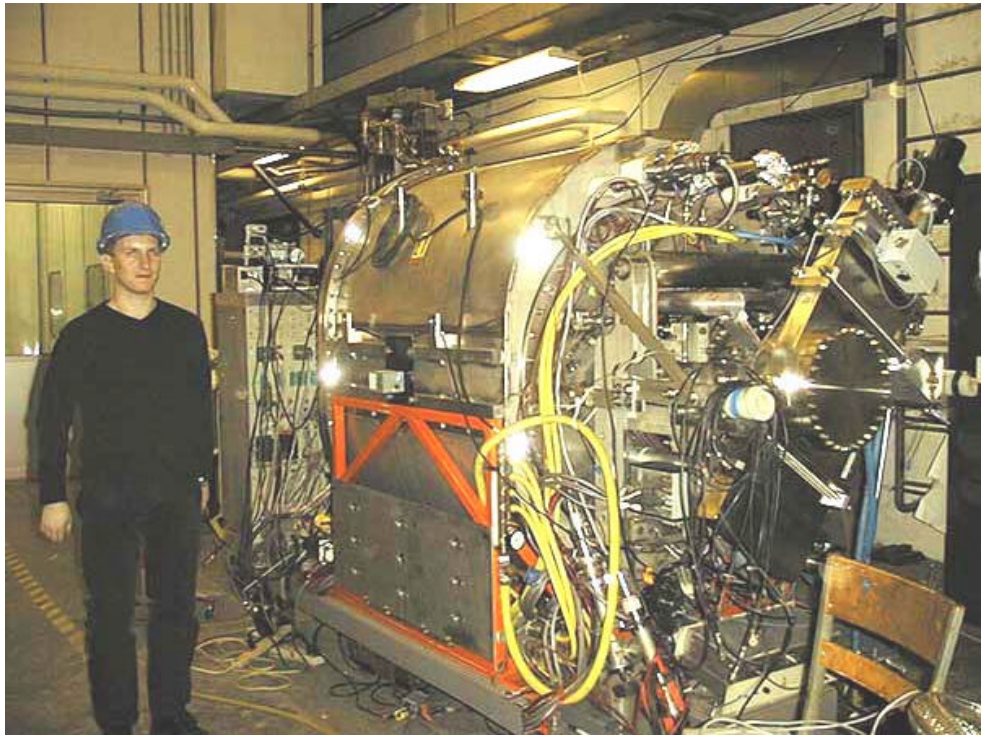
Niobium Cavities



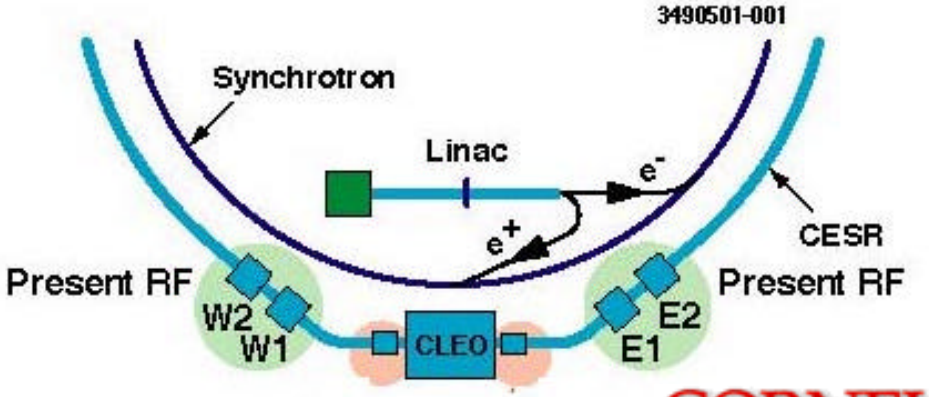


SRF Cryomodules in CESR



Existing Superconducting RF System

- **4** SRF Systems
- **4** 600 kW klystrons
- **1** cavity per klystron
- P_{beam} up to 1.13 MW total



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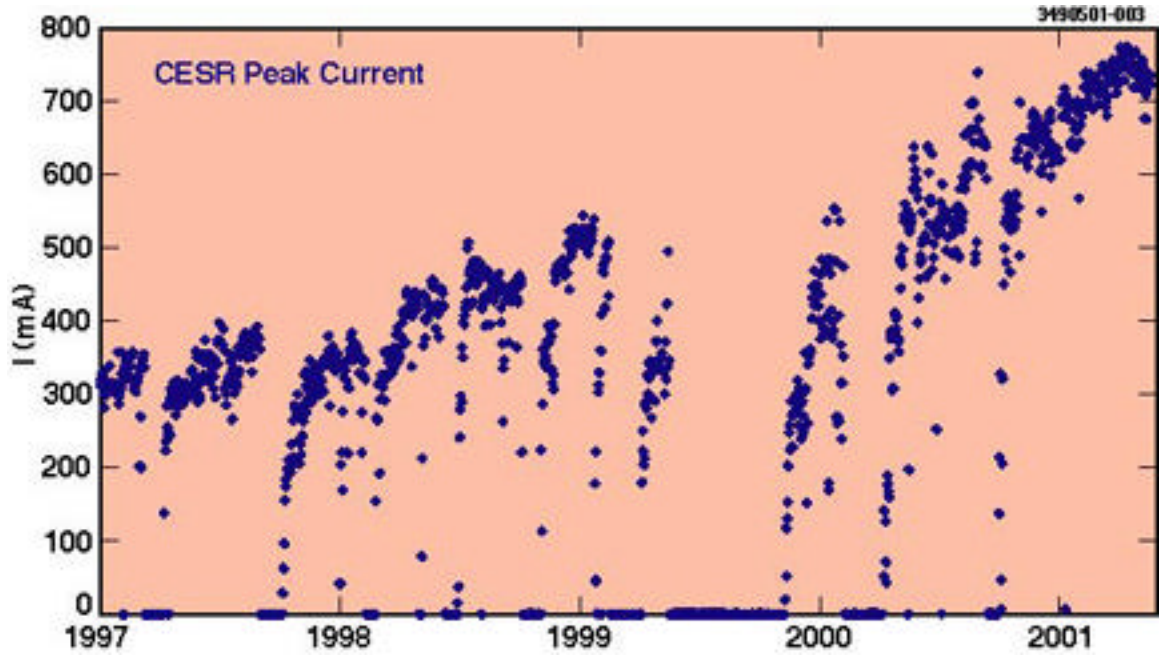
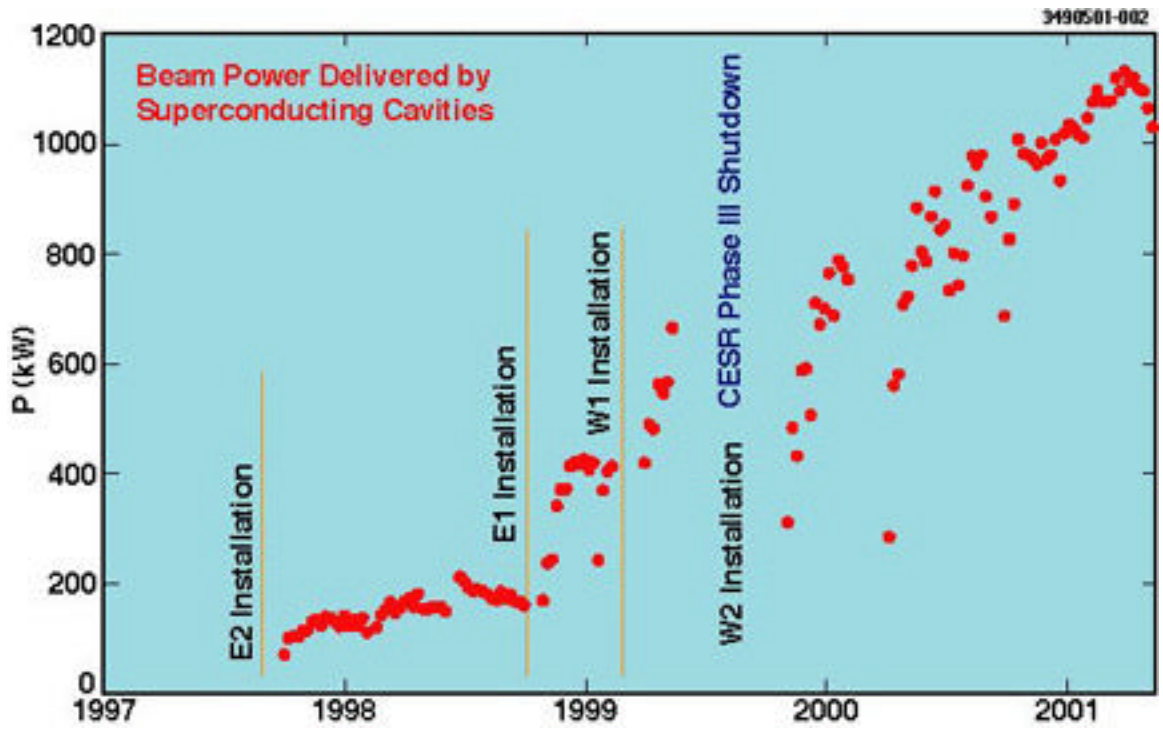
Steady increase in CESR beam current



Made possible by higher beam power through SC cavities



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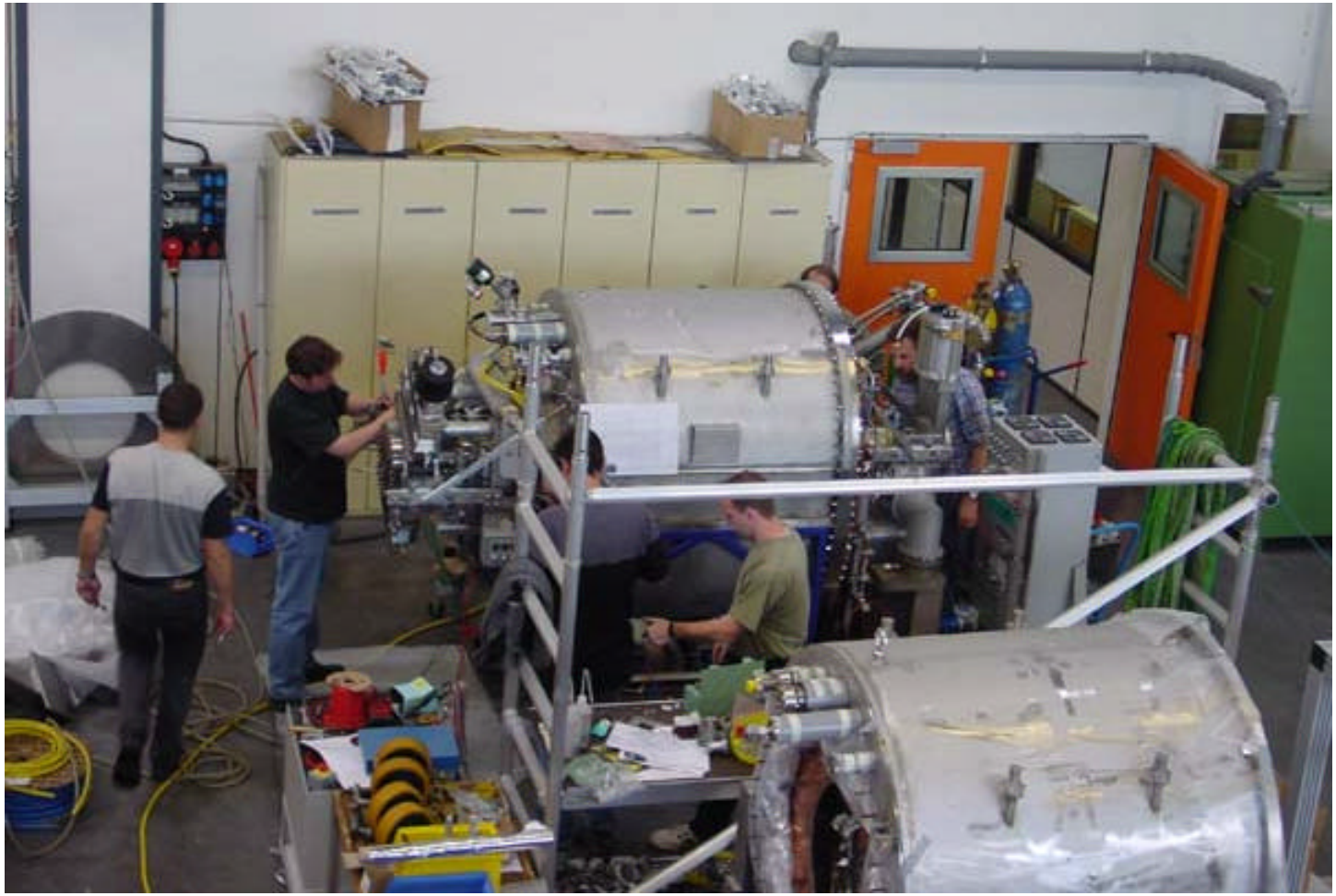
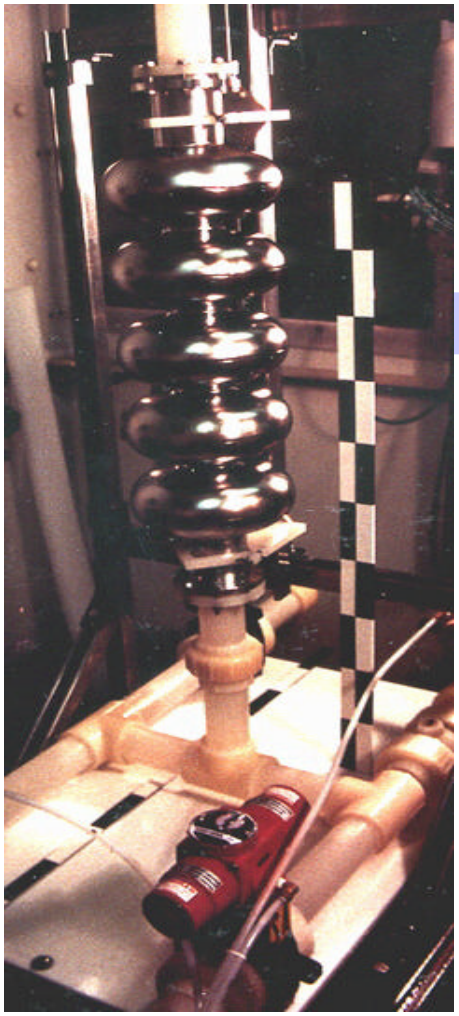
Technology Transfer to Industry:
Production of CESR-SRF Modules at ACCEL for:

CESR-C
Taiwan Light Source
Canadian Light Source
Diamond (U.K.)…..?

First industrial module
reached Eacc = 9 MV/m, 13 MV/m pulsed

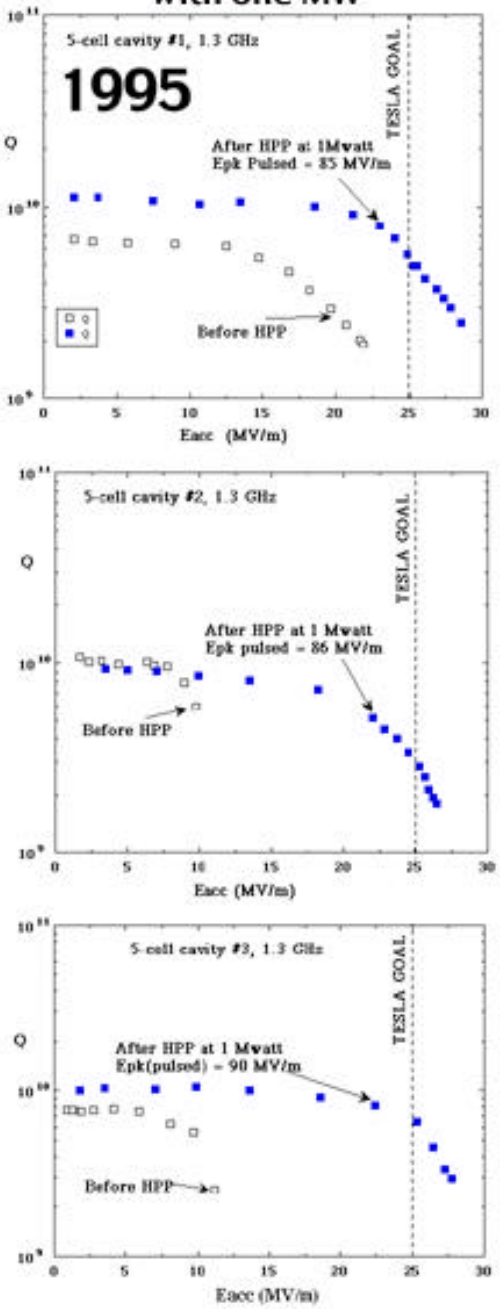


Push for High Gradients :
We were first to surpass TESLA goal in several 5-cell 1300 MHz
Gradients > 25 MV/m



1995

5-cell 1.3 GHz cavities
High Pulse Power Processing
with one MW



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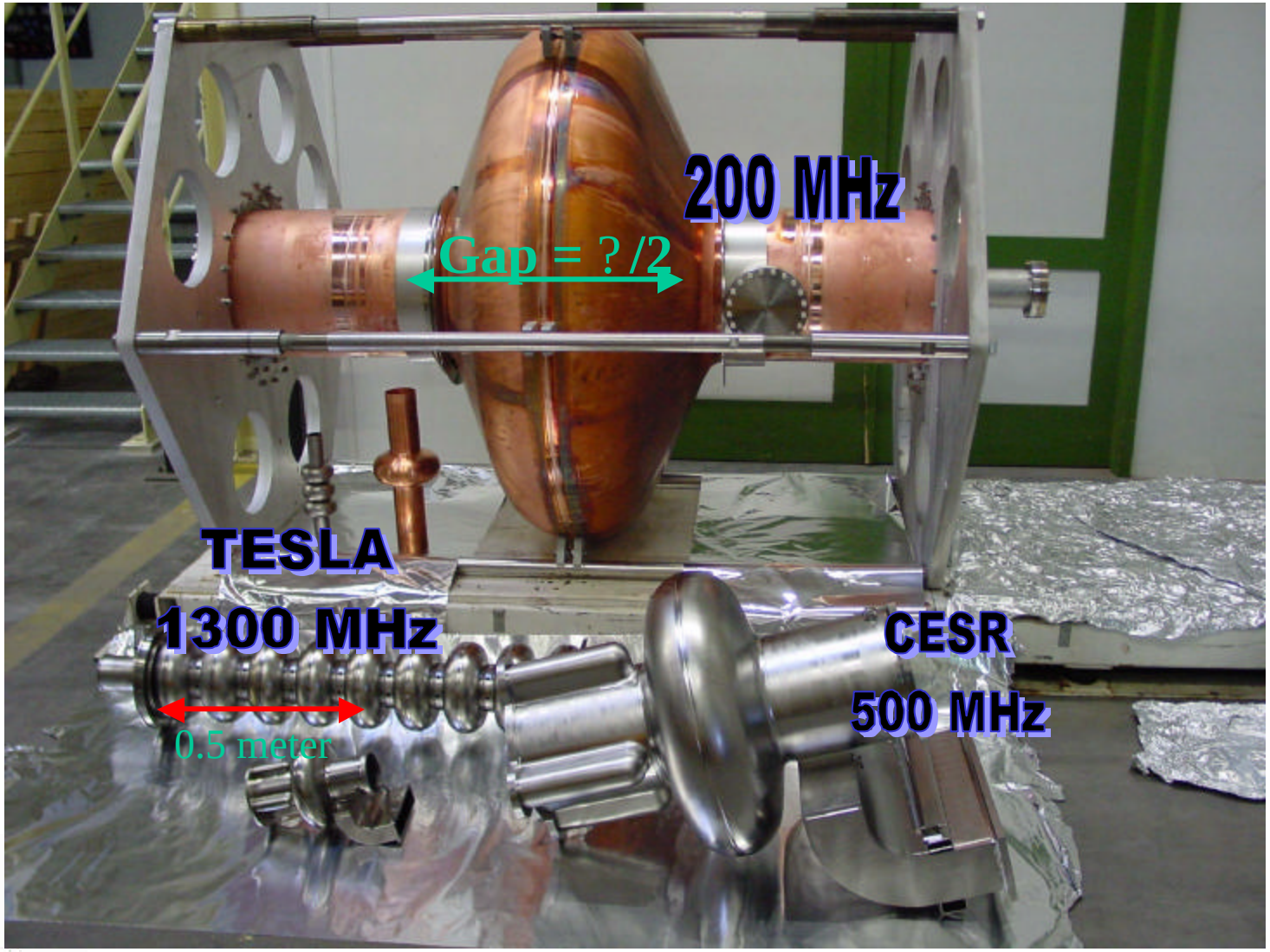
First 200 MHz Superconducting Cavity for NuFactory



Muon Collaboration

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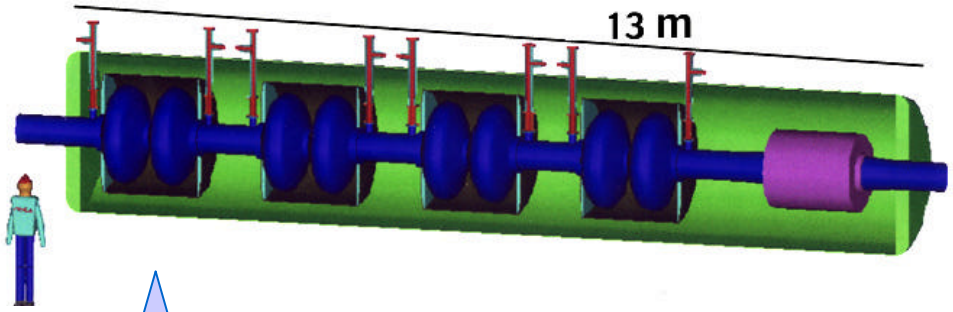
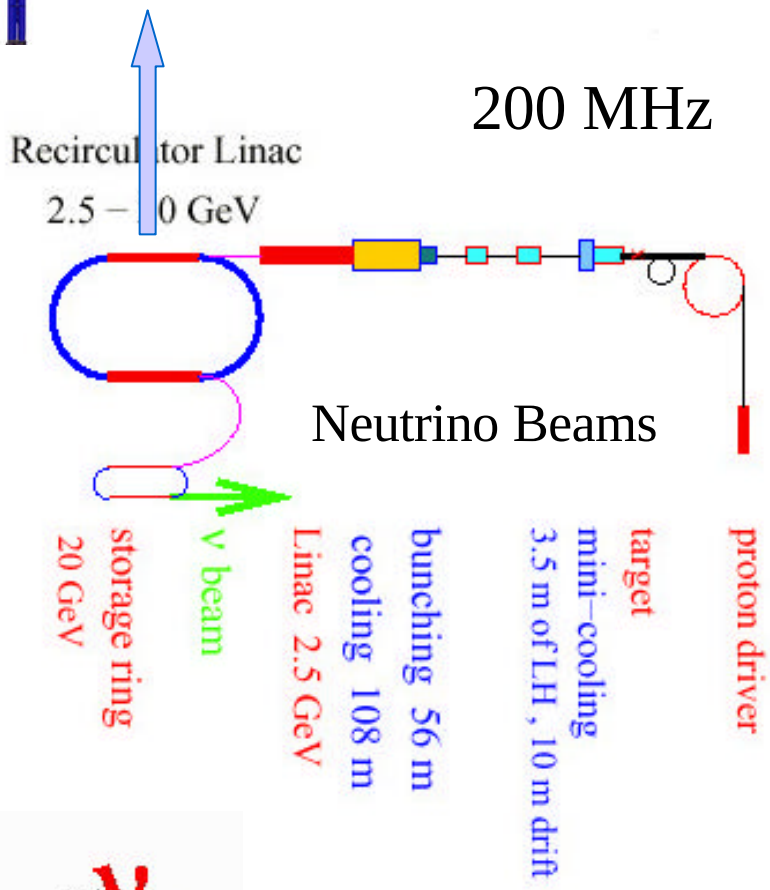
Future Cryomodule



200 MHz



Nb-Cu Cavity Prototype
Fabrication : CERN
Testing : Cornell

Participated in the Neutrino Factory Feasibility Studies I and II

Facilities Upgrade at Cornell for Testing

Radiation shielded test-pits under construction

Muon Collaboration

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Test-Pit Construction Complete

Muon Collaboration

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1000 sq ft Clean Room Construction

Muon Collaboration

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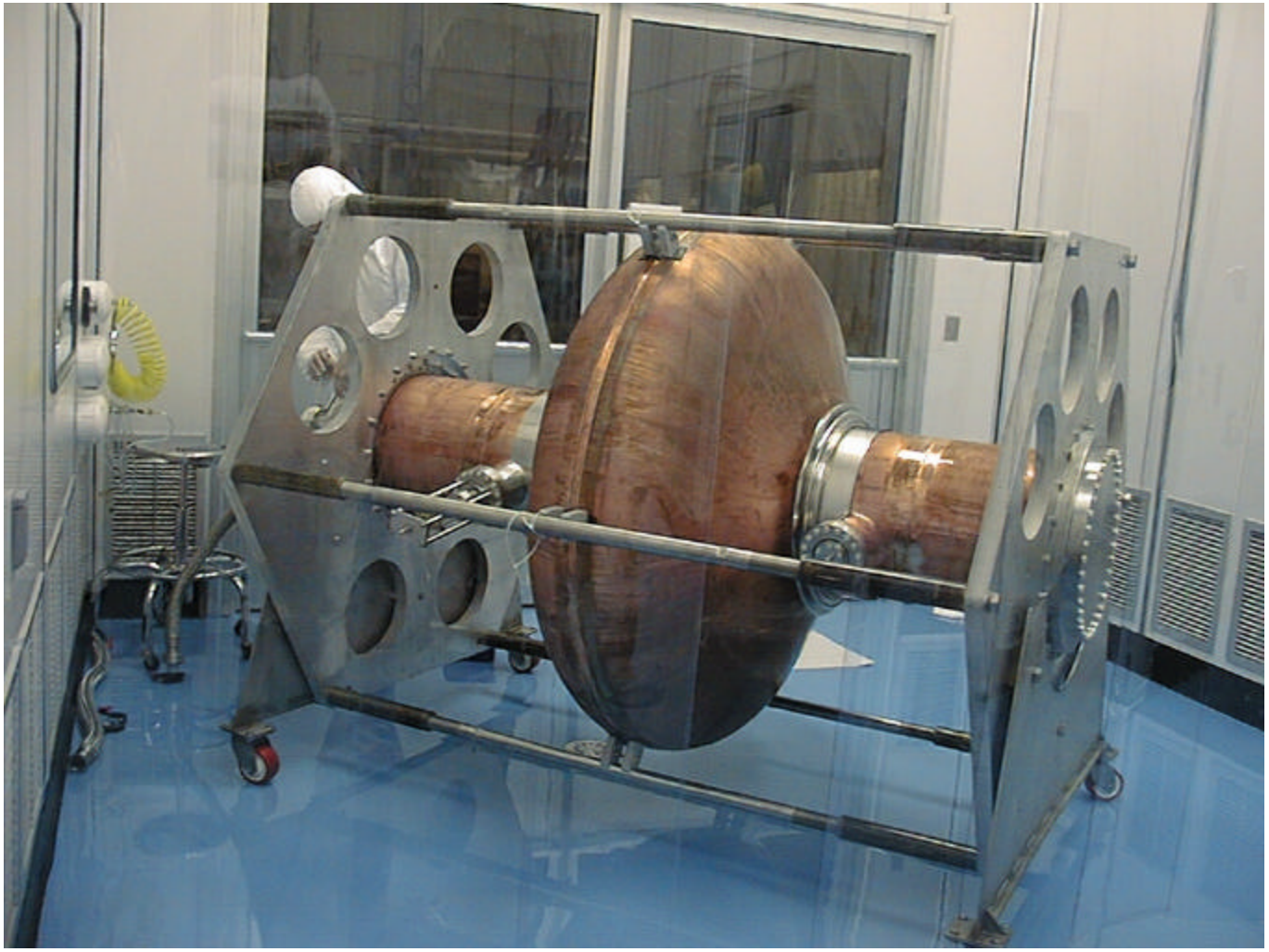
Nb/Cu Cavity Arrives at Cornell



Ready for Test

Muon Collaboration

CERN

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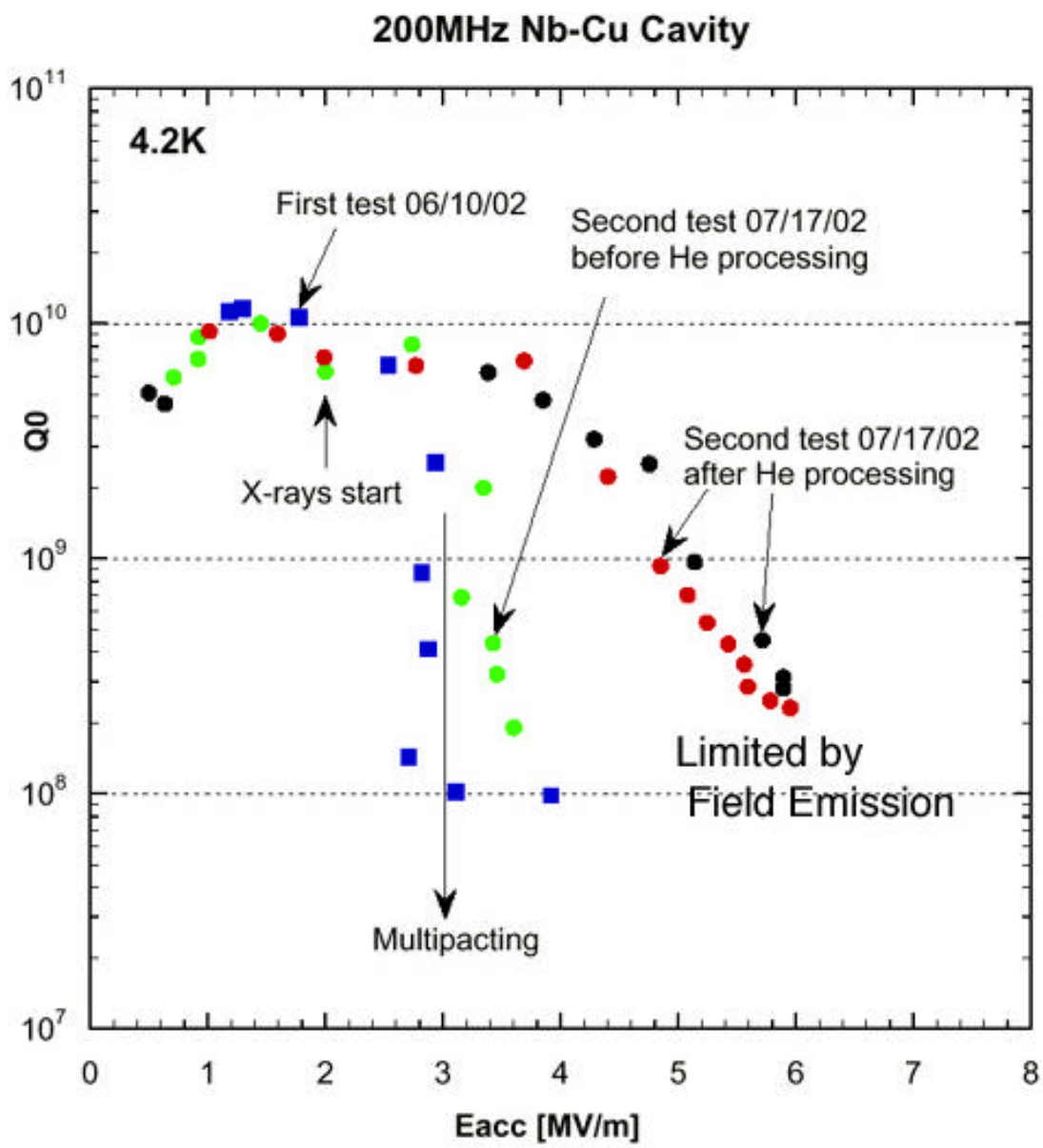
First Test Results



Need to

- Reduce field emission
- Improve processing

Future R&D for Linear Colliders

- Higher Q's

  $1 \times 10^{10} \rightarrow 5 \times 10^{10}$

- Higher Gradients for SRF Cavities

  30 -> 45 MV/m

  in incremental steps

- Cost Reduction Paths
- Advances in basic science of voltage breakdown

  -important for high gradient copper cavities

  -experiments and simulations

Possible Benefits from higher Q
1×10^{10} -> 5×10^{10}

TESLA Parameter Exploration Shows:

- Double luminosity with 1.6 x AC power
  - (eg by doubling the rep rate)
- Decrease number of klystrons for TESLA
  - from 680 to 330 by doubling rf pulse length,
  - => fewer klystrons: higher reliability
- Reduce AC power of 800 GeV TESLA at 35 MV/m

Achieved in single cells already at Saclay,

Future Cornell Program : Aim for 10^{11} in 9-cell structures

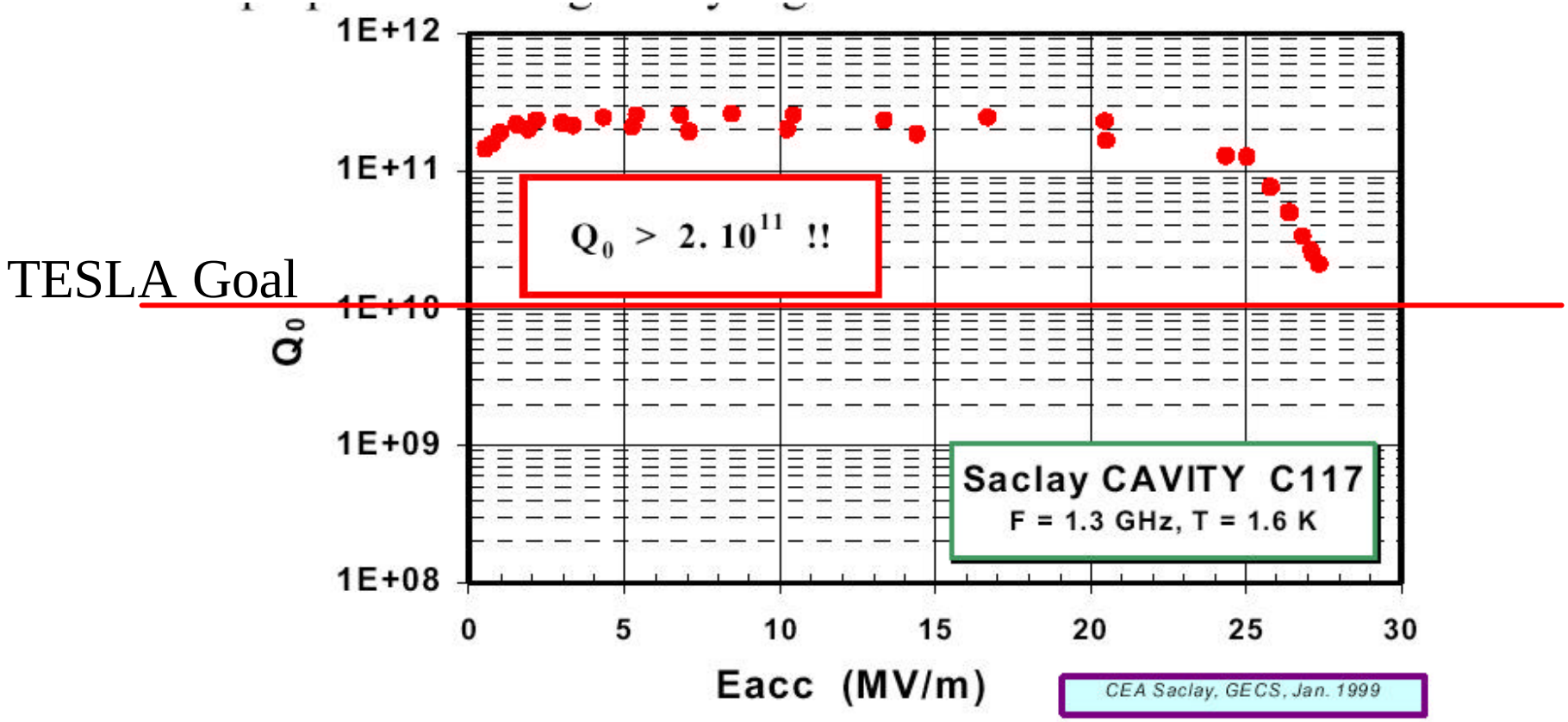
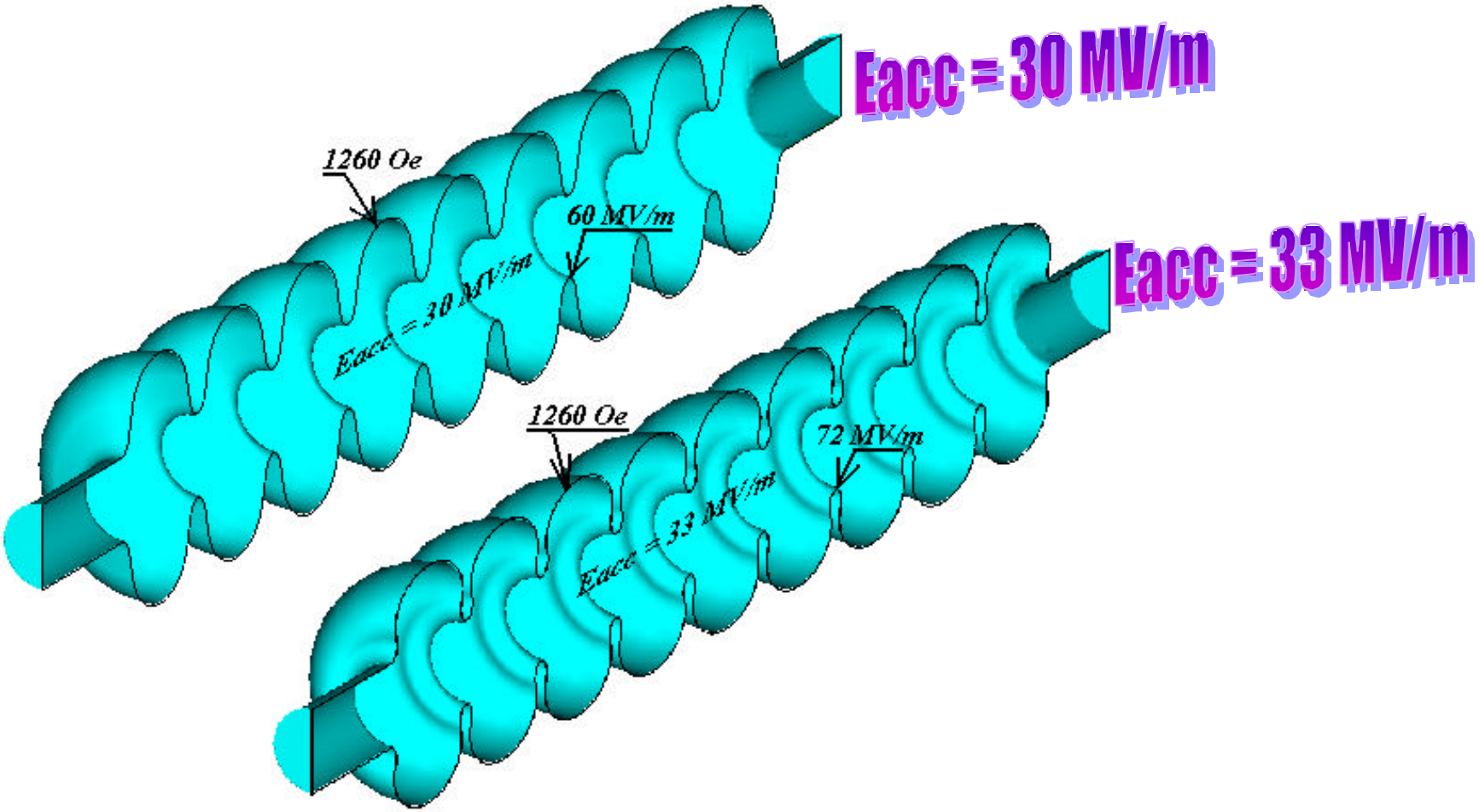


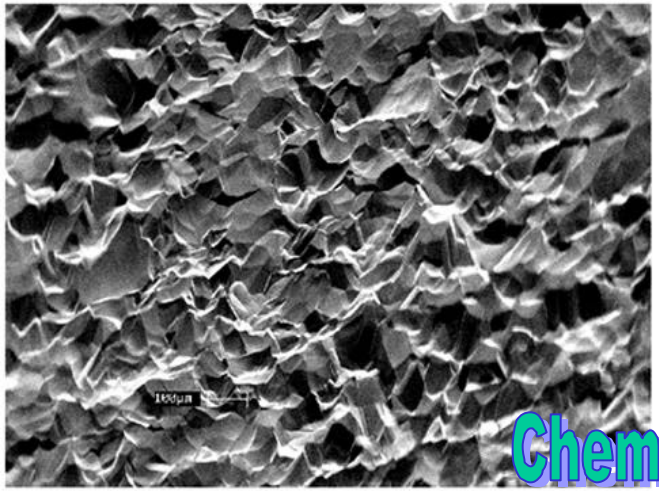
Figure 2 – Residual resistance as low as 0.5 nΩ is actually measured on large area cavities, giving an intrinsic quality factor Q_0 exceeding 2.10^{11}.

High Gradient R&D Topics

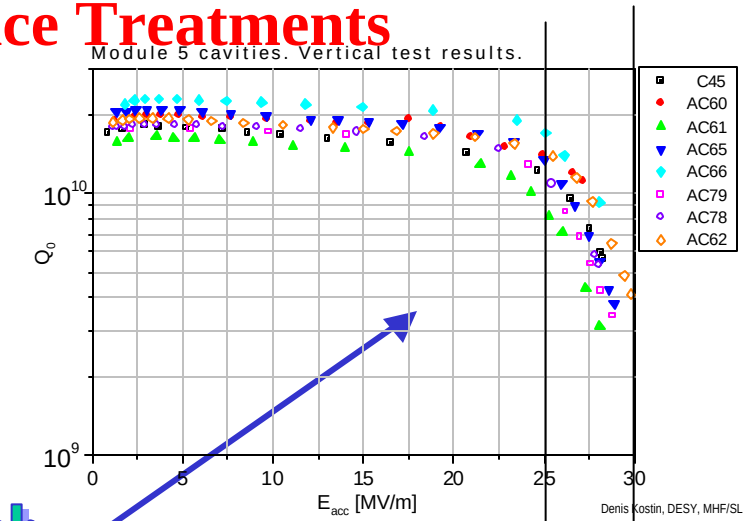
- Improve geometry of TESLA cavity to increase accelerating field
  - reduce peak magnetic field by 10%
  - allow peak electric field to rise 20%



--> 40 MV/m? Explore Better Surface Treatments

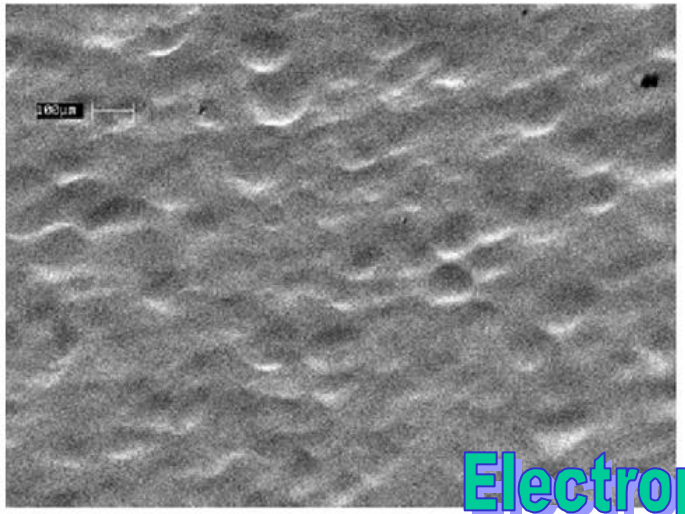


Chemical Polish

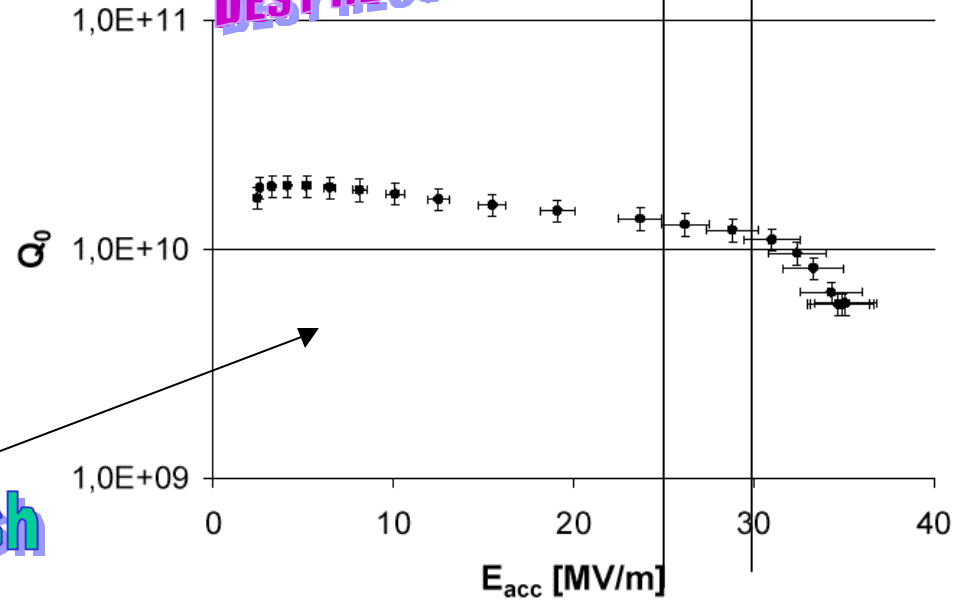


2002
DESY RESULTS

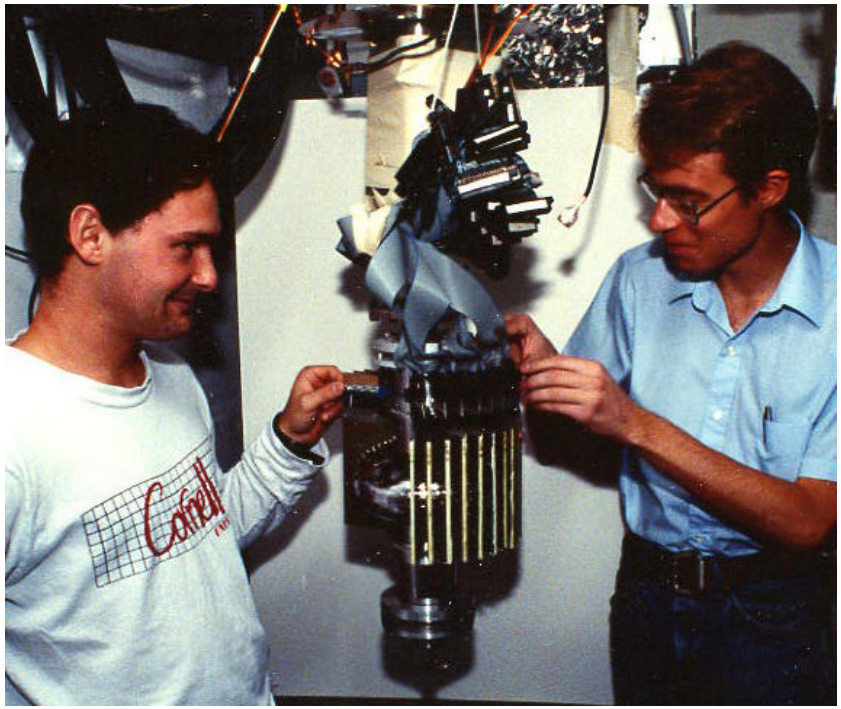
100 ? m

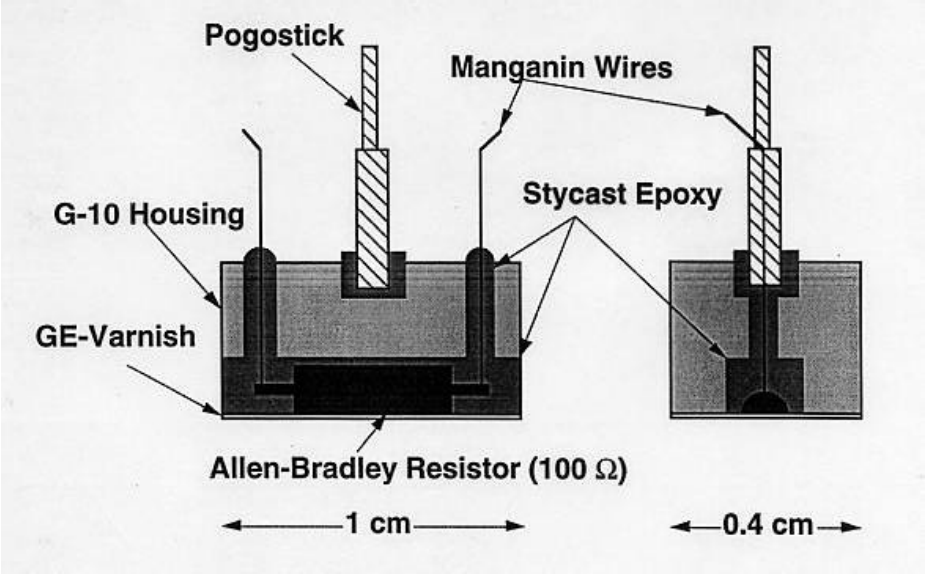


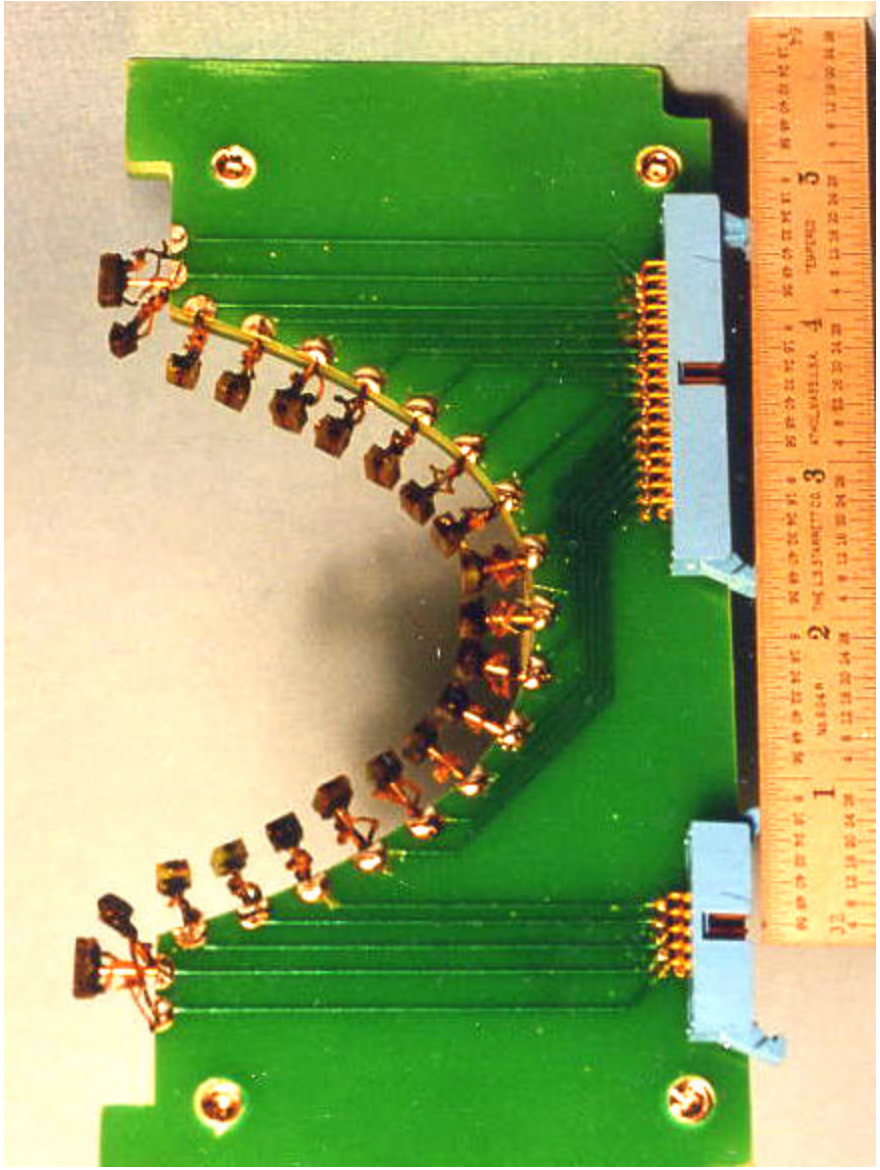
Electropolish



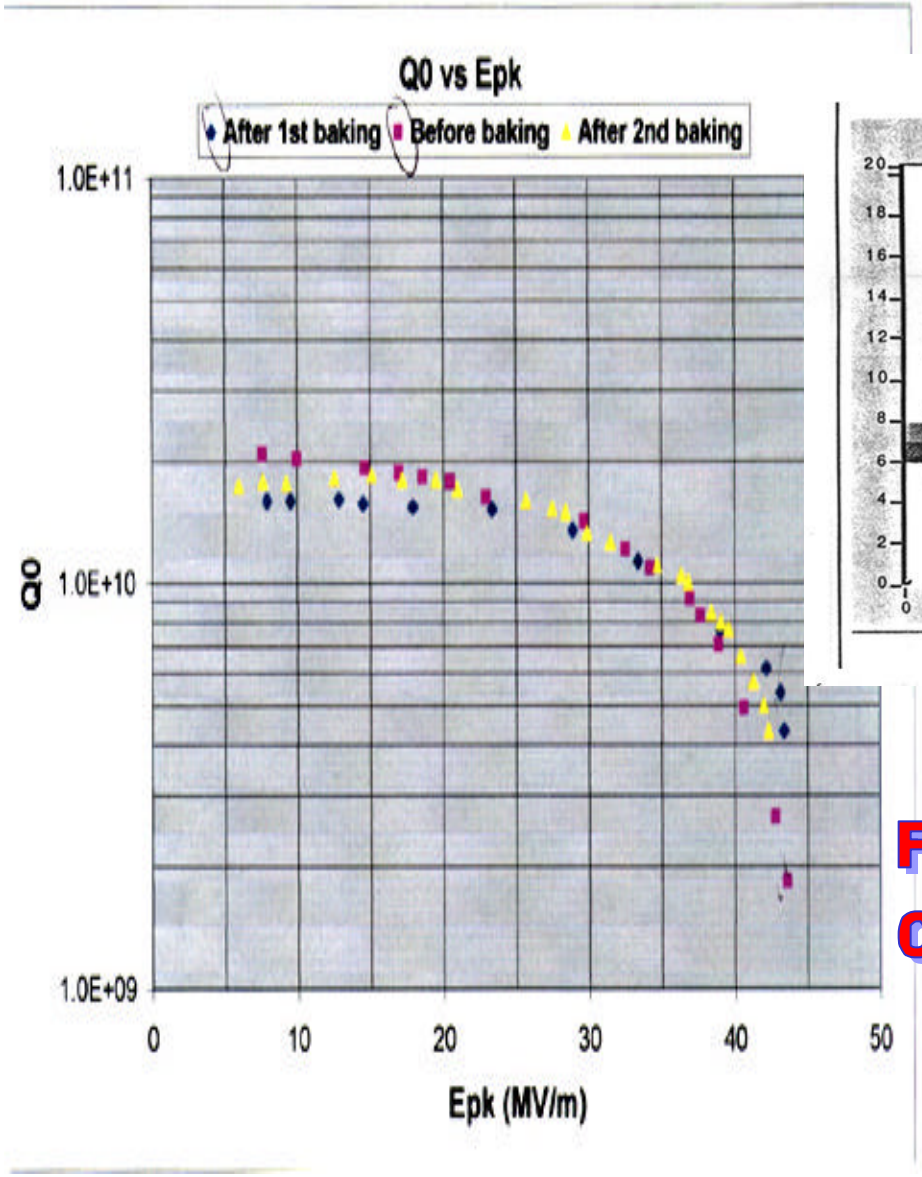
Thermometry/ surface studies in progress

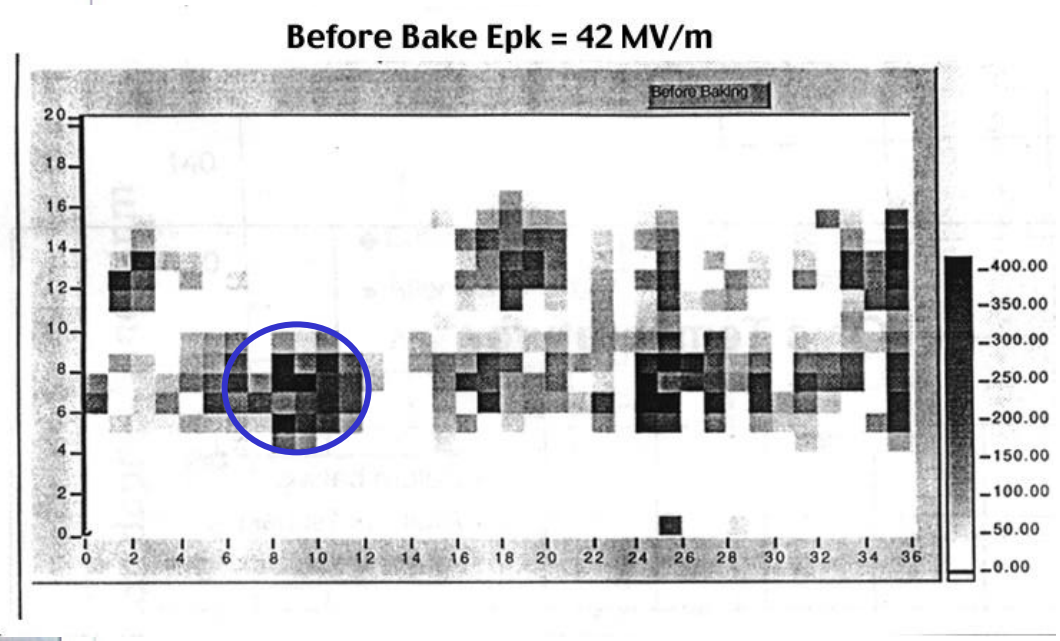






Thermometry

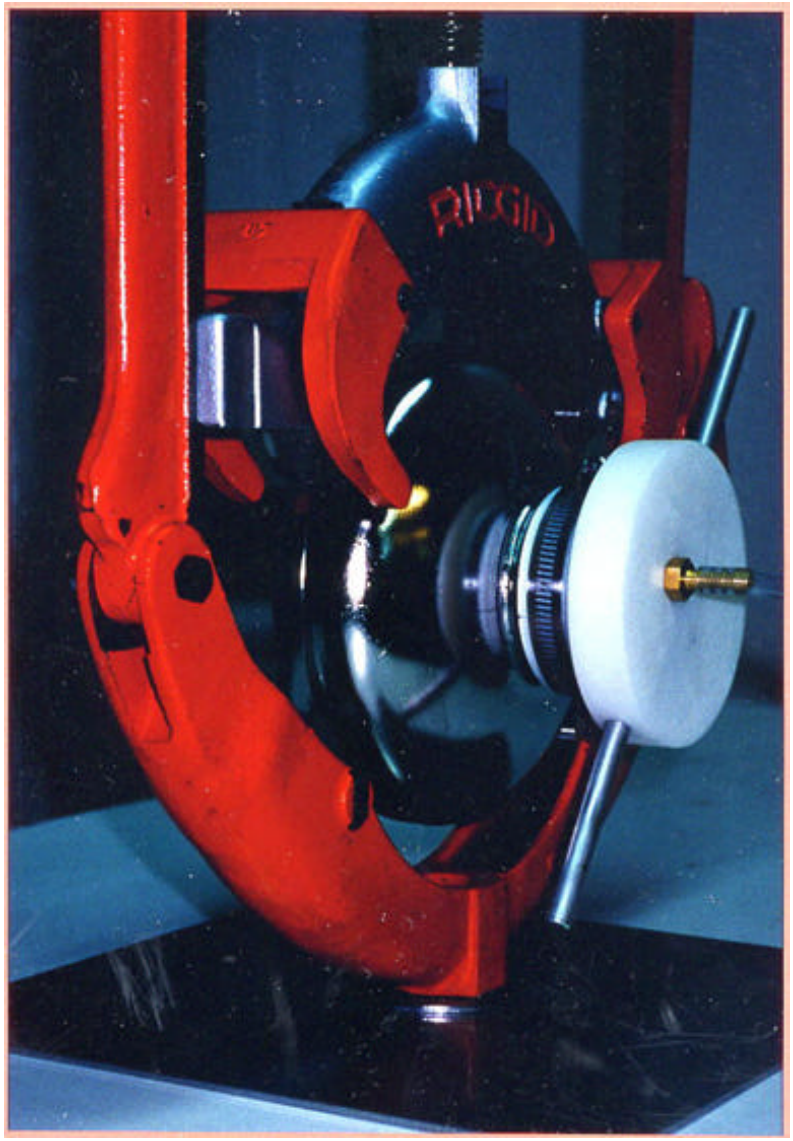


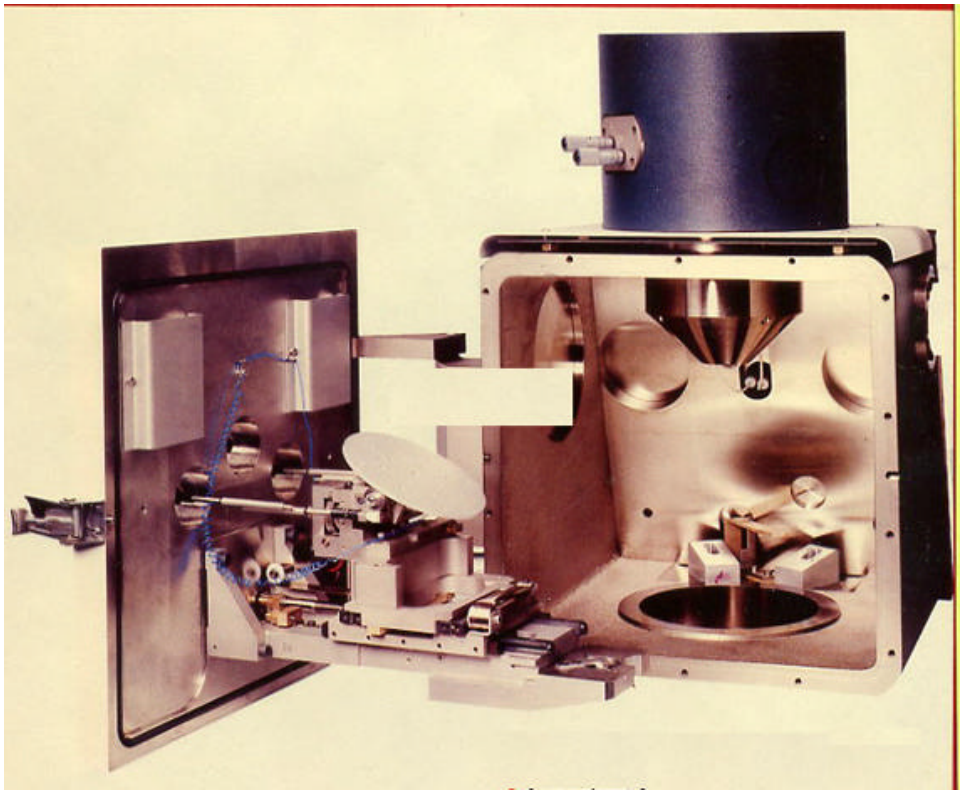


Find lossy areas with thermometry

Carry out surface analysis

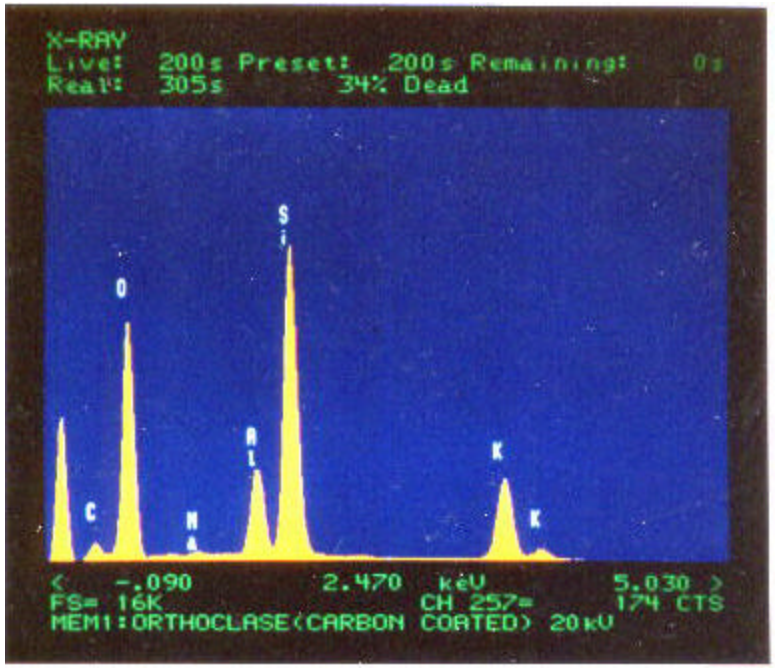
Dissection and SEM





EDX System

Elemental Analysis
on the micron scale

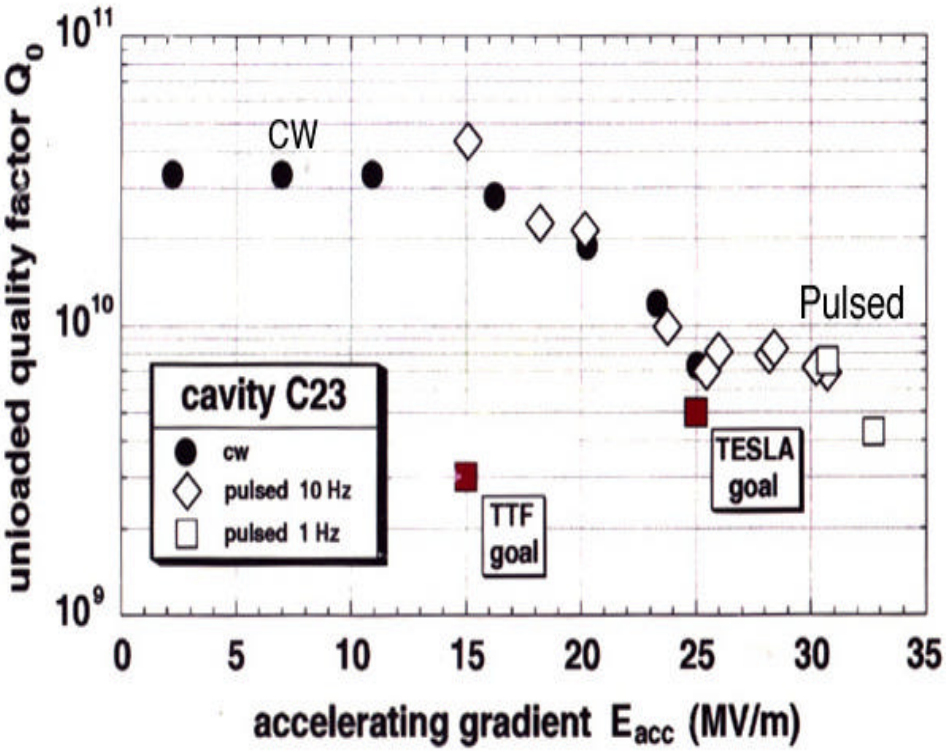


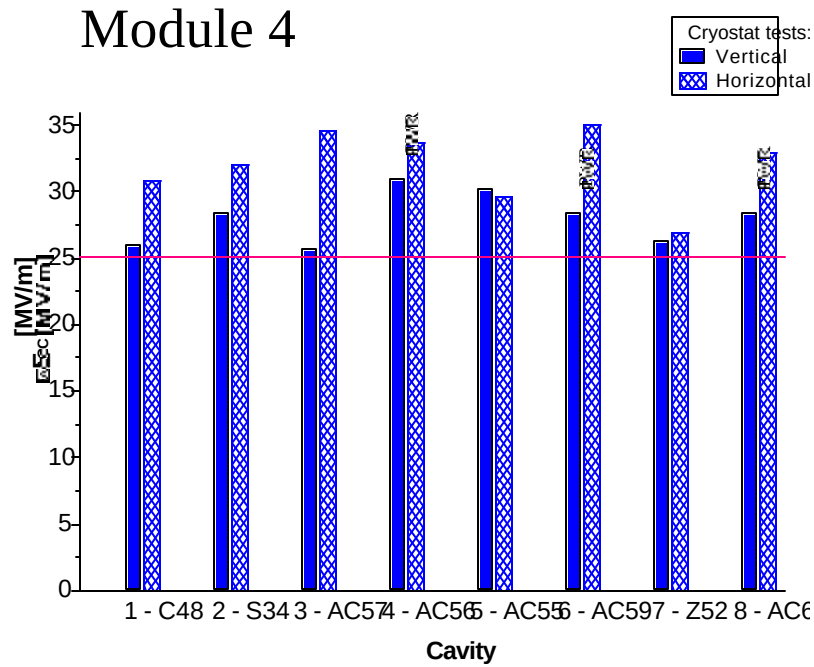
PHI 660 Scanning Auger Micrcoscope (SAM)

Sensitive to first
10 - 100 nm

Gradient R&D con't (> 40 MV/m?)

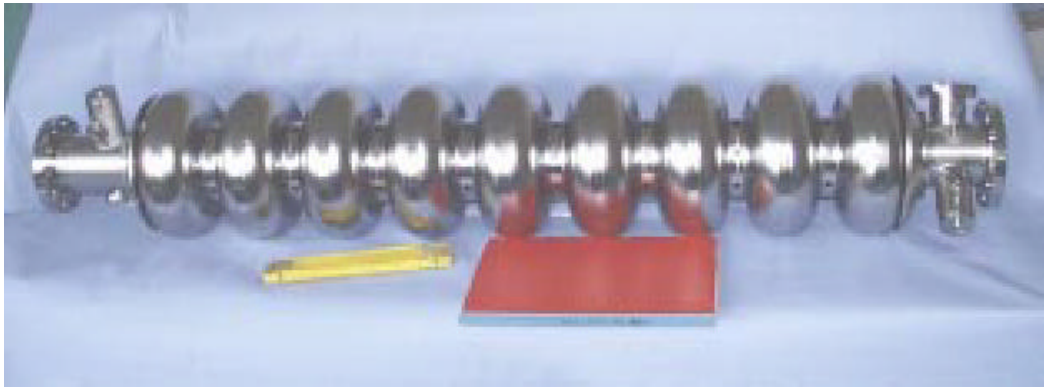
- Gradients are higher in pulsed operation with higher power
  - e.g 25 -->> 30 - 35
- Study gradient vs rf pulse length for TESLA
  - e.g. 40 MV/m for 100 ? sec instead of 30 MV/m for 1000 ? sec
  - Useful to probe higher energy (TeV) at lower luminosity





Streamline TESLA cavity production and preparation

21,000, 9-cell cavities



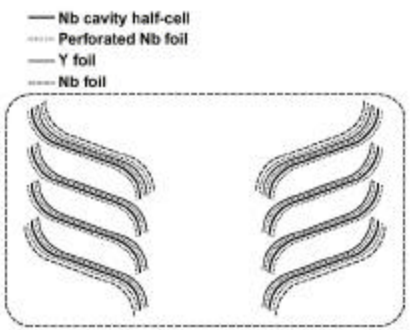
– Heat treat stack of half-cells, electropolish half-cell (instead of 9-cell structure)

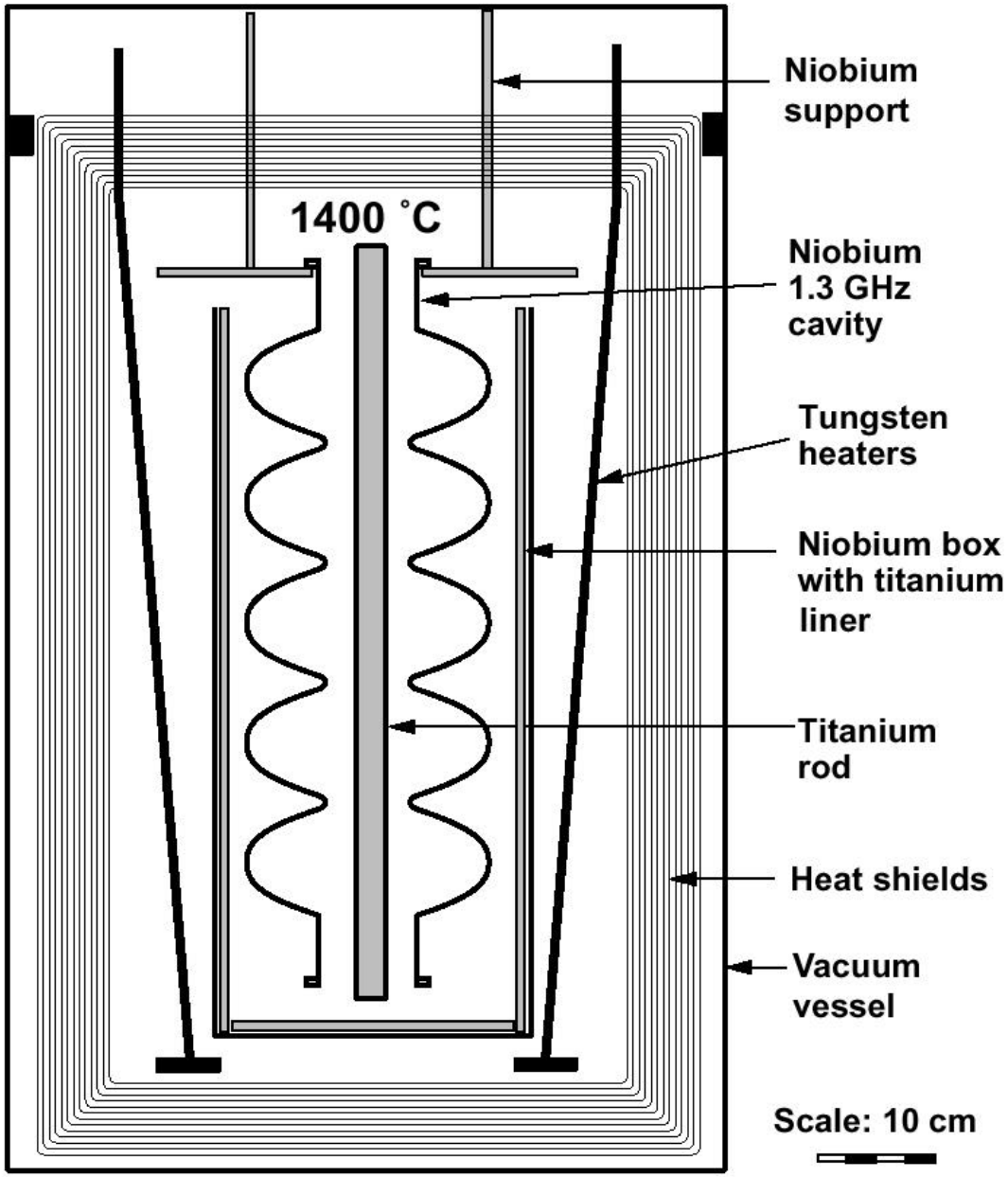
Post Purifying Niobium

1400 C UHV Furnace
Expensive

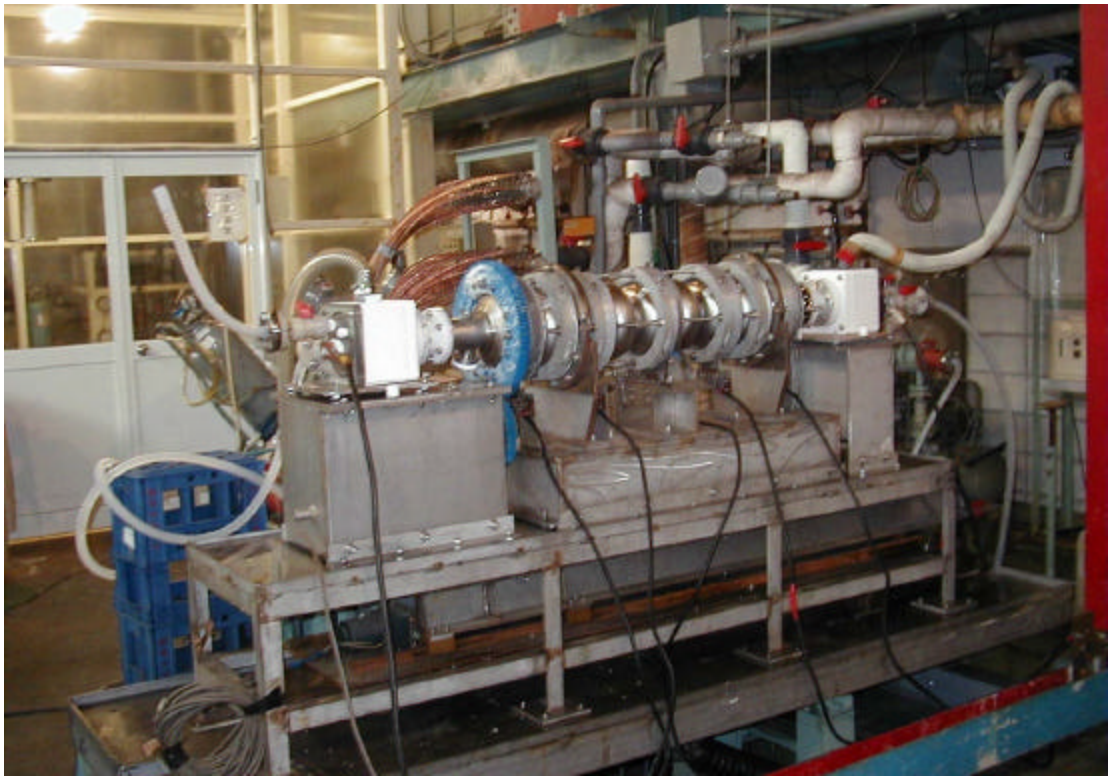
Can heat treat the equivalent of two 9-cell units in one furnace

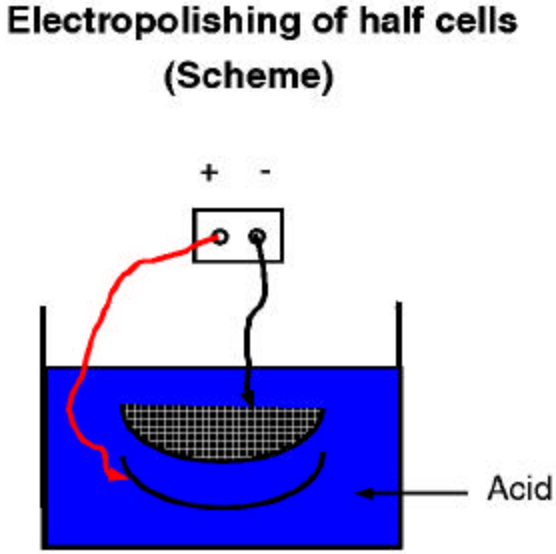
By stacking half-cells

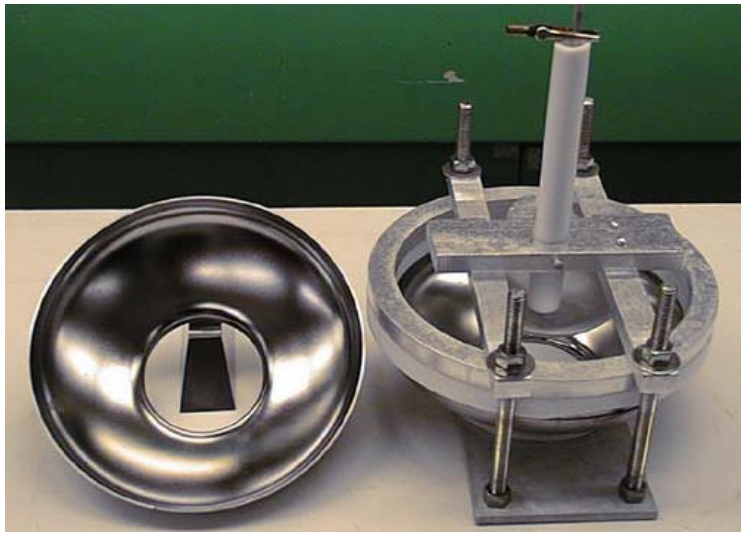




Electropolishing of Multi-cell Resonators







Small opening of long closed structure
=> danger of hydrogen contamination

R&D in physics of RF breakdown for Warm NLC

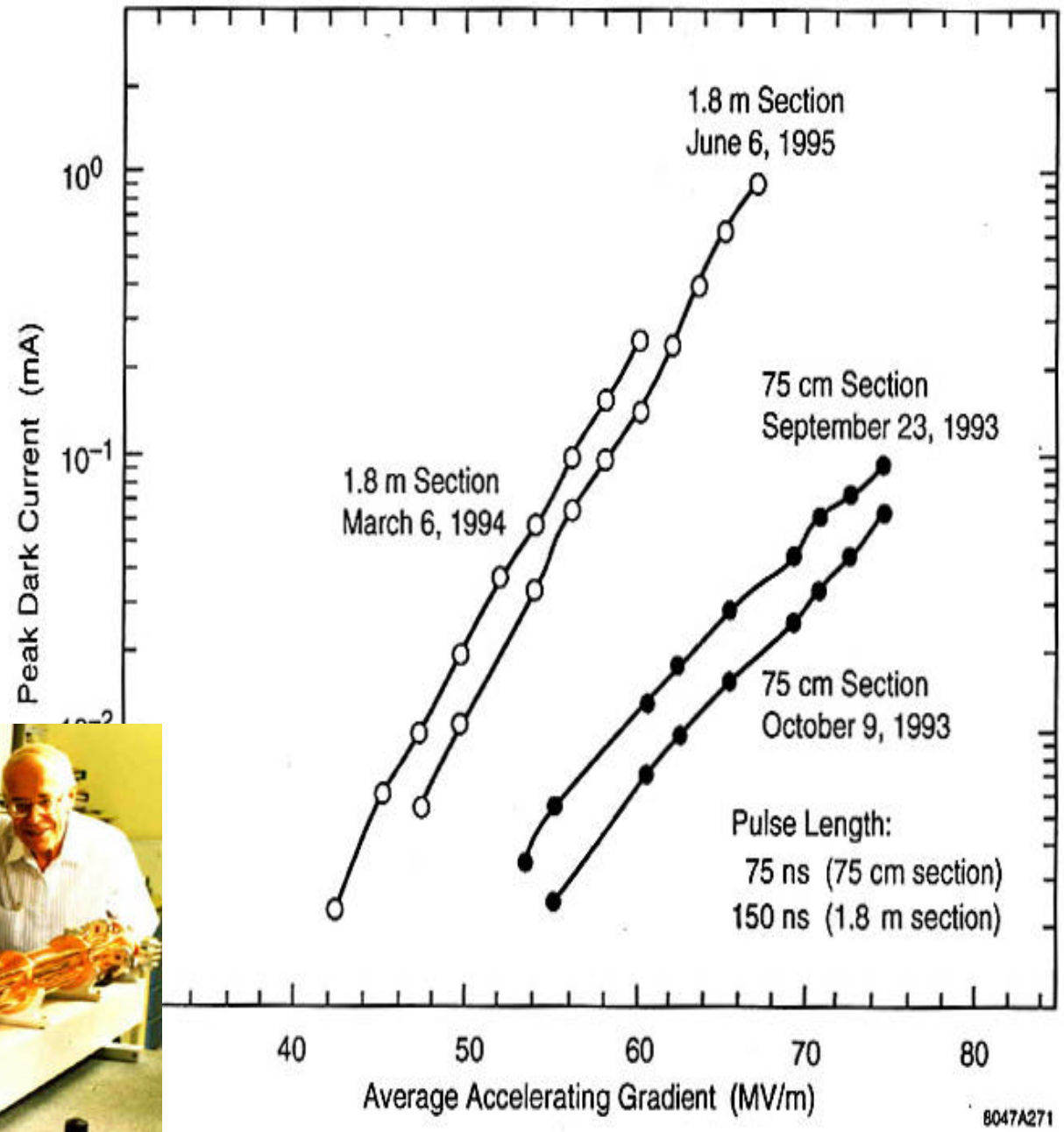
(Collaboration with SLAC - R. Kirby)

- What is the trigger for breakdown?
  - Field emission from micro-particles?
  - Gas evolution from ion bombardment?
- How to keep the overall emission current low at operating gradient?
  - one mA means there are still plenty of active emitters that will spark during operation
- How to get low spark rate ?

Dark Current and Voltage Breakdown Studies Important for Warm NLC

J. Wang 1995

Eacc = 65-75 MV/m

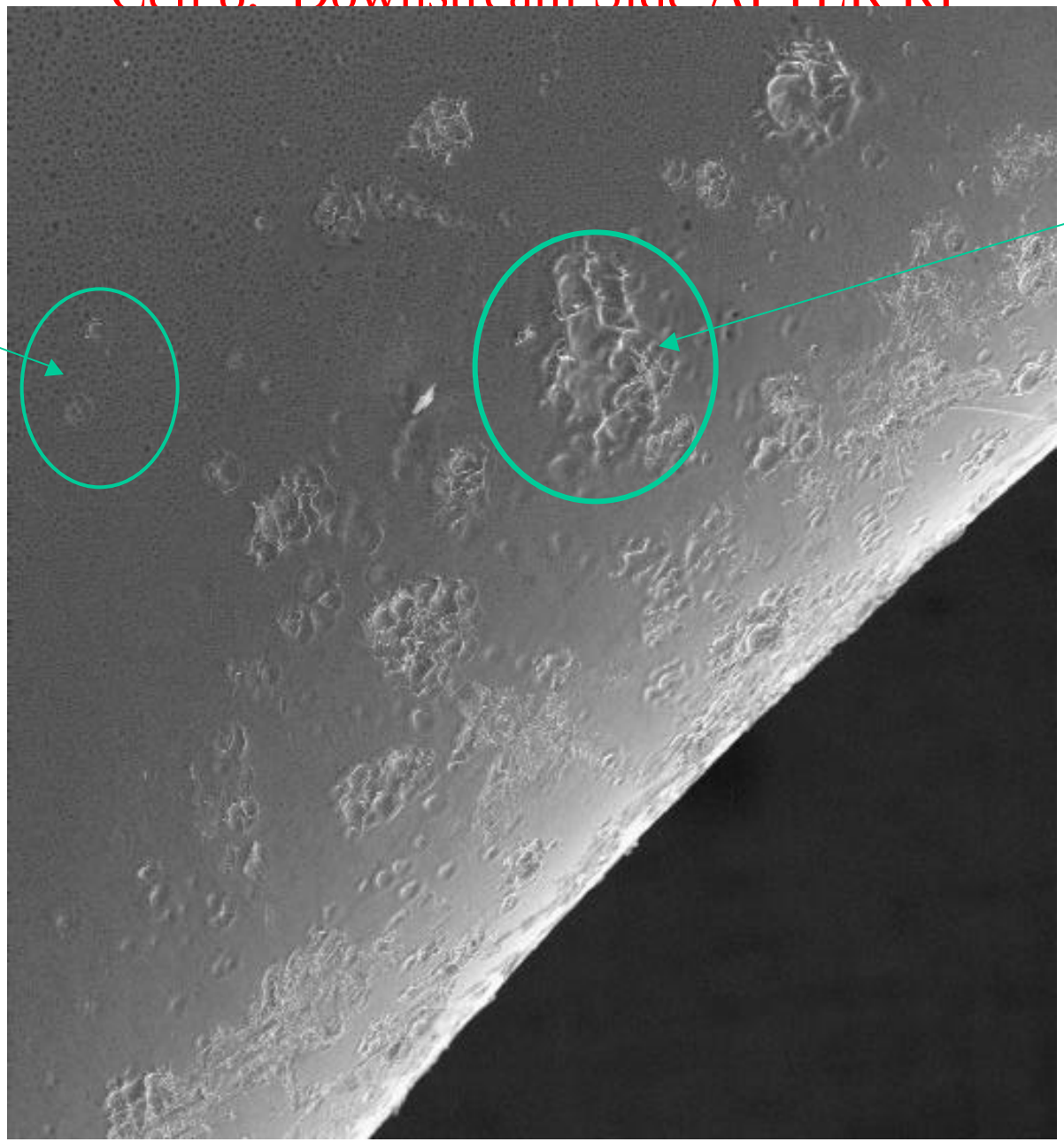


R. Kirby/SLAC

SLAC DS2 1.8 m long structure
- Cell 8, Downstream Side AFTER RF

Individual sparks reduce dark current (conditioning)

Individual craters are not harmful

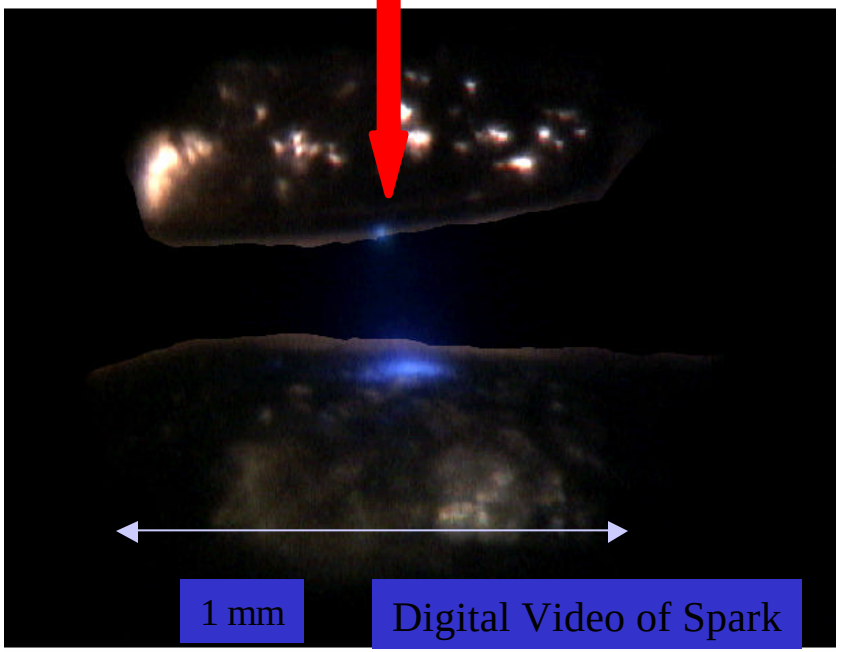


But Sustained Sparks Cause

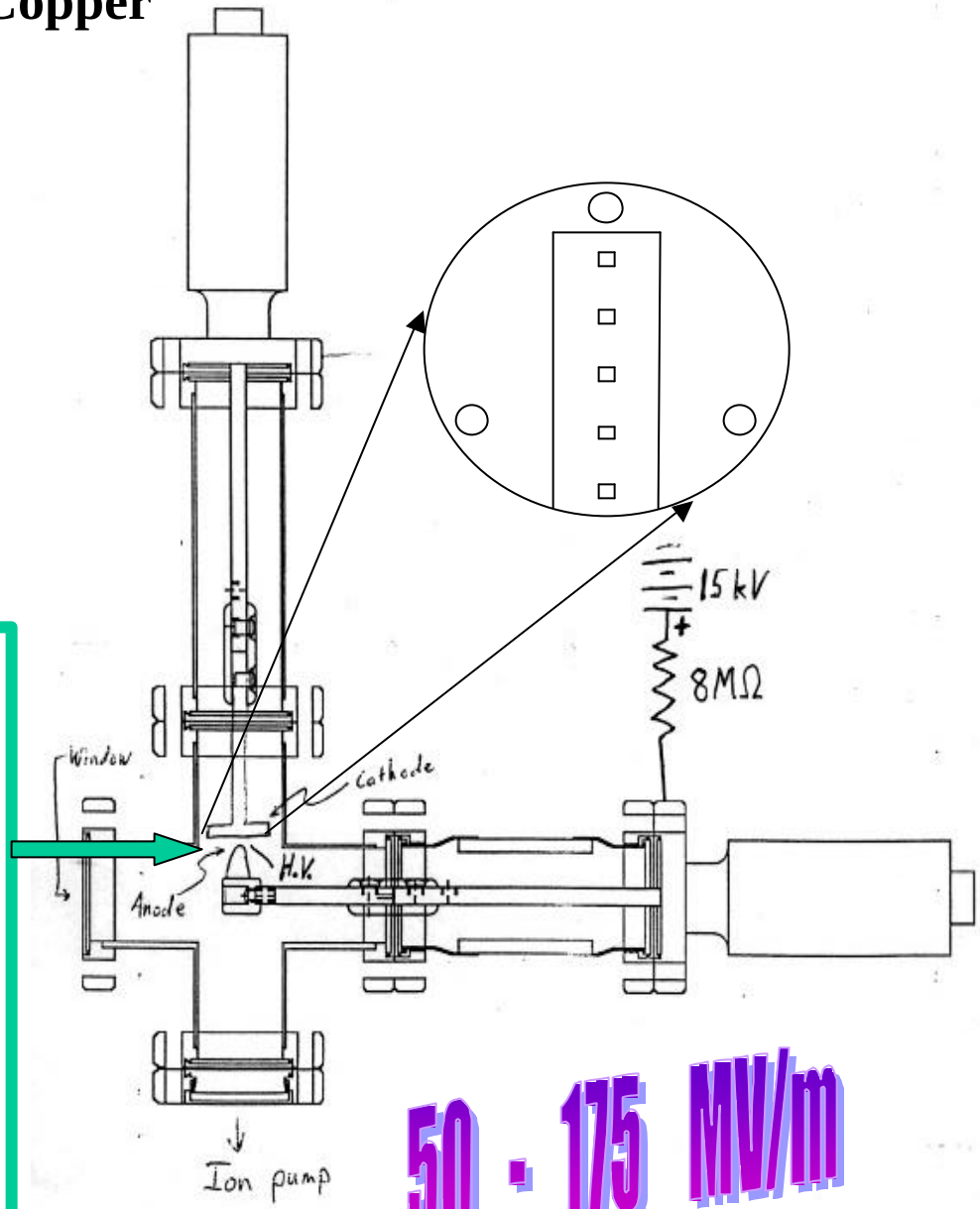
Too many craters=> surface erosion=> cavity detuning

Previous Studies Show Many Common Features between RF and DC Breakdown

- DC single breakdown events are very fast (few ns) like in cavities
- Cause few isolated craters (not harmful) emission halted! (processing)
- But multiple breakdown events can be long and cause severe surface damage (erosion)

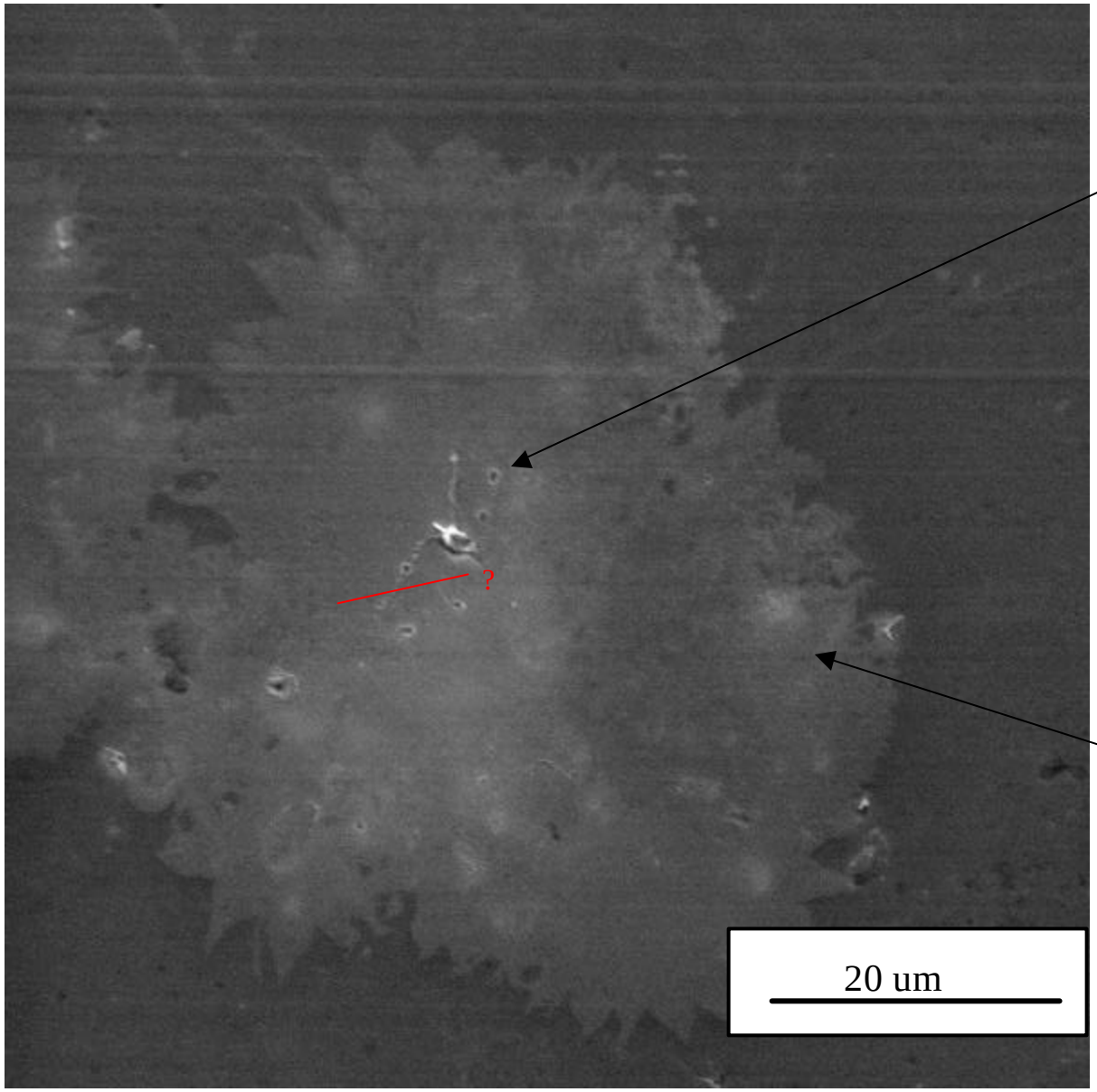


Copper



50 - 175 MV/m

CERN Diamond Machined Copper cathode, HPR

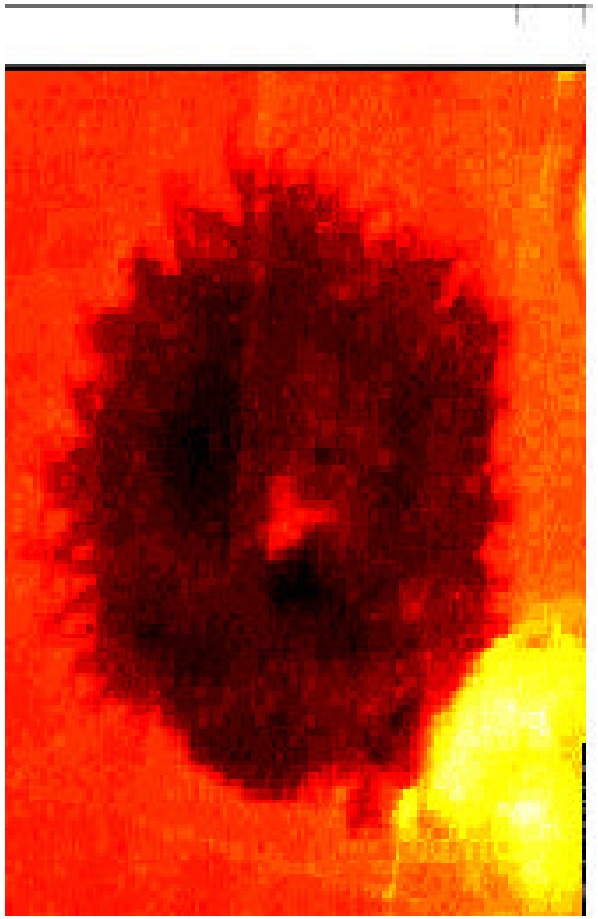


Craters from single breakdown event

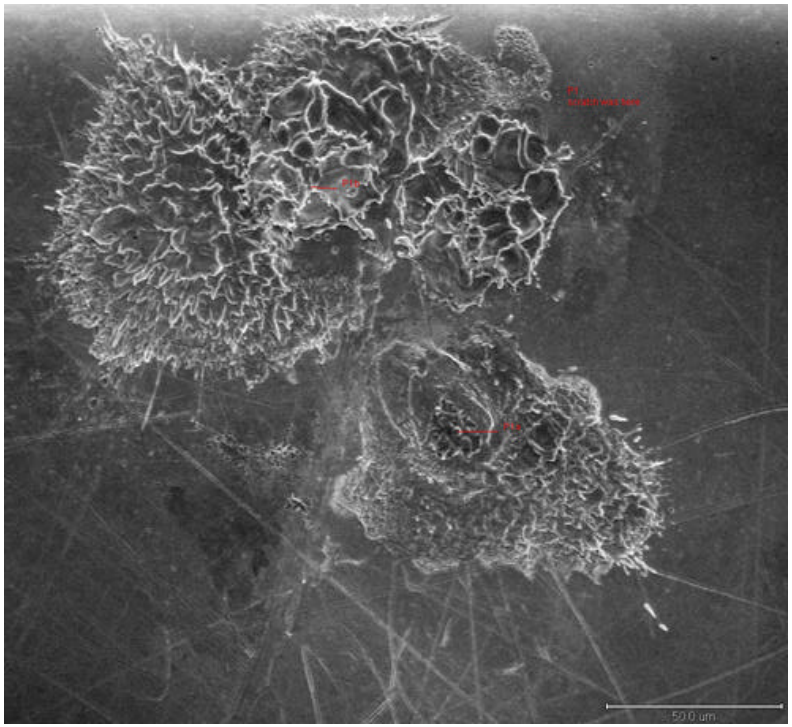
Ion bombardment Starburst region=> Strong evidence for role of gas in breakdown

Starbursts present on copper
are carbon depleted areas
found by Auger Detection

C

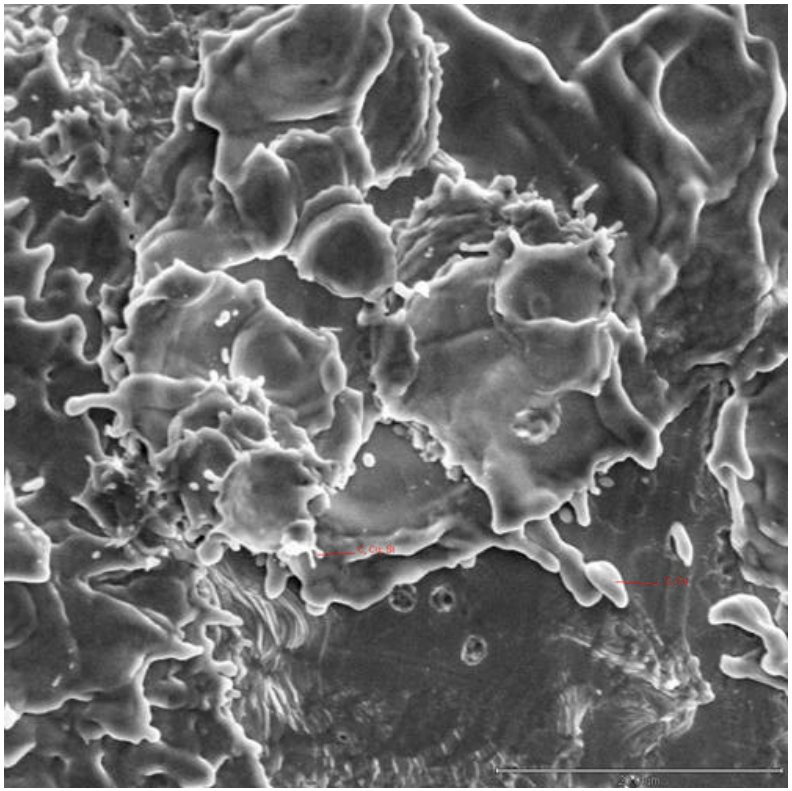


Sustained Spark ! (movie available for interested folks)



SEM

50 microns



20 microns

Copper after 170 MV/m

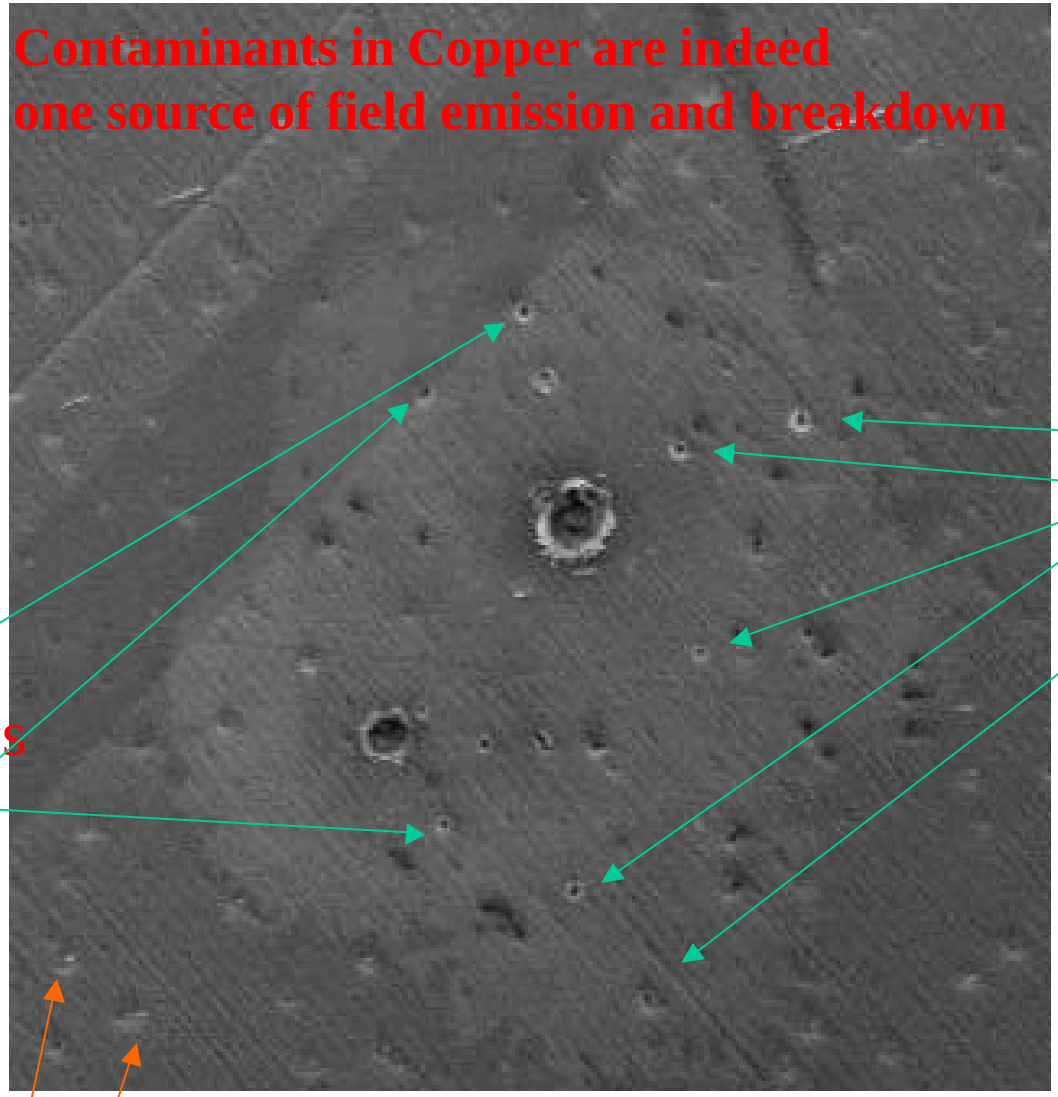
Damage due to Sustained Breakdown

1) Diamond
Machined
Cu, as for cavities

2) Mn
Particles found
After furnace
brazing

3) Sparked

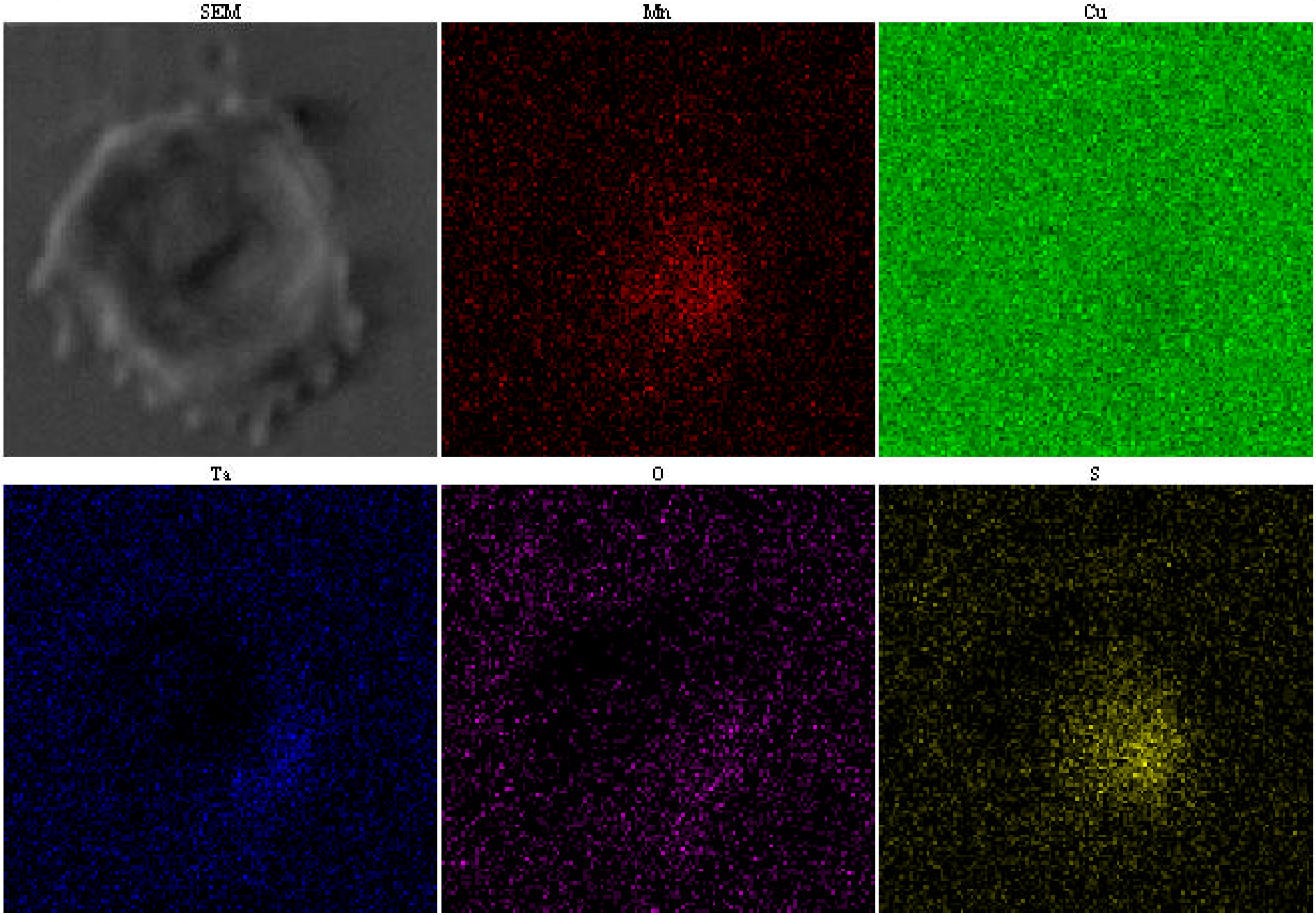
4) Mn particles
Were here -
Now craters



Mn particles
Were here -
Now empty
craters

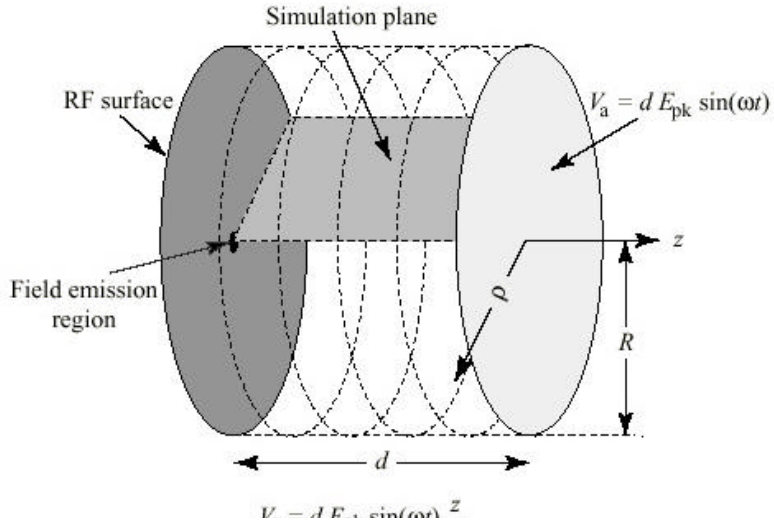
Mn particles outside starburst survived the spark

FastMap1

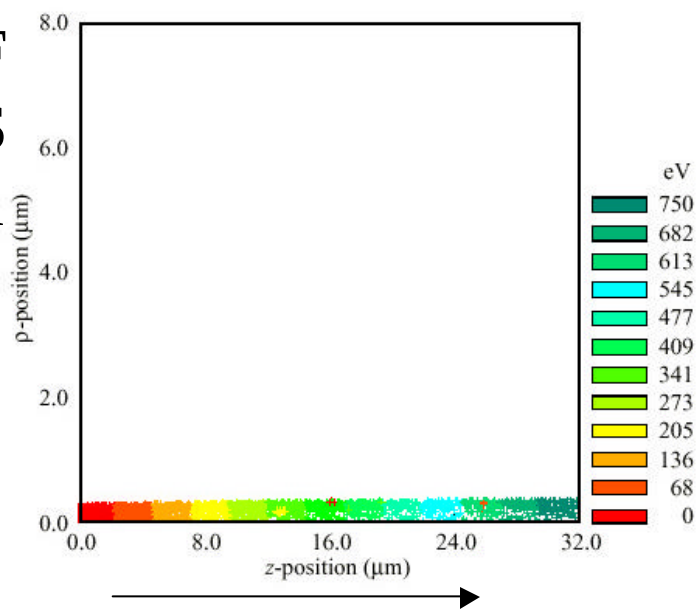


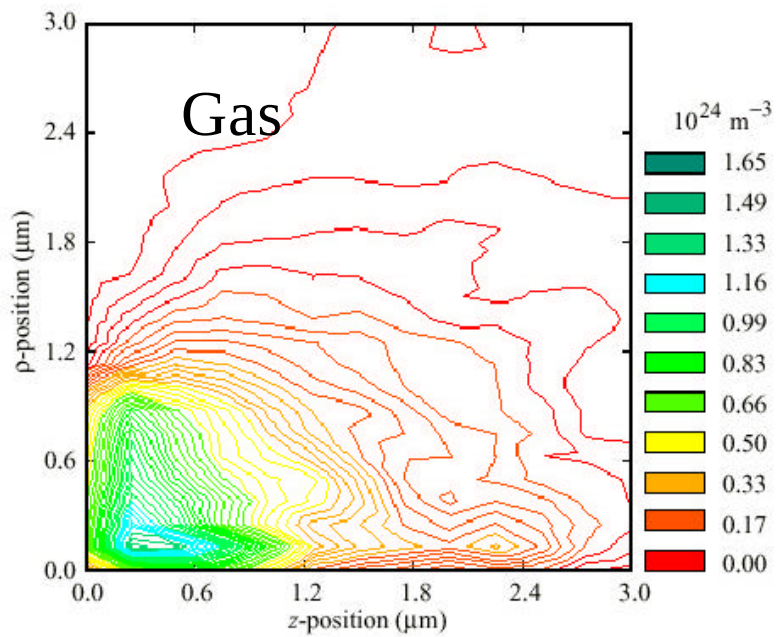
Simulations: How Field Emission Leads to Voltage Breakdown

More Simulations Needed



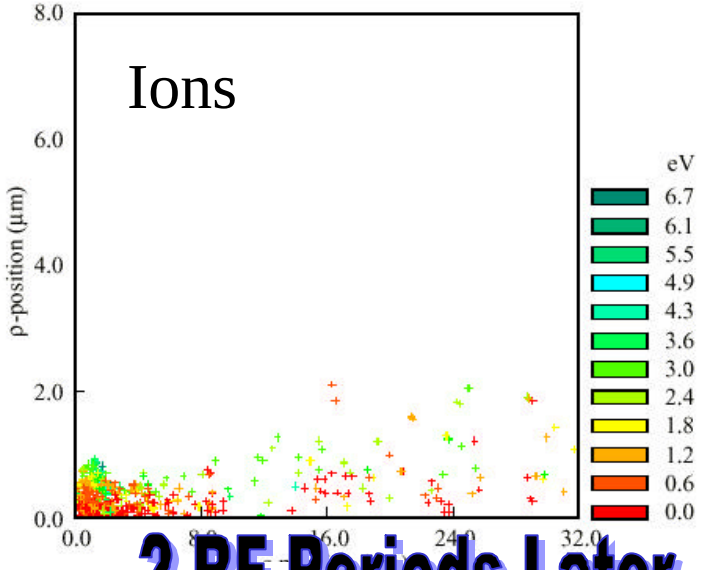
RF Surface



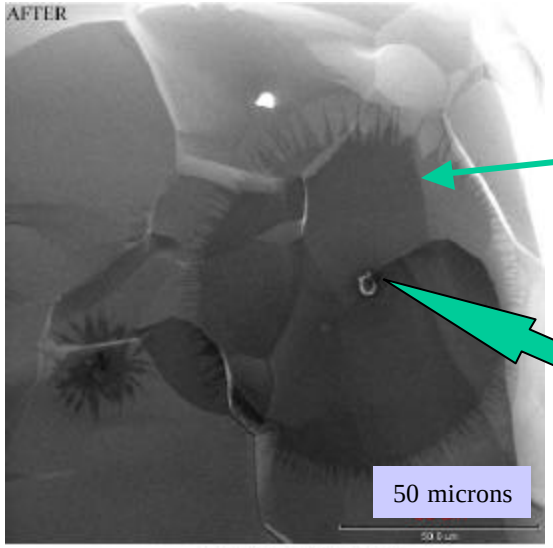


1.25 RF Periods Later

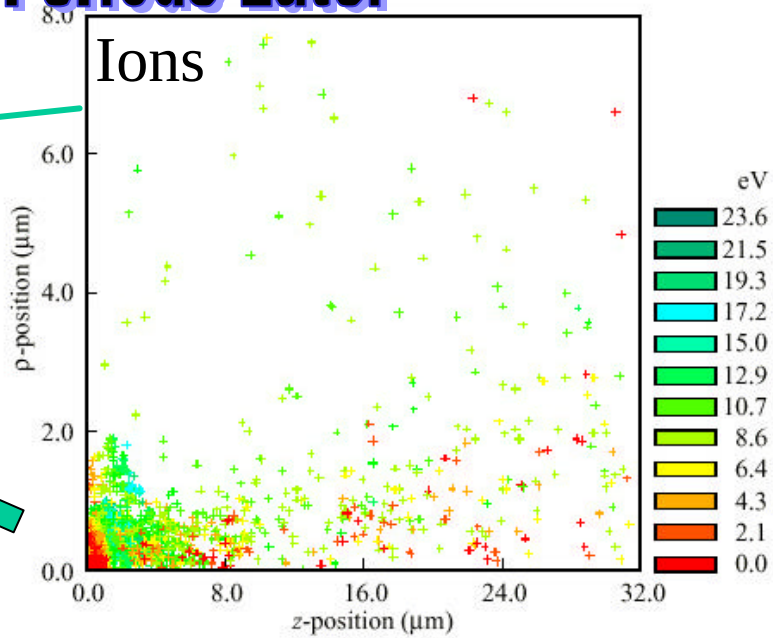
Mask Simulations



2 RF Periods Later



50 MV/m, 225 um gap



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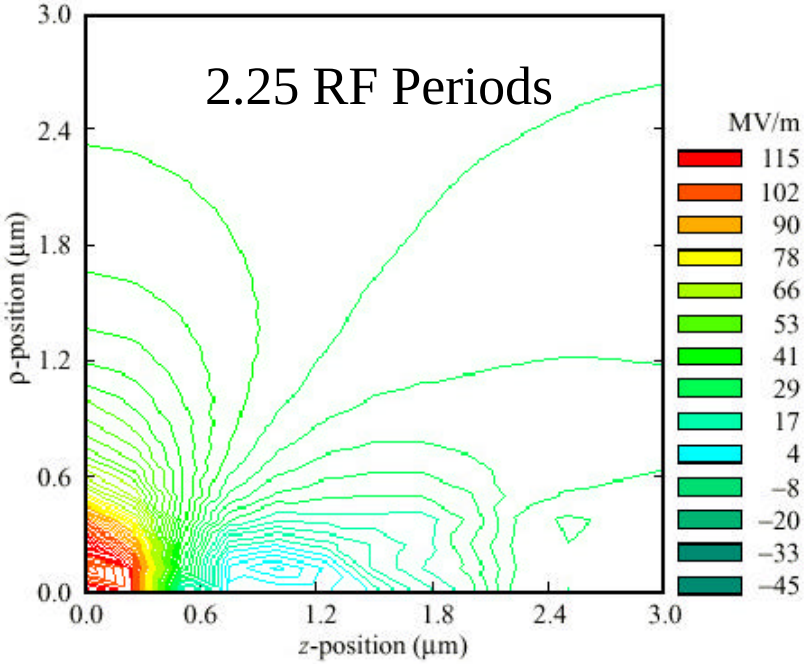
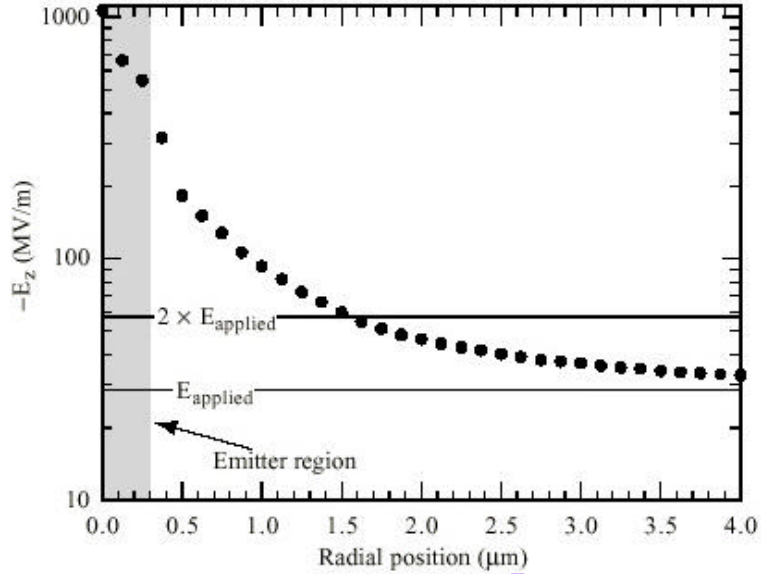
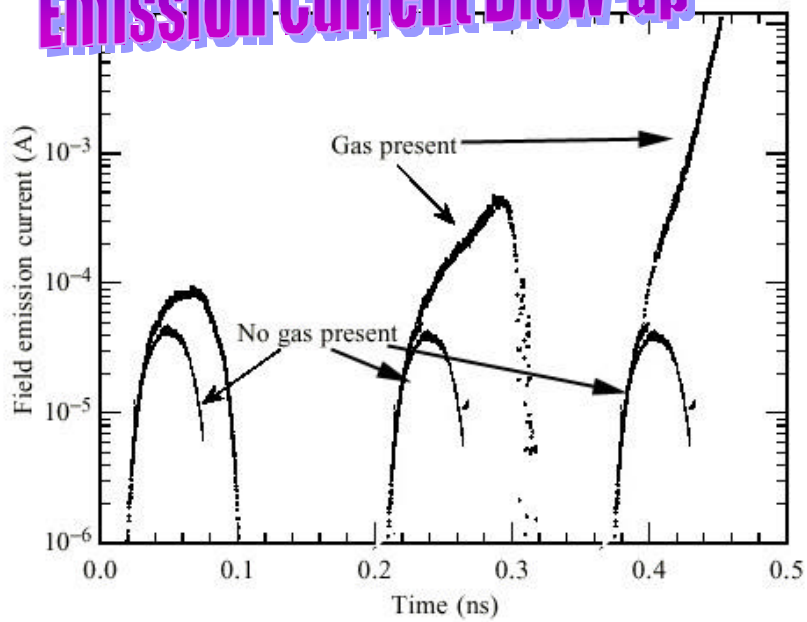
Electric Field



Field Enhancement



Emission Current Blow-up



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Oopic -
Object Oriented Particle-in-Cell Code

Oopic simulates a wide variety of problems such as:

- Plasma display panels
- Ion implantation
- High-power microwave devices
- Next-generation particle accelerator concepts

- Oopic allows a wide variety of input parameters.

- Electric Field
- Magnetic Field
- Current
- Temperature
- Conductors
- Pressure
- Gas
- Collision Model
- Electrons EmitPort
- Grids

Movie of Field Enhancement

Conclusions

HEP:

- Better understanding of surfaces will lead to higher gradients
  - Both for NC and SC options for the Linear Collider

- SRF Technology advances will help many accelerators now under consideration for

NP: Rare Isotope Accelerator (RIA), CEBAF Upgrade

Light Sources: Storage Rings,
FELs: IR, UV, X-ray…
Energy Recovery Linac (ERL)

Neutron Sources: Oak Ridge Spallation Neutron Source (SNS)
Waste Transmutation AAA, TRASCO...