Summary of the Mar, 3-4
US High Gradient Collaboration Workshop

http://www.hep.anl.gov/ushighgradient/

J. Norem
ANL/HEP

NFMCC / MCTF
3/11/09

Agenda for High-Gradient Collaboration Workshop

First Morning Session Chair: Richard Temkin

9:00 am Wei Gai Welcome and some announcements
9:05 am Phil Debenham/Sami Tantawi (SLAC)"A few words from DOE and Advisory Council"
9:15am Sami Tantawi "High Gradient Research Activity at SLAC"
9:45am Shuji Matsumoto "Update of KEK X-band activities."
10:05 am Antoine Descoeudres "CERN DC vacuum breakdown experiments for CLIC."
10:25 am Juwen Wang "SLAC activities for CLIC High Gradient Structure R&D."

Second Morning Session Chair: Sami Tantawi

11:00 am. Manoel Conde (ANL) "Update on ANL AWA Facility."
11:20 am Shigeki Fukuda (KEK) "Design Studies of X-band multi-beam Klystron."
11:35 am Michael LaPointe (Yale University) "Pulse compression at 34 and 11 Ghz."
11:50 am Steve Gold (NRL) "Update on the Magnicon Facility Activities."
12:05 pm Derun Li (LBL) "Normal Conducting RF cavity R&D for Muon Ionization Cooling."

First Afternoon Session Chair: Jay Hirshfield

1:30 pm Kazue Yokoyama (KEK) "Status of high gradient experiments at Nextef."
1:50 pm Rich Temkin/Michael Shapiro (MIT)"Progress on High Gradient Photonic Structures."
2:10 pm Lisa Laurent. (SLAC) "Pulse Heating Experiment and status report."
2:30 pm Valery Dolgashev (SLAC) "Status of single cell tests at SLAC."
3:00 pm Wenxi Zhu (UMD) "Temp. and Stress rise induced by cracks in accelerating structure."

Second Afternoon Session Chair: Steven Gold

3:40 pm Wang Faya "Breakdown study of L-band SW and X-band CLIC structure."
4:00 pm Chris Adolphsen (SLAC) "Recent Tests of CERN X-Band Structures at NLCTA."

4:20 pm Jing Chunguang (ETech/ANL) "Transverse mode damped structure."
4:40 pm Jim Norem (ANL HEP) "Recent results from the other US high gradient collaboration."
5:00 pm Jay Hirshfield (Omega-p) "Multi-mode cavity for raising RF breakdown threshold."
5:20 pm Alexey Kanareykin (ETech) "New material and design for HG accelerator applications."
5:40 pm Diktys Stratakis (BNL) "Breakdown Studies under External Magnetic Fields."

Wednesday, March 4
First Morning Session Chair: Gregory Nusinouvich
9:00 am Zenghai Li (SLAC) "MP and dark current."
9:30 am Seth Veitzer (Tech-X) "Surface emission and Plasma radiation models for RF breakdown studies."
9:50 am Oleksandr Sinitsyn (UMD) "Self-consistent non-stationary 2D model of Multipactor in DLA structure)."
10:10 am Helga Timko (CERN) "Multiscale modelling of breakdowns."

Second Morning Session Chair: Wei Gai
10:50 am Grigory Kazakevich (Omega-P) "High Power 20 GHz 7th harmonic frequency multiplier for HG acceleratorR&D."
11:10 am Sergey Shchelkunov (Yale) "Diel.-lined structures for high-gradient WF accelerators."
11:25 am Jacob Haimson (Haimson Res. Corp) **"**17GHz Choppertron.Test Results and Status
11:40 am Paul Schoessow (ETech) "Studies of multipactor in dielectric accelerating structures."
12:00 noon Rolland Johnson (Muons, Inc) "RF Breakdown in Pressurized RF Cavities."

Topics discussed

CLIC centered efforts
- SLAC cavity testing program
- CERN DC arc program
- KEK rf program (facility and results)
- Field emission and multipactor backgrounds
- Experimental measurement of Pulse heating damage
  - Modeling of crack formation
- Single and multicell structure development

Dielectric acceleration
- Experimental results
- Multipactoring

Misc efforts
- Klystron development
- Multimode cavities
- Photonic band gap structures
- Frequency multipliers
- New materials (dielectrics etc)

NFMCC
- Overview
- High pressure
- Magnetic field

Misc Theoretical efforts
- CERN arc modeling
- NFMCC arc modeling

CLIC Tantawi, Wang, Dolgashev, Adolphsen Yokoyama, Li, Laurant

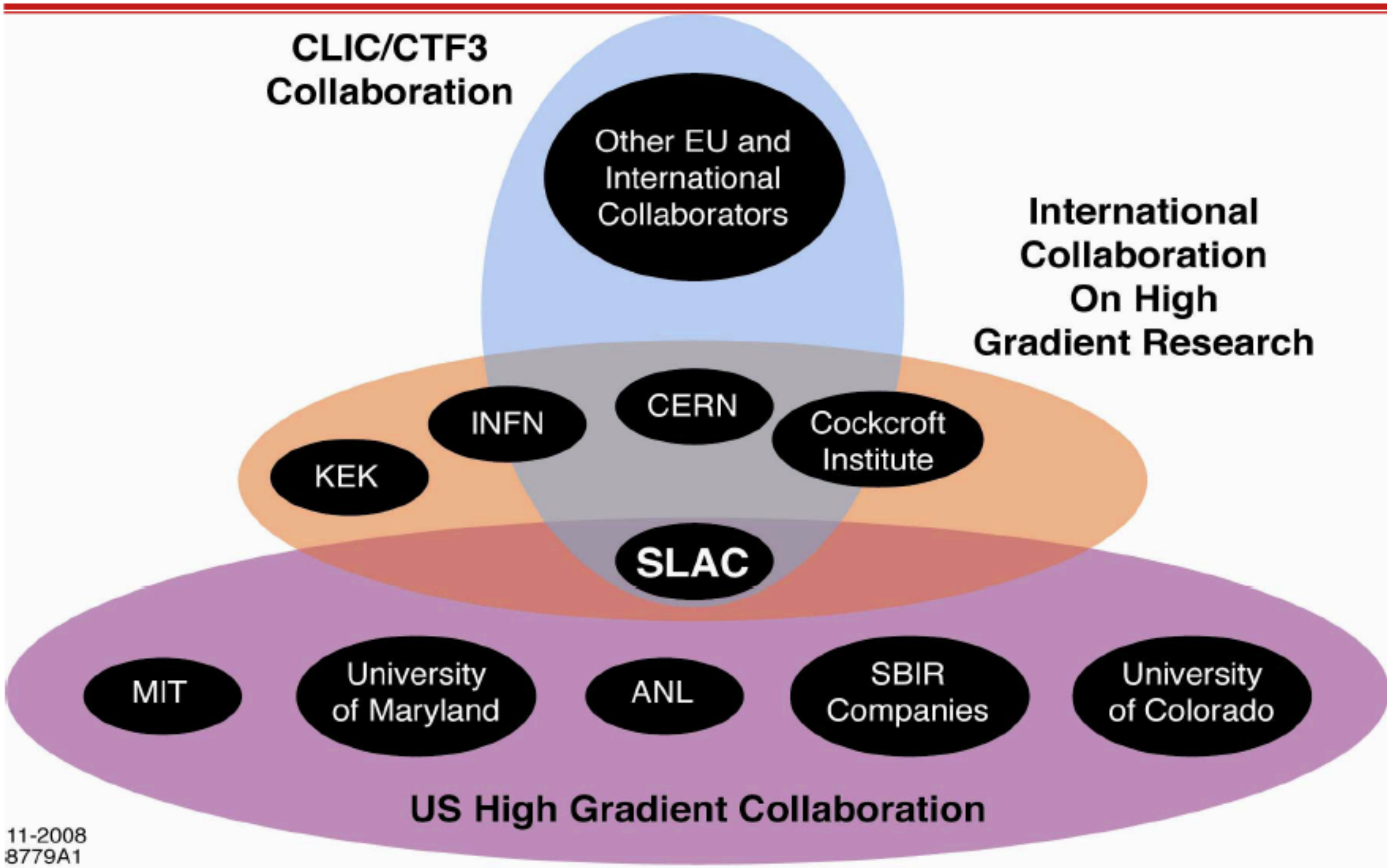
The CLIC program now demonstrated the gradient and pulse length they need.
The result of a 25 year R&D program

Breakdown rates are under control.

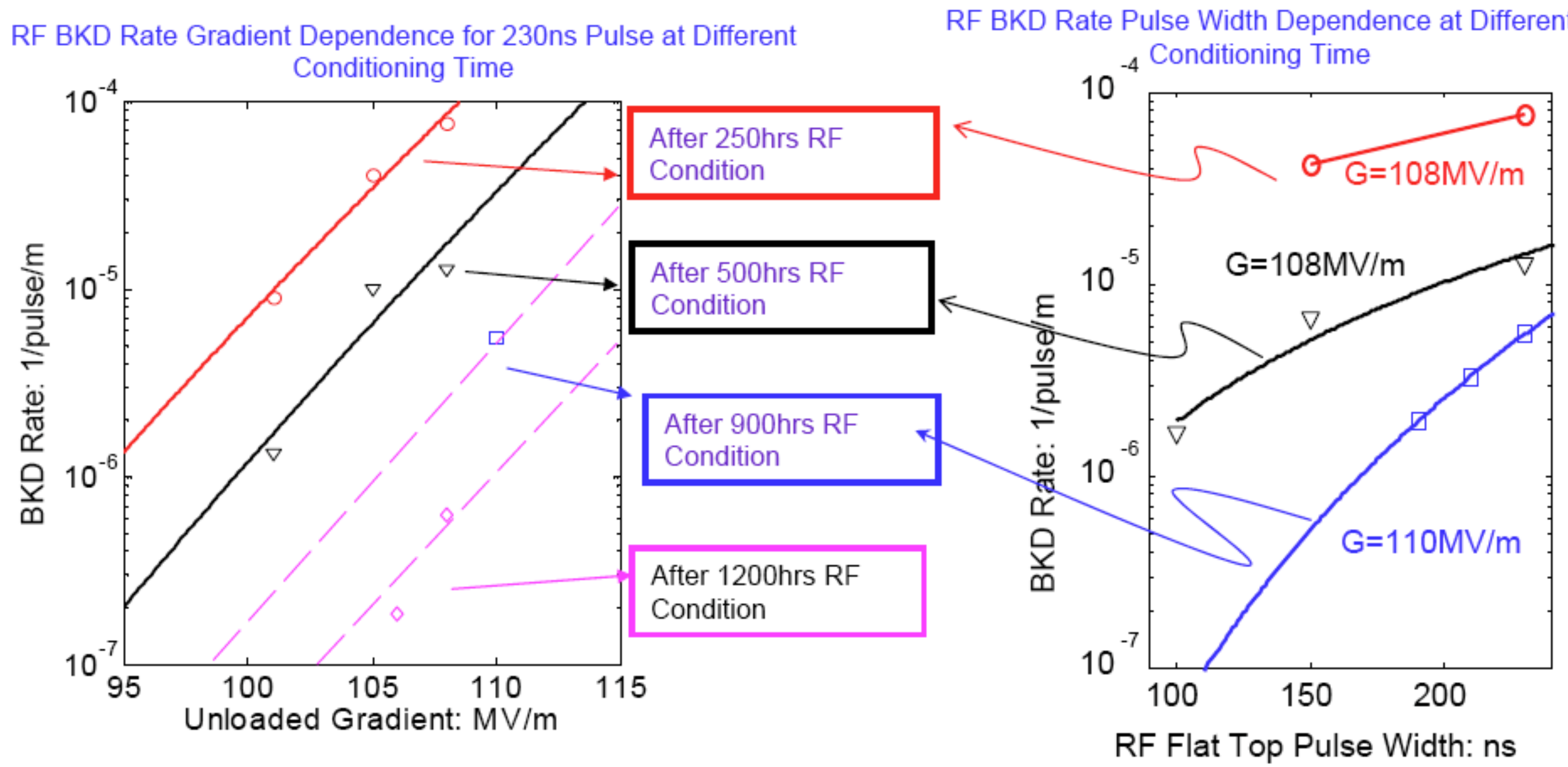
They worry about pulse heating, different alloys, etc..

They are looking at DC arc measurements and models.

Collaborations



RF Processing of the T18 Structure

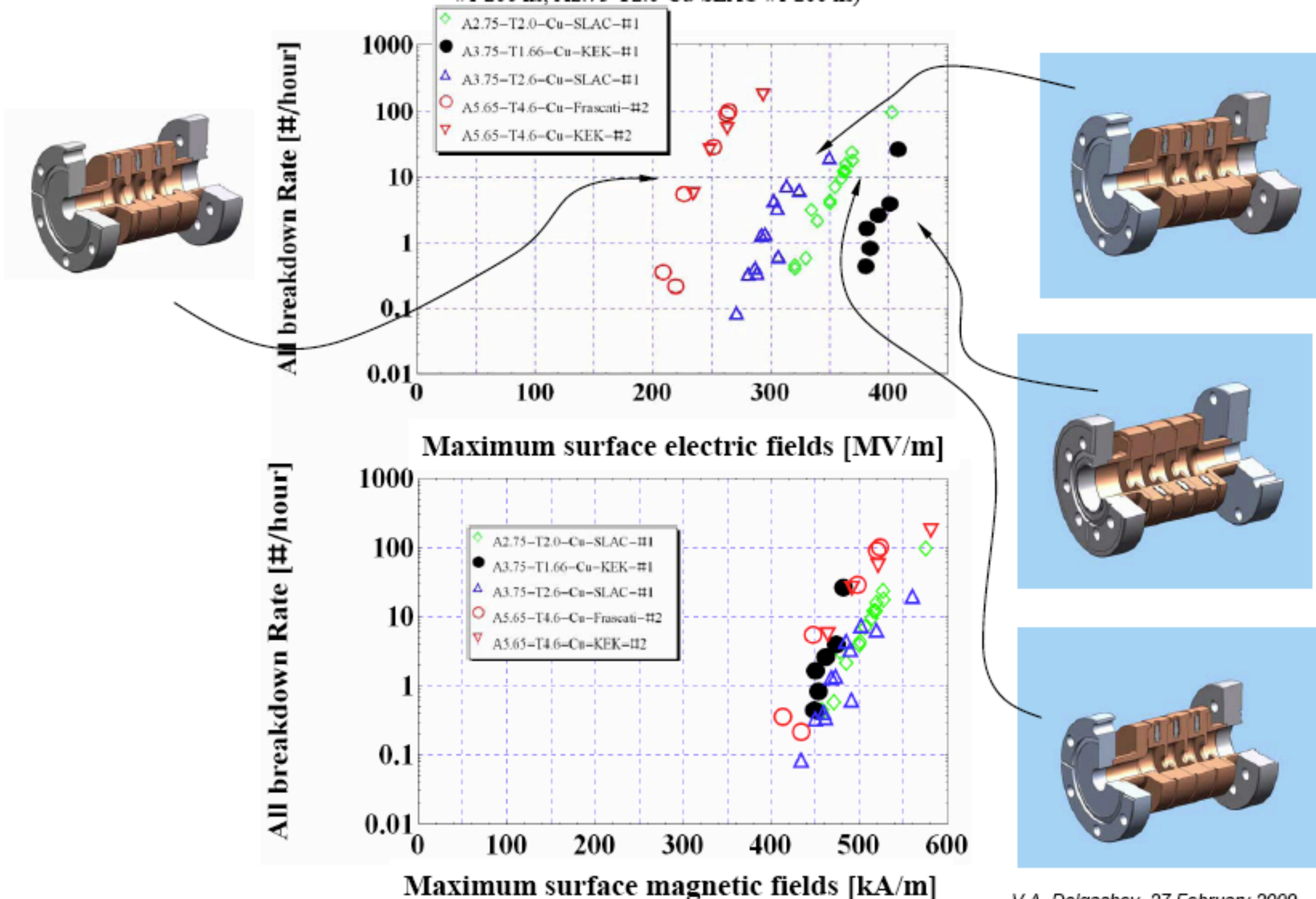


This performance *may be* good enough for 100MV/m structure for a warm collider, however, it does not yet contain all necessary features such as wakefield damping. Future traveling wave structure designs will also have better efficiency

Dolgashev

Surface fields for 5 different single cell structures, *shaped* pulse

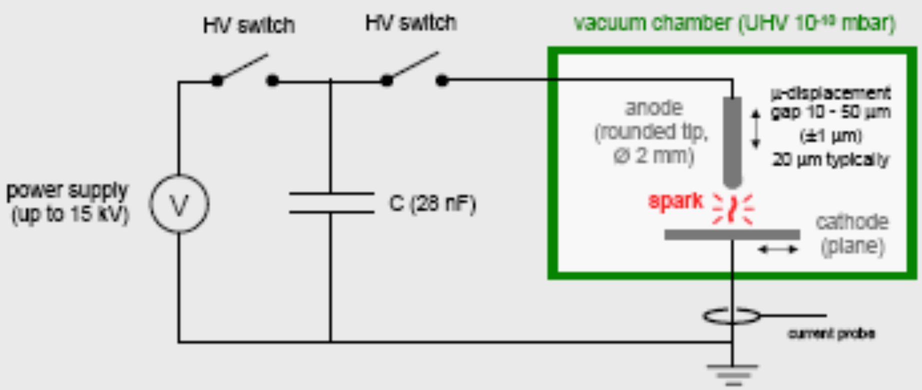
(*flat* part: A5.65-T4.6-KEK-#2- 150 ns, A5.65-T4.6-Frascati-#2- 150 ns, A3.75-T2.6-Cu-SLAC-#1: 150 ns, A3.75-T1.66-Cu-KEK-#1 200 ns, A2.75-T2.0-Cu-SLAC-#1 200 ns)



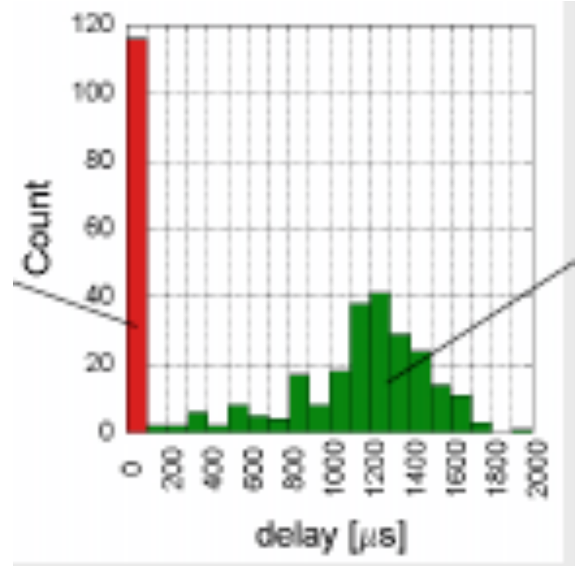
V.A. Dolgashev, 27 February 2009

Descoeudres

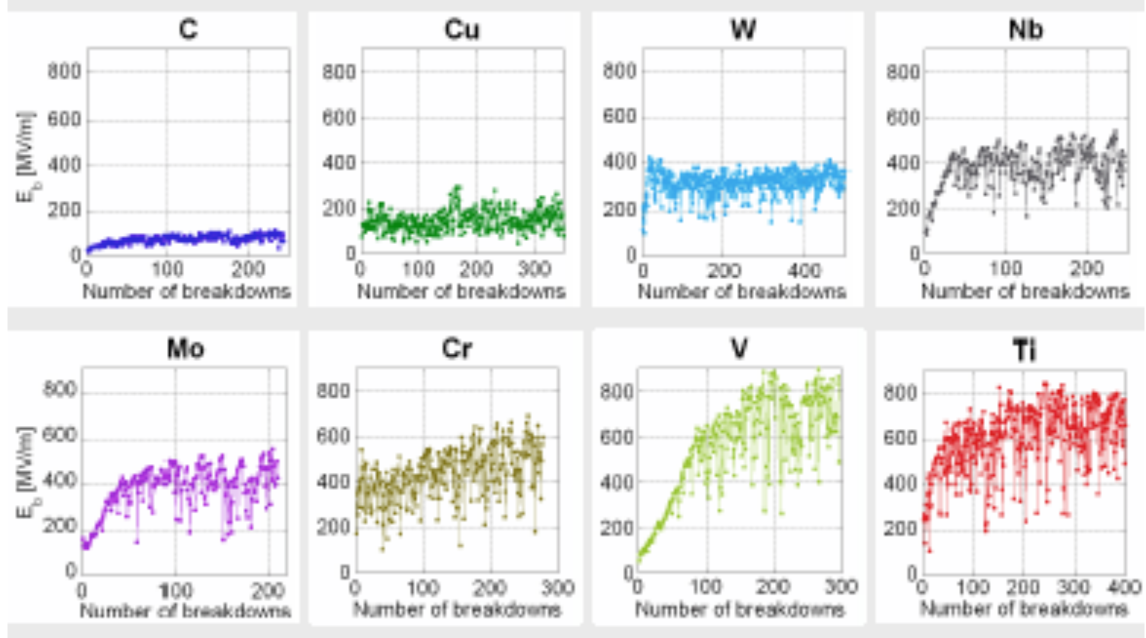
Experimental set-up : “ the spark system ”



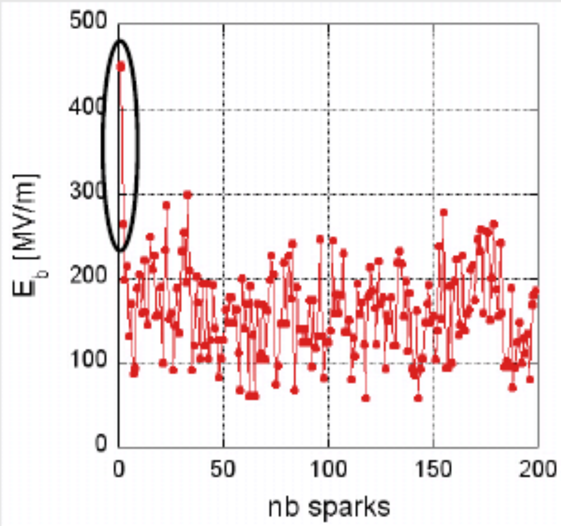
- Two similar systems are running in parallel
- Types of measurements : 1) Field Emission (→ β)
  2) Conditioning (→ breakdown field E_b)
  3) Breakdown Rate (→ BDR vs E)

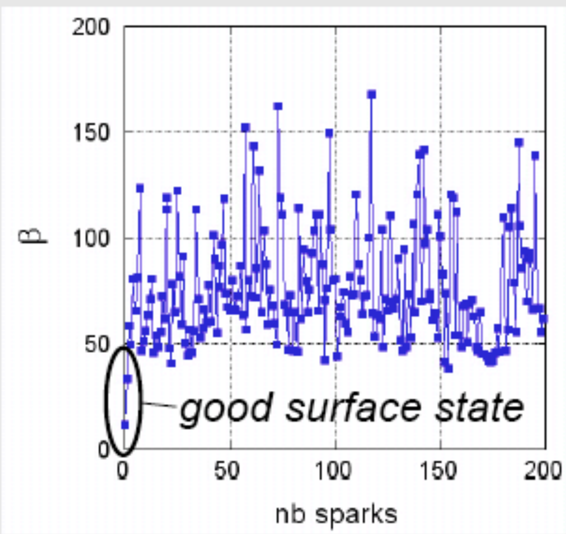


Conditioning curves of pure metals



Local field $\beta \cdot E_b$ (Cu)



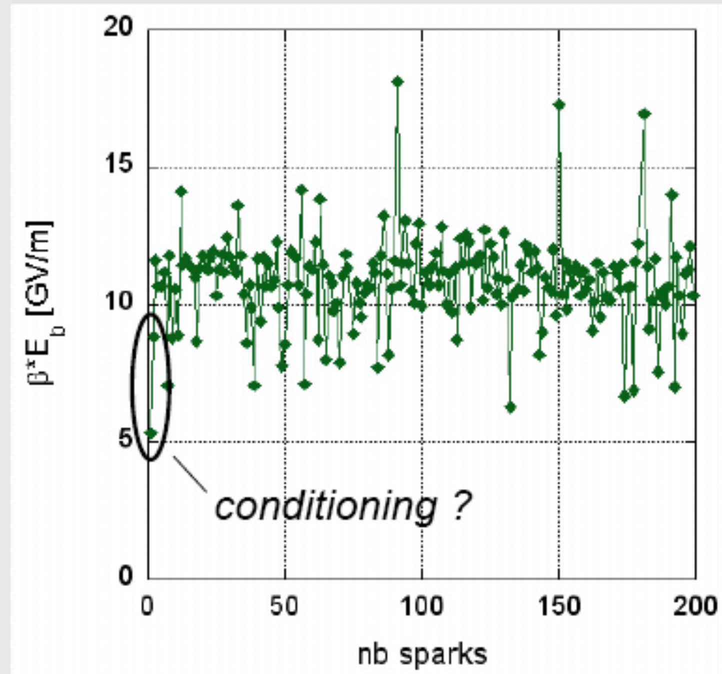


$\overline{E_b}$ = 159 MV/m

(± 32%)

$\overline{\beta}$ = 77

(± 36%)

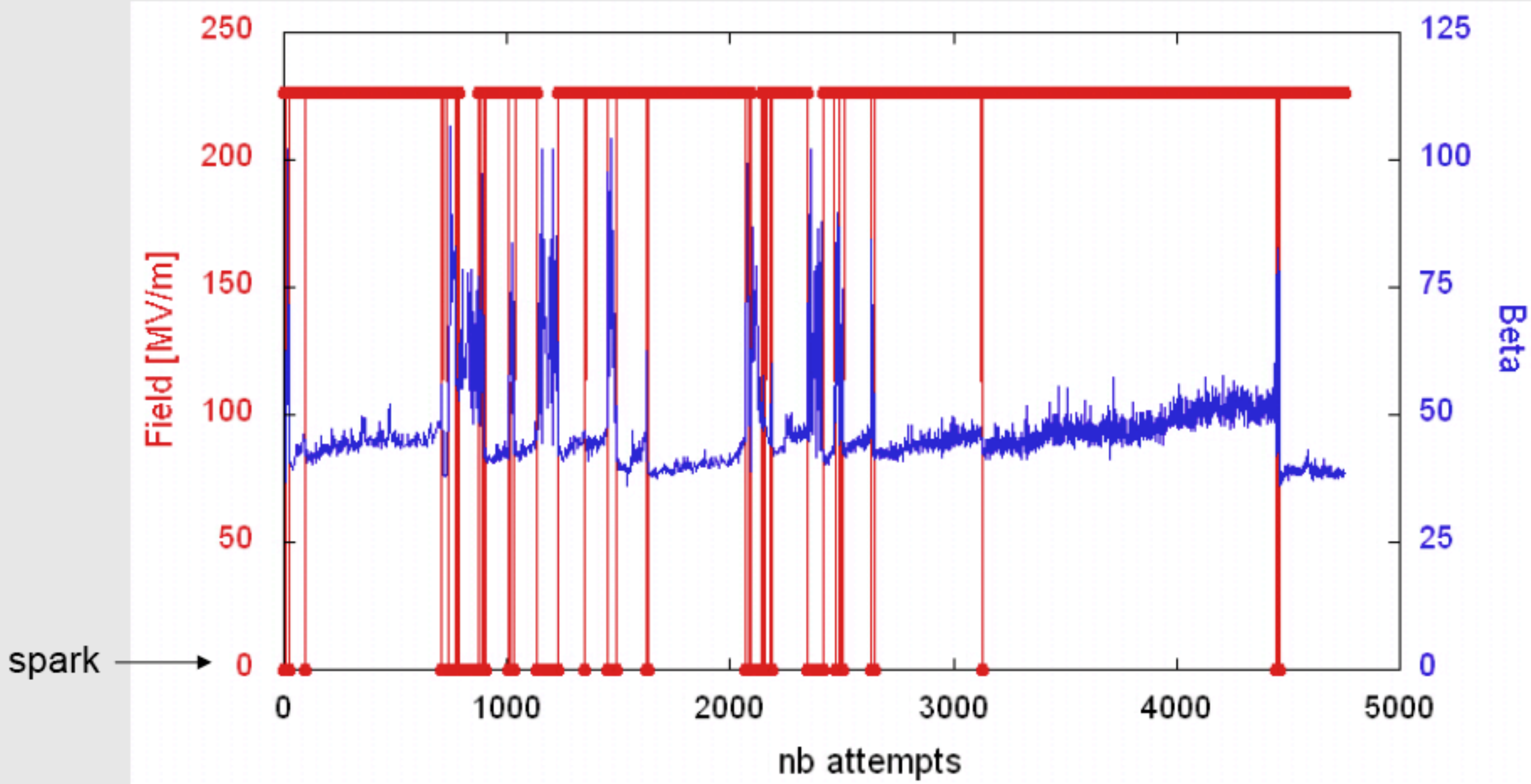


$\overline{\beta \cdot E_b}$ = 10.8 GV/m

(± 16%)

→ Local field = cst = 10.8 GV/m for Cu

Evolution of β during BDR measurements (Cu)



- General pattern : clusters of consecutive breakdowns / quiet periods
- β slightly increases during a quiet period ***if E is sufficiently high***

→ The surface is modified by the presence of the field (are tips pulled?)

Matsumoto

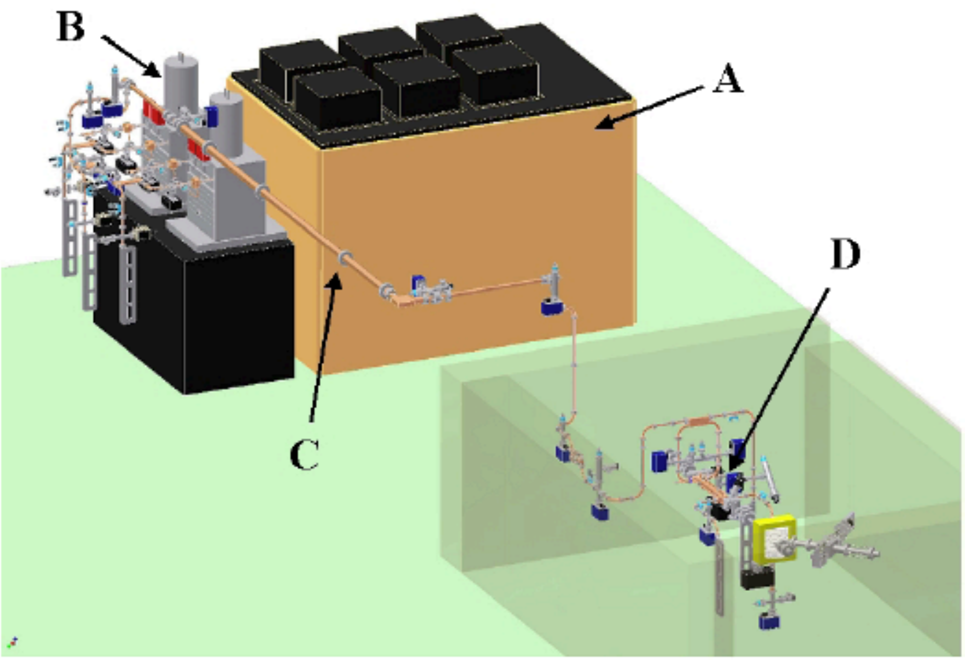
KEK X-band High Power Stations

Nextef stands for NEw X-band TEst Facility.

•Reassembled old XTF in 2007.
•A 100MW high power station for the X-band accelerator structure tests.
•We use Nextef for the collaboration work with SLAC and CERN on developing high gradient accelerator structures of 100MV/m by 2011.
•Currently, the high power test of T18_VG2.4_Disk#2 is ongoing.

KT-1stands for Klystron Test stand #1.
•For small size fundamental studies on high gradient and RF breakdown tests such as narrow waveguides are done at KT-1 50MW station.

Nextef Configuration



A: Modulator B: Klystrons C: Circular Waveguide D: Accelerator Structure in Shield-A. The control hut is not shown explicitly in the figure.

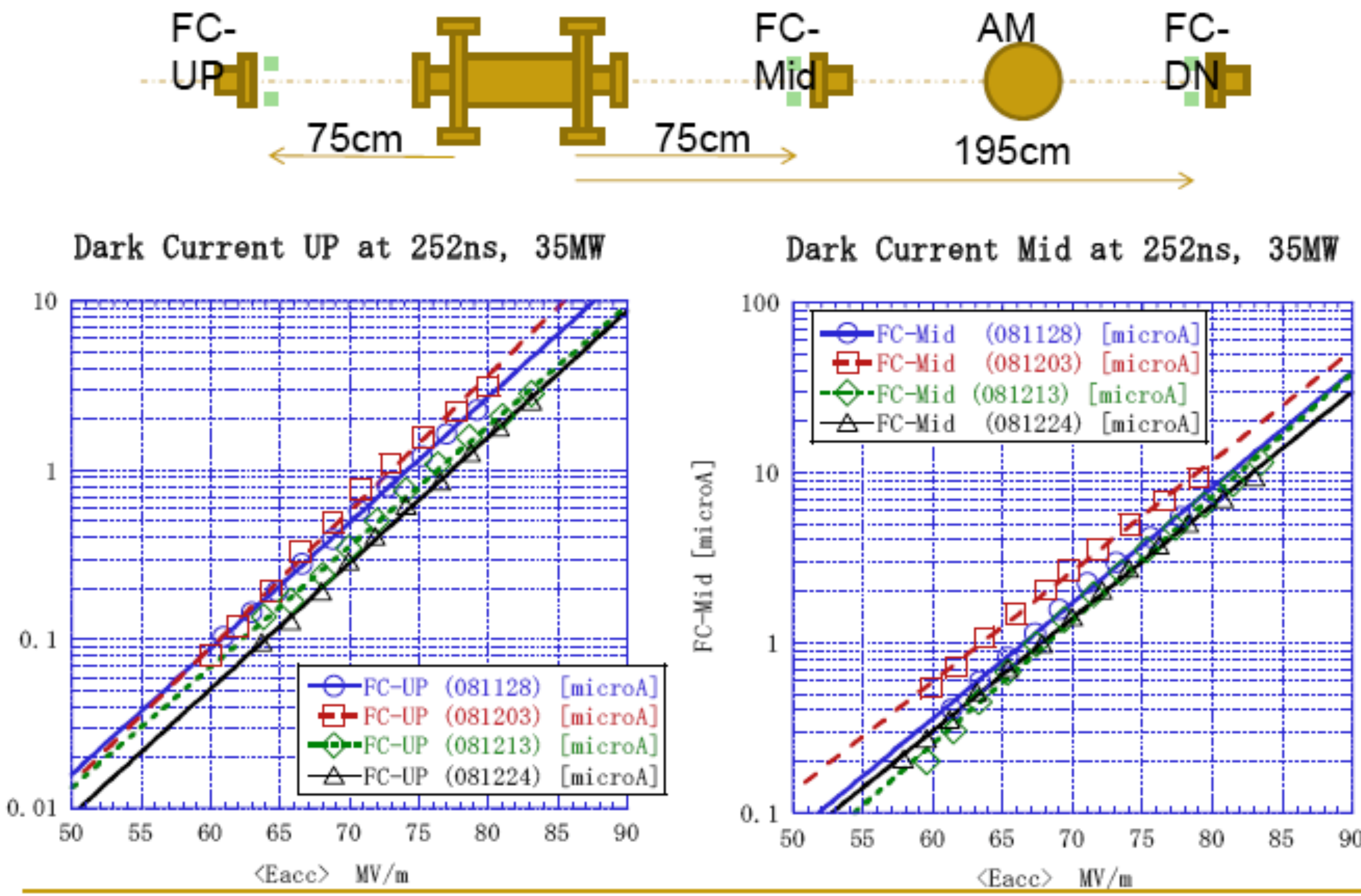
Frequency	11.424GHz
Max power production	100MW
Max power for test*	75MW
Pulse width	400ns
Repetition rate	50pps

* 25% power loss in the waveguide.

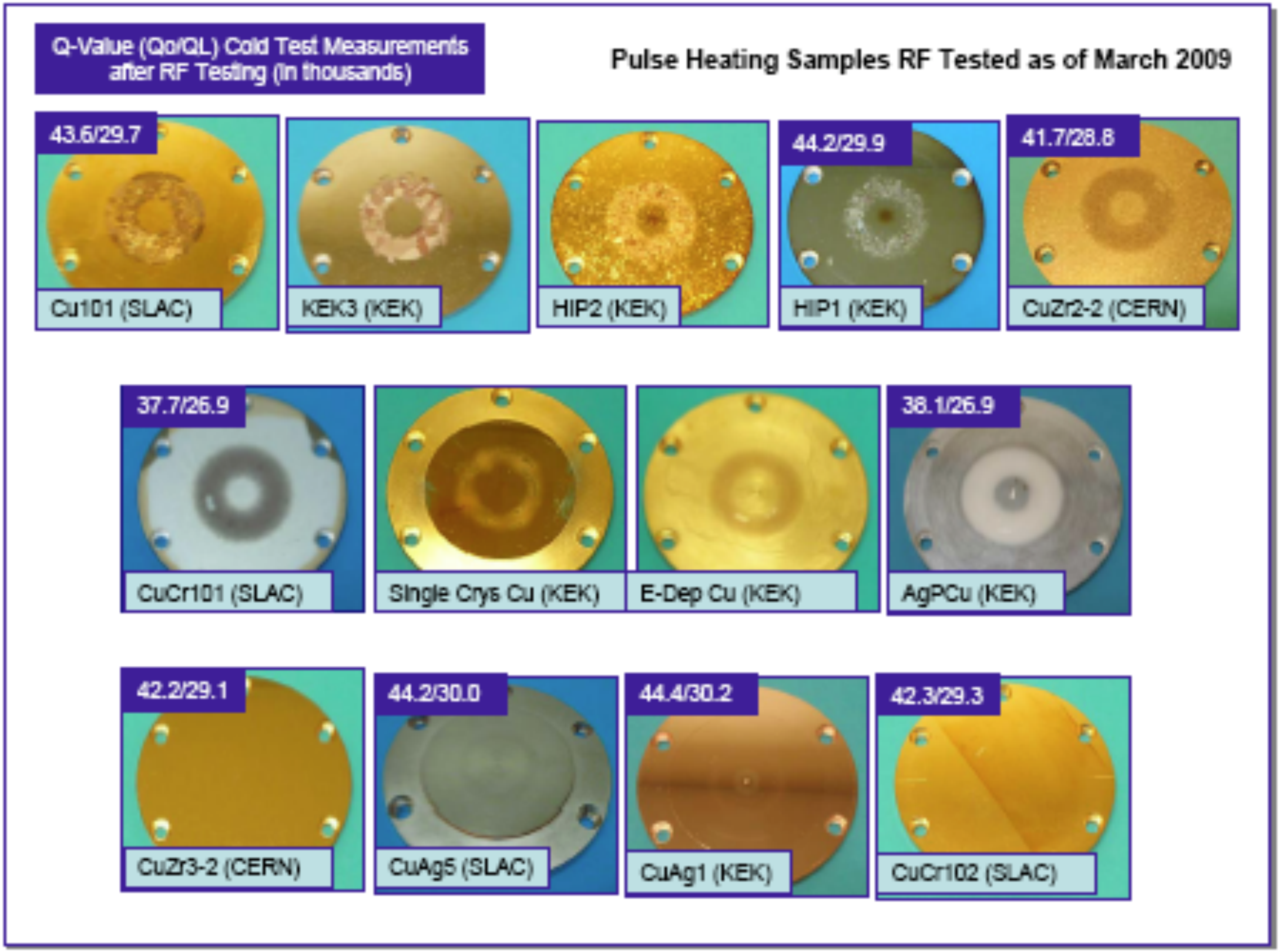
Yokoyama

Dark currents show Rad ~ E^{14}, E_{local} ~ 8 GV/m

Dark current trend during 35MW run

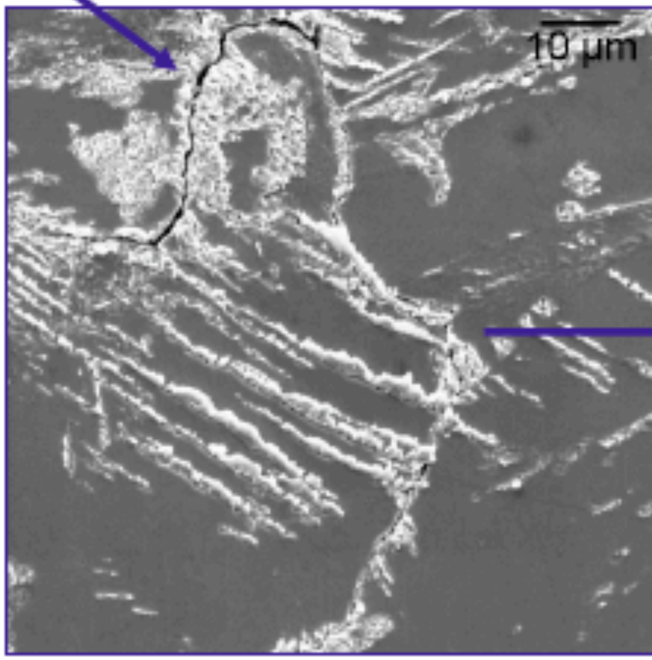


Laurent

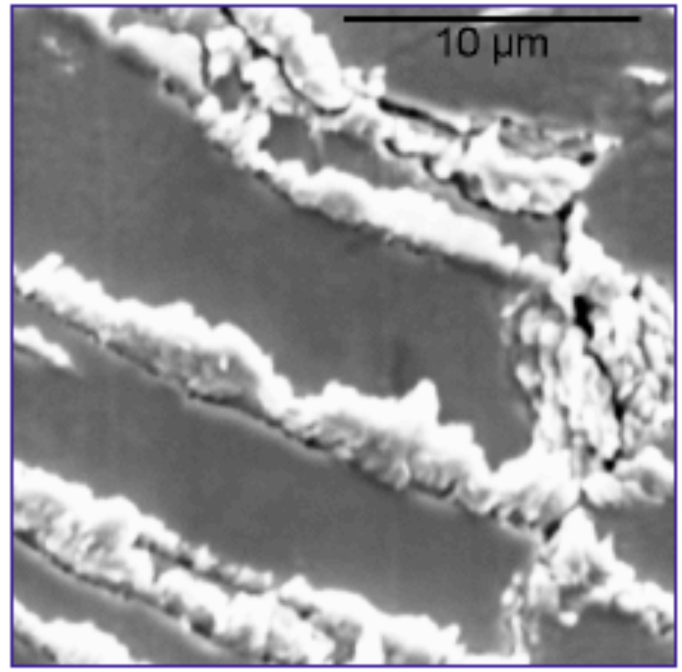

Q-Value (Qo/QL) Cold Test Measurements after RF Testing (In thousands)
Pulse Heating Samples RF Tested as of March 2009
43.6/29.7
Cu101 (SLAC)
KEK3 (KEK)
HIP2 (KEK)
44.2/29.9
HIP1 (KEK)
41.7/28.8
CuZr2-2 (CERN)
37.7/26.9
CuCr101 (SLAC)
Single Crys Cu (KEK)
E-Dep Cu (KEK)
38.1/26.9
AgPCu (KEK)
42.2/29.1
CuZr3-2 (CERN)
44.2/30.0
CuAg5 (SLAC)
44.4/30.2
CuAg1 (KEK)
42.3/29.3
CuCr102 (SLAC)

Copper1-2 (CERN)

Intergranular fracture



High Magnification



Transgranular fractures

Intergranular fractures dominate at edge of pulse heating ring

Intergranular fractures 500X

Dielectric acc. Conde, Power, Kenereykin, Simitsyn, Schehelkunov

They have demonstrated 100 MV/m for short pulses, expect more

They can model multipactor, but have no data at high power.

DLA (Dielectric-Loaded Accelerator)

- Low-loss dielectric liner, instead of irises, used to reduce v_{ph} to c.

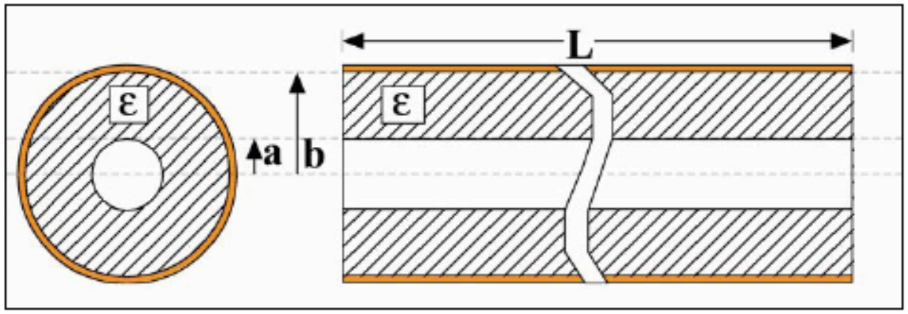
Advantages

- Simple geometry
- No field enhancements on irises
- High gradient potential
- Comparable shunt impedance
- Easy to damp HOM

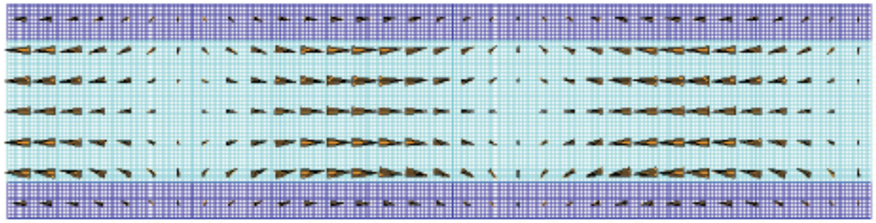
Major Issues

- Multipactor
- Breakdown

Geometry



Electric Field Vectors



→ *Goal: Demonstrate high gradient, low loss structures and use to accelerate a test beam*

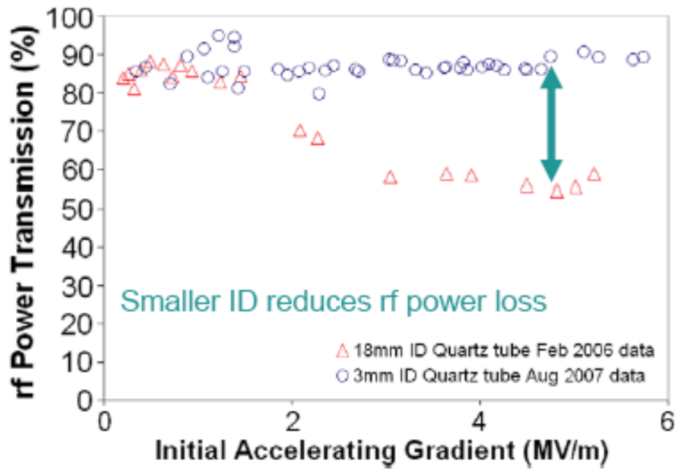
With Upgrade, AWA will produce beams capable of:

- Higher gradient excitation: ~ 0.5 GV/m in structures (3 mm apertures)
- Higher RF power extraction: ~ GW level (25 MeV, 130 Amps, 10 ns, 3 GW beam power)

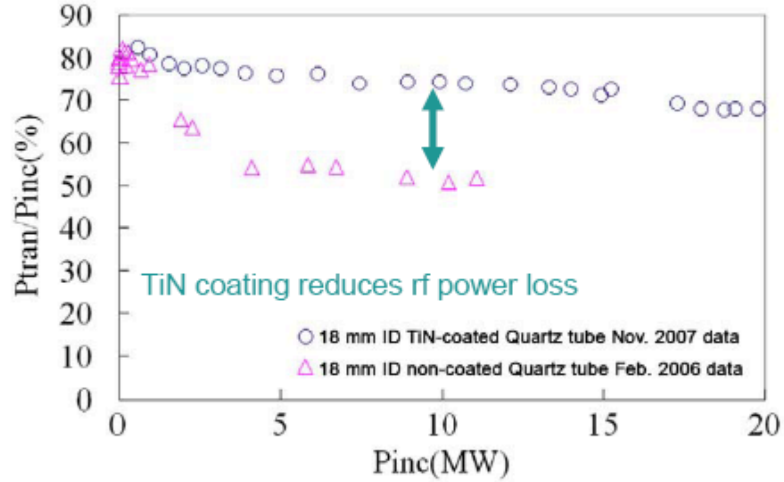
Gold

Recent DLA Results

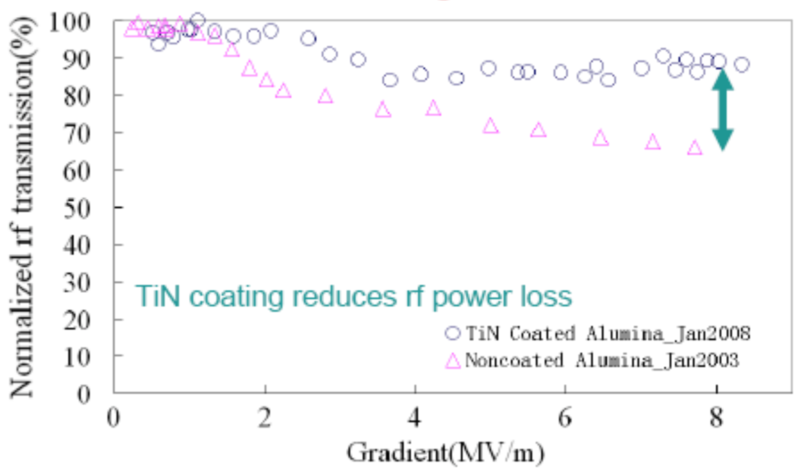
Effect of radius on quartz DLA



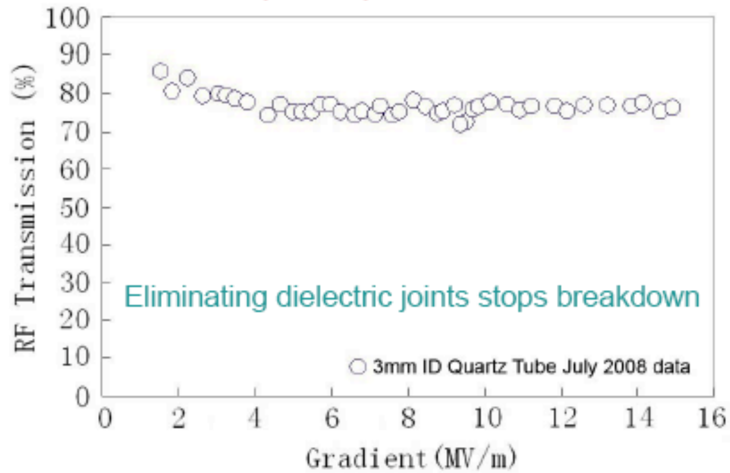
Effect of TiN coating on Quartz DLA



Effect of TiN coating on Alumina DLA



Test of clamped quartz DLA structure



Misc efforts, **Hirshfield, Temkin, Fukuda,**

Multimode klystrons

Multimode cavities

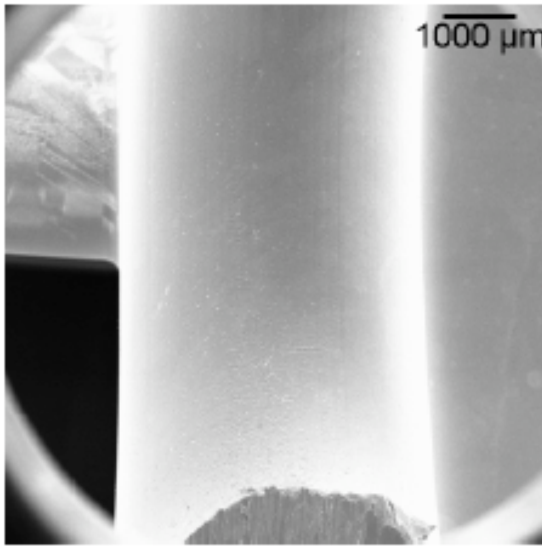
Photonic band gap structures

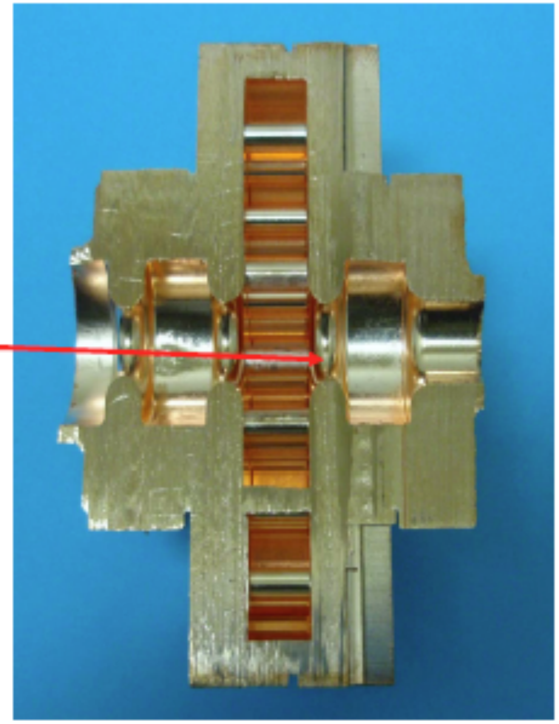
Frequency multiplication

New materials

SEM Photos of IRIS After Testing

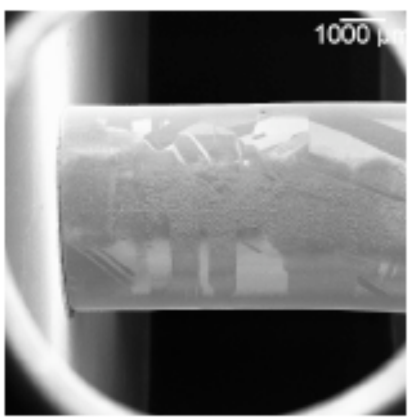
(SEM Photo of Iris)



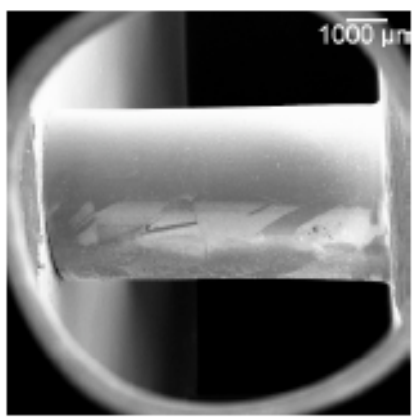


- Iris has no damage

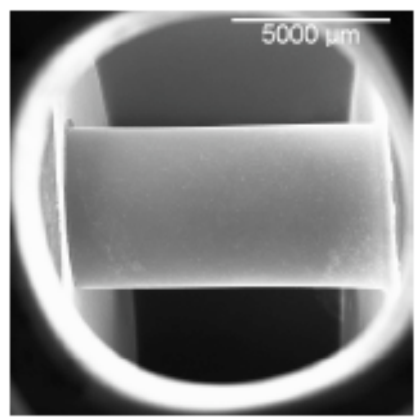
SEM Photos of Rods After Testing



R1 (Inner Rod)



R2 (Inner Rod)



R6 (Outer Rod)

Fukuda

Accelerator Laboratory, KEK

Project and Parameters (1)

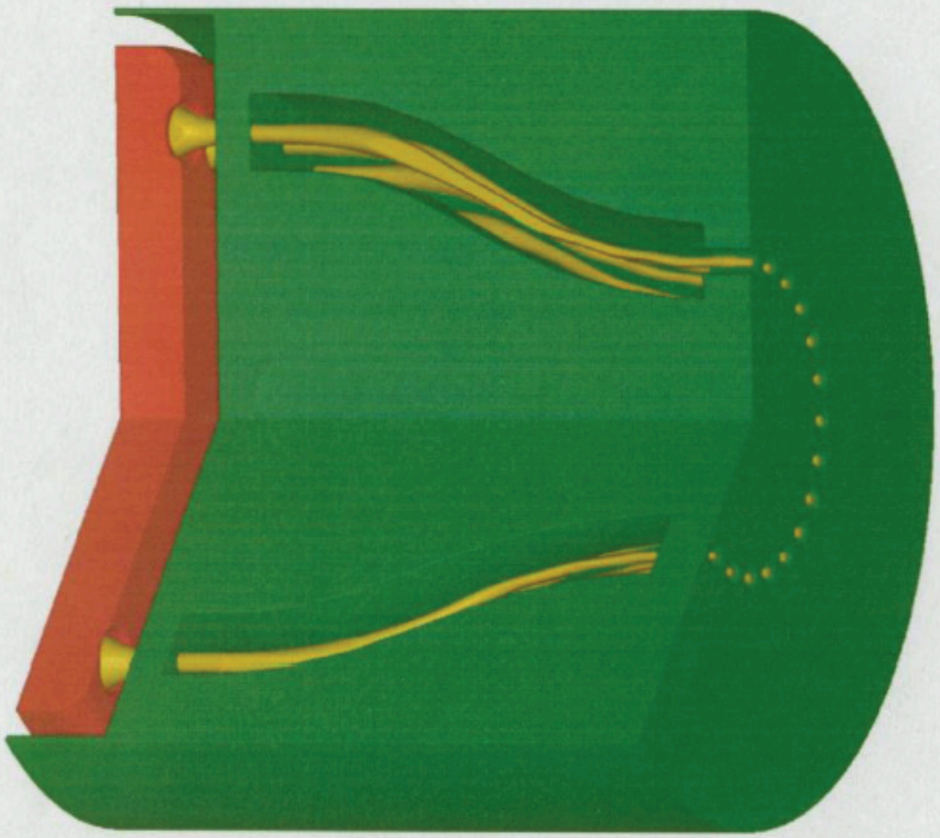
Required parameters:

- V_{beam} =50kV
- P_{rf} out =2MW
- P_{rf} in < 50W
- Loading of the cathode should be no more than 7A/cm^2

XB 8 MBK

Operating Frequency	11424	MHz
Operating Mode	TM 410	
Beam Voltage	50	kV
Total Beam Current	112	A
Total Micro Perveance	10	
Number of Beam-lets	8	
Beam-let Current	14	A
Beam-let Micro Perveance	1.252	
Simulation Efficiency (P_{cavity}/ P_{beam})	41	%
Output Efficiency ($P_{output\ WG}$/ P_{beam})	37	%
Output RF Power (in Waveguide)	2	MW
Saturated Input RF Power	24	W
Saturated Gain	49	dB
Peak Electric Field in Output Cavity	460	kV/cm
Solenoid Magnetic Field	2500	Gs
Drift Tube Diameter	6	mm
Cavity Gap	3.2	mm
Interaction Region Length	112	mm
Magnetic system Diameter	260	mm
Magnetic system length	280	mm
Total klystron Length	400	mm

Example of the multiple beam gun modeling by using the GUN3D code



U=60 kV

I=287 A

N=24 beamlets

$J_{cathode}$<2.6A/cm^2

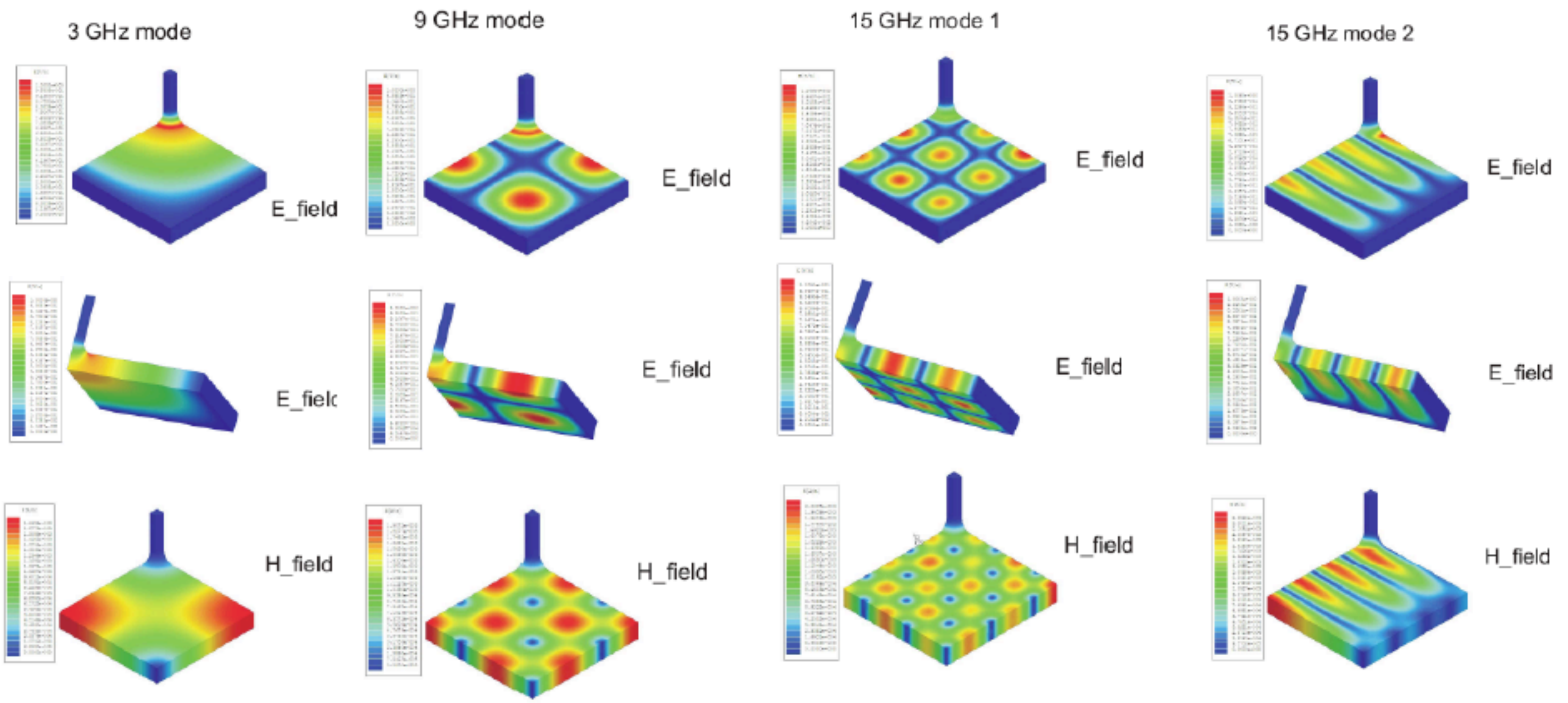
Max. magnetic field in the compression lens

B_{max}≈1.5 kGs

Hirshfeld

Multimode cavity

Field patterns



NFMCC Derun, Diktas, Rolland

. . .should give their own talks

Modeling Arcs, Timko, me, Veitzer

Hilga Timko presented results from CERN modeling efforts

- Mostly aimed at the DC test stand
- Collaboration between CERN, University of Finland and Max Planck Inst.

Me

- Same old stuff

Veitzer

Accurate Simulation of RF Breakdown Will Help Researchers Design New Accelerators

- Breakdown represents real limits to achievable field gradients
- Forthcoming accelerators require higher field gradients to operate efficiently
  - Muon accelerators
  - Neutrino factory
  - CLIC
  - ILC
- To develop accurate predictive models we need to understand the physics involved in breakdown, both in the triggers, and how to measure breakdown
- We are developing new simulation capabilities to model breakdown
  - Generalized emission field/thermal emission model (Jensen)
  - Plasma radiation and transport models

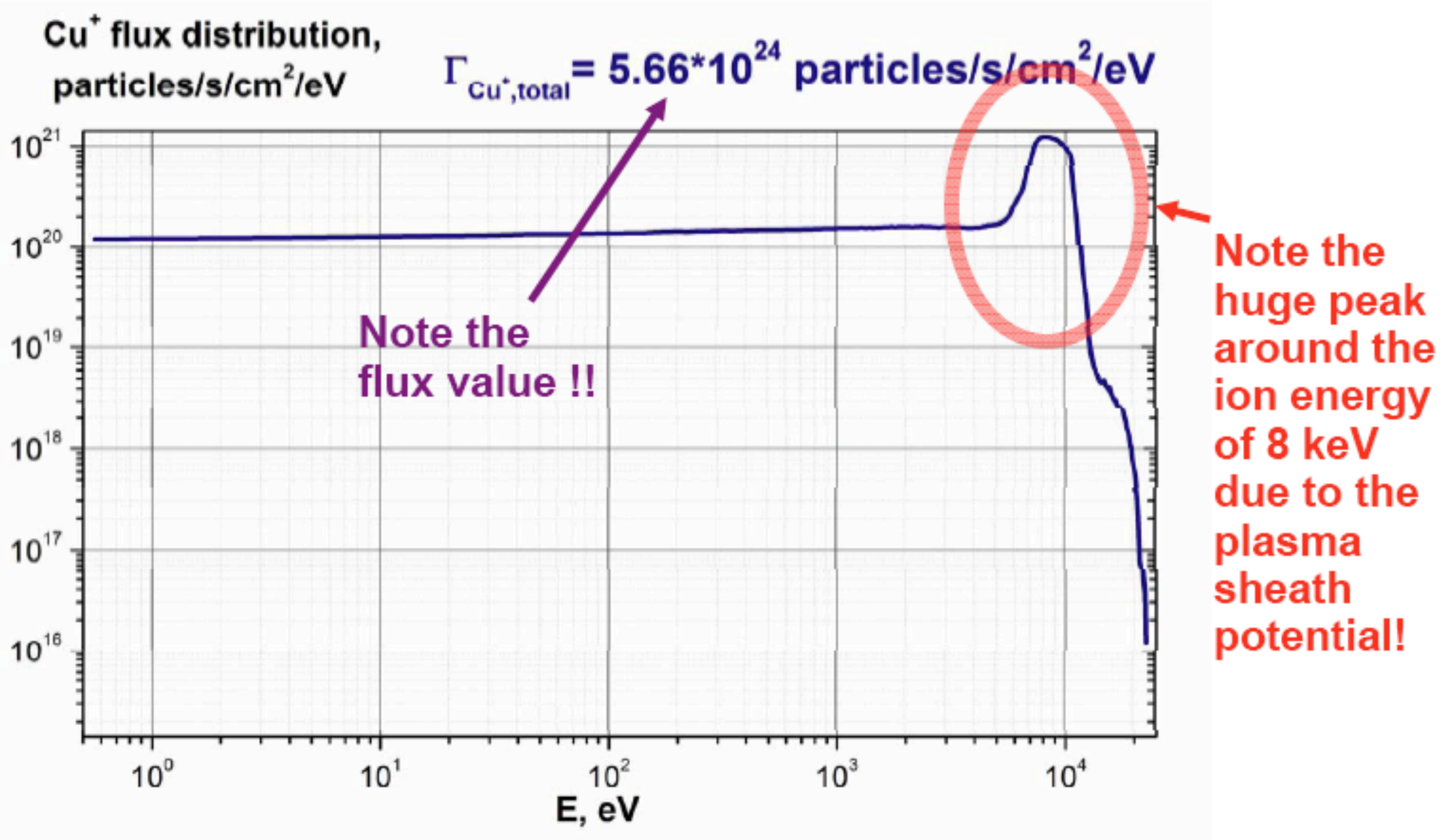
Multiscale Model

- Onset: In literature, not much understood yet
  - F. Djurabekova is modelling this phase
  - Possibly added to the multiscale model later

- To get insight into the phenomenon of arcing, we have started a two-step simulation approach:
  - Build-up of densities in the arc plasma: Particle-in-cell (PIC) method
    - Emphasis on the surface interaction model
  - Surface erosion & cratering: Classical molecular dynamics (MD) simulations of surface bombardment
  - Coupling between these two

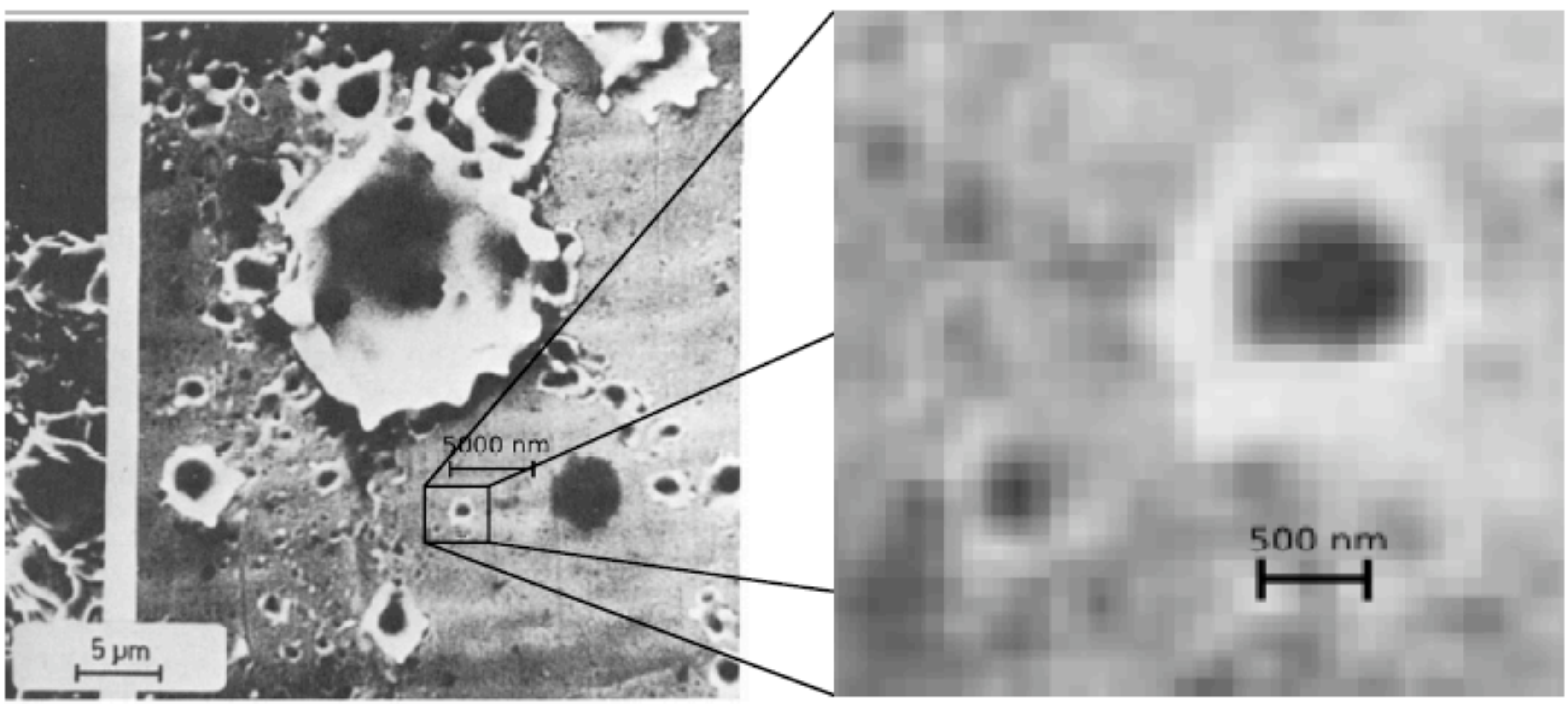
Multiscale Model: Coupling PIC and MD Simulations

- PIC simulations gave particle flux and energies for MD



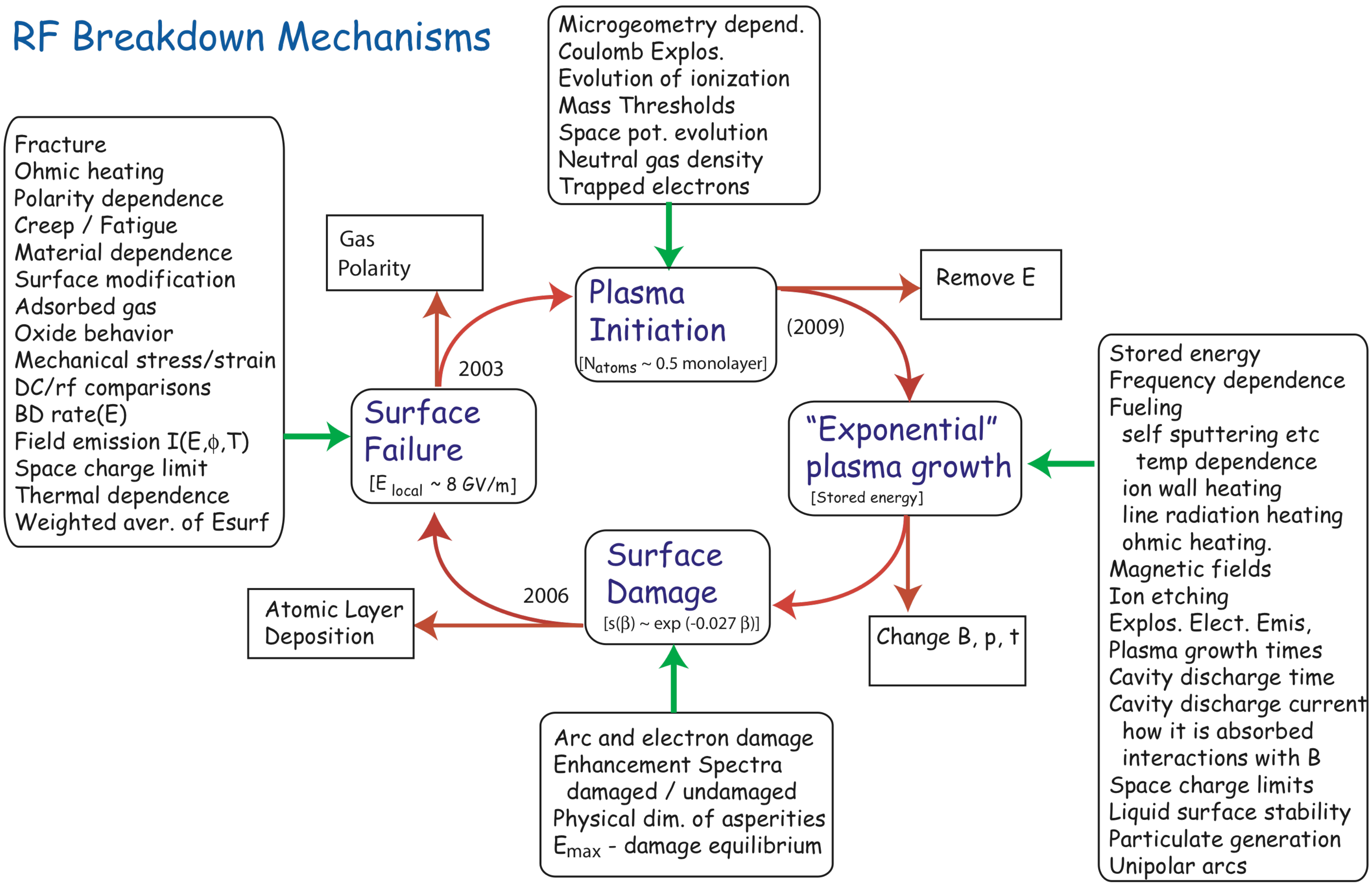
Comparison with Experiments

- Experiments show a wide variety of spark crater sizes
  - But they appear to be self-similar over size scales:



Norem

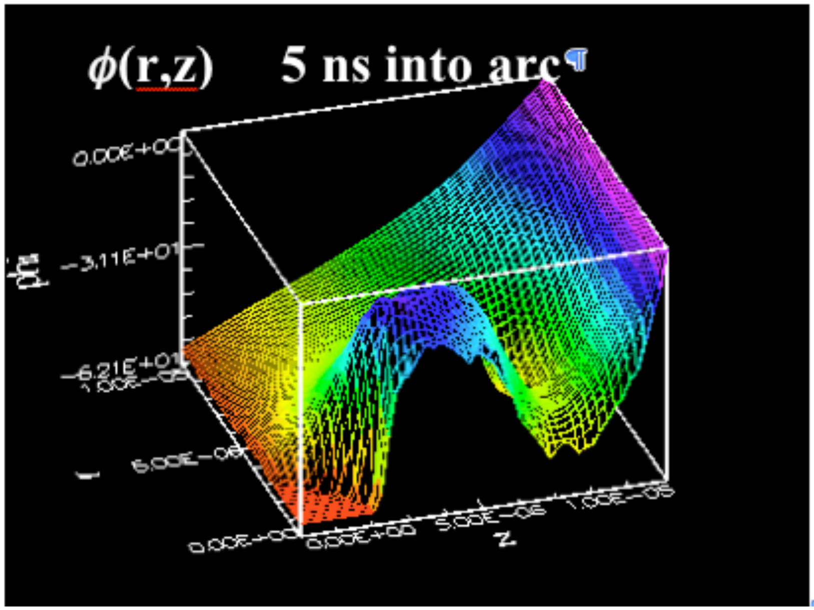
There are many mechanisms and many parameters at each stage.

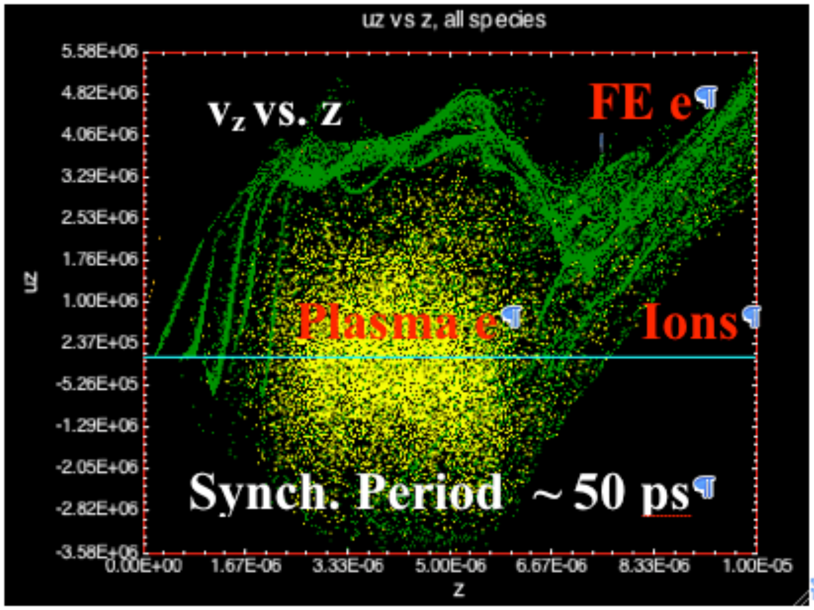


FE electrons are not the only source of ionization.

- These arcs are high beta, inhomogeneous, non – equilibrium, cold, weakly ionized, non-neutral, collisional, inertially confined plasmas with two weakly interacting electron populations - different from laboratory / fusion plasma experience.

- The space potential is produced by inertially confined ions whose electrons have gone to the far wall. The potential traps electrons, and the "sheath" is a function of the proximity of the ion cloud to the ionization source.





- The net result is that field emitted currents are: 1) enhanced and, 2) extend over a larger range of rf phase. The electrons execute synchrotron motion.

Summary

The modeling effort is beginning to be productive.

- We now have a first iteration of almost the complete breakdown process.
- We can make predictions of all parameters at all times in the discharge.
- The first iteration needs to be more complete and consistent.
- We need experimental data
- We need support to finish the modeling

The Muon Collaboration is active and has unique capabilities,

- Magnetic fields provide useful perturbations.
- We look at high pressure gas, beam loading,

Molecular Dynamics calculations are essential to understand arcs.

We are looking at how surface modification can improve both SRF and NC cavities.

Wikipedia: A **breakdown** is an instrumental form that features a series of breaks, each played by a different instrument. Examples of the form are "Bluegrass Breakdown" by Bill Monroe as well as "Earl's Breakdown" and "Foggy Mountain Breakdown", both of which were written by Earl Scruggs.