RF Modeling

Four almost unrelated issues

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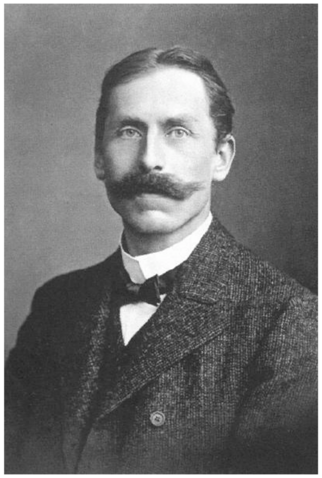
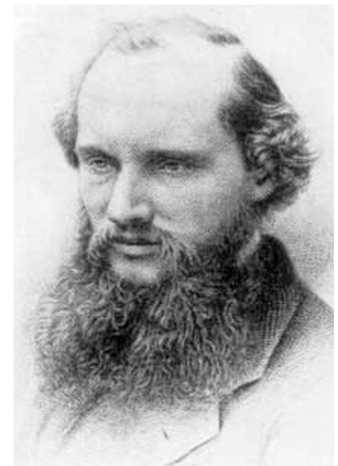
Gradient limits have been well understood for >100 years.

Many have contributed - very early:

Paschen, Millikan Michelson, Lord Kelvin

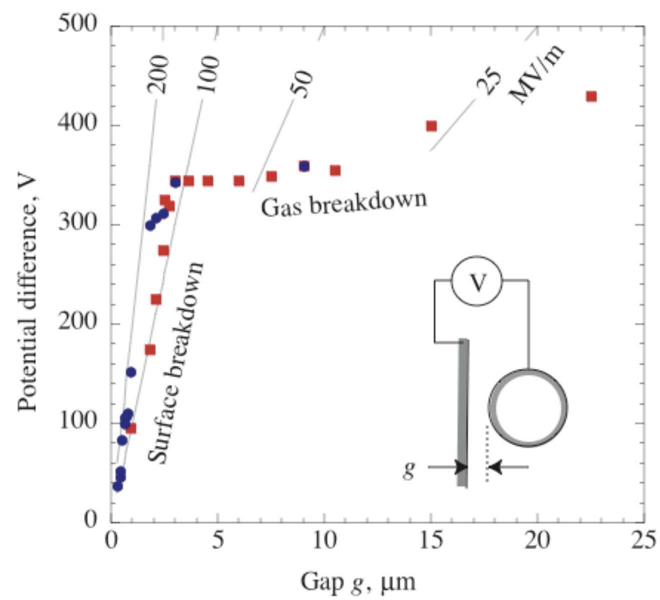




In 1904, Lord Kelvin argued that:

- Field emission is electrons (electrions),
- Electron emission may imply ion emission (damage),
- Local fields of ~ 9.6 GV/m would do this,
- Tensile strength is an important parameter,
- Better experiments are needed.

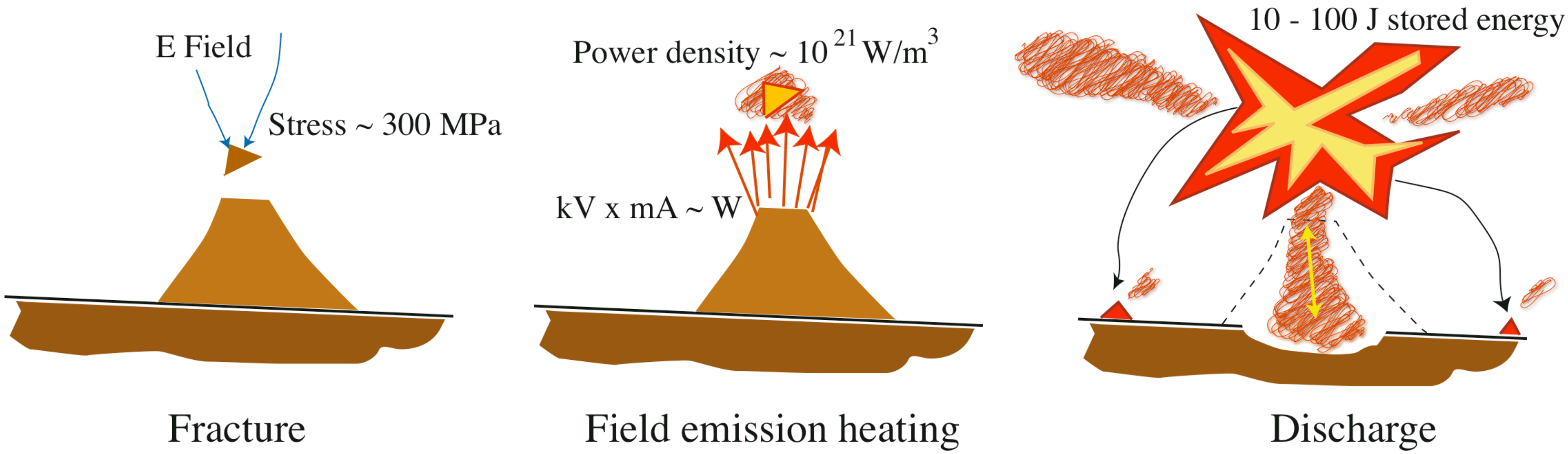
We agree.



1 RF Breakdown and gradient limits

- It would be nice to have everything important on one page. (slide)

- Three new ideas:
  - ✔ Breakdown triggers
  - ✔ Surface damage
  - ? Arc Physics



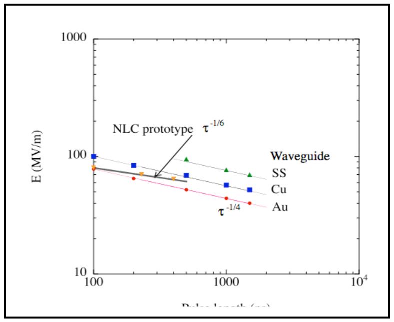
Bibliography

Major papers (70 pages in refereed journals):

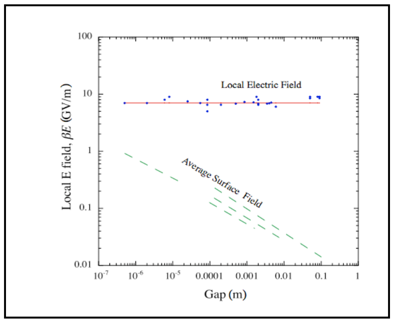
- X ray Spectra, Nucl. Instrum. Meth. Phys. Rev. A. **472**, 600 (2001)
  http://www-mucool.fnal.gov/mcnotes/public/pdf/muc0139/muc0139.pdf
  Measurements of x-rays from a single cell cavity
- Open Cell Cavity, Phys. Rev. STAB **6**, 072001 (2003)
  http://link.aps.org/doi/10.1103/PhysRevSTAB.6.072001
  Measurements of 6 cell cavity, dark current measurements, w/wo B fields, comp. with other cavities, tensile stress
- Cluster emission, Phys. Rev. STAB **7**, 122001 (2004)
  http://link.aps.org/doi/10.1103/PhysRevSTAB.7.122001
  Emission of clusters, thermal and field dependence,
- Breakdown mechanics, Nucl. Instrum. and Meth A **537**, 510, (2005)
  http://www-mucool.fnal.gov/mcnotes/public/pdf/muc0286/muc0286.pdf
  General theory of tensile stress triggered breakdown
- Magnetic fields, Phys. Rev. STAB **8**, 072001 (2005)
  http://link.aps.org/doi/10.1103/PhysRevSTAB.8.072001
  Measurements with 805 MHz pillbox, measurement of $s_2(\beta)$
- Surface damage, Phys. Rev. STAB **9**, 062001 (2006)
  http://link.aps.org/doi/10.1103/PhysRevSTAB.9.062001
  Relationship between surface damage and maximum operating fields.

We can calculate all aspects normal DC & rf operation.

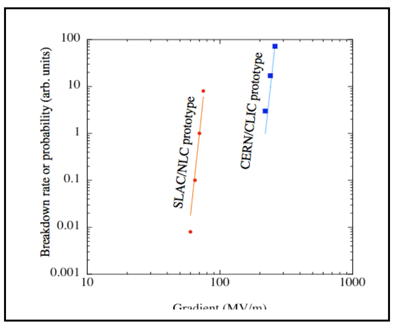
- Emax vs. Pulse Len.



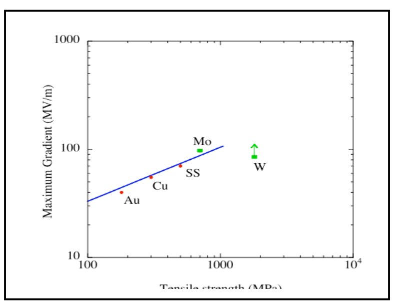
- DC breakdown



- BD rate vs. E

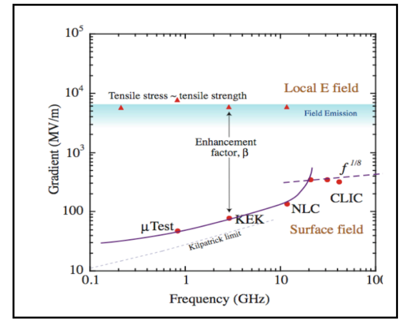


- Material dep.

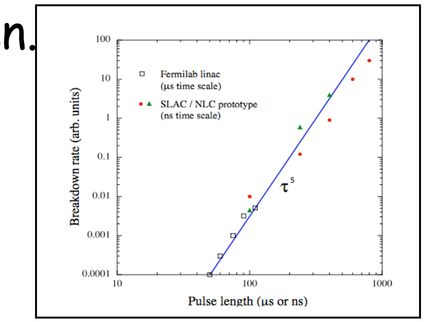


- and more . . .

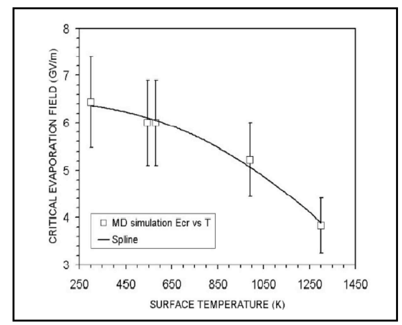
- Emax vs. f



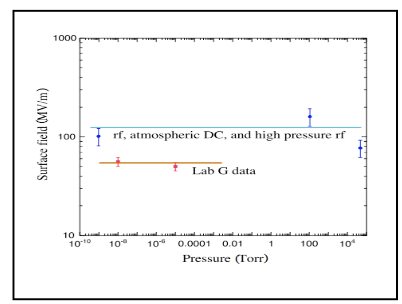
- BD rate vs. Pulse len.



- Emax vs. T



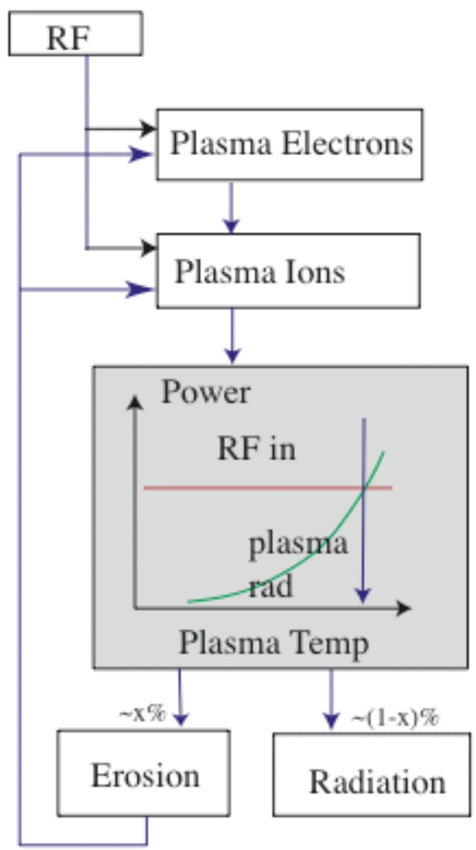
- E_{max} vs. pressure

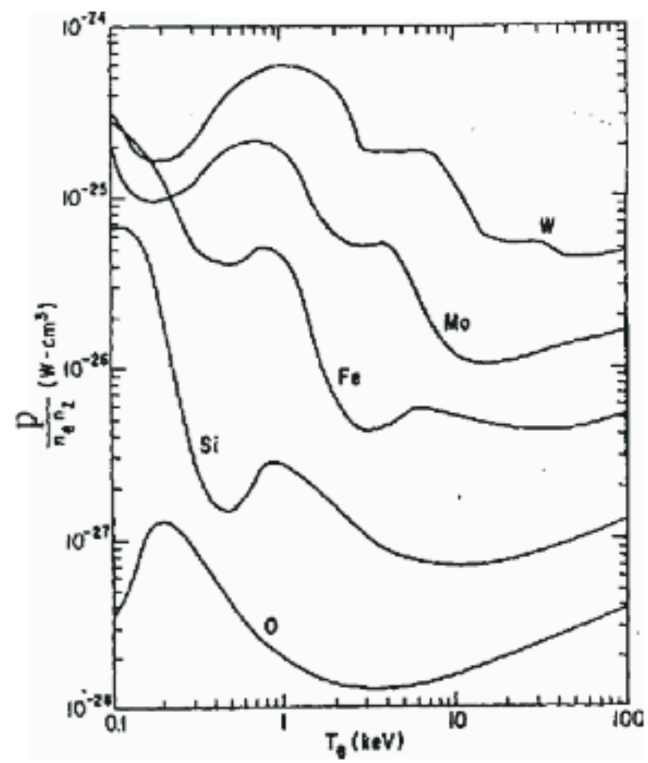


The plasma physics of the discharge has not been explored.

- In a dense, metallic plasma, recombination radiation (called impurity radiation in the fusion community) seems to be the dominant effect & is not well understood.

- Arcs happen fast, and ions don't drift far ⇒ very dense plasmas



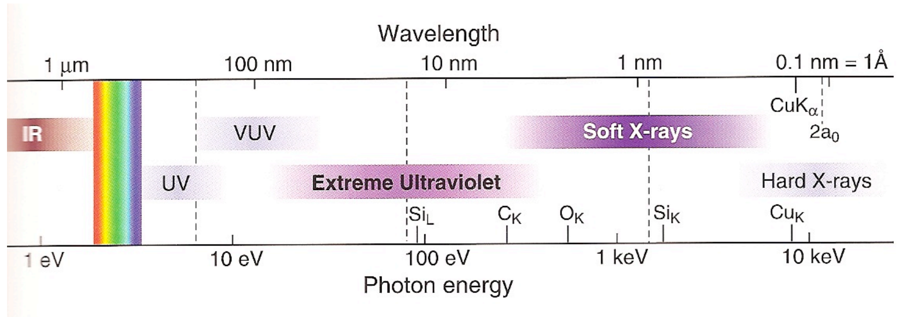


“Reasonable” guesses at plasma parameters

- From the crater dimensions, one guesses ~10^{17} atoms, ~10^{16} ions are produced
- Assuming a discharge length of 0.1 μs (short for us, long for SLAC), the ions will only move 0.05 cm,
- This gives ion densities on the order of 10^{19}cm^{-3}.
- With electron temps of 10 – 100 eV, this gives many MW of UV and x- rays.
- We need a discharge model (PIC code) to do this right.
  We have started to use OOPIC, which we got from Peter Stoltz of Tech-X.
  They have a SBIR proposal in to consider recombination (impurity) radiation.
- Many questions:
  Power coupling in to plasma?, thermal equilibrium? Line/blackbody/brems rad?

Understanding Arcs

- The radiation can cover a wide range of wavelengths. – makes expt's messy.



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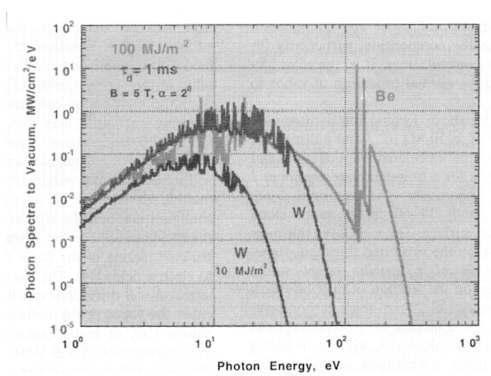
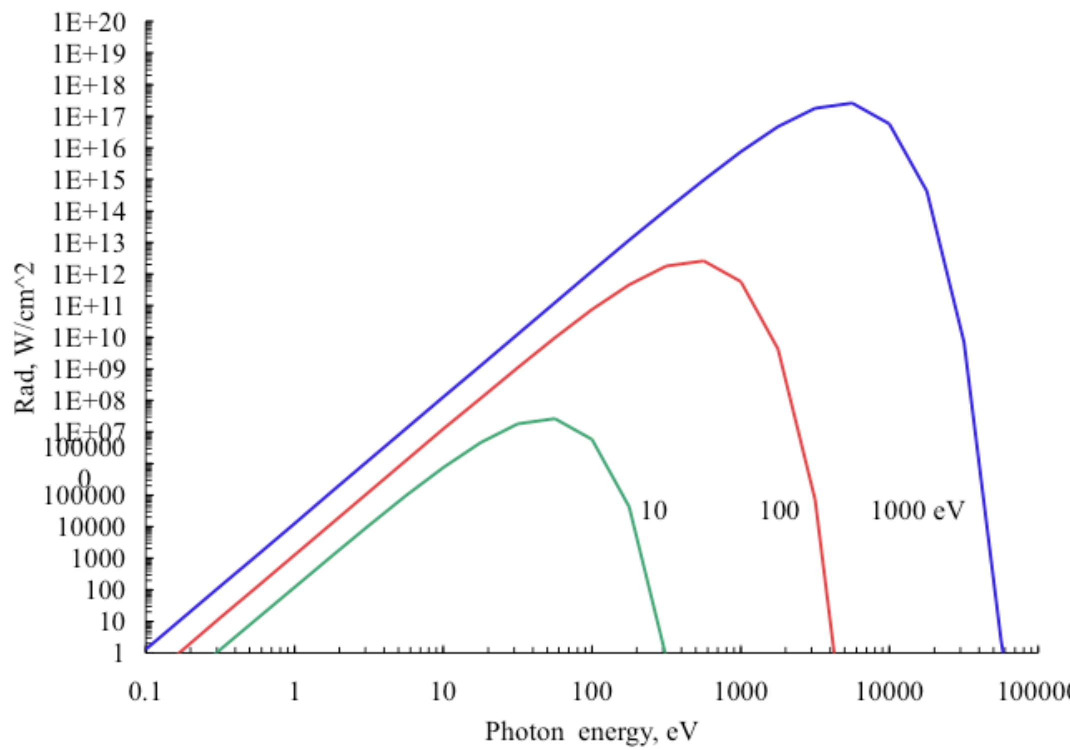
- 10s of MW from 10s of μ ??

- Tokamak edge radiation
  (Hassanein. 2002)

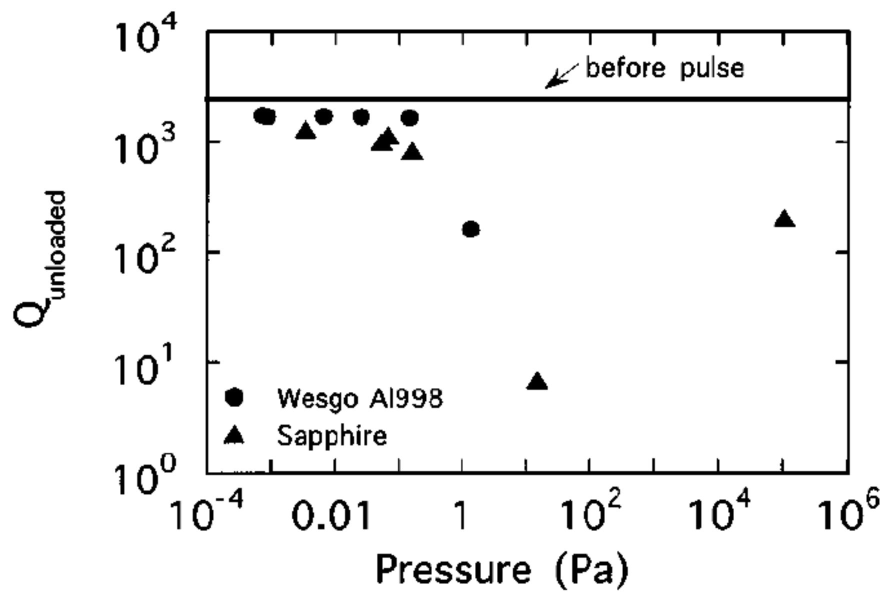




- Non-equilibrium?.

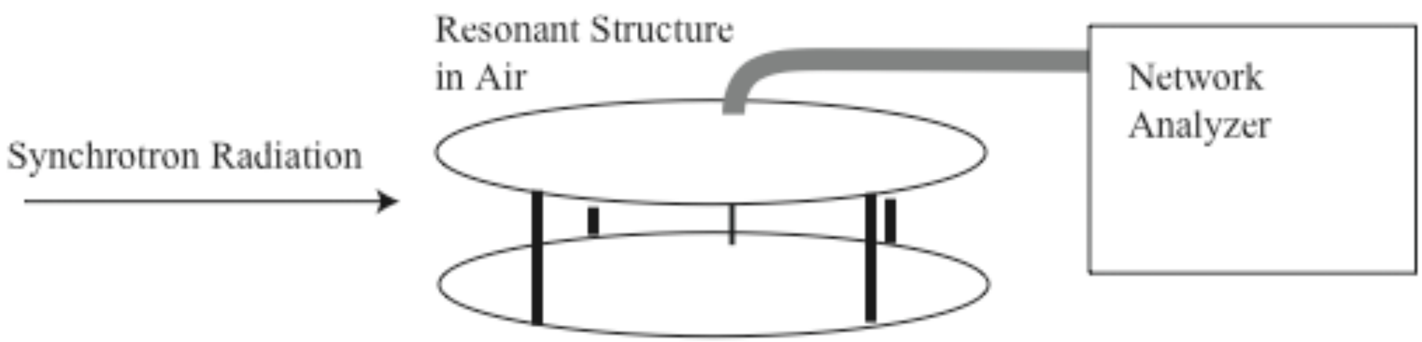
2 High-pressure cavities

- The high pressure + high magnetic field environment is not well understood.. Modeling will help, but some mechanisms are new.
- If intense particle beams transverse high pressure cavities with high electric fields, **transient radiation-induced conductivity** will be produced.
- This ionization will take some time to recombine, and during this period the gas will become resistive.
- Radiation induced loss of Q has been measured in a reactor environment.



Measuring radiation-induced conductivity in gasses.

- We will try to measure it with a synchrotron radiation beam.
- The first experiment is almost trivial. Requires a bending magnet beam.

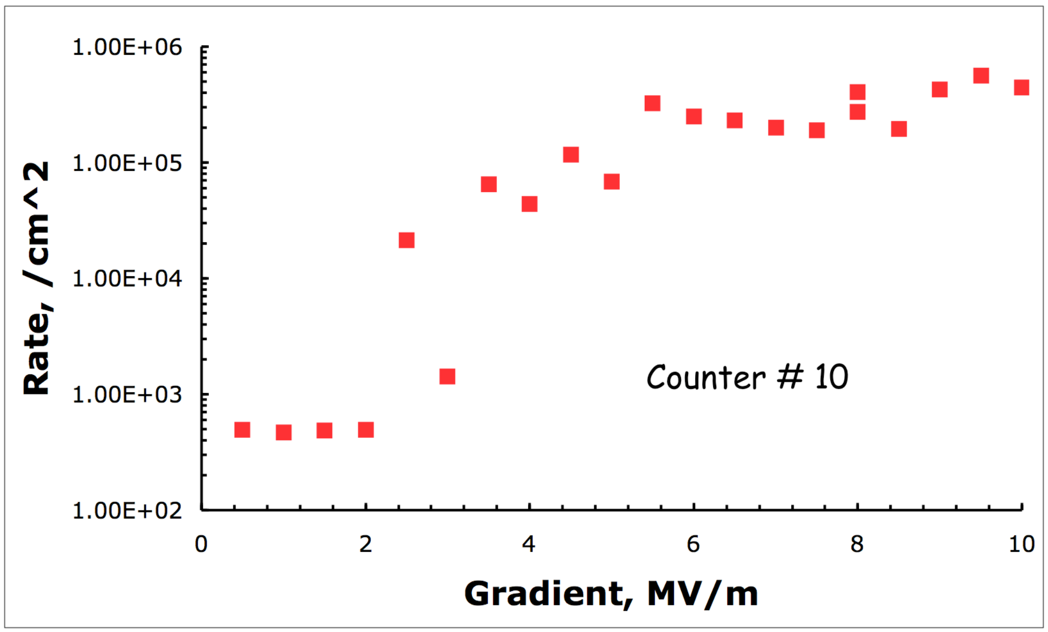


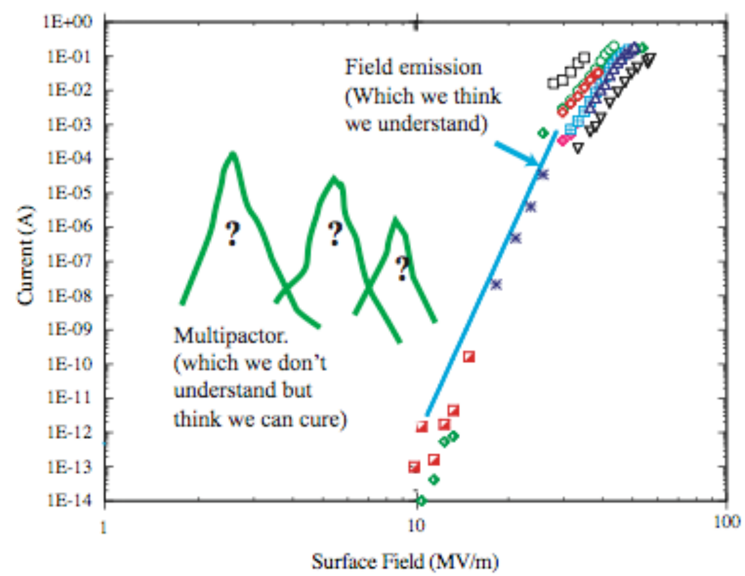
- Need this as a function of E.
- Scaling: $n_e \sim p$, (recomb rate $\sim 1/\tau_{recomb} \sim p$), so $\tau_{coll} \sim f(E/p)$, near Paschen limit
- EMP physics

3 MICE RF Backgrounds

- We claimed in the MICE proposal that we understood backgrounds.
- Data from the MTA has shown that multipactor may be a factor in backgrounds.
- What we saw:

What's happening:

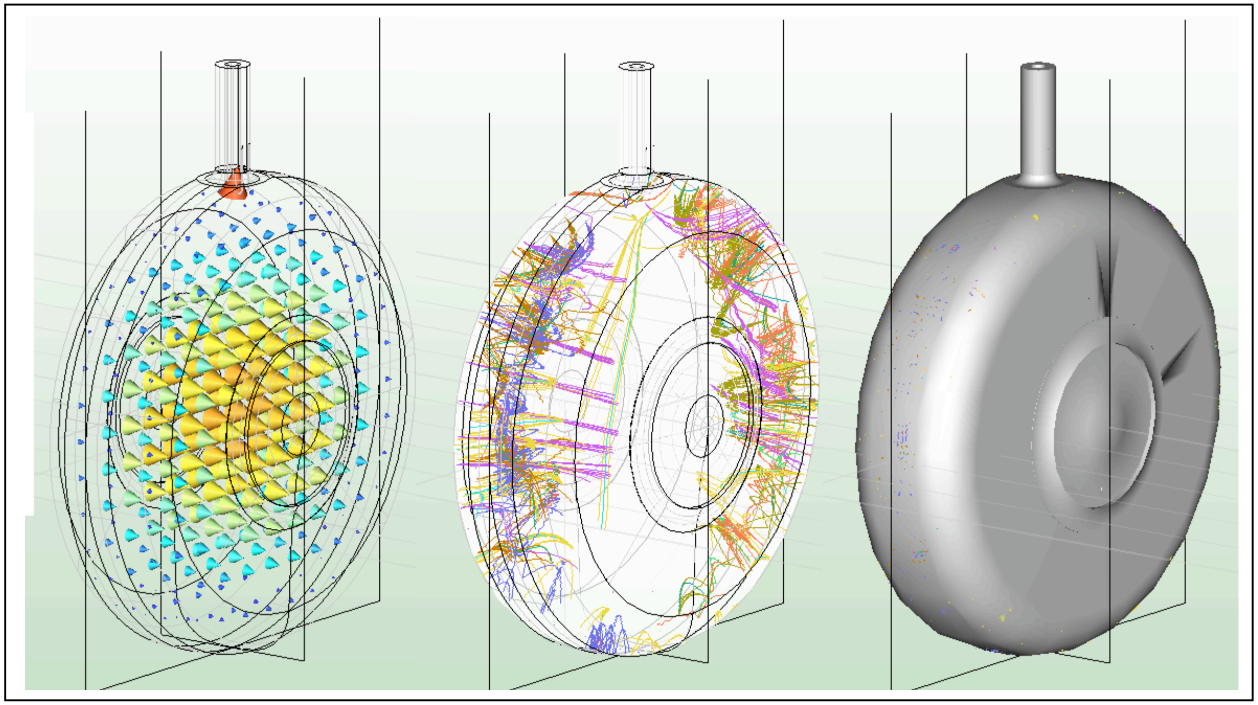




- We should be able to cure this. With TiN coatings.

What is multipactor?

Multipactor is resonant amplification of loose electrons in the cavity.



- The rates we measure will have to be corrected for the absorption and scattering in the walls and supporting structure of the cavity. This is underway.

4 Superconducting rf R&D

- All the HEP energy frontier machines (ILC, CLIC, NFMCC) rely on acceleration gradients larger than those generally produced.

- The technology of RF superconductivity is not mature.
  - Cavities don't routinely meet theoretical limits.
  - Surface treatments are not understood.

- Argonne is basically a material science lab (with accelerators).

- A workshop at Argonne in November tried to bring material science and ILC/SRF communities together.

- This meeting was very successful:
  - We have started a program to look at Atomic Layer Deposition of Nb for SCRF.
  - Planning a coordinated ILC / SRF materials proposal with Claire Antoine
  - Had a Fermilab ILC/SRF materials Seminar at Argonne Jan 15.
  - Interest in using ANL instrumentation.
  - ANL management is very involved (Four divisions).

Atomic Layer Deposition

- Atomic Layer Deposition is not strictly a coating technique. Single monolayer surfaces are grown one-at-a-time by a repetitive process with a deposition rate of ~microns/hr. Size and shape of substrate do not matter.

- The failure modes of SCRF . . . . . . can be cured with this technique

Field Emission:	Coatings increase radii of asperities, lowering local field
H_{c1}:	Multiple coatings can shield quench fields (A. Gurevich)
High field Q slope:	Pure coating on good substrate eliminates most causes
Contamination	Materials can protect the niobium surface

- An experimental program is underway..
  Pellin, Elam, Antoine, Seidman, Norem + . .

  Phase I: study small samples, Understand chemistry
  Ellipsometry, Atom Probe Tomography, SIMS

  Phase II: coat and test single cell cavity

Conclusions:

- MTA work is progressing slowly. We have discovered low power multipactor in the 201 cavity

- We are extending modeling and experimental work to high pressure cavities, arc parameters and other gradient limits.

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- We can understand and predict all aspects of warm cavity limits, are extending the model to SCRF. Muons need SCRF too.

- Argonne management seems eager to get into this business. It is not crowded.