Dark Current Simulation for the T18vg2.6 Structure

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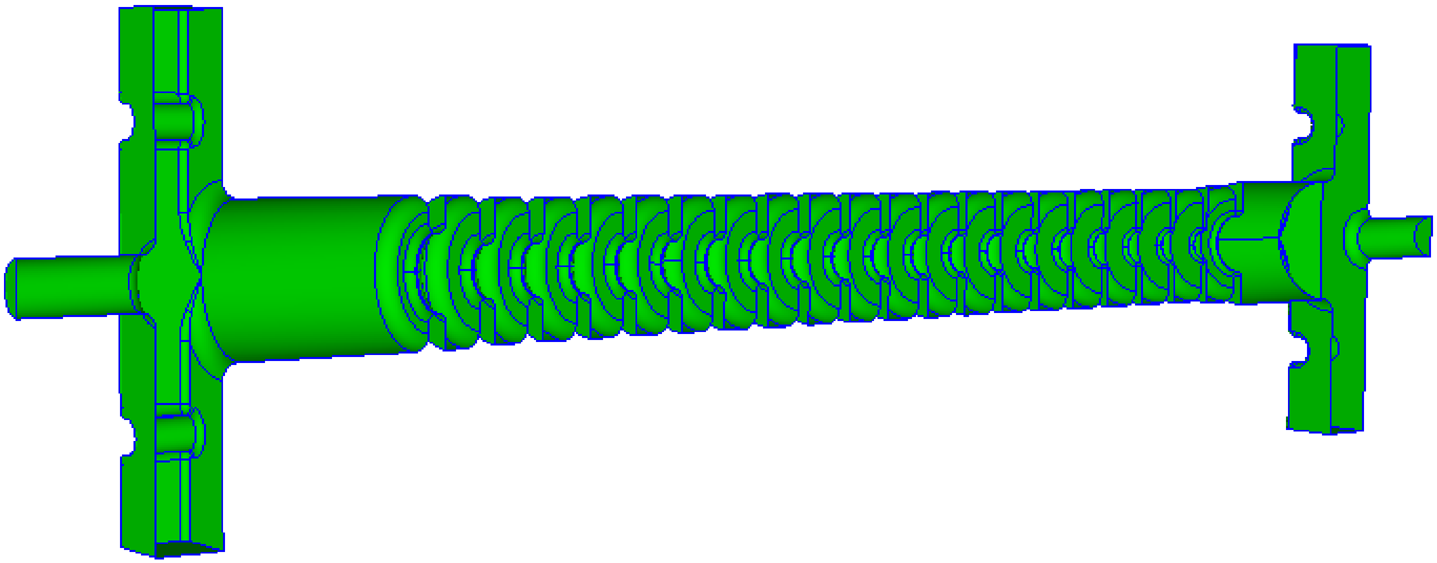
Outline

- T18vg2.6 Dark Current Simulation
- Dark current spectrum vs measurement
- Field emitter modeling
  - PIC simulation of emitter emission (Arno's talk)
  - Emitter heating due to emission current
  - Emitter heating due to RF field enhancement

T18vg2.6 Structure

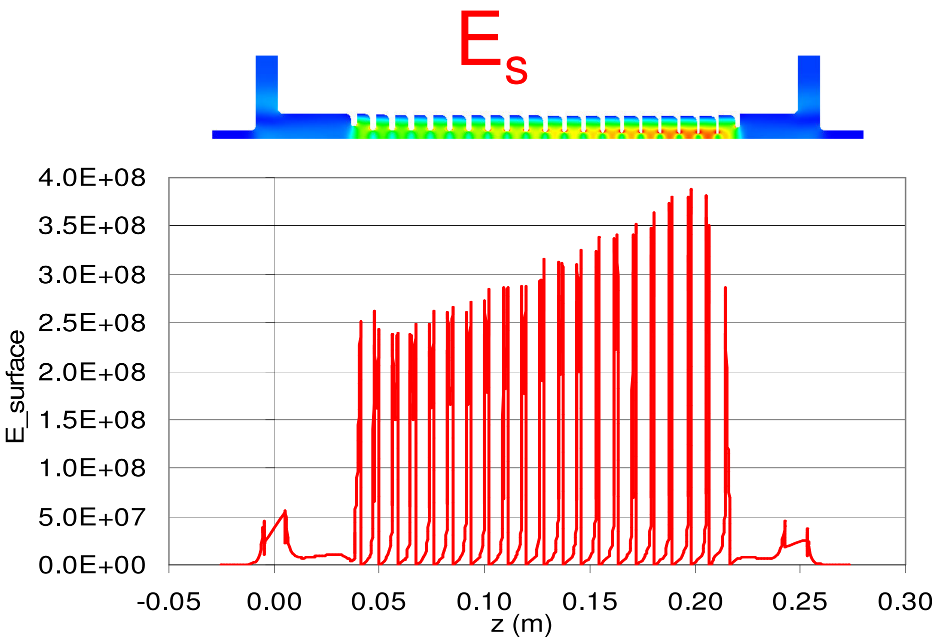


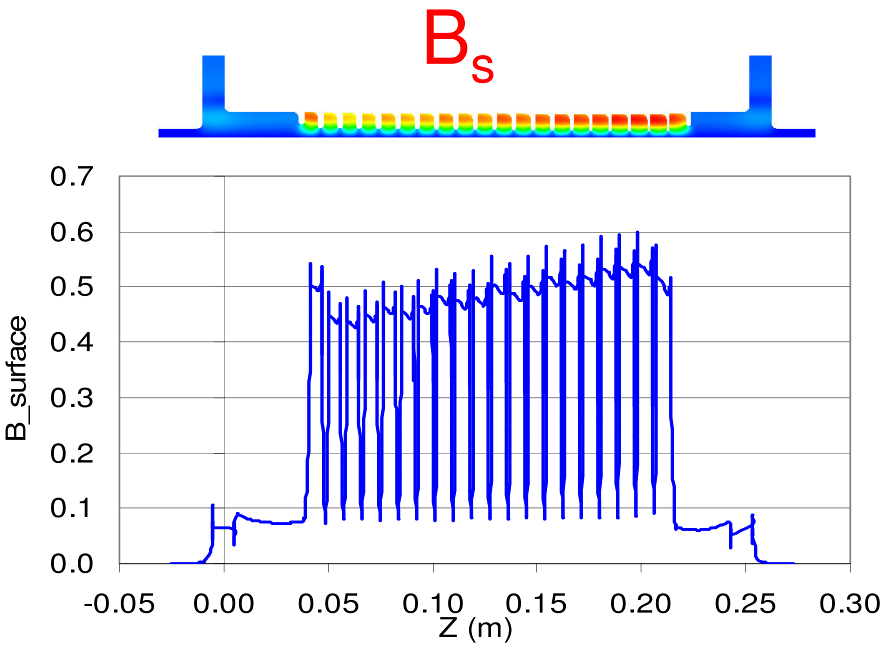
- Structure being tested at KEK and SLAC
- Simulation Code: (ACE3P)
  - S3P - S-Parameter & Fields
  - Track3P- Particle Tracking

T18 Structure Fields

RF fields obtained using S3P with surface loss

S11=0.014;   S22=0.032;   S12=0.82





Structure tapered: higher E fields at output end

Higher B field at the output end, not as significant as E field

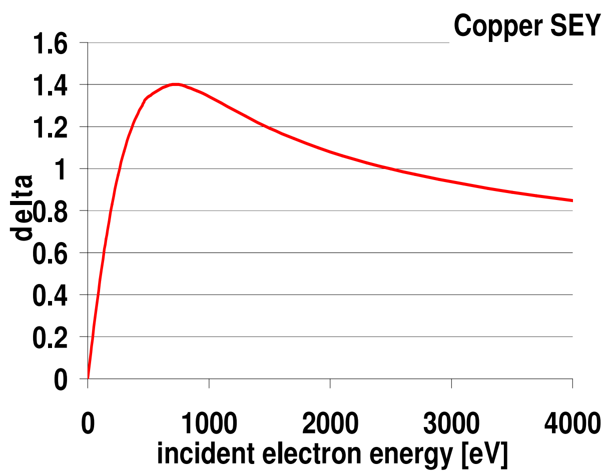
Dark Current Simulation Using Track3P

Dark Current Simulation

- Fowler-Nordheim field emission

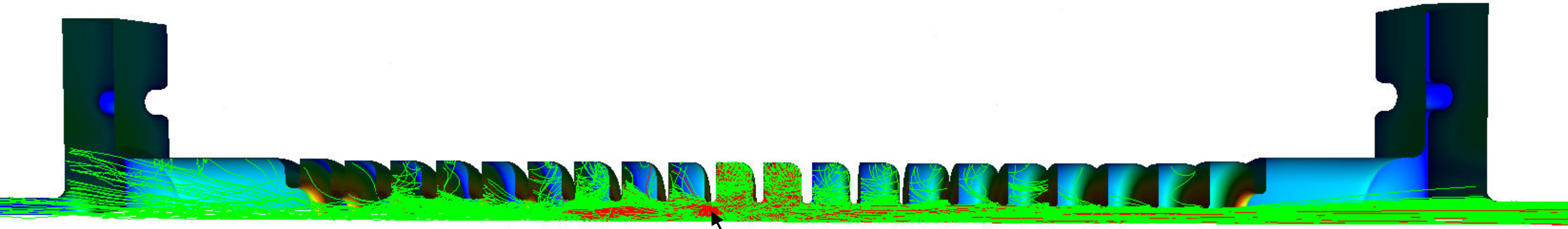
$$J(\varphi, \beta E) = 1.54 \times 10^{\left(-6 + \frac{4.52}{\sqrt{\varphi}}\right)} \frac{(\beta E)^2}{\varphi} e^{\left(\frac{-6.53 \times 10^9 \varphi^{1.5}}{\beta E}\right)}$$

- Secondary Electrons



- Analyze accumulated effects of DC current & power

Dark Current Emitter Simulation

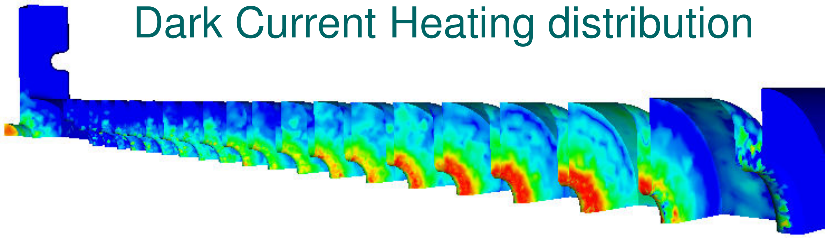


Emitted from
iris #6

- Intercepted electrons - dark current heating on surface
  - Deposit energy into the wall results in surface heating
- Captured electrons: energy spectrum
  - Emitter (disk) location - energy
  - Emitter density on disk – amplitude
- Heating on dark current emitter
  - Due to emission current
  - Due to RF field enhancement on emitter

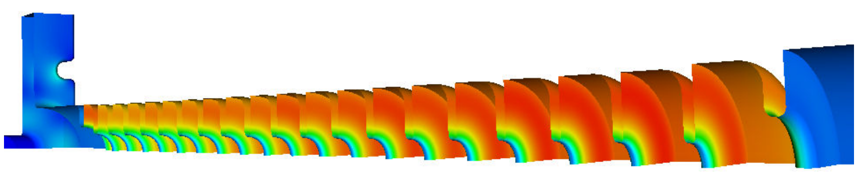
Dark Current vs RF Heating

Dark Current Heating distribution



Assumed emitters uniformly distributed. In reality, most likely clusters of emitters, result in local hot spots.

RF Heating distribution



Dark Current Heating

- Impact concentrated in high E region around iris
- Impact energy could be as high as a few MeV
- Depth of energy deposit ~ 1-2 hundred microns
- Significantly higher heating power at output end

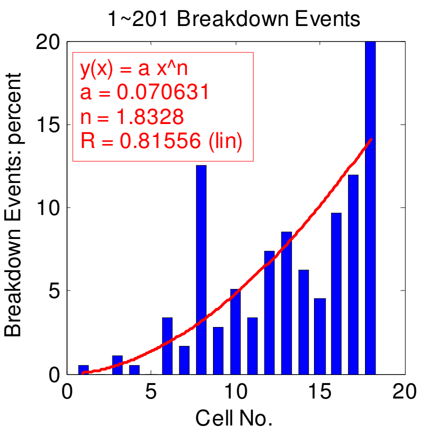
RF Pulse Heating

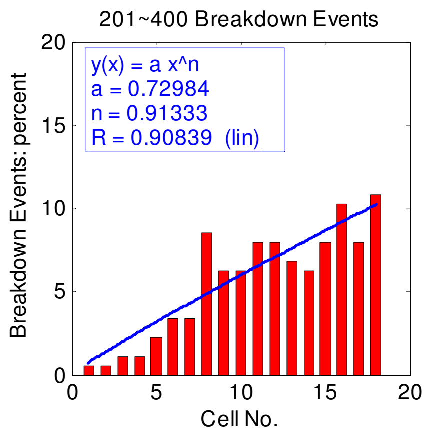
- High on outer wall where E field is “low”.
- Depth ~ skin depth
- Temperature rise is around 25^0C at 100MV/m, 200ns pulse length
- At Eacc=80 MV/m; (Hs/Ea~0.004), Power_max=1.4 GW/m^2

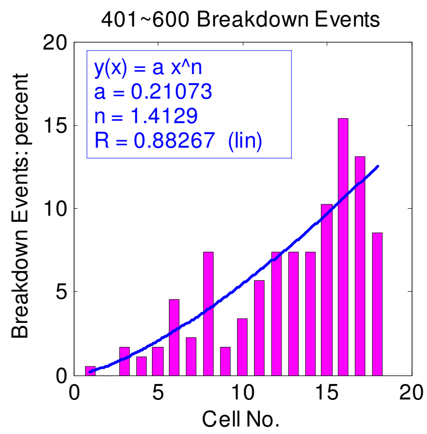
High Power Test Data - Breakdown Distribution

F. Wang

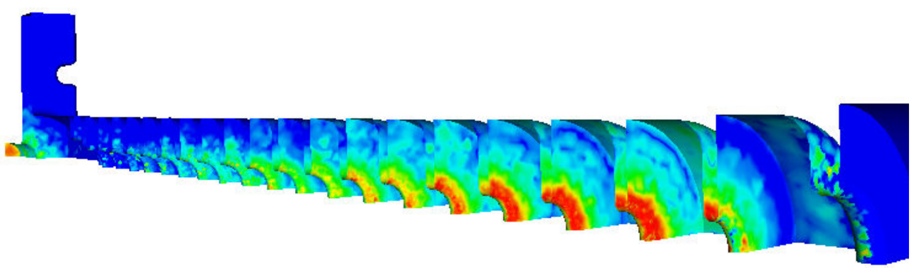
KEK, Higo, Doebert





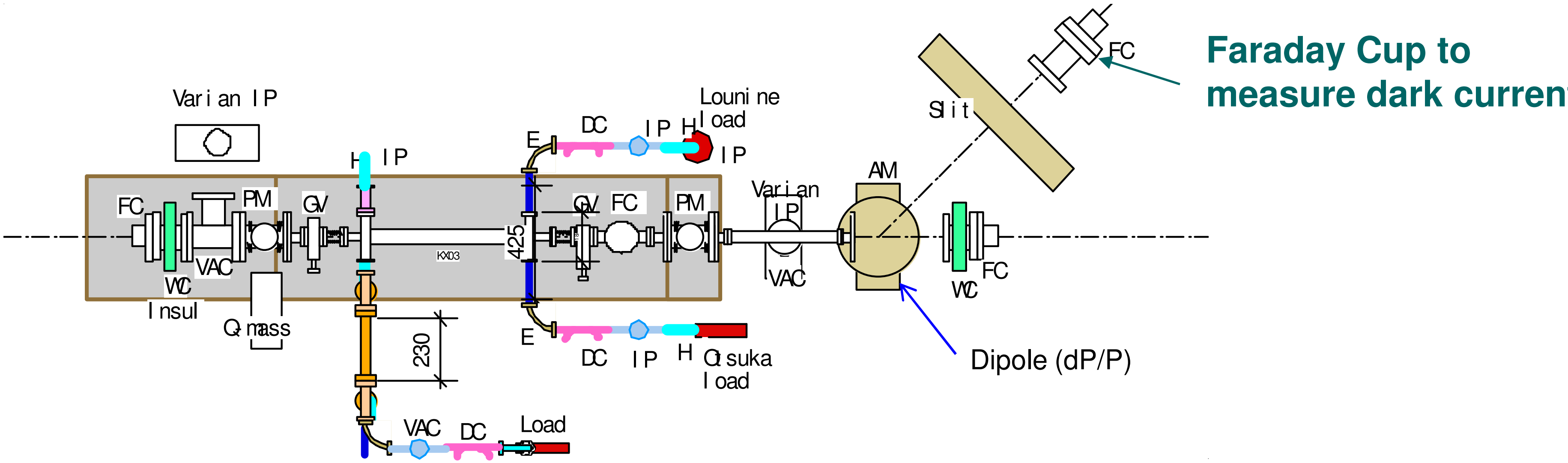


Red: real cell timing
Blue: linear cell timing

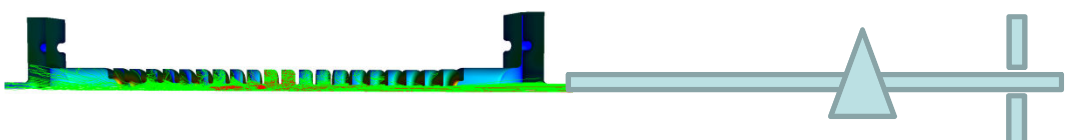


- Breakdown rate significantly higher at the output end
- Good correlation with field enhancement and dark current heating at the output end

Dark Current Measurement & Simulation



Schematic of KEK high power test and dark current measurement

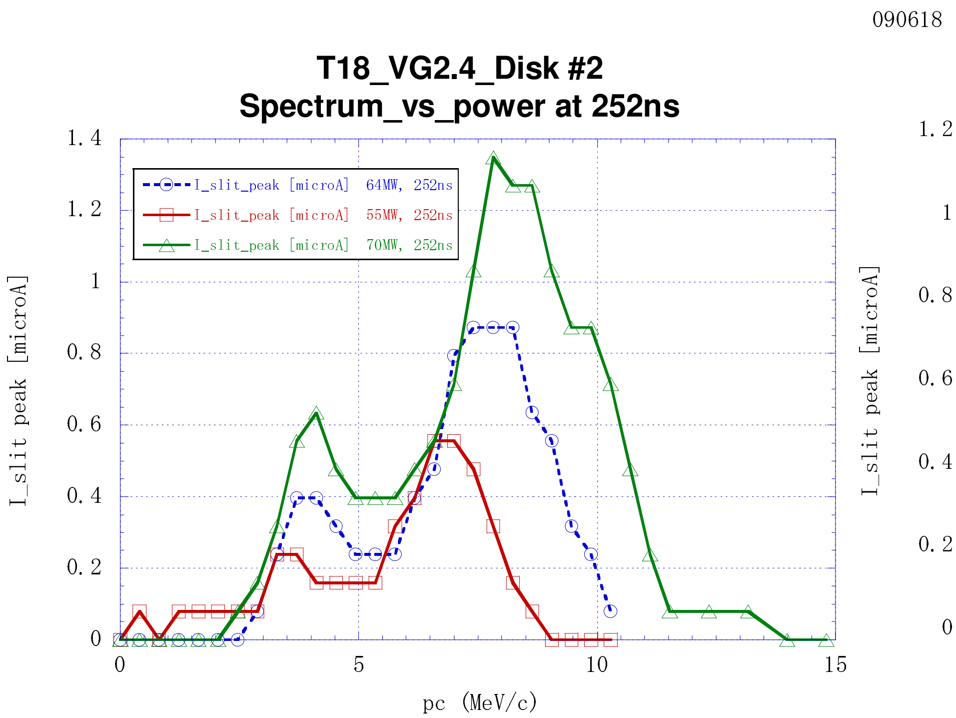


Simulation "schematics"

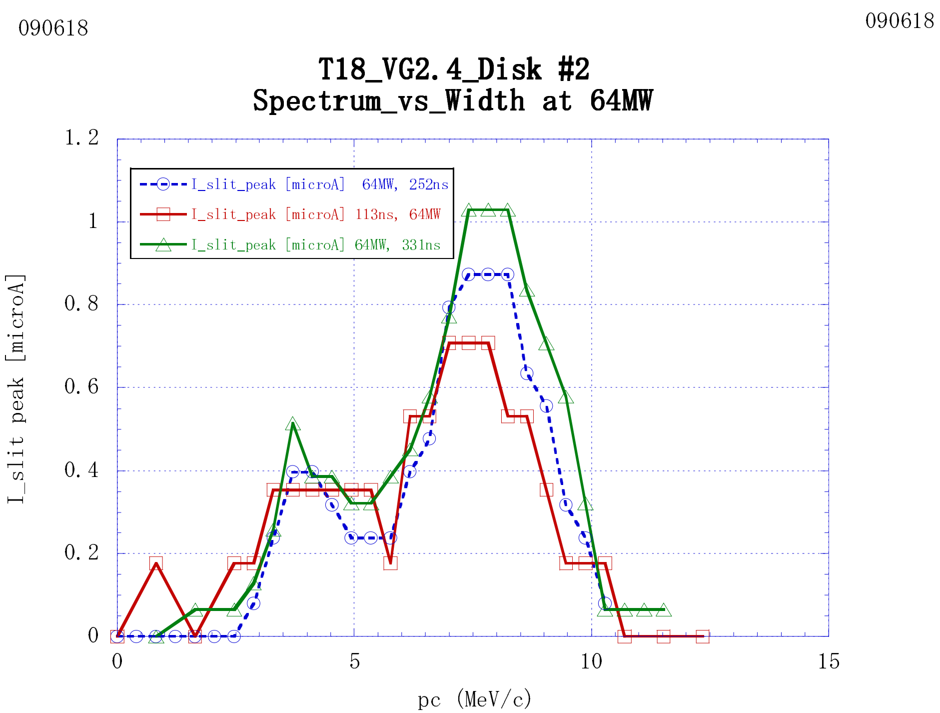
T18_VG2.4_Disk_#2

Dark current spectra measured 18 June 2009

Dependence on power

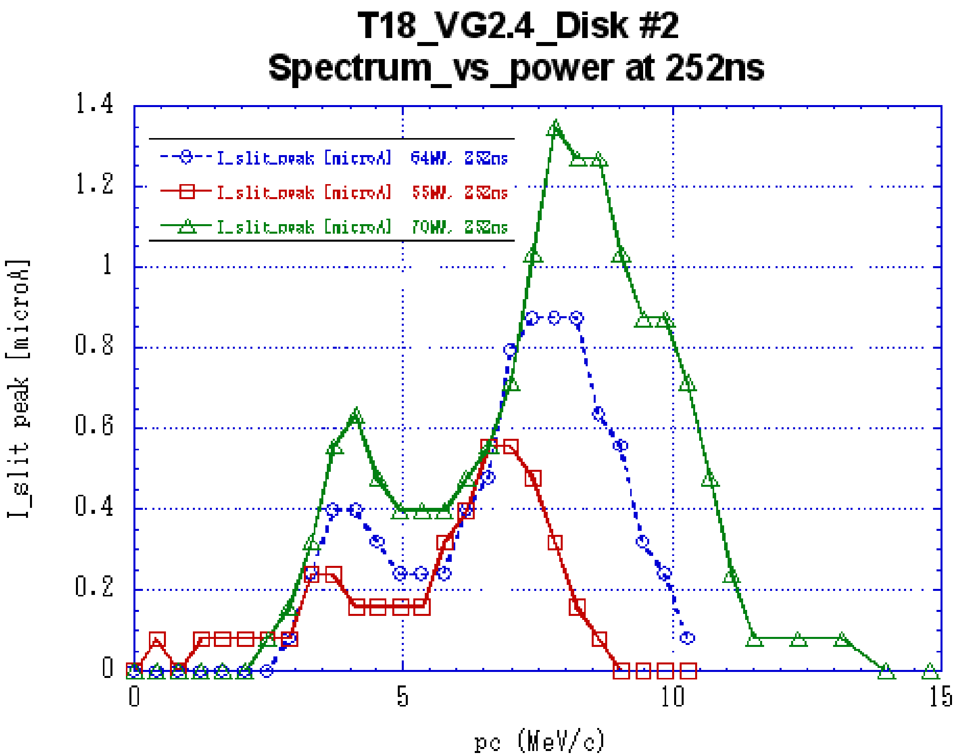


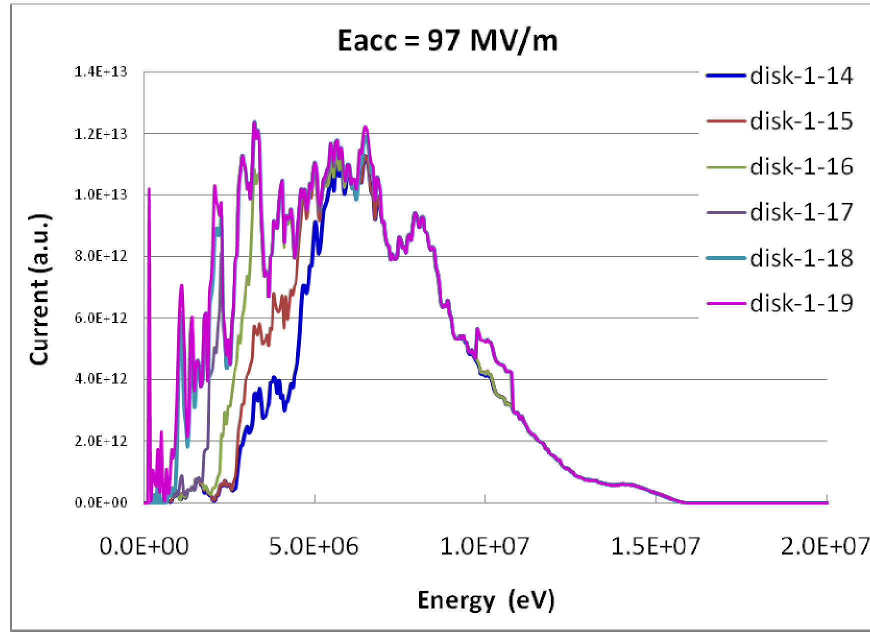
Dependence on width



Measurement Data at KEK (Higo)

Dark Current Spectrum Comparison





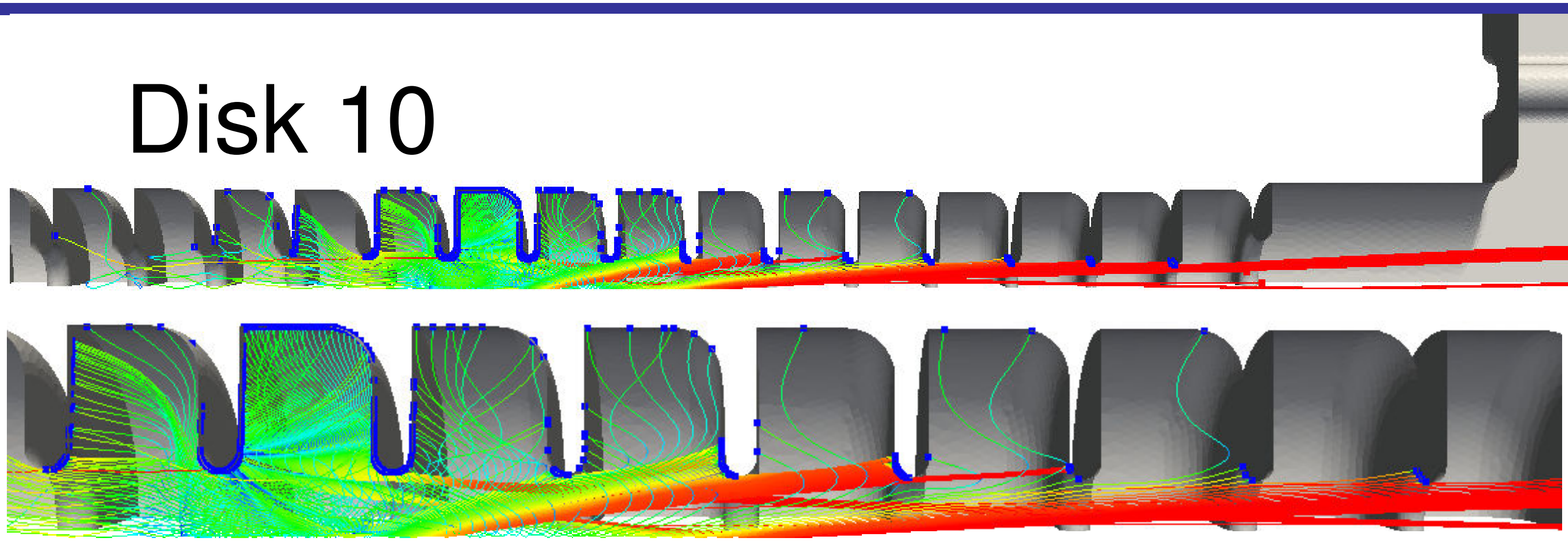
Measured dark current energy spectrum at downstream

Simulation
Eacc=97MV/m.
dE/E=0.1, zbp=2.9m

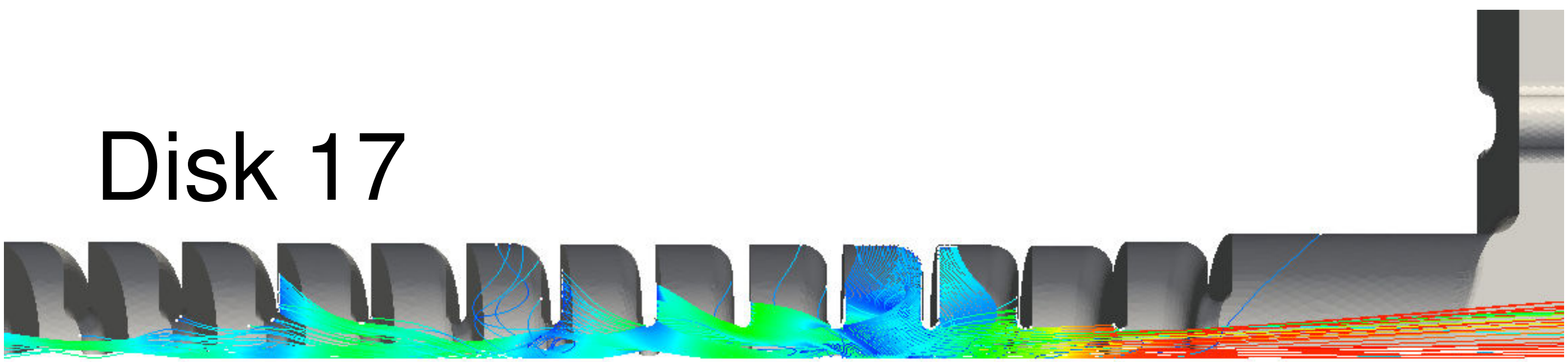
Differences?
Measured dark current spectrum details would depend on the number of emitters on the disks

Heating Due to Dark Current Impact ?

Disk 10

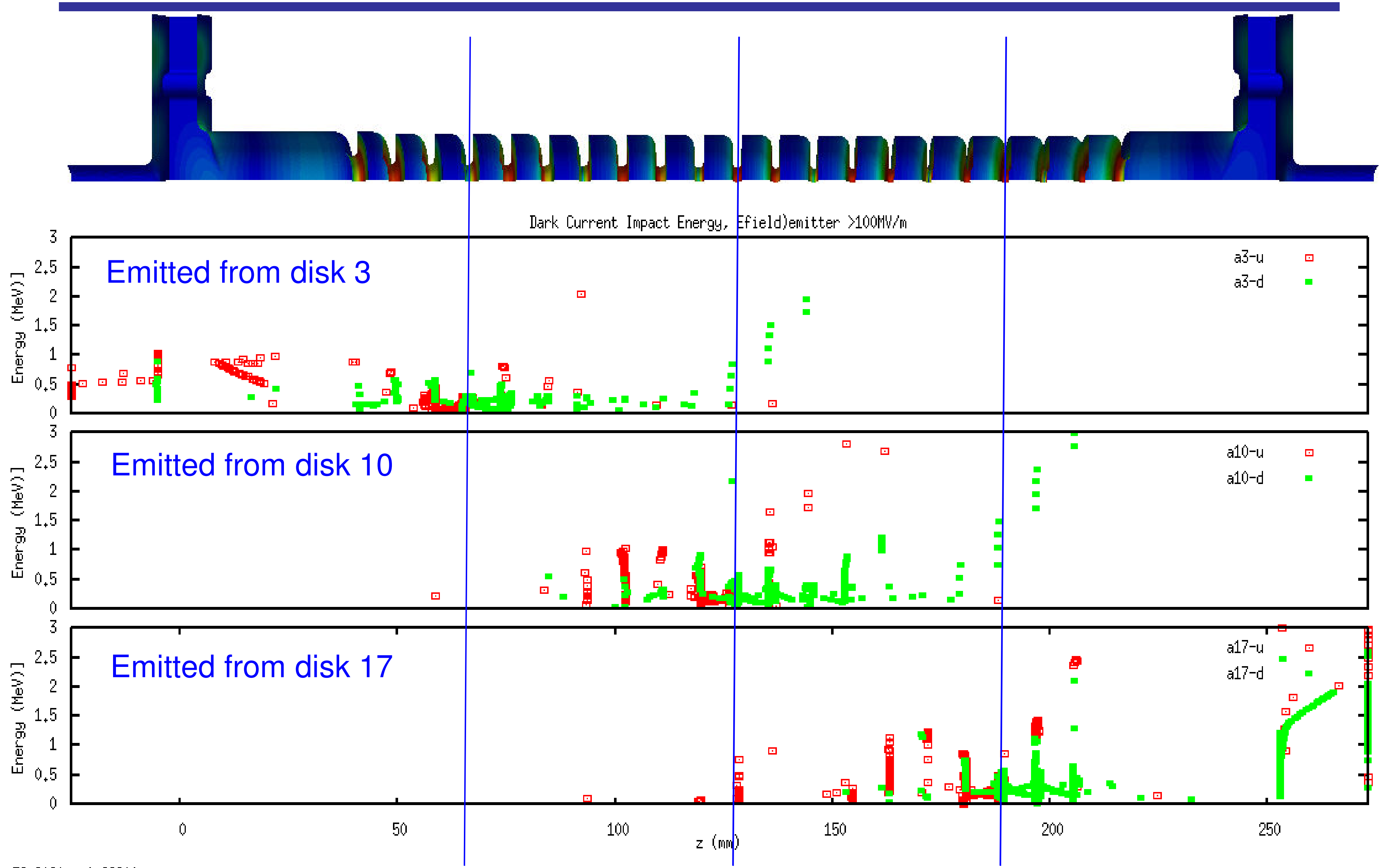


Disk 17

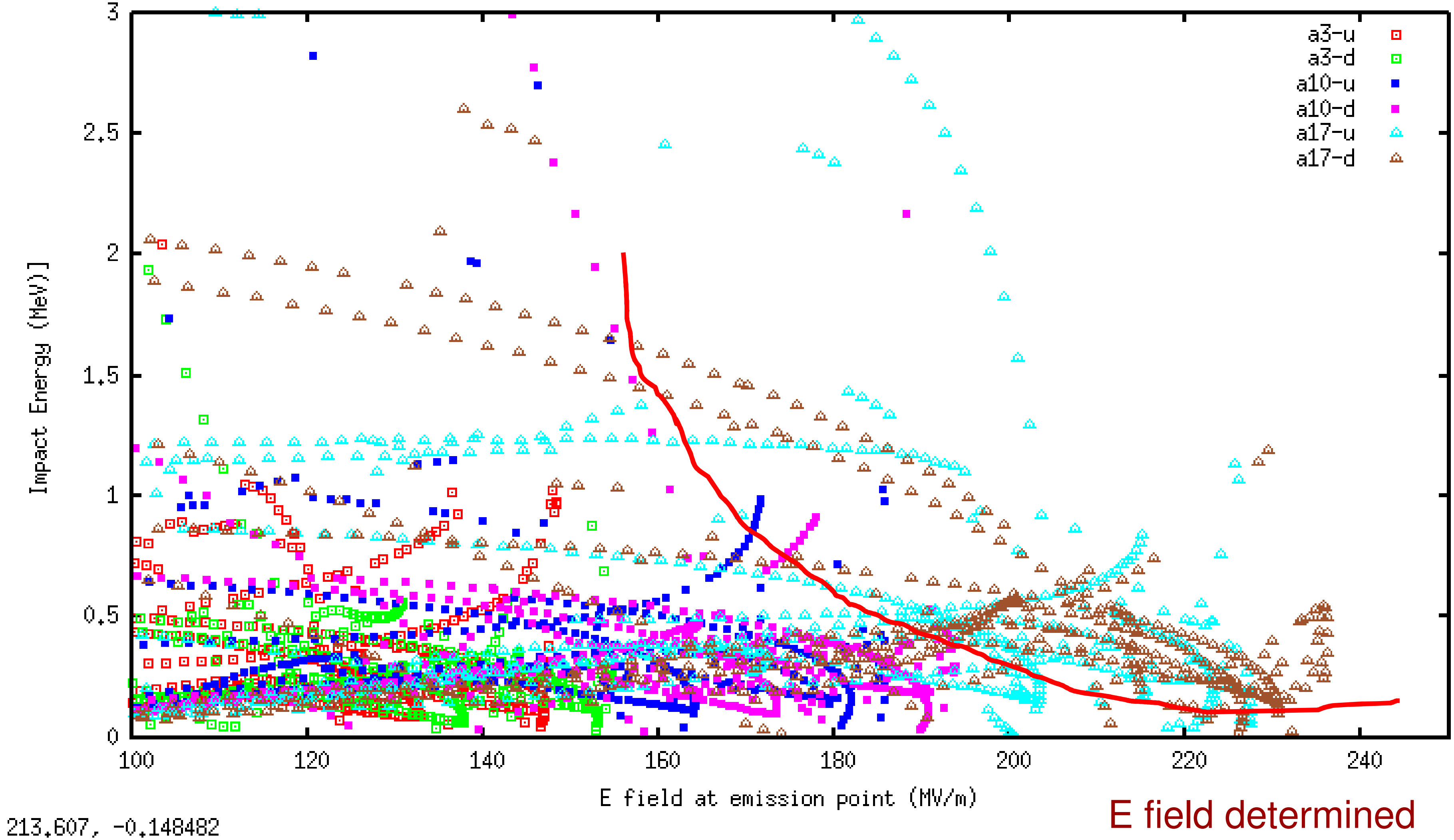


- Dark Current Collimation By Disk Iris.
- Some electrons have very high impact energies.

Electron Impact Energy



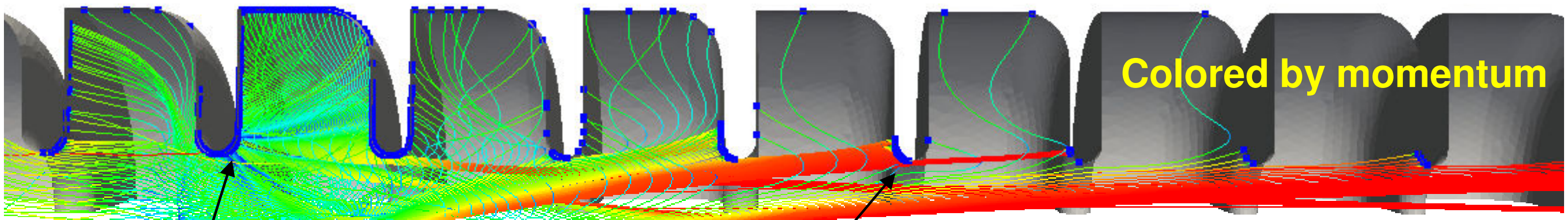
Impact Energy vs Emission Site Field

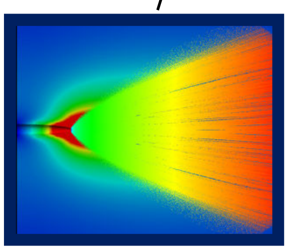


E field determined amount of emission

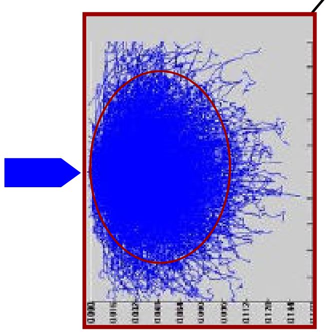
Heating Due to Dark Current Impact

- Field emission current density based on FN can be significant
  - with beta=50, Eacc=100 MV/m,
  - $J_{peak} \sim 10^{13}$ A/m^2
- Need to study effects of individual emitters
  - PIC simulation of initial emitter phase space





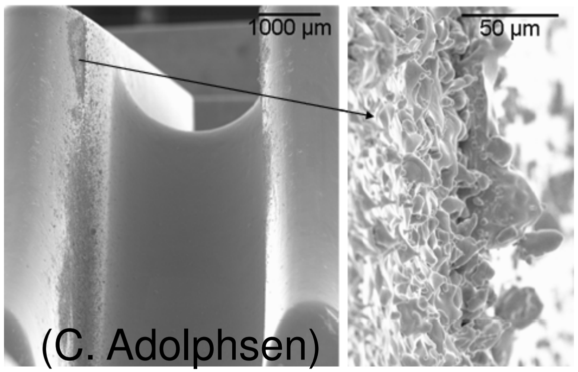
Emitter - micron or less in size

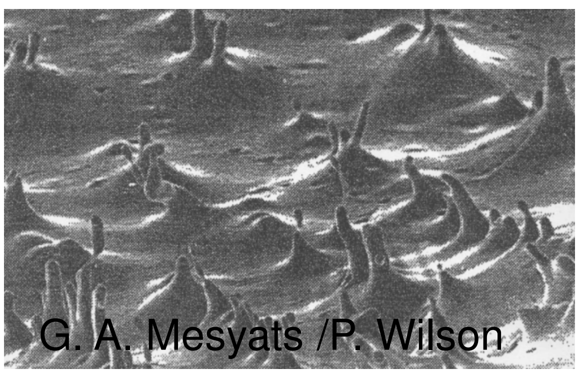


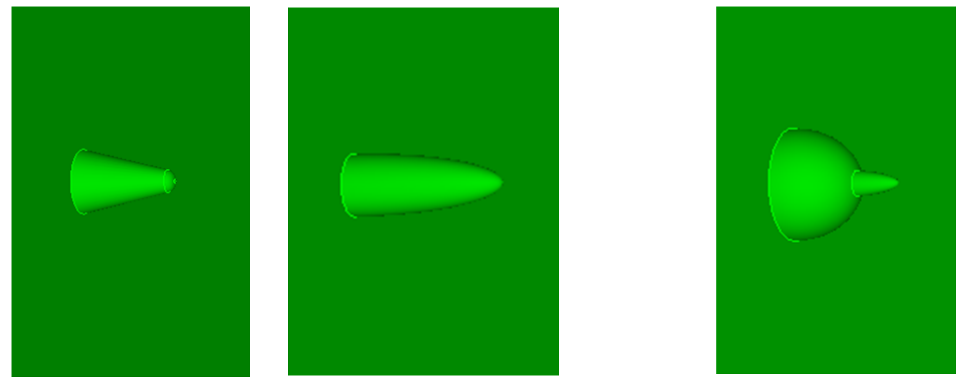
Sharon Lee
ICSE2006

- MeV energy electrons
- Larger spot and deep depth
  - ➢ localized heating may not be as significant
- Current may be much higher when breakdown is being developed?
  - ➢ site of future emitter?

“Modeling” Of Field Emitters



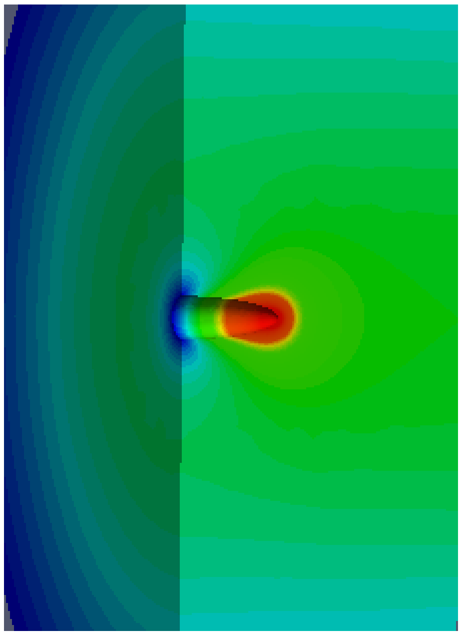




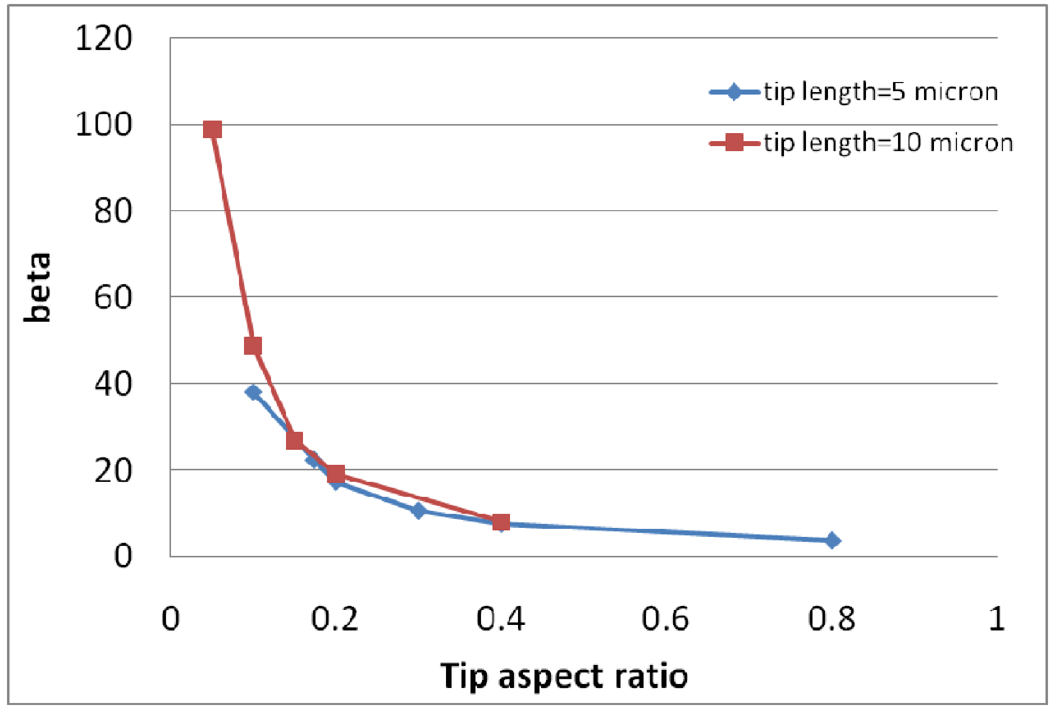
cone asperities double tip

- Calculate field enhancement beta of emitter protrusion
- PIC simulation: FN + self consistent space charge effect
  – Using a emitter shape with right beta vale (50 as measured)
  – Initial emitter phase space – impact heating distribution
  – Emission current - emission heating of emitter

Single Tip: Beta vs Shape

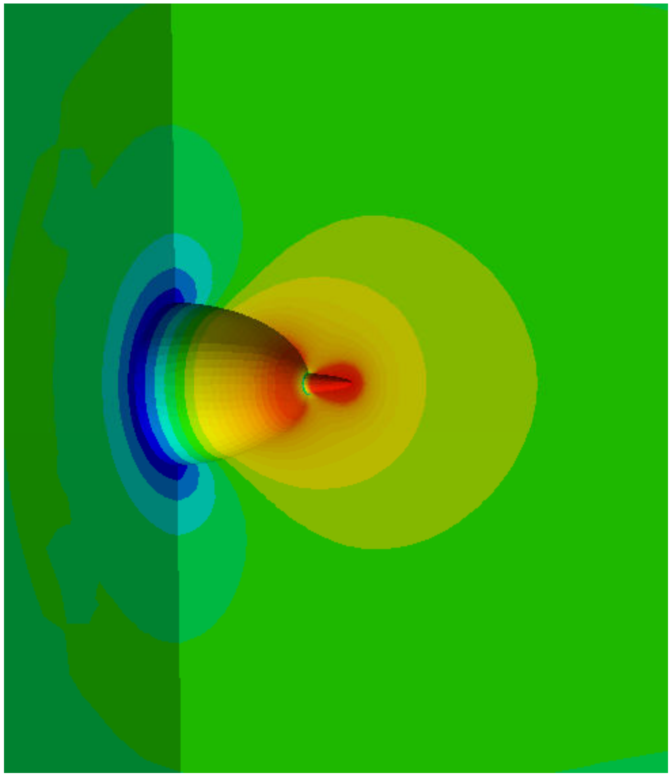


Field contour plot



Field enhancement beta vs tip elongate ratio and tip length

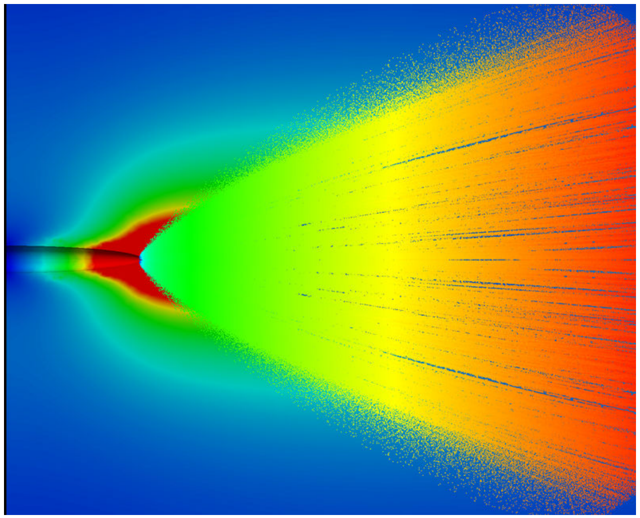
Double Tip: Beta vs Shape

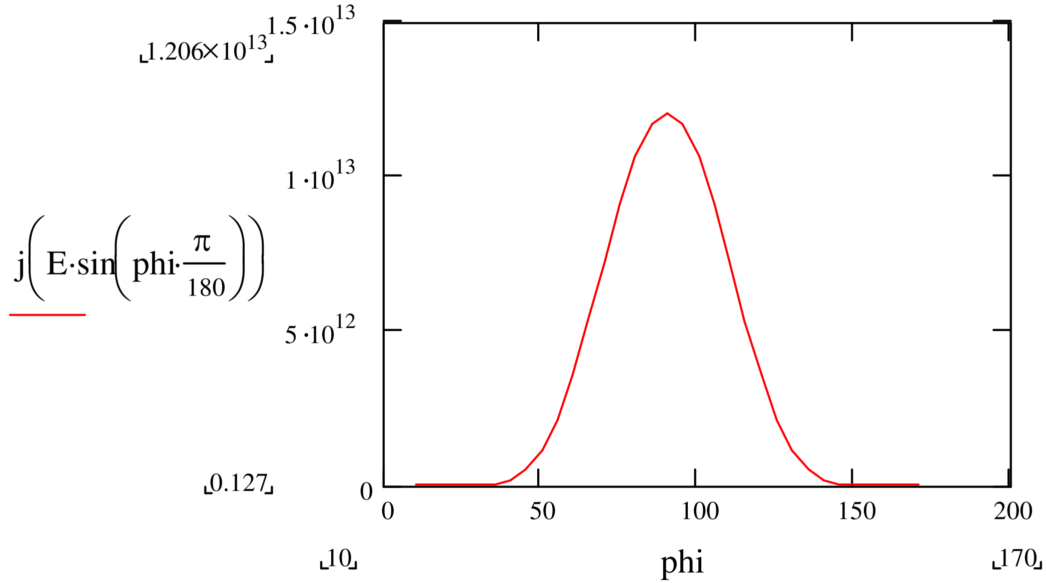


base_height	Base_r	height2	base_r2	dztip	beta
6	3	5	1	2	23
6	3	5	0.5	2	54
5	2	5	1	2	23
5	4	5	1	2	21
5	4	5	1	4	27
5	4	5	0.5	4	52

Single-tip		
base_height	base_r	Beta
5	0.5	38
5	0.87	22
5	1	17
5	1.5	11
5	2	8
5	4	4

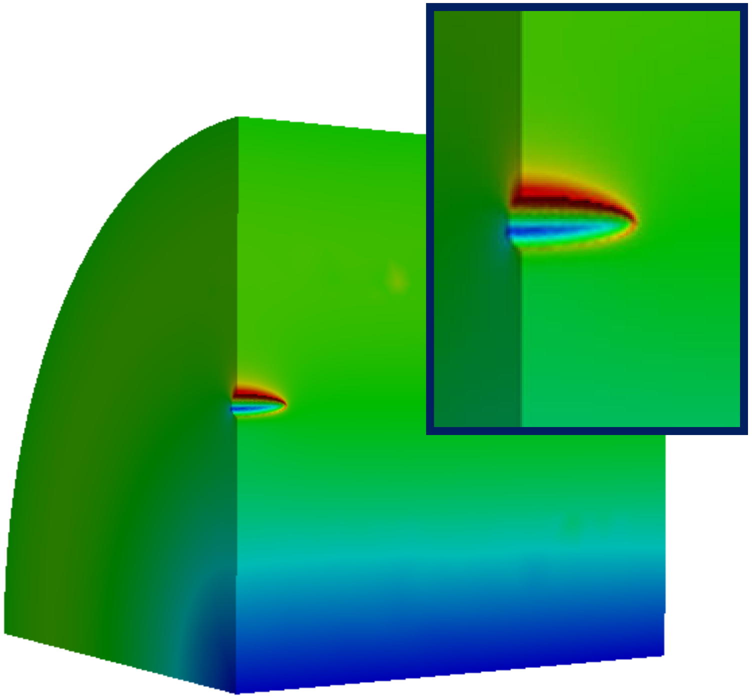
Field Emission Heating

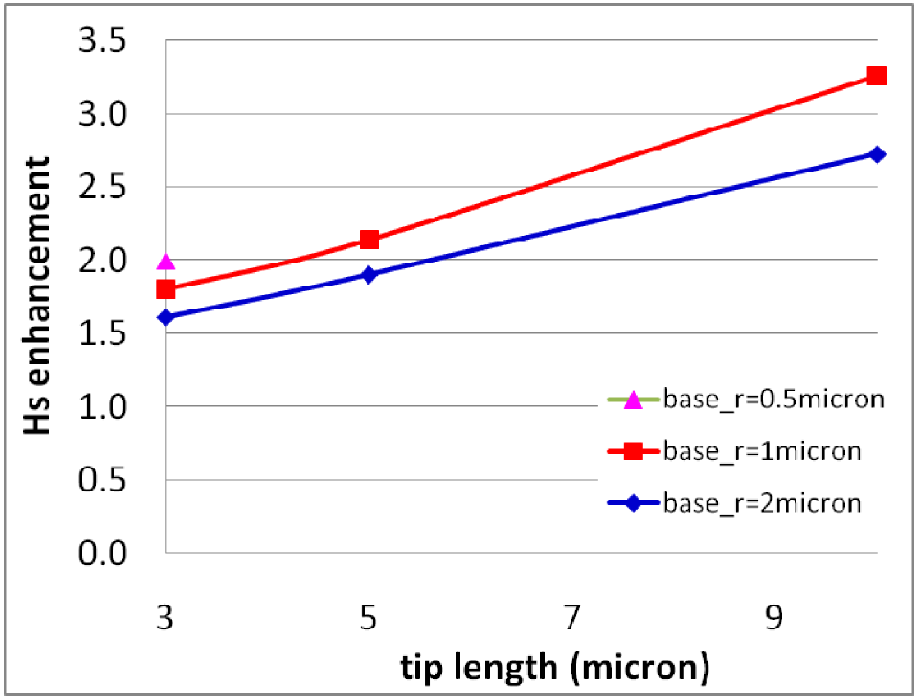




- Current is pulled out in ~ ± 40deg rf phase (FN model)
- Field emission current density
  - J_{peak} ~10^{13} A/m^2 with beta=50, Eacc=100 MV/m
  - Need PIC to include space charge effects (Arno’s talk)
- This current produce heating on emitter

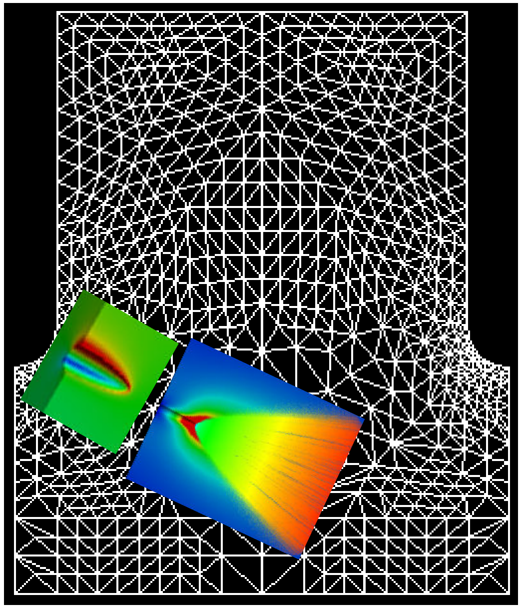
Emitter Heating Due to RF

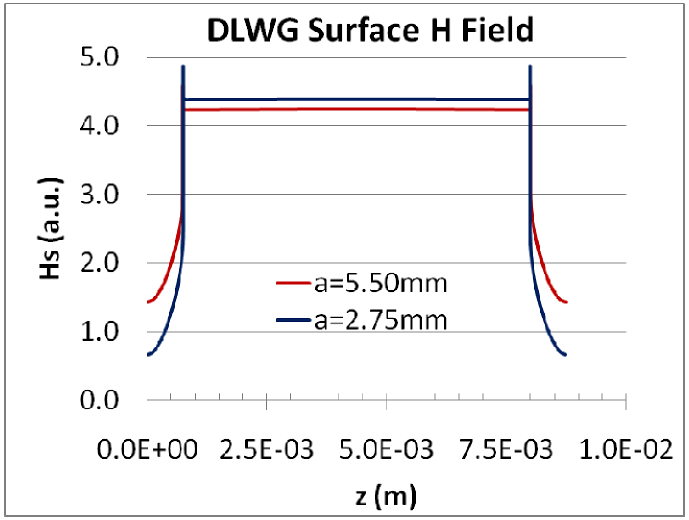




- Emitter protrusion can produce significant surface magnetic field enhancement
- May lead to higher local heating on emitter tip due to RF magnetic field

Heating On Emitter

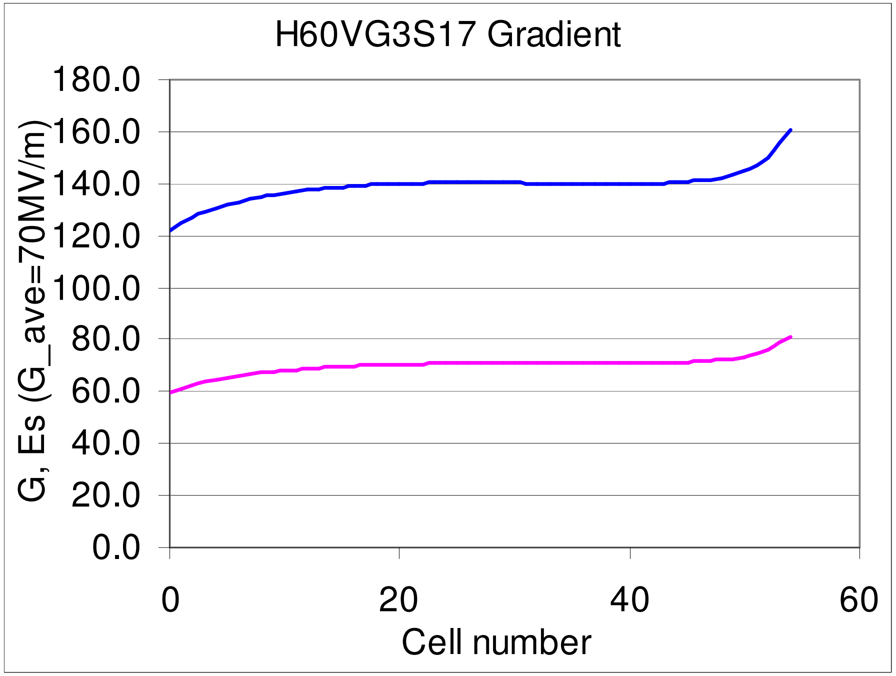




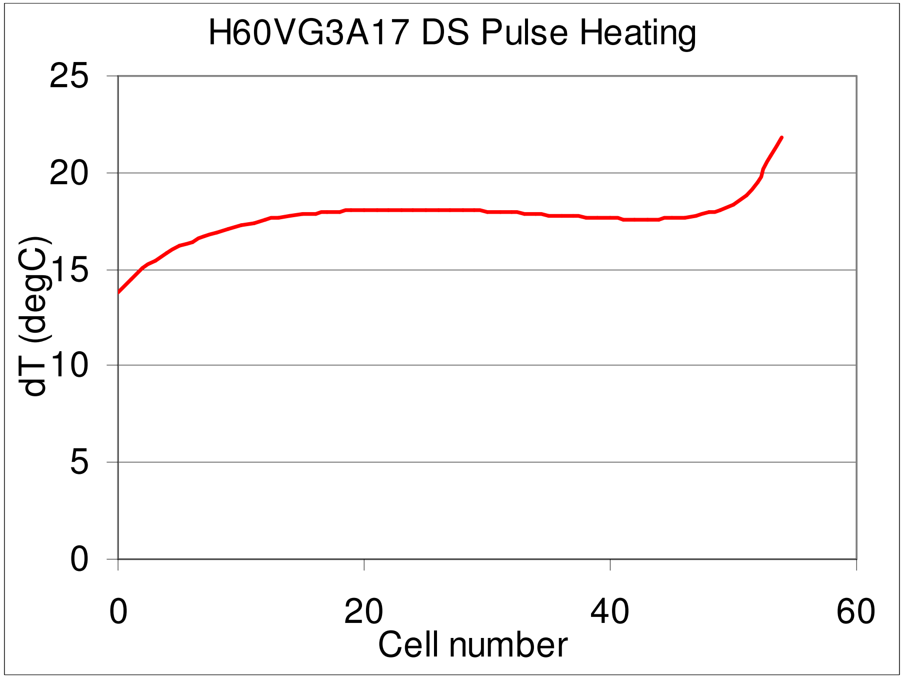
- Both RF and Emission (field+thermal) contribute to emitter heating
  - Larger cell iris – higher RF heating
  - Smaller iris (but high E) – higher emission heating
- In high E region, strong E force pull the tip outward
  - may result in development of “sharp” emitters over time
  - lead to breakdown when dark current and dark current heating exceed threshold

NLC H60VG3S17 Structure

Surface Field



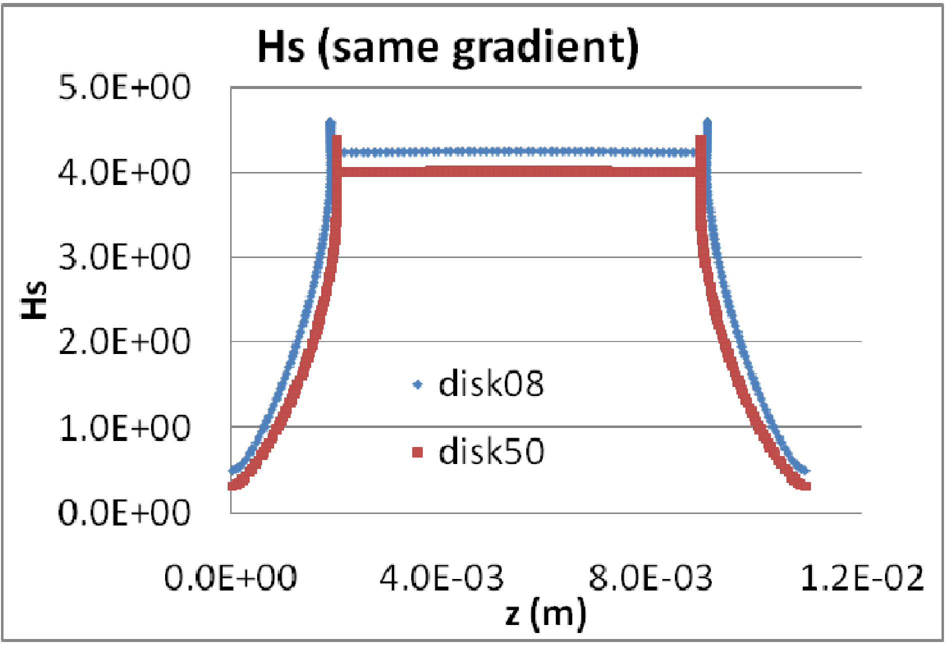
RF Heating

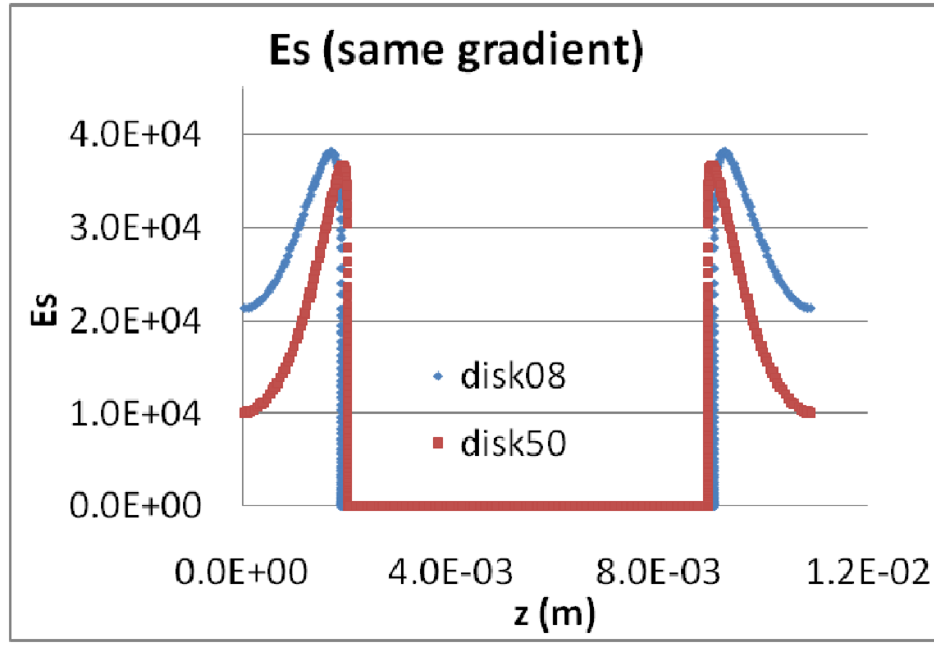


Peak Surface Field & Heating

- Surface E field and RF heating higher at the output end
- Most breakdowns in the front

NLC H60VG3S17 Structure





- Surface field along disk contour
- Disk 8 and 50 comparison (same acceleration gradient)

Summary

- Progress being made in simulating CLIC T18 structures using Track3P. Dark current spectrum compared with measurement – which may provide information of field emission conditions of disks
- Both RF and field emission contribute to emitter heating
  - High temperature plus strong E force pulling (of emitter tip) could lead to development of "sharp" emitters over time, may eventually reach breakdown threshold
  - Self consistent (space charge) emitter emission being performed using PIC to study emission heating
  - Surface field enhancement due emitter protrusion being calculated using Omega3P to study RF heating
- Detailed of modeling of field emitters in progress