Field Enhancement and Breakdown Studies at the Argonne Wakefield Accelerator Facility

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MOTIVATIONS

- A direct determination of the field-enhancement factor on the cathode surface. This technique may produce an electron beam with ultra-low intrinsic emittance (Yusof *et al*. PRL 93, 114801 (2004));

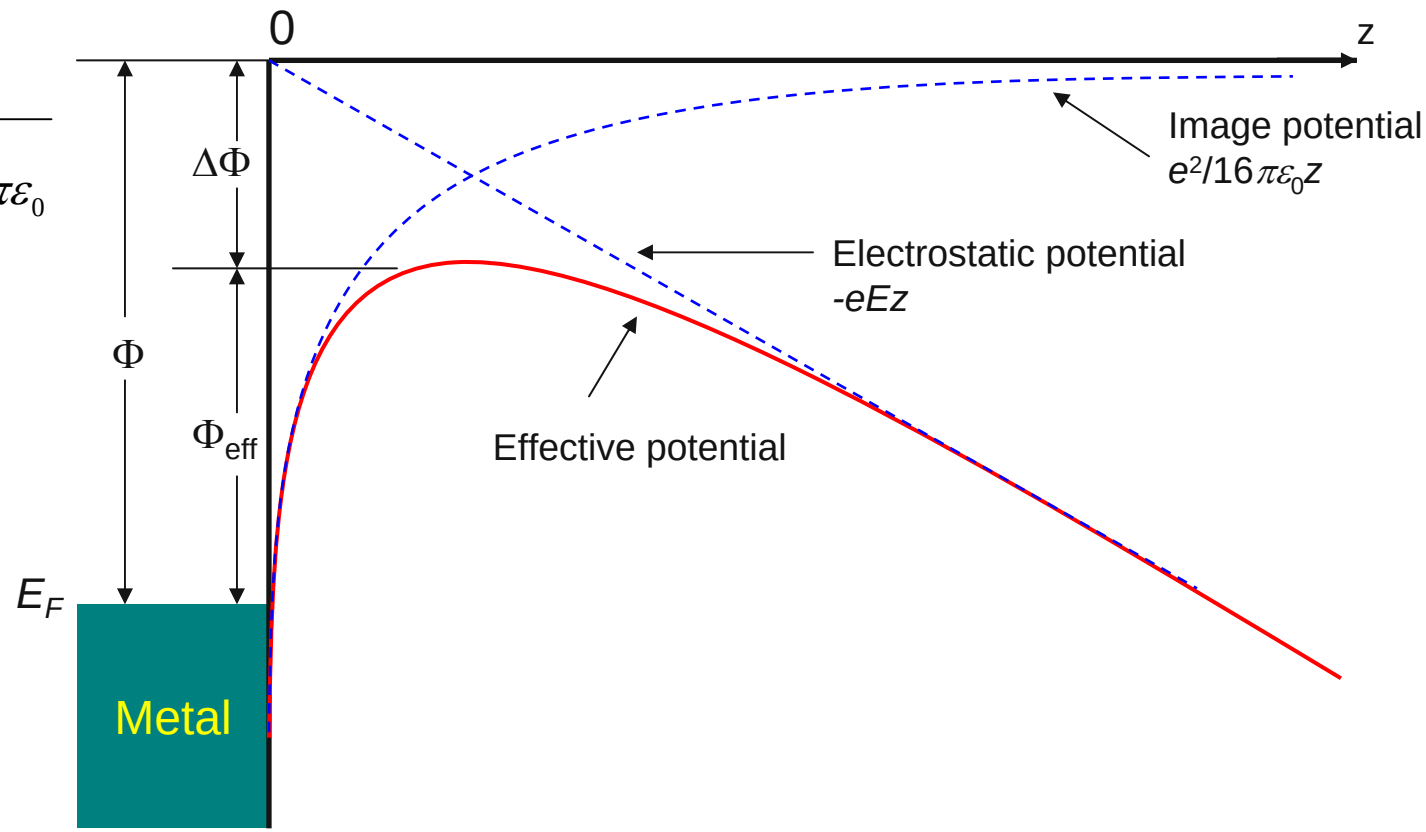
- May help to understand breakdown occurrence in RF cavity;

- Study of there is a correlation between “melting” and breakdown;

- We are setting up a dedicated RF gun for cathode and breakdown studies where a combination of RF field and laser power can induce melting at field-enhanced region.

Schottky Effect

$$\Delta\Phi = \sqrt{e^3 E / 4\pi\varepsilon_0}$$



$$\Phi_{eff} = \Phi - \Delta\Phi$$

PHOTOEMISSION IN RF PHOTOINJECTOR

For a typical cathode: $E_{kin} = h\nu - \Phi$

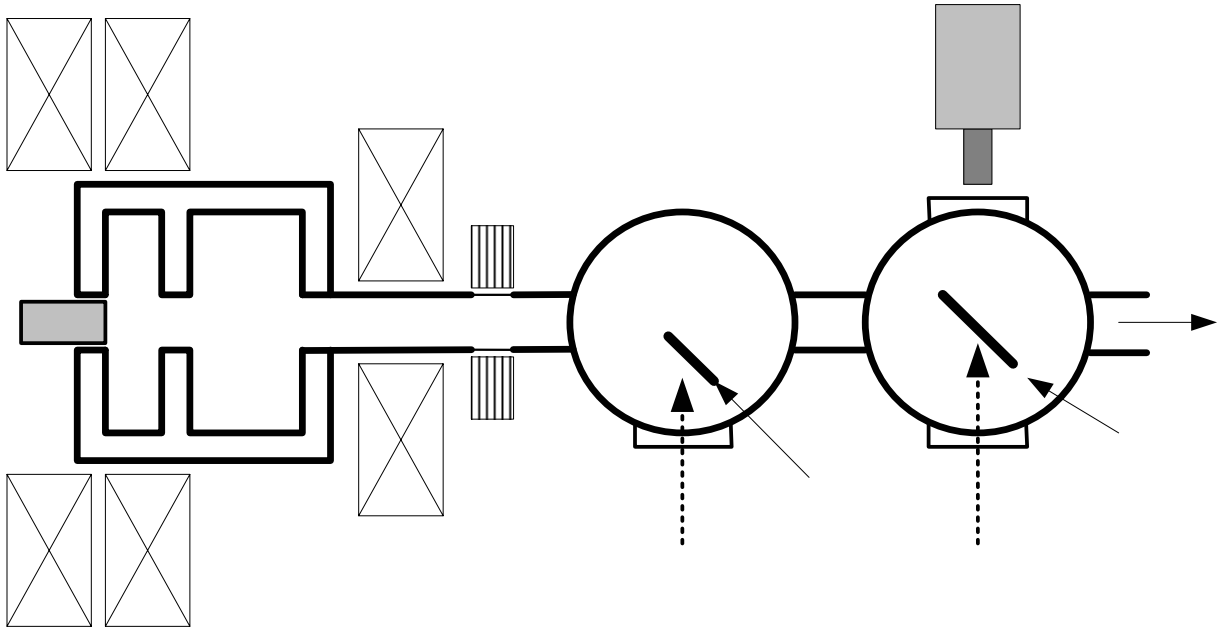
However, for a cathode in an electric field E: $E_{kin} = h\nu \underbrace{- \Phi + \alpha\sqrt{\beta E(\phi)}}_{-\Phi_{eff}}$

where $h\nu$: photon energy
Φ : material's bulk work function
α : a constant
β : field enhancement factor
ϕ : RF phase
E : Electric field magnitude

Our scheme is to use $h\nu < \Phi$, and then employ the Schottky effect to lower the effective work function Φ_{eff}, where

$$\Phi_{eff} = \Phi - \alpha\sqrt{\beta E(\theta)}$$

SCHEMATICS OF BEAMLINE

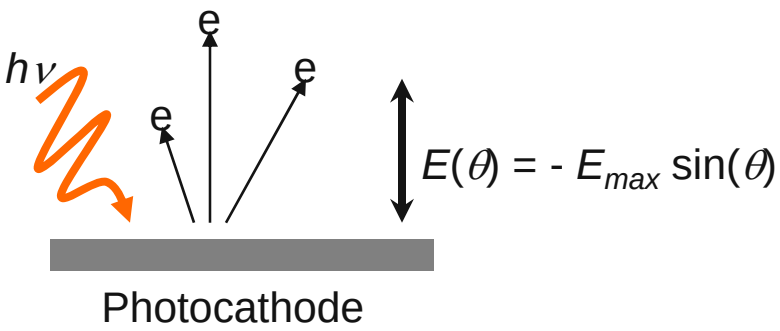


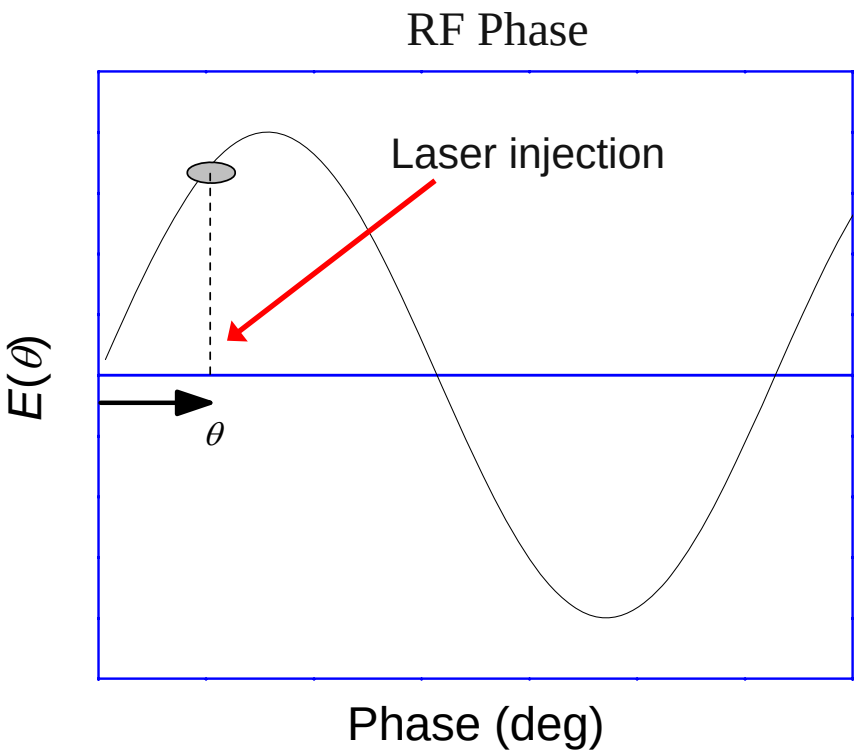
Light source: Frequency-doubled Ti:Sapphire laser 372 nm (3.3 eV), 1 – 4 mJ, 8ps.

Photocathode: Mg, Φ = 3.6 eV.

Example of Schottky effect on the cathode: at $E(\theta)$ = 60 MV/m, $\Delta\Phi$ ~ 0.3 eV

RF PHASE SCAN





RF frequency = 1.3 GHz (Period ~ 770 ps)

Laser pulse length = 6 – 8 ps

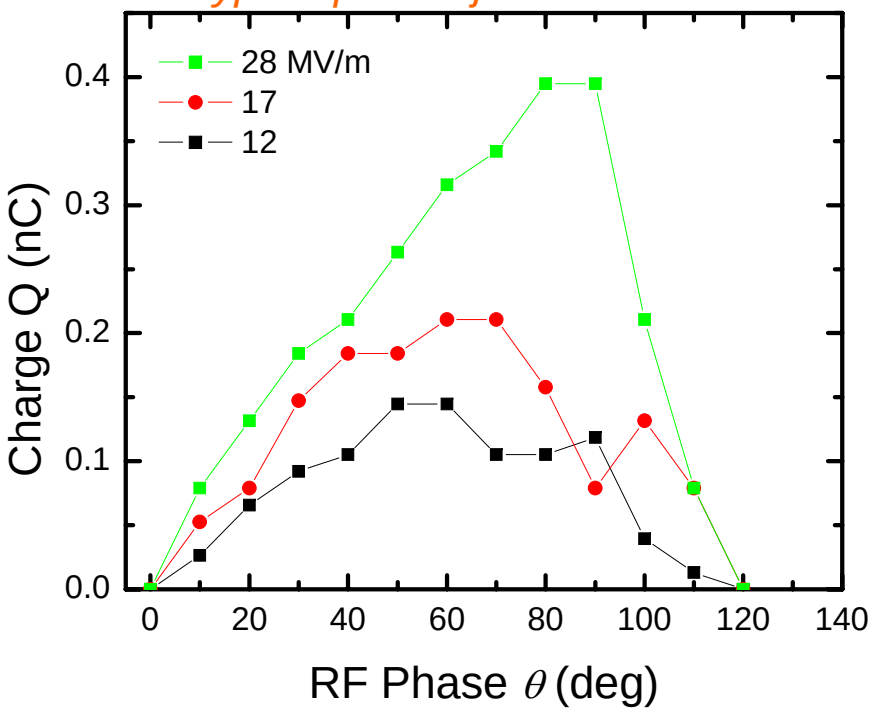
Metallic photocathode response time ~ fs

We can safely assume that all the photoelectrons emitted in each pulse see the same *E*-field strength

EXPERIMENTAL RESULTS 1 – RF PHASE SCANS

An RF phase scan allows us to impose different electric field magnitude on the cathode at the instant that a laser pulse impinges on the surface, i.e. $E(\theta) = E_{max} \sin(\theta)$.

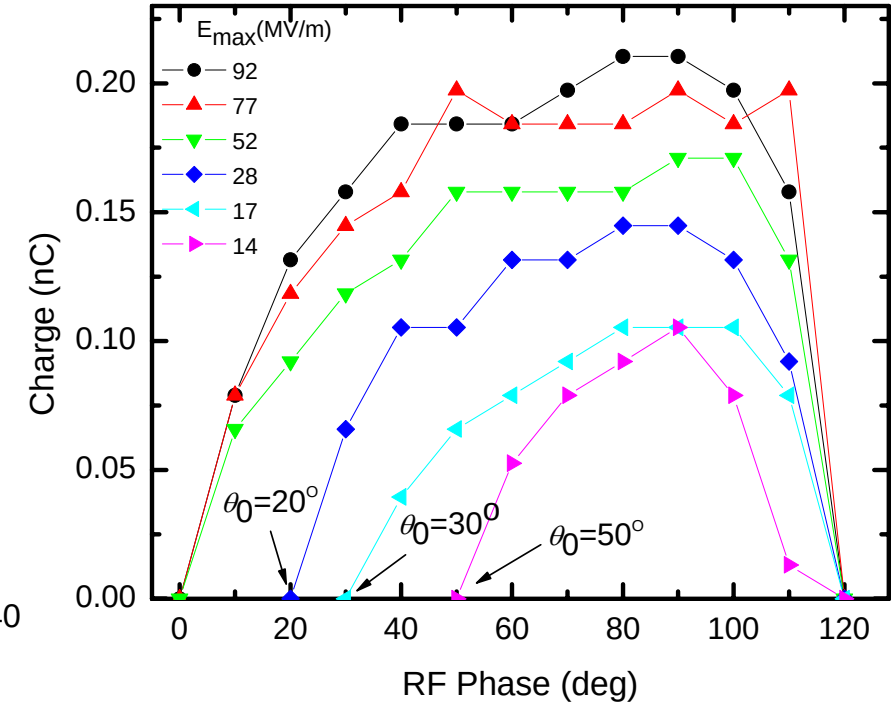
Typical photoinjector conditions



$h\nu$ = 5 eV, Φ = 3.6 eV

No change in the phase range over all RF power.

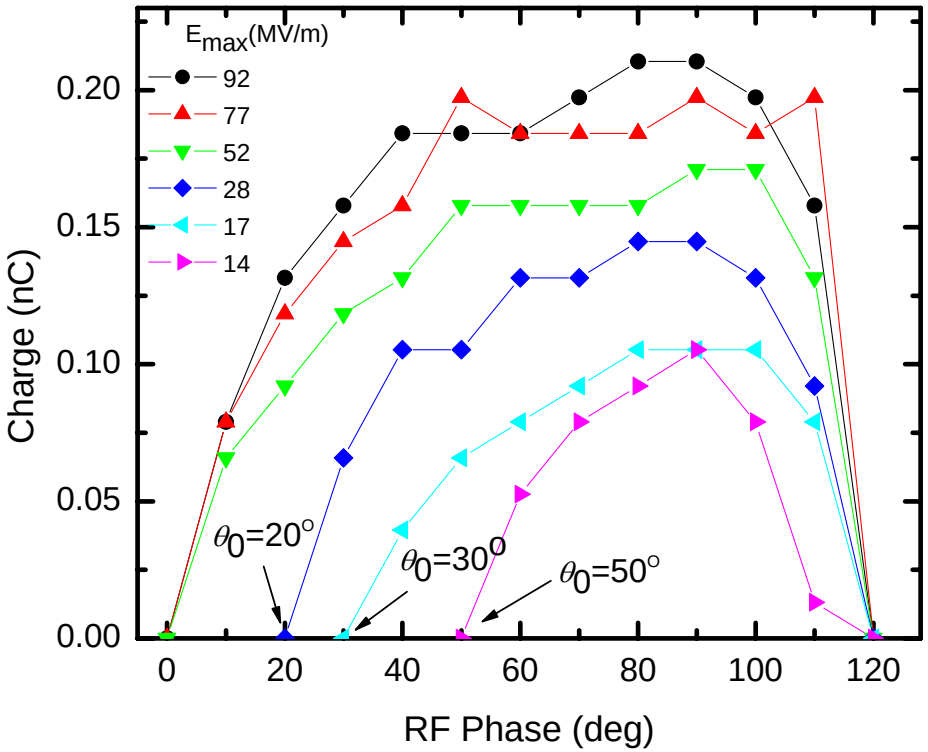
New observation



$h\nu$ = 3.3 eV; Φ = 3.6 Ev; Laser beam diameter = 2 cm (0.35 mJ/cm^2)

A noticeable shift of the onset of photoelectron production with decreasing RF power.

DETERMINATION OF FIELD EHANCEMENT FACTOR



$h\nu$ = 3.3 eV; Φ = 3.6 eV

$$Q \propto \left[h\nu - \Phi + \alpha\sqrt{\beta E(\theta)}\right]^2$$

$$E(\theta) = E_{\max}\sin(\theta)$$

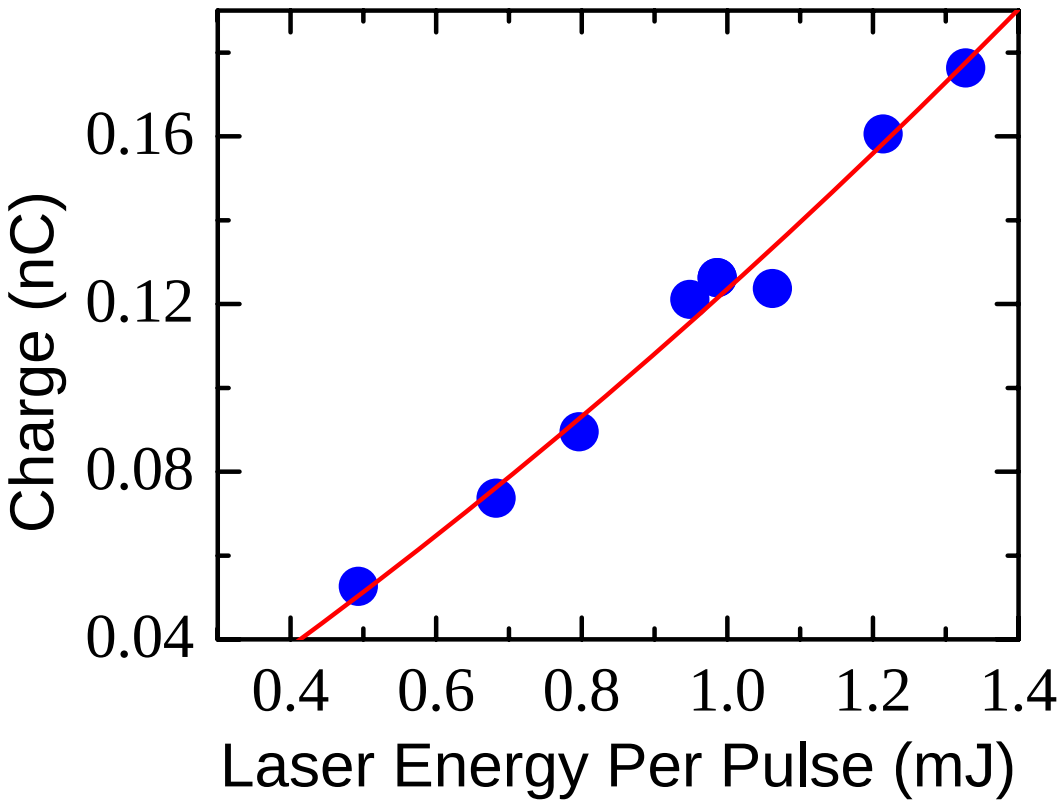
$$\alpha = \sqrt{e/4\pi\varepsilon_0}$$

At threshold, Q = 0. This allows us to make a reasonable estimate of the maximum β.

θ_0 (deg)	E_{max} (MV/m)	$E_0 = E_{max}\sin(\theta_0)$ (MV/m)	β
20	28	9.2	6.8
30	17	8.5	7.3
50	14	11	5.8

This is a *new* and viable technique to realistically determine the field enhancement factor of the cathode in a photoinjector

EXPERIMENTAL RESULTS 2 – CHARGE VS. INTENSITY



Parameters:

$h\nu$ = 3.3 eV

Φ= 3.6 eV

E field on cathode: 80 MV/m

Laser spot diameter: 2 cm

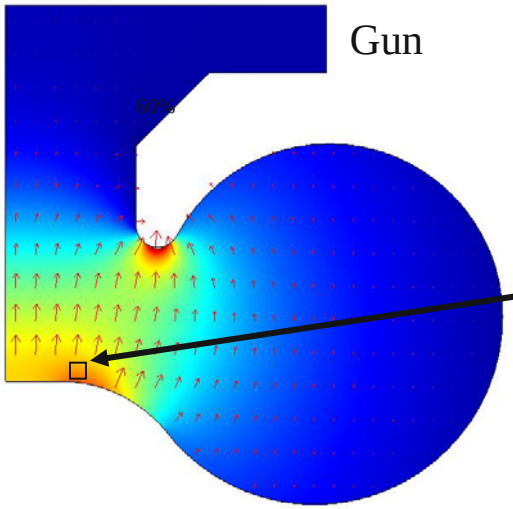
As we increase the laser intensity, we detect more charge. We *definitely* are detecting photoelectrons and not dark currents!

PLANNED FIELD ENHANCEMENT STUDIES

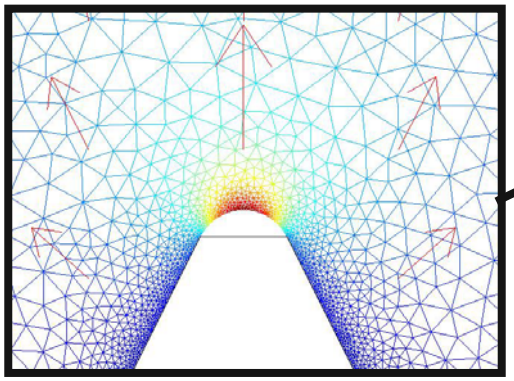
- We are assembling a ½ cell gun, capable of reaching up to 120 MV/m at 1.3 GHz.
- Allows us to study field-enhancement factor of different surface treatments and different materials
- Diagnostics includes Faraday cup, high-speed gated camera (few ns), field probe, etc.
- A natural consequence of this setup is our ability to extend this to study breakdown in RF cavity – we know we can already cause explosive emission on our cathode. Can this be correlated to a form of breakdown in RF cavities?
- To do that, we propose to study the correlation between “melting” and breakdown effects (Sergey Antipov’s poster last Tuesday)

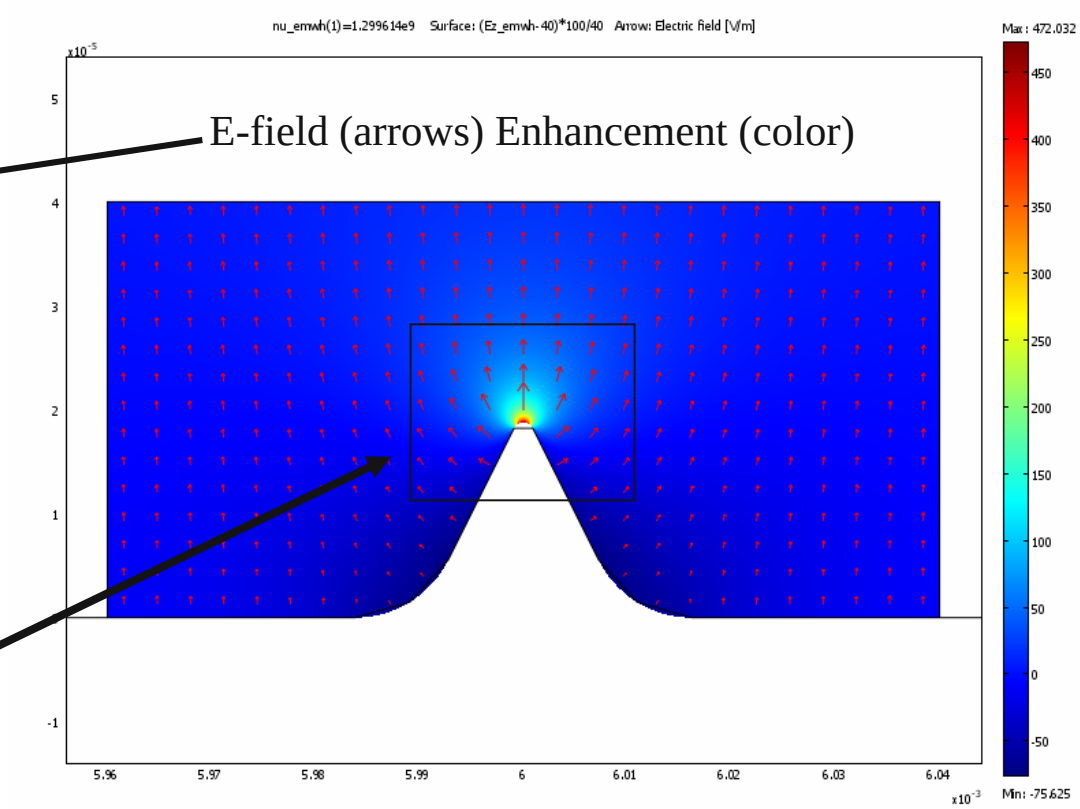
SO WE KNOW β. NOW WHAT?

- Simulation of RF field (using FEMLAB) in the gun cavity that includes a protrusion with a particular β value;
- This allows us to determine the field right at the field enhancement region;



Mesh





Field enhancement on the defect is about 475%

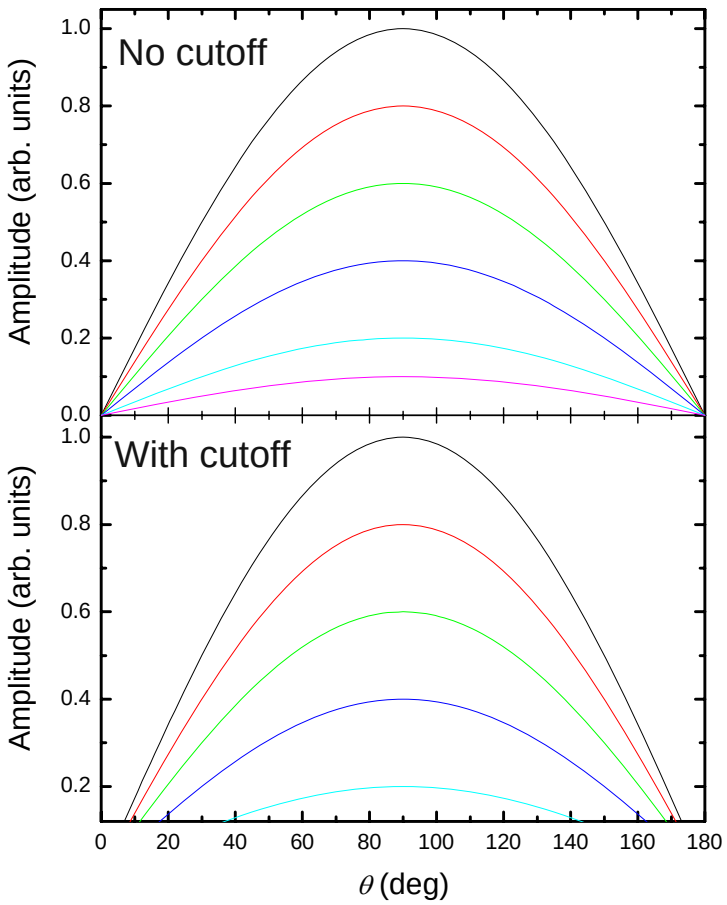
I'M MELTING!! I'M MELTING!!

- Knowing the field-enhancement factor, we know roughly, from simulations, high to set the RF field before any possible breakdown due to heating/melting
- We will then attempt to induce melting on the surface using high powered laser – using either UV and/or IR
- We hope to be able to capture the dynamics of the process by monitoring the field in the gun, the emitted charge, and image capture
- Examine the surface afterwards – we have access to a SEM to compare surface before and after.

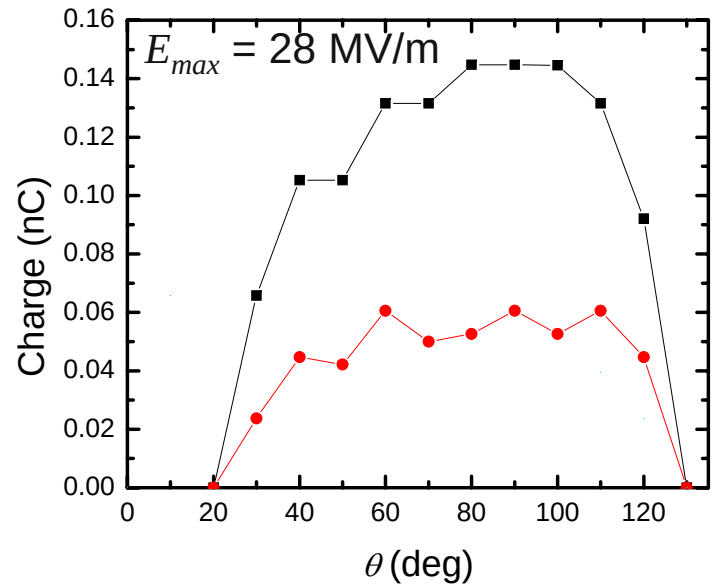
To be continued….

EXPERIMENTAL RESULTS 3 – DETECTION THRESHOLD?

Simulated Detection Threshold
Using A Sine Function



Experimental Observation



Two different scans with different amount of charge produced, but with the same RF amplitude, show the same phase angle for the photoemission threshold.

The shift in the photoemisson threshold is ***not*** due to the detection threshold.