Time Dependent Emission from Metal Cathodes

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- Motivation
  - Schottky Scan
  - Charge vs Laser Energy
- Emission Model
  - Assumptions
  - Theoretical QE
  - Theoretical Thermal Emittance
- Difference between Laser and Electron Pulse Shape
  - Flat top laser
  - Flat top electron beam
  - Chirp
- Other Effects
  - Cathode response time
  - Surface roughness

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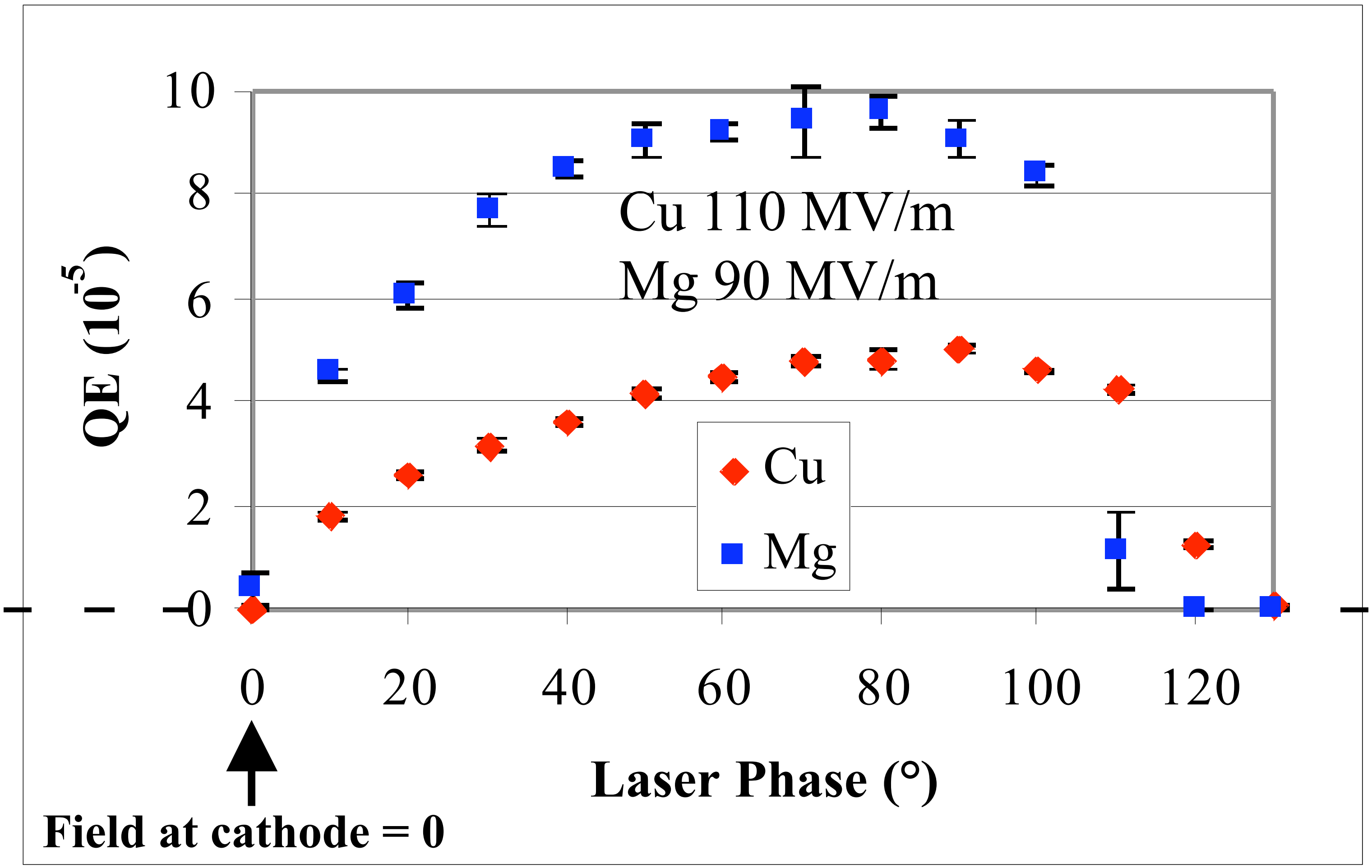
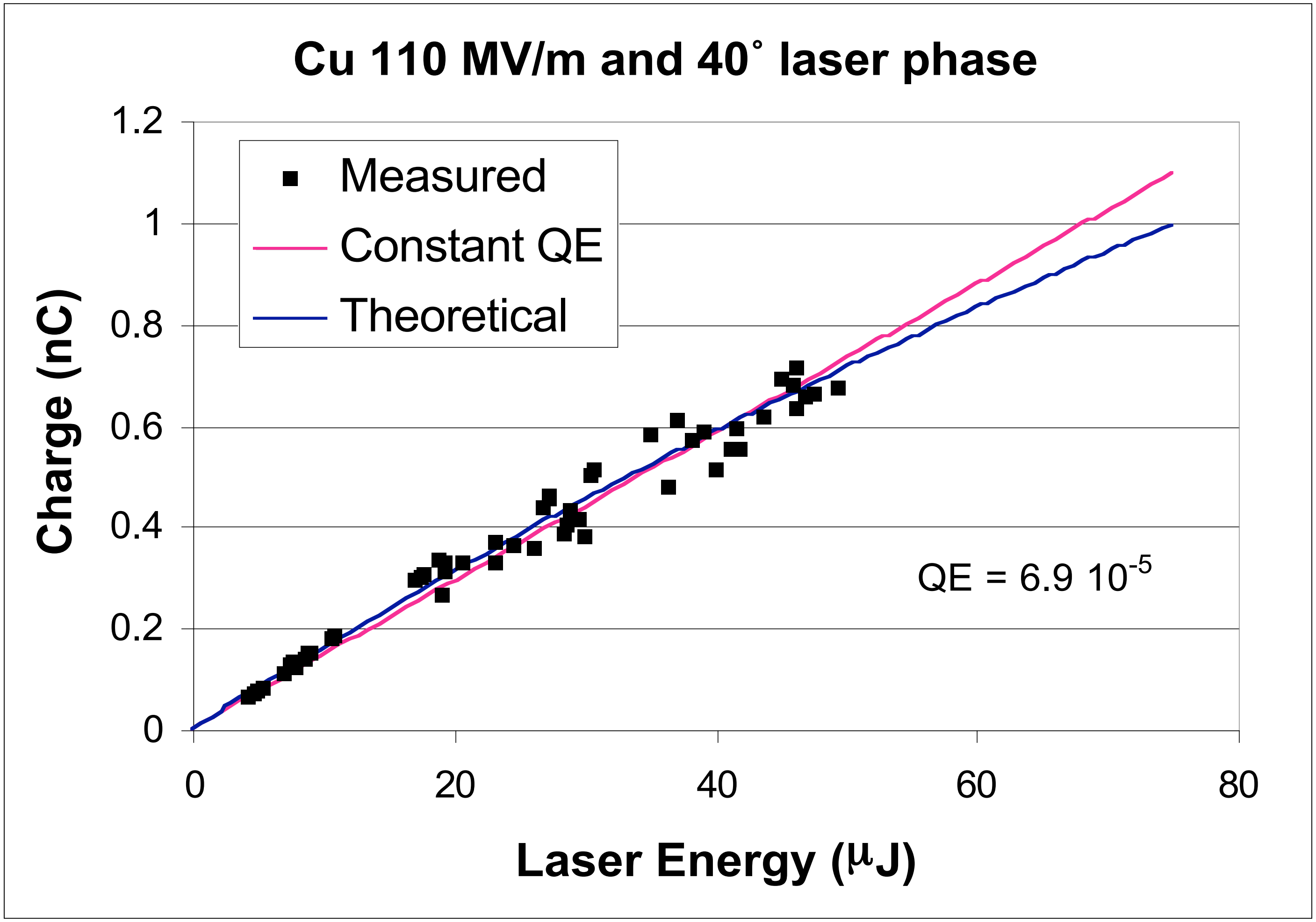
QE Measurement

- QE defined as ratio of number of electrons emitted to number of incident photons
- Measure charge on Faraday Cup 75 cm from cathode
  - Background subtraction and temporal gating to eliminate dark current
  - Solenoid used to focus electrons on to FC
- Measure laser energy on joule meter
  - 2% of laser energy picked off from window approximately 100 cm upstream of cathode for shot to shot energy measurement
  - Pickoff located upstream of vacuum window so measurement corrected for vacuum window transmission and in vacuum mirror reflectance

Schottky Scan



Measured Charge vs Laser Energy



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Cathode Emission Model

- Schottky Effect included
  - Applied RF field (no field enhancement factor)
  - Space Charge field
- Electrons emitted from bulk material and no surface effects included
- Energy and Momentum Effects Included
  - Only electrons with sufficient momentum to overcome surface barrier are emitted
  - Model assumes Fermi-Dirac electron energy distribution
  - Photon bandwidth ignored (except when investigating laser chirp effects)
- Single photon absorption
- Electron-electron scattering ignored
- Flat planar surface
- No polarization effect other than reflectance

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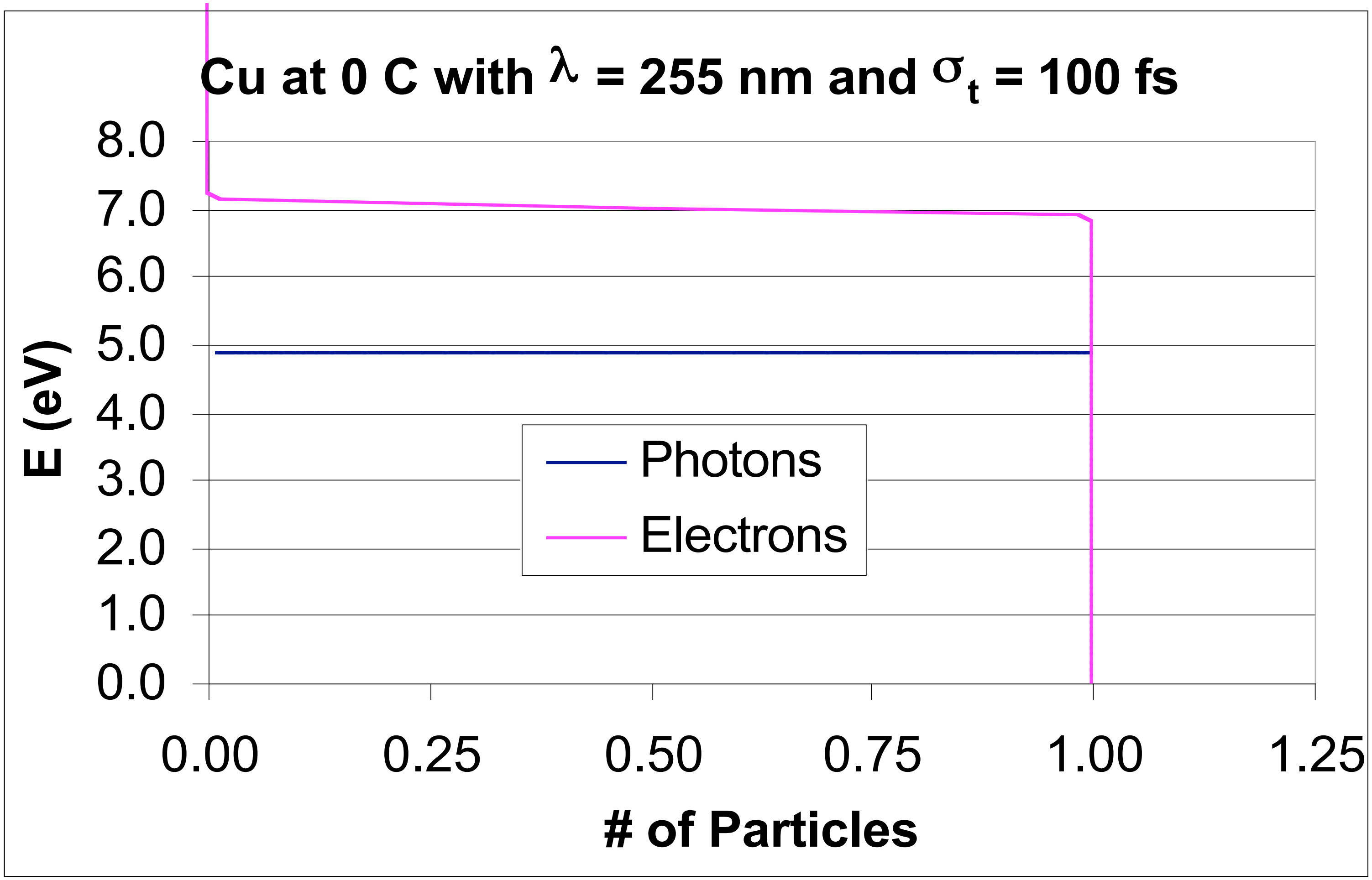
Fermi-Dirac Energy Distribution



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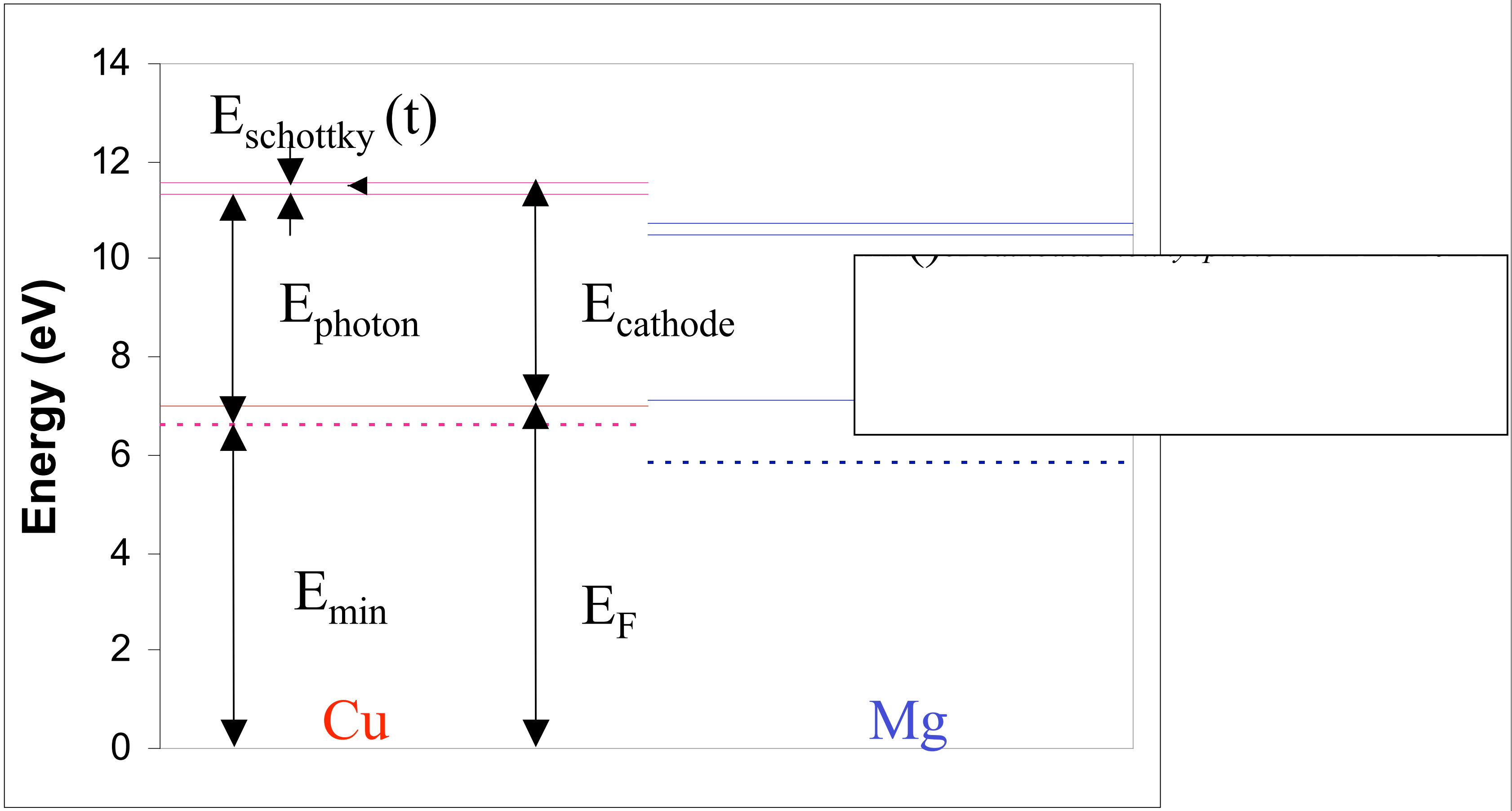
Metal Cathode Energy Levels



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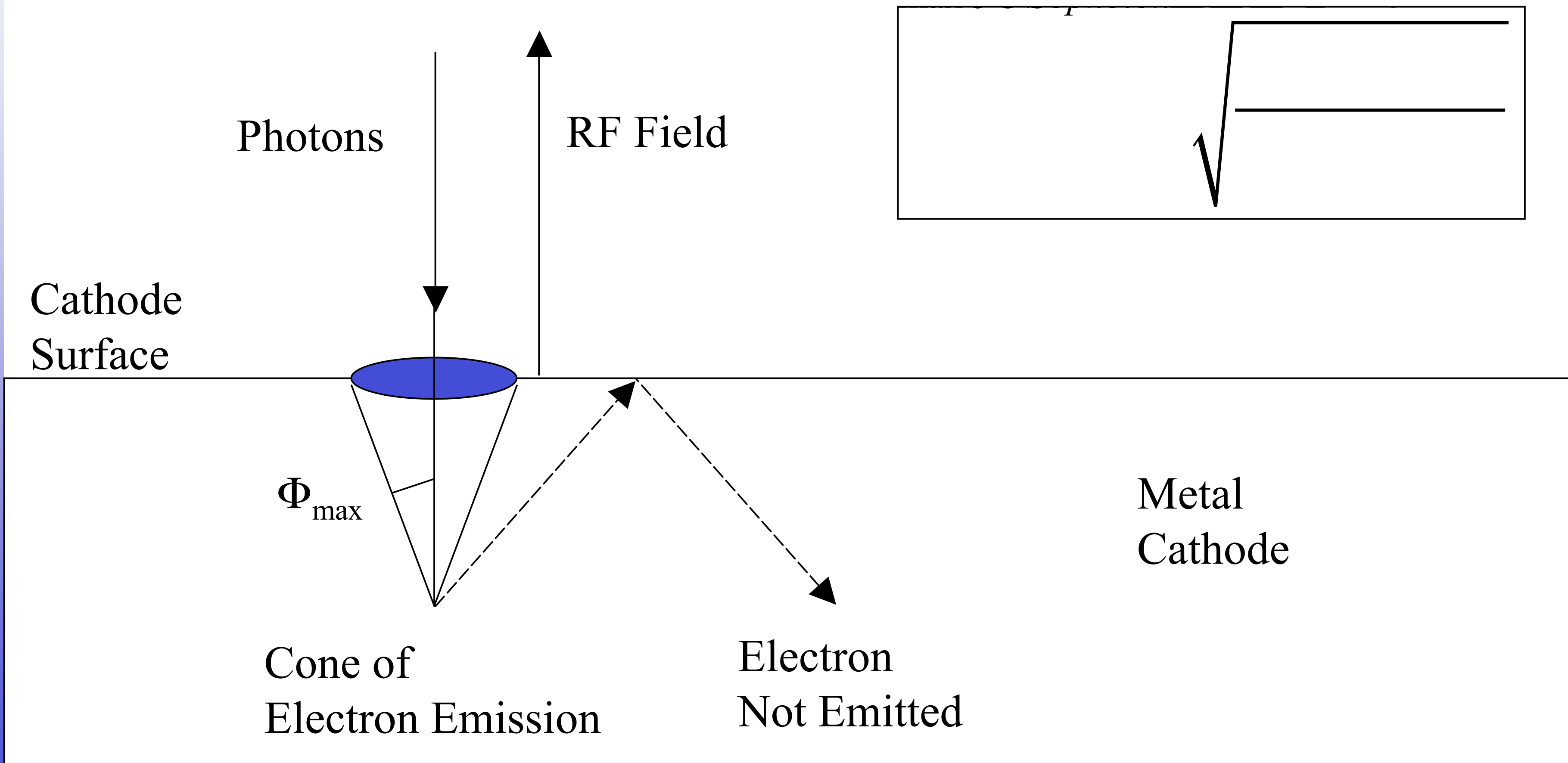
Emission Geometry



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Theoretical QE

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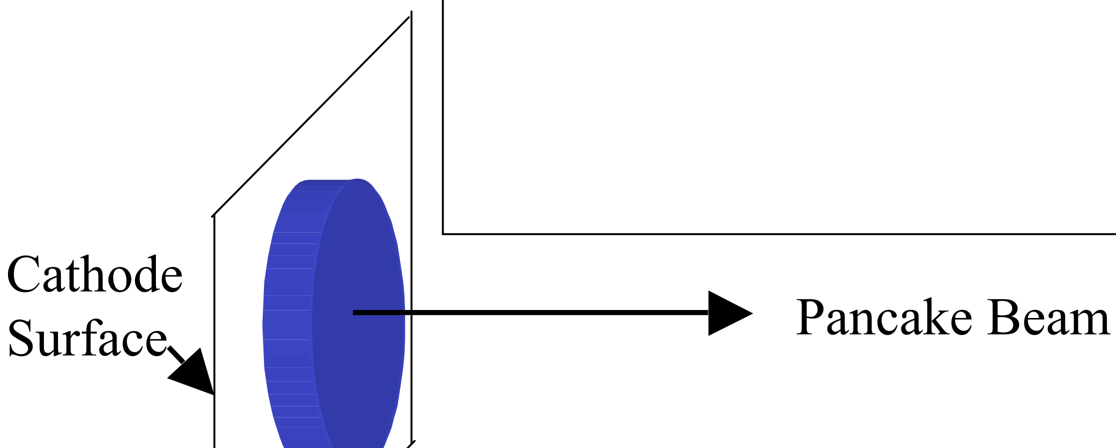
Schottky Effect



$\Delta z = 0.5$ mm for $\Delta z_{laser} = 3$ mm
With 120 MV/m at 30°
LCLS case $\Phi/\Delta z \approx 5$

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Theoretical Thermal Emittance

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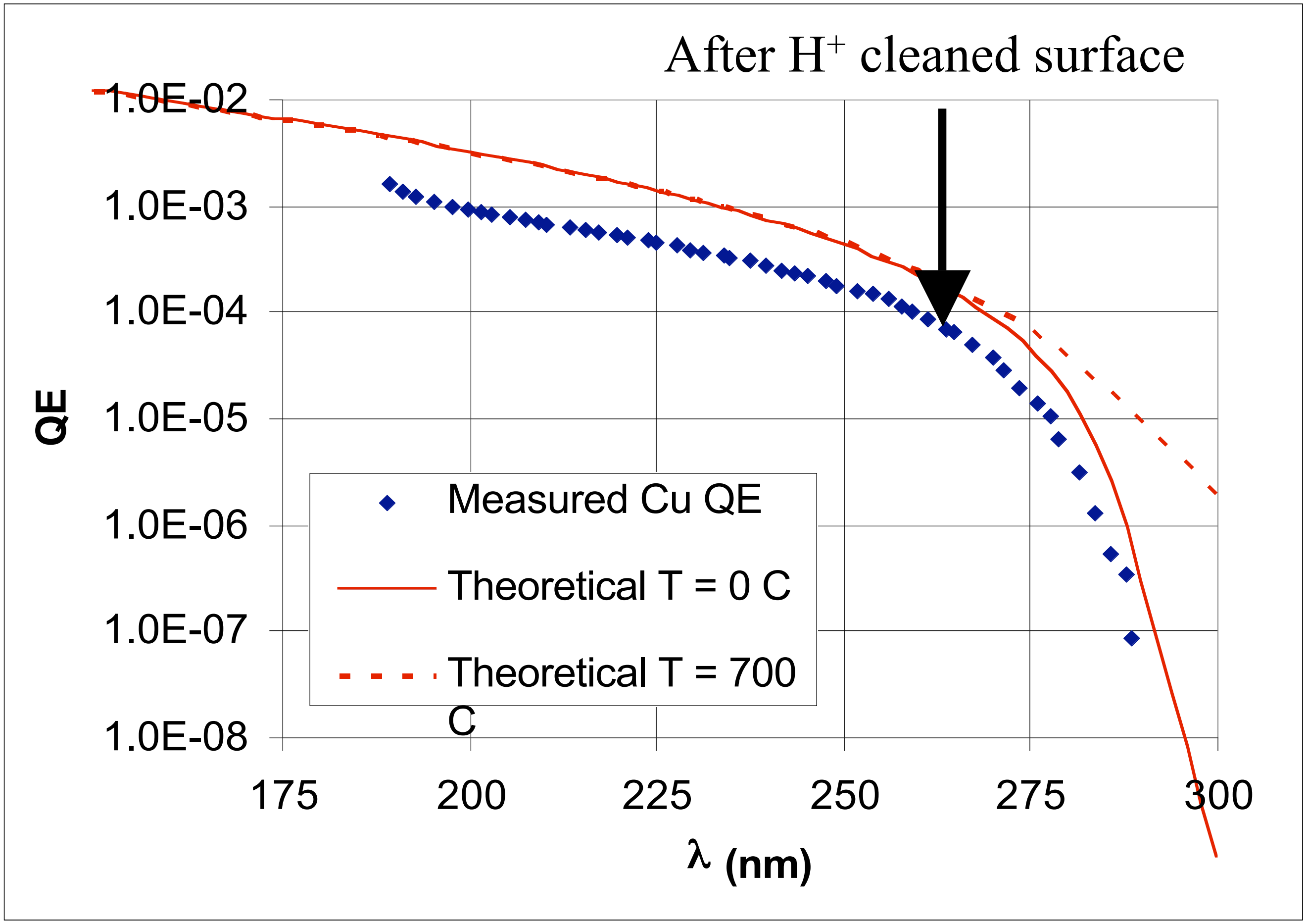
Cu QE vs Wavelength in dummy gun (no rf)



Measured data courtesy of D.H. Dowell

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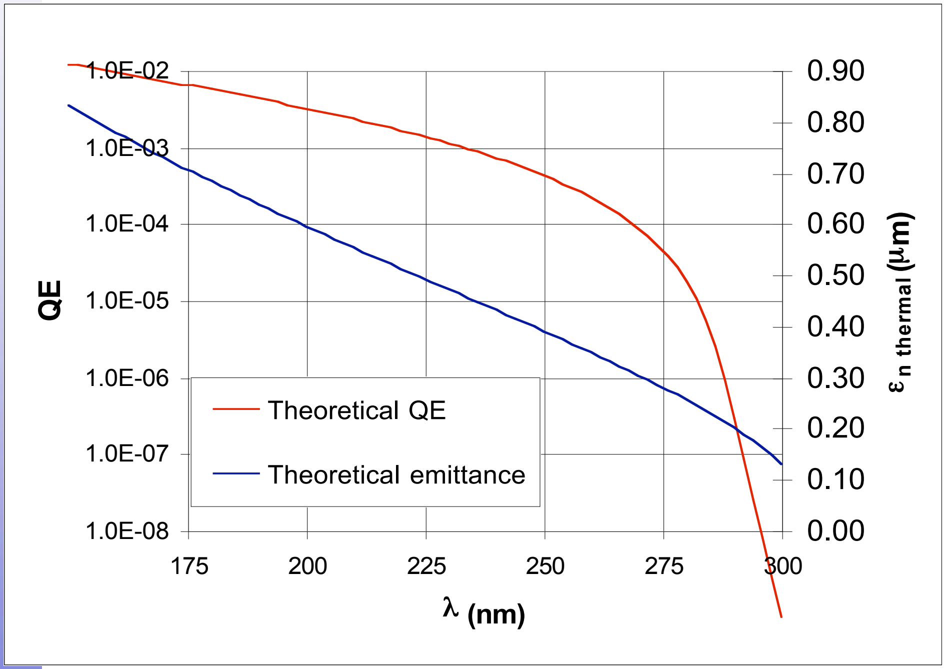
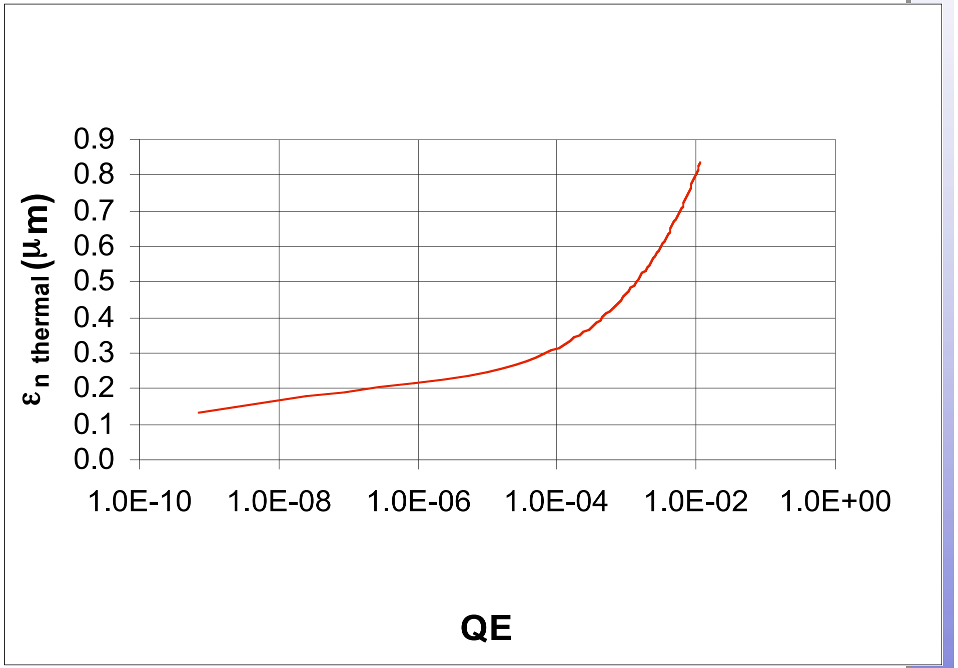
Thermal Emittance as a Function of QE





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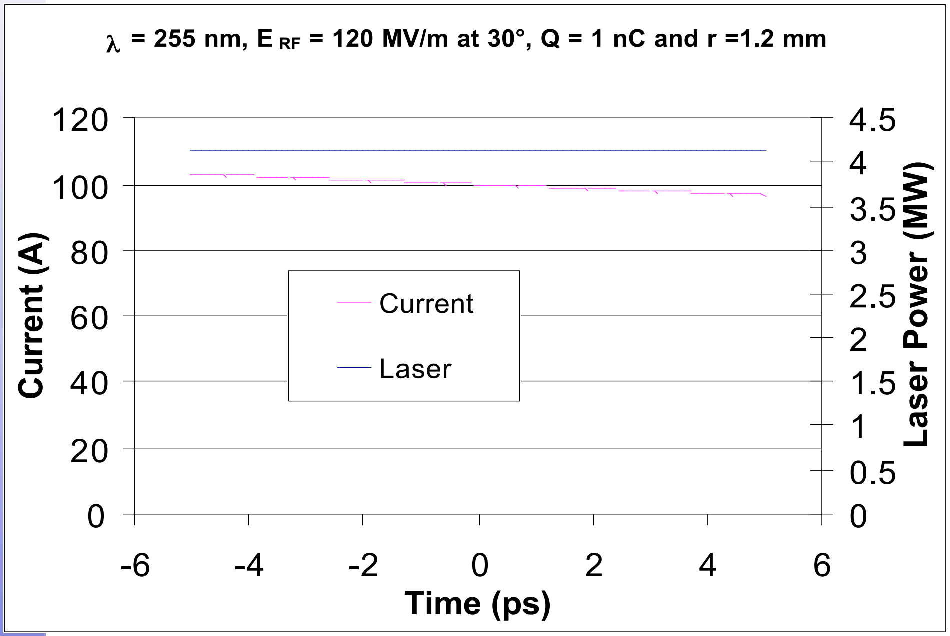
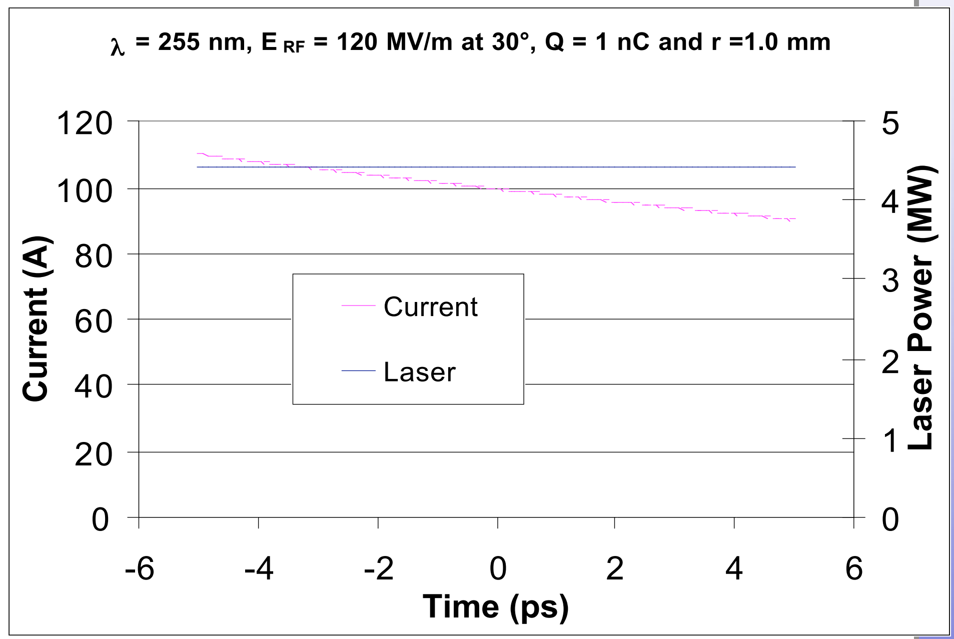
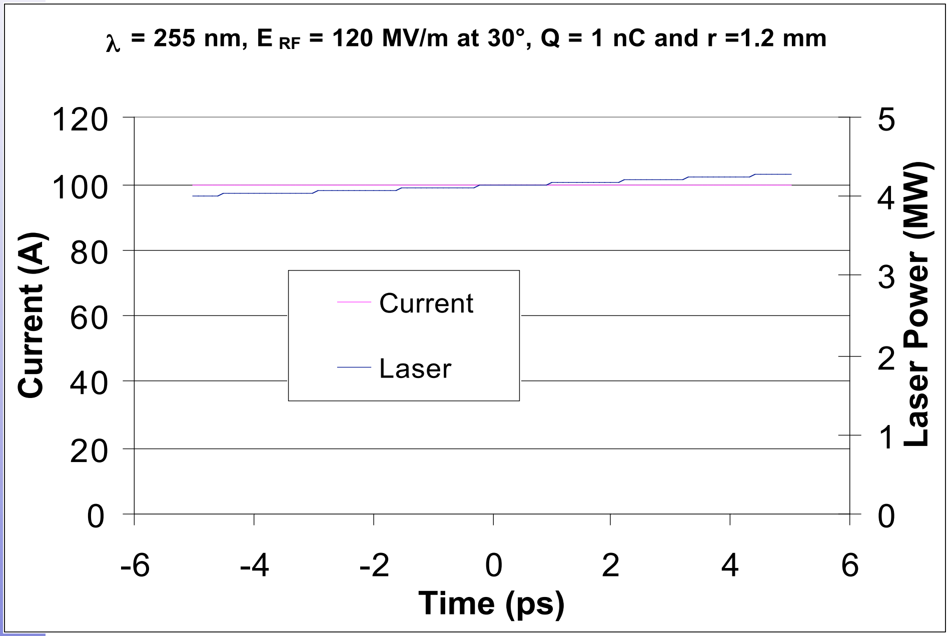
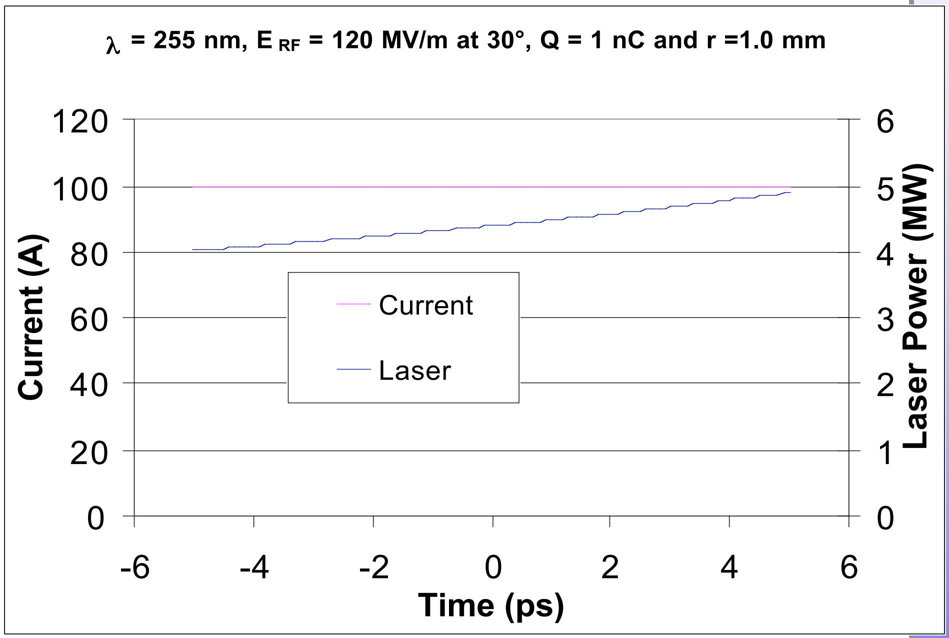
Beam Current with Temporal Flat Top Laser Pulse





Laser Temporal Pulse with Flat Top Beam Current





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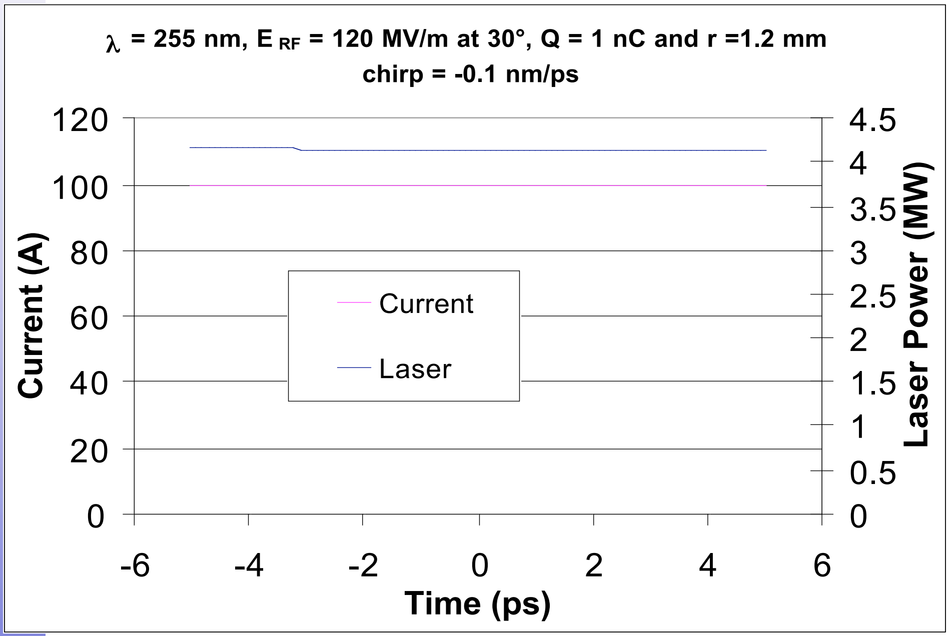
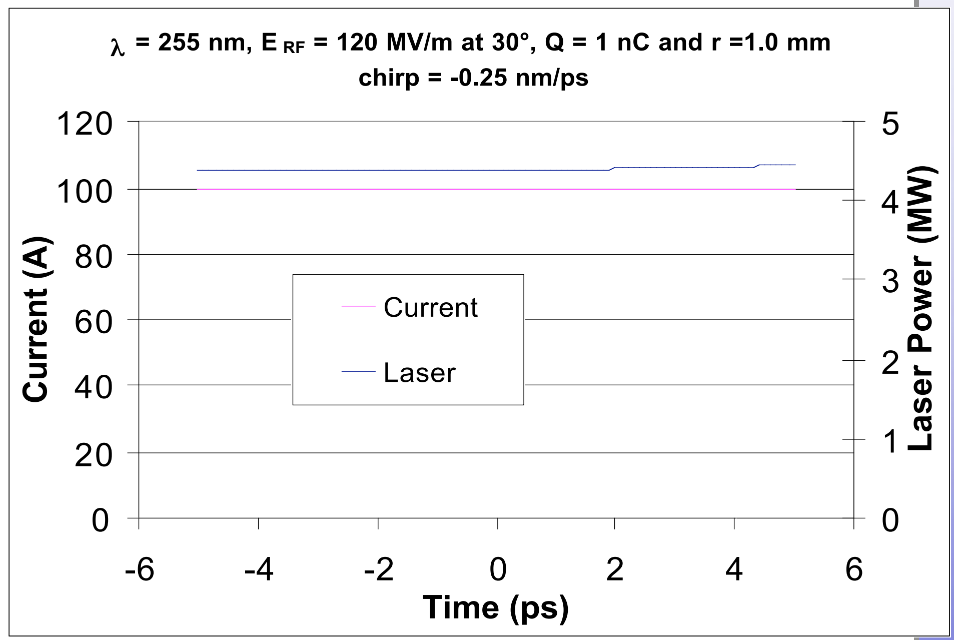
Laser Temporal Pulse with Flat Top Beam Current Including Laser Chirp





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Metal Time Response

- Prompt emission
- Exponential decay due to emission from below the surface following optical absorption
- Time constant for Cu is approximately 17 fs (optical skin depth is 25 nm)
- Scattering and the angular distribution will slightly modify the time constant

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Surface Roughness

- No effect on QE
- Will increase thermal emittance
  - Increases average transverse momentum of emitted electrons since electron distribution is peaked normal to the surface
  - Additional transverse momentum will be gained from transverse component of applied rf field
  - May explain part of discrepancy between theoretical and measured thermal emittance in metals

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Theoretical Cu and Mg parameters

Parameter	Cu	Mg	Units
Work Function	4.59	3.66	eV
Schottky Reduction	0.28	0.25	eV
Fermi Energy	7.0	7.1	eV
Power Reflectivity	34	92	%
Skin depth	25	19	nm
QE	16	21	10^{-5}
$\varepsilon_{n\text{-thermal}}$	0.25	0.46	µm/mm

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Summary

- QE is time dependent in metal cathode due to strong Schottky effect
- Thermal emittance also time dependent since QE and thermal emittance are related
- Temporal shaping the laser pulse may be required to produce a flat top laser pulse
- Beam induced field can cancel the applied rf field variation in time
- Laser beam chirp also has strong effect
- Emission process not included in simulations

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