Diamond Amplifier
Status and Prospects

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Workshop on Future Light Sources
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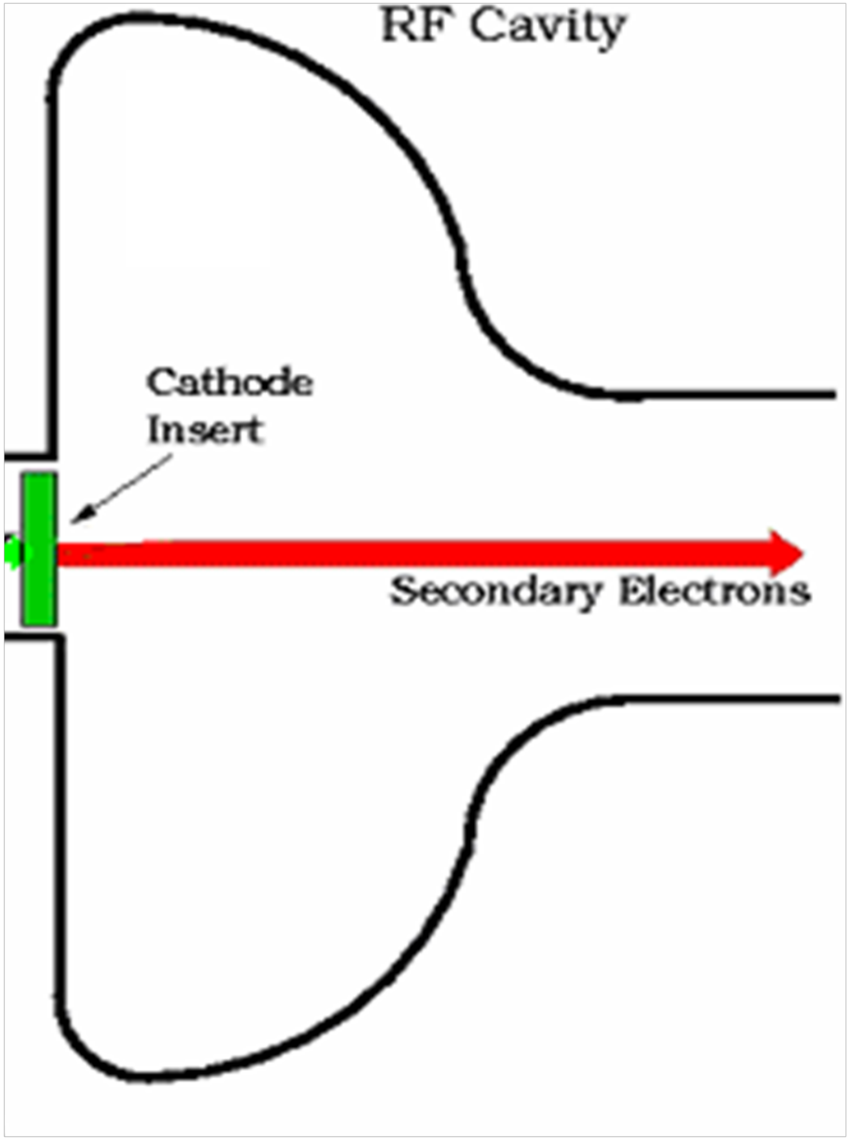
BROOKHAVEN
NATIONAL LABORATORY

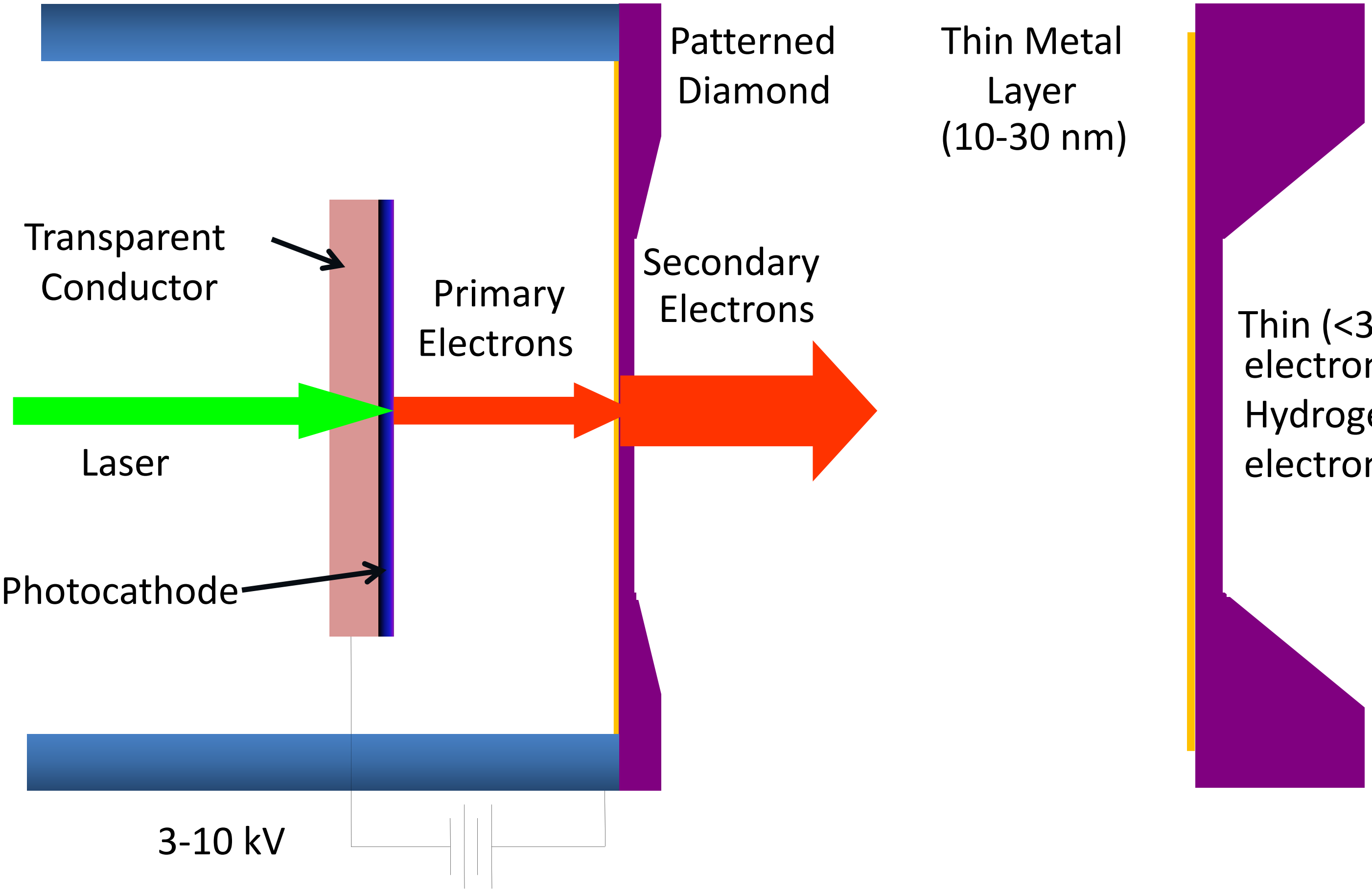
Diamond Amplifier Concept

Advantages

- Secondary current can be >300x primary current
  - Lower laser power
  - Higher average currents
- Diamond acts as vacuum barrier
  - Protects cathode from cavity vacuum and ion bombardment
  - Protects cavity from cathode (prevents Cs migration)
  - Should improve cathode lifetime
- e^- thermalize to near conduction-band minimum
  - Minimize thermal emittance



Diamond Amplifier Concept



Patterned Diamond

Thin Metal Layer (10-30 nm)

Transparent Conductor

Primary Electrons

Secondary Electrons

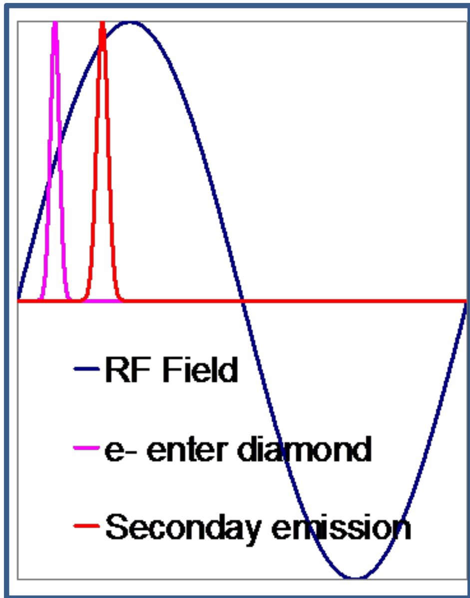
Laser

Photocathode

3-10 kV

Thin (<30 µm) for electron transmission

Hydrogen terminated for electron emission



Electron saturation velocity in Diamond is ~.2 µm/ps

Takes 150 ps to go 30 µm = 40 degrees of RF

Electrons must exit diamond in time to escape injector

Irregularity of surface will cause bunch spreading

Diamond Science at BNL

Imaging

SEM	Scanning Electron Microscopy	Surface morphology
LEEM	Low Energy Electron Microscopy	Imaging of hydrogenated surface, spatially localized LEED, work function mapping
AFM	Atomic Force Microscopy	Surface morphology

Diffraction

XRD	X-ray diffraction, time resolved	Characterization of metal contacts, including temperature of formation and crystalline texture
XRD	X-ray diffraction	Diamond crystal quality; evaluation of stress caused by laser shaping
Topography		Diamond crystal quality, localization and identification of defects
LEED	Low Energy Electron Diffraction	Surface crystal analysis, evaluation of hydrogenated surface

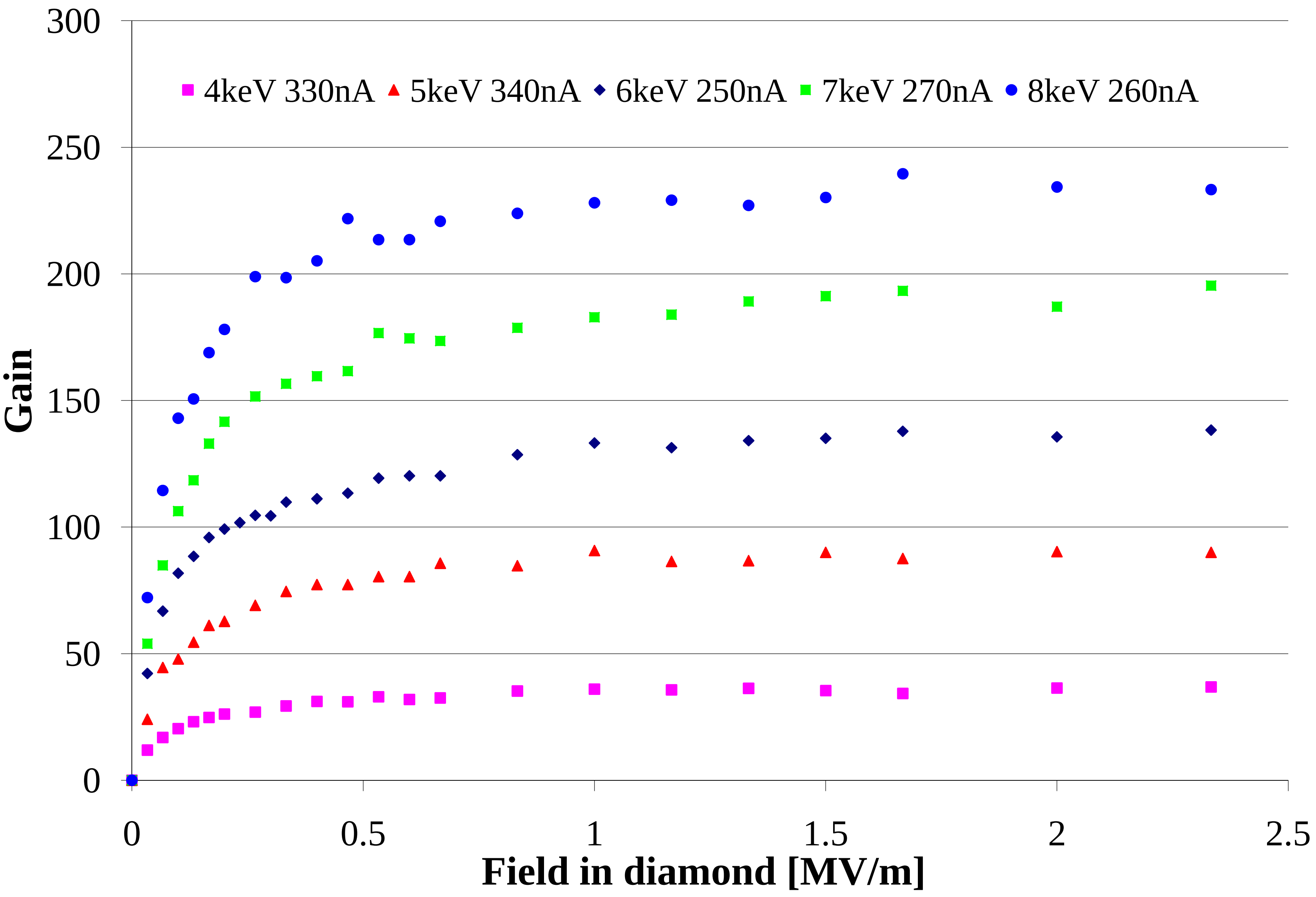
Spectroscopy

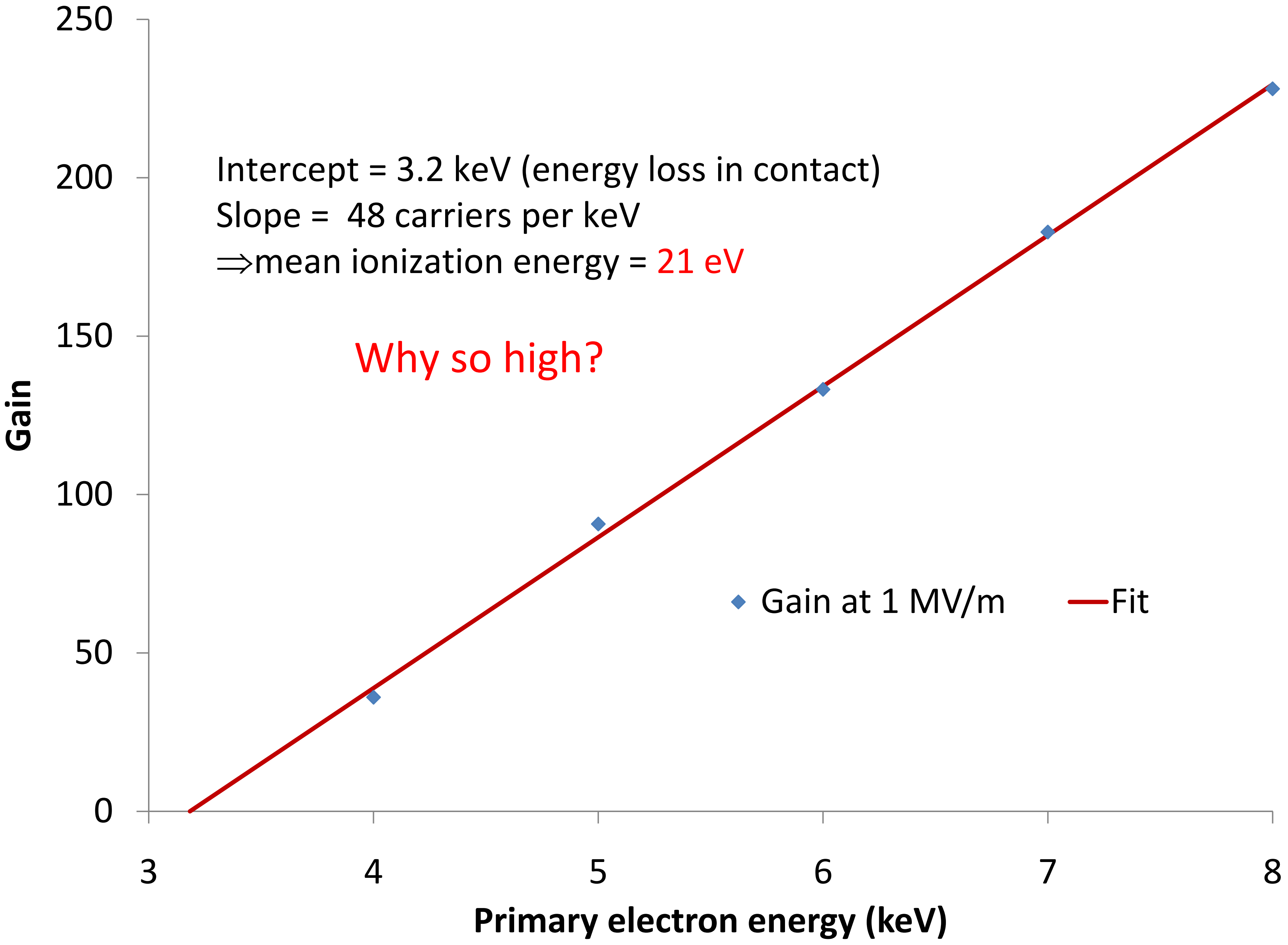
UPS/ARPES	Ultraviolet Photoemission Spectroscopy	Electron affinity, energy & angular distribution of emitted electrons, lifetime of NEA surface
TYS	Total Yield Spectroscopy	Evaluation of hydrogenated surface, lifetime
NEXAFS	Near Edge X-ray Absorption Fine Structure	Surface elemental analysis, characterization of surface bonding, carbon formation
XAFS	X-ray absorption fine structure	Titanium/diamond surface chemistry
EDS	Energy Dispersive X-ray Spectroscopy	Surface elemental analysis
FTIR	Fourier Transform Infrared Spectroscopy	Impurities in diamond
Photoluminescence & Raman Spectroscopy		Impurity analysis, identification of carbon chemistry, mapping

Carrier Transport and Emission

Electron Generated	Carrier Transport vs Field, Emission, Gain, Thermal Emittance
Soft X-ray, Monochromatic	Charge collection distance, Charge trapping/detrapping effects
Hard X-ray, Monochromatic	Measurement of mean ionization energy (gain)
High Flux White beam	Current Limits, Contact requirements, Heat management
Micro-beam Mapping	Localization of electrically active sites

Transmission Mode Gain

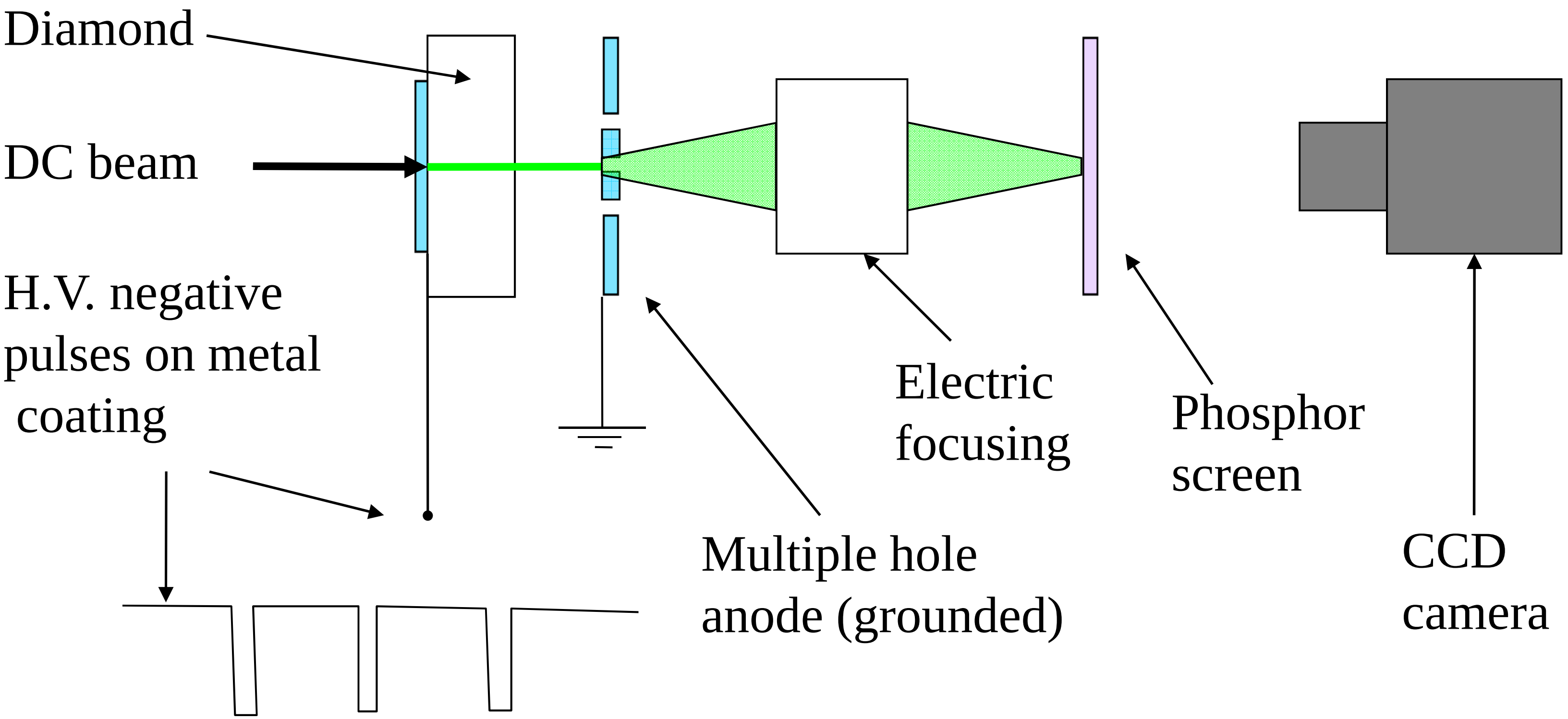




Intercept = 3.2 keV (energy loss in contact)
Slope = 48 carriers per keV
⇒mean ionization energy = 21 eV

Why so high?

Emission Test System



Diamond

DC beam

H.V. negative
pulses on metal
coating

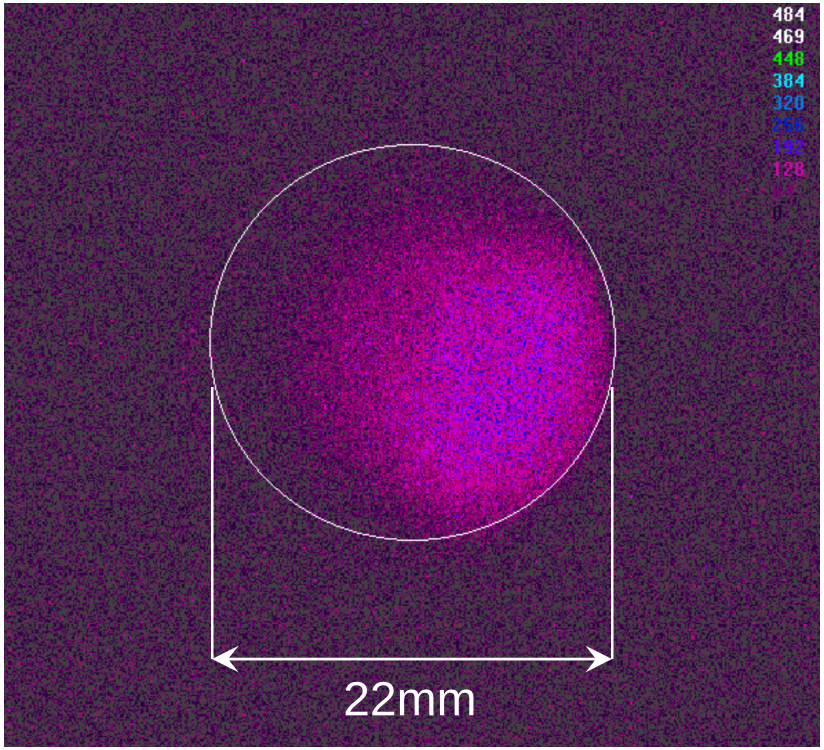
Electric
focusing

Phosphor
screen

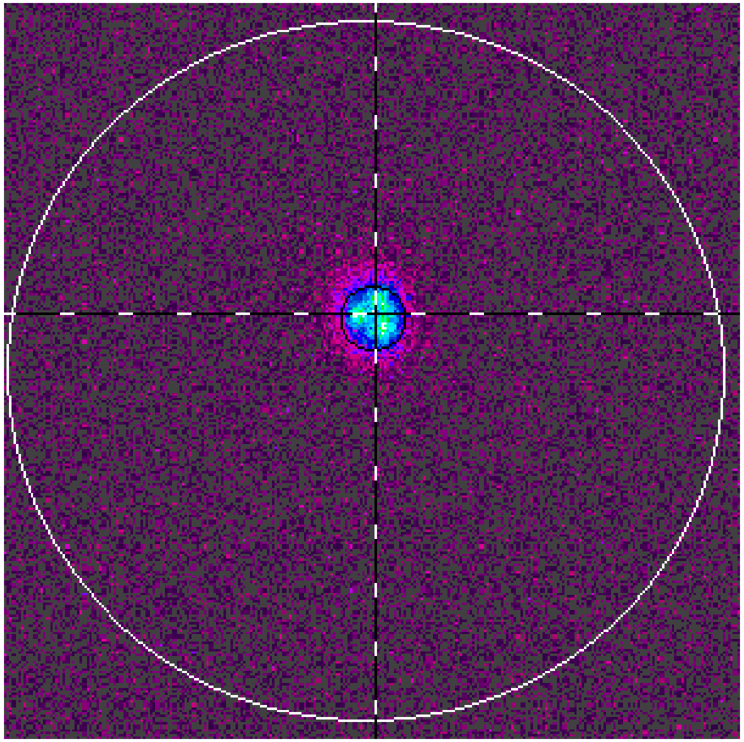
Multiple hole
anode (grounded)

CCD
camera

Beam from diamond



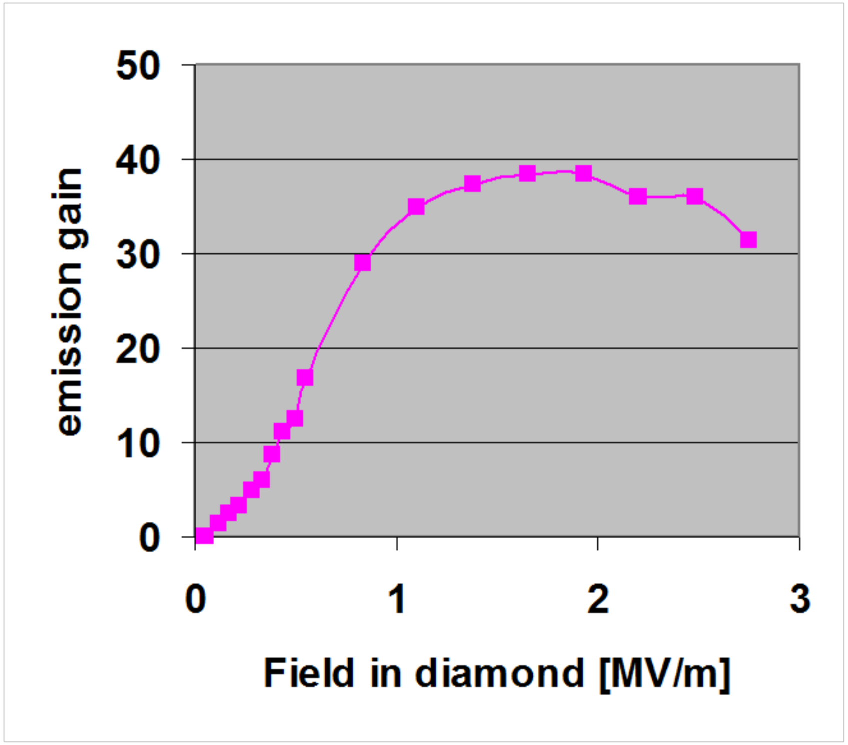
Without focusing

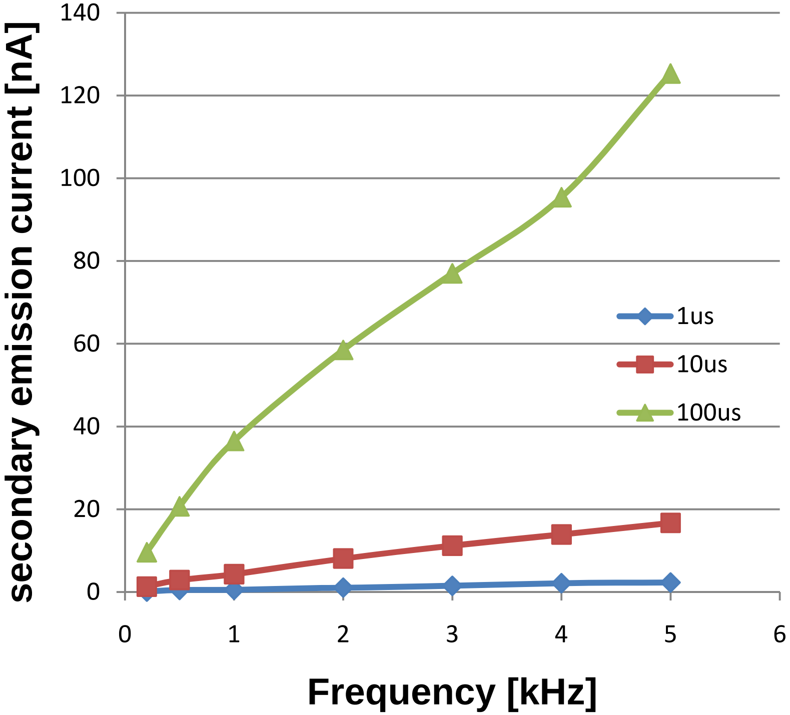


With focusing and reduced primary current

IPri=300nA. HV: 3kV (1.7MV/m in diamond).
Freq. = 1kHz, Duty cycle = 0.001

Emission Mode Gain

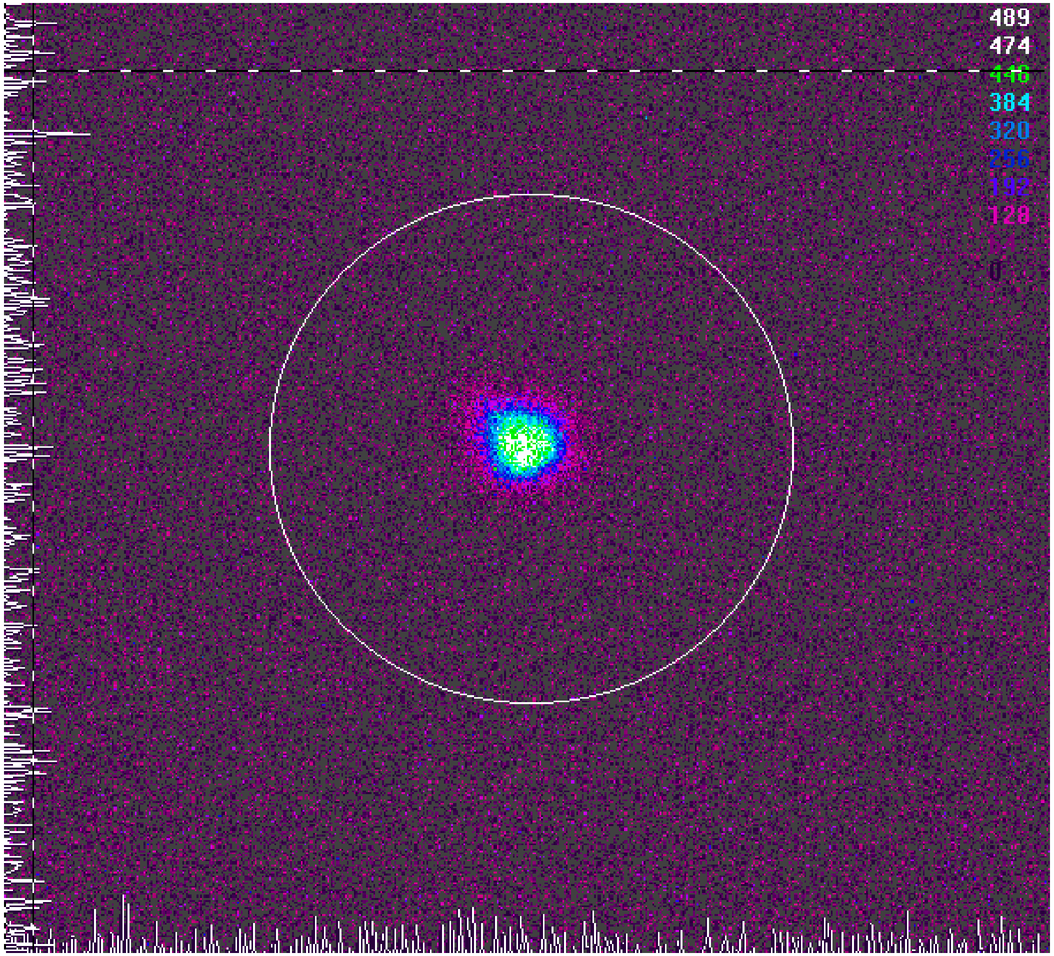




Gain is roughly 25% of expected, based on transmission mode

Gain is highest at low pulse duration, suggesting surface charge trapping is causing field screening followed by loss to diffusion

Emission after 1 year in air



Why use photons?

- Penetration depth is a strong function of energy -> Can differentiate between surface and bulk effects
- Electron energy from photo-absorption is well defined – can accurately measure mean ionization energy w
- Absorption edges allow differentiation of attenuation from metal vs loss of carriers to diffusion into surface
- Distinguish between electron and hole effects
- Shorter pulses and higher flux available
- Calibrated diagnostic beamlines available at NSLS

Responsivity and "Gain"

- In the detector business, the term gain is generally reserved for amplification mechanisms which add energy to the signal in the conversion mechanism (avalanche in a gas detector, for example)
- For the electron "amplifier", this is not the case – the incident electron is losing it's energy, and this energy is converted into carriers, much like an ionization mode gas detector (ion chamber)
- Similarly, in a photodetector, the energetic electron produced via absorption of an x-ray photon will produce many carriers
- The "responsivity" of a photodetector (in A/W) is given by:

$$S = \frac{1}{w} e^{-t_{window}/\lambda_{window}} \left(1 - e^{-L_{active}/\lambda_{active}}\right) CE[v, F]$$

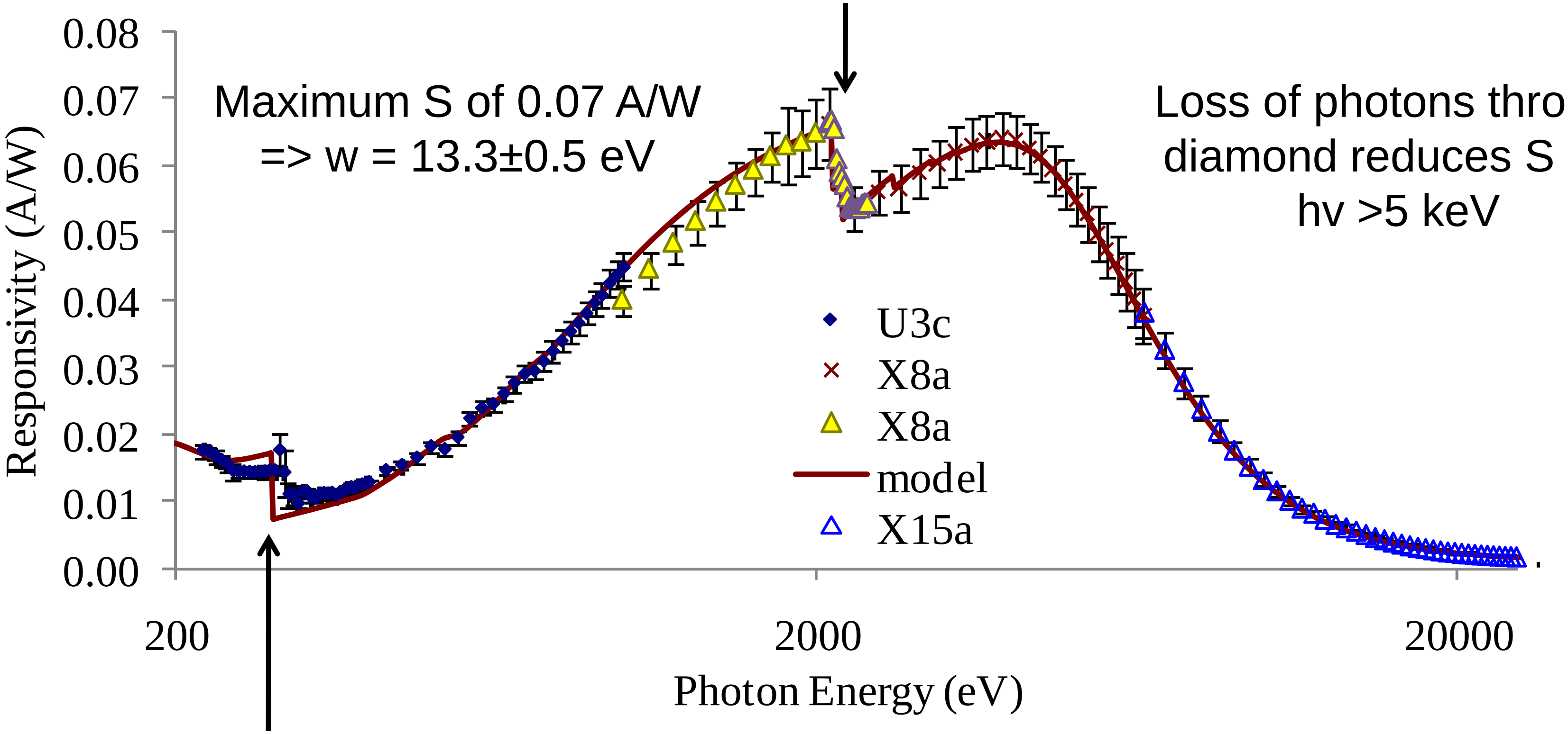
w: mean ionization energy – energy required to create an e-h pair

CE: Collection efficiency, based on Monte Carlo modeling

Responsivity vs Photon Energy

0.4 MV/m, 95% Duty Cycle for hv<1 keV, 100% for hv>1 keV

Platinum M edge feature due to loss of photons absorbed by incident contact not field dependent



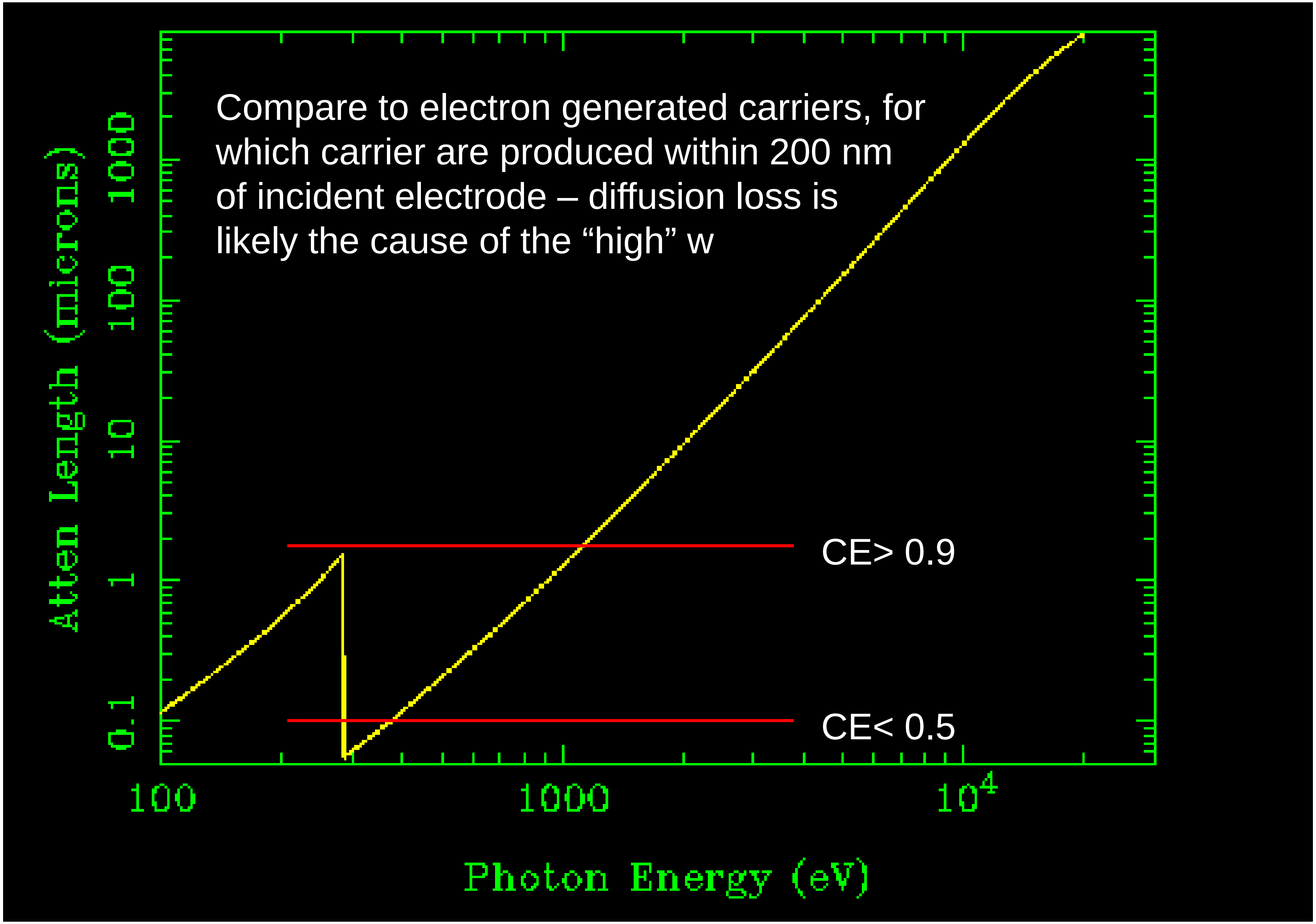
Maximum S of 0.07 A/W
=> w = 13.3±0.5 eV

Loss of photons through diamond reduces S for hv >5 keV

C K edge feature is field dependent, caused by incomplete carrier collection for carriers produced near incident electrode – electrons diffuse into incident contact and are lost

J. Keister and J. Smedley, NIM A **606**, (2009), 774

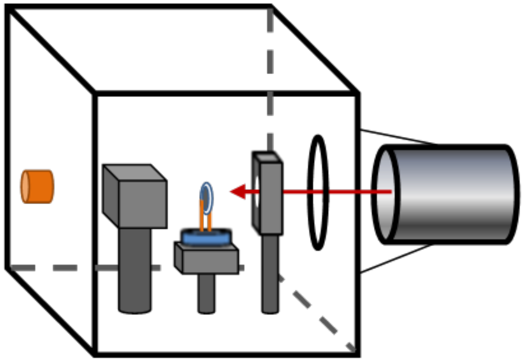
Photon Absorption Length

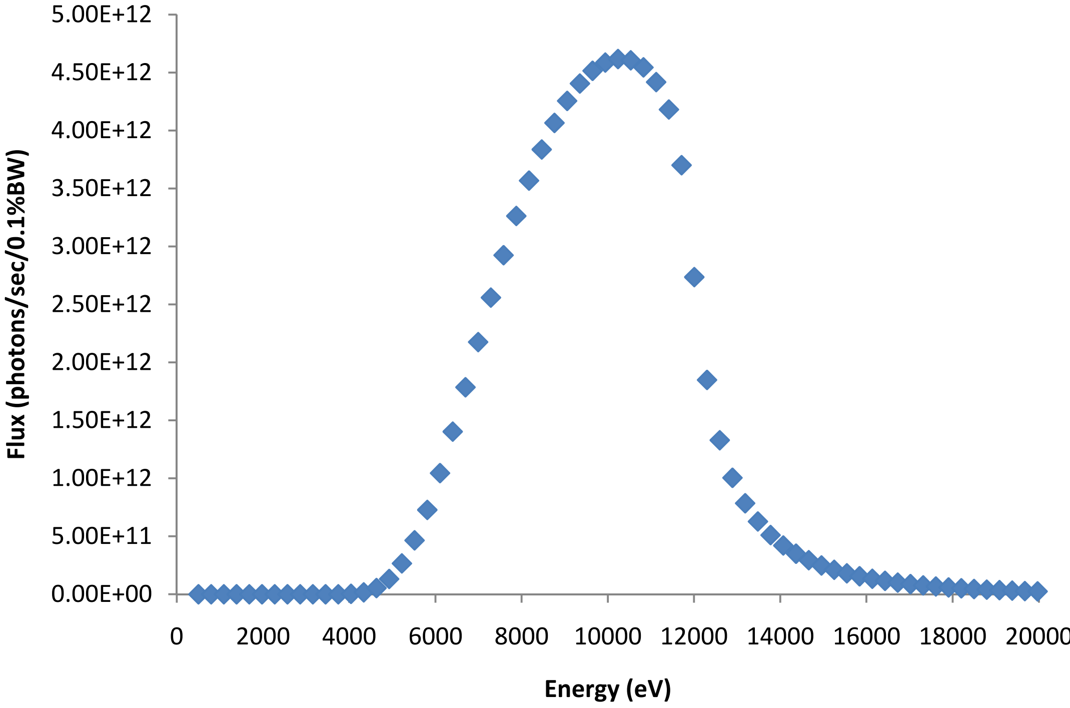


Compare to electron generated carriers, for which carrier are produced within 200 nm of incident electrode – diffusion loss is likely the cause of the “high” w

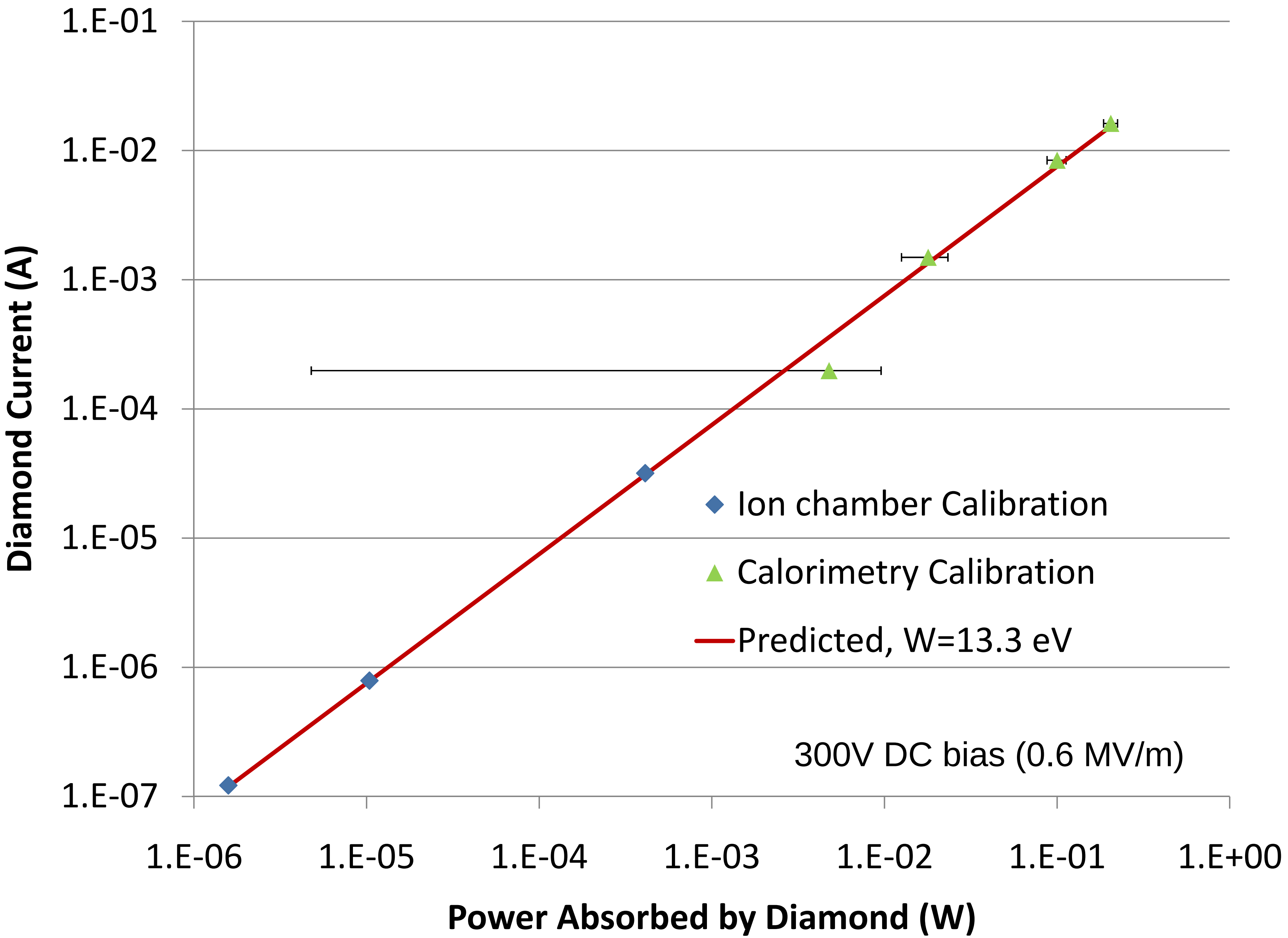
Flux Linearity and Current Limit

- X-ray focused white beam used to generate carriers
- Up to 11 W of x-ray power focused to 1.1x0.6 mm^2
- Diamond absorbs ~10%
- 85 mA current
- 13 A/cm^2
- Response is linear over *11 orders of magnitude*



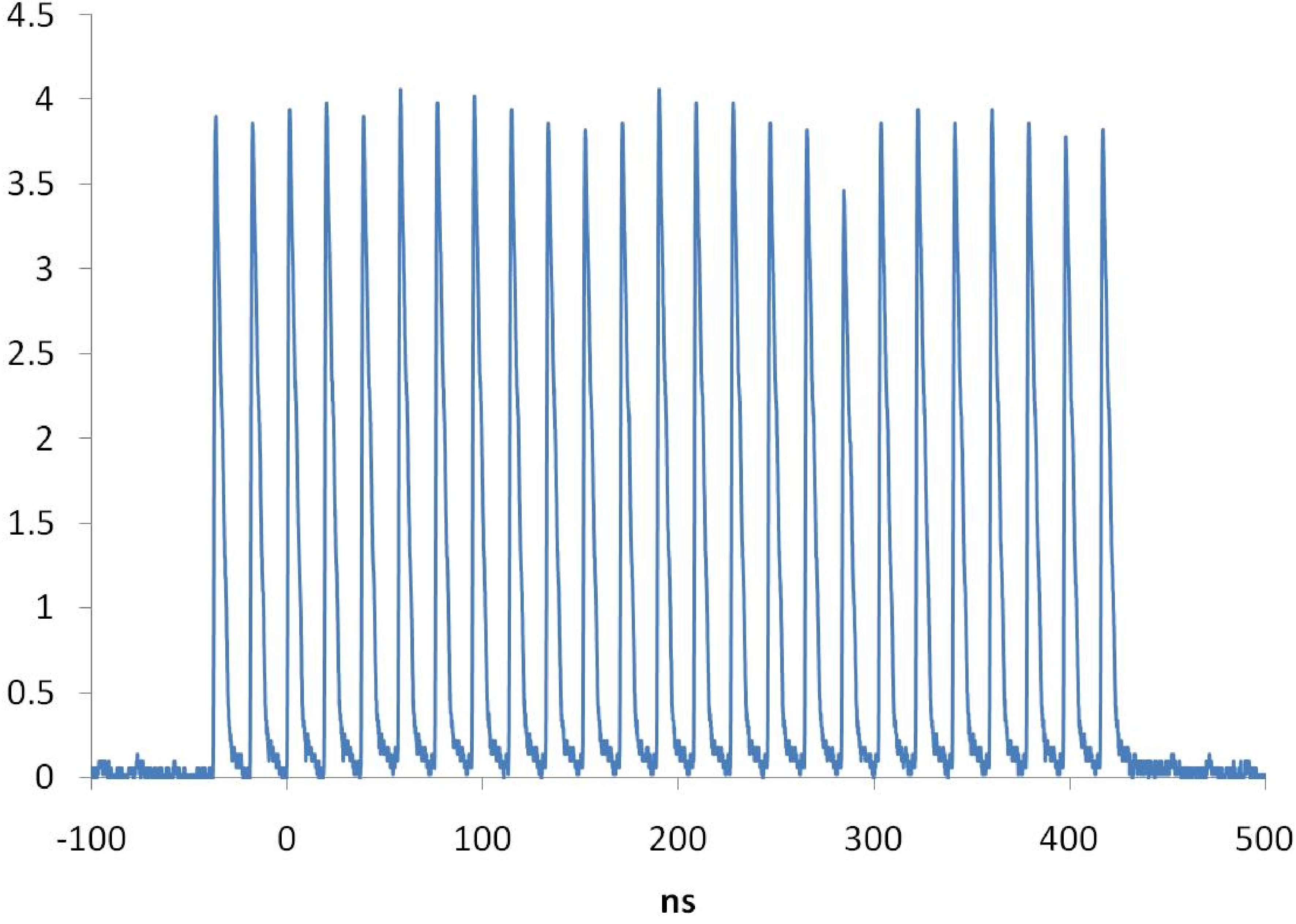


Flux Linearity and Current Limit



300V DC bias (0.6 MV/m)

Pulse response, 2 MV/m



Prospects and Requirements

Gun Prospects

- Charge detrapping is necessary; simplest with pulsed (or RF) bias
  - Can be done with “off-phase” electron injection
- Required diamond thickness scales with frequency
  - 700 MHz -> 30 microns (hard, but possible)
  - Easier with lower frequency (200 MHz would be easy)
- Field in diamond of ~3 MV/m to saturate e^- velocity
  - Dielectric constant of 5.7 -> 17 MV/m in gun at phase of primary launch

Material and Beam Size

- High purity, synthetic single crystal material is optimum
  - Better crystals -> less trapping
  - Lower impurities -> less trapping and lower RF heat load
  - Currently limits available beam size to few mm
  - Larger crystals on the horizon

Prospects and Requirements

- Energy spread out of cathode will depend on NEA level
  - May need to engineer surface to achieve lower emittance
- Surface can be exposed to atmosphere, but requires significant bake afterward. May require bake during operation.
- Sealed “capsule” is a possibility
  - e^- stimulated desorption is a significant issue
  - Pumping difficult due to small dimensions
- Multi-stage amplifier seems possible
- Higher energy primaries
  - Lower loss in contact
  - Less loss to diffusion
  - Lower heat load for given current
  - More penetration depth -> More bunch spreading

- X-ray generated carriers (x-ray photocathode?)
  - ~1 keV photons

Thank you for your attention!

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- Beamlines: U2A, U2B, U3C, U7A, X3B, X6B, X8A, X16C, X19C, X20A&C, X28C