Progress on the Vanderbilt Table Top THz FEL

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28 April 2005

Acknowledgements

- Group at Vanderbilt
  - Charles Brau
  - Chase Boulware
  - Jonathan Jarvis
  - Carlos Hernandez

- Useful discussions
  - Hayden Brownell
  - Jack Donohue and Jacques Gardelle

WANTED: a narrowband THz source for spectroscopy

Problem

- Want to do frequency domain spectroscopy at THz frequencies
- No existing narrowband source provides good power in THz range
- Short pulse sources - good for time-domain spectroscopy

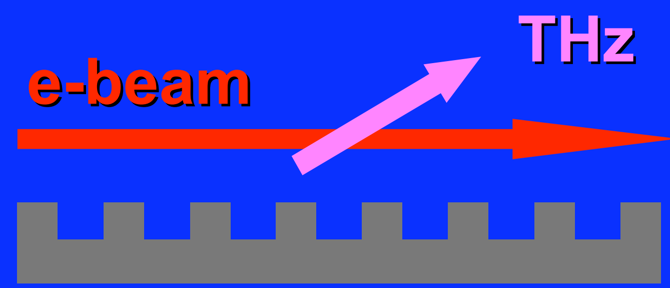
* CW - good for imaging if you have enough power

Solution Requirements

- Want a source which will produce
  - 300-1000 micron radiation (0.3-1 THz)
  - ~1 Watt peak power
  - ~5 nanosecond pulses
  - Narrowband

Source requires needle cathode and Smith-Purcell effect

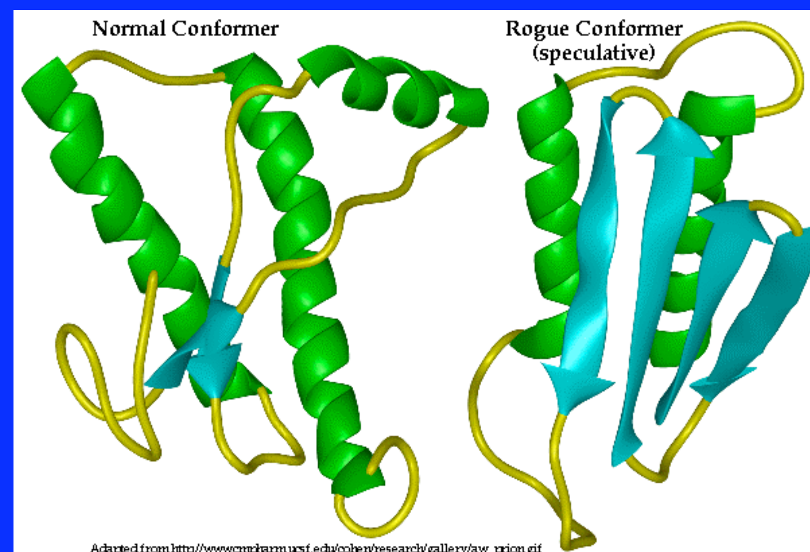
- Needle photo-cathodes provide high brightness electron beam
- Smith-Purcell (SP) radiation provides a compact, tunable radiation source
- Requires a high brightness beam for high power output



- Voltage = 30 - 80 kV
- Current = 1-10 mA
- Brightness ~ 10^{11} A/m^2-steradian
- Wavelength 300 - 1000 m

Examine protein secondary structure

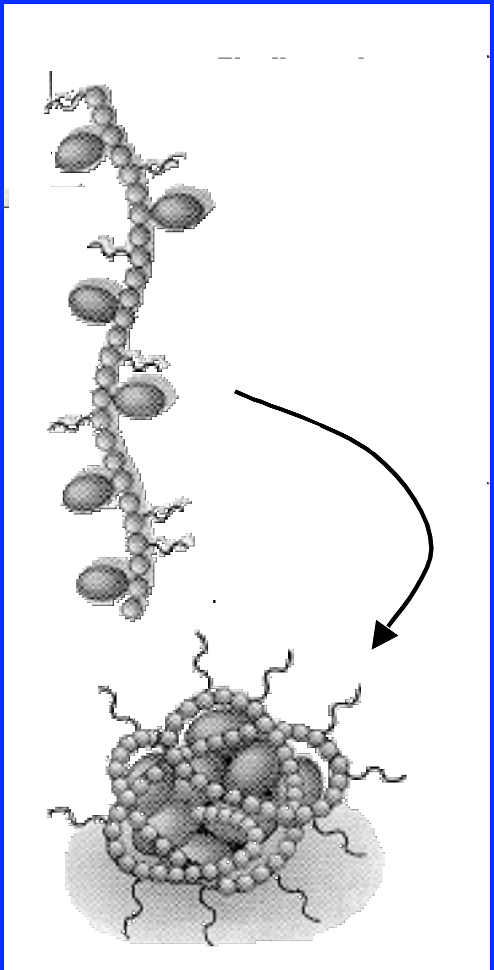
- Large molecules and structures have characteristic vibrations in THz region
- Reconformation could be examined using nonlinear spectroscopy
- Pump-probe nonlinear spectroscopy possible using THz/THz or THz/mid-IR radiation



Additional applications

- Examine protein folding

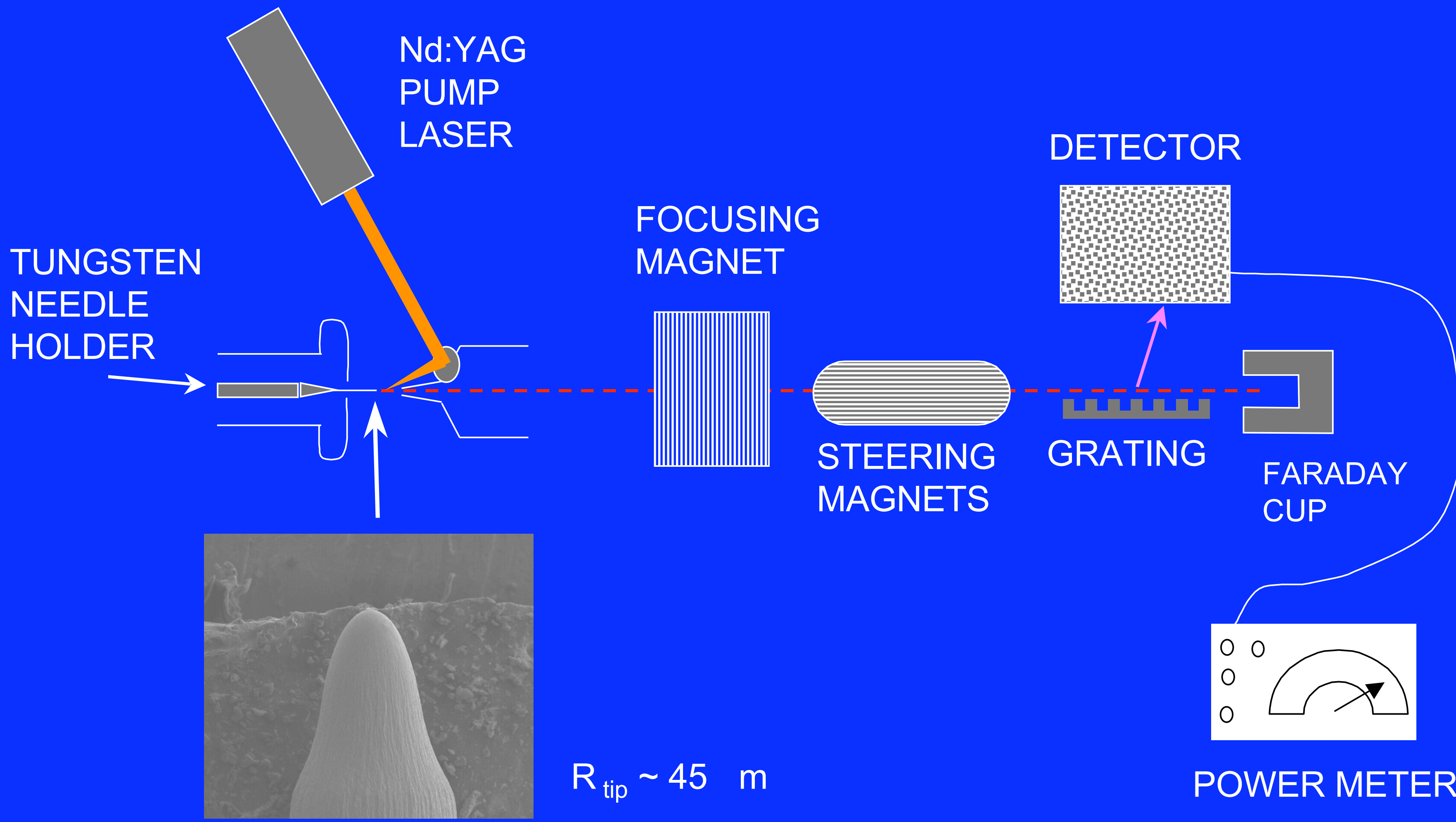
- High field EPR spectroscopy



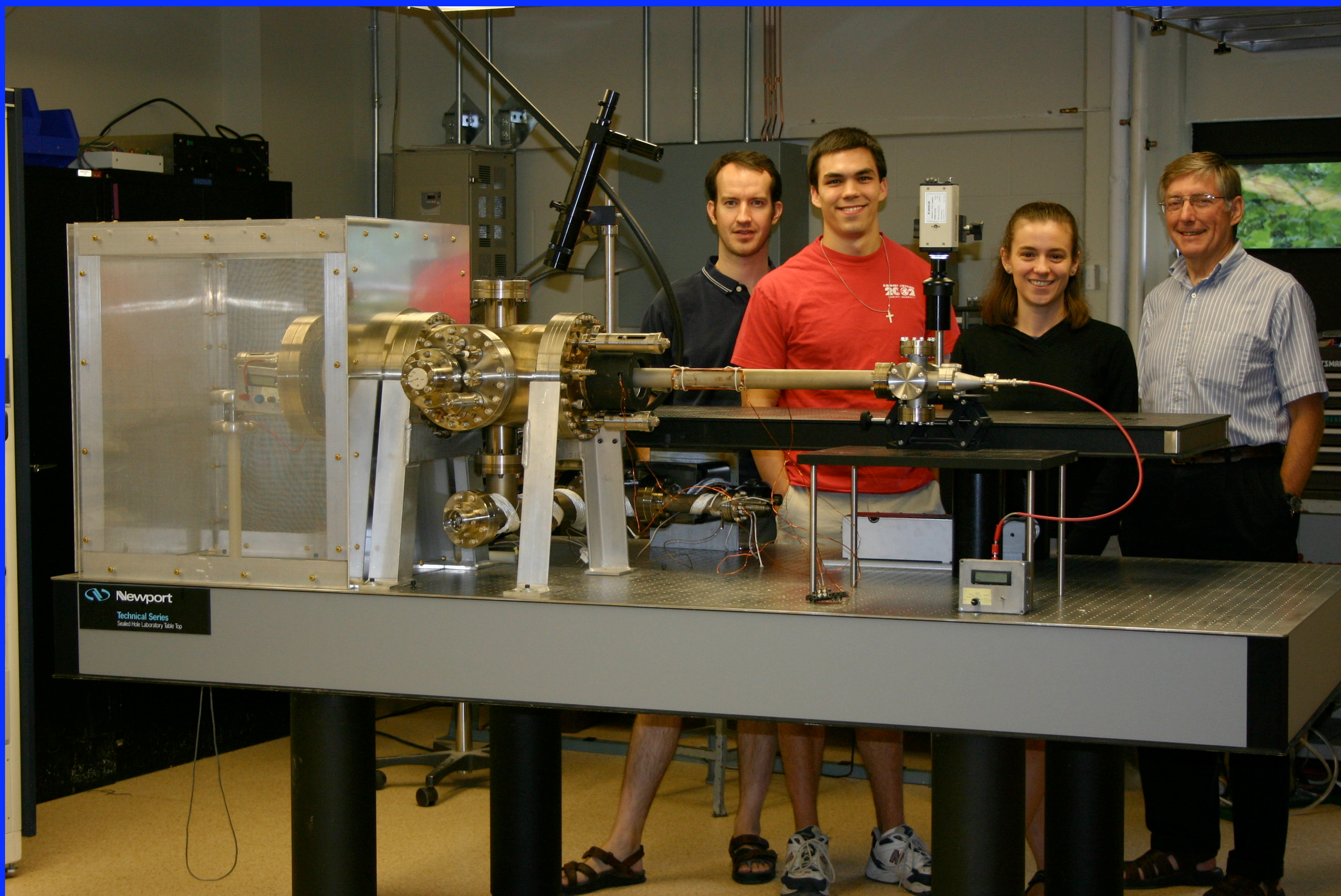
How this compares to other THz sources

THz Source	Comparison to SP-FEL
UCSB FEL	Longer pulses (microsecond as opposed to nanosecond), higher power
Synchrotron sources	Lower spectral brightness, much shorter pulses, broadband
Optically pumped FIR lasers	Not tunable
Optical rectification techniques	Very short pulses, low power, broadband
Backward Wave Oscillators (BWO)	Low power, longer wavelengths, very similar operating mechanism

Experimental Set Up

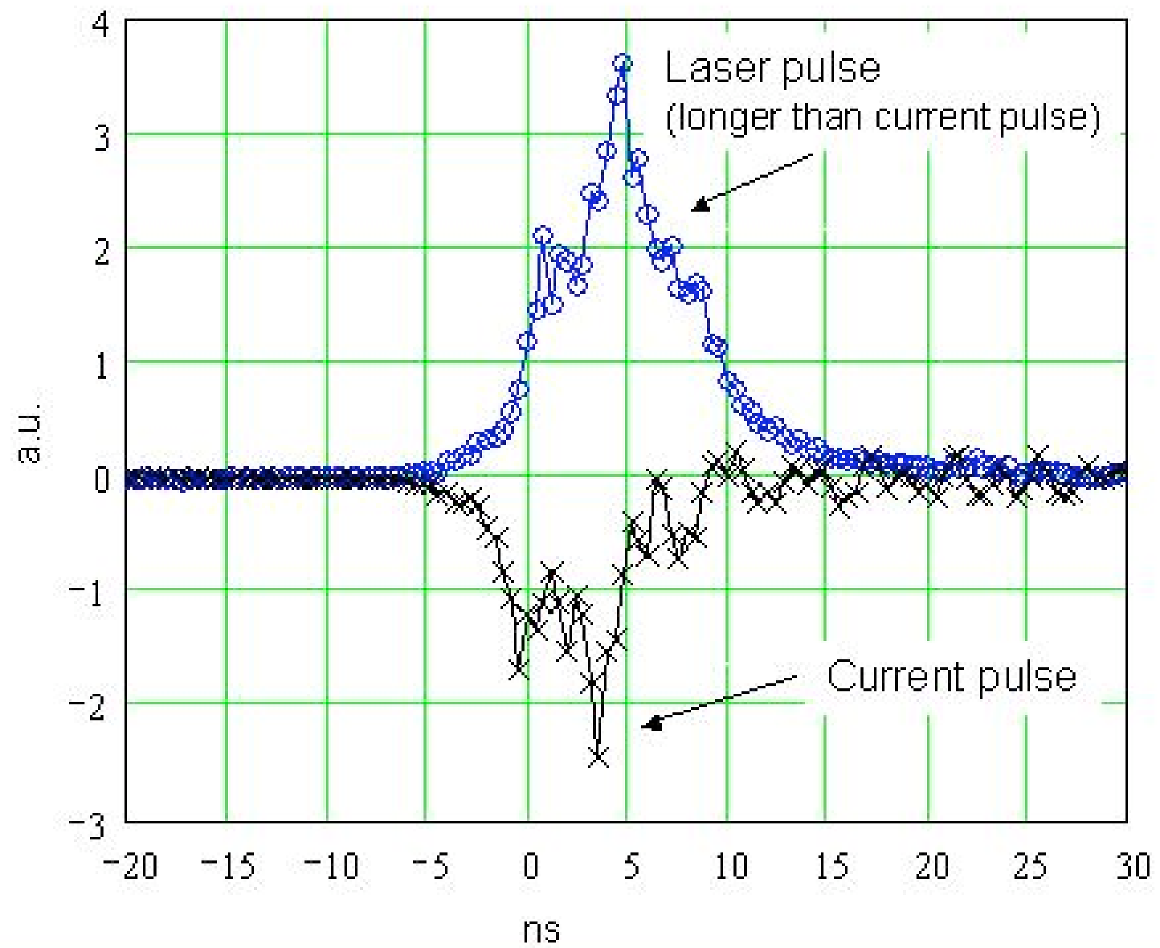


Experimental apparatus

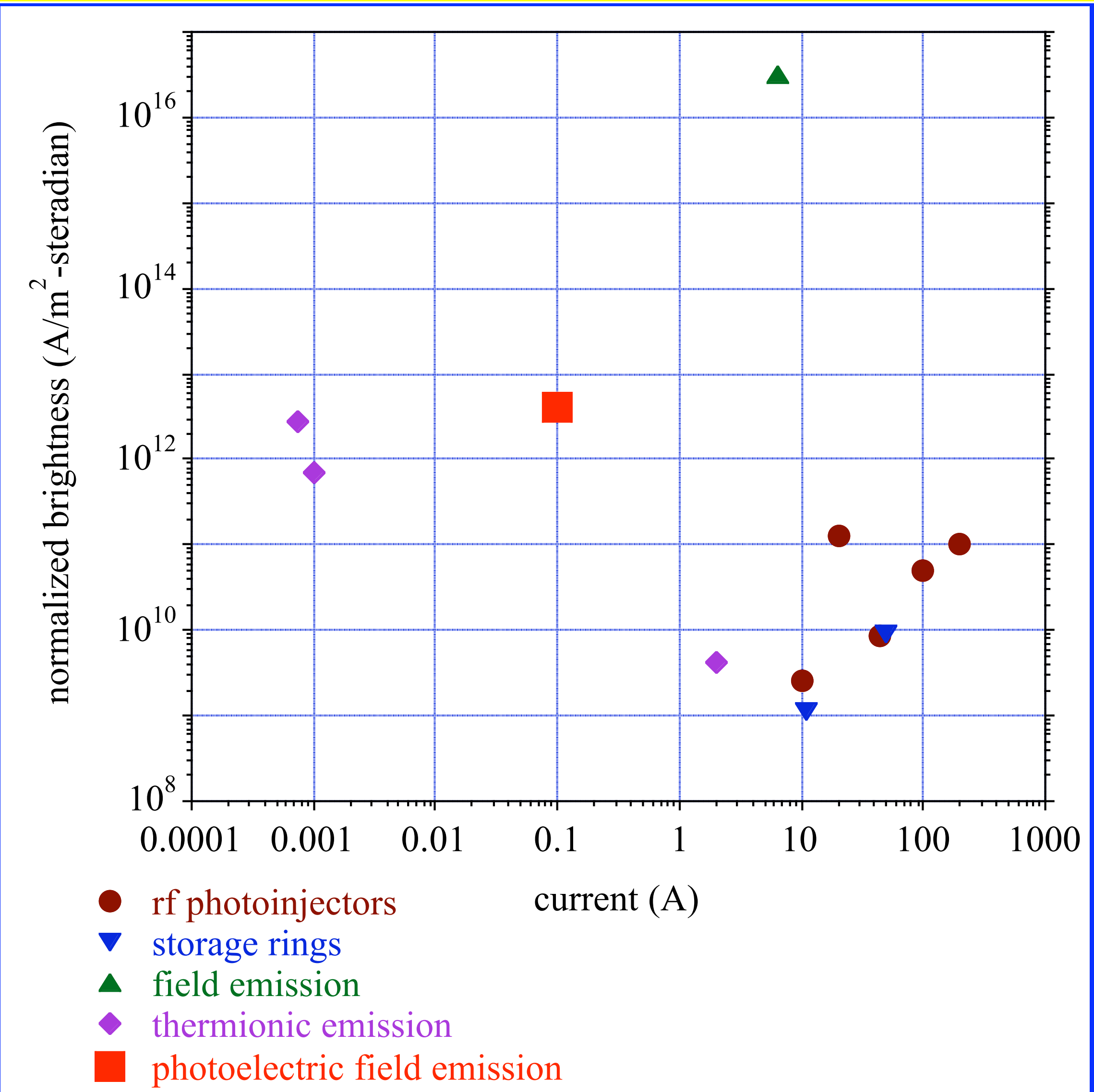


We have achieved current densities high enough to build tabletop FELs

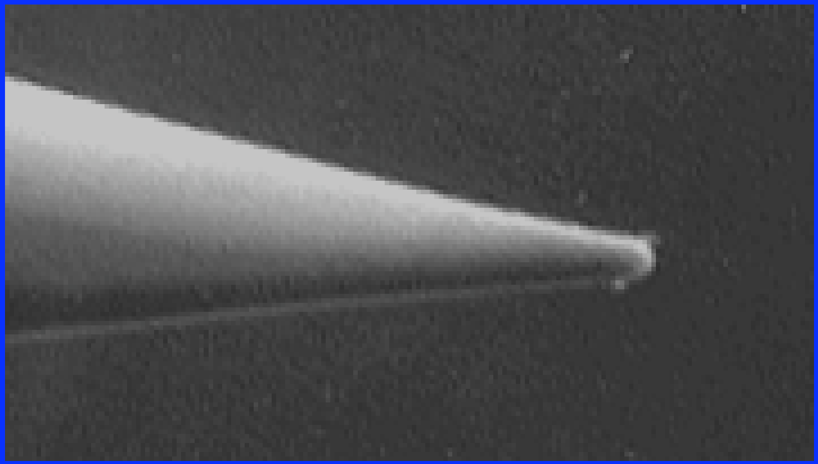
- Photocurrent was
  - Up to 100 mA
  - Shorter pulse than laser
  - Limited by damage to needle
- 4th harmonic Nd:YAG at 266 m with 7 ns, 200 mJ pulse
- Quantum efficiency is increased by 10^2 by laser

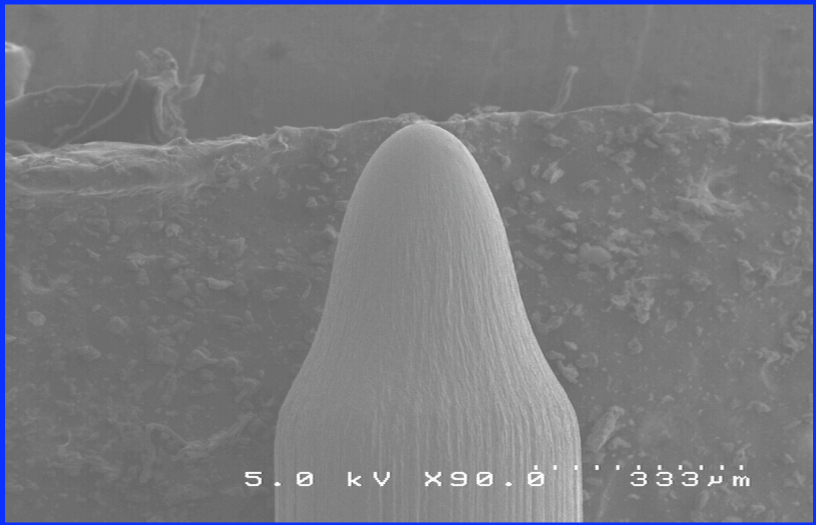


Needle cathode e-beam has high brightness



Recent needle cathode developments

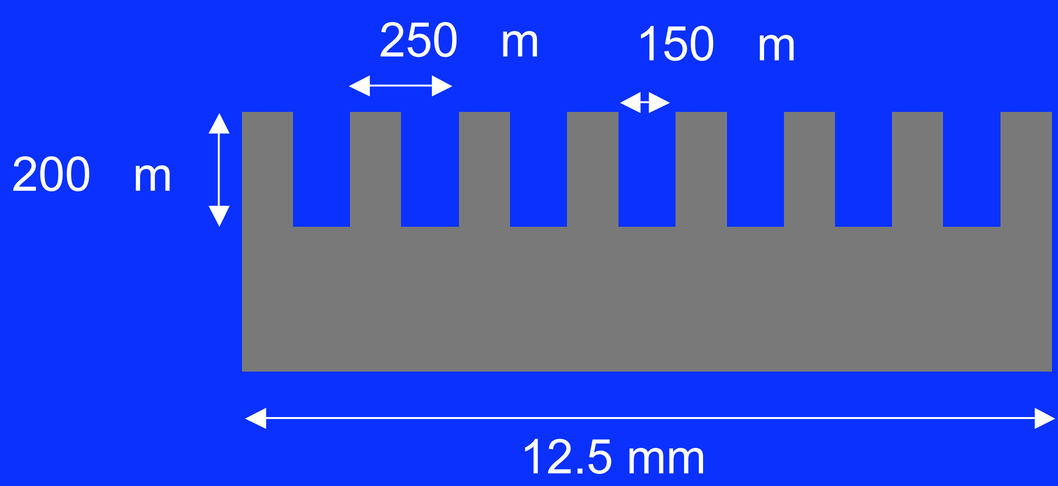




- Bigger needles = more current
- Use 5th harmonic Nd:YAG, 5 ns pulse, maximum 50 J/pulse

Dimensions of the aluminum grating

- Gratings are fabricated out of aluminum using very thin saw blades
- Dimensions will be 12.5 mm long (1/2 inch), with 250 m period, 150 m grove width and 200 m depth
- 173 m period, 62 m width and 100 m depth used for calculations*



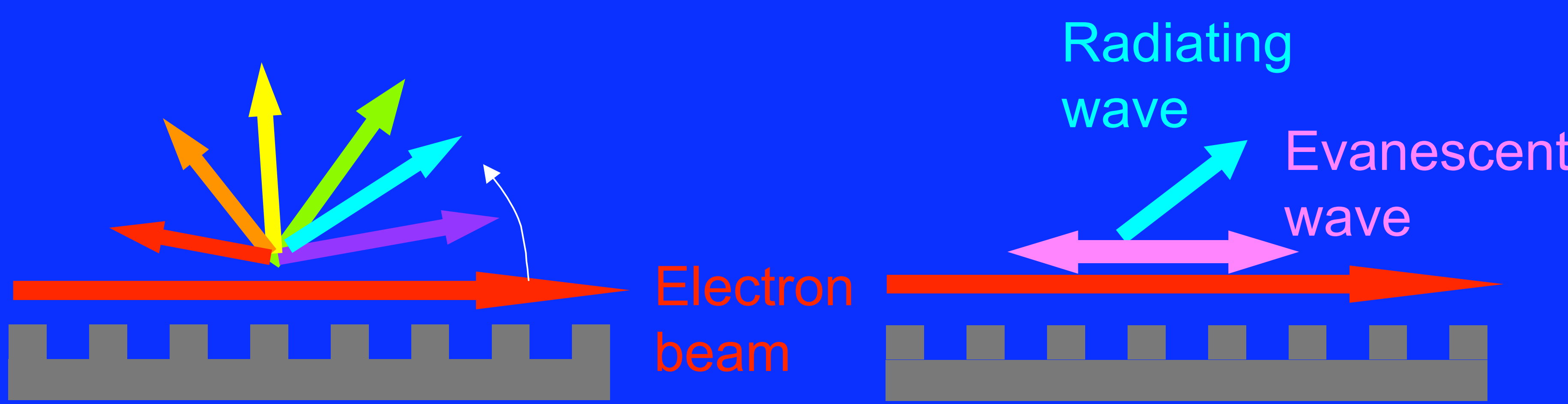
*Parameters used at Dartmouth, Urata et. al., PRL, **80**, 516, (1998)

Smith-Purcell laser produces two types of radiation

Below threshold current:

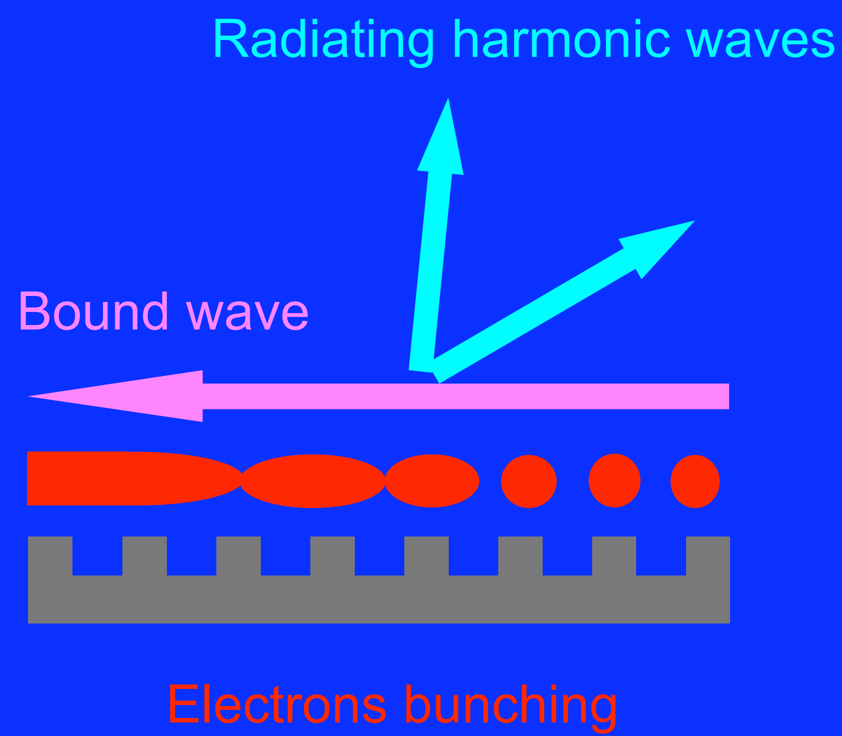
$$= \frac{\ell}{|n|} \quad \frac{1}{\ } \quad \cos$$

Above threshold current:

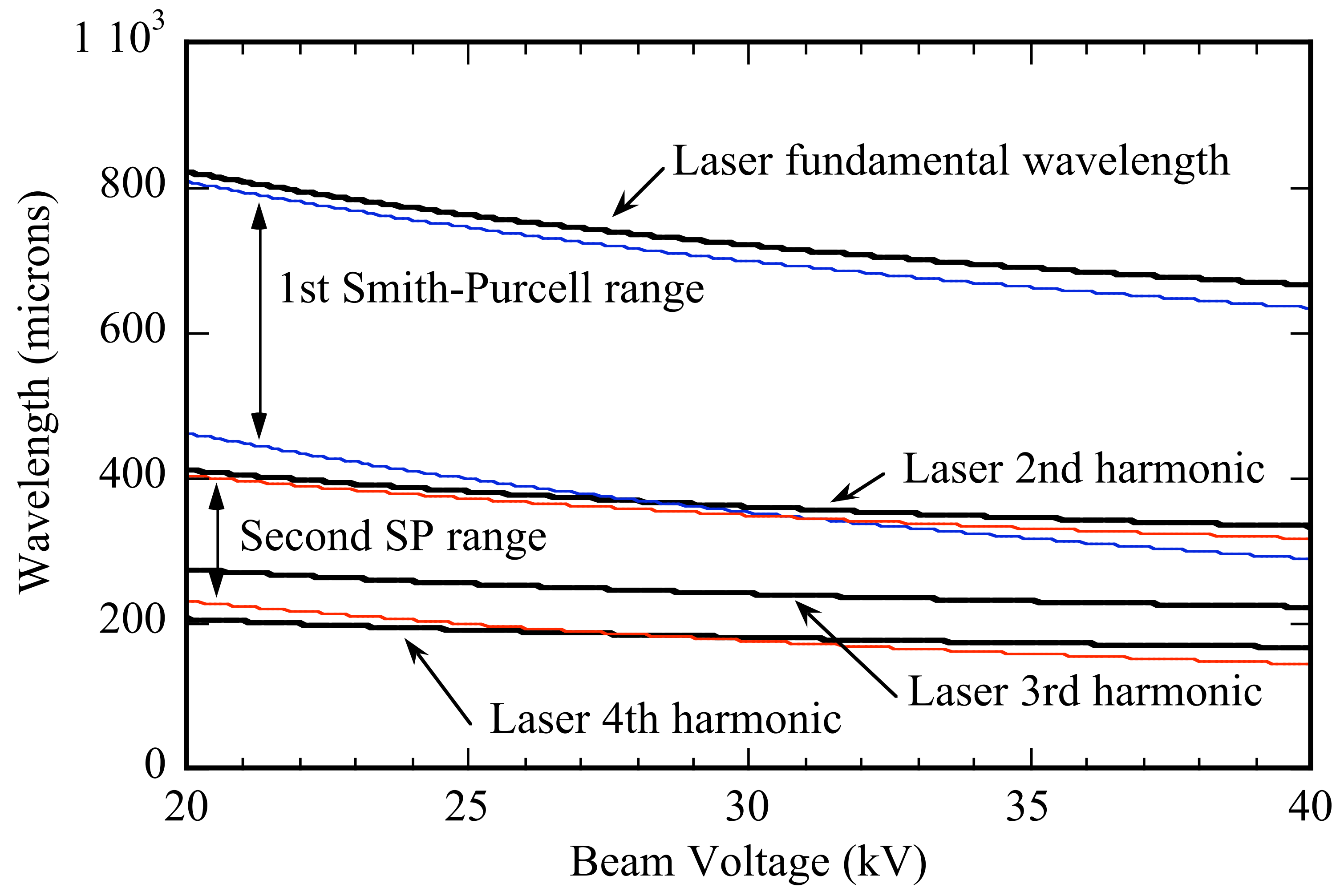


Details of laser radiation

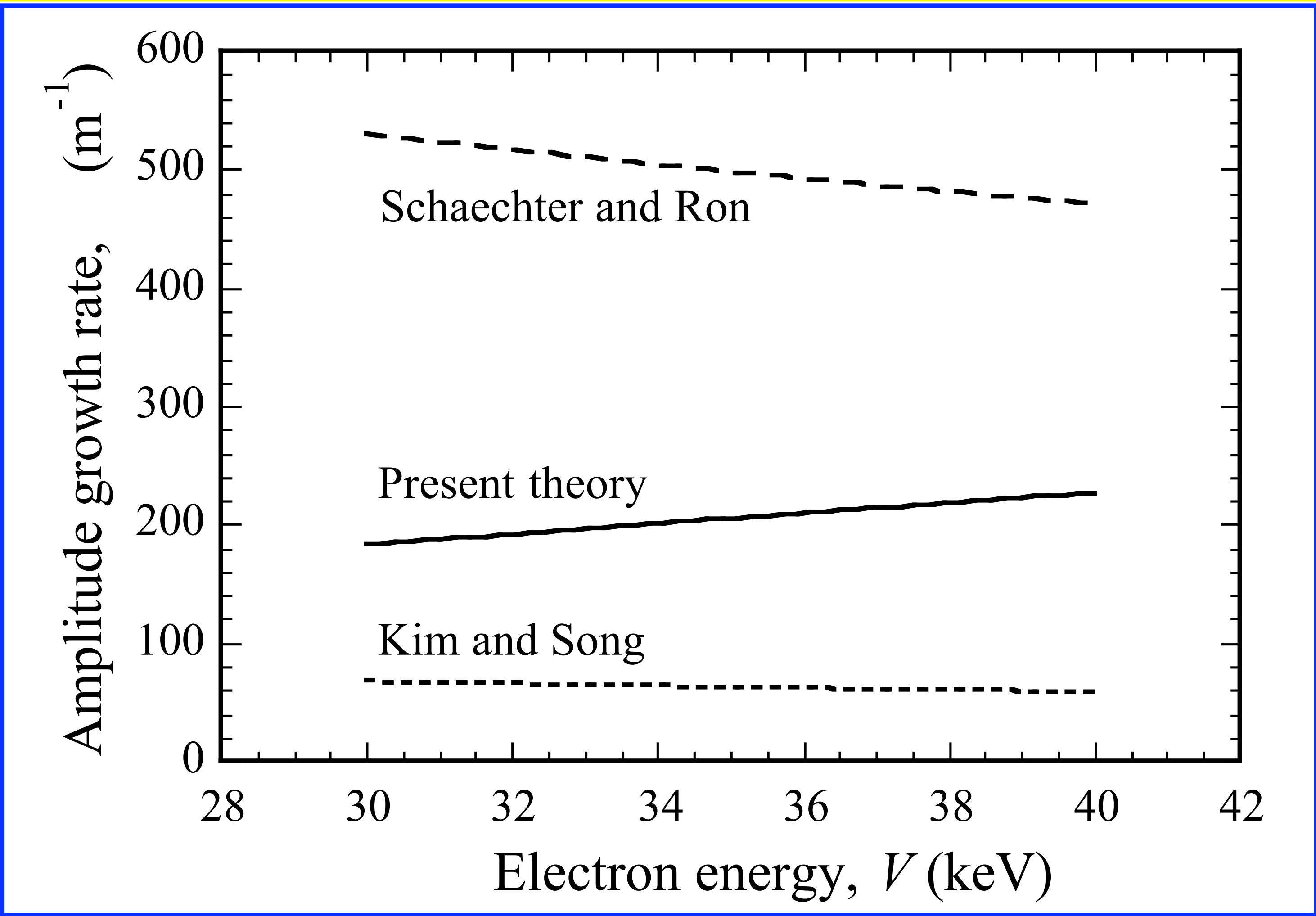
- Evanescent wave:
  - Phase velocity parallel to electon beam, group velocity opposite
  - Bunches electrons
  - Produces harmonics within the SP spectrum which radiate



Expected wavelengths



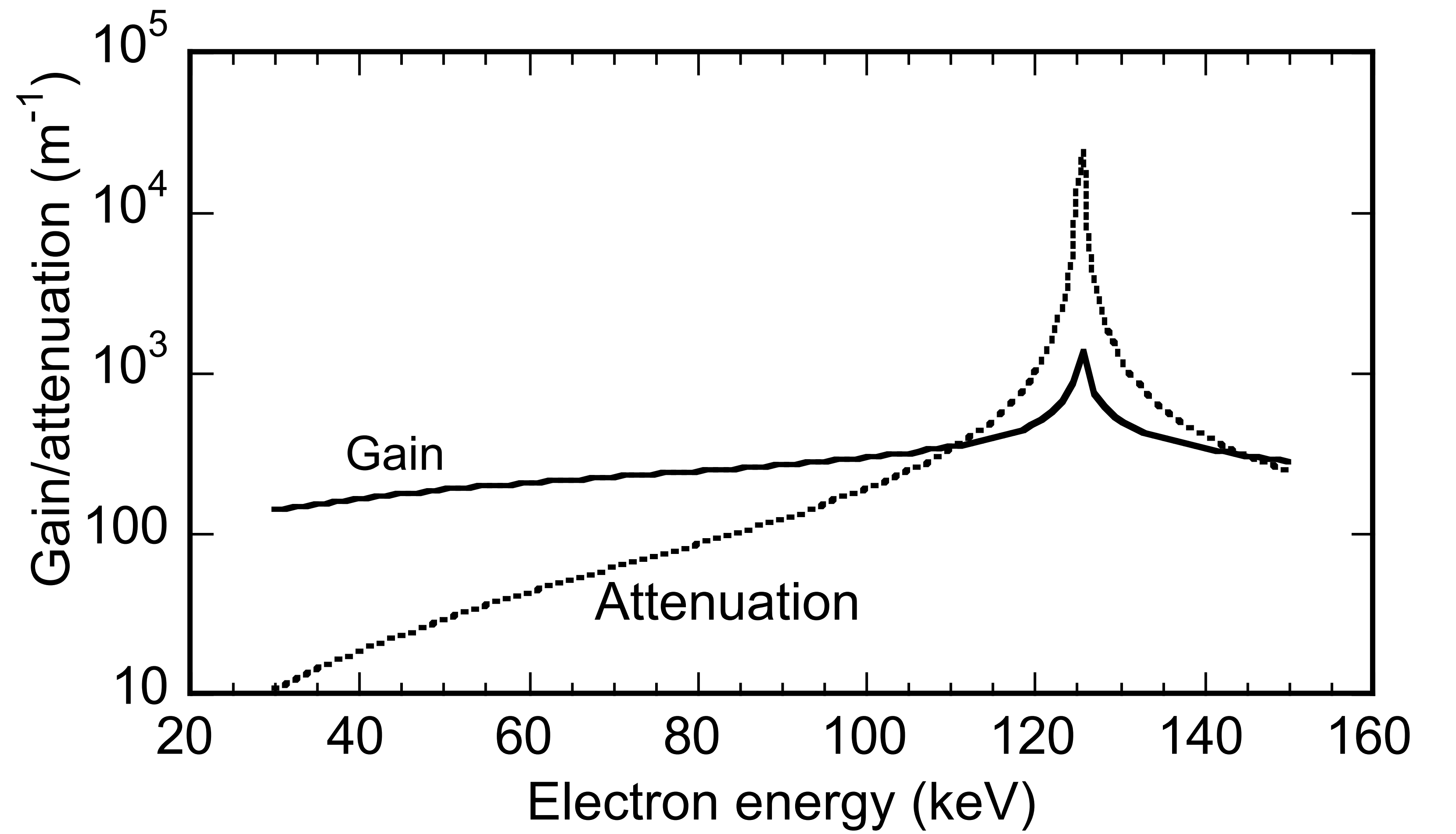
Comparison of gain theories



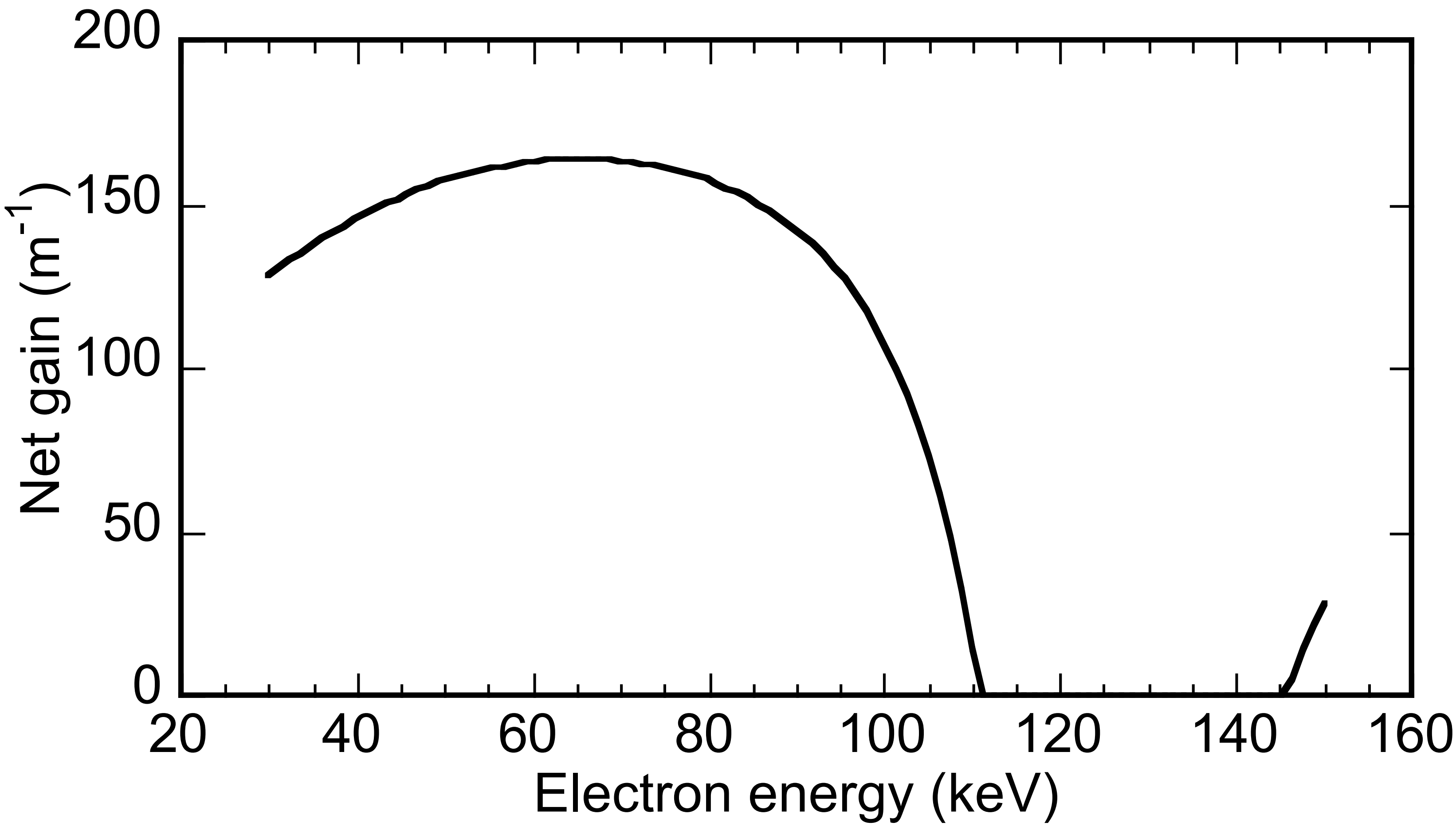
Schaechter and Ron, Phys. Rev., **A40**, 876 (1989)
Kim and Song, Nucl. Inst. Meth., **A475**, 159 (2001)

Gain and attenuation peak at v_g=0

Gain $\left(1/v_g\right)^{\frac{1}{3}}$ Attenuation $1/v_g$



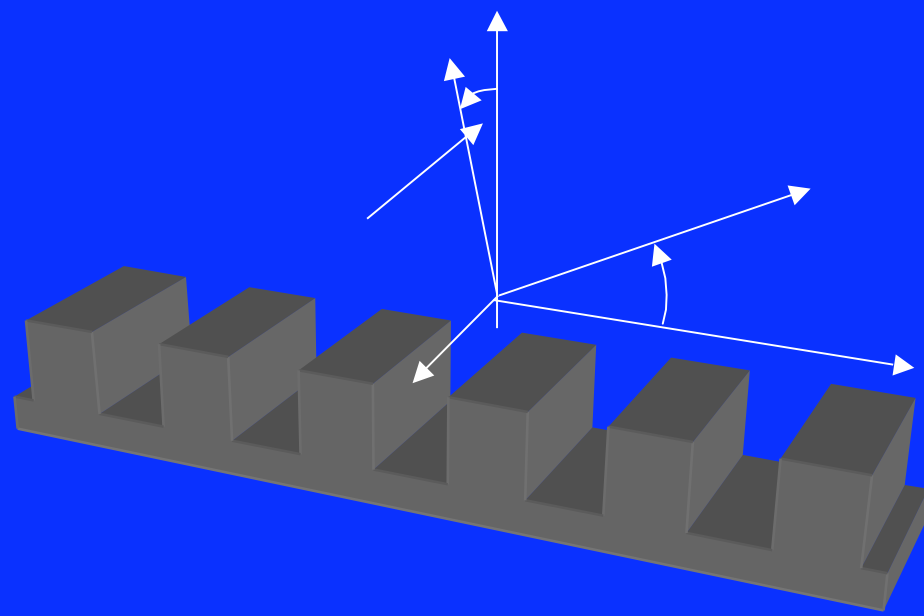
Net gain peaks before v_g=0



Net gain = gain - attenuation

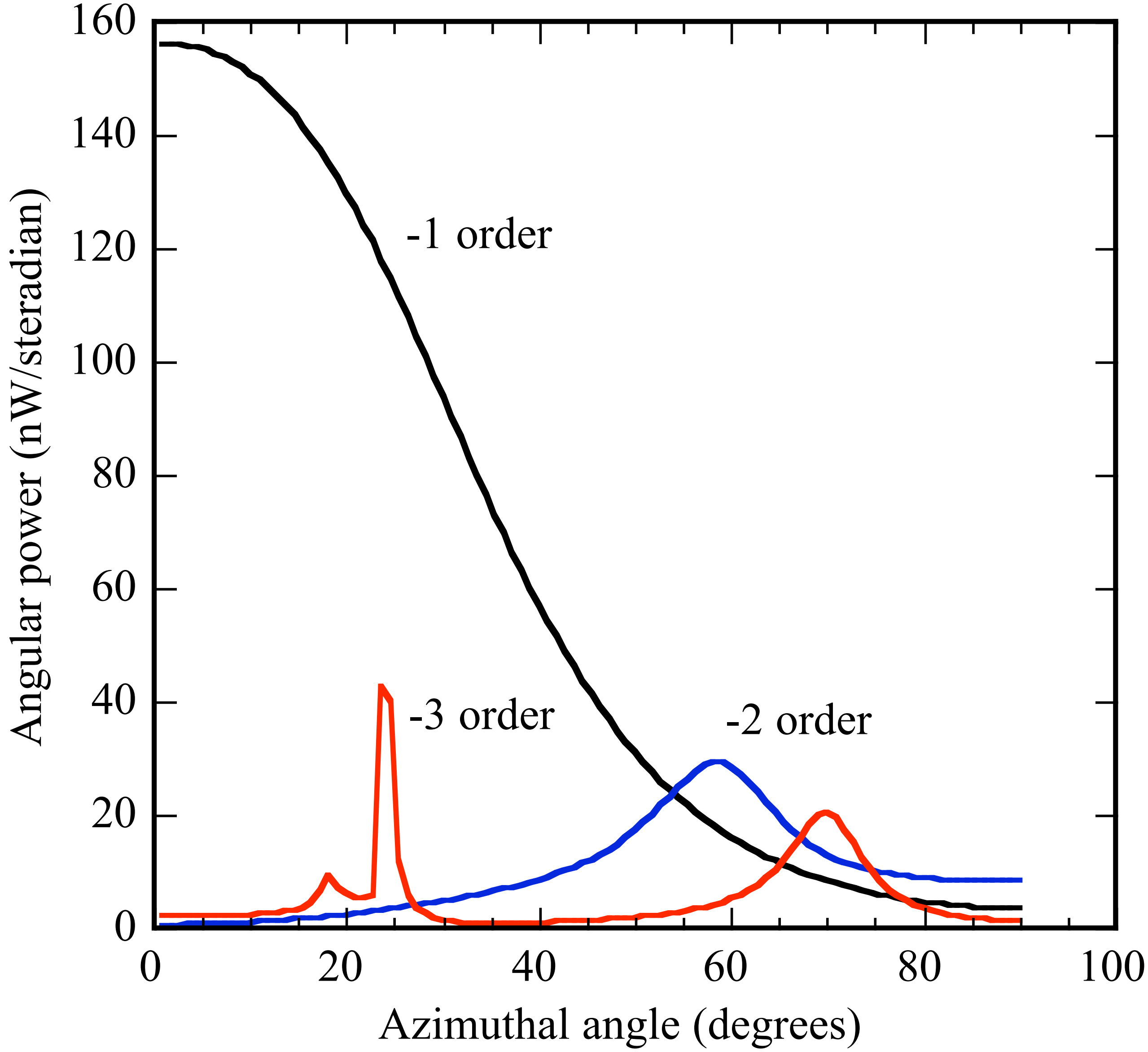
Refresher on Smith-Purcell parameters

$$= \frac{\ell}{|n|} \quad \frac{1}{\;} \quad \cos$$



- n = order number, = angle from electron beam,
  = azimuthal angle

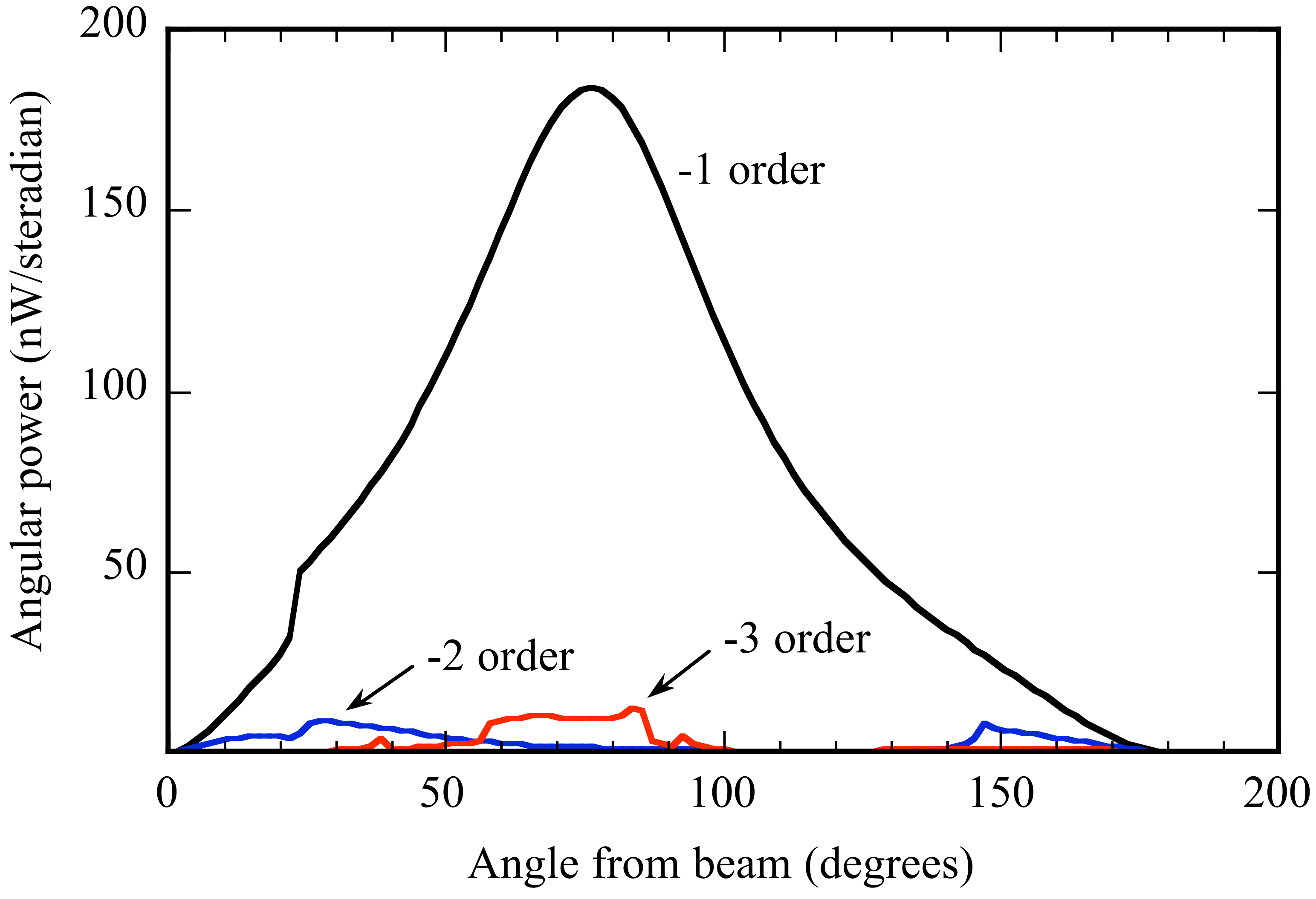
Spontaneous azimuthal power



= 90

Spontaneous power peaks near 90 degrees

= 0



We will conduct the following experiments

- Verify that we observe the laser emission
  - Hard to see because it will scatter
  - Should be strongest radiation in the chamber
- Observe harmonics of laser radiation
  - Do angular intensity scan - verify increase in intensity at predicted harmonic angles
  - Verify wavelengths of emission at different angles
- Observe intensity as a function of beam voltage
  - Look for peak intensity at voltage for peak gain
  - Look for intensity drop near voltage for $v_g=0$

Summary

- Vanderbilt table top THz source will produce:
  - wavelengths of 300-1000 microns (0.3-1 THz)
  - peak power ~1 W
  - pulse length ~5 ns
- Will use the Smith-Purcell effect in conjunction with a high brightness tungsten needle cathode
- Expect to be able to confirm recent theoretical developments experimentally
- Eventually will use device in conjunction with other sources available at Vanderbilt FEL Center