High-Field Short-Period Microwave Undulators

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Permanent Magnet Undulators

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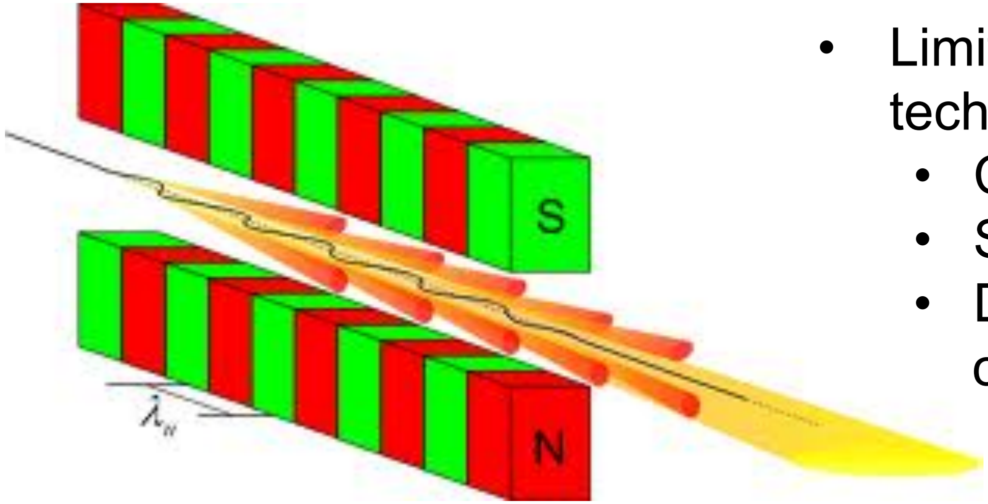
- Periodic arrangement of dipole magnet generates alternating magnetic field which deflects beam sinusoidally
- Synchrotron radiation emitted at wavelength

$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\theta^2\right)$$

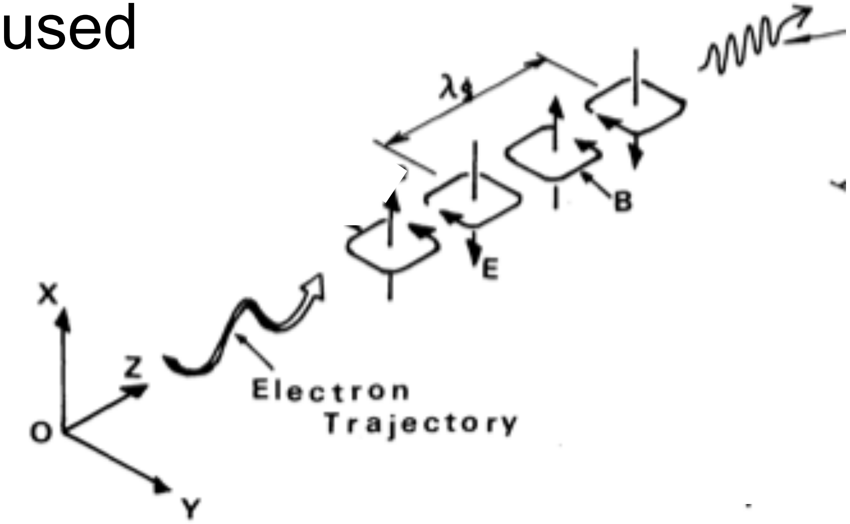
- λ_u typically >2 cm, K (interaction strength) 1 to 3



- Limitations of static undulator technology
  - Cannot be dynamically tuned
  - Small beam aperture
  - Difficult to build with λ_u < 1 cm

RF Undulator

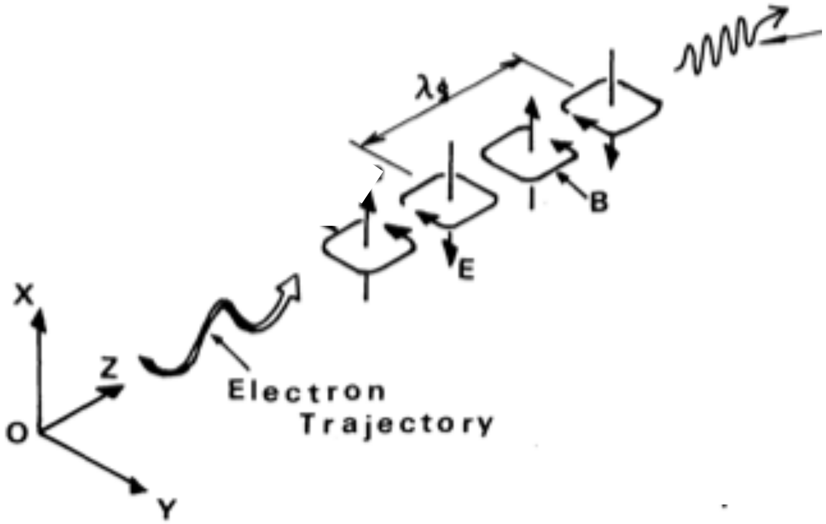
- Time varying RF fields can be used in place of static undulator



- Many desirable features
  - Fast dynamic control of
    - Polarization
    - Radiation Wavelength
  - Large aperture (cm vs mm for static undulator)
  - No issue with permanent magnet damage by radiation

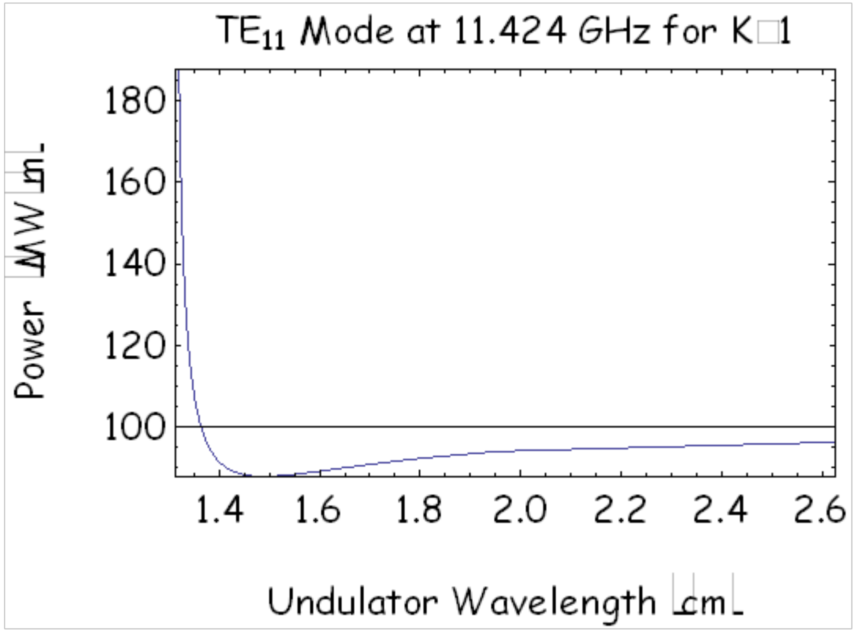
RF Undulator - Cont

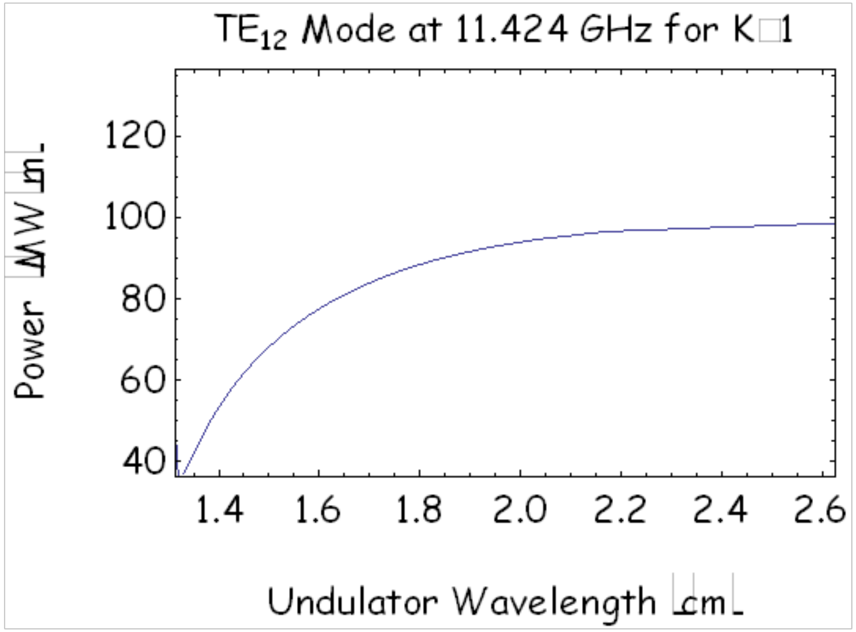
- All designs to date produce too low of K value to be of much interest



- Limitations
  - Excessive field level/loss on metallic surfaces
  - Power levels exceeding available sources
- Undulator with 1.4 cm period and K parameter of 1 using a travelling wave TE_{11} mode in circular guide requires 6 GW

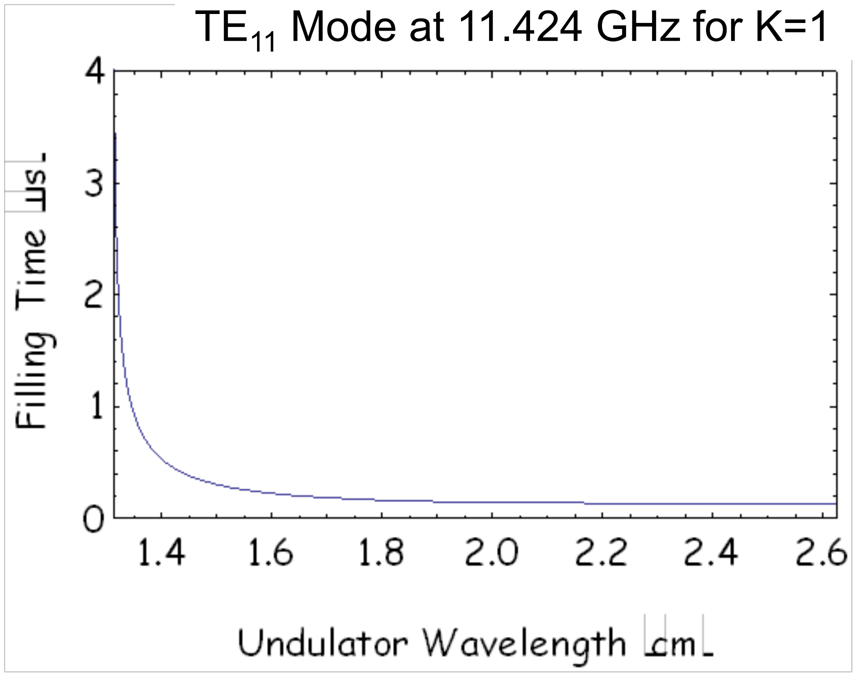
Resonant RF Undulator in Circular Guide

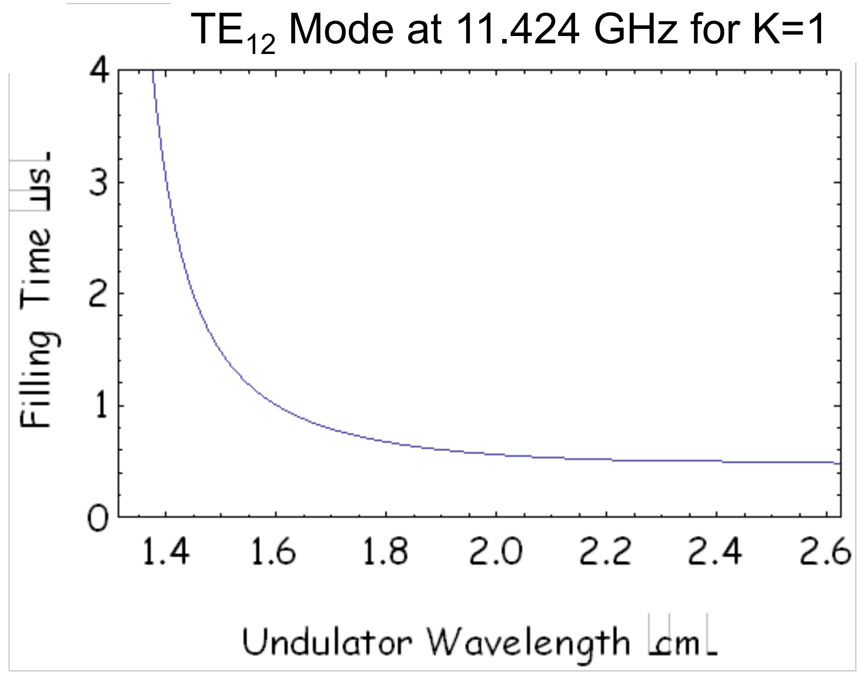




- Resonant structures reduce required power by order of magnitude
- Power requirements reduced further by use of higher order modes

Resonant RF Undulator in Circular Guide - Cont

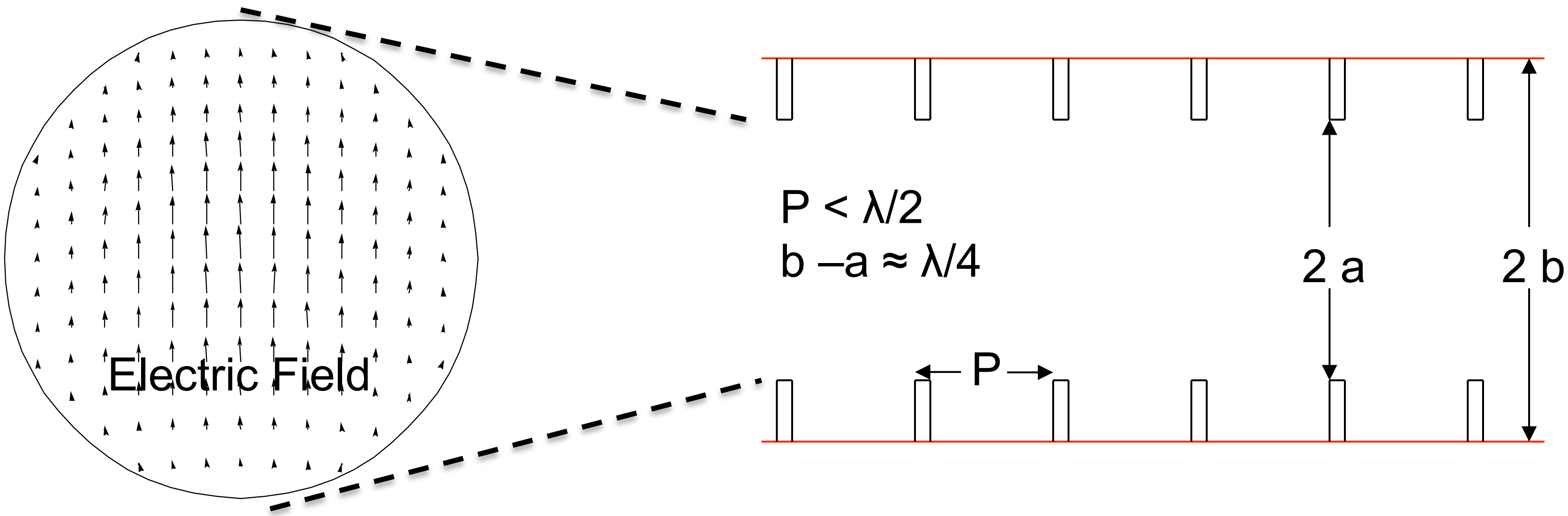




- Higher-order modes require more stored energy, hence longer filling times
- Same issue applies to other overmoded structures that have been proposed

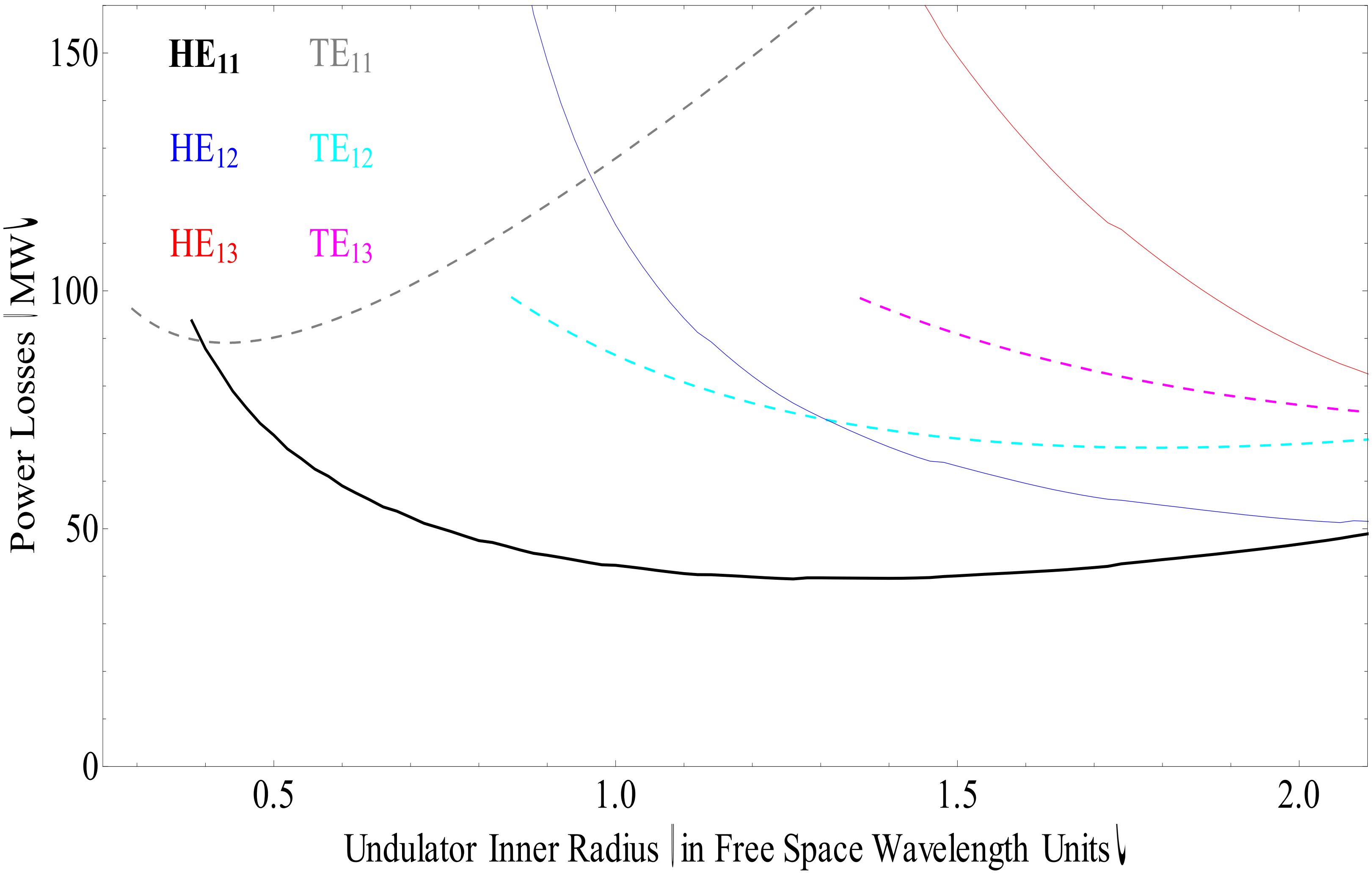
=> Need a lower loss mode than available in conventional waveguides

HE_{11} Mode in Corrugated Guide

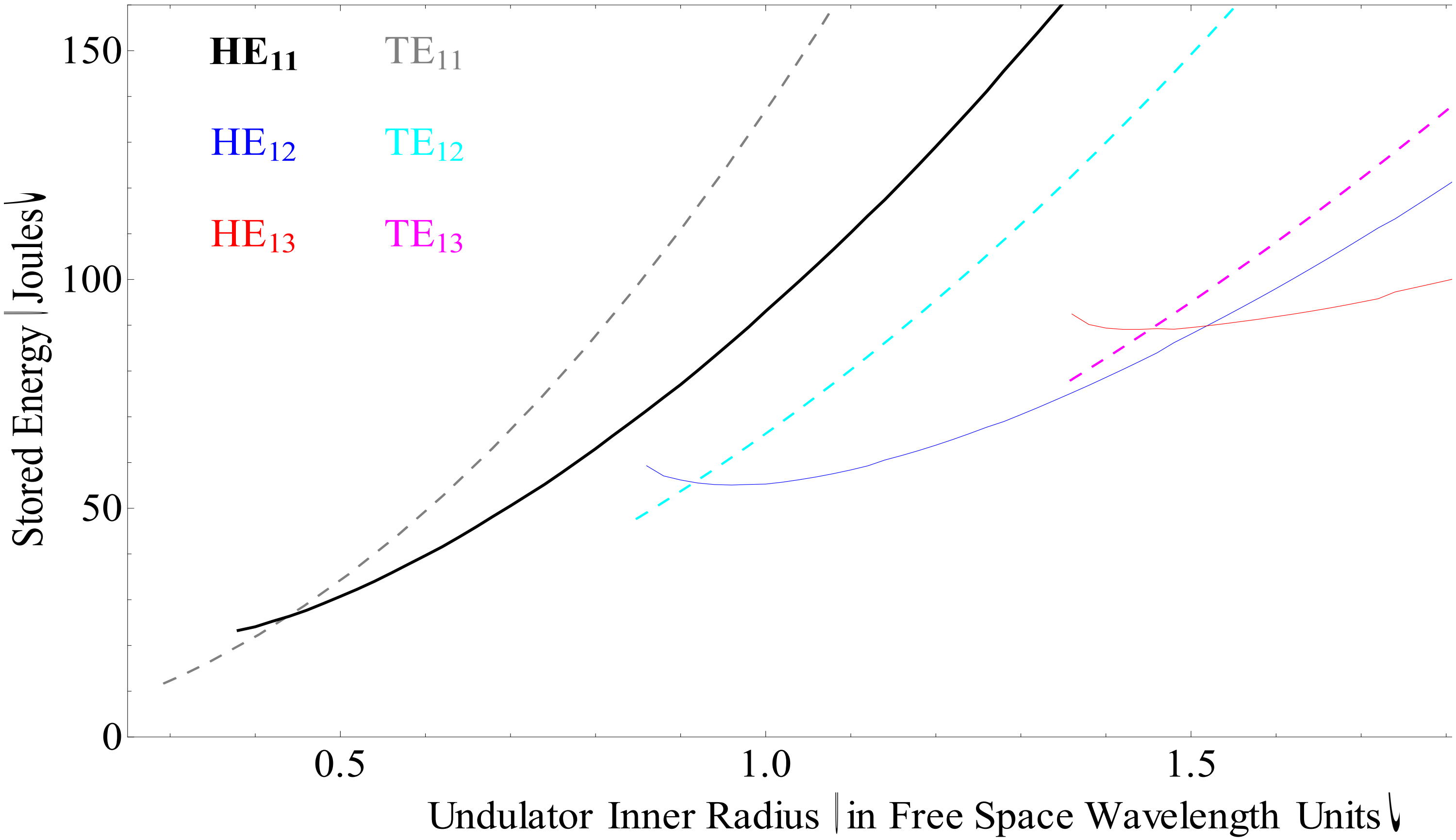


- Lowest order mode (HE_{11}) is a combination of primarily TE_{11} and TM_{11} modes
- Magnetic field is extremely low on waveguide walls – attenuation can be less than that of smooth wall cylindrical TE_{01} mode
- Field configuration ideal for beam interaction

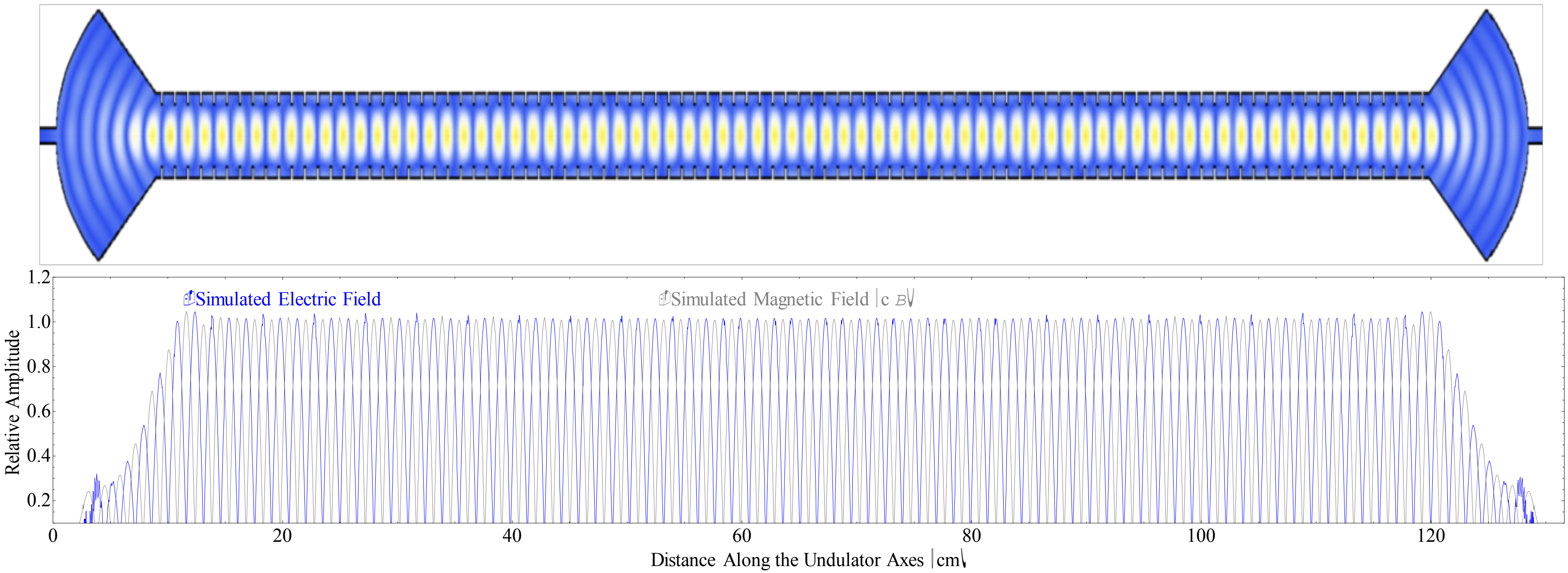
Resonator Power Requirements for K = 1



Resonator Stored Energy for K = 1



HE_{11} Resonator Design



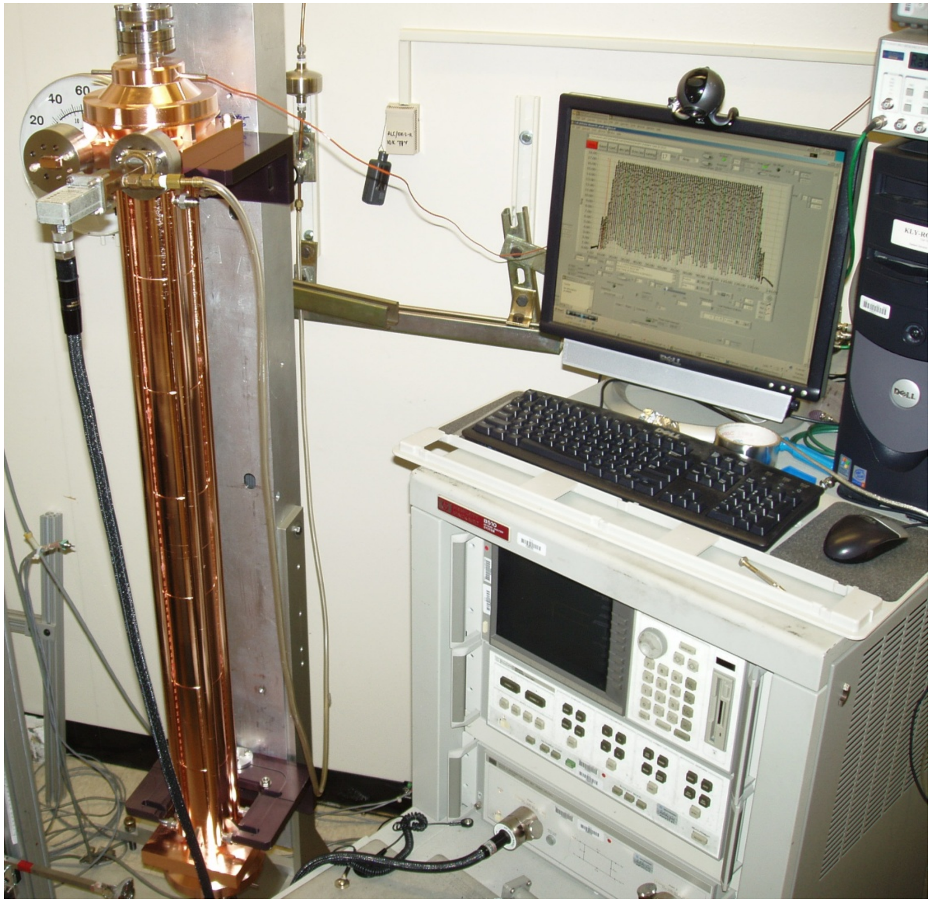
Design parameters

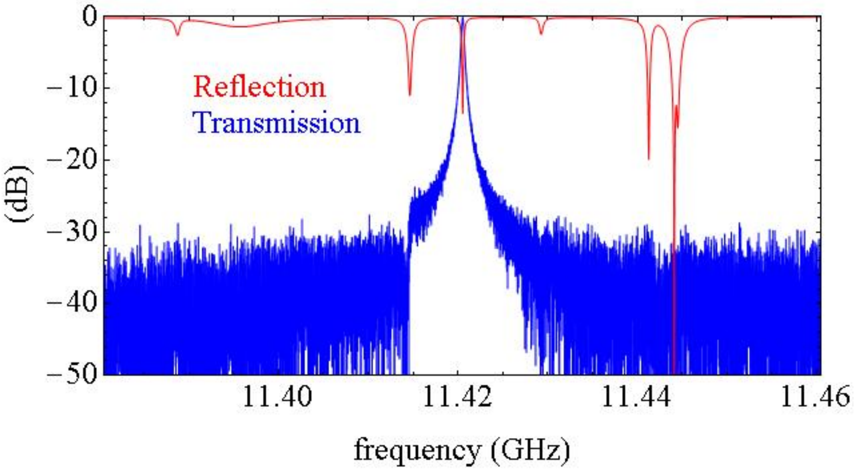
- 70 periods, 1 meter
- Q_0 = 94,000
- K = 1 for 50 MW
- Fr = 11.424 GHz

Design Issues

- High mode density (1.5λ diameter, 40λ long)
- High peak surface heating at end walls

Cold Test

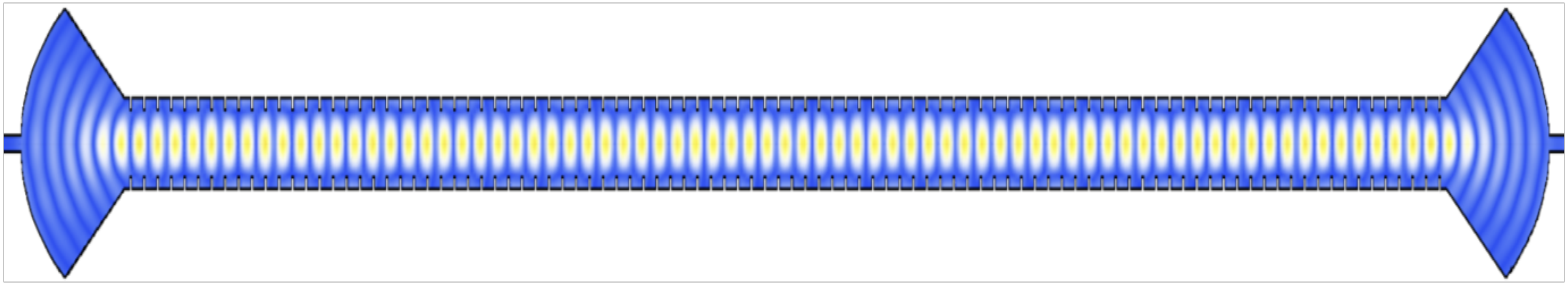


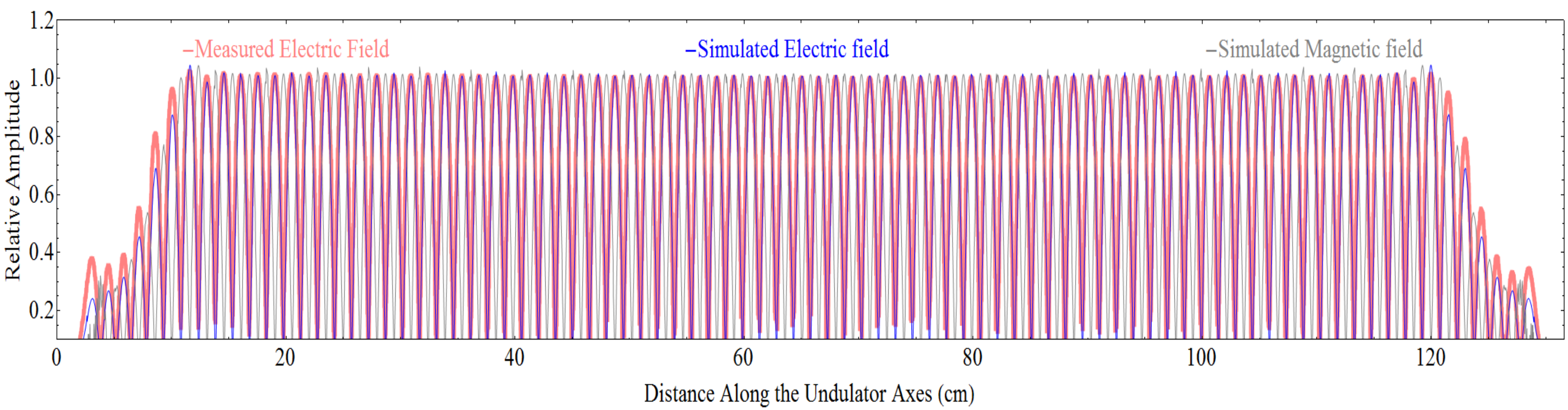


Measured resonance frequency
Room temp in air : 11.419 GHz
12.1 °C in vacuum : 11.424 GHz

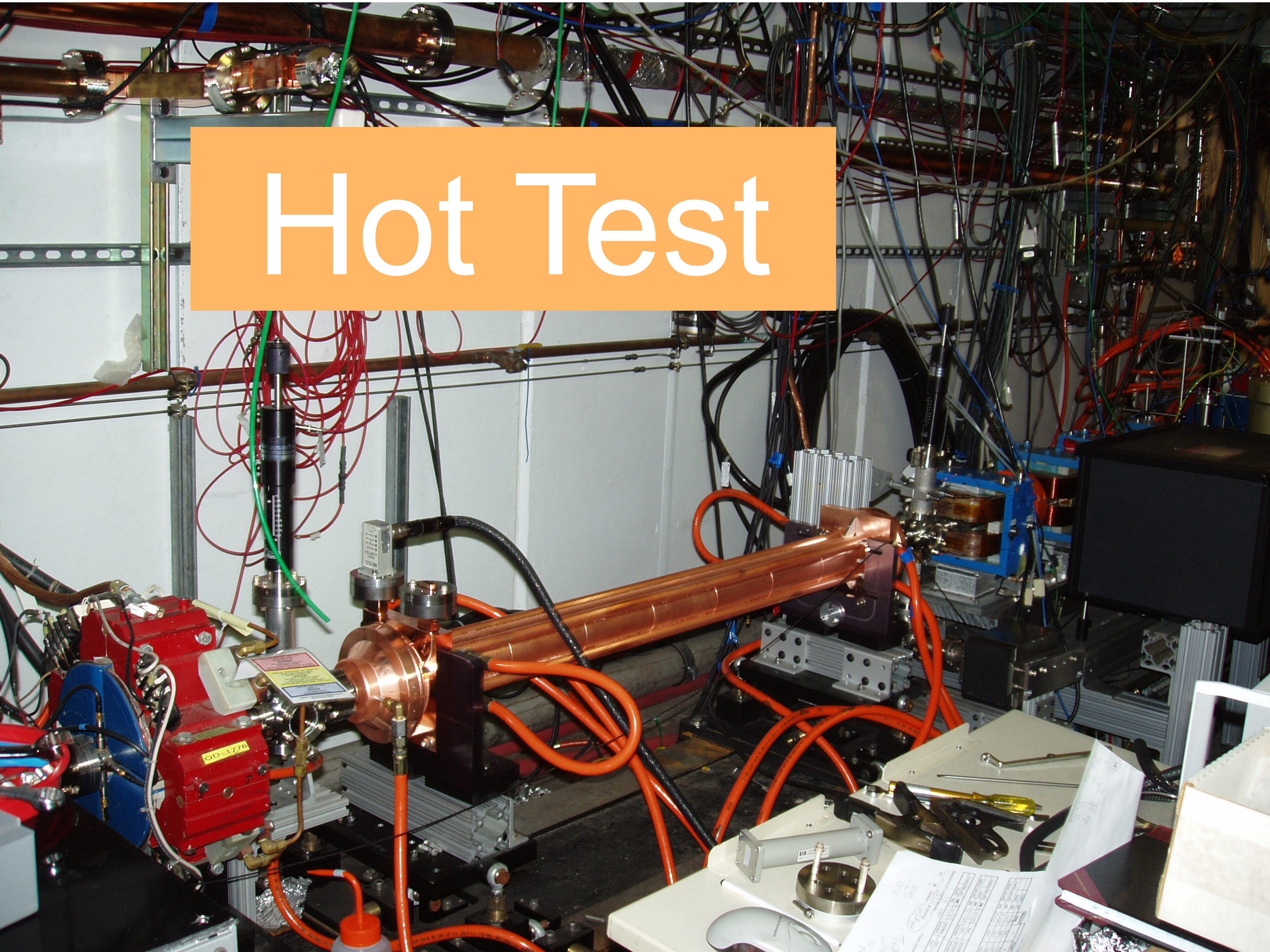
Q_0 = 91,000 (94,000 calculated)

Cold Test - Cont





Hot Test



Light!

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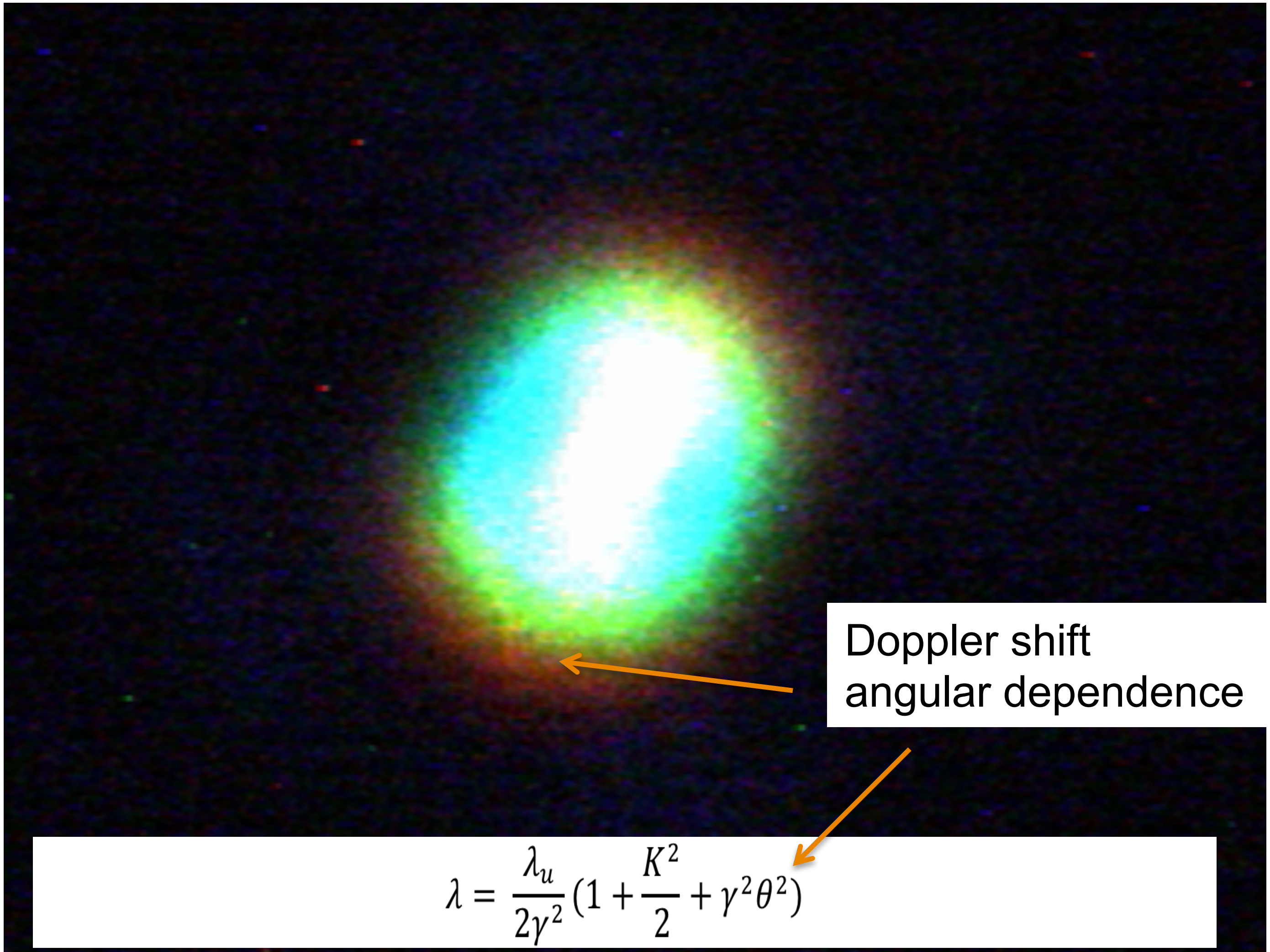

Doppler shift
angular dependence
$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\theta^2\right)$$

Wavelength versus K for 70 MeV Beam Energy

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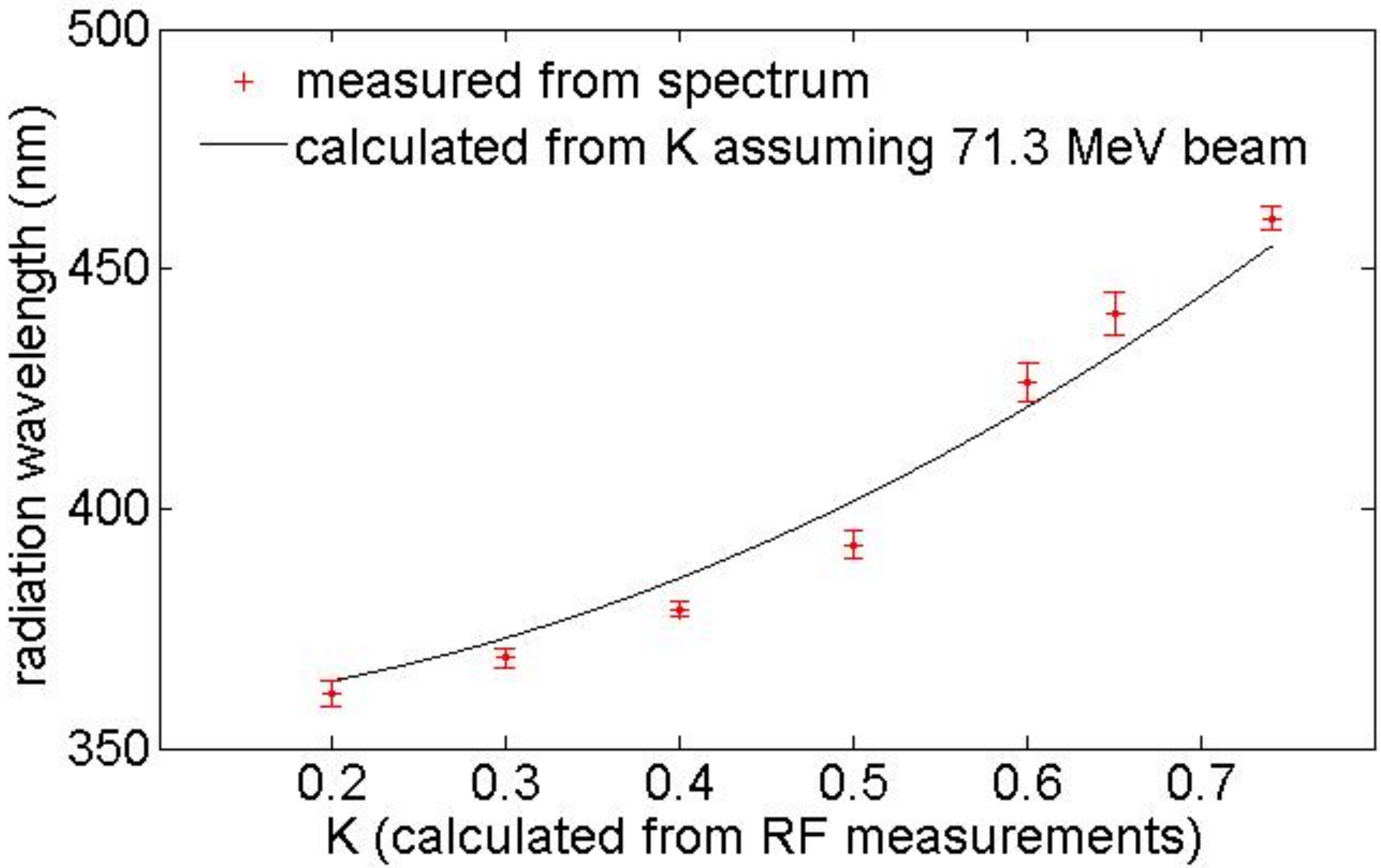

$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\theta^2\right)$$

Seeding

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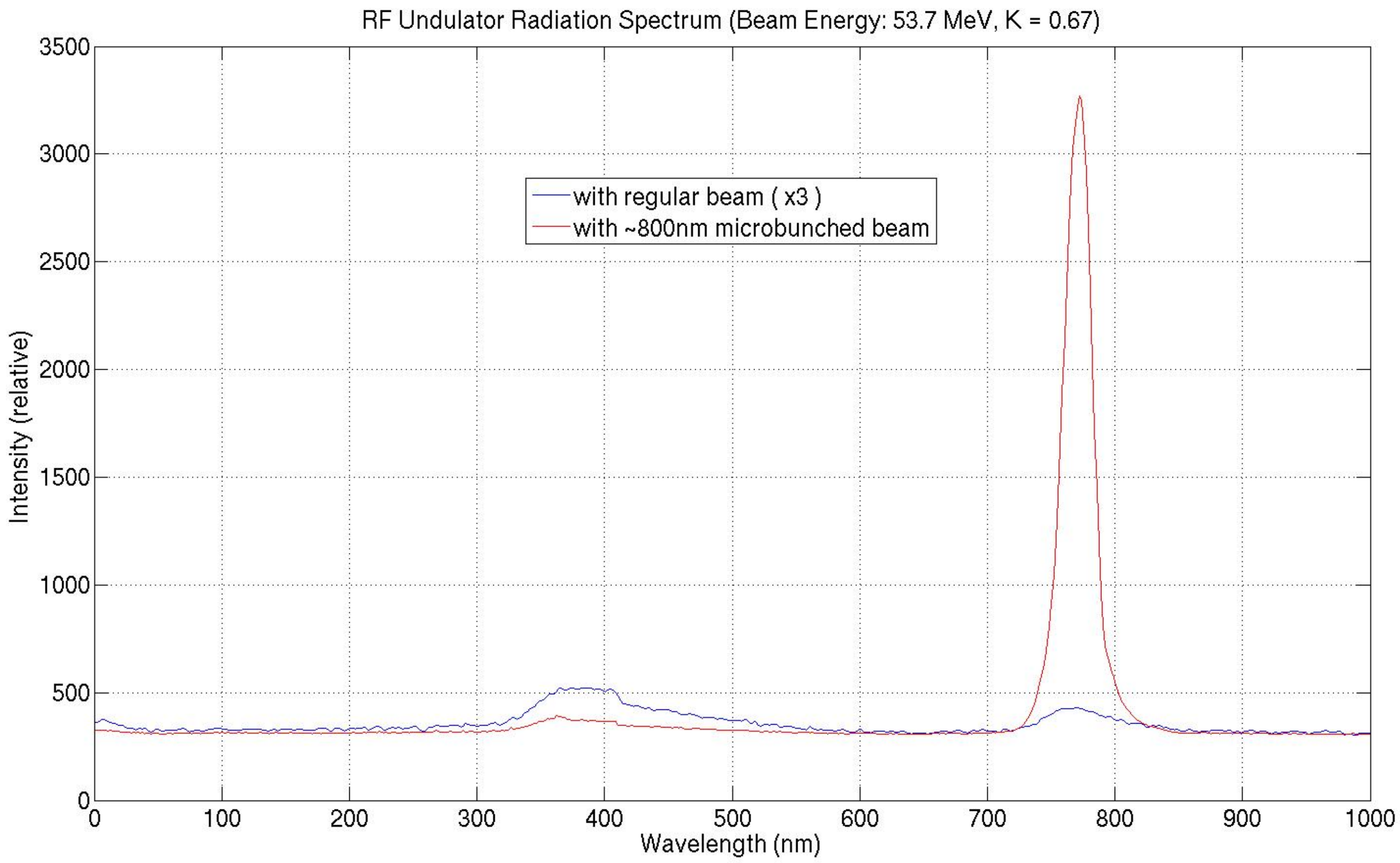
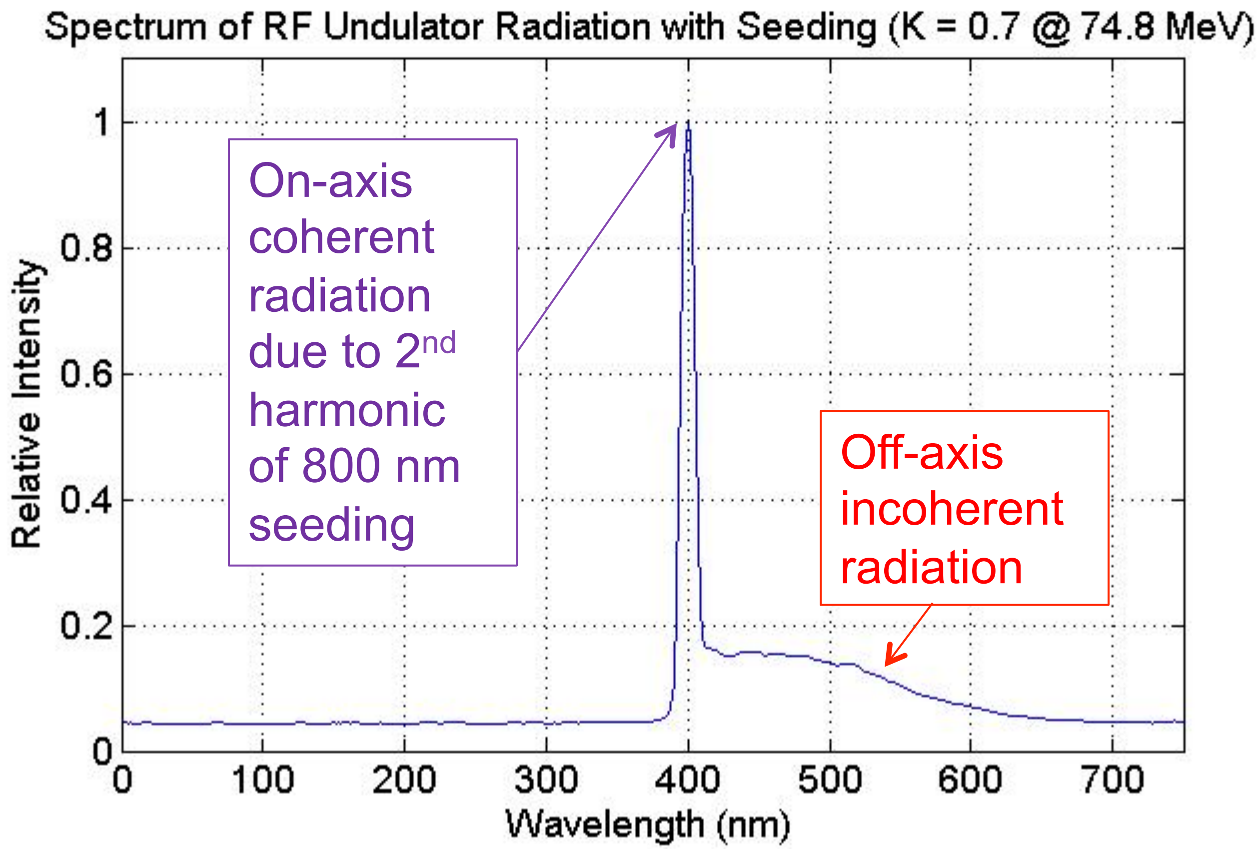
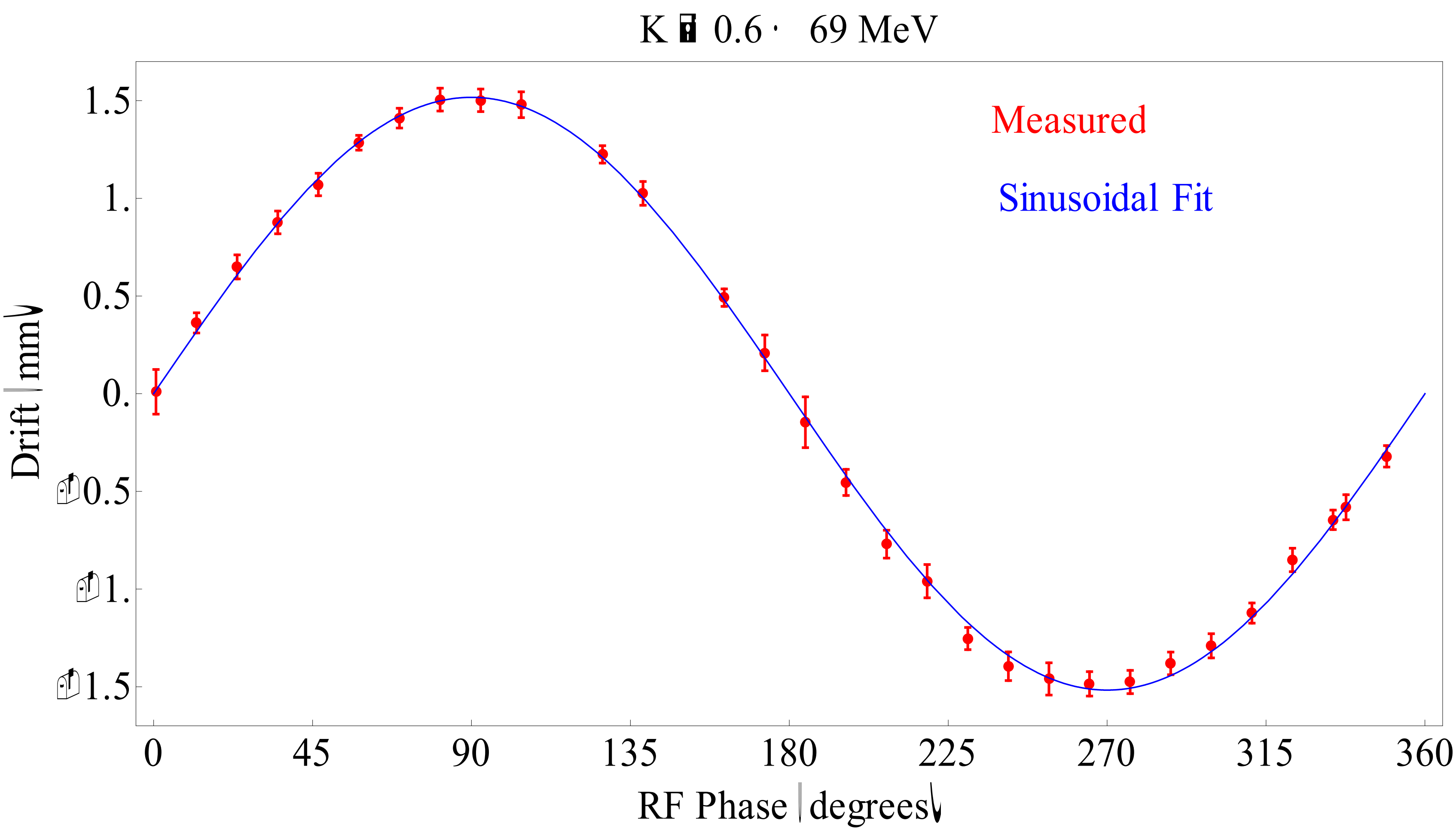


Second Harmonic Seeding



Beam Position Drift

Max drift (measured) = 1.52 ± 0.03 mm (assuming 0.094 ± 0.002 mm/pixel)
Max drift (calculated) = 1.27 mm



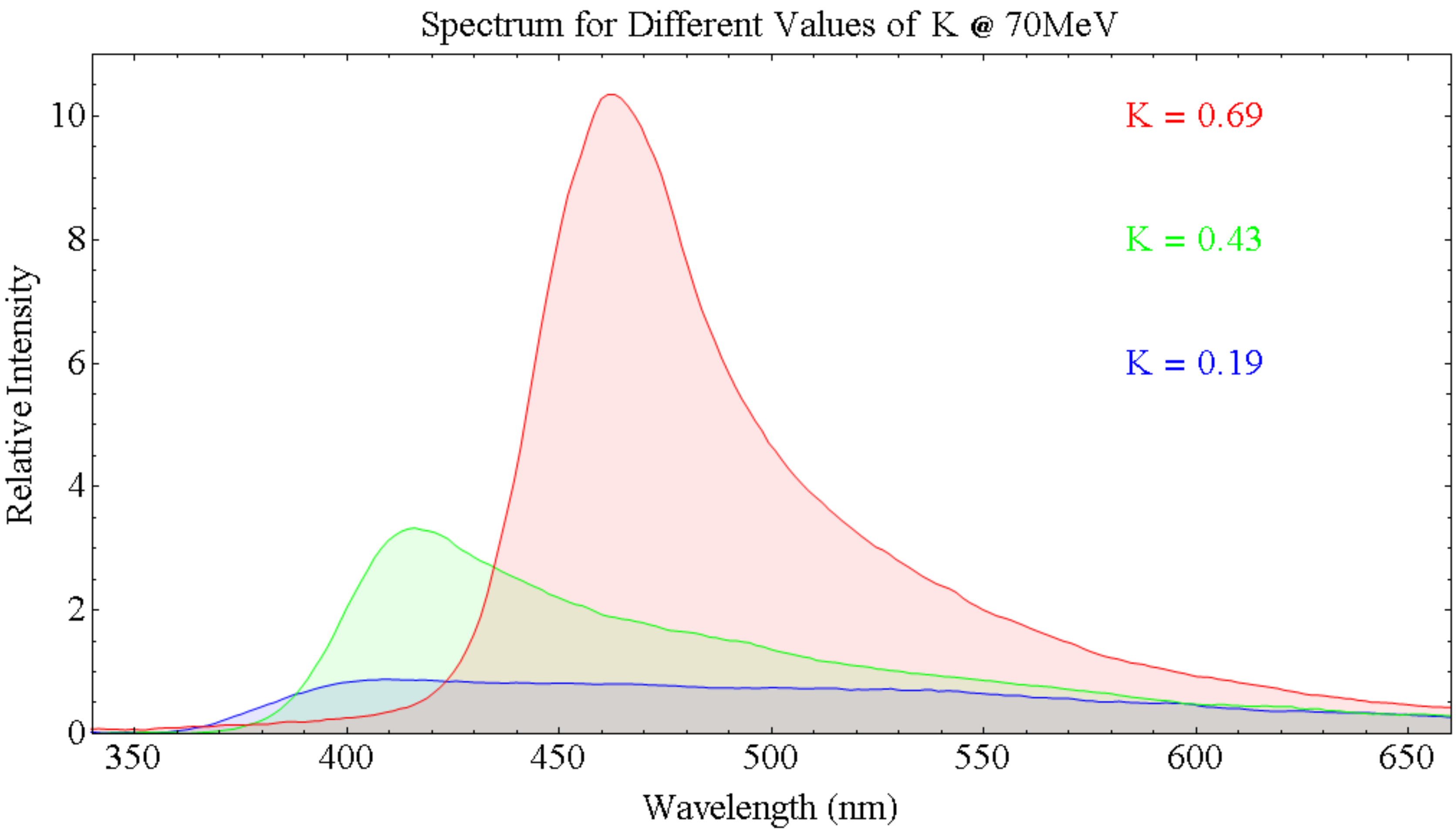
Conclusions & Next Steps

- First demonstration of a viable approach for an RF undulator
- Not an inexpensive solution, $1M+ / meter for X-band ($\lambda_u$ 1.4 cm)
- Scaling to shorter undulator periods (higher RF frequency) limited by available RF sources

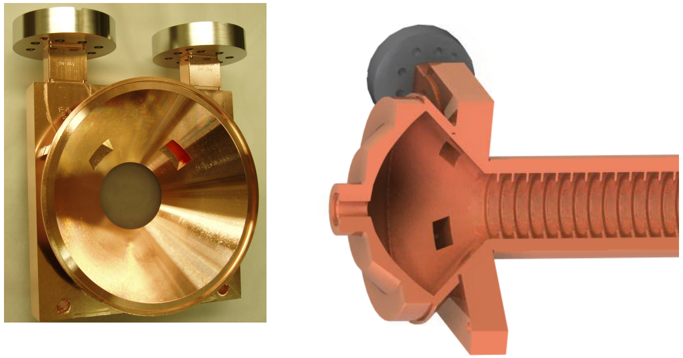
Next Steps:

- “After burner” for LCLS – dynamic control of polarization
- Teaming with commercial company to develop superconducting undulator – will allow use of solid state sources

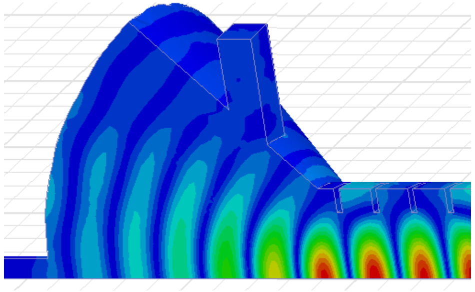
Spectrum Intensity vs K for 70 MeV Beam Energy



Small Glitch



Two coupling ports 90^o apart



Coupler Field Configuration

Input coupler intended to excite two polarizations independently

- Hybrid feed would generate circular polarization
- Reflection in opposite phase would go to load
- Design error coupled orthogonal polarizations
- Ran experiment in single polarization

Coupling error limited power, maximized hassle…