# THE WISCONSIN SUPERCONDUCTING RF ELECTRON GUN

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**PROPOSAL TITLE**

Construction and Test of a Novel Superconducting RF Electron Gun

August 22, 2011

DOE Award # DE-SC0005264

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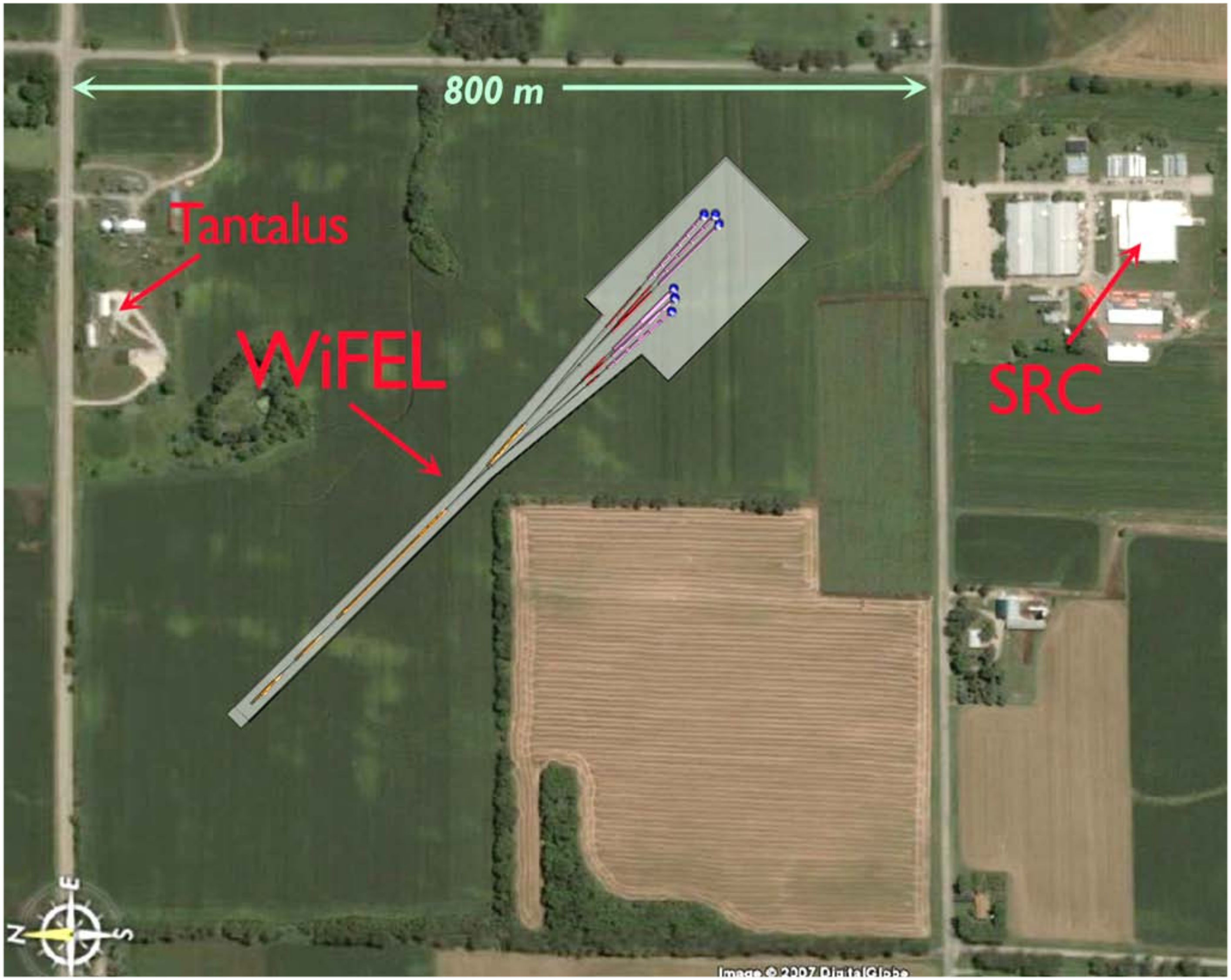
# Starting Point:
# Next Generation VUV/Soft X-ray Source

- Probe physical, chemical, and biological systems on their critical temporal, spatial, and energy scales—femtoseconds, nanometers, and millivolts
- Performance goals
  - Full 6D coherence
  - Short pulses
  - High repetition rates into megahertz
  - High peak and average flux
  - Tunability and polarization control
  - Many beamlines operating independently and simultaneously to spread costs
- Superconducting-linac-driven FEL "farm" is an ideal solution
  - CW
  - Naturally a coherent process
  - Seeding ensures temporal as well as transverse coherence

# For example:

## Wisconsin Free Electron Laser Concept (WiFEL)



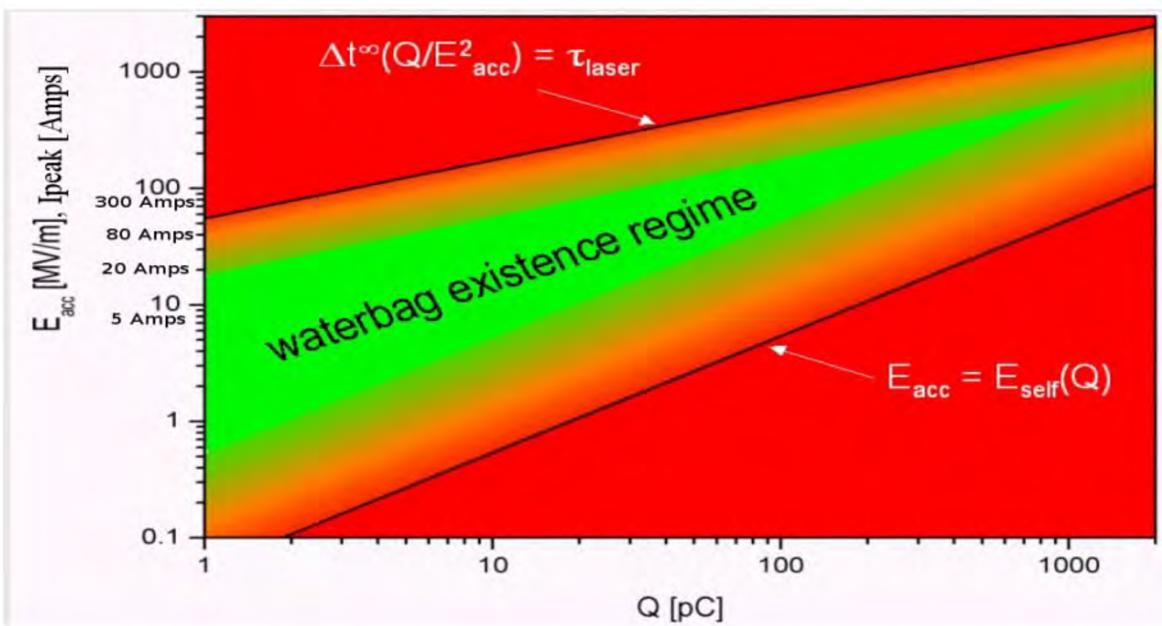

www.wifel.wisc.edu

# CW Electron Gun is a Critical Element
# Requirements Driven by FEL

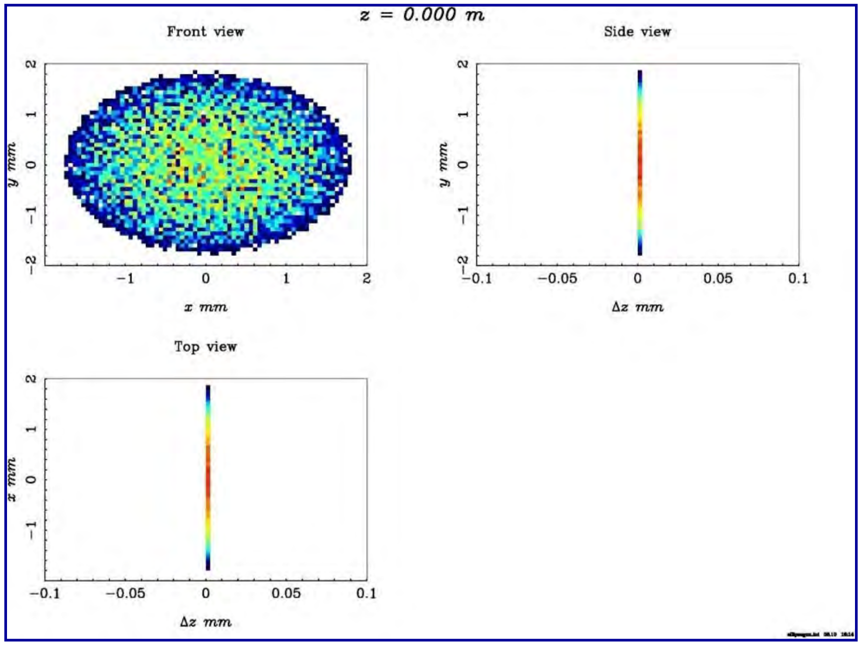
| | |
|---|---|
| Gun repetition frequency | Up to 5 MHz |
| I peak at undulator | 1000 Amps |
| $\Delta E/E$ at undulator | < few $10^{-4}$ |
| Normalized $\varepsilon_{Transverse}$ | <1 mm-mrad |
| Bunch length, rms | 70 fsec |
| Charge/bunch (derived) | 200 pC |
| I average (derived) | 1 mA |

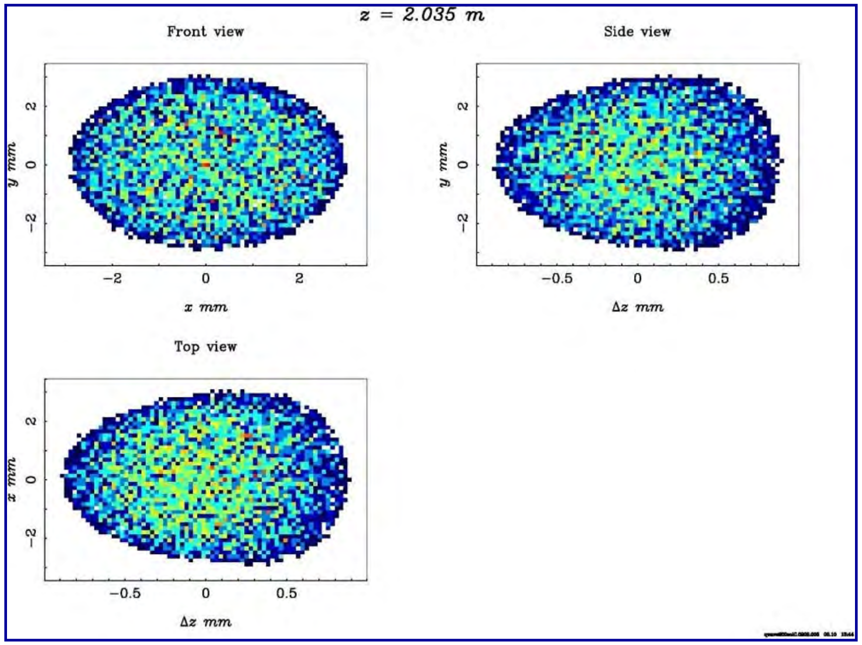
# Wisconsin Superconducting RF Electron Gun

- SRF offers advantages for high average current electron gun
  - Higher gradients achievable at cathode (~ 40  MV/m)
  - Without  need to optimize for heat load, integrated field in gap can be large, yielding substantial increase in output beam energy (to ~4 MeV)
- Lower frequency for temporal field flatness (quasi-DC)
- High gradient allows operation in so-called “blow out” mode



# Ellipsoidal bunch expansion

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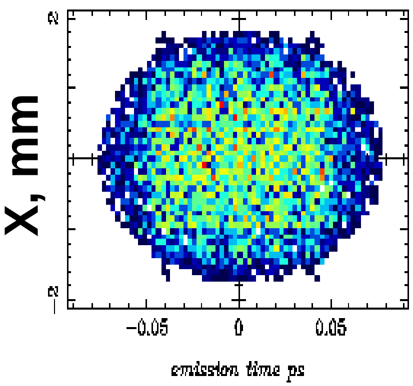
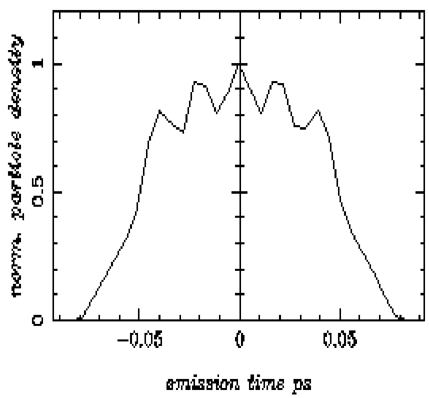
# Blow-Out Mode Smooths Initial Distribution Errors

Z=0



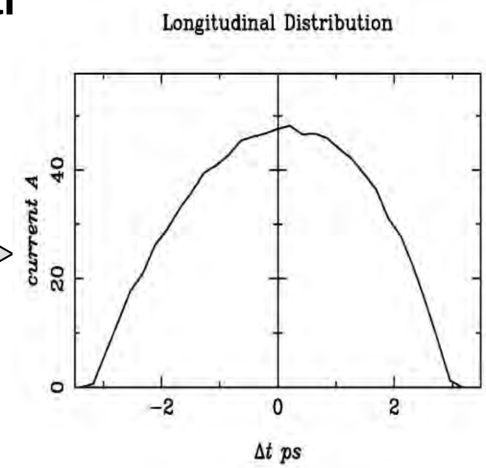

T, psec




Distribution in t

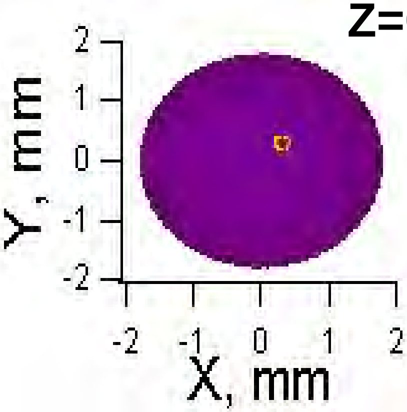
Bunch with Initial Longitudinal Modulation

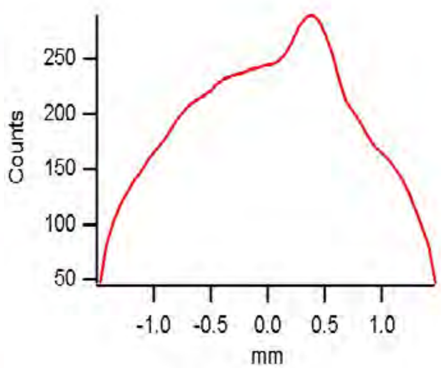
"Bad" laser




Distribution in t, Z=13 m

Z=0

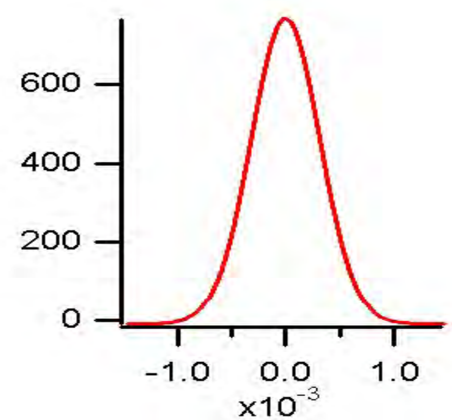



Histogram in x

Bunch with Initial Transverse Modulation

"Bad" cathode




Histogram in x, Z=13 m

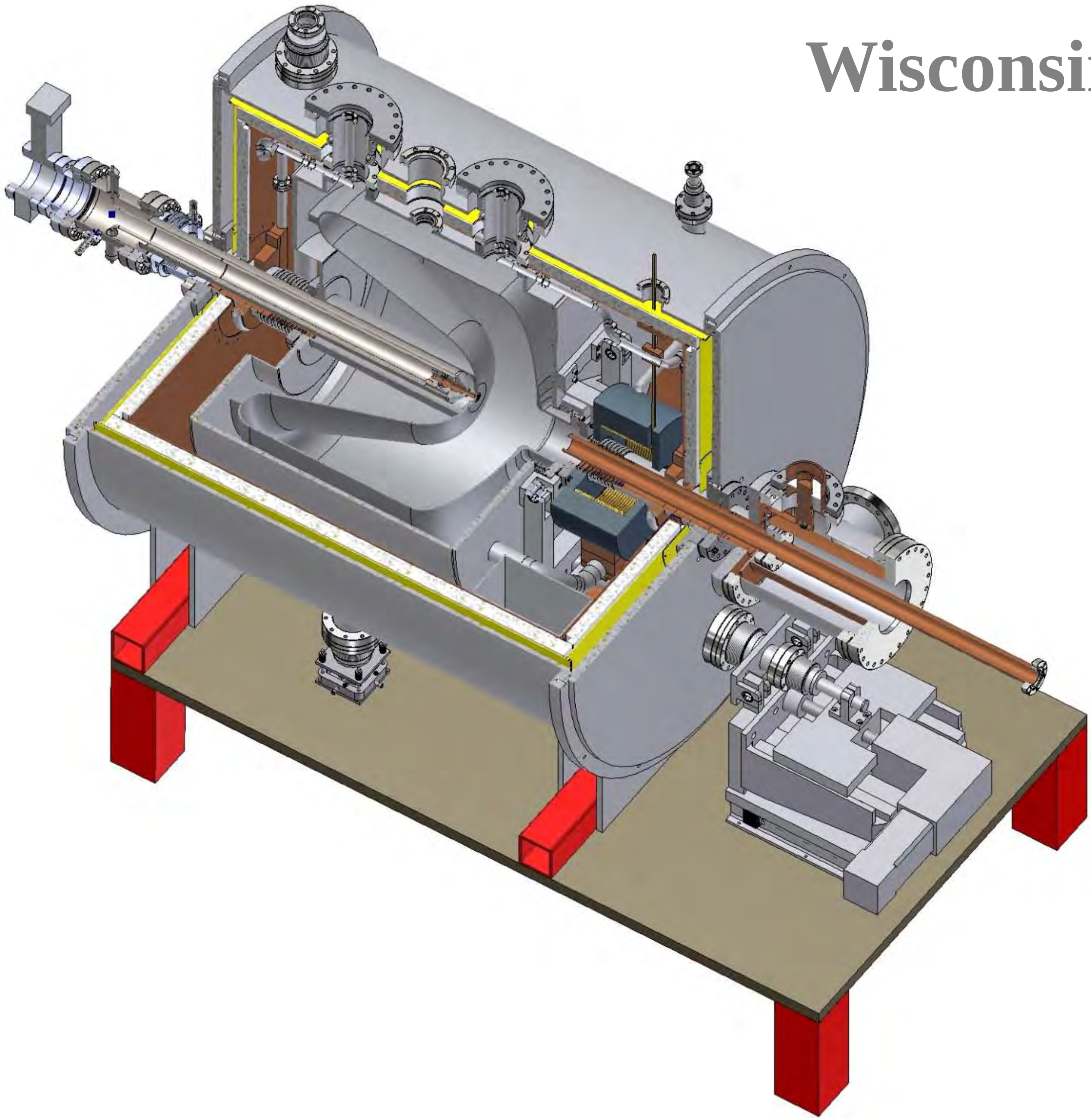
# Key Gun Parameters

- Electric field at cathode – up to 45 MV/m
- Peak surface magnetic field – 93 mT
- Dynamic power loss into He – 39 W at 4K
- Q – 2.5E9
- Frequency – 199.6 MHz

# Key Bunch Parameters

- RMS bunch length at gun exit – 0.18 mm
- Cathode spot ~1 mm for 0.85 mm-mrad thermal emittance
- At gun exit, $\delta p/p$ ~ 2.5%, divergence – 7 mrad
- Q – 200 pC
- Kinetic energy – 4.0 MeV
- With smaller spot, can be operated in lower charge modes with lowered emittance

# Wisconsin SRF e-gun



# Sequence of Events

- Start in August 2010
- ~FY 2011:  final design, procurements, and vault prep
- ~FY 2012: fabrication, installation, and commissioning
- ~FY 2013: beam tests to establish necessary performance

- Key procurements are in place: superconducting cavity, low level RF, RF amplifier, High-Tc solenoid, laser
- Total DOE program $4.5 million
- UW providing supplemental funds; for example, vault refurbishment
- Expect delivery and installation on schedule

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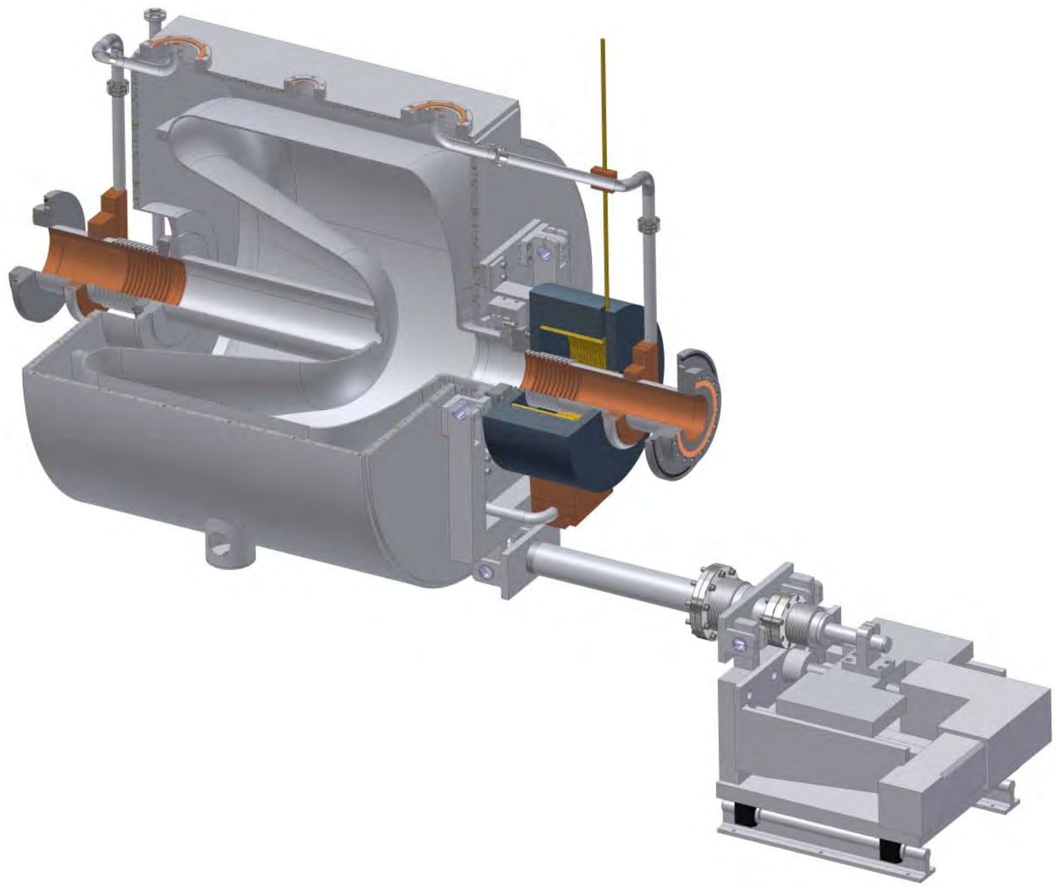
# Key Systems

- Cavity and helium vessel-Niowave contract
  - Spring 2012 delivery
  - JLab will be doing heat treatment to avoid Q-disease
- High temperature superconducting solenoid from Danfysik
- RF Systems
  - Power amplifier delivered
  - LLRF from JLab, with delivery at end of year
- Drive laser "off shelf," with delivery at end of year
- Cryostat and beamline diagnostics in final design phase
- Vault area adjacent to Aladdin storage ring under refurbishment
- Cryogenics—using campus expertise to finalize delivery system

# Final Design Review of Cavity/He Vessel at Niowave Completed and Fabrication Under Way



# Fabrication Moving Forward

Figure 5: Outer Shell Halves

Figure 1: Copper Prototype for Cake Pan

Figure 6: Cathode Tube (machining weld seat)

Figure 2: NbTi Cathode Flange

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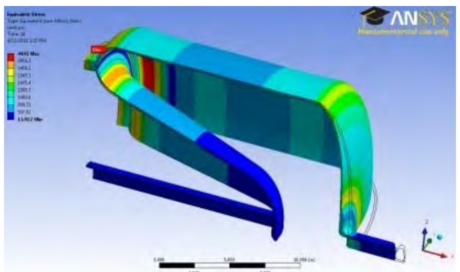
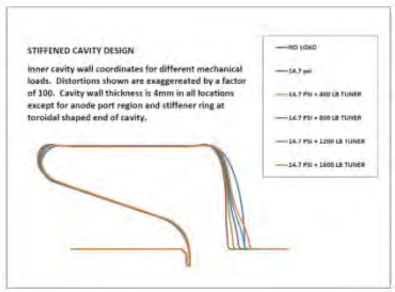
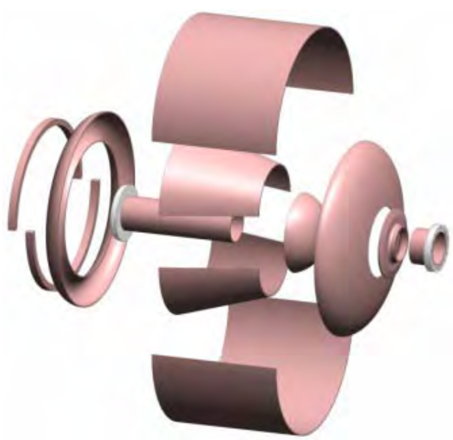
# Frequency Map

- Map which starts with a cold cavity at the correct frequency and moves back through the series of production steps producing an expected resonant frequency at each step
- Goal is to understand any deviations from the calculated frequency map and apply that knowledge to next generation

**FEA to Evaluate Stress and Deformation**





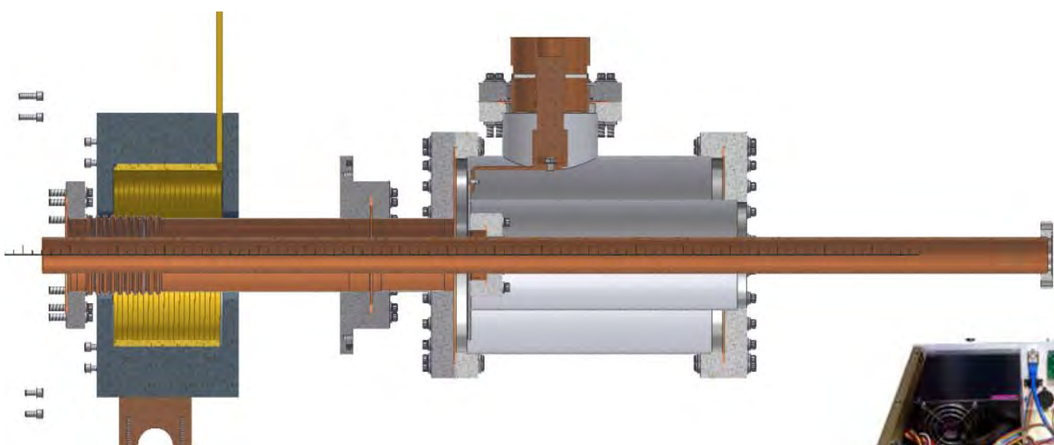



| State | Freq, MHz | D Freq, MHz | Volume, in^3 | D volume, in^3 |
|---|---|---|---|---|
| Nominal, 4 K | 199.58953 | - | 6269.213 | |
| Remove 1600 lb preload on tuner | 199.65256 | 0.06303 | 6267.753 | -1.46 |
| Warmed to 273 K | 199.3704 | -0.28216 | 6294.653 | 26.9 |
| Skin depth vs temp at 200 MHz | 199.3185945 | -0.05180 | 6295.853 | 1.2 |
| Remove vacuum load | 199.2485945 | -0.07 | 6300.243 | 4.39 |
| Change in permitivity, fvac/fair | 199.1947645 | -0.05383 | 6300.243 | 0 |
| Undo BCP etch | 199.3688075 | 0.174042 | 6282.793 | -17.45 |
| Final weld shrinkage, 0.7 mm | 199.280 | -0.088 | 6294.87 | 12.08 |

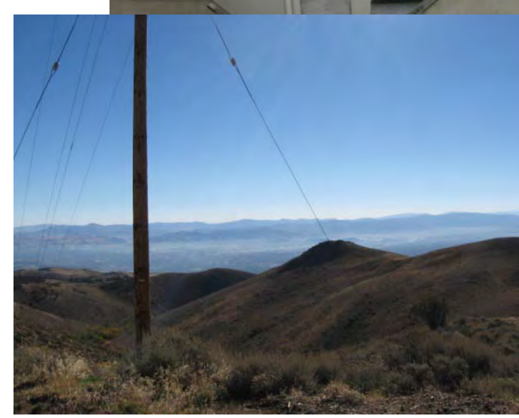
TABLE 1. Steps from cavity blank to final frequency

# RF Coupler and HPA and LLRF

- Power is introduced through a ceramic rf window and a tuned resonant structure.
- Relatively low power, <10kW, at 1 mA of beam
- 20 kW solid state amplifier procured



**Harris Corporation Broadcast Communications Division**



**Based on Jlab 12 GeV upgrade module**

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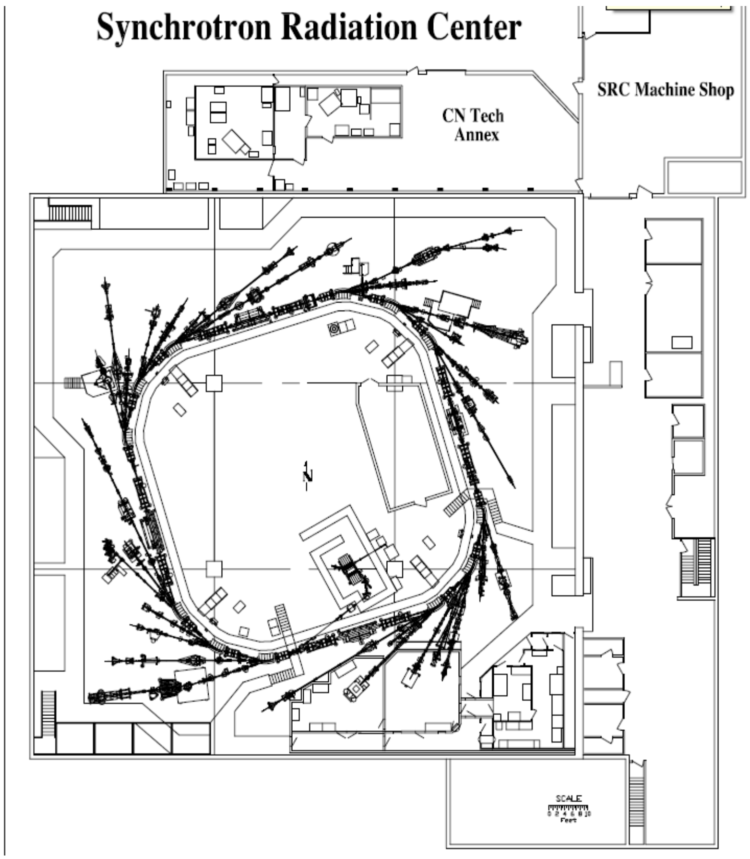
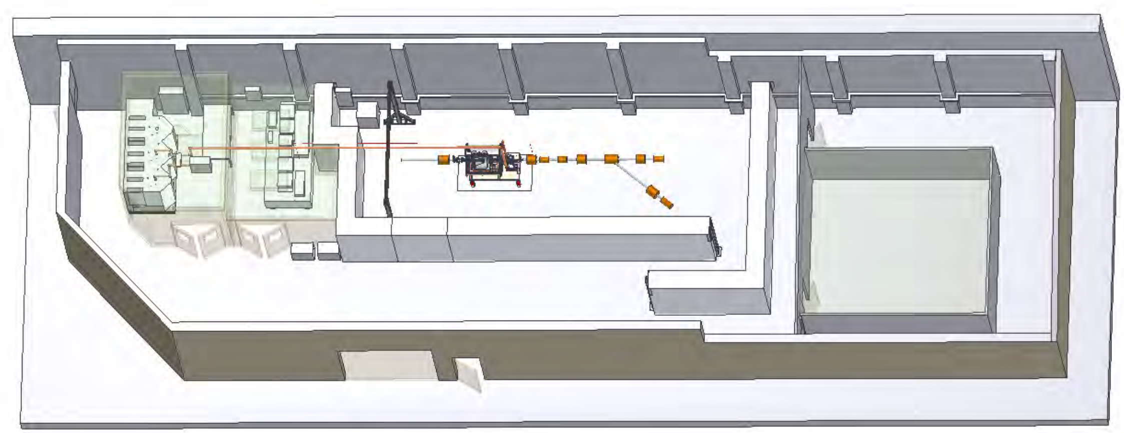
# Vault Layout



# Laser Room

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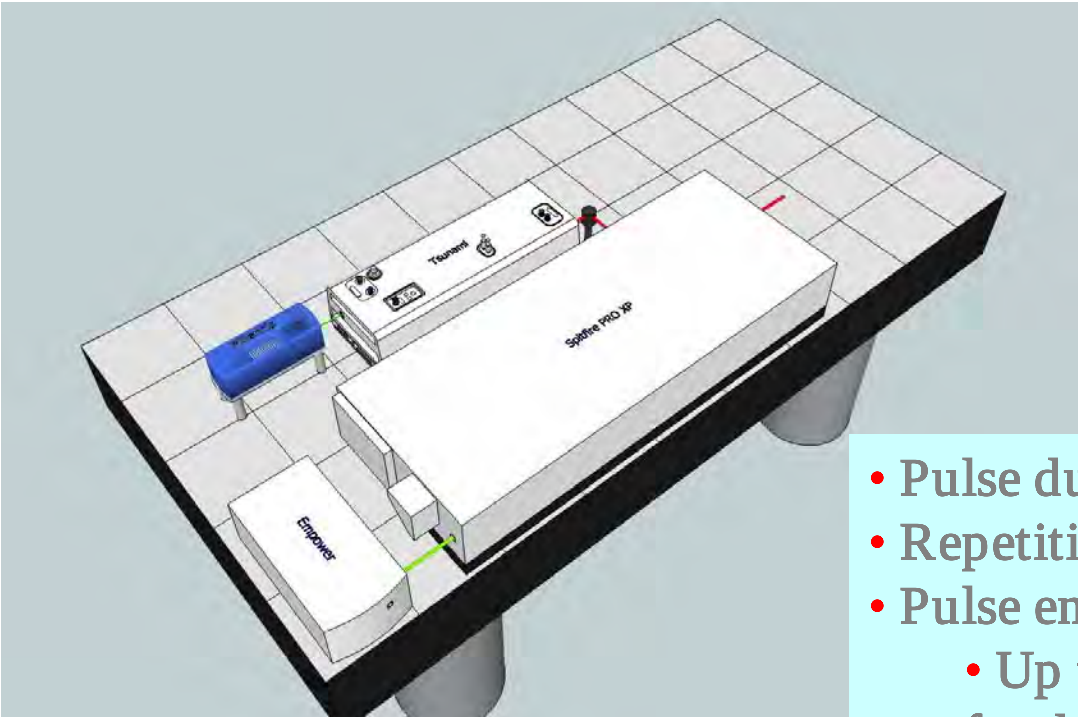
# Spectra-physics Tsunami (oscillator) + Spitfire (amplifier) system




- Pulse duration: 100 femtoseconds
- Repetition rate: 1 kHz – 1 Hz
- Pulse energy
  - Up to 4 mJ per pulse at the fundamental (800 nm)
  - ~ 1 mJ per pulse at the second harmonic (400 nm)
  - ~ 300 microjoule per pulse at the third harmonic (266 nm)
- Average power: 4 W

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# Current Scope

- Demonstrate single bunch beam dynamics and operation of SRF gun
- Low repetition rate drive laser
  - Allows option of using doubled or tripled Ti:Sapphire laser
- Cu Cathode Used for Initial Operation
  - Little chance of cavity contamination from evaporated cathode material
  - Cathode will not degrade over time like semiconductor
  - No cathode preparation chamber needed

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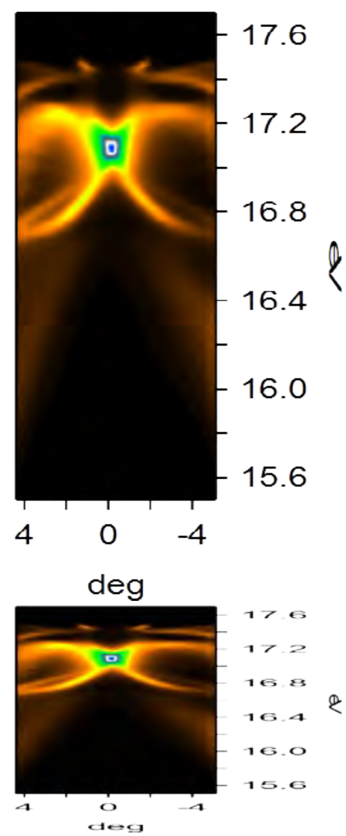
# Coming Attractions

- Cathode Preparation Chamber
- High repetition rate drive laser for milliamp current
- Photocathode physics program for more exotic cathodes

**Bi thin film in the rombohedral phase. The surface state ~0.4 eV below the Fermi edge (blue spot) only has ±2° emission angle.**

**This involves accessing a specific surface state without thermalization.**




G. Bian, T. Miller, and T.-C. Chiang, Phys. Rev. B 80, 245407 (2009)

# Overall WiFEL R&D Plan

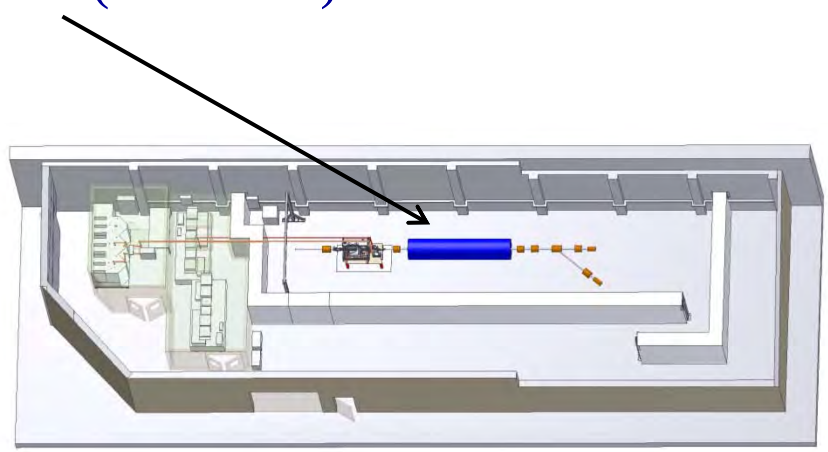
- Development of a high repetition rate, VHF superconducting RF electron gun, including a high repetition rate (several megahertz) photocathode drive laser

- R&D on photocathode materials, including novel approaches, by Angle Resolved Photo Emission Spectroscopy (ARPES) studies on the Aladdin storage ring at SRC

- Studies of the laser high harmonic generation (HHG) process to establish the necessary noise performance as a seed laser source

- Evaluation of FEL facility architectures with the specific goal of cost containment

- Ultimately, addition of post acceleration (~50 MeV) as test bed for beam and FEL physics



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# Summary

- Wisconsin SRF electron gun development moving forward as planned
- Offers attractive capabilities as CW electron source for FELs and other applications
- In a year, we hope to have made our first low emittance electron bunch

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