The Wisconsin Superconducting RF Gun*

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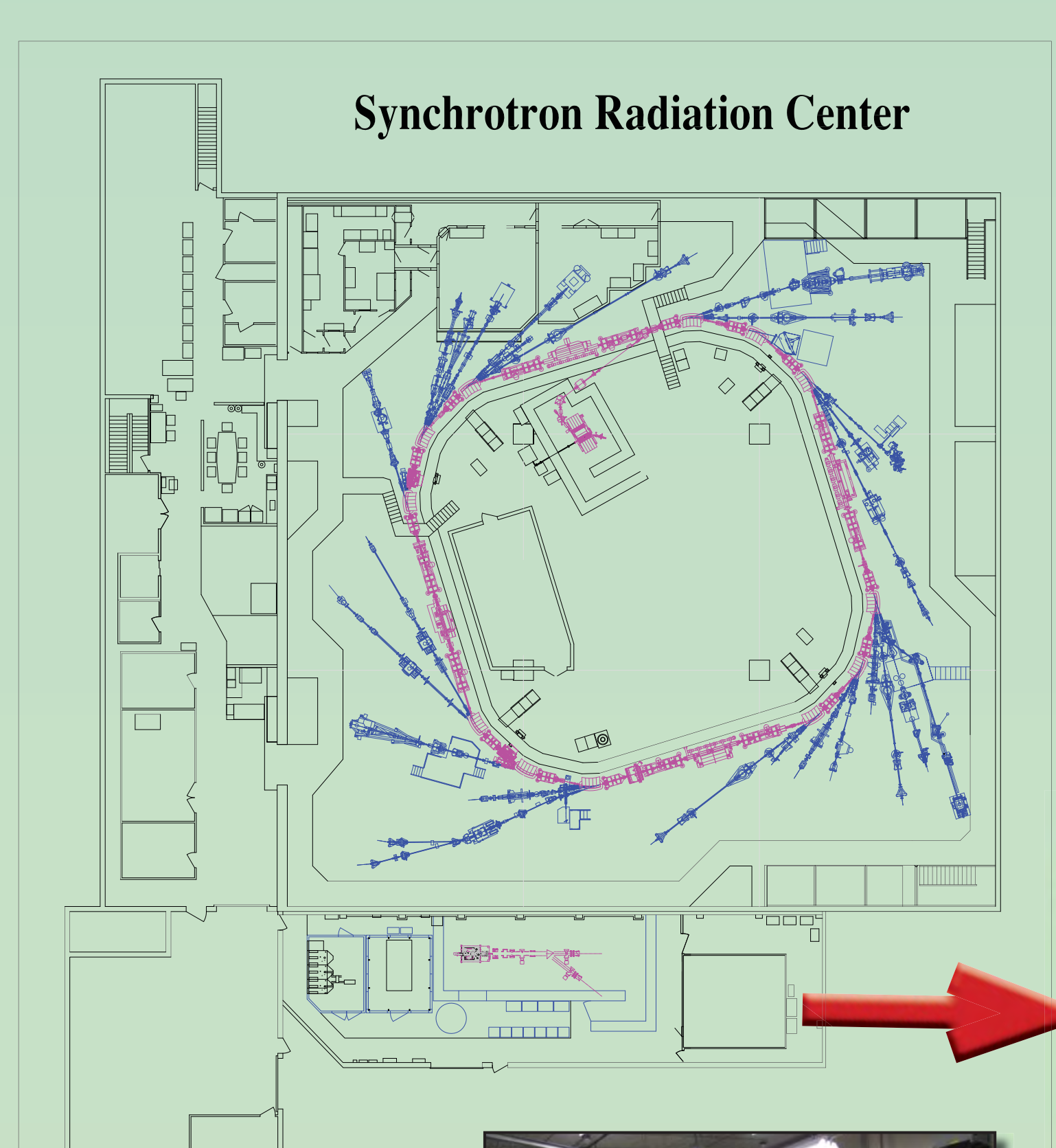
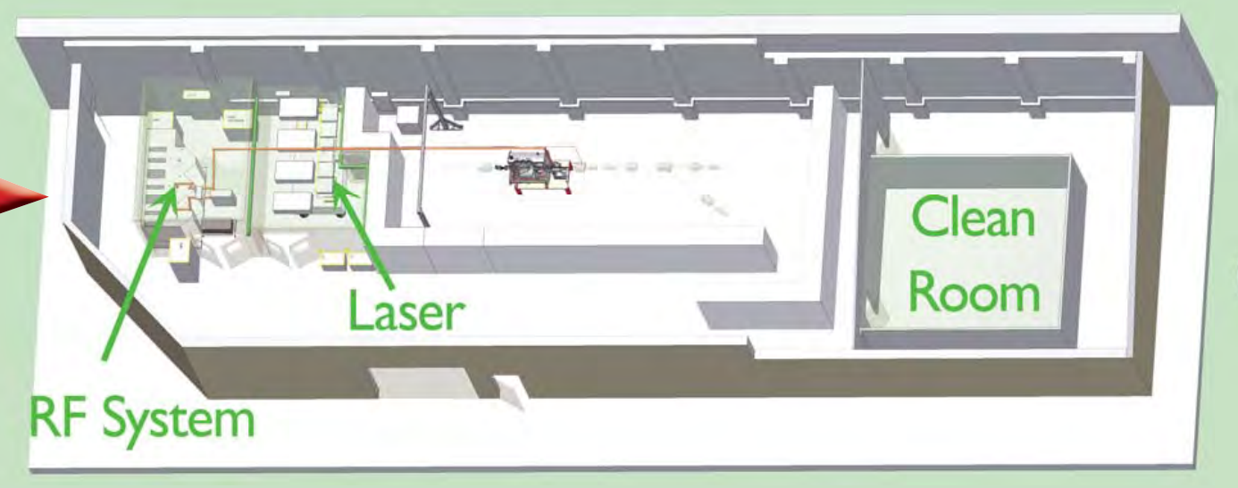
Construction and Test of a Novel Superconducting RF Electron Gun

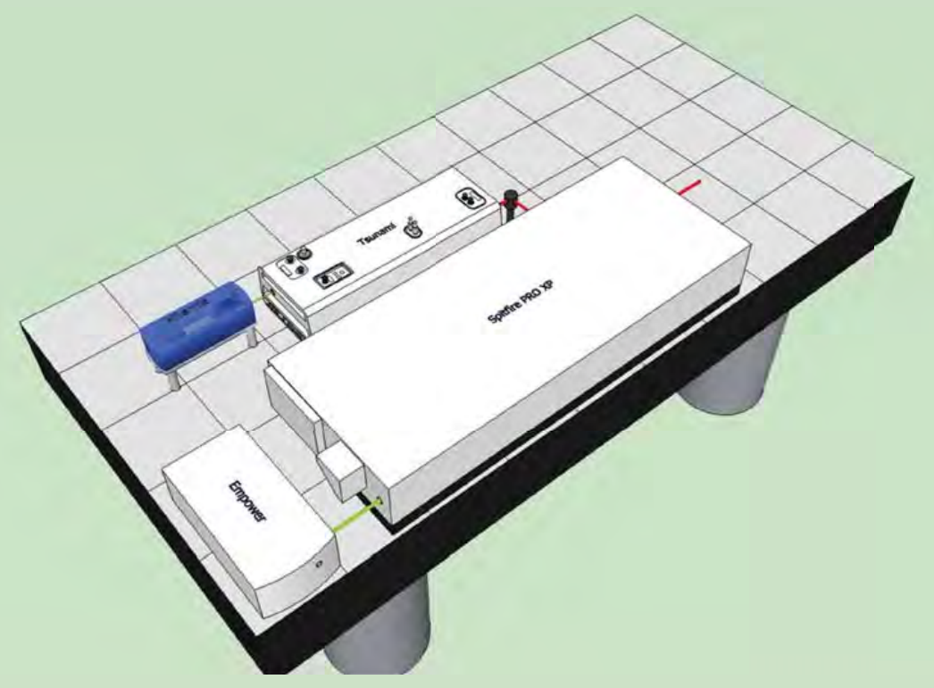
The University of Wisconsin FEL team is moving forward with the development a 199.6 MHz superconducting RF gun that meets the required specifications for a CW FEL in the soft X-ray region. A three year program is under way, with key procurements in place and installation of the hardware and commissioning in a one year time frame.





Superconducting RF Gun Vault

Vault Refurbishment



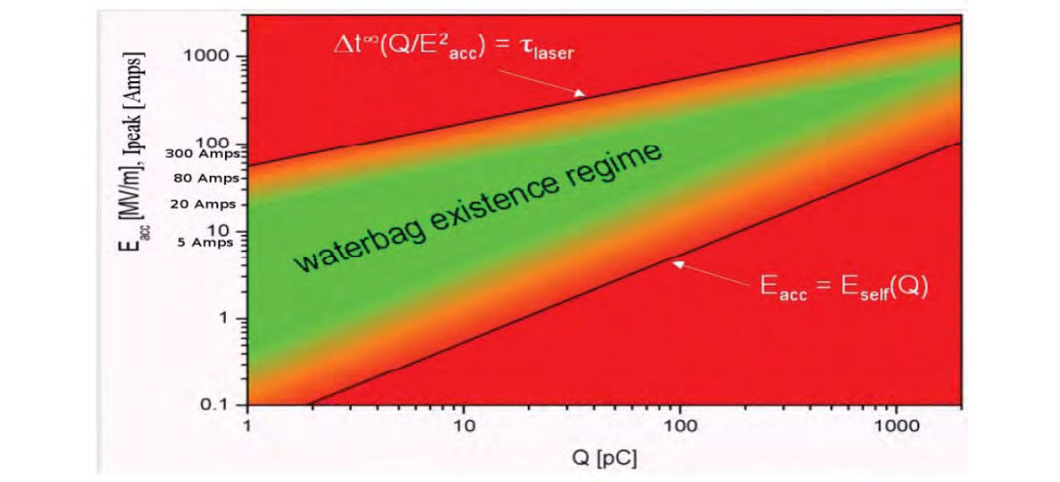
Spectra-physics Tsunami (oscillator) + Spitfire (amplifier) system

RF Power Amplifier

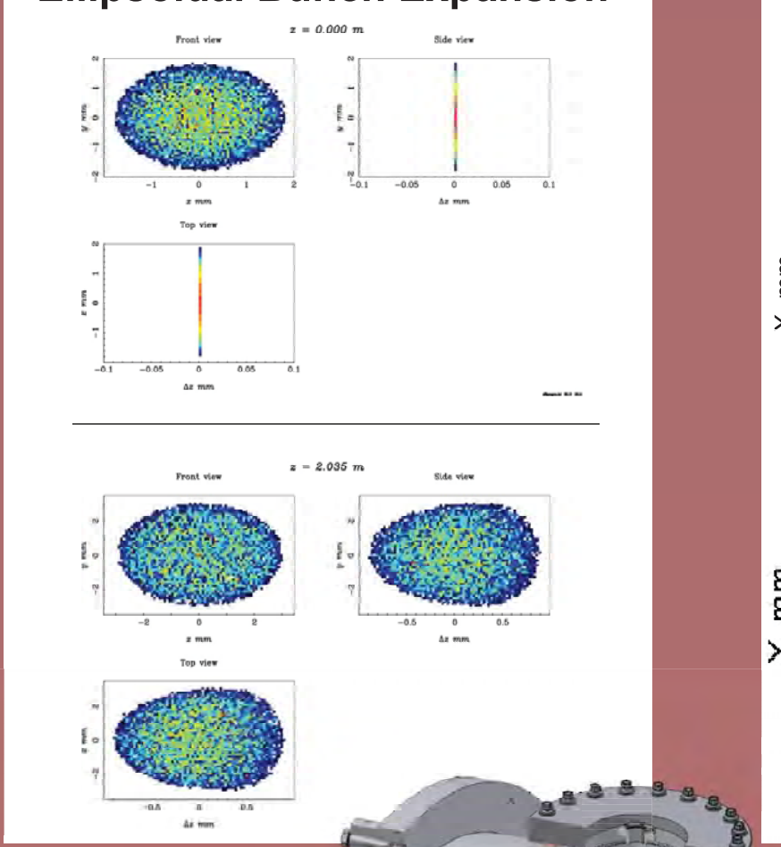
JLAB LLRF

Wisconsin Superconducting RF Electron Gun

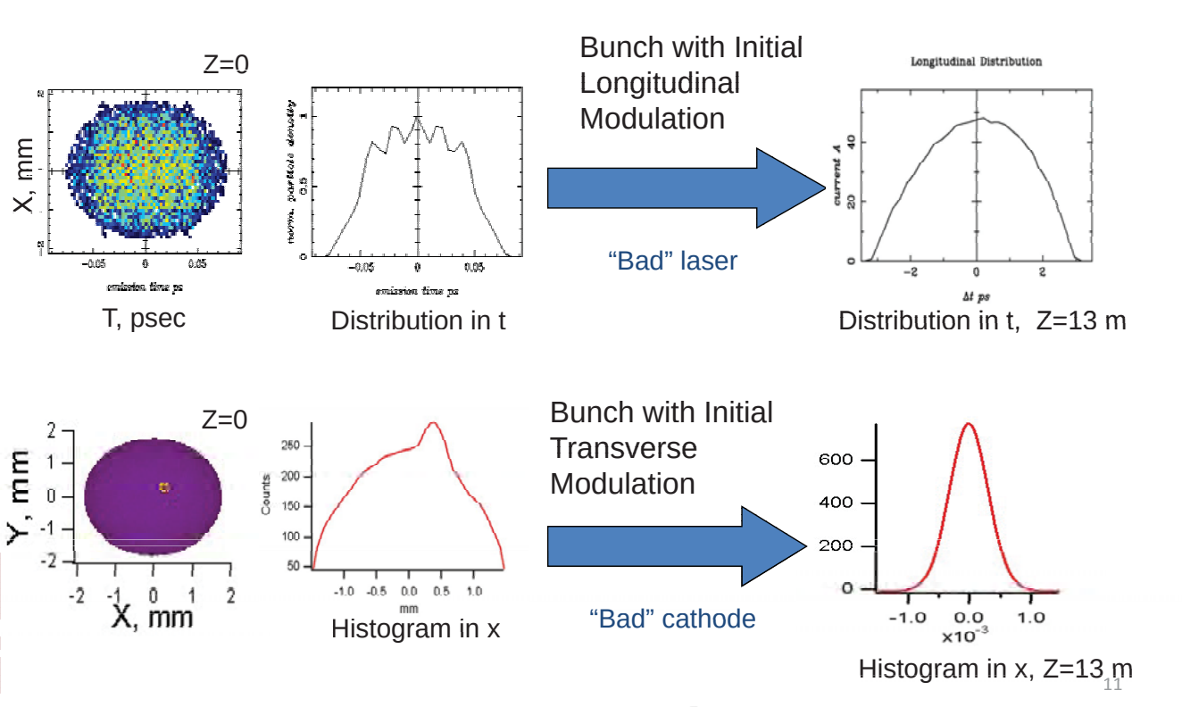
- SRF offers advantages for high average current electron gun
  - Higher gradients achievable at cathode (~ 40 MV/m)
  - Without need to optimize for heat load, acceleration gap can be large, yielding substantial increase in output beam energy (~4 MeV)
- Lower frequency for temporal field flatness (quasi-DC)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



Ellipsoidal Bunch Expansion

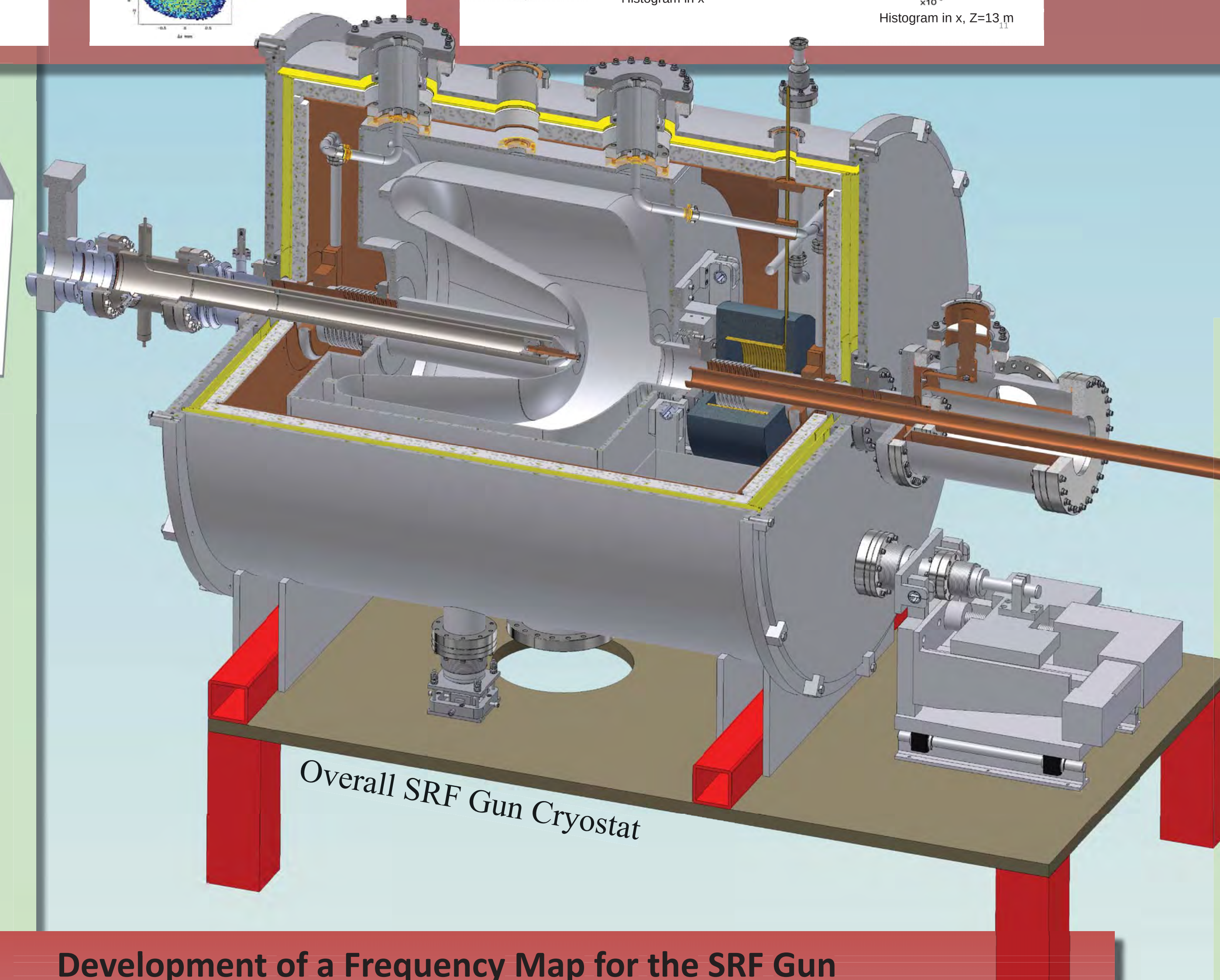


Blow-Out Mode Smooths Initial Distribution Errors



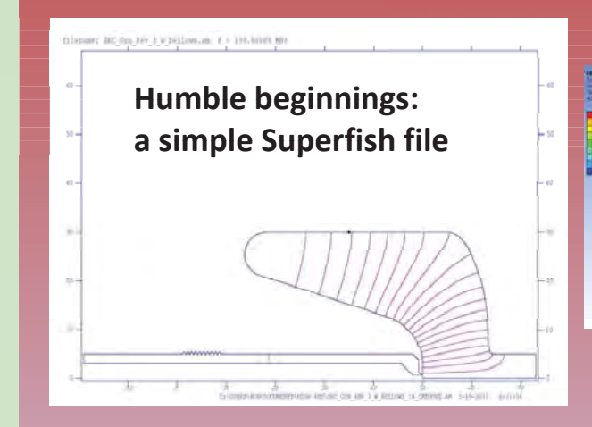
SRF Electron Gun Parameters

Parameter	**Value**
Beam kinetic energy	4.0 MeV
Bunch charge	10–200 pC
Norm. trans. emittance	0.2–0.9 mmmr
Max. average beam current	1.0 mA
Peak current (at 100 MeV)	50 A
Photocathode	varied
Driving laser wavelength	266 nm
Pulse duration (FWHM)	0.100 ps
Bunch repetition rate	5 MHz
Electric field at cathode	45 MV/m

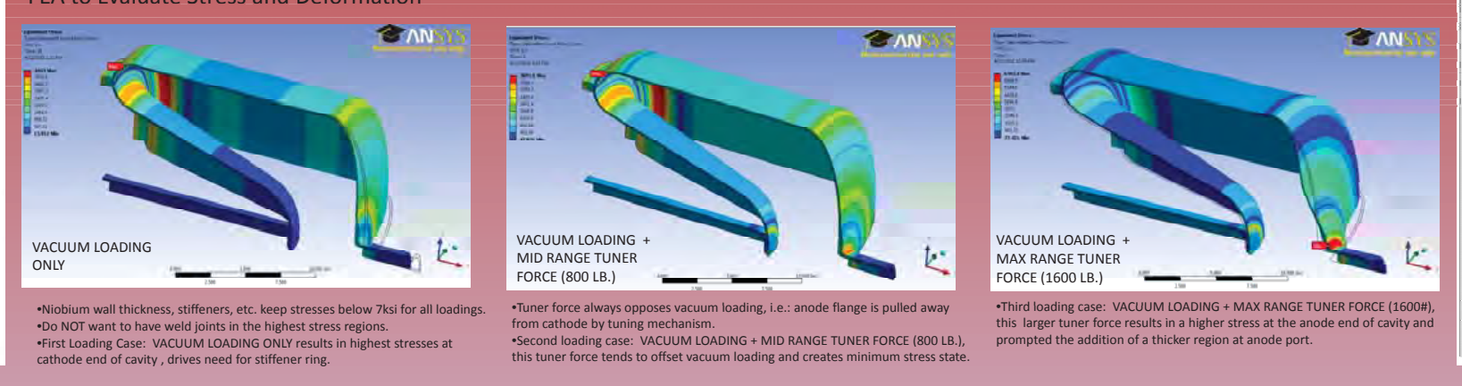


Overall SRF Gun Cryostat

Development of a Frequency Map for the SRF Gun

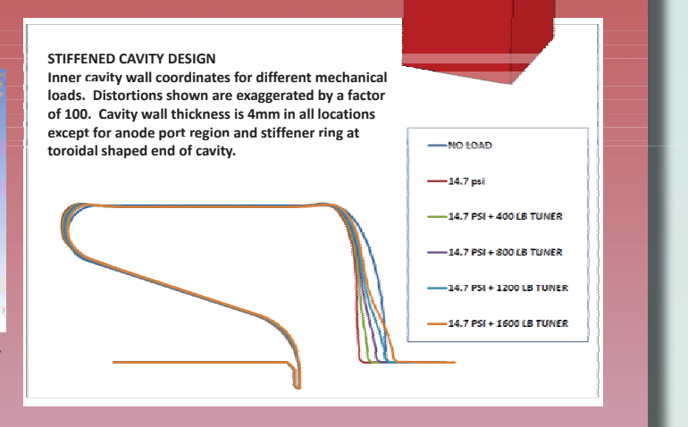


FEA to Evaluate Stress and Deformation

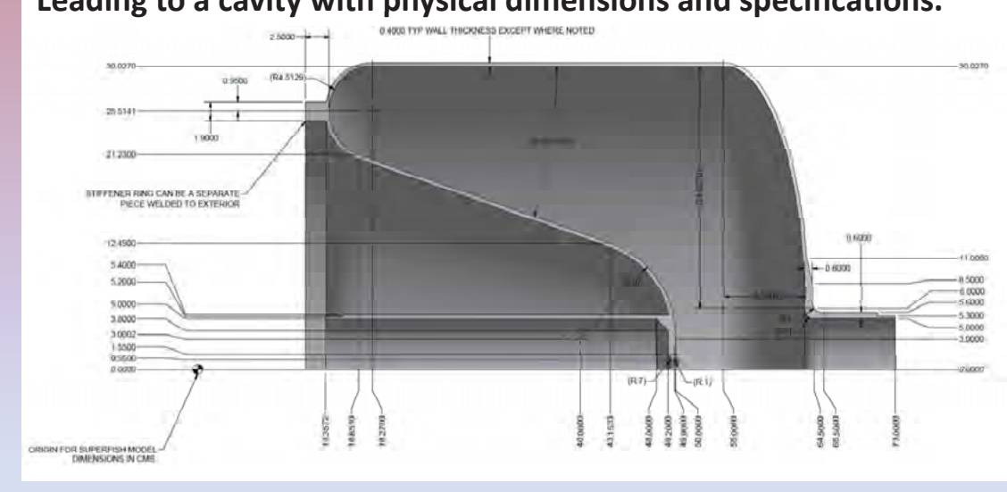


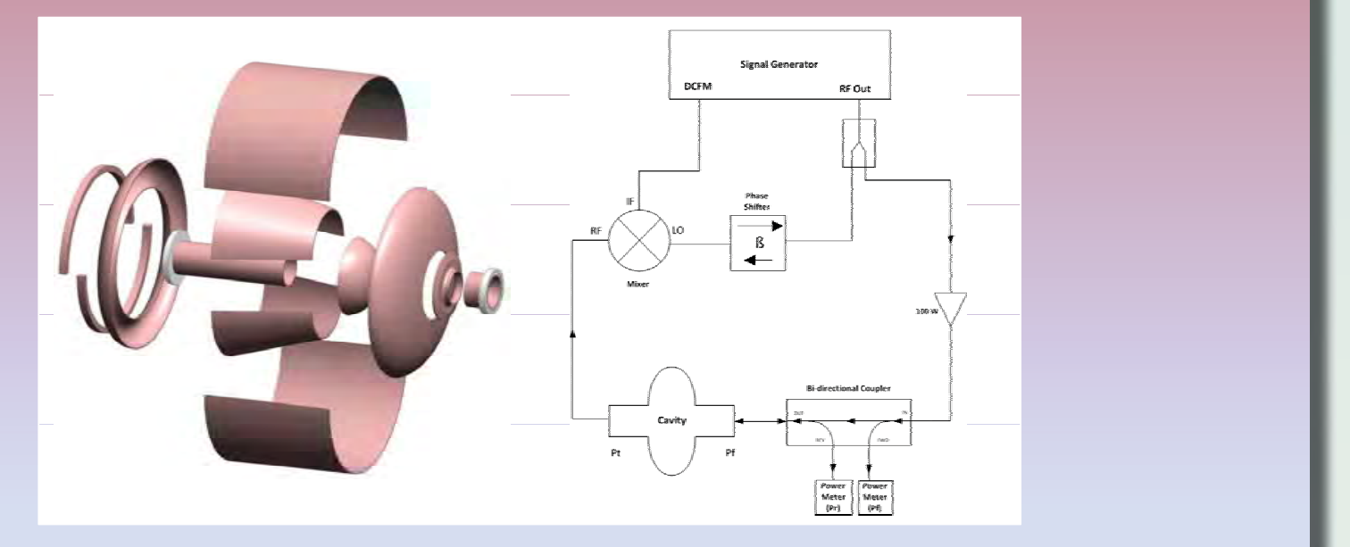
- •Niobium wall thickness, stiffeners, etc. keep stresses below 7ksi for all loadings.
- •Do NOT want to have weld joints in the highest stress regions.
- •First Loading Case: VACUUM LOADING ONLY results in highest stresses at cathode end of cavity , drives need for stiffener ring.
- •Tuner force always opposes vacuum loading, i.e.: anode flange is pulled away from cathode by tuning mechanism.
- •Second loading case: VACUUM LOADING + MID RANGE TUNER FORCE (800 LB.), this tuner force tends to offset vacuum loading and creates minimum stress state.
- •Third loading case: VACUUM LOADING + MAX RANGE TUNER FORCE (1600#), this larger tuner force results in a higher stress at the anode end of cavity and prompted the addition of a thicker region at anode port.

STIFFENED CAVITY DESIGN
Inner cavity wall coordinates for different mechanical loads. Distortions shown are exaggerated by a factor of 100. Cavity wall thickness is 4mm in all locations except for anode port region and stiffener ring at toroidal shaped end of cavity.



Leading to a cavity with physical dimensions and specifications.

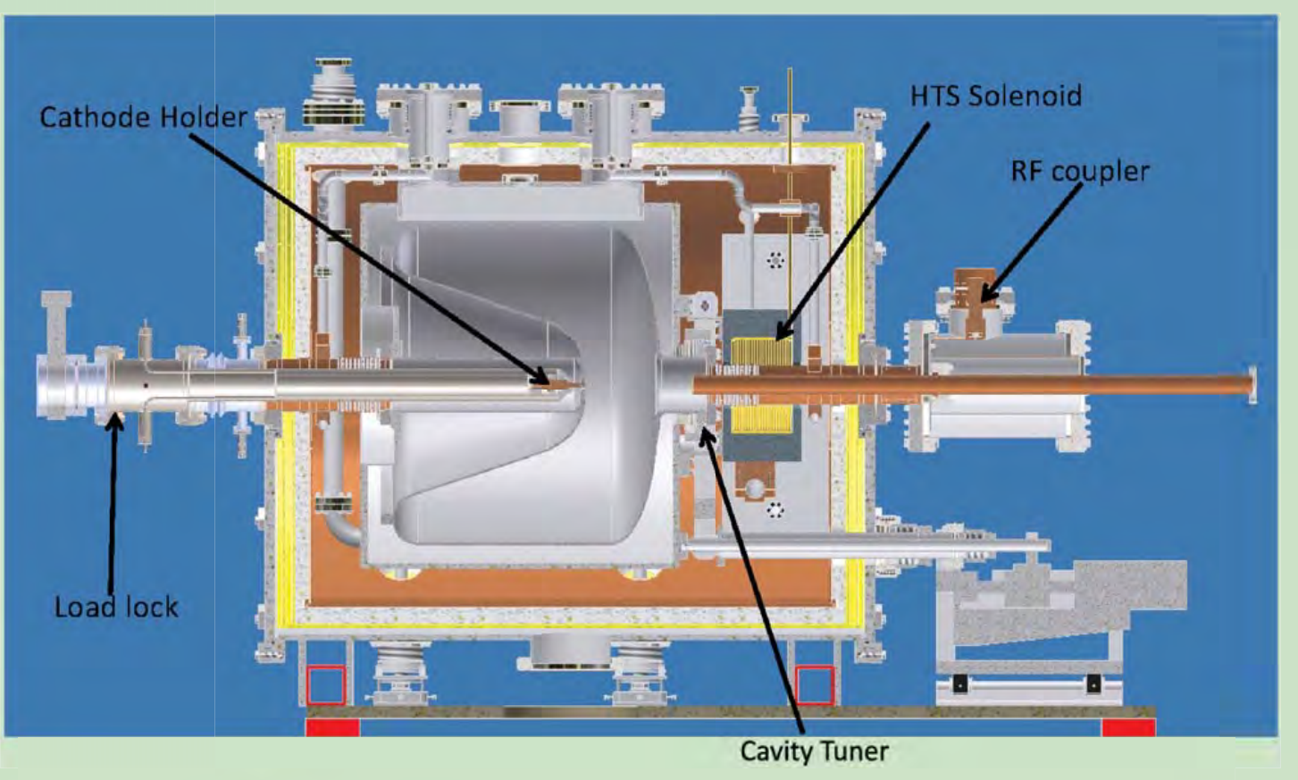


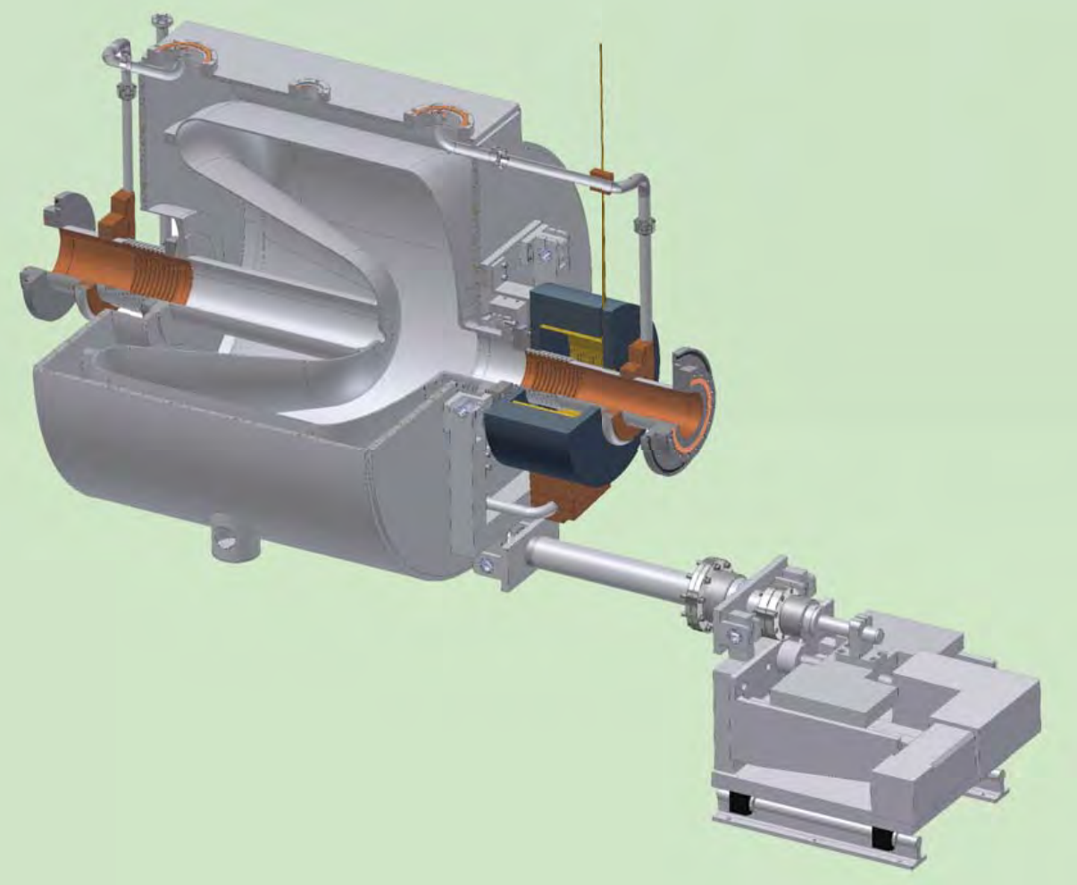


State	Freq, MHz	D Freq, MHz	Volume, in^3	D volume, in^3
Nominal, 4 K	199.58953	-	6269.213	
Remove 1600 lb preload on tuner	199.65256	0.06303	6267.753	-1.46
Warmed to 273 K	199.3704	-0.28216	6294.653	26.9
Skin depth vs temp at 200 MHz	199.3185945	-0.05180	6295.853	1.2
Remove vacuum load	199.2485945	-0.07	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

Steps from cavity blank to final frequency

University of Wisconsin SRF Gun



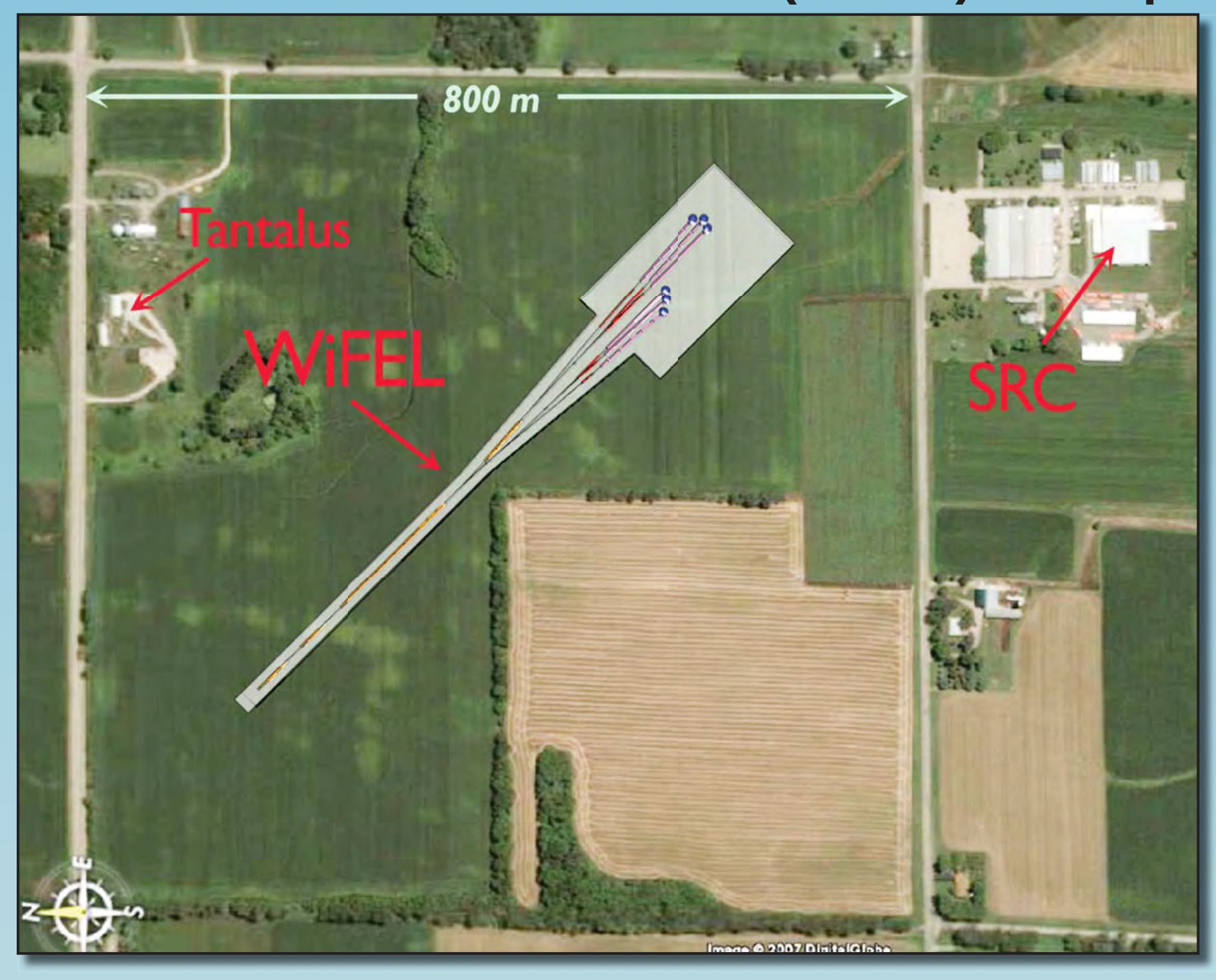


Isometric Cross-Section of Niowave 3-D Model of Cavity and Helium Vessel as Approved in FDR

Copper Prototype for Cake Pan

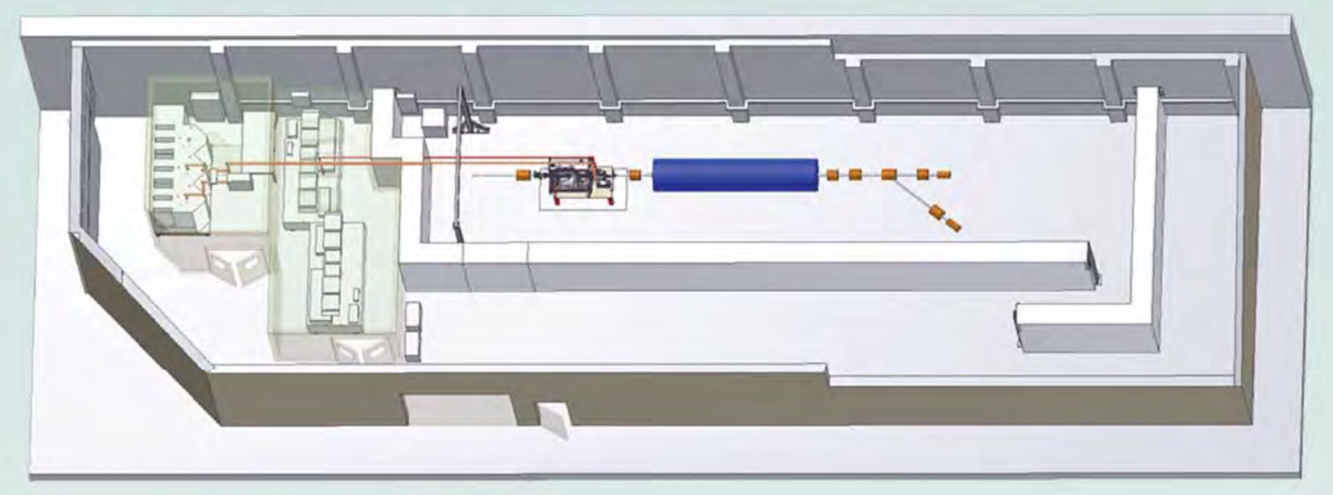
NbTi Cathode Flange

Wisconsin Free Electron Laser (WiFEL) Concept



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***
- ***Addition of post acceleration (~50 MeV) as test bed for beam and FEL physics***



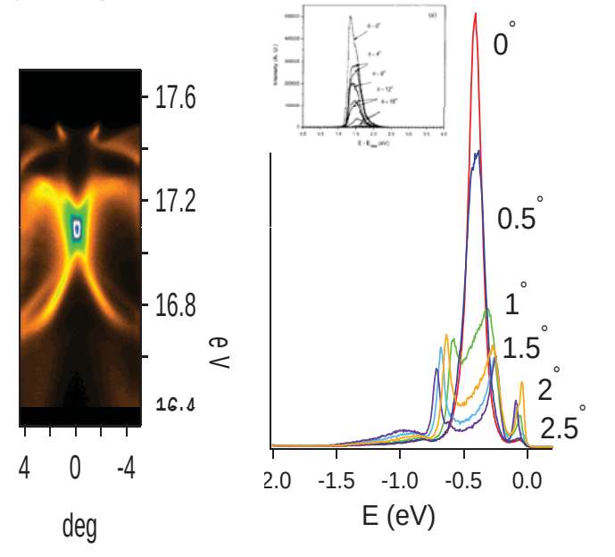
Post Acceleration Cryomodule

Coming Attractions

- Cathode Preparation Chamber
- High repetition rate drive laser
- Photocathode physics program

Bi thin film in the rombohedral phase. The surface state ~0.4 eV below the Fermi edge (blue spot) only has ±2° emission angle. The angular EDCs for Cs:GaAs are shown (inset) for comparison.

This involves accessing a specific surface state without thermalization.



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

Abstract

An SRF electron gun was chosen because it is well suited to the requirements of an accelerator based lightsource. [1] It uses low charge bunches with a high peak current at the exit of the injector to minimize downstream magnetic compression and reduce collective effects. The electric fields on the cathode in an SRF gun are higher than other CW sources (>20 MV/m) resulting in greater ultimate brightness. Finally, the electron bunch pulse repetition rates for SRF guns are only limited by the RF power couplers and HOM suppression, meaning that user beamlines can be driven at megahertz repetition rates by a single accelerator. These features make the SRF gun very attractive at moderate currents compared to other devices proposed. Further details of the design may be found in reference [2]. This approach complements programs in room temperature RF guns at LBNL, DC guns at Cornell, and L-band guns in Europe.

The electromagnetic design itself was optimized to produce maximum electric field at the cathode while minimizing the peak electric field in the cavity. This will reduce the possibility of field emission limiting the cavity gradient. Similarly, the peak surface magnetic field was minimized to reduce the possibility of magnetic quench of the cavity. The cavity was also optimized to produce a large integrated field between the cathode and anode gap in order that the gun should have a large exit energy. The overall design produces very bright bunches that have sufficient momentum to use the demonstrated LCLS emittance compensation scheme (gun / solenoid / linac section) as part of the injector for an FEL. The cathode is warm with respect to the cavity. Another feature of the design is a high Tc superconducting solenoid for emittance compensation.

To meet the stringent requirements on the longitudinal distribution of the bunch to avoid density modulations in the FEL, we plan to use self inflating (blow out mode) bunches for the FEL. Blow out mode is a scheme in which a laser pulse that is significantly shorter than the final bunch length is used to create a charge pancake on the surface of the cathode, which then expands under its own self space charge force to an ellipsoidal bunch with uniform charge density [3].

Major procurements are now in place. Niowave is fabricating the cavity/helium vessel, and Danfysik is responsible for the High Tc emittance compensation solenoid. A variant of the Jefferson Lab 12-GeV low level RF control module will used to operate the 20 kW solid state RF system that has been delivered. The photocathode laser system has been selected and is scheduled for delivery at the end of the year. A vault area adjacent to the Aladdin synchrotron is currently being refurbished as the home of the electron gun, and there is sufficient space to allow installation of a post-accelerator at a later date. Installation and system commissioning is scheduled for early 2012 with beam testing scheduled for fall 2012.

References

[1] J. Bisognano, et al., "The Wisconsin Free Electron Laser Initiative," in: Proceedings of the 2009 Part. Accel. Conf. (2009).

[2] R. Legg, et al., "SRF Photoinjector R&D at University of Wisconsin," in: Proceedings of ERL09, 45th ICFA Advanced Beam Dynamics Workshop.

[3] O.J. Luiten, et al., "How to Realize Uniform Three-Dimensional Ellipsoidal Electron Bunches," Phys. Rev. Lett. 93, 094802 (2004).

Publications

- J. Bisognano et al., "Progress toward the Wisconsin Free Electron Laser Facility," 2011 Particle Accelerator Conference, 2011.
- R. Legg, "Gun R&D at Wisconsin," Mini-workshop on Compact X-ray FELs, LBNL, Berkeley, CA, August 5-6, 2010.
- R. Legg, M. Fisher, K. Kleman, "Development of a Frequency Map for the WIFEL SRF Gun," SRF 2011, Chicago, IL, July 25-29, 2011.

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Project Timeline

- 10/1/10
- 11/10 High Power RF Delivery
- 3/11 JLAB CRADA LLRF
- 4/11 Niowave Cavity Contract
- 6/11 Danfysik HTS Solenoid Contract
- 9/11 Laser Procurement
- 10/1/11
- 12/11 Vault Completion
- 1/12 Laser Delivery
- 3/12 Solenoid Delivery
- 3/12 Cavity Delivery
- Assembly & Installation Including Diagnostic Controls
- 9/12 First Beam
- 10/1/12
- Beam Tests
- 10/1/13

Fiscal Year 2011
Design, Procurement, Site Preparation

Fiscal Year 2012
Fabrication, Installation

Fiscal Year 2013
Commissioning, Data Taking