Status and Plans for the LBNL Normal-Conducting CW VHF Photo-Injector

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A Team Work

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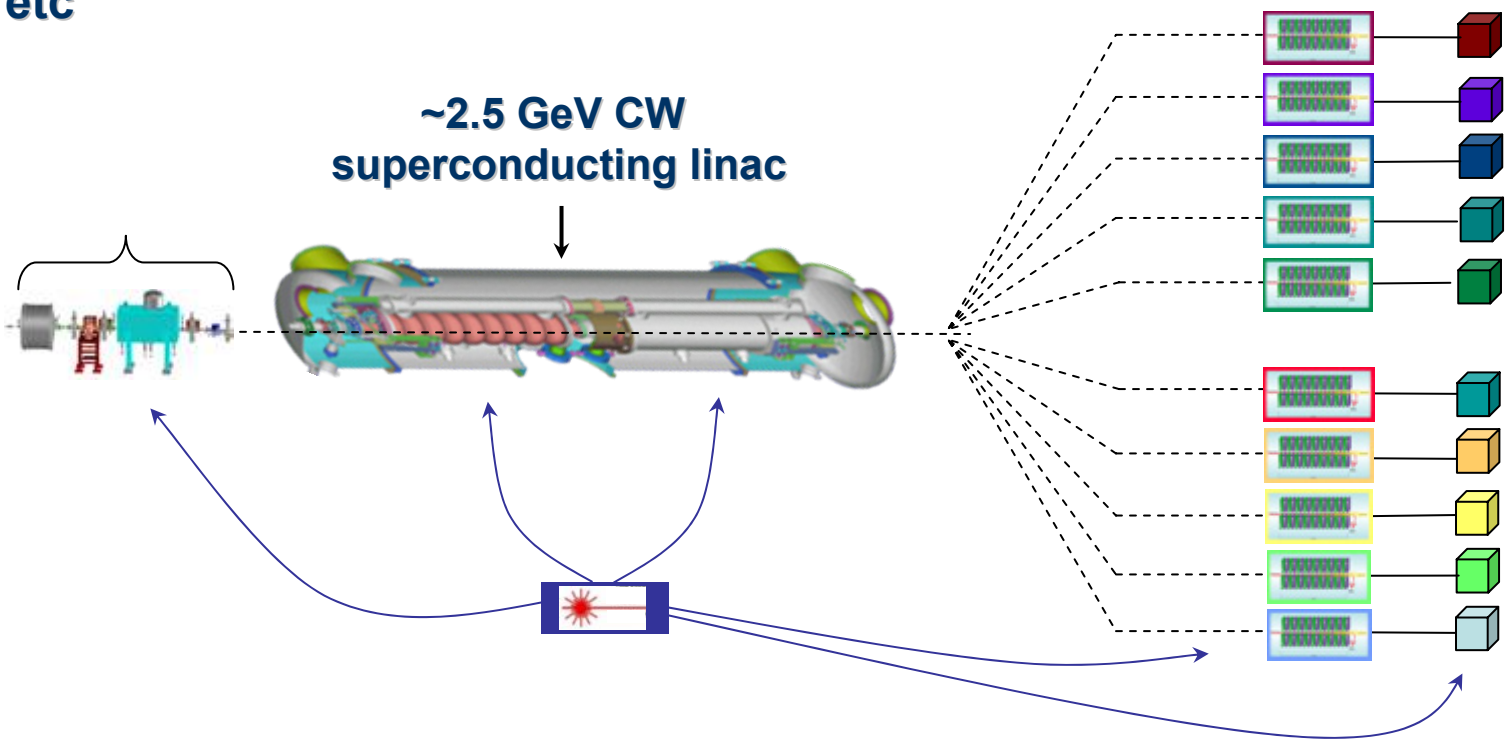
The LBNL FEL Scheme (since 2005)

A HIGH REP-RATE (MHz), SEEDED VUV — SOFT X-RAY FEL ARRAY

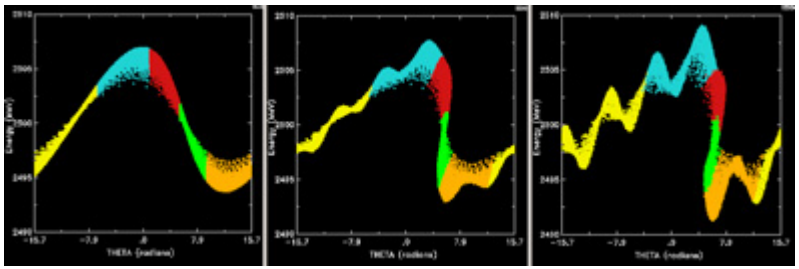
- Array of configurable FELs (up to 100KHz/FEL)
- Independent control of wavelength, pulse duration, polarization
- Each FEL configured for experimental requirements: seeded, EEHG, attosecond, ESASE, etc

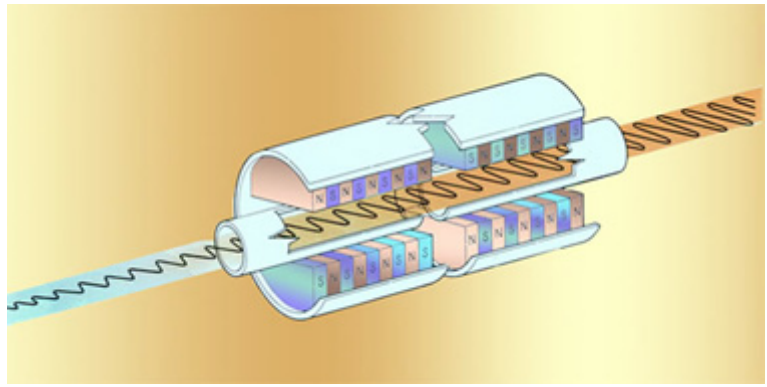


A Science Driven Facility

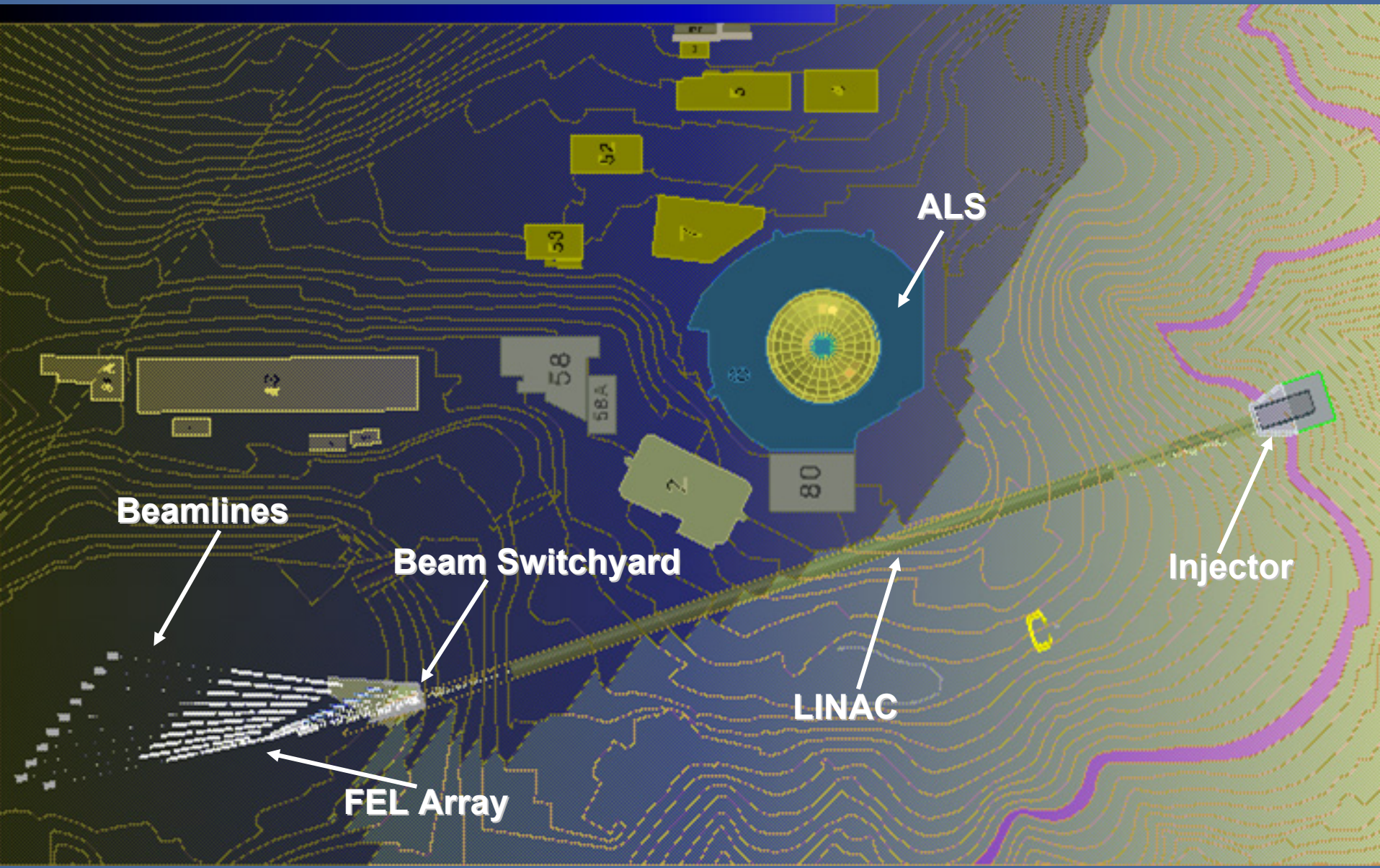
Science for a New Class of Soft X-ray Light Sources
Workshop on October 8 - 10, 2007 | Berkeley, California

1. Atomic, Molecular and Optical Physics
2. Chemical Physics
3. Correlated Materials
4. Magnetization and Spin Dynamics
5. Nanoscience and Coherence





The LBNL FEL: a Possible Location



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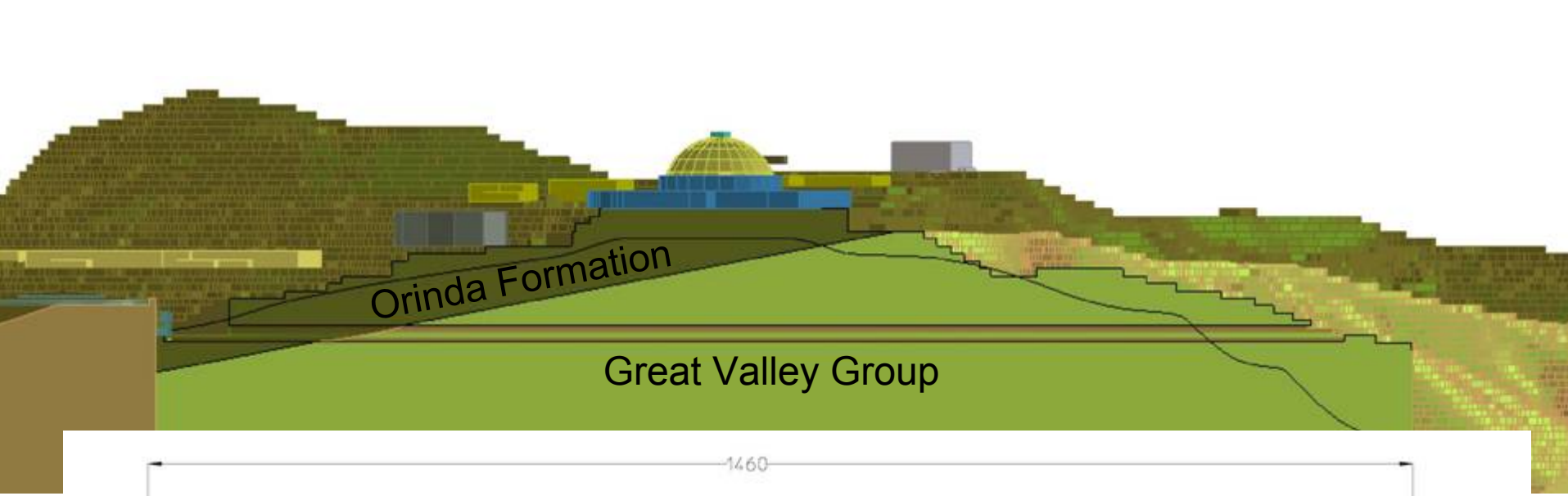
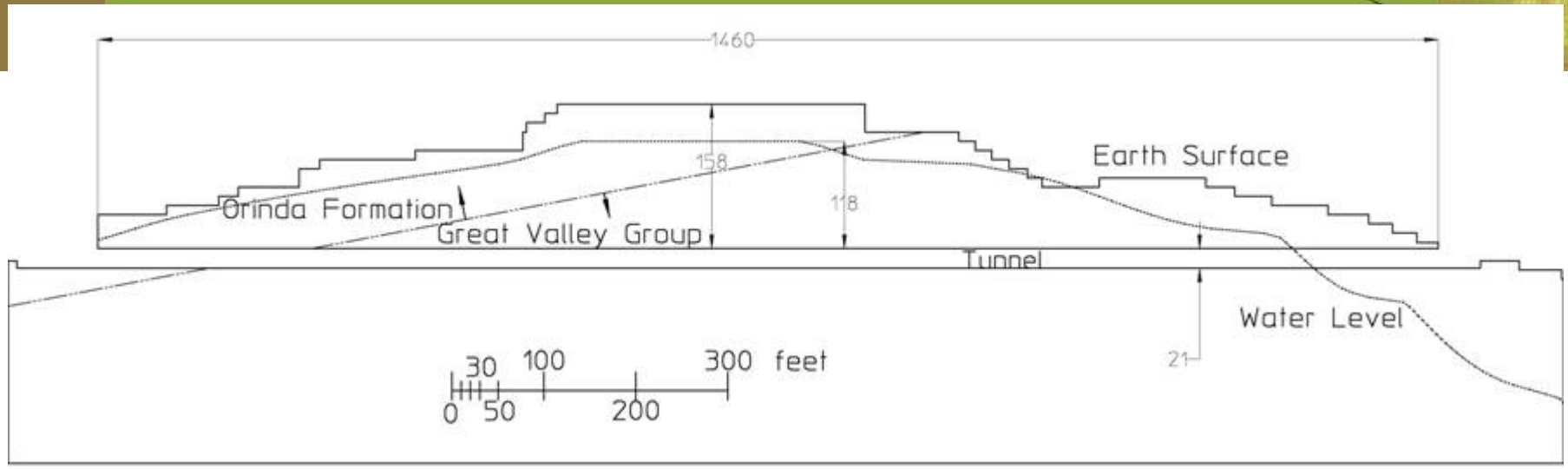
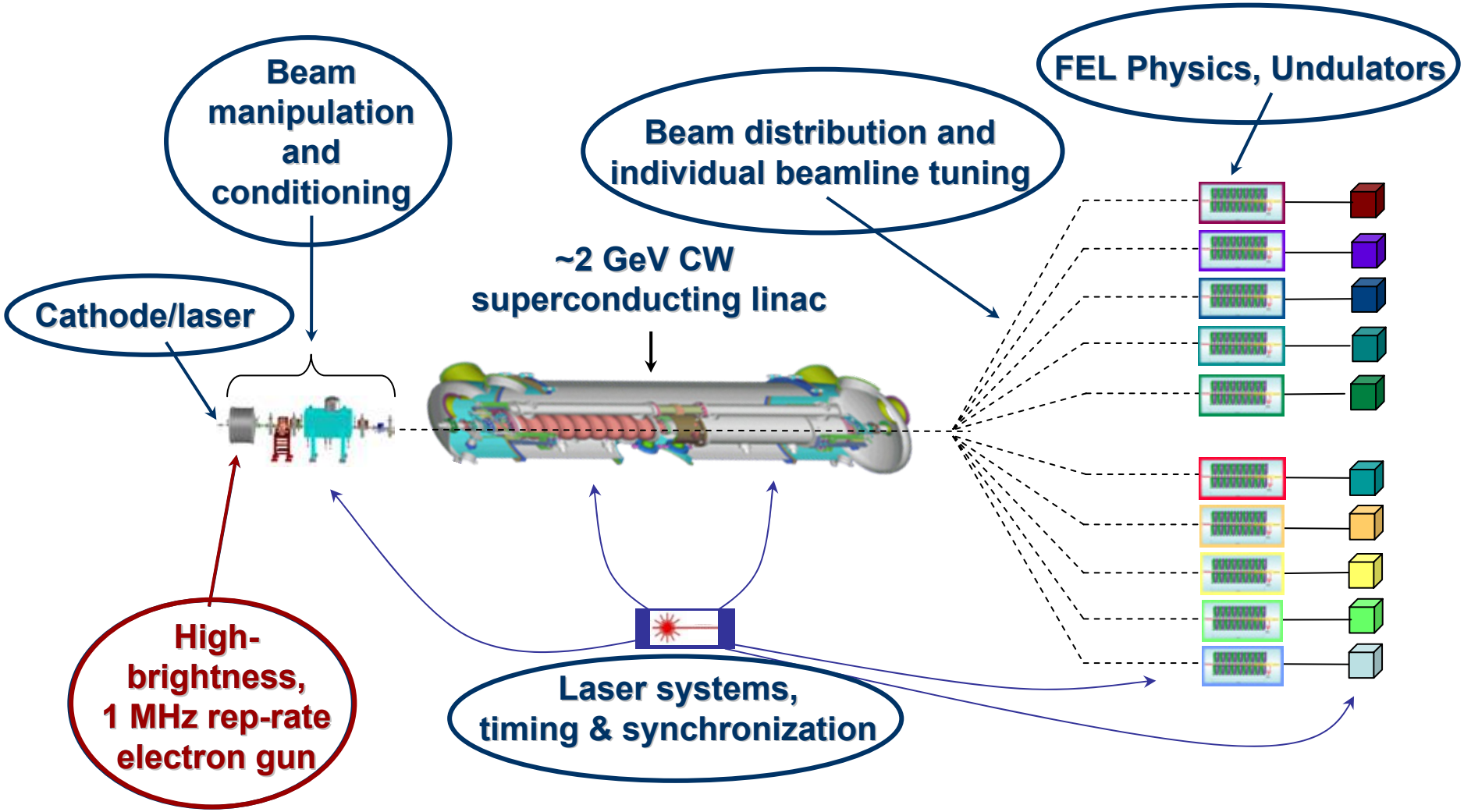




An R&D Program and Studies for the Critical Parts



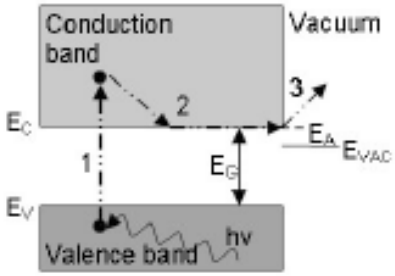
Most of such R&D areas are funded

Electron Source Requirements

To achieve the LBNL FEL goals, the electron source should simultaneously allow for:

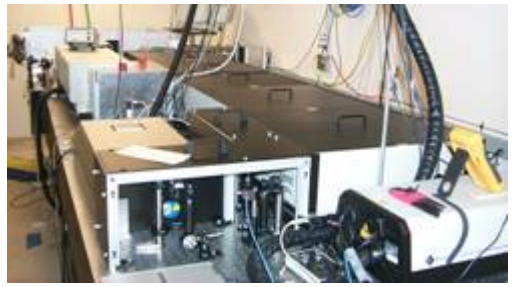
- **repetition rates of up to ~ 1 MHz,**
- **charge per bunch from few tens of pC to ~ 1 nC,**
- **sub 10^{-6} m normalized beam emittance,**
- **beam energy at the gun exit greater than ~ 500 keV,**
- **electric field at the cathode greater than ~ 10 MV/m,**
- **bunch length control for minimizing space charge effects,**
- **compatibility with magnetic fields in the cathode and gun regions (mainly for emittance compensation)**
- **10^{-11} Torr operation vacuum pressure,**
- **"easy" installation and test of different kind of cathodes,**
- **high reliability compatible with the operation of a user facility.**

Available Gun Technologies

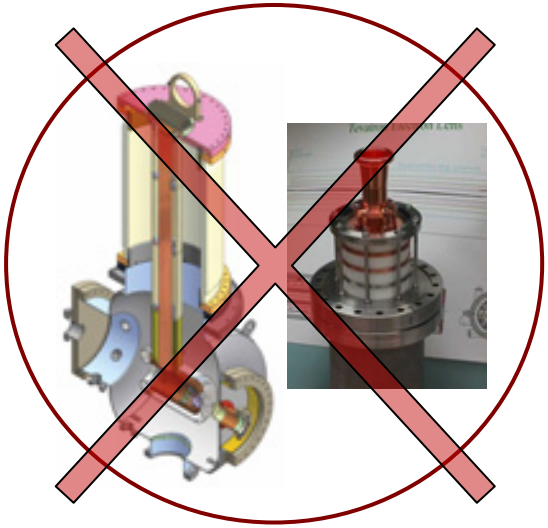


Low emittance, high quantum efficiency photo-cathodes
(for high repetition rates)

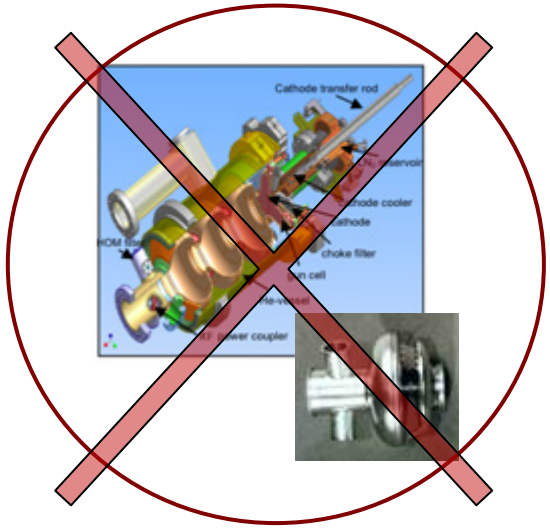
High charge, low emittance and high reprate require photo guns



Photocathode laser systems including pulse shaping



DC gun

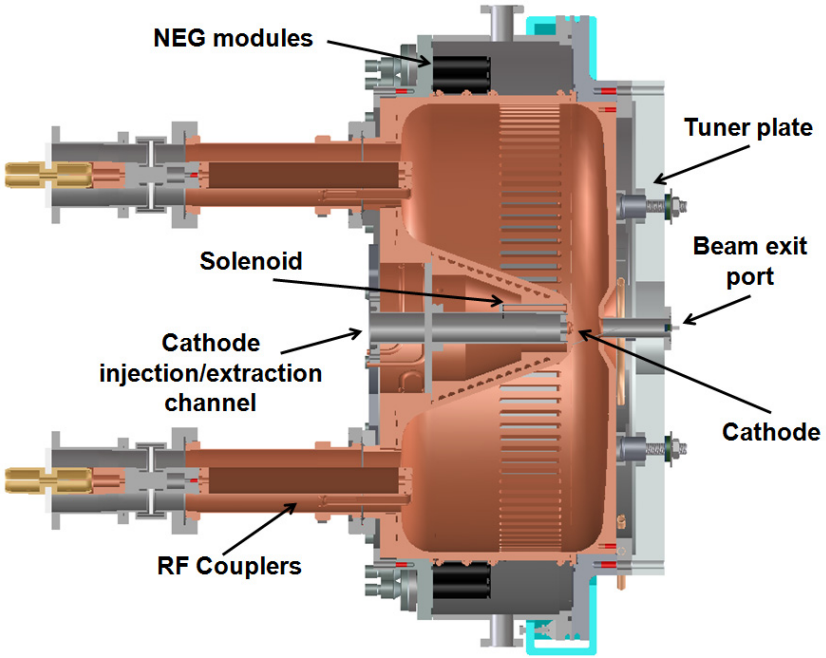


Super-conducting RF

High frequency (> 1 GHz) normal-conducting RF

The LBNL VHF gun

The Berkeley normal-conducting scheme satisfies all the LBNL FEL requirements simultaneously.



J. Staples, F. Sannibale, S. Virostek, CBP Tech Note 366, Oct. 2006

K. Baptiste, et al, NIM A 599, 9 (2009)

Frequency	187 MHz
Operation mode	CW
Gap voltage	750 kV
Field at the cathode	19.47 MV/m
Q_0	30887
Shunt impedance	6.5 MΩ
RF Power	87.5 kW
Stored energy	2.3 J
Peak surface field	24.1 MV/m
Peak wall power density	25.0 W/cm^2
Accelerating gap	4 cm
Diameter	69.4 cm
Total length	35.0 cm

- **At the VHF frequency, the cavity structure is large enough to withstand the heat load and operate in CW mode at the required gradients.**
- **Also, the long λ_{RF} allows for large apertures and thus for high vacuum conductivity.**
- **Based on mature and reliable normal-conducting RF and mechanical technologies.**
- **187 MHz compatible with both 1.3 and 1.5 GHz super-conducting linac technologies.**

Low Frequency CW or Quasi-CW RF Guns

A VHF (144 MHz) gun is used at the ELSA 19 MeV linac and produces high charge-low emittance beams within a 150 μs macropulse at 10 Hz repetition rate.

R. Dei-cas, *et al.*, NIM A, **296**, pp. 209 (1990).
R. Dei-cas, *et al.*, NIM A, **331**, pp. 199 (1993).
J.-G. Marmouget, *et al.*, EPAC 2002, Paris, France, June 2002, p. 1795.
D. Guilhem, *et al*., EPAC 2006, Edinburgh, Scotland, July 2006, p. 1927.

The Boeing gun has achieved 25% duty cycle operation at 433 MHz.

D. Dowell, *et al*., Appl. Phys. Lett., **63** (15), 2035 (1993).

A Los Alamos/AES completed the construction of a 700 MHz normal-conducting RF gun where a sophisticated and state of the art cooling system allows the gun to operate in CW mode.

S.S. Kurennoy, *et al.*, NIM A **528**, 392 (2004).

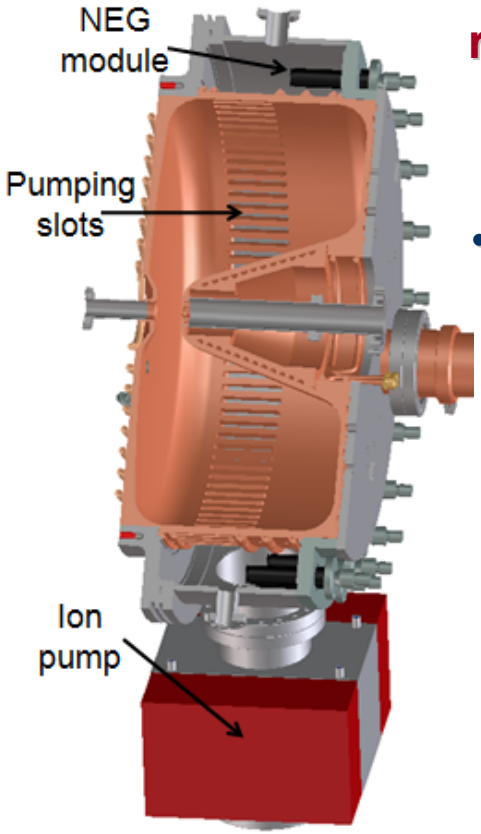
A 700 MHz CW normal conducting gun was studied at JLAB.

R. A. Rimmer, PAC05, pag. 3049.

A 144 MHz CW normal conducting gun was studied at BNL.

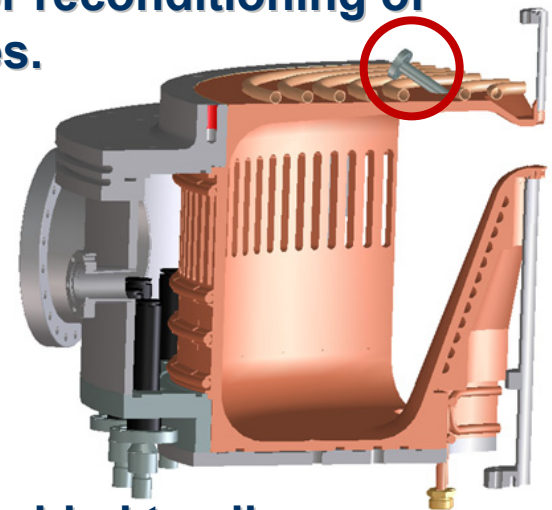
X. Chang, *et al.*, PAC07, pag. 2547.

A Cathode Test Facility



- The vacuum system has been designed to achieve an operational vacuum pressure down into the low 10^{-11} Torr range. NEGs pumps are used (very effective with H_2O and O_2). This arrangement will allow testing a variety of cathodes including "delicate" multi-alkali and/or GaAs cathodes.
- An ion pump accounts for noble gasses and hydrocarbons.
- Cathode area designed to operate with a vacuum load-lock mechanism (based on the FLASH, FNAL, INFN design) for an easy in-vacuum replacement or reconditioning of photocathodes.

The nominal laser illumination configuration for the cathode is quasi-perpendicular with laser entrance in the beam exit pipe.



An additional 30 deg laser entrance port has been added to allow testing of more exotic cathodes (surface plasma wave cathodes, ...)

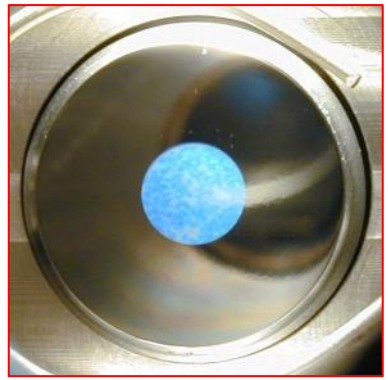
Cathodes & Lasers

PEA Semiconductor: Alkali Antimonides, eg. $SbNa_2KCs$
(also under development at BNL and at Daresbury)

- fast
- fairly reactive; requires UHV ~ 10^{-10} Torr pressure.
- high QE (typ. 10%).
- requires green light (eg. frequency doubled Nd:YVO4 = 532nm: high efficiency)
- nC, 1 MHz….40 mW of IR required (laser oscillator)
- unproven at high rep rate and high average current

PEA Semiconductor: Cs_2Te (used at FLASH for example)

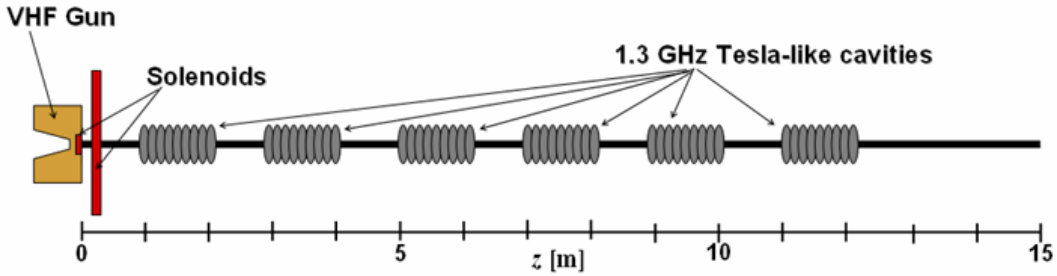
- fast
- relatively robust and un-reactive
  - can be used in a high gradient rf gun
- high QE; typ. 10%
- requires UV (eg. 3rd harm. of Ti:Sapphire: 5% conversion effic.).
- For 1 nC - 1 MHz reprate, ~ 1 W 1060nm required

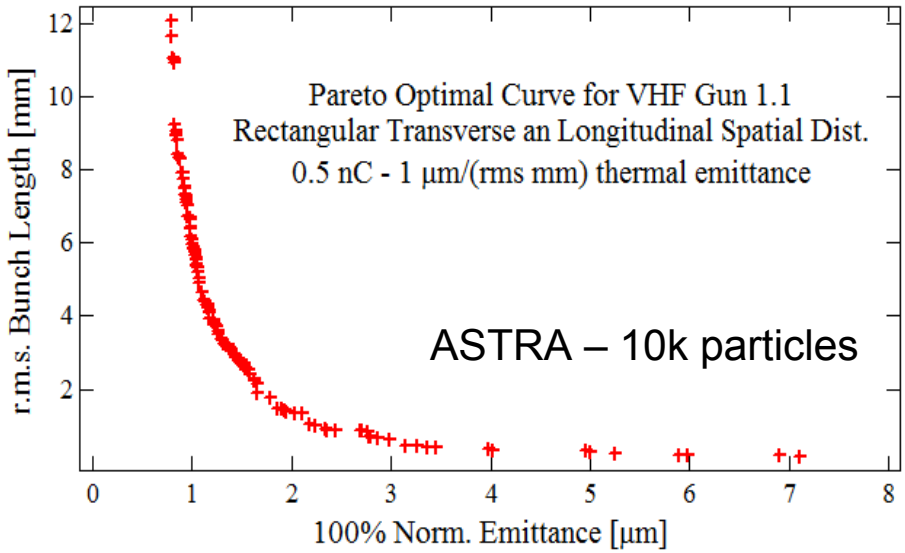


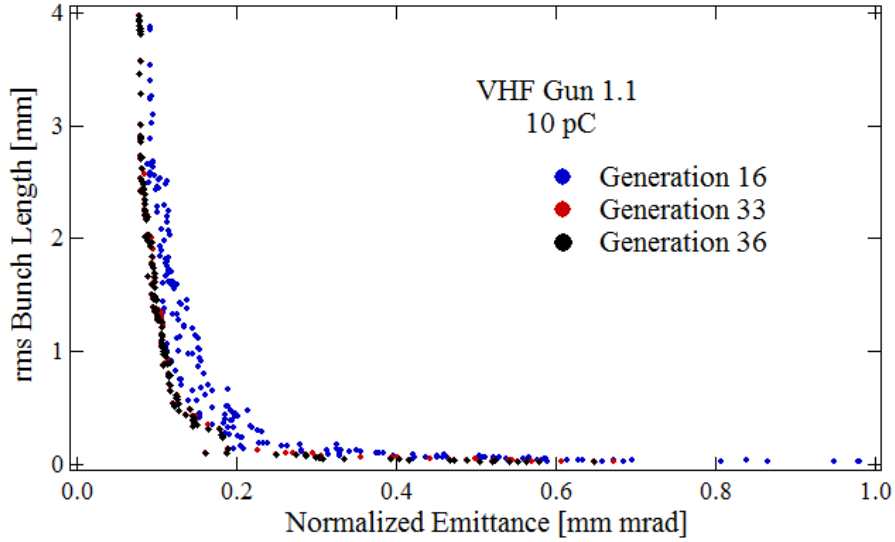
At LBNL we are developing fabrication capability for both types
(H. Padmore et al.)

Ongoing Beam Dynamics Studies

- **EXAMPLE: No pre-buncher or buncher. Just main linac cavities**
- **Velocity bunching by de-phasing the first cavity**
- **Emittance compensation by a single solenoid (plus embedded bucking coil)**
- **Multi-Objective Genetic Algorithms optimization, trading between final emittance and bunch length.**





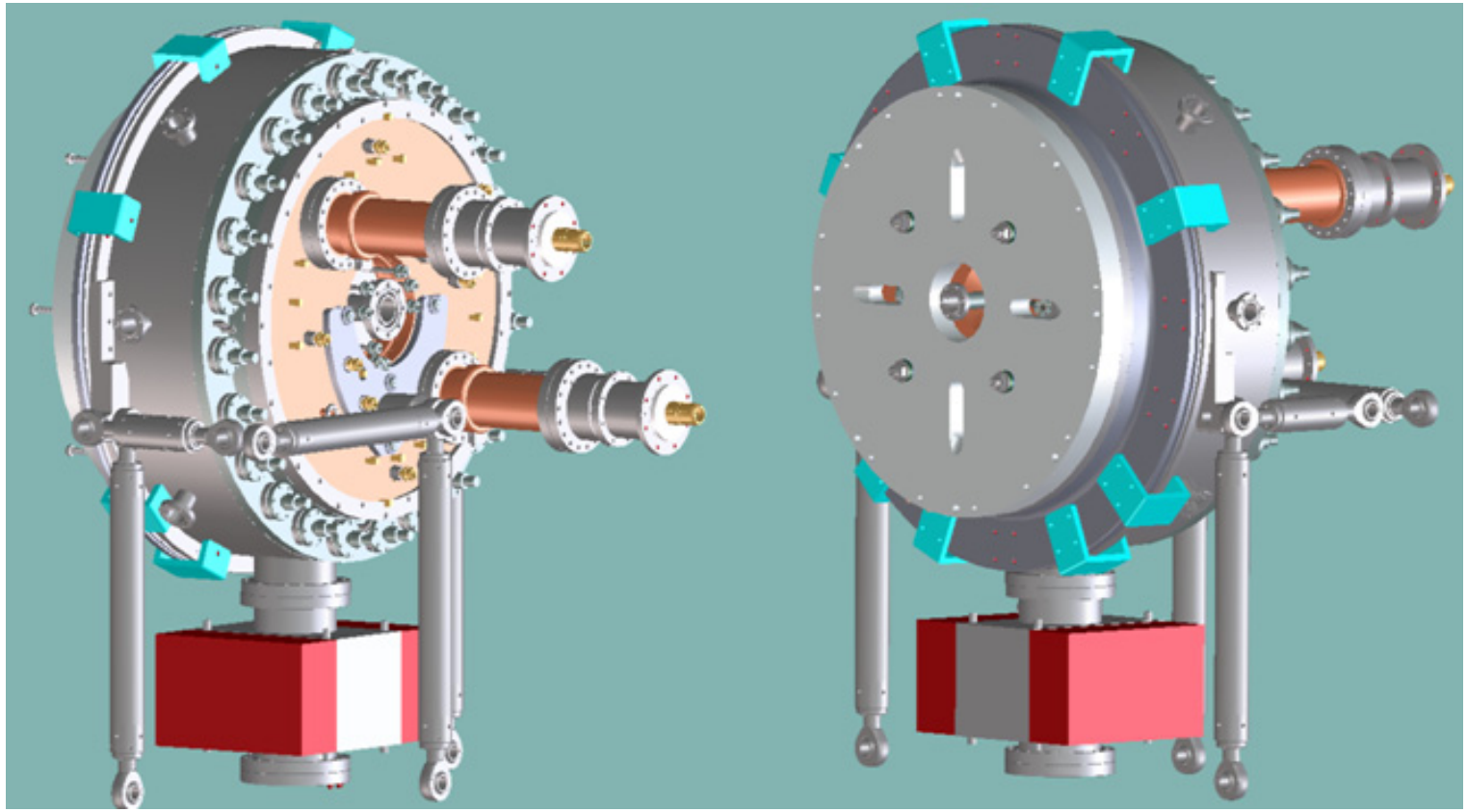


- **Work in progress but already showed the VHF gun capability to operate in a FEL scheme**

Cavity Engineering Design Completed

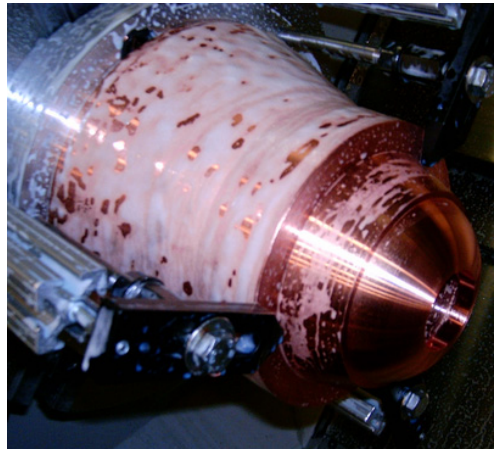
- **The cavity design finalized**

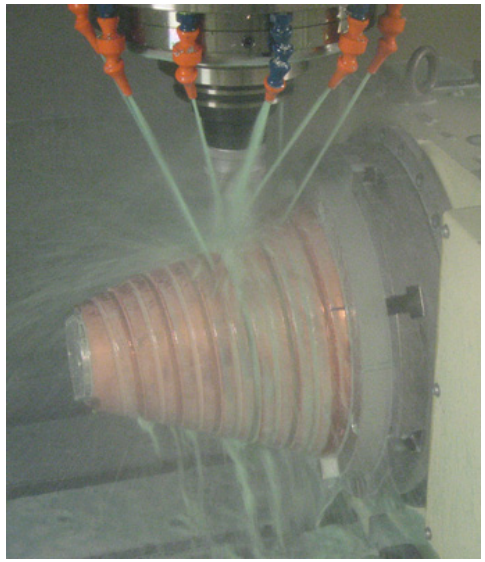
(The process involved two external review committees)



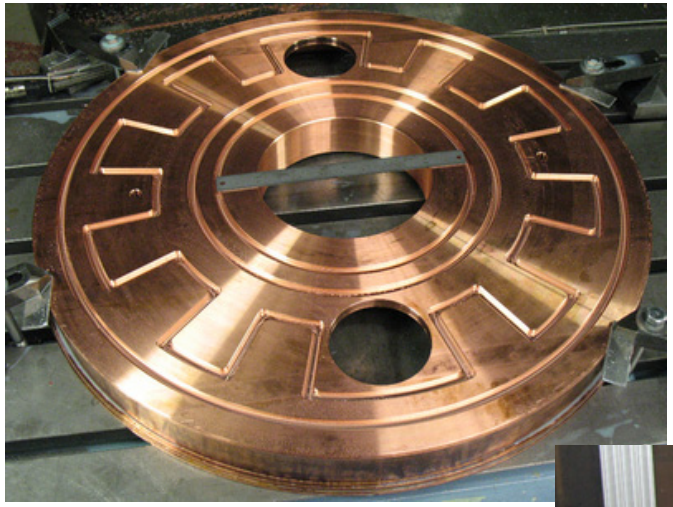
Cavity Construction

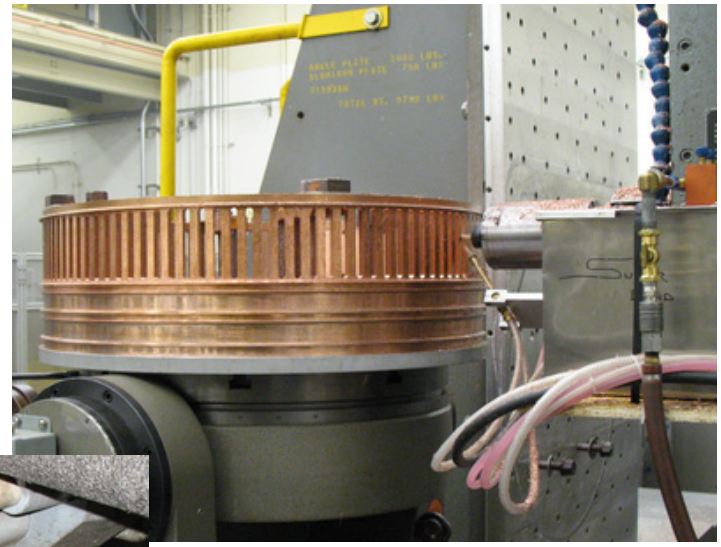
- **The cavity is being entirely fabricated at the LBNL mechanical shop**





More Hardware

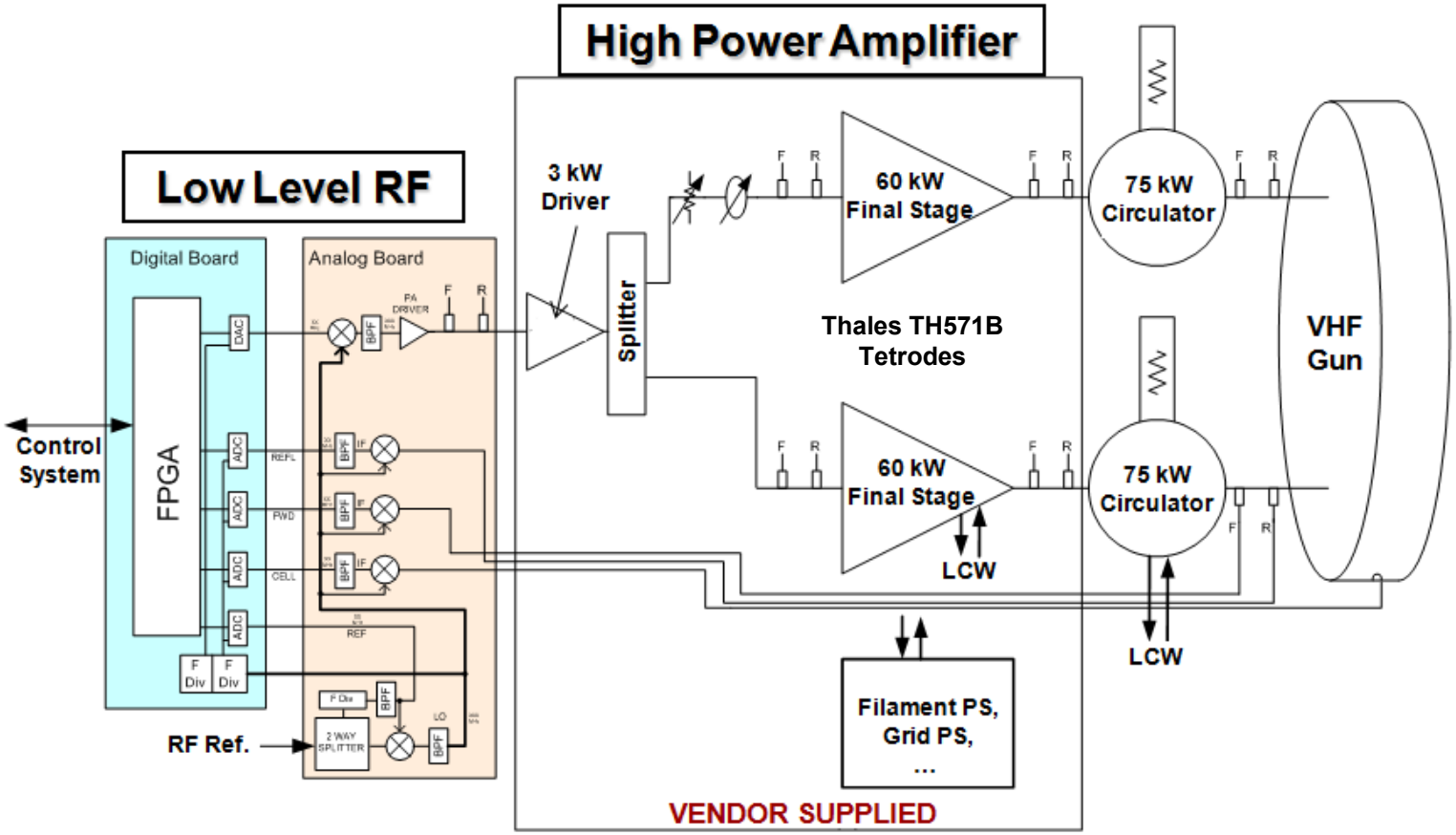




- **Fabrication completion in early spring 2010**

The RF Power Source

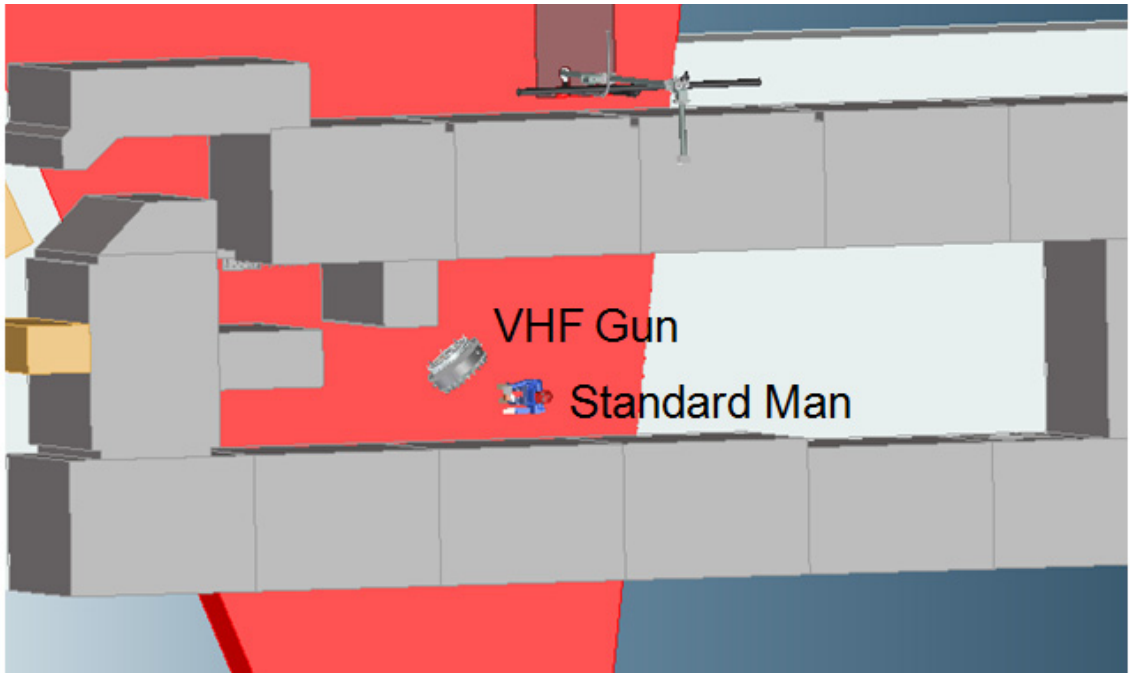
- **The 120 kW CW RF amplifier required to operate the VHF gun is being developed and manufactured by ETM Electromatic.**



- **Expected delivery at LBNL in February 2010**

The VHF Gun Test Facility

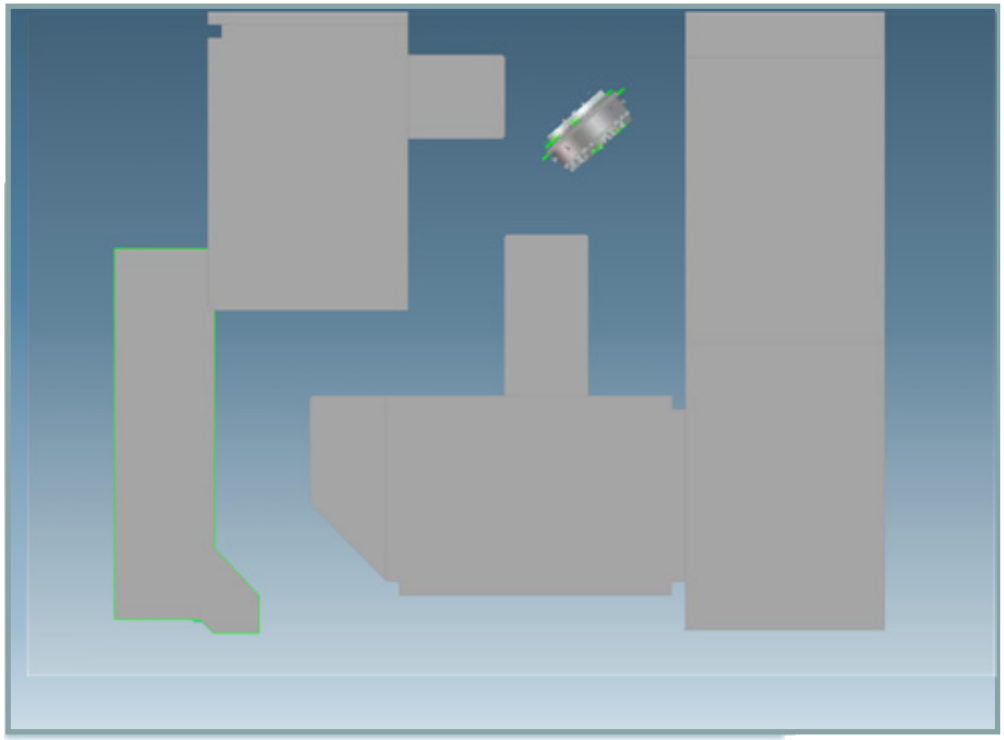
All the photo-injector system will be accommodated in the existing ALS Beam Test Facility (BTF) for full characterization.
The BTF footprint is large enough to accommodate also the structures to accelerate the beam to few tens of MeV.



The preparation of the BTF is under way and will be completed in the early spring of 2010.

Fundamental Question

Does the cavity go through the door?



Yes, it does!!!

Phase 1 Test Plan

Fully funded.

- **Perform cold and full power RF tests of the VHF cavity**
- **Demonstrate the system vacuum performance**
- **Install and characterize the first generation cathode.**
- **Characterize the electron beam at the gun energy at full repetition rate**

Phase 2 Test Plan

Requires funding continuation

- **Develop and install accelerating section for few tens of MeV energy**
- **Develop and install high energy diagnostic beamline**
- **Upgrade the BTF radiation safety interlock system**
- **Perform full characterization of the beam parameters at high energy (probably at low repetition rate)**

The LBNL VHF Gun References

J. Staples, F. Sannibale, S. Virostek, "VHF-band Photoinjector", CBP Tech Note 366, October 2006

S. Lidia, et. al., ”Development of a High Brightness VHF Electron Source at LBNL”, Proceedings of the 41st Advanced ICFA Beam Dynamics Workshop on Energy Recovery Linacs, Daresbury Laboratory, UK, May 21-25, 2007.

J. W. Staples, et al., "Design of a VHF-band RF Photoinjector with MegaHertz Beam Repetition Rate". 2007 Particle Accelerator Conference, Albuquerque, New Mexico, June 2007.

K. Baptiste, et al., "The LBNLnormal-Conducting RF gun for free electron laser and energy recovery linac applications", NIM A **599**, 9 (2009).

K. Baptiste, et al., Status of the LBNL normal-conducting CW VHF photo-injector, Proceedings of the 2009 Particle Accelerator Conference, Vancouver, Canada, May 2009.