A CW VHF Laser Photocathode Gun using a Room Temperature Copper Cavity

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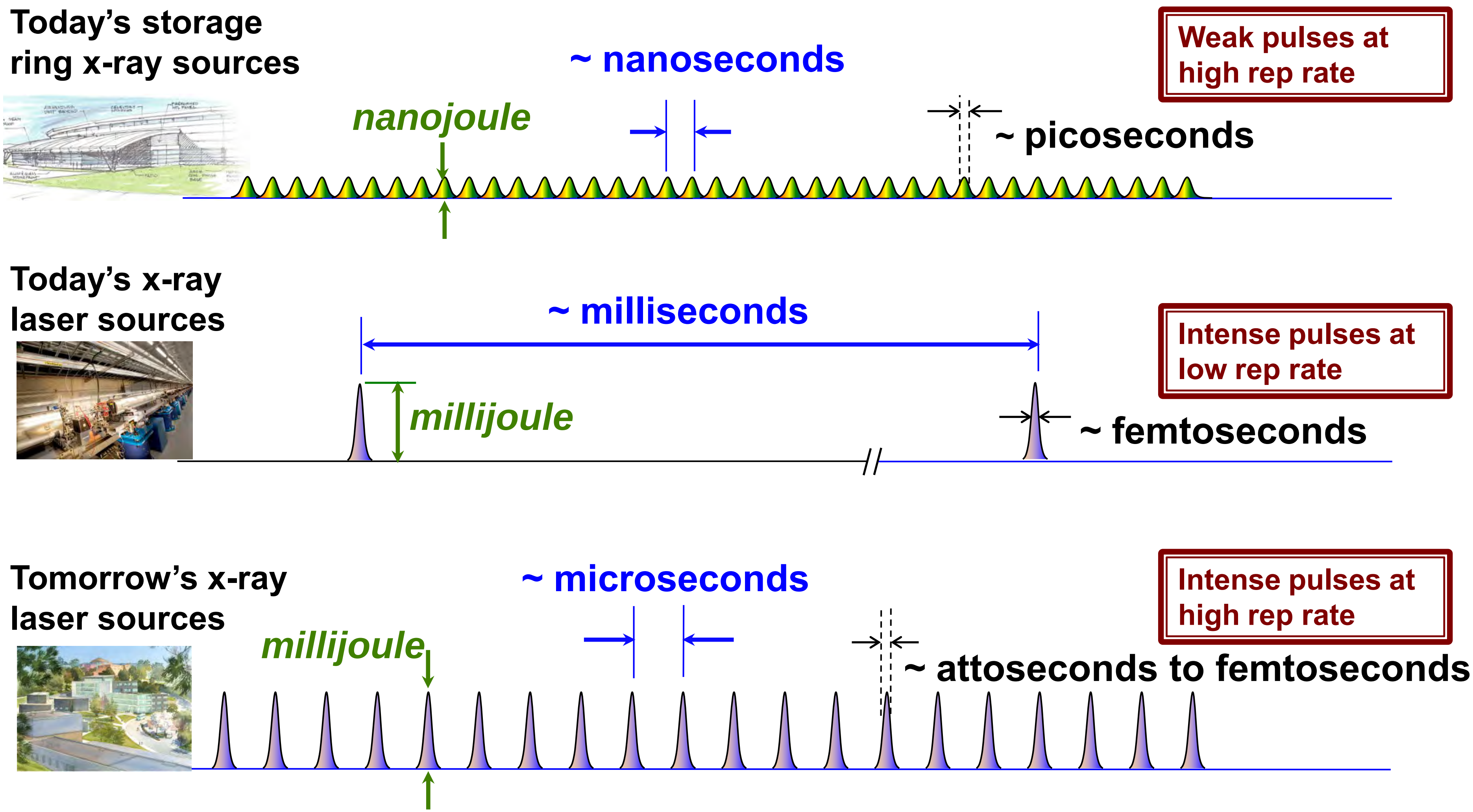
Accelerator and Detector Research and Development
2011 Contractors Meeting

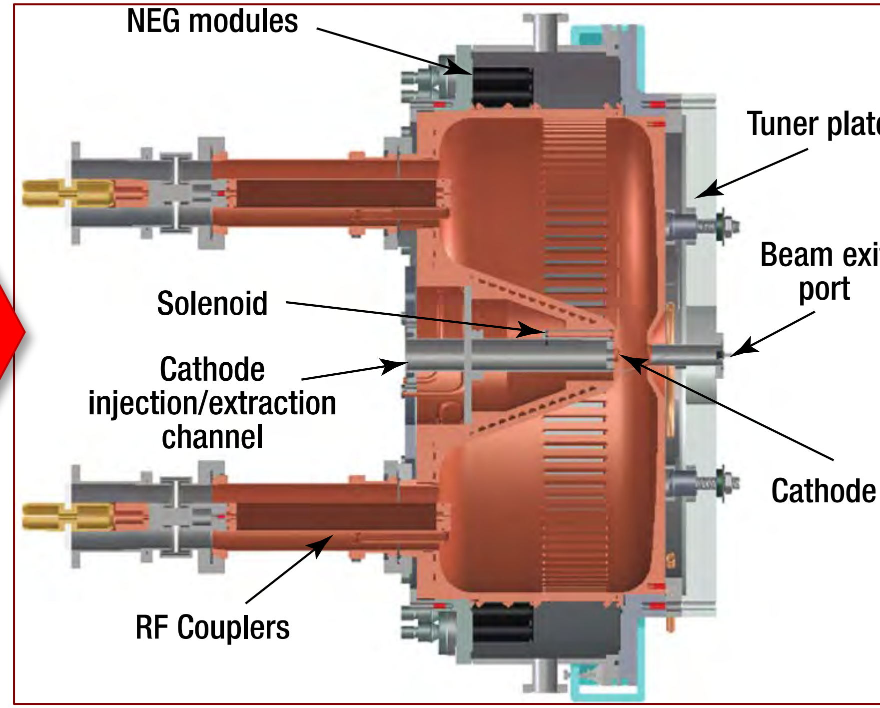
Motivation: coherent X-rays with high repetition rate, unprecedented average brightness, ultrafast pulses



The technical challenge: the injector defines the beam quality and repetition rate

Design goals:

- Repetition rate 1 MHz
- Charge per bunch from ~10 pC to ~1 nC
- Emittance <10^{-6} mm-mrad (normalized)
- Electric field at the cathode ≥~10 MV/m (space charge emission limit)
- Beam energy at the gun exit ≥~500 keV (space charge control)
- Bunch length ~100 fs to ~10 ps for handling space charge effects, and for allowing different modes of operation
- Compatible with magnetic field control within the gun (emittance exchange and compensation)
- 10^{-11} Torr vacuum capability (cathode lifetime)
- Accommodates a variety of cathode materials



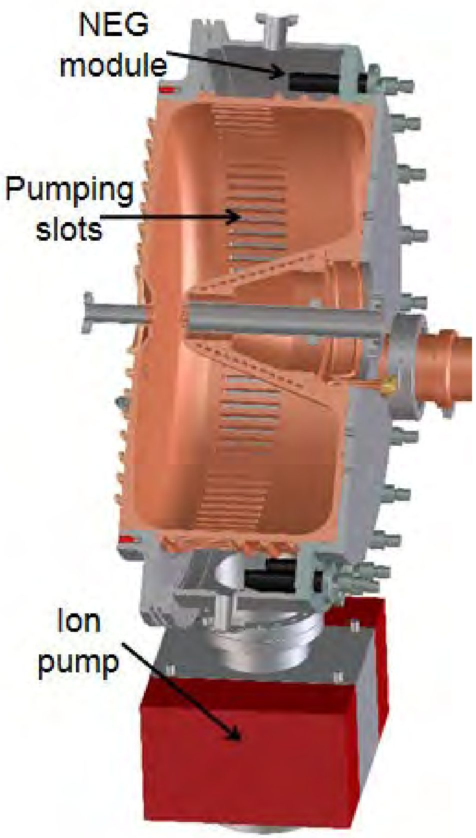
The LBNL approach uses a CW photogun designed to meet all requirements

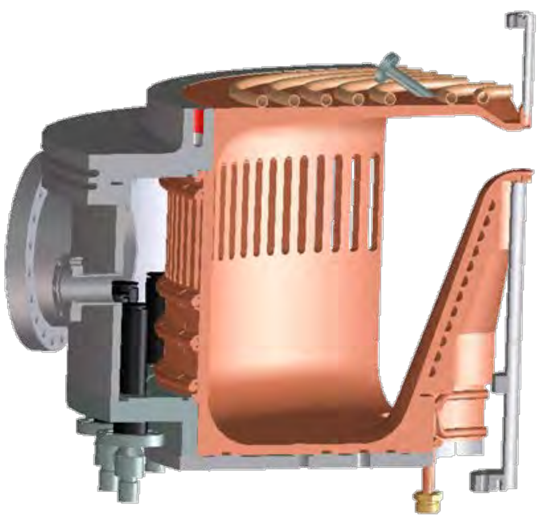
K. Baptiste, et al., NIM A 599, 9 (2009)

“APEX” gun design features and specifications

VHF cavity operates in CW mode
- Low power density
- High conductance vacuum slots
- High gradient at cathode

Frequency	187 MHz
Operation mode	CW
Gap voltage	750 kV
Field at the cathode	19 MV/m
Q_0	30887
Shunt impedance	6.5 MΩ
RF Power	90 kW
Stored energy	2.3 J
Peak surface field	24 MV/m
Peak wall power density	25 W/cm^2
Accelerating gap	4 cm
Diameter/Length	70/35 cm
Operating pressure	< 10^{-11} Torr



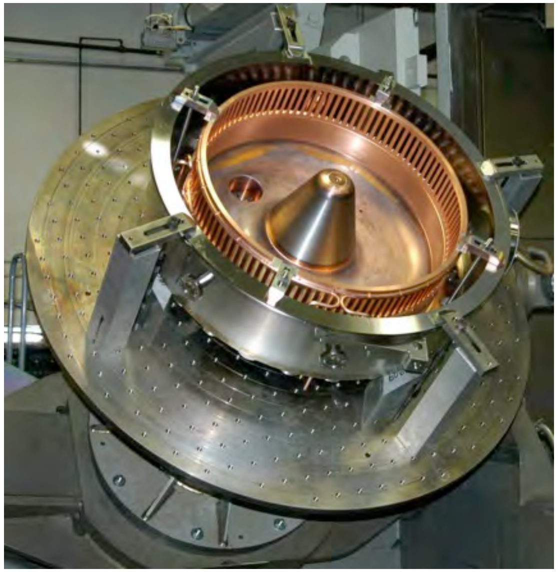


Gun major components during manufacture

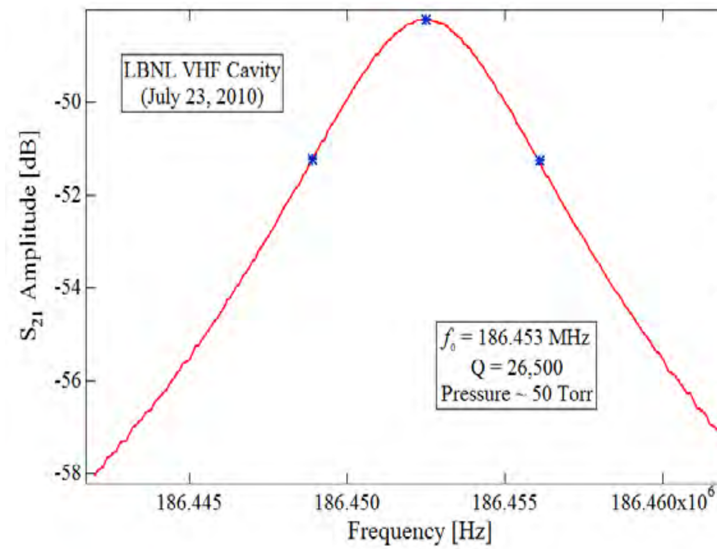
The “sombrero” – re-entrant nosecone

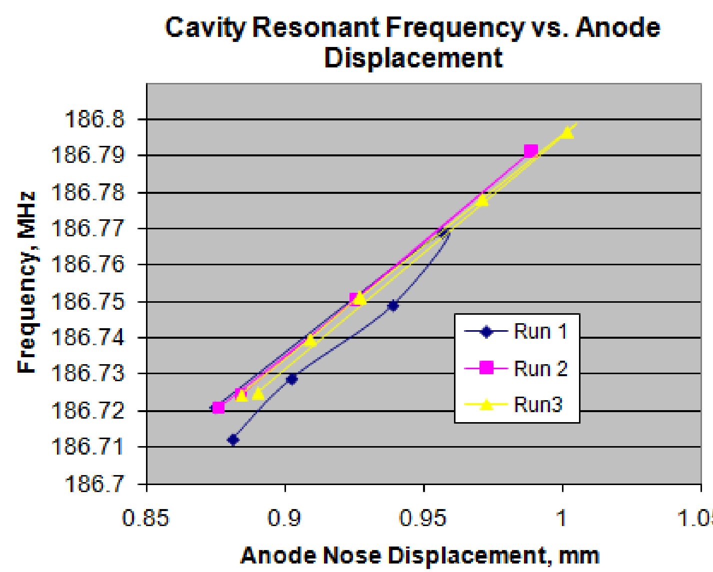
The “Coloseum” – RF surface and vacuum pumping apertures

Steel vacuum enclosure – looking inside with the anode plate not yet installed



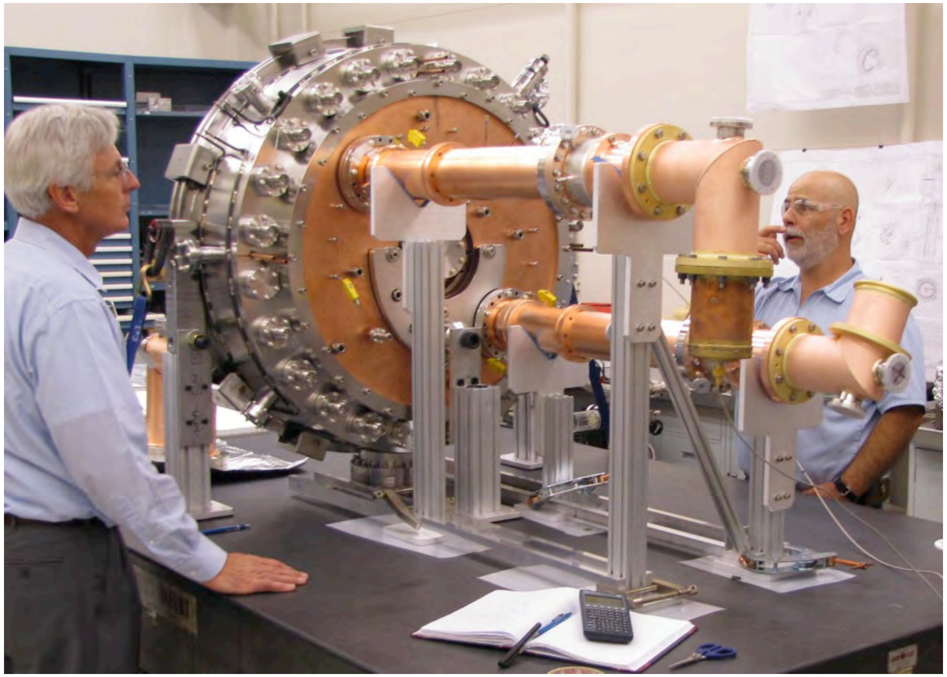
Successful low-power RF and vacuum tests

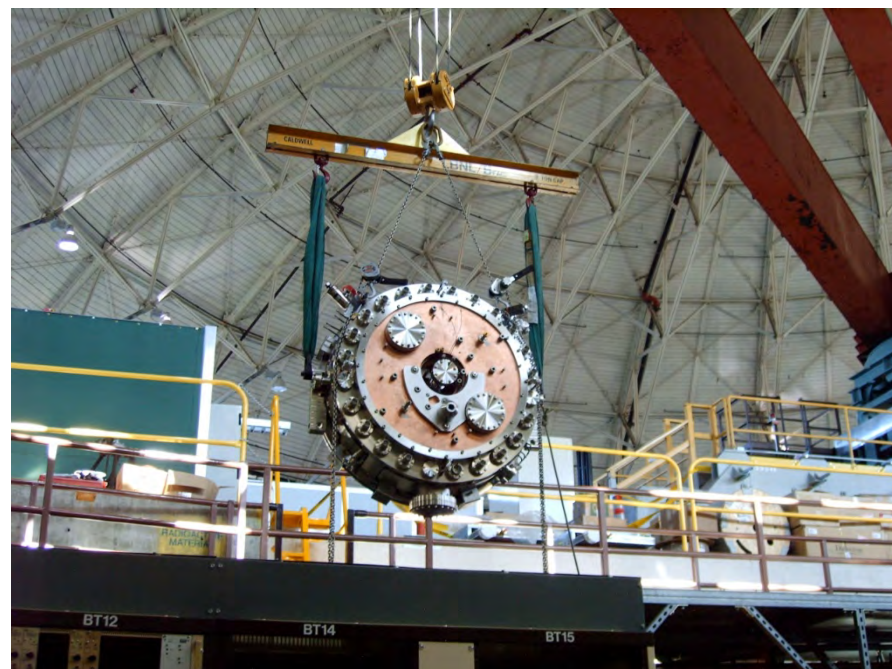




- Successful vacuum leak test
- 10^{-9} Torr achieved
  - 1 NEG pump, no bake
  - 20 NEG pumps installed, each 400 l/s

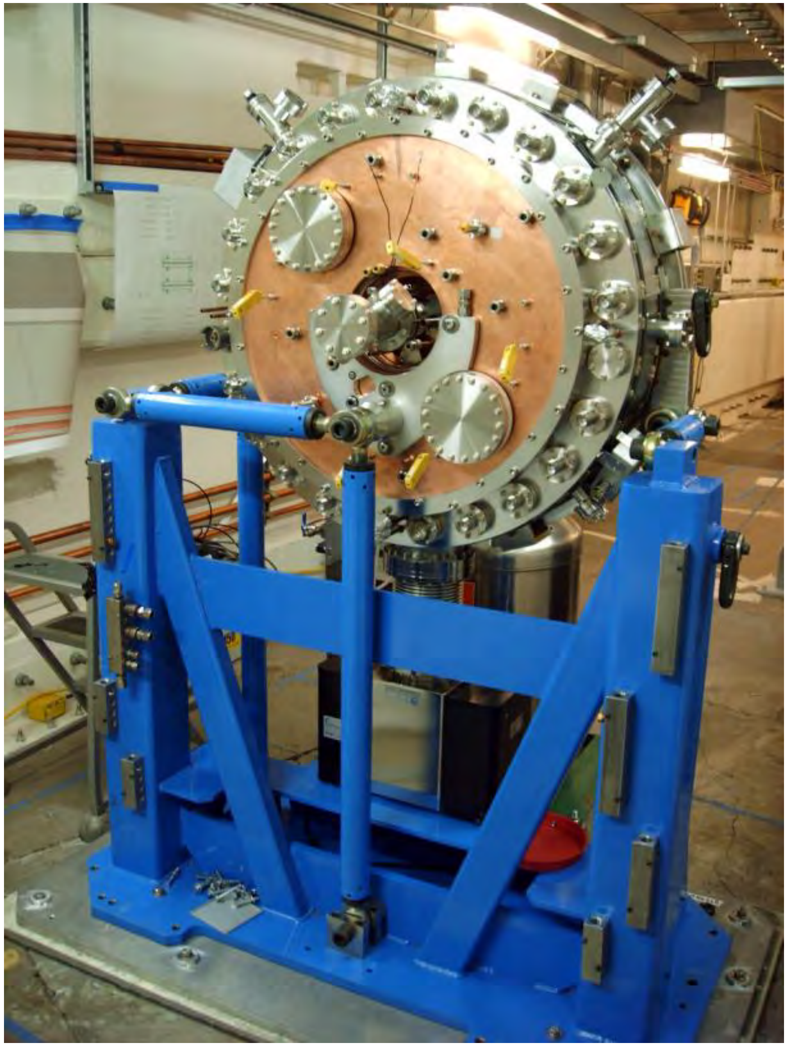
RF coaxial power lines fitted; transport to the ALS beam test facility



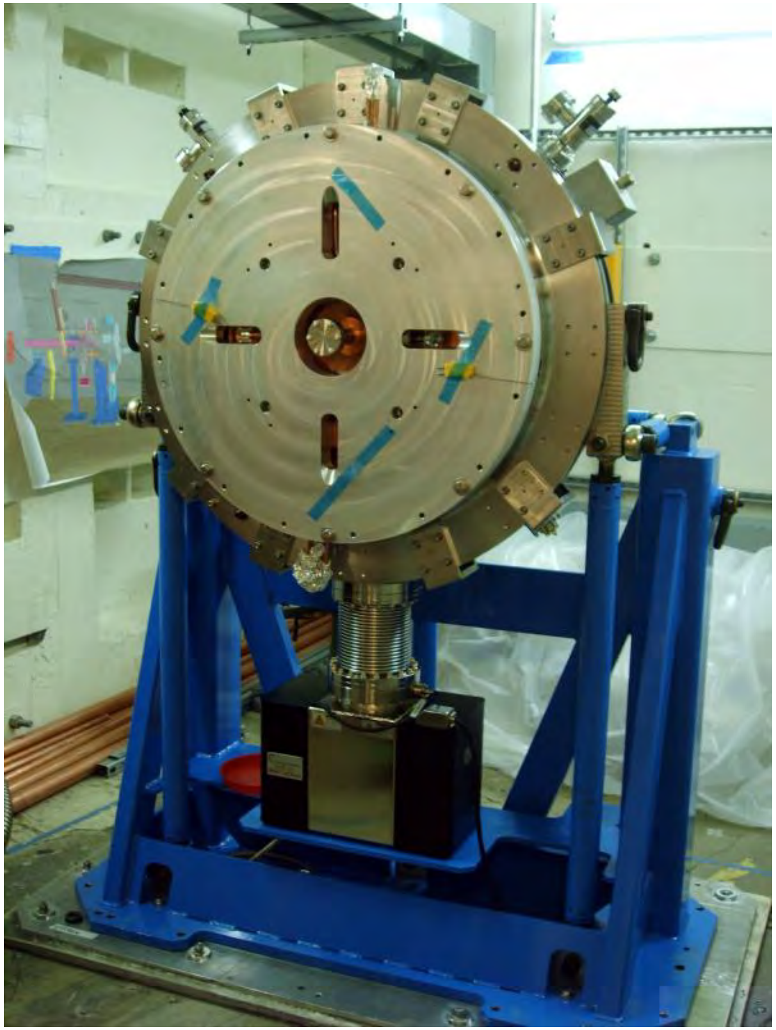


Gun installed in the ALS beam test facility, an existing shielded cave

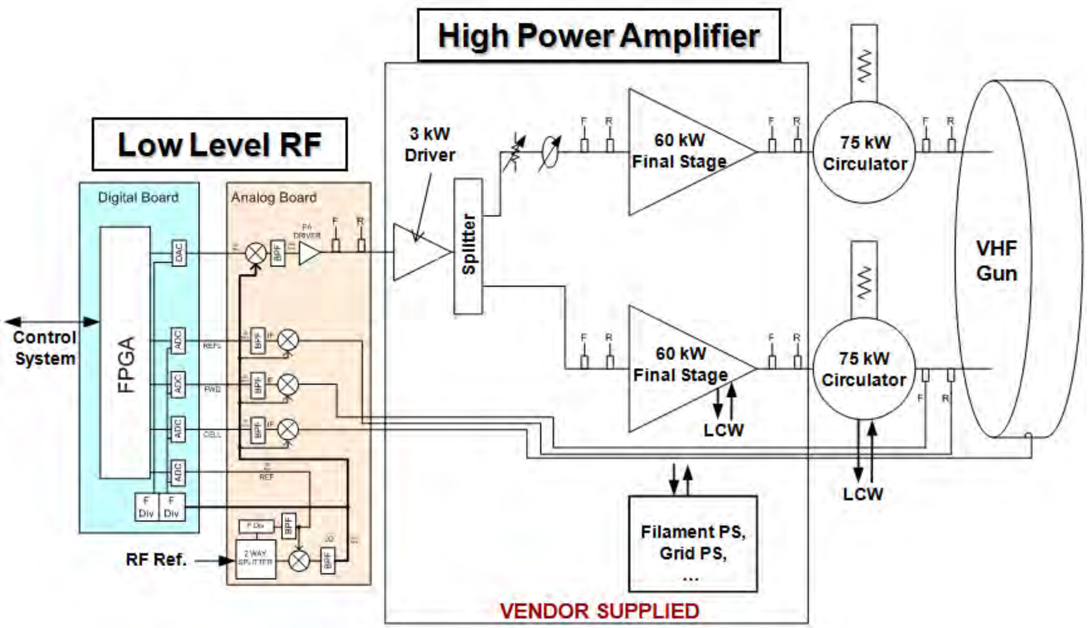
Looking downstream



Looking upstream

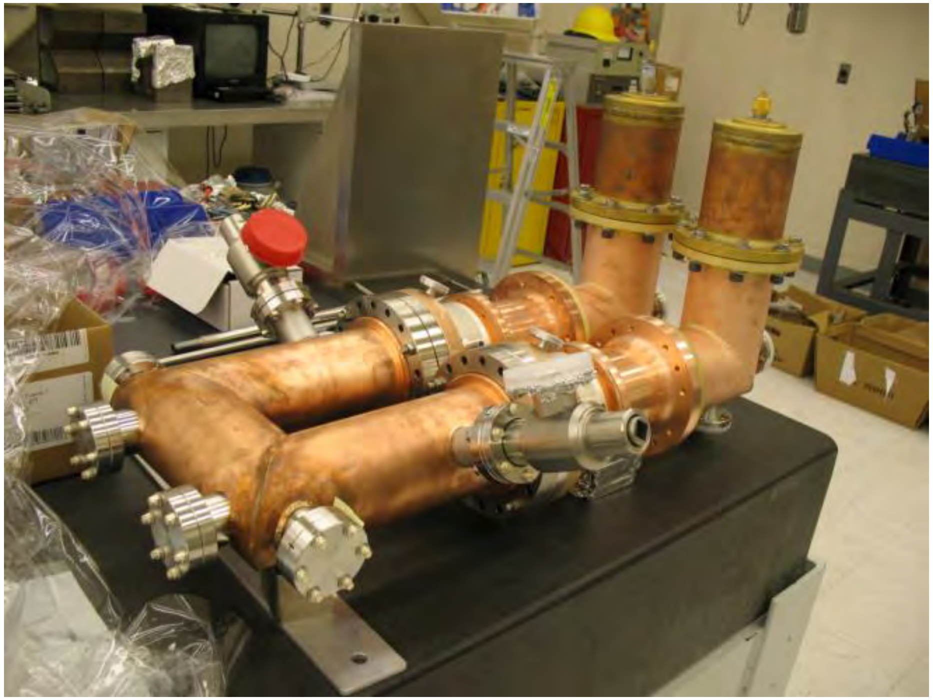


120 kW, 187 MHz power systems installed and commissioned at LBNL



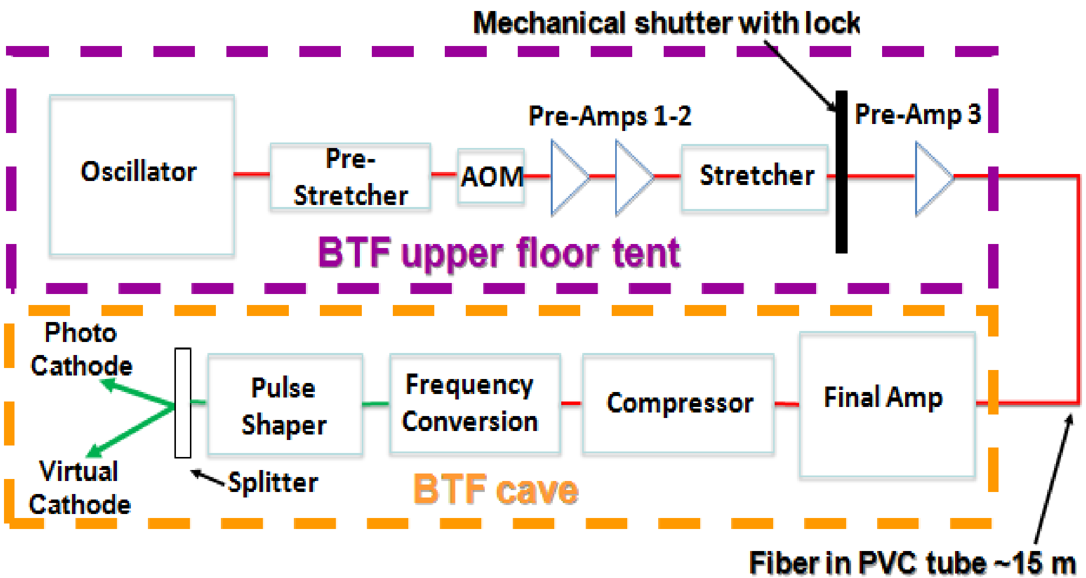
Developed and manufactured by ETM Electromatic

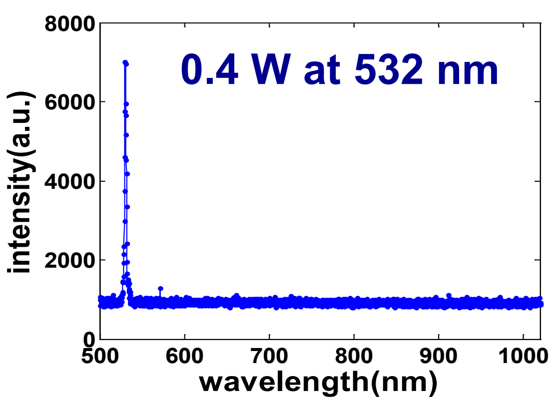
RF coaxial power couplers and windows configured for power conditioning

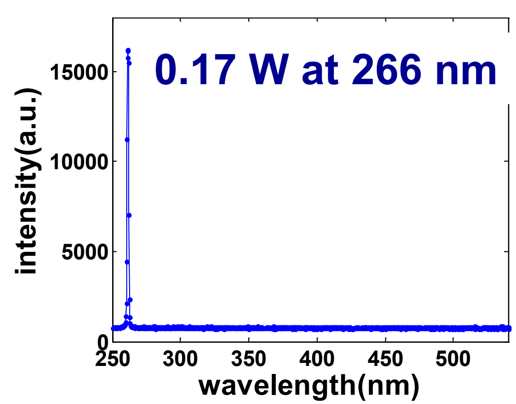


Yb fiber photocathode drive laser delivered, supplied by UC Berkeley and LLNL

- **1.6 W in IR**







Photocathode materials

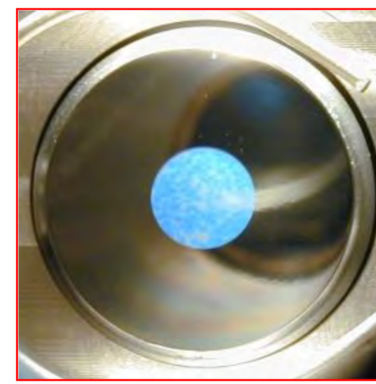
Alkali Antimonides eg. K_2CsSb

- Fast
- Reactive; requires UHV ~10^{-10} Torr pressure
- High QE (typically >5%)
- No pulse charge saturation
- Requires green light (532 nm, 2nd harm. conversion from IR)
- For 1 nC & 1 MHz rep-rate, ~ 1 W IR required
- Unproven lifetime at high rep-rate and high average current

see talk by John Smedley – LBNL/BNL/Stony Brook collaboration

Cs_2Te (developed by INFN/LASA and ready to ship to LBNL)

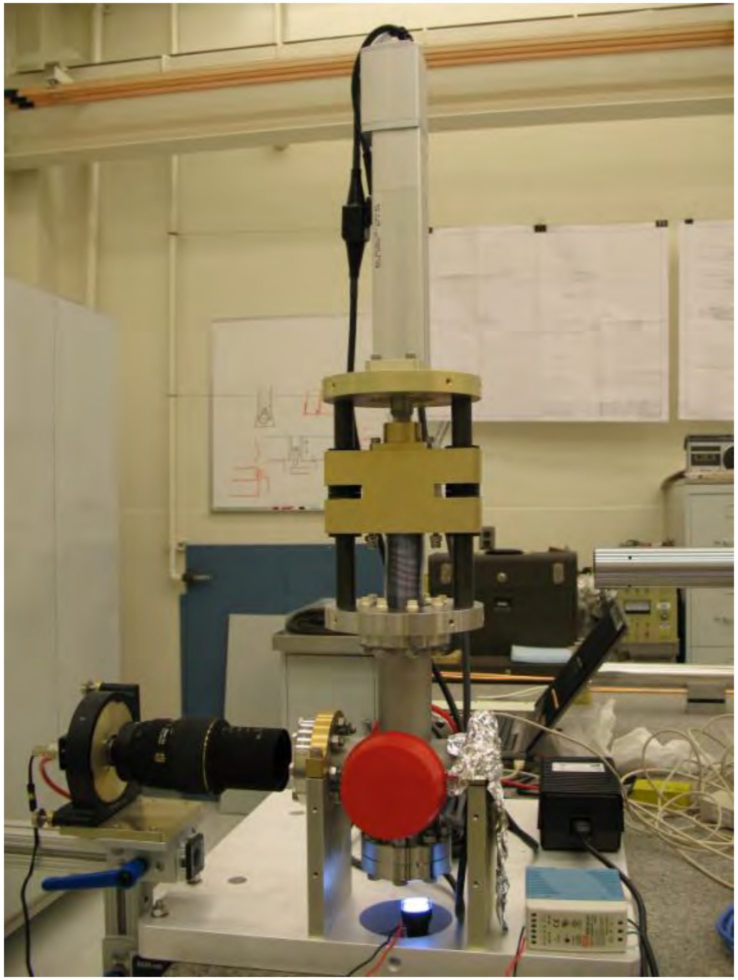
- Fast
- Relatively robust and un-reactive (~10^{-9} Torr)
  - Demonstrated in a high gradient rf gun
- High QE (typically >5%)
- No pulse charge saturation
- Requires UV 250 nm, 3rd or 4th harm. from IR laser)
- For 1 nC - 1 MHz reprate, ~ 10 W IR required
- Unproven at high rep-rate and high average current



The LBNL APEX gun will also be used to test the BNL diamond amplifier cathode

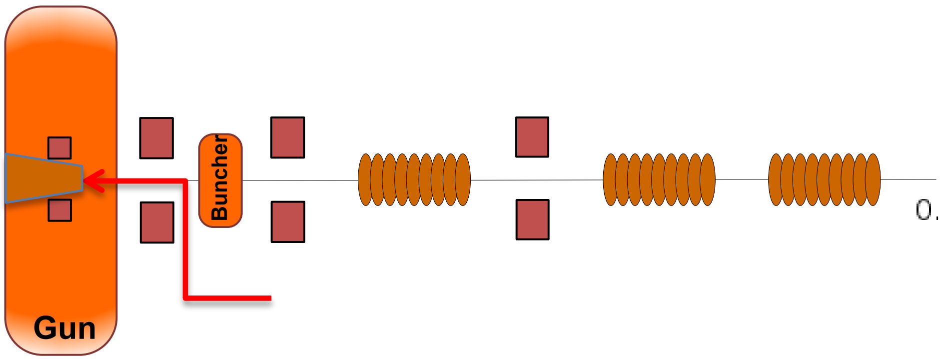
Instrumentation and diagnostics being assembled

Beam profile monitor under test



Injector design and beam dynamics – multiobjective genetic optimization

Find global optima with multiple, non-linearly coupled machine parameters

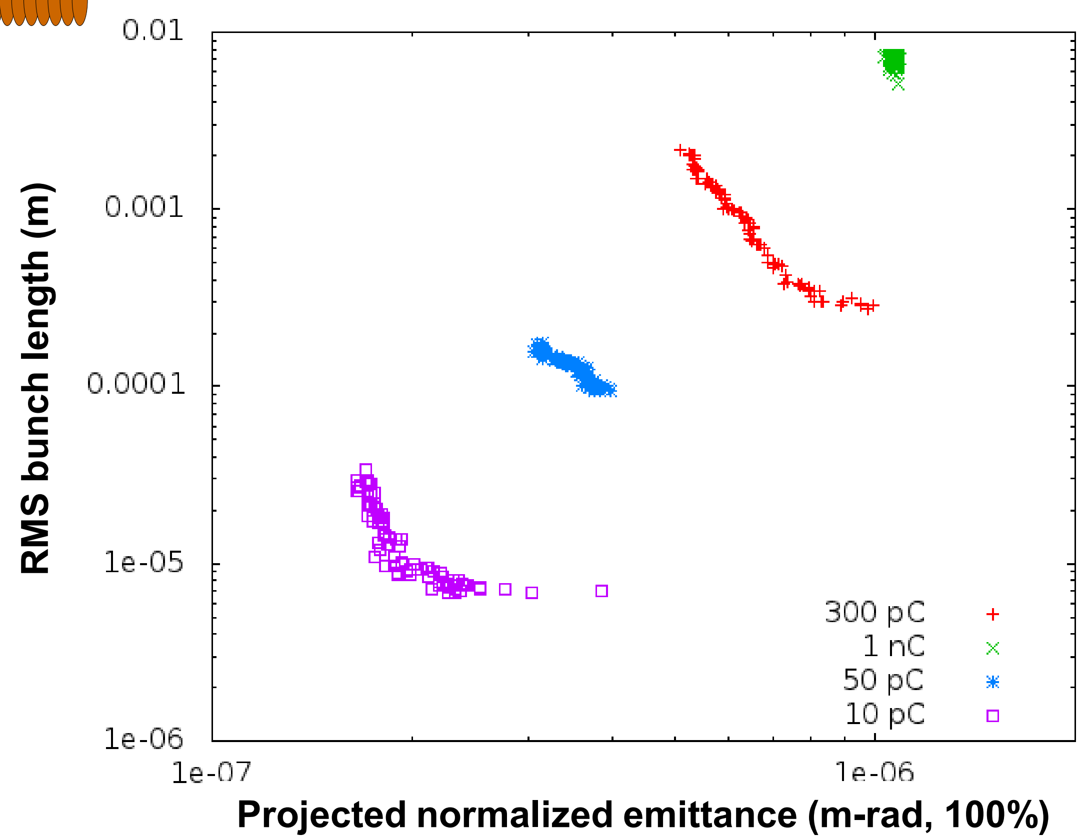


Solenoid magnet
– control strengths

Single-cell RF cavity
– control phase & amplitude

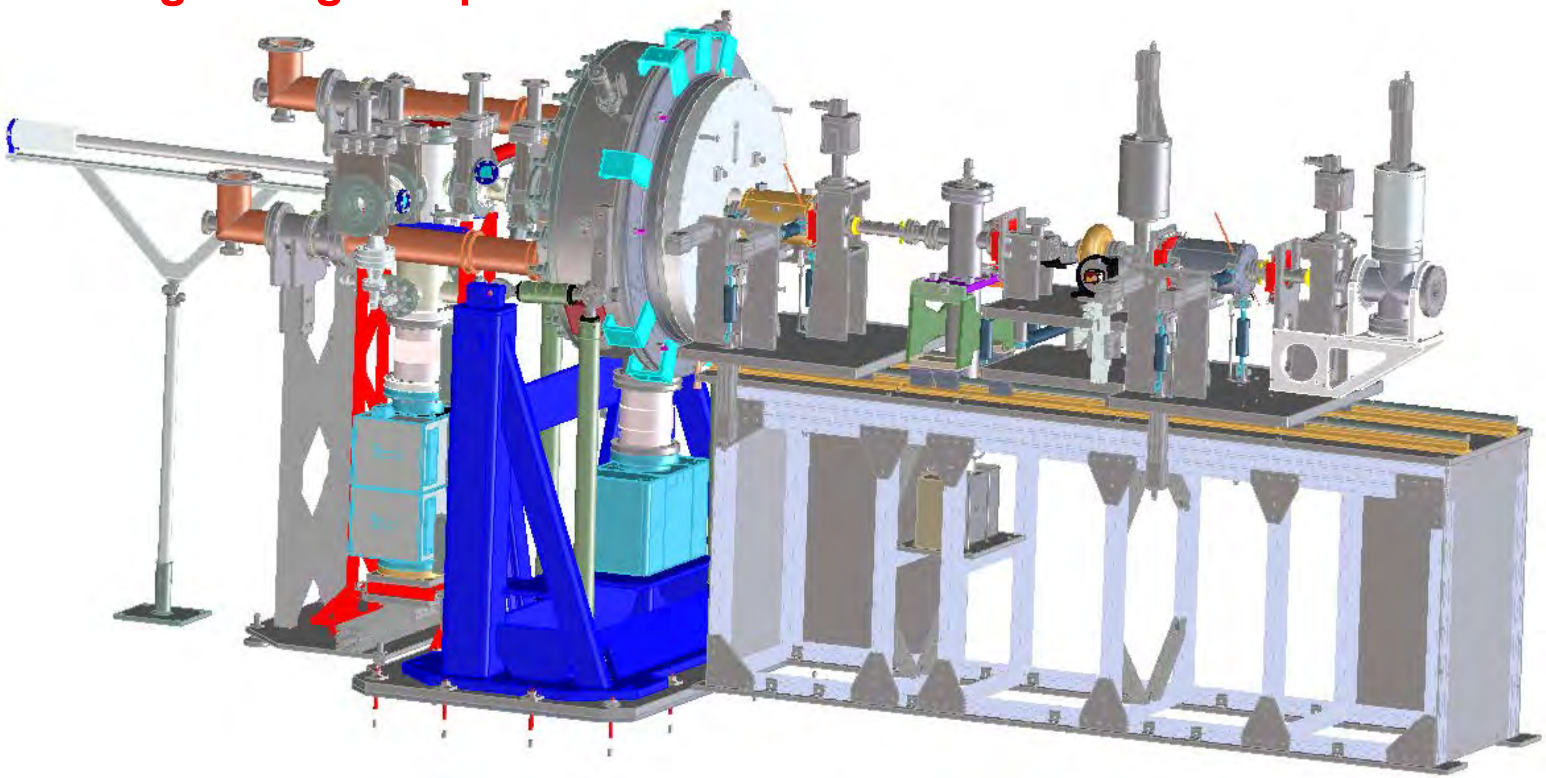
Multi-cell RF cavity
– control phase & amplitude

Laser pulse
– control transverse and longitudinal profile



Scope, status, and goals: Phase 0

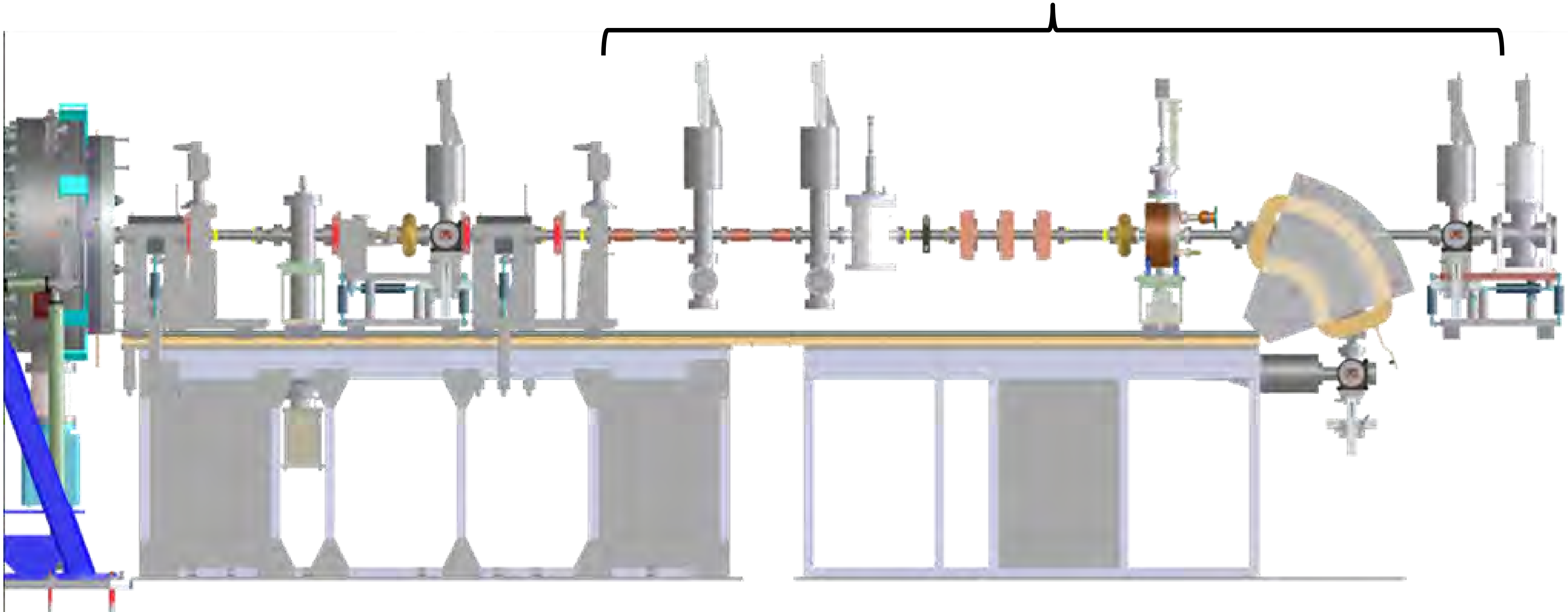
- Demonstration of the gun RF performance at full repetition rate
- Demonstration of the vacuum performance with RF power
- Dark current characterization
- Cathode physics (lifetime, QE, intrinsic emittance)
- Gun complete and installed, RF power installed, beamline components under fabrication and final assembly
- RF conditioning to begin September 2011



Scope, status, and goals: Phase I adds diagnostics

- **Beam dynamics (6-D measurements)**
- **Diagnostics tests**
- **Low energy beam characterization**
- **Planned for spring 2012**

- Quadrupole triplet
- X-Y corrector
- Retractable slits
- Deflecting cavity
- YAG screens
- Spectrometer

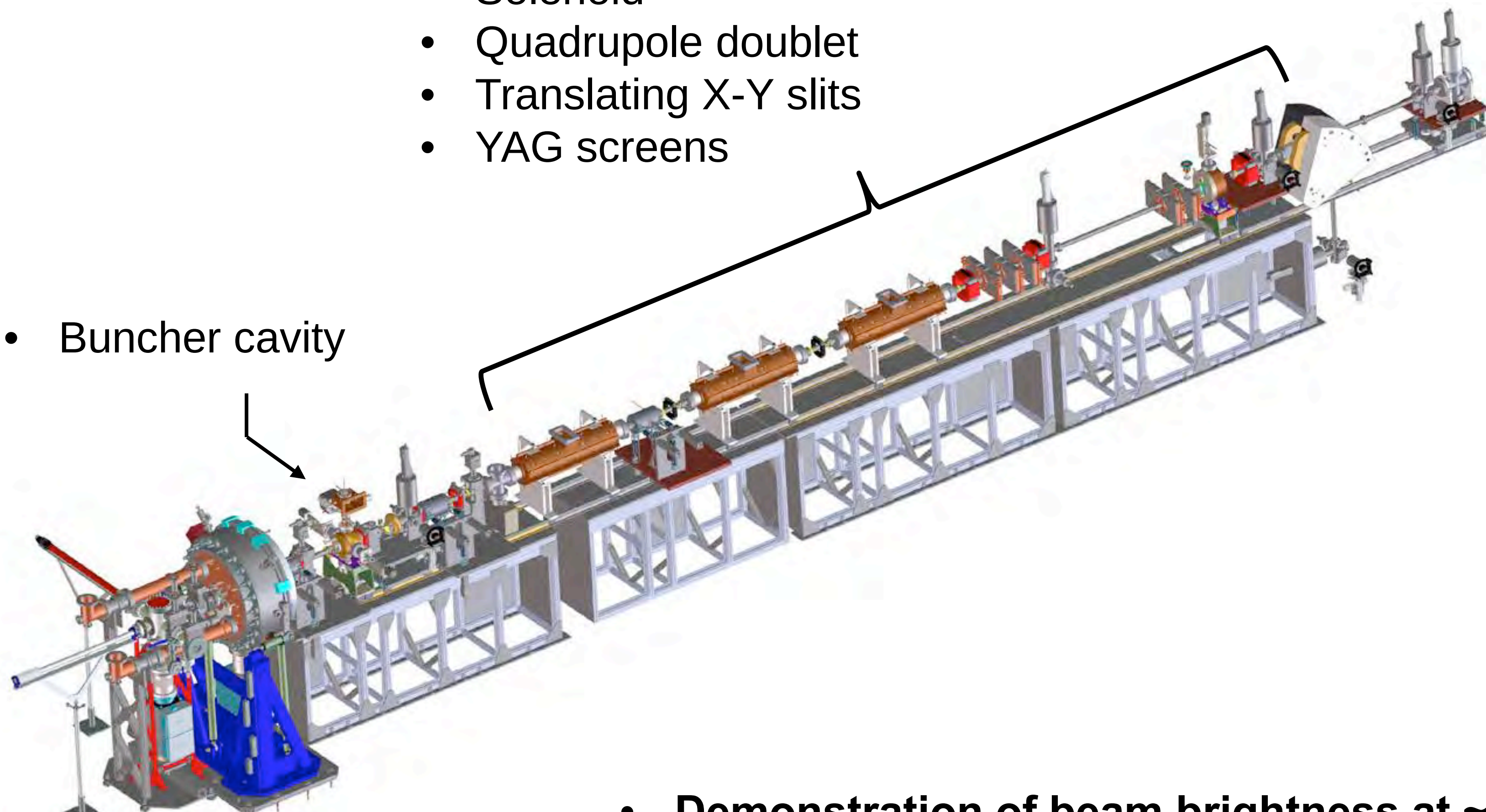


Diagnostics systems in collaboration with Cornell CLASSE

Scope, status, and goals:
Phase II adds acceleration and bunching

- Accelerating cavities
- Solenoid
- Quadrupole doublet
- Translating X-Y slits
- YAG screens

- Buncher cavity



Accelerating cavities in collaboration with ANL AWA

- **Demonstration of beam brightness at ~30 MeV**
- **At reduced repetition rate**
- **Goal for installation late 2013**

Publications

[1] *Low Energy 6D Beam Diagnostic for APEX, the LBNL VHF Photo-injector.* D. Filippetto, J.M. Byrd, M.J. Chin, C.W. Cork, S. De Santis, L.R. Doolittle, J. Feng, W.E. Norum, C. F. Papadopoulos, G.J. Portmann, D.G. Quintas, F. Sannibale, M.E. Stuart, R.P. Wells, M.S. Zolotorev. 2011 Particle Accelerator Conference, New York, NY USA, March 2011.

[2] *Photoinjector beam dynamics for a next generation x-ray FEL.* C.F. Papadopoulos, J. Corlett, D. Filippetto, G. Penn, J. Qiang, F. Sannibale, J. Staples, R. Wells, M. Venturini, M. Zolotorev. 2011 Particle Accelerator Conference, New York, NY USA, March 2011.

[3] *Drive Laser System for the Advanced Photo-Injector Project at the LBNL.* J. Feng, D. Filippetto, H.A. Padmore, F. Sannibale, R.P. Wells, M. J. Messerly, M.A. Prantil. 2011 Particle Accelerator Conference, New York, NY USA, March 2011.

[4] *Studies of a Linac Driver for a High Repetition Rate X-ray FEL*. M. Venturini, J.N. Corlett, L.R. Doolittle, D. Filippetto, C. F. Papadopoulos, G. Penn, D. Prosnitz, J. Qiang, M.W. Reinsch, R.D. Ryne, F. Sannibale, J.W. Staples, R.P. Wells, J.S. Wurtele, M.S. Zolotorev, A.A. Zholents. 2011 Particle Accelerator Conference, New York, NY USA, March 2011.

[6] *Status of the LBNL Normal-Conducting CW VHF Electron Photo-Gun.* F. Sannibale, B. Bailey, K. Baptiste, A. Catalano, D. Colomb, J. Corlett, S. De Santis, L. Doolittle, J. Feng, D. Filippetto, G. Huang, R. Kraft, D. Li, M. Messerly, H. Padmore, C. F. Papadopoulos, G. Portmann, M. Prantil, S. Prestemon, J. Qiang, J. Staples, M. Stuart, T. Vecchione, R. Wells, M. Yoon, M. Zolotorev. Proceedings of the 2010 Free Electron Laser Conference, Malmo, Sweden, August 2010.

[7] *Multiobjective Optimization for the Advanced Photo-injector EXperiment (APEX).* C.F. Papadopoulos, J. Corlett, D. Filippetto, J. Qiang, F. Sannibale, J. Staples, M. Venturini, M. Zolotorev. Proceedings of the 2010 Free Electron Laser Conference, Malmo, Sweden, August 2010.

Thank you for your attention