A CW VHF Laser Photocathode Gun Using a Room Temperature Copper Cavity and Diagnostics*

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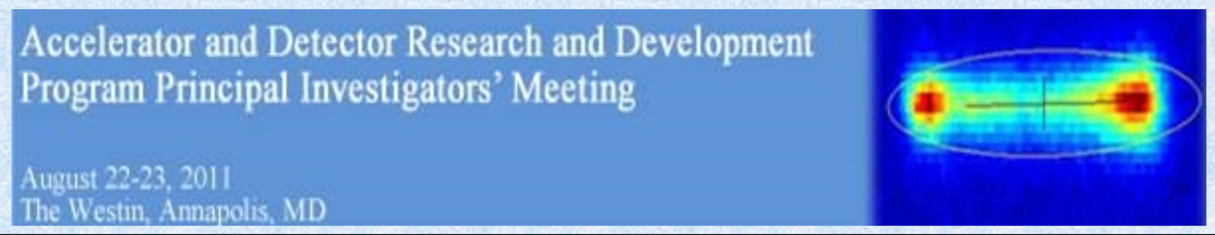
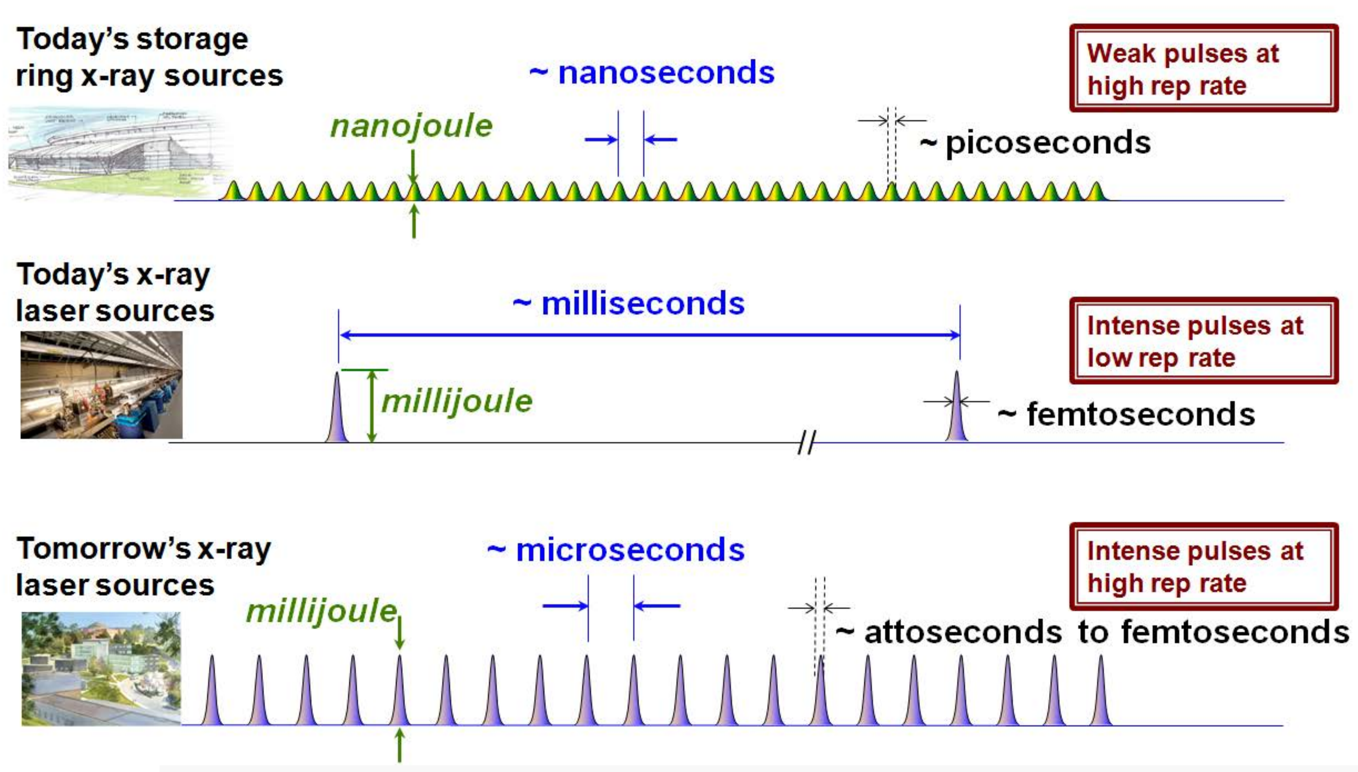
*Work supported by the Director of the Office of Science of the US Department of Energy under Contract no. DEAC02-05CH11231.



We describe the development of a new concept high repetition rate high-brightness electron source for free electron laser (FEL) and energy recovery linac (ERL) applications. The successful development of such source will critically impact the performance of future 4th generation light sources when high-repetition rates (> 10 kHz) are required. The core of the system is a normal-conducting continuous wave (CW) RF cavity where the electrons are generated by laser-induced photo-emission on high quantum efficiency (QE) photo-cathodes and accelerated by the cavity fields up to about 750 keV energy. The cavity has been designed to resonate at about 200 MHz in the VHF frequency region. The low frequency choice makes the resonator size large enough to lower the power density on the structure walls at a level that conventional cooling techniques can be used when the cavity is run in CW mode. Another advantage of the low frequency is the relatively long wavelength that allows for large apertures on the cavity walls with negligible distortion of the field in the cavity. Such apertures are necessary for achieving high vacuum conductance allowing for the very low pressures required by the high QE semiconductor cathodes sensitive to contamination. An additional advantage of such a scheme is that it is based on mature and reliable RF and mechanical technology, a very important characteristic to achieve the reliability required to operate in a user facility.
The Phases 0 and I of the Advanced Photo-injector Experiment (APEX) at LBNL are designed to demonstrate the RF and vacuum performance of the gun, and to perform cathode physics and low energy electron beam tests.
We also describe the conceptual design of APEX Phase II that includes acceleration and characterization of the beam at few tens of MeV for demonstrating the brightness performance of an injector based on the VHF gun.

High Repetition Rate x-ray FELs

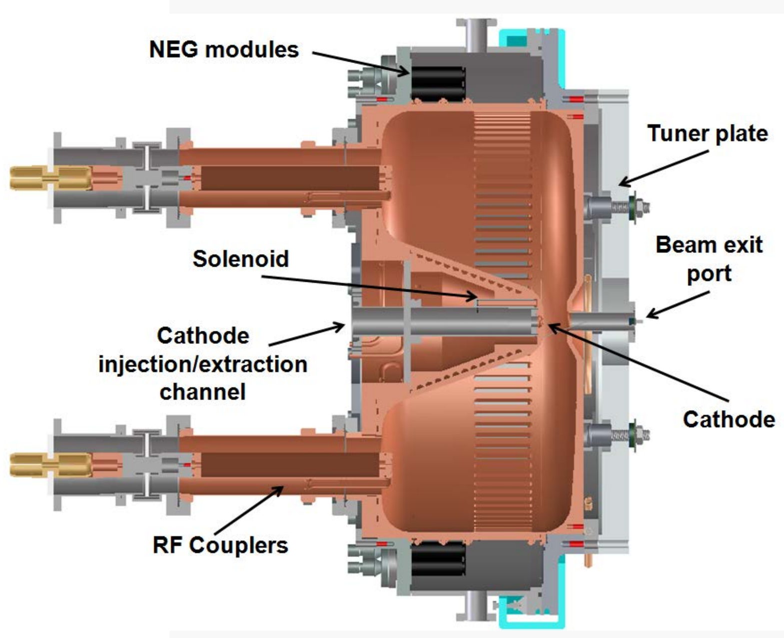


High Repetition Rate FELs: Gun Requirements

To operate in a high repetition rate x-ray FEL, the electron source should simultaneously allow for:

- repetition rates up to ~ 1 MHz
- charge per bunch from few pC to ~ 1 nC,
- sub 10^{-7} (low charge) to 10^{-6} m normalized beam emittance,
- beam energy at the gun exit greater than ~ 500 keV (space charge),
- electric field at the cathode greater than ~ 10 MV/m (space charge limit),
- bunch length control from tens of fs to tens of ps for handling space charge effects, and for allowing the different modes of operation,
- compatibility with significant magnetic fields in the cathode and gun regions (for emittance compensation, exchange, …)
- 10^{-9} - 10^{-11} Torr operation vacuum pressure (high QE photo-cathodes)
- "easy" installation and conditioning of different kind of cathodes,
- high reliability compatible with the operation of a user facility.

The LBNL VHF CW RF-Gun

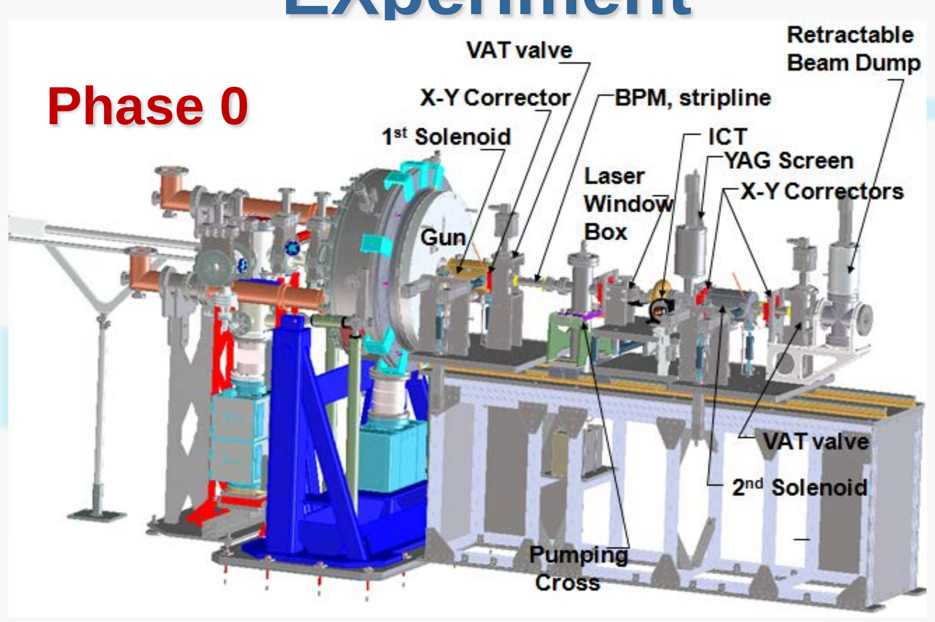


Frequency	187 MHz
Operation mode	CW
Gap voltage	750 kV
Field at the cathode	19.47 MV/m
Q_0 (ideal copper)	30887
Shunt impedance	6.5 MΩ
RF Power	87.5 kW
Stored energy	2.3 J
Peak surface field	24.1 MV/m
Peak wall power density	25.0 W/cm²
Accelerating gap	4 cm
Diameter/Length	69.4/35.0 cm
Operating pressure	< 10^{-11} Torr

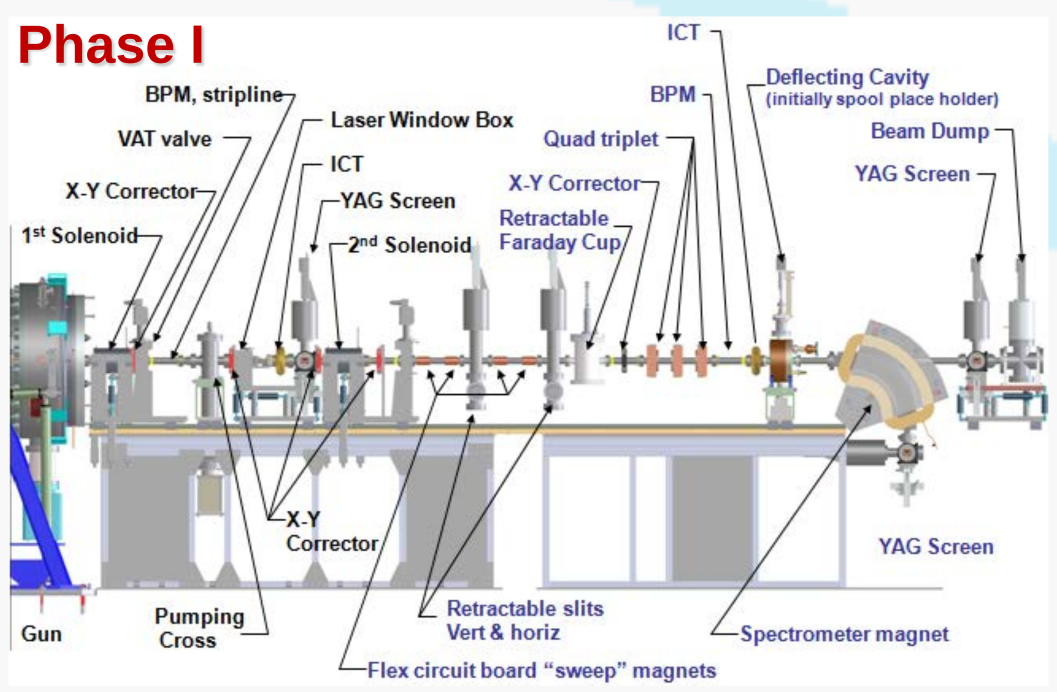
The Berkeley normal-conducting scheme is designed to satisfy all the LBNL FEL requirements simultaneously.

- Based on mature and reliable normal-conducting RF and mechanical technologies.
- 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.
- 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, CO, O_2, …). This arrangement will allow testing a variety of cathodes including "delicate" multi-alkali and/or GaAs cathodes.
- Cathode area designed to operate with a vacuum load-lock mechanism for an easy in-vacuum replacement or reconditioning of photocathodes.
- A mechanical "squeezer" allows tuning the frequency within a ~ 0.5 MHz range by reversibly compressing the beam exit wall reversibly).
- 187 MHz compatible with 1.3 and 1.5 GHz super-conducting linac technologies.

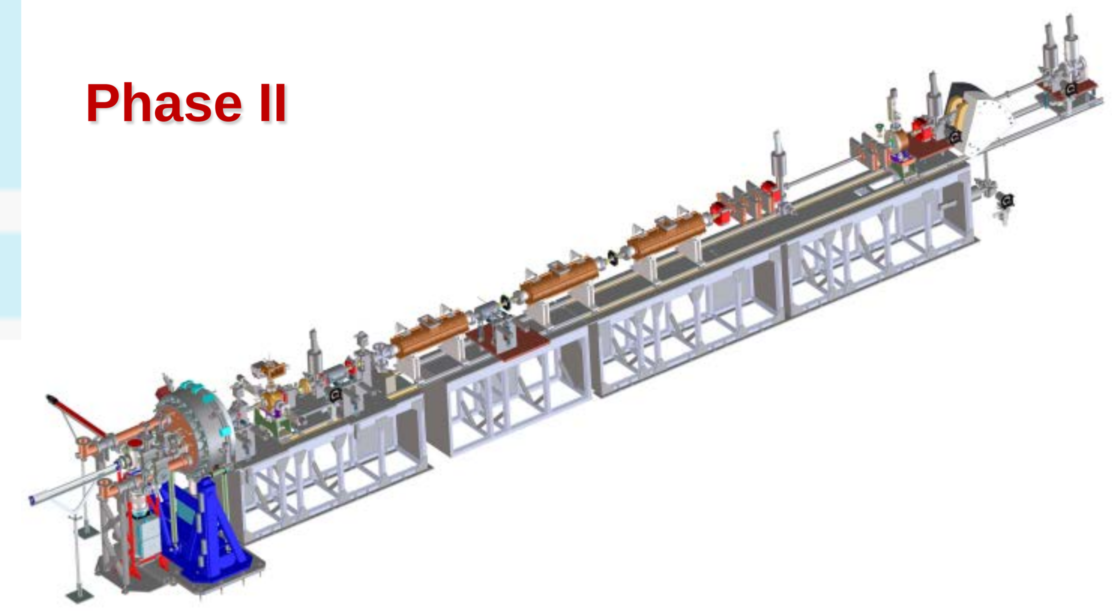
APEX, the Advanced Photo-injector EXperiment



Phase 0 scope:
- Demonstration of the RF performance at full repetition rate.
- Demonstration of the vacuum performance.
- High QE cathode physics
- Dark current characterization

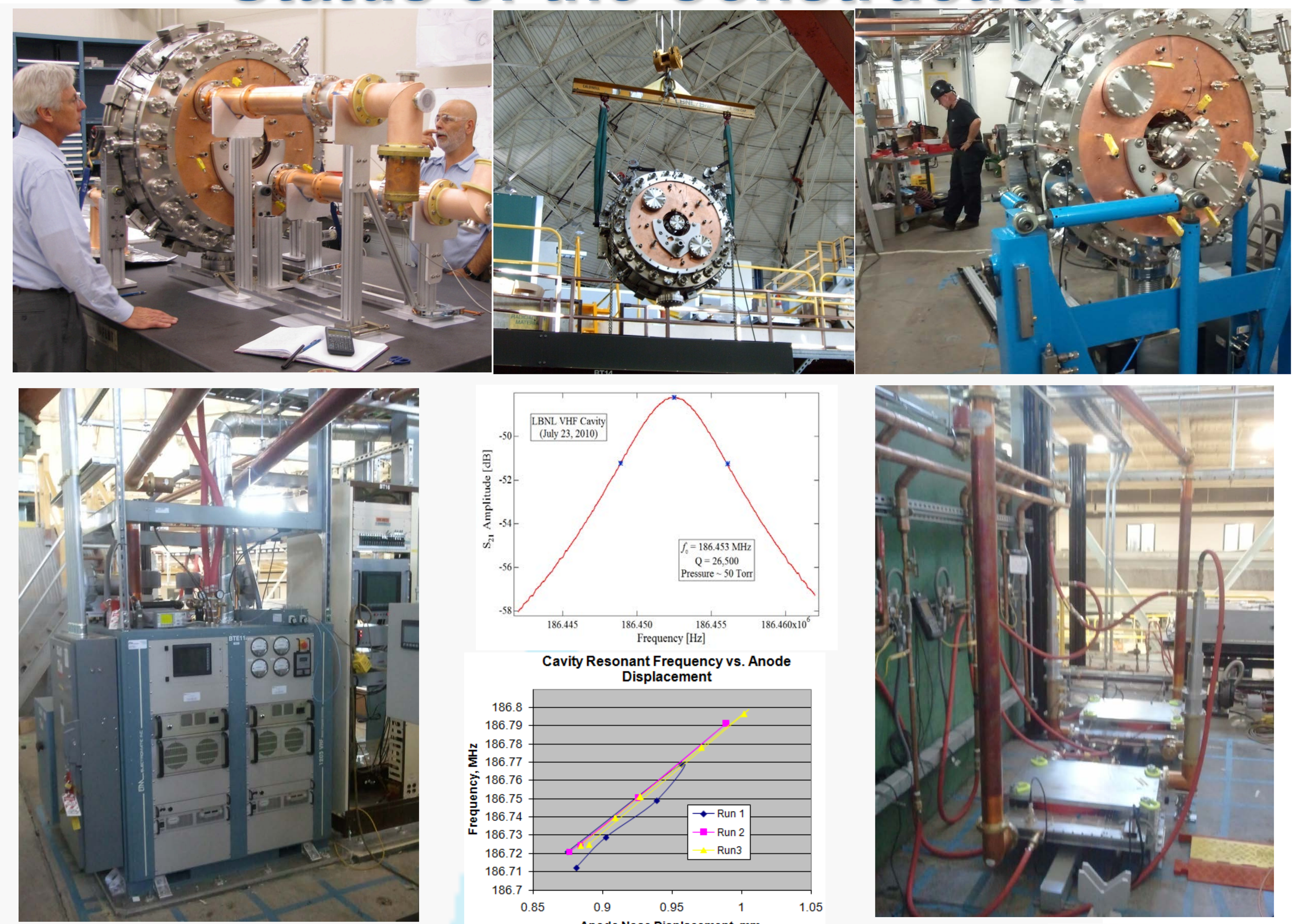


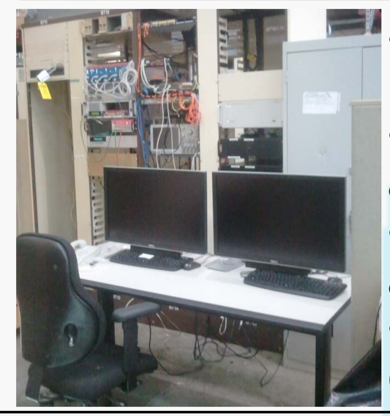
Phase I scope:
- High QE cathode physics
- Electron beam characterization at the gun energy



Phase II scope:
- Demonstration of the brightness performance at ~ 30 MeV at reduced repetition rate (radiation shielding limited).

Status of the Construction





- VHF Gun: completed, installed, low power RF tested, initial vacuum tested
- VHF RF source 120 W CW: installed and fully tested.
- Beam line & diagnostics: systems in advanced fabrication phase.
- Controls: mostly ready for debugging

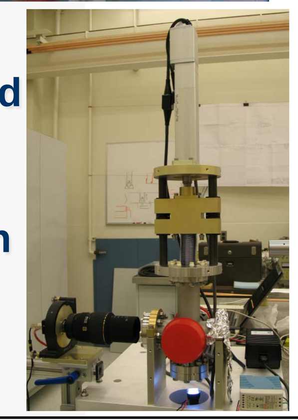


Photo-Cathode/Laser Systems

Alkali Antimonide, K_2CsSb
- fast, reactive; requires ~ 10^{-11} Torr
- high QE; typ. >5% at 532 nm
- Photo-emits in the visible (~530 nm)
For nC, 1 MHz reprate,~ 1 W of IR

- Under development at LBNL in collaboration with BNL
- Measured ~ 0.5 µm/ mm rms "thermal" emittance (Cornell[1] and LBNL[2])
- Promising lifetime measurements (Cornell[1] and LBNL[2]) indicate potential compatibility with operation in a facility

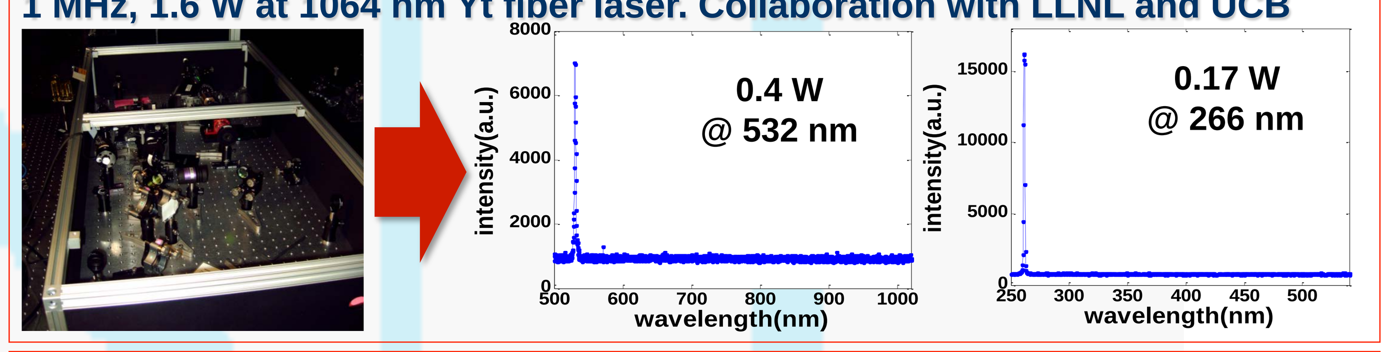
[1]APL 98, 224101; [2]APL 99, 034103.

Cs_2Te
- fast, relatively robust and un-reactive
- high QE; typ. >5% at 266 nm
- requires UV
For nC, 1 MHz reprate, ~ 10 W of IR

- Cathodes by INFN-LASA in Milano
- Measured < 1.0 µm/ mm rms "thermal" emittance and good lifetimes (DESY-PITZ)

Also: collaboration with BNL for diamond amplifier test.

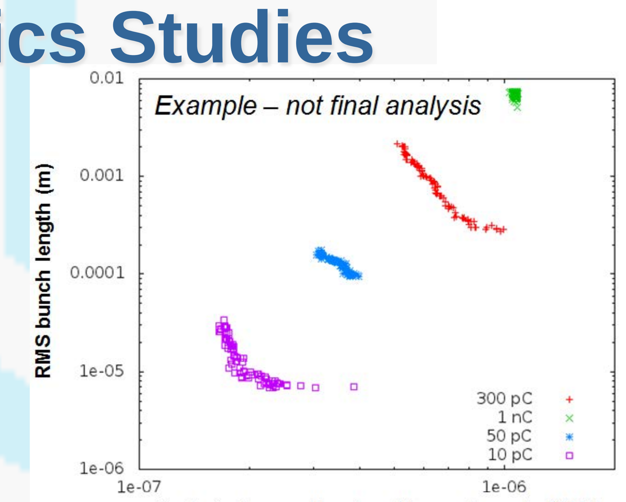
LASER 1: Commissioned at LBNL.
1 MHz, 1.6 W at 1064 nm Yt fiber laser. Collaboration with LLNL and UCB



LASER 2: Cryo-cooled Yb:YAG Laser from Qpeak Inc (STTR).
1 MHz, measured > 100 W at 1064. Delivered to LBNL

Beam Dynamics Studies

- Optimization studies for all APEX Phases.
- Pareto Optimal Fronts (trade-off solutions) calculated by using multi-objective genetic algorithms (MOGA).
- Find global optima with multiple, non-linearly coupled "knobs".



Schedule

Phases 0 and I
- RF conditioning completed during fall 2011
- Initial low energy electron beam tests by end of 2011

Collaborations:
- Cornell University, beam diagnostics and buncher cavity
- AWA Argonne National Laboratory, linac accelerating sections