APEX PROJECT PHASES 0 AND I STATUS AND PLANS AND ACTIVITIES FOR PHASE II*

F. Sannibale#1, B. Bailey1, K. Baptiste1, J. Byrd1, A. Catalano1, D. Colomb1, J. Corlett1, C. Cork1, S. De Santis1, L. Doolittle1, J. Feng1, D. Filippetto1, D. Garcia Quintas1, G. Huang1, S. Kwiatkowski1, M. Messerly2, W. E. Norun1, H. Padmore1, C. F. Papadopoulos1, C. Pellegrini3, G. Penn1, G. Portmann1, M. Prantil2, S. Prestemon1, J. Qiang1, J. Staples1, M. Stuart1, T. Vecchione1, M. Venturini1, M. Vinco1, W. Wan1, R. Wells1, M. Yoon3, M. Zolotorev1, F. Zucca1,
1LBNL, Berkeley, CA, USA, 2LLNL, Livermore, CA, USA, 3UCLA, Los Angeles, CA, USA, 4PAL, POSTECH, Pohang, Korea.

Abstract

The APEX project at the Lawrence Berkeley National Laboratory is devoted to the development of a high repetition rate (MHz-class) electron injector for X-ray FEL applications. The injector is based on a new concept photo-gun, utilizing a normal conducting 186 MHz (VHF) RF cavity operating in CW mode in conjunction with high quantum efficiency photo-cathodes able to deliver the required repetition rates with available laser technology. The APEX activities are staged in phases. In Phases 0 and I, the electron photo-gun is constructed, tested and several different photo-cathodes, such as multi-alkali antimonides, cesium telluride [1], and diamond amplifiers [2], are tested at full repetition rate. In Phase II, a pulsed linac is added for accelerating the beam at several tens of MeV to prove the high brightness performance of the gun when integrated in an injector scheme. APEX is located in an existing area with a radiation shielding configuration limiting the repetition rate at Phase II energies down to several Hz. Based on funding availability, after Phase II the program could also include testing of new undulator technologies and FEL studies. The status of Phases 0 and I, in the initial experimental phase, is described together with plans and activities for Phase II and beyond.

INTRODUCTION

The Advanced Photo-injector Experiment (APEX) is an electron injector based on a normal-conducting (NC) constant-wave (CW) RF photo-gun under construction at the Lawrence Berkeley National Laboratory (LBNL) in the framework of the R&D activities promoting the development of the Next Generation Light Source (NGLS), a soft x-ray light source based on an array of independently tunable free electron lasers (FELs) [3, 4]. The NGLS design addresses the interest of a large scientific community in the XUV and soft x-rays requiring extremely high brightness sources with photon energies ranging from about 10 eV to 1 keV at repetition rates as high as ~ 100 kHz per beamline [5, 6].

Particularly challenging are the requirements for the electron injector to operate in the NGLS or in any other high repetition rate FEL. Indeed, such injectors, which must deliver beams at MHz repetition rate with the required high brightness over a broad range of charge per bunch, presently do not exist. A detailed discussion on all injector requirements necessary to operate in a high repetition rate FEL facility can be found in [7].

A number of groups around the world have undertaken R&D activities focused on the development of such an injector, and several technologies are being explored (DC guns, superconducting RF guns, and normal-conducting RF guns, see references in [7]).

The gun scheme developed and constructed at LBNL to address such a need is based on reliable and mature mechanical and RF technologies. The core of the gun is a NC copper RF cavity operating in CW mode in the VHF band at 186 MHz (7th sub-harmonic of 1.3 GHz), whose field is used to accelerate the electrons emitted by a photocathode. Figure 1 shows a cross section of the VHF gun with the main components, while Table 1 includes the cavity main parameters.

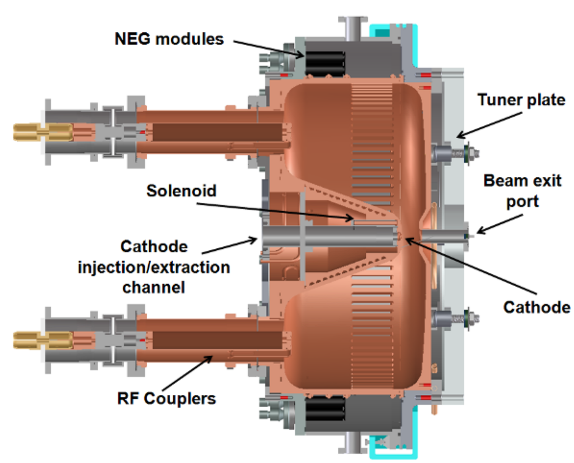

Figure 1: The VHF gun cross-section.

More information on the LBNL gun can be found elsewhere [8-10]. Here we want only to point out the two major goals that were targeted by this design: the CW operation capability at high accelerating gradient at the cathode, and the low vacuum pressure performance required to operate high quantum efficiency (QE) semiconductor photo-cathodes.

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#FSannibale@lbl.gov

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Table 1: VHF CW Cavity Main Parameters

Total length [m]	0.35
Cavity internal diameter [m]	0.694
Accelerating gap [mm]	40
Frequency [MHz]	186
Q_0 (ideal copper)	30877
Q_{0M} (measured)	26500
Gap voltage [MV]	0.75
Electric field at the cathode [MV/m]	19.5
Peak surface electric field [MV/m]	24.1
Stored energy [J]	2.3
Shunt impedance [MΩ]	6.5
RF power for 0.75 MV at Q_0 [kW]	87.5
Peak wall power density at 0.75 MV [W/cm^2]	25.0
Operation vacuum pressure [Torr]	10^{-11}

THE APEX EXPERIMENT

In order to demonstrate the performance of the VHF gun, the APEX experiment was initiated at LBNL in the Beam Test Facility (BTF), an existing shielded area within the Advanced Light Source structure. The APEX activity has been organized in three chronologically distinct experimental phases.

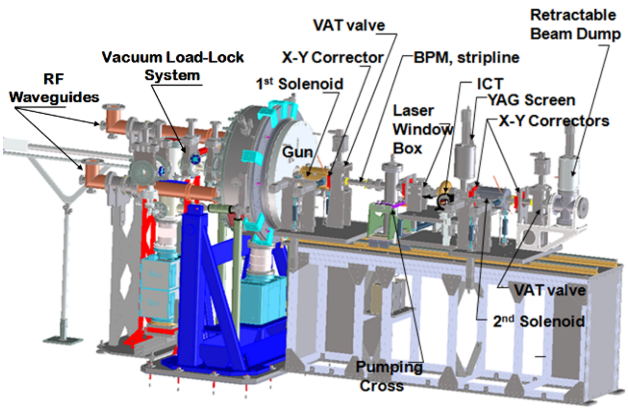

Figure 2: APEX Phase 0 layout.

APEX Phase 0

The layout of Phase 0, the first of such phases, is shown in Figure 2, and includes the VHF gun, a vacuum load-lock system (a clone of the INFN-LASA/PITZ unit) that allows replacing cathodes without breaking vacuum, and a number of diagnostics systems for the characterization of the photocathode performance.

The RF gun is powered by a tethrode based 186 MHz amplifier operating in CW mode and capable to deliver up to 60 kW in each of its two branches.

The scope of Phase 0 includes the demonstration of: i) the full-power CW RF performance of the VHF gun; ii) the gun vacuum performance; iii) the dark current characterization; iv) and the test and characterization of several different photocathodes.

In particular, the beam diagnostics will allow for measurements of cathode QE maps, intrinsic emittance and lifetime. The principal IR laser that will be used for driving the photoemission has been developed in collaboration with Lawrence Livermore National Laboratory and UC Berkeley. The IR pulses at 1064 nm are frequency converted to generate 532 and 266 nm in 2nd and 4th harmonic. This photon energy flexibility allows driving photoemission in various different cathode materials. Planned cathodes to be tested includes K_2CsSb produced at LBNL [11], Cs_2Te [1] and copper with diamond amplifier [2].

APEX Phase I

The layout of Phase I is shown in Figure 3. Phase I is an extension of Phase 0 where a number of electron beam diagnostic systems have been added.

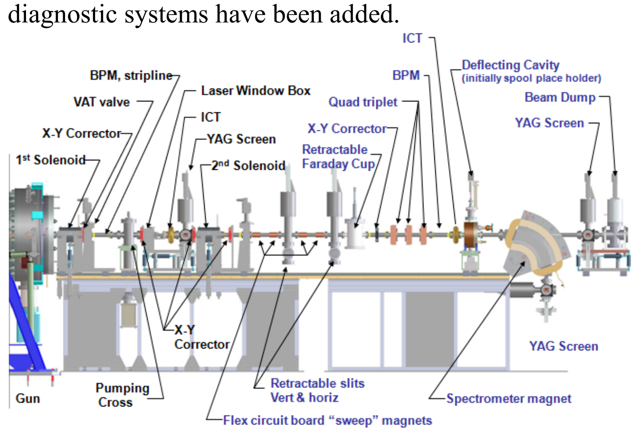

Figure 3: APEX Phase I layout..

In particular, the addition of a 1.3 GHz transverse deflecting cavity, of a double slit H&V emittance meter (both based on Cornell design [12, 13]), and of a spectrometer, will allow for a full 6D characterization of the beam phase space at the gun energy.

The scope for Phase I includes electron beam dynamics studies and comparison with simulation results at the gun energy, and continuation of photocathode physics studies.

APEX Phase II

The layout of Phase II is shown in Figure 4.

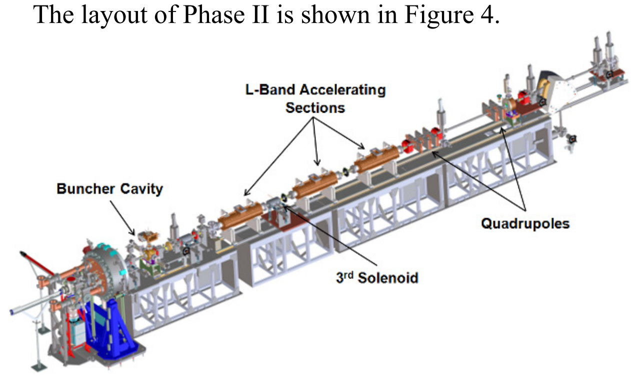

Figure 4: APEX Phase II layout.

In Phase II, three L-band NC pulsed 1.3 GHz accelerating sections (ANL-AWA type [14]) are added together with a 1.3 GHz buncher cavity (Cornell type [15]), to accelerate the beam up to ~30 MeV and to perform "ballistic" bunch compression at the gun energy. The diagnostic systems of Phase I will be now moved

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downstream the accelerating sections and reconfigured to operate at the higher energy.

The operation of the accelerating sections will be limited to a maximum repetition rate of about 10 Hz. This limitation is driven by the radiation shielding capability of the BTF area. The accelerating sections, the buncher, and the deflecting cavity will be powered by a single klystron (Thales TV2022F) capable to deliver 25 MW over a 10 μs RF pulse. Independent phase and amplitude control for each individual accelerating section and cavity is ensured by the RF distribution design.

The scope for Phase II includes the demonstration of the brightness performance of an injector based on the LBNL VHF gun at the level required by a x-ray FEL.

According to simulation studies [16], Phase II beam energy is sufficient to perform emittance compensation and to measure the beam characteristics in a situation of moderate and controllable space charge forces.

APEX CONSTRUCTION STATUS

VHF Gun

The VHF gun has been fabricated and installed inside the BTF. Figure 5 shows the gun in its final destination.

The gun underwent to low power RF tests, where a comfortable Q value of 26500 was measured, and to preliminary vacuum tests, where a pressure of 1.2 10^{-9} Torr was achieved without baking and with only one (out of the 20 available) NEG module activated. The cavity tuning mechanism was also tested and performed according to expectations. More details on the above tests can be found elsewhere [10].

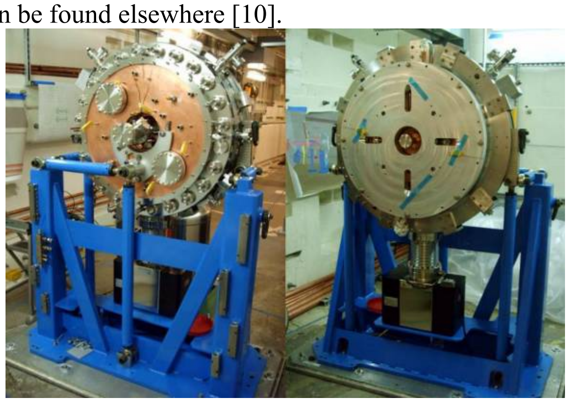

Figure 5: The VHF gun installed inside the BTF. The figure shows the gun back wall on the left, and the front wall with the beam exit port in the right.

186 MHz RF Source

The construction of the RF power source, by ETM Electromatic, was completed. The unit was installed at LBNL and successfully demonstrated the required performance. A picture of the unit is visible in the left part of Fig. 6. The 186 MHz CW RF source is based on two final amplifier branches using tethrode tubes (Thales TH571B) generating up to 60 kW RF power each. Each branch will feed, through high power coaxial lines and a circulator, the power to each of the two RF couplers on the gun. Toshiba RF windows separate the vacuum on the gun side from the atmospheric pressure on the waveguide side. Figure 7 shows in the right the two circulators and some of the coaxial waveguides that connect the parts.

Figure 6: The 186 MHz CW 120 kW RF system. The tethrode-based amplifier (left), and the two circulators situated in the two branch lines (right) are visible.

The two RF window/coupler assemblies will be conditioned at full power (60 kW) before being installed on the RF gun. After this operation, which should be completed in the next few weeks, the installation of gun RF distribution system will be finalized and the RF conditioning of the gun will follow.

Photocathode/Laser System

The requirement for 1 nC, 1 MHz bunches from the photo-injector, jointly with the presently available laser power, lead to the need for high QE cathodes (> 1%). At LBNL, we are pursuing 2 different cathode/laser systems.

In the first case, our group at LBNL is developing K_2CsSb, a multi-alkali antimonide cathode photo-emitting in the visible [11]. Such a material was previously tested in RF guns [17] and showed high QE but poor lifetime due to its sensitivity to contamination by residual gas molecules. The LBNL VHF gun has been designed to achieve pressures low enough to run such cathodes with a acceptable lifetimes. Recent measurements [18, 19] have demonstrated excellent thermal/intrinsic emittance characteristics and promising lifetime for such a material if the proper vacuum condition is achieved.

The second system includes Cs_2Te cathodes photo-emitting in the UV. This option, well tested at the FLASH FEL in Germany, where it showed high QE and good lifetimes, is pursued in collaboration with INFN-LASA. Three cathodes have been already produced and are ready to be shipped to LBNL to be used in APEX.

Additionally, diamond-amplified copper photo-cathodes have been designed for testing in APEX [2].

The main laser has been fabricated at LLNL in collaboration with UC Berkeley and LBNL. The system, an Yb-doped fiber-laser, delivers 1.6 W in the IR at 1064 nm with ~ 1ps FWHM pulses at 1 MHz repetition rate. The laser is now in operation at LBNL where is frequency converted to generate 0.4 W at 532 nm and 0.17 W at 266

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nm. Figure 7 shows a picture of the system and examples of spectral measurements at 532 and 266 nm.

A second laser system, with power > 100 W at 1064 nm (by QPeak Inc.), is presently under test at LBNL.

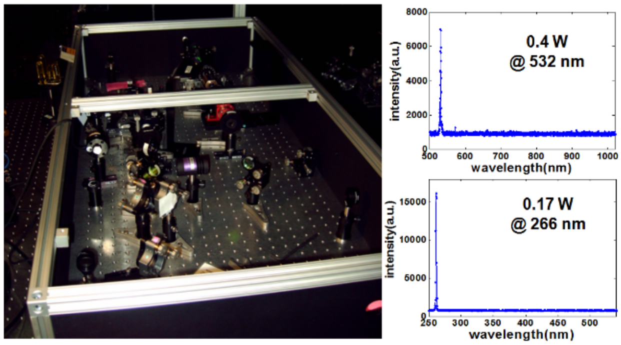

Figure 7: The LLNL-UCB laser at LBNL and examples of measured spectra at 532 and 266 nm.

Other Subsystems

Most of the diagnostic systems are in advanced phase of construction. Figure 8 on the right shows for example one of the beam profile stations being bench tested. On the left side of the figure, a view of the APEX control room is showed. In the background, the racks with some of the diagnostics and power supplies are visible. The control system, based on EPICS, is ready to be debugged with the real beam. More details on the APEX beam diagnostics can be found elsewhere [20].

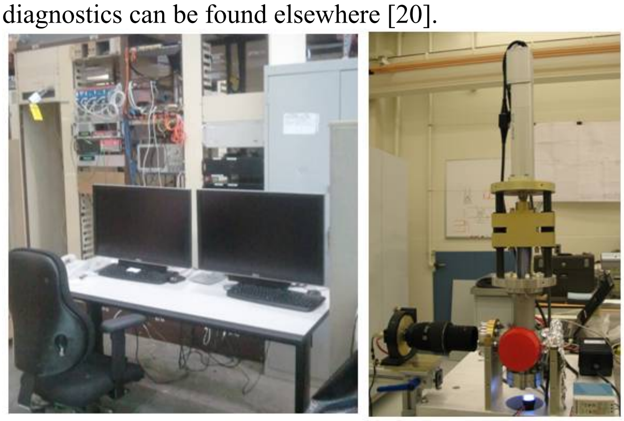

Figure 8: Left: the APEX control room. Right a beam profile measurement station.

SCHEDULE AND FUTURE PLANS

The RF conditioning of the GUN should be completed in October 2011. Initial beam tests will follow with cathode beam physics experiments (diamond amplifier first, followed by Cs_2Te and K_2CsSb). A shutdown period during spring 2012 will allow for Phase I installation. If a proper fund profile will be maintained, Phase II installation should start at the beginning of 2013.

Beyond Phase II, and after the brightness performance of the APEX injector will be proved, we are proposing to use the APEX beam for the BTFEL experiment, aimed to test a new short-period superconducting undulator technology and to perform FEL experiments with it [21].

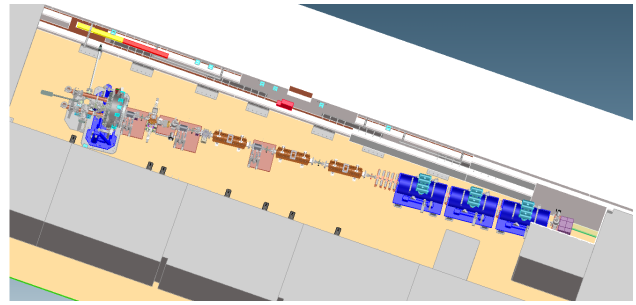

Figure 9: The APEX/BTFEL layout inside the BTF.

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