

# X-BAND TEST STATION AT LAWRENCE LIVERMORE NATIONAL LABORATORY\*

R.A. Marsh<sup>†</sup>, F. Albert, S.G. Anderson, G. Beer, R.R. Cross, G.A. Deis, C.A. Ebberts, D.J. Gibson, F.V. Hartemann, T.L. Houck, C.P.J. Barty, LLNL, Livermore, CA USA  
C. Adolphsen, A. Candel, T.S. Chu, E.N. Jongewaard, Z. Li, C. Limborg-Deprey, S.G. Tantawi, A.E. Vlieks, F. Wang, J.W. Wang, F. Zhou, T.O. Raubenheimer, SLAC, Menlo Park, CA USA

## Abstract

An X-band multi-bunch test station is being built at LLNL to investigate the science and technology paths required to boost the current mono-energetic gamma-ray (MEGa-Ray) brightness by orders of magnitude. The test station will consist of a 5.5 cell X-band RF photoinjector, single accelerator section, and beam diagnostics. Beam quality must be exceedingly high in order to produce narrow-bandwidth gamma-rays, requiring a robust state of the art photoinjector. The photoinjector will be a high gradient (200 MV/m peak surface field on the cathode) standing wave structure, featuring a dual feed racetrack coupler, elliptical irises, and an optimized first cell length. A solid-state Scandinova modulator will power a single SLAC XL4 11.424 GHz 50 MW klystron. RF distribution will allow for full powering of the photoinjector with the balance of the RF powering a single accelerator section so that the electron parameters can be measured. The status of the facility will be presented including commissioning schedule and first experiment plans. Future experimental programs pertinent to Compton scattering R&D, high gradient structure testing, and light source development will be discussed.

## INTRODUCTION

Extremely bright, narrow bandwidth gamma-ray sources are expanding the application of accelerator technology and light sources in new directions. Mono-energetic gamma-rays enable new features in nuclear applications by tapping into the very narrow unique nuclear resonances of various isotopes. Advancements in nuclear material detection, fuel rod assay, and waste management only begin to hint at the possibilities made possible by this transformational technology. Narrow bandwidth gamma-rays place very stringent demands on the laser and electron beams that interact to produce them. Next generation advancements in gamma-ray production require these demands be satisfied, while simultaneously increasing the average flux of gamma-rays at a specific energy (that is,  $N/eV/sec$  at the energy of interest). In order to increase the total flux, the machine currently being constructed at LLNL will operate

at 120 Hz, while researching methods to raise the effective repetition rate of the machine to greater than kHz.

The effective repetition rate will be increased by operating the RF photoinjector in a multi-bunch mode, accelerating multiple electron bunches per RF pulse. This multi-bunch mode will require the same stringent requirements for the electron bunch properties including low emittance and energy spread, but across multiple bunches. The strategy for achieving multi-bunch operation at very low emittance and energy spread is as follows. 1) Redesign RF photoinjector for more robust high brightness operation, 2) Model effects that will degrade multi-bunch gamma-ray quality including: dark current, wakefields, and beam-loading, 3) Measure simulated effect in experiment, 4) Redesign RF photoinjector as necessary. An independent test station has been planned and designed to carry out multi-bunch experiments to benchmark design performance and theoretical modeling. This paper will summarize the Mark 1 RF photoinjector design, and current plans for the completion of the test station, including location and RF distribution.

## TEST STATION LAYOUT

The advanced X-band test station will be an independent beamline capable of performing experiments on future improvements to the LLNL Nuclear Photonics Facility. Until the full facility is built in B391, the test station will be established in the North-South caves of B194. Early establishment of the test station will enable operational experience, and allow multi-bunch experiments to begin in advance of the full B391 facility being available for occupancy. The parameters for the test station are shown in Table 1. The test station layout is shown in Figure 1. The test station will consist of a control room with equipment racks, the high power solid-state modulator and XL-4 klystron, RF distribution, a Mark 1 RF photoinjector and single traveling wave accelerator section with beamline transport magnets and diagnostics. The system is discussed in more detail in other work including: the beam dynamics [1], laser systems [2], and RF distribution [3]. A similar system is being built at SLAC for testing X-band RF photoinjectors, as discussed in [4].

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<sup>†</sup>marsh19@llnl.gov

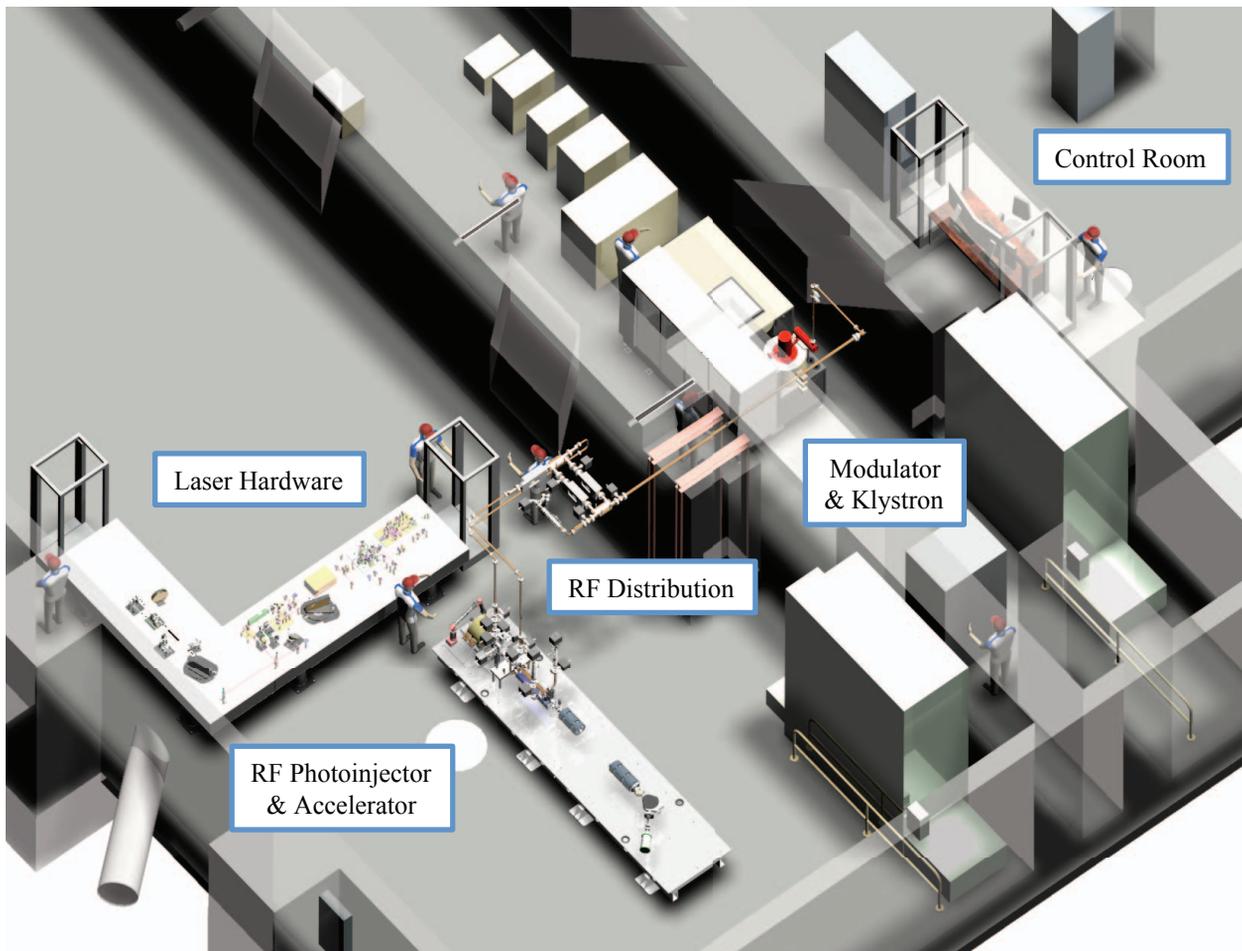


Figure 1: CAD rendering of test station layout in B194.

Table 1: Test Station Parameters

Charge	250 pC
Bunch Duration	2 ps
Bunch Rise/Fall	<250 fs
Normalized Emittance	<1 mm-mrad
Gun Energy	7 MeV
Cathode Field	200 MV/m
Coupling $\beta$	1.7
Section Gradient	$\sim 75$ MV/m
Final Energy	30–50 MeV

## RF PHOTOINJECTOR

The Mark 1 X-band RF photoinjector was based on an earlier design (Mark 0) developed by A. Vlieks at SLAC [5, 6]. The Mark 0 was the first X-band photoinjector, and was operated successfully at cathode electric fields of 200 MV/m. The Mark 0 photoinjector was a 5.5 cell design, and as such supported 6 eigenmodes near the operating  $\pi$ -mode. The mode separation between the operating mode and its nearest neighbor was less than 10 MHz, leading to simultaneous excitation of both modes by the drive

RF, resulting in mode beating of the fields on the cathode, and degradation in achievable beam brightness.

The Mark 1 photoinjector advances on the Mark 0 design by increasing the mode separation to 25 MHz, and incorporates other significant improvements to enhance its robust operation as the *VELOCIRAPTOR* electron source. A CAD rendering of the Mark 1 RF photoinjector is shown in Figure 2. The major design changes include: iris geometry change from circular cross-section irises to elliptical contoured; iris thickness adjustment to improve mode separation; a longer initial half cell; a racetrack coupler; and coupling optimization to balance pulsed heating with cavity fill time. A description of the detailed design process and supporting simulations will be presented in [7]. A combination of design codes were used including PARMELA, HFSS, and the ACE3P suite of codes developed at SLAC.

## TEST STATION STATUS & PLANS

Future modeling efforts will focus on the predicted performance of the new RF photoinjector, specifically on the multi-bunch performance of the RF gun. Simulation of beam loading will determine the predicted bunch to bunch energy spread, and drive compensation efforts. The test

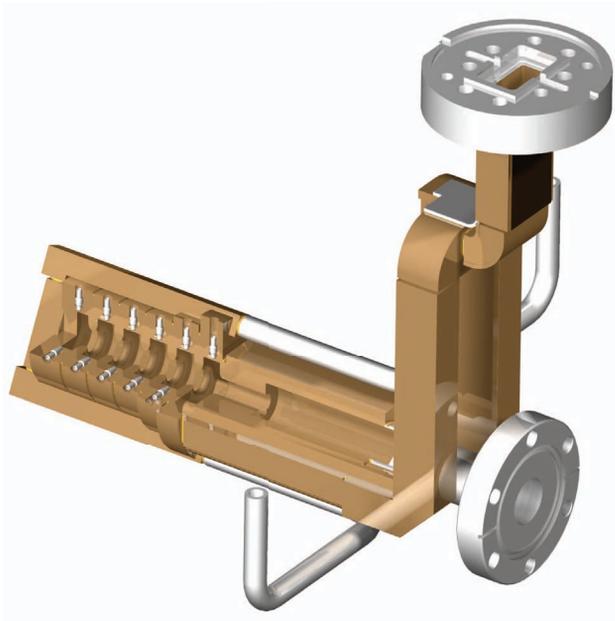


Figure 2: CAD rendering of Mark 1 X-band RF photoinjector.



Figure 4: The LLNL XL4 klystron awaiting final testing at SLAC.

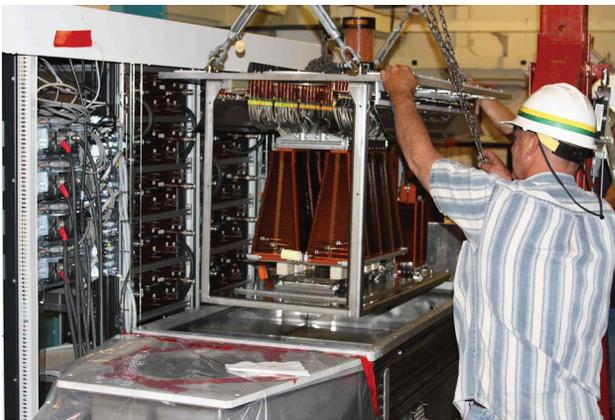


Figure 3: Final modifications to ScandiNova K2-3X high voltage modulator.

station experimental program will focus on installation and commissioning. We have completed the process of preparing the facility, e.g. bringing in additional electrical power and cooling water. The K2-3X modulator is ready and has been installed. Initial on site testing of the klystron will occur this Fall. The RF distribution system will be installed and tested in sections over the next several months as components arrive. The test station is schedule to be completed this calendar year.

Experiments will benchmark modeling results and focus future research and development on solving the technical challenges to increasing gamma-ray flux and repetition rates. The technology developed on the test station will serve as the basis for future upgrades to LLNL's center for gamma-ray applied science to further increase the

gamma-ray production. A fully functioning multi-bunch high brightness X-band RF photoinjector and accelerator section make the test station a valuable platform for future X-ray and gamma-ray research; both as a test bed for upgrades, and as an independent source of electrons for further study.

## REFERENCES

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