THE ORION FACILITY*

R.J. Noble#, E.R. Colby, D.T. Palmer, R.H. Siemann, D. Walz, SLAC, Stanford, CA, USA
R. Byer, Stanford University, Stanford, CA, USA
C. Joshi, W. Mori, J. Rosenzweig, UCLA, Los Angeles, CA, USA
T. Katsouleas, USC, Los Angeles, CA, USA

Abstract

ORION will be a user-oriented research facility for understanding the physics and developing the technology for future high-energy particle accelerators, as well as for research in related fields. The facility has as its centerpiece the Next Linear Collider Test Accelerator (NLCTA) at the Stanford Linear Accelerator Center (SLAC). The NLCTA will be modified with the addition of a new, high-brightness photoinjector, its drive laser, an S-band rf power system, a user laser room, a low-energy experimental hall supplied with electron beams up to 60 MeV in energy, and a high-energy hall supplied with beams up to 350 MeV. The facility design and parameters are described here along with highlights from the 2nd ORION Workshop held in February 2003.

INTRODUCTION

ORION will be a user-oriented research facility for understanding the physics and developing the technology for future high-energy particle accelerators, as well as for research in related fields [1]. The facility has as its centerpiece the Next Linear Collider Test Accelerator (NLCTA) at SLAC. The NLCTA will be modified with the addition of a new, high-brightness photoinjector, its drive laser, an S-band rf power system, a user laser room, a low-energy experimental hall supplied with electron beams up to 60 MeV in energy, and a high-energy hall supplied with beams up to 350 MeV. Facility construction is anticipated to start in October 2003, contingent upon funding approval, and first beam is planned for 2005. Notably, the first experiment, E163, "Laser Acceleration at the NLCTA", has been approved by SLAC. In February 2003, about 90 participants attended the 2nd ORION Workshop, and new suggestions were received regarding possible experiments and the facility design [2].

FACILITY DESIGN

The general parameters for the ORION Facility are given in Table 1, and the conceptual layout is shown in Figure 1. The parameters have evolved from the input of many potential users, and various anticipated experiments are tabulated in the ORION Technical Design Study [3]. User requests indicate the need for bunch charges of 2 pC to 4 nC, 1 to 2 bunches (drive-witness), normalized rms emittances of <2 to 40 mm-mrad, rms bunch lengths of 0.1 to 2 psec, and minimum relative energy spreads $\leq 10^{-3}$. For certain plasma wakefield acceleration experiments, a drive bunch with greater than 1 nC charge and a witness bunch up to 0.3 nC will be desired, and this can be accommodated by splitting the laser pulse energy to produce two bunches from the photoinjector. The Mg cathode and specified laser energy at ORION are sufficient to produce several nC of total charge. Beam dynamics studies [3] have shown that a single bunch of 4 to 5 nC can clear the aperture of the NLCTA X-band prebuncher cavity, which is the limiting device of the injector. Overall the parameters in Table 1 are consistent with experimental needs anticipated in the first years of ORION operation.

Table 1. Parameters of the ORION Facility

Beam Energies	7 MeV (Source); 7-67 MeV (LE Hall); 67-350 MeV (HE Hall)
Charge per Bunch	0.25 nC optimum, adjustable up to a nominal maximum of 1 nC
Number of Bunches	1 or 2 (split charge)
Transverse Emittance	$\leq 2\times10^{-6}$ m, normalized rms (0.25 nC)
Bunch Length	1.8 psec, rms (0.25 nC)
Charge Stability	±2.5%, pulse-to-pulse
Timing Jitter	0.25 picosec, rms
Repetition Rate	10 Hz
Average Beam Power	0.67 W at 67 MeV; 3.5 W at 350 MeV (1 nC bunches)
Electron Source	1.6 cell, S-band (2.856 GHz) Photoinjector, Mg cathode
Drive Laser	Commercial Ti:Sapphire, 266 nm wavelength, 1 mJ output
Source RF System	SLAC 5045 Klystron; Solid-State, NLC-type Modulator
Injector Linac	Two X-band (11.4 GHz), 0.9 m, 30 MV, NLC structures
High-Energy Linac	Four X-band, 1.8 m, 72 MV, NLC structures

ORION modifications to the NLCTA consist of the S-band photoinjector, its drive laser, the radio-frequency power system, the beamlines to the experimental halls, the drive laser room, user laser room, and the low-energy and high-energy experimental halls.

*Work supported by DOE contract DE-AC03-76SF00515.
#noble@slac.stanford.edu

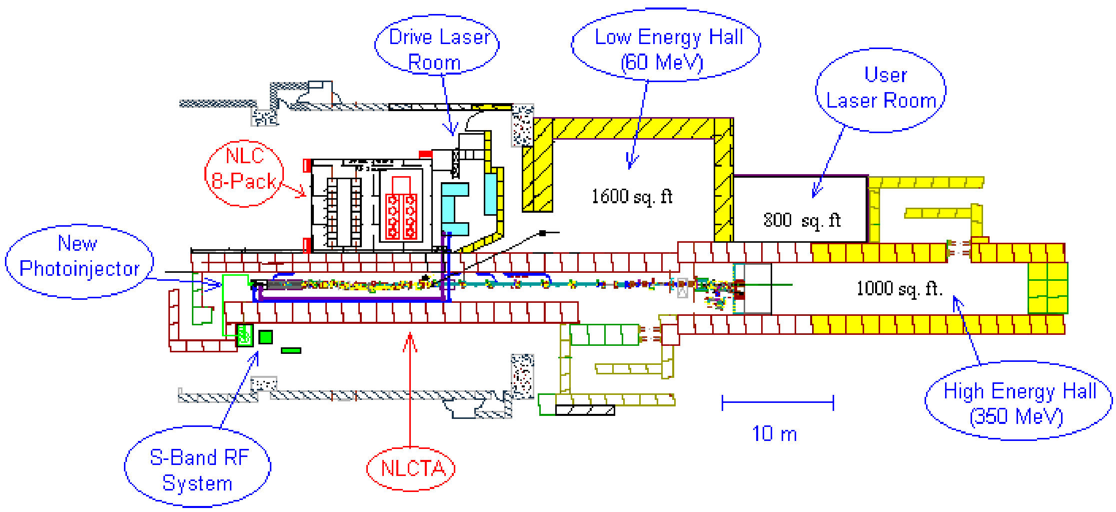

Figure 1. Conceptual layout of the ORION Facility at the NLCTA.

The S-band rf gun for ORION is the standard 1.6 cell design used at BNL, ANL and UCLA. The gun was fabricated by J. Rosenzweig's group at UCLA and brazed at SLAC (Figure 2). Power conditioning of the gun is in progress at SLAC. Prior to actual use on ORION, an Mg cathode will be installed in place of the temporary Cu cathode plate. With its higher quantum efficiency (photoelectrons per laser photon), Mg will permit the use of a less expensive, low-power laser for E163, the first experiment planned for the ORION facility, while also providing 1 nC bunches for NLC cavity phase shift measurements. The use of Mg cathodes on these guns is well established, including several years of operation at the BNL Accelerator Test Facility.

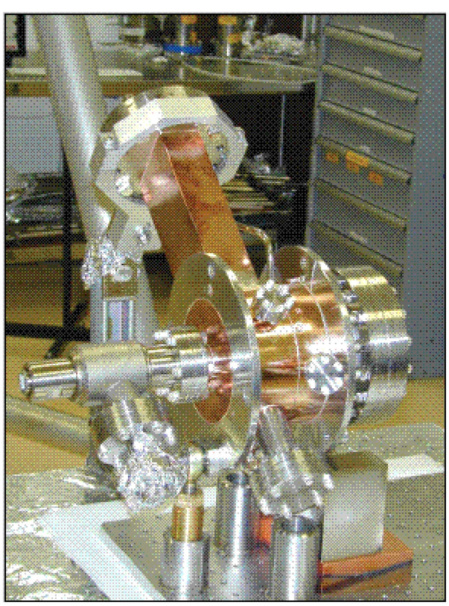

Figure 2. ORION rf gun after the final braze at SLAC.

BEAM DYNAMICS STUDIES

The production and successful transport of a wide variety of beams is essential to the flexibility of the ORION facility. Detailed simulations of the beam dynamics for the NLCTA with the rf gun installed have been completed using the computer codes Parmela [4] and Elegant [5] through the NLCTA beamlines into the low- and high-energy halls. With many experiments calling for high charge, high brightness beams, the production and preservation of these beams has been carefully studied [3]. The beamlines pose several challenges unique to the ORION facility: injection from an S-band gun into an X-band accelerator requires the production of higher density bunches than is typically optimal to suppress rf-induced emittance growth in the accelerator; the present NLCTA chicane is a 3π design permitting wide variation of the temporal dispersion (R_{56}), but at the expense of strong second-order aberrations in the horizontal plane; beamlines leading to the low energy hall are connected via a 25° dogleg with rather inflexible optics, requiring careful matching and second-order temporal dispersion (T_{566}) control to preserve the profile of high charge bunches. Each of these challenges is soluble, and will provide ample opportunity for exploring injector operation in a new range of parameter space.

ORION WORKSHOP HIGHLIGHTS

The Second ORION Workshop was held in February 2003 at SLAC to revisit the anticipated experiments at ORION, invite new experimental ideas, discuss the on-site needs of potential users, and to generate input on the facility design. There were about 90 participants and 54 papers were published in the proceedings [2]. The four working groups were Beam-Plasma Physics (chair T. Katsouleas, USC), Laser Acceleration (co-chairs R. Byer, Stanford Univ., Yen-Chieh Huang, National Tsinghua Univ.), Laboratory Astrophysics (chair P. Chen, SLAC), and Particle and Radiation Sources (chair J. Rosenzweig, UCLA). Each working group generated a final summary report, and the interested reader can find those documents in the proceedings.

The Beam-Plasma group made a significant effort to specify the needs for experiments probing the details of plasma wakefields, to investigate efficient energy extraction by an accelerated bunch (the beam-loading issue), and to characterize the tunnel-ionization of gases by intense drive beams, which would eliminate the need for laser-ionization. Plasma wakefield accelerators driven with 10 μm bunches hold the promise of 10 to 100 GeV/m gradients, but dedicated studies of wake phenomena will be required to design a prototype accelerator. Participants concluded that witness bunches ranging from 0.1 to 0.3 nC and sub-picosecond duration are essential for ORION wakefield experiments. The higher charge witness beam has the advantage of "flattening" the wakefield locally, leading to uniform energy gain across the bunch and the associated reduced energy spread essential for colliders. Beam-plasma experiments are very demanding in terms of ultra-fast diagnostics and the need for physics simulations. This group discussed the hardware and software for real time computer modeling of experiments to permit users to perform essential end-to-end simulations from source to the experimental diagnostics.

The Laser Acceleration group explored in detail the beam and facility requirements for seven distinct experiments, providing important input for the facility design. Today laser acceleration is at a stage analogous to where copper-cavity acceleration was in the 1940's. Participants agreed that commercial terawatt peak-power lasers (the analog of klystrons) have now opened a path toward realizing an all-optical accelerator with 1 GeV/m gradients limited only by the surface damage threshold. Optical accelerators based on periodic metal or dielectric arrays, planar waveguides, fiber structures and photonic band-gap devices were all considered at the workshop. Initial calculations of shunt impedances and accelerating efficiencies for some generic structures were presented, and experiments to measure these at ORION were proposed.

The LabAstro group was a new addition to ORION for this workshop, and enthusiastic participants explored possible experiments to calibrate cosmic ray measurement techniques, to investigate the dynamics of cosmic acceleration in the lab, and to use laser and particle beams as probes for fundamental astrophysics. The availability of large area halls with electron energies from less than an MeV to hundreds of MeV was seen as a new opportunity for calibrating cosmic-ray, air fluorescence and radio emission detection methods. Six experiments were suggested to investigate the dynamics of astrophysical processes, including Alfven shock particle acceleration, hybrid-mode excitation and particle trapping in beam-driven, magnetized plasmas (jet physics), beam interactions with magnetosonic solitons and shocklets, diamagnetic pulse acceleration, the behavior of positron-electron plasmas produced via laser-matter interaction, and the simulation of electroweak, neutrino-plasma instabilities (relevant to supernova energy transport) with conventional electron-plasma instabilities. Electron and laser beams can be used to both excite and diagnose simulated astrophysical plasma phenomena. Participants recognized that with the space available for lasers at ORION, the opportunity to use both lasers and particle beams at *one facility* would be unique for lab-astro experiments, enabling rapid progress in the field.

The Particle and Radiation Sources group hosted a wide variety of talks on the electron source and diagnostic requirements needed for the proposed ORION experimental program. The NLCTA chicane with its second-order aberrations and lack of diagnostics is not well suited to transport the high-brightness, short bunches for ORION plasma wakefield experiments, and replacement with alternate transport was recommended. Velocity bunching at the source was suggested for further study to achieve short ORION bunches with small energy spread. Dedicated diagnostic systems for longitudinal beam measurements after the injector and after the transport line to the low-energy hall were also suggested.

The basic ORION facility design with two experimental halls and one user laser room has remained the same in light of the 2nd ORION Workshop. The option for expanding the High Energy Hall to roughly 5000 square feet in the future needs serious consideration given the list of new high-energy experiments suggested at the workshop. For beam-plasma and lab-astro experiments, the option for electron beams up to 700 MeV is attractive for studying the energy dependence of various instabilities and beam-wakefield interactions. With the completion of the so-called NLC 8-Pack klystron/modulator array this year, such higher energy beams will be achievable once new NLC cavities are perfected and installed permanently at the NLCTA.

Originally envisioned for advanced accelerator work, the ORION concept is now evolving to serve researchers in plasmas, lasers and astrophysics as well. ORION's greatest returns are likely to be the many unanticipated discoveries from its multidisciplinary group of users.

REFERENCES

[1] http://www-project.slac.stanford.edu/orion/
[2] Presentations from the Second ORION Workshop, February 18-20, 2003, Stanford, CA, R. Noble and R. Reitmeyer, editors, SLAC-WP-026, at web address: http://www.slac.stanford.edu/cgi-wrap/pubpage?SLAC-WP-026
[3] ORION Research Facility Technical Design Study, April 12, 2002, available at the ORION website [1].
[4] H. S. Deavon, *et al,* LA-UR-90-1766, p. 137 (1990).
[5] M. Borland, APS LS-287, Sept. (2000).